JOVIAL/JIVE

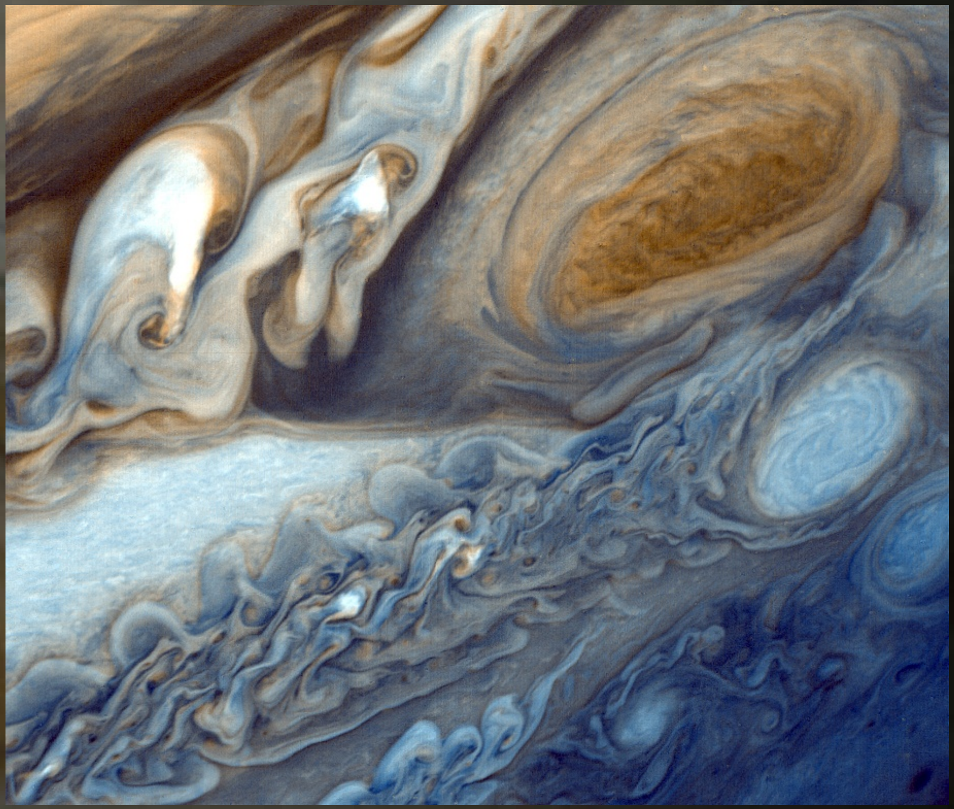
Jovian Oscillations through radial Velocity Imaging observations At several Longitudes

Jovian Interior from Velocimetry Experiment

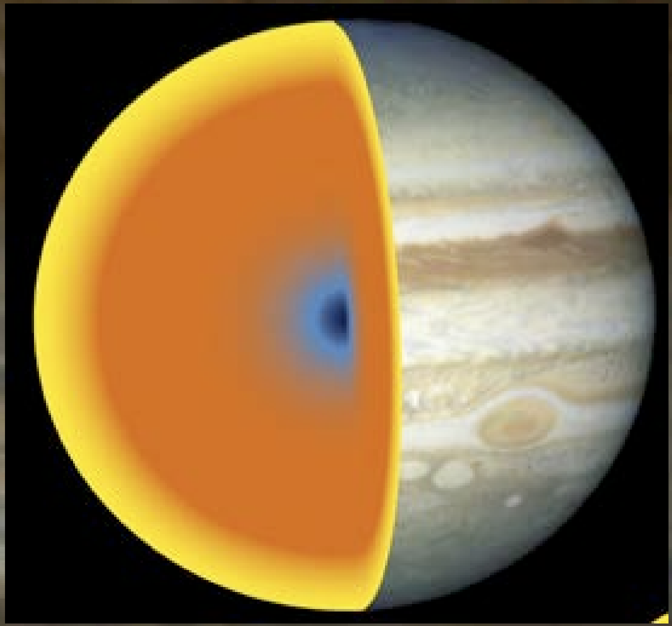
LAGRANGE

NM STATE UNIVERSITY

IAS Institut d'Astrophysique Spatiale Orsay



JOVIAL/JIVE in brief



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

- Observation strategy
  - Fourier imaging tachometer
  - Observation network

Historical reminder

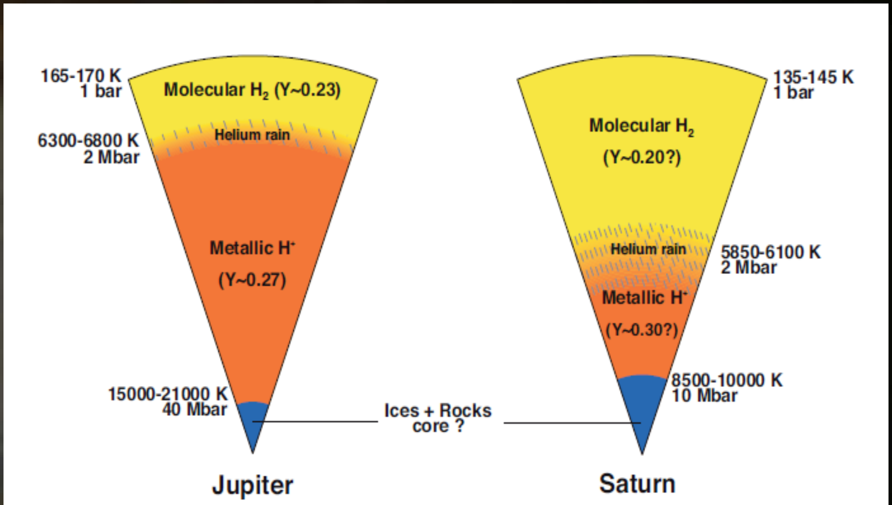
- DSI: proposal of space instrument for the JUICE mission (2007-2011)
- R&T CNES Mach-Zehnder 2009-2012
- JUNO launch 2011
- JUICE instrument submission 2012
  - Echoes not selected 2013
- R&T CNES: validation on the sky at MEO telescope 2013-2014
- Funding JIVE in NM by NASA/EPSCOR 2015-2018
- Funding JOVIAL by ANR 2016-2019: 420243 € (Total cost 2336445 €)
- JUNO arrives at Jupiter July 4th, 2016
- Funding support Okayama observatory by Kakenhi 2018-2020 (30 MY)

Detection of Jovian oscillations 2011

Detection of f modes on Saturn 2013

Internal structure of giant planets

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



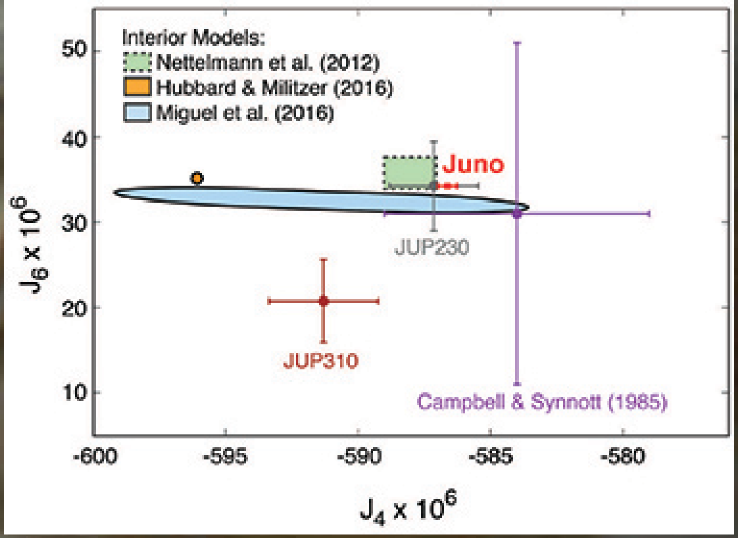
- Non uniqueness
  - Initial conditions (formation)
  - Evolution (core erosion)
  - Equations Of State

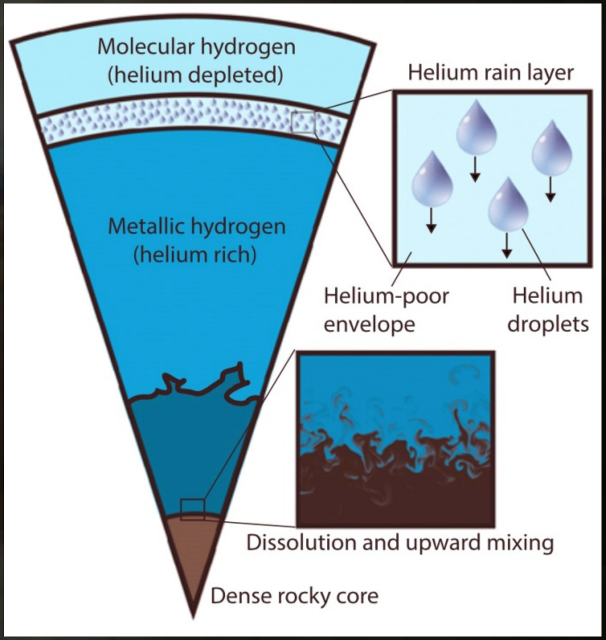
Having access to the internal structure would give unique clues to formation and evolution of the Solar System

Gravitational moments

JUNO entered the jovian system on 2016, July 4th
Mission prolongated for 32 orbits of 53 days

