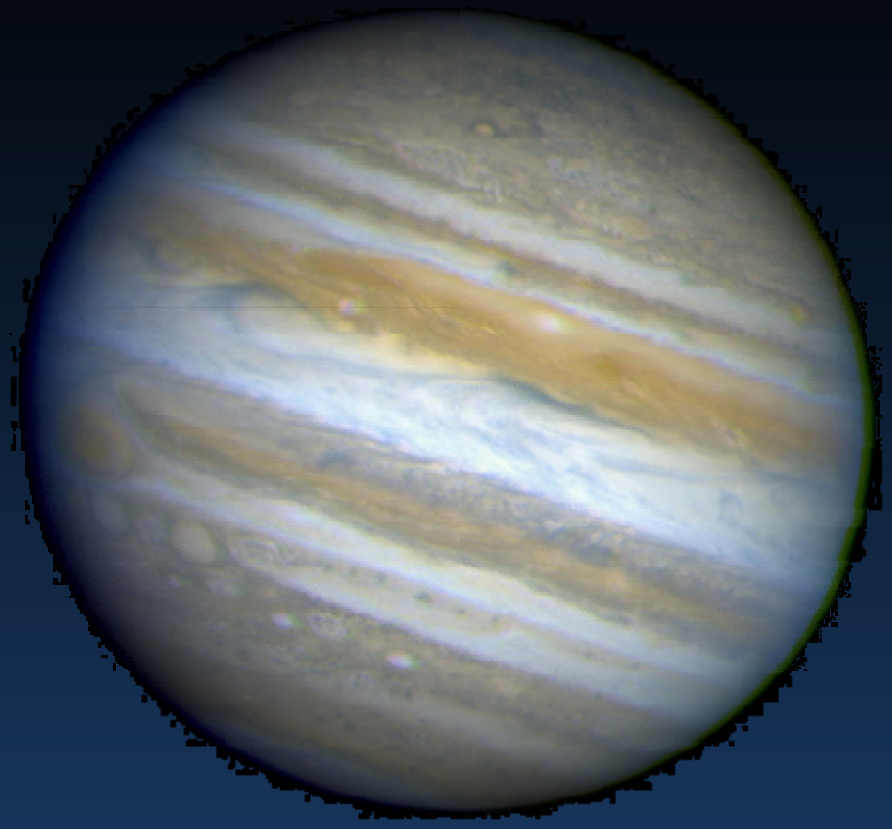
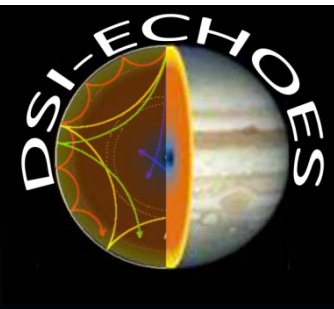
Doppler Spectro Imager



F.X. Schmider and the DSI-ECHOES team

Doppler Spectro Imager



- Context
  - History of the project
  - Previous observations
  - EJSM Mission overview
- DSI – ECHOES Instrument
  - Main objectives
  - Instrument principle
  - Preliminary design
  - Consortium organisation and tasks
- Other projects

History of the project

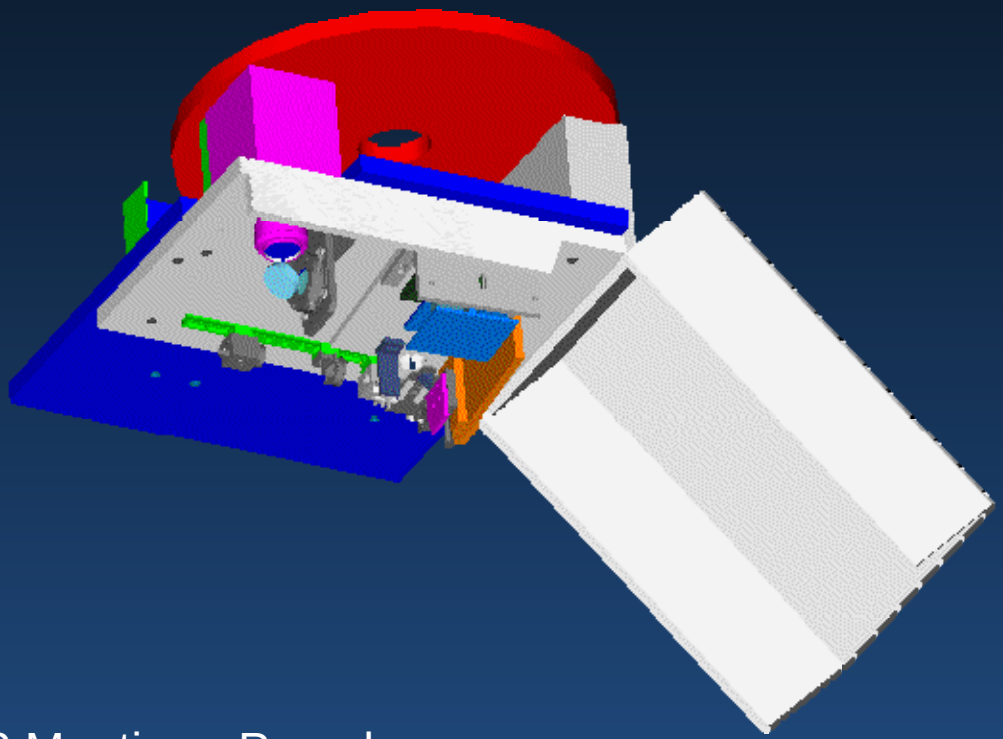
- Jovian Seismology
  - Vorontsov & Zarkhov 1976
  - Bercovici & Schubert 1987
  - Gudkova & Zarkhov, 1999
  - Lognonné 2007
- Previous Projects
  - MOF (Sodium cell): 1986
  - Fourier Transform Spectrometry (CFHT): 1991
  - SYMPA Project: 2000
- Cosmic Vision Laplace proposal (M. Blanc)
  - Jovian seismology: 2007
  - DSI proposal for EJSM/JGO: 2009

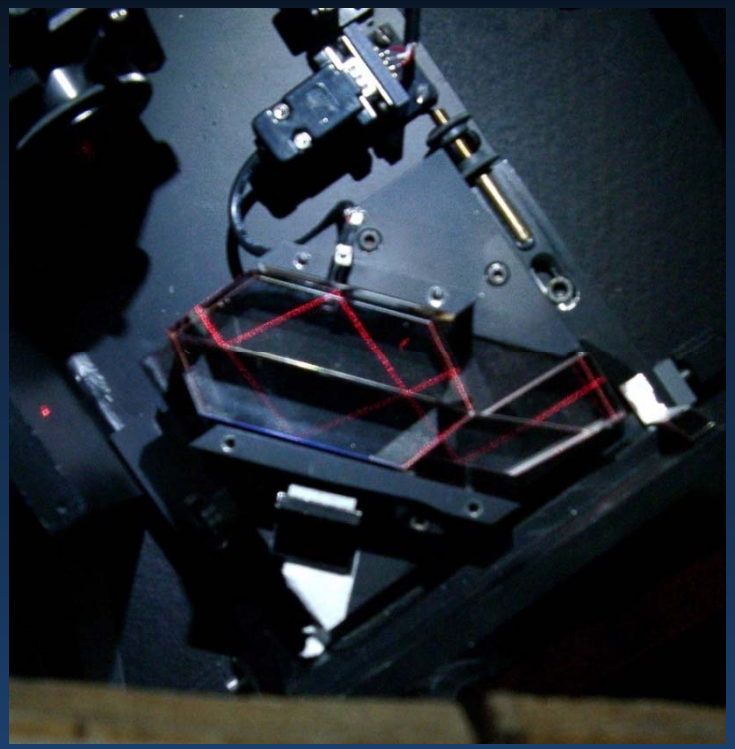
SYMPA project

Ground based network: 2 (3) instrument on 1.5 m telescopes

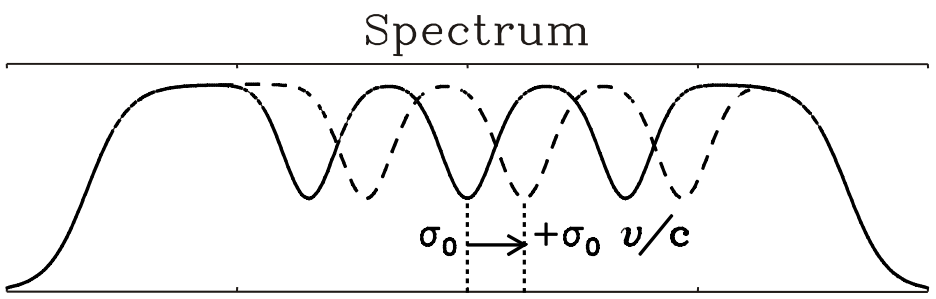
Radial velocity measurement with spatial resolution

