Observing the Solar System with a Far-Infrared Space Telescope

Stefanie Milam

June 4, 2015

NASA/GSFC

Credit: NASA and E. Karkoschka (University of Arizona)

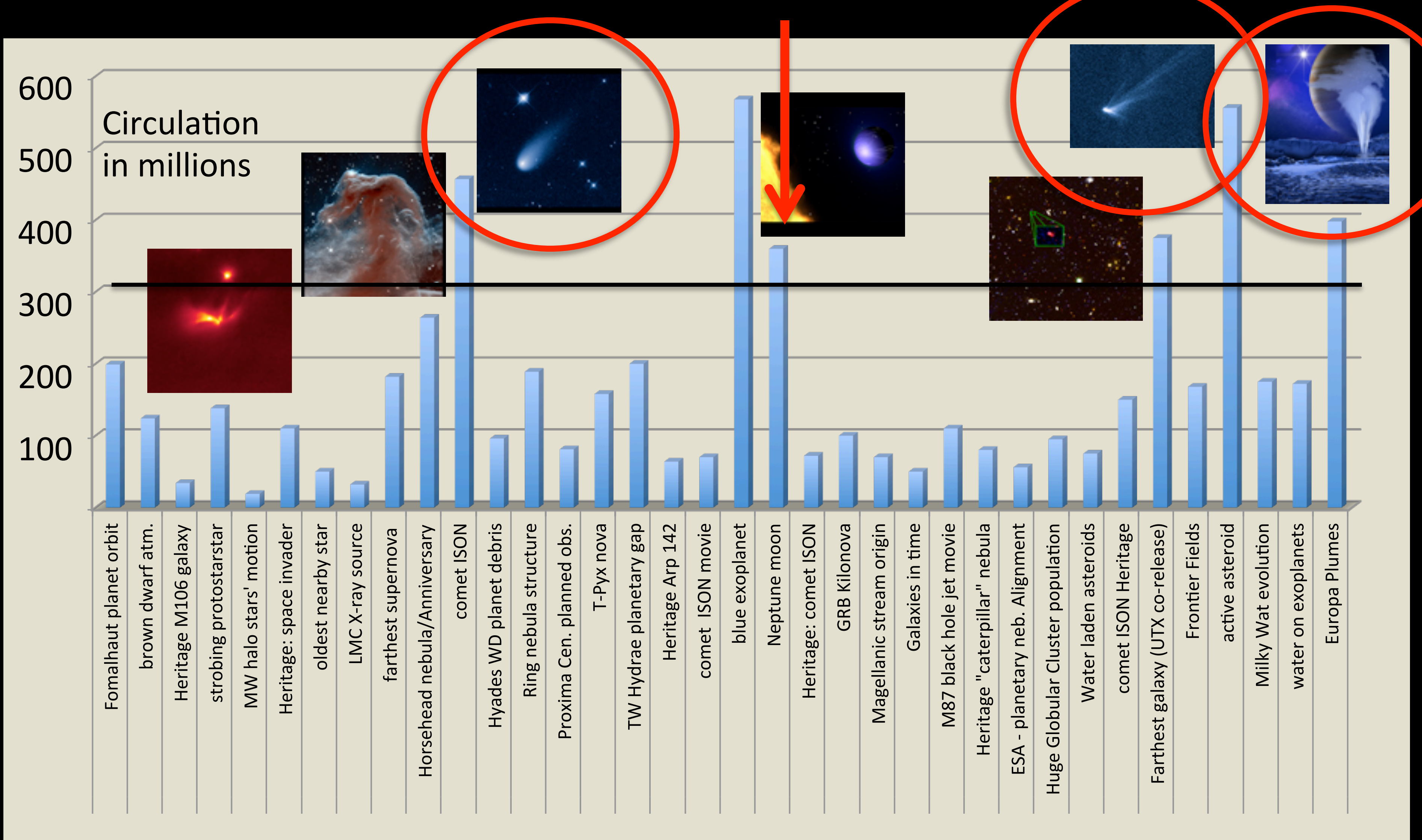
Infrared Missions and Planetary Science

- MB asteroids, Centaurs and Trans-Neptunians science
  - Spitzer 51, HST 62, Herschel 15, ISO 17
- Comets study
  - Spitzer 33, HST 82, Herschel 7, ISO 13
- Dust ring discoveries and analysis
  - Spitzer 1, HST 14
- Giant Planet Atmospheres study
  - Spitzer 1, HST 110, Herschel 5, ISO 10

From Palomba

Hubble press releases can reach hundreds of millions of people

HST News Circulation - Calendar 2013 (Source: Meltwater News)



Our Solar System

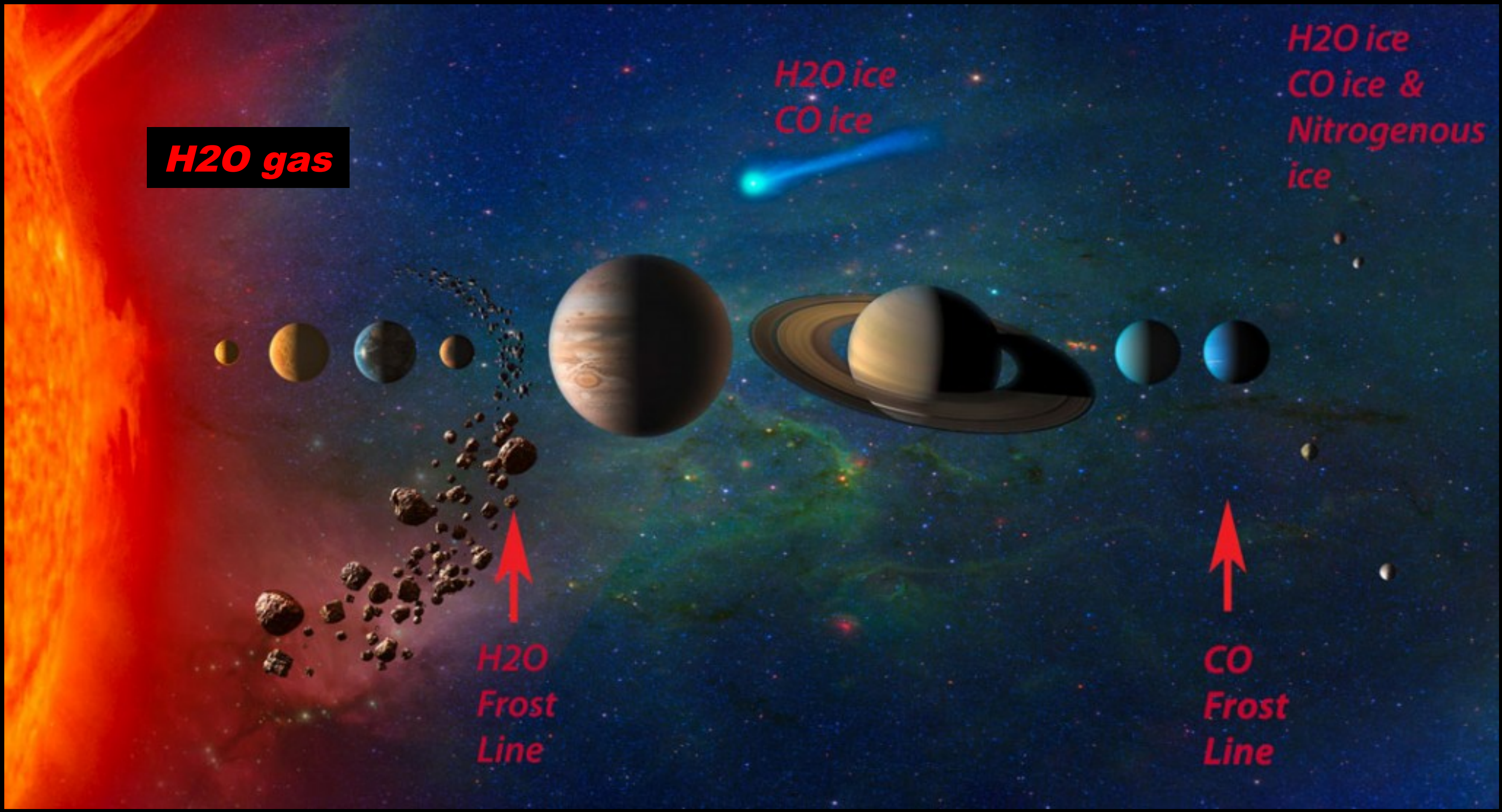
HOW DID THE EARTH BECOME HABITABLE?

- Water?
  - D/H ratios in small bodies
  - Search for water across the Solar System

IS EARTH UNIQUE?

