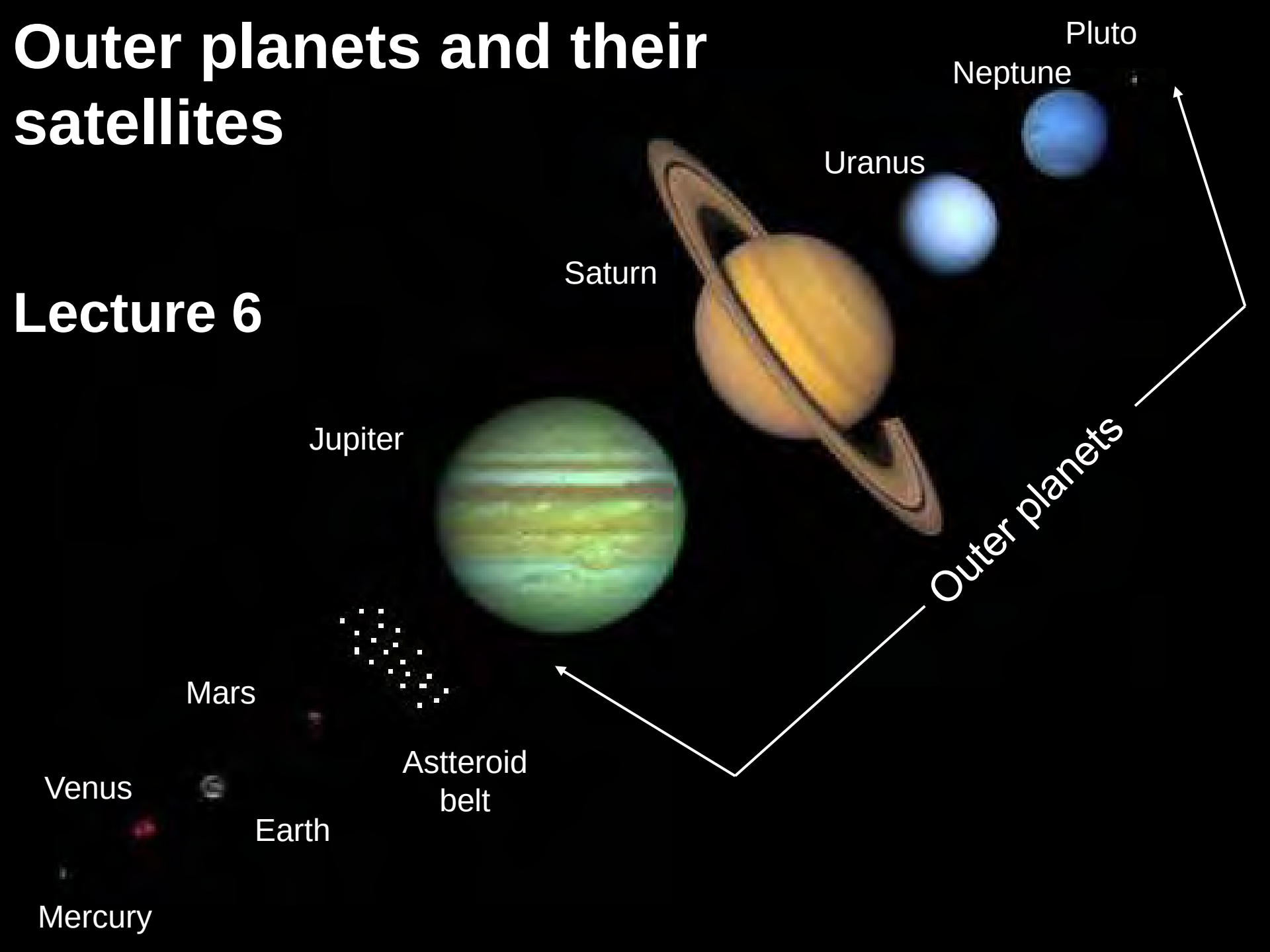
Outer planets and their satellites

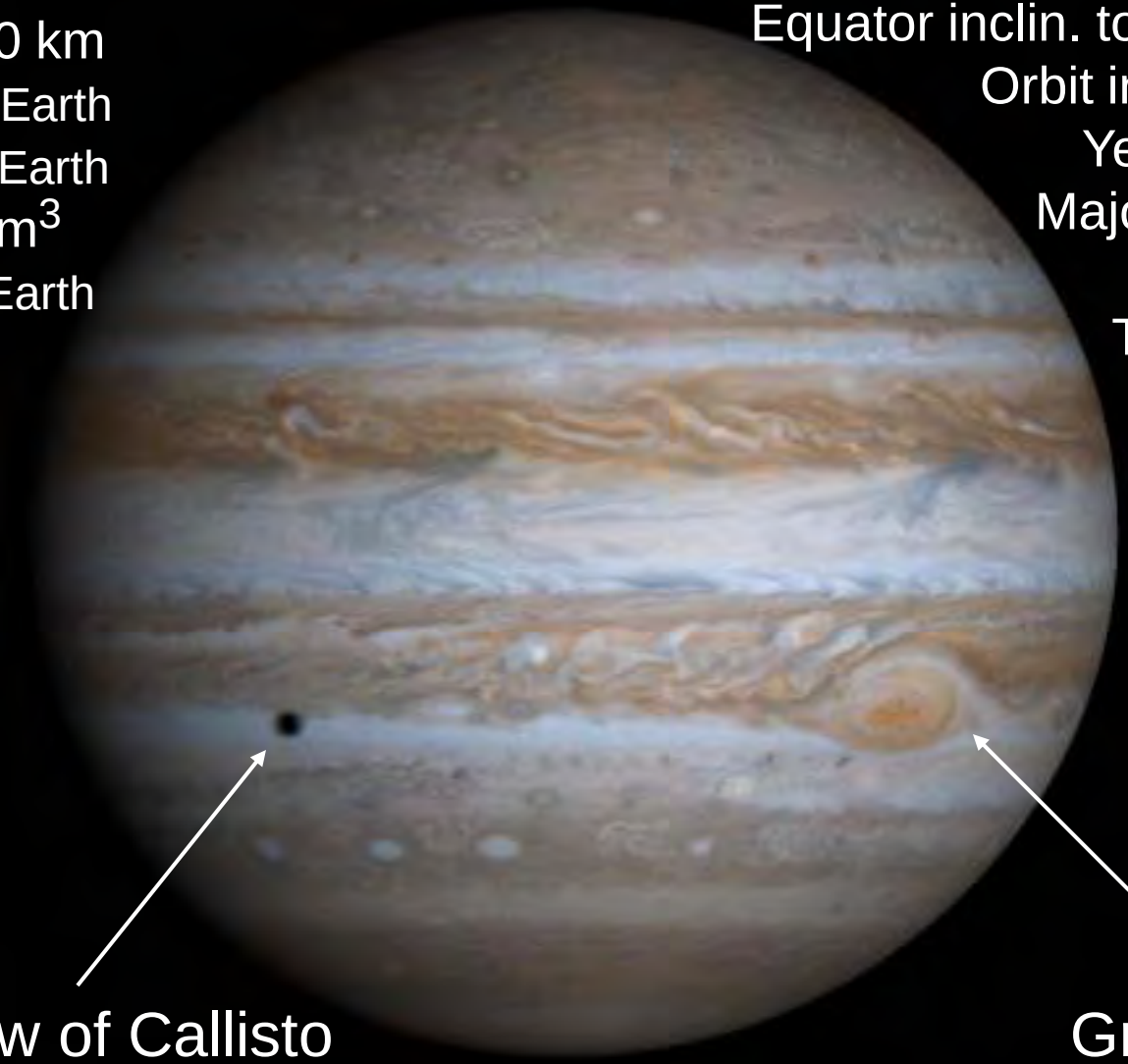
Lecture 6



Jupiter – 5th from the Sun planet, ~60 known satellites

Distance from Sun 5.2 a.u.
D = 143,000 km
11.2 D Earth
M = 318 M Earth
ρ= 1.33 g/cm^3
g = 2.36 g Earth

Rotation period 0.41 Earth' days
Equator inclin. to the orbit plane 3.1°
Orbit inclin to ecliptics 1.3°
Year 11.9 Earth. years
Major atm. components
H_2, He
Temp. at 1 bar level:
165 K



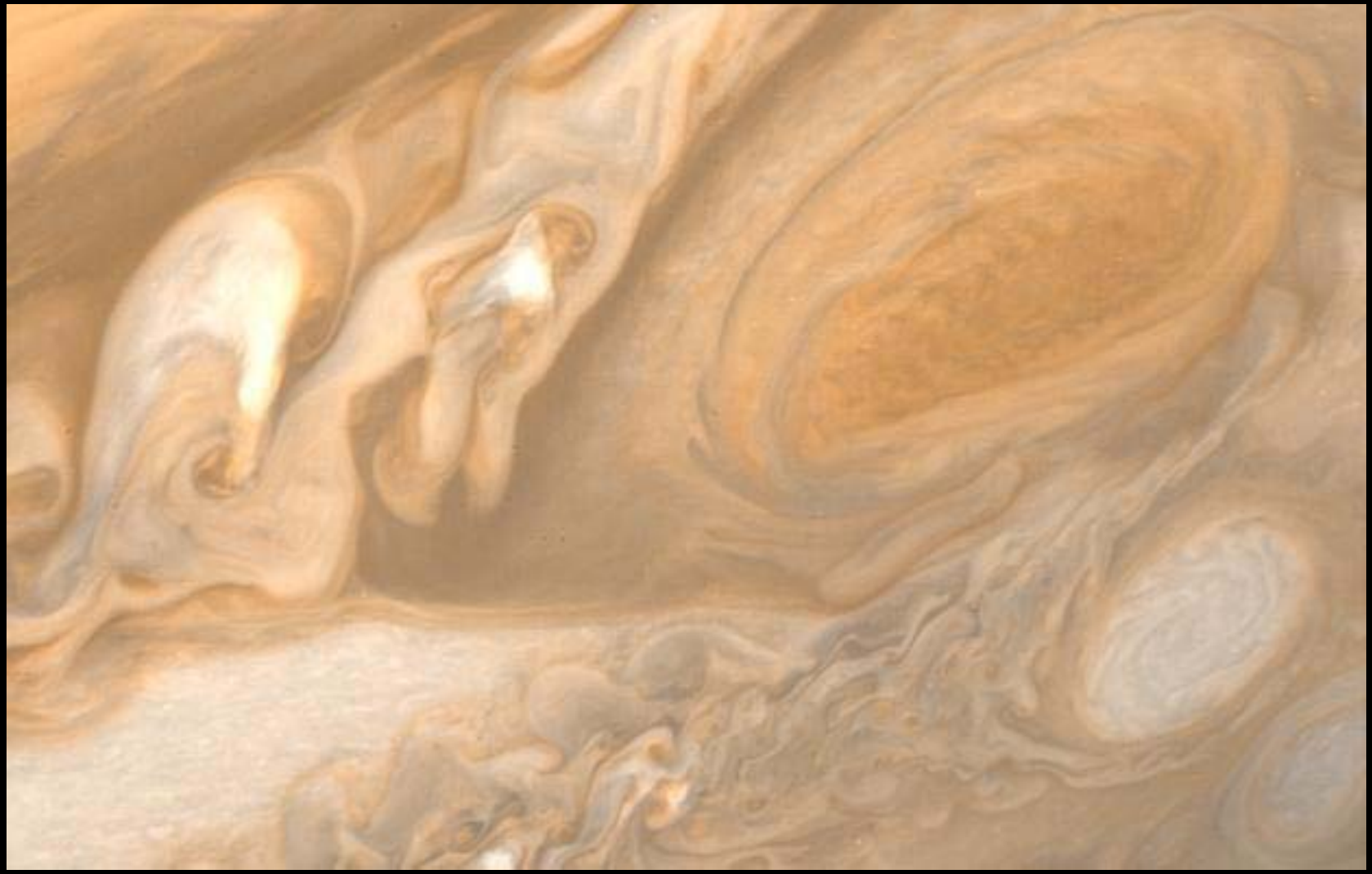
Shadow of Callisto

Great Red Spot

Color is close to real one

Image of Cassini

Great Red Spot (40,000 km)



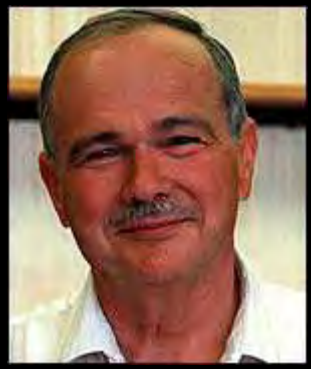
Atmosphere: H_2 (81%), He(18%), Σ NH_3, CH_4, PH_3, , C_2H_2 = 1% .
Clouds: Snow flakes of ammonia, ammonia hydrosulfide, H_2O.
Color of clouds is due to admixture of H_2S, organics, metallic Na.

Fragments of Shoemaker-Levy-9 comet

Discovered on March 24 1993 by E and K Shoemaker and D. Levy already as a chain of separate bodies. Based on calculations , on July 1992, the comet flew by at 15,000 km distance from Jupiter and was disrupted by tidal forces.

Hubble telescope image

Collision of the comet
Fragments with Jupiter
July 1994



Eugene Shoemaker

Galilean satellites of Jupiter

	Io	Europa	Ganymede	Callisto
Dist.	421,000	671,000	1,070,000	1,883,000 km
from	5.9	9.4	15	26 R Jupiter

Jupiter Distance of the Moon from Earth 384,000 км = 60 R Earth

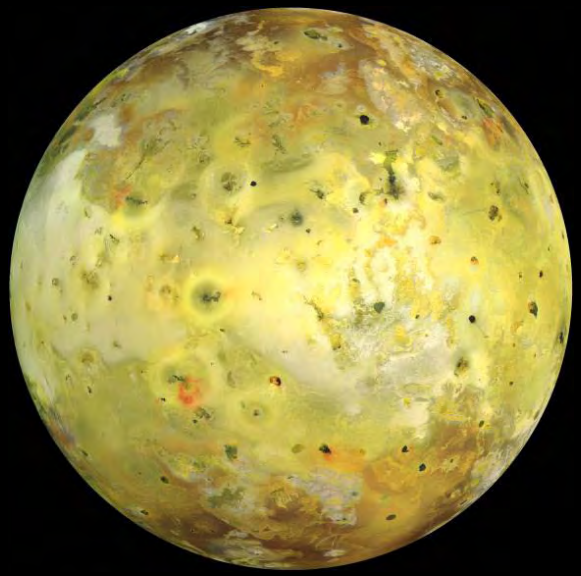


Image taken by Galileo

Io is closest to Jupiter
Galilean satellite of the planet

D = 1.05 D Moon

ρ= 1.05 ρ Moon

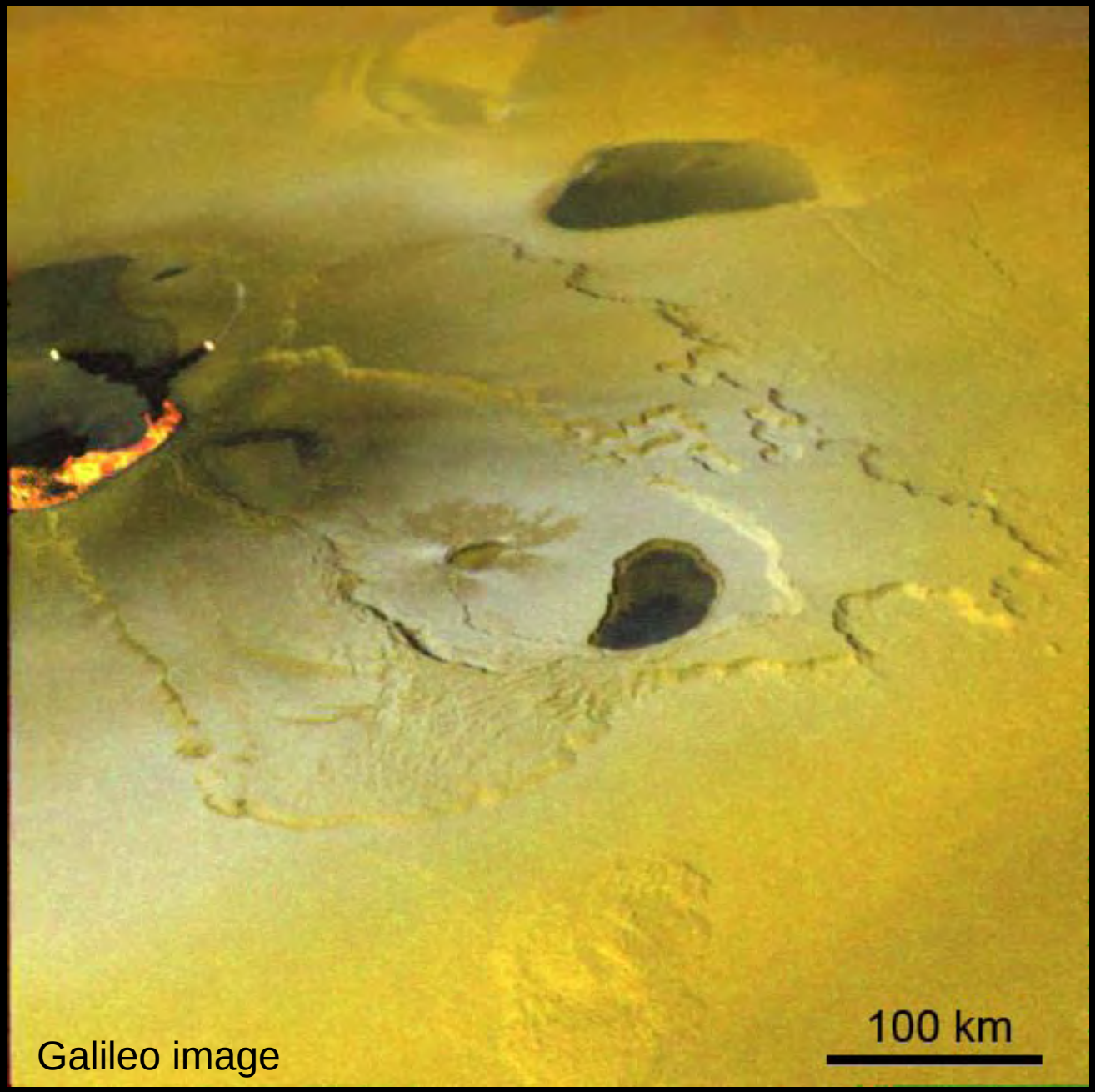
Distance center of Jupiter ~6 R Jup.

Tidal heating
Plumes of volcanic eruptions
Orange color – sulfur
But lavas are basaltic
No impact craters
=> very young surface

The eruption plume height is 160 km

Voyager 1 image

Chain of volcanic calderas Twashtar



Galileo image

Europa - second from Jupiter
Galilean satellite of the planet

D = 1.05 D Moon

ρ= 1.05 ρ Moon

Distance from the center of Jupiter ~9 R Jup.

Tidal heating

Water ice on the surface

Galileo image

Most part of the body are silicates

Topmost 100 km are ice / water

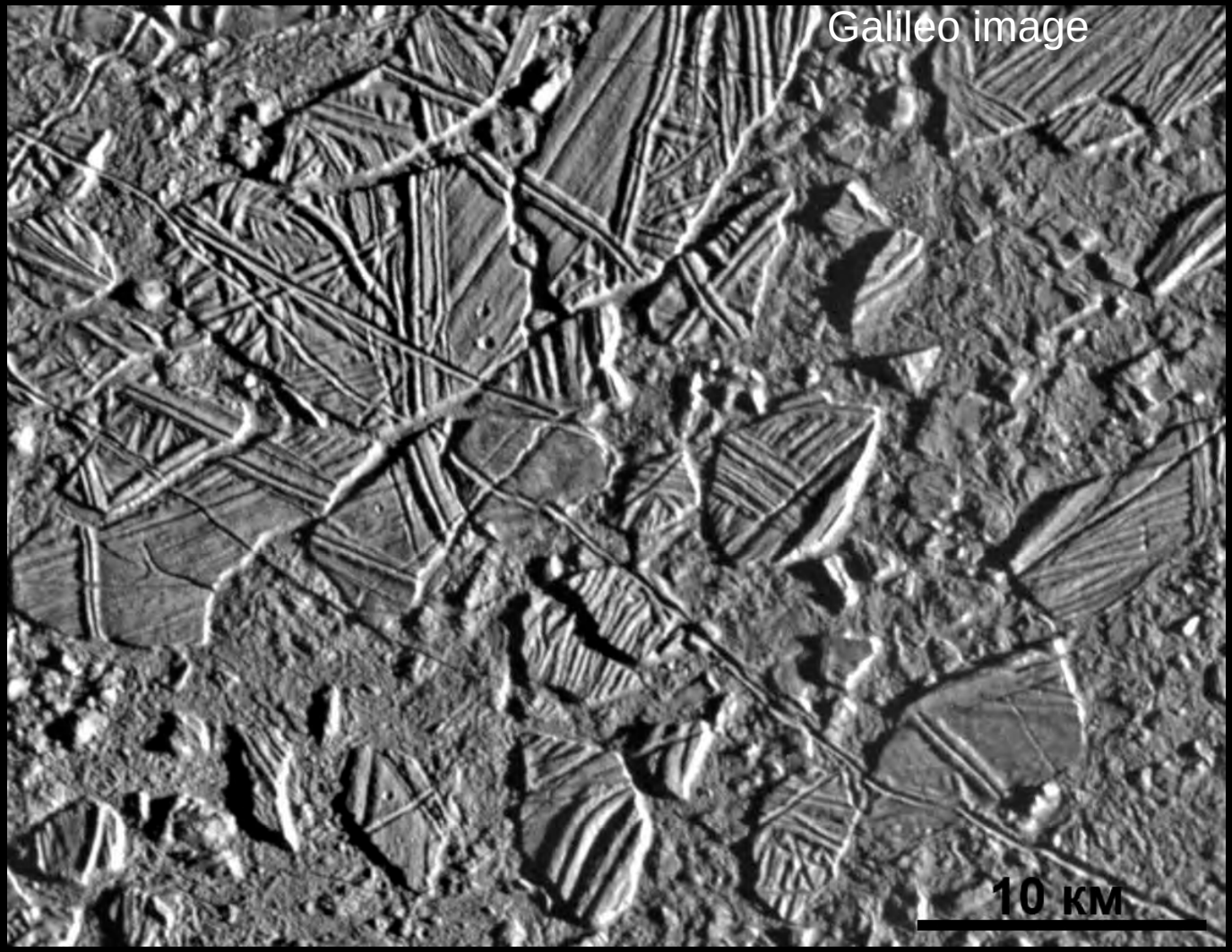
Impact craters are rare

=> young surface

Europa – faults, domes and reddish spots and bands

Multiphase tectonics / water-ice (cryo) volcanism

Europa – “rafted” terrain



Rafted terrain resembles pack ices on Earth

Ocean beneath relatively thin (<10-20 km) layer of ice:

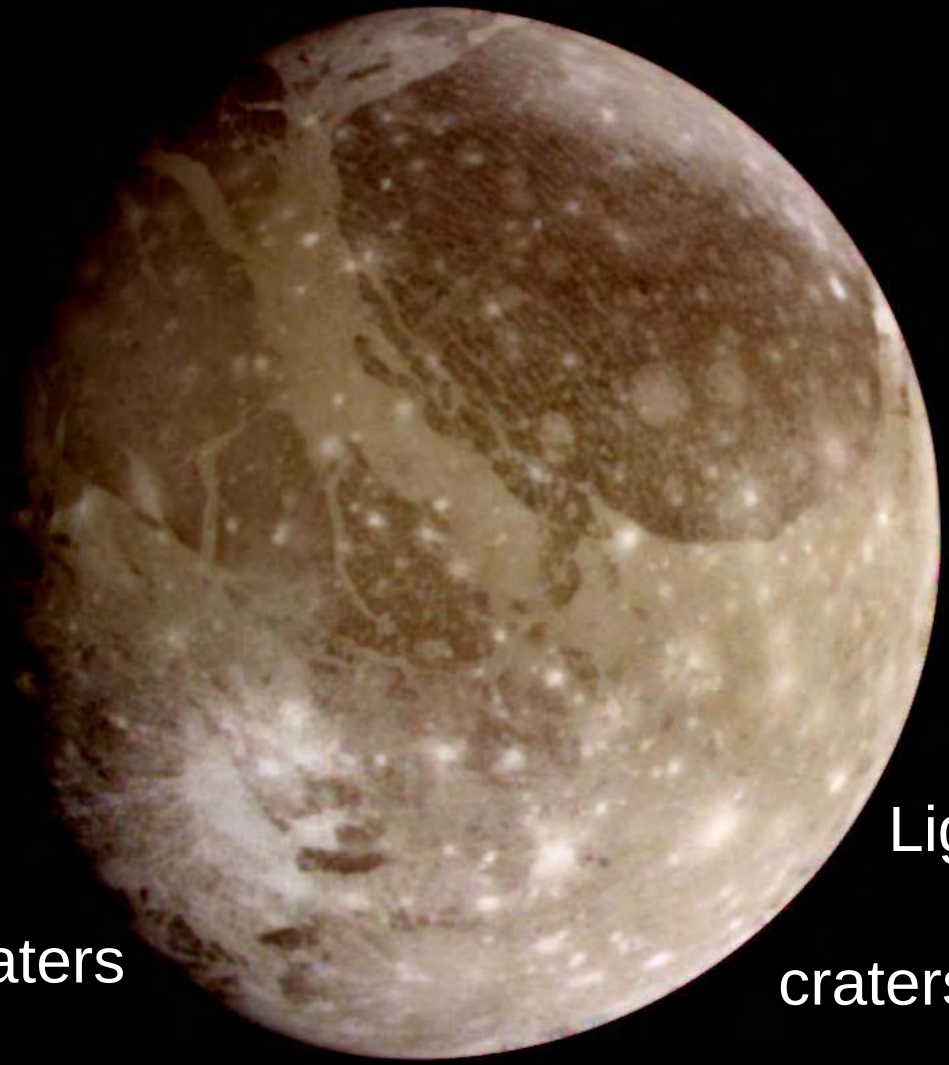
Life?

Ganymede - third from Jupiter
Galilean satellite of the planet

D = 1.5 D Moon

ρ= 0.6 ρ Moon

Distance from the center of Jupiter ~15 R Jup.

