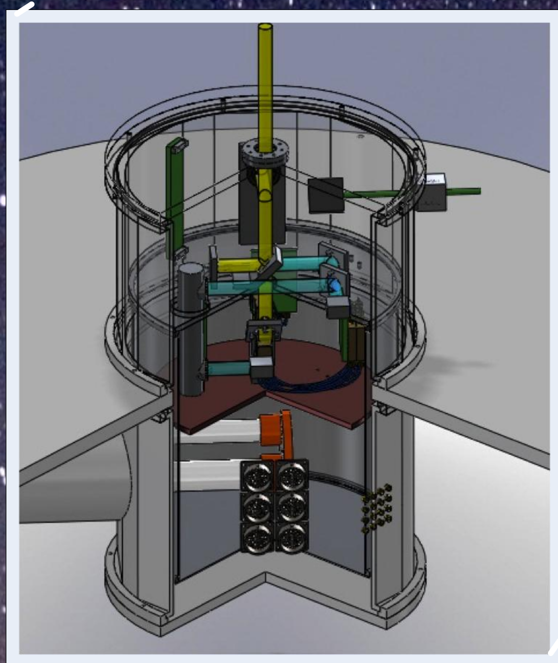
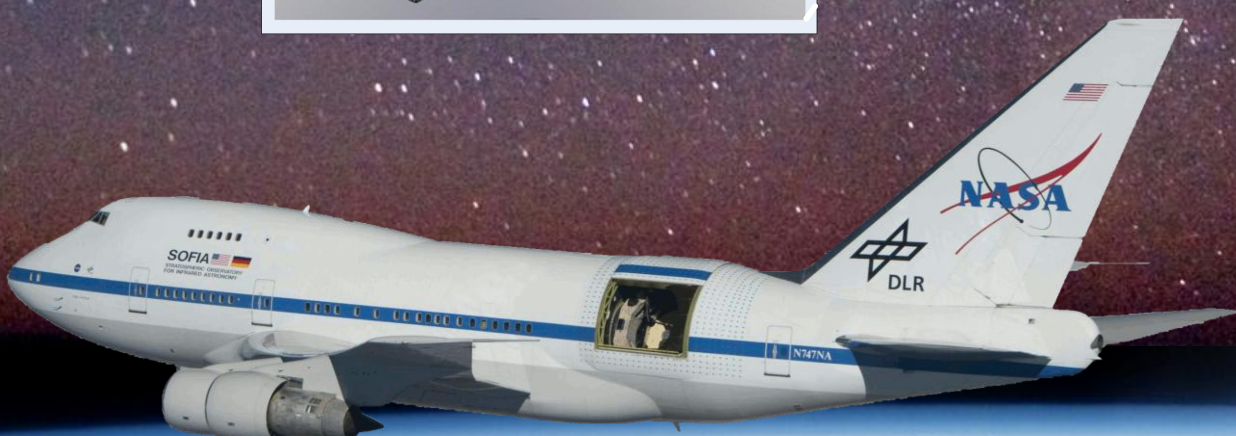
OCAM

An Oxygen Heterodyne Camera for SOFIA





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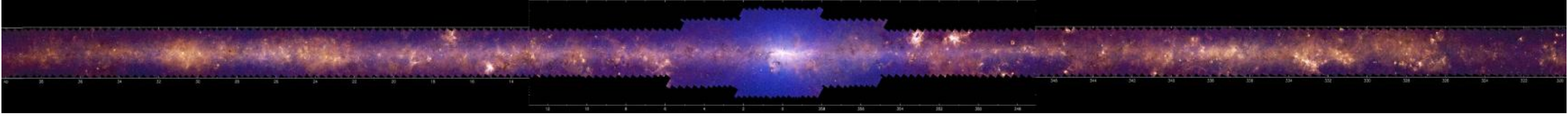


OCAM: Oxygen Heterodyne Camera for SOFIA

Science Objectives

The **Oxygen Heterodyne Camera (OCAM)** is a technology demonstration, 4 x 4, `Super'-THz heterodyne array instrument for SOFIA. It is optimized to observe the 63 µm [OI] fine-structure line. OCAM will be a new, powerful probe of the interaction of stars with their environment and serve as a pathfinder for future, large format, heterodyne arrays.

OCAM's receivers will provide the spectral and spatial resolution needed to untangle the complexities of the interstellar medium. OCAM directly addresses the **NASA Strategic Plan (2011) Goal 2.4:** *Discover how the universe works, explore how it began and evolved, and search for Earth-like planets.*

Goal 1: Investigate the radiative interaction of massive stars with their natal clouds.

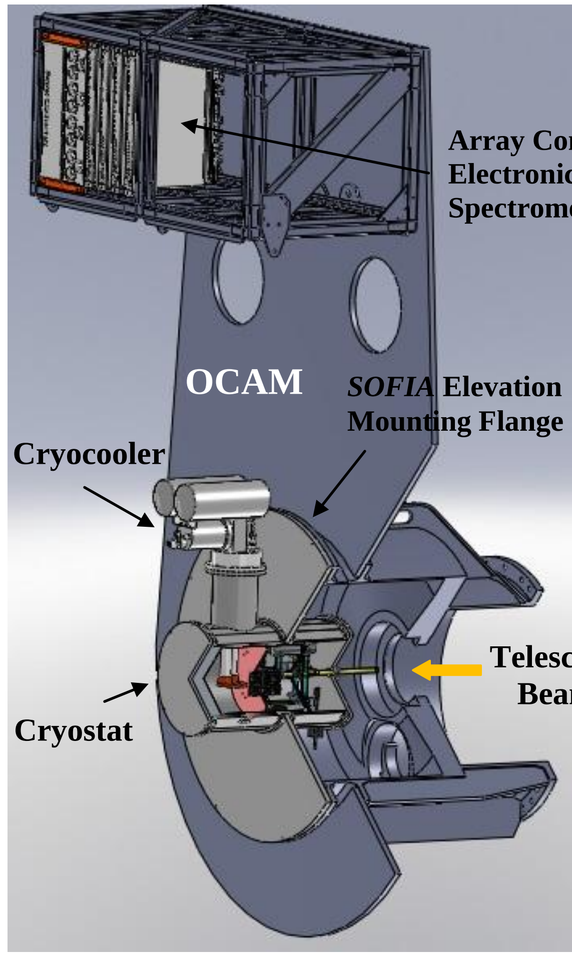
Goal 2: Investigate the interaction of protostellar winds and jets with their natal clouds.

Goal 3: Investigate the interaction of massive stars with their environment in the Galactic Center.

Goal 4: Uniquely probe conditions in the nuclei of nearby, face-on, normal & starburst galaxies.

Data Products

1. **Fully sampled, velocity-resolved, 25–250 square arc minute surveys of [OI] (63µm) line emission and/or absorption toward the Galactic Center, Orion, Cepheus, and M33 (see Fold-Out 1, Fig. 1.1-1.4).**
2. **Database of existing complementary line and continuum surveys.**

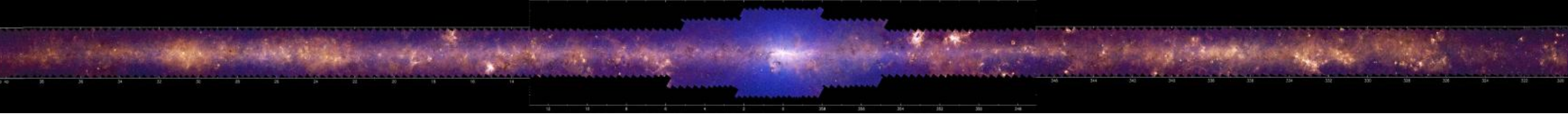


Major Mission Characteristics

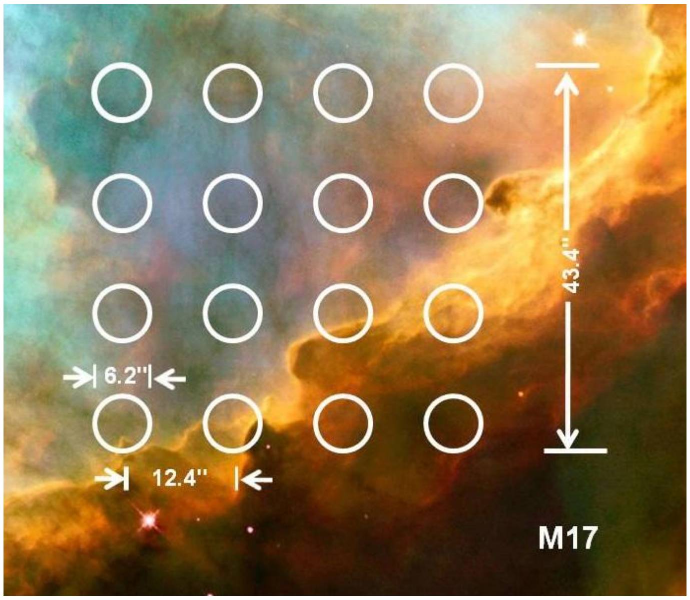
Mission mode : SOFIA 2nd Generation Instrument
Mission duration: 3 Science Demonstration Flights
Flight constraints: Spring/Summer (preferred)

Key Instrument Characteristics

Heritage: Herschel, STO, ODIN, SWAS technology
Receiver type: 16 pixel heterodyne array
Receiver Sensitivity: ~1000K DSB
Spectrometer: digital correlators: <1 km/s resolution, ~350 km/s velocity coverage per pixel
Cryogenic system: Helium-free, closed-cycle cryostat
Instrument Power: 9 kW
Instrument CBE Mass: 90 kg Flange; 230 kg SI pallet, (uncertainty 25%)



OCAM's 16 pixel array will dramatically increase the ability of SOFIA to conduct the high spectral resolution [OI] surveys needed to untangle the complex interactions of stars with the ISM. OCAM will utilize On-The-Fly (OTF) mapping techniques to make fully sampled maps of Orion, Cepheus A, the Galactic Center, and M33. >1,000 [OI] lines of sight will be observed on each flight; orders of magnitude more than all previous observations ***combined!***



OCAM/*SOFIA* Beam Footprint

The [OI] 63 µm line is superior to the [CII] 158 µm line in probing regions of massive star formation and the centers of galaxies. It is a unique probe of PDRs, shock waves from stellar winds/jets, supernova explosions, and cloud-cloud collisions.

Mission Management

Christopher Walker, (University of Arizona) PI

STO PI, 28 years experience designing, building, and using THz instruments for astronomy.

Craig Kulesa (University of Arizona) DPI

STO DPI, HEAT PI, 15 years experience designing/building astronomical instruments.

Brian Duffy (University of Arizona) PM

25 years management of military, oceanographic, and astrophysics projects, 3 years STO PM

S.H. Bailey (University of Arizona) DPM

20 years of spaceflight project management experience on four instruments

Teaming Arrangements – Direct Expertise Applied

UofA – Overall Project Lead

Provided multiple space-based instruments for astrophysics and planetary science.

SRON – 4.7 THz Mixers (J. R. Gao)

Provided mixer expertise and I&T for Herschel

MIT/Sandia – 4.7 THz LO (Qing Hu, John Reno)

World leader in QCL's for THz receivers

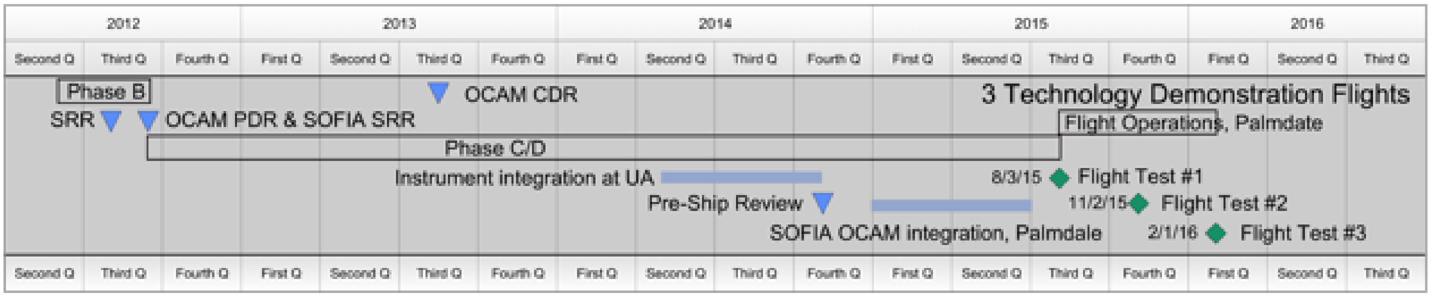
CIT – Low-noise Cryogenic amplifiers (S. Weinreb)

Extensive experience in receivers, amplifiers, and radio astronomy instruments

Science Team – World-Class Experience (Foldout 1)

Alexander Tielens (U.Leiden) –*OCAM Project Scientist*

Cost (Real Year Dollars)			
	Phase B	**Phase C/D**	**Total**
Cost	$814 K	$6,212 K	$7,026 K
Reserve	$204 K	$1,553 K	$1,757 K
NASA Totals	**$1,018 K**	**$7,765 K**	**$8,783 K**
Contributed			
Reserve			
Total	**$1,018 K**	**$7,765 K**	**$8,783 K**
Reserve %	25%	25%	25%



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D OVERVIEW

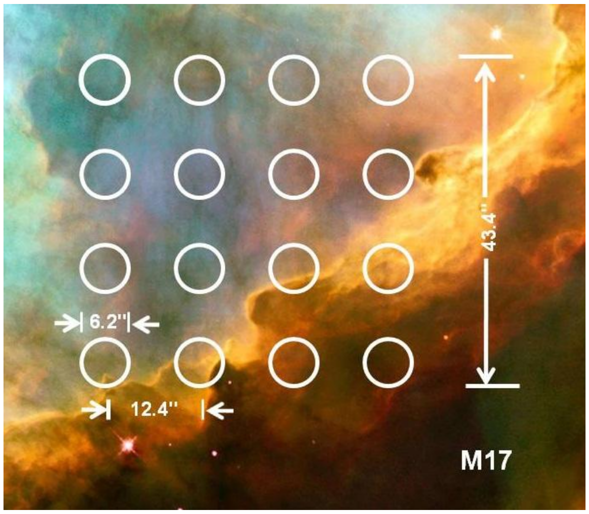


Fig. D-1.0: *OCAM's beam footprint on M17.*

The Oxygen Heterodyne Camera (OCAM) is a technology demonstration, 4 x 4, `Super'-THz heterodyne array instrument for SOFIA. It is optimized to observe the 63 µm [OI] fine-structure line (see Fig. D-1.0). OCAM will be a new, powerful probe of the interaction of stars with their environment and serve as a pathfinder for future, large format, heterodyne arrays.

The 63 µm (4.7 THz) [OI] fine-structure line is the dominant cooling line of warm, dense, neutral atomic gas. Because of its far greater intensity in high UV photodissociation regions (PDRs) and shocks, **the [OI] 63 µm line is superior to the [CII] 158 µm line in probing regions of massive star formation and the centers of galaxies. It is a unique probe of PDRs, shock waves from stellar winds/jets, supernova explosions, and cloud-cloud collisions.** These radiative and mechanical interactions shape the interstellar medium of galaxies and drives galactic evolution. The size scale of the interactions can excite [OI] emission over many parsecs. Moreover, the emission regions are often complex, with multiple energetic sources processing the environment. Spectrally resolved observations of the [OI] line with OCAM will allow users to disentangle this convoluted interaction and permit the study of the energy balance, physical conditions, morphology and dynamics of these extended regions. In this way, OCAM will provide new, unique, insights into the interrelationship of stars and gas in a wide range of galactic and extragalactic environments. The OCAM focal plane will contain 16, low-noise, hot electron bolometer (HEB) mixers each producing a 6.2" diffraction limited beam on the sky, with a total field of view (FOV) of 43.4". For a line width of δv = 0.4km s^{-1}, OCAM will achieve a 1σ antenna temperature [OI] detection limit of 0.30 K in 100 seconds. These limits vary as $\delta v^{-0.5}$. The 1σ intensity detection limit is $6x10^{-5}$ erg s^{-1} cm^{-2} sr^{-1} in [OI]. This limit varies as $\delta v^{+0.5}$.

0.1 Primary Goals

OCAM directly addresses the **NASA Strategic Plan (2011) Goal 2.4:** *Discover how the universe works, explore how it began and evolved, and search for Earth-like planets.*

The primary goals of the Science Demonstration flights are to use [OI] emission to:

Goal 1: Investigate the radiative interaction of massive stars with their natal clouds.

Goal 2: Investigate the interaction of protostellar winds and jets with their natal clouds.

Goal 3: Investigate the interaction of massive stars with their environment in the Galactic Center.

Goal 4: Uniquely probe conditions in the nuclei of nearby, face-on, normal & starburst galaxies.

0.2 Mission Approach

During its 3 science demonstration flights on SOFIA, OCAM will image a number of regions in the Galactic Center at 6.2" spatial and 0.4 km/sec velocity resolution. Maps will also be made toward star forming regions (e.g. Orion, W3A, M17, Cepheus) and towards a spiral arm region of the nearby, face-on galaxy, M33. The proposed observations will provide powerful, new insights into the evolution of the ISM both in the Milky Way and beyond.

0.3 Data Products

1. **Fully sampled, velocity-resolved, large area surveys of [OI] 63μm line emission and/or absorption toward the Galactic Center, Orion, Cepheus, W3A, M17, and M33 (see Fold-Out 1, Science, Fig. 1.1-1.4).**
2. **A database of existing complementary line and continuum surveys.**

The data products from OCAM will be data cubes of spectral line maps, a standard radio astronomy product.

0.4 Complementarity to Other Missions

OCAM surveys directly complement the spatially limited (single pixel) [OI] observations planned with the GREAT heterodyne receiver on SOFIA; increasing the volume of science data gathered on any given flight by more than an order of magnitude. The OCAM data set will serve as a Rosetta Stone for interpreting the lower spectral resolution [OI] data being collected on *Herschel* and, in the future, with FIFI-LS on *SOFIA*.

D- 1 SCIENCE GOALS & OBJECTIVES

The radiative and mechanical interaction of stars with their environment drives turbulence and the dispersal of molecular clouds, an essential part of the life cycle of the ISM, breaks and reforms molecules, resetting the organic inventory of space, and, in partnership with gravity, sculpts the Universe in which we live. High spectral resolution observations of the 63 μm (4.7 THz) line of [OI] with OCAM on SOFIA will provide a new, powerful probe of this interaction, previously unattainable on extended size scales. High spectral resolving power is essential for disentangling the complex, violent interactions of stars and gas.

OCAM exploits dramatic developments in THz technology and digital signal processing to fly a multi-pixel, 4.7 THz heterodyne camera. Due to severe atmospheric attenuation at ground and mountain-top altitudes, ***observations of this line can only be conducted from suborbital or space-based platforms.*** At SOFIA altitudes (~41,000 ft) the atmosphere has ~75% transmission. Obtaining extended, velocity-resolved images of [OI] will (for the first time) offer the possibility of disentangling the complex interaction of protostars with their natal clouds and fully understanding the effects of stellar feedback.

D- 1.1 Overview of OCAM Capability

The main capabilities of OCAM are:

1. **High spectral (<1 km/s with 300km/s instantaneous bandwidth) and high spatial (6.2") resolution.**
2. **High speed mapping capabilities (collect more than ~1,000, high quality (T_{rms}< 1K), [OI] spectra per flight).**
3. **High sensitivity (detect [OI] emission from the gas around every B star in the galaxy and detect [OI] in absorption in clouds with A_v > 0.5-1 in surveyed regions).**

D-1.2 Specific Goals and Objectives

D-1.2.1 Goal 1: Radiative interaction of massive stars with their natal clouds

The [OI] 63 μm line is the dominant cooling line of dense PDRs and provides a unique probe of the physical conditions and dynamics of photo-evaporating clumps and cloud surfaces illuminated by strong UV radiation fields. We propose to study the [OI] emission from a small sample of PDRs surrounding HII regions, spanning the full evolutionary range from deeply embedded ultracompact HII regions to highly evolved regions in their champagne phase to study the dispersal of molecular clouds due to FUV radiation from OB stars.

Most stars form in cold Giant Molecular Clouds (GMC) with sizes of tens of parsecs, average gas densities of order 50 H_2 molecules cm^{-3}, and masses of order 10^5 $M_\odot$. The clouds, however, are very clumpy and the typical density of the clumps well exceeds 10^3 cm^{-3}. The massive O and B stars, with luminosities of 10^4 to 10^6 $L_\odot$, radiate mainly FUV (6-13.6 eV) and EUV (> 13.6 eV) photons that ionize, photodissociate, and heat their surroundings. Once an OB star is formed, the EUV creates 10^4 K HII regions of extremely high thermal pressures. These HII regions expand into the GMC and eventually breakout, creating ionized flows that disperse the GMC (see Figure D-1.1). The FUV radiation photodissociates and heats (T~ 100-3000 K) a neutral layer of hydrogen column (N ~ 10^{21} to 10^{22} cm^{-2}) that surrounds the HII region until breakout, after which it forms a surface layer on the GMC. This layer is called a photodissociation region or PDR (Hollenbach & Tielens 1999). Clumps in the PDR will be photoevaporated by the FUV heating of their surfaces. The warm neutral gas in the PDR can partake in the dispersion of the GMC and, because FUV photons penetrate more gas column than EUV photons, the FUV may actually dominate this process.

The evolution of the HII region begins with the early ultracompact stage, where the electron densities are n_e~ 10^5 cm^{-3}, the sizes ~ 0.01 pc, and the surrounding PDRs have hydrogen densities of n~10^6 cm^{-3} and FUV fluxes given by G_0 ~ 10^6, where G_0 is the FUV flux in units of the local interstellar field, or $1.6x10^{-3}$ erg cm^{-2} s^{-1}. This stage may last ~ 10^5 years. As the HII region and surrounding PDR expand, the electron and surrounding neutral hydrogen densities decrease, and the FUV flux on the PDR declines. In this way, the dynamics of the expanding HII region adds turbulence and supersonic internal motions in the GMC. By the time the HII region breaks out of the cloud, which typically occurs in ~ $3x10^5$ years when n_e ~ 100 cm^{-3}, the PDR density n~10^4 cm^{-3}, and the FUV flux is G_0~1000. The HII region size is typically~ 3 pc. After breakout, the EUV and FUV photons erode the surface of the GMC, and push it away from the OB association. This is the period of GMC dispersal. Here, the PDR densities and G_0 drop further. This “blister” period lasts the life of the OB stars, or the life of the GMC, whichever is shorter, but in any case is of order 10^6 to 10^7 years. During both the embedded period and the blister period the typical flow velocities of the neutral gas traced by [OI] is of order ~ 1-10 km/s. Clumpiness inside the GMC means that the HII region is by no means spherical, and the PDRs that are formed trace the clumpy structure of the cloud. This interaction between massive stars and their natal cloud controls the star formation process by compressing gas clumps

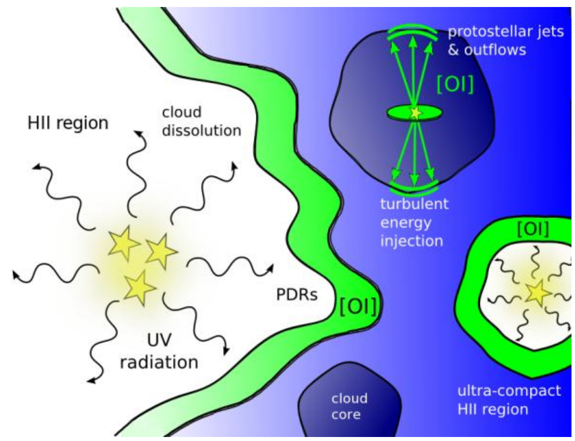


Figure D-1.1 *Different stages in the evolution of the interaction of newly formed stars with their natal clouds. Protostellar jets and winds drive strong shocks in their surroundings, injecting turbulent energy. EUV and FUV radiation create (ultra)compact HII regions surrounded by PDRs that will expand into the cloud until they break out as a ‘champagne’ flow. In this way, molecular clouds are stirred up, dispersed, and their star formation is stopped. OCAM is uniquely suited to trace this dynamic and energetic interaction between stars and their natal clouds.*

through shocks – triggering subsequent star formation – photo-ionizing and photoevaporating envelopes around low mass protostars in the cluster – creating prominent globules, fingers, and proplyds – and dispersing gas in ionized and neutral gas flows. As illustrated in Figure D-1.1, the formation and evolution of stars in GMC's drives turbulence, photo-evaporation, and cloud dispersal, which are key parts of the Life Cycle of the ISM. ***The primary goal of OCAM is to better understand how the intense radiation fields and jets and winds from newly formed stars drive these processes.*** Besides the fundamental interest in tracing the energy flow in the Galaxy, the proposed observations coupled with theoretical models (Fig. D-1.2) will provide the gas physical conditions (temperature, density, and incident UV fields on clouds).

[OI] 63 μm emission mapped at high spatial and spectral resolution is an ideal probe for the radiative interaction of massive stars with GMCs. This line dominates the cooling of PDRs for G_0 > 100 and n>100 cm^{-3}, see Figure D-1.2. Typically, the [OI] luminosity is 10^{-3} -10^{-2} of the luminosity of the OB star or stars which power the HII region and PDR.

OB associations range in luminosity from ~10^4 $L_\odot$ (a single B star) to 10^7 $L_\odot$ (superstar clusters with hundreds of OB stars). Therefore, we anticipate [OI] luminosities of ~ 10^2-10^5 $L_\odot$ from the surrounding PDRs. In the later stages of evolution, this luminosity arises from an extended region (e.g., 3 pc at 1 kpc is ~ 10') so that only a small fraction of the luminosity lies in an individual *SOFIA* pixel. Nevertheless, in massive star formations regions like Orion, the [OI] surface brightness is expected to be ~2x10^{-3} erg cm^{-2} s^{-1} sr^{-1} on a size scale of 10'. At this brightness, OCAM can directly trace the evolution of the gas and follow the dispersion of clouds.

At high gas densities, the [OI] 63 μm line dominates the cooling, with the [OI]/[CII] ratio reaching ~100 at n ~10^6 cm^{-3}. [CII] dominates the cooling at lower densities (n ≤1000

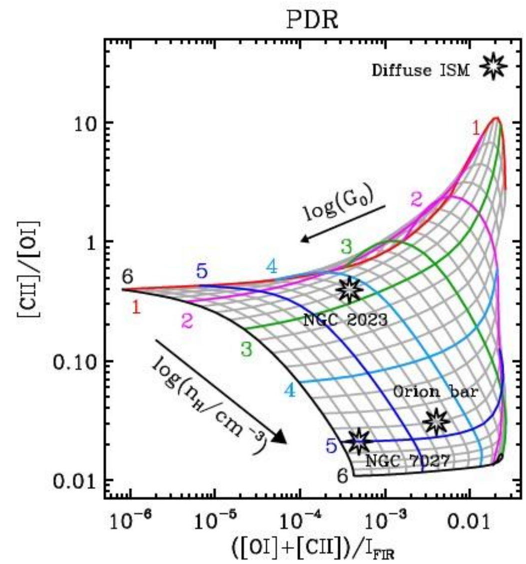


Figure D-1.2*: Diagnostic diagram for the [OI] & [CII] emission from PDRs in terms of the density, n_H, and incident UV field, G_0 (Kaufman et al 2006). [OI] is brighter than [CII] in all regions with G_0>10^3. Comparison of line intensities and dust continuum levels directly probes the density and incident FUV field of a PDR. Observations of a few prototypical PDRs are indicated.*

cm^{-3}). The [OI]/[CII] line ratio at n >1000cm^{-3} is mainly sensitive to density, while at lower density the [OI]/[CII] ratio is mainly sensitive to gas temperature or incident UV radiation field. Figure D-1.2 demonstrates how the [OI] line, in combination with the [CII] line and the bolometric IR continuum, can be used to diagnose gas density, FUV flux, and thereby gas temperature. In addition, the ([CII]+[OI]) /FIR (far infrared) continuum from GLIMPSE, MIPSGAL, and HiGAL) provides an observational measure of the grain photoelectric heating efficiency. This procedure is well established and has been used to analyze previous *KAO*, *ISO*, and *Herschel* observations (Kaufman et al 2006; Steiman-Cameron et al 1997).

We propose to investigate the energetics and dynamics of the radiative interaction of massive stars with their parental clouds using OCAM. We have selected a sample of sources which span the full evolutionary sequence of this interaction; from the earliest phase as a deeply embedded ultracompact HII region (e.g., W3A), through the compact HII region phase where a champagne flow has just broken out of the cloud (M42-Orion), to more fully developed flows (e.g., M17). The sample also probes the embedded cluster size, ranging from HII regions powered by single or a few O stars (W3A, Orion; See Fold-Out 1, Science, Fig. 1.1), to those powered by 10-50 O stars (M17), to regions powered by 100's of O stars (Arches, Quintuplet clusters, see section D-1.2.3). In each of these types of objects, we have selected a region with a size of 4'x4' centered on regions we expect to be dynamically representative for the star-cloud interaction – such as prominent ionization bars, evaporating globules, fingers or other dynamically evolving structures – which we will fully sample with OCAM. Supporting dust continuum and [CII] observations of all these regions exist through Spitzer and Herschel programs but only OCAM can provide the required spectral resolution to disentangle PDR and shock contributions in these dynamically confused regions and measure the photo-evaporation of molecular clouds due to OB stars.

D-1.2.2 Goal 2: Protostellar winds and jets interacting with their natal clouds

The [OI] 63 μm line is one of the strongest shock emission lines of the galaxy and provides an excellent diagnostic of mass loss from protostellar winds and jets. We propose to measure the [OI] associated with the outflows in the Cepheus cloud and study the global input of turbulent energy into molecular clouds by winds and jets of embedded low mass protostars.

Both forming and dying stars produce spectacular jets and outflows. Protostellar jets and wider-angle winds drive shocks into the surrounding cloud and entrain swept-up shells whose influence can reach up to 10 pc or more from the driving sources (See Fold-Out 1, Science, Fig. 1.2).

As accelerated gas interacts with its environment, it can generate turbulence, sputter grains, dissociate molecules, ionize atoms, and even disrupt the parent cloud, stopping further accretion and star formation. Outflows dominate feedback in regions forming only low-to intermediate-mass stars and may therefore contribute to the shaping of the IMF. Some massive star-forming regions such as Orion OMC-1 produce poorly collimated explosive outflows. Dying stars produce expanding envelopes. Their collapsing cores propel jets and fast winds into these envelopes during the proto-planetary nebula phase, often producing outflow structures resembling those powered by forming stars.

Radio, mm, near-IR, and visual tracers provide measurements of the velocities and masses in various flow components. Since each is a highly selective tracer of specific shock velocities, densities, and states, they provide an incomplete picture of the outflow. For example, species such as CO are calorimeters of the mass and momentum of swept-up, molecular gas; visual and near IR lines of H, [SII], [FeII], and H_2 trace the locations and velocities of fast (> 20 km/s shocks). ***However, because of its low-excitation (excited state only 228 K above ground) and the high abundance of elemental O, the 63 μm [OI] line is one of the strongest and most ubiquitous shock emission lines in galaxies.*** In fast (> 50 km/s) shocks where the cooling is dominated by optical and UV lines, the [OI] line is an excellent diagnostic of the mass loss in the wind or jet being shocked as it impacts the environment around young stars (Hollenbach 1985).

High extinction in embedded and distant regions renders near IR and optical tracers useless. For example, while the 2 μm lines of H_2 can be used to probe outflows in nearby, low-opacity regions, attempts to observe this tracer in clouds more than a few kpc from the Sun have mostly failed due to high extinction. In contrast, the long wavelength [OI] line can be observed nearly anywhere in the Galaxy.

A heterodyne focal plane-array is needed because mapping of the velocity and line-width is essential for discriminating between source models. [OI] associated with outflow lobes will closely follow the jets and cavity walls traced by reflection nebulae, heated PAH layers detected by *Spitzer*, or traced by molecular emission lines. Photo-excited emission from PDRs and from slow-shocks associated with D-type ionization fronts are expected to follow the warm-dust traced by *Herschel/*PACS 70μm and *Spitzer* 8 and 24 μm emission. In addition, the resolved line profiles can discriminate the broader emission from shocks from the narrow emission from PDRs. Low mass protostars often form in clusters, and in nearby star-forming clouds the extent of these clusters is of order arcminutes. The mapping capability of OCAM, with its 16 pixels, will enable a quick census of the mass and momentum input of the winds and jets of these outflows, and their contribution to the observed turbulence in molecular clouds.

OCAM will extend the investigation of outflows in the distant, highly obscured regions of the Galactic plane and Central Molecular Zone (CMZ) where the most massive stars and star clusters in our Galaxy are forming. Examples of such regions include: the Sgr B2 complex, the most massive and luminous star forming complex in the Milky Way, W43, W49, and W51 – three `mini-starbursts' which are the closest analogs to the super-star-cluster (SSC) forming regions in nearby galaxies such as M82 and the Antennae. The 6.2" angular resolution of *SOFIA*, combined with the sub-km/s spectral resolution and several hundred km/s bandwidth of OCAM, will enable the detection of outflow such as Orion OMC-1 in these distant complexes without the line-of-sight confusion seen in CO or HCO^+ towards the inner-galaxy or the CMZ.

D-1.2.3 Goal 3: The interaction of massive stars with their environment in the galactic center.

OCAM is well suited to probe the unique star forming environment of the galactic center and measure the energetics, physical characteristics, and kinematics of the warm, dense gas in the PDRs associated with the super star clusters in this environment. This will be a key stepping stone for our detailed understanding of the interaction of massive stars and their environment on the scale of galactic nuclei.

At a distance of only 8 kpc, the center of the Galaxy provides a unique opportunity for studies of the physical and chemical conditions of the interstellar medium and the star formation process in the nuclei of galaxies. Molecular clouds in the Galactic Center are unique because they have higher temperatures and densities, and stronger turbulent velocity fields (e.g., Guesten & Philipp 2004). Magnetic fields with mG field strength have been reported, that – at least locally – control the dynamics of some clouds. The heating is manifold with OB stars near the center creating diffuse ionized regions surrounded by PDRs at the edges of the cavities. Clouds compressed at the edges of the expanding bubbles are shock heated (e.g., Martin- Pintado et al. 1999). The dense gas phase in shielded cloud cores is heated by dissipation of small-scale turbulence (Wilson et al. 1982) and/or magnetic viscous heating (Guesten et al. 1987). It is therefore not surprising that the galactic center is a unique star forming environment. Several dense clusters containing thousands of OB stars are interacting vigorously with the surroundings through strong radiation fields and intense shock waves. Velocity and spatially resolved [OI] studies will provide a new view of the interaction of massive stars with their natal clouds in this unique setting.

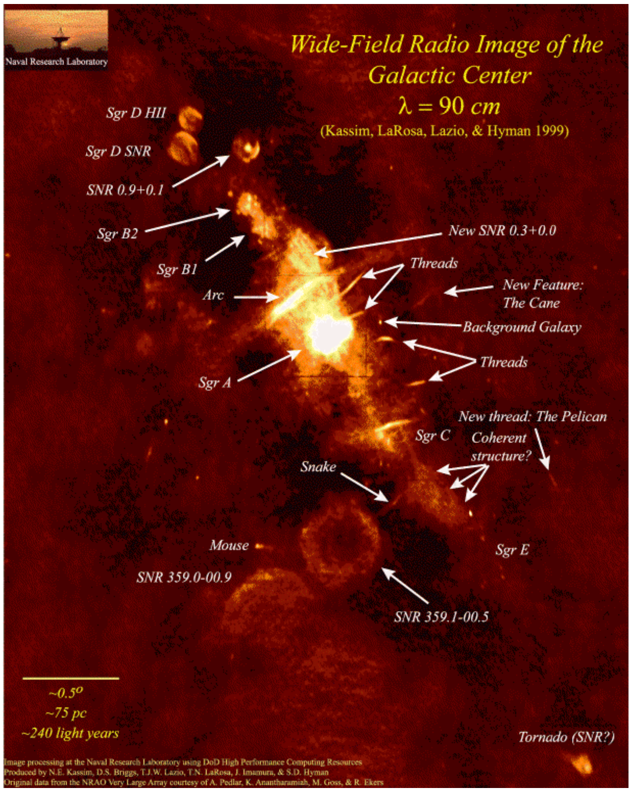


Figure D-1.3: *Large-scale VLA image of the galactic center, showing the mix of prominent HII regions, supernova remnants, and non-thermal filaments (Kassim et al. 1999).*

Most of the ~4 x 10^7 $M_\odot$ of gas within the central 300 pc of our Galaxy resides in relatively dense molecular clouds, although an atomic component globally comprising a few percent of the total mass is evident in HI (Lang et al. 2010, & references therein). The atomic component resides largely in PDRs around prominent HII regions created by massive stellar clusters, such as the Arches, Quintuplet, and Central Parsec clusters, and around embedded, compact HII regions around massive clusters in formation, such as Sgr B2 and Sgr C (see Figure D-1.3). One of the most spectacular HII complexes in the Galaxy surrounds the Arches and Quintuplet clusters, which produce the large-scale "Radio Arc Bubble" (Foldout 1, Science, Figure 1.3), a strong shock colliding with its immediate environment (e.g., Simpson et al. 2007). Extended [OI] and [CII] have been observed with ISO toward the Sickle and Arches Filament molecular clouds lying at the upper rim of this Bubble (Cotera et al 2005; Poglitsch et al. 1991) but the limited spatial resolution and possible absorption by foreground material hamper interpretation in terms of the PDR density, temperature, and FUV field as well as the energy and momentum of the extensive shocks surrounding the Radio Arc Bubble.

The Circumnuclear Disk (CND) – *the presumed reservoir for future episodes of accretion on to the central black hole* – surrounds the central stellar cluster of young, massive stars, and has been regarded by theorists as a rather porous PDR. In a previous study with the KAO, Jackson et al. (1993) measured strong [OI] emission from the ionized interior of the CND – Sgr A West – and pointed out that the atomic component of the central CND cavity carries an order of magnitude more mass than the ionized gas. Their [OI] mapping indicated that the inside edge of the CND itself may have some emission, but their resolution and sensitivity were not adequate to characterize the CND in any detail. Both the porous structure and the large atomic-to-ionized gas mass set this interaction zone between the central cluster and its surroundings apart from other regions of star formation in the galaxy. The CND is therefore an ideal target for OCAM on SOFIA.

Our strategy for observing the GC with OCAM is to map the 63μm line in four extended regions in the GC, as shown in Foldout 1, Science, Figure 1.3. The first, and largest – 14'x8' – is centered on the CND, and includes the compressed rim of the supernova remnant Sgr A East, which surrounds the CND in projection and possibly in 3D and the prominent 20 and 50 km s^{-1} molecular clouds. With OTF mapping to a sensitivity of 7×10^{-5} erg cm^{-2} s^{-1} sr^{-1} at 1 km/s resolution, and regridding to 12" spatial resolution, the CND-centered region can be observed in one 3-hour observing leg, allowing for overhead. The high spectral resolution is important for the characterization of foreground absorbing clouds (discussed below), but better sensitivity is achievable on the broad-lined GC clouds by smoothing the emission lines to a resolution of ~5 - 10 km/s.

The other three regions – all 6'x6' in extent – are centered on the Sickle and Arches HII regions and on Sgr B2 – a dramatic massive cluster in formation (Figure D-1.3). OTF mapping to a sensitivity of $2x10^{-5}$ erg cm^{-2} s^{-1} sr^{-1} would require about two hours per region, with overhead, so these three regions could be mapped in two 3-hour flight legs. As outlined in section D-1.2.2 and D-1.2.3, at the regridded resolution, the observed [OI] 63 µm emission can be analyzed together with existing dust continuum and (spectrally unresolved) [CII] 158 µm maps from Spitzer and Herschel to provide the density, temperature, UV field in the PDRs and the mass loss and kinetic energy input by massive stellar winds.

An important secondary benefit of the proposed observations is that they will probe foreground gas. The CMZ is a strong continuum source at 63µm (e.g., Molinari et al. 2011), so gas in cold foreground clouds in the 3 kpc, Scutum, and Sagitarius-Carina arms should be visible in absorption. The narrow lines from these clouds – seen in absorption in many molecular lines – make them relatively easy to distinguish from the CMZ emission. In this way we can probe the oxygen abundance in different regions in the galaxy (see D-1.2.5.2). Most importantly, we are likely to see in absorption gas that is orbiting the GC in the innermost X1 orbits (sometimes referred to as the expanding molecular ring, or EMR). According to the prevailing paradigm (Binney et al. 1991), this gas has recently undergone the transition from atomic to molecular, as it migrates inwards via interactions with the Galactic bar. This gas has a relatively low density, so [OI] in the near side of the EMR would be seen in absorption against the bright continuum from warm dust in the CMZ, much as molecules such as OH and H_2CO in the near side of the EMR are seen in absorption against the radio synchrotron background. The EMR features are usually separable from the CMZ emission features because of large velocity offsets.

D-1.2.4 Goal 4: [OI] in Nearby Galaxies

OCAM allows the study of the interaction of massive stars on the global scale of OB associations in local group galaxies. Here, we propose to measure the [OI] emission in the nucleus of M33 and several prominent HII region complexes in order to measure the energetics, physical characteristics, and kinematics of the warm, dense gas in the PDRs as the massive stars destroy their natal clouds.

For a comprehensive view of the processes that drive star formation and the evolution of the interstellar medium, the conditions affecting star formation locally must be considered in the context of the overall dynamics of the galaxy. As gas is compressed in spiral arms, molecular cloud complexes are formed and star formation is triggered (Elmegreen 2011), resulting in rich star clusters and OB associations. The combined radiative and mechanical action of these stars will in turn shred the clouds stopping further star formation. The interstellar medium changes state as it flows through the stellar spiral density wave. This interaction is difficult to follow in our own galaxy because of the vast scales involved and the line-of-sight confusion but yet it is at the core of the life cycle of the interstellar medium. [OI] 63 µm observations of extragalactic HII region complexes provide an excellent tool for the study of the relevant processes on a global scale.

Existing observations and detection of the [OI] 63µm line in galaxies demonstrate the value of OCAM for extragalactic sources. The [OI] 63µm line was detected in emission from M82 (Watson et al. 1984), NGC 253, and NGC3256 (Carral et al. 1994) using the Kuiper Airborne Observatory. Subsequent studies have used ISO/LWS (Malhotra et al. 2001, Higdon et al. 2003, Kramer et al. 2005), and *Herschel*/PACS (Mookerjea et al. 2011). The observations fall into two categories: (1) single spectra, with arcminute spatial resolution and ~ 100 km s^{-1} spectral resolution, of a galaxy's central region, and (2) small maps (2′×2′), with 7″ resolution and ~100 km s^{-1} spectral resolution, of star-forming regions in spiral arms. OCAM data will have substantially higher spectral resolution, providing valuable insight to the physical processes involved. The flux of the [OI] 63µm line is comparable to or greater than that of the [C II] 158µm line in luminous regions and is a significant fraction (~0.2%) of the total power emitted by spiral and irregular galaxies. The [OI] line flux, in combination with the [CII] 158 µm line flux and the far-infrared continuum flux provide the physical conditions in the emitting gas; e.g., the comparison of [OI] to [CII] and ([OI] + [CII]) to the IR continuum measure the gas density and strength of the illuminating UV field (Fig. D-1.2). Malhotra et al. (2001) were able to determine these values over broad regions in the centers of galaxies. OCAM maps of these galaxies will have 100 spatial resolution elements and 100 velocity resolution elements for each ISO/LWS beam. The value of improved spatial resolution is exemplified by *Herschel*/PACS maps of the HII region BCLMP302 in M33 (Mookerjea et al. 2011, Figure D-1.4). The [OI] emission varies strongly over a 2′ region and its distribution provides substantially new information, and new insight into the spiral arm phenomenon. **The observed extent and variability of the [OI] emission underscores the need for large format heterodyne arrays on SOFIA.**

OCAM will dramatically improve [OI] observations over the current state of the art, having both higher spatial resolution and orders-of-magnitude better velocity resolution. A region in a spiral galaxy like that shown in Figure D-1.4 will typically have an overall linewidth of 20 km/s comprised of multiple components. OCAM will, for the first time, resolve those components and show their dynamical interactions. Spiral density wave phenomena that create and destroy molecular clouds result in dynamical effects having velocities that are typically a few kilometers per second, velocities that can, for the first time, be resolved and measured by OCAM.

