LUVOIR Solar System Science

Synergy with Exoplanets and Cosmic Origins

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Planetary Habitability At Tech

Solar System Targets for Exoplanet and Cosmic Origins Synergy

1. Giant and Ice Giant Planets

→ These span a range of exoplanet size ranges

→ In the solar system, we can ground-truth what's happening in other systems,

→→→ ***There is not enough of this happening, let's talk!!***

2. Moons around the Giants

→ Examples of "exotic" configurations

→ These are *PLANET SIZED*

→ Early atmospheres, active processes, ***habitable worlds***

3. Asteroid and Kuiper Belt Objects

→ Dynamic field, actively changing right now

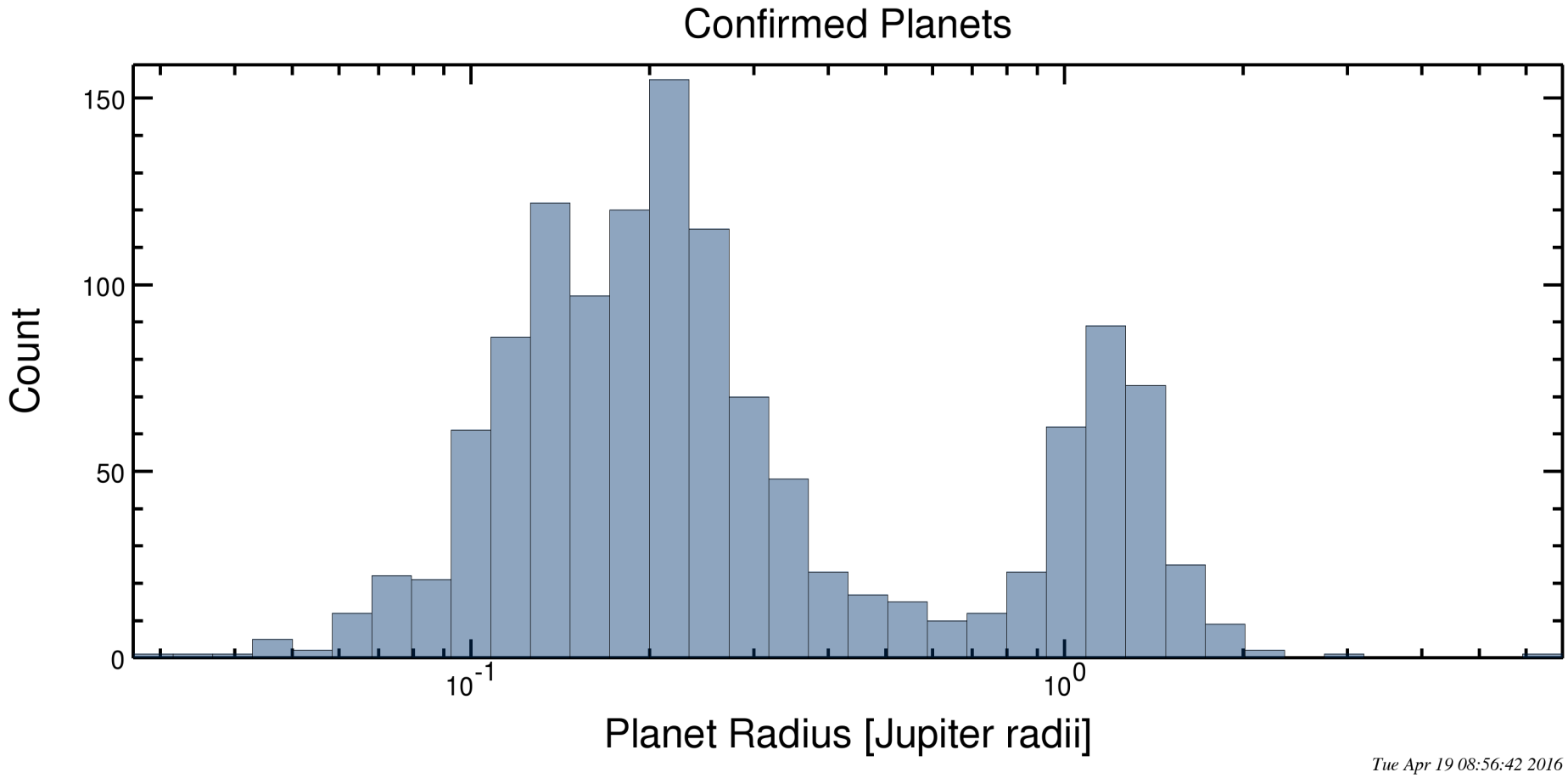
→ Directly relevant to system dynamics and debris/protoplanetary disks

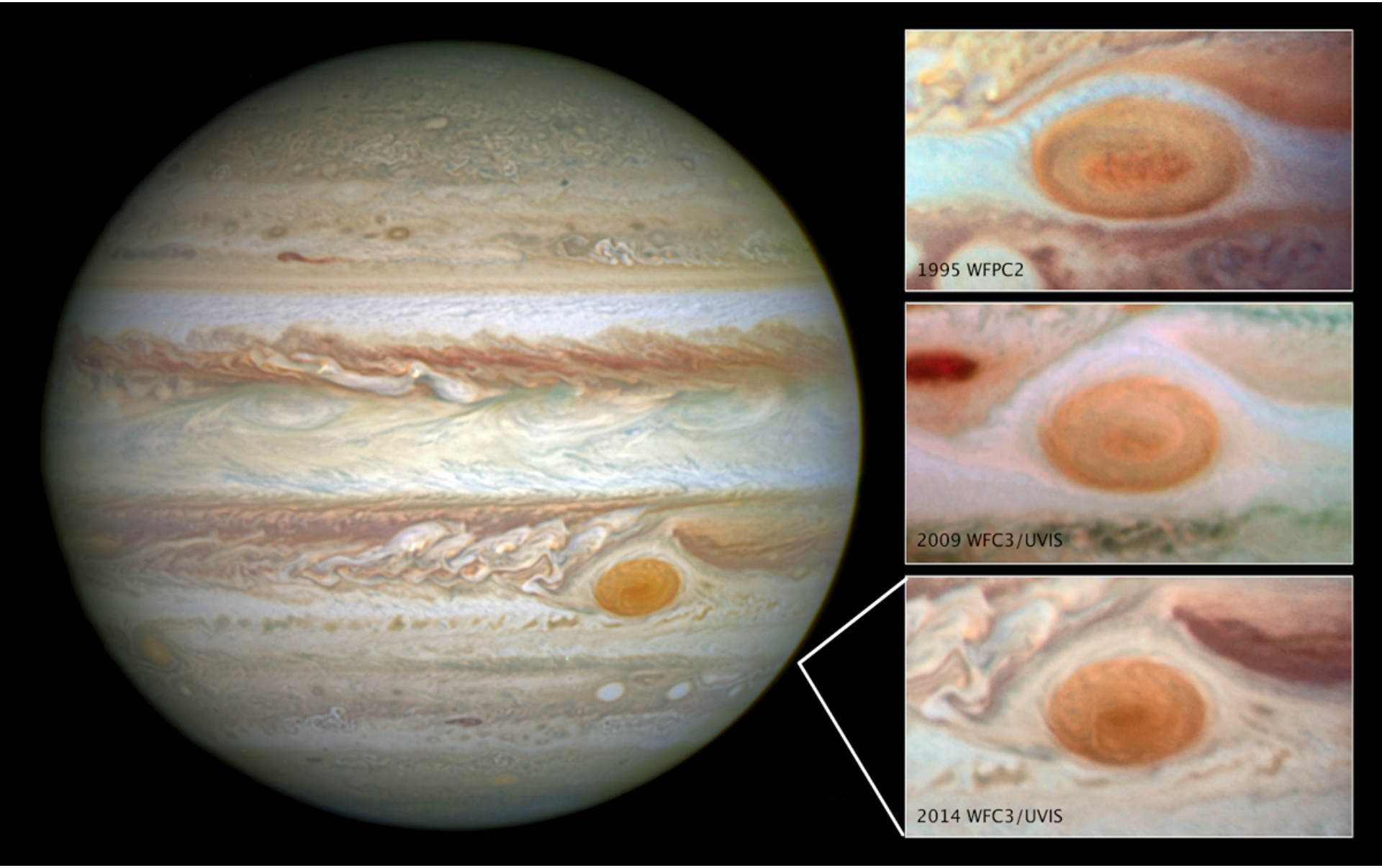
→ Synergy with planet formation/cosmic origins

Solar System Target Requirements

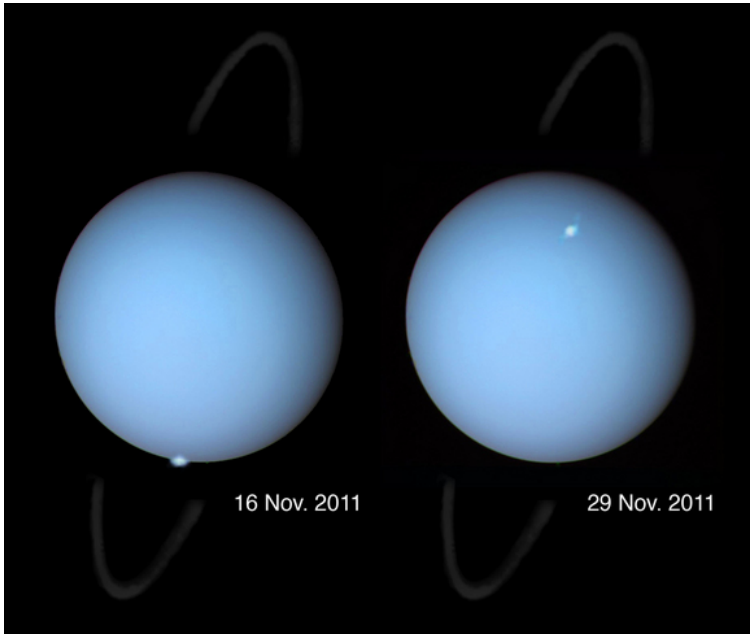
1. Moving Target Tracking Capabilities
   → HST/JWST can do >30mas/sec, which is good
   → WFIRST's moving target tracking capability is TBD
   →It would be silly not to have tracking on LUVOIR
2. Bright objects
   → Avoid being inflexible for SS targets
3. Imaging near Bright Objects
   → If not planned in advance, no moon/ring science, Giants are too bright
4. Diffraction limited Imaging & Integral Field Capability
   → "Resolved" science
   → Fly-by mission capability in single visit; mission caliber science in a few sets of orbits

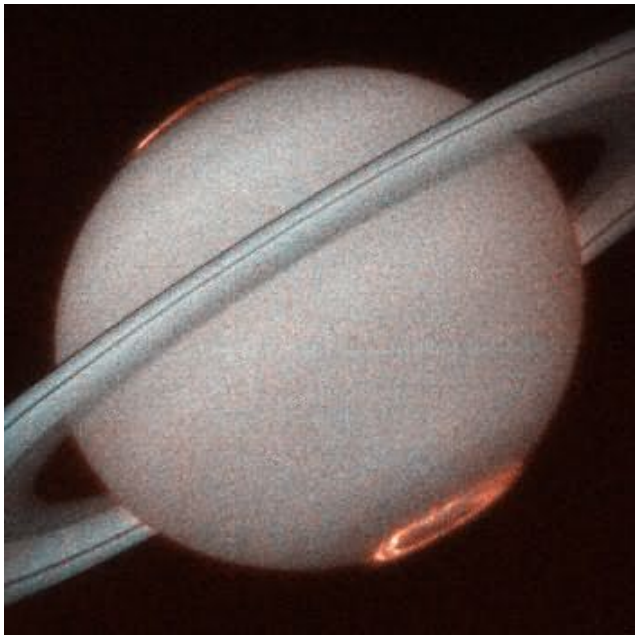
Giant and Ice Giant Planets—Resolving Dynamics and Establishing Exoplanet Baselines

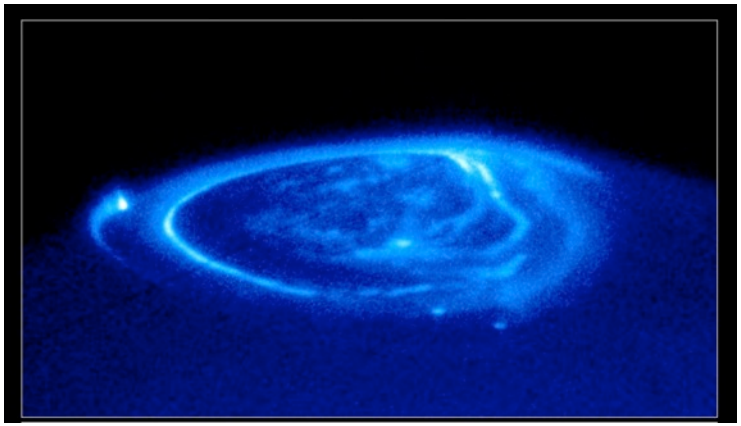

Confirmed Planets
Count
150
100
50
0
10^{-1}
10^{0}
Planet Radius [Jupiter radii]
Tue Apr 19 08:56:42 2016

