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Project Title – "JIVE in NM: Jovian Interiors from Velocimetry Experiment in New Mexico"

1 Project Description

1.a Project Purpose

NASA's critical planetary science goal is to answer the question "How did the Sun's family of planets originate and evolve?" Jupiter played a major role in the formation of our Solar System. However, the manner in which Jupiter formed is still debated. This is due to the fact that its interior composition and structure is so poorly known that it could contain as little as none or as much as 40 Earth masses of elements other than hydrogen and helium. A similar uncertainty exists for Saturn. For both planets, the mass of their cores - the seeds of planetary formation in the early Solar System - are only crudely constrained by current observations. The large uncertainties in our understanding of these two massive planets that motivate this project are portrayed in Figure 1.

The Jovian Interiors from Velocimetry Experiment in New Mexico (JIVE IN NM) is a NASA EPSCoR project whose research activities are designed to address this question and determine *for the first time* the interior structure and composition of Jupiter and Saturn and to gain new insights into their dynamic atmospheres. This will be carried out by constructing an optimized instrument that is capable of detecting Jovian oscillations to allow for seismic measurements of the planetary interiors and direct inferences of atmospheric winds. It builds and improves upon the successful design of an instrument that provided the first ever confirmed oscillations on Jupiter (see Sec. 1.c.i). The seismic results obtained in this project will reduce the range in possible core mass and interior composition in Figure 1 by a factor of 5-10, allowing us to finally discriminate between competing theories of planetary formation.

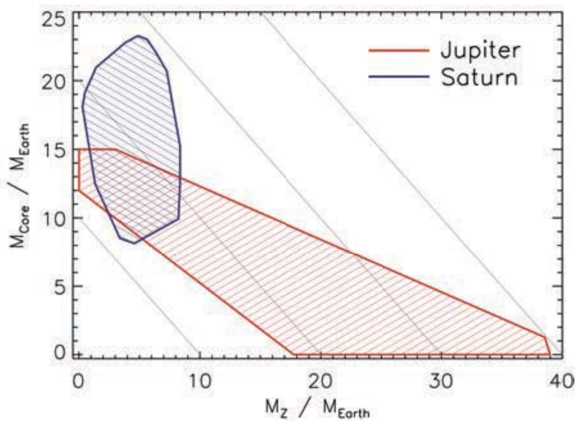

Figure 1: The range of Jupiter and Saturn core masses allowed by current theory. The core (M_{core}) and heavy element (M_Z) masses permitted by the gravitational harmonics and planetary rotation rates are shown. There is over a factor of two uncertainty in Saturn's core mass and only an upper limit ($15\,M_{Earth}$) on Jupiter's core mass.

JIVE strongly aligns with several current and planned space missions carried out in the Planetary Division of the Science Mission Directorate. For example, NASA's Juno mission, whose primary scientific goal is to *significantly improve our understanding of the formation, evolution and structure of Jupiter*, will arrive at Jupiter in July 2016. Juno will make key contributions with precise measurements of Jupiter's gravity and magnetic fields and will radiometrically sound the deep atmosphere. While these gravitational measurements are primarily sensitive to the outer envelope of the planet, the acoustic waves that JIVE will measure propagate all the way to the core and are thus sensitive throughout the interior. Indeed, as Section 1.c.vi describes, JIVE is a perfect complement to Juno, and its observational campaigns will overlap with Juno's mission in Jupiter's orbit. Thus it extends Juno's capability, adds to its scientific return, and allows the possibility of critical cross-comparisons of results from two distinct types of measurements.

The NASA Cassini spacecraft at Saturn has recently discovered features in the ring system that are induced by oscillations in the planet [Hedman and Nicholson, 2013]. JIVE will be able to confirm these exciting results by directly detecting the oscillations at the planetary surface, paving the way for seismology of Saturn too. Finally, the joint ESA/NASA JUpiter ICy moons Explorer (JUICE) mission planned for the next decade will also make detailed studies of the Jovian system. Clearly, a better understanding of Jupiter and Saturn is a research priority for NASA, and three key NASA planetary scientists at Ames, the Jet Propulsion Lab (JPL), and Goddard Space Flight Center (GSFC) are a part of the JIVE collaboration (see "Partnerships," Sec. 1.e).

New Mexico has a history of ground-breaking planetary science research and associated technology. Jovian seismology has been a pursuit for over forty years, but can now become a reality: the success of JIVE IN NM will establish the state as a center for seismological studies of planets, attracting new students, building connections to three NASA centers, and contributing to an expanding research infrastructure. Planetary seismology is a new research direction for New Mexico that can leverage human and technological resources in the state and beyond. The project strengthens collaborations between two Minority Serving Institutions (MSI) in the state: New Mexico State University (NMSU) and the New Mexico Institute of Mining and Technology (NMT), and builds ties to a major research facility: Los Alamos National Laboratory (LANL). Finally, a team of scientists from two institutes in France, the Laboratoire Lagrange at the Observatoire de la Côte d'Azur (OCA) and the Institut d'Astrophysique Spatiale (IAS), will play a critical role in the overall project (see Section 1.e).

The JIVE instrument will be mounted on NMSU's 1-meter (1m) telescope at Apache Point Observatory (APO) on Sacramento Peak, NM, two hours from campus. The telescope is owned and operated by the Department of Astronomy, which has an active planetary science group. Since JIVE will be conveniently accessible, it will have a large role in academic research at NMSU in the coming years. Similarly, the Planetary Astronomy Group at NMT in the Physics Department is comprised of a diverse group of faculty and students interested in physical processes in gas-giant planets in our Solar System and in exoplanetary systems, and will make JIVE a strong focus in its research priorities.

JIVE IN NM involves close collaboration among students, faculty, and other team members. It will lead to a cultivation of expertise in advanced astronomical instrumentation development and state-of-the-art scientific data analysis in New Mexico during the award period and well into the future.

1.b Goals and Objectives

There are five important goals for JIVE IN NM that span instrumentation, science, education, and collaboration. Each goal below has its own itemized objectives that will be met to guarantee the success of the project.

(1) Instrumentation Goal: *Build an imaging spectrograph capable of measuring Jovian oscillations within the three-year award period.*

- Adapt an instrument design that has an expected order of magnitude more sensitivity than previous instruments;
- Mount the instrument on a suitable telescope to carry out monitoring of giant planets;
- Develop the software needed to control the instrument and perform data acquisition and reduction;
- Assemble a team of experts who regularly meet and review construction progress.

(2) Science Goal: *Determine the interior structures of Jupiter and Saturn to a precision better than ever achieved, enabling the resolution of competing theories about the formation of our giant planets.*

- Measure Jupiter and Saturn's core mass to within several Earth masses;
- Measure the total mass of heavy elements to within several Earth masses;
- Identify structural discontinuities of the interior density and sound-speed profiles;
- Validate and compare JIVE sub-surface inferences with those from the NASA Juno mission.

(3) Science Goal: *Uncover new details of the dynamic atmospheres and climatology of the Jovian planets.*

- Determine wind speeds directly from JIVE maps and compare to cloud-tracking results;
- Measure the momentum cycle driving zonal jets by calculating eddy momentum fluxes;

- Directly characterize the planetary-scale waves in the wind signatures in the Jovian atmosphere;
- Indirectly probe the deep convective region of the planet to advance our understanding of tropospheric-stratospheric coupling.

(4) Education Goal: *Train students in technical areas of astronomical instrumentation and modern planetary science to prepare them for careers in related fields.*

- Hire three graduate students in engineering and astronomy whose work in JIVE will form the bulk of their graduate degrees;
- Involve up to six undergraduate students in all aspects of the project;
- Provide effective mentoring and advising practices to help form pathways for future student participation in JIVE.

(5) Collaboration Goal: *Develop long-lasting and diverse research partnerships within New Mexico and beyond.*

- Engage researchers in New Mexico's universities and national laboratories whose interests overlap with JIVE;
- Utilize existing collaborations with key NASA partners to strengthen the relevance of the project to NASA's scientific priorities;
- Leverage existing international collaborations with critical expertise in this area, and build the case for a future global network of similar instruments.

Jupiter and Saturn are confirmed pulsating planets. The rationale for JIVE IN NM to achieve its science and instrumentation objectives is to build and implement a portable, ultra-stable Doppler imaging spectrograph that will make observations of the planets' surface velocity at a rapid cadence and sufficient spatial resolution. We will revolutionize the study of these planets' interior structure by precisely measuring the frequencies of their global oscillations and performing seismology - sounding their deep interiors and cores - and revealing the seeds of planetary formation to help answer fundamental in planetary science.

In what follows we describe the background of Jovian seismology, the technical requirements for the instrument, how it will be built and installed at the telescope, and the observation and analysis plans.

1.c Project Content

1.c.i Introduction to Jovian seismology and atmospheric dynamics

The composition, internal structure, and thermal evolution of Jupiter and Saturn are key ingredients to our overall understanding of the history of the Solar System.[1] Unfortunately, both the mass of heavy elements and their distribution throughout the planetary interiors remain extremely uncertain [Saumon and Guillot, 2004, Militzer et al., 2008, Nettelmann et al., 2008, Fortney and Nettelmann, 2010]. Because any model of Jupiter's formation must account for the core mass, definitive measurements would have profound implications for our understanding of planetary formation and evolution [Pollack et al., 1996, Ida and Lin, 2005, Alibert et al., 2005]. Jupiter's density profile through the metallic and molecular hydrogen envelopes surrounding the core constrains the equation of state governing matter at high pressure and the distribution of heavy elements through the planet. If mixing processes have distributed heavy elements unevenly in the interior, the thermal evolution of the planet would be extremely affected [Stevenson, 1985, Leconte and Chabrier, 2012]. Furthermore, new constraints on the interior structure

[1] Hereafter, instead of referring to both planets, whenever Jupiter is mentioned the same general discussion applies to Saturn as well, unless otherwise explicitly noted.

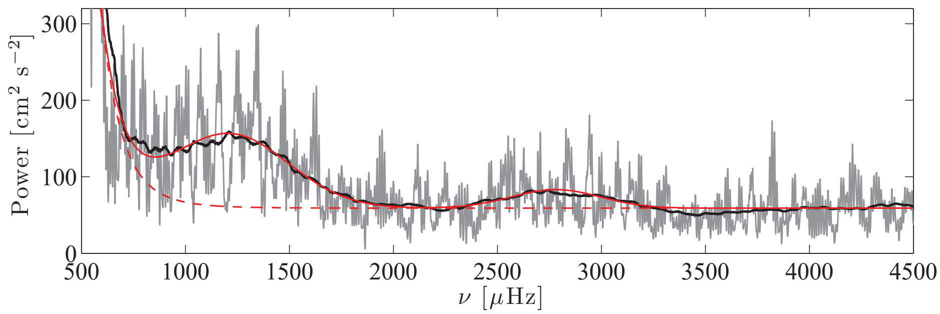

Figure 2: Evidence of the first detection of Jupiter's global modes from the SYMPA instrument, similar to the one to be built in this project. It shows the power spectrum of the mean velocity time series obtained in 2005. Excess oscillation power is detected between 800 and 3400 μHz, as well as a comb-like structure of regularly spaced peaks. The thick lines are smoothed data. From Gaulme et al. [2011].

allow a better understanding of the tidal dissipation in Jupiter and the resulting evolution of the Jovian moons [Ogilvie and Lin, 2004, Lainey et al., 2009, Remus et al., 2012].

The most promising way to infer the interior structure of giant planets is through seismology. While measurements of planets' gravity fields (gravimetry) can be used to discern the internal distribution of mass within, these data are most useful in the outer portions of the planet. Jovian seismology, on the other hand, provides a way to unambiguously determine interior structure using well-tested methods originally developed for the Sun and now being carried out on other pulsating stars [Christensen-Dalsgaard et al., 1996, Jackiewicz et al., 2012a, Chaplin and Miglio, 2013]. Seismology concerns the observations and interpretation of global resonant sound waves that, once excited, propagate throughout stars and planets. The observed frequencies of these oscillations are compared to those computed from theoretical interior models of the planet. The models are tuned so that they give frequencies that match as well as possible the observed frequencies. Very generally, the best resulting interior model describes the planet accurately. More detail about this type of analysis is given in Section 1.c.vi.

Jupiter pulsates in a spectrum of acoustic modes that are driven by convective motions similar to the Sun. It has been recognized for four decades that the detection of oscillations would provide a powerful probe of the interior structure [Vorontsov et al., 1976], and numerous studies have been carried out to theoretically investigate the nature of Jupiter's oscillation modes [Vorontsov, 1981, Marley, 1991, Mosser et al., 1991, Lee, 1993, Provost et al., 1993, Gudkova and Zharkov, 1999, Jackiewicz et al., 2012b]. Because of the expected rapid variations and structural discontinuities in the interior, these are challenging computations. Nonetheless, agreement has been reached that the modes that are excited and probe the core pulsate at frequencies between about 1000 and 3000 μHz (periods of 5 to 15 min), where this range depends fundamentally on the properties of the sound speed in the metallic and molecular hydrogen layers of Jupiter.

Observationally, there have been several attempts to detect Jovian oscillations using infrared photometry [Deming et al., 1989], Doppler spectrometry [Schmider et al., 1991, Mosser et al., 1993, 2000], and careful searches for excitation of acoustic waves due to the impact of the Shoemaker-Levy 9 comet [Walter et al., 1996, Mosser, 1996]. In most of these campaigns, the signal-to-noise (SNR) ratio was too low or instrumental artifacts were present that inhibited any positive detection. The fast rotation of Jupiter also limits the precision these instruments were able to obtain.

Jovian seismology had to wait until 2011 to get the first strong evidence of the detection of oscillations using the SYMPA instrument, an imaging spectrometer upon which the Jive design is based [Schmider et al., 2007, Gaulme et al., 2008, 2011]. This instrument was designed to overcome some of the earlier limitations by imaging the full planetary disk, similar to solar helioseismic instruments like GONG [Harvey et al., 1996], MDI/SOHO [Scherrer et al., 1995], and HMI/SDO [Scherrer et al., 2012]. As part of a 10-day observing run in 2005, the SYMPA instrument was able to produce a power spectrum of Jupiter's oscillations shown in Figure 2. An excess of acoustic power is observed in the frequency range predicted by theory, as well as the comb-like structure of peaks that is also expected from interior models, thereby confirming Jupiter's global pulsations. Unfortunately, the level of noise in the data is too high to identify individual modes and decisively probe Jupiter's interior (see Sec 1.c.vi).

Regarding seismology of Saturn, recent analysis of occultation observations using the NASA Cassini spacecraft at Saturn shows exciting evidence of planetary modes that manifest themselves in its rings [Hedman and Nicholson, 2013, Fuller et al., 2014, Marley, 2014]. This possibility was first proposed by a Jive team member [Marley, 1991, Marley and Porco, 1993]. The basic idea is that wave features in Saturn's C rings could be created by resonant interactions with internal oscillation modes, since these modes perturb the internal density profile and, therefore, the external gravity field. The observations of Hedman and Nicholson [2013] are the *indirect* evidence of these wave forcings [Marley, 2014]. Jive will be able to confirm this with *direct* observations of the global resonant oscillations on the planet.