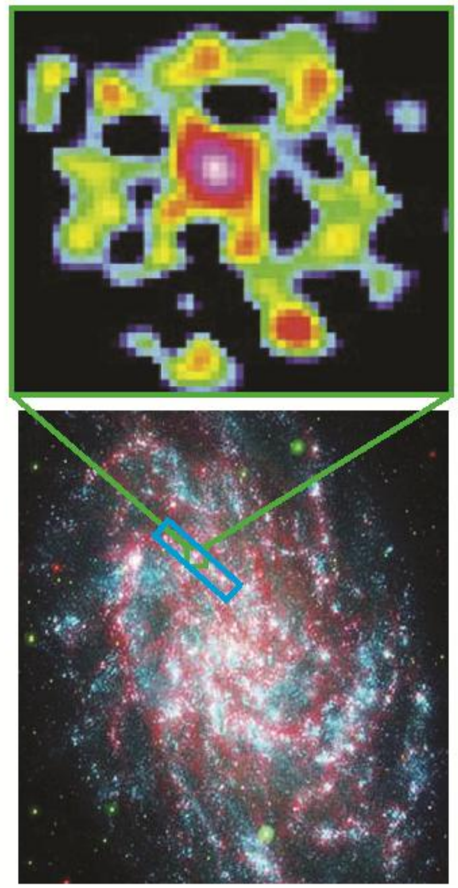


Figure D-1.4: (lower*) False color image of the nearby galaxy M33 obtained by GALEX and Spitzer. Far-ultraviolet light from young stars glimmers blue, near-ultraviolet light from intermediate age stars glows green, while the red traces the photodissociation regions through the fluorescent emission of PAH molecules pumped by these ultraviolet photons.* (upper) *intensity of the [OI] line with 12″ resolution in the small region shown in green in the lower map, from Mookerjea et al. (2011). High spectral resolution [OI] mapping* *of M33 with OCAM (cyan box in lower frame) will trace the energetics and dynamics of the UV photons from the young massive stars with their environment.*

The local group, late-type spiral galaxy, M33, is an ideal target for studying the global aspects of the interaction of massive stars with their natal clouds. With its fairly face-on view (inclination is 56 degrees) and loose SA(s)cd structure, the open spiral arms resolve into a multitude of individual stellar clusters and HII regions. At a distance of 840 kpc, OCAM's pixels correspond to 25 pc and are well matched to the size scale of well-developed OB associations and their associated giant HII region complexes. M33 is also a regular, relatively unperturbed disk galaxy and has been well studied at X-ray, UV, optical, far-infrared, submm and radio wavelengths. Of key importance to this proposal, dust continuum observations and (spectrally) unresolved [CII] observations have been obtained with Herschel. With OCAM we will target the nucleus of M33 and the prominent HII regions, NGC604, NGC 595, IC142, BCLMP302, and BCLMP691.

D-1.2.5 Enabled science

The development of a sensitive heterodyne array at the [OI] frequency will enable a broad range of science questions to be addressed. These include the inner winds of Asymptotic-Giants Branch (AGB) stars, the interaction of the superwind with previous ejecta in post-AGB objects and planetary nebulae, the effect of the reverse shock on ejecta in young supernova remnants such as Cas A, the inner winds of red supergiants such as alpha Ori, the [OI] emission from nearby protoplanetary disks, the [OI] emission from X-ray excited gas, and the oxygen elemental abundance in the ISM. Extended absorption line studies with OCAM will be particularly powerful, as they provide the only measure of cold oxygen gas in the neutral ISM.

D-1.3 OCAM Complements Past Work

D-1.3.1 Relationship to Existing Data Sets

The data from the proposed OCAM science investigation will be highly complementary to existing observations performed in other atomic and molecular species, as well as continuum surveys. These include observations carried out by *Herschel* and other space missions.

CO: The CO surveys in the Galaxy[41,42,43] and LMC[44,45] will complement the OCAM survey by identifying molecular clouds whose surfaces OCAM detects and in which embedded young stars drive [OI]-producing shocks.

H I: OCAM observations enhance substantially the interpretation of existing H I surveys, allowing the PDR region where these two neutral atomic species coexist to be explored.

[CII] & [C I]: The velocity resolved [OI] 63 μm OCAM data will greatly enhanced the spectrally unresolved [CII] 158 and [CI] 609 and 370 μm studies obtained with PACS and SPIRE on Herschel. Coupled with CO data, this will provide a powerful probe of PDR chemistry, dynamics, and physical conditions.

Infrared Continuum Surveys: MSX, *Infrared Astronomical Satellite* (*IRAS*), *Infrared Space Observatory* (*ISO*), *Spitzer* GLIMPSE and MIPSGAL, and *Herschel* HIGAL Galactic plane surveys, and *Spitzer* SAGE and *Herschel* HERITAGE LMC surveys permit locating dark clouds, supershells, filaments and star forming regions using the IR continuum. The proposed OCAM Galactic Center survey provides the best corresponding interstellar cloud survey in [OI] that will place these 2D imaged structures in a broader context by identifying them with different phases of the ISM, providing a 3-dimensional location in the Galaxy via their Doppler shift, and measuring their internal velocities and velocity dispersions.

D-1.3.2 Complementarity to Other Missions/Instruments

SOFIA is the ***only existing*** platform for conducting high spectral resolution [OI] 63 μm observations (the *KAO* having been the only other). OCAM observations will complement the ongoing lower spectral resolution [OI] observations being conducted on *Herschel* by PACS and soon on *SOFIA* by FIFI-LS. The spectral resolving power ($\lambda/\Delta\lambda$) of OCAM is ~1000x greater than these instruments. The GREAT instrument on SOFIA can provide similar high spectral resolution, but OCAM will have several times the instantaneous bandwidth and far greater mapping speed.

D-2 INVESTIGATION REQUIREMENTS

D-2.1 Spectral Resolution

OCAM instrument requirements are summarized in the Science Traceability Matrix (see Fold-Out 1). Proposed survey regions in Orion, Cepheus A, the Galactic Center, and M33 are indicated with white boxes in Fold-Out 1, Figs. 1.1 – 1.4.

The flow motions of the neutral gas heated by energetic radiation are typically of order 1–10 km/s. The thermal and/or microturbulent velocities are of order 1 km/s. Therefore, we require spectral resolution of somewhat less than 1 km/s.

D-2.2 Spatial Resolution and Mapping Capability

An expanding HII region with a PDR shell surrounding it starts with a size of order 0.01 pc and expands to sizes of order many pc. At 1 kpc these sizes correspond to angular sizes from 2" to > 200". Therefore, to observe numerous expanding HII regions at various epochs (and therefore sizes) requires a single pixel beam size of order a few arc seconds, but at the same time the ability to map regions of size ~ several arcminutes, or a region perhaps 1 to 10% of the area of a GMC. Typically, the angular size of young, low mass clusters is of order arcminutes in nearby molecular clouds. The typical separation of individual low mass stars is of order 5-10". Thus, a single pixel beam size of 5-10" and a mapping capability of a few arcminutes is required.

D-2.3 Sensitivity

For the sensitivity estimate, we consider an OB association at a distance of 10 kpc with FUV luminosity of ~ 10^4 $L_\odot$ (i.e., single B star) and assume that this source is smaller than the 6" diffraction limit of *SOFIA* at 63 μm, and that the [OI] luminosity is 100 $L_\odot$ (see section D-1.2.1) and the line width is 10 km/. Also, assume a velocity resolution of 1 km/s. The flux on a single pixel and in a single velocity channel is then $3x10^{-12}$ erg cm^{-2} s^{-1}. Thus, we require a single velocity channel line flux sensitivity of ~ 10^{-12} erg cm^{-2} s^{-1}.

D-3.0 OCAM Data Products

The OCAM data products will be comprised of a set of FITS (Flexible Image Transport System) files that contain a cube of data corresponding to line intensity as a function of the 2 angular coordinates and spectroscopic axis. The data cubes are generated in a pipeline that consolidates the raw, On-the-Fly Mapping data into a grid of Nyquist-sampled spectra. There will be a separate FITS cube for each measured spectral line observation. Each data cube will be fully calibrated with subtracted spectral baselines. For each FITS cube, the OCAM team will also deliver a set of two dimensional images that includes a statistical error image of intensity values and a masked moment image equivalent to integrating over the full spectral bandpass.

D-4.0 Minimum Science/Technology Mission

<u>OCAM's goals are twofold; demonstrate the path forward to achieving large-format, high frequency, THz heterodyne focal plane arrays on SOFIA and to conduct groundbreaking science with a building-block prototype, 4.7THz array.</u> These goals could potentially be achieved using one of OCAM's 1x4, [OI] subarrays and two flights on SOFIA. The principal science goals would be achieved by making 10'x10' maps of the Galactic Center, M33, and Orion. The minimum mission would eliminate

a full year from the project budget, resulting in a savings of ~$2M.

D-5.0 Science Implementation

D-5.1.0 Instrument Summary

OCAM benefits tremendously from hot electron bolometer (HEB) mixer and low-noise amplifier (LNA) technology developments for Herschel and STO, as well as NASA's investment in Quantum Cascade Laser (QCL) LO technology. OCAM will utilize digital autocorrelator spectrometers with heritage from ESA (Odin) and NASA (MLS & STO) missions.

The instrumental goal of OCAM is to demonstrate the technology required to make high spectral (<1 km/s) and angular resolution (6.2") maps of the Galactic Center, star forming regions, jets/shocks, and nearby galaxies in [OI]. SOFIA's operational altitude and telescope aperture make it an ideal observational platform for such an array. To achieve the target spectral resolution, OCAM will utilize heterodyne receivers. OCAM consists of: (1) a 16-pixel heterodyne receiver tuned to the 4.7 THz (63 μm) [OI] line; (2) autocorrelator spectrometers; (3) instrument control electronics; and (4) a closed-cycle cryostat (see Fold-Out 2, Instrument). Much of the OCAM instrument architecture and hardware is based on the experience gained in developing the 64 pixel, 345 GHz, Superheterodyne Camera (SuperCam) array and the instrument package for the Stratospheric THz Observatory (STO).

A Block Diagram of the OCAM instrument is shown in Fold-Out 2, Instrument, Figure 2.1. Key instrument parameters are listed in Fold-Out 2, Instrument, Table 2.0. OCAM's optics are simple, low-loss and designed to provide a 6.2" full-width-half-maximum (FWHM) beam size on the sky with a 44" x 44" field of view. Our observing strategy is to make adjacent On-the-Fly (OTF) strip maps of survey regions. An ambient load/cold-sky calibration (CAL) will be performed at the beginning and end of each strip map. During each strip map (lasting as long as ~10 minutes) a calibration load will be regularly observed. This mode of operation reduces the reliance on secondary chopping.

D-5.1.1 System Description

The OCAM instrument has a simple, modular design (see Fold-Out 2, Instrument, Fig. 2.1). The instrument optics, local oscillator, mixer arrays, and first-stage, low-noise amplifiers reside in a removable cryostat insert (Figure D- 1.5a, below). The insert consists of 300K (ambient) vacuum plate, a 45K plate, and a 4K plate, all rigidly held together with low thermal conductivity, G-10 struts. The f/19.5 beam from the SOFIA telescope enters the insert through a resonant, low-loss, polyethylene, pressure window. It then passes through a metal mesh 4.7 THz bandpass filter mounted to a 45K radiation shield (not shown). The filter prevents bolometric heating of the hot electron bolometer (HEB) mixer array. The beam then passes through the location of a solenoid activated pick-off mirror. With the mirror 'in' (as shown) the back-side of the mirror directs light from a precision, temperature regulated, blackbody load down into the 16 pixel, [OI] 4.7 THz HEB array. With the pick-off mirror out of the way, the telescope beam passes through a 10% reflective dielectric beam splitter that combines the sky and 4.7 THz local oscillator (LO) beam. The 4.7 THz LO beam (shown in blue) is generated by a solid-state, quantum cascade laser (QCL) mounted to the 45K plate. A beam splitter directs a few percent of the LO beam to a 10-cm long absorption tube containing methanol gas. A methanol absorption line is used to frequency lock the QCL as demonstrated by Richter et. al. (2010) and Ren et. al. (2011). The LO beam is then reflected off a phase grating designed to illuminate each pixel in the focal plane array with the proper amount of LO power. Once through the sky beam splitter/combiner, the combined signal and LO beams are divided into hori-

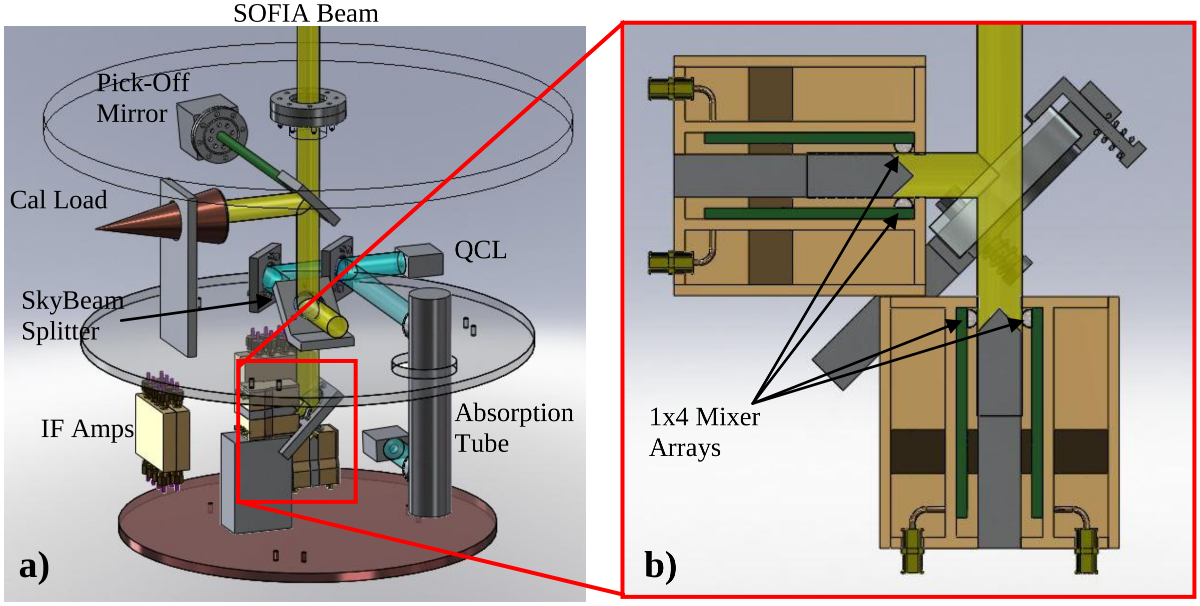


Figure D-1.5: *OCAM Cryostat Insert. a) Sky (yellow) and local oscillator (blue) signal paths through the insert. b) Combined sky and LO beams is divided into vertical and horizontal polarization components, each of which is split between two, 1x4 mixer arrays by a roof mirror.*

zontal and vertical components by a polarizing grid (see Figure 1.5b). Each polarization component encounters a roof mirror which spatially separates and reflects it into two, 1x4 arrays of AR coated, elliptical lenses. Each lens is designed to efficiently couple an f/19.5 SOFIA beam to a 2x2 mm HEB mixer chip mounted on its base. To achieve the designated beam spacing on the sky, the center to center separation of lenses is 3.1mm. Just above each lens the roof mirror is machined to correct for any measured squint that occurs due to mounting errors between the lens and the mixer chip. Each 1x4 subarray of HEB mixers is integrated into a common mount.

The HEB mixers downconvert the high frequency sky signals to microwave frequencies by multiplying the incident sky and LO beams together across a resistive nonlinearity in the HEB's micron-size Niobium Nitride (NbN) bridge. The product of the multiplication contains sum and difference frequencies. Filtering permits only the difference or intermediate frequency (IF) signal to appear at the mixer output. From there, coax conveys the downconverted sky signal to a series of low-noise cryogenic and room temperature microwave amplifiers, which boost signal levels to ~0.1 uW, suitable for digitization.

The critical, first stage IF low-noise amplifiers (LNAs) will utilize the same high-performance, low-power technology developed for STO. The IF signals will have a center frequency between 1 and 3GHz and an instantaneous bandwidth of 2 to 5 GHz. At our observing frequency (4.7 THz, the [OI] line) a 5 GHz IF bandwidth will deliver 319 km/s of velocity coverage. Velocity coverage of this order is needed to accommodate the wide velocity dispersion expected in the data toward the inner parts of the Galaxy.

Each OCAM pixel will have its own 1024-lag, autocorrelator spectrometer to produce a power spectrum of the input signal (see discussion below). The power spectra from all 16 pixels are read by the instrument computer and passed on to SOFIA's data acquisition system via an ethernet link. All OCAM electronics including (1) the IF/correlator boards, (2) the HEB/LNA bias board, (3) the QCL frequency lock box, (4) the pick-off mirror controller board, and (5) the instrument computer will be mounted in the `counter-balance' equipment rack attached to the elevation flange (see Fold-Out 2, Instrument, Figure 2.2).

D-5.1.2 Expected Sensitivity

Recent lab measurements by OCAM SRON team members on quasi-optical HEBs at ~5 THz have yielded double side band (DSB) receiver noise temperatures of <1000 K (see Fold-Out 2, Instrument, Fig. 2.6). At SOFIA altitudes the noise added by the atmosphere is usually less than the receiver noise. For our sensitivity calculations we have assumed a receiver noise temperature of 1000K and single-sideband (SSB) system temperature (including atmospheric and optical losses) of T_{sys} = 4000K. For a 1 km/s line width (δv), we will achieve a 1σ, T_{rms}~0.3K in integration time ($\delta\tau$) of 100sec. This limit varies as $(\delta v\tau)^{-0.5}$. The OCAM instrument characteristics are summarized in Fold-Out 2, Instrument, Table 2.0.

D-5.1.3 Component Selection

D-5.1.3.1 Mixers

OCAM will utilize HEB mixer technology originally developed for *Herschel* by SRON and Technical University Delft. At the `super' THz frequency of OCAM, quasi-optical mixers are the proven technology and have been shown to provide the sensitivity needed for the proposed OCAM science investigations. A plot of the noise temperature of HEB receivers as a function of frequency is provided in Fold-Out 2, Instrument, Figure 2.6. Transitioning these HEB mixers to the 4x4 array for OCAM is a straightforward repackaging of proven technology. Additional concept drawings of the mixer arrays are provided in the Fold-Out 2, Instrument, Fig. 2.5. OCAM's 4.7 THz HEB devices will be fabricated by SRON/TU Delft. The UofA will use the devices in the assembly of the 1x4 mixer subarrays.

Poor Allan times have been a major issue for HEB mixers. However, recently our SRON Co-Is have demonstrated a method to stabilize a hot electron bolometer (HEB) mixer at 2.5THz (Hayton et al. 2011). The technique utilizes PID feedback control of the local oscillator (LO) laser intensity by means of a voice-coil based actuator placed in the beam path, effectively acting as an LO AGC loop. They show that a factor of ~50 improvement in the measured total power Allan variance is possible with this technique in addition to the

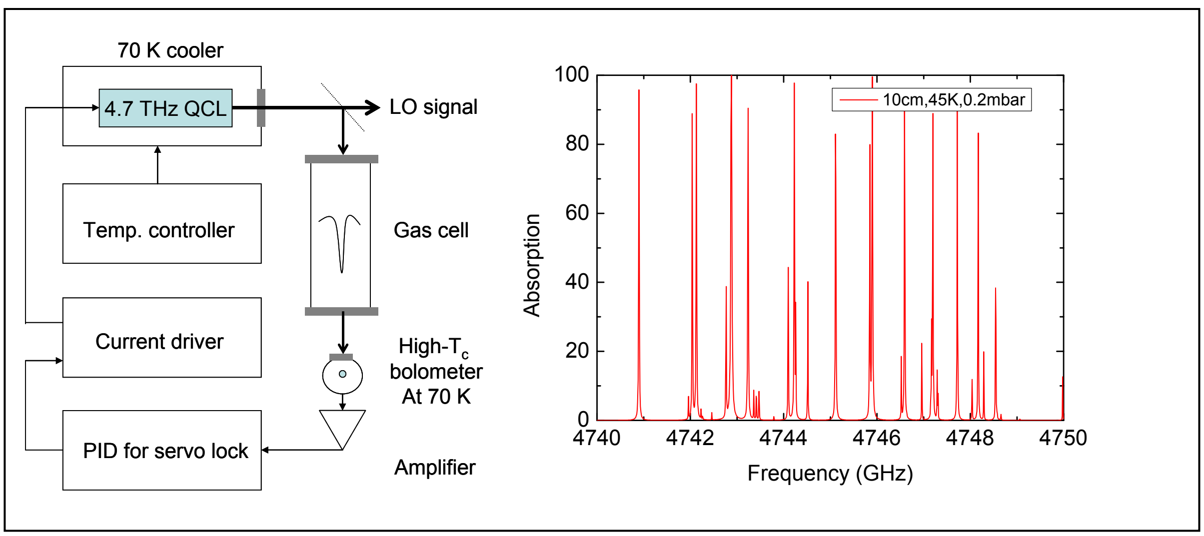


Figure D-1.6: *Left: Schematic block diagram to illustrate the frequency locking by using a gas cell. Right: Absorption lines of methanol near the [OI] line at 4.744 THz (Ren et. al. 2011).*

factor ~10 improvement gained in spectroscopic mode. In this stabilized mode of operation the HEB bias current becomes the set point for the PID loop and is maintained through rapid correction of the LO intensity. This has the effect of significantly reducing multiple instability sources including: LO amplitude noise, LO mechanical instability, and even signal direct detection in the event that large changes in signal are present. Spectroscopic Allan times of >30sec in a 16MHz bandwidth were measured. We will use this LO stabilization approach in OCAM. Such long Allan times will dramatically reduce the required number of calibrations and dramatically increase the data quality and mapping speed.

D-5.1.3.2 LO's

At the frequency of the [OI] line (4.744THz), the only viable option for a compact local oscillator is a THz Quantum-Cascade laser (QCL) (Kohler et al. 2002). LO's based on multipliers have not been demonstrated above ~2.7 THz. A gas laser was built as an LO for the satellite, EOS MLS, launched by NASA. However, it made use of a line at 2.5 THz, which is very strong. At 4.7 THz, there is only a relatively weak line available. This line is roughly 8 GHz from the [OI] line. A frequency difference of 8 GHz is too great for HEB mixers because of their limited IF noise bandwidth (6 GHz).

Co-I Hu's group at MIT has demonstrated a 4.7 THz source that can be used as an LO (see Fold-out 2, Instrument, Fig 2.4. To build the 4.7 THz LO sub-system for OCAM, the UofA, MIT, and SRON/TU-Delft will work as a team. The MIT-SRON team has pioneered QCL/HEB technology (Ren et al. 2010) and will utilize this experience for OCAM. MIT is responsible for delivering the required QCLs. SRON/TU Delft is responsible for frequency locking the QCL and testing it with HEB mixers. Figure D-1.6 illustrates the frequency locking approach. UofA will build the flight LO system per the SRON/MIT design.

D-5.1.3.3 Spectrometers

The OCAM spectrometer system will be an Omnisys Instruments autocorrelator unit capable of processing 16 x 5.5 GHz receiver inputs at 6.45 MHz resolution. The OCAM spectrometer architecture is based upon a proven ASIC design (HIFAS) and has been operated up to a 14 GHz clock rate (Fold-Out 2, Instrument, Fig. 2.7). The preliminary OCAM design is based on using four of the pictured blocks. The total spectrometer volume is just 8 x 16 x 16cm.

D-5.1.4 Cryostat

A 3-D rendition of the OCAM cryostat is shown in Fold-Out 2, Instrument, Figure 2.3. The cryostat is a cylinder 50cm long and 30 cm in diameter. Light from the telescope enters the cryostat through a resonant, 25mm diameter low density polyethylene window and passes through an IR blocking filter mounted on the 45 K radiation shield. OCAM will use a CryoMech PT410 cryocooler. The cooler has 1.0 W of thermal load capacity at 4.0 K and 35W at 45K with orientation-independent operation for elevation swings < ±30˚. The operating temperature of the cryocooler is stabilized by the addition of a helium gas pot on the 2nd stage. Once the 2nd stage cools to 4 K, the helium gas liquifies. The OCAM HEB array is heatsunk to this pot via low-loss, vibration-damping copper straps. Calculations indicate the PT410 load capacity is sufficient to cool the mixers and amplifiers to the proper operating temperatures. The PT410 cold head will be driven by a gymbaled, water-cooled compressor mounted to the aircraft at the location of the SI equipment racks. CryoMech has given us an estimated cost for the custom refrigerator/compressor and Universal Cryogenics of Tucson, Arizona has provided a quote for the cryostat and compressor mount fabrication.

D-5.2 Mission Design

The OCAM baseline mission is to have 3 SOFIA science demonstration flights, with the goal of mapping ~0.25 square degrees of the Galactic Center, star forming regions, and nearby galaxies. An efficient On-The-Fly (OTF) mapping algorithm will be utilized to achieve maximum science throughput. Further discussion may be found in Sections E-1 and E-4.

D- 5.3 Data Analysis and Archiving

OCAM has 16 heterodyne pixels, each with 1024 spectroscopic channels. The diffraction limited beam size is 6.2" with a FOV of order 1 arcminute. The beams will be scanned at about 10"/sec. This implies a readout rate of 1/4 second or faster, in order to avoid beam smearing. For 12 bit numbers the data rate is of order ~1Mbit/sec. The real time data stream will be used to optimize observing strategies when required. The primary data pipeline task is to regrid the irregularly sampled On-the-Fly data onto a regular grid. The science team has extensive experience in this area. Because the OCAM surveys will provide new insights into the role [OI] emission line plays in several different types of astrophysical environments and are expected to be of value to the broader astronomical community, the science team is favors waiving a normal data proprietary period in favor of direct data releases to the community. The OCAM data products will be in the form of FITS data cubes distributed from the University of Arizona and registered to the National Virtual Observatory (NVO). The data will be released as soon as calibration and formatting is complete.

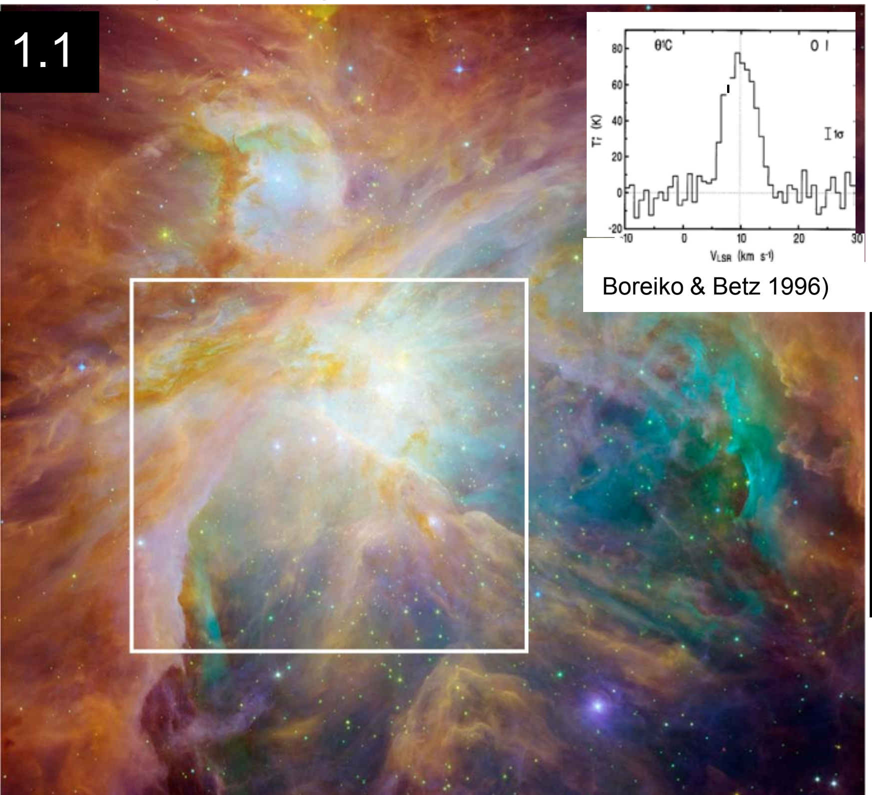
D- 5.4 OCAM Team

The OCAM mission is supported by an outstanding team of scientists with extensive experience in observations, modeling, theory, and interpretation of the interstellar medium, star formation, and galactic nuclei (including ours). The roles, responsibilities, and experience of each Science Team member are summarized in Table D-2. Instrument Team members include leading experts in HEB mixers (J.R. Gao of SRON) and QCL local oscillator technology (Qing Hu of MIT and John Reno of Sandia National Laboratories). Chris Walker (PI), Craig Kulesa (Co-PI), Tony Stark, Chris Groppi, and Chris Martin all have extensive experience designing, building, and deploying THz receiver systems.

Table D-2 Science Team Roles, Responsibilities, Capabilities and Experience

Science Team Member	Role and Responsibility	Relevant Capabilities and Experience
Chris Walker (UA)	Principal Investigator	Sub-mm Instruments, Star Formation, PI- STO
Alexander Tielens (U Leiden)	Project Scientist: PDR Co-Lead	ISM Physics, Star Formation, Herschel/HIFI Project Scientist
John Bally (U. Colorado)	Jets/Shock Lead	IR/Submm Observations of Jets/Shocks
Chris Groppi (ASU)	Deputy Instrument Scientist	Sub-mm Instruments, Star Formation
Frank Helmich (SRON)	[OI] Survey Lead: SRON	ISM Physics, Star Formation
David Hollenbach (SETI)	PDR & Jet/Shock Co-Lead	ISM Physics, Star Formation
Craig Kulesa (UA)	DPI: Instrument Scientist	Sub-mm Instruments, ISM Physics, D-PI STO
Chris Martin (Oberlin)	Synergy with Herschel Programs	Herschel HIGGS program PI, Submm Instruments
Gary Melnick (SAO)	Absorption Line Studies Co-Lead	SWAS PI, ISM Physics and Chemistry
Mark Morris (UCLA)	Galactic Center Lead	Galactic Center Optical, IR, Radio Observations
David Neufeld (JHU)	Absorption Line Studies Co-Lead	Physics and Chemistry of the ISM
Antony Stark (SAO)	Nearby Galaxy Lead	CO Surveys, Physics of Galactic Center

Fold-Out 1 (Science). Science Requirements Flow: *OCAM's 16 pixel, `Super'-TeraHertz array will provide unprecedented access to the 63μm [OI] line; the dominant cooling line in dense, high luminosity regions. These regions include star forming clouds, jets/shocks, and the centers of galaxies. OCAM observations will contribute significantly to our understanding of how stars form, the life cycle of the interstellar clouds which form stars, the intricate dynamics of gas and stars in the Galactic Center, and help provide a template for interpreting these processes in distant galaxies.*



Above: Orion nebula image obtained (ACS/Hubble and IRAC/Spitzer) illustrates the dynamic nature of the interaction of massive stars with their parental cloud. Top-Right: Single line of sight (LOS) spectra of [OI] (*KAO*) taken toward Orion (T_{pk}~80K). OCAM can observe ~25,000 LOS at higher sensitivity and spectral resolution in a single *SOFIA* flight. *Herschel / HIFI* is not capable of observing this line.
White box (15' x 15') frames OCAM survey region.

OCAM relates strongly to NASA's research objectives of Evolution of Galaxies and Star Formation

Mission Goal

Better understand the nature of the far-infrared Universe by probing the topology and ecology of interstellar gas in the Milky Way and nearby galaxies with the 63μm [OI] line. OCAM will be used to uniquely probe

- radiative interactions of massive stars with their natal clouds.
- interactions of protostellar winds/jets with their natal clouds.
- interactions of massive stars with their environment in the Galactic Center.
- conditions in the nuclei of nearby, face-on galaxies.

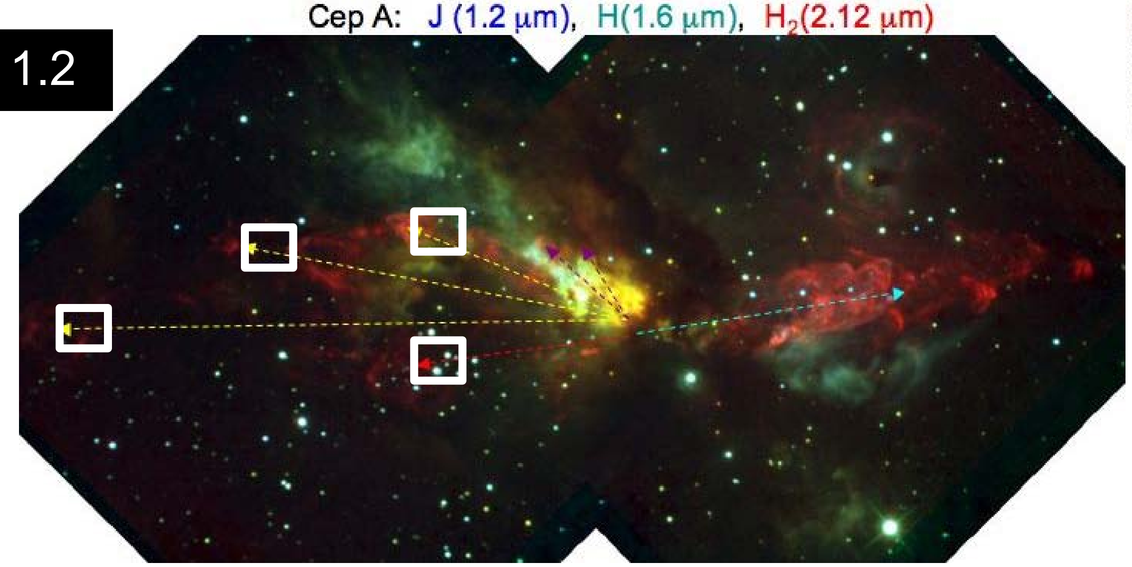
Data Products

1. Fully sampled, velocity-resolved, large area surveys of [OI] (63μm) line emission and absorption toward the Galactic Center, Orion, Cepheus A, and M33.
2. A database of existing complementary line and continuum surveys will be created.

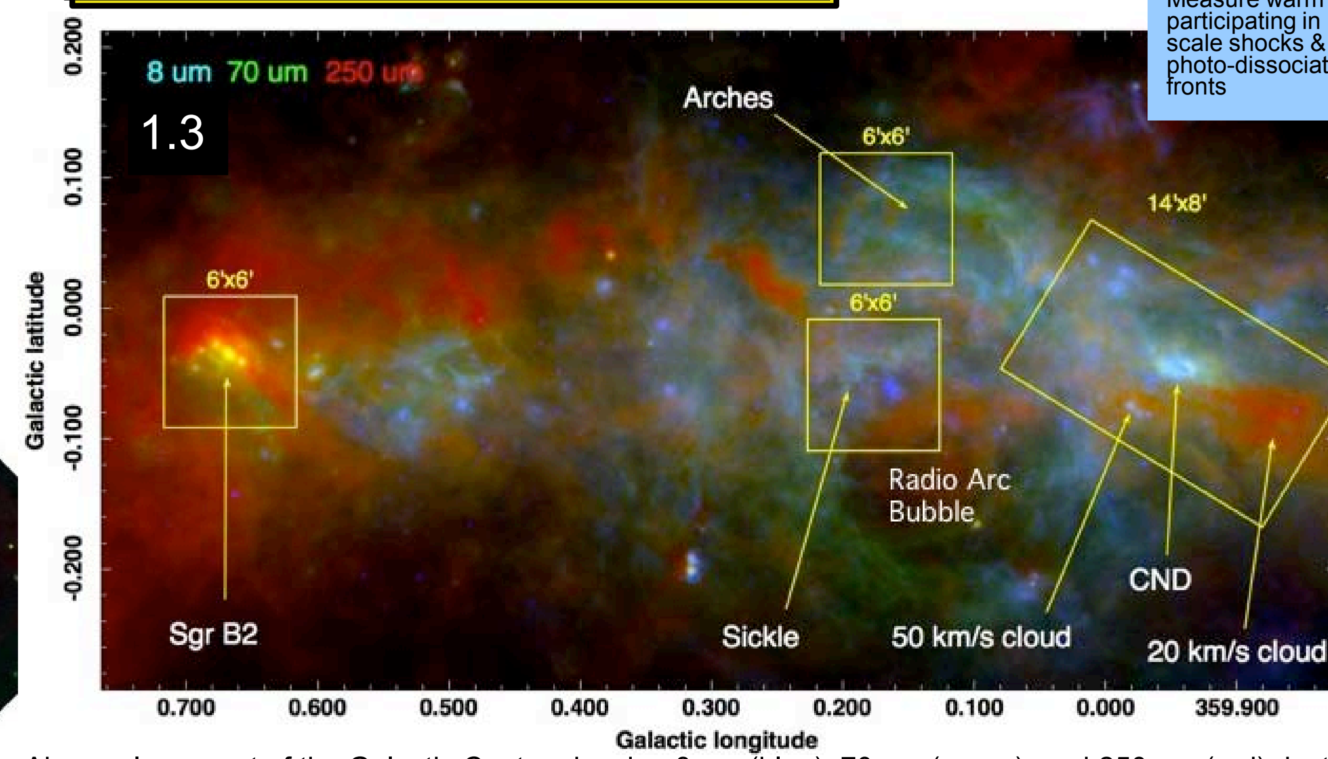
Science measurement requirements drive instrument design

Science Measurement Requirements

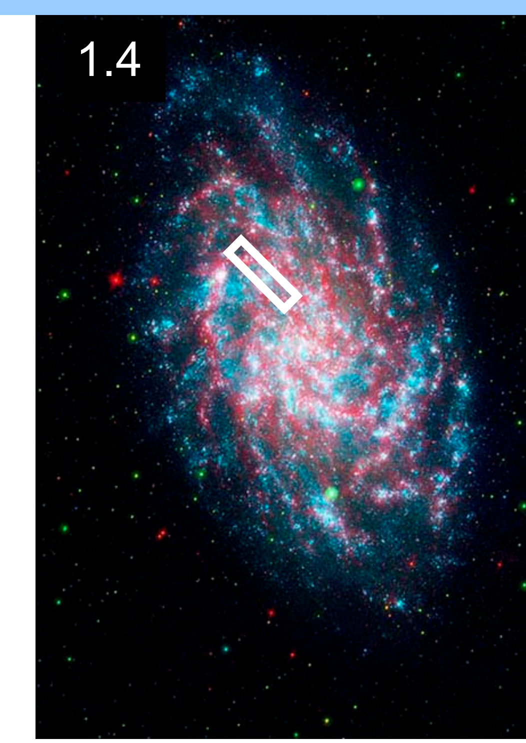
Science Objective	Science Measurement Requirement	Instrument Functional Requirement	Mission Functional Requirement
Probe the energetics and dynamics of high luminosity regions	Spectrally-resolved maps of the 63 micron [OI] line	4.7 THz heterodyne receivers	SOFIA required for measurable atmospheric transmission
Observe global environments of star formation and cloud dissipation	Large maps spanning significant fractions of a square degree	Mapping speed >100 $arcmin^2$ per flight leg requires array receiver with 16 spatial pixels	SOFIA flight legs ~3 hours in order to complete a map
Spatially resolve cloud (sub) structure at the Galactic Center	<10" angular resolution	>2m primary antenna	2" pointing knowledge
Spectrally resolve interstellar cloud structure	< 1 km/s velocity resolution	Spectrometers with <16 MHz resolution	1 Mbps data rate
Span large range of Galactic radial velocities	>300 km/s instantaneous velocity coverage	IF & spectrometer bandwidth >5 GHz per pixel	1 Mbps data rate
Measure warm gas participating in large scale shocks & photo-dissociation fronts	Detect N(O) $>2x10^{17} cm^{-2}$, or T_B<1K km/s in 30 sec	T_{rec} < 2000K DSB: Hot electron bolometer mixer receivers at 4Kelvin	Closed cycle 4K cryostat Optimal SOFIA altitude >39 kft



Above: Cepheus A outflow complex in the near IR. The 15 M_o protostar HW2 appears to drive a pulsed, precessing jet; three yellow arrows mark the 1st three pulses; 2 maroon arrows mark the two most recent eruptions. 63 μm [OI] spectroscopy with OCAM is needed to measure the radial velocities of the components on the left (~3' x 3') white boxes) to confirm or deny the pulsed/precessing jet hypothesis.



Above: Inner part of the Galactic Center showing 8 um (blue), 70 um (green), and 250 um (red) dust emission. OCAM observations of the Galactic Center will provide a unique opportunity for studying the physical and chemical conditions of the interstellar medium and star formation process in galactic nuclei. In its 3 science demonstration flights, OCAM will perform extensive high spectral/spatial resolution [OI] surveys towards the central black hole circumnuclear disk (CND) orbiting the Galactic black hole, the most massive molecular cloud in the galaxy (Sagittarius B2), and one of the most spectacular HII regions in the Milky Way (the Sickle HII region, surrounding a massive young cluster). [OI] is expected to be the dominant cooling line in each region (gold boxes). The OCAM high spectral/spatial resolution surveys will help disentangle the energetics and dynamics of the Galactic Center and provide a Rosetta Stone for interpreting lower resolution [OI] observations of more distant galaxies.



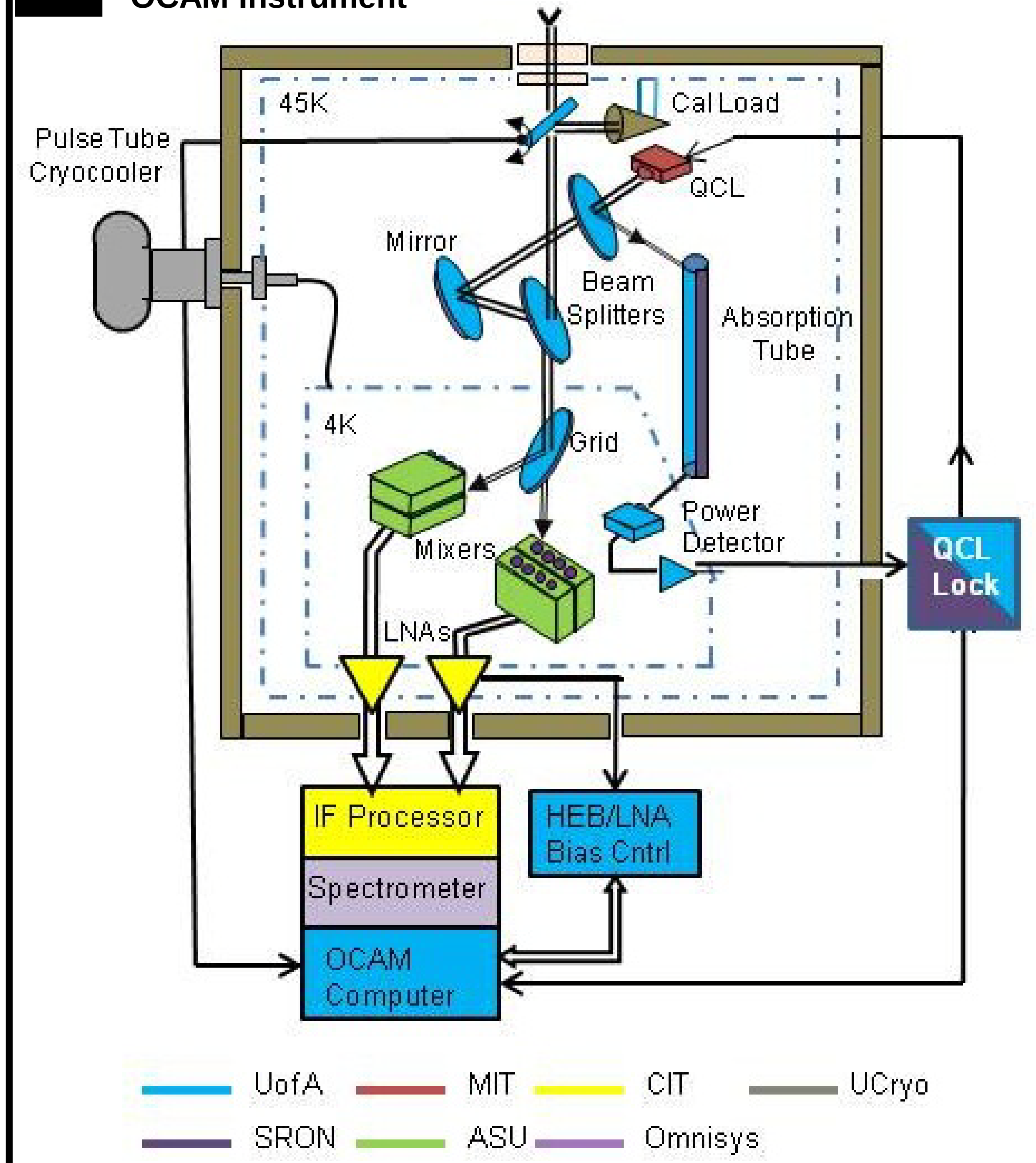
Above: M33 image obtained by GALEX and Spitzer. Far-UV light from young stars glimmers blue, near-ultraviolet light from intermediate age stars glows green, while the red traces PDRs. High spectral resolution [OI] maps of a 4x2' region of M33 (white box) will provide insight into the destruction of GMCs and the recycling of their material into low-density gas.

