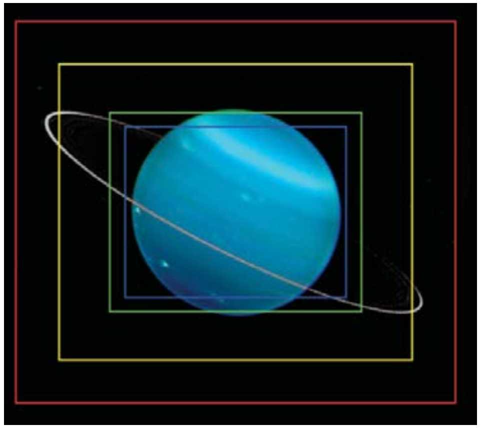
JWST and the Solar System

P. Ferruit
(ESA JWST project scientist)

Presentation based on work and presentations done/prepared by the JWST solar system working group and a set of 10 focus groups (more later).



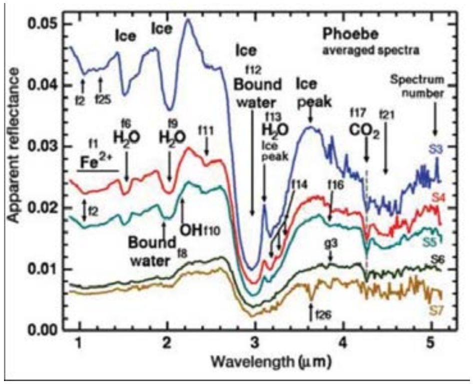


Table of contents

- **Before talking about science.**
    - Groups, who’s who…
    - White paper, resources…
- **A few generic points**
    - Moving targets
    - Reminder on the visibilities.
    - Some size and surf. brightness numbers for reference…
    - On the bright side…
- **A superficial tour (using slides from the focus groups).**
    - Big and bright.
    - Moons galore.
    - Rocks in space.
    - Ice is nice.
- **Timeline & conclusion**
    - Great observatory, community organisation.

JWST solar system working group

JWST Solar System Working Group (SSWG)

Role

- Conduct JWST outreach to the Solar System science community
- Contact point for information on JWST instruments, observatory, science policy, …
- Conduit for Solar System community input on JWST operations and capabilities.
  - Explore science "use cases"
  - Technical inputs

Members

- Interdisciplinary Scientists
  - Heidi Hammel, Jonathan Lunine
- JWST Project – Goddard
  - Stefanie Milam, George Sonneborn
- Science & Operations – STScI
  - John Stansberry, Dean Hines
- JWST ESA (and NIRSpec)
  - Pierre Ferruit (ESTEC)
- Community Members
  - Nancy Chanover (NMSU)
  - Jim Norwood (NMSU)
  - Matt Tiscareno (Cornell)
  - Mike Brown (CalTech)

4

I am the intruder.
I brought in the NIRSpec expertise only…

JWST solar system focus groups

10 Focus Groups

- **Asteroids** (Andy Rivkin, JHU/APL)
- **Comets** (Chick Woodward, U. Minnesota)
- **Giant Planets** (Jim Norwood, NMSU)
- **Mars** (Geronimo Villanueva, GSFC)
- **NEOs** (Cristina Thomas, GSFC)
- **Occultations** (Pablo Santos-Sanz, IAA-CSIC, Spain)
- **Rings** (Matt Tiscareno, Cornell)
- **Satellites** (Laszlo Kestay, USGS)
- **Titan** (Conor Nixon, GSFC)
- **TNOs** (Alex Parker, UC Berkeley)

7

Great work by Stefanie Milam who has been organising this work and got things going.

Participation of some European scientists to these working groups.

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JWST solar system advisory group for STScI

Solar System Observer's Advisory Panel (SSOAP)

- Science Planning, Operations and Data Pipeline technical advice
  - John Clarke (Boston University)
  - Will Grundy (Lowell Observatory)
  - Thomas Mueller (Max Planck Garching)
  - Mark Showalter (SETI)
  - Amy Simon-Miller (Goddard)
  - Hal Weaver (Applied Physics Lab)

Different type of role. Advising STScI to help making sure everything will be in place for solar system observations. Group set up by John Stansberry at STScI.

White paper - resources

- **Recommended starting point: the solar system white paper**
  - In http://www.stsci.edu/jwst/doc-archive/white-papers
  - Norwood et al. 2014, “Solar system observations with JWST”.
- **A page dedicated to solar system observation with JWST**
  - http://www.stsci.edu/jwst/science/solar-system
- **Flyers**
  - http://www.stsci.edu/jwst/doc-archive/flyers/

Generic points – observing moving targets with JWST

- **JWST capability:**
  - Able to track moving targets with an apparent rate of motion up to 30 mas / s.
  - Pointing stability for moving target observations of 50 mas (3 sigma). To be compared to 21 mas for "normal" observations.

Table 1. Movement rates of various Solar System targets.

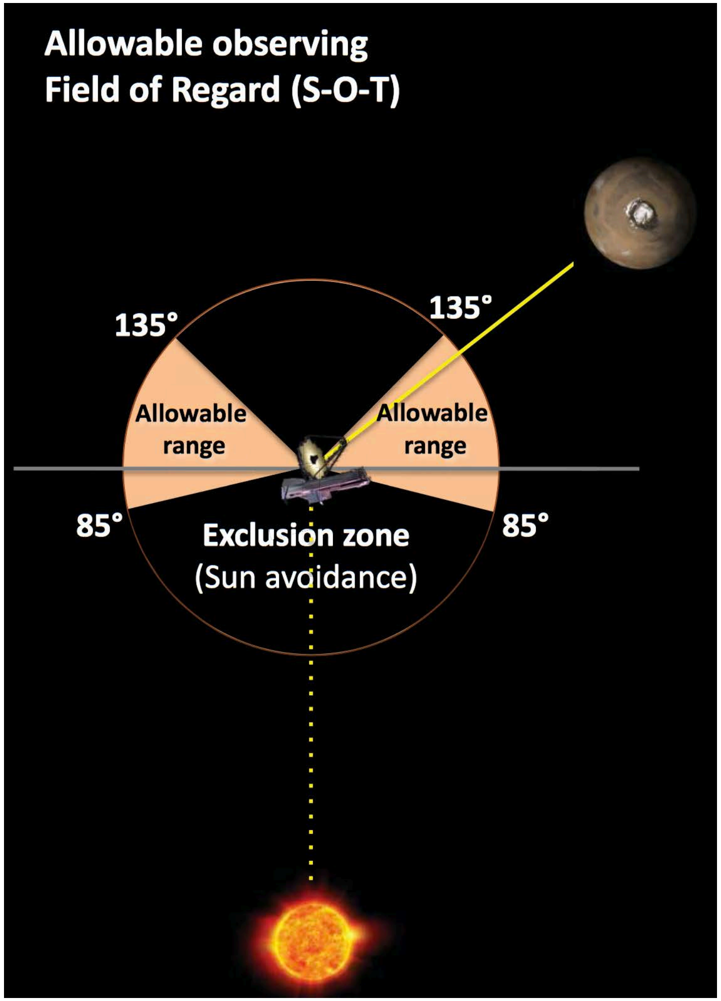
Object	Minimum rate (mas/sec)	Maximum rate (mas/sec)
Mars	0.485	28.27
Ceres	0.152	11.81
Jupiter	0.019	4.48
Saturn	0.016	1.74
Uranus	0.012	1.09
Neptune	0.020	0.74
Pluto	0.004	0.65
Haumea	0.372	0.62
Eris	0.058	0.30

→ Good coverage of solar system objects.

"Solar system observations with JWST", Norwood et al., 2014, white paper

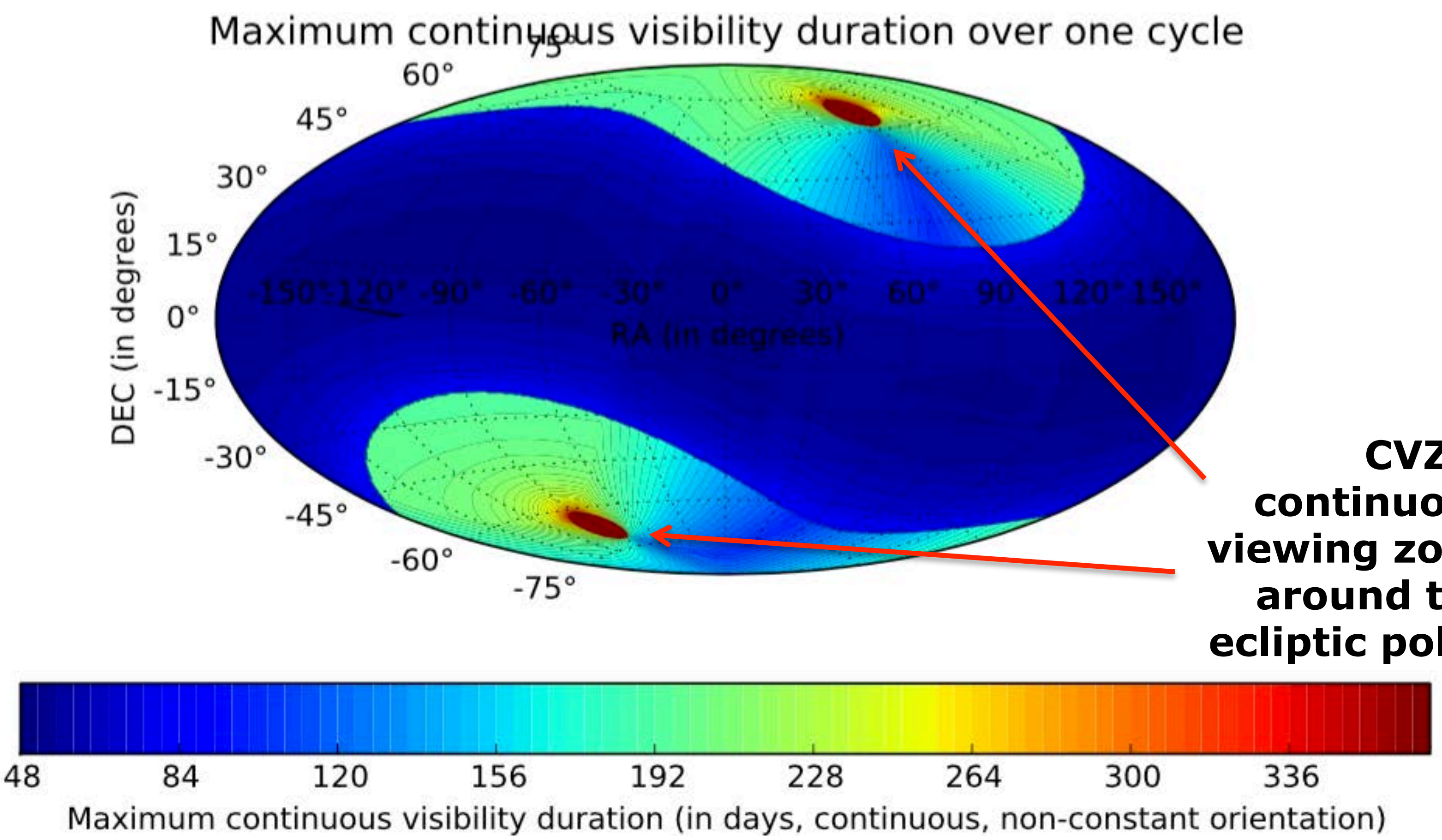
Generic points - visibility constraints

- **Remember the generic JWST talk of yesterday.**
  - The need to keep the telescope and the instruments in the shadow of the sunshield restricts the possible telescope orientations and defines the field of regard of the telescope.
- **The ecliptic plane where most of the solar system observations will take place is a fairly special place.**
- **And do not forget, you can only observe the "outer" solar system…**
  - Nothing within the Earth orbit (and if you see the Earth something is really wrong…).



