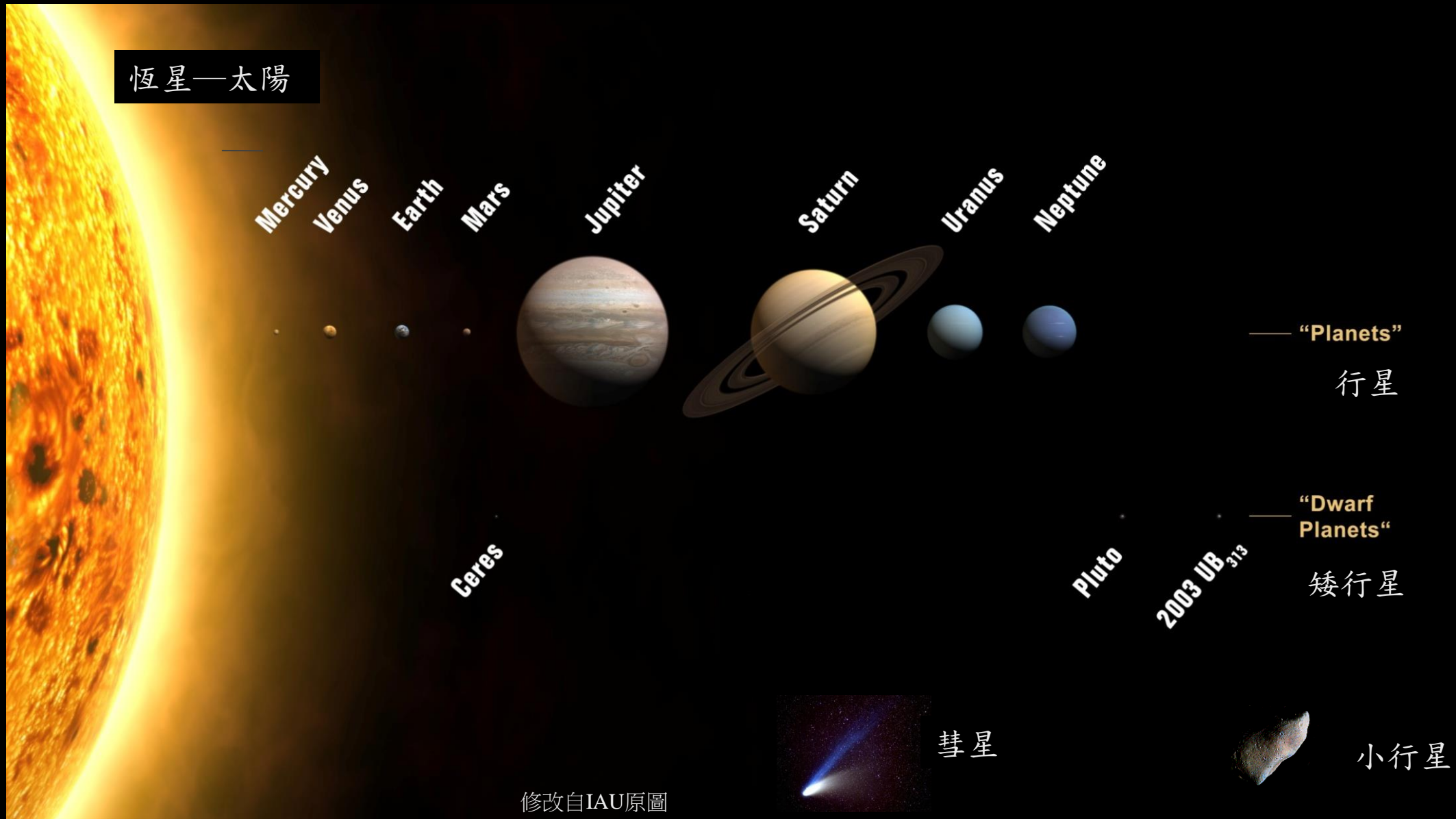
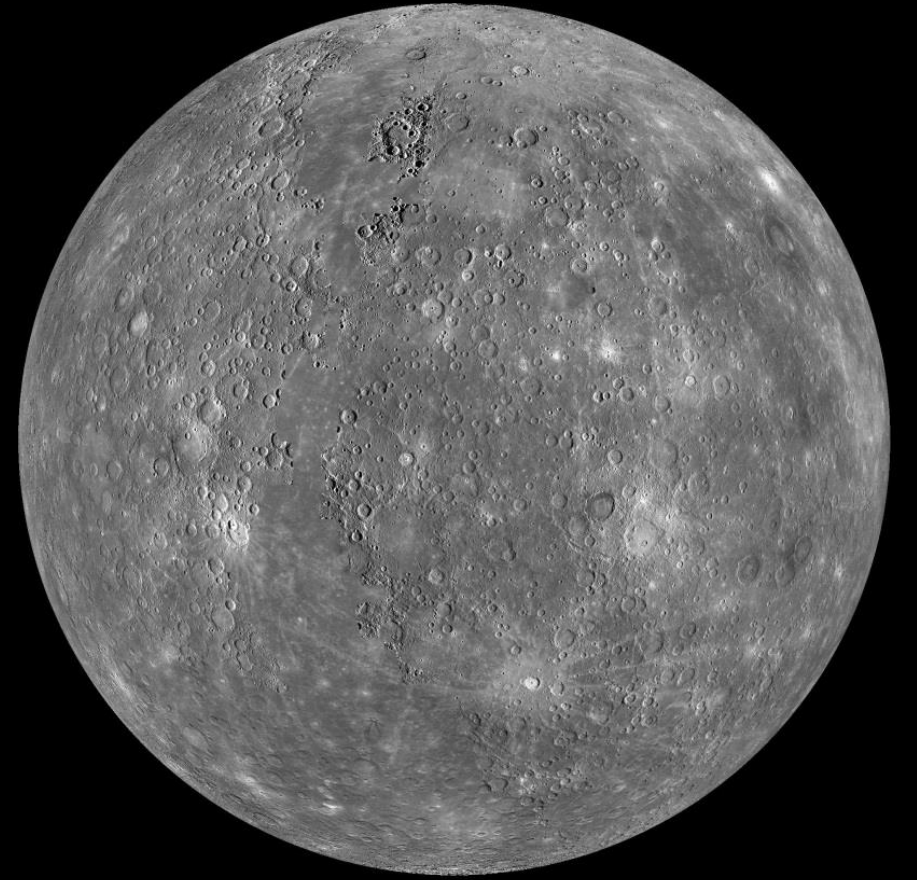


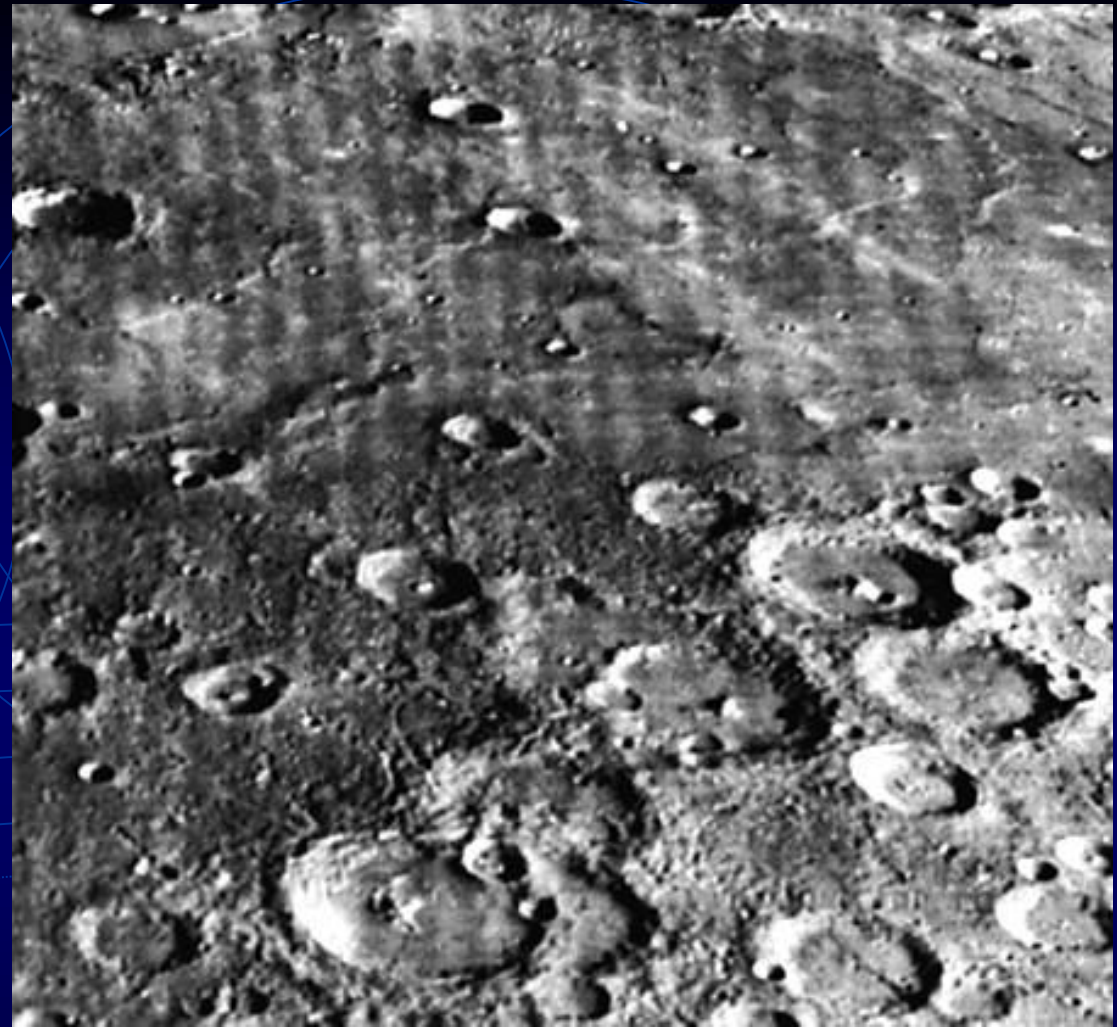
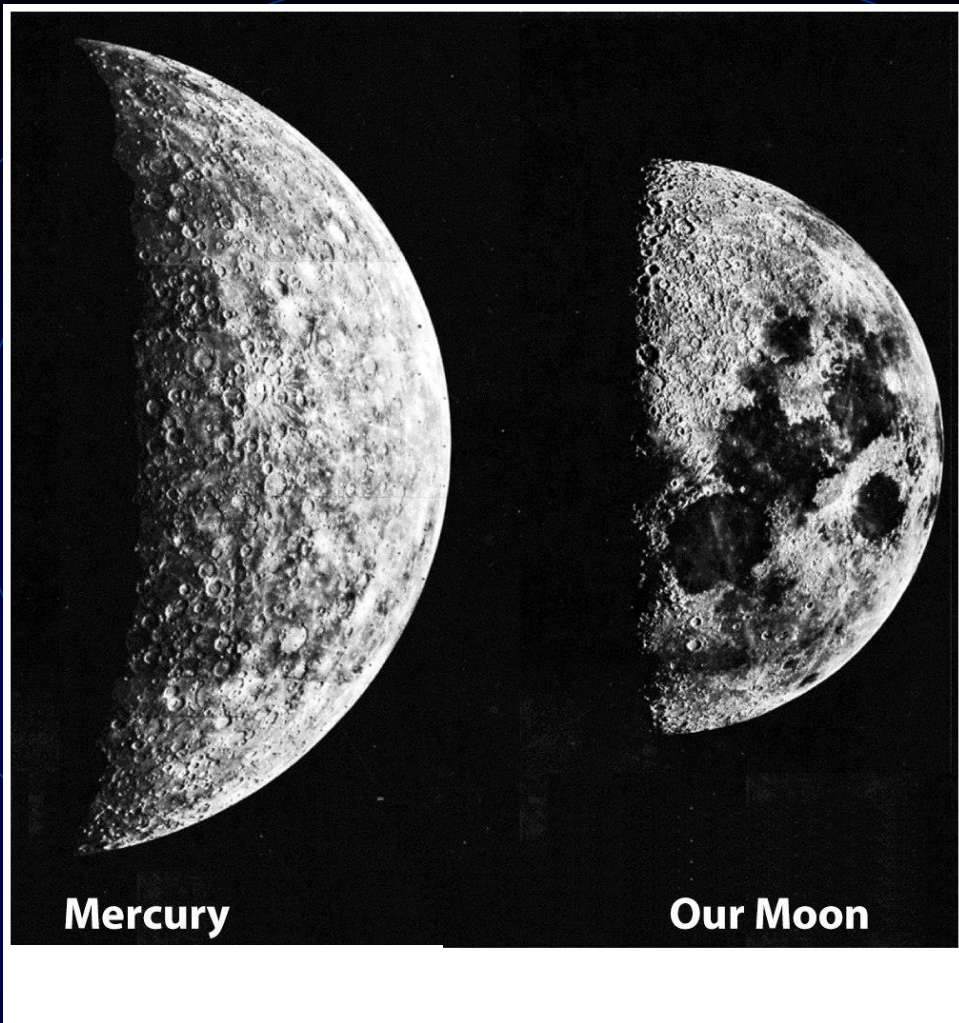
# Other Planets and Their Moons



# 水星 (Mercury)

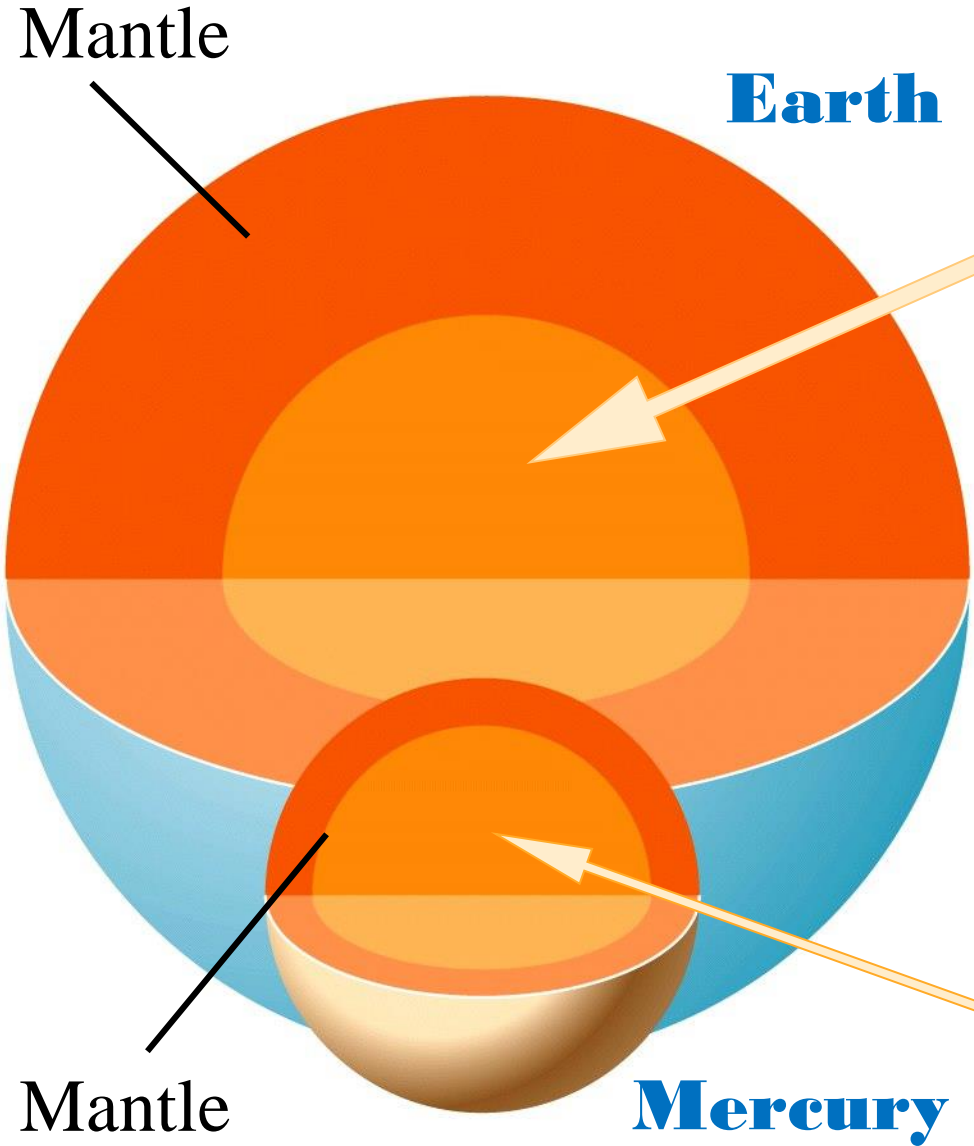
- 38% 地球半徑
- 隕石坑多 (外觀→月球)
- 離太陽最近的行星
- 幾乎沒有大氣層 為什麼？  
少數氣體來自岩石擠壓，  
以及太陽風 (主要是氫與氦)
- 日、夜溫差大  $350^{\circ}\text{C}$  to  $-170^{\circ}\text{C}$
- 太陽潮汐力 (公轉<sub>88天</sub>兩次，自轉<sub>58.7天</sub>三次)





1974 by *Mariner*

水星的兩極有些隕石坑沒有日照，似乎有冰。  
是彗星撞擊所致，還是來自水星內部的氣體造成？



Earth's iron core is 55% of the diameter of the entire planet, or 17% of its volume...

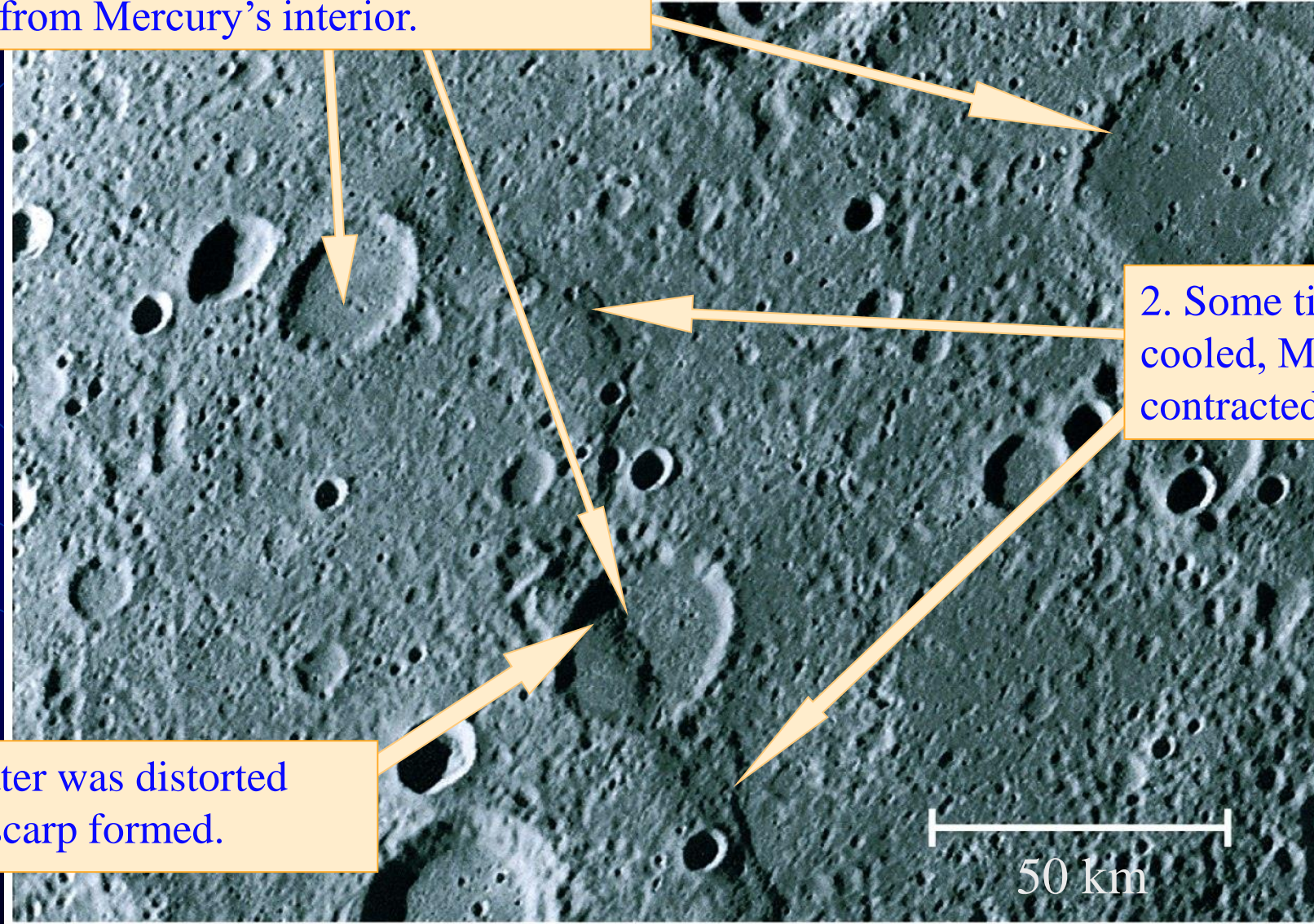
Mercury 和地球一樣有個鐵核心，但比例大得多；水星是太陽系中鐵含量最豐富的行星

...whereas Mercury's iron core is about 75% of the planet's diameter, or 42% of its volume.

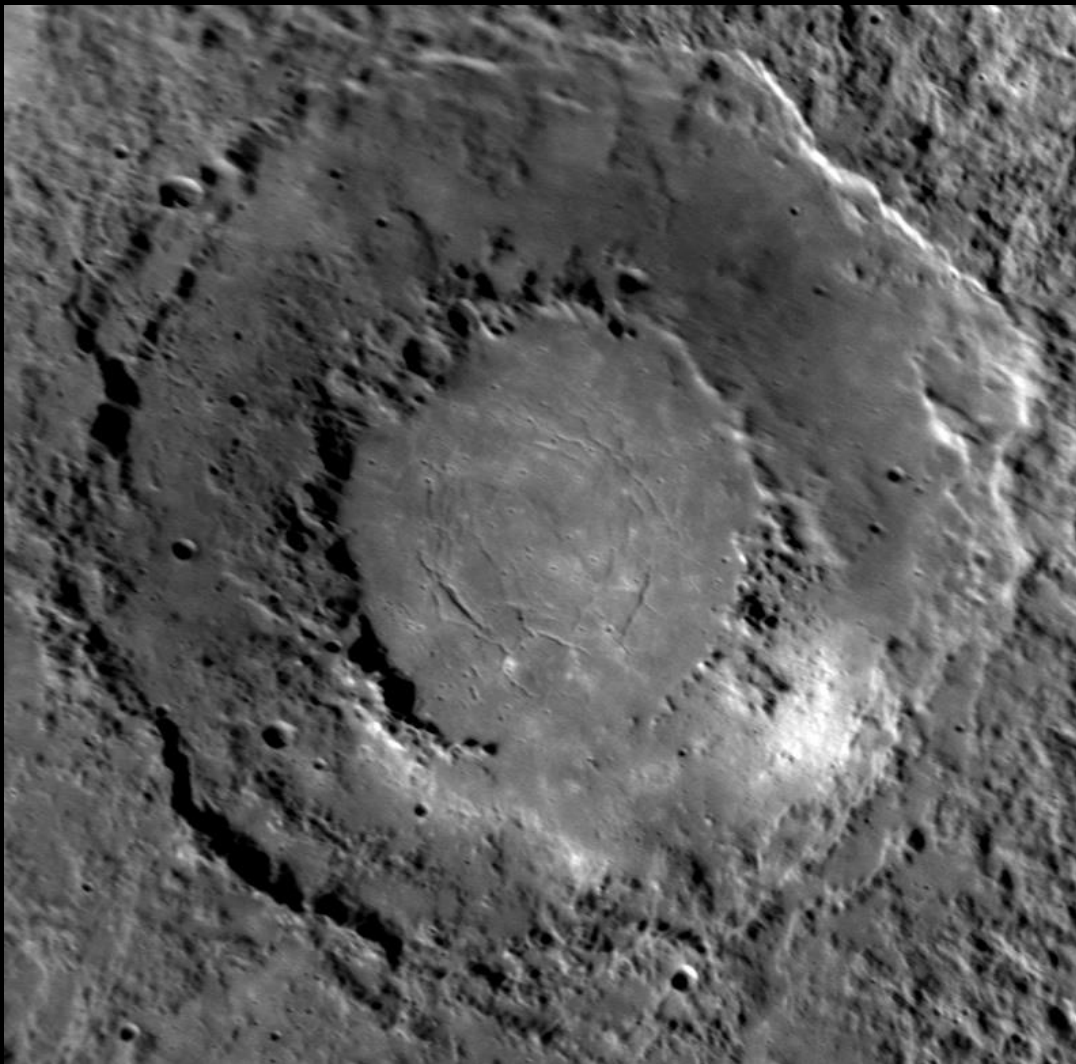
1. The floors of these craters were flooded by lava from Mercury's interior.