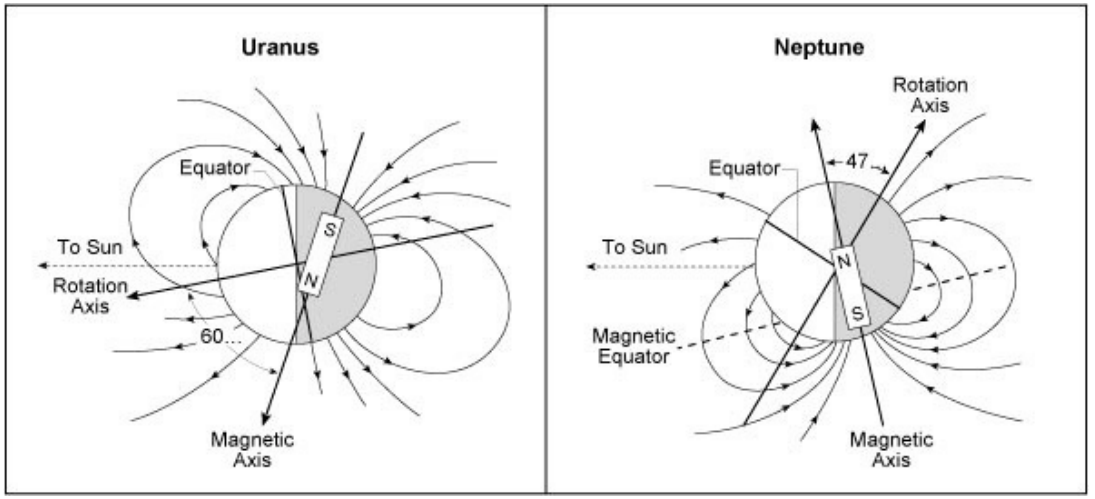

1995 WFPC2
2009 WFC3/UVIS
2014 WFC3/UVIS

UV Aurora & Rings—Dynamics

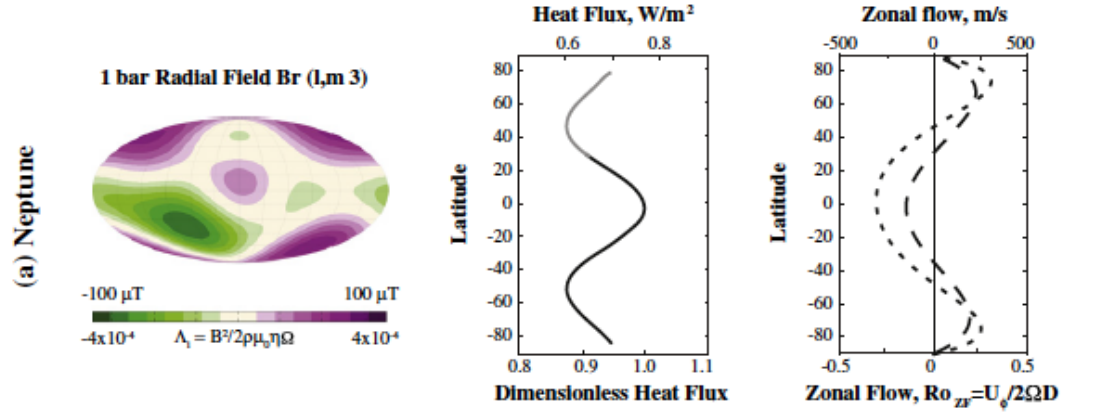


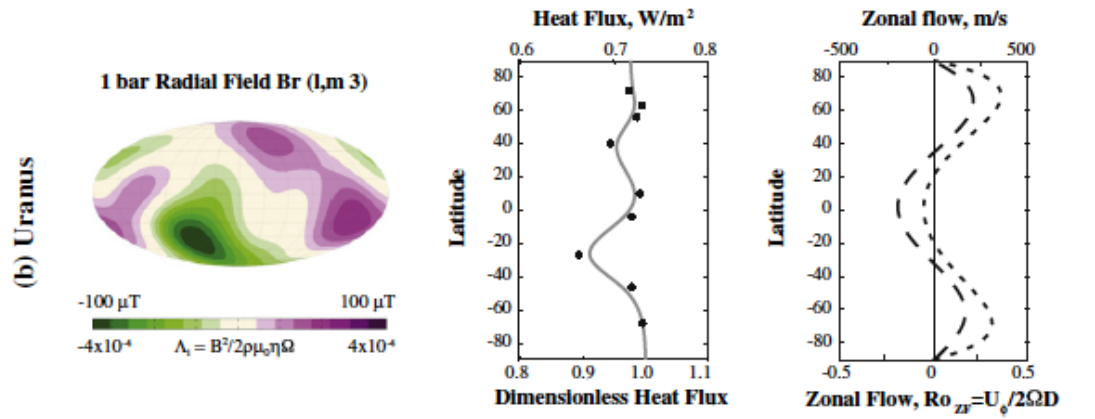


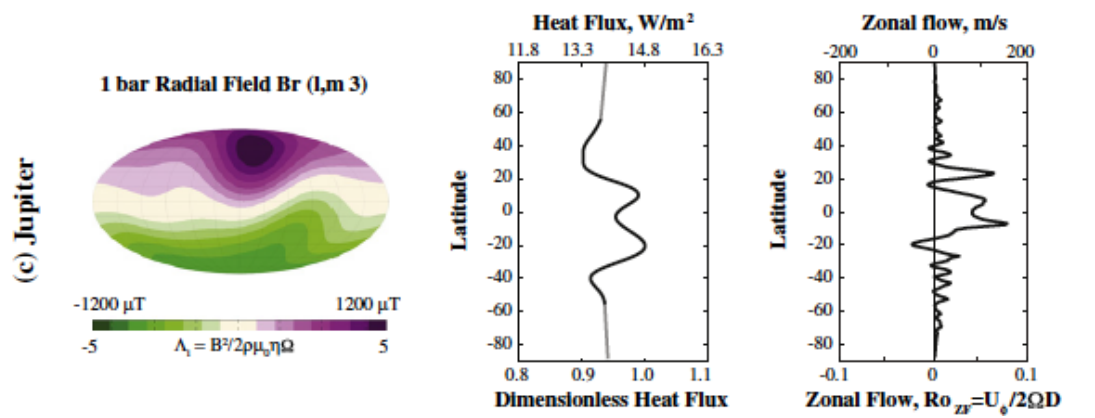


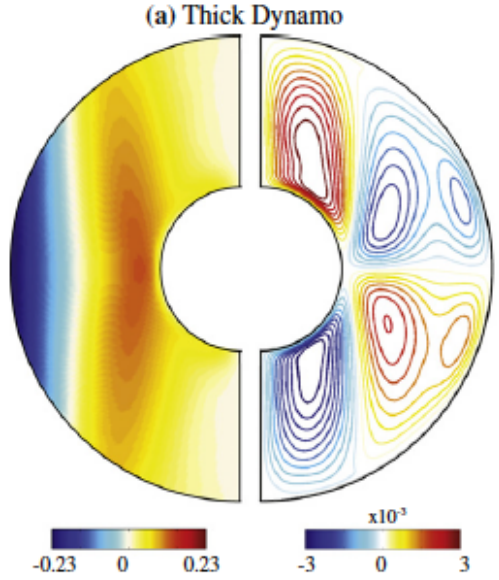


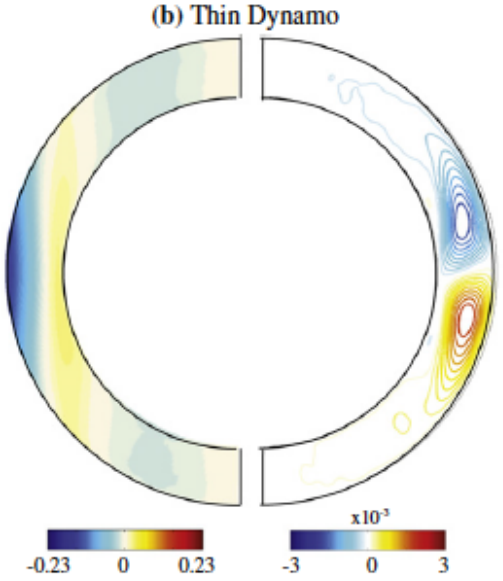
Internal Structure and Dynamics



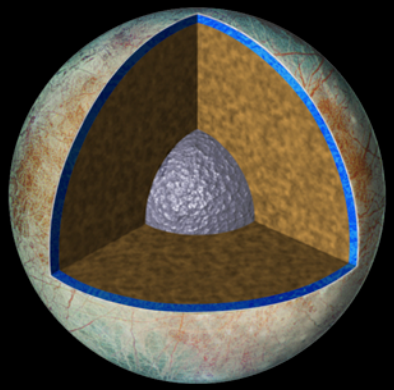




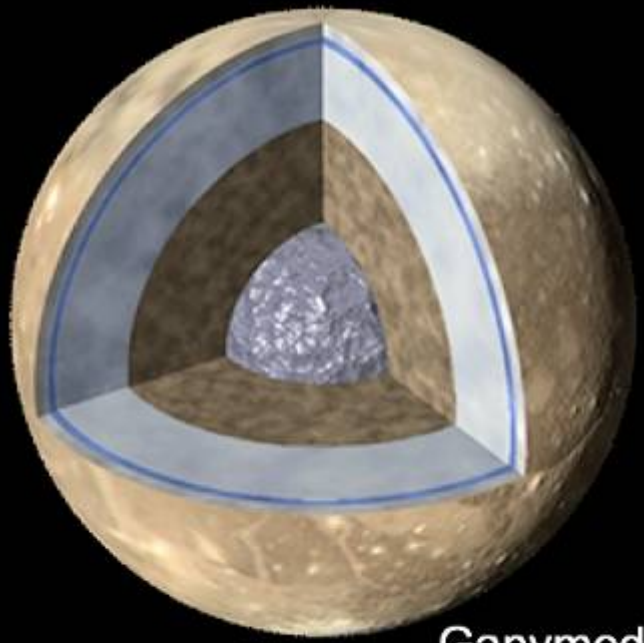


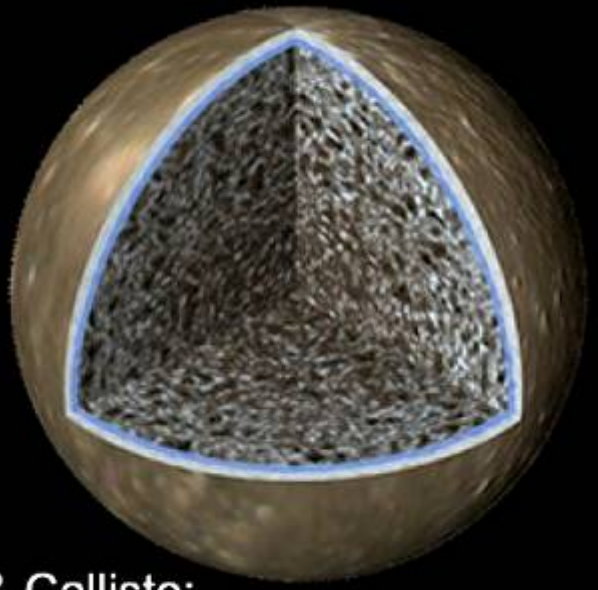


Icy Moons—
Exotic Habitable Worlds



Europa:
warm salty H_2O, mantle contact, high energy

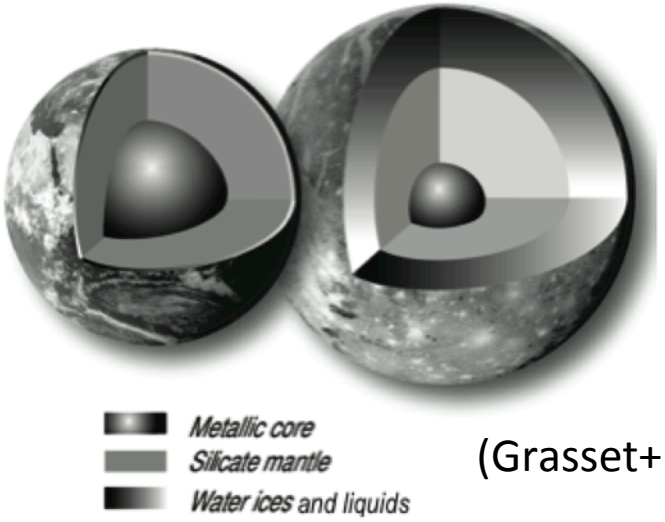




Ganymede & Callisto:
perched salty H_2O(-NH_3?)

e.g. Schubert et al, 1998

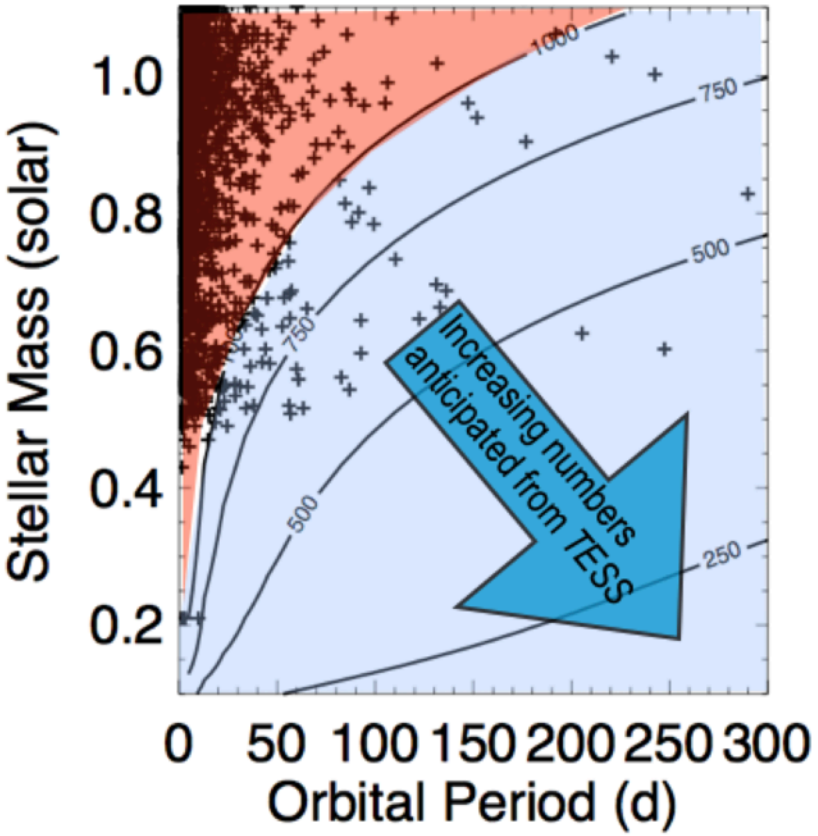
Super-Ganymedes
Super-Earths
Super-Europas?



