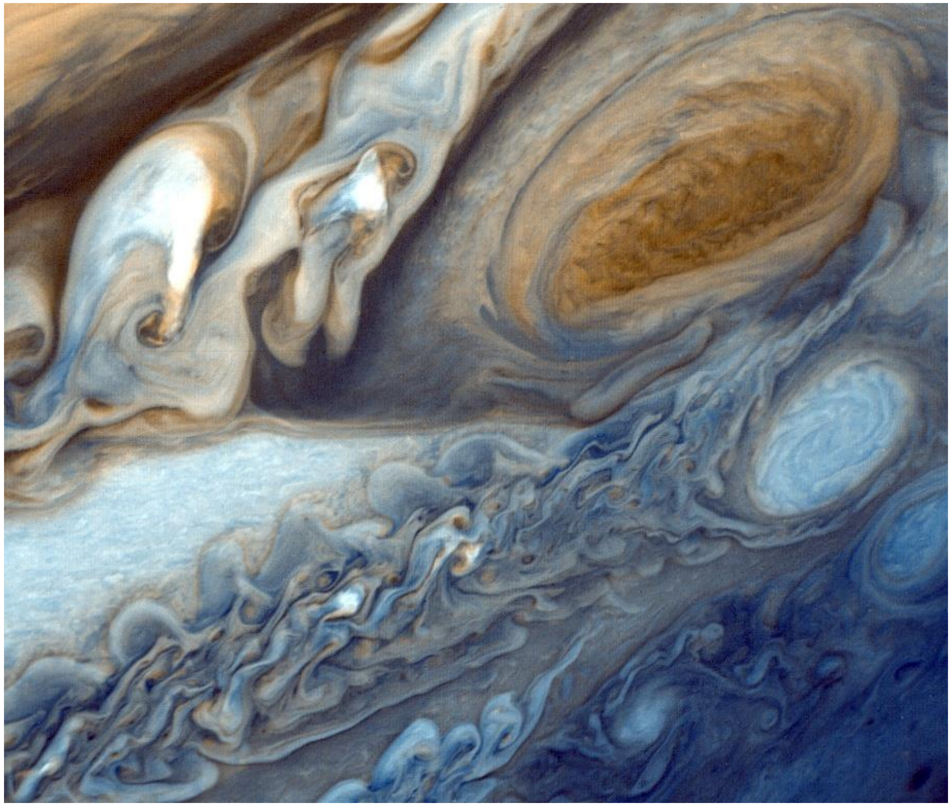
JOVIAL

Jovian Oscillations through radial Velocimetry ImAging observations at several Longitudes

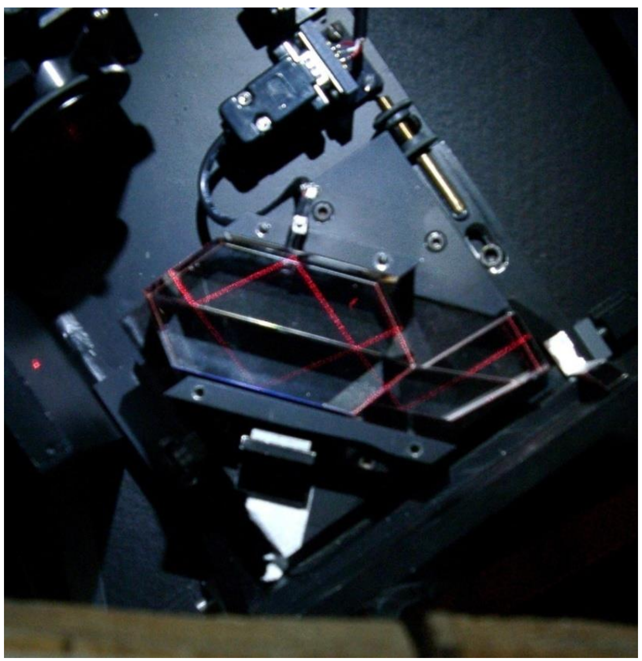


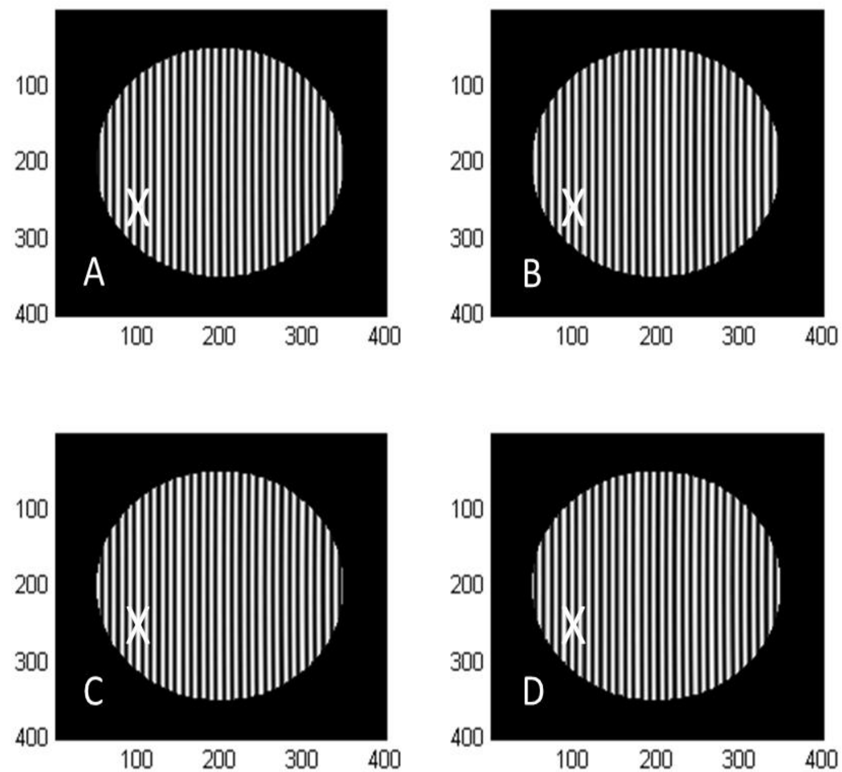
Instrumental Concept

- JOVIAL instrument is a Doppler Spectro-Imager
  - It heritates SYMPA principle
  - Spectral Fourier Transform on each pixel
  - Measures Doppler shift of solar spectral lines reflected at the surface of the planet
  - Solves a number of SYMPA issues

SYMPA design

- Imaging Fourier tachometer
- Mach-Zehnder design
- Phase shift of $\pi/2$ between polarisation
- Four outputs

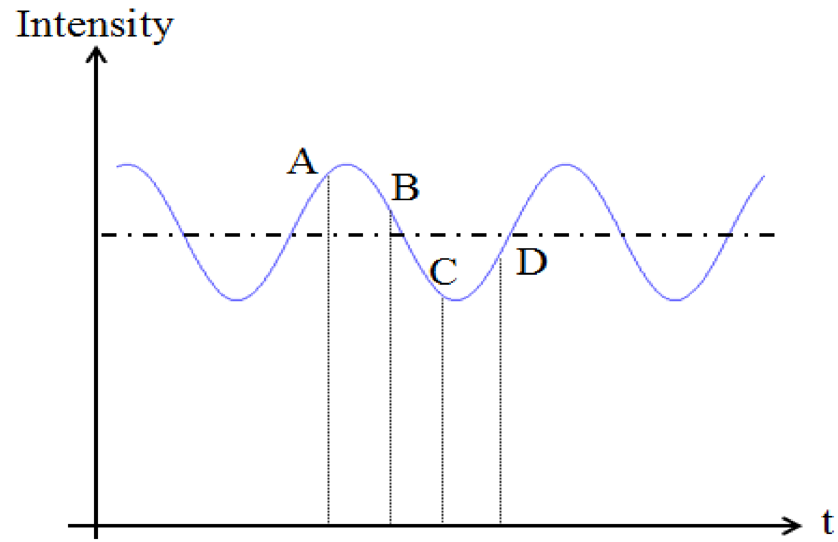




Measurement principle

- Interference phase proportional to Doppler shift

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



- Phase fringe determination with "ABCD" method

$$I_1 = \frac{I_0}{4}\{1 + \gamma \cos\phi\} \qquad I_2 = \frac{I_0}{4}\{1 + \gamma \sin\phi\}$$

$$I_3 = \frac{I_0}{4}\{1 - \gamma \cos\phi\} \qquad I_4 = \frac{I_0}{4}\{1 - \gamma \sin\phi\}$$

$$U = \frac{I_1 - I_3}{I_1 + I_3} = \gamma \cos\phi \quad and \quad V = \frac{I_2 - I_4}{I_2 + I_4} = \gamma \sin\phi$$

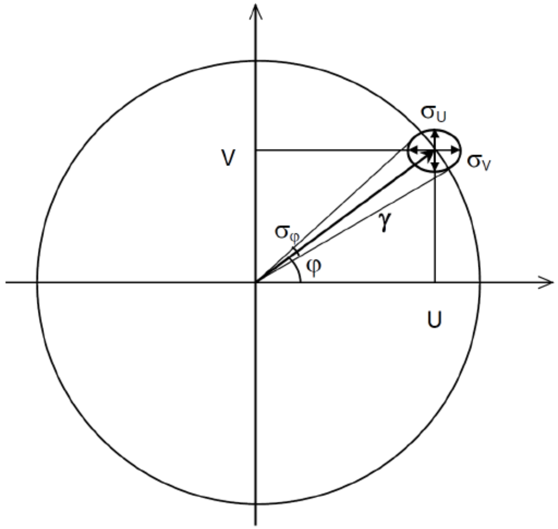
$$\boldsymbol{Z = U + iV = |Z| e^{i\phi}}$$

