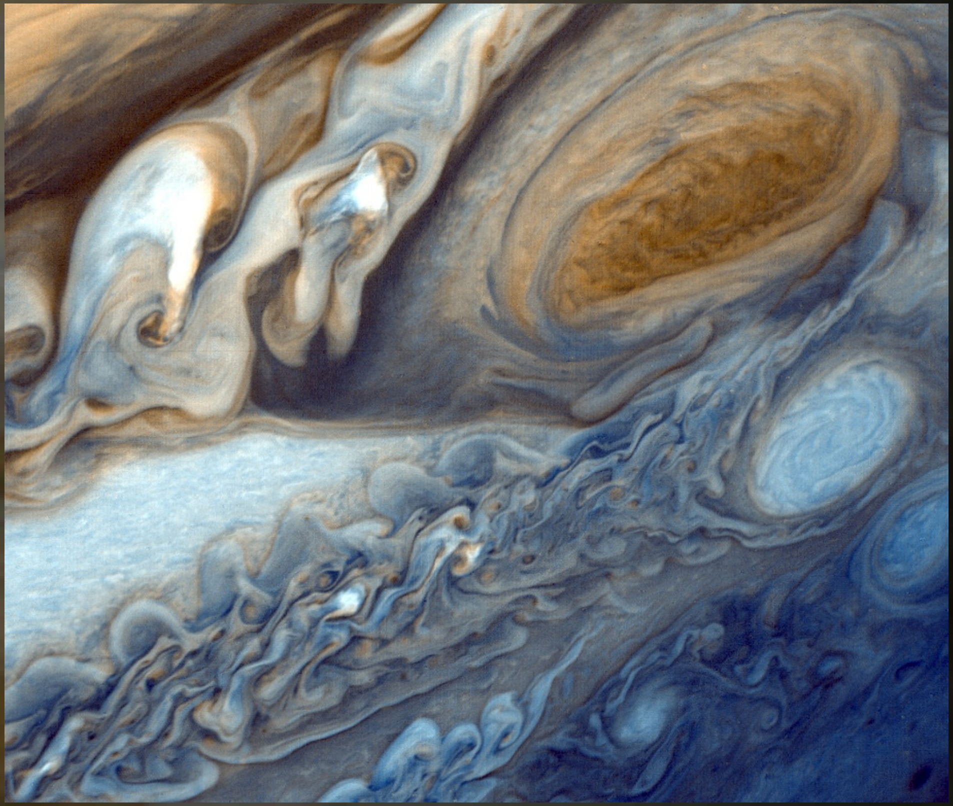
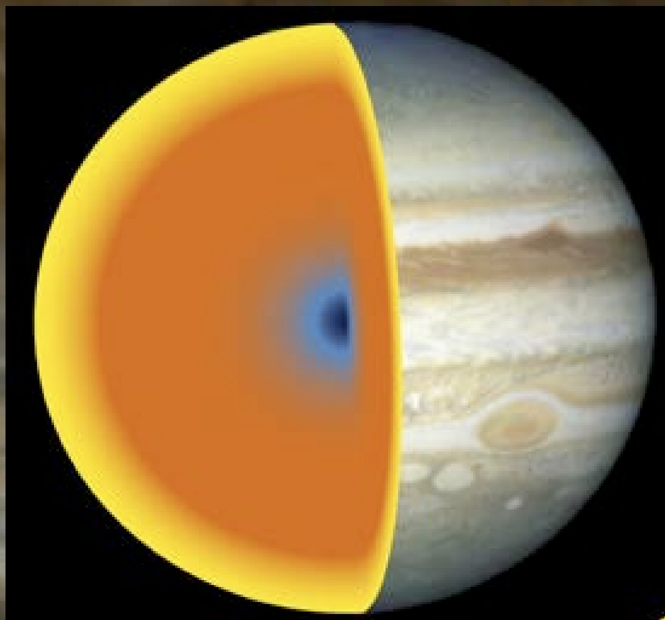
JOVIAL

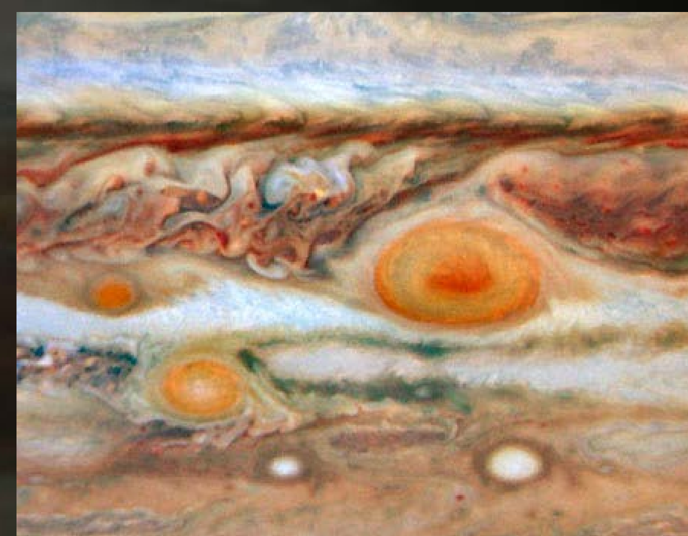
Jovian Oscillations through radial Velocimetry ImAging observations at several Longitudes



JOVIAL in brief



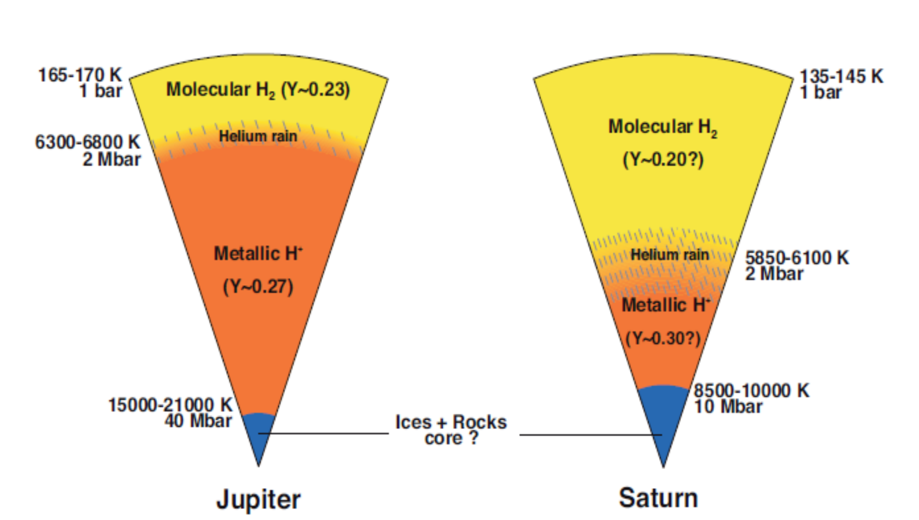
- Scientific goals
  - Internal structure of giant planets by seismology
  - Study of planetary atmosphere dynamics