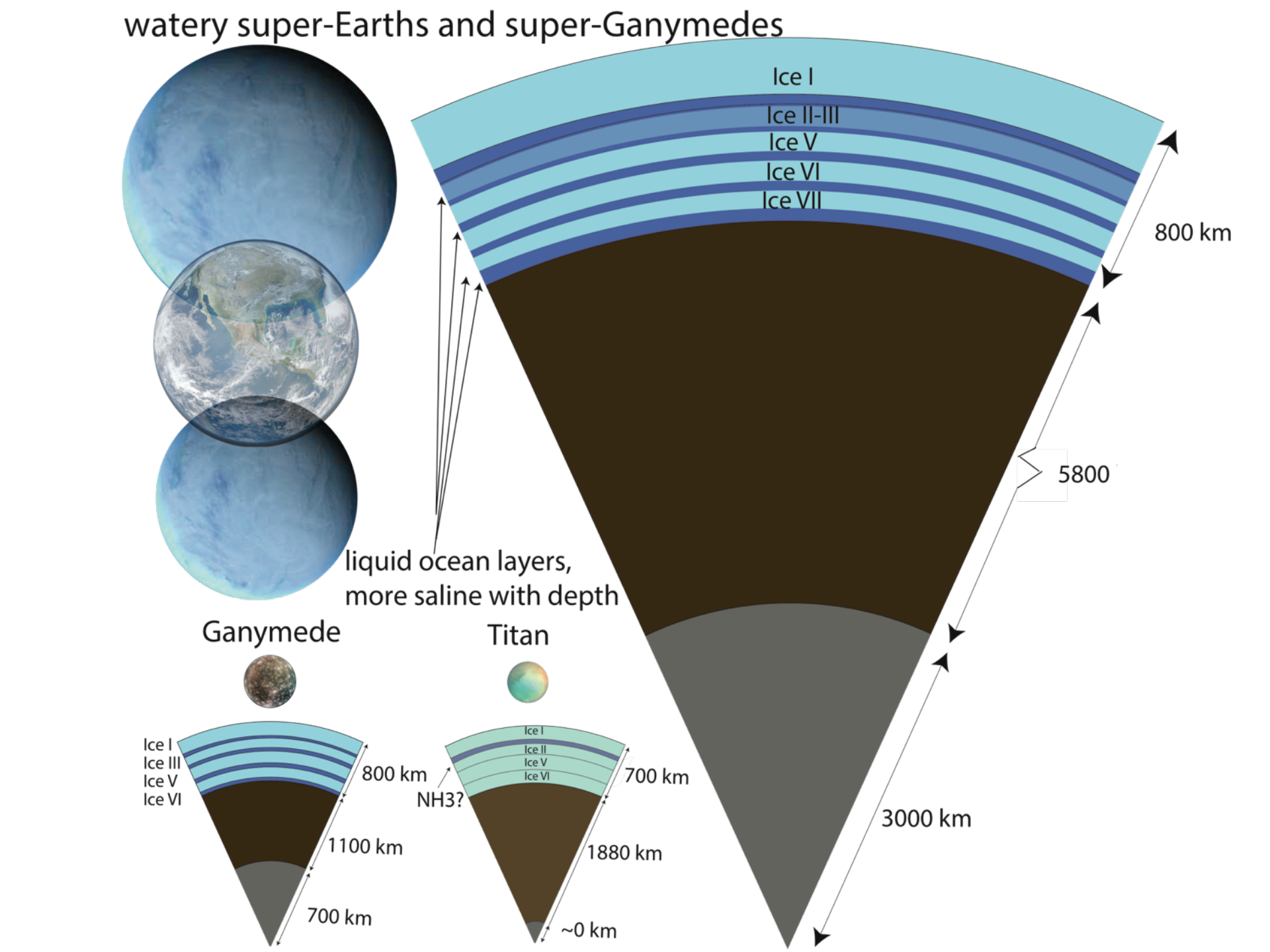
(Grasset+ 2009)

Kepler planets R<2.5R_{Earth}

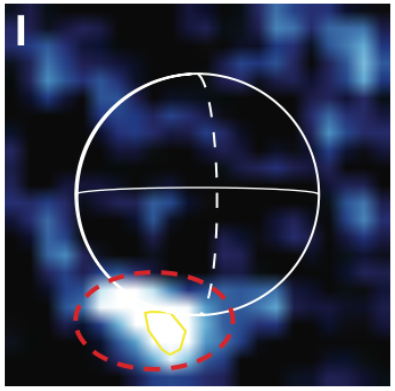
contours: $T_{surface}$ (K)

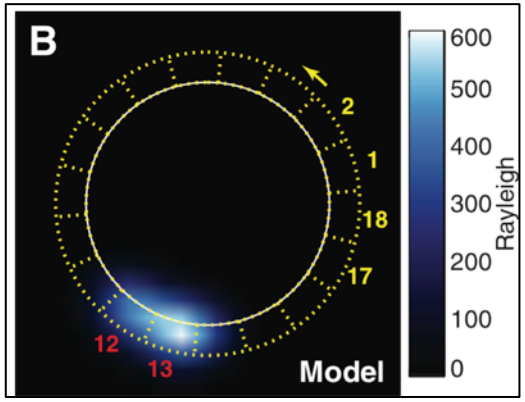


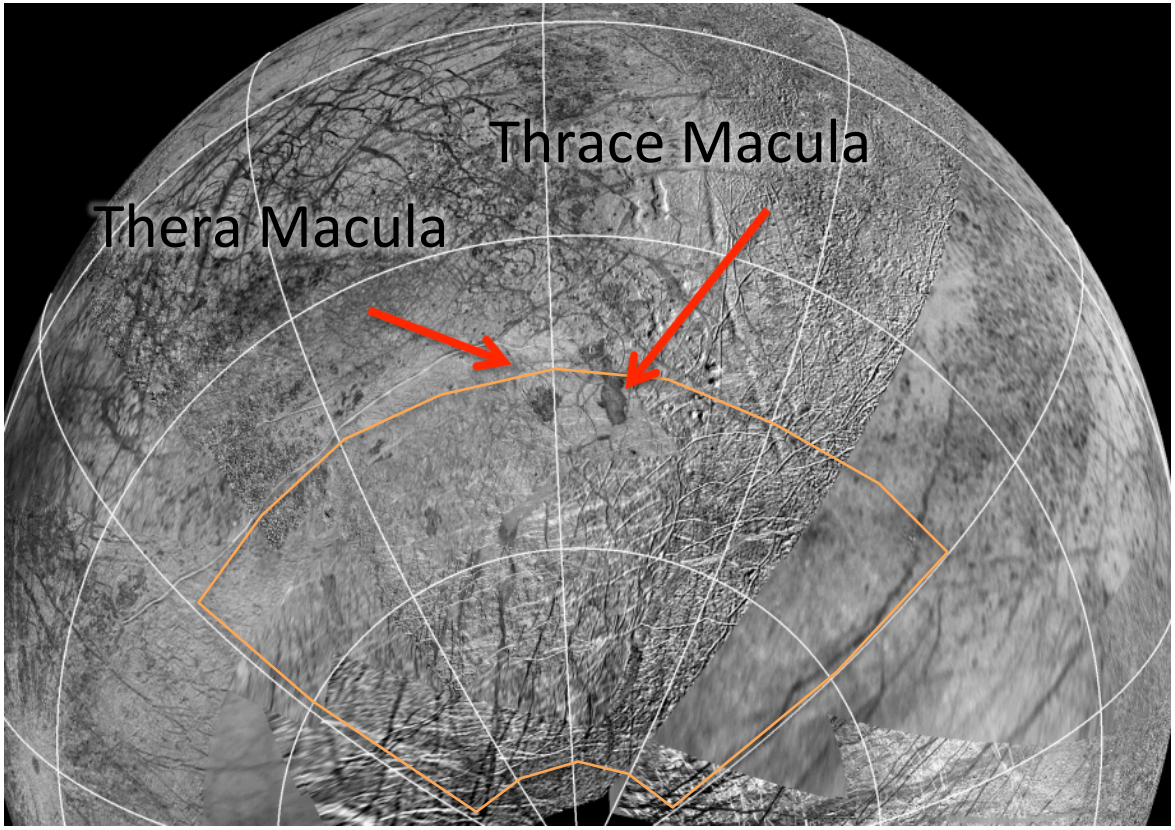
TESS: Transiting Exoplanet Survey Satellite (Ricker+2014)


watery super-Earths and super-Ganymedes
Ice I
Ice II-III
Ice V
Ice VI
Ice VII
800 km
5800
liquid ocean layers,
more saline with depth
3000 km
Ganymede
Ice I
Ice III
Ice V
Ice VI
800 km
1100 km
700 km
Titan
Ice I
Ice II
Ice V
Ice VI
NH3?
700 km
1880 km
~0 km

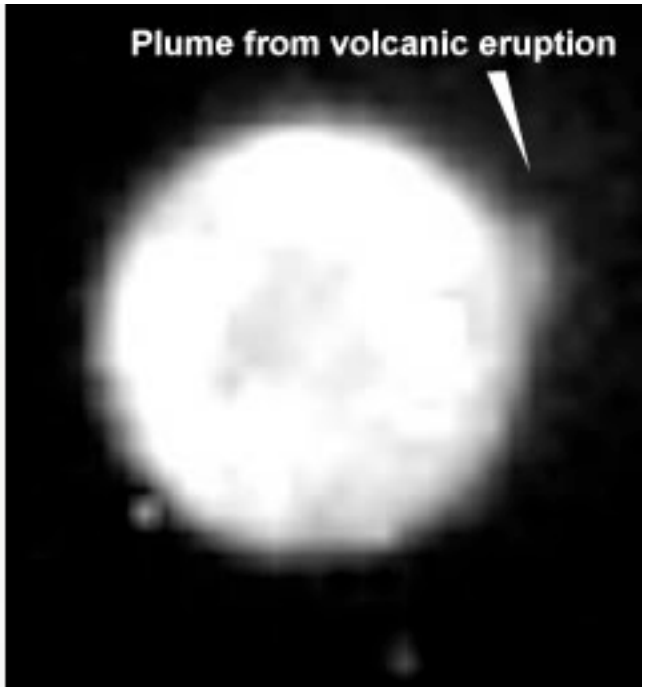
Europa Plume Location & Variability



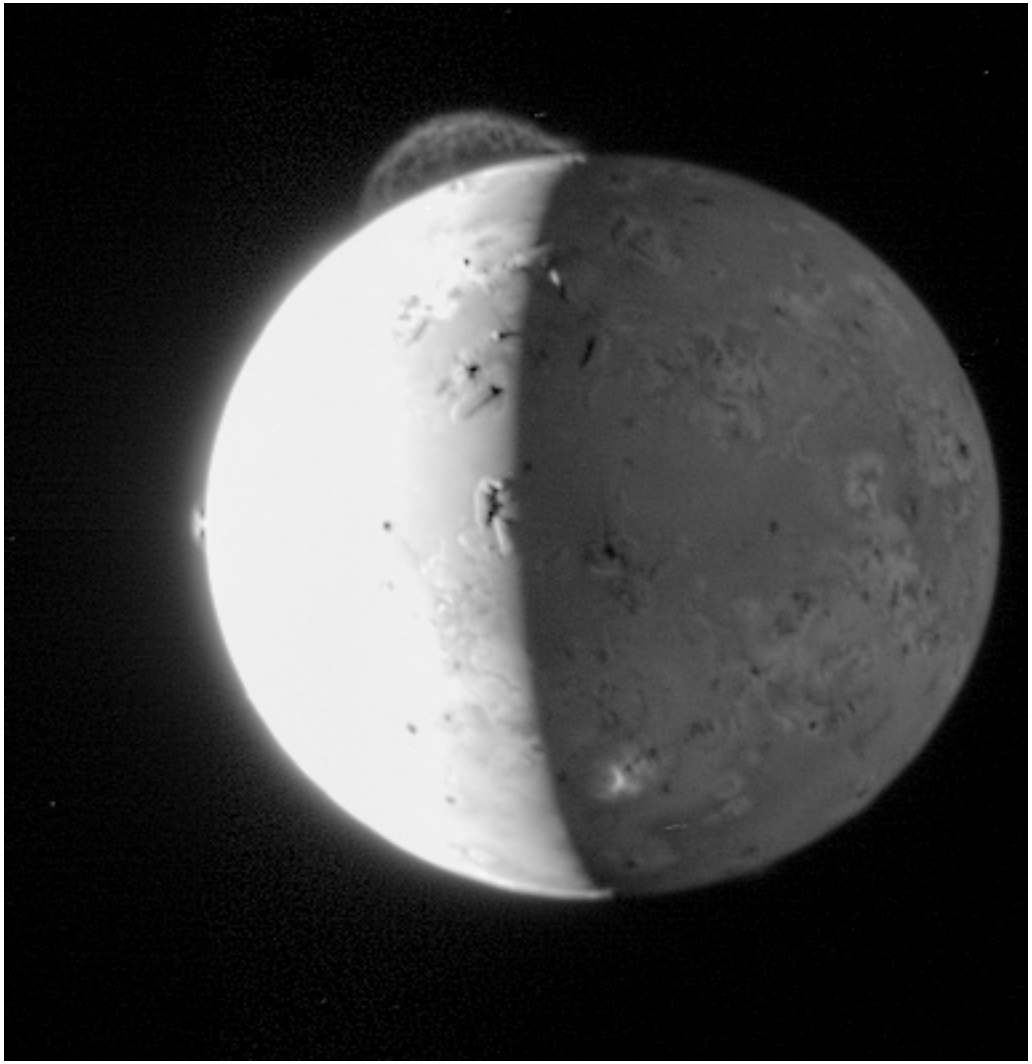




Roth et al 2014, *Science,*
Schmidt et al in prep.