2. Some time after the lava cooled, Mercury's crust contracted to form this scarp.

3. This crater was distorted when the scarp formed.



50 km



A double-ring basin Sep 29, 2009  
Outer ring D=260 km



"Hundred mile scarp on Mercury"  
Copyright © Walter Myers  
<http://www.arcadiastreet.com>

A long scarp (=cliff)  
Sep 29, 2009

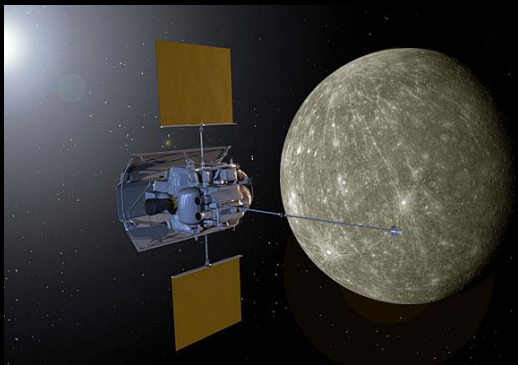
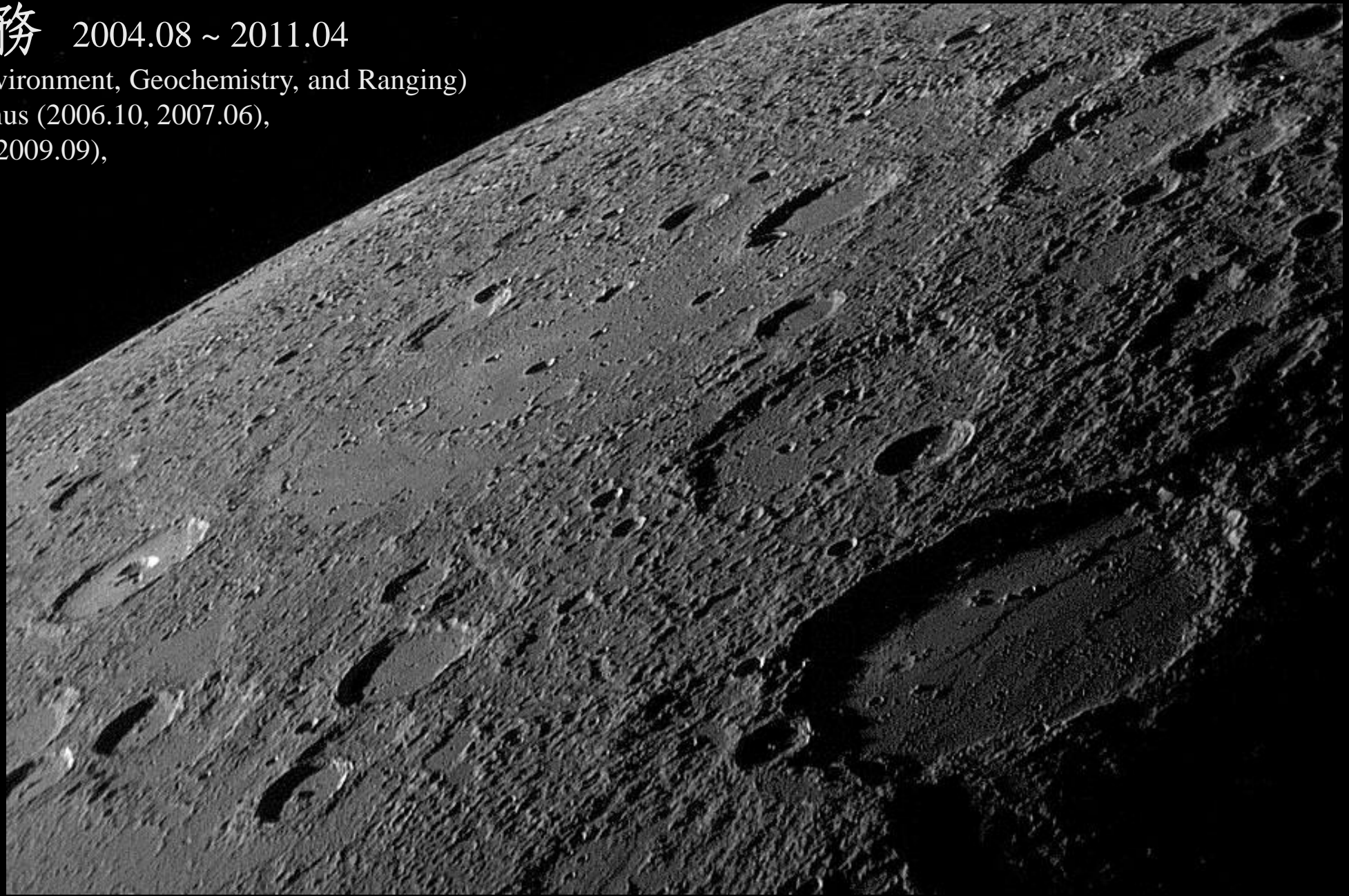
# *Messenger* 任務 2004.08 ~ 2011.04

(MErcury Surface, Space Environment, Geochemistry, and Ranging)

flyby of Earth (2005.08), Venus (2006.10, 2007.06),

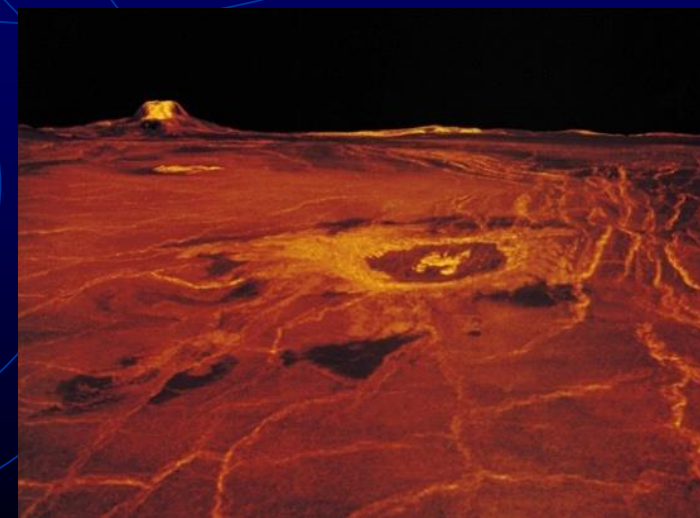
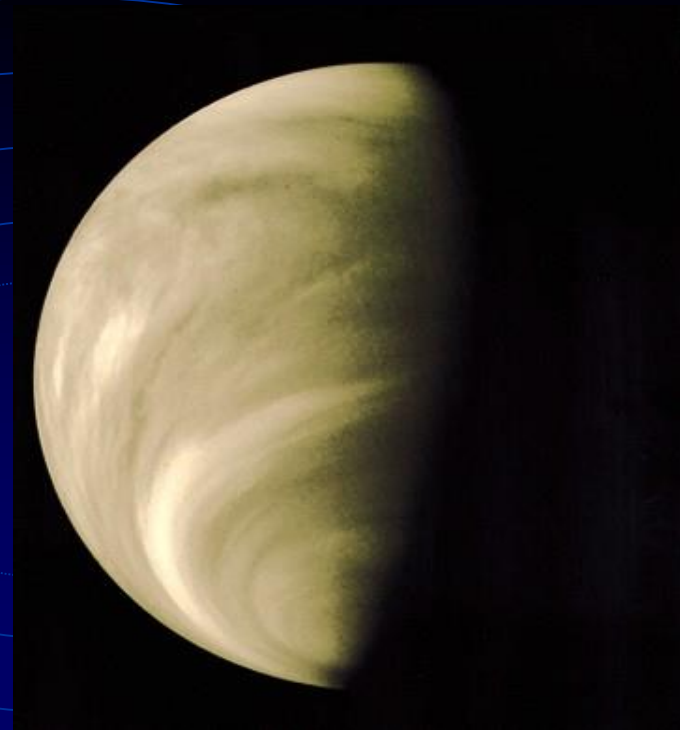
Mercury (2008.01, 2008.10, 2009.09),

and orbiter (2011.03)

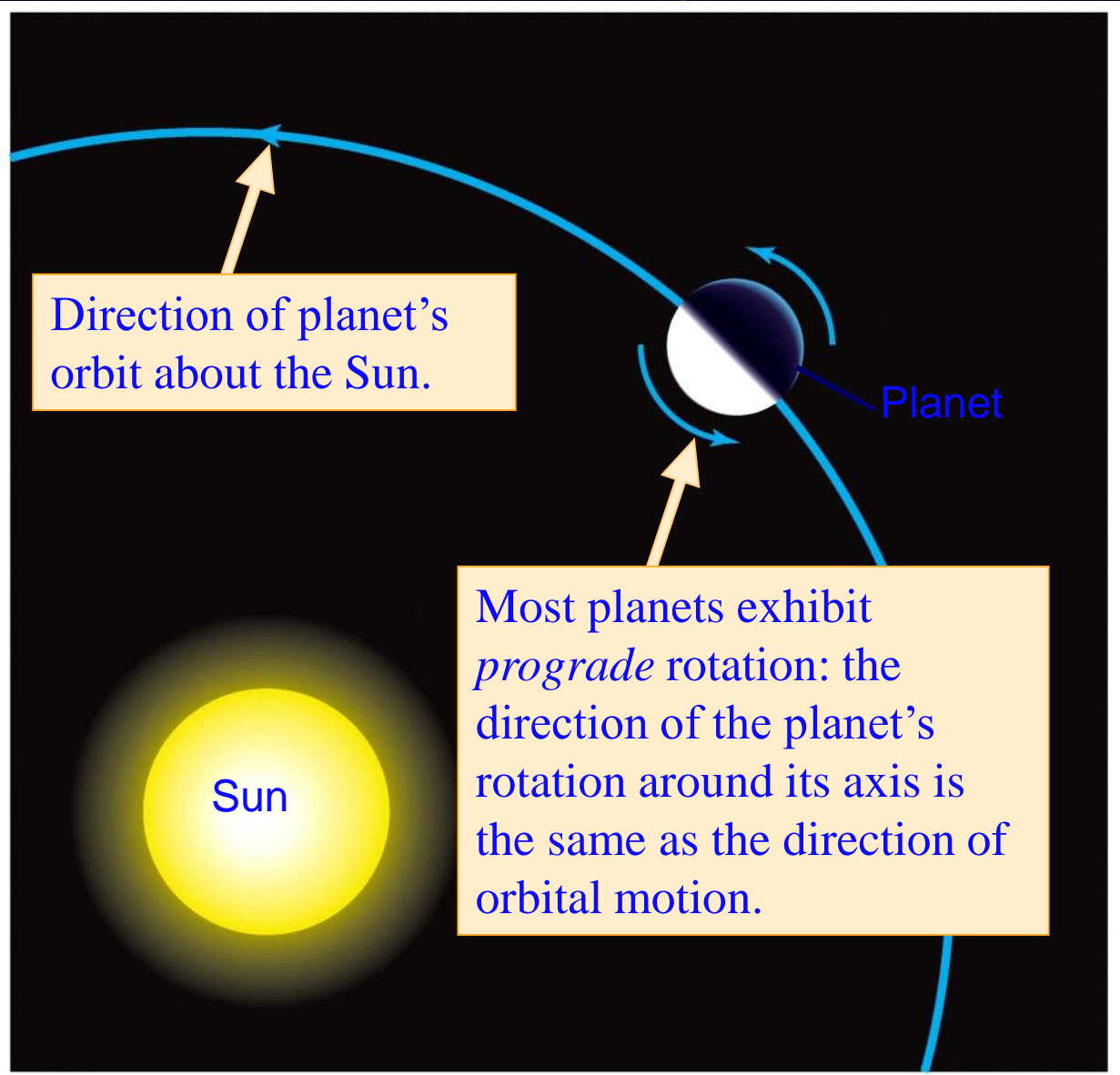


# 金星 (Venus)

- 凌晨，黃昏地平面上；耀眼
- 離地球最近的行星
- 沒有磁場
- 大小與地球相當 ( $=0.948 \mathcal{R}_{\oplus}$ )
- 自轉方向與其他行星相反
- 厚重的大氣
  - 嚴重的「**溫室效應**」(Greenhouse effect)
  - 表面溫度極高 (太陽系中最熱的行星)
- 麥哲倫號發現曾經有火山 (岩漿) 活動

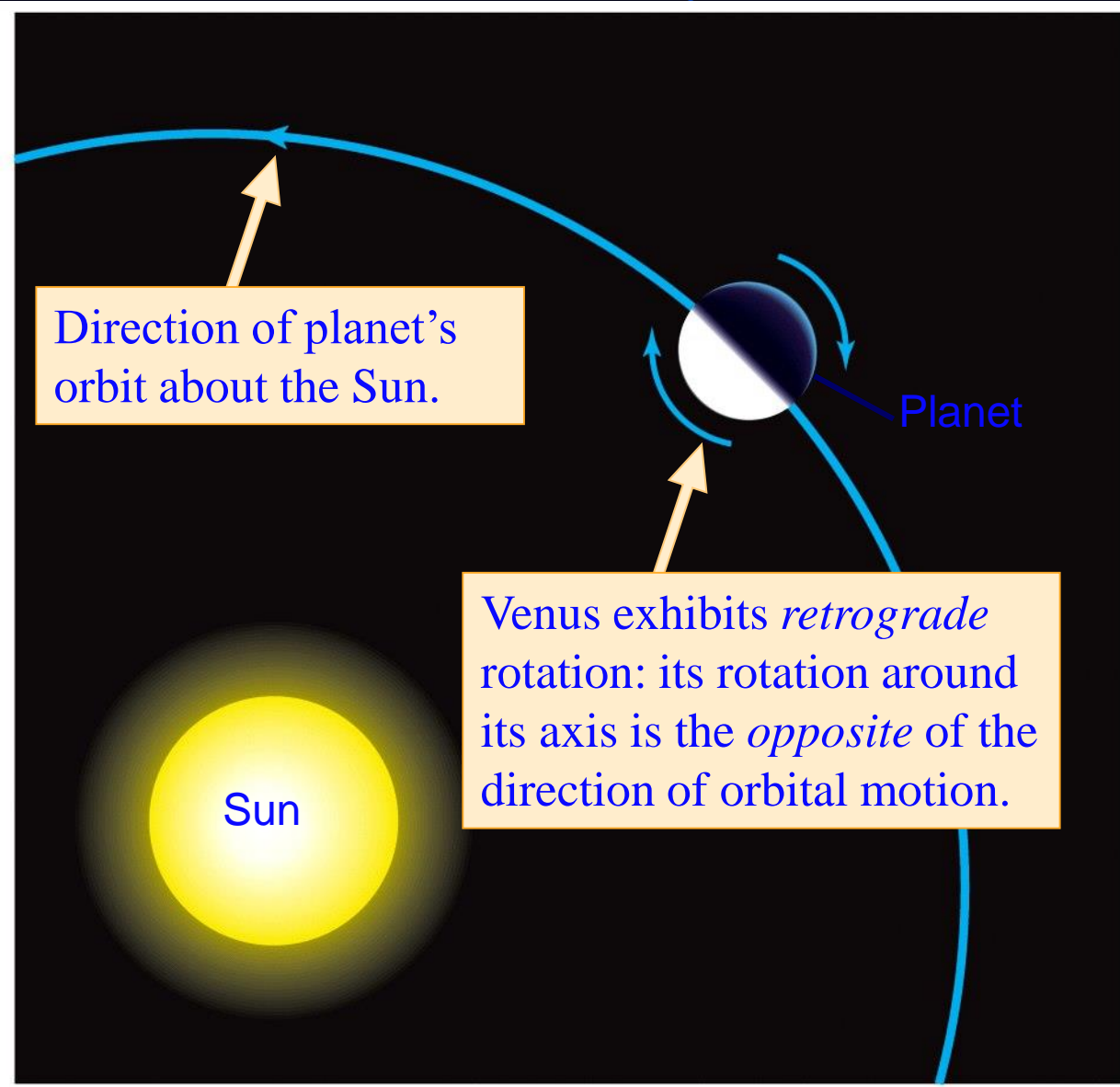






Prograde rotation

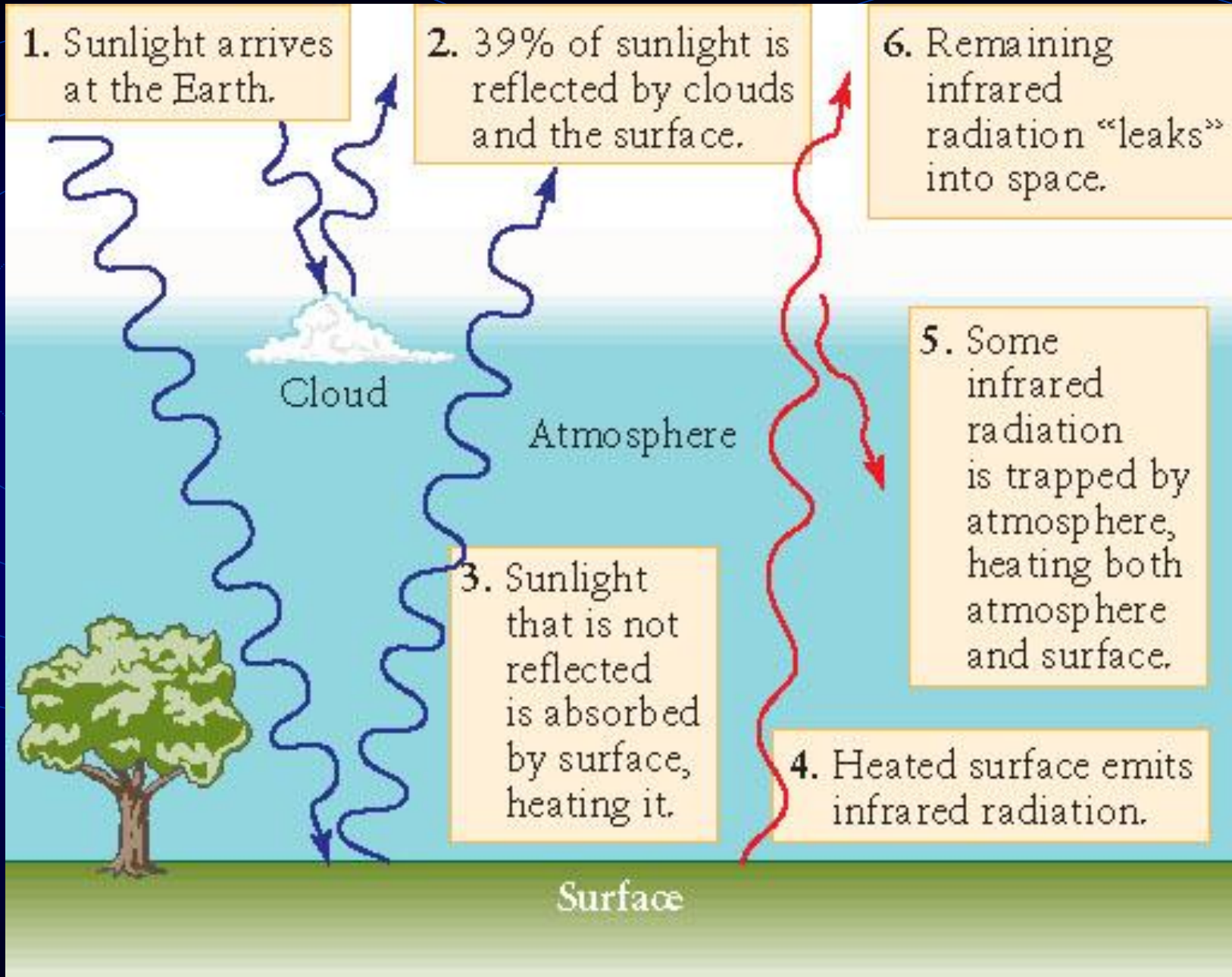
# 金星的逆向自轉



Direction of planet's orbit about the Sun.

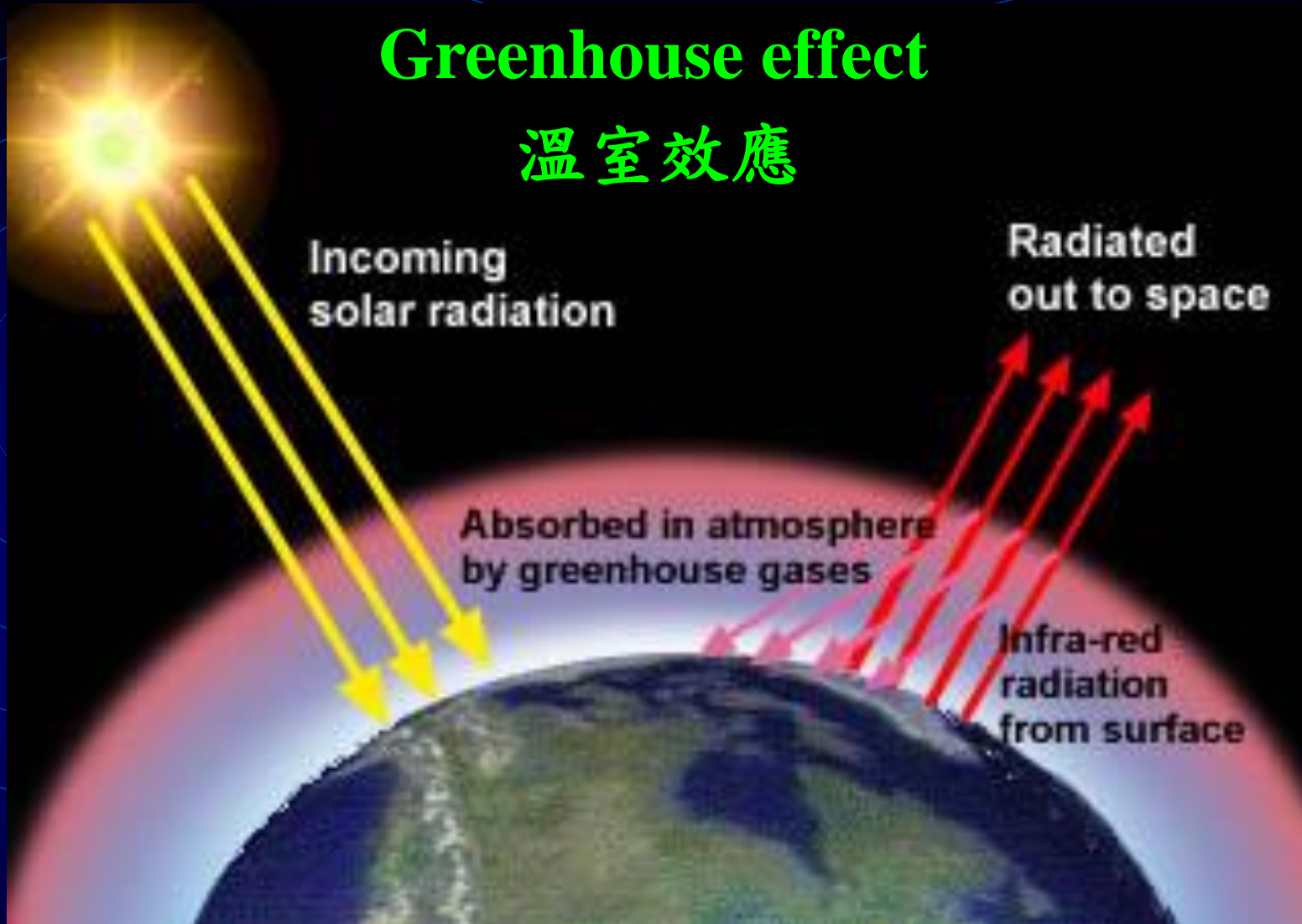
Venus exhibits *retrograde* rotation: its rotation around its axis is the *opposite* of the direction of orbital motion.

