Solar-system research with the JWST and the ELTs

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ESO Conference JWST/ELT

13-16 April 2010

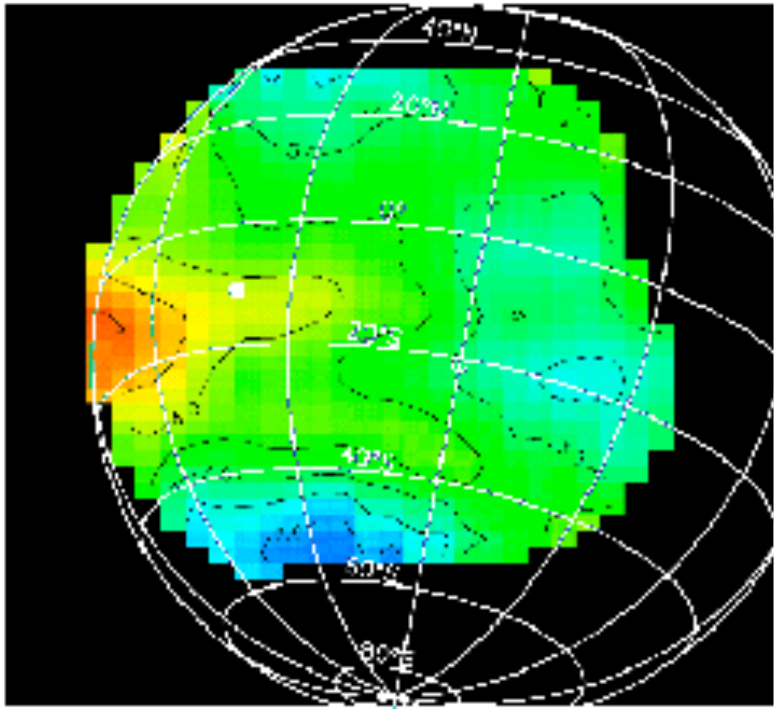
The solar system: some key questions (origin and evolution)

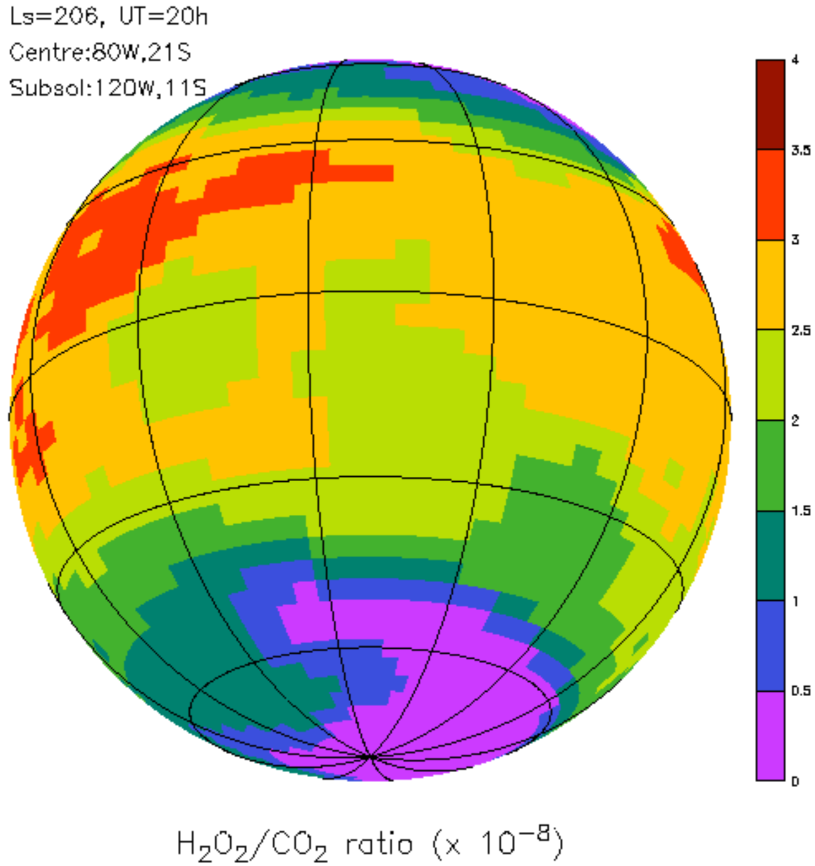
- Terrestrial planets: what are the reasons of their diverging evolution?
- Early history of Mars: could life have appeared?
- Gaseous and icy giant planets: why are they so different? Was there some migration?
- Comets: where do they come from?
- Kuiper Belt: can it be a diagnostic of early planetary migration?
- The Solar system : a peculiar planetary system for in-depth studies (ground truth)

Terrestrial planets

- Mars : Need for Earth-based exploration in complement of in-situ space missions [TEXES/IRTF, CRIRES/VLT; IRAM, JCMT]
  - Narrow lines -> high-resolution spectroscopy required (H_2O_2, CH_4)
  - Global mapping from Earth -> transient phenomena (dust storms, daily variations)
  - Open questions:
    - Detecting & monitoring minor species (incl. H_2O_2, CH_4)
    - Exchanges surface/atmosphere
    - D/H : implication on early history of water

