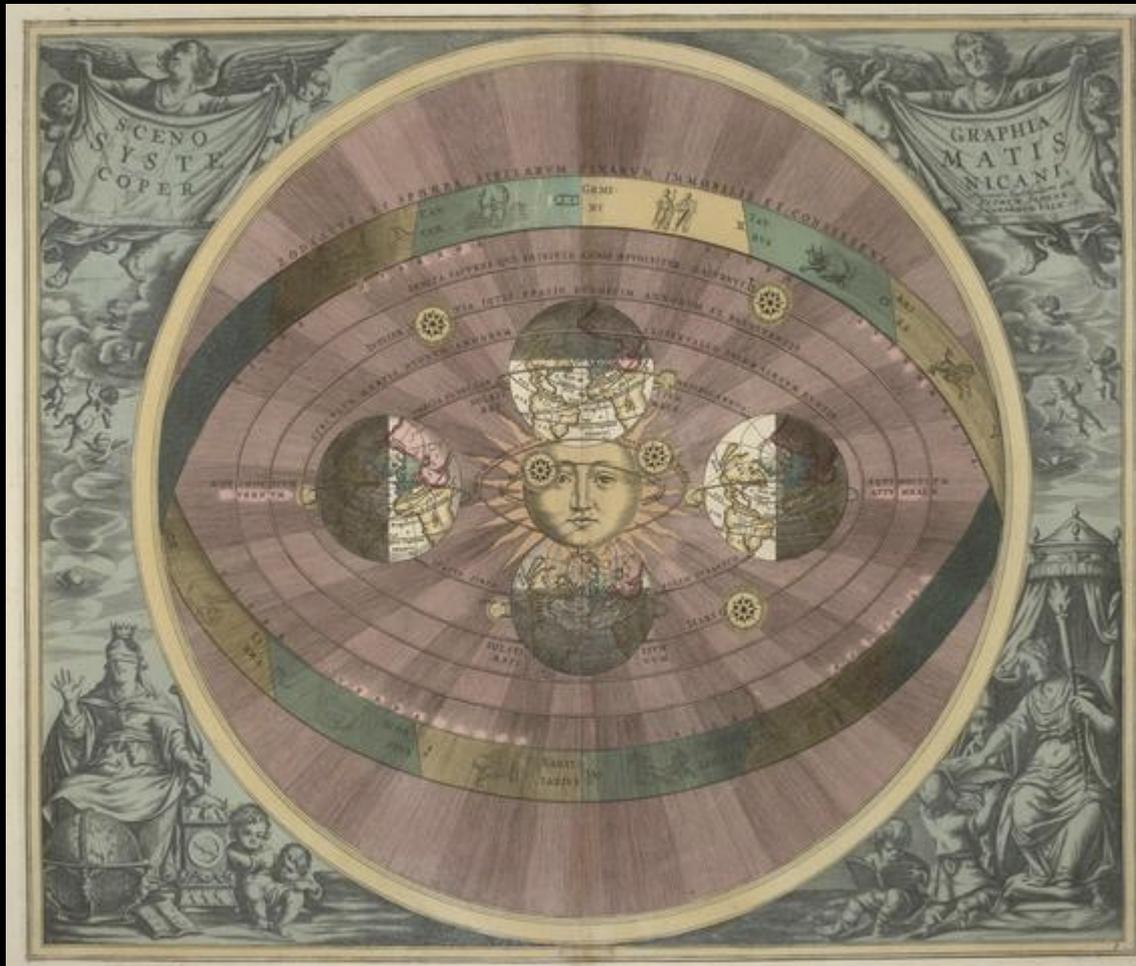


# Propriedades do SS

Aula 7 – Tópicos 2018-1

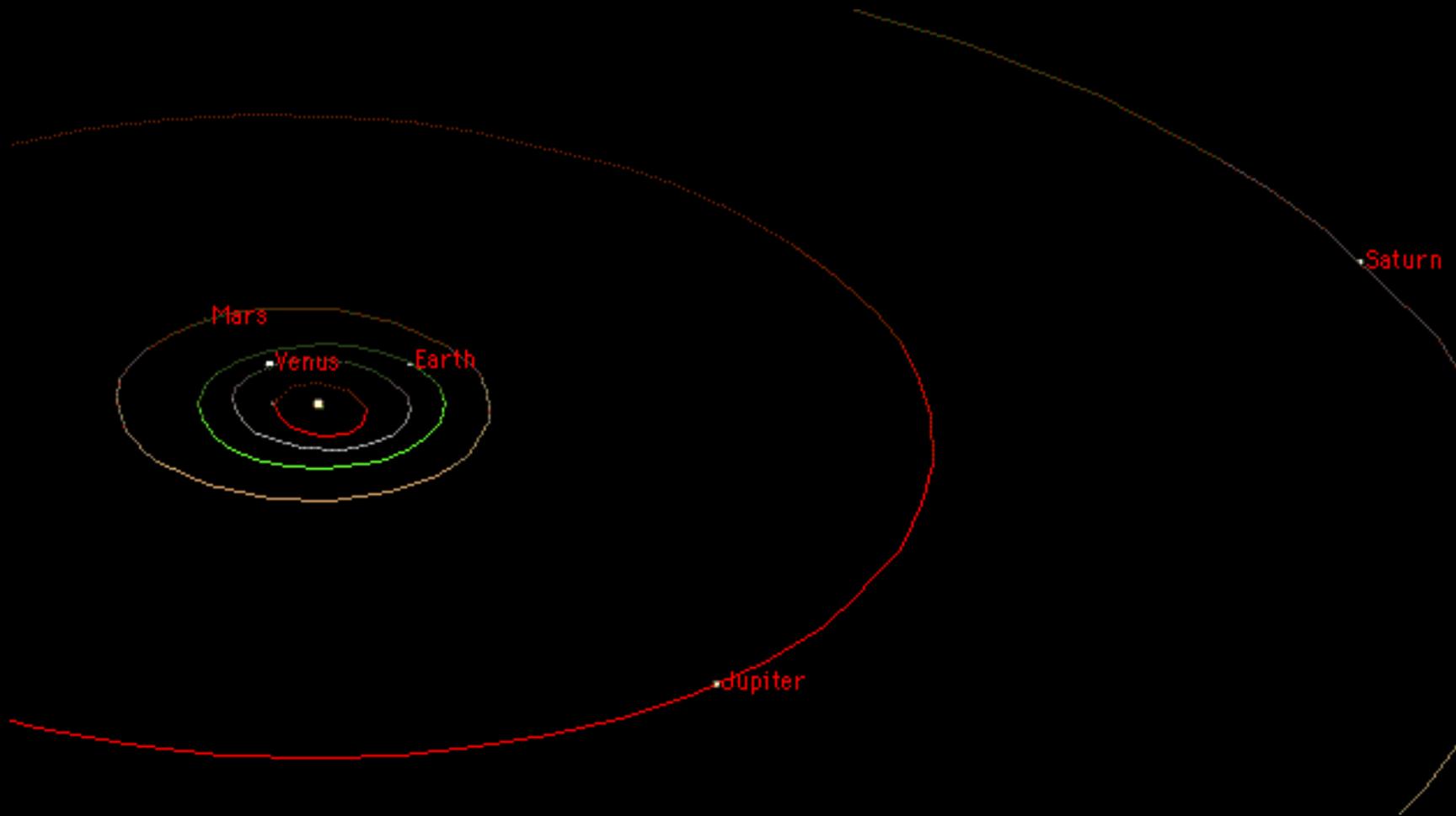


Andreas Cellarius's illustration of the Copernican system, from the *Harmonia Macrocosmica* (1660)

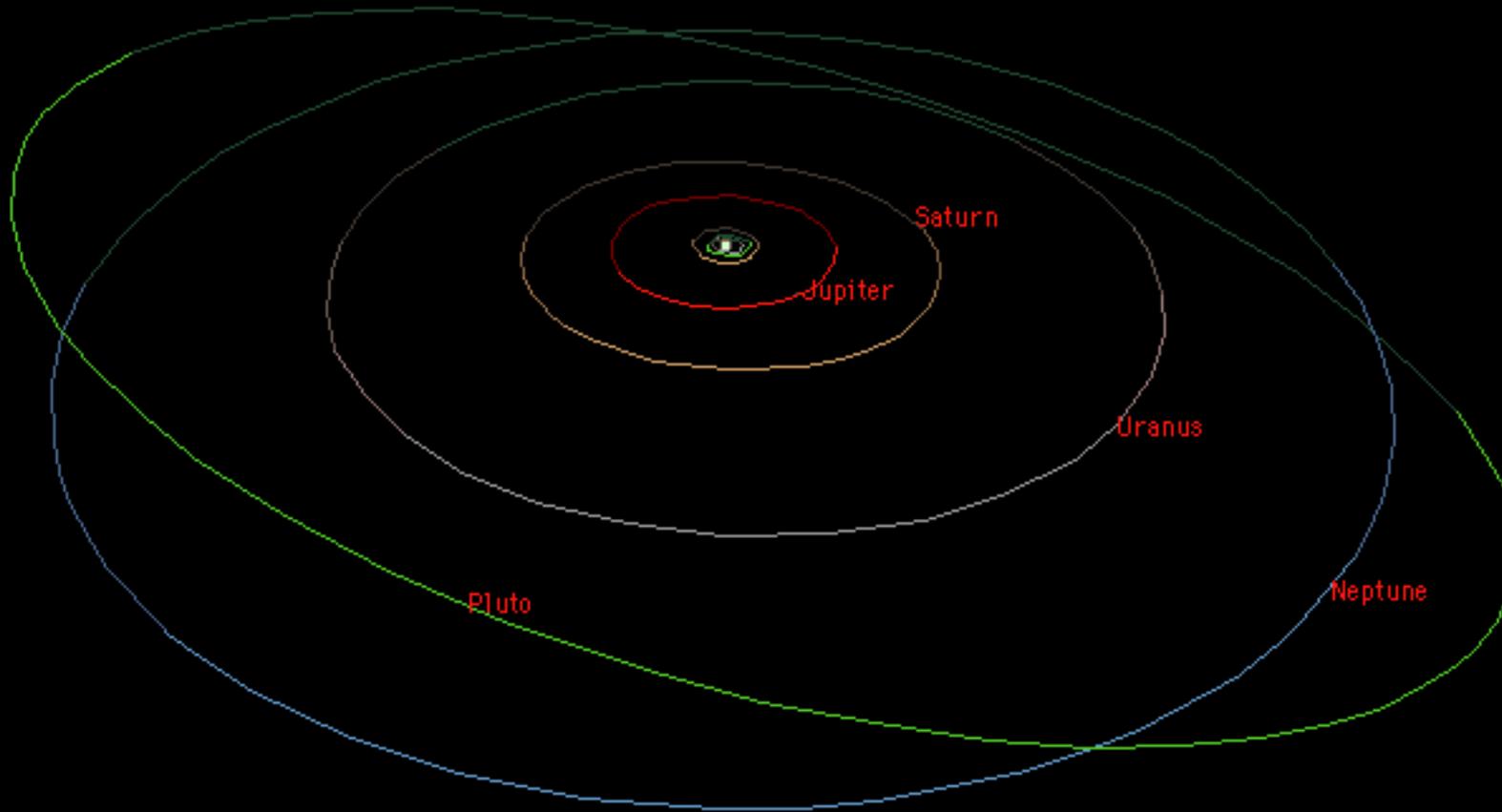
# Sistema Solar

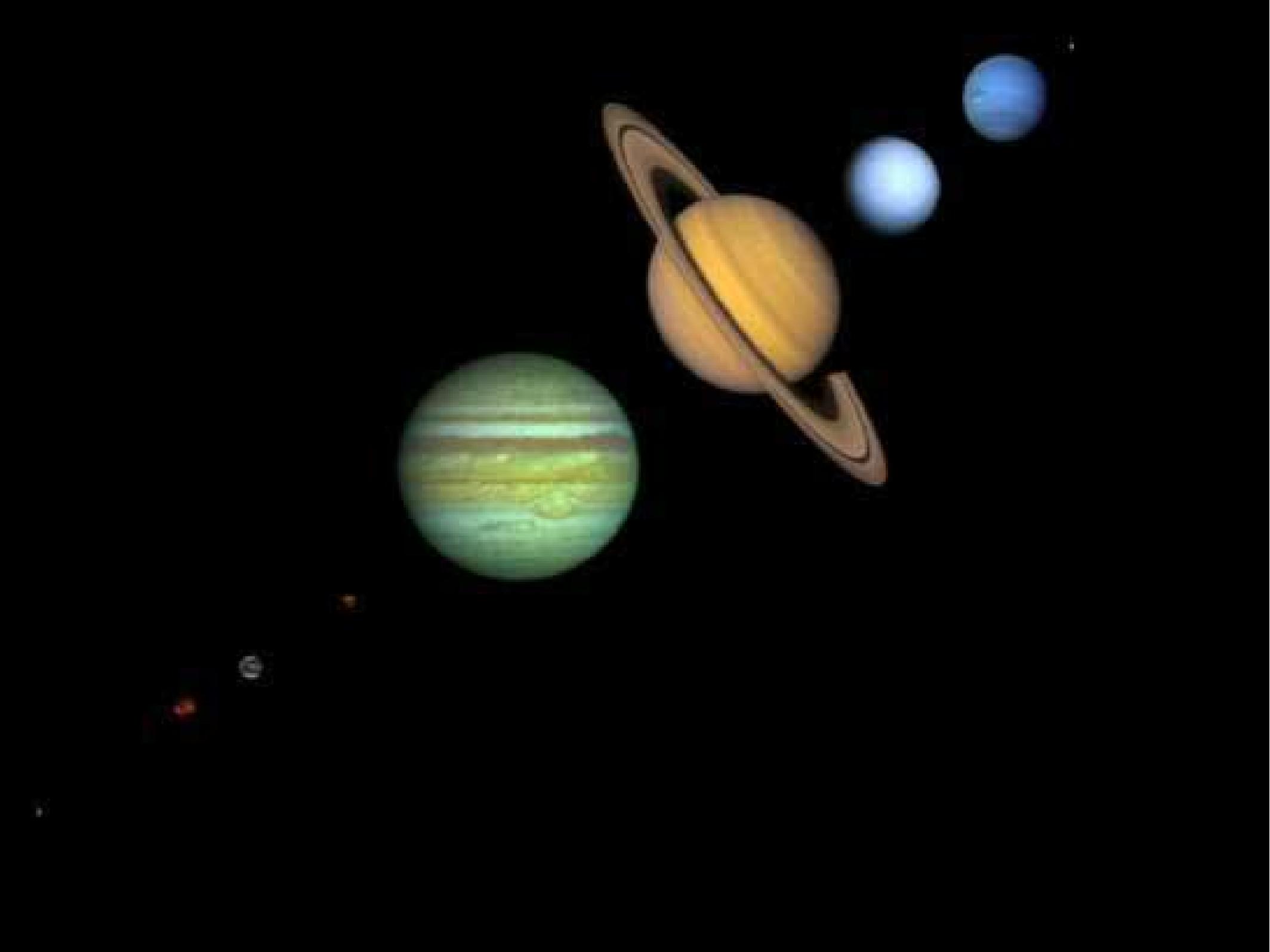
- Sistema gravitacional composto pelo Sol e os corpos celestes que estão em órbita em torno dele.
- Mercúrio, Venus, Terra, Marte, Júpiter, Saturno, Urano, Netuno, planetas anões (Plutão, Ceres, etc) e mais de 130 satélites, meio interplanetário
- o cinturão de asteróides
- os cometas
- o cinturão de Edgeword-Kuiper
- a Nuvem de Oort

# Sistema Solar “Interno”: Sol, Mercúrio, Vênus, Terra e Marte



# Sistema Solar “Externo”: Júpiter, Saturno, Urano, Netuno, Plutão (planeta anão)





# O que é e o que não é um planeta?

- A discussão em torno do status de Plutão na XXVI Assembleia Geral da IAU mostrou o quão confusa pode ser a definição de uma classe de corpos celestes **definida antes pela tradição do que pela ciência.**
- *Planeta : corpo celeste que esteja em órbita de uma estrela, que tenha massa suficiente para que sua autogravidade supere as forças de corpo rígido e o permita assumir forma de equilíbrio hidrostático (i.e., aproximadamente esférica) e que tenha limpado sua vizinhança orbital.*

# Planetas anões

- In 2006, a IAU decidiu criar uma nova classificação para objetos do Sistema Solar chamada “**Planetas Anões**”.
- Plutão foi reclassificado nesta categoria
- 5 no total
- É provável que no futuro muitos outros planetas anões sejam descobertos no cinturão de Kuiper Belt.

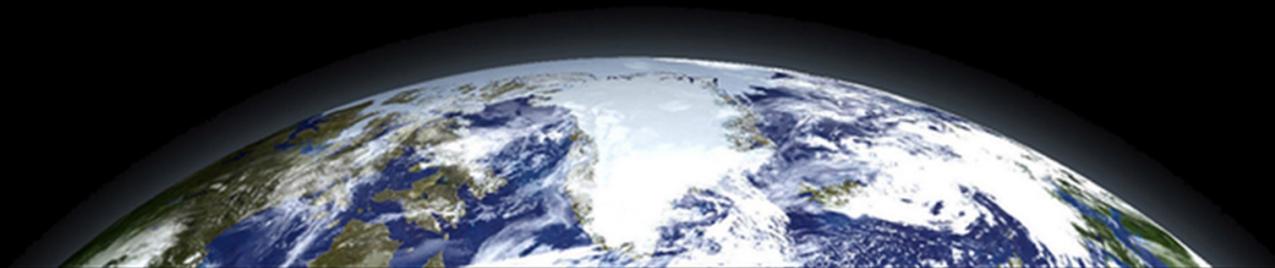
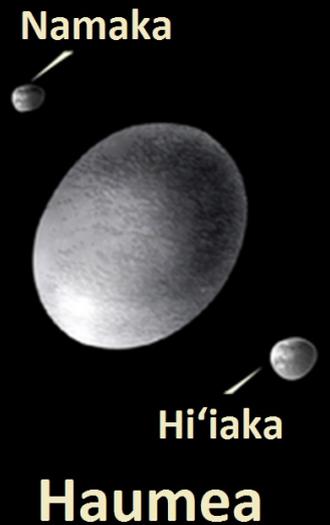
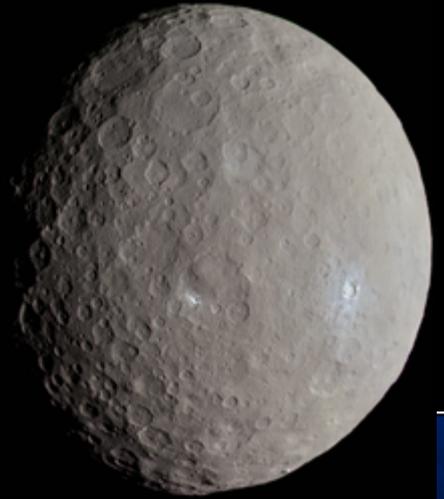
# Definição: planeta anão

- Está em órbita do Sol,
- Tem massa suficiente para se tornar um corpo rígido e esférico
- Não tem nada nas vizinhanças
- Não é um satélite

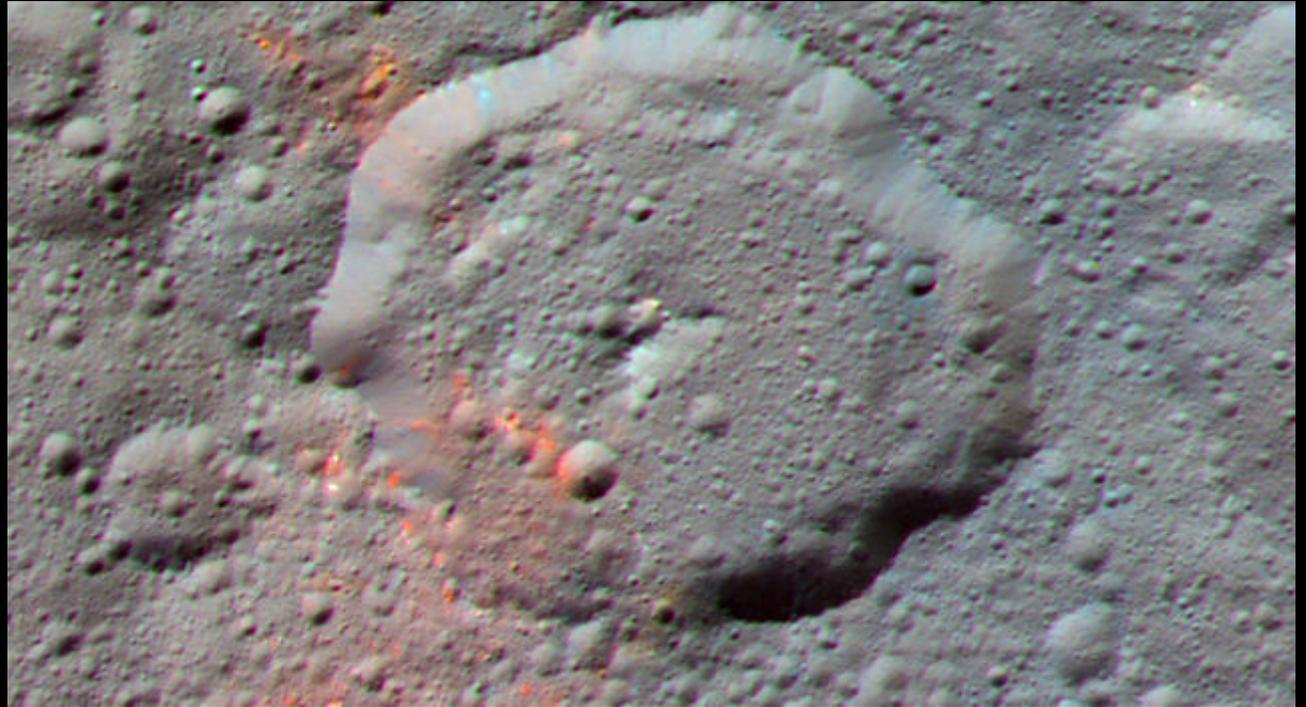
- Plutão
- Ceres
- Eris
- Makemake
- Haumea

# Planetas anões

Ceres



# Ceres



## **Dawn Discovers Evidence for Organic Material on Ceres**

"This is the first clear detection of organic molecules from orbit on a main belt body," said Maria Cristina De Sanctis, lead author of the study, based at the National Institute of Astrophysics, Rome. The discovery is reported in the journal *Science*.

Em 2015, NASA's New Horizons enviou o primeiro close-up de Plutão e suas 5 luas

Essa imagem composta mostra This composite of enhanced color images of **Plutão (abaixo, a direita) e Caronte (acima, a esquerda)**, feita pela New Horizons-NASA em 14-7-2015

Credits: NASA/JHUAPL/SwRi

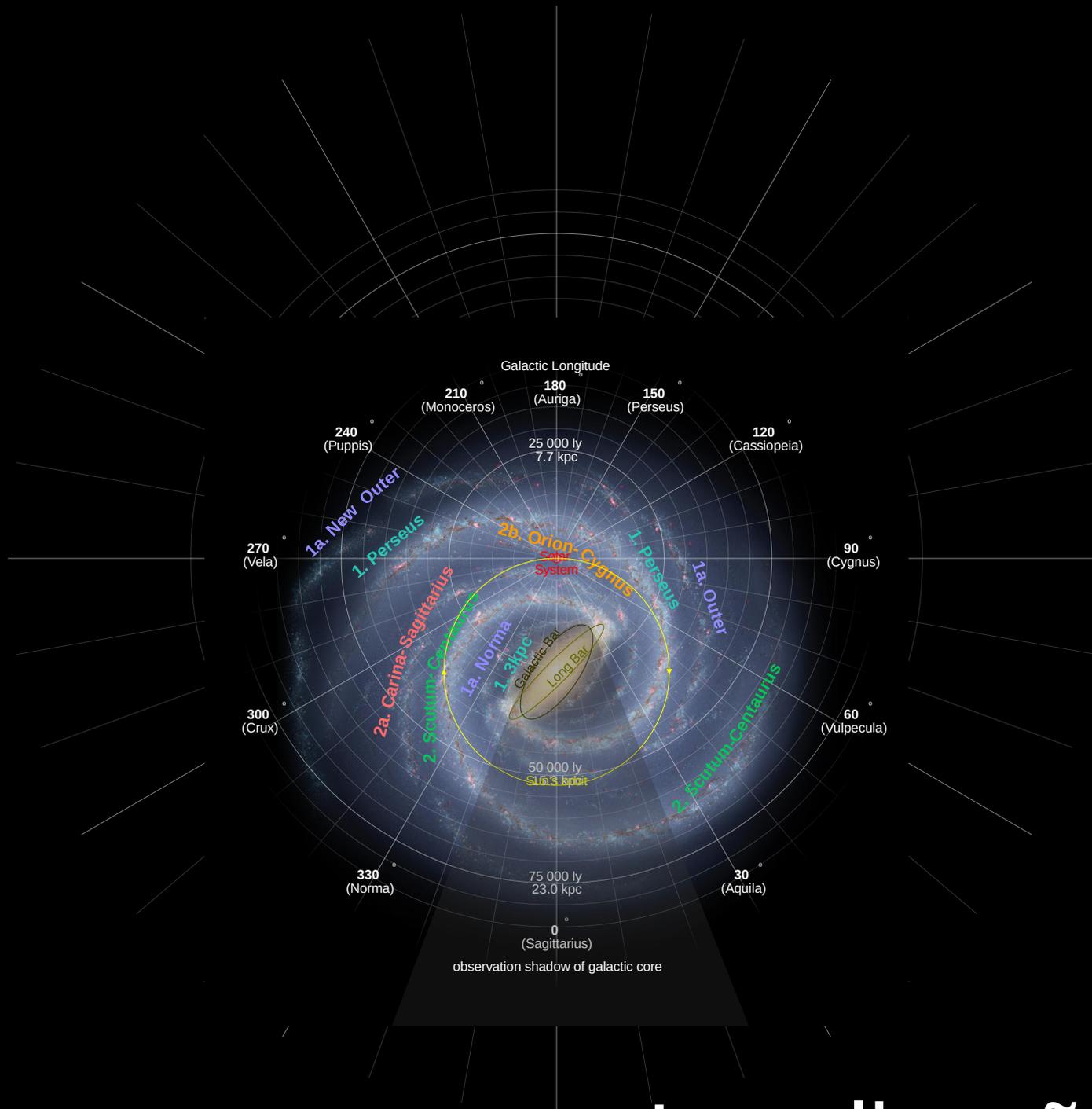


**TABLE 6.1 Properties of Some Solar-System Objects**

<b>Object</b>	<b>Orbital Semimajor Axis (A.U.)</b>	<b>Orbital Period (Earth Years)</b>	<b>Mass (Earth Masses)</b>	<b>Radius (Earth Radii)</b>	<b>Number of Known Satellites</b>	<b>Rotation Period* (days)</b>	<b>Average Density (kg/m<sup>3</sup>) (g/cm<sup>3</sup>)</b>	
Mercury	0.39	0.24	0.055	0.38	0	59	5400	5.4
Venus	0.72	0.62	0.82	0.95	0	-243	5200	5.2
Earth	1.0	1.0	1.0	1.0	1	1.0	5500	5.5
Moon	—	—	0.012	0.27	—	27.3	3300	3.3
Mars	1.52	1.9	0.11	0.53	2	1.0	3900	3.9
Ceres (anão)	2.8	4.7	0.00015	0.073	0	0.38	2700	2.7
Jupiter	5.2	11.9	318	11.2	61	0.41	1300	1.3
Saturn	9.5	29.4	95	9.5	31	0.44	700	0.7
Uranus	19.2	84	15	4.0	27	-0.72	1300	1.3
Neptune	30.1	164	17	3.9	12	0.67	1600	1.6
Pluto (anão)	39.5	248	0.002	0.2	1	-6.4	2100	2.1
Comet Hale-Bopp	180	2400	$1.0 \times 10^{-9}$	0.004	—	0.47	100	0.1
Sun	—	—	332,000	109	—	25.8	1400	1.4

\*A negative rotation period indicates retrograde (backward) rotation relative to the sense in which all planets orbit the Sun.

