SF2A 2006
D. Barret, F. Casoli, T. Contini, G. Lagache, A. Lecavelier, and L. Pagani (eds)

JOVIAN SEISMOLOGY: PRELIMINARY RESULTS OF THE SYMPA INSTRUMENT

P. Gaulme[1], F. X. Schmider[1], J. Gay[2], C. Jacob[1], F. Jeanneaux[1], M. Alvarez[3], M. Reyes[3], J. C. Valtier[2], E. Fossat[1], P. L. Palle[4], J C. Belmonte[4] and B. Gelly[5]

Abstract. Jupiter's internal structure is poorly known (Guillot et al. 2004). Seismology is a powerful tool to investigate the internal structure of planets and stars, by analyzing how acoustic waves propagate. Mosser (1997) and Gudkova & Zarkhov (1999) showed that the detection and the identification of non-radial modes up to degree $\ell = 25$ can constrain strongly the internal structure. SŸMPA is a ground-based network project dedicated to the Jovian oscillations (Schmider et al. 2002). The instrument is composed of a Mach-Zehnder interferometer producing four interferograms of the planetary spectrum. The combination of the four images in phase quadrature allows the reconstruction of the incident light phase, which is related to the Doppler shift generated by the oscillations. Two SŸMPA instruments were built at the Nice university and were used simultaneously during two observation campaigns, in 2004 and 2005, at the San Pedro Martir observatory (Mexico) and the Teide observatory (Las Canarias). We will present for the first time the data processing and the preliminary results of the experiment.

1 Introduction

First theoretical studies about Jupiter's oscillations began in the mid 1970's with the Vorontsov and Zarkhov works, whereas first attempts to observe them began in the late 1980's (Deming et al. 1989 and Schmider et al. 1991). Different ways may be used to observe seismic waves which propagate through the interior and that are trapped below the tropopause (Mosser 1995). Doppler spectrometry is used to measure the velocity field in the upper troposphere. Infrared photometry is sensitive to the temperature fluctuations associated to the acoustic waves. Visible photometry is sensitive to the reflected solar flux changes related to the wave displacements and their effects (Gaulme & Mosser 2005). The thermal infrared photometric measurements of Deming et al. (1989) did not detect oscillations but yielded an upper limit to the velocity field amplitude around 1 m s^{-1}. The sodium cell spectrometric observations of Schmider et al. (1991) and the Fourier transform spectrometric observations of Mosser et al. (1993, 2000) did not clearly detect oscillation modes but proposed the identification of a typical oscillation signature: the removal of degeneracy due to the planetary rotation. Moreover, the upper limit of the velocity field has been reduced to 0.6 m s^{-1}.

All these observations have been done with instruments which were not specially dedicated to Jupiter seismology, and so not perfectly adapted. The new internal structure models of Guillot (e.g. 2004) need strong observational constraints. Mosser et al. (1997) and Gudkova & Zharkov (1999) showed that the detection and the identification of non-radial modes up to degree $\ell = 25$ can constrain strongly the internal structure. These works have justified two new instrumental projects: JOVIS, a space photometer proposed to the French space agency (Mosser et al. 2004) and SŸMPA, a multi-site Doppler spectrometer (Schmider et al. 2002). Two SŸMPA instruments were built and used simultaneously during two observation campaigns in both observatories of San Pedro Martir (Mexico) and Teide (Canaries Islands) in 2004 and 2005. The data processing is now in its final phase; we present the preliminary results.

[1] Université de Nice, LUAN, CNRS UMR 6525, 06108 Nice Cedex 2, France
[2] Observatoire de la Côte d'Azur, Boulevard de l'Observatoire B.P. 4229, 06304 Nice Cedex 4, France
[3] Instituto de Astronomia de la UNAM, Ensenada, BC, Mexico
[4] Instituto de Astrofisica de Canarias, C/ Vía Láctea, s/n 38205 La Laguna (Tenerife),Spain.
[5] Observatoire Themis, C/ Vía Láctea, s/n 38205 La Laguna (Tenerife),Spain.