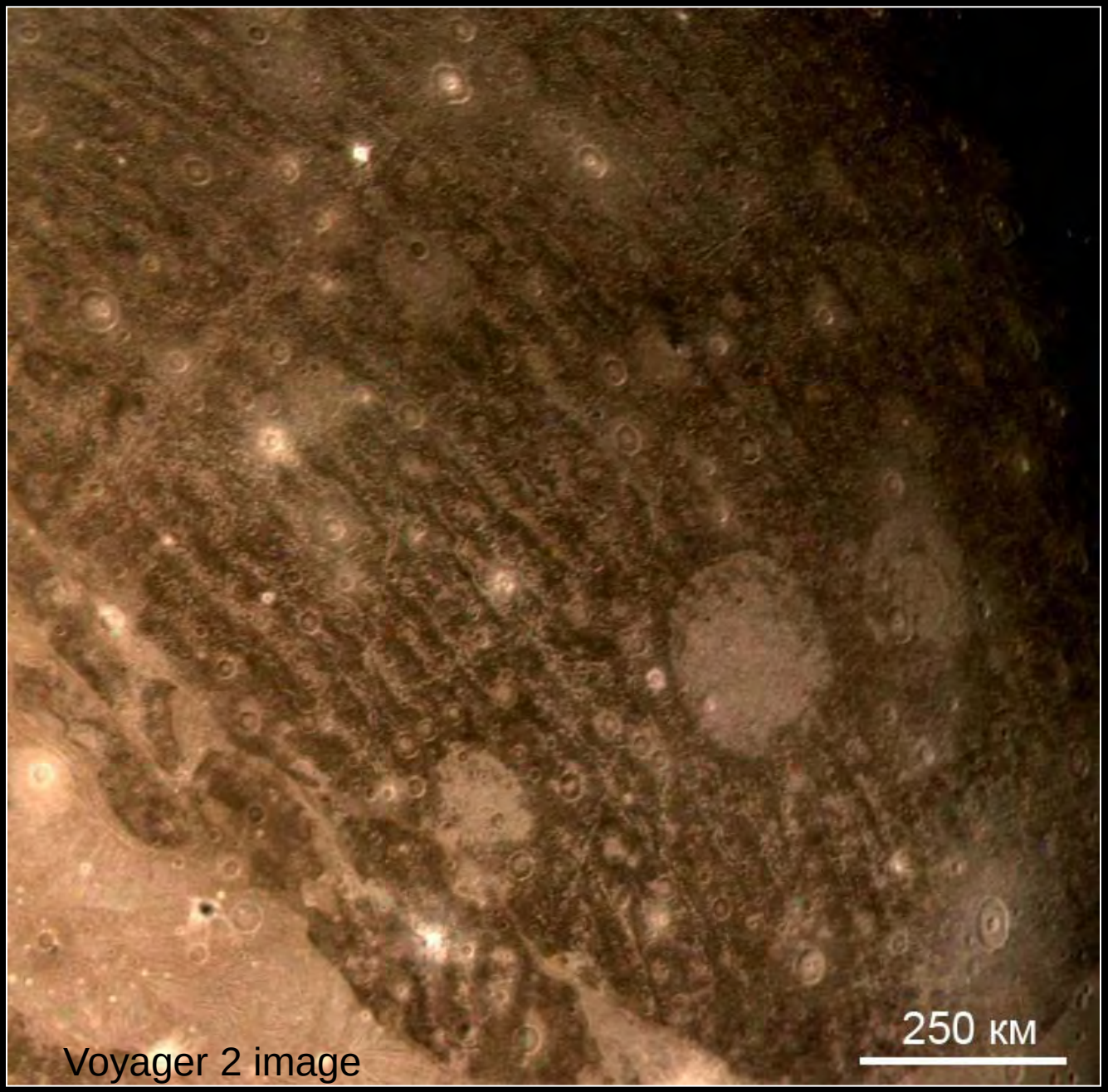


Galileo image

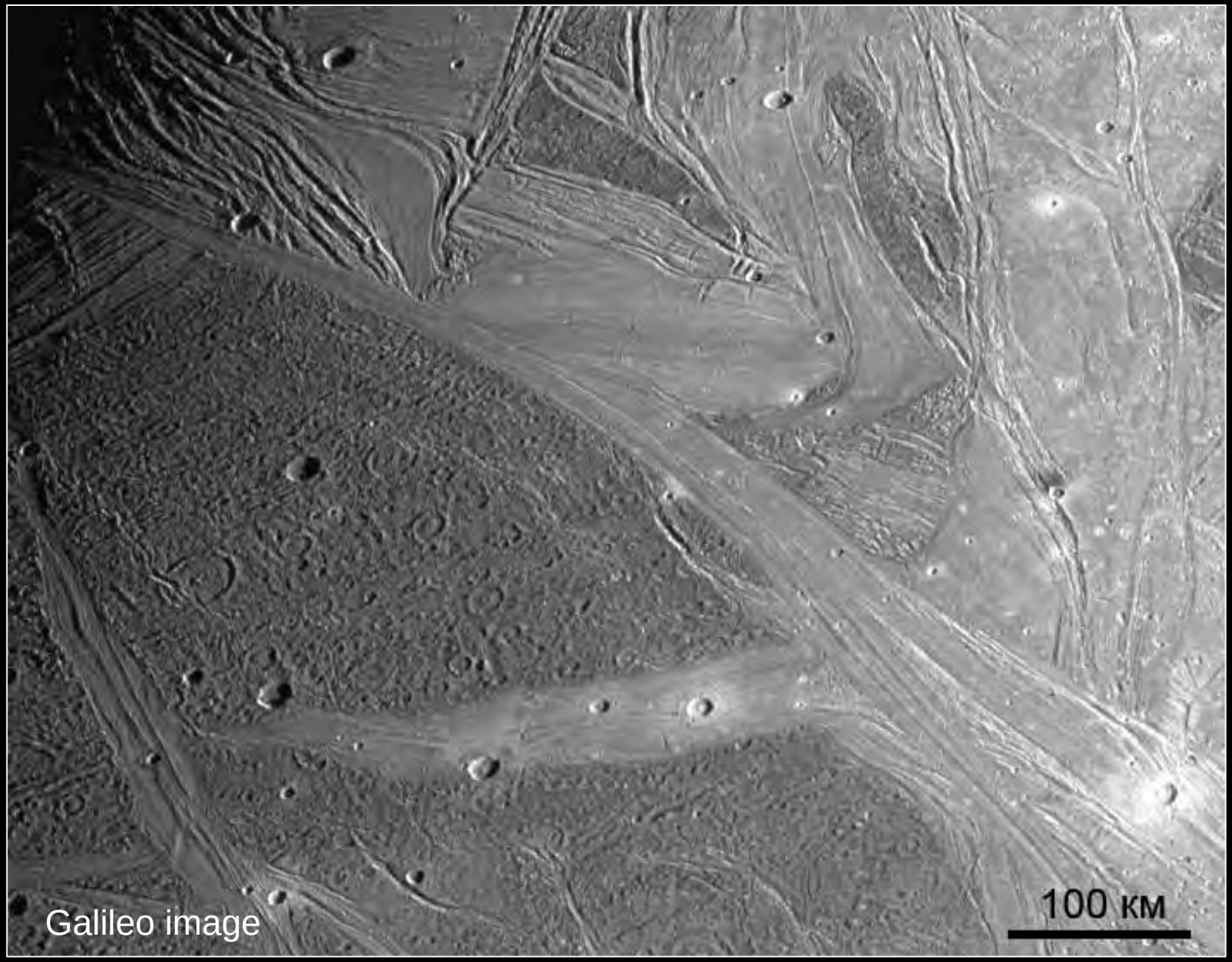
Dark regiones have many craters => ancient

Light regiones have small amount of craters => young faults, cryovolcanism?

Craters and fossae on Ganymede



Fossae on Ganymede

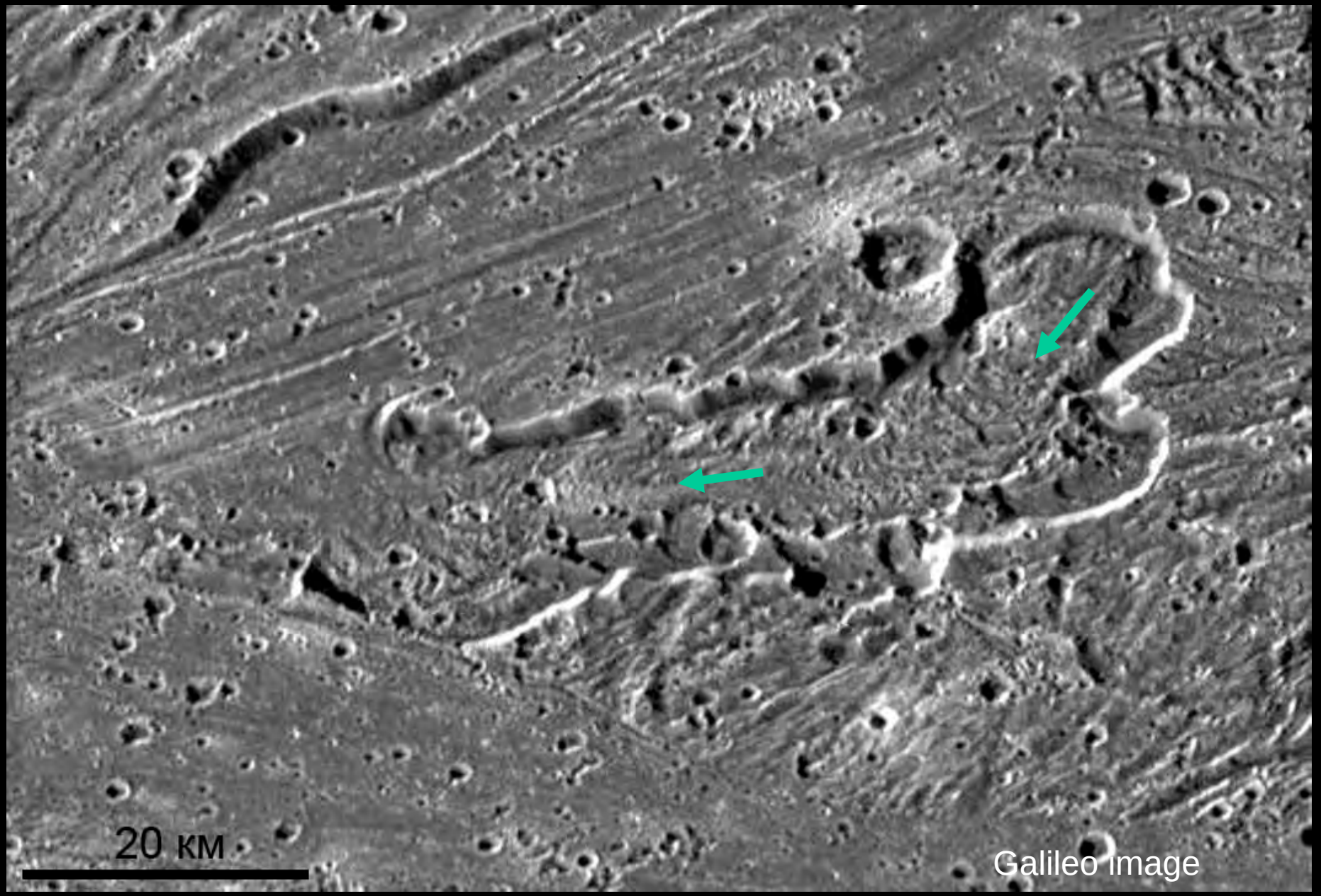


Chain Enki on Ganymede – trace of cometary impact

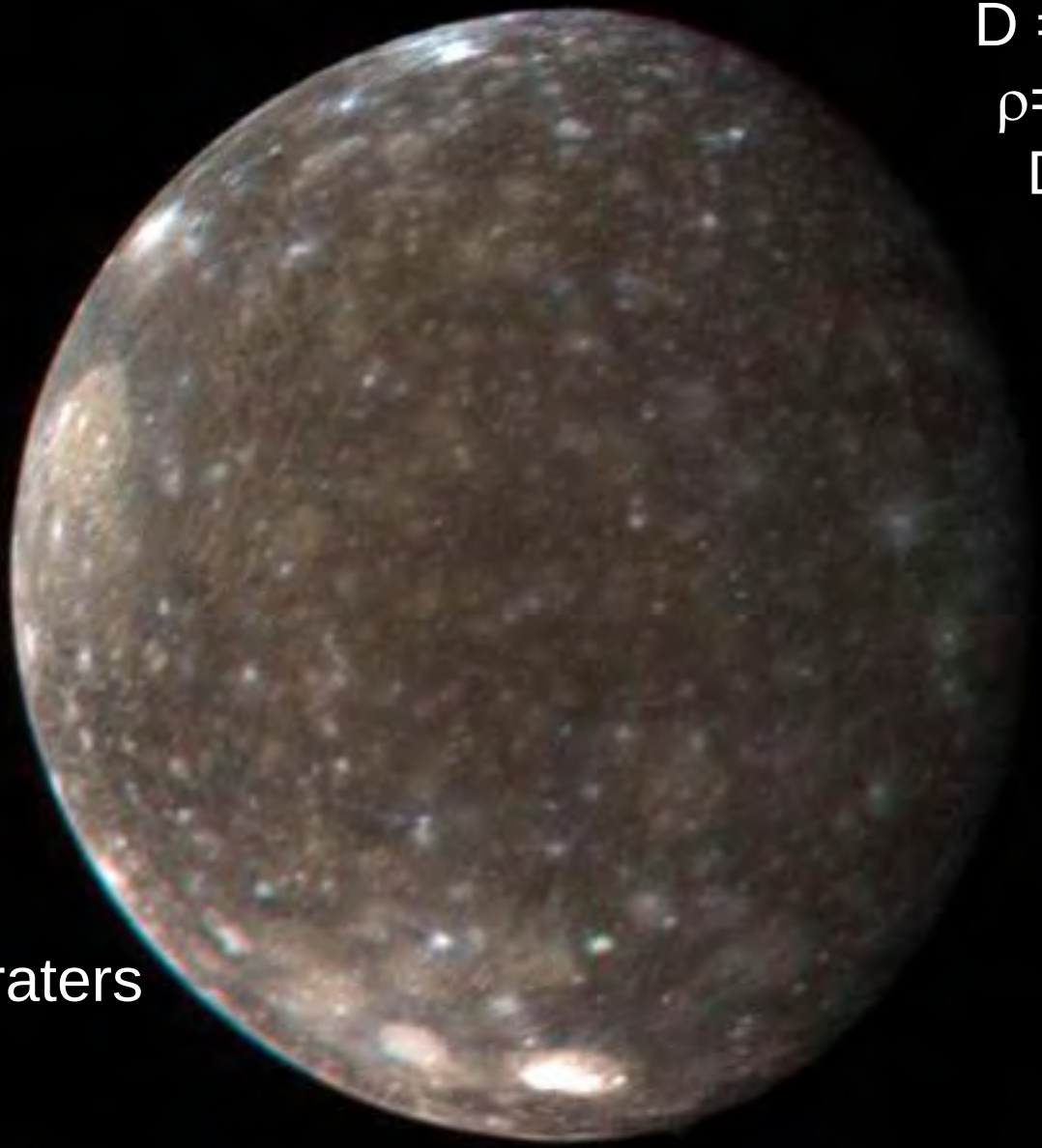
Comet Shoemaker-Levy (1993)

Hubble Space Telescope May 1994

“Caldera” on Ganymede – water-ice volcanism?



Callisto - fourth from Jupiter
Galilean satellite of the planet



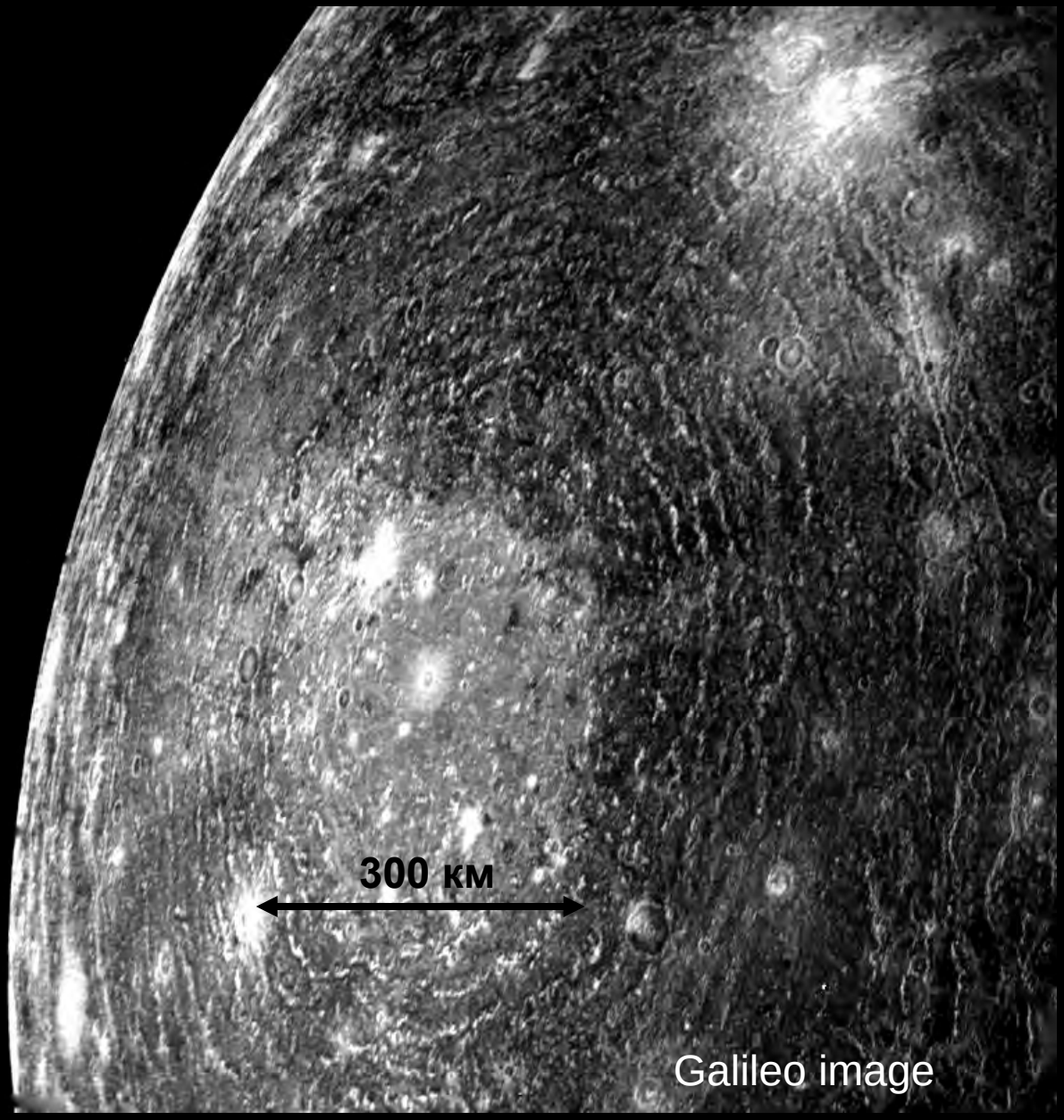
D = 1.4 D Moon

ρ= 0.55 ρ Moon

Distance from center of Jupiter ~26 R Jup.

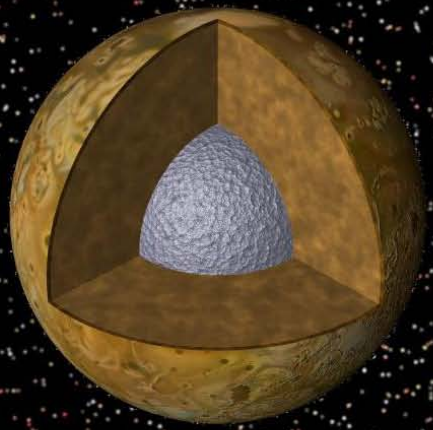
Dark surface
- numerous craters
=> ancient

Impact basin on Callisto

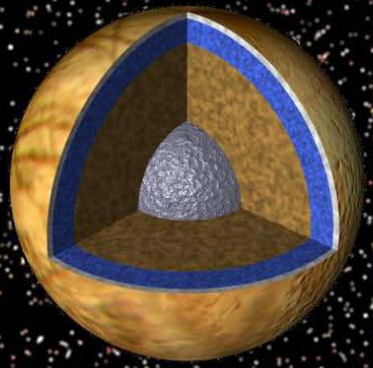


One of the scarps outcircling impact basin Valhalla

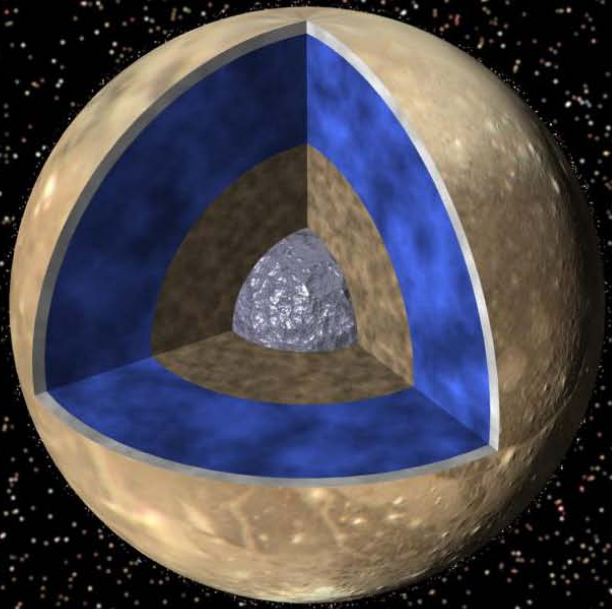
Models of internal structure of Galilean satellites



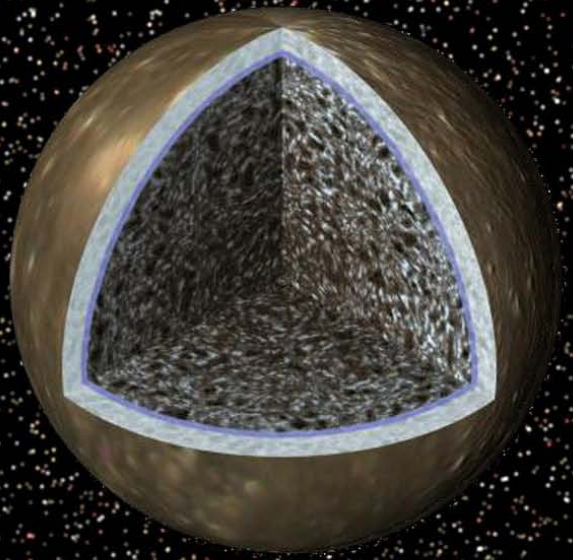
Io



Europa

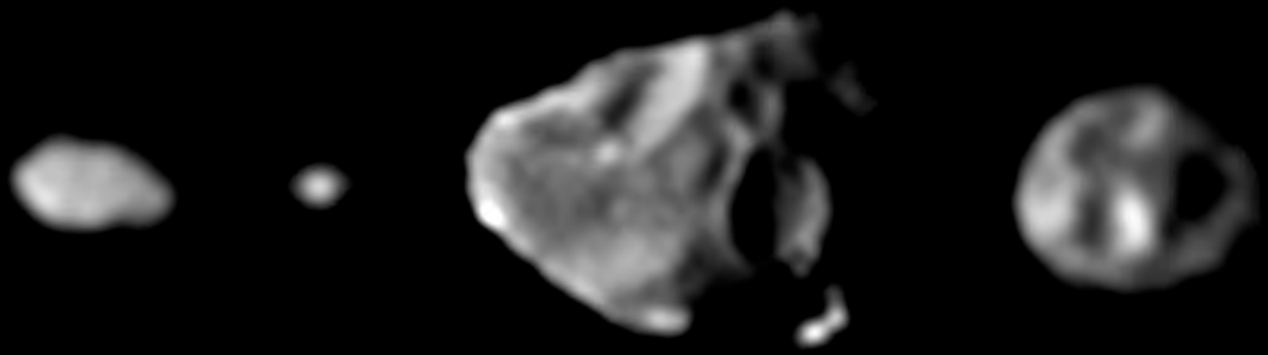


Ganimede

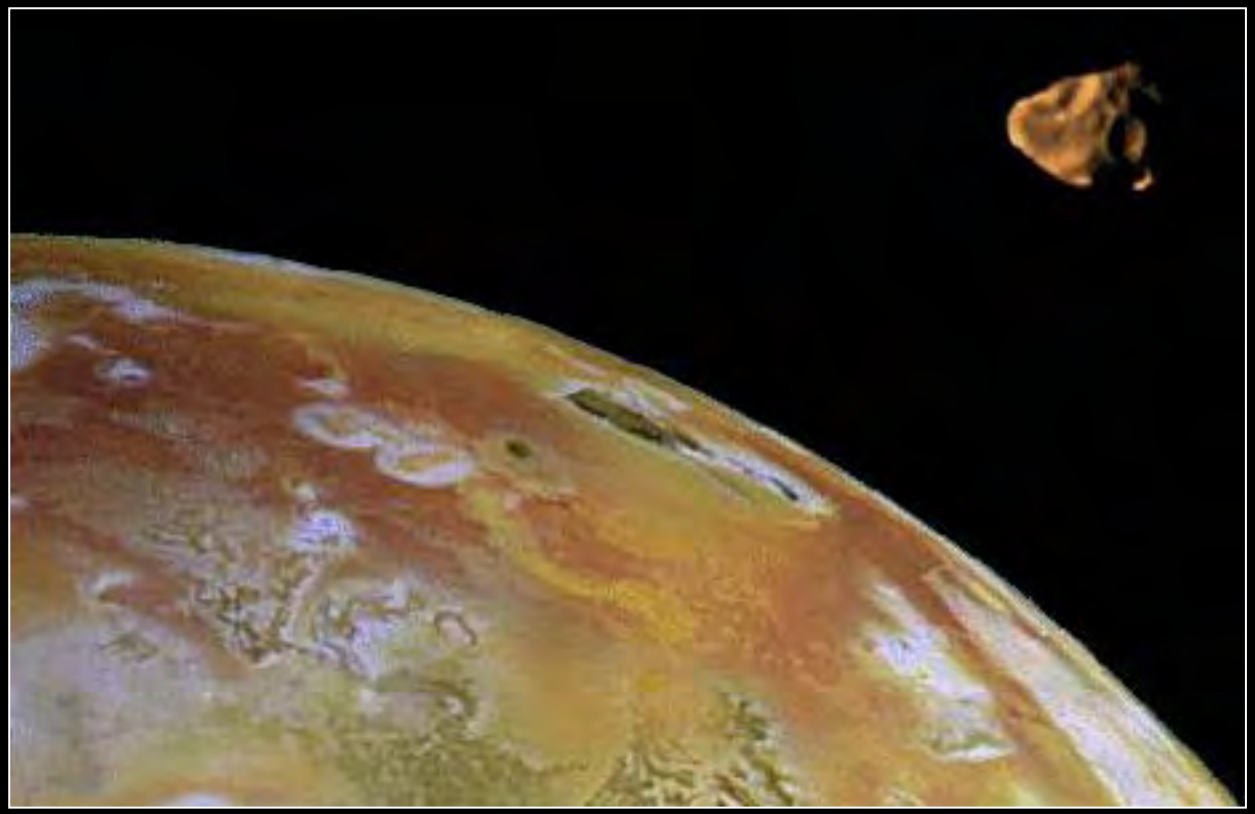


Callisto

Small satellites of Jupiter



Methis, 60 km Adrastea, 20 km Amalthea, 247 km Thebe, 116 км



Jupiter ring

View from the shadow

Galileo image

Jupiter system– miniature Solar system : Now ~ 60 satellites are known. The largest four were discovered by Galileo Galilei in 1610 (Galilean satellites).

Jupiter surface is banded: dark bands and light zones => strong winds from east to west, systems of storms. The largest one – Great Red Spot (D = 40,000 km, observed for more than 100 years).

Composition of atmosphere H_2 81 mass %, He 18%, ∑ NH_3, CH_4, PH_3, C_2H_6, C_2H_2 = 1%. H/He ratio like on the Sun.
Clouds from snow flakes of ammonia, ammonia hydrosulfide, H_2O.

IR irradiation from Jupiter is x 2 higher than energy, received from the Sun (difference – energy of gravitational compression, not thermonuclear)

In the center of Jupiter pressure is 30 millions bar. There is dense hot liquid. Its rotation => strong magnetic field. Possibly Jupiter has iron-silicate core (twice larger than Earth).

Io

D = 1.05 D Moon, ρ = 1.05 ρ Moon

It was expected that Io is now endogenically passive like the Moon.

Voyager 1 and 2 images => ongoing volcanism on Io.

Orange surface color – sulfur lavas, plumes of SO_2, frost SO_2.

No impact craters => very young surface.

Tidal heating due to gravity interaction with Jupiter and Europa.

Galileo results:

Volcanic activity continues. Some volcanic centers moved.

T eruption is too high for sulfur lavas => basalts, even komatiites

Radio-tracking => specifics of gravity field => Io has iron core.

Europa

D = 0.9 D Moon, ρ = 0.9 ρ Moon
Water ice on the surface.
Relatively dark lineaments (tectonics).

Almost no craters => very young surface.
Tidal heating due to gravity interaction with Jupiter and Io.
Most mass of Europa – silicates (liquid water beneath ice?).

Galileo results;
Multiphase tectonics / Icy volcanism
Rafted terrain resembled pack ices in polar seas of Earth.
Ocean beneath relatively thin (kilometers – 10-20 km) ice.

Life?

Europa orbiter mission?

Ganymede

D = 1.5 D Moon, ρ = 0.6 ρ Moon
Dark regiones - numerous craters => ancient surface.
Light regiones - fossae, less numerous craters
=> water /ice volcanism?, tectonic deformations,
the younger surface.

Galileo results:
Intrinsic magnetic field => liquid core
Light regiones: tectonics (tension and shear), no volcanism?
Dark regiones: Fossae => also tectonics, deficit of small craters => resurfacing / formation of dark mantle.
Sublimation / condensation controlled by solar radiation .

Callisto

D = 1.4 D Moon, ρ = 0.55 ρ Moon
Surface resembling dark regiones of Ganymede:
numerous craters => ancient.
Dark smooth plains (rare) => could be volcanic.
Impact basins Valhalla and Asgard.

Galileo results:
Magnetic measurements => Interaction with Jupiter's magnetosphere => salted water in interiors (subsurface ocean?) Life?
Deficit of small craters => resurfacing / sublimation of ice / formation of dark mantle.
Reliable evidence of volcanism is not found.