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# Localização do SS

# Características do Sistema Solar

- Um modelo que seja capaz de explicar a formação do Sistema Solar deve dar conta de algumas características desse sistema:
  1. Órbitas planetárias coplanares
  2. O plano equatorial do Sol jaz nesse mesmo plano
  3. Os planetas e o Sol revolucionam no mesmo sentido prógrado (ou direto)
  4. As órbitas planetárias são aproximadamente circulares
  5. Os planetas possuem mais momento angular do que o Sol e este possui menos momento angular do que deveria ter se tivesse conservado o momento angular da nebulosa solar
  6. Alguns **meteoritos** possuem inclusões de material formado a temperaturas mais elevadas do que aquele do meteorito em si. Essas inclusões possuem razões isotópicas distintas
  7. Os planetas diferem em composição; essa diferença correlaciona-se com a distância ao Sol
  8. **Meteoritos** diferem em composição e propriedades geológicas de todas as rochas terrestres e lunares
  9. Todos os planetas e satélites estudados mais de perto apresentam crateras de impacto
  10. Exceto Vênus e Urano, todos os planetas rotam progradamente com inclinação menor do que  $29^\circ$
  11. A maioria dos planetas rotacionam com período de 5 a 10 hs, exceto aqueles que foram desacelerados por força de maré
  12. Como um grupo, as órbitas cometárias formam um enxame esférico ao redor do Sistema Solar
  13. Os principais sistemas de satélites assemelham-se ao Sistema Solar em miniatura.

# Hipótese Nebular da Cosmogonia

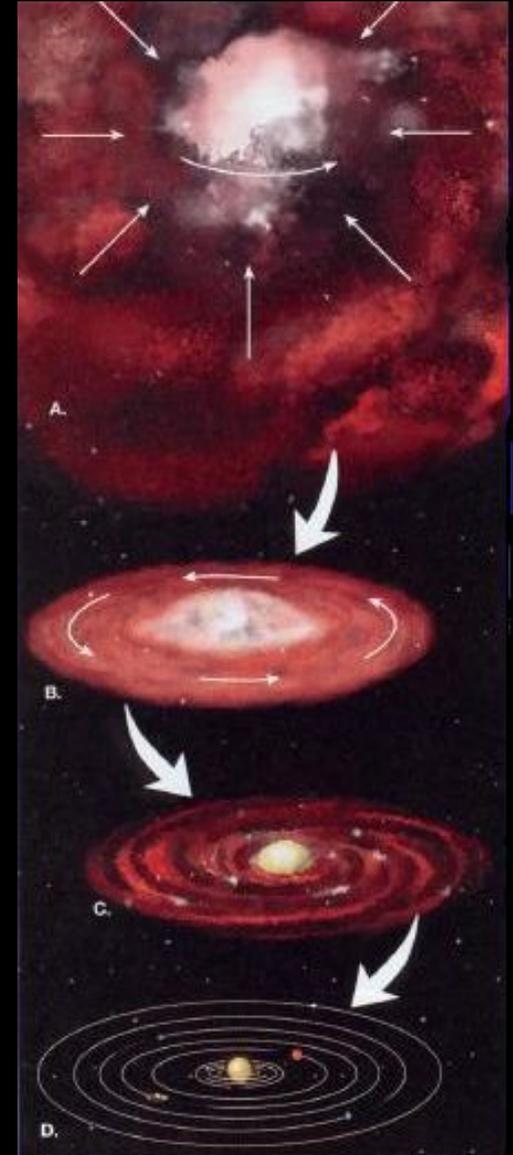
- O fato de os planetas do Sistema Solar orbitarem o Sol progradamente em planos orbitais relativamente próximos deu origem à **hipótese nebular** da Cosmogonia.
- Kant foi o proponente dessa idéia, que, posteriormente, foi melhor elaborada por Laplace.



Kant



Laplace



# Evidências da Formação Estelar



# Nuvens Moleculares

- Por muitos anos a formação de moléculas no espaço foi um mistério, pois os átomos ficam muito separados uns dos outros.
- Estudos mostraram que as moléculas poderiam formar-se em nuvens muito densas e frias do meio interestelar, as quais foram chamadas de nuvens moleculares.

# Nuvens Moleculares

- Nessas nuvens, uma parcela de cada par de átomos de H que colidem podem formar H<sub>2</sub> (se há presença de poeira). O mesmo vale para a formação de outras moléculas.
- É nessas nuvens que as moléculas têm maior probabilidade de sobreviver às intempéries espaciais.
- O estudo das moléculas (e grãos de poeira) deve ser feito no infravermelho, microondas ou ondas de rádio.



The Horsehead Nebula in Infrared from Hubble  
Image Credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)



The Pelican Nebula in Gas, Dust, and Stars  
Image Credit & Copyright: Roberto Colombari



The Rosette Nebula in Hydrogen and Oxygen  
Image Credit & Copyright: Arno Rottal (Far-Light-Photography)

© Arno Rottal

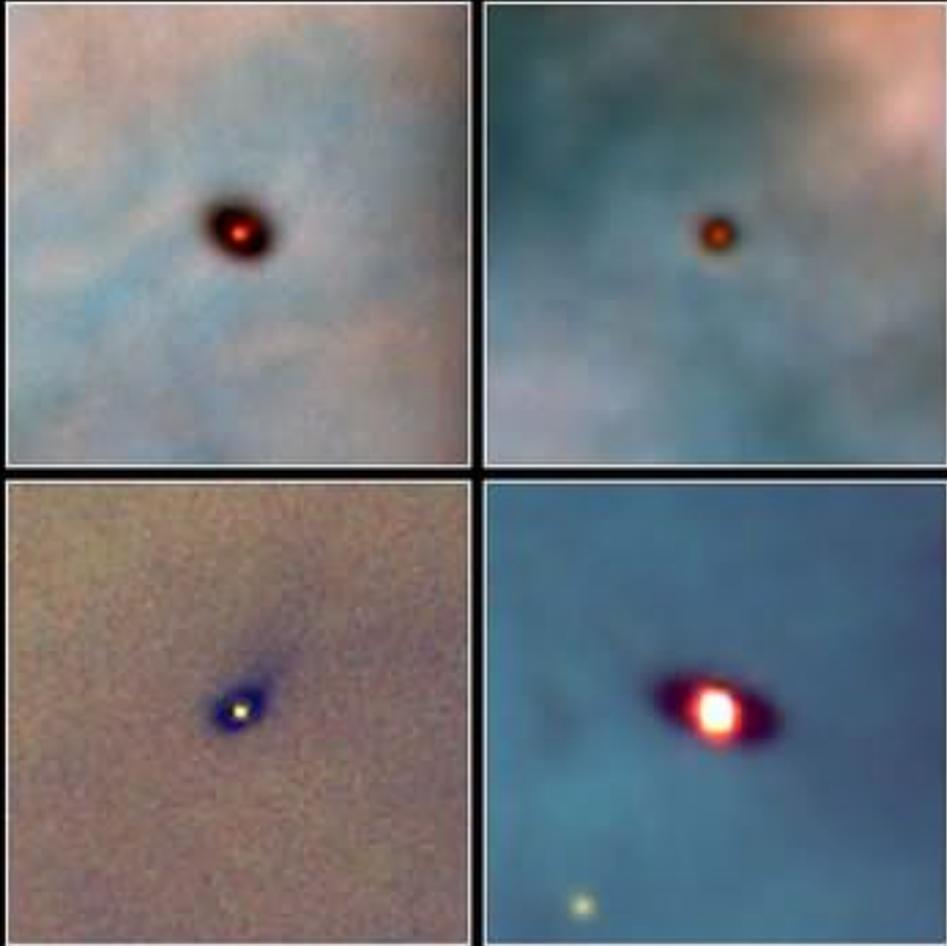
# Colapso Gravitacional

- Se uma nuvem interestelar for suficientemente densa, a atração gravitacional de suas partículas torna-se grande o bastante para forçar o colapso da nuvem.
- Contra o colapso, a nuvem oferece resistência na forma de pressão interna, seja devido ao movimento térmico dos átomos, seja devido à existência de campos magnéticos e turbulência no gás.
- Durante o **colapso gravitacional**, a nuvem pode se fragmentar
- Fragmentação → **protoestrela**.

# Origem do Sistema Solar

- Nuvem de gás e poeira : sofre uma perturbação (SN) e colapsa
- Aquece e comprime o centro; a poeira evapora. **Colapso inicial:** 100.000 anos
- O centro: forma uma proto-estrela, e o gás restante orbita em torno dela (disco de acreção)
- Disco resfria
  - Forma uma segunda estrela, ou
  - O gás frio e distante condensa pequenas partículas de rochas, gelos, metais

# Discos de acresção



Protoplanetary Disks  
Orion Nebula

HST · WFPC2

PRC95-45b · ST Sci OPO · November 20, 1995

M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA



- Metais condensam quando o **disco é formado**: 4.55 bilhões de anos atrás
- Rochas: entre 4.4 e 4.5 bilhões de anos
- Os grãos de poeira colidem e acretam: formam-se asteróides
- Aumento da gravidade acelera o crescimento: formam-se planetesimais
  - SS interno: tamanho Lunar;
  - SS externo: 10-15 Terras
  - Colidem e crescem
- Vento solar: expulsa o gás que é capturado pelos planetas mais distantes (gasosos)

# Sumário da formação de planetas

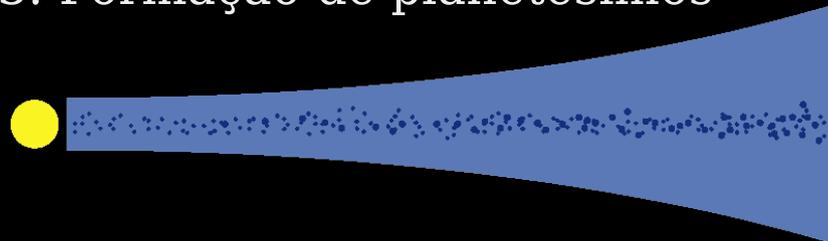
1. Formação do disco



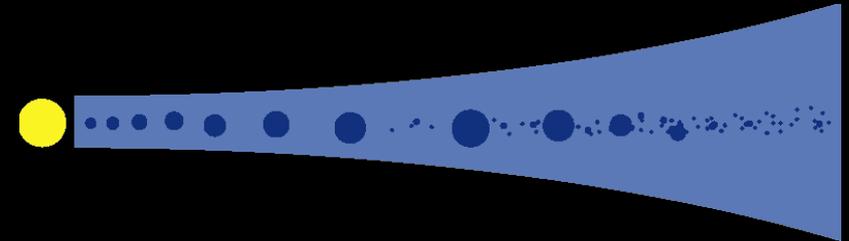
2. Sedimentação do disco



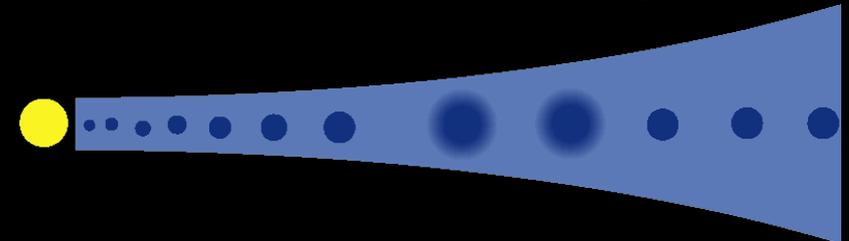
3. Formação de planetésimos



4. Formação de planetas sólidos



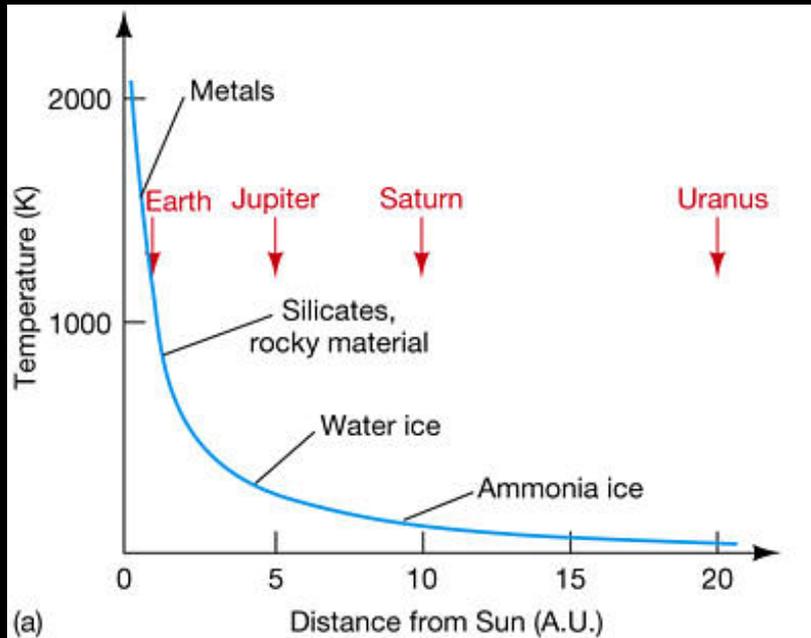
5. Formação de planetas gasosos



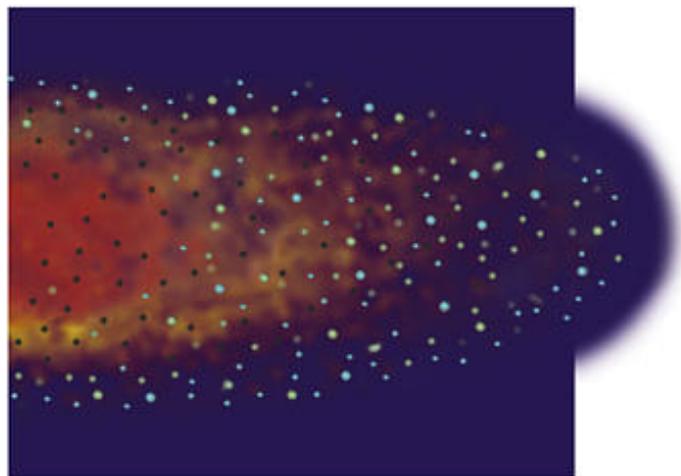
6. Dissipação do disco



# Resfriamento da Nebulosa Solar



(a)



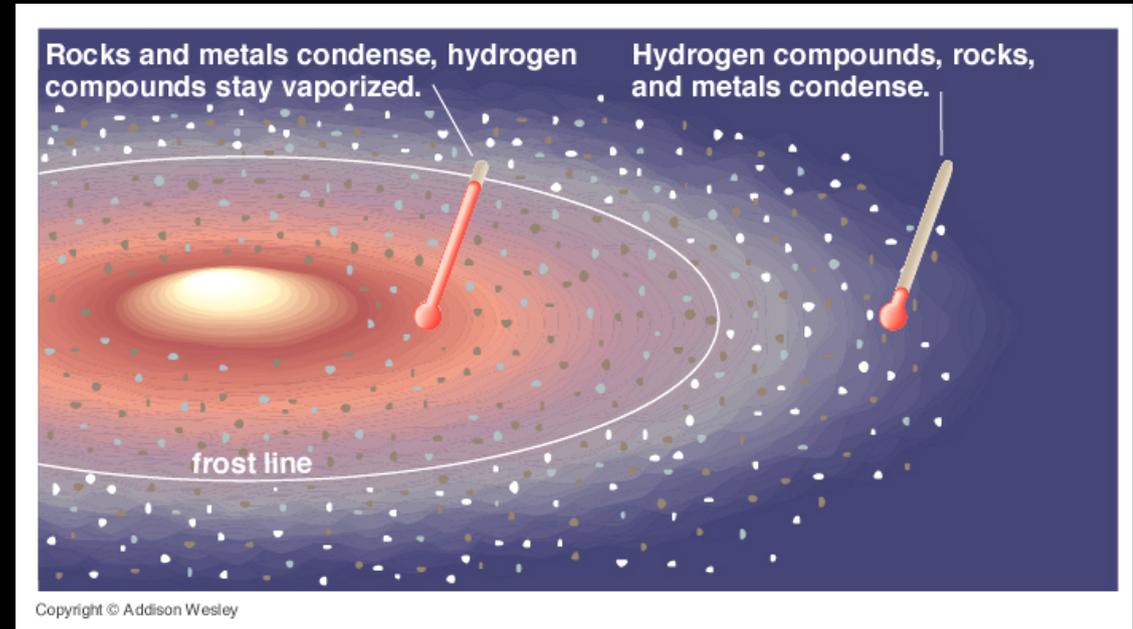
(b)

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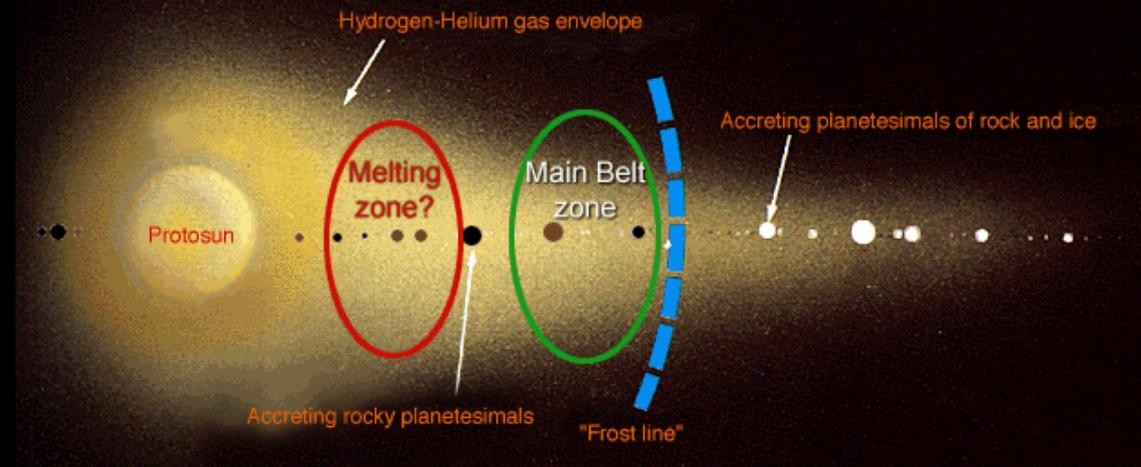
- Durante o colapso gravitacional, a nebulosa solar aqueceu-se.
- Todavia, uma vez que o gás se depositou num disco em equilíbrio hidrostático, o colapso cessou, e a nebulosa deve ter se resfriado a temperaturas menores do que 800 K.
- Esse resfriamento levou à condensação de materiais diferentes em diferentes distâncias ao Sol.

# Linha do Gelo

- A linha do gelo é o raio astrocêntrico a partir do qual a água pode existir em estado sólido estável.
- Possui importância na formação de planetas gasosos, pois, além da linha de gelo, os planetesimais crescem mais.



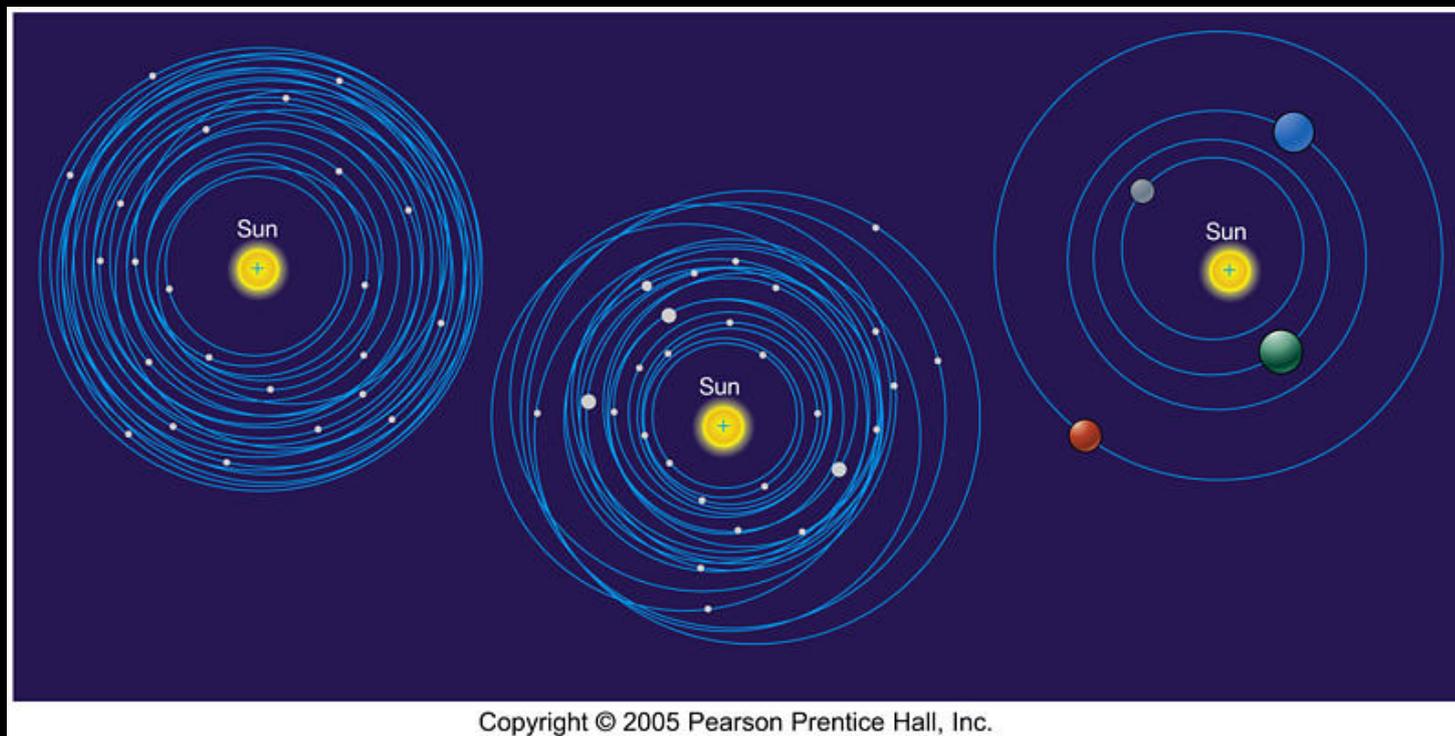
*Solar System Formation*



(Background graphic courtesy of Windows to the Universe, <http://www.windows.ucar.edu>  
Ellipses added for emphasis.)

# Origem das Órbitas Circulares

- As órbitas circulares do sistema solar são pistas para a formação planetária.
  - No disco protoplanetário, os planetesimais eram confinados a órbitas circulares devido a colisões com outros planetesimais. Protoplanetas que tenham se deslocado dessas órbitas acabam colidindo com outros. Houve uma seleção por órbitas mais estáveis.



