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Towards a breakthrough in the knowledge of internal structure of giant planets

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Abstract

Knowledge of Jupiter's deep interior will provide unique constraints on the formation of the Solar system. Seismology, which consists of identifying acoustic eigenmodes, offers a way to directly measure the deep sound speed profile, and thus the physical properties. The recent detection of global modes of Jupiter opens the way to the investigation of the inner structure of the solar system's giant planets based on seismology techniques, in particular in the context of the ESA's JUICE mission.

1. Jovian seismology

The internal structure of Jupiter is still mostly unknown. This limits considerably our understanding of the formation of the solar system, both because it yields a large uncertainty on the amount of solids that went into planet, and also because Jupiter has played a crucial role in shaping the solar system. An efficient constraint on the solar system formation scenario would be given by measuring the total amount of heavy elements inside Jupiter and the size of the planetary core.

1.1 Ambiguous detections in the 1990s

Jovian seismology has long been considered as a potentially powerful tool to probe the interior of Jupiter [1] and as a natural extension of helioseismology [2,3], because the common fluid nature of Jupiter and the Sun is expected to lead to similar oscillations and the possibility to use similar observational techniques. Theoretical works [4,5] predict that Jovian global oscillations should have a frequency range of [800, 3500] μHz with 10 to 100 cm s^{-1} amplitude, values that are comparable to the Sun's. Several attempts to observe Jovian global modes have been carried out since the mid-1980s, with thermal infrared photometry [6], Doppler spectrometry with magneto-optic [7] and Fourier transform spectrometers [8,9], respectively. Moreover, in 1994, infrared observations [10,11] were performed to look for pressure waves excited by the impact of the comet Shoemaker-Levy 9. Infrared observations are affected by atmospheric inhomogeneities and have been unsuccessful so far. In contrast, all of the Doppler measurements exhibit an excess power of about 1 m^2s^{-2} between 800 and 2000 μHz, which could not be *a priori* explained by instrumental systematics or by spurious atmospheric signals.

1.2 Discovery of Jupiter's global modes

The need for a specific instrumentation able to combine high spectral and spatial resolution emerged from the 1980 and 1990s experiments. The major difficulty of seismic observations of Jupiter is related to its rapid rotation, which diminishes the instrument's velocity sensitivity and makes it extremely sensitive to pointing errors. The SYMPA instrument [12] is a visible Fourier tachometer designed to circumvent this difficulty and whose principle is based on the spectro-imaging of the full planetary disk in a non-scanning mode, and inherits from the helioseismic instruments GONG [13] and MDI/SOHO [14]. It produces radial velocity maps of Jupiter's upper troposphere by measuring the Doppler shift of solar lines that are reflected by Jupiter's clouds.

The best observation sequence with SYMPA was acquired in April 2005 at the Teide Observatory. As in previous Doppler measurements, the time series exhibits excess power between 800 and 3400 μHz (Fig.1) [15]. This time it is modulated by a clear, high signal-to-noise comb-like structure of mean spacing Δnu = 155.3±2.2 μHz, with 24 peaks of velocity about 40 cm s^{-1}.

(2)

This situation agrees with theoretical expectations [5, 16] and would correspond to the signature of modes of consecutive degrees (e.g. l=1 and l=2). Oscillating stars also present similar signatures [17, 18].

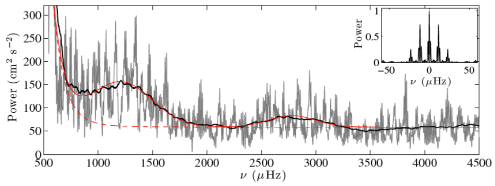

Figure 1: Power spectrum of the time series obtained with SYMPA instrument [15].

2. Prospects with Juno and JUICE

If these results are compatible with current models of Jupiter, an observational breakthrough still has to be overcome to constrain Jupiter's inner structure. Individual modes in terms of spherical harmonics must be identified to invert the density profile [Jackiewicz et al., in press]. This is the objective of the project of Doppler Imager *Echoes*, which is payload candidate onboard on the JUICE mission. As SYMPA, the instrument is designed to provide instantaneous velocity maps of the whole surface of Jupiter, with spatial resolution limited by the pixel size. It will benefit from the close distance to Jupiter to increase the velocity sensitivity by a factor 50.

The measurements to be performed by the DI-*Echoes* would be complementary to those that will be performed by the NASA *Juno* mission. *Juno*'s information regarding the internal structure of Jupiter will come from two main sources of data: (i) An extremely accurate measurement of the planet's gravity field using X- and Ka- band transponders as precision Doppler vehicles; (ii) Radiometric brightness measurements at wavelengths up to 60 cm to detect ammonia and water emission down to pressures of a few 100s bars. These measurements will be extremely valuable to retrieve the planet's gravitational moments with extremely high accuracy, differential rotation in the planet deep below the photospheric levels [19], and constrain the water abundance. These constraints will be used in planet interior structure models to better constrain the planet's composition, in particular its heavy elements and core mass. However, it is important to stress that the basic data concern the outer layers of the planet: gravity data probes more deeply, but nearly all of the information concerns the outer 20 to 40% in radius.

6. Summary and Conclusions

The recent detection of Jupiter global oscillations with SYMPA opens a new window in planetology. After the major success of seismology with Earth, the Sun, and thousands of stars (CoRoT, Kepler), the time of giant planets has come. It requires continuous observations from a dedicated instrument, ideally from space. This is the purpose of the Doppler Imager *Echoes* proposed to the ESA JUICE Mission.

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