Theoretical performances

- U=(I1-I3)/(I1+I3)
- V=(I2-I4)/(I2+I4)
- φ=arg (U+iV)

$$\sigma_v = \frac{C}{Q\sqrt{N}}$$

$$Q = \frac{2\pi\Delta\gamma}{\lambda_0\sqrt{2}}$$

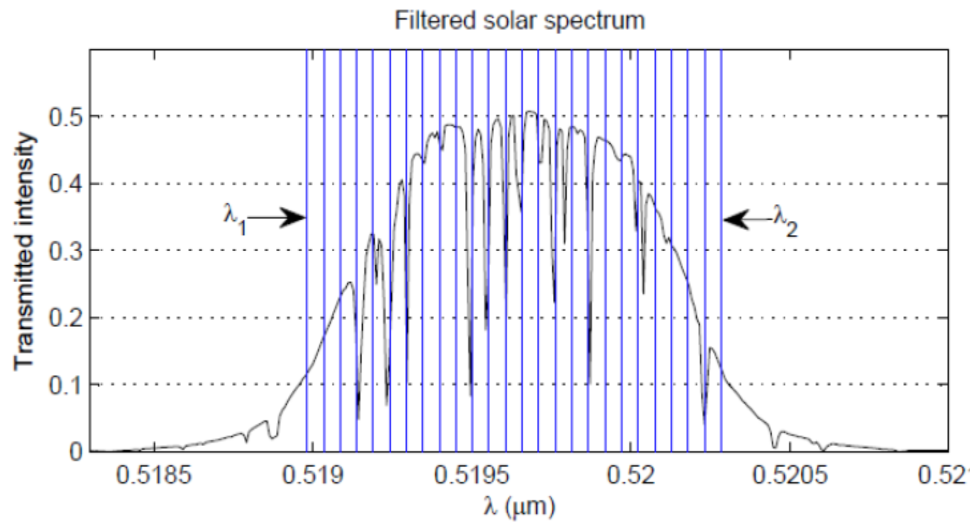


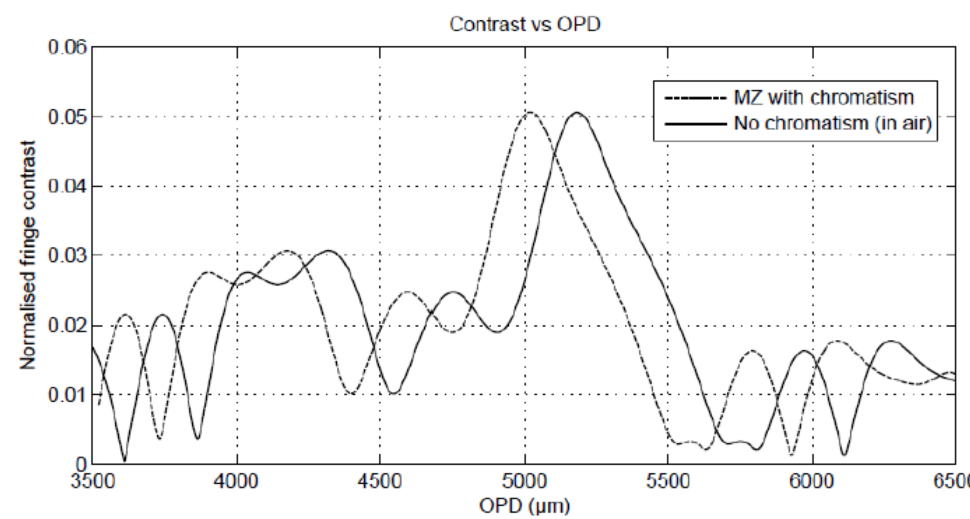
5

Optimisation of the sensitivity

- Wavelength: 519.5 nm
- Optical Path Difference: 5048 µm
- Filter bandwidth: 1 nm
- Fringe contrast: 5%

$$Q = \frac{2\pi\Delta\gamma}{\lambda_0\sqrt{2}} = 2147$$





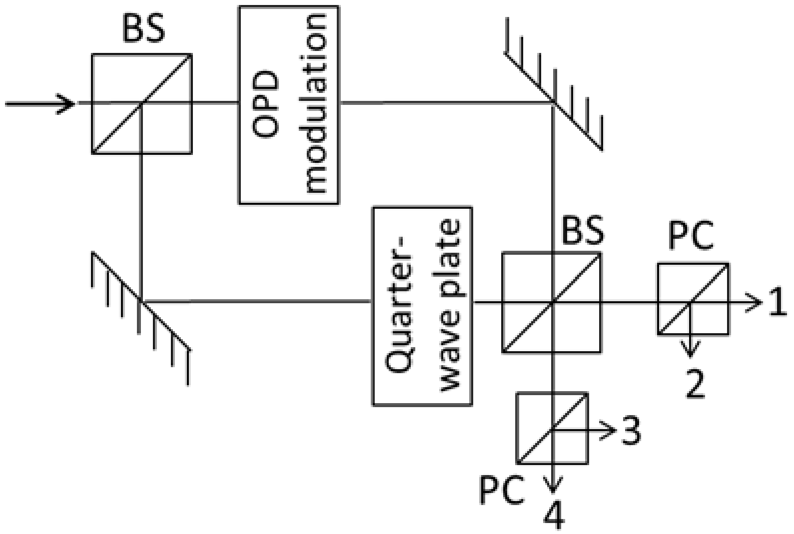
DSI design

Conceived for a space instrument

Solve some SYMPA issues

- Better sensitivity
- Higher contrast
- Self calibration
  - OPD modulation

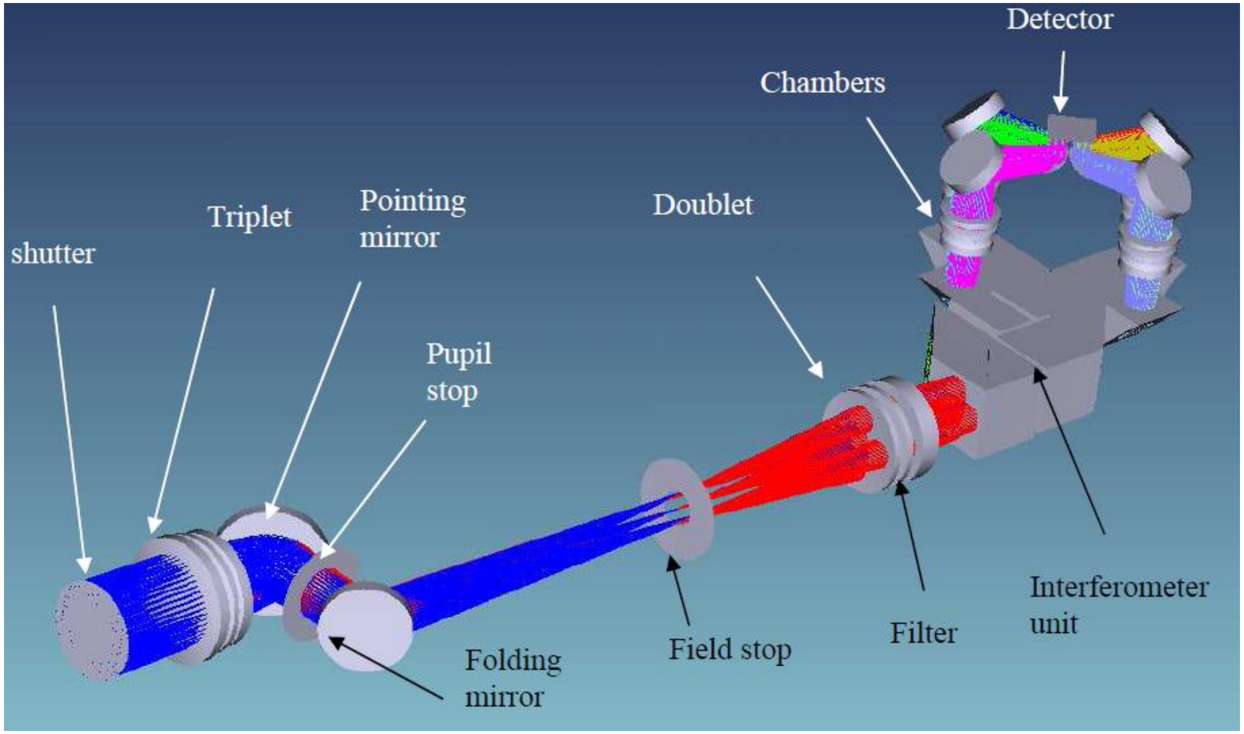
- Regular fringes
- Optical distortion
- Thermal stability



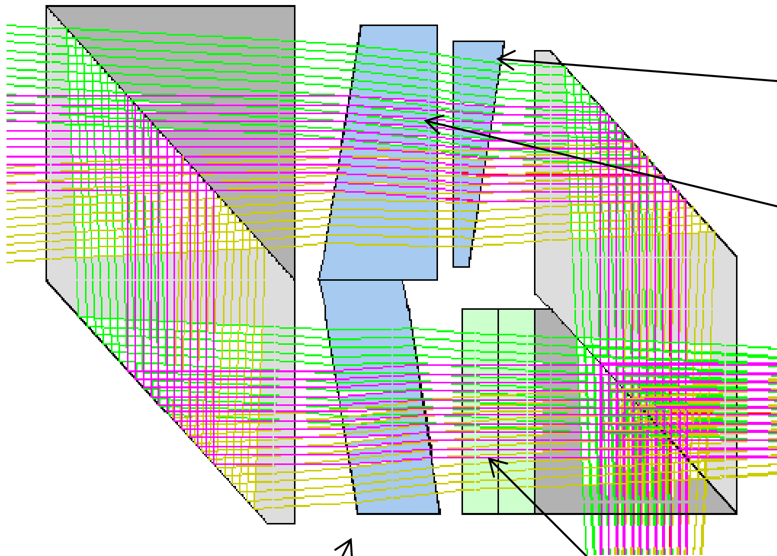
Echoes instrument

Study for the JUICE mission

- D=3.2 cm (from 0.05 AU) equivalent to 2.5 m from ground
- FoV=2.9 deg
- Noise level < 1 $cm^2/s^2/\mu Hz$