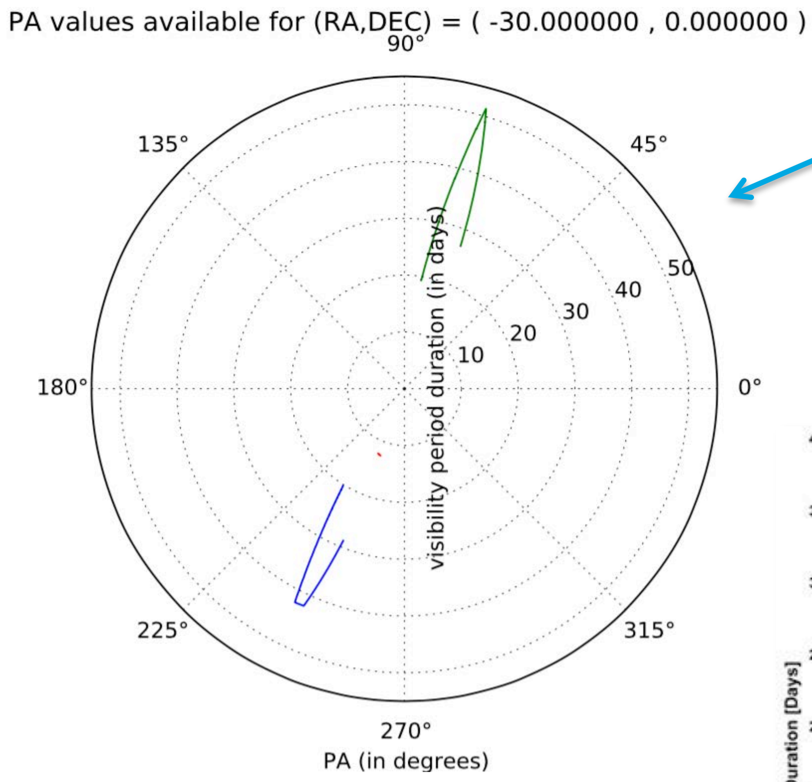
MARS focus group

Generic points - visibility constraints

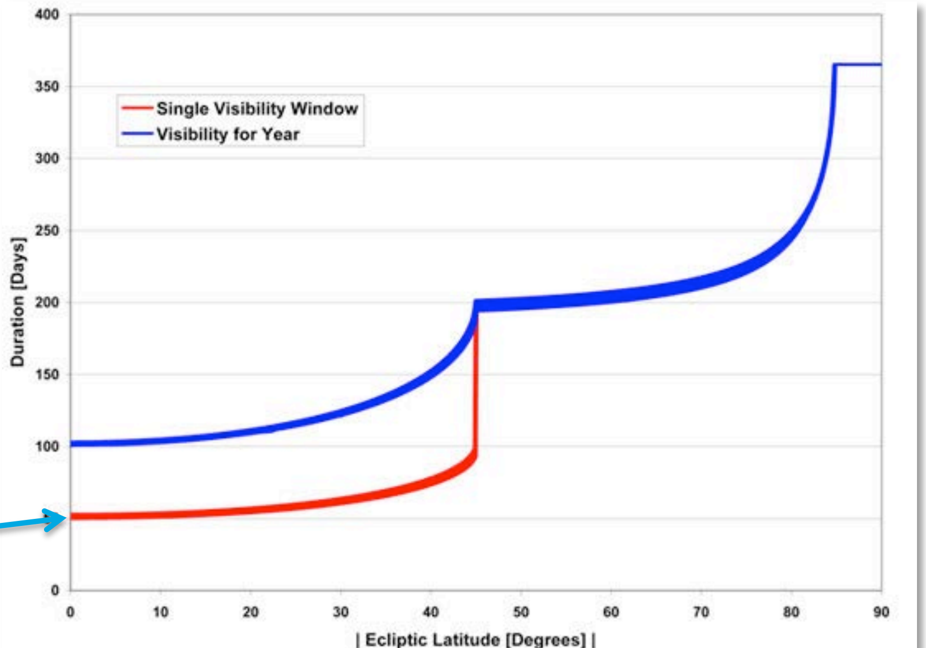


CVZ = continuous viewing zone around the ecliptic poles

Generic points - visibility constraints

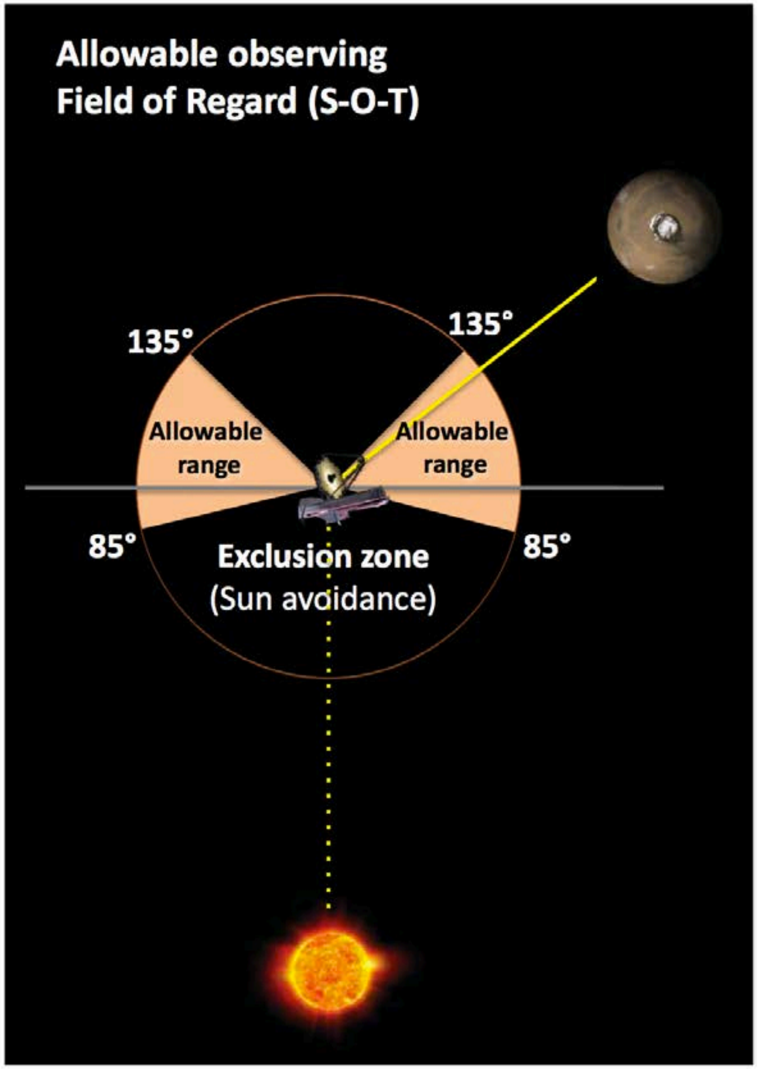


Along the ecliptic: restricted range of orientations, 2 windows per year, long time with the same orientation (~50 days).



You are here…

Generic points - visibility constraints



Observing windows
(approaching, receding)

2018	Launch (Oct/2018) LS 306 - 14/December/2018
2020	LS 206 - 22/May/2020 to LS 273 - 07/September/2020 LS 319 - 21/November/2020 to LS 2 - 10/February/2021
2022	LS 289 - 16/August/2022 LS 333 - 04/November/2022 LS 9 - 13/January/2023 LS 42 - 25/March/2023

- Polar caps only observed when illuminated. Most windows will sample the Southern cap.
- We will mainly sample the day side. Day-side fraction: 84 – 93%
- When approaching, we will sample the *evening* terminator, and when receding the *morning* terminator.

Generic points – some size and surface brightness numbers

- **Just to give you an idea of the expected size and surface brightnesses one can expect when observing planets in the near/ mid-infrared.**