Saturn – 6th from the Sun planet, ~30 satellites

Dist. from the Sun 9.5 a.u.
D = 120,000 km
9.5 D Earth
M = 95 M Earth
ρ= 0.7 g/см^3
g = 0.92 g Earth

Rotation period 0.44 Earth's. day
Inclination of equator to the orbit plane 26.7^o
Inclination of orbit to ecliplics 2.5^o
Year 11.9 Earth years
Major components of atmosphere:
H_2, He
Temp. at 1 bar level:
134 K

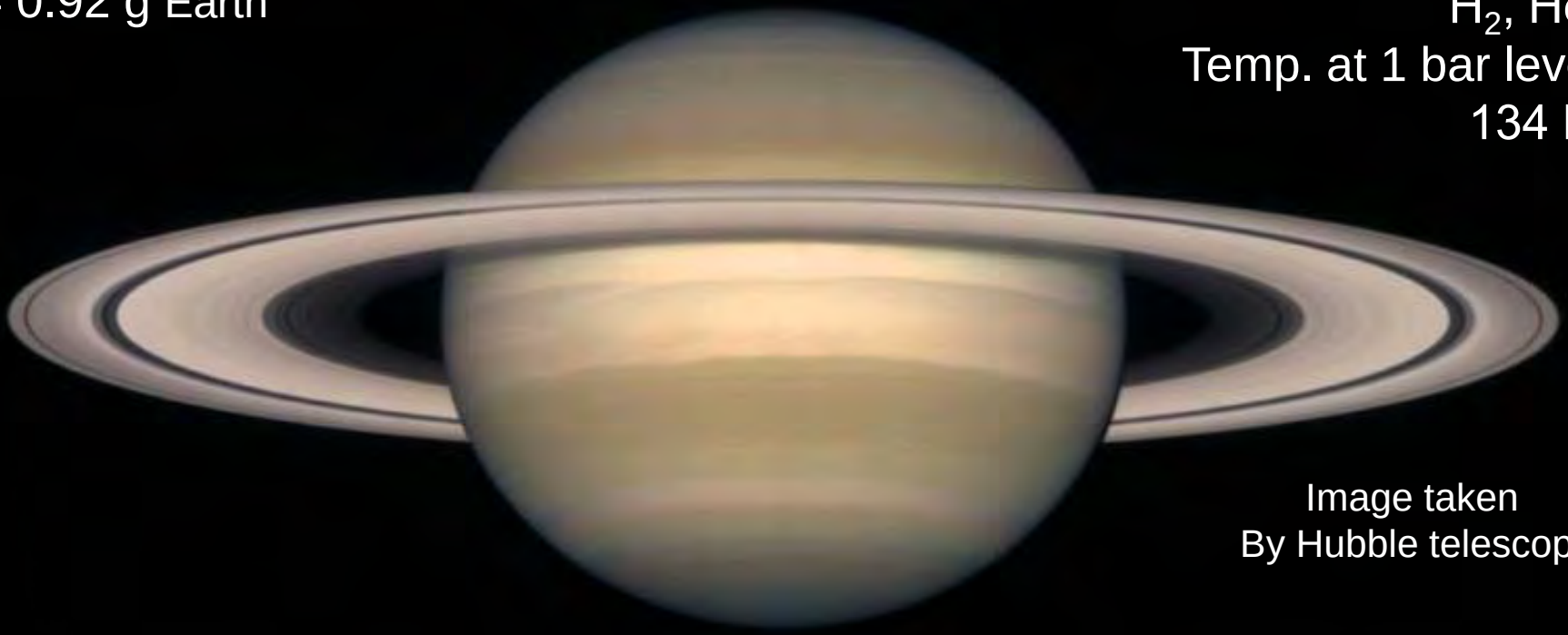


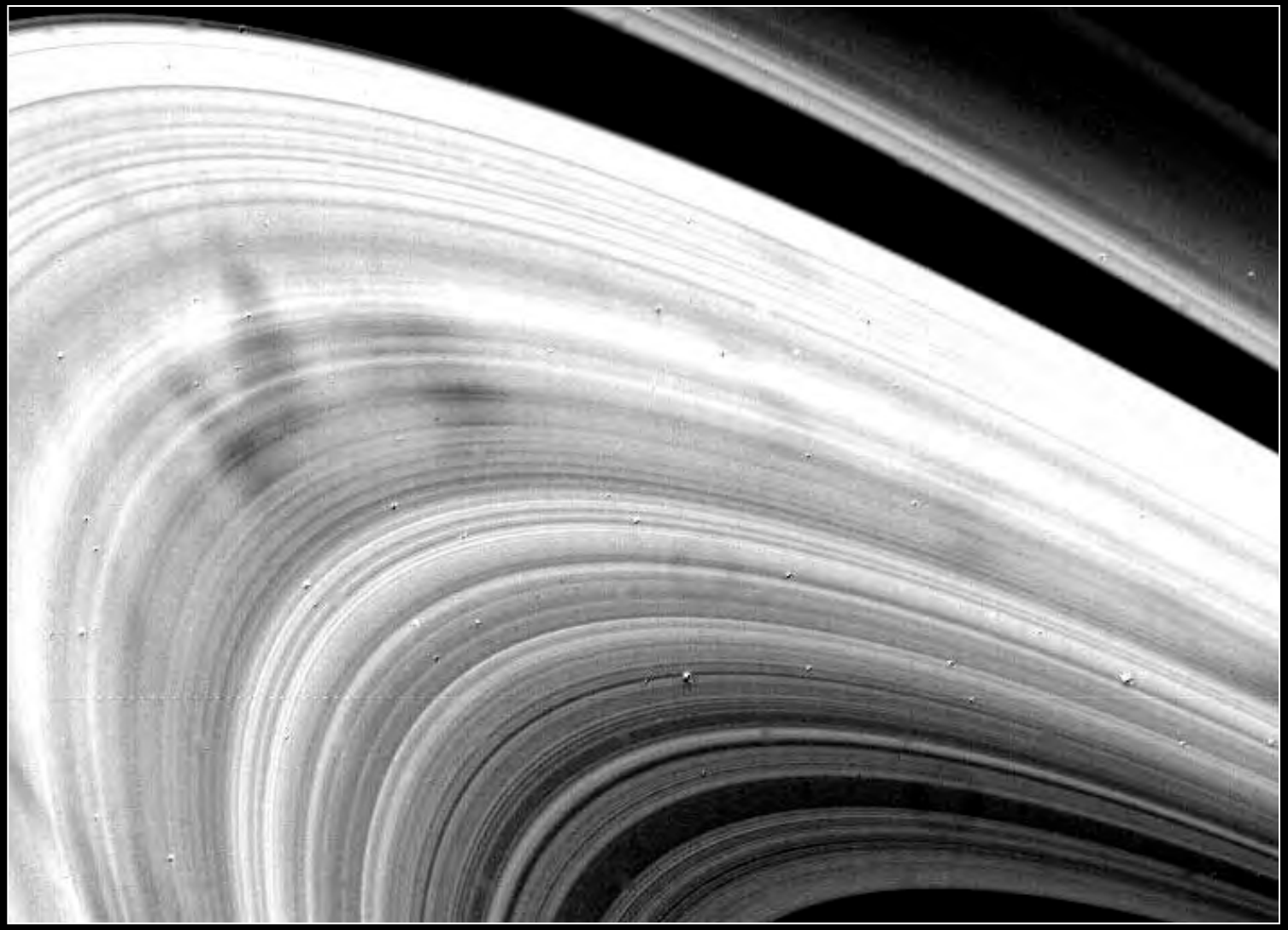
Image taken
By Hubble telescope

Diameter of the ring system 270,000 km. Particles of ice D = cm – tens of m.
Each of them orbits around the planet "by itself", like cars on highway.
Systems of rings do not last long.

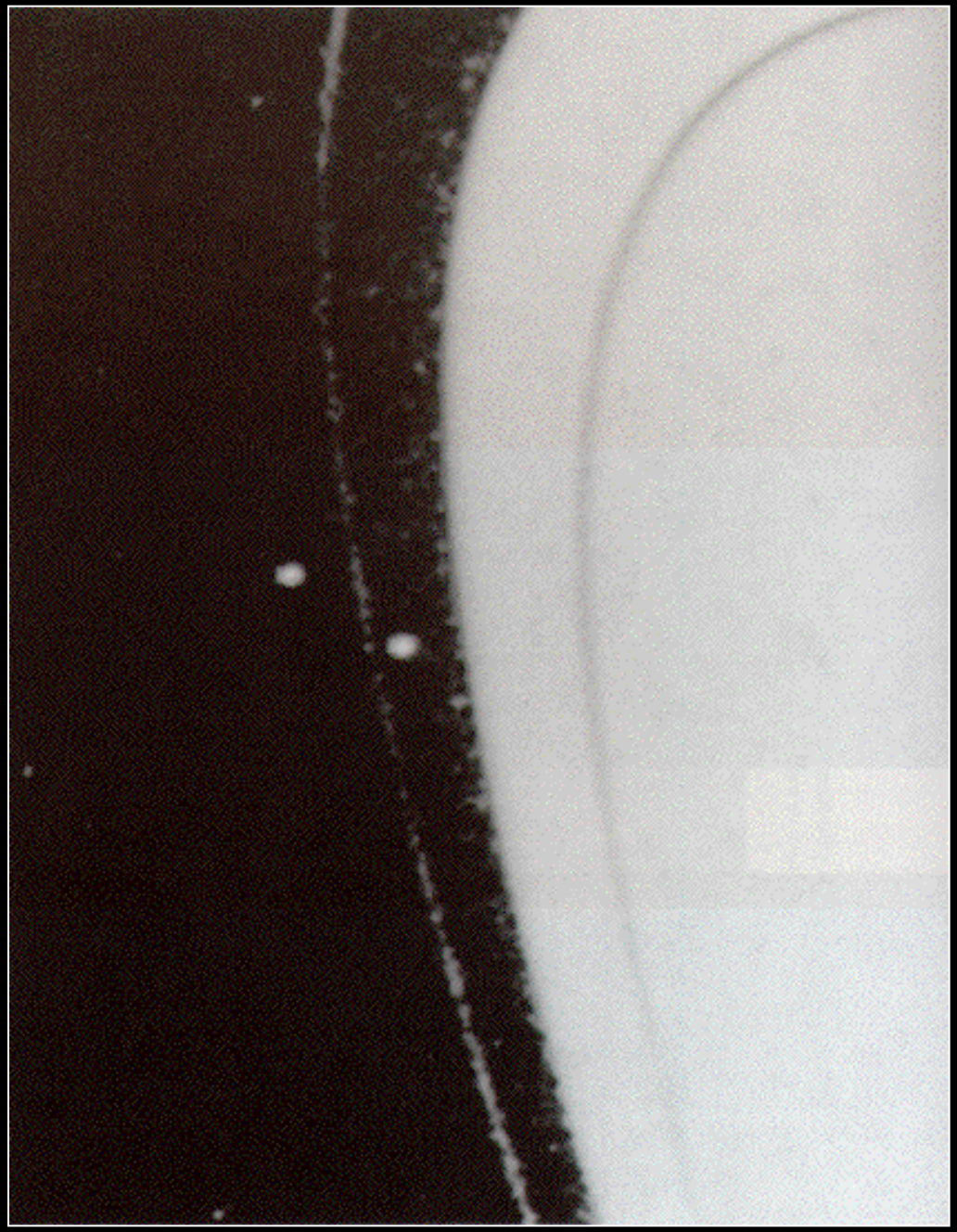
Rings of Saturn

Color contrast enchansed. Difference in color may reflect difference in composition.

Transverse diffuse bands in rings of Saturn

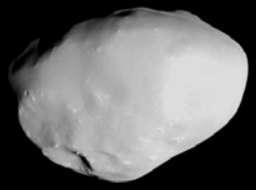


Could appear due to electromagnetic forces?

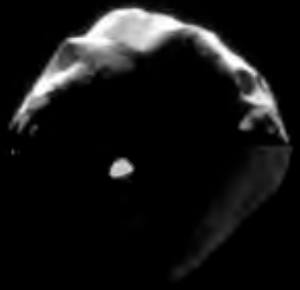


Pandora and Prometeus - satellites-shepherds, “herding” ring F

Small satellites of Saturn



Telesto
16 x 30 km



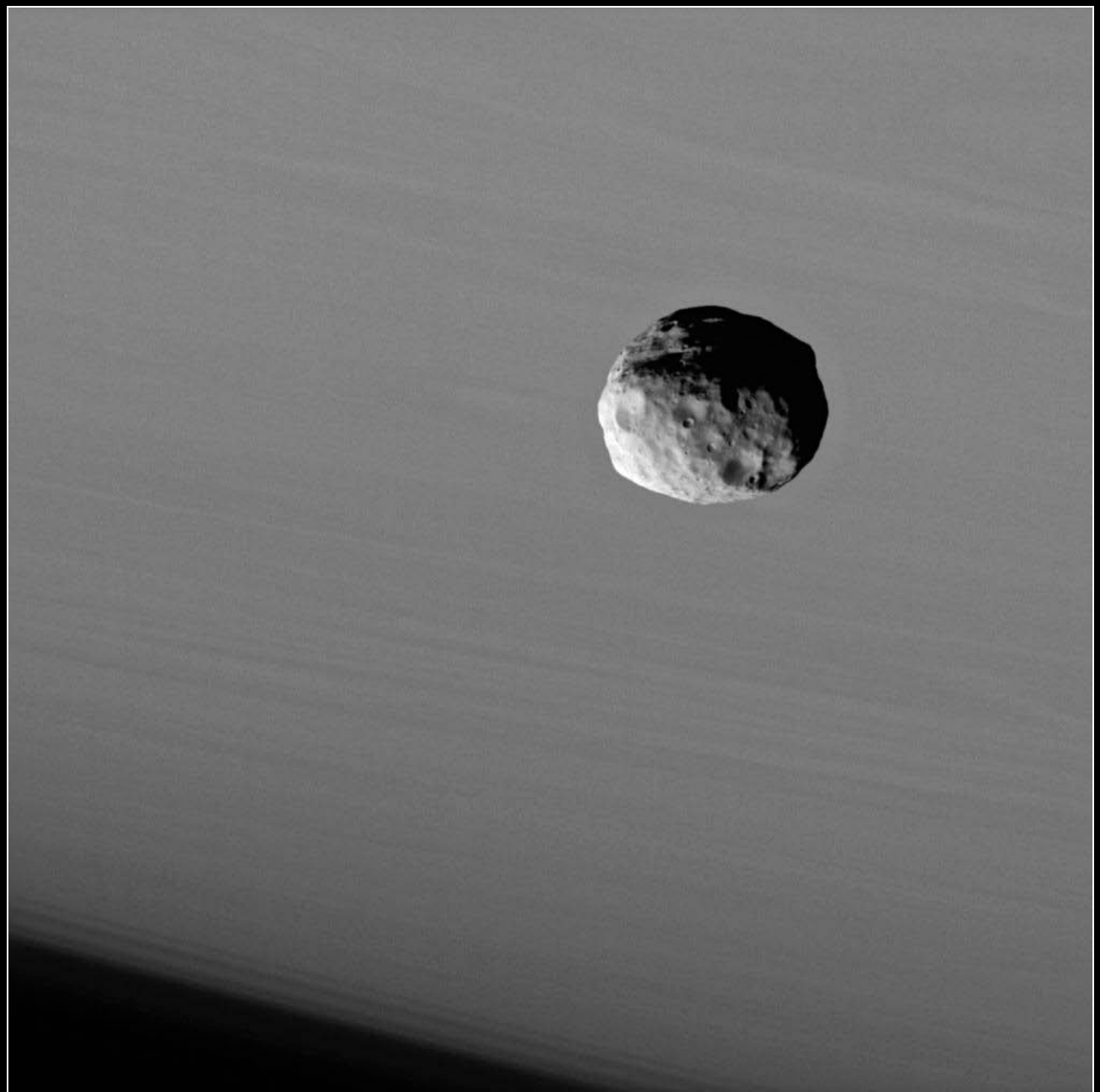
Elena
D = 32 km

Pandora
62 x 110 km

Calipso
16 x 30 km

Prometeus
68 x 148 km

Janus (152 x 198 km) on the background of Saturn

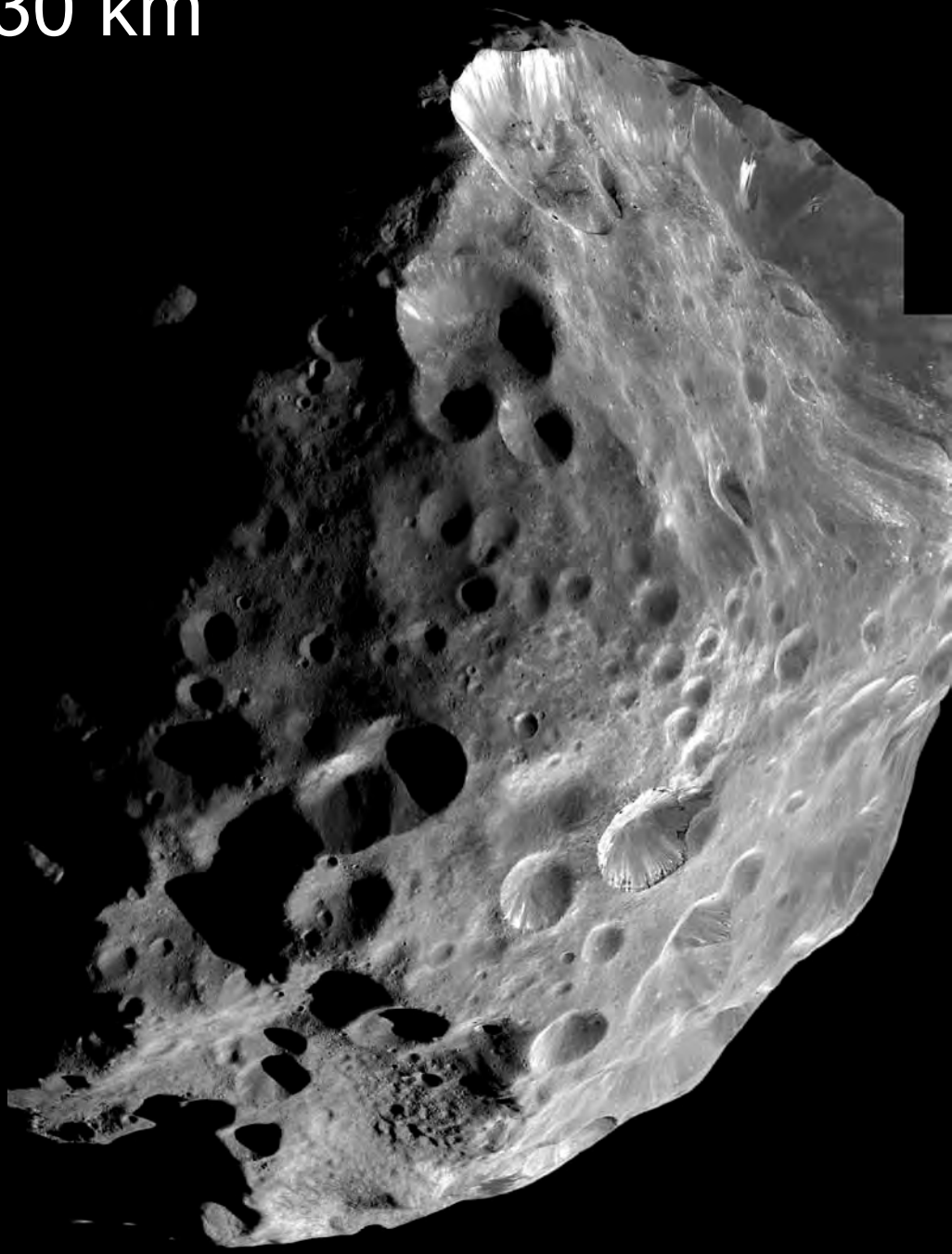


Phoebe, 210 x 230 km

Impact craters

ρ = ?

Composition: ice H_2O with admixture of silicates?

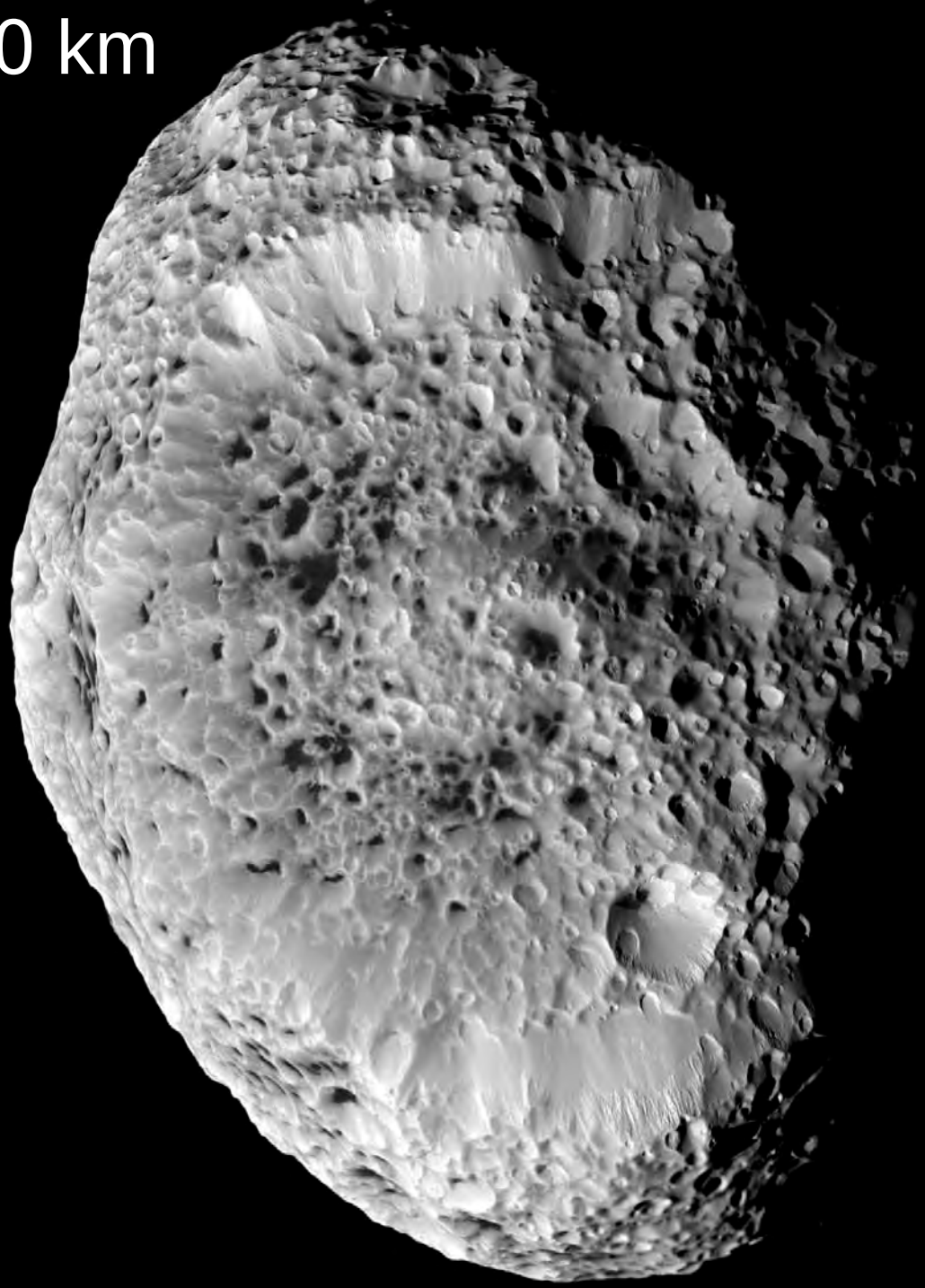


Hyperion, 225 x 370 km

Impact craters

ρ = ?

Composition: ice H_2O with admixture of silicates?



Mimas, D = 400 km

Impact craters

$\rho = 1.12$ g/cm^3

Composition: ice H_2O with admixture of silicates?

Enceladus, 496 x 502 x 512 km

Semi-major axis 238, 000 km

~8 R Saturn

Orbit eccentricity 0.0047

ρ = 1.6 g/cm^3

Albedo at 0.55 mkm = 1.37

Composition: above H_2O ice

Below silicates

Impact craters

Tectonic faults

Geisers!