H_2O_2 mapping on Mars, Ls = 207°: ground-based HR-IR spectroscopy





TEXES
$Q(H_2O_2)_{max}= 4\ 10^{-8}$

GCM
$Q(H_2O_2)_{max}= 4\ 10^{-8}$

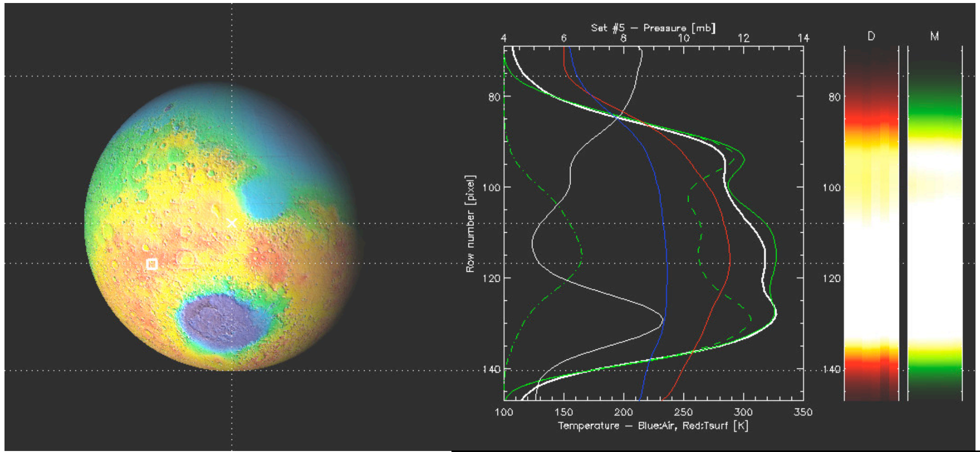
Encrenaz et al. 2004

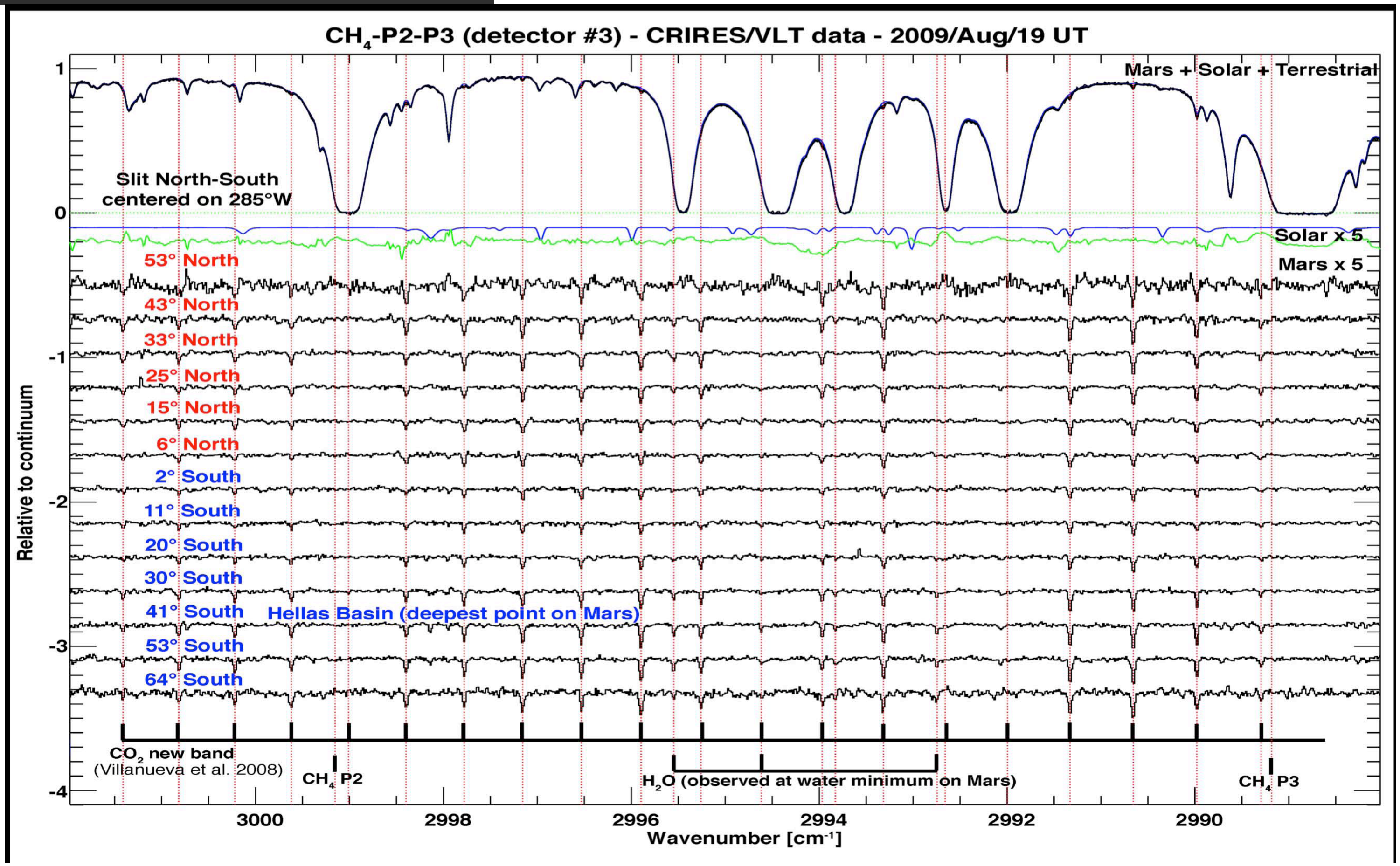
Mars : perspectives

- Near-term
  - Herschel -> H_2O, HDO -> water cycle and history of water
  - ALMA: dipolar minor species
  - SOFIA -> CH_4, D/H, search for SO_2
- JWST
  - Visible mapping : monitoring of dust storms and clouds (TFI)
- ELT : search for localized sources of trace species (ex: CH_4) (METIS)
  - ELT spatial resolution: about 10 km @ 3 μm
  - > Possible to search for CH_4 sources on a global scale
  - > More efficient than present in-situ space missions

Search for trace species with CRIRES @ VLT (Mumma et al., 2009) -> <u>A program for METIS</u>