# Mercúrio

- Sumérios 3000 A.C.:
- Gregos: (sabiam que era o mesmo corpo)
  - Apolo – manhã
  - Hermes – tarde
- Heraclitus – Mercúrio e Vênus orbitavam o Sol

# Mercúrio

- distância : 0,387 U.A.
- planeta terrestre
- rochoso e pequeno
- R : 2439 Km
- $\rho$  : 5.42 g/cm<sup>3</sup>
- $P_{\text{rot}}$  : 58.6 dias terrestres
- $P_{\text{sid}}$  : 85.97 dias terrest.
- T : 90 – 700 K
- Atmosfera → exosfera  
uma camada muito tênue



# Mercúrio

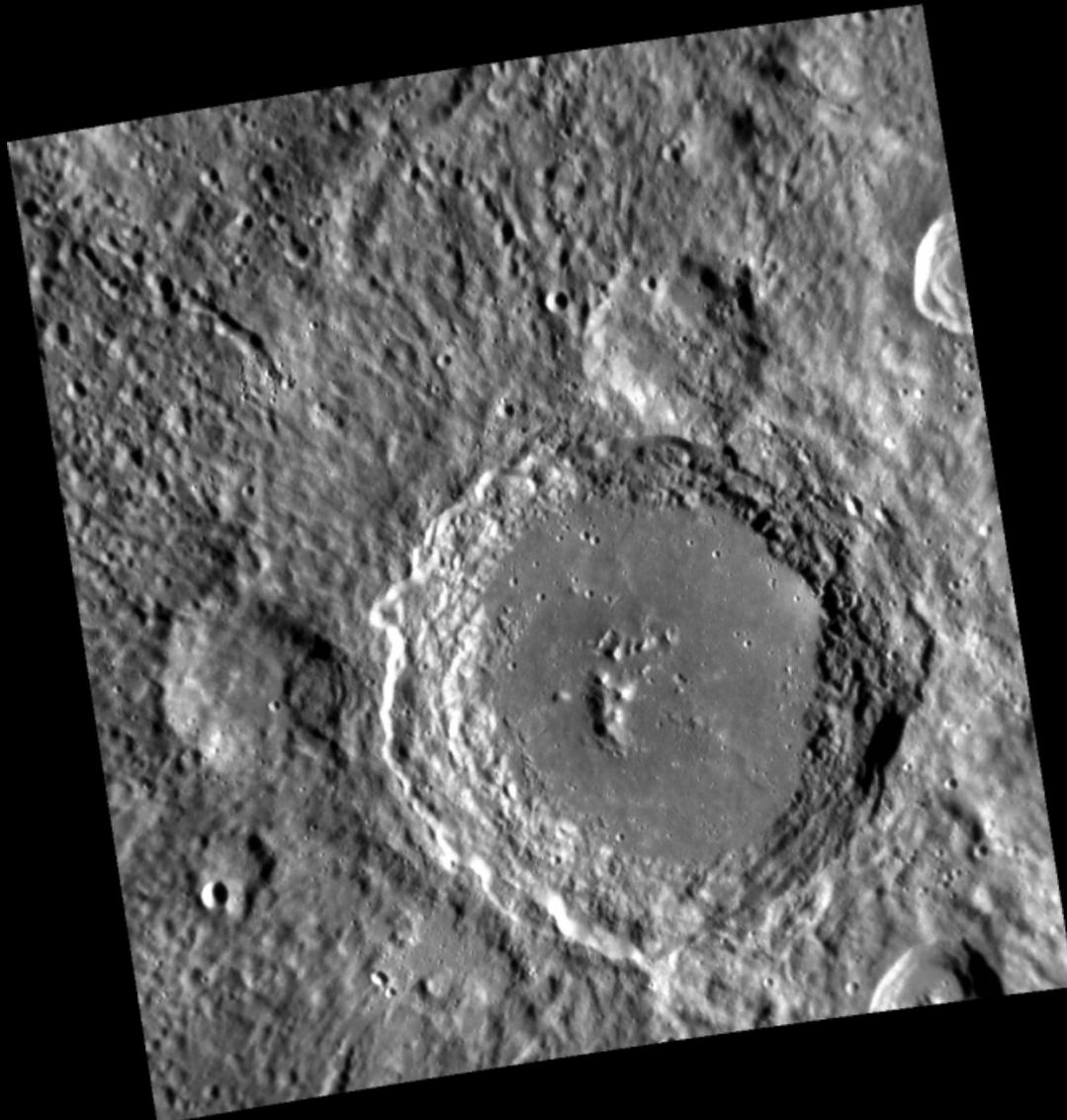


- **Mariner 10 – 1974/75**
- **45% superfície mapeada**
- **MESSENGER (Mercury Surface, Space Environment, Geochemistry and Ranging), 2004 -- 2011**

# Messenger

Em 2011, foi a primeira sonda espacial a entrar em órbita em torno de Mercúrio

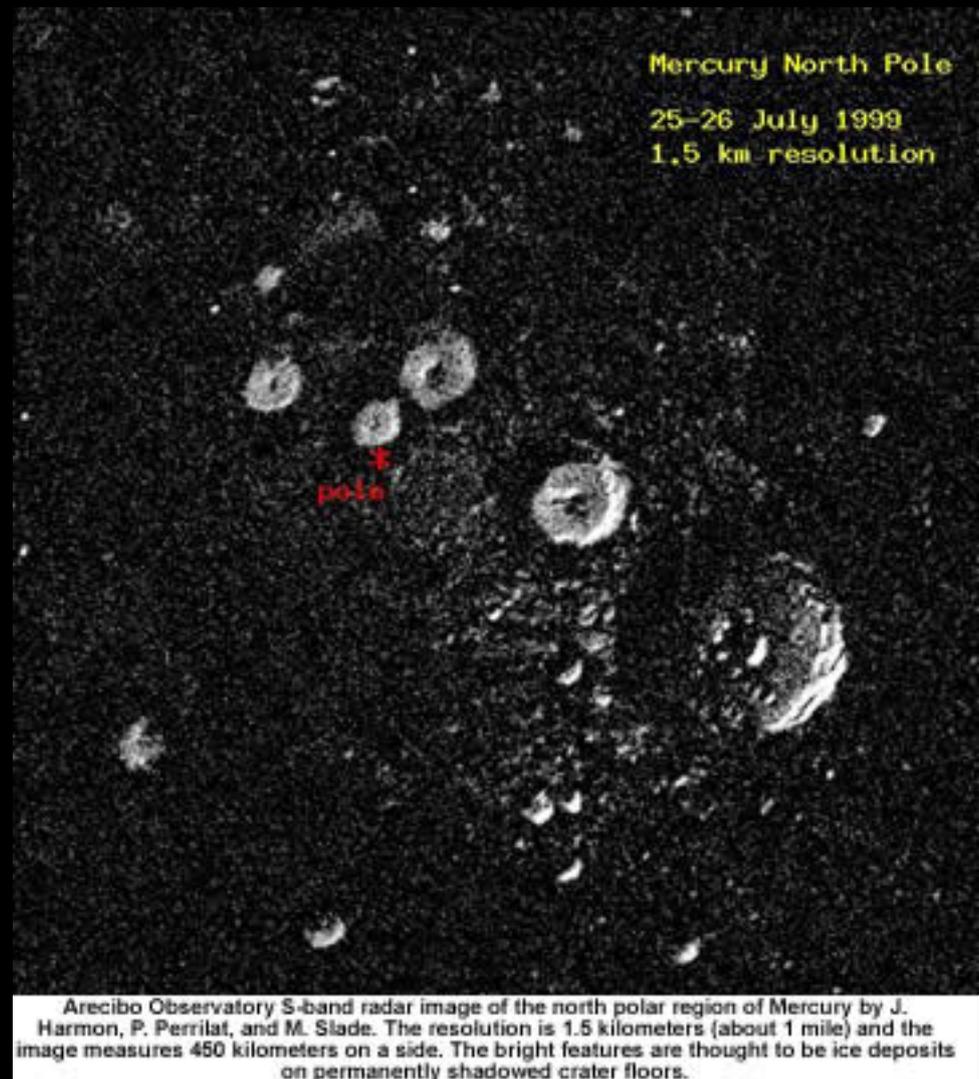
- Menor e mais denso dos planetas terrestres



Lennon crater

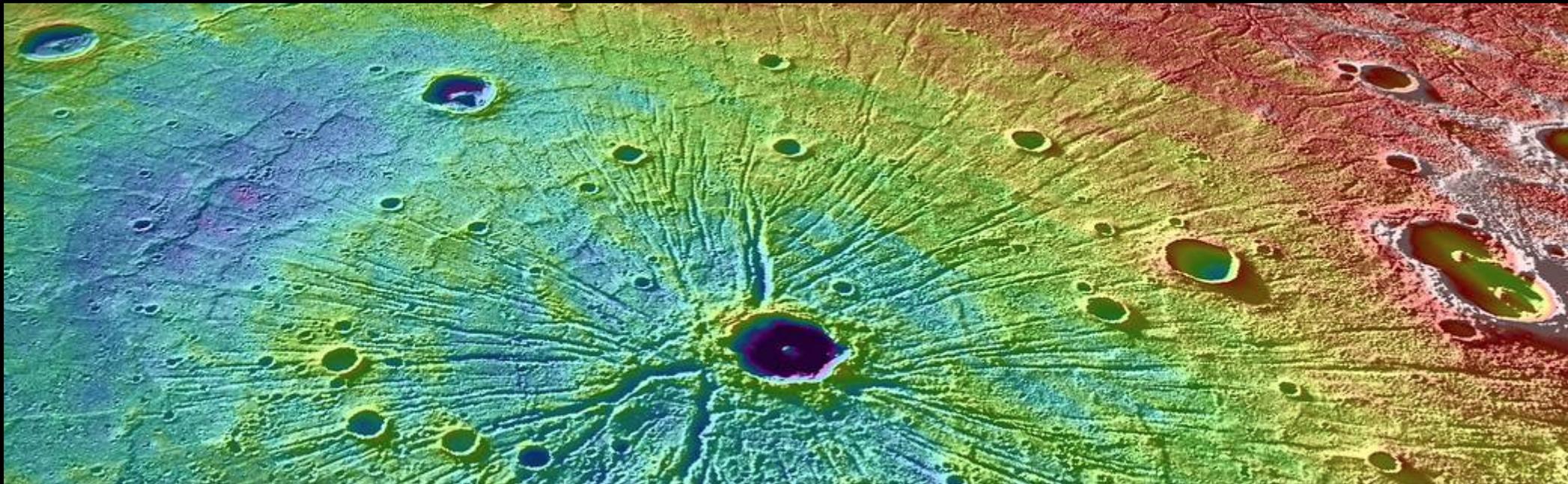


# Polo norte – Mariner MESSENGER: questões



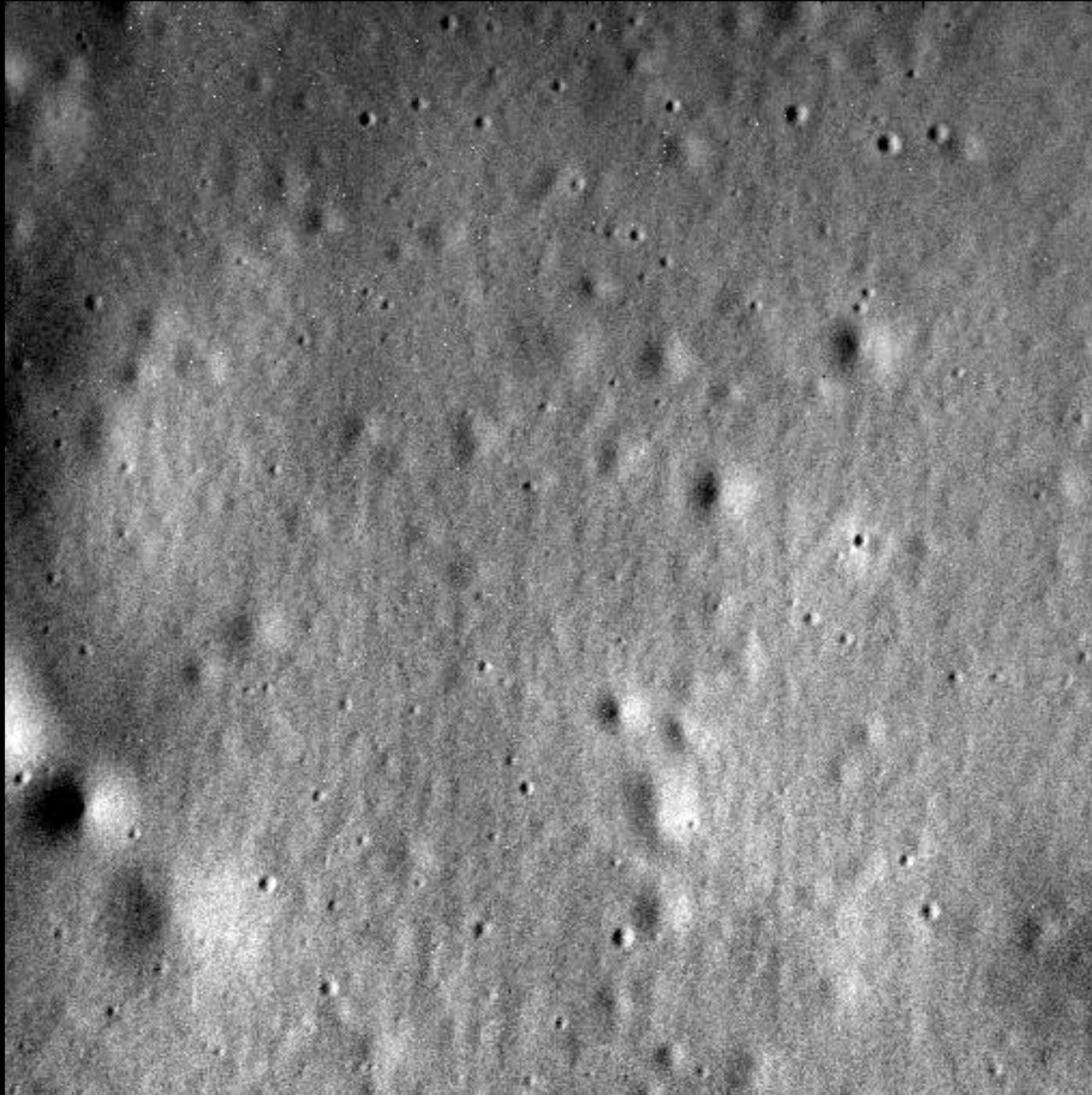
- Mais velha superfície, mais denso, maior variação de temperatura superficial – como se formou a Terra

Os dados mais recentes da MESSENGER indicam que gelo de água é o maior constituinte do polo norte de Mercúrio



Novas observações → novas questões:

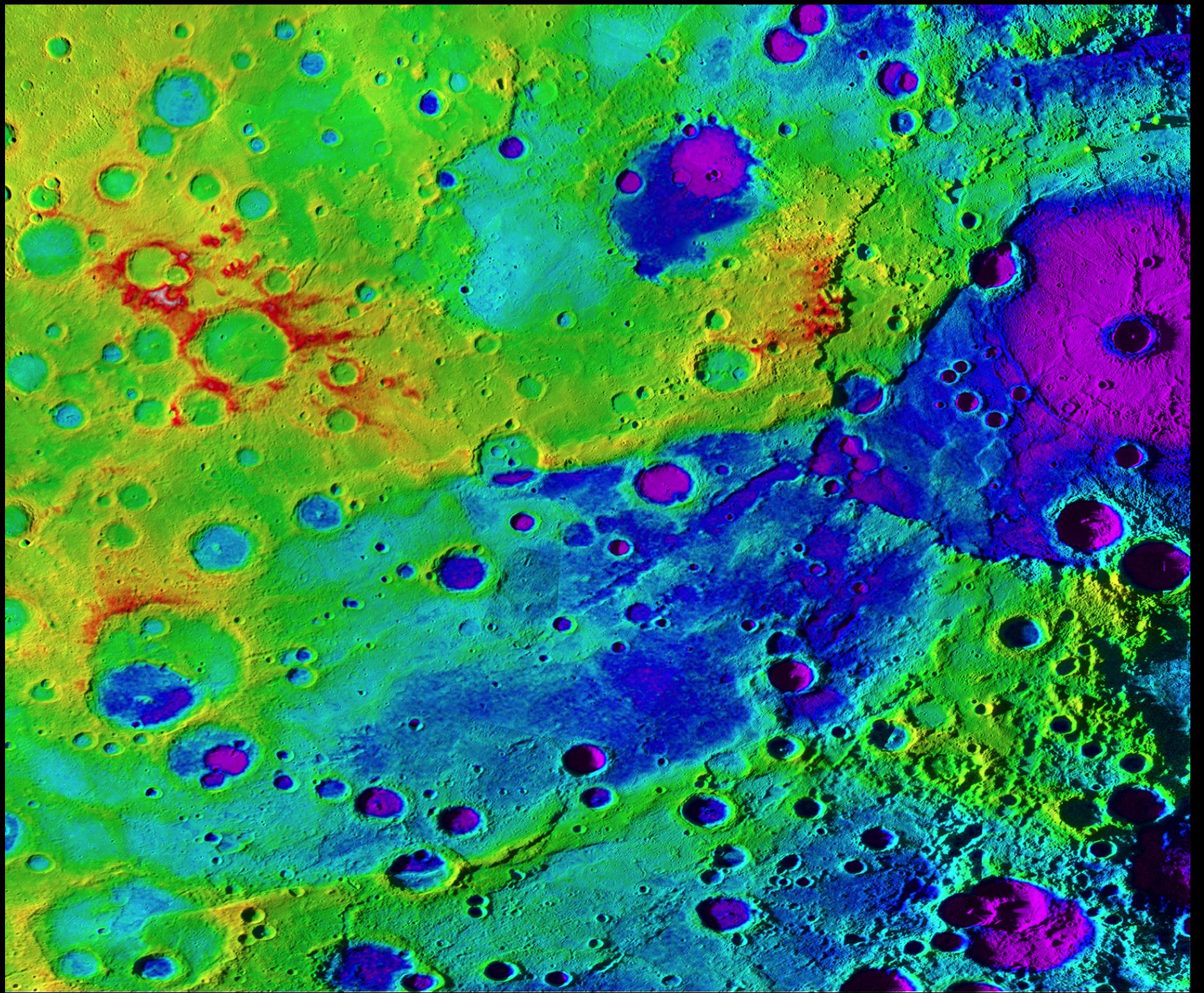
- (1) "A matéria escura nos polos consiste de matéria orgânica?"
- (2) Quais tipos de reações químicas tal matéria sofreu?"
- (3) Existe alguma região onde haja água e matéria orgânica (dentro ou na superfície)?"
- (4) Somente continuando a exploração de Mercúrio saberemos."



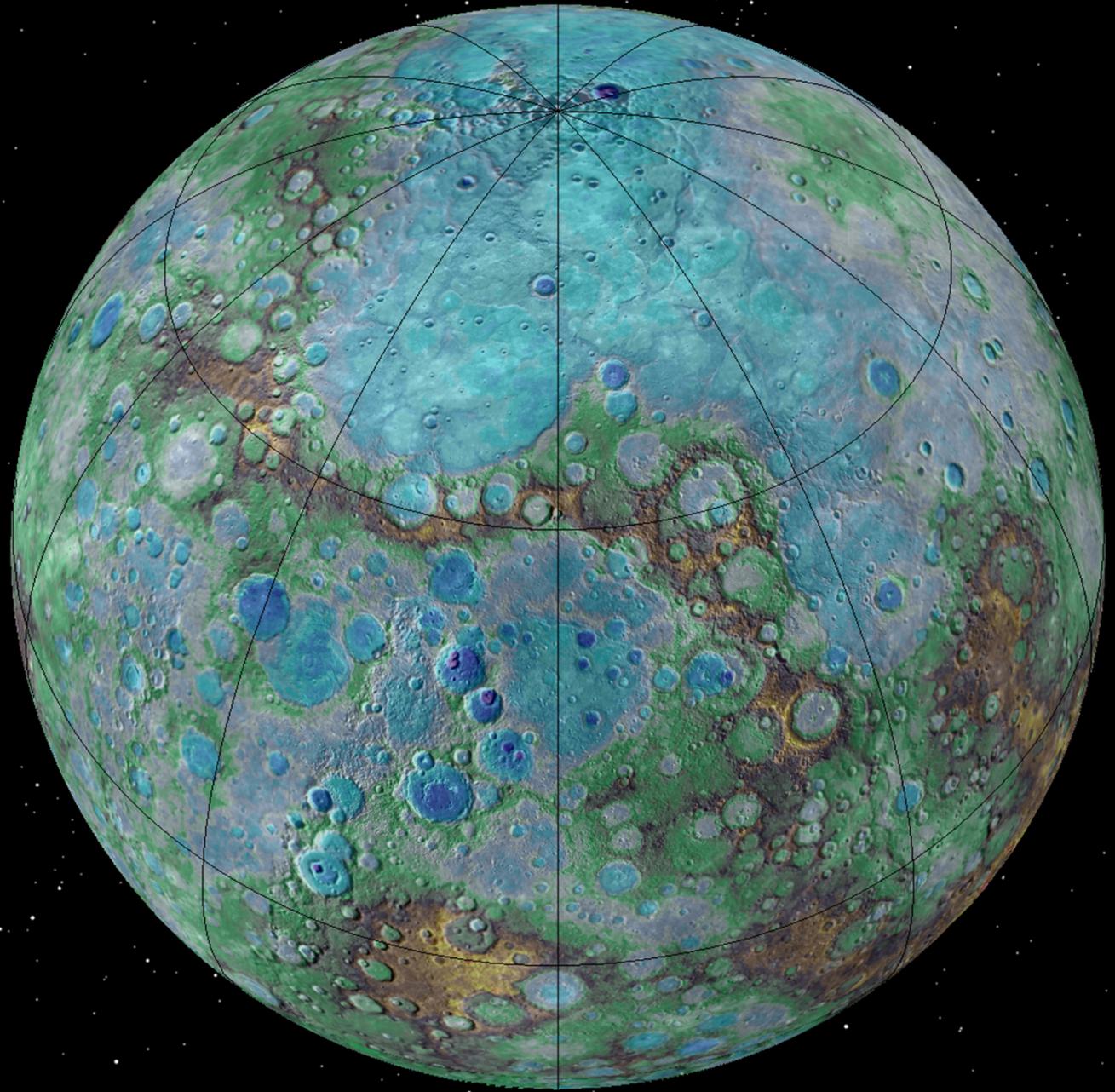
April 30, 2015  
MESSENGER's Final Image

# A dinâmica

- Entender as origens de Mercúrio, o menor planeta do Sistema Solar, é um dos problemas em aberto da dinâmica planetária que mais perturbam os especialistas.
- Massa → quase 20 vezes menor que a da Terra + órbita alongada e inclinada
- A explicação mais aceita era a de que todos os planetas do sistema solar teriam se formado mais ou menos na mesma posição em que hoje se encontram.
- <http://revistapesquisa.fapesp.br/2016/07/14/jupiter-pos-mercurio-na-linha/?cat=ciencia>



Imagens obtidas pela MESSENGER revelaram escarpas e outras formas na paisagem semelhantes a degraus. Tais estruturas são muito pequenas e levaram os cientistas a acreditarem que elas são geologicamente jovens. Isso significa que Mercúrio ainda está se contraindo e que a Terra não seria o único planeta com atividade tectônica.



**THE INTERPLAY BETWEEN VOLCANISM AND TECTONICS ON MERCURY.** Paul K. Byrne<sup>1,2</sup>, Caleb I. Fassett<sup>3</sup>, Christian Klimczak<sup>4,2</sup>, Lillian R. Ostrach<sup>5</sup>, Clark R. Chapman<sup>6</sup>, Brett W. Denevi<sup>7</sup>, A. M. Celâl Şengör<sup>8</sup>, Steven A. Hauck, II<sup>9</sup>, Alexander J. Evans<sup>6,10</sup>, Maria E. Banks<sup>11,12</sup>, Thomas R. Watters<sup>11</sup>, James W. Head<sup>13</sup>, and Sean C. Solomon<sup>10,2</sup>. <sup>1</sup>Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA ([paul.byrne@ncsu.edu](mailto:paul.byrne@ncsu.edu)); <sup>2</sup>Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC 20015, USA; <sup>3</sup>Department of Astronomy, Mount Holyoke College, South Hadley, MA 01075, USA; <sup>4</sup>Department of Geology, University of Georgia, Athens, GA 30602, USA; <sup>5</sup>Solar System Exploration Division, NASA Goddard Space Flight Center, MD 20771, USA; <sup>6</sup>Department of Space Studies, Southwest Research Institute, Boulder, CO 80302, USA; <sup>7</sup>The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA; <sup>8</sup>Department of Geology, Faculty of Mines and the Eurasia Institute of Earth Sciences, Istanbul Technical University, 34469 Maslak, Istanbul, Turkey; <sup>9</sup>Department of Earth, Environmental, and Planetary Sciences, Case Western Reserve University, Cleveland, OH 44106, USA; <sup>10</sup>Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA; <sup>11</sup>Center for Earth and Planetary Studies, Smithsonian National Air and Space Museum, Washington, DC 20013, USA; <sup>12</sup>Planetary Science Institute, Tucson, AZ 85719, USA; <sup>13</sup>Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA.

**Introduction:** That tectonic activity has occurred on Mercury was confirmed by observations of the planet returned by the Mariner 10 mission in the 1970s [e.g., 1]. Evidence for volcanism having operated on Mercury, however, remained ambiguous following that mission [2,3], but image data acquired by the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft during 2008–15 affirmed the volcanic character of the planet [4,5].

The MESSENGER mission generated sufficient data to characterize comprehensively past volcanic and tectonic processes on Mercury (**Figure 1**). Notably, there have been strong spatial, and possibly temporal, correlations between these processes that provide insight into the thermal evolution and geological history of the innermost planet.

**Volcanism on Mercury:** The most prominent volcanic landforms on Mercury are extensive, relatively sparsely cratered effusive basaltic deposits that constitute the majority of mapped “smooth plains” units [6] (**Figure 1**). The largest such deposits are situated in the northern hemisphere and include the northern plains [5] and the plains within and surrounding the Caloris impact basin [7]. Many smaller though still substantial deposits occur inside other impact structures [6], especially in the southern hemisphere.

Notably, all major smooth plains units have relatively similar crater areal density values [e.g., 5,6,8,9], indicating that they were emplaced by about the same time. These values correspond to model ages

color, often found in association with irregularly shaped depressions lacking raised rims, provide evidence for pyroclastic volcanism [e.g., 12]. Sites of explosive volcanism are largely confined to the vicinities of impact craters and basins, although numerous examples are collocated with tectonic shortening structures; few examples are found in smooth plains units [e.g., 13].

**Tectonics on Mercury:** Deformation on the innermost planet is dominated by crustal shortening, manifest as linear to arcuate, positive-relief landforms that occur globally [14] (**Figure 1**). Terms such as “wrinkle ridge” and “lobate scarp” have been applied historically to these landforms on the basis of dimension (with the former having less structural relief and planform length than the latter) [15]. Despite the morphological variety of such landforms on Mercury, they likely resulted collectively from horizontal shortening involving some combination of thrust faulting and folding [e.g., 16,] and are thus forms of fault-propagation monoclines and anticlines [17]. Many such structures may have formed above large-scale décollement surfaces between lava flows and probably along older regolith layers [14].