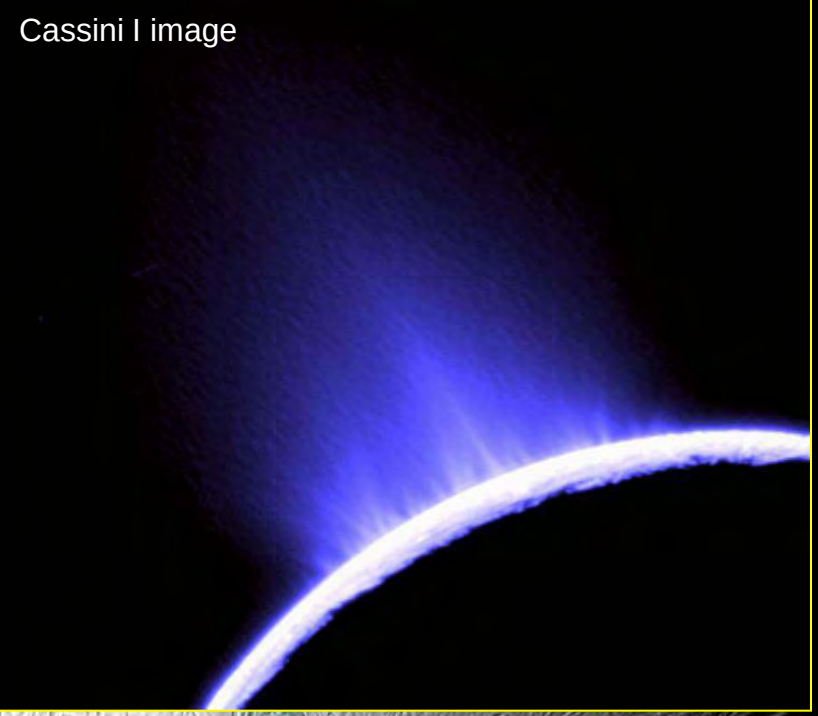
Снимок Cassini

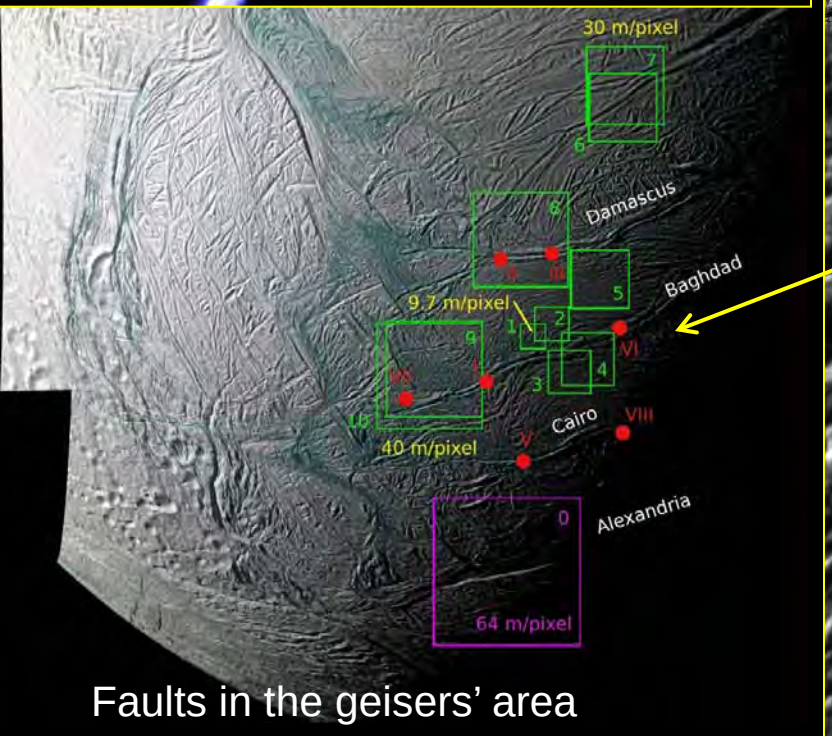
Cassini I image

Encelladus: South pole

Geisers of H_2O vapor

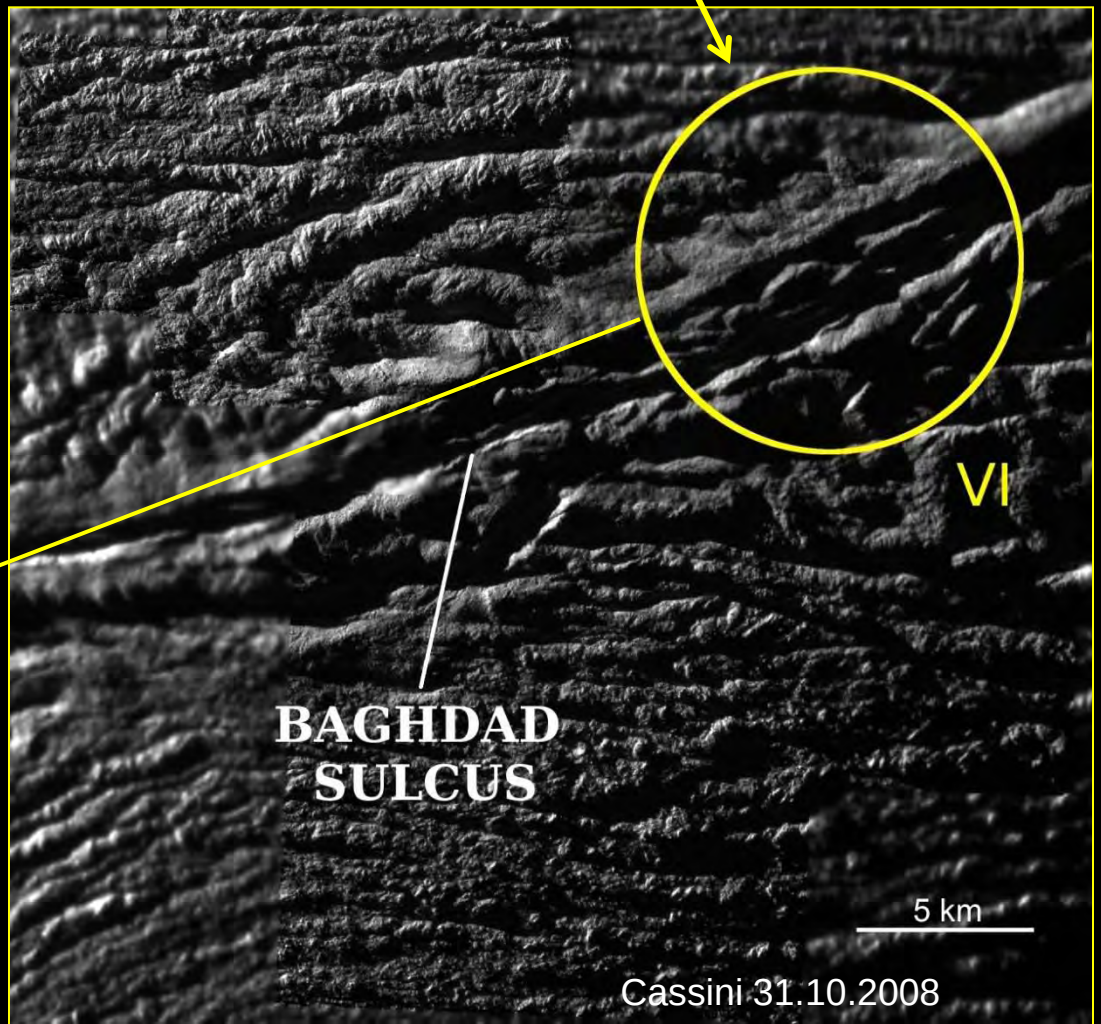
=> Result of tidal heating





Faults in the geisers' area

Source area of Geiser #6



Cassini 31.10.2008

Tethus, D = 1058 km

Semi-major axis 295 000 km

~10 R saturn

Orbit eccentricity 0.0001

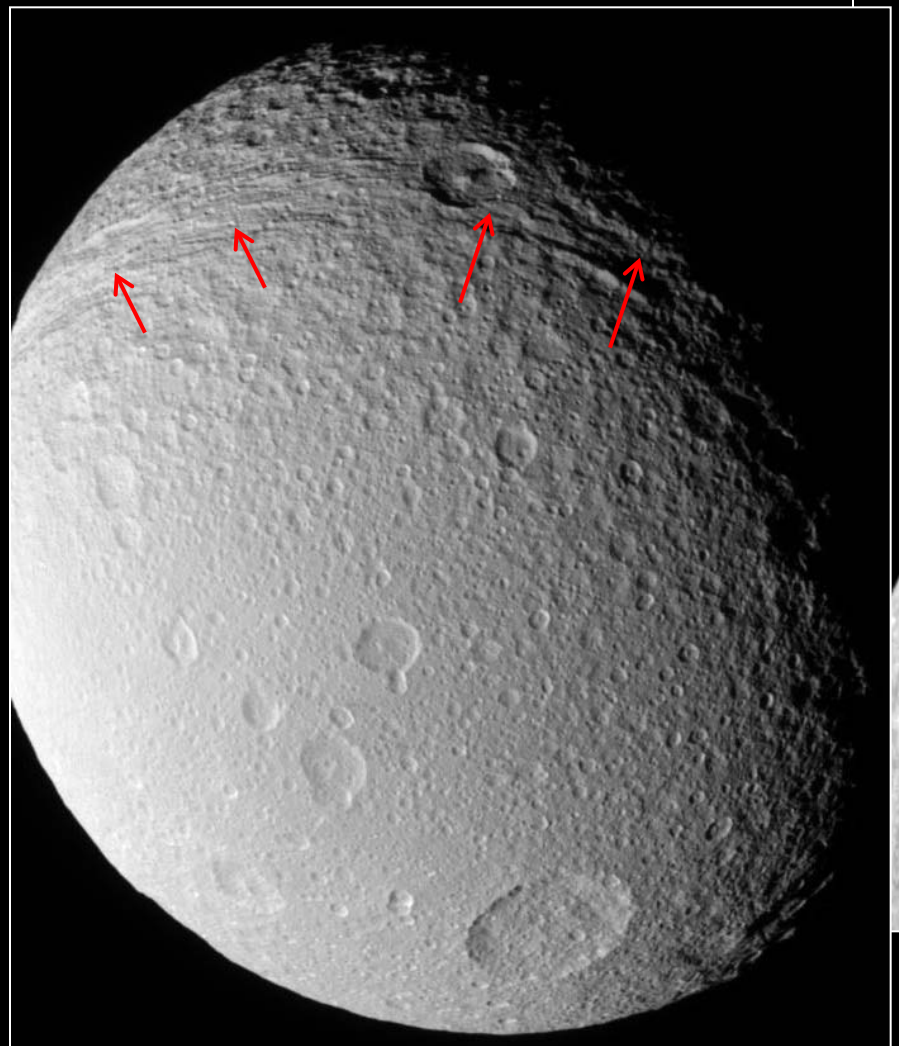
Impact craters and faults

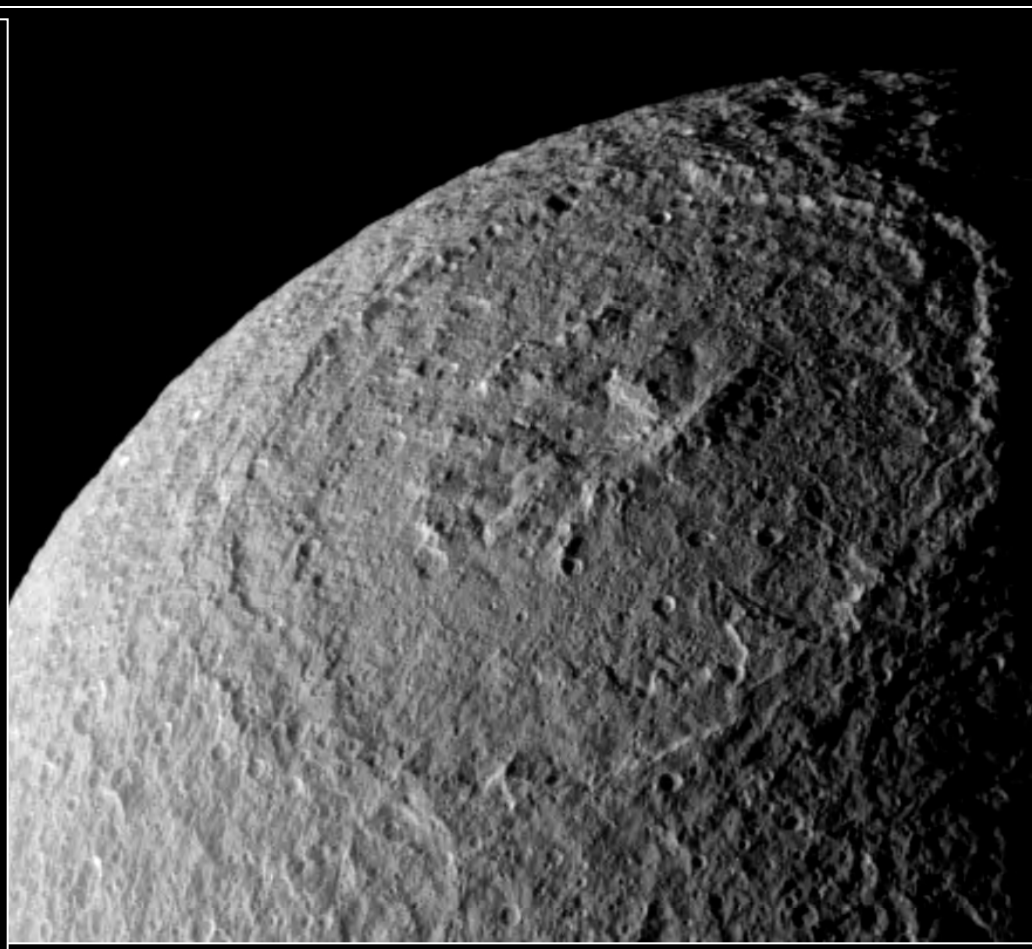
ρ = 0.98 g/см^3

Albedo 1.223

Composition: ice H_2O C

Cassini images



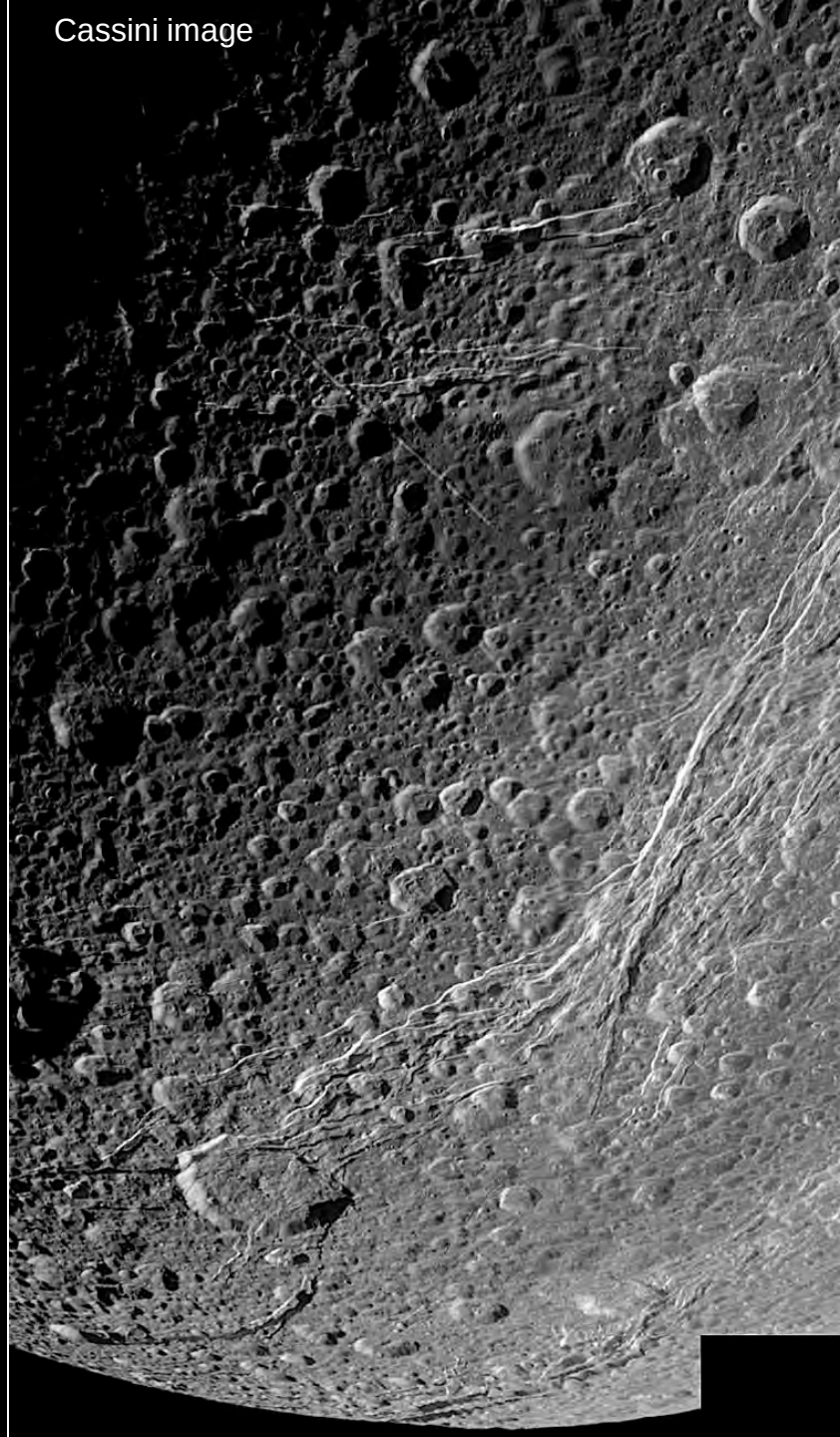


Impact basin Odyssey (450 km)

Dione, D = 1120 km

Semi-major axis 377 000 km
~12 R Saturn
Orbit eccentricity 0.002

Impact craters and faults
albedo 0.998 ρ = 1.5 g/cm^3
Composition: H_2O ice + silicates

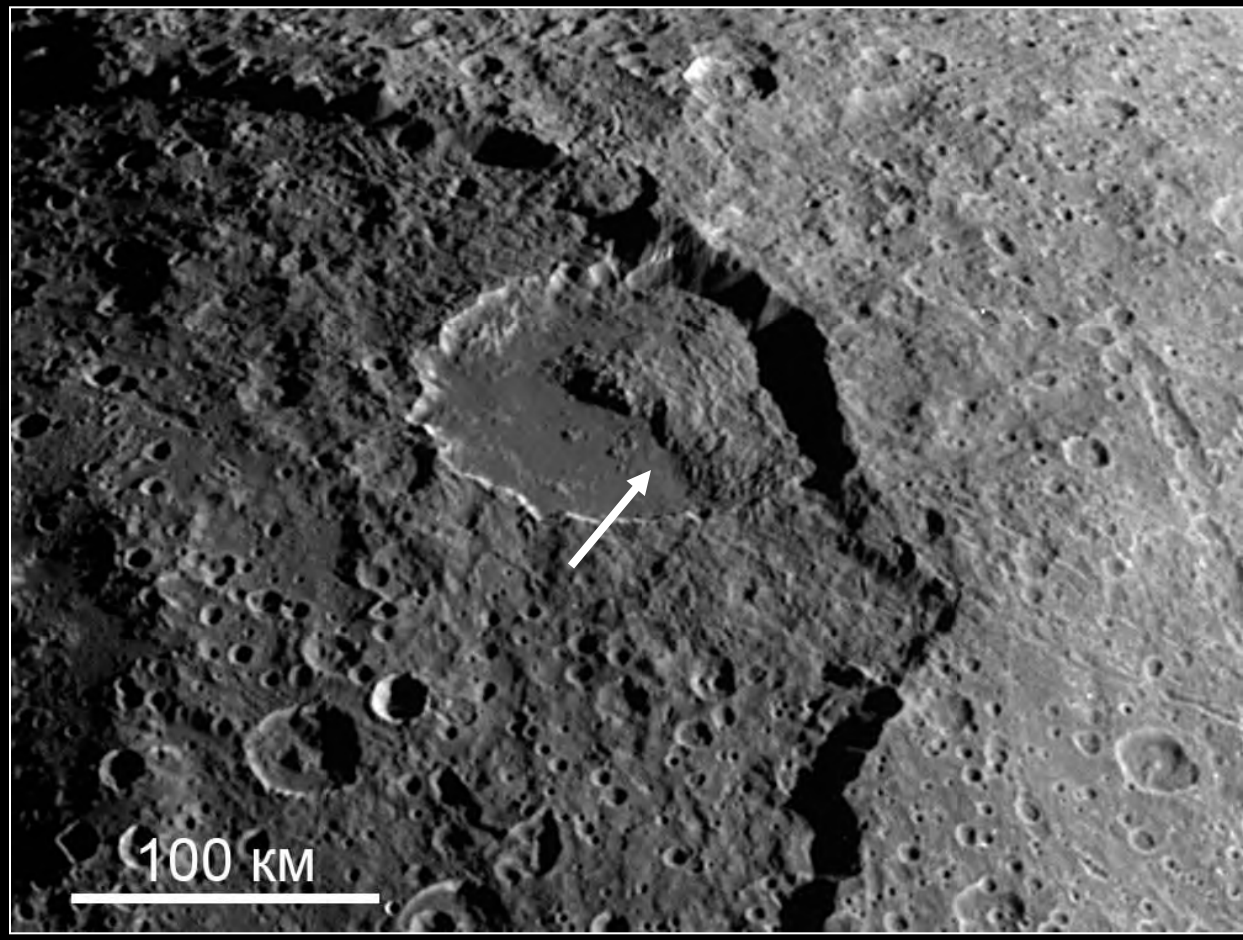


Japetus, D = 1440 km

Semi-major axis 3 560 000 km
~120 R Saturn
Orbit eccentricity 0.028

Impact craters
Mountain belt
Albedo 0.05 – 0.5
ρ = 1.0 g/cm^3
Composition: H_2O ice

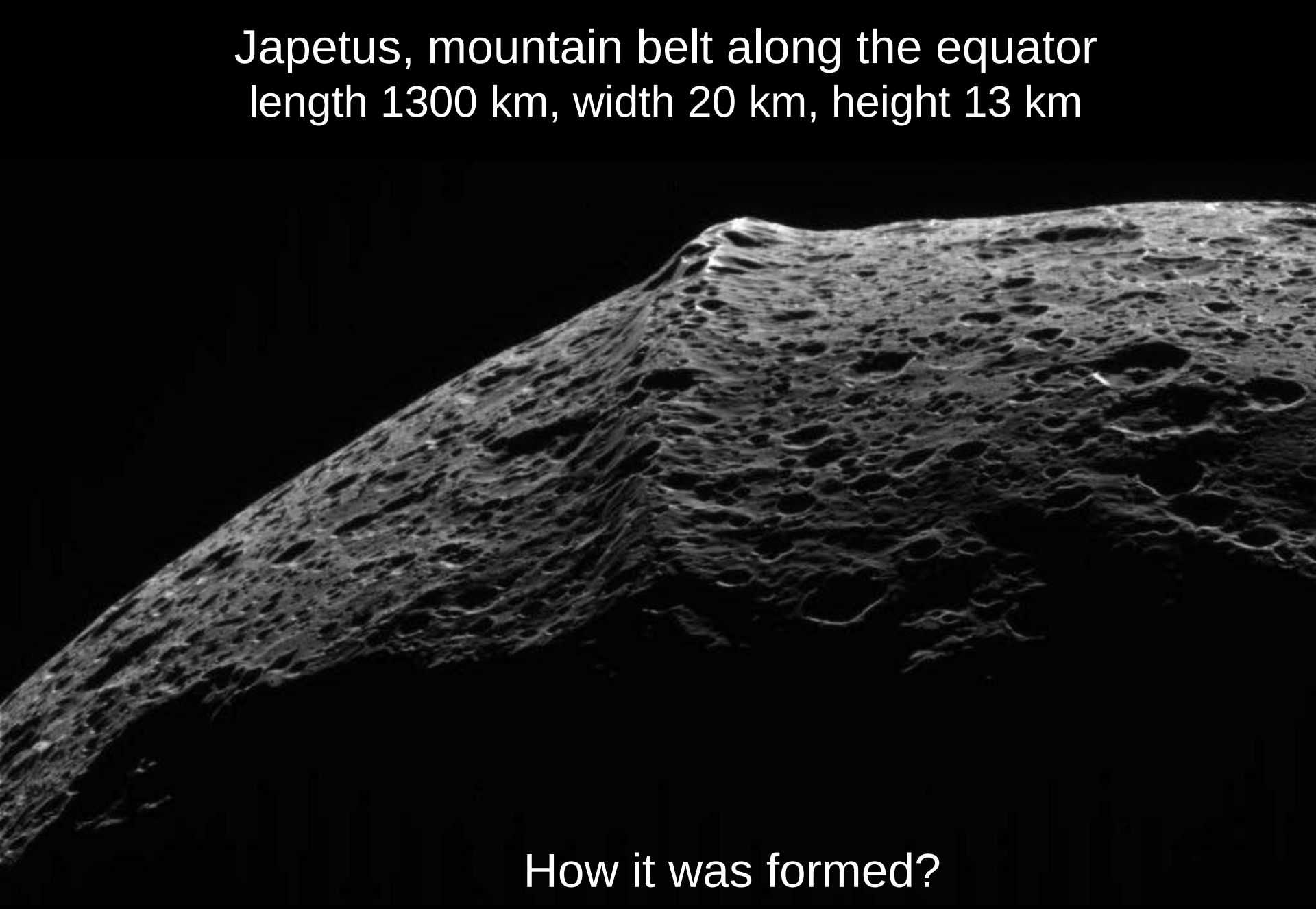
Leading hemisphere
dark
Rear - light



Landslide moved from 15 km scarp

Cassini Cassini

Japetus, mountain belt along the equator
length 1300 km, width 20 km, height 13 km



How it was formed?

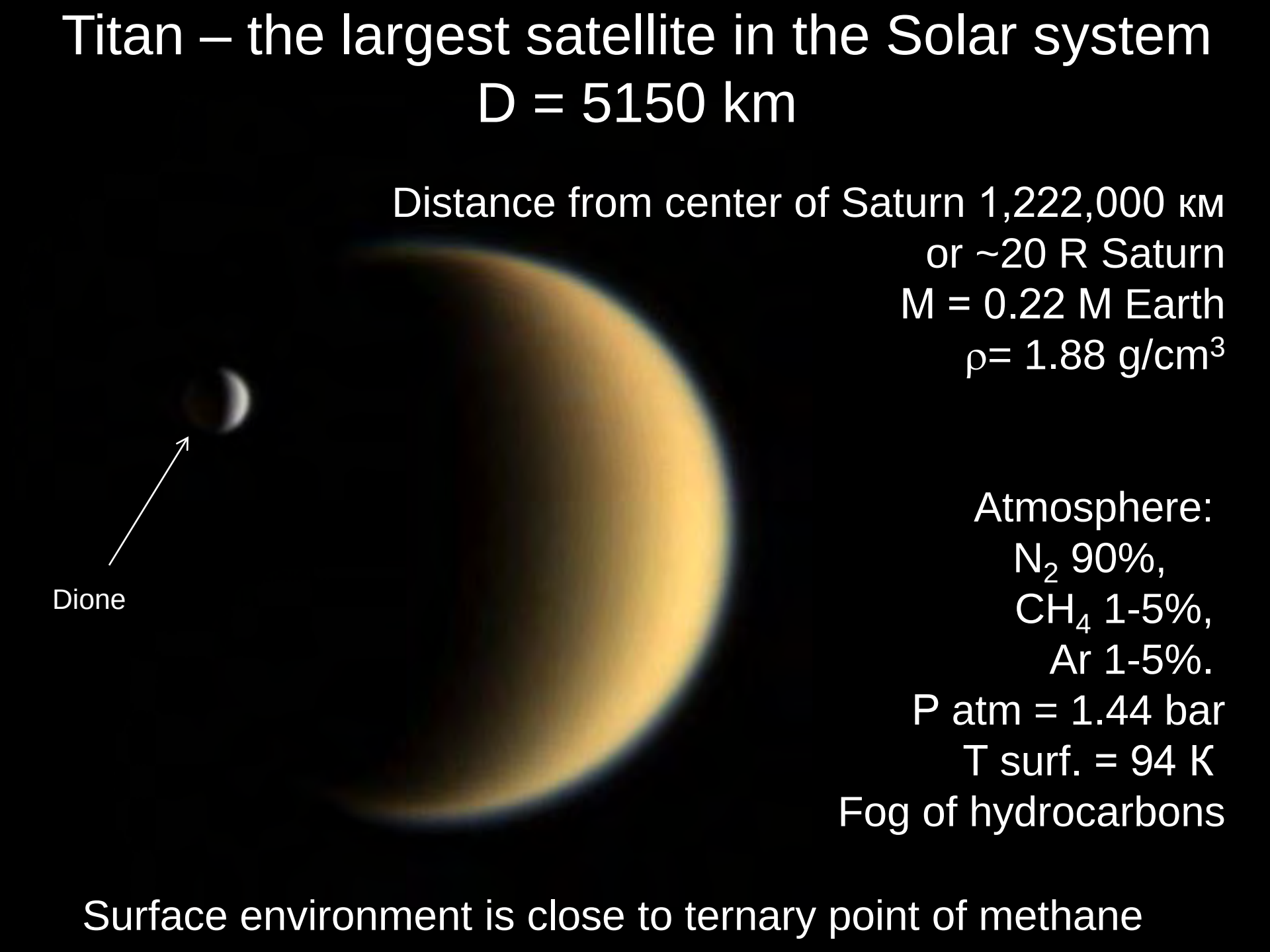
Cassini image

Rhea, D = 1528 km

Semi-major orbit 527 000 км
~18 R Saturn
Orbit eccentricity орбиты 0.001

Impact craters and marginally seen faults
ρ= 1.24 g/см^3
Albedo 0.95
Composition: ice H_2O + silicates

Titan – the largest satellite in the Solar system
D = 5150 km

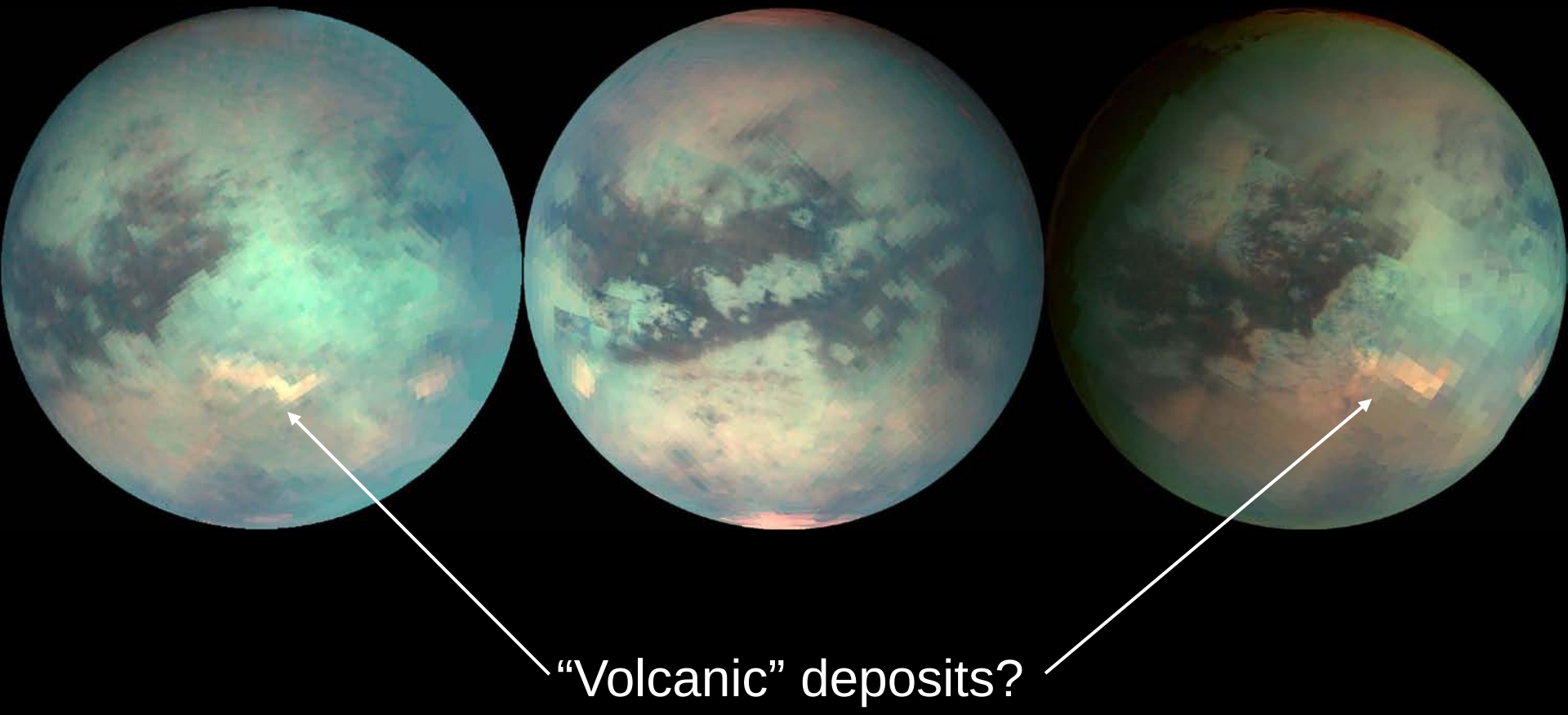


Distance from center of Saturn 1,222,000 км
or ~20 R Saturn
M = 0.22 M Earth
ρ= 1.88 g/cm^3

