Table of Contents

Proposed Research

1. Executive Summary

1. The central purpose of this project is to build a unique spectrometer (NESSI) expressly suited for near-infrared spectro-photometric and timing observations of transiting extrasolar planets to provide chemical and thermal information about these far distant bodies.
2. This type of work is fundamentally difficult from the ground because of time-variable telluric absorption in the Earth's atmosphere, along with instrumental variability. However, we have developed data deconvolution algorithms to extract highly interpretable data using this ground-based approach.
3. NESSI's design will emphasize stability in design along with in-situ calibration of telluric effects.
4. We hope to maximize our chances of success with a threefold strategy; design with a good knowledge of the atmosphere's limitations in mind; design for optomechanical stability; calibration-heavy observing strategy with lots of dedicated telescope time.
5. The broader scientific objectives include characterization of the atmospheres of exoplanets in terms of dominant atmospheric chemistry and thermal features. Such critical information will enable us to create Planetary Profiles for each object extrapolating to other possible features that bear on their properties compared to our own Solar System's set of planets and provides a basis for assessing their potential as homes for life.

This new near-infrared spectrometer, NESSI (New Mexico Tech Extrasolar Spectroscopic Survey Instrument), will be deployed at New Mexico Tech's (NMT) 2.4m Magdalena Ridge Observatory (MRO) and will allow our team to characterize the molecular constituents in the atmospheres of transiting extrasolar planets from the ground. This type of work has only been previously possible from space-based platforms because time-variable telluric features and instrumental variability throughout an observation could not be adequately calibrated out. NESSI's design attempts to address all foreseeable issues contributing to calibration errors seen in other ground-based spectrometers, ultimately delivering spectra of the exoplanet accurate at the 0.01% level relative to its parent star. We have already begun the conceptual design process for this instrument with our collaborators at the Jet Propulsion Lab (JPL), who are a leading research team in extrasolar planetary atmospheres. JPL and NMT are in the process of developing a Memorandum of Understanding between the institutions for this development work. Additionally, the MRO Principle Investigator and Vice President for Research and Economic Development has pledged *one million dollars* of funding set aside for instrumentation development for the facility. The study of extrasolar planets is identified in the NASA Strategic plan and clearly comprises a large portion of the NASA Mission Directorates including support of facilities such as JWST and TPF.

After construction NESSI will become a facility instrument at the newly commissioned MRO 2.4m fast-tracking telescope. As such, it will be available for research by scientists and students throughout the country, but particularly to those in New Mexico. Disseminating results from this state-of-the-art instrument and involving researchers will go beyond the "standard approaches" in two important ways. First, we will further make NESSI explicitly available to undergraduate students and secondary education teachers and students in the state of NM by soliciting and developing a suite of observing projects during the third year of the proposal period, and bringing in the university students and statewide educators from smaller higher educational institutions to conduct the observations and analyze the data. To insure success of this portion of the program two faculty representing those smaller institutions will be awarded small fellowships to participate directly with an NMT faculty member in the selection of student participants and programs to utilize NESSI at the 2.4m. Second, to develop expertise and interest in extrasolar planetary research in NM, we are planning to form a NESSI Tiger Team of researchers, including planetary and brown dwarf atmospheres experts, geologists, microbiologists and astrobiologists. Nationally recognized experts in these fields will also be invited to attend a workshop in order to discuss what we are learning about these new worlds. This team will initially meet in NM at the beginning of the second year of the project to discuss and formalize theories about the data already taken with other facilities like the Hubble and Spitzer telescopes, and to prepare for the new data to be taken by NESSI. Subsequent meetings and proposals to develop scientific strategies/ideas arising from the workshop will be funded via traditional NASA ROSES and NSF proposals.

2. Scientific Goals and Objectives of the NESSI Project

NESSI is a unique concept that builds on recent lessons learned from spectroscopy of molecules in exoplanet atmospheres at other ground and space-based facilities. NESSI will be deployed on the MRO 2.4 m telescope and is expected to devote about 50 nights a year for surveying exoplanets via infrared spectroscopy. Using NESSI we will focus on three important exoplanet topics: composition (determined by detecting molecules), dynamics (measured by detecting variability), and comparative planetology (assessed by observing many planets). NESSI is optimal for executing this demanding, high-impact science program because it is: (1) a purpose-built instrument that will implement a novel calibration scheme, and (2) being engineered for high-stability. As we show in this proposal, NESSI deployed on the MRO 2.4m telescope will have a powerful impact on the field of exoplanet characterization. To our knowledge, NESSI represents an extraordinary and probably unique opportunity for a modest-cost instrument, on a relatively small telescope, to have a decisive scientific role in a highly competitive, cutting-edge topic in astronomy.

2.1 Background: State of a Rapidly Changing Field

Observations with the Spitzer and Hubble Space Telescopes (HST) have revolutionized the field of exoplanet characterization with an extraordinary series of observations. These results include the first detection of infrared emission from an exoplanet (Deming et al. 2005, Charbonneau et al. 2005), the first detection of day and night on an exoplanet (Harrington et al. 2006), the first emission spectrum of an exoplanet (Richardson et al.

2007, Grillmair et al. 2007), the measurement of an orbital light curve (Knutson et al. 2007), the detection of an atmospheric temperature inversion (Knutson et al. 2008), the detection of H_2O in an exoplanet atmosphere (Tinetti 2007), and the measurement of the dayside temperature of a hot-Neptune (Deming et al. 2008). Spitzer observations have profoundly changed the way we understand exoplanets by allowing us to ask detailed questions about the nature of their atmospheres, such as "what is the vertical and longitudinal temperature structure" and "how is heat redistributed from the dayside to the nightside". A limited number of "repeated" exoplanet measurements have now been made with Spitzer. Significantly, differences in the eclipse depth at the ~ 2–3 σ level have been reported (Fortney et al. 2007, Charbonneau et al. 2008). However, the most compelling evidence for variability is from recent Spitzer Infrared Spectrometer (IRS) measurements (Grillmair et al. 2008); these data show an unambiguous, significant change in the dayside emission spectrum (see Fig. 1).

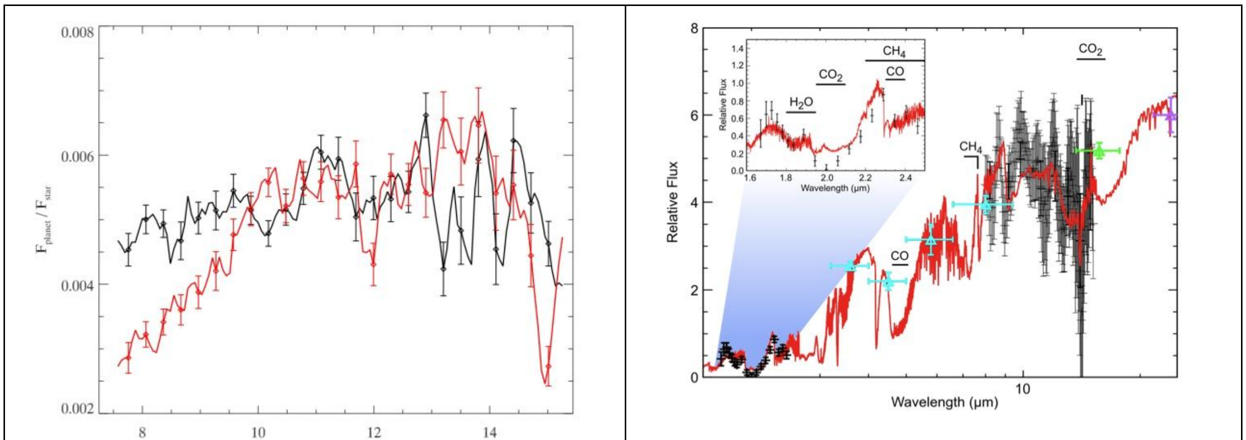

Fig. 1:**left:** Significant spectral variability in HD 189733b spectra taken 4.4 days apart by Spitzer IRS; significant variability based on these and previous observations was reported by Grillmair et al. (2008). The figure shown here is based on the data reduction method used by our team (Swain et al. 2008), and our results support the original Grillmair et al. (2008) findings. **Right:** A composite spectrum of the dayside emission from HD 189733b. This broad spectral coverage is needed to break the temperature-composition ambiguity in the interpretation of the spectra. However, the presence of variability poses serious questions for attempts to make a spectrum with broad wavelength coverage from non-contemporaneous data. This collective result contains data from several groups (Charbonneau et al. 2008, Knutson et al. 2008, Deming et al. 2006, Grillmair et al. 2007, Swain et al. 2009).