2 Instrumental concept

SŸMPA is an integrated project of giant planet seismology. It has to satisfy the specific needs of asteroseismology, in particular to permit continuous observations during several weeks. A network of telescopes, correctly distributed along the Earth, is equipped with identical instruments, conceived to measure the Jovian oscillations. The main difference with the previous observations is the spatial resolution, whereas all previous works used full disk integrated data. The instrumental principle is the velocity field measurement in each point of the planet, by measurement of the Doppler shift.

The main element of SŸMPA is a Mach-Zehnder interferometer, followed by a double bi-refringent prism (Fig. 1). First, the incident light beam is filtered in order to select the solar Mg lines at 517 nm. Then, it pass through the Mach-Zehnder and the prisms, after which it is divided into four beams in phase quadrature :

$$I_1 = \frac{I_0}{4}(1-\gamma\cos\phi) \qquad I_2 = \frac{I_0}{4}(1-\gamma\sin\phi) \tag{2.1}$$

$$I_3 = \frac{I_0}{4}(1+\gamma\cos\phi) \qquad I_4 = \frac{I_0}{4}(1+\gamma\sin\phi) \tag{2.2}$$

where γ is the fringe contrast and ϕ is the incident light phase. The combination of the four interferograms allows to establish the phase map, which is proportional to the velocity field measurement v :

$$\phi = 2\pi\sigma\Delta \left(1 + 2\frac{v}{c}\right) \tag{2.3}$$

where σ indicates the wave number, Δ the optical path difference and c the light velocity. The Doppler term is enhanced by a factor 2 because of the reflection of the solar light on the Jovian surface.

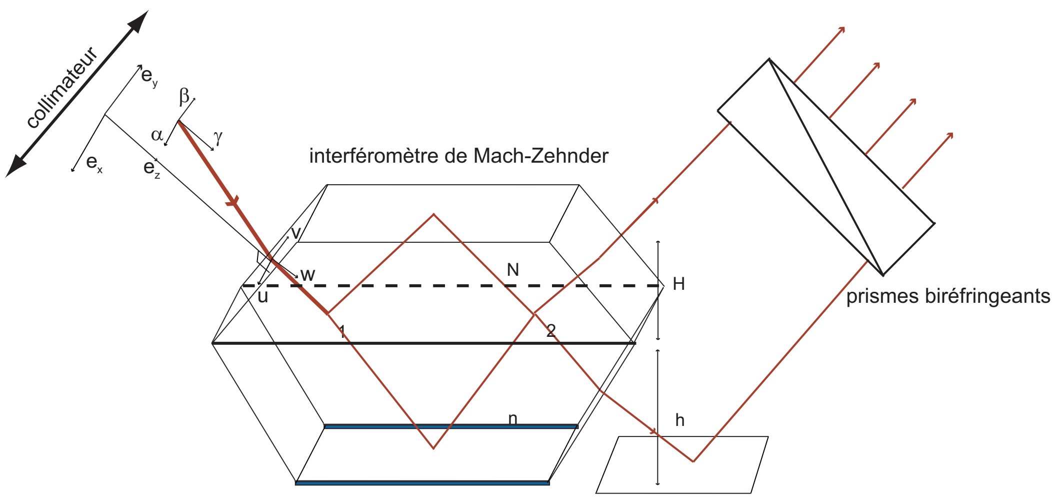

Fig. 1. The Mach-Zehnder interferometer is composed of two prisms of different refraction index, N and n. Incident collimated light gets separated in point number 1. Then, the upper and lower optical path differ and introduce interference pattern in the exiting light beam, after recombination (point 2). The bi-refringent prisms separated the perpendicular and parallel polarization components. Metallic reflection on the lower face produces a phase shift of almost $\pi/2$ between both polarizations.