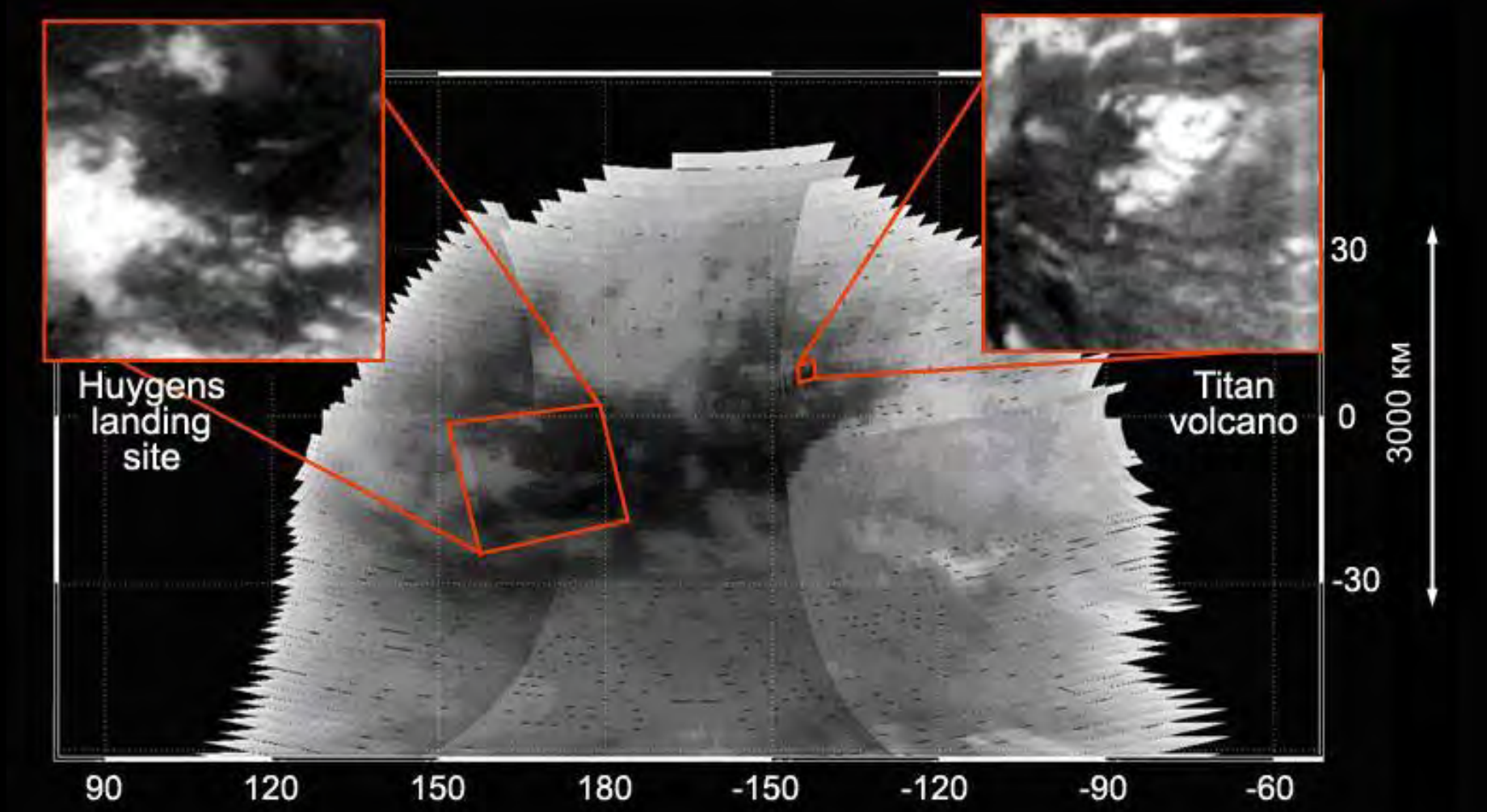
Atmosphere:
N_2 90%,
CH_4 1-5%,
Ar 1-5%.
P atm = 1.44 bar
T surf. = 94 K
Fog of hydrocarbons

Surface environment is close to ternary point of methane

Titan, IR images taken by Cassini

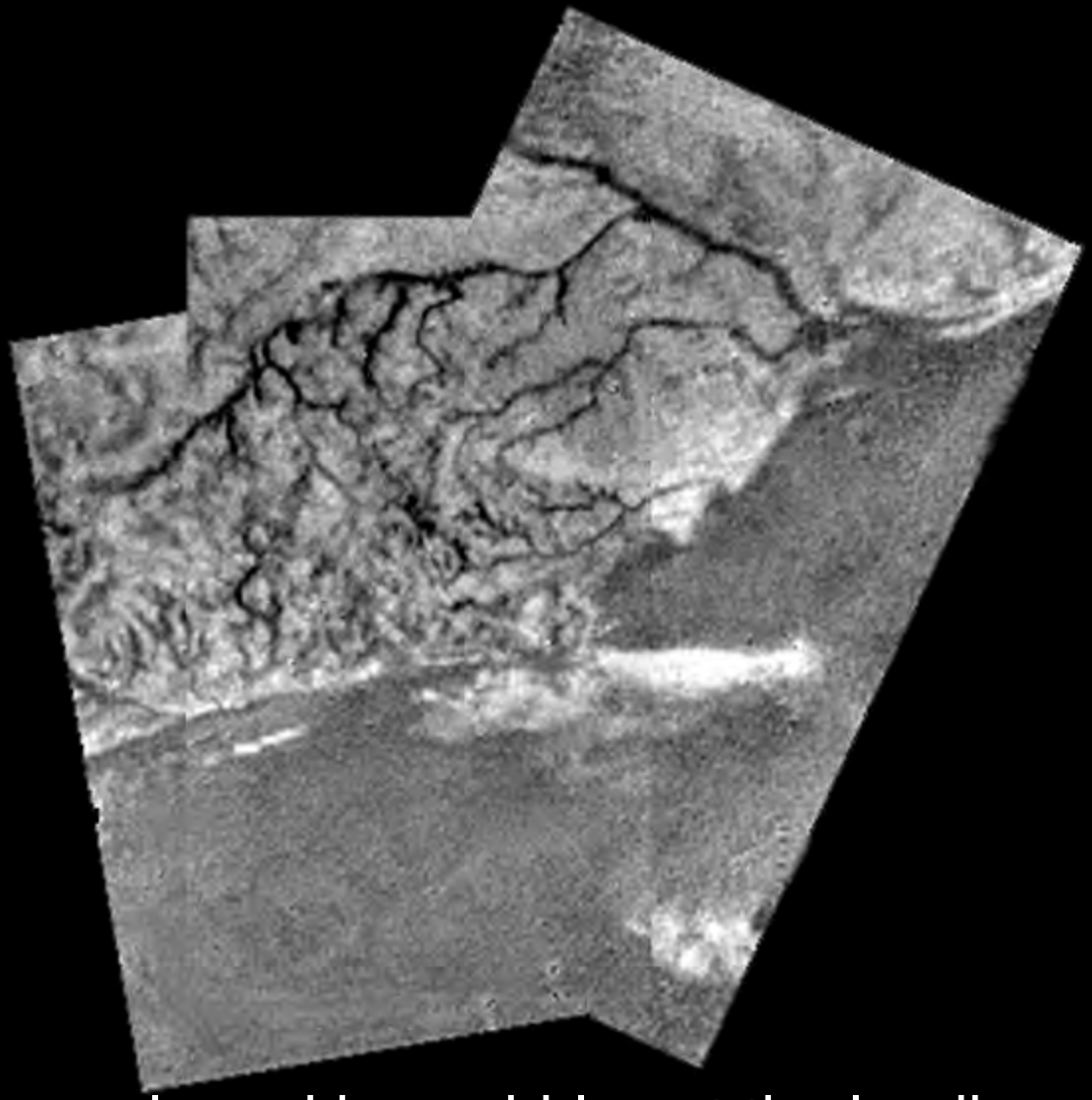


Titan, Images taken by Cassini in visible and IR diapasons



Huigens probe – a passenger of Cassini spacecraf

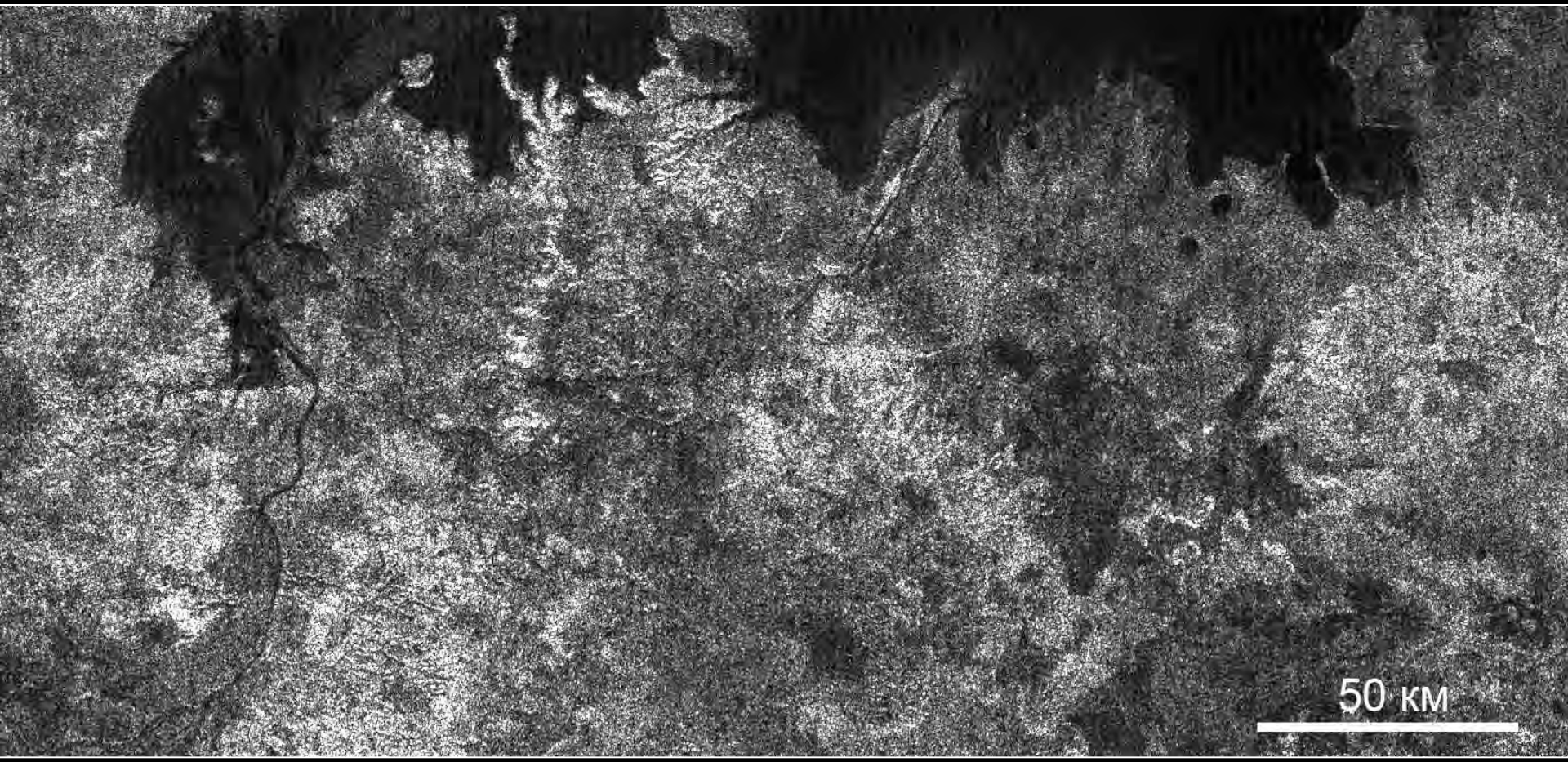
Images taken by Huigens from the 10 km altitude and on the surface



Channels and ice pebbles at the landing site

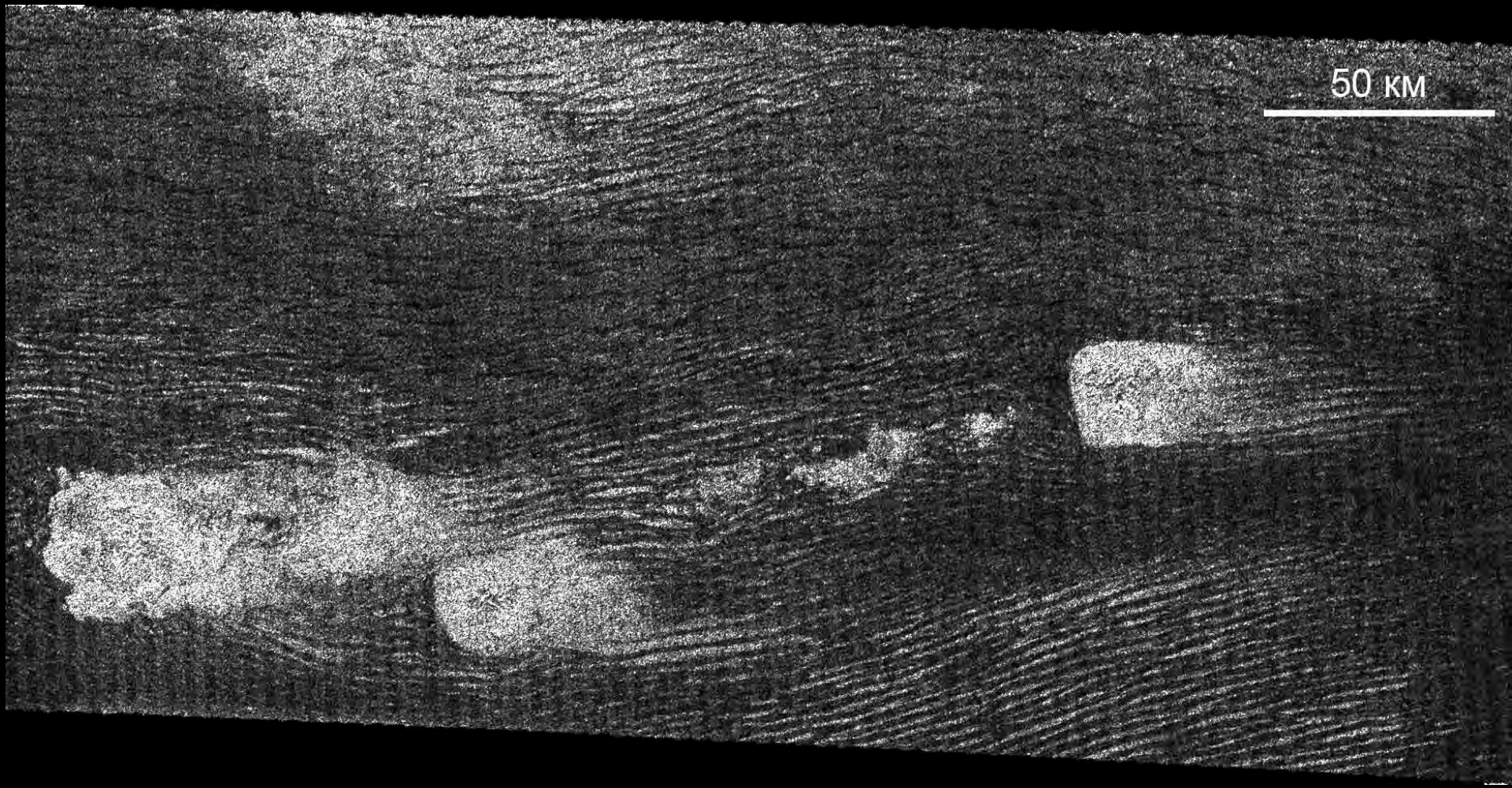
Apollo 11

Channels and methane lakes



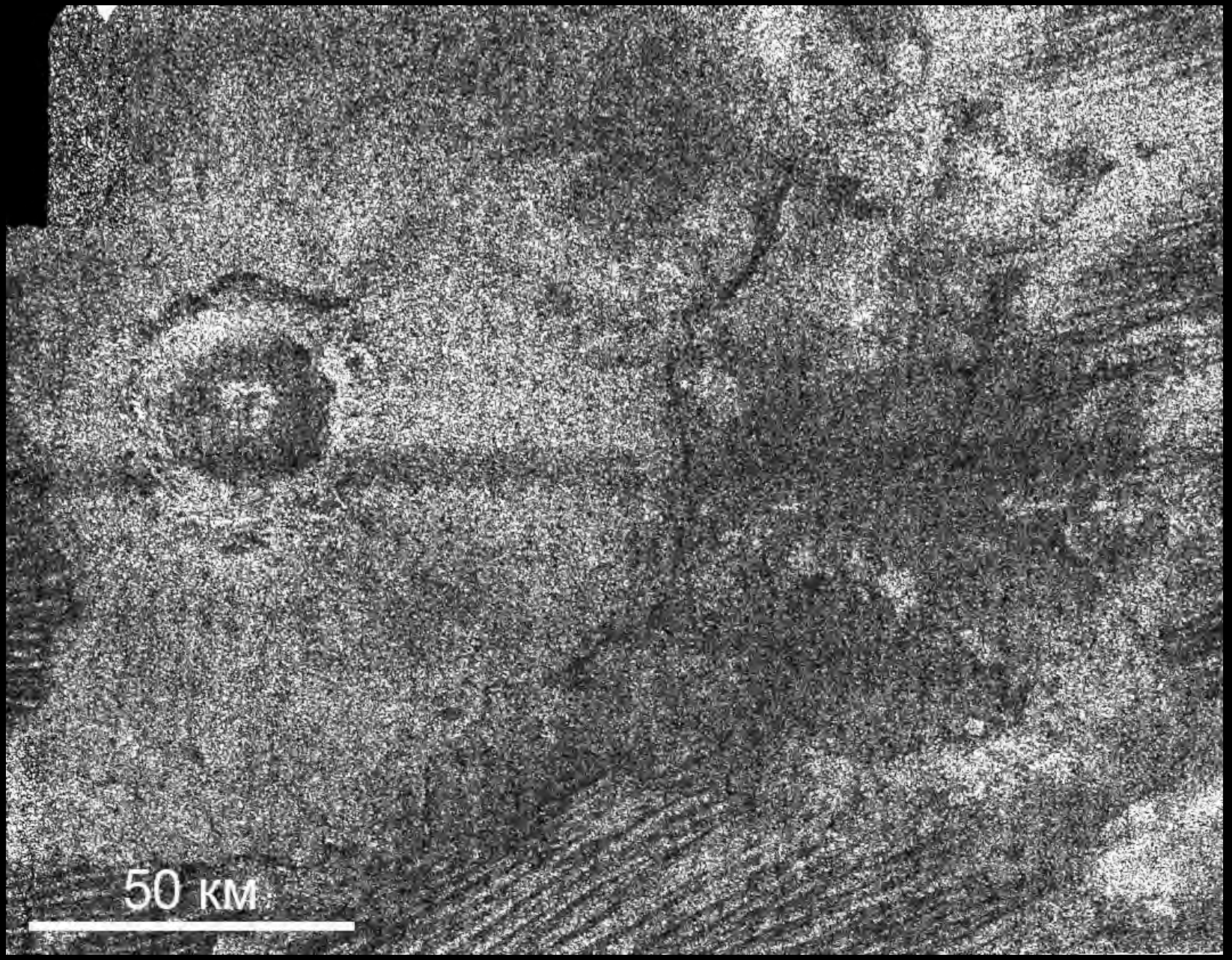
Cassini radar images

Linear dunes



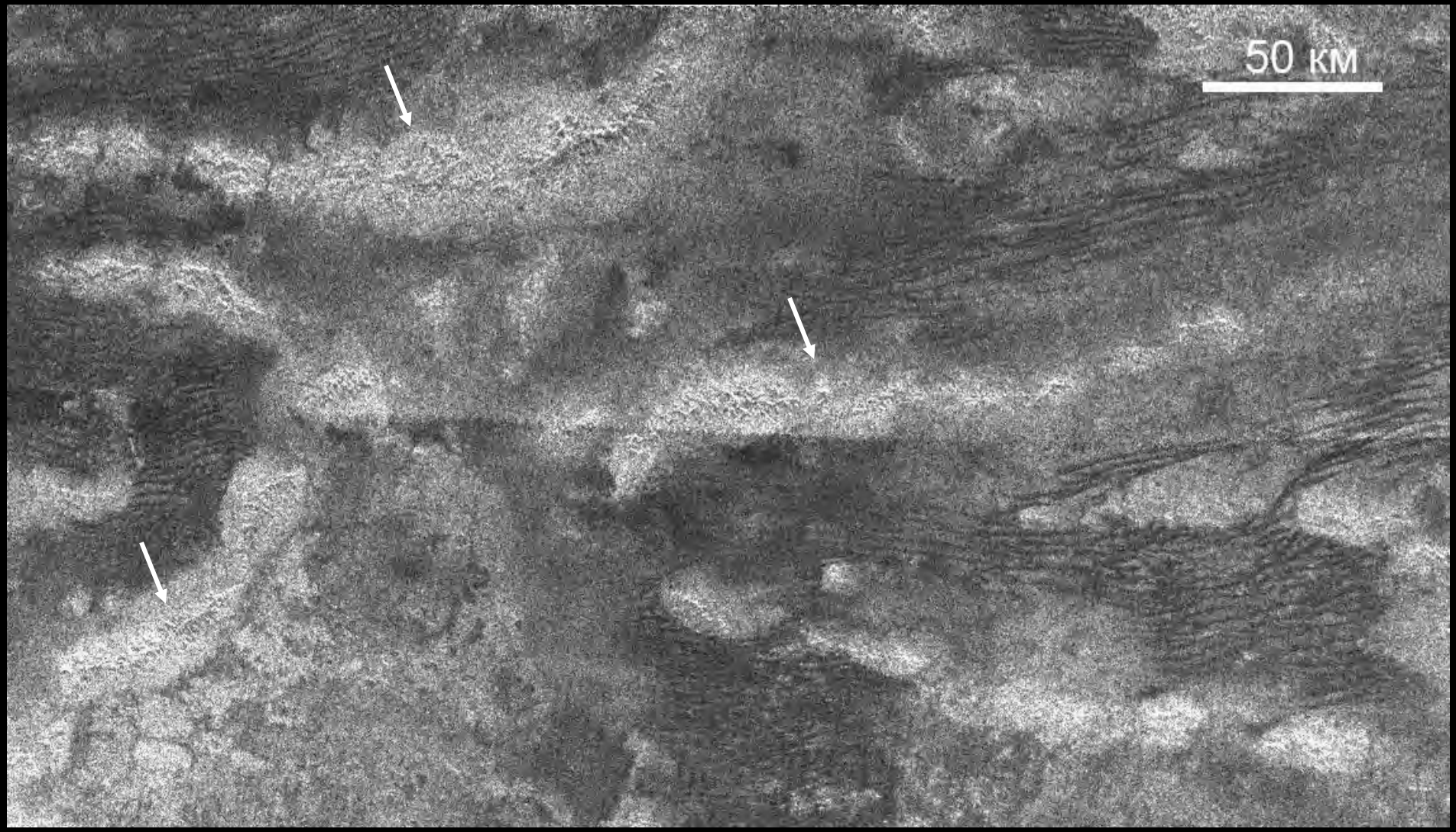
Cassini radar images

Impact crater



Cassini radar image

Tectonic ? ridges



Cassini radar image

Saturn

Resembling Jupiter, but smaller in size.

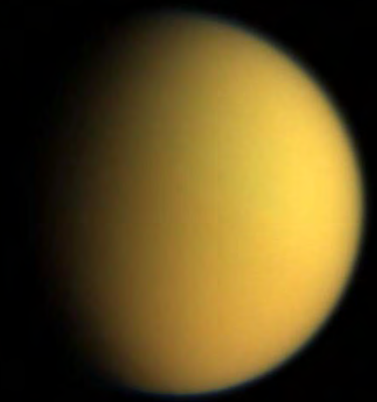
The Saturn system – also Solar system in miniature: satellites with diameters of tens km – a few hundred km – to 1000-1500 km, one (Titan) – 5150 km in diameter. Faults are seen on larger satellites.

Saturn looks banded, bands are diffuse. Color yellow-brownish. Compo-sition of atmosphere H_2 88 mass %, He 11%, $\sum CH_4$, NH_3, C_2H_6 = 1%.

Rings. Galileo saw rings of Saturn “in profile”, but did not understa what was that; did think – triple planet. Consist of separate rings, the latter consist of separate particles of ice. Short-lived system.

Saturn has the lowest (among the planets) bulk density– 710 kg/м

Internal structure of Saturn - like that of Jupiter: compressed (clos the center to state of liquid) gas. Possibly has iron-silicate core.



Titan – planetary body with traces of geologically recent activity

endogenic:

volcanism + tectonics

and

exogenic:

eolian processes + fluvial erosoin.

Energy for endogenic activity – decay of K, U, Th in Titan interior.

Energy for exogenic activity – light of the Sun, ~1% of solar light intensity on Earth.

Media supporting exogenic activity – N_2 and CH_4, the latter with solid – liguid – gas transitions. Water ice plays the role of rocks.

Uranus – 7th from the Sun planet, ≥24 satellites

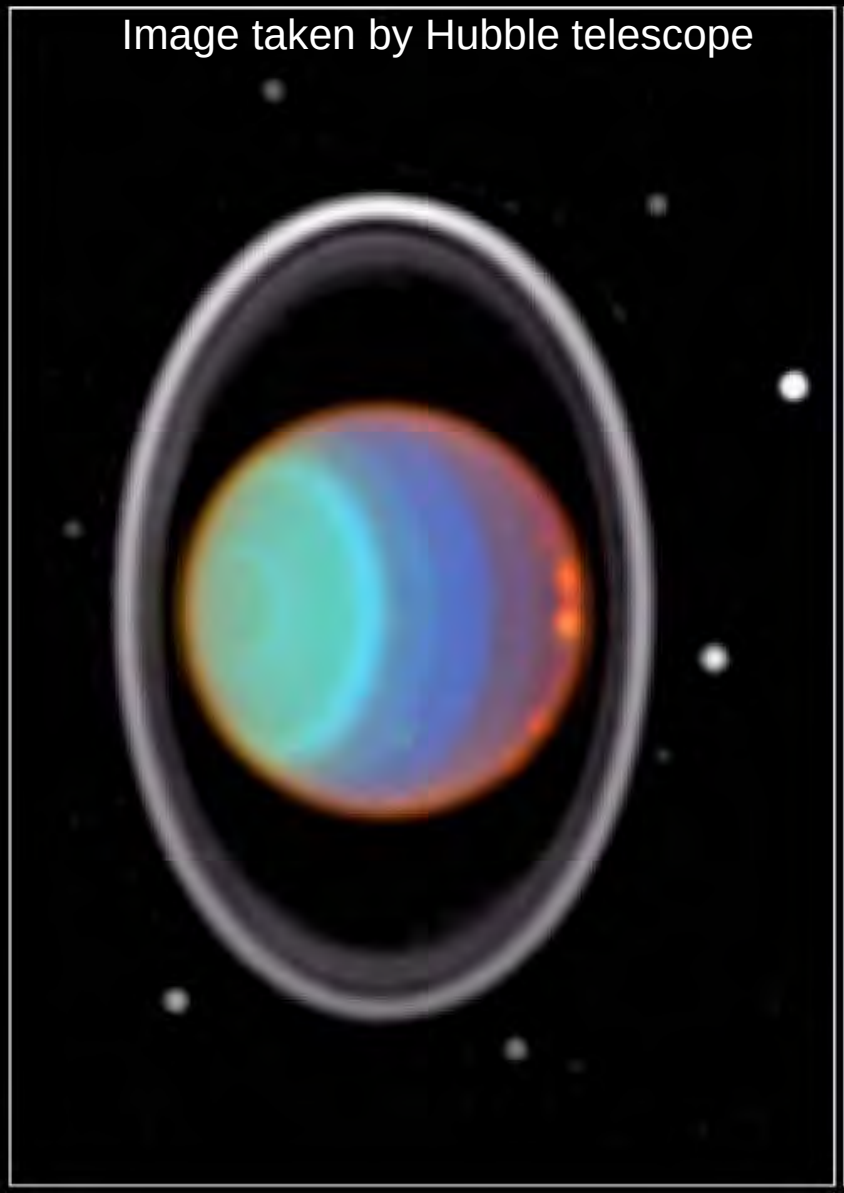
Distance from the Sun 19.2 a.u.
D = 51,000 km
4 D Earth
M = 14.5 M Earth
ρ= 1.3 g/см^3
g = 0.89 g Earth

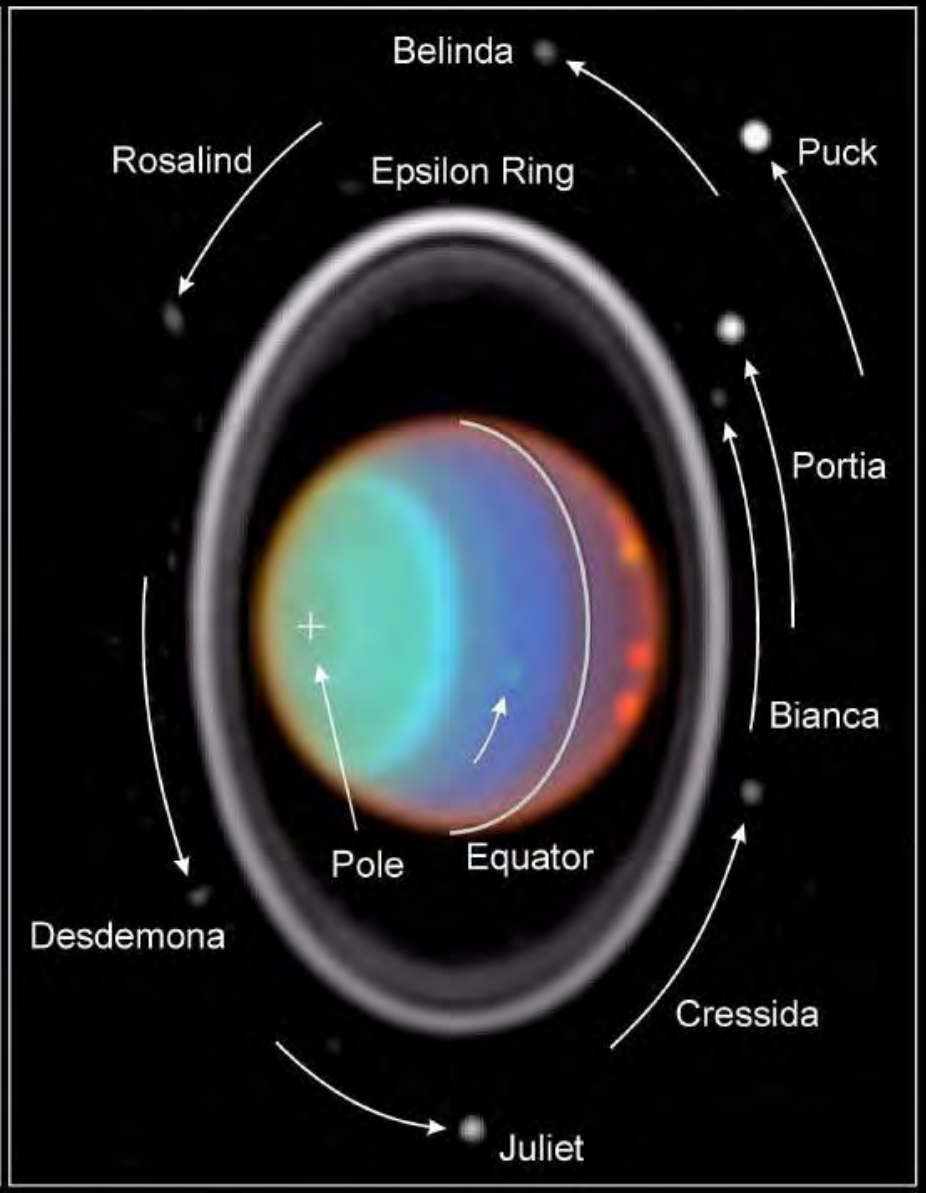
Rotation period 0.71 Earth day
Inclination of equator to the orbit plane 97.9º
Inclination of orbit to ecliptics 0.77º
Year = 84 Earth years
Major atmosphere components: H_2, He, CH_4
Temperature at 1 bar level: 76 K

Voyager 2 image

Uranus – faint rings, small satellites.

