Studies of tenuous atmospheres, comets and trans-neptunian objects with JWST

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Based on focus groups white papers (PASP, in press)

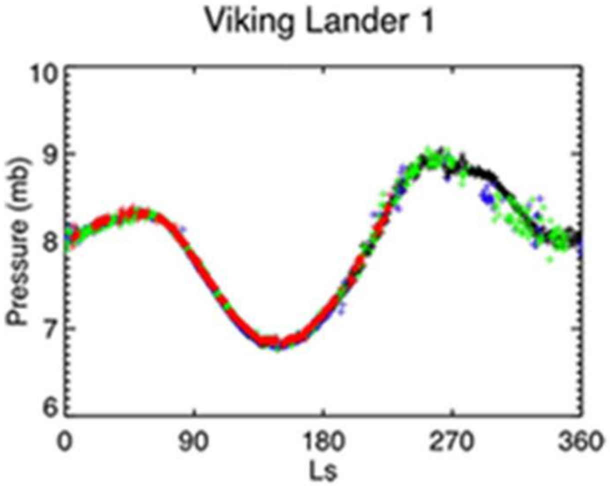
- Mars (Villanueva et al.)
- Comets (Kelley et al.)
- TNOs (Parker et al.)

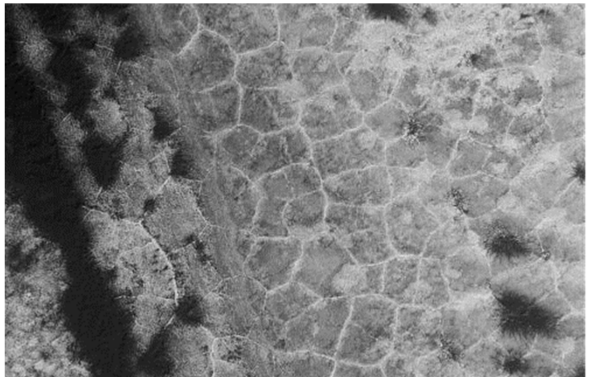
Tenuous solar system atmospheres

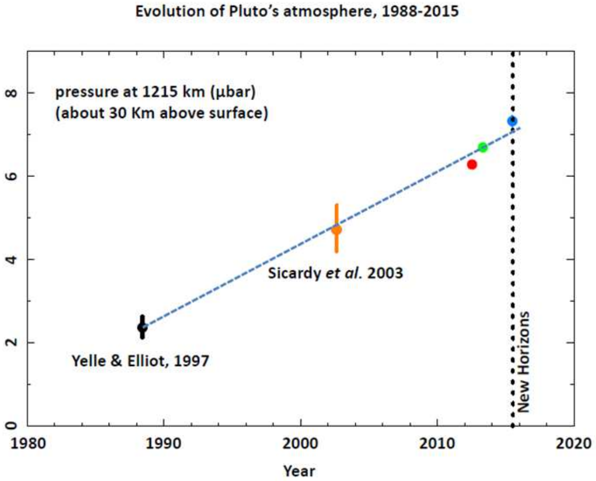
- Mars, dwarfs planets, Giant Planet satellites, comets
- Role of surface ice as partial or dominant source of atmosphere (sublimation)
  - CO_2 and H_2O on Mars (polar caps)
  - N_2 (+ CH_4, CO) on Pluto and Triton
    - A few other TNOs (Makemake, Quaoar, Eric…) have volatile ices on their surfaces but no detected atmosphere yet.
  - SO_2 on Io, H_2O on other galilean satellites
  - H_2O + many other (sub)surface ices in comets

- These "thin" atmospheres present large differences in terms of atmospheric "robustness"
    - Mars (~7 mbar), and Pluto/Triton (~10 µbar)
      - Dense enough that the atmosphere buffers the ice temperature from latent heat exchanges → pressure and ice temperature are ~uniform over the object, but pressure can vary seasonally
      - Atmospheric condensation/sublimation cycles influence surface morphology

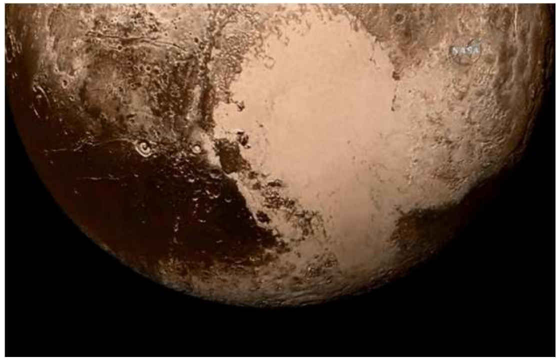
Mars vs Pluto



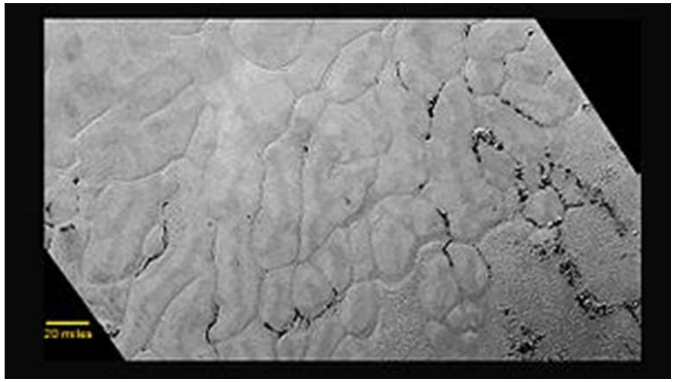




Pressure evolution (Sicardy et al. 2015)



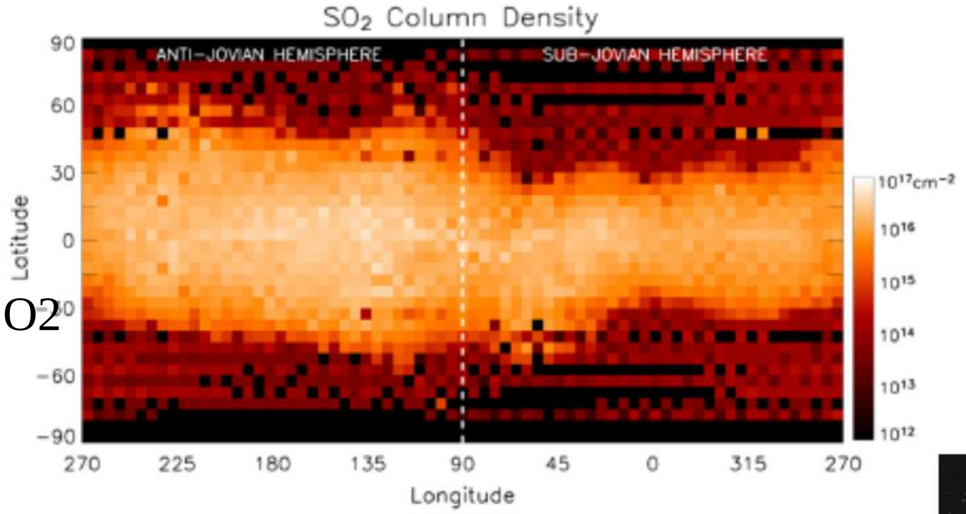
New Horizons



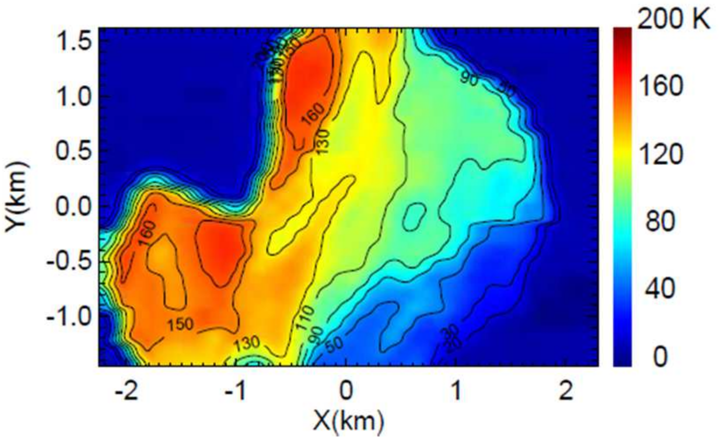
– Atmospheric “robustness”

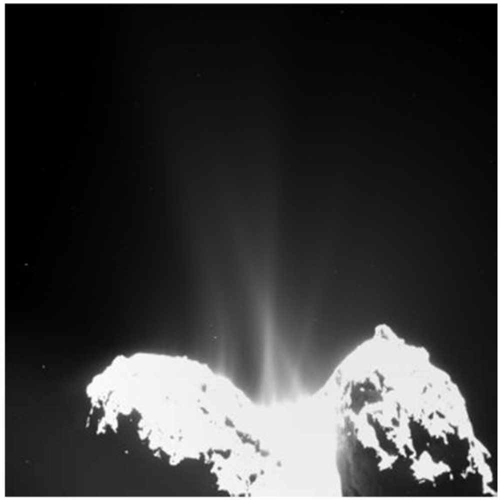
- Io (~10 nbar), other galilean satellites(~0.1-1 nbar? H_2O), comets
  - Atmosphere has negligible impact on surface heat budget
  - Surface temperature and atmosphere present large spatial variations

Io SO2



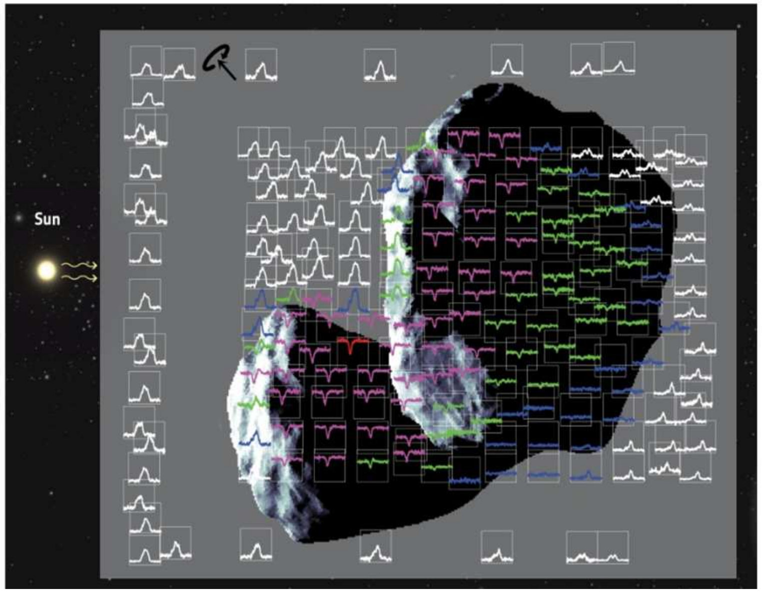
ROSETTA/MIRO: Surface temperature on 67P





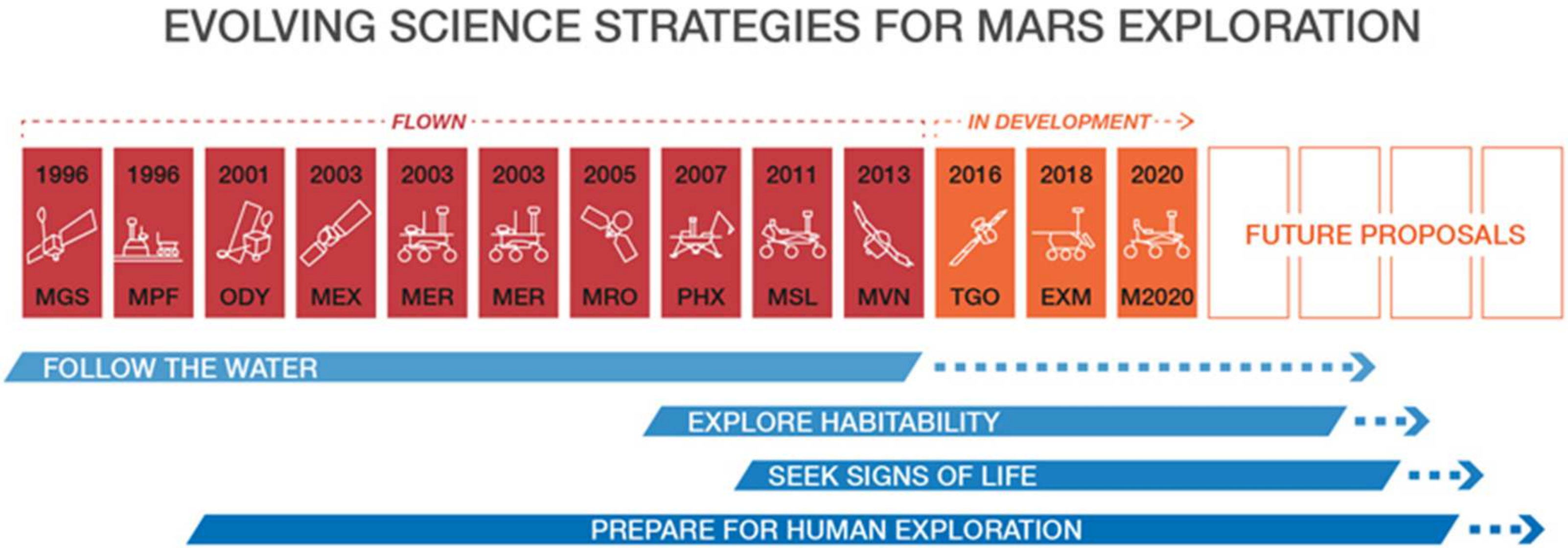
ROSETTA/NAVCAM

MIRO – 557 GHz H_2O line
September 2014 – 3.5 AU



Biver et al.(2015)