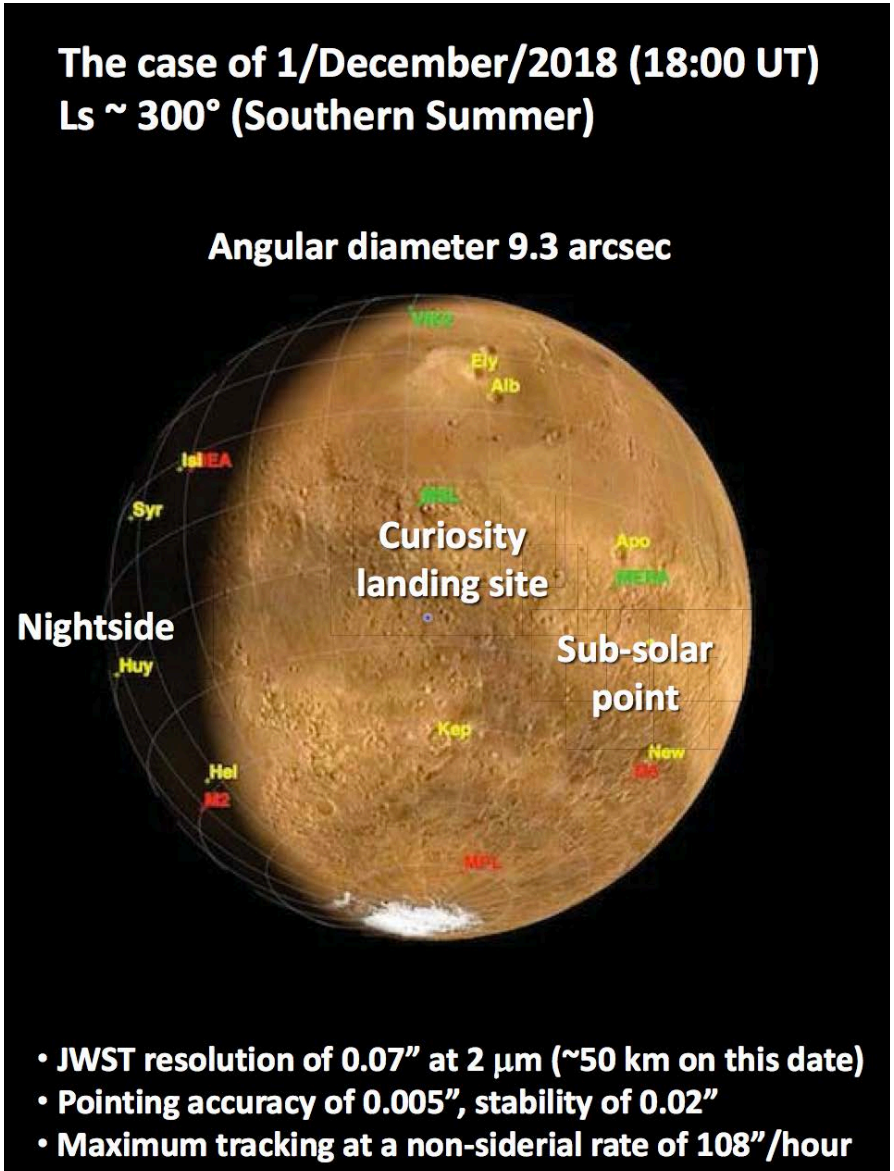
Table 2. Estimated surface brightness (Jy/□″) of outer planets and Pluto.

Planet	Heliocentric Dist. (AU)	Radius (km)	albedo	2 μm (Jy/□″)	4-5μm	10-12 μm	Diam. (″)	Area (□″)
Mars	1.67	3397	0.2	100	34	2800	7.0	39
Jupiter	5.2	71492	0.52	22	100	35	39	1172
Saturn	9.5	60268	0.47	6.0	2	10	18	243
Uranus	19.2	25559	0.51	1.6	0.47	0.3	3.7	11
Neptune	30.1	24766	0.41	0.5	0.16	100	2.3	4
Pluto	33.0	1150	0.55	5.5 mJy	1.6	0.3	0.10	0.008

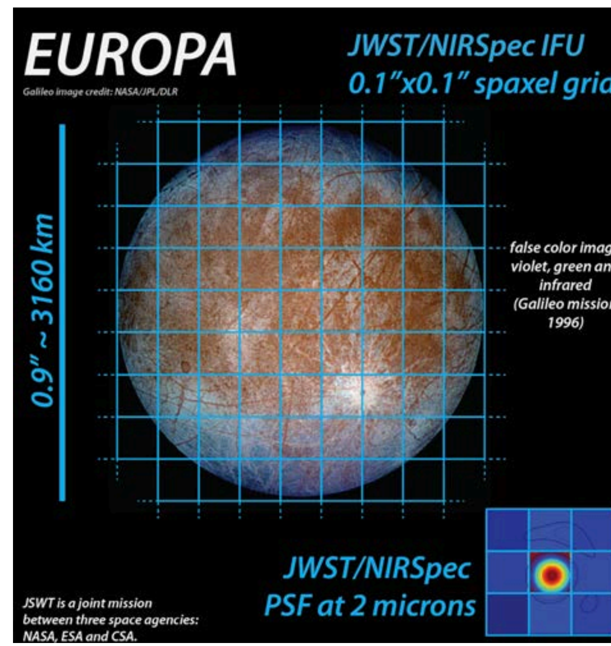
Notes: These values are the sum of reflected solar flux and thermal emission. Jupiter's surface brightness is for a Jovian "hot spot," which is brighter than the disk average. Pluto's brightness is for full disk, not surface brightness. Angular sizes assume each target is at a solar elongation of 90°, and therefore within the JWST field of regard. Mars is assumed to be near aphelion, when it is at its dimmest.

"Solar system observations with JWST", Norwood et al., 2014, white paper

Generic points – some size and surface brightness numbers



- **HST spatial resolution in the near-infrared.**
  - Cannot be compared to what you get when you orbit a planet but still very good.



“Solar system observations with JWST”, Norwood et al., 2014, white paper

Generic points – on the bright side

- **For many targets in the solar system, one really really has to worry about saturation limits.**

Imaging with NIRCam

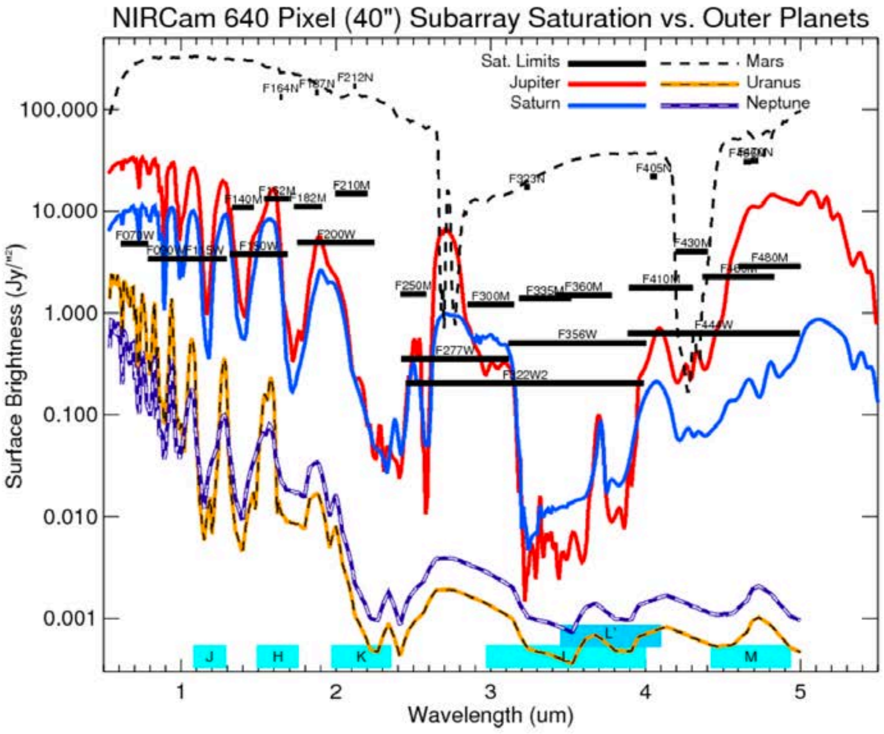
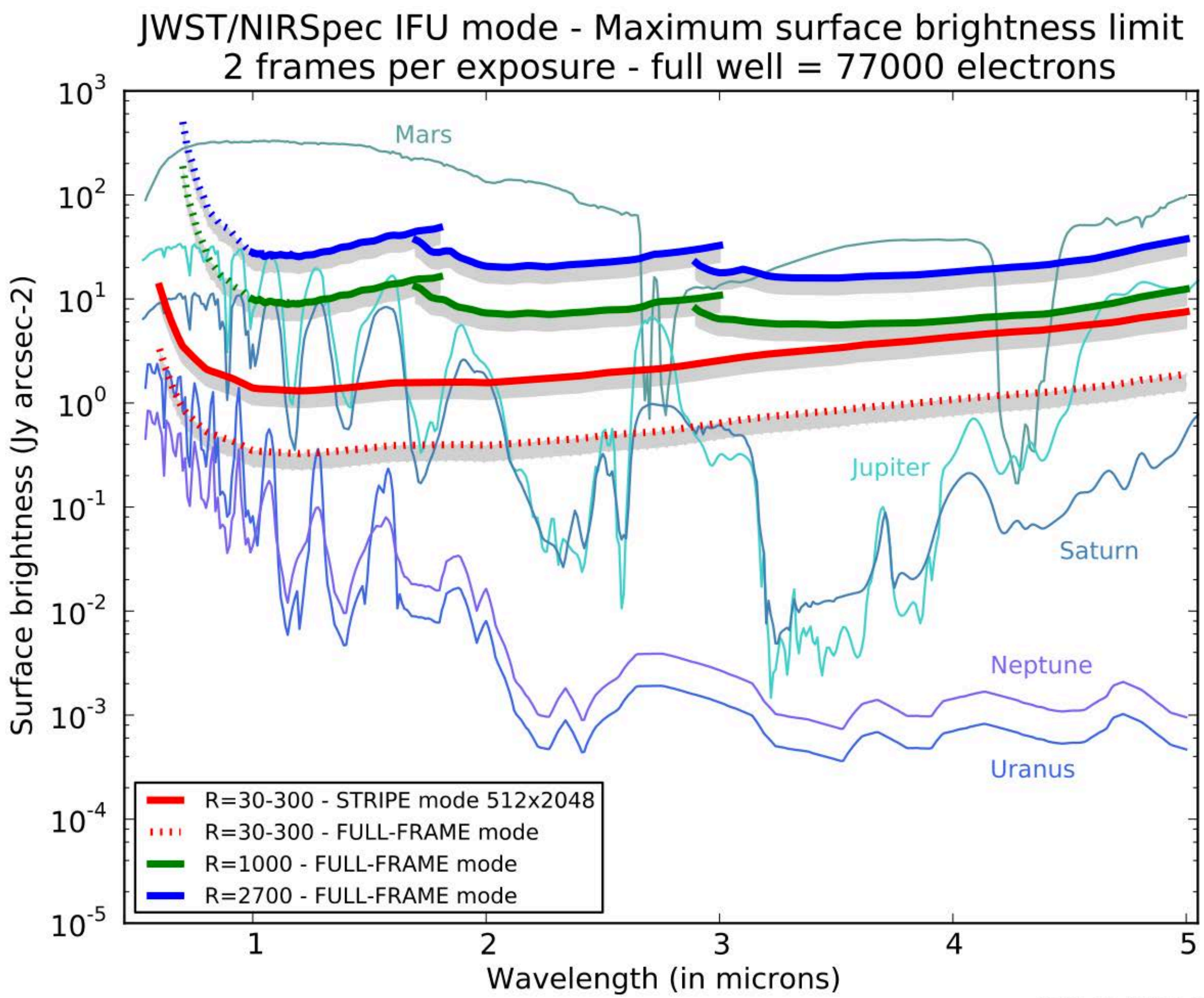


Figure 2. Saturation limits (black) for the NIRCam filters employing the subarray configuration in Figure 1, compared to planetary spectra.

