JIVE: Jovian Interiors Velocimetry Experiment

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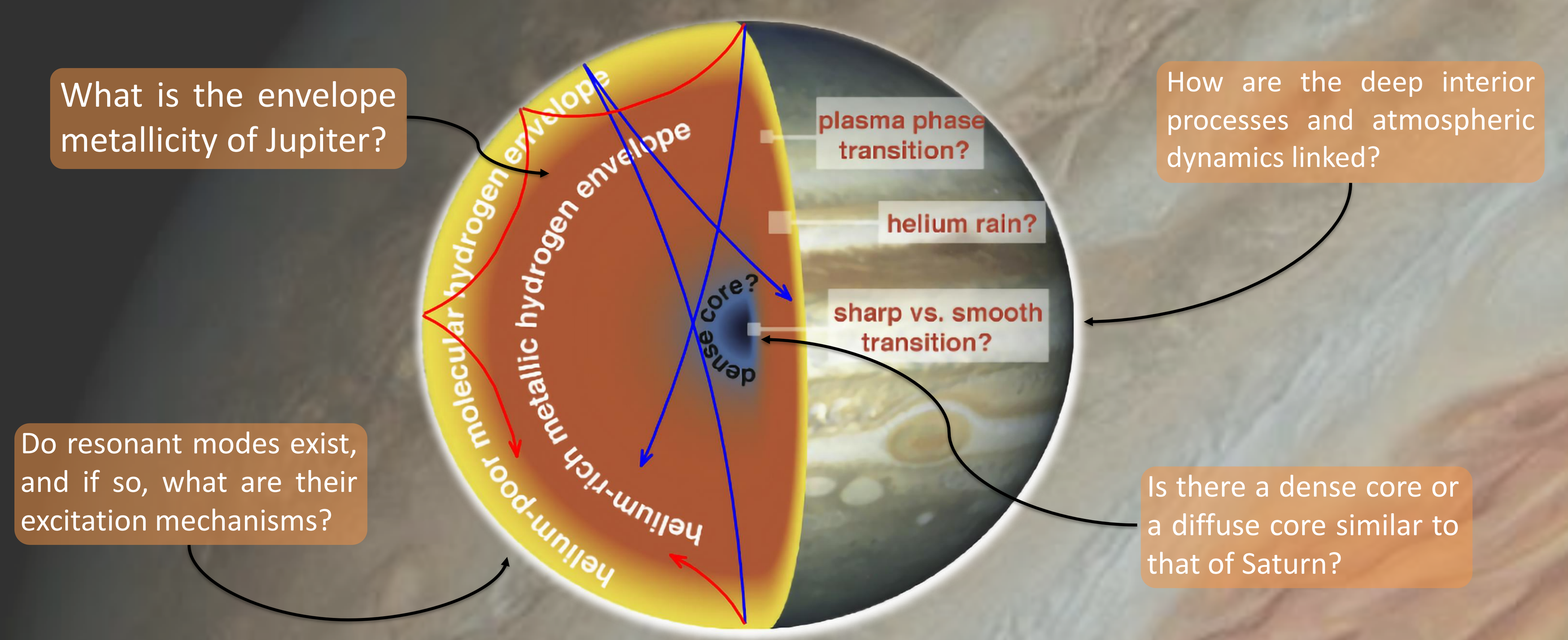
Abstract

Classical photometric and spectroscopic observations of Jupiter and Saturn do not constrain their interior structure, composition, core mass, sub-surface rotation, etc. Such inferences would help resolve competing theories of giant-planet formation, which predict specific interior signatures. Furthermore, giant-planet atmospheres show a rich variety of dynamical phenomena that could help us understand how energy is transferred and is coupled to interior processes. Seismological observations are an exciting potential tool for accessing the deep interiors of giant planets, as well as directly quantifying atmospheric dynamics. JIVE is a project that will provide nearly-continuous Doppler-imaging data for our solar system's giant planets and allow for new ways to study their interior and atmospheric properties. It is quite complementary to the science goals of the JUNO mission and could provide instrumentation guidelines for future gas- or ice-giant missions.