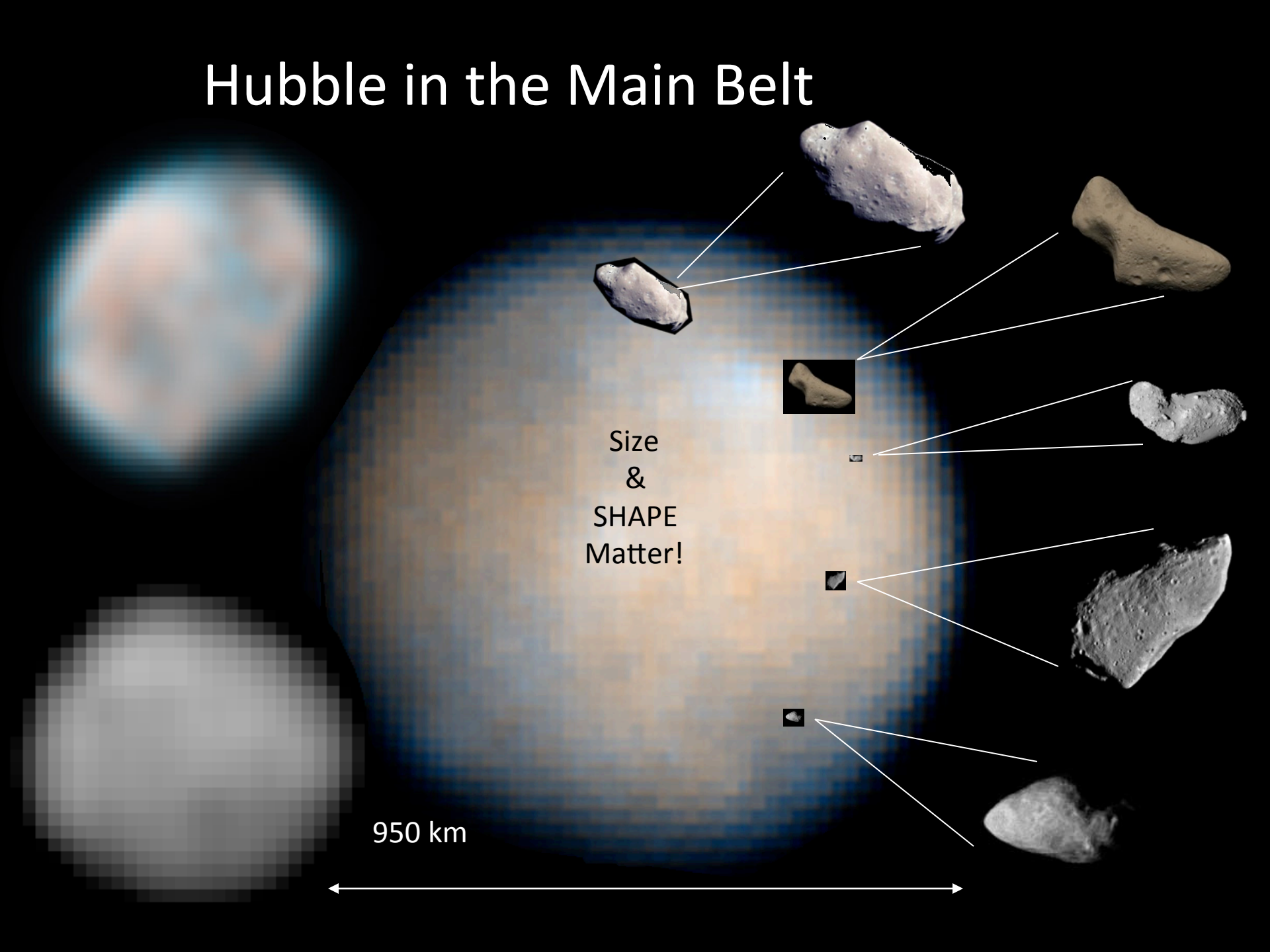


Io Volcano Monitoring- Exotic Heat Transfer



Kuiper and Asteroid Belts—
Seeing Planets
& Informing Disk Processes

Hubble in the Main Belt



Interior from Shape and Density Observations

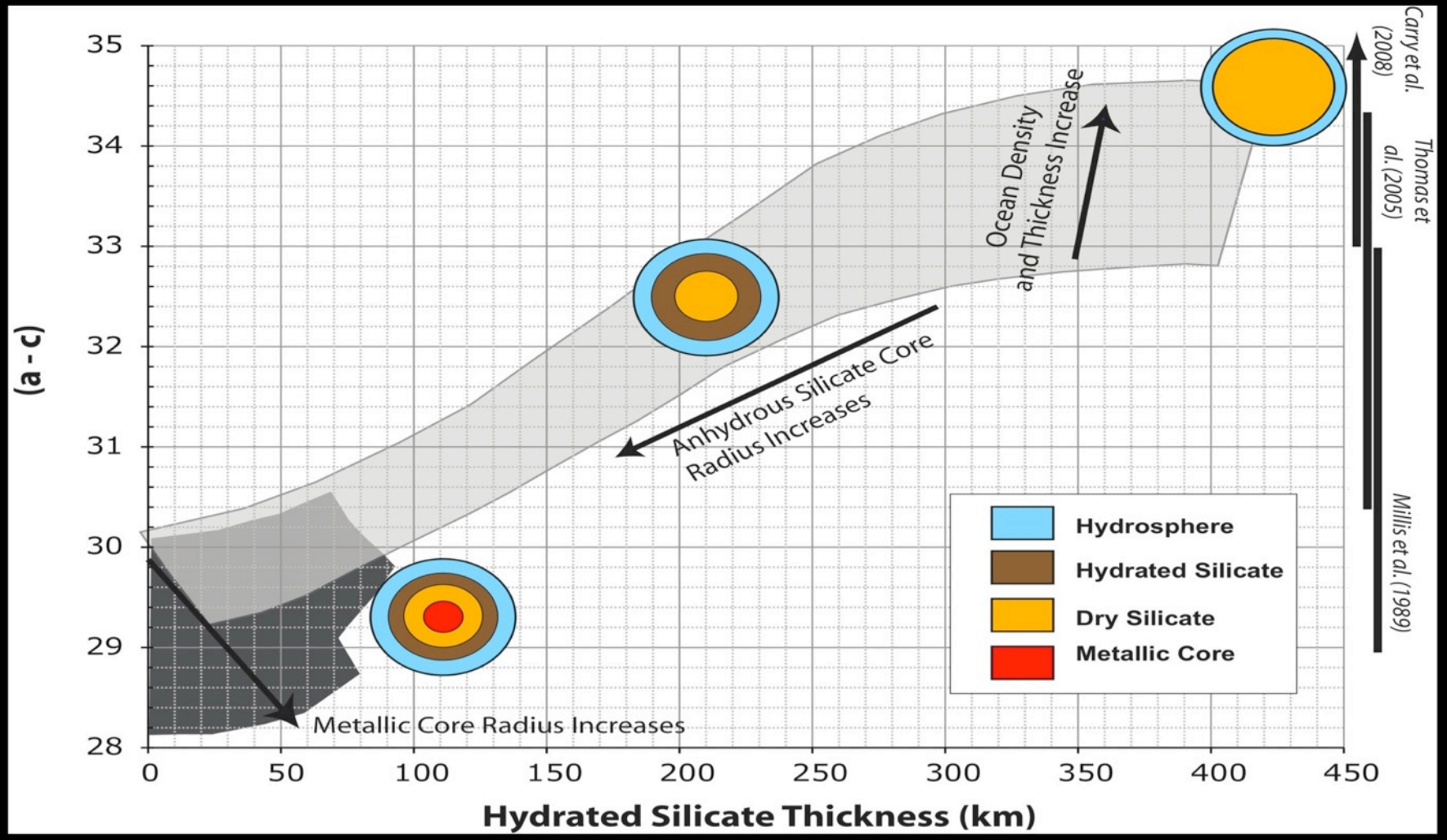


Figure Credit: Castillo-Rogez & McCord, 2010

Interior from Shape and Density Observations

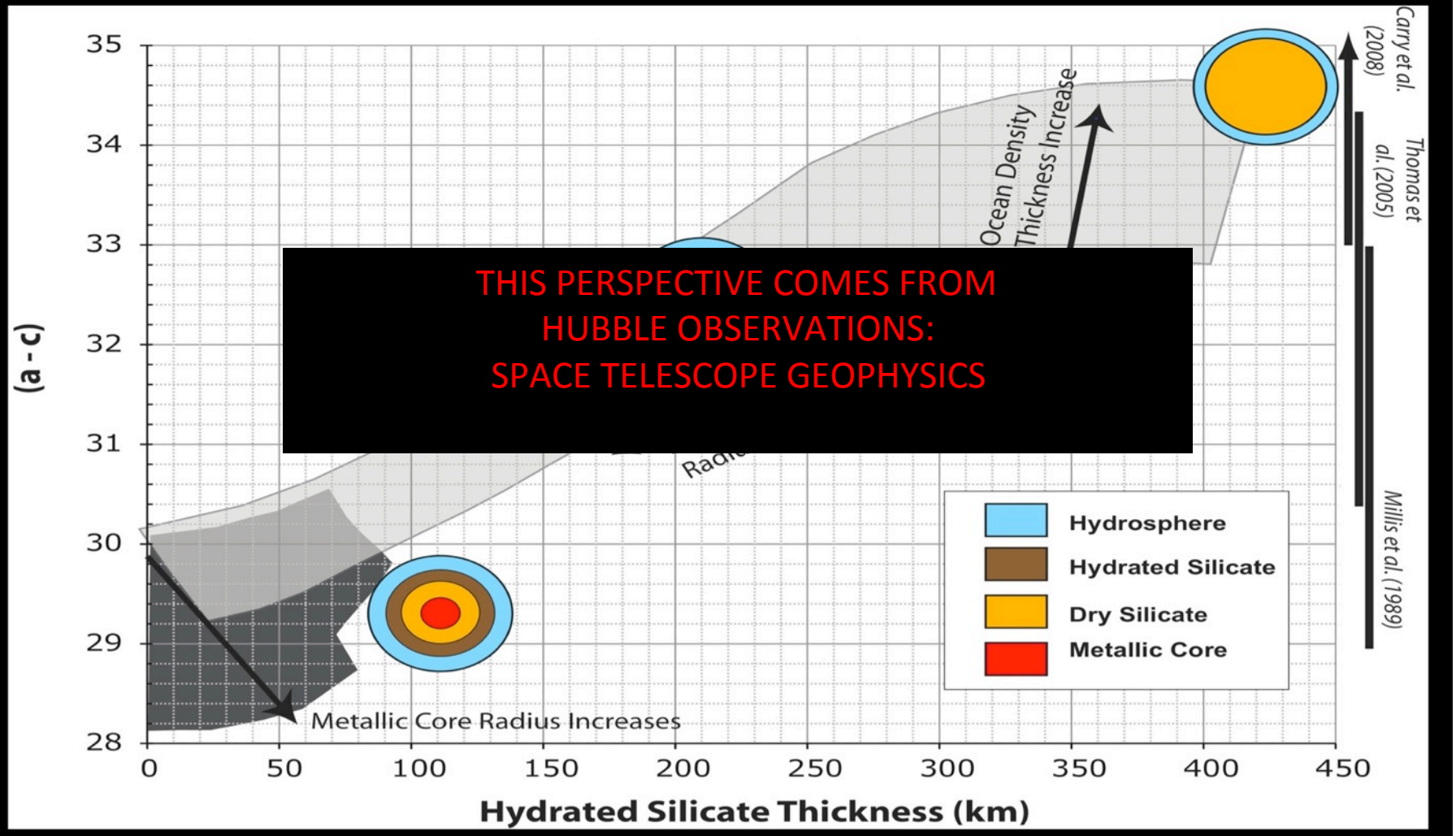
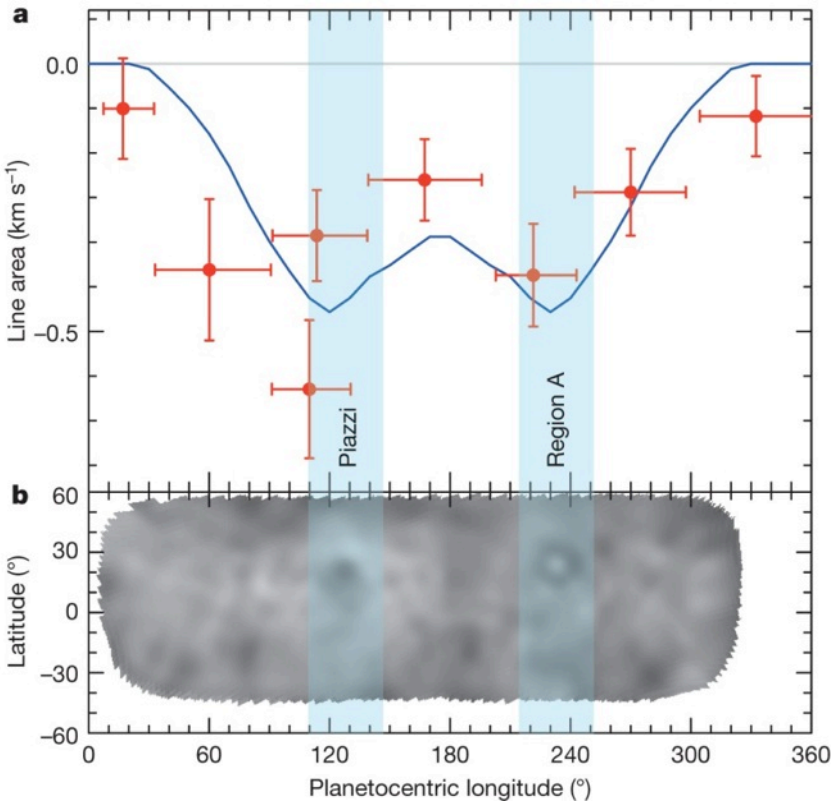
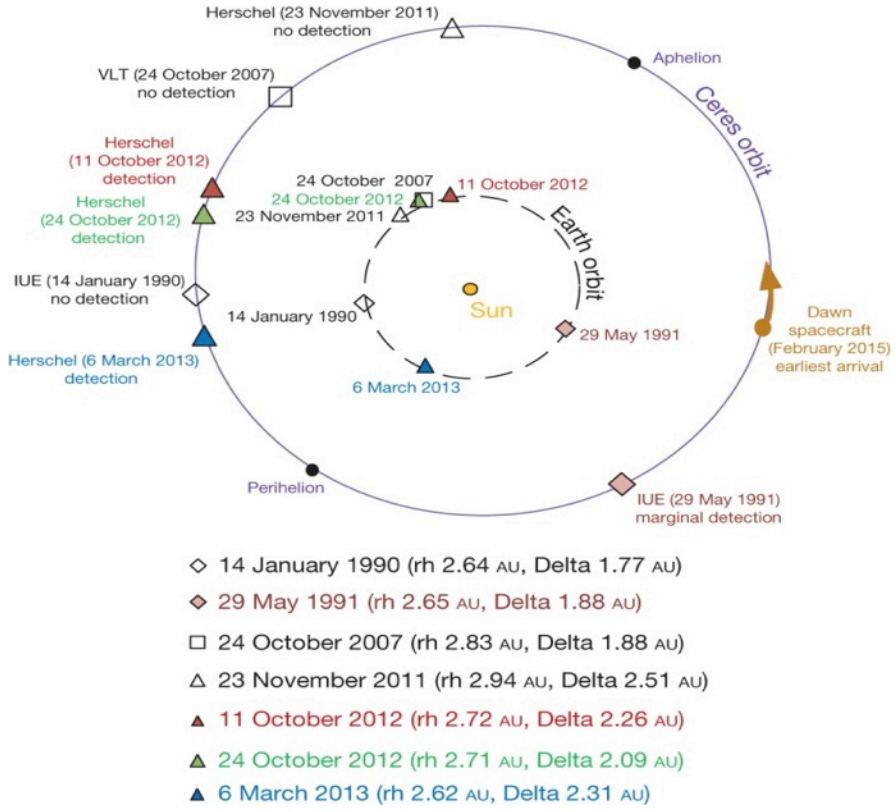


