HORUS: HeterOdyne Regolith Universal Surveyor

Summary

Our University of Arizona team proposes to build and fly **HORUS: HeterOdyne Regolith Universal Surveyor** for the NASA OSIRIS Rex Student Collaboration Experiment (SCE). HORUS will consist of a compact, low-power submillimeter-wave telescope and dual polarization heterodyne receiver-spectrometer tuned to observe the 557 GHz 1_{10}-1_{01} ground state transition of H_2O and 551 GHz J=5-4 transition of ^{13}CO. HORUS can collect data virtually at any phase of the mission. While in orbit HORUS will make repeated radiometric maps of the surface of RQ36 at a spatial resolution of 2.3 m. These maps, combined with data from other OSIRIS instruments and ground based data, will provide new, valuable information about the physical conditions and evolutionary history of RQ36. HORUS' dual polarization receiver can be used to probe the asteroid's surface roughness and dielectric properties on and just below the surface. HORUS will also be capable of searching for trace amounts of water vapor sublimating off the asteroid's surface. These measurements could be made both before and after sample collection, thereby providing a means for detecting water vapor potentially released as a result of the encounter.

During the multi-year voyage to and from the asteroid, HORUS will be used to survey the distribution of water vapor in the Milky Way with unprecedented coverage. Due to H_2O in the Earth's atmosphere, these observations can only be done from space. Water plays a pivotal role in the formation and evolution of molecular species in the interstellar medium (ISM). However, where water comes from and how it is distributed in the ISM is still poorly known. The HORUS Galactic water survey will help provide answers to these important questions. During the cruise phase of OSIRIS, HORUS could potentially survey more than 20 square degrees of sky per year.

All HORUS components are estimated to be at a high TRL ($\geq$5) and fit within the size, mass, and power envelope for the SCE. HORUS will be student led, under the mentorship of an experienced team of researchers from academia and industry. Students will play key roles in the detailed design of HORUS, participate in its fabrication and space qualification, conduct complementary pre-encounter laboratory investigations of proxy asteroid regolith, and design radiometric imaging and water observing programs for both the encounter and cruise phases of OSIRIS. Students will take leadership roles in compiling, analyzing, and publishing HORUS data.

1. Science Investigation

1.1 Asteroid/Planetary Science

A number of astronomical studies based on multispectral reflectance, radar, and orbital dynamics indicate that RQ36 is a spectral B-class asteroid, similar to heated (but still hydrated) CI and CM carbonaceous chondrite meteorites. However, some fundamental questions remain about the origin and evolutionary status of RQ36. What are the properties of its regolith? Is RQ36 a heavily hydrated CI, CM or similar carbonaceous chondrite, but not icy? Is it a dead or dying ice-bearing "Main Belt Comet" or transition object? Is RQ36 representative of the source population of objects that supplied Earth with water, or is it more typical of comets or carbonaceous chondrites? HORUS provides unique capabilities to address these questions. It has the ability to use passive emissions from the asteroid to assess the surface temperature-emissivity distribution and deduce regolith properties. HORUS also has the ability to interrogate the space surrounding RQ36 for spectral indicators of outgassed volatiles, especially water.

1.1.1 Deducing Regolith Properties

Mapping the surface of RQ36 using HORUS'radiometric spectrometer will allow variations in the temperature and emissivity of its surface to be investigated at a spatial resolution of 2.3m (for an orbital distance of 700 m). The interdependency between observed temperature and emissivity will be broken by 1) making multiple observations of the same spots on the surface on multiple occasions during the asteroid's day and night, and 2) using the polarization sensitivity of HORUS to probe variations in emissivity related to changes in the electromagnetic properties of the surface materials. HORUS radiometry can be used to globally map the scattering phase function and hence the effective particle grain-size-frequency distribution of the upper several millimeters of the asteroid. To test the viability of this approach, measurements of the submillimeter wavelength electromagnetic properties of a meteoritic sample expected to be similar in composition to 1999 RQ36 were made. A THz Time Domain Spectrometer (THz-TDS) was used to extract the complex index of refraction near the frequency of interest of 557 GHz. The sample was research grade wire saw dust of a carbonaceous chondrite, designated NWA 5515.The measured index of refraction at 557 GHz is $\tilde{n} = 1.967 + i0.056$ with the loss generally increasing with frequency and the real part remaining constant. Such results can be used to calculate both the total thermal emission, as well as the contribution of radiation emitted from more than ***5mm beneath*** the surface. HORUS will measure the degree of polarization at oblique angles, providing constraints on the allowable optical properties of the material (complex index of refraction and roughness). This approach has been demonstrated experimentally for both high- and low-conductivity materials (Jordan, Lewis & Jakeman 1996) and has been used in the long wave IR to characterize effective complex index in emissive measurements (Wellems, Ortega, Bowers, Boger & Fetrow 2006).

1.1.2 Searching for Volatile Emissions

How detectable are RQ36's possible volatile emissions? HORUS has powerful capability to detect outgassed H_2O and CO. We expect H_2O to be detectable when molecular column densities approach ~10^{10} molecules/cm^2. For a "Main Belt Comet" or "comet-asteroid transition object" (Hsieh and Jewitt 2006, Emery et al. 2010, Hsieh 2010, Licandro et al. 2007) find the H_2O outgassing rate to be ~10^{22} molecules/s (~ 0.001% the rate of a typical small comet). From this we calculate a column density of ~10^{13} molecules/cm^2 along a surface-tangent chord out to a radius of 500 m. This estimation assumes radial ejection of neutral gases, a noncollisional atmosphere and surface-thermalized rms ejection speeds ~500 m/s. The estimated abundance is ***~1000 times*** the detection level for our instrument. A much more weakly active transition object could still have measurable outgassing. If the volatiles are emitted in jets or from other localized sources, the local abundance might be highly variable and much greater over some regions. If emissions are modulated by diurnal temperature variations due to transient adsorption in the regolith, further fluctuations would occur with solar longitude (time of day) and latitude, whereas if volatile jets arise from deeper than the diurnal skin depth and do not exist long as transient adsorbed species, we won't see diurnal variability. CO is likely to be measurable for almost any typical comet-like volatile assemblage of gases or a mixture comparable to Enceladus' plume.

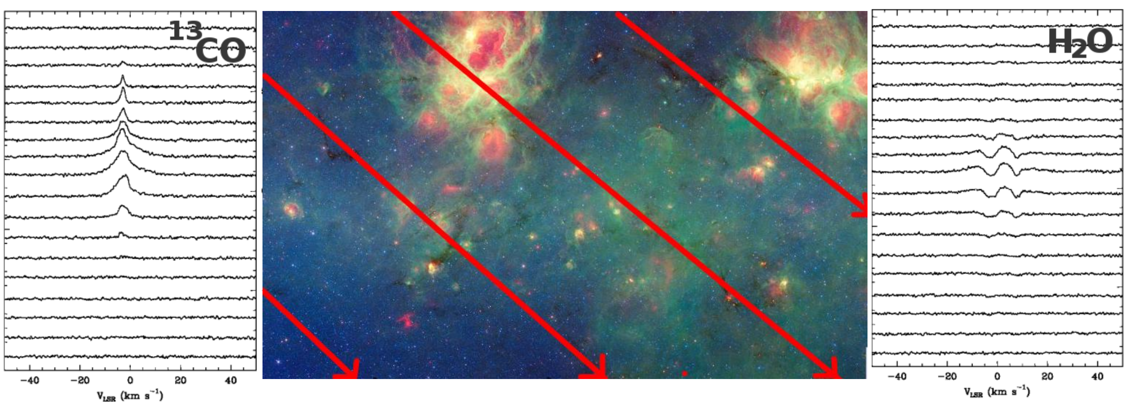

Figure 1. Simulation of HORUS data through a spectral slice through an active star forming region in the 550 GHz lines of ^{13}CO and ortho-H_2O, overlaid on a Spitzer 8 & 24 um map of a 3 degree portion of the Galactic Plane. Note that both spectral lines are clearly resolved and are markedly different from each other, reflecting the unique chemical and physical origin of each species. As a dedicated instrument with a long lifetime, HORUS could probe the 550-557 GHz lines of **hundreds** of star forming regions during the cruise phase of the OSIRIS-ReX mission, well beyond the capabilities of all previous or planned missions combined.

1.2 Galactic Science

Water plays a pivotal role in the chemical evolution and energy balance of the interstellar medium (ISM), analogous to its role in the evolution of life on Earth. *Water is also the very best molecular diagnostic of the star and planet formation process*, as its abundance is critically sensitive to environment. In quiescent dark clouds, water lies comparatively dormant at an abundance of 10^{-8} relative to hydrogen. However, once heated by radiation or shocks, its abundance rises to 10^{-4} and can be the dominant carrier of interstellar oxygen in active star-forming regions. Its spectral line radiation is then a significant coolant, and thus a regulating force on the global star formation. On smaller scales, it governs the detailed chemical and physical evolution of both circumstellar disks and planets. In sharp contrast to this sensitive behavior of H_2O, the 'typical' probe of molecular clouds, carbon monoxide (CO), does not vary at all between dark interstellar clouds and star forming regions.

The importance of water to the global picture of star, planet, and life formation of course is widely recognized. Two space missions, the Submillimeter Wave Astronomy Satellite (*SWAS*) and the Herschel Space Observatory have both dedicated large portions of their observing time to the understanding of interstellar water. Both facilities have measured the 557 GHz ground state transition of ortho-H_2O in dense molecular clouds, in the dynamic regions associated with the formation and evolution of young stars and planetary systems, and even in what is believed to be the evaporation of the analog to Kuiper Belt objects associated with a nearby evolved star.

Despite these great advances, the area of the sky targeted by *SWAS* and *Herschel* in water lines still amounts to about 1 square degree, about 1/1000th of the molecular material in the Milky Way Galaxy. In order to understand the formation, abundance, and evolution of water in the larger context of the Galaxy, a much larger, systematic survey must be undertaken. During the long cruise phases of the OSIRIS-ReX mission, HORUS will perform the first *large scale surveys* of the Galactic Plane in the 557 GHz line of water, in combination with the J=5-4 line of ^{13}CO. The surveys are conducted toward regions of the Milky Way the HORUS telescope can see along the trajectory to and/or from RQ36. The HORUS survey could observe 20 square degrees of the Galactic Plane per year to a mean noise level of 0.1 K, comparable to the quality of the spectra obtained by *SWAS* and *Herschel* (see Figure 1). The survey will provide new insights into the distribution, abundance, and role H_2O plays in sculpting the formation of stellar and planetary systems within the Milky Way, and will place the detailed study of interstellar water from *SWAS* and *Herschel* in a far broader, richer context.

2.0 HORUS Instrument Description

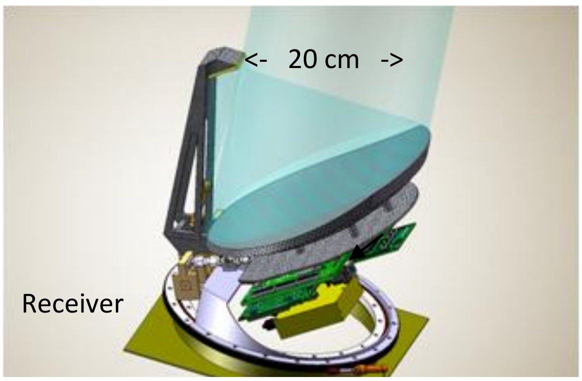

Figure 2: HORUS is a 20 cm off-axis Gregorian telescope with heterodyne receiver and associated electronics. The telescope looks perpendicular to the instrument platform.

The observational goals of HORUS are to make polarization sensitive, high angular resolution (5') and spectral (>10^6) maps of RQ36 and the Galactic plane at 553 GHz. This frequency puts the ground state water line in the upper sideband of the receiver and the ^{13}CO J=5-4 line in the lower sideband (same as on *SWAS*). To achieve this angular resolution and fit within the designated SCE instrument volume, HORUS will utilize a light-weight (carbon-fiber), off-axis, Gregorian telescope with an aperture of 20 cm. To achieve the target spectral resolution and polarization sensitivity, HORUS will utilize a dual polarization, heterodyne receiver system. A view of HORUS showing the placement of the receiver system is shown in Figure 2. The compact, low-power receiver will consist of two, ambient temperature Schottky diode mixers, a solid-state local oscillator source, intermediate frequency (IF) amplifiers, and a correlator spectrometer & computer. A block diagram of the receiver system is shown in Figure 3. All HORUS components -technologies are estimated to be at a high TRL ($\geq$5) and fit within the size/mass/power/data volume envelope for the SCE (Table 1).

The complete HORUS instrument will be made of space-rated components and undergo qualification in thermal-vacuum chambers made available by Raytheon Inc. (see support letter). The testing will be conducted primarily by students under the supervision of Raytheon and/or senior HORUS team members. HORUS will have two primary observing modes: 1) Frequency Switched (FS) and 2) On-the-Fly (OTF). In FS mode the instrument performs a series of integrations ON and OFF the frequency of the water line. By subtracting ON and OFF integrations, the

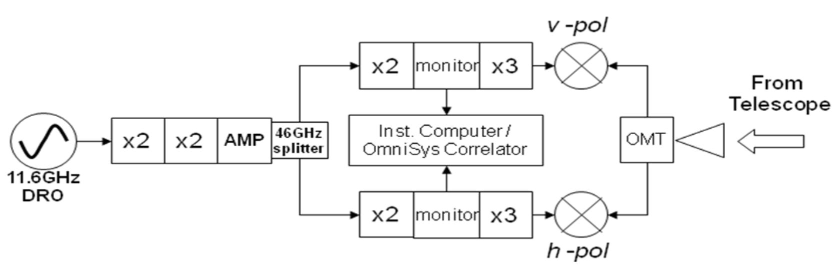

Figure 3. Instrument Block Diagram: 553 GHz light from the telescope is collected with a corrugated feedhorn and split into horizontal (H) and vertical (V) components by a waveguide orthomode transducer (OMT). The two polarization components are downconverted by a pair of Schottky diode mixers to baseband (0-1 GHz). The power spectrum is then generated using a low-power digital autocorrelator. The autocorrelator is read-out by the instrument control computer which stores the data and transfers it to the spacecraft when appropriate.

instrumental response of the receiver system is normalized out. The FS mode will be used, for example, when OSIRIS is on approach to RQ36 and the asteroid is unresolved in the HORUS beam. The asteroid and Galactic Plane will be mapped by making (when possible) adjacent On-the-Fly (OTF) strip maps. In OTF mode the spectrometer is read-out at a Nyquist rate as the HORUS beam moves across the target. A map of the target area is generated in post processing where the raw data is re-gridded and a clean algorithm applied. Absolute calibration of the FS and OTF data will be obtained using a calibrated noise diode integrated into the receiver. The data will be pre-processed on-board to meet data bandwidth requirements: 30-50 Mbit of preprocessed asteroid data and less than 1 Mbit of spectral data per square degree of mapped area during the 'astronomical' cruise phase. With this approach, for example, multiple radiometric maps of RQ36 can be made when OSIRIS is in orbit. At an orbital distance of 700m a map of RQ36 will have a spatial resolution of 2.3m. Where needed, maps can be co-added to increase sensitivity. The same strategy will be used to make strip maps of the Galactic Plane during the cruise phase.