Meeting the **instrumentation goal** and **first science goal** ensures that with Jive we will make better observations than any ever achieved and be able to address the fundamental questions about giant-planet interiors and evolution. Reaching the specific objectives will reduce the range of uncertainties of the interior parameters in Figure 1 by a factor of up to ten.

Atmospheres: By tracking the motion of visible clouds in the troposphere we know that the predominant weather pattern in the Jovian atmosphere consists of a series of alternating eastward and westward zonal jets that are remarkably steady over long time scales [Limaye, 1986, Stamp and Dowling, 1993, García-Melendo and Sánchez-Lavega, 2001, Porco et al., 2003]. We also know that, embedded between these alternating jets, other dynamical structures such as vortices and waves develop [Mac Low and Ingersoll, 1986, Deming et al., 1997, Morales-Juberías et al., 2002a,b, Li et al., 2004, Young et al., 2005, Reuter et al., 2007, Simon-Miller et al., 2012, Choi et al., 2013a]. Some of the most prominent of these features, like the Great Red Spot (GRS), are well characterized [Mitchell et al., 1981, Vasavada et al., 1998, Simon-Miller et al., 2002, Choi et al., 2007, Asay-Davis et al., 2009], and infrared observations indicate that Jupiter has a strong equatorial stratospheric jet [Flasar et al., 2004, Liming et al., 2008].

Despite the wealth of atmospheric information derived from ground-based observational campaigns and from space missions like Voyager and Galileo, many questions still remain unanswered. The mechanisms maintaing the dominant alternating jets, vortices and waves in the troposphere as well as their structure below the visible cloud level is largely unconstrained by the existing observations. The relationship between small-scale variability in the jets and the observed atmospheric morphology variability is also poorly understood. Finally, it remains unclear the precise role that eddies (large and small) and waves (large and small) play in governing Jupiter's weather pattern and its variability (both in the troposphere and in the stratosphere). Overall, the Jovian weather pattern is a complex system involving many different phenomena at different spatial and temporal scales, and we lack the continuous high-resolution observations of Jupiter's weather system as a whole needed to understand such dynamics.

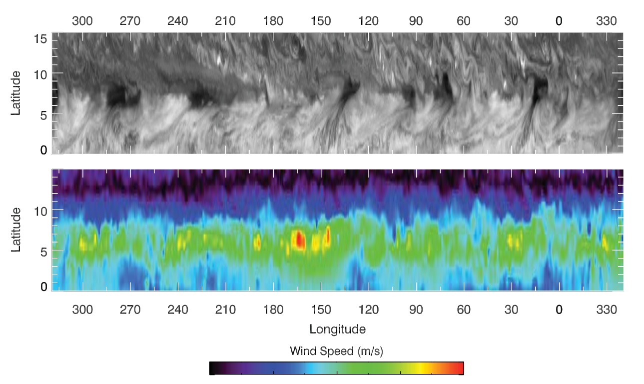

Figure 3: Example intensity image (top panel) whose clouds are tracked to give an *estimated* velocity map (bottom panel) within a zonal band on Jupiter. Jive will be able to distinguish wave motion and zonal flows, critical for understanding what powers the jets. From Choi et al. [2013b].

Jive will extend our knowledge by providing two-dimensional maps of wind velocities in Jupiter's atmosphere with a precision of $10 - 20\,\mathrm{m\,s^{-1}}$ for each Jovian rotation, and an averaged latitudinal profile at the level of $1-2\,\mathrm{m\,s^{-1}}$. Unlike the winds derived from cloud tracking techniques [Choi et al., 2007, Asay-Davis et al., 2009] that assume cloud motions represent wind motions and can only be carried out where cloud features actually exist (see Fig. 3), JIVE will measure wind motions directly. Such data will allow new calculations to be performed with unprecedented accuracy, and the objectives reached for the **second science goal** will show us what powers Jupiter's Great Red Spot, how it and similar structures evolve, and how the zonal jet streams and cloud bands are connected to the interior. Detailed studies of Jovian climatology will not only provide new insights about the solar system's largest planets, but will also enable the framework for the characterization of exoplanets.

1.c.ii Science requirements and instrument concept

Theoretical models [Vorontsov, 1981, Bercovici and Schubert, 1987, Mosser, 1990, 1995, Gudkova and Zharkov, 1999, 2003, Jackiewicz et al., 2012b, Le Bihan and Burrows, 2013, Fuller et al., 2014] and the Gaulme et al. [2011] and Hedman and Nicholson [2013] observations suggest that that our giant gas planets oscillate with periods of about 5 to 15 minutes, and amplitudes in the $10-100\,\mathrm{cm\,s^{-1}}$ range. The average amplitudes of the detected modes from SYMPA (see Fig. 2) are approximately $40\,\mathrm{cm\,s^{-1}}$ using about 50 hr of data with a duty cycle of 22%. The SNR of these measurements was only about 3. To reach our **instrumentation goal** for JIVE, one of the objectives is to improve the performance over SYMPA by approximately an order of magnitude, so that we can perform the seismic analysis described in Section 1.c.vi using as many detected oscillations as possible. Thus, to carry out this groundbreaking science we require JIVE to provide:

- the sensitivity to detect modes with amplitudes as low as $1-10\,\mathrm{cm\,s^{-1}}$;
- a SNR to exceed 10;
- a target frequency range of $[500-4000\,\mu\mathrm{Hz}]$;
- a frequency resolution of better than $1\,\mu\mathrm{Hz}$;
- accuracy of averaged zonal wind measurements in the Jovian atmosphere of approximately $1-2\,\mathrm{m\,s^{-1}}$.

No such Jovian ground-based instrument with these capabilities exists, nor does one for current or planned space missions to the giant planets. JIVE is an imaging spectrometer specifically designed to help achieve the scientific goals of this project and to meet these technical specifications. It will measure the Doppler shift in solar absorption lines from light that is reflected by clouds in Jupiter's upper troposphere, providing spatially resolved line-of-sight velocity images of the whole planet at that altitude. More precisely, JIVE is a Fourier transform tachometer that will simultaneously produce a visible image **and** a Doppler-velocity image of the planet at a regular temporal interval.

Jovian oscillation periods and wavelengths dictate the rate and resolution that JIVE samples the surface velocity. Thus, JIVE is designed to provide Doppler-velocity images every 1 minute with a spatial resolution of about 1 arcsec (dependent on seeing), corresponding on average to about 3000 km on Jupiter (diameter of 140,000 km), or about 6000 km on Saturn (diameter of 120,000 km). The velocity images will be used to compute seismic observables like power spectra for mode identification, and can be averaged to obtain a latitudinal profile of winds sensitive to $1-2\,\mathrm{m\,s^{-1}}$ fluctuations.

Why have previous instruments failed where JIVE will succeed? The main difficulty encountered in past measurements is caused by the rapid ($\sim$ 11 hr period) Jovian rotation that overwhelms other dynamic signals at any specific location on the surface. SYMPA circumvented this problem by using full-disk imaging observations that enable subtraction of this strong signal. While SYMPA was successful (see Fig. 2), optical problems prevented its interferometric fringes from having sufficient contrast, and there was limited access to telescopes. JIVE's 50% allocation of telescope time, an optimized instrument design, and recent theoretical advances in Jovian seismology by members of this team will allow for the study of Jupiter and Saturn in detail and overcome the obstacles that prevented past experiments from exploiting the full potential of planetary oscillations.

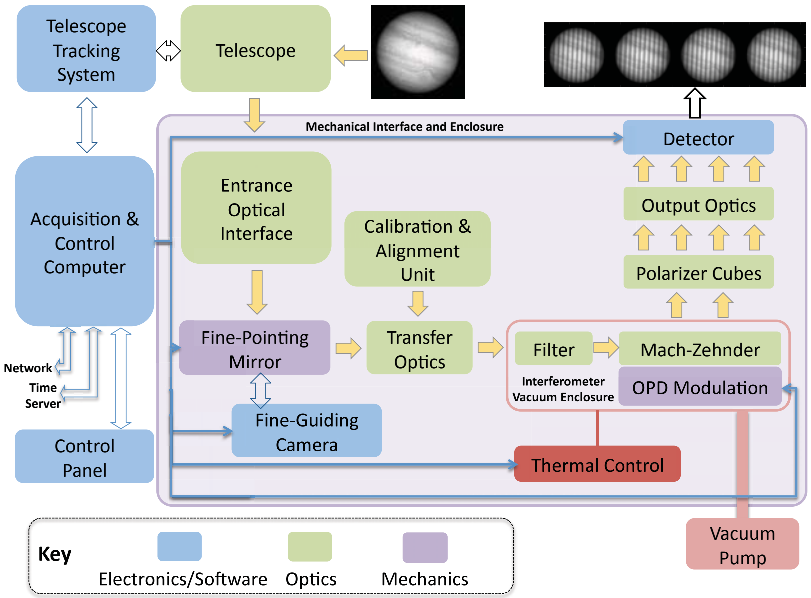

Figure 4: Schematic of JIVE's main components. Light from Jupiter enters the telescope and a small pre-optical interface controls the image size (see Sec. 1.c.iv). A fine-guiding system (tip-tilt mirror and camera) keeps accurate pointing on the target and reduces instrumental jitter. After calibration and distortion control, light enters a vacuum chamber through a narrow filter and into the thermally-controlled interferometer and beam splitter. Upon exiting, polarizer cubes split each beam again to produce four images in phase quadrature, superposed with interferometric fringes, that are collimated onto a passively-cooled CCD detector to record the science images. This camera is controlled by an external computer system (left blue boxes) to take images at specified times and cadence.

1.c.iii Instrument details and construction

JIVE will be built using a design based on the heritage of SYMPA and a recent iteration called DSI (Doppler Spectro-Imager) that was constructed by our French collaborators as a prototype for a potential space mission. At the heart of JIVE is a Mach-Zehnder interferometer with a fixed optical-path difference (OPD). The spectrograph operates in the visible spectrum centered around 519 nm where there is a high density of narrow solar spectral lines that are uniformly spaced. This will provide a favorable superposition of interference fringes. A filter of bandwidth about 1 nm will be used to maximize the tradeoff between photon number and fringe contrast [Soulat et al., 2014]. The optical design of the Mach-Zehnder requires a minimal 2.75° field-of-view (FoV). A thermal control system inside a vacuum chamber that also holds the interferometer helps keep the OPD constant. As given in the letter of collaboration by the director of the OCA, the manufactured and tested Mach-Zehnder - the most critical component of the instrument - will be purchased with project funds and delivered to NMSU.

A block diagram schematic of the entire JIVE design and interface with the telescope is shown in Figure 4. An example input image of Jupiter is used to show the layout of the optical path and how the 1000×1000 pixel camera records four final output images with interference fringes that are used to measure velocities. A functioning DSI prototype has already been built in France using this general layout and is shown in Figure 5. The large cylinder in the top panel of Fig. 5 is the vacuum enclosure inside which sits the Mach-Zehnder, filter, and thermal control ring. The two output channels from the chamber align with the polarizer cubes visible in the bottom right of the assembly, that then feed light to the output optics and camera (not shown in photograph).

Initial experimental data from test observations in January 2014 from France are also shown in Figure 5. Fringes are seen across the 4 images of Jupiter at a higher contrast than SYMPA, indicating that this design is effective. Since the DSI prototype was designed for a space mission, small modifications will be needed for JIVE; however, it is anticipated that we will reproduce most of the optical plans that will be provided by the OCA team. We will be replicating a design that is known to work!

Construction: JIVE will be built by students and faculty in close collaboration with the OCA team in an optical engineering lab in the Electrical and Computer Engineering department at NMSU. The Instrument PI (Voelz) has vast experience in optical design, construction, and calibration of instruments. Indeed, he was a critical member of the team that built an instrument for a previous EPSCoR award [see Sec. 1.k, Chanover et al., 2011, Tawalbeh et al., 2013]. The lab houses research projects funded by NASA, the National Science Foundation, the Air Force Office of Scientific Research, Sandia National Laboratories, and the National Geo-spatial Intelligence Agency. The laboratories provide 3,465 square feet of space for optics research, containing a variety of general use equipment including lasers, interferometers, optical mounts, detectors, cameras and diagnostic equipment. One of the main laboratories and necessary support equipment will be available for this effort. In the last ten years over 30 Master's students and 5 PhD students have graduated with thesis or dissertation topics directly associated with Voelz's research.

Software control: The JIVE instrument has several components that need to be controlled by a computer (see the blue-colored boxes in Fig. 4). We will utilize initial software designs by French collaborators and carry out extended development to integrate these components with the already existing software control of the telescope.

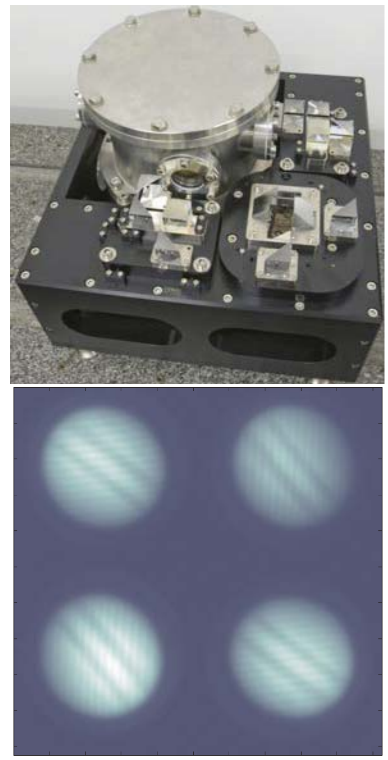

Figure 5: Prototype instrument and preliminary observations. The top panel shows the instrument, with components corresponding to those in the main block in Fig. 4 (without the camera). On the bottom are the four output images of Jupiter used to compute velocity maps from the interferometric fringes (barely seen in this image rendering). The two main bands in each image at about 45° are zonal features of Jupiter's clouds.

1.c.iv Instrument deployment at telescope

JIVE will be mounted at the 1m telescope at APO [Holtzman et al., 2010]. It is an altitude-azimuth, $f/6$ RC design with a $f/2.5$ primary. Located at one Nasmyth focus is an image rotator and an optical photometric imaging system. The tertiary mount has been redesigned to rotate to allow instrumentation at both Nasmyth foci. The second port will be adapted to feed light to JIVE. A dedicated control-room is provided inside the main APO operations building. The telescope operates robotically (note tracking system in Fig. 4), making it ideal for long-term monitoring programs. APO staff perform routine service and maintenance when required.

The "seeing" at APO overall is excellent, on average reaching 1 arcsec and often down to 0.5" or so. The seeing specifically at the 1m in its dome on average is slightly worse, but again often reaches subarcsecond quality, well in line with the science requirements for spatial resolution. As mentioned in Section 1.c.iii, a small configuration of pre-optical lenses will be developed and installed at the point that light from the telescope reaches JIVE's main interface, to provide the correct FoV for the fine-pointing mirror and the Mach-Zehnder.

1.c.v Observation plan

JIVE IN NM will be allocated a significant amount of observation time to carry out this project in the second, third, and subsequent years (50%). Effectively, whenever Jupiter/Saturn is favorably visible, the telescope will be observing them using JIVE. First light and commissioning observations are expected after 24 months of the project (approximately Fall 2016, see "Timeline" in Sec. 1.f). Venus and Saturn will be used to calibrate and test image quality, instrument performance, and telescope pointing during the commissioning period. Venus has maximum elongation in January 2017. Jupiter will begin to be visible during early mornings in December 2016, with an opposition set to occur in April 2017 when full science observations are scheduled. Since Saturn is about 15 times fainter than Jupiter, most of the science in the three-year period will be carried out for Jupiter. However, significant observations of Saturn will take place (for instance, when Jupiter is not visible) to determine how well JIVE meets the instrument requirements for a faint object. A future goal would be to test JIVE at the 3.5m telescope at APO for detailed Saturnian observations.