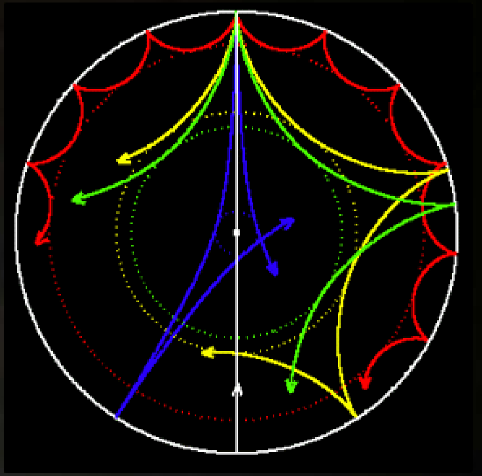
New values of J4-J6
Diluted core ?
Importance of differential rotation



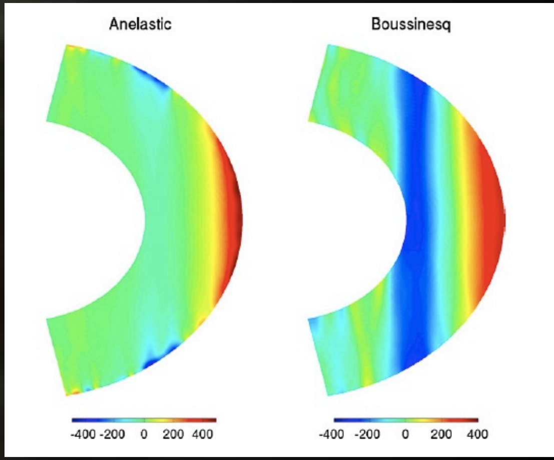


Probing internal structure by seismology

	$\delta\nu(n,l)/\nu(n,l)$	Degree
Core	4 %	$l = 0\text{-}2$
H2-H transition	3-7 %	$l = 15\text{-}25$
Enveloppe dynamics	0.1-0.5 %	$l = 50\text{-}100$

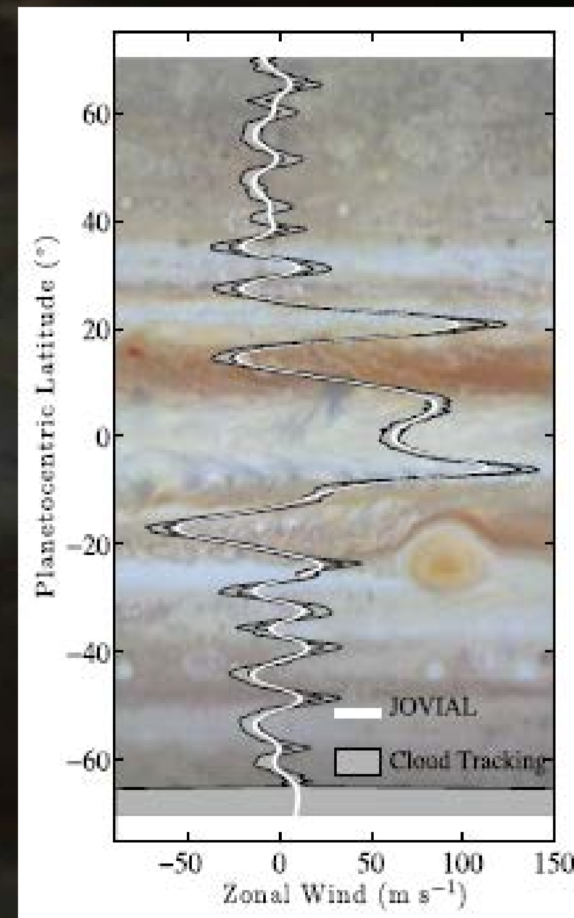


- Complete gravitational moments (JUNO)
- Measure the size and shape of the core
- Investigate H-H2 transition
- Give internal rotation profile



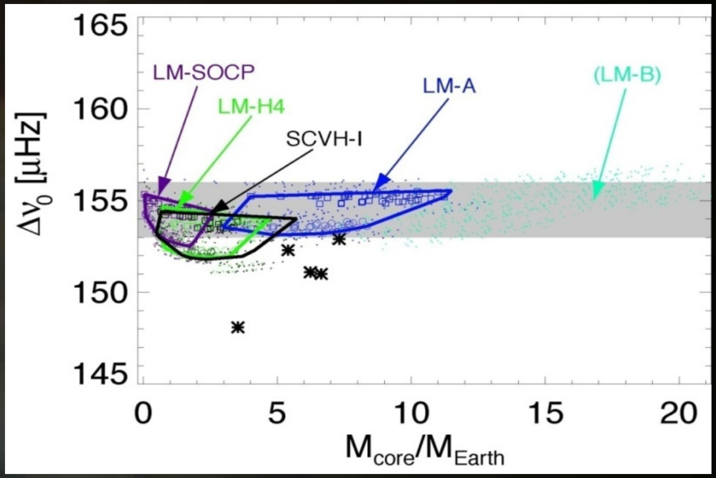
Wind speed measurement

- Cloud-tracking is affected by cloud deformation and waves
- Doppler measurements give true aerosol displacement
- Complete High Angular Resolution follow-up

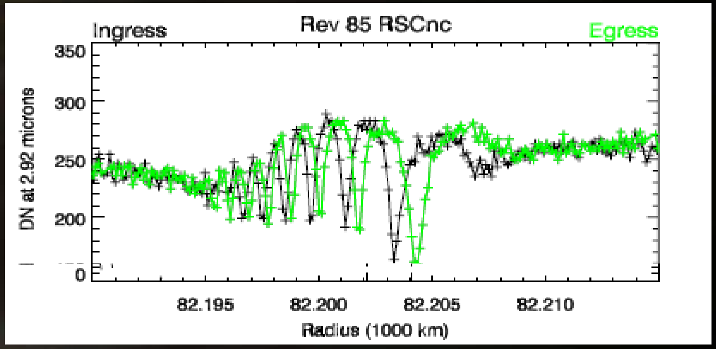


Recent results in seismology of giant planets

- Jupiter (Gaulme et al 2011)
  - SYMPA project: 2000 – 2010
  - ~ 20 Regularly spaced individual peaks with mean amplitude 30 cm/s ± 10 cm/s separated by $\Delta\nu_0$= 154.5 μHz ± 1.5 μHz
  - Need for continuous observations



- Saturn (Hedman & Nicholson 2013)
  - Prediction by Porco & Marley
  - Stellar occultations by the rings observed by Cassini
  - Identifition of m value
  - Possible stable region above the core (Fuller 2015)

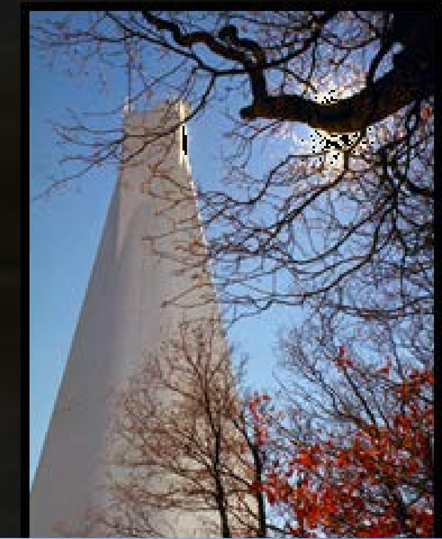


The JOVIAL network

Goal: Simultaneous observations from 3 sites

Target: Duty-cycle > 50 % over three weeks

- Observatoire de Calern (France)
  - C2PU 1 m telescope
- New Mexico (USA)
  - Dunn Solar telescope (Sacramento Peak)
- Okayama Observatory (Japan)
  - Telescope de 1.88 m
  - Other options ?



Project organisation

- Management — OCA+IAS
  - Instrumental development — OCA
    - Optics — OCA
    - Mechanics — OCA
    - Thermal studies — IAS
    - Instrument Control — OCA+NMSU
  - AIV — OCA
    - Vacuum Tank Test — IAS
    - Integration and tests — OCA
    - Transport & Commissioning — OCA NMSU
  - Observations — OCA+NMSU+EPS
    - Calern (France) — OCA
    - Okayama (Japan) — EPS
    - Apache Point (USA) — NMSU
  - Data processing — IAS
    - Image processing — OCA
    - Frequency — IAS
    - Wind speed maps — NMSU
  - Science — OCA
    - Mode physics and inversion — Jackiewicz
    - Interior model — Guillot
    - Atmosphere — Morales
    - Formation of solar system — Ida

Collaboration with NMSU

- NMSU involved in Echoes/DSI proposal
- JIVE: Funding by NASA/EPSCOR (July 2014)
  - 1.3 M$ on 4 years
- JIVE Kick-off meeting: December 2014
  - Visit of observatories Apache Point (1 m) et Sunspot (Dunn Solar Telescope)
  - Decision: installation of DSI at Dunn Solar Telescope (0.7 m)
- Convention NMSU-OCA: Novembre 2015
  - OCA provides MZ interferometer and expertise to build a copy of DSI
- JOVIAL Kick-off meeting at Nice: April 2016
  - Decision: build two copies of JOVIAL new design

Collaboration with Japan

- Tokyo Institute of Technology, partner ANR JOVIAL
- August 2016: Visit of observatories Okayama and Ishigaki

- October 2016: Application to Kakenhi grant
  - Acccepted February 2017
  - Funding 30 MYen on 3 years
  - Support for 1.88m telescope operation
  - Support for logistics and travel
  - Funding of a post-doc, in charge of observations

