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The Stratospheric Terahertz Observatory (STO):
An LDB Experiment to Investigate the Life Cycle of the Interstellar Medium

Science Investigation

1 Executive Summary

The structure of the interstellar medium, the life cycle of interstellar clouds, and their relationship with star formation are processes crucial to deciphering the internal evolution of galaxies. Rapid, high resolution spectral line imaging of key gas tracers not accessible from the ground are needed to fill in major missing pieces of Galactic structure and witness the formation and dissipation of interstellar clouds. The Stratospheric Terahertz Observatory (STO), a balloon-borne 0.8-meter telescope with an 8-beam far-infrared heterodyne spectrometer, will address these issues and significantly advance NASA's Strategic Sub-goal 3D (discovering the origin, structure, evolution and destiny of the universe) and research objectives 3D.2 (the evolution of galaxies) and 3D.3 (star formation).

In its first long duration flight, STO will survey part of the Galactic plane in [C II] line emission at 158 μm, the brightest spectral line in the Galaxy; and [N II] line emission at 205 μm, a tracer of the star formation rate. At $\sim 1'$ angular resolution and <1 km/s velocity resolution, **STO will detect every interstellar cloud with $A_V \geq 0.4$ in the surveyed region**, and, through excitation and kinematic diagnostics provided by [C II] and [N II] line emission, **will illustrate how atomic and molecular clouds are formed and dispersed in the Galaxy**. STO will make 3-dimensional maps of the structure, dynamics, turbulence, energy balance, and pressure of the Milky Way's Interstellar Medium (ISM), as well as the star formation rate. While this proposal focuses on the science from the first long duration (∼10-14 day) flight, we briefly discuss subsequent flights since the possibility of additional flights with new instrument configurations is one of the core strengths of a balloon project. Subsequent flights will target [C II] and [N II] in the Galactic center and the outer Galaxy, and selected mapping of denser regions with infrared [O I], [N II] and HD lines. This summary section briefly describes science goals, mission approach, and complementarity with other missions; subsequent sections 2-5 go into more detail on each topic.

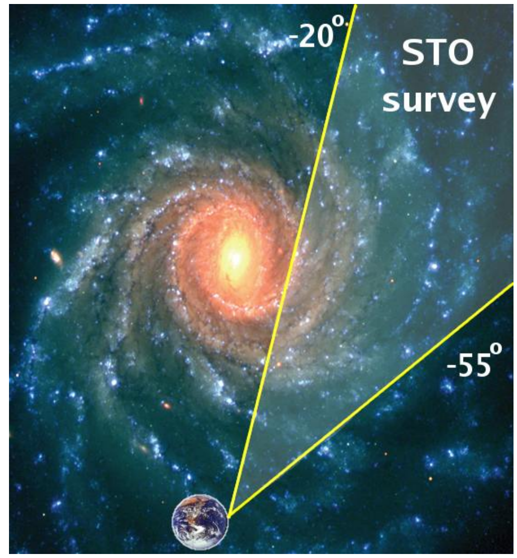

Figure 1: Overview of the region to be surveyed by STO. This 35° longitudinal swath of the Galactic Plane reveals major components of the Milky Way ISM, such as the molecular ring, the Scutum-Crux spiral arm, and the interarm region.

1.1 *Summary: Science Goals and Objectives*

STO will provide a comprehensive understanding of the inner workings of our Galaxy by exploring the connection between star formation and the life cycle of interstellar clouds. We will study the formation of molecular clouds from diffuse atomic gas, the feedback of high mass star formation on the lives of atomic and molecular clouds, and the effect of these processes upon the global structure and evolution of the Galaxy. The detailed understanding of star formation and evolution of stars and gas in the Galaxy is directly relevant to star formation in other galaxies. The nature of the feedback mechanism of massive star formation with its interstellar environment is pivotal to the evolution of galaxies. STO thus addresses NASA's goals and research objectives on galaxy evolution and star formation. **In its first flight, STO addresses the high priority goals:**

1. **Determine the life cycle of Galactic interstellar gas.**
2. **Study the creation and disruption of star-**

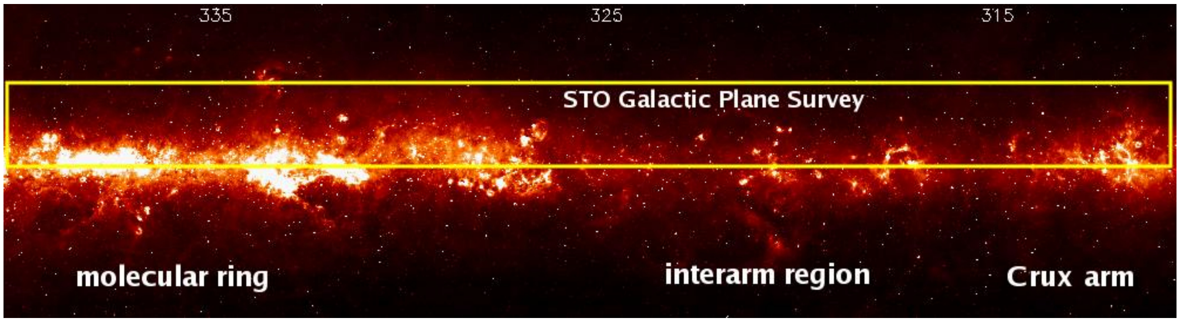

Figure 2: Midcourse Space Experiment (MSX) 8.3 μm map of the Galactic Plane from the Molecular Ring through the Scutum-Crux Spiral Arm ($-20° > l > -55°$). The yellow rectangle highlights the region to be explored by STO on its first long duration flight.

forming clouds in the Galaxy.

3. **Determine the parameters that affect the star formation rate in a galaxy.**
4. **Provide templates for star formation and stellar/interstellar feedback in other galaxies.**

1.2 Summary: Mission Approach

STO will utilize two heterodyne receiver arrays to produce a total of eight $\sim 1'$ pixels in the focal plane, each with 1024 spectral channels. In the first long duration (10-14 day) flight STO will map a 35 square degree area including the Galactic molecular ring (Figures 1 & 2) as well as two deeper, 1/2 square degree maps in arm and interarm regions. STO has the sensitivity to detect and the ability to resolve spectrally and spatially all Giant Molecular Clouds (GMCs), all significant H II regions, and all cold neutral medium (CNM) atomic clouds with $A_V \geq 0.4$ mag in the surveyed region.

The STO heterodyne receivers provide sub-km/s velocity discrimination and sufficient bandwidth to detect and resolve line emission from every Galactic cloud in the surveyed region. The data products envisioned include:

1. A high fidelity database of spatially and velocity resolved far-infrared [C II] 158 μm and [N II] 205 μm fine-structure line emission in the Galaxy.
2. A combination of STO's data products with existing line and continuum surveys to characterize the structure and dynamics of interstellar clouds and their relation to star formation.

The data are produced in large scale (Galactic Plane Survey) and selective (Deep Survey) modes:

- **GPS: Galactic Plane Survey**: $-20° > l > -55°$; $0° < b < 1°$
- **DS: Deep Survey** of arm and interarm regions: $l \sim -50°$ and $l \sim -40°$; $\sim 0.5 - 0.7°$ in b

STO's potential for additional flights provides the ability to more fully map the Galaxy in the [C II] and [N II] lines and to change receivers to include other important interstellar lines such as [N II] 122 μm, [O I] 63 & 145 μm, and HD 112 μm.

1.3 Summary: Complementarity with Other Missions and Existing Data

STO is timely. STO will provide the best corresponding interstellar cloud survey to the GLIMPSE and MIPSGAL Spitzer Legacy programs and contemporary H I and CO line surveys. STO will enhance the interpretation of these data sets by completing the observational links required to trace the cloud life cycle. In addition, STO complements other [C II] and [N II] observations taken on the Cosmic Background Explorer (COBE) and the Balloon-borne Infrared Carbon Explorer (BICE) in having much greater spatial and spectral resolution. Using Galactic rotation to place the clouds along the line of sight, STO's high spectral resolution enables 3 dimensional maps of Galactic interstellar matter, from which many physical parameters in the Galaxy (e.g., pressure and star formation rate) can be extracted.

STO also complements the capabilities of heterodyne receivers on contemporary far-IR platforms. The Herschel Space Observatory (Science phase:2009-2013) and the Stratospheric Observatory for Infrared Astronomy (SOFIA, 2009+) will have the capability to observe both [C II] and [N II] using the same high spectral resolution heterodyne techniques used on STO. However, due to their much larger apertures each facility will map only a few percent of the area of STO's first survey during their lifetimes.

2 Overview

2.1 *Background and Objectives*

Via spatially and spectroscopically resolved [C II] and [N II] line emission, STO probes uniquely the pivotal formative and disruptive stages in the life cycles of interstellar clouds. It reveals new insight into the relationship between interstellar clouds and the stars that form from them, a central component of galactic evolution.

Neutral interstellar gas is the dominant mass component of the ISM, and tends to exist as two phases in rough thermal pressure equilibrium: a diffuse warm neutral medium (WNM) with hydrogen densities at the solar circle of $n \sim 0.3$ cm^{-3} and T$\sim$8000 K, and a denser, colder CNM with $n \sim$40 cm^{-3} and T$\sim$70 K (Kulkarni & Heiles, 1987; Wolfire et al., 2003). Turbulence provides a broader spectrum of conditions (Mac Low et al., 2005; Gazol et al., 2005), but thermal balance drives neutral gas toward these phases. With sufficient shielding column, $N > 10^{20} - 10^{21}$ cm^{-2} of hydrogen nuclei, the CNM clouds begin to harbor molecular interiors. Above $N \sim 10^{22}$ cm^{-2} they become fully-molecular, gravitationally bound and stars may form in their interiors (McKee, 1989). The largest condensations take the form of GMCs with large masses $10^5 - 10^6$ $M_\odot$ and are responsible for most of the star formation in the Galaxy. These ISM components are shown schematically in Figure 3.

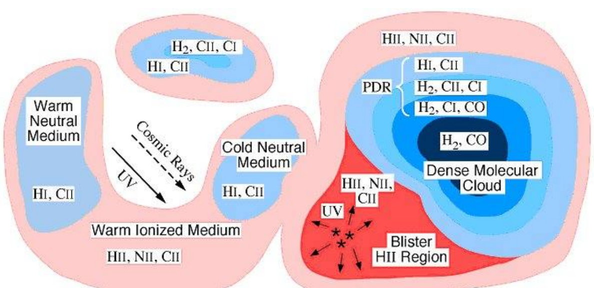

Figure 3: Schematic representation of ISM components. STO detects and maps in the Galaxy the higher column density CNM component, the H_2/C^+ component, the photodissociation region (PDR) surfaces of molecular clouds, the H II component and (with H I) the WNM/CNM ratio.

WNM is converted into CNM clouds via thermal instability either if the ultraviolet radiation field (heating) diminishes (Parravano et al., 2003) or if the pressure increases because of the passage of a (e.g., supernova) shock wave (McKee & Ostriker, 1977). GMCs presumably form from a large assemblage of CNM clouds; the leading theoretical models invoke gravitational instabilities in huge regions 0.5-1 kpc in size along spiral arms (Ostriker & Kim, 2004) although this assemblage process has never been directly observed and other mechanisms have been invoked such as the convergence of flows in a turbulent medium (Hennebelle & Pérault, 2000; Heitsch et al., 2006).

The ultraviolet radiation from massive stars not only heats the CNM and WNM and determines the relative portions of these phases, but it also ionizes gas and heats it to 10^4 K, producing H II regions. [N II] line emission provides an extinction-free measure of ionizing radiation from young, massive stars (a direct measure of star formation rates), and [C II] and [N II] together measure the disruptive impact of UV radiation on the surfaces of neighboring clouds; a key part of the stellar/interstellar feedback that governs galactic evolution. GMCs are primarily destroyed by the ultraviolet radiation from OB stars which form inside and lie relatively close to their natal GMCs (Williams & McKee, 1997). This stellar feedback likely determines the fraction of cloud gas which is converted to stars. CNM clouds are destroyed by the interstellar UV field produced by the global (many hundreds of pc) OB stellar population. If global star formation rates are high, the interstellar field is high, thereby lowering the CNM population by converting them to ionized or WNM gas. This conversion then lowers the rate of GMC formation, and thus the global star formation rate. These stellar feedback effects could regulate star formation rates in galaxies.

Joined with other surveys, STO will:

1. Map as a function of Galactic position the size and mass distribution and internal velocity dispersion of atomic, molecular and ionized clouds in the Galaxy.
2. Construct the first barometric map of the Galaxy, the first map of the gas heating rate, and a more sensitive and detailed map of the star formation rate.
3. Reveal clouds clustering and forming in spiral arms and supershells, and follow the growth of clouds to sufficient column densities to shield molecules and to become gravitationally bound
4. Measure the destruction rate of clouds via the

conversion to warm ($\sim 10^4$ K), diffuse neutral and ionized gas.

5. Observe the formation and destruction of clouds throughout the Galaxy, test turbulent theories of these processes, and directly observe the feedback effects caused by supernovae and the ultraviolet radiation from young massive stars.
6. In conjunction with H I surveys, map the mass ratio of CNM to WNM, so that we may correlate this ratio with thermal pressure, ultraviolet radiation field, and star formation rate.
7. Probe the relation between the mass surface density (on kpc scales) and the star formation rate, so that we may be able to understand the empirical Schmidt Law, which relates star formation rates to gas mass surface density.

2.2 *Overview of STO Capability*

STO achieves 3σ intensity limits of 2.0×10^{-5} (t/1 sec)$^{-1/2}$ and 8.0×10^{-6} (t/1 sec)$^{-1/2}$ erg s^{-1} cm^{-2} sr^{-1} in the [C II] and [N II] lines. With this sensitivity, STO can detect the GMCs, CNM clouds, and H II regions discussed above. The CNM clouds typically have sizes r$\sim$3 pc and subtend $> 1'$ of angle at a distance of 8.5 kpc, filling the STO beam. These CNM clouds will therefore be both spatially and spectrally resolved. STO will resolve in [C II] the surfaces of all GMCs illuminated by the local (or brighter) interstellar radiation field and the [C II] and [N II] emission from H II regions with Emission Measure (EM) > 50 cm^{-6} pc. [C II] originates in both neutral and ionized gas, whereas [N II] arises solely from ionized gas. STO [N II] observations will provide the most sensitive and detailed maps of star formation rates in the Galaxy, and are crucial for separating the ionized and neutral components of [C II] emission.

The main features of STO surveying modes are:

- High spatial resolution, $\sim$1 arcmin (3 pc at $d = 10$ kpc).
- Very high spectral resolution, <1 km/s.
- High dynamic range: 10^4 spatially and 10^3 spectrally
- More than 10^5 spatial pixels
- High sensitivity: 10^4 times better than FIRAS/COBE when convolved to the same resolution. STO will catalogue all neutral clouds with columns $N > 5 \times 10^{20}$ cm^{-2} and all ionized clouds with EM > 50 cm^{-6} pc

Figure 4 shows the STO sensitivity to various cloud components, and Figure 5 shows a simulation of [C II], CO and H I spectra along a line of sight through the Galaxy. Observed CO and H I spectra (top) and simulated [C II] spectrum are provided for 10s integration (middle) and 200s integration (bottom). The simulations indicate that three distant CNM clouds of columns (left to right) of 3, 5, and 7 $\times 10^{20}$ cm^{-2} are detectable. The H I has a considerable WNM component. The blue peaks shown in the figure are surfaces of molecular clouds. Toward illuminated cloud surfaces, particularly in deep surveys, STO will detect the [^{13}CII] fine structure line, which exhibits three hyperfine components at shifts of +11, +63, and -65 km/s relative to the [^{12}CII] line. Here, measurements of the [^{13}CII]/ [^{12}CII] line ratio will probe the [^{12}CII] optical depth and the ^{13}C/^{12}C abundance ratio (Boreiko & Betz 1996).

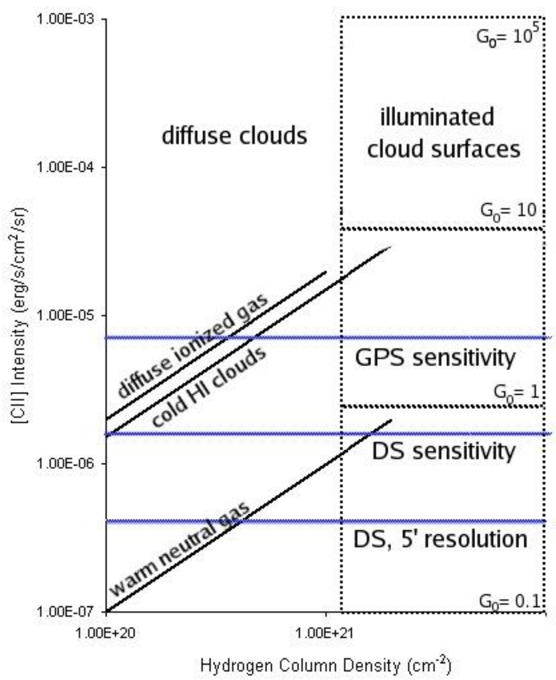

Figure 4: Comparison of STO's sensitivity with [C II] integrated intensity for diffuse interstellar components which constitute the building blocks for molecular clouds (diagonal lines), and UV-irradiated molecular cloud surfaces (dotted boxes). The external radiation fields are quantified in units of the local interstellar radiation field G_0. The corresponding sensitivities (3σ rms noise) of STO's two survey modes (see section 1.2 for definitions) are indicated by solid blue lines.

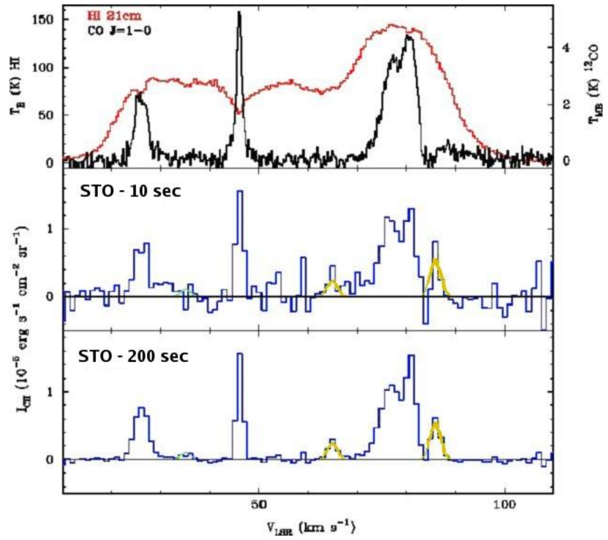

Figure 5: Observed CO and H I spectra (top) and simulated [C II] spectra for 10 seconds (middle) and 200 seconds (bottom) integration. The green curves indicate three distant CNM clouds.

3 Specific Science Goals and Objectives

Goal 1: Anatomy of Interstellar Gas

STO's unique blend of sensitivity, angular resolution and spectral resolving power allows it to map and diagnose *all components of the warm and cold interstellar medium*. STO will survey spiral arm, interarm regions and a large portion of the molecular ring, where much of the star formation occurs in the Galaxy. Galactic rotation allows velocity separation of the clouds along the line of sight. Therefore, *STO will provide an unprecedented 3D global map of the distribution of clouds of ionized gas, atomic gas, and molecular clouds (via their dense atomic surfaces) as a function of Galactocentric radius (R) and height (z) in the Galaxy*. We can compute the density of clouds (i.e., the number of clouds per kpc^3) and their size distribution as functions of R and z, and see how clouds are clumped together in spiral arms or supershells. In regions of cloud clustering, the superb velocity resolution of STO will measure the random motions of clouds, and diagnose *large scale turbulence*.

COBE FIRAS observations show that the ionized component of the ISM radiates strongly in both [C II] 158 μm and [N II] 205 μm (Wright et al., 1991). To distinguish the origin(s) of [C II] emission, velocity-resolved measurements of the small scale distribution of the ionized gas must be made in [N II] and compared to the [C II] distribution. *STO will conclusively determine the origin of the [C II] emission from various regions in the Galaxy*, and will enable the portion of the [C II] emission coming from the CNM neutral gas to be unambiguously determined.

If the CNM clouds are seen in H I, which determines their column and mass, the ratio of CNM [C II] to H I intensity provides a measure of the [C II] emissivity per H atom which rises monotonically with gas density and thermal gas pressure. *The STO survey over a large portion of the Galactic Plane thereby enables the construction of the first barometric maps of the Galactic disk*, determining the ambient thermal pressure in different environments (e.g., the spiral arms versus interarm regions, turbulent versus quiescent regions). The STO team's theoretical models are vital to determining the density, temperatures, and thermal pressures in the clouds. These pressure maps and the maps of cloud distributions and properties can be correlated with star formation rates to understand stellar/interstellar feedback mechanisms.

Where extended emission is seen in H I with no [C II] counterpart, we can attribute the H I emission to extended low density gas – either WNM or thermally unstable gas with densities below that of CNM (Figure 5). To achieve the required sensitivity, we will smooth the data to larger ($\sim$10 km/s) velocity and spatial ($\sim$ 10′) bins. In this way, STO can map the CNM/WNM mass fraction in the Galaxy, and determine how much of the neutral gas is in clouds rather than in warm or unstable components. This ratio can be correlated to the thermal pressure, to the ultraviolet radiation field, and to the star formation rate to probe the stellar feedback processes that regulate star formation.

In addition, the [C II] line dominates the cooling of CNM clouds. Therefore, we directly obtain the gas heating rate of clouds as a function of radius throughout the Galaxy. Besides the fundamental interest in tracing the energy flow in the Galaxy, the observations also can test our theoretical hypothesis that the heating is provided by the grain photoelectric heating mechanism in diffuse clouds. This hypothesis has been tested (positively) in denser clouds illuminated by stronger fields, but it is not yet certain that in weak UV fields other mechanisms may be important. The test involves correlating the heating with the observed incident radiation field and the gas density in a sample of clouds.

Goal 2: Formation & Destruction of Clouds

The formation of interstellar clouds is a prerequisite for star formation, yet the process has not yet been directly observed! **STO is designed with the unique combination of sensitivity and resolution needed to observe cold atomic clouds assembling giant molecular clouds (GMCs).**

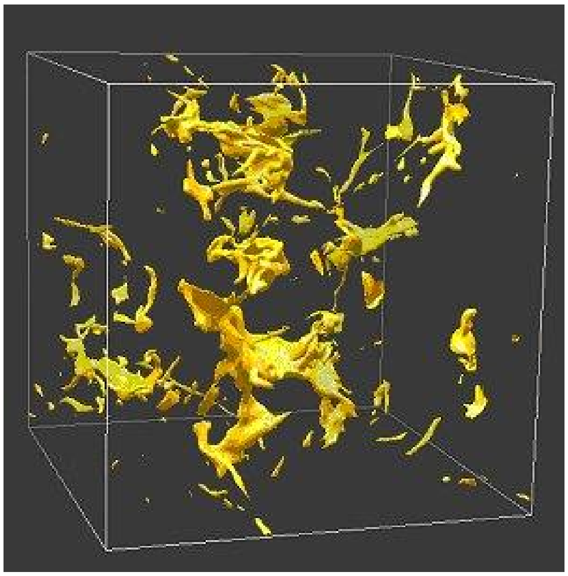

Figure 6: The ISM is a complex environment with structures on all scales and velocity dispersions. The surfaces of clouds corresponding to $n = 30$ cm^{-3} are shown within a 6 pc region from a 3-D magnetohydrodynamical simulation of cloud formation (Juvela et al., 2003). Neither COBE nor BICE had the spatial and spectral resolution to unravel the structure of the interstellar clouds or their formation process.

Turbulence may play an important role in the formation and evolution of interstellar clouds. In a standard scenario where CNM clouds are formed from WNM gas by thermal instability, we can picture the role of turbulence in two ways: large scale instabilities, density waves and supernovae drive compressional motions that can trigger the thermal instability (de Avillez & Breitschwerdt, 2005). Alternatively, regions undergoing thermal instability experience a dynamic radiative transition from the WNM to the CNM, due to the large density contrast between these two phases. This transition is known to generate turbulence and to set up the CNM into a complex network of pancakes and filaments (Kritsuk & Norman, 2002, also Figure 6). Because of this dynamic nature of both the triggering and evolution of the thermal instability, departures from thermal pressure equilibrium may be widespread in the ISM (Heiles & Troland, 2003), and the notion of a dynamic multiphase ISM has been proposed, where turbulent diffusion regulates phase exchange processes. Only a careful study of both the spatial structure and kinematics of gas in transition between phases can tell us the role of turbulence and dynamic pressure in the life-cycle of the ISM.

Other theories of (molecular) cloud formation are also guided and constrained by observations of the atomic and molecular gas components. Four mechanisms have been proposed to consolidate gas into GMC complexes (Figure 7): (1) self-gravitating instabilities (Kim & Ostriker 2002,2007) within the diffuse gas component (often in a spiral arm where density is highest and the Jeans time is shortest), (2) collisional agglomeration of small, long-lived molecular clouds, (3) accumulation of material within high pressure environments such as shells and rings generated by OB associations, and (4) compression in the randomly converging parts of a turbulent medium. STO can distinguish these processes from each other and consider new cloud formation schemes by:

- Accounting for all the molecular hydrogen mass (the H_2/C^+ clouds as well as the H_2/CO clouds) when computing global measures of the interstellar medium.
- Making a more complete, better characterized catalogue of interstellar clouds than CO or H I surveys.
- Constructing spatial and kinematic comparisons with sufficient resolution, spatial coverage and dynamic range to probe a wide range of interstellar phases and environments.

Currently, associating diffuse gas (H I) with molecular gas (CO) is difficult owing to the large differences of emitting volumes of the H I line and the CO line (see Figure 8). Unlike [C II], a significant fraction of the H I emission can come from low density WNM gas. [C II] emission barometrically picks out clouds of atomic CNM gas and H_2 clouds with little CO. Regions of GMC formation may therefore be tracked by higher than average cloud densities (number of clouds per kpc^3), or regions with individual clouds with higher than average columns or pressures. With STOs velocity resolution, these regions can be identified with superrings or spiral arms or convergent parts of a turbulent medium.

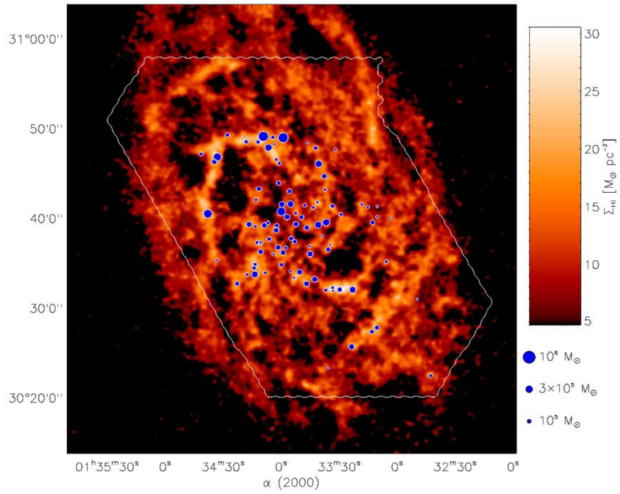

Figure 7: The location of GMCs in the nearby spiral galaxy M33 are overlaid upon an integrated intensity map of the H I 21 cm line (Engargiola et al., 2003). These observations show that GMCs are formed from large structures of atomic gas, and foreshadow the detailed study of GMC formation that STO provides in the Milky Way.

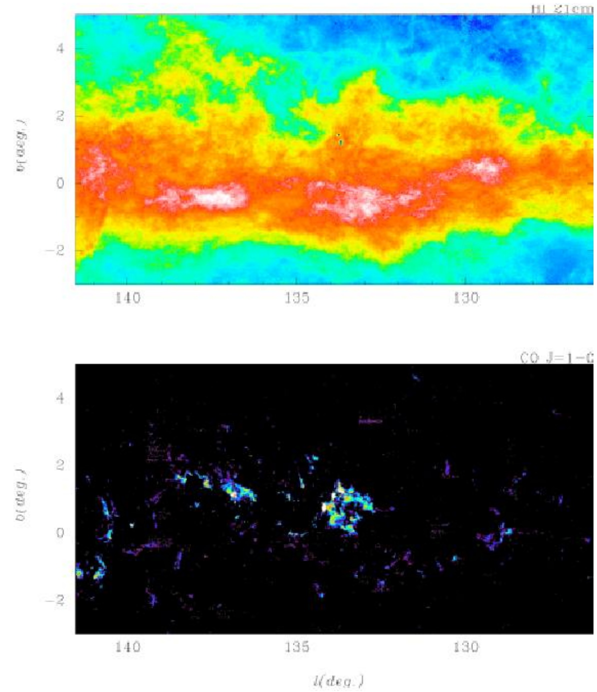

Figure 8: The integrated 21 cm line (top) and CO J=1-0 (bottom) emission from the Perseus spiral arm. The H I and ^{12}CO data are from the Canadian Galactic Plane Survey (Taylor et al., 2003) and the Five College Radio Astronomy Observatory CO Survey of the Outer Galaxy (Heyer et al., 1998), respectively. STO enables a more direct comparison of diffuse gas with the underlying molecular cloud.

STO will identify the sequence of phase transitions as the gas transits through the spiral potential, and *will witness the process of cloud formation* directly from the atomic substrate or from small H_2 clouds. For example, dust lanes along the inner edges of spiral arms often show neither H I nor CO emission (Wiklind et al., 1990; Tilanus & Allen, 1991), and are therefore likely to be in an intermediate phase; sufficiently dense and self-shielded to harbor H_2 but not CO (Grenier et al. 2005, see also Figure 3). These clouds will be seen in [C II] by STO.