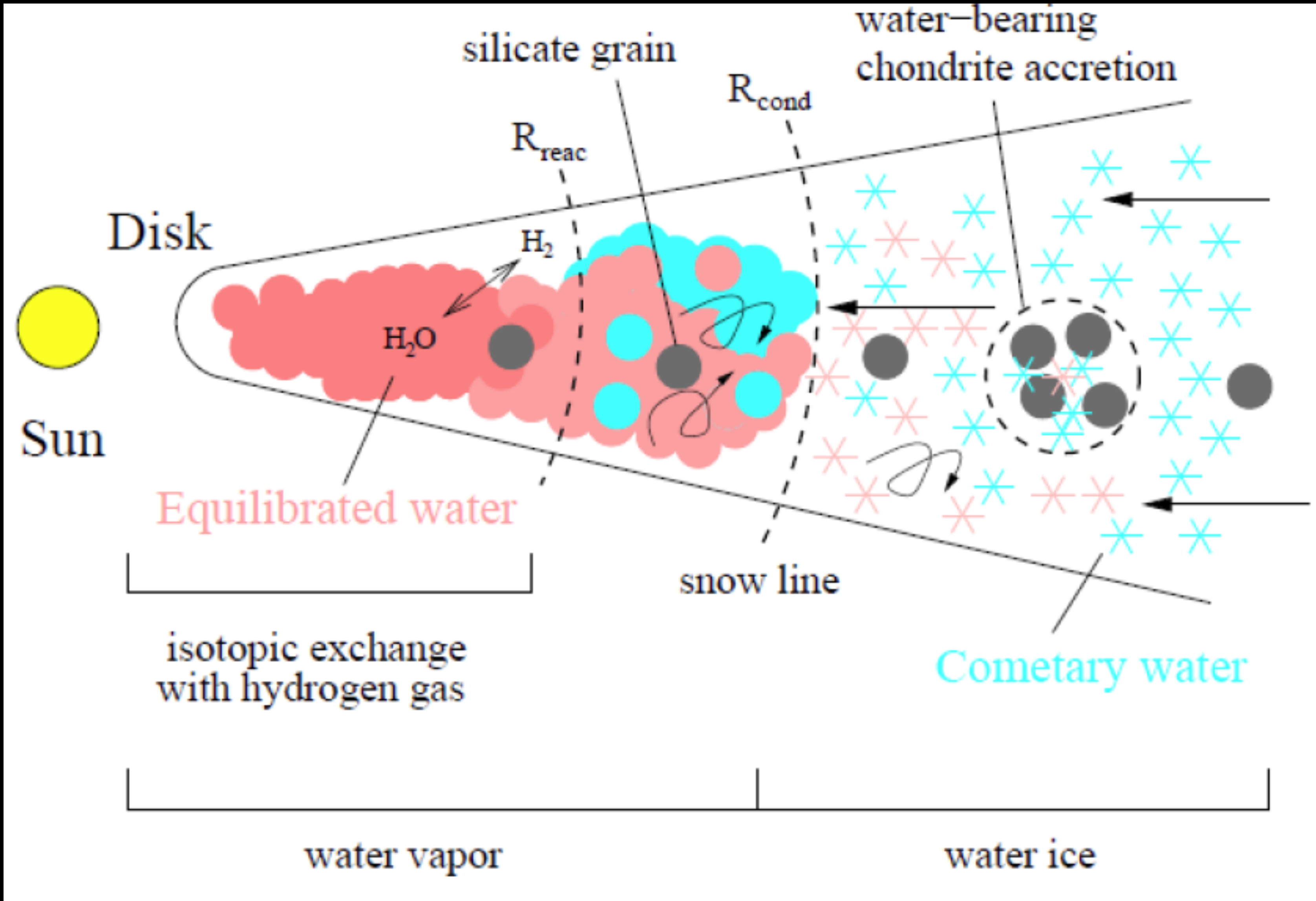
- Compositional studies of primitive bodies
  - Similar to presolar disk/cloud?
  - Volatile Isotopes
- Other planets/satellites in the solar system

Frost Lines in the Solar System



D/H Ratios

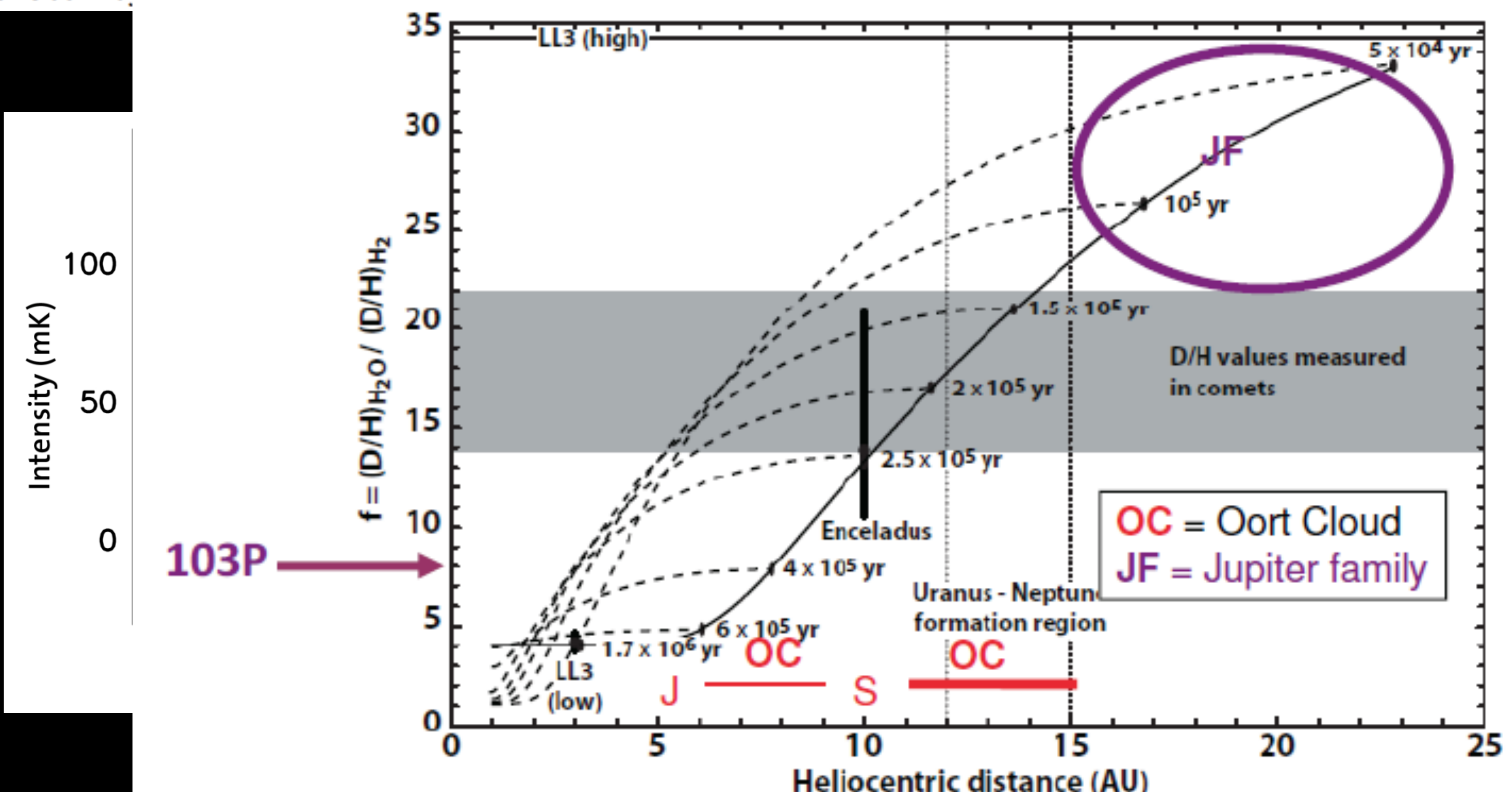
- Protosolar D/H ratio in H_2 is ~2.5×10^{-5} (same as the Big Bang)
- Earth ocean ratio (Vienna Standard Mean Ocean Water) is 1.56×10^{-4}
- D/H measured in several Oort cloud comets is ~2 times enrichment over the Earth ocean value
- Comets source of Terrestrial water?


water−bearing
chondrite accretion
silicate grain
R_{cond}
R_{reac}
Disk
H_2
H_2O
Sun
Equilibrated water
snow line
isotopic exchange
with hydrogen gas
Cometary water
water vapor
water ice

Ocean-like water in the Jupiter-family comet 103P/Hartley 2

Paul Hartc ... üppers[4],
Martin Em ... zutowicz[6]
& Geoffrey

Kaveelars et al. (2011)