Table 1: Power & Mass Budget	CBE (W)	Mature(W)	CBE(Kg)	Mature(Kg)
CFP Telescope/Support Structure	0	0	1.3	1.6
557 GHz Mixer/LO (VDI):	3	4	0.2	0.3
Miteq PLDRO:	3	4	0.13	0.17
Spectrometer/Instr.Comp.:	4	5	0.3	0.4
Total		**13**	**2.0**	**2.5**

3.0 Project Management

Our overall HORUS management approach is to integrate a strong educational experience with an ad-hoc organizational structure to achieve a tight schedule in a cost-cap environment. The first step is to develop a Project Implementation Plan (PIP) containing processes and management strategies that include weekly telecons and reports, monthly and quarterly reviews, and data management tools. Earned Value Management (EVM) will be the major tool employed to measure progresses. The HORUS management structure will ensure a hierarchical traceability that provides the management with insight into schedule, performance risk, changes, status, reserves and lesson-learned.

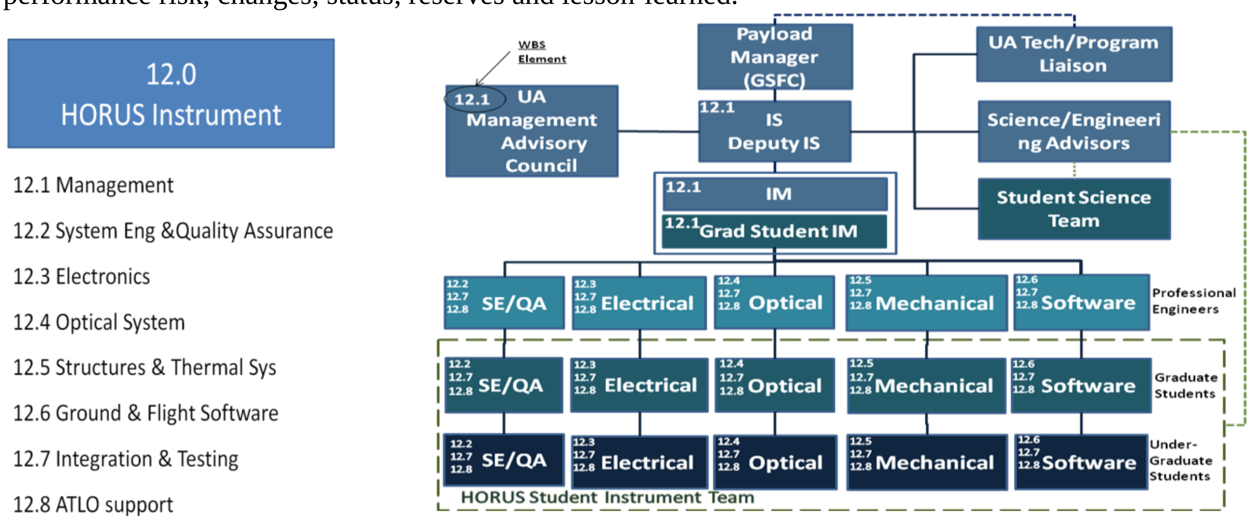

Figure 4: HORUS Work Breakdown Structure (WBS, left box) and HORUS Org Chart (Right box)

3.1 Team Members roles and responsibilities

The HORUS organization and Work Breakdown Structure (WBS) are shown in Figure 4. The IS (Dr. Chris Walker) and deputy IS (Dr. Roberto Furfaro) are responsible for delivering HORUS to ATLO and for making the final science, engineering and management decision. Key roles such as HORUS Instrument Manager, System Engineer and all subsystem engineers are covered by professionals that support the HORUS student team. The professionals are identified from UA, TeraVision and Raytheon (see personnel section for individual role). The student team is organized hierarchically with graduate students covering the lead positions and overseeing undergraduate team members. Science advisor (Dr. Jeffrey Kargel) and Engineering advisor (Dr. Scott Tyo) will help guide student teams with proper scientific and technical knowledge. Raytheon engineering personnel have agreed (see appendices) to help guide the students in developing and implementing successful strategies for the overall design, building, integration and space qualification of the HORUS instrument.

3.2 Decision-Making Process

The HORUS team is comprised of experienced individuals that will oversee a team of students by actively helping them address the challenges that arise in taking an instrument from concept to ATLO. Day-to-day decisions will be made by the student management team and reviewed by the corresponding professional mentors. All decisions are based on a global assessment of the instrument science requirements, performance, risks, budget, and schedule. The HORUS decision-making process is documented in the project plan and SEMP. We will also establish a Management Advisory Council comprised of senior UA personnel involved in OSIRIS REx mission. The Council will provide external assistance, organizational impasse resolution, and response to unforeseen events or requirements.

TABLE 2

Risk Title	Cost and Technical Mitigation Approach
Student Space Qualification Approach	HORUS Team develops and implements a tightly controlled QA plan. Assistance from RMS experienced engineers Large reserves for hiring more senior professionals during the testing and integration phase
Instrument Cost Development	HORUS team has already performed a preliminary heritage assessment Students are guided by experienced professional personnel HORUS Team is implementing a EVM-based reporting mechanism 15% cost reserve has been implemented A Descope List has been identified (see table 3)
Instrument Power Overrun	Students are assisted by experienced RMS personnel A Descope List has been identified(see table 3)

3.3 Risk Management, Top Risks, Descope Options and Mitigation Strategies

The HORUS team is set to manage risks according to NPR 8000.4. A risk board, chaired by both IM and student IM and comprising IS and deputy IS, technical advisors and subsystems leads (professionals and students), will meet monthly. Risk entries come from HORUS staff/students, fault tree analysis, peer reviews, and probabilistic risk assessment. The risk board assesses each new entry and decides whether to declare it a risk needing action. Risks are captured and tracked using an integrated, project-wide database. HORUS has been designed to reduce risk by leveraging high heritage components, technologies, and/or approaches and providing adequate mass, power, cost and schedule reserves. Early risk analysis and classification has been conducted to capture the top risks. Table 2 shows risk title and cost/technical mitigation approach. The top risk is represented by the need to space qualify electronics. RMS will permit use relevant test facilities on a non-interference basis. Morever, RMS engineers will assist students during the space qualification approach. Our team has already identified a Descope List as reported in Table 3.

3.4 Additional training opportunities for students

Student training and educational experience will be enhanced by establishing a set of academic activities in support of the HORUS program. Leveraging on existing classes offered by IS and deputy IS, we will formally train students on the fundamentals of science and engineering behind HORUS. Dr. Walker's TeraHertz lab will be used by UA students involved in experimental activities in support of HORUS, including instrument development and the characterization of asteroid-like materials. We have established a collaborative effort with the Southwest Meteoritic Institute which will provide meteoritic material for student-based experiments.

TABLE 3

Descope Options	Δ Mass	Δ Power	Δ Cost	Decision Date	Rationale/Consequences
No spectroscopy	-0.2 kg	-3W	-$300K	11/2013	Reduce cost/complexity, lose cruise & outgassing science
Ops at RQ36 only	0 kg	0 W	-$200K	9/2016	Reduce cost/complexity, lose cruise science phase
Single polarization	-0.2 kg	-2W	-$250K	11/2013	Reduce cost/complexity, lose polarization science

4.0 Budget

The HORUS instrument is estimated to cost $4,792,434 in FY10 dollars. Including 16% reserve ($907K FY10), the overall instrument cost is projected to be $5,699,434. Details of the budget, staffing plan and HORUS master schedule can be found in the appendices.

Appendix A

References

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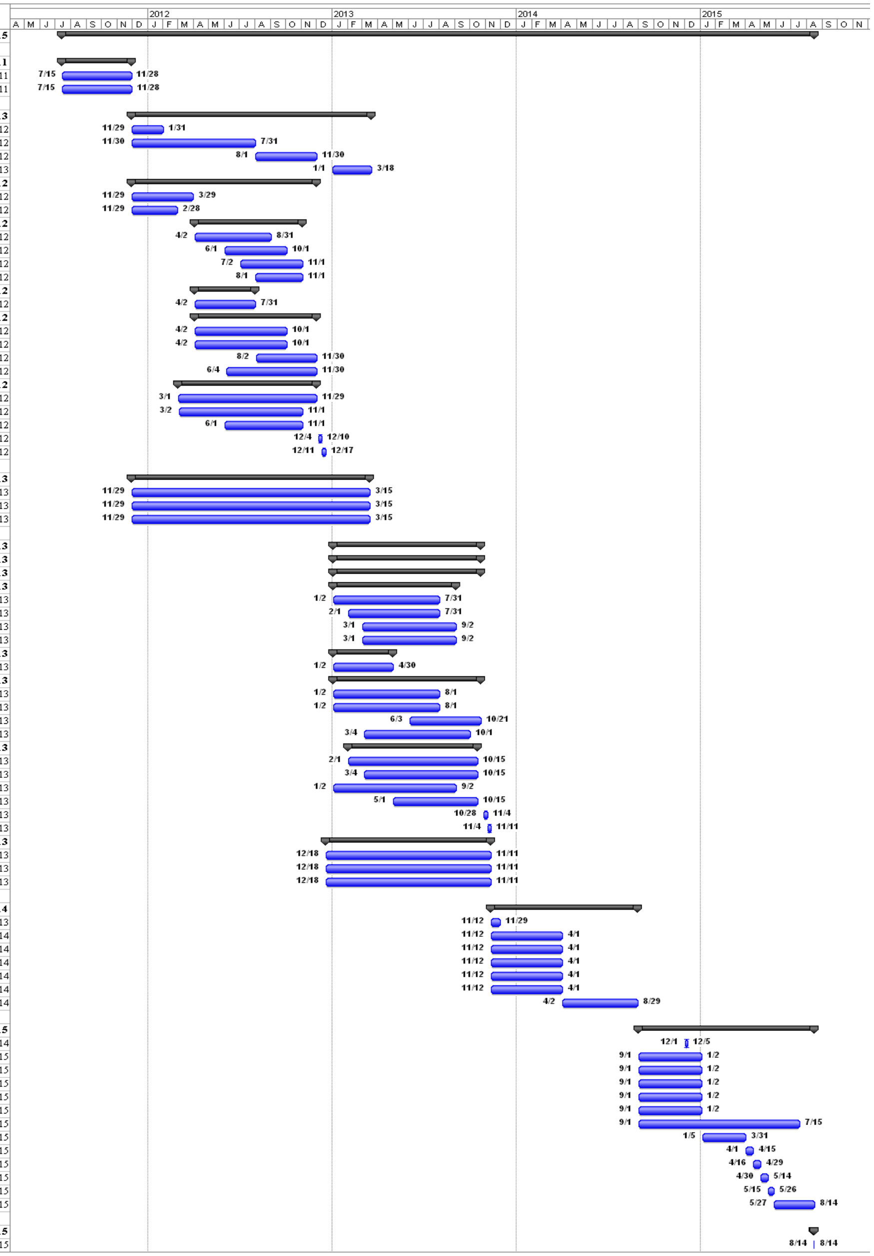
Appendix B: HORUS Preliminary Master Schedule