The high spectral resolution of STO enables crucial kinematic studies of the Galaxy to be made. The expansion of stellar outflows and supernova remnants create supershells that sweep up surrounding ISM and overrun surviving molecular clouds and cloud fragments. The high pressures in the shells convert swept-up WNM gas to CNM clouds via thermal instability. The resulting supershell can grow to several times the typical thickness of the gas layer in a galactic disk, creating superrings that can contain millions of solar masses of swept-up gas. Gravitational fragmentation of superrings may be an important mechanism for the formation of GMCs (Elmegreen, 1989; McCray & Kafatos, 1987).

STO will determine the kinematics and thermal pressures of most supershells, fossil superrings, and molecular clouds just condensing via gravitational instability of old superrings. STO will detect many of the CNM clouds formed out of WNM in the shells, and the larger column density clouds, which may harbor H_2. With these detections STO will determine the role of OB association-driven supershells and superrings in the production of molecular clouds and the cycling of gas between the various phases of the ISM.

STO witnesses the disruption of clouds: [C II] and [N II] measure the photoevaporating atomic or ionized gas driven from clouds with UV-illuminated surfaces, thereby converting the clouds to WNM or to diffuse H II regions. Thus, STO can directly determine the rate of mass loss from all catalogued clouds, and their destruction timescales.

Goal 3: Star Formation Rate in the Galaxy

Star formation within galaxies is commonly described by two empirical relationships: the variation of the star formation rate per unit area with the gas surface density (atomic + molecular), $\Sigma_{\rm SFR} \sim \Sigma^n_{\rm gas}$

(Schmidt, 1959) and a surface density threshold below which star formation is suppressed (Kennicutt, 1989; Martin & Kennicutt, 2001). The Schmidt Law has been evaluated from the radial profiles of Hα, H I, and CO emissions for tens of galaxies. The mean value of the Schmidt index, n, is 1.3 ± 0.3 (Kennicutt, 1989), valid for kpc scales. This empirical relationship is used in most models of galaxy evolution with surprising success given its simplicity. Oddly, there has been little effort to evaluate the Schmidt Law in the Milky Way owing to the difficulty in deriving the star formation rate as a function of radius within the plane.

The STO survey of [C II] and [N II] emission provides the optimum set of data to calculate the Schmidt Law in the Milky Way. The [N II] line is an excellent tracer of the star formation rate as it measures ionizing luminosity with unmatched sensitivity, angular and spectral resolution, and is unaffected by extinction. The [C II] line, in conjunction with H I 21-cm and CO line emissions, provide the first coherent map of the neutral interstellar gas surface density and its variation with radius.

STO may help us understand the origin of the Schmidt Law. For example, it will correlate the thermal pressures on the surfaces of GMCs (which may relate to the star formation rate inside) with surface densities of H I and CO. It may uncover regions around OB associations devoid of GMC-forming CNM clouds. The current high rate of star formation in associations may impoverish large regions of the clouds needed to start the star formation cycle in the future. Such measurements are pivotal to models of star formation feedback & global galactic evolution.

Goal 4: The Milky Way Template

[C II] 158 μm, the strongest Galactic cooling line, will be the premier diagnostic tool for studying external galaxies with future far-infrared (FIR) observatories (SOFIA, Herschel) and in the submillimeter for galaxies with large redshifts (Atacama Large Millimeter Array). In such spatially unresolved galaxies, however, only global properties can be measured. To interpret the measurement of extragalactic [C II] one must turn to the Milky Way for the spatial resolution needed to disentangle the various contributors to the total [C II] emission. At present, there is debate on the dominant origin of the [C II] emission in the Galaxy: diffuse H II regions, CNM clouds, or the surfaces of GMCs. STO will solve this mystery. The [C II] and [N II] intensities depend on the strength of the UV heating and on the amount of gas in the appropriate ISM phase. The STO mission covers a broad range of density and UV intensity, thus establishing the relationship between physical properties, [C II], [N II], CO, H I, FIR emission, and star formation. This study will provide the "Rosetta Stone" for translating the global properties of distant galaxies into reliable estimators of star formation rate and state of the ISM.

Possible Additional STO Flights

STO, as a balloon-borne mission, has the great potential to be reflown, possibly with new receiver modules that enable different spectral lines to be surveyed. The first flight is designed for the science described in previous sections and focuses on the Galactic disk between 3 kpc and 8.5 kpc. However, there are a number of extremely interesting scientific goals that could be met on subsequent flights. We briefly list here a possible sequence of flights to give the flavor of this enormous potential.

Flight 2. Flight 2 could map [C II] and [N II] in the very interesting center of the Galaxy, as well as conducting deep maps directed towards the outer galaxy. The compressed and turbulent interstellar medium of galactic nuclei provides a completely different environment for star formation than the relatively quiescent disk. STO could explore the Galactic Center with sufficient spatial ($\sim$3 pc) and spectral resolution to separate large clouds and trace material as it falls into and through the center region. STO could study the origin of the mysteriously low [C II]/FIR flux ratio (Nakagawa et al., 1998), all of the center's massive cloud complexes, and the bar. High-velocity resolution observations will provide a new kinematic map of the gas, ultraviolet fields, and star formation in the nucleus.

The outer Galaxy provides a testing ground for understanding cloud formation and star formation in lower surface density and lower metallicity environments. STO will answer what determines the threshold in gas surface density which causes massive star formation to rapidly diminish.

Flight 3. Flight 3 could allow us to change wavelengths, and pursue the [O I] 63 μm or 145 μm line as well as the [N II] 122 μm line. These lines increase in strength in dense gas and we envision deep surveys in regions selected by our flights 1 and 2. The [O I] maps will "light up" the regions of higher thermal pressures (or densities) and higher incident UV fields, like the surfaces of GMCs. Combined with the [C II] line, [O I] constrains these diagnostics of star forming clouds. In addition, warm cores are bright background continuum sources towards which [O I] 63 μm line absorption can be observed (e.g. Vastel et al. 2002). Such observations will address a key puzzle in our understanding of the oxygen budget in dark clouds; is oxygen present in the gas phase, or is it largely depleted onto icy grain mantles?

The [N II] 122 μm line, combined with the [N II] 205 μm line from previous flights, gives a measure of the electron density (n_e) in H II regions, and therefore the thermal pressure in ionized gas. The electron density enables us to check our measurement of the star formation rate by [N II] 205 μm, since at high density ($n_e > 100\ \mathrm{cm}^{-3}$), it is the [N II] 205 μm luminosity times n_e which scales as the star formation rate.

Flight 4. Another change of wavelength could bring the ground state rotational line of HD at 112 μm into view. This line would principally be detected toward the sites of massive star formation, so many targeted pointings would be planned. Combined with observations of the dust continuum and other molecules, the HD line would provide a measure of the deuterium abundance in molecular gas. When compared to theoretical models of deuterium destruction by astration, previous UV observations of DI and mid-IR observations of HD (Neufeld et al. 2006) have yielded elemental D abundances that are both surprisingly small and variable, a discrepancy which may indicate that interstellar deuterium might be significantly depleted onto large aromatic hydrocarbons (Linsky et al. 2006). STO observations of HD J=1-0 will provide two important advantages over current mid-IR observations: they will probe cold molecular clouds in which mid-IR HD transitions are not excited, and provide enough spectral resolution to discriminate between multiple clouds along a given sight-line.

4 Science Requirements

4.1 *High Resolution Spectroscopy*

The superposition of many clouds along the line of sight can be disentangled with spectral line techniques. Fitting to a model of Galactic rotation is often the only way to determine each cloud's distance and location within the Galaxy. It is the spectral resolution that gives us a 3D rather than a projected 2D map of the Galaxy. Moreover, internal dynamics are revealed from the variance of measured velocities and profile line widths within interstellar clouds. With resolution finer than 1 km s^{-1}, a line profile can disentangle processes such as turbulence, rotation, and local effects such as protostellar outflows. These kinematic components play a vital role in the sculpting of interstellar clouds, and a survey that has the goal of understanding their evolution **must** be able to separate the velocity components.

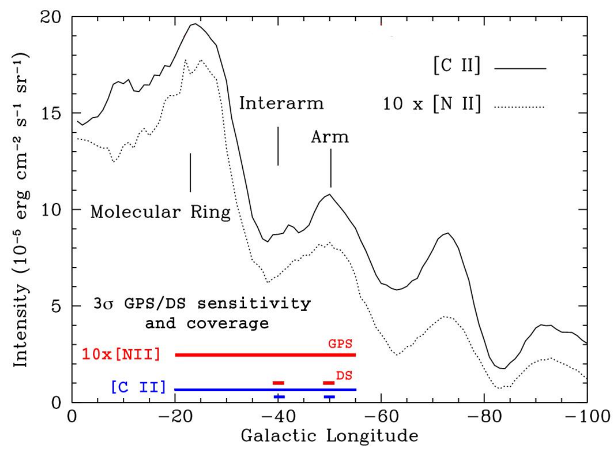

Figure 9: [C II] and [N II] intensity in the Galactic plane seen in the COBE beam (Steiman-Cameron et al., 2007). STO's sensitivity to [NII] (red) and [CII] (blue) and coverage of the Galactic Plane in its two survey modes is shown. Note that this sensitivity is obtained while simultaneously providing unparalled velocity and angular resolution.

4.2 *Large Scale Mapping*

Interstellar pressure, elemental abundances, and radiation field vary as a function of Galactic radius, so it is necessary to probe from the inner Galaxy out to at least the solar circle to obtain a statistically meaningful survey that encompasses the broad dynamic range of conditions in the Galaxy. Large cloud ensembles, as gathered by surveys, are required to average properties extracted from clouds at varying stages of evolution. Large scale mapping places detected interstellar structures in an environmental context. To meet these objectives we will carry out an unbiased Galactic plane survey (GPS), and deep surveys (DS) of selected areas in the Galactic plane.

Galactic Plane Survey (GPS)

This moderate sensitivity survey will sample the Galactic plane at longitudes $-20^\circ > l > -55^\circ$ and $0^\circ < b < 1^\circ$ in 12 second integrations per convolved $1.5'$ beam. This survey region crosses the molecular ring ($l \sim -23^\circ$), spiral arm regions ($l \sim -50^\circ$), and interarm regions ($l \sim -40°$). The molecular ring, arm, and interarm environments are clearly identified in both [C II] and [N II] emission in the COBE 7° beam (Figure 9). In addition, numerous shells, bubbles, and star formation regions appear throughout our survey area as seen, for example, on MSX 8μm emission maps (Figure 2). Thus, our survey probes the Galactic regions where the full cycle of cloud formation and destruction occurs.

Deep Surveys (DS)

The deep sensitivity survey will consist of observations at 90 seconds of integration per 1′ beam towards arm ($l \sim -50°$) and interarm regions ($l \sim -40°$) in the GPS shallower survey region. These maps cover a total area of one square degree and include the Scutum-Crux arm (seen in H II regions, ionized gas, [N II] and [C II]) and the adjacent interarm region between Scutum-Crux and the molecular ring. The GPS survey only allows detection of clouds with columns of $A_V \geq 0.4$, and so only uncovers the most massive CNM diffuse clouds. Our deep surveys allow a much broader range of diffuse clouds to be studied, down to a column $A_V \sim 0.1$. In addition, for fixed A_V, CNM clouds in lower pressure regions, or in regions with lower heating rates are more difficult to detect. Deep surveys therefore also extend our ability to detect clouds along the line of sight in such regions.

4.3 Angular Resolution and Full Sampled Maps

Previous surveys of [N II] and [C II] were limited to very small regions (KAO, ISO) or had low angular resolution (COBE, BICE) (Bennett et al., 1994; Nakagawa et al., 1998). STO will fully sample both species over large regions of sky to their diffraction limited resolution of 1.1′ and 0.8′, respectively. Arcminute resolution with proper sampling is crucial to disentangling different clouds and cloud components over large distances in the Galaxy. At a distance of 10 kpc, GMCs subtend 10′, CNM clouds or small molecular clouds subtend 1-2′, diffuse H II regions about 20′. Such diffuse H II regions tend to dominate [N II] and [C II] emission from ionized gas (McKee & Williams, 1997) and are a substantial component of the ionized gas in the Galaxy.

4.4 High Sensitivity

Figure 4 shows the required STO sensitivity for detecting [C II] and [N II] from photodissociated cloud surfaces and for distant (∼10 kpc) clouds in the inner Galaxy. Our most demanding requirements lie in the search for the formation of molecular clouds and the measurement of the warm ionized medium in the Galaxy. A flux limit of 10^{-6} erg s^{-1} cm^{-2} sr^{-1} will detect [N II] in diffuse H II regions as far away as the Molecular Ring, achievable in 12 seconds of integration with velocity smoothing to 5 km s^{-1}, appropriate for ionized gas. Tracing the formation of GMCs requires the detection of cold neutral clouds of relatively low column densities of $\sim 5 \times 10^{20}$ cm^{-2}. The expected [C II] emission at high interstellar pressures would be 10^{-5} erg s^{-1} cm^{-2} sr^{-1}, detectable in 8 seconds with STO. The STO Deep Survey allows the study of smaller columns of gas, and/or regions of lower interstellar pressure, such as in the Solar vicinity.

5 Complementarity with Existing Data Sets and Other Missions

STO will provide the community with a totally unique [C II] and [N II] survey, enabling quantitative extraction of many physical parameters of the interstellar medium in a 3D data cube. Its spatial resolution exceeds Galactic Plane surveys of CO emission in the southern hemisphere (Dame et al., 2001; Onishi et al., 2005) and is comparable to the Southern Galactic Plane HI Survey (McClure-Griffiths, 2005), allowing placement of the [C II] 158 μm and [N II] 205 μm emission along the line of sight with respect to the CO and H I emission.

5.1 Relationship to Existing Data Sets

CO: For tenuous clouds of column less than about $N < 2 \times 10^{21}$ cm^{-2}, the CO is photodissociated and the CO emission either disappears entirely, or if present, is a very unreliable measure of the molecular mass. The more opaque clouds in the 5×10^{20} to 3×10^{21} cm^{-2} range may be primarily H_2, which is extremely difficult to detect directly. These clouds have most of the carbon in C^+, which makes [C II] the only reliable probe. [C II] not only detects the CO clouds (via the emission from their C^+ surfaces), but also the H_2 clouds at intermediate column, and the mainly atomic clouds with $N < 5 \times 10^{20}$ cm^{-2}. Recent J-K extinction maps (Figure 10) confirm these components are present. Thus, the [C II] detects a broader range of clouds than the CO, and allows us to see the possible assemblage of clouds of ever greater column, from atomic clouds, to H_2 clouds, to CO clouds.

The CO surveys will complement the STO survey by helping to identify molecular clouds whose

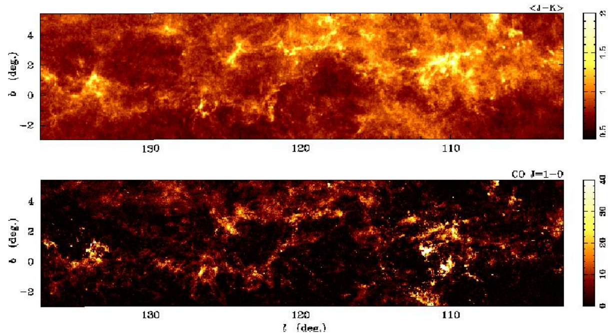

Figure 10: Near infrared $J - K$ extinction maps (top) depict significant interstellar gas not probed by CO (bottom). [C II] line emission will barometrically select young molecular clouds that have formed H_2 but not CO.

surfaces STO detects and whose ionized gas seen in [N II] may be expanding into the ISM (Dame et al., 2001; Onishi et al., 2005).

H I: The STO surveys enhance substantially the interpretation of existing H I surveys. The H I emission maps are sensitive only to column, whereas [C II] is sensitive to density times column. The [C II] therefore picks out the cloud regions with density $>$ 30 cm^{-3}, whereas the H I is often dominated by the WNM emission (see Figure 5). In fact, H I clouds can appear in absorption, in emission or undetected against the confused background and foreground WNM. When H I and [C II] are both seen in emission, the ratio provides the gas density and pressure in the cloud. When extended and broad H I emission is seen without a [C II] counterpart, WNM or thermally unstable gas is identified. For H I, the relevant dataset for STO is the Southern Galactic Plane Survey with 1′ resolution (McClure-Griffiths, 2005).

[C I]: Moving from the CNM through the surfaces of molecular clouds to their cores, the predominant form of carbon transitions from C^+ to CO, with high abundances of C in the transition region. Unbiased surveys of the [C I] fine structure lines, with parameters similar to the STO survey, have recently become feasible (Martin et al., 2004; Zhang et al., 2001). Maps from STO coupled with CO and [C I] data, will follow carbon in all its forms in position, velocity, cooling rate, temperature and pressure as the interstellar gas evolves.

Infrared Continuum Surveys: MSX, Infrared Astronomical Satellite (IRAS), and Spitzer GLIMPSE and MIPSGAL Galactic plane surveys permit locating dark clouds, supershells, and star forming regions using the IR continuum.

5.2 *Complementarity to Other Missions*

STO builds upon the heritage of three pioneering surveys which provided coarse pictures of [C II] and [N II] emission in the Galaxy. COBE (spatial resolution 7°, velocity resolution >1000 km/s), BICE (spatial resolution 15′, velocity resolution 175 km/s), and the Infrared Telescope in Space (IRTS, spatial resolution 10′, velocity resolution 750 km/s). *STO has about the same sensitivity to surface brightness as these missions, but adds orders of magnitude in spatial and spectral resolution.* None of these missions had sufficient spectral or spatial resolution to locate clouds, or separate one cloud from another along a given line of sight, and thus could not draw specific conclusions about cloud properties or distributions, or even the origin of the [C II] or [N II] emission (Hollenbach & Tielens, 1999).

Besides COBE, BICE and IRTS, other platforms include the now defunct Kuiper Astronomical Observatory and Infrared Space Observatory, which did not survey the Galaxy in [C II] and [N II], but made pointed observations. The Spitzer Space Telescope has no spectroscopic capability at these wavelengths. Herschel's HIFI instrument (2009-2013) and (SOFIA, 2009+) will have the capability to observe both [C II] and [N II] at high spectral resolution. The advantage of STO, however, is its ability to provide large scale coverage. Herschel and SOFIA are complementary to STO in providing higher angular resolutions at the [C II] and [N II] lines, $\sim 10''$ as compared to STO's $60''$. Given that Herschel's [SOFIA's] beam covers an area 2% [4%] the area of STO's beam, there will not be sufficient time on these other facilities to complete even a small fraction of the Nyquist-sampled Galactic survey of the scale proposed for STO. Indeed, Herschel & SOFIA are general purpose observatories with a variety of instruments and science goals. We estimate that each facility will map only a few percent of the area of STO's survey in the [C II] and [N II] lines with heterodyne instruments during their lifetimes. It is important that these higher spatial resolution maps be well chosen and STO can provide guidance.

6 Science Implementation

6.1 *Instrument Summary*

The observational goal of STO is to make high spectral (<1 km/s) and angular resolution (∼1 arcminute) maps of the Galactic plane in two astrophysically important atomic transitions: [N II] at 1.5 THz (205 μm) and [C II] at 1.9 THz (158 μm). To achieve the angular resolution requirement we have designed STO to utilize an aperture of 80 cm. To achieve the target spectral resolution, STO will utilize a heterodyne receiver system. STO will be a long duration, balloon-borne observatory which will be launched from McMurdo, Antarctica to an altitude of 120,000 ft, where it will remain for 10-14 days. The instrument portion of STO consists of (1) the telescope, (2) eight heterodyne receivers: four at the 1.5 THz [N II] line and four at the 1.9 THz [C II] line, (3) an eight-channel FFT spectrometer system, (4) the instrument control electronics, (5) the hybrid ^{4}He cryostat, and (6) the gondola.

Requirement	Specification
Telescope:	
Aperture	0.8m
Type	on-axis Cassegrain
Spectral Range	60 to 210 μm
Pointing Knowledge	$\sim$15″
Chopper Throw	$\pm 0.4°$ @ $\sim$1 Hz
Receiver:	
Target Frequencies	[C II]1.901 THz
	[N II]1.461 THz
Angular Resolution	$\sim$1′
Receiver Type	4-pixel HEB Mixer Arrays
Receiver Noise	$\sim$1500K (DSB)
Spectrometer:	
Type	8x1 GHz FFT analyzers
Bandwidth	1 GHz (160-205 km s^{-1})
Resolution	1 MHz (0.2 km s^{-1})
Cryogenic System	
Type	^{4}He+60K cryocooler
Hold time	>14 days

Table 1: Key Instrument Parameters for STO

The STO gondola is based on previous successful JHU/Applied Physics Laboratory (APL) designs and includes (1) the solar arrays and power regulation system, (2) the attitude control system, and (3) NASA-CSBF command & telemetry system. The primary science mission of STO will be achieved in the first 10 days of flight. STO will benefit tremendously from hot electron bolometer (HEB) mixer and solid-state LO technology that has been developed in support of the Herschel mission. The focal plane will be cooled to 4K by a simple ^{4}He cryostat with a mechanical cryocooler to cool radiation shields to <60K to maximize helium hold time while minimizing instrument mass.

6.1.1 STO Telescope

The scientific program for the STO requires that the telescope optics allow a large beam throw ($\sim \pm 0.4°$) out of the Galactic Plane at a speed of $\sim$1 Hz.

For STO we use the same telescope that APL previously employed for its successful balloon instrument the Flare Genesis Experiment (FGE) (Bernasconi et al., 2000) depicted in Figures 11 and 17. The telescope was originally developed by the Strategic Defense Initiative Organization (SDIO) for the Starlab program. Subsequently, it was acquired by APL and modified to fit the science objectives of FGE. The primary mirror is an 80-cm diameter, f/1.5 hyperboloid made of Ultra Low Expansion titanium silicate glass (ULE), and honeycombed to a weight of just 50 Kg. Its surface is polished to visible optical quality, therefore over-specified for imaging in the 100 to 200 μm range. Its support and spider arms are made of graphite-epoxy, which is very light weight, and provides high thermal stability over a wide range of temperatures. Figure 11 shows the FGE telescope during a Sun pointing test session. The same telescope will be used for STO with only minor modifications.

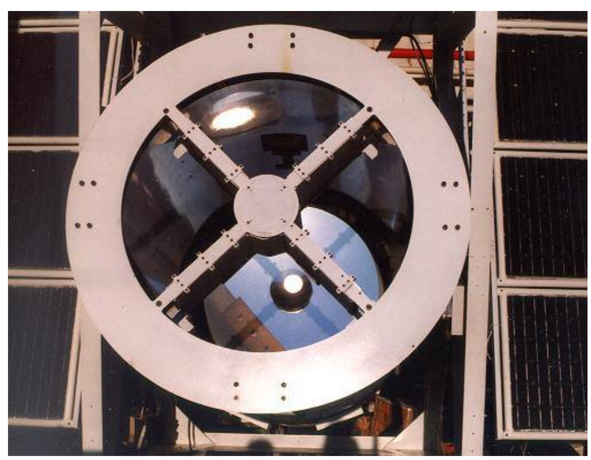

Figure 11: The Flare Genesis telescope while pointing at the Sun

For STO the secondary mirror is redesigned to provide an f/7 beam in the focal plane. The secondary is machined from solid aluminum, with an rms surface accuracy of <4 μm. It is light weighted by machining pockets in the back. The tertiary chopper is located near the back side of the main mirror on a counterbalanced mount to minimize reaction forces. The secondary is oversized so that spillover does not change significantly as a function of chopper throw.

There is a small calibration box located between the telescope and the receiver dewar. This subsystem places blackbody loads at known temperatures in the path of the detectors using linear actuators and moving mirrors. One of the loads is allowed to come into thermal equilibrium with the temperature of the surrounding air: its temperature is monitored by an embedded RTD and recorded. Another load is located on the 60K stage of the receiver dewar. Periodic measurements of the power radiated from these loads allow determination of the detector gain. The power from these loads will also be compared to the variation in power resulting from a change in telescope elevation: a skydip. These measurements suffice to determine the detector noise, the telescope efficiency, and the opacity of the atmosphere and the absolute flux of astronomical sources (Ulich & Haas, 1976).

6.1.2 Receiver Description

The design of the receiver leverages strongly off experience gained by the PI and Co-I's in constructing numerous receiver systems. These receivers have served as facility instruments on the Caltech Submillimeter Observatory (CSO), the University of Arizona Submillimeter Telescope (SMT), the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO), and the SAO Receiver Lab THz Telescope (RLT). A cut-away view of the STO cryostat showing the placement of the receiver system is shown in Figure 12. A diagram showing integration with the telescope is shown in Figure 13a and a block diagram of the instrument in Figure 13b.

The f/7 telescope beam first encounters a freestanding wire grid that divides the incident light into horizontal and vertical polarization components. One polarization passes through the grid into the first vacuum window. The other polarization reflects off a 45° mirror and enters a second vacuum window. The vacuum windows and subsequent 60 and 4 K IR filters are made from low-loss, AR coated, single crystal quartz. The first flight receiver will consist of two, orthogonally polarized 1x4 arrays of superconductive hot-electron bolometer (HEB) mixers operating at 4K. One array is optimized for the [C II] (1.90 THz) line, the other for the [N II] (1.46 THz) line. The mixers will be pumped by two, frequency tunable, solid-state Local Oscillators (LO's). The final multiplier stage is mounted to the

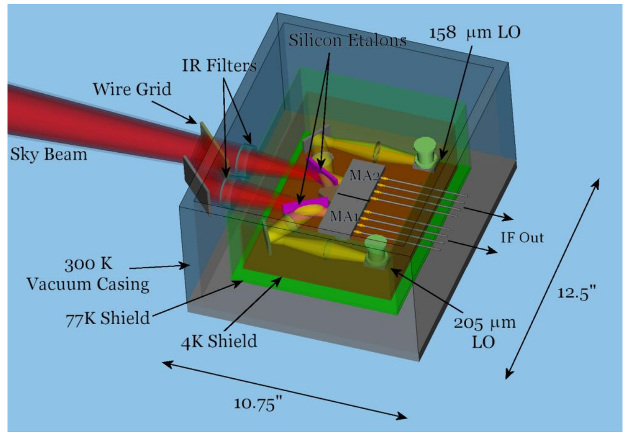

Figure 12: 3-D cutaway rendering of the flight instrument cryostat

4 K cold plate via G-10 stand-offs to the 60K stage. At this temperature the multiplier emits approximately twice the power it would at ambient temperatures. An integrated, waveguide power splitter at the output of each multiplier efficiently divides the LO power four ways and couples it via a silicon etalon into each mixer. The silicon etalon is designed to pass $\sim 95\%$ of the sky signal and reflect $\sim 68\%$ of the LO signal (Mueller & Waldman, 1994).

Low-noise, InP High Electron Mobility Transistors (HEMT) amplifiers are integrated into each array mixer and serve as the first stage intermediate frequency (IF) amplifiers (Puetz et al. 2006). The IF center frequency will be ~2 GHz, with an instantaneous bandwidth of ~1 GHz. This IF frequency and bandwidth can be supported by NbN phonon-cooled mixers. At our highest observing frequency (1.9 THz, the [C II] line) a 1 GHz IF bandwidth will provide 160 km/s of velocity coverage. A velocity coverage of this order is needed to accommodate the wide velocity dispersion expected toward the inner parts of the Galaxy. Doppler tracking of the LO frequency will keep the received signal centered within the IF band. The eight IF signals from the mixers pass through an ambient temperature IF processor where they are further amplified and downconverted to baseband (0-1 GHz). STO will use eight 1 GHz wide, 1024 channel digital FFT analyzers as backend spectrometers for the mixer arrays. A flight instrument electronics box will house (1) the IF processor board, (2) the 8x1 GHz spectrometer boards, (2) the LO/HEB/LNA bias board, (4) calibration flip mirror controller board, and (5) the Instrument Computer. The Instrument Computer communicates to the Gondola computer via an RS-

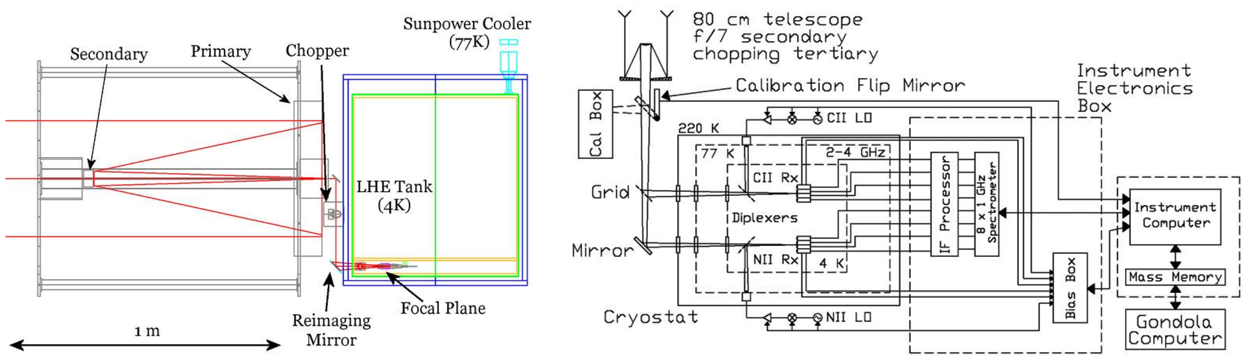

Figure 13: (a) Instrument and telescope integration configuration, demonstrating how the complete STO instrument will fit into the payload footprint of the previous Flare Genesis instrument. (b) Block diagram of the instrument flight package.

422 bus. Prototype versions of all boards exist.

6.1.3 Expected Sensitivity

Recent lab measurements on waveguide and quasi-optical HEBs in the 1 to 2 THz range have yielded double side band (DSB) receiver noise temperatures in the 1000-2000K range. For our sensitivity calculations we have assumed a receiver noise temperature of 1000-1500K and T_{sys} = 2000-3000K. With the 12 second integration time per Nyquist-sampled resolution element characteristic of the unbiased, Galactic Plane survey (GPS) mode, we will be able to achieve an rms noise level of 0.4 K at a 1 km/s velocity resolution. The STO instrument characteristics are summarized in Table 1.