Understanding the origin and degree of variability is one of the most urgent topics in exoplanet characterization today. This is best illustrated by the challenge of modeling observed exoplanet emission where there is a natural ambiguity between the atmospheric temperature structure and composition. For an emission spectrum, the shape of the temperature profile is crucial; a semi-isothermal temperature profile hides the presence of molecules, a decreasing T-profile shows absorption features, while an increasing T-profile shows emission features. The only observational method to effectively constrain the temperature profile is to measure the emission spectrum over a wide range of wavelengths. Different wavelengths probe the atmosphere at different levels, and thus broad spectral coverage provides the only way of resolving the temperature-composition ambiguity. Today, it is standard practice to assemble a "composite spectrum" using all available spectral and photometry data (see Fig. 1 for an example); however, it is impossible to obtain the broad range of spectral measurements simultaneously, and thus significant variability raises questions about the validity of a composite spectrum.

Exoplanet molecular spectroscopy is now possible with sufficient precision to identify the presence and quantify the abundance of the primary oxygen and carbon-bearing molecules and constrain the dayside temperature-pressure profile. Molecular spectroscopy of the transiting hot-Jupiter HD 189733b has been demonstrated with the detection of CH_4 and H_2O (Swain, Vasisht, & Tinetti 2008b) at the terminator during primary eclipse. Recently dayside CO_2, H_2O, and CO were found via secondary eclipse spectroscopy of HD 189733b using HST (Swain et al. 2009). The ability to determine the composition and thermal structure, and to reveal composition changes between the dayside and terminator regions, makes exoplanet molecular spectroscopy one of the most powerful methods available for characterizing exoplanet atmospheres. However, before one can undertake a detailed, multi-epoch spectroscopy investigation, the question of variability must be addressed decisively; answering this question is a key part of the NESSI science program. *It is absolutely crucial that we understand the extent to which the interpretation of spectroscopic results could be affected by atmospheric variability.*

Recently Grillmair et al. (2008) analyzed new Spitzer IRS observations of HD 189733b and reported significant variations in the dayside emission spectrum; we have reduced these new observations, and we confirm that they show evidence for significant variability (see Fig. 1). The IRS spectra show that variation is strongest at the shortest wavelengths in the IRS SL1 bandpass. Rauscher et al. (2007, 2008) studied dynamical models for hot-Jupiters and found emission variability arising from the precessing of cold circumpolar vortices. They found that the emission spectrum variations caused by this effect were a factor of 2 stronger in the Spitzer IRAC 1 channel (3.6 μm) than in the IRAC 4 channel (8 μm). This prediction is especially interesting since the IRS spectra show the variation to be increasing towards shorter wavelengths (see Figure 2). Clearly, significant variations in the emission spectrum of HD 189733b exist. Our proposal takes the "next step" by determining if there is a correlation between variation in the emitted light (secondary eclipse) and the absorbed light (primary eclipse); the beauty of this measurement is the result is important regardless of the answer.

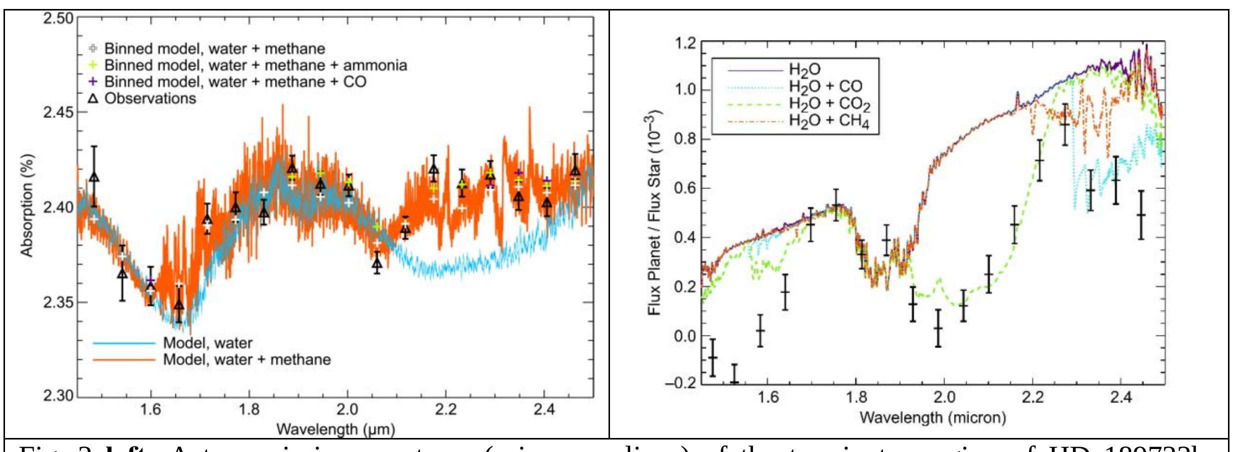

Fig. 2 **left:** A transmission spectrum (primary eclipse) of the terminator region of HD 189733b, showing the presence of water and methane (Swain et al. 2008). **right:** An emission spectrum (secondary eclipse) of the dayside region of HD 189733b, showing the presence of water, carbon dioxide, and carbon monoxide (Swain et al. 2009). Taken together, these spectra probe how the atmosphere changes from the hotter dayside to the cooler terminator regions. These results show the maturity of exoplanet molecular spectroscopy. There are observations for at least four additional exoplanets in the Hubble archive where we expect to detect molecules via infrared spectroscopy.

Because temporal variability in a hot-Jupiter atmosphere may arise either from changes in temperature or changes in composition (or both), characterizing variability requires long-term, precision monitoring of *both the primary and secondary eclipse depths*. Primary and secondary eclipses probe composition and temperature differently and thus both are needed understand the origins of variability.

- **Primary eclipse:** The primary eclipse depth preferentially **probes composition**. Because the primary eclipse is a transmission measurement, where the light from the parent star is viewed through the planet's atmosphere, the primary eclipse depth is predominantly a probe of composition at the terminator.
- **Secondary eclipse:** The secondary eclipse depth primarily **probes temperature (**although composition can affect the measurement). Because the secondary eclipse depth is a measure of emergent thermal emission, it is a good indicator of temperature at the τ=1 layer in the planet's atmosphere on the dayside.

In order to search for temporal variability and/or long-term changes in exoplanet atmospheres, NESSI will make repeated observations of both primary and secondary eclipse events.

Only repeated measurements of the same object can clearly determine the difference between instrument uncertainty and variability in the objects. NESSI is expected to devote about 50 nights a year for at least 3 years to exoplanet spectroscopy at MRO; NESSI results will have value to all other exoplanet programs undertaken, including the Spitzer warm mission and all spectroscopic observations of exoplanets made with HST.