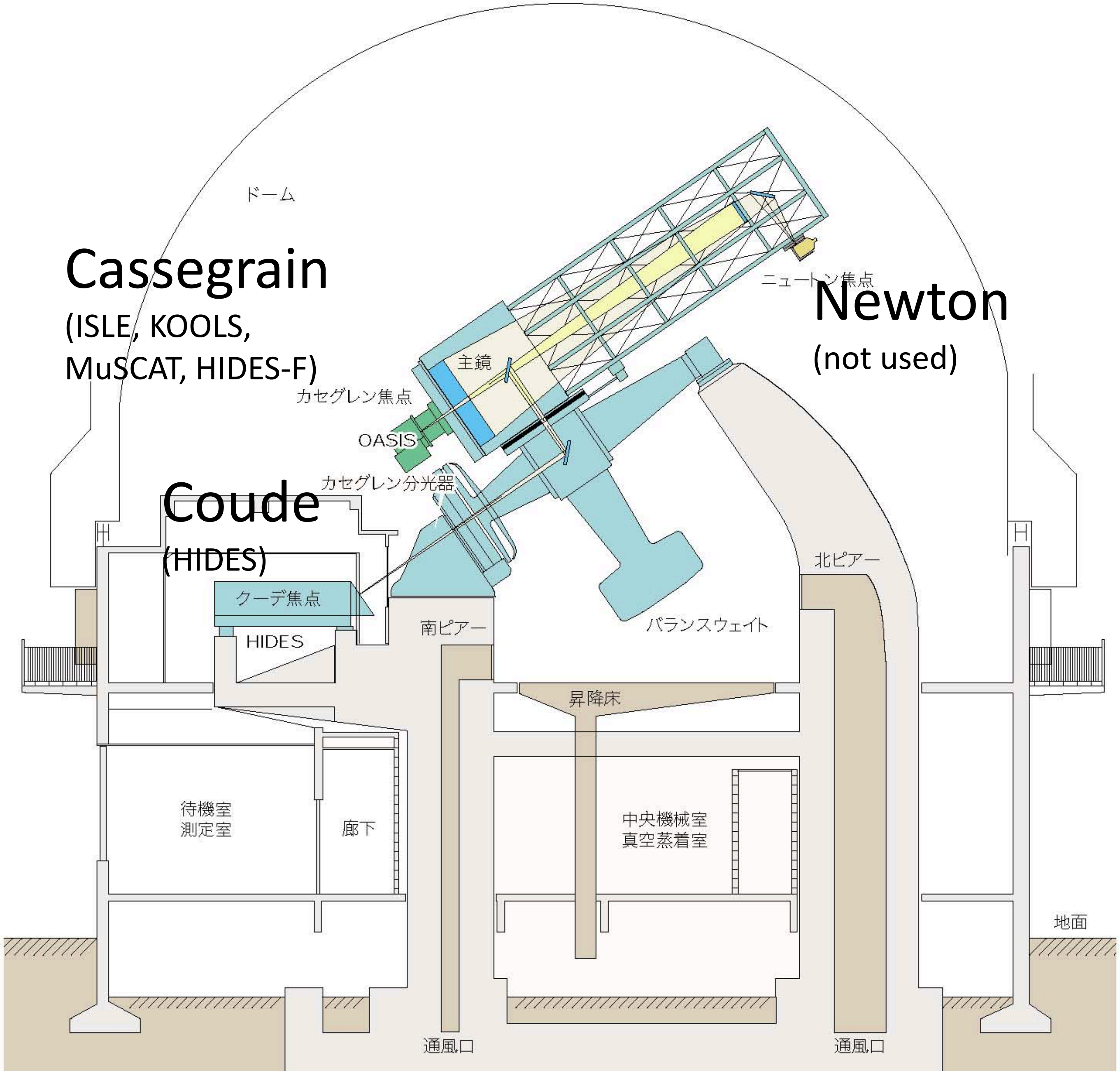
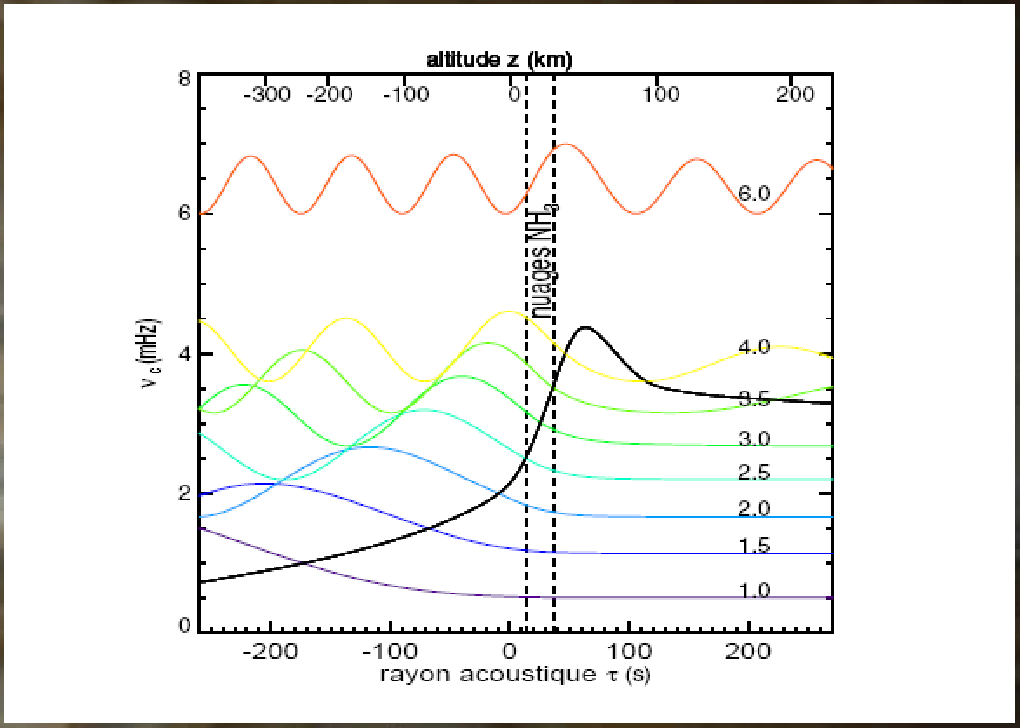
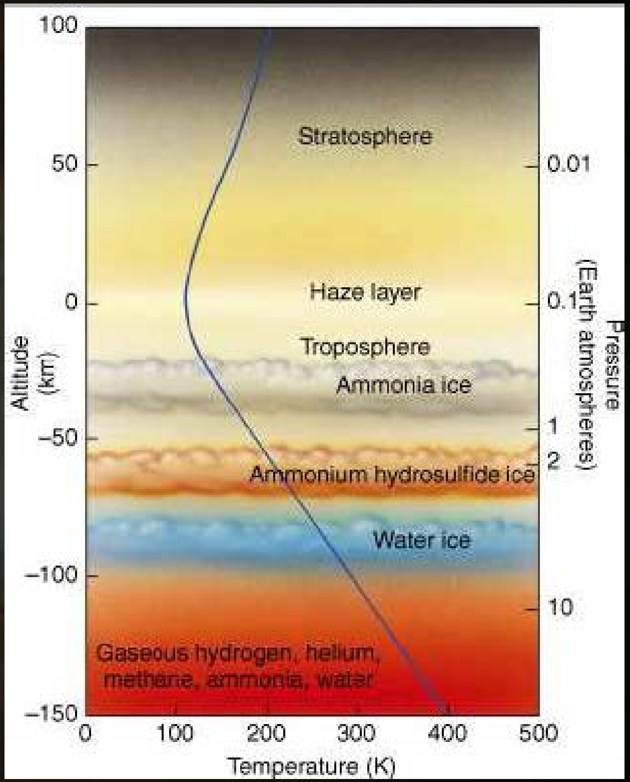