Fourier transform tachometer

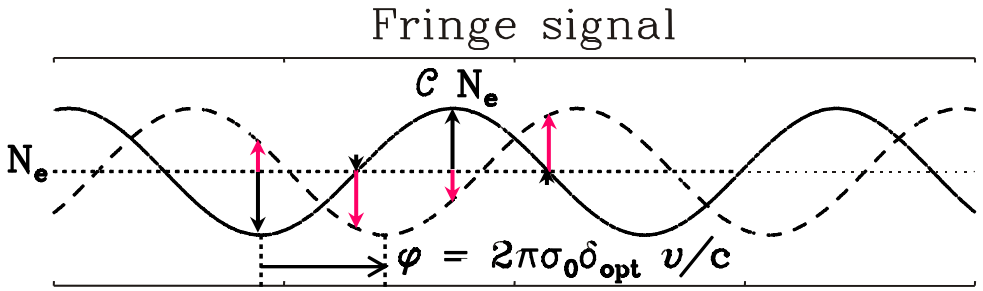




SYMPA principle

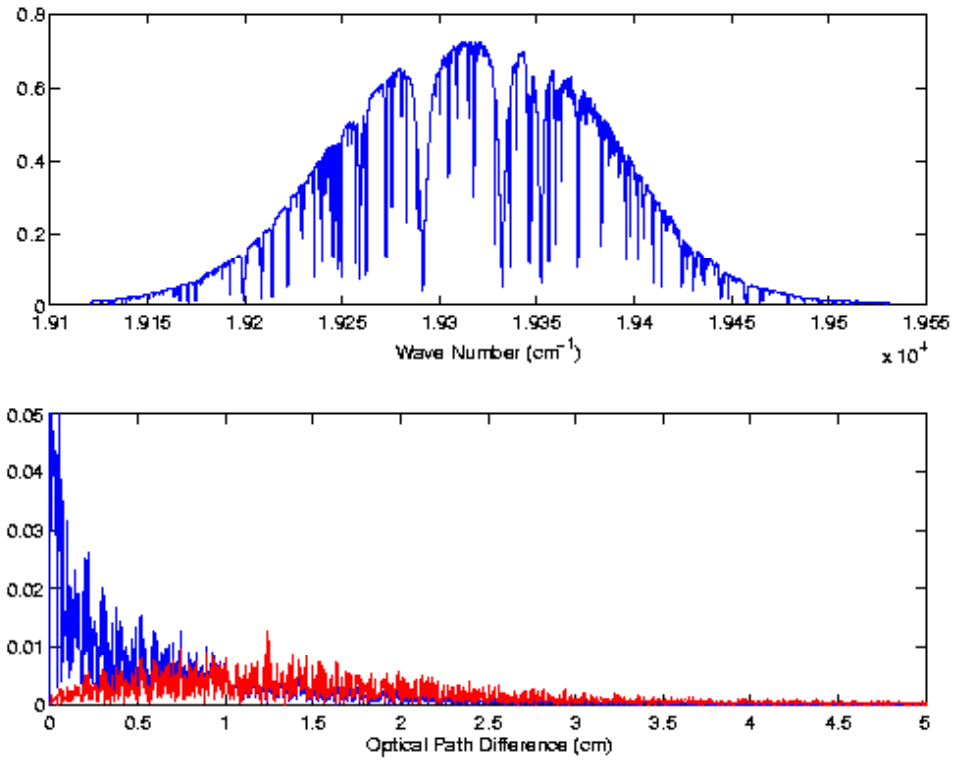


Wavenumber σ_0 (cm^{-1})



Phase ϕ (rad)

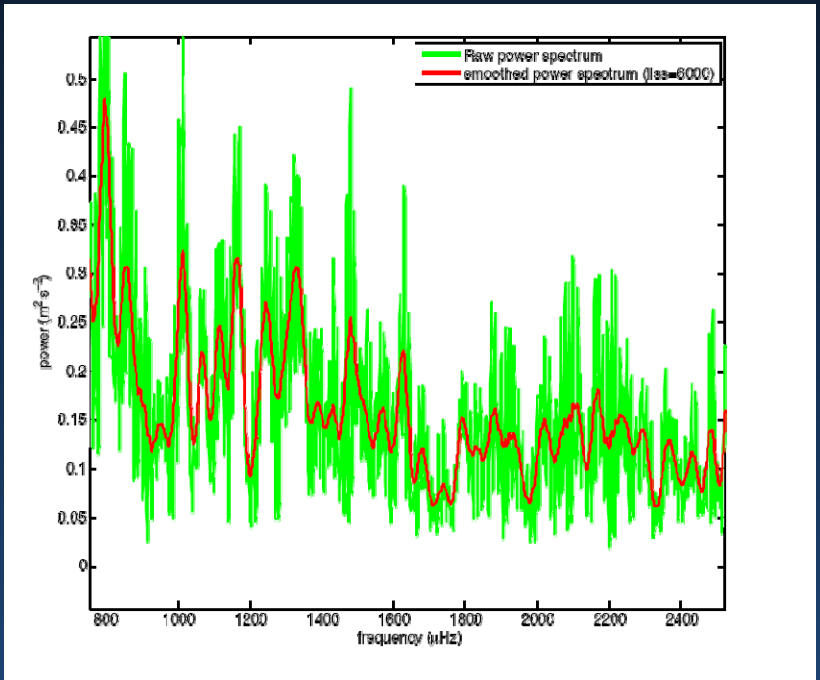
$$\delta\nu = \frac{c}{2\Pi\sigma_0\Delta C\sqrt{N_e}}$$

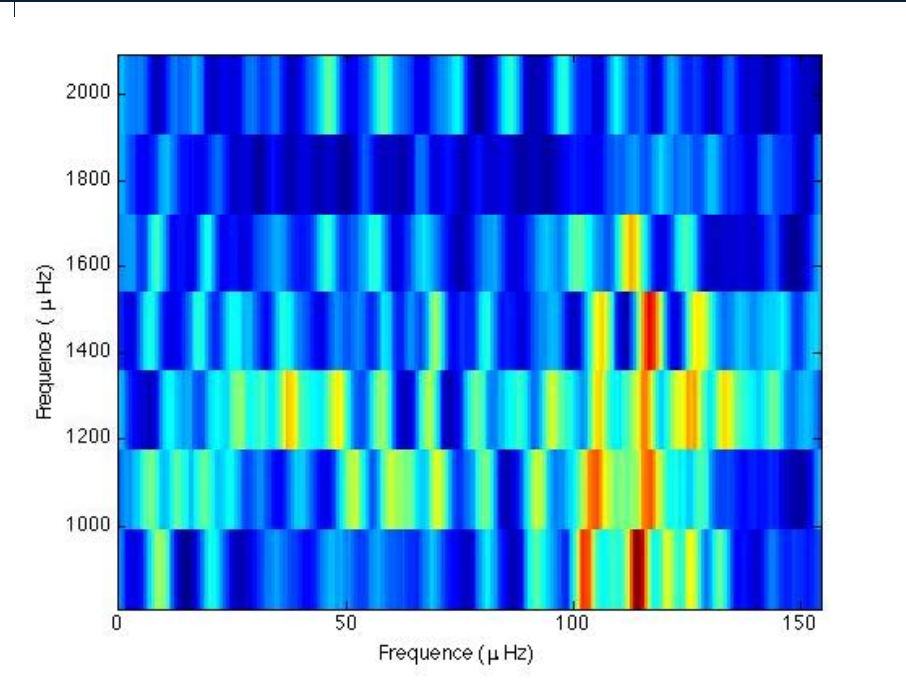


Choice of Optical Path Difference

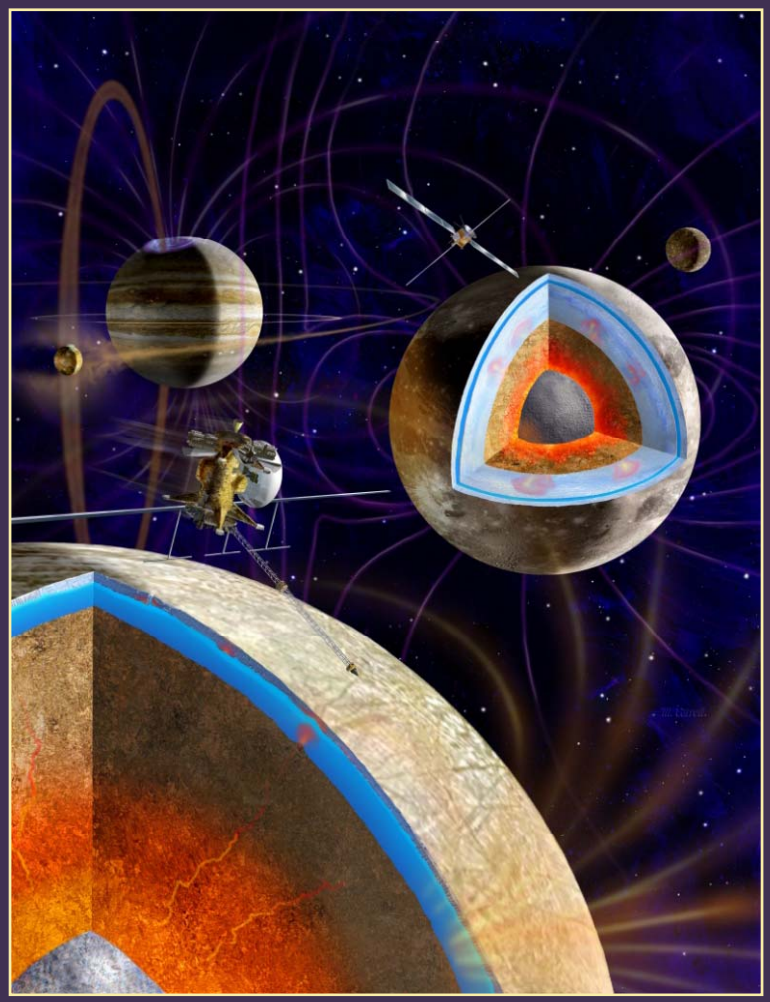
SYMPA data analysis

- 2 network observation runs 2004, 2005
- Noise level at 12 cm/s with a 7-night run
- Actual performances close to theoretical (gain of 5)
- Preliminary result compatible with previous observations: presence of a periodicity of 156 µHz in the density power spectrum l = 0 and l=1

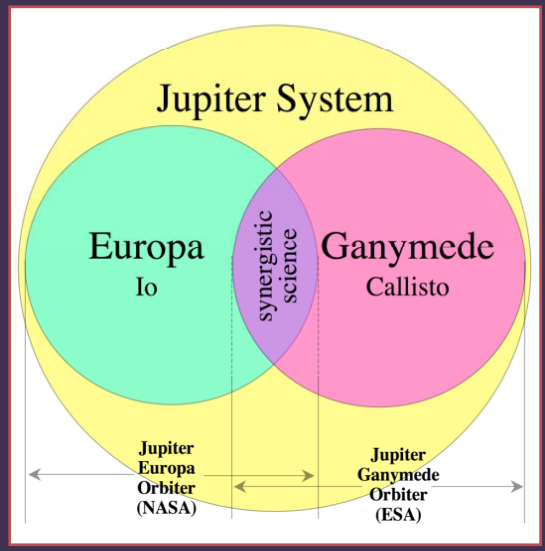




Europa Jupiter Science Mission (EJSM)