- 3-4 μm -> CH_4
- 7-13 μm -> H_2O_2, O_3, SO_2



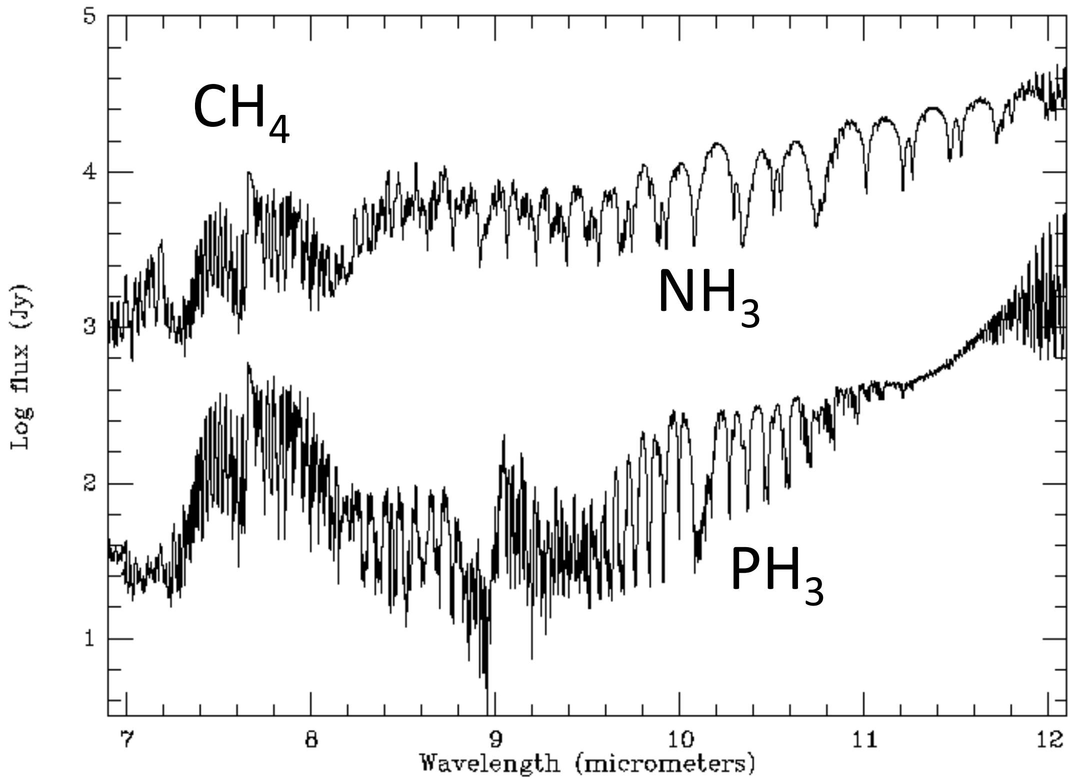


Villanueva, 2009
&
METIS Science Analysis Report, B. Brandl et al. 2009

Gaseous Giants

Extended in-situ exploration with Galileo and Cassini

Earth-orbit observations: HST, ISO



Jupiter

Saturn

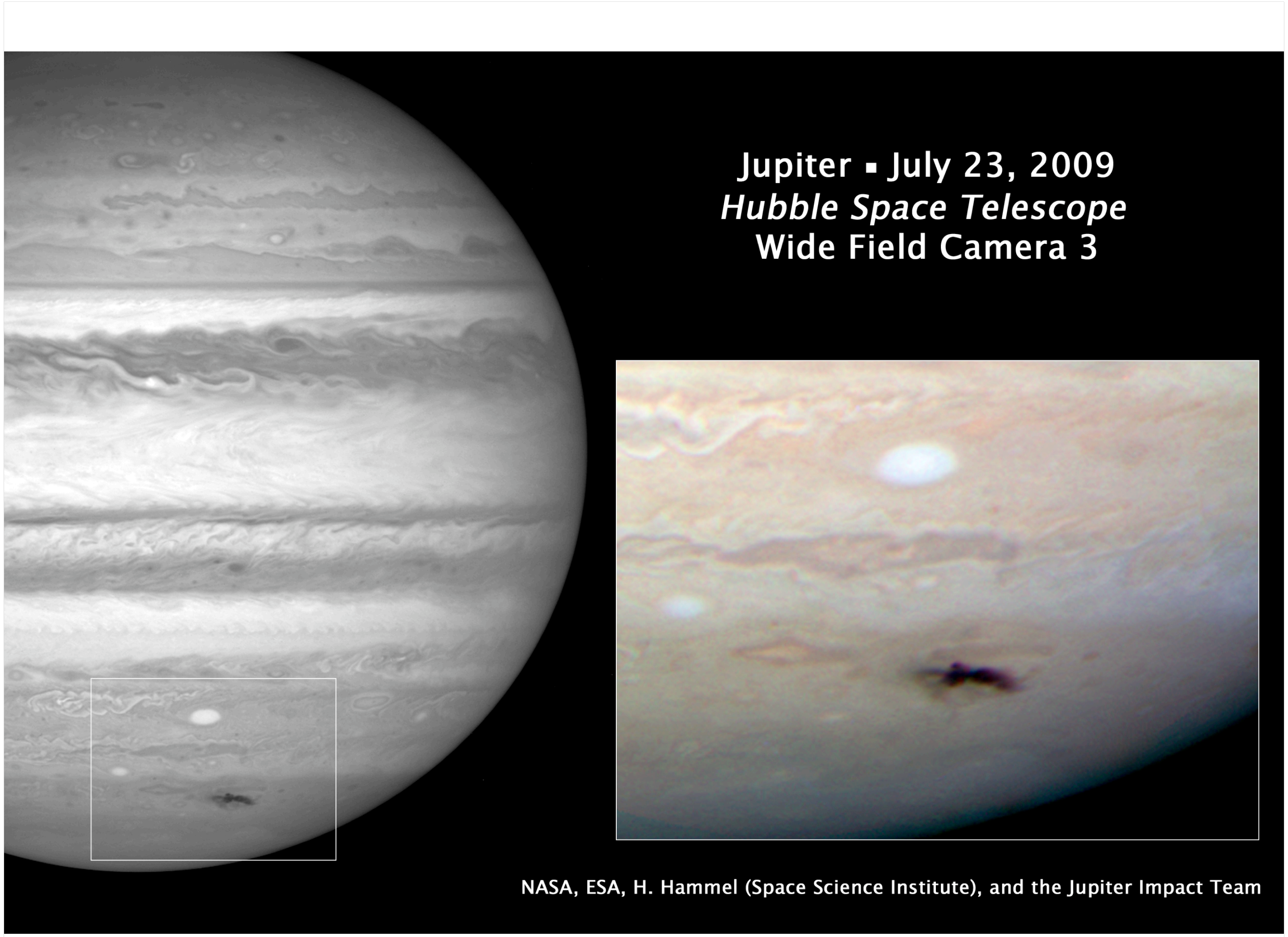
ISO-SWS

Why are Jupiter and Saturn different?

-Saturn is colder -> thicker NH_3 cloud

-Saturn is more dynamically active (origin of internal energy?)