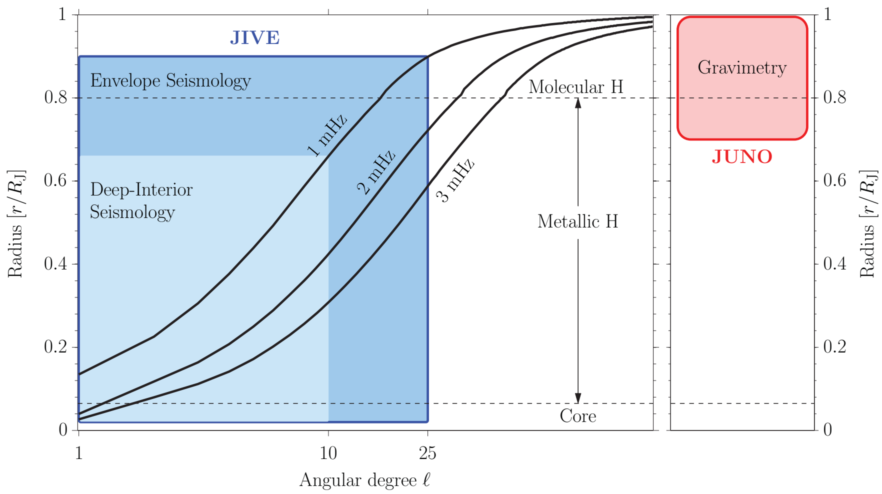

Figure 6: Jive and Juno are complementary. The blue box shows the interior range of Jupiter that will be possible to seismically explore with modes detected with Jive. This includes a deep-interior program (light blue) using low-degree modes, and an envelope program (darker blue) for higher-degree up to $\ell = 25$ when there is good telescope seeing. The red box shows the near-surface sensitivity possible from gravimetry with the Juno mission. Probe depths of a few example modes at the given frequencies and angular degree are shown (solid lines), as well as the expected transition locations for current Jupiter models (dashed lines). The x-scale is logarithmic.

1.c.vi Data analysis

Interiors: Jive will measure the phase shift from fringe interference patterns caused by a Doppler shift of the observed spectrum reflected from Jupiter. The shift is caused by motions in the Jovian atmosphere, such as those from waves and flows. The basic data product will be line-of-sight velocity maps at each pixel across Jupiter's disk about every minute. Data analysis from velocity maps will proceed very similarly to that used in helioseismology, with which our team has vast experience. By projecting the velocity measurements onto a basis of spherical harmonics, we will identify modes of particular radial order n, angular degree ℓ, and azimuthal order m. Mode identification requires reference theoretical interior models that will be provided by team members Marley, Saumon, and Guillot.

The first and perhaps the most powerful analysis will be to compute power spectra (as in Fig. 2) from a velocity time series and look for variations in the frequency spacing of the peaks of the modes (large frequency separation), which indicate the presence of interior discontinuities [as demonstrated in stars, e.g. Miglio et al., 2010]. This is particularly important for Jupiter, where a number of structural discontinuities may arise, most importantly: (1) at the core-envelope interface; and (2) in the region where helium separates from metallic hydrogen to possibly form droplets [Morales et al., 2009].

Next, as part of a "deep-interior seismology program" using Jive, we will carry out a detailed analysis of a time series for all modes of amplitudes above $5\,\mathrm{cm\,s^{-1}}$ and $\ell \leq 10$. Once these modes are identified and frequencies measured, our analysis will proceed through well-known forward and inversion techniques [e.g., Jackiewicz et al., 2008, 2012b, and Fig. 7]. With the modes measured in the deep-interior program, the structure of the core, its size, and whether it is well defined or diluted will be determined. With good seeing at the telescope, we anticipate reaching sufficient spatial resolution to measure up to $\ell \leq 25$, which will allow us to probe the near-surface layers and the molecular/metallic hydrogen transition [Vorontsov et al., 1989, Gudkova et al., 1995, Jackiewicz et al., 2012b]. We denote this the "envelope seismology program." Figure 6 illustrates the distinct interior regions we will be able to study using Jive. In particular, note the overlap between the Jive and Juno experiments near the expected metallic-to-molecular hydrogen transition in Jupiter. Juno is designed to measure Jupiter's gravity and magnetic fields, and Jive will therefore allow for a crucial inter-comparison between gravimetry and seismology. All of these tasks address the objectives of the **first science goal**.

Additional powerful inferences will be explored based on the quality of data. For example, an exciting possibility would be to extract information related to the internal rotation of Jupiter through its mode frequency splittings caused by the planet's rapid rotation [Vorontsov, 1981]. To measure these splittings, we estimate requiring a frequency precision of about $0.25\,\mu$Hz, or roughly four observing periods of 9-11 days. With the significant telescope time allocated to Jive in NM, this study will be certainly feasible.

Atmospheres: JIVE measures wind motion directly, and will be used initially to observe Jupiter's atmosphere for at least 20 rotations ($\sim$ 10 Earth days) with a spatial resolution of 3000 km for studying short time scale atmospheric evolution. Such observations can be repeated yearly to characterize the evolution of the Jovian system on even longer time scales. Eddy momentum fluxes, a critical diagnostic tool for determining the momentum cycle driving the zonal jets in Jupiter [Beebe et al., 1980, Ingersoll et al., 1981, Salyk et al., 2006], will be computed from these observations. We will also perform spatial and temporal harmonic analysis of Doppler velocities to detect and characterize large-scale atmospheric wave content (different spatially and temporally than the internal acoustic waves) in the winds signature. Measurements of wave average flux, amplitudes, and phase speeds are closely related to their causal mechanism and to the properties of the regions of the atmosphere from which they originate [Alexander et al., 1995]. Given that convection is known to be strong in Jupiter's equatorial region [Ingersoll et al., 2000, Gierasch et al., 2000], we postulate that most of the observed wave activity observed in the atmosphere has it origin in the convective layer of the planet, allowing us to indirectly probe it. These tasks address all of the objectives of the **second science goal**.

Another critical analysis component will be combining the observational efforts with realistic modeling of the Jovian atmosphere. Dynamical models for gas-giant atmospheres have matured and now include most of the relevant physical processes, either directly or with established parameterizations [Yamazaki et al., 2004, Dowling et al., 2006, Lian and Showman, 2010, Friedson and Moses, 2012]. Co-I Morales-Juberías has wide familiarity with the general circulation model EPIC [Explicit Planetary Isentropic Code, Dowling et al., 1998, 2006] and with its applicability to forward-modeling problems. The EPIC atmospheric model integrates the hydrostatic, primitive equations on an oblate sphere, and its dynamical core includes Rossby waves and gravity waves that are resolved down to the grid's Nyquist wavenumber. In addition, the model includes physical components that are critical to the study of the Jovian weather system such as radiative transfer [Dowling et al., 2012], cloud microphysics [Palotai and Dowling, 2008], and sub-grid wave drag parameterizations [Cosentino et al., 2012]. These computations will allow very detailed interpretation of Jive observations.

Data policy: Data from Jive will be released to the community after one year. We anticipate providing raw data, as well as a few higher-level data products such as time series of velocity maps, to enable new analysis and science to be extracted from these unique data sets. The data will be stored on a local server and made available through a dedicated project website (see "Dissemination," Sec. 1.h).

1.d Anticipated Results

Jive in NM will make transformational discoveries about the solar system's gas-giant planets in terms of their interior structure and atmospheric dynamics that are captured by the science objectives. It is crucial to note that, as has been done for the Earth [Deguen, 2012], the Sun [Christensen-Dalsgaard, 2002], and stars [Metcalfe et al., 2012], directly constraining the core mass and the interior density and sound-speed profile with seismology will allow us to discriminate between competing models of Jupiter's interior, such as the fully convective one [e.g., Saumon and Guillot, 2004, Nettelmann et al., 2008] or one that is semi-convective [e.g., Leconte and Chabrier, 2012].

An example of the type of result we anticipate is demonstrated in Figure 7. It shows the modes that we expect to observe *at minimum* with Jive, so that the deep-seismology program can be carried out (as in Fig. 6). Combining all of the modes in a seismic inversion procedure shows that we can obtain sensitivity to the density changes in the very narrow region in the interior where the core boundary

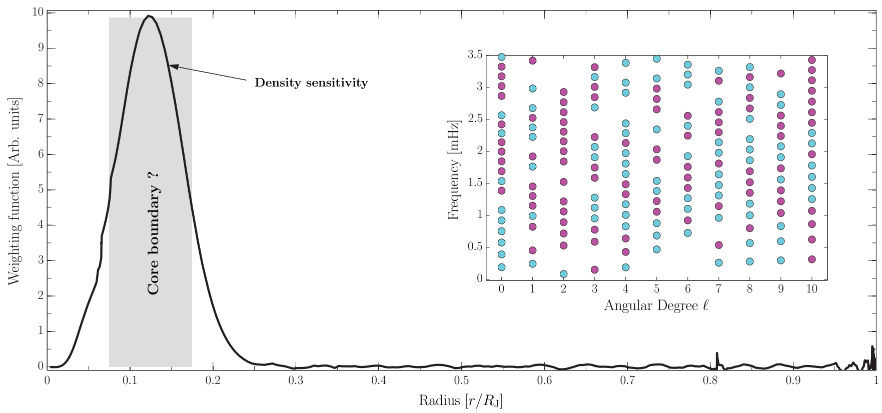

Figure 7: Seismic sensitivity to Jupiter's density in the deep interior. The solid curve is the weighted average probing potential of the Jovian oscillations expected to be detected up to $\ell = 10$, shown in the inset as a function of their frequency and angular degree (colors denote positive and negative weighting). In this case the core boundary could be determined to within ∼5%. Adapted from Jackiewicz et al. [2012b].

is expected. The modes can be combined in different ways to probe other regions too, particularly those that Juno will probe nearer to the surface. This analysis will result in the determination of the core mass to a precision never before achieved. Such inferences will ultimately lead to differentiating planetary-formation scenarios.

In a larger planetary and astrophysical context, reaching the seismic and atmospheric science goals detailed in Section 1.b will have a broad community impact and enable complementary research towards the following key areas: (i) understanding Jovian atmospheres as complex, coupled systems; (ii) the variability of Jovian climatology over long time scales; (iii) the characterization of the Jovian system for direct comparison to other giant planets in the Solar System and the exoplanets in other stellar systems; (iv) exploration of the chemical and physical processes responsible for shaping Jupiter and its diverse satellite system; and (v) constraints on the formation and evolution scenarios of giant planets in general. Each one of these fundamental NASA science priorities will be enabled by JIVE .

1.e Partnerships and Interactions

This effort's **collaboration goal** is to foster long-lasting relationships between NMSU and NMT, LANL, partners at NASA AMES, JPL, and GSFC, and colleagues in France. It leverages jurisdiction resources such as our access to an excellent NM telescope facility, strong statewide researchers, and our ties to an international team that has developed the JIVE design and built a prototype. We can demonstrate past interactions among the proposing team members, and expected ones that JIVE will make possible and formalize. *In fact, much of the past collaboration was enabled by previous EPSCoR projects, demonstrating that the jurisdiction is building on valuable experience.*

Past interactions: NMSU has strengthened its solar and stellar astrophysics research capabilities in the Department of Astronomy over the past six years with faculty hires and strong graduate-student recruitment. It has made this a priority in order to establish ties with many of the state's research facilities. A NASA EPSCoR award (2009 - 2014) in solar and stellar seismology has been crucial in establishing these relationships, and has contributed to this proposing team's ability to build the necessary scientific expertise and infrastructure to carry out this transformational planetary science project. For example, Co-I Gaulme who came from partner institutions OCA and the IAS, was hired as a postdoc at NMSU during that EPSCoR award. His doctoral work at OCA with the SYMPA instrument led to the only published detection of Jupiter's oscillations, and his experience will allow us to build an improved instrument that will have a sensitivity far greater than any previous ones. The prior award established our relationship with collaborator Saumon at LANL, and also led to essential graduate-student training.

A completed EPSCoR award involving Co-I Voelz (detailed in Sec. 1.k) that focused on sophisticated space-based instrumentation helped develop the necessary experience in the optics lab that will be critical for the successful construction and testing of JIVE. NASA collaborator Simon at GSFC was also a key member of that earlier project.[2]

Project PI Jackiewicz and NASA partner Marley were awarded funds from a project in NASA's "Outer Planets Research" (OPR) program in 2011/2012 that was successful in providing a theoretical justification of the importance of global-mode detection in constraining Jovian interiors. Another OPR proposal (currently under review) is aimed at developing new seismic models that would further validate the JIVE instrument's capabilities. NMSU PIs, OCA and IAS collaborators, and NASA partners Murphy and Marley recently proposed a space-based variant of the JIVE instrument for the JUICE mission payload. A team meeting was held at NMSU in 2012 to initiate the proposal writing. While the proposal was not selected, it received excellent reviews for its strong scientific justification and scope, demonstrating NASA's continued interest in Jovian interior research. In addition, Co-I Morales-Juberías and NASA collaborator Simon have worked for years together on Jovian atmospheric dynamics studies, as have LANL collaborator Saumon and NASA collaborator Marley on interior modeling.

Planned interactions: JIVE IN NM enables rich collaboration possibilities. A subcontract to NMT has been agreed upon, and this minority-serving institution about two hours from NMSU and the telescope site is a valuable partner. Co-I Morales Juberías has experience using ground and space-based observations of planetary atmospheres as well as using numerical models to interpret those observations in a comparative framework. His strong collaboration with NASA partner Simon will continue into this project, and an NMT graduate student will be hired to participate in JIVE IN NM.

It is important to emphasize the agreement reached with the OCA and IAS in France. They will provide to the project the instrument designs they have developed over the past several years, a fabricated Mach-Zehnder interferometer, and their expertise - shown by willingness to come to New Mexico for consultations and to host US team members. This contribution is crucial to the project's success.

Our partnerships and agreements with NASA and LANL scientists fill critical areas of expertise for the instrumentation and science goals of the project, and serve to help keep us aware of federal research priorities and opportunities. Supporting letters from all institutional partners (NMSU, NMT, LANL, OCA, IAS) that describe the planned partnerships, and commitment letters from NASA personnel are provided in Sections 5 and 6. In-person team meetings will be held at important times each year (see Sec. 1.f), and virtual interactions will be held quite frequently.

Future possibilities: In the near-term, the OCA and IAS scientists have also proposed for funding in Europe for a JIVE instrument, raising the exciting possibility of a collaboration centered around several Jovian instruments. We envision establishing a network of globally-distributed telescopes continuously observing the oscillations of giant planets, increasing the likelihood of transformational science. This is a similar model to the very successful solar oscillations networks. This would increase the chances for more partnerships of this kind, ensuring continued scientific progress, equipment utilization, and student training long after the initial three-year award period. Finally, it is reasonable to suggest that the success of JIVE could spur the development of a space-based instrument (like DSI), the way successful ground-based solar seismology experiments such as BISON and GONG led to dedicated space missions like NASA's SOHO and SDO. Indeed, inspired by the very positive reviews that came from the JUICE instrument proposal mentioned above, discussions with our NASA collaborators regarding proposing a future "flyby" instrument for seismology of Jupiter and Uranus have already begun.