ID	ID	Task Name	Duration	Start	Finish
1	**1**	**HORUS Instrument**	**1067 days**	**Fri 7/15/11**	**Fri 8/14/15**
2	2				
3	**3**	**Concept Design, Phase B Bridge**	**97 days**	**Fri 7/15/11**	**Mon 11/28/11**
4	4	Refine Science Requirements	97 days	Fri 7/15/11	Mon 11/28/11
5	5	Refine Concept Design	97 days	Fri 7/15/11	Mon 11/28/11
6	6				
7	**7**	**Preliminary Design, Phase B**	**341 days**	**Tue 11/29/11**	**Mon 3/18/13**
8	8	HORUS Master Schedule Development	46 days	Tue 11/29/11	Tue 1/31/12
9	9	Project Interface and Requirements Development	176 days	Wed 11/30/11	Tue 7/31/12
10	10	HORUS Requirements Development	88 days	Wed 8/1/12	Fri 11/30/12
11	11	Spacecraft Interface Document Configuration (IDC) Development	55 days	Tue 1/1/13	Mon 3/18/13
12	**12**	**HORUS Preliminary Design and Verification**	**265 days**	**Tue 11/29/11**	**Fri 11/30/12**
13	13	System Engineering Model	89 days	Tue 11/29/11	Thu 3/29/12
14	14	Trade Studies	66 days	Tue 11/29/11	Tue 2/28/12
15	**15**	**Electrical and Electronics Engineering**	**154 days**	**Mon 4/2/12**	**Thu 11/1/12**
16	16	Heterodyne Receiver Analysis and Design	110 days	Mon 4/2/12	Fri 8/31/12
17	17	Spectrometer Analysis and Design	87 days	Fri 6/1/12	Mon 10/1/12
18	18	Flight Computer Analysis and Design	89 days	Mon 7/2/12	Thu 11/1/12
19	19	Power Distribution Analysis and Design	67 days	Wed 8/1/12	Thu 11/1/12
20	**20**	**Optical Engineering**	**87 days**	**Mon 4/2/12**	**Tue 7/31/12**
21	21	Optical System Analysis and Design	87 days	Mon 4/2/12	Tue 7/31/12
22	**22**	**Structures and Thermal Engineering**	**175 days**	**Mon 4/2/12**	**Fri 11/30/12**
23	23	Antenna Dish Structural Analysis	131 days	Mon 4/2/12	Mon 10/1/12
24	24	Secondary Mirror Structural Analysis	131 days	Mon 4/2/12	Mon 10/1/12
25	25	S/C Interface Structure and Chase Design	87 days	Thu 8/2/12	Fri 11/30/12
26	26	Thermal Management	130 days	Mon 6/4/12	Fri 11/30/12
27	**27**	**Software Engineering**	**197 days**	**Thu 3/1/12**	**Thu 11/29/12**
28	28	Software Preliminary Analysis	197 days	Thu 3/1/12	Thu 11/29/12
29	29	Preliminary Ground Data System Engineering	176 days	Fri 3/2/12	Thu 11/1/12
30	30	Preliminary System Performance Model	110 days	Fri 6/1/12	Thu 11/1/12
31	31	Prepare for HORUS Preliminary Design Review (PDR)	5 days	Tue 12/4/12	Mon 12/10/12
32	32	HORUS PDR	5 days	Tue 12/11/12	Mon 12/17/12
33	33				
34	**34**	**Engineering Model Long Lead Procurements**	**340 days**	**Tue 11/29/11**	**Fri 3/15/13**
35	35	Long Lead Electrical Procurement (estimated time)	340 days	Tue 11/29/11	Fri 3/15/13
36	36	Long Lead Mechanical Procurement (estimated time)	340 days	Tue 11/29/11	Fri 3/15/13
37	37	Long Lead Electronics Procurement (estimated time)	340 days	Tue 11/29/11	Fri 3/15/13
38	38				
39	**39**	**Detailed Design, Phase C**	**209 days**	**Wed 1/2/13**	**Mon 10/21/13**
40	**40**	**Engineering Model Development**	**209 days**	**Wed 1/2/13**	**Mon 10/21/13**
41	**41**	**Detailed Subsystem Design**	**209 days**	**Wed 1/2/13**	**Mon 10/21/13**
42	**42**	**Electrical and Electronics**	**174 days**	**Wed 1/2/13**	**Mon 9/2/13**
43	43	Heterodyne Receiver Detailed Design	151 days	Wed 1/2/13	Wed 7/31/13
44	44	Spectrometer Detailed Design	129 days	Fri 2/1/13	Wed 7/31/13
45	45	Flight Computer detailed Design	132 days	Fri 3/1/13	Mon 9/2/13
46	46	Power Distribution Detailed Design	132 days	Fri 3/1/13	Mon 9/2/13
47	**47**	**Optical Engineering**	**85 days**	**Wed 1/2/13**	**Tue 4/30/13**
48	48	Optical System Detailed Design	85 days	Wed 1/2/13	Tue 4/30/13
49	**49**	**Structures and Thermal Engineering**	**209 days**	**Wed 1/2/13**	**Mon 10/21/13**
50	50	Antenna Dish Detailed Structural Analysis	152 days	Wed 1/2/13	Thu 8/1/13
51	51	Secondary Mirror Detailed Structural Analysis	152 days	Wed 1/2/13	Thu 8/1/13
52	52	S/C Interface Structure and Chase Detailed Design and Analysis	101 days	Mon 6/3/13	Mon 10/21/13
53	53	Thermal Management Detailed Analysis and Design	152 days	Mon 3/4/13	Tue 10/1/13
54	**54**	**Software Engineering**	**183 days**	**Fri 2/1/13**	**Tue 10/15/13**
55	55	Software Architecture Design	183 days	Fri 2/1/13	Tue 10/15/13
56	56	Command and Data Handling	162 days	Mon 3/4/13	Tue 10/15/13
57	57	Detailed Ground Data System Engineering	174 days	Wed 1/2/13	Mon 9/2/13
58	58	Detailed System Performance Model	120 days	Wed 5/1/13	Tue 10/15/13
59	59	Prepare for HORUS Critical Design Review	6 days	Mon 10/28/13	Mon 11/4/13
60	60	HORUS CDR	6 days	Mon 11/4/13	Mon 11/11/13
61	**61**	**Long Lead Procurement**	**235 days**	**Tue 12/18/12**	**Mon 11/11/13**
62	62	Long Lead Electrical Procurement (estimated time)	235 days	Tue 12/18/12	Mon 11/11/13
63	63	Long Lead Mechanical Procurement (estimated time)	235 days	Tue 12/18/12	Mon 11/11/13
64	64	Long Lead Electronics Procurement (estimated time)	235 days	Tue 12/18/12	Mon 11/11/13
65	65				
66	**66**	**Engineering Unit Development, Phase C-D**	**209 days**	**Tue 11/12/13**	**Fri 8/29/14**
67	67	Inheritance Review	14 days	Tue 11/12/13	Fri 11/29/13
68	68	Electronics and Electrical Subsystem Development	101 days	Tue 11/12/13	Tue 4/1/14
69	69	Opto-Mechanical Susystem Development	101 days	Tue 11/12/13	Tue 4/1/14
70	70	Thermal Subsystem Development	101 days	Tue 11/12/13	Tue 4/1/14
71	71	CHD Subsystem Development (Software)	101 days	Tue 11/12/13	Tue 4/1/14
72	72	Top Assembly Summary	101 days	Tue 11/12/13	Tue 4/1/14
73	73	System Integration and Testing	108 days	Wed 4/2/14	Fri 8/29/14
74	74				
75	**75**	**Flight Unit Development, Phase C-D**	**250 days**	**Mon 9/1/14**	**Fri 8/14/15**
76	76	Inheritance Review	5 days	Mon 12/1/14	Fri 12/5/14
77	77	Electronics and Electrical Subsystem Development	90 days	Mon 9/1/14	Fri 1/2/15
78	78	Opto-Mechanical Susystem Development	90 days	Mon 9/1/14	Fri 1/2/15
79	79	Thermal Subsystem Development	90 days	Mon 9/1/14	Fri 1/2/15
80	80	CHD Subsystem Development (Software)	90 days	Mon 9/1/14	Fri 1/2/15
81	81	Top Assembly Summary	90 days	Mon 9/1/14	Fri 1/2/15
82	82	Simulator Model	228 days	Mon 9/1/14	Wed 7/15/15
83	83	System Integration and Testing	62 days	Mon 1/5/15	Tue 3/31/15
84	84	Vibration Testing	11 days	Wed 4/1/15	Wed 4/15/15
85	85	EMI Testing	10 days	Thu 4/16/15	Wed 4/29/15
86	86	Thermal Vacuum Test	11 days	Thu 4/30/15	Thu 5/14/15
87	87	Post-Environment System test	8 days	Fri 5/15/15	Tue 5/26/15
88	88	Funded Scheduled Reserve	58 days	Wed 5/27/15	Fri 8/14/15
89	89				
90	**90**	**HORUS Delivery to ATLO, Phase D**	**1 day**	**Fri 8/14/15**	**Fri 8/14/15**
91	91	HORUS Delivery to ATLO, Phase D	1 day	Fri 8/14/15	Fri 8/14/15



Appendix C: HORUS Instrument Master Budget (in FY10$ and FY09$)

WBS #	WBS Elements	Phase BBR (FY10$)		Phase B(FY10$)				Phase C-D(FY10$)					Phase E(FY10$)										
		July-Nov 2010		Dec 2011-Mar 2013				Jan 2013-Aug 2015					Sept 2016-Aug 2023										
		FY11	Total	FY 11	FY12	FY13	Total	FY13	FY14	FY15	FY16	Total	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	Total	FY10$ Total	FY09$ Total
12.1	IS	$10,000	$10,000	$0	$10,000	$0	**$10,000**	$10,000	$10,000	$10,000	$10,000	**$40,000**	$0	$5,000	$5,000	$5,000	$10,000	$10,000	$10,000	$0	**$45,000**	**$105,000**	**$101,942**
12.1	Deputy IS	$10,000	$10,000	$0	$10,000	$0	**$10,000**	$10,000	$10,000	$10,000	$10,000	**$40,000**	$0	$0	$0	$0	$10,000	$10,000	$10,000	$0	**$30,000**	**$90,000**	**$87,379**
	Science Advisor	$10,000	$10,000	$0	$20,000	$0	**$20,000**	$20,000	$20,000	$20,000	$20,000	**$80,000**	$0	$0	$0	$0	$10,000	$10,000	$0	$0	**$20,000**	**$130,000**	**$126,214**
12.1	Engineering Advisor	$10,000	$10,000	$0	$10,000	$0	**$10,000**	$10,000	$10,000	$10,000	$10,000	**$40,000**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$60,000**	**$58,252**
12.1	Instrument Manager	$0	$0	$1,250	$16,354	$3,750	**$21,354**	$15,000	$15,000	$15,000	$11,250	**$56,250**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$77,604**	**$75,344**
12.1	IM Grad Student	$0	$0	$958	$12,538	$2,875	**$16,372**	$11,500	$23,000	$11,500	$8,625	**$54,625**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$70,997**	**$68,929**
12.1	IM Undergrad Student	$0	$0	$292	$3,816	$875	**$4,983**	$3,500	$3,500	$3,500	$2,625	**$13,125**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$18,108**	**$17,580**
12.2; 12.8	SE/QA Engineer	$6,250	$6,250	$1,250	$16,354	$3,750	**$21,354**	$15,000	$20,000	$25,000	$11,250	**$71,250**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$98,854**	**$95,975**
12.2; 12.8	SE/QA Grad Student	$0	$0	$958	$12,538	$2,875	**$16,372**	$11,500	$15,333	$19,167	$8,625	**$54,625**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$70,997**	**$68,929**
12.2; 12.8	SE/QA Undergrad Student	$0	$0	$292	$3,816	$438	**$4,545**	$3,208	$3,500	$5,250	$1,313	**$13,271**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$17,816**	**$17,297**
12.3; 12.7; 12.8	EE Engineer	$6,250	$6,250	$0	$8,750	$0	**$8,750**	$15,000	$25,000	$30,000	$22,500	**$92,500**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$107,500**	**$104,369**
12.3; 12.7; 12.8	EE Grad Student	$0	$0	$958	$19,247	$0	**$20,205**	$21,083	$23,000	$23,000	$17,250	**$84,333**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$104,538**	**$101,493**
12.3; 12.7; 12.8	EE Undergrad Student	$0	$0	$0	$4,083	$0	**$4,083**	$15,167	$23,333	$28,000	$21,000	**$87,500**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$91,583**	**$88,916**
12.4; 12.7; 12.8	Optical Engineer	$6,250	$6,250	$0	$6,250	$0	**$6,250**	$15,000	$30,000	$20,000	$0	**$65,000**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$77,500**	**$75,243**
12.4; 12.7; 12.8	OpSci Grad Student	$0	$0	$0	$7,667	$0	**$7,667**	$12,458	$11,500	$7,667	$0	**$31,625**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$39,292**	**$38,147**
12.4; 12.7; 12.8	OpSci Undergrad Student	$0	$0	$0	$1,667	$0	**$1,667**	$5,000	$15,833	$13,333	$0	**$34,167**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$35,833**	**$34,790**
12.5; 12.7; 12.8	ME Engineer	$6,250	$6,250	$0	$8,750	$0	**$8,750**	$16,250	$30,000	$30,000	$22,500	**$98,750**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$113,750**	**$110,437**
12.5; 12.7; 12.8	ME Grad Student	$0	$0	$958	$19,247	$0	**$20,205**	$11,500	$16,292	$23,000	$17,250	**$68,042**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$88,247**	**$85,676**
12.5; 12.7; 12.8	ME Undergrad Student	$0	$0	$0	$2,917	$0	**$2,917**	$11,667	$15,833	$16,667	$15,000	**$59,167**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$62,083**	**$60,275**
12.6; 12.7; 12.8	Software Engineer	$6,250	$6,250	$0	$11,250	$0	**$11,250**	$15,000	$15,000	$15,000	$11,250	**$56,250**	$0	$0	$0	$0	$15,000	$0	$0	$0	**$15,000**	**$88,750**	**$86,165**
12.6; 12.7; 12.8	CS Grad Student	$0	$0	$958	$12,538	$0	**$13,497**	$11,500	$11,500	$23,000	$17,250	**$63,250**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$76,747**	**$74,511**
12.6; 12.7; 12.8	CS Undergrad Student	$0	$0	$0	$3,750	$0	**$3,750**	$11,667	$16,667	$17,500	$7,500	**$53,333**	$0	$0	$0	$0	$5,000	$5,000	$5,000	$0	**$15,000**	**$72,083**	**$69,984**
	PlSci/Astr Grad Student	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	$0	**$0**	$0	$11,500	$11,500	$11,500	$23,000	$23,000	$11,500	$0	**$92,000**	**$92,000**	**$89,320**
	PlSci/Astr Undergrad Student	$0	$0	$0	$0	$0	**$0**	$0	$0	$0	$0	**$0**	$0	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$0	**$30,000**	**$30,000**	**$29,126**
	Administrative	$6,000	$6,000	$0	$6,000	$6,000	**$12,000**	$0	$6,000	$6,000	$6,000	**$18,000**	$0	$0	$0	$0	$6,000	$6,000	$0	$0	**$12,000**	**$48,000**	**$46,602**
	Total Labor Cost	**$77,250**	**$77,250**	**$7,875**	**$227,531**	**$20,563**	**$255,969**	**$271,000**	**$370,292**	**$382,583**	**$251,188**	**$1,275,063**	**$0**	**$21,500**	**$21,500**	**$21,500**	**$84,000**	**$69,000**	**$41,500**	**$0**	**$259,000**	**$1,867,281**	**$1,812,894**
	Operations	**$1,545**	**$1,545**	**$158**	**$4,551**	**$411**	**$5,119**	**$5,420**	**$7,406**	**$7,652**	**$5,024**	**$25,501**	**$0**	**$430**	**$430**	**$430**	**$1,680**	**$1,380**	**$830**	**$0**	**$5,180**	**$37,346**	**$36,258**
	Travel	**$2,000**	**$2,000**	**$0**	**$2,000**	**$2,000**	**$4,000**	**$0**	**$2,000**	**$10,000**	**$10,000**	**$22,000**	**$0**	**$0**	**$0**	**$0**	**$0**	**$2,000**	**$2,000**	**$0**	**$4,000**	**$32,000**	**$31,068**
	Benefits	**$21,939**	**$21,939**	**$2,771**	**$71,503**	**$6,328**	**$80,602**	**$75,707**	**$99,785**	**$102,833**	**$69,276**	**$347,600**	**$0**	**$6,489**	**$6,489**	**$6,489**	**$24,622**	**$20,362**	**$10,919**	**$0**	**$75,370**	**$525,511**	**$510,205**
	Indirect Costs	**$52,908**	**$52,908**	**$4,093**	**$131,657**	**$13,325**	**$149,075**	**$156,926**	**$216,042**	**$226,128**	**$151,593**	**$750,689**	**$0**	**$11,105**	**$11,105**	**$11,105**	**$49,745**	**$40,701**	**$24,923**	**$0**	**$148,684**	**$1,101,357**	**$1,069,278**
	Telescope Support Structure (ATK	$0	$0	$0	$249,000	$0	**$249,000**	$0	$0	$0	$0	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$249,000**	**$241,748**
	Spectrometer (Omnisys, 3 units)	$0	$0	$0	$400,000	$0	**$400,000**	$0	$0	$0	$0	**$0**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$400,000**	**$388,350**
	Receiver (VDI, 3 Units)	$0	$0	$0	$0	$0	**$0**	$344,500	$0	$0	$0	**$344,500**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$344,500**	**$334,466**
	Tunable DRO (Miteq, 3 Units)	$0	$0	$0	$0	$0	**$0**	$75,000	$0	$0	$0	**$75,000**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$75,000**	**$72,816**
	OMT (ASU, 3 Units)	$0	$0	$0	$0	$0	**$0**	$33,440	$0	$0	$0	**$33,440**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$33,440**	**$32,466**
	Horns (CMI, 3 Units)	$0	$0	$0	$0	$0	**$0**	$27,000	$0	$0	$0	**$27,000**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$27,000**	**$26,214**
	Laboratory Equipment	$0	$0	$0	$50,000	$0	**$50,000**	$50,000	$0	$0	$0	**$50,000**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$100,000**	**$97,087**
	Total Capital Equipment	**$0**	**$0**	**$0**	**$699,000**	**$0**	**$699,000**	**$529,940**	**$0**	**$0**	**$0**	**$529,940**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$1,228,940**	**$1,193,146**
	Total HORUS Cost w/o Reserves	**$155,642**	**$155,642**	**$14,896**	**$1,136,242**	**$42,627**	**$1,193,765**	**$1,038,993**	**$695,524**	**$729,196**	**$487,080**	**$2,950,793**	**$0**	**$39,524**	**$39,524**	**$39,524**	**$160,047**	**$133,443**	**$80,172**	**$0**	**$492,234**	**$4,792,434**	**$4,652,849**
	Reserves	$0	$0	$0	$107,000	$0	**$107,000**	$0	$250,000	$275,000	$275,000	**$800,000**	$0	$0	$0	$0	$0	$0	$0	$0	**$0**	**$907,000**	**$880,583**
	Total PI-managed HORUS Cost	**$155,642**	**$155,642**	**$14,896**	**$1,243,242**	**$42,627**	**$1,300,765**	**$1,038,993**	**$945,524**	**$1,004,196**	**$762,080**	**$3,750,793**	**$0**	**$39,524**	**$39,524**	**$39,524**	**$160,047**	**$133,443**	**$80,172**	**$0**	**$492,234**	**$5,699,434**	**$5,533,431**