6.1.4 Component Selection

Technical Approach to Mixers

HEB mixers (both in the lab and in the field) have been shown to have the sensitivity needed for the proposed STO science investigations. The STO mixer design follows the very successful and practical HEB instruments that were developed by the submillimeter receiver groups at the Smithsonian Astrophysical Observatory (SAO) and the University of Cologne. A plot of the noise temperature of these HEB receivers as a function of frequency is shown in Figure 14a. JPL/SAO has tested receivers up to 1.5 THz and the Cologne group up to 1.9 THz. The SAO instrument has been used on a telescope in the high Atacama over a two-year period and used to detect line emission from celestial sources from 0.69 THz to 1.46 THz. A University of Cologne receiver was also field tested in this frequency range on a telescope in the Atacama. Transitioning these superconductive HEB mixers to a gondola instrument will be straight forward. The mixers utilize a fixed-tuned waveguide design with high efficiency feedhorns. Traditional machining methods are used to fabricate the mixer blocks. The mixer circuitry, including the mixer element, waveguide probe and choke structure, is fabricated on a thin substrate which is laid in a suspended microstrip channel intersecting reduced-height waveguide (see Figure 14b). Using SOI substrates for the HEBs, this type of mixer can be scaled for operation to 4.7 THz (the 63 μm [OI] line). HEB mixer operation has been demonstrated to frequencies above 5 THz (Gao et al., 2004).

The 1x4, 1.46 THz array will be provided by JPL and the 1x4, 1.9 THz array by the Univ. of Cologne.

Technical Approach for the LO hardware

The 1.46 and 1.9 THz solid-state local oscillator sources required for the first flight instrument are commercially available from Virginia Diodes Inc. (see Figure 15). The LO's have a tuning range suitable for Doppler tracking of sources and have sufficient output power when cooled to pump the array mixers. The LO chains are driven by small, low-cost, programmable 13-15 GHz synthesizers which are available, for example, from CTI/Herley. The Instrument Computer will routinely update the synthesizer frequency to maintain Doppler tracking during observations.

Solid state LO's as described here do not provide sufficient power to drive arrays of mixers above ∼2 THz. Fortunately, in this frequency regime quantum cascade lasers (QCLs) (Hu et al. 2005) and compact gas lasers (Mueller 2006) can be fabricated that provide more than enough power to drive HEB arrays for future STO flights.

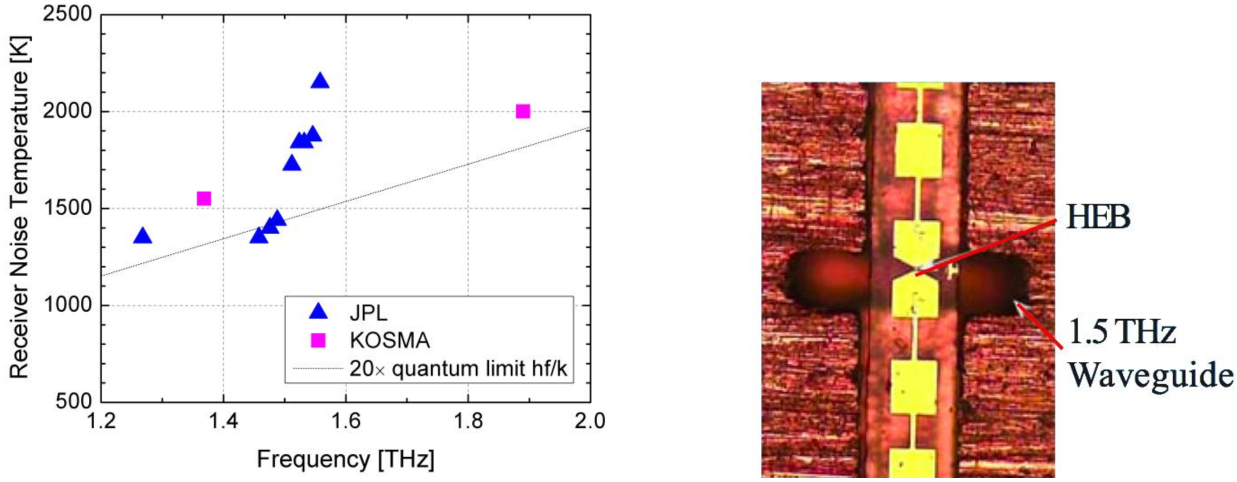

Figure 14: (a) THz HEB mixer performance from SAO using JPL-supplied NbTiN mixers and the University of Cologne. (b) SAO waveguide HEB implementation

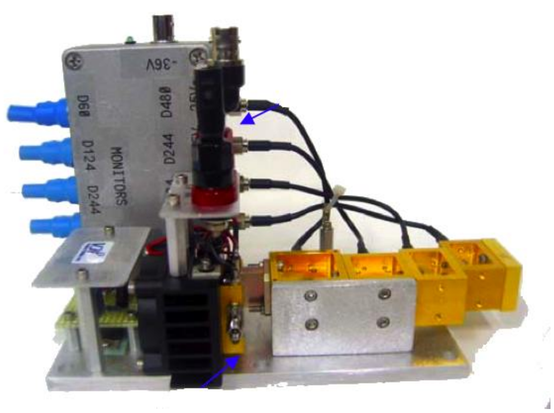

Figure 15: Virginia Diodes 1.5 THz synthesizer driven local oscillator chain

Figure 16: The assembled 16 GHz FFT spectrometer from the PI's Supercam project is no larger than a rack-mounted PC! The equivalent of half of this spectrometer will be purchased for STO.

6.1.5 Digital Spectrometer

Thanks to rapid advances in digital processing, single-board digital spectrometers that meet STO's requirements are now commercially available. One such spectrometer board is available from Omnisys Inc. Developed originally for the PI's 64-beam 345 GHz heterodyne array ("SuperCam") project, the Omnisys board has four 1 Gs, 8-bit digitizers and a Xilinx Virtex4 FPGA which together perform a realtime FFT of the IF signal. The baseline spectrometer card has 2 GHz of total bandwidth and achieves excellent performance and stability. A picture of the delivered 16 GHz spectrometer system for SuperCam is shown in Figure 16. Four Omnisys boards will be baselined for STO, providing 8 IF inputs with 1 GHz of bandwidth each. The demonstrated power dissipation of the complete 8 x 1 GHz spectrometer system is <100W.

6.1.6 Cryogenic System

The STO flight cryostat will use liquid ^{4}He to cool the instrument to the required operating temperatures. An off-the-shelf mechanical cryocooler will cool the radiation shields to 60K to give the 4K helium stage a >14 day holdtime. The flight cryostat is based on a thin wall cylinder design that utilizes stiffening rings located at critical segment interfaces. A finite element analysis will determine actual material thickness from acceleration data typical for a gondola payload. Certificate compliance forms will trace all materials and fabrication used in manufacturing the cryostat. The internal support structure will use G10 supports to maintain stiffness and allow for thermal contraction. The cryostat will have an aluminum case with welded internal vessel and use high performance vapor shields to enclose the inner ^{4}He vessel.

6.2 STO Gondola

6.2.1 Heritage

The STO program will build upon the 15 years experience in ballooning resident at APL. In the early 1990s, APL started developing a balloon system for the NASA funded Flare Genesis Experiment (Figure 17) to conduct high spatial resolution solar vector polarimetric imaging (Bernasconi et al., 2000). FGE required high stability pointing on the order of a few arc seconds. APL developed a balloon attitude control system that was able to point at the Sun with an accuracy of 20″ and a stability of <8″ RMS. Subsequently, APL used the same gondola and attitude system with the Solar Bolometric Imager (SBI) for conducting solar irradiance studies (Bernasconi et al., 2004). SBI was also funded in most part by NASA. Both efforts heavily involved APL's space department engineering group as well as the APL Technical Services Department. This pool of expertise will be utilized in the implementation of STO. Mr. Harry Eaton of TSD will be the gondola lead systems engineer. Mr. Eaton is a very experienced electrical engineer who contributed to all APL balloon programs since the mid 1990s and is currently the lead engineer for the SBI program.

Figure 17: APL's Flare Genesis gondola during integration tests in Palestine, TX in 1999.

6.2.2 Gondola Structure

The STO observing platform (gondola), shown in Figure 18, is the one previously used by APL for its FGE (Figure 17) and SBI balloon programs. The gondola has successfully endured two test flights in New Mexico (in 1994 and 2003) and three Antarctic flights (in 1996, 2000, and 2006). During the past ten years the gondola and its subsystems have undergone many improvements and upgrades. The STO project will benefit directly from this flight heritage. There is no need to design, manufacture and test a new gondola.

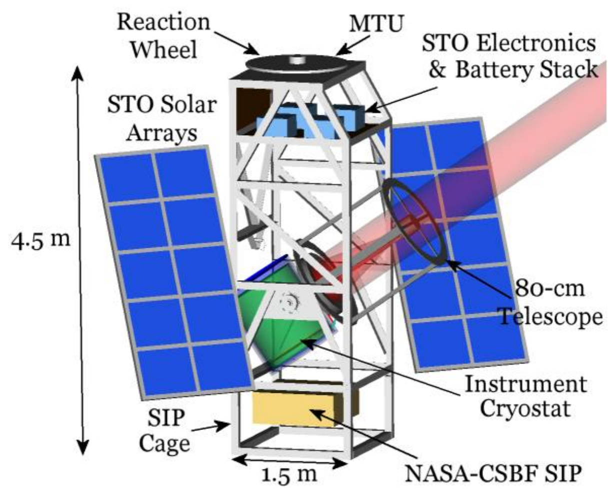

Figure 18: 3-D rendering of the gondola package, including 80-cm telescope and science payload.

The gondola carries and protects the telescope and attached Dewar and detectors, houses the command and control systems for both STO and NASA-CSBF, and the power system. Its basic dimensions (without solar arrays) are: 2m wide, 1.5m deep, and 4.5m high. The frame is made of standard aluminum angles bolted together and painted with a white thermal coating. The structure is strong enough to support up to 2000 Kg even under the 10 g shock experienced at the end of the flight when the parachute inflates. It is rigid enough to allow the required telescope pointing stability of <15″. The gondola can be separated into lighter components for easy post-flight retrieval in the field.

The gondola structural and servo systems are designed for the estimated masses shown in Table 2. The total mass of the STO payload is well below the design structural limit of the APL gondola.

NASA-CSBF balloon command and control electronics (the Support Instrument Package, SIP) is attached below the telescope, inside a protective alu-

Item	Weight lbs	Kg
Gondola with command & control:	2200	998
Telescope:	200	91
Heterodyne spectrometer/He dewar:	200	91
CSBF Equipment:	570	258
Ballast allotment:	600	272
Total:	3770	1710

Table 2: Launch weights estimates for STO payload.

minum cage the same way it was for FGE and SBI. Communications from the SIP to the balloon and parachute control mechanism are guaranteed via slip rings through the rotating part of the Momentum Transfer Unit on top of the gondola. APL will use the same slip rings successfully tested for the FGE and SBI programs.

APL already has detailed thermal and structural models for the current configuration of the APL gondola. The models will be modified to take into consideration the mechanical and electronics changes necessary to fit the STO program. Subsequently, APL will perform a new thermal and structural analysis with the modified models to ensure the overall experiment can achieve its science goals and satisfy all NASA-CSBF structural and thermal requirements. APL has sufficient data taken on previous balloon flights to make highly reliable thermal and mechanical predictions. System testing will be conducted at APL's high-bay Balloon Payload Integration facility with a suspension system comparable to the balloon train.

6.2.3 *Pointing system*

The pointing system will use part of the current SBI system. However, since STO will target objects other than the Sun, a substantial design change will be required to accommodate STO science objectives. The STO pointing specifications are a pointing range of 360° in azimuth and 0 to 54° in elevation, stability <30″, pointing knowledge <15″, and source acquisition accuracy <40″.

The telescope is attached to the gondola on its elevation axis as shown in Figure 18. To point in azimuth the entire gondola will rotate on the vertical axis with angular momentum compensated for by a reaction wheel.

Two operating modes are provided for telescope pointing. Position Mode is used to acquire a source while Inertial Mode is used in inertial tracking and source scanning. In Position Mode STO will use the SBI coarse and intermediate Sun sensors to orient itself towards the target in azimuth with an accuracy of about 0.5°, and it will set the elevation of the telescope according to computed ephemeris with a precision of a 0.17°; see (Bernasconi et al., 2000) and (Bernasconi et al., 2004). The fine acquisition of the target will be done with a star tracker mounted parallel to the telescope optical axis. It will have a field of view of 2°, a position accuracy of 40″, and a readout rate of 2Hz. APL will select a star tracker based on either BLAST or HERO balloon experiments.

Once fine position knowledge and stability is achieved with the star tracker, the pointing system will transition into Inertial Mode by using position information from two optical Inertial Measurement Units (IMUs), model NL-200 by Northrop Grumman. One IMU will be attached in line with the gondola azimuth rotation axis and used for the gondola fine azimuth control. The second IMU will be attached to the telescope and provide fine elevation pointing error information. Source fine positioning is achieved in both axes by introducing artificial gyro-drift. This method is also used to create line scans, raster patterns and fine source positioning.

The digital control system will be the same as used for FGE and SBI. It uses a Proportional-Integral-Derivative (PID) controller to determine motor drive from sensor position errors. Each pointing mode has 4 control coefficients per axis that can be adjusted in flight for optimum performance.

6.2.4 *Power system*

The STO power system design will be essentially the same used for SBI (Bernasconi et al., 2004). It consists mainly of three elements: the solar arrays, the charge controller, and the battery stack.

The solar arrays are composed of eight panels each with 65 cells for a total of 520 cells covering a total surface of 8.2 m^2. These model A300 cells from SunPower Corp have 21.5% efficiency. The total power delivered by the arrays is about 1400 W while the estimated total STO power requirement will be only 830 W. This gives us a margin of 570 W. The arrays will be assembled by SunCat Solar of Arizona who previously built the arrays for SBI. The cells will be encased in a transparent laminate on honeycomb substrate that will ensure rigidity and offer good protection to the cells. In 2006 SBI's flight the same type of arrays survived the harsh landing virtually undamaged. To provide the optimum Sun viewing angle while conducting the scientific measurements, APL will attach the STO solar arrays at at 45° with respect to the front of the gondola and facing to the right (see Figure 18).

The charge controller was originally designed and built for FGE by Meer Instruments of San Diego (CA) who delivered power systems for several NASA LDB payloads including HIGHREGS, BOOMERANG, and ATTIC. It distributes the load across the panels as the power demand changes. It also ensures that the system's battery stacks are maintained at full charge, sunlight permitting, and provides on/off power switching capability from ground commands. It will be the same used for SBI and will require only minor adjustments and updates to accomodate STO's requirements.

The battery stack is composed of four sealed lead-acid ODISSEY PC1700 batteries in an arrangement of two pairs in series connected in parallel. The stack has a capacity of 130 amp-hours with a nominal bus voltage of 24 V. The ODISSEY batteries can operate in vacuum, exhibit great performance characteristics and have an excellent operating temperature range from -40°C to +80°C. We used these batteries for SBI with excellent results.

6.2.5 *Command and Control System*

Some modifications in the SBI command and control system hardware and software will be required to account for the new STO science control computer and modified attitude control system. Figure 19 gives an overview of the control system.

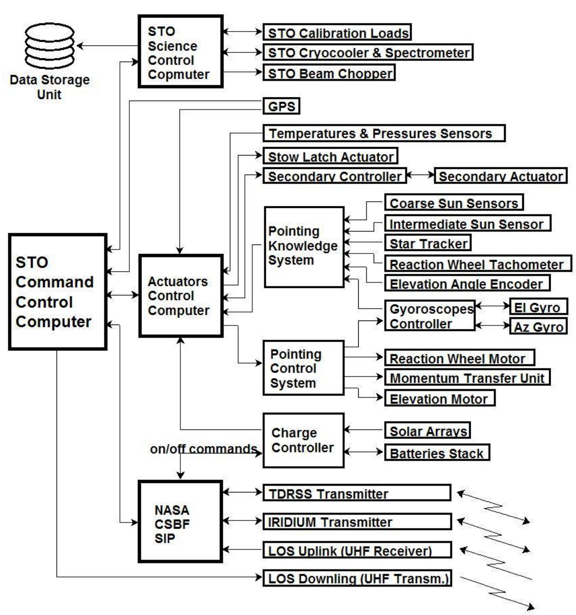

Figure 19: Gondola subsystems block diagram.

There are two main gondola computers on-board: the Command and Control Computer (CCC) and the Actuators Control Computer (ACC). Both computers use a commercial ATX mother board with a Pentium-based CPU, solid state hard drives and Linux as the operating system. They are housed in two pressurized vessels that maintain 1 atmosphere pressure throughout the flight, allowing to use off-the-shelf commercial grade electronic components. The CCC is responsible to schedule all the operations performed by the gondola and handles the communications between the gondola subsystems and the ground. It also communicates to the science computer via an RS232 serial channel. It can operate fully autonomously or execute commands received from the ground. The ACC acts as interface between the CCC computer and all the other gondola subsystems. It gathers all the housekeeping data (temperatures, pressures, voltages, ...) and sends them to the CCC for delivery to the ground. The ACC also handles the attitude control system. It receives position information from all the attitude sensors on-board and computes the control signals for the reaction wheel, momentum dump, and elevation motors to control and stabilize the pointing.

6.2.6 *Telecommunications*

Similar to the SBI, STO will rely entirely on the NASA-CSBF provided remote link to/from the gondola for the communications between STO and the ground. The communications interface through the SIP is shown in Figure 20. The current communication system works flawlessly and virtually no modifications are needed to adapt it for the STO mission.

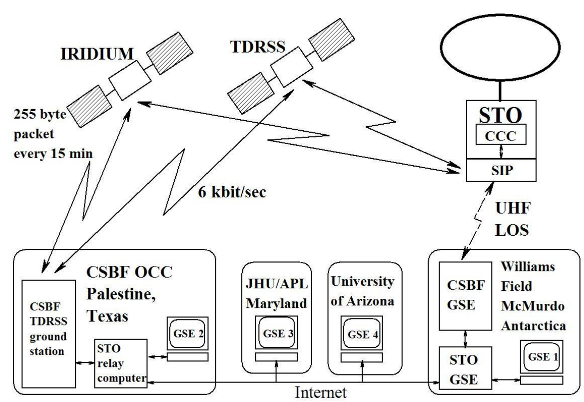

Figure 20: Schematic of the telecommunication system between STO and the ground

The SIP has three available channels to/from the ground. For 24 hours the gondola will be within the

Line-of-Sight (LOS) to the launch station at Williams Field in Antarctica and will use a UHF radio link at a data rate of 38.4 Kb/s. Commands directly from the ground can be used to override normal subsystems automatic operations if necessary. During LOS operations ample amounts of housekeeping data will be available for analysis of both science and gondola performance. Most of the science data will be downlinked through the LOS channel and stored on the ground computers to guarantee a minimum data return from the mission.

After loss of the LOS radio link, communications will be maintained via a 6-Kb/s TDRSS satellite relay and a lower rate IRIDIUM relay (one 255 bytes packet every 15 minutes). The TDRSS and IRIDIUM signals will be received at NASA-CSBF's Operations Control Center (OCC) in Palestine (TX) and relayed to a local STO ground support computer that will redistribute the data packets to other STO ground stations at APL, Univ. of Arizona and to the team in Antarctica. All the STO ground stations will be able to display and store the same telemetry information received at the OCC, and commands can be sent to the gondola computers from any station. Outside of LOS, a reduced data set will be recorded on the ground that will be sufficient to meet the minimum science goals in the case of loss of the payload. The ground support computers will use the software package GSEOS, by GSE Software, Inc., that was previously used for FGE & SBI. This package is widely used at APL to interface with space missions like MESSENGER and New Horizons.

6.3 *Data Analysis and Archiving*

A primary challenge of On-The-Fly mapping is data management. We therefore plan to adopt a scheme similar to that developed at FCRAO, whereby coadded and regridded data is written as FITS & CLASS files, and headers for each scan are written into a MySQL relational database, which facilitates efficient logging and retrieval of the data. The most demanding storage requirements for 35 sq. degree spectral maps is 10 GB. This volume can be readily handled by embedded computers with nonvolatile FLASH memory. The spatially & spectrally regridded final data product encompasses $<$500 MB.

While the entire science team will be involved in analysis and interpretation of the data in Spring 2011, near-immediate access of these data products to the greater scientific community will be provided through a web browser interface that interfaces with MySQL and the FITS data cubes. There will be three data product releases in the proposal performance period: (1) a "first flight" data release of the Orion Molecular Cloud in [C II] line emission following the Palestine TX test flight in summer 2010; (2) a preliminary release after the first Antarctic mission in March 2011, and (3) a final release of all data in June 2011. The final release will be fully calibrated and will include all science products.

All science tools, packaged reduction software, data products and catalog products will be made available from the STO survey web page.

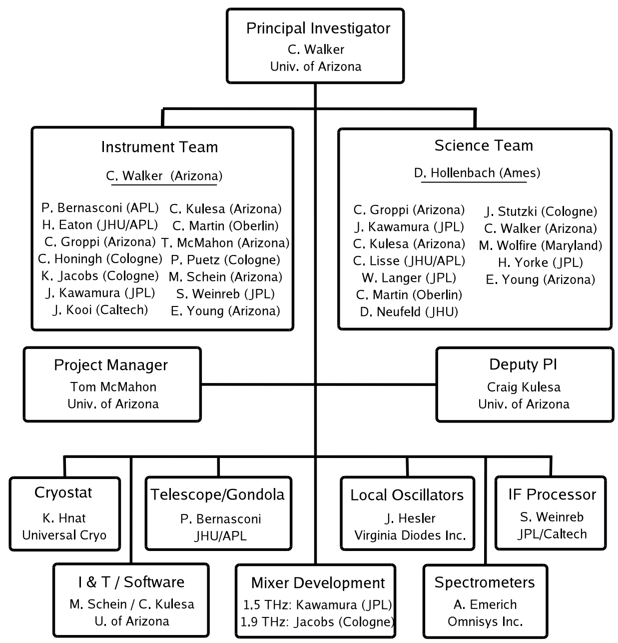

Figure 21: STO Organizational Diagram

7 Management

The STO project brings together an experienced team of researchers from 8 institutions; the University of Arizona, Johns Hopkins Applied Physics Laboratories, NASA Ames Research Center, Jet Propulsion Laboratory, Caltech, Univ. of Maryland, Oberlin College, and the University of Cologne. These organizations and individuals have successfully collaborated on a wide variety of projects in the past and look forward to making STO and the science it will produce a reality.

7.1 *Project Management & Organization*

The organizational structure of STO, shown in Figure 21 is designed to provide effective control of the project while allowing delegation of authority

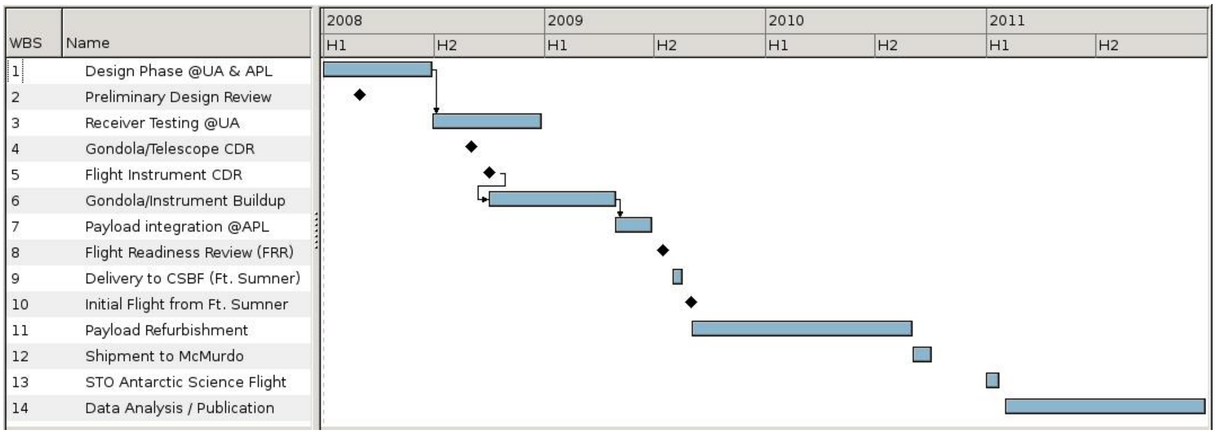

Figure 22: STO Master Schedule

to be made at the proper level within the team. Dr. Walker (PI) is responsible for all aspects of the success and scientific integrity of STO. He will be assisted at the University of Arizona by Dr. Craig Kulesa, who will serve as Deputy PI and Tom McMahon, Project Manager (PM). The STO science team will be led by Dr. David Hollenbach (NASA Ames) who will be STO Project Scientist (PS). The Instrument Team will be led by the PI (Walker). Dr. Bernasconi (APL Institutional PI) will oversee the STO gondola efforts at APL. Dr. Jonathan Kawamura will oversee the 1.46 THz mixer development at JPL. Dr. Karl Jacobs and Dr. Patrick Puetz will oversee the 1.9 THz mixer development at the University of Cologne. Dr. Sander Weinreb will oversee the IF chain development at Caltech. The STO team will make extensive use of electronic communication and management tools including e-mail, secure websites, on-line meetings and video communications to expedite accurate information dissemination. All pertinent management and control information will be posted on a secure STO website maintained by the UA and available to all participants. These tools will be used in daily interactions as well as in weekly team telecons and monthly status briefings to ensure that major issues are visible to and addressed by all affected team members. In addition, face-to-face team meetings will be conducted when appropriate, often in conjunction with program milestones.

7.2 *Master Schedule*

The master schedule shown in Figure 22 identifies the project's major milestones and development activities. Starting at the Jan. 1 2008 start date, the project would launch into a focused preliminary design phase for the flight hardware and software. This effort culminates in a Preliminary Design Review (PDR) in late March 2008. The scope of the PDR covers the entire flight payload. The project then moves into the critical design phase with Critical Design Reviews for the gondola/telescope and flight instrument held in August and September 2008 respectively. Tests of the [C II] receiver in a lab cryostat are scheduled to commence in December 2008. The flight cryostat construction will be complete in March 2009 with integration and testing of the [C II] receiver in the cryostat in May 2009. Delivery of the flight instrument to JHU/APL for integration into the STO gondola will take place in June 2009. Full system tests will be carried out at APL through July 2009 ending with a Flight Readiness Review (FRR). Following the successful FRR, the STO will be shipped to the CSBF facility for US flight trials in September 2009. After the initial test flight the STO gondola/telescope will be refurbished at APL and the [N II] receiver added to the flight cryostat at the Univ. of Arizona. The final instrument and gondola integration and test will take place at APL in the Spring of 2010. STO will be shipped to Palestine in July-August 2010 where APL will integrate the STO payload with CSBF's balloon control and communication equipment. STO will then be shipped to McMurdo in September 2010. The flight support team members will deploy to McMurdo in Oct. 2010 to prepare STO for the Antarctic flight. The window for flight operations is December 2010 through January 2011. Science data reduction and analysis will start immediately after conclusion of flight operations.

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Summary of Personnel and Work Efforts

Each member of the Stratospheric Terahertz Observatory Team has a clearly defined role in the mission. Each has been selected based both on their specific expertise and the desire and commitment of the organizations and individuals to contribute their unique experience in this mission. Table 1 summarizes the project role and experience that supports their selection as a team member.

Participant	**Team**	**Affiliation**	**Participation Activity**	**% Effort per year**			
				1	**2**	**3**	**4**
Christopher Walker	I, S	Arizona	Project PI, star formation	8	8	8	8
Pietro Bernasconi	I	JHU/APL	Gondola and Telescope Systems	21	29	21	17
Paul Goldsmith	I, S	JPL	Heterodyne Systems, ISM physics	0	5	5	5
David Hollenbach	S	NASA Ames	Project Scientist, ISM Processes	10	10	30	35
Jonathan Kawamura	I, S	JPL	1.5 THz Receiver System, ISM	25	25	25	25
Craig Kulesa	I, S	Arizona	Deputy PI, software, ISM physics	25	50	50	50
William Langer	S	JPL	ISM Physics and Star Formation	0	5	5	5
Carey Lisse	I	JHU/APL	Gondola system Bus	4	5	5	17
Chris Martin	I, S	Oberlin	Receiver Systems, Submm Surveys	8	8	8	8
Thomas McMahon	I	Arizona	Project Manager	15	25	25	15
Patrick Pütz	I	Arizona	STO Postdoc; 1.9 THz HEB receiver	50	50	50	50
Michael Schein	I	Arizona	Gondola Integration Consultant	0	15	0	0
Anders Skalare	I	JPL	1.5 THz HEB receiver	20	10	5	0
Jeffrey Stern	I	JPL	1.5 THz HEB receiver	20	10	5	0
Mark Wolfire	S	Maryland	Physics of the ISM	0	0	25	33
Harold Yorke	S	JPL	Synergy with Herschel surveys	0	5	5	5

Table 1: Activities of the Science (**S**) and Instrumentation (**I**) Teams

Facilities and Equipment

University of Arizona, Steward Observatory

Steward Observatory has a large technical staff with many years of experience in the design and construction of state-of-the-art telescopes and instrumentation for use from optical (e.g. MMT, Magellan, and Large Binocular Telescope (LBT)) to millimeter/submillimeter wavelengths (e.g. Heinrich Hertz Telescope (HHT)). This expertise will be augmented by Instrument Team members with Polar experience and utilized during the development of STO.