1.f Timeline

The goals and objectives outlined in the proposal will be achieved by carrying out eight main tasks provided in the work plan in Figure 8. The roles and responsibilities of team members described in Section 1.j will demonstrate that there is sufficient expertise to achieve all goals in this project. The key milestones (M#) as indicated in Figure 8 are:

[2] Simon, who obtained her PhD from NMSU, was also a New Mexico Spacegrant scholar as a graduate student.

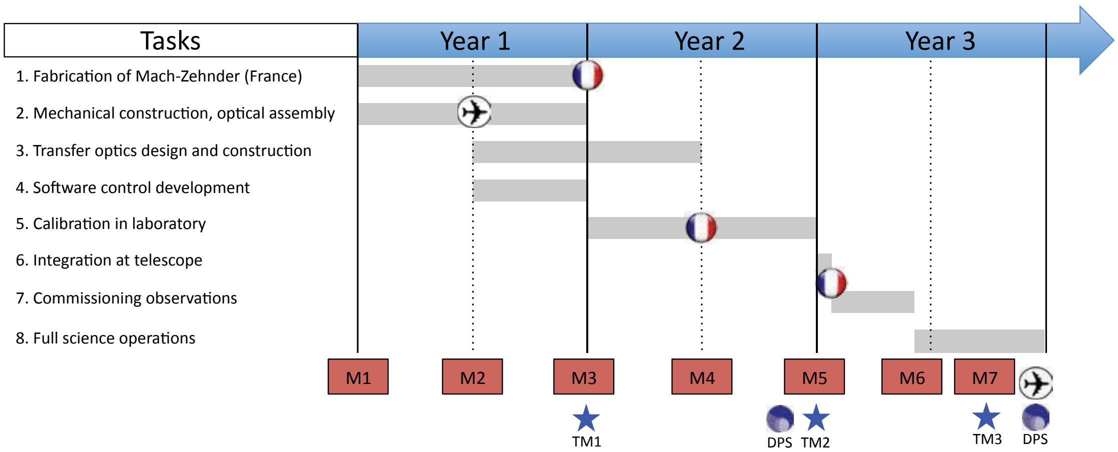

Figure 8: Timeline of main work tasks and key milestones. Three team meetings (TM#) will be held at critical times in the project, denoted by stars. Visits by French collaborators for instrument construction and consulting are given by the blue/white/red circles. Two trips to France are given by airplane symbols, while the Division of Planetary Science (DPS) meetings are noted at appropriate times for dissemination. The seven key milestones (M#) are described in the text.

M1 and M2: Hire graduate and undergraduate students. Immediately upon award notification an engineering student will begin participation in the project, while the NMSU astronomy graduate student will be recruited from an incoming pool of students. The NMT student will be selected from current candidates. At month 6, a trip to France to study details of the prototype and present the initial progress report will be carried out by Co-Is Voelz and/or Gaulme.

M3: After 1 year, the fully fabricated and tested Mach-Zehnder will be delivered from France to NMSU. At this time, a team meeting will be held with French and U.S. collaborators and serve as a design review. We will also plan the next steps of the integration of the optical and mechanical assembly.

M4: At month 18, another visit by French collaborators will occur to study our integration progress and software control operations, as well as the pre-optical configuration that was developed for the telescope. An instrument paper will be published on initial performance tests.

M5: **First light**, including packaging and transporting JIVE and mounting to the 1m telescope. A team meeting will be convened just prior to this to make sure all necessary calibrations have been completed using spectral lamps and other sources. Once the instrument is ready for installation, a final visit by French collaborators will be necessary for their expertise in the telescope coupling that was used with the prototype. Test observations of Venus and Saturn will begin.

M6: Beginning of full science observations of Jupiter. Saturn opposition occurs shortly after.

M7: First science paper on Jovian seismology from initial observations and confirmed mode detection. Science paper describing initial findings about Jupiter's atmosphere from direct wind measurements. A team meeting will be held to organize these papers and develop new observational strategies based on initial results. The DPS meeting will be held in Europe at the end of 2017 where we will present initial findings. We will also visit the French lab to report on performance quality and any possible design modifications that might be necessary. Possibly at this time a second instrument will be in construction from European funding sources, and our experience with JIVE will be discussed at this time.

1.g Sustainability

As described in Section 1.e, the planned and future partnerships will create many sustainable opportunities. JIVE IN NM *has an enormous potential to help develop research competitiveness in New Mexico, not only in the three-year EPSCoR award period, but well into the future.* Jovian seismology has never been done, and the results from this project will open up entirely new directions for research. For example, new avenues of theoretical work based on our findings of the planetary interiors is certain, and revised models will be required to explain them. As this happens, the science will be attractive to a broader community of planetary (and exoplanetary) scientists. The possibility of additional instruments to JIVE in a global network would allow for even better data and even more precise inferences of the interior structure and better monitoring of the variations of Jovian atmospheres.

Many specific possibilities exist for supplemental funding to continue and expand the scope of JIVE IN NM. Even within the jurisdiction, LANL's Institue for Geophysics, Planetary Physics and Signatures (IGPPS) promotes and coordinates basic research, such as "the understanding of the origin, structure and evolution of the Solar System." This program encourages university interactions with lab scientists performing creative and innovative research, and PI Jackiewicz had one of these awards for stellar seismology in the past. NASA's OPR program, which funded a tean project mentioned earlier, is another possibility, as are various basic planetary science and development programs within the NSF. Students can seek support from the NM Spacegrant program, which has funded five astronomy students at NMSU in the past three years. The successful demonstration of the JIVE instrument could realistically be used as a benchmark for a space mission and would fit nicely into the budget and payload of a NASA "Discovery Program" effort. *We will develop the appropriate expertise within our partnership to position ourselves for engaging in future science mission opportunities.*

1.h Dissemination

Project results and progress will be disseminated in standard ways with refereed publications in appropriate journals (*Icarus*, *ApJ*, etc.) and at national and international conferences (AAS, DPS, EPSC, IAU, etc.). Regular team meetings will keep all members aware of the status of JIVE IN NM, and partners at the three NASA centers ensure that NASA is aware of the project results. In particular, collaborator Simon at GSFC will assist with identifying appropriate dissemination channels at NASA. A project website will also be set up to collect information on team members, results, publications, and serve as the JIVE data access entry point for the community.

1.i Evaluation

The key milestones described in Section 1.f will serve as convenient metrics that will be used to assess progress. Targets such as conference presentations, publications, and selected follow-on funding proposals are external and objective means of evaluating the project's success and will be recorded in all reports. Other evaluation outcomes for the project and their metrics are:

1. *Contribute to and promote the development of research infrastructure in New Mexico in areas important to NASA's priorities.* Metrics: Number of participating partners, university faculty, and students; evidence of how EPSCoR activities have furthered jurisdiction priorities; financial commitment from jurisdiction and participating institutions (student fellowships, faculty hires, awards, etc.); extent to which collaborations with NASA partners have evolved and strengthened.

2. *Work in close collaboration with the New Mexico Space Grant Consortium (NMSGC) to promote rigorous STEM training, workforce development, and diversity.* Metrics: Number of graduate qualifying exams passed; number of student-participant graduates; number of student talks and presentations given at NMSGC and non-NMSGC events; number of publications with student authors, number and gender/ethnicity of students participating in program research.

Continuous refinement and improvement of our work plan will also be a key consideration in demonstrating the effectiveness of this program. As students will be employed with NASA EPSCoR funds, we will institute mechanisms for assessing their performance, including recording publication contributions and long-term tracking of future employment in STEM-related fields in industry or academia. Student data such as the number of participants who are underrepresented minorities and/or female will also be collected and distributed to the NMSGC and compiled in its reports. PI Hynes will provide evaluation reports and assessment of these metrics, along with feedback and strategies to increase program efficiency and success regarding science and education goals.

Tracking program progress: The research in this project aligns very strongly with the research interests at the relevant institutions in New Mexico, with NASA, and with planetary scientists internationally. As the science operations of JIVE ramp up and we seek follow-on funding to support the continued data acquisition and analysis, the same metrics discussed above will be used to assess progress toward self sufficiency. The potential for this research area to continue to grow in importance in NASA-related fields will be evaluated by monitoring NASA's planning documents, funded proposals, and calls for new research proposals during the award period. Our NASA partners will be instrumental in keeping the collaboration aware of directions for the future in this field.

Continuity through education: This EPSCoR program's broad scope involves instrumentation, seismology, and planetary atmospheres. Training in these fields gives JIVE IN NM student participants many options for career opportunities. For example, solar and stellar seismology is entering a golden age of discovery due to the tremendous amount of high-quality data from space missions such as NASA's *SDO* and *Kepler*. Familiarity with seismic techniques allows for relatively easy transition among diverse fields of astrophysics. Engineering students who have never worked at a telescope will obtain very valuable hands-on technical training with a working scientific instrument. This directly addresses the **education goal and objectives**.

We anticipate future cohorts of students beyond the third year of JIVE IN NM to participate in new scientific investigations. The 1m telescope will continue to operate, and JIVE is designed to be flexible enough to interface with larger telescopes. This will enable more detailed studies of Saturn's interior, as it is fainter than Jupiter on average and may prove difficult to adequately observe with a 1m telescope. NMSU owns a significant share of the 3.5m telescope at APO where instruments can be installed.

1.j Management

The management structure of the collaboration team is illustrated in Figure 9. Since the international partners have spent several years developing, constructing, and testing a prototype instrument successfully, the U.S. team has modeled this structure to facilitate communication during the construction stage and science operations. Team meetings will also be a critical component. Open communication channels will exist through all points in this structure to get the instrument built and operational on time and on budget, and ready for first light and full science operations in the third year.

Defined science roles are complementary in terms of realizing the seismology and atmosphere science goals. The scientific expertise is well balanced by the interiors data-analysis group at NMSU, the atmospheric dynamics expert at NMT, and the theoretical work in planetary interior physics at LANL. The instrumentation team is also extremely qualified. Each of the three main areas has a NASA counterpart, as well as a counterpart from collaborators in France. Students will be involved in all project aspects. Below are listed the participants and their assigned roles and responsibilities within the overall management structure and work plan:

- **Administrative PI: Dr. Patricia Hynes**, Director of the New Mexico NASA EPSCoR Program and of the New Mexico Space Grant Consortium. Hynes will oversee the project management, and collect all project evaluation data and provide feedback to the Co-Is on its progress toward its benchmarks, particularly regarding student participation, sustainability, and partnerships.
- **Project PI: Dr. Jason Jackiewicz**, Assistant Professor of Astronomy at NMSU. Expertise: inversion of seismological data. Jackiewicz will oversee all aspects of the instrument assembly, its integration at the telescope, and the subsequent data analysis. He will manage the recruiting, hiring, and mentoring of the NMSU astronomy graduate student and the undergraduate students. He will organize the team

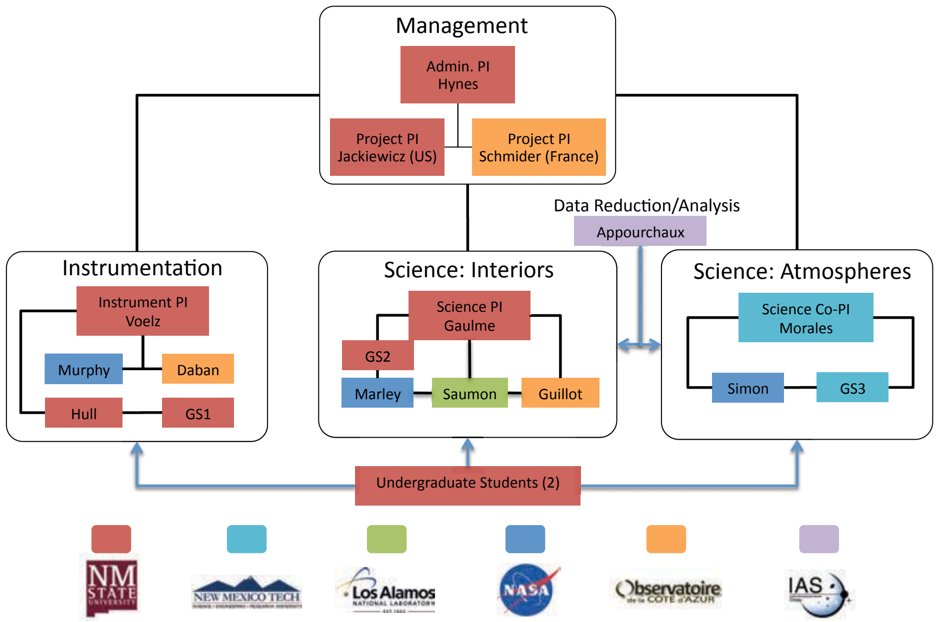

Figure 9: Management and collaboration structure for this EPSCoR project. Each of the science and instrumentation project areas have lead PIs with corresponding NASA and French partners. Students are involved in all areas. This structure is motivated by the project's defined goals.

meetings and any visits by French counterparts, and be in frequent communication with counterpart Schmider. He will also carry out the seismic inversions and the interior-structure determination with NASA partner Marley, Gaulme, Saumon, and Guillot in the third year.

• **Instrument PI: Dr. David Voelz**, Professor of Electrical and Computer Engineering at NMSU. Expertise: instrumentation, optical systems, software control. Voelz will manage the instrumentation development and construction in his lab with the assistance of engineering technician (**Robert Hull**), including the pricing and ordering of needed fabricated parts. He will hire and mentor the NMSU engineering graduate student, and assist with undergraduate training tasks. He will directly communicate with instrument specialists Daban and NASA partner Murphy. Voelz will also manage the instrumental software control package with students.

• **Science PI: Dr. Patrick Gaulme**, staff astronomer at Apache Point Observatory at NMSU. Expertise: stellar and planetary seismology, planetary observations, and spectro-imaging data analysis. Gaulme will contribute his expertise in similar instrumentation during the construction phase and be involved in optical testing and calibration, as well as software control development. He will be the lead in coupling JIVE to the 1m telescope and in the initial observations and data analysis, along with counterparts Guillot and Appourchaux.

• **Science Co-PI/Institutional PI: Dr. Raúl Morales-Juberías**, Associate Professor of Physics at NMT. Expertise: atmospheric studies of giant planets, Jovian climatology. Morales-Juberías will lead the analysis of the atmospheric data obtained from JIVE, and hire a graduate student at NMT. He will collaborate closely with NASA partner Simon in developing the tools (observational and numerical) to study Jovian climatology. They will help devise new atmospheric data-analysis tools and models before first light. He will serve as a member of the NMSU astronomy student's external PhD committee.

• **Collaborator Dr. Didier Saumon**, Scientist at Los Alamos National Laboratory. Expertise: planetary interior structure, equations of state of astrophysical matter. Saumon will attend team meetings and help plan the interior modeling that will be needed to compare to observed frequency inferences. His current work on improved equations of state of deuterium will be critical in the interpretation of our findings. As all other collaborators, he is willing to host students involved in JIVE research.

