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

KISS Meeting - Pasadena

2010, March 16th
SYMPA principle

Spectrum

Wavenumber $\sigma_0$ (cm$^{-1}$)

Fringe signal

Phase $\phi$ (rad)

$$\delta v = \frac{C}{2\pi \sigma_0 \Delta C \sqrt{N_e}}$$

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

KISS Meeting - Pasadena
2010, March 16th
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**

KISS Meeting - Pasadena 2010, March 16th
Cosmic Vision 2015-2025

Assessment Phase 0/A  Definition Phase A/B1  Implementation Phase B2/C/D

Euclid  Plato  Spica  Marco-Polo  Cross-Scale  Solar Orbiter

Instruments

DOI  AO  LOE  MLA

TRL ≥5

M-class missions

EJSM/Laplace  TSSM/Tandem  Lisa  IXO

Instruments

DOI  AO  LOE  MLA

TRL ≥5

L-class missions

M1 launch  M2 launch  L1 launch


DOI: Declaration of Interest
AO: Announcement of Opportunity
LOE: Letter of Endorsement
MLA: Multi-Lateral Agreement

KISS Meeting - Pasadena  2010, March 16th
EJSM Schedule

Calendar Year

<table>
<thead>
<tr>
<th>2020</th>
<th>~</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
</tr>
</thead>
<tbody>
<tr>
<td>JEO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch</td>
<td>Feb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JGO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch</td>
<td>Mar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Io

Europa

Ganymede

Callisto

Resonant orbits

Circular

Elliptical

Launch: Feb

JOI: Dec

EOI: Jul

EOM: Mar

GOI: May

EOM: Feb
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
<table>
<thead>
<tr>
<th>Goal</th>
<th>Science objective</th>
<th>Science investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. The upper atmosphere</td>
<td>J1. Determination of general circulation &amp; composition in the upper atmosphere</td>
<td></td>
</tr>
<tr>
<td></td>
<td>J2. Characterization of the vertical coupling in the atmosphere &amp; of its drivers, ion drag or wave activity)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>J3. Temperature structure retrieval from upper atmosphere to the troposphere</td>
<td></td>
</tr>
<tr>
<td></td>
<td>J4. Characterization of ionospheric total electron densities &amp; variations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>J5. Characterization of the wave activity at low- to mid-latitudes and eddy activity and eddy meridional transport</td>
<td></td>
</tr>
<tr>
<td>K. The stratosphere</td>
<td>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</td>
<td></td>
</tr>
<tr>
<td></td>
<td>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).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>K3. Determination of the general circulation in the stratosphere</td>
<td></td>
</tr>
<tr>
<td>L. The troposphere</td>
<td>L1. Determination of chemical composition: condensable species (NH3, H2O) and disequilibrium species (PH3, CO)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L2. Characterization of the strength of the vertical coupling in the atmosphere down to the troposphere</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L3. Determination of the composition &amp; vertical structure of clouds and cloud size distribution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L4. Study of the relation between the upper troposphere circulation &amp; the deep circulation below the clouds &amp; processes driving the jets circulation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Potential vorticity retrieval from combined dynamics and thermal measurements</td>
<td></td>
</tr>
<tr>
<td>M. Internal structure of Jupiter</td>
<td>M1. Constrain the existence and size of a core, and the nature of the Ż H-H2 phase transition -</td>
<td></td>
</tr>
</tbody>
</table>
Jovian Tour Example

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

KISS Meeting - Pasadena

2010, February 15th
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

KISS Meeting - Pasadena
2010, March 16th
DSI – ECHOES
Probing internal structure


<table>
<thead>
<tr>
<th></th>
<th>$\delta v(n,l)/v(n,l)$</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>4 %</td>
<td>$l = 0-2$</td>
</tr>
<tr>
<td>H2-H transition</td>
<td>3-7 %</td>
<td>$l = 15-25$</td>
</tr>
<tr>
<td>Enveloppe dynamics</td>
<td>0.1-0.5 %</td>
<td>$l = 50-100$</td>
</tr>
</tbody>
</table>
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 ($\nabla \times v = 0$)