Jupiter as seen with the HST



Jupiter collision with a comet/asteroid

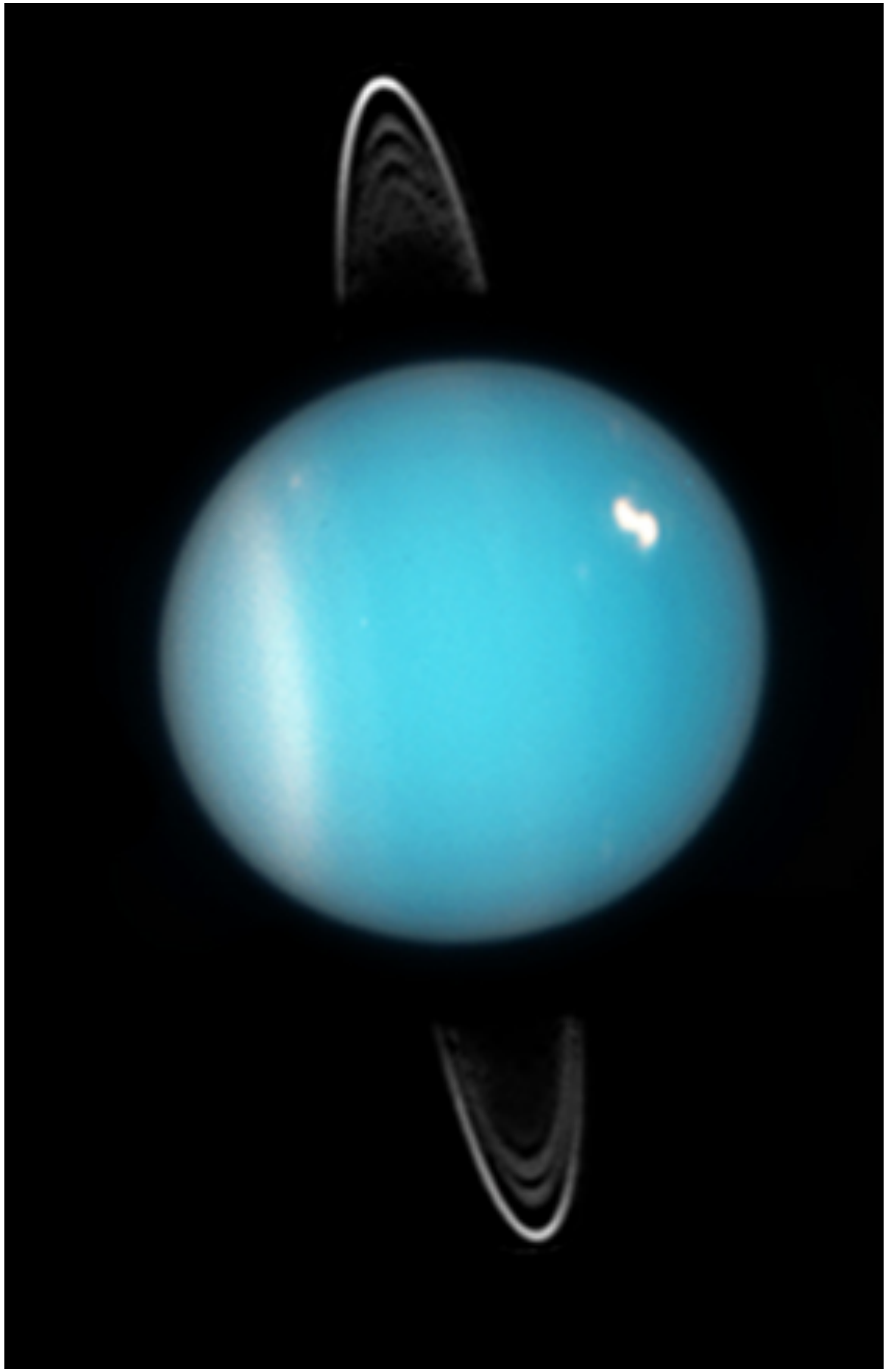
July 23, 2009

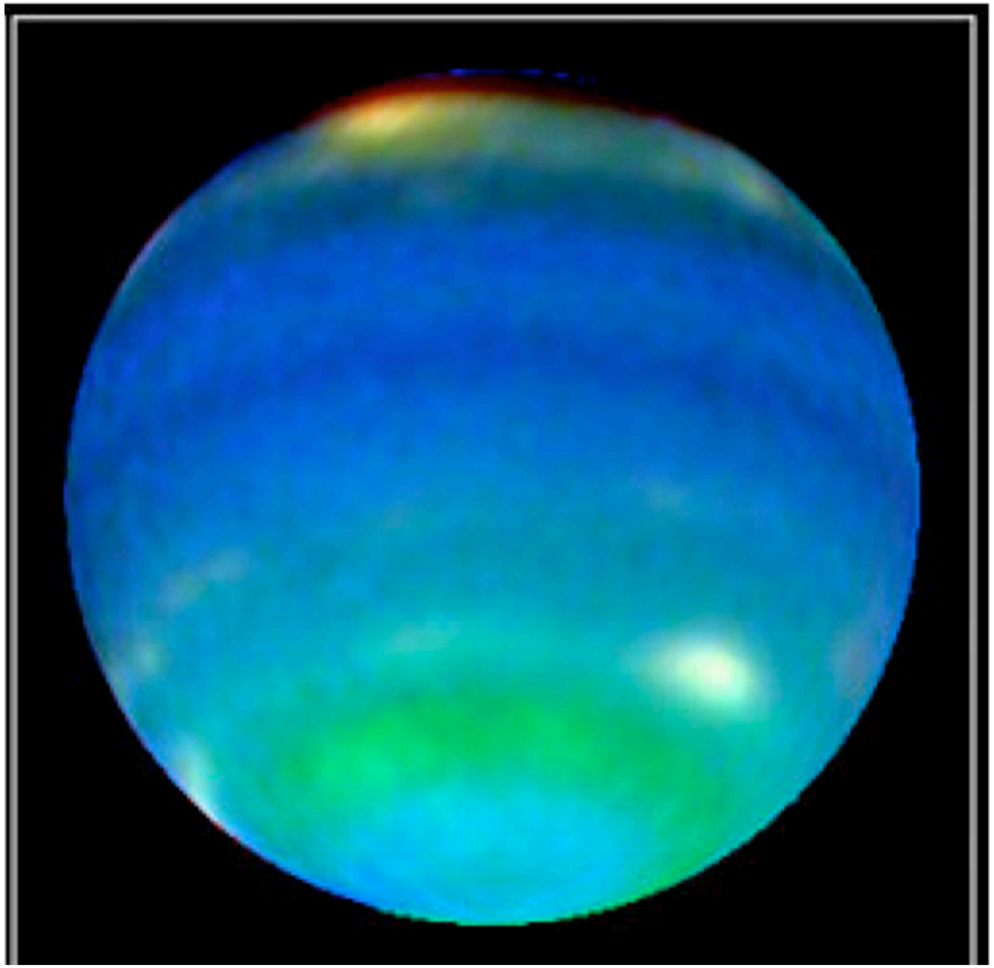
JWST/TFI: Imaging in narrow filters /Search for H_2O

Icy giants

- No in-situ exploration since Voyager
- Earth-based exploration
  - Visible monitoring (HST)
  - External oxygen source (ISO)
  - Stratospheric CO and HCN (N): VLT, IRAM, JCMT
  - VISIR/VLT IR thermal mapping
- Again two different worlds:
  - Neptune is much more dynamically active
  - Origin? Different orbital configuration? Different internal structure?