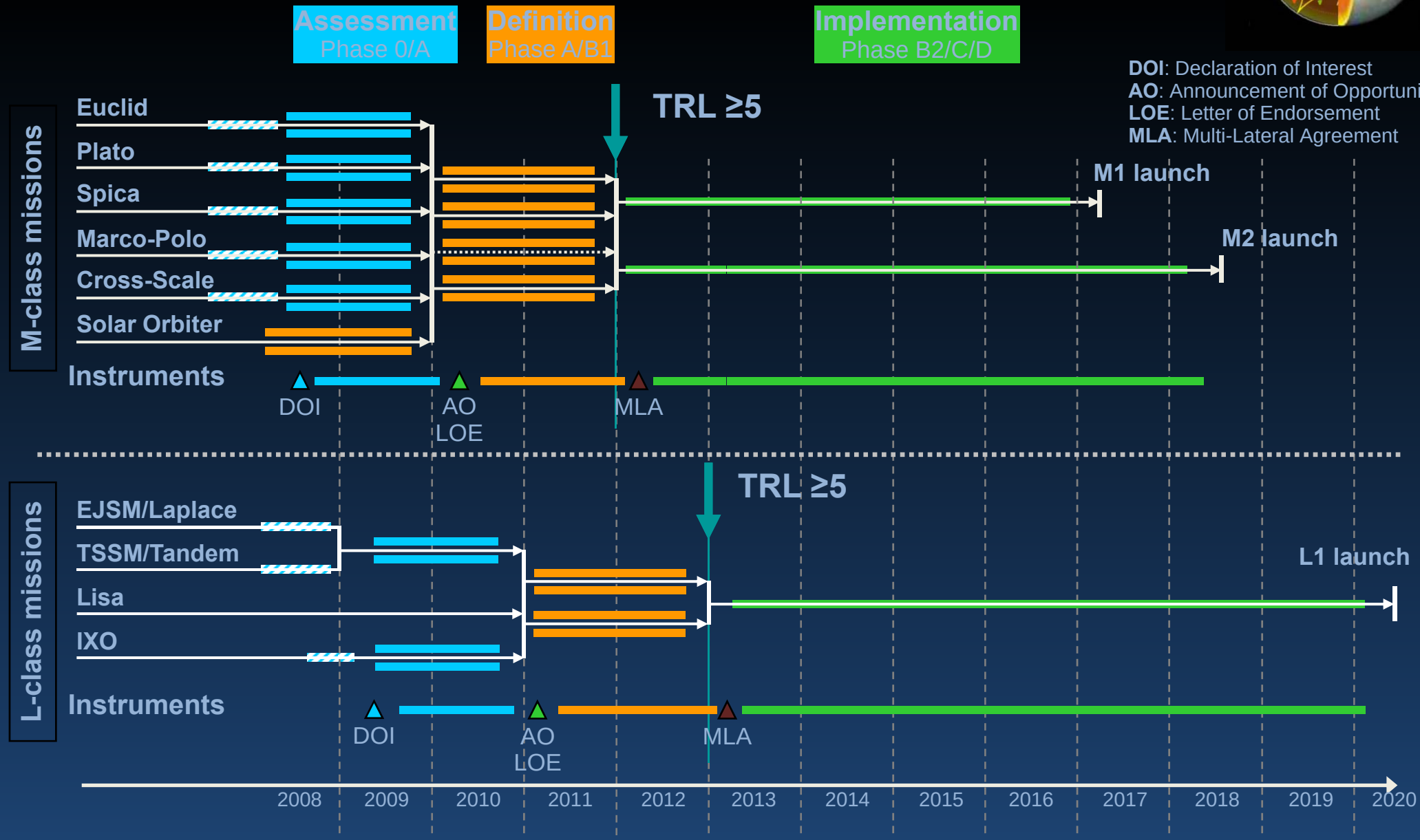


- NASA and ESA: Shared mission leadership
- Independently launched and operated orbiters
  - NASA-led Jupiter Europa Orbiter (JEO)
  - ESA-led Jupiter Ganymede Orbiter (JGO)
- Complementary science and payloads
  - JEO concentrates on Europa and Io
  - JGO concentrates on Ganymede and Callisto
  - Synergistic overlap
  - 11-12 instruments each
- Science goals:
  - Icy world habitability
  - Jupiter system processes

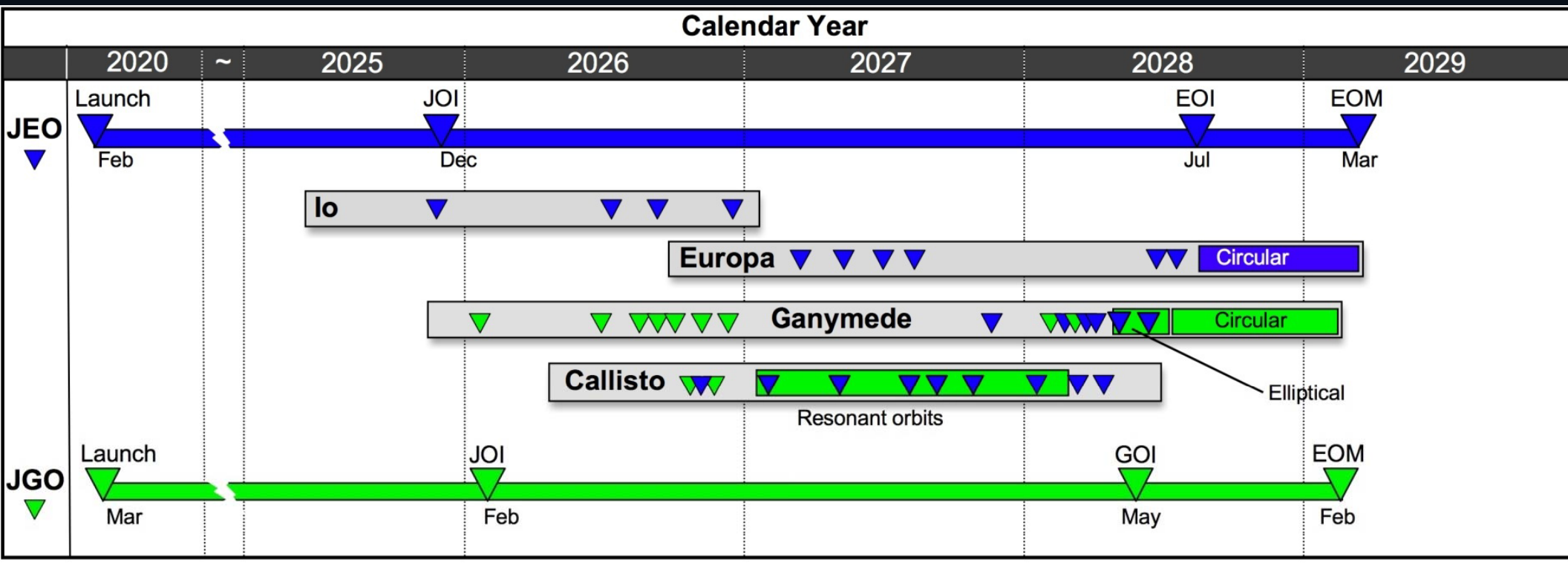


Synergistic science: The sum of JEO + JGO is greater than the parts

Cosmic Vision 2015-2025

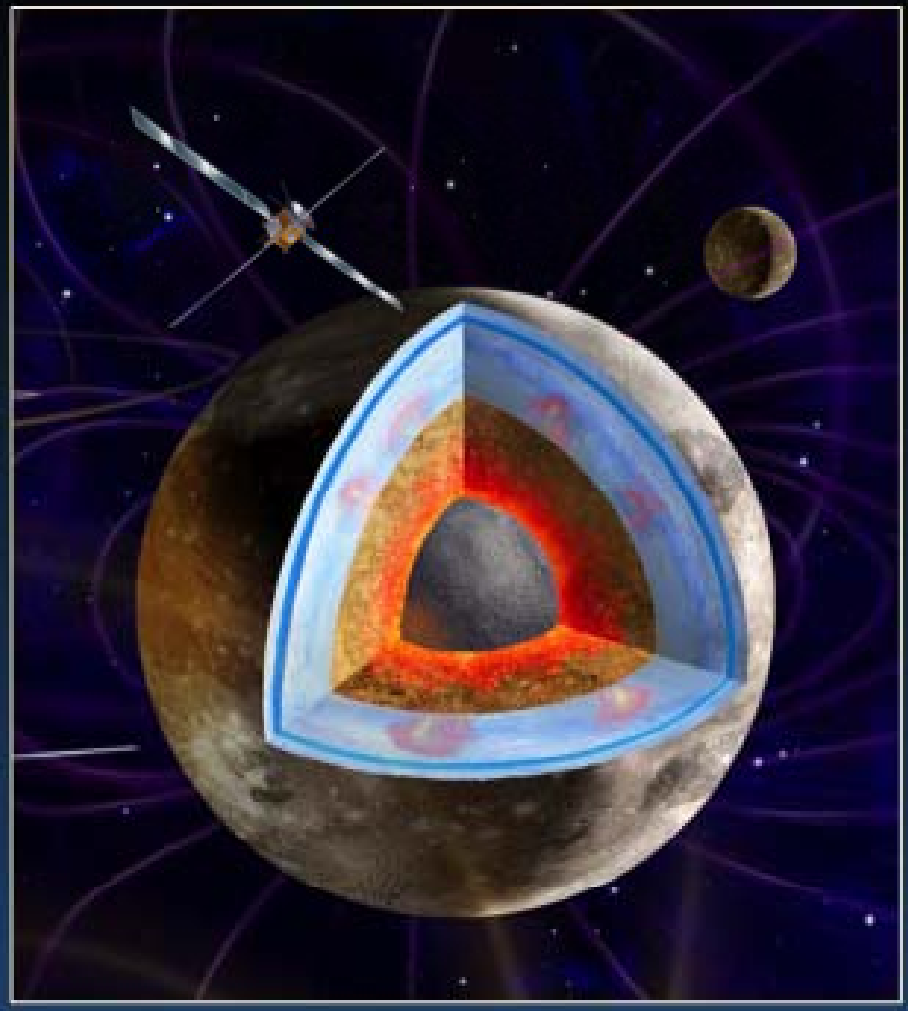


EJSM Schedule



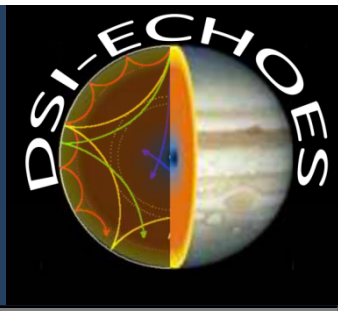
JGO Science

- Key JGO science phases
  - **Jupiter system:** In-depth exploration
    - From Jupiter orbit, synergistically with JEO
  - **Callisto:** In-depth study and mapping
    - Multiple flybys using a resonant orbit
  - **Ganymede:** Detailed orbital study
    - Elliptical orbit first, then circular orbit
- Science Objectives:
  - **Ganymede:** Characterize Ganymede as a planetary object, including its potential habitability
  - **Satellite System:** Study the Jovian satellite system
  - **Jupiter:** Study the Jovian atmosphere
  - **Magnetosphere:** Study the Jovian magnetodisk / magnetosphere
  - **Jupiter system:** Study the interactions occurring in the Jovian system



