Atmospheres of icy giant planets in the Solar System

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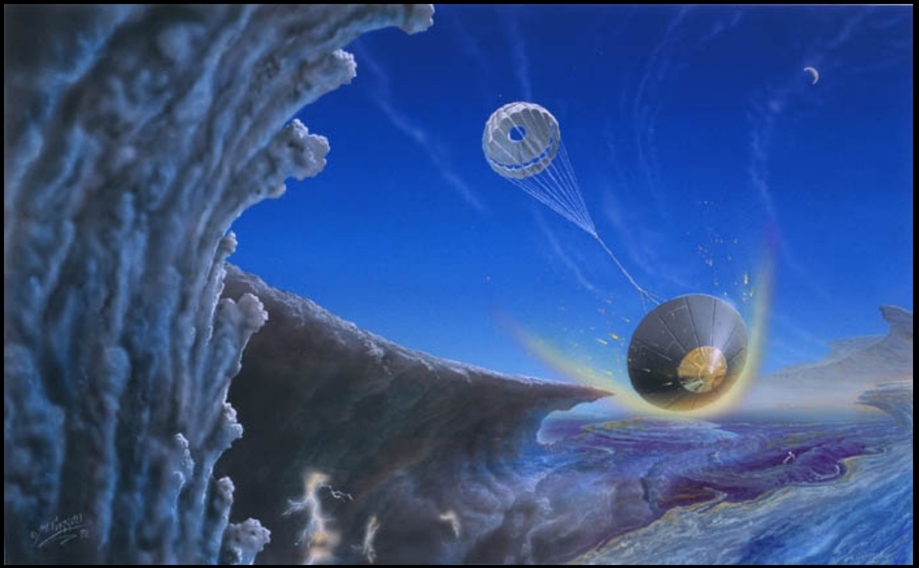
Outline

- Rationale for telescopic observations of Solar System bodies
- Assumed properties of a future Far-IR telescope
- Potential science targets
  - Icy giants (Uranus & Neptune)
  - Satellites of Gas Giants (Jupiter & Saturn)
  - Kupier Belt objects

Rationale for telescopic observations of Solar System bodies (1)

- Observations by dedicated spacecraft missions (orbiters and entry probes) will remain the optimal approach to investigate solar system bodies:
  - For the variety of instruments available (including several “non-photonic” devices, such as plasma and neutral packages, gravity...)
  - For the achievable spatial resolution (even *in situ* measurements)
- But......

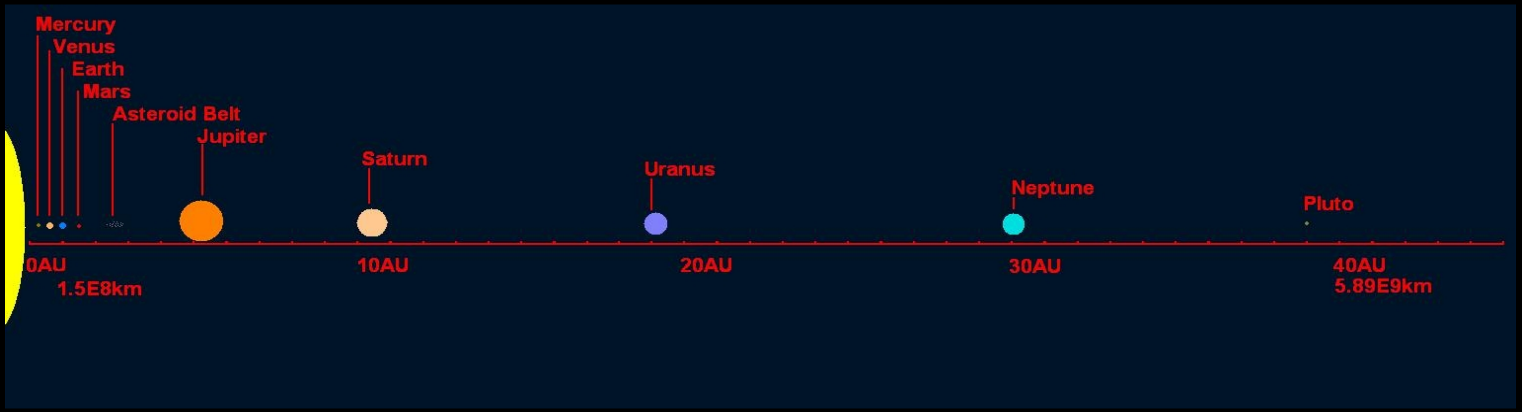


Artist impression of a Neptune entry probe
Credit: Michael Carroll's Space Art

Rationale for telescopic observations of Solar System bodies (2)