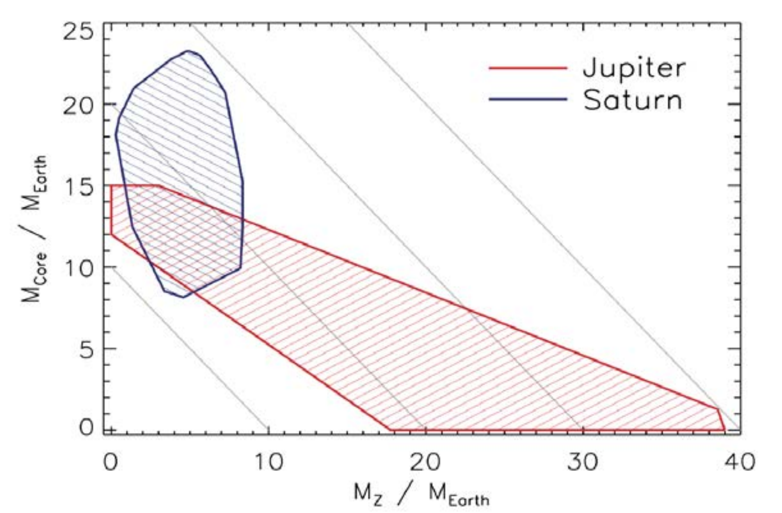
- Observation strategy
  - Fourier imaging tachometer
  - Observation network

Internal structure of giant planets

- Only few constraints
  - Mass, radius
  - Gravitational moments
  - Heat flux
  - Surface composition



- Non uniqueness
  - Initial conditions (formation)
  - Evolution (core erosion)
  - Equations Of State

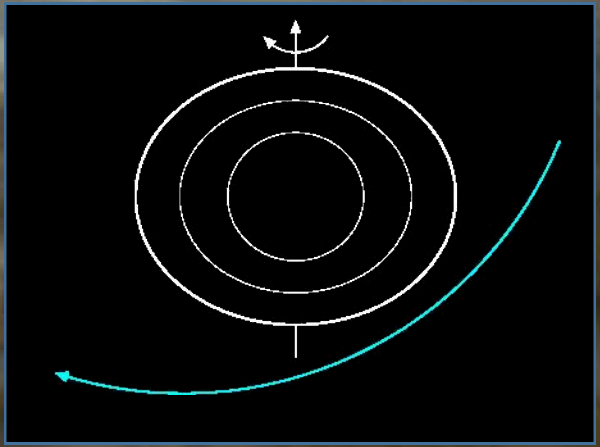


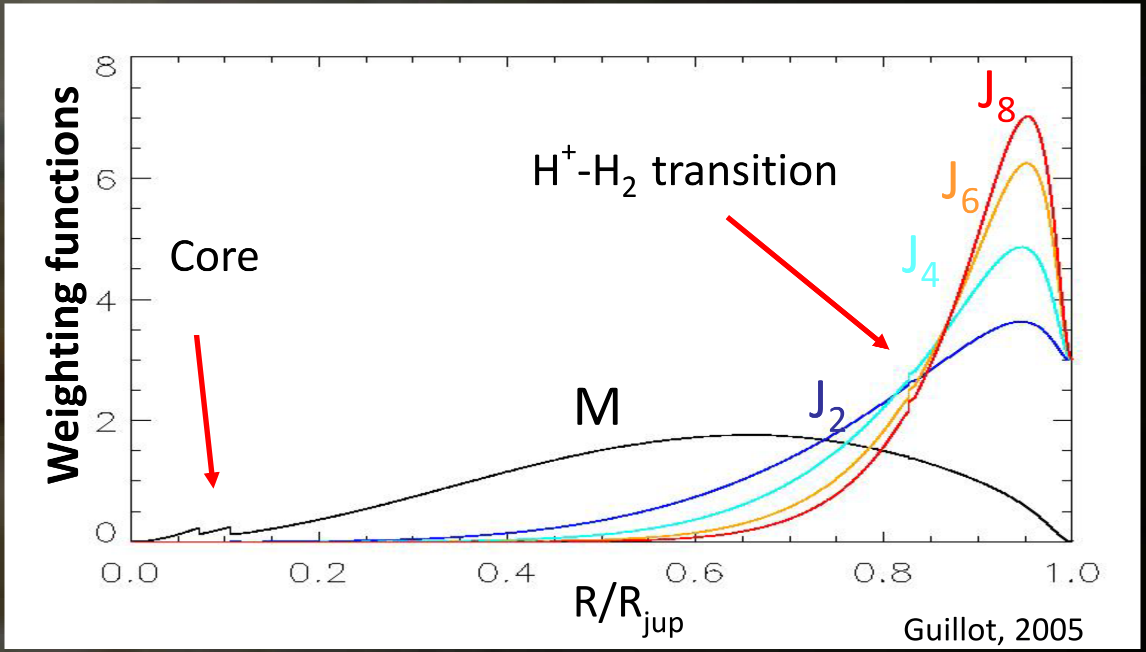
Having access to the internal structure would give unique clues to formation and evolution of the Solar System

Gravitational moments

JUNO will enter the jovian system on July 4th

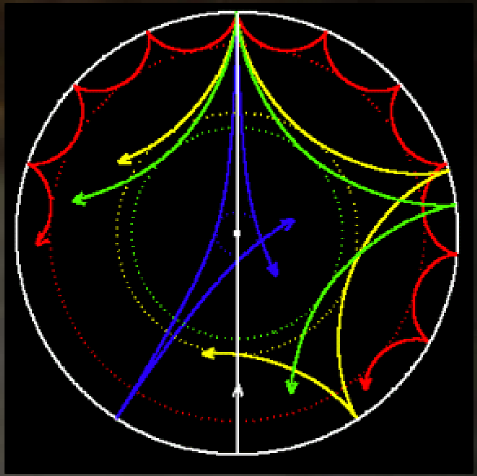
Gravitational moments measurements directly probe the outer regions

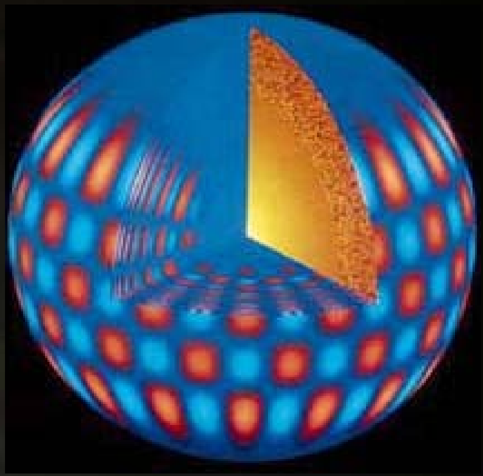




Seismology of giant planets

- As terrestrial seismology, asteroseismology allows the study of internal structure
- Acoustic modes frequencies depends on density
- Modes of different degrees penetrate to different depths