3 Data processing method

The phase map is the sum of two contributions: an instrumental term, $\phi_{\text{instru}} = 2\pi\sigma\Delta$, which corresponds to the interferogram in case of absence of any velocity field, and the Doppler term $\phi_{\text{doppler}} = 4\pi\sigma\Delta v/c$. Moreover, the velocity field is the sum of the relative motion of Jupiter with respect to Earth (distance Jupiter-Earth and Earth rotation), the Jovian rotation and finally of the oscillation modes. The art of processing the data is the ability of eliminating each "spurious" component of the signal, in order to only keep the seismic signal. Therefore, the first step is the calibration of the instrumental term, by using interferograms made with solar light. The Jovian rotation can be easily eliminated since Jovian rotation is precisely known, and the radial component of rotation velocity describes iso-velocity lines, which are parallel to the rotation axis. The relative motion of Jupiter with respect to the observer introduces a slow drift of the phase, which is accurately corrigible since all motions are well known. Oscillation amplitude is too weak to be directly detected in the phase maps, which are obtained after all the spurious term. So, after this first step, we have to obtain noisy phase maps of uniform value. The mode identification is performed by taking the spectrum of the temporal series obtained with the whole data set.

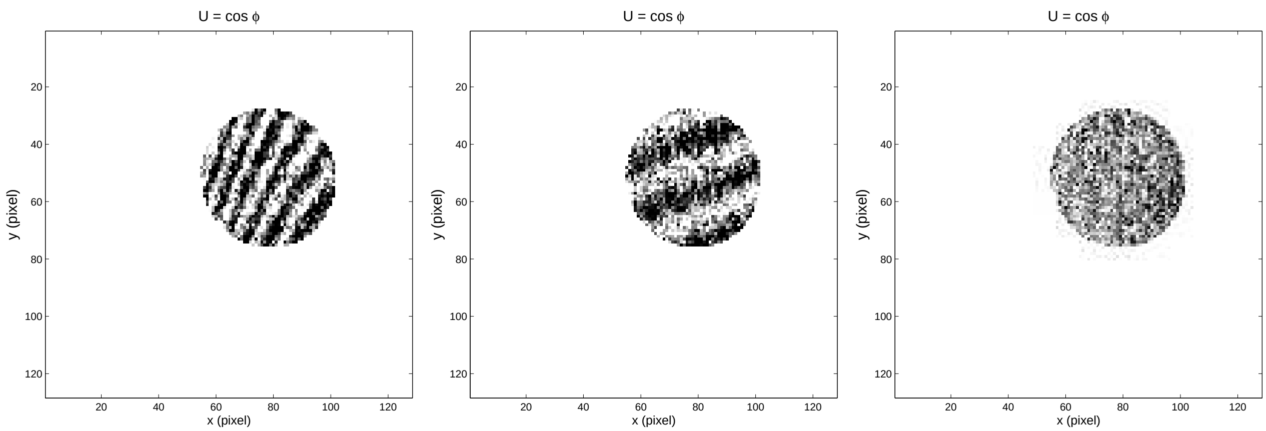

Fig. 2. Representation of the three main steps of data processing. Left, rough interferogram. Middle, interferogram where the instrumental contribution has been eliminated. Right, Jupiter's rotation has been eliminated too, leaving only seismic signal and noise.

4 Preliminary results

The 2004 observation campaign allowed to have almost 10 consecutive nights in Mexico, whereas the 2005 campaign gave almost 7 nights in Mexico and 7 nights in Canaries. Now, previous steps of data processing are well controlled, and have been tested on an entire night of data, obtained at Canaries observatory in 2005. It represents 7 hours of imaging on Jupiter. The mean noise is equivalent to 15-20 $\mathrm{m\,s^{-1}}$ on a full disc image, of 6 s integration time. Consequently, it is possible to detect periodic movements of 25 cm $\mathrm{s^{-1}}$ for one night, by supposing that we are only limited by photon noise. If such a level is maintained for each night of the 2005 campaign, oscillations of 8 cm $\mathrm{s^{-1}}$ should be measured. This has to be compared to the 1980's and 1990's observation performances, which hardly reached 60 cm $\mathrm{s^{-1}}$ (Mosser et al. 2000).

