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......
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: *we are really far away!*
  - Long cruise time
  - High $\Delta v$
  - Very low data rate

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.
- Telescopic observations represents therefore the most realistic mean to explore extensively these remote regions in the next couple of decades.
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 long term variability of atmospheres.
  - 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

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 $0.042 \pm 0.047 \text{ W/m}^2$). 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 $40 \mu m$.

- High spatial resolution is important to characterize the local variability due to transient meteorological phenomena.
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)

From Hanel et al., 2003

From Orton et al., 2007
Atmospheric temperatures (2)

- If spectral coverage reaches $\lambda \sim 25 \ \mu m$, the thermal emission from the stratosphere at the center of main $H_2S$ 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$_2$O] (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 ($\lambda > 50 \, \mu m$) 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 spectrally local or regional features of gas giants.
- Study of H$_2$O 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.
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$_2$O rotational bands will allow us to investigate the structure of exospheres of Europa, Ganymede and Callisto

*Expected H$_2$O 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 CH₄)
- 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.