Fold-Out 2 (Instrument): *OCAM will demonstrate the key technologies needed to realize large-format, `Super'-teraHertz heterodyne arrays on SOFIA. OCAM's 16 pixel array will dramatically increase the ability of SOFIA to conduct the high spectral resolution surveys needed to untangle the complex nature of the ISM.*

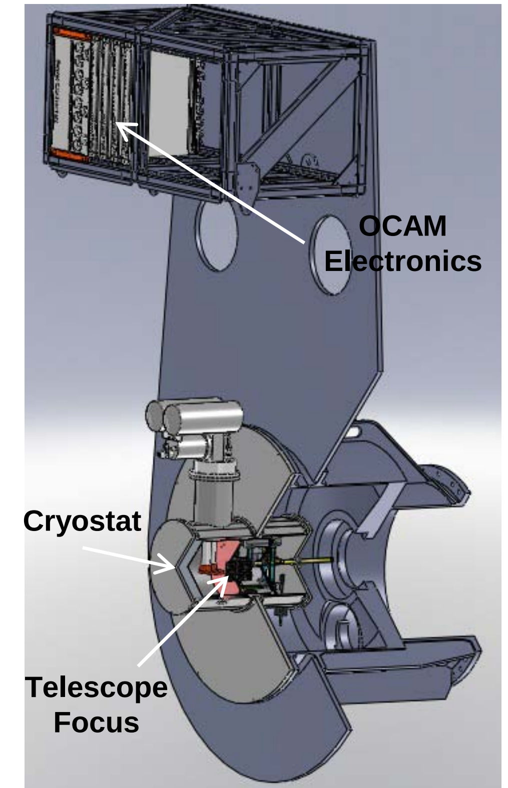
Table 2.0 Mission Parameters

Item	Description
Telescope	2.5m Cassegrain
Target Frequency	[OI]: 4.7448 THz
Angular Resolution	6.2 arc seconds
Receiver Type	16-Pixel HEB Mixer Array
System Noise Temp	~2000K (DSB)
Spectrometer	Digital Correlators
Spectrometer Bandwidths	5.5 GHz - Corresponds to 347 km/s for [OI]
Spectrometer Resolution	6.45 MHz – Corresponds to 0.41 km/s for [OI]
Cryogenic System	4K Pulse Tube Cryocooler
Instrument Mass	100 kg on flange, 290 kg in PI racks
Instrument Power	10.8 kW
Platform	SOFIA

2.1 OCAM Instrument



2.2 OCAM's Telescope Mount



- Full Flange/No-coupler config.
- Compact, Light weight
- Self-Contained

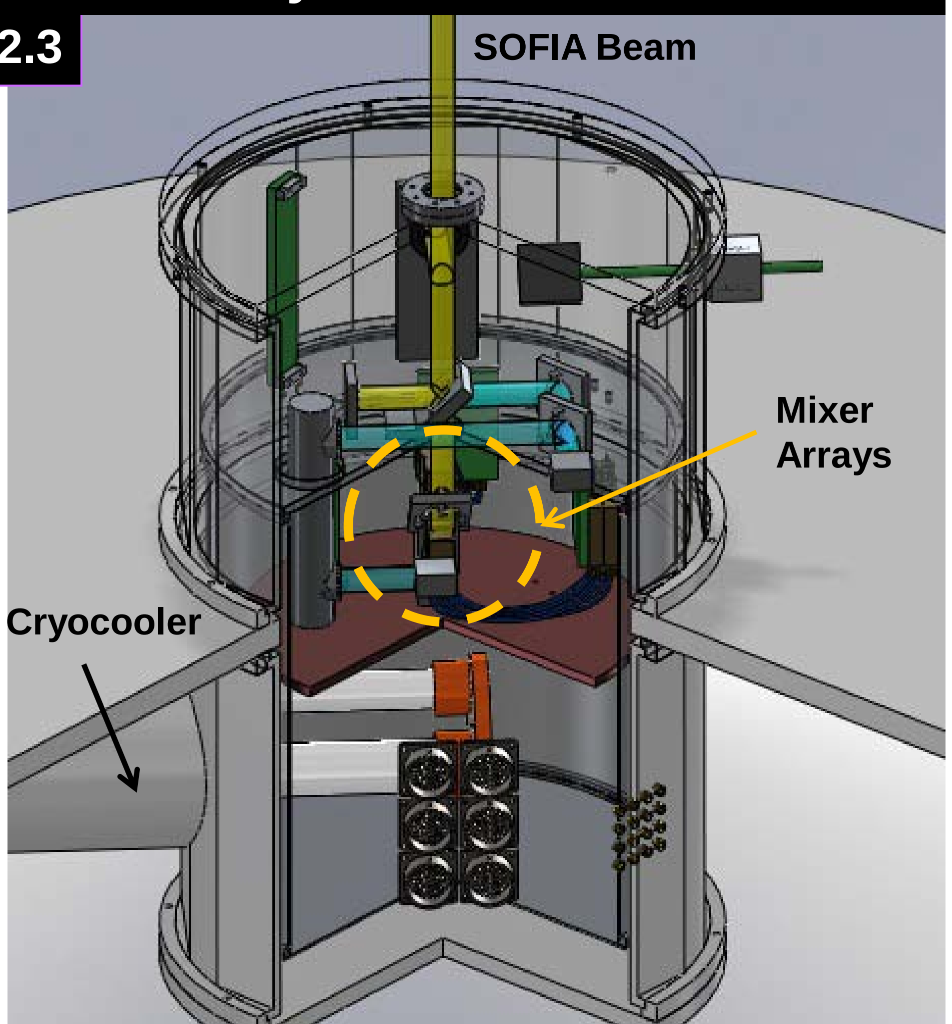
OCAM's Autocorrelation Spectrometer System

- Provides 16 x 5.5GHz bandwidth @ 6 MHz resolution
- Offers 347 km/s of velocity coverage
- ~90% efficient

2.7

OCAM Cryostat

2.3



- Cryogen-Free: Cools instrument stages to 4K and 45K
- Based on reliable, low-microphonic pulse tube cooler

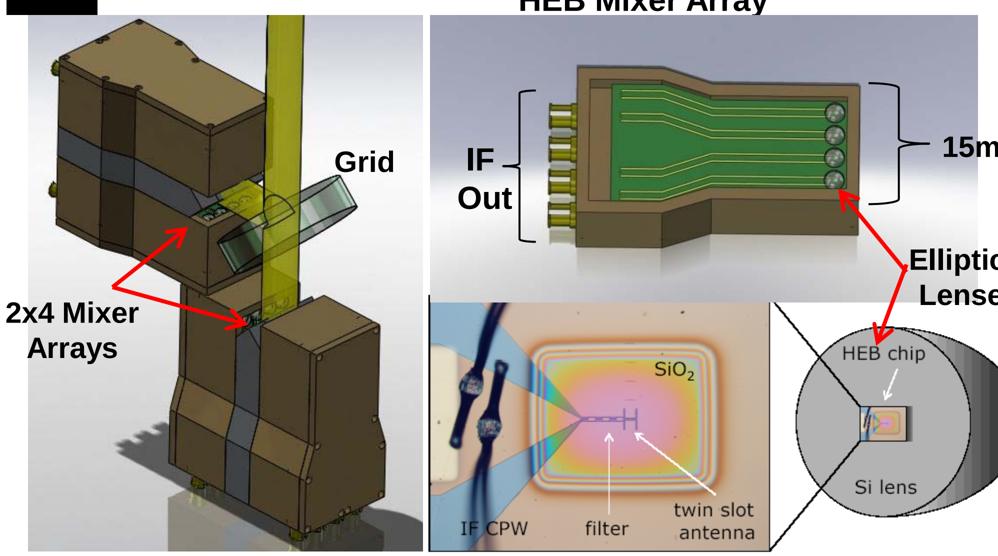
4.7 THz Quantum Cascade Laser

- High output power > 2mW
- Low input power
- Compact

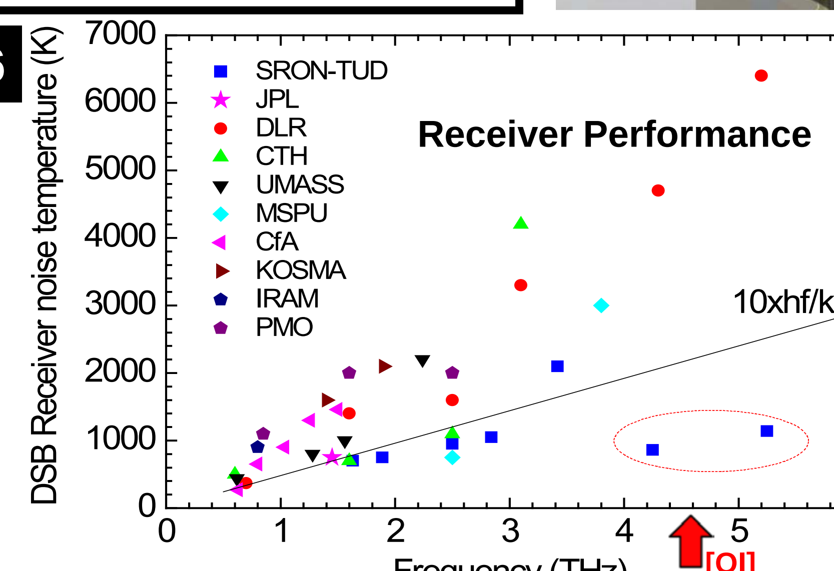
2.4

2.5 OCAM's HEB Mixers:

1 x 4, 4.7 THz Quasi-Optical HEB Mixer Array



2.6



Prototype 500GHz Quasi-optical array- SRON

E. INVESTIGATION IMPLEMENTATION

OCAM's innovative science investigation requires an equally strong implementation plan optimized for SOFIA. The approach outlined here is based on proven laboratory work combined with the technological and managerial heritage of both ground-based and balloon-borne programs. While characterized as a Technology Demonstration proposal, this implementation goes much further; it provides an extensible platform of a closed-cycle cryostat, power systems, modular IF processors, digital spectrometers, command/control systems, and data management that all can be readily extended to a larger focal plane array with only incremental changes. OCAM and/or its focal plane upgrade could potentially serve as an exciting future facility instrument for SOFIA.

E-1 Mission Design

OCAM's natural flow of requirements from science goals to instrument implementation (Science Foldout) allows for the design of a 3-flight design reference mission that addresses conclusively the science questions and goals of Section D. To maximize the opportunity to schedule the instrument on SOFIA, the OCAM Science Team has selected a master list of astronomical targets (Table E-1.1) which provide the basis for the design reference mission. While there are many suitable massive star forming regions along the Galactic Plane and several nearby galaxies of special interest for [OI] mapping, there is only one Galactic Center – whose observations are central to the scientific objectives of this project. Therefore, the desired 3-flight demonstration program is requested when the Galactic Center is observable, from mid-April through September. Using SOFIA flight planning tools, two sample missions spanning this observing window are shown in Tables E-1.2 and E-1.3. These missions are launched from SOFIA's home base in Palmdale, California and maximize the flight duration using a stepped flight profile whose altitude increases throughout the flight, from 37,000 to 43,000 feet MSL as the onboard fuel load decreases. Contiguous flight legs per source are typically 2-3 hours. Coupling instrument sensitivity with atmospheric transmission, the delivered mapping speeds would be >100 square arcminutes per 3 hour flight leg to a sensitivity of 1.8×10^{-4} erg/s/cm^2/sr. While it is anticipated that a technology demonstration program is best supported from Palmdale, the prospect of southern hemisphere SOFIA missions is advantageous for sources like the Galactic Center and could be explored for possible follow-on flights with OCAM.

Object	Science Goal #	Type	Month(s)
M82	4	Starburst galaxy	May
NGC 4038/9	4	Merging galaxies	Jan-July
M83	4	Sc galaxy	Jan-July
VLA 1623	2	SFR	Mar-Sept
Galactic Center	3	Gal. nucleus	April-Sept
M16	1	SFR	April-Sept
M17	1	SFR	April-Sept
W43	1,2	SFR	April-Sept
W49	1,2	SNR	April-Sept
W51	1,2	SFR	April-Oct
NGC 7027	1	PN	May-Sept
Cepheus A	1,2	SFR	June-Sept
M31	4	Sb galaxy	July-Sept
M33	4	Sc galaxy	July-Sept
W3	1,2	SFR	Aug-Sept
M42	1,2	SFR	Sept-Mar
NGC 2023	1	EN	Sept-Mar

Table E-1.1: Master target sample for the OCAM science demonstration flights. From the April to September time period, an outstanding sample of sources can be selected to span the 3 targeted *flights. Abbreviations: SFR=star formation region, SNR=supernova remnant, EN=emission line nebula, PN=planetary nebula. Science goals are defined in Section D-0.1.*

Time (UT 5/1)	Altitude (kft)	Source Name	AZ range (deg) EL range (deg)
03-07h	37	M82	90-60 45-50
07-09h	40	NGC 4038/9	225-270 20-30
09-10h	40	VLA 1623	270 30
10-13h	42	Gal. Center	240-290 20-30

Table E-1.2: Sample flight plan for an OCAM flight in early May

Time (UT 9/15)	Altitude (kft)	Source Name	AZ range (deg) EL range (deg)
02-05h	38	Gal. Center	240-290 20-30
05-08h	39	M33	150-170 20-60
08-09h	41	NGC 7027	30 45-60
09-10h	43	Taurus	140-180 40-50
10-13h	42	Orion (M42)	180-225 20-45

Table E-1.3: Sample flight plan for an OCAM flight in mid September.

E-2 Instrument Requirements & Constraints

E-2.1.1 Optical

OCAM's optics are simple, low-loss and designed to provide a 6.2" full-width-half-maximum (FWHM) beam size on the sky with a 44" x 44" field of view. A full Gaussian beam analysis indicates the HEB mixing devices can achieve efficient coupling to the f/19.5 SOFIA beams using a single, AR-coated, Si elliptical lens. A 4x4 sky beam footprint is achieved by offsetting two, 2x4 HEB mixer arrays in the focal plane via a polarizer (see Figures D-1.5, and Fold-Out 2, Figure 2.5). The secondary mirror chopping function may be utilized during observations with OCAM. The OCAM optical system will be compliant to the detailed telescope specification described in SOF-SPE-KT-1000.0.03.

E-2.1.2 Mechanical

The OCAM mechanical interface to the SOFIA observatory has been chosen to be as simple as possible, leveraging the maximum amount of existing hardware and proven configurations. The OCAM cryostat attaches directly to the SOFIA Instrument Mounting Flange (IMF) directly, forming the pressure bulkhead to the ambient atmosphere. All optics, including calibration loads, are inside the cryostat vacuum vessel, so no additional mechanical interfaces are present within the IMF. The cryostat is relatively compact and light. As shown in the Instrument Foldout, Figures 2.2 and 2.3, the OCAM cryostat fits easily within the dynamic SI envelope, with large clearance margin. The static and installation envelopes are similarly accommodating. All instrument electronics are housed in the Counter Weight Rack (CWR) mounted on the TA Counterweight Plate. OCAM electronics will fill approximately half the available space in the CWR, allowing for straightforward reconfiguration to meet center of gravity restrictions.

The OCAM closed-cycle cryogenic system requires connection between the compressor system, mounted at the PI rack locations. The compressed helium lines consist of two ½” braided stainless steel jacketed line, ~25m in length with an outer diameter of ~1”. These lines will be routed through the Cable Load

Alleviator Device (CLAD) Right Hand Cable Bundle in the outer bundle, where sufficient space is available for the lines. These lines have Aeroquip self-sealing pressure couplings on each end. A bulkhead fitting will be mounted at the TA patch panel for connection to a shorter set of similar line supplying the cold head on the cryostat. No other custom installation is needed in the CLAD.

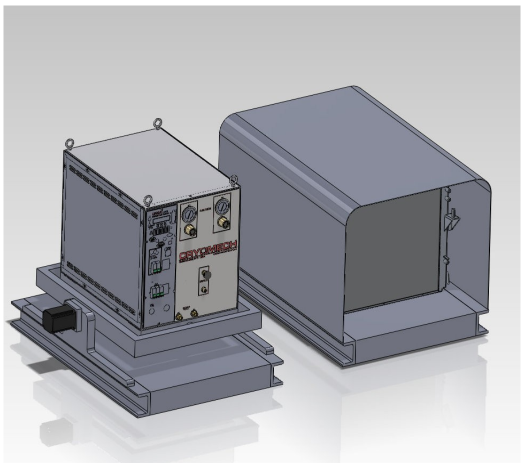


Figure E-2.1: The OCAM cryogenic compressor system. The water cooled compressor and stabilization gimbal are mounted on one PI pallet, with the water-air heat exchanger system on another.

The cryogenic system requires a compressor system to supply compressed helium gas to the cold head, and to dump waste heat from the return gas. OCAM will use a commercially available compressor from Cryomech Inc., modified and tested by Cryomech to meet airworthiness requirements. This compressor is water cooled, so it will be combined with a Cryomech supplied circulator pump and water-air heat exchanger to dump the system waste heat (~8 kW) to the cabin air. The compressor will be mounted on a powered tip-tilt stage with tilt sensors that will maintain the oil-sealed compressor at a level attitude +/-5º. A motor control system will be implemented in Labview to control this stage. The tip-tilt stage and other compressor mounting hardware will be engineered by Universal Cryogenics and the University of Arizona, and fabricated by Universal Cryogenics. The compressor and tip-tilt stage will mount on a modified version of the PI equipment rack: a flat pallet interface to the existing L3 support pallet. This platform will be designed and qualified in consultation with NASA. A second identical pallet will be used to mount the circulator pump and heat exchanger used to transfer heat from the compressor cooling fluid to the cabin air. A CAD model of the proposed configuration is shown in Figure E-2.1. Instrument foldout, Table 2.0 shows the current best estimates for OCAM instrument mass and mass margin, organized by mounting location. The OCAM system has large mass margins for all mounting locations.

E-2.1.3 Pressure

The OCAM pressure bulkhead is formed by the cryostat at the outer IMF location. No optical window will be used. This bulkhead will be formed by the cryostat front plate, in a manner similar to the current generation FORCAST instrument. The cryostat pressure vessel and bulkhead will be engineered using a combination of FEA tools and hydrostatic test verification to assure it meets necessary airworthiness requirements. Since there are no liquid cryogens in OCAM, the mechanical requirements for guard vacuum failure are greatly reduced. With the OCAM closed cycle system, even a catastrophic loss in guard vacuum will result in helium gas pressures no greater than that of the powered-off system at room temperature. The closed cycle cryogenic system (including the cold head, pressurized helium flex lines and compressor) will be engineered and tested by Cryomech Inc. to meet all necessary requirements documented in the SOFIA Science Instrument System Specification document for pressurized systems. Cryomech will modify their standard systems as needed to meet all airworthiness requirements.

E-2.1.4 Electrical

The OCAM system has been designed to maximize simplicity when interfacing electrically to the SOFIA observatory. OCAM uses a distributed computing model, with small, single board computers each controlling OCAM subystems, connected via Ethernet. The backend spectrometer for OCAM is co-located with the instrument in the CWR, so no analog science signals are routed through observatory wiring. The hardware in the CWR will interface with the TA patch panel only via 115VAC power, chopper control, cold head drive and Ethernet. The cold head drive signals will use existing wiring in the PI patch panel (J75 - J79). 1000 BASE-FX to 1000 BASE-T media converters will be used in the CWR and the PI instrument rack to convert to copper wire Ethernet for the SI instrument network. Timing will be obtained from the MCCS LAN via NTP for time synchronization of the OCAM computers. The compressor system will interface to the PI Patch Panel via the 20 kVA power system connectors. There is no ICD for this new power system, so the OCAM team will work with NASA to design this interface.

E-2.1.5 Power

The OCAM power budget is dominated by the ~10 kVA (CBE) of power necessary to operate the compressor, circulator pump and heat exchanger fan for the cryogenic system. This power will be provided by the new 20 kVA power system upgrade for the SOFIA observatory. The compressor system can be operated from 220/230 VAC 3ph 60 Hz, 460 VAC 3ph 60 Hz, 200/220 VAC 50 Hz or 380/420 VAC 3ph 50 Hz power sources as standard, but custom configurations are possible to maintain compatibility with the new SOFIA power system.

Power for the rest of the instrument is modest. The current best estimate for power consumption of the remainder of the OCAM instrument is ~520W, provided by the existing 2 kVA UPS power system. This results in almost a factor of 4 margin on power for that subsystem.

E. 2.1.6 Software

E-2.1.6.1 Mission Command and Control

To interface the OCAM instrument to the SOFIA standard Mission Command and Control System (MCCS), the science instrument rack will contain a computer with a dedicated instrument command and control system (C&C). The C&C computer will consist of a ruggedized Parvus single board computer, redundant industrial SLC solid state disks from PSI, and a MESA 4I71S ethernet switch. The systems are fault-tolerant, conduction cooled, and rated for operation over -40 C to +85 C. The solid state discs are redundant and the system is designed to boot off of the alternate disk whenever it boots without having been shutdown properly. The software interface of the C&C computer to the MCCS will comply with the relevant interface control document (SOF-DA-ICD-SE03-052). The science team has extensive experience producing software for C&C systems on long duration balloon missions and ground based telescopes and will lead the development of the needed software pursuant to the required interfaces. Extensive testing will also be undertaken by members of the OCAM team using the Systems Integration Laboratory to ensure compliance with these interfaces well before the instrument is prepared for its pre-ship review. Similarly the OCAM team will prepare and provide functional specifications and testing plans for all C&C software to confirm that any hazardous elements have hardware mitigations in place to protect from any possible software malfunction.

E-2.1.6.2 Data Cycle System

The C&C computer will also interface with the SOFIA standard data cycle system (DCS) as per the relevant interface control document (SCI-US-ICD-SE03-2023). While the DCS will be utilized to provide on-aircraft data archiving, for redundancy purposes the C&C will also be used to store raw and reduced data.

E-2.1.6.3 Data Reduction Pipeline

While not generally required for a technology demonstration proposal, the team believes it is best practice to conform to the standards required for data reduction pipelines for longer duration SOFIA instrument projects, as detailed in the interface control documents and the general SOFIA data processing plan (SCI-US-PLA-PM17-2010). However, while the pipeline will be provided to the SMO for archival purposes, there is no expectation from the instrument team of any additional support, and the OCAM team will take full responsibility for all aspects of data reduction as is expected for a technology demonstration project. The OCAM supplied pipeline will build upon a pipeline developed by members of the science team for automated on-board reduction of long duration balloon missions. This pipeline begins by taking the raw numbers produced by the spectrometers and immediately formatting each spectrum as a FITS file tagged with housekeeping, position, and calibration data stored directly with the spectrum in the form of FITS headers. These raw FITS files are then stored and passed along to the calibration phase of the pipeline, which uses calibration load data and reference information to produce a calibrated spectrum, which is similarly stored for future reference. Finally calibrated spectra are re-gridded using an optimized On-the-Fly reduction scheme and collectively stored as a single large data cube for a given target upon the completion on observations. These data cubes represent the final product of the pipeline and can be formatted into figures for publication using a wide range of commonly available visualization tools.

E-2.2 Ground Support Equipment

OCAM will require a small suite of ground support equipment for testing and verification before flights. A second cryogenic compressor system will be purchased and installed in the PIF laboratory to allow ground testing of the instrument independent of the flight cryogenic compressor. This will be a standard Cryomech water cooled compressor functionally identical to the flight unit, but available off-the-shelf. A GSE equipment rack will hold all OCAM electronics normally mounted in the CWP rack. Duplicate cable harnesses and cryogenic flex lines will be constructed for testing.

OCAM will use the Telescope Assembly Alignment Simulator (TAAS) to map the location of the 16 beams relative to the telescope boresight. This will set focus and also provide the de-rotation parameters for reconstruction of pixel positions during OTF observations. The instrument IF processors will provide integrated total power measurement across the band, in addition to data from the spectrometer system. OCAM GSE software will use the chopper signal and the total power data from the IF system and spectrometers for lock-in detection during the beam mapping and focus measurements.

Because the OCAM cryostat is very compact and light relative to other SOFIA instruments, the SI Handling Cart's design is simplified. OCAM on the handling cart will meet dimensional and mass requirements for handling operations with large margins. A simple 4 wheel push-cart will be designed and constructed by Universal Cryogenics, the contractor for the EXES handling cart. Locking, large diameter wheels will be used to ensure low wheel pressure and ability to travel over rough surfaces. The cart will be designed to be forklift and lift-gate compatible. The instrument will be raised and lowered on a scissor-jack mechanism. We will explore the use of high-load commercial laboratory lab jack mechanisms for this purpose (i.e. the Newport Model 281 300 lb. lab jack). If no commercial jack meets SOFIA requirements, we will engineer and construct our own jack to meet the 2” vertical travel requirement. The instrument and jack will be mounted on the front of the handling cart, with counterweights installed on the cart to ensure a safe center of gravity. This will allow simple and straightforward instrument mounting to the TA flange, meeting all requirements described in SIC_AS_01.

E-3 Airworthiness

Airworthiness analysis and testing responsibilities will be managed by the University of Arizona and carried out by the University of Arizona and contractors Universal Cryogenics and Cryomech Inc. Mechanical analysis will be performed on all critical OCAM components to meet the requirements set forth in the SOFIA Science Instrument System Specification document. All materials and fasteners will be procured to meet mechanical and traceability requirements. The cryostat and electronics configuration is simple and is similar in layout to existing hardware (i.e. FORCAST). OCAM will use a new, closed cycle cryogenic system that requires the mounting of a compressor on a tip-tilt stage. The mechanical design of this system and its interface to the SOFIA aircraft via custom pallets mounted at the PI equipment rack locations will be done by University of Arizona mechanical engineers and Universal Cryogenics. They will work with SOFIA observatory staff to ensure that the new pallet and compressor tip tilt stage meet all airworthiness requirements.

Pressure testing for the closed cycle cryogenic system will be carried out by Cryomech Inc. before delivery to the OCAM team. Cryomech believes that their systems will meet all pressure test requirements as-is, but will modify them as needed to meet requirements. The cryostat vacuum vessel and cryostat window will be designed by Universal Cryogenics using FEA tools, then tested via hydrostatic testing.

OCAM electrical systems will use aircraft approved wiring and connectors for all electrical connections. COTS aircraft grade cabling will be used where possible, with custom-fabricated cable harnesses implemented when no commercial product is available.

The instrument handling cart will be designed and constructed by Universal Cryogenics, who is currently producing the EXES instrument handling cart. This handling system will be analyzed via FEA tools by Universal Cryogenics and the University of Arizona to assure it meets all observatory requirements.

All airworthiness activities will be planned, overseen and verified by outside consultant Frank Bouchard, who has extensive experience in airworthiness certification for industry, defense and scientific applications in the aerospace field. He will work with the University of Arizona, OCAM contractors and NASA to produce an airworthiness certification plan for all components of the OCAM system. He will then work with the University of Arizona to ensure that the plan is executed and all testing and documentation implemented to meet all observatory requirements.

E-4 Integration, Testing and Observing Implementation

The relative simplicity and independence of the electrical and mechanical interfaces depicted in Section E-2 streamlines the integration and testing process. The unique technologies demonstrated in OCAM can therefore be quickly brought to fruition on SOFIA.

E-4.1 Instrument Operations

E-4.1.1 Integration and Testing

Prior to shipment, a complete demonstration of the OCAM instrument will be performed in the PI's laboratory, in which all of the science instrument interfaces will be completed and documented. All of the SOFIA science instrument interfaces will be described in a series of Interface Control Documents (ICDs) prior to delivery. The OCAM ICDs will include the following:

- **Global:** the overall OCAM instrument layout within the SOFIA observatory is described, including locations of instrument team members during flight operations, focal plane coordinate systems, and instrument grounding scheme.
- **Telescope:** relate the details of all science instrument cables to the telescope and aircraft patch panels, the OCAM mechanical interface to the instrument flange, and use of the telescope counterweight instrument rack. (TA_SI_01–05).
- **MCCS:** provide details of power subsystems for the OCAM cryocooler compressor, instrument power, cooling lines, UPS support, and general I/O such as networking, audio, video, and GPS. It also includes documentation and verification of a functional software observatory interface that can successfully exchange rudimentary commands with the observatory.
- **Aircraft:** relate the use of the simple instrument cart used to transport OCAM on board the aircraft, and onboard use of vacuum equipment.
- **SSMOC:** document laboratory space, test equipment and cryogens to be used during the I&T process.

After shipment, a few weeks would be potentially allocated for the integration and test process at the SSMOC. During this period:

- OCAM would be installed on the TA and MCCS simulators to verify compliance with SOFIA hardware and software interfaces. All electrical connections between OCAM and MCCS will be present and a simulation of observing procedures will be performed to test the observing strategy as faithfully as possible.
- OCAM will use the Telescope Assembly Alignment Simulator (TAAS) to map the location of the 16 beams relative to the telescope boresight using hot and/or cold loads. This will eliminate the need for lengthy on-telescope boresight calibration.
- After OCAM has been checked out on the TA simulators, it can be deployed onto the aircraft. Initially the cryostat will be installed onto the instrument flange, then cryogenic hoses, cables, and compressors will be integrated. If the simulators are faithful, it is expected that the installation on the telescope should require little time (1-2 days or less) and in principle, none of it will require the aircraft to be outside of the hangar.

E-4.1.2 Science Demonstration Flights

The principal advantage of a focal plane array is wide-area mapping. With the exception of initial pointing measurements on bright pointing sources such as planets, using the 2-position chopping technique on SOFIA, OCAM will spend nearly all of its time observing in "On-The-Fly" (OTF) mapping mode, which corresponds to the "data taking, constant velocity scan" mode on SOFIA. This mode uses the fixed stare mode of the chopper (TCM). A typical observing session, after the MCS is calibrated and the telescope is initialized, would look like the following:

1. Point and focus using 2-position TCM chopping
2. Slew to science target, perform 2-position nod wth TCM in stare mode
3. Initiate a series of constant velocity scans while asychronously reading the OCAM spectrometer and the SOFIA broadcast housekeeping

All three of these observational modes have been validated using the GREAT instrument on SOFIA, and OCAM would be utilizing the same style of data flow.

E-4.2 Data Rights & Archiving

In addition to archiving the raw instrument data with the SOFIA Science Mission Operations Center (SMO), the OCAM team intends to exceed the expectations for a technology demonstration project by making the data reduction pipeline and reduced data products rapidly available to the public. The pipeline and reduced products will be delivered to the SMO and the public scientific community as soon as calibration and data formatting is complete, waiving the one year proprietary period. Even if calibration should take longer than anticipated, the data and pipeline will be released no later than one year following the flights, consistent with the standard one year restricted access period for the raw data itself.

F- Management and Schedule

The management of the OCAM project builds on the successful UA Stratospheric TeraHertz Observatory (STO), the clear definition of mission objectives and requirements, and the heritage and maturity of the technical implementation.

F-1 Management approach.

The University of Arizona (UA), under the leadership of Principal Investigator (PI) Dr. Christopher Walker, has the overall responsibility for the performance, cost, and schedule of the OCAM Technology Demonstration Instrument. PI Walker directs the activities of the OCAM Science Team. Program Manager (PM) Mr. Brian Duffy (UA) reports to PI Walker. PM Duffy manages all aspects of the engineering and flight systems, monitors the schedule and costs, and oversees the contracting activities.

PM Duffy is supported by the UA OCAM project office comprised of a Deputy Project manager (Mr. S.H. Bailey with more than 20 years of spaceflight experience) and a Systems Engineering and Safety and Mission Assurance lead. Dr. Craig Kulesa leads the UA Instrument engineering team. PM Duffy lead Mission Operations. The organizational roles and responsibilities are shown above. This management structure builds on the previous successful collaboration on the STO project.

F-2 Development Plan.

OCAM science and measurement requirements and the flow down of these requirements are articulated in the proposal. Prior to the Preliminary Design Review OCAM creates the formal requirements for subsystems and prepares the interface control document between the Instrument and the SOFIA Telescope System culminating in a Systems Requirement Review (SRR) and Experiment Interface Review (EIR). SRR and EIR establish the basis for the detailed Phase B plan. During Phase B the development of the Instrument proceeds with weekly coordination meetings and telecons and the exchange of technical data through preliminary design and PDR and detailed design and CDR. Long lead items for the Instrument will be released to procurement before CDR based on successful peer reviews and the consent of PI Walker and PM Duffy.

Spares shall be procured, tested, and placed in bonded stores to avoid delays. The formal identification and justification of spares will be completed during Phase B.

Instrument components are integrated at the UA prior to test, acceptance, and delivery to SOFIA integration in Palmdale, CA. SRON and ASU deliver detector components and the focal plane subassembly to the UA for integration with the local oscillators provided by MIT. Omnisys delivers the spectrometer. UA integrates and tests the Instrument to acceptance. UA provides pre-SOFIA integration support and OCAM integration onto SOFIA in Palmdale. UA supports three test flights of the OCAM Instrument on SOFIA.

F-3 Systems engineering and safety and mission assurance (SMA).

UA has project-level responsibility for systems engineering and safety and mission assurance, establishing project-level requirements and policies. The UA establishes subordinate requirements flow-down, test plans and procedures, and SMA policies using the best practices of the organization.

Table F-1. *OCAM risks have been identified, mitigated, and included in the development of the project schedule and cost reserves. The mitigation includes the descope strategy.*

Rank	Risk Concern	Mitigation and Descopes	Decision Point	Impact
1	Local Oscillator (LO) output power at [CII] or [OI] initially not sufficient to drive 16 pixels	Use two separate LO units, each driving 8 pixels. Plan for and price a second LO delivery with 10x the required power	Phase C to release 2nd LO delivery	Impact: No cost impact, 2nd delivery in proposed budget.
2	Receiver sensitivity less than expected.	Factor of two less than target sensitivity can be accommodated without impacting minimum science mission.	Phase C	Reduces size of planned survey regions. No cost impact.

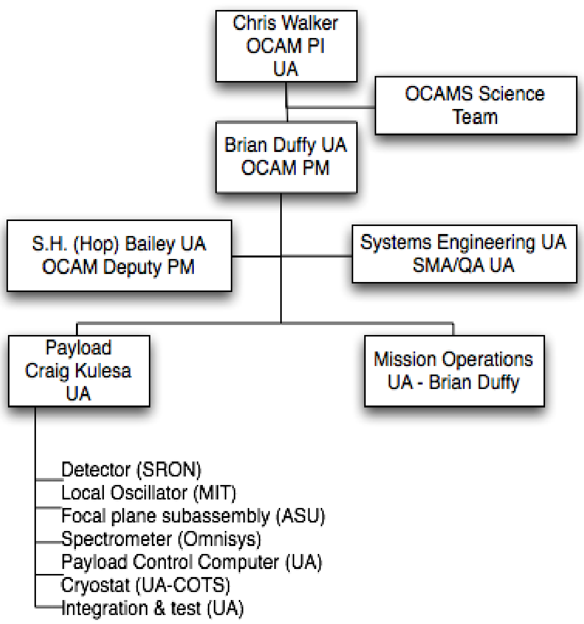


Figure F-1. OCAM Project Organization

F-4 Risk management and risk mitigation. OCAM relies on early identification and tracking throughout the project to manage and minimize risks. Mitigation planning requires consideration of alternative actions, personnel assignments, cost estimates for the alternatives, and a statement of work for the mitigation effort. OCAM incorporates a continuous process to research, accept, watch, and mitigate each risk. Mitigation plans are developed, implemented, and tracked as a function of risk priority and rating; they are required for all risks rated "significant" or higher. "Significant risks" are actively managed and, when required, reserves or margins are allocated at the discretion and approval of the OCAM PI to ensure HiSCI can complete the mitigation plan effort. The management and allocation of OCAM reserves requires continuously updating schedule and costs-to-date to project cost-to-complete. These data combined with the estimated cost of mitigating an identified risk will influence the mitigation strategy adopted. Risk factors rated "high" require new plans and processes, are actively managed, and, when required, are allocated reserves or margin. Risk mitigation progress is carefully tracked and documented. Detailed mitigation plans developed for significant risk items are regularly monitored so that any expenditure of cost or schedule reserves results in lowered risk exposure levels. The results of mitigation activities are archived.

F-5 Acquisition strategy. UA, Instrument component providers (JPL, MIT, CalTech, and SRON), and science team members submitted a joint proposal for OCAM with the UA as the PI organization. On this basis UA authorizes direct-funding by NASA to Sandia Labs (MIT's OCAM partner) and establishes contracts with MIT, CalTech, SRON, and the science team organizations. For direct-funded organizations UA prepares a formal statement of work including technical, schedule, and cost reporting consistent with the overall project plan. All work is performed on a cost reimbursable or cost plus basis with a cost cap consistent with the submitted budgets. UA retains and controls the release of all reserves.

For other procurements each lead organization uses their established processes and procedures to solicit and award purchase orders or contracts consistent with their statement of work and UA-approved project plans.

F-6 Schedule. The OCAM schedule is shown below. UA maintains the OCAM Integrated Master Schedule (IMS) using inputs and updates from team members.

F-7 Decision making process

PI Walker is accountable to NASA for the success of the OCAM Technology Demonstration Instrument, and has full responsibility for its scientific integrity and mission execution within cost and schedule. Final decision authority for all matters impacting level one requirements and science, including descopes and reserves, rests with Dr. Walker. He delegates day-to-day development and operational decision-making authority to PM Duffy. All decisions affecting technical aspects of the OCAM imager are based on a fully integrated assessment of the science requirements, risk, performance, budget, schedule, and available reserves and margin. Final decisions will be comprehensive in nature, drawing information, analysis, and recommendations from the Science Team, project system engineer and engineering leads. Decisions that impact cost, schedule, or requirements are addressed via the Change Control Board (CCB) process, which is led by Dr. Walker.

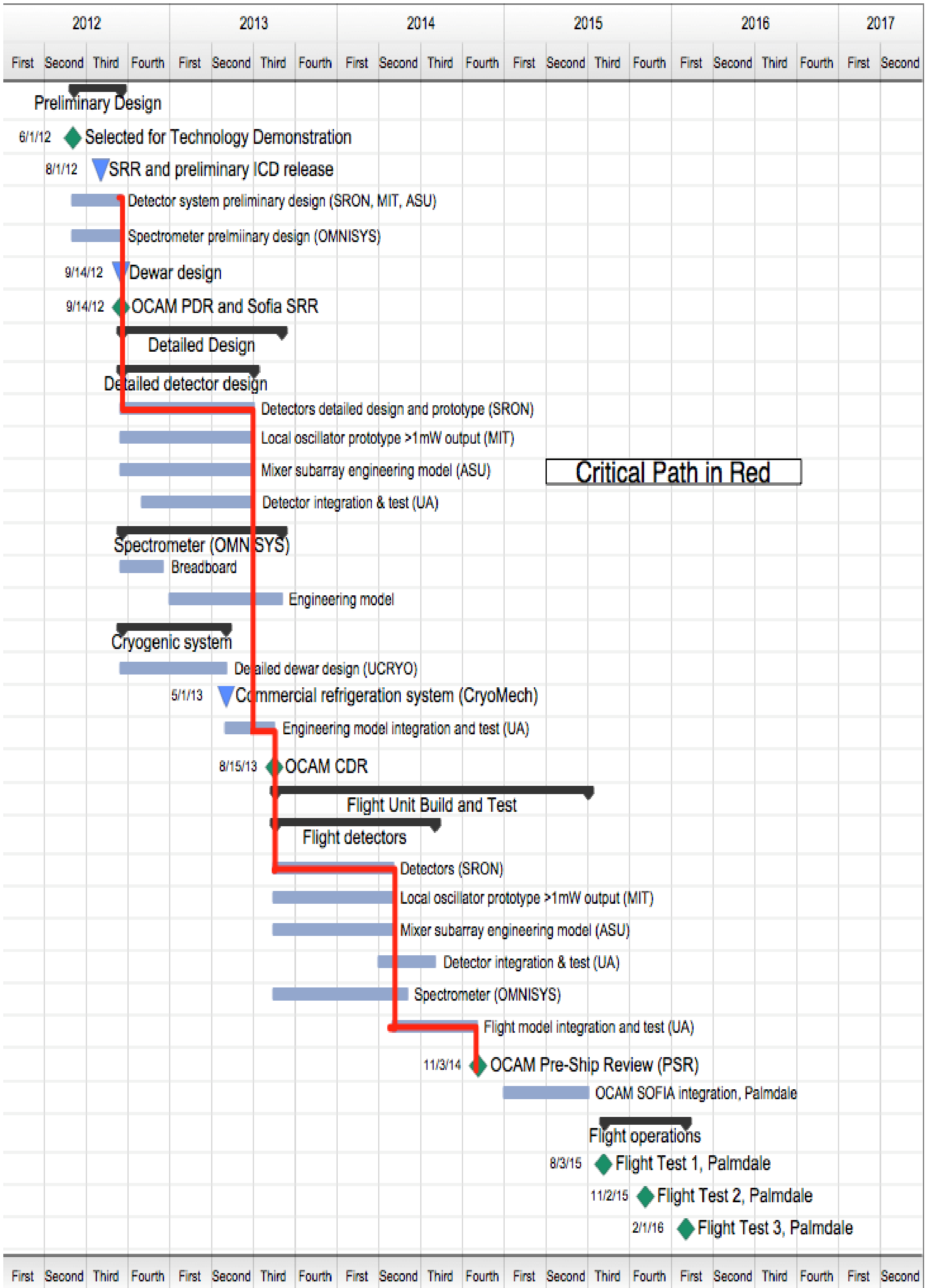
F-8 Resource management strategies (schedule, cost, performance).

UA, working with Instrument component providers (JPL, MIT, SRON, Omnisys), establishes a baseline schedule, cost, and performance (based on the requirements review) prior to PDR. The baseline is updated at PDR to incorporate the preliminary technical data package including all drawings. Changes to the baseline require submission of an engineering change request supported by fully developed cost, schedule, and performance impact. The PI is the decision authority for changes to the baseline.

In addition to the formal change control process, UA conducts weekly telecoms or meetings with all participants to monitor progress and promote thorough and open communication. Working groups will be established for systems engineering, management, and specific design disciplines as required to facilitate complete face-to-face exchange of information.

The schedule is tracked weekly based on the telecoms and/or meetings and updated monthly. Costs are updated monthly consistent with the financial cycles of UA. A Monthly Management Review (MMR) assesses progress, identifies problems, and provides a basis for informed decision making, especially as it pertains to cost and schedule margins.

UA establishes a secure project electronic exchange and decision-making site used to control and document all decision making. All problem failure reports (PFRs), software trouble reports (STRs), and engineering change requests (ECRs) are reported into this system which includes information and flow control rules. Submission of a PFR, STR, or ECR triggers automatic email notification for disposition and decision-making. Decision-making requires archived electronic voting or direction. In addition, the system archives all documents associated with a report so that traceability is maintained to cost and schedule impact estimates, white papers, drawings, analysis, test results and all other information.


2012
2013
2014
2015
2016
2017
First Second Third Fourth First Second Third Fourth First Second Third Fourth First Second Third Fourth First Second Third Fourth First Second
Preliminary Design
6/1/12 Selected for Technology Demonstration
8/1/12 SRR and preliminary ICD release
Detector system preliminary design (SRON, MIT, ASU)
Spectrometer prelmiinary design (OMNISYS)
9/14/12 Dewar design
9/14/12 OCAM PDR and Sofia SRR
Detailed Design
Detailed detector design
Detectors detailed design and prototype (SRON)
Local oscillator prototype >1mW output (MIT)
Mixer subarray engineering model (ASU)
Detector integration & test (UA)
Critical Path in Red
Spectrometer (OMNISYS)
Breadboard
Engineering model
Cryogenic system
Detailed dewar design (UCRYO)
5/1/13 Commercial refrigeration system (CryoMech)
Engineering model integration and test (UA)
8/15/13 OCAM CDR
Flight Unit Build and Test
Flight detectors
Detectors (SRON)
Local oscillator prototype >1mW output (MIT)
Mixer subarray engineering model (ASU)
Detector integration & test (UA)
Spectrometer (OMNISYS)
Flight model integration and test (UA)
11/3/14 OCAM Pre-Ship Review (PSR)
OCAM SOFIA integration, Palmdale
Flight operations
8/3/15 Flight Test 1, Palmdale
11/2/15 Flight Test 2, Palmdale
2/1/16 Flight Test 3, Palmdale
First Second Third Fourth First Second Third Fourth First Second Third Fourth First Second Third Fourth First Second Third Fourth First Second

F-9 Export control

The UA develops a Technology Control Plan (TCP) during after award to ensure compliance with US Export Control Laws. The TCP identifies the participating OCAM personnel, facilities, and technology the requirements for control of defense articles and services, if any, on the OCAM project. After award the UA Export Control Officer, together with the OCAM PI and PM establishes a OCAM Export Control Declaration to determine if any technology element falls under the US Munitions List and is subject to Export Control restrictions. This Declaration serves as the basis for the submission of requests for Export Licenses or Technical Assistance Agreements, if any are required. Technology and articles that fall under the control of the Export Administration Regulations (EAR) are identified using the Commerce Control List. See Appendix 5 for the Draft International Participation Plan.

F-10 Previous experience

The Steward Observatory Radio Observatory (SORAL), under the direction of Professor Chris Walker, has developed state of the art instrumentation for millimeter and submillimeter wavelengths. Current projects include the 64-element SuperCam receiver for the Heinrich Hertz Telescope, receivers for the AST/RO telescope and the South Pole, and the Stratospheric Terahertz Observatory (STO), a long duration submillimeter balloon Instrument. OCAM team members formed a central role in all of these prior projects. STO is the precursor mission to OCAM. The first engineering test flight of STO was from Ft. Sumner, NM on October 15, 2009. The ~30 day science flight is scheduled for December 2011.