2.2 NESSI Science

The NESSI science program is centered around answering three key questions about exoplanet atmospheres. Understanding exoplanet atmospheres is a fundamental aspect of exoplanet characterization, and it is an essential step on the long-term goal of searching for signs of life on exoplanets in the habitable zone. These questions are:

1. **What is the composition of exoplanet atmospheres?** The question of composition is intimately connected with determining the vertical temperature profiles for temperature and the most abundant molecules. The most successful approach to determining composition is the use of forward models to reproduce the observed spectrum. Using the approach, the dayside temperature profile and abundances of molecules with absorption features (in the instrument passband) can be approximately determined. Once the temperature profile has been determined, thermal chemical models can be calculated and compared with the retrieved molecular profiles based on the observed spectrum.
2. **What is the role of dynamics in exoplanet atmospheres?** Dynamics, the origin of variability, in an exoplanet atmosphere has already been discussed in the

previous section. Repeated observations will establish the role of radiation forcing for atmospheric dynamics and the redistribution of heat from the dayside to the nightside.

3. **How different are exoplanet atmospheres?** The variety of exoplanet atmospheres is, at present, almost completely unknown. What is certain is that many exoplanets have no analog in our own solar system. While radial velocity and transit photometry can characterize exoplanet mass, diameter, and density, only molecular-abundance-grade spectroscopic observations can determine the composition, temperature, and chemical environments of exoplanet atmospheres.

When using the "combined-light" method of characterization, in which the planetary emission is determined by taking the difference of measurements taken at different times, sensitivity scales as the *ratio of telescope diameters* for photon-noise limited measurements. This has the interesting consequence of making small telescopes scientifically competitive with large telescopes. This is because the signal-to-noise (SNR) ratio for the combined light observable is proportional to the square root of the number of photons. Thus, NESSI, on the MRO 2.4 m telescope will have large discovery space.

3. *Expected Significance – The New Approach*

Based on comparison of IRTF SPeX and other ground-based spectra with space-based ones (Swain et al. 2008, IRTF Observing Proposal), we have determined the major improvements required to address platform-based differences and obtain stable, calibratible and highly-reliable *ground-based spectra* for this variability campaign on exoplanets. These improvements address two key areas: instrumental stability and ability to simultaneously calibrate out the telluric contaminants. None of the ideas presented herein for our conceptual design of NESSI are new or unproven in the astronomical community, they are simply grounded in solid engineering and the principle of a "purpose-driven" design. They will, however, allow us to attain 0.01% relative (to the parent star) calibration on the exoplanet spectrum, which is currently not feasible with other ground-based facilities for the reasons outlined in the design discussed below.

3.1 Basic Instrument Design and Innovative Philosophy

The two major philosophies of NESSI's hardware design that are unique in approach to near-infrared spectroscopy are: unprecedented instrument stability and in-situ atmospheric characterization. Adhering strictly to these philosophies will allow NESSI to achieve more than a factor of 10 improvement in calibration fidelity and relative sensitivity over other ground-based spectrometers. Stability is achieved by: a) control of the gravity vector changes on the instrument, b) minimizing moving parts and, c) high-fidelity characterization of the focal plane array. In-situ atmospheric characterization is achieved by: a) simultaneous observations of another star in the field during transit observations and, b) never chopping or nodding during the transit observation. Our design approach, to our knowledge, is unique in the world of ground-based instrumentation and goes against conventional approaches in many respects.

In detail, the design includes the following major components: a field de-rotator, an on-axis optical arm with a guide camera and R = 1000 spectrograph, and a NIR arm in multi-object spectrograph configuration, with cold slit masks, filters and dispersing optics, and state-of-the-art infrared and optical detectors. Employing these elements, NESSI will be able to select a field star for instrumental calibration within a 15 arcminute field of view, while guiding in a closed-loop fashion on the exoplanet host star in the optical, and obtaining spectra of the host star plus exoplanet in the infrared simultaneously with the calibration star. This is all accomplished without ever "looking away" during the transit observation. There are multiple benefits of observing in this way:

- Deploying at the telescope's Nasmyth position, NESSI will not experience a differential gravitational effect during the observations and so errors due to issues like flexure and differential light coupling onto dispersing optics will be eliminated.
- Using a large field of view will insure the ability for NESSI to select a suitable calibration target for the removal of telluric contamination in real time.
- Guiding on the exoplanet host star with an optical guide camera operating on-axis from a dichroic in closed-loop to the telescope drive system will minimize drift errors to less than 0.1 arcseconds (well-below the seeing limit). This will prevent the star from "walking around" on the spectrometer slit during the observation, which would result in flux-coupling errors above acceptable levels.
- Obtaining simultaneous spectra of the exoplanet system and the calibration target through a paired set of beam trains will allow removal of both the wet and dry components of the telluric spectroscopic features and attain the 0.01% calibration levels required to make this experiment a success.

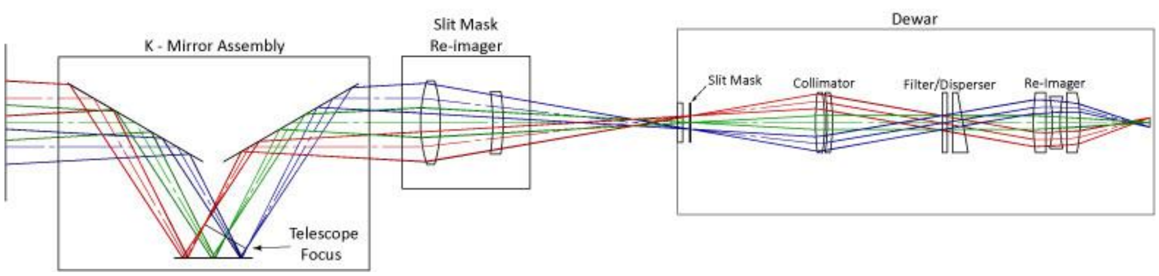

Figure 3: This is a conceptual design of the infrared arm of the NESSI instrument. The actual scale will be approximately 1 meter cubed in size. We expect to have a Zemax-type conceptual design to include in the final proposal to NASA.

The conceptual design for NESSI is well-underway owing to a combined instrumentation design experience of nearly 50 years among four major members of our team: Creech-Eakman, Jurgenson, Swain and Vasisht (c.f. Creech-Eakman et al. (1996) & (2003); Jurgenson & Stencel (2004) & Jurgenson et al. (2008); Herter et al. (1997) & Swain et al. (2002); Vasisht et al. (1998), (2006) & (2008)). A walk through the NESSI beam-train (Figure 3) shows the following elements. The de-rotator function in NESSI will be performed by a large-format K-mirror to enable access to a 15 arcminute field of view (FOV) from the MRO 2.4m's F8 optical system. After this, an optical/infrared dichroic will send the visible light from the exoplanet plus host star (on-axis) to a small-format CCD to be reimaged with high spatial sampling and R ~ 1000 spectroscopy in order to perform closed-loop tracking with the telescope and characterize eclipse depths. The infrared light is re-imaged onto a cooled field star selector, either implemented as a dual-star module (Wallace et al. (1998)) used in interferometric astrometric applications, or as a slit-mask used in multi-object spectrographs. Here an appropriate off-axis calibration star within the FOV can be selected to allow removal of the telluric contamination during the observations, while the exoplanet system light passes through the optical axis of the observing field. At this point both the exoplanet system light and the calibrator light will be recollimated and travel down a pair of identical beam trains (one is shown above) where filtering, dispersion (via grisms over a single passband at R~1000 or a direct-view prism over all of JHK at R~250) and reimaging onto the cryogenically-cooled infrared focal plane detector with Nyquist sampling of the spectrum will occur. This design will allow us to remove common-mode errors and minimize the non-common mode ones during the observations.