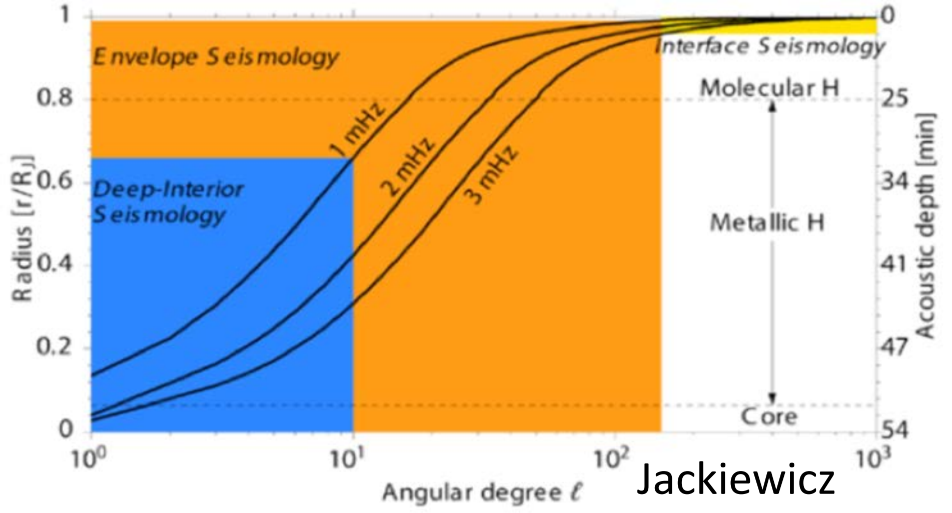
$\nu_{obs} - \nu_{theoretical}$

↓

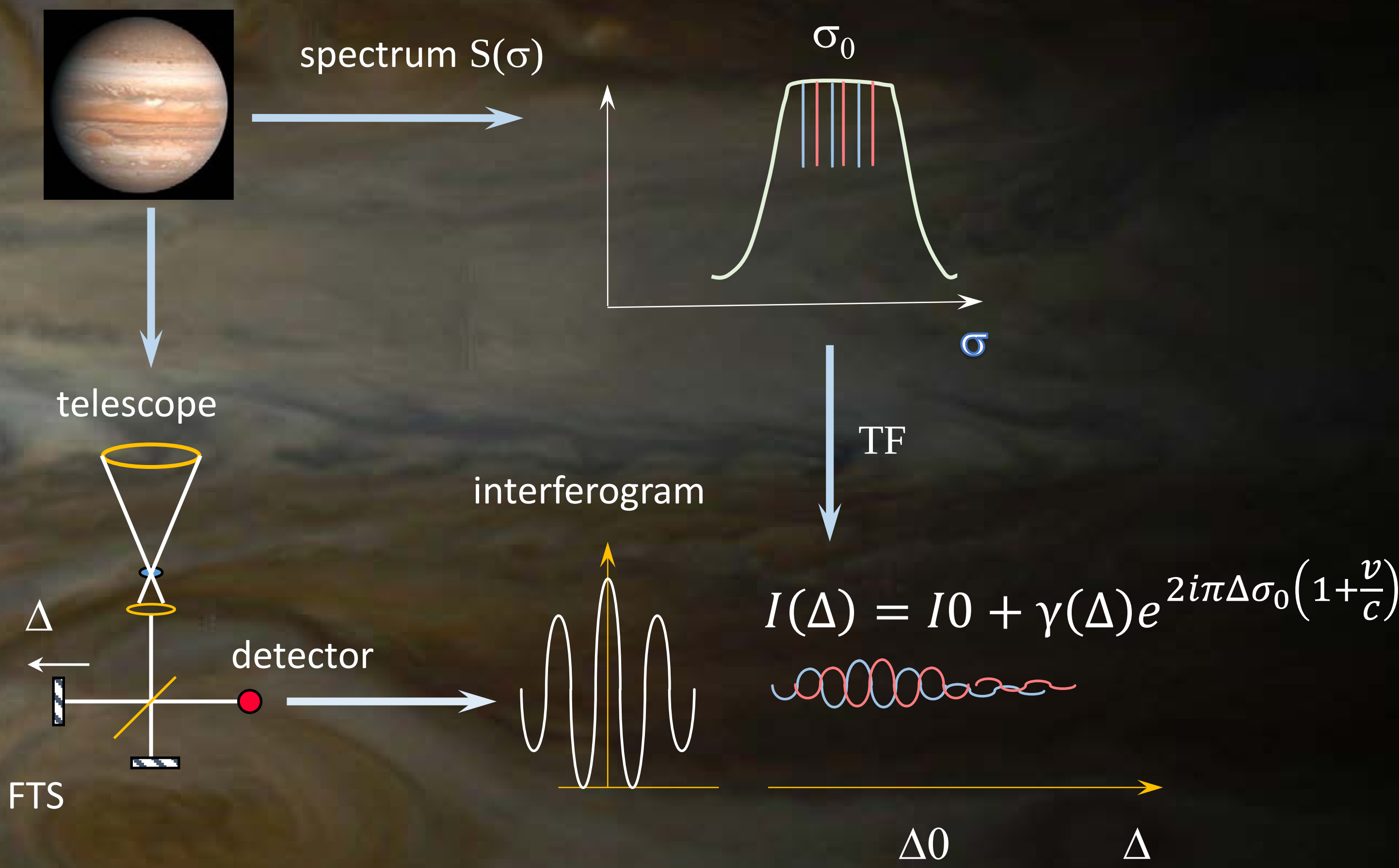
Inversion method

↓

$\rho_{obs} - \rho_{theoretical}$



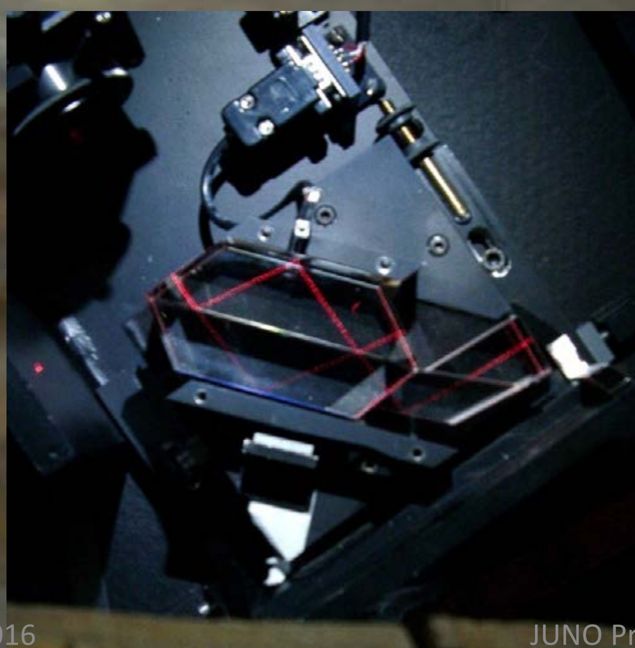
Instrument principle

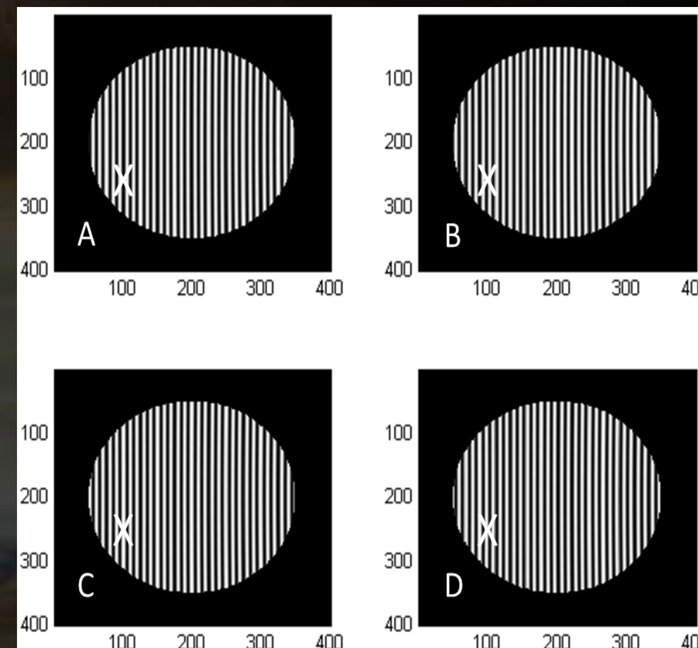


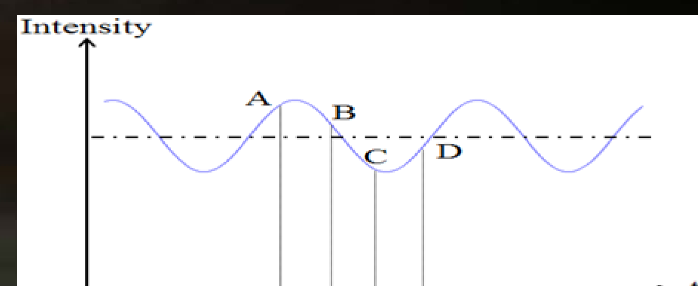
$$I(\Delta) = I0 + \gamma(\Delta)e^{2i\pi\Delta\sigma_0\left(1+\frac{v}{c}\right)}$$

