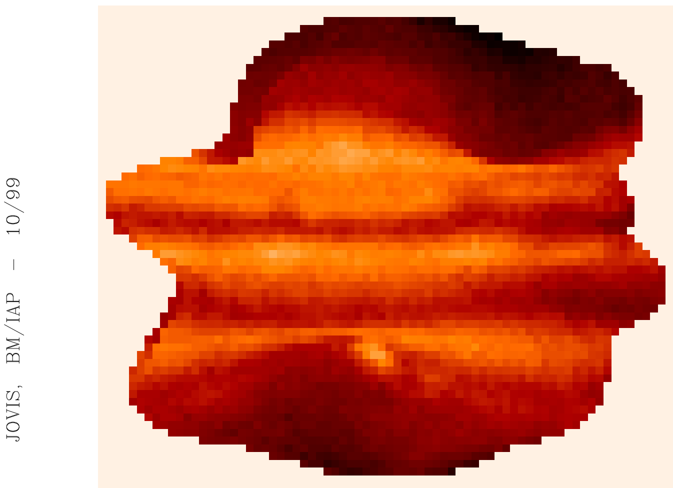
JOVIS – Jupiter, Observation of Variations Imaging and Seismometry

B. Mosser and the JOVIS *team*
DESPA, Observatoire de Meudon
Institut d'Astrophysique de Paris
mosser@iap.fr

April 9, 2002



1 Abstract

JOVIS is a micro-satellite project presented to the French spatial agency (CNES), dedicated to the search of Jovian global oscillations. JOVIS considers the planet Jupiter as a mirror reflecting the solar light, but with a size modulated by the planetary deformation. This modulation will translate into flux variation. The basic principle of the project, derived from the asteroseismological space mission COROT, relies on the ability with CCD high precision photometry to detect periodic oscillation in a noisy signal. The nominal specification for the sensitivity is the detectability in 5 days of fluctuations of about 1 ppm, due to oscillation velocity of about 25 cm.s^{-1}, with a signal to noise-ratio-better than 15.

Imaging capabilities will allow the identification of Jovian oscillation modes up to the degree $\ell \simeq 20$. It will make possible to sound with precision the whole planetary interior, including the supposed core boundary, and the plasma phase transition between molecular and metallic hydrogen. JOVIS will also provide a unique opportunity to follow over several years all varying tropospheric phenomena, with a low spatial resolution, but with a quasi-continuous temporal coverage, and a very high sensitivity.

2 Scientific goals

JOVIS is dedicated to sound very precisely the variability of the Jovian visible flux. The low frequency component of the variability is dominated by meteorological phenomena, whereas the high frequency component is due to global oscillations. The seismic study of Jupiter is the primary goal of JOVIS.

2.1 Jovian seismology

2.1.1 *Jovian interior structure*

The image we have from any astrophysical object is two-dimensional. What we see from the giant planets is in fact a very thin layer, from a few microbars down to the 10-bar level. Some physical data, as pressure, temperature or density, cannot be measured in the deep interior. However, the values of the mass, the gravitational moments, the rotation period and the luminosity constrain interior models. But the density profiles obtained from these quantities are strongly non unique.

- The Jovian interior corresponds to pressure and density ranges where the equations of state (EOS) of hydrogen and helium are very far from the perfect gas law. The determination of the pressure-density profile in the planetary interior would be a unique tool for determining the EOS of a hydrogen-helium gas mixing at very high pressure.

- The precise determination of the current state of the giant planet interior is a clue for their former evolution.

- The measurement of the concentrations of helium or other elements in the whole planet and not only in the upper atmosphere, as well as the determination of the structure discontinuities are key points for planetology.

Seismology is a very powerful tool for the investigation of the interior structure of any object (Gudkova et al. 1995).

We need to "listen" to the Jovian resonances in order to determine of what the planetary interior is made: JOVIS will answer the specific points adressed previously.

2.1.2 *Ground-based giant planet seismology*

A review on Jovian seismology is given in Mosser (1994). Ground-based Jovian seismology has already provided us with important results (Mosser et al. 1999). However, accurate measurements that could be used for strongly constraining the models are currently not achievable. They would need a network of a least three 4-m class telescopes equipped with dedicated detectors, observing during a few months.

Continuous observation, stability, long duration observation are necessary in order to get the required signal-to-noise ratio, and remain the property of observations made from space.