G- Cost & Cost Estimating Methodology

The OCAM Project cost is summarized in the table below. See Cost Table B-3 and the detailed budgets for details.

Cost (Real Year Dollars)			
	Phase B	**Phase C/D**	**Total**
Cost	$814 K	$6,214 K	$7,029 K
Reserve	$204 K	$1,554 K	$1,757 K
NASA Totals	**$1,018 K**	**$7,768 K**	**$8,786 K**
Contributed			
Reserve			
Total	**$1,018 K**	**$7,768 K**	**$8,786 K**
Reserve %	25%	25%	25%

The OCAM Project budget was developed with signed-off inputs from each participating organization. The costing methodology used by each organization is summarized in the table below.

The UA project and instrument budgets were prepared using a grass-roots method with analogy to similar instruments such as the STO Balloon Flight instrument with adjustments for the OCAM requirements. The UA instrument budget incorporates the signed-off costs from all participating organizations as identified in the accompanying table. The UA project and instrument budgets utilize the certified forward pricing rates of the UA. The application of the rates to personnel and material costs has been reviewed and approved by the UA administration.

SRON, MIT, and CalTech prepared signed-off detector element estimates based on similar, previous efforts. Omnisys submitted signed-off costs based on the OCAM requirements and previous experience. Science team budgets were prepared based on the assigned roles and responsibilities for each activity.

G-1 UA Cost & Cost Estimating Methodology

The UA budget includes all OCAM costs including UA-specific costs, direct funded organizations, hardware-providing subcontractors, and science team members. The UA-specific costs for the OCAM project organization and instrument was developed by grassroots and analogy to other missions, specifically the STO mission. A budget is developed by WBS (see Fig. H-1), fiscal year, and mission phase detailing the costs for personnel, equipment, travel, capital, and fabricated equipment. Personnel requirements are based on OCAM project plan and past experience of the STO project, taking into account the experience of the personnel assigned to the OCAM project, to establish the management, engineering, and technician funding requirements. Operations costs for personnel support are calculated from prorated actuals from other, similar programs. These costs are for computer support and research supplies. Travel costs are estimated by counting the number of trips, traveling personnel and days for each destination by fiscal year by using current prices (for FY112 calculations to be escalated with NASA-approved inflation factors for real year dollars). Direct-funded and subcontracted organizations have prepared their own organizationally signed-off budgets. There is no UA overhead charge against direct-funded costs; subcontracted costs include overhead charged against the first $25K of each award. Capital fabricated equipment have been identified and priced. UA indirect costs apply to total personnel costs, operations costs, and fabricated equipment costs plus subcontracts as described above.

G-2 Cost Risk

Cost reserves were allocated as a function of uncertainty and risk. Cost uncertainty has two primary sources: cost estimating uncertainty and cost growth due to unforeseen technical difficulties.

The cost reserve for OCAM (real year) is $1.757M. This represents a conservative approach of 25% reserve for the entire project.

G-3 Small Business Participation

The OCAM team at the UA and its subcontractors have established a contracting plan to include small and disadvantaged businesses in its procurement activities, which is consistent with the overall NASA objective, FAR 52.219-9, and the laws of the State of Arizona. The Arizona Board of Regents has established a Master Subcontracting Plan that includes a Manager of the UA Small Business Supplier Diversity Program, Mr. Ernest Webster. Mr. Webster maintains qualified bidder lists of small, disadvantaged businesses These businesses are routinely included in appropriate solicitations. He also reviews all procurements from the UA for compliance with UA procurement practices relating to fairness in solicitations and awards.

The UA OCAM Team will make solicitations through the UA Procurement Office for hardware and software services to small, disadvantaged business that will result in competitive awards. Candidate tasks for small disadvantaged businesses include machining and qualifying custom mechanical parts, performing test and verification for specialized activities, performing thermal analysis, performing structural analysis, participating in the overall instrument suite qualification process.

Limited SB/SDB/WOSB subcontracting possibilities have been identified for thermal analysis consulting. OCAM will seek to achieve the goals of small/disadvantaged business contracting by: (1) aggressively pursuing project opportunities and (2) purchasing goods and services using UA institutional subcontracts with SBs/SDBs/ WOSBs (e.g., office supplies and temporary technical support).

Participating Organizations

Organization	Role	Basis of Estimate Funding
SRON (Netherlands)	Detector fabrication	Signed-off cost; Cost plus fixed fee, capped
MIT	Detector fabrication	Signed-off cost; Cost reimbursable
Sandia National Lab	Detector fabrication	Signed-off cost; Direct-funded, cost plus fixed fee, capped
Omnisys	Spectrometer	Signed-off ROM; Cost plus fixed fee, capped
CalTech	Detector fabrication	Signed-off cost; Cost reimbursable
UCRYO	Cryostat	Signed-off cost; Cost plus fixed fee, capped
CryoMech	Refrigeration unit for cryostat	Signed-off cost; Cost plus fixed fee, capped
ASU	Science team (Groppi) Focal Plane Subassembly	Signed-off cost; Cost reimbursable
SETI	Science team (Hollenbach)	Signed-off cost; Cost reimbursable
Colorado University	Science team (Bally)	Signed-off cost; Cost reimbursable
UCLA	Science team (Morris)	Signed-off cost; Cost reimbursable
Oberlin College	Science team (Martin)	Signed-off cost; Cost reimbursable
JHU	Science team (Neufeld)	Signed-off cost; Cost reimbursable
SAO	Science team (Melnick & Stark)	Signed-off cost; Cost reimbursable

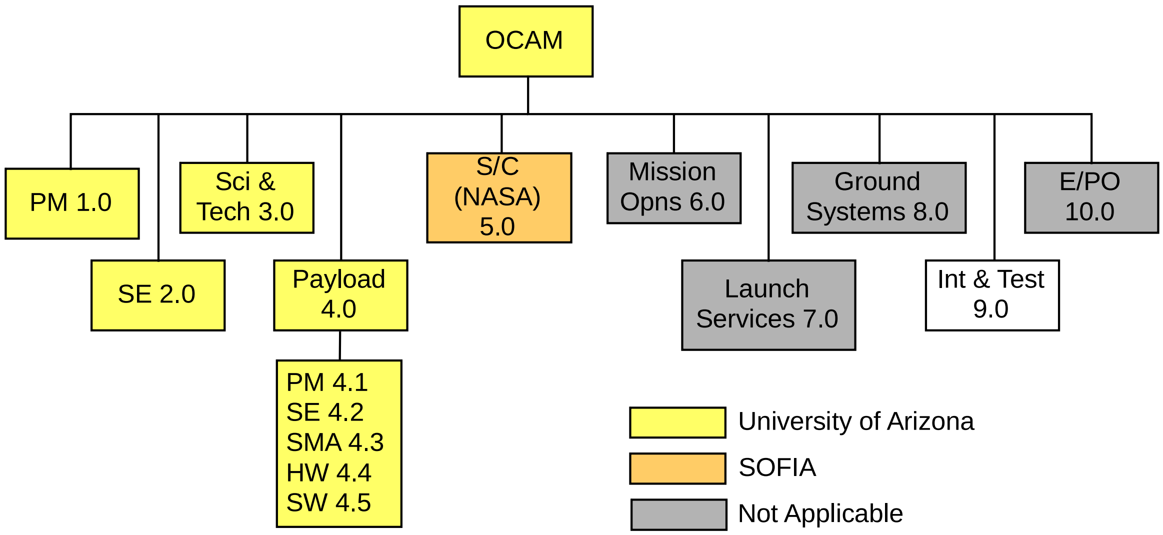
OCAM **Table B-3**

Total Mission Cost Funding Profile (Real Year Dollars)

WBS#	WBS Element	Phase B	Phase C/D					RY$
		FY2012	FY2013	FY2014	FY2015	FY2016	Total	Total
01	Project Management	$56,464	$111,599	$147,195	$201,335	$80,957	$541,087	$597,550
02	Systems Engineering	$10,744	$45,127	$45,258	$47,639	$24,457	$162,481	$173,225
03	Safety & Mission Assurance	$3,581	$15,042	$15,086	$15,880	$8,152	$54,160	$57,742
04	Science / Technology	$201,379	$381,079	$341,000	$359,951	$183,875	$1,265,905	$1,467,283
	Breakout pre-launch science from technology development activities							
05	Payload(s)	$542,137	$1,679,921	$1,241,705	$915,986	$353,111	$4,190,722	$4,732,859
	List each instrument separately							
06	Spacecraft							
	List each major flight system element separately							
07	Mission Operations							
	Breakout separable services, e.g., DSN, etc.							
08	Launch Vehicle / Services							
09	Ground System(s)							
	Breakout non-standard cost, e.g., coordinating ground stations							
10	Systems Integration & Testing							
11	Education and Public Outreach							
	Reserves	$203,576	$558,192	$447,561	$385,198	$162,638	$1,553,589	$1,757,165
	PI-Managed Mission Cost	$1,017,881	$2,790,960	$2,237,805	$1,925,989	$813,190	$7,767,944	$8,785,825
Contributions								
	Student Collaboration Incentive (if applicable)							
	List by organization and WBS element							
	Total Contributions							
	Total Mission Cost							
Other AO-specific Activities								
	List by activity and WBS element							
	Enhanced PI-Managed Mission Cost							
	Phase B Bridge Phase Funding *(included above)*							

OCAM	Qty (mass)	Qty (power)	CBE Mass per unit	CBE Mass Total	Mass Reserve		Flight Mass	CBE Power per Unit	Duty cycle	CBE Average Power	Power Reserve		Average Flight Power	TRL	Source	Prchs	Notes
	Unit	Unit	kg	kg	%	kg	kg	W	%	W	%	W	W			Units	
Instrument Totals				400.0	33.6%	134.30	534.3			10820.0	21.7%	2350.00	13170.00				
Cryostat				50.0	38.6%	19.30	69.3										
Primary Structure and instrument	1	0	31.00	31.0	50.0%	15.50	46.5	0.0	0%	0.0	0.0%	0.00	0.00	6	Universal Cryogenics	1	
PT-410 coldhead	1	0	19.00	19.0	20.0%	3.80	22.8	0.0	0%	0.0	0.0%	0.00	0.00	5	Cryomech inc	1	w/ custom helium stabilization pot
Electronics				50.0	50.0%	25.00	75.0			520.0	50.0%	260.0	780.0				
Bias Electronics	1	1	10.00	10.0	50.0%	5.00	15.0	100.0	100%	100.0	50.0%	50.00	150.00	6	UofA	1	
IF system	1	1	10.00	10.0	50.0%	5.00	15.0	100.0	100%	100.0	50.0%	50.00	150.00	6	Caltech	1	
Spectrometer	1	1	10.00	10.0	50.0%	5.00	15.0	100.0	100%	120.0	50.0%	60.00	180.00	7	Omnisys Inc.	1	
OCL controller	1	1	10.00	10.0	50.0%	5.00	15.0	100.0	100%	100.0	50.0%	50.00	150.00	6	MIT	1	
Instrument Computer	1	1	10.00	10.0	50.0%	5.00	15.0	100.0	100%	100.0	50.0%	50.00	150.00	7	Rack mount industrial computer	1	
Cable Harness	1	1	10.00	10.0	50.0%	5.00	15.0	0.0	0%	0.0	0.0%	0.00	0.00	7	UofA	1	
Compressor System				290.0	13.0%	88.00	378.0			10000.0	20.3%	2030.00	12030.00				
CP289C Compressor	1	1	120.00	120.0	20.0%	24.00	144.0	8400.0	100%	8400.0	20.0%	1680.00	10080.00	5	Cryomech Inc.	1	Modified for airworthiness
Heat exchanger and circulator pump	1	1	50.00	50.0	50.0%	25.00	75.0	1500.0	100%	1500.0	20.0%	300.00	1800.00	5	Cryomech Inc.	1	
Compressor tip-tilt gimbal	1	1	50.00	50.0	50.0%	25.00	75.0	100.0	100%	100.0	50.0%	50.00	150.00	5	Universal Cryogenics	1	
Helium Flex Lines 25m	2	1	31.00	62.0	20.0%	12.40	74.4	0.0	100%	0.0	0.0%	0.00	0.00	5	Cryomech Inc.	2	
Helium Flex lines 3m	2	1	4.00	8.0	20.0%	1.60	9.6	0.0	100%	0.0	0.0%	0.00	0.00	5	Cryomech Inc.	2	
Command & Control				10.0	20.0%	2.00	12.0			300.0	20.0%	60.00	360.00				
Control Computer	1	1	10.00	10.0	20.0%	2.00	12.0	300.0	100%	300.0	20.0%	60.00	360.00	9	Rack mount industrial computer	1	
GSE totals																	
Ground Control																	
GSE Computer Workstations															Dell Precision T3500	4	
GSE Monitors															Dell Ultrashorp U271	4	
GSE Backup storage															Seagate Expansion 750GB	4	
UPS															APC Back-UPS ES 550	4	
System level Integration & Testing																	
GSE Compressor system															Cryomech CP289C	1	
GSE electronics rack															1/2 height COTS 19" rack	1	
Tools																	
Mechanical tool set															CRAFTSMAN 283 pc. Tool set	1	
Electronics tool set															Eclipse 902-123 50 PCs Electronics Tool Kit	1	
EDS mats															ESD-2X3KT	3	
Test Equipment																	
Oscilloscope															Hameg HM1500	1	
Spectrum Analyzer															Agilent E8563E	1	
Power meter															Agilent 437B	1	
Synthesizer															Agilent 83751A	1	
Multimeter															Fluke 28	3	
Field Operations																	
SI Instrument Cart															Universal Cryogenics	1	
Cryostat Transport Container															Reinforced wood crates	1	
Compressor Transport Containers															Reinforced wood crates	3	
GSE & Tools Transport Containers															Pelican 0370 Cube Case	10	

FIGURE H-1: WBS AND WBS



DICTIONARY

WBS	Title	Responsible Organization	Description of the equipment, data, services, human resources and facilities required to develop and produce integrated systems which meet Project level 1 requirements.
1.0	**Project Management**	UA (PI Org)	Element 1 - Project Management: The business and administrative planning, organizing, directing, coordinating, analyzing, controlling, and approval processes used to accomplish overall project objectives, which are not associated with specific hardware or software elements. This element includes project reviews and documentation, non-project owned facilities, and project reserves. It excludes costs associated with technical planning and management and costs associated with delivering specific engineering, hardware and software products.
2.0	**Systems Engineering**	UA (PI Org)	Element 2 - Systems Engineering: The technical and management efforts of directing and controlling an integrated engineering effort for the project. This element includes the efforts sto define the project space flight vehicle(s) and ground system, conducting trade studies, the integrated planning and control of the technical program efforts of design engineering, software engineering, specialty engineering, system architecture development and integrated test planning, system requirements writing, configuration control, technical oversight, control and monitoring of the technical program, and risk management activities. documentation products include requirements documents, interface control documents (ICDs), Risk Management Plan, and master verification and validation (V&V) plan. Excludes any design engineering costs.
3.0	**Safety & Mission Assurance**	UA (PI Org)	Element 3 - Safety and Mission Assurance: The technical and management efforts of directing and controlling the safety and mission assurance elements of the project. This element includes design, development, review, and verification of practices and procedures sand mission success criteria intended to assure that the delivered Aircraft, ground systems, mission operations, and payload(s) meet performance requirements and function for their intended lifetimes. This element excludes mission and product assurance efforts directed at partners and subcontractors other than a review/oversight function, and the direct costs of environmental testing.

4.0	**Science**	UA (PI Org)	Element 4 - Science / Technology: This element includes the managing, directing, and controlling of the science investigation aspects, as well as leading, managing, and performing the technology demonstration elements of the Project. The costs incurred to cover the Principal Investigator, Project Scientist, science team members, and equivalent personnel for technology demonstrations are included. Specific responsibilities include defining the science or demonstration requirements; ensuring the integration of these requirements with the payloads, Aircraft, ground systems, and mission operations; providing the algorithms for data processing and analyses; and performing data analysis sand archiving. This element excludes hardware and software for onboard science investigative instruments/payloads.
5.0	**Project instrument (Payload)**	UA (PI Org)	Element 5 - Payload: This element includes the equipment provided for special purposes sin addition to the normal equipment (i.e., GSE) integral to the Aircraft. This includes leading, managing, and implementing the hardware and software payloads that perform the scientific experimental and data gathering functions placed on board the Aircraft, as well as the technology demonstration for the mission.
6.0	**Flight System (SOFIA Platform)**	NASA	Element 6 - Aircraft: The Aircraft that serves as the platform for carrying payload(s), instrument(s) and other mission-oriented equipment in space to the mission destination(s) to achieve the mission objectives. The Aircraft may be a single Aircraft or multiple Aircraft/modules (i.e., cruise stage, orbiter, Lander, or rover modules). Each Aircraft/module of the system includes the following subsystems, as appropriate: Power, Command & Data Handling, Telecommunications, Mechanical, thermal, Propulsion, Guidance Navigation and Control, Wiring Harness, and Flight software. This element also includes all design, development, production, assembly, test efforts, and associated GSE to deliver the completed system for integration with the launch vehicle and payload. This element does not include integration and test with payloads and other project systems.
7.0	**Mission Operations**	**NA**	Element 7 - Mission Operations System: The management of the development and implementation of personnel, procedures, documentation, and training required to conduct mission operations. This element includes tracking, commanding, receiving/processing telemetry, analyses of system status, trajectory analysis, orbit determination, maneuver analysis, target body orbit/ephemeris updates, and disposal of remaining end-of-mission resources. The same WBS structure is used for Phase E Mission Operation Systems but with inactive elements defined as "not applicable." However, different accounts must be used for Phase E due to NASA cost reporting requirements. This element does not include integration and test with the other project systems.
8.0	**Launch Vehicle**	**NA**	Element 8 - Launch Vehicle / Services: The management and implementation of activities required to place the Aircraft directly into its operational environment, or on a trajectory towards its intended target. This element includes launch vehicle, launch vehicle integration, launch operations, any other associated launch services (frequently includes an upper-stage propulsion system), and associated ground support equipment. This element does not include the integration and test with the other project systems.
9.0	**Ground Systems Development**	**NA**	Element 9 - Ground System(s): The complex of equipment, hardware, software, networks, and mission-unique facilities required to conduct mission operations of the Aircraft systems and payloads. This complex includes the computers, communications, operating systems, and networking equipment needed to interconnect and host the Mission Operations software. This element includes the design, development, implementation, integration, test, and the associated support equipment of the ground system, including the hardware and software needed for processing, archiving, and distributing telemetry and radiometric data and for commanding the Aircraft. Also includes the use and maintenance of the project testbeds and project-owned facilities. This element does not include integration and test with the other project systems and conducting mission operations.
10.0	**Systems Integration & Testing**	UA, UA & SOFIA	Element 10 - Systems Integration and Testing: This element includes the hardware, software, procedures, and project-owned facilities required to perform the integration and testing of the project's systems, payloads, Aircraft, launch vehicle/services, and mission operations.
11.0	**Education & Public Outreach (EPO)**	**NA**	Element 11 - Education and Public Outreach: Provide for the education and public outreach (EPO) responsibilities of NASA's missions, projects, and programs in alignment with the Strategic Plan for Education. Includes management and coordinated activities, formal education, informal education, public outreach, media support, and website development.

H-3 Basis of Estimate Details

Detailed budget attached.

H-4 E/PO Acknowledgement and SC

The SOFIA PEA does not require an Education and Public Outreach plan.

row	OCAM Technology Demonstration Instrument		Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552

University of Arizona, Steward Observatory

Total (includes reserves) = $8,785,825

8	OCAM Technology Demonstration Instrument	check	Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
9	**Labor (dollars)**	OK	$668,994	$52,423	$181,923	$192,912	$197,928	$43,809
10	**Benefits**	OK						
11	Faculty/Appointed	OK	$168,537	$13,221	$44,987	$48,013	$49,261	$13,055
12	Staff	OK						
13	Undergraduate Students	OK						
14	Graduate Students	OK	$11,378	$886	$3,405	$3,497	$3,588	
15	Graduate Student Remission	OK	$27,617	$2,151	$8,266	$8,489	$8,710	
16	**Benefits**	OK	$207,532	$16,258	$56,659	$60,000	$61,560	$13,055
17	**Labor Costs**	OK	$876,526	$68,681	$238,582	$252,911	$259,487	$56,865
18	**Operations (less subcontracts)**	OK	$27,672	$841	$8,564	$2,995	$13,057	$2,215
19	**Subcontracts**	OK						
20	Subcontract	OK	$3,958,858	$498,409	$1,275,277	$1,086,346	$737,451	$361,375
21	Subcontract burden	OK	$141,625	$95,606	$46,019			
22	**Subcontracts (includes burden)**	OK	$4,100,483	$594,016	$1,321,295	$1,086,346	$737,451	$361,375
23	**Fabricated equipment (overhead bearing)**	OK	$449,574		$84,645	$86,930	$186,489	$91,510
24	**Non-overhead bearing equipment (Capital)**	OK	$441,222		$307,800	$60,412	$36,037	$36,974
25	**Travel**	OK	$99,150	$10,608	$3,476	$18,785	$50,399	$15,882
26		OK						
27	**Total Direct Costs (TDC)**	OK	$5,853,003	$578,540	$1,918,344	$1,508,381	$1,282,920	$564,819
28	**Indirect Costs on TDC (includes subcontracts burden)**	OK	$875,657	$135,765	$214,424	$181,864	$257,872	$85,732
29		OK						
30		OK						
31	**Total, Arizona and subcontrators, real year $, A/B/C/D/E1**	**OK**	**$6,728,660**	**$714,305**	**$2,132,768**	**$1,690,244**	**$1,540,791**	**$650,552**
32	**UA excluding subcontracts** $2,769,802			**$714,305**	**$2,847,073**	**$4,537,317**	**$6,078,109**	**$6,728,660**
33								
34	**Direct Funding**							
35	Sandia Lab (John Marino)	OK	$300,000	$100,000	$100,000	$100,000		
36	Not used	OK						
37	Not used	OK						
38								
39	Total before reserve		**$7,028,660**	$814,305	$2,232,768	$1,790,244	$1,540,791	$650,552
40								
41								
42	**Reserve total = $1,757,165**		**$1,757,165**	**$203,576**	**$558,192**	**$447,561**	**$385,198**	**$162,638**
43	**Reserves as a percentage**		**25%**	25%	25%	25%	25%	25%
44								
45								
46								
47	**Total, NASA-provided funds, real year $**		**$8,785,825**	$1,017,881	$2,790,960	$2,237,805	$1,925,989	$813,190
48								
49	**Total, NASA-provided funds, real year $**		**$8,785,825**	**$1,017,881**	**$2,790,960**	**$2,237,805**	**$1,925,989**	**$813,190**
50								
51								
52								

row	OCAM Technology Demonstration Instrument			Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
53	**Rates (fringe benefits, indirect costs, labor rates)**								
54	**Fringe benefits**			FY12 rates					
55	Faculty	1		29.8%	29.8%	29.8%	29.8%	29.8%	29.8%
56	Staff	2		43.7%	43.7%	43.7%	43.7%	43.7%	43.7%
57	Graduate students	3		11.0%	11.0%	11.0%	11.0%	11.0%	11.0%
58	Graduate Student Remission	4		26.7%	26.7%	26.7%	26.7%	26.7%	26.7%
59	Undergraduate Students	5		3.1%	3.1%	3.1%	3.1%	3.1%	3.1%
60	Temporary staff	6		8.7%	8.7%	8.7%	8.7%	8.7%	8.7%
61	**Indirect Cost**			51.5%	51.5%	51.5%	51.5%	51.5%	51.5%
62	**General inflation factors**					2.6%	2.7%	2.6%	2.6%
63	Cumulative inflation factors					2.6%	5.4%	8.1%	10.9%
64	**Salary adjustments**					2.6%	2.7%	2.6%	2.6%
65	Cumulative salary adjustments					2.6%	5.4%	8.1%	10.9%
66				GUSSTO Event	Phase A	Phase A	PDR	CDR	Detailed Design
67					FY12 7/1/12-9/30/12 3.0 months	FY13 10/1/12-9/30/13 12.0 months	FY14 10/1/13-9/30/14 12.0 months	FY15 10/1/14-9/30/15 12.0 months	FY16 10/1/15-9/30/16 12.0 months
68				Start	7/1/12	10/1/12	10/1/13	10/1/14	10/1/15
69				Finish	9/30/12	9/30/13	9/30/14	9/30/15	9/30/16
70				Months	3.0	12.0	12.0	12.0	12.0
71				Phase	**FY12**	**FY13**	**FY14**	**FY15**	**FY16**
72	**Labor Allocations (work months)**	check		**Totals Phase B/C/D/E1**	**FY12 7/1/12-9/30/12 3.0 months $814,305**	**FY13 10/1/12-9/30/13 12.0 months $2,232,768**	**FY14 10/1/13-9/30/14 12.0 months $1,790,244**	**FY15 10/1/14-9/30/15 12.0 months $1,540,791**	**FY16 10/1/15-9/30/16 12.0 months $650,552**
73	Principal Investigator (Chris Walker), academic @ 1600 hours	OK	Faculty						
74	Principal Investigator summer salary @464 hours	OK	Faculty	5.0	1.0	1.0	1.0	1.0	1.0
75	Project Manager (Brian Duffy)	OK	Appointed	22.5	1.5	6.0	6.0	6.0	3.0
76	Deputy Project Manager (Hop Bailey)	OK	Appointed	3.9	0.3	1.2	1.2	1.2	
77	not used	OK	Staff						
78	Program Coordinator (TBD)	OK	Staff						
79	Configuration manager (Stacy Oliver)	OK	Appointed	2.4			1.2	1.2	
80	Engineering	OK							
81	Deputy PI and Systems Engineer (Craig Kulesa)	OK	Appointed	22.5	1.5	6.0	6.0	6.0	3.0
82	Mechanical Engineer (Ruben Dominguez)	OK	Appointed	19.5	1.5	6.0	6.0	6.0	
83	Electrical Engineer (TBD)	OK	Appointed	19.5	1.5	6.0	6.0	6.0	
84	Software Engineer (TBD)	OK	Appointed						
85	Thermal & structural analysis (Cuerden)	OK	Appointed						
86	not used	OK							
100	Research Assistant (grad student), academic year	OK	Grad student	13.5		4.5	4.5	4.5	
101	Research Assistant (grad student), summer	OK	Grad student	11.0	2.0	3.0	3.0	3.0	
102	Research Assistant (grad student), academic year	OK	Grad student						
103	Research Assistant (grad student), summer	OK	Grad student						
104	not used	OK							
119		**Total labor months by FY**		**119.8**	**9.30**	**33.70**	**34.90**	**34.90**	**7.00**
120		FTEs	FTE	9.98	3.10	2.81	2.91	2.91	0.58
121		Total labor hours by	Hours	25700	6473	5864	6073	6073	1218
126	**Labor Rates (hourly)**								
127				***Salaries, FY10***					
128	Principal Investigator (Chris Walker), academic @ 1600 hours		Faculty	*$90,767*					
129	Principal Investigator summer salary @464 hours		Faculty	*$30,322*	$65.35	$67.05	$68.86	$70.65	$72.49
130	Project Manager (Brian Duffy)		Appointed	*$60,000*	$28.74	$29.48	$30.28	$31.07	$31.87
131	Deputy Project Manager (Hop Bailey)		Appointed	*$107,535*	$51.50	$52.84	$54.27	$55.68	
132	not used		Staff						
133	Program Coordinator (TBD)		Staff	*$40,000*					
134	Configuration manager (Stacy Oliver)		Appointed	*$57,671*			$29.10	$29.86	
135	Engineering								
136	Deputy PI and Systems Engineer (Craig Kulesa)		Appointed	*$57,555*	$27.56	$28.28	$29.04	$29.80	$30.57
137	Mechanical Engineer (Ruben Dominguez)		Appointed	*$70,000*	$33.52	$34.40	$35.33	$36.24	
138	Electrical Engineer (TBD)		Appointed	*$65,000*	$31.13	$31.94	$32.80	$33.65	
139	Software Engineer (TBD)		Appointed	*$65,000*					

row	OCAM Technology Demonstration Instrument			Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
140	Thermal & structural analysis (Cuerden)		Appointed	*$103,049*					
141	not used			*$67,123*					
155	Research Assistant (grad student), academic year		Grad student	*$36,177*		$23.20	$23.82	$24.44	
156	Research Assistant (grad student), summer		Grad student	*$12,086*	$26.05	$26.72	$27.45	$28.16	
157	Research Assistant (grad student), academic year		Grad student	*$34,454*					
158	Research Assistant (grad student), summer		Grad student	*$11,512*					
159	not used								
174									
175									
176									
177	**Labor**								
178	Principal Investigator (Chris Walker), academic @ 1600 hours	OK	Faculty						
179	Principal Investigator summer salary @464 hours	OK	Faculty	$53,266	$10,107	$10,370	$10,650	$10,927	$11,211
180	Project Manager (Brian Duffy)	OK	Appointed	$118,962	$7,500	$30,780	$31,611	$32,433	$16,638
181	Deputy Project Manager (Hop Bailey)	OK	Appointed	$36,678	$2,688	$11,033	$11,331	$11,626	
182	not used	OK	Staff						
183	Program Coordinator (TBD)	OK	Staff						
184	Configuration manager (Stacy Oliver)	OK	Appointed	$12,312			$6,077	$6,235	
185	Engineering	OK							
186	Deputy PI and Systems Engineer (Craig Kulesa)	OK	Appointed	$114,114	$7,194	$29,526	$30,323	$31,111	$15,960
187	Mechanical Engineer (Ruben Dominguez)	OK	Appointed	$119,378	$8,750	$35,910	$36,880	$37,838	
188	Electrical Engineer (TBD)	OK	Appointed	$110,851	$8,125	$33,345	$34,245	$35,136	
189	Software Engineer (TBD)	OK	Appointed						
190	Thermal & structural analysis (Cuerden)	OK	Appointed						
191	not used	OK							
205	Research Assistant (grad student), academic year	OK	Grad student	$57,174		$18,559	$19,060	$19,555	
206	Research Assistant (grad student), summer	OK	Grad student	$46,259	$8,057	$12,400	$12,735	$13,066	
207	Research Assistant (grad student), academic year	OK	Grad student						
208	Research Assistant (grad student), summer	OK	Grad student						
209	not used	OK							
224		OK							
225	**Total**	OK		**$668,994**	**$52,423**	**$181,923**	**$192,912**	**$197,928**	**$43,809**

row									
	OCAM **Technology Demonstration Instrument**			**Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves**	**FY12** **7/1/12-9/30/12** **3.0 months** **$814,305**	**FY13** **10/1/12-9/30/13** **12.0 months** **$2,232,768**	**FY14** **10/1/13-9/30/14** **12.0 months** **$1,790,244**	**FY15** **10/1/14-9/30/15** **12.0 months** **$1,540,791**	**FY16** **10/1/15-9/30/16** **12.0 months** **$650,552**
226	**Travel**	check		All dollars are real-year	**FY12** **7/1/12-9/30/12** **3.0 months** **$814,305**	**FY13** **10/1/12-9/30/13** **12.0 months** **$2,232,768**	**FY14** **10/1/13-9/30/14** **12.0 months** **$1,790,244**	**FY15** **10/1/14-9/30/15** **12.0 months** **$1,540,791**	**FY16** **10/1/15-9/30/16** **12.0 months** **$650,552**
227	Management meetings								
228	Programmatic & financial reviews	OK	NASA	$16,940	$3,388	$3,388	$3,388	$3,388	$3,388
229	CalTech vendor	OK	not used						
230	SRON vendor	OK	SRON	$7,664	$3,832		$3,832		
231	MIT vendor	OK	MIT	$6,776	$3,388		$3,388		
235	Integration	OK							
236	Delivery support for SOFIA Integration	OK	Palmdale	$9,530				$9,530	
237	Integration and Test Palmdale	OK	Palmdale	$19,060				$19,060	
238	not used	OK							
239	Flight opertions	OK							
240	SOFIA Flight 1	OK	Palmdale	$3,710				$3,710	
241	SOFIA Flight 2	OK	Palmdale	$3,710				$3,710	
242	SOFIA Flight 3	OK	Palmdale	$3,710					$3,710
264	not used	OK							
265	Science team meetings, west coast	OK	Palmdale						
266	Science team meetings, foreign	OK	SRON	$11,496			$3,832	$3,832	$3,832
267	Science team meetings, east coast	OK	MIT	$10,164			$3,388	$3,388	$3,388
268		OK							
269	**Total Travel, real-year dollars**	OK		$99,150	**$10,608**	**$3,476**	**$18,785**	**$50,399**	**$15,882**
270	**Travel Worksheet** **Purpose Of Trip**		**Destination Code**		**trips, persons, days**	**trips, persons, days**	**trips, persons, days**	**trips, persons, days**	**trips, persons, days**
271	Management meetings								
272	Programmatic & financial reviews	NASA	2		1,2,3	1,2,3	1,2,3	1,2,3	1,2,3
273	CalTech vendor	not used	8		1,2,3		1,2,3		
274	SRON vendor	SRON	4		1,2,3		1,2,3		
275	MIT vendor	MIT	3		1,2,3		1,2,3		
276	not used								
279	Integration								
280	Delivery support for SOFIA Integration	Palmdale	1					1,2,15	
281	Integration and Test Palmdale	Palmdale	1					1,4,15	
282	not used								
283	Flight opertions								
284	SOFIA Flight 1	Palmdale	1					1,2,5	
285	SOFIA Flight 2	Palmdale	1					1,2,5	
286	SOFIA Flight 3	Palmdale	1						1,2,5
309	Science team meetings, west coast	Palmdale	1						
310	Science team meetings, foreign	SRON	4				1,2,3	1,2,3	1,2,3
311	Science team meetings, east coast	MIT	3				1,2,3	1,2,3	1,2,3
316	**Travel lookup table**								
317	**Rates verified with travel agent on:**								
318		code	**1**	**2**	**3**	**4**	**3**	**4**	**5**
319	facility	1	Palmdale	NASA	MIT	SRON	MIT	SRON	CalTech
320	airport	2	LAX	Washington, DC	Boston	Amsterdam	Boston	Amsterdam	LAX
321	airfare	3	$400	$800	$800	$1,100	$800	$1,100	$400
322	airport-hotel miles	4							
323	mileage rate (per mile)	5	$0.38	$0.38	$0.38	$0.38	$0.38	$0.38	$0.38
324	Tucson transp.	6	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00	$5.00
325	transportation	7	$405.00	$805.00	$805.00	$1,105.00	$805.00	$1,105.00	$405.00
326	first day meals	8	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00	$36.00
327	> first day meals	9	$74.00	$74.00	$74.00	$74.00	$74.00	$74.00	$74.00
328	hotel	10	$120.00	$120.00	$120.00	$100.00	$120.00	$100.00	$120.00
329	car	11	$53.00	$60.00	$60.00	$54.00	$60.00	$54.00	$53.00
330	people per car	12	2	2	2	2	2	2	2
331	parking	13							
332	Tucson parking	14	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00	$8.00
333					3	12	12	12	12

row	OCAM Technology Demonstration Instrument			Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
334					FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
335	**Operations and supplies less subcontracts**	1.0		check					
336	Technical consulting 3230		OK						
337	Temporary labor 3240		OK						
338	Consultant expenses 3310		OK						
339	Repair & maintenance, data processing		OK	$3,362		$1,444		$1,571	$348
340	Repair & maintenance services, science		OK	$2,017		$866		$943	$209
341	Repair & maintenance services, software		OK	$1,748		$751		$817	$181
342	Communication 3820-3990		OK	$2,648	$250	$635	$919	$691	$153
343	Data processing internal 4140		OK						
344	Education training 4150		OK						
345	Misc services other internal 4290		OK						
346	Not used		OK						
347	Not used		OK						
348	Rentals data processing equipment 4610		OK						
349	Licenses, data processing software 4620		OK	$4,035		$1,733		$1,885	$417
350	Photocopy (department service center) 4830		OK	$3,186	$250	$866	$919	$943	$209
351	Print and photo other 4990		OK	$1,773	$250	$260	$919	$283	$63
352	Training materials (books, etc) 5140		OK	$336		$144		$157	$35
353	Data processing supplies 5150		OK	$1,681		$722		$785	$174
354	Not used		OK						
355	Not used		OK						
356	Not used		OK						
357	Not used		OK						
358	Not used		OK						
359	Not used		OK						
360	Radioactive materials 5240		OK						
361	Research supplies, shop 5260		OK	$366	$92	$84	$87	$87	$17
362	Research supplies, laboratory 5290		OK						
370	Not used		OK						
371	Instrument Control Controller		OK						
372	Computer		OK	$2,000				$2,000	
373	Power supplies		OK	$1,000				$1,000	
374	Not used		OK						
375	Not used		OK						
382	Not used		OK						
383	Operating supplies, other 5490		OK	$998		$433		$471	$94
384	Freight in/out (noncapitol related) 5560		OK						
385	Conference registration fees 5520		OK						
386	Subscriptions 5620		OK						
387	Misc other 5790		OK	$953		$409		$445	$99
388	**Total Operations A/B/C/D/E1, real-year dollars**	3.2%	OK	**$27,672**	**$841**	**$8,564**	**$2,995**	**$13,057**	**$2,215**
389									

row	OCAM Technology Demonstration Instrument			Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
390	**Subcontracts**		check		FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
391									
392	**Not used**	Total = $0	OK						
393	not used		OK						
394	not used		OK						
395	not used		OK						
396	not used		OK						
397	**Not used**	Total = $0	OK						
398	not used		OK						
399	not used		OK						
400	not used		OK						
401	**Sandia ($300K booked in direct funded)**		OK						
402	**SRON (detector)**		OK	$710,000		$177,500	$177,500	$177,500	$177,500
403	**MIT (Local Oscillator)**		OK	$900,000	$100,000	$300,000	$300,000	$200,000	
404	**Omnisys**		OK	$580,000	$128,571	$251,429	$200,000		
405	not used		OK						
406	not used		OK						
407	Not used		OK						
408	Not used		OK						
409	**Not used**		OK						
410	**CalTech (Weinreb)**		OK	$391,700	$125,441	$198,413	$67,846		
411	**Science Team**		OK						
412	ASU (Chris Groppi)		OK	$413,376	$58,684	$136,742	$122,014	$95,937	
413	Hollenbach		OK	$122,677	$25,070	$26,301	$27,592	$43,715	
414	Bally (CU)		OK	$194,270	$14,989	$45,330	$47,012	$50,725	$36,213
415	Morris (UCLA)		OK	$152,885	$9,355	$28,500	$29,827	$42,063	$43,140
416	JHU (Neufeld)		OK	$113,199	$8,170	$24,680	$25,194	$29,737	$25,419
417	Martin (Oberlin College)		OK	$159,977	$13,312	$40,099	$40,491	$40,082	$25,993
418	SAO (Melnick & Stark)		OK	$220,775	$14,817	$46,284	$48,870	$57,694	$53,110
419	Not used		OK						
420	Not used		OK						
421	Not used		OK						
457	Not used		OK						
458	**Total Subcontract**		OK	**$3,958,858**	**$498,409**	**$1,275,277**	**$1,086,346**	**$737,451**	**$361,375**
459	**Subcontract Burden**		OK						
460			OK						
461	**Not used**		OK						
462	not used		OK						
463	not used		OK						
464	not used		OK						
465	not used		OK						
466	Not used		OK						
467	not used		OK						
468	not used		OK						
469	not used		OK						
470	**Sandia ($300K booked in direct funded)**		OK						
471	**SRON (detector)**		OK	$12,875		$12,875			
472	**MIT (Local Oscillator)**		OK	$12,875	$12,875				
473	**Omnisys**		OK	$12,875	$12,875				
474	**not used**		OK						
475	not used		OK						
476	Not used		OK						
477	Not used		OK						
478	Not used		OK						
479	**CalTech (Weinreb)**		OK	$12,875	$12,875				
480	Science Team		OK						
481	ASU (Chris Groppi)		OK	$12,875	$12,875				
482	Hollenbach		OK	$12,875	$12,875				
483	Bally (CU)		OK	$12,875	$7,720	$5,155			
484	Morris (UCLA)		OK	$12,875	$4,818	$8,057			

row	OCAM Technology Demonstration Instrument		Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
485	JHU (Neufeld)	OK	$12,875	$4,207	$8,668			
486	Martin (Oberlin College)	OK	$12,875	$6,856	$6,019			
487	SAO (Melnick & Stark)	OK	$12,875	$7,631	$5,244			
488	Not used	OK						
489	Not used	OK						
526	Not used	OK						
527		OK						
528	Total Subcontract Burden	OK	**$141,625**	**$95,606**	**$46,019**			
529		**OK**						
530	**Total Subcontract (burdened)**	OK	**$4,100,483**	**$594,016**	**$1,321,295**	**$1,086,346**	**$737,451**	**$361,375**

row	OCAM Technology Demonstration Instrument		Total = $7,028,660 without reserves, with reserves =$8.8K, 25% reserves	FY12 7/1/12-9/30/12 3.0 months $814,305	FY13 10/1/12-9/30/13 12.0 months $2,232,768	FY14 10/1/13-9/30/14 12.0 months $1,790,244	FY15 10/1/14-9/30/15 12.0 months $1,540,791	FY16 10/1/15-9/30/16 12.0 months $650,552
531								
532	**Equipment (non-overhead bearing capital)**		All dollars are real-year	**FY12 7/1/12-9/30/12 3.0 months $814,305**	**FY13 10/1/12-9/30/13 12.0 months $2,232,768**	**FY14 10/1/13-9/30/14 12.0 months $1,790,244**	**FY15 10/1/14-9/30/15 12.0 months $1,540,791**	**FY16 10/1/15-9/30/16 12.0 months $650,552**
533	**Dewar (UCRYO)**	OK	$150,000		$150,000			
534	**Refridgeration system (CryoMech)**	OK	$150,000		$150,000			
535	GSE capital	OK	$124,000			$57,333	$33,333	$33,333
536	Not Used	OK						
607	**Total Non-overhead bearing equipment (Capital), real-year dollars**	OK	**$441,222**		**$307,800**	**$60,412**	**$36,037**	**$36,974**
608								
609	**Fabricated equipment (overhead bearing)**	check	All dollars are real-year	**FY12 7/1/12-9/30/12 3.0 months $814,305**	**FY13 10/1/12-9/30/13 12.0 months $2,232,768**	**FY14 10/1/13-9/30/14 12.0 months $1,790,244**	**FY15 10/1/14-9/30/15 12.0 months $1,540,791**	**FY16 10/1/15-9/30/16 12.0 months $650,552**
610								
611	Not Used	OK						
612	**Optics**	OK	$100,000		$25,000	$25,000	$25,000	$25,000
613	**Mechnical mount**	OK	$100,000		$25,000	$25,000	$25,000	$25,000
614	**Bias control**	OK	$30,000		$7,500	$7,500	$7,500	$7,500
615	Not Used	OK						
616	Not Used	OK						
617	Not Used	OK						
618	Mechanical	OK						
619	Cryostat interface	OK	$30,000				$30,000	
620	Detector housing and mount	OK	$30,000				$30,000	
621	Science Control Computer pressurized housing and mount	OK	$10,000				$10,000	
622	GSE	OK	$100,000		$25,000	$25,000	$25,000	$25,000
623	not used	OK						
624	not used	OK						
625	not used	OK						
626	Not Used	OK						
627	Not Used	OK						
628	Electrical	OK						
629	Cables	OK	$10,000				$10,000	
630	Shop support	OK	$10,000				$10,000	
631	Not Used	OK						
632	Not Used	OK						
670	**Total fabricated equipment (overhead bearing)**	OK	**$449,574**		**$84,645**	**$86,930**	**$186,489**	**$91,510**

APPENDICES

LETTERS OF COMMITMENT

KOPIE

Universiteit Leiden

Sterrewacht Leiden

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

Nummer		*Datum*	August 30, 2011
Onderwerp	acknowledgement	*Doorkiesnr.*	071 527 5737
		Contactpersoon	Prof.dr. K. Kuijken

L.S.,

I acknowledge that professor Alexander Tielens is identified by name as Co-Investigator to the investigation, entitled "OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that he intends to carry out all responsibilities identified for him in this proposal. I understand that the extent and justification of his participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Professor K. Kuijken
Scientific Director Leiden Observatory

Sterrewacht Leiden
Postbus 9513
2300 RA Leiden, Nederland
Telefoon (31) 071 527 5737
Fax 071 527 57 43

SRON
Netherlands Institute for Space Research

Prof. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson, AZ 85721
United States of America

SRON Utrecht
Sorbonnelaan 2, 3584 CA Utrecht,
The Netherlands
T +31 (0)88 777 5600, F +31 (0)88 777 5601
www.sron.nl

Our reference: SRON D-11/006
Direct dialling: +31 (0)88 777 5800
E-mail: L.B.F.M.Waters@sron.nl
Date: September 30th 2011

Dear Prof. Walker,

SRON Netherlands Institute for Space Research (SRON) acknowledges its role in the investigation, entitled "OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by you to the NASA Announcement of Opportunity NNH08ZDA009O.