Science Goal: How are Jupiter and Saturn constructed?

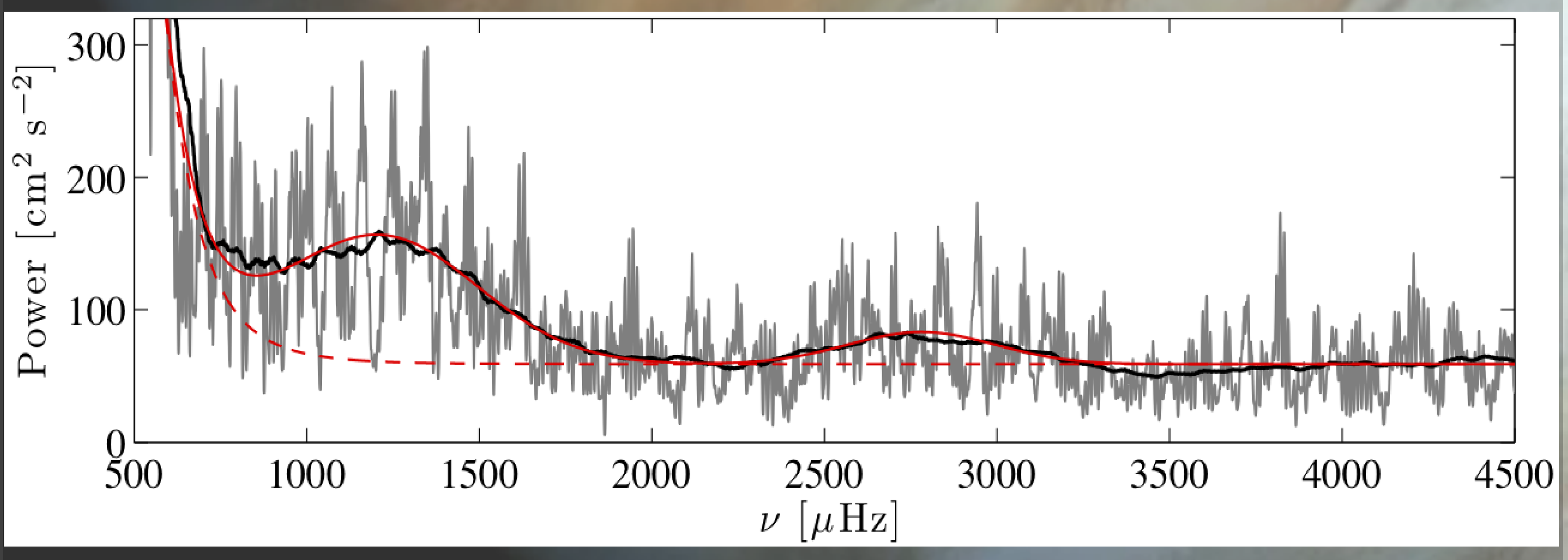


The figure above shows the cross-section of a theorized interior structure of Jupiter. Although this represents one of multiple interior models, it highlights some of the important questions we still do not understand—such as the radial distribution of heavy elements (solid core vs. fuzzy core) or what mechanisms dominate the interior processes.