• **NASA collaborators: Dr. Mark Marley**, Research scientist at NASA Ames. Expertise: planetary interior and atmospheric modeling, brown-dwarf stars, seismology. **Dr. Neil Murphy**, Research scientist at NASA JPL. Expertise: Instrumentation, planetary observations and seismology. **Dr. Amy Simon**, Senior scientist at NASA GSFC. Expertise: giant-planet atmospheres, mission definition, instrument operations, and data analysis. NASA partners will each participate in the three main project areas: instrumentation, interior science, and atmospheric science. They will also attend team meetings, participate in project dissemination through publications and conference presentations, and help keep NASA administrators aware of JIVE IN NM's successes.

• **Three graduate students and two-six undergraduate students** will be supported by this effort. One graduate student will be enrolled in astronomy and one in engineering at NMSU, and one in physics at NMT. NMSU undergraduates will have the chance to work with the project for all three years, if possible, or two different ones will be hired each year. Students will be involved in all aspects of this project, such as ordering parts, developing software control packages for JIVE, traveling to conferences, helping organize team meetings, working with collaborators, JIVE observations, and scientific research. They will work together in the optics lab, in the computer lab, and at the telescope after installation.

• **Dr. F.-X. Schmider, Dr. J.-B. Daban, and Dr. T. Guillot** are scientists at the OCA, France, whose expertise corresponds to their roles (for the French DSI instrument) as PIs of the project, instrument, and science, respectively. They and their team have developed and built the prototype instrument. **Dr. T. Appourchaux** is a scientist at the IAS, France, whose expertise is in instrumentation, as well as reduction and time-series analysis of data from the Sun, stars, and planets. His role is crucial for assessing the quality of the data and how it meets the science requirements (SNR, sensitivity, etc.). Besides the interferometer component, these collaborators will provide the designs of the prototype and the initial control software package. Once per year a key person(s) will visit NMSU to assist with the construction, installation, and operation of JIVE. They will host US participants (possibly students as well) as the project progresses so we can report on JIVE's performance. Schmider is also leading the effort to obtain European funding to build additional instruments.

1.k Prior NASA EPSCoR Research Support

Below are the details of two successful NASA EPSCoR projects administered by PI Hynes that have been completed in the past five years. Those and two current projects ("New Mexico Solar and Stellar Seismology," NNX09AP76A, PI McNamara; and "New Mexico Exoplanet Spectroscopic Survey Instrument (NESSI)," NNX09AP69A, PI Creech-Eakman) have greatly contributed to the ability to submit this current proposal. Listed here are the outcomes of the completed EPSCoR projects' objectives:

1. Structural Health Monitoring and Self-Healing of Aerospace Structures, **NNX07AT64A**. PI Burton, NMSU, $741,144 (10/1/2007 - 9/30/2011). *Outcome #1:* A new methodology for detecting a self-loosening failure in bolted joints that uses electrical resistance as a diagnostic parameter was developed. *Outcome #2:* Self-repairing materials for aerospace structures subjected to accumulated damage and methods to monitor the self-healing process were developed. *Outcome #3:* NMSU is now nationally competitive in aerospace engineering education and research. *Outcome #4:* 37 journal papers and 35 conference papers/presentations reflecting results obtained in the framework of the project have been published. *Outcome #5:* New collaboration with Los Alamos National Laboratory (LANL) led to a funded project in health monitoring. NASA and jurisdiction coordination: Structural health monitoring and damage prognosis are now recognized as important research areas in the NMSU College of Engineering.

2. Infrared Instrument Development for In-Situ Organic Detection, **NNX08AV85A**. PI Chanover, NMSU, $659,386 (7/3/2008 - 1/2/2013). *Outcome:* Development and testing was completed of a point spectrometer based on acousto-optical tunable filter technology to be used for the screening and corroboration of samples collected in situ from planetary surfaces. NASA and jurisdiction coordination: Currently, the Co-I's (Voelz and Simon) are in discussions at GSFC regarding the possibility of proposing a similar instrument for the Mars 2020 rover mission.

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Director, New Mexico Space Grant Consortium
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Administrative Lead, Center of Excellence for Commercial Space Transportation

Education:	B.S.	NMSU	English	1969
	M.S.	NMSU	Higher Education Management	1992
	Ph.D.	NMSU	Business Administration	1998

Appointments:

NM Admin. Lead	FAA COE for Commercial Space Transportation	2010-present
Director	New Mexico Space Grant Consortium (NMSGC)	1998-present
Director	New Mexico NASA EPSCoR	2007-present
Executive Director	NMSU Space Development Foundation	2006-present
Co-Chair	Advancing Leaders Program	2005-2011
Member	President's Commission on the Status of Women	2004-2010
Chair	NSF ADVANCE Research Committee at NMSU	2002-2004
Member	National Space Biomedical Research Institute Industry Forum	2009

Elected Offices:

Treasurer	National Space Grant Foundation	2006-2013
Treasurer	National Space Grant Alliance – 501C4 Corporation	2002-2004
Treasurer	Southwest Space Task Force	2002-2004
Board Member	National Space Grant Alliance - current Board member	2002-2011
Board Member	National Space Grant Executive Committee	2002-2004
Member	National Space Grant Strategic Planning Committee	2002

University Wide Activities:

Department Head	Space Grant	2003-present
Full Professor	NMSU Department of Government	2011-present
Founding Director	NMSU Teaching Academy	2001
Officer	NMSU Development Officer	2003-present
Chair	NMSU Leadership Institute	2006-present
Chair	Staff Roles Sub-committee for NMSU President's Roles and Rewards Task Force	2003
Award	Research Achievement Award	2009, 2010, 2011, 2012

Statewide Programs Created and Managed:

Management of New Mexico Space Grant Consortium
Management of New Mexico NASA EPSCoR
Management of FAA Center of Excellence for Commercial Space Transportation

International Symposium for Personal and Commercial Spaceflight (ISPCS)
Statewide Student Launch Program
Scholarship and Fellowship Program
Summer Internship Program
Research Enhancement Program
Reduced Gravity Student Flight Opportunities Program
Gaining Retention and Achievement for Students Program (GRASP)

Current Funding Responsibility:

NASA – New Mexico Space Grant Consortium - PI	$2,875,000
National Space Grant Student Launch Program: A Consortium of Space-faring States	$500,000
NASA – Summer of Innovation – PI	$370,385
NASA – EPSCoR - PI	694,181
NASA – EPSCoR - PI	748,716
NASA – EPSCoR - PI	732,016
FAA – Center of Excellence for Commercial Space Transportation	40,000
NMSU Endowments - Executive Director	388,725
National Space Grant Foundation	287,985
Total	$ 3,262,008

Selected Publications

Hynes, P.C. (2014) The Development of a Framework to Capture a Body of Knowledge (BOK) for Commercial Spaceport Practices, IAC Conference (submitted)

Hynes P.C. (2013) Develop Framework for Commercial Spaceport Operations that creates a Body of Knowledge that Captures Best Practices, a paper presented at Annual Technical Meeting for the Center of Excellence for Commercial Space Transportation. Washington, DC

Hynes P.C. (2012) Space Transportation, a paper presented at TEDX, Kiruna Sweden

Hynes P.C. (2012) Integrated into the Spaceport Operations Framework Applicable Documents & Relevant Materials; Enable Documents to be Found by Title, Subject or Keyword: Assure Copyright Protections, A paper presented at the Annual Technical Meeting for the Center of Excellence for Commercial Space Transportation. Socorro, NM

Hynes, P.C. (2011) Launch the Future of Commercial Space Transportation Together, A paper presented at the Annual Technical Meeting for the Center of Excellence for Commercial Space Transportation. Titusville, FL

Hynes, P.C. (2009) The Role of the International Symposium for Personal and Commercial Spaceflight (ISPCS) in Growing the Global Commercial Space Industry. A paper presented at Space 2009, Pasadena, CA

Hynes, P.C, (2009) International Symposium for Personal and Commercial Spaceflight. A paper presented at the 60th International Astronautical Congress Space Education and Outreach Symposium, Daejeon, Republic of Korea.

Hynes, P.C. (2008) The role of the International Symposium for Personal and Commercial Spaceflight play in enabling the growth of human spaceflight related business enterprises. A paper presented at the International Astronautical Federation, Glasgow, Scotland.

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Education

- **Boston College** — Chestnut Hill, MA, USA
  Ph.D. in theoretical condensed-matter physics — *1998 – 2005*
- **Duquesne University** — Pittsburgh, PA, USA
  B.S. Physics — *1994 – 1998*

Employment

- **New Mexico State University** — Las Cruces, NM
  Assistant Professor of Astronomy — *Aug. 2008 - present*
- **Max Planck Institute for Solar System Research** — Katlenburg-Lindau, Germany
  Post-doctoral fellow in astrophysics — *Sep. 2005 - Jul. 2008*
- **Boston College** — Chestnut Hill, MA
  Research assistant in condensed-matter physics — *2001 - 2005*

Relevant Publications

- **Surface activity and oscillation amplitudes of Red Giants in eclipsing binaries**. P. Gaulme, J. Jackiewicz, T. Appourchaux, and B. Mosser. *Astrophysical Journal* (accepted) (2014).

- **Meridional flow in the solar convection zone I: Measurements from GONG data**. S. Kholikov, A. Serebryanskiy, J. Jackiewicz. *Astrophysical Journal* (accepted) (2014)

- **Red giants in eclipsing binary systems: Asteroseismic analysis of 53 candidates from Kepler data**. P. Gaulme, J. McKeever, M. Rawls, J. Jackiewicz, B. Mosser. *Astrophysical Journal*, **767** 82 (2013) [arXiv:1303.1197]

- **Solar H-α oscillations from intensity and Doppler observations**. J. Jackiewicz and K.S. Balasubramaniam. *Astrophysical Journal*, **765** 15 (2013) [arXiv:1301.2825]

- **Forward and inverse modeling for Jovian seismology**. J. Jackiewicz, N. Nettelmann, M. Marley, J. Fortney. *Icarus*, **220**, 844-854 (2012) [arXiv:1206.4380]

- **Multichannel three-dimensional OLA inversion for local helioseismology**. J. Jackiewicz, A. C. Birch, L. Gizon, S. Hanasoge, T. Hohage, J.B. Ruffio, M. Svanda. *Solar Physics*. **276**, 19 (2012). [doi:10.1007/s11207-011-9873-8]

- **The classification of Kepler B-star variables**. B.J. McNamara, J. Jackiewicz, J. McKeever. *Astronomical Journal*, **143**, 101 (2012). [arXiv:1202.2329]

- **The forward and inverse problems in time-distance helioseismology**. J. Jackiewicz, L. Gizon, A.C. Birch. *Journal of Physics: Conference Series*. **118**, 012033 (2008). [doi:10.1088/1742-6596/118/1/012033]

- **Time-distance helioseismology: Sensitivity of f-mode travel times to flows**. J. Jackiewicz, L. Gizon, A.C. Birch, T.L. Duvall Jr. *Astrophysical Journal*, **671**, 1051-1064 (2007). [arXiv:0708.3554]

Other Information

Related grant and management activities

- PI: "CAREER: New Constraints on the Solar Dynamo Using Helioseismology." NSF Career Program, 2014 - 2019
- PI: "Probing stellar interiors with asteroseismology." IGPP Program, 2011 - 2013 (LANL)
- PI: "Characterizing the top of the Red Giant Branch using Kepler drop-list stars." Kepler GO Program, 2011 - 2013 (NASA)
- Co-I: "New Mexico Solar and Stellar Seismology." EPSCoR Program, 2009 - 2014 (NASA)
- Co-I: "Developing Physics-Based Procedures for Local Helioseismic Probing of Sunspots and Magnetic Regions." SDO Science Center helioseismology team, 2009 - 2014 (NASA)
- Co-PI: "A PAARE Program Between New Mexico State University, the National Solar Observatory, and the AFRL." PAARE Program, 2009 - 2013 (NSF)
- Co-I: "A fresh look at Jovian seismology." Outer Planets Research Program, 2011 - 2013 (NASA)
- PI: "The National Solar Observatorys Annual Solar Physics Workshops of the American Astronomical Society." 2010 - 2014 (NSF)
- Co-I: "The influence of subsurface (and surface) dynamics on the activity cycle." LWS TR&T, 2012 - 2014 (NASA)
- Co-head of New Mexico State University "Solar, Stellar, and Exoplanets Group"
- Hosted and organized the 2011 AAS Solar Physics Division meeting in Las Cruces, NM.

Collaborators: A.C. Birch (MPS), D. Braun (CoRA), R. Cameron (MPS), J.C.-Dalsgaard (Aarhus Univ.), T. L. Duvall Jr. (NASA Goddard), P. Gaulme (NMSU), L. Gizon (MPS), J. Guzik (LANL), S. Hanasoge (MPS, Princeton), F. Hill (NSO), R. Komm (NSO), M. Marley (NASA Ames), R.T.J. McAteer (NMSU), B.J. McNamara (NMSU), N. Murphy (JPL), J. Neff (Coll. of Charleston), N. Nettelmann (SDSC), M. Rempel (HAO), F.-X. Schmider (OCA), M. J. Thompson (HAO), K. Uytterhoeven (IAC)

Advising: Currently supervising 4 graduate students at NMSU in helioseismology, asteroseismology, and exoplanets.

Completed PhD advisees: M. Kirk (2013).

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EDUCATION

Ph.D. (Electrical Engineering): University of Illinois, Champaign, IL 1987
M.S. (Electrical Engineering): University of Illinois, Champaign, IL 1983
B.S. (Electrical Engineering): New Mexico State University, Las Cruces, NM 1981

EMPLOYMENT

Professor: Klipsch School of ECE, New Mexico State University 2010– present
Associate Professor: Klipsch School of ECE, New Mexico State University 2001–2010
Engineer/Scientist, GS-12 to GS-15: Air Force Research Lab, Albuquerque, NM 1987–2001

RELEVANT PUBLICATIONS (* denotes student-led publication)

1. Tawalbeh*, R., D. Voelz, D. Glenar, X. Xiao, N. Chanover, R. Hull, D. Kuehn, "Infrared acousto-optic tunable filter (AOTF) point-spectrometer for detection of organics on mineral surfaces," Opt. Eng., 52, no. 6, 063604-063604, 2013.
2. Bannister*, S. M., L. E. Boucheron, and D. G. Voelz, "A numerical analysis of a frame calibration method for video-based all-sky camera systems, " Publications of the Astronomical Society of the Pacific , Vol. 125, No. 931, pp. 1108-1118, 2013.
3. Chanover, N., R. Tawalbeh, D. Glenar, D. Voelz, X. Xiao, K. Uckert, P. Boston, S. Getty, W. Brinckerhoff, P. Mahaffy, T. Cornish, S. Ecelberger, "Rapid assessment of high value samples: An AOTF-LDTOF spectrometer suite for planetary surfaces," Aerospace Conference, 2012 IEEE , vol., no., pp.1,10, 3-10, 2012.
4. Nairat*, M. and D. Voelz, "Performance characteristics of a scanning laser imaging system through atmospheric turbulence", Opt. Eng. 51, 101708, 2012.
5. Krishna*, T. V. T., C. D. Creusere, D. G. Voelz, "Passive polarimetric imagery-based material classification robust to illumination source position and viewpoint," IEEE Trans. Image Processing, vol.20, no.1, pp.288-292, 2011.

