A Cover

1. Jovian Interiors from Velocimetry Experiment in New Mexico (JIVE in NM)
2. NNX14AN67A
3. Annual Progress Report YR1
4. 7/16/2014 - 5/16/2015
5. May 17, 2015
6. Patricia Hynes, 575.646.6414, pahynes@ad.nmsu.edu
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8. New Mexico State University

B Narrative Summary

The Jovian Interiors from Velocimetry Experiment in New Mexico (JIVE in NM) is a project, led by New Mexico State University, to probe the interior structures of Jupiter and Saturn and determine for the first time the size and masses of their cores, enabling the resolution of critical questions about the formation of the solar system. The JIVE project will achieve this by building and implementing an ultra-stable Doppler imaging spectrograph to measure the planets' surface velocity every minute. This will enable observations of planetary acoustic waves that permit the use of seismology to ultimately determine the interior structure.

The first year of the project has been critical to refine the scope of the project, set up the management structure, hire personnel, develop an improved instrument design, define instrumentation responsibilities, and exchange visits of key team members. The goals and objectives of the effort involve areas of science, instrumentation, and collaboration (section C1 below), and the progress in year 1 will be discussed against these.

The JIVE project involves a very strong collaboration among two universities in New Mexico, three NASA centers, and the Nice Observatory. As the scientists and engineers in Nice have developed the initial designs for the instrument and have constructed a prototype, one of the first collaborative objectives was to see the prototype in-person to gauge how to divide the work of constructing a second one. In October 2014, Jackiewicz, Voelz, and Underwood visited Nice for three days. Meetings were held with optical, mechanical, and software engineers and a full overview of the instrumental concept was provided to the visitors. A visit was also made to the telescope in Calern where test observations had been carried out in the months prior.

The instrument is an extremely sensitive, well-machined, and highly-calibrated complex interferometer. Certain specialized tools and techniques are required for proper assembly and testing in the laboratory. Based on this, a critical conclusion was reached, in that more responsibility would be taken by the French co-investigators for the assembly of JIVE. Because the designs are in French and in European units and use a European projection convention, it will be far more efficient (and less expensive) for the same team to build most of JIVE, more than originally planned in the proposal. Indeed, this leads to a much cleaner division of labor. The NMSU engineering team will therefore be responsible for the interface of the telescope with JIVE, which itself requires a lot of research and development. So the optics and software to capture the light from the telescope

will be U.S. led, and the light feed coming from that system that goes into JIVE will be French led. There is still plenty of invention required to accomplish the required work, and this does not threaten any PhD project for our engineering student.

The next major accomplishment was to host a team kickoff meeting at NMSU in December, 2014. The main science and engineering investigators, Schmider and Guillot, attended from France, along with most of the U.S. members. The goal was to discuss further plans for assembly, software, and science, but mostly to visit the telescope to study how JIVE will be mounted. The initial plan was to use NMSU's 1m telescope at Apache Point Observatory (APO) for the majority of the observations. However, there are some issues at that telescope that will not be easy to solve in the short term, particularly, the thermal variation of the environment inside the dome. The instrument works optimally in a stable temperature and humidity, whereas the diurnal shifts in the dome are severe. A secondary issue is how to stably mount the instrument to the Nasmyth port that is high in the air.

While these problems are not insurmountable, we want to accomplish as much science as possible during the award period and their resolution would have delayed our schedule. About 0.25 miles from APO is Sunspot, NM, host to the National Solar Observatory (NSO). The NSO operates the Dunn Solar Telescope (DST), which is a very successful facility that has been used sparingly in the past for nighttime (planetary) observations. As we toured the facility, it became obvious that the DST has a much more stable environment, as it is in a very thick-walled building that is temperature controlled. Also, the light feed from the telescope is at waist height on very large optical tables. The field-of-view is also perfect for imaging Jupiter, at roughly 150 arcseconds.

After speaking with the technical staff at NSO that day, a subsequent telecon and a follow-up meeting 1 month later, we've decided to pursue using the DST as our first option for hosting JIVE. We will be able to apply for sufficient time in large chunks to observe Jupiter with some level of continuity. Furthermore, we will be allowed to do tests, calibration, and setup of JIVE on one of their optical tables whenever this will not interfere with solar observations. Indeed, the NSO has been very generous in their support of this project, and have shown willingness to train several of us for nighttime observing. In June 2015, a week of test Jupiter and/or Saturn observations will take place, to monitor the image quality from the telescope and quantify how well it can track and guide on these (non-solar) objects.