A trivial identification method of oscillations modes has been applied to the data of this night : it consists in projecting each phase map on a line, to form a temporal series of the mean phase along a Jovian axis. The two dimensional Fourier transform of this temporal series appears as a kind of "ℓ, ν" diagram, where ℓ indicates the mode degree and ν its frequency, which is usually used in asteroseismology, to highlight a seismic signal. Indeed, at zero order, relation between frequency and degree can be expressed as

$$\nu_{\ell,\nu} = \nu_0 \left(n + \frac{\ell}{2}\right) \tag{4.1}$$

where n is the radial order (e.g., Tassoul 1980). Pressure oscillations modes should appear as point alignments, parallel one to each other. In our case, only one line is clearly obvious (Fig. 3). It cannot be interpreted as an instrumental noise, and is compatible with the presence of oscillations in the frequency range $[0.5, 1]$mHz, for low degree modes ($\ell < 8$). Such a signal is also coherent with previous observations (Schmider et al. 1991; Mosser et al. 1993, 2000). However, il is still impossible to identify the modes; we need to use all the data of the observation campaign.

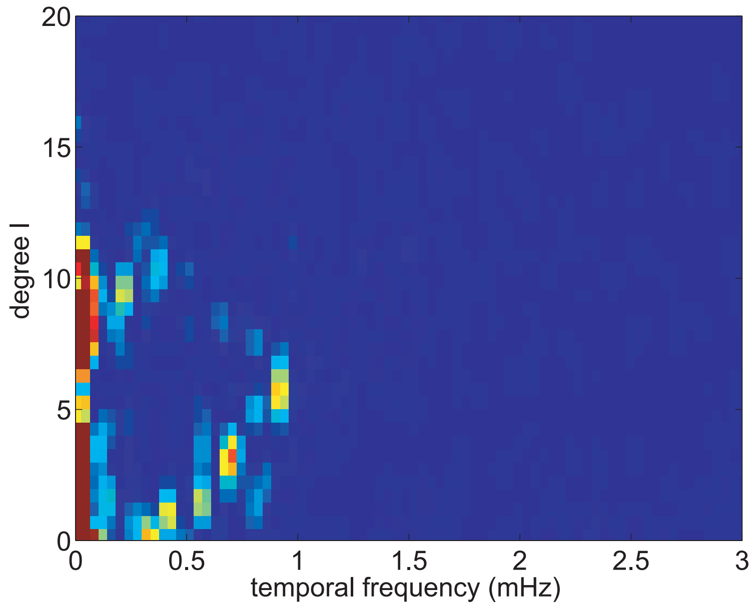

Fig. 3. Diagram of the observed signal upon one night, as a function of the spatial frequency (degree ℓ) and temporal frequency.

5 Conclusion

SŸMPA has demonstrated to reach performances close the expectations. Noise level on velocity measurement is almost 7 time better than during the previous observations. Some steps of the data processing are still in progress, in order to take into account residual effect, as optical path difference variation as a function of temperature or telescope guiding. Precise identification of oscillation modes would open a new way of exploring interior structure of giant planets. Then, it would be possible to use SŸMPA to observe Saturn or even Venus (of which atmosphere is very dense), and imagine an Antarctic version of SŸMPA, which would eliminate the windowing noise to due the diurnal interruption of observations (Schmider et al. 2005).

References

Deming et al. 1989, ApJ, 343, 456

Gudkova & Zarkhov 1999, PSS, 47, 1211

Gaulme & Mosser 2005, Icarus 178, 84

Guillot 1999, PSS, 47, 1183

Guillot et al. 2004, Jupiter, Cambridge Edt, 35

Mosser et al. 1993, A&A, 267, 604

Mosser et al. 1995, A&A, 293, 586

Mosser 1997, IAU symp, 181

Mosser et al. 2000, Icarus, 144, 104

Mosser et al. 2004, SF2A-2004

Schmider et al. 1991, A&A, 248, 281

Schmider et al. 2002, SF2A-2002

Schmider et al. 2005, EAS Publication Series, 285

Tassoul 1980, ApJS, 43, 469

Vorontsov et al. 1976, Icarus, 27, 109