Optical design



Mobile plate: mobile, on piezoelectric plate, achieves the OPD modulation

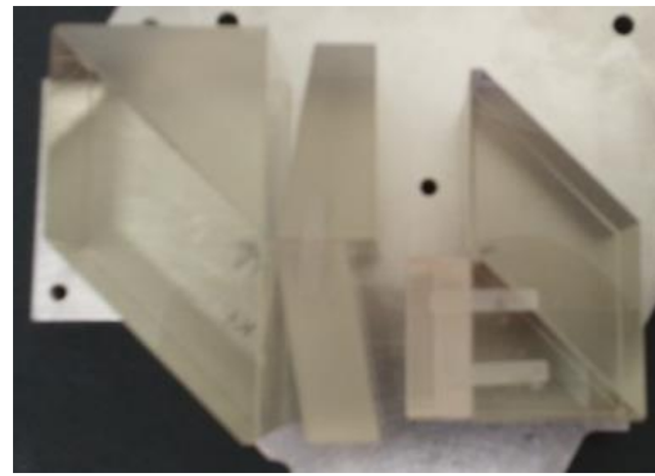
Tilted plate sliced in 2

Output bloc in K5G20

Entry bloc in K5G20

Quartz plates: achieve the phase quadrature

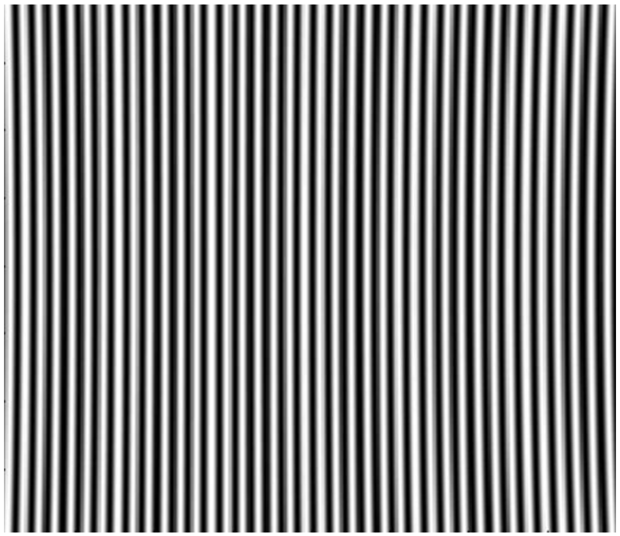
Tilted plates (BK7G18): minimizes stray lights and makes straight fringes



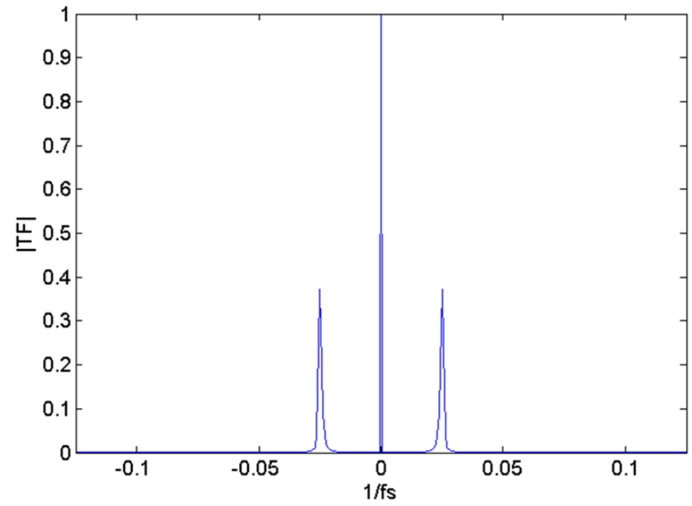
OPD modulation:

- Creates phase shifts of kπ/2
  - Response calibration of each channel
- Blur fringes to achieve flats fields
  - Pixel sensitivity calibration

