The Visible and InfraRed Hyperspectral Imaging Spectrometer (VIRHIS): a study for EJSM


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What is VIRHIS

• **VIRHIS** is a performing imaging spectrometer for JGO-EJSM, operating in the 0.4-5.2 µm spectral range (or beyond), perfectly suitable to study the Galilean satellites and the Jupiter atmosphere

• A delta study is also planned for a similar instrument on board JEO-EJSM

• *The VIRHIS study proposal is in response to the ESA DOI EJSM issued on March 26 2009*
Scientific objectives for Jovian satellites

Study the Jovian satellites system and their connection to the population of minor bodies in the Solar System

- Measurement at high resolution (< 1 km/pixel) of surface icy, non-icy, mineral, organic and inorganic chemical composition
- Determination of the relation between composition and geological processes
- Measurement of volatiles and indicators for life
- Search for sites of recent geological activity
- Identification of tectonic, cryovolcanic and impact features
- Determination of interesting sites for future landing mission
- Mapping surface alterations due to radiation environment
- Monitoring O₂ exosphere on Ganymede with limb scans
- Monitoring Io’s volcanic and thermal activity on day and night sides
- Observations of the irregular satellites and Jupiter’s rings system
- Comparative study of the Galilean satellites
Jovian satellites VIS-NIR spectroscopy

<table>
<thead>
<tr>
<th>Element</th>
<th>Diagnostic bands (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>Crystalline: 1.04, 1.25, 1.5, 1.65, 2.05, 3.0; 3.1 triple Fresnel peak</td>
</tr>
<tr>
<td></td>
<td>Amorphous: 1.04, 1.25, 1.5, 2.00, 3.0; 3.1 single Fresnel peak</td>
</tr>
<tr>
<td></td>
<td>continuum @ 3.6 indicator for grain sizes</td>
</tr>
<tr>
<td></td>
<td>1.65 band indicator for ice temperature</td>
</tr>
<tr>
<td></td>
<td>visible slopes indicators for ice contamination</td>
</tr>
<tr>
<td>SO₂</td>
<td>2.54, 2.80, 2.92, 4.07</td>
</tr>
<tr>
<td>H₂SO₄</td>
<td>1.2, 2.4</td>
</tr>
<tr>
<td>H₂S-S₂O frost</td>
<td>3.75, 3.85, 4.0</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>~3.50</td>
</tr>
<tr>
<td>C-H</td>
<td>1.73, 3.40</td>
</tr>
<tr>
<td>S-H</td>
<td>~3.88</td>
</tr>
<tr>
<td>C≡N</td>
<td>2.42, 4.35, 4.90</td>
</tr>
<tr>
<td>CO₂</td>
<td>2.02, 2.70, 2.78, 4.25</td>
</tr>
<tr>
<td>CO₂</td>
<td>1.56, 2.34, 4.68</td>
</tr>
<tr>
<td>Tholins</td>
<td>4.57, visible slopes</td>
</tr>
<tr>
<td>O₂</td>
<td>0.577, 0.628</td>
</tr>
<tr>
<td>O₃</td>
<td>~0.260</td>
</tr>
<tr>
<td>Hydrated minerals</td>
<td>1.40, 1.95</td>
</tr>
<tr>
<td>PAH</td>
<td>3.28</td>
</tr>
</tbody>
</table>
Scientific objectives for Jupiter

- **Study the stratospheric and thermospheric structure, global circulation dynamics and composition**
- Determination of the general circulation and composition of the atmosphere
- Observation of the auroral emissions (mainly due to \( H_3^+ \))
- Determination of the origin of water in the stratosphere; its latitudinal distribution and role in chemistry and dynamics
- Monitoring clouds and thermal hot spots
- Characterization of the nature of the hydrocarbon chemistry
- Determination of the composition of the primordial material from which Jupiter formed
- Characterization of the strength of the vertical mixing in the stratosphere
Jovian atmosphere VIS-NIR spectroscopy: 5 µm window and hot spots