Larger shortening landforms are typically situated within intercrater plains; their smaller counterparts tend to be localized within smooth plains [14]. There is no globally coherent pattern of tectonic shortening on Mercury, although major shortening landforms show a slight preference toward north–south orientations [18]. Some smooth plains structures may be attributed to

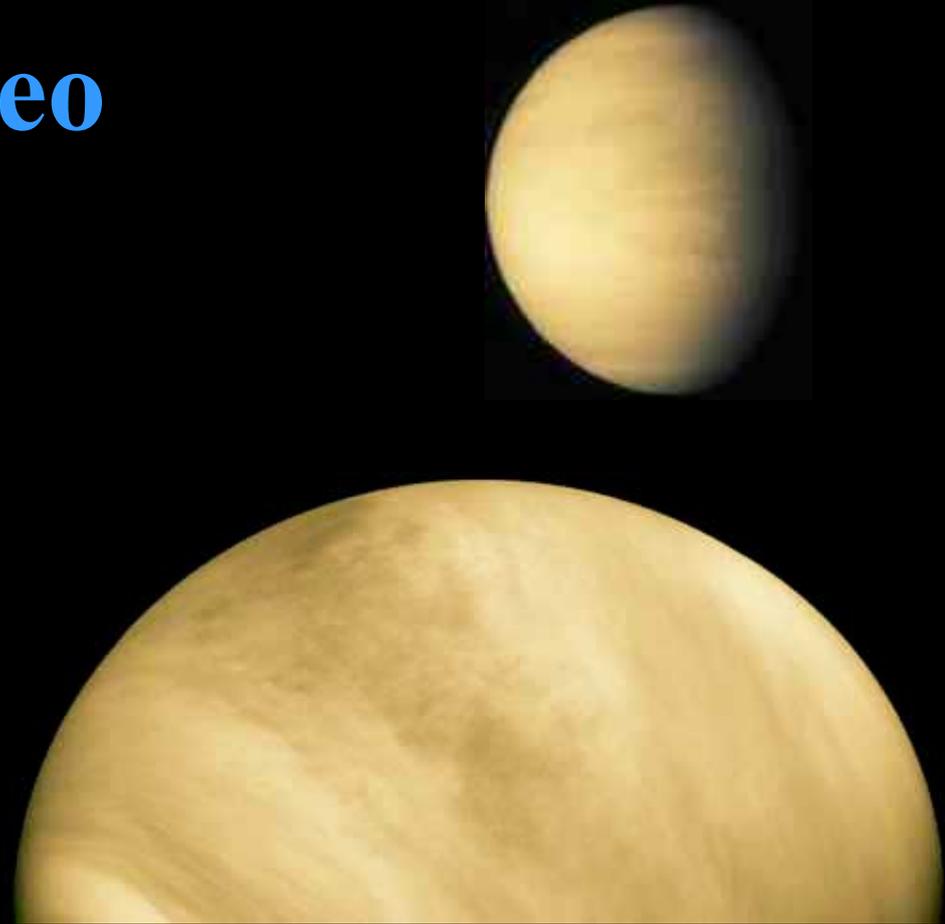
# Vênus

- Pré-história
- Gregos:
  - Eosphorus – manhã
  - Hesperus – tarde
- Fases – importância para a teoria heliocêntrica de Copérnico



# Venus - Galileo

- distância: 0,7 U.A.
- planeta terrestre
- $R : 6052 \text{ Km}$
- $\rho : 5.25 \text{ g/cm}^3$
- $P_{\text{rot}} : 243 \text{ dias terrestres}$
- $P_{\text{sid}} : 224.7 \text{ dias terr.}$
- $T : 400 - 737 \text{ K}$
- Rotação: sentido retrógrado

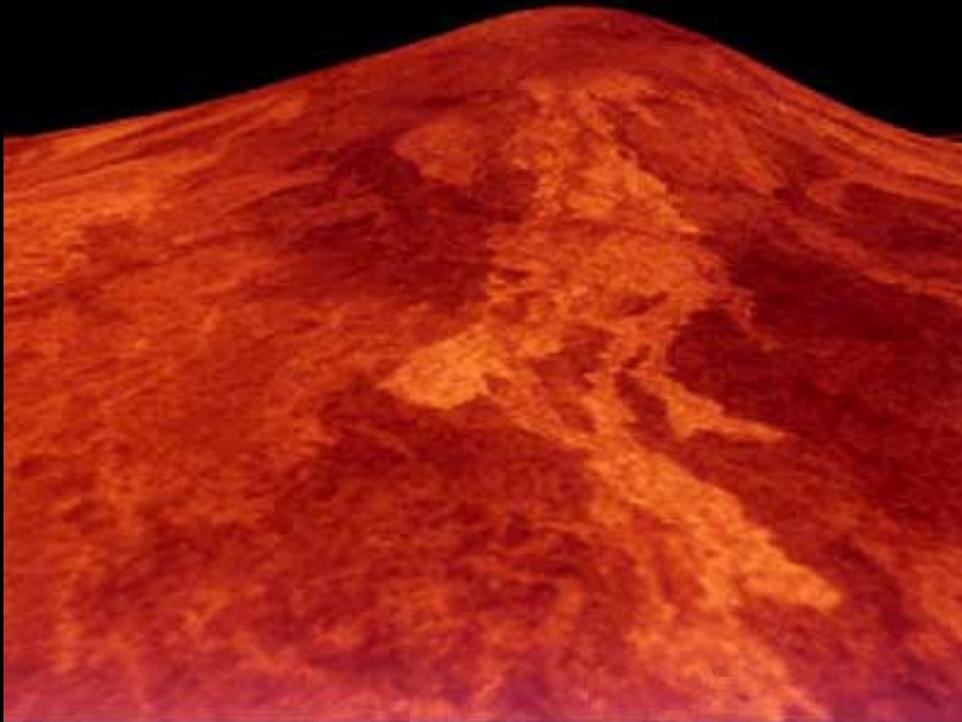


# Venus



- Atmosfera :
- Pressão: 90 atm.
- CO<sub>2</sub>(96%), H<sub>2</sub>O (vapor), CO
- Várias camadas de nuvens de ácido sulfúrico; obscurecem e causam *efeito estufa*
- Superfície: poucos relevos,
- Vários vulcões

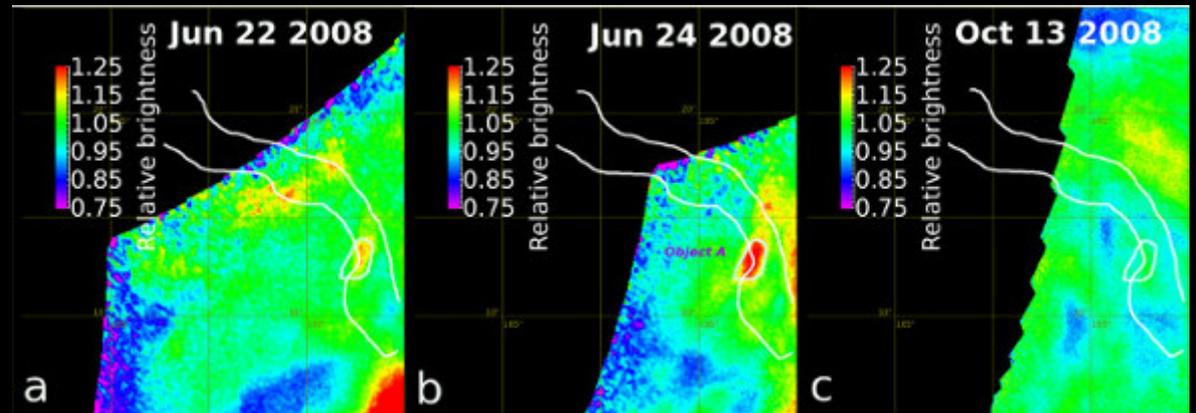
# Vulcão - Vênus



- Cor falsa do vulcão Monte Sif Magellan. Vemos a lava (regiões claras e escuras). A mais clara foi associada com recente atividade vulcânica. MAS... 2.5 milhões de anos.. O vulcão tem 2 km de altura e 200 km de diâmetro.

A lava teria menos de 2.5 milhões de anos mas ainda haveria atividade vulcânica?

**Venus EXPRESS** – medidas sequenciais no NIR → variação térmica



“Os quatro pontos encontrados estão localizados em áreas conhecidas conhecidas como “zonas tectônicas” MAS é a primeira vez que detectamos que elas são quentes e mudam de temperatura dia a dia. Essa seria uma evidência para vulcanismo ativo.”

Eugene Shalygin from the Max Planck Institute for Solar System Research (MPS) in Germany

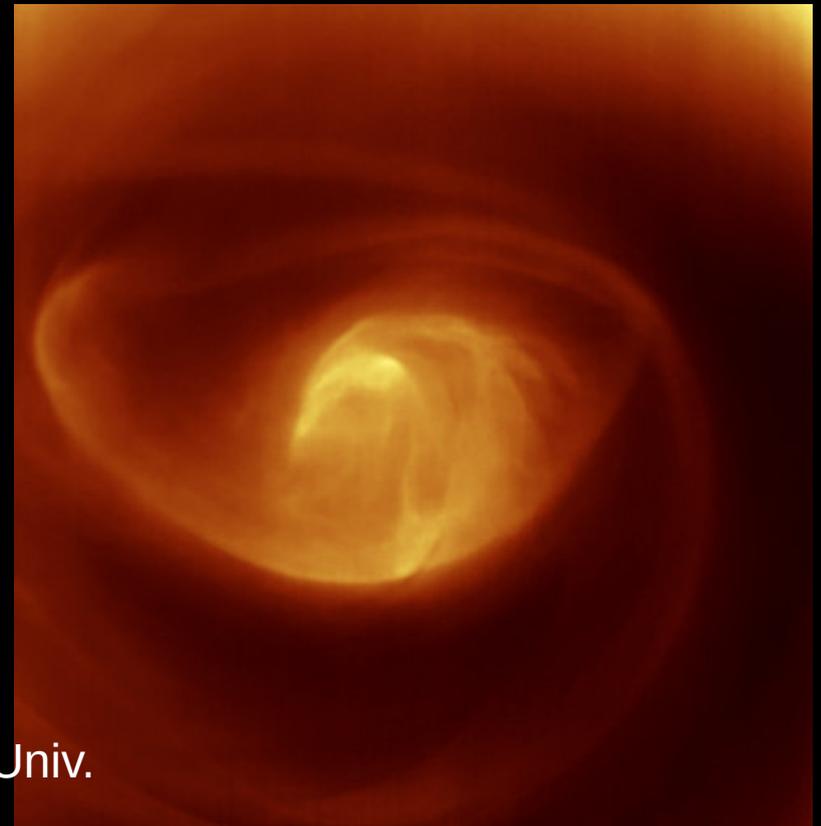
A zona Ganiki Chasma já era considerada uma das mais recentes regiões ativas, geologicamente falando, e ainda é ativa atualmente, como revelam as observações.

# VENUS EXPRESS OBJECTIVES

- Compreender a complexa dinâmica e a química e interações entre a atmosfera e a superfície
- Interações entre a atmosfera e o vento solar
  - evolução do planeta



European Space Agency

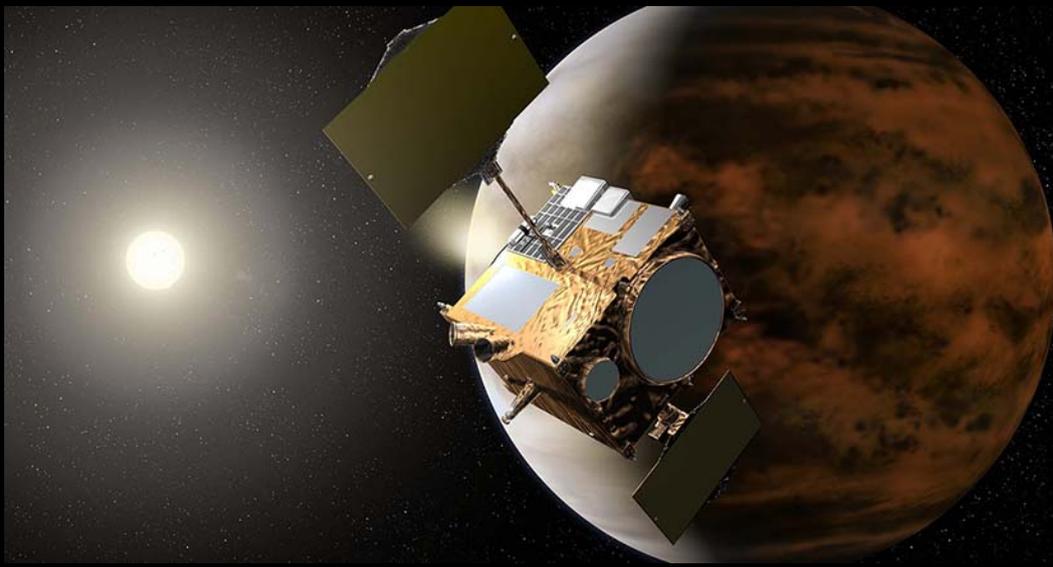


Title Venus Express snaps swirling vortex (polo sul)

Released 19/01/2015 1:51 pm

Copyright ESA/VIRTIS/INAF-IASF/Obs. de Paris-LESIA/Univ.

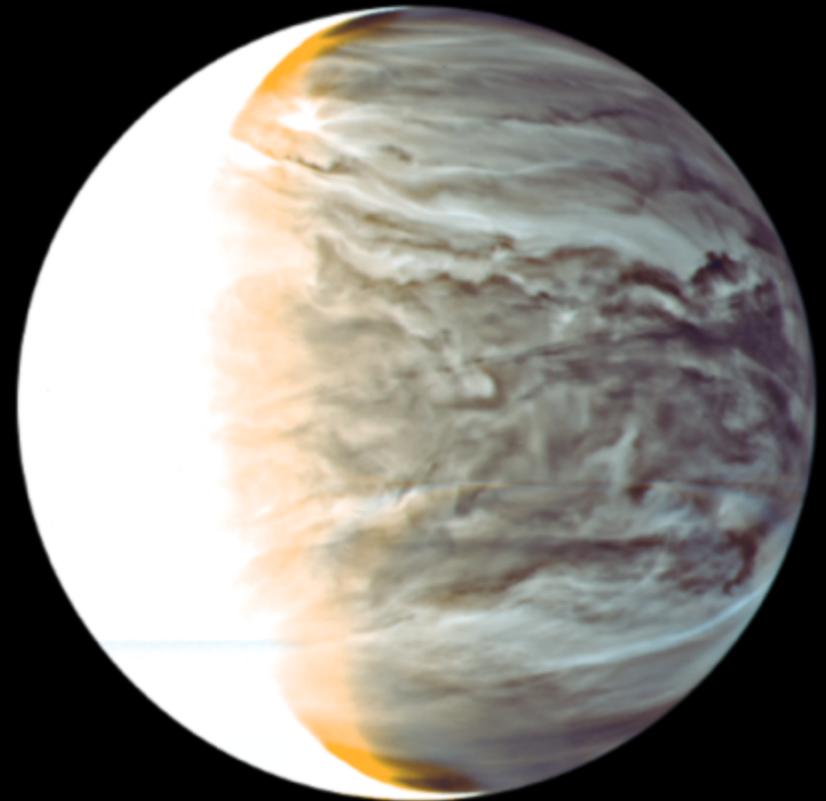
Oxford



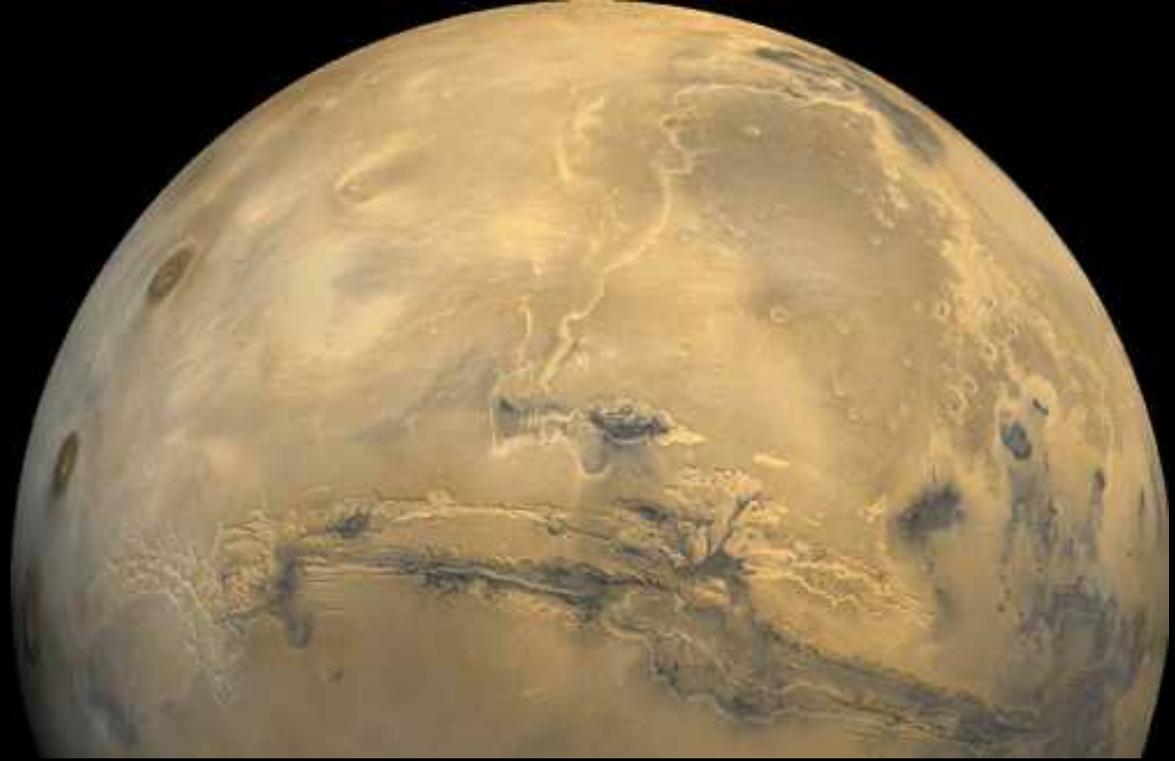
This image of Venus was captured by the Akatsuki spacecraft's Ultraviolet Imager (UVI), at around 12:19 a.m. EST (2:19 p.m. JST) on Dec. 7 at the Venus altitude of approximately 44,700 miles (72,000 kilometers).  
Credits: JAXA

## Next Generation Venus Orbiter

Japan's Akatsuki spacecraft



# Marte



- **Distância: 1.4 U.A. (227.940.000 Km)**
- **R : 3398 Km**
- **$\rho$  : 3.94 g/cm<sup>3</sup>**
- **P<sub>rot</sub> : 24.62 horas**
- **P<sub>sid</sub> : 687 dias**
- **T : -125.2 : 26° C**

# Marte : Estrutura e Atmosfera

- **Estrutura:**
- **Similar a da Terra**
- **Núcleo, mantos e crosta**
- **Atmosfera:**
- **CO<sub>2</sub> (95.32%)**
- **N<sub>2</sub> (2.7%)**
- **O<sub>2</sub> (0.13%)**
- **Vapor d'água**

# Marte : Monte Olimpo



- Mariner 4 (1965):  
1a. Visita
- Mariner 9 : 1970
- Vulcão : 25 Km (alt.) x 402 Km (base)
- **Maior vulcão do Sistema Solar**
- Solo velho e craterizado, mas tb. Planícies novas

# Marte – Cratera Schiaparelli: 461Km diâmetro

## Hemisfério Sul:

crateras, similar a  
Lua

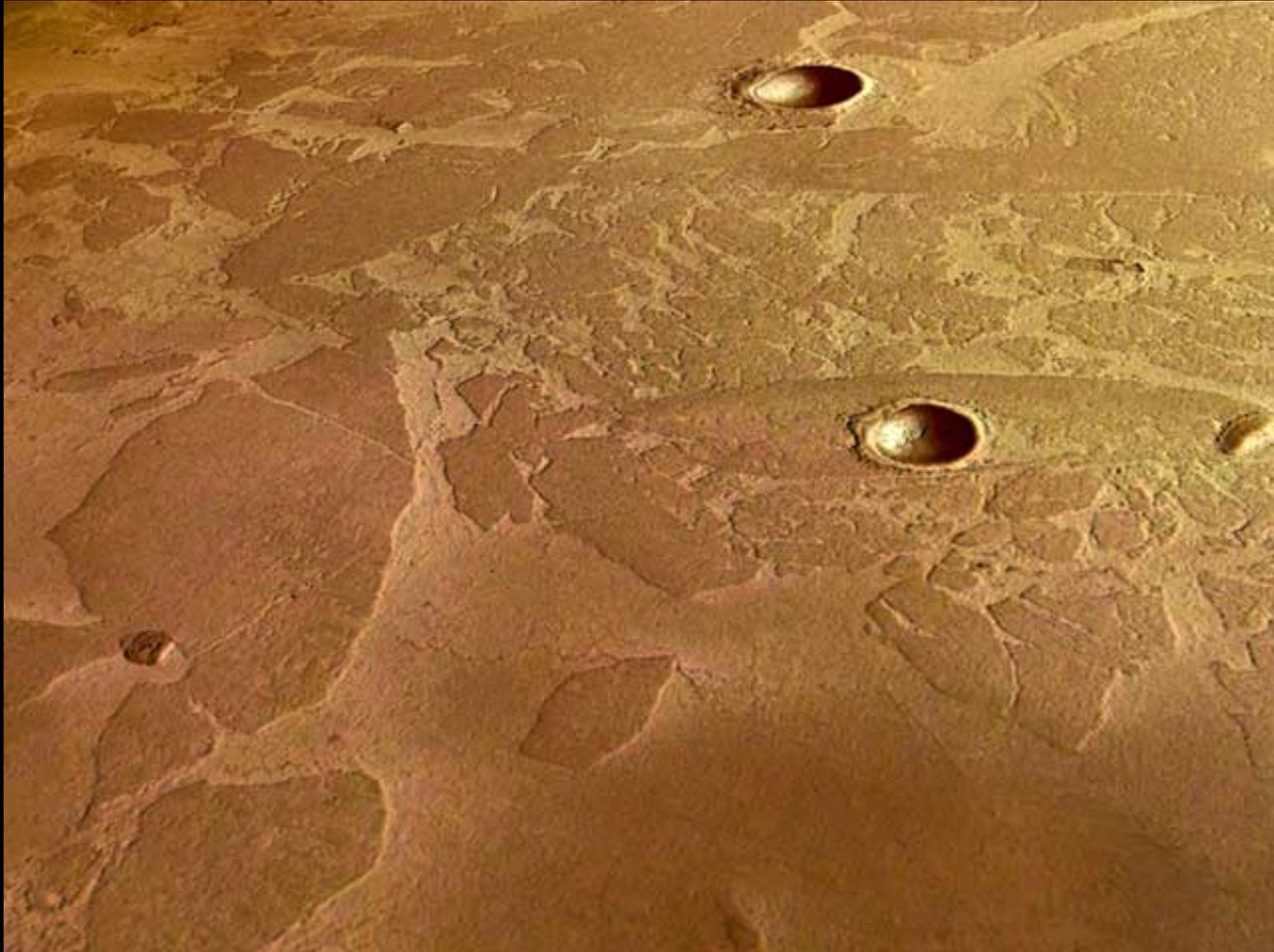
**Hemisfério Norte:** solo  
jovem

⇒ colisão quando  
Marte acretava

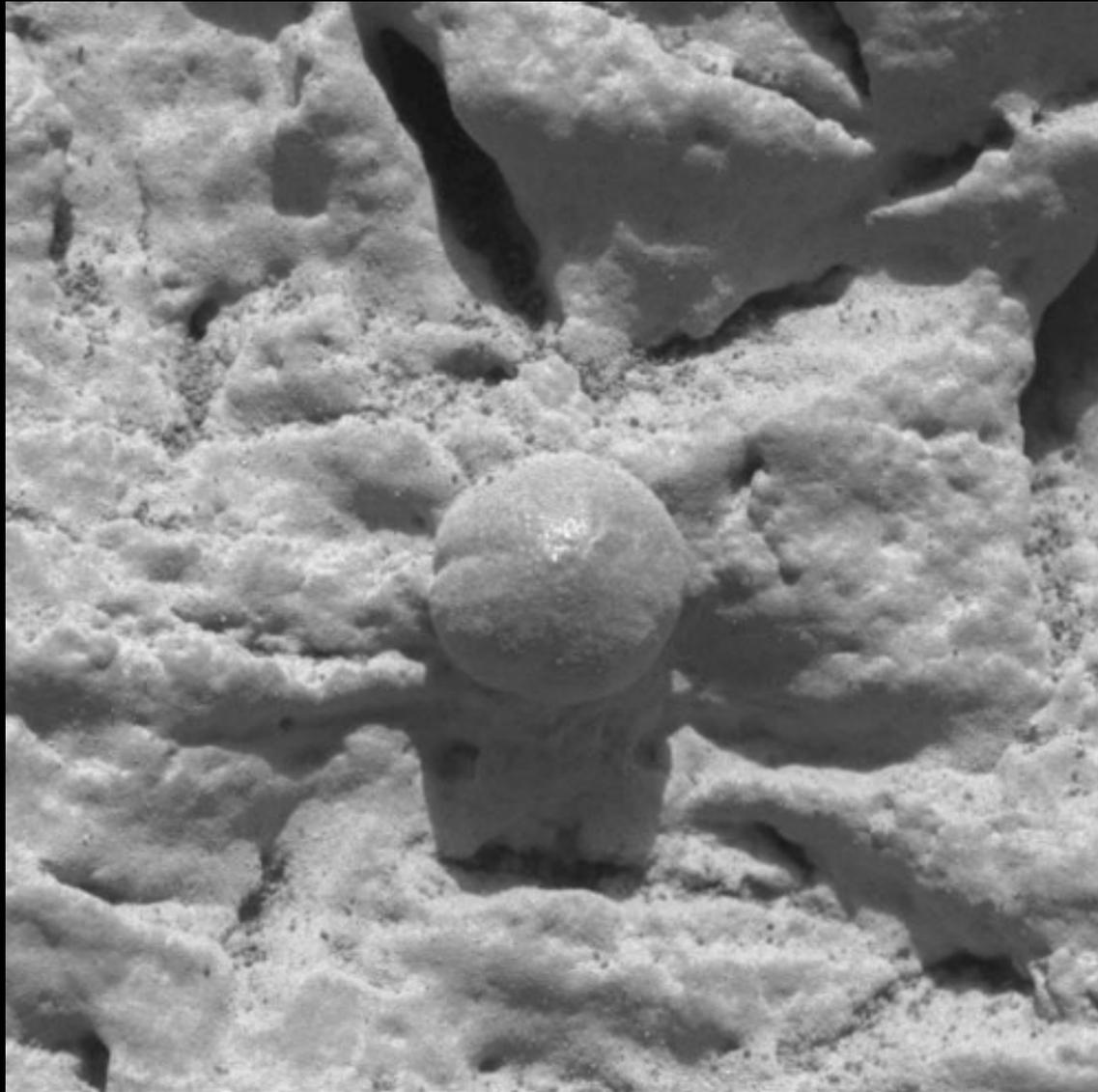
Erosão, sistemas de  
rios



**Mar Gelado em Marte – Mars Express (ESA) – baixa  
abundância de crateras: água (5 milhões de anos)**



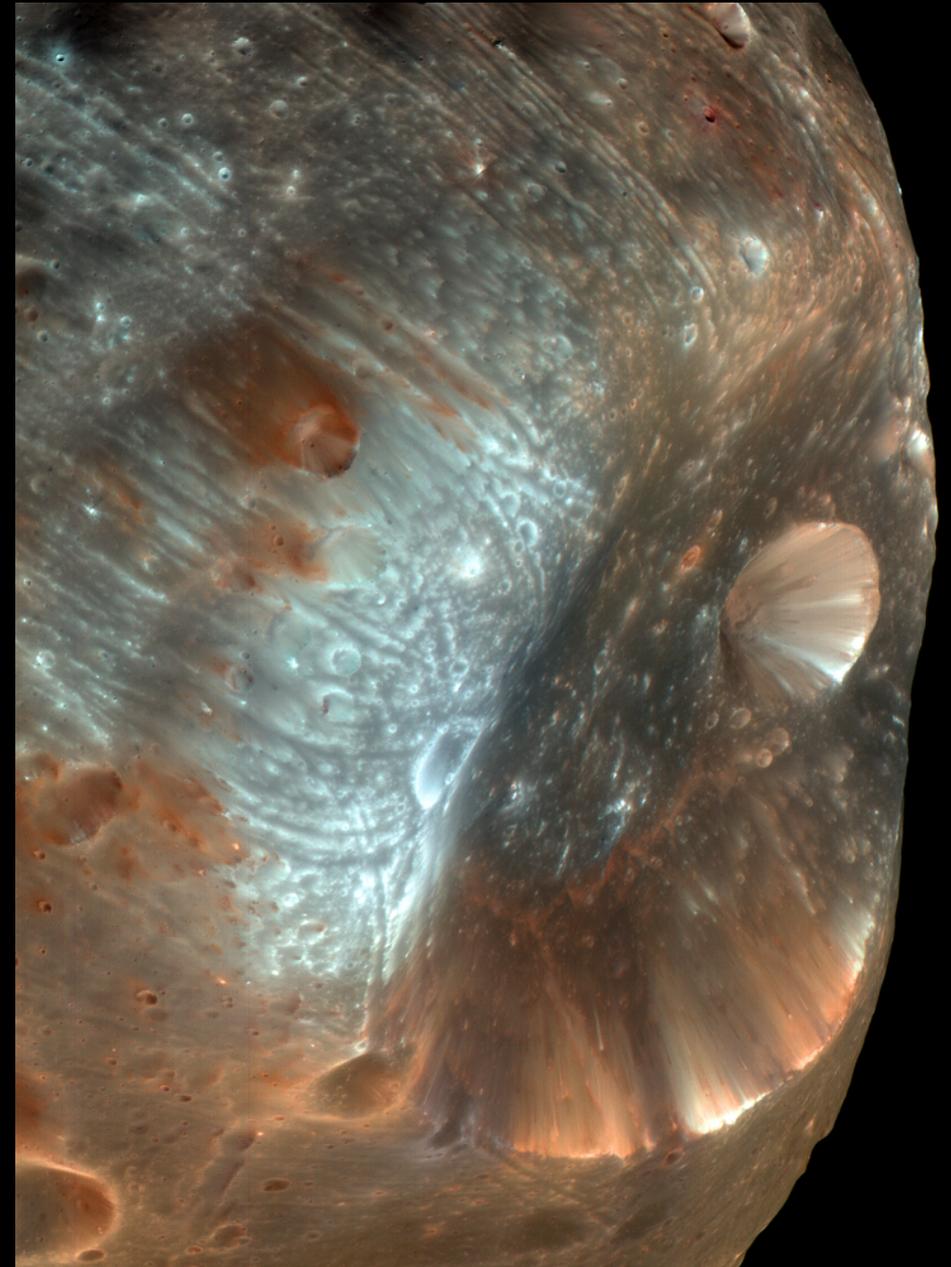
# Água em Marte



Partículas  
esféricas  
formadas por  
acúmulo de  
matéria vindo  
de dentro da  
uma rocha  
encharcada de  
água;  
Água no interior  
de Marte