Takes into account planet migration

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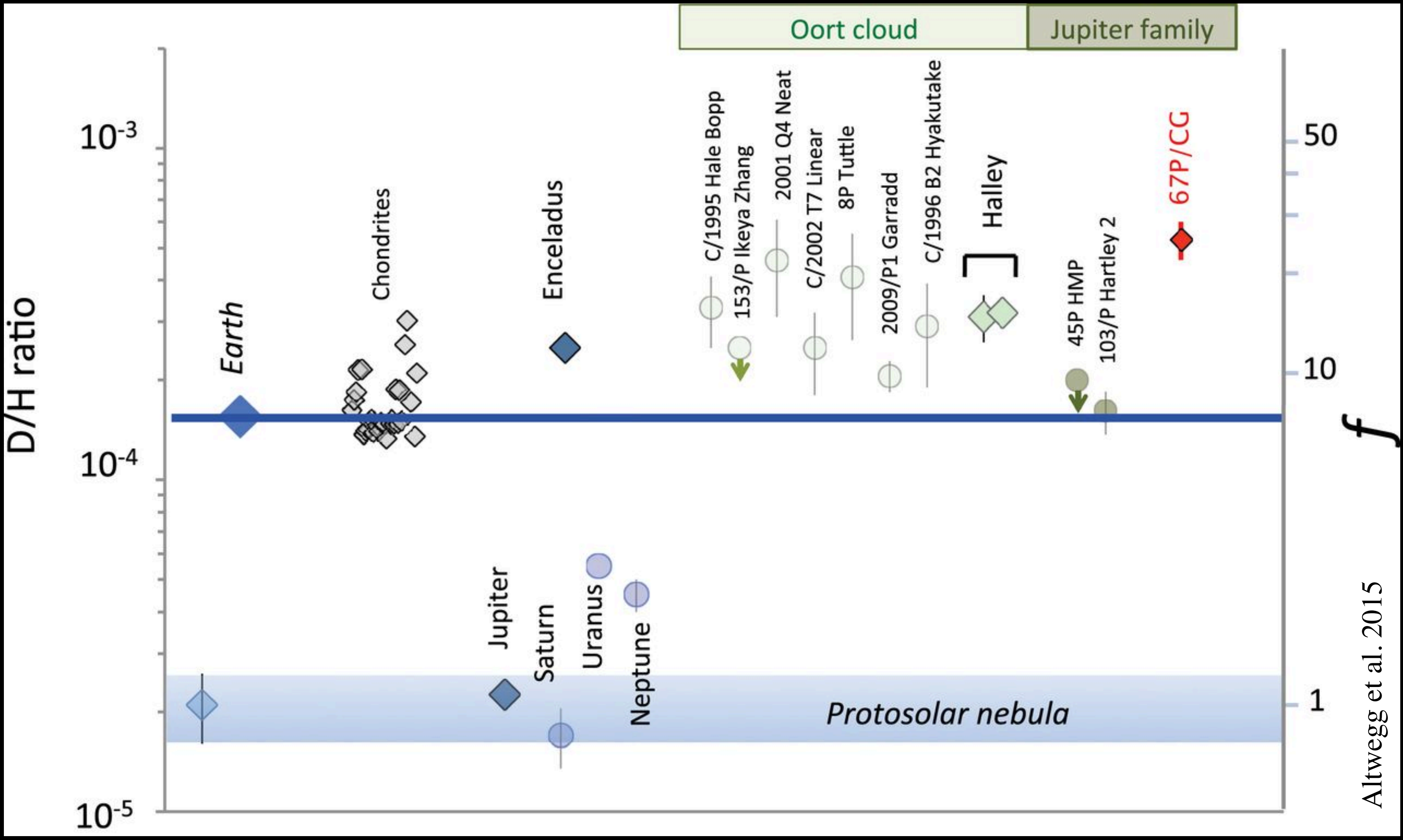
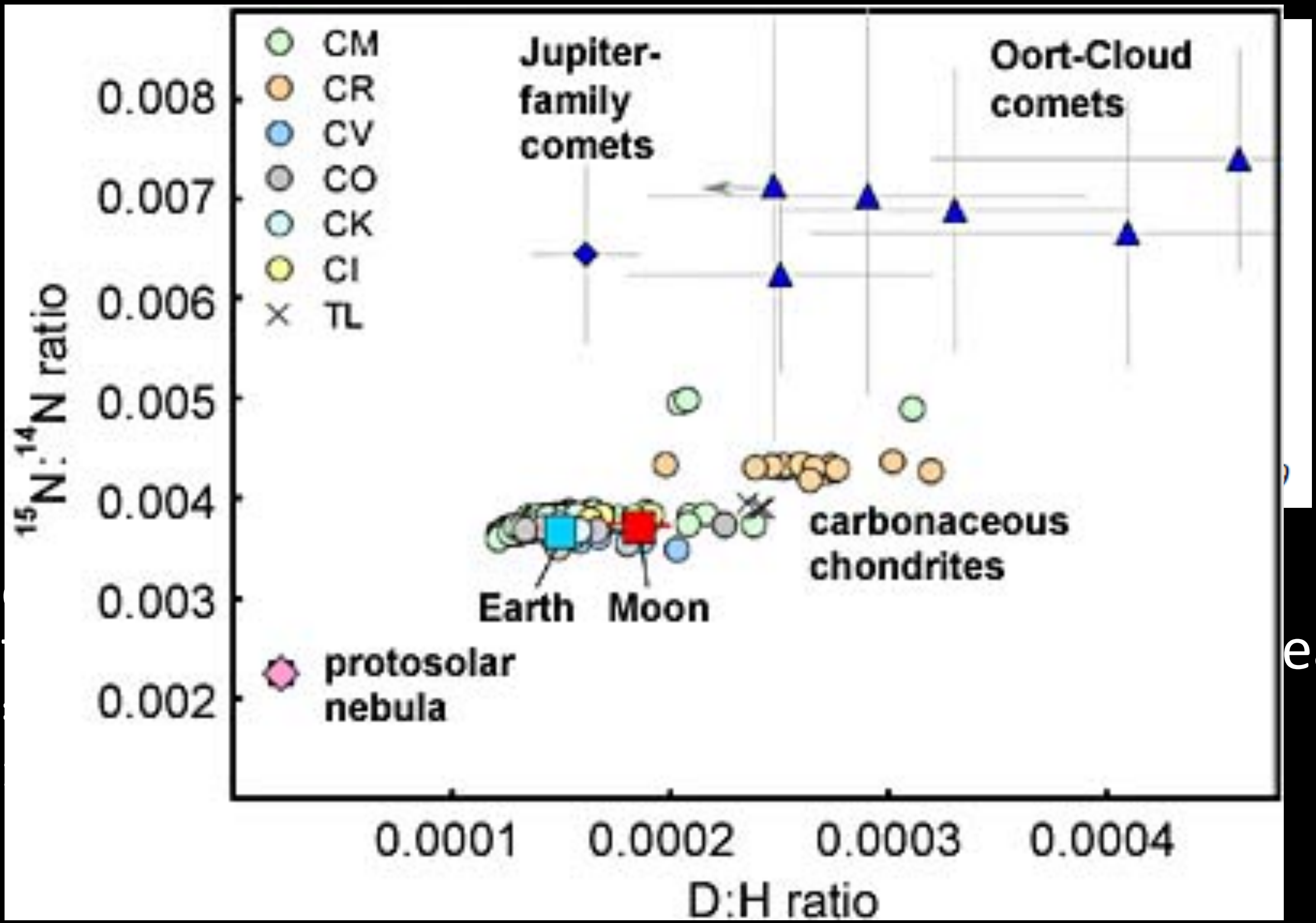
r D/H

D/H in the Solar System



Nitrogen Anomalies



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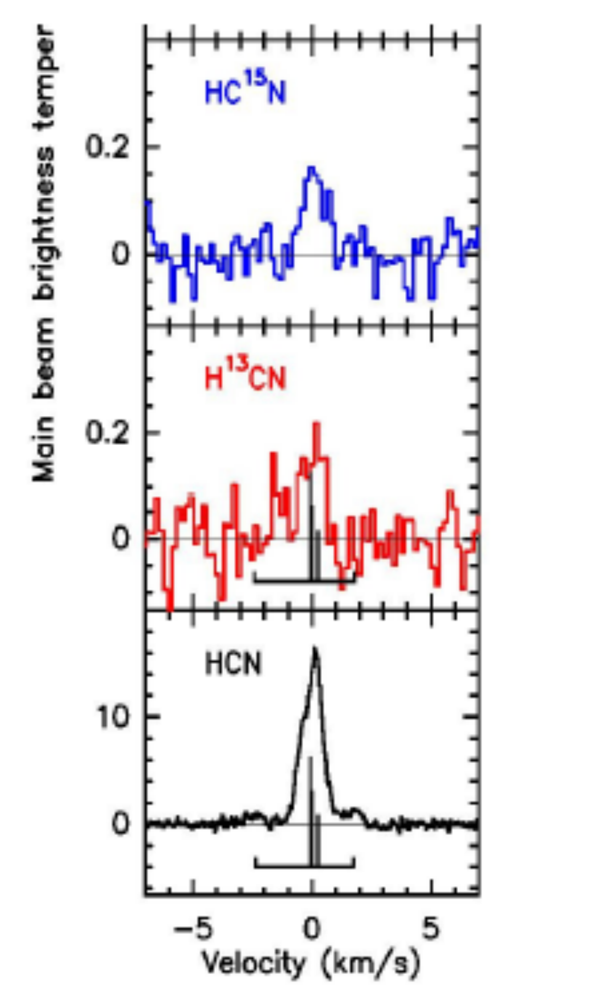
Nitrogen from HCN

- $^{14}N/^{15}N$ ratio in 17P/ Holmes:

  $^{14}N/^{15}N = 139 \pm 26$

  consistent value in CN
- HCN and other major parent of CN are equally enriched in 15-Nitrogen
- Other molecules?