"Solar system observations with JWST", Norwood et al., 2014, white paper

Generic points – on the bright side

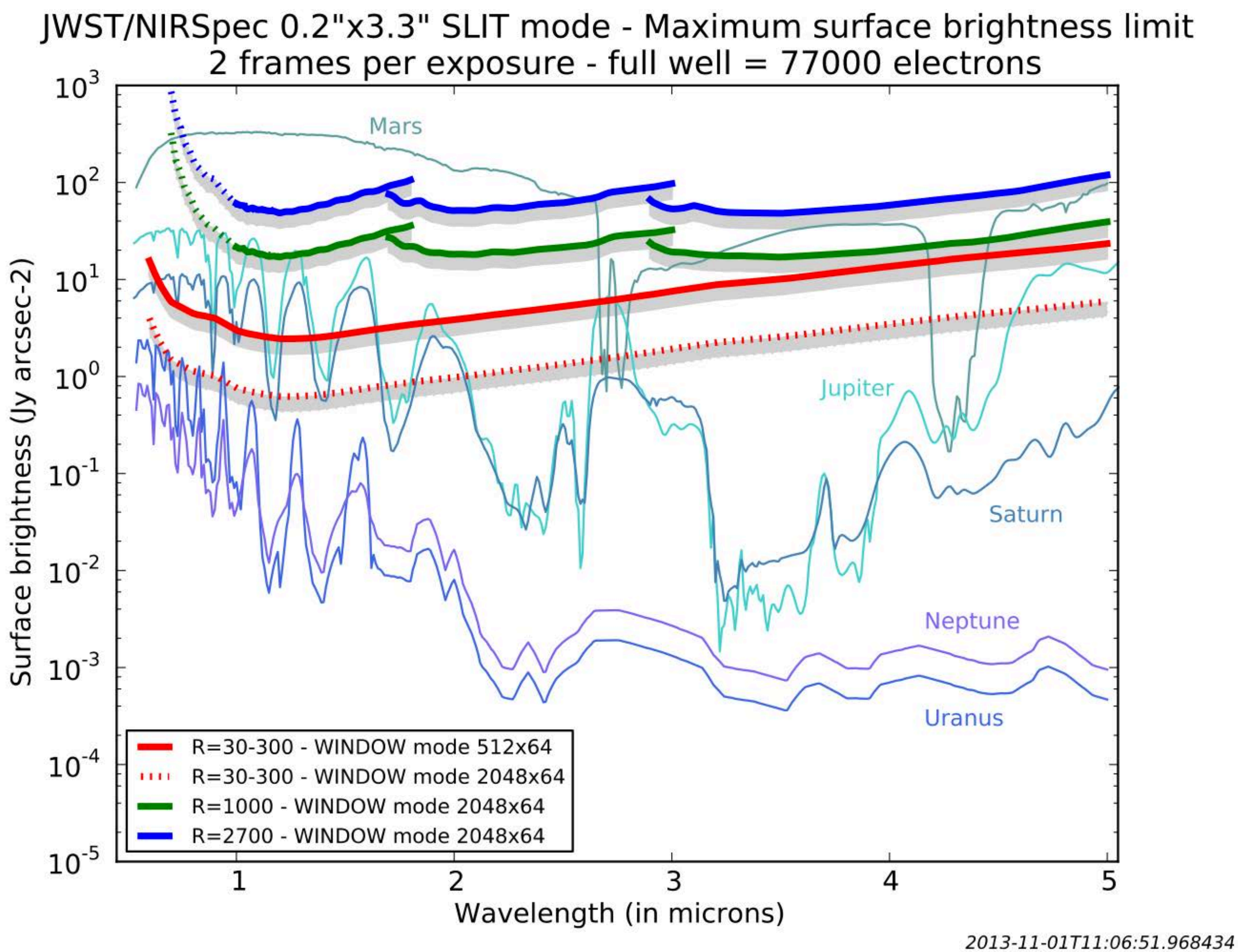
Spectroscopy with NIRSpec IFU



"Solar system observations with JWST", Norwood et al., 2014, white paper

Generic points – on the bright side

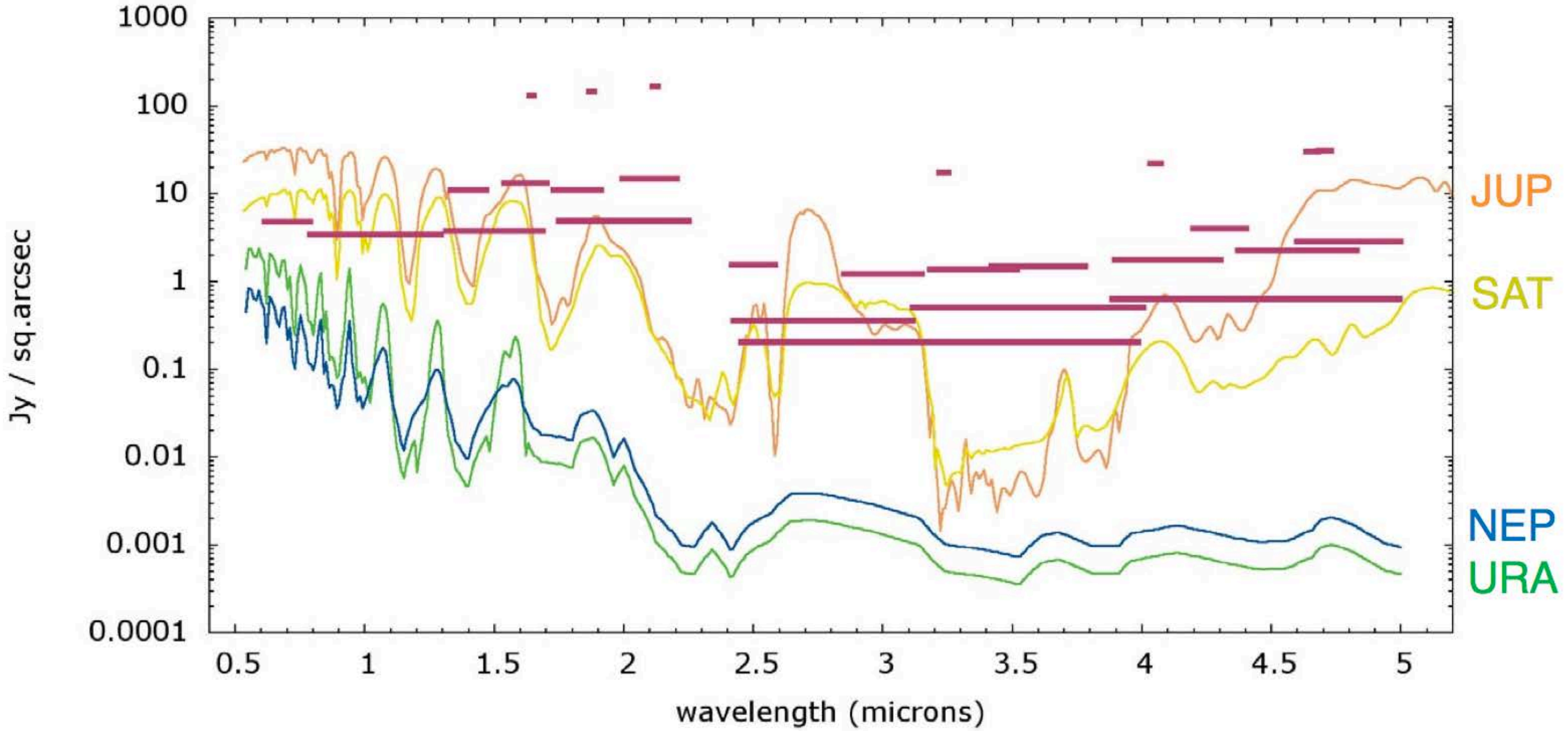
Spectroscopy with NIRSpec SLIT using subarrays.



"Solar system observations with JWST", Norwood et al., 2014, white paper

Generic points – on the bright side

Imaging with MIRI using subarrays



"Big & bright presentation", DPS 2014

Science examples

Sparse sampling of science cases

Contents stolen from the presentations from the focus groups at the DPS in 2014 and from the white paper.

See: http://www.stsci.edu/jwst/science/jwst-solar-system-meetings-docs

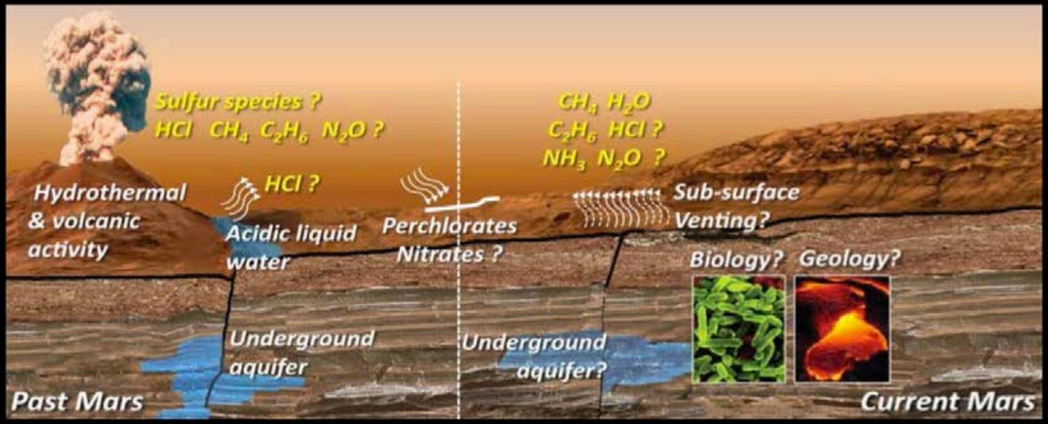
Big and bright… MARS focus group

The unique value of the JWST L2 orbit

- *Seasonal studies, including the stability of the polar caps.*
- *Diurnal studies and of processes near the day/night terminator.*
- *Transient events.*

New Frontiers with JWST

- *Maps of water D/H: revealing possible exchange reservoirs on Mars*
- *Photochemical cycles of CO_2, CO, H_2O and other key trace species: characterizing the climate and the active chemistry.*
- *Formation and evolution of global dust storms and cloud systems over volcanoes.*