# Phobos e Deimos - satélites

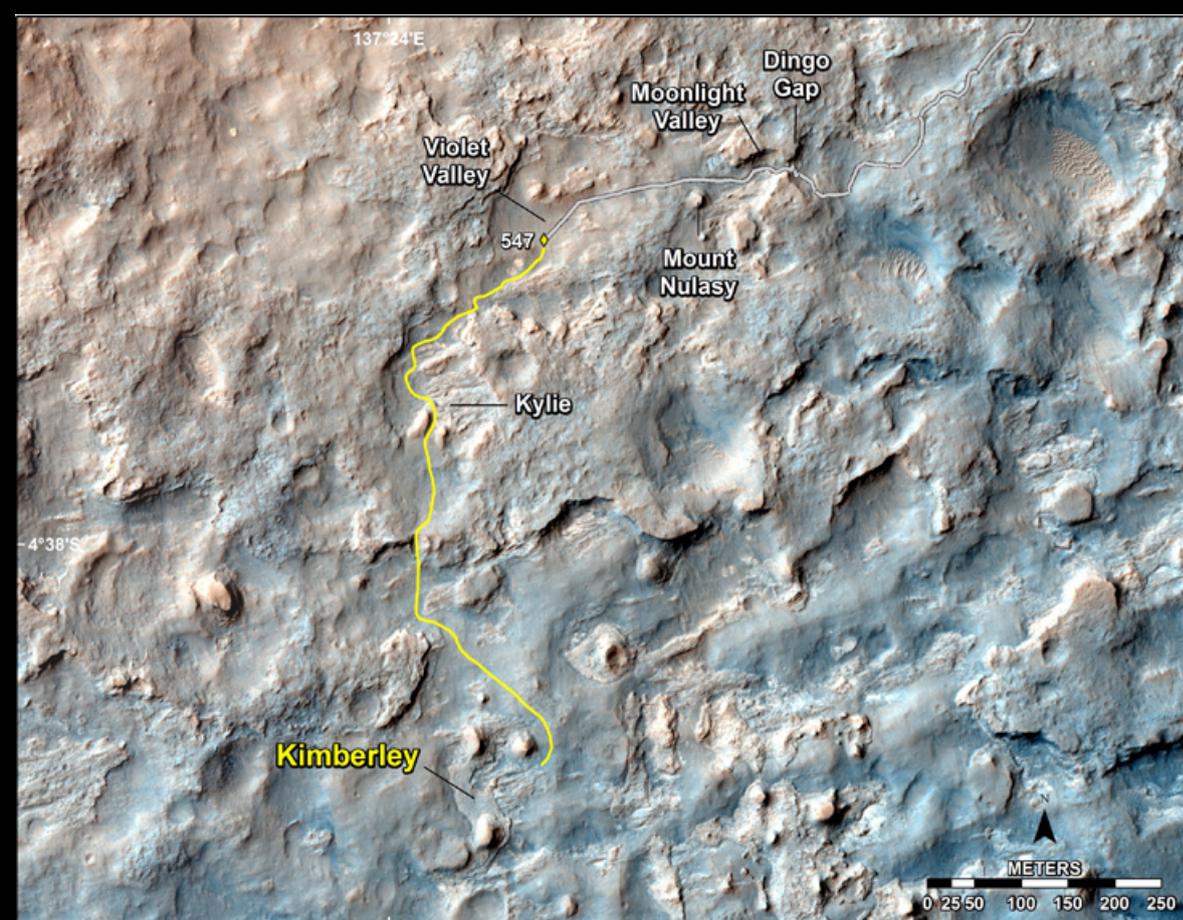
- Phobos: 11 Km
- Deimos: 6 Km



# Missões-presente

- Mars Odyssey: 7 Apr 2001
- Mars Express: 2 Jun 2003
- Mars Exploration Rover Spirit e Opportunity: 10 Jun 2003
- Mars Reconnaissance Orbiter: 12 Aug 2005, NASA
- India's Mars Orbiter Mission (MOM): 24 Sep 2014
- MAVEN (Mars Atmospheric and Volatile Evolution): 15 Dec 2014: NASA
- Mars Science Laboratory/Curiosity: 26 Nov 2011

Map of Recent and Planned Driving by Curiosity as of Feb. 18, 2014

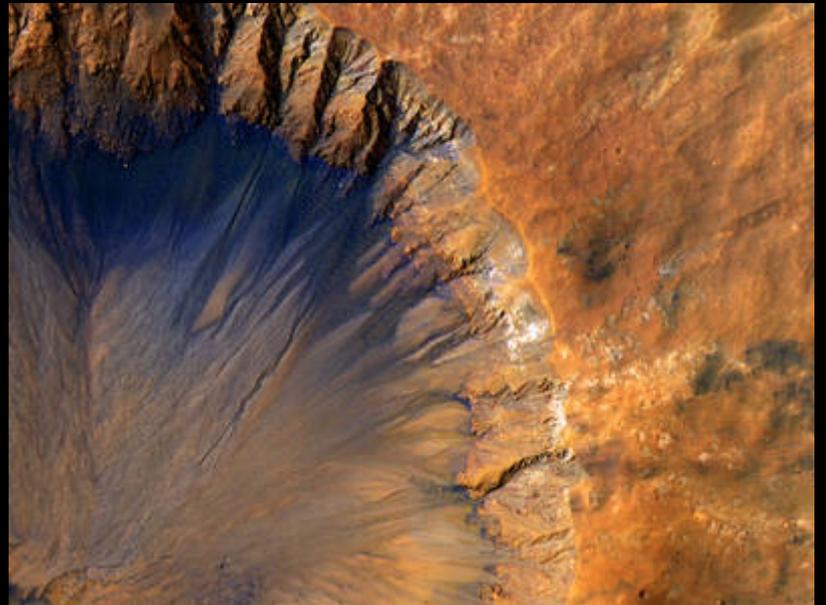
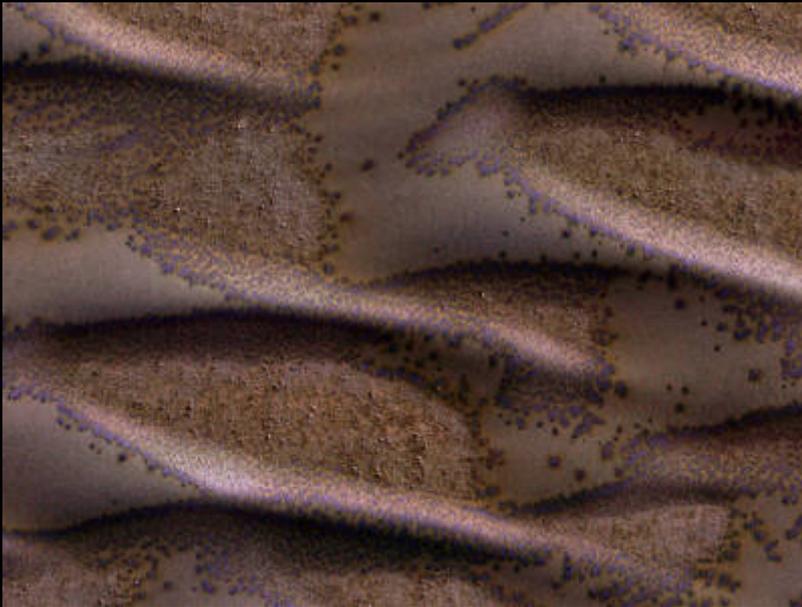


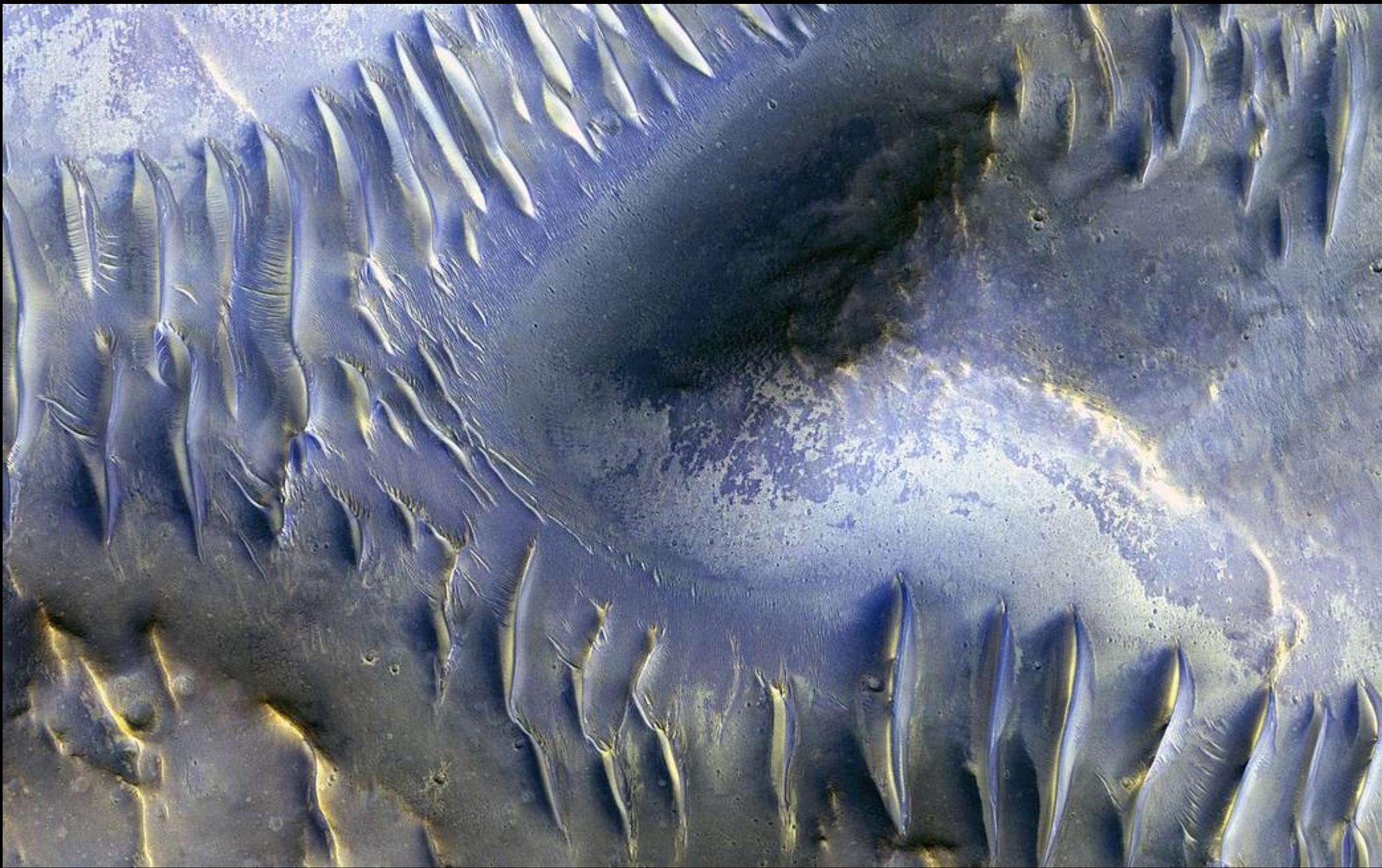
A Spectacular New Martian Impact Crater  
High Resolution Imaging Science  
Experiment (HiRISE) camera on  
NASA's **Mars Reconnaissance Orbiter**  
on 19 Nov. 2013

# Mars Curiosity Image Gallery



# Mars Reconnaissance Orbiter Image Gallery





Mars Reconnaissance Orbiter (MRO) image

NASA is on a journey to Mars, with a goal of sending humans to the Red Planet in the 2030s.



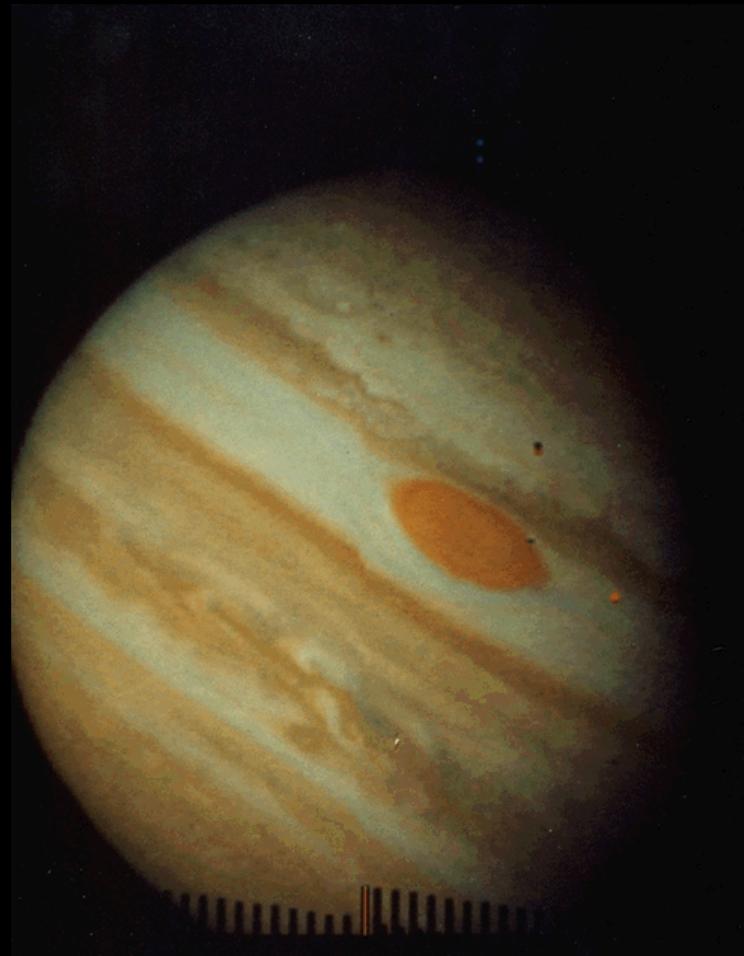
## EARTH RELIANT

NOW - MID-2020s

- International Space Station operation through 2024,
- Commercial development of low-Earth orbit.
- Development of deep space systems, life support and human health

# Júpiter

- Distância: 5.2 u.a.
- R : 71900 Km
- $\rho$  : 1.33 g/cm<sup>3</sup>
- $P_{\text{rot}}$  : 0.410 dias terrestres
- $P_{\text{sid}}$ : 4333 dias, 11.86 anos
- T : -125.2 : 26° C
- Maior planeta do Sistema Solar
- Gigante gasoso



# Estrutura de Júpiter

- Atmosfera delgada – não há superfície sólida
- 70000 – 60000 Km: H e outros gases
- 60000 – 50000 Km: H molecular líquido
- 50000 – 14000 Km: H metálico, líquido e He
- 14000 – 0 Km : núcleo com Fe e silicatos

# Júpiter: Atmosfera



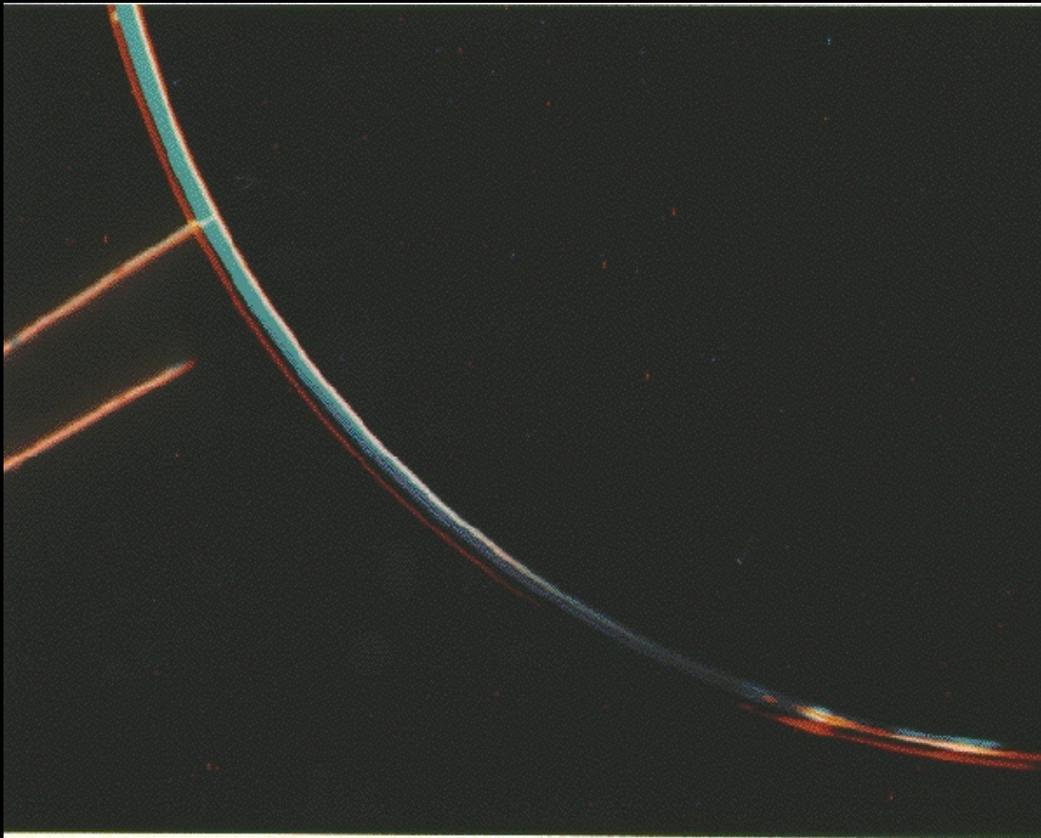
- H (<90%), He (<10%) – Sol
- Metano, água, amônia
- Nuvens de vapor d'água
- Gás, sem superfície sólida
- Núcleo de Fe e silicatos
- Ventos: altas velocidades em direções opostas

# Júpiter: atmosfera dinâmica

- Camada mais externa:  $H_2$ , He
- 3 camadas de nuvens de gelo de amônia, hidrosulfídeo de amônia, e mistura água e gelo



# Jupiter - anéis



- Voyager 1 descobriu os anéis de Júpiter
- Anéis escuros
- Poeira
- Não tem gelo
- Os anéis são constantemente enriquecidos por poeira “nova” (impactos da micrometeoros)

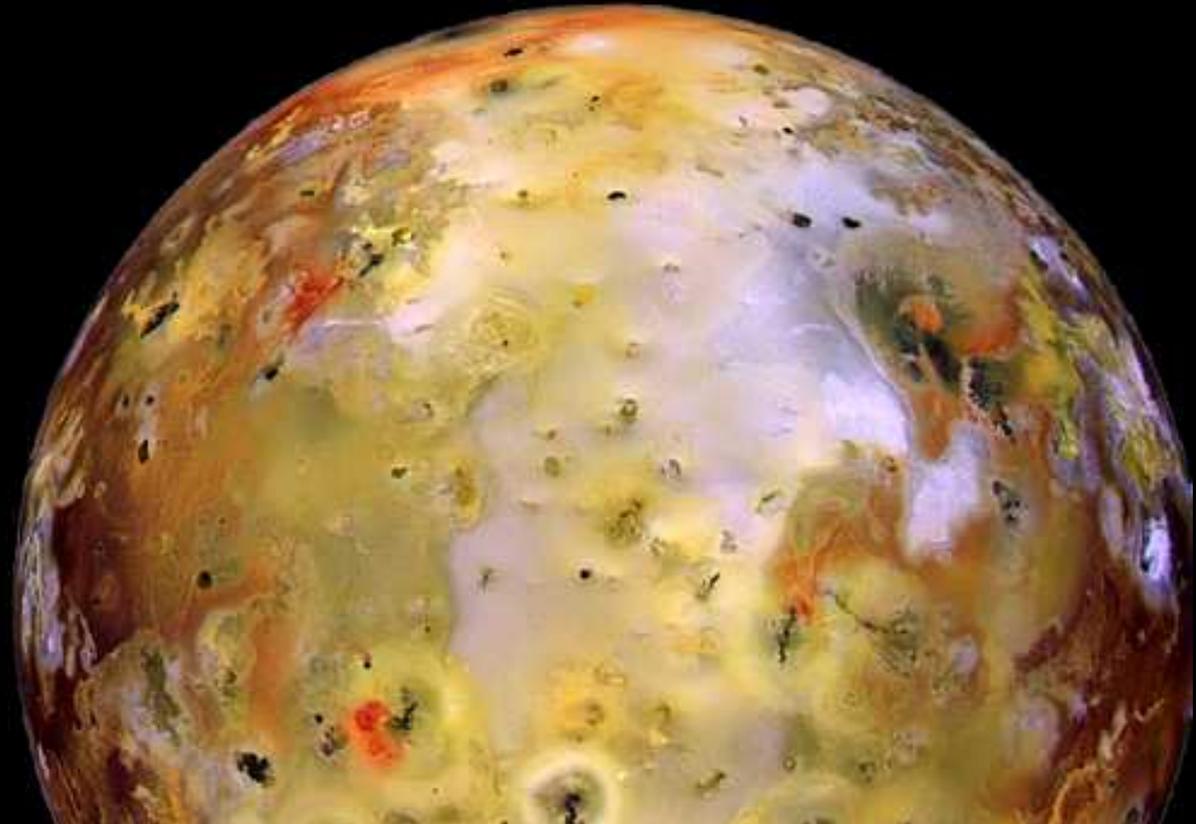
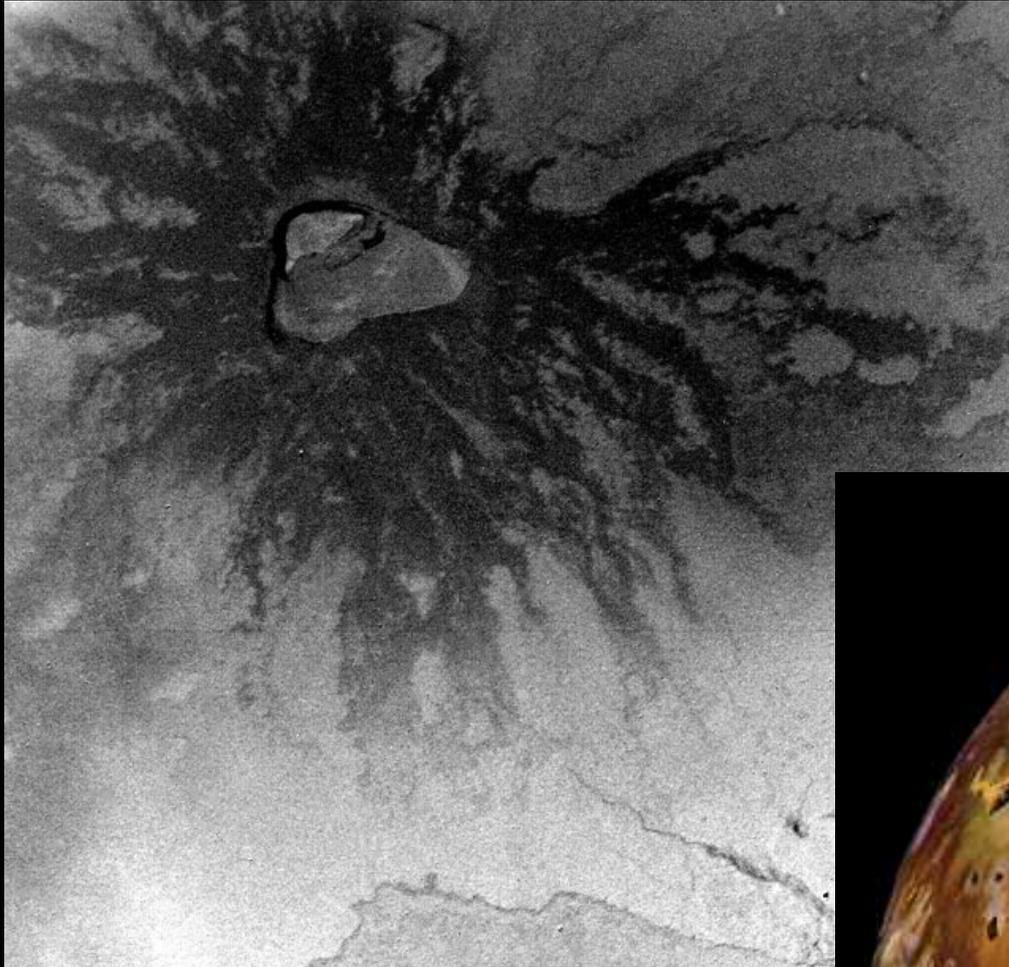
# Jupiter - Satélites

- 1610 – Galileo Galilei– 4 satélites (galileanos) : Io, Europa, **Calisto** **Ganymede** –
- Heliocentrismo (junto com fases de Vênus)
- 63 satélites



# Io - Europa

- Io e Europa tem composição similar aos planetas terrestres
- Poucas crateras - jovem



Io over Jupiter from Voyager 1

Image Credit: NASA, JPL-Caltech, Voyager 1; Processing: Alexis Tranchandon, Solaris

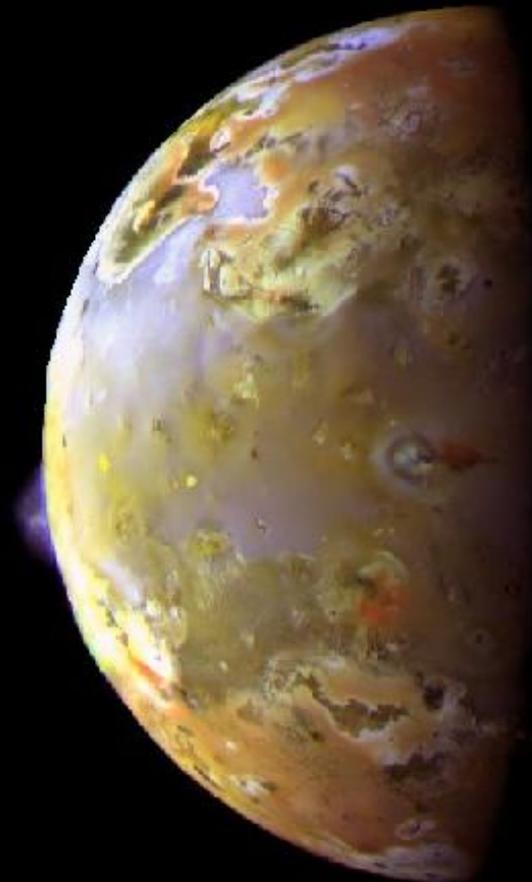


NASA, JPL-Caltech, Voyager 1;  
Processing: Alexis Tranchandon

- Io é o mundo mais ativo do Sistema Solar.