Bockelée-Morvan et al. 2008

^{15}N and D fractionation relations

Table 1: Interstellar & Cometary Nitrogen Isotope Ratios

Source	Type	NH_3	N_2H^+	HCN	HNC	CN	Reference
L1544	dark core	>700	1000±200	140-360	**>27**	500±75	1,2,3,4,5
L1498	dark core	**619±100**	...	**>75**	**>90**	500±75	11,4,4,5
L1521E	dark core	...	...	151±16	...	...	6
L1521F	dark core§	**539±118**	...	**>51**	**24-31**	...	11,4,4
L183	dark core	$530\pm^{570}_{180}$	...	140-250	...	...	1,3
NGC 1333-DCO$^+$	dark core	$360\pm^{260}_{110}$	...	...	...	...	1
L1262-core	dark core	**356±107**	...	...	...	...	11,3
NGC 1333-4A	Class 0 protostar	344±173	...	...	...	...	7
Barnard 1	Class 0 protostar	$300\pm^{55}_{40}$	$400\pm^{100}_{65}$	$330\pm^{60}_{50}$	$225\pm^{75}_{45}$	$290\pm^{160}_{80}$	8
L1689N	Class 0 protostar	$810\pm^{600}_{250}$	...	...	...	...	4
Cha-MMS1	Class 0 protostar	...	...	...	135	...	9
IRAS 16293A	Class 0 protostar	...	...	163±20	242±32	...	10
R Cr A IRS7B	Class 0 protostar	...	...	287±36	259±34	...	10
OMC-3 MMS6	Class 0 protostar	...	...	366±86	460±65	...	10
L1262-YSO	Class I protostar	**453±247**	...	...	...	...	11,3
Comets	JFC & Oort Cloud	127‡	...	139±26	...	135-170†	12,13,14

Boldface entries are unpublished values from our ongoing observational programme. Note that we have recently observed the relevant isotopologues of HCN and HNC at the L1262 positions at Onsala; these data are currently being reduced.

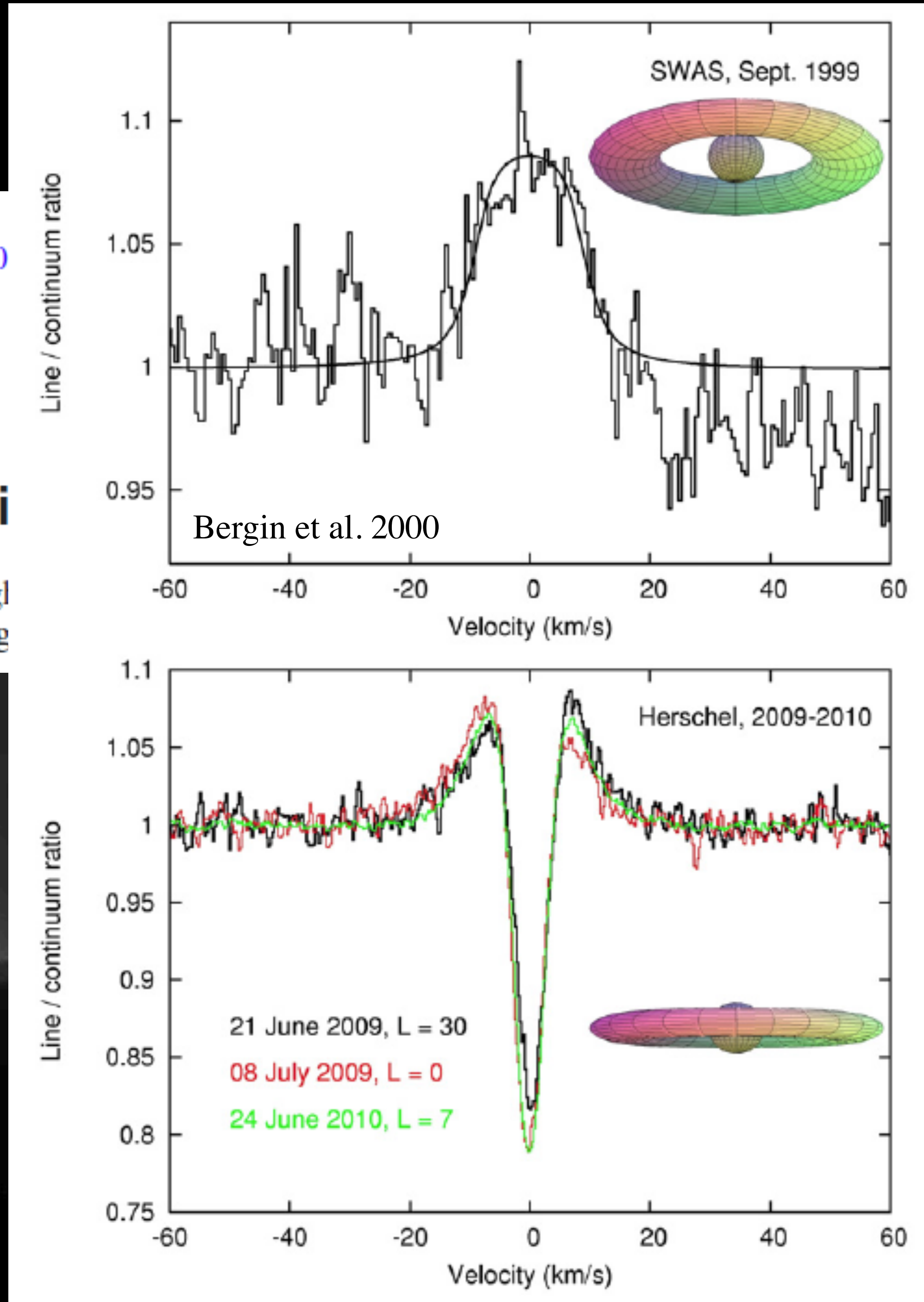
Wirstrom et al. 2012

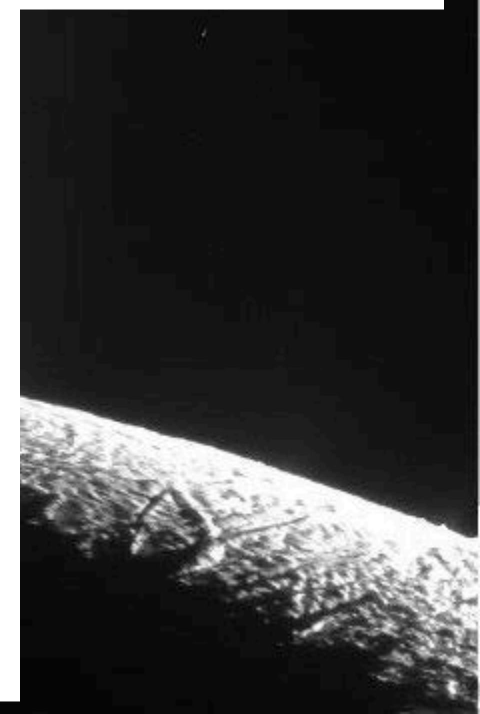
A&A 532, L2 (2011)
DOI: 10.1051/0004-6361/20

Astronomy & Astrophysics

Direct detecti ... Herschel[⋆,⋆⋆]

P. Hartogl ... Cassidy[3],
M. Reng ... Kidger[6]





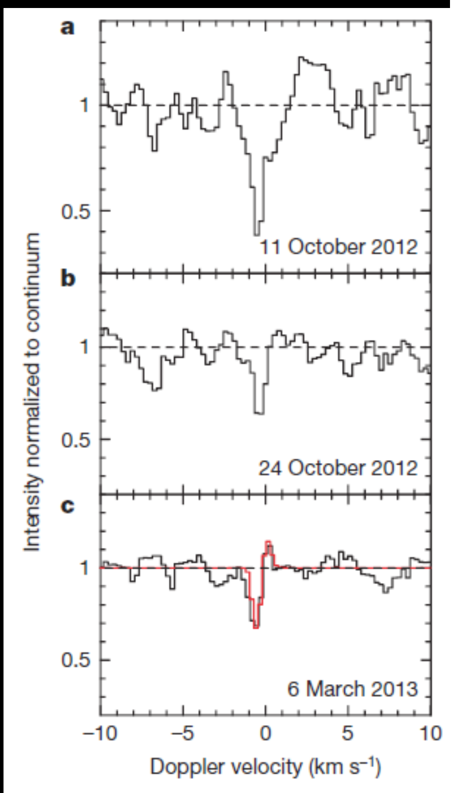
Credit: NASA/JPL.