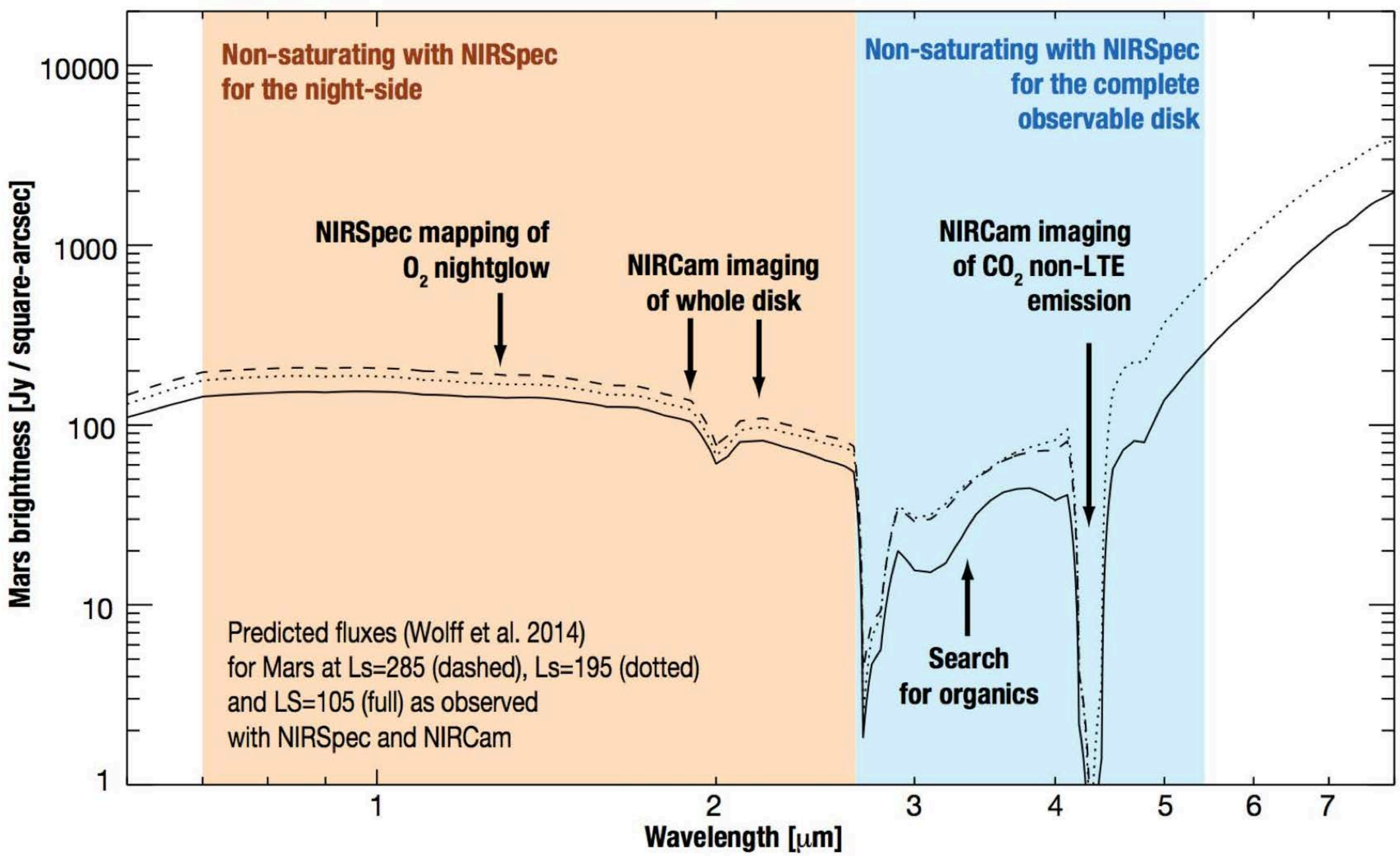
Past/current habitability?

Was Mars Wet? and how much water is currently available?

Stability of the polar caps, surface regolith and atmosphere.

MARS focus group, presentation at the DPS in 2014

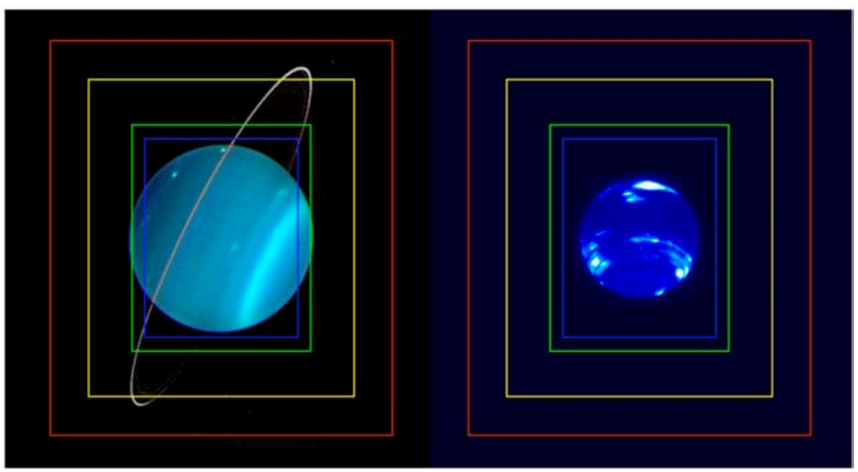
Big and bright... MARS focus group



MARS focus group, presentation at the DPS in 2014

Big and bright… Giant planets

- **Getting in surface brightness ranges where life is easier…**
- **Sensitivity, spatial resolution, wavelength coverage.**
- **Type of studies:**
  - Cloud structure; tracking methane variations; thermal properties (MIRI).
  - Chemical abundance maps. Looking at hydrocarbons.



“Solar system observations with JWST”, Norwood et al., 2014, white paper

MARS focus group, presentation at the DPS in 2014

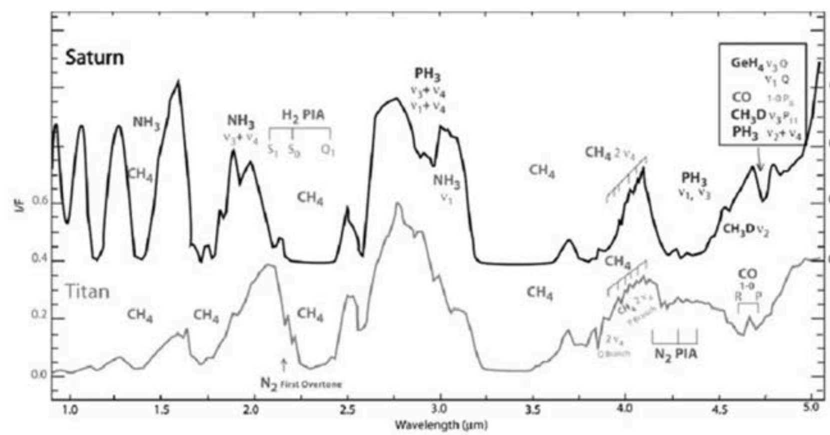
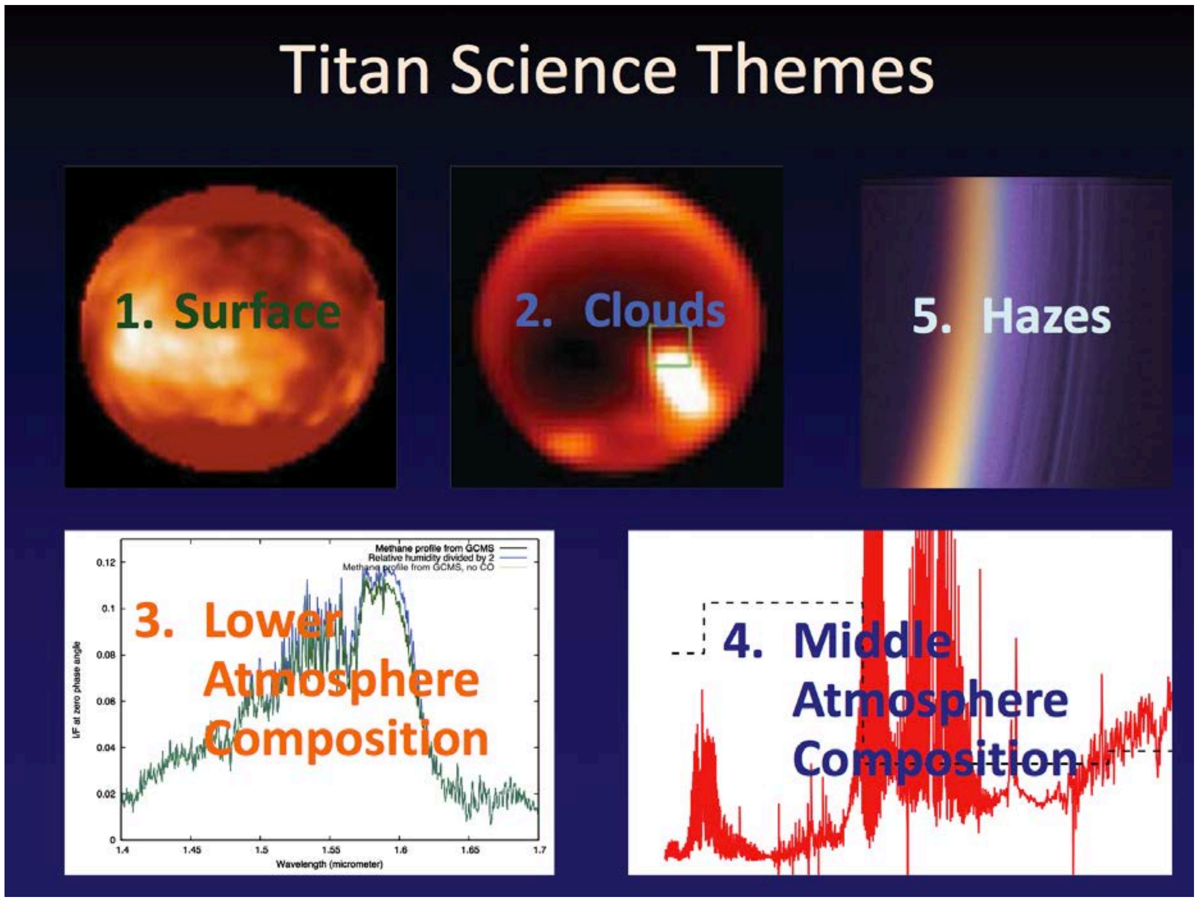


Figure 6. VIMS spectrum of Saturn (darker line) over a spectral region comparable to that of NIRSpec. The spectral resolution of the VIMS data is ~200; NIRSpec will be able to match or exceed this, providing a more detailed understanding of the chemistry and dynamics in the giant planet atmospheres. Figure from Baines et al. (2005).