Large inclination of the rotation axis to the orbit plane





Time interval between these two images 90 min.

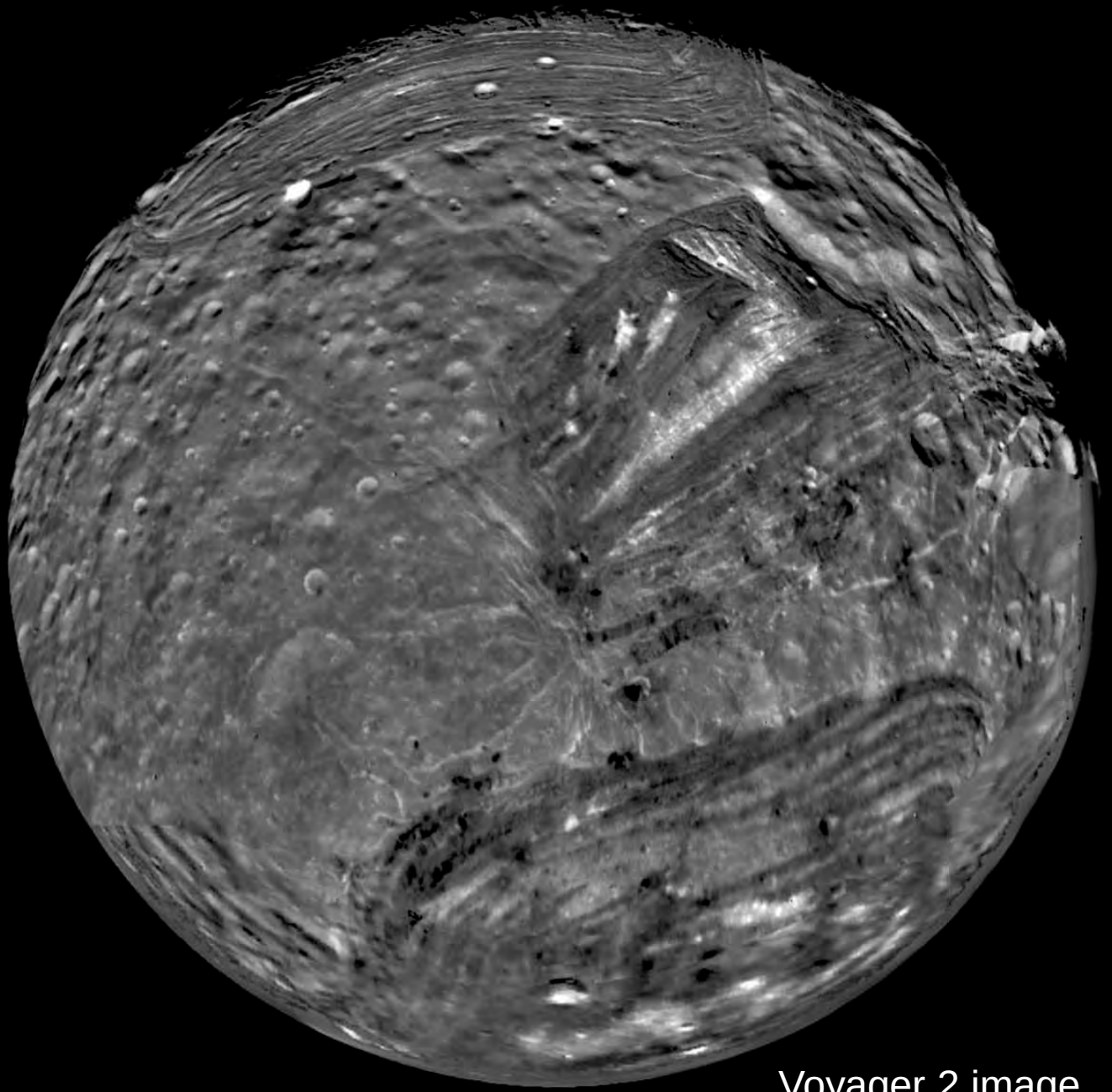
Uranus – small satellites, “shepherding” ring U

Miranda, D = 480 km

Impact craters
and “coronae”

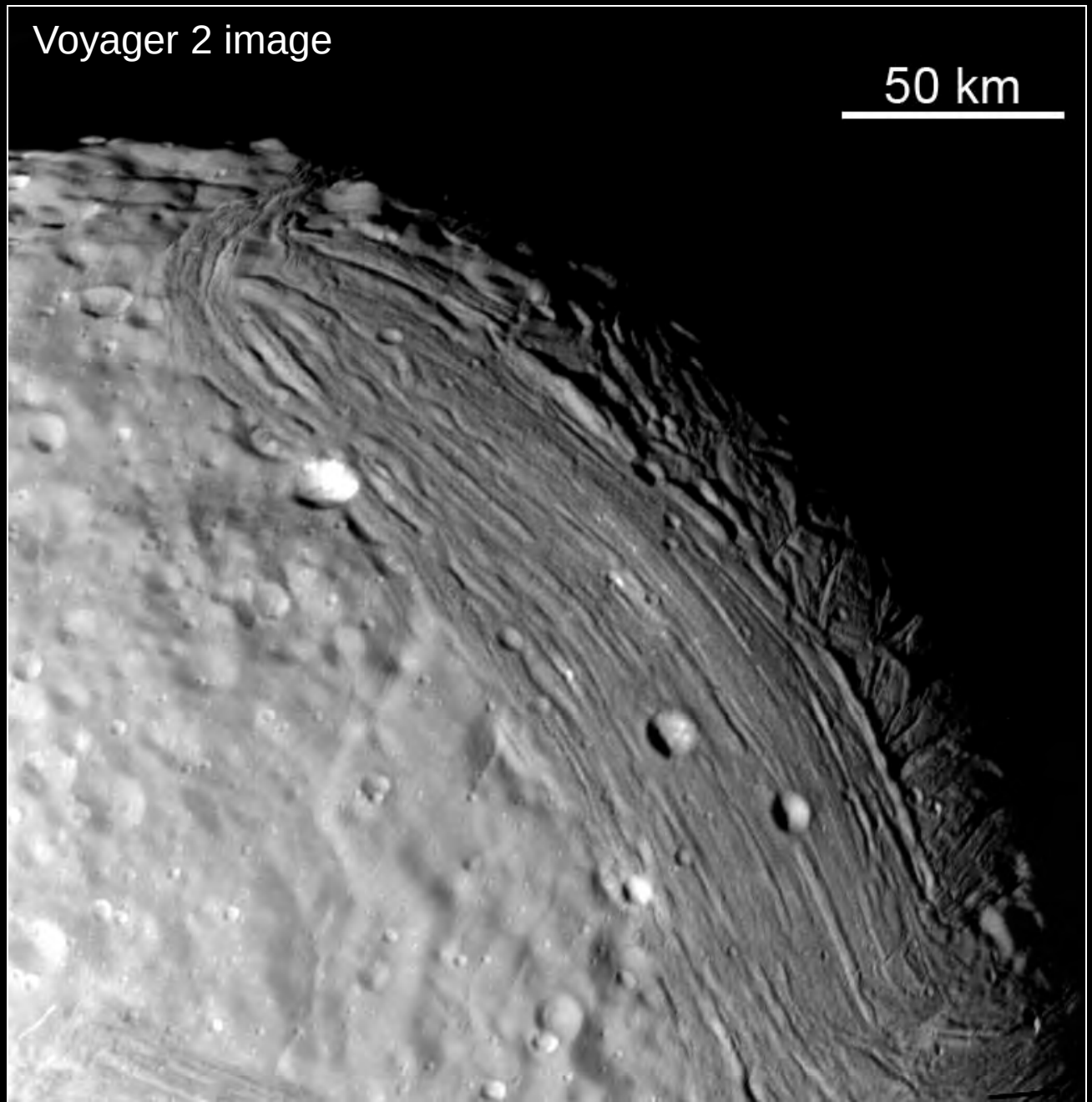
ρ = 1.2 g/см^3

Composition:
ice H_2O + silicates



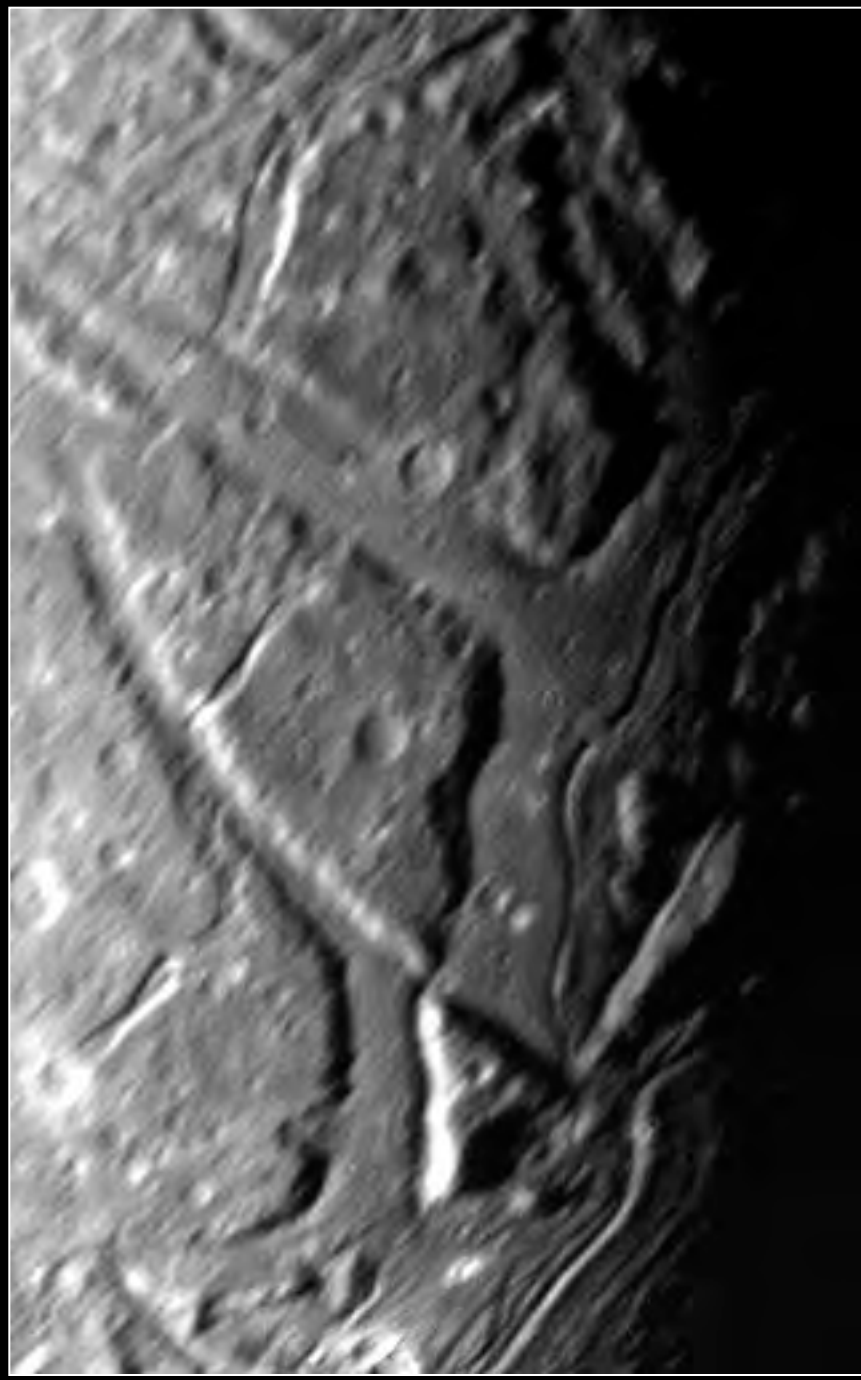
Voyager 2 image

Miranda, corona and cratered terrain



Ariel, D = 1160 km

Impact craters and faults,
filled with smooth material
ρ = 1.67 g/см^3
Composition: ice H_2O + silicates



Images of Voyager 2

Umbriel, D = 1170 km

Impact craters
ρ = 1.4 g/см³
Composition:
ice H_2O + silicates

Frost outlined
a crater.

Voyager 2 image

Oberon, D = 1520 km

Titania, D = 1580 km

Impact craters,
faults.
ρ = 1.71 g/см^3
Composition:
Ice H_2O + silicates

200 km crater,
cut by
a fault

Voyager 2 image

Uranus

System of Uranus – also Solar system in miniature: several satellites of 30 – 150 km in diameter, one (Miranda) – 470 km, 4 satellites (Ariel, Umbriel, Titania, Oberon) – 1000 to 1500 km in diameter. On the largest satellites – faults are seen. Miranda coronae – internal overturn?. Uranus and all its system are in “edgewise position”.

Looks not as Jupiter and Saturn and significantly smaller in size. Looks bluish (methane absorbs red light) and diffuse. Details are almost not seen. Composition of atmosphere – similar to that of Jupiter and Saturn.

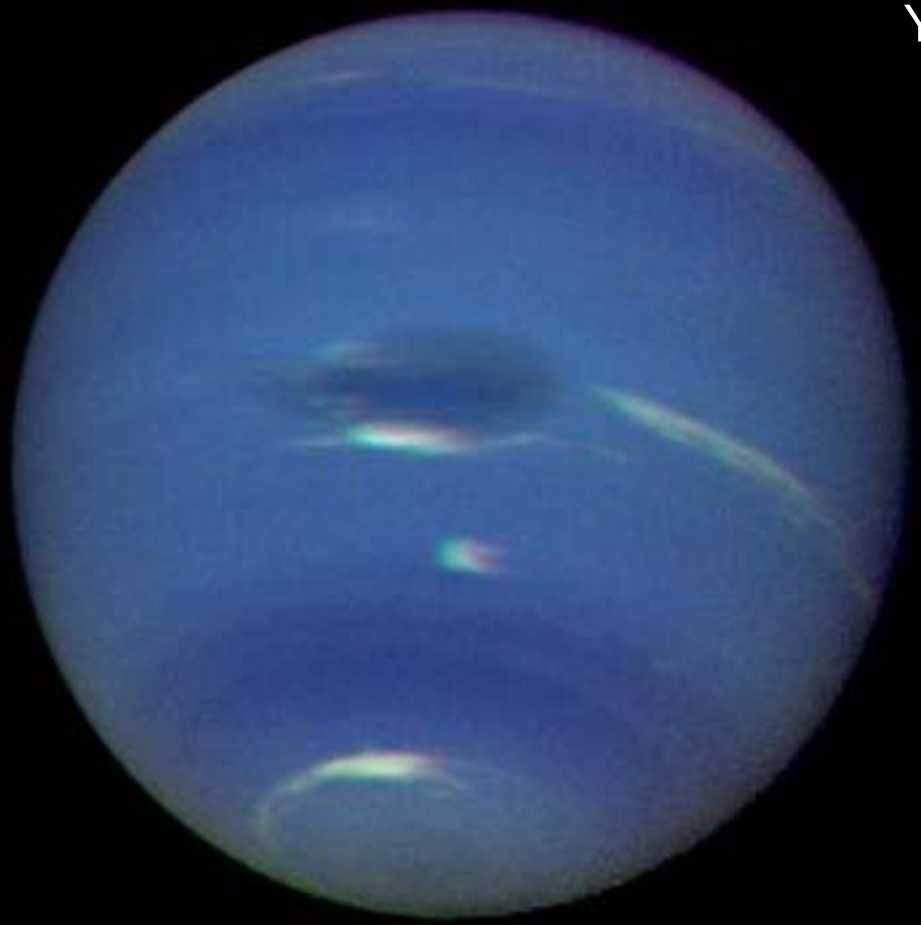
There are faint rings. Possibly these are remnants of more prominent system of rings.

Internal structure of Uranus - like that of Jupiter and Saturn: compressed (closer to the center to the status of liquid) gas. Possibly Uranus has iron-silicate core?.

Neptune – 8th from the Sun planet, ≥ 13 satellites

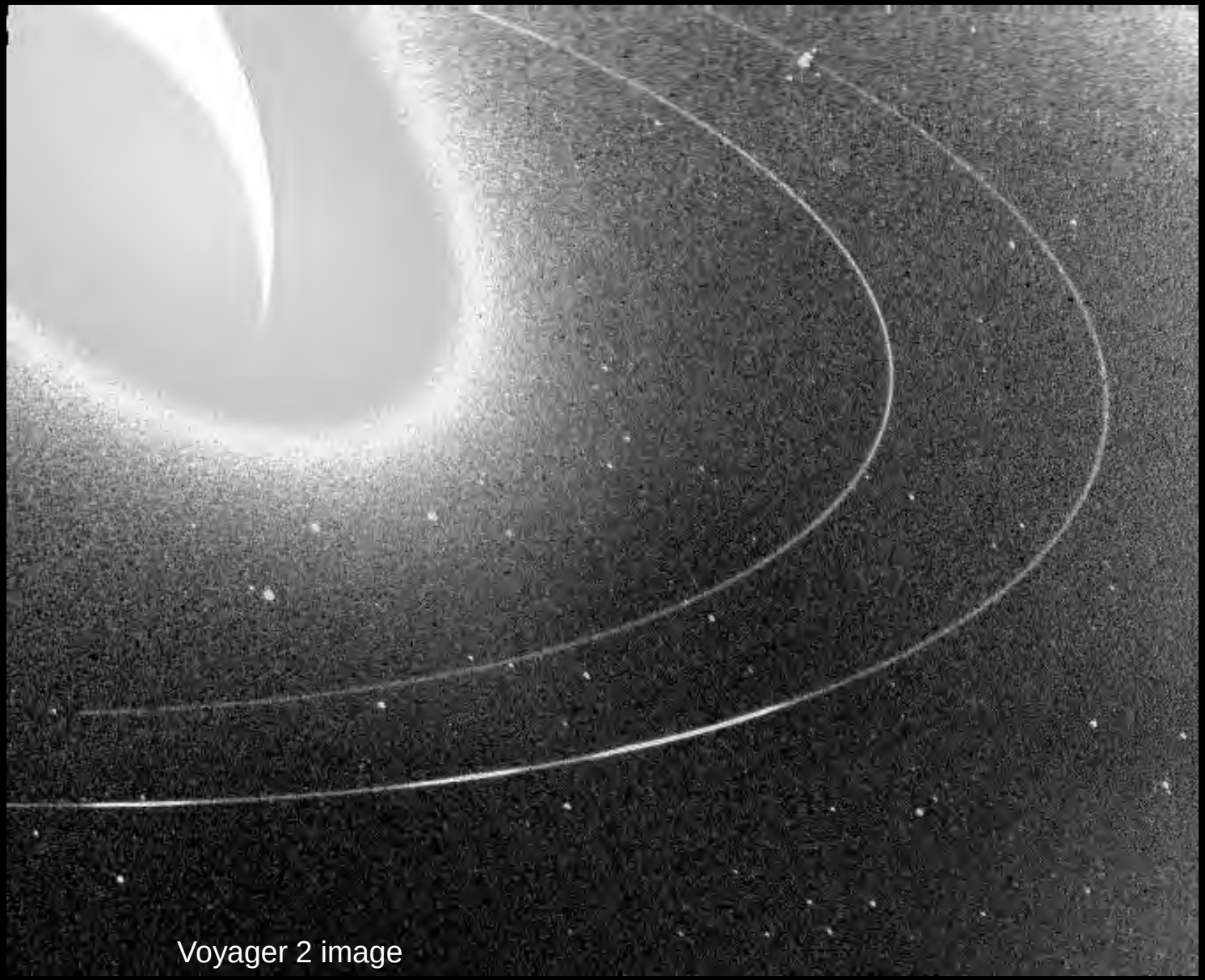
Distance from the Sun 30 a.e.
D = 50,000 km
4 D Earth
M = 17 M Earth
ρ= 1.76 g/см^3
g = 1.12 g Earth

Rotation period 0.67 Earth day
Equator inclination to the orbit plane 29.6^o
Orbit plane inclination to ecliptics 1.77^o
Year = 165 Earth years
Major components of atmosphere:
H_2, He, CH_4
Temp. at 1 bar level:
73 K



Voyager 2 image

Rings around Neptune



Voyager 2 image

Small satellites of Neptune

Voyager 2 image

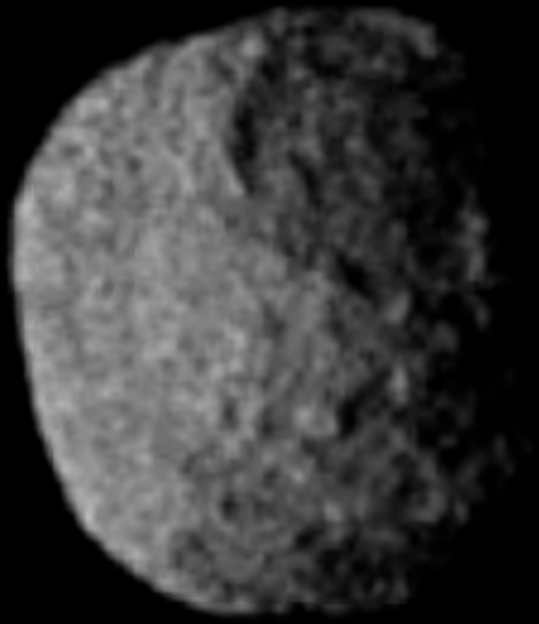
Thalassa, 40 km

Galatea, 75 km

Nereid, 170 km

Despina, 75 km

Larisa, 100 km

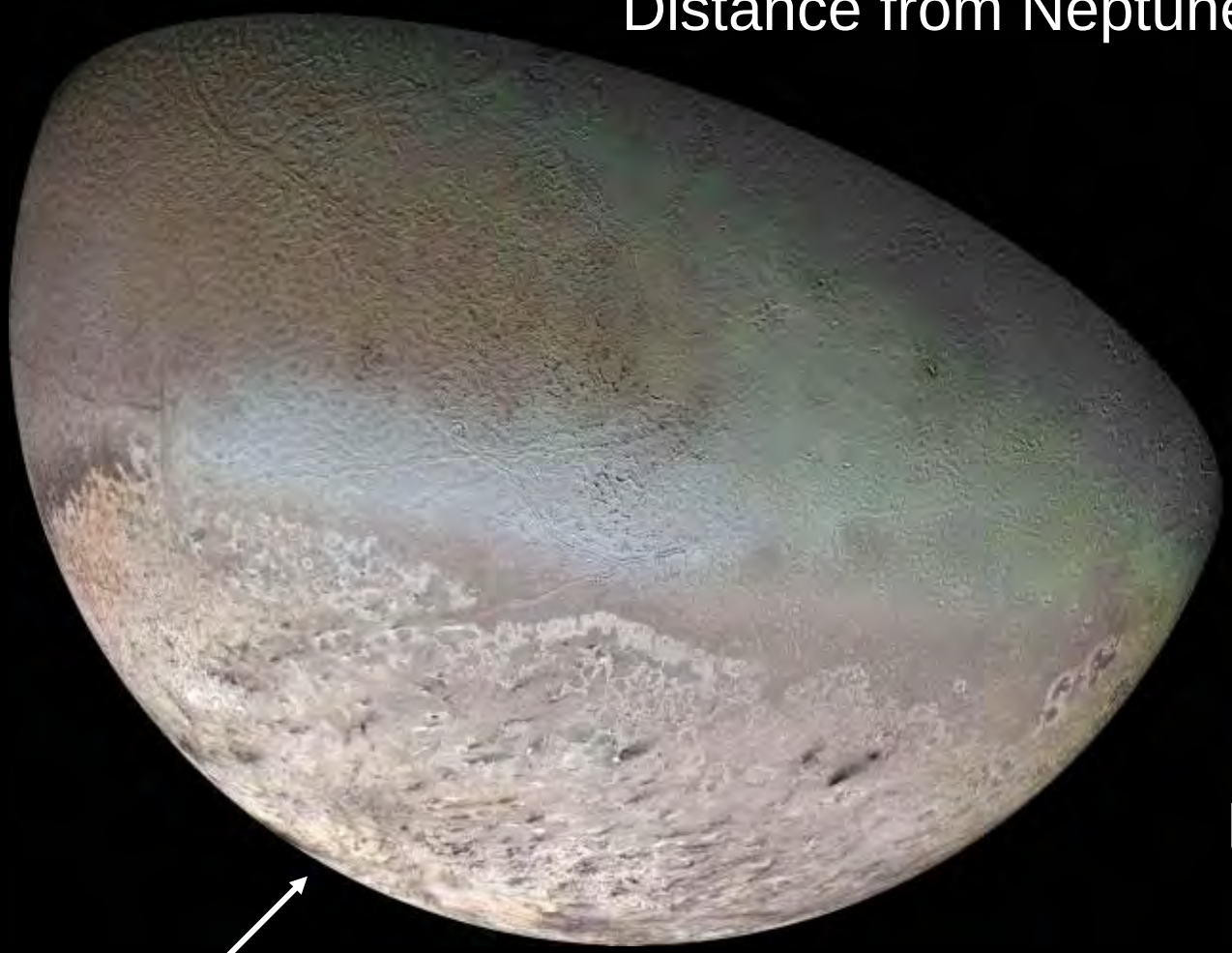


Irregular shape.
Craters (seen if resolution is enough).