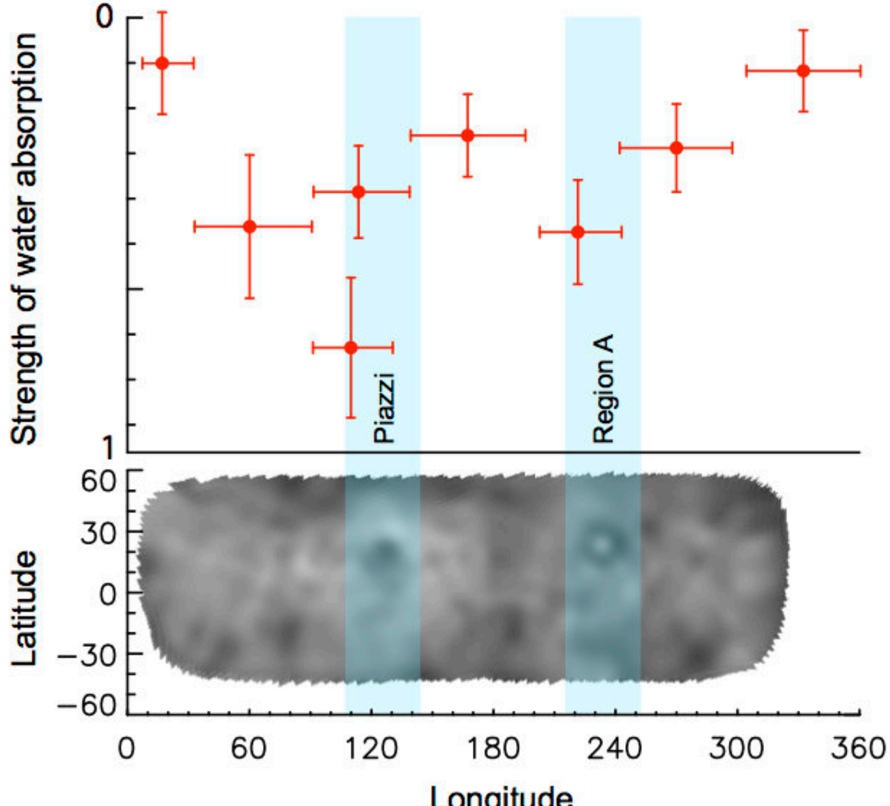
LETTER

doi:10.1038/nature12918

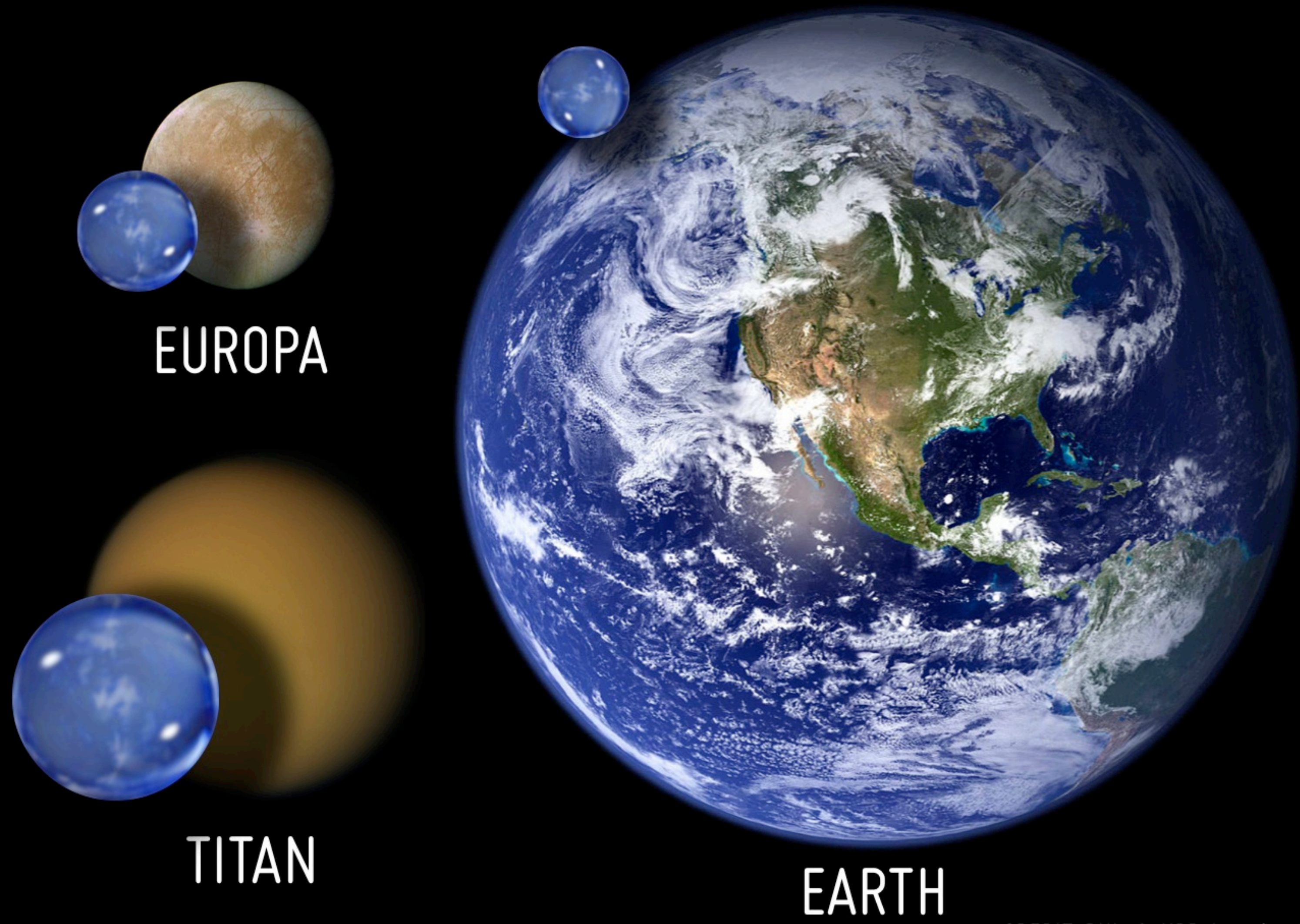
Localized sources of water vapour on the dwarf planet (1) Ceres

Michael Küppers[1], Laurence O'Rourke[1], Dominique Bockelée-Morvan[2], Vladimir Zakharov[2], Seungwon Lee[3], Paul von Allmen[3], Benoît Carry[1,4], David Teyssier[1], Anthony Marston[1], Thomas Müller[5], Jacques Crovisier[2], M. Antonietta Barucci[2] & Raphael Moreno[2]