In 1992 the PI established a laboratory (the Steward Observatory Radio Astronomy Laboratory, SORAL) for the development of state-of-the-art submillimeter-wave receiver systems. SORAL will work closely with JPL and the University of Cologne in the design and development of the STO receiver system. SORAL possess all the equipment (spectrum analyzers, network analyzer's, vacuum pumps, cryogenic support facilities, etc.) needed for the development of receivers. We also have ^{4}He, ^{3}He, and closed-cycle cryostats, a full receiver testbed, local oscillator sources (including a Coherent/DEOS FIR laser), and an antenna test range which allow us to characterize a wide range of receiver systems. SORAL has licenses for Hewlett Packard's High Frequency Structure Simulator (HFSS) and Advanced Design System (ADS) software packages, as well as Agilent HFSS and CST Microwave Studio. These programs are used to accurately model and optimize mixers and other crucial receiver components. In addition, we have licenses for optical and mechanical design packages such as Zemax, Code V, and Inventor.

Using these facilities, SORAL has designed and built a number of receiver systems; including single pixel 230, 490, and 810 GHz receivers and the world's first 345 and 810 GHz arrays. SORAL has been the primary facility instrument builder for both the 10m Heinrich Hertz Telescope on Mt. Graham, Arizona and the AST/RO telescope at the South Pole. Based upon the success of these instruments, the PI was awarded a NSF Major Research Instrumentation (MRI) grant to design and construct the world's largest submillimeter wave heterodyne instrument; a 64 pixel, 345 GHz array receiver. The instrument (known as *SuperCam*, short for Superheterodyne Camera) is a mult-institutional project, much like STO, with many of the same team members. The STO receiver development will leverage greatly from SuperCam. STO will utilize the same state-of-the-art KERN micromilling machine for making mixer blocks and optics as SuperCam, as well as the same multi-pixel heterodyne array bias and control systems. The timing of the STO award would immediately follow the last year of the SuperCam effort.

Budget Justification

BUDGET NARRATIVE INTRODUCTION

This proposal is a resubmission of the 2006 STO proposal which received excellent reviews, but was not selected due to programmatic cost constraints. This year we are fortunate to have an existing gondola and telescope from the Johns Hopkins University Applied Physics Laboratory (APL) available for the project. This gondola/telescope has been demonstrated to be capable of meeting or exceeding our original design specifications. The availability of this gondola (together with a more efficient use of resources) has led to more than a factor of two reduction in STO's overall cost.

This Budget Element explains the total cost the University of Arizona (UA) is expected to incur during the 4 year period of performance of this project (January 1, 2008 – December 31, 2011). The estimates include all labor costs, materials, capital expenses, travel, and indirect (F&A) charges. The UA budget will be one element in a larger budget to be submitted to the NASA ROSES-2007 Announcement of Opportunity (AO). The total project cost is approximately $5 million. This proposal is being submitted as a *Multiple-Institution* proposal with the University of Arizona acting as the lead institution. As instructed by the ROSES AO each of the Co-Investigator institutions will be requesting separate awards by independently submitting their institutional budgets and task statements. The Principal Investigator, Dr. Christopher Walker, is a UA faculty member.

2007 DOLLAR AND SALARY INCREASES

The budget was calculated using 2007 dollars. A salary increase of 3% annually (each January) was used for all staff listed.

DIRECT LABOR

Year	2008	2009	2010	2011	All Years FTE
Faculty & Science	0.9	1.2	1.8	1.8	5.7
Technical Personnel	0	.25	0.5	0	0.75
Management	0.3	0.4	0.4	0.3	1.4
Graduate Student	0.7	0.7	0.7	0.7	2.8

Summary

The labor hours applied to the research in the period specified is 16,532 labor hours. This is averages out to an average of 2.2 FTE per year for the period of performance(based on 1840 hr work year). The labor FTEs are broken down by calendar year in Table B:

Table B1: Annual Labor Breakdown

Layout

The UA budget uses calendar years (Jan-Dec) as the time ordinance and has been divided into the basic categories of: 1) Labor; 2) Capital Equipment; 3) Travel; 4) Operations; 5) Indirect costs (F&A). The budget details start with the direct labor calculations for all participants that are to be directly compensated. The direct labor is calculated using the base hourly wages and the level of effort (number of hours) of each individual. The detailed budget includes the starting hourly wages (based upon April 2006 values). Year 1 direct labor is calculated using this wage. For each subsequent year the hourly wage is increased by a 3% (inflationary increase) factor to arrive at the adjusted labor cost. The grand total of the direct labor is the sum of all wages with the benefits.

$$\text{Annual Wages} = \text{Rate}_{2007} * \text{Effort} * 1.03^{n-1}$$

where n=1,2, or 3.

UA Academic and Summer Terms
The Faculty and Student employee year is broken into the academic and the summer terms. The academic term is 9 months, or 39 weeks in duration. The summer term is 3 months or 13 weeks in duration.

UA Faculty and Student Academic and Summer Hours and Rates

Faculty members are allowed a total of 497 hours of compensation during the summer term and 1760 hours during the Academic term. The faculty summer rate is calculated using 166 hours per month. The faculty hourly rate is calculated using the following formula: *Rate = (Academic Salary)*.00067*.

Graduate students are allowed to work a total of 880 hours (98 hrs/month) during the academic term and 540 hours (180 hrs/month) during the summer term. The hourly rate is calculated using the formula: *Rate = (2*Academic Salary)*.00067*.

UA Appointed Personnel and Classified Staff Hours
Appointed and Classified staff hourly rates are calculated using a 2088-hour work year or approximately a 173-hour work month.

UA Administrative Support for this Project
The project will employ a <u>part-time</u> administrative staff of two, whose primary responsibility is to support the research and researchers. The core administrative support includes, but is not restricted to: project coordination and oversight; purchasing and tracking of specialized research equipment and unusual research support items; shipping and importation: inter-organizational communications and coordination; documentation preparation and production; graphics and document database management; travel coordination and preparation. The project management effort will include detailed financial tracking as well as project requirements and goal tracking. The effort for these duties are over and above the typical departmental duties provided.

The tasks described above fall within the University's designation of a "Major Project" and therefore require direct charging of the administrative support. Listed within the budget are wages and benefits for the administrative support staff. The administrative support costs are subject to the University's Indirect

Table B2: Benefits Schedule

Employee Type	Jan '08 – Dec '11
Faculty	26.7%
Appointed Staff	26.7%
Classified Staff	38.5%
Graduate Students	
Tuition Remission	27.4% (excluded from indirect)
Fringe Benefits	11.2%

Cost. If the proposal is awarded, the Project Manager will officially request Major Project status with Sponsored Projects.

Fringe Benefits Rates
The benefits rates are listed in Table B2. The dollar value is calculated by multiplying the benefits rate to the wages earnings for the specified period.

$$\text{Benefits \$} = \text{Hours x Hourly Rate x Benefit rate}$$

SUBCONTRACTS
No subcontracts are called out within the scope of this proposal.

CONSULTANTS
A consultant is called out within the budget in years 1, 2 , and 3. This consultant will provide expertise on the integration of the science instrument with the balloon gondola. The total amount is estimated at $15000.

EQUIPMENT
Capital equipment purchases ($468,033) are budgeted in in the proposal. The following table (Table B3) describes the capital elements and their function. There is an element of fabricated equipment to be required for the success of the project. Fabricated Equipment is defined as elements that are assembled or fabricated within the University from elements that are non-capital acquisitions.

Table B3: Capital Acquisitions

Capital Item	Description	Cost	Method of Estimate	Notes
Instrument Control Workstation (Qnty 1)	Personal computer systems used for the development of control system software. Unit to be used as lab development platform and lab testing of instrument payload.	$5000	Estimate from recent purchases	
8-Pixel Spectrometer System	Performs autocorrelation on the 8 downconverted signals from the receiver, producing 8 power spectra.	$85,260	Vendor quote	Identified vendors are: OmniSys Inc.
VDI (Local Oscillators)	Used together with the mixer units to downconvert received signals to lower frequencies	$212,273	Vendor quote	Identified vendors are: Viginia Diodes Inc
LO Synthesizers	Used to provide a low frequency, phased-locked tone to pump the VDI LOs	$10,500		Identified vendors are: Miteq Inc. CTI Herley
Flight & Test Cryostat	Two (2) cryogenically cooled (4 Kelvin) vacuum vessels used for: 1. Testing instrument subcomponents (LOs, Mixers, Correlator, etc. in part and as system; 2. Flight instrument	$25,000 (Test Cryostat) $115,000 (flight model)	Vendor quote	Purchase will be conducted through a competitive bid process. Universal Cryostat is one identified vendor.
Telescope Tertiary Chopper	Mechanism that oscillates the secondary mirror to enable background subtraction	$8000	Recent purchase of similar system	
Calibration Box	Blackbody calibrator system	$7000	Recent purchase of similar system	

Table B4: Capital Acquisitions

Equipment Item	Description	Cost	Notes
Mixer Mounts	The waveguide mixer mounts in which the Hot Electron Bolometer (HEB) devices from JPL & the University of Cologne are mounted. They are fabricated at the University of Arizona using a high precision, micromilling machine.	$20,500	Cost estimates derived from SuperCam project
Array Bias System	The computer controlled bias electronics for biasing the HEB mixers and 1st stage Intermediate Frequency (IF) amplifiers.	$10,250	Cost estimates derived from SuperCam project
Instrument Control Computer elements	Subsystems that will augment the Instrument control computer. Elements include PCI cards, RAID storage devices	$5000	
Miscellaneous Machining	Fabrication of various hardware elements to support the build of the test and flight cryostat as well as any repairs needed post-test flights.	$18,820	Item include but are not limited to brackets and small optical components needed for the cryostat and focal plane array.

Table B5: Annual Travel

Travel	2008	2008	2008	2009/2010	2009/2010	2009	2010	2010	2011
Destination	(A) Boston, MA	(B) Pasadena, CA	(C) Austin, TX (AAS)	(D) Palestine (Dallas), TX	(E) Palestine (Dallas), TX	(F) Long Beach, CA (AAS)	(G) AAS (TBD)	(H) Pasadena, CA (meeting)	(I) AAS (TBD)
Airfare	583	300	318	318	318	318	500	347	500
Lodging	360		360	700	700	371	382	382	382
Per Diem	139	45	139	245	245	143	147	147	147
Registration	350		350			361	372	372	372
Rental Car		80	180	191		191	197	197	197
Per Person Totals	1432	**425**	**1347**	**1454**	**1263**	**1384**	**1598**	**1445**	**1598**

Trips	2008	2009	2010	2011
(Type) Number	(A) 1 (B) 2 (C) 1	(D) 1, (E) 3, (F) 2	(D) 1, (F) 2, (G) 5, (H) 2	(I) 2
Cost	$3,629	$8,011	$10,880	$3,196

TRAVEL

Extensive travel is budgeted for this project to facilitate inter-organizational communications as well as project subsystem and system reviews. The baseline trips includes airfare, per diem, rental cars, lodging, airport parking. The cost estimate for the basic trip is described in detail in Table B5. It is expected travel expenses from New Zealand to McMurdo, Antarctica will be covered with other funds. Travel models for 2010 and 2011 are a rough estimate for expenses. There is no information available regarding the location of the AAS conferences for these years. Trip costs are therefore based upon previous years with appropriate inflationary values added.

SUPPLIES, MATERIALS, & OPS

Office Supplies and Services

All supplies described in this budget are charged at the indirect rates described below. All estimates of cost of supplies are based on a history of usage within Steward Observatory. A description of supplies includes office supplies (i.e. copy charges, pens, paper, toner for printers, filers, folders, etc…), small parts, laboratory supplies (unless notes elsewhere), graphic/photo, and other expendable materials, cost of technical and user documentation production, shipping and postage. Steward Observatory requires desktop computer administrative support services to all users connected to the internet. The cost per desktop machine is $280 annually (2008 dollars).

Publication Fees

The main product of the scientific investigation is the publication of journal papers. Estimates for publication fees have been included within the budget. The calculations are based upon the following assumptions: 1) Publication of four UA authored journal paper is expected (these papers are independent of Co-Institutions publications efforts); 2) Journal papers will be approximately 10 pages in length; 3) Journal page fees were estimated from the *Astrophysical Journal Letters* charges ($150 per page, 2007 dollars).

INDIRECT COSTS

University indirect costs (Facilities & Administrative) apply to the subtotal of: 1) Direct Labor (including benefits); 2) Travel; 3) Supplies and materials (including equipment items costing under $5000). The University of Arizona defines capital equipment as equipment items costing $5000 or above.

Indirect Cost Rates

The following table describes the University’s Indirect rates for the period of performance of this proposal.

Table B6: UA Indirect Cost Schedule

	2008 - 2011
Indirect Rate	51.0%%

The total estimated indirect charges for this period of the program is $817,247.

BUDGET PREPARATION

The UA Cost Element summary was

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UNIVERSITY OF ARIZONA BUDGET

Stratospheric TeraHertz Observatory (STO)
Steward Observatory, University of Arizona
Christopher K. Walker, PI

BUDGET SUMMARY
JANUARY 1, 2008 - DECEMBER 31, 2011

	YEAR ONE	YEAR TWO	YEAR THREE	YEAR FOUR	TOTAL YEARS
LABOR					
Sr Personnel					
Chris Walker, 1 su. month per year	12,358	12,728	13,111	13,505	51,702
Craig Kulesa, 3 mos. in Y1; 6 mos. in Y2-Y4	17,362	35,767	36,838	37,949	127,916
Project Manager, 2 mos in Y1 & Y4; 3 mos. in Y2 & Y3	13,647	21,082	21,713	14,909	71,351
Post Doc, 6 mos in Y1 & Y2; 12 mos in Y3 & Y4	31,680	32,632	67,222	69,233	200,767
Sr Personnel	**75,047**	**102,209**	**138,884**	**135,596**	**451,736**
Otr Professional					
Electronic Tech. Sr., 3 mos in Y2; 6 mos in Y3	-	18,060	37,204	-	55,264
Accountant, 1 mo per year	4,058	4,181	4,306	4,435	16,980
Other Professionals	**4,058**	**22,241**	**41,510**	**4,435**	**72,244**
Graduate					
Graduate Student - 9 mos (AY) per year	23,640	24,349	25,081	25,835	98,905
Graduate Student - 3 summer mos per year	17,228	17,749	18,284	18,834	72,095
Graduate Total	**40,868**	**42,098**	**43,365**	**44,669**	**171,000**
Subtotal - direct labor with ERE	**119,973**	**166,548**	**223,759**	**184,700**	**694,980**
OTHER DIRECT COSTS					
Operations	**15,200**	**23,356**	**26,570**	**10,660**	**75,786**
Communications	2,000	2,060	2,120	2,000	8,180
Computer Network Support & Licenses	3,200	3,296	3,180	3,270	12,946
Materials and Supplies	2,000	3,000	3,090	2,120	10,210
Misc. Electronic Components	3,000	10,000	10,000	-	23,000
Consultant (Gondala Designer)	5,000	5,000	5,000		15,000
Publication charges			3,180	3,270	6,450
Equipment - Non-capital (Fabricated)	**25,000**	**21,000**	**5,300**	**3,270**	**54,570**
Mixer Mounts	10,000	10,500			20,500
Array Bias System	5,000	5,250			10,250
Machining, miscell	5,000	5,250	5,300	3,270	18,820
Instrument control computer elements	5,000				
Travel	**3,629**	**8,011**	**10,880**	**3,196**	**25,716**
	3,629	8,011	10,880	3,196	25,716
Capital Equipment	**128,500**	**187,250**	**152,283**	**-**	**468,033**
Tertiary Chopper	8,000				
Calibration Box	7,000				
Instrument Control Computer	5,000				5,000
Local Oscillators (VDI)	108,500		103,773		212,273
Spectrometer System (Omnisys Inc.)		42,000	43,260		85,260
LO Synthesizers		5,250	5,250		10,500
Flight & Test Cryostat (Universal Cryogenics)		140,000			140,000
Subtotal - other direct costs	**172,329**	**239,617**	**195,033**	**17,126**	**624,105**
TOTAL DIRECT COSTS	**292,302**	**406,165**	**418,792**	**201,826**	**1,319,085**
OVERHEAD - Indirect Costs					
Tuition Remission	**8,079**	**8,322**	**8,573**	**8,831**	**33,805**
IDC applied only on 11.2% of Graduate Student ERE:					
Graduate Base Salary	29,486	30,374	31,288	32,229	123,377
27.4% of Grad fringe, no IDC applied	8,079	8,322	8,573	8,831	33,805
MTDC = TDC - Tuition Remission- Capital Equipment	**155,723**	**210,593**	**257,936**	**192,995**	**817,247**
TOTAL INDIRECT COSTS	**79,419**	**107,402**	**131,547**	**98,427**	**416,795**
TOTAL UA COSTS	**371,721**	**513,567**	**550,339**	**300,253**	**1,735,880**
COLLABORATING ORGANIZATION BUDGETS					
JOHN HOPKINS APPLIED PHYSICS LABORATORY	399,958	649,969	449,974	99,990	1,599,891
JET PROPULSION LABORATORY (Receiver Mixers & Science Team)	216,900	206,500	169,800	163,100	756,300
CALIFORNIA INSTITUTE OF TECHNOLOGY (IF System)	96,411	141,732	54,264	-	292,407
UNIVERSITY OF MARYLAND (Science Team)	-	-	34,221	46,138	80,359
NASA AMES RESEARCH CENTER (Science Team)	26,648	27,461	84,107	102,992	241,208
OBERLIN COLLEGE (Instrument and Science Team)	12,296	21,432	31,874	31,470	97,072
TOTAL YEARLY PROJECT COSTS	**1,123,934**	**1,560,661**	**1,374,579**	**743,943**	**4,803,117**

CO-INSTITUTIONS TASK STATEMENTS AND BUDGETS

JOHNS HOPKINS UNIVERSITY, APPLIED PHYSICS LABORATORY

STATEMENT OF WORK

1. SUMMARY

This is a collaboration Co-I Institution proposal for the Stratospheric TeraHertz Observatory (STO) whose lead proposal is submitted by the University of Arizona with Christopher Walker as PI.

For the STO program APL will provide the telescope, observing platform (gondola), pointing system, power system, command and control system, and the ground support equipment to interface with NASA-CSBF telemetry system. APL personnel will provide support for commanding and controlling STO for a test flight in the fall of 2009 and for an Antarctic flight in December 2010. Following the Antarctic flight we will participate in the data analysis and in publication of the results.

BUDGET SUMMARY
The Stratospheric Terahertz Observatory
TA : FG2FY AD-31227

1. Direct Labor

	First Year		Second Year		Third Year		Fourth Year	
	Staff Months	$/Staff Months	Staff Months	$/Staff Months	Staff Months	$/Staff Months	Staff Months	$/Staff Months
Principal Professional Staff	3.02	10,514.57	5.10	10,842.50	1.91	11,287.77		-
Senior Professional Staff Upper	5.95	9,273.43	9.10	9,557.51	6.70	9,956.10	3.42	10,364.41
Senior Professional Staff Lower		-		-		-		-
Associate Professional Staff	5.01	6,065.98	12.06	6,252.54	8.06	6,513.34	0.06	6,768.16
Technical Supporting Staff	1.50	4,083.23	5.00	4,216.11	3.00	4,399.95		-
Clerical Supporting Staff		-		-		-		-
Craft and Service Supporting Staff	1.00	4,485.18	3.50	4,631.67	3.00	4,833.63		-
Resident Subcontract Employees		-		-		-		-

2. Other Direct Costs

	First Year	Second Year	Third Year	Fourth Year
a. Subcontracts:		11,000.00		

The subcontract for this effort is for software licensing. The costs associated with this proposal are based on a vendor quote from GSE Software, Inc.

	First Year	Second Year	Third Year	Fourth Year
b. Consultants				
c. Equipment				
d. Supplies	95,560.00	25,460.50	40,896.00	

Material costs for this effort were obtained by a combination of engineering judgment, vendor quotes and vendor catalog (website) quotes. Dell Computers (2): $3,014.50 quote from Dell website; Northrop Grumman LN-200 position gyroscopes (2): $54,600 quote from Northrop Grumman; SunCat Solar - solar arrays 520 cells: $26,000 email quote from vendor (SunCat Solar); miscellaneous optics, mechanical components, electronics thermal blankets, etc.: $78.302; engineering judgment.

	First Year	Second Year	Third Year	Fourth Year
e. Travel	3,494.00	10,589.00	10,271.00	3,448.00

Travel shall consist of 4 trips for 2 people to Tucson, AZ to meet with University of Arizona collaborators; 1 trip for 3 people to Fort Sumner, NM for instrument balloon flight tests; 1 trip for 2 people to ChristsChurch New Zealand for lodging only; and 1 trip for 1 person to San Francisco, CA for the Fall AGU Meeting. Travel quotes were obtained from the APL Travel Office and the latest government per diems were used.

	First Year	Second Year	Third Year	Fourth Year
f. Other		7,308.00	4,256.00	10,860.00

Miscellaneous Other Direct Costs (MODC) consists of items such as postage, shipping, publications, conference fees, etc. MODC was based on engineering judgment by the PI.

3. Facilities and Administrative (F&A) Costs:

The terms "Facilities and Administrative (F&A) Costs" are not applicable at the Johns Hopkins University Applied Physics Laboratory (JHU/APL). JHU/APL submitted an updated forward pricing rate (FPR) proposal to the Defense Contract Management Agency (DCMA) on 23 February, 2007. The forward pricing rates were revised effective with the new submittal and are reflected in rate memo BSA-FIN-007-L-003 as Rate Table ID 049 effective 23 February, 2007. The rates used in this proposal are consistent with this FPR proposal.

Department Overhead on Direct Labor. Per disclosed practices, the Laboratory employs departmental burden rates that are applied as required. Departmental overhead is applied to the sum of JHU/APL direct labor and RSE direct labor. Details of the rates and calculations by department by fiscal year are provided in the proposal documentation.

Procurement Burden. Procurement burden is proposed as part of the JHU/APL Forward Pricing submittal and, in accordance with disclosed practices, is applied to the sum of Material and Subcontract costs. Details of the rates and calculations by fiscal year are provided in the proposal documentation.

Administrative and Research Burden. In accordance with JHU/APL disclosed practices, Administrative and Research Burden is applied to the sum of Direct Labor Costs, Procurement Burden, and Other Direct Costs. Details of the rates and calculations by fiscal year are provided in the proposal documentation.

UNIVERSITY OF MARYLAND

Statement of Work for Mark Wolfire: University of Maryland

The Stratospheric TeraHertz Observatory

Dr. Wolfire is an expert at modeling the thermal processes and line emission in the dense molecular and diffuse atomic gas in the interstellar medium. He will be providing analysis tools to interpret the observations from STO.

Year 3: Co-I Wolfire along with Co-I Hollenbach will develop line emission models for the [C II] emission from the diffuse neutral atomic gas, the [C II] and [O I] emission from molecular cloud surfaces, and the [N II] emission from diffuse and dense ionized gas. The models will include the important effects of the Galactic metallicity gradient, the close association of stars and clouds, and the effects of H_2 self-shielding. These will be fully self-consistent thermal and chemical equilibrium models. Results will be used to help further define the STO instrument characteristics.

In year 4: Wolfire and Hollenbach will refine the models according to existing Galactic data from BICE, COBE, and if available, SOFIA and Herschel. The models and analysis tools will be applied to the STO data sets. Wolfire will assist in the analysis.

UNIVERSITY OF MARYLAND

Budget for Mark Wolfire: University of Maryland

The Stratospheric TeraHertz Observatory

Year 1 funding 1/1/08-12/31/08 UMD		
No Funding is requested.		
	Total Year 1	0
Year 2 funding 1/1/09-12/31/09 UMD		
No Funding is requested.		
	Total Year 2	0
Year 3 funding 1/1/10-12/31/10 UMD		
1.)Direct Labor		
Mark Wolfire	3.0 months @ 6,230 /mo.	18,690
	Benefits @ 15%	2,804
2.)Travel (Domestic)	Present Results at Meeting	1,500
3.)Other Costs	Long Distance Phone	50
4.)Facilities and Administrative Costs	@ 48.5 % MTDC	11,177
	Total Year 3	34,221
Year 4 funding 1/1/11-12/31/11 UMD		
1.)Direct Labor		
Mark Wolfire	4.0 months @ 6,417 /mo.	25,668
	Benefits @ 15%	3,851
2.)Travel (Domestic)	Meet with collaborators	1,500
3.)Other Costs	Long Distance Phone	50
4.)Facilities and Administrative Costs	@ 48.5 % MTDC	15,069
	Total Year 4	46,138
Total		80,359

OBERLIN COLLEGE

1 Task Statement (Oberlin Group)

1.1 Overview

The Oberlin team brings a variety of skills to the Stratospheric Terahertz Observatory (STO) project. First and foremost the institutional PI (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 a planned deployment to Antarctica, this polar experience should prove valuable in its planning and execution.

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 for transmission via the reduced bandwidth available via the TDRS link on the SIP, as well as the command and control interface for the SIP and GSE computer in Palestine, TX during the flight. 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 PI will be intimately involved in integration and testing to make sure that the software is no impediment to a successful flight.

1.2.4 Instrument Development Assistance

During year 1 of the project, the PI (Martin) will spend a full year in residence with the U. Arizona instrument development group as part of a pre-tenure sabbatical from his appointment at Oberlin College. This immersion in the instrument as it is being designed and developed should greatly enhance the early and complete understanding of calibration issues which will in turn speed development and testing of the both the data acquisition and data reduction software components.

1.2.5 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 Title: Oberlin Component
PI: Chris Martin
Grant Period: 1/2008 – 12/2011

Senior Personnel	**2008**	**2009**	**2010**	**2011**	**Total**
C. Martin					
1 month summer salary @ $69,633/academic year	7,737				7,737
1 month summer salary @ $73,114/academic year		8,124			8,124
1 month summer salary @ $76,770/academic year			8,530		8,530
1 month summer salary @ $80,609/academic year				8,957	8,957
Other Personnel					
Student assistants					
1 academic-year student					
26 weeks @ 10 hours/week @ $8.50/hour			2,210	2,210	4,420
1 summer student					
10 weeks @ 40 hrs/week @ $8.50/hour		3,400	3,400	3,400	10,200
Total Salaries:	7,737	11,524	14,140	14,567	47,967
Fringe					
PI @ 18% for summer salary	1,393	1,462	1,535	1,612	6,003
Summer students @ 7.65% for FICA	0	260	260	260	780
Total Fringe:	1,393	1,722	1,796	1,872	6,783
Travel					
US Travel					
Professional meeting - 1 trip annually @ $1,000	1,000	1,000	1,000	1,000	4,000
Collaboration travel to Univ. of Arizona - 1 trips annually @ $1,000/each		1,000	1,000	1,000	3,000
Balloon Flight from TX/NM- 2 people @ $800/week x 2 weeks			3,200		3,200
International Travel					
Balloon Flight from Christchurch, NZ- 2 people @ $1,000/week x 1 week				2,000	2,000
Total Travel	1,000	2,000	5,200	4,000	12,200
Other direct costs					
Materials and supplies	0	1,000	3,000	1,000	5,000
Publication costs			1,000	1,000	2,000
Total Travel	0	1,000	4,000	2,000	7,000
Total Direct Costs:	**10,130**	**16,246**	**25,136**	**22,439**	**73,950**
Indirect @ 62% of salaries/wages - on-campus rate (yr. 1-0% for PI summer salary; years 2-50% on for PI and student summer salary; year 3-100% on for AY student salary AND 50% on for PI and student summer salary; year 4-100% on for PI summer salary and summer and AY student salary)	**0**	**3,572**	**5,069**	**9,031**	**17,672**
Indirect @ 28% of salaries/wages - off-campus rate (yr. 1-100% off-campus; years 2 and 3-50% off; yr. 4-0% off)	**2,166**	**1,613**	**1,670**	**0**	**5,450**
Amount of Request:	**12,296**	**21,432**	**31,874**	**31,470**	**97,072**

JET PROPULSION LABORATORY

General plan of work: Tasks at JPL

a) Mixer development

JPL will provide the PI institution with a four-element 1.5 THz HEB waveguide mixer array based on a design of Skalare et al. (2005). In a representative receiver system (e.g., warm LO diplexer, first-stage LNA typically T_{input} = 5 K), the performance goal will be approximately T_{RX}(DSB) = 1500 K near the target frequency, at an intermediate frequency of 2.0 GHz. Mixer block machining, per JPL specification, will be done by the University of Arizona. As a goal, JPL will also deliver to the PI institution a four-element 1.9 THz HEB waveguide mixer array, possibly scaled from the 1.5 THz design. The overall requirements will be the same as for the 1.5 THz mixers. The mixer fabrication technology for the baseline delivery is to use silicon-on-insulator (SOI). Should there be significant problems with the SOI process, we will fabricate devices on quartz substrates, fabricated successfully by JPL previously for use in the Smithsonian Astrophysical Observatory's RLT. Final back-up would be to use planar devices, which are very simple to fabricate. In the third year of the proposal, we will populate a mixer block design for 2.5 THz. All testing will be done by using an FIR laser available at JPL at selected frequencies, and, if available, solid-state local-oscillators. JPL brings to this collaboration experience of building mixers and receivers, and deploying them in the field. Briefly, Stern will process the SOI wafers; Kawamura will rf test the mixers; Skalare will redesign the mixer and aid in mixer testing.

b) Science support

As this mission bridges the significant gap between current various ground-based terahertz astronomy efforts (e.g., APEX and RLT), and future missions such as Herschel, it is important to plan the science activity so it capitalizes on previous projects and will ensure maximum returns from succeeding missions. JPL (Kawamura, Yorke, and Stern) is currently involved in a ground-based terahertz astronomy project and Herschel (Goldsmith), so will be able to provide valuable science support to the PI.