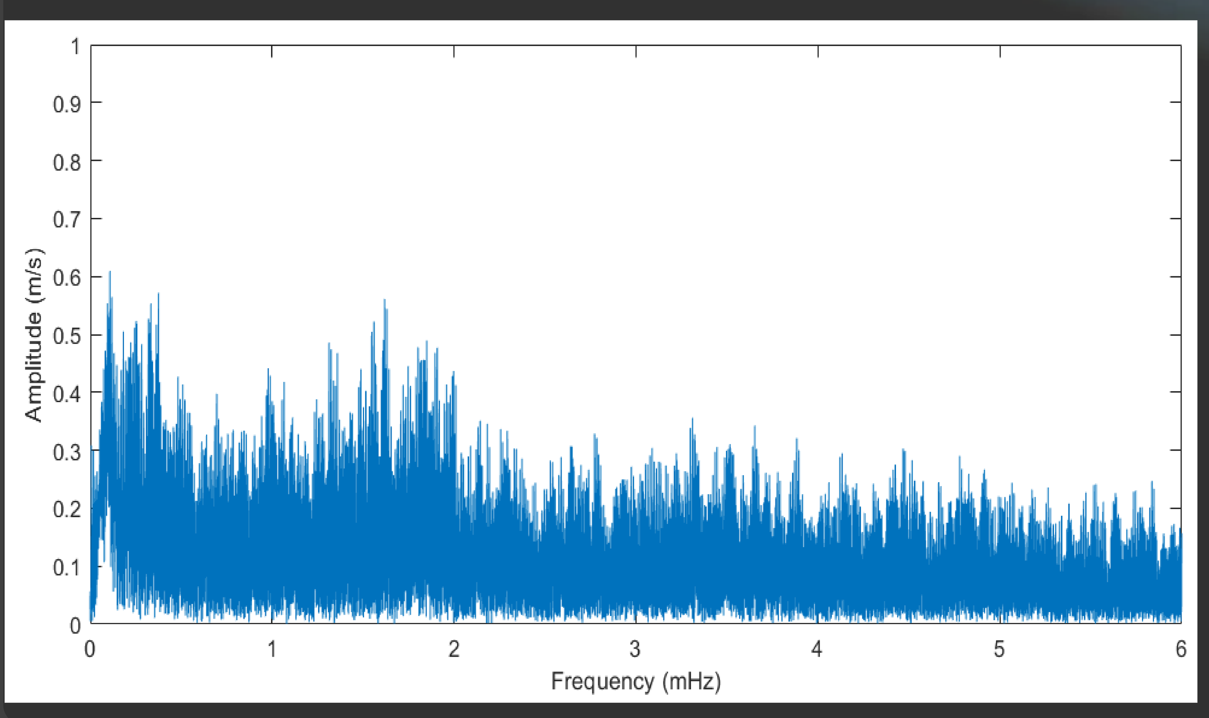
Method: Jovian Seismology

Seismology has proven to be a valuable tool in probing the deep internal structure of the Sun and other stars as seen below. Since the gas giants consist primarily of hydrogen and helium, and have deep convective fluid envelopes, seismology of these planets should be similar to that of our Sun. In other words, the cloudy "surface" of giant planets is slightly distorted by seismic acoustic waves that resonate within.

Jovian seismology is in its infancy and has been attempted for Jupiter [1], which consists of identifying global acoustic pressure-modes by measuring radial velocity shifts of absorption lines in reflected solar light from clouds. For Saturn, density waves have been detected in the rings caused by internal waves [2]. Recent measurements of oscillations in Saturn's rings via Cassini observations revealed the internal structure of Saturn as a fuzzy/diffuse core [3]. These results provide strong implications on the potential of gas giant seismology and its ability to constrain planet formation and evolution.