Appendix C: HORUS Budget Justification

The HORUS budget has been developed to include the following elements: 1) Labor Cost; 2) Operations; 3) Travel; 4) ERE/Benefits; 5) IDC/Indirect Costs; 6) Capital Equipment; 7) Reserves. The next sections provide detailed justification for the individual elements.

Labor Costs

Estimation of the labor cost is derived directly from the staffing profile which is generated by mapping each task from the master schedule into equivalent FTEs required to accomplish it. Nevertheless, the staffing profile needs to account for the special nature of the project which is student-centered and professionally assisted. The HORUS team has been structured to provide an intelligent blend of academics, research scientists and professional engineers to guide the students toward accomplishing the goal of successfully designing, building and testing the proposed instrument. The Work Breakdown Structure (WBS) is organized such that each element includes a hierarchical substructure where every senior professional responsible for the element mentors the associated graduate and undergraduate students. Mentoring is also conceived to flow directly from graduate to undergraduate within the same WBS element and across the project borders.

IS, Deputy IS, Science Advisor and Engineering Advisor workload: Those four key positions are covered by tenured, tenured-track and research professors at University of Arizona. Dr. Chris Walker, Dr. Furfaro and Dr. Tyo have a 9-months academic appointment with UA and will charge 1 month/year in the time-frame 2011-2016. Dr. Kargel is 100% soft money and will charge 2 month/year in the same period. During the cruise, only the IS will be kept at 0.5 month/year. During OSIRIS REx operations (2020-2021), Dr. Walker, Furfaro and Kargel will cost 1 month/year. For all academics, the rate has been established to be 120K/year (1 FTE) with a 28.4% ERE/benefits (according to the UA current rates).

Graduate and undergraduate students workload: During the instrument design, building and testing, the project is expected to employ approximately between 3 and 5 graduate students and between 5 and 15 undergraduate students, depending on the workload established by the various project phases. We expect to have a solid core of graduate students that works consistently on HORUS throughout phase B and C-D. We have already established a set of three highly interdisciplinary and motivated graduate students (see personnel section) that is willing to shift to different duties as function of the project phase. The staffing profile accounts for the needs of the project as function of time and the students FTE fluctuates accordingly. Nevertheless, in a highly multi-disciplinary environment, we are expecting that the graduate students will be able to maintain a 0.5 FTE throughout the duration of the project. Graduate students are expected to cost $46,000/year (1 FTE), with a 42.6% ERE/benefits rate (according to the current UA rates). Conversely, we are expecting to have a high turn-over of undergraduate students during the various phases of the projects. We will ramp-up the number of undergraduate students involved in the project during phase C-D where higher manpower is required for integration, test and instrument space qualification. Undergraduate students are expected to cost $10,000/year (1 FTE) with 3.4% ERE/benefits rate (according to the current UA rates).

During Phase E we will employ one graduate and one graduate student in planetary science/astronomy to perform data collection and interpretation. Moreover, a graduate student in computer science is expected to be employed as responsible of the ground software for data processing.

Professional Engineers workload: Professional engineers are required to a) provide expertise and skills for the most challenging tasks and b) operate as mentors for both graduate and undergraduate students. The following positions are expected to be covered by professionals: Instrument Manager, System Engineer, Electrical Engineer, Optical Engineer, Mechanical Engineer and Software Engineer. The FTE level for each of the abovementioned positions will depend on the nature of the task. From phase B through C-D until ATLO, we are expecting to employ between 2 and 3 FTEs of professionals/year. The HORUS professional engineers cost $60,000/year (1 FTE) with 28.4% ERE/benefits rate (according to the current UA rates).
Raytheon Engineers workload: Raytheon Missile Systems (Tucson, AZ) has agreed to support the HORUS project by allowing volunteering time from engineers within the company interested in participating. RMS engineers (see resumes) have already started working with us on the HORUS instrument concept. Such professionals will have no impact on the HORUS budget. They will provide critical guidance in electronics design, building and testing, including critical help in formulating and implementing a space qualification plan.

Operations

Operations cost have been estimated as 2% of the total labor cost.

Travel

During Phase B-C, travel cost has been budgeted to attend critical OSIRIS REx meetings. In the time-frame 2011-2014 we estimated that travel cost will be $2,000/year. We ramped-up the travel budget in 2015 to $10,000 to account for student trips that may be required to an alternative Raytheon corporate facility (e.g. Raytheon Space and Airborne Systems, El Segundo, CA) if RMS will not have local (Tucson, AZ) environmental facility available upon demand (facilities will be available on a non-interference basis).

Benefits/ERE

Benefits are estimated using current UA rates (see labor cost section for individual rates).

Indirect Costs/IDC

As per University of Arizona policy, indirect costs are applied at 51.5% to salaries with the exception of the 30.6% tuition remission for graduate students, the first $25K of subcontracts, non-capital purchases, operations, and travel.

Capital Equipment

All major expenditures are related to the creation of the observatory and its instrumentation. The most major expenditures and target vendors/sources are:

1) *Receivers:* vendors- Virginia Diodes Inc.: A world leader in millimeter-wave/THz Schottky based receivers/components. VDI has supplied ambient-temperature receivers in the PI's

laboratory and for similar projects. Consolidation, integration, and qualification of these mixers will take place at the University of Arizona and/or at Raytheon Missile Systems.

2) *Spectrometer System:* vendor- Omnisys Inc. has successfully delivered spectrometers of similar type to those being used for HORUS to the University of Arizona for the SuperCam project and the Pre-HEAT telescope prototype successfully deployed to Antarctica. Omnisys will supply three correlator spectrometers to the HORUS project, with one qualified for flight and two as engineering and testing prototypes.

3) *Telescope System:* vendor- ATK in San Diego, CA is a world leader in advanced composite telescope design and construction and will develop and help qualify the mechanical off-axis Gregorian telescope for HORUS.

4) *Waveguide components:* Both the UofA and ASU possess high-accuracy metal micro-milling machines, as well as focused vendors such as Custom Microwave Inc. We have distributed requests for quotes for different microwave components between several sources. We anticipate that CMI will be most cost-effective for feedhorns, whereas more detailed and complex structures such as the ortho-mode transducers needed to drive two mixers with a single feedhorn would be best suited for the UofA and ASU machines.

We have provided the above vendors/sources with detailed specifications of each item and they in turn have provided the costing information used in the budget. Once vendor and component selection has been completed, detailed quotes will be generated and purchase orders will be issued to suppliers when appropriate.

Reserves

We established a 16% reserve for the project, approximately $907,000. Of this, $107,000 are assigned to capital equipment (e.g. unforeseen cost increase of instrument parts) and $800,000 are assigned to mitigate risks associated with the space qualification process. As part of the HORUS space qualification plan we are expecting to fully space-qualify and fully test each of the subsystems and subsequently go through a set of environmental tests for the integrated system. Most of the reserves are held in case more resources are needed during the QA phase.

Testing Facility cost

Raytheon has agreed to support the project by allowing HORUS team members to use the environmental facilities at non-interference basis. We are expected to have relevant testing facilities available after a fully T&I plan is formulated to account for availability. RMS engineers will be participating in the space qualification process to help guiding students.

Appendix D: HORUS Staffing Plan (FTE list)

WBS #	WBS Elements	Phase BBR		Phase B				Phase C-D					Phase E									Total FTEs
		FY11	Total	FY 11	FY12	FY13	Total	FY13	FY14	FY15	FY16	Total	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	Total	
	Percentage of Fiscal Year																					
	Labor Cost																					
12.1	PI	0.08	0.08	0.00	0.08	0.00	**0.08**	0.08	0.08	0.08	0.08	**0.33**	0.00	0.04	0.04	0.04	0.08	0.08	0.08	0.00	**0.38**	**0.88**
12.1	Deputy PI	0.08	0.08	0.00	0.08	0.00	**0.08**	0.08	0.08	0.08	0.08	**0.33**	0.00	0.00	0.00	0.00	0.08	0.08	0.08	0.00	**0.25**	**0.75**
	Science Advisor	0.08	0.08	0.00	0.17	0.00	**0.17**	0.17	0.17	0.17	0.17	**0.67**	0.00	0.00	0.00	0.00	0.08	0.08	0.00	0.00	**0.17**	**1.08**
12.1	Engineering Advisor	0.08	0.08	0.00	0.08	0.00	**0.08**	0.08	0.08	0.08	0.08	**0.33**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**0.50**
12.1	Instrument Manager	0.00	0.00	0.02	0.27	0.06	**0.36**	0.25	0.25	0.25	0.19	**0.94**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.29**
12.1	IM Grad Student	0.00	0.00	0.02	0.27	0.06	**0.36**	0.25	0.50	0.25	0.19	**1.19**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.54**
12.1	IM Undergrad Student	0.00	0.00	0.04	0.55	0.13	**0.71**	0.50	0.50	0.50	0.38	**1.88**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**2.59**
12.2; 12.8	SE/QA Engineer	0.10	0.10	0.02	0.27	0.06	**0.36**	0.25	0.33	0.42	0.19	**1.19**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.65**
12.2; 12.8	SE/QA Grad Student	0.00	0.00	0.02	0.27	0.06	**0.36**	0.25	0.33	0.42	0.19	**1.19**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.54**
12.2; 12.8	SE/QA Undergrad Student	0.00	0.00	0.04	0.55	0.06	**0.65**	0.46	0.50	0.75	0.19	**1.90**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**2.55**
12.3; 12.7; 12.8	EE Engineer	0.10	0.10	0.00	0.15	0.00	**0.15**	0.25	0.42	0.50	0.38	**1.54**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.79**
12.3; 12.7; 12.8	EE Grad Student	0.00	0.00	0.02	0.42	0.00	**0.44**	0.46	0.50	0.50	0.38	**1.83**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**2.27**
12.3; 12.7; 12.8	EE Undergrad Student	0.00	0.00	0.00	0.29	0.00	**0.29**	1.08	1.67	2.00	1.50	**6.25**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**6.54**
12.4; 12.7; 12.8	Optical Engineer	0.10	0.10	0.00	0.10	0.00	**0.10**	0.25	0.50	0.33	0.00	**1.08**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.29**
12.4; 12.7; 12.8	OpSci Grad Student	0.00	0.00	0.00	0.17	0.00	**0.17**	0.27	0.25	0.17	0.00	**0.69**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**0.85**
12.4; 12.7; 12.8	OpSci Undergrad Student	0.00	0.00	0.00	0.17	0.00	**0.17**	0.50	1.58	1.33	0.00	**3.42**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**3.58**
12.5; 12.7; 12.8	ME Engineer	0.10	0.10	0.00	0.15	0.00	**0.15**	0.27	0.50	0.50	0.38	**1.65**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.90**
12.5; 12.7; 12.8	ME Grad Student	0.00	0.00	0.02	0.42	0.00	**0.44**	0.25	0.35	0.50	0.38	**1.48**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.92**
12.5; 12.7; 12.8	ME Undergrad Student	0.00	0.00	0.00	0.29	0.00	**0.29**	1.17	1.58	1.67	1.50	**5.92**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**6.21**
12.6; 12.7; 12.8	Software Engineer	0.10	0.10	0.00	0.19	0.00	**0.19**	0.25	0.25	0.25	0.19	**0.94**	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	**0.25**	**1.48**
12.6; 12.7; 12.8	CS Grad Student	0.00	0.00	0.02	0.27	0.00	**0.29**	0.25	0.25	0.50	0.38	**1.38**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	**1.67**
12.6; 12.7; 12.8	CS Undergrad Student	0.00	0.00	0.00	0.38	0.00	**0.38**	1.17	1.67	1.75	0.75	**5.33**	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.00	**1.50**	**7.21**
	PlSci/Astr Grad Student	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	**0.00**	0.00	0.25	0.25	0.25	0.50	0.50	0.25	0.00	**2.00**	**2.00**
	PlSci/Astr Undergrad Student	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	**0.00**	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.00	**3.00**	**3.00**
	Administrative	0.20	0.20	0.00	0.20	0.20	**0.20**	0.00	0.20	0.20	0.20	**0.60**	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	**0.40**	**1.40**

Appendix E: Facilities and Equipment

Steward Observatory and the Lunar and Planetary Laboratory have a large technical staff with many years of experience in the design and construction of state-of-the-art instrumentation for space (e.g. *Phoenix*, *MGO*, *Cassini*, *Deep Impact*, *Hubble Space Telescope*, *Spitzer*, *IRAS*, *etc*.) and ground based observations (*e.g.* MMT, Magellan, LBT, HHSMT, *etc*.). More recently, the HORUS IS (C. Walker) and his team are leading the development of the *Stratospheric THz Observatory (STO)*, a NASA funded, long duration, balloon experiment to map the Milky Way in the important THz lines of ionized carbon, [CII], and nitrogen [NII]. This expertise will be augmented by *OSIRIS* and Raytheon team members and utilized during the development of HORUS.