As the definition of the project with regards to design, construction, and telescope has matured in the first year, several key students have joined the project. In Engineering, Thomas Underwood is working primarily under Co-PI Voelz on the software control of the instrument and the interface optics with the telescope. Thomas traveled a second time to Nice in February to participate in test observations at the Calern Observatory, and learned exactly how the process works from initial calibration to science-quality data acquisition. This will be critical for the future observations in New Mexico. Ethan Dederick, an astronomy graduate student, is beginning work with Jackiewicz and Gaulme on preparing the necessary theoretical computations so that we are ready for the oscillation data when it arrives. He plans to spend some time in Nice in summer 2015 working with Co-I Guillot on Jupiter interior modeling. At New Mexico Tech, Richard Cosentino joined Co-I Morales-Juberias to study Jovian winds. They are working on a project to use radio telescopes combined with Hubble imagery and our 1-m telescope to detect global-scale wave patters in the atmosphere (see section C4). This will benefit JIVE enormously in the long term when we have Doppler velocity data to complement those data.

To communicate as effectively as possible with our other partners, the colleagues at Nice Obser-

vatory graciously set up a dedicated Subversion (SVN) site to share documentation, drawings, plans, results, software, photos, and reports. Each member can easily access this site and find the most up-to-date version of all relevant documentation. In addition, we have built a website for the project[1] for recording important information within the project, as well as with the greater scientific community as a whole. The site shows participants, publications, news, a scientific overview, etc. We intend to publicize this repository in our efforts to collaborate with the NASA Juno team.

For other visibility, several conference proceedings, a poster, and a publication sent to a refereed journal have been written (see section C6). The journal article lays out the instrument concept and testing of the prototype, and will be an important reference in future publications. Also, a chapter in an upcoming book about "Extraterrestrial Seismology" was written by several investigators from JIVE. This chapter summarizes the 40-year history of Jovian seismology, and points to the exciting prospects of the future.

In summary, the project is well underway. Despite requiring significant time to divide project responsibilities and determine the optimum telescope, the instrument is slated for assembly in year 2, with installation, testing, and science observations in year 3.

C Supporting Documentation

1 The Research

This project has 5 goals and their associated objectives, restated and bulleted below, with accomplishments further indented:

(Goal 1) Instrumentation: *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;
  - This has been completed with collaboration with Co-PIs at the Nice Observatory. The design study is complete.
- Mount the instrument on a suitable telescope to carry out monitoring of giant planets;
  - Will not occur until Year 3 after construction of the instrument. We have chosen an appropriate telescope.
- Develop the software needed to control the instrument and perform data acquisition and reduction;
  - Thomas Underwood (NMSU graduate student) is modifying the control software. Year 2 will be to develop the data acquisition software.
- Assemble a team of experts who regularly meet and review construction progress.
  - Weekly meetings and weekly telecons are held with about 12 team members to continually discuss project progress.

(Goal 2) Science: *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.*

[1] http://astronomy.nmsu.edu/JIVE

- 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.
  - All four of the objectives within this goal will be carried out in Year 3 when data are available.

(Goal 3) Science: *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.
  - All four of the objectives within this goal will be carried out in Year 3 when data are available.

(Goal 4) Education: *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 .
  - Three graduate students have been hired into the project, Thomas Underwood (NMSU, Electrical Engineering), Ethan Dederick (NMSU, Astronomy), and Richard Cosentino (NM Tech, Physics and Astronomy). Undergraduate students will be hired this summer when instrument parts start arriving and cataloging and assembly is required. Regular interaction with faculty and team members through meetings and telecons is taking place.

(Goal 5) Collaboration: *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.

– A three-day team kickoff meeting took place in December 2014, where state and international partners met to discuss the project. The team visited potential telescopes in Souther New Mexico. In April 2015, scientists at the Nice Observatory submitted a proposal to the French national funding agency to build a third instrument, a copy of JIVE, to be installed in Japan and to establish a global network of identical instruments. A decision will come in summer 2015.

2 List of Participants

- Patricia Hynes - New Mexico State University (director)
- Jason Jackiewicz - New Mexico State University (faculty)
- David Voelz - New Mexico State University (faculty)
- Patrick Gaulme - New Mexico State University (researcher)
- Bob Hull - New Mexico State University (researcher)
- Thomas Underwood - New Mexico State University (researcher)
- Ethan Dederick - New Mexico State University (researcher)
- Raul Morales-Juberias - New Mexico Tech (faculty)
- Richard Cosentino - New Mexico Tech (researcher)
- Didier Saumon - Los Alamos National Lab (researcher)
- Mark Marley - NASA Ames (researcher)
- Amy Simon - NASA Goddard Space Flight Center (researcher)
- Neil Murphy - NASA Jet Propulsion Lab (researcher)
- French Leger - University of Washington (researcher)
- Francois Xavier-Schmider - Nice Observatory (researcher)
- Tristan Guillot - Nice Observatory (researcher)

3 Systemic Change

Nothing to report.