Retrograde rotation



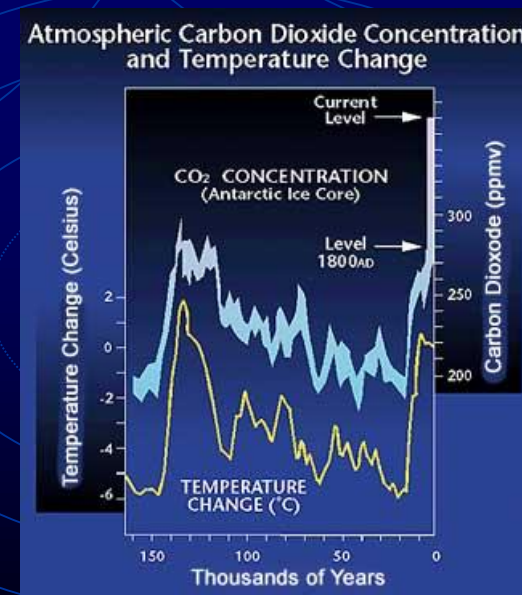
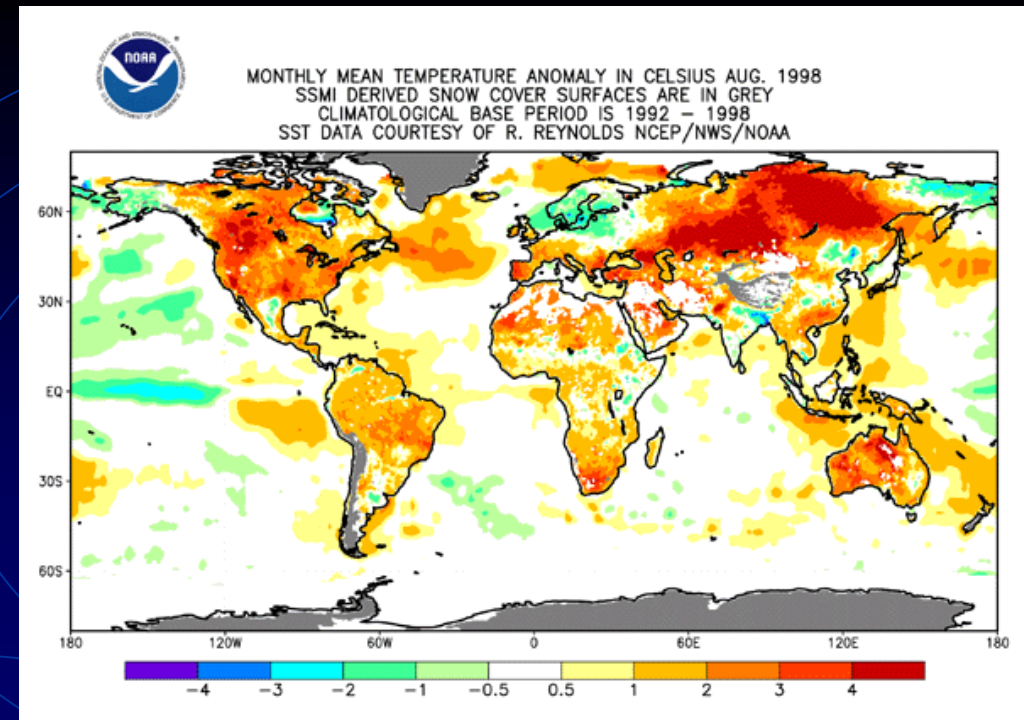
# Greenhouse effect

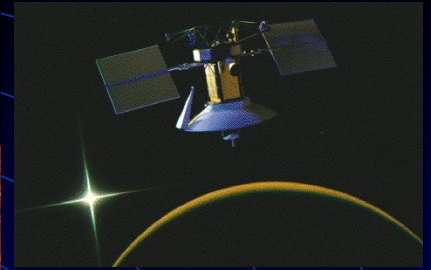
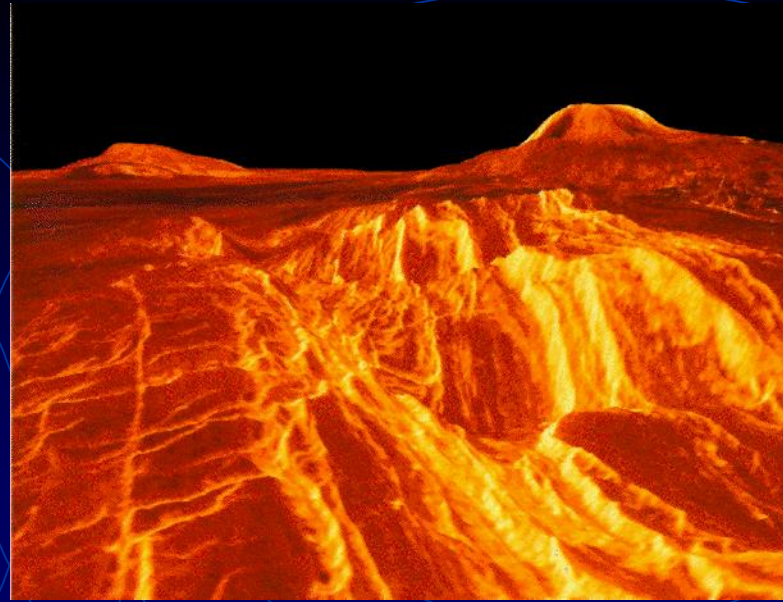
## 溫室效應



陽光（主要是可見光與紫外線）照射，地表受熱後輻射紅外線與微波，這些長波輻射容易被大氣分子吸收

- 因為有溫室效應地球才可能誕生生命
- 如果沒有 greenhouse effect，地球的平均溫度會低攝氏30度，也就不是現在的攝氏15度，而在冰點以下
- 但要是人類製造太多溫室氣體，使溫室效應惡化，便有全球暖化、氣候失調的危機





*Magellan animation*

Volcano (Maat Mons 8 km tall) on Venus by the *Magellan* radar, with the coloring based on the Soviet *Venera 13* lander (1982). *Astronomy Picture of the Day*, 28 September 1995





A global view of Venus by *Magellan*

# 行星是否擁有大氣——逃脫速率

- **Kinetic energy of a moving object**

$$E_k = \frac{1}{2} m v^2$$

- **Kinetic energy of a gas atom/molecule**

$k = 1.38 \times 10^{-23}$  J/K (Boltzmann constant)

$$E_k = \frac{3}{2} kT$$

→ **Average speed of a gas atom/molecule**

$$v = \sqrt{\frac{3kT}{m}}$$

教室中氧分子速率  $\sim 0.5$  km/s

如果有氫分子的話  $\sim 1.9$  km/s



- Escape speed for a planet

M: mass of the planet

R: radius of the planet

$G=6.67 \times 10^{-11} \text{ N m}^2/\text{kg}$

$$v_{\text{escape}} = \sqrt{\frac{2GM}{R}}$$

Planet	Escape speed (km/s)
Mercury	4.3
Venus	10.4
Earth	11.2
Mars	2.4
Moon	5.0
Jupiter	59.5
Saturn	35.5
Uranus	21.3
Neptune	23.5

給定溫度，氣體分子速率成  
Maxwellian distribution

在這裡鍵入方程式。

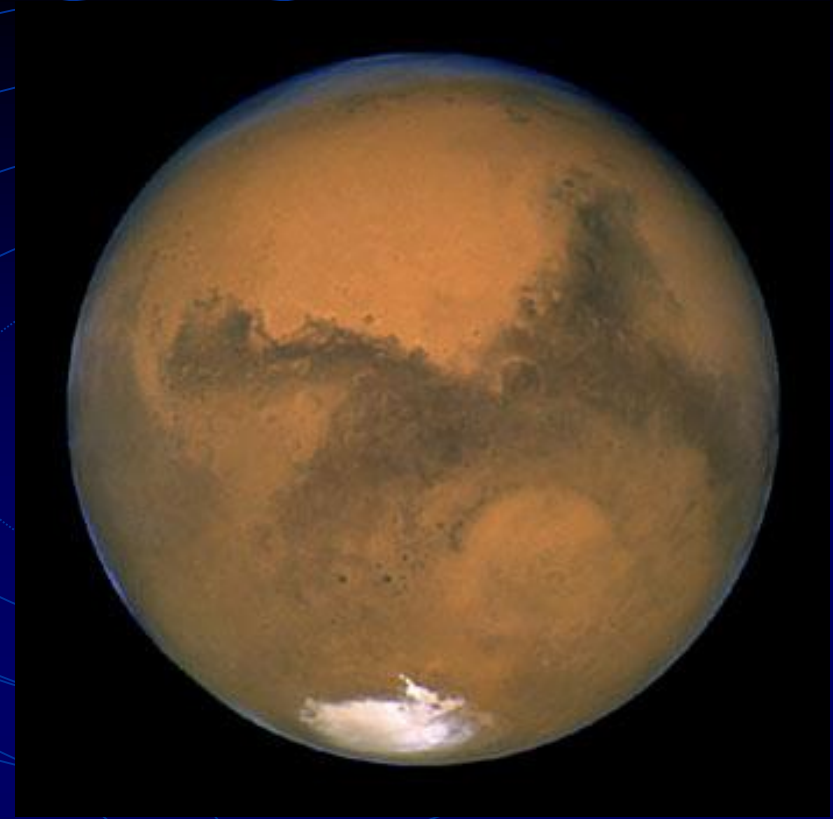
一般來說如果某天體逃脫速度大於氣體平均速率的6倍，該天體便可以保有該氣體。

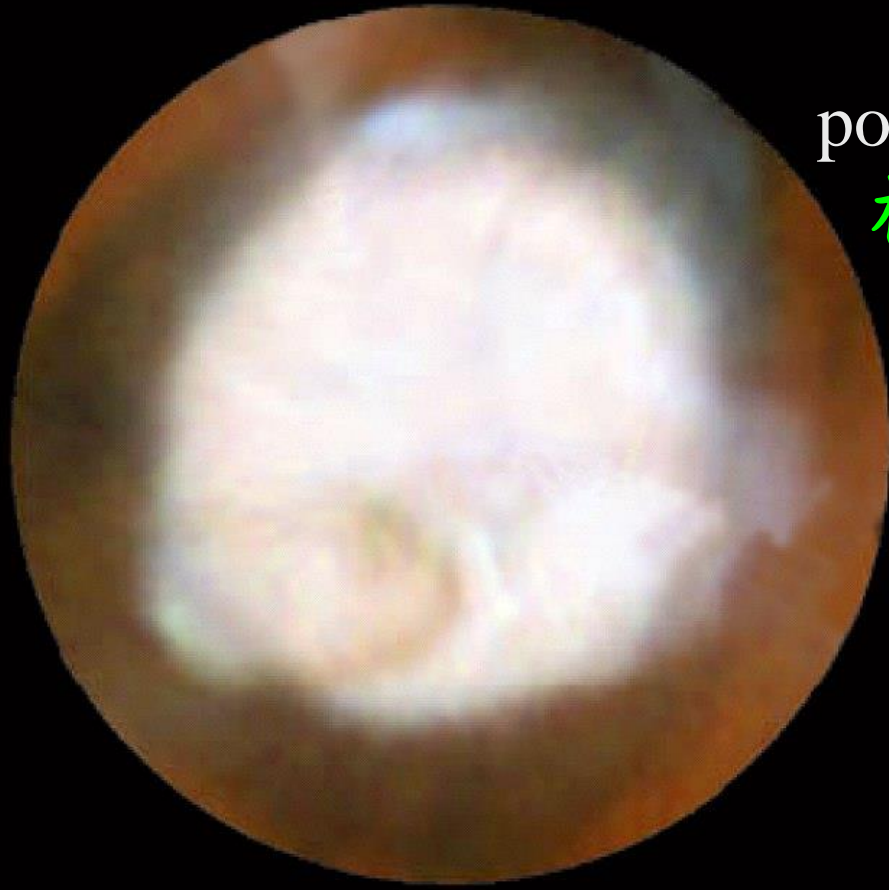
∴ 氧分子 ok....

氫分子就不太抓得住了

# 火星 (Mars)

- **紅色**外觀源於土壤及大氣中的氧化鐵（鐵鏽）
- ✓ 直徑 6792 公里 = 地球 53%
- ✓ 質量為地球 1/10
- ✓ 自轉軸傾斜24度，有季節變化，兩極有冰 → **極帽** (polar caps)
- 二顆小衛星 (<10公里)，Phobos ('fear') 及 Deimos ('panic') 形狀皆不規則，為攫獲之小行星；Phobos 越來越接近火星





**October 1996  
(Winter)**

polar cap  
極帽



**March 1997  
(Summer)**

火星的季節變化

Dish antenna



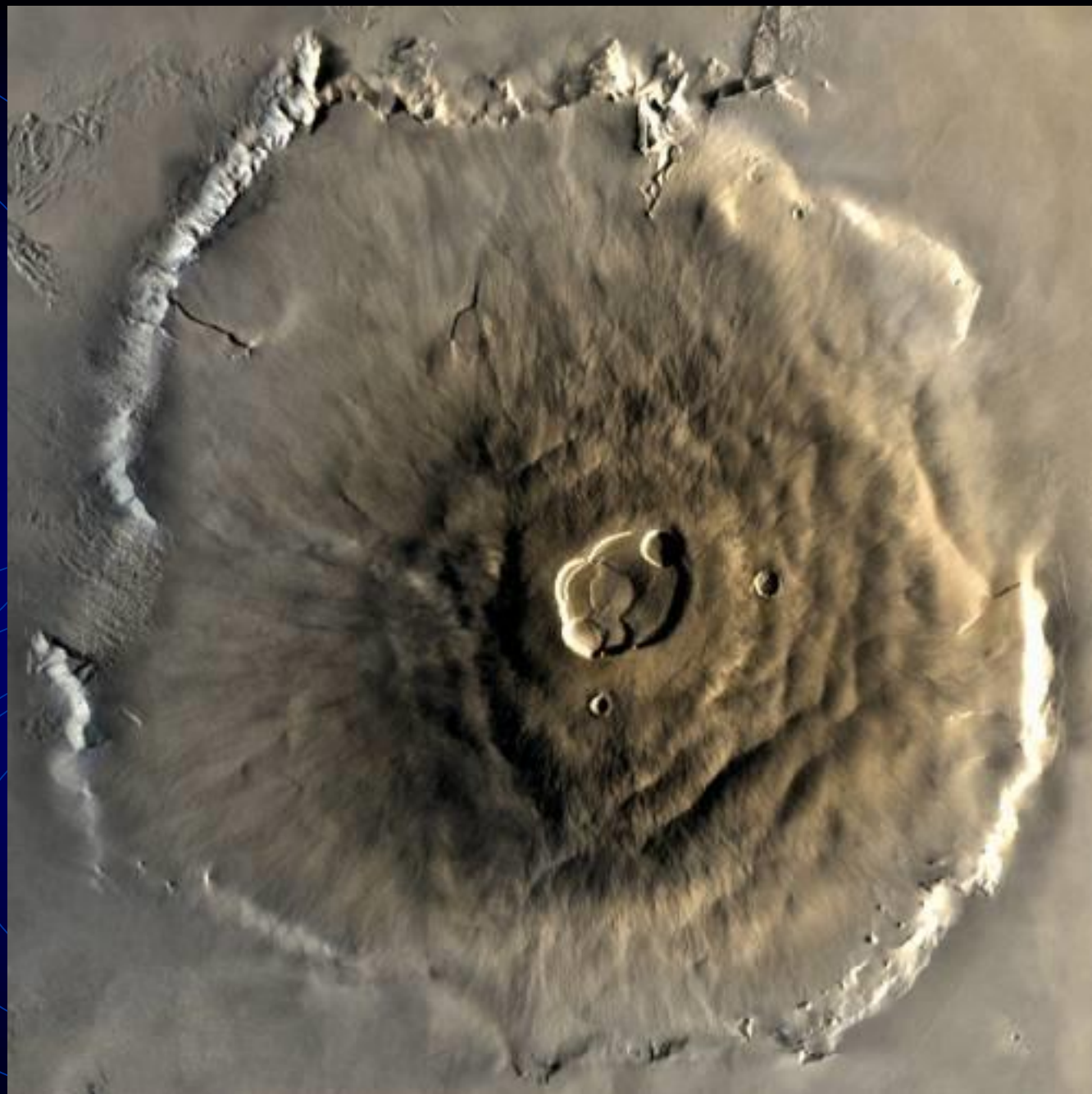
Extendable arm ends in a scoop for retrieving surface samples.

*A Viking Lander*

火星表面的奧林帕斯（火）山  
(Olympus Mons) 達27公里高

caldera  
(火山)

Q：地球也有火山活動，為何  
地表最高的山脈只有8公里高？





Date: 11 Feb 2004

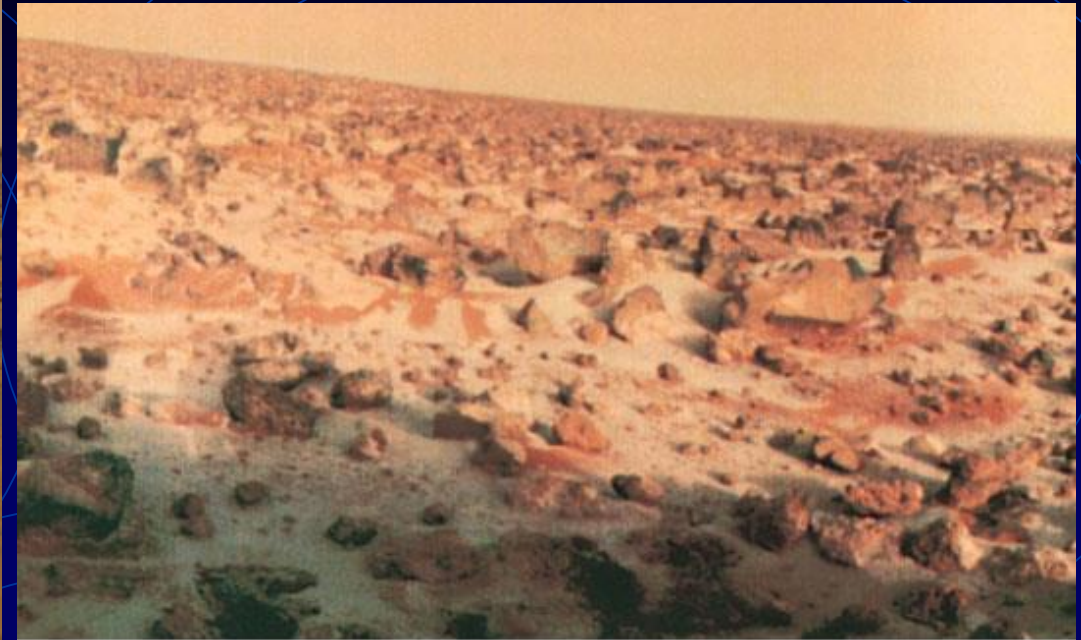
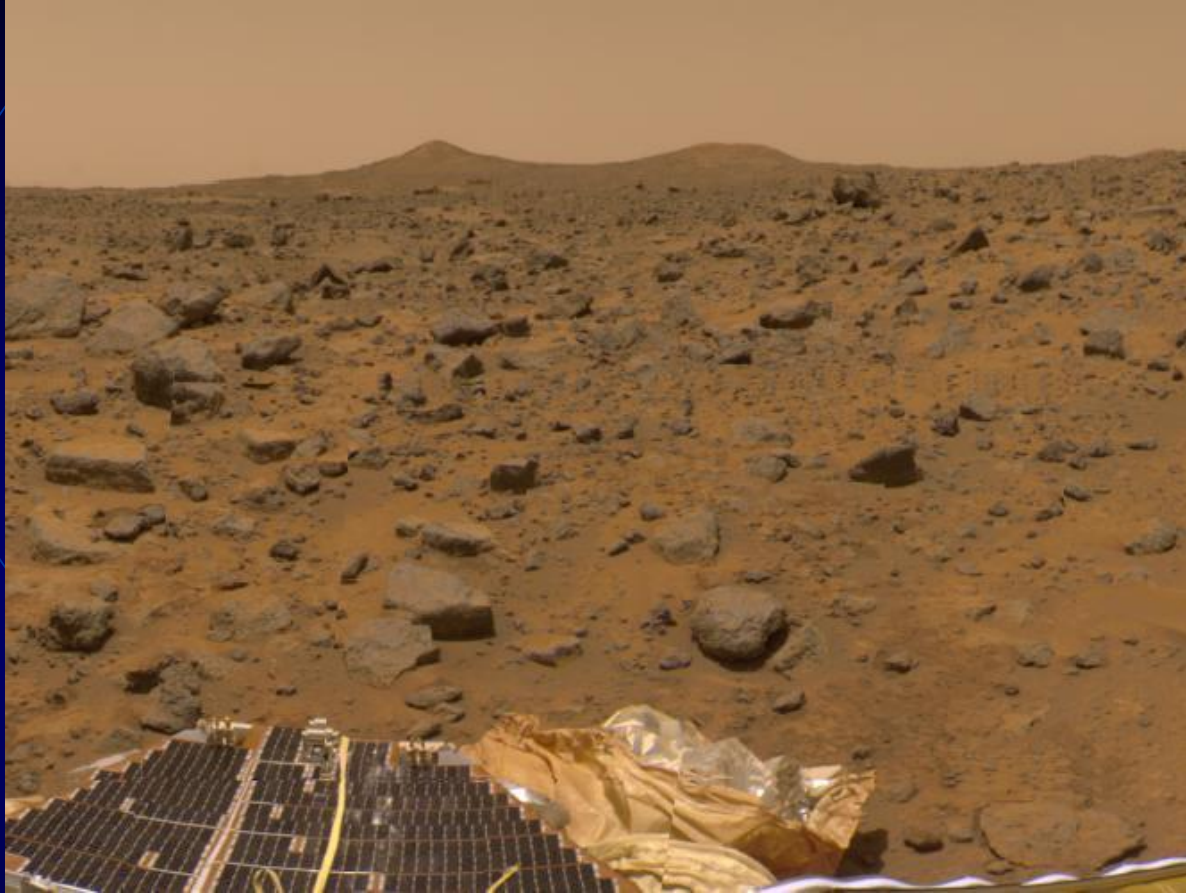
Satellite: Mars Express

Complex caldera region at the summit of Olympus Mons on Mars. The caldera has a depth of about 3 km.

The image is about 102 km across with a resolution of 12 m per pixel, and was taken from a height of 273 km.

Copyright: ESA / DLR / FU Berlin (G. Neukum)

# 火星表面



(b) A wintertime view from *Viking Lander 2*



從 *Pathfinder* lander 看 *Sojourner*

Animation:  
<http://pat.jpl.nasa.gov/public/RIVA/images.html>

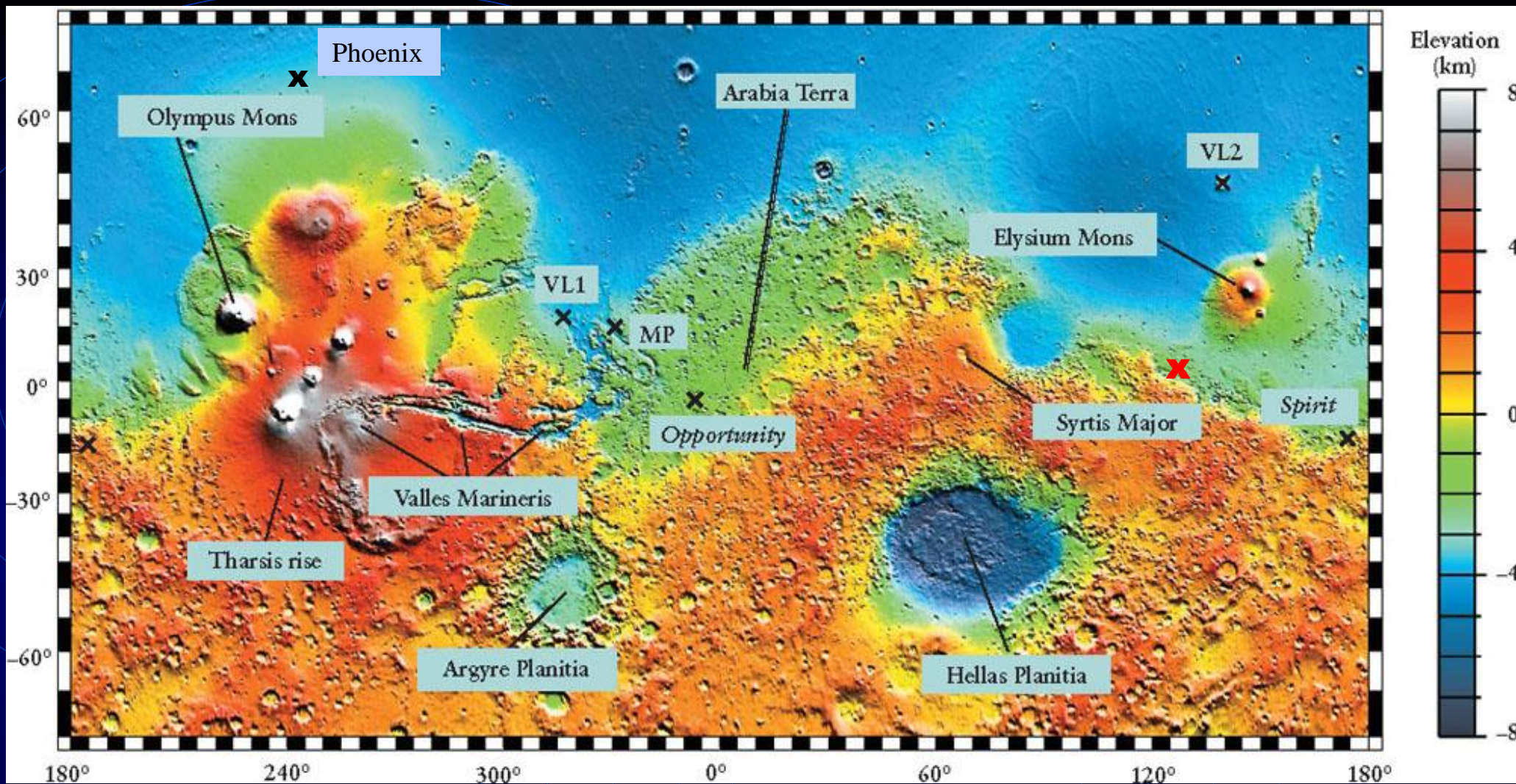
# 火星為什麼這麼紅？



- A：表面覆蓋了氧化鐵，被風揚起到大氣當中
- Q：那為什麼火星（氧化）鐵特別多？
- A：不知道！
- A2：早年火星有大量流水，也有火山活動。  
水被陽光分解，氧化了火山噴發出的鐵
- A3：鐵質隕石撞擊？







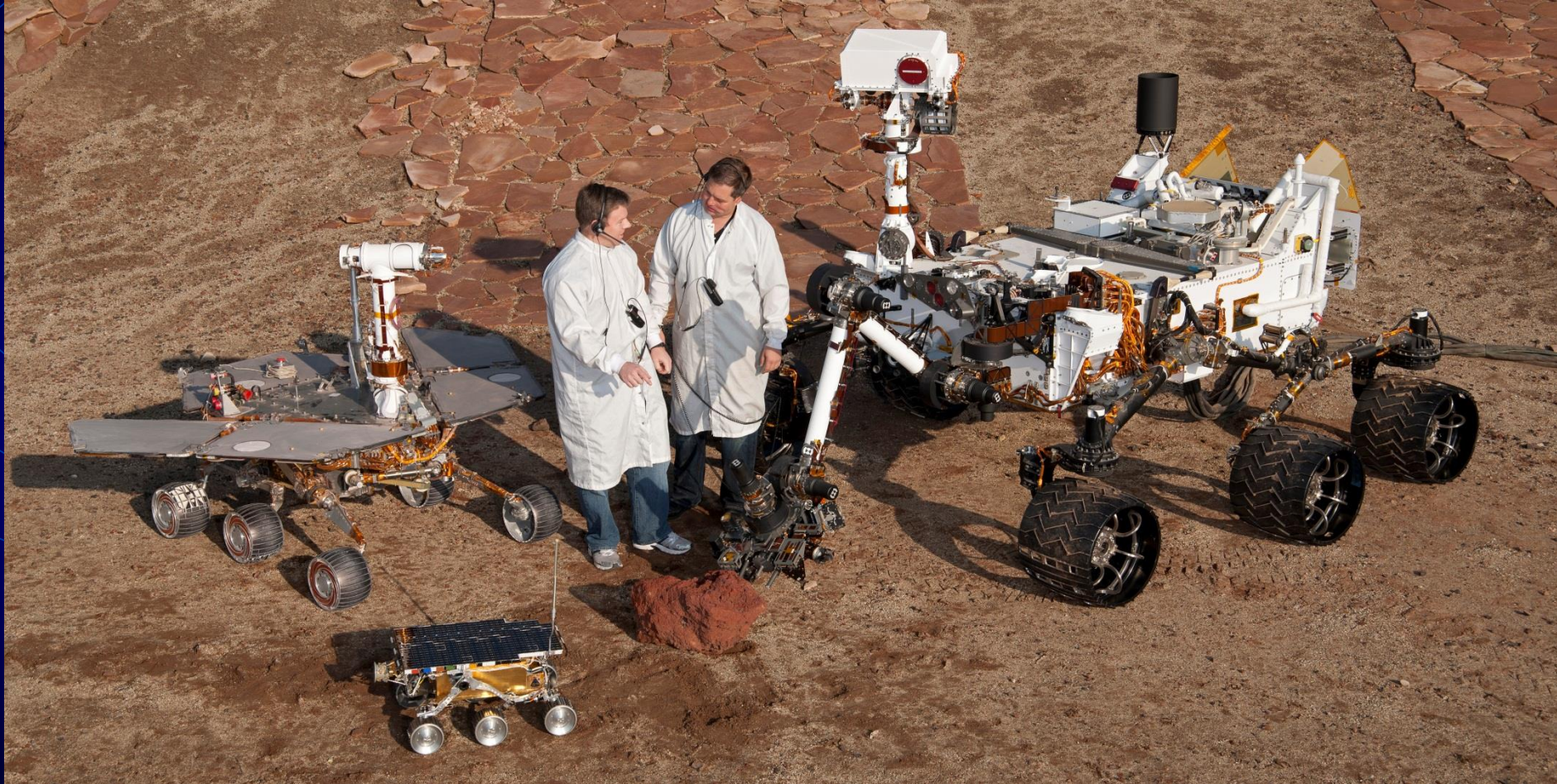
A topographic map of Mars made by the laser altimeter on board the *Mars Global Surveyor*. Colors indicate elevations. Note the elevated southern hemisphere, except the impact feature called Hellas Planitia. Landing sites of *Viking Landers* (VL) 1 and 2, *Mar Pathfinder* (MP), *Mars Exploration Rovers* (*Spirit* and *Opportunity*), and *Phoenix* are marked.