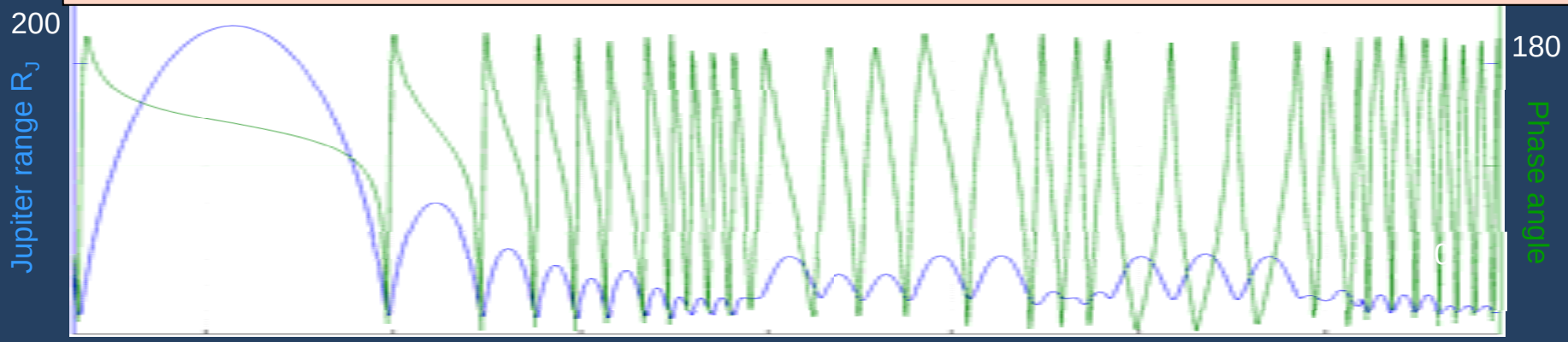
Characterizing the Jupiter system and its outer moons

JGO Traceability: Jupiter



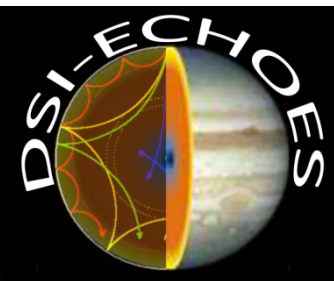
Goal	Science objective	Science investigation	
	J. The upper atmosphere	J1.	Determination of general circulation & composition in the upper atmosphere
		J2.	Characterization of the vertical coupling in the atmosphere & of its drivers , ion drag or wave activity)
		J3.	Temperature structure retrieval from upper atmosphere to the troposphere
		J4.	Characterization of ionospheric total electron densities & variations
		J5.	Characterization of the wave activity at low- to mid-latitudes and eddy activity and eddy meridional transport
	K. The stratosphere	K1.	Determination of the composition : H2O (characterisation of latitudinal variations, dynamics, role in atmospheric chemistry); HCN (dispersion following the SL9 impact), hydrocarbons (stratospheric chemistry) and haze; characterization of the strength of vertical mixing
		K2.	Determination of temperature structure from stellar and solar occultations over a wide range of latitudes in the upper stratosphere (1-km at 20 K per measurement).
		K3.	Determination of the general circulation in the stratosphere
	L. The troposphere	L1.	Determination of chemical composition : condensable species (NH3, H2O) and disequilibrium species (PH3, CO)
		L2.	Characterization of the strength of the vertical coupling in the atmosphere down to the troposphere
		L3.	Determination of the composition & vertical structure of clouds and cloud size distribution
		L4.	Study of the relation between the upper troposphere circulation & the deep circulation below the clouds & processes driving the jets circulation. Potential vorticity retrieval from combined dynamics and thermal measurements
	M. Internal structure of Jupiter	M1.	Constrain the existence and size of a core, and the nature of theŹ H-H2 phase transition -

Jovian Tour Example



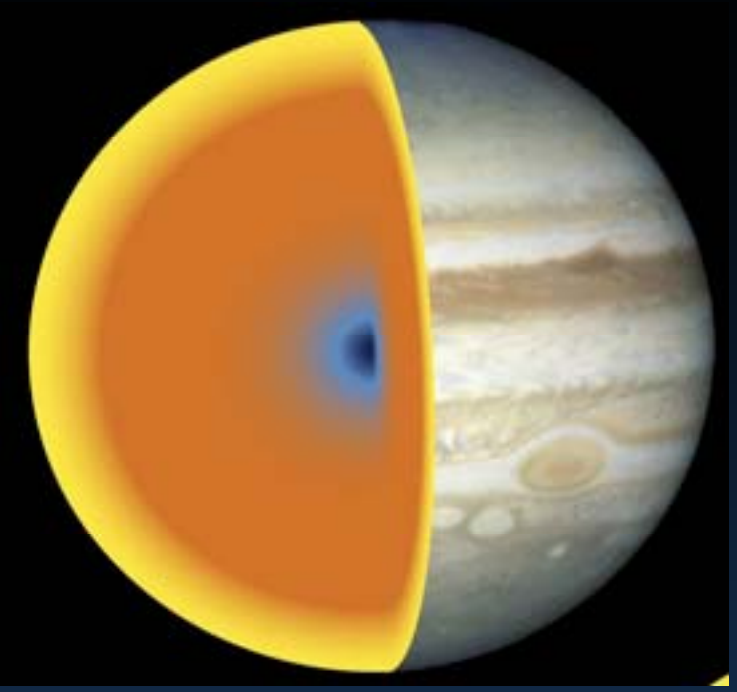
- 17 Callisto flybys
- 8 Ganymede flybys
- 33 peri-Jove at ~15 R_J

DSI – ECHOES
Context



- DSI was proposed for Laplace in 2007
- DSI first priority of “Origin” Working Group in EJSM-JGO
- DOI submitted in Avril 2009
- Technology Development Plan submitted in June 2009
- JSDT meeting 15/06/2009 at ESA HQ
  - DSI is not part of the “Study Payload”
  - DSI scientific objectives kept in the EJSM SRD
- DSI study approved by ESA in September 2009
- **DSI study and R&T funded by CNES January 2010**
- **Technical team Kick-off January 25th**

Doppler Spectro Imager



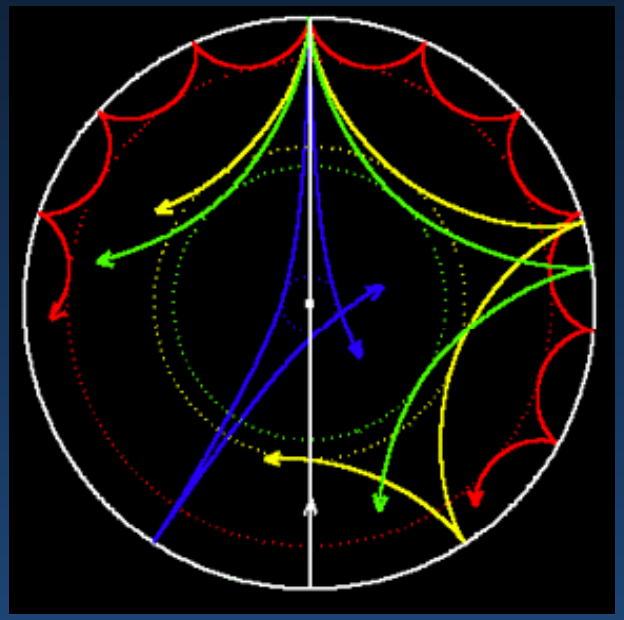
- Concept : Fourier tachometer
- Science goals
  - A. seismological studies of Jupiter's internal structure
  - B. atmospheric studies: dynamics of the upper troposphere

Origin and formation of the Solar System

DSI – ECHOES
Probing internal structure

Theoretical works: Vorontsov 76, Bercovici & Schubert 87, Gudkova & Zarkhov 99, Lognonné 2007

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



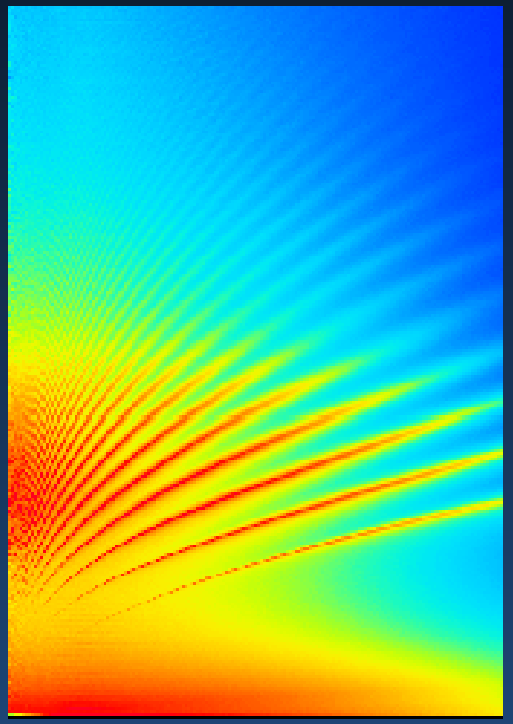
ν_{obs} - $\nu_{theoretical}$

↓

Inversion method

↓

ρ_{obs} - $\rho_{theoretical}$



Aeronomy in upper troposphere

Main goals

Origin of the global circulation of Jupiter,

Structure of the band system: its relation to differential rotation and the connection of this meteorological system with deep and outer layers are unknown.

Key measurements

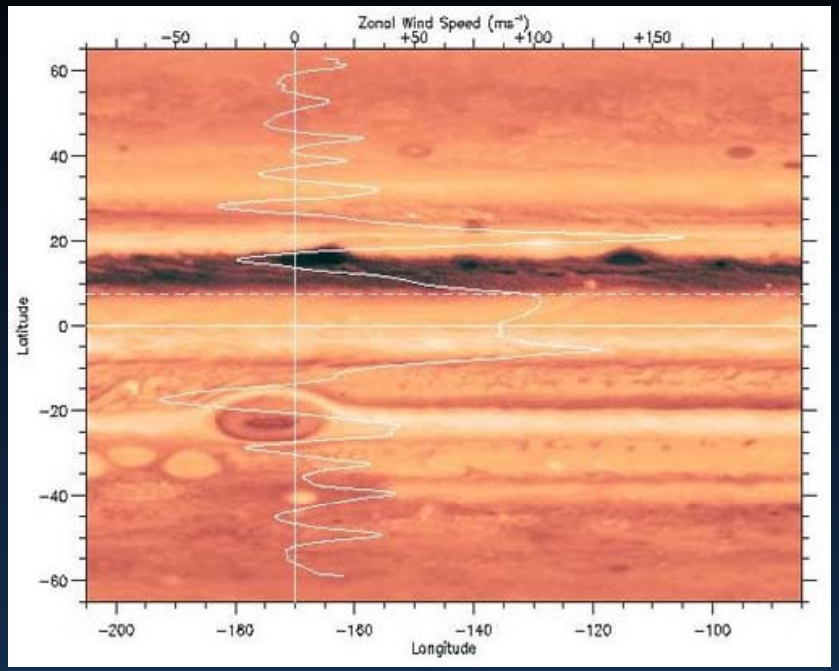
velocities, thermodynamics quantities and the “potential vorticity”, which is conserved in nondissipative flows like a passive tracer, and which is directly calculated in the models.