Proteus, 210 km

Triton, satellite of Neptune, D = 2700 km

Voyager 2 image



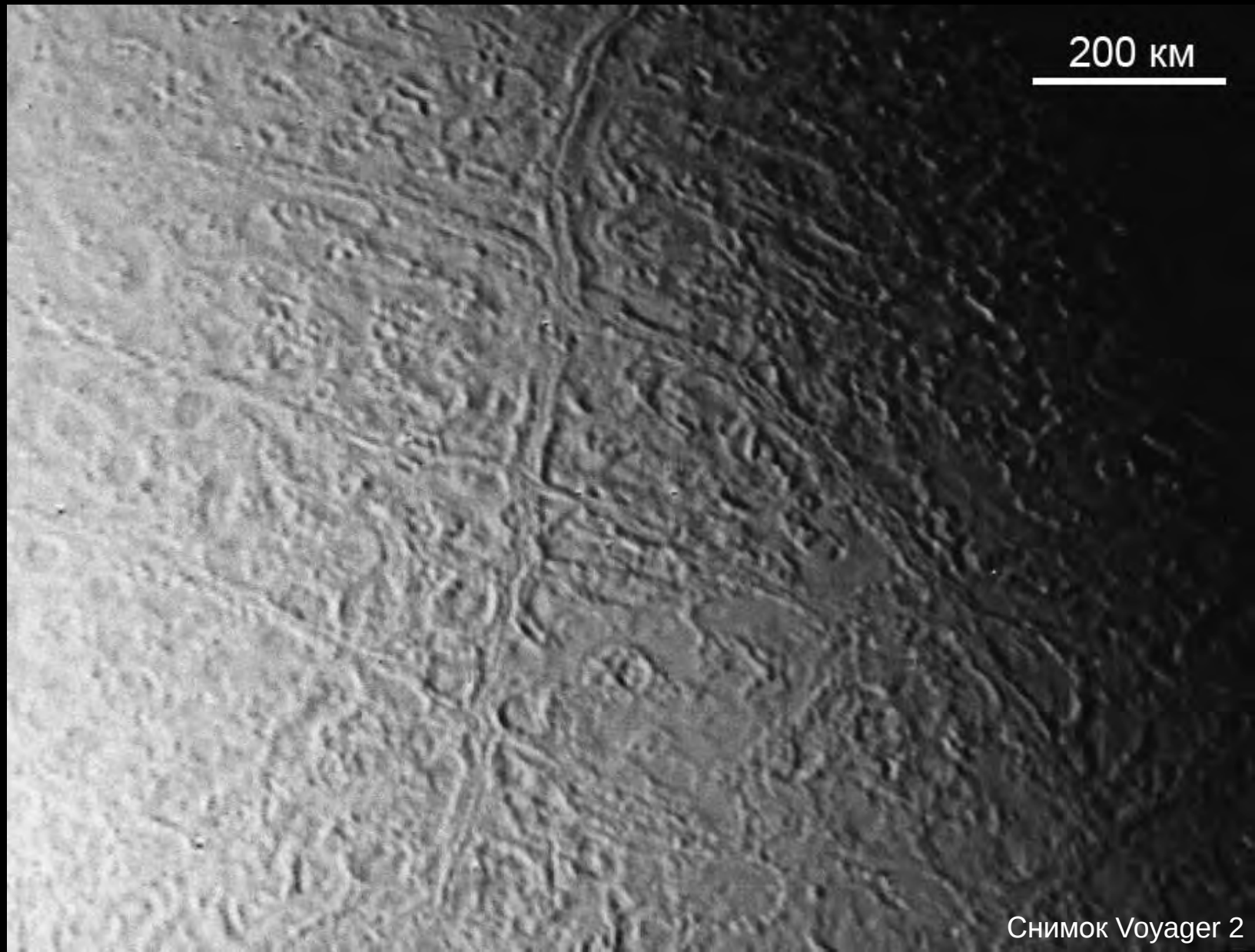
Distance from Neptune center 354,000 km
~14 R Neptune
M = 0.03 M Earth
ρ= 2.06 g/cm^3
g = 0.08 g Earth

Atmosphere:
N_2 dominates,
CH_4 admixture
P atm = 14 microbar
T surf. = 38 K

Polar cap

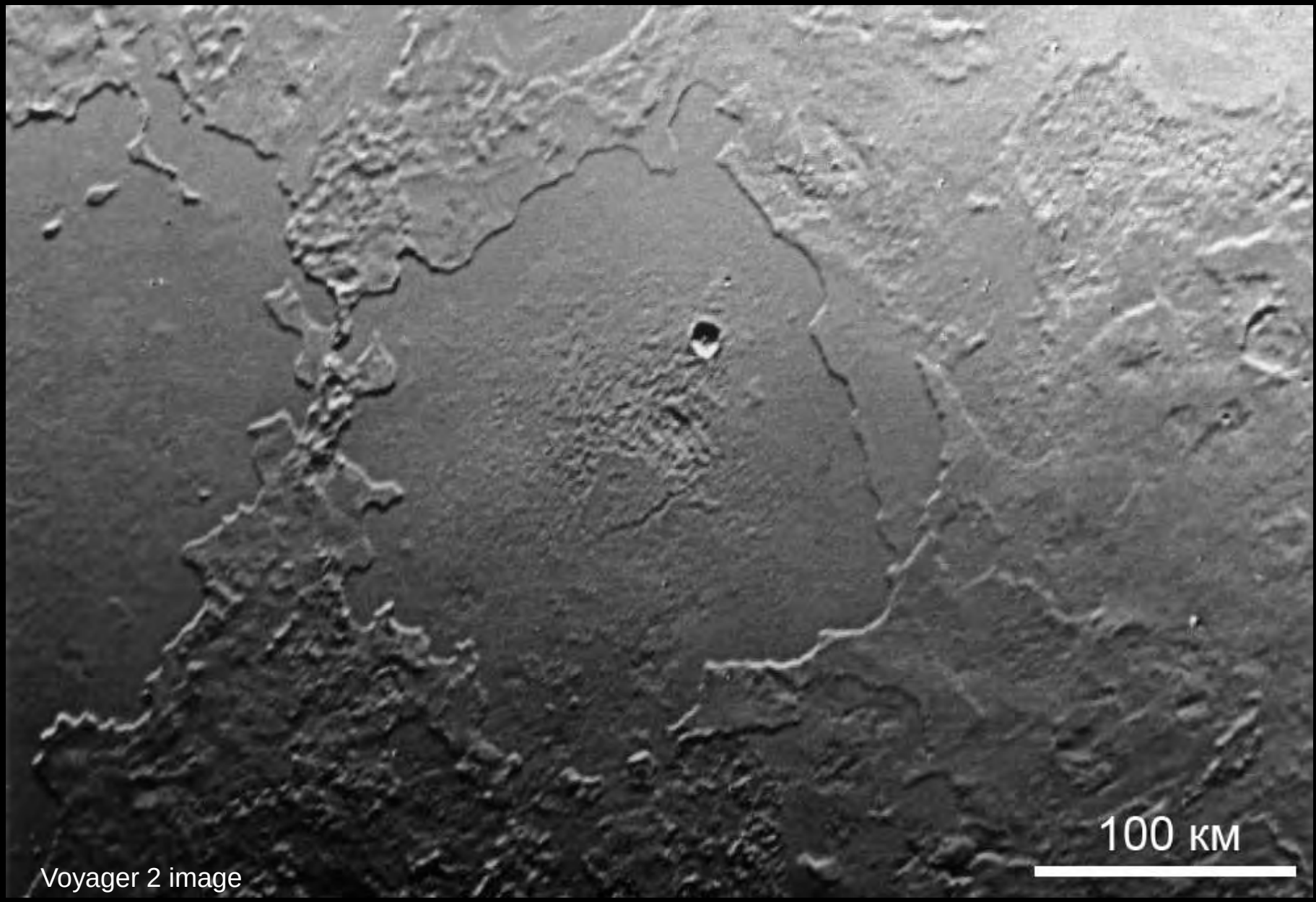
Cantalupa terrain Triton

Tectonic deformations



Снимок Voyager 2

Plains – products of water-ice (cryo) volcanism



Shadows from the nitrogen “geisers”

Outer planets summary:

Jupiter, Saturn, Uranus, Neptune
– large, essent. gaseous, distant from the Sun.

Pluto – small planet, => category of “dwarf planets” for Pluto and …will be considered below

JSUN have systems of satellites - similarity with Solar system

Satellites – from very large (Titan,…) to tiny.

Larger satellites show traces of “endogenic” activity, small ones – only impact cratering.

Larger size and distance from the Sun favor presence of atmosphere

Io and Europa show geologic effects of tidal heating.

Pluto – 9th from the Sun planet (39.4 a.u.), ≥ 3 satellites or Trans-Neptunian object

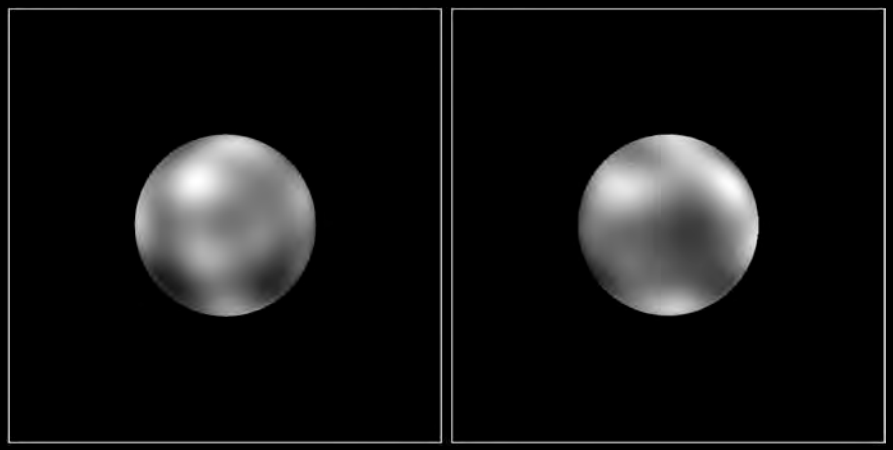
Pluto is classified as a dwarf planet and as an object of Kuiper belt

Binary system Pluto - Charon

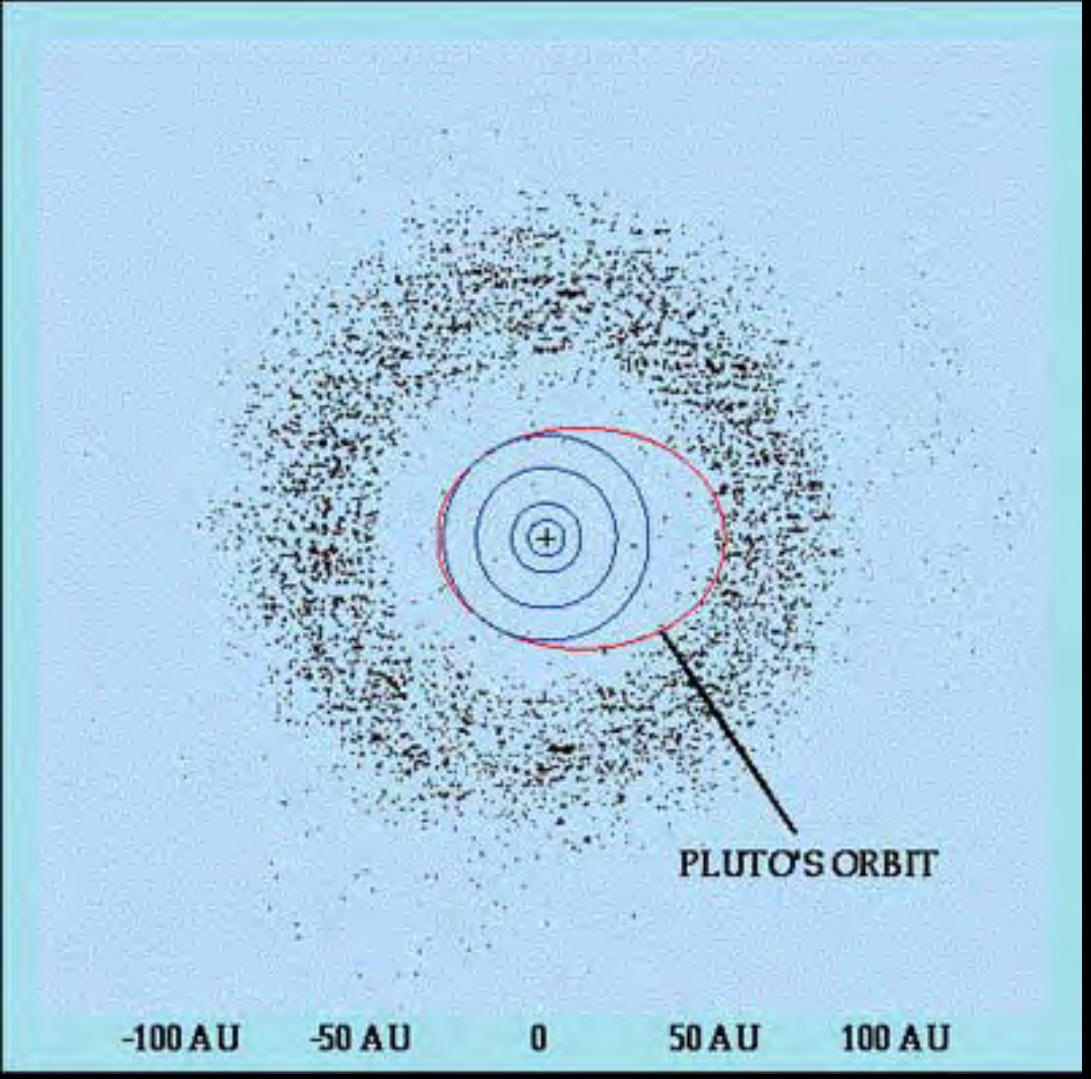
Pluto
D = 1200 km
ρ= 1.9 g/cm^3
Ices H_2O, NH_3
T surf. = 35-40 K
Atmosphere N_2
P atm < 60 microbar

Charon
D = 1200 km
ρ= 1.9 g/cm^3
Льды H_2O, NH_3
T surf. = 35-40 K
Atmospere ?
P atm < 60 microbar

Hubble Telescope images



Albedo details of Pluto surface

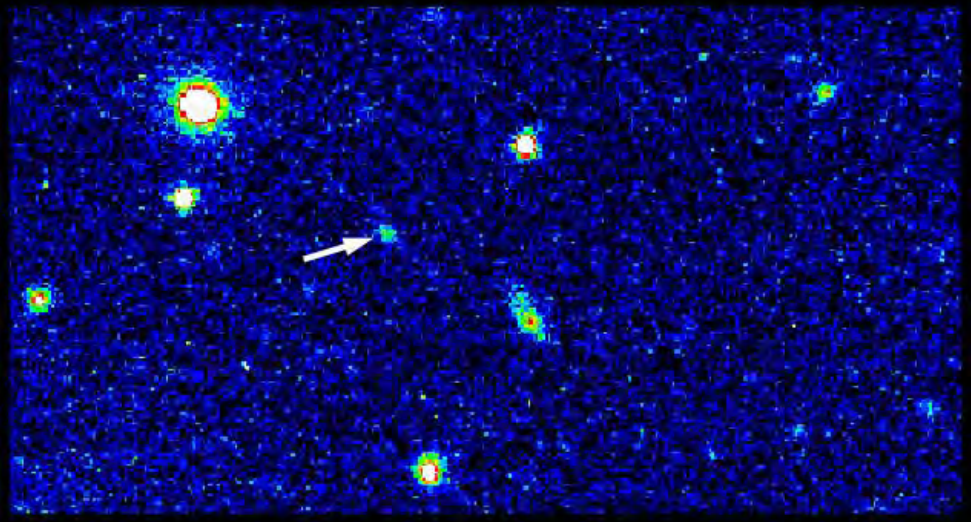


Kuiper belt – region of the Solar system out of Neptune orbit (30 au fro the Sun) and to ~50 au. In this region there are numerous objects the most known but not the largest is Pluto.

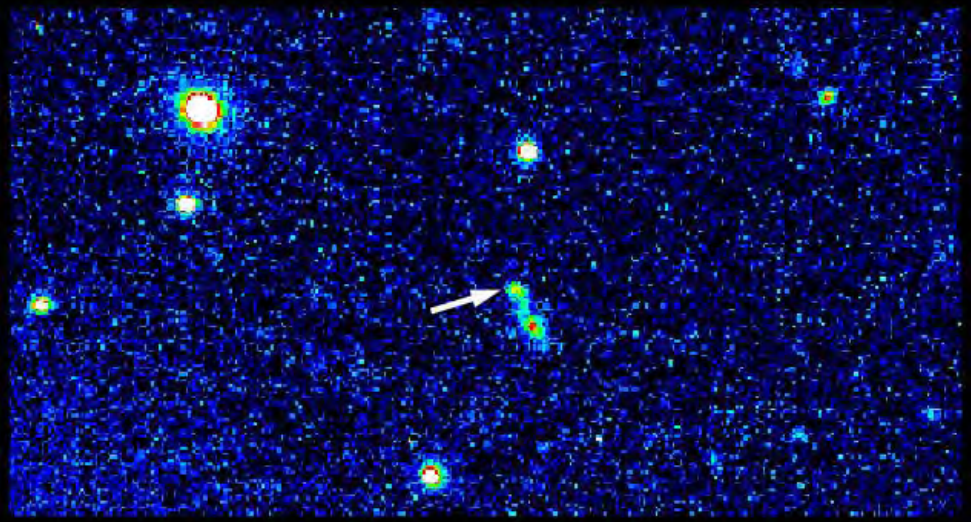
Named after Gerald Kuiper, who suggested its existence in 1951.

The total mass of Kuiper belt objects is by hundreds times larger than that of asteroid belt, but, as believed, Is essentially smaller than mass of the Oort cloud.

Trans-Neptunian objects – Kuiper belt



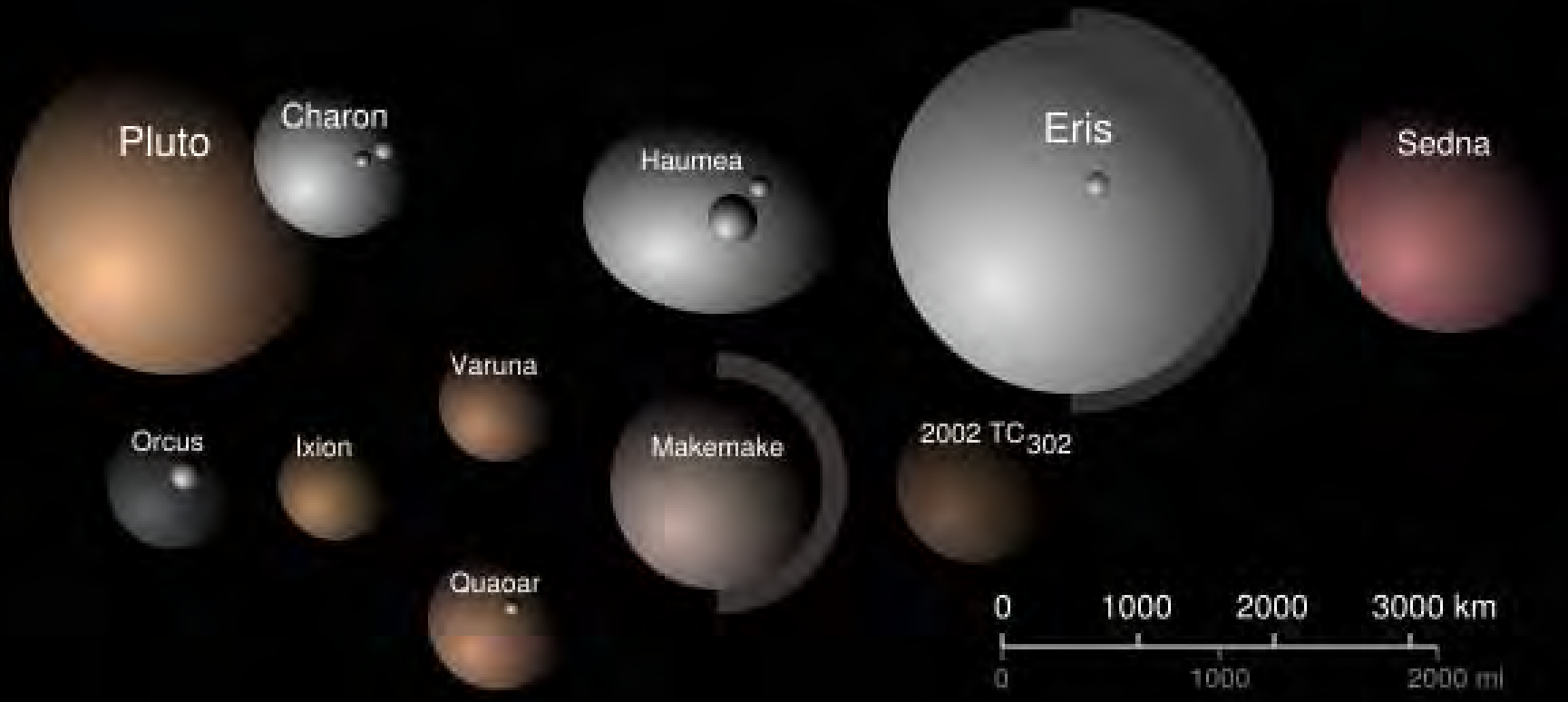
$\Delta T = 4.6$ hours



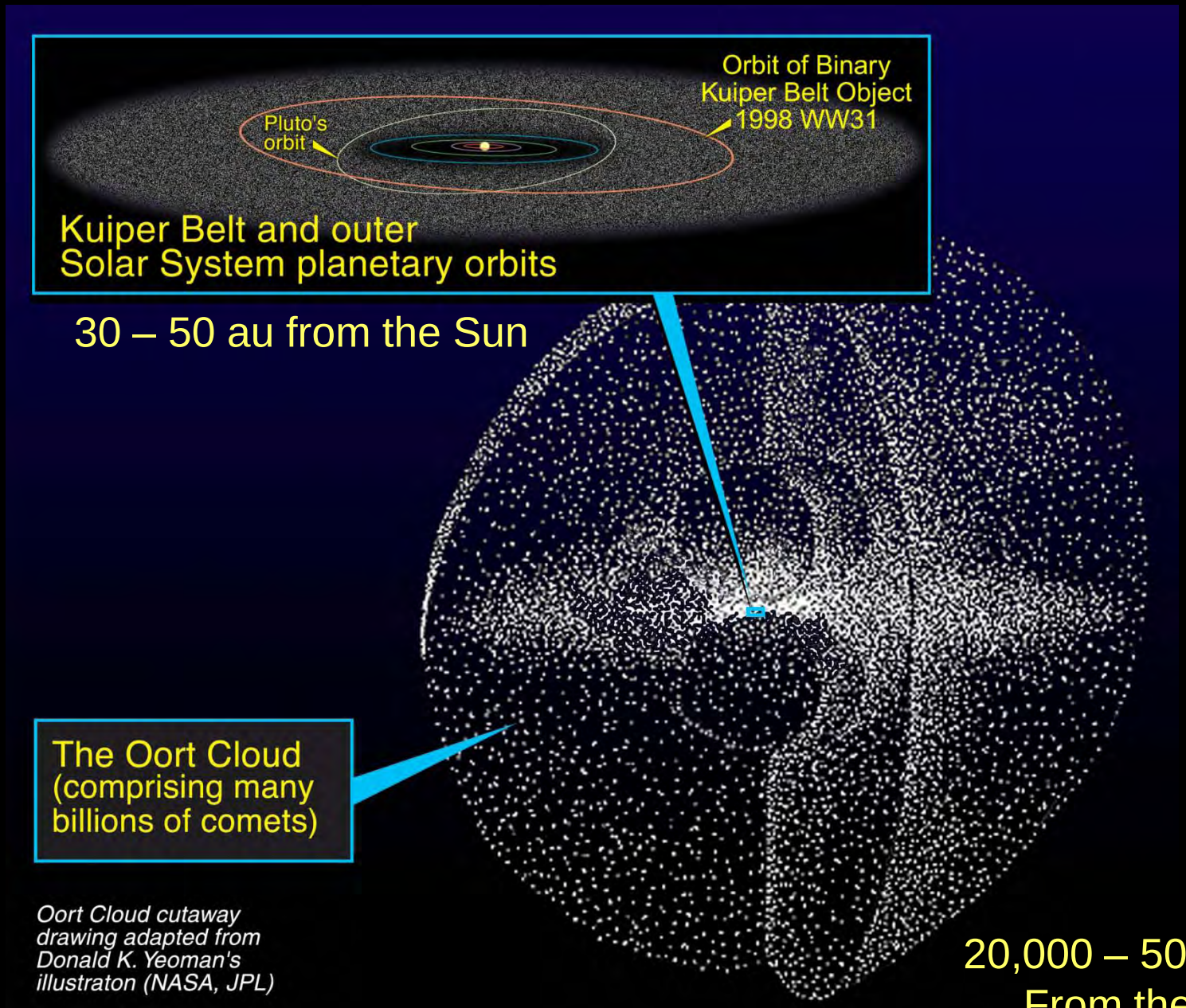
Object 1993 SC

http://www.aanda.org

Transneptunian objects – Kuiper belt
Largest from known: size, albedo, color



Kuiper belt and Oort Cloud



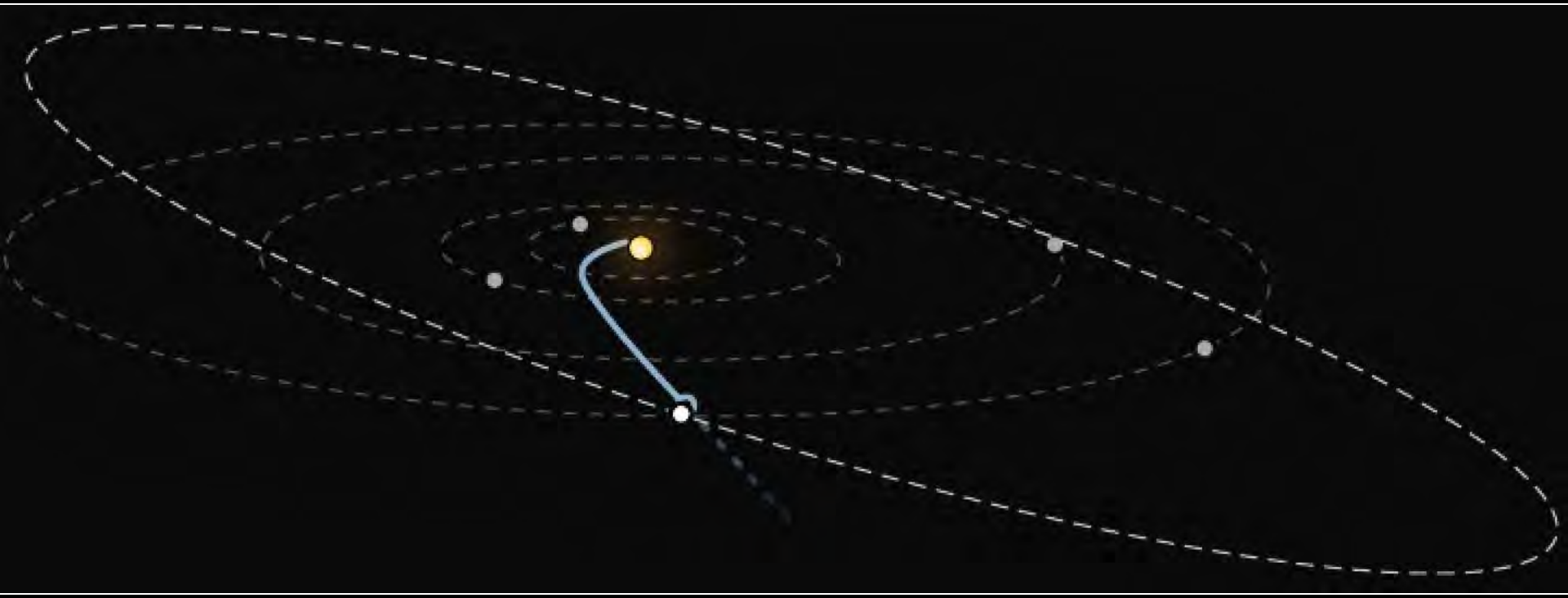
New Horizons – NASA mission to Pluto

Launched in Jan 19, 2006, Pluto flyby 14 July 2015 at 12,500 km from Pluto surface

Probably will study 2014 MU69 or 2014 PN70 ~100 km in diammeter at 1.6 billion km beyond Pluto

7 instruments: mapping spectrometers IR, Visible andи UV, sensors of cosmic dust elementary particles and plasma