2004 Mars Exploration

巡曳車

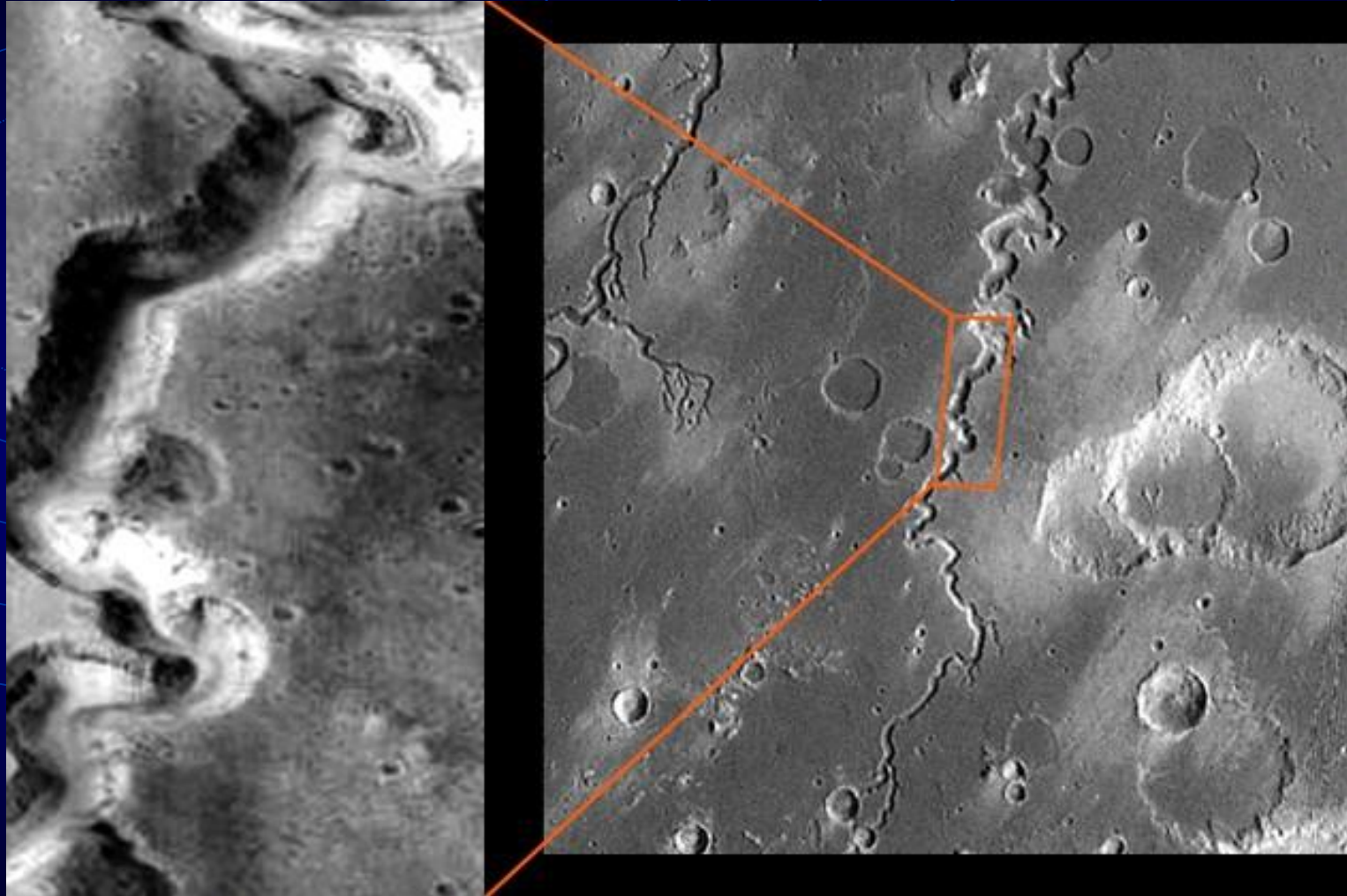
2012 Mars Science Laboratory

巡曳車



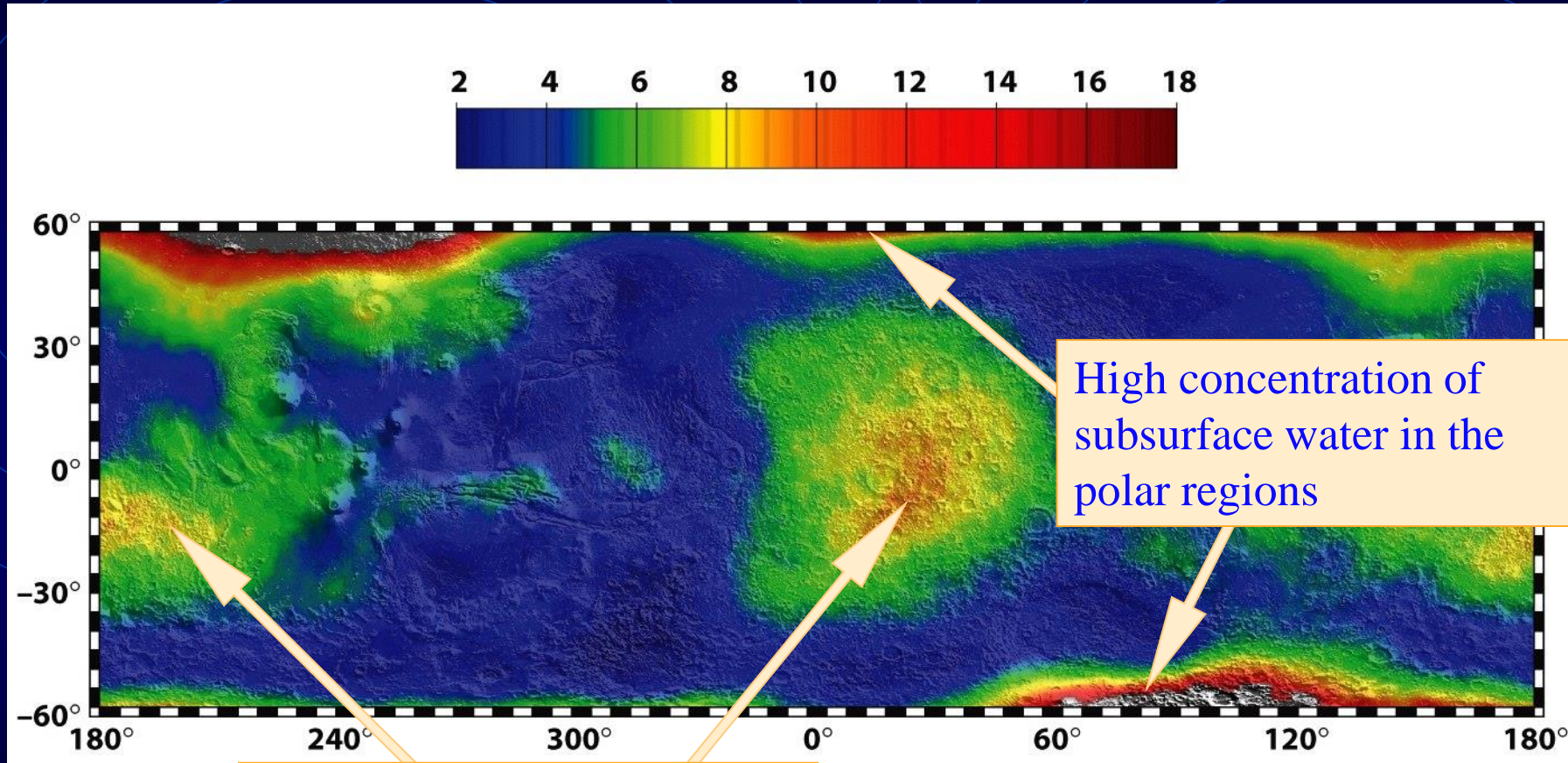
1997 Pathfinder 巡曳車

# 火星表面早年有大量流水



What happened to Mars?

# Percent abundance of water (by mass)



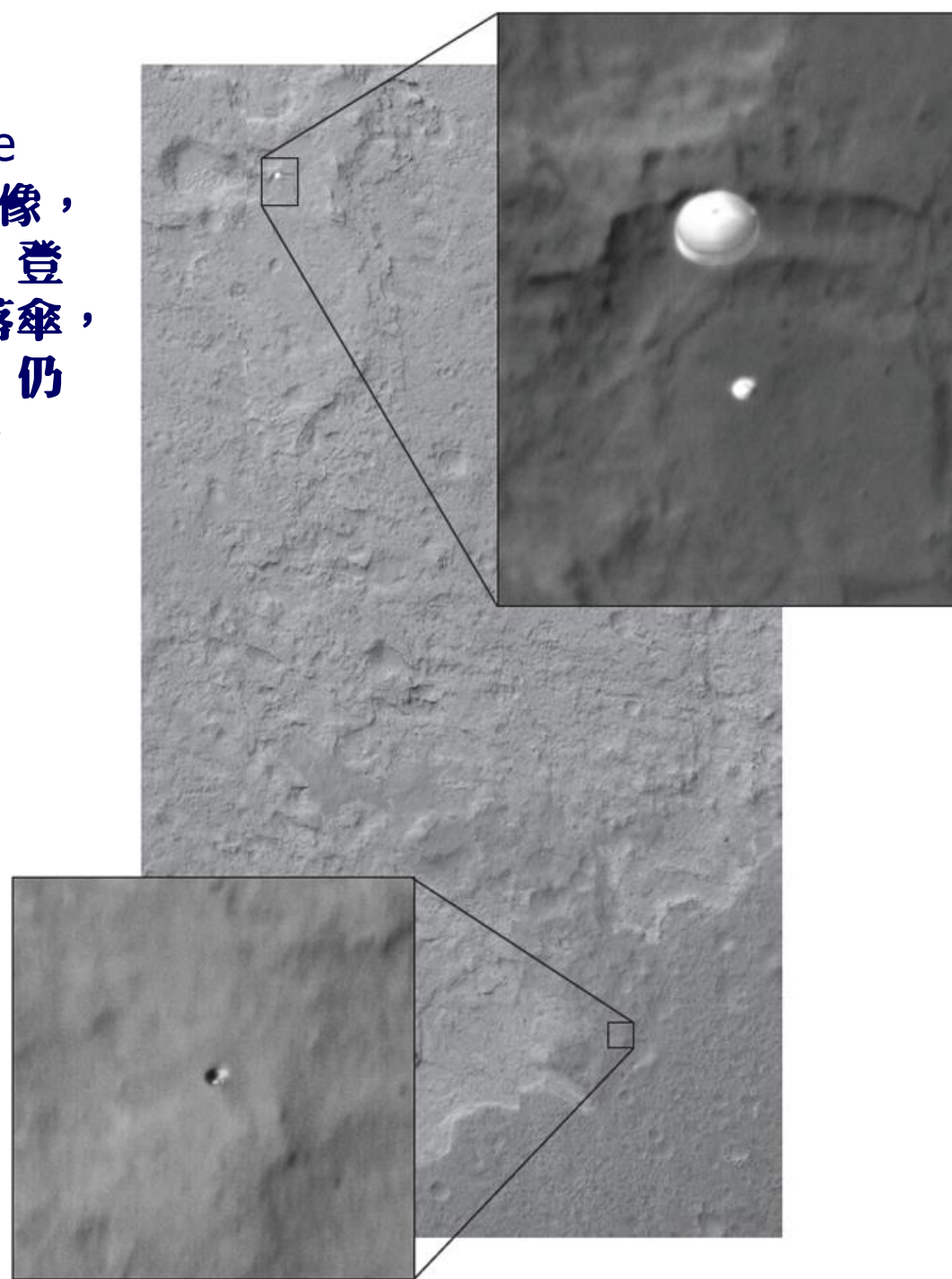
High concentration of subsurface water in the polar regions

High concentration of subsurface water in some locations near the equator

*Curiosity's* first selfie



Mars  
Reconnaissance  
Orbiter 所攝影像，  
顯示「好奇號」登  
陸時打開的降落傘，  
以及之前甩脫，仍  
在飄落的熱盾。

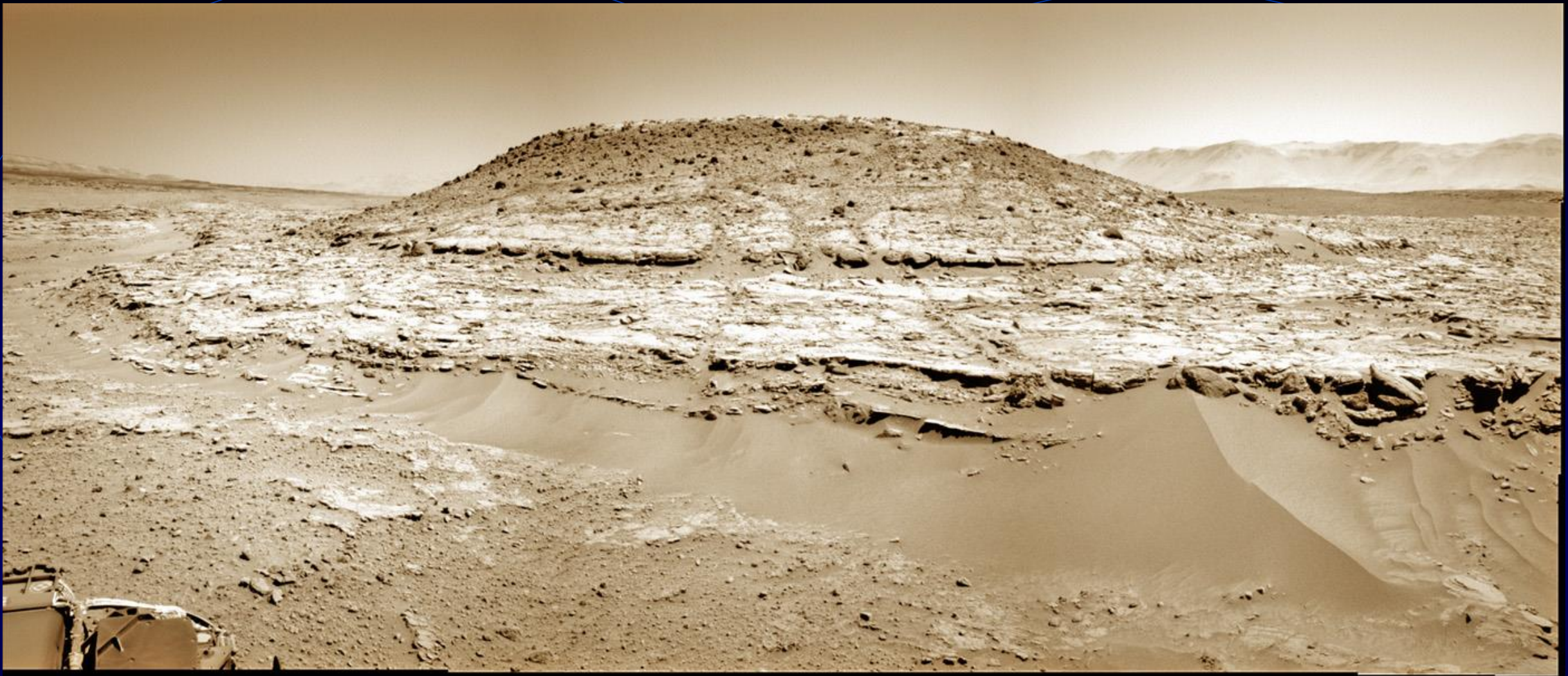




The Gate of Dingo Gap

NASA/JPL-Caltech/MSSS/Damia Bouic - <http://www.db-prods.net>

APOD  
2014.02.18



**Curiosity & Mount Remarkable in Gale Crater**

**Sol 603**

Credit: NASA/JPL-Caltech/Ken Kremer/Marco Di Lorenzo

APOD  
2014.05.07



## NASA Rover Finds Mysterious Methane Emissions on Mars

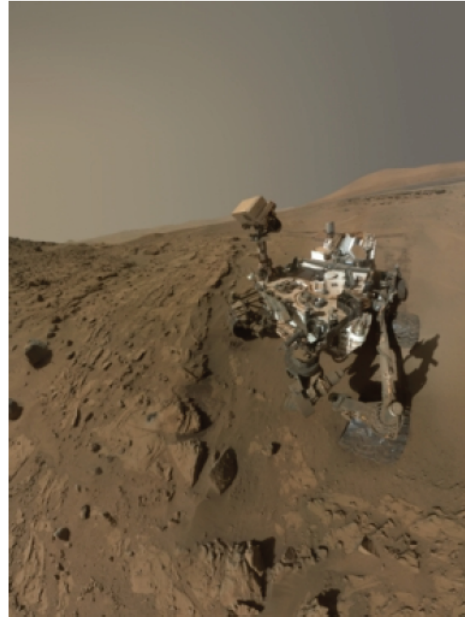
New results suggest evidence for extraterrestrial life could be near at hand

December 16, 2014 | By Lee Billings

Is there life on Mars? The answer may be blowing in the wind.

NASA's Curiosity rover has detected fluctuating traces of methane – a possible sign of life – in the thin, cold air of the Martian atmosphere, researchers announced today at a meeting of the American Geophysical Union.

Across Mars and within Gale Crater, where Curiosity is slowly climbing a spire of sedimentary rock called Mount Sharp, the methane exists at a background concentration of slightly less than one part per billion by volume in the atmosphere (ppb). However, for reasons unknown, four times across a period of two months the rover measured much higher methane abundances, at about ten times the background level. Further in-situ studies of the methane emissions could help pin down whether Mars has life, now or in its deep past, though it is unclear when or if those studies will ever take place. The findings are [published](#) in the journal *Science*.



NASA's Curiosity rover, seen here in a self-portrait from spring 2014, has found conclusive evidence of methane in the atmosphere of Mars. The gas is a potential sign of alien life, though it could also be produced through abiotic mechanisms.  
*Credit: NASA/JPL-Caltech/MSSS*

## 2014.12.16 新聞 火星探測車偵測到甲烷氣體

“Most of the methane on Earth is produced by biology, and the hope has been that ‘methane on Mars’ could be reduced to ‘life on Mars,’” says lead author Chris Webster, a senior research scientist at NASA’s Jet Propulsion Laboratory in Pasadena, Calif. “But we cannot yet distinguish whether the high methane levels we’re seeing are being produced geochemically or biologically.” Webster and his team believe the unexpected bursts of methane are produced relatively nearby, somewhere north of the rover, before being carried to Curiosity on prevailing winds.

The findings are a dramatic reversal from [Curiosity's earlier results](#) released one year ago, in which it used data gathered over a third of a Martian year to all but rule out significant quantities of methane in the Martian air. That null result, it is now clear, was due to the actual background level of Martian methane lying just below the threshold of detectability for the standard operations of Curiosity’s instruments.

**Q:** Apollo 任務曾經在月表安置地震儀，偵測到月震。  
地球由於板塊碰撞，所以地震通常發生在板塊邊緣 ...

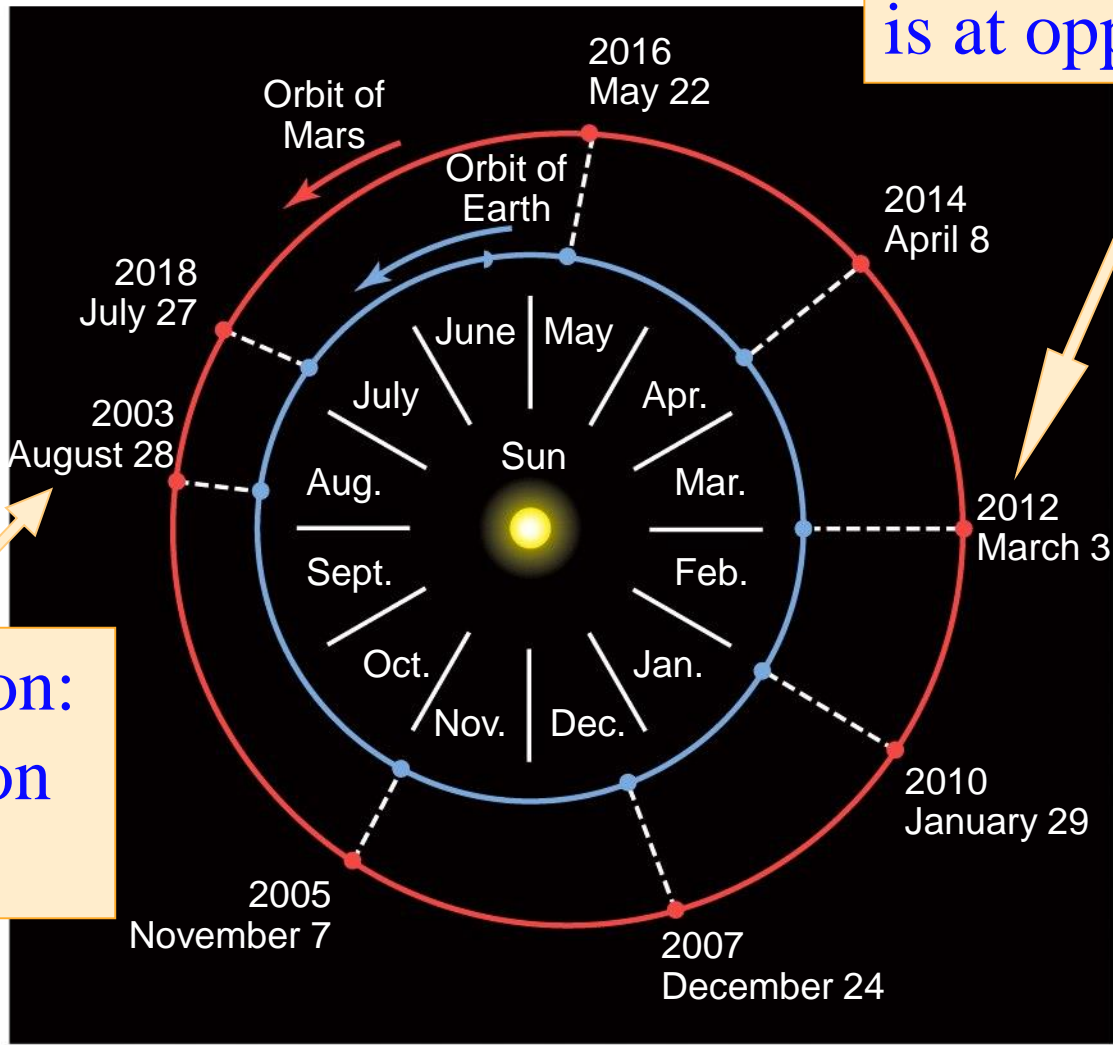
然而月球沒有板塊，怎麼有 moonquakes 呢？

**A:** 地球的潮汐力。

The tidal force by the Earth on the Moon

[At perigee] / [At apogee]  $\approx 1.9$ , or almost twice.

Unfavorable opposition: Mars is at opposition near aphelion.