Io

- Velocidade de ejeção do magma: 0.5-1.0 km/s
- A temperatura típica do magma (420-720 K) sugere lavas sulfúricas. A cor da superfície de Io reforça a tese de se tratar de lavas sulfúricas
  - Enxofre liquefeito é enegrecido. A medida em que vai se solidificando, torna-se vermelho, amarelado e, finalmente, branco (quando se congela)
- Algumas lavas têm até 2000 K de temperatura. Devem conter silicatos liquefeitos
- Polos parecem conter gelo de SO<sub>2</sub>

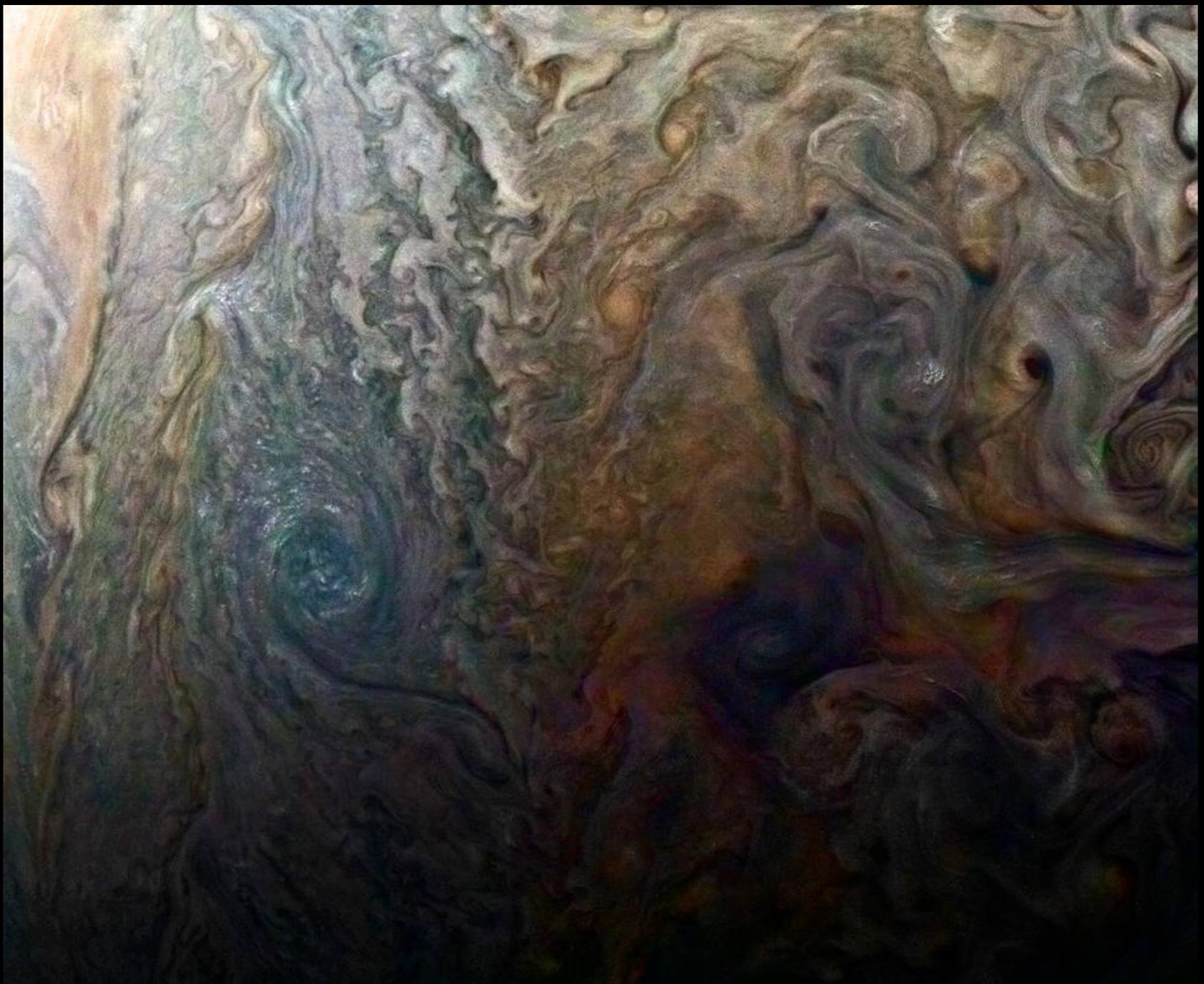


Missões a Jupiter  
Europa Mission  
Galileo  
Hubble  
Juno  
Pioneer  
Voyager



**JUNO:**  
Launched: Aug. 5, 2011  
Arrival at Jupiter: July 4, 2016  
Goal: Understand origin and evolution of Jupiter, look for solid planetary core, map magnetic field, measure water and ammonia in deep atmosphere, observe auroras.





This enhanced-color image of a mysterious dark spot on Jupiter seems to reveal a Jovian “galaxy” of swirling storms. Credits: NASA/JPL-Caltech/SwRI/MSSS/Roman Tkachenko



NASA's Juno spacecraft soared directly over Jupiter's south pole when JunoCam acquired this image on Feb. 2, 2017, from an altitude of about 101,000 kilometers above the cloud tops. This image was processed by citizen scientist John Landino. This enhanced color version highlights the bright high clouds and numerous meandering oval storms. Credits: NASA/JPL-Caltech/SwRI/MSSS/John Landino

[https://www.nasa.gov/mission\\_pages/juno/main/index.html](https://www.nasa.gov/mission_pages/juno/main/index.html)

# JUNO:

[https://www.youtube.com/watch?](https://www.youtube.com/watch?v=SgEsf4QcR0Q&feature=youtu.be&list=PLTiv_XWHnOZpM1iLQr95P4KDXyYnJUOE)

[v=SgEsf4QcR0Q&feature=youtu.be&list=PLTiv\\_XWHnOZpM1iLQr95P4KDXyYnJUOE](https://www.youtube.com/watch?v=SgEsf4QcR0Q&feature=youtu.be&list=PLTiv_XWHnOZpM1iLQr95P4KDXyYnJUOE)

E

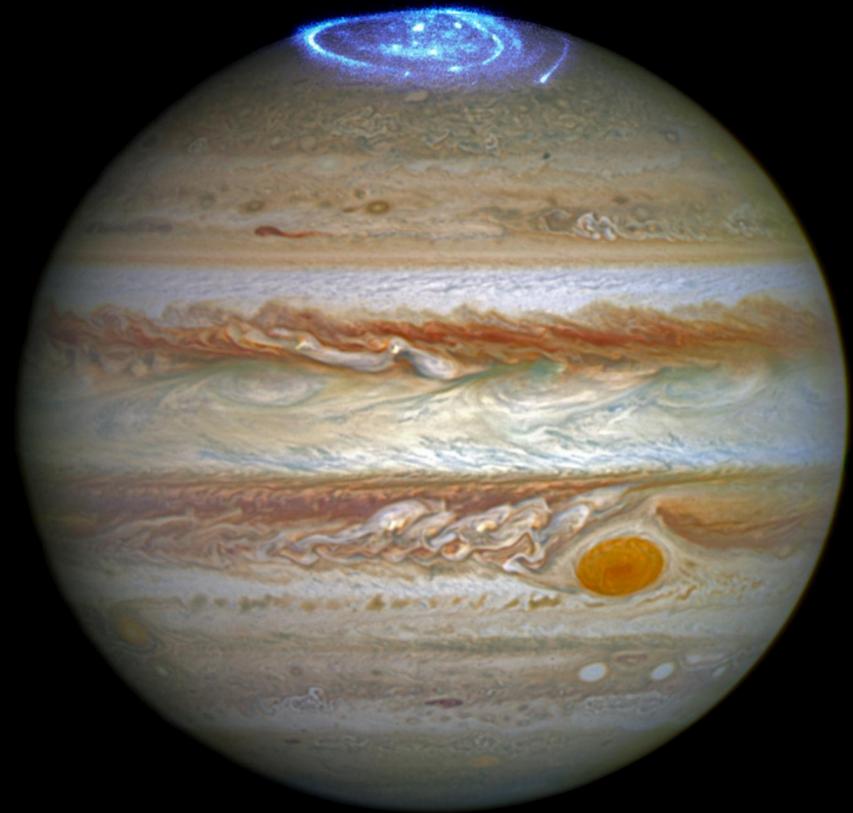
[https://www.youtube.com/watch?](https://www.youtube.com/watch?v=r5SuUY7dF1w&list=PLTiv_XWHnOZpM1iLQr95P4KDXyYnJUOE&index=12)

[v=r5SuUY7dF1w&list=PLTiv\\_XWHnOZpM1iLQr95P4KDXyYnJUOE&index=12](https://www.youtube.com/watch?v=r5SuUY7dF1w&list=PLTiv_XWHnOZpM1iLQr95P4KDXyYnJUOE&index=12)

[https://www.youtube.com/watch?](https://www.youtube.com/watch?v=8CT_txWEo5I&index=13&list=PLTiv_XWHnOZpM1iLQr95P4KDXyYnJUOE)

[v=8CT\\_txWEo5I&index=13&list=PLTiv\\_XWHnOZpM1iLQr95P4KDXyYnJUOE](https://www.youtube.com/watch?v=8CT_txWEo5I&index=13&list=PLTiv_XWHnOZpM1iLQr95P4KDXyYnJUOE)

E

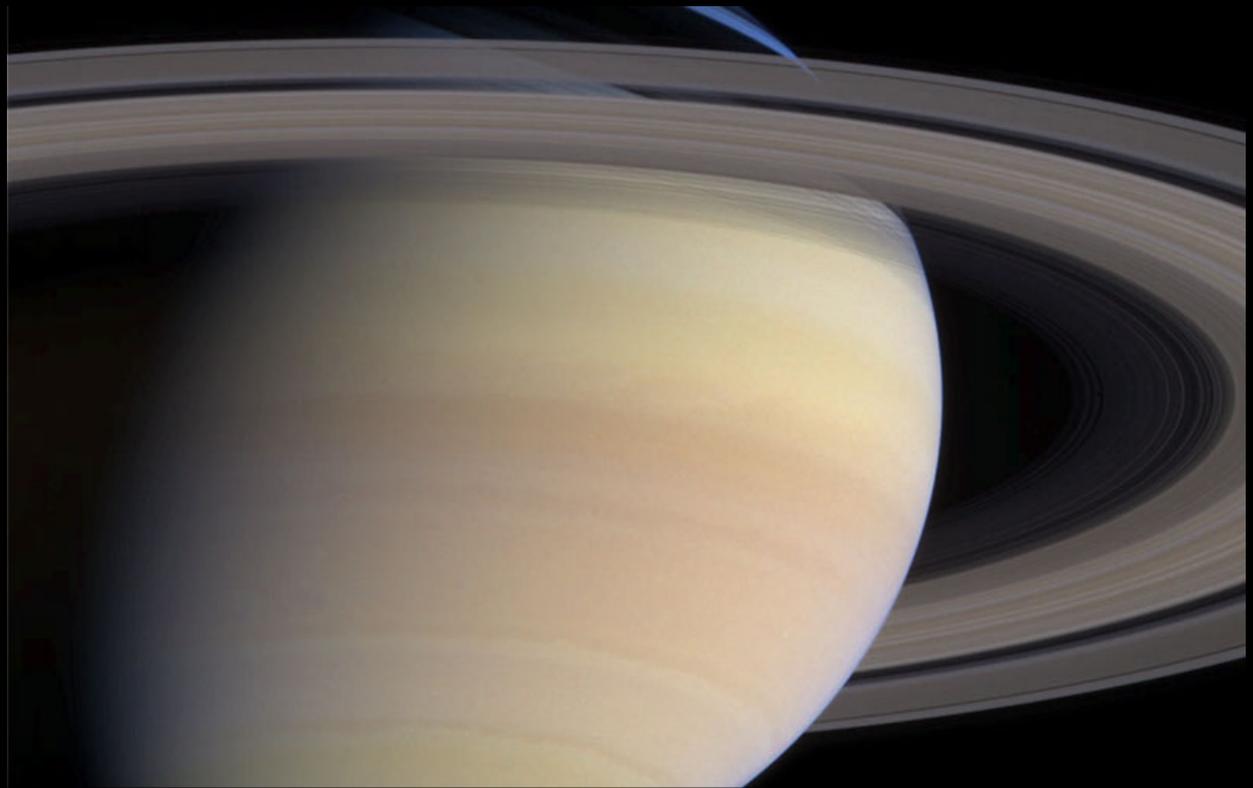


# Saturno



- Distância: 9.54 U.A. (1.429.400.000 Km)
- R : 60268 Km
- $\rho$  : 0.69 g/cm<sup>3</sup>
- $P_{\text{rot}}$  : 0.428 dias
- $P_{\text{sid}}$ : 10559 dias (29.46 anos terr.)
- T : -284 – 207 F

# Atmosfera



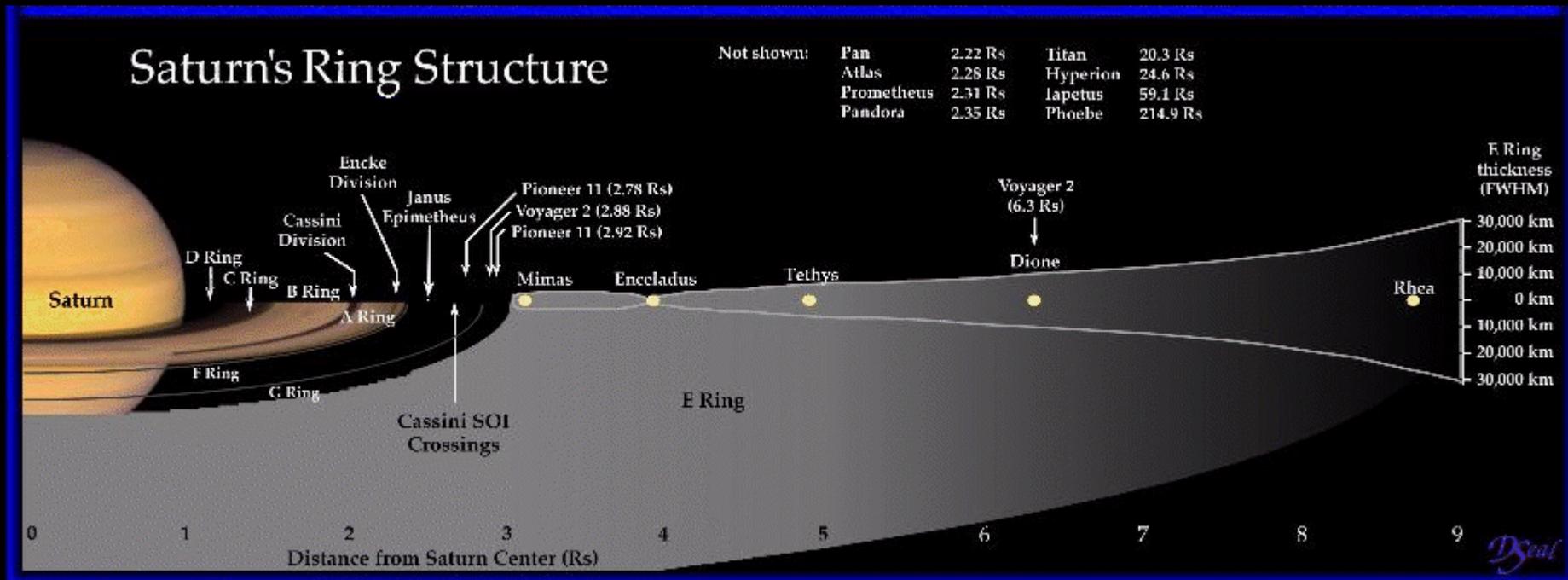
[www.jpl.nasa.gov](http://www.jpl.nasa.gov)

- 75 % H, 25% He, traços de água, metano, amônia e rochas – Nebulosa Solar
- Faixas atmosféricas menos proeminentes que em Júpiter

# Anéis



- Huygens , 1649 –anéis
- A e B – mais proeminentes, C : vistos da Terra
- Divisão de Cassini
- 250.000 Km (diâmetro), menos de 1 Km de espessura
- Gelo de água, poeira, e poeira com manto de gelo



# Satélites



- Thetis e Dione
- 34 satélites com nomes

# Titan

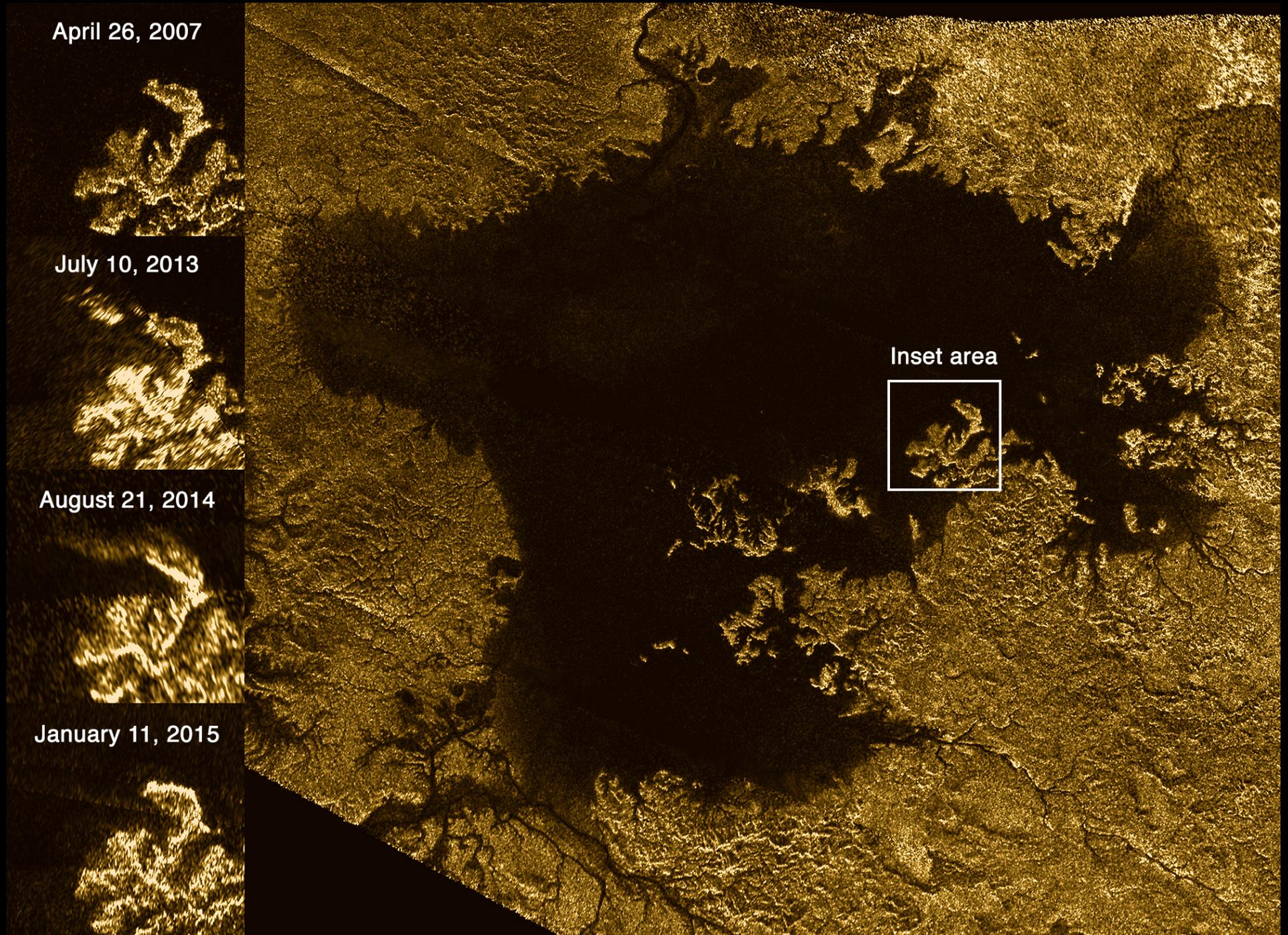


- Titan é o 15o. Satélite de Saturno e o mais conhecido.
- Órbita: 1.221.830 km de Saturno
- Diâmetro: 5150 km **mass:**  $1.35E23$  kg
- Descoberto por Christiaan Huygens em 1655

# Titan

- Pensava-se que Titan era o maior satélite do Sistema Solar, mas dados recentes mostraram que sua atmosfera é muito espessa que sua superfície sólida é ligeiramente menor.
- *Titan é maior em diâmetro que Mercúrio e maior e mais massivo que Plutão.*
- Atmosfera : N<sub>2</sub> (78 %) – como a Terra

These images from the Radar instrument aboard NASA's Cassini spacecraft show the evolution of a transient feature in the large hydrocarbon sea named Ligeia Mare on Saturn's moon Titan.



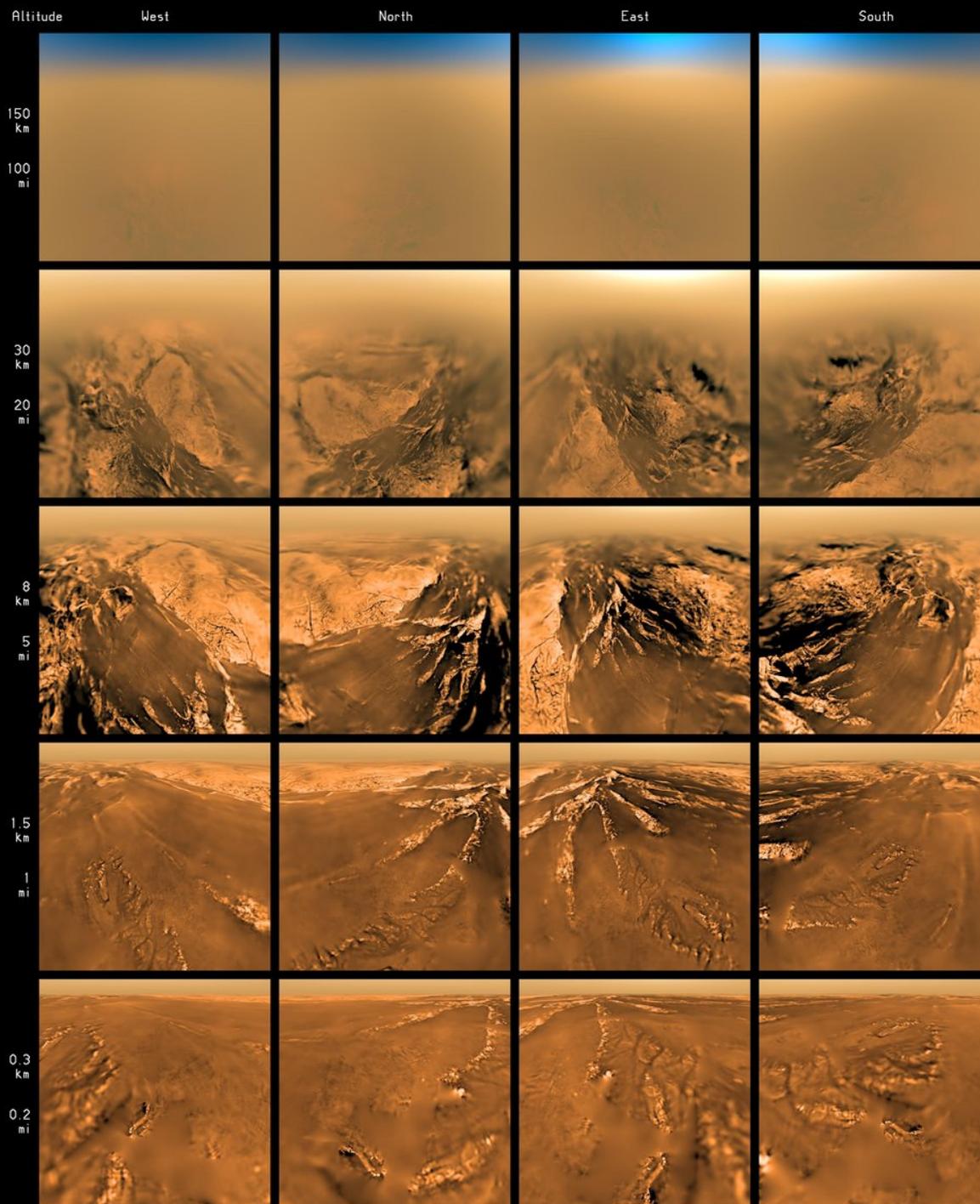
Ten years ago, ESA's Huygens probe entered the history books by descending to the surface of Titan, Saturn's largest moon. Humanity's first successful attempt to land a probe on another world in the outer Solar System took place at 13:34 CET (12:34 GMT) on 14 January 2005.