New Horizons trajectory



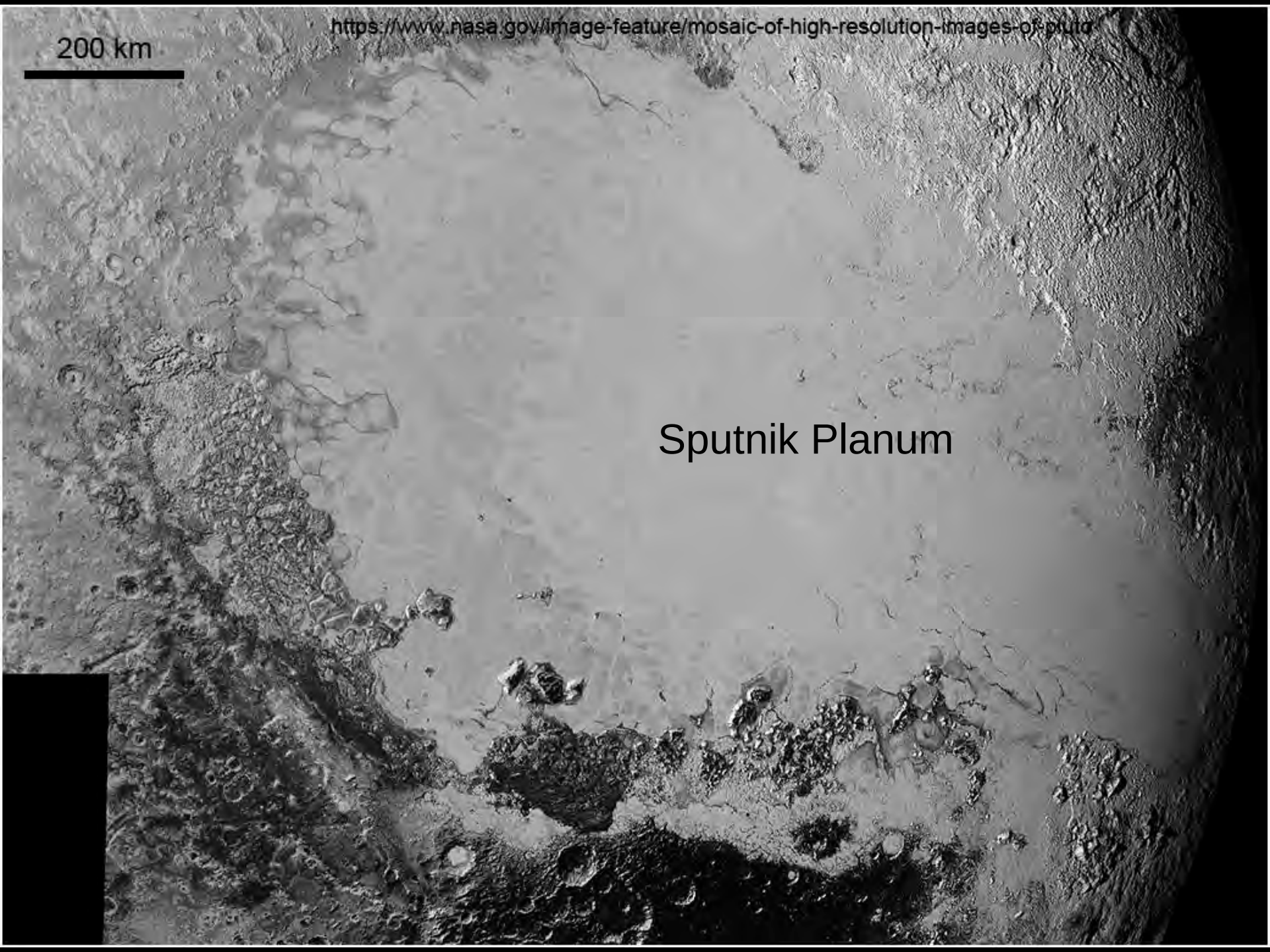
Charon

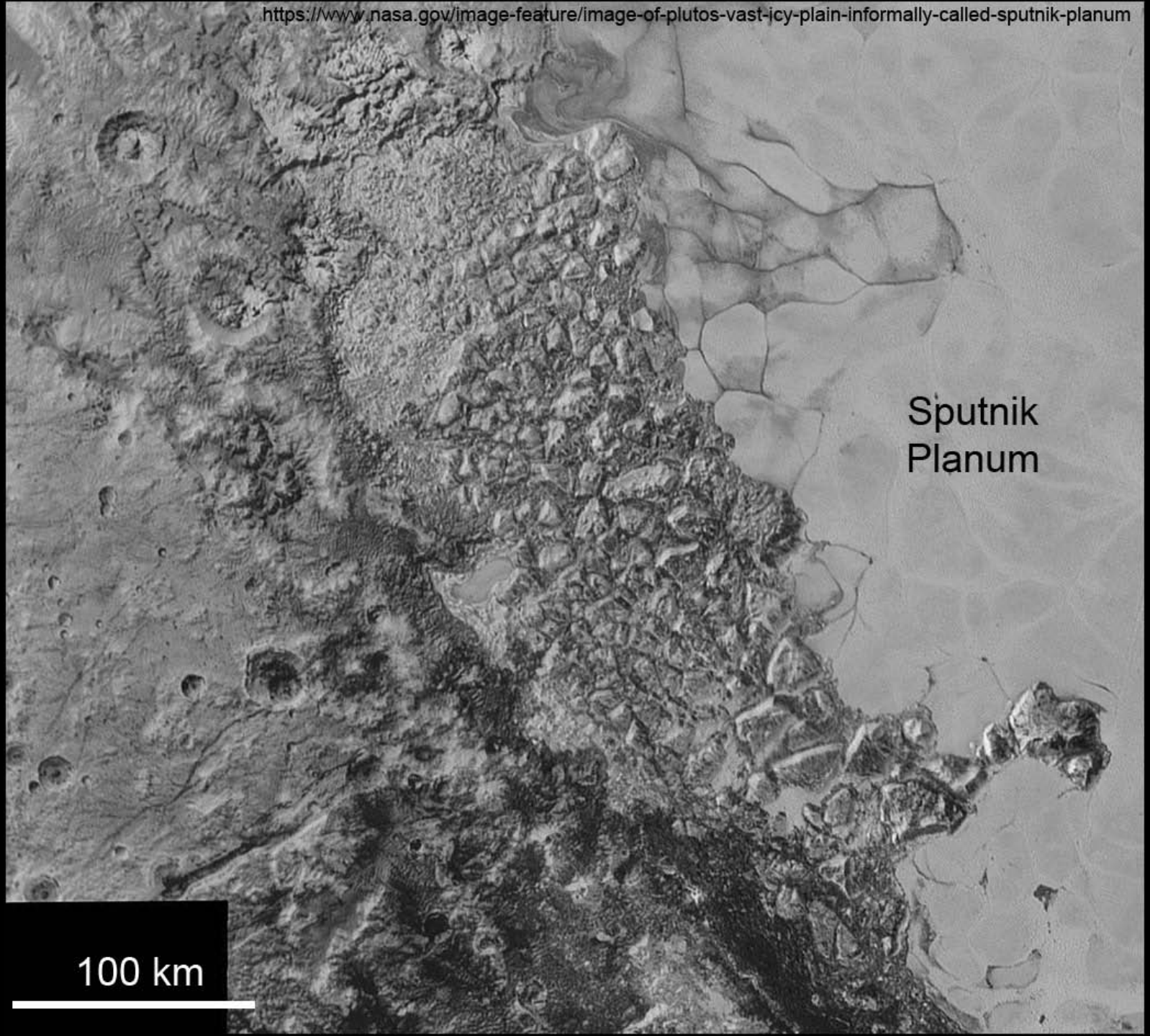
D = 1212 km
0.095 Earth
0.51 Pluto

Pluto

D = 2374 km
0.18 Earth

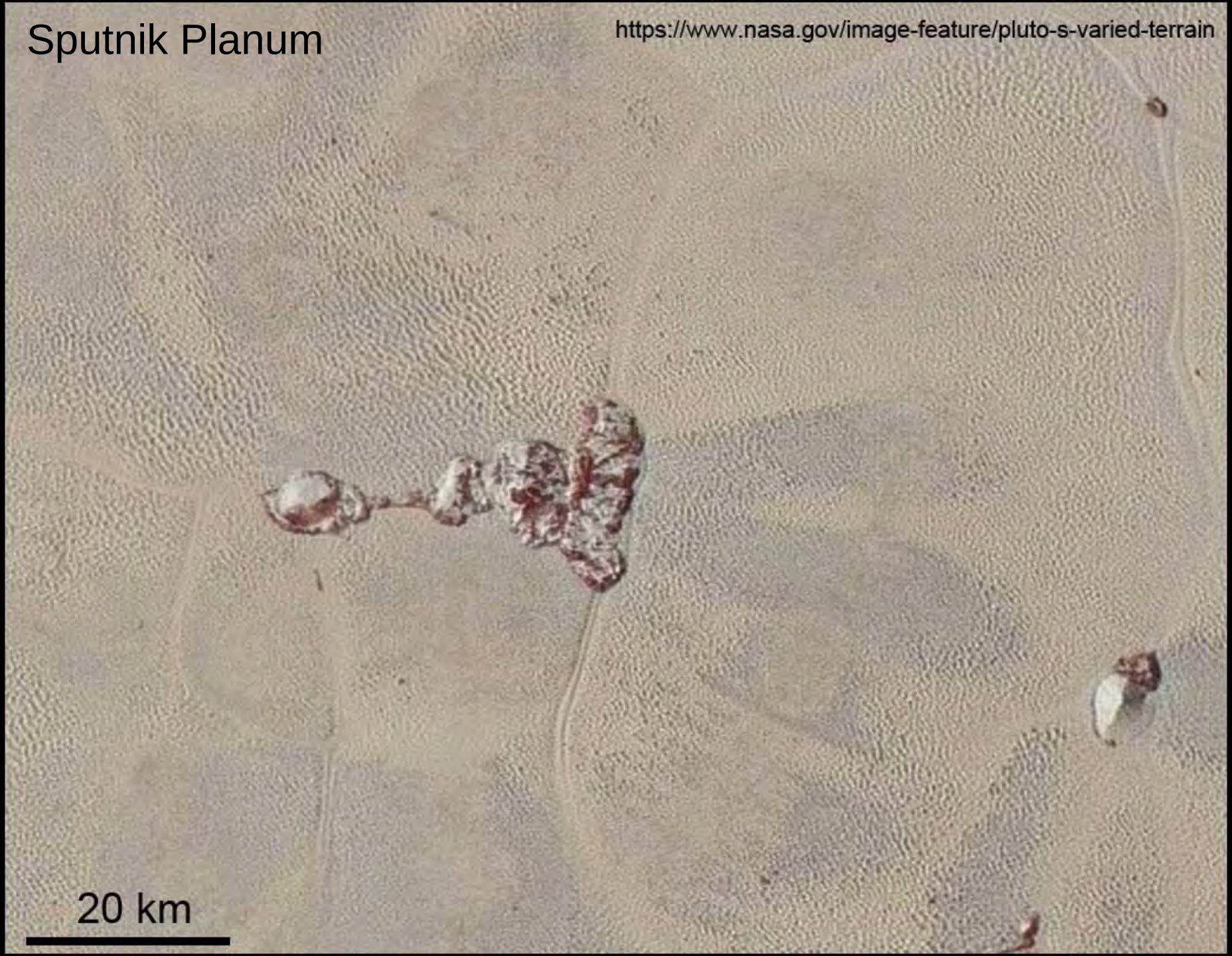
New Horizons


https://www.nasa.gov/image-feature/mosaic-of-high-resolution-images-of-pluto
200 km
Sputnik Planum


https://www.nasa.gov/image-feature/image-of-plutos-vast-icy-plain-informally-called-sputnik-planum
Sputnik
Planum
100 km

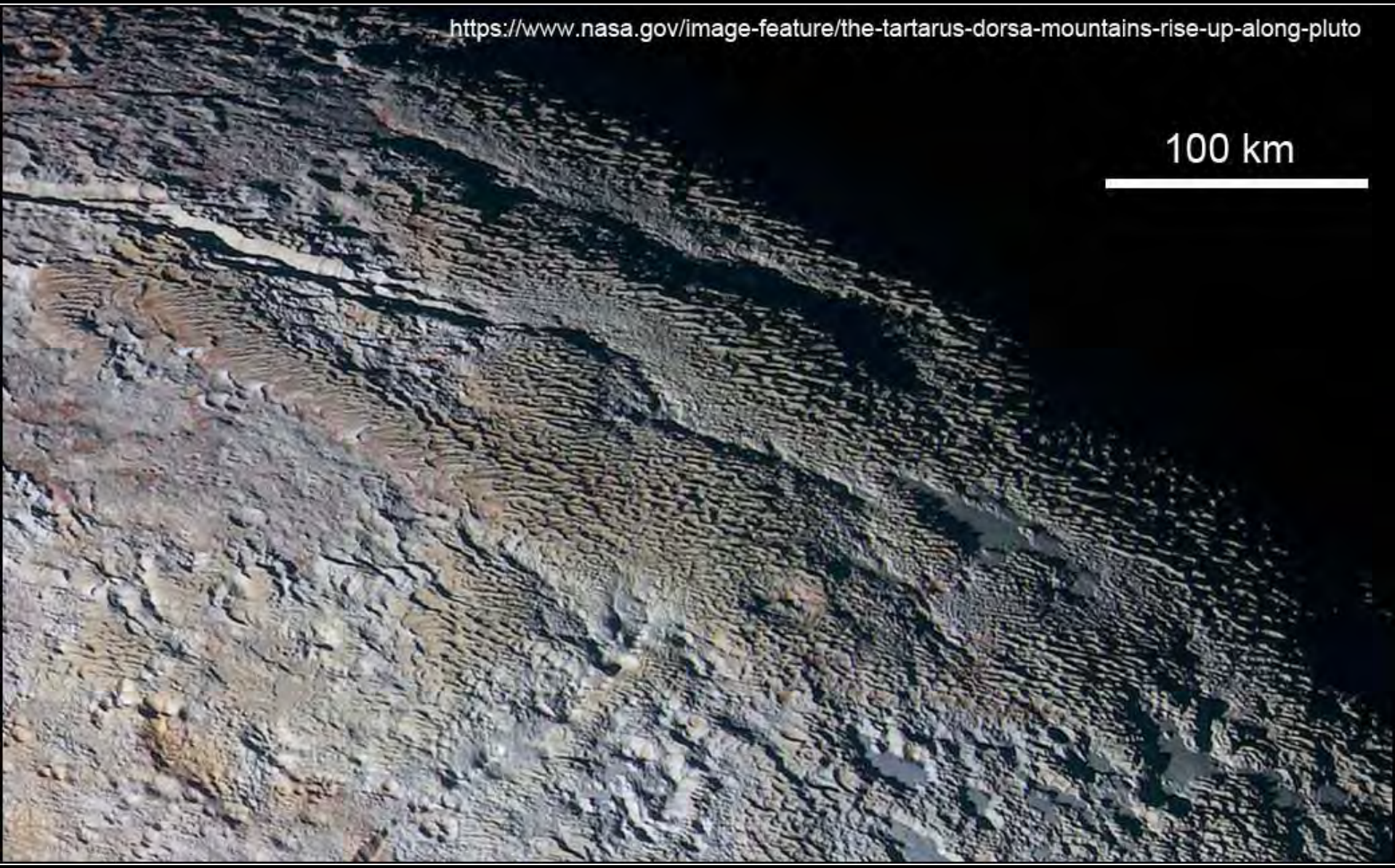
Sputnik Planum

https://www.nasa.gov/image-feature/pluto-s-varied-terrain




https://www.nasa.gov/feature/x-marks-a-curious-corner-on-pluto-s-icy-plains
10 km
Sputnik Planum

Pluto, Tartarus Dorsa

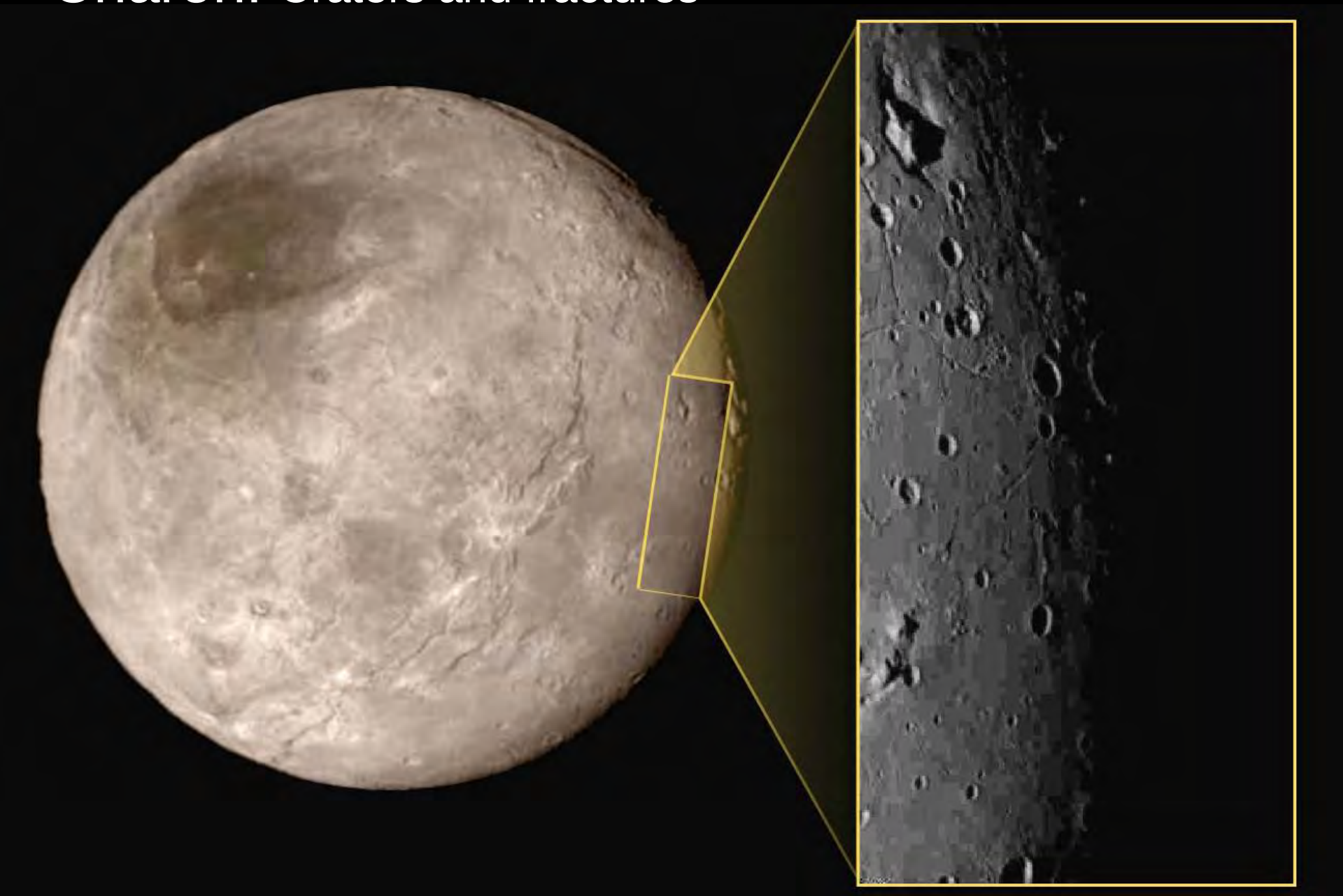


Origin unknown

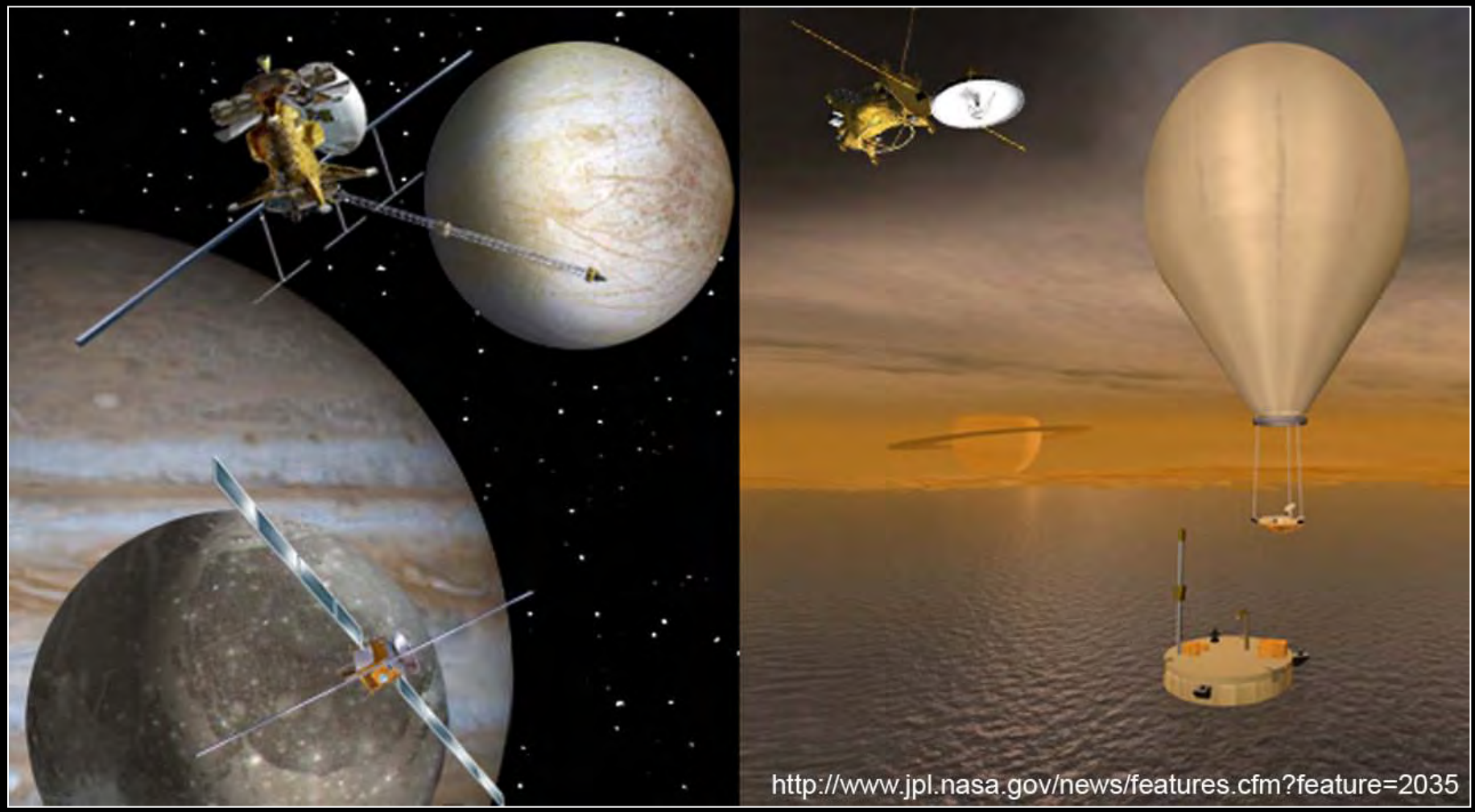
Charon:

Varieties of terrains and colors

Charon: Craters and fractures



Future mission to outer planets

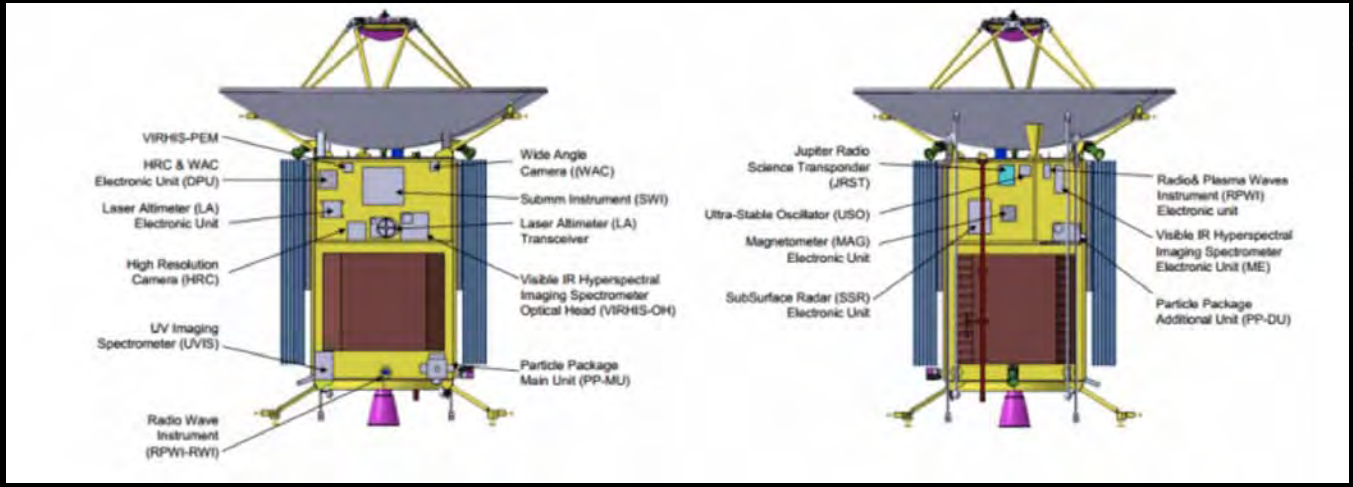


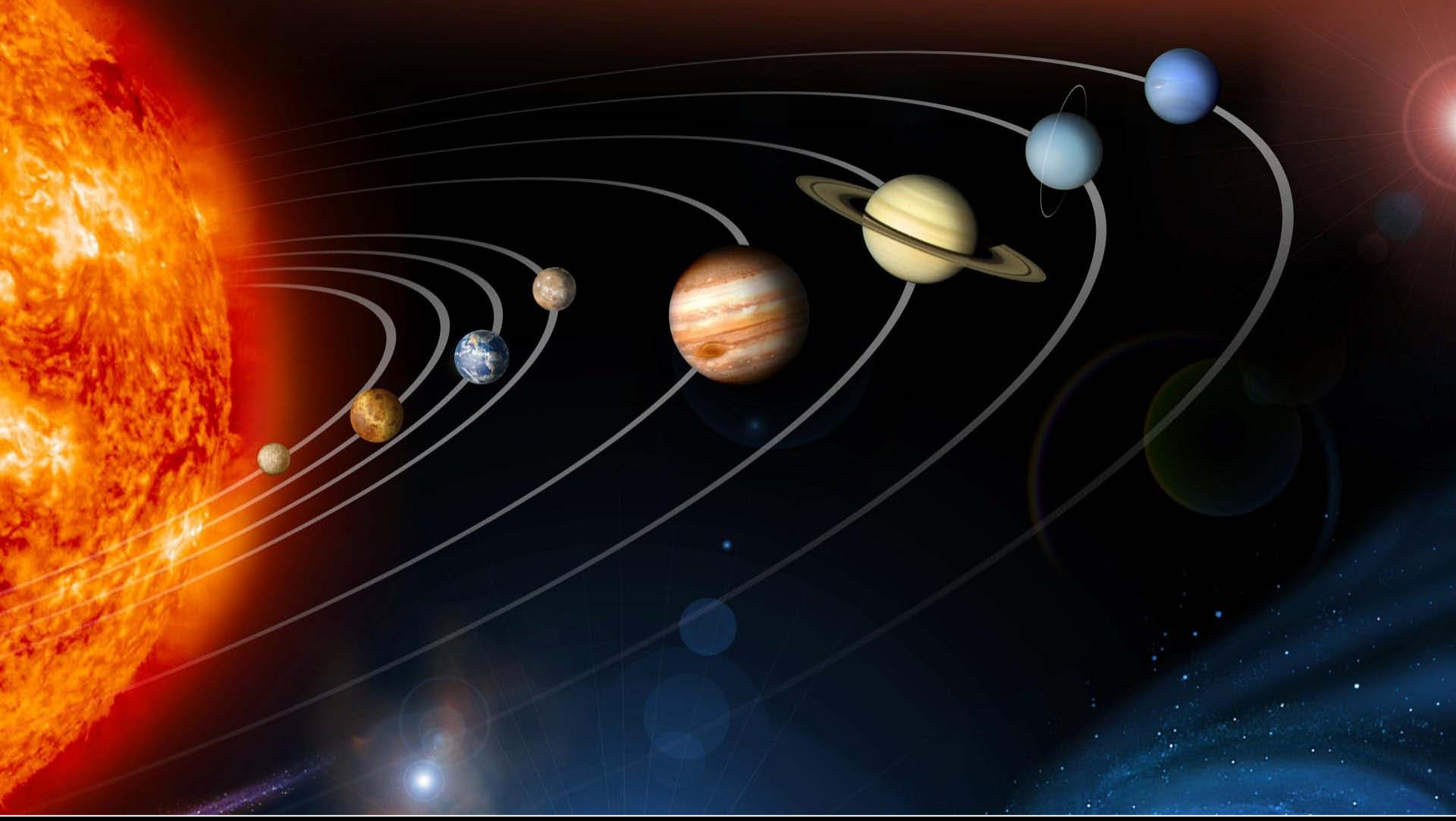
Europa Jupiter System Mission and Titan Saturn System Mission
NASA, ESA, possible participation of Russia

JUICE - JUpiter ICy moons Explorer

is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme.

Planned for launch in 2022 and arrival at Jupiter in 2030, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa





Thank you for your attention!