- Spacecraft exploration of the Solar System beyond Saturn is well within current technology, but remains extremely demanding: *<u>we are really far away!</u>*
  - Long cruise time
  - High Δv
  - <u>Very low data rate</u>

  } Very high cost!

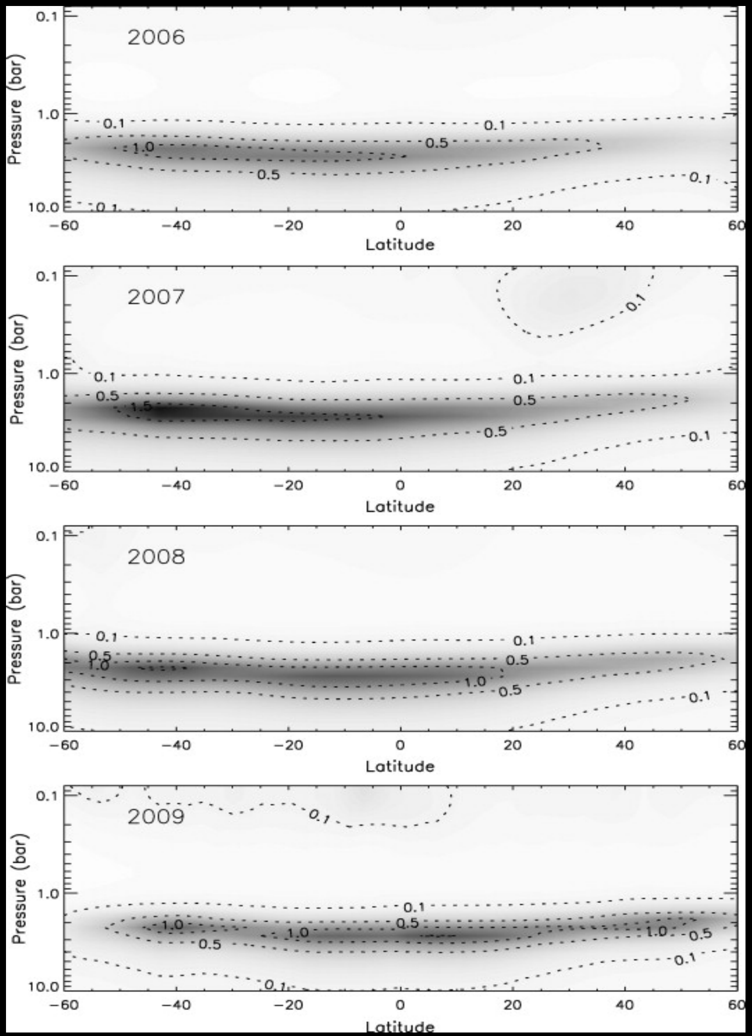


Rationale for telescopic observations of Solar System bodies (3)

- During ESA Cosmic Vision M3 selection phase the concept for an Uranus Explorer was positively evaluated, but not selected
- In the latest ESA L-class science theme selection “*The SSC considered the study of the icy giants to be a theme of very high science quality and perfectly fitting the criteria for an L-class mission*”... but – again - eventually not selected
- Overall, while the study of individual systems such as Uranus or Neptune is still in our realistic hopes, an extensive *in situ* exploration of outer Solar System requires too much resources
- <u>Telescopic observations represents therefore the most realistic mean to explore extensively these remote regions in the next couple of decades</u>

Rationale for telescopic observations of Solar System bodies (4)

- Telescopic observations allow us to extend the time span of observations over several years, a key feature to determine the <u>long term variability of atmospheres.</u>
  - Namely, a long temporal record is a mandatory prerequisite for the selection of possible probes entry sites
  - Telescopic observations in visible and near-, mid-IR represents already today our main dataset for the study of Uranus and Neptune meteorology