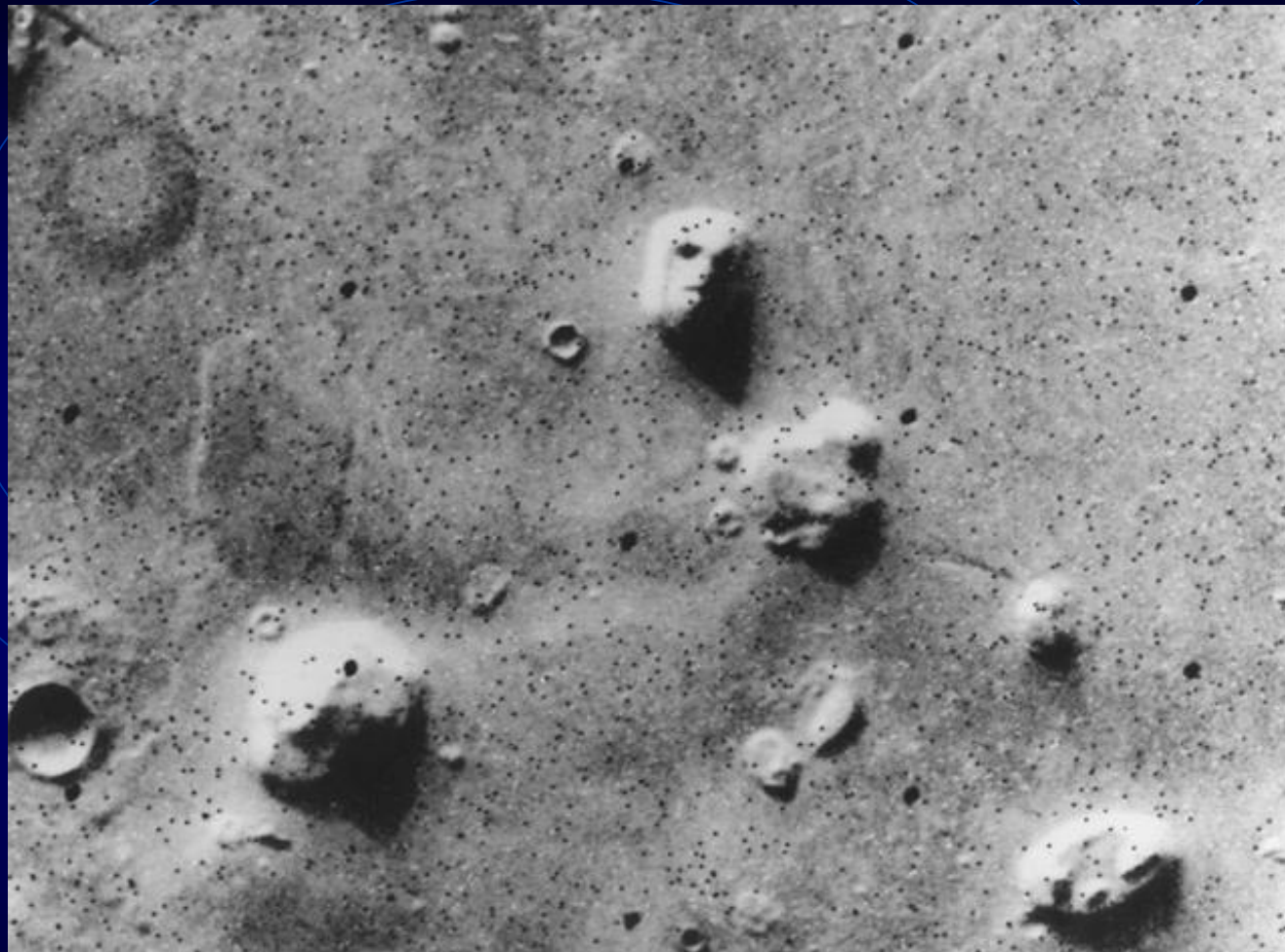


Martian orbital period 1.88 yrs

Favorable opposition: Mars is at opposition near perihelion.

Mars opposition,  $P=780$  d

# 火星上的「人面石」？



**Scientists view haunting pictures sent from the dying planet**

## Stone face on Mars beams TV warning to Earth

**Face-shaped Mars rock is a puzzler**

**Doomsday images are 500,000 years old!**

**Creeps kick blind dad to death**

**Yuppies spark bourbon boom**

**WEEKLY WORLD NEWS**

1976年「海盜號」(Viking) 拍攝到的火星地景 Face on Mars (in Cydonia)。怎麼回事？

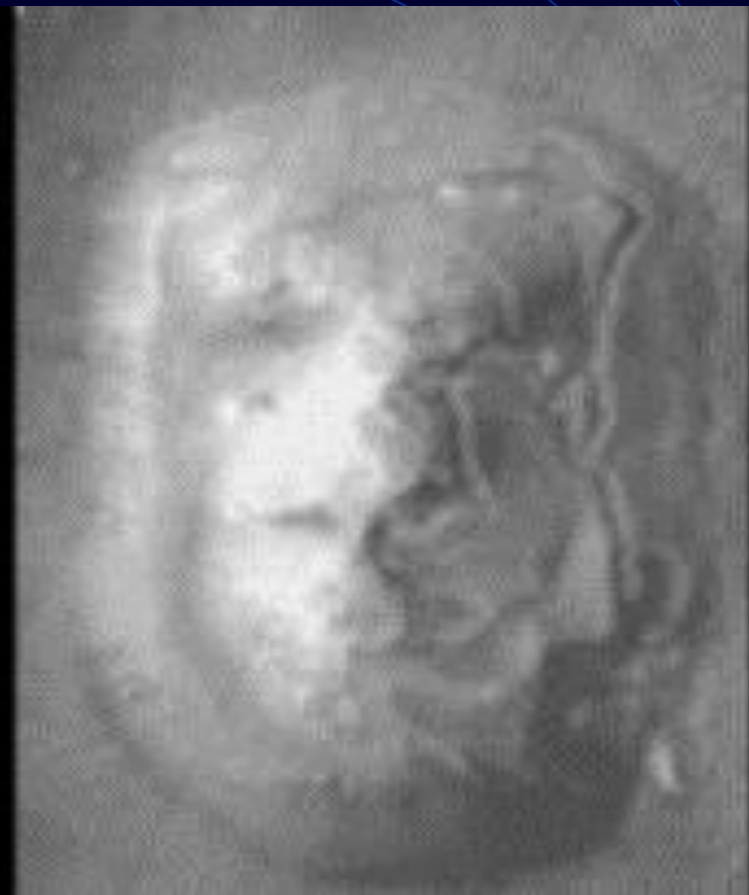
1976 *Viking*



1998 MOC



2001 MOC



陰影？山丘？  
火星人的？

1998 by *Mars Orbiter*

20幾年後，天氣侵蝕的後果...

# pareidolia



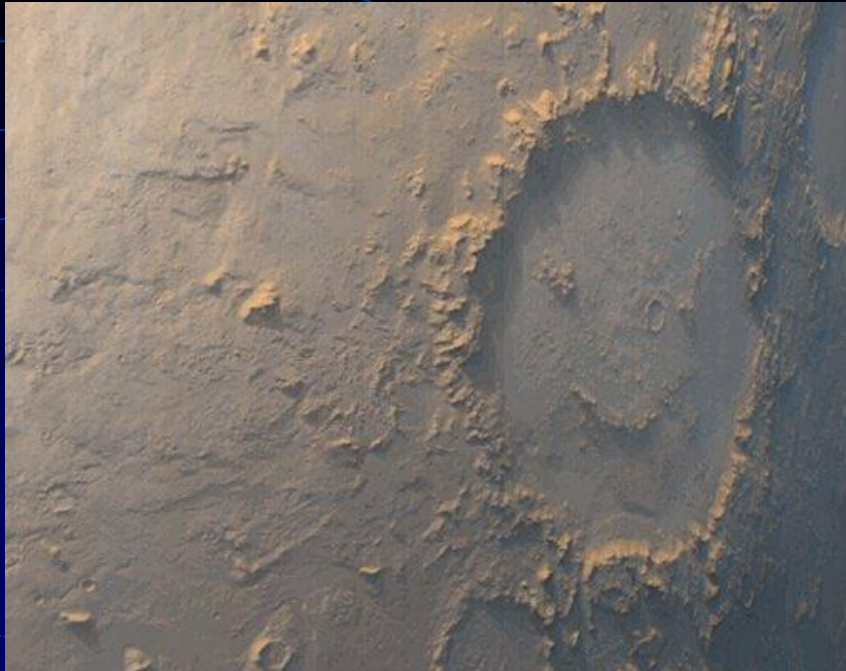
<http://educ.jmu.edu/~johns2ja/illusion/illusion.htm>



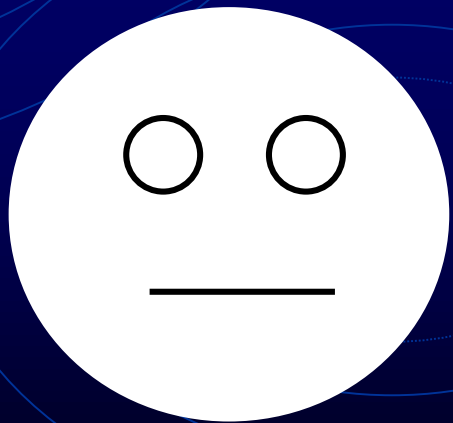
New York Time article [http://www.nytimes.com/2007/02/13/health/psychology/13face.html?pagewanted=1&\\_r=1](http://www.nytimes.com/2007/02/13/health/psychology/13face.html?pagewanted=1&_r=1)

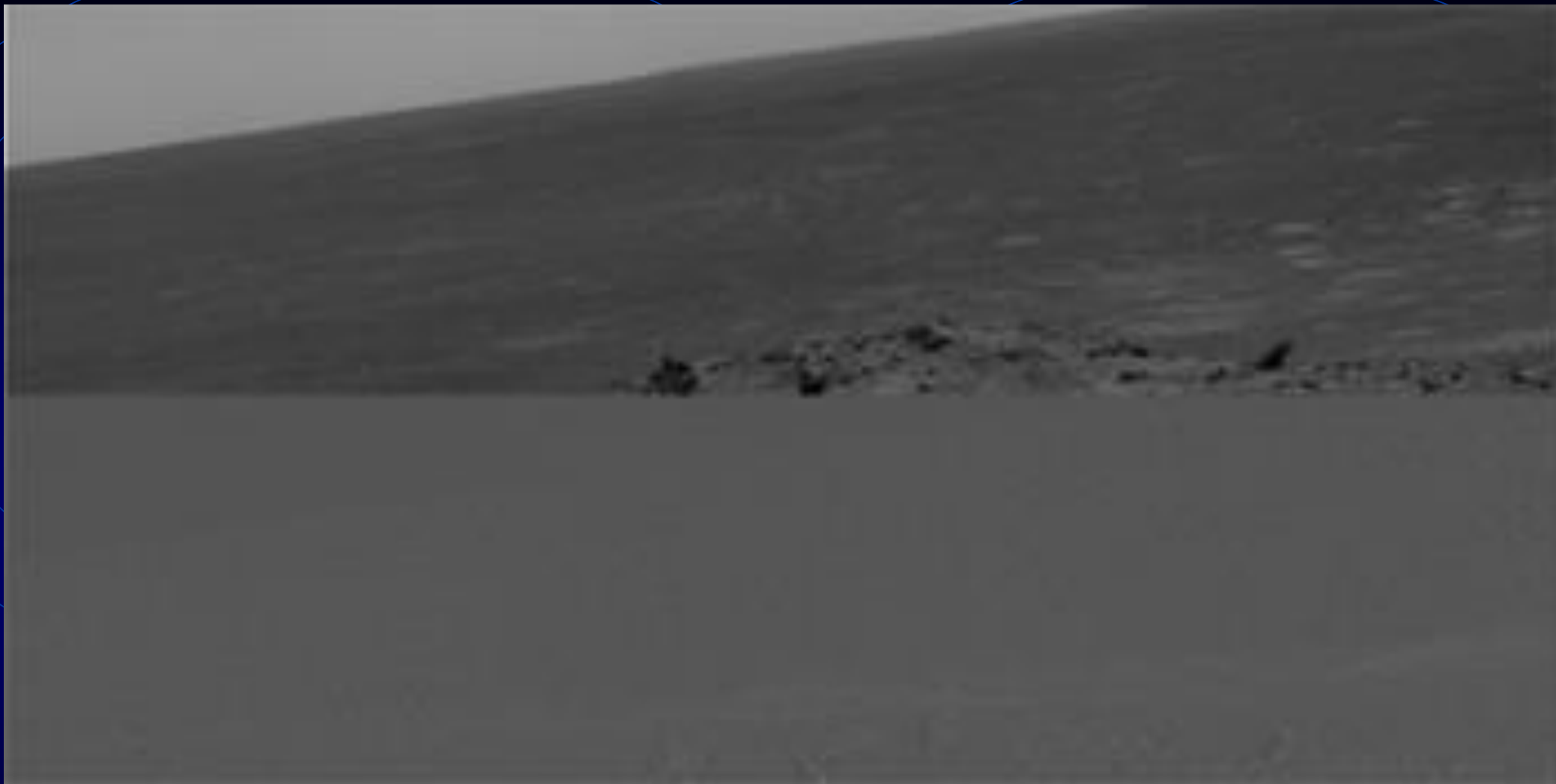


<http://thesituationist.wordpress.com/2008/02/23/seeing-faces/>



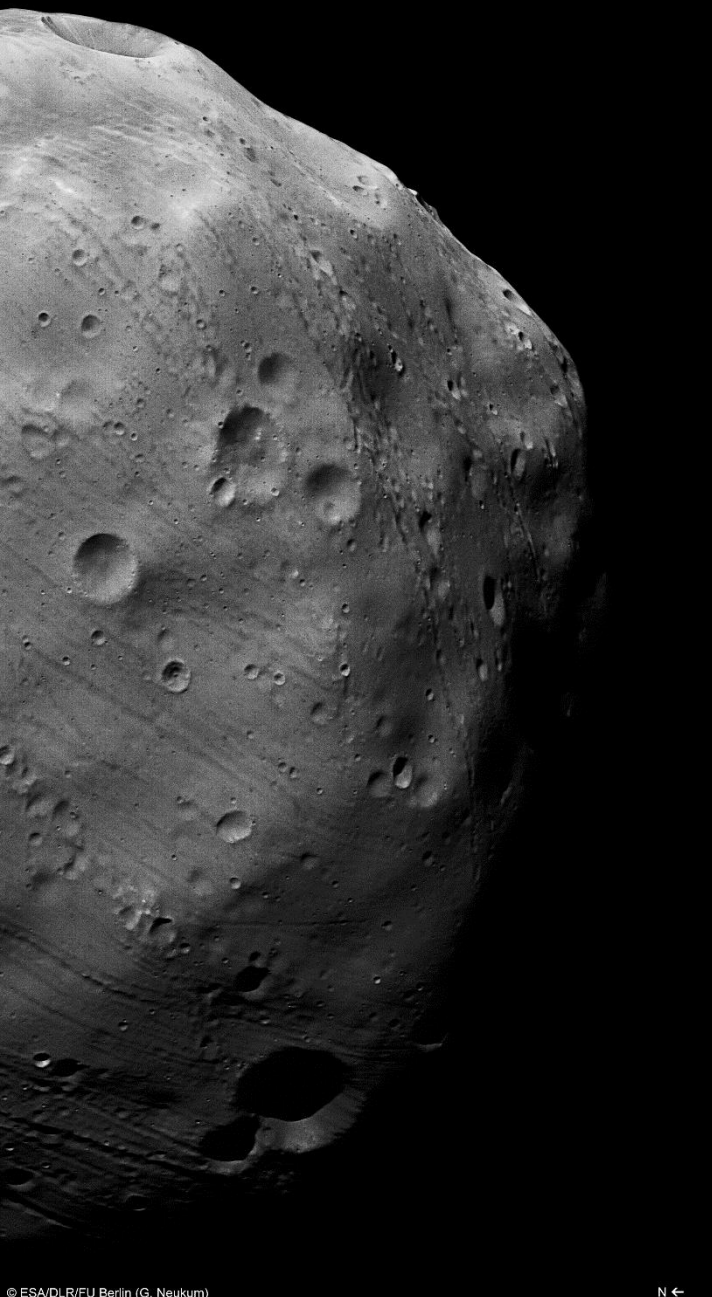
不是火星人特愛「面子」  
而是我們看得太清楚了





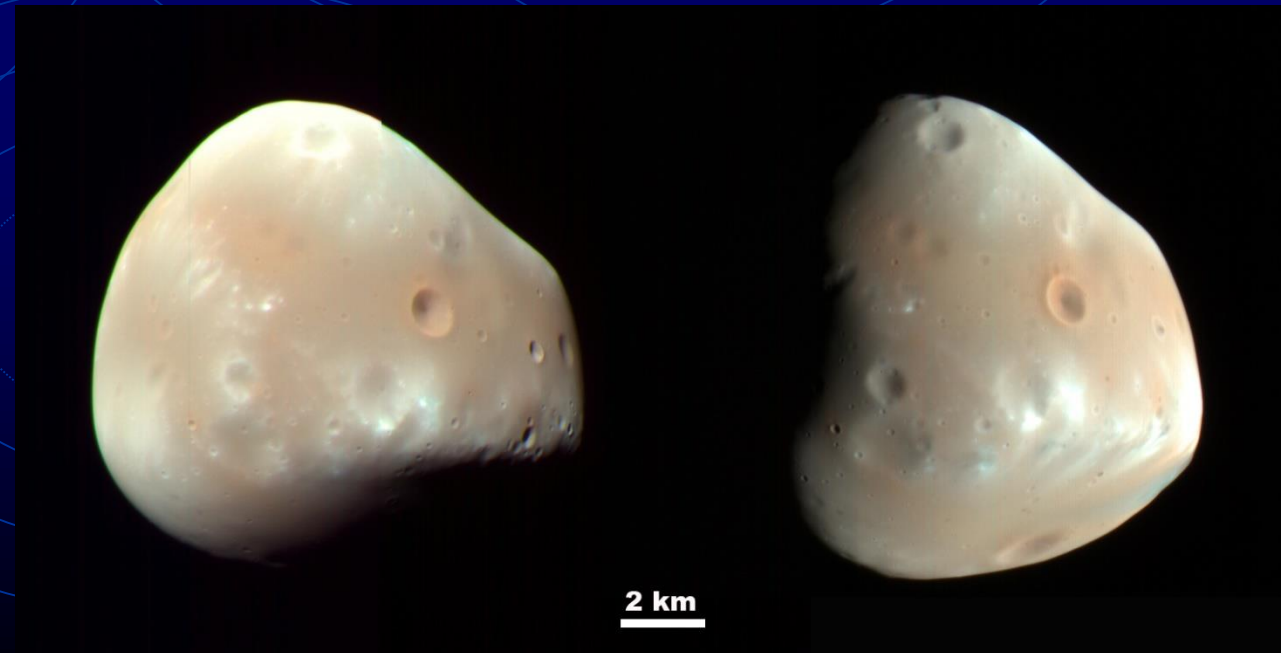
靈異塵暴？ Mars Exploration Rover Spirit 號  
2005年4月15日在 Gusev 隕石坑所拍攝



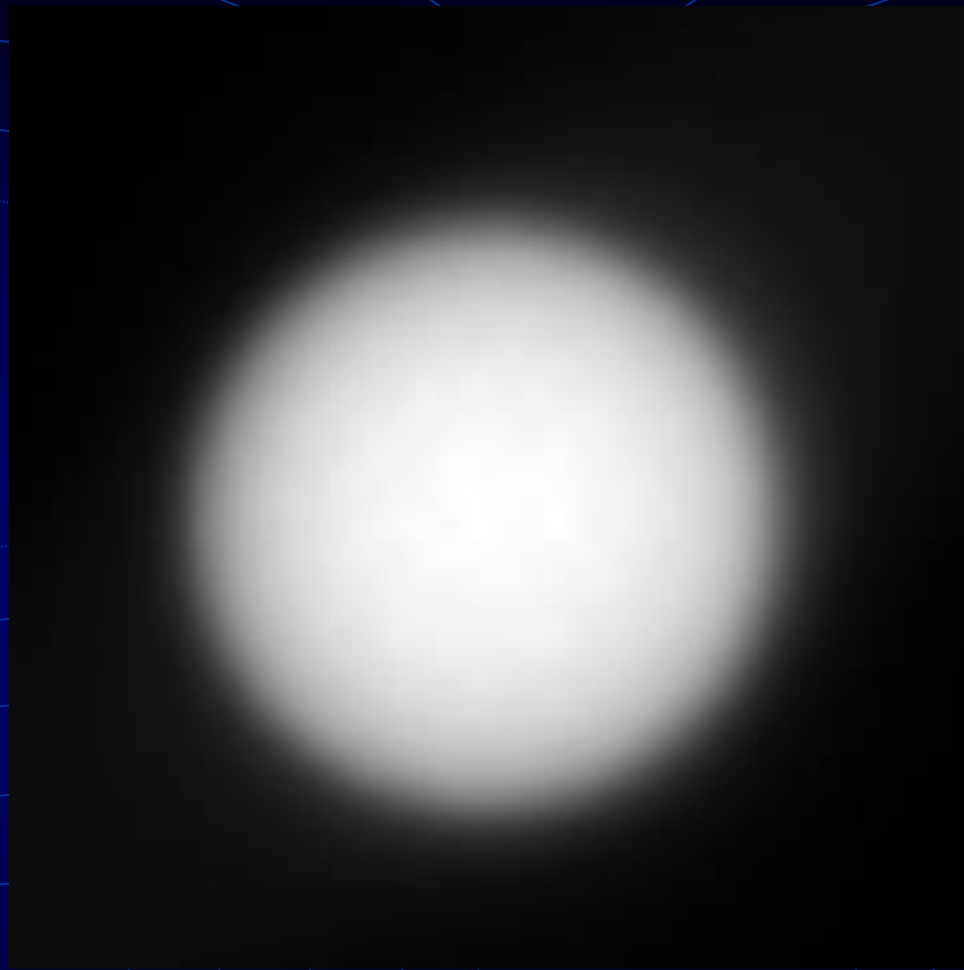


The High Resolution Stereo Camera aboard Mars Express (ESA) took this image of Phobos on March 7, 2010. A flyby distance of 67 km yielded a resolution of about 4.4 m per pixel.

These color-enhanced views of Deimos, the smaller of the two moons of Mars, result from imaging on Feb. 21, 2009, by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter.



# Solar eclipses on Mars



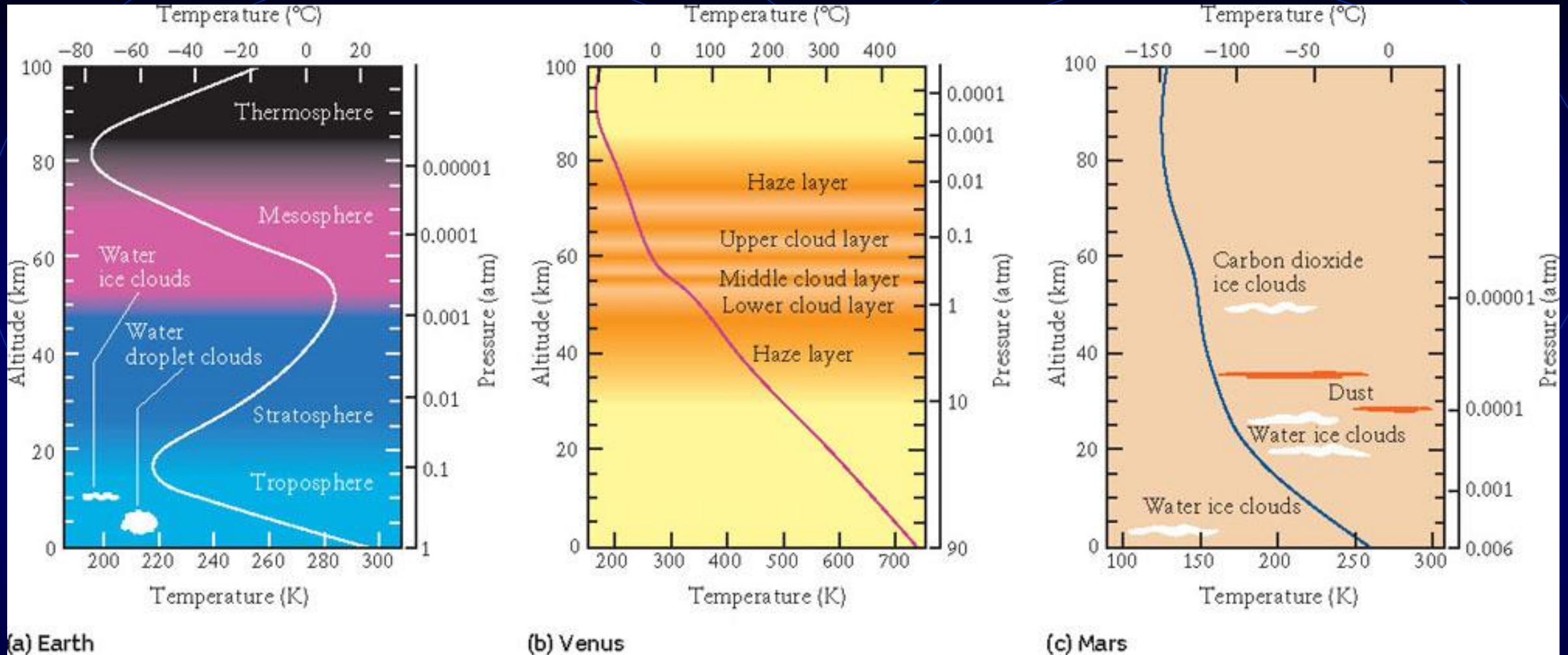
Transit of Phobos as seen by the *Opportunity* rover

<http://www.youtube.com/watch?v=qu8xeA4Pyuw>

# Chemical Composition of 3 Planetary Atmospheres

	Venus	Earth	Mars
Nitrogen N <sub>2</sub>	3.5%	78.08%	2.7%
Oxygen O <sub>2</sub>	~0	20.95%	~0
Carbon dioxide CO <sub>2</sub>	96.5%	0.035%	95.3%
Water vapor H <sub>2</sub> O	0.003%	~1%	0.03%
Other gases	~0	~0	2%

# Atmospheres of the Terrestrial Planets



(a) Earth

(b) Venus

(c) Mars

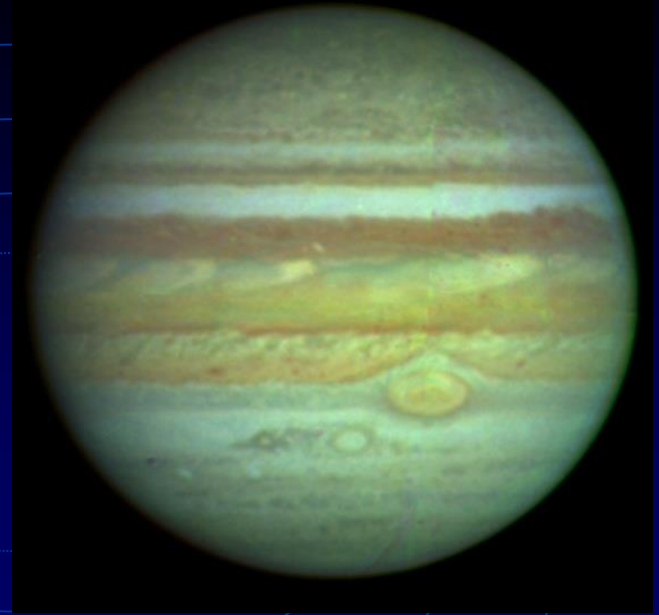
Clouds are rare above 12 km on Earth.