Finally, data will be reduced using a new pipelines closely related to ones already developed at JPL for exoplanet research. These deconvolution pipelines are being used for both space-based and ground-based data to remove various types of common and non-common mode errors related to issues such as telescope pointing, flux coupling onto the slit and array, and array based errors due to calibration of the electronics in a changing environment. We will be developing a version of these algorithms specifically for implementation with NESSI as part of this EPSCoR work. ***All the hardware components for NESSI are being funded by NMT's Vice-President for Research, and therefore NESSI represents an absolutely unique opportunity for NASA and NM to leverage these funds to build a state-of-the-art instrument with a novel approach for high-fidelity spectral characterization, available for a broad astrophysical community***.

3.2 Building the Community of Researchers in New Mexico

Exoplanet characterization is a new and rapidly evolving field in astronomy that has momentous consequences for planetary science, astrobiology, the future and fate of Earth and its lifeforms (including us), and the search for intelligence in the galaxy. In order to bring New Mexico more fully into this far-reaching community of researchers, basic infrastructure and knowledge in the state must be established and convened. We will develop two innovative approaches to build the scientific community in New Mexico. First, we will establish what we are calling the NESSI Tiger Team (NT^2), a group of researchers both within and external to NM. As can be seen from the amazing variety of exoplanets discovered to date, these bodies seem to be vastly different from those that we currently enjoy in our own Solar System. To do the interpretation of likely planetary and life-bearing properties of exoplanets that we characterize will require a sustained, cross-disciplinary effort by a rapid-response team of individuals who will take the data and interpretations and attempt to create planetary concepts and models that fit the thermal, compositional, and density data for the objects. It is a tall order to go from chemical and other information at these great distances to a conceptual picture of an actual place with a sky, landscape, possibly oceans or lakes, perhaps continents or islands, or a planet-wide ice crust, or possibly a gas giant very unlike any of ours. The "open season" on new types of planets has begun and the game is afoot. Atmospheric dynamicists, atmospheric chemists, astrobiologists, evolutionary biologists, planetary geologists, geochemists, geophysicists, physical oceanographers, glaciologists, astronomers, astrophysicists, artists and writers will all make unique contributions to the effort. Obviously, within the constraints of the EPSCoR project budget, we cannot bring that diversity of individuals on for major roles, however, we can act as a catalyst to bring together such a suite of expertise that will translate into further collaborations and activities. To these ends, we plan a three-pronged approach: 1) assembly of NT^2 who will be "on call" to swing into action as data comes in to make a first cut at meaningful interpretation, 2) a focused and intensive workshop to be held early in Year 2 of the project prior to NESSI's anticipated First Light to bring together a wider variety of relevant participants to develop exoplanet interpretation strategies, and 3) to produce publicly available Planetary Profiles as a means of rapidly communicating our interpretations to the broader public including educators.

NT^2 will be coordinated by Co-I Boston and Program Manager Majkowski. As we currently envision the NT^2 process, it will involve interaction between the astrophysicists collecting and analyzing the NESSI data and then making that immediately available to the team for consideration. NT^2 will then swing into action to develop a first cut at a Planetary Profile of the object. These Planetary Profiles will be made publicly available on the project website as part of our ongoing public outreach efforts and will comprise part of our formal and informal education plans. The first workshop will be held in New Mexico, possibly at the Santa Fe Institute, an institution renowned for its leadership in interdisciplinary and cutting-edge intellectual activities. We envision an attendance of 35 to 50 scientists selected for broad scientific coverage of the salient issues. The first workshop has been budgeted in the EPSCoR proposal, while a second workshop will be sponsored by NMT as matching funds during Year 3. Workshop 2, about 1.5 years after NESSI's first light, will be required to interpret incoming data and bring in fresh ideas and interpretations, disseminating further information into the community.

For the second major statewide research-building component of our proposal, we have included funding to establish a NESSI Observing Fellowship for students and two faculty researchers from non-doctoral universities in NM. In particular, we will concentrate on finding these faculty from within the Eastern, Western, CNM, Santa Fe Community College, and Highlands (etc.) communities, which serve primarily underrepresented (e.g. Hispanics, Native Peoples, and women) and undergraduate populations in their communities. The two faculty members will be strategically chosen for their interest and ability to engage students in their home institutions, and these faculty will be brought to NMT during the summer of 2011 for one month (paid by this EPSCoR project). During this month, they will work with an NMT faculty member to identify 3-5 science areas in which to conduct science investigations and will issue a call for proposals before the end of Year 2. They will also learn how to operate NESSI and reduce the spectrometer data. These three faculty members and the science-PI will act as a time allocation committee (TAC) to adjudicate the student proposals that come in and "award" 10 nights of observing time from the proposal. These students and their mentors can then come to the MRO 2.4m and participate in taking their data during Year 3. The theory behind identifying key science areas is to be able to pool and archive all the data to produce a common body of research which the entire Observing Fellowship group of awardees can use. This archive of data and a suite of software data reduction tools will be maintained at the observatory website for the student research groups to download. We plan that new discoveries in these topical areas will lead to student conference posters (e.g. at the New Mexico Symposium held each fall in Socorro) or refereed journal articles for the science teams, and publication of these articles will be led by the three faculty participants and student mentors.

3.3 Work Plan and Preparation for Follow-on Research

During Year 1 the investigators discussed in Section 10 below will undertake the following activities: A) Identify and hire the postdoctoral researcher and students to participate in the instrument and software design and initial instrument build. B) Conduct a final design review with instrumentation experts at JPL and within NM, and then begin purchasing major components for NESSI. C) Assemble the NESSI Tiger Team and begin preparing for Workshop 1.

During Year 2 the investigators and students on the NESSI team will undertake the following activities: A) Complete the build and assembly of NESSI, characterize it in the lab, and commission on the MRO 2.4m telescopes. B) Hold the first NESSI Tiger Team Workshop. C) Identify faculty members from the community and issue call for proposals to students, adjudicated by the TAC. D) Begin taking exoplanet data and publicizing our results and getting feedback from the NESSI Tiger Team.

During Year 3 we will: A) Continue characterizing the exoplanet atmospheres and publicizing/publishing the results. B) Execute the science observing fellowships and host several students and their mentors to learn to use NESSI. C) Hold the second NESSI Tiger Team Workshop.

Data taken with NESSI will place hard constraints on existing models for extrasolar planetary atmospheres. It will also require follow-on work at other wavelengths and using additionally techniques, such as optical eclipse depths, and higher spectral resolution work evaluating particular spectral lines. Optical interferometric characterization of the parent stars in these systems, which can be done at the MRO Interferometer, will allow us to unambiguously obtain the planetary diameters, which will lead to further characterization of planetary compositions. We anticipate proposing for additional funding to support science work on the MRO 2.4m via other NASA and NSF science proposals. Additionally, investigations by student researchers in the state will potentially lead to new science areas being developed in NM, which will require additional external funding to support. Timelines and milestones for all major activities are captured in Figure 4 below.