図2－1　188cm反射望遠鏡ドーム概略図

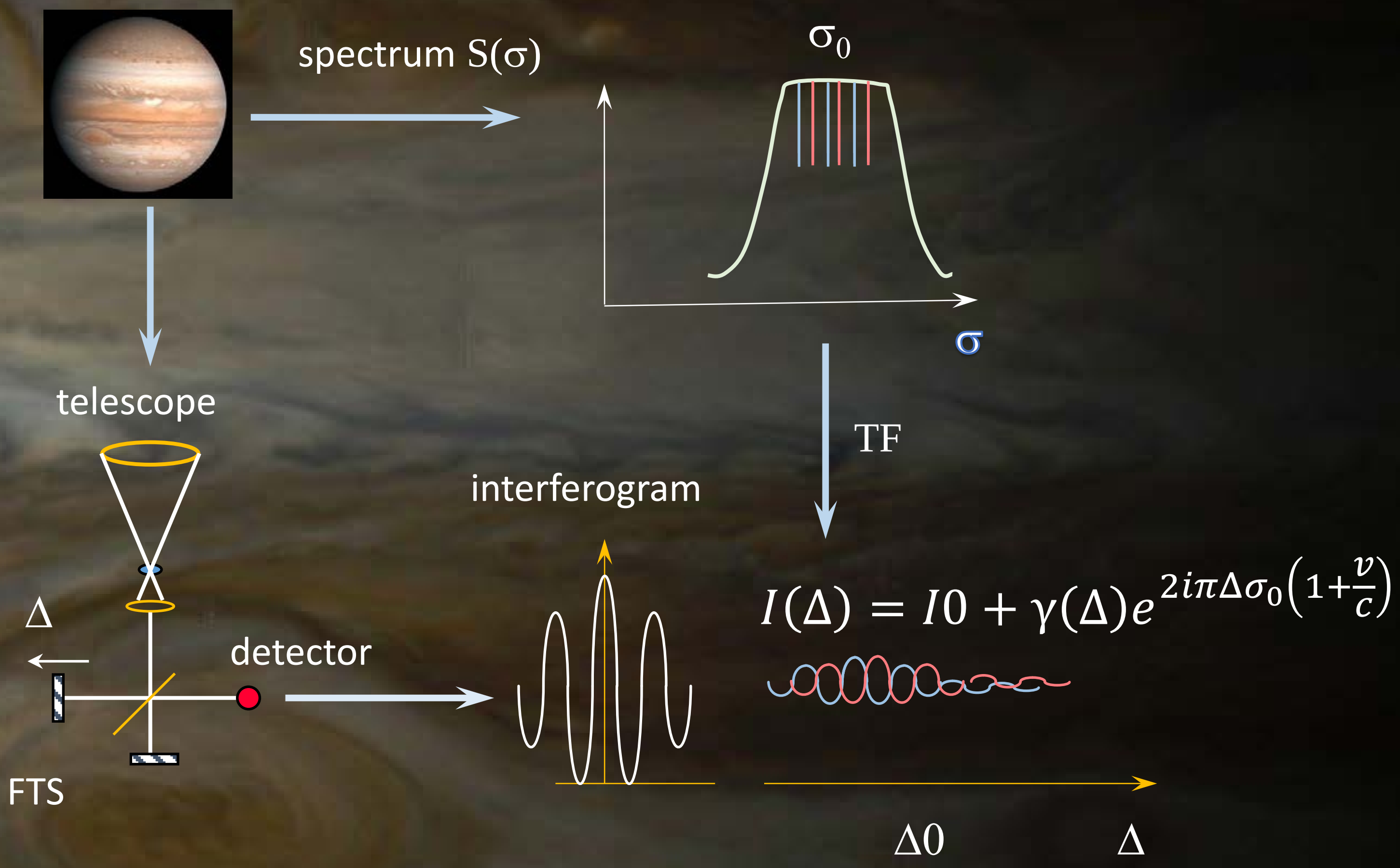
Detection of acoustic modes





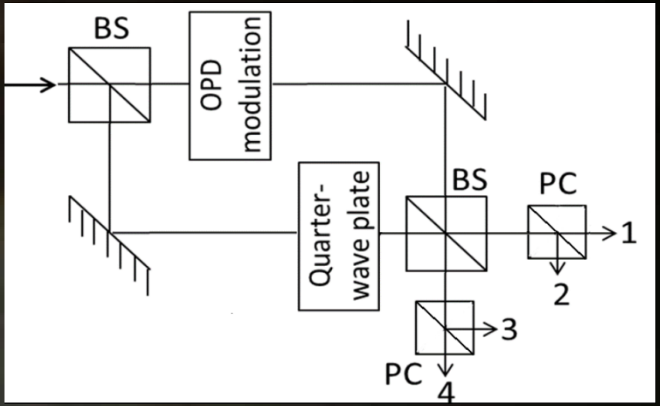
- Modes trapped below the atmosphrere (around 1 bar)
- Top of the cloud (visible)
- Resolved images and velocity maps

Instrument principle

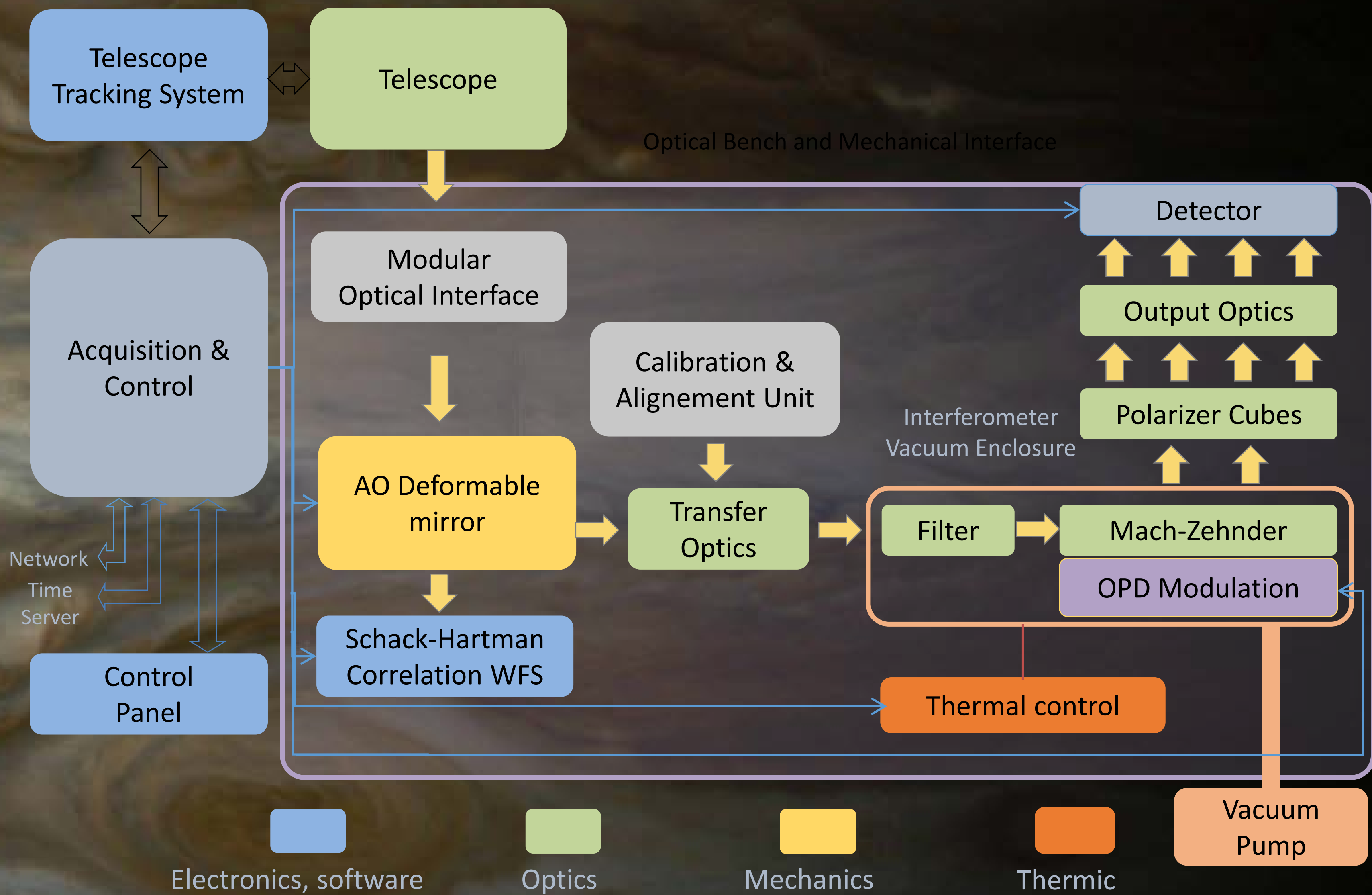


Instrumental Concept

- JOVIAL is a Doppler Spectro-Imager
  - Mach-Zehnder Interferometer:
  - Spectral FT at each point of the image
  - Measures the Doppler shift of reflected solar lines
- Improvement of mesurement stability, precision, resolution
  - Optimised sensitivity and thermal stability
  - Internal calibration
  - Simultaneous multi-sites observations
  - 'Large Field' Adaptive Optics
  - Noise level < 4 cm/s in 3 weeks



Bloc Diagramme



Measurement principle

ABCD method:

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

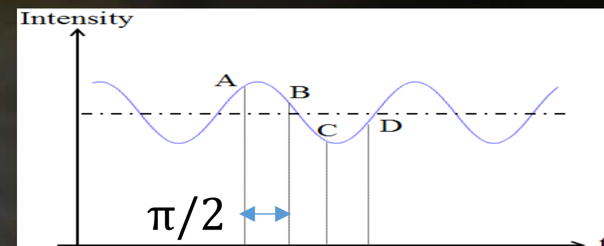
$$U = \frac{i1 - i3}{i1 + i3} = \gamma\cos(\emptyset)$$

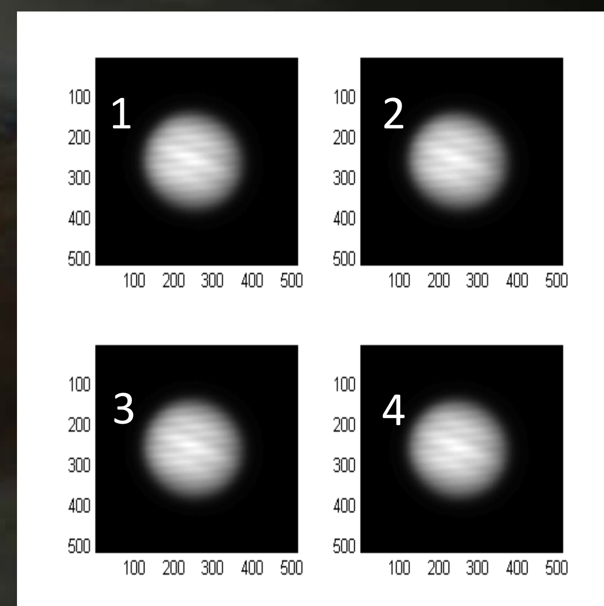
$$V = \frac{i2 - i4}{i2 + i4} = \gamma\sin(\emptyset)$$

$$\boxed{\begin{array}{l} Z = U + iV \\ \emptyset = \mathrm{Arg}(Z) \end{array}}$$