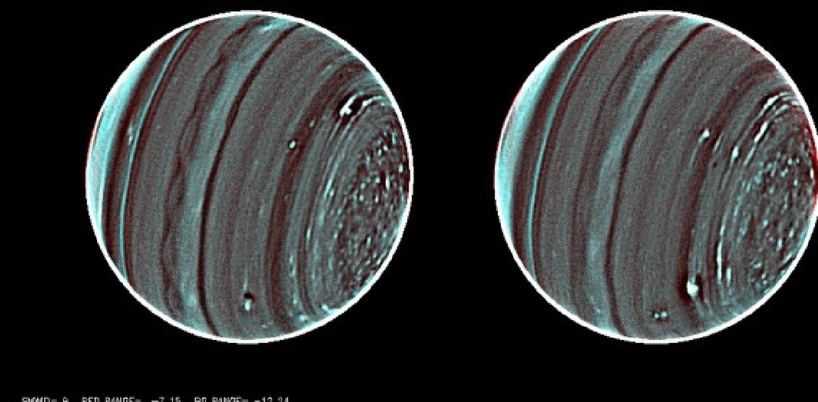


Retrieved vertical–latitudinal distribution of cloud optical depth per bar (at 1.6 μm) in Uranus' atmosphere from a combination of the UKIRT (2006–2008) and Gemini (2009) observations. From Irwin et al., 2010

Sizes of Solar System objects from Earth orbit

Mean diameter at opposition, in arcsec

- Jupiter 43.7
  - Europa 1.02
  - Ganymede 1.72
- Saturn 18.19
  - Titan 0.77
- Uranus 3.85
- Neptune 2.34
  - Triton 0.13
- Pluto 0.08



Uranus as seen by Keck II telescope
From Sromovsky et al., 2102

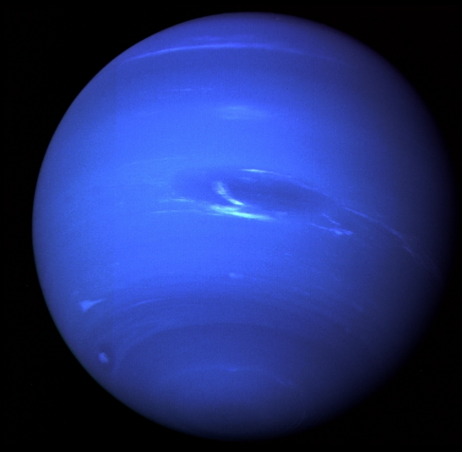
- High spatial resolution (better than 0.1 arcsec) is required
  - to resolve the main atmospheric features on the disks of the icy giants
  - to resolve the surface regions on Galilean satellites (e.g.: Galileo region on Ganymede)
  - to fill at least one 'pixel' entirely with the disk of closer Kuiper belt objects (Triton and Pluto)

Assumed properties of a future Far-IR telescope

- We will present some potential planetary science targets for a telescope with
  - Spectral coverage between 20 and 200 μm
  - Spatial resolution of 0.07 - 0.25 arcsec (@ 30 and 100 μm)
  - Spectral resolution ~ 3000
- Far-IR is valuable since it allows us to study:
  - the pure rotational spectrum of several molecules (better definition of individual lines, not blended in bands)
  - the thermal emission peak of very cold bodies

Thermal budget of icy giants

- Uranus apparently lacks a source of internal heat (flux 0.042 ± 0.047 W/m^2). This fact has profound implications on the planet internal structure (inhibition of convection?) and makes it substantially different from Neptune.
- A full characterization of the thermal balance of icy giants requires simultaneous measurements in VIS-NIR (JWST), and far-IR.
- Expected peak emission falls around 40 μm.
- High spatial resolution is important to characterize the local variability due to transient meteorological phenomena