JET PROPULSION LABORATORY

JPL
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109

Detailed Budget (Basis of Estimate)

08NRA/ROSES3YR Ver 8.4

PROPOSAL TITLE: Stratospheric Terahertz Observatory

PROGRAM:

A. DIRECT COMPENSATION	FY 2008	FY 2009	FY 2010	FY 2011	FY 2008	FY 2009	FY 2010	FY 2011
JPL LABOR CLASS.	2,080	2,080	2,080	2,080	$k	$k	$k	$k
Y J. Kawamura	0.25	0.25	0.25	0.27				
Y J. Stern	0.20	0.10	0.05	-				
Y A. Skalare	0.20	0.10	0.05	-				
Y W. Langer	-	0.05	0.05	0.05				
Y H. Yorke	-	0.05	0.05	0.10				
Y P. Goldsmith -	-	0.05	0.05	0.05				
N - -	-	-	-	-				
N - -	-	-	-	-				
SUBCONTRACTOR WORKHOURS	-	-	-	-				
Estimated Group Supervisor Hours	0.02	0.02	0.02	0.02				
TOTAL WORKHOURS AND WORKYEARS A1	0.67	0.62	0.52	0.49				
LABOR COST SUBTOTAL A2					72.0	74.4	64.9	65.4
APPLIED FRINGES COSTS A3					35.9	37.1	32.4	32.6
JPL DIRECT COMPENSATION TOTAL A					107.9	111.6	97.2	98.0
N Name (Gov't Co-I) -	-	-	-	-				
B. TRAVEL DESTINATION (Cost/Trip)								
1 Tucson, AZ ($0.3k per trip)					1.2	1.2	1.2	-
2 Paletine, TX ($2k per trip)					-	4.0	-	-
TOTAL TRAVEL B					1.2	5.2	1.2	-
C. SERVICE (LIST BY TYPE)								
1 MDL ($4k/FTE-Mo) for Stern					9.6	4.8	2.4	-
2 Cryogenics ($1.0k/60-liter dewar $0.25k/160-liter LN2)					7.0	8.0	8.0	7.0
3 Mechanical fabrication (cryostat modification)					5.0	4.0	-	-
4 Name (Caltech IA Co-I)					-	-	-	-
TOTAL SERVICES C					21.6	16.8	10.4	7.0
D. PROCUREMENTS (LIST BY TYPE, e.g. CONTRACT LABOR, CONSULTANTS, MATERIALS & SUPPLIES, PUBLICATION COSTS, EQUIP., etc.)								
D1.CONTRACTS/ 1 0					-	-	-	-
2 0					-	-	-	-
3 Name (University Co-I 1)					-	-	-	-
4 Name (University Co-I 2)					-	-	-	-
CHARGEBACKS 8 *Chargebacks Autocalc*					6.2	5.9	5.1	4.9
TOTAL CONTRACTS D1					6.2	5.9	5.1	4.9
D2.CONSULTANTS. 4 0					-	-	-	-
6 0					-	-	-	-
TOTAL CONSULTANTS D2					-	-	-	-
TOTAL CONTRACTS AND CONSULTANTS D1+D2					6.2	5.9	5.1	4.9
D3. PO's EQUIP. 1 Lenses (Over $5k)					8.0	-	-	-
2 0 (Over $5k)					-	-	-	-
2 0 (Over $5k)					-	-	-	-
3 Misc (Remainder)					-	-	-	-
TOTAL PO - EQUIPMENT D3					8.0	-	-	-
D4 SUPPLIES & PUBLICATIONS 4 0					-	-	-	-
5 0					-	-	-	-
6 Publication Costs					-	-	-	-
TOTAL PO - SUPPLIES D4					-	-	-	-
TOTAL PO D3+D4					8.0	-	-	-
TOTAL PROCUREMENTS D					14.2	5.9	5.1	4.9
E. FACILITIES (LIST AS EITHER NEW CONSTRUCTION OR MODIFICATION - IF C OF F FUNDED, DO NOT INCLUDE)								
1 0					-	-	-	-
2 0					-	-	-	-
TOTAL FACILITIES E					-	-	-	-
F. MULTIPLE PROGRAM SUPPORT (MPS) ($/HR X A1) F					18.9	18.3	15.5	14.9
G. TOTAL DIRECT COST (SUM A THROUGH F) G					163.9	157.8	129.4	124.9
					-	-	-	-
H. ALLOCATED DIRECT COSTS (ADC)					-	-	-	-
H1. APPLIED ENG & SCI (Labor) ADC H1					30.8	29.1	24.4	23.1
H2. APPLIED CONTRACTS ADC H2					0.2	0.2	0.2	0.2
H3. APPLIED PURCHASE ORDERS (PO) ADC H3					0.8	-	-	-
I. COSTS SUBTOTAL (SUM A THROUGH H) I					195.8	187.1	154.0	148.2
					-	-	-	-
I1. APPLIED GENERAL ADC I1					18.1	16.6	13.4	12.6
J. TOTAL JPL COSTS (I + I1) J					213.9	203.6	167.4	160.8
					-	-	-	-
K. AWARD FEE K					3.0	2.9	2.3	2.3
L. GRAND TOTAL COSTS (J + K) L					216.9	206.5	169.8	163.1

CALIFORNIA INSTITUTE OF TECHNOLOGY

Dr. Sander Weinreb, I-PI - Caltech

Task Statement

1. Develop microwave monolithic integrated circuit (MMIC) low noise amplifiers (LNA's) with <5K noise in the 1 to 3 GHz range when operated at temperatures of 15K or less.

2. Fabricate, test, and deliver to U. of Arizona, ten (10) of the above LNA's.

3. Design IF converters to couple the output of the LNA's to digital spectrometers (supplied by others).

4. Fabricate, test, and deliver three (3) IF converters to U. of Arizona. 5. In Year 3, support the integration and test of the above components in the balloon gondola.

BUDGET SUMMARY:

Cost Element	YR 1	YR 2	YR 3	Total
Direct Labor: Other Personnel	**$27,231**	**$28,049**	**$14,445**	**$69,725**
Travel	**$1,000**	**$3,500**	**$1,500**	**$6,000**
Other Direct Costs Total:	**$46,027**	**$70,783**	**$25,023**	**$141,833**
Material and Supplies	$7,500	$32,000	$5,500	$45,000
Tuition Remission	$8,527	$8,783	$4,523	$21,833
CIT Transfer	$30,000	$30,000	$15,000	$75,000
Total Direct Costs	**$74,258**	**$102,332**	**$40,968**	**$217,558**
Indirect Cost (62%)	$22,153	$39,400	$13,296	$74,849
TOTAL BUDGET-CALTECH	**$96,411**	**$141,732**	**$54,264**	**$292,407**

Budget Justification

Direct Labor-Other Personnel

-Graduate students (50% effort in Year 1 and 2, 25% effort in Year 3) will participate in the design and testing of the balloon-borne radiometer.

-One Research Technician (25% effort in Year 1 and 2, 12.5% effort in Year 3) will assist with construction of the balloon-borne radiometer.

Direct Costs-Travel

Year 1: $1,000 for two 3-days trips to UAZ.

Trip To UAZ

Airfare		$121
Hotel	119/day	$238
Per diem & Ind/day	47/day	$141
Total cost per trip		$500

Year 2: Two 4-days trips to conferences for presentations.

Trip To Conferences

Airfare		$705
Registration		$500
Hotel	119/day	$357
Per diem & Ind/day	47/day	$188
Total cost per trip		$1,750

Year 3: $1,500 for three 3-days trips to UAZ for tests.

Trip To UAZ

Airfare		$121
Hotel	119/day	$238
Per diem & Ind/day	47/day	$141
Total cost per trip		$500

Other Direct Costs:

Materials and Supplies: Electronic parts for construction of the IF converters is budgeted at $7,500 in Year 1 and $5,500 in Year 3. In Year 2, $32,000 is requested for a processing of a portion of an indium-phosphide semiconductor wafer to provide the critical cryogenic low noise amplifier required for the work.

Year 1 - IF Converter parts, total $7500

Bandpass filters - 9 x $500 each = $4500
Printed circuit boards – (4 x $300)+ $900 non-recurring engineering cost = $2100
Electronic small parts - $900

Year 2 - Semiconductor wafer processing, total $32,000
Indium phosphide 4" diameter, 0.1um wafer processing of IC designed in Year 1. Wafer processing cost is $128,000 per wafer shared 75% to other projects, 25% = $32,000 to this project for required cryogenic low noise 1 to 3 GHz low noise amplifiers

Year 3 - IF Converter Parts, revision total $5500
RFI enclosures - 3 x $800 = $2400
Printed circuit revision – (4 x $300) + $900 non-recurring engineering cost = $2100
Electronic small parts - $1000

Others: CIT Transfer
Funds are transferred to JPL to support S. Weinreb (10% effort in Year 1 and Year 2, and 5% effort in Year 3) The transferred funds include all benefit and overhead costs at JPL. No overhead is charged by Caltech on these transfers to JPL.

Others: 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 63.5% of the graduate research assistant salary.

Indirect Costs –The Indirect Cost Rate of 62% is assessed to the direct costs excluding the graduate student benefit and Caltech transfer to JPL.

AMES RESEARCH CENTER

David Hollenbach, Project Scientist, NASA Ames

The project scientist for the Stratospheric TeraHertz Observatory (STO) will oversee all aspects of the science for the Observatory including: science requirements on the instruments, theoretical modelling, collection of ancillary data, analysis and modelling of the final data product, and publication of the papers resulting from the STO surveys. We break down these tasks chronologically into prelaunch activities and postlaunch activities.

Prelaunch activities.

The project scientist will work with other members of the team to collect ancillary data which is necessary to interpret the data. We will collect data from pre-existing surveys of CO J=1-0, 5 Ghz continuum, radio recombination lines and HI 21 cm done at roughly 1 arcminute resolution, comparable to the STO beam. This data will be assembled on a website, for the use of team members, and will later be released to the public once we have taken the STO surveys and added them to this dataset.

In addition, the project scientist will collaborate with other members of the team, including M. Wolfire, to prepare models of the interstellar medium (ISM) of the Milky Way which include cold diffuse clouds, warm neutral medium, diffuse HII regions, and giant molecular clouds (GMCs) with their photodissociation region (PDR) surfaces. These models will be constrained by the current Cosmic Background Exporer (COBE) and Balloon Infrared Carbon Explorer (BICE) observations of [CII] 158um and [NII] 205 um, the CO and HI surveys of the Galaxy, and the radio measurements of the ionized component. It will model the ultraviolet fluxes on these components by observations of the OB stellar content at different galactocentric radii and the ISM dust opacity, and will use these fluxes to determine the thermal structure of the neutral gas. This work will set in place the modeling tools necessary in order to interpret the STO data, which will have much greater spectral and spatial resolution than COBE or BICE.

Prelaunch activities will also mark a period of intense scrutiny of the observing plan for STO. The project scientist will oversee tradeoff studies of the science accomplished if the surveyed area were increased at the expense of the deeper surveys (and vice versa), and of different lines of sight for the deep surveys.

Finally, as the STO telescope is built, the project scientist will attend team meetings in order to provide scientific requirements input to the possible discussions of tradeoffs in cost and schedule versus instrument performance.

Postlaunch activities.

The main activity for the project scientist n the postlaunch period is to oversee the data analysis, comparison with other ancillary data sets, modelling, testing the various hypotheses, and finally the production of published refereed papers.

One aspect of overseeing the data analysis is to organize the science team to review the reduced data, performing a reality check against theoretical expectations to ensure that the data make reasonable sense. In addition, the project scientist will oversee the production of the survey results,with error analysis, and its incorporation into the web based data archive, which will include the ancillary data as well.

The project scientist will oversee and collaborate with other members of the team in the modelling and the testing of various hypotheses set out in the proposal. He will ensure that the complementary ancillary data is properly used to maximize the scientific return on the STO data. The prelaunch models will now be applied to the STO data in order to attain the 4 main science goals.

1. Determine the life cycle of galactic interstellar gas.
2. Study the creation and disruption of star-forming clouds in the Galaxy.
3. Determine the parameters that affect the star formation rate in a galaxy.
4. Provide templates for star formation and stellar/interstellar feedback in other galaxies.

The project scientist, working with the PI, will organize the subteams of STO team members that will write up publishable papers from the results. The project scientist and PI will set up the system of internal reviews, policies for co-authorship, deadlines, and checks that will ensure the rapid dissemination of this exciting data, and high quality analysis and modelling of this data. The project scientist and PI will organize team meetings where the papers in progress are discussed and debated, and where new ideas may be fostered.

D. Hollenbach (Institutional PI)	0.1 FTE (or 1.2months/yr) for 2008 and 2009, 0.25 FTE (or 3 months/yr for 2010, and 0.35 FTE, or 4.2 months/yr for 2011

AMES RESEARCH CENTER

Budget and Budget Justification

Proposal Title: "The Stratospheric Terahertz Observatory (STO): NASA Ames"

Institutional PI: David Hollenbach (Project Scientist), NASA Ames Research Center (w/PI: Chris Walker, Univ. of AZ)

Submitted by: NASA Ames Research Center and the University of Arizona in response to NRA Solicitation: NRA NNH06ZDA001N- APRA2

	Yr. 1 Jan. 2008- Dec. 2008	Yr. 2 Jan. 2009- Dec. 2009	Yr. 3 Jan. 2010- Dec. 2010	Yr. 4 Jan. 2011- Dec. 2011	Yrs.1-4 Jan. 2008- Dec. 2011
DIRECT COSTS:					
Senior /Key Persons:					
Co-Investigator, David Hollenbach (NASA Ames) Workyears: 0.1, 0.1, 0.3, 0.35; Work-months: 1.2, 1.2, 3.6, 4.2					
Salary	$15,478	$15942	$49,262	$59,196	$139,878
Benefits @ 23%	$3,637	$3,746	$11,577	$13,911	$32,871
Subtotal Labor	$19,115	$19,688	$60,839	$73,107	$172,749
Travel Costs:					
D. Hollenbach (misc. domestic travel)	$2,000	$2,000	$2,000	$2,000	$8,000
Subtotal Travel	$2,000	$2,000	$2,000	$2,000	$8,000
Other Direct Costs:					
Computer networking & systems support			$3,190	$3,286	$6,476
Direct Administrative and Technical Support costs [1]	$5,533	$5,773	$18,078	$19,599	$48,983
Subtotal Other Direct Costs	$5,533	$5,773	$21,268	$27,885	$60,459
TOTAL DIRECT COSTS	$26,648	$27,461	$84,107	$102,992	$241,208
INDIRECT COSTS: None. [2]					
TOTAL FUNDING REQUEST	**$26,648**	**$27,461**	**$84,107**	**$102,992**	**$241,208**

Biosketches

Christopher K. Walker
Steward Observatory, University of Arizona, Tucson, AZ 85721

Education

Ph.D.: Astronomy, University of Arizona, 1988
  Advisor: Charles J. Lada
  Thesis: "Observational Studies of Star Forming Regions"
M.S.: Electrical Engineering, Ohio State University, 1981
  Advisor: John D. Kraus
  Thesis: "Upgrading the Ohio State Radio Observatory"
B.S.: Electrical Engineering, Clemson University, 1980
  Graduated with Honors

Experience

- 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

Honors and Awards

- Antarctic Service Medal of the USA (1999)
- NSF Young Investigator (1994-1999)
- Millikan Fellow in Physics at Caltech (1988-1991)
- Graduated Cum Laude B.S.E.E.
- Tau Beta Pi, General Engineering Honors Society
- Eta Kappa Nu, Electrical Engineering Honors Society

Professional Societies

- American Astronomical Society
- International Society of Optical Engineers

Research and Management Experience

The Principal Investigator (PI), Prof. Christopher Walker of the University of Arizona (UA), has over 20 years of experience designing, building, and using state-of-the-art receiver systems for radio 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 manages and coordinates 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). His team is also employing laser micromachining techniques to the fabrication of the first integrated THz array receivers. Prof. Walker has published numerous papers on star formation and protostellar evolution and served as dissertation director for six Ph.D. students (5-Astronomy, 1-Optical Sciences). He currently supervises five graduate (3-Astronomy, 1-Optical Sciences, and 1-Electrical Engineering) and two undergraduate (Physics/Astronomy) students.

Publications

Recent Publications (Refereed Journal)

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.

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

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.

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.

Narayanan, D., Groppi, C., Kulesa, C., and Walker, C., 2005, *Warm, Dense Molecular Gas in the ISM of Starbursts, LIRGs, and ULIRGs, Ap. J.*, **630**, 269.

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.

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

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.

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.

Tieftrunk, A., Jacobs, K., Martin, C., Siebetz, O., Stark, A., Stutzki, J., Walker, C., and Wright, G. 2001, ^{13}*CI in High-mass Star-forming Clouds, A. & A.*, **375L**, 23.

CURRICULUM VITAE

PIETRO NICOLA BERNASCONI

Current Position

The Johns Hopkins University / Applied Physics Laboratory
Senior Scientist
Space Department, Space Science Group, Solar Physics Section

Education

Diploma (Physics) (equivalent to American Master's Thesis), Swiss Federal Institute of Technology Zürich (ETH-Z), 1992
Ph.D. (Natural Science), Swiss Federal Institute of Technology Zürich (ETH-Z), 1997

Relevant experience

2001-present: Project Scientist, Solar Bolometric Imager.
1997-2004: Project Scientist, Flare Genesis Experiment.
1992-1997: Research Fellow, Institute for Astronomy of the Swiss Federal Institute of Technology Zürich, Solar Physics Group.

Professional Societies

Member American Astronomical Society, Solar Physics Division (SPD)
Member American Geophysical Union (AGU)
Member Society of Photo-Optical Instrumentation Engineers (SPIE)

Publications

Bernasconi P.N., Keller C.U., Povel H.P., and Stenflo J.U., Direct measurement of flux tube inclination in solar plages, A&A 302, 533-542 (1995)

Bernasconi P.N., Solanki S.K., Inversion of Stokes vector profiles in terms of a 3-component model, Sol. Phys. 164, 277-290 (1996)

Gale M.T., Pedersen J., Schuetz H., Povel H.P., Gandorfer A., Steiner P., Bernasconi P.N., Active alignment of replicated microlens arrays on a charge-coupled device imager, Opt. Eng. 36(05), 1510-1517 (1997)

Bernasconi P.N., Keller C.U., Solanki S.K., and Stenflo J.O., Complex magnetic fields in an active region, A&A 329, 704-720 (1998)

Bernasconi P.N., Rust D.M., Murphy G.A., Eaton H.A.C., High resolution polarimetry with a balloon-borne telescope: the Flare Genesis Experiment, in High Resolution Solar Physics: Theory, Observations and Techniques, T.R. Rimmele, K.S. Balasubramaniam, and R.R. Radick (Eds.), Astron. Soc. Pacific Conf. Series Vol. 183, 279-287 (1999)

Bernasconi P.N., Rust D.M., Eaton H.A.C., Murphy G.A., A balloon-borne telescope for high resolution solar imaging and polarimetry, in Airborne Telescopes Systems, Ramsey K. Melugin, Hans-Peter Röser (Eds.), Proceedings of SPIE Vol. 4014, 214-225 (2000)

Bernasconi P.N., Rust D.M., Eaton H.A.C., High resolution vector magnetograms with the Flare Genesis vector polarimeter, in Advanced Solar Polarimetry - Theory, Observation, and Instrumentation, M. Sigwarth (Ed.), Astron. Soc. Pacific Conf. Series Vol. 236, 399-406 (2001)

Georgoulis M. K., Rust D. M., Bernasconi P. N., Schmieder B. 2002, Statistics, Morphology, and Energetics of Ellerman Bombs, ApJ 575, 506-528 (2002)

Bernasconi P. N., Rust D. M., Georgoulis M. K., LaBonte B. J. 2002, Moving Dipolar Features in an Emerging Flux Region, Sol. Phys. 209, 119-139 (2002)

Schmieder, B., Rust, D. M., Georgoulis, M. K., Demoulin, P., & Bernasconi, P. N.: Emerging Flux and the Heating of Coronal Loops, Astrophysical Journal 601, 530 (2004)

Pariat, E. G., Aulanier, G., Schmieder, B., Georgoulis, M. K., Rust, D. M., and Bernasconi, P.N., Resistive Flux Emergence in Undolatory Flux Tubes, 614, 1099 (2004)

Bernasconi, P. N., Eaton, H. A. C., Foukal, P., Rust, D. M., The Solar Bolometric Imager, Advances in Space Research 33, 1746 (2004)

Foukal, P., Bernasconi, P. N., Eaton, H. A. C., and Rust, D. M., Broad-band Measurements of Facular Photometric Contrast with the Solar Bolometric Imager, Astrophysical Journal 611, L57, (2004)

Solanki, S.K., Preuss, O., Haugan, M.P., Gandorfer, A., Povel, H.P., Steiner, P., Stucki, K., Bernasconi, P.N., & Soltau, D., Solar constraints on new couplings between electromagnetism and gravity, Physics Review D 69(6), id 062001 (2004)

Bernasconi, P. N., Rust, D. M., Hakim, D., Advanced Automated Solar Filament Detection and Characterization Code: Description, Performance, and Results, Solar Physics 228, 99 (2005)

PAUL F. GOLDSMITH (Co-I)

Paul Goldsmith's astronomical interests are focused on the structure of molecular clouds and how their characteristics affect the star formation that takes place within them. He has been an active observer from cm to submm wavelengths, primarily of spectral line emission. Goldsmith has worked on the molecular depletion on dust grains and its effect on the thermal balance of molecular clouds. He has been invovled in several projects studying dense cores using molecules and dust as probes. He has also been pursuing several projects related to the transition from atomic to molecular hydrogen during the process of molecular cloud formation.
Goldsmith has been involved in the development of a wide range of radio astronomical instrumention, in particular feeds and low noise receivers. From 1993 to 2002 Goldsmith was Director of the National Astronomy and Ionosphere Center, and oversaw the Arecibo Gregorian Upgrade Project which increased the frequency range of the 305m telescope by a factor of 5 and the instantaneous bandwidth by a factor of 20, as well as allowing for use of focal plane array receivers starting with the 7-element ALFA 1.1 to 1.4 GHz system. In 2000, 2001, and 2004 he was Professeur Invité at the Ecole Normale Supérieure, Paris, France, carrying out research and lecturing on molecular cloud structure.
Goldsmith has also been involved in space–borne spectroscopy as a co–investigator on the SWAS submillimeter satellite. He is currently NASA Project Scientist for the Herschel Space Observatory. Goldsmith is a Fellow of the Institute of Electrical and Electronics Engineers, and has published over 200 papers on astronomy and astronomical instrumentation, and is the author of a monograph "Quasioptical Techniques," IEEE Press/Chapman & Hall (1998).

EDUCATION:

1975	UC Berkeley	Ph.D. (Physics)
1969	UC Berkeley	B.A. (Physics)

PROFESSIONAL EMPLOYMENT:

2006 -	Jet Propulsion Laboratory, Calif. Inst. Technology	Senior Research Scientist
2005-2006	Jet Propulsion Laboratory, Calif. Inst. Technology	Principal Scientist
2005 -	Cornell University	Professor Emeritus
1993-2005	Cornell University	Professor
1993-2002	National Astronomy & Ionosphere Center	Director
1986-1992	University of Massachusetts, Amherst	Professor
1982-1992	Millitech Corporation	Vice President, Res. & Devel.
1980-1992	Five College Radio Astronomy Observatory	Associate Director
1981-1986	University of Massachusetts, Amherst	Associate Professor
1977-1981	University of Massachusetts, Amherst	Assistant Professor
1975-1977	Bell Telephone Laboratories, Holmdel	Member Tech. Staff

CURRICULUM VITAE

Christopher Emil Groppi

Steward Observatory - University of Arizona
933 N. Cherry Ave. Tucson, AZ 85721 Tel: 520-626-7882, Fax: 520-621-1532
Email: cgroppi@as.arizona.edu http://wallace.as.arizona.edu/~cgroppi/

Professional Preparation:

Director's Postdoctoral Research Associate, National Radio Astronomy Observatory, 2003-2005.
University of Arizona, Astronomy with minor in Electrical & Computer Engineering, Ph.D. 2003.
B.A. with Honor in Astronomy, Cornell University, 1997

Appointments:

National Science Foundation Astronomy and Astrophysics Postdoctoral Fellow, 2006-present
Assistant Staff Astronomer, Steward Observatory, 2005-present

Awards and Distinctions:

Eleanor and Anthony DeFrancis Fellowship, 2002
Jamieson Astronomy Graduate Award, 2002
Department of Astronomy Graduate Admissions Committee, University of Arizona, 2000
NASA GSRP Graduate Research Fellowship, 1999-2001
Phi Beta Kappa Society, 1997

Professional Societies:

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

Synergistic Activities:

- Involvement in all facets of the design, construction, test and integration of three heterodyne array receivers (PoleSTAR, DesertSTAR and SuperCam) .
- Full wave electromagnetic simulation of sub-mm wave and THz receiver components, including mixers, feedhorns and ortho-mode transducers (OMTs).
- Design and fabrication of mixer bias-tees and low noise SIS receiver bias electronics.
- Development of sub-mm wave and teraHertz waveguide and quasioptical components for low noise receiver systems.
- Star formation research using mm-wave and sub-mm wave telescopes, concentrating on the interaction of protostellar sources with the surrounding ISM, and the dynamics of protostellar accretion disks.

Five most relevant publications:

Groppi, C.E., Walker, C.K., 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. *SuperCam, a 64-Pixel-Heterodyne Imaging Array for the 870 micron Atmospheric Window*, Millimeter and Submillimeter Detectors and Instrumentation for Astronomy III. Edited by Zmuidzinas, J.; Holland, W.S.; Withington,S.; Duncan, W.D. , Proc. SPIE 6275, 2006.

Groppi, C.E., Walker, C.K., Kulesa, C., Golish, D., Hedden, A., Narayanan, G., Lichtenberger, A.W., Kooi, J. W., Graf, U.U., Heyminck, S. *First results from DesertSTAR: a 7-pixel 345-GHz heterodyne array receiver for the Heinrich Hertz Telescope*, Proc. SPIE, v. 5498, 2004.

Groppi, C.E., Drouet d'Aubigny, C.Y., Lichtenberger, A.W. & Walker, C.K., *A broadband finline ortho-mode transducer for THz applications,* 15th International Symposium on Space Terahertz Technology, University of Massachusetts, 2004.

Groppi, C., Walker, C, Jacobs, K & Graf, U., *Pole STAR: An 810 GHz Array Receiver for AST/RO*, Imaging at Radio through Submillimeter Wavelengths, ASP Conference Proceedings, v. 217, 2000.

Groppi, C.E., Kulesa, C.A., Walker, C.K., Martin, C.M., *Millimeter and submillimeter survey of the R Corona Australis Region*, Astrophysical Journal, v. 612, pp. 946, 2004.

INSTITUTIONAL PI: DAVID HOLLENBACH (PROJECT SCIENTIST)

BIOGRAPHICAL DATA: PhD. (Theoretical Physics), Cornell University, 1969; Member of the Large Deployable Telescope Science Coordination Group, 1983-1990; Member of NASA Astronomy and Relativity Management Operation Working Group (ARMOWG), 1985-1987; Principal Investigator of the Center for Star Formation Studies 1985-present; 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-present, Associate Member of SWS Team of ISO, 1989-present; Executive Council of AAS, 1992-1995; Member of the National Academy of Sciences Task Group for Space Astronomy and Astrophysics 1995-1997; Member of numerous review panels including NRAO 12 meter (1993-1995), NASA Long Term Space Astrophysics (1996), HST Cycle 7 (1997), NASA Astrophysical Theory Program (1997), HST Cycle 13 (2004), Spitzer Cycle 1,2 (2004,5); 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 (team leader on one) and on a Key ISO Project team.

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: Research Scientist, Space Science Division, NASA-Ames Research Center (1980-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

Wolfire, M., Hollenbach, D.J., McKee, C., Tielens, A., “The Neutral Atomic Phases of the Interstellar Medium”, Ap. J., 443, 152, 1995.

Wolfire, M. G., McKee, C., Hollenbach, D., and Tielens, A. "The Multiphase Structure of the Galactic Halo: High Velocity Clouds in a Hot Corona", Ap. J., 453, 673, 1995.

Malhotra, S., Helou, G., Stacey, G., Hollenbach, D. et al, "Infrared Space Observatory Measurements of [CII] Line Variations in Galaxies", ApJLett, 491, L27, 1997.

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.

Dale, D., Silbermann, N., Helou, G., Valjavec, E., Malhotra, S., Beichman, C., Brauher, J., Contursi, A., Dinerstein, H., Hollenbach, D., et al., “ISO Mid-Infrared Observations of Normal Star-Forming Galaxies: The Key Project Sample”, AJ, 120, 583, 2000.

Malhotra, S., Kaufman, M.J., Hollenbach, D., et al., "Far-Infrared Spectroscopy of Normal Galaxies: Physical Conditions in the Interstellar Medium", ApJ, 561, 766, 2001.

Hunter, D., Kaufman, M., Hollenbach, D.J., et al, "The Interstellar Medium of Star forming Irregular Galaxies: The View with ISO", ApJ, 553, 121, 2001.

Steiman-Cameron, T., Wolfire, M.G., Hollenbach, D.J. "Morphoplogy of the Milky Way's Spiral Arms", in Galaxy Disks and Disk Galaxies, ed. J. Funes, E. Corsini, (ASP Publishers: San Francisco), p61, 2001

Contursi, A., Kaufman, M., Helou, G., Hollenbach, D. et al., "ISO LWS Observations of the Two Nearby Spiral Galaxies NGC 6946 and NGC 1313", AJ, 124, 751, 2002.