SYMPA instrument

- Imaging Fourier tachometer
- Spectral FT at each point of the image
- Measures the Doppler shift of reflected solar lines
- Mach-Zehnder design
- Four outputs with phase shift of $\pi/2$ between polarisation



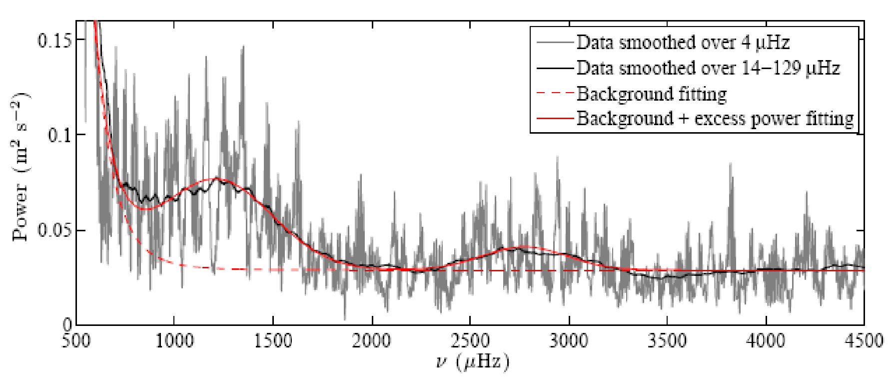


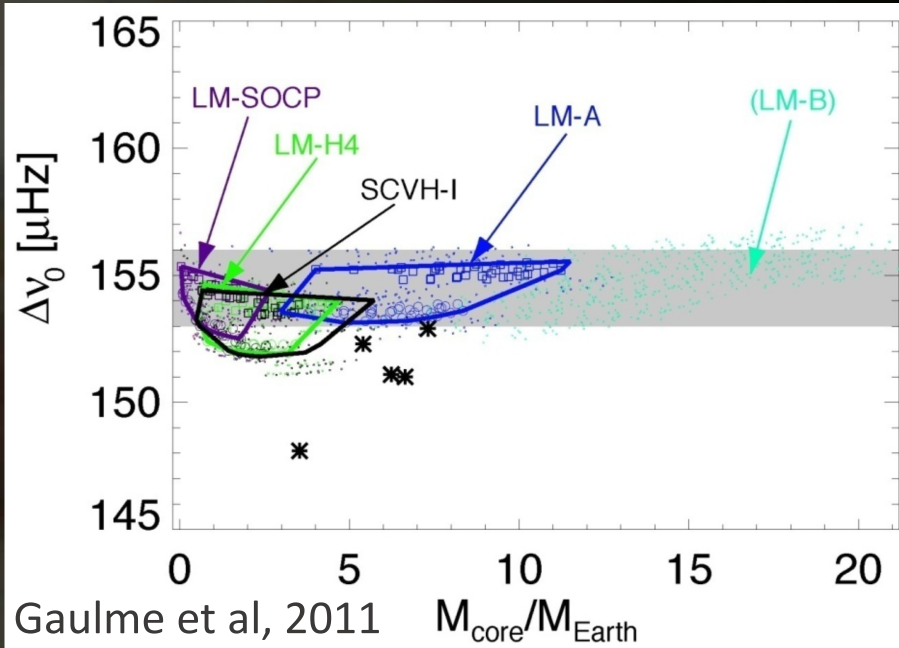


Detection of Jovian oscillations

- Ground based observations with SYMPA
- Power excess in the range [800 – 3000] μHz
- ~ 20 individual peaks with mean amplitude 30 cm/s ± 10 cm/s
- Regularly spaced peaks: $\Delta\nu_0$= 154.5 μHz ± 1.5 μHz
- Fundamental frequency good agreement with most models (mean density)

Individual modes identification requires <u>long continuous observation with good spatial resolution</u>

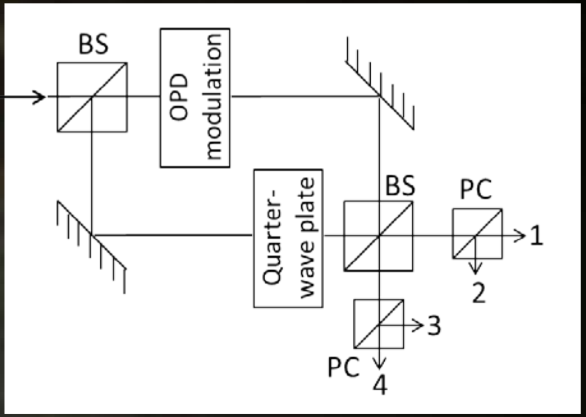


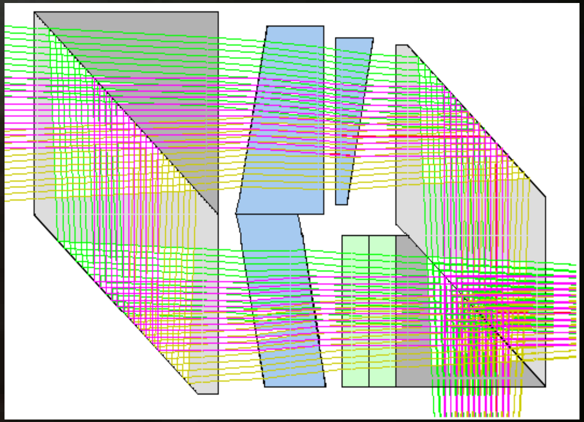


Gaulme et al, 2011

The JOVIAL concept

- JOVIAL is a Doppler Spectro-Imager
  - Based on SYMPA experience
  - Modified Mach-Zehnder design
- Optimisation of mesurement stability, precision, resolution
  - Large Field Optique Adaptative
  - Simultaneous multi-sites observations
  - Noise level < 4 cm/s in 2 weeks





The JOVIAL network

Goal: Simultaneous observations from 3 sites

Target: Duty-cycle > 50 % over two weeks

Observatoire de Calern (France)

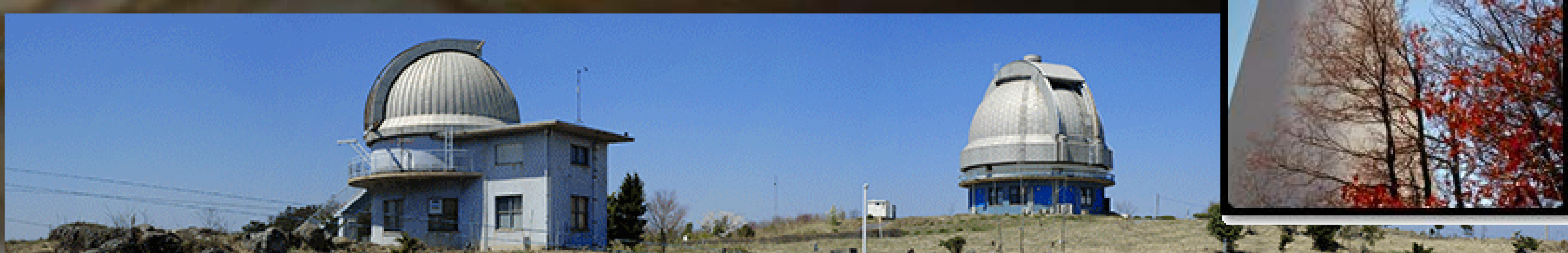
- C2PU: 1 m telescope with DSI prototype