2.1.3 *Principle*

Jupiter acts as mirror that reflects the solar light. The visible flux depends on the size of the mirror, modulated by the Jovian oscillations (Fig. 1, Fig. 2). JOVIS will be sensitive to both radial and non radial modes. The visibility of the modes depends on the degree and azimuthal order of the spherical harmonics $Y_{\ell,m}$ (Table 1).

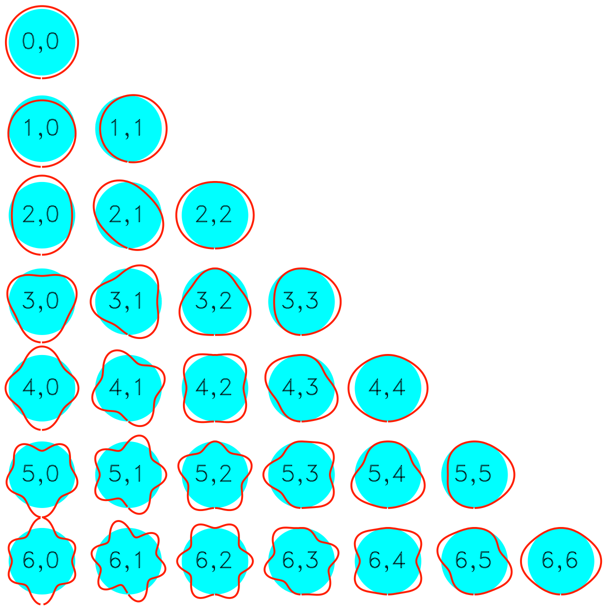


Figure 1:
How the Jovian limb is modified by the different modes with degree and azimuthal order $(\ell,\ m)$

For radial modes, the relative flux variation (Table 2) is related to the velocity v of the mode of frequency ν by:

$$\frac{\delta\Phi}{\Phi}\,(\mathrm{ppm}) \;=\; 4\,\frac{v\;(\mathrm{m.s}^{-1})}{\nu\;(\mathrm{mHz})}$$

2.1.4 *Oscillation spectrum*

The oscillation spectrum of Jupiter was analysed by many authors, numerically or semi-analytically. The eigenfrequencies $\nu_{n,\ell,m}$, depending on 3 intergers (radial order n, degre ℓ, azimuthal order m), express schematically (Provost et al. 1993) as:

$$\begin{aligned} \nu_{n,\ell,m} \;&=\; \left[n + \frac{\ell}{2} \right]\, \nu_0 \\ &+\; \text{2nd order} \;\; (\;V_1\;) \end{aligned}$$

Table 1:
Relative visibility of the Jovian modes seen by JOVIS. This coefficient, scaled at 1000 for radial modes, accounts for the spatial integration of each spherical harmonics Y_ℓ^m with degree ℓ and azimuthal order m. Modes with high azimuthal orders are filtered out because of the limb darkening function.

degree ℓ	azimuthal order $\lvert m\rvert < \ell$						
	0	1	2	3	4	5	6
0	1000						
1	613	389					
2	462	267	60				
3	387	235	47	18			
4	338	197	42	15	7		
5	293	184	40	13	6	3	
7	231	152	38	12	5	2	1
10	186	122	37	13	5	2	1
13	152	107	35	17	4	2	1
17	129	87	35	14	4	1	1

Table 2:
Radial mode velocity related to flux variations. High frequency modes are not efficiently trapped.

Integration time (days)	$\frac{\delta\Phi}{\Phi}$ (ppm)	velocity v (cm.s^{-1})			
		0.5 mHz	1 mHz	2 mHz	3 mHz
5	1.0	12	25	50	75
80	0.25	3	6	12	50
500	0.1	1	2	5	50