RELATED ACTIVITIES

Research. PI: Novel Detection of Optical Orbital Angular Momentum, AFRL, 2/13-5/14; Co-PI: Wave Optics of Deep Atmospheric Turbulence, AFOSR, 8/12-8/15; Co-PI: Development of Plasmon-assisted Quantum Dot Sensors, DoD/ARL, 2/12-2/15; Co:PI: Pulse Complexity Based LIDAR Scene Modeling, NGA, 12/12-12/14; Co-PI: Exploring Surface Texture and Reflectivity of Cave and Related Surface Environments as Harbingers of Life, NASA/EPSCoR-faculty engagement, 6/12-6/14.
Professional Service. SPIE Kingslake Award Committee (best paper). Program committee for SPIE Unconventional Imaging and OSA Propagation through and Characterization of Distributed Volume Turbulence (pcDVT); SPIE Fellow.

ADVISING

Currently advising 5 Ph. D. and 2 M. S. students in electrical engineering - optics emphasis. Completed Ph. D. advisees: R. Tawalbeh, D. Tofsted, M. Nairat, S. Basu, X. Xiao, Q. Wang; and 33 completed M. S. advisees.

Co-Investigator Dr. Patrick Gaulme

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EDUCATION

- **Université Paris VI** — Paris, France
  PhD in Astrophysics — *December 1st, 2005*
- **Université Paris XI and Paris VI** — Orsay, France
  MSc in Physics — *1997-2002*

EMPLOYMENT

- **Apache Point Observatory & NMSU** — Sunspot, NM
  Observing Specialist & researcher — 2014 -
- **New Mexico State University (NMSU)** — Las Cruces, NM
  Post Doc researcher — *2011- 2013*
- **Institut d'Astrophysique Spatiale (IAS) & LESIA-Observatoire de Paris** — Orsay, France — *2007-2011*
  Post Doc researcher and Teacher assistant
- **Observatoire de la Côte d'Azur (OCA)** — Nice, France
  Post Doc researcher — *2006-2007*

RELEVANT PUBLICATIONS (In total: 37 refereed articles, 10 as first author)

- *Seismology of Giant Planets.* Gaulme, Mosser, Guillot, and Schmider. Extraterrestrial Seismology, Book Chapter, Cambridge U. Press, submitted.
- *Surface Activity and Oscillation Amplitudes of Red Giants in Eclipsing Binaries.* Gaulme et al., ApJ in press (2014)
- *Red Giants in Eclipsing Binary and Multiple-Star Systems: Modeling and Asteroseismic Analysis of 70 Candidates from Kepler Data.* Gaulme et al., ApJ 767, 82 (2013)
- *Detection of Jovian seismic waves: a new probe of its interior structure.* Gaulme et al., A&A 531, 104 (2011)
- *SYMPA, a dedicated instrument for Jovian seismology. II. Real performance and first results.* Gaulme et al., A&A, 490, 859 (2008)
- *SYMPA, a dedicated instrument for Jovian seismology. I. Principle and performance.* Schmider et al., A&A 474, 1073 (2007)
- *Coupling of acoustic waves to clouds in the jovian troposphere.* Gaulme & Mosser, Icarus 178, 84 (2005)

OTHER INFORMATIONS

- **Kepler activities**: Member of Kepler Asteroseismic Science Consortium (KASC).
- **Closest collaborators:** J. Jackiewicz (NMSU), T. Appourchaux (IAS), B. Mosser (Obs. Paris), F.X. Schmider (OCA), T. Guillot (OCA), N. Murphy (JPL), J. Leibacher (NSO), J. Guzik (LANL), J. Gay (OCA), Baudin F. (IAS), P. Boumier (IAS), W. J. Chaplin (U. Birmingham), N. Chanover (NMSU)
- **Advising:** Currently co-advising 2 graduate students in asteroseismology

Dr. Raúl Morales-Juberías

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Research Interests

My main research interest is planetary atmospheric dynamics, particularly the dynamics of gas-giants, a large class that includes Jupiter, Saturn, Uranus, Neptune, extrasolar giant planets, and brown dwarfs, and for which there are now extensive observations from ground-based telescopes and interplanetary spacecraft. Researching the atmospheres of different bodies in a comparative way is important because their differences in mass, volume, rotation regimes and energy balances give us a broad critical understanding on how these systems work, which could not be accomplished by studying the Solar System alone.

Academic Appointments

New Mexico Tech. Socorro, New Mexico USA.
Associate Professor of Physics — **2011-present**
Assistant Professor of Physics — **2005-2011**

University of Louisville. Louisville, Kentucky USA.
Postdoctoral Research Associate — **2003-2005**

Education

Univiversity of the Basque Country. Bilbao, Spain.
PhD Applied Physics. Planetary Sciences. — **1998-2002**

University of La Laguna. Tenerife, Spain.
MS Astrophysics. — **1996-1998**

University of the Basque Country. Bilbao, Spain.
BS Physics. — **1992-1996**

Professional Memberships

American Astronomical Society Division of Planetary Sciences (AAS-DPS)
American Geophysical Union (AGU)
Sigma Pi Sigma Physics Honors Society (ΣΠΣ)

Relevant Refereed Journal Publications

1. **Morales-Juberías, R.** and T. E. Dowling (2013). Jupiter's Great Red Spot: Fine-Scale Matches of Model Vorticity Patterns to Prevailing Cloud Patterns. *Icarus* **225**, 216-227.
2. R. Cosentino, **R. Morales-Juberías**, T.E. Dowling and B.J. Butler (2013). Mechanistic Generation of Atmospheric Oscillations in Gas Giant Planets. *2013 AGU Fall Meeting* **P21B-1722**
3. Li, L., R. K. Achterberg, B.J. Conrath, P.J. Gierasch, M. A. Smith, A. A. Simon-Miller, C.A. Nixon, G.S. Orton, F.M. Flasar, K.H. Baines, **R. Morales-Juberías**, A.P. Ingersoll, A. R. Vasavada, A.D. Del Genio, R.A. West, S.P. Ewald (2013). Strong Temporal Variability Over One Saturnian Year: From Voyager to Cassini. *Scientific Reports of Nature Publishing Group* **3** Article number 2410.
4. **Morales-Juberías, R.**, K. M. Sayanagi, T. E. Dowling, and A.P. Ingersoll (2011). Emergence of Polar-Jet Polygons from Jet Instabilities in a Saturn Model. *Icarus* **211**, 1284-1293.
5. Sayanagi, K. M., **R. Morales-Juberías**, and T. E. Dowling (2010). Saturn's Northern Hemisphere Ribbon: Simulations and Comparison with the Meandering Gulf Stream. *Journal of the Atmospheric Sciences* **67**, 2658-2678.
6. Morales-Juberías, R., E. S. Brindle, and T. E. Dowling (2009). Characterization and Simulations of Jupiter's South South Temperate Belt Spots. *Icarus* **206**, 747-754.

Biographical Sketch: Didier Saumon (collaborator)

Didier Saumon's research expertise combines stellar and dense matter physics and has been applied to modeling brown dwarfs, giant planets, exoplanets, and white dwarfs. His two most significant contributions are computing equations of state for hydrogen and helium that are widely used for modeling the above objects, and introducing non-equilibrium chemistry in modeling and analyzing brown dwarf spectra. He has been the PI of several successful NSF and NASA research programs and has authored or co-authored 90 referred publications. His work has been cited 6800 times.

EDUCATION:

1990: Ph.D. Physics, University of Rochester
1985: M.S. Astronomy, University of Illinois at Urbana-Champaign
1983: B.Sc. Physique, Université de Montréal

PROFESSIONAL EXPERIENCE:

2010- Scientist 4, X-Computational Physics Division, Los Alamos National Lab.
2008- 2010 Scientist 3, Applied Physics Division, Los Alamos National Laboratory
2002- 2008 Technical Staff Member, Applied Physics Division, Los Alamos National Laboratory
1996-2002 Assistant Professor of Physics & Astronomy, Vanderbilt University
1994-1996 Senior Research Associate, University of Arizona
1990-1993 Research Associate, University of Arizona

SELECTED BIBLIOGRAPHY:

P. Bodenheimer, G. D'Angelo, J.J. Lissauer, J.J. Fortney & **D. Saumon**, "Deuterium burning in massive giant planets and low-mass brown dwarfs formed by core-nucleated accretion," *Astrophys. J.*, 770, 120 (2013)

C. Starrett & **D. Saumon,** "Electronic and ionic structures of warm and hot dense matter," Phys. Rev. BE, 87, 013104 (2013)

D. Saumon & M.S. Marley, "The evolution of L and T dwarfs in color-magnitude diagrams," *Astrophys. J*., 689, 1327 (2008)

D. Saumon, M.S. Marley, M.C. Cushing, S.K. Leggett, T.L. Roellig, K. Lodders & R.S. Freedman,"Ammonia as a tracer of chemical equilibrium in the T7.5 dwarf Gliese 570D," *Astrophys. J.*, 647, 1079 (2006)

J.J. Fortney, **D. Saumon**, M.S. Marley, K. Lodders & R.S. Freedman, "Atmosphere, interior, and evolution of the metal-rich transiting planet HD 149026b," *Astrophys. J*., 642, 495 (2006)

T. Guillot, D.J. Stevenson, W.B. Hubbard **& D. Saumon**, "The interior of Jupiter," (review) in *Jupiter – The planet, satellites and magnetosphere*, F. Bagenal, W. McKinnon & T. Dowling, eds. (University of Arizona Press: Tucson), (2005)

D. Saumon & T. Guillot, "Shock compression of deuterium and the interiors of Jupiter and Saturn," *Astrophys. J*., 609, 1170 (2004)

D. Saumon, G. Chabrier, & H.M. Van Horn, "An equation of state for low-mass stars and giant planets,'' *Astrophys. J. Supp*., 99, 713 (1995)

CURRICULUM VITAE

Mark S. Marley
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Education

Ph.D. in Planetary Sciences (February, 1990)
Minor in Optical Sciences
The University of Arizona, Tucson
Thesis title: *Nonradial Oscillations of Saturn: Implications for Ring System Structure*
Advisor: Dr. William B. Hubbard

B.S. in Geophysics and Planetary Science (June, 1984)
California Institute of Technology

Current Position

- Research Scientist, NASA Ames Research Center (August 2000 - present)

Previous Positions

(May 1999 – August 2000) Assoc. Prof. of Astronomy, New Mexico State Univ. (with tenure)
(January 1993 – April 1999) Assistant Professor of Astronomy, New Mexico State University
(February 1990 - December 1992) National Research Council, Resident Research Associate

Awards: NASA Medal for Exceptional Scientific Achievement (2007); H. Julien Allen Award (2011)

Research Interests: planetary atmospheres, jovian planets, extrasolar planets, and brown dwarfs

Selected Relevant Publications *(120 refereed articles, 7500 citations)*

Marley, M. (2014) Saturn Ring Seismology: Looking Beyond First Order Resonances, *Icarus,* in press.
Marley, M., Saumon, D., Cushing, M., Ackerman, A., Fortney, J. and Freedman, R. (2012) Masses, Radii, and Cloud Properties of the HR 8799 Planets. *Astrophys. J.* **754**, 135.
Saumon, D., Marley, M.S., Abel, M., Frommhold, L. & Freedman, R. (2012) New H_2 Collision-induced Absorption and NH_3 Opacity and the Spectra of the Coolest Brown Dwarfs. *Astrophys J.,* **750**, 74
Mainzer, A., et al. (2011) The First Ultra-cool Brown Dwarf Discovered by the Wide-field Infrared Survey Explorer. *Astrophys J.*, **726**, 30.
Marley, M. and Sengupta, S. (2011) Probing the physical properties of directly imaged gas giant exoplanets through polarization. *MNRAS* **417**, 2874.
Cahoy, K.L., Marley, M.S., & Fortney, J.J. (2010) Exoplanet Albedo Spectra and Colors as a Function of Planet Phase, Separation, and Metallicity. *Astrophys. J.*, **724**, 189.
Marley, M.S., Fortney, J.J., Hubickyj, O., Bodenheimer, P., & Lissauer, J.J. (2007) On the Luminosity of Young Jupiters, *Astrophys. J.* **655**, 541-549.
Marley, M., Saumon, D., Guillot, T., Freedman, R., Hubbard, W., Burrows, A., Lunine (1996) On the Nature of the Brown Dwarf Gliese 229B, *Science* **272** 1919.
Marley, M.S. (1994) Seismological consequences of the collision of comet Shoemaker-Levy/9 with Jupiter, *Astrophys. J. Let.* **427**, L63-L66.
Marley, M.S. and Porco, C.C. (1993) Planetary acoustic mode seismology: Saturn's rings, *Icarus* **106**, 508-524.
Marley, M.S. (1991) Nonradial oscillations of Saturn, *Icarus* **94**, 420-455
Marley, M.S., Lunine, J.I., and Hubbard, W.B. (1990) The periodicities in the infrared spectra of G29-38: An oscillating brown dwarf?, *Astrophys. J. Let.* **348**, L37-L40.
Hubbard, W.B. and Marley, M.S. (1989) Optimized Jupiter, Saturn, and Uranus Interior Models, *Icarus* **78**, 102-118.

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Education

- B.Sc., Physics, Imperial College, London, 1981
- Ph.D., Space Plasma Physics, Imperial College, London, 1987

Experience Related to the Investigation

Murphy has been a JPL employee since 1992, during which time he has a number of science leadership positions

- Section Staff, Astrophysics and Space Sciences Section, (2011-)
- Manager, Strategic University Research Partnerships Program, (2011-)
- Space and Astrophysical Plasmas Group Supervisor (2002–2011)
- Manager, Heliophysics Advanced Concepts Office (2001-11)
- Science Lead, JPL's Advanced Project Design Team (Team-X) (1999-2001)
- Research Scientist, Space Physics Element (1997–2001)
- Galileo project, Energetic Particle Detector/Heavy Ion Counter Instrument Scientist (1992-1997)

Patents

Rogers, W. E., Erlandson, R. E., Hargis, C. B., Murphy, N., Apparatus and system for wide-angle narrow band optical detection in daylight, US patent 7,570,426 B2, 2009

Selected Publications

Joyce, C. J., C. W. Smith, P. A. Isenberg, S. P. Gary, N. Murphy, P. C. Gray, and L. F. Burlaga, Observation of Bernstein Waves Excited by Newborn Interstellar Pickup Ions in the Solar Wind. *The Astrophysical Journal*, **745**, 112, 2012.

Joyce, Colin J., Charles W. Smith, Philip A. Isenberg, Neil. Murphy, and Nathan A. Schwadron. Excitation of low-frequency waves in the solar wind by newborn interstellar pick-up ions H+ an He+ as seen by Voyager at 4.5 AU, *Astrophysical Journal*, 724:1256–1261, 2010

Moretti, P.F., F. Berrilli, A. Bigazzi, S.M. Jefferies, N. Murphy, L. Roselli, M.P. Di Mauro, Future instrumentation for solar physics: a double channel MOF imager on board ASI Space Mission ADAHELI, *Astrophys Space Sci.* 328: 313–318, 2010

McComas, D. J., et al, Understanding coronal heating and solar wind acceleration: Case for in situ near-Sun measurements, *Rev. Geophys.*, *45*, RG1004, doi:10.1029/2006RG000195., 2007

Murphy, N., E.J. Smith, W. Rodgers and S. Jefferies, Chromospheric observations in the Helium 1083nm line – A new instrument, *Proc. Solar Wind 11 – SOHO 16 "Connecting the Sun and heliosphere" ESA SP-592*, 2005.