4. Impact of the Proposed Work to Exoplanetary Research

- Development of detailed molecular compositions and vertical temperature profiles in the exoplanetary atmospheres will allow us to begin to understand a sample of planetary atmospheres outside our own solar system. This will give us new models on which to base our theory of planetary-system formation.
- Characterizing the interactions of the stellar flux as a radiation force on the atmospheric dynamics in these planets, especially for systems very much unlike those in our solar system, will help us develop deeper understanding of the interactions between planets and their parent stars in shaping the evolution of a planetary atmosphere.
- Understanding of the composition, temperature and chemical environment of exoplanet atmospheres, we can begin to make inroads into identifying potential disequilibrium processes and thus determine factors which expand our understanding of planetary habitable zones.
- The ability to do planetary population statistics based on atmospheric chemistry will enable comparative planetology to move into an entirely new phase and provide significant advances in understanding planetary evolution over the lifetimes of solar systems
- Planetary characterizations will help to pre-select objects of interest for NASA missions, e.g. Kepler and future proposed projects like TPF (Terrestrial Planet-Finder) or SIM PlanetQuest missions.
- Our work will complement ongoing exoplanet detection with the Large Binocular Telescope Interferometer in our neighboring state of Arizona.
- Particularly interesting objects with life-bearing potential may also feed into ongoing SETI detection programs, e.g. The Allen Telescope Array

5. Existing Research

New Mexico has a long tradition of innovation in astronomy and related fields. Clear skies and mild weather have made NM home to the Very Large Array, Magdalena Ridge Observatory, Apache Point and Sunspot. We also have a significant community of planetary scientists at UNM, NMSU, NMT, the Albuquerque Museum of Natural History and Science, and LANL (Center for Space Science and Exploration (CSSE). New Mexico volcanic geology, caves, and other geological features have provided a number of acknowledged planetary analog sites around the state. In addition, astrobiological expertise resides at NMT, UNM, and NMSU that enriches the biological context of the exoplanet work. New Mexico is also home to The Santa Fe Institute which focuses a significant amount of its energy on the emergence, organization and dynamics of living systems and the properties of self organizing systems, all of which pertains to the issue of origins of life under different planetary contexts than our own. In addition, NMT and UNM have several astrobiologists on their faculties involved in research on extremophile habitats that range from hot sulfuric acid habitats, to the deepest mines on the planet in South Africa. This array of expertise can be channeled to provide a comprehensive community spanning the disciplines of astronomy to exotic biogeochemistry. Some of the researchers currently working in these areas in NM whom we expect to engage in these activities include: (NMT) Kieft, Morales-Jubieras, Ryan; (UNM) Brearly, Northup, Newsom, Papike; (NMSU) Beebe, Chanover, Harrison, Murphy; (LANL) Barriman, Saumon; (NM Museum of Natural History) Krumpler.

6. Relevance to NASA and Jurisdiction

NASA's stated mission is to "pioneer the future in space exploration, scientific discovery, and aeronautics research." The research proposed here is directly applicable to a number of special focus areas within the NASA Science Mission Directorate (SMD). These include: 1) Astrophysics Division, study of planets around other stars, and the search for potentially life-bearing planets in the galaxy; 2) Planetary Science Division, the inner rocky terrestrial planets that may resemble Earth and her sister planets, and the outer solar system as a model for the large exoplanet populations discovered to date, and astrobiology and the potential for life-bearing planets around other suns. We are poised for NM to make significant contributions in these arenas. NASA's HST has detected, for the first time ever, the presence of oxygen and carbon in the atmosphere of a planet outside our solar system. Kepler has just been launched with its task of detecting Earth-class planets. This arena is of great interest within NASA and society as a whole. Knowledge of exoplanets will not only inform our understanding of planetary science in general, but provide a backdrop for a more profound understanding of our own rocky terrestrial home world. NM researchers can play a major role in this cutting edge arena.

NASA Big Questions of Relevance to NESSI Interpretive Science

Astrophysics	Planetary	Earth Science	Heliophysics
1) What are the origin, evolution and fate of the Universe?	1) *How did the sun's family of planets & minor bodies originate?*	*1) How will the Earth system change in the future?*	1) *How and why does the Sun vary and what are the consequences?*
2) How do planets, stars, galaxies and cosmic structure come into being?	*2) How did the solar system evolve to its current diverse state?*	*2) What are the consequences of change in the Earth system for human civilization?*	*2) How does solar variability affect ….. the habitability of planets?*
3) Is there life elsewhere?	*3) How did life begin & evolve on Earth, & has it evolved elsewhere in the Solar System?*		
	4) What are the characteristics of the Solar System that lead to the origins of life?		
	5) Is there life elsewhere, & how to we prepare to look for it?		

Table 1: The unique nature of exoplanet studies and the highly interdisciplinary approach that we propose combine to touch on a number of NASA Big Questions within all four of the Divisions of the Science Mission Directorate (http://nasascience.nasa.gov/big-questions). Characterizing other solar systems and the way that exoplanets respond to their solar environment can provide a template for our interpretation of our own Solar System and our own rocky terrestrial home planet. Understanding of other small rocky terrestrial planets will inform how we interpret the science and Big Questions about Earth.

Relevance to New Mexico's goals and research, structure and technology priorities:

Dr. Thomas Bowles, Science Advisor to the Governor of New Mexico, Gov. Richardson has said, "New Mexico is blessed with remarkable breadth and depth in science, engineering, and technology. Those strengths provide a strong foundation that make New Mexico one of the foremost centers of innovative research and development in the world. The State is partnering with our two national laboratories, our research universities, and other innovation-driven institutions and businesses in creating new thrusts in driving technology-based economic development. We are also developing new ways in which we can more effectively use our resources to strengthen our efforts in Science, Technology, Engineering, and Math education. "

We believe that this tradition can extend not only to the human exploration and astronomical sciences that we currently are engaging in, but the unique blending of astronomy, atmospheric physics and chemistry, and astrobiological expertise within the state. NM is gaining a reputation as being "a place for space" from our strong NM Space Grant Consortium efforts to the plans to build our new Spaceport, we are building our statewide competence and involvement in the space arena. Cutting edge exoplanet characterization is a natural outgrowth of this burgeoning capability that will round out our space-related activities into a new and exciting arena.

7. Partnerships/Sustainability

The proposed research is a collaboration between New Mexico Tech and researchers at several other universities and national labs in the state, leveraging in particular off a newly commissioned facility, the MRO 2.4m telescope. During the period of performance the team will collaborate with a large number of cross-disciplinary researchers within and outside of NM. Additionally we will be engaging and training students to use NESSI from smaller, primarily undergraduate institutions in NM who traditionally have no access to research-grade astronomical facilities. There are currently regular course offerings at NMT (e.g. Astrobiology, Geobiology, Planetary Atmospheres), REU opportunities and courses taught through the MST program (e.g. Space Science: Hazardous Asteroids, Optical Astronomy for Teachers) where this information can be easily integrated into an already existing curriculum. All these efforts will significantly raise the profile and engagement of NM researchers and students in the fields relevant to exoplanetary/astronomical science.

Our plan and schedule for achieving national research competitiveness: National research competitiveness will require publication of research results in high-profile peer-reviewed journals, production of students and postdocs who can compete for top research and academic positions nationwide, and the ability to acquire competitive federal funding (e.g. NASA, NSF). The following plans will move us toward national competitiveness:

- Development of a nationally recognized science program and exoplanet Tiger Team, associated with one or several NASA centers, will bring attention, researchers and additional scientific research opportunities to NM.
- Increasing the instrumentation capabilities of MRO and exposure of NM students to astronomical research via the establishment of fellowships.
- Offering courses through the Masters in Science Teaching and Distance Education programs, which will increase scientific understanding and education to a broader community in our state.

8. NASA Interactions

While this proposal is most closely aligned with NASA's Jet Propulsion Laboratory because of the collaboration being established here, the resultant data collected and new insights gained with NESSI will additionally impact research being conducted at Ames Research Center's Astrobiology Institute, Goddard Space Flight Center and potentially the Kennedy Space Center.

The names and titles of NASA researchers with whom the investigators will collaborate most closely for this proposal:

Dr. Mark Swain, Exoplanet Scientist, Jet Propulsion Laboratory, Pasadena, CA, 818-455-2396. Expert in infrared instrumentation and exoplanet atmospheres.
Dr. Gautam Vasisht, Research Scientist, Jet Propulsion Laboratory, Pasadena, CA. Expert in infrared instrumentation and exoplanet atmospheres.
Dr. Peter Deroo, Research Scientist, Jet Propulsion Laboratory, Pasadena, CA. Expert in data reduction from space-based platforms.
Dr. Pin Chen, Research Scientist, Jet Propulsion Laboratory, Pasadena, CA. Expert in data reduction from space and ground-based platforms.