Venus has a thick atmosphere with perpetual cloud layers, with the 1 atm pressure 50 km above the Venusian surface.

Martian atmosphere is thin, with a surface pressure the same as that at an altitude of 35 km on Earth. High clouds are possible.

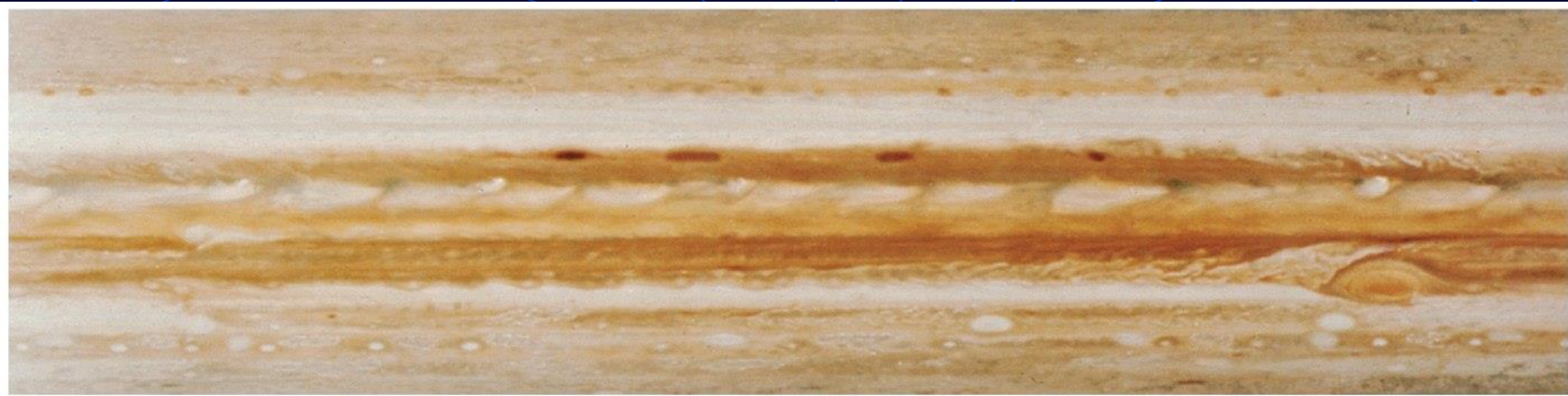
# 木星 (Jupiter)

- 太陽系最大行星（71%行星物質；太陽的千分之一）
- 彩色雲帶
- **大紅斑 (Great Red Spot)**  
乃表面風暴，至少已300年；較周遭冷、高；逆時鐘旋轉；約地球兩倍大小
- 大氣：氫，氦 內部：高壓；液態氫
- 自轉快，呈扁球狀
- 放出熱量為吸自太陽的兩倍：  
目前仍在收縮
- 有不明顯的環

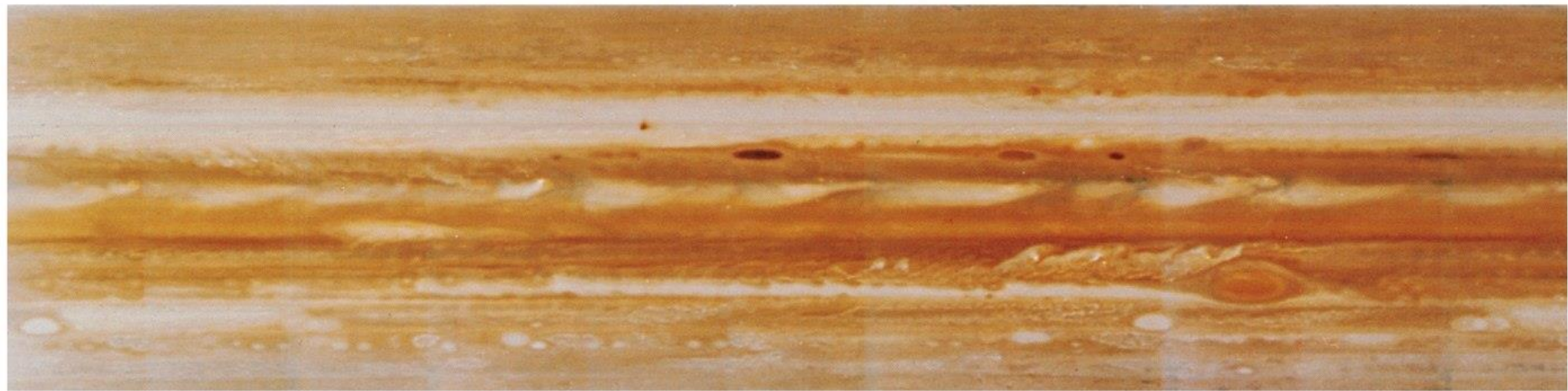


# 木星的大氣 —— 帶狀結構

淡色 → zones 深色 → belts

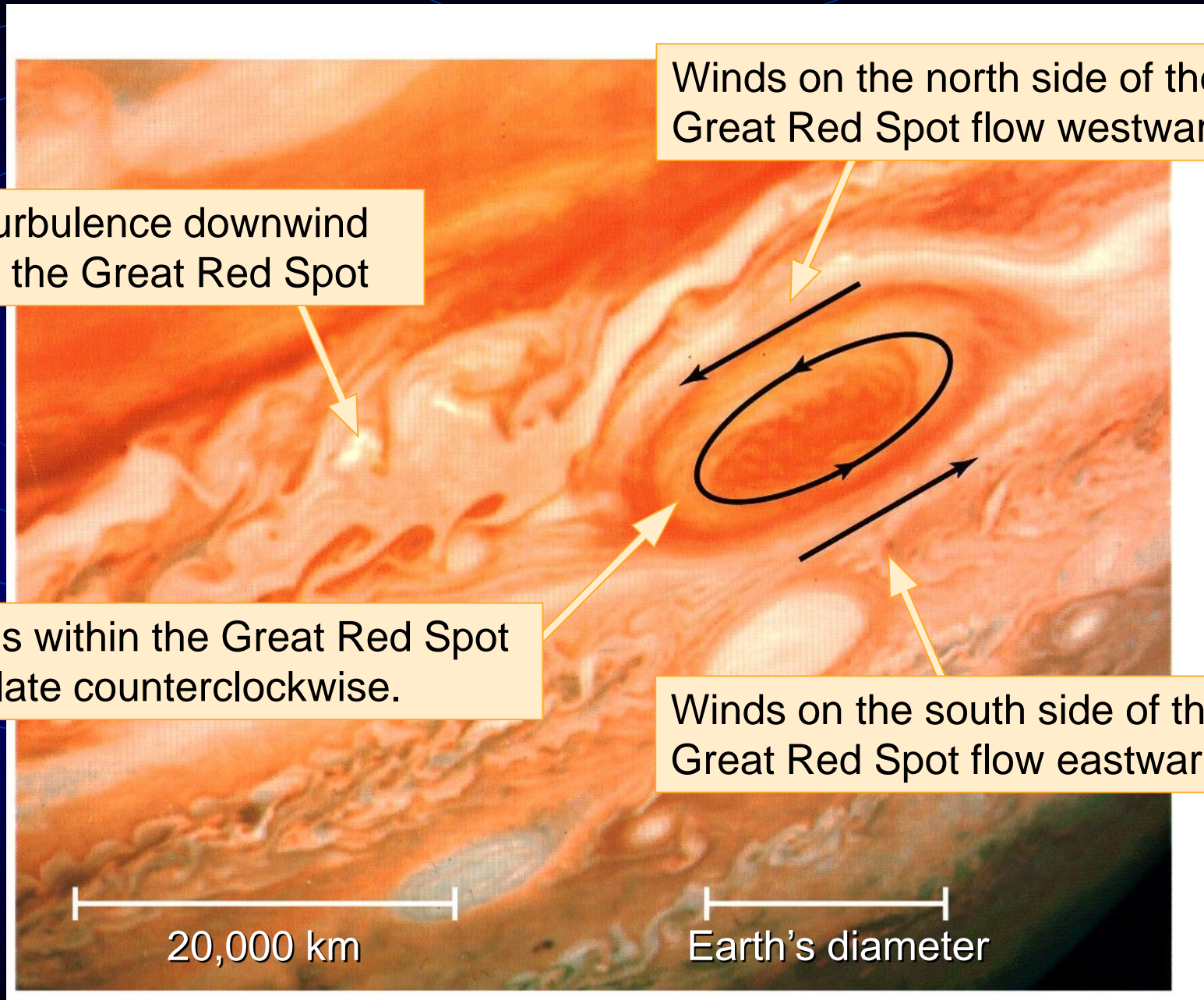


**a** *Voyager 1* view



**b** *Voyager 2* view

狂風、快速自轉、內熱、複雜成分



Winds on the north side of the Great Red Spot flow westward.

Turbulence downwind of the Great Red Spot

Winds within the Great Red Spot circulate counterclockwise.

Winds on the south side of the Great Red Spot flow eastward.

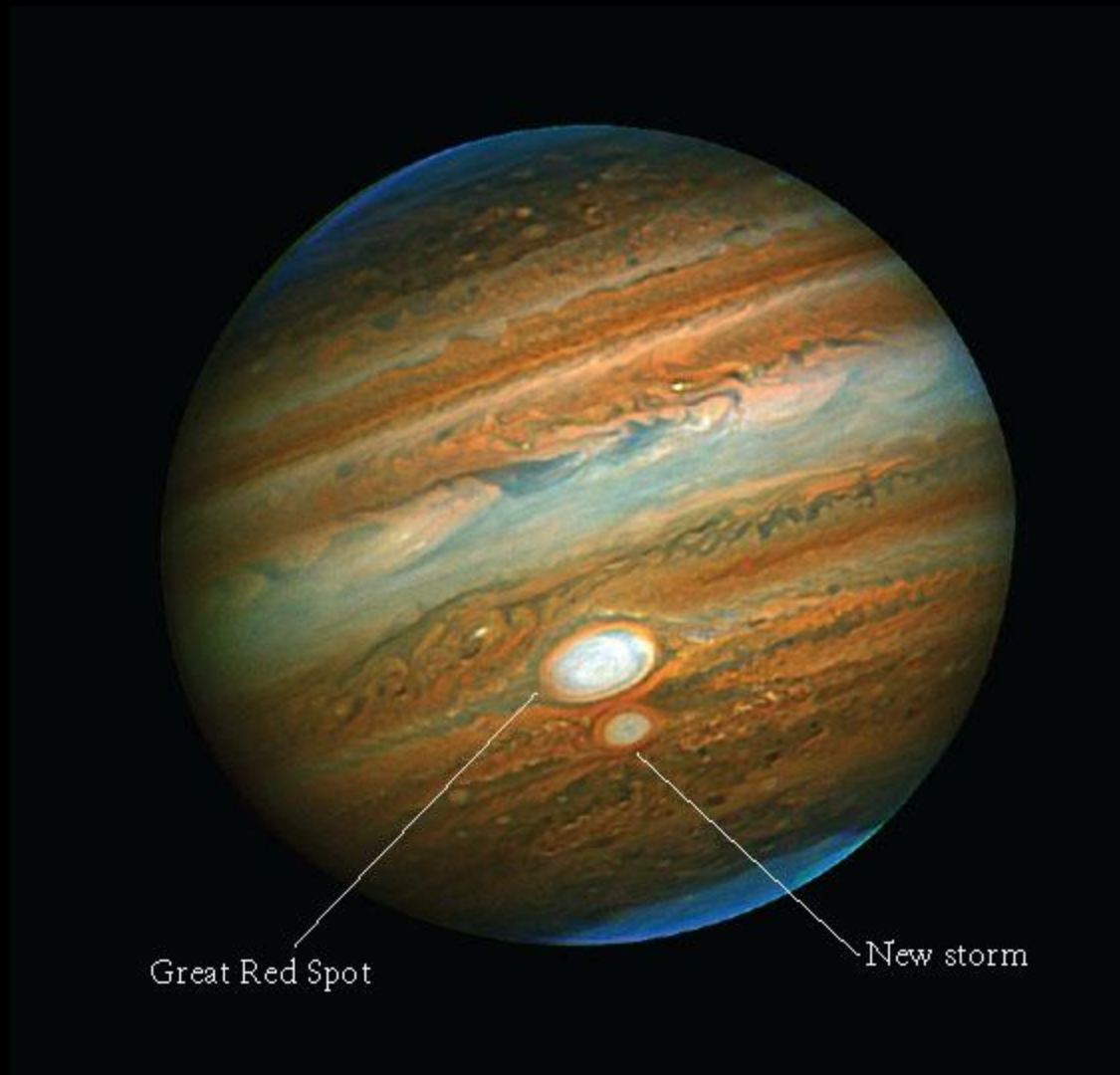
大紅斑逆時鐘旋轉

約6天轉一圈

20,000 km

Earth's diameter

1979年  
航海家二號

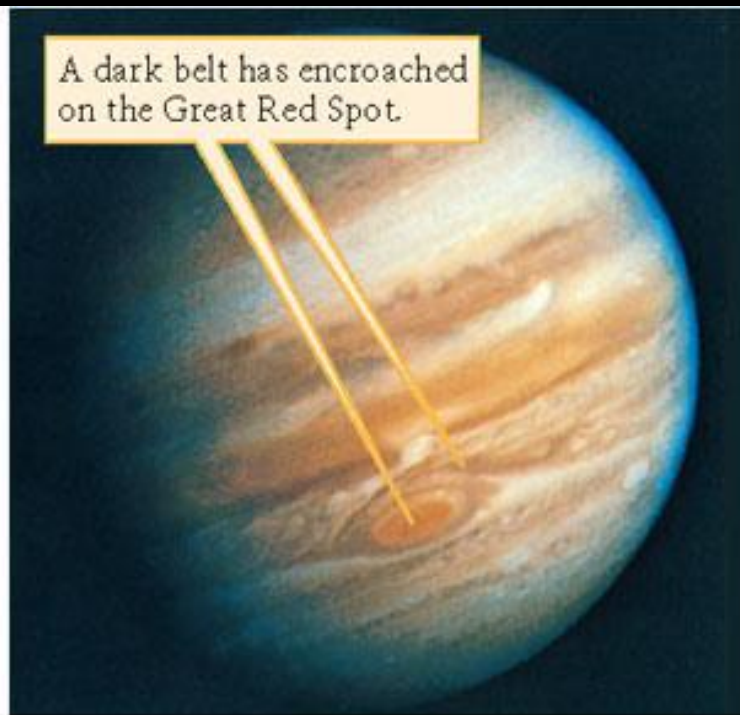


Jupiter's "Red Spot" Jr., a new storm formed between 1998 and 2000, travels around Jupiter at a different rate from the Great Red Spot.

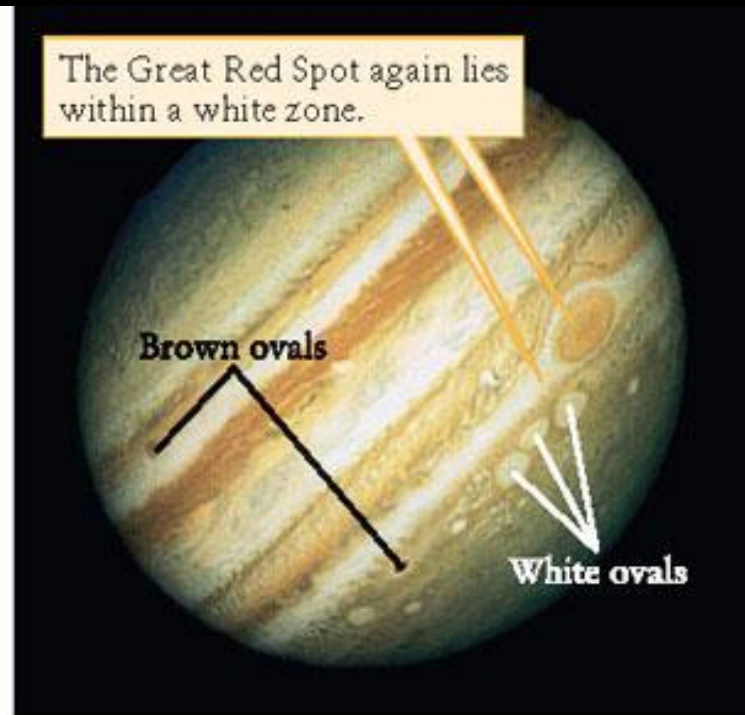




(a) Pioneer 11, December 1974



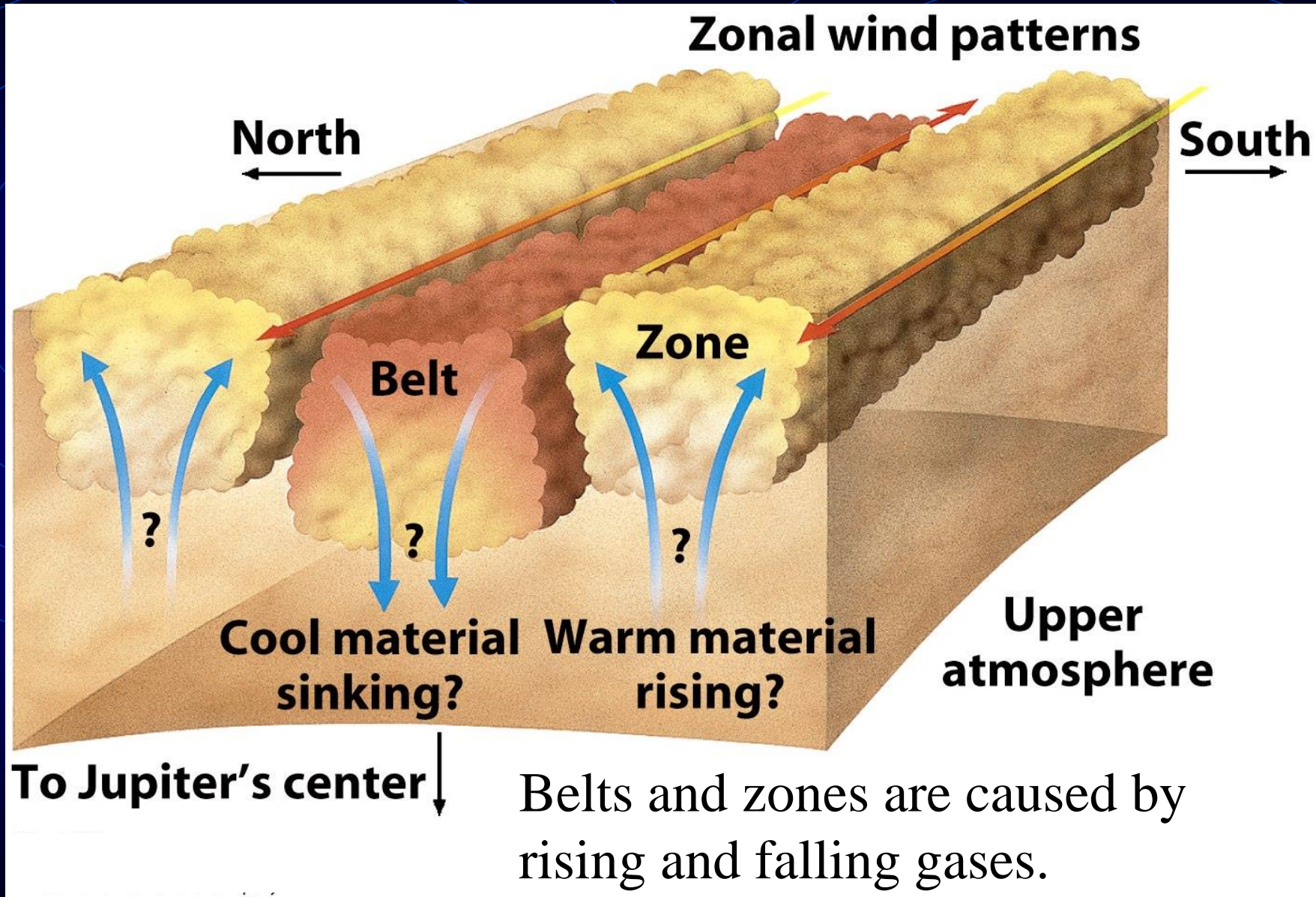
(b) Voyager, July 1979



(c) HST, February 1995

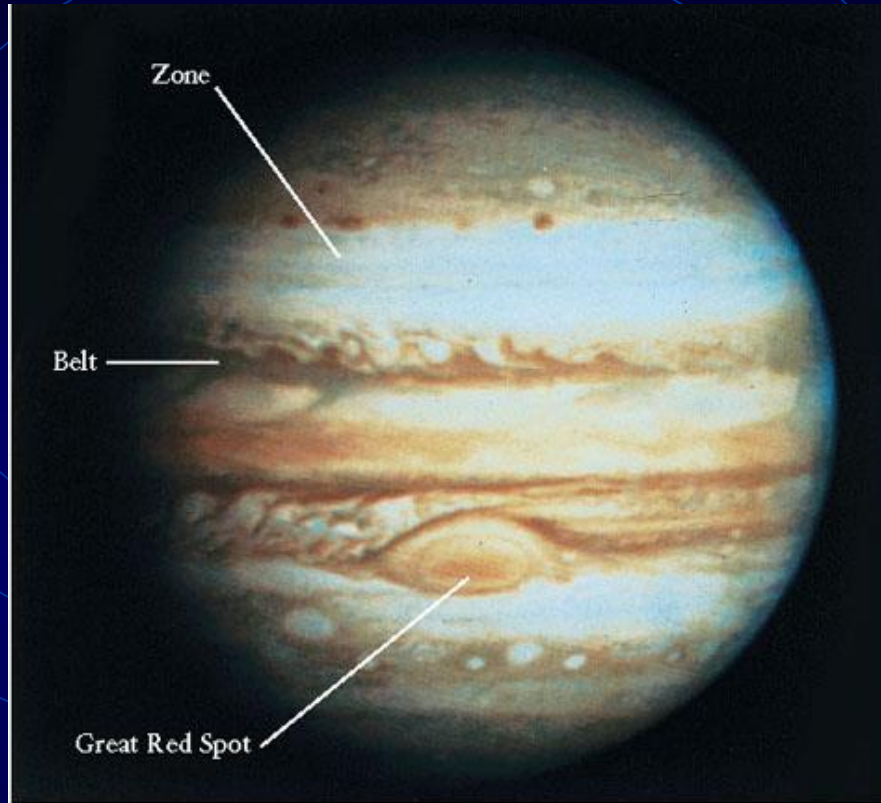
多變的木星大氣，(a), (b) 影像來自太空船，  
(c) 則為哈伯太空望遠鏡所拍攝

Wind speed > 500 km/h



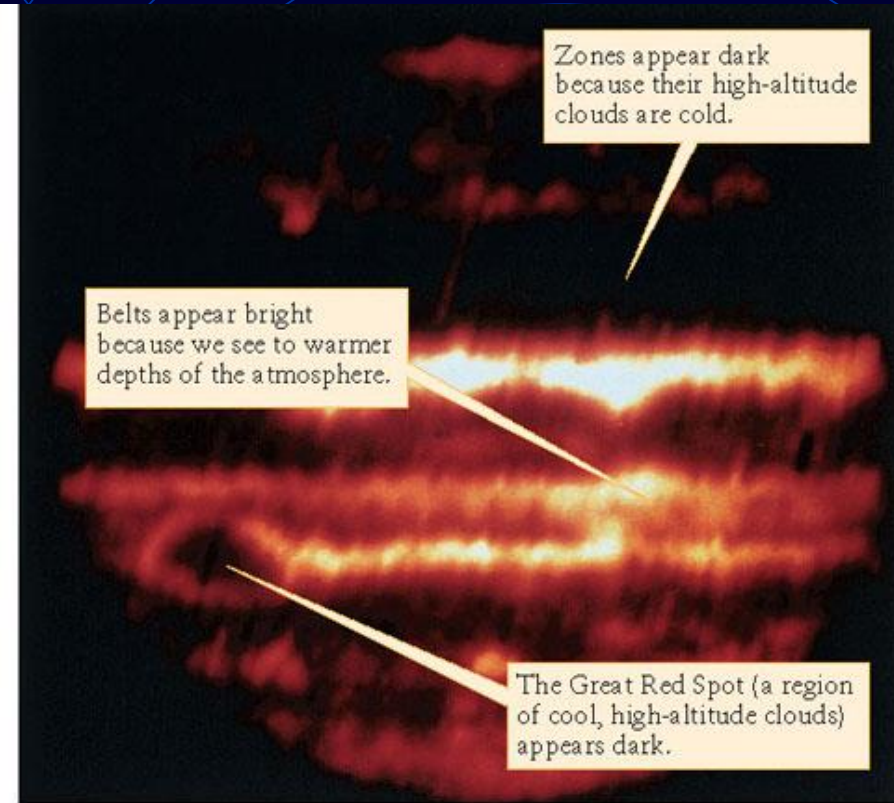
Belts and zones are caused by rising and falling gases.