Figure Credit: Castillo-Rogez & McCord, 2010

Water Vapor at Ceres



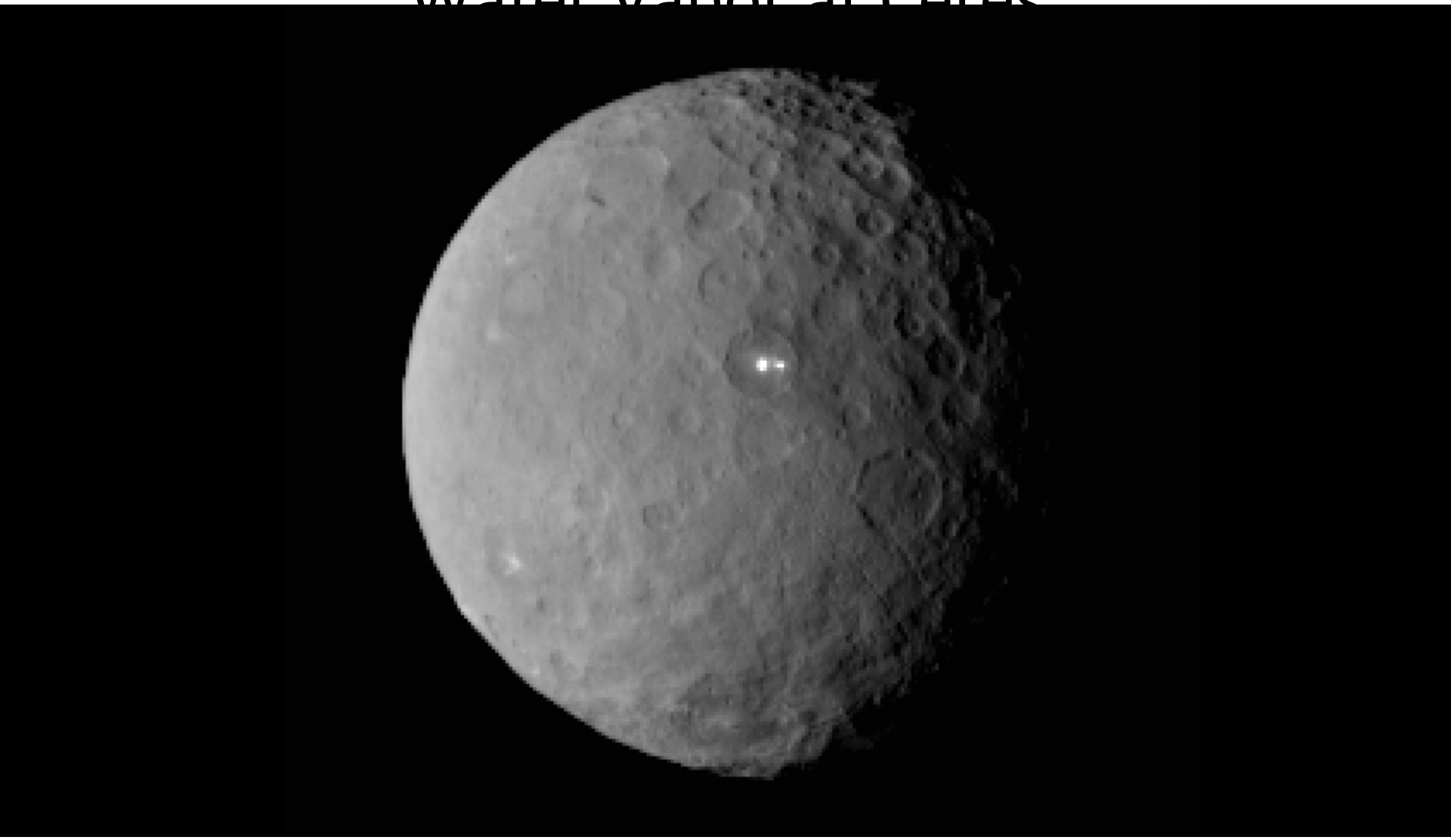
Variability of water absorption on 6 March 2013.



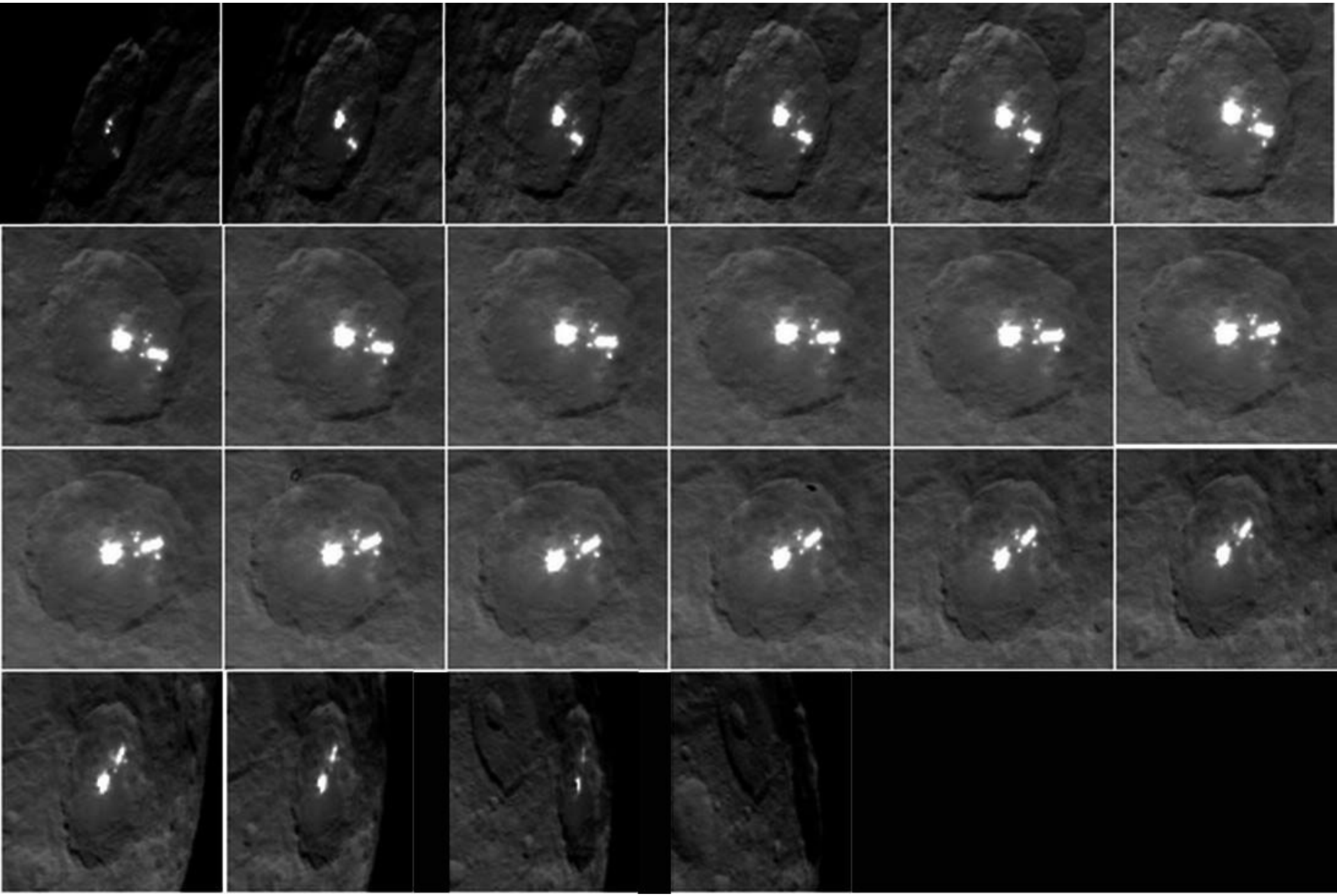
Variability of water along Ceres' Orbit

M Küppers *et al. Nature* **505**, 525-527 (2014) doi:10.1038/nature12918

Water Vapor at Ceres



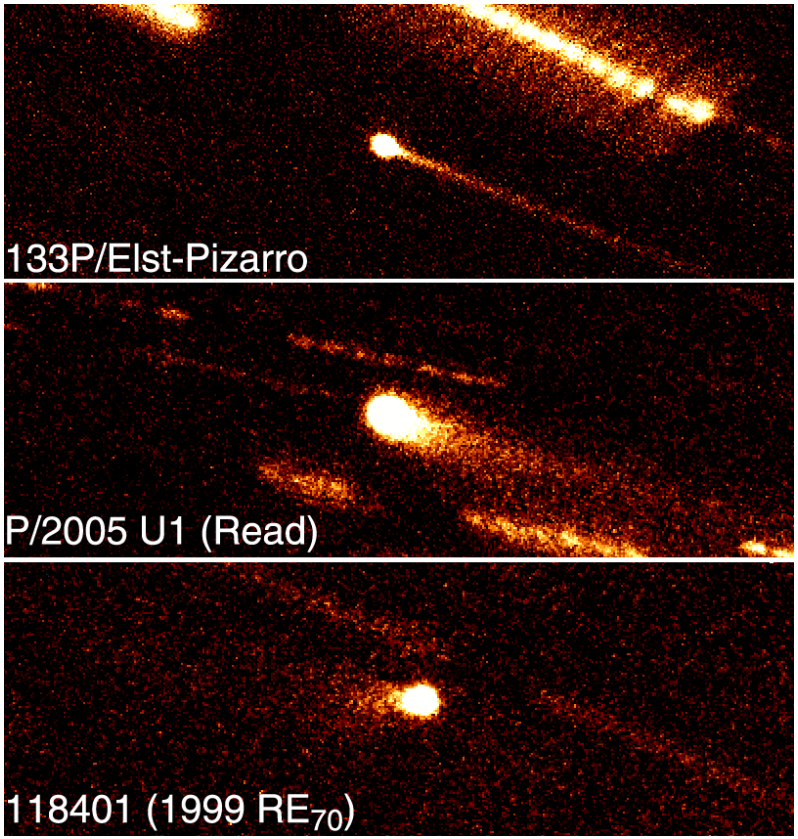
M Küppers *et al. Nature* **505**, 525-527 (2014) doi:10.1038/nature12918



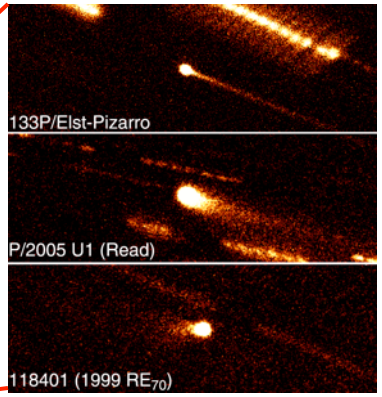
M Küppers *et al. Nature* **505**, 525-527 (2014) doi:10.1038/nature12918

Whole New Worlds: Icy Bodies in the Main Belt

- Twenty C-type asteroids larger than 100 km
  - Densities between 2000 and 2800 kg/m^3
    - Understanding the Ice Line
  - Surface Compositions:
    - Hydrated silicates, organics, carbonates, clays
    - Resolved mapping and spectroscopy are key achievable for LUVOIR
- Main belt comets: B-types, part of Themis family
  - Activity and Dynamics