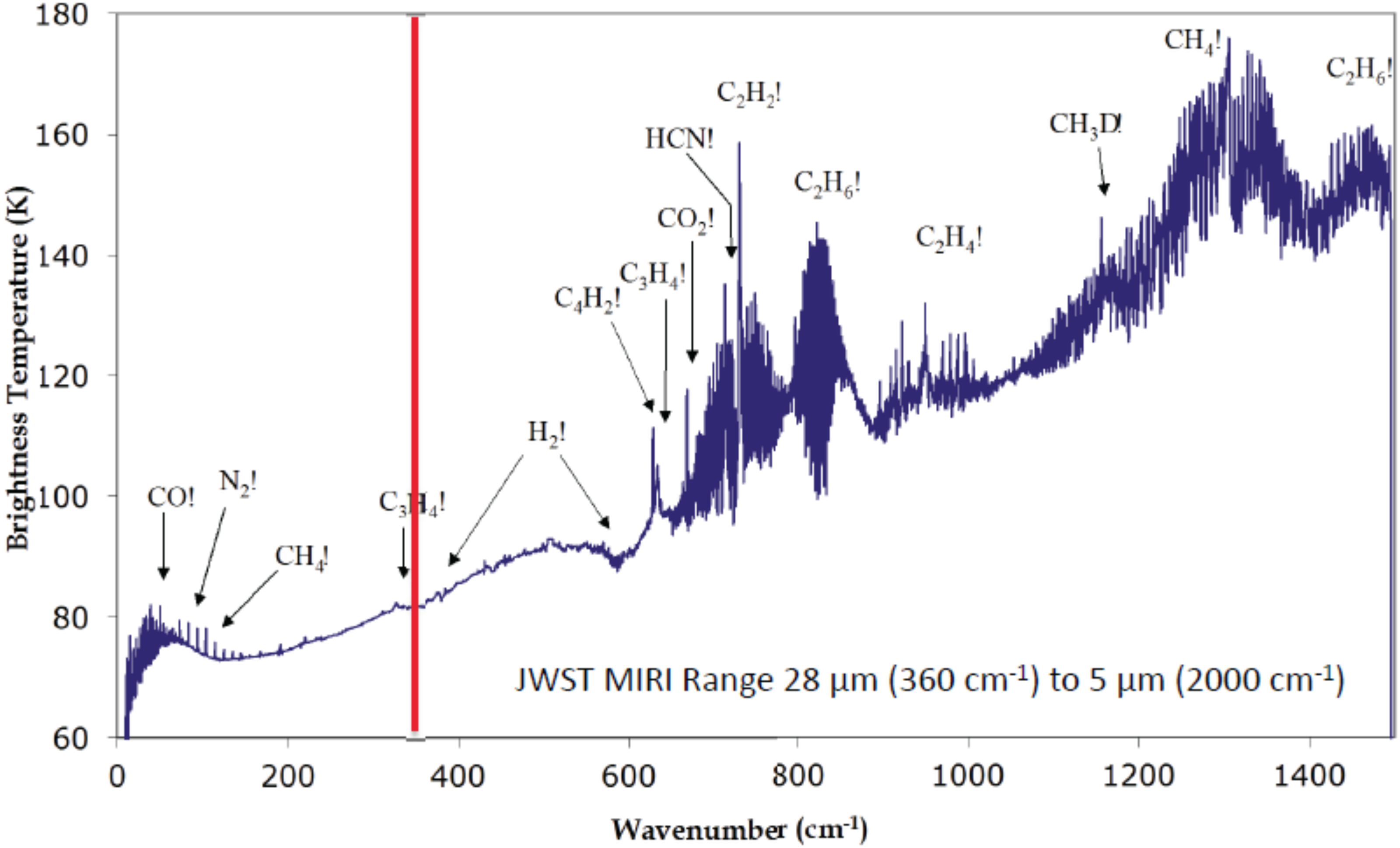


Liquid Water in the Solar System



CREDIT: PHL @ UPR Arecibo, NASA

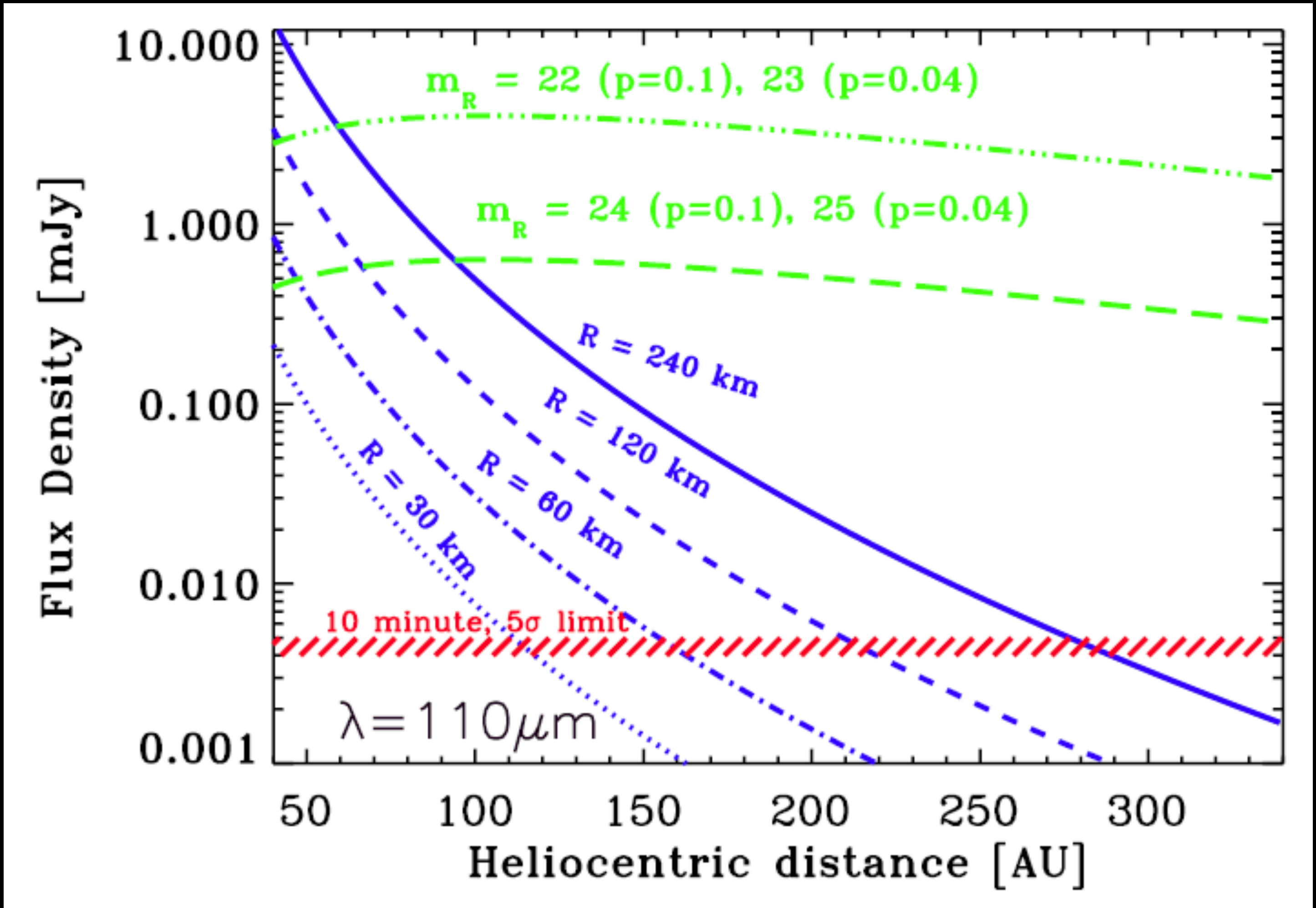
TITAN Stratospheric Composition



Nixon et al.

Labeled Cassini CIRS spectrum (low latitude average) by D. Jennings

TNOs



10.000
1.000
0.100
0.010
0.001
Flux Density [mJy]
50
100
150
200
250
300
Heliocentric distance [AU]
m_R = 22 (p=0.1), 23 (p=0.04)
m_R = 24 (p=0.1), 25 (p=0.04)
R = 240 km
R = 120 km
R = 60 km
R = 30 km
10 minute, 5σ limit
λ=110μm

Angular Sizes

Angular Size	
Object	Size (“)
Mars	7
Jupiter	37
Saturn	17
Uranus	3.5
Neptune	2.2
Pluto	0.1
Titan	0.75
Enceladus	0.08

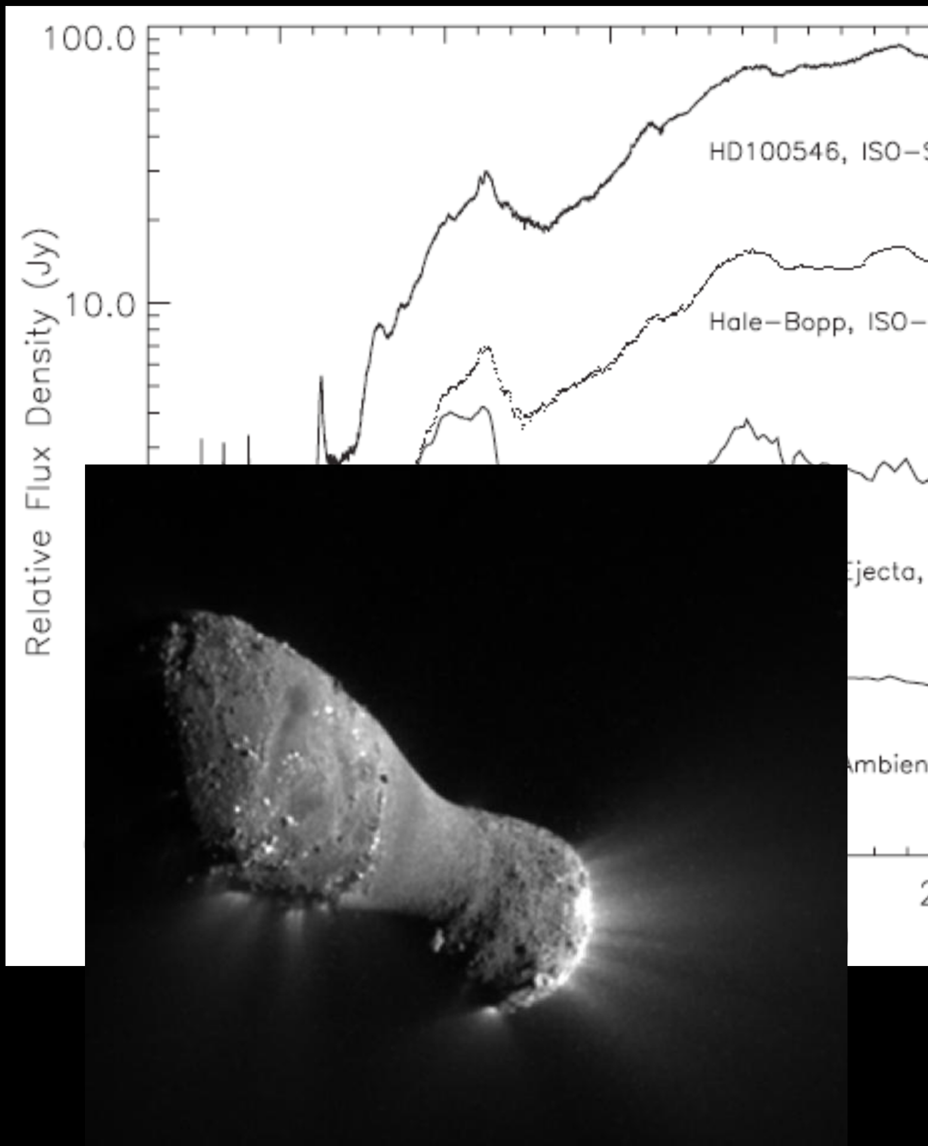
Image Credit: NASA and The Hubble Heritage Team (STScI/AURA)

Other Needs…

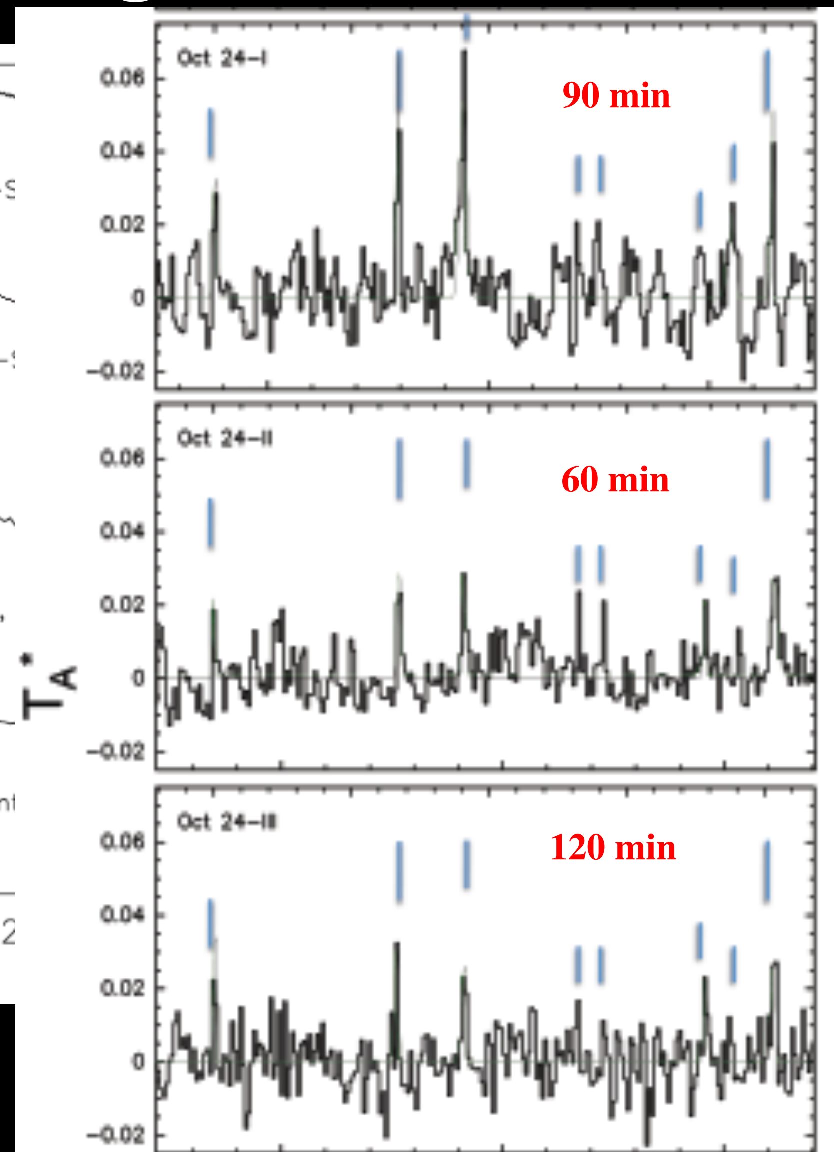
- Moving Targets
  - Tracking at high rates of motion