KISS Meeting - Pasadena

2010, March 16th
Velocity measurement
### DSI-ECHOES

#### Scientific specifications

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oscillations</td>
<td>frequency range [0.5 – 3 mHz] amplitude [1 – 50 cm/s]</td>
</tr>
<tr>
<td>Velocity sensitivity</td>
<td>&lt; 1 cm/s per run, integrated Jovian disk = 10-20 m/s per hour per pixel</td>
</tr>
<tr>
<td>Seismology</td>
<td></td>
</tr>
<tr>
<td>Atmosphere</td>
<td></td>
</tr>
<tr>
<td>Run duration</td>
<td>[10 - 60] day per run (frequencies ~10^{-3})</td>
</tr>
<tr>
<td>Duty cycle</td>
<td>&gt; [70 - 90] % per run</td>
</tr>
<tr>
<td>Time sampling</td>
<td>30 – 60 s</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>full field 500 px</td>
</tr>
<tr>
<td>Seismology</td>
<td>I = 50-100</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>down to 100-200 km</td>
</tr>
</tbody>
</table>
DSI – ECHOES
Mission scenario

KISS Meeting - Pasadena
2010, March 16th
Fourier tachometer

Fixed OPD Mach Zehnder interferometer

Four output images in phase quadrature

OPD Modulation for calibration

Solar reference for absolute velocity
Mach-Zehnder design: Thermally 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

KISS Meeting - Pasadena

2010, March 16th
# DSI – ECHOES

## Interface and resources

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture</td>
<td>32 mm</td>
</tr>
<tr>
<td>Dimension</td>
<td>400 x 180 x 150 mm</td>
</tr>
<tr>
<td>FOV</td>
<td>2.72 °</td>
</tr>
<tr>
<td>Relative Pointing stability</td>
<td>0.5 arcsec/sec (internal)</td>
</tr>
<tr>
<td>Raw Data rate</td>
<td>30 kbps (max.)</td>
</tr>
<tr>
<td>Telemetry data volume</td>
<td>120 Gb total (120 days with 70% DC)</td>
</tr>
<tr>
<td>Mass</td>
<td>5 kg (without DPU)</td>
</tr>
<tr>
<td>Power</td>
<td>8 W</td>
</tr>
<tr>
<td>Present TRL</td>
<td>4-5</td>
</tr>
</tbody>
</table>
DSI Team Organisation

- DOI submitted on April 2009
- Consortium of 10 laboratories
- Led by OCA and IAS
## DSI – ECHOES
### Study Phase Activities