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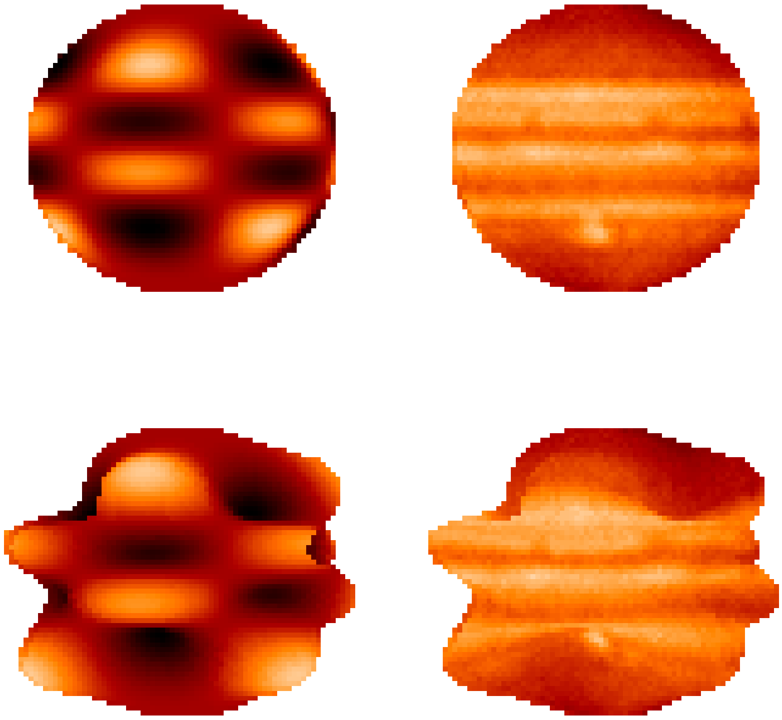

Figure 2:
Normal and somewhat exaggerated simulations of Jupiter oscillating in the mode $(\ell,\ m)$ = (5,3)

$+$ modulation due to the core (N, ε)
$+$ rotational modulation $(m\,\nu_{\rm rot})$

- The large splitting ν_0 describes the global property of the fluid envelop. According to interior models, ν_0 is in the range [152, 157 μHz]; according to observations, $\nu_0 \simeq 142 \pm 3$ μHz
- The frequency V_1 is mostly sensitive to the regions with high sound speed gradients
- The numbers N and ε give the size and the density contrast of the planetary core
- $\nu_{\rm rot}$ is the inverse of the rotation period (9h55min)

The acoustic cutoff frequency occurs around 3.1 mHz. The maximal modes life-time does not exceed 10 days for 3 mHz mode, but may reach 10^4 days at 1 mHz

Figure 4 shows how the characteristic frequencies ν_0 and V_1 can be considered as seismic contraints for Jovian interior models.

2.1.5 ***Varying albedo***

The flux variations due to the global oscillations will be mixed with the albedo variations of the rotating planet. This mixing was already analysed in the framework of the search for global oscillations (Lederer et al 1995). In fact, it is quite easy to disentangle the two phenomena, because their signatures are well distinct in the Fourier space. Albedo variations appear a low frequency, harmonics of the Jovian rotation frequency (28 μHz), whereas seismic oscillations appear at higher frequency (up to 3.1 mHz).

Figure 5 shows a simulation of 10-days observations, based on Jovian radial modes and on a synthetic map of Jupiter, including the dancing of the Galilean satellites. Jovian modes, with amplitude varying between 1 and 4 ppm, appear clearly.

2.2 Meteorology

The study of the evolution of the Jovian clouds consists mainly in the phenomenological description of the observed variations. The global understanding of the

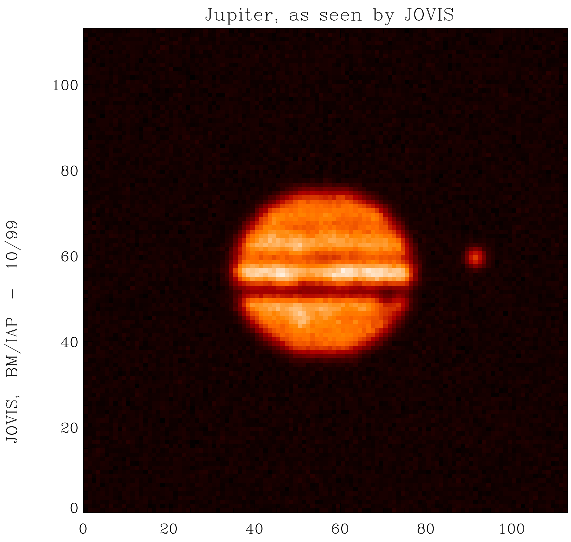

Figure 3:
Jupiter, as seen by JOVIS. The planet image is spread over about 1200 pixels. The image of a Galilean satellite corresponds approximately to the Point Spread Function.

dynamical evolution of Jupiter remains succinct, despite the Voyager and Cassini missions, and the amount of high quality images of Jupiter. In fact, the systematic study of the global evolution of the Jovian atmosphere suffers from the lack of continuity of the observations, or from the poor photometrical accuracy.