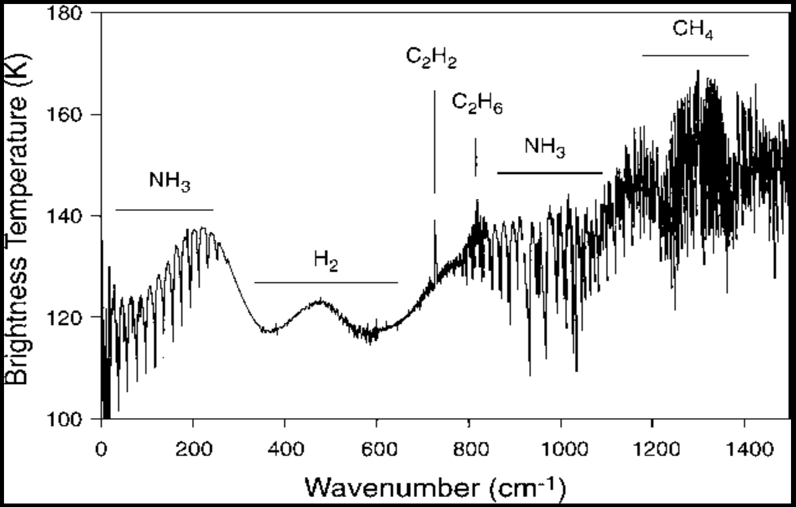


Neptune by Voyager 2

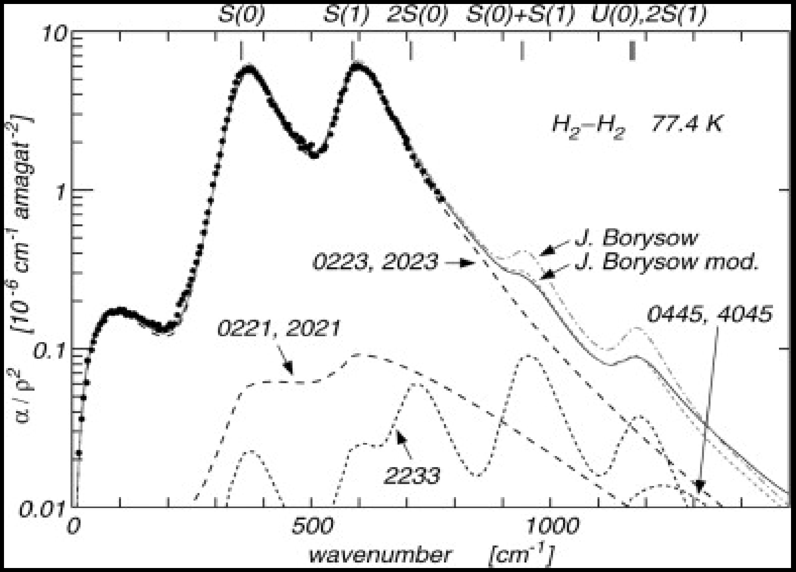
Uranus by Voyager 2

Atmospheric temperatures (1)

- Molecular hydrogen is the main atmospheric component of giant planets atmospheres.
- The relatively high pressures found there made possible for us to observe the collision-induced absorption bands
- The main bands (centered at 28 and 17 µm) allow us to determine:
  - The air temperature at the level of clouds top (key parameter for atmosphere dynamic modeling)
  - Ortho/para (constraint for effectiveness of vertical mixing)