SRON's track record includes the Principal Investigator role of the HIFI instrument, now operating on Herschel, and contributions to the receivers for Band 9 of the Atacama Large Millimeter Array. SRON still maintains a research and development program dedicated to SuperTeraHertz technology and towards heterodyne receivers. If OCAM is selected by NASA, SRON is committed, in collaboration with Delft University of Technology, to provide technical expertise in HEB mixer and THz LO technology to realize a 4.7 THz [OI] array receiver for OCAM. In particular, SRON will optimize and characterize HEB mixers at 4.7 THz, and realize frequency locking of a THz quantum cascade laser as a local oscillator for OCAM.

SRON will also participate in the OCAM Science Team, helping in the planning, execution, and interpretation of OCAM observations. We believe OCAM will provide a new window on the Universe at THz frequencies.

SRON understands that the extent and justification of its participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

We propose that subsequent contacts will be maintained by Dr. J.R. Gao (SRON, division Sensor Research and Technology) and Dr. F.P. Helmich (SRON, division Low-Energy Astrophysics, regarding OCAM's science team).

We wish you and your team all success and look forward to a fruitful collaboration.

Sincerely,

Prof.dr. L.B.F.M.Waters
Scientific Director

Date September 26, 2011
our reference U2011.02.03/JRG/MR
Contactperson dr J.R. Gao
Phone/fax +31 (0)31 15 2781370/+31 (0)15 2781413
E-mail j.r.gao@tudelft.nl
Subject OCAM

TUDelft

Technical University Delft

Applied Sciences, Kavli Institute of NanoScience, Dept. of Quantum Nanoscience
Physics of NanoElectronics

Adres
Lorentzweg 1
2628 CJ Delft
The Netherlands

http://www.nf.tudelft.nl/

Prof. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson, AZ 85721
USA

Dear Prof. Walker,

Delft University of Technology in the Netherlands (TU Delft), in particular the Kavli Institute of Nanoscience, acknowledges its role in the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by you to the NASA Announcement of Opportunity NNH08ZDA009O.

TU Delft has contributed the detector technology for the HIFI instrument operating on Herschel and to Band 9 (602-720 GHz) of the Atacama Large Millimeter Array. Through its research TU Delft is also at the fore-front of SuperTeraHertz technology. If OCAM is selected by NASA, TU Delft is committed, in collaboration with SRON, to provide the technical expertise in HEB mixer and THz LO technology necessary to realize a 4.7 THz [OI] array receiver for OCAM. In particular, TU Delft will design, fabricate, characterize and optimize the associated HEB devices to the University of Arizona for OCAM.

TU Delft understands that the extent and justification of our participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. We believe OCAM will provide a new window on the Universe at THz frequencies and wish you and your team all success! We propose that subsequent contacts will be maintained by Dr. J.R. Gao, who is part-time employed at our university, working in the group of prof. Klapwijk, and for the remainder at SRON.

We look forward to a fruitful collaboration.

Sincerely,

Prof.dr.ir. T.M. Klapwijk
Group leader Physics of NanoElectronics

Prof.dr.ir. T.H.J.J. van der Hagen
Dean of the Faculty of Applied Sciences

CALIFORNIA INSTITUTE OF TECHNOLOGY

Pasadena, California 91125

Office of Sponsored Research
(626) 395-6357

Mail Stop 201-15
Fax: (626) 795-4571

September 27, 2011

Dr. Christopher K. Walker
Steward Observatory
University of Arizona
933 N. Cherry Ave.
Tucson, AZ 85712

SUBJECT: Subcontract Proposal to the University of Arizona

Dear Dr. Walker:

On behalf of the California Institute of Technology and Dr. Sander Weinreb, I am pleased to submit the enclosed proposal for a project entitled, "IF Amplifier System for the OCAM Project." I understand that the work of Dr. Weinreb will be incorporated into a proposal to be submitted by the University of Arizona to NASA in response to NNH08ZDA009O-SOFIA2G.

The Caltech proposal contemplates a 2 year project beginning January 1, 2012, at an estimated cost of $391,403. Caltech anticipates participating in the project under a cost reimbursement subcontract agreement that is subject to mutually agreeable terms and conditions.

It is Caltech's policy not to accept export controlled material or data that would compromise its ability to perform its research activities as Fundamental Research or which contain restrictions on employee citizenship. It is also Caltech policy to retain the right to publish freely from the results of any research conducted by the faculty. Caltech must be able to retain title to any Caltech developed intellectual property.

Please contact me at (626) 395-3339 if you have any questions about the budget or other administrative matters pertaining to this proposal.

Sincerely yours,

Lisa Miller

Lisa Miller
Contract and Grant Analyst
Office of Sponsored Research

Enclosure

University of Colorado at Boulder

Center for Astrophysics and Space Astronomy

Prof. John Bally
389 UCB
Boulder, Colorado 80309-0389
(303) 492-5786
Fax: (303) 492-7178
John.Bally@colorado.edu

16 September 2011

To: Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

I acknowledge that I am identified by name as Co-Investigator on the investigation, entitled ***"OCAM - An Oxygen Heterodyne Camera for SOFIA"***, that is being submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Dr. John Bally

University of Colorado at Boulder
John.Bally@colorado.edu

303 492 5786

SRON
Netherlands Institute for Space Research

Prof. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson, AZ 85721
United States of America

SRON Utrecht
Sorbonnelaan 2, 3584 CA Utrecht,
The Netherlands
T +31 (0)88 777 5600, F +31 (0)88 777 5601
www.sron.nl
Your reference:
Our reference:
Direct dialling: +31(0)15-2781370
E-mail: j.r.gao@tudelft.nl
Date: October 3, 2011

Re: letter of commitment for OCAM!

To whom it may concern

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely yours,

Dr. Jian-Rong Gao
Project leader of the super-THz technology at SRON and TU Delft
Senior Instrument Scientist in SRON Netherlands Institute for Space Research
Part time senior researcher in Delft University of Technology

ARIZONA STATE UNIVERSITY

October 5, 2011

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled "OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Christopher E. Groppi

Dr. Christopher Groppi
Assistant Professor
School of Earth and Space Exploration
Arizona State University

COLLEGE OF LIBERAL ARTS AND SCIENCES
School of Earth and Space Exploration
PO BOX 871404, TEMPE, AZ 85287-1404
(480) 965-5081 FAX: (480) 965-8102
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SRON

Netherlands Institute for Space Research

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

SRON Groningen
P.O. Box 800, 9700 AV Groningen, The Netherlands
T +31 (0)50 363 4074, F +31 (0)50 363 4033
www.sron.nl

Your reference:
Our reference:
Direct dialling: +31(0)50 3634799
E-mail: F.P.Helmich@sron.nl
Date: October 4, 2011

Re: letter of commitment for OCAM

To whom it may concern

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ``OCAM – An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08OZDA009O-SOFIA2G, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Your's sincerely,

F.P. Helmich

Dr. Frank Helmich
Program Scientist for SRON Netherlands Institute for Space Research
Principal Investigator for Herschel-HIFI

SETI INSTITUTE

September 5, 2011

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

Dear Dr. Walker:

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

David Hollenbach

Senior Research Scientist

SETI Institute

Steward Observatory
933 North Cherry Avenue
Tucson, Arizona 85721-0065

THE UNIVERSITY OF
ARIZONA®
TUCSON ARIZONA

Telephone: (520) 621-2288
Telefax: (520) 621-1532

5 October 2011

Dr. Christopher K. Walker
The University of Arizona
933 N. Cherry Ave.
Tucson, AZ 85721

Dear Chris,

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled "*OCAM – An Oxygen Heterodyne Camera for SOFIA*" that is being submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

This is a strong collaborative effort that builds on a heritage of many prior successful projects. As Co-I, I will focus on the responsibility of making the flight instrument capable of achieving the scientific goals of the proposal – from instrument control, electronics and software to overall system integration. Scientifically, I will be involved in the detailed intepretation and modeling of spectral line data derived from the observations, and the coordination of data and science products. As D-PI of the Stratospheric Terahertz Observatory (STO) and PI of the High Elevation Antarctic Terahertz (HEAT) telescope, I will help coordinate ancillary programs with STO, HEAT and ground-based telescopes in Arizona that will serve to complement the OCAM dataset.

This project represents a bold new advance in the capabilities of high-terahertz astronomy. I look forward to the opportunities and challenges that OCAM will provide.

Best regards,

Craig Kulesa

Dr. Craig A. Kulesa
Assistant Astronomer
The University of Arizona

University of Virginia Microfabrication Laboratory

Dr. Arthur Lichtenberger - Director of the Virginia Microfabrication Laboratory
University of Virginia Department of Electrical and Computer Engineering
351 McCormick Road Charlottesville Virginia 22904
(434) 924-6085 (lab) 924-7545 (office) 989-2000 (cell)
ArthurW@virginia.edu

OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G)

Letter of Commitment

Date: 09-22-2011
Submitted by: Research Professor A. W. Lichtenberger, Director
University of Virginia Microfabrication Laboratories
Department of Electrical and Computer Engineering
School of Engineering and Applied Science
351 McCormick Road, Thornton Hall
Charlottesville, VA 22904-4743
Phone (434) 989-2000 [cell] (434) 924-6085 [lab]
(434) 924-8818 [fax]
E-mail: arthurW@virginia.edu

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Professor Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Dr A. W. Lichtenberger

Arthur W. Lichtenberger

OBERLIN

Oberlin College
Department of Physics and Astronomy
Wright Laboratory
110 North Professor St.
Oberlin, OH 44074-1088
440/775-6730

September 21, 2011

Prof. Christopher K. Walker
Steward Observatory
933 N. Cherry Avenue
University of Arizona.
Tucson, AZ 85721

Dear Dr. Walker:

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled “OCAM - An Oxygen Heterodyne Camera for SOFIA”, that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely yours,

Christopher L. Martin

Smithsonian Astrophysical Observatory

October 5, 2011

Dr. Christopher Walker
University of Arizona
Steward Observatory, Room 211
Tucson, Arizona 85721

Dear Dr. Walker:

I acknowledge that I'm identified by name as a Co-Investigator to the investigation entitled Oxygen Heterodyne Camera (OCAM) for SOFIA that is submitted by Dr. Christopher Walker to the NASA Research Announcement AO NNH08ZDA009O-SOFIA2G. I intend to carry out all responsibilities identified for me in this proposal, in particular: (1) continuing science input to the design and development of the instrument; (2) participation in flight planning and science flights; and, (3) participation in the data analysis and publication of results. I will dedicate the time necessary to successfully carry out these tasks.

Sincerely yours,

Gary J. Melnick

Dr. Gary J. Melnick
Senior Astronomer,
Smithsonian Astrophysical Observatory

SMITHSONIAN INSTITUTION
60 Garden Street
Cambridge MA 02138-1516
www.cfa.harvard.edu

UNIVERSITY OF CALIFORNIA, LOS ANGELES **UCLA**

BERKELEY • DAVIS • IRVINE • LOS ANGELES • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

DIVISION OF ASTRONOMY
DEPARTMENT OF PHYSICS & ASTRONOMY
BOX 951547
LOS ANGELES, CA 90095-1547

August 23, 2011

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Dr. Mark Morris

telephone: (310) 825-3320 fax: (310) 206-2096 email: morris@astro.ucla.edu

JOHNS HOPKINS
UNIVERSITY

Zanvyl Krieger School of Arts and Science

Business and Research Administration
Suite 225 Mergenthaler Hall / 3400 N. Charles Street
Baltimore MD 21218-2685
Business Extension 410-516-8218
Research Extension 410-516-8841
Office Fax 410-516-5063

September 14, 2011

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

Reference: OCAM – An Oxygen Heterodyne Camera for SOFIA

Subject: Letter of Intent

Dear Dr. Walker:

JHU acknowledges that Professor David Neufeld is identified by name as Co-Investigator to the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is to be submitted by Prof. Christopher K. Walker in response to NASA Announcement of Opportunity, number NNH08ZDA009O-SOFIA2G, and that he intends to carry out all responsibilities identified for him in this proposal.

He understands that the extent and justification of his participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. In addition Johns Hopkins University supports Doctor Neufeld in this endeavor.

Sincerely,

Susanna S. Ormond

Susanna S. Ormond
Contract/Compliance Officer
Johns Hopkins University

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, MA 02139

Room 36-465
qhu@mit.edu

Tel: 617-253-1573
Fax: 617-258-7864

September 9, 2011

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

Dear Chris,

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G, and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely yours,

Qing Hu

Qing Hu

Professor of Electrical Engineering
Fellow of AAAS, APS, IEEE, OSA

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation
Center for Integrate Nanotechnology
P.O. Box 5800
Albuquerque, NM 87185
February 10, 2011
Phone: (505) 844-9677
Fax: (505) 284-7778
Internet: jlreno@sandia.gov

Dr. Chris K. Walker
University of Arizona
Steward Observatory, Room 211
Tucson, AZ 85721

Dear Chris,

I acknowledge that I am identified by name as Co-Investigator to the investigation entitled ***"OCAM - An Oxygen Heterodyne Camera for SOFIA***", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G. I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely yours,

John Reno

John Reno
PMTS
CINT, Sandia National Laboratories

Smithsonian Astrophysical Observatory

3 October 2011

Dr. Christopher Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

Dear Dr. Walker:

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled "OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity (NNH08ZDA009O SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely,

Antony A. Stark

SMITHSONIAN INSTITUTION
60 Garden Street
Cambridge, MA 02138-1516
617.495.7000 Telephone

Sterrewacht Leiden

Professor A.G.G.M. Tielens
Leiden Observatory
Niels Bohrweg 2
2333 CL Leiden
The Netherlands
tielens@strw.leidenuniv.nl

October 5, 2011

To: Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85712

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled ``OCAM - An Oxygen Heterodyne Camera for SOFIA", that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G), and that I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sincerely yours,

[prof. A.G.G.M. Tielens]

CALIFORNIA INSTITUTE OF TECHNOLOGY
ELECTRICAL ENGINEERING/MS 136-93
1200 E. California Blvd.
Pasadena, CA 91125

October 5, 2011

Dr. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85721-0065

I acknowledge that I am identified by name as Co-Investigator to the investigation, OCAM for the NASA SOFIA program, that is submitted by Prof. Christopher K. Walker to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G. I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal.

Sander Weinreb

Sander Weinreb
Sr.Faculty Associate
California Institute of Technology

STATEMENTS OF WORK

Mary A. McGonagle
Senior Contract Administrator

Massachusetts Institute of Technology
77 Massachusetts Avenue, Building E19-750
Cambridge, Massachusetts 02139-4307 USA

Office of Sponsored Programs

Phone 617-258-8017
Fax 617-253-4734
Email mam@mit.edu
http://web.mit.edu/osp/www/

September 19, 2011

Professor Christopher K. Walker
University of Arizona
Steward Observatory
933 N. Cherry Avenue
Tucson, AZ 85712

Reference: NASA Research Announcement No. NNH08ZDA009O-SOFIA2G

Dear Professor Walker:

Massachusetts Institute of Technology formally submits herewith a proposal entitled "OCAM – An Oxygen Heterodyne Camera for SOFIA." The proposed research would be performed by the MIT Research Laboratory of Electronics. Professor Qing Hu would serve as Principal Investigator.

Our estimate of the cost for the period June 1, 2012 through May 31, 2015 is $900,000.

Questions relating to technical aspects of this proposal should be directed to Professor Hu at (617) 253-1573. Questions of an administrative nature should be addressed to the undersigned.

Sincerely yours,

Mary McGonagle

Mary A. McGonagle
Senior Contract Administrator

Massachusetts Institute of Technology
Proposal Summary Form

Activity Type	Research
Proposal Type	New
Class Code	

Print Form

MIT WBS #

Title of Project: OCAM - An Oxygen Heterodyne Camera for SOFIA

Investigator Data

	Name	Department, Lab or Center (DLC)	DLC #	PI Status
PI Name	Prof. Hu	RLE	267100	Faculty
Co-PI 1				Faculty
Co-PI 2				Faculty
Co-PI 3				Faculty

Sponsor Data

Sponsor	**Steward Observatory**
Contact	**Christopher K. Walker**
Phone	
Address	Steward Observatory 933 N. Cherry Ave. Tucson AZ 85712 iras16293@gmail.com

Deadline Date	Sep 16, 2011	Receipt
Submission Method *Paper Submissions: OSP does not mail proposals*	Other Electronic	
Submission Type	Federal Solicitation	
Notice of Opportunity *(Identify Program Number or Provide URL)*	NNH08ZDA009O-SOFIA2G	

Budget Data

	Initial Period	Total Project Period
Requested Start Date	Jun 1, 2012	Jun 1, 2012
Requested End Date	May 31, 2013	May 31, 2015
Total Direct Costs	201,354	604,840
Total F&A	98,646	295,160
Total Direct + F&A	300,000	900,000

Cost Sharing: None

F&A Base: MTDC

X if Budgeted Subrecipients

On Campus Rate: 60.5 %

Off Campus Rate: %

Under recovery of F&A (amount and source of funds)

Special Reviews

	Protocol Number	Application Date	Approval Date
None			
None			

Check if any space change, renovation or additional infrastructure is required. This includes additional space, changes in space configuration, power and/or cooling to accommodate computers or other equipment.

Attach Additional Sheets as Necessary for Additional Budget Cost Sharing, Special Reviews and Space Change Explanations

Export Controls

( ) Yes (•) No Will any equipment be exported by MIT in the course of this project?

( ) Yes (•) No Will this project require any export controlled information to be received on campus? Contact David Quimby at x3-2822 or dquimby@mit.edu if you have questions.

Embryonic Stem Cells

( ) Yes (•) No Does this project involve the use of pre-existing human embryonic stem cells? (if yes, please submit approval letter from the MIT Committee on Assessment of Biohazards) or the **derivation** of human embryonic stem cells (if yes, submit approval letter from MIT Embryonic Stem Cell Research Oversight committee)? Contact the MIT Biosafety Program or Dr. Claudia Mickelson at 2-3477 if you have questions.

Conflict of Interest

Indicate Yes or No if there are any potential real or perceived conflict of interest as defined in MIT Policies and Procedures, 4.4?

	Yes	No
PI	( )	(•)
Co-PI/Co-I #1	( )	(•)
Co-PI/Co-I #2	( )	(•)
Co-PI/Co-I #3	( )	(•)

Also, for NIH and NSF Proposals, indicate the date the required Financial Disclosure was made on-line in the space provided for all investigators.

PI Date

Co-PI /Co-I#1 Date

Co-PI /Co-I#2 Date

Co-PI /Co-I#3 Date

My Signature below confirms my review of the proposal. It also certifies that:

1) I am not presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from current transactions by a federal department or agency (**http://web.mit.edu/osp/www/debarmen.htm).**
2) I have not and will not lobby any federal agency on behalf of this award (**http://web.mit.edu/osp/www/fedlobrg.htm).**
3) I am familiar with the requirements of the Procurement Integrity Act [OFPP, Section 27 (1-3)] and will report any violations to the Office of Sponsored Programs; (**http://web.mit.edu/osp/www/Procuint.htm**).
4) I certify a) that the information submitted within this application is true, complete and accurate to the best of my knowledge; b) that any false, fictitious, or fraudulent statements or claims may subject me, as the PI/Co-PI/Co-I to criminal, civil or administrative penalties; and, c) that I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application. [*This certification is being added at this time to meet a specific NIH requirement. It also reflects current federal regulations.*]
5) Applicable to the Principal Investigator Only: As the principal investigator, I confirm that I have reviewed all subawards included in this proposal. All subaward direct costs have been reviewed and appear reasonable given the proposed statement of work.

All Investigators Must Sign (attach additional sheets if necessary)

[signature] 9/12/11

PI Signature | Date | Co-PI /Co-I #1 Signature | Date

Co-PI/Co-I #2 Signature | Date | Co-PI/Co-I #3 Signature | Date

Notice: Proposals in final format must reach OSP at least five working days prior to the Sponsor's deadline. Failure to meet the deadline may jeopardize the on-time submission of the proposal and may result in incomplete review by OSP. If subsequent review reveals that the proposal is incomplete or does not conform with Institute or Sponsor requirements, OSP may, on behalf of the Institute, withdraw the proposal from Sponsor consideration.

Institutional Approvals

Department or Laboratory Head

[signature] Signature	9/12/14 Date	Signature	Date
Signature	Date	Signature	Date

Other Approvals (Deans and/or VP Research, if required)

Note: Signature of VP for Research required for international programs and proposals

Signature	Date	Signature	Date
Signature	Date	Signature	Date

OSP Administrative Approval

Signature	Date	Signature	Date
Signature	Date	Signature	Date

OSP Use Only:

Sponsor Code

Prime Sponsor Code

Proposal Number

Statement of Work

MIT Subcontract
for
University of Arizona Program entitled:

OCAM - An Oxygen Heterodyne Camera for SOFIA

The proposed program is in response to the NASA Announcement of Opportunity NNH08ZDA009O-SOFIA2G to develop a heterodyne camera for SOFIA. The task for the MIT subcontractor is to develop and deliver local oscillators for a heterodyne receiver array aimed for the OI spectral line at 4.744 THz. Specifically, we will perform the following tasks during the project.

Year 1 (6/1/2012 – 5/31/2013)
— By end of the first year, we will provide a single-mode DFB laser within ~10-20 GHz from the target 4.744 THz and with ~1 mW output for the Delft/SRON group to test their receiver, or even a small receiver array (~4 elements).

Year 2 (6/1/2013 – 5/31/2014)
— By end of the second year, we will provide a single-mode DFB laser to be around 3 GHz from 4.744 THz with >1 mW output power. With such lasers, the Delft/SRON group should develop a frequency stabilization system using a gas cell, and demonstrate long-term heterodyne receiver observation of the OI line in a lab environment.

Year 3 (6/1/2014 – 5/31/2015)
— By end of the third year, we will provide single-mode DFB lasers with the same frequency characteristics as in 2, but with output power ~10 mW, which should be sufficient to pump a 16-element array.

Proposed Budget

A. Salaries and Wages		Period	Percent Effort	Person-Months	Year 1 06/01/12 05/31/13	Year 2 06/01/13 05/31/14	Year 3 06/01/14 05/31/15	Total 06/01/12 05/31/15
*	Prof. Hu, Principal Investigator	Summer	33%	1.0	17,274	17,965	18,684	53,923
*	Postdoctoral Associate	Calendar	100%	12.0	47,500	49,400	51,376	148,276
*	Graduate Research Assistant (Ph.D)	Calendar	100%	12.0	30,701	31,929	33,206	95,836
*	UROP Undergraduate	Calendar			6,000	6,000	6,000	18,000
**	8.2% RLE Allocated Salaries and Wages				11,444	11,313	11,197	33,954
	Sub-total Salaries and Wages				**112,919**	**116,607**	**120,463**	**349,989**
B. Employee Benefits and Vacation Accrual								
	1. Employee Benefits, 26% to 6/30/12 and 30% thereafter							
*	Salaries (less RAs, Allocated S&W, and UROP)				19,216	20,210	21,018	60,444
**	RLE Allocated Salaries and Wages				3,395	3,394	3,359	10,148
	2. Research Vacation Accrual, 9%							
*	Sponsored Research Staff				4,275	4,446	4,624	13,345
**	RLE Allocated Salaries and Wages				1,030	1,018	1,008	3,056
	Sub-total Employee Benefits and Vacation Accrual				**27,916**	**29,067**	**30,009**	**86,993**
C. Other Direct Costs								
**	Tuition for Graduate Research Assistant				21,039	21,881	22,756	65,676
*	Travel				3,000	3,000	3,000	9,000
*	Materials and Services				35,084	29,676	24,282	89,042
**	1% RLE Allocated Expense				1,396	1,380	1,365	4,141
	Sub-total Operating Expenses				**60,519**	**55,937**	**51,403**	**167,859**
D. Total Direct Costs					**201,354**	**201,611**	**201,875**	**604,840**
E. Facilities and Administrative Costs: 60.5%					**98,646**	**98,389**	**98,125**	**295,160**
F. Total Costs					**300,000**	**300,000**	**300,000**	**900,000**
MTDC Base					**163,050**	**162,625**	**162,190**	**487,865**
Allocation Base					**139,559**	**137,970**	**136,548**	**414,077**

Budget Justification for Cost Proposal

A. Key Personnel:

Prof. Hu will be the PI on this proposal. He will be committing one summer month each year on this proposal. MIT fully supports the academic year salaries of professors, associate professors, and assistant professors, but makes no specific commitment of time or salary to any individual research project.

Other Personnel:

1. Postdoctoral Associate
One postdoc will be working on this project full time on Phase C and half time on Phase D and E at the annual salary of $50k. with 4% inflation each year.

2. Research Assistants
One full-time Research Assistants (RAs, each at 12 calendar months/yr) will be working on this project. 100% of the RA stipend will be charged to this project. The RA stipend is not subject to employee benefits. For the period 6/1/11-5/31/12 the stipend is $2,460/month for a Ph.D. student and $2,250/month for a Master's student; RA stipend increase each year on June 1. A 4% inflator is applied to this multi-year cost proposal.

3. Undergraduate Research Assistants (UROPs)
MIT allows Undergraduate students to work on projects up to 20 hours per week during academic months and 40 hours per week during summer. The average hourly salary is $12/hr.

4. RLE Allocated Salaries and Wages
The Research Laboratory of Electronics (RLE) at MIT, which will house this effort, provides a wide range of technical and administrative services to all of its research grants and contracts. These services apply to RLE activities. They are distributed to RLE activities on a percentage basis as direct costs. They are not part of MIT's Modified Total Direct Costs (MTDC) base, and therefore, generate no Facilities and Administration Costs. This expense is approved and mandated by MIT's cognizant federal agency, the Office of Naval Research (ONR). The recovery base (against which the rate is applied) is the sum of all direct costs in the MTDC base less employee benefits and research vacation accrual. The FY12 rate for the Salary Allocation is 8.2%. The Allocation Base is shown below in Table 1:

Allocation	Year 1	Year 2	Year 3		
Base	139,559	137,970	136,548		

Table 1: Allocation base versus funding period

B. Fringe Benefits

The EB rates for FY12 are based on a negotiated provisional rate (26%). The EB rates for FY13 and beyond are based on estimated rates (30%) and are for budget purposes only. MIT charges actual rates to awards. The research vacation benefit (excluding faculty and research assistants) is calculated at a rate of 9%. The fringe benefit rates are negotiated with, and approved by ONR.

C. Other Direct Cost

1. Travel - $3k/phase is requested for supporting project staff attending domestic conferences. An estimated cost for each person per trip is $1,000 which includes airfare, lodging, registration, meals and ground transportation cost.

2. Material & Supplies – Material & Supplies: Material and supplies budgeted under operating expenses for this proposal are costs that can be identified specifically with this particular sponsored project and are required in the direct performance of the research.

3. RA tuition – For academic year 11-12, MIT's 9-month tuition is $40,460. MIT will provide 50% subsidy on academic year tuition, leaving 50% to be charged to the research project. During the summer, MIT provides 100% tuition subsidy. Tuition increases each year on September 1. A 4% inflator is applied to this multi-year cost proposal.

5. RLE Allocated Expenses (Material and Services):
The Research Laboratory of Electronics (RLE) at MIT, which houses this effort, provides a wide range of technical and administrative services to all of its research grants and contracts. These services apply to RLE activities. They are distributed to RLE activities on a percentage basis as direct costs. They are not part of MIT's Modified Total Direct Costs (MTDC) base, and therefore, generate no Facilities and Administration Costs. This expense is approved and mandated by MIT's cognizant federal agency, ONR. The FY10 rate for the Material and Services allocation is 1%. Please refer to the Allocation Base shown above in Table 1.

D. Indirect Costs (Facilities & Administrative Costs):

Facilities and Administrative Costs are calculated by applying the negotiated rate of 60.5% to the Modified Total Direct Cost (MTDC) base. The MTDC base includes all direct costs, except Equipment, Subcontract expenditures excess of $25,000, Graduate Students' Tuition, the Salary Allocation and its associated benefits. Current F&A rate was approved by ONR on 7/5/11.

Note: MIT Fiscal Year begins on July 1st and Academic Year begins on September 1st Each year.

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation
Center for Integrated Nanotechnology
Albuquerque, New Mexico 87185-

date: September 21, 2011

to: Chris K. Walker
University of Arizona
Steward Observatory, Room 211
Tucson, AZ 85721

from: John Reno
Center for Integrated Nanotechnologies
Sandia National Laboratories

subject: **Sandia Statement of Work for**
"OCAM - An Oxygen Heterodyne Camera for SOFIA"

Sandia's involvement in the proposed program is to participate in building a 4.744 THz QCL emitter to serve as a local oscillated. Accordingly, the Sandia task in this program is to provide the MIT team with state-of-the-art MBE grown QCL material from which to fabricate the operating laser. Specifically, we will perform up to fifteen growth runs annually, making our best effort to match the designs supplied by MIT within 0.5% for aluminum concentration, 2% for period, and 25% for doping densities. The results from the runs will be shipped to MIT for laser fabrication and testing.

Sandia National Laboratories

Operated for the U.S. Department of Energy by
Sandia Corporation
Center for Integrated Nanotechnology
Albuquerque, New Mexico 87185-

date: September 21, 2011

to: Chris K. Walker
University of Arizona
Steward Observatory, Room 211
Tucson, AZ 85721

from: John Reno
Center for Integrated Nanotechnologies
Sandia National Laboratories

subject: **Sandia Annual Budget for**
"OCAM - An Oxygen Heterodyne Camera for SOFIA"

Salaries	$70,000
Supplies	30,000
Total	$100,000

Note: Sandia National Laboratories does not supply loading or overhead rates.

SRON
Netherlands Institute for Space Research

Prof. Christopher K. Walker
Steward Observatory
933 N. Cherry Ave.
Tucson, AZ 85721
United States of America

SRON Utrecht
Sorbonnelaan 2, 3584 CA Utrecht,
The Netherlands
T +31 (0)88 777 5600, F +31 (0)88 777 5601
www.sron.nl
Your reference:
Our reference:
Direct dialling: +31(0)15-2781370
E-mail: j.r.gao@tudelft.nl

Re: Quotation for HEB mixers and frequency locking technology for OCAM on SOFIA!

Date: September 21, 2011

SRON/TU Delft will deliver two wafers of optimised hot electron bolometer mixer devices (with typically 80 devices each) to the University of Arizona for the OCAM 4.7 THz array.

SRON/TU Delft is responsible for the design, performance optimisation and characterization of single pixel mixers and will verify a selected number of detectors at the THz frequency (four of each wafer) of the final batches for flight before shipping to the University of Arizona.

SRON/TU Delft is responsible to realize frequency locking of a THz quantum cascade laser at 4.7 THz (the quantum cascade laser is provided through the University of Arizona) in their test set-up; SRON will provide all documentation relevant to the University of Arizona to replicate this in the OCAM instrument.

We quote the cost of above contribution to be:

Total: 534 k€,

which does not include the contingency reserve.

Sincerely yours

Dr. Jian-Rong Gao
Senior Instrument Scientist in SRON Netherlands Institute for Space Research
Part time senior researcher in Delft University of Technology

IF Amplifier System for the OCAM Project

September 2, 2011

Background

The University of Arizona is submitting a proposal entitled OCAM (Optical Camera) to the NASA SOFIA program and has requested that Caltech supply the cryogenic and room temperature IF amplifiers for the program. SOFIA is a airborne THZ radio telescope flown on a dedicated 747 aircraft. The OCAM radiometer system is comprised of 16 hot-electron bolometer (HEB) mixers cooled to 4K cooled with liquid helium. Thus 16 channels of IF amplifiers are required with each channel consisting of a low power consumption LNA at 20K followed by amplifiers at 300K to provide -10dBm of IF power into a digital spectrometer. The key parameters of the IF system are very low noise temperature (<10K), frequency range of 0.5 to 5.5 GHz, high input return loss (.10dB), and low power consumption.

IF System Block Diagram

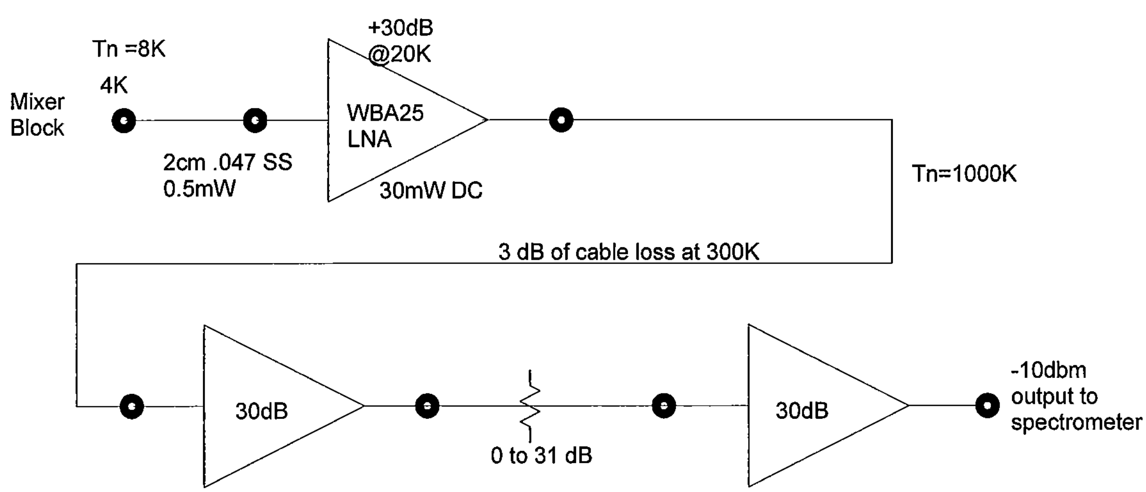


Figure 1 - IF system block diagram Sixteen channels of the above arranged in blocks of 4 are required.

Cryogenic Configuration

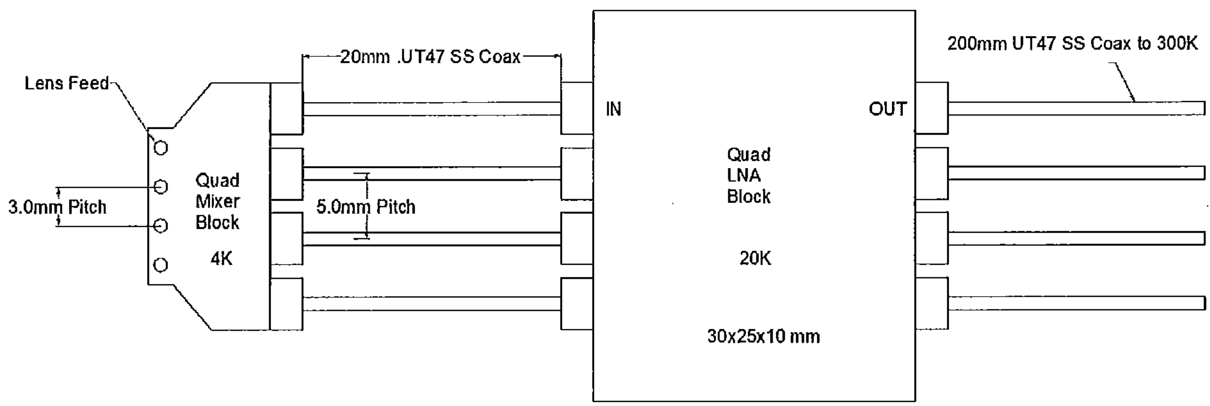


Figure 2 - Suggested configuration to interface a quad mixer block with 3mm pixel spacing with LNA's which consume too much (~30mW) power to mount directly on the 4K mixer block. To keep short connections to the LNA's either GPO push-on connectors or direct-solder connection is required. See thermal analysis in Figure 3. A mirror image of the configuration allows 2 x 4mm pixels with close spacing.

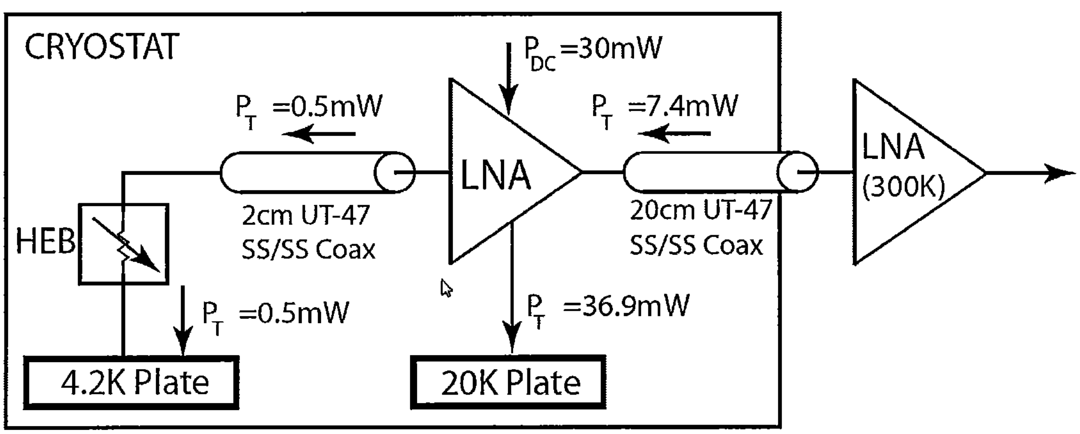
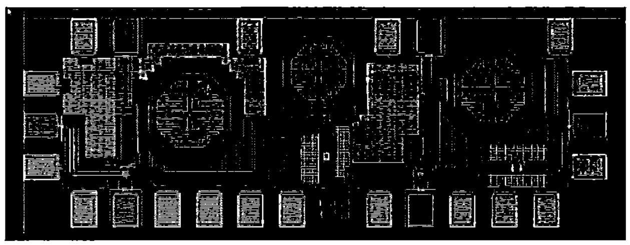


Figure 3 - Thermal analysis of one pixel of configuration. The 0.5mW per pixel thermal loading at 4K facilitates low helium boil off rate. The noise contribution of 2cm of stainless steel coax is < 1K and the ripple period is broad (~5 GHz) to minimize baseline confusion with observed spectral lines.

Proposed Amplifiers

The current status of amplifiers relevant to this proposal is summarized in the preprint, "Low Power, Very Low Noise, Cryogenic SiGe IF Amplifiers for THz Mixer Receivers" available under "Publications" at the web site http://radiometer.caltech.edu. Three amplifiers are described but do not quite meet the requirements for use in OCAM.. However, the two MMIC amplifiers and miniature amplifier packaging form an excellent basis for improved designs and packaging compatible with the tight configuration of a 1 x 4 mixer array with 3mm pitch. The miniature amplifier package can mount in line with 5mm pitch and can accommodate either a two stage discrete transistor amplifier or a MMIC design. .

A SiGe MMIC amplifier meeting OCAM requirements has been designed and is described in Figure 4. This MMIC will be processed in future wafer runs by ST Microelectronics in France. The chip requires 27mW of DC power but can operate at 1/2 this power with some degradation of noise temperature. These powers are too high for operation at 4K so the installation at 20K with a low thermal conductivity connection to the mixer at 4K is suggested as shown in Figure 3. The LNA is connected to the mixer with a short length, 1 or 2 cm, of UT47 stainless-steel coax which will contribute < 1K to noise temperature and is short enough to avoid baseline ripple problems. Type GPO push on connectors would be utilized to accommodate the 5mm pitch. If these connectors do not have the required stability then direct soldered connections from mixer to LNA's could be used. The stability will be evaluated in early stages of the program.



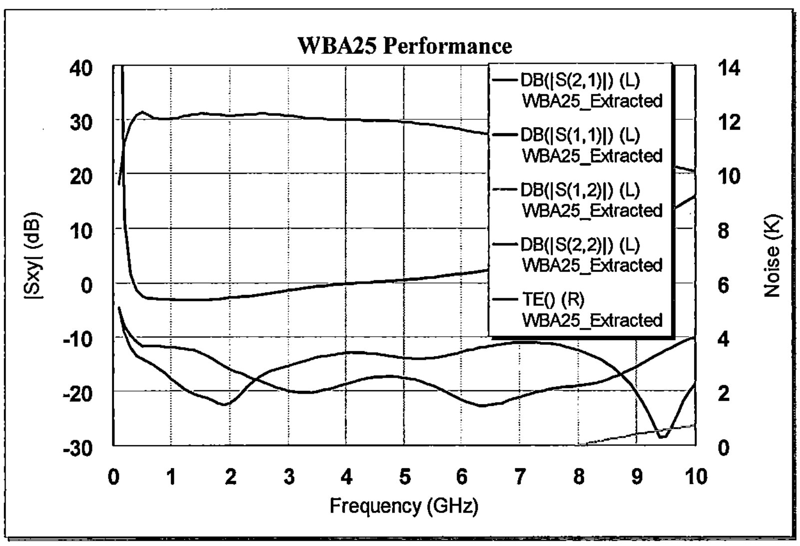


Figure 4 - Layout and simulated S parameters and noise temperature of WBA25 SiGe MMIC LNA appropriate for this program. This is a 2nd iteration design to correct measured deficiencies in previously fabricated WBA 23 and WBA 24 MMICs. Chip size is 1.5 x 0.4 mm.

IF Amplifier System for the OCAM Project

Statement of Work

1) Develop a cryogenic LNA with <10K noise in the 0.5 to 5.5 GHz frequency range.Test prototype LNA's to confirm system compatibility with respect to noise temperature, input match, and power consumption

2) Fabricate, test, and deliver 18 channels (2 are spare) of the IF system

3) Support system integration of IF system

Budget

	CY12	CY13	
Cost Element	Year 1	Year 2	Total
Graduate Research Assistant	$ 26,000		$ 26,000
Research Staffs	$ 3,000	$ 50,000	$ 53,000
Fringe Benefits	$ 825	$ 13,750	$ 14,575
Materials and Supplies	$ 50,000	$ 36,000	$ 86,000
Tuition Remission	$ 16,900		$ 16,900
Others: CIT Transfer	$ 40,000	$ 40,000	$ 80,000
Total Direct Costs	$ 136,725	$ 139,750	$ 276,475
Based for IDC calculation	$ 79,825	$ 99,750	$ 179,575
Indirect Cost (64%)	$ 51,088	$ 63,840	$ 114,928
Total Cost	$ 187,813	$ 203,590	$ 391,403

Budget Justification

Personnel:
Dr. Sander Weinreb: His compensation will be directly paid by JPL via CIT Transfer.
Graduate Research Assistant: Year 1: salary is requested for full time of GRA support.
Research Staffs: Year 1: salary is requested for support of Technician @15%. Year 2: salary is requested for support of Sr. Research Engineer @50%.

Fringe Benefits:
The Fringe Benefit Rate of 27.5% is assessed on all salaries excluding the graduate student salaries.

Materials and Supplies:
Year 1: $50,000 for semiconductor wafer fabrication at ST Microelectronics. ST was used for prototype fabrication and must be used for revised LNA's at a charge of $5,000 per mm^2 with 10mm^2 required.
Year 2: 18 sets of Figure 1 components at module machining $200, attenuator $300, cables $100, and purchased 2 amplifiers @$700 each. Total is 18 x $2,000 =$36,000.

Tuition Remission: Institute Policy is to provide each graduate student employee, who meets a required average work week, with full tuition and fees. A portion of this cost is requested as a benefit (exempt from indirect costs), equivalent to 65% of the graduate research assistant salary.

Others: CIT Transfer
Funds are transferred to JPL to support Dr. Weinreb (~20% effort for Year 1 and 2). The transferred funds include salary, benefits, and overhead.

Indirect Costs:
The Indirect Cost Rate of 64% is assessed to the direct costs excluding the graduate student tuition remission and CIT transfer to JPL.

Personnel Effort	Year 1	Year 2
Dr. Weinreb	20%	20%
GRA	100%	
Technician	15%	
Sr. Research Engineer		50%

Facilities

Caltech has all the equipment and facilities needed to perform the work of this proposal. This includes cryogenic test dewars, network analyzers, and noise measuring equipment.

OMNISYS INSTRUMENTS
August Barks Gata 6B
S-421 30 Västra Frölunda
Sweden
Email: ae@omnisys.se
Tel. +46 31 7343401
Fax. +46 31 7343429
Date: 15/08/2011

Quotation

SOFIA HEB back-ends

Quotation reference: Q110815A
Dr. Anders Emrich
Tel: +46 31 7343401
Email: ae@omnisys.se
Omnisys Instruments AB
August Barks Gata 6B
SE-421 32 Västra Frölunda, Sweden

Dear Sir,

We are hereby submitting a ROM estimate on cost and performance of the HEB array for SOFIA back-ends based on the Omnisys developed autocorrelation ASIC.

The SOFIA HEB array operates at 4.74 THz with 16 pixels.

The HIFAS ASIC has been operated up to 14 GHz clock rate in several different applications and can be used in both complex and real mode.

GUSSTO Back-end specification:

	4.74 THz	
Bandwidth	5.5	GHz
IF band	0.5-6.2	GHz
Clock	13.2	GHz
Resolution	6.45	MHz
Sampling	direct	
Input power	-10	dBm
# band	16	
Pwr	120	W
Volume	80x160x160	mm
Mass	<4	kg
I/O	Spacewire	20 MBit/s
Cost	580	kUSD

The frequency coverage will be from 0.1-6.2 GHz.