Hot spots are regions of anomalous high emission at 5 µm (methane transparency window):
• Thinner cloud deck allows radiation from deeper (warmer) troposphere to escape
• Observed more often in northern edge of the Equatorial Zone
• Dynamical nature still controversial
• Galileo Entry Probe (GEP) provided in situ measurements of hot spot conditions

5 µm windows transparency windows of methane encompasses spectral features of:
• Water (main oxygen bringing molecule)
• Ammonia (main nitrogen bringing molecule)
• Phosphine (disequilibrium molecule)
• and many others....

Hotspots potentially provide a mean to probe the deeper atmosphere:
• Retrieval of 'bulk' mixing ratios for main element bringing molecules =>
• Constraints on the formation scenario of the planet
• Constraints on cloud properties and planet's radiative budget
• Detection of disequilibrium species, tracers for deep convective motion
The VIRHIS study team is a *consortium* of scientists and engineers from the following international institutes:

- INAF-IASF Rome, Italy (*instrument study proposal leader*)
- INAF-IFSI Rome, Italy
- Physics department, Università del Salento, Lecce, Italy
- IAS (Institut d’Astrophysique Spatiale), Centre universitaire d’Orsay, France
- Bear Fight Center, WA, United States
- DLR Institute of Planetary Research, Berlin, Germany
- Dpto. Física Aplicada, Universidad del Pais Vasco, Bilbao, Spain
- Engineering department, Università di Padova, Italy
- GALILEO AVIONICA, Campi Bisenzio, Florence, Italy
- NASA/JPL, Pasadena, CA, United States
- Institut für Planetologie, Münster, Germany
- LESIA, Observatoire de Paris/Meudon, France
- Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany
- NASA/GSFC, Greenbelt, MD, United States
- Southwest Research Institute, San Antonio, TX, United States
- University of Oxford, Clarendon Laboratory, Oxford, United Kingdom
## VIRHIS characteristics summary

### OPTICS

<table>
<thead>
<tr>
<th>Design</th>
<th>Three mirror anastigmatic telescope, with scanning mirror (TBC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>min IFOV</td>
<td>125 µrad (JGO) – 250 µrad (JEO)</td>
</tr>
<tr>
<td>FOV</td>
<td>3.4° (JGO) – 9.17° (JEO)</td>
</tr>
<tr>
<td>Aperture</td>
<td>34 mm - 60 mm</td>
</tr>
<tr>
<td>Focal length</td>
<td>192 mm</td>
</tr>
<tr>
<td>f/#</td>
<td>5.6 - 3.2</td>
</tr>
</tbody>
</table>

### SPECTROMETER

| Design | Offner spectrometer, with convex grating (TBC) |
| Spectral range | 0.4±2.2 µm – 2.0±5.2 µm (with possible extension above 5.2 µm) |
| Spectral sampling | 2.8 nm/band - 5.0 nm/band (JGO) 5.0 nm/band - 10.0 nm/band (JEO) |
| λ/Δλ | 143±786 – 400±1040 (JGO) 80±440 – 200±520 (JEO) |
| Order sorting filters | LVF (TBC) |
| Operative temperature | < 150 K (TBC) |

### DETECTORS

| Technology | HgCdTe with HgCdZn substrate removed, CMOS multiplexer HgCdTe, CMOS multiplexer |
| Format and pixel pitch | 640×480, 27 µm (TBC) |
| Full well capacity | 2Me⁻ |
| Operative temperature | 180±10 K - 70±10 K (TBC) |

### RESOURCES

| Mass | 17 kg (OH, PEM, ME); harness not included (JGO) 20 kg (OH, PEM, ME); harness and radiation shielding not included (JEO) |
| Power | 20 W (average) |
## VIRHIS on ground spot size