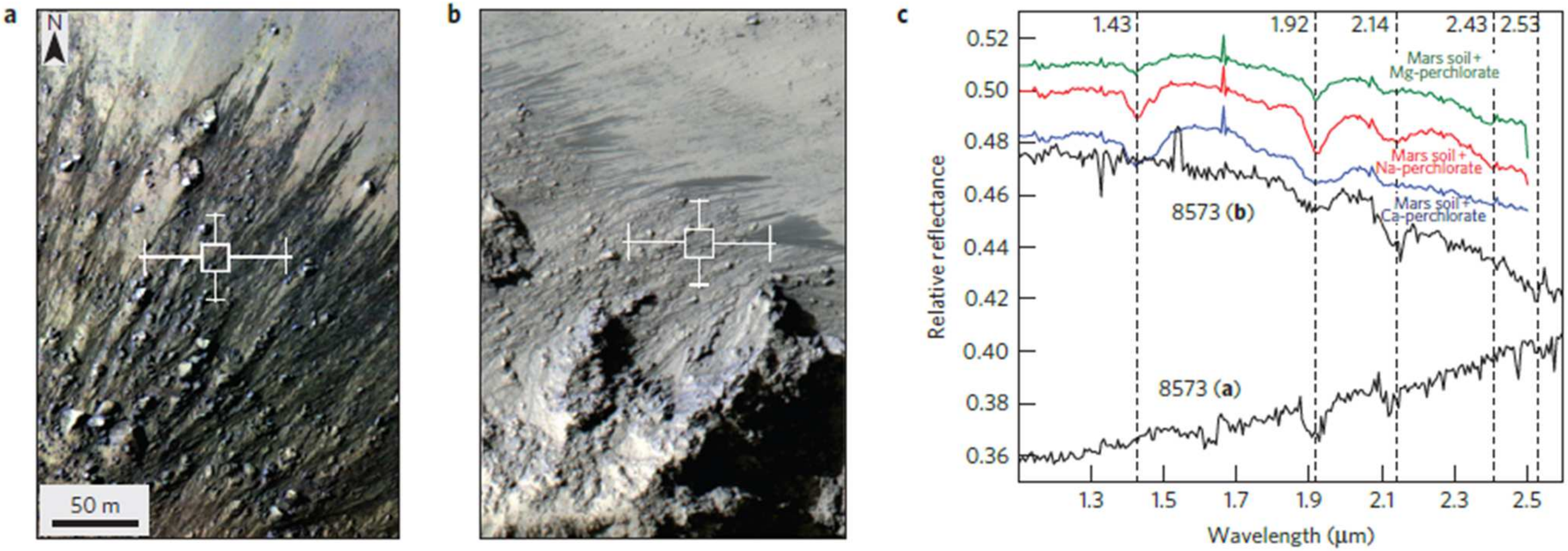
Mars



SAM (Sample Analysis at Mars) on Curiosity reports detection of organics (chlorobenzene and chloroalkanes) – Freissinet et al. (2015)

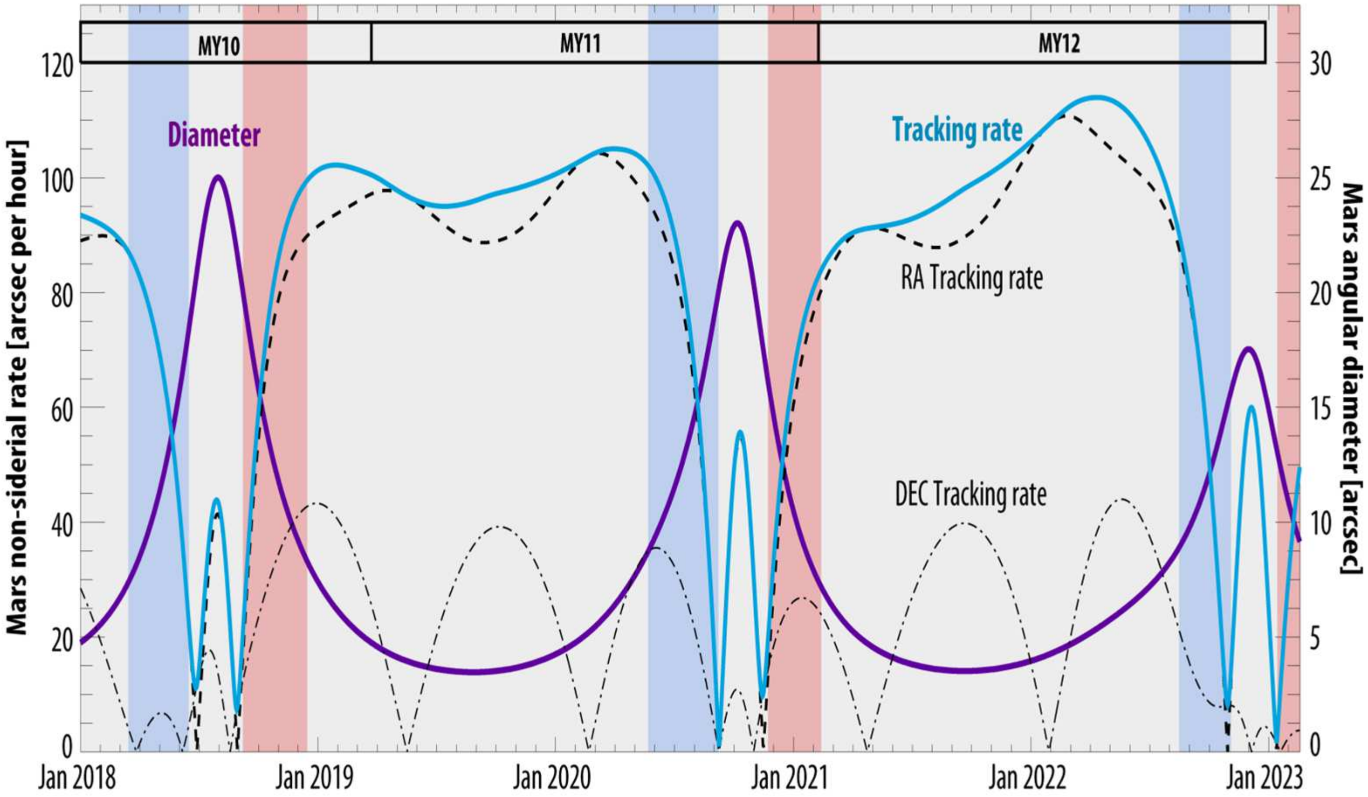
Mars: remote sensing spectroscopy can still lead to discoveries !

Present-day transient flows of hydrated salts, indicative of briny water on steep slopes
Mars Reconnaissance Orbiter / CRISM (Ojha et al. 2015)



Mars with JWST

- Limited windows ! A few months before/after opposition



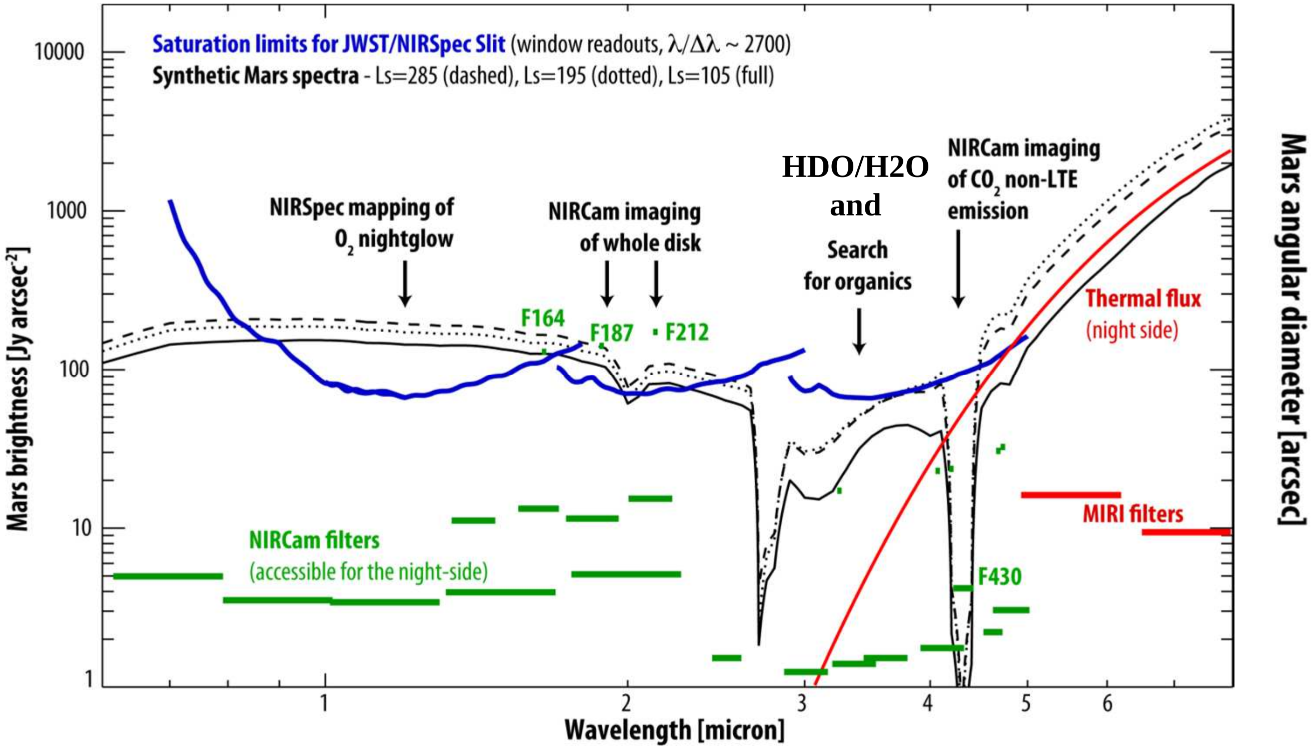
Mars with JWST

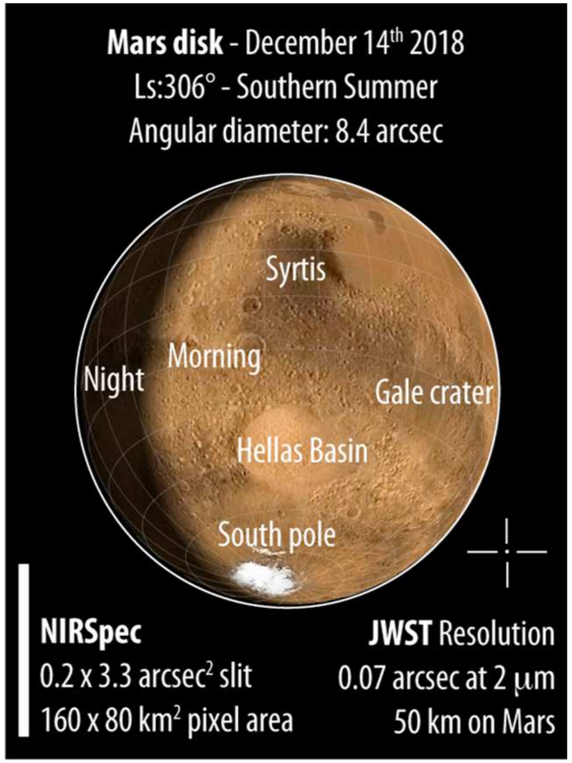
- Saturation issues

- Dayside brightness comparable to saturation level of NIRSPEC – except at 2.7-5 micron.

- High spatial resolution: 0.2 arcsec for NIRSPEC ⇔ 150 km at Mars– usually not achievable from ground

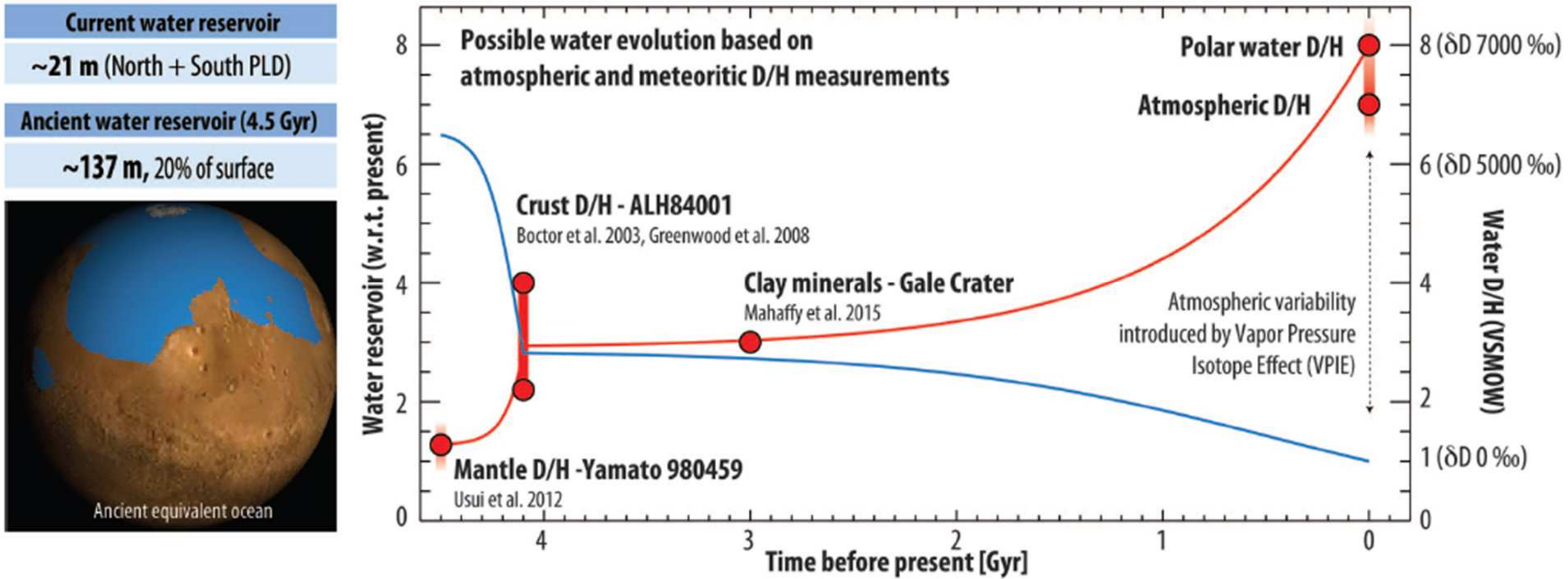
- Permits to isolate nightside





D/H on Mars: water history

- D/H in water enhanced compared to Earth → escape (thermal escape favors escape of H vs D).
- Can be used to estimate the **lost Global Equivalent Water Layer** (combining D/H and current GEL – polar layered deposits) : **~100 m**
- BUT: the atmosphere holds a fraction of Mars water → a buffer between the H2O main reservoir and the exosphere , and **atmospheric fractionation** effects occur.