4 List of Collaborations

Several important and exciting collaborative efforts have begun due to this EPSCoR award:

- International university: A team at the Nice Observatory has been given permission to submit a final proposal to the French Research Agency (ANR) to construct a third spectrograph instrument. It will be a replica of JIVE and the prototype. If funded, the instrument will be installed in Japan, therefore providing near continuous observations of Jupiter because of longitudes in France and New Mexico. Members of JIVE are co-investigators of that proposal.
- Jurisdiction university and NASA Center: A collaboration between team members at NMSU (Gaulme), NM Tech (Morales-Juberias), and NASA Goddard (Simon) has begun to observe Jupiter with the Very Large Array (VLA) radio telescope and the Hubble Space Telescope

(HST). The goal is to study planetary-scale waves in Jupiter's atmosphere. As part of this effort, complementary and contextual images of Jupiter are being obtained simultaneously with NMSU's 1m telescope at APO.

- Jurisdiction agency: A new collaboration has begun with the National Solar Observatory (NSO) in Sunspot, NM. After much discussion, the ideal telescope for JIVE turns out to be the Dunn Solar Telescope (DST) operated by the NSO in New Mexico. Initial test observations are being carried out by Dr. Han Uitenbroek at NSO and his observing team. If these successfully demonstrate that Jupiter is a viable target for this solar telescope, an intensive collaboration to install JIVE at the DST will take place in the coming year.

5 Space Grant Interaction

No significant interaction this reporting period. Over the next year, the consortium director and staff will begin evaluation of the project in terms of student participation, external funding, and statewide participants. We will look for guidance from the consortium on how to engage other state entities to become involved in the project, not just from a scientific perspective but also from an outreach and education perspective.

6 List of Success Stories

- Experimental test of a Doppler spectro-imager devoted to giant-planet seismology and atmospheric dynamics. L. Soulat, F.-X. Schmider, S. Robbe-Dubois, Y. Bresson, J.-B. Daban, J. Gay, C. Gouvret, Y. Fantei, C. Combier, T. Appourchaux, G. Morinaud, J.C. Leclech, J.P. Dubois, and P. Gaulme. (Submitted for review to *Monthly Notices of the Royal Academy of Science*). 2015
- Seismology of Giant Planets. P. Gaulme, B. Mosser, F.-X. Schmider, T. Guillot. (Book chapter, to appear in *Extraterrestrial Seismology*, published by Cambridge University Press). 2015
- JIVE in NM: Jovian Interiors Velocimetry Experiment. P. Gaulme, J. Jackiewicz, JIVE team. (Poster, presented at the New Mexico State University Research and Creative Activities Fair. Las Cruces, NM.) October 2014
- "NASA EPSCoR to fund planetary seismology research at NMSU." (Press release at NMSU[2] describing the JIVE project). September 2014

7 Patent Applications and Patents Pending

Nothing to report.

8 Patents Awarded

Nothing to report.

9 Technology Transfer

Nothing to report.

[2] http://newscenter.nmsu.edu/Articles/view/10585/nasa-epscor-to-fund-planetary-seismology-research-at-nmsu

10 New Non-EPSCoR Grants

- May 2015. NMSU College of Arts and Sciences graduate student travel award. Recipient: Ethan Dederick, for travel to Nice, France. $600.

11 New Courses

Nothing to report.

Figure 1: Team members stand in front of the telescope at Apache Point Observatory, NM from which JIVE will one day make observations of Jupiter and Saturn oscillations.

12 PR Material

One of the main questions in planetary astronomy is how did the solar system form, and how did the planets come together and then evolve? Jupiter is the most massive planet, representing 70 percent of the mass in the solar system apart from the Sun. An international team of researchers working on the "Jovian Interiors from Velocimetry Experiment (JIVE) in New Mexico," is developing a ground-based instrument that will measure oscillations on Jupiter. Its results could help understand the interior structure and composition of the planet and the solar systems development for the first time.

Giant planets like Jupiter or Saturn are mostly fluid (they contain no solid surface), which makes their seismology much closer to that of stars than that of rocky planets like Earth. Furthermore, observations of the circulation speeds of planet atmospheres is usually not very accurate. With JIVE, we'll be able to measure the instantaneous speed of the clouds directly, helping to understand large storm systems.

The project has strong alignment with NASA's plans for planetary exploration and the importance of the proposed low-cost approach by NMSU to use ground-based support will enable verification of NASAs Juno mission space observation data. The installation of the instrument could make NMSU a hub for planetary seismology, and the project is well underway.