Uranus and Neptune as seen by the HST

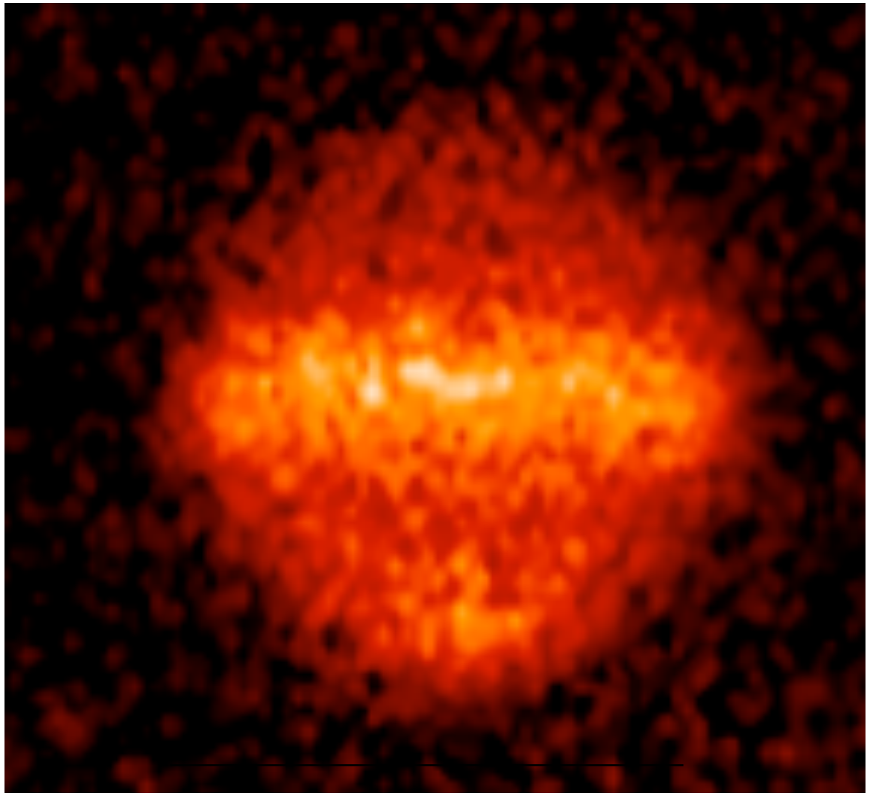




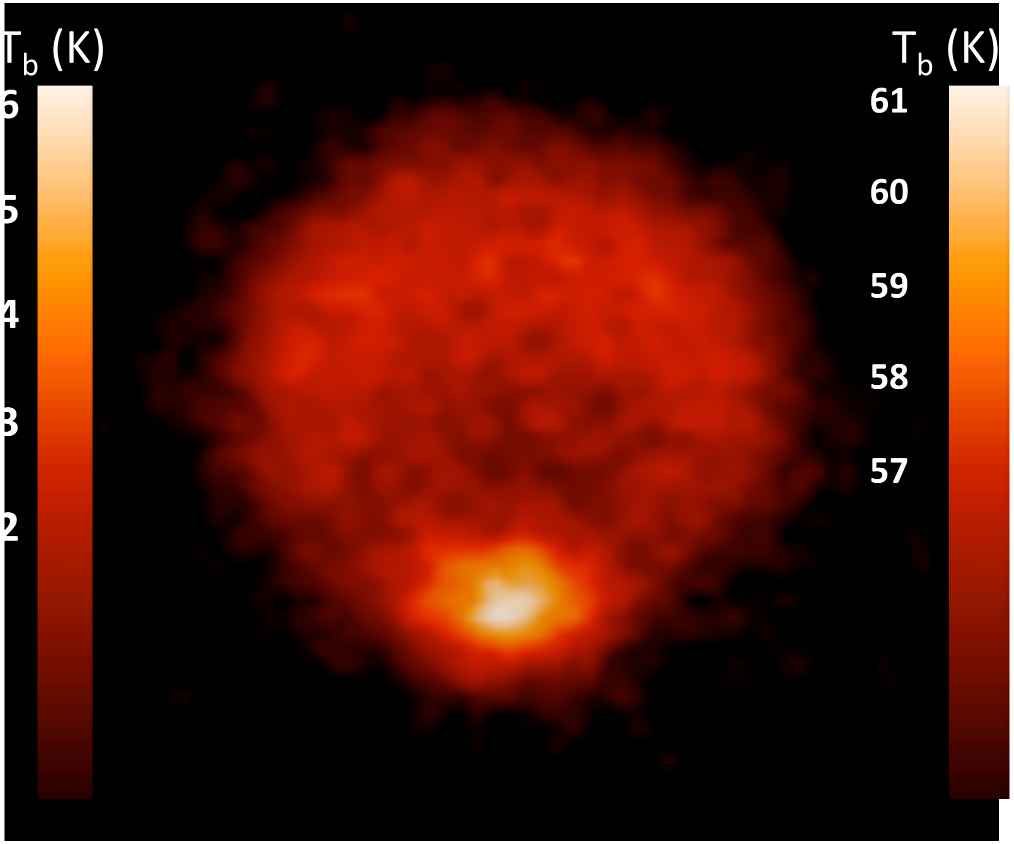
Why are Uranus and Neptune different?

Data: VLT/VISIR, ESO, September 2006

3 Sep 2006, 4:02 UT



3 Sep 2006, 1:44 UT



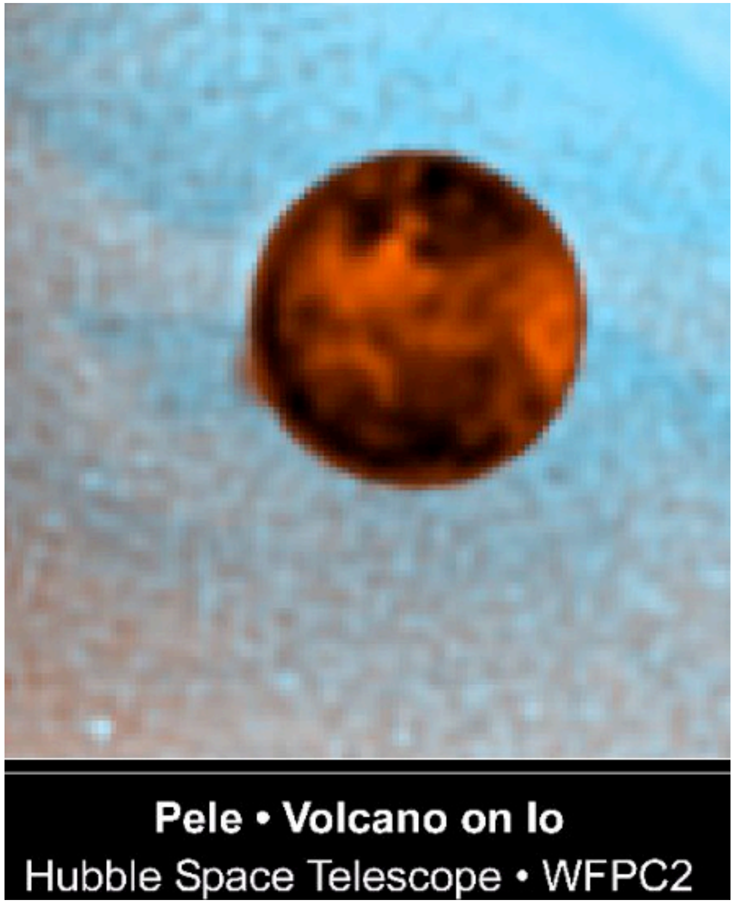
Neptune: Temperature enhancement at the southpole (southern solstice in 2004)