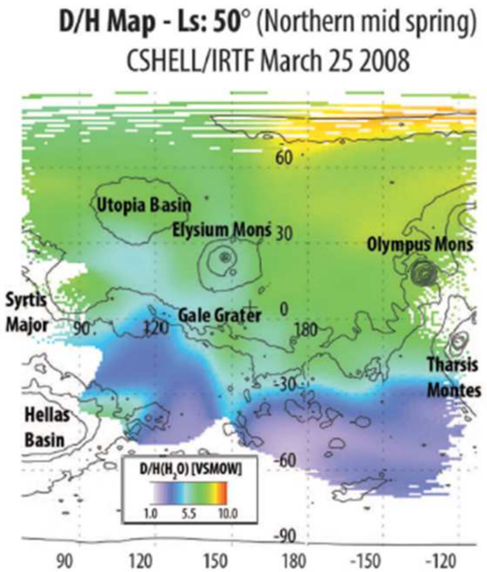
Villanueva et al. 2015

D/H on Mars:

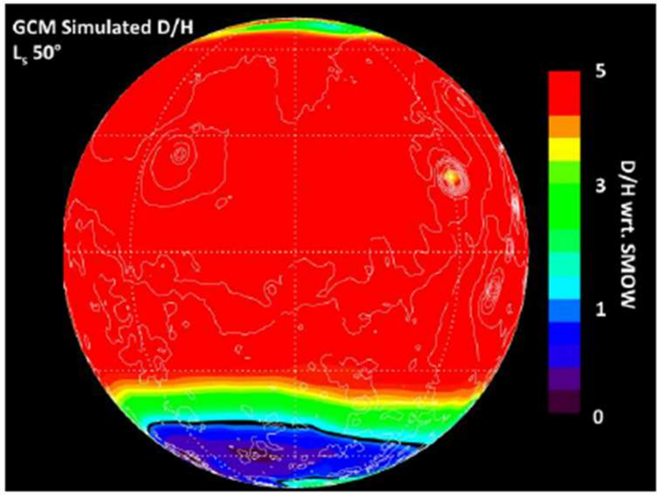
- H_2O can condense in atmosphere, and HDO condenses differentially (lower vapor pressure)
- Thus, the mean atmospheric D/H is not directly representative of that of the H2O polar reservoir and a model (GCM) is needed
- Recent discovery of large D/H variations (winter < summer) + regional variability, in poor agreement with model predictions.
- **Need to characterize this variability** on small spatial (~100 km) and temporal (day) scales and at very low H_2O abundances. Inform models and improve (D/H)bulk

Summer

Winter



Villanueva et al. 2015

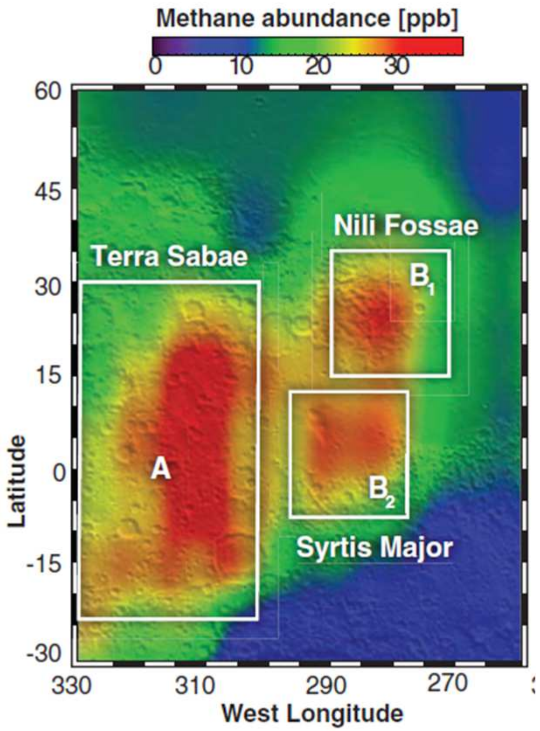


GCM

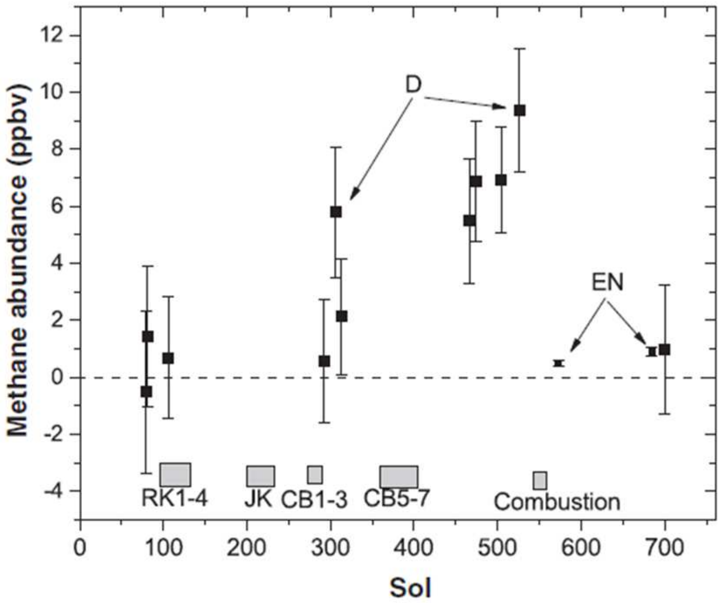
Montmessin et al. 2004

Organics on Mars: methane

- Detection of methane announced several times. Ppb amounts
- Different sources are possible – including abiotic ones (e.g. serpentinization, release from clathrates, external sources)
- Reports of large spatial/temporal variations, inconsistent with CH_4 chemical lifetime of ~300 years → Contamination of measurements? **Presence of methane on Mars still unconfirmed.**

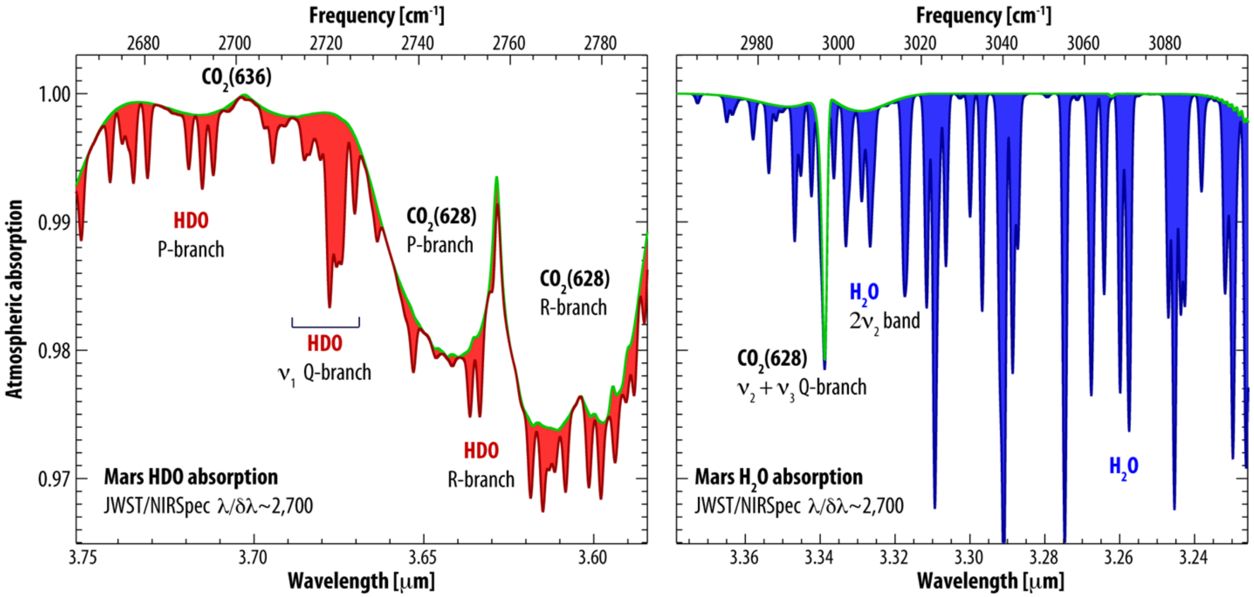


Mumma et al. 2009
3.3 um spectroscopy

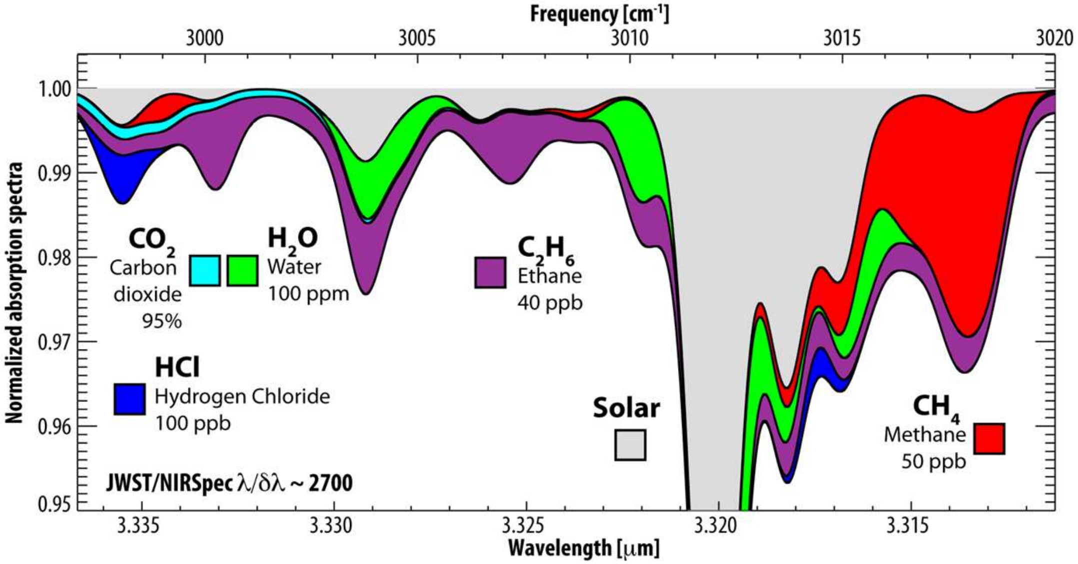


Webster et al. 2015
MSL/Curiosity / SAM

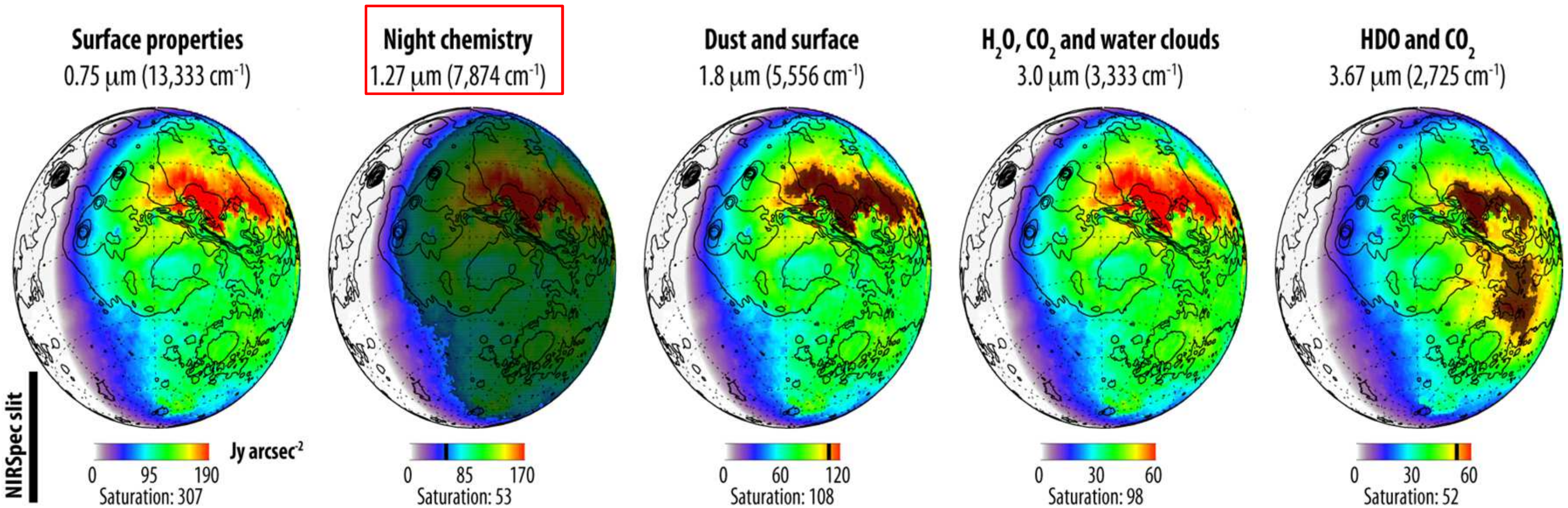
D/H and organics on Mars with JWST



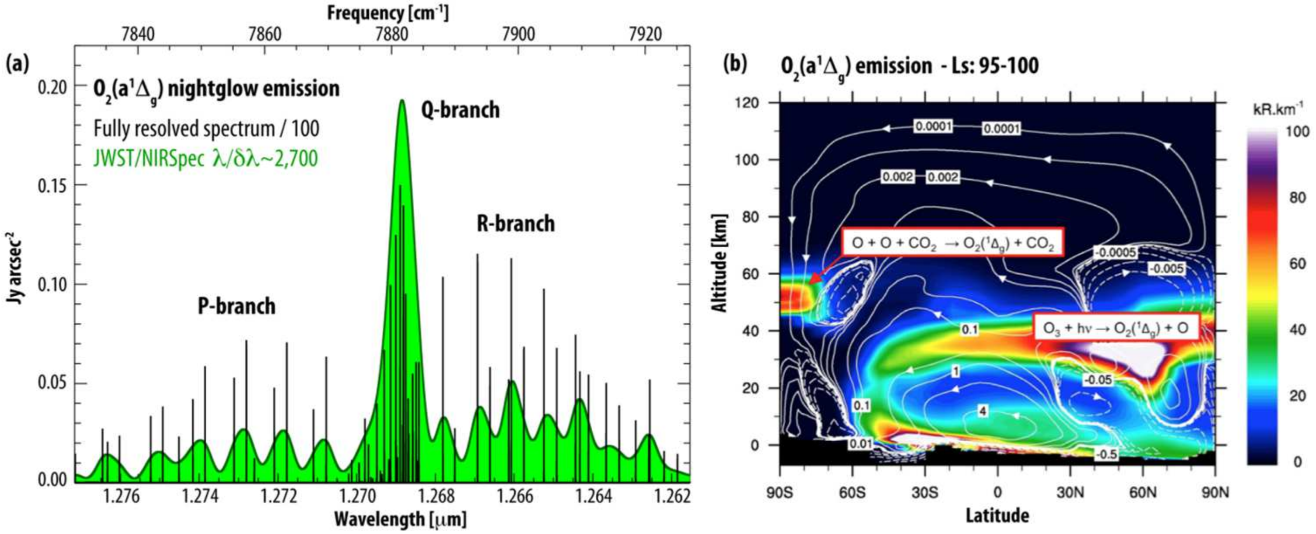
Strong complementarity to
ExoMars Trace Gas Orbiter (TGO)
2017-2019