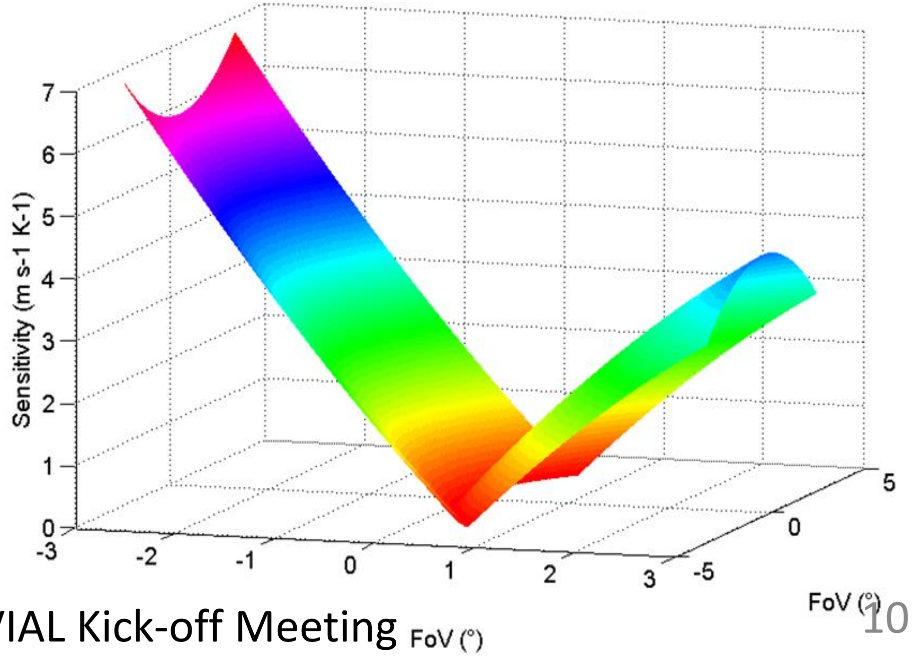
Numerical simulations



Fringe pattern

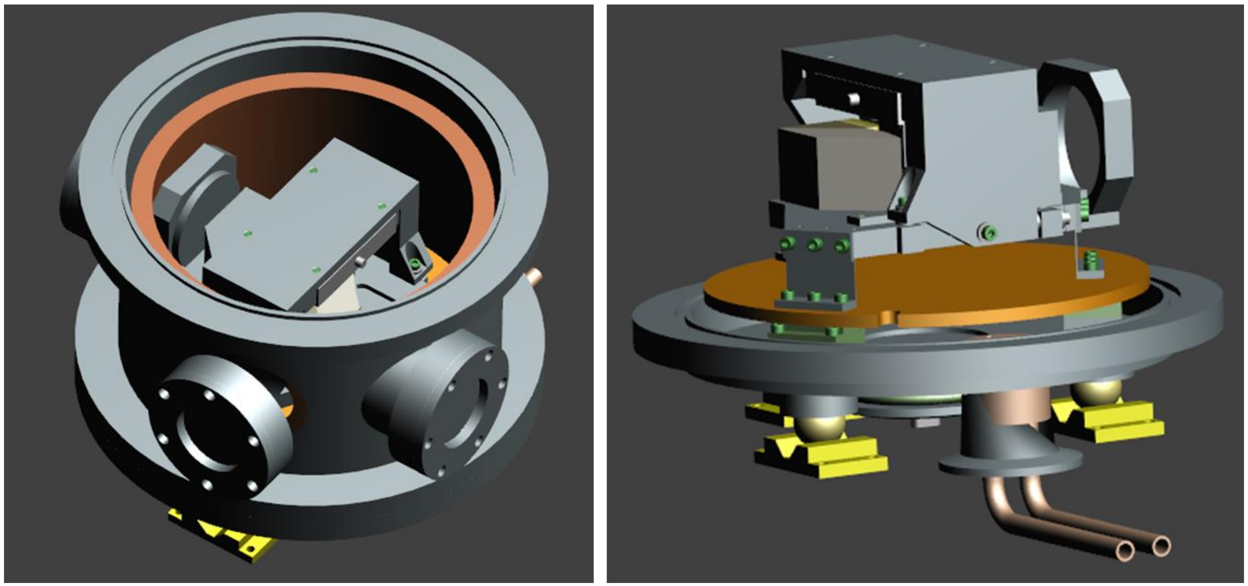


Thermal sensitivity



Vacuum tank

- Mechanical and thermal studies made by IAS



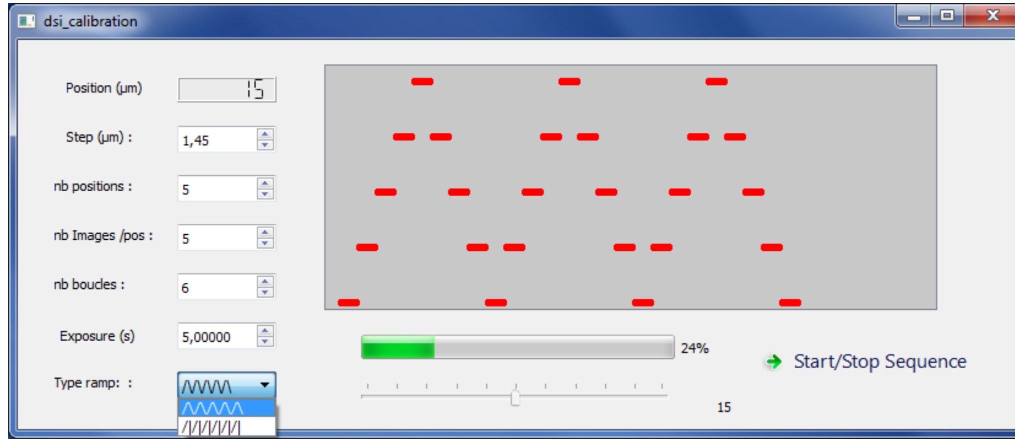
Modèle CAO, Gilles Morinaud

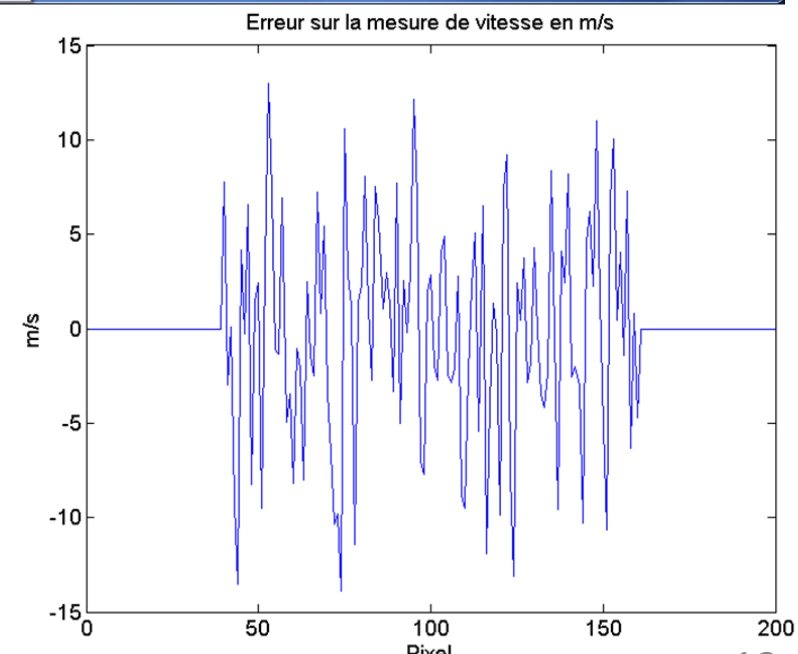
- Ensure a temperature homogeneity of ± 0,4°C

Calibration

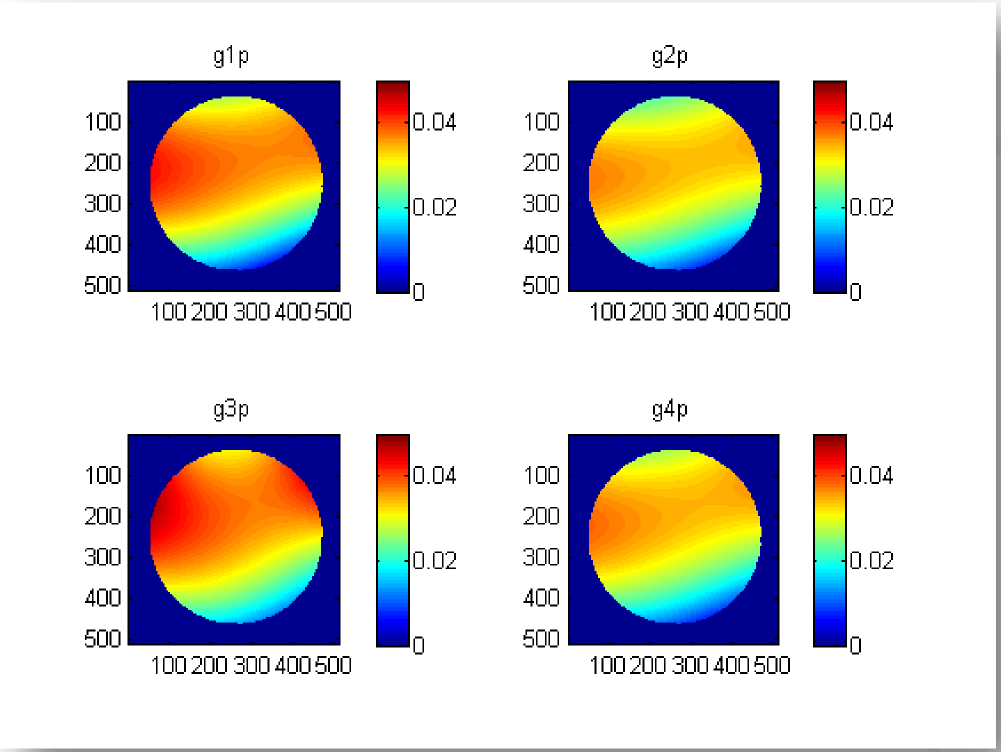
- Modulation of OPD
  - Steps of π/2
- Calibration of

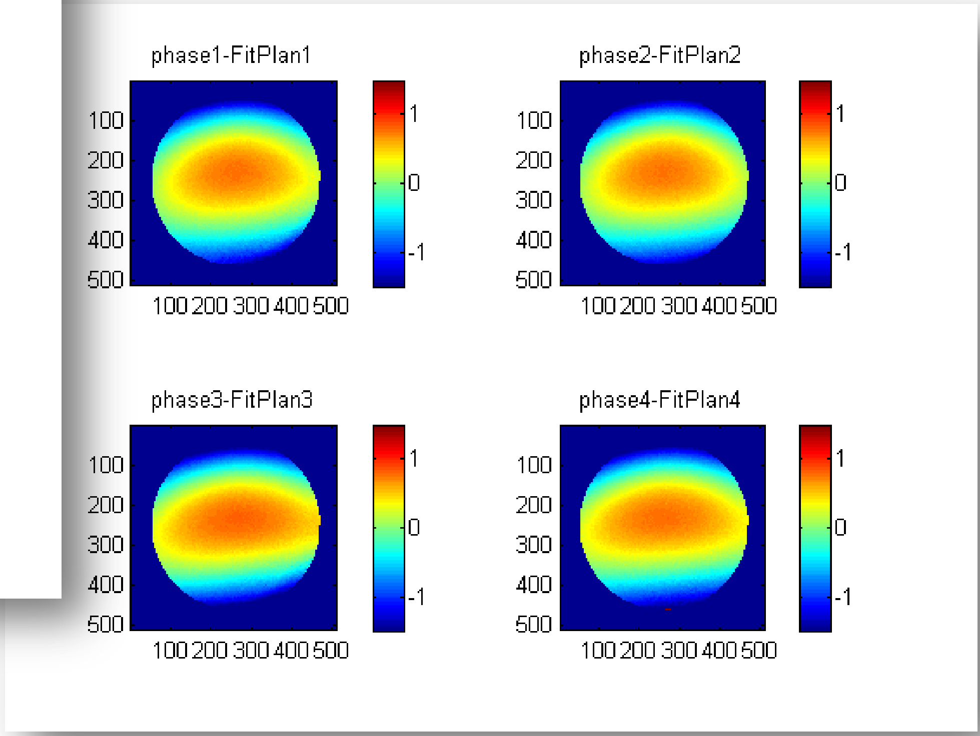
  velocity maps
  - Specification 10 m/s/px
  - respected for a variation of pixel sensitivity 0,03%
- Error on phase
  - Modulation should be made with precision better than π/300, or 0,9 nm



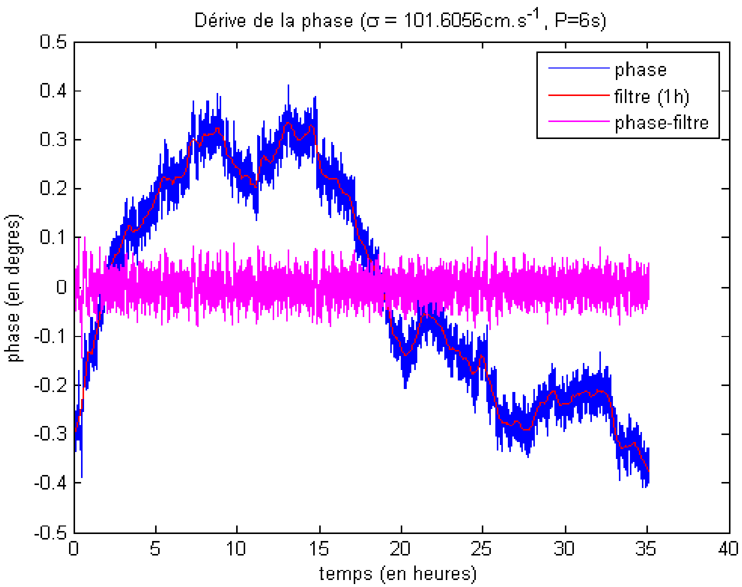


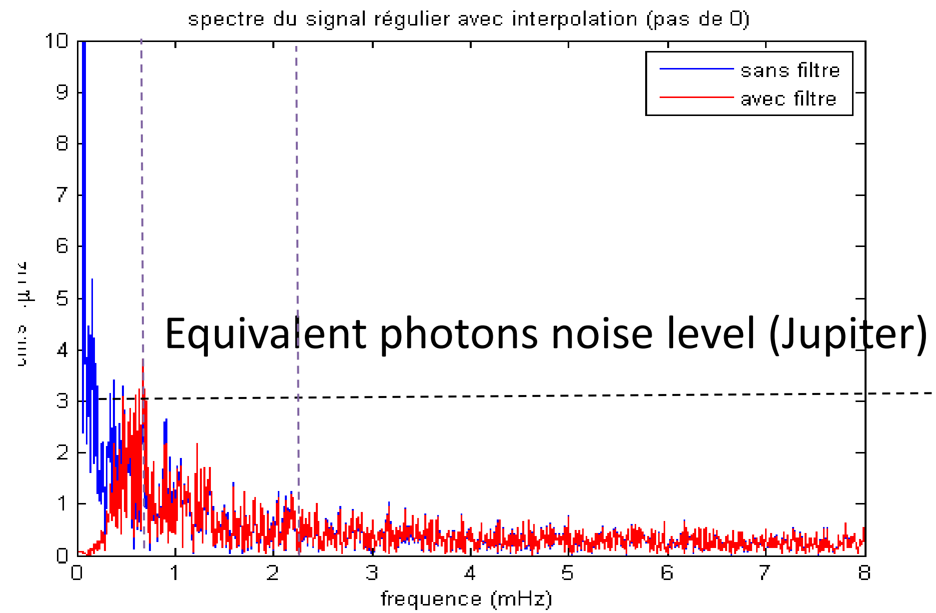
Instrumental fringes





Laboratory tests





Tests on the sky

- Proposed to CNES in 2013
- Finalisation of R&T (TRL 5)
  - Verification of real performances on Jupiter
  - Jupiter: velocity field (non reproducible in lab)