Project

	Time	Cost (kUSD)	Delivery
Study phase	March 2012- June 2012	60	Study Report
Breadboard phase	June 2012 - Dec 2012	120	Test Report
Engineering model phase	Jan 2013 - Sept 2013	200	1 x EM = 1 x 4 pixel
Flight Model phase	Sept 2013 - June 2014	200	1 x FM = 1 x 16 pixel

A picture of a HIFAS based spectrometer is shown below.

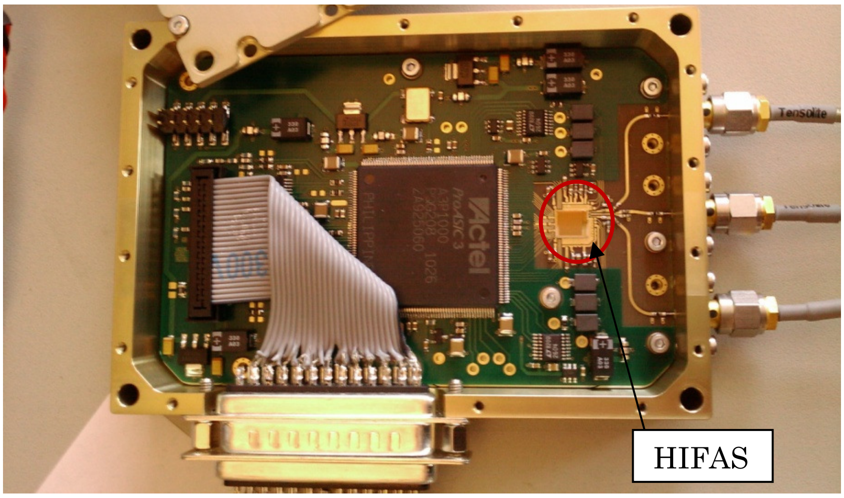


FIGURE 1 Single HIFAS ASIC prototype block.

The preliminary offered design is based on blocks of 20x160x160 mm housing four HIFAS devices, sharing resources and four such units make up one 16 pixel back-end unit (80x160x160 mm).

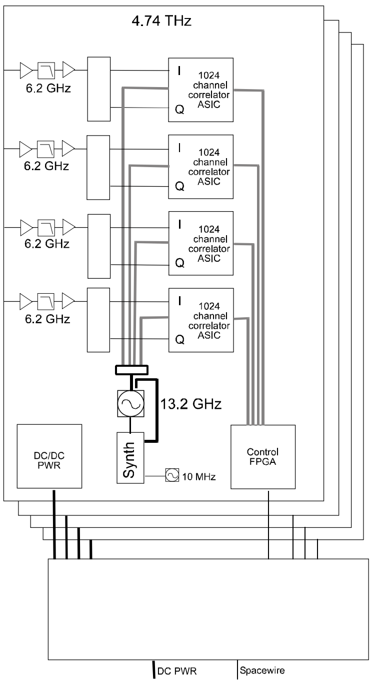


FIGURE 2 The proposed spectrometer back-end.

The signal enters the spectrometer box through a coaxial interface (SMA, TBC) and is conditioned with amplification and filtering. As the HIFAS autocorrelation ASIC can be operated both in complex as well as in real mode, it use two inputs. For real mode, as suggested for these spectrometers, a power splitter is needed in front of the HIFAS ASIC.

The bandwidth and resolution is set by the sampling clock.

Examples of test results of HIFAS based spectrometer prototypes are shown below.

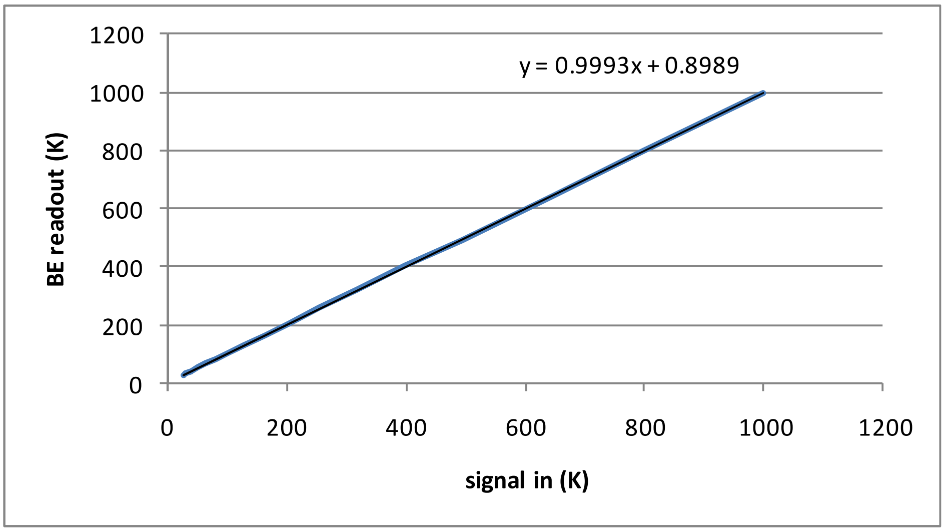


FIGURE 3 Linearity fit for the STEAMR HIFAS based spectrometer prototype.

The linearity of the plot above is limited by the linearity accuracy of the test set.

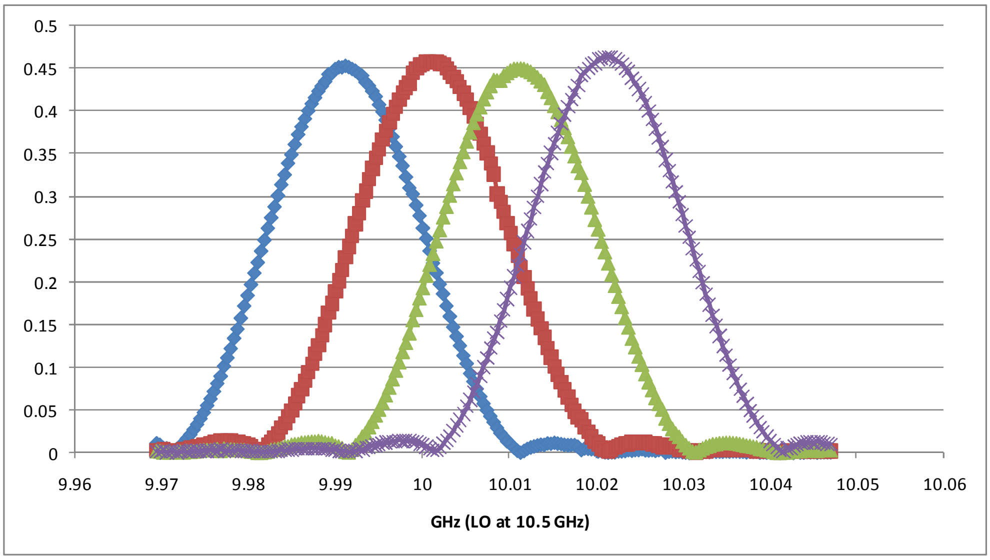


FIGURE 4 Frequency response for the STEAMR HIFAS based spectrometer prototype.

The spectral response shown above is limited by the test set-up and the IF system prototype. The channel shape is expected to follow the sinc function more or less perfectly, i.e. the effective resolution is very high compared to AOS or filterbanks were the channel response functions vary.

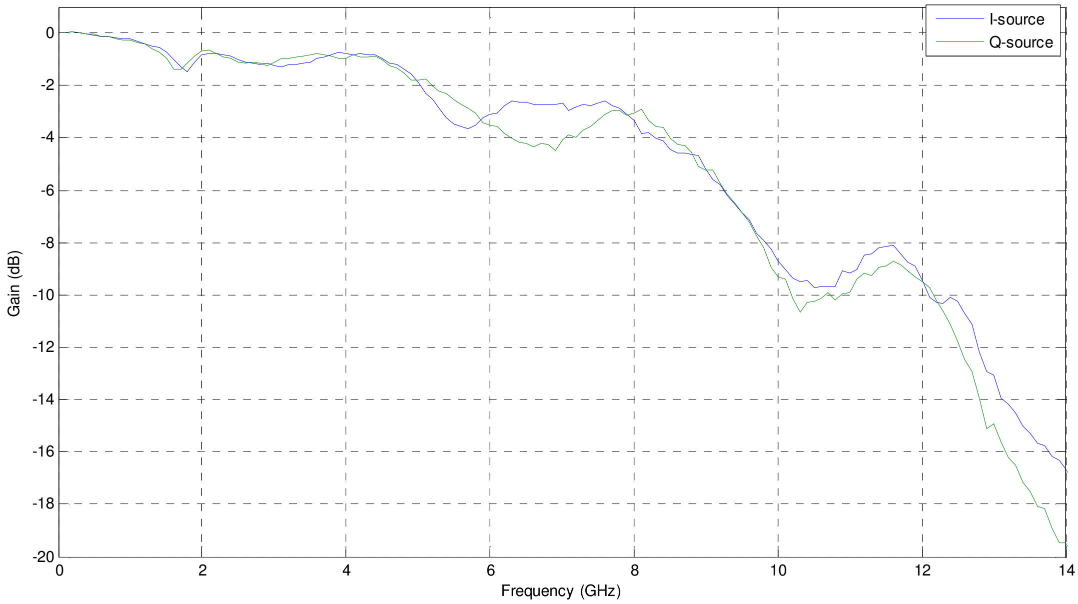


FIGURE 5 Gain response from first HIFAS tests.

The first tested gain response is shown above (tested early 2008). The gain dip at 4.5 GHz is due to PCB layout issues and DC/AC coupling scheme on the test board. This has been verified. The 3 dB drop at 8 GHz is more expected and should be closer to 2-2.5 GHz when compensated for 50 mm microstrip and coaxial connector on the test board.

The expected slope of 1.5 dB could be expected and this should have no impact on the operation or performance of the spectrometers.

Dr. Anders Emrich
Omnisys Instruments AB

ASU Statement of Work for OCAM Project

Over the course of the project, ASU will be responsible for the design and fabrication of the cold optics assembly for OCAM, metal micromachining for the 4.7 THz detector arrays, local oscillator unit, and cold optics assembly, oversight of the cryogenic system specification, procurement and acceptance testing, assistance with integration and test and flight operations, airworthiness certification efforts and participation in data analysis and publication.

ASU will produce detailed mechanical designs for the OCAM detector array housings, cold optics assembly and local oscillator components and analyze this design for manufacturability and mechanical tolerances. The design will be refined to ensure that ASU will be able to manufacture the design within the required tolerances demanded by the optical design. ASU will also work with the detector and local oscillator groups at MIT, University of Arizona and SRON to optimize their designs for manufacturability.

ASU will fabricate and deliver OCAM cold optics assemblies and micromachined components as required by the project. A machinist/engineer will be dedicated at the 25% level for the first three years of the project to perform design and fabrication work. A graduate student is funded in years 2-4 to assist with instrument I&T, flight operations and publication of data. Co-I Groppi will work with Universal Cryogenics and Cryomech Inc. to assure that the design and fabrication of the cryogenic system meets the needs of OCAM and will interface properly with SOFIA.

ORGANIZATION	DURATION (MONTHS)	
ARIZONA STATE UNIVERSITY	Proposed	48
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR		
Groppi		

A. SENIOR PERSONNEL:	NSF- Funded Person-months CAL	ACA	SUMR	YEAR ONE 2012	YEAR TWO 2013	YEAR THREE 2014	YEAR FOUR 2015	CUMULATIVE	Rate	ERE 2012 Actual	2013	2014	2015	2016
1. PI: C. Groppi			1.000	$9,167	$9,442	$9,725	$10,017	$38,351	82503					
2. Co-PI:			1.000	$0	$0	$0	$0	$0	0					
3. Co-PI:			1.000	$0	$0	$0	$0	$0	0					
4.				$0	$0	$0	$0	$0						
5.														
6. ( ) OTHERS														
7. ( ) TOTAL SENIOR PERSONNEL (1-6)				$9,167	$9,442	$9,725	$10,017	$38,351		30.70%	33.20%	34.20%	35.22%	36.28%
B. OTHER PERSONNEL														
1. ( ) POST DOCTORAL ASSOCIATES				$0	$0	$0	$0	$0		40.00%	44.70%	46.04%	47.42%	48.84%
2. (1) OTHER PROFESSIONAL	12.00			$12,500	$12,875	$13,261	$0	$38,636		40.00%	44.70%	46.04%	47.42%	48.84%
3. (1) GRADUATE STUDENTS				$0	$24,509	$25,244	$26,002	$75,755	23795	9.00%	10.60%	10.92%	11.25%	11.58%
4. (0) UNDERGRADUATE STUDENTS				$0	$0	$0	$0	$0		1.50%	2.10%	2.16%	2.23%	2.29%
5. ( ) SECRETARIAL - CLERICAL				$0	$0	$0	$0	$0		40.00%	44.70%	46.04%	47.42%	48.84%
6. ( ) OTHER				$0	$0	$0	$0	$0		40.00%	44.70%	46.04%	47.42%	48.84%
TOTAL SALARIES AND WAGES (A+B)				$21,667	$46,826	$48,231	$36,019	$152,742						
C. FRINGE BENEFITS				$7,814	$11,488	$12,188	$6,453	$37,943						
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$29,481	$58,314	$60,419	$42,472	$190,686						
D. EQUIPMENT Kern 5 axis upgrade														
TOTAL EQUIPMENT				$0	$19,134	$0	$0	$19,134						
E. TRAVEL 1. DOMESTIC				$4,000	$4,000	$4,000	$4,000	$16,000						
2. FOREIGN				$0	$0	$0	$0	$0						
				$4,000	$4,000	$4,000	$4,000	$16,000						
F. PARTICIPANT SUPPORT CC 1. STIPENDS 2. TRAVEL $0 3. SUBSISTENCE $0 4. OTHER $0														
( ) TOTAL PARTICIPANT COSTS				$0	$0	$0	$0	$0						
G. OTHER DIRECT COSTS														
1. MATERIALS AND SUPPLIES				$5,000	$5,000	$5,000	$5,000	$20,000						
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				$0	$0	$0	$0	$0						
3. CONSULTANT SERVICES				$0	$0	$0	$0	$0						
4. Facility Use Fees				$0	$0	$0	$0	$0						
5. SUBAWARDS				$0	$0	$0	$0	$0						
6. OTHER Tuition				$0	$14,954	$16,150	$17,442	$48,546	excluded from idc base					
TOTAL OTHER DIRECT COSTS				$5,000	$19,954	$21,150	$22,442	$68,546						
H. TOTAL DIRECT COSTS (A THROUGH G)				$38,481	$101,402	$85,569	$68,914	$294,366						
I. INDIRECT COSTS (F&A) (SPECIFY RATE AND BASE)														
52.5% MTDC				$38,481	$67,314	$69,419	$51,472	$226,686	DHHS agreement dated 6/16/09					
TOTAL INDIRECT COSTS (F&A)				$20,203	$35,340	$36,445	$27,023	$119,010						
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				$58,684	$136,742	$122,014	$95,937	$413,376						
K. RESIDUAL FUNDS														
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)								$413,376						
M. COST SHARING: Proposed Level														

NSF Form 1030 (10/98) *Supersedes All Previous Editions*

Tuition Rates -8% escalation chg eff 6/20/11

	FY2012	FY2013	FY2014	FY2015	FY2016
AY	$13,000	$14,040	$15,163	$16,376	$17,686
Sumr	$846	$914	$987	$1,066	$1,151
Total	$13,846	$14,954	$16,150	$17,442	$18,837

ERE Rates

	FY2012-Act	FY2013	FY2014	FY2015	FY2016
Faculty	30.70%	33.20%	34.20%	35.22%	36.28%
Staff	40.00%	44.70%	46.04%	47.42%	48.84%
Part-time	40.00%	44.70%	46.04%	47.42%	48.84%
Students	9.00%	10.60%	10.92%	11.25%	11.58%
RA/TA	1.50%	2.10%	2.16%	2.23%	2.29%

Budget Justification

The proposed work is performed over a 4-year period. An itemized budget listing expenditures over this period is provided.

Employee-Related Expenses (ERE)
ASU has negotiated ERE rates with DHHS that are effective 06/19/09 and have been used in the proposal for budget planning:

	FY2012	FY2013	FY2014	FY2015	FY2016
Faculty	30.70%	33.20%	34.20%	35.22%	36.28%
Staff	40.00%	44.70%	46.04%	47.42%	48.84%
Part-time	40.00%	44.70%	46.04%	47.42%	48.84%
Students	9.00%	10.60%	10.92%	11.25%	11.58%
RA/TA	1.50%	2.10%	2.16%	2.23%	2.29%

Tuition and Fees
Tuition for graduate students is included as a benefit for graduate students and is charged to projects in proportion to the amount of effort the graduate student will work on the project. The tuition charge for graduate students is $13,846 for FY 12, $14,954 for FY13, $16,150 for FY14 and $17,442 for FY15. Tuition charges are exempt from the Facilities and Administrative (F&A) costs.

Personnel: In each of the 4 years, funds are requested for 1 month of summer salary for the PI (C. Groppi). PI Groppi is responsible for overseeing all aspects of the project. A graduate student is funded full time (including summer salary) for 3 years. The graduate student will be responsible for system design and testing, assistance in instrument I&T, flight support and analysis and publication of data. A technician is funded at the 520 hour/year level during the first three years for mechanical design and fabrication of the optical and micromachined detector components.

Travel: Four trips per year for project personnel are requested each year.

Materials and Supplies: Funding is requested to support fabrication of the optical and micromachined components for O-Cam. Funds will pay for materials, tools, gold plating and other miscellaneous supplies.

Capital Equipment: We will purchase upgraded components for the ASU Kern model 44 micromilling system to enable the fabrication of O-Cam components.

1. System 3R chuck for machine table to allow part inspection without losing machine calibration ($8,165, based on quote from Kern Precision Inc.)
2. Blum LaserControl Nano tool measurement system for laser measurement of tools smaller than 100um diameter. ($10,969, based on quote from Kern Precision Inc.)

QUOTE from Universal Cryogenics

JOB CODE	Date	Quote #
UOFAHQ22K	9/21/2011	1510

UNIVERSAL CRYOGENICS
1815 W. Gardner Ln.
Tucson, AZ. 85705
520-622-6277 ph
520-623-3167 fx
www.ucryo.com
kirby@ucryo.com

QUOTE VALID FOR 90 DAYS FROM DATE OF THIS CONTRACT

SHIPPING WILL BE ADDED TO FINAL INVOICE.

PROGRESS PAYMENTS MAY APPLY WITH PO.

Ship To

The University of Arizona
Attn CHRIS WALKER

Customer Name / Address

The University of Arizona

Customer Contact	Customer Contact Ph	Rep	Project
CHRIS WALKER		KH	

Line	Item	Description	Qty	Rate	Total
1	Dewar	OCAM DEWAR DESIGN - FABRICATION - TESTING DESIGN Dewar Design -Modular style assembly, allows insert of receiver instrument for multiple design formats. -Front pressure plate interface to SOFIA telescope input source. -Internal G10 supports, designed for flight G-force operation. Closed Cycle Compressor Gantry -Multi-axis pivot cage for allowing helium compressor to pivot during flight. -Motor control passive operation allowing vertical orientation of pivot cage. 2nd Dewar Case for 2X pressure Testing -Manufacture a second dewar case to pressure test for flight acceptance. CORRESPONDENCE -Bi-weekly meetings at UofA for design presentation and updates. -PDR Presentation. -CDR Presentation. CONCEPT DEVELOPMENT -Prototype manufacturing for concept development.	1	150,000.00	150,000.00

UNIVERSAL CRYOGENICS TERMS AND CONDITIONS 2011 APPLY, THANK YOU FROM UNIVERSAL CRYOGENICS!

Total

QUOTE from Universal Cryogenics

JOB CODE	Date	Quote #
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The University of Arizona
Attn CHRIS WALKER

Customer Name / Address

The University of Arizona

Customer Contact	Customer Contact Ph	Rep	Project
CHRIS WALKER		KH	

Line	Item	Description	Qty	Rate	Total
2	DELIVERY TERMS	MANUFACTURING -Dewar manufacturing. -Insert manufacturing. TESTING -Closed cycle dewar testing. -Compressor gantry testing for +/-20 deg max tipping. FINITE ELEMENT ANALYSIS (FEA) -18G FEA for safe failure mode. -FEA analysis Contanment cage. -Report identifying FEA analysis for safe operating in any operational mode. DELIVERY OF SYSTEM IS WILL FOLLOW SCHEDULE: -DESIGN CONCEPT AND SOLID MODEL AND DOCUMENTATION FOR PDR PRESENTATION, 6-MONTHS. -DESIGN UPDATES FROM PDR AND RE-DESIGN FOR CDR, 2-MONTHS. -MANUFACTURING DEWAR AND SUPPORT COMPONENTS, 6-MONTHS. -TESTING AND FLIGHT VERIFICATION, 4-MONTHS.			

UNIVERSAL CRYOGENICS TERMS AND CONDITIONS 2011 APPLY, THANK YOU FROM UNIVERSAL CRYOGENICS!

Total $150,000.00

QUOTE from Universal Cryogenics

JOB CODE	Date	Quote #
UOFAHQ22K	9/21/2011	1510

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Tucson, AZ. 85705
520-622-6277 ph
520-623-3167 fx
www.ucryo.com
kirby@ucryo.com

QUOTE VALID FOR 90 DAYS FROM DATE OF THIS CONTRACT	Ship To
SHIPPING WILL BE ADDED TO FINAL INVOICE.	The University of Arizona Attn CHRIS WALKER
PROGRESS PAYMENTS MAY APPLY WITH PO.	

Customer Name / Address

The University of Arizona

Customer Contact	Customer Contact Ph	Rep	Project
CHRIS WALKER		KH	

Line	Item	Description	Qty	Rate	Total
1	Dewar	OCAM DEWAR DESIGN - FABRICATION - TESTING DESIGN Dewar Design -Modular style assembly, allows insert of receiver instrument for multiple design formats. -Front pressure plate interface to SOFIA telescope input source. -Internal G10 supports, designed for flight G-force operation. Closed Cycle Compressor Gantry -Multi-axis pivot cage for allowing helium compressor to pivot during flight. -Motor control passive operation allowing vertical orientation of pivot cage. 2nd Dewar Case for 2X pressure Testing -Manufacture a second dewar case to pressure test for flight acceptance. CORRESPONDENCE -Bi-weekly meetings at UofA for design presentation and updates. -PDR Presentation. -CDR Presentation. CONCEPT DEVELOPMENT -Prototype manufacturing for concept development.	1	150,000.00	150,000.00

UNIVERSAL CRYOGENICS TERMS AND CONDITIONS 2011 APPLY, THANK YOU FROM UNIVERSAL CRYOGENICS!	**Total**

QUOTE from Universal Cryogenics

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The University of Arizona
Attn CHRIS WALKER

Customer Name / Address

The University of Arizona

Customer Contact	Customer Contact Ph	Rep	Project
CHRIS WALKER		KH	

Line	Item	Description	Qty	Rate	Total
2	DELIVERY TERMS	MANUFACTURING -Dewar manufacturing. -Insert manufacturing. TESTING -Closed cycle dewar testing. -Compressor gantry testing for +/-20 deg max tipping. FINITE ELEMENT ANALYSIS (FEA) -18G FEA for safe failure mode. -FEA analysis Contanment cage. -Report identifying FEA analysis for safe operating in any operational mode. DELIVERY OF SYSTEM IS WILL FOLLOW SCHEDULE: -DESIGN CONCEPT AND SOLID MODEL AND DOCUMENTATION FOR PDR PRESENTATION, 6-MONTHS. -DESIGN UPDATES FROM PDR AND RE-DESIGN FOR CDR, 2-MONTHS. -MANUFACTURING DEWAR AND SUPPORT COMPONENTS, 6-MONTHS. -TESTING AND FLIGHT VERIFICATION, 4-MONTHS.			

UNIVERSAL CRYOGENICS TERMS AND CONDITIONS 2011 APPLY, THANK YOU FROM UNIVERSAL CRYOGENICS!

Total $150,000.00

CRYOMECH

September 9, 2011

Prof. Chris Walker
Steward Observatory
933 N. Cherry Ave.
Tucson AZ 85721

Dear Professor Walker,

After reviewing the requirements for the SOFIA project, we have determined that we can provide the following:

1. Fly required PT410 with air-cooled compressor. The temperature oscillation is< ± 50 mK.
2. The pressure test for our volumes in the system for the pressure vessel certification. If needed, we will use thicker wall for those volumes.
3. Provide support to your engineer for any necessary testing and certification.

The total cost this project will be ~ $150,000.

Best regards,

Chao Wang

Dr. Chao Wang
Director of Research & Development

113 Falso Drive • Syracuse, NY 13211 • USA
v 1 315 455 2555 • f 1 315 455 2544
cryosales@cryomech.com
www.cryomech.com

Statement of Work: John Bally

John Bally will support to this proposal by supporting the development of scientific requirements, the planning of observations, analysis of resulting data, and, providing access to various supporting data sets. He has access several proprietary Galactic plane survey data sets such as the Herschel Space Observatory Hi-GAL galactic plane survey covering the 70 to 500 mm wavelength region and the 1.1 mm Bolocam Galactic Plane Survey, BGPS. Additionally, he has obtained near-IR and visual ground-based observations of several of the prime targets in this proposal. These data sets will be used to develop initial candidates targets whose properties provide partial drivers for the science requirement.

During instrument design, construction, and integration, he will work to acquire supporting data sets for targets being proposed for the first three SOFIA flights such as the Galactic center, low- and high-mass star forming regions such as Orion. Supporting data include observations with ground-based near-IR, sub-mm, and radio facilities such as Gemini, ALMA, and EVLA. (Some of these activities will be supported by his current NSF grants).

During commissioning and the first three SOFIA flights, he will participate in data acquisition, reduction, and analysis. He will supervise a part-time graduate student being supported by this grant who will also provide support to all of the above activities.

PROPOSED BUDGET DETAILS

Institution: The Regents of the
University of Colorado
572 UCB
Boulder, CO 80309-0572

Title: A 16-element 63 Micron Heterodyne
for Sofia:OCAM

Principal Investigator: John Bally

Duration: 6/1/2012-5/31/2016

	Year 1	Year 2	Year 3	Year 4
A. Salaries and Wages				
Principal Investigator: Bally				
100% time, 1 mo effort, yrs 1-3	14,884	15,331	15,791	16,264
Graduate Research Asst #1: To be named				
100% time, 3 mos Summer	4,592	4,729	4,871	5,018
Total Salaries and Wages	19,476	20,060	20,662	21,282
B. Fringe Benefits				
PI: 26.2%	3,900	4,017	4,137	4,261
GRAs: 8.1%	372	383	395	406
Total Fringe Benefits	4,272	4,400	4,532	4,668
C. Permanent Equipment				
Name of equipment	0	0	0	0
	0	0	0	0
D. Travel				
International: Launch site				
Airfare: $1000; Per diem: 14 days@ $320/day;				
Ground transportation: $200				5680
Domestic				
Airfare: $500; Per diem: 5days@ $150/day;				
Ground transportation: $100: 3 trips per yr	4,050	4,050	4,050	
Total Travel	4,050	4,050	4,050	5,680
E. Other Direct Costs				
Publications:10 & 20 pgs/115 per pg			1,150	2300
Computer Services	1,690	1,690	1,690	1,690
Tuition remission				
Total Other Direct Costs	1,690	1,690	2,840	3,990
F. Total Direct Costs	29,487	30,200	32,084	35,619
G. Indirect Costs				
On Campus: 51.5% of MTDC, predetermined for the period 7/1/10-6/30/11; 52.5% of MTDC pre-determined for the period 7/1/11-6/30-13, provisional thereafter. Per HHS agreement dated 5/21/2010.	15,481	15,855	16,844	18,700
H. Total Costs	44,968	46,055	48,927	54,320

Total requested for four years: **194,270**

Statement of Work
OCAM - An Oxygen Heterodyne Camera for SOFIA

David Hollenbach, Co-Investigator, SETI Institute

OCAM is a heterodyne array spectrometer for SOFIA designed to map [OI] 63 μm emission in the Milky Way and nearby galaxies. OCAM will have a spatial resolution of about 6 arcsec per pixel, 16 pixels, and spectral resolution of < 1 km s^{-1}. Among its many important goals are the understanding of the impact of massive OB stars on their natal molecular clouds, the role winds and jets from low mass protostars in generating turbulence in molecular clouds, oxygen chemistry in interstellar clouds, and the nature of the high pressure and high radiation field environment of the center of our Galaxy. Studying our Galaxy in detail, OCAM will provide a template for understanding the [OI] emission from distant galaxies. The three nights of observing with OCAM will be used to demonstrate its capabilities in these areas to the SOFIA community. As a Co-Investigator, D. Hollenbach will provide theoretical and modeling expertise which will aid in the interpretation of the data taken by OCAM in these three nights, will help set science requirements for OCAM, and will aid in the analysis of the final data products and in the publication of papers derived from these flights.

During the first three years of the development of the instrument (June 1, 2012 to May 31, 2015), the main activity for Co-I Hollenbach will be to provide insight into the science requirements for OCAM, refining the areas to be mapped, the sensitivity needs, the ancillary observations that are required, and the theoretical models which will need to be developed. D. Hollenbach will participate in the regular telecons and will generate reports on the above topics as needed. Finally, as OCAM is built, D. Hollenbach will attend team meetings in order to provide scientific requirements input to the possible discussions of tradeoffs in cost and schedule versus instrument performance.

One theoretical model that will be constructed in the early prelaunch years of instrument development involves the interaction of the ultraviolet fields from OB stars on giant molecular clouds (GMCs). Hollenbach (working with outside collaborator Mark Wolfire, U. Maryland) will model the enhanced ultraviolet fields on GMCs caused by the massive stars that are born inside them. These UV fields create ionized HII regions that burst out of the GMC, leaving exposed massive stars outside the GMC that illuminate the exterior surface of the GMC. These fluxes pressurize the GMC, thereby affecting the star formation rates inside the GMC, and they also photoevaporate the GMC and are instrumental in the destruction of the GMC, thus determining the lifetime of the GMC and the efficiency of the GMC in converting its gas and dust into stars and planets. The [OI] 63 μm line is the strongest line and dominant coolant in this interaction of the FUV field with the molecular cloud. Two papers are envisioned for this effort. Much of this work will be supported by other grants, but the OCAM project will supply some publication costs and a minimal amount of salary for this effort.

The main activities for D. Hollenbach in the fourth year (June 1, 2015 to May 31, 2016) are somewhat different since the three SOFIA flights demonstrating OCAM will have been completed. Besides the activities mentioned above, the work will involve participating in the data analysis, comparing the SOFIA data with other ancillary data sets, modeling, testing the various hypotheses, and finally producing published refereed papers. Again, CoI Hollenbach will participate in all OCAM telecons and meetings during this period.

OCAM – An Oxygen Heterodyne Camera for SOFIA

Detailed Institutional Budget--SETI Institute

	Salary base	# of Mos.	YEAR 1	Salary base	# of Mos.	YEAR 2	Salary base	# of Mos.	YEAR 3	Salary base	# of Mos.	YEAR 4	**Total**
Senior/Key Personnel													
David Hollenbach, Principal Investigator	128,750	1.50	16,094	135,188	1.50	16,898	141,947	1.50	17,743	149,044	2	24,841	**75,576**
Benefits	Rate	18%	2,897	Rate	18%	3,042	Rate	18%	3,194	Rate	18%	4,471	**13,604**
Subtotal Key Personnel			**18,991**			**19,940**			**20,937**			**29,312**	**89,180**
Other Personnel													
None	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Subtotal Other Personnel			**0**			**0**			**0**			**0**	**0**
Total Direct Labor			**18,991**			**19,940**			**20,937**			**29,312**	**89,180**
Equipment Description													
None			0			0			0			0	**0**
Total Equipment			**0**			**0**			**0**			**0**	**0**
Travel													
Domestic Travel (see detail)			919			947			975			1,004	**3,845**
Foreign Travel (see detail)			0			0			0			0	**0**
Total Travel			**919**			**947**			**975**			**1,004**	**3,845**
Other Direct Costs													
Materials and Supplies			**0**			**0**			**0**			**0**	**0**
Publication Costs			**0**			**0**			**0**			**4,400**	**4,400**
Consultant Services			**0**			**0**			**0**			**0**	**0**
Subawards/Consortium/Contractual Costs			**0**			**0**			**0**			**0**	**0**
Total Other			**0**			**0**			**0**			**4,400**	**4,400**
Total Direct Costs			**19,910**			**20,887**			**21,912**			**34,716**	**97,425**
Indirect Costs--at 25.92%													
Key Personnel IDC			4,922			5,168			5,427			7,598	**23,115**
Other Personnel IDC			0			0			0			0	**0**
Equipment (no IDC per definition)			0			0			0			0	**0**
Travel IDC			238			245			253			260	**997**
Materials and Supplies IDC			0			0			0			0	**0**
Publication Costs IDC			0			0			0			1,140	**1,140**
Consultant Services IDC			0			0			0			0	**0**
SubContracts IDC (first $25K only)			0			0			0			**0**	**0**
Total IDC @ 25.92%			**5,161**			**5,414**			**5,680**			**8,998**	**25,252**
Total Requested Funds			**25,070**			**26,301**			**27,592**			**43,715**	**122,677**

Indirect costs are computed consistent with the SETI Institute's approval from the Office of Naval Research on 4/11/11 for a negotiated FY 2011 Indirect Cost rate. The approved indirect cost rate is 25.92%. Items of equipment with a unit purchase price of $5,000 or more are excluded from indirect cost application. Subcontract amounts above $25,000 per subcontract are excluded from IDC.

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	Total
TRAVEL DETAIL --Domestic					
San Jose to Tucson, AZ					
1 traveler for 3 days					
Airfare	304	313	323	332	**1,272**
Per Diem	390	402	414	426	**1,632**
Conference fees	0	0	0	0	**0**
Car rental, parking, rental fuel	225	232	239	246	**941**
Total Domestic Travel	919	947	975	1,004	**3,845**
TRAVEL DETAIL --Foreign					
Event and dates if known					
Departure City and Destination City					
# of Travelers and # of days					
Airfare	0	0	0	0	**0**
Per Diem	0	0	0	0	**0**
Conference fees	0	0	0	0	**0**
Car rental, parking, rental fuel	0	0	0	0	**0**
Total Foreign Travel	0	0	0	0	**0**
TOTAL TRAVEL COSTS	919	947	975	1,004	**3,845**

1 Task Statement (Oberlin Group)

1.1 Overview

The Oberlin team brings a variety of skills to the Oxygen Heterodyne Camera for SOFIA (OCAM) project. First and foremost the Oberlin Co-I (Martin) has a great deal of experience with data collection and reduction software for large sub-millimeter surveys. As the primary observer and lead author for the AST/RO (Antarctic Sub-mm Telescope and Remote Observatory) Galactic Center Survey of 2001–2004 (Martin *et al.* ApJS 150, 239 (2004)), Martin developed an extensive data acquisition and data reduction pipeline for handling sub-mm and Terahertz observations of the Galactic Center. This survey spanned hundreds of thousands of distinct pointings over the space of multiple years and thus required careful attention to data quality and calibration. It is expected that substantial portions of this data-pipeline can be modified and reused for this project.

Additionally as Antarctic winter-over on the AST/RO project (spending two full years at the South Pole Station) the PI developed tremendous skill in working with sub-mm instrumentation in the difficult conditions of the Antarctic plateau. As this experiment moves toward installation on SOFIA, this experience in difficult environments with no tolerance for error should prove useful.

Finally as a primarily undergraduate institution, the Oberlin group will bring direct involvement in a cutting-edge research experiment to the scientific leaders of the next generation. Talented undergraduates will be involved in all aspects of the tasks described above and will be incorporated as full team members in the project.

1.2 Specific Tasks

1.2.1 Data Acquisition Software

By the end of year two, a fully documented and tested data acquisition software package will be made available for integration with the observatory payload. An important part of the design of this package will be the extraction of a spatially regridded data stream. As other aspects of the instrument reach completion, calibration and integration tests will be performed to ensure readiness for the first test flight.

1.2.2 Data Reduction Software

As the data acquisition software is developed in years 1 and 2, the data reduction pipeline will be developed in parallel. In this way the reduction software can be tested and calibrated at the earliest possible stages of the project, leaving plenty of time for correction of any problems that may be discovered.

1.2.3 Integration and Testing

As the rest of the instrument reaches completion, the Co-I will be intimately involved in integration and testing to make sure that the software is no impediment to a successful flight.

OBERLIN

Oberlin College
Office of Sponsored Programs
Cox Administration Building
70 North Professor Street
Oberlin, Ohio 44074-1090
440/775-8461; Fax: 440/775-8944

September 26, 2011

Dr. Chris Walker
Steward Observatory
933 N. Cherry Avenue
University of Arizona
Tucson, AZ 85721

Dear Dr. Walker:

Attached please find the budget for the Oberlin College component of "OCAM – An Oxygen Heterodyne Camera for SOFIA," which is being submitted to NASA Announcement Opportunity NNH08ZDA009O-SOFIA2G. Associate Professor of Physics and Astronomy Dr. Chris Martin will direct the project activities at Oberlin and serve as co-investigator on the project, and appropriate administrators at Oberlin College have approved the budget and his participation. Professor Martin's statement of work, letter of commitment, and *curriculum vitae* for the project are also attached.

Please contact me at 440-775-8461 or psnyder@oberlin.edu if you have questions or need additional information about the Oberlin subaward, and thank you in advance for sending a copy of the final proposal to my attention for Oberlin's records.

Sincerely,

Pamela Snyder
Director of Sponsored Programs

cc: Chris Martin

1 Task Statement (Oberlin Group)

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As the rest of the instrument reaches completion, the Co-I will be intimately involved in integration and testing to make sure that the software is no impediment to a successful flight.

1.2.4 Involvement of Undergraduates

At all stages of this proposal the full and complete participation of a number of talented undergraduate students is both expected and desired. While it is obviously impossible to predict what any student will do with this experience, it is certainly hoped that it will serve as a launching point for future excellent research in graduate school and beyond.

Based on past experience, Oberlin students have benefited from research experience such as this and gone on to do great things. According to the Franklin and Marshall studies of baccalaureate origins of doctorate recipients, Oberlin led all four-year, private institutions in the number of graduates who received the Ph.D. in all fields and in the sciences during the entire period of the studies, 1920 to 2000. NSF CASPAR data from 1966 to 2003 confirm Oberlin's continued leadership in preparing future PhDs. Most recently (1994–2003), Oberlin is cited as the baccalaureate origin of 1,107 doctorates (including 25 in physics and 6 in astronomy), the highest of any undergraduate institution. Moreover, according to a study published by the NSF Advisory Council, Oberlin ranks first among four-year undergraduate institutions with enrollments of 5,000 or fewer as the institution of origin for science Ph.D.s on the faculties of the 45 leading research universities.

Project:	NASA subaward: OCAM - An Oxygen Heterodyne Camera for SOFIA				
Oberlin PI:	Chris Martin				
Lead Institution:	University of Arizona				
Dates:	June 1, 2012 - July 31, 2016				
Salary	**6/2012-7/2013**	**6/2013-7/2014**	**6/2014-7/2015**	**6/2015-7/2016**	**Total**
PI summer salary	8,992	9,262	9,539	9,826	37,618
Academic-year student assistant: 1 @ $10/hr. x 5 hrs./wk. x 26 wks.	1,300	1,300	1,300	1,300	5,200
Summer student assistants: 2 @ $10/hr. x 40 hrs./wk. x 10 wks.	8,000	8,000	8,000	8,000	32,000
Total Salary & Wages	**18,292**	**18,562**	**18,839**	**19,126**	**74,818**
Fringe					
PI summer salary @ 18%	1,619	1,667	1,717	1,717	6,720
Summer students @ 7.65% for FICA	612	612	612	612	2,448
Total Fringe	**2,231**	**2,279**	**2,329**	**2,329**	**9,168**
Equipment (over $5,000 per unit)					
Total Equipment	**0**	**0**	**0**	**0**	**0**
Travel					
PI/student conference and collaboration meeting travel					
Conference travel: PI and 2 students @ $1,000/each/year	3,000	3,000	3,000	3,000	12,000
Collaboration meeting travel: PI and 1 student @ $1,000/each/year	2,000	2,000	2,000	2,000	8,000
International conference: PI in year 3 @ $2,000	0	0	2,000	0	2,000
PI/student research travel					
Research travel to SOFIA flight: PI and 1 student @ $2,000/each	0	0	0	0	0
per year In years 3 and 4	0	0	4,000	4,000	8,000
Total Travel	**5,000**	**5,000**	**11,000**	**9,000**	**30,000**
Other Direct Costs					
Pieces of equipment counted as supply since under $5,000/unit	0	0		0	0
Materials/Supplies	2,000	2,000	2,000	2,000	8,000
Publication costs	1,000	1,000	1,000	1,000	4,000
Other	0	0	0	0	0
Total Other Direct	**3,000**	**3,000**	**3,000**	**3,000**	**12,000**
TOTAL DIRECT COSTS	**28,522**	**28,841**	**35,168**	**33,455**	**125,986**
Indirect @ 62.4% of salary/wages on-campus	**11,414**	**11,582**	**811**	**811**	24,619
Indirect @ 26.5% of salary/wages off-campus	**0**	**0**	**4,648**	**4,724**	9,372
TOTAL PROJECT COSTS	**39,936**	**40,423**	**40,628**	**38,990**	**159,977**
Indirect cost calculation base					
PI on-campus wages (100% on campus years 1 & 2)	8,992	9,262	0	0	18,253
Academic-year student on-campus wages (100% on-campus annually)	1,300	1,300	1,300	1,300	5,200
Summer student on-campus wages (100% on campus years 1 & 2)	8,000	8,000	0	0	16,000
Total on-campus wages	**18,292**	**18,562**	**1,300**	**1,300**	**39,453**
PI off-campus wages (100% off campus years 3 and 4)	0	0	9,539	9,826	19,365
Summer student off-campus wages (100% off campus years 3 & 4)	0	0	8,000	8,000	16,000
Total off-campus wages	**0**	**0**	**17,539**	**17,826**	**35,365**
Total salary and wages	**18,292**	**18,562**	**18,839**	**19,126**	**74,818**
Indirect Cost Agreement Cognizant Federal Agency:	DHHS				
Rate:	62.4% of salaries/wages for on-campus work				
	26.5% of salaries/wages for off-campus work				

UNIVERSITY OF CALIFORNIA, LOS ANGELES **UCLA**

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LOS ANGELES, CALIFORNIA 90095-1406

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www.research.ucla.edu/ocga

September 23, 2011

University of Arizona
Department of Astronomy/Steward Observatory
933 North Cherry Avenue, Rm N204
Tucson, AZ 85721-0065

Attention: Professor Christopher K. Walker

On behalf of the Regents of the University of California, we are pleased to submit this proposal in support of the Galactic center science program:

Title: "OCAM – An Oxygen Heterodyne Camera for SOFIA"

Period of Performance: June 1, 2012 to May 30, 2016

Funding Requested: $152,885.
(Direct - $99,275, Indirect - $53,610)

PI: Professor Mark Morris
Department of Physics and Astronomy
Email: Morris@astro.ucla.edu

If you have any questions, or need additional information please do not hesitate to Contact me at (310) 7940179 or via email at: bharris-holdrege@research.ucla.edu.

Thank you,

Barbara Harris-Holdrege
Contract & Grant Officer
UCLA Office of Contract & Grant Administration

Statement of Work – Mark Morris

As the team expert on Galactic center science, Co-I Mark Morris will oversee the planning and execution of the Galactic center science program. In years 1 – 3, his tasks will include the following:

1) Monitor the instrument characteristics as development progresses and using them to construct and modify, as necessary, a realistic and detailed science program involving mapping OI emission across a large region of the Galactic center.
2) Interact closely with other team members to refine models for the production of atomic oxygen under conditions prevailing in the Galactic center, and to prepare models for the excitation and radiative transfer pertaining to emission or absorption in the 63 micron line.
3) Work with team members to produce a flight plan for SOFIA that maximizes the scientific return from observations of all of the targets described in this proposal.

In year 4, Morris will carry out the following tasks:

1) Participate in carrying out the observations, offering judgments in real time about how best to meet the science goals as a function of the observing conditions and the implications of the quick-look science data.
2) Reduce the data on the Galactic center, or oversee the reduction so that the results are produced and displayed in the most useful format.
3) Undertake planning for subsequent flights beyond the first, based on the results of the first flight.
4) Interpret the Galactic center data in terms of the known phenomenology of the Galactic center, using the models that were developed and refined in years 1 – 3. Use these interpretations to draw new conclusions about the physics and chemistry of the Galaxy's central molecular zone.
5) Write and publish research papers on the results of the observations and on the detailed interpretations that are based on those results.
6) Present the conclusions of the Galactic center O I study at relevant international conferences.

In the latter stages of this project, Morris will endeavor to engage graduate students in various facets of the proposed research. He will also design and carry out follow-up science projects in response to what has been learned.