Parravano, A., Hollenbach, D., McKee, C. "Time Dependence of the Ultraviolet Radiation Field in the Local Interstellar Medium", ApJ, 584, 797, 2003

Wolfire, M., McKee, C., Hollenbach, D., Tielens, A. "Neutral Atomic Phases of the Interstellar Medium in the Galaxy", ApJ, 587, 278, 2003

McKee, C.F., Hollenbach, D. Wolfire, M.G. "Phases of the Interstellar Medium in the Milky Way;" in The Dense Interstellar Medium in Galaxies; eds. S. Pfalzner, C. Kramer, C. Straubmeier, A. Heithausen (Berlin: Springer-Verlag), p. 395, 2004

Smith, J., Dale, D., Armus, L, Draine, B., Hollenbach, D., et al. "Mid-Infrared IRS Spectroscopy of NGC 7331: A First Look at the SINGS Legacy", ApJS, 154, 199, 2004.

Curriculum Vitae

Name: Honingh
First Name : Cornelia
Date of Birth: 20-04-1958
Place of Birth: Amsterdam, the Netherlands

Education	***Date of Completion***
Technical University Delft : Ir. Technical Physics (Ir. is a Dutch title without a US equivalent)	February 1986
Rijksuniversiteit Groningen: PhD Physics and Mathematics Title: A Quantum Mixer at 350 GHz based on Superconductor Insulator Superconductor (SIS) tunnel junctions	June 1993

Relevant Work experience	***Time frame***
Teaching Assistent for Physics at Erasmus University Rotterdam, Faculty of Medicine (0.3-0.5 FTE), the Netherlands	September 1980-December 1985
Student Assistent Operation Dilution Refrigerator (0.5FTE) at Technical University Delft, the Netherlands	September 1985-February 1986
Scientific Employee (full time) at Space Research of the Netherlands (SRON) in Groningen, the Netherlands	March 1986-October1992
Scientific Employee (full time) at University of Cologne , Germany Project Leader HIFI Mixer Band 2 Development	April 1993-- now January 2000- now

Curriculum vitae of

Dr. Karl Jacobs, Senior Research Scientist

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Karl Jacobs was born in Bergheim, Germany, in 1955. He received the Diploma Degree in physics and astronomy from the University of Bonn, Germany in 1981. His PhD thesis work was performed at the I. Physikalisches Institut of the University of Cologne, Germany beginning in 1981. The subject was a millimeter-wave heterodyne receiver for the 3m diameter KOSMA radio telescope operated by the University of Cologne. He received the Dr. rer. nat. degree from the University of Cologne in 1984. As a Postdoc at the I. Physikalisches Institut he was involved in the installation of the KOSMA observatory on Gornergrat, Switzerland. In 1988/1989 he worked as a Visiting Scientist at the Jet Propulsion Laboratory (NASA/California Institute of Technology) on a 620 GHz superconducting receiver. In 1988 he became leader of the project "Superconducting devices for mm- and submm-wave receivers". He founded the Superconducting Devices Laboratory at KOSMA. The group, consisting of an engineer, a technician, several PhD students and two senior scientists, specialized in the development and microfabrication of superconducting mixers with broad-band integrated matching circuits and thus helped to open up the submm-wavelength range for sensitive heterodyne spectroscopy. Wide-band fixed-tuned mixers developed in the lab are ore have been operating at several observatories, including the AST/RO telescope at Amundsen-Scott South Pole station. Dr. Jacobs is a Co-Investigator on the Herschel FIR-submm wave space observatory, an ESA Conerstone Mission, for which his lab has developed and delivered the Band 2 superconducting heterodyne mixers. Current interests include the development of Terahertz waveguide mixers using Hot Electron Bolometers, to be used in the heterodyne receivers on SOFIA and on ground based telescopes.
Karl Jacobs has published more than 50 papers and conference contributions in the field and served in the steering committee of the International Symposium on Space Terahertz Technology.

Karl Jacobs

Curriculum Vitae

Jonathan Kawamura

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Education:

Ph. D., Astronomy, Harvard University, 1997; A. M., 1994.
B. S., Astronomy, California Institute of Technology, 1992.

Employment:

Senior Electronics Engineer, 2000-; *Affiliate*, 1998-2000. Jet Propulsion Laboratory, California Institute of Technology. Development of superconductive detectors and mixers; astronomical observations at terahertz frequencies. Formerly responsible for NASA's contribution to the highest frequency (1.6 THz) heterodyne mixer receiver for the Herschel Space Observatory.

Postdoctoral Scholar in Physics, 1997-2000. California Institute of Technology. Development of superconducting detectors for astronomy: submillimeter heterodyne receivers; direct detectors for submillimeter and optical waves. Observational radio astronomy.

Research Assistant, 1992—1997. Harvard College Observatory. Thesis research, entitled, "Superconducting Hot-electron Bolometric Mixer Receivers, and Evolution of Ionized Nebulae." Additional work included the design of, construction of, and experiments with a far-infrared Fourier transform spectrometer.

Selected publications:

J. Kawamura, et al. "Heterodyne Measurement of the 205 mm [N II] Line Emission Toward Galactic H II Regions," *Astrophysical Journal*, submitted (2007)

J. Kawamura, T. R. Hunter, C.-Y. E. Tong, R. Blundell, D. C. Papa, F. Patt, W. Peters, T. L. Wilson, C. Henkel, G. Gol'tsman, & E. M. Gershenzon, "Ground-based Terahertz CO Spectroscopy towards Orion," *Astronomy & Astrophysics*, **394**, 271-274 (2002)

J. Kawamura, J. Chen, D. Miller, J. Kooi, J. Zmuidzinas, B. Bumble, H. G. LeDuc, & J. A. Stern, "Low-noise Submillimeter-wave NbTiN Superconducting Tunnel Junction Mixers," *Applied Physics Letters*, **75**, 4013-4015 (1999)

J. Kawamura, R. Blundell, C.-Y. E. Tong, G. Gol'tsman, E. Gershenzon, B. Voronov, & S. Cherednichenko, "Low Noise NbN Lattice-cooled Superconducting Hot-electron Bolometric Mixers at Submillimeter Wavelengths," *Applied Physics Letters*, **70**, 1619-1621 (1997)

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Applied Physics
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Education: **MS Electrical Engineering**

California Institute of Technology
Field of specialization: Microwave and Millimeterwave Engineering, Applied Physics, Analog VLSI
GPA: 4.0/4.0

BS Degree in Electronic Engineering

California Polytechnic State University
Field of specialization: RF and Microwave Engineering.
GPA: 3.01/4.0

-Expert in RF and Microwave electromagnetic field simulators such as Ansoft's 3D High Frequency Structure Simulator (HFSS) and 2.5D finite element simulators like Sonnet and Momentum.
-Thoroughly familiar with Microwave theory and techniques, and very comfortable with the use of analytical software tools such as MMICAD, ADS, Spice, Harmonica and Libra.
-Proficient in MathCad, Mathematica, Mathlab, AutoCAD, Labview, Ledit, Latex, and MS products.
-Knowledgeable in Gausian optics, digital/analog low noise and high speed electronics and Analog
-Very Large Scale Integrated circuit design (Analog VLSI).

Award: HEWLETT PACKARD AWARD for outstanding senior research thesis on video and digital data transmission and reception at 10.290 GHz.

WWW: http://www.submm.caltech.edu/cso/receivers/
http://www.submm.caltech.edu/cso/receivers/pubs.html

Experience: **Senior Research Engineer**
1989- Present **California Institute of Technology (CIT)**

Responsible for the design and implementation of sub-millimeter wave (200-1000 GHz) waveguide instrumentation for the Caltech Submillimeter wave Observatory (CSO) on Mauna Kea, Hawaii.
Specific areas of expertise include: Superconducting NbTiN and Nb SIS tunnel junction receivers, a large variety of microwave and millimeter wave devices such as low noise (cryogenic) microwave HEMT amplifiers, RF filters and matching network techniques, planar circuitry that utilizes a variety of transmission lines such as "loaded" CPW and Mircostrip, waveguide theory and quasi-optical techniques as well as analog/digital control electronics and cryogenics.
Associated area's of professional and personal interest are: Gausian beam diffraction optics, Fourier Transform Spectrometer (FTS) techniques to characterize material properties, antenna theory, high speed GaAs heterojunction bipolar techniques as applied to A/D converters, digital and analog correlator technology as well as analog VLSI.
Responsible for guidance of up to 10 PhD students and a small staff who assist me in the development of low noise sub-millimeter wave instrumentation.

1998-present **Co-Investigator AST/RO,**
Harvard-Smithsonian Center for Astrophysics.

The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO) is located at the Earth's geographic South-Pole Station, Antarctica.
Duties include technical analyses and advice on optical systems and sub-millimeter wave instrumentation (200-1500 GHz). Work includes characterization of receiver and telescope diffraction optics, IF amplifier and Phase Lock Loop (PLL) behavior as well as repair and calibration of the back-end electronics that runs the observatory.
http://cfa-www.harvard.edu/~adair/AST_RO

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Professional Preparation

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

Appointments

2006-	Assistant Astronomer University of Arizona
2003-2006	Assistant Staff Scientist Steward Observatory University of Arizona
1998-2002	Research Assistant (Science and Instrumentation) University of Arizona
1994-1996	Research Assistant (Science) University of Arizona

Selected Papers Relevant to This Study

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., ApJ, 625, 194

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

3. "CO Emission from Disks around AB Aurigae and HD 141569: Implications for Disk Structure and Planet Formation Timescales", Brittain, S. D., Rettig, T. W., Simon, T., Kulesa, C., DiSanti, M. A., & Dello Russo, N. 2003, ApJ, 588, 535

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. "DesertSTAR: a 7 pixel 345 GHz heterodyne array receiver for the Heinrich Hertz Telescope", Groppi, C., Walker, C., Kulesa, C., Golish, D., Hedden, A., Gensheimer, P., Narayanan, G., Lichtenberger, A., Graf, U., Heyminck, S., 2003, SPIE, 4855 : 330

Synergistic Activities:

- Development of new techniques for molecular cloud modeling of physical structure, chemistry, radiative transfer and dynamics.
- Dissemination of research results to the wider public by lectures and presentations, e.g. through Steward Observatory programs, student organizations, and primary/secondary schools.

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Dr. William Langer is a Senior Research Scientist at the Jet Propulsion Laboratory, Caltech. He has over thirty-five years experience in astrophysics and is author, or co-author, on over 130 research papers. His contributions include various time dependent chemical - dynamical codes for interstellar clouds. He is involved in research on the thermal, chemical, structural, and dynamical properties of interstellar clouds, protostellar cores, and protoplanetary disks. Dr. Langer is also an active radio and infrared astronomer. He made many of the first detections of complex molecules in space, including carbon cumulenes, deuterated carbon chains, and deuterated formaldehyde in protostellar cores, and methanol in protoplanetary disks. He has over much of his career been involved in studying the isotopic abundances of deuterium, carbon, oxygen, and nitrogen to understand Galactic nucleosynthesis and its relationship to the isotopic composition of the solar system. He was the former Project Scientist for Herschel, and is currently a Herschel co-I.

Relevant Publications:

Bergin, E. A., **Langer, W. D**., & Goldsmith, P. F., (1995), *Gas-Grain Chemistry in Dense Clouds Including Grain Surface Interactions*, ApJ., **441**, 222.

Bergin, E. A. & **Langer, W. D**., (1997), *Chemical Evolution in Pre-protostellar and Protostellar Cores*, ApJ, **486**, 316

Velusamy, T., **Langer, W.D.** & Levin, S., (1997), *Detection, Formation, and evolution of Complex Hydrocarbons in Protostellar Cores*, <u>in Sixth Symposium on Chemical Evolution and the Origin and Evolution of Life</u>, NASA Ames Research Center

Willacy, K., **Langer, W. D.** & Allen, M. (2002) *HI: A Chemical Tracer of Diffusion in Molecular Clouds*, ApJ, 573, L119.

Padoan, P., Cambresy, L., & **Langer, W**., (2002), *Structure Function Scaling of a 2MASS Extinction Map of Taurus*, Ap J Letters, 580, L57-L60.

Padoan, P; Boldyrev, S; **Langer, W**; & Nordlund, Å, (2003), *Structure Function Scaling in the Taurus and Perseus Molecular Cloud Complexes*, Ap J., 583, 308- 313.

Lai, S-P., Velusamy, T., & **Langer, W. D**., (2003), *The High Angular Resolution Measurement of Ion and Neutral Spectra as a Probe of The Magnetic Field Structure in DR21(OH)*, Ap J., Letters, 596, L239-L242.

Lai, S-P., Velusamy, T., **Langer, W. D.**, & Kuiper, T. B. H.,(2004), *The Physical and Chemical Status of Pre-Protostellar Core B68*, Astronomical J., 126, 311-318.

Padoan, P., Willacy, K., **Langer, W**., & Juvela, M., (2004), *Electron Abundance in Protostellar Cores*, Ap J., 614, 203 - 210.

Padoan, P., Cambresy, L., Juvela, M., Kritsuk, A., **Langer, W**., & Norman, M., (2006), *Can We Trust the Dust*, 2006, Ap J., 649, 807.

Li, D., Velusamy, T., Goldsmith, P. F., & **Langer, W. D**., (2007), *Massive Quiescent Cores in Orion II. Core Mass Function*, Ap. J., 655, L351.

CAREY M. LISSE CO-INVESTIGATOR

Current Position
The Johns Hopkins University / Applied Physics Laboratory
Senior Research Scientist
Space Department, Planetary Exploration Group, Surfaces and Atmospheres Section
Science Team, EPOCh/Deep Impact Extended Mission. Deputy PI for APL TYCHO project. PI for Chandra, Spitzer Deep Impact Remote Observing teams.

Education
1981 - B.A. Chemistry, Princeton University
1984 - M.S. Chemistry, University of California at Berkeley
1990 - M.S. Physics, University of Maryland
1992 - Ph.D. Physics, University of Maryland
1995 - Radiation Detection Methods Course, GSFC
1999 - Modern Infrared Detectors and System Applications, UCSB

Relevant Experience
1985-1995	Astrophysicist, NASA/Goddard Spaceflight Center
1995-1999	Associate Research Scientist, University of Maryland
1990-2001	HST Instrument Scientist, Space Telescope Science Institute
2001-2004	Senior Research Scientist, University of Maryland
2004 - Present	Senior Research Scientist, JHU-APL

Achievements/Awards
- Magna Cum Laude, Princeton University, 1981
- NASA COBE Group Achievement Award, 1990
- NASA/GSFC Productivity Group Award, 1993
- NASA/GSFC COBE Science Team Group Achievement Award, 1996
- STScI Science Merit Award, 2000
- Space Foundation Space Achievement Award, STScI, 2001
- Asteroid 12226 Caseylisse, named 2001
- Elected AAAS Fellow, 2004
- NASA/JPL Stardust Flight Team Group Achievement Award, 2005
- JHU/APL Special Achievement Award, 2006

Relevant Publications

Lisse, C.M., C.A. Beichman, G. Bryden, M.C.Wyatt. The Nature of the Dust in the Debris Disk Around HD69830. Ap J 658, 584 - 592.

Kraemer, K.E. C. M. Lisse, et al. 2005. MSX Observations of Small Solar System Bodies. AJ 130, 2363 - 2382.

Lisse, C.M. et al. 2002. A Search For Trends in Cometary Dust Emission, COSPAR Colloquia Series 15, Dust in the Solar System and Other Planetary Systems (eds. S.F. Green, I.P. Williams, J.A.M. McDonnell), 259 - 268.

Lisse, C.M. 2002. On the Role of Dust Mass Loss in the Evolution of Comets and Dusty Disk Systems, Earth, Moon, and Planets 90, 497-506.

Lisse, C.M. et al. 1998. Infrared Observations of Comets By COBE, Ap J 496, 971 - 991.

E. Dwek, (and 8 authors, including C.M. Lisse), "Morphology, Near-Infrared Luminosity and Mass of the Galactic Bulge From COBE DIRBE Observations", Ap J 445:716 (1995)

J.L. Weiland, (and 11 authors, including C.M. Lisse), "COBE/Diffuse Infrared Background Experiment Observations of The Milky Way Galactic Bulge", Ap J Lett 425:L81 (1994)

T.J. Sodroski, (and 18 authors, including C.M. Lisse), "Observations of the Large-Scale Infrared Emission from the Galactic Plane Region by the Diffuse Infrared Background Experiment", SPIE 2019, 202 (1993)

J.C. Mather and 25 co-authors (including C.M. Lisse),"Early Results From the Cosmic Background Explorer (COBE)", Adv. Space Res. 11, 181 (1991)

A. Omont, S.H. Moseley, T. Forveille, W. Glaccum, P.M. Harvey, L.Likkel, R.F. Lowenstein, C.M. Lisse, "Observations of the 40-70 Micron Bands of Ice in IRAS 09371-1212 and Other Stars", Ap J Lett 355:L27 (1990)

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

2004–	Asst. Professor, Oberlin College
2004–2006	Principal Investigator, NSF Grant ANT-0338150 studying the dynamics of the middle atmosphere using data from radio telescopes.
2002–2004	Astronomer, Harvard-Smithsonian Center for Astrophysics. Winterover scientist with the Antarctic Sub-millimeter Telescope / Remote Observatory (AST/RO), responsible for all aspects of telescope operation and maintenance while performing observations for myself and others.
1999–2002	Smithsonian Postdoctoral Fellow, Harvard-Smithsonian Center for Astrophysics. Post-doctoral advisor: Antony A. Stark

Honors

2001	NSF Antarctica Service Medal with Gold Winterover Bar

Publications

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," Astrophysical Journal, Letters **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," Astrophysical Journal **612**, 946 (2004).

C. L. Martin, W. M. Walsh, K. Xiao, A. P. Lane, C. K. Walker, and A. A. Stark, "The Inner 200pc: Hot Dense Gas," Astronomische Nachrichten Supplement **324**, 93 (2003).

S. Kim, C. L. Martin, A. A. Stark, and A. P. Lane, "Antarctic Submillimeter Telescope and Remote Observatory Observations of CO $J = 7 \rightarrow 6$ and $J = 4 \rightarrow 3$ Emission toward the Galactic Center Region," Astrophysical Journal **580**, 896 (2002).

Biographical sketch: David A. Neufeld

Current position:

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

Education:

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

Research interests:

Interstellar medium; molecular astrophysics. submillimeter and far-infrared astronomy; astrophysical masers

- Co-I on Submillimeter Wave Astronomy Satellite (SWAS, past NASA SMEX Mission)
- PI or Co-I on four Spitzer GO programs
- Astronomy Co-I on HIFI (future Herschel Space Observatory heterodyne instrument)

Selected publications

"Submillimeter Wave Astronomy Satellite and Arecibo Observations of H_2O and OH in a Diffuse Cloud along the Line of Sight to W51," Neufeld, D. A., et al. ApJ, 580, 278 – 284 (2002)

"The Chemistry of Fluorine-bearing Molecules in Diffuse and Dense Interstellar Gas Clouds," Neufeld, D. A., Wolfire, M. G., Schilke, P., ApJ, 628, 260 (2005)

"Discovery of interstellar CF^+," Neufeld, D. A., et al.. A&A, 454, L37 (2006)

"Spitzer Observations of HH 54 and HH 7-11: Mapping the H_2 Ortho-to-Para Ratio in Shocked Molecular Gas," Neufeld, D. A., et al., ApJ, 649, 816 (2006)

"Spitzer Observations of Hydrogen Deuteride," Neufeld, D. A., et al., ApJ, 647, L33 (2006)

Biographical sketch of Dr. Patrick Pütz

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academic education:
1991 – 2003: at the I. Physikalisches Institut, Universität zu Köln, Germany
- 1997 diploma (Diplom Experimentalphysik)
- 2003 PhD (Dr. rer. nat. Experimentalphysik)

thesis work:
PhD thesis work was performed at the Superconducting Mixers and Devices Group of the Kölner Observatorium für Submm Astronomie (KOSMA) on the development of several new processing steps in the institute's cleanroom for THz SIS device fabrication.

postdoc acitivities:
2003 – 2005: postdoc at KOSMA, Universität zu Köln, Germany
- device fabrication for the Herschel Space Telescope / HIFI Band 2 mixers
- November 2003 visit to the AST/RO telescope (Amundsen-Scott South Pole Station) exchanging two KOSMA 810 GHz SIS mixers

2005 – 2007: postdoc at the Steward Observatory Radio Laboratory, University of Arizona
- upgrade of 345 GHz 7-pixel DesertSTAR array receiver: mixer assembly and heterodyne characterization
- SuperCAM 64-pixel 345 GHz array receiver: in charge for SOI SIS device handling, selection and heterodyne characterization, mixer hardware
- research stay at the Space Research Organization of the Netherlands (SRON): 1.2 THz measurements with HEB receiver
- laser micromachining of 1.4 THz silicon feed horn structures, collaboration (PI J. Stern, JPL)
- characterization of submm RF performance of diffusion-cooled HEB, collaboration (PI D. Prober, Yale)
- investigation of performance of 2.7 THz micromachined spatial filters in order to improve the beam pattern of a quantum cascade laser source, collaboration (Q. Hu, MIT)
- design and fabrication of THz waveguide mixer hardware in collaboration with KOSMA

2007 – … : postdoc at KOSMA, Universität zu Köln, Germany
- HEB device fabrication for the SOFIA/GREAT receiver
- THz mixer development

MICHAEL E. SCHEIN, CV - Aerosp. Engineer / Instrument Builder

- ***Senior Opto-Mechanical Engineer, U of Ariz   2006 - Present***
- ***Principal Engineer, Andrews Space Inc.   2005 - 2006***

Performed a 12 month full time consultancy developing new launch propulsion system technology for DARPA. This involved design of a high g rotary air separation system providing liquid oxygen at first stage boost, eliminating the need for oxidizer at takeoff and dramatically decreasing launch weight and cost.

- ***Lead Engineer, National Oceanic & Atmospheric Administration Aeronomy Lab 94 - 05***

Primary program engineer/designer/analyst for several high altitude atmospheric research payloads. These packages were carried on board NASA and NOAA research aircraft and provided in many cases the first analyses of a number of atmospheric particles and gases.

- ***Aerospace/Cryogenic Engineering Consultant   94 - 06***

- Developed concept for keeping high power laser optics in vacuum free from particulate contamination to prevent mirror burning in operation, for the Airborne Laser Project, Northrop-Grumman Space & Technology.

- Designed and equipped a large facility with machine shop, assembly areas, and test labs for aircraft and spaceflight hardware. Included machining tool specification, clean room integration, tool & part storage, etc.

- Designed and built a new concept combination helium instrument cooler / envelope gas replenishment system with the capacity for up to quadrupling the lifetime of NASA scientific balloon systems.

- Provided design and on-site engineering support for a variety of engineering projects, including manned around the world ballooning, world record speed rocket cars, single stage to orbit vehicles, Mars habitability and soil processing equipment design studies, long range hang gliders, Mars flyers, research dropsonde design, etc.

- ***Senior Engineer, Cryogenic Technical Services Inc.   92 - 94***

- Member of the team supporting the EarthWinds Manned Balloon Project circumglobal flight. Responsible for liquid helium gas makeup tank design, servicing, and numerous real time modifications to all balloon systems.

- Designed, built, & tested a prototype miniature liquid oxygen generator for home medical use. Concept was bought by a major company in the field and is now a widely used product.

- Designed and supervised the construction of the first large diborane (a toxic chemical used for chip etching) cryogenic liquid storage system.

- Designed innovative thermal multilayer insulation schemes and high speed rotating cryogenic fluid carrythru designs for several national-scale projects, including the National Superconducting Mag. Energy Storage Project.

- ***Aerospace /Cryogenics Engineer, NASA Goddard Space Flight Center 84 – 92***

- Lead Servicing Engineer for the Superfluid Helium On-Orbit Transfer (SHOOT) experiment, the STS-57 Space Shuttle payload aimed at developing zero gravity liquid helium storage and transfer technology.

- Task Leader for Broad Band X-Ray Telescope (BBXRT) Shuttle Payload Cryogenic Operations. Responsible for dual solid argon cooler design, fabrication, and servicing.

- Developed and patented a new technology liquid cryogen cooler for zero-g use. Built working model for sounding rocket observation of the 1987A supernova.

- Member of the NASA-Goddard Mechanical Cooler Development Group. Involved in the procurement and evaluation of industry state of the art space qualified coolers. Suggested future improvements to venders.

EDUCATION: B.S.   Aerospace & Ocean Engineering, Virginia Tech, 1985
Materials Engineering, New Mexico Tech, 1982

Anders Skalare
Jet Propulsion Laboratory, Mail Stop 168-314, 4800 Oak Grove Drive, Pasadena, CA 91109
Phone: (818)-3549383, email: anders.skalare@jpl.nasa.gov
Technical Staff, Senior Member, Section 385, Jet Propulsion Laboratory, Pasadena, California
M.Sc., Engineering Physics 1985; Lic. Tech. 1991; Ph.D. Applied Electron Physics 1993; All from Chalmers University of Technology, Gothenburg, Sweden
Awards: 2 NASA Tech Brief Awards, JPL Group Award, JPL Award for Technology , NASA Space Act Award. Skalare is currently PI on a JPL Research & Technology Development project for Hot-Electron Bolometer Mixers, and PI on an existing NASA APRA award to demonstrate a 2-pixel brass waveguide mixer array at 1.5 THz.
Earlier research activities at Chalmers University (Sweden) and at the National Space Research Organization (Netherlands) include studies of Superconductor-Insulator-Superconductor (SIS) tunnel junction mixers including device research, microwave design and construction of heterodyne receiver systems. Work at JPL (1993 to present) has been primarily focused on superconducting hot-electron bolometer (HEB) mixers. Among the results are the first measurement with a submillimeter-wave HEB receiver fast enough to operate with gigahertz intermediate frequency bandwidths, and a mathematical model that allows detailed numerical predictions of mixer conversion efficiency and noise in a diffusion-cooled bolometer.

Selected Publications:

1. Skalare, “Determining Embedding Circuit Parameters from DC Measurements on Quasiparticle Mixers”, Int. J. of IR & mm Waves, Nov. 1989
2. Skalare, Dierichs, Mees, van de Stadt, Panhuyzen, de Graauw, Klapwijk, "SIS mixers using endfire and broadside double dipole antennas at 425 and 480 GHz", Proc. Fourth Int. Symp. Space Terahertz Tech., pp.639-651, March 30 - April 1, 1993, Univ. of California in Los Angeles, Los Angeles, California
3. Skalare, McGrath, Bumble, LeDuc, Burke, Verheijen, Schoelkopf, Prober,"Large bandwidth and low noise in a diffusion-cooled hot-electron bolometer mixer", Appl. Physics Lett., Vol. **68** (11), 11 March 1996
4. Skalare, McGrath, Bumble, LeDuc, "Receiver Measurements at 1267 GHz using a diffusion-cooled superconducting transition-edge bolometer", IEEE Trans. Appl. Superconductivity, Vol.AS-7, pp.3568-3571, (1997).
5. Skalare, McGrath, "A frequency-domain mixer model for diffusion-cooled hot-electron bolometers", Accepted for publication in IEEE Trans. Applied Superconductivity, 1999.
6. Skalare, McGrath, Echternach, LeDuc, Siddiqi, Verevkin, Prober, “Aluminum Hot-Electron Bolometer Mixers at Submillimeter Wavelengths”, IEEE Trans. Applied Superconductivity, Vol.11, No.1, pp.641-644, March 2001
7. Skalare, McGrath, Bumble, LeDuc, “Tantalum Hot-Electron Bolometers for Low-Noise Heterodyne Receivers”, Proc. Far-IR, Sub-MM & MM Detector Technology Workshop, 1-3 April 2002, Monterey, CA.
8 Stern, Bumble, Kawamura, Skalare, "Fabrication of Terahertz Frequency Phonon Cooled HEB Mixers," IEEE Transactions on Appl. Superconductivity, accepted for publication 2004.
9 Skalare, Stern, Bumble, Maiwald, “Hot-Electron Bolometer Mixers on Silicon-On-Insulator Substrates for Terahertz Frequencies”, Proc. 16th Int. Symp. on Space Terahertz Technology (ISTT2005), held at Chalmers University, Gothenburg, Sweden , May 2-4, 2005.

Jeffrey A. Stern
MS 302-231
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
818-354-0029

Employment and Education:
2001 to present, Senior Member of the Technical Staff, JPL
1990 to 2001 Member of the Technical Staff, JPL
1991: PhD Applied Physics, California Institute of Technology
1983: BS Physics, Rensselaer Polytechnic Institute

During his tenure at JPL, Dr. Stern has been involved with superconducting sensors. Currently he is fabricating both single photon optical detectors and phonon cooled mixers based on ultra-think NbN. He recently developed a process for fabricating mixers on ultra-thin (6 µm) Si with free standing Au beam-leads[1]. He has also recently fabricated a 15 by 15 μm^2 SNSPD with 40% quantum efficiency at 1064nm. Previously, he fabricated, tested and space qualified superconductor-insulator-superconductor (SIS) mixer chips for band 5 (1140-1250 GHz) of the HIFI instrument on the Hershel Space Observatory. He also worked on several tasks including NbTiN and Nb based SIS mixers under funding from NASA. Over the course of this program substantial progress was made on extending SIS mixers from 200 GHz up to 1.25 THz. He also has worked to manage a task to fabricate mixer chips (both SIS and phonon cooled HEBs) for the Smithsonian Astrophysical Observatory's Submillimeter Array. Dr. Stern or employees working on his task fabricated all of the detectors on this state-of-the-art submillimeter interferometer. In conjunction with the SAO, an 800 GHz NbTiN phonon cooled mixer was demonstrated with exceptionally low noise[3]. This mixer has been in use on the University or Arizona's Mt. Graham telescope for over three years now. More recently a 1.4 THz NbTiN HEB mixer was successfully used in Chile on the Smithsonian's Receiver Lab Telescope. Dr. Stern has also managed a smaller task to deliver SIS mixer chips for Caltech's millimeter array at the Owens Valley Radio Observatory for use at 115 and 230 GHz.