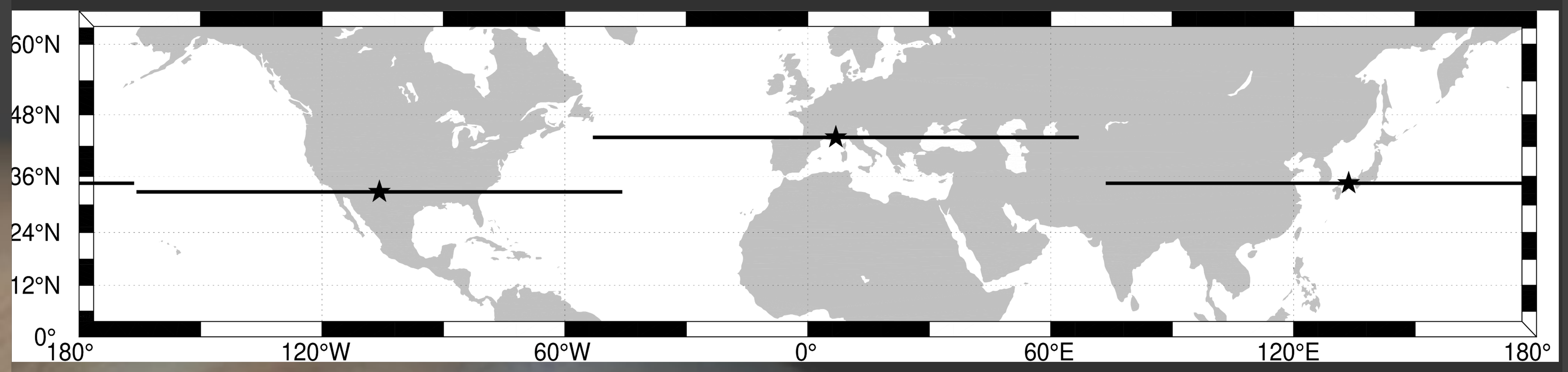


Above: evidence of the first detection of Jupiter's global modes from the SYMPA instrument, the predecessor to the current instrument in the JIVE project. Excess oscillation power is detected between 800 and 3400 μHz, as well as comb-like structure of regularly spaced peaks [1].



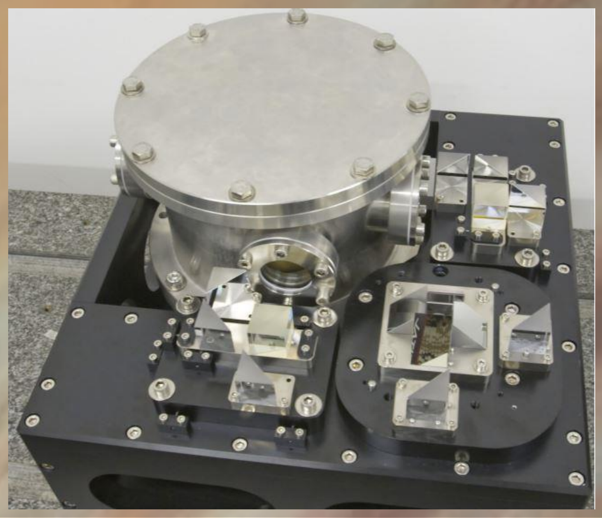
Left: preliminary results of the $Y_l^m = (1,0)$ power spectrum for a full observation campaign by the JIVE instrument in 2018. Future analysis of this dataset will place strict upper limits on the maximum amplitude for global modes of Jupiter and constrain potential excitation mechanisms.