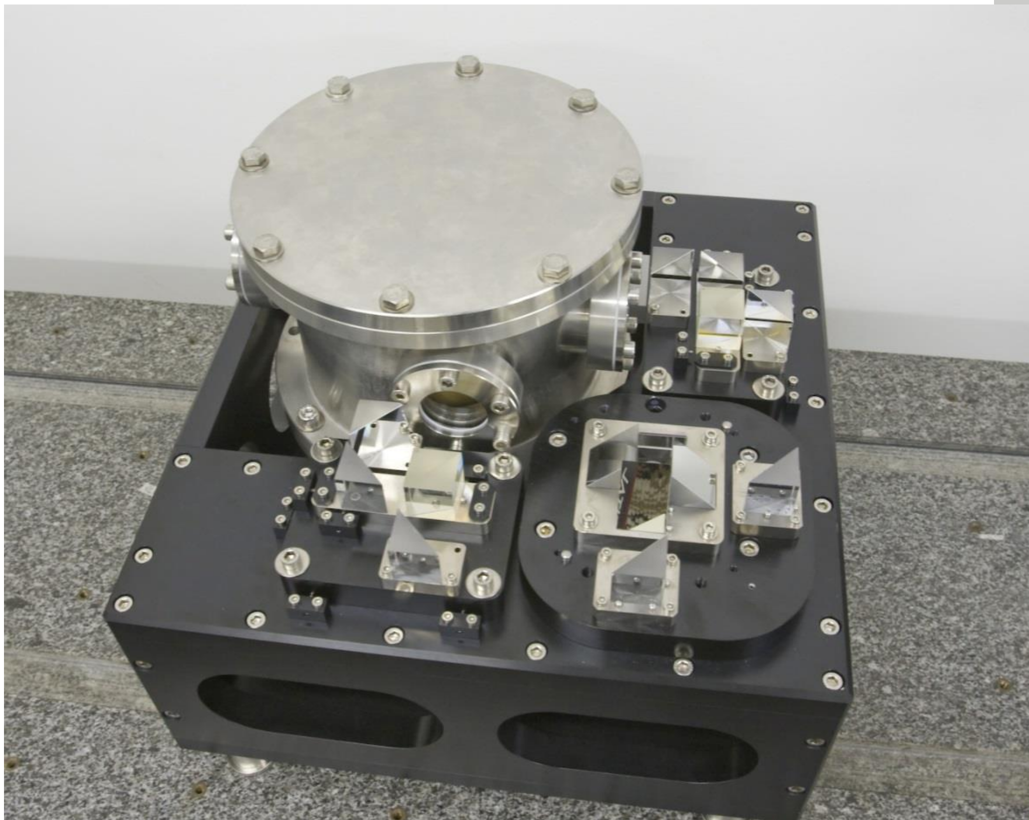
- Possibility of coordinated observations with other sites
- Analyse of results DSI
  - Comparaison with other concepts
  - Development of data processing tools

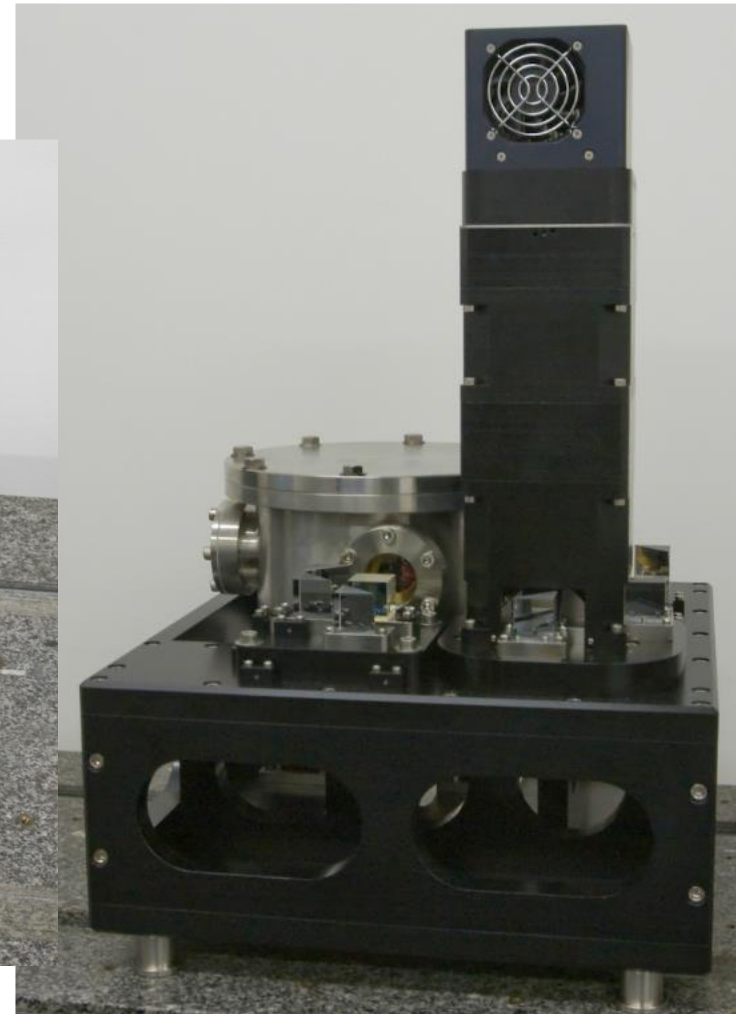
Observations at Calern

- Telescope MeO at Calern observatory
- 1.5m
- Laser ranging
- Refurbished in 2009
- Coudé focus
- Observations available:
  - a few weeks per year