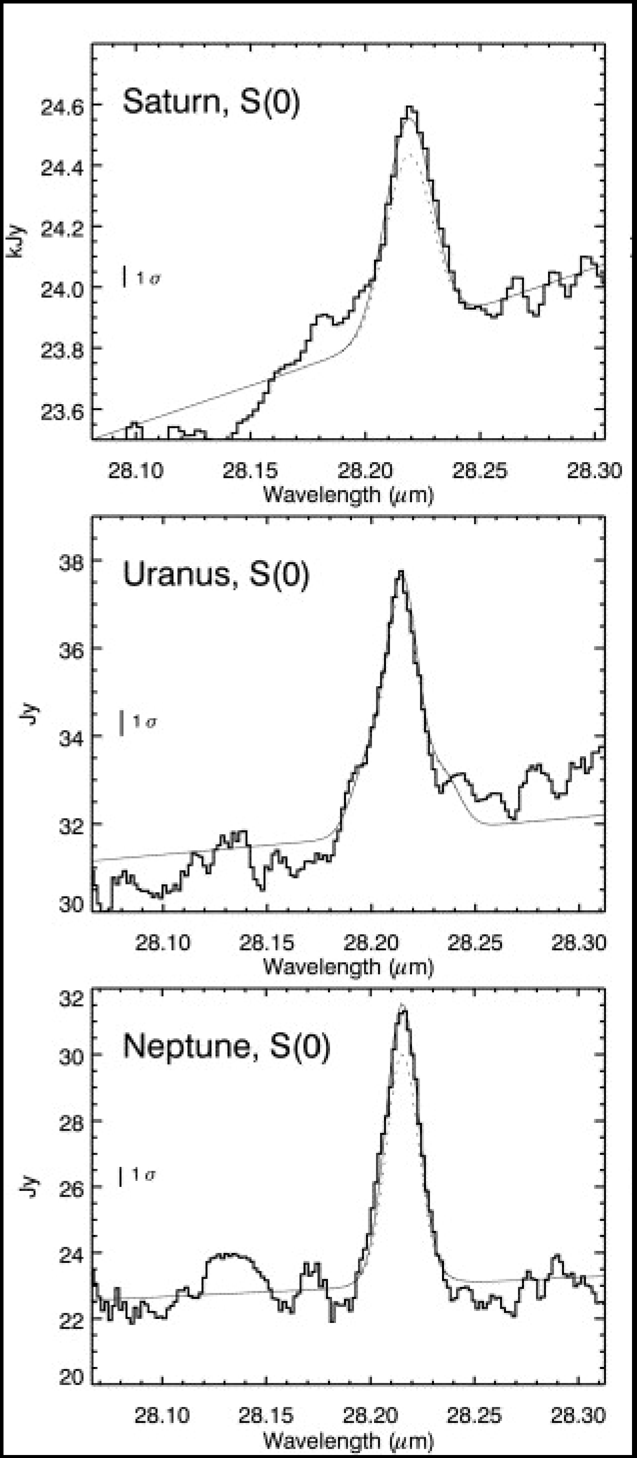
Jupiter as seen by CIRS (from Hanel et al., 2003)



From Orton et al., 2007

Atmospheric temperatures (2)

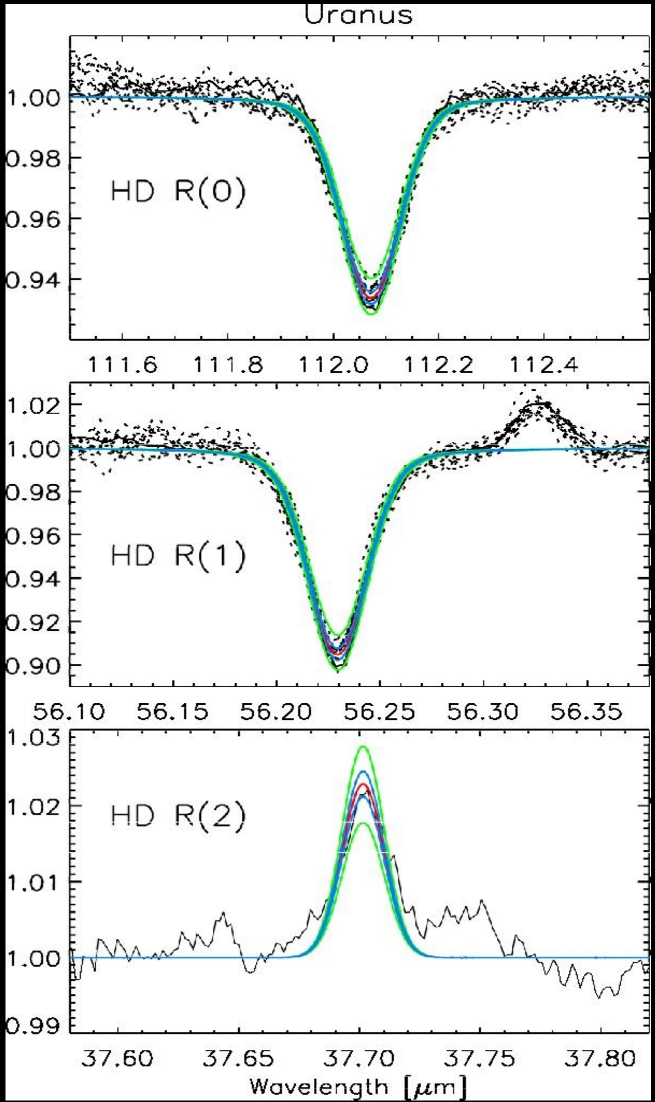
- If spectral coverage reaches λ ~ 25 μm, the thermal emission from the stratosphere at the center of main H_2 S(0) band can be observed, allowing us to constraint the air temperature in a larger span of altitudes
- Telescopic observations will be important also for the case of Saturn - to extend the records of CIRS instrument - and Jupiter – since JUICE will not host a thermal-IR instrument.