<table>
<thead>
<tr>
<th>N°</th>
<th>Nom de la tâche</th>
<th>Début</th>
<th>Fin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General : EJSM / Laplace Mission (JGO)</td>
<td>Mer 01/07/09</td>
<td>Lun 31/12/12</td>
</tr>
<tr>
<td>6</td>
<td>DSI project - Instrument development</td>
<td>Lun 19/10/09</td>
<td>Lun 31/12/12</td>
</tr>
<tr>
<td>7</td>
<td>Phase 0 / A</td>
<td>Lun 19/10/09</td>
<td>Mer 30/06/10</td>
</tr>
<tr>
<td>10</td>
<td>Phase A/ B1</td>
<td>Lun 03/01/11</td>
<td>Lun 31/12/12</td>
</tr>
<tr>
<td>13</td>
<td>Technological Development Activities</td>
<td>Mer 21/10/09</td>
<td>Ven 30/11/12</td>
</tr>
<tr>
<td>14</td>
<td>Modulated Mach-Zehnder interferometer</td>
<td>Mer 21/10/09</td>
<td>Ven 30/11/12</td>
</tr>
<tr>
<td>15</td>
<td>STEP 1 : Preliminary test based on standard equipment (i.e. on shelves - procurement included)</td>
<td>Mer 21/10/09</td>
<td>Mer 30/06/10</td>
</tr>
<tr>
<td>16</td>
<td>STEP 2 : Procurement specific MZH (after system / sub-system study)</td>
<td>Jeu 31/03/11</td>
<td>Mar 31/01/12</td>
</tr>
<tr>
<td>17</td>
<td>STEP 3 : Test (assembly included)</td>
<td>Mer 01/02/12</td>
<td>Ven 30/11/12</td>
</tr>
<tr>
<td>18</td>
<td>DPU - Component qualification at radiation</td>
<td>Jeu 01/07/10</td>
<td>Ven 30/11/12</td>
</tr>
<tr>
<td>19</td>
<td>Main critical component identification (based on external sub-system study)</td>
<td>Jeu 01/07/10</td>
<td>Mar 17/05/11</td>
</tr>
<tr>
<td>20</td>
<td>Procurement (including pre-assembly - card level)</td>
<td>Mer 18/09/11</td>
<td>Mer 31/10/12</td>
</tr>
<tr>
<td>21</td>
<td>Test</td>
<td>Jeu 01/11/12</td>
<td>Ven 30/11/12</td>
</tr>
<tr>
<td>22</td>
<td>Pointing sub-system preliminary validation</td>
<td>Jeu 31/03/11</td>
<td>Ven 06/07/12</td>
</tr>
<tr>
<td>23</td>
<td>Preliminary architecture definition (based on system study / sub-system study)</td>
<td>Jeu 31/03/11</td>
<td>Ven 29/07/11</td>
</tr>
<tr>
<td>24</td>
<td>Procurement</td>
<td>Lun 01/08/11</td>
<td>Ven 13/01/12</td>
</tr>
<tr>
<td>25</td>
<td>Assembly</td>
<td>Lun 16/01/12</td>
<td>Ven 09/03/12</td>
</tr>
<tr>
<td>26</td>
<td>End to end Test : incremental process (Test plan included)</td>
<td>Lun 12/03/12</td>
<td>Ven 06/07/12</td>
</tr>
<tr>
<td>27</td>
<td>Detector qualification (focusing on PRNU stability)</td>
<td>Jeu 01/07/10</td>
<td>Mer 24/08/11</td>
</tr>
<tr>
<td>28</td>
<td>Preliminary architecture definition (including FEE)</td>
<td>Jeu 01/07/10</td>
<td>Ven 29/10/10</td>
</tr>
<tr>
<td>29</td>
<td>Procurement (assuming detector on shelves ) with standard packaging</td>
<td>Lun 01/11/10</td>
<td>Mer 29/12/10</td>
</tr>
<tr>
<td>30</td>
<td>Test (stability PRNU before / after radiation)</td>
<td>Jeu 31/03/11</td>
<td>Mer 24/08/11</td>
</tr>
<tr>
<td>31</td>
<td>Front end electronic (FEE) qualification</td>
<td>Lun 01/11/10</td>
<td>Mer 30/03/11</td>
</tr>
<tr>
<td>32</td>
<td>Procurement</td>
<td>Lun 01/11/10</td>
<td>Mer 23/02/11</td>
</tr>
<tr>
<td>33</td>
<td>Test</td>
<td>Jeu 28/02/11</td>
<td>Mer 30/03/11</td>
</tr>
<tr>
<td>34</td>
<td>Solar light calibration subsystem</td>
<td>Jeu 01/07/10</td>
<td>Lun 30/05/11</td>
</tr>
</tbody>
</table>
DSI Science Workshop
Nice, February 15th -16th, 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 Opportunity: early 2011

KISS Meeting - Pasadena 2010, March 16th 27
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 conjunction of Jupiter in 2018

- Test with a 40 cm telescope
- PLT Polar Large Telescope: a project of 2.5 m telescope