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

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

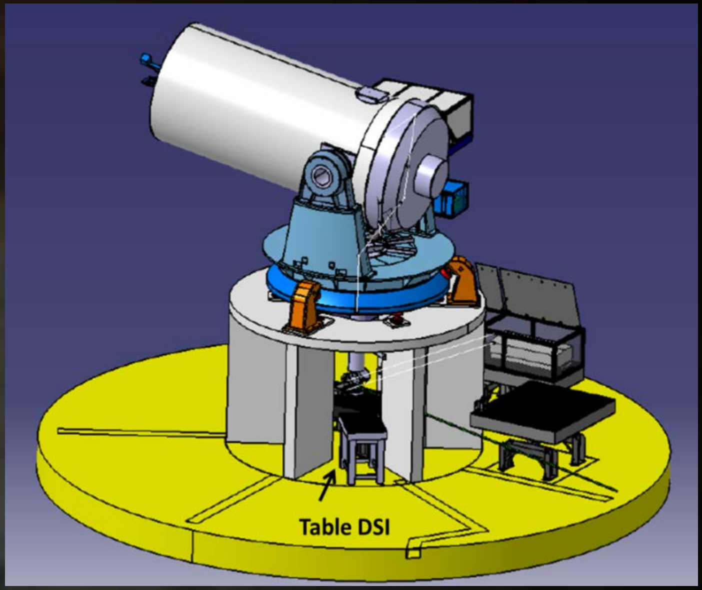


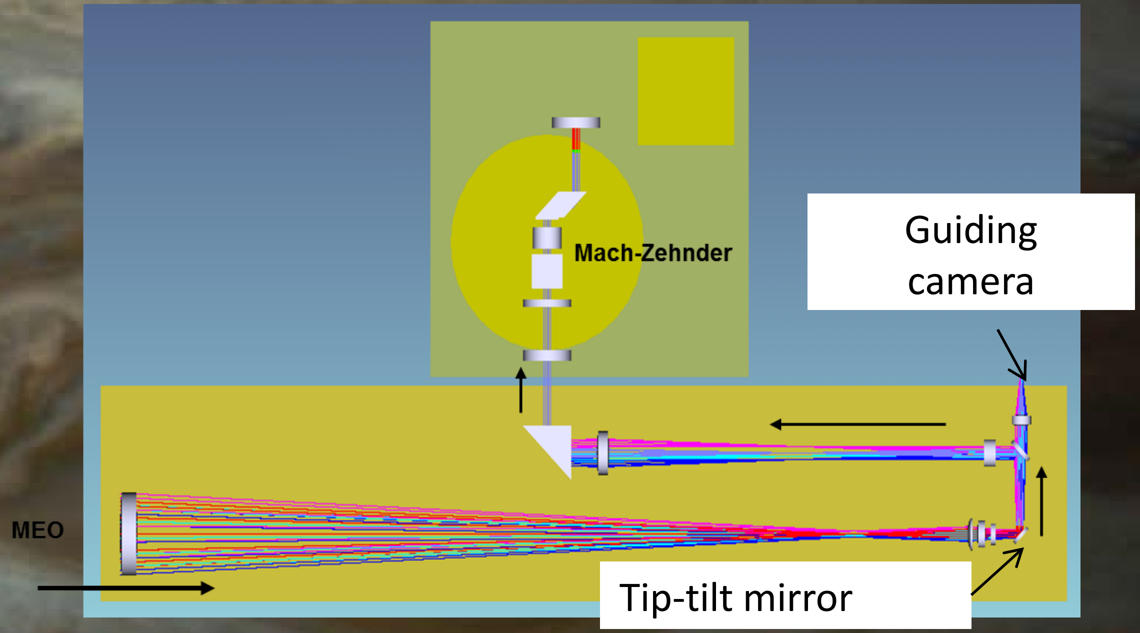


First tests on the sky

Implementation at MEO telescope

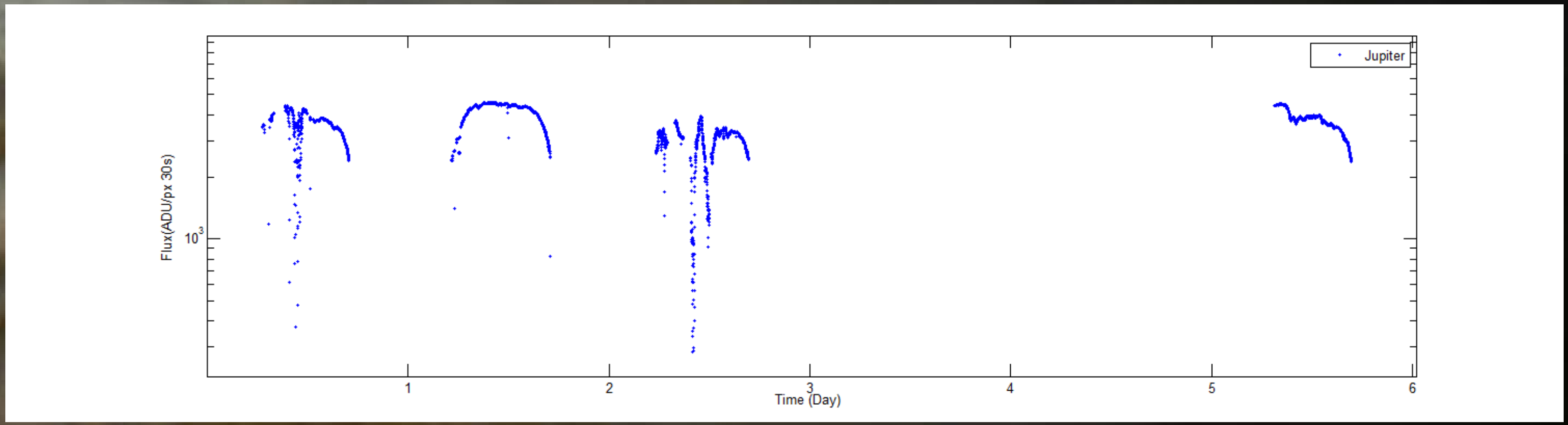
- October 2014
- 1.5m alt-az at Calern Observatory
- Coude focus
- Tip-tilt image stabilization: 200 Hz





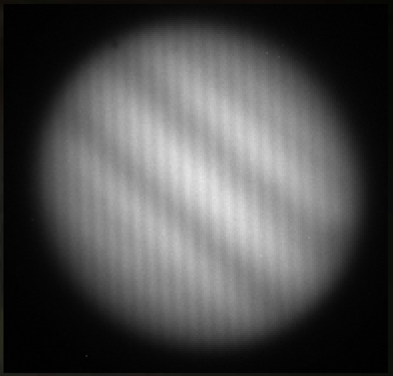
Observation campaign 2015

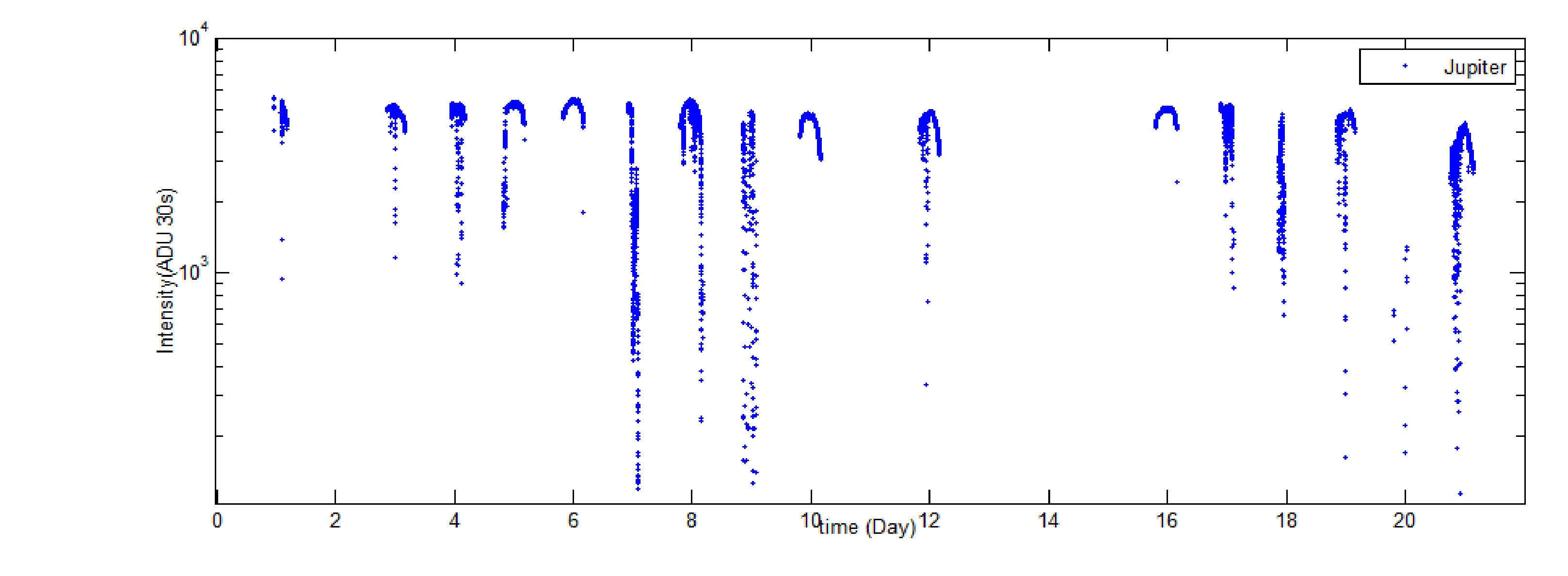
- 4 nights on Jupiter (4340 images of 30s, 36h)
- Duty Cycle : 26%
- Mean flux: 4900 e-/px ($7e^8$ e- by images)
- Fringes contrast on Jupiter ~2.5% (3% max)
- Total transmission (Telescope+Instrument): 3.0%