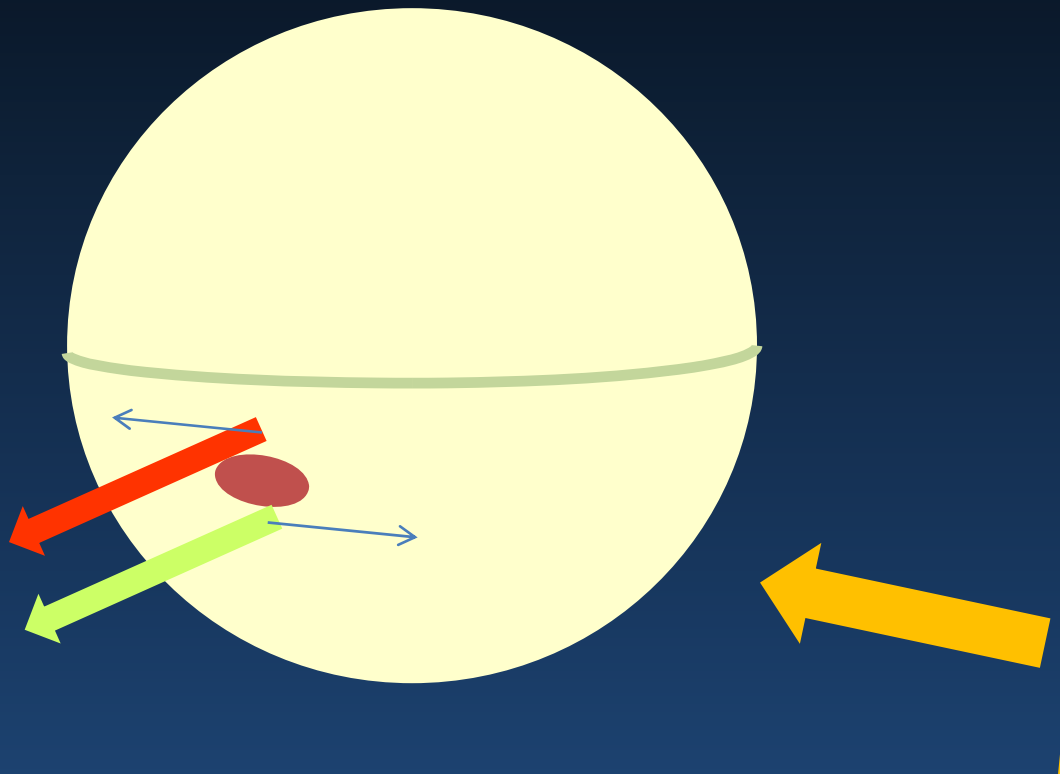
This latter quantity can be deduced from observations of the wind field, together with temperature profiles of the atmosphere.

The tool

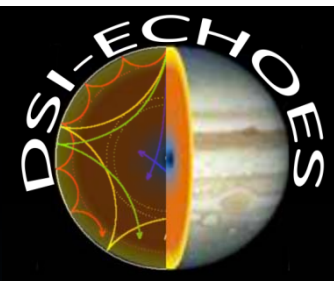
Doppler measurements
➔ 3D velocity maps (∇ v = 0)

Velocity measurement





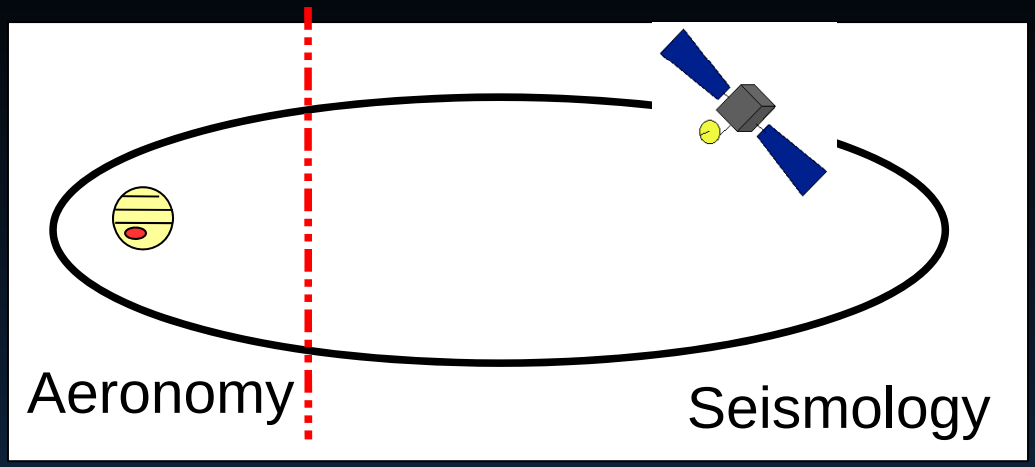
DSI-ECHOES
Scientific specifications

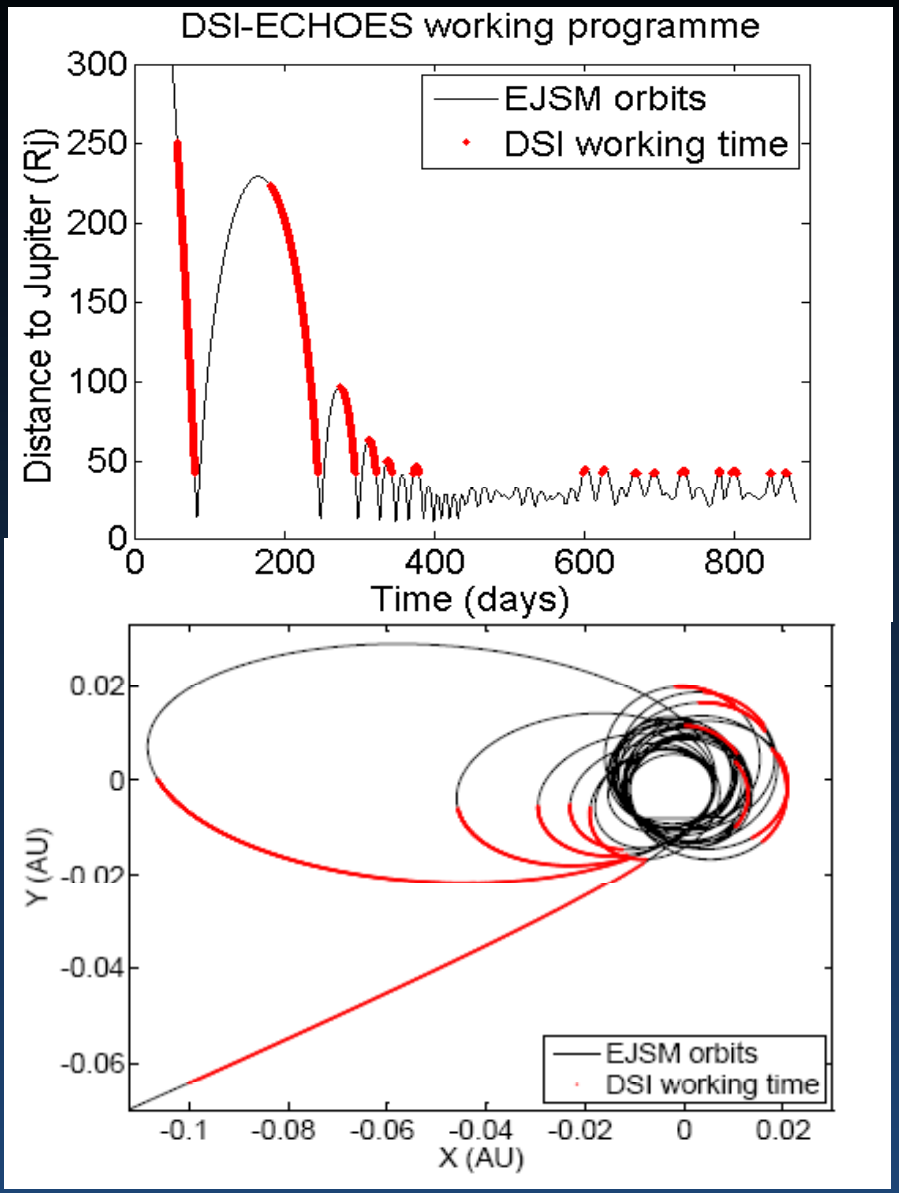


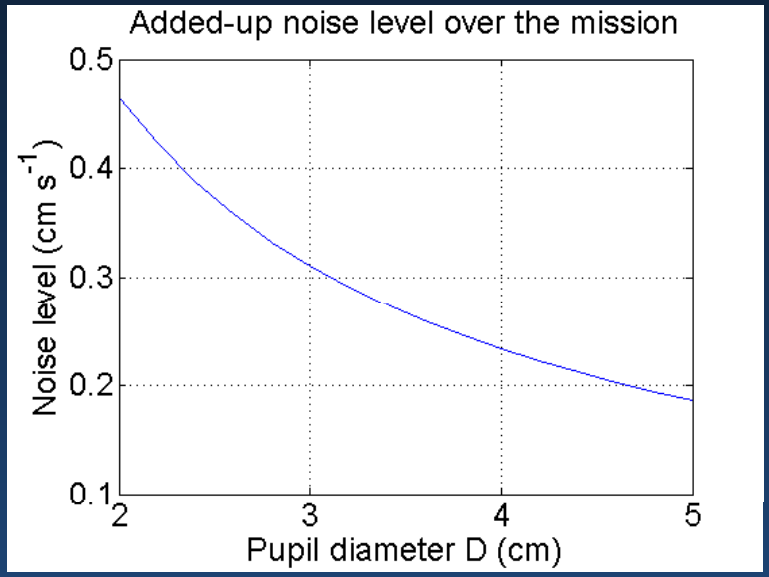
▪ Oscillations	frequency range [0.5 – 3 mHz] amplitude [1 – 50 cm/s]
▪ Velocity sensitivity - seismology - atmosphere	 < 1 cm/s per run, integrated Jovian disk = 10-20 m/s per hour *per pixel*
▪ Run duration ▪ Duty cycle ▪ Time sampling	[10 - 60] day per run (frequencies ~10^{-3}) > [70 - 90] % per run 30 – 60 s
▪ Spatial resolution - seismology - atmosphere	full field 500 px l = 50-100 down to 100-200 km