Observations based at the Pic du Midi Observatory (Pyrénées, France) have shown the great interest of images taken regularly within a few days, in order to test meteorological models. Such spherically symmetric models, developped over cylindrical maps (Yano et al. 2000), can predict the evolution of the main vortices. Mid-infrared observations, systematically conducted at the IRTF (Mauna-Kea, Hawaii), have produced interesting results on tropospheric and stratospheric waves (Ortiz et al. 1998). The evolution of the hot spots seems to be related to the propagation of Rossby waves, what suggests that the hot spots are the dynamical signature of deep convection.

The global variability study does not need a high spatial resolution, contrary to the morphological study done by the Voyager and Galileo missions or with the HST. About 50 points along the planetary diameter are enough for the monitoring

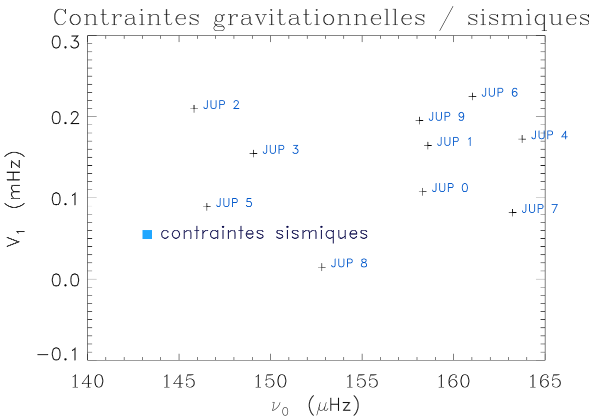

Figure 4:
All the Jovian interior models of this diagram fit the gravitational constraints. However, when displayed in this HR-like diagram, with the characteristic frequencies ν_0 and V_1 as x- and y-axis, they are very different according to the seismic information. This proves how seismic data constrain interior models.

of the Jovian clouds. JOVIS will provide one image every minute, in order to get for each Jovian rotation a cylindrical map.

The global variability study, in opposite to local morphological studies, can be achieved with a moderate spatial resolution. This database, unique in term of stability and continuity, will permit the follow-up of long term evolution, such as periodicities asssociated to Rossby waves. Furthermore, JOVIS will give access to the very long term variability.

3 Specifications

The basic principle relies on the capability to detect a periodic oscillation in a noisy signal and to measure the its principal parameters with a great accuracy.

3.1 Scientific specifications

JOVIS is intended to fulfill requirements that cannot be achieved by ground-based measurements.

The orbit has to insure a duty cycle as long as possible, in order to reduce the modes aliases due to discontinuous observation. The sources of noise, extensively

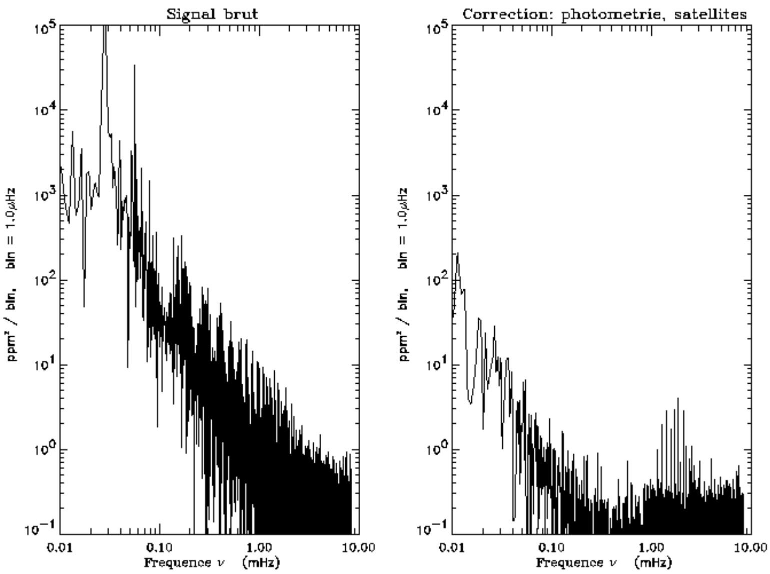

Figure 5:
Simulation of the radial modes spectrum. Left panel: low frequencies are not filtered, so that the low frequency range is dominated by the planetary rotation and the dancing of the satellites

analysed in the preparation of the COROT mission, have to be reduced as low as possible, in order to reach the photon noise. The mission life-time will permit to obtain a very high accuracy in the Fourier space.

3.2 Payload concept

JOVIS is conceived to benefit from the development of the french "petite mission" COROT, managed by the french spatial agency CNES[1].

The specifications of JOVIS are intended to measure a 1-ppm variation in 5 days, photon noise limited. This limit is derived from the COROT project. Compared to COROT, the performances are enhanced by different factors (smaller CCD, brighter target).