Moons galore

- **As for the giant planets, infrared spectroscopy is a powerful tool.**
- **Example with Titan. See also e.g. Europa in the white paper.**



Moons galore, presentation at the DPS in 2014

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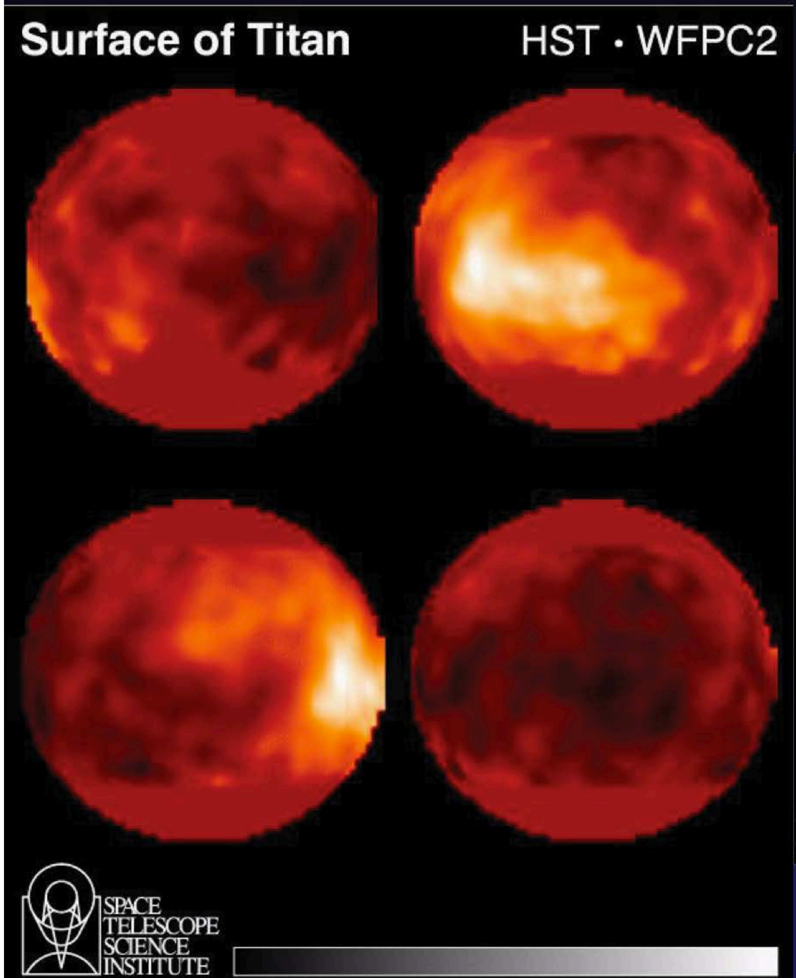
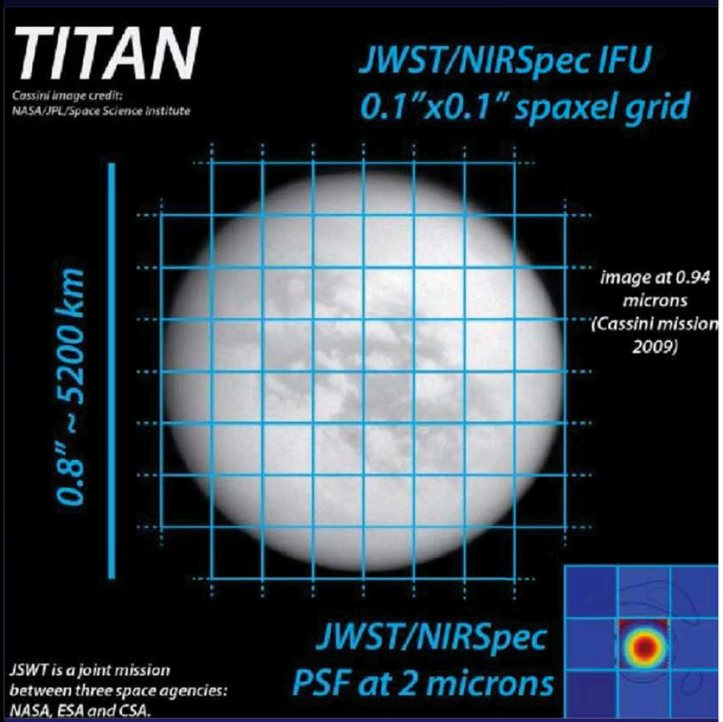
European Space Agency

1. Surface



- Titan's surface has been observed by HST and ground-based observatories since mid-1990s.
- JWST spatial resolution is ~2.5x Hubble based on primary aperture.

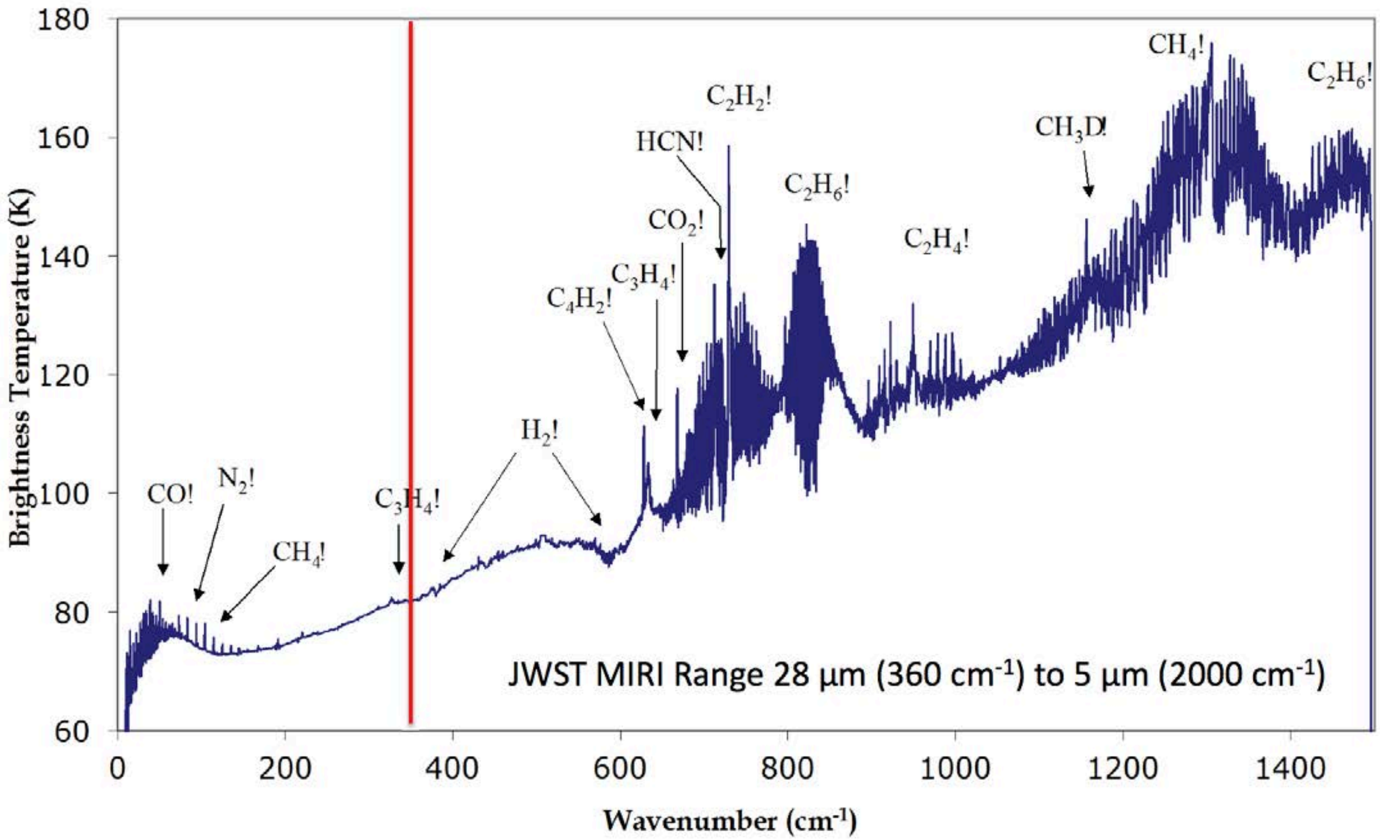


Left: HST from Smith et al. 1998
Above: from Norwood et al. 2014

Moons galore, presentation at the DPS in 2014

Moons galore

4. Stratospheric Composition



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

Rocks in space
(forget the bright guys! Almost...)

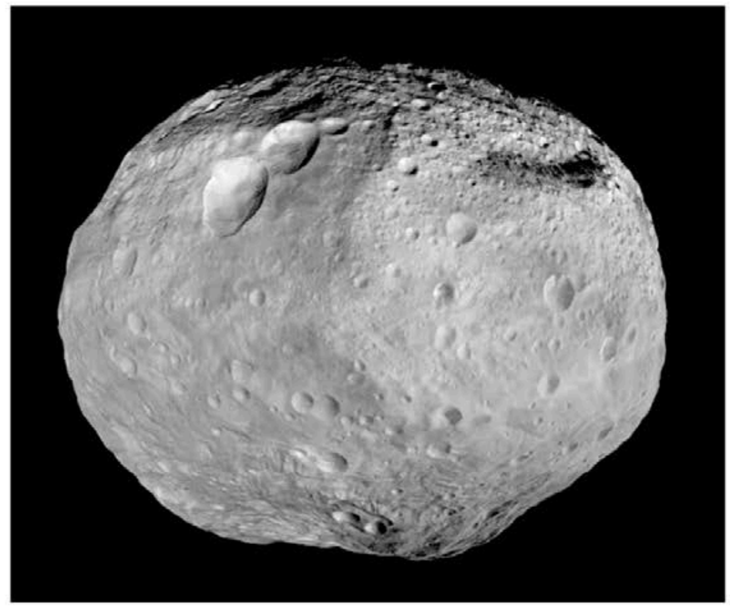
What benefit does JWST offer asteroid studies?