DSI – ECHOES

Mission scenario







DSI – ECHOES
Instrument principle

Instrumental co

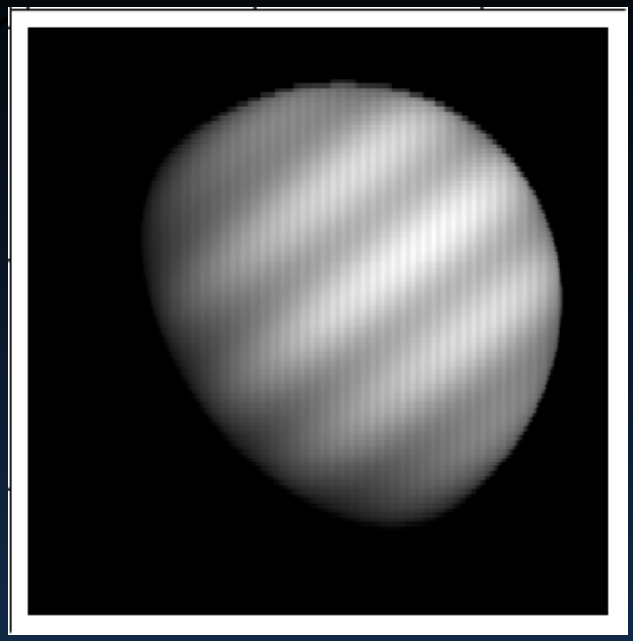
Fourier tachometer

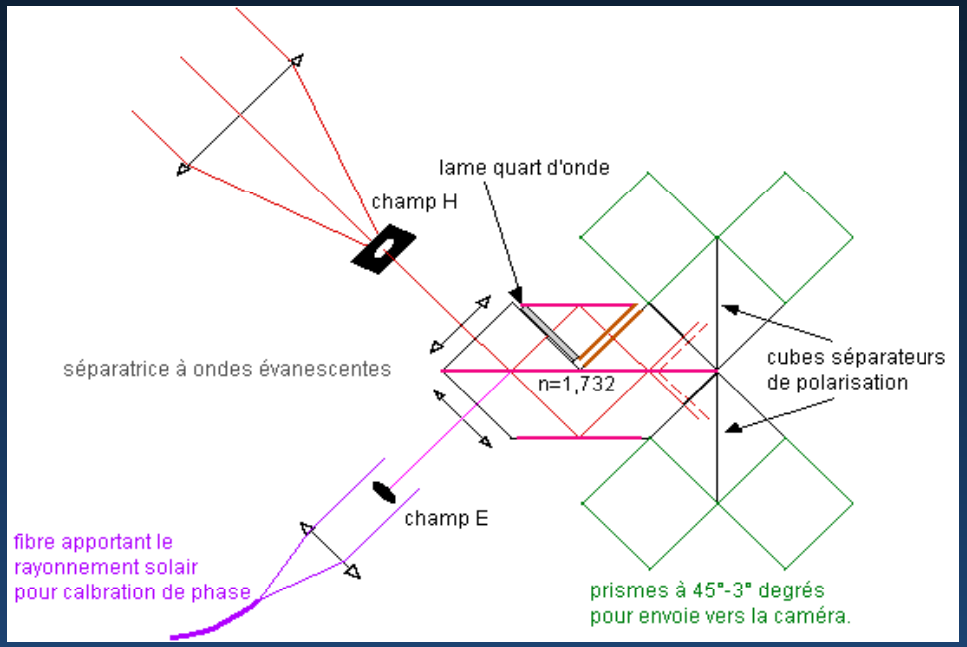
Fixed OPD Mach Zehnder interferometer

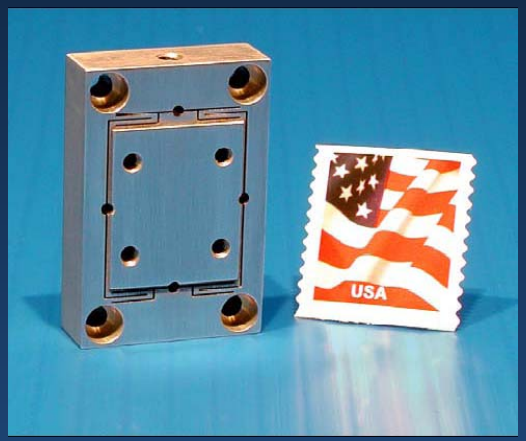
Four output images in phase quadrature

OPD Modulation for calibration

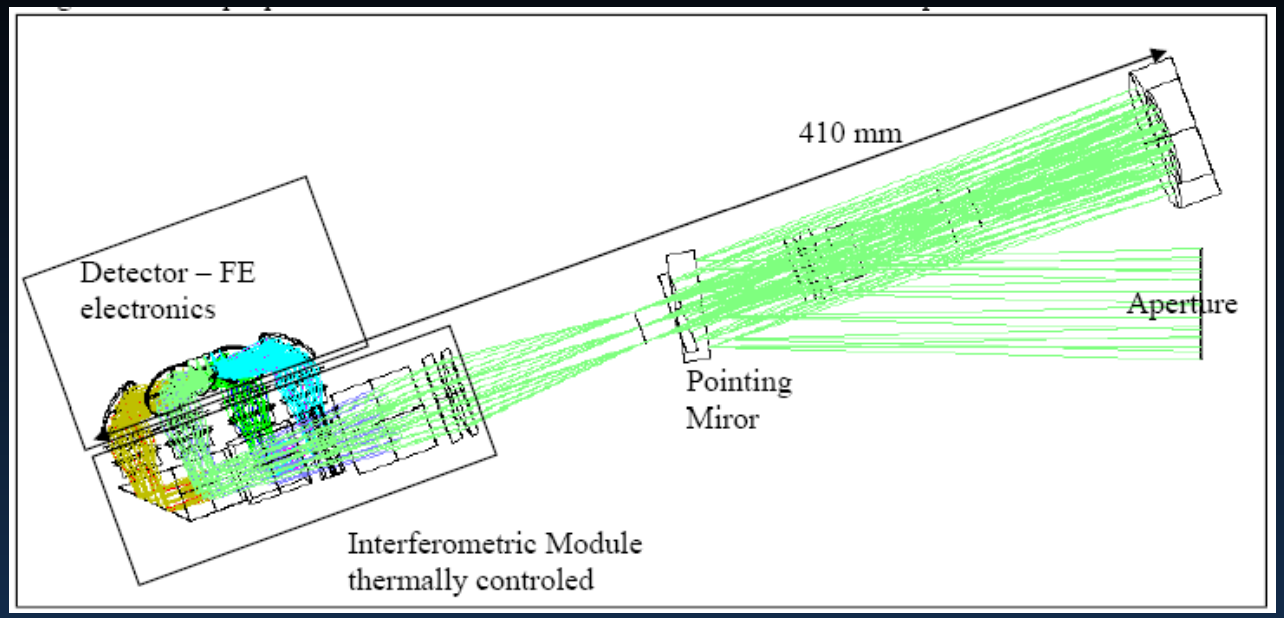
Solar reference for absolute velocity

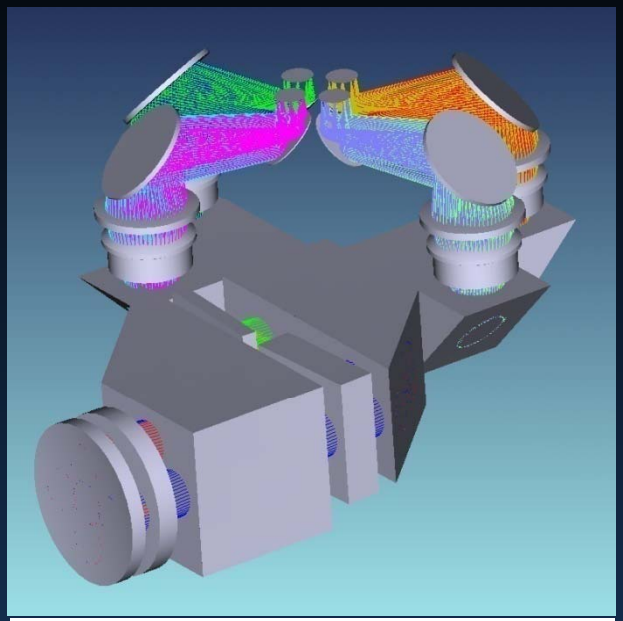


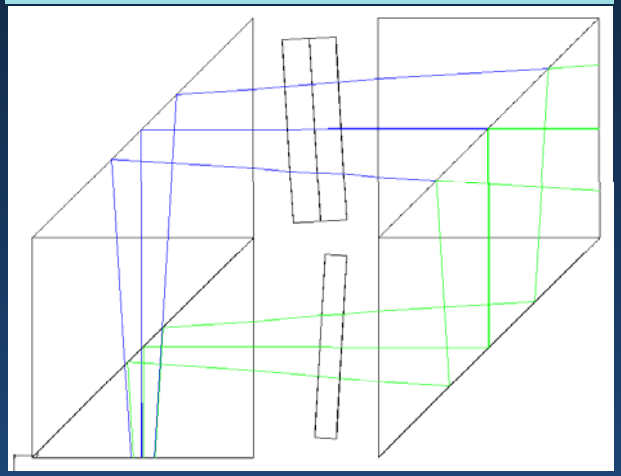




DSI-ECHOES
Optical study





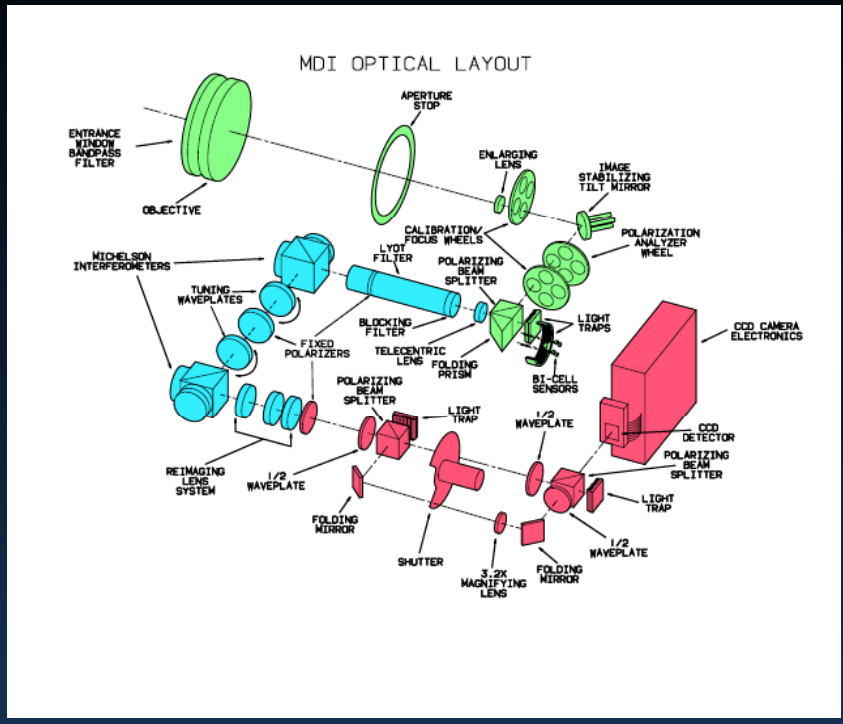


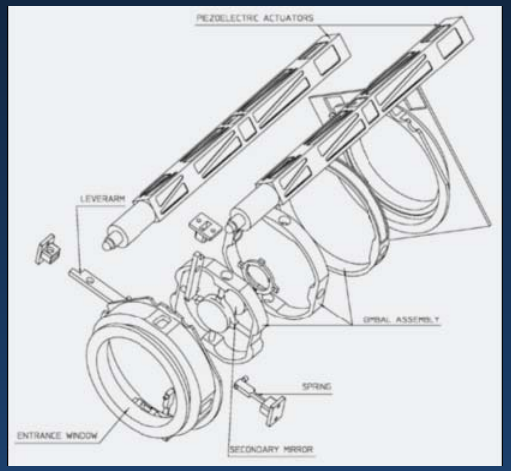
Mach-Zehnder design: Thermaly stable
Phase shift between polarisation: Quarter-wave plate