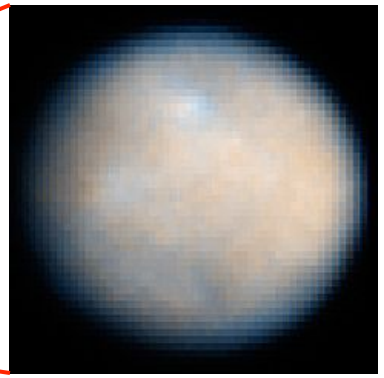


Implications for Ice & the C-class Asteroids

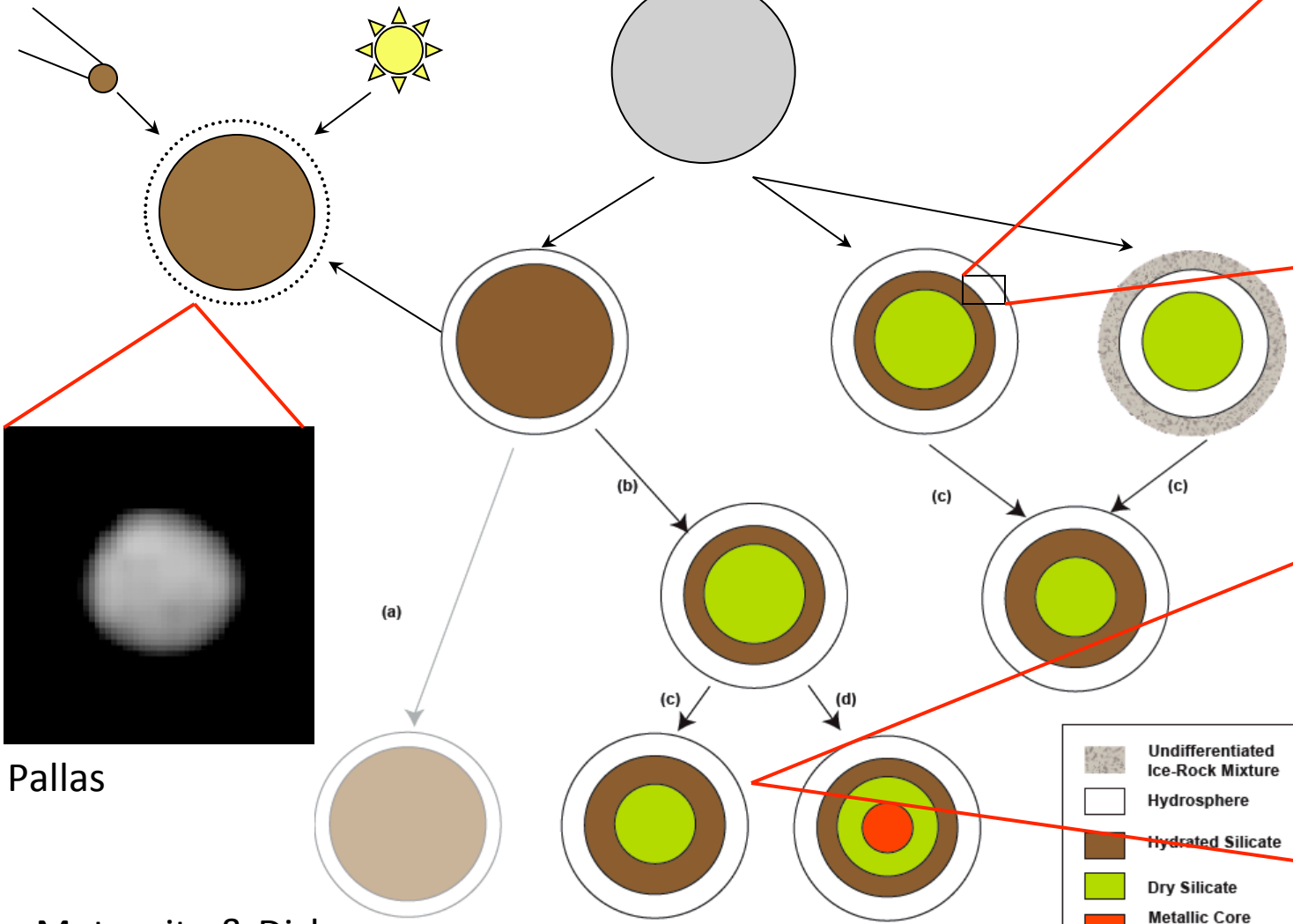


24 Themis,
65 Cybele

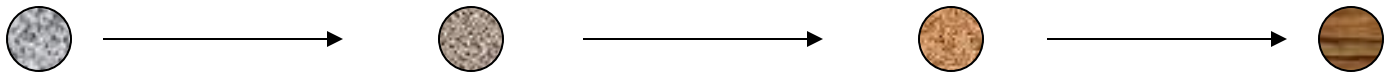
Pallas



Ceres

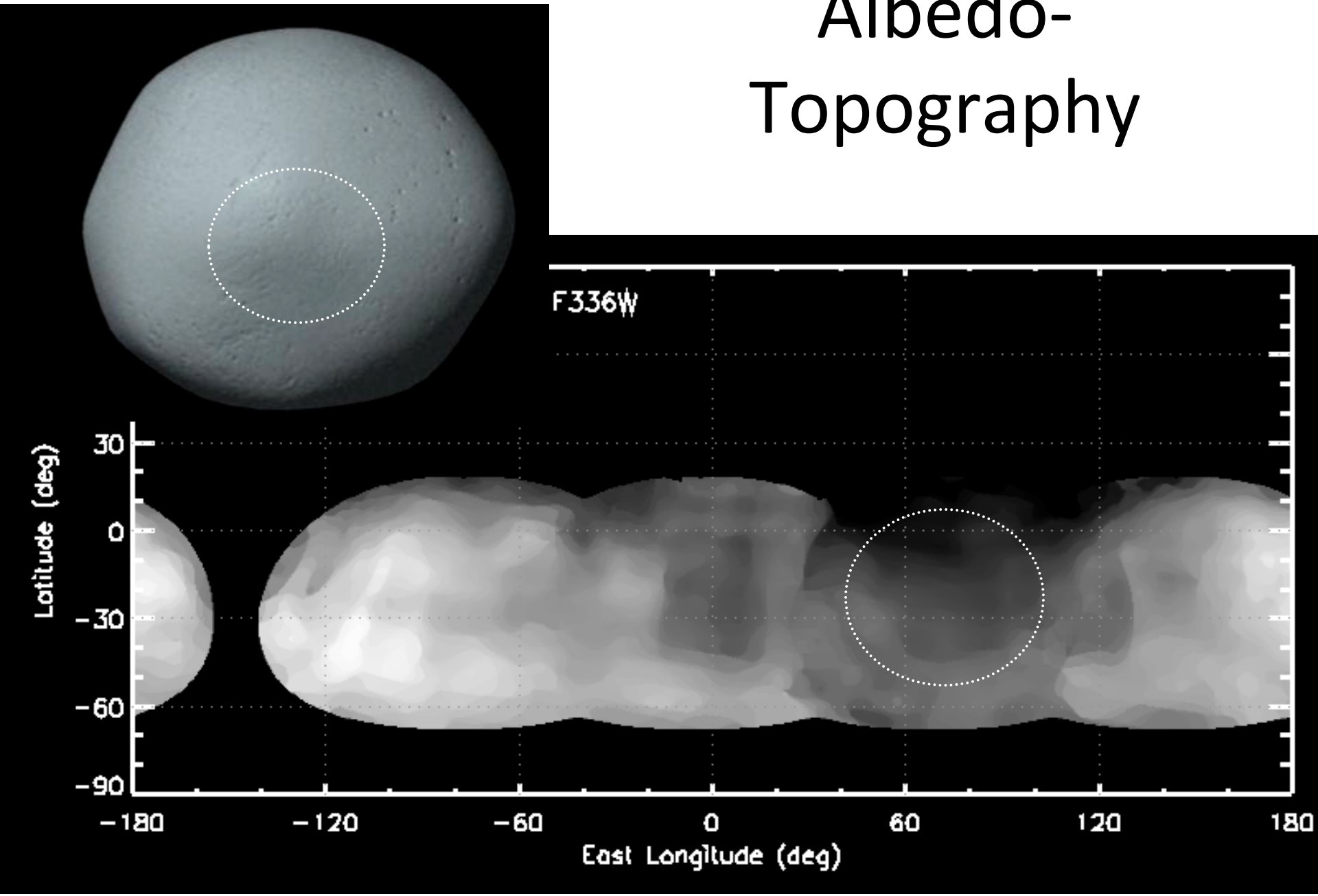


Meteorite & Disk Implications



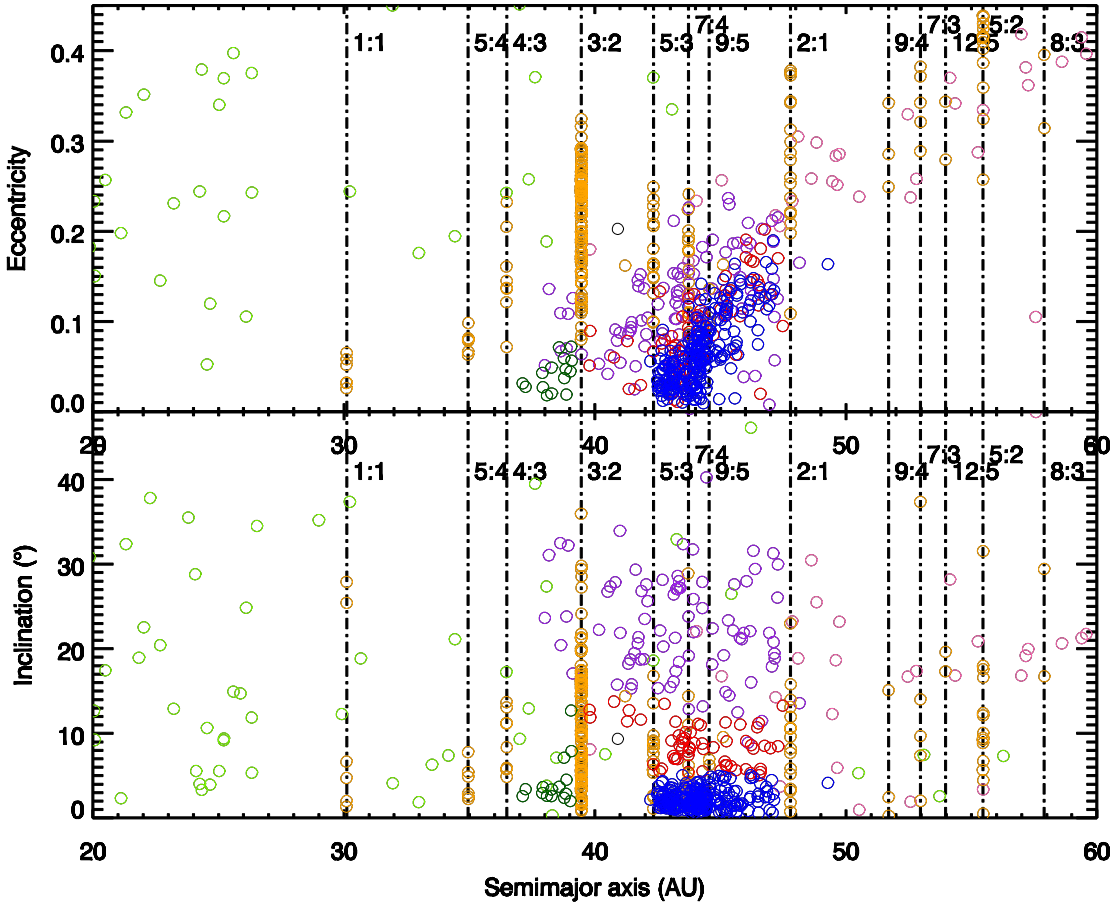
Schmidt et al, Science 2009

Albedo-Topography

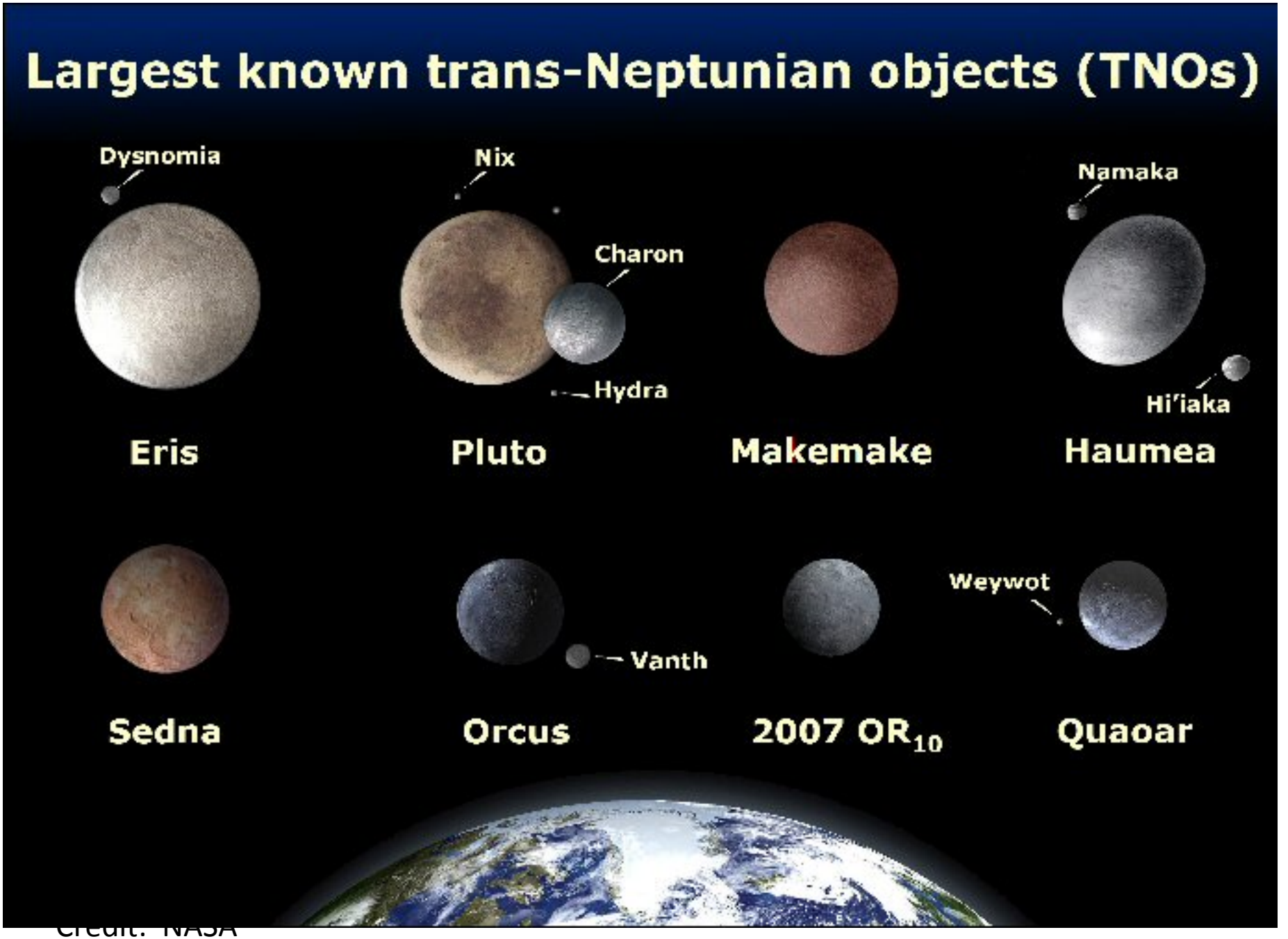


Kuiper Belt—Seeing Planets & Informing Disk Processes

Classification of KBOs to 1km

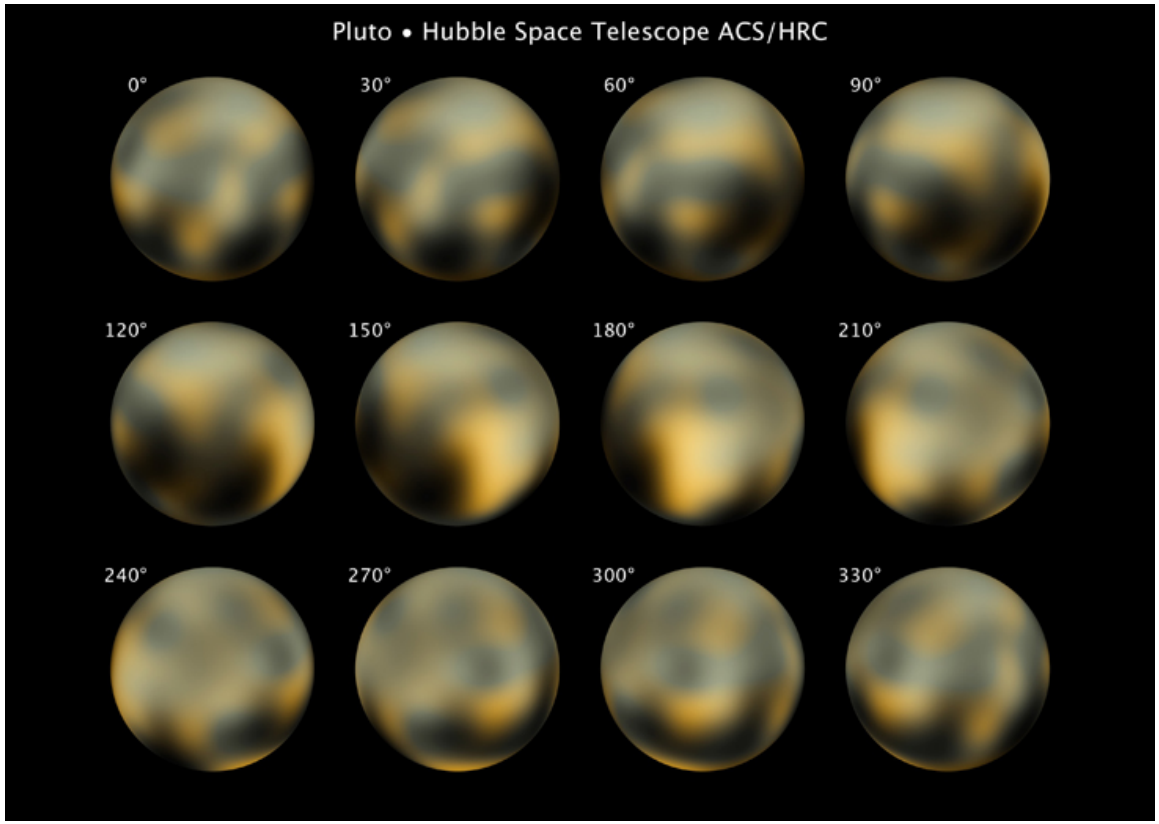


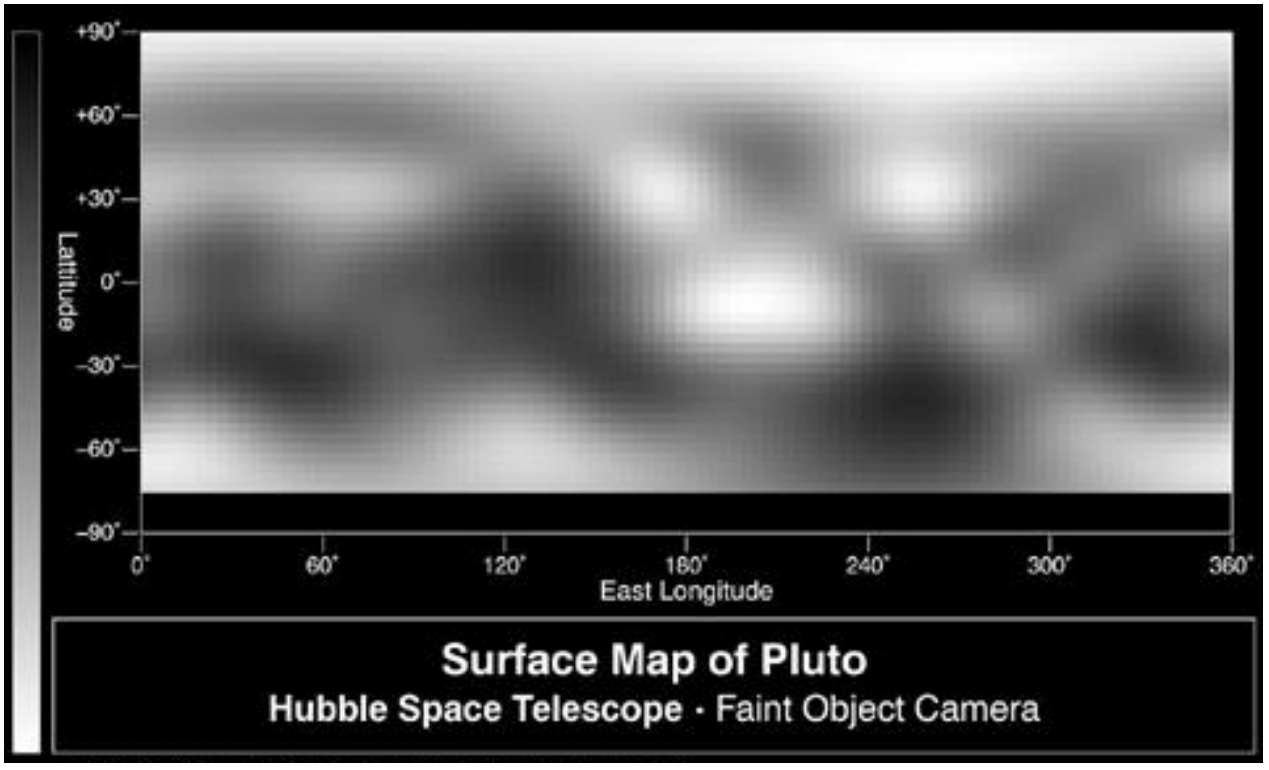
Centaur
Scattered-Near
Scattered-Extended
Inner Classical
Cold Classical
Hot Classical
Resonant

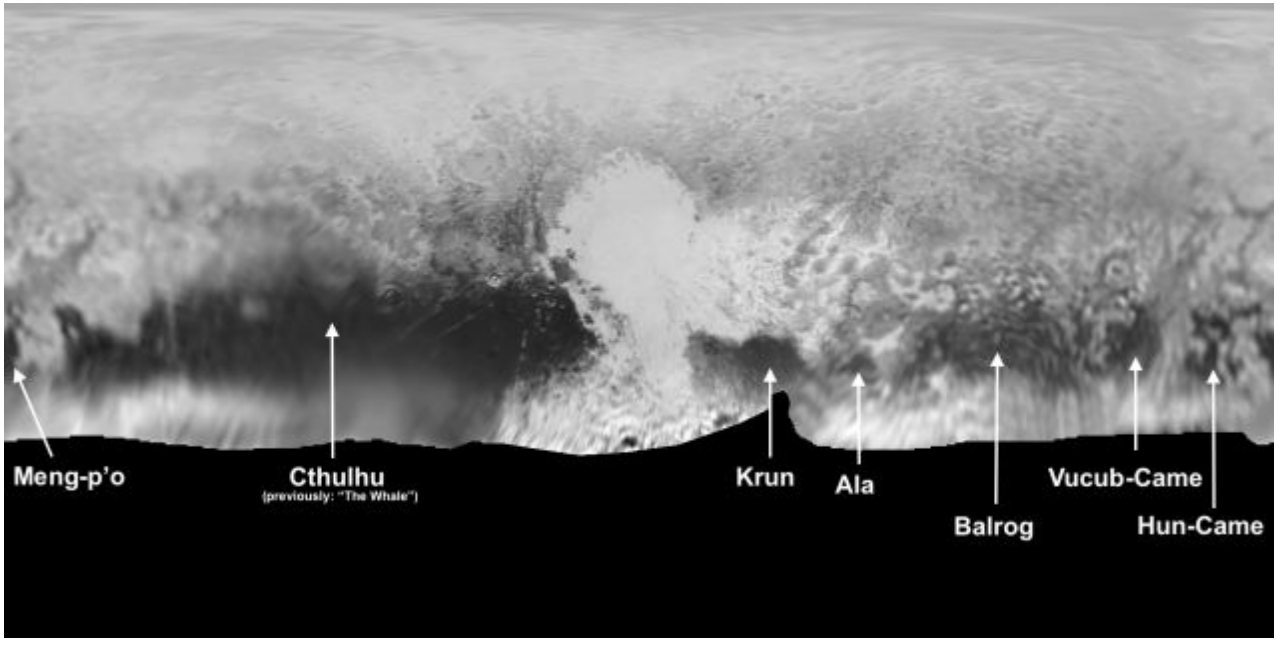

Largest known trans-Neptunian objects (TNOs)
Dysnomia
Eris
Nix
Charon
Hydra
Pluto
Makemake
Namaka
Hi'iaka
Haumea
Sedna
Vanth