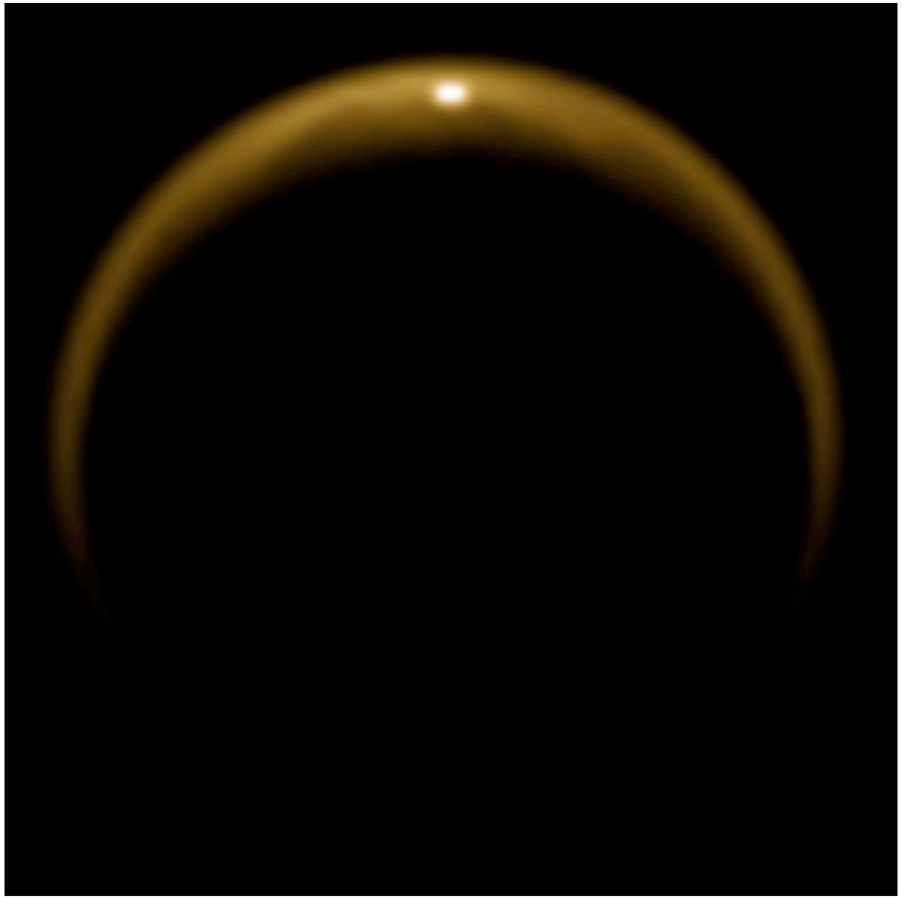
Giant planets: Perspectives

- Near-term
  - Herschel (H_2O and dipolar minor species)
  - ALMA (dipolar minor species)
  - SOFIA (CH_4 and hydrocarbons)
- JWST
  - Visible-NIR mapping/Seasonal variability (TFI, NIRCam)
  - Stratospheric H_2O &CO_2/Origin of oxygen source (MIRI)
- ELT
  - Visible mapping/Seasonal variability
  - Thermal mapping/seasonal variability (METIS)
  - Stratospheric hydrocarbons (METIS)

Outer satellites with JWST/ELT: Monitoring transient/seasonal phenomena

Io: active volcanism (HST) Titan: evidence for lakes (Cassini)





JWST: Imaging, SO_2 mapping (Io), IR spectroscopy (Titan)

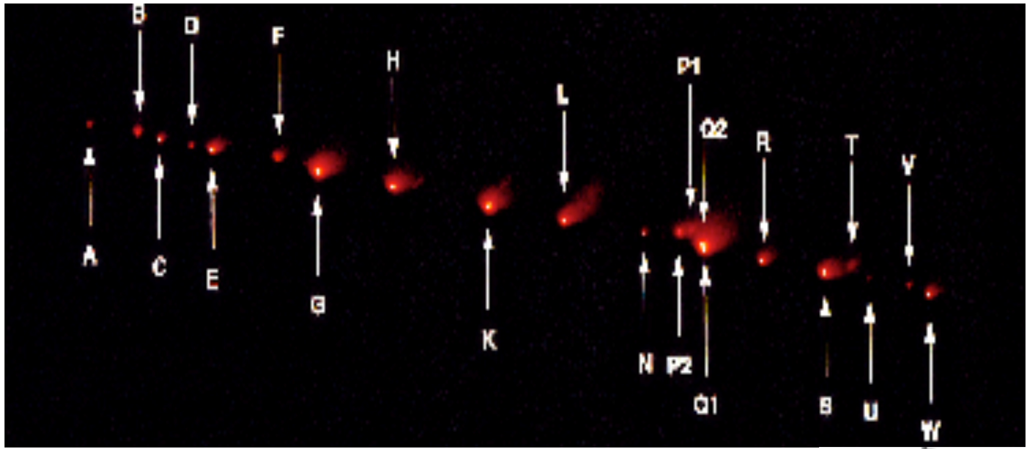
ELT: Io & Titan monitoring (1 px = 25 km @ 1 μm and 10 AU)

Comets

- Key question: origin of comets ?
  - Oort cloud, Kuiper Belt, Outer main asteroid belt

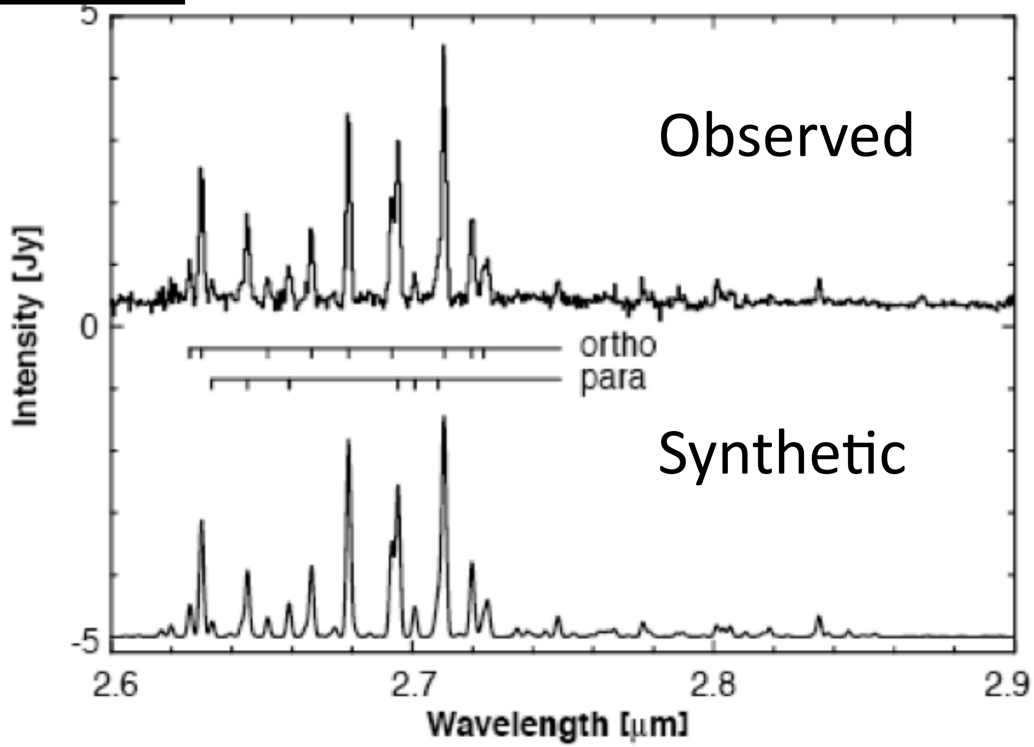
Earth-based observations: HST (SL9) : visible imaging
ISO (Hale-Bopp): H_2O + Mid-IR mineralogy
VLT/CRIRES : IR fluorescence of non-polar parents
IRAM/JCMT: dipolar parent molecules