AGENCY: NASA, subaward Univ of Arizona

BUDGET PERIOD: June 1, 2012 – May 31, 2016	Y1	Y2	Y3	Y4	CUMULATIVE
SALARIES:					
Mark Morris	$15,034	$15,785	$16,575	$34,807	$82,201
Professor					
100% for 3 weeks (1.5 months in year 4)					
Current Salary: $20,045					
TOTAL SALARIES	$15,034	$15,785	$16,575	$34,807	$82,201
BENEFITS:					
ACADEMIC SUMMER: 12.7%	$1,909	$2,005	$2,105	$4,420	$10,439
					$0
TOTAL BENEFITS	$1,909	$2,005	$2,105	$4,420	$10,439
TOTAL SALARIES & BENEFITS:	$16,943	$17,790	$18,680	$39,227	$92,640
SUPPLIES & EXPENSE:					
					$0
Computer supplies	$500	$500	$500	$500	$2,000
Technology Infrastructure fee	$31	$31	$31	$42	$135
					$0
					$0
PUBLICATIONS:				$1,500	$1,500
					$0
					$0
TRAVEL:					$0
Domestic : -	$750	$750	$750	$750	$3,000
Trips for team meetings					$0
					$0
:T COSTS	$18,224	$19,071	$19,961	$42,019	$99,275
INDIRECT COSTS *base*					
54% *$18,224*	$9,841				$9,841
54% *$19,071*		$10,298			$10,298
54% *$19,961*			$10,779		$10,779
54% *$42,019*				$22,691	$22,691
3UDGET	$28,065	$29,370	$30,740	$64,710	$152,885

Budget Justification
for Mark Morris' participation in the OCAM project

As Project Leader for the Galactic Center project, Morris will meet with colleagues during years 1 - 3 to plan the observations, and to contribute to the generation of computer codes for the analysis and interpretation of the data. His budget therefore includes travel funds to one team meeting per year, computer expenses, and three weeks of summer salary. In year 4, the budget includes 1.5 months of summer salary and publication costs because the observing, data analysis, and paper writing will take during this time. The travel and computer costs remain the same in year 4.

Statement of Work – Johns Hopkins University

David Neufeld will participate during all phases of the OCAM program.

Prior to the OCAM flight series, Neufeld will

(1) participate in planning the observing strategy,

(2) participate in Science Team telecons and meetings as needed,

and

(3) help evaluate any science tradeoffs that may arise.

Following the OCAM flight series, Neufeld will

(4) participate in the scientific analysis of the OCAM data,

and

5) participate in the preparation of manuscripts for publication

Yellow highlighted cells are for data entry
Green highlighted cells contain formulas
Orange highlighed cells contain rates

Last Update: 9/2/2011

The Johns Hopkins University
Department of Physics and Astronomy
PI: David Neufeld
Sponsor: University of Arizona / NASA
Title: JHU participation in OCAM

Project Dates: Start 6/1/2012 End 5/31/2016

Expense Category	Description	Additional Information	Base Salary	% Effort	Person months	Other	Year 1 (6/1/2012 to 5/31/2013)	Year 2 (6/1/2013 to 5/31/2014)	Year 3 (6/1/2014 to 5/31/2015)	Year 4 (6/1/2015 to 5/31/2016)	Total
Salaries	Faculty										
	D. Neufeld	Co-PI		6.25%	0.750		$10,243	$10,448	$10,657	-	$31,348
	D. Neufeld (YR4)	Co-PI		8.33%	1.000		$0	$0	$0	$14,487	$14,487
	Buffer										
	Subtotal Faculty Salaries						$10,243	$10,448	$10,657	$14,487	$45,835
	Total Salaries						$10,243	$10,448	$10,657	$14,487	$45,835
Fringe Benefits											
	Fringe Benefits FT/Staff	35.5%	35.5%	35.5%	35.5%	35.5%	$3,636	$3,709	$3,783	$5,143	$16,271
	Total Fringe Benefits						$3,636	$3,709	$3,783	$5,143	$16,271
	Total Salary & Fringe Benefits						$13,879	$14,157	$14,440	$19,630	$62,106
Other Direct Costs											
	Materials/Supplies/Chemicals						$0	$0	$0	$0	$0
	Publications						$0	$0	$0	$2,540	$2,540
	Pages per year two 10-pg.	-	-	-	20	-					
	Price per page	$116	$119	$123	$127	$131					
	Total Publication Cost	$0	$0	$0	$2,540	$0					
	Network Connection Fee	$29.87	$30.77	$31.69	$32.64	$33.62					
	Total Computer Services	$0	$0	$0	$0	$0					
	Travel-Domestic (from travel calculator)						$1,250	$1,288	$1,326	$1,366	$5,230
	Total Other Direct Costs						$1,250	$1,288	$1,326	$3,906	$7,770
Tuition and Fees	Number of Students	0	0	0	0	0					
	Tuition (20%)	42,280	$ 42,270	$ 43,920	$ 45,630	$ -	$0	$0	$0	$0	$0
	Graduate Student Health Insurance	$ 1,772	$ 1,825	$ 1,880	$ 1,936	$ 1,994	$0	$0	$0	$0	$0
	Subtotal Tuition & Fees						$0	$0	$0	$0	$0
	Total Direct Costs						$15,129	$15,445	$15,766	$23,536	$69,876
	Modified Total Direct Costs (MTDC)						$15,129	$15,445	$15,766	$23,536	$69,876
	Indirect Costs (F&A)	62.0%	62.0%	62.0%	62.0%	62.0%	$9,380	$9,576	$9,775	$14,592	$43,323
	Total						$24,509	$25,021	$25,541	$38,128	$113,199

Yellow highlighted cells are for data entry
Green highlighted cells contain formulas
Orange highlighed cells contain rates

Last Update: 9/2/2011

The Johns Hopkins University
Department of Physics and Astronomy
PI: David Neufeld
Sponsor: University of Arizona / NASA
Title: JHU participation in OCAM

	Start	End
Project Dates:	6/1/2012	5/31/2016

Expense Category	Description	Additional Information	Base Salary	% Effort	Person months	Other	Year 1 (6/1/2012 to 5/31/2013)	Year 2 (6/1/2013 to 5/31/2014)	Year 3 (6/1/2014 to 5/31/2015)	Year 4 (6/1/2015 to 5/31/2016)	Total

Travel Calculator

Domestic Travel	YR1	YR2	YR3	YR4	YR5
Number of trips	1	1	1	1	
Number of days	5	5	5	5	
Mileage	0				
Mileage Rate	55.50	55.50	55.50	55.50	55.50
Mileage Expense (# miles X mileage rate)	$0	$0	$0	$0	$0
Per Diem	$149	$153	$158	$163	
Subtotal	$745	$767	$790	$814	$0
Misc: parking , cab, ...	$99	$102	$105	$108	
Airfare	$406	$418	$431	$444	
Total Domestic Travel	$1,250	$1,288	$1,326	$1,366	$0

Foreign Travel	FY11	FY12	FY13	FY 14	FY 15
Number of trips	0				
Number of days	0				
Per Diem	$0				
Subtotal((# trips X days X per diem)	$0	$0	$0	$0	$0
Airfare	$0				
Total Foreign Travel	$0	$0	$0	$0	$0

OCAM Statement of Work, Smithsonian Astrophysical Observatory

Antony A. Stark and Gary Melnick

Antony Stark and Gary Melnick are Co-Investigators on the Stratospheric Observatory For Infrared Astronomy (SOFIA) OCAM instrument proposal to NASA. OCAM is a 16-pixel heterodyne "camera" designed to obtain high velocity resolution (i.e., < 1 km s^{-1}) spectra in each of its 16 spatial pixels at wavelengths around the ground-state 63.1837 μm fine-structure transition of [OI]. Stark and Melnick's roles are to: (1) provide science input to the proposal; (2) provide science guidance during the instrument development phase – i.e., help in assessing the impact of any potential hardware design changes on the science return; (3) help in constructing observing scenarios that are translated into SOFIA flight plans; (4) participate in the OCAM observing flights in 2015-2016; and, (5) participate in the data analysis, data analysis programming, and the writing of science papers. To carry out the above tasks, they will attend one team meeting per year leading up to the flight year and then additional travel in the flight year to support the OCAM observations. They will also participate in all necessary teleconferences. Also budgeted is partial support for two additional scientist's time to help with the above tasks. (Gary Melnick's time is provided at no cost to the OCAM effort.)

OCAM Statement of Work and Budget Justification
Smithsonian Astrophysical Observatory
Antony A. Stark and Gary Melnick

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To carry out the above tasks, the Smithsonian's budget includes:
Salary: Three weeks support each for PI Stark and Tolls, and 1 week for Stalder in Years 1 – 4, with support for Tolls increasing to 4 weeks in the flight year. Administrative support is included at approximately 2 days per year. Co-I Melnick's participation is provided at no cost to the OCAM effort.

Travel: Stark and Melnick will attend one team meeting in Tucson AZ per year leading up to the flight year and the SAO team will travel to Palmdale CA twice in the flight year to support the OCAM observations.

Materials: A data storage disk will be purchased in Years 1 and 4. A workstation will be required in Year 2 for project data reduction and related tasks.

OCAM -- An Oxygen Heterodyne Camera for SOFIA

Estimate of Cost

DRAFT FOR BUDGET ESTIMATION ONLY **NOT FOR OFFICIAL USE**

Period of Performance: 1 June 2012 through 31 May 2016

	Year 1 6/1/12 - 5/31/13		Year 2 6/1/13 - 5/31/14		Year 3 6/1/14 - 5/31/15		Year 4 6/1/15 - 5/31/16		Total	
Productive Labor:	Hrs.	Dollars	Hrs.	Dollars	Hrs.	Dollars	Hrs.	Dollars	Hrs.	Dollars
		$		$		$		$		$
Dr. A. Stark, Principal Investigator	120	8,941	120	8,941	120	8,941	120	8,941	480	35,764
Dr. G. Melnick, Co-Investigator			----------------------- Services at No Cost to Univ. Arizona -----------------------							
Dr. V. Tolls, Research Scientist	120	6,686	120	6,686	120	6,686	160	8,915	520	28,973
Dr. B. Stalder, Astronomer	60	1,804	60	1,864	60	1,925	60	1,985	240	7,578
Admin. Support Assistant	9	263	9	263	9	263	12	351	39	1,140
Administrator	9	352	9	352	9	352	12	469	39	1,525
Total Productive Labor	318	18,046	318	18,106	318	18,167	364	20,661	1,318	74,980
Leave @ 19.3%		3,483		3,494		3,506		3,988		14,471
Total Direct Labor		21,529		21,600		21,673		24,649		89,451
Fringe Benefits @ 26.8%		5,770		5,789		5,808		6,606		23,973
Direct Operating Overhead Base		27,299		27,389		27,481		31,255		113,424
Direct Operating Overhead @ 26.7%		7,289		7,313		7,337		8,345		30,284
Travel (see schedule)		2,454		2,454		2,454		18,070		25,432
Printing & Reproduction (see schedule)		0		0		0		4,000		4,000
Materials Overhead @ 4.9% of Material Base Below		15		196		0		15		226
G & A Base		37,057		37,352		37,272		61,685		173,366
G & A @ 13.0%		4,817		4,856		4,845		8,019		22,537
Materials (see schedule)	300		4,000		0		300		4,600	
Material Base		300		4,000		0		300		4,600
TOTAL ESTIMATED COST EXCLUDING INFLATION		**42,174**		**46,208**		**42,117**		**70,004**		**200,503**
Inflation		2,277		3,743		4,591		9,661		20,272
TOTAL ESTIMATED COST INCLUDING INFLATION		**44,451**		**49,951**		**46,708**		**79,665**		**220,775**
Inflation Rate		2.70%		2.60%		2.60%		2.60%		

BIOSKETCHES

Biographical Sketch: CHRISTOPHER K. WALKER

PROFESSIONAL PREPARATION

Clemson University	Electrical Engineering	B.S. 1980
Ohio State University	Electrical Engineering	M.S. 1981
University of Arizona	Astronomy	Ph.D. 1988

APPOINTMENTS

- Professor of Astronomy and Optical Sciences, Associate Professor of Electrical Engineering, University of Arizona, 2003-
- Associate Professor of Astronomy, Optical Sciences, and Electrical Engineering, University of Arizona, 2002-2003
- Associate Professor of Astronomy & Optical Sciences, University of Arizona, 2000-2002
- Associate Professor, Steward Observatory, University of Arizona, 1997-2000
- Assistant Professor, Steward Observatory, University of Arizona, 1991-1997
- Millikan Research Fellow in Physics, Caltech, 1988-1991
- Graduate Research Assistant, Steward Observatory, 1983-1991
- Research and Development Engineer, Jet Propulsion Laboratory, 1983
- Electrical Engineer, TRW Aerospace Division, 1981-1983

Research and Management Experience

Co-PI Christopher Walker of the University of Arizona (UA), has over 25 years of experience designing, building, and using state-of-the-art receiver systems for THz astronomy. He has advanced degrees in both astronomy and electrical engineering and has worked in industry (TRW Aerospace and JPL) as well as academia. As a Millikan Fellow in Physics at Caltech, he led the effort to develop the first low-noise, SIS waveguide receiver above 400 GHz. At the University of Arizona he began the Steward Observatory Radio Astronomy Lab (SORAL), which has become a world leader in developing leading-edge submillimeter-wave receiver systems. SORAL constructed the world’s first 810 and 345 GHz heterodyne array receivers and helped developed one of the first 1.5 THz HEB receiver systems for radio astronomy. These instruments are multi-institutional efforts, with key components coming from JPL, several universities, and a number of industrial partners. Prof. Walker managed and coordinated these efforts. Instruments developed by Prof. Walker’s team have served as primary facility instruments at the Heinrich Hertz Telescope and the AST/RO telescope at the South Pole for over a decade. Funded by the NSF, Prof. Walker is leading the effort to design and build the world’s largest submillimeter-wave heterodyne array receiver (64 pixels). He is also PI of the NASA funded long duration balloon project ``The Stratospheric THz Observatory (STO)’’. Prof. Walker has published numerous papers on star formation and protostellar evolution. He has served as dissertation director for nine Ph.D. students (7-Astronomy and 2-Optical Sciences).

RELATED PUBLICATIONS

Bussmann, R. S., Wong, T. W., Hedden, A., Kulesa, C., and Walker, C. K., 2007, *A CO (J=3-2) Outflow Survey of the Elias 29 Region, Ap.J.,* 657, Issue 1, pp. L33-L36.

Hedden, A. S., Walker, C. K., Groppi, C. E., and Butner, H. A., 2006, Star *Formation in the Northern Cloud Complex of NGC 2264, Ap.J.*, **645**, p.345.

Kulesa, C., Hungerford, a., Walker, C., Zhang, X., and Lane, A., 2005, *Large-Scale CO and [CI] Emission in the Rho Ohiuchi Molecular Cloud, Ap. J.,* **625**, 194.

Stark, A., Martin, C., Walsh, W., Xiao, K., Lane, A., and Walker, C., 2004, "*Gas Density, Stability, and Starbursts near the Inner Lindblad Resonance of the Milky Way*", *Ap.J.*, **614**, Issue 1, pp. L41-L44.

Martin, C., Walsh, W., Xiao, K., Lane, A., and Stark, A., 2004, *The AST/RO Survey of the Galactic Center Region. I. The Inner 3 Degrees*, *Ap.J.S.*, **150**, 239.

OTHER SIGNIFICANT PUBLICATIONS

Narayanan, D., Kulesa, C., Boss, A., and Walker, C. K., 2006, *Molecular Line Emission from Gravitationally Unstable Protoplanetary Disks*, *Ap.J.*, **647**, Issue 2, pp. 1426-1436.

Narayanan, D., Cox, T., Robertson, B., Dave', R., Di Matteo, T., Hernquist, L., Hopkins, P., Kulesa, C., and Walker, C. K., 2006, *Molecular Outflows in Galaxy Merger Simulations with Embedded Active Galactic Nuclei*, *Ap.J.*., 642, Issue 2, pp. L107-L110.

Groppi, C., Kulesa, C., Walker, C., and Martin, C., 2004, *Millimeter and Submillimeter Survey of the R   Coronae Australis Region*, *Ap. J.,* **612**, 946.

Narayanan, G., Moriarty-Schieven, G., Walker, C.K., and Butner, H.M. 2002, *Detection of Infall Signatures Towards SMM4*, *Ap.J.*, **565**, 319.

Melia, F., Bromley, B., Liu, S., and Walker, C.K. 2001, *Measuring the Black Hole Spin in Sag A**, *Ap. J. Letters*, **554**, 37.

Ph.D. ADVISEES

Grace Wolf (Hansen Planetarium), Jason Glenn (UC Boulder), Gopal Narayanan (U. Mass), Craig Kulesa (UofA), Christian d'Aubigny (Teravision Inc.), Christopher Groppi (UofA), Desika Narayanan (CfA), Abigail Hedden (SAO), Dathon Golish (Teravision Inc.)

RECENT COLLABORATORS (48 Months)

Pietro Bernasconi (JHAPL)
Paul Goldsmith (JPL)
Christopher Groppi (ASU)
David Hollenbach (SETI Institute)
Karl Jacobs (U. Cologne)
John Kawamura (JPL)
Craig Kulesa (UofA)
William Langer (JPL)
Arthur Lichtenberger (UVa)
Carey Lisse (JHAPL)
Christopher Martin (Oberlin College)
David Neufeld (JHU)
Gordon Stacey (Cornell)
Antony Stark (SAO)
Jeffrey Stern (JPL)
Juergen Stutzki (U. Cologne)
Sander Weinreb (CIT/JPL)
Mark Wolfire (U. Maryland)
Harold Yorke (JPL)
Eric Young (SOFIA)

JOHN BALLY
Department of Astrophysical and Planetary Sciences
Center for Astrophysics and Space Astronomy
Campus Box 389, University of Colorado at Boulder, Boulder CO 80309
Phone: (303) 492-5786; FAX: (303) 492-7178; e-mail: john.bally@colorado.edu
Internet: http://casa.colorado.edu/~bally

Educational Background:

1972	B.S	(Astronomy)	University of California, Berkeley
1977	M.S.	(Physics)	University of Massachusetts, Amherst
1980	Ph.D.	(Astrophysics)	University of Massachusetts, Amherst

Professional Employment:

2000 - present	Professor	Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO
1991 - 1999	Associate Professor	Department of Astrophysical and Planetary Sciences, University of Colorado, Boulder, CO
1996 - 1999	Director	Center for Astrophysics and Space Astronomy, University of Colorado, Boulder, CO
1982 - 1991	Member of Technical Staff	AT&T Bell Laboratories, Holmdel, NJ
1980 - 1982	Post-Doctoral MTS	AT&T Bell Laboratories, Holmdel, NJ
1978 -1980	Research Assistant	Five College Radio Astronomy Observatory (FCRAO) University of Massachusetts, Amherst, MA
1974 - 1974	Instructor (Physics)	California State University, Hayward, CA

Areas of Research:

The astrophysics of star formation, disks and outflows associated with young stars, the formation of planetary systems, and investigations of the interstellar medium. Line and continuum observations at millimeter, sub-mm, infrared, and visual wavelengths. The hydrodynamics of shocks and ionization fronts. *Other interests:* Galaxy formation and evolution, and the search for extra-Solar planets. Cosmology and fundamental physics. *Hardware/engineering experience:* Cryogenic mm-wave mixers, IF systems, and superconducting (SIS) receivers, near-infrared arrays and cameras, optics, and astronomical site characterization.

Some Recent Publications (out of 538 listed on ADS**):**

Bally, J., Cunningham, N. J., Moeckel, N., Burton, M.~G., Smith, N., Frank, A., Nordlund, A. 2011. *Explosive Outflows Powered by the Decay of Non-hierarchical Multiple Systems of Massive Stars: Orion BN/KL.* **ApJ**, 727, 113

Molinari, S., Bally, J. and 40 coauthors 2011, **ApJ**, 735, L33 *A 100 pc Elliptical and Twisted Ring of Cold and Dense Molecular Clouds Revealed by Herschel Around the Galactic Center*

Armond, T., Reipurth, B., Bally, J., Aspin, C. 2011. *Star Formation in the Gulf of Mexico.* **A&A**, 528, 125

Bally, J., and 19 colleagues 2010. *The Bolocam Galactic Plane Survey: $\lambda = 1.1$ and 0.35 mm Dust Continuum Emission in the Galactic Center Region*. **ApJ**, 721, 137

Bally, J. 2010. *Astrophysics: Waves on Orion's shores.* **Nature**, 466, 928

CV of dr. Jian-Rong Gao (SRON/TU Delft)

Born on 30, October 1959, Shanghai, P.R. China
Nationality: Dutch
BSc & MSc, Fudan University, Shanghai, China, 1985
Ph.D in Physics, Delft University of Technology, The Netherlands, 1991
Post-doctor, University of Groningen, Groningen, Netherlands 1992-1994

Now he is a senior instrument scientist in the Division of Sensor Research & Technology of SRON Netherlands Institute for Space Research located at Utrecht and Groningen. He is the leader of HEB/QCL project at SRON and is also the project leader for the TES development for an European instrument (SAFARI) on the SPICA space telescope. At Delft he is a senior researcher, through a SRON-TU Delft research contract, serving as a staff member in the group Physics of Nanoelectronics, Kavli Institute of Nanoscience, Delft University of technology.

His prime interests are superconducting detectors and semiconductor THz sources for space application. He is particularly interested in innovative ideas on physics, device structure, and microwave circuitry, which can lead to detection systems with state-of-the-art performance.

He is one of the very few experts in the field of terahertz superconducting hot electron bolometer (HEB) mixers, the most sensitive heterodyne detectors available for frequencies far above 1 THz, and which have various astronomical and atmospheric applications. A joint SRON-Delft HEB team led by Dr Gao holds the record sensitivity of phonon-cooled HEB mixers at 1.9, 2.5, 4.3, and 5.3 THz and has reported the first experimental demonstration of a THz quantum cascade laser-HEB receiver. Such a receiver offers the technological possibility to build highly sensitive solid-state heterodyne receivers at the super-THz frequencies for future space and airborne telescopes.

Dr Gao has pioneered THz quantum cascade lasers for local oscillator application. Besides, he is also working on the development of TES detectors for the SPICA space telescope. As the co-leader in the past he has worked on the development of superconductor-insulator-superconductor (SIS) mixers, which were successfully applied in different heterodyne instruments, such as HIFI in Herschel. He has about 180 publications.

Five relevant publications of dr. J.R. Gao

1. J.R. Gao, J.N. Hovenier, Z.Q. Yang, J.J.A. Baselmans, A. Baryshev, M. Hajenius, T.M. Klapwijk, A.J.L. Adam, T.O. Klaassen. B.S. Williams, S. Kumar, Q. Hu, and J.L. Reno, "*Terahertz heterodyne receiver based on a quantum cascade laser and a superconducting bolometer*" Appl. Phys. Lett. **86**, 244104 (2005).
2. P. Khosropanah, J. R. Gao, W. M. Laauwen, M. Hajenius, and T. M. Klapwijk, " *Low noise NbN hot electron bolometer mixer at 4.3 THz*", Appl. Phys. Lett. **91**, 221111 (2007).
3. P. Khosropanah, A. Baryshev, W. Zhang, W. Jellema, J. N. Hovenier, J. R. Gao, T. M. Klapwijk, D. G. Paveliev, B. S. Williams, S. Kumar, Q. Hu, J. L. Reno, B. Klein, and J. L. Hesler, "Phase locking of a 2.7 THz quantum cascade laser to a microwave reference," Opt. Lett. **34**, 2958-2960 (2009)
4. W. Zhang, P. Khosropanah, J. R. Gao, T. Bansal, T. M. Klapwijk, W. Miao, and S. C. Shi, "Noise temperature and beam pattern of a NbN hot electron bolometer mixer at 5.25 THz", J. of Appl. Phys., **108**, 093102(2010).
5. Y. Ren, J.N. Hovenier, R. Higgins, J.R. Gao, T.M. Klapwijk, S.C. Shi, B. Klein, T-Y. Kao, Q. Hu, and J. L. Reno, High-resolution heterodyne spectroscopy using a tunable quantum cascade laser around 3.5 THz. Applied Physics Letters, **98**, 231109(2011).

CURRICULUM VITAE

Christopher Emil Groppi

School of Earth and Space Exploration, Arizona State University

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Tel: 480-965-6436, Fax: 480-965-8102

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Education:

Ph.D. in Astronomy with minor in Electrical and Computer Engineering, University of Arizona, 2003
B.A. with Honor in Astronomy, Cornell University, 1997

Positions Held:

Assistant Professor, Arizona State University School of Earth and Space Exploration: 2009-present
National Science Foundation Astronomy and Astrophysics Postdoctoral Fellow: 2006-2009
Assistant Staff Astronomer, Steward Observatory, 2004-2009
Director's Postdoctoral Research Associate, National Radio Astronomy Observatory, 2003-2005
NASA Graduate Student Research Program Fellow, 2000-2002
Graduate Research Assistant, University of Arizona, 1997-2003

Education and Public Outreach:

Instructor, SES330, Practical Electronics and Instrumentation, Spring 2011
Instructor, AST111, Solar System Astronomy, Fall 2010
Instructor, AST112, Stars, Galaxies and Cosmology, Spring 2010
Instructor, GLG591, Faculty Research Seminar, Fall 2009
Advisor for Steward Observatory Student Radio Telescope re-commissioning 2006-2009
Project ASTRO, Public outreach, 1999-2000
Graduate Teaching Assistant, Observational Astronomy (for majors), 1998-1999
Graduate Teaching Assistant, Introductory Astronomy Lab, 1997-1998

Professional Societies:

Member, American Astronomical Society, 1997-present
Member, International Union of Radio Science (URSI), 2005-present

Professional Interests:

Millimeter and terahertz observations of molecular clouds, protostellar and protoplanetary objects
Millimeter and terahertz instrumentation for astronomy
Earth and Planetary Science remote sensing instrumentation
Millimeter and terahertz device development
Microfabrication techniques for terahertz circuits
Full-wave electromagnetic simulation
Undergraduate research in astronomical instrumentation and terahertz electronics

Curriculum Vitae

Personal data

name :	Frank Paul Helmich
work address :	SRON Netherlands Institute for Space Research Landleven 12 9747 AD Groningen
phone	work : (31)-50-3634799
Email :	F.P.Helmich@sron.nl
date of birth :	31-07-1966
place of birth :	Rotterdam
nationality :	Netherlands

Education

1984 - 1990	Study of astronomy at the University of Groningen. Graduation in February 1990.
1991 - 1995	Thesis research at the Leiden Observatory, under supervision of Prof. dr. E.F. van Dishoeck. Thesis defence was on April 3 1996.

Work experience

1990 - 1996	Associate investigator for the Short Wavelength Spectrometer of ISO.
1996	Postdoctoral Fellow at the Sterrewacht Leiden.
1997 - 1999	Scientist in the Earth Oriented Science Division of SRON Utrecht - working on stratospheric balloon SPHINX.
1999 - 2007	Scientist in the Low Energy Astrophysics Division of SRON in Groningen, a.o. responsible for the HIFI calibration.
2007 - 2010	Head of SRON's Low Energy Astrophysics Division in Groningen
2008 - now	Principal Investigator for the HIFI instrument on board of ESA's Herschel Space Observatory; member of the Herschel Science Team
2010 - now	Program Scientist for SRON's Low Energy Astrophysics Division
2010 - now	Netherlands lead Co-I for the SPICA-SAFARI instrument

Frank Helmich participated in 64 refereed papers, the majority related to the first results of the Heterodyne Instrument for the Far-Infrared (HIFI) and to results of the Infrared Space Observatory. He has given many invited reviews on HIFI and its first result science. He has been the organiser of several workshops in Europe to define new instrument concepts for the time beyond Herschel. He has been leading a proposal to ESA Cosmic Vision for a Far-InfraRed Interferometer (FIRI). Frank Helmich has been the main scientific organiser for three COSPAR conferences on far-IR/submm space missions and the science resulting from these missions.

CO-INVESTIGATOR: DAVID HOLLENBACH

BIOGRAPHICAL DATA: PhD. (Theoretical Physics), Cornell University, 1969; Member of NASA Astronomy and Relativity Management Operation Working Group (ARMOWG), 1985-1987; Principal Investigator of the Center for Star Formation Studies 1985-2002; Member of the core IR panel of the Bahcall Committee, 1989-1990; Member of the SOFIA Science Working Group, 1990-1996; Member of the Submillimeter Science Working Group, 1990-1996; Member of the Submillimeter Wave Astronomy Satellite Team, 1988-2005, Executive Council of AAS, 1992-1995; Member of the National Academy of Sciences Task Group for Space Astronomy and Astrophysics 1995-1997; Executive Officer of the Astronomy and Astrophysics Survey Committee (National Research Council for the National Academy of Sciences) (1998-2000); Member of the National Academy of Sciences Committee on Astronomy and Astrophysics (2003-2005); Member of the ALMA North American Science Advisory Committee (2003-2005); CoI on 2 Spitzer Legacy Teams; Project Scientist for the Stratospheric Terahertz Observatory (STO) 2008-present.

AWARDS: Woodrow Wilson Fellow, Danforth Fellow, National Science Foundation Graduate Fellow, Ames Associate Fellow (1991-1992), H. Julian Allen Award (1992), Exceptional Scientist Award (NASA 1995), Outstanding Leadership Medal (NASA 2002), H. Julian Allen Award (NASA 2003), NASA Group Achievement Award (NASA 2004, for SWAS team), NASA Exceptional Achievement Medal (NASA 2005)

CURRENT POSITION: Senior Research Scientist, SETI Institute (2008-present)

RESEARCH INTERESTS: Star formation, the physics and chemistry of the interstellar medium, radiative transfer, thermal balance, the evolution of galaxies, the structure and evolution of protoplanetary disks.

RELEVANT RECENT PUBLICATIONS

Hollenbach, D. “Mass Loss Rates from Protostars and OI(63 micron) Shock Luminosities”, Icarus, 61, 36, 1985.

Hollenbach, D. J. & McKee, C. “Molecule Formation and Infrared Emission in Fast Interstellar Shocks. III - Results for J Shocks in Molecular Clouds”, ApJ, 342, 306, 1989.

Hollenbach, D. and Tielens, A., "Photodissociation Regions (PDRs) in the Interstellar Medium of Galaxies", Rev. Mod. Phys., 71, 173, 1999.

Kaufman, M., Wolfire, M., Hollenbach, D., Luhman, M., "Far Infrared and Sub-millimeter Emission from Galactic and Extragalactic Photodissociation Regions", ApJ, 527, 795, 1999.

Hollenbach, D. & Gorti, U. “Diagnostic Line Emission from Extreme Ultraviolet and X-ray-illuminated Disks and Shocks Around Low-mass Stars”, ApJ, 703, 1203, 2009.

Craig A. Kulesa

Steward Observatory
University of Arizona
Tucson, AZ 85721

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Email: ckulesa@email.arizona.edu

Professional Preparation

Ph.D., Astronomy	December 2002	The University of Arizona
B.S., Physics	June 1993	Miami University (Ohio)

Appointments

2006-	Assistant Astronomer Steward Observatory / University of Arizona
2003-2006	Assistant Staff Scientist Steward Observatory / University of Arizona
1994-2002	Research Assistant (Science and Instrumentation) University of Arizona

Selected Papers Relevant to This Proposal

1. "Large Scale CO and [CI] Emission in the Rho Ophiuchi Molecular Cloud", Kulesa, C.A., Hungerford, A.L., Walker, C.K., Zhang X., & Lane, A., 2005, ApJ, 625, 194
2. "Pre-HEAT: submillimeter site testing and astronomical spectra from Dome A, Antarctica", Kulesa, C. A. et al., 2008, Proc. SPIE, 7012, 145.
3. "Exceptional Terahertz Transparency and Stability above Dome A, Antarctica", Yang, H., Kulesa, C. A., Walker, C. K., Tothill, N. F. H., Yang, J., Ashley, M. C. B., Cui, X., Feng, L., Lawrence, J. S., Luong-van, D. M., McCaughrean, M. J., Storey, J. W. V., Wang, L., Zhou, X., Zhu, Z., 2010, PASP, 122, 490.
4. "Abundances of H_2, H_3^+ & CO in Molecular Clouds and Pre-planetary Disks", Kulesa, C. A. & Black, J. H. 2002, Chemistry as a Diagnostic of Star Formation, 60
5. "SuperCam: a 64-pixel heterodyne imaging array for the 870-micron atmospheric window", Groppi, C., Walker, C., Kulesa, C., Puetz, P., Golish, D., Gensheimer, P., Hedden, A., Bussmann, S., Weinreb, S., Kuiper, T., Kooi, J., Jones, G., Bardin, J., Mani, H., Lichtenberger, A., Narayanan, G., 2006, Proc. SPIE, vol 6275, 62750O.

Instrumentation Experience Relevant to this Proposal:

1. Deputy-PI of the *Stratospheric Terahertz Observatory* (STO), a balloon-borne telescope with heterodyne spectrometer. As D-PI, responsible for the overall system engineering and integration of the flight instrument.
2. Deputy-PI of *Supercam*, a 64-beam, 345 GHz heterodyne receiver to be deployed at the 10-meter HHT telescope in Arizona. Responsibilities focus on the I&T of IF processor and spectrometer, system level testing, telescope integration, data system.
3. Constructed *Pre-HEAT*, an automated 0.2-meter terahertz telescope with heterodyne receiver deployed in January 2008 to the isolated summit of the Antarctic ice plateau. As PI, currently deploying *HEAT*, a follow-on THz instrument to South Pole and Ridge A, with a 0.65 cm aperture and 800-1900 GHz heterodyne receivers.

Arthur W. Lichtenberger

Director University of Virginia Microfabrication Laboratories,
www.ece.virginia.edu/UVML/
Department of Electrical and Computer Engineering,
University of Virginia, Charlottesville, VA 22904.
Tel: (434) 989-2000, Email: awl1l@virginia.edu

a. Degrees

Amherst College, Amherst, MA	Bachelor of Arts-Physics BA,	1980
University of Virginia, Charlottesville, VA	Electrical Engineering M.S.,	1984
University of Virginia, Charlottesville, VA	Electrical Engineering Ph.D.,	1987

b. Appointments

Full Professor of Electrical Engineering, University of Virginia,	7/08-present
Director, University of Virginia Microfabrication Laboratories	3/03-present
Associate Professor of Electrical Engineering, University of Virginia,	8/93-7/08
Assistant Professor of Electrical Engineering, University of Virginia,	7/87-8/93

c. Publications

1. "Integrated 585 GHz hot electron mixer focal-plane arrays based on annular slot antennas for imaging applications," L. Liu, H. Xu, A.W. Lichtenberger, and R.M. Weikle, II, *IEEE Trans. Microwave Theory and Tech.*, Special Issue on THz Technology: Bridging the Microwave-to-Photonics Gap, vol. 58, no. 7, pp. 1943–1951, July 2010.
2. L "A Broadband Quasi-Optical Terahertz Detector Utilizing a Zero Bias Schottky Diodes," L. Liu, J.L. Hesler, H. Xu, A.W. Lichtenberger, and R.M. Weikle, II, *IEEE Microwave and Wireless Components Letters.*, pp. 504-507, September 2010.
3. "The design, fabrication and test results of a 1.6 THz superconducting hot electron bolometer mixer, Jon Schultz, Delbert Herald, Haiyong Xu, Lei Liu, Arthur Lichtenberger, IEEE Transactions on Applied Superconductivity, Vol 19, Issue 3, pp. 297-300, June 2009.
4. "Development of Integrated Terahertz Broadband Detectors Utilizing Superconducting Hot-Electron Bolometers", L. Liu, H. Xu, R. Percy, D. Herald, J. Hesler, A. W. Lichtenberger, R. M. Weikle, IEEE Trans on Applied Superconductivity, Vol 19, Issue 3, pp. 282-286, June 2009.
5. Supercam: A 64 pixel heterodyne array receiver for the 350 GHz Atmospheric Window" C. Groppi, C. Walker, C. Kulesa, D. Golish, J. Kloosterman, S. Weinreb, G. Jones, J. Barden, H. Mandi, T. Kuiper, J. Kooi, A. Lichtenberger, T. Cecil, G. Narayanan, P. Pütz, A. Hedden, International Symposium On Space THz Technology, August 2009.
6. *"A 585 GHz Annular-Slot Antenna Coupled Two-Dimensional Focal-Plane Array Utilizing Twin-HEB Devices",* L. Liu, R. Percy, H. Xu, G. Wu, A. W. Lichtenberger, and R. M. Weikle, II, Infrared, Millimeter and Terahertz Waves, 15-19 Sept. 2008
7. *"A Nb-Based 180-Degree IF Hybrid for Balanced SIS Mixers,"* Christine M. Lyons, Arthur W. Lichtenberger, Anthony R. Kerr, Eugene F. Lauria, and Lucy M. Ziurys, IEEE Transactions on Applied Superconductivity, Vol 17 (2) 1, 194-197, June 2007.
8. "Investigation of novel superconducting hot electron bolometer geometries fabricated with UV lithograph", J. C. Schultz, R. M. Weikle II, A.W. Lichtenberger, IEEE Transactions on Applied Superconductivity 2007.

d. Synergistic Activities

Infrastructure of Radio Astronomy: Have collaborated with a number of astronomical receiver groups for the past 20 years to develop state of the art millimeter and submm wavelength receivers for use on radio telescopes throughout the world.

2 Biographical Sketch

Curriculum Vitæ
Christopher L. Martin

Education

1994–1999	Ph.D. in Physics University of California Santa Barbara, CA Thesis Advisors: Robert L. Sugar & Douglas Scalapino

Professional Experience

2010–	Assoc. Professor, Oberlin College
2008–	Co-Investigator, NASA Stratospheric TeraHertz Observatory, involved in observation planning, scheduling, and reduction. (NASA Grant NNX08AG51G)
2007–	Principal Investigator, Herschel Space Observatory Open Time Key Project: HIGGS (Herschel Inner Galaxy Gas Survey), coordinating all aspects including the data reduction pipeline for the group. (JPL RSA #1413648)
2004–2010	Asst. Professor, Oberlin College

Honors

2001	NSF Antarctica Service Medal with Gold Winterover Bar

Publications

F. Yusef-Zadeh, H. Bushouse, M. Wardle, C. Heinke, D. A. Roberts, C. D. Dowell, A. Brunthaler, M. J. Reid, C. L. Martin, D. P. Marrone, D. Porquet, N. Grosso, K. Dodds-Eden, G. C. Bower, H. Wiesemeyer, A. Miyazaki, S. Pal, S. Gillessen, A. Goldwurm, G. Trap, and H. Maness, "Simultaneous Multi-Wavelength Observations of Sgr A* During 2007 April 1-11," ApJ**706**, 348 (2009).

S. M. Burrows, C. L. Martin, and E. A. Roberts, "High-latitude remote sensing of mesospheric wind speeds and carbon monoxide," J. Geophys. Res. — Atmospheres **112**, D17109, doi:10.1029/2006JD007993 (2007).

A. A. Stark, C. L. Martin, W. M. Walsh, K. Xiao, A. P. Lane, and C. K. Walker, "Gas Density, Stability, and Starbursts near the Inner Lindblad Resonance of the Milky Way," ApJL**614**, L41 (2004).

C. L. Martin, W. M. Walsh, K. Xiao, A. P. Lane, C. K. Walker, and A. A. Stark, "The AST/RO Survey of the Galactic Center Region. I. The Inner 3 Degrees," Astrophysical Journal, Supplement **150**, 239 (2004).

C. E. Groppi, C. Kulesa, C. Walker, and C. L. Martin, "Millimeter and Submillimeter Survey of the R Coronae Australis Region," ApJ**612**, 946 (2004).

GARY JOEL MELNICK

Harvard-Smithsonian Center for Astrophysics — Citizenship: U.S.
60 Garden Street
Cambridge, MA 02138
(617) 495-7388

Educational Background:

Ph.D., Astronomy, Cornell University, 1980.
M.S., Astronomy, Cornell University, 1979.
B.A., Physics, Cornell University, 1974.

Professional Employment:

Senior Astronomer, Smithsonian Astrophysical Observatory, 1995 – present.
Astronomer, Smithsonian Astrophysical Observatory, 1980 – 1995.
Lecturer, Harvard University Department of Astronomy, 1980 – present.
Postdoctoral Research Associate, Cornell University, 1980.
Research Fellow, IBM Thomas J. Watson Research Center, 1976.

Relevant Space Astronomy Experience:

Principal Investigator, Submillimeter Wave Astronomy Satellite (SWAS).
Deputy Principal Investigator, Infrared Array Camera (IRAC)/Spitzer Space Observatory.
Co-Investigator, Herschel Space Observatory Heterodyne Instrument for the Far-Infrared (HIFI).
Co-Investigator, Infrared Telescope/Spacelab II.
Principal Investigator, Cosmic Inflation Probe (CIP), a NASA Astrophysics Strategic Mission Concept Study.
Deputy-Principal Investigator, Extrasolar Planetary Imaging Coronagraph (EPIC), a NASA Astrophysics Strategic Mission Concept Study.

Honors and Awards:

NASA Group Achievement Award, 2004.
Smithsonian Institution Award for Superior Performance, 1999.
Goddard Space Flight Center Group Achievement Award, 1999.
Smithsonian Institution Award for Superior Accomplishment, 1996
Smithsonian Institution Award for Superior Performance, 1990.
Smithsonian Institution Award for Exceptional Service, 1987.
National Aeronautics and Space Administration Public Service Group Achievement Award, 1987.
Smithsonian Institution Award for Exceptional Service, 1986.

Recent Membership on National and International Committees:

NASA Goddard Space Flight Center, Exploration Directorate Visiting Committee, 2001 – 2006, (*Chair*), 2005 – 2006.
NASA Herschel/HIFI Review Board (*Chair*), 2001.
NASA Herschel Science Center Review Committee (*Chair*), 2000 – 2007.
Review Committee for Herschel & Planck Missions, September 2001.
Review Committee for HIFI Band 6 Instrument for Herschel (*Chair*), December 2001.
Terrestrial Planet Finder, Science Working Group, 2002 – 2005.
Stratospheric Observatory for Infrared Astronomy (SOFIA), Independent Review Team, 2003 – 2004.
NASA Independent Cost, Schedule, and Management Review for SOFIA, 2004.
NASA Independent Science Operations Review for SOFIA, 2004.
NASA Space Infrared Interferometric Telescope Review Panel (*Chair*), 2004.
The National Academies Space Studies Board – Committee on PI-Led Missions in Space, 2004 – 2006.
NASA Interdisciplinary Exploration Science Review Panel (*Chair*), 2005.
Scientific Organizing Committee for the “Advances in Far-Infrared and Submillimeter Astrophysics” session of the Beijing, China, COSPAR meeting, 16-23 July 2006.
SOFIA Science, Management and Operations Review (*Chair*), 2006 – 2008.
NASA/NSF Exoplanet Task Force, 2007 – 2008.
Spitzer Cryogenic Mission Closeout Review Board, 2008.
NASA Stratospheric Observatory for Infrared Astronomy (SOFIA) Blue Ribbon Science Review Panel, 2008 – 2009.
NASA/DOE Joint Dark Energy Mission Science Coordination Group, 2008 – 2009.
SOFIA Science Council, 2008 – present.
Spitzer Science Center Oversight Committee, 2010 – present.

Curriculum Vitae

MARK R. MORRIS, Professor of Astronomy, UCLA

Address: Division of Astronomy, Department of Physics & Astronomy
Box 951547, UCLA, Los Angeles, CA 90095-1547

Education:

Ph.D., Department of Physics, University of Chicago, 1975
B.A., Department of Physics, Univ. of California, Riverside (*magna cum laude*, ΦBK)

Positions Held:

7/85 to present: Professor, Dept. of Astronomy and Dept. of Physics & Astronomy, UCLA
9/98 to 1/99: CNRS Chercheur Associé, Institut d'Astrophysique de Paris
7/96 to 8/96: Professeur Associé, Univ. Paris 6 (Institut d'Astrophysique, Paris)
11/94 to 6/95 and 10/06 to present: Vice-Chair, Division of Astronomy & Astrophysics, Dept. of Physics and Astronomy, UCLA
7/92 to 10/94: Chairman, Department of Astronomy, UCLA
7-8/92, 7/93: Visiting Scientist, Service D'Astrophysique, CEA Saclay, France
9/90 to 7/91: Chaire Municipale, Université Joseph Fourier, Grenoble, France
1/83 to 6/85: Associate Professor, Department of Astronomy, UCLA
9/81 to 1/82, 7/84, and 7/93: Professeur Associé, Groupe d'Astrophysique, Université Joseph Fourier, Grenoble, France
6/80 to 7/80: Visiting Scientist, Observatoire de Paris, Meudon, France
7/77 to 12/82: Assistant Professor, Dept. of Astronomy, Columbia University, NY
10/74 to 6/77: Research Fellow, Owens Valley Radio Observatory, Caltech

Professional Organizations:

American Astronomical Society, International Astronomical Union

Current Research Areas

- The Galactic center – stellar populations & dynamics, star formation, magnetic fields, chemistry, gas dynamics
- Mass loss from AGB stars & preplanetary nebulae
- Protoplanetary disks
- Techniques employed: radio, millimeter, IR, & X-ray observations. Computational modeling.