unique wavelength coverage

- **Wavelengths unavailable from Earth**
  - **Including important fundamental and overtones associated with water/OH!**
- **Spatial resolution unavailable from Earth**
- **Reach fainter targets**

spatial resolution

sensitivity



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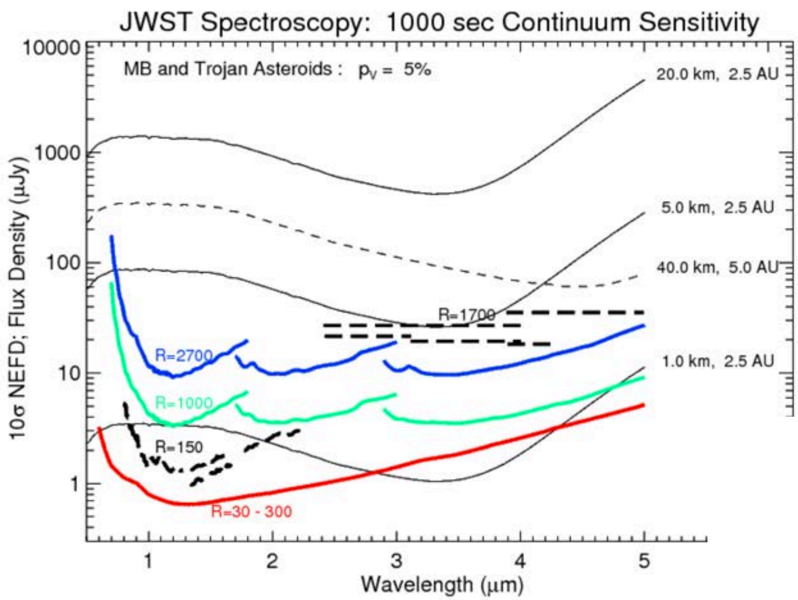
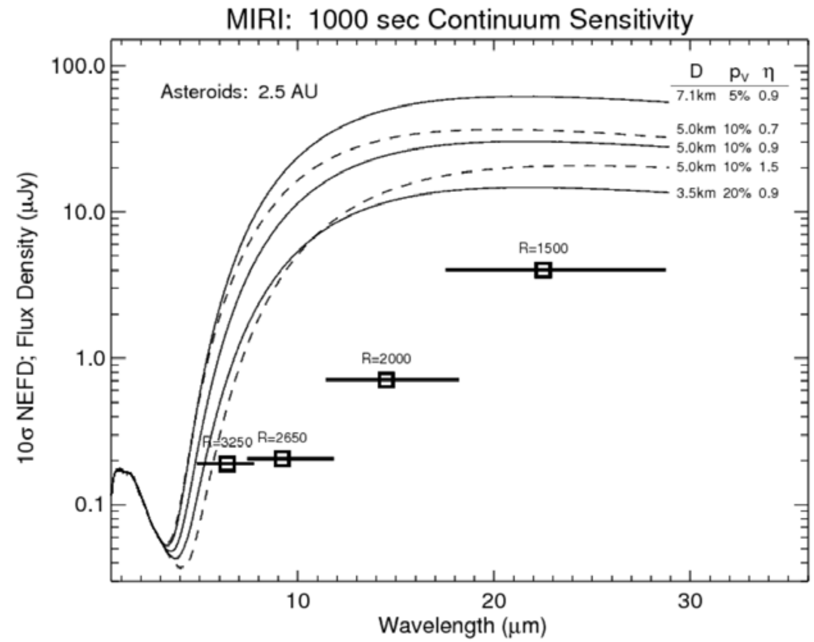
Space APL

Rocks in space (start to forget the bright guys!)



Extensive wavelength coverage at good S/N for small asteroids.

Getting reflectance & emission.



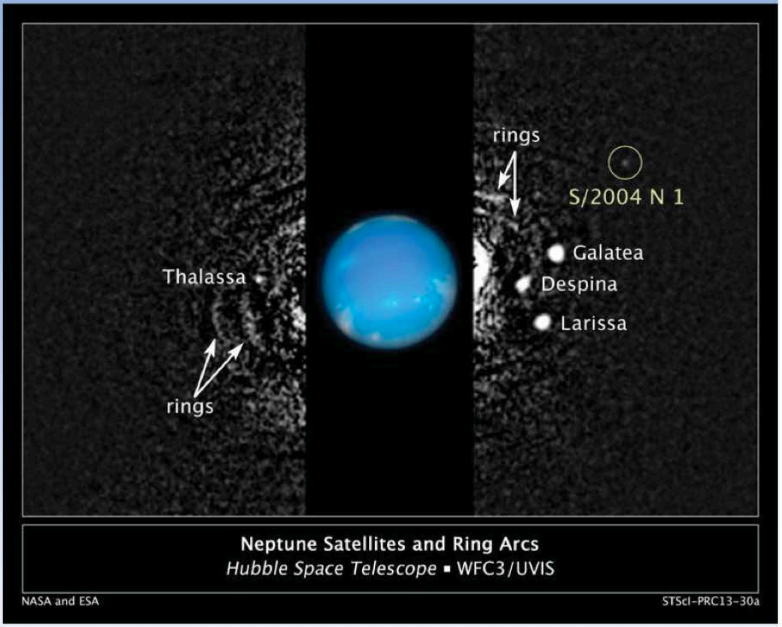
Saturation will start to become a problem with MIRI for the big guys…

Rocks in space, presentation at the DPS in 2014

Discovering new rings and moons

Tiscareno (7/13)

- Hubble has set the standard for faint rings and moons at Uranus and Neptune
- JWST will improve upon Hubble, as it has
  - Comparable spatial resolution, but
  - At longer wavelengths, so cool objects are brighter
  - Greater sensitivity overall
- Major challenge: Bright planet nearby
  - With filters, can image in IR methane bands, planet is dark!



Only 18 km across, S/2004 N 1 (discovered in 2013 by Showalter et al.) is >10x fainter than any moon seen by Voyager 2

Ice is nice, presentation at the DPS in 2014

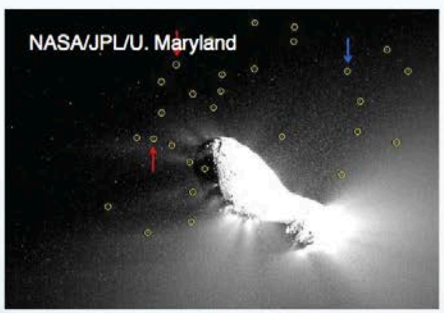
JWST Challenge – Comet Science

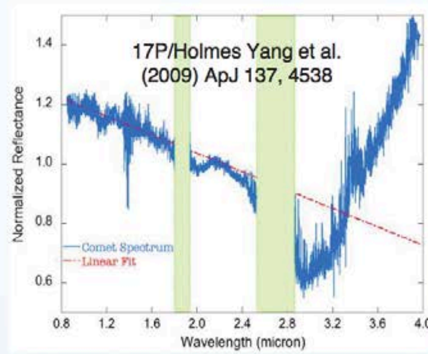
Water Ice in Comet Comae :

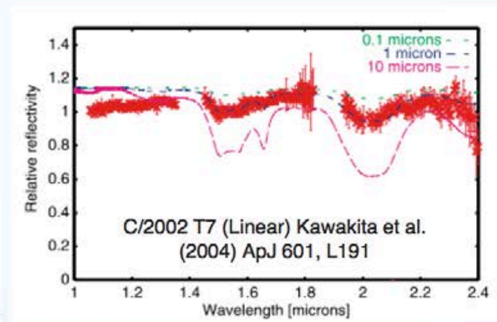
Comets serve as a Probe for Study of Pristine Water Ice.

Water ice displays absorption bands at 1.5, 2.0, and 3.0 µm.

- Feature Strength Shape – Impurity Presence, Ice Abundances, Size
- Crystalline vs. Amorphous Component (narrow 1.65 µm feature)







NIRSpec (Prism Mode) :

Test Case – C/2012 S1 (ISON) at r_h 4.15 (AU) – Li et al. (2013)
A(θ)fρ of 1300 cm at 0.6 µm within a distance of 5000 km from the nucleus
$F(Jy)_{0.6}$ ~ 5e-5 $F(Jy)_{3.0}$ ~ 2e-5 –– Slit 0.4” x 3.8” (1200km x11400km)

3.0 µm SNR ~ 600 in 20 mins near nucleus to SNR ~ 40 in 180 mins in coma

Ice is nice, presentation at the DPS in 2014

TNOs/KBOs

TNOs: Distant, cold, primordial

Distant:
- small angular sizes
- small binary separations
- faint in reflected light

+/- slow rates of motion

Cold:
- thermal peak ~100 um

+ retain volatiles on surfaces

Primordial:

+ cosmogony!

Ice is nice, presentation at the DPS in 2014

TNOs/KBOs

Where can JWST contribute?

Diameters/Albedos

Wavelength coverage does not extend to thermal peak of typical TNOs.

However, sensitivity blueward of peak is high; partially compensates.