# Voyager 1 optical image



(a) Visible-light image

# IR image taken at the same time

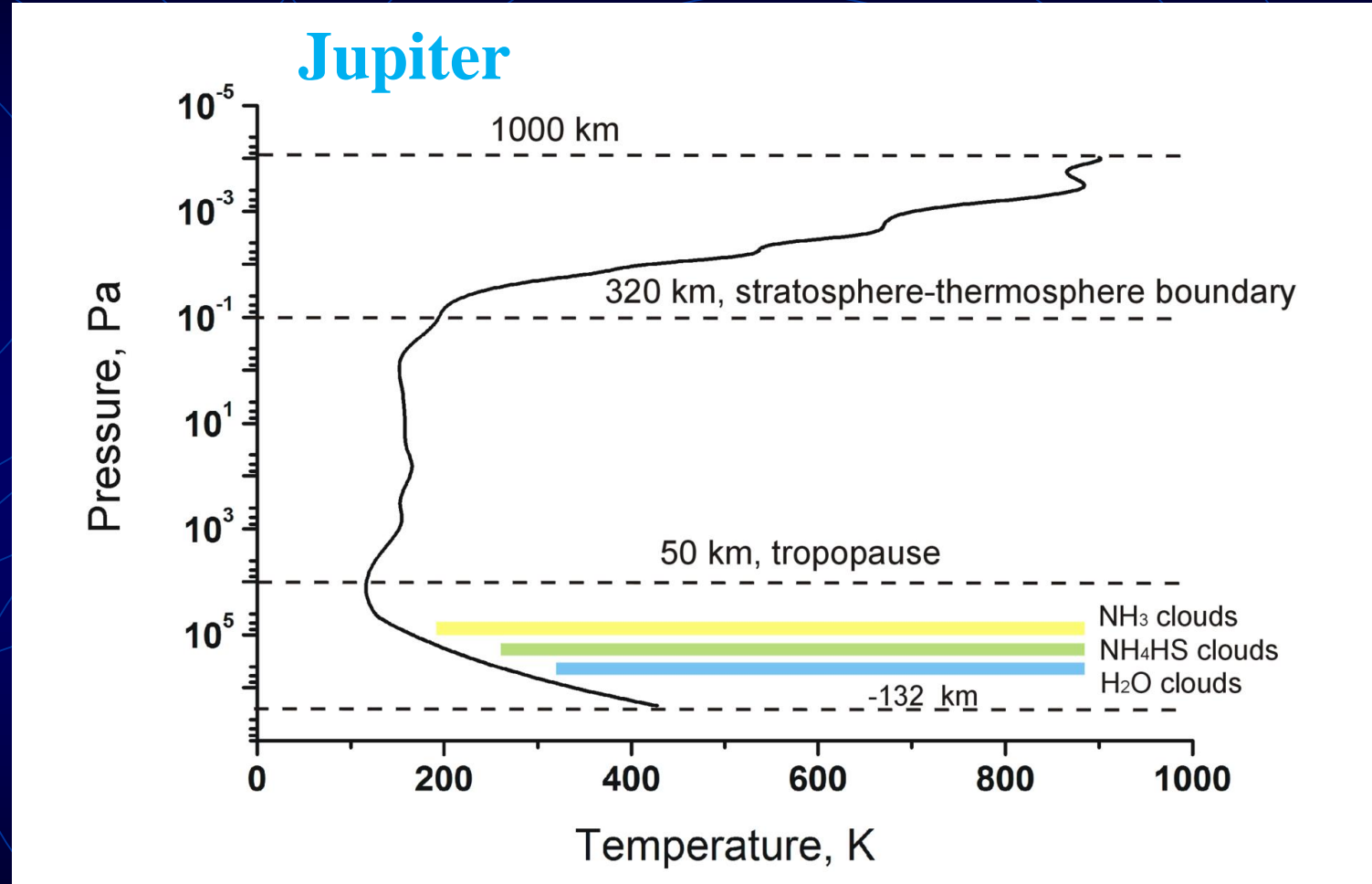
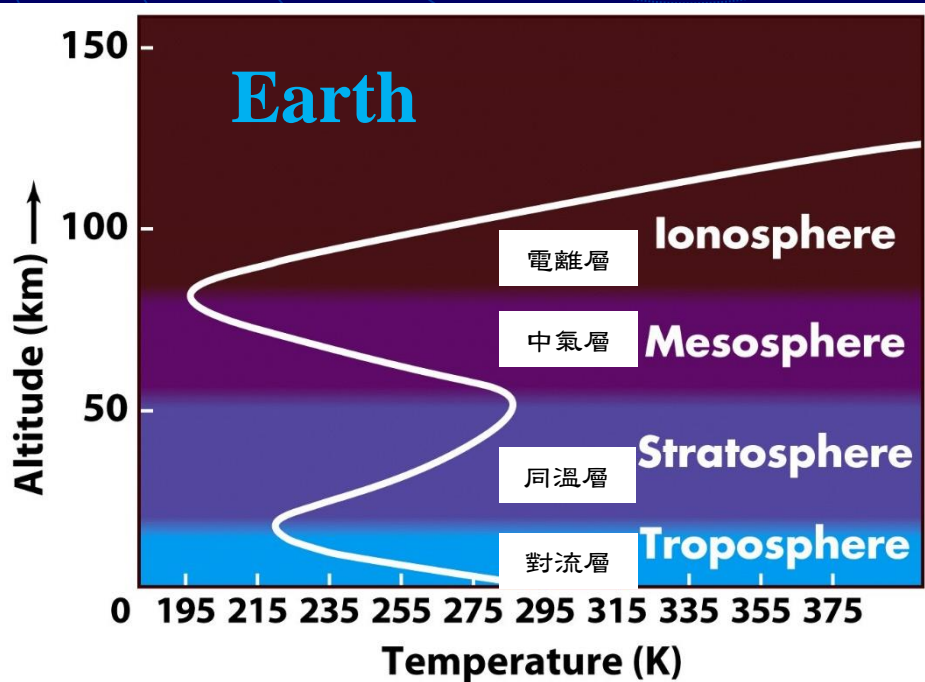


(b) Infrared image

Warm belts and cool zones

# Vertical structure of the atmosphere of Jupiter

The temperature drops together with altitude above the tropopause. The Galileo atmospheric probe stopped transmitting at a depth of 132 km below the 1 bar "surface" of Jupiter. No 'mesosphere'.



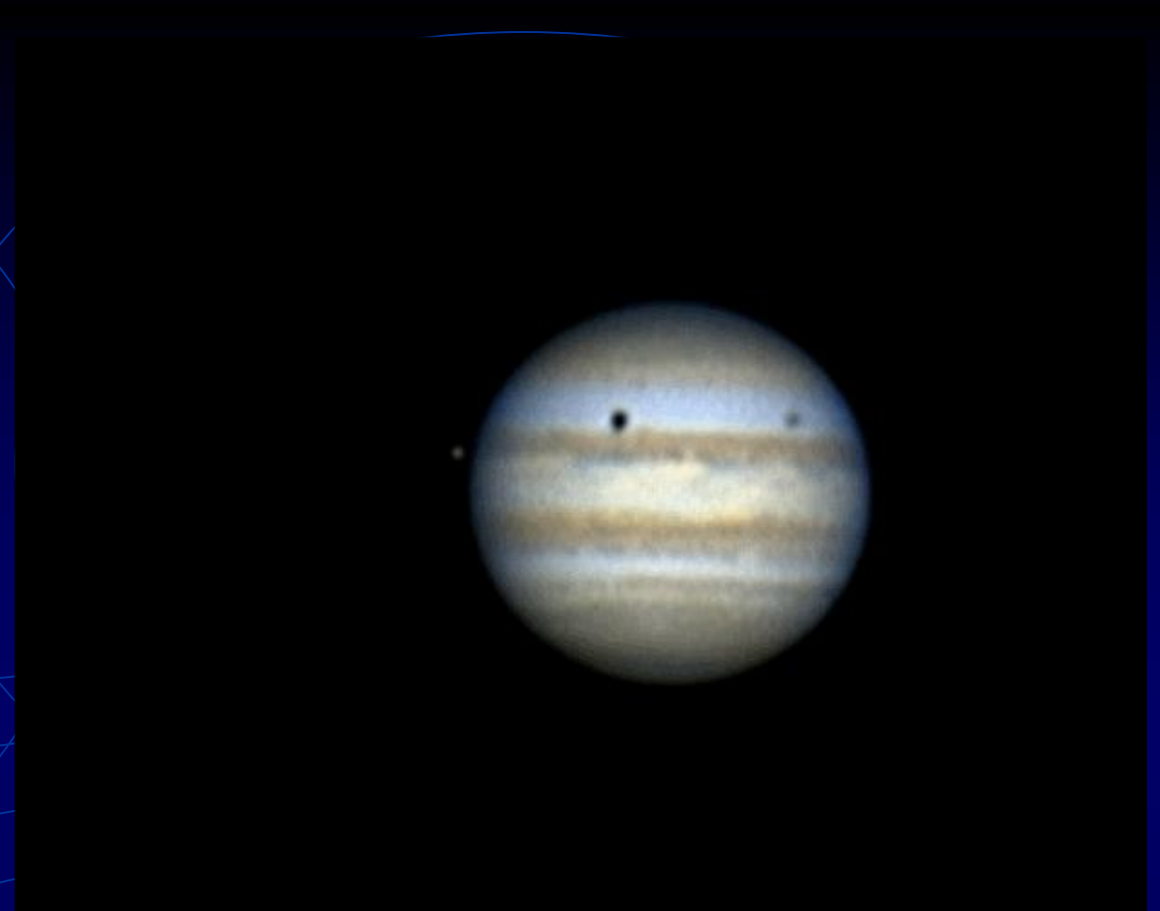
加利略1610年發現木星四顆衛星  
(Galileo satellites)：

Io (木衛一)

Europa (木衛二)

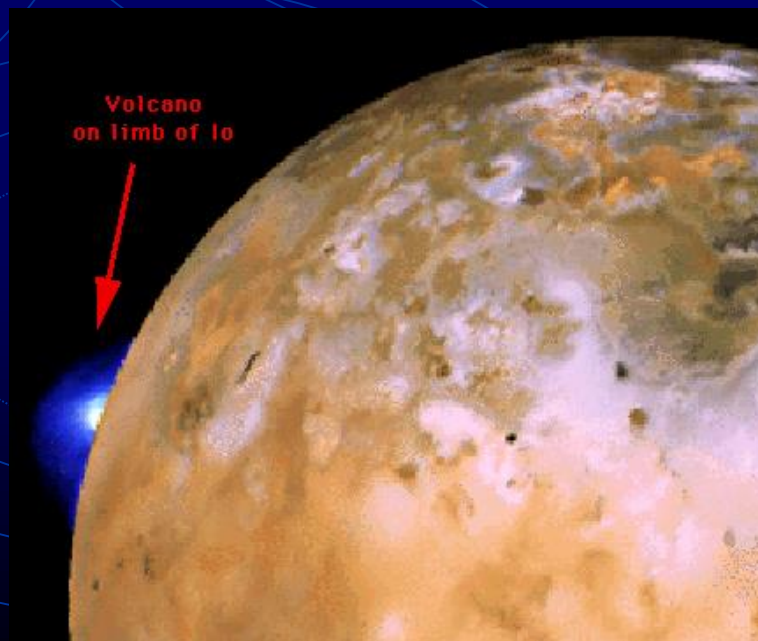
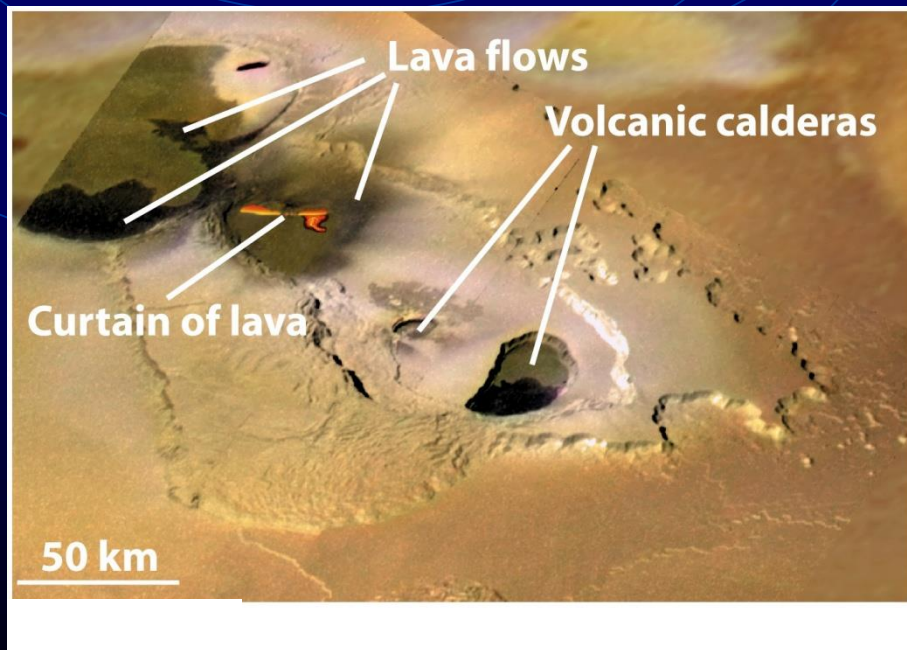
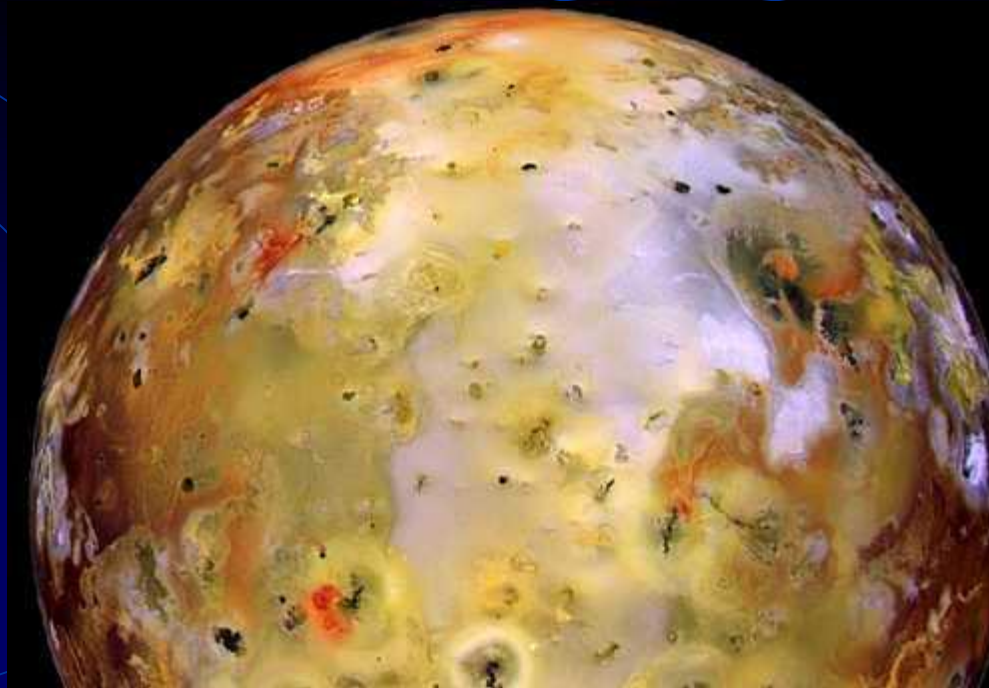
Ganymede (木衛三)

Callisto (木衛四)

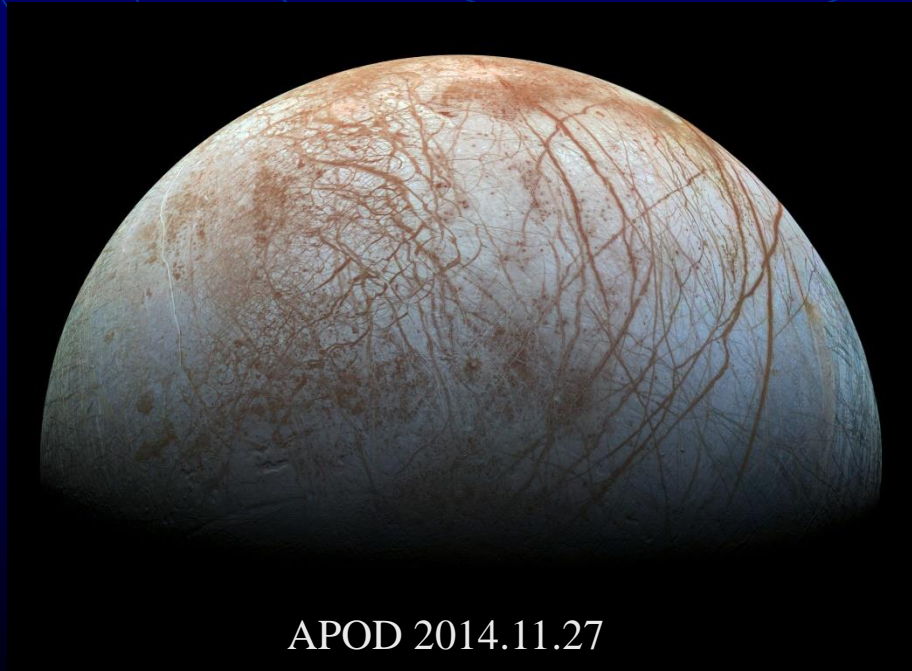


木星的衛星埃歐 (Io)  
表面缺乏隕石坑，  
為什麼？

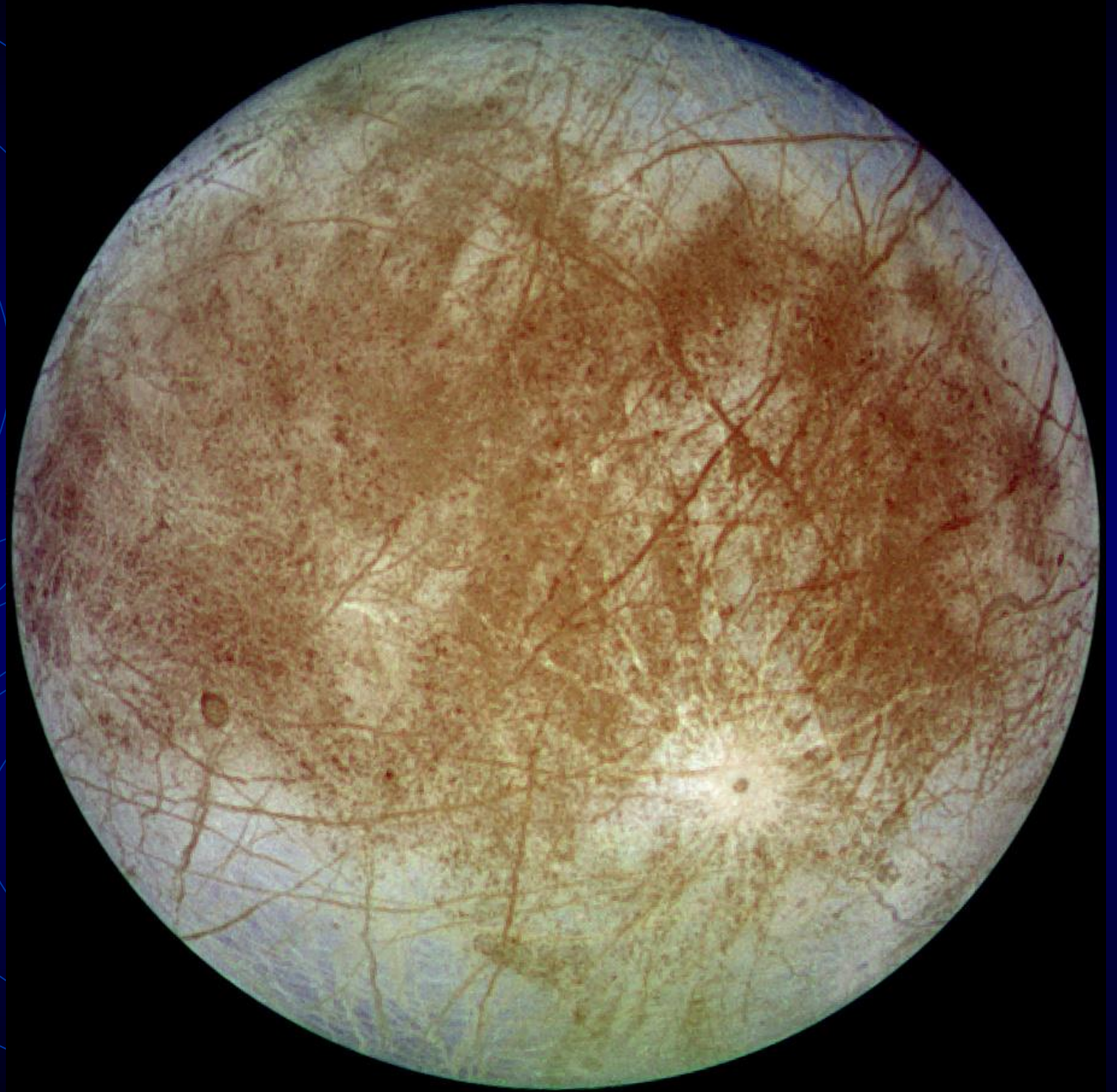
表面有火山活動，  
噴發大量硫化物



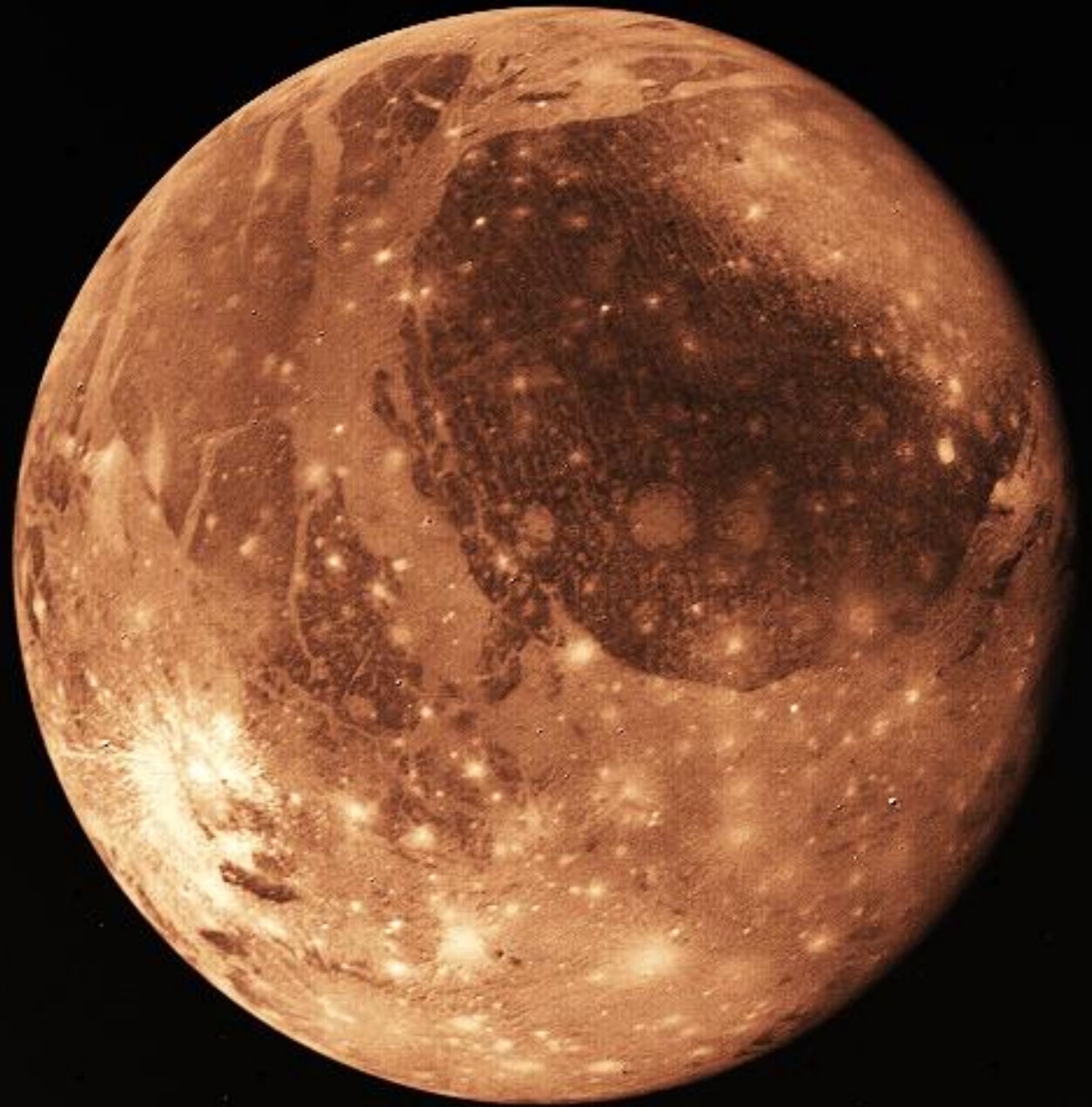
木星的衛星歐羅巴  
(Europa)直徑略大於3100  
公里，比月球稍小；表面  
有彩色裂痕，表層之下有  
水，甚至可能有海洋