Selected Publications:

1. Fabrication and Characterization of Superconducting NbN Nanowire Single Photon Detectors, J. A. Stern, W. H. Farr, accepted for publication IEEE Transactions on Appl. Superconductivity, 2006.

2. Fabrication of Terahertz Frequency Phonon Cooled HEB Mixers, J. A. Stern, B. Bumble, J. Kawamura, and A. Skalare, IEEE Transactions on Appl. Superconductivity, **15,** No. 2, (June 2005)

3. A 650 GHz fixed-tuned waveguide SIS distributed mixer with no integrated tuning circuit, C.-Y. E. Tong, R. Blundell, K. G. Megerian, J. A. Stern, H. G. LeDuc, IEEE Transactions on Appl. Superconductivity, **13,** 2 (June, 2003).

4. A Low-noise NbTiN Hot Electron Bolometer Mixer, C.E. Tong, J. Stern, K. Megerian, H. LeDuc, T.K. Sridharan, H. Gibson, & R. Blundell, Proc. 12th Space THz Tech. Symp., San Diego, CA, (February 2001).

5. Fabrication of Nb/Al-N_x/NbTiN junctions for SIS mixer applications, B. Bumble, H. G. LeDuc, J. A. Stern, K. G. Megerian, IEEE Transactions on Appl. Superconductivity, **11,** 1, (Mach, 2001).

6. Characterization of submillimeter quasi-optical twin-slot double-junction SIS mixers, M. C. Gaidis, M. Bin, D. Miller, J. Zmuidzinas, H. G. LeDuc, J. A. Stern, Superconducting Sci Technology, **9,** No 4A, (April 1996).

7. Quasi-optical Josephson-junction oscillator arrays, J. A. Stern, H. G. LeDuc, J. Zmuidzinas, IEEE Transactions on Appl. Superconductivity, **3,** 1, (March 1993).

8. Characaterization of NbN films and tunnel junctions, J. A. Stern, H. G. LeDuc, IEEE Transactions on Magnetics, **27,** 2, (March 1991).

9. Energy-gap spectroscopy of superconductors using a tunneling microscope, H. G. LeDuc, W. J. Kaiser, and J. A. Stern, Appl. Phys. Lett., **50,** 1921, (1987).

curriculum vitae (short form)
for
Jürgen Stutzki

Contact Information:
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Zülpicher Straße 77, D-50937 Köln, Germany
Tel.: +49 (221) 470-3494, e-mail: stutzki@ph1.uni-koeln.de

Education:
Ph.D. Physics, May 1984, Universität zu Köln
Thesis Advisor: Prof. Dr. Gisbert Winnewisser
Physics Diploma, 1981, Technische Universität München
Diploma thesis advisor: Prof. Dr. W. Brenig

Professional History:
07/1990 -- Professor of Physics, Universität zu Köln
10/1986 -- Senior Scientist, MPI für Extraterrestrische Physik, Garching b. München
01/1985 -- Research Scientist, UC Berkeley, CA, USA
05/1984 -- Postdoc, Universität zu Köln

Six Most Related Publications:

"The cooling of atomic and molecular gas in DR21", Jakob, H.; Kramer, C.; Simon, R.; Schneider, N.; Ossenkopf, V.; Bontemps, S.; Graf, U. U.; Stutzki, J., Astron. Astrophys. 461, 999-1012, 2007

"A KOSMA 7 deg^2 ^{13}CO 2-1 and ^{12}CO 3-2 survey of the Perseus cloud. I. Structure analysis", Sun, K.; Kramer, C.; Ossenkopf, V.; Bensch, F.; Stutzki, J.; Miller, M. Astron. Astrophys. 451, 539-549, 2006

"First observations with CONDOR, a 1.5 THz heterodyne receiver", Wiedner, M. C.; Wieching, G.; Bielau, F.; Rettenbacher, K.; Volgenau, N. H.; Emprechtinger, M.; Graf, U. U.; Honingh, C. E.; Jacobs, K.; Vowinkel, B.; Menten, K. M.; Nyman, L.-Ã….; Güsten, R.; Philipp, S.; Rabanus, D.; Stutzki, J.; Wyrowski, F. Astron. Astrophys. 454,.L33-L36, 2006

"CI 492 GHz Mapping Observations of the High-Latitude Translucent Cloud MCLD 123.5+24.9", Bensch, F:, Leuenhagen, U., Stutzki, J., Schieder, R., 2003, ApJ 591, 101.

"Photon Dominated Regions in the Spiral Arms of M83 and M51", Kramer, C., Mookerjea, B., Bayet, E., Garcia-Burillo, S., Gerin, M., Israel, F.P., Stutzki, J., and Wouterloot, J.G.A., 2005, A&A 414, 961.

"Heterodyne Instrument for FIRST (HIFI): Preliminary Design", de Graauw, Th., Whyborn, N.D:, van de Stadt, H., Beaudin, G., Beintema, D.A., Belitsky, Y.V., Cais, P., Caus, E., Cros, A., de Groene, P., Emrich, A., Erickson, N..N.R., Gaier, T.C., Gallego-Puyol, J.D., Gao, J.R:, Hartogh, P., Honingh, C.E., Jacobs, K., Kruising, R., Lecacheux, A:, Natale, V., Orfei, R., Pearson, J.C., Phillips. T.G., Roelfsema, P.R., Rosolen, C., Salez, M., Schieder, R., Schuster, K.-F., Schwwab, G., Starsky, J.P., Stutzki, J., Torchinsky, S., van Leeuwen, B.-J., Visser, H., Wildeman, K.J., Withington, S. and Zmuidzinas, J., *3rd Cologne Zermatt Symposium on "The Physics and Chemistry of Interstellar Medium",* Zermatt, 1998.

Other Significant Related Publications:

"Atomic Carbon in M82: Physical Conditions Derived from Simultaneous Observations of the [CI] Fine-structure Submillimeter-wave Transitions", Stutzki, J., Graf, U.U., Haas, Sybille; Honingh, C.E.; Winnewisser, Gisbert; McMullin, J.P.; Hottgenroth, D., Jacobs, K., Schieder, R., Simon, R., Staguhn, J., Martin, R.N., and Peters, W., Astrophys.J. (Letters) 477, L33-L37, 1997.

"On the Fractal Structure of Molecular Clouds", Stutzki, J., Bensch, F. and Heithausen, A., Astron. Astrophys., 336, 697-720, 1998

"GREAT: the first-generation German heterodyne receiver for SOFIA", Güsten, R., Hartogh, P., Hübers, H.-W., Graf, U.U., Jacobs, K., Röser, H.-P., Schäfer, F., Schieder, R., Stark, R., Stutzki, J., Van der Wal, P., and Wunsch, A., SPIE. 4014, 23-30, 2000

"On the isotopomeric CO line brightnesses in clumpy photon dominated regions: apparent fractionation of $^{13}CO/C^{18}O$", Zielinsky, Maik; Stutzki, Jürgen; Störzer, Herbert, A&A 358,.723-727, 2000

"SOFIA terahertz array receiver (STAR)", Michael, Ernest A.; Graf, Urs U.; Honingh, C.E., Jacobs, K., Lewen, F., Schieder, R., and Stutzki, J., SPIE.4014,.109-115, 2000

"The Antarctic Submillimeter Telescope and Remote Observatory (AST/RO)", 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., PASP, Vol. 113, Issue 783, pp. 567-585, 2001

"1.4 THz receiver for APEX and for GREAT on SOFIA", Schmidt, G., Bielau, F., Graf, U.U., Honingh, C.E., Jacobs, K., Rettenbacher, K., Stutzki, J., Wiedner, M.,C., 2004, SPIE 5498, 675

"Emission of CO, CI and CII in W3 Main", Kramer, C:, Jakob, H., Mookerjea, B., Schneider, N., Brüll, M., Stutzki, J., 2004, A&A 424, 887.

"The Cologne Database for Molecular Spectroscopy, CDMS: a useful tool for astronoers and spectroscopists", Müller, H.S.P., Schlöder, F., Stutzki, J., Winnewisser, G., 2005, JMoSt 742, 215.

Examples of Synergistic Activities:

- Co-PI of the HIFI instrument for ESA/NASA mission Herschel;
- member of SOFIA science steering committee;
- PI of SOFIA Terahertz Array Receiver;
- chair of Sonderforschungsbereich 494 ``Evolution of Interstellar Matter: THz Spectroscopy in Lab and Space";
- operation of the KOSMA 3m-submm-telescope on Gornergrat/Switzerland;
- collaborator with the NANTEN2-4m submm in Chile, Pampa La Bola
- coordination of the Submm/THz instrumentation in these programs;
- directing the instrument development program at KOSMA/Universität zu Köln;
- directing the astrophysics research program (interstellar matter: structure and PDR-modelling);
- supervising graduate and undergraduate students in astrophysics and instrumentation programs at KOSMA;

Curriculum Vitae for Sander Weinreb

Professional Preparation

Massachusetts Institute of Technology	EE	BS, 1958
Massachusetts Institute of Technology	EE	Ph.D, 1953

Appointments

1999 – Current	Principal Scientist, JPL and Faculty Associate, Caltech
1996- 1999	Research Professor, U. of Massachusetts
1989-1996	Principal Scientist, Martin Marietta Laboratories
1987-1989	Research Professor, U. of Virginia
1984-1987	Assistant Director, National Radio Astronomy Observatory
1965-1984	Head, Electronics Division, NRAO
1963-1965	Staff Member, MIT Lincoln Laboratory

Publications

Relevant to the Proposed Work

S. Weinreb, “Noise Temperature Estimates For A Next Generation Very Large Microwave Array”, Digest of Papers, 1998 IEEE MTT Symposium

S. Weinreb, "SIS-Mixer to HEMT-Amplifier Optimum Coupling Network," IEEE Trans. on Microwave Theory & Tech., vol. MTT-35, no. 11, pp. 1067-1069, November 1987.

S. Weinreb, "Low-Noise IF Components for Millimeter Wave Receivers," presented at URSI Symposium on Millimeter Wave Technology, Grenoble, France, August 1980.

S.. Weinreb, "Low-Noise Cooled GASFET Amplifiers," IEEE Microwave Theory and Techniques, vol. 28, no. 10, October 1980, pp. 104l-1054. Also NRAO Electronics Division Internal Report No. 202

.S. Weinreb, R. Harris, and M. Rothman, "Millimeter-Wave Noise Parameters of High Performance HEMT's at 300K and 17K", IEEE 1989 MTT-S Digest

Significant Publications

S. Weinreb, "A New Upper Limit to the Galactic Deuterium-to-Hydrogen Ratio," Nature, 195, 367, 1962.

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.

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.

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.

S. Weinreb, "Low-Noise Cooled GASFET Amplifiers," IEEE Microwave Theory and Techniques, vol. 28, no. 10, October 1980, pp. 1041-1054.

Synergistic Activities

Outreach - K-12 Education - Radiometers for Lewis Center for Educational Research, CA, 2006-

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

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.

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

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

Collaborators & Other Affiliations

Collaborators of S. Weinreb during the past 48 months, May 24, 2005

Bardin, J.	UCLA
Bagri, D.	Caltech JPL
Cordes, J.	Cornell
Cressler, J.	Georgia Tech
Daddario, L.	Caltech JPL
Dawson, D.	Caltech JPL
DeBoer, D.	SETI Institute
Erickson, N.	U. of Mass
Ericsson, D.	Chalmers University
Gaier, T.	Caltech JPL
Gatti, M.	Caltech JPL
Gawande, R.	Caltech
Grundbacher, R.	Northrop Grumman
Hajimiri, A.	Caltech
Hu, R.	SINCA, Taiwan
Imbriale, W.	Caltech JPL
Jones, G.	Caltech
Kiladal, P.	Chalmers University
Lai, R.	Northrop Grumman
Leong, Y.	Singapore Company
Morgan, M.	Nat. Radio Astronomy Obs.
Rutledge, D.	Caltech
Samoska, L.	Caltech JPL
Schulman, J.	HRL Laboratories
Sholley, M.	Northrop Grumman
Tarter, J.	SETI Institute
Wadefalk, N.	Caltech
Walker, C.	U. of Arizona
Welch, W.	U.C.Berkeley

Graduate Students (11)

Person	**Present Location**
Y. C. Leong	Singapore Company
S.Srinivath	Agilent
S. Rivera	Calamp
M. Rothman	Unknown
M. Morgan	NRAO
Y. Tang	Triquint
P. Laufer	JPL
R. Gawande	U. of Virginia
J. Bardin	Caltech
G. Jones	Caltech
M. Ahmed	Unknown

Ph.D. Thesis Advisor – J. B. Wiesner (Scientific advisor to President Kennedy)

Curriculum Vitae

Mark G. Wolfire (Co-I)

Associate Research Scientist

Current Address: University of Maryland
Astronomy Department
College Park, MD 20742
e-mail: mwolfire@astro.umd.edu

Education

Ph. D. Astronomy, University of Wisconsin-Madison, Madison, Wisconsin - 1985.
M. S. Astronomy, University of Wisconsin-Madison, Madison, Wisconsin - 1982.
B. S. Astronomy, Case Western Reserve University, Cleveland, Ohio - 1980.

Employment

2002 - present: Associate Research Scientist, Astronomy Department University of Maryland, College Park

2005: Senior National Research Council Associate, NASA Ames Research Center

1996 - 2002: Assistant Research Scientist (promoted 1999), Research Associate, Astronomy Department University of Maryland, College Park

1995 - 1996: Smithsonian Fellow, Air & Space Museum Laboratory for Astrophysics

1994 - 1995: Visiting Assistant Researcher, University of California, Berkeley

1992 - 1994: Senior National Research Council Associate, NASA Ames Research Center

1990 - 1992: Postdoctoral Fellowship, Harvard Smithsonian Center for Astrophysics

1998 - 1990: Postdoctoral Research Assistant: Department of Astronomy and Astrophysics, University of Chicago

Selected Publications

M.G. Kaufman, M.G. Wolfire, & D.J. Hollenbach, "[Si II], [Fe II] and H_2 Emission from Massive Star Forming Regions",2006, ApJ, 644, 283.

D. A. Neufeld, P. Schilke, K. M. Menten, M. G. Wolfire, et al. "Discovery of Interstellar CF^+", 2006, A&A, 454, L37.

D. A. Neufeld, M. G. Wolfire, & P. Schilke "The Chemistry of Fluorine-bearing Molecules in Diffuse and Dense Interstellar Gas Clouds", 2005, ApJ, 628, 260

M. G. Wolfire, C. F. McKee, D. J. Hollenbach, & A. G. G. M. Tielens "Neutral Atomic Phases of the ISM in the Galaxy", 2003, ApJ, 587, 278.

M. L. Luhman, S. Satyapal, J. Fischer, J., M. G. Wolfire et al. 2003, "The [C II] 158 Micron Line Deficit in Ultraluminous Infrared Galaxies Revisited" ApJ, 594, 758

A. Sternberg, C. F. McKee, & M. G. Wolfire "Atomic Hydrogen Gas in Dark Matter Minihalos and the Compact HVCs", 2003, ApJS, 143, 419

M. J. Kaufman, M. G. Wolfire, D. J. Hollenbach, & M. L. Luhman "Far Infrared Submillimeter Emission from Galactic and Extragalactic Photo-Dissociation Regions: Models" 1999, ApJ, 527, 795.

M. G. Wolfire, D. Hollenbach, C. F. McKee, A.G.G.M. Tielens, & E.L.O. Bakes, "The Neutral Atomic Phases of the ISM", 1995, ApJ, 443, 152

M.G. Wolfire, D. Hollenbach, & A.G.G.M. Tielens, "CO(J=1-0) Line Emission from Giant Molecular Clouds", 1993, ApJ, 402, 195

Mark Wolfire: Description of Scientific, Technical, & Management Performance

Relevant prior research efforts include the NASA Long Term Space Astrophysics grants "Photodissociation Regions: Laboratories for Astrochemistry" (award period: 3/15/05-3/14/10) and "PDRs in Galaxies: From the Local Universe to High Z Starbursts" (award period: 3/15/00-3/14/07). Dr. Wolfire is principal investigator on both of these grants. The Co-Is and collaborators on these projects are in separate institutions including David Hollenbach (NASA/Ames), Michael Kaufman (San Jose State University), Chris McKee (University of California, Berkeley), and Alexander Tielens (NASA/Ames). Dr. Wolfire is responsible for managing the entire effort including coordinating between Co-Is, taking the lead role in writing papers, submitting reports to the program manager, managing funding, and distributing subcontracts. The results of these efforts have resulted in highly successful (as judged by their citation count), peer reviewed, research papers.

The main focus of this work is to analyze and interpret the photodissociation region (PDR) emission line and continuum observations from a diverse set of NASA space missions, including COBE, FUSE, Spitzer, and future observations from SOFIA and Herschel. We are drawing upon detailed modeling tools which we have developed over the years to develop a detailed understanding of the interaction of the light of young, luminous, massive stars with the ISM in the Milky Way and other galaxies.

Associated with Galactic PDR studies we constructed a model for the PDR emission associated with the Galactic diffuse interstellar medium. We calculated the physical conditions, and infrared line emission, from the neutral atomic gas in the disk, from the inner $R \sim 3$ kpc to outer $R \sim 18$ kpc Galaxy. We demonstrated that the photoelectric heating from small grains and PAHs produces a stable two-phase (cold + warm) medium throughout the Galactic disk. The warm medium is cooled by Lyα, [C II], [O I], and electron recombination onto positively charged grains. The cold medium is cooled primarily by [C II]. Comparing estimates of the thermal pressure in the outer Galaxy to the two-phase thermal pressure, we find that cold gas should exist in the Galaxy and at no point do we find that gas must be entirely in the warm phase. These results are important in understanding the distribution of gas phases in the Galaxy, the distribution of star formation in the Galaxy, and in interpreting infrared line emission from other galaxies.

To plan and prepare for Spitzer observations we have completed a parameter study of the diagnostic emission lines from PDRs which are directly applicable to Spitzer. We have provided diagnostic plots including ro-vibrational and pure rotational emission lines from H_2 as well as fine-structure line emission from [Si II], [C II], and [Fe II]. In an important new addition to previous work we have included the emission from both ionized (H II) and neutral PDR gas so that observers may separate the component emission. We have also submitted successful GO1, GO2, and GO3 Spitzer proposals to study molecular hydrogen emission from edge-on PDRs. These will allow us to determine the temperature distribution and calibrate our heating and cooling rates directly against the observed temperature.

The efforts of the PI and collaborators on these projects have resulted in 13 papers, 10 abstracts or short contributions, and 7 invited and contributed talks.

Harold W. Yorke
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Dr. Yorke's scientific interests in astronomy are broad and varied. He has observing experience at X-ray, optical, UV, IR, and mm-radio wavelengths. As PI or Co-I on observing proposals he has contributed to the direct modeling and interpretation of astrophysical data from modern instruments. Currently he is Manager of JPL's Science Division.

In recent years Dr. Yorke has focused his research efforts in the study of early phases of star formation and the associated formation and early evolution of protostellar disks. His emphasis has been on the radiation hydrodynamical behavior of the dusty gas including the influence of UV irradiation on the disk by both the central (proto-)star and by external sources. Having also made significant contributions to the theory of formation of massive stars and their effect on their local environment, he has begun studying the coagulation and growth of dust grains by numerical means simultaneously with the hydrodynamic evolution of the disks surrounding low mass stars.

Academic Degrees: B.S. (UCLA, 1970), Physik-Diplom (1972, Göttingen), Dr. rer.nat. (1974, Göttingen), Habilitation (1979, Göttingen)

Scientific Positions: Senior Research Scientist (Jet Propulsion Laboratory, 1998-present), C3-Prof. (Univ. Würzburg: 1988-98), Prof. (Göttingen: 1983-88), tenured Research Scientist (Göttingen: 1978-83); Scientist (MPI for Astrophysics Munich: 1975-78; Göttingen: 1973-75), R.A. (Caltech, 1970-71)

Memberships: AAS, IAU, Science Advisory Council of MPI Astronomy (Heidelberg), Editorial Board of *Astronomy Notes* (founded 1821)

Recent Relevant Publications:

Bodenheimer P, Laughlin GP, Rózycka M, Yorke HW. 2007, *Numerical Methods in Astrophysics - An Introduction*, New York: Taylor & Francis, pp. 329 + accompanying CD

Turner N, Willacy,K, Bryden, G, Yorke HW, 2006, *Turbulent Mixing in the Outer Solar Nebula*, **ApJ**, 639, 1218

Freyer T, Hensler G, Yorke HW, 2006, *Massive stars and the energy balance of the ISM. II. The 35 Mo Star and a Solution to the "Missing Wind Problem"*, **ApJ**, 638, 262

Burkert A, Lin DNC, Bodenheimer PH, Jones CA, Yorke HW, 2005, *On the Surface Heating of Synchronously Spinning Short-Period Jovian Planets*, **ApJ**, 618, 512

Yorke HW, 2004, *The Formation of Massive Stars via Accretion*, invited review, **IAU Symp.** 221, 141

Freyer T, Hensler G, Yorke HW, 2003, *Massive stars and the energy balance of the ISM. I. The impact of an isolated 60 Mo star*, **ApJ**, 594, 888

Yorke HW, Sonnhalter C, 2002, *On the Formation of Massive Stars*, **ApJ**, 569, 846

Suttner G, Yorke HW, 2001, *Early Dust Evolution in Protostellar Accretion Disks*, **ApJ**, 551, 461

Richling S, Yorke HW, 2000, *Photoevaporation of protostellar disks V. Circumstellar disks under the influence of both EUV and FUV radiation*, **ApJ,** 539, 258

Hollenbach D, Yorke HW, Johnstone D, 2000, *Disk Dispersal around Young Stars*, in **Protostars and Planets IV**, eds. Mannings, Boss, Russell, Tucson: U. Ariz. Press, 401

Yorke HW, Bodenheimer P, 1999, *The Formation of Protostellar Disks III. The Influence of Gravitationally Induced Angular Momentum Transport on Disk Structure and Appearance*, **ApJ** 525, 330

Erick T. Young

University of Arizona
Steward Observatory, 933 N. Cherry Ave, Tucson AZ 85721
Telephone : 520-621-4119 ; Fax : 520-621-9555 ; email : eyoung@as.arizona.edu

EXPERIENCE

Employment

- 9/98 – present Astronomer, Steward Observatory, University of Arizona
- 7/84 – 9/98 Associate Astronomer, Steward Observatory, University of Arizona
- 7/80 – 6/84 Assistant Astronomer, Steward Observatory, University of Arizona

EDUCATION

- Ph.D. State University of New York, Stony Brook; Astronomy, 1978
- M.S. State University of New York, Stony Brook; Astronomy, 1972
- B.S. University of California, Davis; Physics, 1970

PROFESSIONAL ACTIVITIES

- 2000 – present Advisory Panel, Academia Sinica Institute for Astronomy and Astrophysics
- 2001 – present Science Oversight Committee, Wide-Field Camera 3
- 2004 – SOFIA Independent Cost, Management, and Schedule Review Team
- 2004 – SOFIA Independent Science and Mission Operations Review Team
- 1997 – 2002 Facility Scientist Team, Space Infrared Telescope Facility
- 2000 – 2002 NASA Astronomy and Physics Working Group
- 2001 – 2002 NASA Infrared, Sub-mm, and MM Detector Working Group (Chair)
  Edited "Detectors Needs for Long Wavelength Astrophysics"

HONORS/AWARDS

- Maria and Eric Muhlmann Award
  Astronomical Society of the Pacific
  NICMOS Instrument Definition Team, 2003
- NASA Group Achievement Award
  IRAS Sky Survey Atlas Team, 1992
- NASA Public Service Group Achievement Award
  Spacelab II Principal Investigator Team, 1986
- NASA Group Achievement Award
  IRAS U.S. Science Team, 1984
- NASA Group Achievement Award
  IRAS Mission Scientific Data Analysis System Development and Operations Team, 1984
- Van Biesbroeck Award, 1982

Current and Pending Research Support

Current and Pending Research Support
Investigator: Christopher K. Walker

CURRENT SUPPORT:

Project title: Development of a Submillimeter-wave Superheterodyne Camera (SuperCam) for the Heinrich Hertz Telescope
Source of Support: NSF MRI Program AST-0421499
POC: Andrew Clegg, aclegg@nsf.gov, (703) 292-4892
Total Award Amount: $1,742,356 Total Award Period Covered: 09/01/04 - 08/31/07
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Project title: A High Elevation Antarctic TeraHertz Telescope -HEAT-
Source of Support: NSF- OPP Antarctic Aeronomy & Astrophysics
POC: Bernhardt Lettau, blettau@nsf.gov, (703) 292-8033
Total Award Amount: $79,695 Total Award Period Covered: 07/15/06 - 06/30/07
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Project title: Computing a Universe of Galaxies (Co-I)
Source of Support: NSF 05-627 DMS Infrastructure Program
POC: Dean M. Evasius, devasius@nsf.gov, (703) 292-8132
Total Award Amount: $99,681 Total Award Period Covered: 08/01/06 - 07/31/07
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 0

Project title: Hazal: A Portable System for Detecting Hazardous Materials Using Terahertz Absorption Line Spectroscopy
Source of Support: Teravision, Inc.
POC: Christian Drouet D'Aubigny, cdaubigny@as.arizona.edu, (520) 621-6540
Total Award Amount: $323,253 Total Award Period Covered: 11/26/06 - 12/31/07
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.69

Project title: Hazal: Identification of hazardous Materials Using High Resolution Spectroscopy Between 0.14 and 0.9 THz
Source of Support: Air Force Office of Scientific Research - DURIP
POC:
Total Award Amount: $235,000 Total Award Period Covered: 04/01/07 - 03/31/08
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: 0.36 Sumr:

PENDING SUPPORT:

Project title: HEAT: the High Elevation Antarctic TeraHertz Telescope
Source of Support: NSF- 07-510 - ANT - MRI
POC: Dean M. Evasius, devasius@nsf.gov, (703) 292-8132
Total Award Amount: $1,985,459 Total Award Period Covered: 09/01/07 - 08/31/09
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 1.0

Current and Pending Research Support
Investigator: Christopher K. Walker

Project title: A 1.45 THz Receiver for Dome A, Antarctica: A Dress Rehearsal for Future Space Science & Manned Mars Missions
Source of Support: JPL - DRDF
POC: Anders Skalare, anders.skalare@jpl.nasa.gov, (818) 354-9383
Total Award Amount: $99,800 Total Award Period Covered: 07/01/07 - 06/30/08
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 0.56

Project title: A Strategic Research Group for the Development and Commercialization of TeraHertz Technology
Source of Support: Science Foundation Arizona
POC: Patrick L. Jones, pljones@ott.arizona.edu, (520) 621-5000
Total Award Amount: $1,422,690 Total Award Period Covered: 06/15/07 - 06/14/09
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: Sumr: 2.0

Project title: Development of a Submillimeter-wave Superheterodyne Camera (SuperCam) for the Heinrich Hertz Telescope (Supplement)
Source of Support: NSF
POC: Andrew Clegg, aclegg@nsf.gov, (703) 292-4892
Total Award Amount: $395,125 Total Award Period Covered: 03/01/07 - 12/31/07
Location of Project: The University of Arizona
Person-Months Per Year Committed to the Project: Cal: Acad: 1.0 Sumr:

CURRENT AND PENDING SUPPORT

PIETRO N. BERNASCONI

Current Support

Project Title	**PI**	**Sponsoring agency**	**Total**	**Period**	**Mm/yr**
Bolometric Solar Imaging at Solar Minimum	David M. Rust	NASA William J. Wagner (202) 358-0911 William.J.Wagner@nasa.gov	$1,872,656	01/2004 to 12/2007	9

Pending Support

Project Title	**PI**	**Sponsoring agency**	**Total**	**Period**	**Mm/yr**
A Bolometric Imager for Investigating the Sources of Solar Irradiance Variability	Pietro, N. Bernasconi	NASA William J. Wagner (202) 358-0911 William.J.Wagner@nasa.gov	$400,955	01/2008 to 12/2009	3

Current and Pending Grants for David Hollenbach
(Project Scientist)

<u>*Current Awards*</u>

1. Project title: Modelling protoplanetary disks and probing our understanding of planet formation and disk evolution
Name of PI on award: Uma Gorti
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address) Origins of Solar Systems Program NASA, Dave Lindstrom (202 358 0311) dlindstr@hq.nasa.gov
Performance period; 10/01/04-09/30/07
Total budget: $85,000 per year
Commitment by Co-I : (1 months/yr)

2. Project title: SIRTF SINGS: The SIRTF Nearby Galaxy Survey
Name of PI on award: R. Kennicutt
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address): NASA, Jeffrey Hayes (301-286-6290), Jeffrey.Hayes@nasa.gov
Performance period; 1/1/01-9/30/06
Total budget: $23,600 per year (for CoI Hollenbach)
Commitment by Co-I : (2 months/yr)

3. Project title: The Formation and Evolution of Planetary Systems: Placing our Solar System in Context
Name of PI on award: M. Meyer (U. Arizona)
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address): NASA, Jeffrey Hayes (301-286-6290), Jeffrey.Hayes@nasa.gov
Performance period; 1/1/01-9/30/06
Total budget: $24,000 per year (for Co-I Hollenbach)
Commitment by Co-I : (2 months/yr)

4. Project title: Optically thin circumstellar dust and gas disks
Name of PI on award: L. Hillenbrand
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address): Long Term Space Astrophysics Program, NASA, Jeffrey Hayes (301-286-6290), Jeffrey.Hayes@nasa.gov,
Performance period; 10/01/01-09/30/06
Total budget: $95,000 in FY 06 for CoI Hollenbach
Commitment by Co-I : (1 month/yr)