New Mexico (USA)

- Dunn Solar telescope (Sacramento Peak)

Okayama Observatory (Japan)

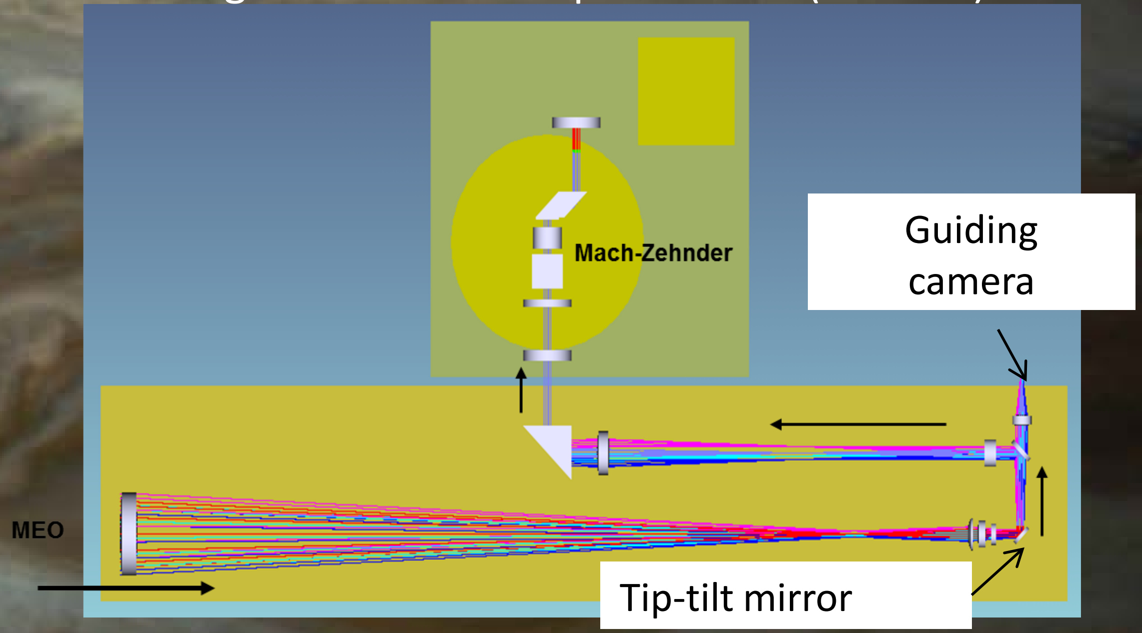
- Telescope de 1.88 m

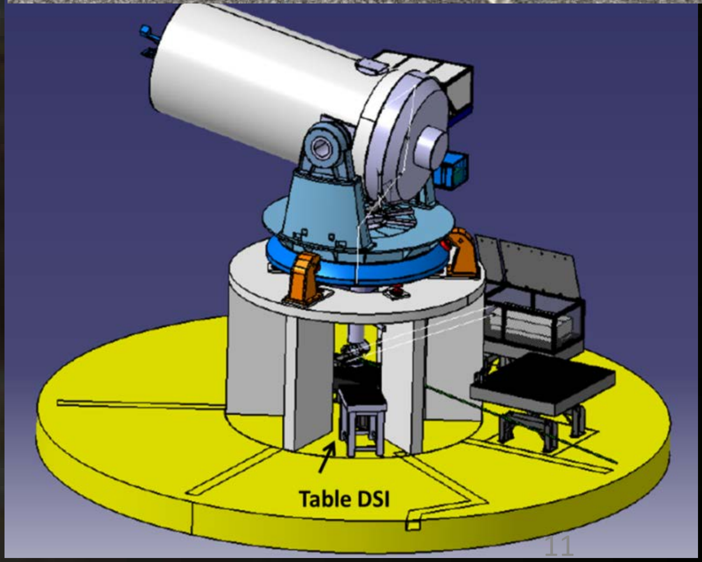


First tests on the sky

Implementation at MEO telescope (1,5m, altaz) Calern

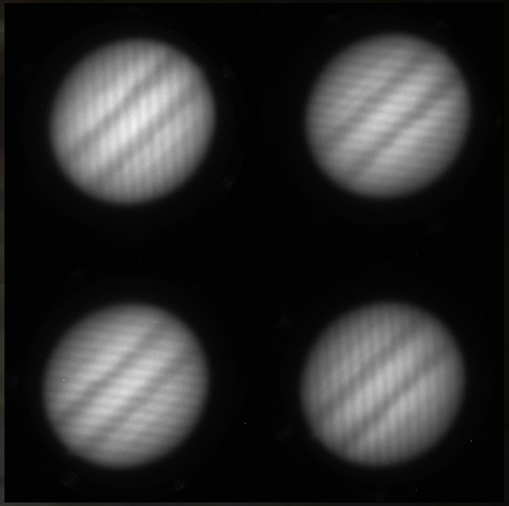
- Tip-tilt image stabilization: 200 Hz
- Observing run February 2015
- 4 nights on Jupiter (4340 images of 30s, 36h)
- Duty Cycle : 26%
- Mean flux: 4900 e-/px (7e8 e- by images)
- Fringes contrast on Jupiter ~2.5% (3% max)