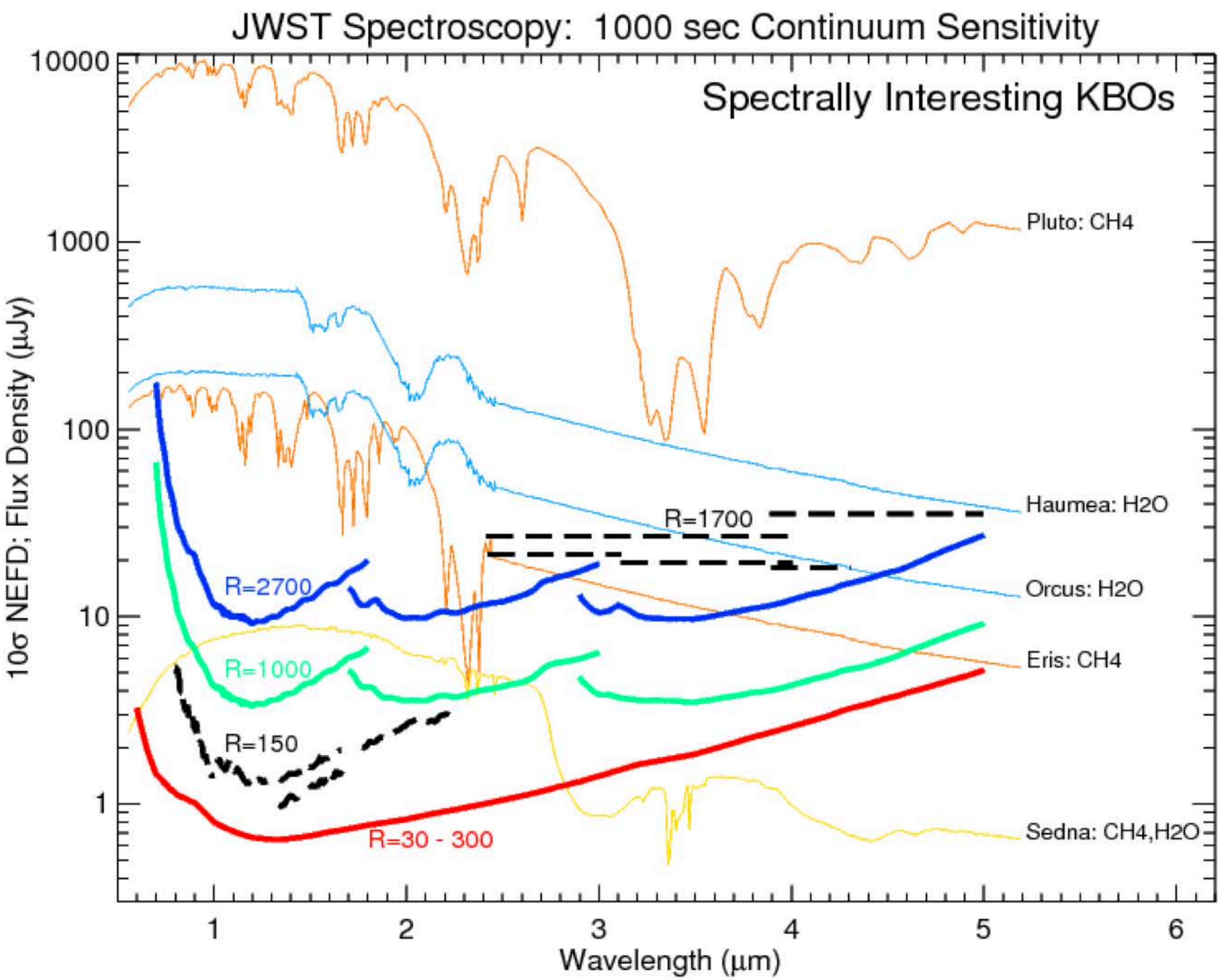
Composition

Sensitivity enables high-precision recovery of surface compositions for many TNOs with reasonable observing demands.

Molecular ices more accessible than ever before.

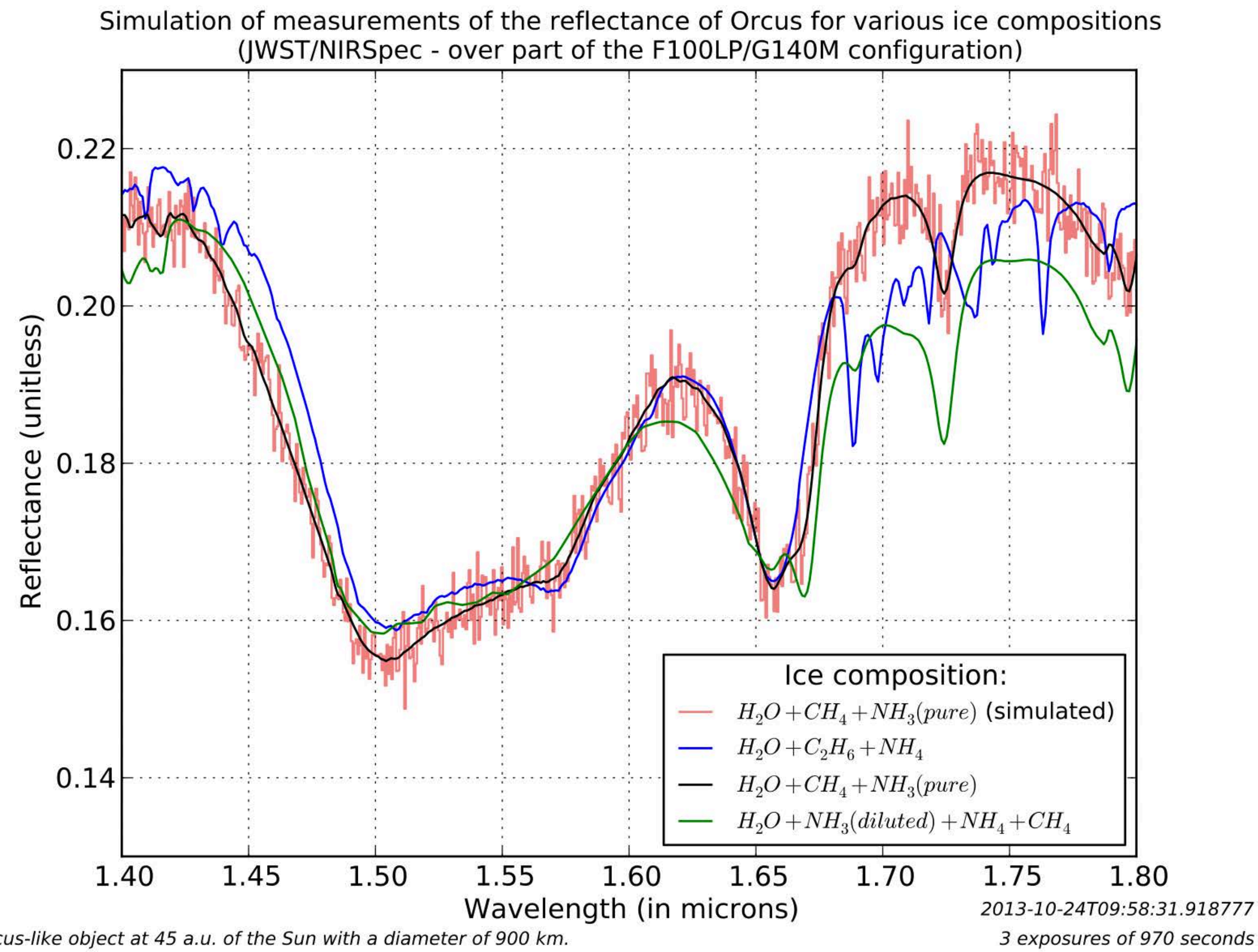
Ice is nice, presentation at the DPS in 2014

TNOs/KBOs



Ice is nice, presentation at the DPS in 2014

TNOs/KBOs



Ice is nice, presentation at the DPS in 2014

TNOs/KBOs

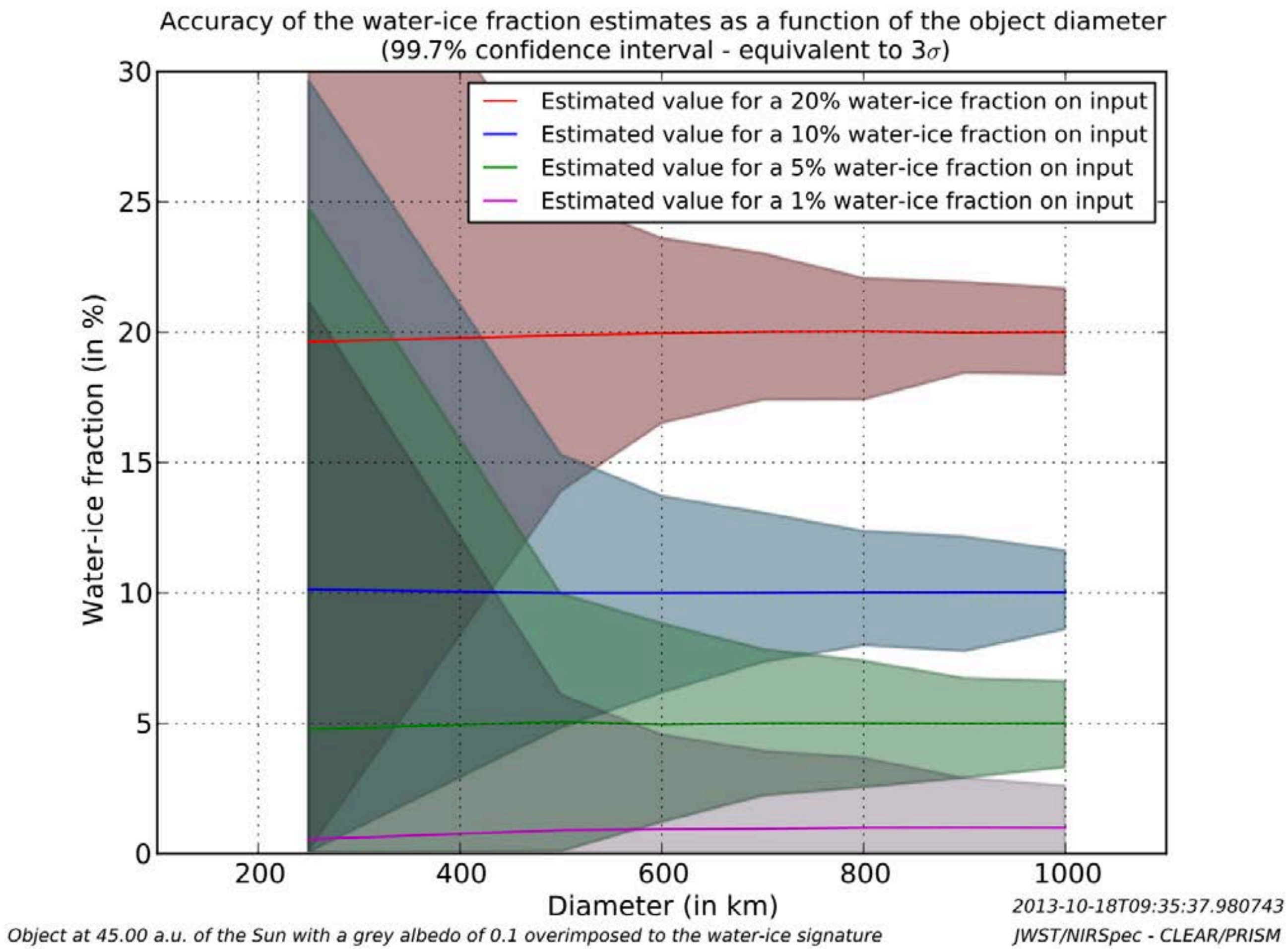


Figure 23. Accuracy of the water ice fraction estimates as a function of the object diameter and of the input water ice fraction. Simulations based on inputs from A. Guilbert-Lepoutre.

Ice is nice, presentation at the DPS in 2014

Conclusions
Great observatory – Organisation of the community

- **I hope that this fairly sparse sampling of solar system science case examples by a speaker with a very superficial knowledge of solar system science has convinced you that JWST will be a powerful tool to study our solar system.**

- **Very structured groups on the US side already but they are very open.**
  - Participate to the focus groups.
- **Opportunities for discussion.**
  - "Exploring the Universe with JWST" at ESA/ESTEC (12-16 October 2015). ➔ solar system sessions.
  - Joint DPS/EPSC meeting in 2016.
  - More?

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esa European Space Agency