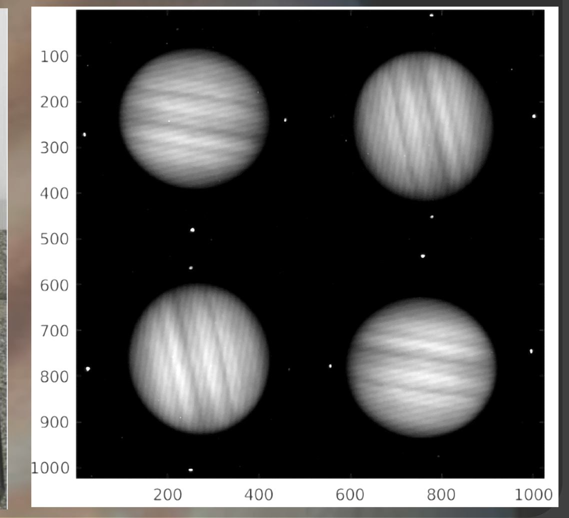
Instrumentation + Network Operations



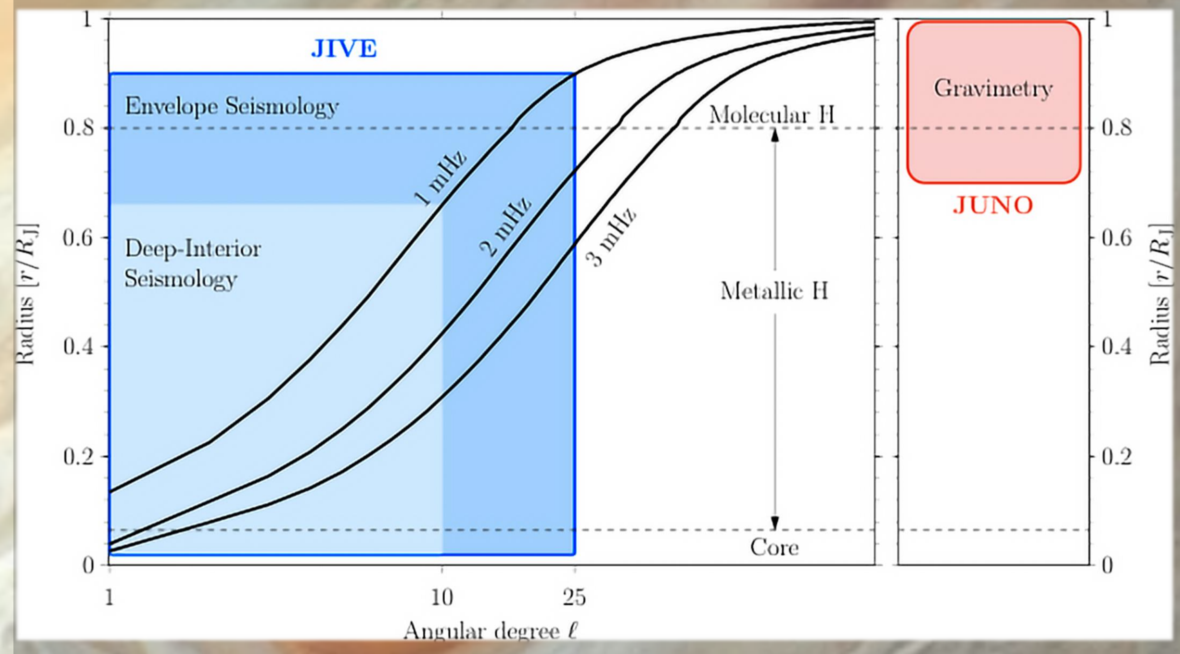
As seen above, the Jovian Interiors Velocimetry Experiment (JIVE) project is a collaboration between Sunspot Solar Observatory in New Mexico (below), Calern Observatory in France, and Okayama Observatory in Japan. Each telescope is outfitted with a Doppler imaging spectrograph that has been optimized for Jovian seismology and atmospheric dynamics. The JIVE instrument is based on a Mach-Zehnder interferometer design with a fixed optical path difference. It provides spatially-resolved line-of-sight velocity images of the whole planet at the altitude where visible solar light is reflected.

The left panel below shows the corresponding interferometer components, and the right panel shows four output images of Jupiter used to compute velocity maps from interferometric fringes.