[1] http://www.astrsp-mrs.fr/www/pagecorot.html

Telescope : off-axis telescope with a primary mirror of 10 cm, and aperture f/30; PSF: 2” at 800 nm; Jovian image: 1200 pixels; +5.4 magnitude on 1 pixel.

Detector : frame transfer CCD, back-side illuminated light-sensitive area of 512$\times$256 pixels; 13 μm pixels; total field of view: 8.4’$\times$4.2’ The 1-ppm level be reached after 5 days. The detector will also receive directly the solar flux for reference.

Orbit : A low Earth quasi-polar orbit is compatible with the μ-mission budget and an ASAP launch, and can provide an acceptable duty cycle; mission life-time: 3 years

Attitude control system : JOVIS should be 3-axis stabilized, with stellar sensors, and guiding on the planet, the scientific signal being used by the platform. A slow drift of the planetary image on the CCD is acceptable.

Platform : The platform, developped for the micro-missions, with property similar to the PROTEUS platform, shall provide a pointing precision with a noise less than 0.1” in 1 min, without recurrent component between 5 and 30 min.

Thermal control : Passive, with Peltier effect cooling.

On board computer, communication : Required memory about 200 Mbit. The transfer of two 1200-pixel images every minute needs about 63 Mbit/day

Power, mass : in agreement with the μ-satellite specifications: 30 W, 30 kg

3.3 Mission profile

The ideal orbit shall provide a continuous observation of Jupiter. A low Earth quasi-polar orbit, compatible with an ASAP mission, should track on Jupiter, that moves about 30° per year. The Jovian synodic year (about 13 months) is then divided in 6 parts:

- 5 months: continuous observation (centered on the planetary opposition)
- 2 months: discontinuous observation, with occultation by the Earth
- 1 month: continuous observation

- 2 months: no observation of Jupiter, too close to the Sun. Secondary programs will then be made.
- 1 month: continuous observation
- 2 months: discontinuous observation, with occultation by the Earth

The launch should occur in 2005.

3.4 Collaborations

The instrument will be realized by the Département de Recherche Spatiale of the Observatoire de Paris-Meudon. The payload is estimated to 18 MF (about 3 M$).

The JOVIS team is currently composed of researchers from the following laboratories:

- DESPA, Observatoire de Paris
- DASGAL, Observatoire de Paris
- Institut d'Astrophysique de Paris
- Laboratoire de Météorologie Dynamique, Paris
- Département Cassini, Observatoire de la Côte d'Azur
- ESTS, Université de Bilbao

International collaborations are searched for the platform and for the operations.

References

[1] Gudkova, T., B. Mosser, J. Provost, G. Chabrier, D. Gautier, and T. Guillot 1995. Seismological comparison of giant planets interior models. Astron. Astrophys. 303, 594-603

[2] Guillot T. 1999. A comparison of the interiors of Jupiter and Saturn. Planet. Space Science, 47, 1183

[3] Lederer S. M., M. S. Marley, B. Mosser , J-P. Maillard, N. J. Chanover, R. Beebe 1995. Albedo features and Jovian seismology. Icarus 114, 269-277

[4] Mosser, B., D. Mékarnia, J.P. Maillard, J. Gay, D. Gautier, and Ph. Delache 1993. Seismological observations with a Fourier transform spectrometer: detection of Jovian oscillations. Astron. Astrophys. 267, 604-622

[5] Mosser, B., Jovian seismology. *The equation of state in astrophysics*, IAU Colloquium 147, (G. Chabrier and E. Schatzman Ed.), p. 481, Cambridge University Press, 1994.

[6] Mosser B., Maillard J.P., Mékarnia D. New attempt of detection of the Jovian oscillations. *Icarus* 144, 104

[7] Ortiz et al. 1998. Evloution and persistence of 5-μm hot spots at the Galileo probe entry latitude. JGR 103, 23051-23069

[8] Provost J., B. Mosser, G. Berthomieu 1993. A new asymptotic formalism for Jovian seismology. Astron. Astrophys. 274, 595-611

[9] Schmider, F.-X., B. Mosser, and E. Fossat 1991. A possible detection of Jovian global oscillations. Astron. Astrophys. 248, 281-291

[10] Yano J.I., P. Drossart, O. Talagrand, A. Mangeney, J. Tribbia, 2000. Global simulation of the Jovian atmospheric motion toward assimilation of remote sensing data. Adv. Space Res. 25, 1081