DSI Output optics

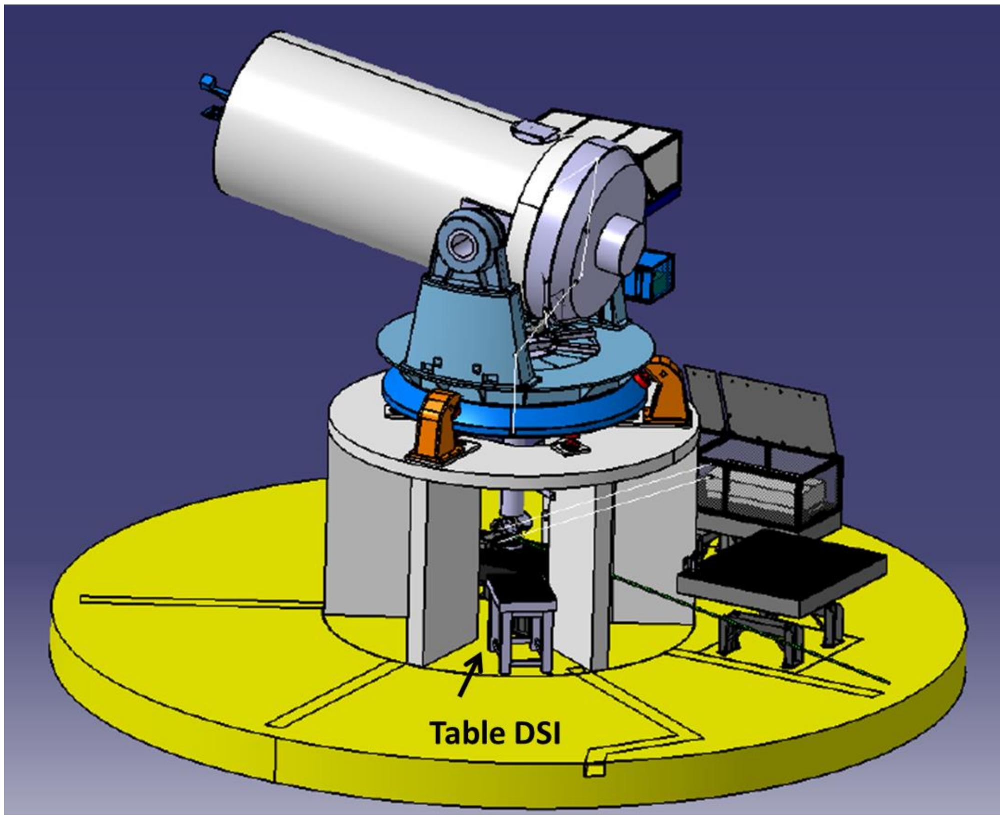
- December 2013-January 2014

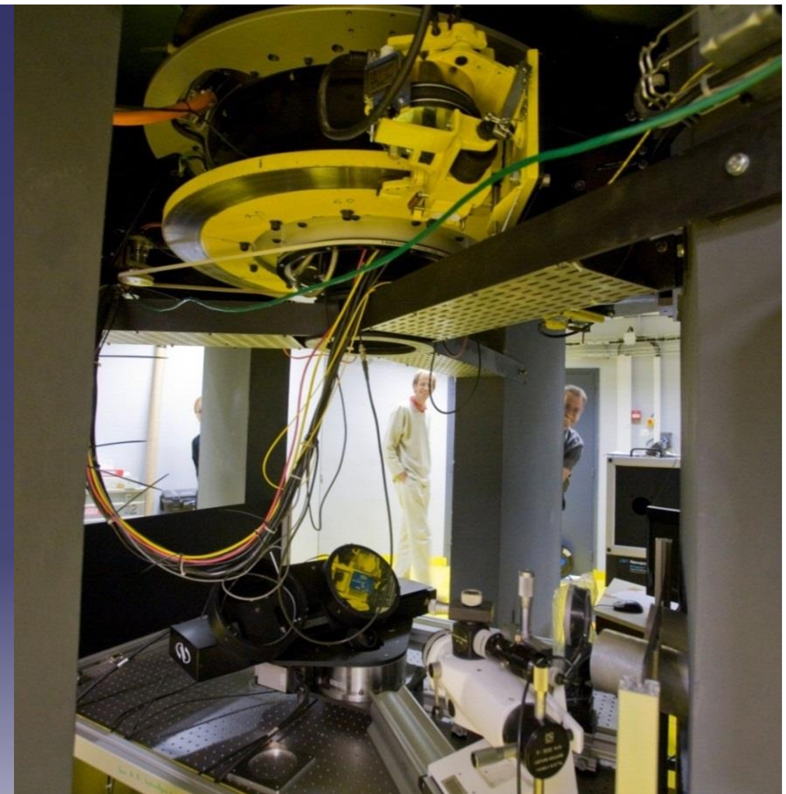




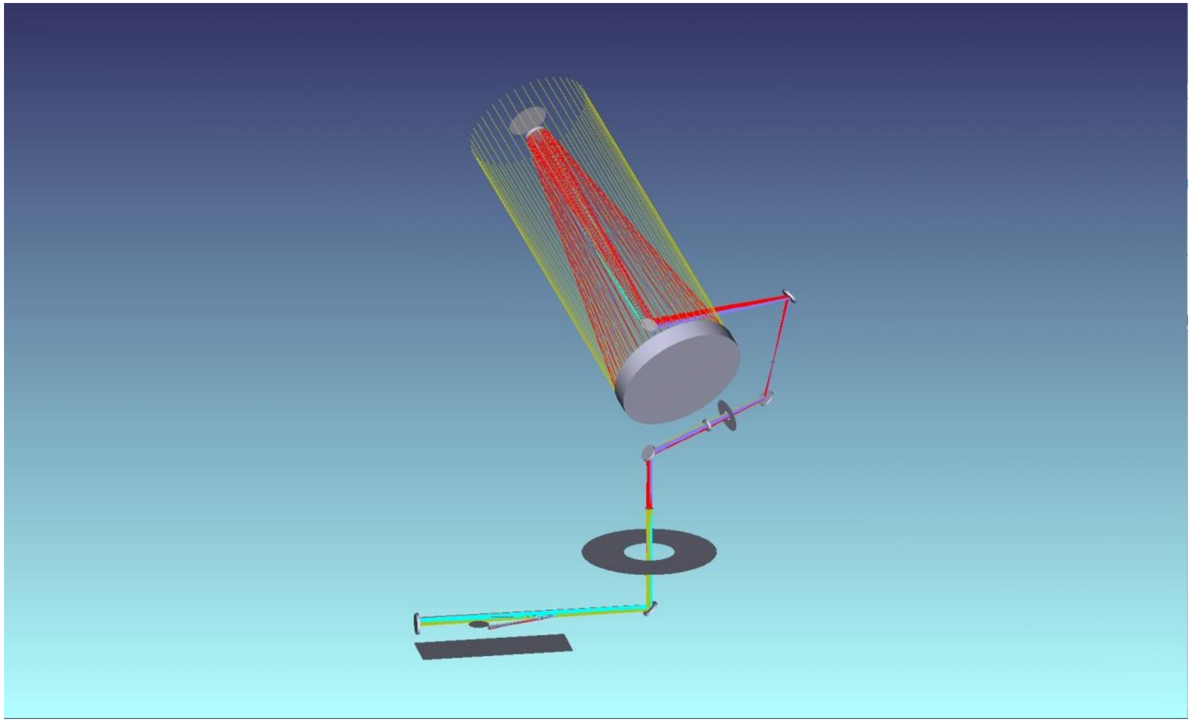
DSI @ MéO

- Observations of Jupiter in January 2014
- DSI placed at Coudé focus of MeO telescope at Calern observatory