Mars: additional goals



O_2 nightside airglow: tracer of chemistry and circulation in the upper atmosphere (> 50 km)



Comets

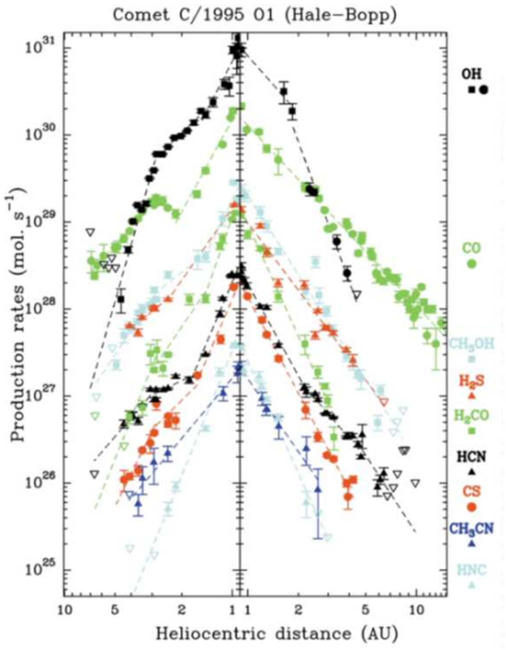
- Primitive material, providing information on the composition of the solar nebula at the time of their formation, 4.6 Gyr ago
- Very rich composition, dominated by water (50-80 % of ice content)
- The composition of comets, i.e. **the *relative abundance of different species***

\- **varies** from comet to comet

\- **varies** with heliocentric distance

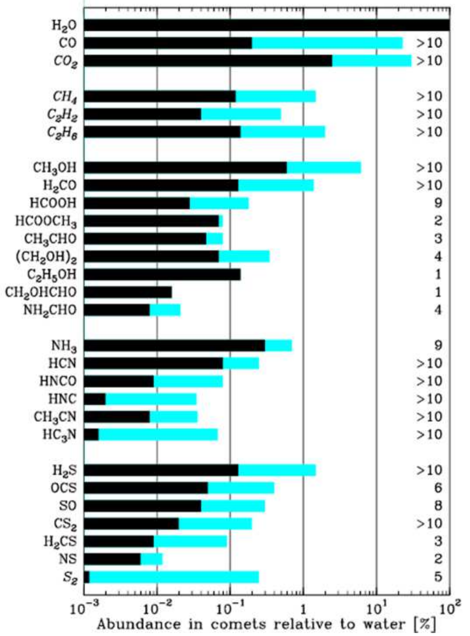
\- **varies** spatially on a comet (Rosetta)

Hale-Bopp; variation with distance



Biver et al. 1999

Comet diversity



Bockelée-Morvan et al. 2004

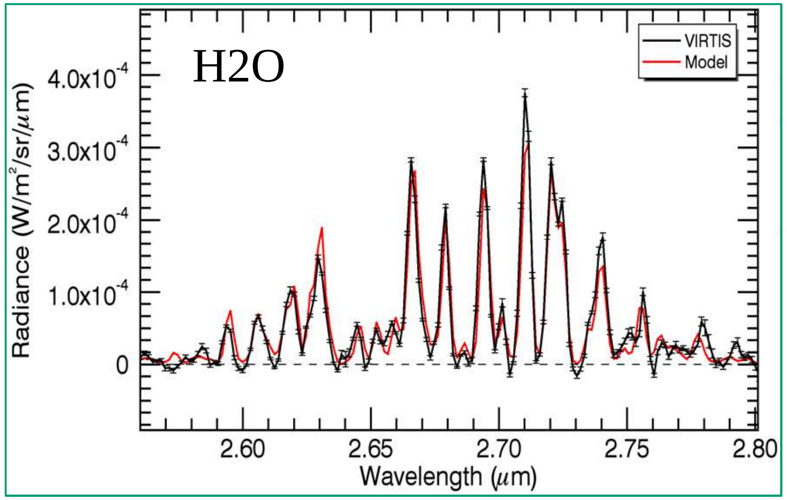
~30 species from spectroscopy

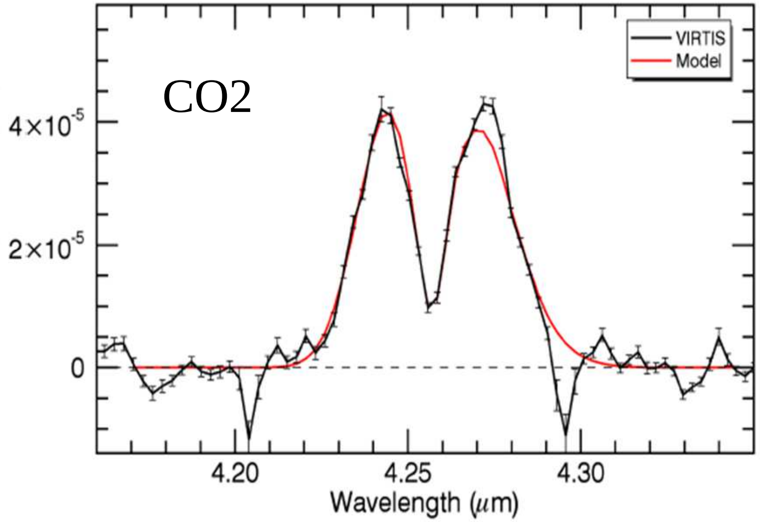
Ethanol (C2H5OH) and glycol aldehyde (CH2OHCHO) recently identified in C/2014 Q2 Lovejoy (Biver et al. 2015)

Many other species from Rosetta Mass Spectro. (ROSINA) and Philae Gas Chromatography (Philae)

IR spectroscopy from Rosetta

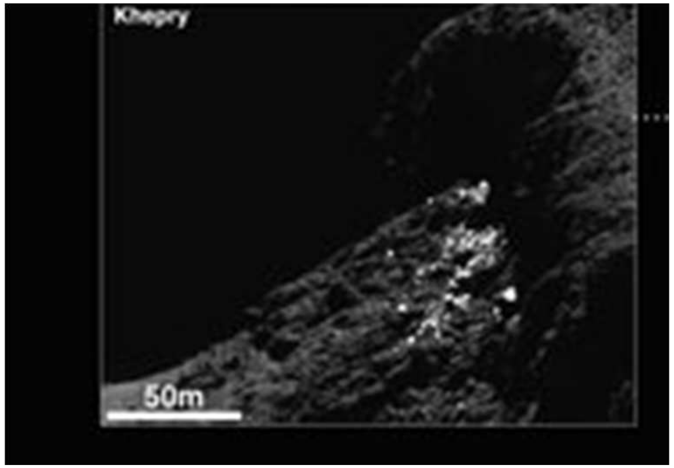
VIRTIS-H

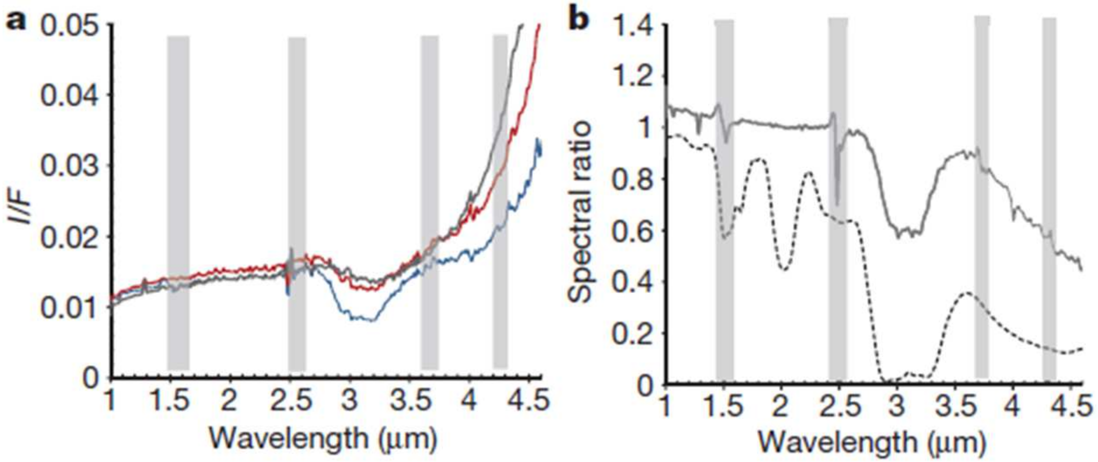

H2O


CO2

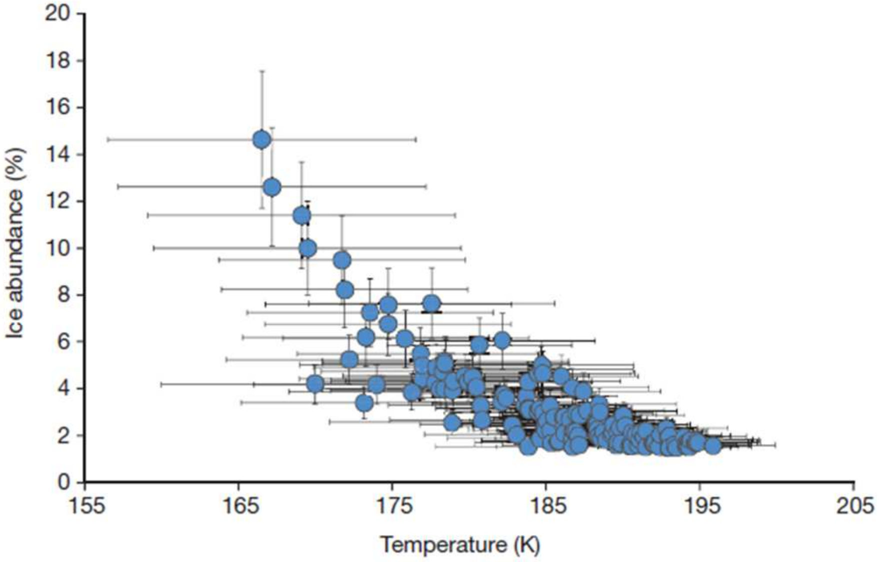
Bockelée-Morvan et al. 2015

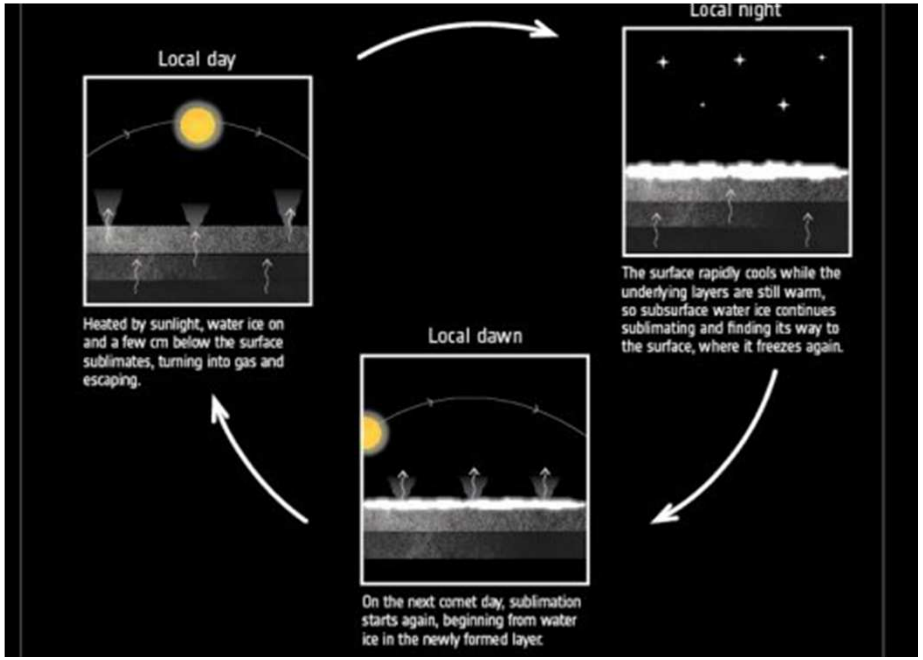
IR spectroscopy from Rosetta: H_2O ice cycle





De Sanctis et al. 2015



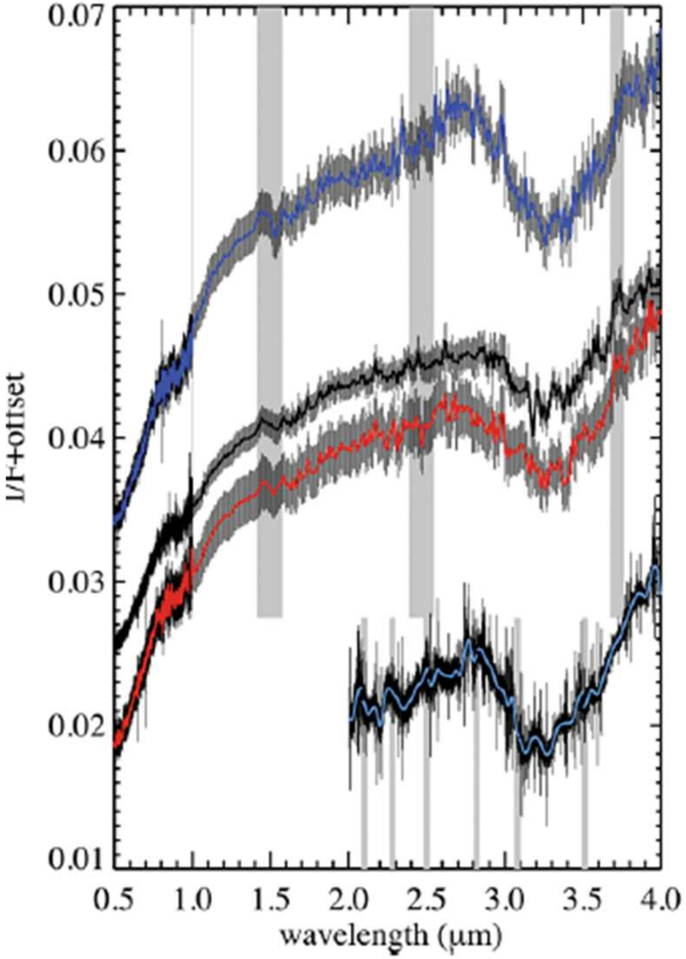


Heated by sunlight, water ice on and a few cm below the surface sublimates, turning into gas and escaping.