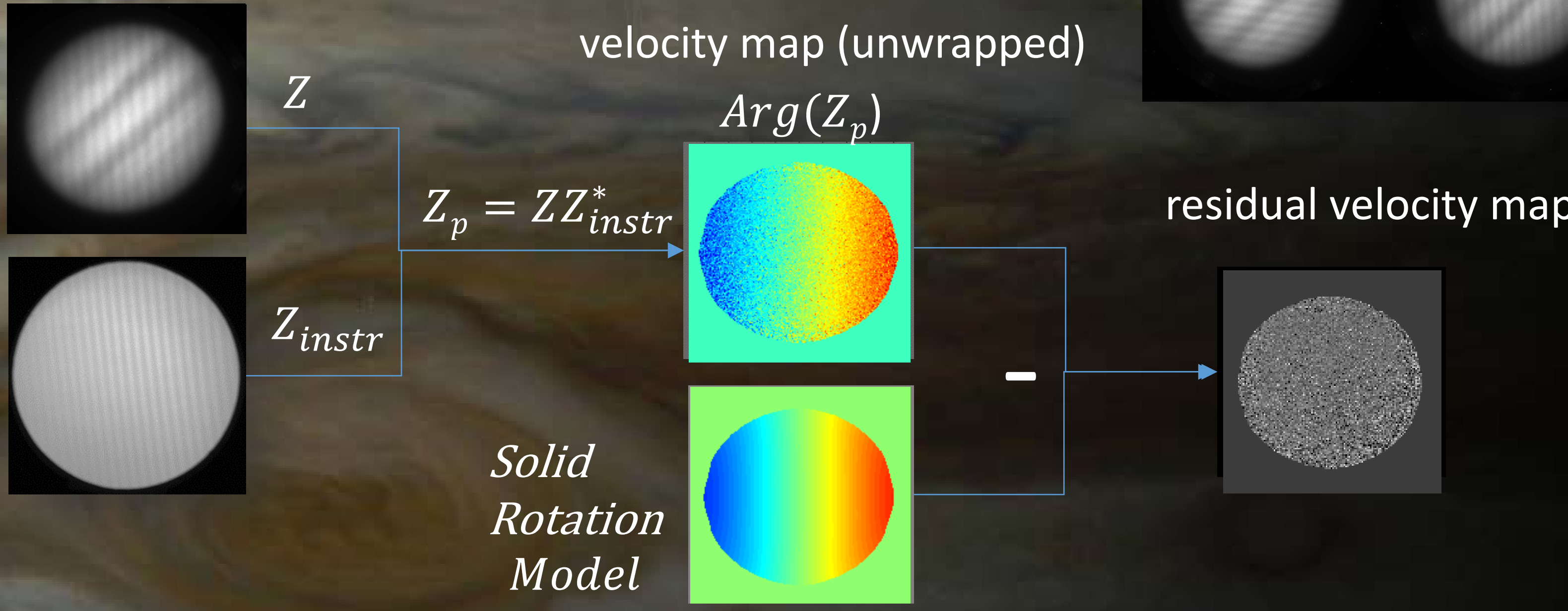




Data reduction

- Adjustment of the four images
  - Position, geometrical distortion
  - Photometric response
- Radial velocity map construction



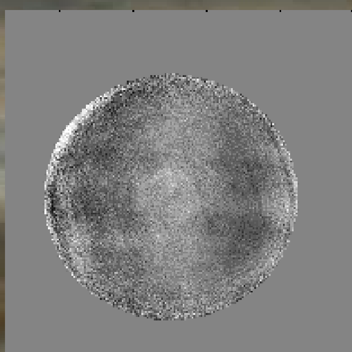


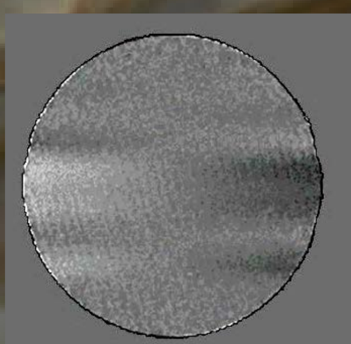
Wind measurements

Cloud-tracking is affected by cloud deformation and waves

Doppler measurements give true aerosol displacement

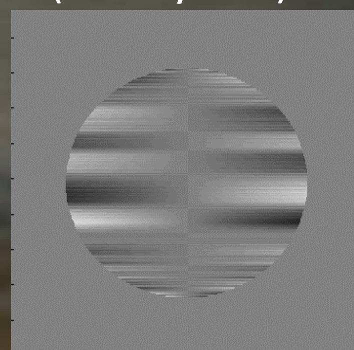
Sum of all residuals
(measurement)



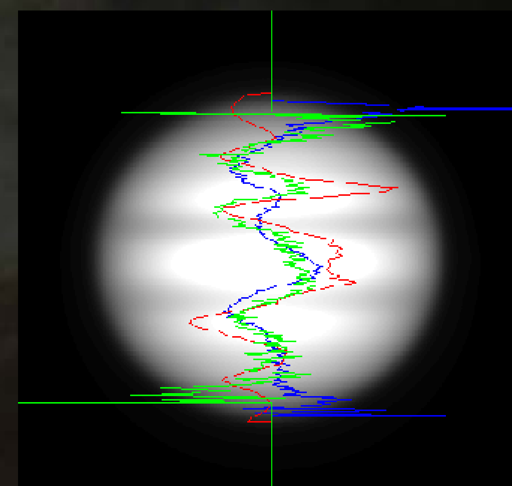


Simulation

Slope fitting
(line by line)



Zonal wind profile



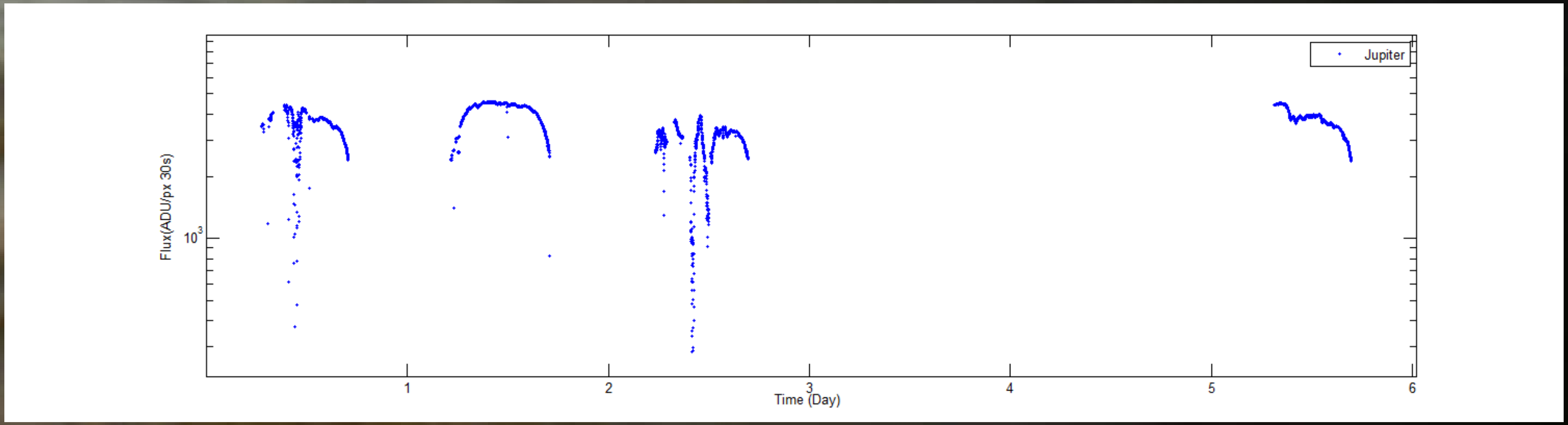
Wind speed from cloud tracking
(Hueso et al)
Simulated Doppler measurement
JOVIAL measurement

JOVIAL Planning

Observing run at C2PU	March 2016
JOVIAL Kick-off	April 2016
New instrumental design and integration	April 2017
2 sites measurements	May 2017
Achievement of 3rd instrument	December 2017
Observations of Jupiter	May 2018
Observations of Saturn	July 2019
Archiving, dissemination	December 2019