9. Diversity and Outreach

NMT is a Hispanic Serving Institution with a 25% minority student body. Further, female students at NMT comprise 34% of the population. The two lead PIs at NMT on this proposal are women and both have strong track records of involving female and minority students in their research. The Physics department employs the greatest number of female faculty members of any STEM department at NMT. Physics has the highest departmental total of PhD candidates and supports the largest number of female PhD students.

The Physics department is committed to increasing under-represented minority participation and will leverage existing programs at NMT (LS-AMP, summer REUs, active SACNAS, AISES and SHPE chapters) to increase minority student enrollment. Additionally the department plans to seek assistance from the American Physical Society through their Climate for Minorities Site Visit Program, which is designed to help organizations improve the climate that minorities in physics sometimes experience. The department will use the program's assessment to make changes that will increase recruitment and retention of minority faculty and students.

10. Management and Evaluation

10.1 Personnel

- PI – Patricia Hynes, Director of the NM NASA EPSCoR Program and Director of the NM Space Grant Consortium. She will be responsible for the overall administration of the effort as well as program

- Science-PI – Michelle Creech-Eakman, Associate Professor of Physics, MRO Interferometer Project Scientist. She will be responsible for directing the design, procurement, build and assembly of NESSI and coordinating activities at NMT.
- Co-I – Penelope Boston, Associate Professor of Earth and Environmental Sciences, Co-Director, Caves and Karsts Project. She will be responsible for assembling the NT^2 activities/workshops and coordinating education and outreach components.
- Co-I – Colby Jurgenson, Instrument Scientist, MRO Interferometer. He will be responsible for initial NESSI design and assisting postdoc and students in testing.
- Research Assistants and other Personnel: Lisa Majkowski – She will program manage the budget and matching components at NMT and assist in the NT^2 workshops.
- Yet-to-be-identified: One faculty member to assist in Observing Fellowship Activities, one postdoc to assist in all aspects of NESSI instrumentation, two graduate students (one to be paid in matching funds) to assist in design, assembly, software and NESSI implementation/commissioning, two or more undergraduate students to assist in same activities according to skills and interests.

All students supported by this funding will be US citizens in an effort to build the technical workforce prepared to work for NASA and its contractors. NM NASA EPSCoR is committed to supporting diversity and will encourage females, minorities and persons with disabilities to actively participate in the program.

10.2 Program Management and Timeline

The generalized timeline for the activities is discussed above and is shown in the Gantt chart below (Fig. 4). Technical aspects of the proposed research will be performed by the following co-I's and investigators with participation as follows: (institutional leads in each area underlined)

- NESSI design, reviews and quality control: Creech-Eakman, <u>Jurgenson</u>, Swain, <u>Vasisht</u>
- NESSI procurement and assembly: <u>Creech-Eakman</u>, Jurgenson, <u>new postdoc</u> and graduate students
- NESSI testing and commissioning: Creech-Eakman, <u>Jurgenson</u>, Vasisht<u>, new postdoc</u> and graduate students
- NESSI software and calibration: <u>Creech-Eakman, Deroo</u>, Swain, Chin and new graduate student
- NESSI Tiger Team workshops: <u>Boston</u>, Majkowski, <u>Swain</u>
- NESSI Observing fellowship: Creech-Eakman, <u>NMT faculty member</u>, two other faculty

NM EPSCoR will be managed through the NM EPSCoR/Space Grant lead office at NMSU. Dr. Patricia C. Hynes, Director of New Mexico Space Grant, will also serve as the Director of NASA EPSCoR and will be responsible for the management of the NASA EPSCoR program, including interactions among collaborating institutions, NASA Field

Centers, and space and aerospace related industry. The NM EPSCoR Director will work with the State of New Mexico EPSCoR Committee to facilitate interactions and coordination between these organizations. The NM EPSCoR Director will work closely with the Technical Advisory Committee (TAC) to align our research focus to meet NASA and New Mexico research priorities. The EPSCoR office will be responsible for contract requirements including budgeting and reporting requirements. NASA EPSCoR office will also organize annual meetings for NM faculty to facilitate research collaborations among colleges and universities.

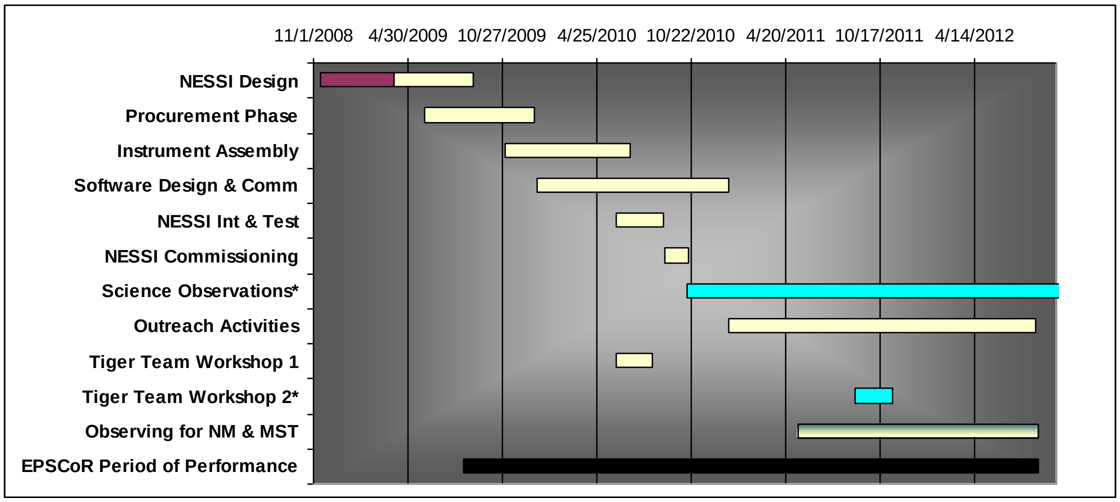

Figure 4: In the Gantt chart above, the EPSCoR period of performance is indicated by the heavy black line along the bottom of the chart – note NESSI activities have already begun. The main EPSCoR-related activities appear in pale yellow. Activities in light blue will be funded via other avenues or matching, but are included for clarity. The bi-colored activity is partially funded by this proposal and is expected to be used as a seed for further education and outreach.

10.3 Program Evaluation

Evaluation is a key consideration not only in the demonstration of effectiveness of the program, but also in continuous improvement and program refinement. New Mexico EPSCoR Director Dr. Patricia Hynes has conducted extensive activities in assessment. She will design and implement the evaluation plan. Evaluation data will be collected from researchers each year as part of their report to NASA EPSCoR. The evaluation will allow us to monitor our progress and document benchmarks toward achievement of program goals and objectives.

The evaluation will be both formative and summative. Formative evaluation will include an annual assessment of the proposed research metrics. Formative evaluation results will be brought to the NASA EPSCoR Technical Advisory Committee (TAC) for feedback and strategies to increase program success. Annually, we will be looking for faculty and research areas which show promise for additional funding. Summative evaluation will include a comparison of pre-award and post-award data analysis.

Research faculty will involve undergraduate and graduate students in their research. This will not only contribute to workforce development in NASA research areas but encourage student retention. Students receiving $5,000 or more in support will be tracked through first employment. We will track students through the university registration systems, confirming students are still enrolled and succeeding in their STEM degrees.

10.4 Program Progress

The progress during the development of this program will be tracked using PLONE open source software for management of activities, document sharing and preparing and tracking reviews. Spend-rate and activities tracked against this spend will be traced through NMT's budgeting software using work-effort charting. The progress and potential towards achieving self-sufficiency beyond the award period of the research capabilities under this grant will be realized via the success of our students, researchers and the workshop and outreach activities.