Huygens hitched a ride to the Saturn system during an epic, seven-year voyage attached to NASA's Cassini spacecraft. The final chapter of the interplanetary trek was a 21-day solo cruise toward the haze-shrouded moon. Plunging into Titan's atmosphere, the probe survived the hazardous 2 hour 27 minute descent to touch down safely on Titan's frozen surface.

**Huygens continued to transmit back to Earth for another 72 minutes before contact was lost with Cassini** as it dipped below the horizon. The stream of data provided a unique treasure trove of in situ measurements from the planet-sized satellite which scientists are still mining today. To mark the 10th anniversary of Huygens landing on Titan, we have selected 10 important results from the pioneering mission.

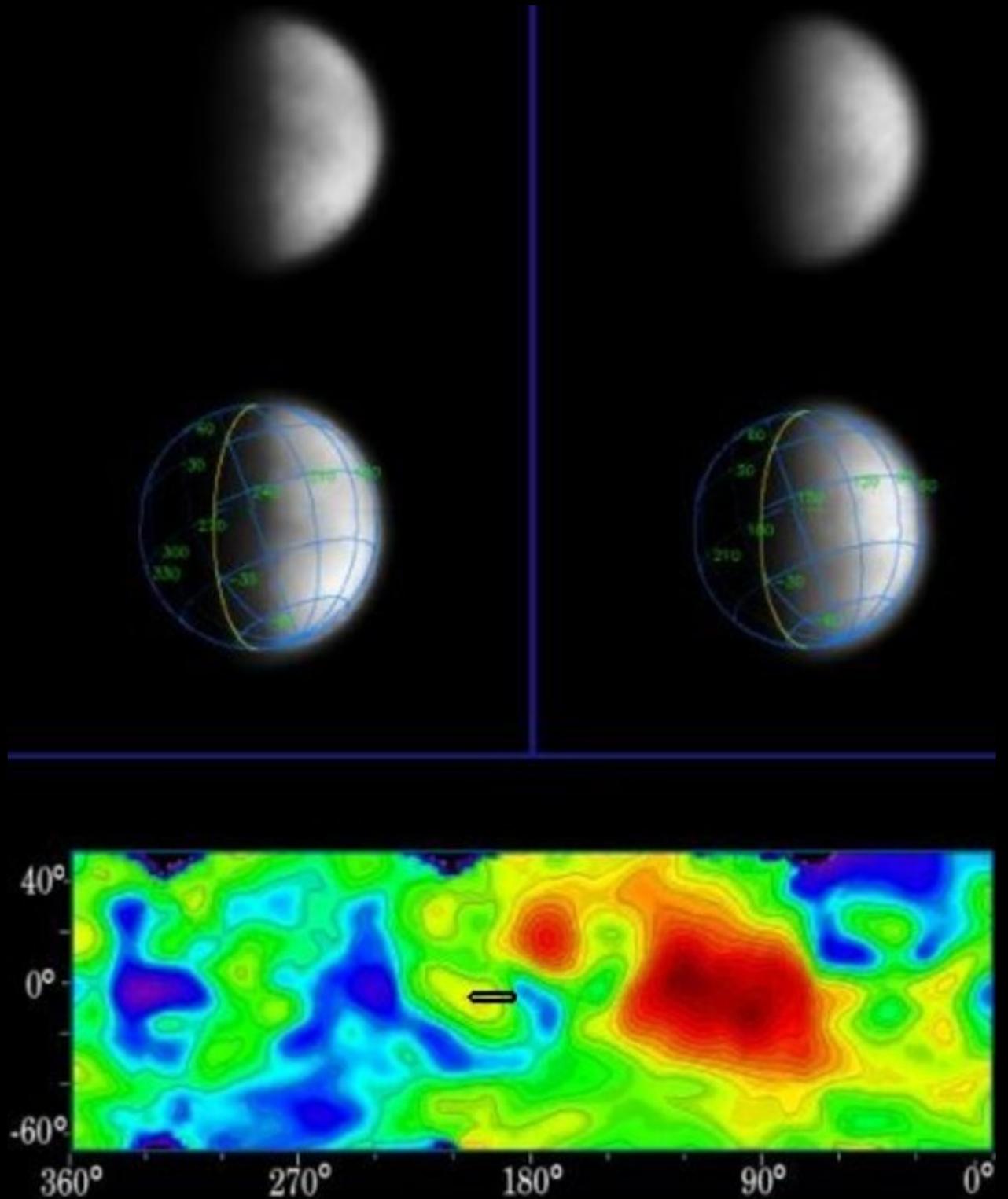
ESA/NASA/JPL/University of Arizona

Aerial Views of Titan Around the Huygens Landing Site



# Titan's surface

It is unclear whether Xanadu (red) is a mountain range, a giant basin, a smooth plain or a combination of all three. It may be dotted with hydrocarbon lakes but that is also unknown.





# Titan

## BY THE NUMBERS

In the decade since NASA's Cassini spacecraft delivered ESA's Huygens probe to the hidden surface of Titan, our knowledge of Saturn's largest moon has grown by leaps and bounds.

**1** **st PROBE**  
to LAND ON Titan's  
unknown surface

**1** GLOBAL  
SUBSURFACE  
WATER OCEAN

**108** TARGETED  
flybys

**35** NAMED HYDROCARBON  
lakes and seas

**37,000** IMAGES  
TAKEN

**17** MOLECULES IDENTIFIED  
IN THICK ATMOSPHERE

**43%** of surface mapped  
by RADAR

**-180°** CELSIUS SURFACE  
temperature

**1160**  
SCIENCE PAPERS  
published

**1.45 x**  
SURFACE PRESSURE  
OF EARTH

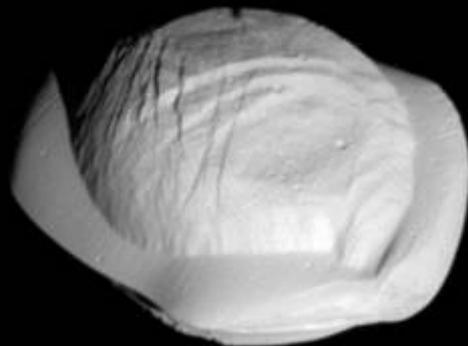


<https://www.nasa.gov/feature/jpl/huygens-ground-truth-from-an-alien-moon>

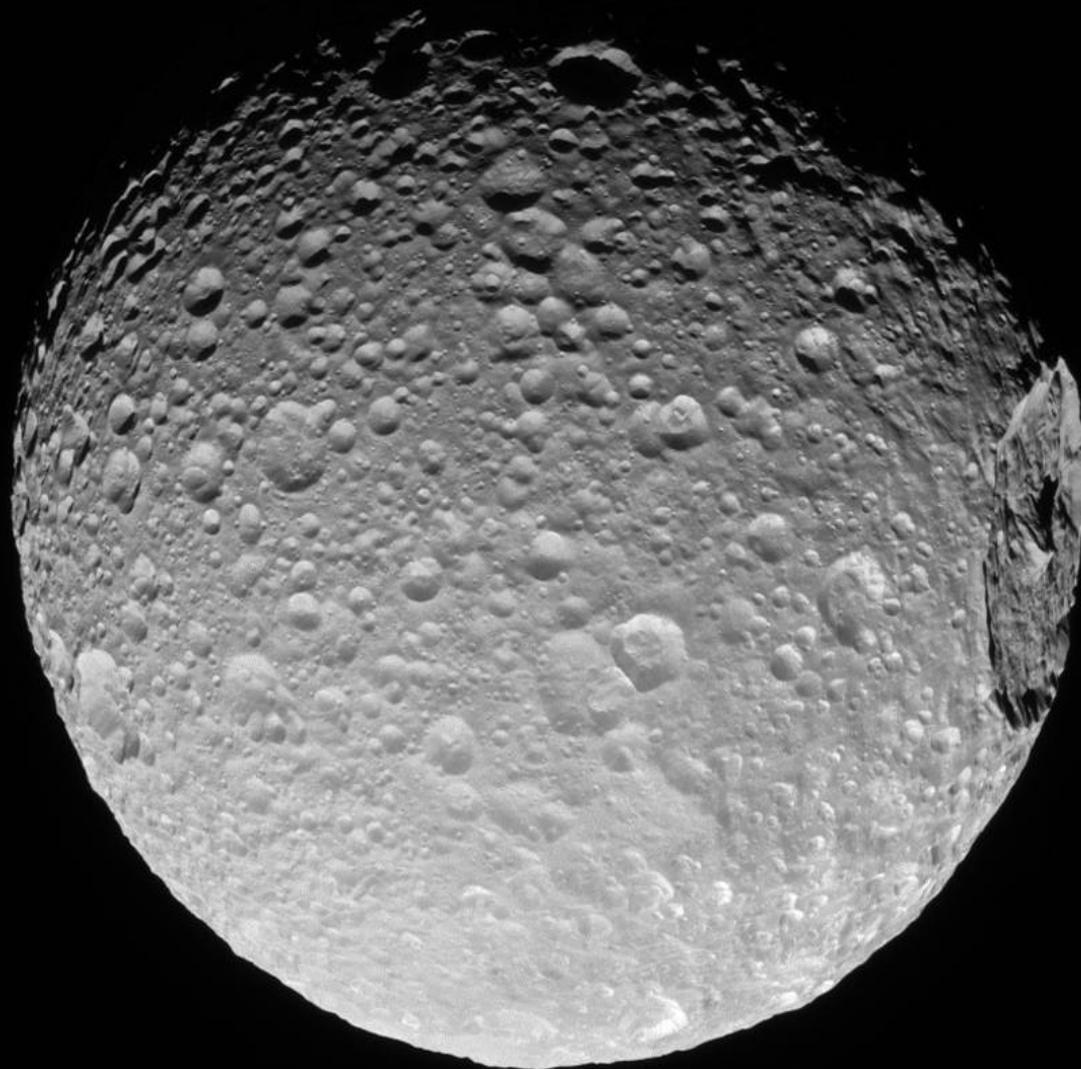
[http://www.esa.int/Our\\_Activities/Space\\_Science/Highlights/Ten\\_years\\_at\\_Titan](http://www.esa.int/Our_Activities/Space_Science/Highlights/Ten_years_at_Titan)

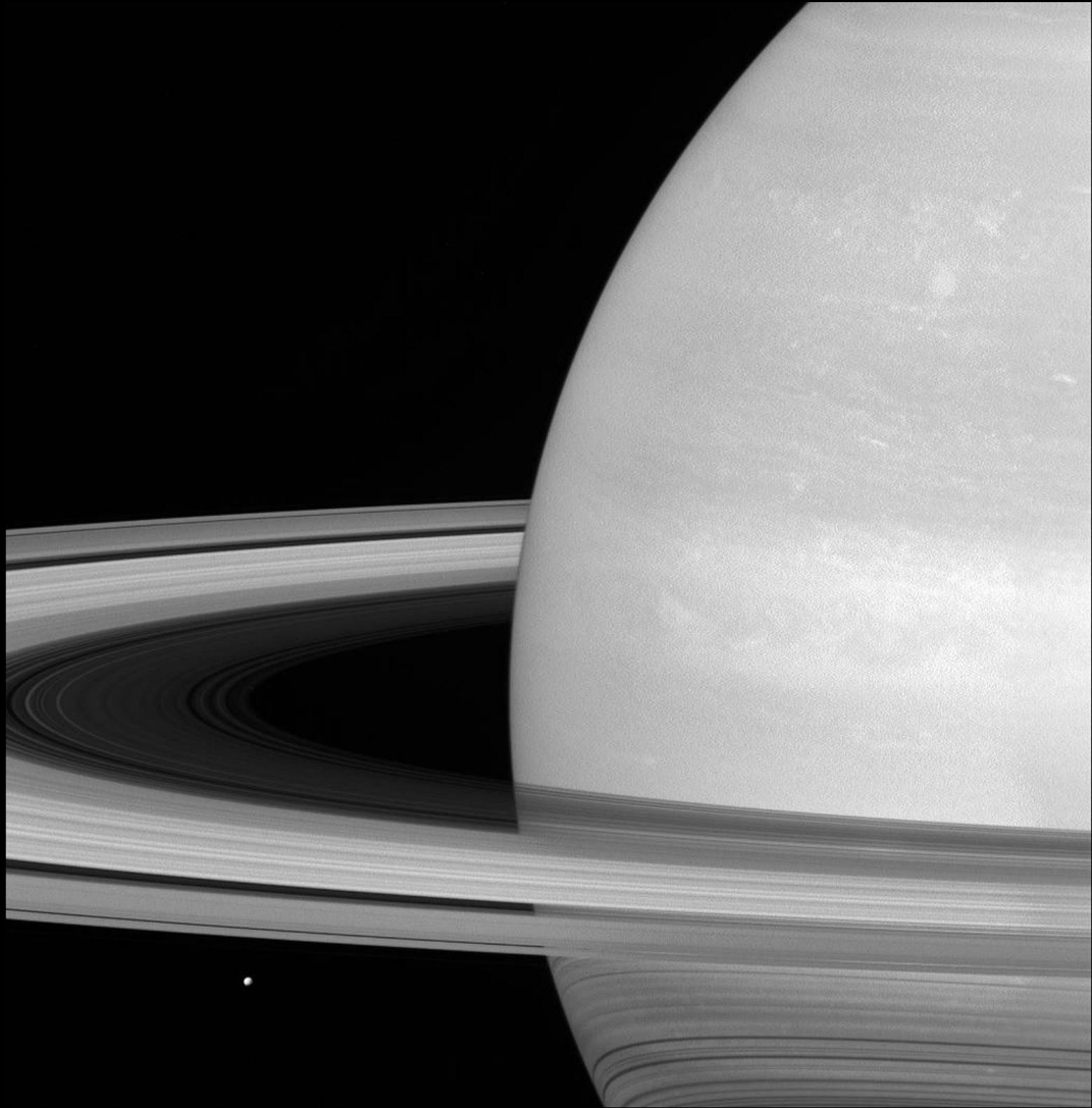
# Pan Revealed

These two images from NASA's Cassini spacecraft show how the spacecraft's perspective changed as it passed within 15,300 miles (24,600 kilometers) of Saturn's moon Pan on March 7, 2017.



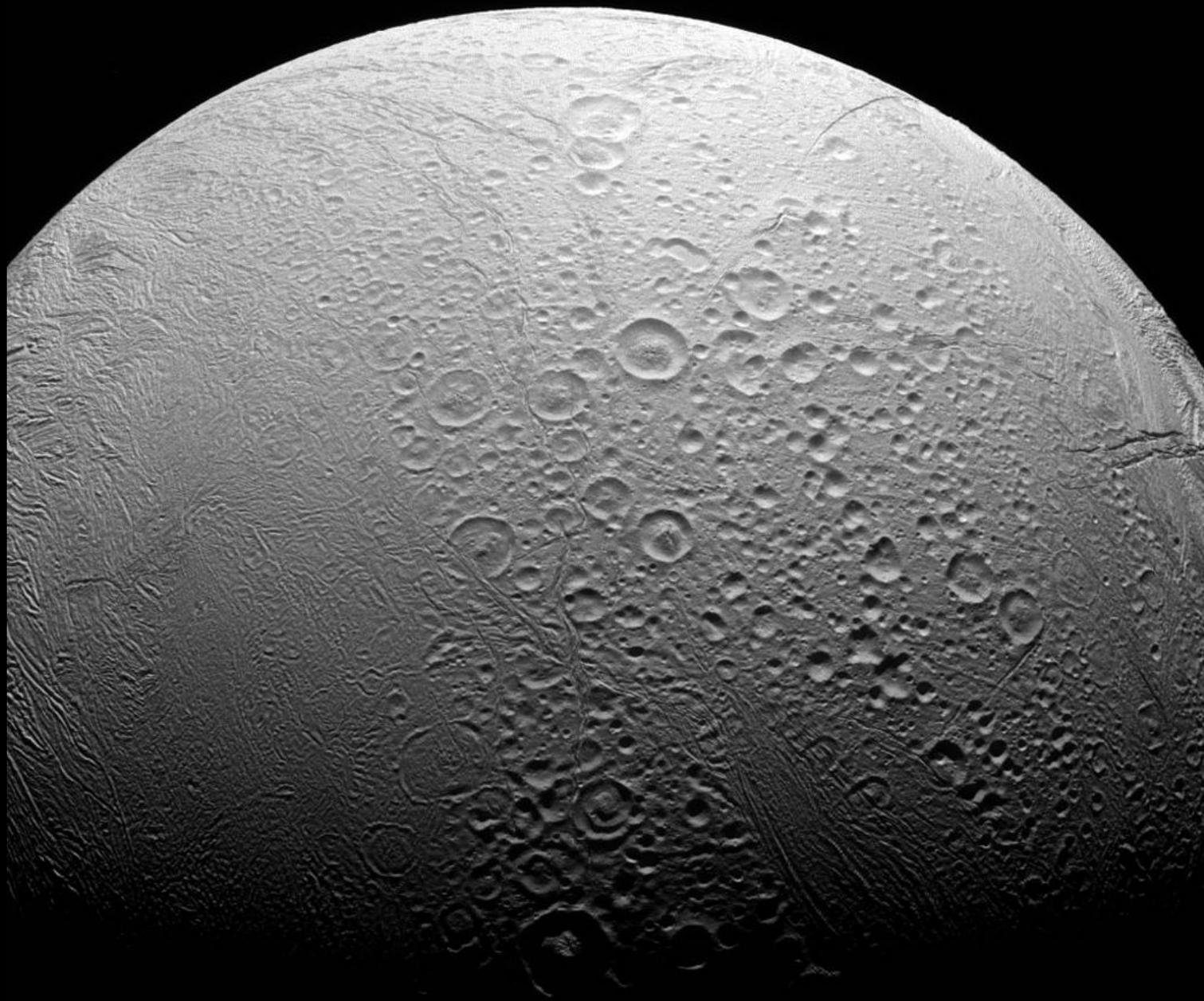
# Mimas





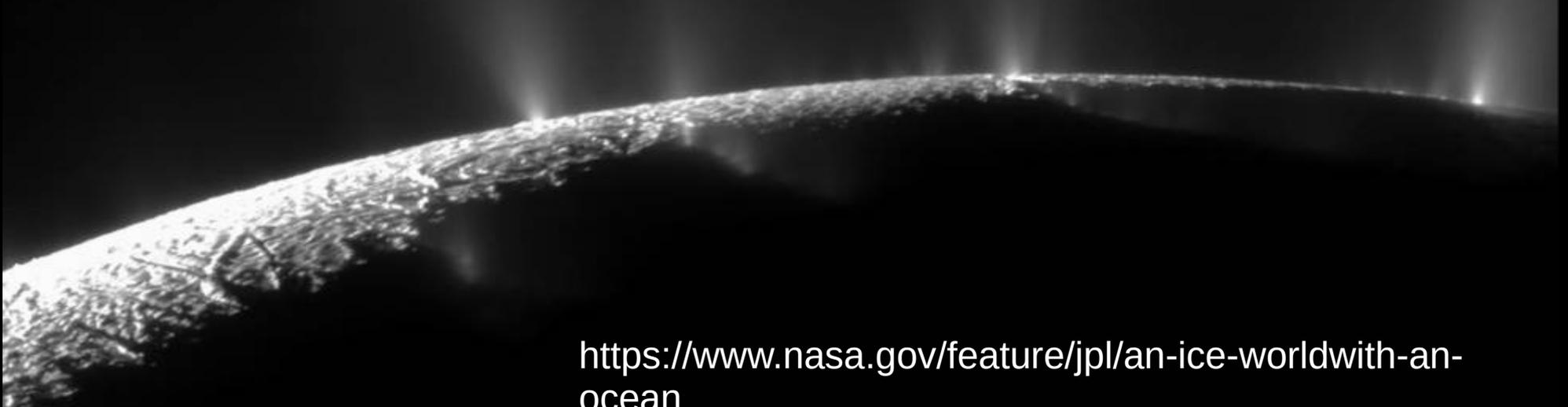
Mimas

Enceladus é um mundo dividido. No **norte vemos uma grande quantidade de crateras**, evidencia dos muitos impactos no seu passado. Entretanto, no **sul vemos um corpo mais 'liso'** com 'rugas' devido a atividade geológica.



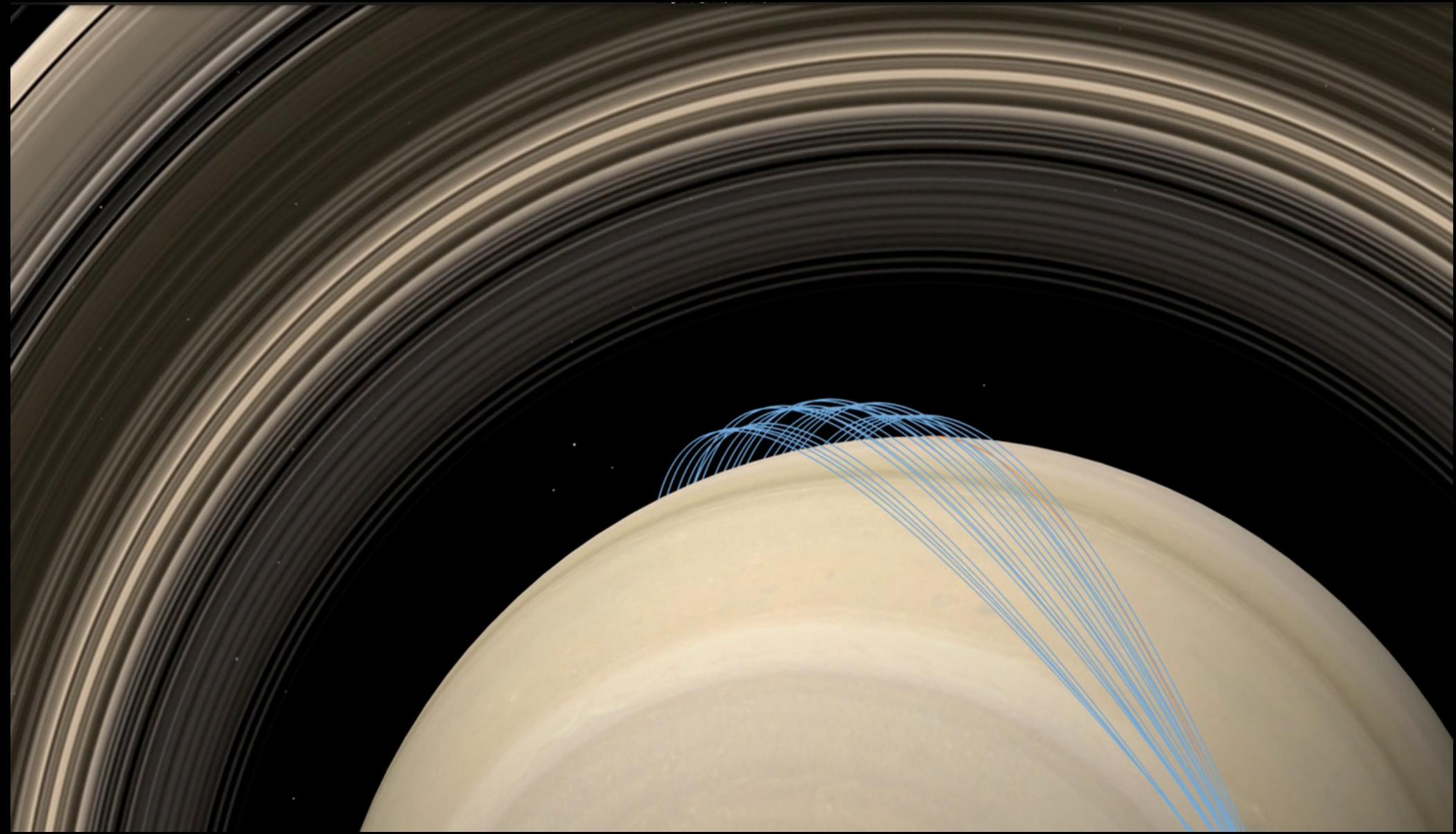
# Activity at Enceladus

A importância da descoberta é que plumas e vulcões deste tipo são indícios de oceano subterrâneo, o que é essencial para a existência de vida como a conhecemos.