Murphy, N., E.J. Smith and N. A. Schwadron, Strongly Underwound magnetic fields in co-rotating interaction regions: Observations and Implications, *Geophys. Res. Lett.,* 29, (22) 2066, doi:10.1029/2002GL015164, 2002

Cohen, C.M.S., T.L. Garrard, E.C. Stone, J.F. Cooper, N. Murphy and N. Gehrels, Io encounters past and present: A heavy ion comparison, *J. Geophys. Res*., 105, A4, 7775, 2000

Biography: Dr. Amy A. Simon

Dr. Simon received her BS in Space Sciences from the Florida Institute of Technology in 1993, and her PhD in Astronomy in 1998 from New Mexico State University. She joined NASA in 2001, after a postdoctoral position at Cornell University. Her scientific interest is in the study of giant planet atmospheres, including the cloud structure, dynamics, chemistry, and temporal evolution. She currently serves as the Senior Scientist for Planetary Atmospheres Research at the NASA Goddard Space Flight Center, and is an author on more than 65 published manuscripts, two book chapters, and more than 210 scientific meeting abstracts and conference proceedings. She has several spaceflight mission and instrument development roles, as well.

In addition, Dr. Simon has participated in future mission concept development, serving on NASA Science Definition Teams and leading mission design studies. She has served in advocacy and leadership roles for the scientific community, with professional society positions, as well as on the Planetary Science Decadal Survey. She is a frequent reviewer of manuscripts and funding proposals. Finally, she is active in public outreach, giving numerous public lectures and events, producing two narrated movies for the NOAA science on a sphere, and serving as a frequent scientific collaborator for museums and popular science magazines.

Spaceflight Mission Experience:

- Spectral ImageR/Spectrometer for Europa, Co-Investigator/Deputy Instrument Scientist: design and radiation testing for the future NASA Europa Clipper.
- ESA JUICE Janus, Co-investigator: L-class mission to Europa and Ganymede
- NASA OSIRIS-REx, Co-investigator/OVIRS Deputy Instrument Scientist: hardware development, build, test and operations, calibration lead.
- NASA Cassini CIRS, Co-investigator: Jupiter and Saturn observation planning and spacecraft sequencing, instrument operations, mission science integration, data analysis.
- NASA Galileo SSI, Team Associate: Jupiter observation planning, data (playback) selection, validation and analysis, in-flight instrument calibration.

Selected Community Service, Advocacy and Leadership Positions:

2013	Co-convener, AGU Chapman Conference: *"Crossing the Boundaries in Planetary Atmospheres: from Earth to Exoplanets"*
2013	Study on Applications of Large Space Optics, Technical Area Expert
2011	Steering Committee, 9th IAA Low-Cost Planetary Missions Conference
2009-2011	NRC SSB Planetary Science Decadal Survey Steering Committee/Giant Planets Panel Vice-Chair
2009-2010	NASA Europa-Jupiter System Mission Joint SDT, Jupiter Science co-lead.
2009	Organizing Committee, Women in Astronomy and Space Science III
2008	NASA Titan Saturn System Flagship Mission Study, Science Definition Team
2007	NASA Enceladus Flagship Mission Concept Study, SDT Co-Chair
2007	Scientific Organizing Committee, NASA Planetary Atmospheres Conference
2005-2008	Division of Planetary Sciences (DPS) Executive Committee
2005-2007	Outer Planet Assessment Group Steering Committee
2003-2005	NASA Jupiter Icy Moon Orbiter (JIMO) Science Definition Team
2003	Organizing Committee, Women in Astronomy II Workshop

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Education

Ecole Normale Supérieure de Saint-Cloud, 1979-1983
Master degree in Astrophysics (DEA), 1983
PhD in Astrophysics, Université Paris 7, 1989

Employement

10/1992 : Université de Nice-Sophia-Antipolis, Laboratoire Lagrange	*Senior researcher*
10/1990-09/1992: Instituto de Astrofisica de Canarias, Tenerife, Spain	*Post-doctoral position*
10/1989-09/1990: Queen Mary and Westfield College, London, UK	*Research Assistant*
04/1984–09/1986: European Southern Observatory, La Silla Observatory, Chile	*Resident astronomer*

Experience Related to the Investigation

01/2009- : PI of DSI R&D. Development of a space instrument for giant planet seismology
01/2012-02/2013: Deputy-PI of Echoes proposal for the JUICE mission in collaboration with JPL
01/2008–10/2012: Instrument Scientist of A-STEP, Antarctic telescope for transiting exoplanet
04/2001–04/2011: PI of SYMPA project, first dedicated project for Jovian seismology
10/1990-06/2001: CoI of IRIS network for helioseismology
10/1986–09/1992: PI of ETOILE asteroseismology project, based on a sodium cell MOF

Advising and other tasks

-Supervision of 5 PhD and 1 post-doc
-Deputy Director of the laboratory for 11 years (1997-2008)
-Member of National Council of Astronomers and Physicians (CNAP), member of the Observatoire de la Côte d'Azur Scientific Council and Administrative Council, former member of the University Scientific Council, former member of the Institut National des Sciences de l'Univers Scientific Council and INSU Astronomy&Astrophysices Advisory Board, former member of Comité National de la Recherche Scientifique

Related Publications

GAULME P., SCHMIDER F.-X., GAY J., GUILLOT T., JACOB C., 2011, Detection of Jovian seismic waves: a new probe of its interior structure, A&A, **531**, 104
SCHMIDER F. X., GAY J., GAULME P., JACOB C., ABE L., ALVAREZ M., BELMONTE J. A., FOSSAT E., GELLY B., GUILLOT T., JEANNEAUX F., MOSSER B., VALTIER J.-C., 2007, SYMPA, a dedicated instrument for Jovian Seismology. Principle and performances, A&A, **474**, 1073
GAULME P., SCHMIDER F.X., GAY J., JACOB C., ABE L., ALVAREZ M., REYES M., BELMONTE J.A., FOSSAT E., GUILLOT T., JEANNEAUX F., MOSSER B., VALTIER J.C., 2008, SYMPA, a dedicated instrument for Jovian Seismology. II. Real performances and first results, A&A, **490**, 858
FIERRY FRAILLON, D.; GELLY, B.; SCHMIDER, F.-X.; HILL, F.; FOSSAT, E.; PANTEL, A, 1998, Power spectrum modelisation of helioseismic data: an application to the measurement of solar p-mode uncertainties, A&A, **333**, 362
SCHMIDER, F.-X.; FOSSAT, E.; MOSSER, B., 1991, Possible detection of Jovian global oscillations, A&A, **248**, 281

Jean-Baptiste DABAN
Laboratoire Lagrange, Observatoire de la Côte d'Azur
e-mail : daban@oca.eu / Phone : +334 9200 1966

Education:
Engineering degree (MS) in Aeronautics and Space Sciences (1989)

Current position: Senior Research Engineer at Centre National de la Recherche Scientifique.

Professional experience:
2004-2008: technical deputy director of the laboratory of astrophysics of Nice.
2010-now: technical deputy director of the Lagrange laboratory, Observatoire de la Côte d'Azur.
2005-2007: head of the Apodized Lyot Coronagraph WP of the instrument SPHERE/VLT.
2007-2009: manager of the opto-mechanical studies of the telescope ASTEP400, Antarctic telescope for transiting exoplanet observations.
2010-now: local project manager of DSI-Echoes, instrument for the JUICE spacecraft for Jupiter seismology. Manager of studies and prototyping activities.

Publications:

Echoes, a new concept of spectro-imaging for Jovian seismology
L. Soulat, F.-X. Schmider, T. Appourchaux, S. Robbe-Dubois, P. Gaulme, Y. Bresson, J. Gay, **J.-B. Daban**, C. Gouvret.
Proc. SPIE, Ground-based and Airborne Instrumentation for Astronomy, (2012)

Apodized Lyot coronagraph for SPHERE/VLT: Part II. Laboratory tests and performance.
Guerri, G., **Daban, J-B**., Robbe-Dubois, S., Douet, R., Abe, L., Baudrand, J., Carbillet, M., Boccaletti, A., Bendjoya, P. and Gouvret, C.
Experimental Astronomy, Vol. 30, Number 1, 59-81, 2011.

Apodized Lyot coronagraph for SPHERE/VLT, Part I. Detailed numerical study.
Carbillet, M., Bendjoya, P., Abe, L., Guerri, G., Boccaletti, A., **Daban, J-B**., Dohlen, K., Ferrari, A., Robbe-Dubois, S. and Douet, R.
Experimental Astronomy, Vol. 30, Number 1, 39-58, 2011.

ASTEP 400: a telescope designed for exoplanet transit detection from Dome C, Antarctica.
J.B. Daban, C. Gouvret, T. Guillot, A. Agabi, N. Crouzet, J.P. Rivet, D. Mekarnia, L. Abe, E. Bondoux, Y. Fanteï-Caujolle, F. Fressin, F.X Schmider, F. Valbousquet, Pierre-Eric Blanc, A. Le Van Suu, H. Rauer, A. Erikson, F. Pont, S. Aigrain
Proceedings of the SPIE, Ground-based and Airborne Instrumentation for Astronomy, III, vol. 7733, 77334T, 2010.

CURRICULUM VITAE
Tristan, Yves, Nicolas GUILLOT
March 3, 2014

Date and place of birth: 11 January 1970 at Fontenay-aux-Roses (France) **Gender:** male

Nationality: French **Familial Situation:** 2 children

Working address:
Observatoire de la Côte d'Azur
Laboratoire Lagrange, CNRS UMR 7293
CS 34229
06304 Nice Cedex 04, France
Tel: +33-4-92 00 30 47 Fax: +33-4-92 00 31 21
E-mail: tristan.guillot@oca.eu

Personal address:
15 corniche André de Joly
06300 Nice

Professional Experience:

2009–	Directeur de Recherche C.N.R.S., Observatoire de la Côte d'Azur
2008–	Associate Editor for Astronomy & Astrophysics
1998–2009	Chargé de Recherche C.N.R.S., Observatoire de la Côte d'Azur
1996–1997	Research fellow, Meteorology Department, University of Reading, UK
1994–1996	Research associate, Lunar and Planetary Laboratory, University of Arizona, USA
1991–1994	PhD Student, Observatoire de la Côte d'Azur, Nice

Awards:

2006	Urey Prize of the *Division for Planetary Sciences* of the AAS
2006	Zeldovich medal of the *Committee on Space Research*(COSPAR)
2002	Bronze medal of the CNRS
1996–1997	Marie Curie Fellowship (Training and Mobility of Researchers Program of the European Community)
1994–1996	Fellowship of the European Space Agency

Research works: Internal structure and evolution of the giant planets
Planet formation
Radiative transfer, condensation and convection in planetary atmospheres
Photometric observations of transiting exoplanets

Implication in large programs and space missions

- Co-I of the NASA "New frontier" Juno mission (Jupiter orbiter)
- Member of the scientific committee and Co-I of the space mission COROT (Convection, Rotation of stars and planetary Transits)
- PI of A STEP (Antarctica Search for Transiting Extrasolar Planets), photometric observatory installed at Concordia in 2009 (ANR, IPEV, INSU, CNRS, OCA, UNSA)

5 Articles:

- Parmentier V., Guillot T. 2014. A non-grey analytical model for irradiated atmospheres. I. Derivation. *A&A* **562**, A133, 17pp.
- Gaulme P., Schmider F.-X., Gay J., Guillot T., Jacob, C. 2011. Detection of Jovian seismic waves: a new probe of its interior structure. *A&A* **531**, A104, 7pp.
- Guillot T., Santos N.C., Pont F., Iro N., Melo C., Ribas I. 2006. A correlation between the heavy element content of transiting extrasolar planets and the metallicity of their parent stars. *A&A* **453**, L21–24.
- Guillot T. 2005. The Interiors of Giant Planets: Models and Outstanding Questions. *Ann. Rev. Earth Plan. Sci.* **33**, 493–530.
- Guillot T., Burrows A., Hubbard W.B., Lunine J.I., Saumon D. 1996. Giant planets at small orbital distances. *Astrophys. J. Letters* **459**, L35–38.

117 articles in refereed journals, 6393 citations (1649 normalized), H index 41 (19 normalized)

CV T.Appourchaux

Name : Thierry Appourchaux
Age and date of birth : 14/12/1959 (54 ans)
Professional situation : Directeur de Recherches 2^{ième} classe
Institution : Institut d'Astrophysique Spatiale, UMR 8617
Mail address : Bâtiment 121, 91405 Orsay Cedex
Tel : 01 69 85 86 29
E-mail : Thierry.Appourchaux@ias.u-psud.fr

Research domains helioseismology, asteroseismology, space instrumentation, data analysis

Research experiences and education

- since 2004: Directeur de Recherches à l'Institut d'Astrophysique Spatiale
- 1988-2004: Staff member of the European Space Agency
- 2000: *Habilitation à Diriger des Recherches*, Université de Nice Sophia-Antipolis
- 1984-1988 : Boursier CNES (Johns Hopkins University / Applied Physics Laboratory ; Service d'Aéronomie)
- 1984: *Thèse de 3^{ième} cycle* (PhD) in astrophysics (supervisor: J.Blamont), Service d'Aéronomie, Université Paris Pierre et Marie Curier

Responsibilities

- 2009-2013: Deputy Director of the Institut d'Astrophysique Spatiale
- 2007-2011: Member of the committee SHM of CNES (Soleil-Héliosphère-Magnétophère)
- 2005-2014: Member of the committee PNST (Programme National des Relations Soleil-Terre)
- 2005-2008 : Head of the Solar and Stellar Physics Department of the Institut d'Astrophysique Spatiale
- 2005-2008 : Member of the THEMIS Scientific committee

Instrumentation and space missions

- 2008-now: Lead Co-I of the Polarimetric and Helioseismic Imager of Solar Orbiter
- 2008-now: Co-PI of the Extreme Ultraviolet Imager of Solar Orbiter (then Co-I since 2013)
- 2008-now: Co-I of the SPectral Imaging of the Coronal Environment of Solar Orbiter
- 1988-now : Lead Co-Investigator of VIRGO for the Luminosity Oscillations Imager
- PhD advisor of C.Trosseille (2005-2008) and of C.Ruiz de la Galaretta (2009-2013)

Publications

- Appourchaux, T., Chaplin, W.J., Garcia, R.A., Gruberbauer, M., Verner, G.A., Antia, H.M., Benomar, O., Campante, T.L., Davies, G.R., Deheuvels, S., Handberg, R., Hekker, S., Howe, R., Régulo, C., Salabert, D., Bedding, T.R., White, T.R., Ballot, J., Mathur, S., Silva Aguirre, V., Elsworth, Y.P., Basu, S., Gilliland, R.L., Christensen-Dalsgaard, J., Kjeldsen, H., Uddin, K., Stumpe, M.C., and Barclay, T., 2012, "Oscillation mode frequencies of 61 main-sequence and subgiant stars observed by *Kepler*", *Astronomy and Astrophysics*, 543, A54

- Appourchaux, T., Belkacem, K., Broomhall, A.-M., Chaplin, W.J., Gough, D.O., Houdek, G., Provost, J., Baudin, F., Boumier, P., Elsworth, Y., Garcia, R.A., Andersen, B., Finsterle, W., Fröhlich, C., Gabriel, A., Grec, G., Jiménez, A., Kosovichev, A., Sekii, T., Toutain, T. & Turck-Chièze, S., 2010, "The quest for the solar g modes", *Astronomy and Astrophysics Review*, 18, 197

- Appourchaux, T., Michel, E. et al, 2008, "CoRoT sounds the stars: p-mode parameters of Sun-like oscillations on HD49933", *A&A*, 488, 705

- Appourchaux, T., Gizon, L. et Rabello-Soares, M.C., 1998, "The art of fitting p-mode spectra. I. Maximum Likelihood Estimation", *A&A Sup. Series*, 132, 107

- Appourchaux, T., Andersen, B.N., Fröhlich, C et al, 1997, "In-flight performances of the VIRGO Luminosity Oscillations Imager aboard SOHO", *Solar Physics*, 170, 27

Total number of refereed publications : 128 (source: ADS)

H-index: 40

National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

Reply to Attn of: SST:245-3

March 10, 2014

Dear Jason,

I am pleased to extend my support the NASA EPSCoR project “Jovian Interiors from Velocimetry Experiment in New Mexico (JIVE in NM).” It is clear to me that the science goals outlined in the proposal are closely aligned with NASA research interests. In particular understanding the internal structure of Jupiter aids our efforts to understand the origin and evolution of this planet. It is also clear that this project will train students in this important technical area.