10.5 Continuity

Through their participation in this research, students are prepared for employment in disciplines needed to achieve NASA's mission and strategic goals. We will encourage participation from NM students enrolled in other NASA sponsored programs including NMSGC students, and USRP, GSRP or ESMD programs. Through this research and internships and fellowships students become participants in NASA's Mission Directorates. The EPSCoR funding provides researchers with the opportunity to advance research in the state of NM. This funding also supports faculty and student publications, research and attendance at conferences, increasing their potential for non-EPSCoR funding and bringing the team and the state to a level of national competitiveness.

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Harrington et al. 2006, Science, 314, 623
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Swain et al. 2002, AAS, 2011, 2101
Swain, et al. 2008a, ApJ, 674, 482
Swain, Vasisht, & Tinetti 2008b, Nature, 452, 329
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Biographical Sketch – Michelle J. Creech-Eakman

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a) Professional Preparation
i) Undergraduate Institution: Majors in Physics and Applied Mathematics, Minors in Latin and Music Theory, B.S , cum laude, Univ of North Dakota, Grand Forks, ND, 1990.
ii) Graduate Institutions: M. S. in Physics, Univ. of North Dakota, Grand Forks, ND, 1992. "Stellar Pulsation Theory of Cepheid Variable Stars";
Ph.D. in Physics, concentration in Astrophysics, Univ. of Denver, Denver, CO, 1997. "Silicate Variation in Long Period Variable Stars"
iii) Postdoctoral Institutions:
1) Research Scholar, California Institute of Technology, Pasadena, CA, 1997-1999
2) Research Scholar, Jet Propulsion Lab, California Institute of Technology, Pasadena, CA, 1999-2002

b) Appointments:
1) 2003-present: Assistant Professor, Department of Physics, New Mexico Institute of Mining and Technology, Socorro, NM
2) 2002-2003: Research Scientist, Keck Interferometer Project, Jet Propulsion Lab, California Institute of Technology, Pasadena, CA
3) 2002: Visiting Professor, Astronomy Department, one course: "Astrobiology", Univ. of California, Los Angeles, CA
4) 1992-1993: Lecturer, Department of Physics, Rainy River Community College, International Falls, MN

c) Publications
i) Publications closely related to proposed activities:
1) Creech-Eakman, M. J., Bakker, E. J., Buscher, D. F., Coleman, T. A., Haniff, C. A., Jurgenson, C. A., Klinglesmith, D. A., Parameswariah, C. B., Romero, V. D., Shtromberg, A. V. and Young, J. S., "Magdalena Ridge Observatory Interferometer: status update", ed. by J. Monnier, M. Scholler & W. Danchi, Proc of SPIE, vol 6268, 116, 2006.
2) Baron, F., Buscher, D. F., Coyne, J., Creech-Eakman, M. J., Haniff, C. A., Jurenson, C. A. and Young, J. S., "Beam Combiner Studies for the Magdalena Ridge Observatory Interferometer", ed. by J. Monnier, M. Scholler & W. Danchi, Proc of SPIE, vol 6268, 56, 2006.
3) Serabyn, E., Appleby, Bell, J., Booth, A., Chin, J. Colavita, M. M., Crawford, S., Creech-Eakman, M. J. and 23 coauthors, "The Keck Interferometer Nuller (KIN): configuration, measurement approach and first results", ed. by D. Coulter, Proc of SPIE, vol 5905, 272, 2005.
4) Creech-Eakman, M. J.; Moore, J.; Palmer, D.; Serabyn, E. "KALI Camera: mid-infrared camera for the Keck Interferometer Nuller", ed. by M. Iye and A. Moorwood, Proc of SPIE, vol 4841, 330, 2003.
5) Creech-Eakman, M. J., Klebe, D; Stencel, R.; Williams, W. "TGIRS: a two-grating (mid) infrared spectrometer", ed. by L. Burriesci and J. Heaney, Proc. of SPIE, vol 2814, 115, 1996.

ii) Other selected publications:
1) van Belle, G. T., van Belle, G., Creech-Eakman, M. J., Coyne, J., Boden, A. F., Akeson, R. L., Ciardi, D. R., Rykoski, K. M., Thompson, R. R., Lane, B. F. & the PTI Collaboration, "The Palomar Testbed Interferometer Calibrator Catalog", ApJ, in press, 2008.

2) Mennesson, B.; Koresko, C.; Creech-Eakman, M. J. & 37 coauthors, "The Dusty AGB Star RS CrB: First Mid-Infrared Interferometric Observations with the Keck Telescopes", ApJ, 634, 169, 2005.
3) Swain, M.; Vasisht, G.; Akeson, R.; Monnier, J.; Millan-Gabet, R.; Serabyn, E.; Creech-Eakman, M. & 18 coauthors, "Interferometer Observations of Subparsec-Scale Infrared Emission in the Nucleus of NGC 4151", ApJ, 596, 163, 2003.
4) Thompson, R. R.; Creech-Eakman, M. J.; van Belle, G. T., "Multiepoch Interferometric Study of Mira Variables. I. Narrowband Diameters of RZ Pegasi and S Lacertae", ApJ, 577, 447, 2002.
5) Lane, B. F.; Kuchner, M. J.; Boden, A. F.; Creech-Eakman, M.; Kulkarni, S. R., "Direct detection of pulsations of the Cepheid star zeta Gem and an independent calibration of the period-luminosity relation", Nature, 407, 485, 2000.

d) Synergistic Activities:

1) Member and chair of United States Interferometry Consortium (USIC) organized to feed into Decadal Survey for 2010.
2) Served on NASA APRA panel for ground-based instrumentation: 2007
3) NASA Management Operations Working Group for Keck and IRTF Telescopes: 2007-2010
4) Served on NSF panels for Stellar Evolution and Evolved Stars: 2004, 2005.
5) SPIE Scientific Organizing Committee member for SPIE Interferometry session in Orlando, FL, May, 2006. Helped determine invited speakers list, and presentations for talks and posters. Served on best dissertation award committee. Invited speaker about MROI.
6) Michelson Summer Workshop Scientific Organizing Committee member for 2006 workshop in Pasadena, CA. Helped determine invited speaker list, topics for presentations, and gave invited talk on observing preparation. Previous speaker at Workshop in Pasadena, CA (2003) and Cambridge, MA (2002) speaking about calibration and nulling interferometry.
7) Member of Committee on Ground-Based Interferometry. Organized by NOAO to feed into the Decadal Survey for 2010.
8) Invited attendee to NOAO "Building the System From the Ground-Up II" Workshop in May, 2004, Washington, DC. Gave presentation on MROI.

e) Collaborators and Other Affiliations:

i) Collaborators and principal co-authors:
Akeson, R. (Caltech);Araya, E. (NMT); Bakker, E. (MRO); Baron, F. (Cambridge, UK); Blake, G. (Caltech); Boden, A. (Caltech); Buscher, D. (Cambridge, UK); Chiang, E. (Berkeley); Ciardi, D. (Caltech); Colavita, M. (JPL); Coyne, J. (Cambridge, UK); Elvis, M. (CfA); Evans, N. (CfA); Friedson, J. (JPL); Haniff, C. (Cambridge, UK); Hofner, P. (NMT); Hron, J. (CfA); Ivezic, Z. (Washington); Karovska, M. (CfA); Klinglesmith, D. (MRO); Lane, B. (MIT); Luttermoser, D. (East Tennessee); Marengo, M. (CfA); Mennesson, B. (France – Ecole Polytechnique); Millan-Gabet, R. (Caltech); Monnier, J. (Michigan); Orton, G. (JPL); Serabyn, E. (JPL); Shao, M. (JPL); Stencel, R. (Univ. of Denver); Swain, M. (JPL); Thompson, R. (CHARA array); van Belle, G. (VLTI); van Dishoeck, E. (Leiden, Netherlands); Vasisht, G. (JPL); Westpfahl, D. (NMT)

Biographical Sketch – Penny Boston

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Current and Recent Affiliations:

2002 – Present. Director of Cave and Karst Studies Program, Assoc. Prof., Earth & Environmental Sci. Dept., New Mexico Inst. Mining & Tech., Socorro, NM.