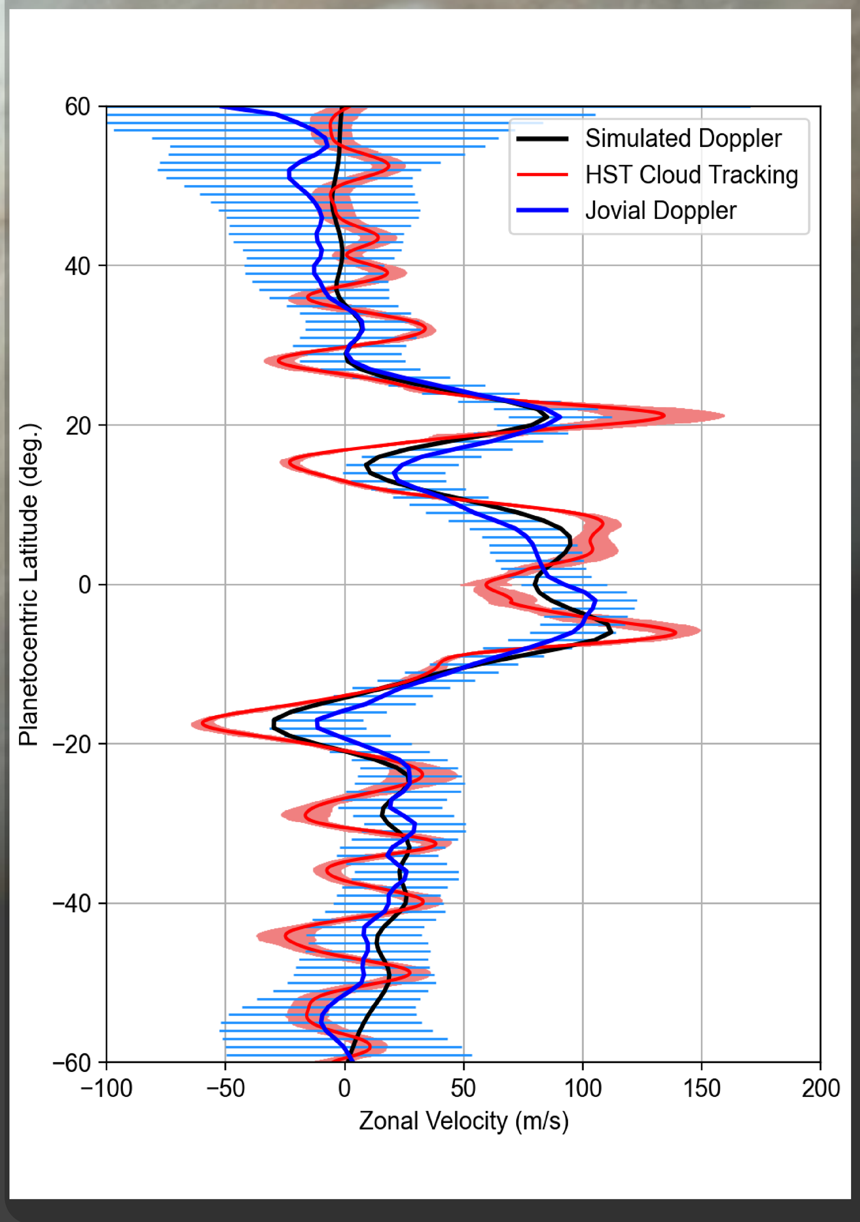


Complementarity with JUNO



The figure above (left) depicts how JIVE and JUNO are complementary. The blue box shows the sensitivity within Jupiter for seismic waves of a given frequency and angular degree. This includes a deep-interior program (light blue) using low-degree modes and an envelope program (darker blue) for higher-degree up to ℓ=25 when there is good telescope seeing. The right panel shows where JUNO has most sensitivity, including the near-surface regions where seismology may not be possible [5].

Initial Results + Future Work



JIVE's unique dataset of Doppler imaging also provides an avenue to study the zonal winds in the upper troposphere of Jupiter. The left figure shows average velocities of these using Doppler spectroscopy [6][7]. Here, Doppler imaging results from JOVIAL-JIVE are compared to both zonal wind profiles obtained from simulations (solid black) and Hubble Space Telescope (HST) cloud-tracking observations (solid red). All three show overall good agreement.

Once JIVE observations measure and identify the planets' global modes of oscillation, we will finally be able to directly probe the deep interior of the gas giant planets for the first time and lead to a fundamental breakthrough in our understanding of planetary formation and atmospheric dynamics.

References: (1) Gaulme et al. 2011, A&A 531:A104. (2) Hedman & Nicholson 2014, AJ, 146-12 (3) Mankovich & Fuller 2021, NatAs, 5, 1103. (4) Shaw et al. 2022, FrASS, 9, 768452. (5) Bolton et al. 2017, Science, 356, 821B. (6) Gonçalves et al. 2019, Icarus 319. (7) Schmider et al. 2023 (in prep).

For more information, scan here:

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