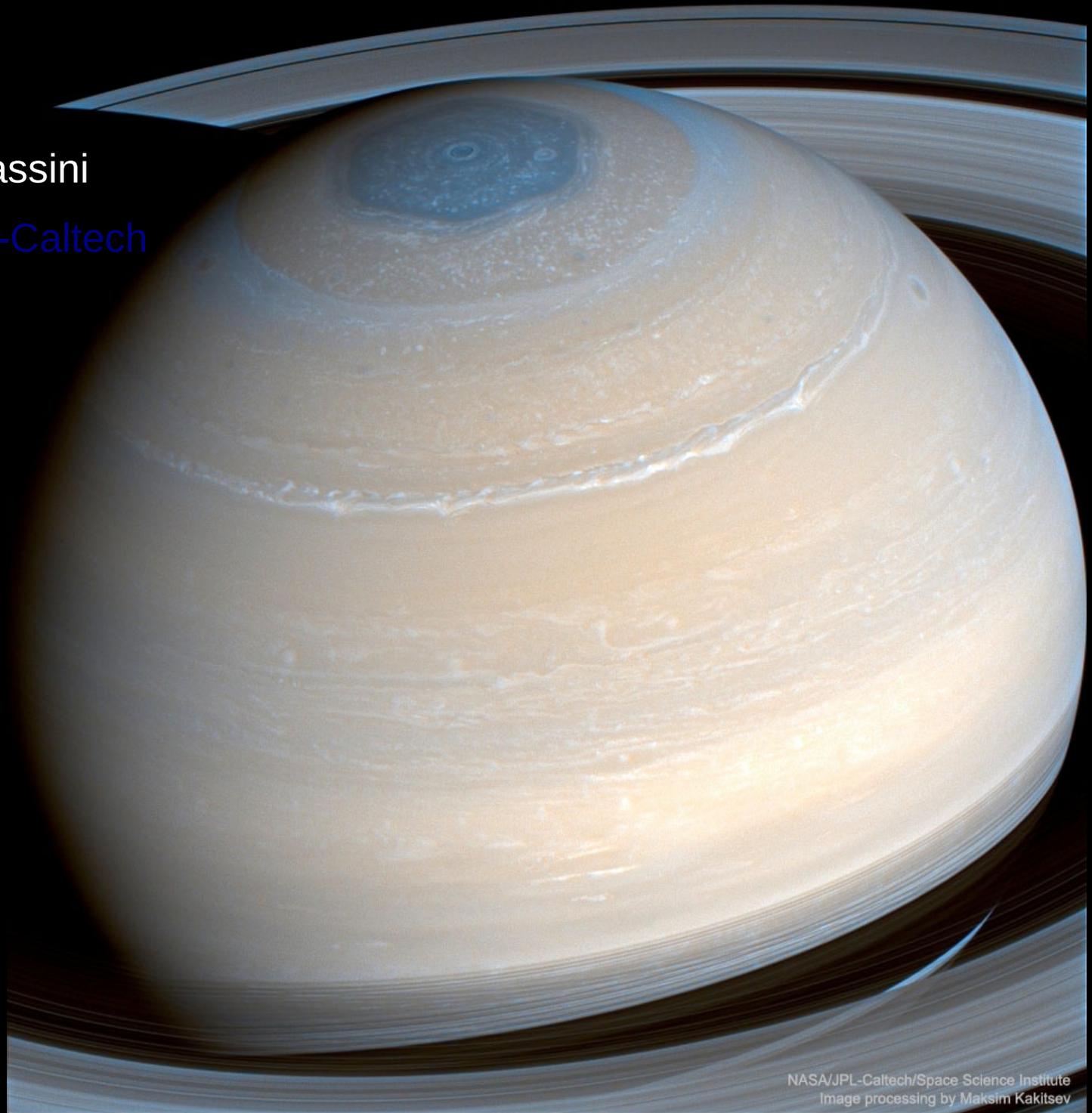
<https://www.nasa.gov/feature/jpl/an-ice-worldwith-an-ocean>

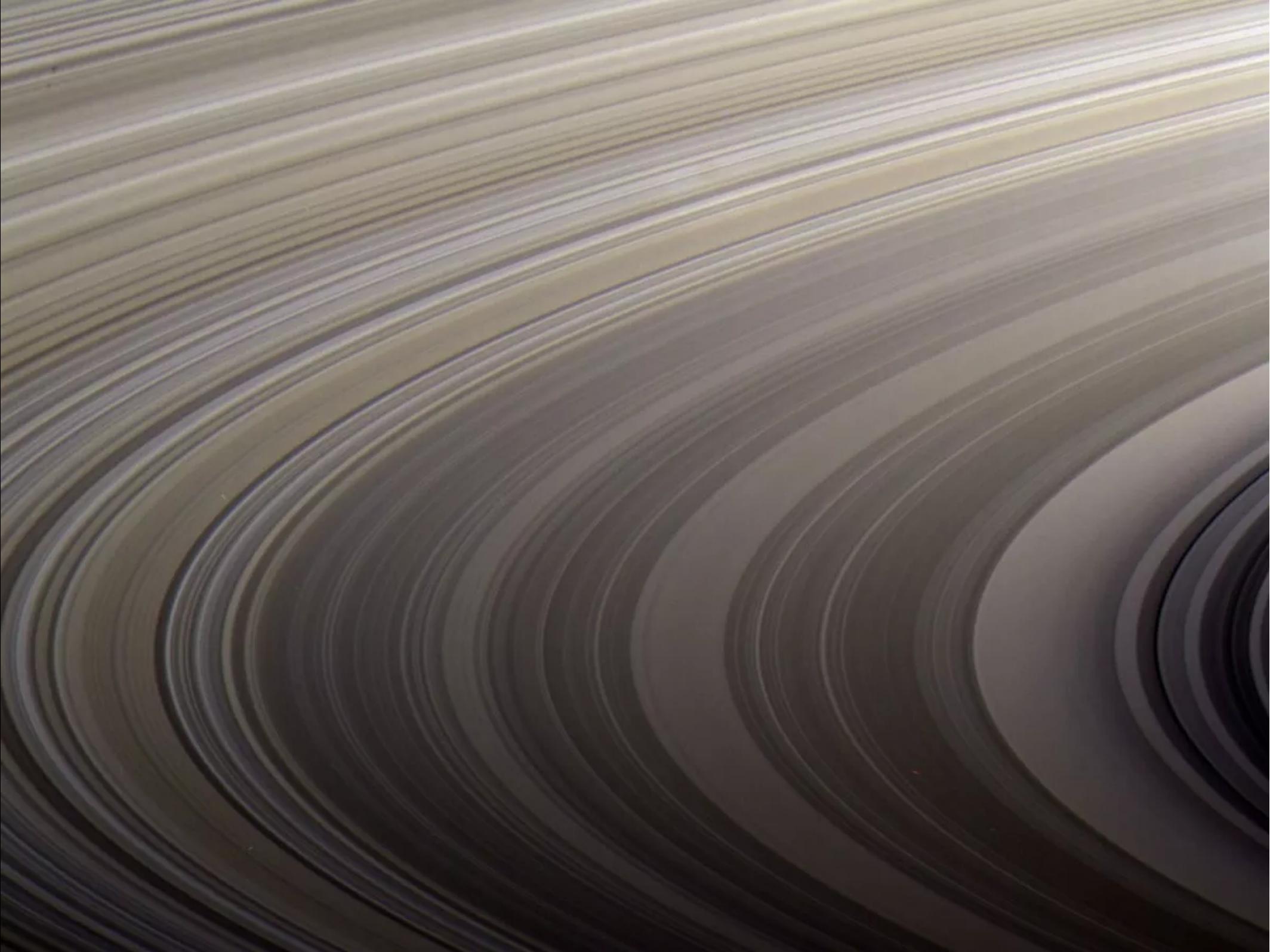
# Cassini at Saturn



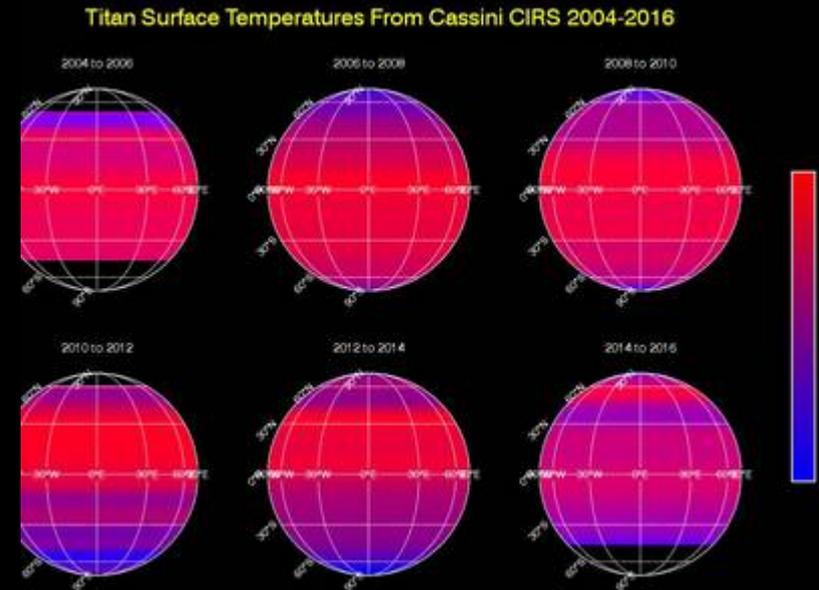
# Saturn in Infrared from Cassini

Image Credit: [NASA](#), [JPL-Caltech](#),  
[SSI](#); Processing:  
[Maksim Kakitsev](#)

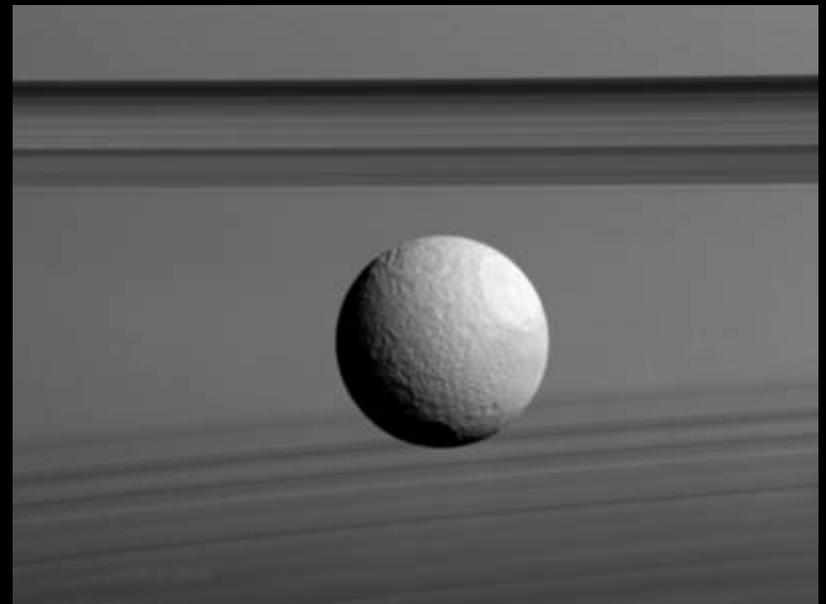
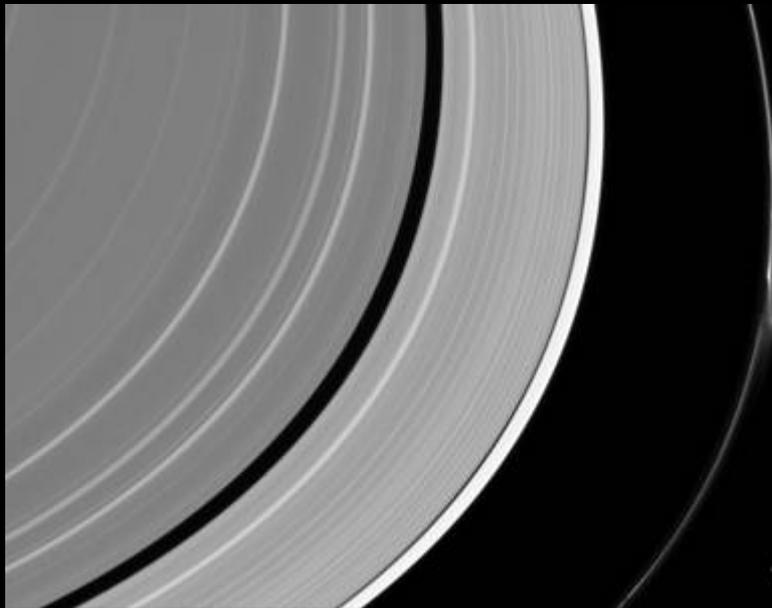




# Cassini at Saturn



<https://revistagalileu.globo.com/Ciencia/noticia/2017/09/cassini-tudo-sobre-missao-que-chegou-mais-perto-de-saturno.html>



<https://www.youtube.com/watch?v=XITah0sxFFQ> - ouvir o som de Saturno

# Urano



- Distância: 19.21 U.A.
- R : 25559 Km
- $\rho$  : 1.29 g/cm<sup>3</sup>
- $P_{\text{rot}}$  : 0.748 dias
- $P_{\text{sid}}$ : 30685 dias (84 anos terr.)
- T : -190  $\Rightarrow$  -366 F
- Cor azul: absorção da luz vermelha pelo metano

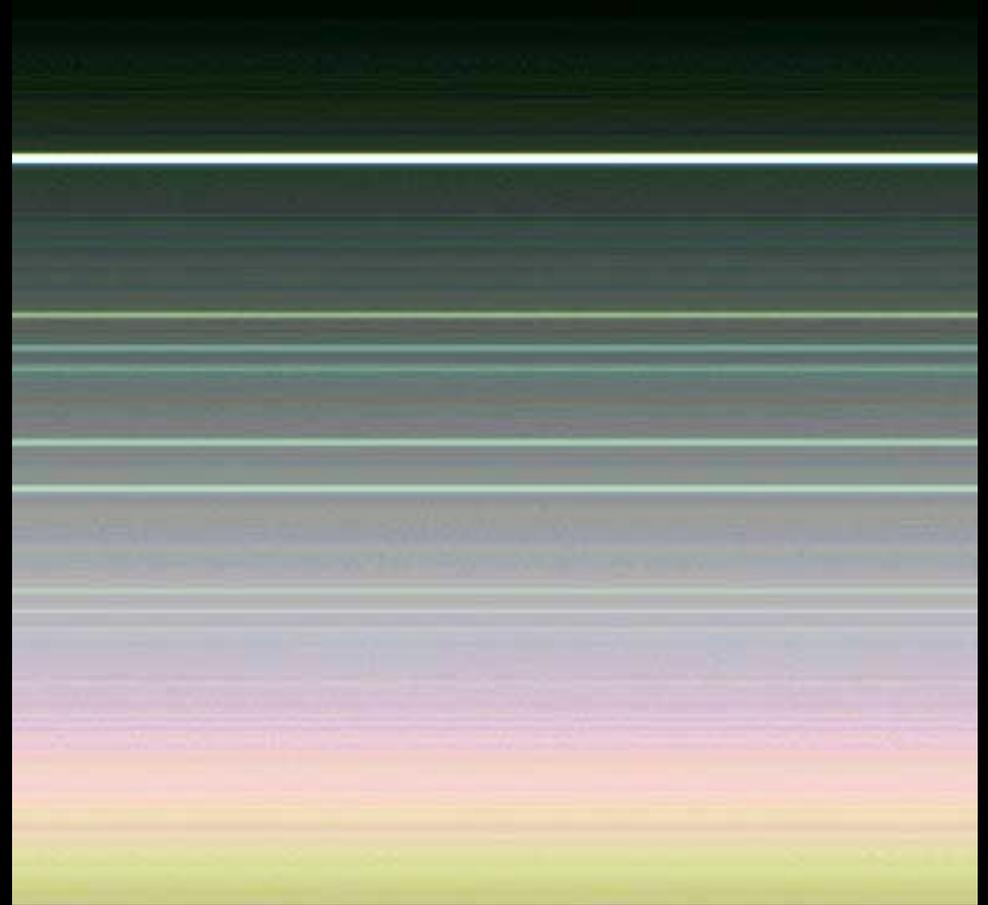
# Urano - anéis

■ Atmosfera: 83%  
H, 15% He e 2%  
metano

■ Bandas de nuvens  
rodando  
rapidamente

■ Rochas e gelo

- Voyager (1986) – única sonda a visitar
- 11 anéis conhecidos



# Satélites de Urano



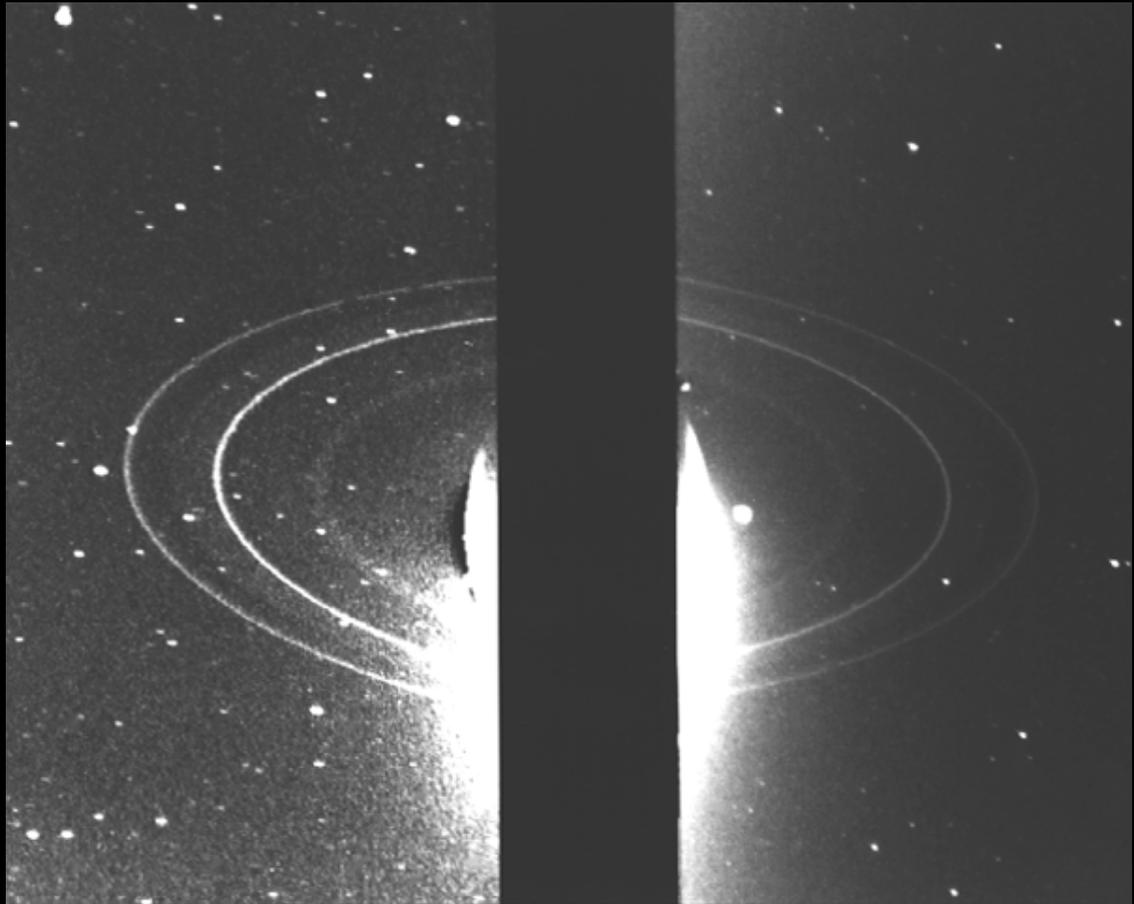
- satélites naturais: 21 com nomes e 6 sem nomes
- Miranda, Ariel, Umbriel, **Titânia**, Oberon

# Netuno



- Distância: 30.6 U.A.
- $R$  : 24.766 Km
- $\rho$  : 1.64 g/cm<sup>3</sup>
- $P_{\text{rot}}$  : 0.802 dias
- $P_{\text{sid}}$ : 60200 dias (165 anos terr.)
- $T$  : -350  $\Rightarrow$  -390 F

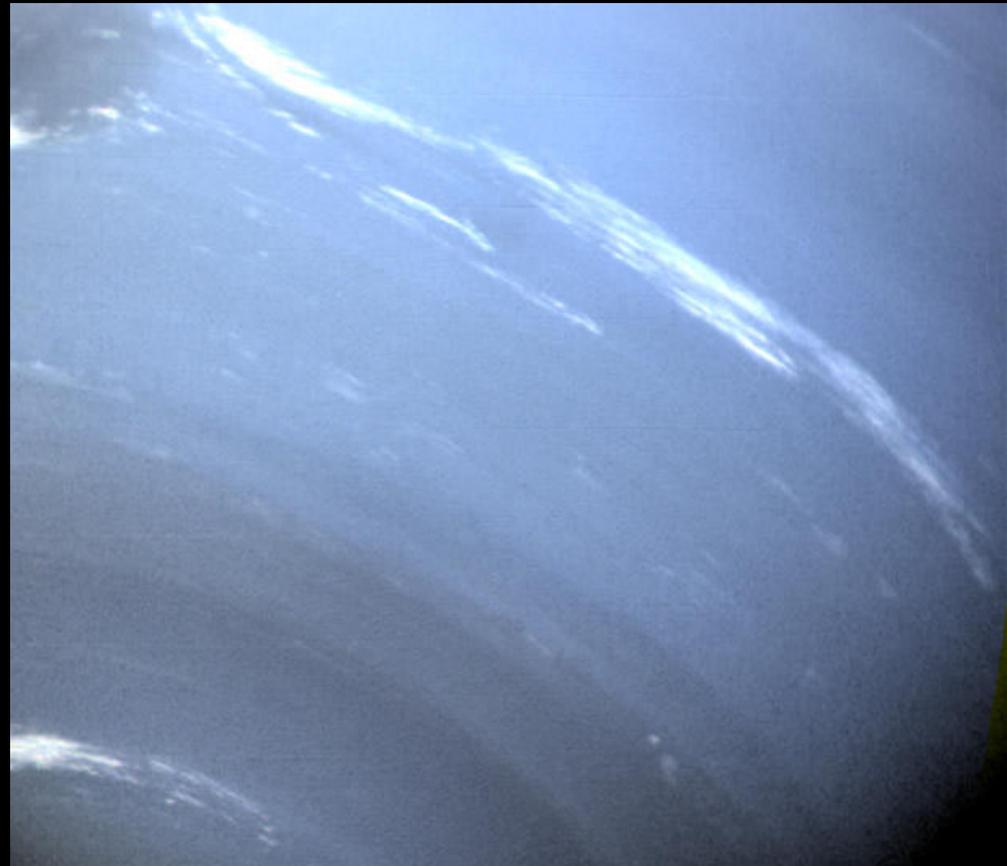
# Anéis



- Anéis completos com “clumps”  
(pedaços aglomerados)
- Composição desconhecida

# Netuno – Voyager 2

- Atmosfera:  
similar a Urano  
H, He pouco,  
metano
- Metano: azul
- Composição  
uniforme
- Núcleo sólido



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## EVIDENCE FOR A DISTANT GIANT PLANET IN THE SOLAR SYSTEM

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### ABSTRACT

Recent analyses have shown that distant orbits within the scattered disk population of the Kuiper Belt exhibit an unexpected clustering in their respective arguments of perihelion. While several hypotheses have been put forward to explain this alignment, to date, a theoretical model that can successfully account for the observations remains elusive. In this work we show that the orbits of distant Kuiper Belt objects (KBOs) cluster not only in argument of perihelion, but also in physical space. We demonstrate that the perihelion positions and orbital planes of the objects are tightly confined and that such a clustering has only a probability of 0.007% to be due to chance, thus requiring a dynamical origin. We find that the observed orbital alignment can be maintained by a distant eccentric planet with mass  $\gtrsim 10 m_{\oplus}$  whose orbit lies in approximately the same plane as those of the distant KBOs, but whose perihelion is  $180^{\circ}$  away from the perihelia of the minor bodies. In addition to accounting for the observed orbital alignment, the existence of such a planet naturally explains the presence of high-perihelion Sedna-like objects, as well as the known collection of high semimajor axis objects with inclinations between  $60^{\circ}$  and  $150^{\circ}$  whose origin was previously unclear. Continued analysis of both distant and highly inclined outer solar system objects provides the opportunity for testing our hypothesis as well as further constraining the orbital elements and mass of the distant planet.

*Key words:* Kuiper Belt: general – planets and satellites: dynamical evolution and stability

### 1. INTRODUCTION

The recent discovery of 2012VP113, a Sedna-like body and a potential additional member of the inner Oort cloud, prompted Trujillo & Sheppard (2014) to note that a set of Kuiper Belt objects (KBOs) in the distant solar system exhibits unexplained clustering in orbital elements. Specifically, objects with a perihelion distance larger than the orbit of Neptune and semimajor axis greater than 150 AU—including 2012VP113 and Sedna—have arguments of perihelia,  $\omega$ , clustered approximately around zero. A value of  $\omega = 0$  requires that the object's perihelion lies precisely at the ecliptic, and during ecliptic-crossing the object moves from south to north (i.e., intersects the ascending node). While observational bias does preferentially select objects with perihelia (where they are closest and brightest) at the heavily observed ecliptic, no possible bias could select only for objects moving from south to north.

ratio of the object to perturber semimajor axis to be nearly unity. This means that trapping all of the distant objects within the known range of semimajor axes into Kozai resonances likely requires multiple planets, finely tuned to explain the particular data set.

Further problems may potentially arise with the Kozai hypothesis. Trujillo & Sheppard (2014) point out that the Kozai mechanism allows libration about both  $\omega = 0$  as well as  $\omega = 180$ , and the lack of  $\omega \sim 180$  objects suggests that some additional process originally caused the objects to obtain  $\omega \sim 0$ . To this end, they invoke a strong stellar encounter to generate the desired configuration. Recent work (Jílková et al. 2015) shows how such an encounter could, in principle, lead to initial conditions that would be compatible with this narrative. Perhaps a greater difficulty lies in that the dynamical effects of such a massive perturber might have already been

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## THE INCLINATION OF THE PLANETARY SYSTEM RELATIVE TO THE SOLAR EQUATOR MAY BE EXPLAINED BY THE PRESENCE OF PLANET 9

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### Abstract

We evaluate the effects of a distant planet, commonly known as planet 9, on the dynamics of the giant planets of the solar system. We find that the dynamics of the giant planets can be decomposed into a classic Lagrange–Laplace dynamics relative to their own invariant plane and a slow precession of said plane relative to the total angular momentum vector of the solar system, including planet 9. Under specific configurations for planet 9, this precession can explain the current tilt of  $\sim 6^\circ$  between the invariant plane of the giant planets and the solar equator. An analytical model is developed to map the evolution of the inclination of the inner giant planets' invariant plane as a function of the planet 9's mass and orbital elements, and numerical simulations of the equations of motion are performed to validate our analytical approach. The longitude of the ascending node of planet 9 is found to be linked to the longitude of the ascending node of the giant planets' invariant plane, which also constrains the longitude

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