The surface rapidly cools while the underlying layers are still warm, so subsurface water ice continues sublimating and finding its way to the surface, where it freezes again.

On the next comet day, sublimation starts again, beginning from water ice in the newly formed layer.

Organics in 67P from Rosetta / VIRTIS



Capaccioni et al. 2015

3.2 um absorption on nucleus
OH-bond (carboxylic or alcoholic groups)

Ubiquitous: representative of the bulk pristine material of the nucleus?

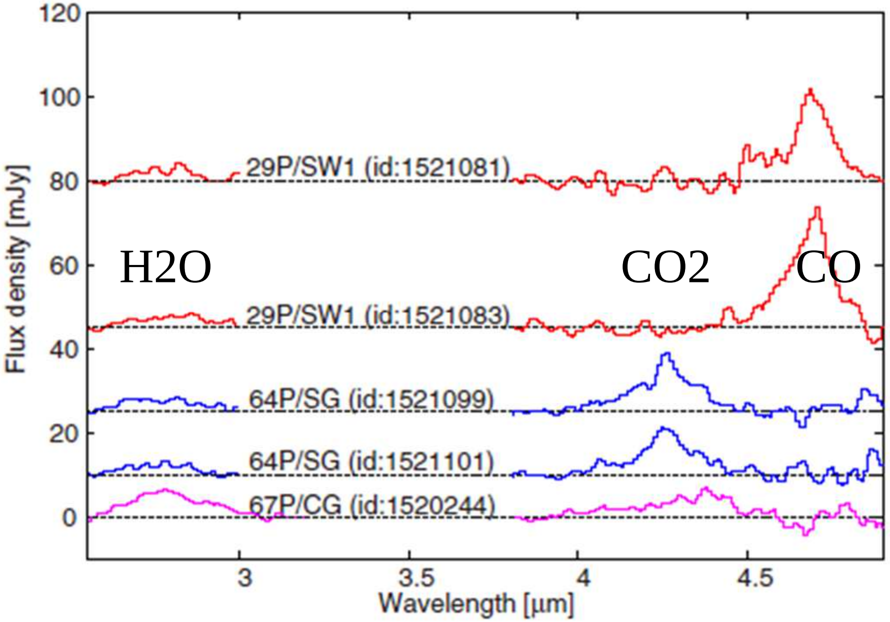
Comets with JWST

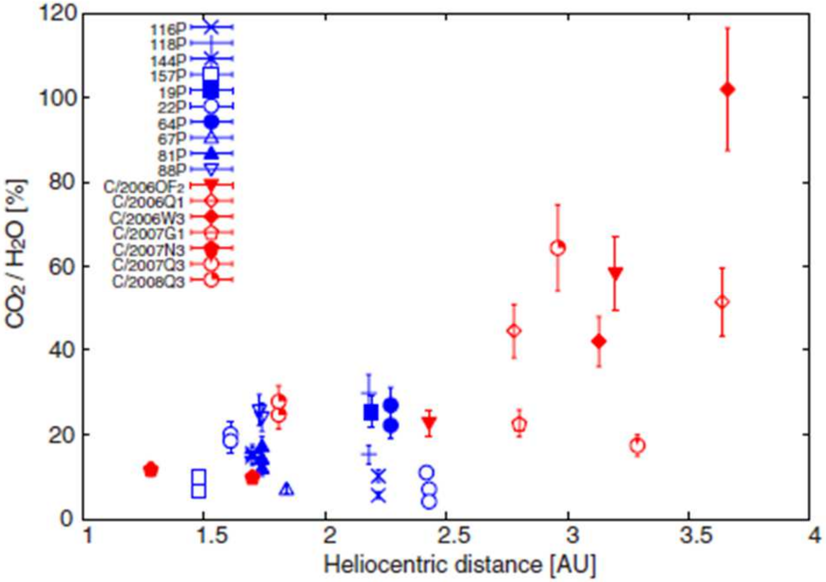
- **Study evolution of H_2O:CO_2:CO gas vs heliocentric distance**
- Study of icy grains in distant comets and determination of their crystalline vs amorphous nature
- Search for H_2O gas in weak and/or distant comets and in main-belt asteroids
- Search for surface ice and organics on distant inactive comets
- Simultaneously mapping of gas and dust in coma (MIRI)

See also poster by S. Milam et al.

Simultaneous measurements of H2O/CO2/CO vs rh

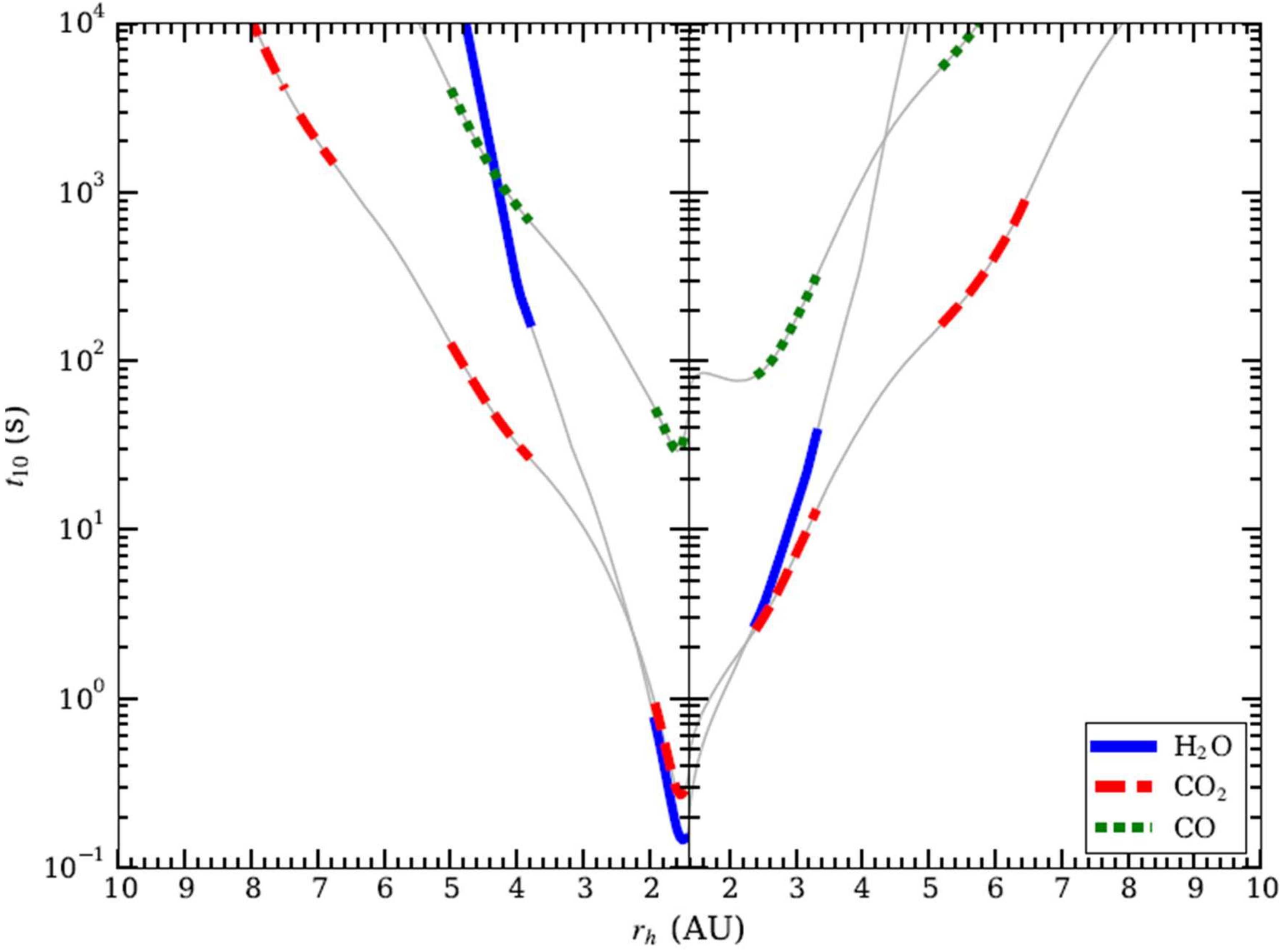
Akari: Ootsubo et al. 2013





- Mechanism for driving activity at large heliocentric distance?
  - Direct sublimation of pure CO2, CO ices ?
  - Exothermic crystallization of amorphous water ice accompanied by release of trapped gases (also proposed for distant comet outbursts)

JWST / NIRSPEC sensitivity: H2O/CO2/CO for S/N = 10 on typical comet (C2013 A1 Siding Spring)



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H_2O icy grains: amorphous or crystalline

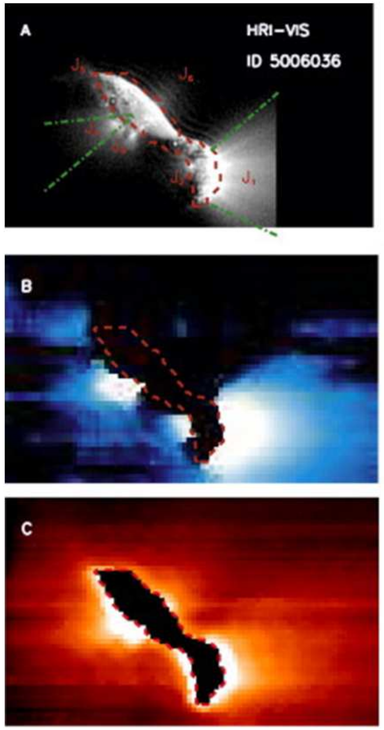
- Icy grains are observed in cometary comae

Important secondary source of H_2O production

- Could be a diagnostic of the form in which

ices accreted to form cometary material:

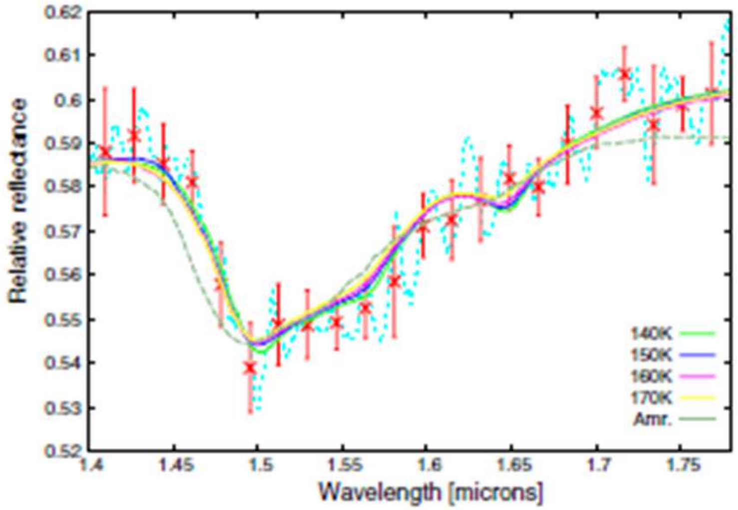
  - Amorphous?
  - Crystalline?
  - Clathrates?