Publications

- 223 total publications in refereed journals – 114 on the Galactic center, 4 major review articles, editor of 3 conference proceedings books, 139 other non-abstract publications. h-index: 64
- relevant recent publications:

"HST/NICMOS Paschen-α Survey of the Galactic Centre: Overview," Q.D. Wang, H. Dong, A. Cotera, S. Stolovy, M. Morris, C.C. Lang, M.P. Muno, G. Schneider & D. Calzetti, *MNRAS*, **402**, 895-902 (2010) arXiv:0911.2226

The Galactic Center: A Window to the Nuclear Environment of Disk Galaxies, M.R. Morris, Q.D. Wang and F. Yuan, ASP Conf. Ser. **439**, 494 pages (2011).

CURRICULUM VITAE

David A. Neufeld

Current position:

1997 – present	Professor, Department of Physics & Astronomy, The Johns Hopkins University

Education:

1987:	Ph.D. (Astronomy), Harvard University
1983:	M.Sc. (Astronomy), Sussex University
1981:	B.A. (Natural Sciences), Cambridge University

Research interests:

Molecular astrophysics; astrochemistry; submillimeter and far-infrared astronomy; astrophysical masers; interstellar medium

- Co-I on Submillimeter Wave Astronomy Satellite (SWAS, past NASA SMEX Mission)
- Astronomy Co-I on HIFI (Herschel Space Observatory instrument)
- Co-I on Submillimeter Terahertz Observatory (balloon-borne telescope)
- PI on multiple Spitzer and Herschel programs
- Co-I on SOFIA short science program (GREAT)
- PI on SOFIA basic science program ("Searching for interstellar mercapto radicals with SOFIA")

Selected recent publications

"Spitzer Observations of HH 54 and HH 7-11: Mapping the H_2 Ortho-to-Para Ratio in Shocked Molecular Gas," Neufeld, D. A., Melnick, G. J., Sonnentrucker, P., Bergin, E. A., Green, J. D., Kim, K. H., Watson, D. M., Forrest, W. J., Pipher, J. L., ApJ, 649, 816 (2006)

Spitzer Spectral Line Mapping of Protostellar Outflows. I. Basic Data and Outflow Energetics. Neufeld, D. A., Nisini, B., Giannini, T., Melnick, G. J., Bergin, E. A., Yuan, Y., Maret, S., Tolls, V., Gusten, R., Kaufman, M. J., ApJ, 706, 170 (2009)

"The Chemistry of Interstellar Molecules Containing the Halogen Elements," Neufeld, D. A., and Wolfire, M. G. ApJ, 706, 1594 (2009)

"Strong absorption by interstellar hydrogen fluoride: PRISMAS observations of the sight-line to G10.6–0.4 (W31C)" Neufeld, D. A., et al., A&A, 518, L108 (2010)

"Herschel/HIFI observations of interstellar OH^+ and H_2O^+ towards W49: a probe of diffuse clouds with a small molecular fraction." Neufeld, D. A., et al., A&A, 521, L10 (2010)

Biographical Sketches of the co-Investigator Qing Hu

Education and Professional Preparation:

Harvard University	Physics	M.A.	1983
Harvard University	Physics	PhD.	1987
University of California at Berkeley	Physics	Postdoc	1987-1989

Appointments:

1/1990 - 6/1995	Assistant Professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology
7/1995 - 6/2002	Associate Professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology
7/2002 - Present	Full Professor, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology

Selected Publications, invited talks, and patents:

- B. S. Williams, H. Callebaut, S. Kumar, **Q. Hu**, and J. L. Reno, "3.4-THz quantum cascade laser based on LO-phonon scattering for depopulation," Appl. Phys, Lett. **82**, 1015 (2003).
- J. R. Gao, J. N. Hovenier, Z. Q. Yang, J. J. A. Baselmans, A. Baryshev, M. Majenius, T. M. Klapwijk, A. J. L. Adam, T. O. Klassen, B. S. Williams, S. Kumar, **Q. Hu**, and J. L. Reno, "A terahertz heterodyne receiver based on a quantum cascade laser and a superconducting bolometer," Appl. Phys. lett. **86**, 244104 (2005).
- A. L. Betz, R. T. Boreiko, B. S. Williams, S. Kumar, **Q. Hu**, and J. L. Reno, "Frequency and Phaselock Control of a 3-THz Quantum Cascade Laser," Opt. Lett. **30**, 1837 (2005).
- B. S. Williams, S. Kumar, **Q. Hu**, and J. L. Reno, "Operation of terahertz quantum-cascade lasers at 164 K in pulsed mode and at 117 K in continuous-wave mode," Optics Express, **13**, 3331-3339 (2005).
- S. Kumar, **Q. Hu**, and J. L. Reno, "186 K operation of THz quantum cascade lasers based on a diagonal design," Appl. Phys. Lett. **94**, 131105 (2009).
- T. Y. Kao, Q. Hu, and J. L. Reno, "Phase-Locked Arrays of Surface-Emitting Terahertz Quantum-Cascade Lasers," Appl. Phys. Lett. **96**, 101106 (2010).

Synergistic Activities:

- Member, International Organizing Committee, IRMMW/THz Conferences, 6/2005-present
- Member, International steering committee on 17th International Symposium on Space Terahertz Technology, 5/2005-5/2006
- Workshop Co-Chair, *2nd International Workshop on Quantum Cascade Lasers*, 2006 (http://www.rle.mit.edu/2006qcl/)
- Associate Editor, *Applied Physics Letters*, 6/2006-present

Honors and Professional Memberships:

Fellow, American Association for the Advancement of Science (AAAS)
Fellow, American Physical Society (APS)
Fellow, Institute of Electrical and Electronic Engineering (IEEE)
Fellow, Optical Society of America (OSA)

JOHN L. RENO

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Education

Ph.D. Physics University of Illinois at Chicago, 1987
M.S. Physics University of Illinois at Chicago, 1984
M.S. Applied Mathematics Northern Illinois University, 1982
B.S. Physics & Mathematics Wheaton College, 1978

Appointments

Principal Member of Technical Staff, Sandia National Laboratories, 2005 – Present
Instructor, Central New Mexico University, 2001 – Present
Senior Member of Technical Staff, Sandia National Laboratories, 1987 - 2005
Research Associate, University of Illinois at Chicago, January 1987 – July 1987

Selected Recent Publications (from over 250 refereed publications)

1. *A terahertz plasmon cavity detector*, Dyer, G. C., Vinh, N. Q., Allen, S. J., Aizin, G. R., Mikalopas, J., Reno, J. L., Shaner, E. A., Applied Physics Letters **97**, 193507 (2010).
2. *MEMS-based tunable terahertz wire-laser over 330 GHz*, Qin, Q., Reno, J. L., Hu, Q., Optics Letters **36**, 692, 2011
3. *High-resolution heterodyne spectroscopy using a tunable quantum cascade laser around 3.5 THz,* Ren, Y., Hovenier, J.N., Higgins, R., Gao, J.R., Klapwijk, T.M., Shi, S.C., Klein, B., Kao, T-Y., Hu, Q., Reno, J. L., Applied Physics Letters **98**, 231109, 2011
4. *Monolithically Integrated Solid-state Terahertz Transceivers*, Wanke, M. C., E. W. Young, C. D. Nordquist, M. J. Cich, A. D. Grine, C. T. Fuller, J. L. Reno, M. Lee, Nature Photonics,**4**, (8) 565, Aug 2010.
5. *Tunable terahertz quantum cascade lasers based on external-cavity gratings*, Lee, A. W. M., B. Williams, S. Kumar, Q. Hu, J. L. Reno, Optics Letters, **35**, (7) 910, April 1, 2010
6. *A 1:8 THz quantum-cascade laser operating up to 163 K; significantly breaking the* $\hbar\omega/k_B$ *temperature barrier*, Kumar, S., C. W. I. Chan, Q. Hu, J. L. Reno, Nature Physics,**7**, 166, February 2011
7. *Probing the microscopic structure of bound states in quantum point contacts*, Yoon, Y; Mourokh, L; Morimoto, T; Aoki, N; Ochiai, Y; Reno, JL; Bird, JP, Physical Review Letters, 99, September 28, 2009.
8. *Hot-Electron Thermocouple and the Diffusion Thermopower of Two-Dimensional Electrons in GaAs*, Chickering, WE; Eisenstein, JP; Reno, JL, Physical Review Letters, 103, July 24, 2009.
9. *Observation of Chiral Heat Transport in the Quantum Hall Regime*, Granger, G; Eisenstein, JP; Reno, JL, Physical Review Letters, 102, February 27, 2009.
10. *Magnetic-field-assisted terahertz quantum cascade laser operating up to 225 K*, Wade, A; Fedorov, G; Smirnov, D; Kumar, S; Williams, BS; Hu, Q; Reno, JL, Nature Photonics, 3, January 2009.
11. *Terahertz response of quantum point contacts*, Song, JW; Kabir, NA; Kawano, Y; Ishibashi, K; Aizin, GR; Mourokh, L; Reno, JL; Markelz, AG; Bird, JP, Applied Physics Letters, 92, June 2, 2008.
12. *Terahertz time-domain magnetospectroscopy of a high-mobility two-dimensional electron gas*, Wang, XF; Hilton, DJ; Ren, L; Mittleman, DM; Kono, J; Reno, JL, Optics Letters, 332, July 1, 2007.
13. *Surface-emitting distributed feedback terahertz quantum-cascade lasers in metal-metal waveguides*, Kumar, S; Williams, BS; Qin, Q; Lee, AWM; Hu, Q; Reno, JL, Optics Express, 15, January 8, 2007.
14. *Two-dimensional metal-insulator transition as a percolation transition in a high-mobility electron system*, S. Das Sarma, M.P. Lilly, E.H. Hwang, L.N. Pfeiffer, K.W. West, J.L. Reno, Physical Review Letters, 94, (2005).

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Education:

1975 B.S. with Honors, Physics and Astronomy, California Institute of Technology

1977 M.A., Astrophysical Sciences, Princeton University

1979 Ph.D., Astrophysical Sciences, Princeton University

Professional history:

1991— Astronomer, Harvard-Smithsonian Center for Astrophysics

2002— Co-Investigator, South Pole Telescope

1989—2007 Principal Investigator, Antarctic Submillimeter Telescope and Remote Observatory

1980—1992 Visiting Lecturer, Department of Astrophysical Sciences, Princeton University

1979—1991 Member of Technical Staff, Radio Physics Research Department, Bell Laboratories, Holmdel, NJ

1976 Physicist, Lawrence Livermore National Laboratory

1975 Summer Student, Lawrence Livermore National Laboratory

1974—1975 Programmer, Space Radiation Laboratory, Caltech

1973 Observing Assistant, Owens Valley Radio Observatory, Big Pine, CA

1972—1973 Research Assistant, Kellogg Radiation Laboratory, Caltech

Stark, A. A., Bally, J., Balm, S. P., Bania, T. M., Bolatto, A. D., Chamberlin, R. A., Engargiola, G., Huang, M., Ingalls, J. G., Jacobs, K., Jackson, J. M., Kooi, J. W., Lane, A. P., Lo, K.-Y., Marks, R. D., Martin, C. L., Mumma, D., Ojha, R., Schieder, R., Staguhn, J., Stutzki, J., Walker, C. K., Wilson, R. W., Wright, G. A., Zhang, X., Zimmermann, P., and Zimmermann, R. 2001, "The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO)", PASP, 113, 567.

Stark, A. A., Chamberlin, R. A., Cheng, J., Ingalls, J. G., and Wright, G. A. 1997, "The Optical and Mechanical Design of the Antarctic Submillimeter Telescope and Remote Observatory", Rev. Sci. Instr., 68, 2200.

Martin, C. L., Walsh, W. M., Xiao, K., Lane, A. P., Walker, C. K., and Stark, A. A. 2004 "The AST/RO Survey of the Galactic Center Region. I. The Inner 3 Degrees", ApJS, 150, 239.

Stark, A. A. & Lee, Y. 2005 "The Scale Height of Giant Molecular Clouds is Less than That of Smaller Clouds", ApJ, 619L, 159.

Bally, J., Stark, A. A., Wilson, R. W., and Henkel, C. 1988, "Galactic Center Molecular Clouds. II. Distribution and Kinematics", ApJ, 324, 223.

CURRICULUM VITAE OF A.G.G.M. TIELENS

Personal: Born: Nov 3, 1953, Maastricht, the Netherlands.

Education: 1982 University of Leiden, Ph.D. in Natural Sciences.

Professional History: 2008-present, professor of astrophysics, Leiden Observatory, Leiden University 2005-2008, Senior scientist NASA Ames Research Center. 2004–2005, Professor of astrophysics, University of Groningen. 1997–february 2004 Professor of astrophysics, University of Groningen & Senior scientist, Dutch Space Organization, SRON. 1989–97, Senior scientist NASA Ames Research Center. 1984–88, Research Associate, University of California, Berkeley. 1984–87, National Research Council Associate.

Awards: H. Julian Allen Award for the best technical or scientific paper in 1986 and 1992 at NASA Ames Research Center. Dutch astronomy Award "Pastoor Schmeits Prijs". Visiting Miller Research Professor, University of California, Berkeley, October 2002–February 2003. Original member of the Highly Cited researchers list for space sciences compiled by the Institute for Scientific Information ISI/Thomson Science. Honorary professor University of Groningen 2009 Advanced ERC grant from the European Union 2010 Jubilee professor Chalmers Technical University

Projects: 1998-present, project scientist of HIFI the heterodyne instrument on Herschel, ESA's far-infrared satellite launched in 2009. 2004-2008, coordinator of "The Molecular Universe"; a consortium of 21 European research groups in physics, chemistry, and astronomy funded by the Marie Curie Research and Training Network under the European Commision Framework Program #6. 2005-2007, Project Scientist, NASA's Stratospheric Observatory For Infrared Astronomy, SOFIA. 2010-present, Coordinator of the Dutch Astrochemical Network.

Relevant Publication:

- The physics and Chemistry of the Interstellar Medium, Tielens, A.G.G.M., 2005, University of Cambridge Press (2nd printing 2006)
- Photodissociation regions in the interstellar medium of galaxies, D.J. Hollenbach, A.G.G.M. Tielens, 1999, Rev Mod Phys, 71, 173
- Dense Photodissociation Regions (PDRs), D.J. Hollenbach and A.G.G.M. Tielens, 1997, Annu, Rev Astron Ap, 35, 179.
- Photodissociation Regions: I. Basic Model; A.G.G.M. Tielens and D. Hollenbach, 1985, Ap.J., 291, 722.
- Photodissociation Regions: II. A Model for the Orion Photodissociation Region; A.G.G.M. Tielens and D. Hollenbach, 1985, Ap.J., 291, 747.

CV - Sander Weinreb

Present Position

Principal Staff Member, Section 382 Caltech Jet Propulsion Laboratory and Faculty Associate, Caltech Electrical Engineering Department. (1999-present).

Education

Ph.D., Electrical Engineering, M.I.T., 1963. Thesis: "A Digital Spectral Analysis Technique and Its Application to Radio Astronomy"
B.S. , Electrical Engineering, M.I.T., 1958

Summary of Major Technical Accomplishments

1. Developed coarse-quantization, digital correlation techniques that have been widely used in radio astronomy systems for past 30 years.
2. Co-discoverer of the first radio molecular line, OH, observed in radio astronomy (1963)
3. Introduced cooled field-effect transistor and HEMT amplifiers to radio astronomy.(1980)
4. Led the electronics design of the Very Large Array.

Experience

Caltech (1999-Present) - Principal Staff JPL and Faculty Associate Caltech. DSN array development at JPL and research low noise amplifiers at Caltech.

U. of Massachusetts (1996-1998) - Research Professor in the Five College Radio Observatory, Department of Physics and Astronomy.

Lockheed Martin Laboratories (1989-1995): Principal Scientist and Leader of the Millimeter-Wave Design and Test Group. Provided expertise in the areas of millimeter-wave system and component design. He designed or led the design of a radar seeker, a prototype IFF system, two phased-array receiver systems, a radiometric focal plane array system, several high sensitivity radiometer modules, a W-band power amplifier module, and MMIC amplifiers, mixers, multipliers, phase-shifters, detectors, and switches.

U. of Virginia (1988-1989) and U. of California (1976-1978): Taught courses in microwave theory and techniques as a visiting professor.

National Radio Astronomy Observatory (1965-1988): Head of the Electronics Division (1965-1985) and Assistant Director (1985-1988). Led a team of 30 to 70 engineers and technicians and was responsible for the design, construction, operation, and maintenance of radio astronomy receivers at the Green Bank, WV, and Kitt Peak, AZ observatories. Led the design of the $17M electronics system of the Very Large Array, Socorro, NM, on schedule and in-budget. He led the addition of 8.4 GHz cooled HEMT receivers to of the VLA to augment the DSN and receive images from the NASA Voyager Neptune encounter mission; this was successfully accomplished within budget.

Publications

Over 110 publications in the areas of digital correlation techniques, array receivers, low-noise amplifiers, and millimeter-wave receivers. Key publications are:

1. S. Weinreb, "A New Upper Limit to the Galactic Deuterium-to-Hydrogen Ratio," Nature, 195, 367, 1962.
2. S. Weinreb, A. H. Barrett, M. L. Meeks, and J. C. Henry, "Radio Observations of OH in the Interstellar Medium," Nature, 200, 829-831, 1963.
3. S. Weinreb and A. R. Kerr, "Cryogenic Cooling of Mixers for Millimeter and Centimeter Wavelengths," IEEE J. of Solid-State Circuits, vol. SC-8, Feb. 1973.
4. S. Weinreb, R. Predmore, M. Ogai and A. Parrish, "Waveguide System for a Very Large Antenna Array," Microwave Journal, vol. 20, no. 3, March 1977.
5. S. Weinreb, M. Balister, S. Maas, and P. J. Napier, "Multi-Band, Low-Noise Receivers for a Very Large Array," IEEE Trans.MTT, vol. MTT-25, no. 4, April 1977.
6. S. Weinreb, "Low-Noise Cooled GASFET Amplifiers," IEEE Microwave Theory and Techniques, vol. 28, no. 10, October 1980, pp. 1041-1054.
7. S. Weinreb, M. Pospieszalski, and R. Norrod, "Cryogenic, HEMT, Low-Noise Receivers for the 1.3 to 43 GHz Range", S. Weinreb, M. Pospieszalski, and R. Norrod, IEEE 1988 MTT-S Digest

National and International Activities

Visiting Committee, National Radio Astronomy Observatory, Charlottesville, VA, 2001-2004

Life Fellow of the IEEE (1978) - Elected for "Contributions to Instrumentation in Radio Astronomy

U. S. Delegate to the Soviet Space Research Institute Radioastron Technical Committee, 1986-1987

U.S. Delegate to International Radio Science (URSI) meetings - 1966, 1969, 1972, 1978, and 1995.

Member of Advisory Committee - NASA Search for Extraterrestrial Life Program - Moffett Field, CA, 1991-97.

National Lecturer, 1984, IEEE Microwave Theory and Techniques Society (35 lectures in U.S., Canada, Australia, and New Zealand)

Member of Visiting Committee - Nat. Astronomy & Ionospheric Center (Arecibo),1970-72; Chairman, 1972

Member of Visiting Committee - Netherlands Foundation for Radio Astronomy - 1971 - 1974

Review Papers for IEEE Transactions on Microwave Theory and Techniques and Proposals for NSF

Nominated to Army Science Board, 1991 (Nomination by Assistant Secretary of the Army)

Reber Prize (2008) Medal for Lifetime Contributions to Radio Astronomy Instrumentation.

SUMMARY OF PROPOSED PROGRAM COOPERATIVE AGREEMENT

Appendix 4 Summary of Proposed Program Cooperative Contributions

The OCAM project does not include any cooperative contributions.

DRAFT INTERNATIONAL PARTICIPATION PLAN

Appendix 5 Draft International Participation Plan - Discussion on Compliance with U.S. Export Laws and Regulations

The Arms Export Control Act (AECA), 22 U.S.C. 2778 governs the export of defense articles and services. The International Traffic in Arms Regulations (ITAR), 22 CFR 120-130 is issued and regulated pursuant to AECA by the U.S. Department of State (Directorate of Defense Trade Controls – DDTC) in conjunction with the U.S. Department of Defense. The ITAR lists all technology controlled through the U.S. Munitions List (USML).

A review of the OCAM proposal has determined that the project does not include defense services or defense articles pursuant to the Arms Export Control Act (22 U.S.C. 2778 and 2794(7) since the services and articles are not listed in the USML.

Exports of technical data or articles is regulated by the Export Administration Regulations (EAR) of the U.S. Department of Commerce.

Export Control Compliance at The University of Arizona is the responsibility of the Vice President for Research, the Principal Investigator of Sponsored Research and all University employees working on Sponsored Research. Ms Kay Ellis, (520) 626-2437 Email: ellisk@email.arizona.edu, is the University Export Control Officer.

The OCAM project will adhere to the processes below throughout the project to establish compliance with the export laws of the United States:

Publication Restrictions

a) Need Waiver of Publication Rights

b) Export Checklist for Principal Investigators

c) Technology Control Plan, if export-controlled

d) Export License, if export-controlled and foreign involvement

Restrictions on Participation of Foreign Nationals

a) Need Export Checklist for Principal Investigators

b) Technology Control Plan, if export-controlled

c) Export License, if export-controlled and foreign involvement

Export Control Clauses

a) Need Export Checklist for Principal Investigators

b) Technology Control Plan, if export-controlled

c) Export License, if export-controlled and foreign involvement

International deliverables (physical exports or meetings)

a) Need Export Checklist for Principal Investigators

b) Export License, if export-controlled

Exports of technical data by all U.S. parties are treated as a permanent export. Hardware in furtherance of a technical assistance agreement will be a temporary export and a permanent import, if required.

The parties to OCAM are as follows:

U.S. Parties

1. NASA

2. University of Arizona
3. Massachusetts Institute of Technology
4. California Institute of Technology

Foreign Parties

1. SRON (the Netherlands)
2. Omnisys (Sweden)

The roles of the parties to OCAM are as follows:

1. NASA
   Organization/Management Role: NASA is the funding agency for the Explorer Mission of Opportunity, Small Standalone Missions.

   Technical Role: N/A

   Integration Role: N/A

2. UNIVERSITY OF ARIZONA (UA)
   Organization/Management Role: UA will provide the Principal Investigator and perform all aspects of Contract Management.

   Technical Role: Overall technical management and science team leadership, Telescope and detector development.

   Integration Role: Telescope and detector integration and test; system integration and test; flight operations.

3. MIT
   Organization/Management Role: Manage detector element development.

   Technical Role: Detector element development, fabrication and test.

   Integration Role: N/A

4. California Institute of Technology
   Organization/Management Role: Manage detector element development.

   Technical Role: Detector element development, fabrication and test.

   Integration Role: N/A

5. SRON (Netherlands)
   Organization/Management Role: Manage detector element development.

   Technical Role: Detector element fabrication and test.

   Integration Role: N/A

6. Omnisys (Sweden)
   Organization/Management Role: Manage spectrometer development.

   Technical Role: Spectrometer fabrication and test.

   Integration Role: N/A

The two non-US persons (SRON and Omnisys) are providing hardware developed to specification and do not participate in the development of the overall instrument.

DRAFT OUTLINE OF TECHNICAL RESPONSIBILITIES FOR INTERNATIONAL PARTICIPATION

Appendix 6 Draft Outline of Assignment of Technical Responsibilities between U.S. and International Partners

Table A6-1 shows the roles and responsibilities on the OCAM project as described in this proposal. The Netherlands Institute for Space Research (SRON) has agreed to provide the OCAM HEB Mixer and THz LO technology to realize a 4.7THz array receiver to the OCAM project on a contract basis..

Table A6-1. *Roles and responsibilities.*

Organization	Management Role	Technical Role	Integration Role	Flight Role
University of Arizona PI organization	Overall OCAM management	Payload development	Payload integration	Flight operations Data processing and science analysis
SRON/TU Delft	Detector element development	Deliver the OCAM HEB Mixer devices and provide expertise in QCL frequency locking technology to realize a 4.7THz array receiver to the UA.	Technical consult as needed.	Technical/Science consult as needed.

Responsibilities of SRON/TU Delft.

SRON will use reasonable efforts to carry out the following responsibilities:
Deliver the OCAM HEB Mixer devices and provide expertise in QCL frequency locking technology to realize a 4.7THz array receiver to the UA.

Financial Arrangements. The University of Arizona will purchase the 4.7THz mixer devices from SRON on a contract basis. The UA will provide a specification to SRON for this purpose.

Data Rights. The Parties shall have access to and use of the scientific data generated under this Agreement. In accordance with NASA policy, the scientific data applicable to this Agreement will be treated as a public resource and will be made available for public access as soon as is practical. This contract requirement to release data includes both raw and processed data and ancillary data needed to calibrate and understand the science data.

Exchange of Technical Data and Goods. The Parties are obligated to transfer only those technical data and goods necessary to fulfill their respective responsibilities under this Agreement in compliance with all U.S. government export regulations.

All activities of the Parties will be carried out in accordance with their national laws and regulations, including those pertaining to export control and the control of classified information.

The transfer of technical data for the purpose of discharging the Parties' responsibilities with regard to interface, integration, and safety shall normally be made without restriction.

All transfers of goods and proprietary or export-controlled technical data are subject to the following provisions. In the event a Party or its related entity (e.g., contractor, subcontractor, investigators, grant recipient, cooperating entity) finds it necessary to transfer goods or to transfer proprietary or export-controlled technical data, for which protection is to be maintained, such goods shall be specifically identified and such proprietary or export-controlled technical data shall be marked. The identification for goods and the marking on proprietary or export- controlled technical data will indicate that the goods and proprietary or export-controlled technical data shall be used by the receiving Party or related entities only for the purposes of fulfilling the receiving Party's or related entity's responsibilities under this Agreement, and that the identified goods and marked proprietary technical data or marked export-controlled technical data shall not be disclosed or retransferred to any other entity without the prior written permission of the furnishing Party or its related entity. The receiving Party or related entity shall abide by the terms of the notice and protect any such identified goods and marked proprietary technical data or marked export-controlled technical data from unauthorized use and disclosure. The Parties to this Agreement will cause their related entities to be bound by the provisions of this Article related to use, disclosure, and retransfer of goods and marked technical data through contractual mechanisms or equivalent measures.

All goods exchanged in the performance of this Agreement shall be used by the receiving Party or related entity exclusively for the purposes of the Agreement. Upon completion of the activities under this Agreement, the receiving Party or related entity shall return or, at the request of the furnishing Party or its related entity, otherwise dispose of all goods and marked proprietary technical data or marked export-controlled technical data provided under this Agreement, as directed by the furnishing Party or related entity.

For the purposes of this Article, "Related Entity" includes but is not limited to contractors, subcontractors, grantees, or cooperating entities (or any lower tier contractor, subcontractor, grantee, or cooperating entities) of a Party.

PATENTS Nothing in this Agreement shall be construed as granting, either expressly or by implication, to the other Party any rights to, or interest in, any inventions of a Party or its Related Entities made prior to the entry into force of, or outside the scope of, this Agreement, including any patents or other forms of protection (in any country) corresponding to such inventions. Any rights to, or interest in, any invention made in the performance of this Agreement solely by one Party or any of its Related Entities, including any patents or other forms of protection (in any country) corresponding to such invention, shall be owned by such Party or, subject to paragraph 2.D of this Article, such Related Entity. It is not anticipated that there will be any joint inventions made in the performance of this Agreement. Nevertheless, in the event that an invention is jointly made by the Parties in the performance of this Agreement, the Parties shall, in good faith, consult and agree as to: a) the allocation of rights to, or interest in, such joint invention, including any patents or other forms of protection (in any country) corresponding to such joint invention; b) the responsibilities, costs, and actions to be taken to establish and maintain patents or other forms of protection (in any country) for each such joint invention; and c) the terms and conditions of any license or other rights to be exchanged between the Parties or granted by one Party to the other Party. With respect to any invention created in the performance of this Agreement and involving a Related Entity, allocation of rights between a Party and its Related Entity to such invention, including any patents or other forms of protection (in any country) corresponding to such invention, shall be determined by such Party's laws, regulations, and applicable contractual obligations.

COPYRIGHTS Nothing in this Agreement shall be construed as granting, either expressly or by implication, to the other Party any rights to, or interest in, any copyrights of a Party or its Related Entities created prior to the entry into force of, or outside the scope of, this Agreement. Any copyrights in works created solely by one Party or any of its Related Entities, as a result of activities undertaken in performance of this Agreement, shall be owned by such Party or Related Entity. Allocation of rights between such Party and its Related Entities to such copyrights shall be determined by such Party's laws, regulations, and applicable contractual obligations.

For any jointly authored work, should the Parties decide to register the copyright in such work, they shall, in good faith, consult and agree as to the responsibilities, costs, and actions to be taken to register copyrights and maintain copyright protection (in any country).

Subject to the provisions of the Articles entitled, "Exchange of Technical Data and Goods," and "Release of Results and Public Information," each Party shall have an irrevocable, royalty free right to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, and authorize others to do so on its behalf, any copyrighted work resulting from activities undertaken in the performance of this Agreement for its own purposes, regardless of whether the work was created solely by, or on behalf of, the other Party or jointly with the other Party, and without consulting with or accounting to the other Party.

Release of Results and Public Information. The Parties retain the right to release public information regarding their own activities under this Agreement. The Parties shall coordinate with each other in advance concerning releasing to the public information that relates to the other Party's responsibilities or performance under this Agreement. As appropriate, full acknowledgement shall be made by both Parties of the role of the other Party in the OCAM instrument.

The Parties shall make the final results obtained from the OCAM instrument available to the general scientific community through publication in appropriate journals or by presentations at scientific conferences as soon as possible and in a manner consistent with good scientific practices.

Each Party shall have an irrevocable, royalty free right to reproduce, prepare derivative works from, distribute to the public copies of, present publicly, and authorize others to do so on its behalf, the scientific information included in each such publication or presentation for its own purposes. The royalty free right shall exist irrespective of any copyright protection applicable to each such publication or presentation.

The Parties acknowledge that the following data or information does not constitute public information and that such data or information shall not be included in any publication or presentation by a Party under this article without the other Party's prior written permission: 1) data furnished by the other Party in accordance with the "Exchange of Technical Data and Goods" section of this Agreement which is export-controlled, classified or proprietary; or 2) information about an invention of the other Party before a patent application has been filed covering the same, or a decision not to file has been made.

Customs Clearance. In accordance with its laws and regulations, each Party shall facilitate free customs clearance and waiver of all applicable customs duties and taxes for equipment and related goods necessary for the implementation of this Agreement. In the event that any customs duties or taxes of any kind are nonetheless levied on such equipments and related goods, such customs duties or taxes shall be borne by the Party of the country levying such customs duties or taxes. The Parties' obligation to facilitate duty-free entry and exit of equipment and related goods is fully reciprocal. Each of the Parties shall facilitate the movement of the persons and goods necessary to comply with this Agreement into and out of its territory, subject of its laws and regulations.

Liability and Risk of Loss. With regard to activities undertaken pursuant to this Agreement, neither Party shall make any claim against the other, employees of the other, the other's related entities (e.g., contractors, subcontractors, investigators, or their contractors, subcontractors, or employees of the other's related entities), for any injury to, or death of its own employees or employees of its related entities or for damage to or loss of its own property or that of its related entities, whether such injury, death, damage or loss arises through negligence or otherwise.

The Parties further agree to extend this provision to their own related entities by requiring them, by contract or otherwise, to waive all claims against the other Party, related entities of the other party, and employees of the other party or of its related entities for injury, death, damage or loss arising from activities undertaken pursuant to this Agreement.

This cross-waiver of liability shall not be applicable to:

1. Claims between a Party and its own related entity or between its own related entities

2. Claims made by a natural person, hislher estate, survivors or subrogates for bodily injury, other impairment of health, or death of such natural person

3. Claims for damage caused by willful misconduct

4. Intellectual property claims

5. Claims for damage based upon a failure of the Parties to extend the provision as set forth above or from a failure of the Parties to ensure that their related entities extend the provision as set forth above

6. Contract claims between the Parties based on express contractual provisions

For avoidance of doubt, this cross-waiver of liability includes a cross-waiver of liability arising from the Convention on International Liability for Damage Caused by Space Objects (which entered into force on September 1, 1972), where the person, entity, or property causing the damage is involved in Protected Space Operations, and the person, entity, or property damaged is damaged by virtue of its involvement in Protected Space Operations.

Nothing in this section shall be construed to create the basis for a claim or suit where none would otherwise exist.

Consultations/Settlement of Disputes. The points of contact shall consult promptly with each other on all issues involving interpretation or implementation of this Agreement.

Any matter that has not been settled in accordance with the above paragraph shall be referred to the appropriate program managers for both NASA and the University of Bern. These program managers will attempt to resolve all issues arising from the implementation of this Agreement. If they are unable to come to agreement on any issue, then the dispute will be referred to the Agreement signatories, or their designated representatives, for joint resolution.

Continuing Obligations. The obligations of the Parties set forth in the provisions of this Agreement concerning Liability and Risks of Loss, Inventions and Patent Rights; Exchange of Technical Data and Goods and Customs Clearance shall continue to apply after the expiration or termination of this Agreement.

Choice of Law. U.S. Federal law governs this agreement for all purposes, including, but not limited to, determining the validity of the agreement, the meaning of its provisions, and the rights, obligations and remedies of the parties.

Entry into Force and Termination. This Letter of Agreement will enter into force upon the date of the University of Bern's affirmative reply. It shall remain in-force for five (5) years from this letter date. It may be extended or amended by mutual written agreement of the Parties. Either Party may terminate this Agreement after at least six months written notice of its intention to terminate the Agreement.

Letter of Commitment from SRON/TU Delft to the University of Arizona (attached).

ORBITAL DEBRIS GENERATION ACKNOWLEDGEMENT

Appendix 7 Orbital Debris Generation Acknowledgement

Not applicable.

COMPLIANCE WITH PROCUREMENT REGULATIONS BY NASA PI

Appendix 8 Compliance with Procurement Regulations by NASA PI Proposals

Not applicable.

INSTRUMENT HERITAGE

Appendix I9: Instrument Heritage

I9.1 Overview

OCAM benefits tremendously from hot electron bolometer (HEB) mixer and low-noise amplifier (LNA) technology developments for Herschel and STO, as well as NASA's investment in Quantum Cascade Laser (QCL) LO technology. OCAM will utilize digital autocorrelator spectrometers with heritage from ESA (Odin) and NASA (MLS & STO) missions. The UofA team has extensive experience designing and building large format heterodyne arrays at submillimeter wavelengths; including SuperCam, a 64 pixel, 345 GHz array receiver for the Heinrich Hertz Telescope. Much of the bias and instrument control electronics/software developed for SuperCam are being used in the 4 pixel, 1.9 and 1.45 THz HEB array receivers for STO. The same subsystems may also be repackaged for OCAM, leveraging many man years of development time.

I9.2. 4.7THz Mixers

We choose NbN phonon cooled HEB detector technology for 4.7 THz mixers because it is well understood and a mature technology. The same detector technology has been sucessfully applied for the high frequency bands in the Heterodyne Instrument for the Far Infrared (HIFI) for *Herschel*. We plan to use thin NbN films from a commercial company, SCONTEL, located in Moscow,Russia, as a spin-off of Moscow State Pedagogical University. The same company has provided thin NbN films for the HIFI mixers in *Herschel*.

To couple to the GUSSTO telescope beam we will use a standard, AR-coated, elliptical Si lens based on high resistive Si. A 4x4 array mixer configuration will be used by GUSSTO, and will follow an approach similar to that used at SRON. A 9-pixel array (shown in the Foldout 2) was assembled in such a way, in which each individual pixel was tested and selected before it was mounted in the array. There are very few development challenges, except for having all the pixels with the same local oscillator power. It is known that LO power variation from one to another originates from the fact that there are local variations in the thickness of NbN thin film. The variation in the LO power among different HEBs is not a fundamental issue for the uniform performance of an array, but imposes addition work to select the devices which have similar LO power. This can be done in two steps: first, measuring DC current-voltage (IV) curves of HEBs from a chip, which typically contains more than 100 devices. The DC tests, done in a dipstick and in a He4 vessel, are relatively easy and less time consuming. It is known that the measured critical current of a HEB can indicate required LO power. Based on the selected devices, we will test them at the THz frequency with regard to the noise temperature and LO power to further down select devices for the array. Two senior research stuffs, including the co-I, Dr. Gao at SRON and TU Delft who have worked for the HEB mixers for HIFI, will work for or contribute to the GUSSTO project. We plan to demonstrate a GUSSTO 4.7THz prototype mixer by the end of Phase A. These devices operate in a cooled vacuum space, and therefore meet thermal-vacuum requirements associated with a balloon payload.

I9.3. 4.7THz LO

At the high frequency around 4.744 THz for OI line, the only option for a compact local oscillator is a THz quantum-cascade laser (QCL). Although there are a few other potential local oscillator technologies at THz frequencies, such as HIFI-like LOs using multipliers and FIR gas lasers, they are not suitable for the 4.7 THz channel because multipliers cannot produce sufficient power levels and FIR gas lasers do not have lines within the specified IF bandwidth from the target line.

QCLs with a single frequency have been demonstrated nearly for any frequency between 1.2 THz and 5 THz. Prof. Hu’s group at MIT in collaboration with Sandia is at the very forefront in this development and has demonstrated key performances required for the 4.7 THz LO. For example, the highest CW operating temperature of ~117 K and the highest CW output power of 140 mW. Most relevant for this proposed project, the MIT group has demonstrated a QCL lasing at 4.77 THz, which is already in the vicinity of the OI line. The Delft/SRON group in collaboration with the MIT group has reported the first heterodyne demonstration and the gas spectroscopy using a HEB receiver pumped by a QCL as the local oscillator. We plan to demonstrate a 4.7 THz QCL source that generates single-mode radiation within ~3 GHz of the [OI] line (needed for an LO) by the end of Phase A. These devices operate in a cooled vacuum space, and therefore meet thermal-vacuum requirements associated with a balloon payload.

I9.4. IF System (CIT)

GUSSTO will utilize high performance, low-power, SiGe IF amplifier technology that was developed for STO by Sander Weinreb’s team at Caltech. Versions of these amplifiers built from discrete components were flown during the STO Test Flight (Oct. 2009) and will be used on the upcoming STO Science Flight (Dec. 2011). The GUSSTO low noise amplifiers (LNAs) will differ from those flown on STO only in their packaging, instead of being made of discrete components they are made using photolithographic techniques into a compact MMMIC package. A smaller package size is needed to fit all 48 amplifiers into the GUSSTO flight cryostat. These MMIC packaged LNAs have been fabricated and are now under test. They will be environmentally tested to bring them up to TRL 6 by the end of Phase A.

I9.5. Spectrometer System (Omnisys Inc.)

The GUSSTO spectrometer will be provided by Omnisys Instruments. Omisys spectrometers were successfully used on ODIN and on the STO test flight. For GUSSTO an autocorrelator spectrometer approach (similar to that used on ODIN) will be utilized. This approach has the advantage of being both efficient and low power. A HIFAS ASCI is at the heart of the correlator. Omnisys has built and delivered auotocorrelator spectrometers of this type. Together with Omnisys, we will environmentally test these units so that they are at TRL 6 at the end of Phase A.

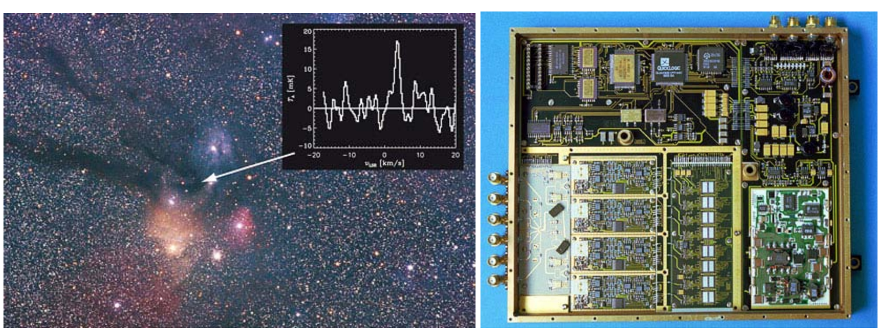

Fig. I19-26: The development of the ODIN ACS has included two ASIC designs, one correlator chip (CC) and one Analog to Digital Converter (ADC).

I9.6. Control electronics (UofA)
The bias, house-keeping, data processing, and I/O hardware to be used on GUSSTO utilizes the same components as those that were successfully flown on the STO test flight (see Fig. I9-27).

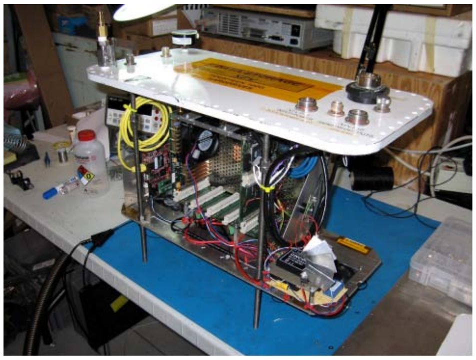

Figure I19-27: Pressure vessel containing the data acquisition and control computer, solid state storage, network router, and Omnisys FFT spectrometer.

Since OCAM has twice as many detectors, a flight package will be developed that is able to accommodate the larger number of electronic boards.

I9.7 Cyostat (Universal Cryogenics))
The closed-cycle OCAM cryostat is similar in design to one built by Universal Cryogenics (UCryo) for the UofA's SuperCam instrument. UCryo also worked closely with the UofA team in the design and fabrication of the focal plane array insert used in the STO flight cryostat. UCryo will work with a UofA airworthiness consultant to insure the OCAM system meets the required standards.

ACRONYMS

I-10. Acronyms and Abbreviations

A-hr	Ampere Hour
ALMA	Atacama Large Millimeter Array
APL	Johns Hopkins University Applied Physics Laboratory
arcmin	arc minute: angular aperture 1/60 degree
arcsec	arc second: angular aperture 1/3600 degree
ASIC	Application Specific Integrated Circuit
AST/RO	Antarctic Submillimeter Telescope and Remote Observatory
Az	Azimuth
bps	Bits per second
B	Byte
BPO	Balloon Program Office
CAL	Calibration
C&C	Command & Control system
CBE	Current Best Estimate
CG	Center of Gravity
CIT	California Institute of Technology
Cmds	Commands
CNM	Cold Neutral Medium
COBE	Cosmic Microwave Background Explorer
CSBF	Columbia Scientific Balloon Facility
°	degree
DAQ	Data Acquisition System
DSB	Double Side Band
El	Elevation
E/PO	Education / Public Outreach
EVMS	Earned Value Management System
FCRAO	Five Colleges Radio Astronomy Observatory
FGE	Flare Genesis Experiment
FIRAS	Far Infrared Absolute Spectrophotometer
FWHM	Full Width Half Maximum
FPU	Focal Plane Unit
GB	Gigabyte
GLIMPSE	Galactic Legacy Infrared Mid-Plane Survey Extraordinaire
GMC	Giant Molecular Cloud
GPS	Galactic Plane Survey
GUSSTO	Gal/Xgal U/LDB Spectroscopic/Stratospheric THz Observatory
hr	Hour
HEB	Hot Electron Bolometer
HIFI	HIFI Heterodyne Instrument for the Far Infrared, on Herschel Space Observatory
Hz	Hertz
I&T	Integration and Test
IF	Intermediate Frequency

ISM	Interstellar Medium
JWST	James Webb Space Telescope
kg	Kilogram
km	Kilometers
kbps	Kilobits per second
LDB	Long Duration Balloon flight
LMC	Large Magellanic Cloud
LMCS	Large Magellanic Cloud Survey
LNA	Low Noise Amplifier
LO	Local Oscillator
LOS	Line of Sight
m	Meter
MA	Mission Assurance
Mbps	Megabits per second
MB	Megabyte
min	Minute
mm	Millimeter
MIT	Massachusetts Institute of Technology
MLI	Multi-Layer Insulation
MMIC	Monolithic Microwave Integrated Circuit
MIPSGAL	Inner Galactic Plane Survey
MS	Mission Scientist
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
OD	Outer Diameter
OTF	On-the-Fly mapping
PDR	Photodissociation Region
PS	Project Scientist
QCL	Quantum Cascade Laser
RMS	Root-Mean-Square
SAO	Smithsonian Astrophysical Observatory
SiGe	Silicon Germanium
SMC	Small Magellanic Cloud
SNR	Signal-to-Noise Ratio
SOFIA	Stratospheric Observatory for Far-Infrared Astronomy
SORAL	Steward Observatory Radio Astronomy Laboratory
SRON	Stichting Ruimte Onderzoek Nederland (Netherlands Institute for Space Science)
SSB	Single Sideband
STO	Stratospheric TeraHertz Observatory balloon mission
SWAS	Submillimeter Wave Astronomical Satellite
TDS	Targeted Deep Survey
THz	TeraHertz
TRL	Technical Readiness Level
T_{sys}	System Noise Temperature

UA	University of Arizona
UofA	University of Arizona
UHF	Ultra High Frequency
ULDB	Ultra Long Duration Balloon Flight
V	Volt
VPN	Virtual Private Network
W	Watt
WBS	Work Breakdown Structure
WNM	Warm Neutral Medium

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