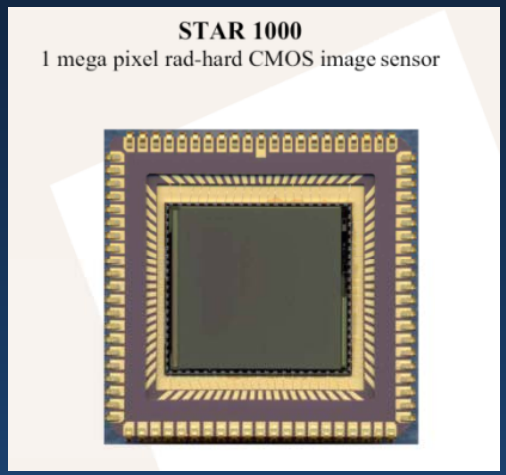
DSI – ECHOES

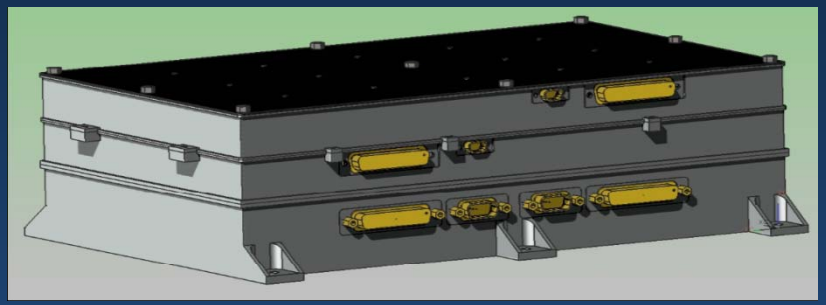
Heritage

- Michelson Doppler Imager SOHO
- SYMPA Jovian seismometer
- Fabry-Perot study for Solar Orbiter
- Guiding from LOI on SOHO
- DPU from Bepi-Colombo







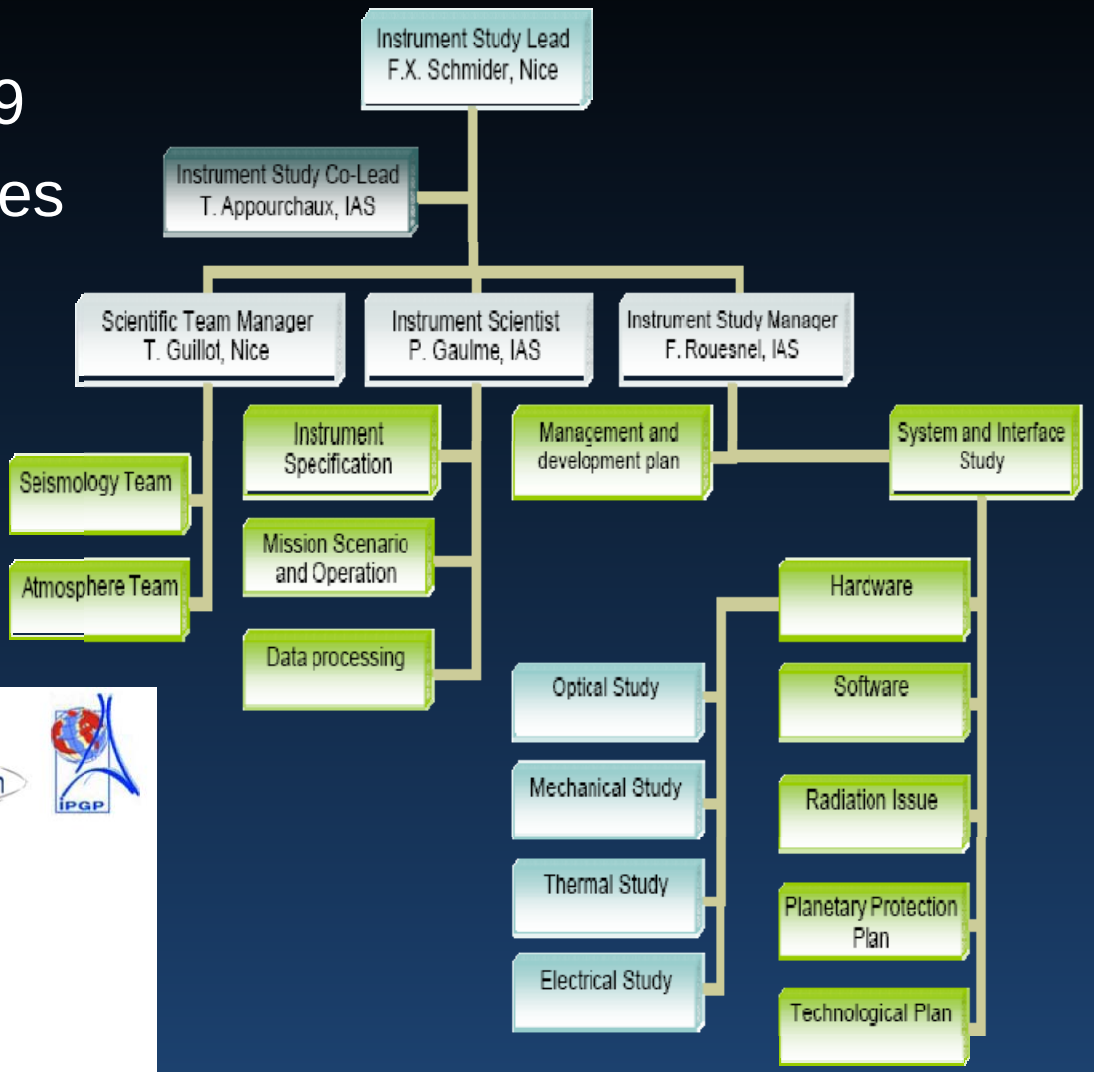


DSI – ECHOES
Interface and resources

Aperture	32 mm
Dimension	400 x 180 x 150 mm
FOV	2,72 °
Relative Pointing stability	0.5 arcsec/sec (internal)
Raw Data rate	30 kbps (max.)
Telemetry data volume	120 Gb total (120 days with 70% DC)
Mass	5 kg (without DPU)
Power	8 W
Present TRL	4-5

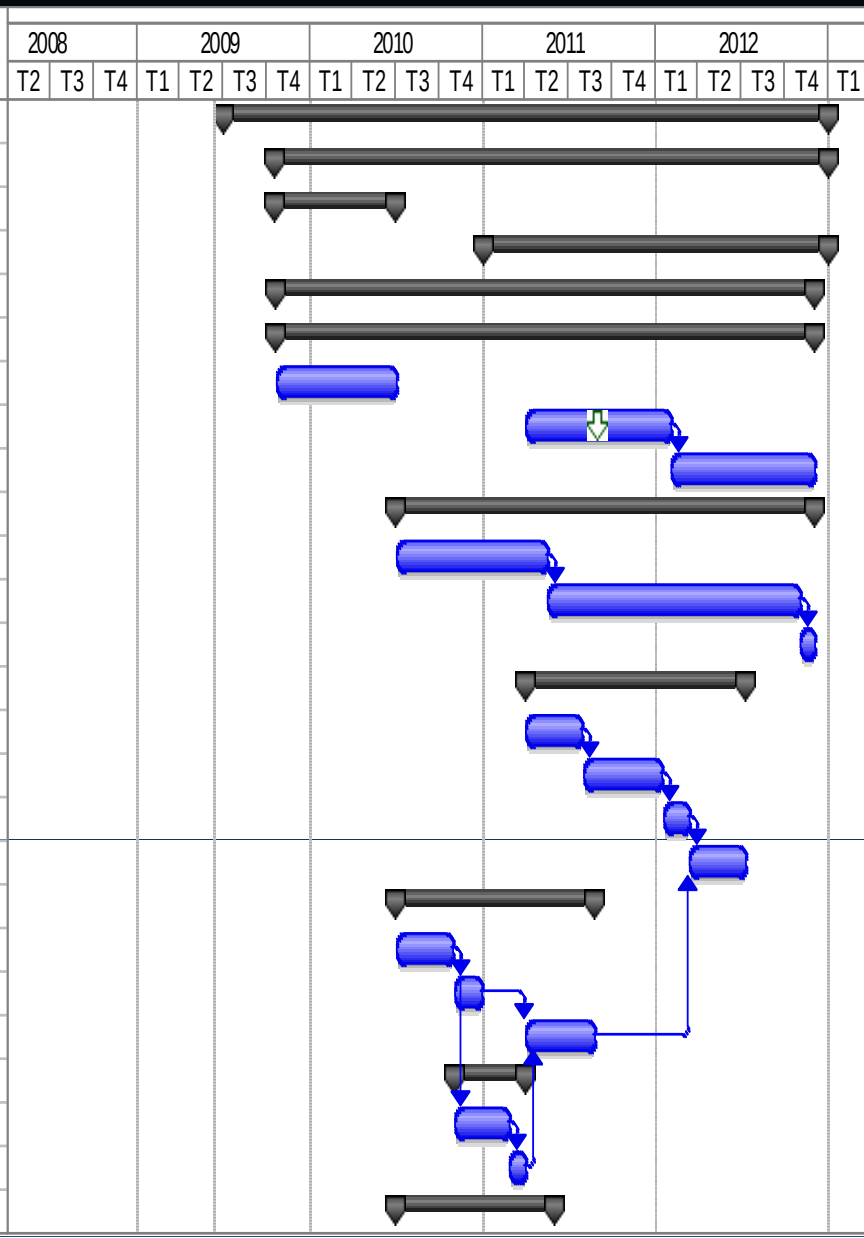
DSI Team Organisation

- DOI submitted on April 2009
- Consortium of 10 laboratories
- Leaded by OCA and IAS