In 1992 C. Walker established a laboratory (the Steward Observatory Radio Astronomy Laboratory, SORAL) for the development of state-of-the-art submillimeter-wave receiver systems. ***The majority of work in SORAL is performed by students.*** Indeed, many of SORAL's past students have won prestigious fellowships, postdocs, and gone on to faculty positions. SORAL will work closely with the *OSIRIS* team and Raytheon in the design and development of HORUS. SORAL possess a variety of equipment (spectrum analyzers, network analyzer's, vacuum pumps, cryogenic support facilities, etc.) needed for the development of receiver systems and characterizing material properties at THz frequencies. 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 allows us to characterize a wide range of receiver systems. SORAL has licenses for Advanced Design System (ADS) software packages 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 Solid Works.

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 HHSMT on Mt. Graham, Arizona and the AST/RO telescope at the South Pole. Based upon the success of these instruments, Walker's team 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* and HORUS. The HORUS receiver development will leverage greatly from *STO* and SuperCam.

Appendix F: HORUS Team Roles and Responsibilities

Name	Affil.	Dept.	Responsibility
C. Walker	UofA	Astr/OpSci/ECE	Instrument Scientist
R. Furfaro	UofA	AME/IE	Deputy Instrument Scientist
C. Kulesa	UofA	Astr	Instrument Manager
J. Kloosterman	UofA	ECE/Astr (Grad)	***Student*** Instrument Manager
J. Kargel	UofA	HWR	Science Advisor
S. Tyo	UofA	OpSci	Engineering Advisor
C. d'Aubigny	TeraVision Inc.		Optical Lead
S. Albanna	UofA	OpSci (Grad)	***Student*** Optical Lead
A. Young	TeraVision Inc.		Electrical Lead
D. Lesser	UofA	Astr/ECE (Grad)	***Student*** Electrical Lead
B. Ferrell	RMS		Electrical Advisor
E. Lauria	RMS		Electrical Advisor

Appendix G: Institutional Support Letters

- Raytheon Missile Systems
- Teravision Inc.

Raytheon

Randall E. Gricius
Director, Space Applications
AS&DES Product Line
520.794.5841 office
520.907.8178 cell

Missile Systems
PO Box 11337
Tucson, Arizona
85734-1337 USA
520.794.3000

12 August 2010

Christopher K Walker, PhD
Professor of Astronomy
Stewart Observatory
933 N Cherry Avenue
Tucson, Arizona 85721

Subject: Student Collaboration Experiment for OSIRIS-REx

Dear Dr. Walker,

It is a pleasure to support your proposal for the HORUS Student Collaboration Experiment for the OSIRIS-REx asteroid sample and return mission. Raytheon Missile Systems is excited to be part of your team because the potential technical approach and concepts are synergistic to technology being developed in our Advanced Security and Directed Energy Systems product line. We offer significant advantage in RF oscillators that have the potential to meet or exceed your requirements for: low cost with reliability, ultra-low phase noise, low mass and power consumption. Our RF oscillators are developed with modular intent to meet the needs of a family of products.

With this letter we offer our strong encouragement and enthusiasm for your efforts to develop a space-qualified THz radiotelescope/spectrometer and associated signal processing hardware. We will begin to define the needed parameters and the resources we have available to support the project and work needed.

We already have a highly successful history of collaboration with the University of Arizona and are excited to work with you on this effort. We are sure this will be a similar success.

Respectfully,

Randall E. Gricius
Director, Space Applications
Advanced Security and Directed Energy Systems
Raytheon Missile Systems

REG/kem

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

August 12, 2010

Subject: HORUS Student Collaboration Experiment for the OSIRIS-REx

Dear Dr. Walker,

This letter is to express TeraVision's support for, and acknowledge our participation in the Student Collaboration Experiment you are proposing for OSIRIS-Rex mission. This project is a very good fit to our company's core expertise and we're looking forward to continue working with your group and University of Arizona undergraduate and graduate students in the future.

The technical requirements of this project are not unlike those of other efforts our company has led in the past. We believe the HORUS instrument could relatively easily be reconfigured for other applications ranging from climate science to national security, and are excited at that prospect.

TeraVision will bring a variety of technical expertise and resources to the project. In particular Mr. Abram Young and myself have agreed to provide RF/Microwave and Optical engineering support to the project.

We have successfully collaborated with your group and others at the University on a variety of projects. We look forward to working with you on the development, fabrication and testing of this exciting instrument.

Please do not hesitate to contact me if you require additional support materials

Sincerely,

Christian d'Aubigny, PhD.
VP Engineering
Phone (520) 465 1909
cdaubign@teravision-inc.com

Appendix H: Curriculum Vitae

- Christopher Walker
- Roberto Furfaro
- Jeffrey Kargel
- J. Scott Tyo
- Christian Drouet d'Aubigny
- Bruce Ferrell
- Eugene Lauria
- Abram Young
- Craig Kulesa
- Jenna Kloosterman
- Sarmad Albanna
- David Lesser

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, Associate Professor of Optical Sciences, and 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

Five Selected Publications

Walker, C., Kulesa, C., Groppi, C., Young, E., Bernasconi, P., Eaton, H., Rolander, N., Lisse, C., Hollenbach, D., Kawamura, J., 2009, *A Test Flight Instrument for the Stratospheric Terahertz Observatory (STO)*, Proc. 20th International Symposium on Space Terahertz Technology, p.107.

Groppi, C., Walker, C., Kulesa, C., Golish, D., Kloosterman, J., Weinreb, S., Jones, G., Barden, J., Mani, H., Kuiper, T., 2009, *SuperCam: A 64 Pixel Heterodyne Array Receiver for the 350 GHz Atmospheric Window*, Proc. 20th International Symposium on Space Terahertz Technology, p.90.

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

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

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.

Roberto Furfaro, Ph.D.

Assistant Professor
Department of Systems and Industrial Engineering, Department of Aerospace and Mechanical Engineering
University of Arizona, Tucson, AZ, robertof@email.arizona.edu

Research Area: Intelligent Systems for Planetary Exploration, Space Systems Design, Guidance Control and Navigation, Radiative Transfer theory, Remote Sensing of Glacier using ASTER images

Education: Ph.D., Aerospace Engineering, 2004, University of Arizona
Laurea Degree (M.S. equivalent), Aeronautical Engineering 1998, University of Rome "La Sapienza"

Professional Experience: Roberto Furfaro has a broad range of expertise and interests. He is an interdisciplinary engineer that aims at bridging planetary science and space engineering in a coherent framework. He has been working on a numerous and diverse projects including remote sensing of vegetation from satellite and UAV platforms, guidance navigation and control of lunar landers, fuzzy expert systems for life detection on planetary bodies, wind-based hot-air balloon navigation for Titan and thermal modeling of Martian surface as well as NASA funded projects involving glacier mapping and intelligent data analysis algorithm development.

Professional History: Roberto Furfaro is currently Assistant Professor in the Department of Systems and Industrial Engineering and in the Department of Aerospace and Mechanical Engineering Department, University of Arizona. He graduated with a laurea-degree in aeronautical engineering (MS equivalent) from University of Rome in 1998 and with a PhD in aerospace engineering from University of Arizona in 2004. He has been interested in space exploration since 1998 when he joined the NASA SERC at University of Arizona to become the project manager for the development of two robotic research devices designed to utilize Martian local resources. In 2000, he collaborated (as Research Assistant) with Arcon Corporation and US Airforce Research Lab to devise passive methods for detection of concealed objects under vegetation.. In 2002, he joined the NASA Ames "Coffee Project" team to devise a model-based intelligent algorithm for estimation of real-time coffee ripeness using UAV aerial images. Currently he is involved on a large variety of projects ranging from space exploration to earth-based remote sensing. Notably, he is part of the world coordination center for Global Land and Ice Measurements from Space (GLIMS) consortium and he has been active in performing ASTER data analysis and algorithm application/development, including RT models for vegetation and ice/soil, mapping glacier terrains using clustering algorithm, intelligent determination of glacier boundaries, among others. He is part of the NASA Astrobiology Institute (NAI, Titan). He is the SCE Phase-A lead for OSIRIS REx sample return mission and lead for the Student Lyman Alpha Mapper in the Io Volcano Obeserver Mission (Discovery 13 proposal)

Selected Referred Publications:

Furfaro, R., Kargel, J., S., Lunine, J., I., Fink, W., Bishop, M. P., 2010, Identification of Cryovolcanism on Titan Using Fuzzy Cognitive Maps, Planetary and Space Science, Volume 5, Issue 5, Pages 761–779

Furfaro, R., Dohm, J.M., Fink, W., Kargel, J., Schulze-Makuch, D., Fairén, A.G., Palmero-Rodriguez, A., Bake, V.R., Ferré, P.T., Hare, T.M., Tarbell, M.A., Miyamoto, H., and Komatsu, G., 2008, The search for life beyond Earth through fuzzy expert systems, Planetary and Space Science, Volume 56, Issues 3-4, 448-472.

Furfaro R., Lunine, J., Kargel, J., S., Fink, W., 2008, Intelligent Systems for the Autonomous Exploration of Titan and Enceladus, Space Exploration Technology Conference, Proceedings of the SPIE, Orlando, FL, March 2008.

Morris, R. D., Kottas, A., **Furfaro, R**., Taddy, M., and Ganapol, B.., A Statistical Framework for the Sensitivity Analysis of Radiative Transfer Models Used in Remote Sensed Data Product Generation, *IEEE Trans. Geosci. Remote Sens.* Vol 46, No 12, December 2008.

Ganapol, B.D. **Furfaro, R**., 2008, The Art of Analytical Benchmarking, Lecture Notes in Computational Science and Engineering, VOL 62, pages 105-134, New York; Springer; 1999.

Kargel, J.S., **R. Furfaro**, A.P. Rodriguez, et al., 2007, Martian hydrogeology sustained by thermally insulating gas and salt hydrates, Geology, November 2007, v.35, no.11,p.975-978.

Furfaro, R., Ganapol, B. D., Johnson, L. F., and Herwitz, S. R., 2007, Coffee Ripeness Monitoring with Airborne Imagery: Neural Network Algorithm for Field Ripeness Evaluation Using Reduced a priori Information., *Appl. Eng. Ag.* **23**:379-387, 2007.

Furfaro, R. and Ganapol, B., 2007, Spectral Theory for Photon Transport in Dense Vegetation Media: Caseology for the Canopy Equation, *Transp. Theory Stat. Phys.* **36**, 107-135, 2007..

Jeffrey S. Kargel

Adjunct Professor and Senior Research Scientist

Vitae and Bibliography

Department of Hydrology & Water Resources, University of Arizona, Tucson, AZ 85721
Voice (Home): 520-579-3194, Cell: 520-780-7759, Email: kargel@hwr.arizona.edu

Education:

B.S., Geological Sciences, Ohio State University, Columbus	December 1981
M.S., Geological Sciences, Ohio State University, Columbus	March 1987
Ph.D., Planetary Sciences, University of Arizona, Tucson	December 1990

Major research interests:

Cosmochemistry: planetary and satellite compositions, low temperature aqueous geochemistry and global differentiation of planets and satellites. Physical chemistry and geologic processes of ices, salts, and aqueous materials. Cryospheric processes and landforms on Mars and Earth. Extraterrestrial resources of asteroids, Mars, and the Moon; development of space-based solar power in low Earth orbit and of a Mars-based civilization.

Awards, other non-publication achievements and current roles:

Principle investigator and international coordinator of GLIMS (Glacier Land Ice Measurements from Space), a 29-nation glacier remote sensing consortium (http://www.glims.org). ASTER Science Team member. Editorial Board for *Astrobiology*. Visiting Professor (JSPS Fellow), University of Tokyo, Oct-Dec 2007.

Research and teaching experience:

Graduate Teaching and Research Assistant, Ohio State Univ., Geological Sciences	1/1983–12/1984
Graduate Research Assistant, Univ. of Arizona, Planetary Sciences	1/1985–12/1990
Research Associate, Univ. of Arizona, Lunar and Planetary Laboratory	1/1991–9/1992
Geologist, U.S. Geological Survey, Astrogeology Team (Flagstaff, AZ)	10/1992–04/2005
Senior Assoc. Res. Scientist, Hydrology & Water Resources, University of Arizona	04/2005-06/2006
Adjunct Professor, Hydrology & Water Resources, U of Arizona	06/2006-Present

Affiliations: Amer. Geophys. Union, Internat. Glaciol. Soc., Div. of Planet. Sci. of the Amer. Astronom. Soc.

Publications: Over 70 peer-reviewed papers and >200 abstracts, articles for pop-science media, and tech. pubs.

Selected publications on extraterrestrial resources:

Baker, V. R.; Gulick, V. C.; Kargel, J. S.; Strom, R. G., 1993, Water resources and hydrology of Mars, in: Resources of Near-Earth Space. J.S. Lewis, M.S. Matthews, and M.L. Guerrieri (Eds.). Space Science Series. Tucson: The University of Arizona Press, p.765.

Kargel, J.S. 1994, Metalliferous Asteroids as potential sources of precious metals, Journal of Geophysical Research, v. 99, no E10, p. 21129-21141.

Kargel, J. S., 1996. Market Value of Asteroidal Precious Metals in an Age of Diminishing Terrestrial Resources, in Engineering, Construction, and Operations in Space V, Proc. 5th Int'l Conf. on Space '96 (ed. S. W. Johnson).

Kargel, J. S., 1997. Semiconductor and Precious-Metal Resources of Metallic Asteroids, Princeton Conference on Space Manufacturing, Space Studies Institute.

Selected other recent publications:

Kargel, J.S., 2004, *Mars: A Warmer Wetter Planet*, Praxis-Springer (publ.), 603 pp.

Kargel, J.S., M. J. Abrams, M.P. Bishop, A. Bush, G. Hamilton, H. Jiskoot, A. Kääb, H.H. Kieffer, E.M. Lee, F. Paul, F. Rau, B. Raup, J.F. Shroder, D.L. Soltesz, L. Stearns, and R. Wessels, 2005. Multispectral Imaging Contributions to Global Land Ice Measurements from Space, *Remote Sensing of Environment* 99, 187-219.