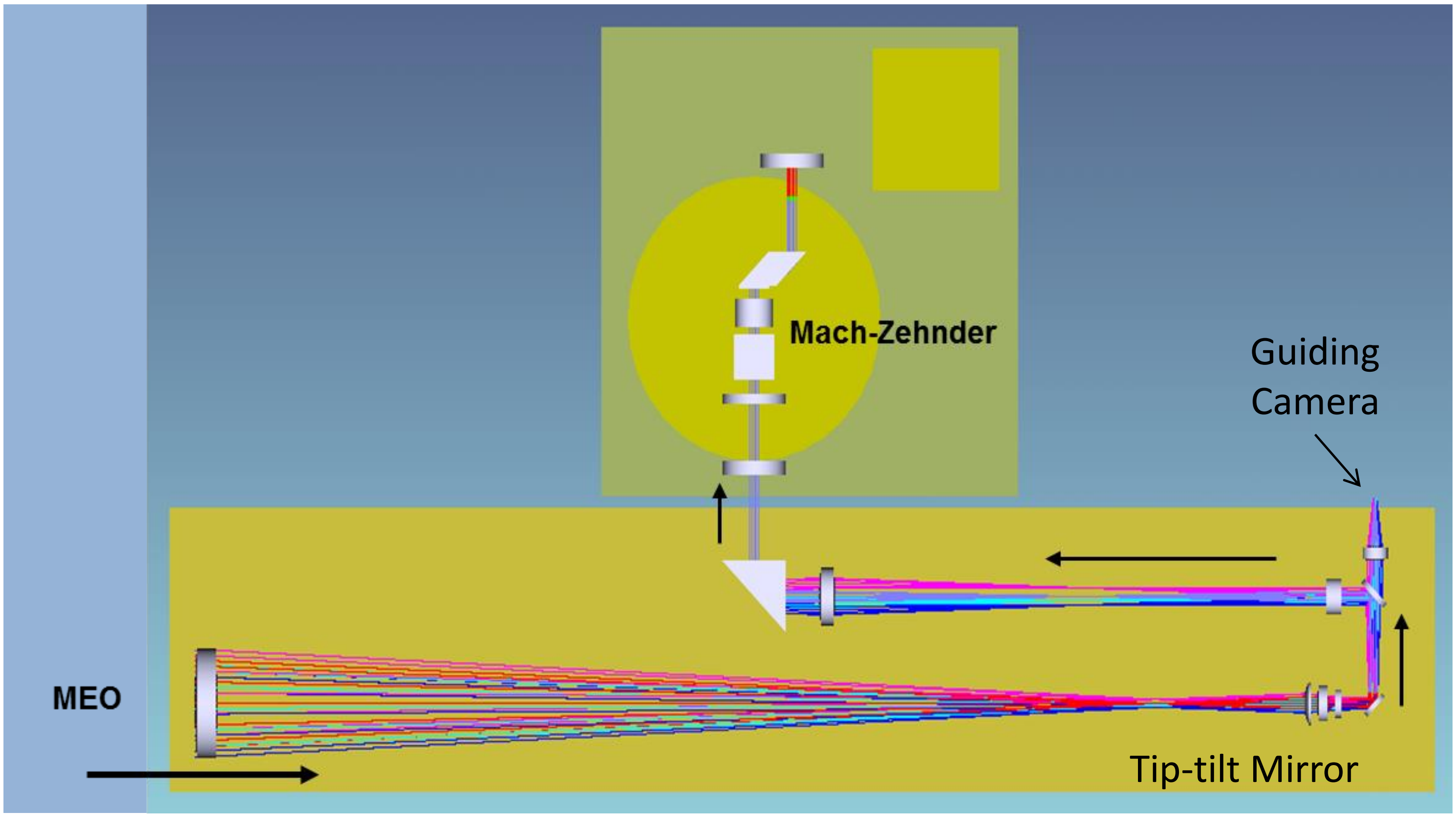


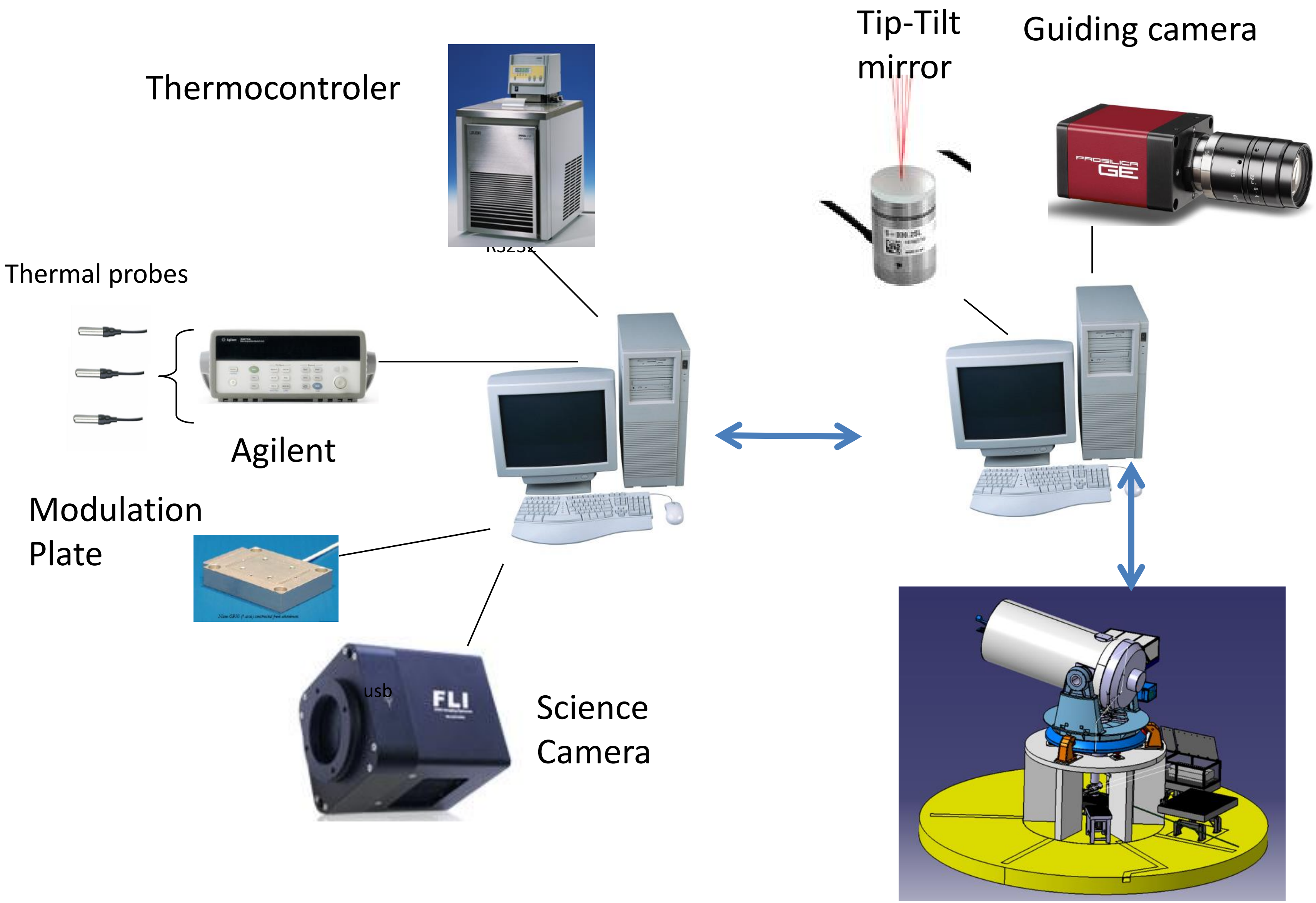


MeO Optical path



Optical interface and guiding

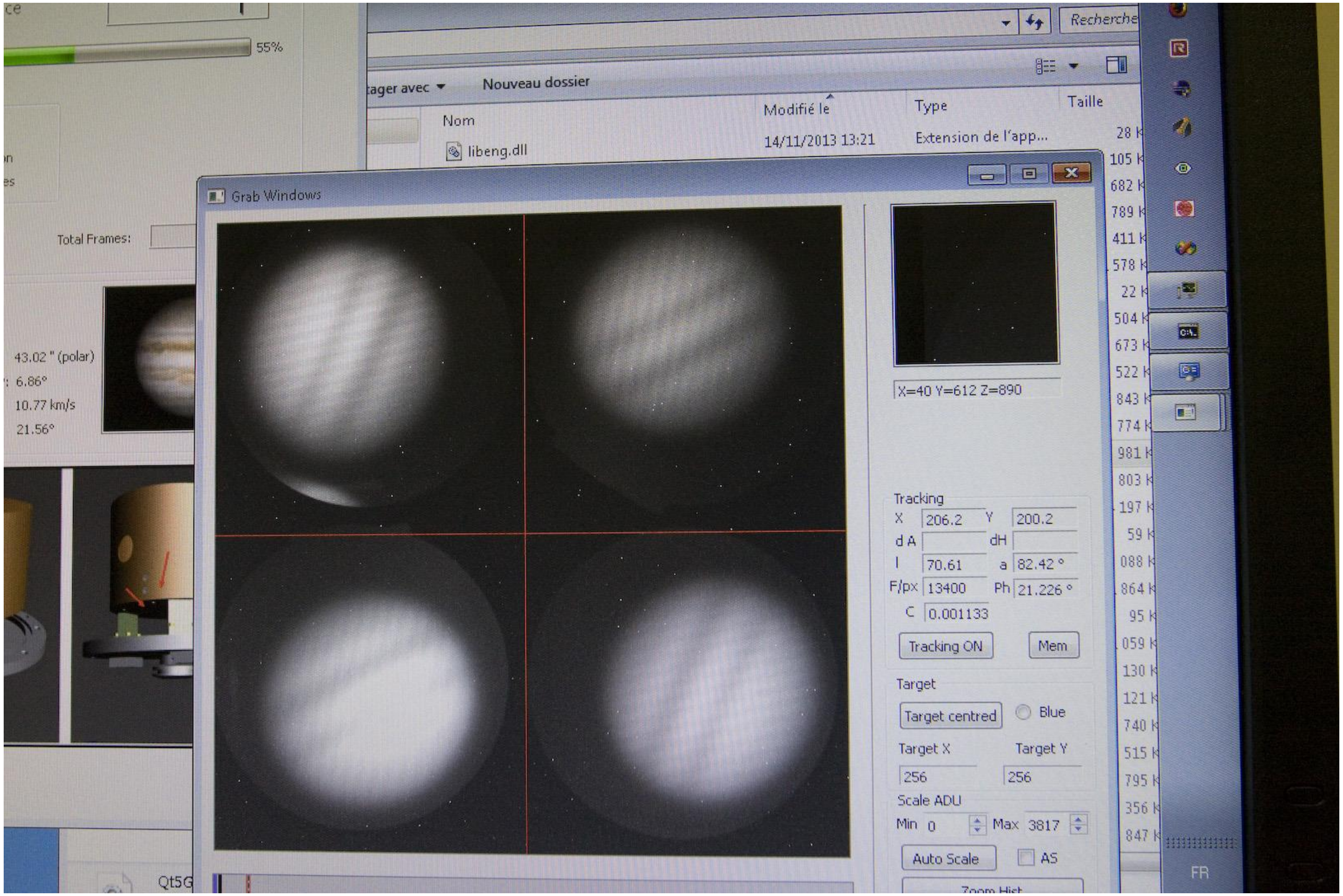



Thermocontroler
Tip-Tilt mirror
Guiding camera
Thermal probes
Agilent
Modulation Plate
usb
FLI
Science Camera

Instrument at MEO

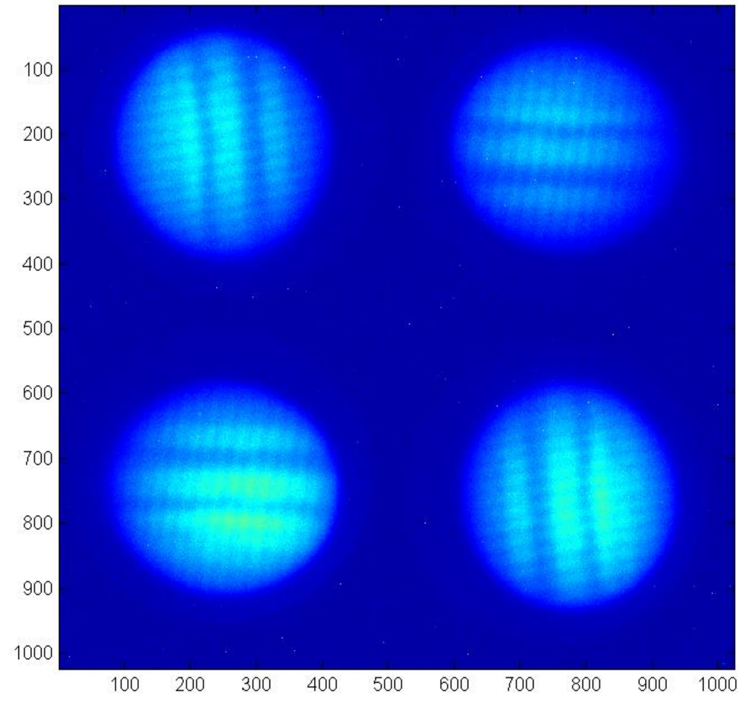
January 24th, 2014

First light


55%
Nouveau dossier
Nom
Modifié le
Type
Taille
libeng.dll
14/11/2013 13:21
Extension de l'app...
Grab Windows
Total Frames:
43.02 " (polar)
6.86°
10.77 km/s
21.56°
X=40 Y=612 Z=890
Tracking
X 206.2 Y 200.2
d A dH
I 70.61 a 82.42 °
F/px 13400 Ph 21.226 °
C 0.001133
Tracking ON
Mem
Target
Target centred
Blue
Target X Target Y
256 256
Scale ADU
Min 0 Max 3817
Auto Scale
AS
FR

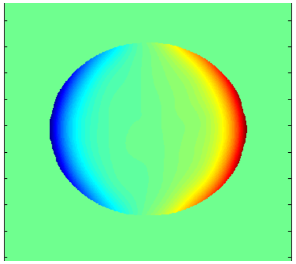
Estimated performances

- 2 nights and half
- Total Transmission : 4% (Instrument + Tél.)
- Flux 8 10^8 φ in 1 mn
- Contrast 3 %
- Noise level : 3 cm/s/μ$Hz^{1/2}$
- Gain vs SYMPA ~2
- Velocity precision: 20 m/s/'' in 1h

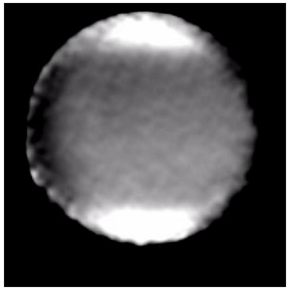


Identified issues & bias

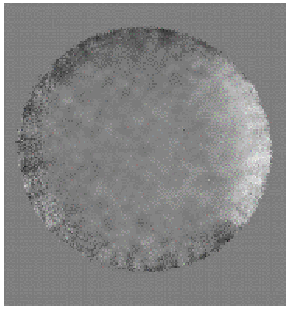
- Effect of PSF (atmospheric turbulence)



- Polarisation on Jupiter
- Polarisation of the telescope



- Drift of the optical pupil during the night
- Field rotation



PSF effects

The PSF is dominated by atmospheric turbulence

30 s integration

Around 1.5 arcsec

It decreases the fringe contrast on Jupiter : 4% -> 3.3%

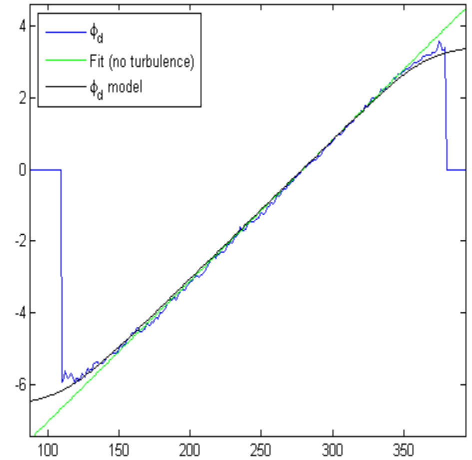
A bias affects any Doppler shift measurements