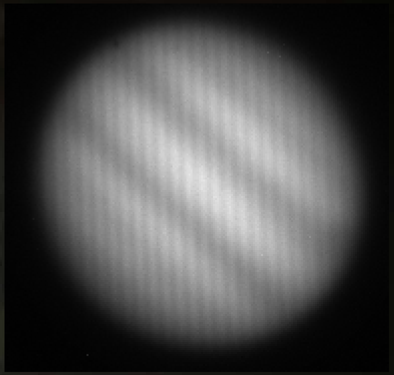
Observation campaign 2015

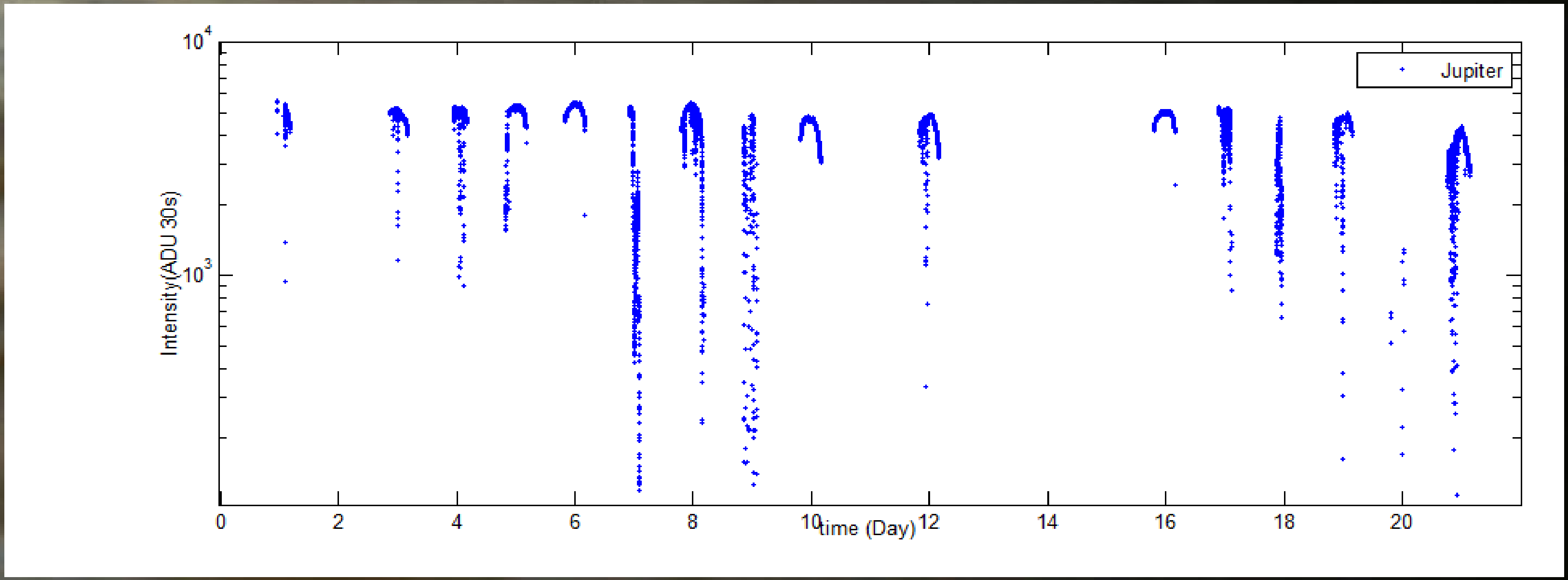
- 4 nights on Jupiter (4340 images of 30s, 36h)
- Duty Cycle : 26%
- Mean flux: 4900 e-/px (7e8 e- by images)
- Fringes contrast on Jupiter ~2.5% (3% max)
- Total transmission (Telescope+Instrument): 3.0%



Observation campaign 2016

- 15 nights on Jupiter (10750 images of 30s, ~90 h)
- Duty cycle : 18%
- Mean flux: 5900 e-/px (~8e8 e- by images)
- Fringes contrast on Jupiter ~3%
- Total transmission: 8.9%
- Data reduction in progress

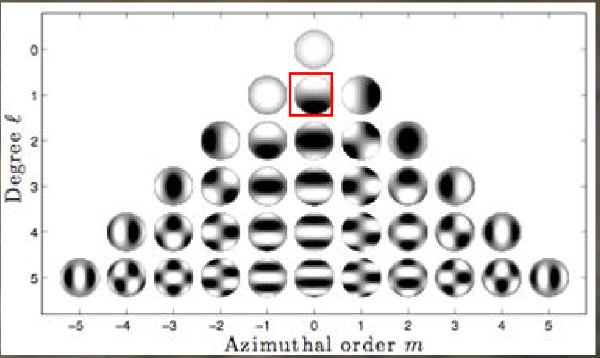




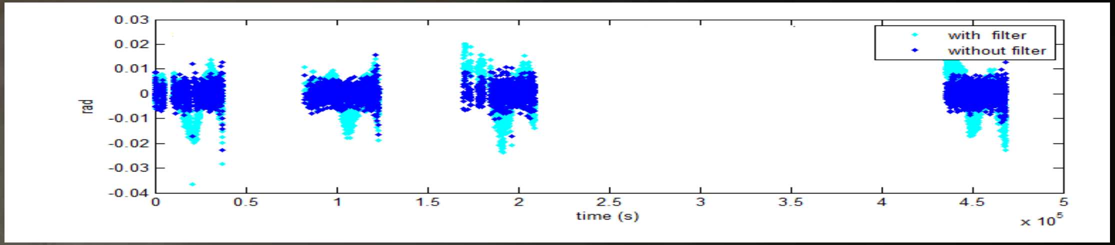
Data reduction

- Analysis of the time series (mode l=1 m=0)

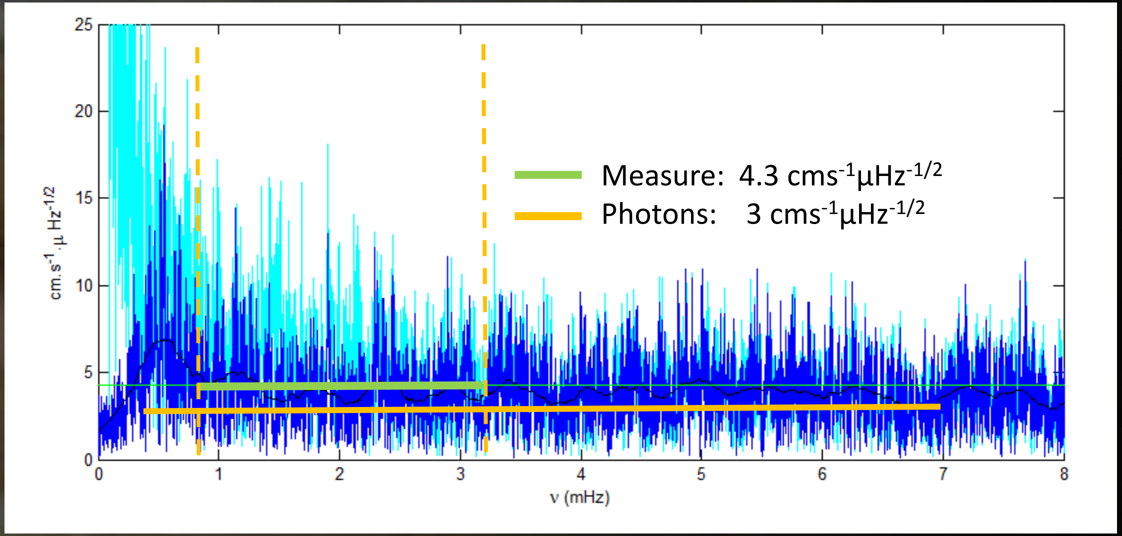
Jupiter modes:



Temporal series of residual velocity (mask)

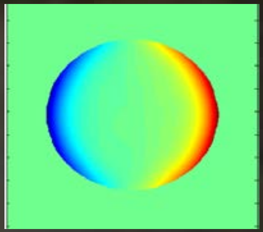


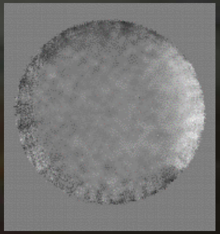
Spectrum (DSP)$^{1/2}$ of temporal sequence