Earth-orbit observations of comets



Comet Shoemaker-Levy 9
HST, 1993

Comet Hale-Bopp
H_2O emission
ISO-SWS, 1997



Comets: Perspectives

- Near-term
  - Herschel, ALMA :
    - H_2O, HDO: D/H, OPR -> origin of comets
    - Dipolar parent molecules/link with interstellar matter
- JWST
  - H_2O -> activity; D/H, OPR -> origin (NIRSpec)
  - Near-IR spectroscopy : non-dipolar parent molecules (NIRSpec)
  - Mid-IR spectroscopy -> cometary dust composition (MIRI)
- ELT
  - Parent molecules at $\lambda > 3$ μm (HR spectroscopy, HARMONI, METIS)
  - Nature of silicates (crystalline/amorphous)

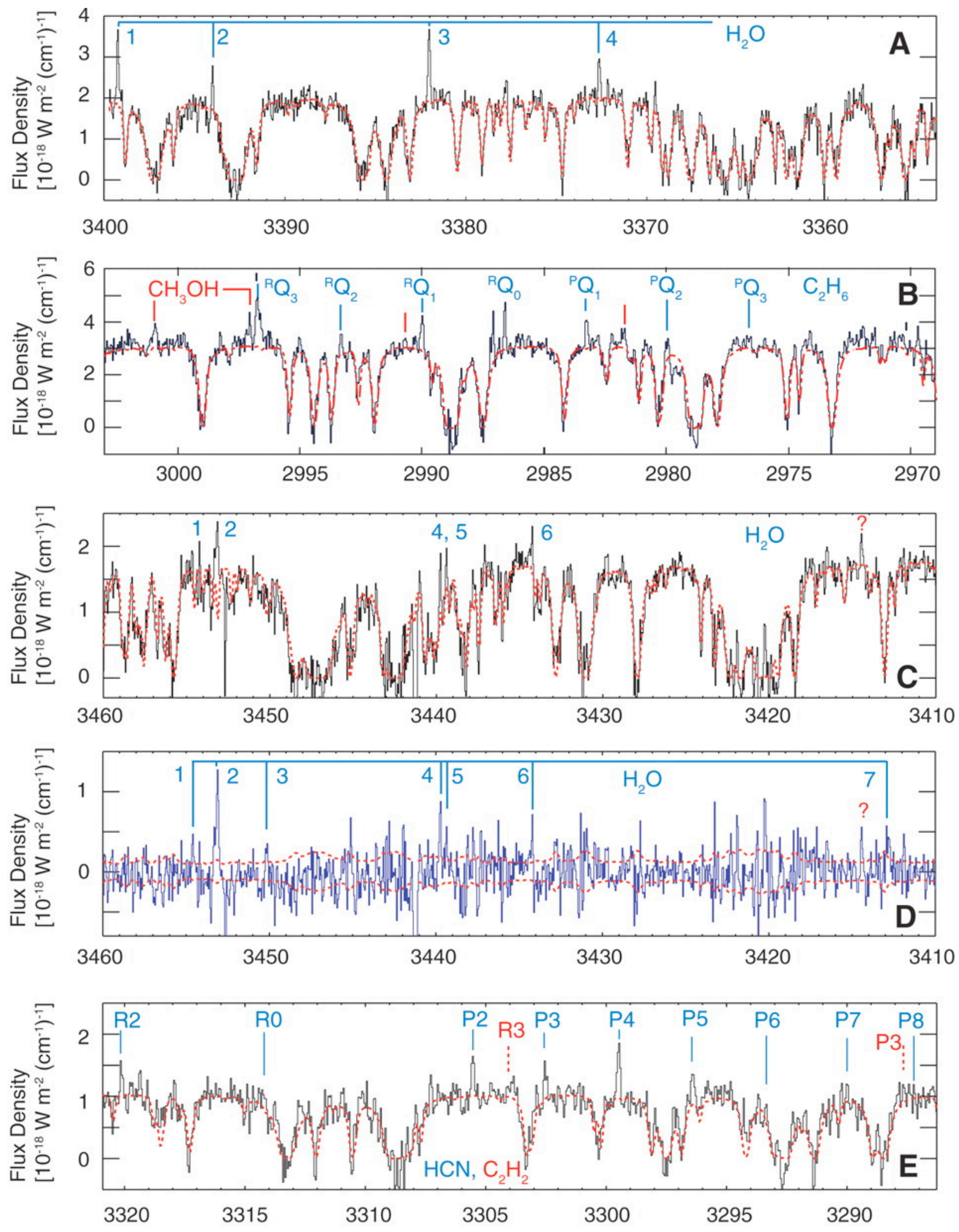
    (N-band spectrophotometry, METIS)

HR spectroscopy of parent molecules in comets at 2.9 – 5 μm

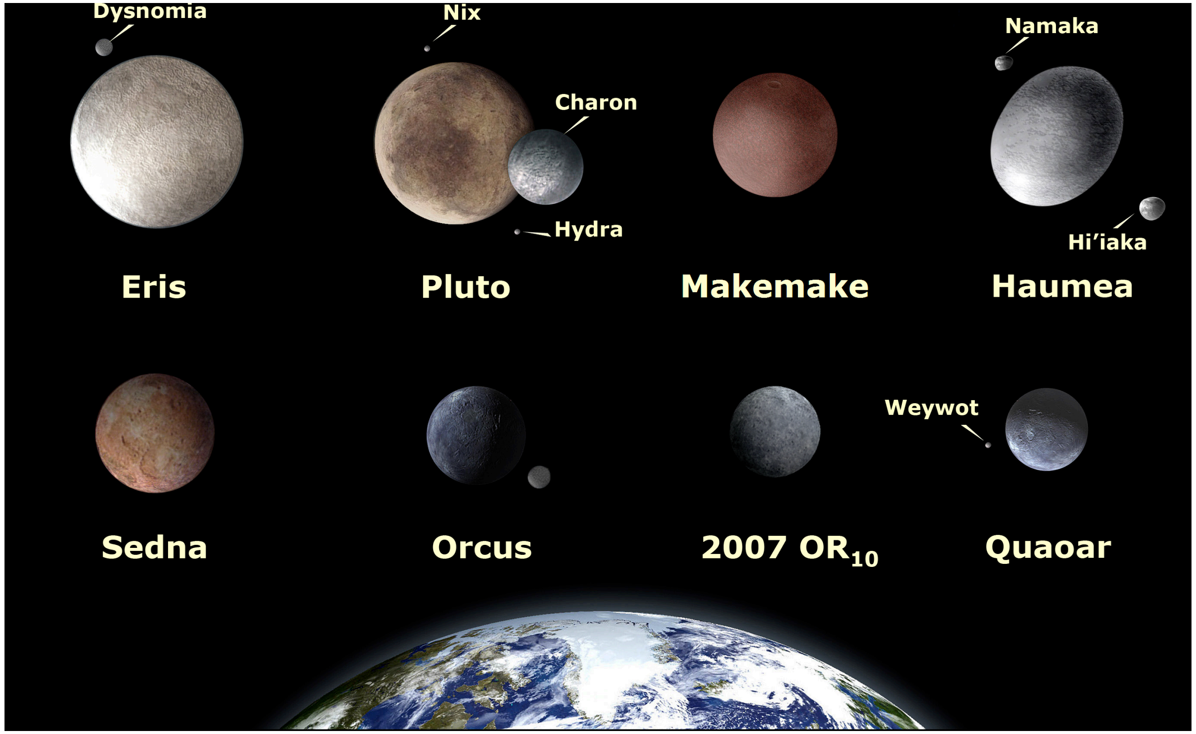
NIRSPEC, Keck-2
(Mumma et al., 2003) :
Detection of H_2O, CH_3OH, C_2H_2 and HCN