Orcus
2007 OR10
Weywot
Quaoar

Credit: NASA

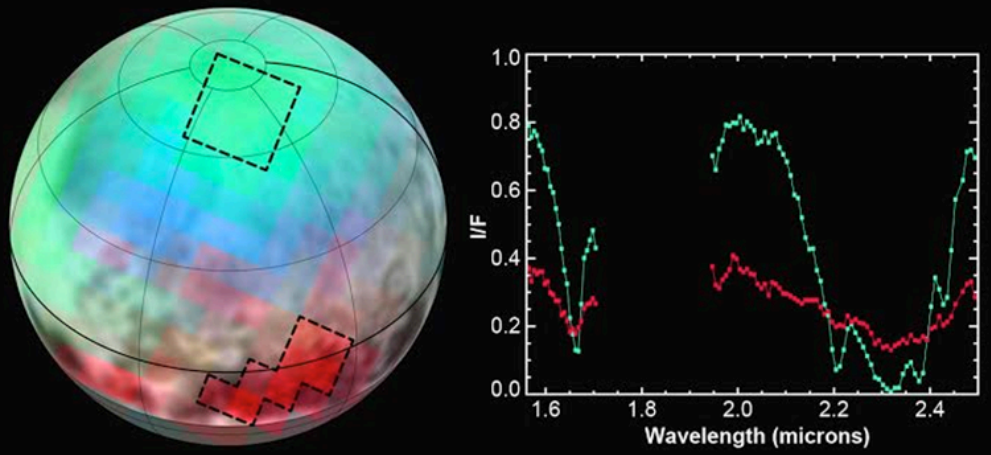
Pluto

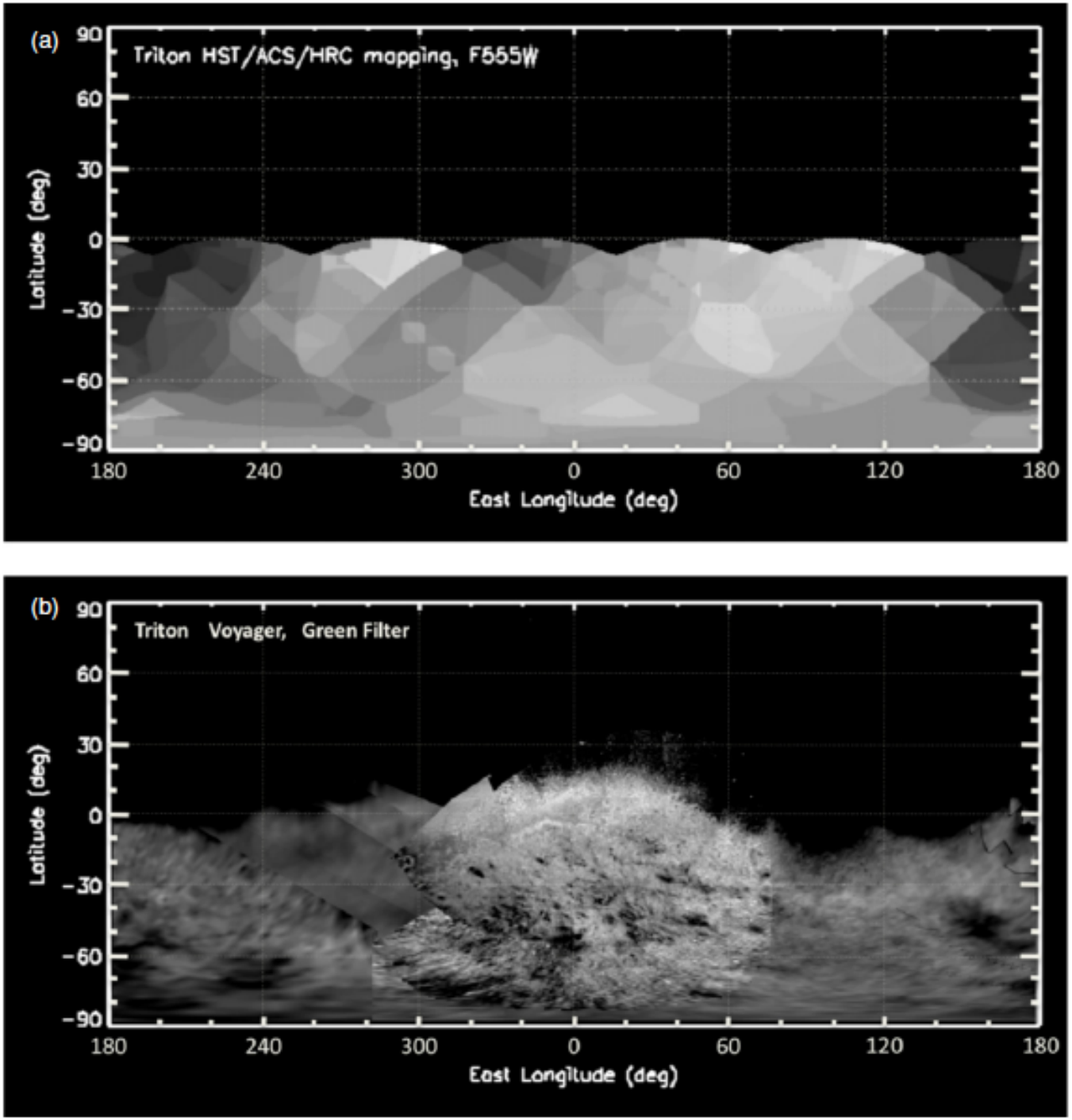

Pluto • Hubble Space Telescope ACS/HRC
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°


+90°
+60°
+30°
0°
−30°
−60°
−90°
Latitude
0°
60°
120°
180°
240°
300°
360°
East Longitude
Surface Map of Pluto
Hubble Space Telescope · Faint Object Camera

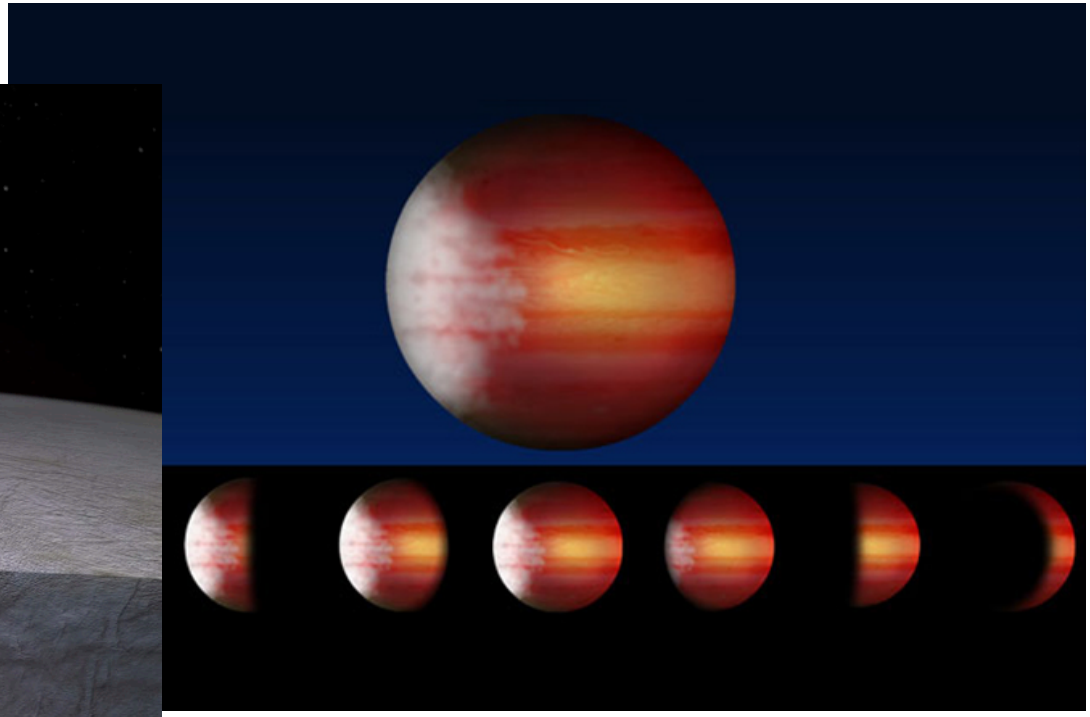

Meng-p'o
Cthulhu
(previously: "The Whale")
Krun
Ala
Balrog
Vucub-Came
Hun-Came

Methane on Pluto

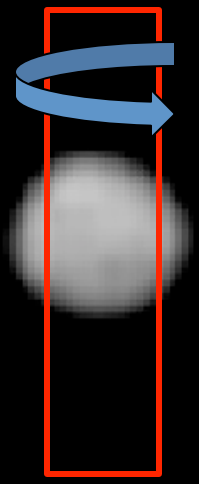


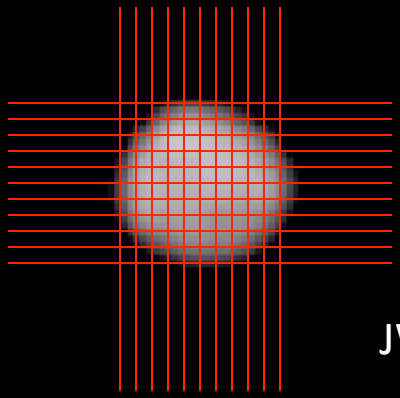

(a)
Triton HST/ACS/HRC mapping, F555W
90
60
30
0
-30
-60
-90
Latitude (deg)
180
240
300
0
60
120
180
East Longitude (deg)
(b)
Triton Voyager, Green Filter
90
60
30
0
-30
-60
-90
Latitude (deg)
180
240
300
0
60
120
180
East Longitude (deg)