2002 – Present, Associate Director, National Cave & Karst Research Inst., Carlsbad, NM

1997- 2001. Research Assoc. Prof., Dept. of Biology, Univ. New Mexico, Albuquerque, NM.

Formal Education:

PhD - 1985. Environmental, Population, Organismic Biology Dept., Univ. Colorado & Nat. Ctr. for Atmospheric Research, Boulder, CO. Microbiology & atmospheric chemistry.

MS - 1981. University of Colorado, Boulder, CO. Microbiology.

BS - 1979 - University of Colorado, Boulder, CO. Microbiology, geology, and psychology.
1975. Florida Atlantic Univ., Boca Raton, FL. Biology & philosophy. Faculty Scholar accelerated program.

Professional Activities & Meritoria:

NASA Advisory Council Planetary Protection Subcommittee – 2008 to present

COMPLEX (Comm. Planetary Explor.), National Academy of Sciences, 2006 – Present

AME (Association of Mars Explorers) – President, 2006-2008

Mars Architecture Review Panel, National Academy of Sciences, Jan. – May, 2006

Biohazard/Planetary Protection Focus Team. Johnson Space Center, 2004.

Senior Editor, *Astrobiology Journal*, 2003-present. Editorial board, 2001-2003.

GSA – Secretary, new section *Geobiology and Geomicrobiology*. 2001-2006.

International Space University Summer Program –Astrobiology Instr., July, 2002, Aug, 2009.

NASA Institute for Advanced Concepts Fellow – May, 2000.

Nasa Astrobiology Roadmap Taskforce team-member. NASA-Ames Research Center, Moffett Field, CA. July – December,1998.

National Research Council Post-doc Fellowship - National Academy of Sciences, 1986-1988.

National Center for Atmospheric Research - Advanced Stud. Prog., Grad. Fellowship - 1982-1985.

Space Foundation Award – Plants in low pressure environments & space applications, Nov., 1982.

Sigma Xi Research Award - Awarded for work on nitrogen fixation. May, 1982.

Selection of Publications Relevant to this Proposal:

Boston, P.J. 2008. Extremophiles and life on other planets (Chapter). In, *The Seventy Great Mysteries of the Natural World.* Thames & Hudson, Ltd., London, UK. Pp. 171-173.

Boston, P.J. 2008. Global Ecology: Gaia. In, Sven Erik Jorgensen & Brian D. Fath (Eds.), *Encyclopedia of Ecology*, 1st Edition. Elsevier B.V., Oxford, UK. Pp. 1727-1730.

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Boston, P.J. 2004. Extraterrestrial Caves. *Encyclopedia of Cave and Karst Science*. Fitzroy-Dearborn Publishers, Ltd., London, UK. Pp. 355-358.

Biographical Sketch – Colby Jurgenson

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Education:

PhD, Physics, University of Denver 2005
Bachelor of Physics, Minor Engelish Literature, Lewis and Clark College 1998

Current and Recent Affiliations and Professional Societies:

Magdalena Ridge Observatory, Postdoc and Instrument Scientist 2004-Present
Equinox Intersciences, Denver CO – Optical Design Consulting 2002-Present
American Astronomical Society
Sigma Xi (ΣΧ)
Sigma Pi Sigma (ΣΠΣ)

Software Expertise:

Optical Design & Analysis: Zemax & Code V, Thin Film Design: The Essential Macleod, SolidWorks & AutoCAD, Mathematical: IDL, MathCAD, & MATLAB, LabVIEW

Five Relevant Publications:

- Jurgenson, C.A., Stencel, R.E., Theil, D.S., Klebe, D.I., & Ueta, T., "Mid-IR Imaging Polarimetry of NGC 7027, ApJ, 528, L35-L38, 2003."
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- Jurgenson, C.A., Buscher, D.F., Creech-Eakman, M.J., Haniff, C.A., Young, J.S., Coleman, T.A., Parameswariah, C.B., Seneta, E., MROI’s Automated Alignment System, SPIE, Vol. 6268, 2006.

Biographical Sketch – Mark Swain

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Education:

1989	B.A., Physics, University of Virginia
1992	M.A., Physics, University of Rochester
1996	Ph.D., Physics and Astronomy, University of Rochester

Position and Professional Experience:

- **Research Scientist,** Jet Propulsion Laboratory
- PI for high-dynamic-range exoplanet spectroscopy project
- Led discovery team for spectroscopic detection of CH_4, CO_2, H_2O, & CO in an exoplanet atmosphere
- PI for the THESIS exoplanet characterization mission concept
- PI for numerous exoplanet spectroscopy observing proposals

Expertise:

- Exoplanet spectroscopic characterization
- High dynamic range spectroscopy
- Interferometry techniques
- Infrared instrumentation
- Integration and test
- Instrument architecture and system engineering
- Atmospheric modelling

Five Refereed Publications:

- Swain, M. R., Vasisht, G., Tinetti, G., Bouwman, J., Chen, P., Yung, Y., Deming, D., and Deroo, P. “Molecular Signatures in the Near Infrared Dayside Spectrum of HD 189733b”. 2009 *Ap. J. Letters*, **960**, 114.
- Swain, M. R., Vasisht, G., & Tinetti, G. 2008 “The presence of methane in the atmosphere of an extrasolar planet”, *Nature*, **452**, 329.
- Swain, M. R., Bouwman, J., Akeson, R., Lawler, S., & Beichman, C. A. 2008, “The mid-infrared spectrum of the transiting exoplanet HD 209458b”, *Ap. J.*, **647**, 428.
- Swain, M.R. & Gallée, H. 2006, “Antarctic Boundary Layer Seeing”, *PASP*, **118**, 1190.
- Swain, M.R., et al. 2003, “Interferometer Observations of Subparsec-scale Infrared Emission in the Nucleus of NGC 4151", *Ap. J. Ltrs.*, **596**, L163.

Biographical Sketch – Gautam Vasisht

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Positions

Senior Member of Staff, Jet Propulsion Laboratory	2002-2008
Visiting Scientist, European Southern Observatory	2006-2007
Member of Staff, Jet Propulsion Laboratory	1998-2002

Education

Ph.D., Astronomy, June 1996, California Institute of Technology, Pasadena, CA
B.S., EE, June 1990, Indian Institute of Technology, Kanpur, India

Memberships

American Astronomical Society
American Physical Society
SPIE

Recent Invited Talks

"Space-based Spectro-photometry of Transiting Exoplanets", Exeter Exoplanet Workshop, Exeter Univ. (UK), Sept. 2008.
"NICMOS spectrum of the Dayside of HD 189733b", in Molecules in the Atmospheres of Extrasolar Planets, Observatoire de Paris, Paris, Nov. 2008

Recent Publications (in Exoplanets)

1 "Molecular Signatures in the Near Infrared Dayside Spectrum of HD 189733b", Swain, M., Vasisht, G., Tinetti, G., et al. *ApJL*, in press (2008).

2."DAVINCI: a Dilute Aperture Visible Nulling Coronagraph Instrument", Shao, M., et al., *Proc. SPIE.*, Vol. 7013, p. 70132T-70132T-13 (2008).

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