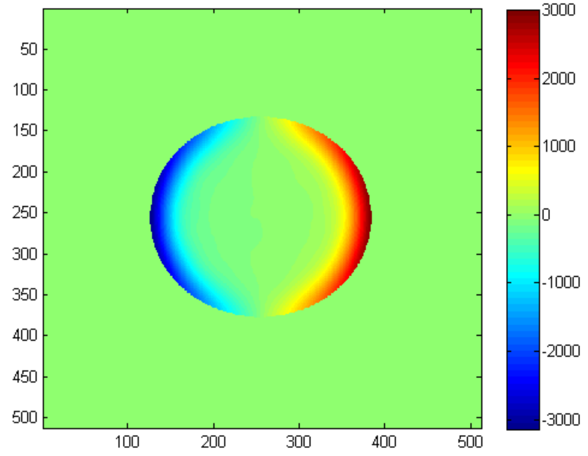
(independently of the instrument)

$$\overline{v_{rad}}(x,y) = \frac{\int v_{rad}(u,v)F(u,v)PSF(x-u,y-v)dudv}{\int F(u,v)PSF(x-u,y-v)dudv}$$

It can be minimized by improving the size of the PSF

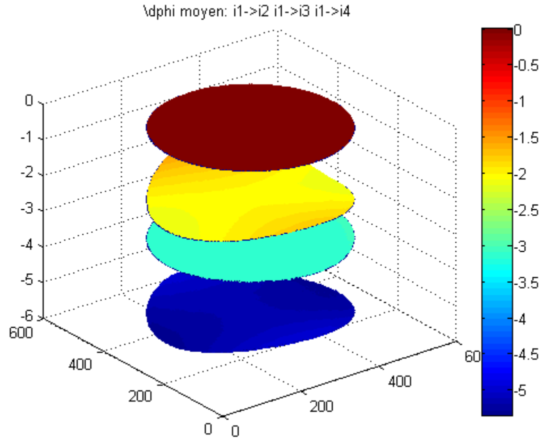
-> Adaptive Optics





Polarisation

- Contaminations between outputs ~ %
- Changes in the phase of each output
- Bias in phase measurement
- Correction depends on polarisation rate and direction



- Identified contamination from beam splitter (non uniform in the field)
  - Will be fixed
- Monitoring of polarisation direction

Phase estimation bias

$$U = \gamma \cos \emptyset + \delta U$$

$$V = \gamma \sin(\emptyset + \theta) + \delta V$$

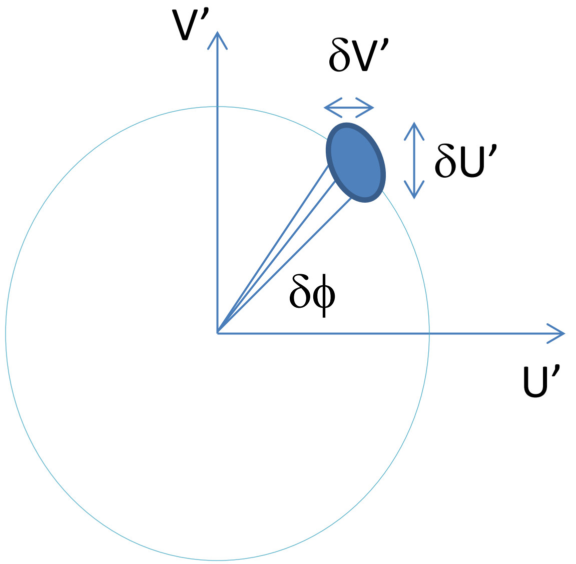
$$U' = U = \gamma \cos \emptyset + \delta U'$$

$$V' = \frac{V - U \sin \theta}{\cos \theta} = \gamma \sin \emptyset + \delta V'$$

$$\sigma^2{}_{V'} = \frac{\sigma^2{}_V}{\cos^2 \theta} + \sigma^2{}_U \frac{\sin^2 \theta}{\cos^2 \theta}$$

$$\emptyset = \mathrm{atan}\left(\frac{V'}{U'}\right)$$

$$\epsilon_\emptyset = \frac{1}{2\gamma^2(1 - \sin 2\emptyset \sin \theta)}\left[(\sigma_U{}^2 - \sigma_V{}^2) \sin 2\emptyset \cos \theta + \sin 2\theta(\sigma_V{}^2 cos^2\emptyset - \sigma_U{}^2 sin^2\emptyset)\right]$$



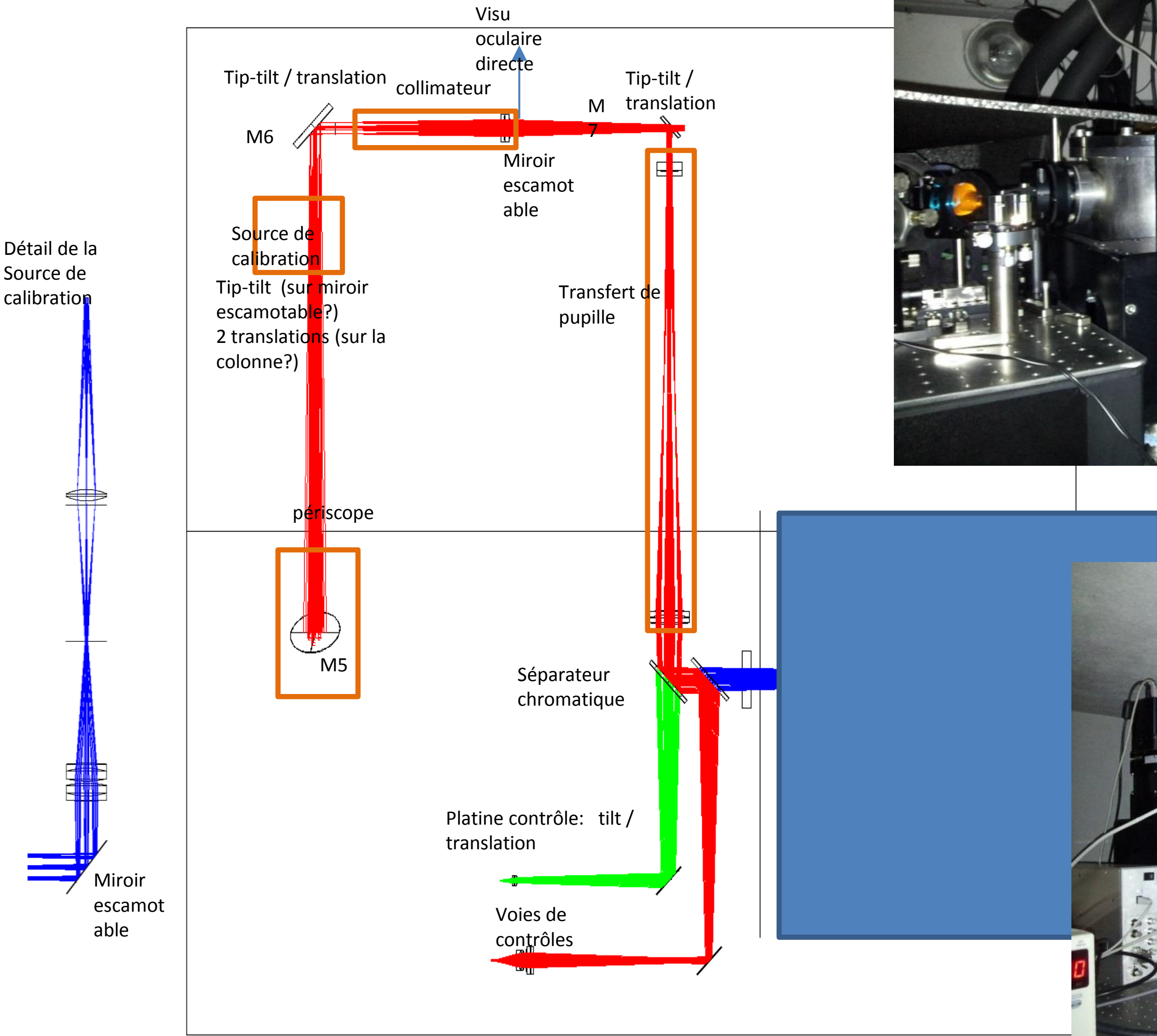
2016 observations

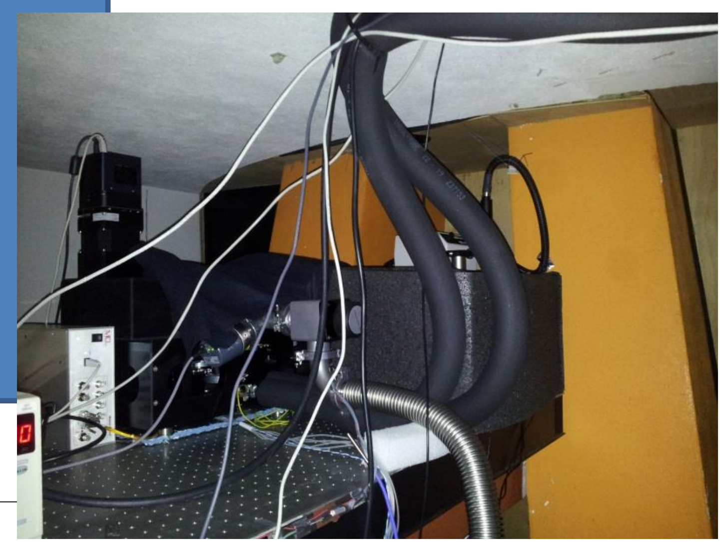
- C2PU telescope 1 m telescope
- Simplified coudé train :

less polarisation

- Better transmission
- Pupil stabilisation
- Longer observations

DSI – C2PU


Visu
oculaire
directe
Tip-tilt / translation
collimateur
M6
M
7
Tip-tilt /
translation
Miroir
escamot
able
Détail de la
Source de
calibration
Source de
calibration
Tip-tilt (sur miroir
escamotable?)
2 translations (sur la
colonne?)
Transfert de
pupille
périscope
M5
Séparateur
chromatique
Platine contrôle: tilt /
translation
Voies de
contrôles
Miroir
escamot
able



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