<table>
<thead>
<tr>
<th>Slant distance</th>
<th>200 km</th>
<th>10000 km</th>
<th>20000 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full FOV</td>
<td>12 km</td>
<td>600 km</td>
<td>1200 km</td>
</tr>
<tr>
<td>Nominal (x4)</td>
<td>100 m</td>
<td>5 km</td>
<td>10 km</td>
</tr>
<tr>
<td>High res</td>
<td>25 m</td>
<td>1.25 km</td>
<td>2.5 km</td>
</tr>
</tbody>
</table>

Target
**Instrument subsystems:**

1. Alignment reference cubic mirror;
2. Optical head cover (Optional);
3. Cover mechanism (Optional);
4. Scan mirror;
5. Scan mirror mechanism;
6. Telescope;
7. Internal calibration unit, VIS-NIR reference source;
8. Internal calibration unit, IR source;
9. Slit with motorized shutter;
10. Shutter mechanism;
11. Spectrometer;
12. Heaters (for annealing and surviving);
13. Passive radiator, coupled to the OH structure;
14. VIS-NIR FPA, with radhard shield;
15. IR FPA, with radhard shield;
16. IR FPA coldfinger (S/C provided);
17. High speed I/O interface for data downlink to ME, VIS-NIR channel;
18. FPGA controller, VIS-NIR channel;
19. FPGA controller, IR channel;
20. High speed I/O interface for data downlink to ME, IR channel;
21. Shutter mechanism controller card;
22. Internal calibration unit controller card;
23. Scan mirror mechanism controller card;
24. Cover mechanism controller card (Optional);
25. Power supply;
26. High speed I/O interface for data downlink from PEM, VIS-NIR and IR channels;
27. High speed I/O interface for data downlink to S/C bus, VIS-NIR and IR channels;
28. Data compressor;
29. DPU, including mass memory.

**Instrument links:**

a. Cover mechanism to ME, power and telemetry;
b. Scan mirror mechanism to ME, power and telemetry;
c. Internal calibration unit to ME, power;
d. Shutter mechanism to ME, power and telemetry;
e. Heaters to ME and S/C bus, power and temperature readings;
f. VIS-NIR FPA to PEM, high speed analog datalink;
g. IR FPA to PEM, high speed analog datalink;
h. PEM to ME, high speed digital datalink for VIS-NIR channel;
i. PEM to ME, high speed digital datalink for IR channel;
j. ME to PEM, power line;
k. S/C bus to ME, power line;
l. ME to S/C bus, high speed digital datalink for VIS-NIR channel;
m. ME to S/C bus, high speed digital datalink for IR channel.

**Mechanical Structures - Radhard shielding**

**Optical elements - Calibration unit and sources**

Electro-mechanical actuators and servos - Thermisters

Coldfingers and passive radiator - Detectors and packaging

Electronics subsystem card

**Power/Telemetry link - High speed data link**

Block Diagram of VIRHIS
VIRHIS Team meetings

• December 10 2009 : meeting #1 in Rome (after pre-assessment)
• February 17-18 2010 : meeting #2 in Paris (progress)
• Around May (TBD) : meeting #3 in MPS-Lindau (progress)
Main tasks

- **Radiometric model** (parameterization running)
- **Optics** (analysis on the preliminary architecture running)
- **Thermal model** (preliminary sensitivity analysis running)
- **Main Electronics and Power Supply** (running)
- **IR detector and its proximity electronics** (running)
- **VIS-NIR detector and its proximity electronics** (running)
- **In flight calibration tools** (awaiting a first preliminary analysis on the optical configuration)
- **Radiation and Planetary Protection** (active)
Optics architecture

• Two configurations are currently under study:
  • Offner with convex or plane grating
  • Double compact spectrometers with double or single slit sharing a unique telescope
Preliminary results from the thermal model sensitivity analysis

Radiator surface assumption = 0.15 m² as starting point, but actual area is TBC

Radiator partially embedded (obscured), PCBZ - white paint coated

Radiator temperature variation between no input flux case (deep space) and Ganymede, Jupiter or Sun fluxes cases (worst condition):