ICE

DUST

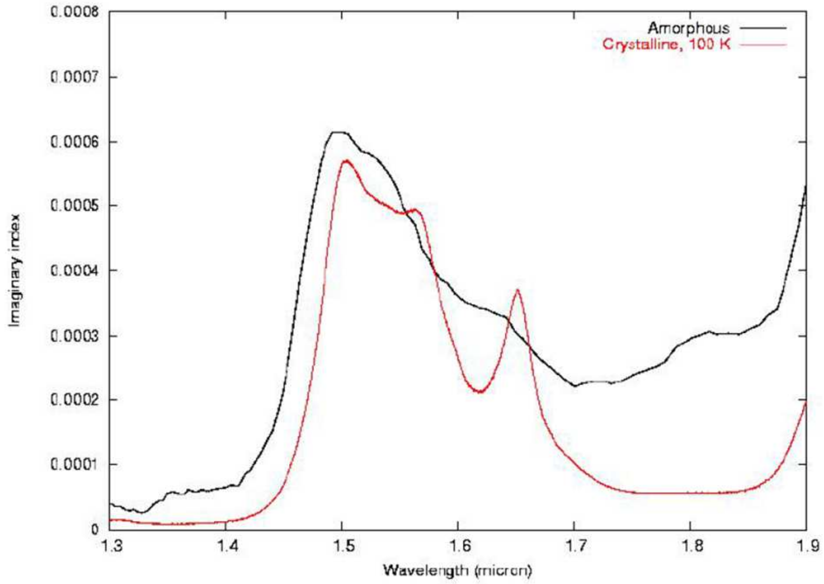
103P Hartley 2
Protopapa et al. 2014



C/2002 T7
Kawakita et al. 2006

H_2O icy grains: amorphous or crystalline

- Diagnostic for crystallinity: 1.65 um feature
- But requires a distant comet (T < 140 K, i.e. rh > ~3.5 AU) ; otherwise grain crystallization may occur by solar heating in coma



- Well suited to JWST/NIRSPEC with R=0.1” resolving the coma

Comets with JWST

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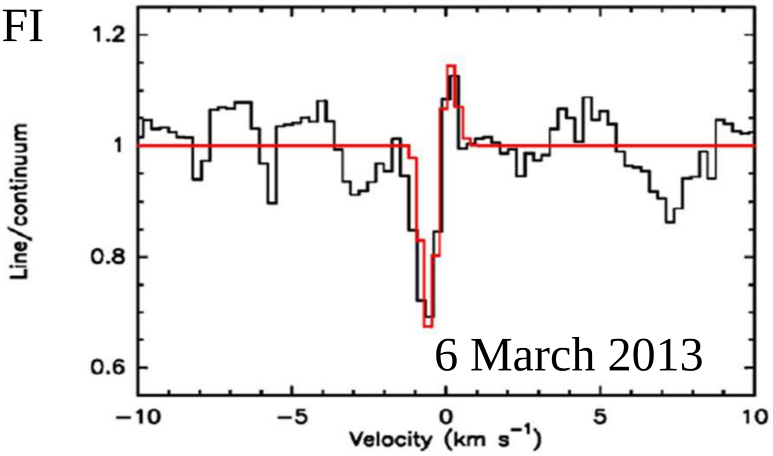
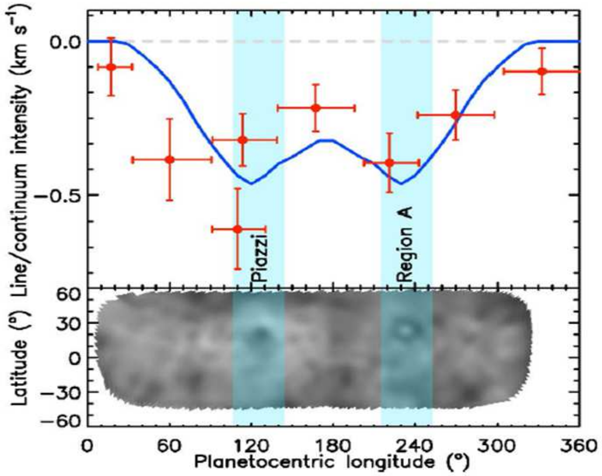
H2O in weak comets / asteroids

HIFI



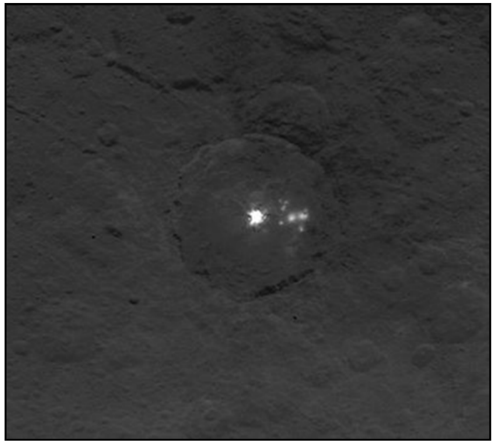
6 March 2013



CERES: *Kueppers et al. 2014*

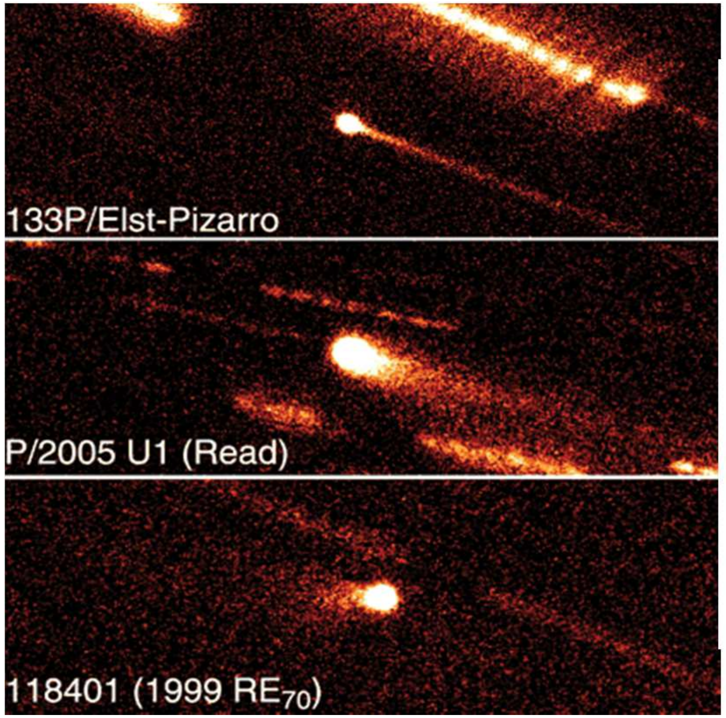
- $Q(H_2O) = 10^{26}$ mol/s (3 kg/s) ⬄ 0.6 km^2 of ice
- 10^{-7} of Ceres surface
- variable on hour and months time scales

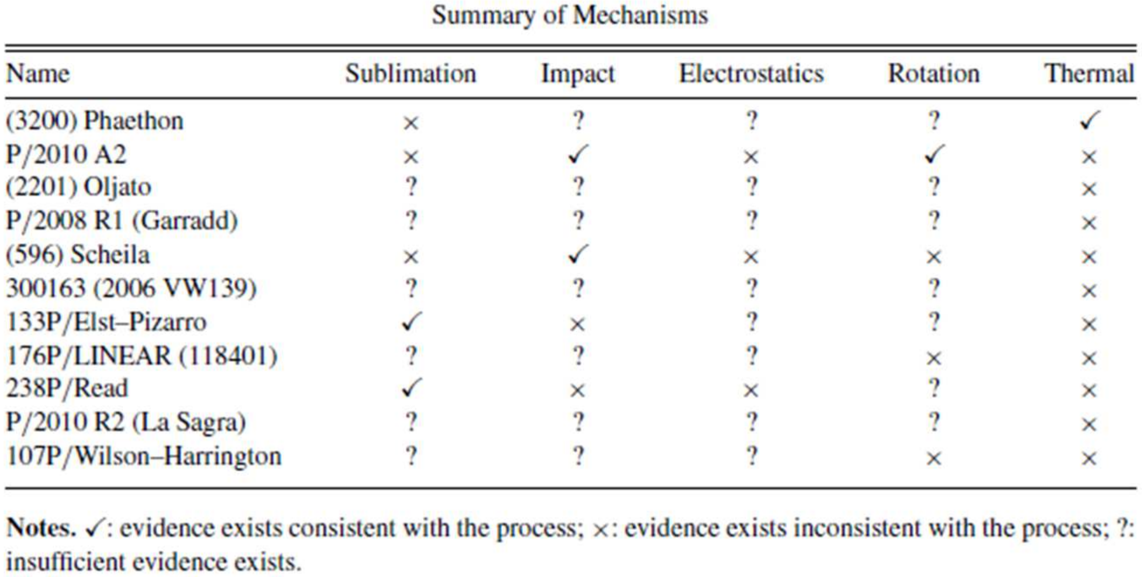
Asteroids can emit gas and be water-rich
Blurring of the comet/asteroid distinction



NASA/Dawn

Transition objects: main-belt comets aka active asteroids





Summary of Mechanisms

Name	Sublimation	Impact	Electrostatics	Rotation	Thermal
(3200) Phaethon	×	?	?	?	✓
P/2010 A2	×	✓	×	✓	×
(2201) Oljato	?	?	?	?	×
P/2008 R1 (Garradd)	?	?	?	?	×
(596) Scheila	×	✓	×	×	×
300163 (2006 VW139)	?	?	?	?	×
133P/Elst–Pizarro	✓	×	?	?	×
176P/LINEAR (118401)	?	?	?	×	×
238P/Read	✓	×	×	?	×
P/2010 R2 (La Sagra)	?	?	?	?	×
107P/Wilson–Harrington	?	?	?	×	×

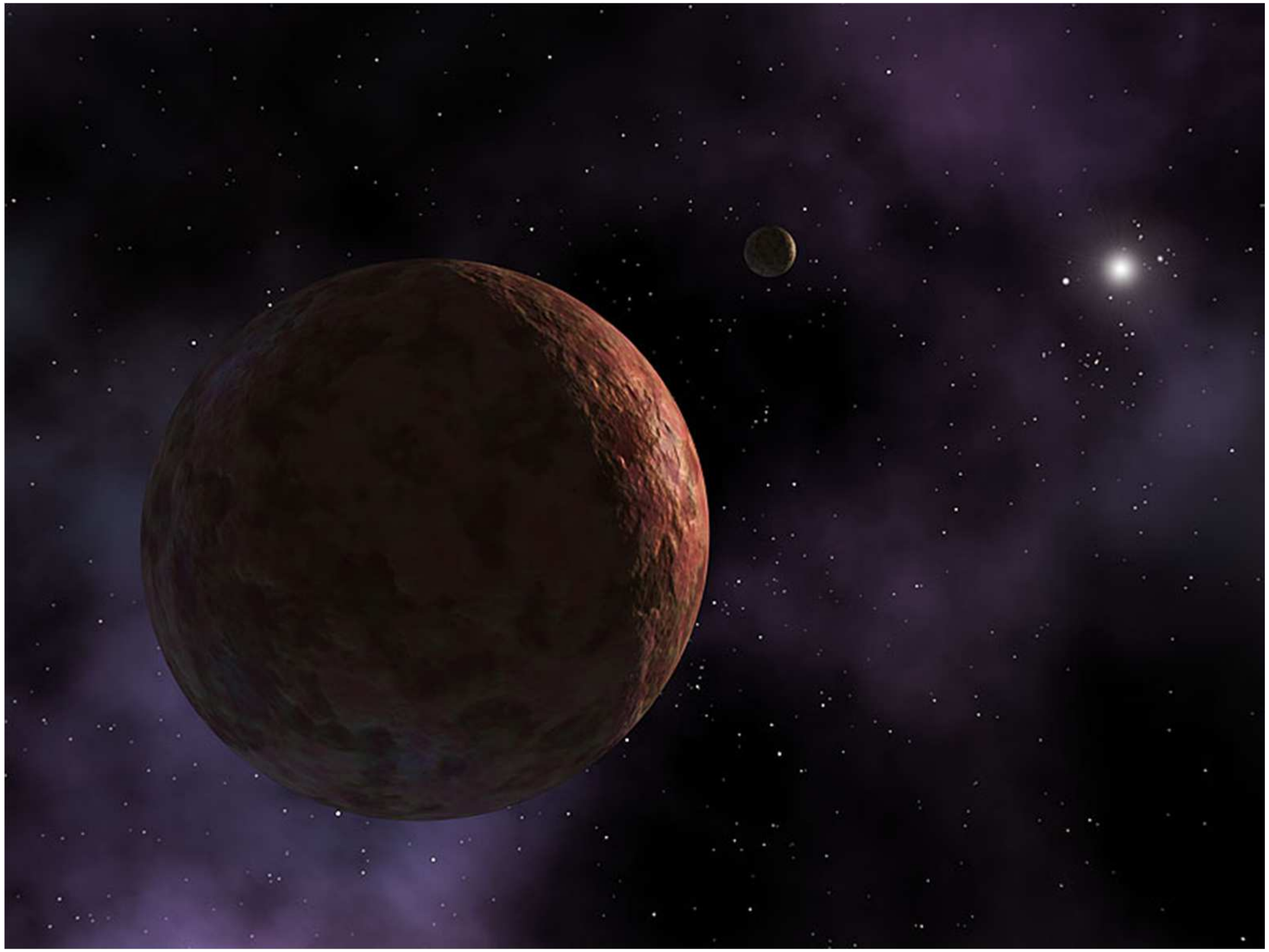
Notes. ✓: evidence exists consistent with the process; ×: evidence exists inconsistent with the process; ?: insufficient evidence exists.

Jewitt 2012

To date, no successful searches for volatiles in these objects

Sensitivity for H2O at 2.7 μm
NIRSPEC/ R= 100: **$Q(H_2O)$ = 10^{25} mol/s,** S/N = 4 in 1 hr.
Typically 10 times more sensitive than Herschel/HIFI

Trans-neptunian objects: composition and thermal properties

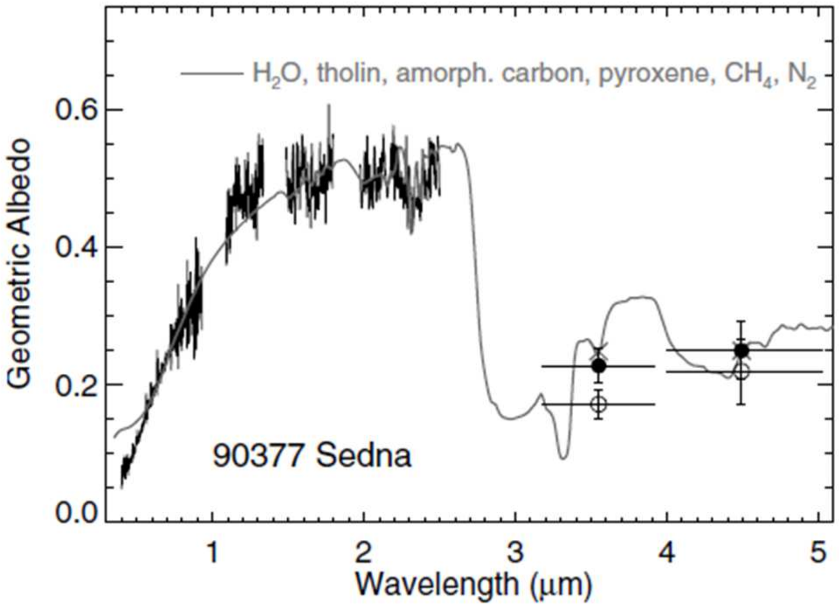


For New Horizons
image,
wait until 2019…

TNO composition (and Centaurs, and cometary nuclei)