Synergy & Moving Forward

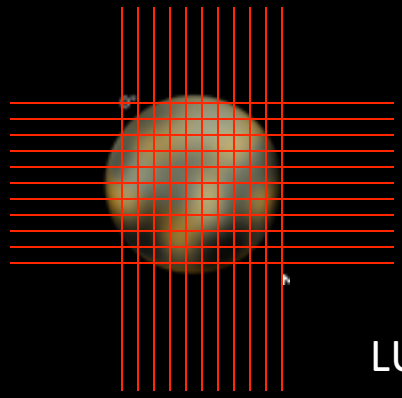


Some Potential JWST vs 8m-class Observations



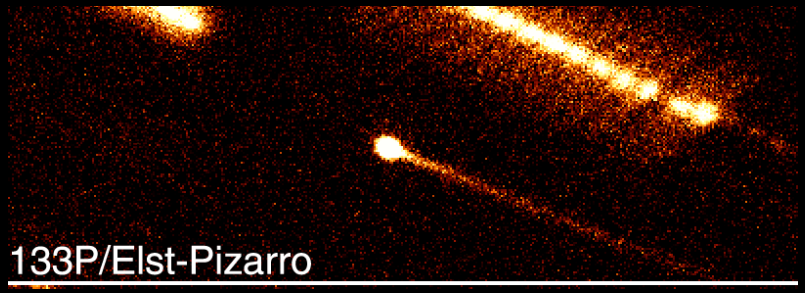


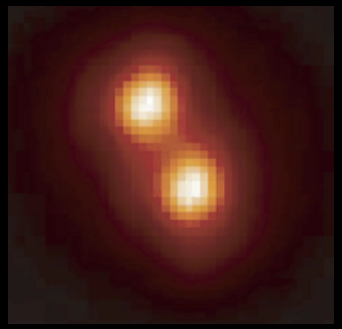
JWST



LUVOIR

Pluto, Ceres, Haumea, Themis family & smaller/more distant targets

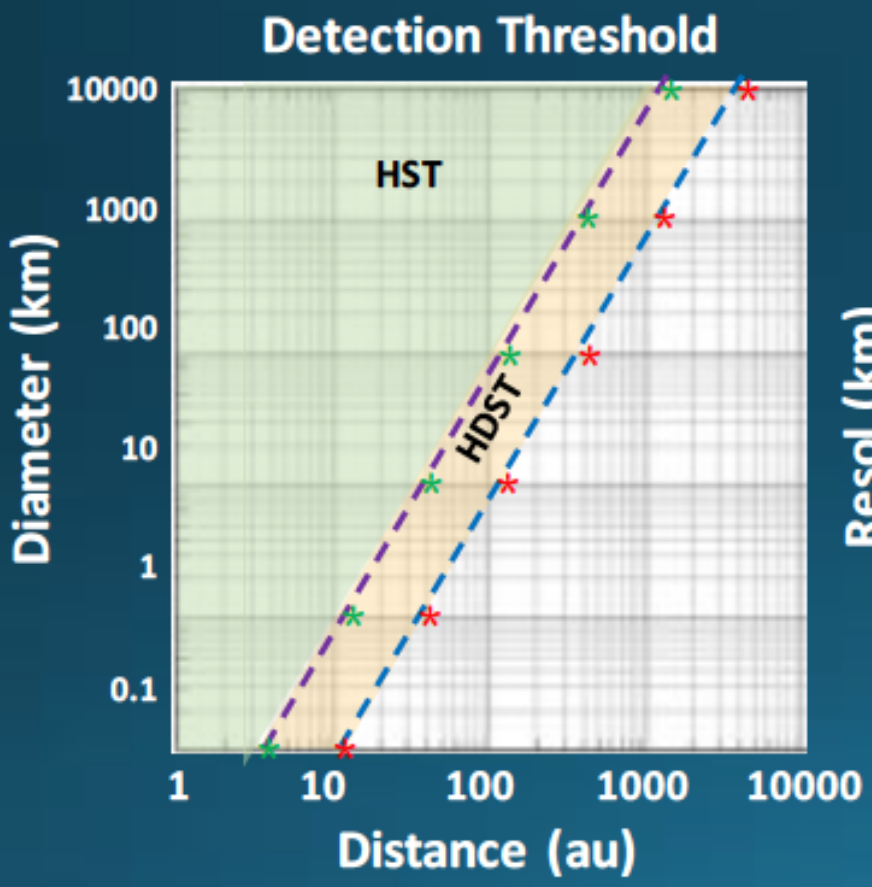


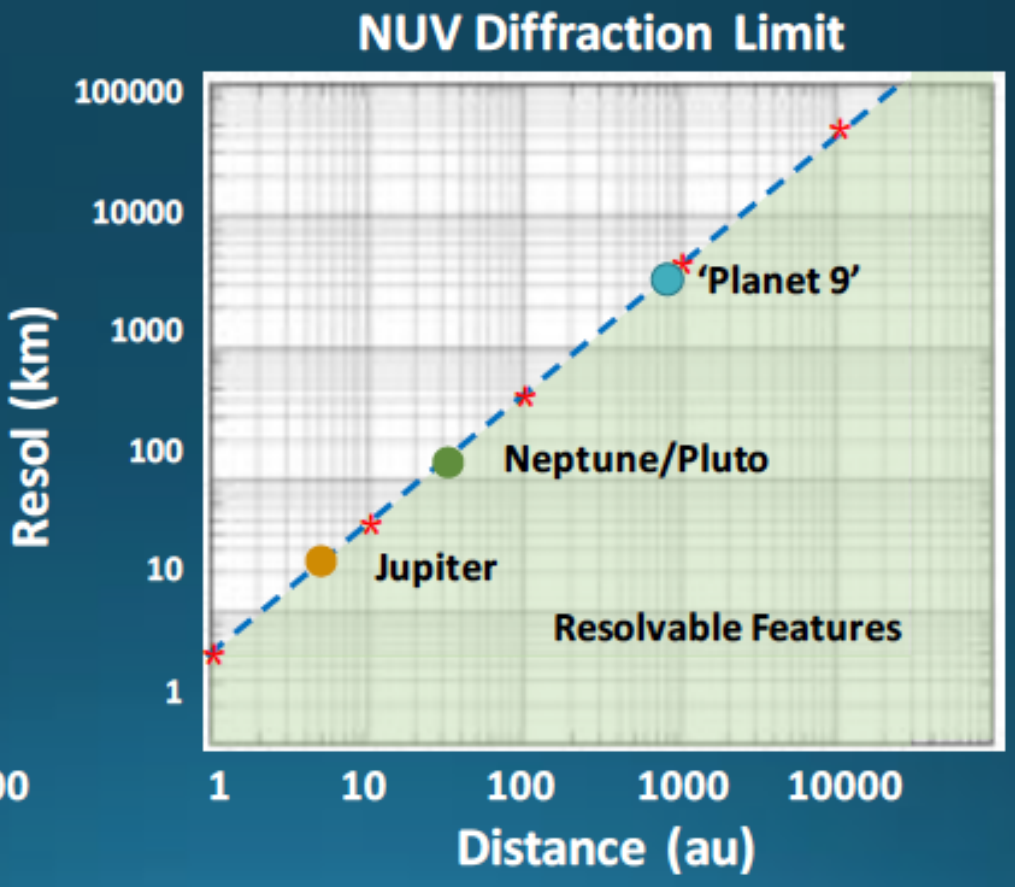


LUVOIR

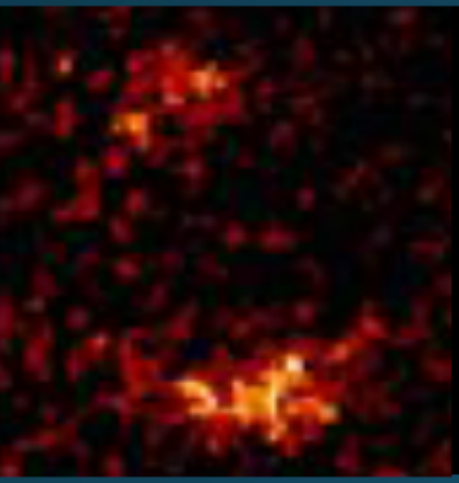
Colors→(Resolved)Spectra→Resolved Imaging→ water, CHANGE!

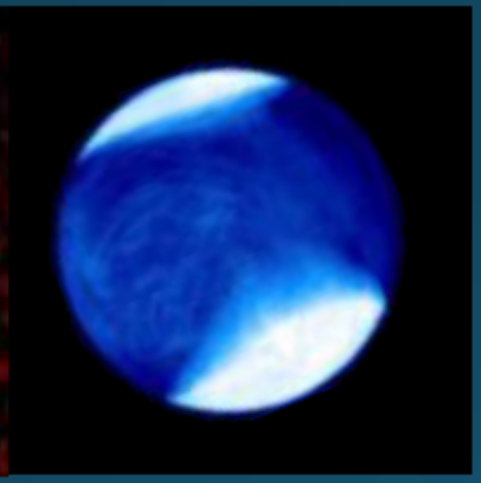
The HDST diffraction limit would exceed HST by a factor of up to 5 into the NUV. The combination of aperture and technology improvement targets will increase the sensitivity limit of HDST by a factor of 50-100 times over HST.

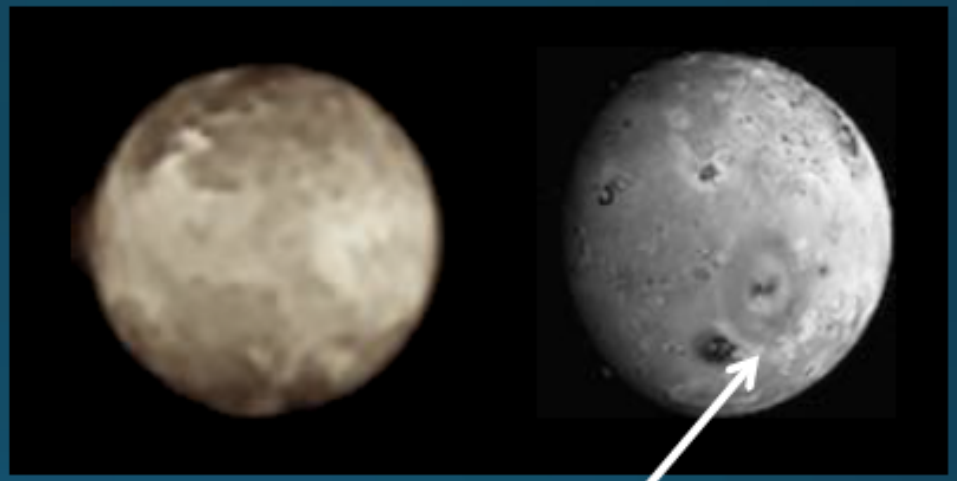




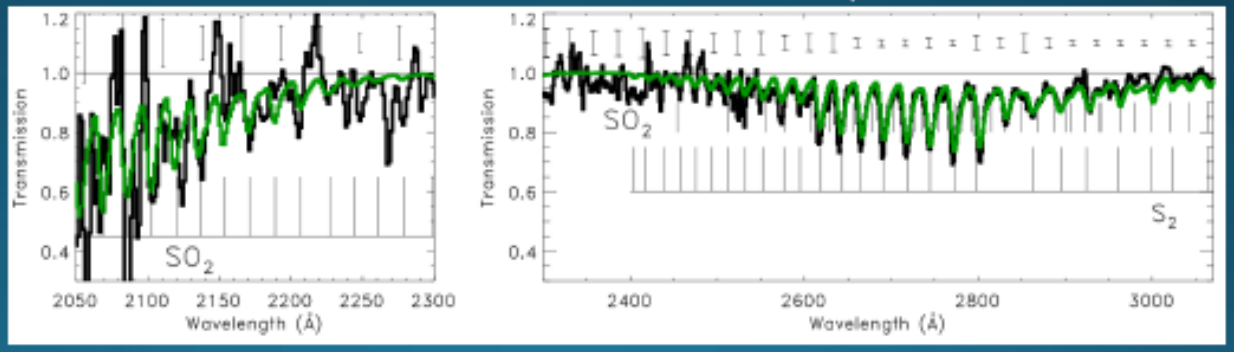
At Jupiter the visible resolution of HDST would enable monitoring of surface features on the Galilean satellites at a spatial resolution comparable to *Voyager*. In the UV, the increased sensitivity and spatial resolution would permit characterization of auroral features.







Small scale features can be resolved spectrally with integral field capability.



8-m Class Observatory Game-Changers

- Pluto: 0.1” 14 mag—resolved imaging, change detection, atmospheric science, imaging Charon and its dynamics
- Neptune: 2.3” 7.8-8 mag, imaging moons, rings, aurora→magnetospheres, interior
- Uranus: ~3” 8-9th mag, imaging moons, rings, aurora→magnetospheres, interior
- Haumea: 17th mag, first resolved images/spectra? Size measurement, colors, changes? Moons—1 now confirmed
- Makemake: 16-17th mag first resolved images/spectra? Size measurement, colors, changes? Moons?
- Pallas: .2-.3” 8-10th mag, High spatial resolution, resolved spectra, UV of C-class asteroids, centaurs
- Europa: .7-1” 5.5-6 mag, spatial resolution, UV activity monitoring
- Main belt comets— sub .1”, 21-24 mag, first spectroscopy, any resolved science?

Solar System Science Provides the Foundation!