- Ganymede flux contribution (worst case) => $\Delta T = 6$ K
- Jupiter flux contribution (worst case) => $\Delta T = 3$ K
- Sun flux contribution (worst case) => $\Delta T = 14$ K

Radiator not embedded, PCBZ - white paint coated

Radiator temperature variation between no input flux case (deep space) and Sun flux case (worst condition):

- Sun flux contribution (worst case) => $\Delta T = 12$ K

Radiator not embedded, OSR coated

Radiator temperature variation between no input flux case (deep space) and Sun flux case (worst condition):

- Sun flux contribution (worst case) => $\Delta T = 6$ K
Detector

HgCdTe technology can cover the full range of VIRHIS

Bandgap dependence on $\text{Hg}_{1-x}\text{Cd}_x$ mixture and temperature (Hansen et al. 1982)

Dark current

HgCdTe Dark current vs temperature from Teledyne Rule 07

- 1.7 $\mu$m
- 2.5 $\mu$m
- 5 $\mu$m
- 2.6 $\mu$m

Operating Temperature (K)
Main electronics functional block diagram

- Interface satellite (Power Conditioning and Distribution Unit)
- Command and process control unit (TC/TM)
- Interface with the IFEs
- Data compression
Flexibility

- VIRHIS can potentially provide a lot of data (and also a lot of science).
- The mission datarate/volume resources limitation is a driver to consider an high level of flexibility for the instrument - this is not an issue but a great advantage for the different phases of the mission.
**Survey GEO**

Compression factor \( f(\text{compr}) = 2 \)

Acquisition only on the dayside and only if \( t_{\text{exp}} > t_{\text{dwell}} > 1 \) s

Total downlink data < \( f \times 37 \) Gbit

Spectral channels: 512 (2 * 256)

<table>
<thead>
<tr>
<th>Binn</th>
<th>f(rand)</th>
<th>N(orb)</th>
<th>Delta tCoverage (days)</th>
<th>(Cov red)</th>
<th>Data vol (Gbit)</th>
<th>Downlink vol (Gbit)</th>
<th>Mem resid (Gbit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4x4</td>
<td>&lt;0.5</td>
<td>110</td>
<td>53.8</td>
<td>0.75105</td>
<td>1.98240</td>
<td>0.3622E+02</td>
<td>0.7227E+02</td>
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<tr>
<td>4x4</td>
<td>&lt;0.25</td>
<td>162</td>
<td>79.7</td>
<td>0.79153</td>
<td>2.49902</td>
<td>0.2777E+02</td>
<td>0.5538E+02</td>
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<tr>
<td>4x4</td>
<td>&lt;0.125</td>
<td>162</td>
<td>79.7</td>
<td>0.72868</td>
<td>2.04344</td>
<td>0.1367E+02</td>
<td>0.2727E+02</td>
</tr>
<tr>
<td>2x2</td>
<td>&lt;0.5</td>
<td>70</td>
<td>34.1</td>
<td>0.51874</td>
<td>1.10166</td>
<td>0.1609E+02</td>
<td>0.7227E+02</td>
</tr>
<tr>
<td>2x2</td>
<td>&lt;0.25</td>
<td>72</td>
<td>35.1</td>
<td>0.50543</td>
<td>1.06575</td>
<td>0.8469E+02</td>
<td>0.7227E+02</td>
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<tr>
<td>2x2</td>
<td>&lt;0.125</td>
<td>72</td>
<td>35.1</td>
<td>0.46851</td>
<td>0.95609</td>
<td>0.4522E+02</td>
<td>0.7227E+02</td>
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<td>8x8</td>
<td>1.0</td>
<td>162</td>
<td>79.7</td>
<td>0.82632</td>
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<td>0.3046E+02</td>
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<tr>
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<td>72</td>
<td>35.1</td>
<td>0.57162</td>
<td>1.27883</td>
<td>0.4884E+02</td>
<td>0.7227E+02</td>
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<tr>
<td>2x2</td>
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<td>70</td>
<td>34.1</td>
<td>0.30272</td>
<td>0.54296</td>
<td>0.1609E+03</td>
<td>0.7227E+02</td>
</tr>
<tr>
<td>1x1</td>
<td>1.0</td>
<td>70</td>
<td>34.1</td>
<td>0.08215</td>
<td>0.12524</td>
<td>0.1609E+03</td>
<td>0.7227E+02</td>
</tr>
</tbody>
</table>