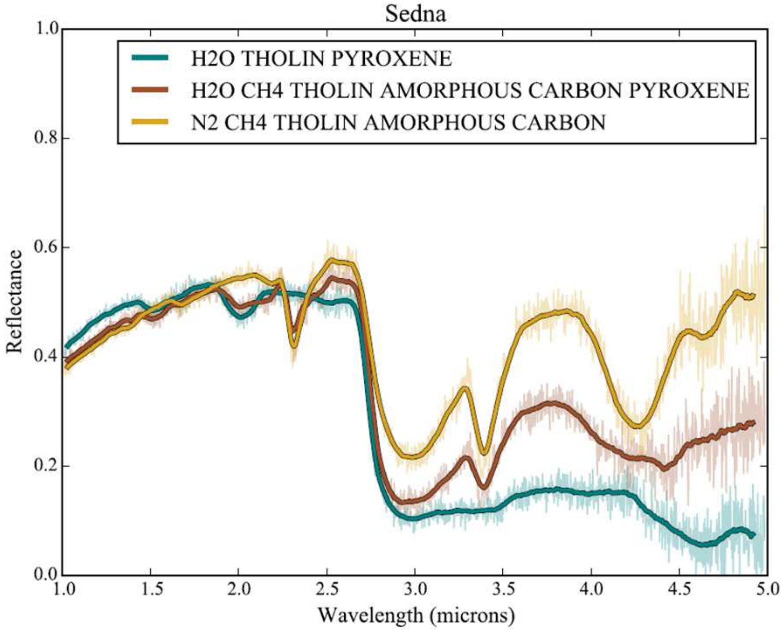
- Current knowledge of TNO composition is based on (optical and) near-IR (1 – 2.5 um) spectroscopy.
  - Only several tens of objects (out of population of ~1600) reasonably well-characterized
  - Classes include: (i) water ice rich (ii) featureless (iii) volatile-rich (a few large ones) (iv) other (methanol, ammonia…) few)
- Opening of the 2.5-5 um range (NIRSpec, NIRCam) gives access to the strong fundamental vibration modes, permitting to:
  - Confirm / identify new volatiles (e.g. N2, CH4, CH3OH…) and their irradiation products (ethane, ethylene, etc…)
  - Help with identification of the coloring agents of KBO surfaces: methanol, complex organics…
  - More generally, try to relate composition to other physical parameters (color, size, etc…) and orbital parameters → evolution diagnostics

KBO Spectroscopy with NIRSpec

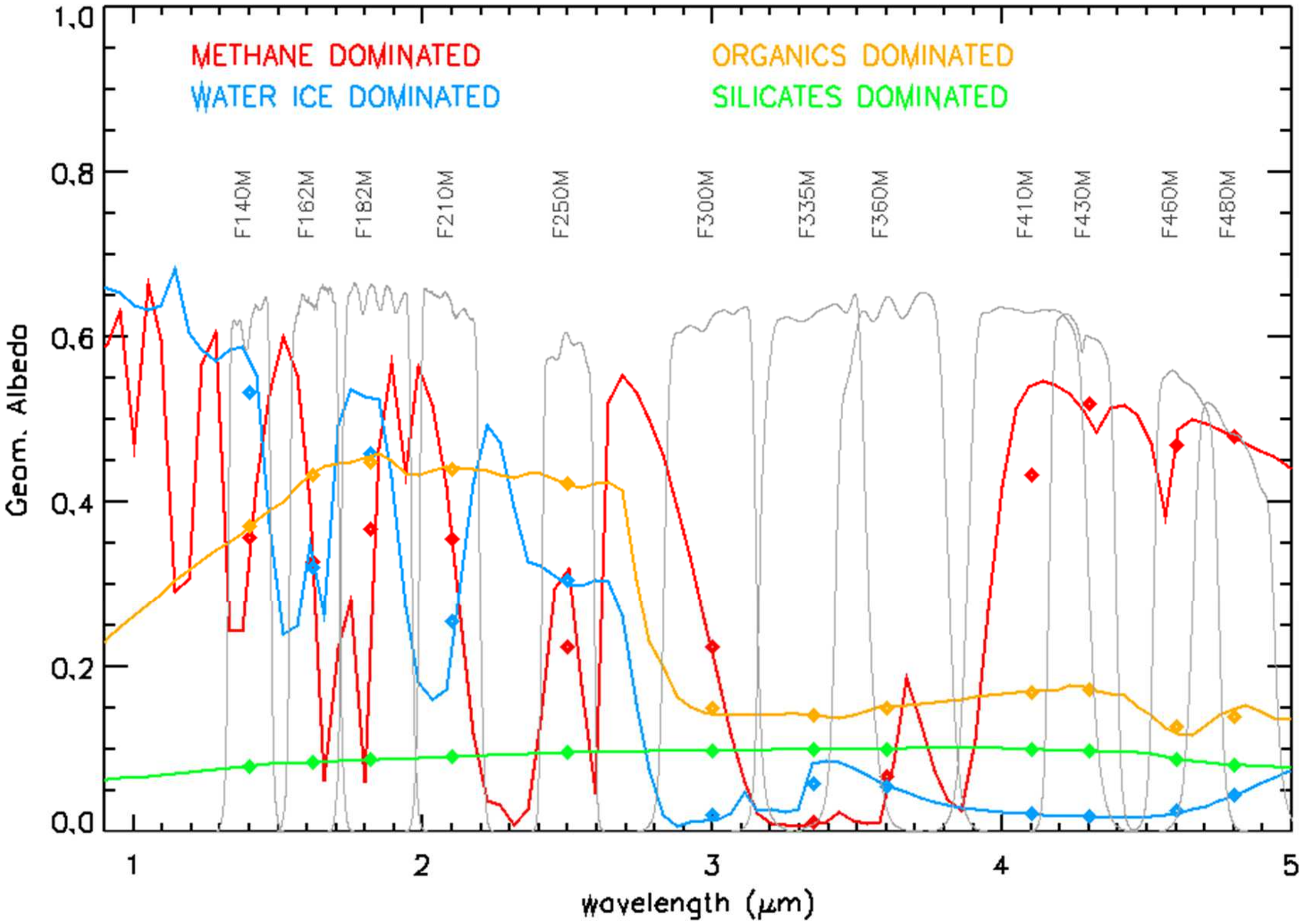


Emery et al. 2007

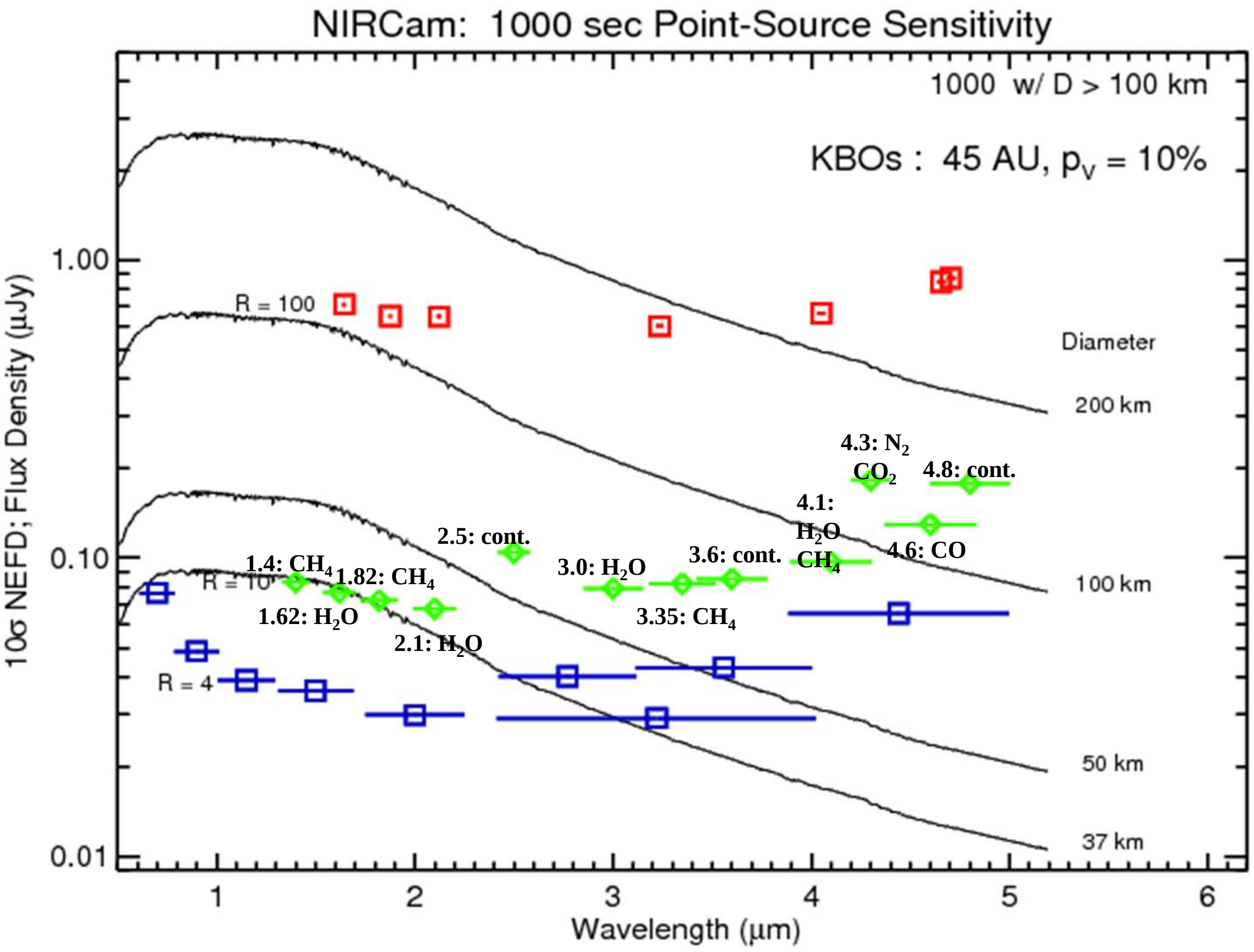
Sedna (76 AU)
NIRSPEC
10000 sec integration, noise included



KBO Photometry with NIRCam



KBO Photometry with NIRCam

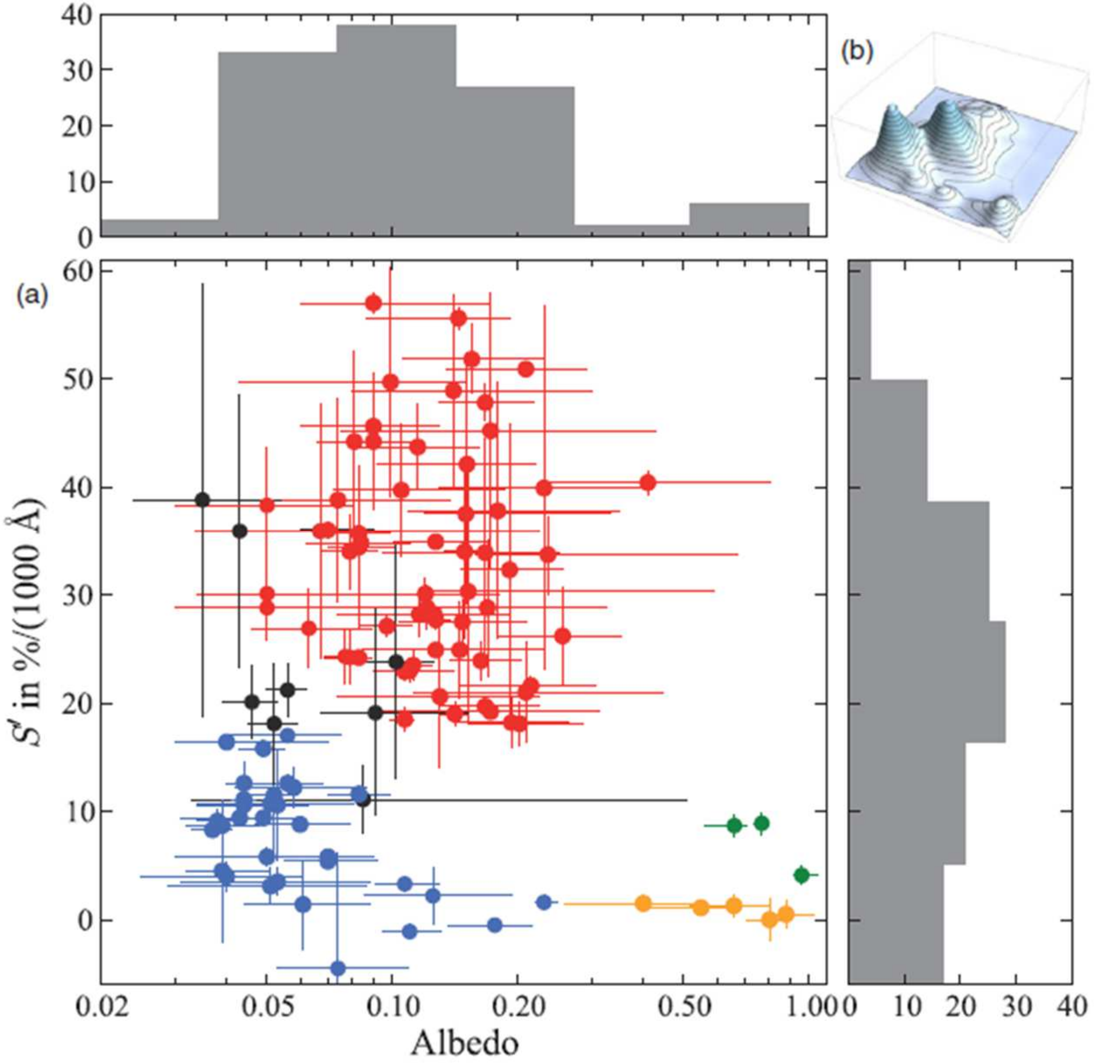


A first-order “photometric approach” of composition on large samples (all objects > 100 km). Permits a more global assessment of the compositional trends, esp. determine abundance of water at surface

Relating albedo to colors
… and to composition ?