5. Project title: Linking our origins to our future
Name of PI on award: D. DesMarais
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address): Astrobiology, NASA, M. Meyer (202 358 0307) Michael.Meyer@nasa.gov
Performance period; 10/01/03-9/30/08
Total budget: $75,000 per year for CoI Hollenbach
Commitment by Co-I : (2 months/yr in 06, 1 month per year after 06)

6. Project title: Photodissociation Regions: Laboratories for Astrochemistry
Name of PI on award: M. Wolfire
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address): Long Term Space Astrophysics Program, NASA, Jeffrey Hayes (301-286-6290), Jeffrey.Hayes@nasa.gov
Performance period; 02/01/05-01/31/10
Total budget: $26,000 per year for CoI Hollenbach
Commitment by Co-I : (1 month/yr)

7. Project title: The evolution and dispersal of protoplanetary disks
Name of PI on award: D. Hollenbach
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address): Astrophysical Theory Program, NASA, Michael Salamon (202 358 0307), Michael.Salamon@nasa.gov
Performance period; 10/01/04-9/30/07
Total budget: $90,000 per year
Commitment by PI : (2 months/yr)

8. Project title: The water cycle, the oxygen budget, and the structure of interstellar clouds
Name of PI on award: G. Melnick
Sponsoring agency or organization: (including a point of contact with his/her telephone number and E-mail address): Long Term Space Astrophysics Program, NASA, Jeffrey Hayes (301-286-6290), Jeffrey.Hayes@nasa.gov
Performance period; 2/01/06-01/31/10
Total budget: $70,000 per year for C oI Hollenbach
Commitment by Co-I : (1 month/yr in 06, 2 months/yr after 06)

Current and Pending Support

Current and Pending Support —J. Kawamura (PI)

Current Support

Proposal Title: "Observations of Interstellar Ionized Nitrogen from the Cerro Sairecabur Telescope using an All-solid-state Superconductive Hot-electron Bolometer Heterodyne Receiver" PI: Jonathan Kawamura, Jet Propulsion Laboratory
Sponsor: NASA APRA; POC: Pamela Marcum Pamela.marcum@nasa.gov 202-358-0377
Performance of Period: FY2004-2007; Budget: $885,000
Time commitment: 3 months in FY07

Proposal Title: "Advanced film fabrication for ultra-fast phonon-cooled FIR and IR detectors" PI: Jonathan Kawamura, Jet Propulsion Laboratory
Sponsor: NASA APRA; POC: Pamela Marcum Pamela.marcum@nasa.gov 202-358-0377
Performance Period: FY2006-2007; Budget: $515,000
Time commitment: 6 months in FY07

Pending support

Proposal Title: "The Stratospheric Terahertz Observatory (STO): An LDB Experiment to Investigate the Life Cycle of the Interstellar Medium," PI: Dr. Christopher Walker, University of Arizona
Sponsor: NASA APRA; POC: Pamela Marcum Pamela.marcum@nasa.gov 202-358-0377
Performance Period: FY08-11
Budget: JPL's portion is approximately $680,000; Time Commitment: 3 months per year

Proposal Title: "A Micromachined MSQUID-Multiplexed Array of Hot-Electron Direct Detectors" PI: Dr. Boris Karasik, Jet Propulsion Laboratory
Sponsor: NASA APRA; POC: Pamela Marcum Pamela.marcum@nasa.gov 202-358-0377
Performance Period: FY08-10
Budget: $1M; Time Commitment: 1 month per year

Proposal Title: "Ground based terahertz spectral line astronomy" PI: Dr. Jonathan Kawamura, Jet Propulsion Laboratory
Sponsor: NASA APRA; POC: Pamela Marcum Pamela.marcum@nasa.gov 202-358-0377
Performance Period: FY08-10
Budget: $360,000; Time Commitment: 3 month per year

Craig Kulesa

Current & Pending Support

Title ***Program Name***	***Agency***	***Performance Period*** ***Budget***	***Total Commitment*** (calendar months)
Development of a Submillimeter-wave Superheterodyne Camera (SuperCam) for the Heinrich Hertz Telescope	NSF/MRI	09/2004 - 08/2007 $1,742,356	6
HEAT: The High Elevation Antarctic Terahertz Telescope	NSF/OPP	07/2006 – 06/2007 $80,000	5
PENDING: Mapping the connections between molecular clouds, star formation, and stellar feedback	NSF/AST	07/2007 – 6/2010 $282,553	1
PENDING: Identifying molecular cloud formation in the Galaxy	NSF/AST	7/2007 – 6/2010 $224,175	5
PENDING: HEAT: The High Elevation Antarctic Terahertz Telescope	NSF/OPP	09/2007 – 08/2009 $1,985,536	18

Current and Pending Support: Dr. William D. Langer (Co-I)

Current Funding:
1. Spitzer GO-1: Chemical Evolution of Dust Grains in Prestellar Cores
William Langer (PI) 0.1 FTE
CoIs: T. Velusamy, K. Willacy
Funding level $100K (last year)

3. LTSA: Cloud Dynamics and Chemistry
T. Velusamy (PI), K. Willacy
W. Langer (Co-I) 0.05 FTE
NASA LTSA Program
Funded FY02-FY06
Funding FY06: $90K (last year).

Pending Funding:

1) Spitzer Cycle 4 AR Proposal: Structure and Evolution of Outflows
T. Velusamy (PI)
CoIs: William Langer and K. A. Marsh
Funding requested $115K for one year. 0.1 FTE.

2) Spitzer Cycle 4 GO: IRS Spectral Mapping of NGC2316
D. Li (PI)
CoIs: W. Langer, P. Goldsmith, and T. Velusamy
Funding to be determined by amount of time awarded. 0.1 FTE.

Remainder of support: For administrative and management responsibilities.

CAREY LISSE

Current Support

Project Title	**Sponsoring agency**	**Total**	**Period**	**Mm**
Chandra Observations of Comet 9P/Tempel 1 During the DI Encounter	NASA SMAO (CXO)	$150,000	12/2005 to 06/2007	Total 6 Mm over 2 years
Spitzer Observations of Comet 9P/Tempel During the DI Encounter	NASA JPL (SST)	$83,000	12/2005 to 05/2008	Total 3 Mm over 3 years
A Spitzer Survey of Cometary Nuclei	NASA JPL (SST)	$364,000	11/2006 to 10/2009	Total 3 Mm over 3 years
Spitzer Cycle 2 Observations of Small Solar System Bodies	NASA JPL (SST)	$19,200	01/2006 to 12/2009	Total 1 Mm over 3 years
DDT - Comet SW3 During its 2006 Close Approach	NASA STScI (HST)	$40,000	05/2006 to 04/2007	Total 1 Mm over 3 years
EPOXI MoO	NASA Discovery 2006	$27,8000,000	01/2007 to 01/2010	Total 12 Mm over 3 years
Infrared Studies of the Material Excavated by the Deep Impact Experiment	NASA ROSES (Discovery Data Analysis Program)	$355,800	03/2007 to 02/2009	Total 6 Mm over 2 years

Pending Support

Project Title	**Sponsoring agency**	**Total**	**Period**	**Mm**
Development of a Fast Imaging LIDAR Sensor for Planetary Surface Studies and Navigation	NASA PIDDIP	$546K	05/2007 to 04/2010	Total 5 Mm over 3 years
Chandra Observations of Venus During the MESSENGER V2 Encounter	NASA SMAO (CXO)	$25K	06/2007 to 01/2009	Total 1 Mm over 2 years

Current and Pending Support

Christopher L. Martin

Current support:

NSF Grant ANT-0338150

- “Middle atmosphere dynamics using sub-mm radiometry”
- PI: Christopher L. Martin,
- Program Manager: Vladamir Papitashvili, vpapita@nsf.gov
- Performance Period: Sept. 2004 – Sept. 2007
- Total Budget: $60,419
- Time Committed: One summer month per year

Current Support for David Neufeld
(Updated 4-13-07)

Title:	**Molecular Astrophysics from Space: The Physical and Chemical Effects of Star Formation and the Destruction of Planetary Systems around Evolved Stars** (D. Neufeld, PI)
Sponsor:	NASA /LTSA
Sponsor ID:	NAG5-13114
Point of Contact:	Jeffrey Hayes, 202-358-0353, jhayes@nasa.gov
Period of Performance:	3/15/2003 - 3/14/2008
Total Budget:	$662,611
Commitment:	1.5 months/year

Title:	**IRS Spectroscopy of Shocked Molecular Gas in SN Remnants: Probing the Interaction of a SN with a Molecular Cloud** (D. Neufeld, PI)
Sponsor:	JPL/ Spitzer Cycle 1
Sponsor ID:	RSA Agreement No. 1263841
Point of Contact:	Lisa Storrie-Lombardi, 626-395-8665, Lisa.J.Storrie-Lombardi@jpl.nasa.gov
Period of Performance:	7/13/2004 - 7/30/2007
Total Budget:	$33,500
Commitment:	None remaining.

Title:	**The Structure and Evolution of Proto-Stellar Outflow Shocks** (D. Neufeld, PI)
Sponsor:	JPL/ Spitzer Cycle 1
Sponsor ID:	RSA Agreement No. 1264305
Point of Contact:	Lisa Storrie-Lombardi, 626-395-8665, Lisa.J.Storrie-Lombardi@jpl.nasa.gov
Period of Performance:	7/26/2004 - 07/30/2007
Total Budget:	$25,900
Commitment:	None remaining

Title:	**Molecular Hydrogen as a Probe of Warm Interstellar Gas on Parsec Scales** (D. Neufeld, PI)
Sponsor:	JPL/ Spitzer Cycle 2
Sponsor ID:	RSA Agreement No. 1276295
Point of Contact:	Lisa Storrie-Lombardi, 626-395-8665, Lisa.J.Storrie-Lombardi@jpl.nasa.gov
Award Period:	8/11/2005 - 5/31/2008
Total Budget:	$43,235
Commitment:	0.25 month/year

Title:	**Spitzer Observations of Hydrogen Deuteride (HD)** (D. Neufeld, PI)
Sponsor:	JPL/ Spitzer Cycle 3
Sponsor ID:	RSA Agreement No. 1287634
Point of Contact:	Lisa Storrie-Lombardi, 626-395-8665, Lisa.J.Storrie-Lombardi@jpl.nasa.gov
Award Period:	08/09/2006 - 09/30/2008
Total Budget:	$88,120
Commitment:	0.25 month/year

Current Support for David Neufeld
(Updated 4-12-07)

Title:	**Hershel Guaranteed Time Observer (GTO)** (D. Neufeld, PI @ JHU)
Sponsor:	JPL
Sponsor ID:	RSA Agreement No. 1295113
Point of Contact:	Lisa Storrie-Lombardi, 626-395-8665, Lisa.J.Storrie-Lombardi@jpl.nasa.gov
Award Period:	02/27/2007 - 09/30/2008
Total Budget:	$25,000
Commitment:	1 month/year

The Stratospheric TeraHertz Observatory (STO)-Caltech Receiver Components

Current and Pending Support – Sander Weinreb

Project/Proposal Title: **Stratospheric TeraHertz Observatory (STO) – Caltech Receiver Components** - This Proposal (PI: Christopher Walker)
Source of Support: NASA
Total Award Period Covered: 1/1/08-12/31/10
Total Budget Amount: $292,407
Location of Project: Caltech
Person-Month Per Year Committed to Project: Cal: 1.2 in Year 1 and 2, 0.6 in Year 2
Support: Pending

Project/Proposal Title: **Silicon Germanium Low Noise Amplifiers**
Source of Support: JPL Directors Fund
Total Award Period Covered: 10/1/06-12/31/07
Total Budget Amount: $166,138
Location of Project: Caltech and JPL
Person-Month Per Year Committed to Project: Cal: 3
Support: Current

Project/Proposal Title: **Development of a Submillimeter-wave Superheterodyne Camera -SuperCam ((**PI: Christopher Walker)
Source of Support: U. of Arizona (NSF)
Total Award Period Covered: 9/1/04-8/31/07
Total Budget Amount: $350,598
Location of Project: Caltech
Person-Month Per Year Committed to Project: Cal: 0.6
Support: Current

Project/Proposal Title: **Wideband Radiometer for an Educational Radio Telescope**
Source of Support: Lewis Center for Educational Research (Army)
Total Award Period Covered: 7/1/06-6/30/07
Total Budget Amount: $114,895
Location of Project: Caltech and JPL
Person-Month Per Year Committed to Project: Cal: 3.6
Support: Current

Project/Proposal Title: **Technology Development for the Square Km Array**
Source of Support: Cornell University (NSF)
Total Award Period Covered: 1/1/08-12/13/08
Total Budget Amount: $1,400,000
Location of Project: Caltech and JPL
Person-Month Per Year Committed to Project: Cal: 3
Support: Pending

Co-I: Mark Wolfire

Current Awards
Project title: “Photodissociation Regions: Laboratories for Astrochemistry”
Name of PI on Award: Mark Wolfire (University of Maryland)
Agency: NASA LTSA, Dr. Jeffrey Hayes, 202-358-0353, Jeffrey.J.Hayes@nasa.gov
Performance period: 3/15/05-3/14/10
Total budget: $463 K for UMD
Commitment by Co-I: 8 months.

Project title: “Tracking H_2 in Photodissociation Regions”
Name of PI on Award: Mark Wolfire (University of Maryland)
Agency: NASA Spitzer, Dr. Lisa Storrie-Lombardi, 626-395-8665, lisa@ipac.caltech.edu
Performance period: 08/17/04-07/30/07
Total budget: $22 K for UMD
Commitment by Co-I: 0.6 months.

Project title: “Tracking H_2 in Photodissociation Regions”
Name of PI on Award: Mark Wolfire (University of Maryland)
Agency: NASA Spitzer, Dr. Lisa Storrie-Lombardi, 626-395-8665, lisa@ipac.caltech.edu
Performance period: 08/22/05-05/31/08
Total budget: $21 K for UMD
Commitment by Co-I: 0.5 months.

Project title: “PAH Emission in the Giant H II Region RCW49”
Name of PI on Award: Mark Wolfire (University of Maryland)
Agency: NASA Spitzer, Dr. Lisa Storrie-Lombardi, 626-395-8665, lisa@ipac.caltech.edu
Performance period: 08/22/05-05/31/08
Total budget: $36 K for UMD
Commitment by Co-I: 0.5 months.

Project title: “Tracking H_2 in Photodissociation Regions”
Name of PI on Award: Mark Wolfire (University of Maryland)
Agency: NASA Spitzer, Dr. Lisa Storrie-Lombardi, 626-395-8665, lisa@ipac.caltech.edu
Performance period: 08/09/06-09/30/08
Total budget: $39 K for UMD
Commitment by Co-I: 0.5 months

Project title: "Gas and Dust in 30 Doradus"
Name of PI on Award: Remy Indebetouw (University of Virginia)
Agency: NASA Spitzer, Dr. Lisa Storrie-Lombardi, 626-395-8665, lisa@ipac.caltech.edu
Performance period: 08/09/06-09/30/08
Total budget: $30 K for UMD
Commitment by Co-I: 0.5 months

CURRENT RESEARCH SUPPORT

[1] Formation and Evolution of Planetary Systems: Predicting the Frequency of Earth-like Planets Around Nearby Stars

Harold Yorke / JPL (Role: Principal Investigator; Commitment: 0.1 WY)

NASA NRA-03-OSS-01-TPF, FY04-FY07 $352K

[2] Observations of Interstellar Ionized Nitrogen from the Cerro Sairecabur Telescope using an All-solid-state Superconductive Hot-electron Bolometer Heterodyne Receiver

Jonathan Kawamura / JPL, Principal Investigator

Harold Yorke, (Role: Co-Investigator; Commitment: 0.05 WY)

NASA NRA-03-OSS-01-APRA, FY04-FY07 $885K

[3] Grain Growth in Turbulent Protoplanetary Disks

Harold Yorke / JPL (Role: Principal Investigator; Commitment: 0.1 WY)

NNH05ZDA001N (ROSS-2005), FY06-FY08 $250K

Statements of Commitment

JOHNS HOPKINS
UNIVERSITY

Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel MD 20723-6099
240-228-5000 / Washington
443-778-5000 / Baltimore

29 March 2007

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

Dear Prof. Walker

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA2, 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.

I look forward to collaborating with you and the rest of the STO team on this program.

Sincerely,

Pietro N. Bernasconi

27 March 2007

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

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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 project will have a major impact on our understanding of the interstellar medium in the Milky Way and other galaxies. The fine structure lines to be observed are the key coolants of dense, hot clouds associated with massive young stars. Determining their structure requires high spectral resolution observations of large areas of the sky, observations which can only be carried out from a dedicated space platform such as the Stratospheric TeraHertz Observatory.

Sincerely,

Paul F. Goldsmith
Senior Research Scientist
Jet Propulsion Laboratory

Steward Observatory

THE UNIVERSITY OF
ARIZONA®
TUCSON ARIZONA

933 N. Cherry Avenue
Tucson, AZ 85721-0065
(520) 621-2288
FAX: (520) 621-1532

27 March 2007

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

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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.

STO is a scientifically vital mission that will vastly improve our understanding of the lifecycle of the interstellar medium in our own Galaxy, and in others. In addition, STO is an important technological driver for the application of terahertz technology to astrophysics.

Sincerely,

Dr. Christopher Groppi

Christopher Groppi

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, CA 94035-1000

Reply to Attn of:

27 March 2007

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

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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. I look forward to being Project Scientist on this very exciting and significant mission.

Sincerely,

David Hollenbach
Planetary Systems Branch
NASA Ames Research Center

Universität zu Köln
I. Physikalisches Institut

Kölner Observatorium für MM- und Submm-Astronomie

Universität Köln, I.Physik. Inst., Zülpicherstr.77, D-50937 Köln

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

Dr. Netty Honingh
Universität zu Köln
I. Physikalisches Institut
Zülpicher Straße 77
D-50937 Köln
Germany

Tel: (+49) 221-470-4528
FAX: (+49) 221-470-5162
E-Mail: honingh@ph1.uni-koeln.de
Date: March 30, 2007

Letter of Committment

Dear Prof. Walker,

I acknowledge that I am identified by name as Co-Investigator and Collaborator to the investigation, entitled **The Stratospheric TeraHertz Observatory (STO)**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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,

Universität zu Köln
I. Physikalisches Institut

Kölner Observatorium für MM- und Submm-Astronomie

Universität Köln, I.Physik. Inst., Zülpicherstr.77, D-50937 Köln

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

Dr. Karl Jacobs
Universität zu Köln
I. Physikalisches Institut
Zülpicher Straße 77
D-50937 Köln
Germany

Tel: (+49) 221-470-3484
FAX: (+49) 221-470-5162
E-Mail: jacobs@ph1.uni-koeln.de
Date: March 30, 2007

Letter of Committment

Dear Chris,

I acknowledge that I am identified by name as Co-Investigator and Collaborator to the investigation, entitled **The Stratospheric TeraHertz Observatory (STO)**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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 project will provide a unique opportunity to extensively study the ISM in a frequency range where high spectral resolution data is very scarce or even non-existent. It also takes full advantage of technology that has only recently become available. I would be very much pleased to provide part of this technology to the project.

Sincerely,

Karl Jacobs

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099
(818) 354-4321

JPL

27 March 2007

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

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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,

Jonathan Kawamura

14 April 2007

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

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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, J.W. Kooi

Jacob W. Kooi
MS 320-47
Caltech
Pasadena, Ca 91125

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

THE UNIVERSITY OF ARIZONA®
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Telephone: (520) 621-2288
Telefax: (520) 621-1532

11 April 2007

Prof. Christopher K. Walker
Steward Observatory University of Arizona
Tucson, AZ 85721
USA

Dear Prof. Walker,

I acknowledge that I am identified by name as a Co-Investigator to the investigation "*The Stratospheric Terahertz Observatory*" that is being submitted by Christopher Walker to NASA Astronomy and Physics Research and Analysis (solicitation NNH06ZDA001N-APRA) and that I intend to carry out all responsibilities identified for me in this proposal.

This is a strong collaborative effort that builds on a heritage of many prior successful projects. As DP-I, my organizational portion of this effort will focus on assisting the PI (Walker) and be partially responsible for instrument control, electronics, software and overall system integration. Scientifically, my work will will involve the intepretation and modeling of spectral line data derived from the observations, the construction of data and science products, and ancillary programs at optical/IR telescopes in Arizona that will serve to complement the Polar dataset.

STO represents a bold new advance in the capabilities of suborbital astronomy, and will lead the way for new capabilities at THz frequencies. I look forward to the opportunities and challenges that STO will provide.

Best regards,

Craig Kulesa

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

27 March 2007

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

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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 Observatory will allow us to address many fundamental questions about the nature of the life-cycle of the interstellar medium that cannot be addressed from ground-based observatories. These science objectives have long been a part of NASA's interest in understanding how our Galaxy works.

Sincerely,

William Langer

William Langer, PhD
MS 180-500
JPL
4800 Oak Grove Drive
Pasadena, CA 91109
818-354-5823

03 April 2007

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

I. Dr. Carey M. Lisse of the Johns Hopkins University Applied Physics Laboratory, acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, and that it presents an exciting step forward in studies of star formation and the total energy budget of the galaxy, 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. Carey M. Lisse

OBERLIN

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

April 9, 2007

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 The Stratospheric TeraHertz Observatory (STO), that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA2, 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.

My students and I are very excited by this project and we look forward to working with you.

Sincerely yours,

Christopher L. Martin

Christopher L. Martin

JOHNS HOPKINS
UNIVERSITY

Center for Astrophysical Sciences
Bloomberg Center for Physics and Astronomy
Baltimore MD 21218-2695

11 April 2007

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

I acknowledge that I am identified by name as a Co-Investigator to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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. I am very excited about the science that will come out of this program, which promises to yield key advances in our understanding of the ISM, and I look forward to working with you on the analysis and interpretation of the data.

Sincerely,

David Neufeld

David Neufeld
Professor of Physics and Astronomy
The Johns Hopkins University

27 March 2007

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

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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.

I believe that the Astronomy STO will facilitate will be a perfect match to the single source observations of Herschel and SOFIA and prove invaluable for achieving better understanding of the "big picture" of the ISM.

Sincerely,

Dr. Patrick Pütz

KOSMA, I. Physikalisches Institut
Universität zu Köln
Zülpicher Str. 77
50937 Köln
Germany

puetz@ph1.uni-koeln.de
++49 221 470 3484

27 March 2007

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

I acknowledge that I am identified by name as a Collaborator to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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,

Michael E. Schein
Senior Opto-Mechanical Engineer
University of Arizona

Jonathan Kawamura

From: Anders Skalare [Anders.Skalare@jpl.nasa.gov]
Sent: Tuesday, April 03, 2007 4:15 PM
To: Jonathan.H.Kawamura@jpl.nasa.gov
Subject: Statement...

To whom it may concern,

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled The Stratospheric TeraHertz Observatory, that is submitted by Jonathan Kawamura to the NASA Research Announcement NNH06ZDA001N-APRA2, 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.

Anders Skalare

818-3549383
anders.skalare@jpl.nasa.gov

Jonathan Kawamura

From:	Jeffrey Stern [Jeffrey.Stern@jpl.nasa.gov]
Sent:	Monday, April 02, 2007 5:09 PM
To:	Jonathan Kawamura
Subject:	Re: Walker STO/CV and Letter of acknowledgement request
Attachments:	CV 4-2-2007.doc

CV
:-2007.doc (30 I

Jon

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled The Stratospheric TeraHertz Observatory, that is submitted by Jonathan Kawamura to the NASA Research Announcement NNH06ZDA001N-APRA2, 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.

Jeff

UNIVERSITÄT ZU KÖLN
I. PHYSIKALISCHES INSTITUT
PROF. DR. JÜRGEN STUTZKI

Adresse: I. PHYSIKALISCHES INSTITUT
ZÜLPICHER STRASSE 77
UNIVERSITÄTSSTRASSE 14
D-50937 KÖLN
Telefon: VERMITTLUNG +49 221 470 - 1
DURCHWAHL - 3494
SEKRETARIAT - 5737
- 5736
Telefax: +49 221 470 5162
e-mail: stutzki@ph1.uni-koeln.de

Prof. Christopher K. Walker
Steward Observatory
933 N. Cherry Avenue
University of Arizona.

Tucson, AZ 85721
U.S.A.

Datum: 5. April 2007
Unser Zeichen: JSt

Dear Chris,

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory (STO)**, that is submitted by You, Christopher K. Walker, to the NASA Research Announcement NNH06ZDA001N-APRA, 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.

The opportunity of a FIR balloon-borne heterodyne experiment will provide unique scientific opportunities and is also very important from the side of the instrumentation/technology as a development efforts towards future applications in larger missions.

Sincerely Yours,

Jürgen Stutzki

(Jürgen Stutzki)

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

April 6, 2007

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

Dear Chris:

I acknowledge that I am identified by name as Co-Investigator or Collaborator to the investigation, entitled, **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher Walker, to the NASA Research Announcement, NNH06ZDA001N-APRA, 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.

I believe the technology required for this proposal is entirely feasible and represents excellent value in terms of the science that is enabled by a balloon-born THz radiometer

Sincerely,

Sander Weinreb

Sander Weinreb

UNIVERSITY OF MARYLAND
DEPARTMENT OF ASTRONOMY

College Park, Maryland 20742-2421
USA
301.405.3001 TEL 301.314.9067 FAX

Dr. Christopher K. Walker
The University of Arizona
Steward Observatory

Dear Chris

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled "The Stratospheric TeraHertz Observatory" that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA: Astronomy and Physics Research and Analysis, 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.

The [C II] 158 μm line is the dominant coolant of the neutral atomic gas in the Galaxy. Velocity resolved maps of this transition are crucial for our understanding of the evolution of gas from the warm to cold phases which ultimately lead to the formation of stars. In fact, I find it quite astonishing that we do not have this data already!

Sincerely

Mark Wolfire

Mark Wolfire
Associate Research Scientist
Astronomy Department
University of Maryland

JPL

April 10, 2007

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

To whom it may concern:

I acknowledge that I am identified by name as Co-Investigator to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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,

Harold W. Yorke

Dr. Harold Yorke

Manager, Science Division
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

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

THE UNIVERSITY OF
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Telefax: (520) 621-1532

9 April 2007

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

Dear Chris,

I acknowledge that I am identified by name as Co-Investigator [and/or Collaborator(s)] to the investigation, entitled **The Stratospheric TeraHertz Observatory**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, 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,

Erick T. Young

Erick Young
Astronomer

Institutional Letters of Support

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099
(818) 354-4321

JPL

April 4, 2007

Refer to: 700-MWW:kp

Dr. Christopher Walker
Department of Astronomy
University of Arizona
Steward Observatory 211
933 North Cherry Avenue
Tucson, AZ 885721

Dear Dr. Walker:

Subject: Proposal entitled, "Stratospheric Terahertz Observatory (STO): An LDB Experiment to Understand the Life Cycle of the Interstellar Medium"

Reference: NASA Research Announcement entitled, "Astronomy and Physics Research and Analysis," dated January 23, 2006 (NNH06ZDA001N-APRA2)

The Jet Propulsion Laboratory is pleased to be your partner on the subject proposal and endorses the participation of Mr. Jonathan Kawamura as the JPL Institutional Principal Investigator and Drs. Harold Yorke, Jeffrey Stern, Ander Skalare, Paul Goldsmith, and William Langer as co-investigators.

The Jet Propulsion Laboratory is committed to providing the support described in the proposal on cost and schedule assuming NASA funds the proposal.

Please refer to Proposal Number 71-11982 on all written correspondence to JPL pertaining to this proposal.

If you have any questions regarding JPL's participation on this proposal, please contact Dr. James Ling of my staff at (818) 354-2819.

Sincerely,

Michael W. Werner
Chief Scientist
Astronomy and Physics Directorate

UNIVERSITÄT ZU KÖLN
I. PHYSIKALISCHES INSTITUT
PROF. DR. JÜRGEN STUTZKI

Adresse: I. PHYSIKALISCHES INSTITUT
ZÜLPICHER STRASSE 77
UNIVERSITÄTSSTRASSE 14
D-50937 KÖLN
Telefon: VERMITTLUNG +49 221 470 - 1
DURCHWAHL - 3494
SEKRETARIAT - 5737
- 5736
Telefax: +49 221 470 5162
e-mail: stutzki@ph1.uni-koeln.de

Datum: 5. April 2007
Unser Zeichen: JSt

To whom it may concern:

We, KOSMA, I. Physikalisches Institut of the University of Cologne, confirm that we intend to participate in the investigation, entitled **The Stratospheric TeraHertz Observatory (STO)**, that is submitted by Christopher K. Walker to the NASA Research Announcement NNH06ZDA001N-APRA, on a „no exchange of funds“ basis.

The deliverables will be four heterodyne mixer modules plus two spares for the 1.9 THz channel of the proposed instrument. The production of these mixers is a joint effort between KOSMA and the PI institute's Steward Observatory Radio Astronomy Laboratory (SORAL). KOSMA will make available its microfabrication laboratory and mixer fabrication infrastructure to personnel funded by this proposal at the University of Arizona (Dr. Patrick Puetz, CO-I). Dr. Puetz, who has been working in the KOSMA environment for several years before, will work together with CO-I's Dr. C.E. Honingh and Dr. Karl Jacobs from KOSMA. The joint effort includes the integration of MMIC amplifiers, provided by the project, into the mixer modules. Materials needed for the fabrication of the mixer modules will be procured by the PI institution at the University of Arizona and made available at no additional cost to KOSMA, to an amount to be agreed upon. In addition, the waveguide horns for the mixers will be procured by the PI with specifications to be agreed upon. Travel associated with this effort will be arranged by the project.

Sincerely Yours

Jürgen Stutzki

(Jürgen Stutzki)