Survey GCO

Compression factor \( f(\text{compr}) = 6 \)

Acquisition only on the dayside and only if \( t_{\text{exp}} > t_{\text{dwell}} > 0.01 \) s

Total downlink data < \( f \times 18 \) Gbit

Spectral channels: 640 (full IR focal plane)

<table>
<thead>
<tr>
<th>Binn</th>
<th>N(orb)</th>
<th>Delta tCoverage (Cov red)</th>
<th>Data vol (Gbit)</th>
<th>Downlink vol (Gbit)</th>
<th>Mem resid (Gbit)</th>
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</thead>
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<tr>
<td>8x8</td>
<td>1.0</td>
<td>206</td>
<td>22.3</td>
<td>0.01125</td>
<td>0.01239</td>
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<tr>
<td>8x8</td>
<td>0.25</td>
<td>206</td>
<td>22.3</td>
<td>0.01130</td>
<td>0.01252</td>
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<tr>
<td>8x8</td>
<td>0.025</td>
<td>206</td>
<td>22.3</td>
<td>0.0201</td>
<td>0.00204</td>
</tr>
</tbody>
</table>

Unfeasible for global mapping

Feasible, but not the best option

Fully feasible for global mapping
Technological Development
Activity on Linear Variable Filters

• A TDA on LVF has been proposed
• The proposal is under evaluation
Rationale for a wavelength extension above \(5.2 \, \mu m\) (delta study)
Ganymede geometrical albedo

Ganymede temperature map (Galileo radiometer)
Ganymede

Continuum spectral radiance rough estimation
Albedo: 0.1
Different Temperature

Albedo: 0.1
T = 120 K

Albedo: 0.1
T = 160 K

Nominal range
Callisto geometrical albedo
Callisto

Continuum spectral radiance rough estimation
Albedo: 0.2
Different Temperature

Albedo: 0.2
T = 140 K

Albedo: 0.2
T = 170 K

Nominal range
Jupiter

\[ \frac{\partial l_{\text{ch}}}{\partial (\log_{10} \alpha_i)} \mid [10^{-3} \text{ erg/(sec cm}^2\text{ ster nm})] \]

Nominal range

Jacobian for water

Add on science for delta study

H$_2$O - VIRHIS

Grassi D. et al., submitted PSS 2009
Jupiter

\[
|\partial I_{ch}/\partial (\log_{10} \alpha_i)| \left[ 10^{-3} \text{ erg/(sec cm}^2\text{ ster nm)} \right]
\]

Nominal range

Jacobian for ammonia

Add on science for delta study

Grassi D. et al., submitted PSS 2009
Improvement of retrieval capability for Jupiter in case of extension up to 6 microns

**OPTION00** = JUNO-JIRAM-like (range up to 5.01 um, spectral sampling 9 nm)

**OPTION01** = Best option for VIRHIS (range up to 6. um, spectral sampling 5 nm)

**OPTION02** = 2nd option for VIRHIS (range up to 6. um, spectral sampling 7 nm)

Grassi D. et al., submitted PSS 2009
Summary

• VIRHIS study is on going, now entering the phase with an higher level of details

• Funding of the study is not yet available, formal procedure is on going with ASI, CNES and DLR

• No stopping point is identified til now

• A more tight interaction or exchange of information between instrument study and science definition teams is very desirable in order to optimize the efforts on both sides