DSI – ECHOES
Study Phase Activities

N°	Nom de la tâche	Début	Fin
1	**General : EJSM / Laplace Mission (JGO)**	**Mer 01/07/09**	**Lun 31/12/12**
6	**DSI project - Instrument development**	**Lun 19/10/09**	**Lun 31/12/12**
7	**Phase 0 / A**	**Lun 19/10/09**	**Mer 30/06/10**
10	**Phase A / B1**	**Lun 03/01/11**	**Lun 31/12/12**
13	**Technological Development Activities**	**Mer 21/10/09**	**Ven 30/11/12**
14	**Modulated Mach-Zehnder interferometer**	**Mer 21/10/09**	**Ven 30/11/12**
15	STEP 1 : Preliminary test based on standard equipment (i.e. on shelves - procurment included)	Mer 21/10/09	Mer 30/06/10
16	STEP 2 : Procurement specific MZH (after system / sub-system study)	Jeu 31/03/11	Mar 31/01/12
17	STEP 3 : Test (assembly included)	Mer 01/02/12	Ven 30/11/12
18	**DPU - Component qualification at radiation**	**Jeu 01/07/10**	**Ven 30/11/12**
19	Main critical component identification (based on external sub-system study)	Jeu 01/07/10	Mar 17/05/11
20	Procurement (including pre-assembly - card level)	Mer 18/05/11	Mer 31/10/12
21	Test	Jeu 01/11/12	Ven 30/11/12
22	**Pointing sub-system preliminary validation**	**Jeu 31/03/11**	**Ven 06/07/12**
23	Preliminary architecture definition (based on system study / sub-system study)	Jeu 31/03/11	Ven 29/07/11
24	Procurement	Lun 01/08/11	Ven 13/01/12
25	Assembly	Lun 16/01/12	Ven 09/03/12
26	End to end Test : incremental process (Test plan included)	Lun 12/03/12	Ven 06/07/12
27	**Detector qualification (focusing on PRNU stability)**	**Jeu 01/07/10**	**Mer 24/08/11**
28	Preliminary architecture definition (including FEE)	Jeu 01/07/10	Ven 29/10/10
29	Procurement (assuming detector on shelves) with standard packaging	Lun 01/11/10	Mer 29/12/10
30	Test (stability PRNU before / after radiation)	Jeu 31/03/11	Mer 24/08/11
31	**Front end electronic (FEE) qualification**	**Lun 01/11/10**	**Mer 30/03/11**
32	Procurement	Lun 01/11/10	Mer 23/02/11
33	Test	Jeu 24/02/11	Mer 30/03/11
34	**Solar light calibration subsystem**	**Jeu 01/07/10**	**Lun 30/05/11**



DSI Science Workshop

Nice, February 15 th -16 th, 2010

DSI Scientific objectives

- Seismology (WG 1: B. Mosser)
  - Core, PPT, Equation of state
  - Differential rotation
  - Inertial modes
- Atmosphere science (WG 2: P. Read)
  - Vortices, Velocity vs cloud tracking
  - Vertical convective motions, storms
- Wave tomography (WG 3: P. Lognonné)
  - Cross correlation
- Night science (WG 4: F.X. Schmider)
  - Lightings, Io torus
- Venus fly-by (WG 5: P. Lognonné)

Tasks
- Identify possible participant and invite them
- Define scientific requirement on the DSI instrument to achieve WG objectives
- Report by June 15th
- Redaction of DSI Science Definition Document (August 31th)

ESA Announcement of Opportunitiy: early 2011

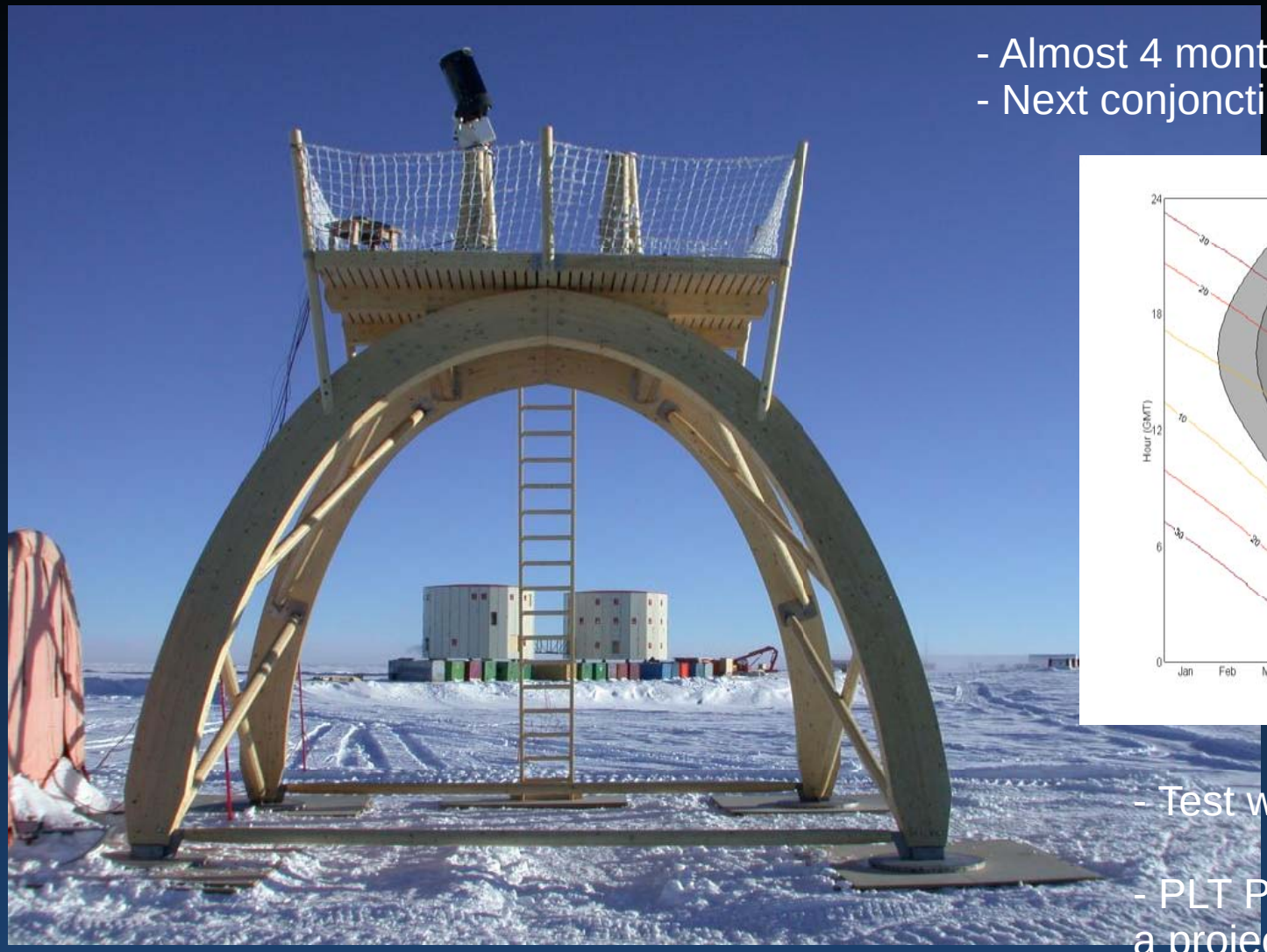
Other projects

MOST observations:
- Jupiter (M. Marley),
- Uranus-Neptune (P. Gaulme)

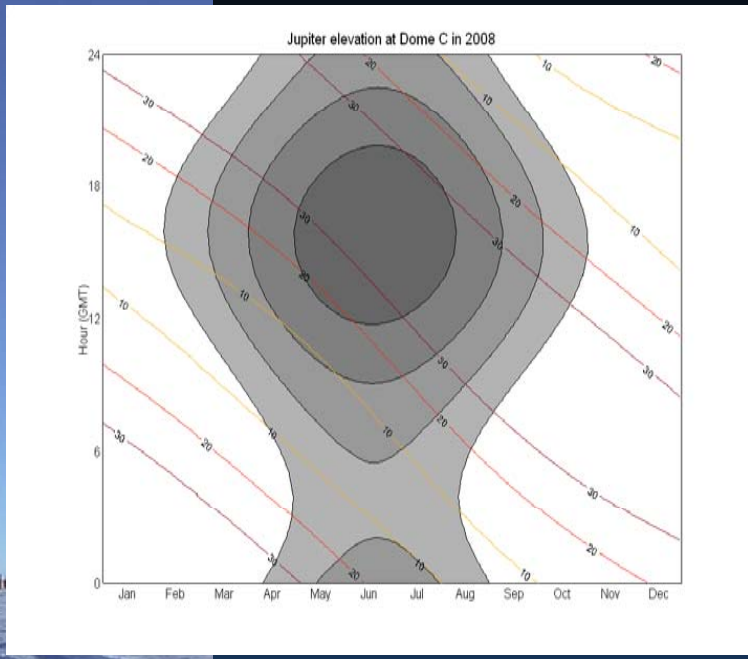
Resume SYMPA activity:
- Install a permanent instrument at MEO (Moon Laser Telescope) in Calern observatory (2011)

JISCO: Jupiter Interferometric Seismometer at Concordia Observatory
- Prepare for next conjunction in Antarctica in 2018

Other projects: JISCO



- Almost 4 months with more than 50 %
- Next conjonction of Jupiter in 2018



- Test with a 40 cm telescope

- PLT Polar Large Telescope: a project of 2.5 m telescope