Object	Minimum rate (mas/sec)	Maximum rate (mas/sec)	Time to move 2 arcmin at min rate (hrs)	Time to move 2 arcmin at max rate (hrs)
Mars	2.5	28.6	13.3	1.2
Ceres	1.0	18.4	33.3	1.8
Jupiter	0.07	4.5	476	7.4
Saturn	0.04	2.9	833	11.4
Uranus	0.02	1.4	1667	24
Neptune	0.004	1.0	8333	34
Pluto	0.16	1.0	208	34
Haumea	0.35	0.89	95	37
Eris	0.22	0.56	152	59

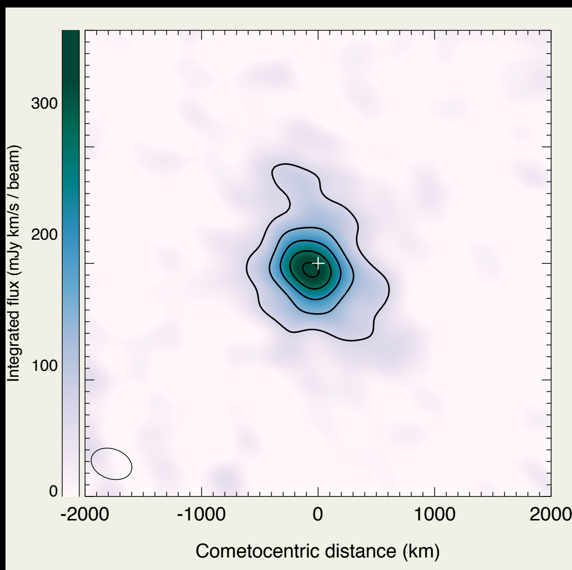
Variable Targets



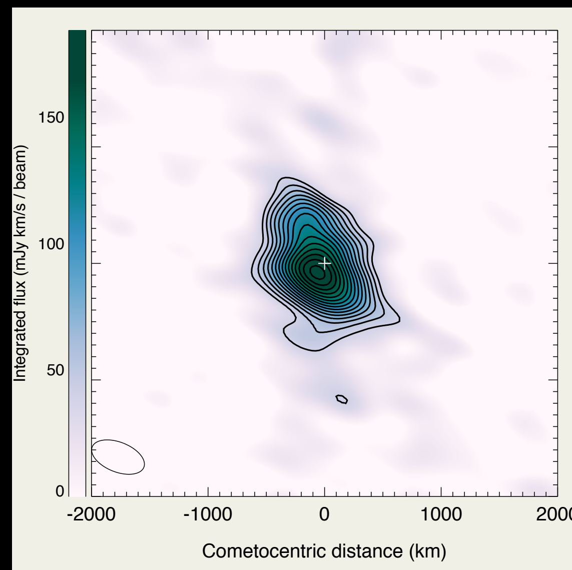
CH3OH in Hartley 2



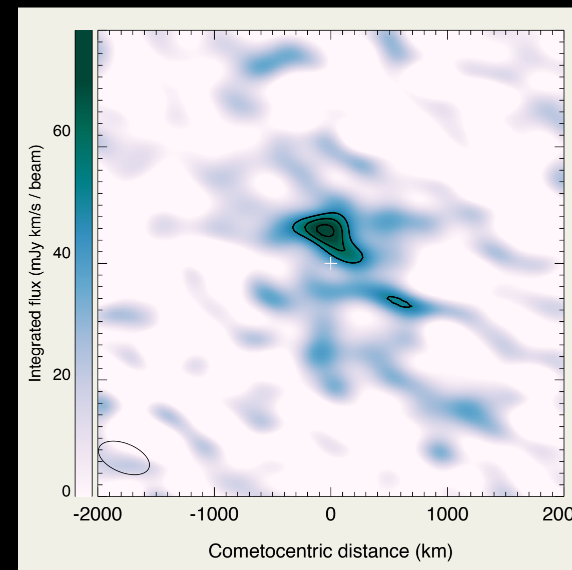
ISON Integrated Flux maps



HCN 4-3



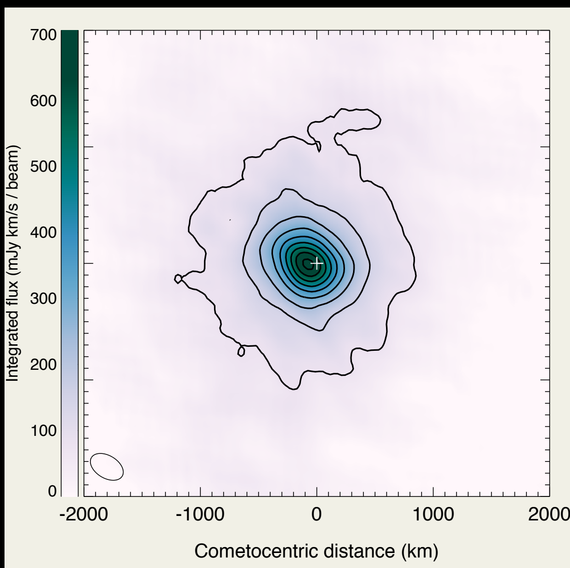
H_2CO 5_{15}-4_{14}



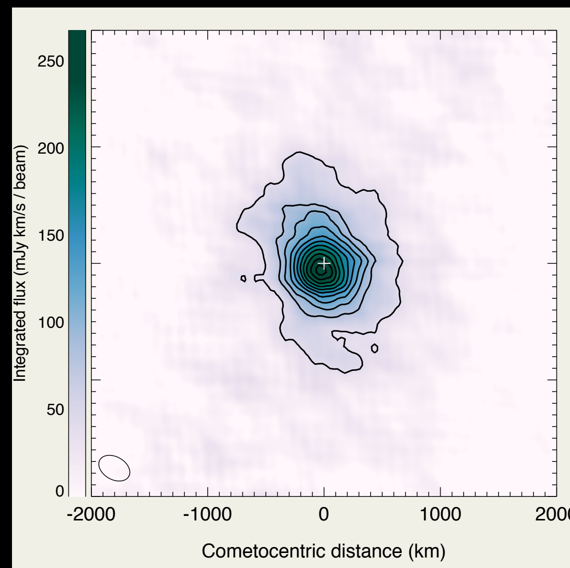
HNC 4-3

Observation date: November 16 2013

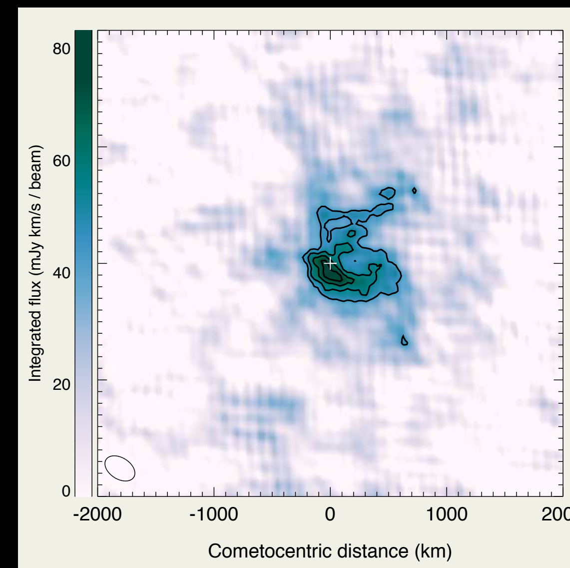
ISON Integrated Flux maps



HCN 4-3



$H_2CO\ 5_{15}\text{-}4_{14}$

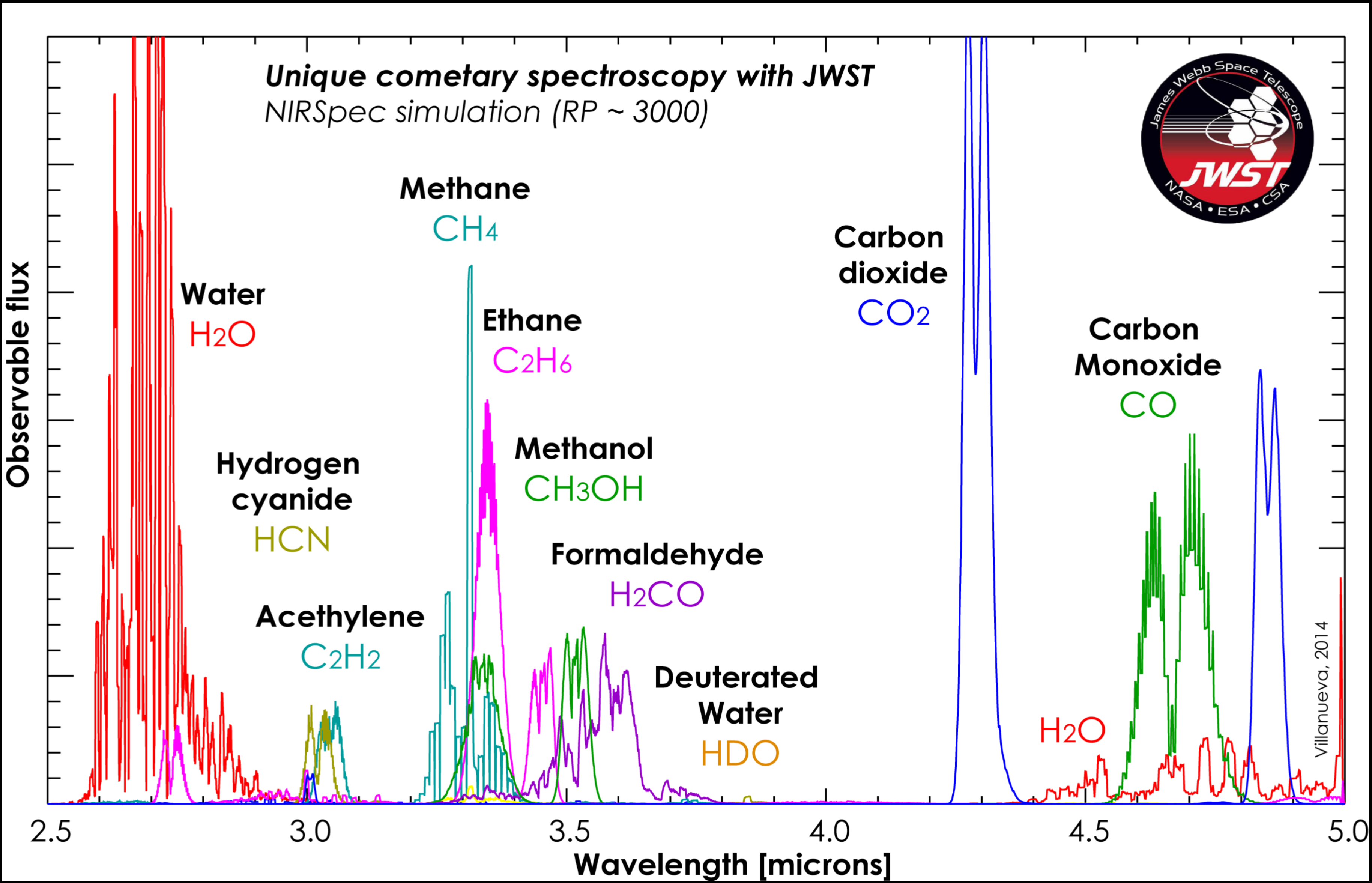


HNC 4-3

Observation date: November 17 2013

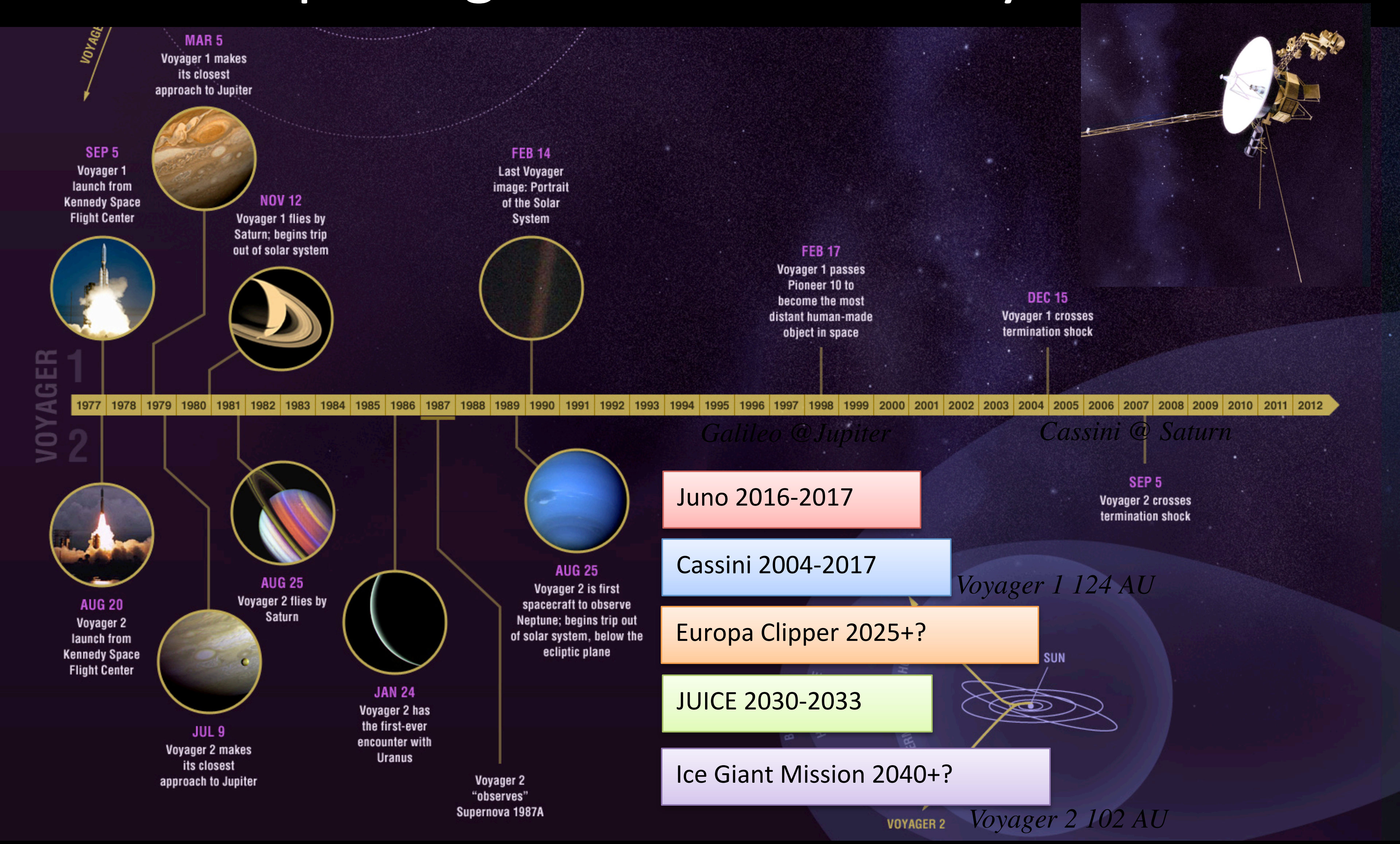
Need Multiple Species SIMULTANEOUSLY!!!

Synergies?



Unique cometary spectroscopy with JWST
NIRSpec simulation (RP ~ 3000)
Water
H2O
Methane
CH4
Ethane
C2H6
Methanol
CH3OH
Hydrogen cyanide
HCN
Acethylene
C2H2
Formaldehyde
H2CO
Deuterated Water
HDO
Carbon dioxide
CO2
Carbon Monoxide
CO
H2O
James Webb Space Telescope
JWST
NASA • ESA • CSA
Villanueva, 2014
Observable flux
2.5
3.0
3.5
4.0
4.5
5.0
Wavelength [microns]

