Developing a Planetary Doppler Imager

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Outline

• Science:
  - Intro to giant planets and their importance
  - Helioseismology and theory

• Design:
  - Past attempts
  - Improved optical design
  - Optical and mechanical layout

• Implementation:
  - Physical assembly
  - Alignment and testing
  - Deployment and expectations
Why is studying giant planets important?

- The giant planets, Jupiter, Saturn, Uranus, and Neptune are typical of most of the planets so far discovered.
- As of 16 August 2016, there have been 3,501 exoplanets in 2,623 planetary systems (http://exoplanet.eu/catalog/)
- Giant planets can dominate the planetary system formation process as they capture a significant part of the planetary mass of a system.
- Understanding their structure and evolution can also tell us about the conditions under which they formed – studying planets in our solar system will help us understand the formation of other planetary systems.
How have we learned about the solar system’s giant planets?

- From **observations** of the planets and their moons we know their sizes, shapes, masses and approximate rotation rates.
- From **spectroscopic measurements**, and **in-situ samples** and some assumptions we have constraints on their composition.
- From our **understanding of the physics of dense materials**, we can make inferences about the state of matter in their interiors.
- From spacecraft flyby’s we have additional information on their **gravity fields**, which gives us information on their internal structure.
- From **lab experiments** on hydrogen and water at very high pressures and temperatures.
Our Solar System’s Giant Planets

- **JUPITER**
  - Molecular hydrogen
  - Metallic hydrogen

- **SATURN**
  - Hydrogen, helium, methane gas

- **URANUS**
  - Mantle (water, ammonia, methane ices)

- **NEPTUNE**
  - Core (rock, ice)

Image Credit: Lunar and Planetary Institute
What’s left to learn for Jupiter?

- Jupiter is our most studied giant planet, but there’s still a great deal we don’t understand.

There are two measurement techniques that can help us resolve questions about Jupiter and the other giant planets – high precision gravity measurements and seismology.
Seismology of giant planets? - The sun’s 5-minute oscillations

• In the early 1960’s, there was a puzzling observation that the solar surface pulsates with a period of about 5 minutes.
  – (this was an accidental discovery, made when scientists were trying to measure surface flows on the sun using Doppler shifts in sunlight, with an instrument originally designed to measure the sun’s magnetic field via Zeeman splitting)

• Over the following 15 years or so, scientists realized that the 5 minute oscillations were caused by resonant oscillations within the sun – i.e., normal modes
What causes the solar 5-minute oscillations?

- These oscillations involve the whole sun and can be used as a tool to probe the solar interior; their study is known as helioseismology.

Waves that have fewer nodes at the surface penetrate more deeply into the interior.

We can use this to probe the properties of the interior, because the frequency of any mode depends on the average sound speed along the ray path.

We measure these modes by imaging Doppler shifts in the solar spectrum.
Some promising recent results for Jupiter

From Gaulme et al., 2011, data taken using an imaging interferometer
How do we make Doppler images?

The instrument we use (in our case a Doppler imager based on a magneto-optical filter) only allows light to pass in two narrow pass-bands – the sun or planet is imaged in each pass-band.

When the line is Doppler shifted, the intensity in one pass-band goes up while the other goes down.

Doppler image is \( \frac{I_R - I_B}{I_R + I_B} \)

Filter pass-bands (red and blue), compared to the K 770 nm solar absorption line (green).
First Attempt

Laser spectrum of MOF pass-bands (blue line), compared to model (green line)
Ground-Based Measurements

Raw data from Jupiter and Saturn - taken at the Bok 90” telescope on Kitt Peak

These Saturn images taken using the same approach as for solar observations (first attempt)

Jupiter data taken in a mode where both pass-bands are added on the same image and a separate reference image is taken (second attempt)
Improved Design

- We need more photons!
- Two arms, so no light is “thrown away”
- No wing selector
- Better camera (quantum efficiency ~80%)  
- 8x more photons than first attempt
- Bigger telescope

![Diagram of the improved design]
Optical Design

- Polarization considerations
- Both arms need to be equal length
- Series of many lenses and mirrors used
- Achromatic lens pairs to minimize spherical aberration
- Final images need to be certain size
Mechanical Layout Design

Schematic

CAD Design
Challenges
Assembly and Alignment
Deployment and Testing

• Taking the completed Doppler Imager up to Lick Observatory in San Jose
• Using Shane 3 meter telescope
• Imaging Saturn over course of three nights
• Validate new imaging approach
• Prove that subtracting images “takes out” brightness variation due to reasons other than velocity
Expectations

• Development of another Doppler Imager scheduled for January 2017
• In March 2017 there will be a ten night observation run of Jupiter
• Proposals for flight instruments to Saturn and Uranus
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