-> A program for METIS
(limiting magnitude: 9-10
-> 3-5 periodic comets/year)

METIS Science Analysis Report, B. Brandl et al., 2009



The Kuiper Belt



Key Questions :

- Dynamical history of # families (plutinos, regular, scattered)
  -> test for planetary migration models

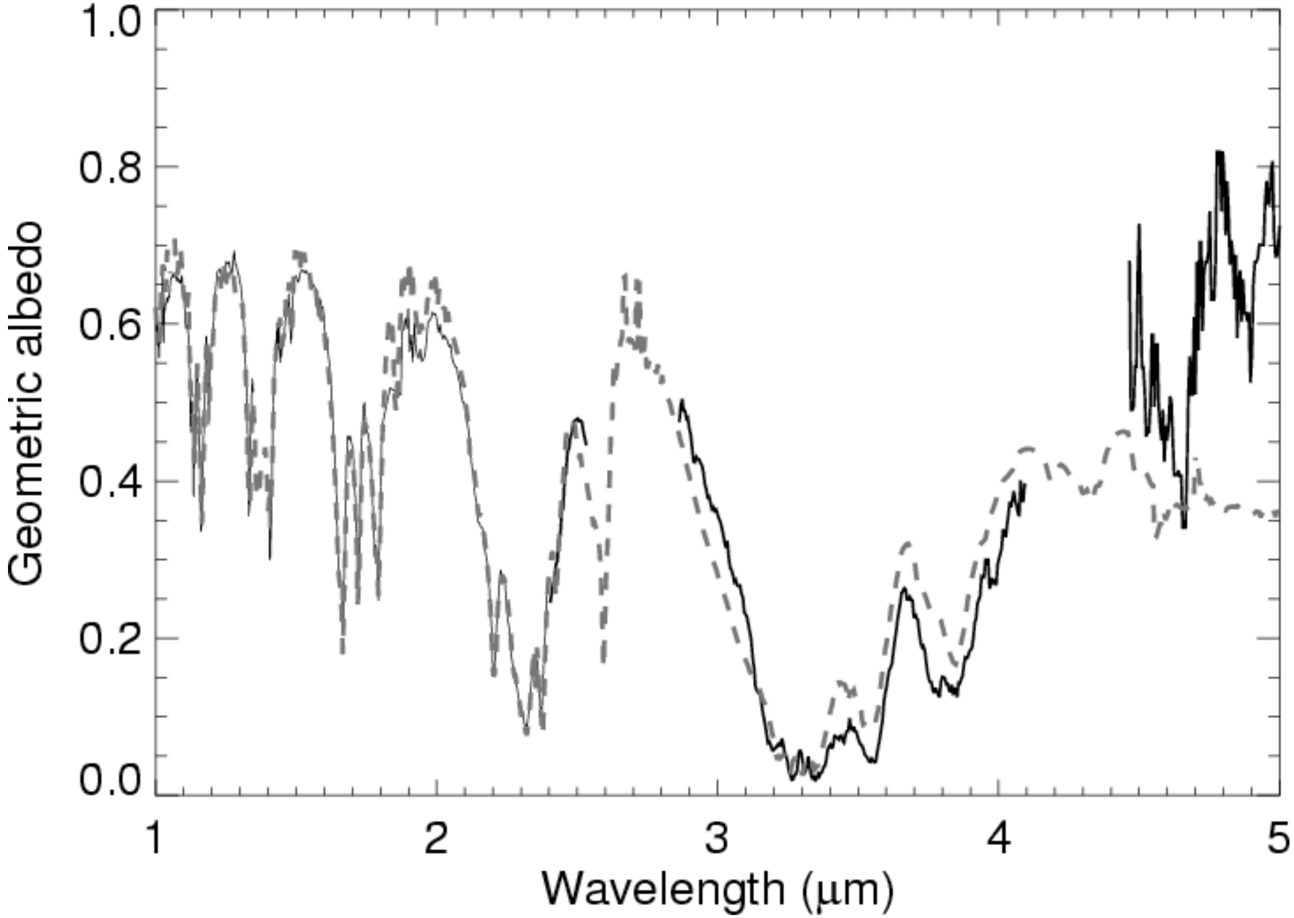
Earth-based observations (>1200 objects detected) :

- NIR spectrophotometry (VLT), Spitzer survey (-> a, T, d)

The Kuiper belt: Perspectives

- Near-term
  - Herschel, ALMA : survey of thermal emission -> T, a, d
- JWST
  - Spectra of all KBOs with R=100 (λ < 5 μm, NIRSpec)
  - Mid-IR spectrophotometry of all KBOs (5-30 μm, MIRI)
  - > definition of source regions for different types of KBOs
  - > Tests of migration models
- ELT
  - Deeper survey in the near and mid-IR (HARMONI, METIS)
  - Search for companions (MICADO)

Surface composition of Pluto (Keck, VLT)
(Ices : N_2, H_2O, CH_4, CO_2, NH_3 CH_3D…)



Program for JWST/NIRSPEC: all KBOs (mv<25) with R = 100

Program for ELT/METIS:10-20 KBOs in L and M bands with R = 100-1000

Protopapa et al. 2008; Sonneborn et al. 2006; METIS Science Analysis Report, Brandl et al. 2009

Conclusions

- Solar-system studies must be revisited in the light of the discovery of planetary systems
- Terrestrial planets: ELT studies are complementary to in-situ space missions
- Giant icy planets: JWST and ELT are the only tools
- Comets and KBOs: JWST and ELT are needed for statistical studies
- JWST will come first, with complete IR coverage, but with a limited spectral resolving power (3000)(well suited for outer satellites, TNOs and comets)
- ELT will be ideal for high-resolution imaging spectroscopy in the near and mid-IR (well suited for planets and comets)