Exploring the Outer Solar System



From Fletcher

Parameter	Units	Value or Range
Wavelength range	μm	25-500
Angular resolution	arcsec	<0.5
Spectral resolution, ($\lambda/\Delta\lambda$)	dimensionless	Better than 3000
Continuum sensitivity	μJy	<10
Spectral line sensitivity	10^{-19} W m^{-2}	
Instantaneous FoV	arcmin	~1
Number of target fields	dimensionless	multiple
Field of Regard	sr	

Summary

- Solar System targets are ideal for appealing to the public and provide a tremendous asset to astrophysics missions.
- Most objects are extended and bright – may cause saturation issues.
- Moving targets with rates of motion up to >100 mas/s for NEOs (average is around 60 mas/s).
- Targets themselves or other phenomena (storms, impact events, etc) are often variable or short lived.
  - Rapid Response?
- Timing well suited for outer solar system.

Infrared Missions and Planetary Science

- MB asteroids, Centaurs and Trans-Neptunians science
  - Surface mineral composition, physical (e.g. size, mass, orbital parameters, albedo) and thermal propeties (inertia, beaming factor)
- Comets study
  - Coma, tail, nucleus and ejecta investigations –
  - Dust mineral composition
  - Volatiles degassing rate
  - Gas isotopic ratios
- Dust ring discoveries and analysis
- Giant Planet Atmospheres study
  - Search for minor organic species

From Palomba