Kargel, J.S, 2006, Enceladus: Cosmic gymnast, Volatile miniworld, *Science* 311, 1389-1391 (Invited Perspective on Cassini at Enceladus special issue).

Zolotov, M.Yu., & J.S. Kargel, 2010, Chemical composition of Europa's icy shell, ocean, and underlying rocks, in *Europa*, ISBN: 9780816528448, (R. Pappalardo, et al., Eds.), Univ. Arizona Press, pp 431-458.

Kargel, J.S. R. Furfaro, G. Kaser, G.J. Leonard, W. Fink, C. Huggel, A. Kääb, B.H. Raup, and M. Zapata, 2010, ASTER imaging and analysis of glacier hazards, chapter for inclusion in Terra book, B. Ramachandran, A. Gillespie, and M. Abrams, Eds., Springer (Publ.) (in press).

NAME	POSITION TITLE
J. Scott Tyo	Professor of Optical Sciences University of Arizona

EDUCATION

University of Pennsylvania Ph.D., 1997,	Electrical Engineering
University of Pennsylvania MSE, 1996,	Electrical Engineering
University of Pennsylvania BSE, 1994,	Electrical Engineering

EXPERIENCE

2006 – Pres	Professor, College of Optical Sciences University of Arizona, Tucson, AZ (Assoc prof. '06 – '09)
2001 – 2006	Associate Professor, Electrical and Computer Engineering Dept. University of New Mexico, Albuquerque, NM (Assistant 01 – 05)
1999 – 2001	Assistant Professor, Electrical and Computer Engineering Dept. US Naval Postrgraduate School, Monterey, CA
1996 – 1999	Research Engineer, Air Force Research Lab/Directed Energy Kirtland AFB, NM
1994 – 2001	Officer, US Air Force (Separated at rank of Captain)

RECENT RELATED PUBLICATIONS:

J. S. Tyo, Z. Wang, S. J. Johnson, and B. G. Hoover, "Design and optimization of partial Mueller matrix polarimeters," *Appl. Opt.* **49**: 2326 – 2333 (2010)

M. Armanious and J. S. Tyo, "UWB Self-Compensating Antennas: Numerical Demonstration of the Electromagnetic Working Principle," *IEEE Trans. Antennas Propagat.* **57**:3736 – 3745 (2009)

J. S. Tyo, C. F. LaCasse, and B. M. Ratliff, "Total elimination of sampling errors in polarization imagery obtained with integrated microgrid polarimeters," *Opt. Lett.* **34**:3187 – 3189 (2009)

W.-Y. Jang, M. M. Hayat, J. S. Tyo, R. S. Attaluri, T. E. Vandervelde, Y. D. Sharma, R. Shenoi, A. Stintz, E. R. Cantwell, S. C. Bender, S. J. Lee, S. K. Noh, and S. Krishna, "Demonstration of Bias Controlled Algorithmic Tuning of Quantum Dots in a Well (DWELL) Mid-IR Detectors," *IEEE J. Quantum Electron.*, **45** pp. 674 – 683 (2009)

B. M. Ratliff, C. F LaCasse, and J. S. Tyo "Quantifying IFOV error and compensating its effects in DoFP Polarimeters," *Optics Express* **17**:9112 – 9125 (2009)

M. Piñeros, E. Ritchie, and J. S. Tyo, "Objective Measures of Tropical Cyclone Structure and Intensity Change From Remotely Sensed Infrared Image Data," *IEEE Trans. Geosci. Remote Sens.* **46**:3574 – 3580 (2008)

B. Paskaleva, M. M. Hayat, Z. Wang, and J. S. Tyo, "Canonical Correlation Feature Selection for Sensors with Overlapping Bands: Theory and Application," *IEEE Trans. Geosci. Remote Sens*., **46**:3346 – 3358 (2008)

Z. Wang, J. S. Tyo, and M. M. Hayat, "Generalized SNR for Spectral Sensors with Highly Correlated Bands," *J. Opt. Soc. Am. A* 25: 2528 – 2534 (2008)

J. S. Tyo and T. S. Turner, "Sensing Polarization with Variable Coherence Tomography," *J. Opt. Soc. Am. A* 25:2383 – 2389 (2008)

Christian Drouet d'Aubigny

5516 E. South Wilshire Dr. Tucson, AZ 85711
520 465 1909 - cdaubigny@cox.net

Education

PhD. Optical Sciences, University of Arizona, 2003
M.S. Optical Sciences, University of Arizona, 2001
B.S. Space Sciences & Astronomy and Astrophysics, Florida Tech, Highest Honors, 1996

Experience

V.P. Engineering & New Products, TeraVision Inc. 2006-Present

- Secured and managed $2.9M in R&D funding.
- Led and managed interdisciplinary design teams which developed:
  - Terahertz (THz) imaging and spectroscopy systems for the US Department of Defense
  - High power THz sources
  - Cryogenic Bolometers for Far-IR and THz imaging and spectroscopy
  - Commercial laser micro-machining system: TeraVision LCE Mark II
- Maintained ties with the University of Arizona. Lead Optical Engineer for:
  - STO: A high altitude balloon borne 0.8 m telescope with two heterodyne arrays (1.45 and 1.9 THz)
  - SuperCam: A 64-pixel 0.35 THz heterodyne imaging array for the 10-meter HHT on Mt. Graham
  - HORUS: A proposed $6M student instrument for the OSIRIS Mission: 20 cm, 0.55 THz telescope
- Planned and delivered undergraduate and graduate level optics classes and labs: (Geometric Optics, Gaussian Beam Optics, Interferometry, Fourier Transform Spectroscopy).

Radio Astronomy Laboratory Manager, Steward Observatory, Tucson, AZ, 2005-06

- Led/Managed Raytheon project to retrofit a thermal IR scanning imager to operate at 3 THz.
- Managed Raytheon "New Electron Beam THz sources" project
- Led development of optical system for the NASA Hertz Polarimetric Imager
- Supervised development of SuperCam receiver optics
- Supervised micro-fabrication of 1 THz Ortho-Mode Transducer for NRAO
- Managed SORAL accounts and business related activities

Optical Research Engineer, Steward Observatory, Tucson, AZ, 03-05

- Managed THz photonic-crystal micro-fabrication contract for Raytheon
- Contributed to the development of thin-film wide-band mid-infrared beam splitters for the Terrestrial Planet Finder (TPF) / Large Binocular Telescope (LBT)
- Technical lead for new high NA, UV Laser Chemical Etcher (LCE) to fabricate Far-IR waveguide devices for NASA's Terrestrial Planet Finder mission

Research Associate, Steward Observatory, Tucson, AZ, 01-03

- Ph.D. dissertation: "*Laser chemical etching of waveguides and quasi-optical devices*"
- Designed, fabricated and tested silicon based quasi-optical devices (800 GHz – 5 THz)

Research Assistant, Steward Observatory, Tucson, AZ, 97-01

- Designed, built and characterized a Laser chemical etching system for THz device fabrication.
- Designed, tested, and devised optical alignment procedures for several instruments attached to the AST/RO telescope (South Pole) and Heinrich Hertz sub-mm telescope (Mt. Graham AZ).
- Designed a proposed interferometric camera for the Large Binocular Telescope (Mt. Graham AZ).

Researcher, European Southern Observatory, Munich, Germany, 96-97

- Developed and validated image processing software for Adaptive-Optics, Fabry-Perot and fiber fed imaging-spectrometers.

Summer Intern, Harvard University and Itek Corp., Cambridge and Lexington, MA, 95

- Modeled the mechanical and thermal properties of the optical bench of a proposed space interferometry mission (POINTS).

Research Assistant, Florida Institute of Technology, Melbourne, FL, 94-96

- Researched the age of white dwarf stars. Initiated the construction of a 4m diameter, 21cm-wave student radio-telescope project as president of the FIT Astronomy Society.

Bruce Ferrell
Senior Principal Multi-Discipline Engineer, Raytheon Company
B.S. Physics (with Distinction) University of Arizona, 1983

Mr. Ferrell has 27 years experience, gained at five aerospace companies, in development of advanced RF imaging systems, spanning the spectrum from VHF to W-band. He has significant experience in development, system integration and flight test of airborne radar systems. Early in his career, he developed algorithms and real-time embedded software to control and exploit data from a miniature X-band Synthetic Aperture Radar (SAR) system. He analyzed test data for the first bistatic imaging SAR, performing simulation/analysis for a 2nd generation bistatic design.

As project engineer on several small research contracts, Mr. Ferrell contributed significantly to development of the first successful foliage penetration imaging SAR system. He has performed detailed studies of algorithms and techniques for remote interferometric determination of land surface height and detection of land surface changes. Recently, he investigated algorithms for clutter-based and reflector-based polarimetric calibration for a miniature airborne ground-imaging Ka-band Synthetic Aperture radar system.

As part of the pilot program for the joint Raytheon-U of A Virtual Solutions Development laboratory, Mr. Ferrell served as technical lead on preliminary design efforts for two spaceborne SAR systems: a relatively narrow-swath, fine resolution X-band system and a wide-swath C-band system. On these efforts he worked closely with antenna experts and RF oscillator, receiver and transmitter engineers, to specify subsystem requirements. In addition, over the past several years he has functioned in a mentoring role for eight junior engineers and University of Arizona students, both undergraduate and graduate.

PATENTS
US Patent 5,852,418 "Swept Frequency Spectral Notching Apparatus and Method Therefor," 22 December 1998. First of two listed inventors.

US Patent 5,546,085 "Separating Coherent Radio-Frequency Interference from Synthetic Aperture Data," 13 August 1996. Second of three listed inventors.

PUBLICATIONS (Does not include numerous contract final reports)
"C-band Synthetic Aperture Radar (SAR) for Remote Sensing of Oceans and the Cryosphere" B. Ferrell, Raytheon Company, 18 June 2010.

"Multi-Mission Tactical SAR Sensor" B. Ferrell, Raytheon Company, 24 July 2009.

"Calibration of a Synthetic Aperture Radar," B. Ferrell et al.,Raytheon Company, 8 May 2008.

"Interference Suppression in UHF SAR," B. Ferrell; Proceedings of the 1995 SPIE International Symposium on Optical Engineering in Aerospace Sensing, April 1995
.
"Ultra-wideband Foliage Penetration Measurements," B. Ferrell; Record of the 1994 IEEE National Radar Conference, pp. 80-84, March 1994.

“Simulation of High-Resolution SAR Imagery for Radar System Detection Algorithm Design,'” S. M. Kilberg, B. Ferrell, et al; 38th Annual Tri-Service Radar Symposium, June 1992.

“Application of Simulated Forest Clutter Scenes to the Development of Long Wavelength Radar Target Detection Algorithms,'” B. P. Radza, B. Ferrell and R. Koesel; 36th Annual Tri-Service Radar Symposium, June 1990.

“Bistatic SAR Targeting” B. Ferrell, Proceedings of the First Annual Bistatic Radar Symposium, 1987.

CURRICULUM VITAE

Eugene F. Lauria
4717 N. Paseo de los Cerritos
Tucson, Arizona 85745

EMPLOYMENT

MICROWAVE/RF ENGINEER (2008 - PRESENT)
Raytheon Missile Systems, Tucson, AZ

- Worked in the Advanced Programs/Concepts Section in the RF Electronics Center to perform rapid prototyping and investigate new technologies in RF electronics
- Provided road maps in technologies related to frequency agile tunable filters and THz electronics
- Part of a design team which provides support and solutions for RF systems and components
- Subject matter expert within Raytheon in microwave engineering and THz electronics
- Active within an environment which fosters strong teambuilding and organizational skills
- Organized an internal cooperate-wide workshop on THz RF electronics

RECEIVER ENGINEER (2005 - 2008)
Arizona Radio Observatory, Tucson, AZ

- Built the first receiver which utilized an ALMA band 6 sideband-separating mixer that was used for astronomical observations *(ref. ALMA Memo 553)*
- Designed and constructed a 0.5mm receiver
- Successfully constructed receiver systems under tight time constraints with a modest amount of resources

MICROWAVE ELECTRONICS ENGINEER (1999 - 2005)
National Radio Astronomy Observatory Central Development Lab, Charlottesville, VA

- Designed a 4-12 GHz IF cryogenic amplifier that is directly integrated to the ALMA band 6 SIS mixer without using an isolator *(ref. ALMA memo 378)*
- Designed and built the mixer/preamp evaluation test Dewar for the ALMA band 6 mixers at NRAO/Charlottesville

RECEIVER ENGINEER (1993-99)
National Astronomy and Ionosphere Center, Cornell University, Ithaca, NY

- Receiver engineer lead for NAIC during the Arecibo Observatory Gregorian upgrade
- Built seven front ends covering the frequency range from 420 MHz to 12 GHz

EDUCATION

M.S. ELECTRICAL AND COMPUTER ENGINEERING (1988 - 92)
University of Massachusetts, Amherst, MA

B.S. ELECTRICAL ENGINEERING (1985 - 88)
University of Massachusetts, Amherst, MA

Abram G. Young

6765 N Los Arboles Circle
Tucson, Arizona 85704
(520) 247-5055
young@physics.arizona.edu

Educational Background:

May 1998 – BS Physics, University of Arizona, Tucson, Az.
August 2003 – Dec 2008, graduate studies in physics Non-degree seeking, University of Arizona.

Professional Employment:

May 1993 – December 1998, Research Assistant, Theodore Bowen, University of Arizona Physics.
November 1998 – July 2000, Project Manager, Canyon Building and Design, Tucson, Az.
May 2001 – July 2007, Physicist, Raytheon Missile Systems Company, Tucson, Az.
January 2007 – Present, Physicist, TeraVision, Inc, Tucson, Az.

Research Experiences:

1995 – 1998, Mountain Altitude search for Muon event rate fluctuation with Sidereal time as a component to the Galactic Dark Matter Halo.
1996 – Monte Carlo simulations of Cerenkov detectors for Pierre Auger.
1993 – 1995, Time-Of-Flight Search for Strongly Interacting Massive Particles as a component to the Galactic Dark Matter Halo.
2001 – 2004, Laser Radar Imaging – Analysis of system and beam propagation in turbulent atmosphere. Raytheon Missile Systems
2003 – 2006, Electromagnetic and Atomic applications of Metamaterials (THz, RF – Optical Photonic Crystals, Negative Index Materials, and Carbon Nanotubes), Raytheon Missile Systems
2004 – 2005, Generation of High Frequency Radiation by Electron Beam – RF interactions, Raytheon Missile Systems.
2007 – 2010, THz Vacuum Electronic Amplifier, TeraVision, Inc.
2007 – 2009, Portable Standoff THz Spectroscopy of Explosives, TeraVision, Inc.
2010 – Present, ATOMMS, an Active Temperature, Ozone, and Moisture Microwave Spectrometer, TeraVision, Inc.