From Fouchet et al., 2003

Atmospheric composition

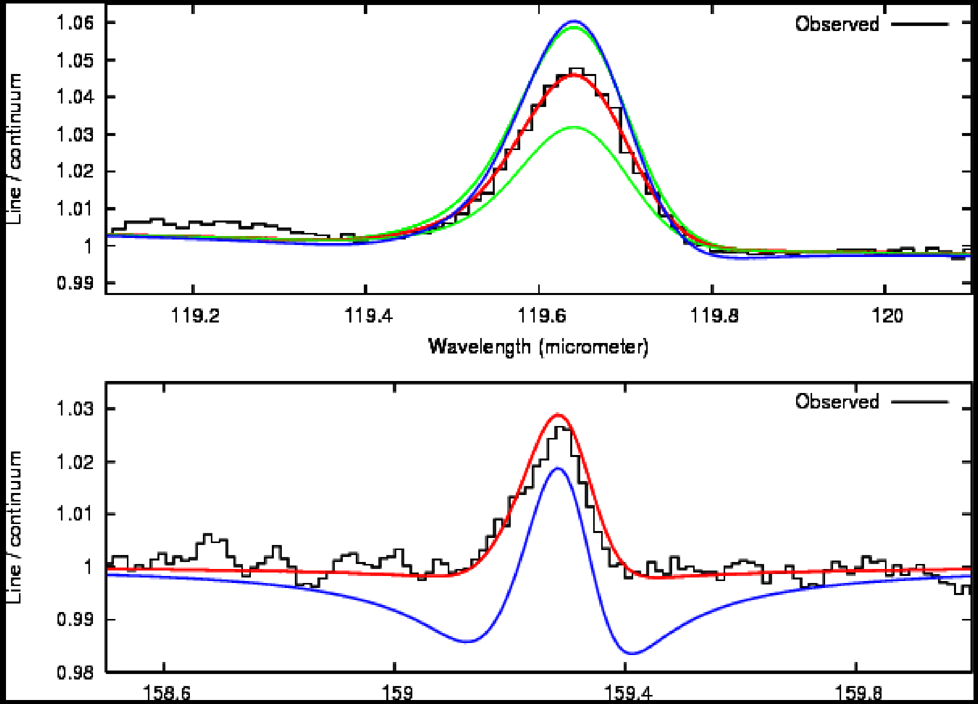
- Herschel already demonstrated the importance of far-IR in studying the composition of icy giant atmospheres
  - H/D (with implications on formation scenarios)
  - Stratospheric [CO] and [H_2O] (with implications on the origin of exogenic materials)
- Improved spectral resolution will allow us to disentangle local effects related to transient phenomena and achieve higher accuracy



HD lines at Uranus
(from Feuchtgruber et al., 2013)

Atmospheric composition (2)