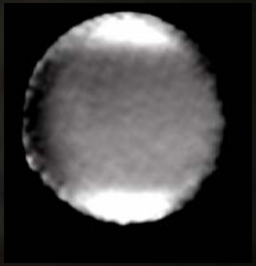


Bias and drift problems

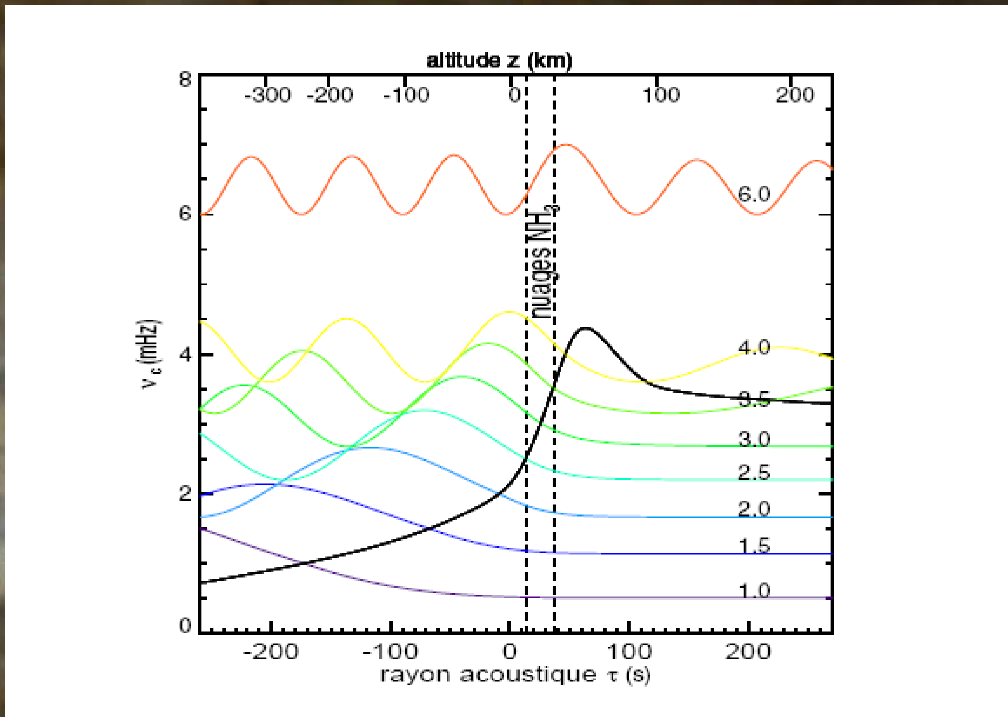
- PSF effect (and seeing)
- Jupiter polarization
- Telescope polarization
- Pupil drift
- Jupiter rotation in the field

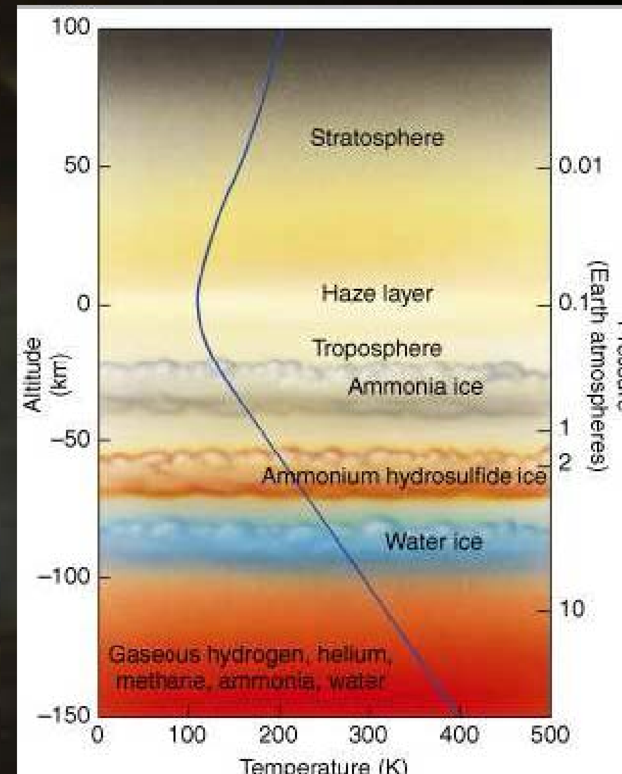






Detection of acoustic modes





- Modes trapped below the atmosphrere (around 1 bar)
- Top of the cloud (visible)
- Resolved images and velocity maps

Measurement principle

ABCD method:

- $i1 = I_0(1 + \gamma \cos(\emptyset))$
- $i2 = I_0(1 + \gamma \cos(\emptyset + \pi/2))$
- $i3 = I_0(1 + \gamma \cos(\emptyset + \pi))$
- $i4 = I_0(1 + \gamma \cos(\emptyset + 3\pi/2))$

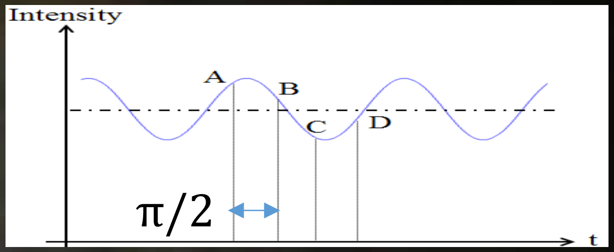
$$U = \frac{i1 - i3}{i1 + i3} = \gamma \cos(\emptyset)$$

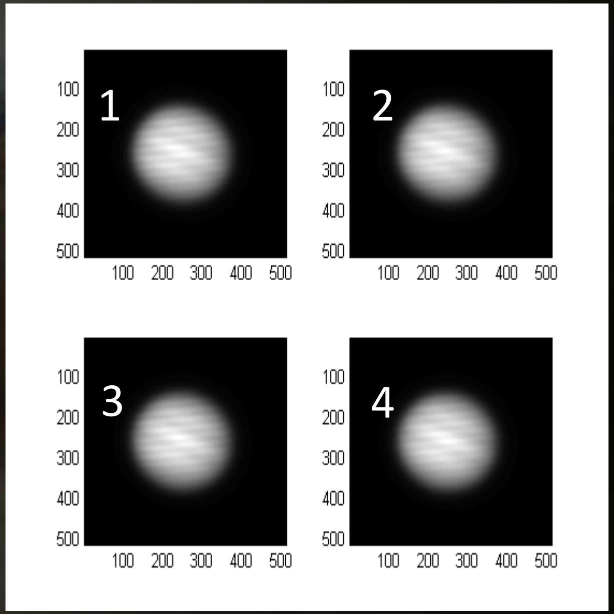
$$V = \frac{i2 - i4}{i2 + i4} = \gamma \sin(\emptyset)$$

$Z = U + iV$
$\emptyset = \mathrm{Arg}(Z)$

$$\langle|\delta\emptyset|^2\rangle \cong \frac{2}{\gamma^2 N}$$

$$I(\Delta) = I0 + \gamma(\Delta)e^{2i\pi\Delta\sigma_0\left(1+\frac{v}{c}\right)}$$





JOVIAL improvements

- New thermal control: less sensitivity to thermal environment
- Vacuum tank with longer life time (no pipes)
- Optical design for any telescope (up to 3.5m)
- Optimised transmission: better coatings
- Simultaneous fast-camera imaging
- Monitoring of polarisation?
- PSF width: Adaptive Optics