Software and Hardware experience:

Operating Systems: UNIX (SunOS, Linux), VAX/VMS, DOS, Windows, MAC.
Languages: C, Object Oriented Pascal, Fortran, LATEX, HTML, Scheme, Guile.
Software: Eigenmode solvers, Finite Difference Time Domain (FDTD), Matlab, MathCad, Physics Analysis Workstation (Cern's PAW), Monte Carlo simulation, data acquisition programs for CAMAC, MS Project, Excel, Word, Powerpoint, CST Particle Studio simulation of Carbon Ion optics for atomic mass spectrometry, CST simulation of RF interactions with frequency selective surfaces (FSSs)

Hardware: Serial and Parallel communications, CAMAC, NIM, TTL, MECL, Embedded Programmable Logic, coincidence circuits, digital and analog electronics, Photomultiplier Tubes, vacuum systems, Printed Circuit Board, Antenna Theory in Amateur Radio, machine shop tools.

Scanning Electron Microscopy, Short Pulse THz Time-Domain Spectroscopy, Fourier Transform Spectroscopy, Cryogenic applications (LN2 and LHe), Design of Solid State Optical Resonators, Carbon Nanotubes, Laser Milling with short pulse UV Lasers, Schottky diode RF mixers and multipliers, cold cathode test, high vacuum design.

Abram Young received the B.Sc. degree in physics from the University of Arizona, Tucson, in 1998. He then worked as a Physicist at Raytheon, Tucson, AZ, in such diverse areas as laser remote sensing, positron annihilation spectroscopy, and novel applications of photonic bandgap devices from millimeter wave to optical regimes where he was the author and coauthor of several patents. He is currently Visiting Faculty in the Accelerator Mass Spectrometry Group in physics at the University of Arizona. In addition, he is also working at TeraVision, Inc.,Tuscon, AZ, on sub-millimeter wave device physics.

Craig A. Kulesa

Steward Observatory
University of Arizona
Tucson, AZ 85721

Telephone: (520) 621-6540
FAX: (520) 621-1532
Email: ckulesa@email.arizona.edu

Professional Preparation

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

Appointments

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

Selected Papers Relevant to This Proposal

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

Instrumentation Experience Relevant to this Proposal:

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

Jenna L. Kloosterman

933 N Cherry Ave, Rm N204 • Tucson, AZ 85721 • (520) 621-2026 • jlkloost@email.arizona.edu

Education

B.A.: Physics, University of California – Berkeley, 2004
M.S.: Astronomy, University of Arizona, 2010
Ph.D.: Electrical Engineering, University of Arizona, expected 2013

Research Experience

Graduate Research Assistant **2007-present**
Astronomy Department, University of Arizona

- Advisor: Professor Christopher Walker
- Building and testing of Supercam – a 350 GHz 64-pixel heterodyne array receiver
- Building and testing of STO (Statospheric Terahertz Observatory) – a long duration balloon project designed to detect and map the terahertz spectroscopic lines of ionized carbon and nitrogen in the Milky Way utilizing heterodyne receivers
- Modeling of chemical tracers in protoplanetary disks using a 3-D radiative transfer code

Teaching Experience

Graduate Teaching Assistant for Astronomy 202: Life in the Universe **2008-2009**
Astronomy Department, University of Arizona

Publications

Kloosterman, J. L., Narayanan, D., Boss, A., Walker, C. "Model Predictions for ALMA: Spectroscopic Signatures of Disk Dynamics and Gas Giant Planet Formation in HCO+ J=7-6", *submitted*.

Kloosterman, J., Bulter, B., de Pater, I. 2008, "VLA observations of synchrotron radiation at 15 GHz", *Icarus* **193**, 644.

Beck, S.C., Turner, J.L., **Kloosterman, J.** 2007, "The extraordinary infrared spectrum of NGC 1222 (Markarian 603)", *Astronomical Journal* **134**, 1237.

Kloosterman, J., Dunn, D.E., de Pater, I. 2005, "Jupiter's Synchrotron Radiation Mapped with the Very Large Array from 1981 to 1998", *Astrophysical Journal Supplement* **161**, 520.

Selected Conference Proceedings

Kloosterman, J., Narayanan, D., Boss, A. P., Walker, C. K. 2010, "Model Predictions for ALMA: Spectroscopic Signatures of Disk Dynamics and Gas Giant Planet Formation in HCO+ J=7-6", Am. Astron. Soc. 216, 315.03

Groppi, C., Walker, C., Kulesa, C., Golish, D., **Kloosterman, J.**, Weinreb, S., Jones, G., Bardin, J., Mani, H., Kuiper, T., Kooi, J., Lichtenberger, A., Cecil, T., Narayanan, G., Putz, P., Hedden, A. 2009, "Supercam: A 64 Pixel Heterodyne Array Receiver for the 350 GHz Atmospheric Window", 20th International Symposium on Space Terahertz Technology, 90.

Groppi, C., Walker, C., Kulesa, C., Golish, D., **Kloosterman, J.**, Putz, P., Weinreb, S., Kuiper, T., Kooi, J., Jones, G., Bardin, J., Mani, H., Lichtenberger, A., Cecil, T., Hedden, A., Narayanan, G. 2008, "Supercam: a 64 pixel heterodyne imaging spectrometer", SPIE 7020, 702011.

Martin, S., de Pater, I., **Kloosterman, J.**, Gibbard, S., Hammel, H. B. 2006, "Multi-wavelength imaging of Neptune at high spatial resolution", Am. Astron. Soc. 38, 502.

Affiliations

SPIE student member – The Society for Optical Engineering
American Astronomical Society student member

Sarmad Albanna

salbanna@optics.arizona.edu

EDUCATION

PhD student in Optical Science University of Arizona *Jan 08* **-***current*
Research Assistant (RA): Astronomy Department and Physical Atmospheric Science
Exploring THz & sub-THz technologies for remote sensing applications. Currently developing the 18-25 GHz and 183-205 GHz transmission and receiving Microwave & optics systems for ATOMMS (The Active Temperature, Ozone and Moisture Microwave Spectrometer to water and ozone lines in the atmosphere for earth using specialized NASA aircrafts.

Ms in Optical Science University of Arizona *Aug 05 -May 08*
Msc. Thesis: Optical Phase Measurement and Dynamic Stabilization for a Transmitted Low Phase Noise 80 GHz Microwave Photonics signal through SMF under Controlled Motion.

Ms EE Department of Electrical Engineering University of Kentucky *Jan 94-Jan 97*
EE Ms. Thesis: Researched the process of using UV-Excimer laser beam for the fabrication of hybrids microwave circuits.

BSc EE Department of Electrical Engineering University of Baghdad *Aug 85 May 90*
BSc Project: Designing an optimum 230VAC Power Line System.

PROFESSIONAL EXPERIENCE

- **National Radio Astronomy Observatory (NRAO) Tucson**, AZ *Jun 02 –feb 08*

Photonics Engineer ALMA Development www.alma.nrao.edu
Developing the Photonic based Local Oscillator (30 GHz to 1 THz) and the fiber based phase stabilization system for the ALMA array to stabilize induced phase in 20 km SMF down to 1.5 micrometer.

- **Broadwings Communications (formally Corvis Corp), Columbia, MD** www.level3.com *Jul00 - Dec01*

DWDM OC-192 Transmission & Optical Amplifier (Raman & EDFA) –Electro-Optical Component & system test Engineer
Performed functional system verification testing on the OC-192 10Gps TX & RX transport systems and their SONET and SDH subassemblies eye mask measurements, BER and OSNR for NRZ and RZ signaling. Performed functional and DVT testing including HALT&HASS environmental tests on DWDM optical pump amplifiers.

- **Hughes Network Systems**, **Germantown, MD** www.hns.com *Jan 97 - Jun 00*

EMC-Microwave Engineer- Wireless Network Division (WND) and Satellite Network Division (SND)
Lead the effort in EMI/EMC testing for FCC and EU standards, and designing custom made EMI filtered cables and other I/O interfaces. In addition, manage outside contractors to carefully manufacture the custom design parts per specifications and tolerances. Performed Point-Point and Point-Multipoint transmission test.

SCHOLARSHIPS AND AWARDS

- TRIFF Imaging scholarship 2010/2011
- SPIE 2008 scholarship
- U of A 2008 Mexico International Research Scholarship

PROFFESTIONAL ASSOCIATION

- IEEE
- Optical Society of America (OSA)
- SPIE (The Society of Photo-Optical Instrumentation Engineers)

FEW SELECTED PUBLICATIONS

- "A Single 30 cm Aperture Antenna Design for The Operation of 2 Widely Separated Frequency Bands for the Active Temperature, Ozone and Moisture Microwave Spectrometer (ATOMMS)", Sarmad. H. AlBanna, Chris Groppi, Christian Drouet d'Aubigny, Abram Young, Angel Otarola. 20th International Symposium on Space Terahertz Technology, Charlottesville, 20-22 April 2009 Conference Proceedings. http://www.nrao.edu/meetings/isstt/2009.shtml.
- "Polarization Mode Noise in an Ultra-low Temporal Drift Photonic LO Distribution System", P. Shen, N. J. Gomes, Senior Member, IEEE, W. P. Shillue, S. Albanna, IEEE Journal of Lightwave Technology Jan 2008.
- "Optical phase measurement and dynamic stabilization for a transmitted 80-GHz microwave photonic ultralow phase noise reference through single-mode fiber under controlled bending motion, S.Albanna Jan 08 SPIE Photonic West Conference.
- "Transmission of Low Phase Noise, Low Phase Drift Millimeter-Wavelength References by a Stabilized Fiber Distribution System" B. Shillue, S. Albanna, and L. D'Addario Oct 2004 International Topical Meeting on Microwave Photonics. Technical Digest (IEEE Cat. No.04EX859C) ISBN 0-7803-8492-x copy writes 2004.
- "Electroless Copper plating on laser Patterned Aluminum Nitride (ALN) using UV Excimer pulsed laser)" Sarmad Albanna, Janet K. Lumpp. ISHM 1996 Proceedings (International Society of Hybrid Microelectronics), Minneapolis, MN. Application for building Low cost high performance RF and Microwave devices.
- "Qualification Of LEDs For Cameras On NASA's Phoenix Mars Lander" Robert O. Reynolds, Roger D. Tanner, & Sarmad Albanna, Aug 26th 2008 SPIE Conference on Optics and Photonics Vol7095.

Contact Information:

David Henry Lesser, dlesser@as.arizona.edu
cell- (202) 251-7374
933 N Cherry Ave.
Tucson, AZ 85721-0065

Fall 2010
Steward Observatory,
University of Arizona

Education:

Oberlin College: BA with Honors in Physics (astrophysics concentration) 2010.
Steward Observatory, University of Arizona: PhD candidate, ongoing.

Experience:

- Oberlin College
  - Research Assistant, Fall 2008 to Spring 2010.
    - Aided the STO and SuperCAM projects (see below), and built a millimeter-band telescope for student use.
  - Teaching Assistant, Spring 2009 to Spring 2010.
    - Helped teach lab courses for 2nd (E&M) and 3rd (Modern Physics) semester classes for physics majors.
- Johns Hopkins University, Applied Physics Lab (APL)
  - Summer Research Intern, Summer 2009
    - Helped advance the STO project, a balloon-borne radio telescope.
    - Participated in intern project, the design of a hypothetical New Frontiers-class mission to Uranus.
- University of Arizona, Steward Observatory Radio Astronomy Lab (SORAL)
  - Summer Research Assistant, Summer 2008
    - Primarily worked on building SuperCAM, a state-of-the-art radio telescope receiver.
- TIC Technology Summer Camp
  - Camp Councilor, programming and robotics teacher, Summer 2007
    - Taught campers aged 7-13 fundamentals of programming and lego robotics.
- ABC Welding Shop
  - Apprentice Welder/Machinist, Summer 2006

Practical Skills:

Soldering, circuit design and debugging
Data analysis
Machining and mechanical design
Software coding
Use of standard lab equipment (cryogenics, vacuum equipment, etc)
Familiarity with construction and use of millimeter spectrometers

References:

- Chris Martin- Physics professor, Oberlin College. chris.martin@oberlin.edu (440)-775-6730
- Chris Walker- Astronomy professor, U. of Arizona. cwalker@as.arizona.edu (520) 621-8783
- Pietro Bernasconi – Senior Staff Physicist, APL. pietro.bernasconi@jhuapl.edu (443) 778-8970

Appendix I: Vendor Quotes

- ATK (telescope structure)
- Virginia Diodes (THz mixer receiver)
- Custom Microwave (feedhorns)
- ASU (ortho-mode transducer)
- Omnisys AB (digital autocorrelation spectrometer)
- Miteq Microwave (RF exciter for local oscillator system)

ATK Space Systems Inc.
9617 Distribution Avenue
San Diego, CA 92121

Tel: 858-621-5700
Fax: 858-621-5770
Kelly.Dodson@ATK.com

August 13, 2010

Via e-mail: cdaubign@teravision-inc.com

University of Arizona
Steward Observatory
933 North Cherry Avenue
Tucson, AZ 85721

Attention: Christian d'Aubigny, PhD.
HORUS Program Chief Engineer

Subject: Rough-Order-of-Magnitude (ROM) Proposal #PRS.SAND.2011.10362 for the HORUS Instrument

References:

1. Email Request for Quotation No. from Christian d'Aubigny to K. Dodson dated July 7, 2010
2. Email Update Scope of Work from C. d'Aubigny to K. Dodson dated August 11, 2010

Dear Dr. d'Aubigny:

ATK Space Systems Inc. ("ATK") is pleased to provide a Rough-Order-of-Magnitude (ROM) proposal for the HORUS Instrument as requested in the referenced document. Attachment 1 provides ATK's ROM pricing, as well as technical and pricing assumptions.

The HORUS telescope is an interesting project to us in that it blends technologies from several previous programs we have executed. It resembles several larger communications antenna systems we have designed and built for longer wavelengths, and blends this with composite mirror and telescope technology that we have exploited in the submillimeter spectrum.

This proposal is provided on a Rough-Order-of-Magnitude (ROM) basis and shall be used for budgetary or planning purposes only and shall not be construed as an offer for sale. As such, it is understood an order will not be issued nor is it expected based upon this letter. As program and technical requirements mature or become better defined that will enable us to prepare a firm offer, please notify the undersigned and we will be happy to respond.

If you have questions regarding any aspect of this ROM proposal, please contact either of the following ATK representatives: **Program and Technical Issues:** Kelly Dodson at (858) 621-5722, fax number (858) 621-5770, or e-mail kelly.dodson@atk.com. **Contractual Issues:** Kathleen Dunham at (858) 621-6906 or e-mail kathleen.dunham@atk.com.