I look forward to collaborating with New Mexico State University. As you know I have maintained strong research ties with the NMSU Astronomy department since my departure in 2000 and this project certainly continues to align well with my research interests in Jovian seismology and planetary formation. The connection with Los Alamos National Laboratory will also build on my longtime collaboration with Dr. Didier Saumon. I also look forward to forging stronger ties with New Mexico Tech and the team from the Laboratoire Lagrange at the Observatoire de la Cote d'Azur and the Institut d'Astrophysique Spatiale.

I understand that my role will be to attend team meetings and provide advice on the desired datasets that will best help to constrain models of the origin and evolution of Jupiter. Once data is obtained I will collaborate on its interpretation and publication.

Sincerely,

Mark Marley

Mark S. Marley
Research Scientist
Mark.S.Marley@NASA.gov
(650) 604-0805

Murphy, Neil (1211) <neil.murphy@jpl.nasa.gov> Sun, Mar 2, 2014 at 7:21 PM
To: Jason Jackiewicz <jasonj@nmsu.edu>

Dear Jason,

I am pleased to support the NASA EPSCoR project "Jovian Interiors from Velocimetry Experiment in New Mexico (JIVE in NM)." My research at JPL has a strong synergy with the science goals that this project will achieve, and I'm looking forward to being involved in the cutting edge research JIVE promises.

I look forward to collaborating with New Mexico State University, furthering the collaborations we have had on mission concept development, with New Mexico Tech., Los Alamos National Lab, and the French teams of the Laboratoire Lagrange at the Observatoire de la Cote d'Azur, (with which I have strong collaborations on mission and instrument development), and the Institut d'Astrophysique Spatiale.

My roles in JIVE in NM include participating in team meetings, coordinating with ground based measurements made by our group at JPL, and providing the opportunity for student internships and faculty exchanges with team members.

Bres regards

Neil

Neil Murphy
Manager, Strategic University Research Partnership Program
Office of the Chief Scientist
Jet Propulsion Laboratory
m/s 180 600
4800 Oak Grove Drive
Pasadena CA 91109
Tel 818 354 8718

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

March 4, 2014

Dear Jason,

I am pleased to support the NASA EPSCoR project "Jovian Interiors from Velocimetry Experiment in New Mexico (JIVE in NM)." NASA has a strong interest in the science goals that this project will achieve, in particular, the deep interior structure of the giant planets, as well as the training of students in this technical area.

I look forward to collaborating with New Mexico State University, and, as a former graduate student, reestablishing connections with the faculty and students. This project will also strengthen ties with New Mexico Tech, where I have held a long collaboration with Dr. Morales-Juberias, as well as forming new partnerships with Los Alamos National Lab and the French teams of the Laboratoire Lagrange at the Observatoire de la Cote d'Azur and the Institut d'Astrophysique Spatiale.

My roles in JIVE in NM will include participating in team meetings, helping to plan Jupiter observations, and collaborations with faculty and graduate students on data analysis of atmospheric dynamics. In addition, I am very familiar with the Planetary Data System archives and can help with dissemination of data and results. Lastly, I have much instrument experience and will offer my expertise in instrument design and operations, as needed.

Sincerely,

Amy A Simon-Miller

Amy Simon-Miller

6 Institutional Letters of Commitment

NM STATE UNIVERSITY

Vice President for Research
MSC 3RES
New Mexico State University
P.O. Box 30001
Las Cruces, NM 88003-88001
575-646-2481, fax: 575-646-5717

March 21, 2014

Jeppie R. Compton
Project Manager, NASA EPSCoR
Office of Education
NASA Kennedy Space Center, HQ EX-E
Kennedy Space Center, FL 32899-0001

Subject: NASA EPSCoR application titled "JIVE in NM: Jovian Interiors from Velocimetry Experiment in New Mexico"

Dear Mr. Compton,

New Mexico State University (NMSU) enthusiastically endorses the proposal submitted for the EPSCoR research effort titled "JIVE in NM: Jovian Interiors from Velocimetry Experiment in New Mexico." NMSU is a land-grant institution founded in 1888, designated as a Hispanic Serving Institution, and classified by the Carnegie Foundation as RU/H (Research University with high research activity). A research institution with a significant portfolio, NMSU's research expenditures exceeded $133 million for FY13. In addition, NSF ranks NMSU third among all Hispanic Serving Institutions in research expenditures.

NMSU has significant capabilities to contribute to this effort as space and aerospace research is a strategic area of research and education. The Astronomy department is actively involved in solar physics research, including global seismology, chromospheric heating, solar flares and coronal mass ejections using SoHO, the Solar Dynamics Observatory, and ground-based facilities at the National Solar Observatory. In addition, because of its role as the operator of Apache Point Observatory, 25% telescope time on the NMSU 1-m telescope will be allocated to this project in year two and 50% in year three.

JIVE in NM will make transformational discoveries about the solar system's gas-giant planets in terms of interior structure and atmospheric dynamics, and will complement NASA missions Juno and Cassini. New Mexico has a history of ground-breaking planetary science and associated technology, and I look forward to the development in this research area. Success of this effort will establish New Mexico as a center for seismological studies of planets, attract new students and researchers, build critical ties to NASA centers and national laboratories, contribute to New Mexico's economic viability, and expand our nation's aerospace research and development capabilities.

I am pleased to commit $397,708 in matching funds for this effort on behalf of NMSU. Our match well exceeds the 50% minimum required as our partner New Mexico Institute of Mining has also committed $33,650 for a total match of $431,358. The proposed project is an excellent fit for NMSU as it will enhance research and teaching in astronomical instrumentation and planetary science, both areas of focus at our institutions.

Sincerely,

Vimal Chaitanya, Ph.D.
Vice President for Research

New Mexico Tech

OFFICE OF THE VICE PRESIDENT
RESEARCH & ECONOMIC DEVELOPMENT

February 20, 2014

Dr. Jason Jackiewicz
Assistant Professor of Astronomy
Department of Astronomy
New Mexico State University
PO box 30001, MSC 4500
Las Cruces, NM 88003

Subject: Proposal entitled, Jovian Interiors from Velocimetry Experiment in New Mexico
Reference: NASA-EPSCOR-2014

Dear Dr. Jackiewicz,

The New Mexico Institute of Mining and Technology (NMT) is pleased to be your partner on the subject proposal and endorses the participation of Dr. Raúl Morales-Juberías as Co-Investigator.

NMT is committed to providing the support described in the proposal on the cost and schedule assuming that NASA funds the proposal.

If you have any questions regarding NMT's participation on this proposal, please contact Andrea Peralta at phone #575-835-5918

Sincerely,

Van Romero
Vice President of Research & Economic Development

801 LEROY PLACE + SOCORRO, NEW MEXICO 87801 + (575) 835-5646 + FAX: (575) 835-6934

Reiner Friedel
LANL NASA/NSF Program Manger
Space Science and Applications, ISR-1
P.O.Box 1663, Mail Stop D-466
Los Alamos, New Mexico 87545
505-665-3877 / Fax 505-665-7395

Date: Thursday, March 20, 2014
Refer To: NASA/NSF-14-105

To:
Jason Jackiewicz
Assistant Professor
Dept of Astronomy
New Mexico State University
PO Box 30001
1780 E University Ave, Las Cruces, NM 88003-8001

Re: Letter of support for NASA EPSCoR program

Dear Dr. Jackiewicz:

Los Alamos National Laboratory is pleased to support the attached NASA EPSCoR program titled "JIVE in NM: Jovian Interiors from Velocimetry Experiment in New Mexico". LANL has a continuing interest in these research fields and remains a potential host for its students and graduates.

LANL supports research projects in the areas described in the proposal. These include student and postdoc funding opportunities from the LANL Institute for Geophysics, Planetary Physics and Signatures (IGPPS), and research support from the LANL Laboratory Directed Research and Development (LDRD) program. The LANL NASA/NSF program is particularly interested in programs such as described in this proposal that have the potential of preparing LANL and its collaborators for future participation in hardware programs for NASA flight opportunities.

I am pleased to support Dr. Didier Saumon's participation in this project, a well-respected expert in the field of planetary interior structure and equations of state of astrophysical matter.

LANL also looks forward to strengthening and building on the existing relationship between LANL and NMSU researchers, on the basis of past and present NASA EPSCoR and NASA "Outer Planets Research" (OPR) programs. Extending this collaboration to include additional New Mexico Partner Institutes such as the New Mexico Institute of Mining and Technology (NMT) is of particular interest to LANL.

Finally, LANL supports a balanced workplace and is very interested in adding under-represented groups in scientific and engineering fields such as woman and minorities to our staff. NMSU and NMT are minority serving institutions and collaborations such as the one proposal can serve to provide greater access of such groups to LANL.

Sincerely,

Reiner Friedel
Los Alamos Program Manger for NASA and NSF Programs
LDRD Exploratory Research (Earth and Environmental Sciences, & Space Physics) Chair

LAGRANGE

Le Directeur

February 28, 2014

Letter of Intent : Jovian Interiors by Velocimetry Experiment (JIVE)

To whom it may concern:

Summary
The Jovian Interiors by Velocimetry Experiment (JIVE) aims to install at the Apache Point Observatory (New Mexico) an instrument able to study the internal structure of the giant planets by measuring the frequency of their global oscillations. Laboratoire Lagrange at Observatoire de la Côte d'Azur in Nice, France, fully supports the JIVE proposal submitted by the New Mexico State University and will provide technical and scientific support to assist in reaching this objective.

Context
The internal structure and dynamics of the giant planets of the Solar System remains poorly known, leaving in the shadow a number of unanswered questions about the Solar System formation, the evolution of giant planets as compared to exoplanets, and questions about the properties of matter under harsh pressure conditions. Seismology of giant planets is the best way, if not the only one, to improve this situation. The measurement of acoustic oscillations in giant planets, like in the Sun, requires specific equipment. Only recently, oscillations were detected on Jupiter with the SYMPA instrument, build in Nice for this purpose. In the perspective of a future space mission, we studied a Doppler Spectrometer Imager (**DSI**) in depth, based on the heritage from the ground-based instrument SYMPA, dedicated to measure the Jovian oscillations from a spaceborne plateform.
The DSI study was undertaken in the framework of a collaboration between the Lagrange Laboratory at Observatoire de la Côte d'Azur and the Institut d'Astrophysique Spatiale (IAS) at Université Paris-Sud, with the support of the French Space Agency (CNES). A prototype of the instrument was build and fully tested at Observatoire de la Côte d'Azur between 2010 and 2013, and showed performances compatible with the theoretical expectations. Preliminary observations of Jupiter with the DSI prototype, realized on 2014 January 25-31 at Calern Observatory, proved that the instrument is suitable for the measurement of oscillations on Jupiter and Saturn from ground-based observations with 1-2 meter-class telescopes.

Task
A full instrument based on this study and placed permanently at Apache Point Observatory would provide brand-new scientific reward on giant planets' internal structure and dynamics. We therefore intend to support the NMSU team with the necessary technical and scientific assistance for the achievement of the **JIVE** project. Within the project, we will

- deliver to NMSU a Mach-Zender interferometer, fully assembled and verified;
- provide all the plans for the optical, mechanical and thermal assembly allowing the realization of a complete instrument;
- give the technical informations to the NMSU team in charge of the optical and mechanical interface and collaborate to the study;

Laboratoire J.-L. Lagrange
Observatoire de la Côte d'Azur, CNRS, Université de Nice-Sophia Antipolis
Téléphone : +33 4 92 07 63 60 Télécopie : +33 4 92 07 63 21 www : http://lagrange.oca.eu

- share our experience in instrumental control and data processing, as developed on the data already obtained from the prototype at Calern Observatory near Nice;
- participate with the NMSU team to the scientific exploitation of future observations carried out at Apache Point Observatory;
- if more data are to be obtained in France, simultaneously with the Apache Point DSI instrument or not, they will be shared and added to the Apache Point database, in order to increase the scientific return of the **JIVE** experiment, in view of preparing of future space missions.

The Nice support team, which composition is to be completed in the final JIVE agreement, is primarily made up by people from the Lagrange Laboratory, and listed below :

Name	**Contact**	**Responsability**
François-Xavier Schmider	schmider@unice.fr	International collaboration PI
Tristan Guillot	tristan.guillot@oca.eu	Science PI
Jean-Baptiste Daban	Jean-Baptiste.Daban@oca.eu	Instrument Project Manager

Thierry Lanz
Director

Laboratoire J.-L. Lagrange
Observatoire de la Côte d'Azur, CNRS, Université de Nice-Sophia Antipolis
Téléphone : +33 4 92 07 63 60 Télécopie : +33 4 92 07 63 21 www : http://lagrange.oca.eu

IAS Orsay

Institut d'Astrophysique Spatiale
http://www.ias.u-psud.fr

Bâtiment 121, Université Paris-Sud
91405 Orsay, Cedex, France

Dr J. Jackiewicz
Department of Astronomy
New Mexico State University
P.O.Box 30001, MSC 4500
Las Cruces, NM 88003-8001
New Mexico

Orsay on February 27th, 2014

Dear Dr Jackiewicz,

The Institut d'Astrophysique Spatiale extends its full support for the proposal of the Jovian Interiors from Velocimetry Experiment (JIVE) that you will be submitting as Principal Investigator for the NASA EPSCoR program.

The responsibilities of the laboratory within your proposal will be related to data analysis, instrument expertise (thermal and optical aspects) and data archiving.

The institute endorses the participation of Thierry Appourchaux and assures that all resources required by the IAS team to carry out their responsibilities as stated above will be available for the JIVE project.

Best regards,

Donald Hassler

Director of IAS

Université Paris-Sud
Centre National de la Recherche Scientifique