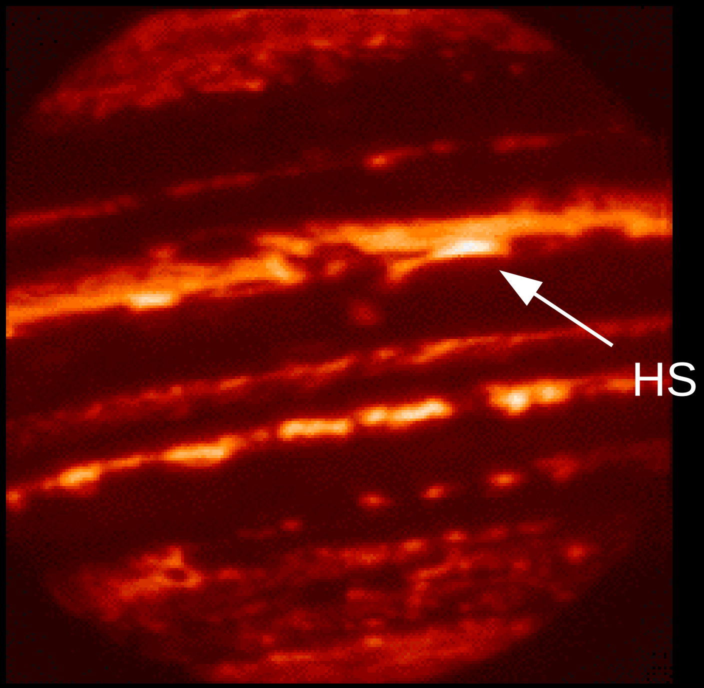
- Important compositional topic to address
  - Measures of ammonia in the troposphere of Jupiter (λ > 50 μm) will allow us to constraint the cloud condensation scenarios and to complement the JUICE data
  - Measurements of water in all four giant planets (with emphasis on local enhancements)
  - Measurements of methane vertical profiles in icy giants (where its condensation is expected)
  - Search of new stratospheric components (enabled by unprecedented spectral range and resolution)



CH_4 methane line in Neptune, as observed by PACS. Different theoretical curves are computed from different mixing ratios profiles.
(from Lellouch et al., 2010)

Study of local phenomena in gaseous giants

- A high spatial resolution telescope will allow us to study spectroscopically local or regional features of gas giants
- Study of H_2O and CO in the Jupiter hot spot
  - High spectral resolution will allow determination of water profiles with accuracy not achievable by the JUICE or JUNO payloads.
- Enhancements of ammonia or water in correspondence of transient plumes
- Potential compositional peculiarities in the polar atmospheres of Jupiter and Saturn