Observation campaign 2016

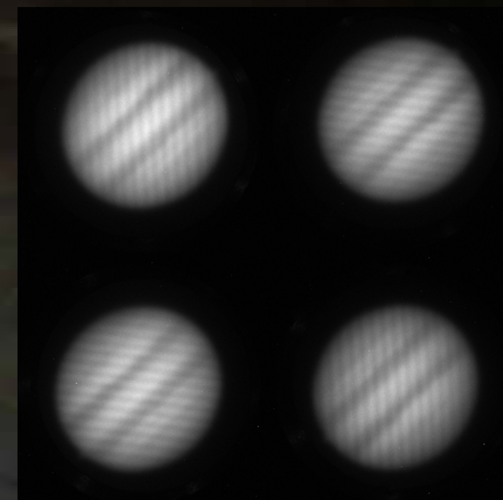
- 15 nights on Jupiter (10750 images of 30s, ~90 h)
- Duty cycle : 18%
- Mean flux: 5900 e-/px (~8e^{8} e- by images)
- Fringes contrast on Jupiter ~3%
- Total transmission: 8.9%

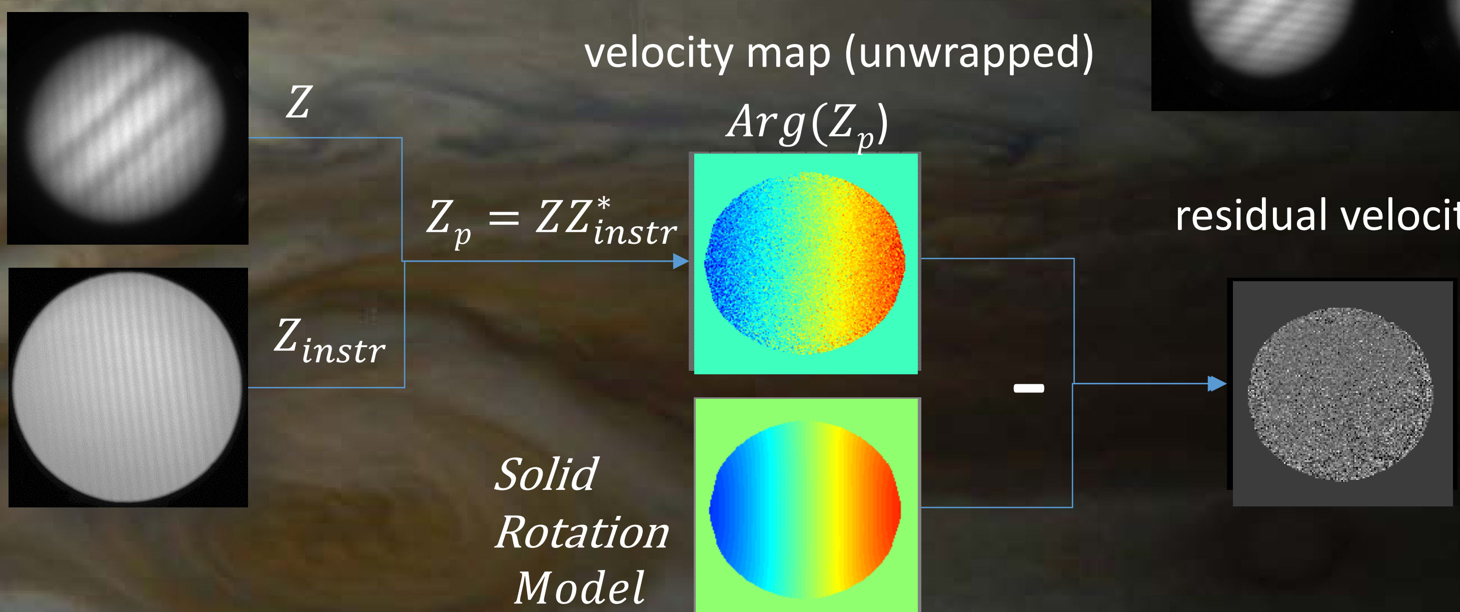




Data reduction

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

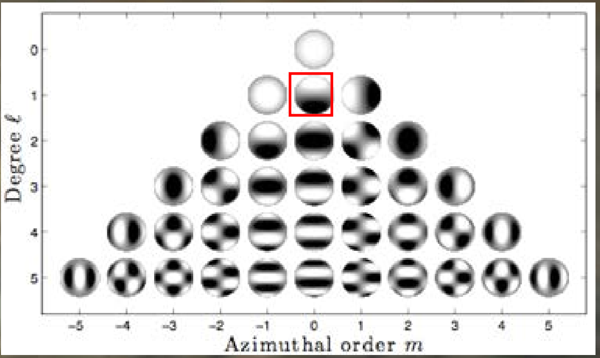




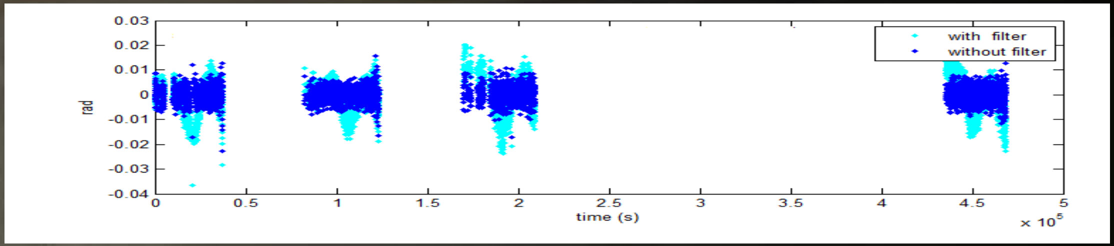
Performances

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

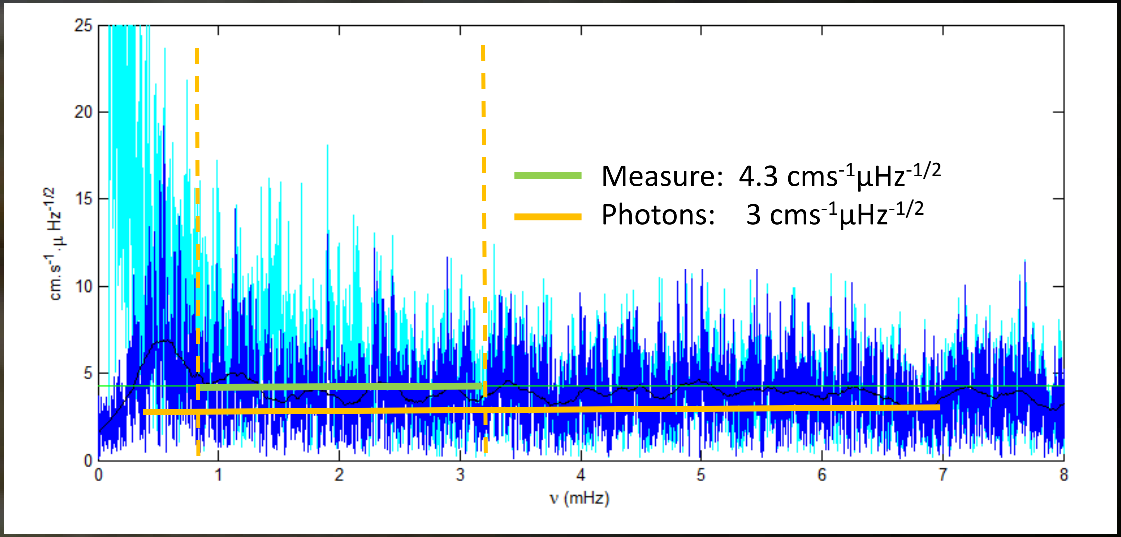
Jupiter modes:



Temporal series of residual velocity (mask) 



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

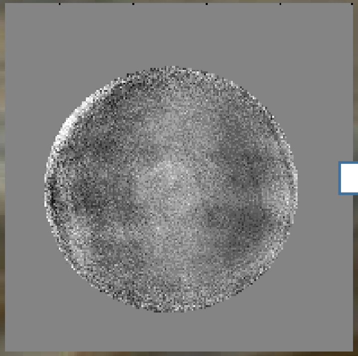


Wind measurements

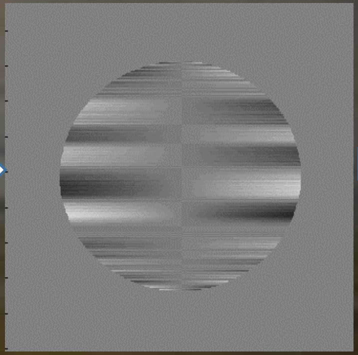
Cloud-tracking is affected by cloud deformation and waves

