Exoplanet and Solar System Synergy with Future Missions

Britney Schmidt
Georgia Tech
OPAG Steering Committee

Steve Vance, Jet Propulsion Lab
Kunio Sayanagi, Hampton University

Planetary Habitability At Tech

Solar System Targets for Exosystem 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

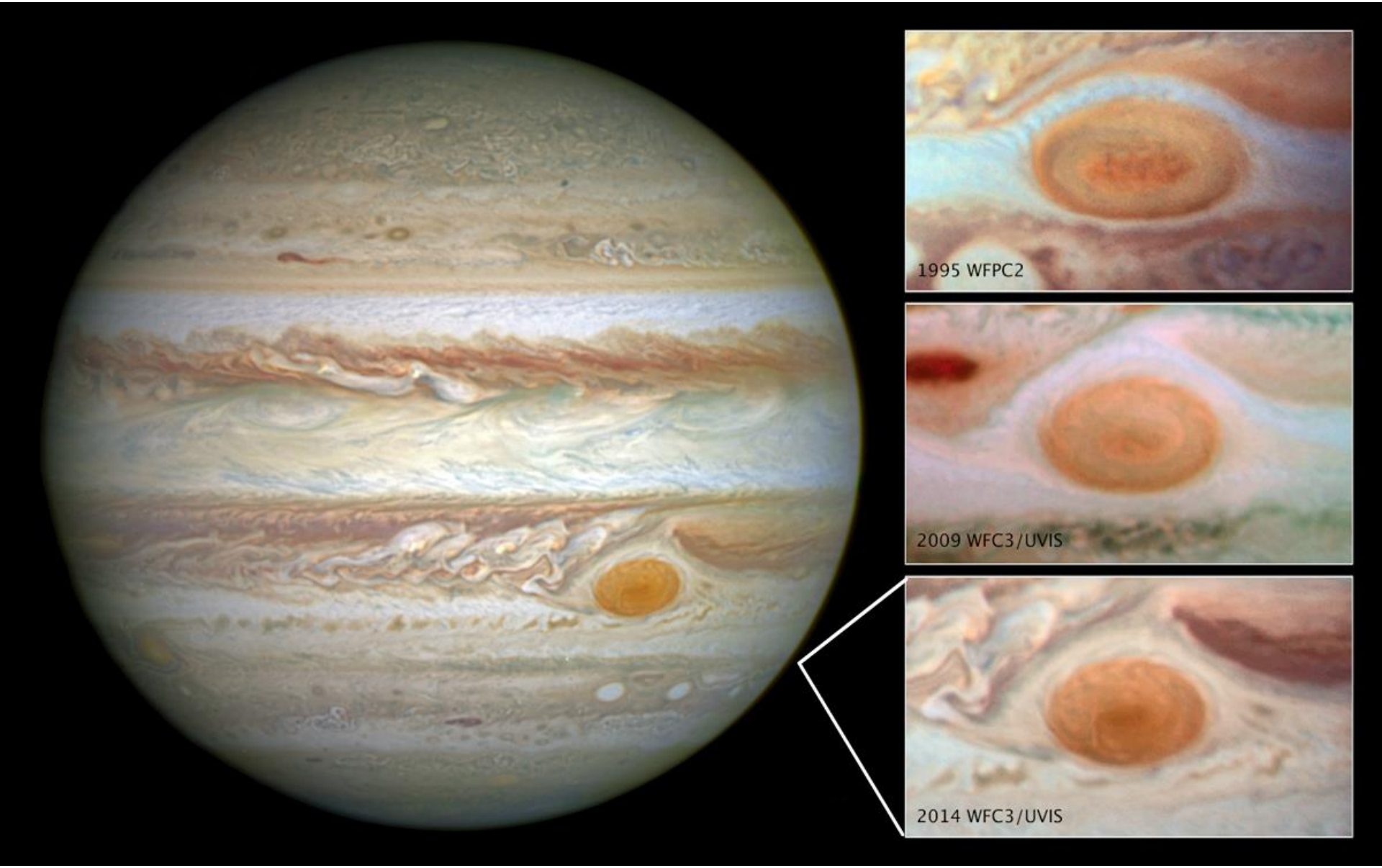
→ Directly relevant to system dynamics and debris/protoplanetary disks

→ Synergy with planet formation

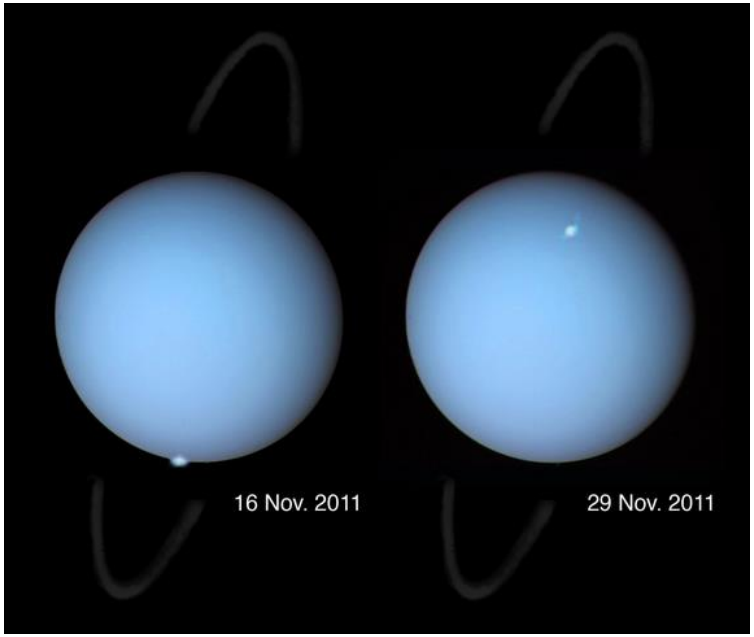
Solar System Target Requirements

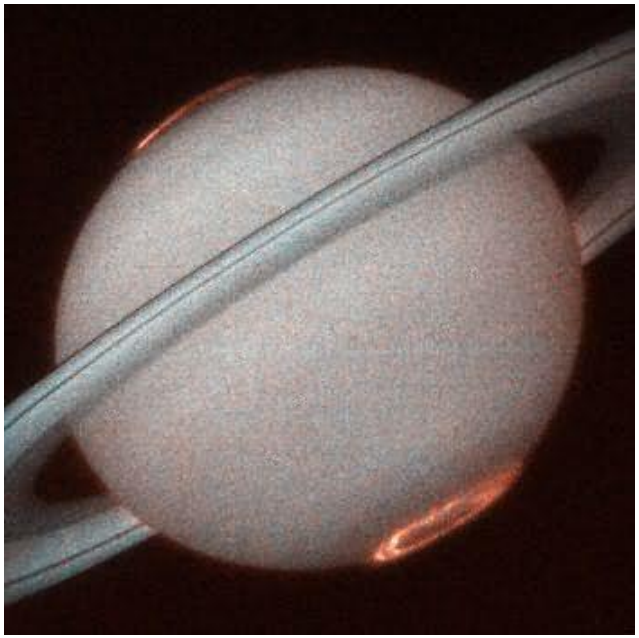
1. Moving Target Tracking Capabilities
   → JWST can do 30mas/sec, which is good
   → WFIRST's moving target tracking capability is TBD
   → LUVOIR????
2. Bright objects
   → JWST is too sensitive for many SS targets
   → JWST will NOT have the neutral density filter required for Giant planet observation (will be ok for Ice Giants)
   → WFIRST's Integrated Field Spectrometer will have HST-like sensitivity and wavelength coverage.
3. Imaging near Bright Objects
   → Space Telescopes Can't Observe Venus or Mercury
   → If not planned in advance, no moon/ring science, Giants are too bright

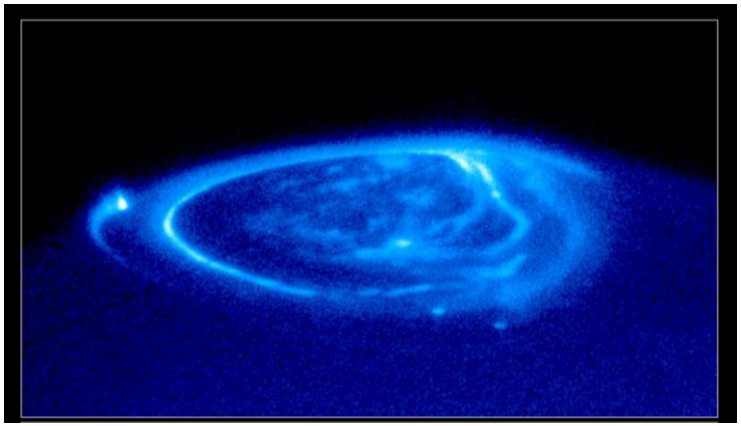
Giant Planets—Resolving Dynamics for Exoplanet Baselines

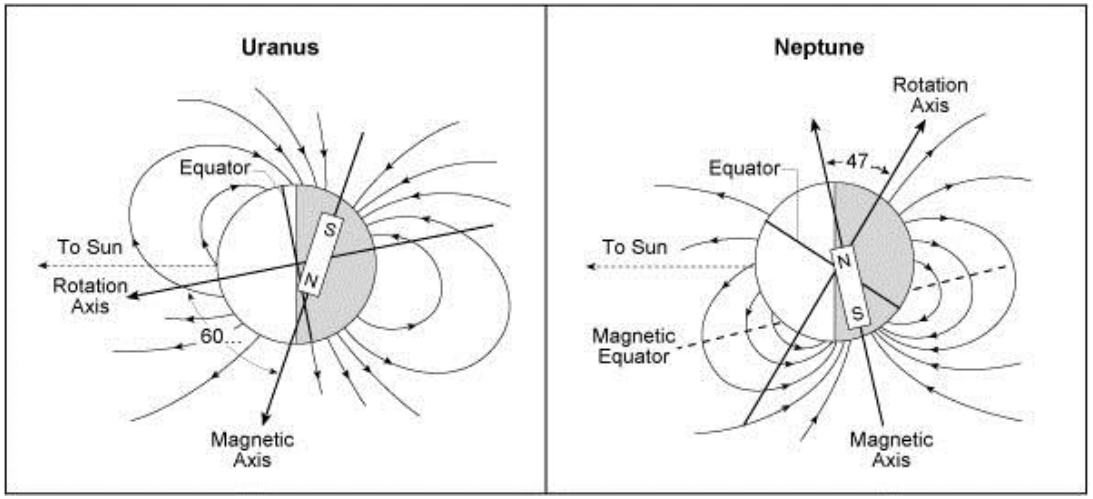

1995 WFPC2
2009 WFC3/UVIS
2014 WFC3/UVIS

UV Aurora & Rings—Dynamics



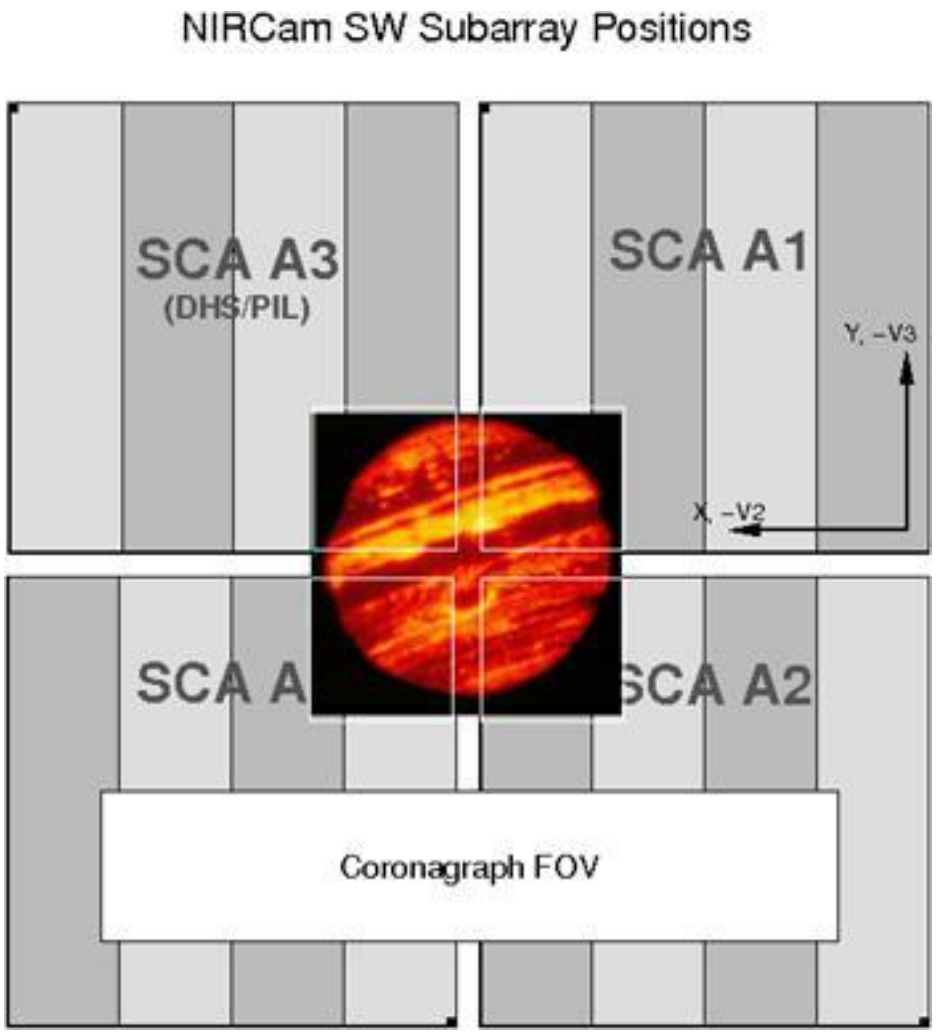




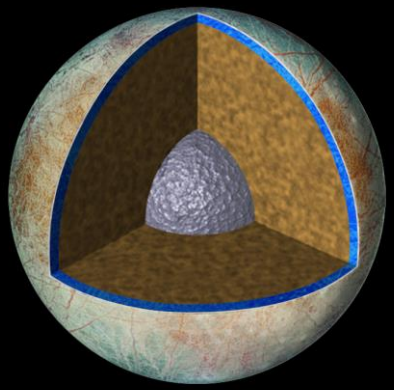


Proposed JWST Sub-Array Config for Bright Objects

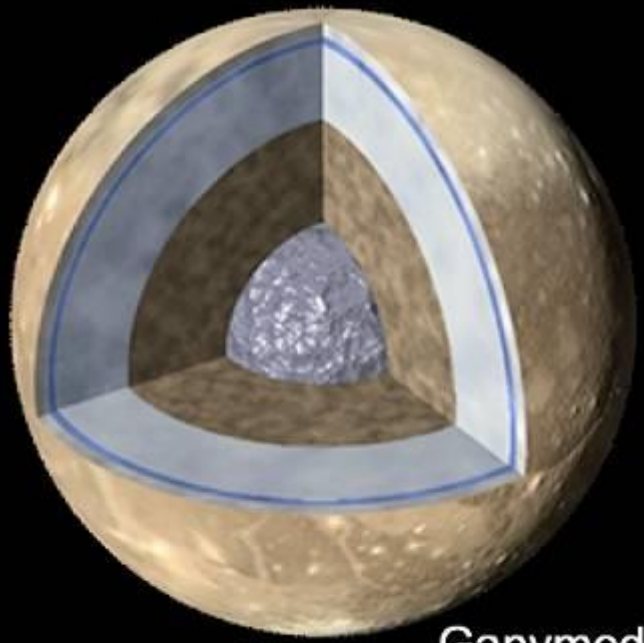
- Solar System Planets could be observed with JWST if the sub-arrays could be read out separately like below:

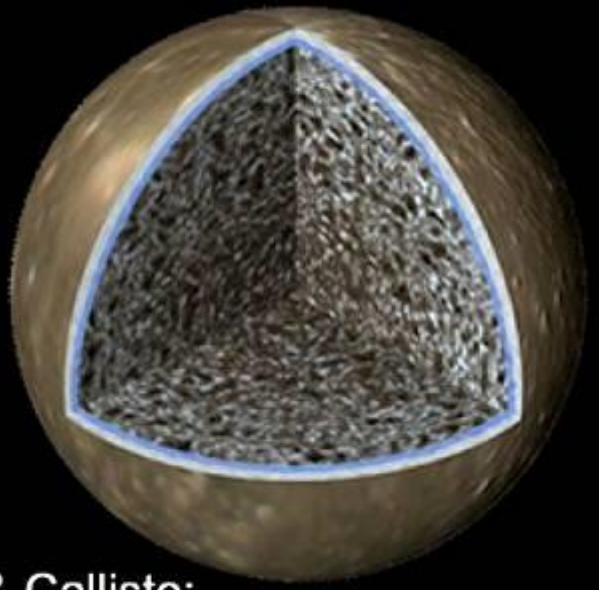


Icy Moons—
Exotic Habitable Worlds



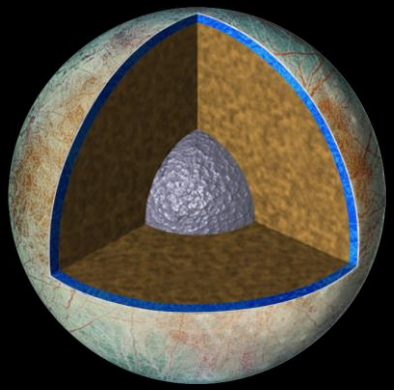
Europa:
warm salty H_2O, mantle contact, high energy



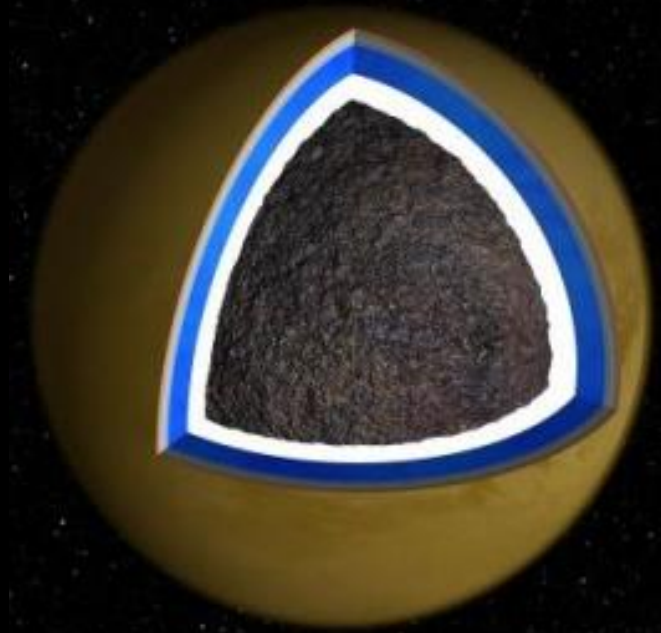


Ganymede & Callisto:
perched salty $H_2O(-NH_3?)$

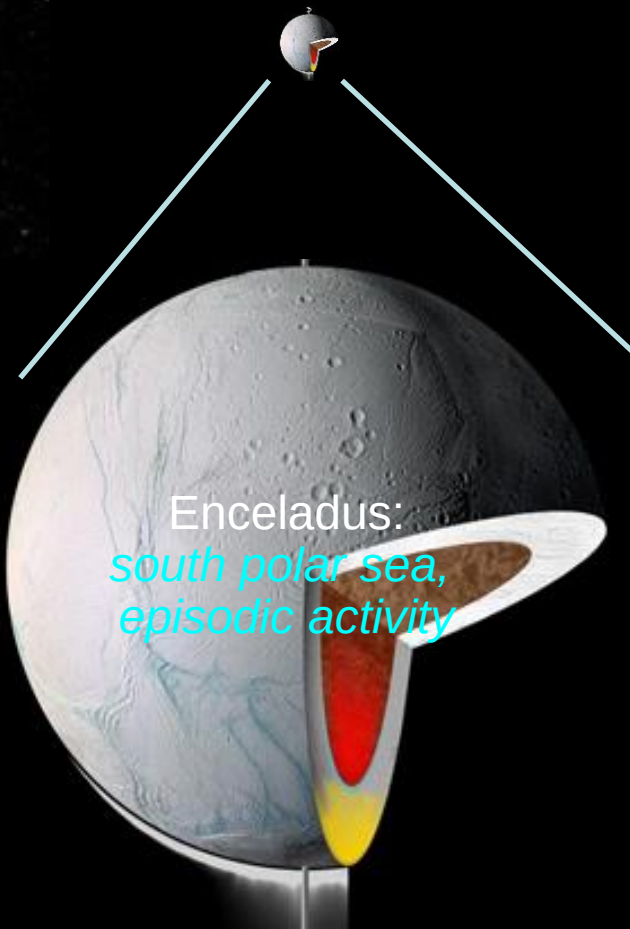
e.g. Schubert et al, 1998



Europa:
warm salty H_2O, mantle contact, high energy



Titan:
perched H_2O, high pressure ices, undifferentiated core?



Enceladus:
south polar sea, episodic activity

e.g. Schubert et al, 1998

Icy World and Exoplanet Oceans

Advances in computational capabilities enable **new equations of state** based on experiments

Using realistic ocean thermodynamics drastically affects **how extraterrestrial oceans work**:

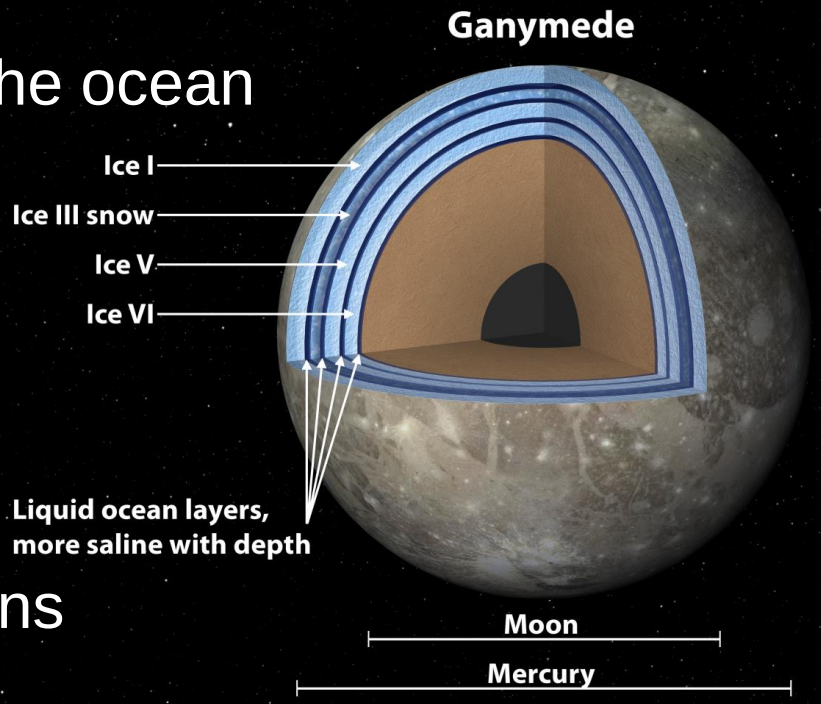
-alters **temperature structure** of the ocean

-reduces **presence of ices**

-lead to layered oceans-ices

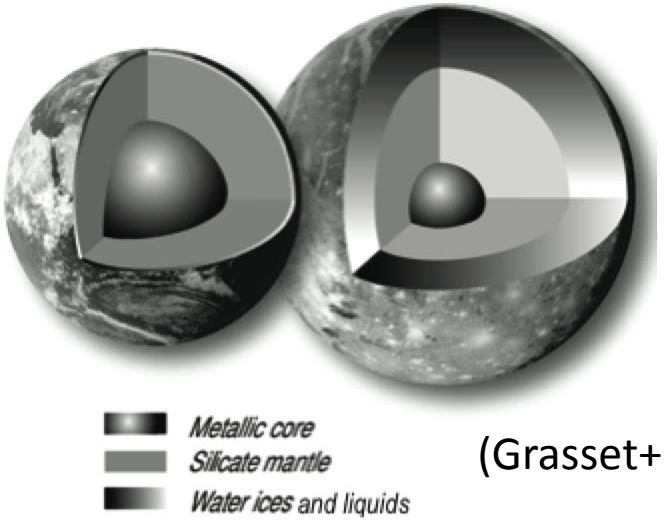
—> when does ice float or sink?

—> how might water-rock reactions create food for life



Vance, Bouffard, Choukroun, and Sotin,2014

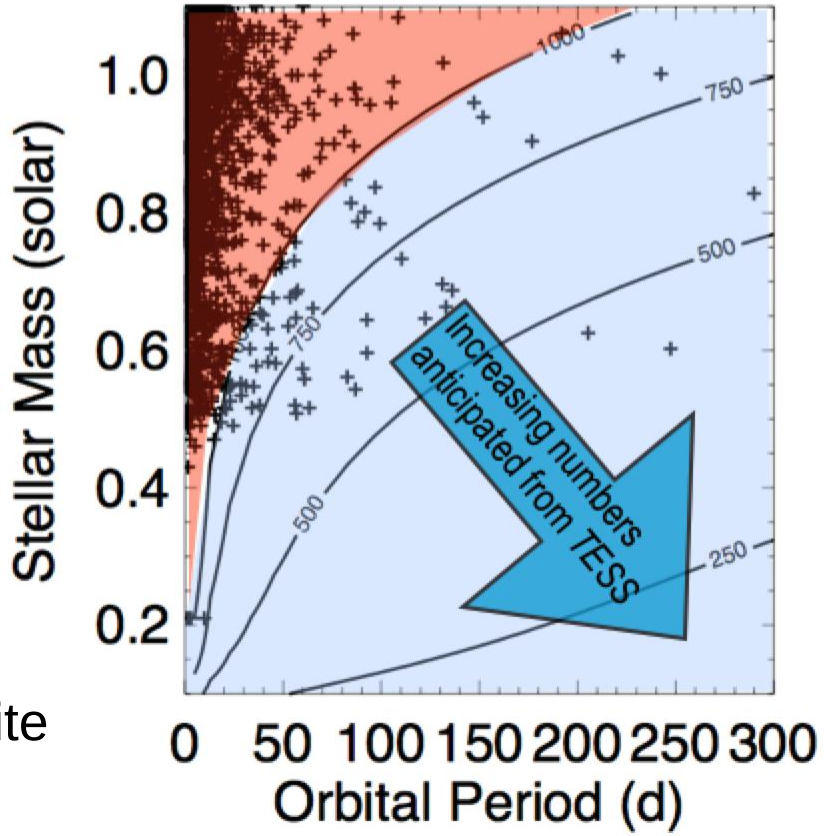
Super-Ganymedes
Super-Earths
Super-Europas?



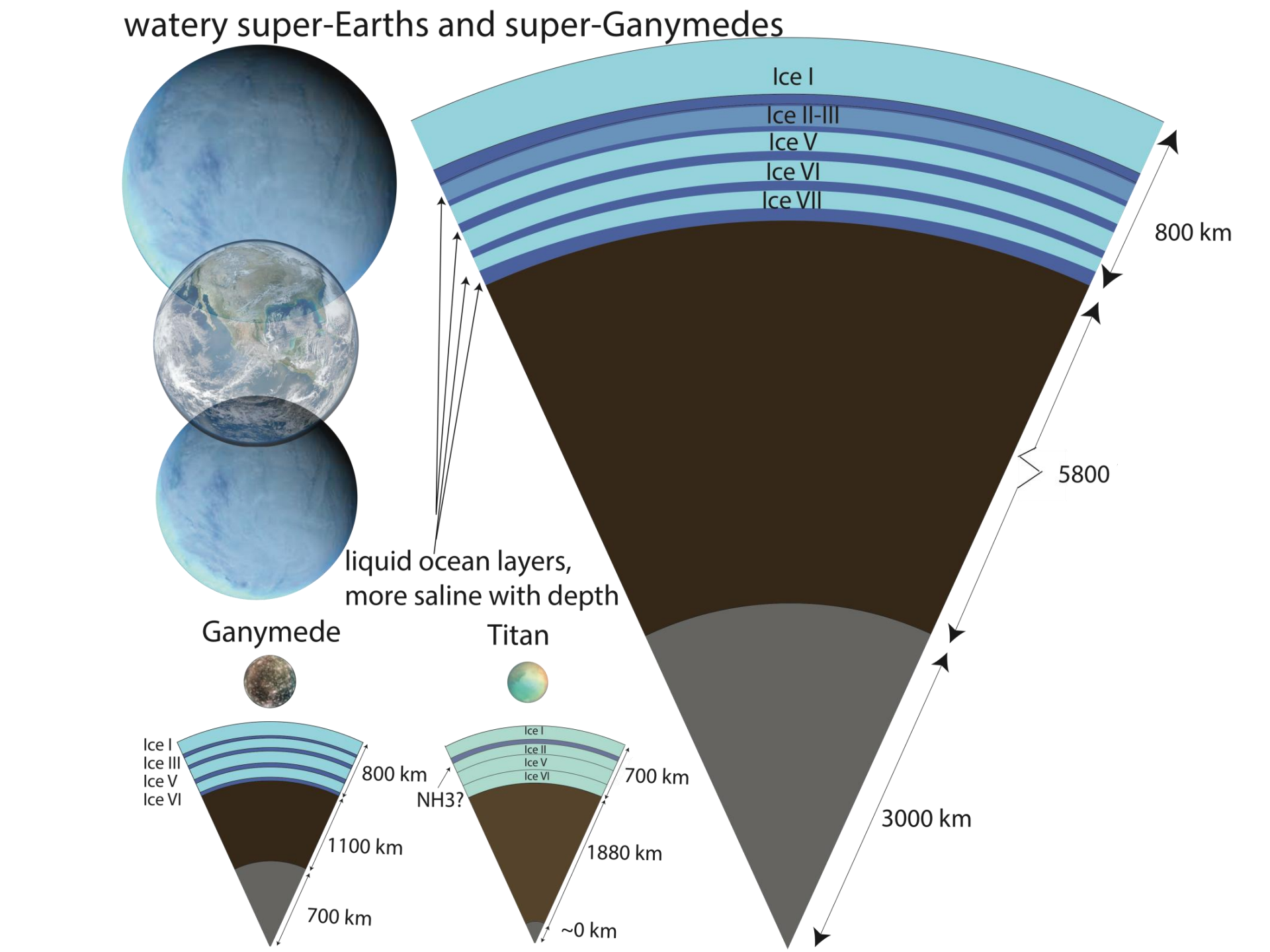
(Grasset+ 2009)

Kepler planets R<2.5R_{Earth}

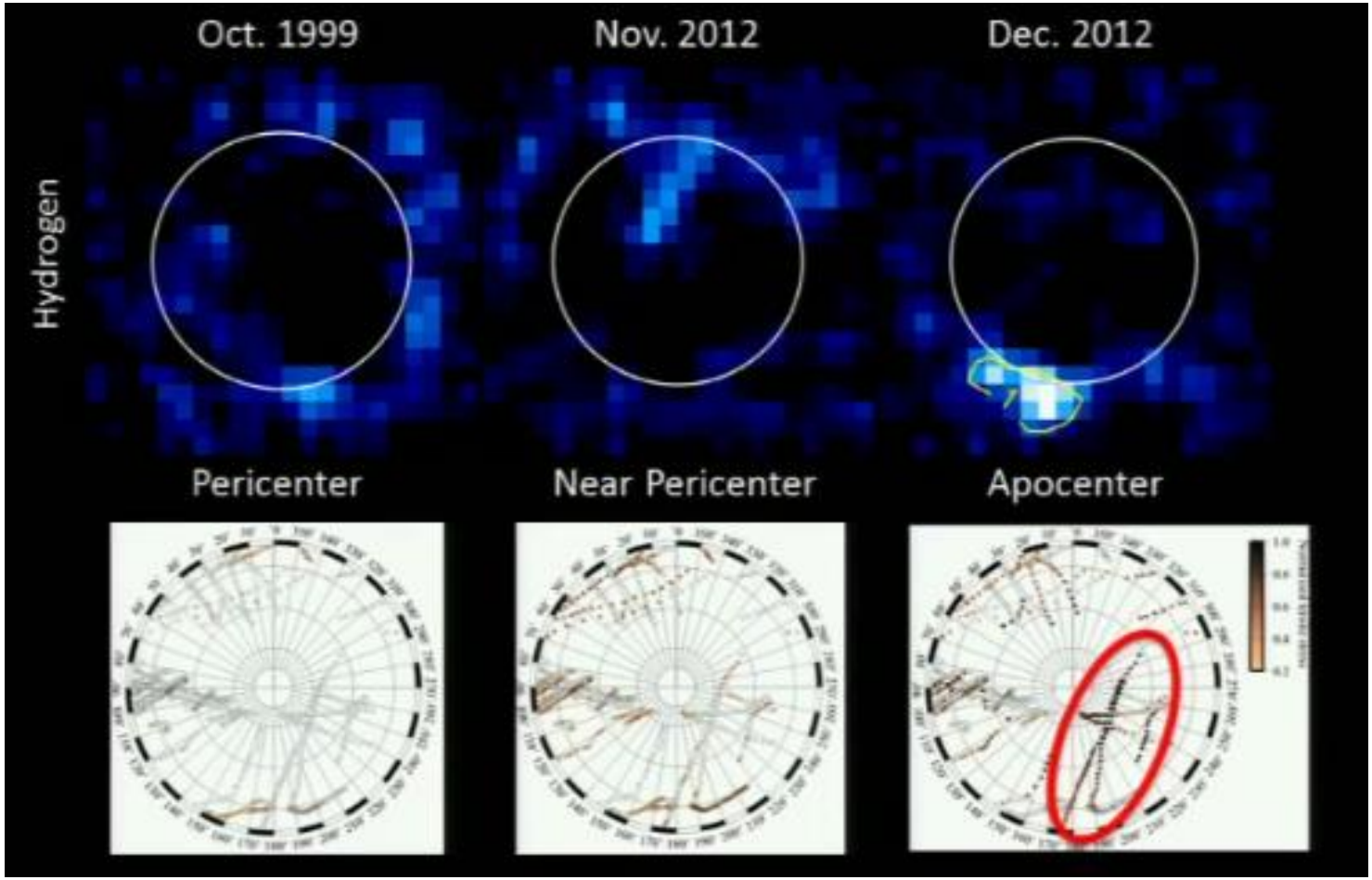
contours: $T_{surface}$ (K)



TESS: Transiting Exoplanet Survey Satellite (Ricker+2014)

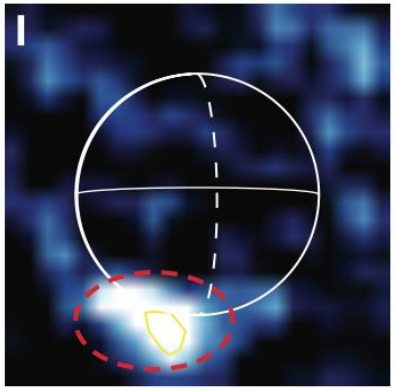

watery super-Earths and super-Ganymedes
Ice I
Ice II-III
Ice V
Ice VI
Ice VII
800 km
5800
3000 km
liquid ocean layers,
more saline with depth
Ganymede
Ice I
Ice III
Ice V
Ice VI
800 km
1100 km
700 km
Titan
Ice I
Ice II
Ice V
Ice VI
NH3?
700 km
1880 km
~0 km

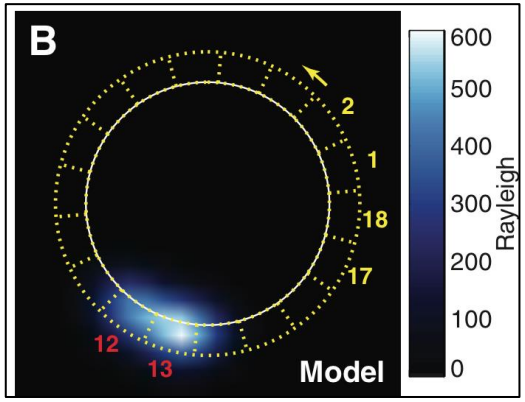
Europa Plume Location & Variability

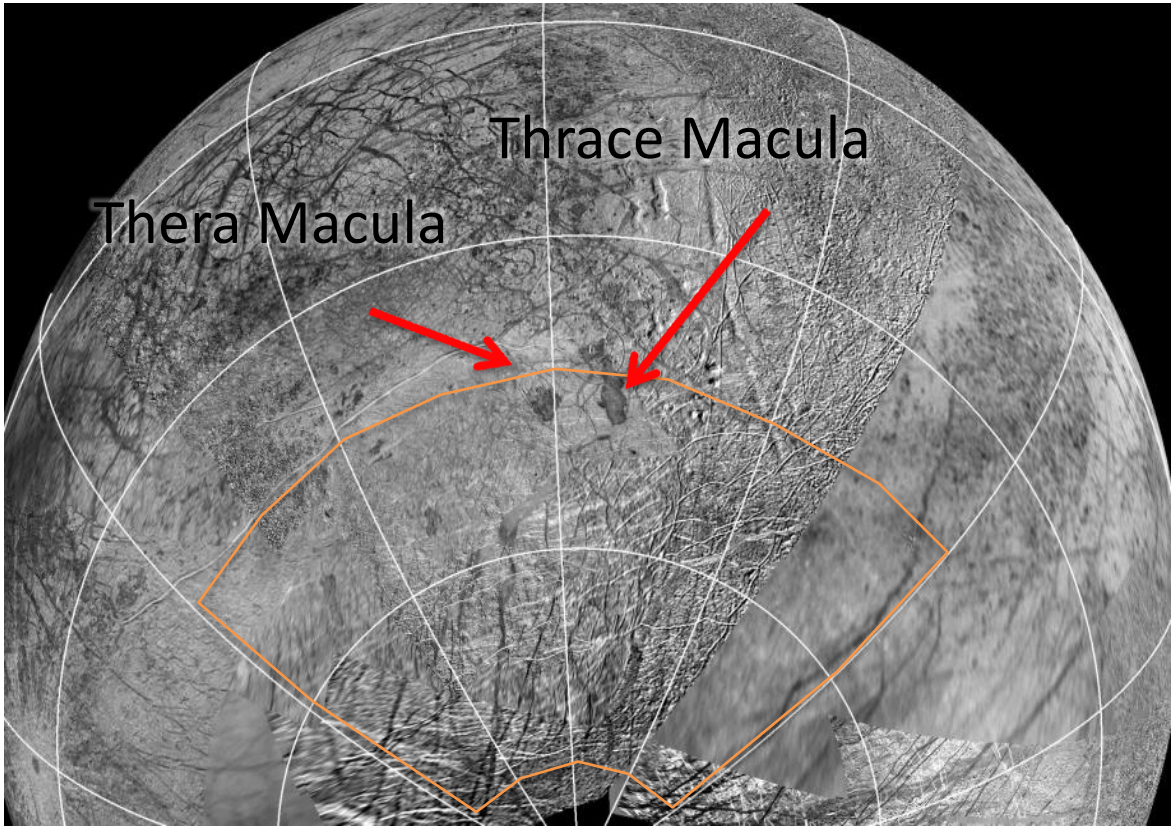


Roth et al 2014, *Science*

Europa Plume Location & Variability



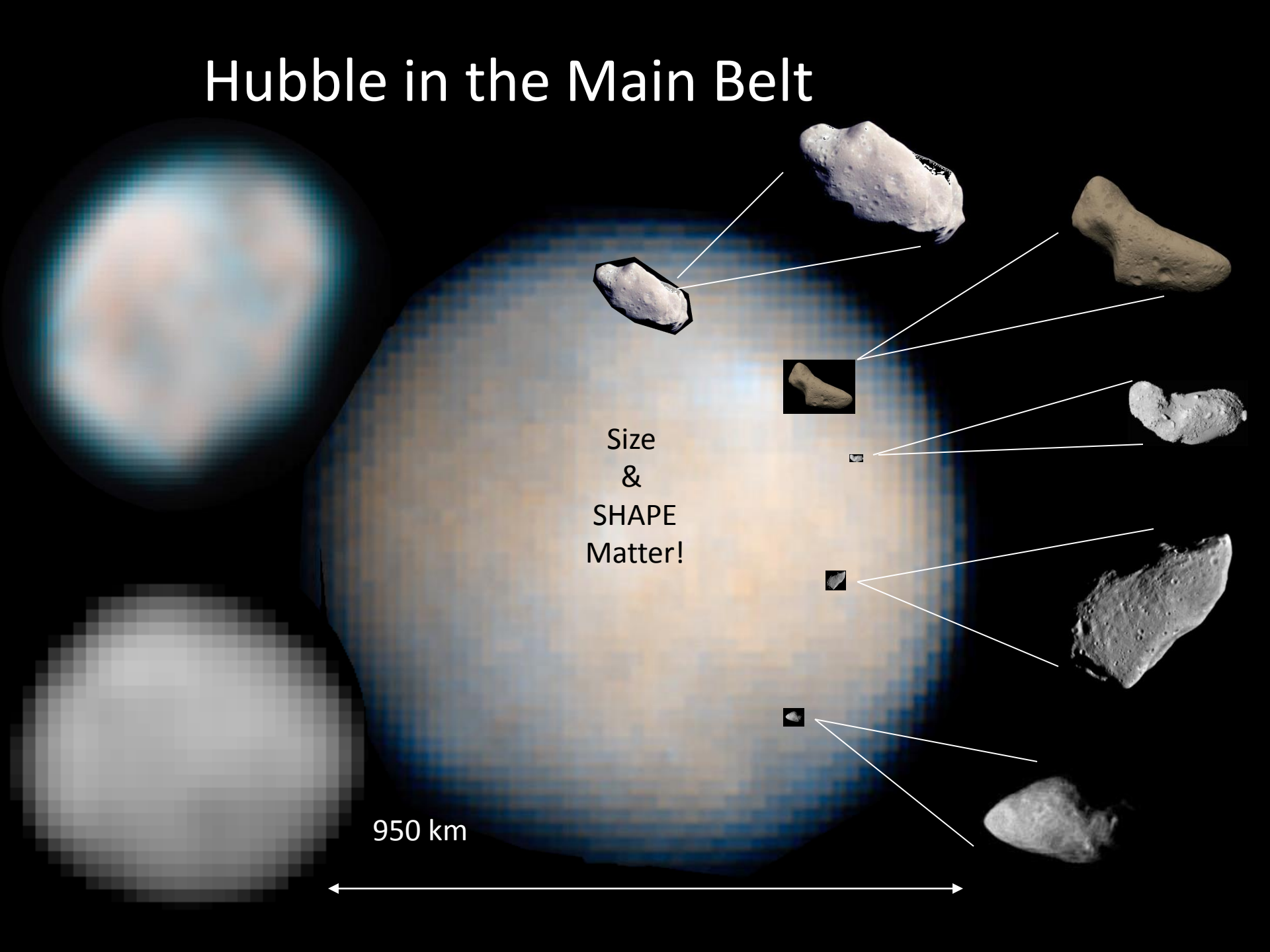




Roth et al 2014, *Science,*
Schmidt et al in prep.

Kuiper and Asteroid Belts—
Seeing Planets
& Informing Disk Processes

Hubble in the Main Belt



Interior from Shape and Density Observations

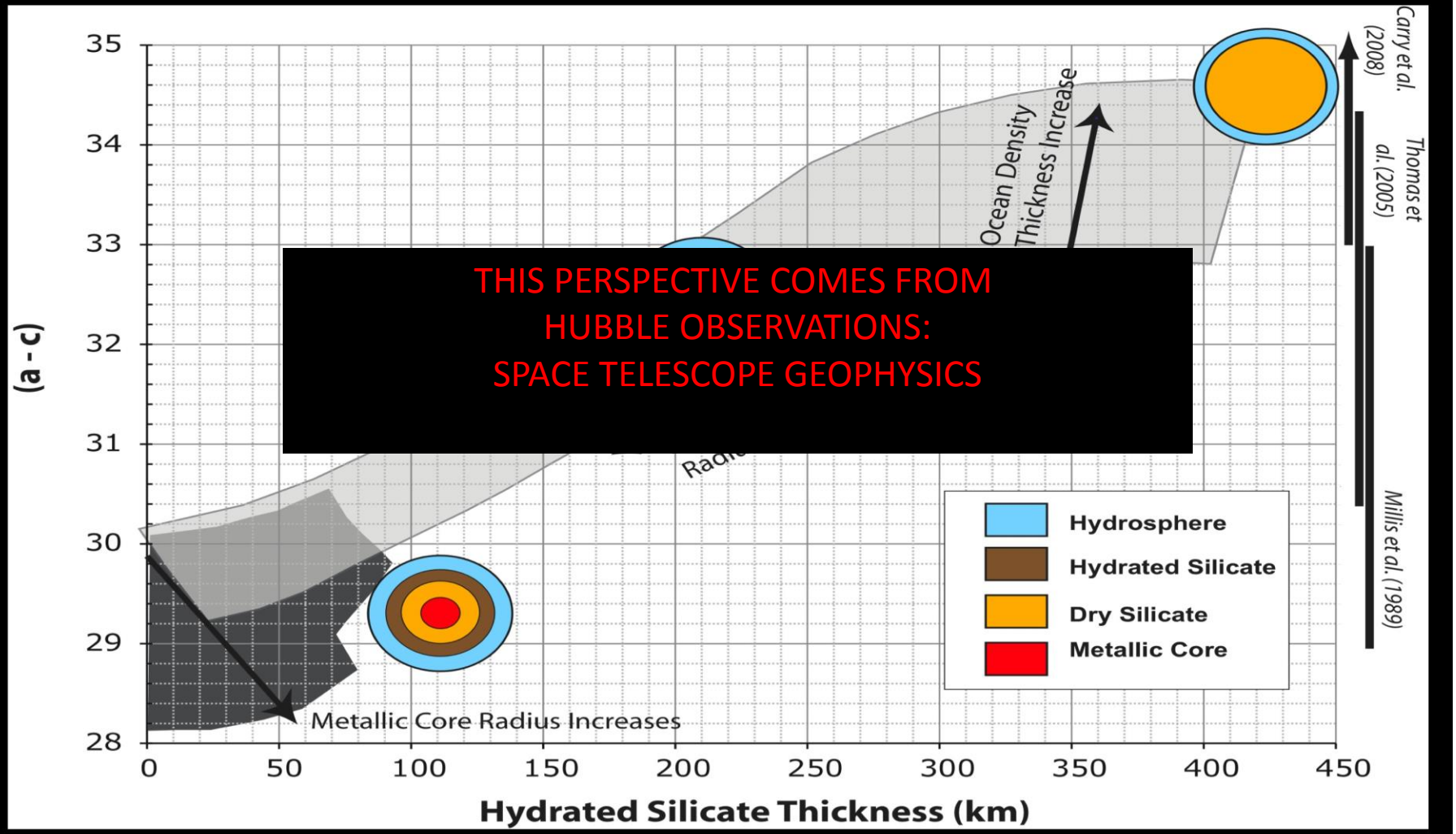
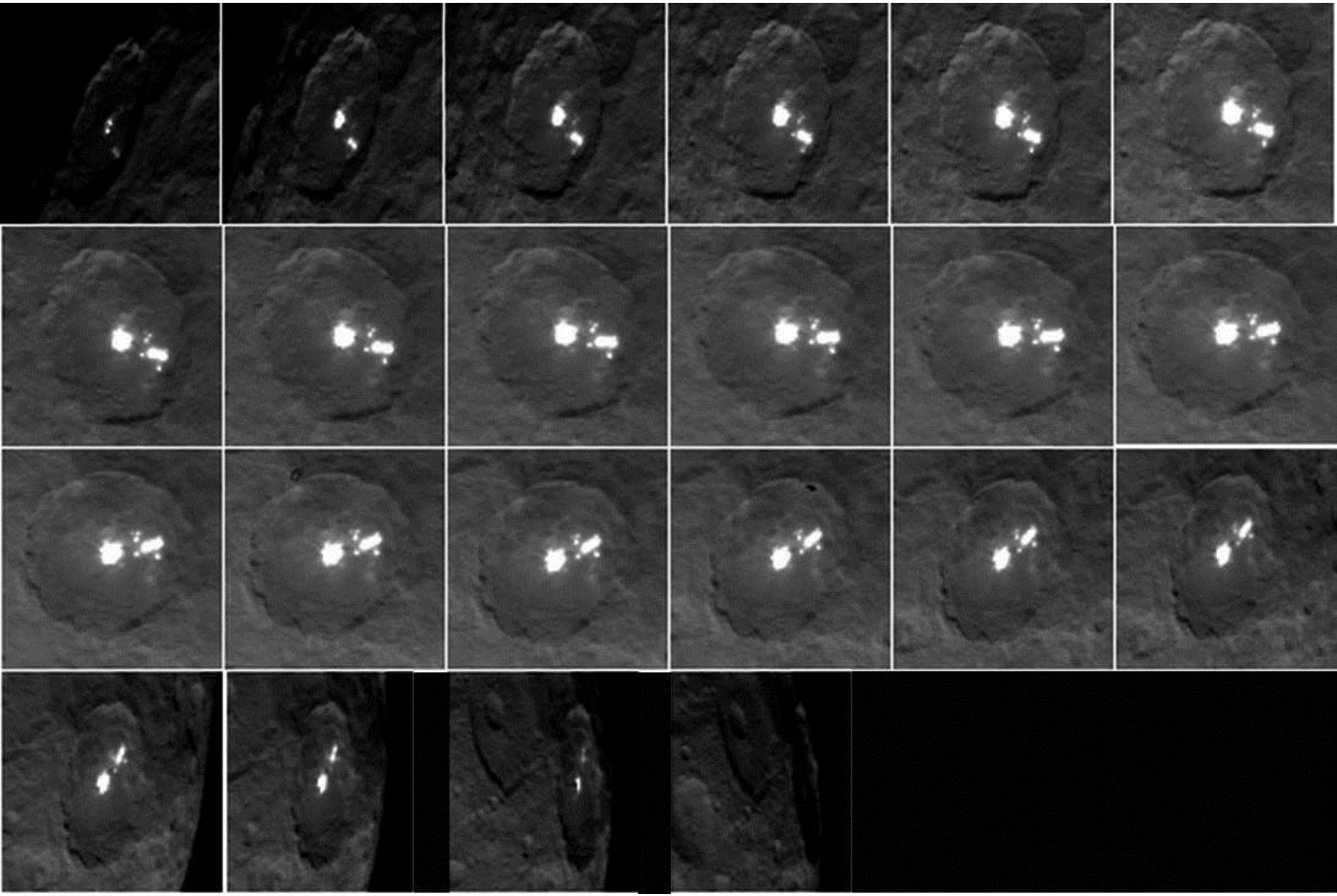


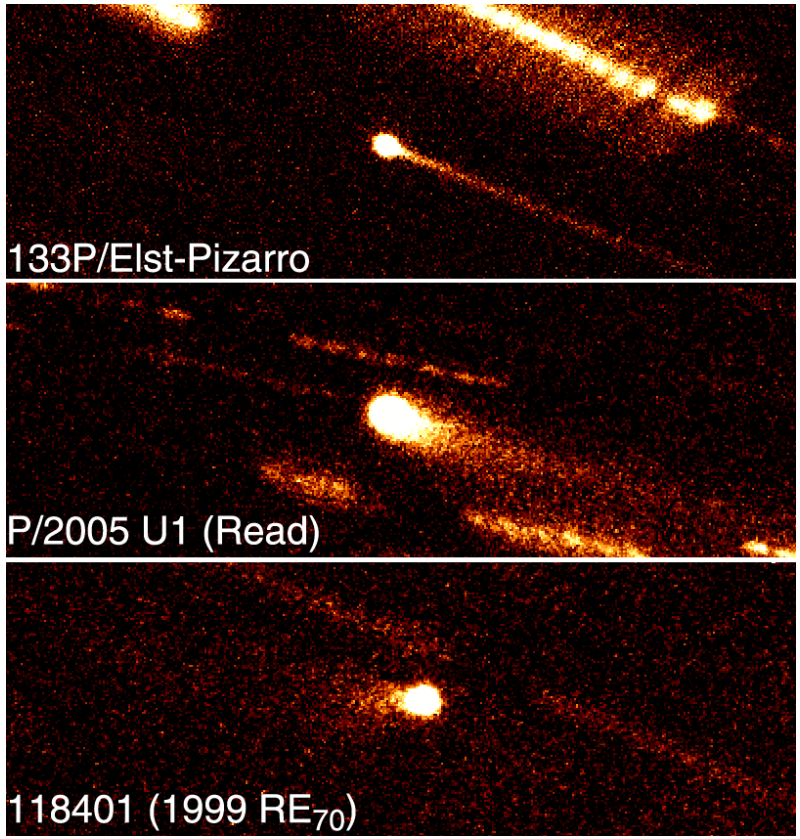
Figure Credit: Castillo-Rogez & McCord, 2010



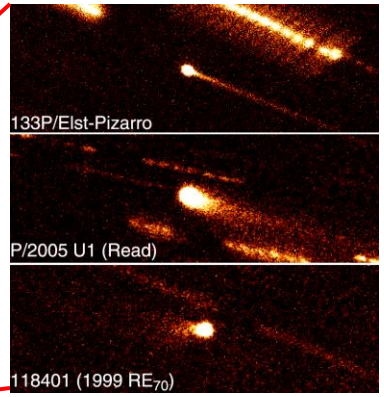
M Küppers *et al. Nature* **505**, 525-527 (2014)
doi:10.1038/nature12918

Whole New Worlds: Icy Bodies in the Main Belt

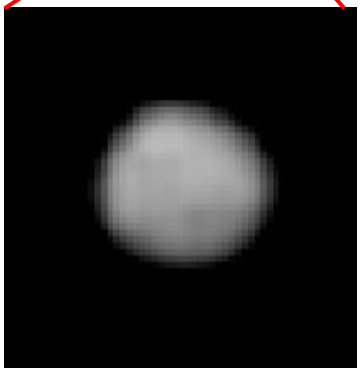
- Twenty C-type asteroids larger than 100 km
  - Densities between 2000 and 2800 kg/m^3
    - Can be interpreted as 5-30 % wt. water
  - Surface Temperature is greater than 160 K
    - Water ice creep temperature is 176 K
  - Surface Compositions:
    - Hydrated silicates, organics, carbonates, clays
    - Signatures of water-rock reactions?
- Main belt comets: B-types, part of Themis family



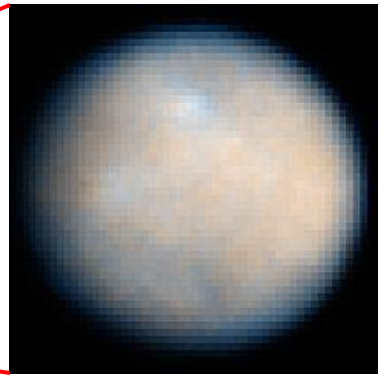
Implications for Ice & the C-class Asteroids



24 Themis,
65 Cybele

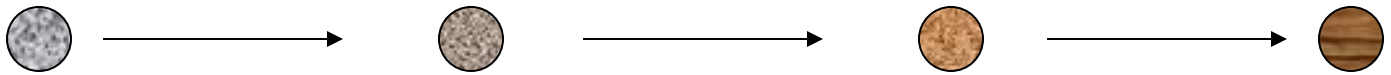


Pallas



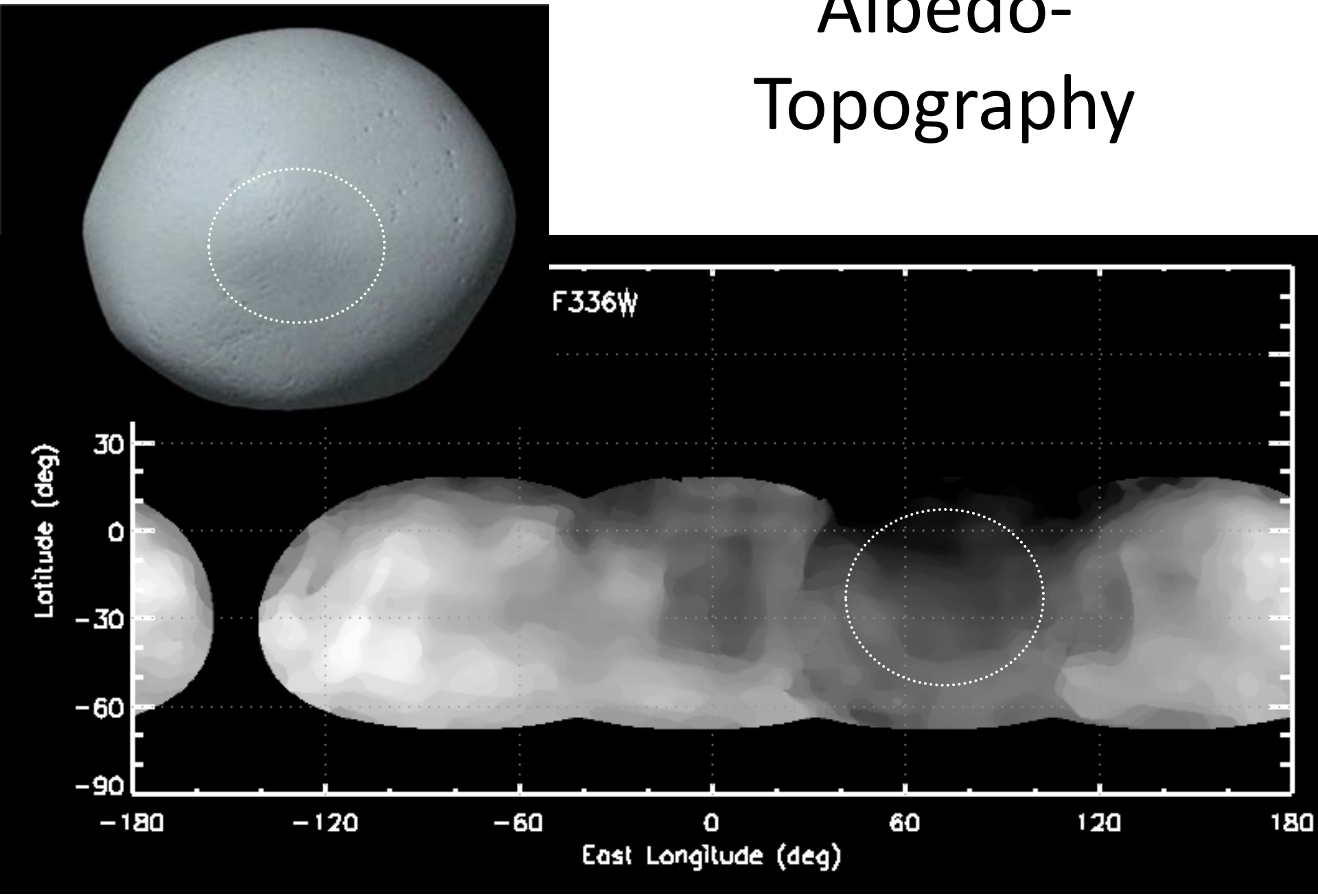
Ceres

Meteorite & Disk Implications



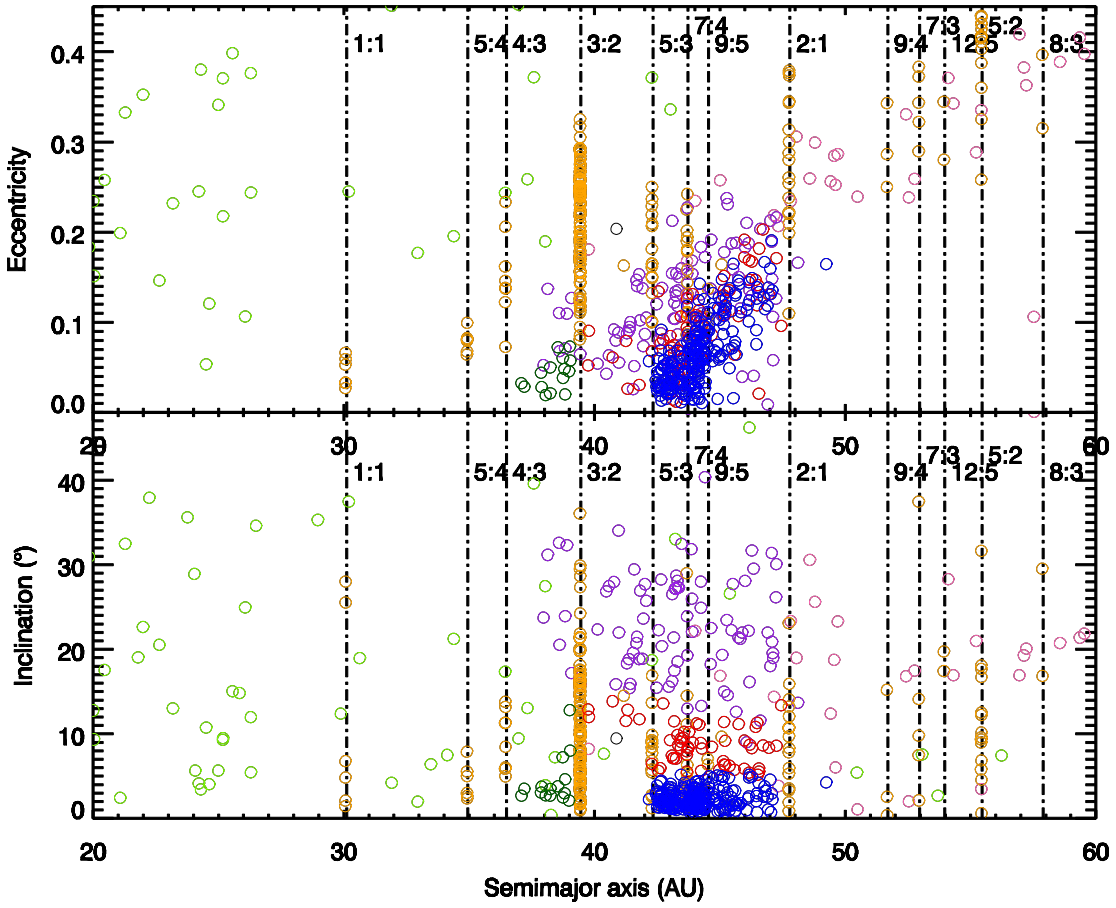
Schmidt et al, Science 2009

Albedo-Topography

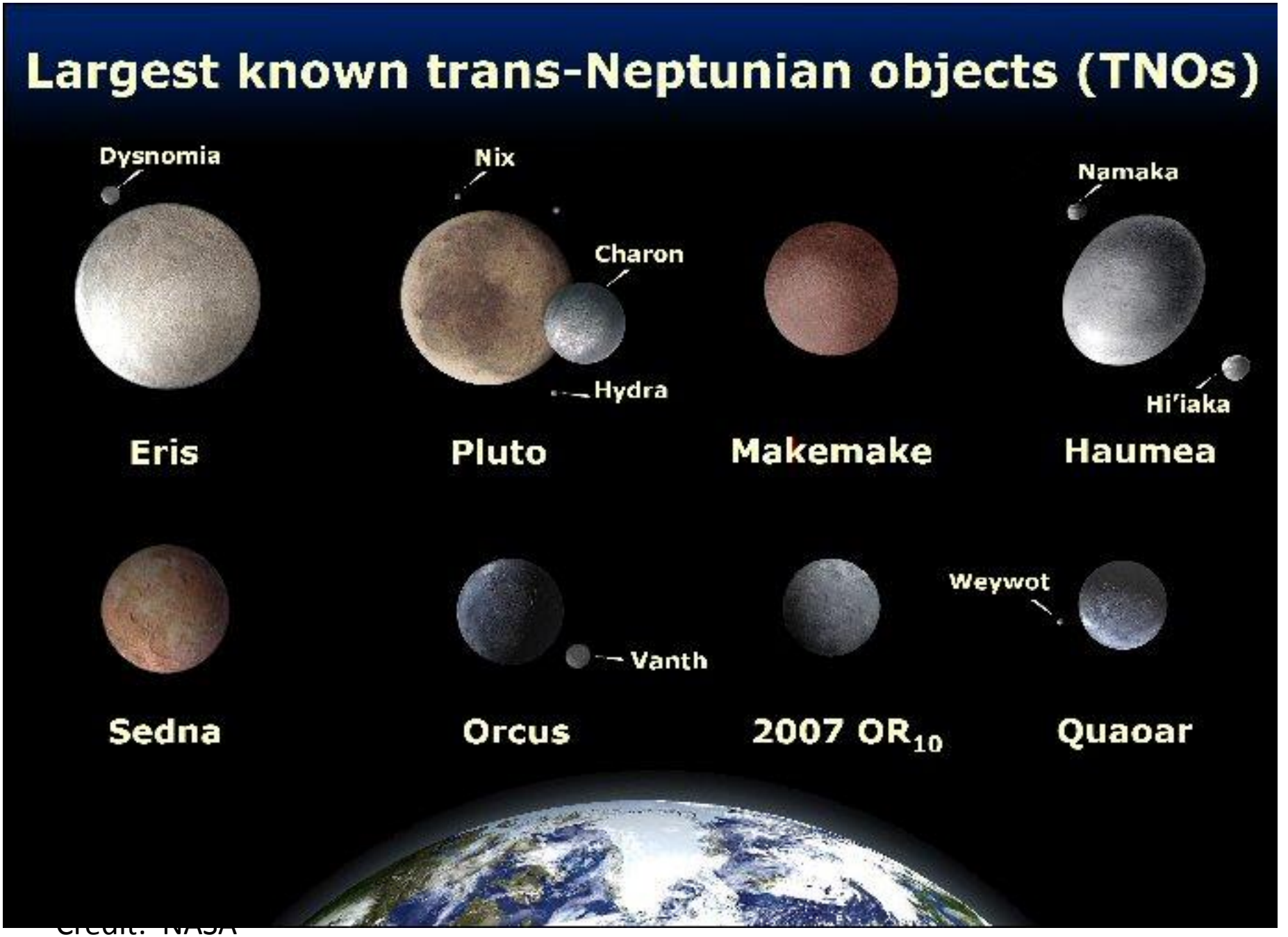


Kuiper Belt—Seeing Planets & Informing Disk Processes

Dynamical Classification

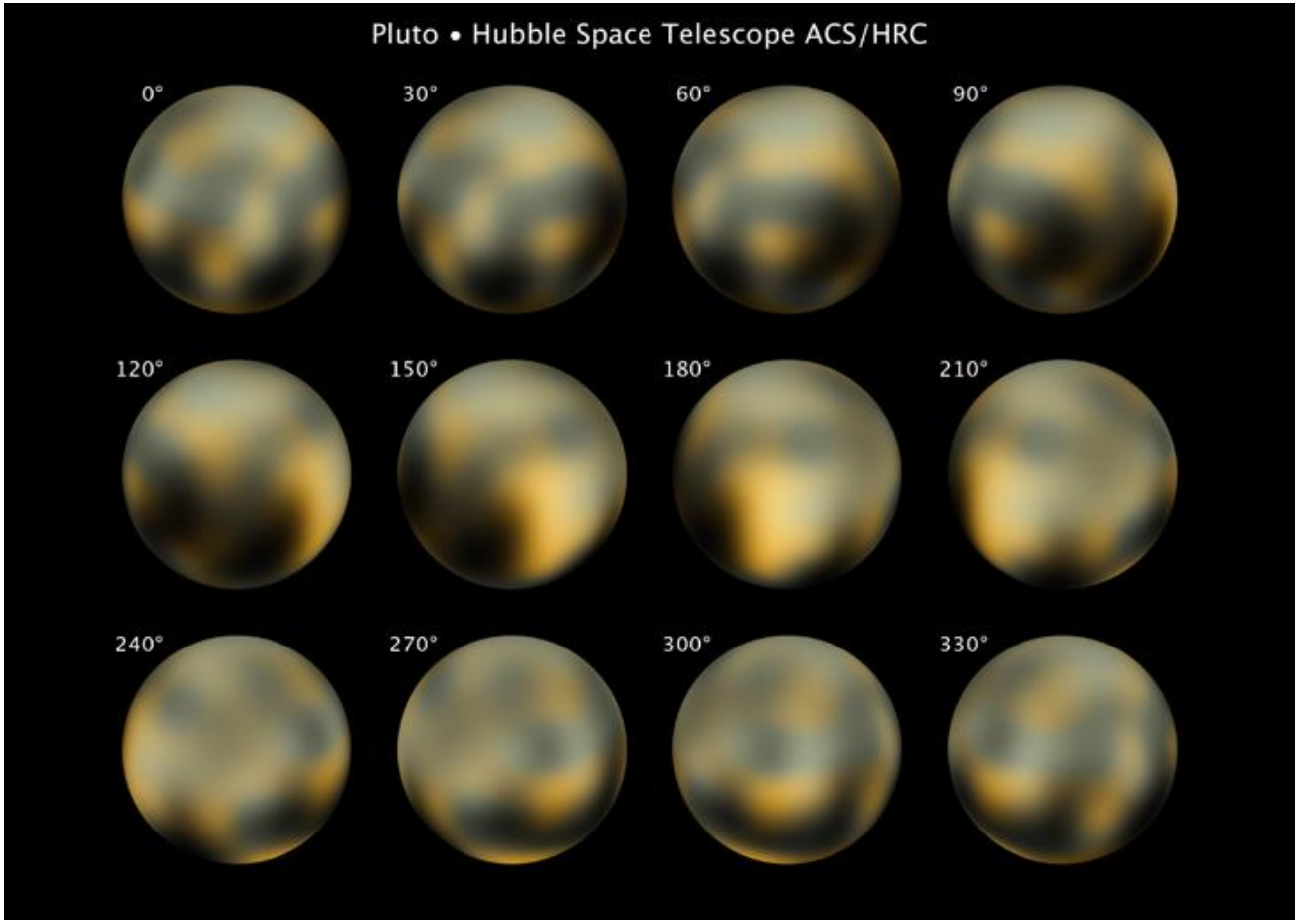


- Centaur
- Scattered-Near
- Scattered-Extended
- Inner Classical
- Cold Classical
- Hot Classical
- Resonant

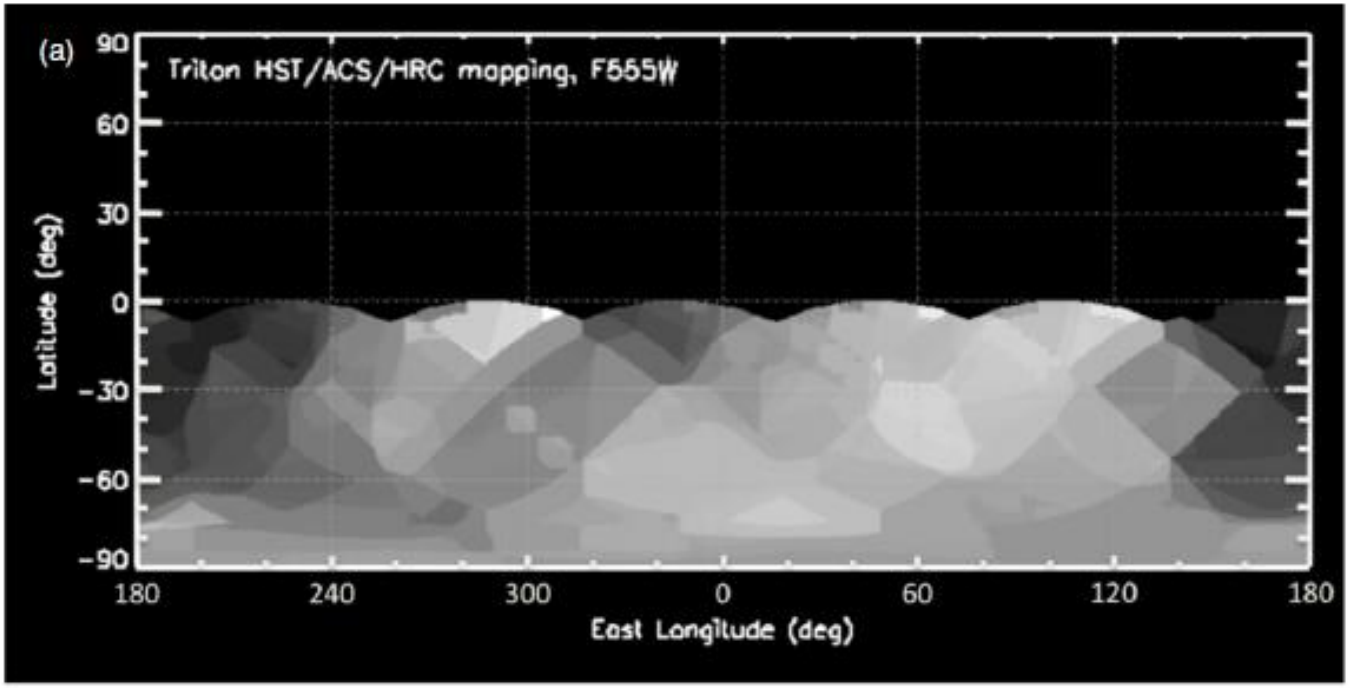

Largest known trans-Neptunian objects (TNOs)
Dysnomia
Eris
Nix
Charon
Hydra
Pluto
Makemake
Namaka
Hi'iaka
Haumea
Sedna
Vanth
Orcus
2007 OR10
Weywot
Quaoar

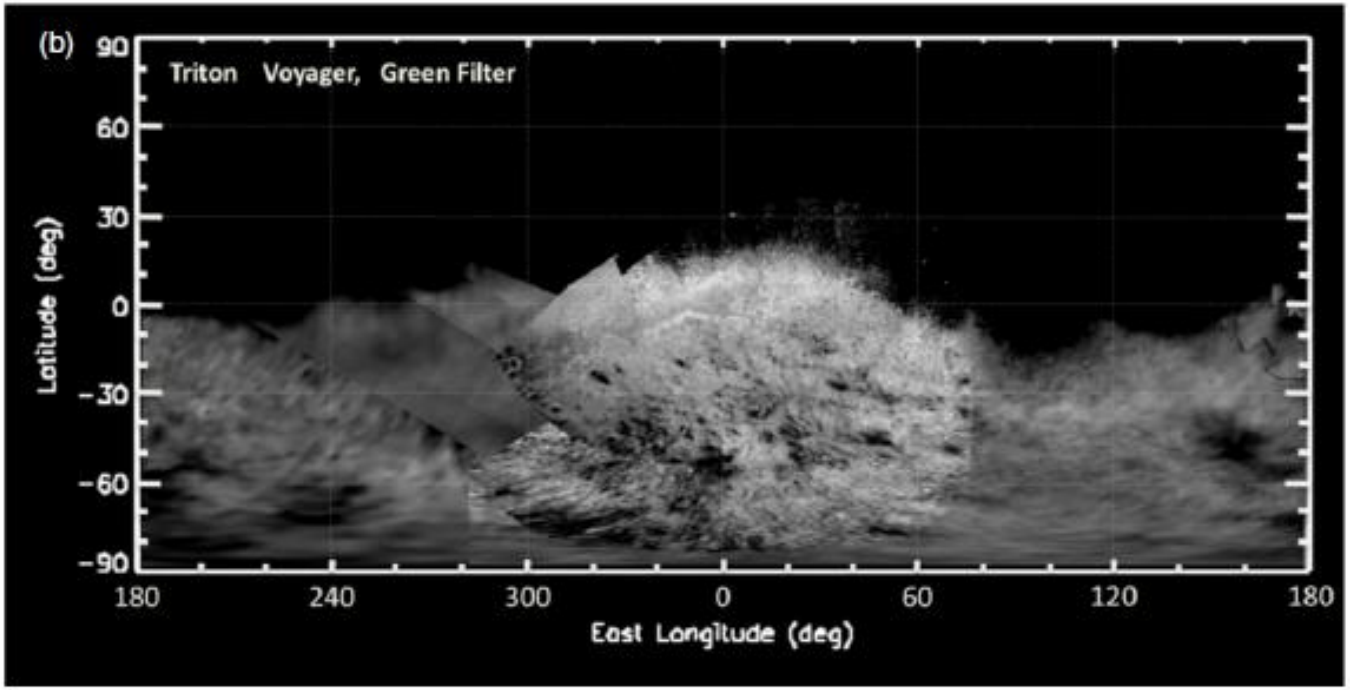
Credit: NASA

Pluto

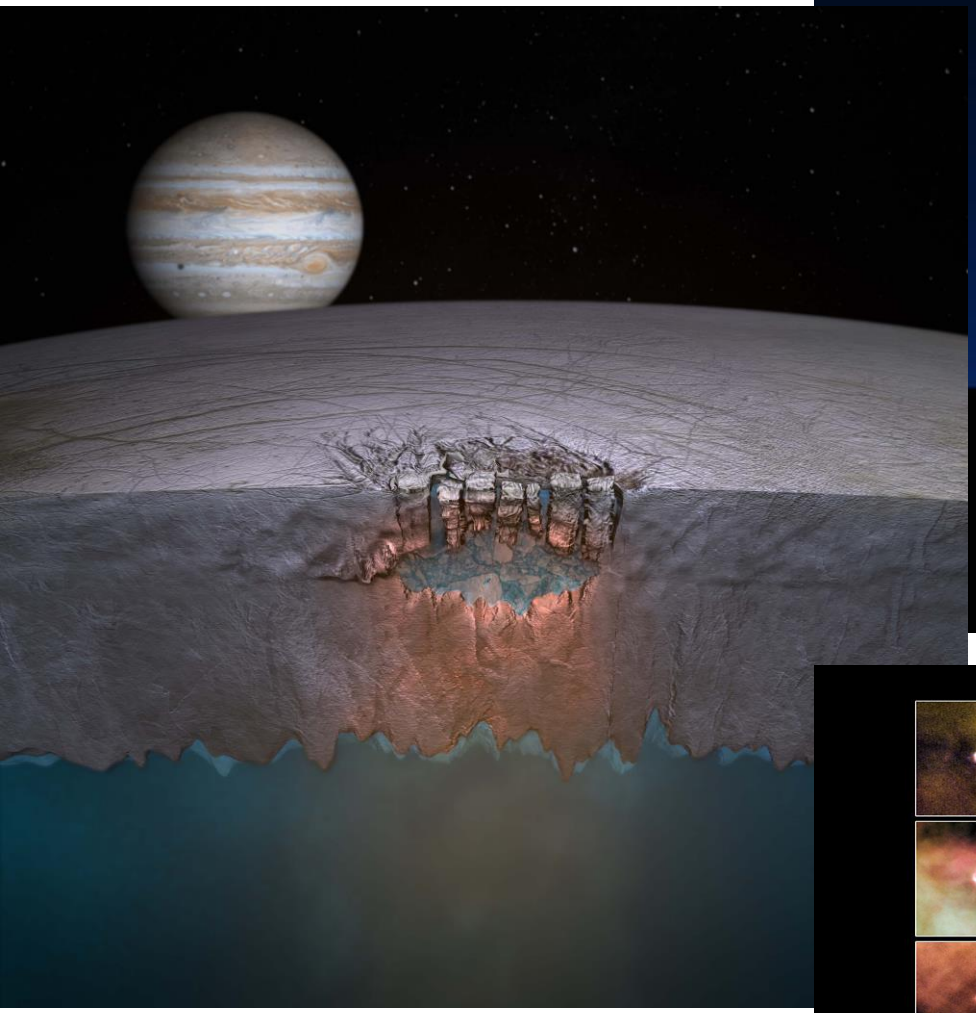


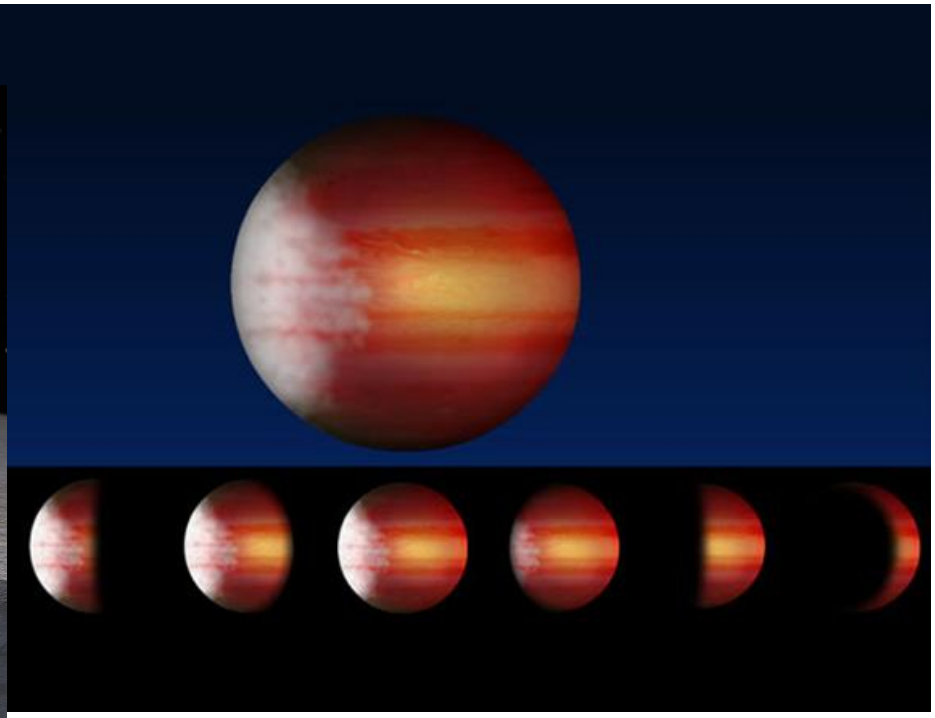
Credit: NASA

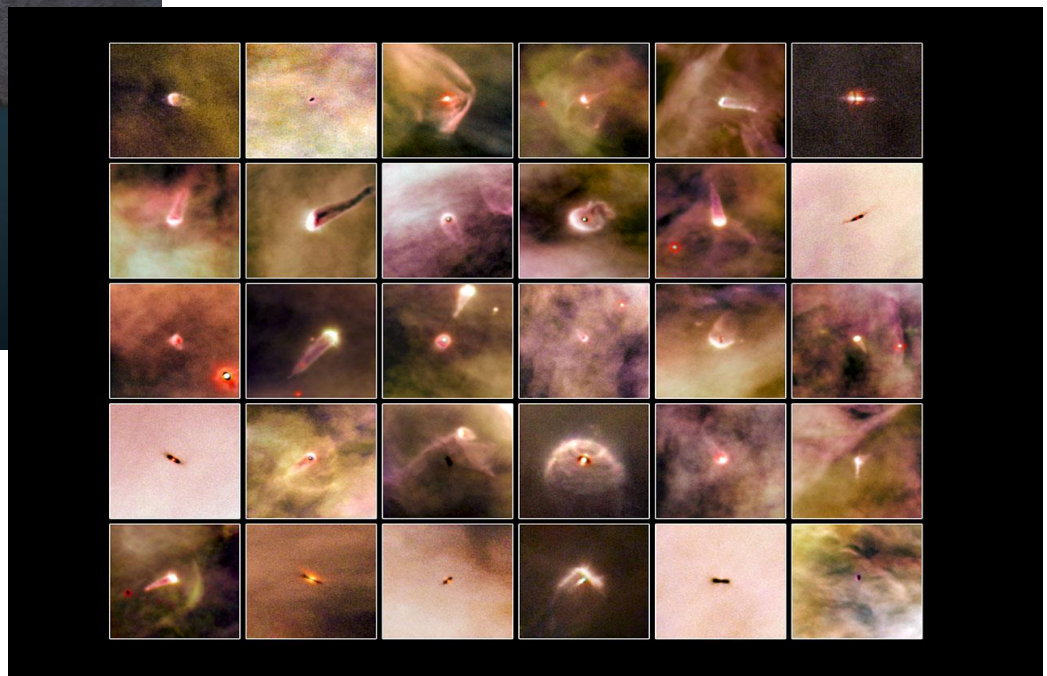

(a)
Triton HST/ACS/HRC mapping, F555W
90
60
30
0
-30
-60
-90
Latitude (deg)
180
240
300
0
60
120
180
East Longitude (deg)


(b)
Triton Voyager, Green Filter
90
60
30
0
-30
-60
-90
Latitude (deg)
180
240
300
0
60
120
180
East Longitude (deg)

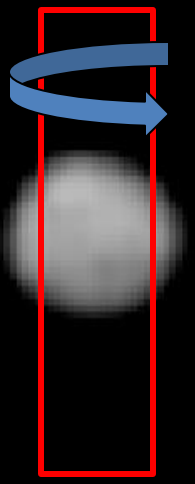
Synergy & Moving Forward

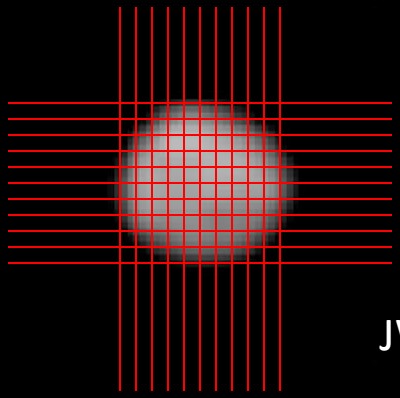




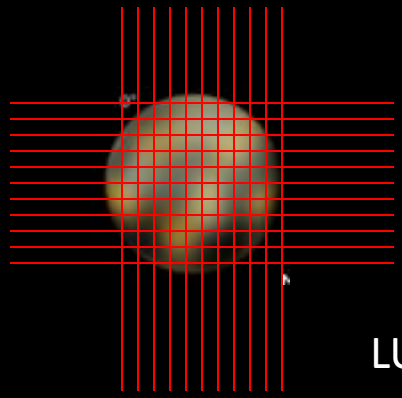


Some Potential JWST vs 8m-class Observations



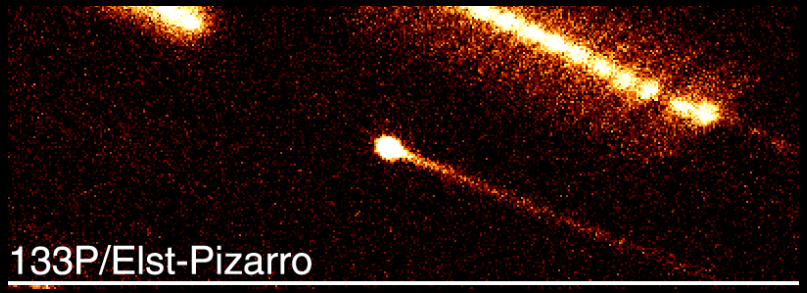


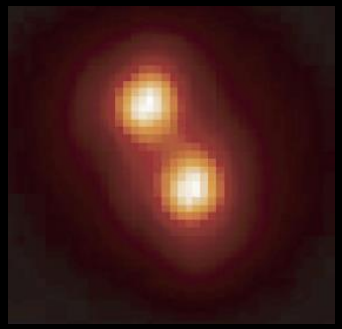
JWST



LUVOIR

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





Ground/WISE, NIRSPEC, LUVOIR

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

Sample Solar System Obs. Req.

- Spatial Resolution:
  < 100 milli-arcsec PSF sampled at <40 milli-arcsec/pixel
- Sensitivity for photometry and imaging:
  V $\leq$ 24 (w/o filter for cold small bodies)
  Surface Brightness < 100 Jy/arcsec^2 (w/ filter for giant planets)
  Imaging SNR > 100 for resolving low-contrast features on GPs.
- Spectral Resolution:
  R = $\lambda / \Delta \lambda$ > ~150 in 400-800 nm
  R = $\lambda / \Delta \lambda$ > ~50 in 800-1600 nm
  SNR > 50
- Moving Target Requirement:
  30 milli-arcsec / sec to observe objects at/near Mars orbit
- Coronagraph / Starshade:
  We could use Coronagraph/Starshade observe rings, moons, aurorae, image binaries (issue: Jupiter appears much larger than Neptune; difficult to tune the size of the shade)

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?
- 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 and Exoplanet Scientists Need to Stick Together!