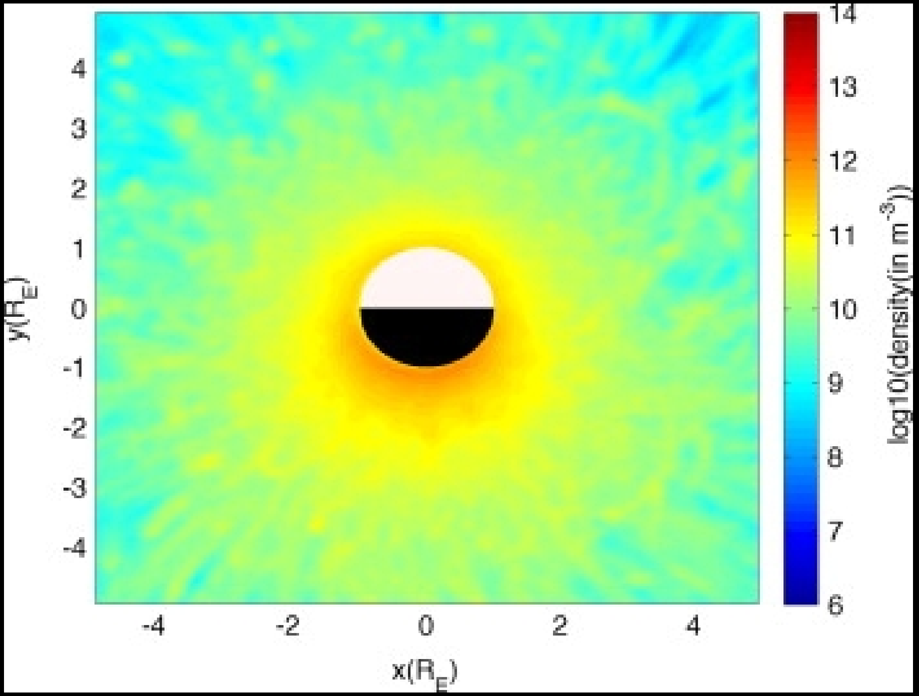


$4.85\,\mu m$

Credit: NASA IRTF

Spectroscopy of Galilean satellites

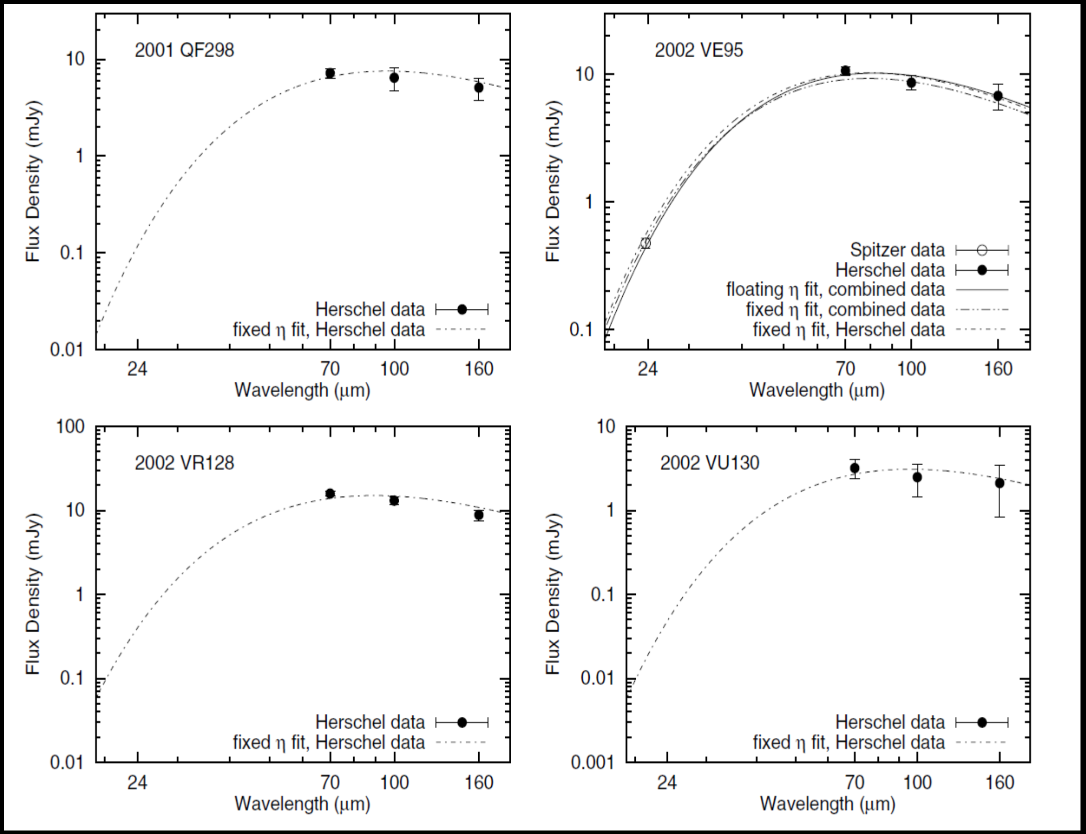
- The high spatial resolution will allow us to map surface temperatures on regional scale (JUICE lacks a thermal infrared instrument)
- The coverage of H_2O rotational bands will allow us to investigate the structure of exospheres of Europa, Ganymede and Callisto



Expected H_2O exospheric density at Europa
Courtesy by C. Plainaki (IAPS-INAF)

Spectroscopy of TNO

- A spatial resolution of 0.1 arcsec is comparable to the apparent disk diameter of Triton and Pluto, enabling therefore:
  - monitoring of surface temperatures
  - Tentative detection of atmospheres (CO and CH_4)
- The high spatial resolution will allow us to determine relative flux (and therefore temperature) for a KBO population much more extended than possible with Herschel.
- Continuous coverage between 30 and 300 μm will allow us to cover the Planck function peak for the temperatures expected for TNO and reduce substantially the current uncertainties



from Mommert et al., 2012

Other potential Solar System targets

- Thermal properties of asteroids and cometary nuclei in the inner Solar System
- D/H ratio of comets
- Spectroscopy of comae of chiron-type comets (no sublimation of water expected)

Conclusions

- A Far-Infrared telescope with full spectroscopy capability represents a key facility for planetary sciences
- Observations of external Solar System (beyond Saturn) are particularly important to overcome the difficulties related to extended in situ observations
- Long-term temporal coverage for the study of atmospheres is realistically achievable only by means of telescopic observations