Doppler measurements give true aerosol displacement

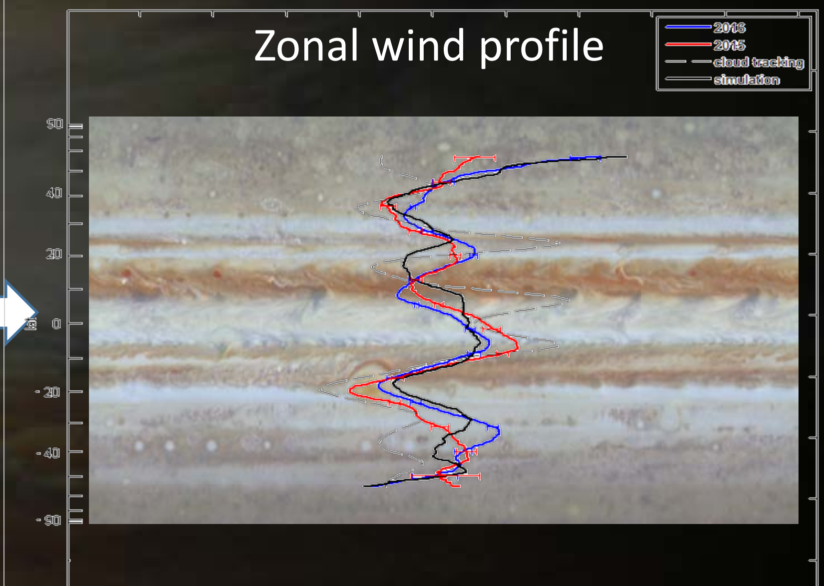
Sum of all residuals (measurement)



Slope fitting (line by line)



Zonal wind profile



Wind speed from cloud tracking (Hueso et al)

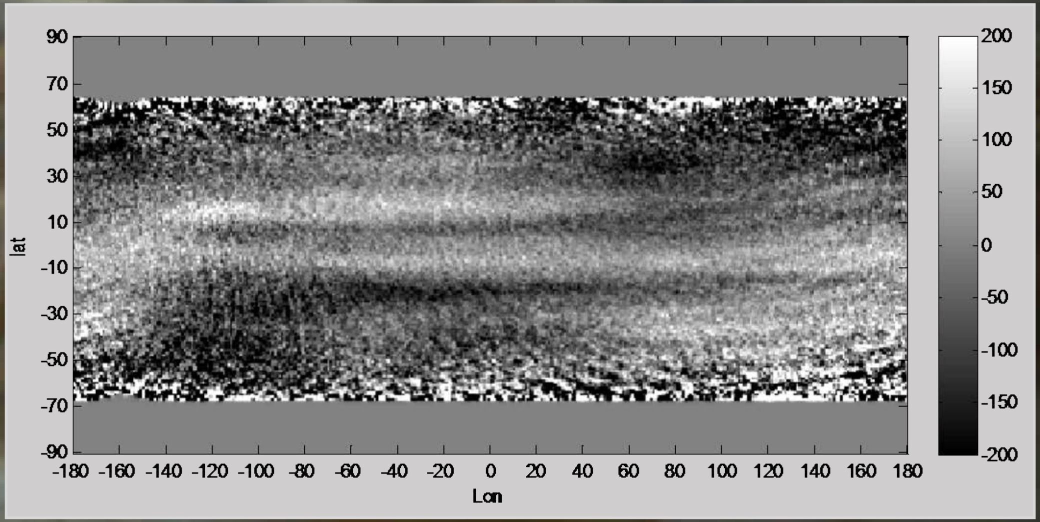
Simulated Doppler measurement

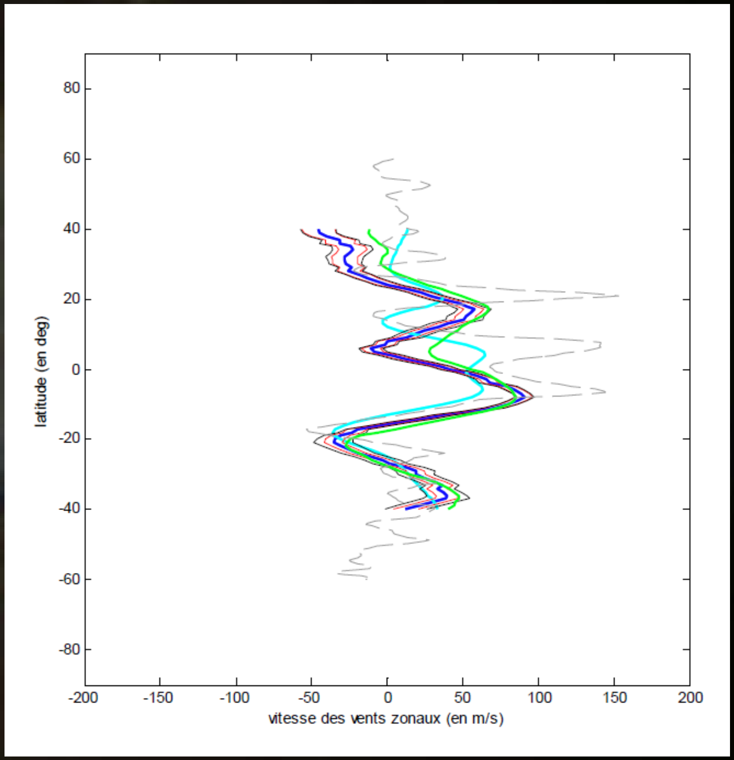
JOVIAL measurements 2015

JOVIAL measurements 2016

Latest results

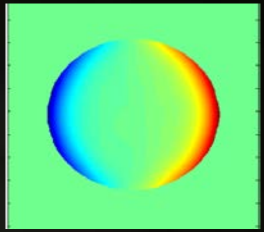
- Maps of zonal winds
- Confirmation of discrepancy between Doppler shift and cloud tracking in northern equatorial band

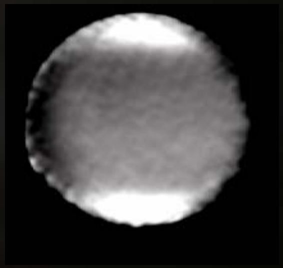


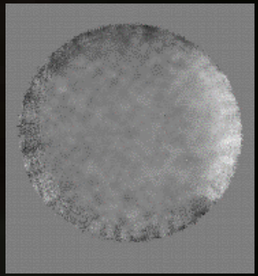


Bias and drift problems

- PSF effect (dominated by the seeing)
  - Angular resolution limitation
  - Contrast loss
  - Bias
- Jupiter polarization
- Telescope polarization
- Pupil drift
  - solved: pupil stabilization
- Jupiter rotation in the field

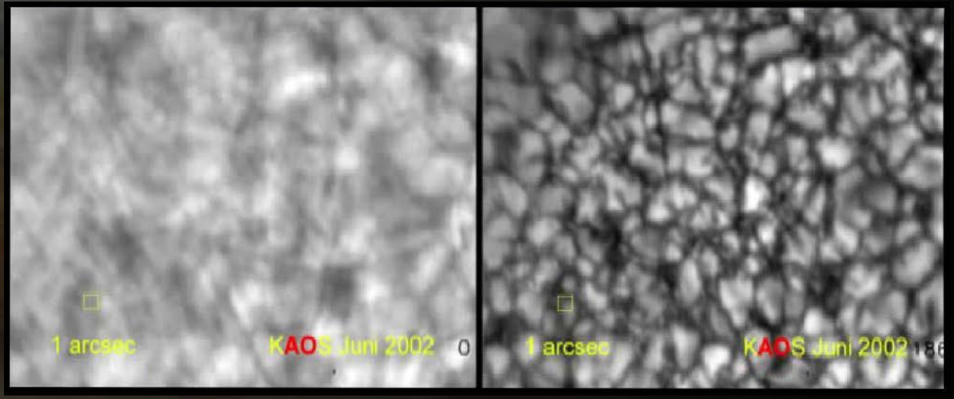






JOVIAL improvements

- Optical design for any telescope (up to 2.4 m)
- Optimised transmission: better coatings
- Pupil stabilization
- Polarisation mitigation
  - Monitoring ?
  - Depolariser
- PSF width: Adaptive Optics
  - 1’ field
  - Based on solar AO principle
  - Correction up to 3000 m