Red

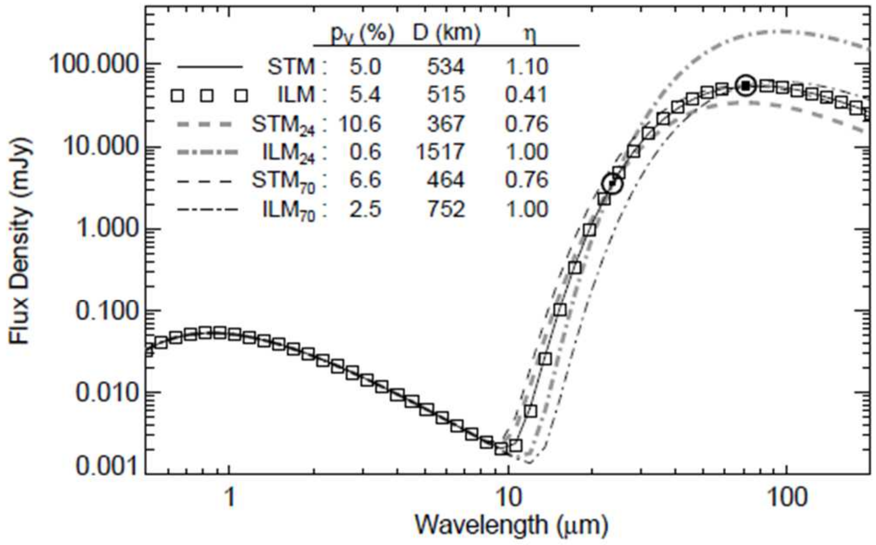
Neutral



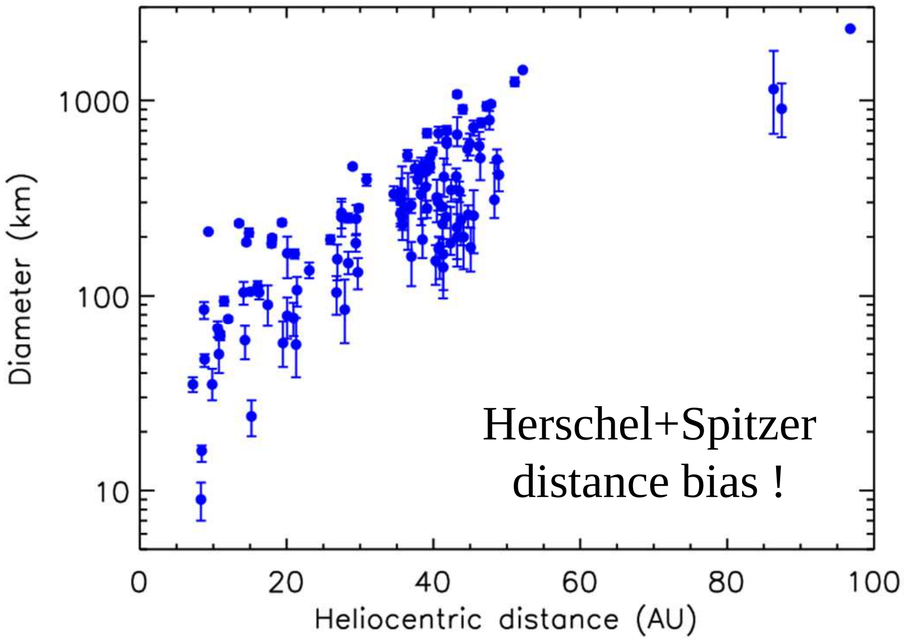
Lacerda et al 2014

KBO radiometry: size, albedo & thermal properties

- Thermal flux at several λ, combined with optical flux provides: diameter, albedo and thermal regime (thermal inertia)
- Was extensively used by Spitzer and Herschel surveys; most efficient when both the Wien tail and the maximum (or beyond) of the Planck function are probed.



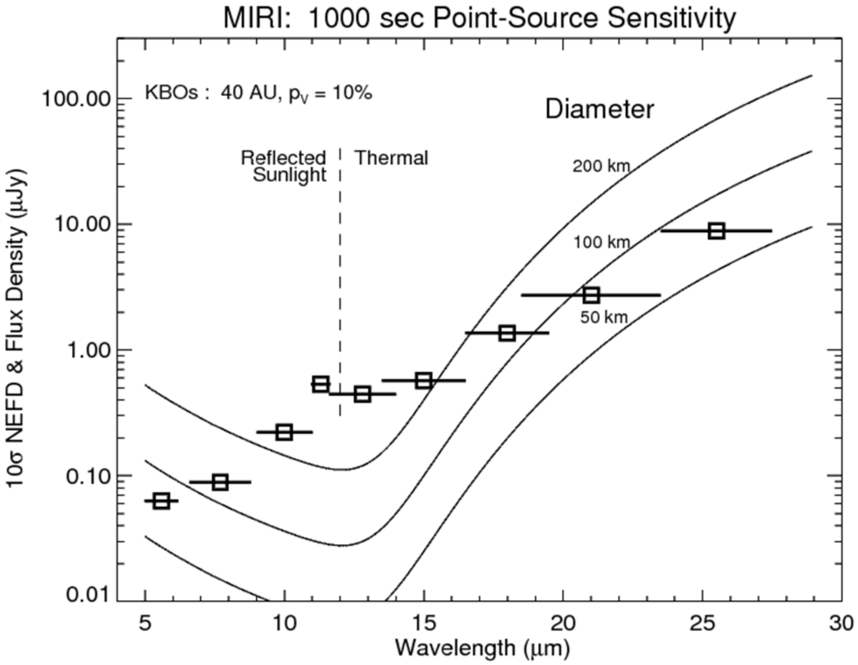
- Stansberry et al. 2008



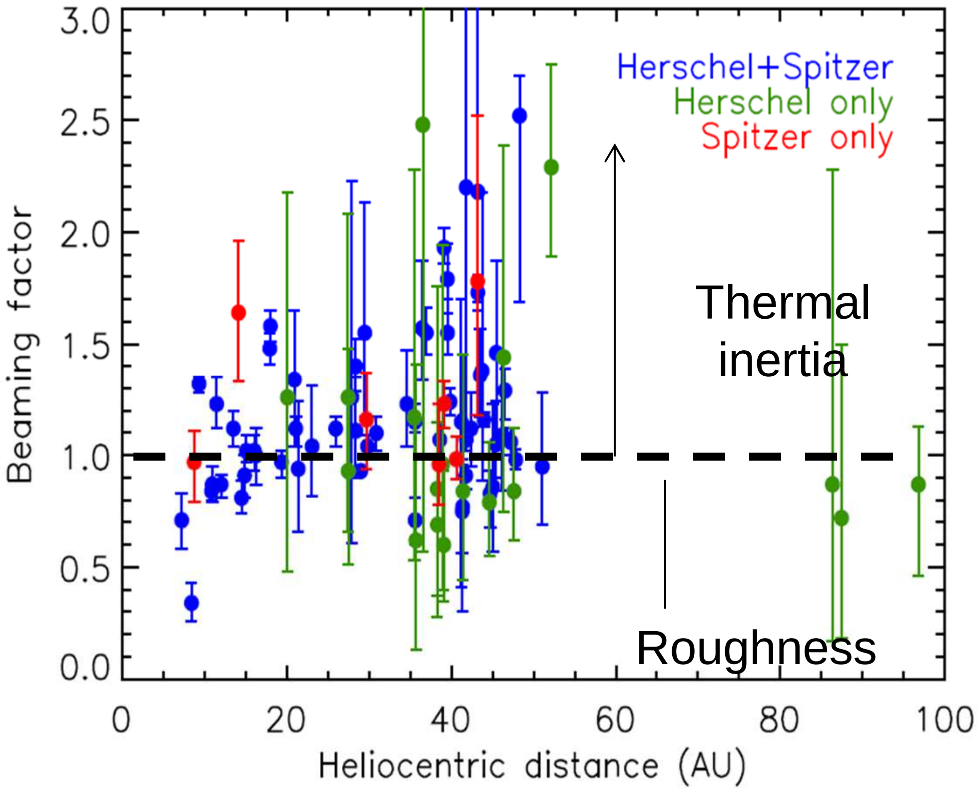
Herschel+Spitzer distance bias !

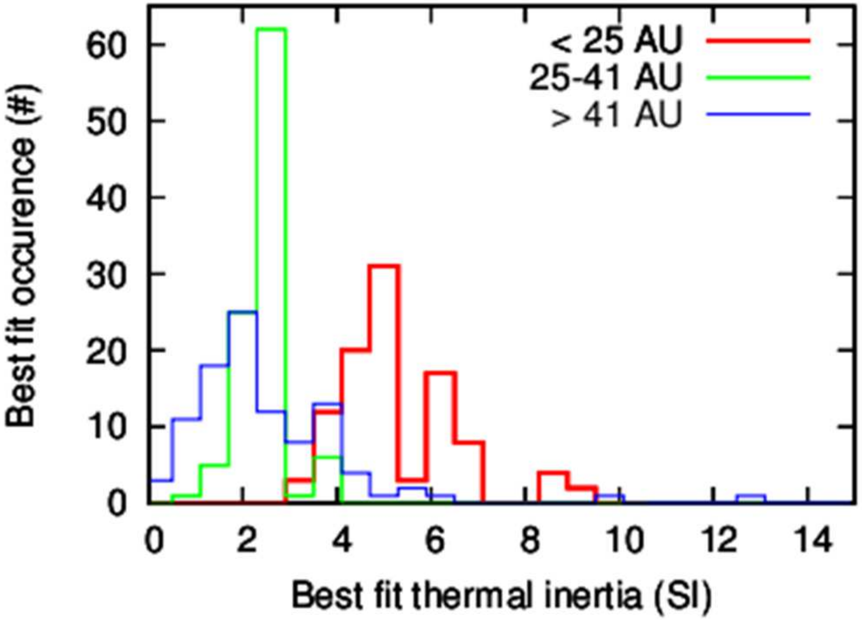
KBO radiometry with JWST / MIRI

- In spite of increased sensitivity w.r.t. Spitzer (giving access to objects < 100 km), MIRI *alone* is not an efficient absolute TNO size radiometer because the wavelength range ends at 28 micron.
  - Needs to combine with other measurements
    - ALMA: 500 objects reachable (but emissivity issues?)
    - SPICA ?
    - **Occultations** – growing number as predictions improve (GAIA)
  - If size is known independently, MIRI becomes an outstanding tool to study **surface thermal properties**



TNOs thermal properties

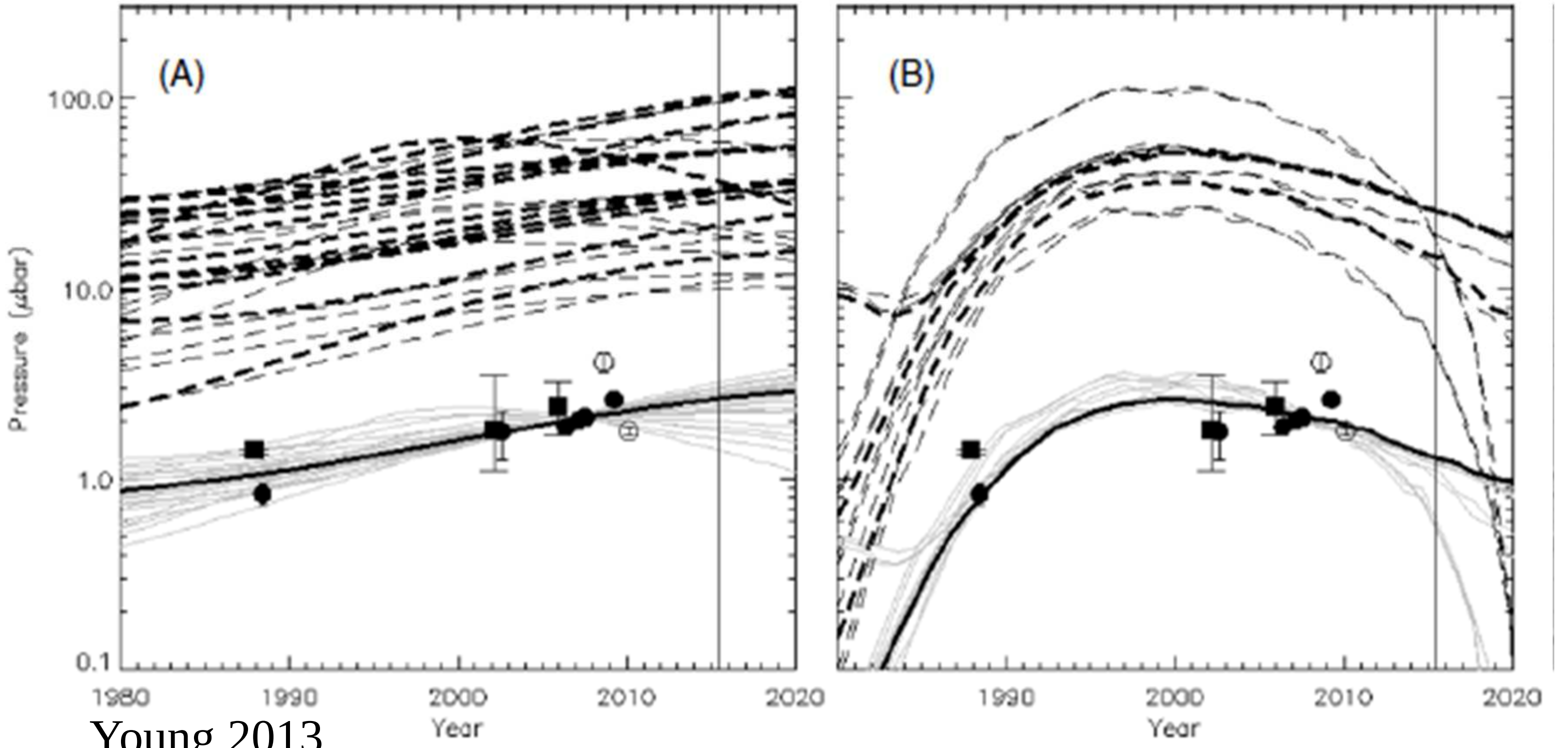




Lellouch et al. 2013

- Could be extended to more objects and start investigating possible correlations of thermal properties with other physical properties (density, composition…)

And finally, back to atmospheres…
The evolution of Pluto’s atmosphere



Young 2013

JWST cannot observe the N2 atmosphere, but can monitor CH_4 (0.5 % of N2) from NIRSPEC spectroscopy at 1.7 and 2.3 um.

THE END