Respectfully submitted,

Kelly J. Dodson
Director Advanced Systems

Attachment 1 – ROM Proposal # PRS.SAND.2011.10362

cc: Mark Pryor, Dan Federico, Grant Ager, Kathy Dunham

ATK-0810-36538

ATTACHMENT 1

ROM PROPOSAL # PRS.SAND.2011.10362

WBS	Description	ROM ($k)
1.0	Non Recurring	$ 103
2.0	Tooling	$ 50
3.0	Fabrication	$ 83
4.0	End Item Test	$ 13
	Total ROM Proposal:	**$ 249k**

Distribution Restriction: This ROM proposal is submitted for the exclusive use of the recipient and shall not be forwarded, disclosed, or further distributed without the express written permission of ATK.

Assumptions:

We have made several assumptions regarding what we believe you would like our work scope to include, and are providing an estimate accordingly.

1. The overall payload is to weigh no more than 2.0 kg, including a 50% mass contingency. Therefore, the actual mass budget is 1.33 kg at this time. Whereas we can build a composite structure within that weight budget, it was not clear how this mass is partitioned. We are assuming that this mass does not include the mass of the turntable bearing.
2. ATK will design and fabricate a lightweight 20 cm diameter off-axis Gregorian telescope (including structure, optical surfaces, anchor points for 4 small electronics modules and three (3) mounts to secure the telescope to the spacecraft instrument platform).
3. This information is provided for the fixed base option. It includes the telescope structure, mirrors and a 3 point mount.
4. Alignment Tolerances are as follows:
   - Optical Surface rms error 1/5 wave at 557 GHz (0.5mm wavelength)
   - Decenters (mirror offset from optical axis) less than +/-1 mm
   - Distance between primary and secondary mirrors exact to +/-0.5mm
   - Mirror tilt errors less than +/-0.5 degree
5. U of A team will be responsible for Quality Assurance, Vacuum / Thermal / Vibration testing and for all documentation required for space qualification.
6. There will be a quantity of one (1) Protoflight telescope.
7. Generally when we build a system that looks like this, it is much larger. The final structural acceptance program generally would include a comprehensive dynamic test program

including sine burst and/or random vibration testing, possibly acoustic testing, and so forth. Due to the unique small size, it would seem the risk reduction one buys by performing this testing at the structural level may not be a good value. The end item testing will happen at the payload level versus at the structure level. We have included a thermal cycle test, however.

8. We are assuming that you will perform the thermal analysis and provide us the temperature environments for the structure.
9. We assume that your program team is responsible for all the electrical aspects of the design (feeds, wg, diplexers, etc).
10. ATK scope is limited to the structure and mirrors. (We do have RF test capabilities, however, if you would like for us to perform testing.)
11. ATK will design the primary reflector/mirror integrally with the secondary mirror tower.
12. We will fabricate or procure the secondary mirror and align it to mechanical tolerances.
13. The primary mirror will be designed with a 3 point support.
14. How a program is managed can do more to affect cost and schedule than the difficulty of what one is actually doing. We are assuming we will mutually work this program as efficiently as possible. We envision 2 technical interface meetings (TIM's) and one design review at our facility. Adequate engineering will be performed to ensure the design will meet requirements. However, we have not bid an engineering effort typical for a New Frontiers Class NASA program, but rather typical of a GAS or SCE payload. For example, drawings will be released engineering sketches rather than formal drawings. The engineering report will be in a Powerpoint™ format.
15. The coating for the primary mirror has not been included in the cost at this time until it is better understood. For instance, is the coating gold, silver or aluminum? Is there a protective overcoat? And so forth.
16. The University of Arizona will be responsible for the Mission Assurance requirements.

General Contract Terms and Conditions:

1. Shipping and Delivery: FOB Origin
2. Payment Terms: Net 30 days. No Discount.

   Payments to be made by wire transfer. For assistance on banking details please contact Accounts Receivable at (858) 621-5700.
3. Unit pricing is based upon receipt of a single order. Buyer changes to above quantities would require Seller evaluation for potential cost impacts, prior to contract award.

   If this proposed effort is tied to one of Buyer's prime contracts with U.S. Government, Buyer will provide prime contract number and priority rating in body of purchase order.

ATK PROPRIETARY – DO NOT DISCLOSE

4. ATK and the University of Arizona will negotiate specifically the general Terms and Conditions upon notification of University of Arizona's intent to award contract, or at other mutually agreeable time prior to contract award. Terms and Conditions expected to include, per ATK corporate policy:
    a. Notwithstanding any other provision of this Contract, in no event shall either Buyer or Seller be liable to the other for any special, incidental, indirect or consequential damages, through indemnity or otherwise, including without limitation lost profits or revenues, whether arising in tort, contract or otherwise.
    b. Any indemnities will be reciprocal and only to the extent and proportional to degree of actual fault of Buyer or Seller.
    c. ATK standard one year warranty (replace, repair or refund) will apply; acceptance period shall not exceed 30 days from date of delivery.
    d. Seller's maximum aggregate liability for all damages for which liability is not or cannot be disclaimed shall in no event exceed the total ATK contract price."
    e. "The express warranties set out in this Contract are the only warranties provided by seller. ALL OTHER WARRANTIES, WHETHER EXPRESS, IMPLIED OR STATUTORY, ARE EXCLUDED, INCLUDING WITHOUT LIMITATION THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE."
5. The University of Arizona agrees to comply fully with all applicable U.S. laws and regulations as they may apply to the export of any hardware, software, defense service or technical data (collectively "Data") provided by, through or with the cooperation of Seller in the performance of this subcontract in the U.S. or abroad or under any export license or exemption issued to ATK. University agrees that it will not permit the re-export of Data, including to foreign students, employed by or associated with, or under contract to the University or Universities lower-tier suppliers, without prior written consent of ATK.

    In further compliance with the ITAR and related rules on export controls, deemed exports and related licensing requirements, the University shall only assign students/personnel to perform services under this Agreement who are currently (1) U.S. citizens; (2) lawful permanent residents of the Unites States; or (3) foreign nationals who have been granted refugee or asylee status.

    By law, the University of Arizona must control access to any/all ATK export controlled technical data within its facilities.

Quote

Customer:
TeraVision, Inc. Abe Young 5516 E. South Wilshire Dr. Tucson, AZ 85711

Rep	Date	Quote #
CR	7/20/2010	10-0546

Email Text

557 GHz Dual-Polarization Radiometer (MixAMC)

Performance: Tmix <4,000K ,
Expected Configuration: x2/Amp/Splitter/x2/x3/SHM
System will consist of two identical x2/x3/SHM chains fed by the Amp/Splitter, one for each polarization

Available IF Frequency: DC-20GHz
A turn-key frequency sweepable system.
Required Input: 11.6 or 23.2 GHz TBD, <18dBm
RF Flange: WR-1.5 UG-387/U-M
IF Flange: SMA mm(f)
RF Bandwidth ~30GHz expected
OMT to be provided by customer

$73,000.00

*Note: Items below are for one optional LO Monitor, prices would double if both chains require a monitor

WR10 20dB 3-Port Coupler

WR-10 Zero-Bias Detector (75-110 GHz)
Typical Responsivity 2,000-3,500V/W, NEP~1E-11W/Hz^1/2
Flanges: WR10 UG387/UM, SMA(f)

$4250.00

Custom Microwave, Inc.
24 Boston Court
Longmont, CO 80501
www.custommicrowave.com

QUOTATION

Date: 8/10/10

To: Christian D'Aubigny
Jet Propulsion Laboratory

From: Clency Lee-Yow
303-651-0707 ext. 19
303-651-0706 fax
clency@custommicrowave.com

Subject: 550 GHz Corrugated Feed horn for OSIRIS Project

Total Pages (Incl. Cover): **1**

Dear Christian,

Thank you for the opportunity. Here is our quote

1 x Corrugated Horn, Fabrication	@$5,600 each
1 x NRE, Corrugated Horn	@$2,400 each

Assumptions:

Frequency: 510 to 570 GHz
Gain: 24 dBi

Delivery:
12 weeks ARO

Please feel free to contact me if you have any questions.

Sincerely,

Clency Lee-Yow

President

ARIZONA STATE UNIVERSITY

August 2, 2010

Dr. Christian Drouet d'Aubigny
Steward Observatory
933 N. Cherry Ave.
Tucson, AZ 85721

Dear Dr. d'Aubigny,

We are happy to issue a ROM quote for the design of a 550 GHz backward wave ortho-mode transducer, branch line 20 dB directional coupler, and the fabrication of 3 OMTs and 6 directional coupler assemblies.

Tolerances:
+/- 2um for critical waveguide dimensions, surface roughness Ra<100 nm typical. Non-critical dimensions +/- 0.01mm unless otherwise specified. Metrology and measurement report is provided with completed parts, but may not be sufficient for spaceflight applications.

Material:
QC-10 aluminum, gold plated with 0.5um hard gold over 0.5um nickel flash. If material traceability is required, the customer will supply the required material. Gold plating will be provided by commercial contractor. Estimate is based on standard gold plating fees, which may not be sufficient for spaceflight applications.

Cost:

Design Services:	$10,200
NRE:	$3,520
Tools and Materials:	$1,500
Machinist Labor:	$13,000
Machine Run Time:	$2,600
8.5% ASU service charge:	$2,620

Total ROM Cost: **$33,440**

Delivery Time:
Estimated 16 weeks ARO.

Terms:
100% of cost will be invoiced upon shipping, with payment net 30.

Sincerely,

Christopher Groppi
Assistant Professor
ASU School of Earth and Space Exploration

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

ROM quotation

ASIC correlator based spectrometer system

Quotation reference Q100412A
Dr. Anders Emrich
Tel: +46 31 7343401
Email: ae@omnisys.se
Omnisys Instruments AB
Grugvgatan 8
SE-421 30 Vaestra Froelunda, Sweden

Dear Craig,

We are hereby offering a spectrometer system based on the HIFAS (Highly Integrated Full-Custom Autocorrelation Spectrometer) correlator ASIC, with the following specification:

Format:	Integrated ASIC on a custom SOC board
RF I/O:	2 SMA connectors
Main clock:	Synthesized on board
Data I/O:	100 Mbit/s Ethernet
Power:	1.2, 1.8, 3.3V
Configuration:	2 IFs x 1 GHz, 1024 lags default
Integration time:	0.1-10 seconds
Cost:	150 000 Euro; 200 000 USD
	includes one qualified flight unit plus two engineering models
Delivery time:	9 months after order
Payment plan:	50% at order
	50 % 30 days after delivery

Note: The system will be shipped with a spare parts kit, such as a spare power supply and an embedded control computer.

Dr. Anders Emrich

Q U O T A T I O N

MITEQ Inc
100 Davids Drive, Hauppauge, NY 11788-2034
Tel: (631) 436-7400   Fax: (631) 436 7430

MITEQ Quote No. 10081308

Please reference this Quote No. in all correspondence and when ordering.
Fax orders to: (631) 436-7430

TO: Chris Walker
Universtiy of Arizona
AZ
USA

DATE 13/Aug/2010

YOUR REF. ceramic oscillator non quailed space

PHONE: 520-621-8783

E-Mail: cwalker@as.arizona.edu

ITEM NO.	QUANTITY	D E S C R I P T I O N	UNIT PRICE	ESTIMATED DELIVERY
		In response to your request for quotation, MITEQ is pleased to furnish the following ROM price and delivery proposalIn response to your request for quotation, MITEQ is pleased to furnish the following ROM price and delivery proposal		
1	3	Model No.: ARZ-050-11600-ET2-12P	$20,000	each 180 days
	1	Description: 11600 center with 2 MHz tuning	$25,000	NRE

ARZ-050-11600-ET2-12P

Operating Frequency	11600 MHz +/-1 MHz
Frequency Stability	+/- 10 PPM
Step Size	Xtal Controlled (analog) only 2 freq required
Output power	+13 dBm minimum
Output PWR over temperature	+/- 2.5 dB
Harmonics	-40 dBc
Non Harmonic/sub- harmonic	-65 dBc
Phase Noise	TBD
Power Consumption	3 watts @+12 Vdc (can use +11 Vdc to +14 Vdc @+/-5%)
Temperature	
Operating Full Spec	-20 C to +60 C
Operating (unit must stay in lock)	-30C to +80 C
Mechanical Size (not to exceed)	3.0" X 2.5" X 1.0"

Note: Program Management analysis and SDRLs not included

VALIDITY: Firm for 60 days

PREPARED BY: Mike Greco Ext:9195

APPROVED BY:

QUOTATION

MITEQ Inc
100 Davids Drive, Hauppauge, NY 11788-2034
Tel: (631) 436-7400 Fax: (631) 436 7430

MITEQ No. 10081308

DATE 13/Aug/2010

TO: Chris Walker
Universtiy of Arizona

YOUR REF. ceramic oscillator non quailed space

ITEM NO.	QUANTITY	DESCRIPTION	UNIT PRICE	ESTIMATED DELIVERY
		F.O.B. point and points of final inspection are at MITEQ, Inc., Hauppauge, New York. Our standard Payment Terms apply. This quotation and any purchase order resulting from it are subject to all provisions contained in MITEQ's Terms and Conditions of Sale, a copy of which is available for review on MITEQ's website at www.miteq.com/general/support/miteq_terms_condition.pdf. The commodities, technology or software quoted herein are subject to U.S. Export Regulations. If exported, such export must be in compliance with Export Administration Regulations (EAR) or the International Traffic in Arms Regulations (ITAR) as applicable. Diversion contrary to U.S. Law is prohibited. All pricing herein is based on Purchase Orders originating in the United States and shipment to destinations within the United States. Please direct any resultant order(s) to: MITEQ, Inc., ORDER PROCESSING DEPT. By Mail: 100 Davids Drive, Hauppauge, NY 11788-2043 By FAX: 631-436-7430 By E-MAIL: orders@miteq.com Order acknowledgement: It is MITEQ's policy to furnish a written acknowledgement of that order typically within 7 days of receipt. This policy is to assure the customer that the order has been properly received and is being processed. If you do not receive this acknowledgement within 14 days of the issuance of your order, please contact MITEQ immediately. The items proposed herein are not compliant to the requirements of the RoHS (Restriction of Hazardous Substances) Directive, 2002/95/EC of the European Parliament. Should compliance to the RoHS Directive be a requirement of this procurement, please advise and MITEQ will amend our quotation accordingly.		

VALIDITY: Firm for 60 days

PREPARED BY: Mike Greco Ext:9195

APPROVED BY: