Planetary Science Group Journal Club

"Six Topics in Planetary Astronomy"

D. Jewitt. 2009. "Small Bodies in Planetary Systems", Lecture Notes in Physics 758, p. 259-291, I.Mann *et al*. (Eds), Springer.

Background info

- Collection of lectures on *"Origin and Evolution of Planetary Systems"* given at Kobe Univ., Japan (Dec. 2006).

- Full book now available at ESO-Chile Library
- Electronic version also available at: http://www.springerlink.com/content/978-3-540-76934-7 from ESO IPs.

- Topics:
  - From Protoplanetary Disks to Planetary Disks: Gas Dispersal and Dust Growth
  - Dynamics of Small Bodies in Planetary Systems
  - Asteroids and Their Collisional Disruption
  - On the Strength and Disruption Mechanisms of Small Bodies in the Solar System
  - Meteoroids and Meteors: Observations and Connection to Parent Bodies
  - Optical Properties of Dust
  - Evolution of Dust and Small Bodies: Physical Processes
  - Observational Studies of Interplanetary Dust
  - Six Hot Topics in Planetary Astronomy
  - Detection of Extrasolar Planets and Circumstellar Disks

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  - Six Hot Topics in Planetary Astronomy (D. Jewitt)
    - Lightcurves and densities
    - Color distributions
    - Spectroscopy of primitive matter
    - Irregular satellites
    - Main-belt comets
    - Comets and their debris

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    - **Crystalinity of ice in outer solar system**
    - Irregular satellites
    - Main-belt comets
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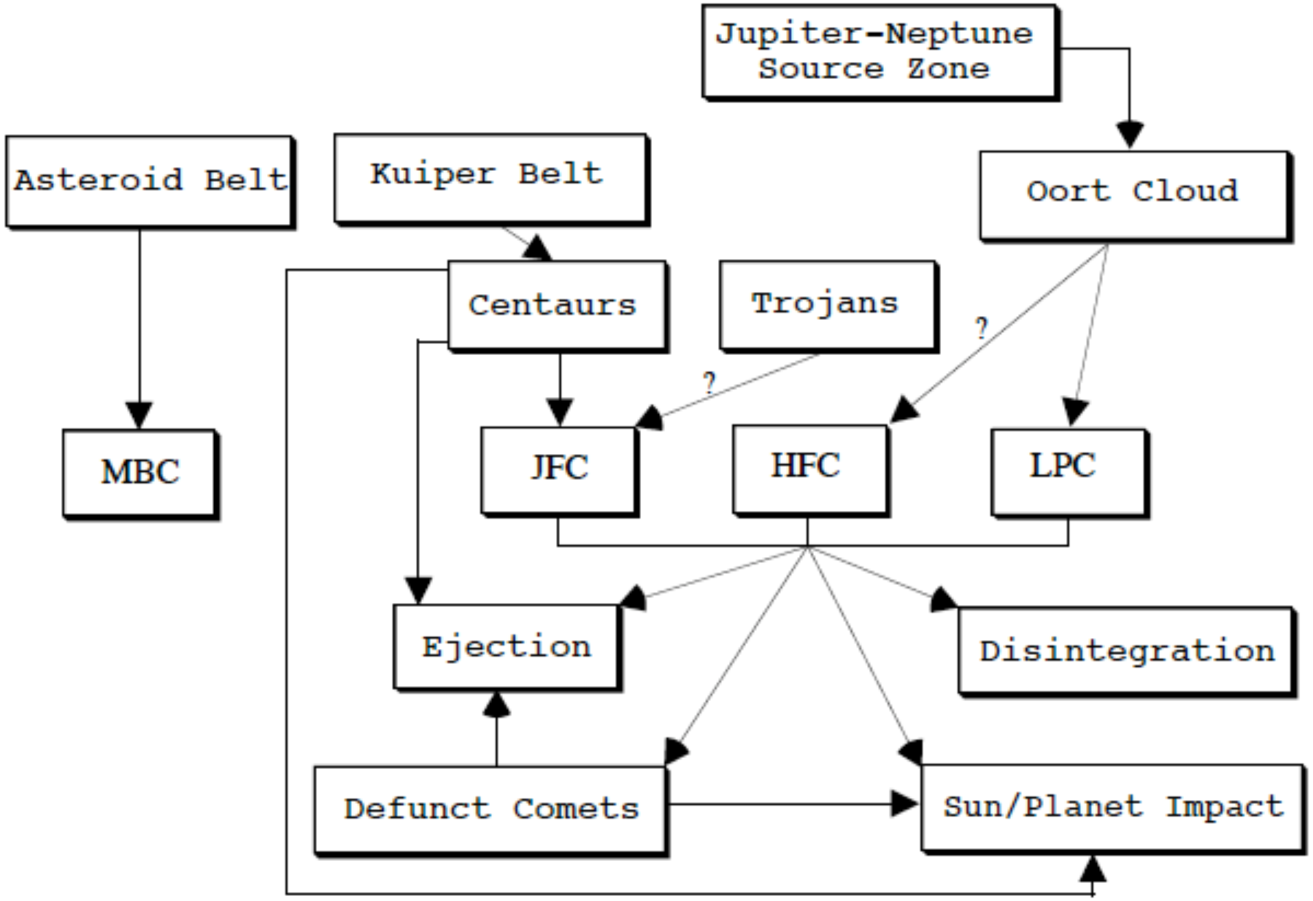
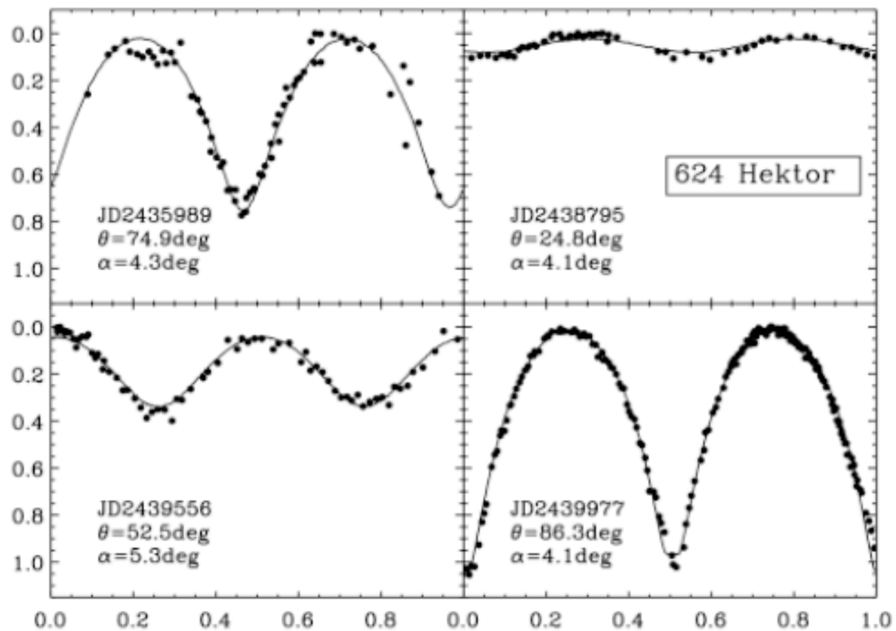
  – Observational Studies of Interplanetary Dust
  – Six Hot Topics in Planetary Astronomy
  – Detection of Extrasolar Planets and Circumstellar Disks

A note about the author

- D. Jewitt:
  - Professor University of Hawaii since 1993 (at UCLA this June)
  - Discoverer of first Kuiper-Belt object (1992 QB1)
  - Research interest:
    - Outer Solar System
    - Solar System Formation
    - Physical Properties of Comets
    - Comet - Asteroid Interrelations
    - Submillimeter Properties of Comets &


Jupiter-Neptune
Source Zone
Asteroid Belt
Kuiper Belt
Oort Cloud
Centaurs
Trojans
?
?
MBC
JFC
HFC
LPC
Ejection
Disintegration
Defunct Comets
Sun/Planet Impact

- Lightcurves & Densities
  - See talk from last week by Benoit (in comb. with AO images)
  - Example (below): Hektor's case of an equilibrium binary asteroid



- Lightcurves & Densities (Cont'd)
  - Great value to assess:
    - Shapes
    - Rotational states of bodies and physical parameters (spin, density)

  - Assumption: informs us on shape, not surface heterogeneity (body is assumed uniform in albdeo)
  - Let's face it: albedo contrasts are not common among SSSBodies (Iapetus, Vesta)
  - Other assumption: material with no strength (as a liquid) - helps models which work quite well!
  - As a result body shape relax to an equilibrium configuration, which is function of the body's density and ang. momentum:
    - Sphere (not rotating!!!)
    - Oblate spheroids (b=c, e.g. Ceres)
    - Tri-axial Jacobi ellipsoids … then limit in rotation rate.
    - Beyond a certain angular momentum ----> fission (contact binaries or near-contact)

exist. After all, small Solar system bodies are rocks, not liquids, and so they cannot literally be strengthless, especially in compression. Even if they lack overall tensile or cohesive strength, pressure-induced shear strength between components gravitationally bound in an aggregate should inhibit complete relaxation to the equilibrium state, much as grains of sand in a pile do not flow under gravity like a liquid because of frictional forces between the grains

Despite these legitimate reservations, the evidence suggests that equilibrium models can indeed work very well when the bodies and their lightcurve ranges (a measure of the equatorial variation of the radius) are large. As

- # Lightcurves & Densities (Cont'd)

  - Jacobi ellpsoids do not fit all the cases (see example of binary KBO 2001 QG298).

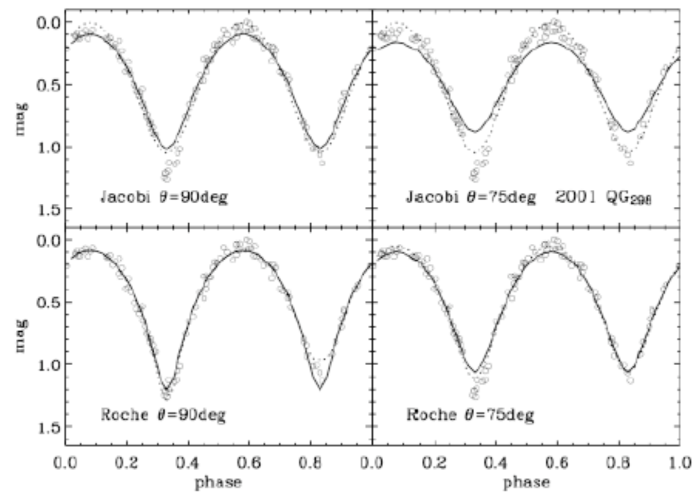


Fig. 4. Lightcurve of KBO 2001 QG298 compared with models. The top two panels show the best-fitting Jacobi ellipsoid models for aspect angles $\theta = 90°$ and $\theta = 75°$. The bottom two panels show best fit Roche binary models for the same aspect angles. The Roche binary model for $\theta = 90°$ (lower left panel) provides the best fit to the data, including the asymmetric lightcurve minima. No comparably good Jacobi (single-body) models were found. Data from [79], figure from [47].

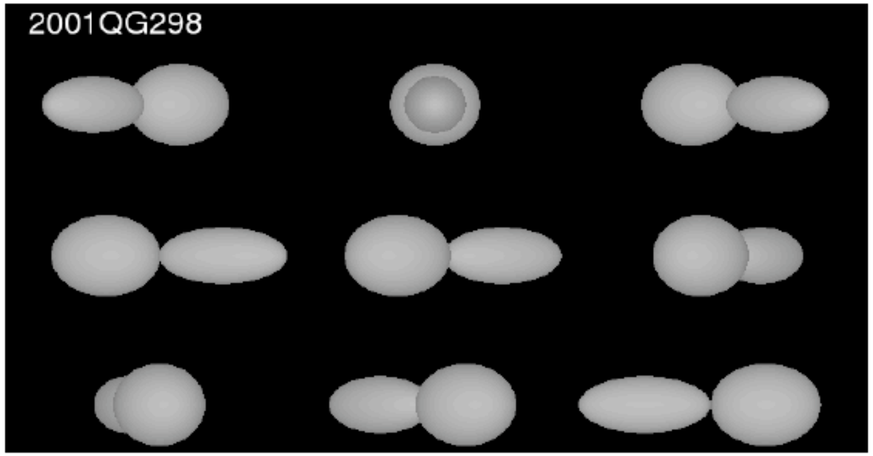


Fig. 5. Visualization of 2001 QG298 as a function of rotational phase based on the best-fit Roche binary model from the lower-left panel in Figure 4. The binary components are elongated by mutual gravitational attraction. Figure from [47].

- Lightcurves & Densities
  (Cont'd)

  - Densities:
    - Spacecraft
    - Mutual event data (Pluto/Charon)
    - Lightcurves
  - Obvious trend (larger bodies are denser)
  - Self-compression negligible below 1000km diameter
  - Below 1000kg/m^3: porous bodies

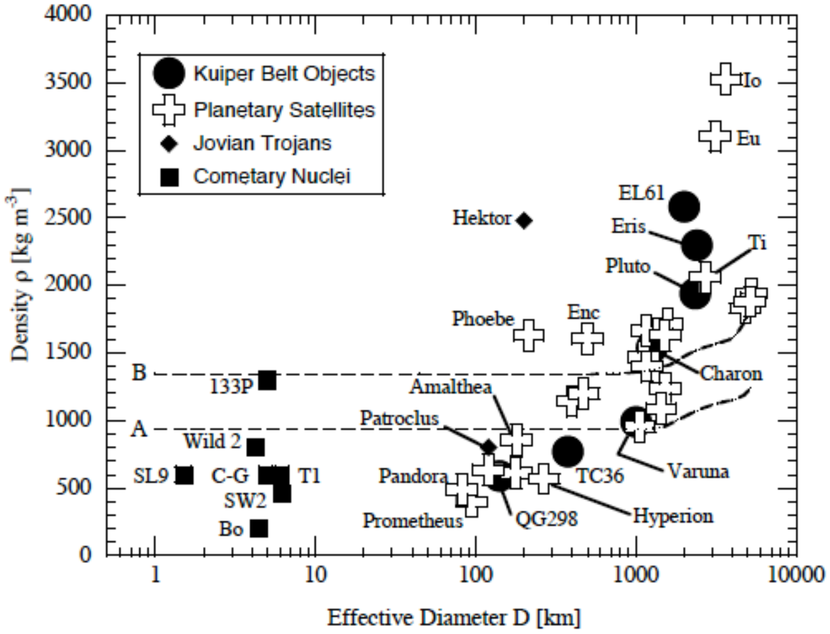


Fig. 6. Density as a function of diameter for mostly icy bodies in the outer Solar system. Abbreviations SL9=D/Shoemaker-Levy 9, C-G=P/Churyumov-Gerasimenko, SW2=P/Schwassmann-Wachmann 2, Bo=P/Borrelly, T1=P/Tempel 1, QG298=2001 QG298, TC36=1999 TC36, EL61=2003 EL61, Enc=Enceladus, Ti=Titan, Eu=Europa. Labeled curves are isothermal self-compression models for (A) pure water ice and (B) a 40% rock and ice mixture from [54], for comparison purposes only (see text). Figure modified from [31].

- Lightcurves & Densities
  (Cont'd)

  – Example of porous body (40% porosity!!!); **Hyperion**

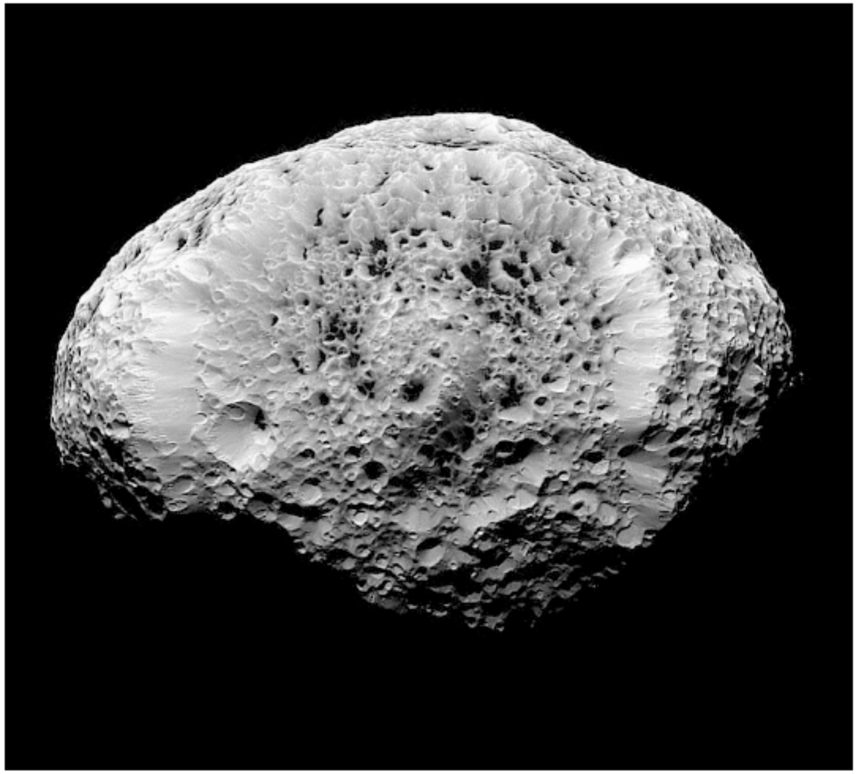


Fig. 7. Saturn's satellite Hyperion. This aspherical body has a mean effective diameter of 270±8 km, a bulk density estimated from perturbations on a passing spacecraft as $\rho = 540 \pm 50$ kg m^{-3} and a porosity ∼40% [87]. Image courtesy Cassini Imaging Team and NASA/JPL/SSI.

- Colors
  - Widespread colors indicate something is special for the case of TNOs …
  - Resurfacing: competition irradiation *vs* impacts
  - BUT not much hemispheric variationsa mong the population ….
  - Compositional variations? OK for main-belt asteroids … but TNOs???
  - Why are Centaurs bi-modal in color?

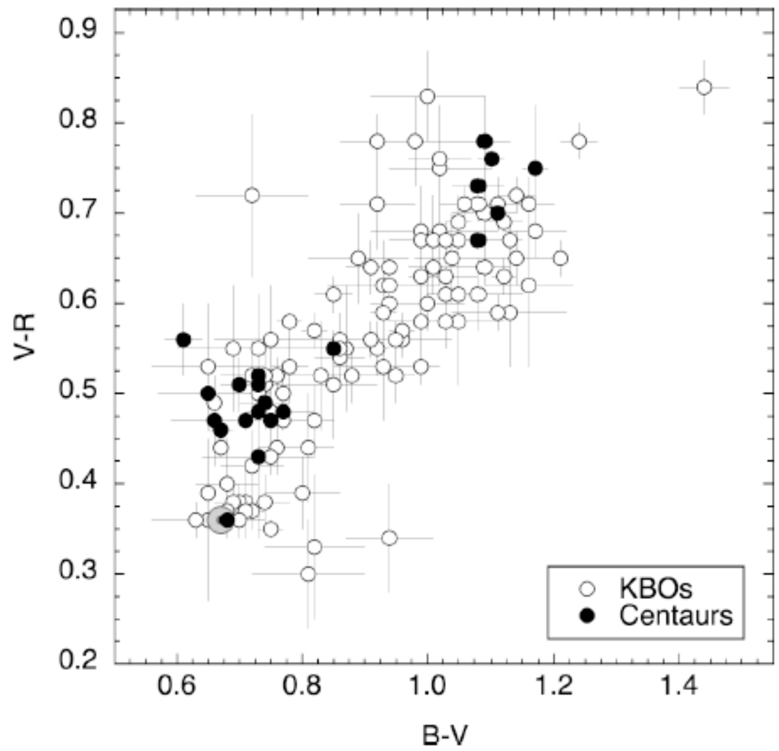


Fig. 8. $B-V$ vs. $V-R$ color-color diagram showing the KBOs (empty circles) and Centaurs (filled circles). Only objects with 1σ photometric uncertainties < 0.1 mag. are plotted. The Sun is marked by a grey circle. Figure courtesy of Nuno Peixinho.

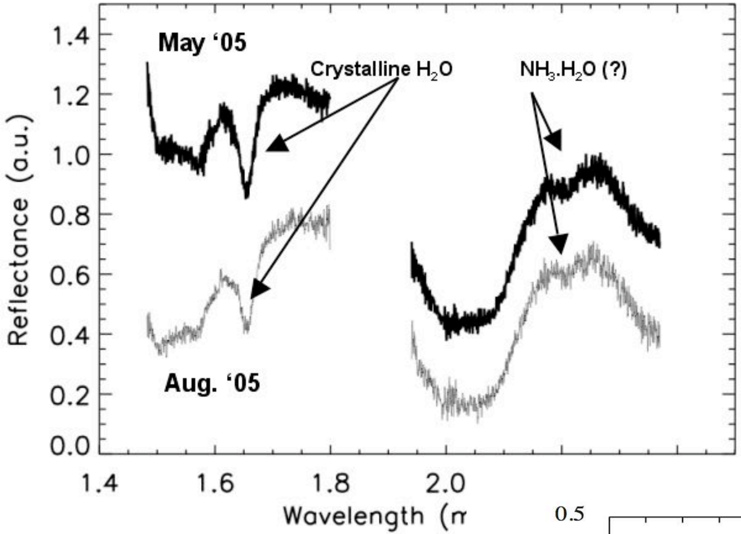
- Spectroscopy
  - Near-IR is good: vibrations/rotations main and overtones bands of molecules
  - Big question: why is crystalline ice a common thing?
    - Low temperature: amorphous
    - Amorphous ice unstable …. Transformation to crystalline over time:

$$\tau_{cr} = 3.0 \times 10^{-21} e^{\left[\frac{E_A}{kT}\right]} \qquad (2)$$

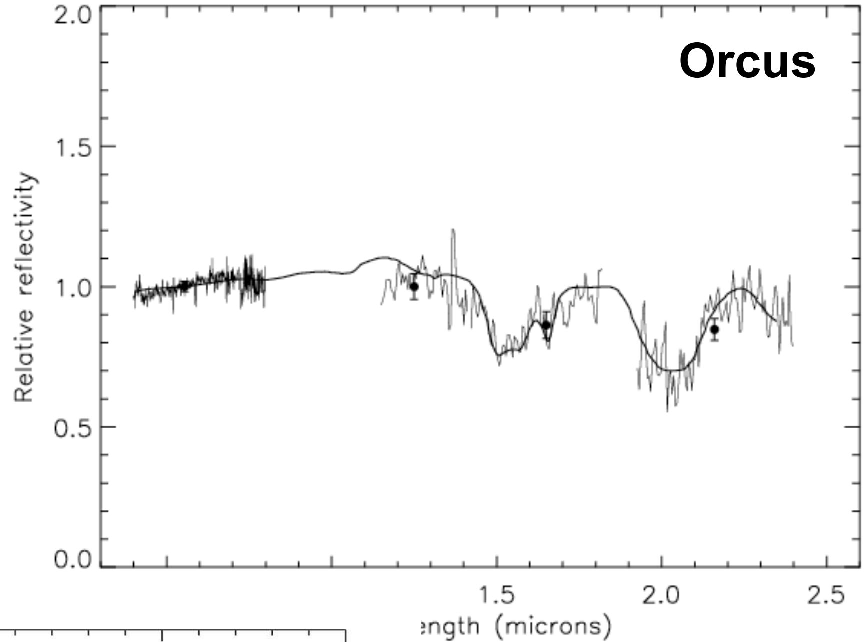
where E_A is the activation energy, k is Boltzmann's Constant, T is the temperature and $E_A/k = 5370$ K [78]. The phase transition is potentially important

    - Exothermic … chain reaction?
    - Amorphous ice can trap gas efficiently, which is released during crystallization (comets)
    - To escape crystallization, amorphous ice should have remained below 77K (distance of Saturn) for the age of the solar system

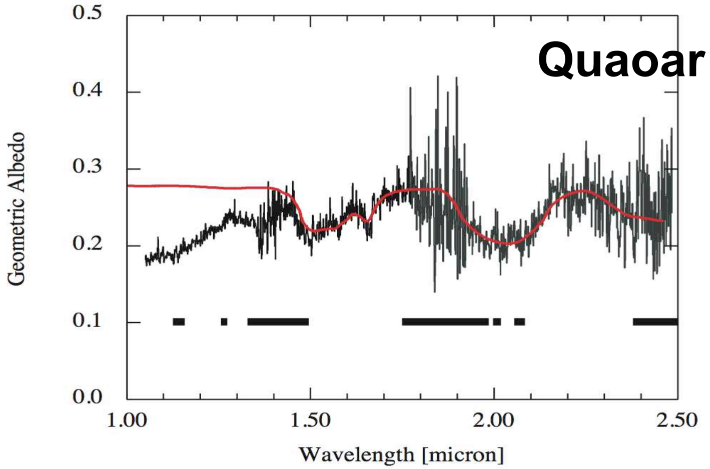
- Spectroscopy
  - BUT …. amorphization under irradiation (solar wind, cosmic rays) is fast (1-10million years).
  - SO WHY crystalline???



SINFONI CHARON data

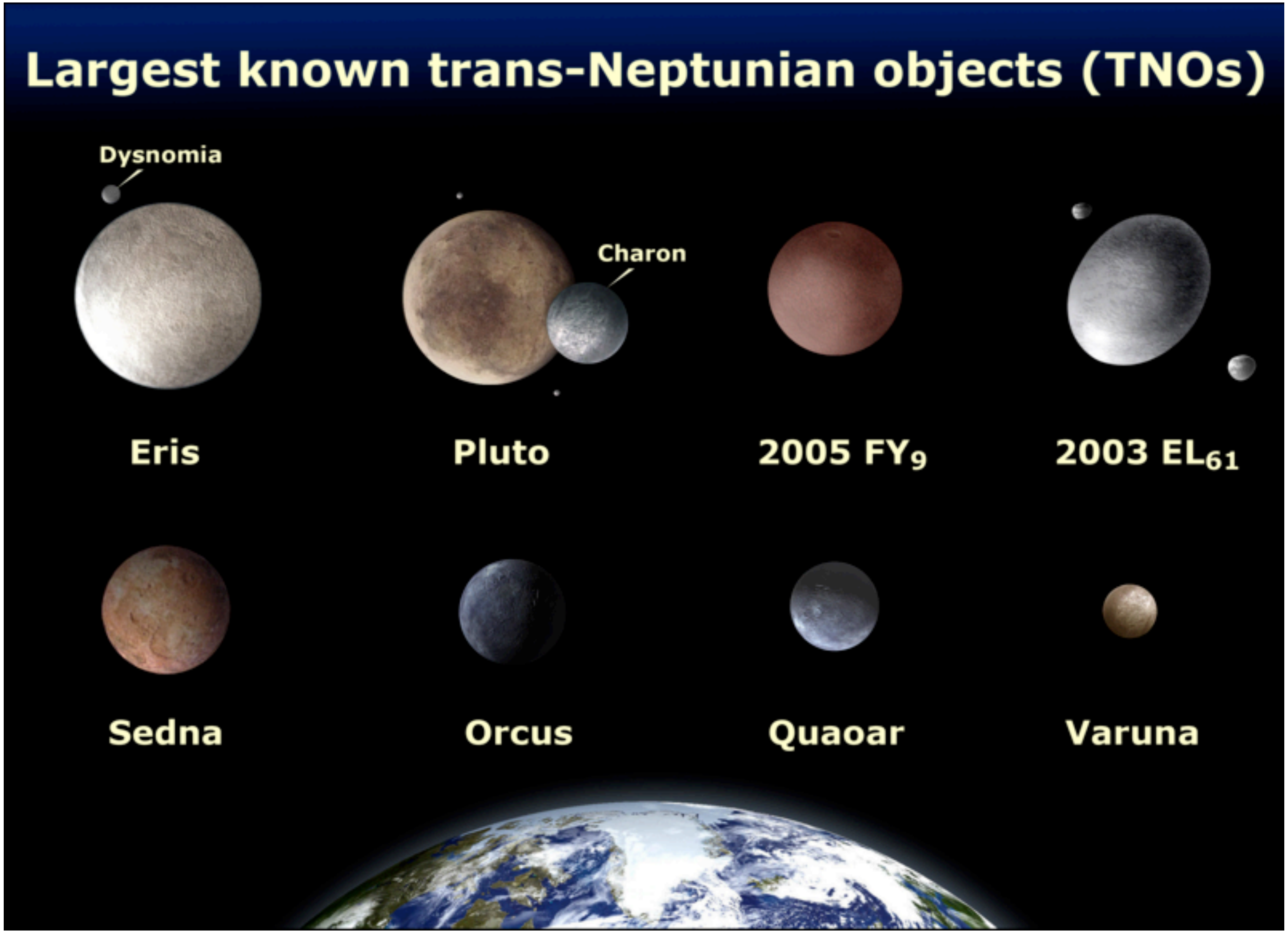


De Bergh et al., 2005

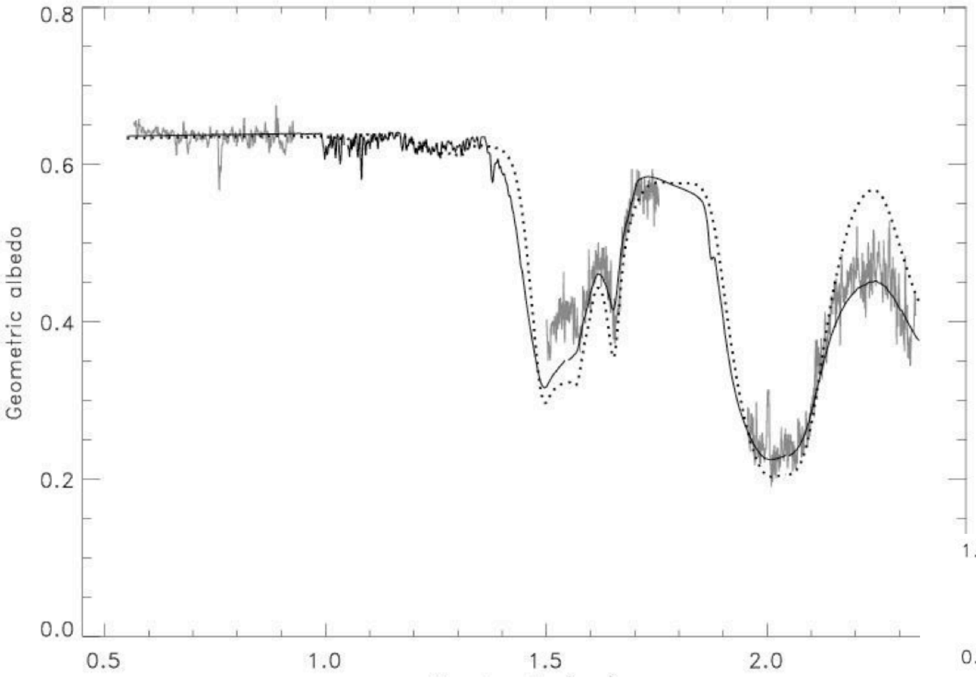


Jewitt and Luu, 2004

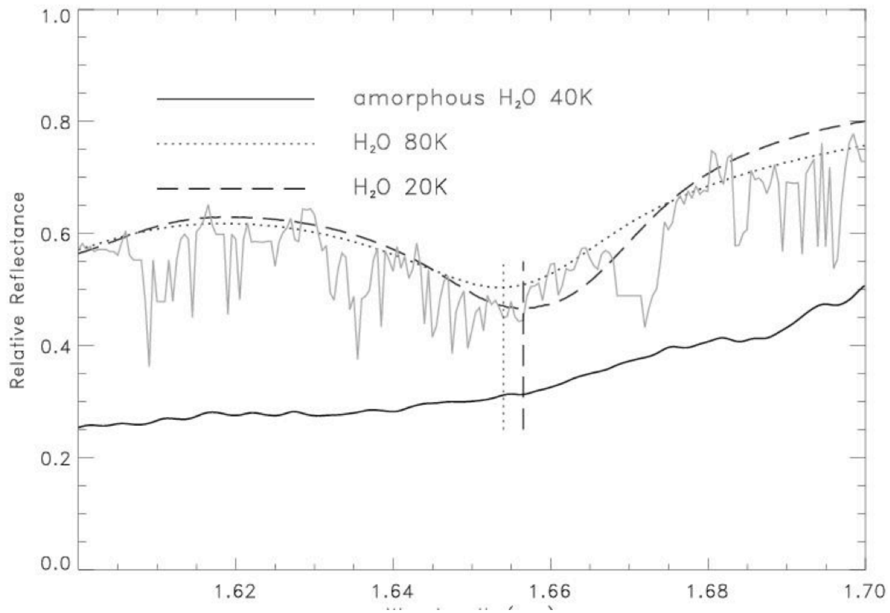
- Spectroscopy (Cont'd)



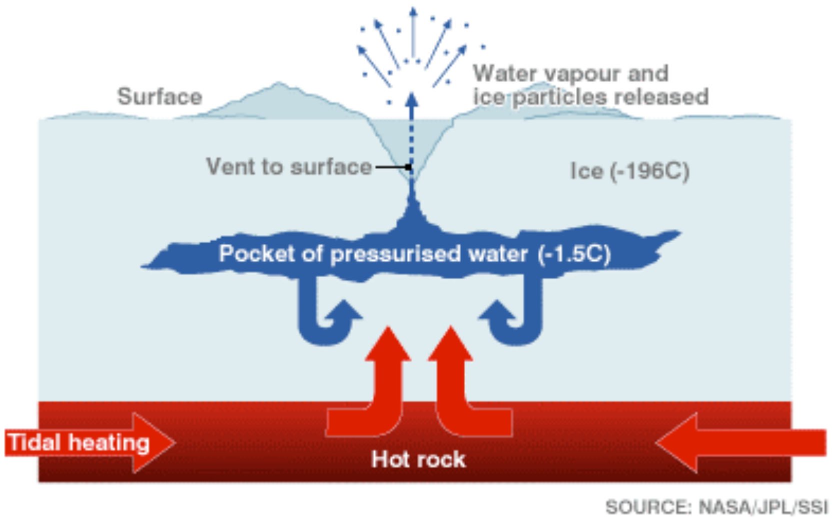
- Spectroscopy (Cont'd)
  - Case of EL61



Merlin et al., 2007



- Spectroscopy (Cont'd)
  - Possible explanations:
    - Resurfacing
      - Impact gardening
      - Cryovolcanysm



Heating source:
- Radiogenic decay
- Tidal forces
- Translucent icy deposit (diffuse light, scattering effect)

Heated material:
- Water ice (with/without ammonia), salts
- CH_4 clathrate hydrate (non polar gas)
- methanol, N_2-CH_4

- Spectroscopy (Cont'd)

  - **Cryovolcanism**

Main considerations:

Ammonia lower melting temperature (273K to 176 K).

Importance of ammonia known prior to Voyager Era, confirmed by Voyager images

Two main types of cryovolcanism:
- low viscosity "lava", thin flow, as seen on Jupiter/Saturn system
- highly viscous lava, thick flows, explosive (cryoclastic) volcanism on Uranus/Neptune

Properties of some cryomagmas:

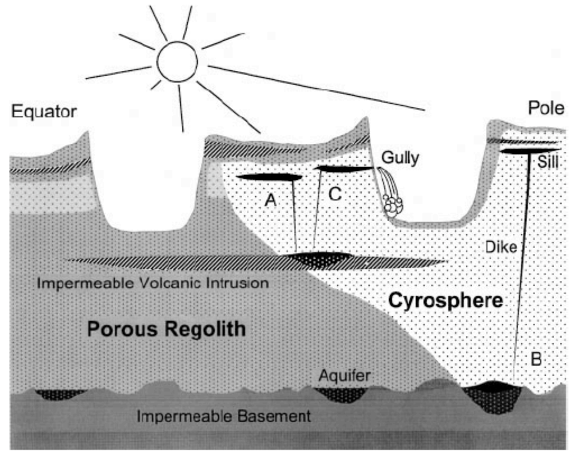
Compounds	Melting point	Viscosity	Volcanism end-result
Water H_2O	273 K	0.02	Plain volcanism galilean sat.
Brine $H_2O/MgSO_4/Na_2SO_4$	268 K	0.07	Idem
Ammonia water	176K	40	Saturnian satellites
Ammonia water + gas (CH_4)	176K	40	Explosive volcanism, Triton
Ammonia water + methanol	150K	40,000	Thick flow Ariel, Miranda, Triton
Nitrogen methane	60K	0.003	sublimable lava, Triton geysers

- Spectroscopy (Cont'd)

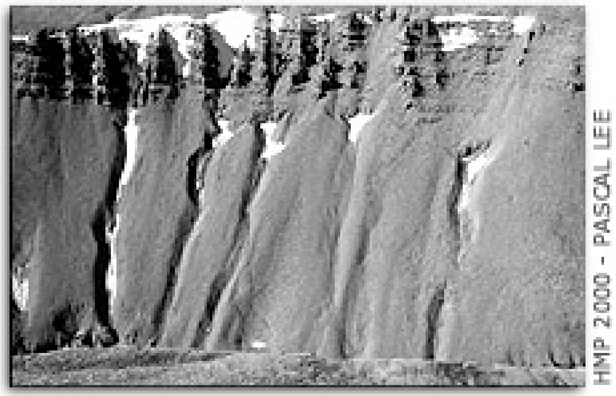
  – **Cryovolcanism**

Mars:

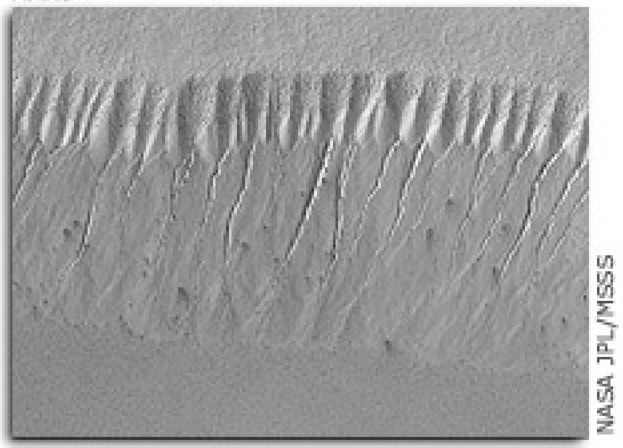
- Too cold and dry to allow surface water
-Still "gullies" have been detected
- Pancake shaped domes
- Climate (seasonal) cycles freeze/thaw water, which lead to pressure changes and ultimately explulsion towards the surface

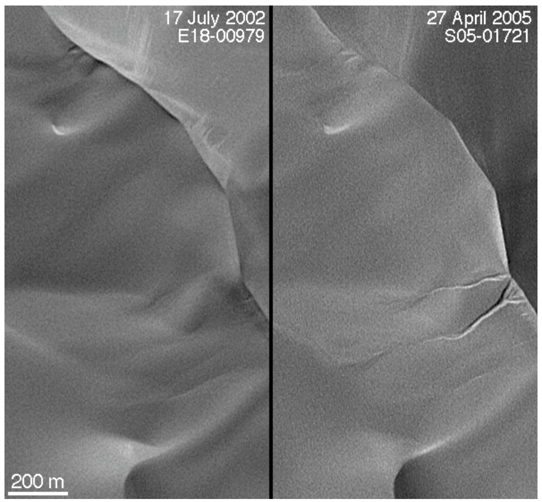


EARTH - DEVON ISLAND



MARS



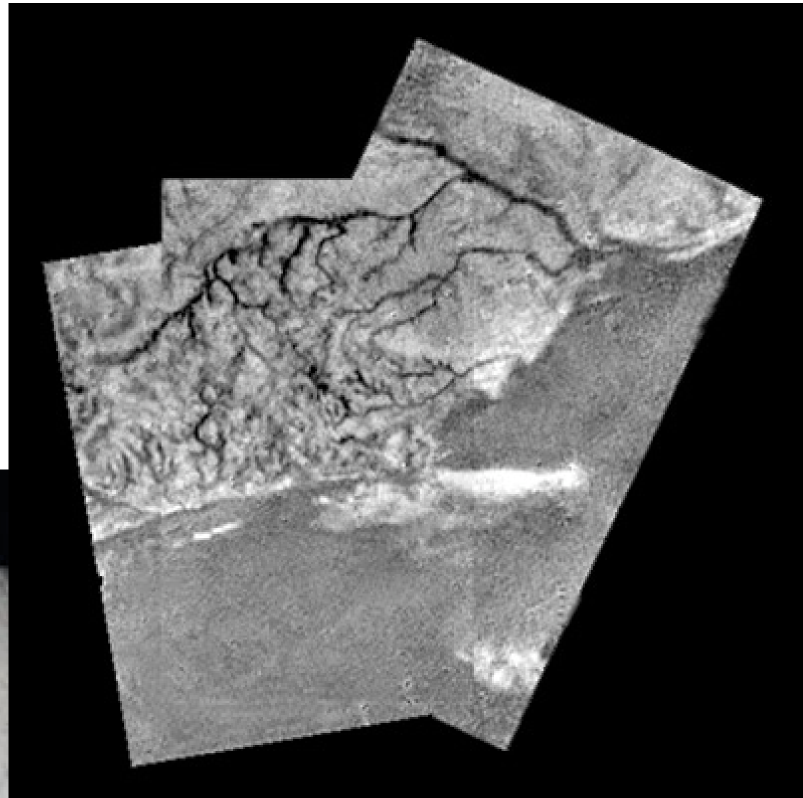


- Spectroscopy (Cont'd)

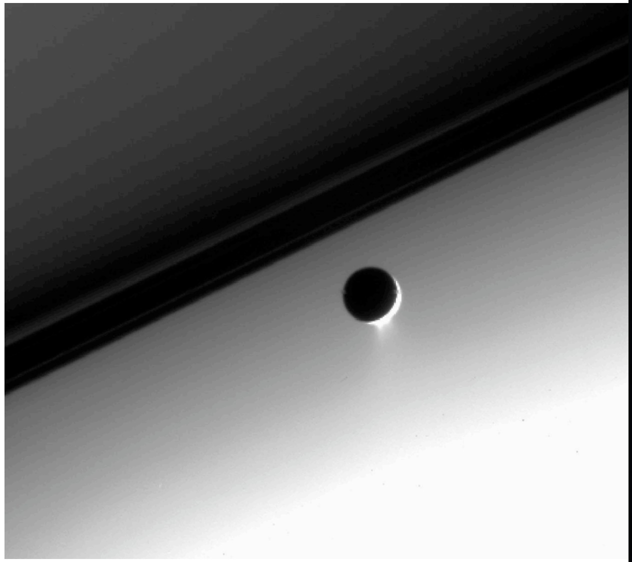
Titan:

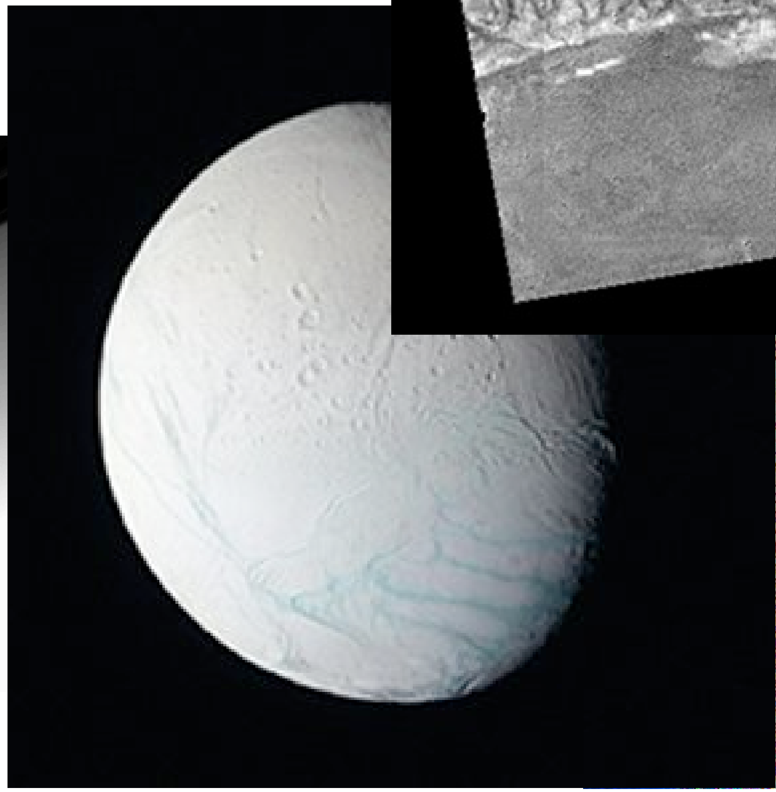
– **Cryovolcanism**

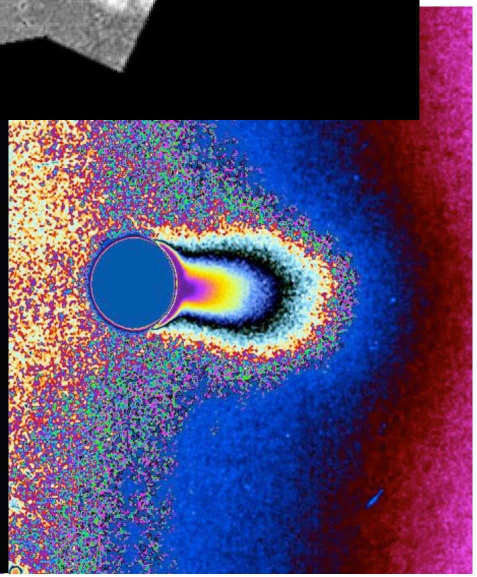
NH3reported by Huygens
Ammonia-water cryovolcanism enriches atmosphere in N_2



Enceladus:

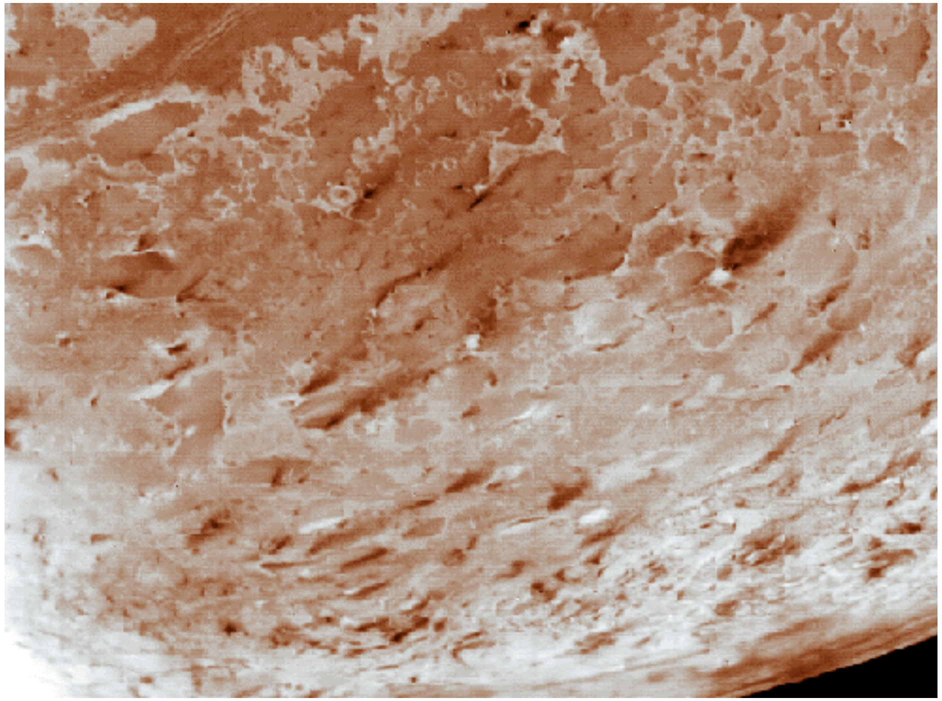






- Spectroscopy (Cont'd)

Triton – Cryovolcanism



Geysers found near sub-solar point: solar heating of translucent material, N_2 ice in this case.

Tidal forces produced by retrograde orbit could heat up inetyrior as well

ΔT ~ 4K would be sufficient to explain phenomena

- # Spectroscopy (Cont'd)
  - ## Possible explanations:
    - Resurfacing
      - Impact gardening
      - Cryovolcanysm
      - Jewitt:

crystalline ice on the surface. Very recent work with an ultra-high vacuum chamber in the Chemistry Laboratory of the University of Hawaii suggests a more likely explanation. We find that the amorphization efficiency is a function of temperature such that amorphization is nearly 100% efficient at $T \sim 10$ K but only $\sim$50% efficient at $T = 50$ K. Presumably, this is because slight

- But remains the problem of the origin of the heat source …
  - » Convertion of gravitational energy at time of formation
  - » Trapped radio-nuclides
  - » Micrometeorites bombardments
- Amorphous ices mainly in comets?
  - » For the Centaurs: crystallization of amorphous ice responsible for activity?