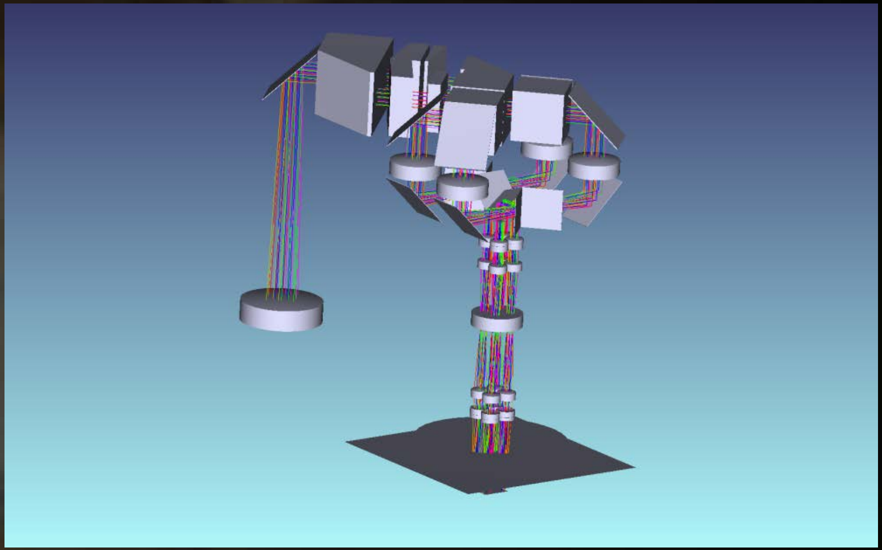
Optical design

Conception and optical design

- Almost finished

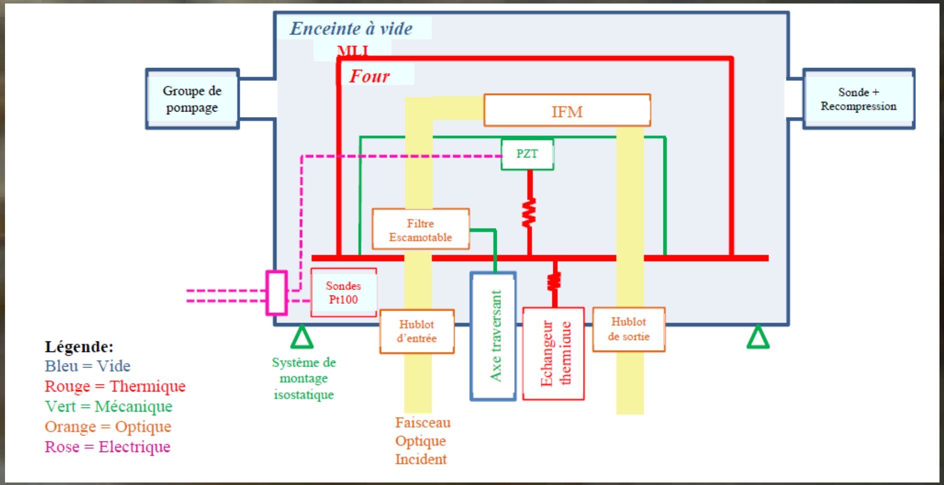
Realisation of MZ

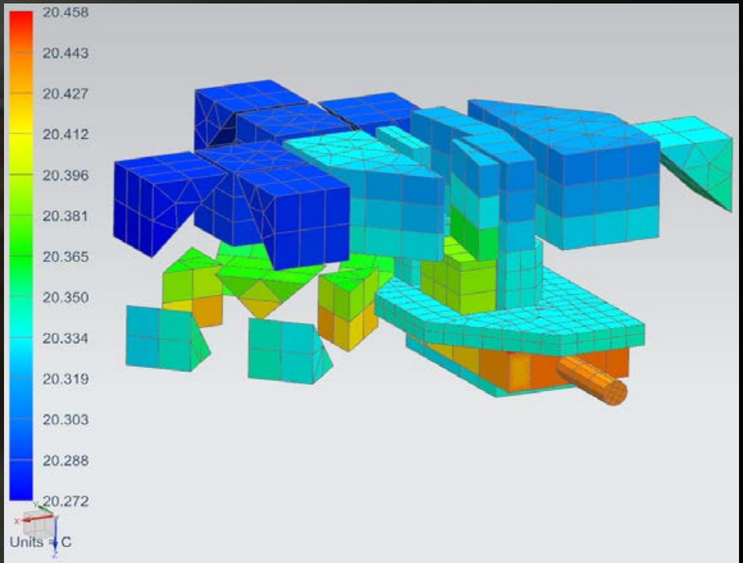
- Prisms do exist
- Builder (SEOP) cessation
- Coating in course
- Gluing and tests at the laboratory
  - Foreseen in Octobre



Thermal studies and vaccuum tank design

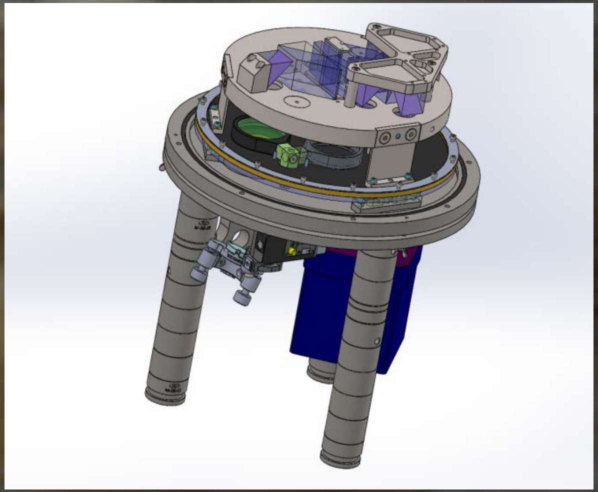
- Concept of vaccuum tank and oven: J.C. Leclech (IAS)
- Thermal studies: 0.1°C sur le MZ
- Design OK
  - Drawings in progress
  - Fabrication 2nd semester 2017

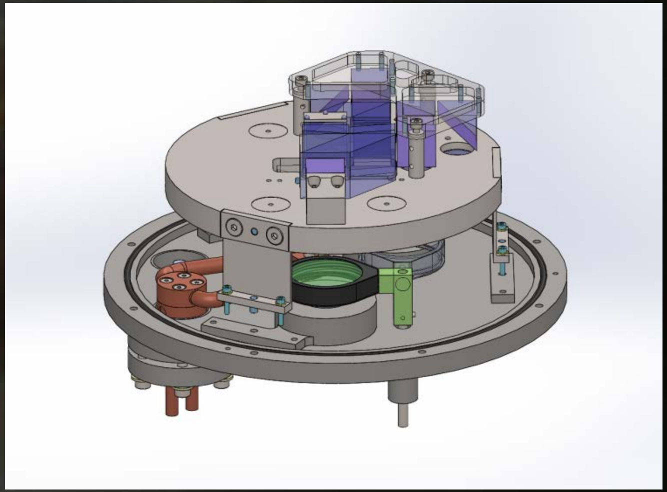




Mecanical design

- Design MZ integration finalised
- Design optical input and output
- Interface for Dunn telescope already installed
- Design interface for Okayama telescope to be done

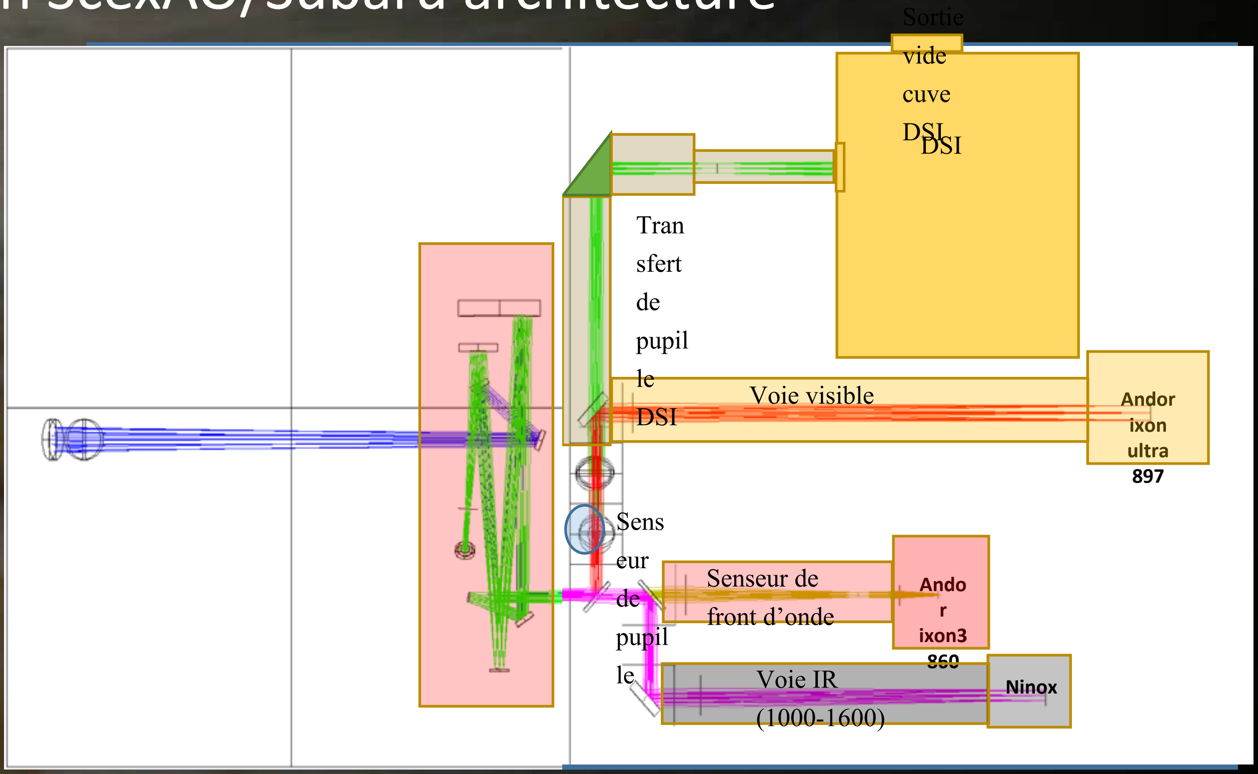




CIAO
Calern instrument Adaptive Optics

- New optical interface at C2PU
- DM97 ALPAO + Andor EMCCD
- Software based on ScexAO/Subaru architecture

- Tests in July
- Interface with TCS TBD
- WFS on large objects under study (post-doc)



Software development

- Adaptation of acquisition/control to new design
  - 2 more motors
  - Change/simplification of observation sequence
  - New target/telescope configuration
- Adaptive optics software under development
- Telescope interface to be adapted
  - Dunn: Tom Underwood
- Interface for Okayama telescope to be done
- Capability of remote operations

JOVIAL Planning

JOVIAL Kick-off	April 2016
New instrumental design	February 2017
Installation DSI at Sunspot	September 2017
Achievement of two new instruments	January 2018
Simultaneous observations of Jupiter	May 2018
Data + pipeline distribution	December 2018
Observations of Jupiter/Saturn	June-July 2019
Archiving, dissemination	December 2019

Perspective

Network prolongation after 2019

- Better visibility of Jupiter
- JUNO mission continuing
- AO generalisation
- Larger telescopes (Saturn)

Space mission proposal

- Hera: Saturn (ESA M5)
  - Probe + carrier or orbiter
  - Doppler Imager for cruise observations and context determination
- Uranus Explorer
  - NASA Decadal survey
  - Doppler imager