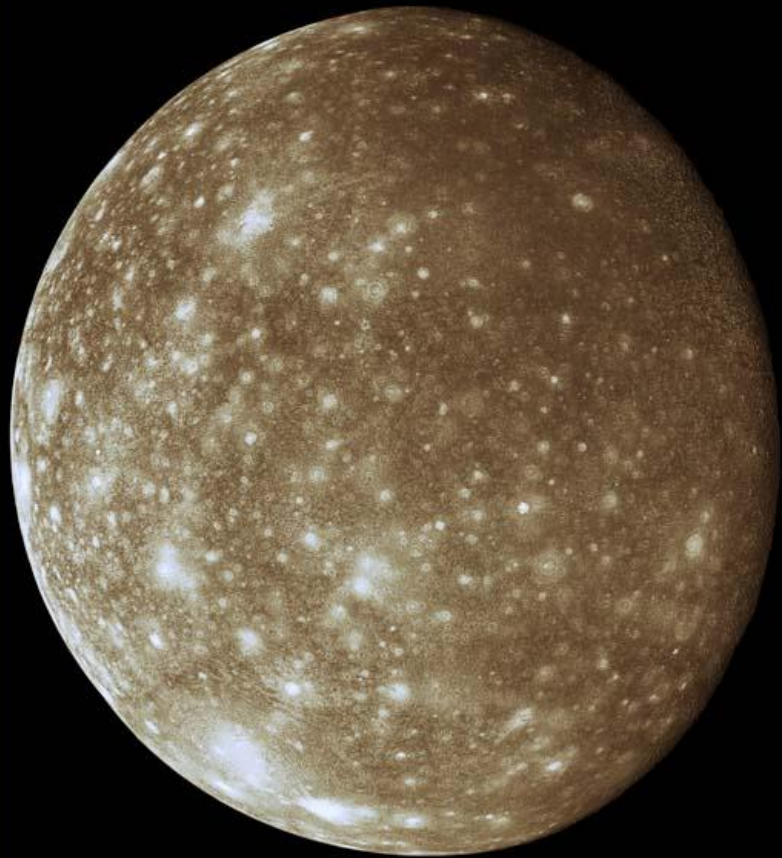
APOD 2014.11.27



甘尼米德 (Ganymede)  
直徑達5262公里，是太陽系當中最大的衛星。  
甘尼米德有複雜的地質活動（例如高山、窪地、隕石坑、岩漿流）。表面的暗黑區域有大量隕石坑，表示地質年齡比較老。



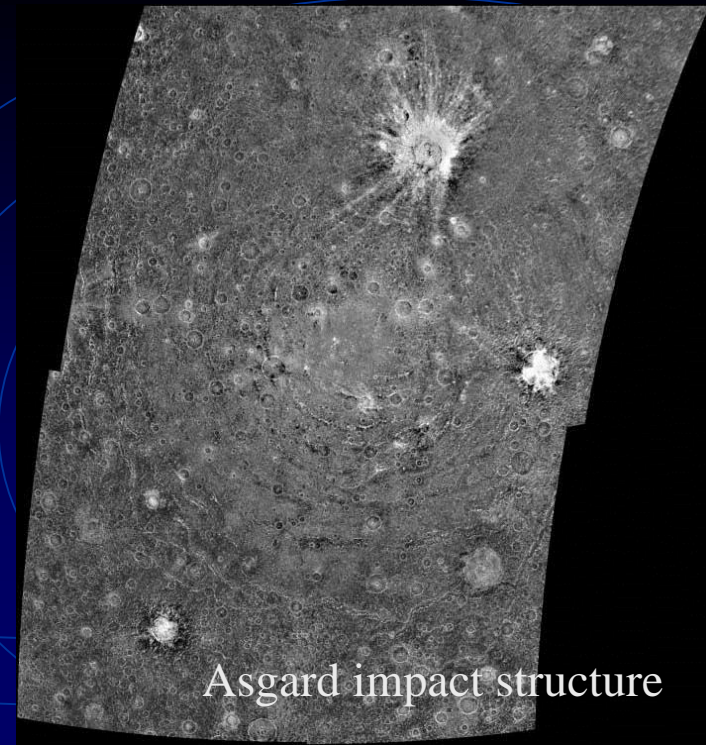




Callisto

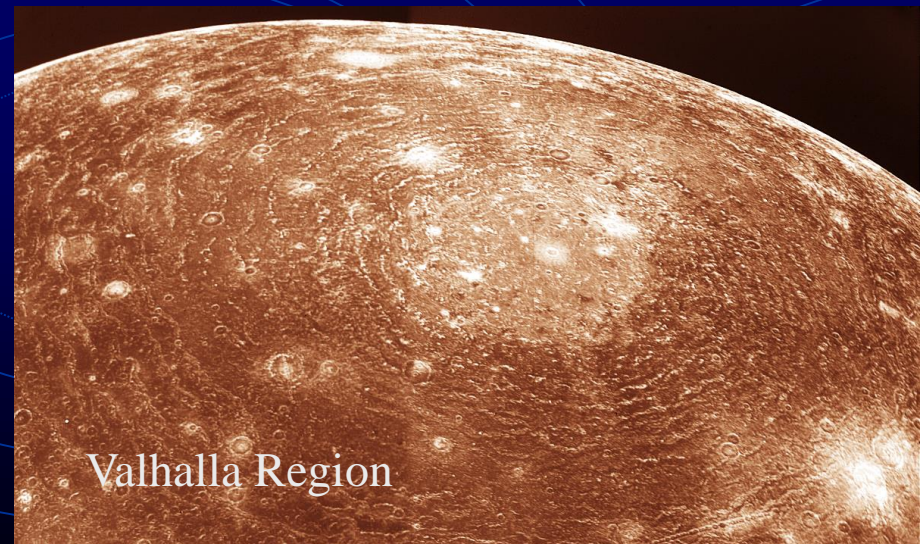
Copyright © 2004 Calvin J. Hamilton

卡利斯多 (Callisto) 大小與水星相當，是太陽系當中隕石坑最多的衛星

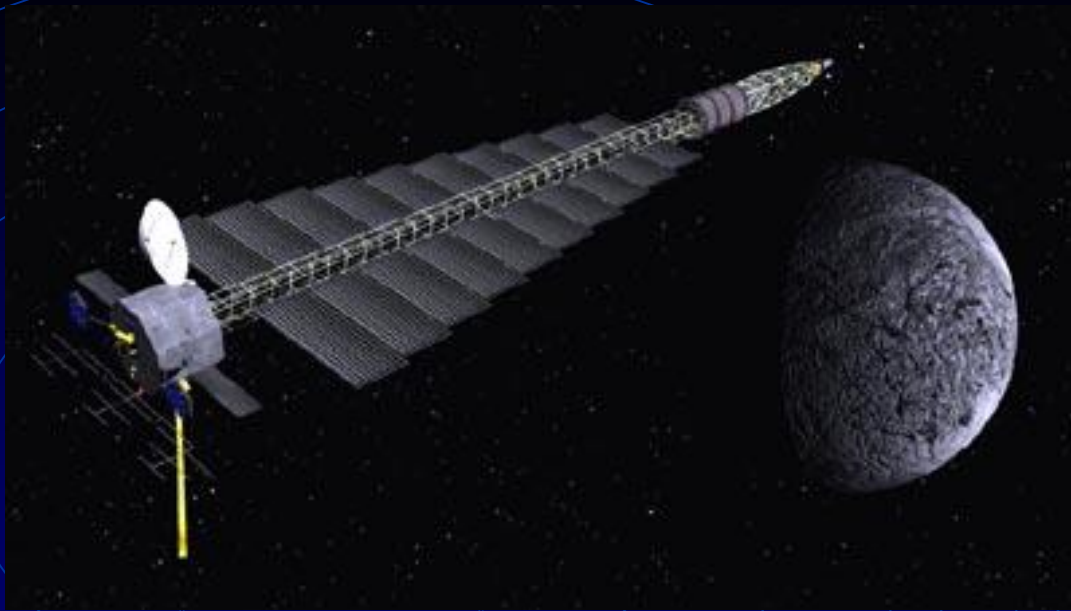


Asgard impact structure

隕石坑周圍的同心環結構



Valhalla Region



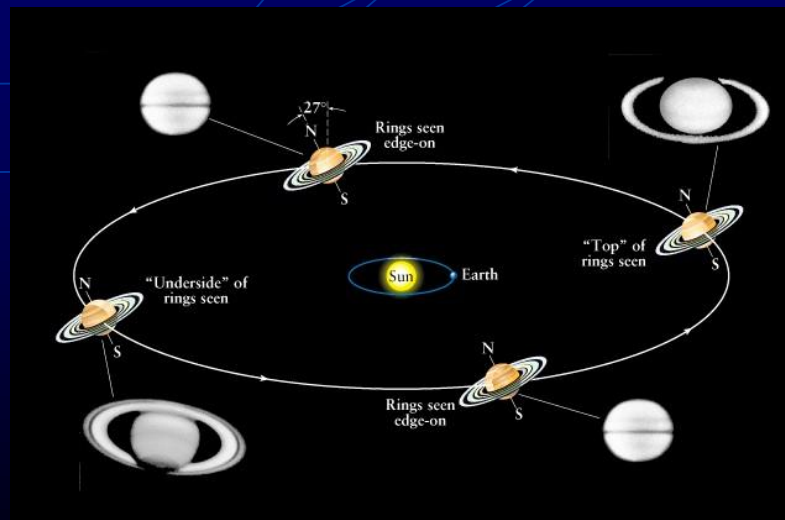
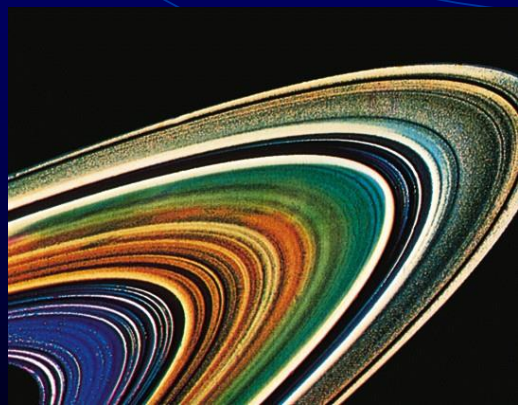
NASA 規劃  
2011 年以後發  
射 Jupiter Icy  
Moons Orbiter

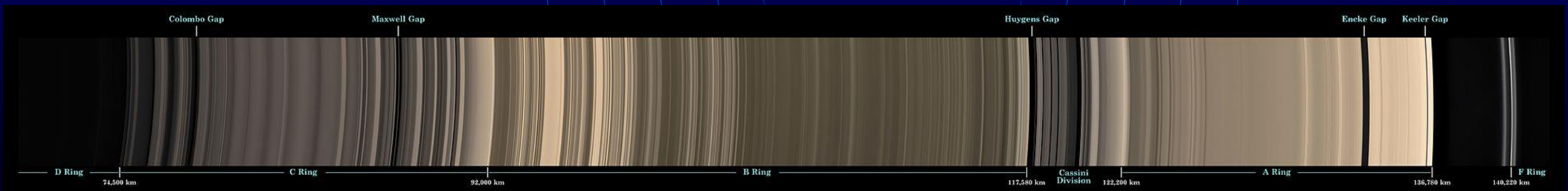
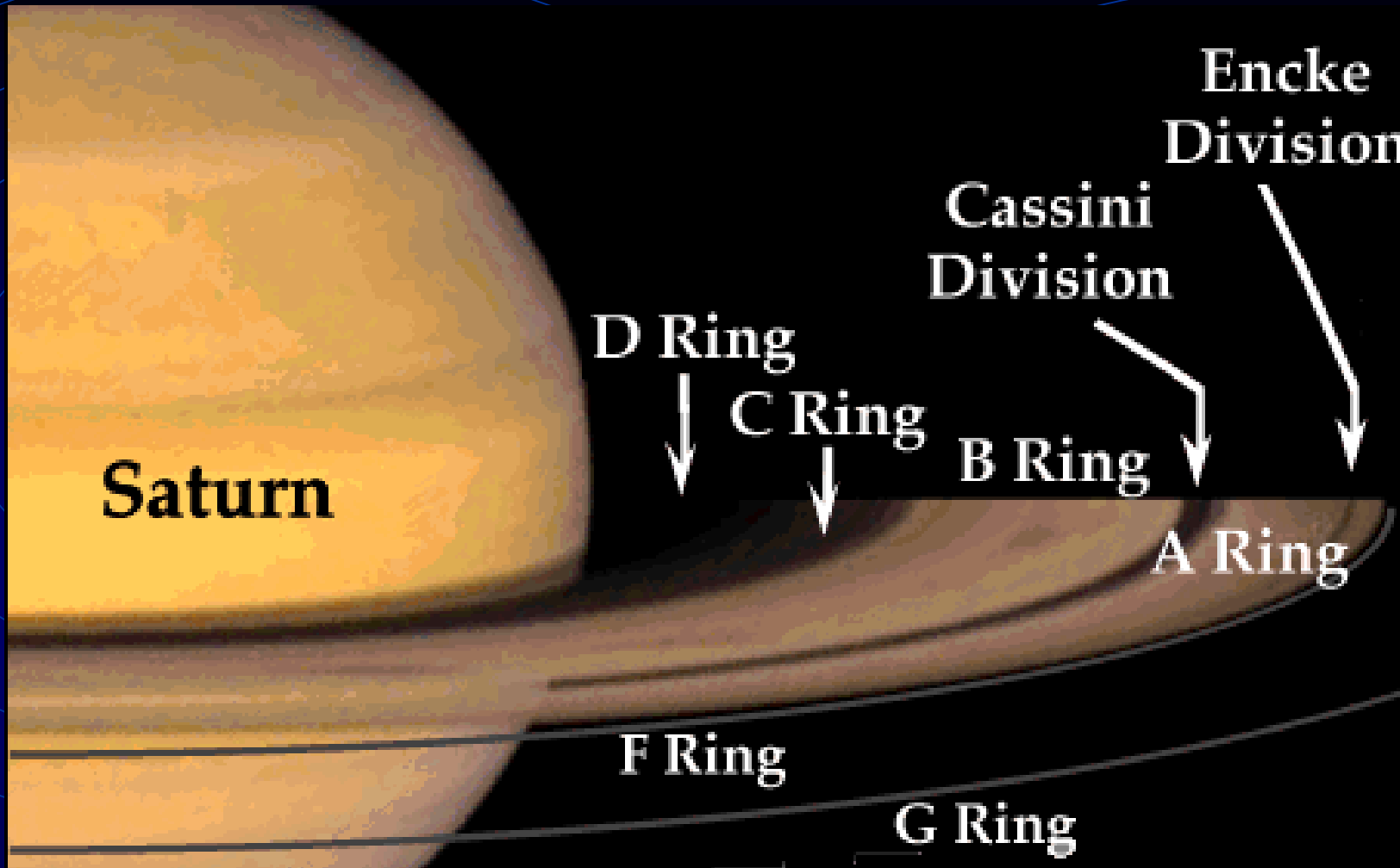
利用 cryobot/hydrobot 穿  
越 Europa 的冰層後，會  
看到這樣的光景嗎？→

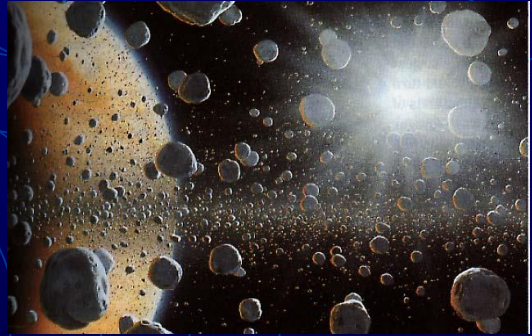
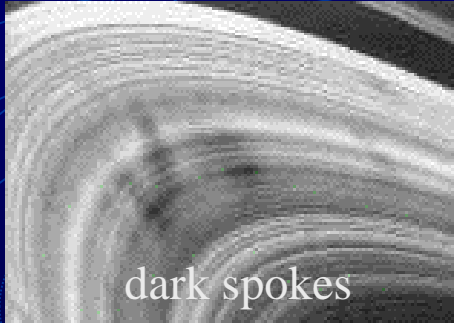
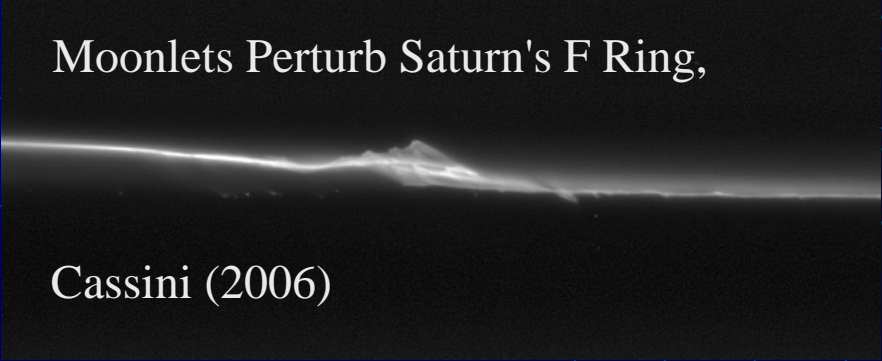
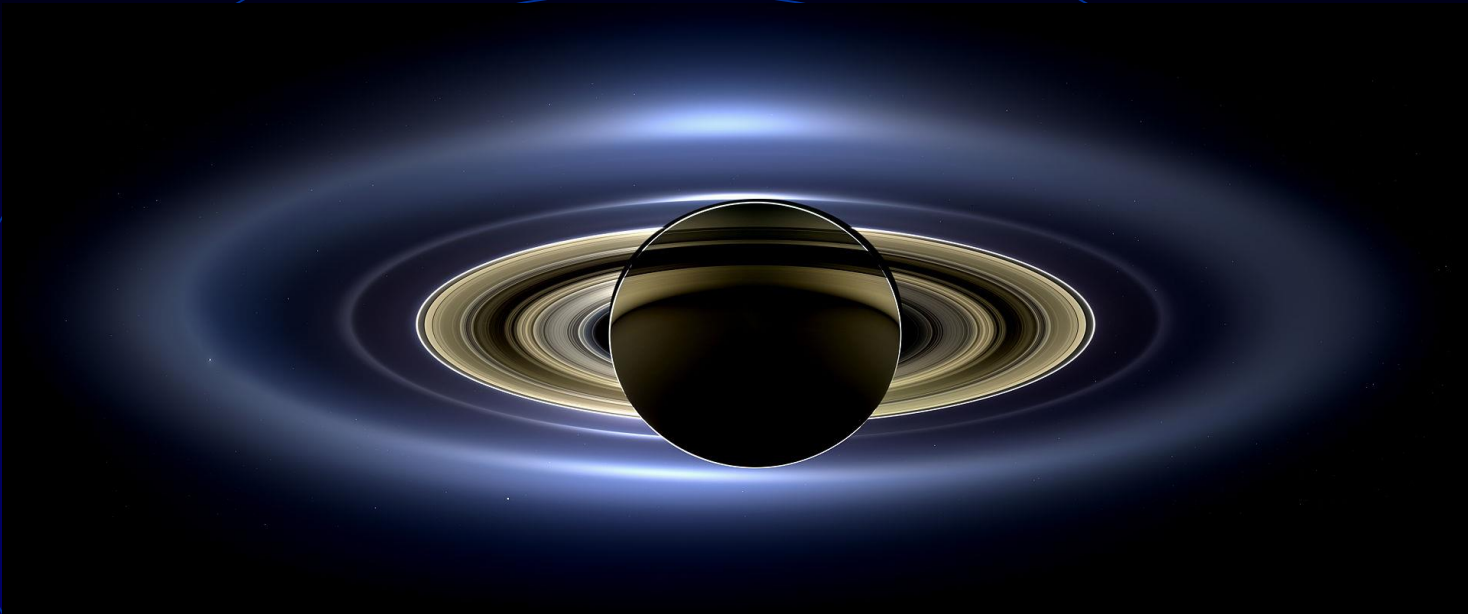


# 土星 (Saturn)

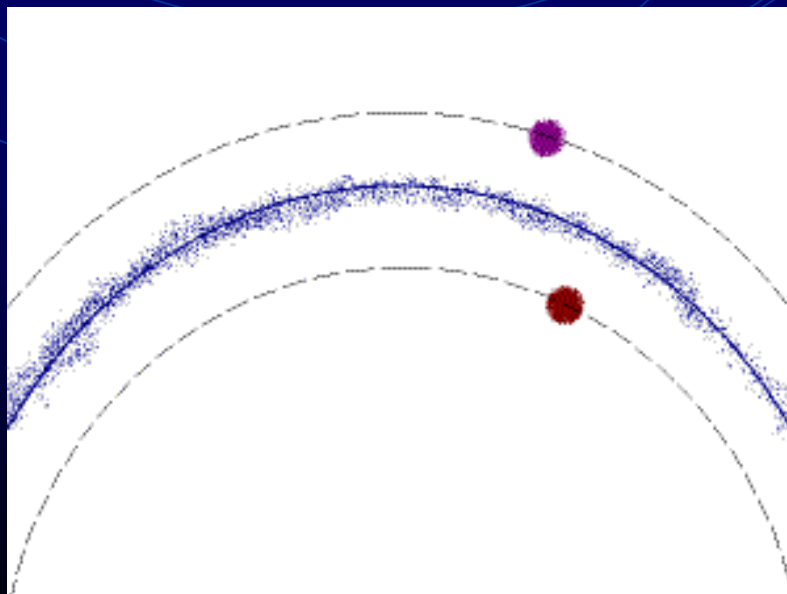
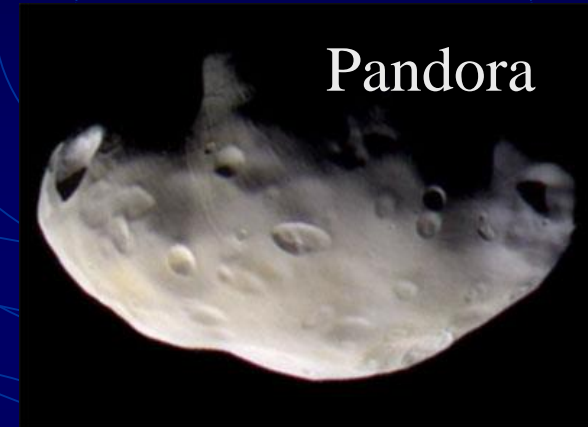
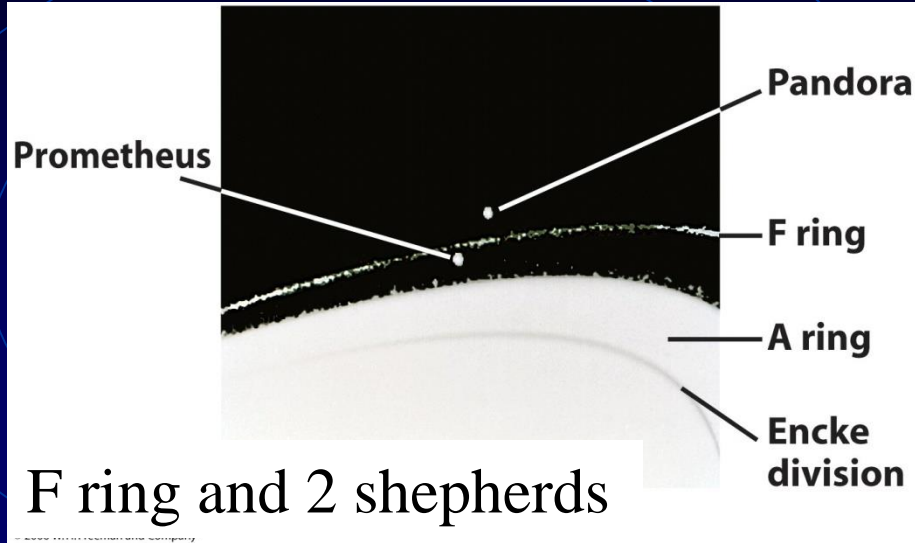
- 美麗炫目的光環，從地球觀看角度（時間）不同，光環呈現不同景觀
- 光環由無數小環組成，環寬而薄，成分為碎冰（水、阿摩尼亞、甲烷）
- 也有彩色雲帶



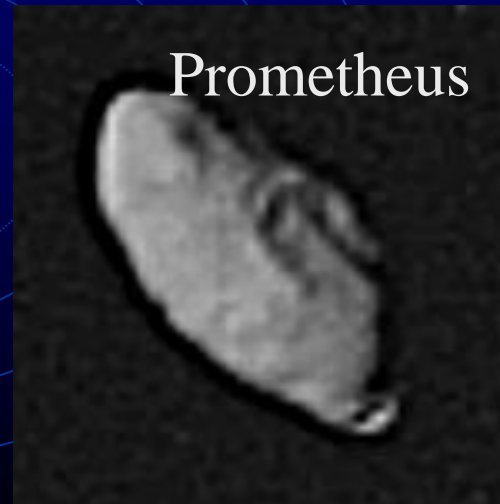




# Rings and Shepherd Moons



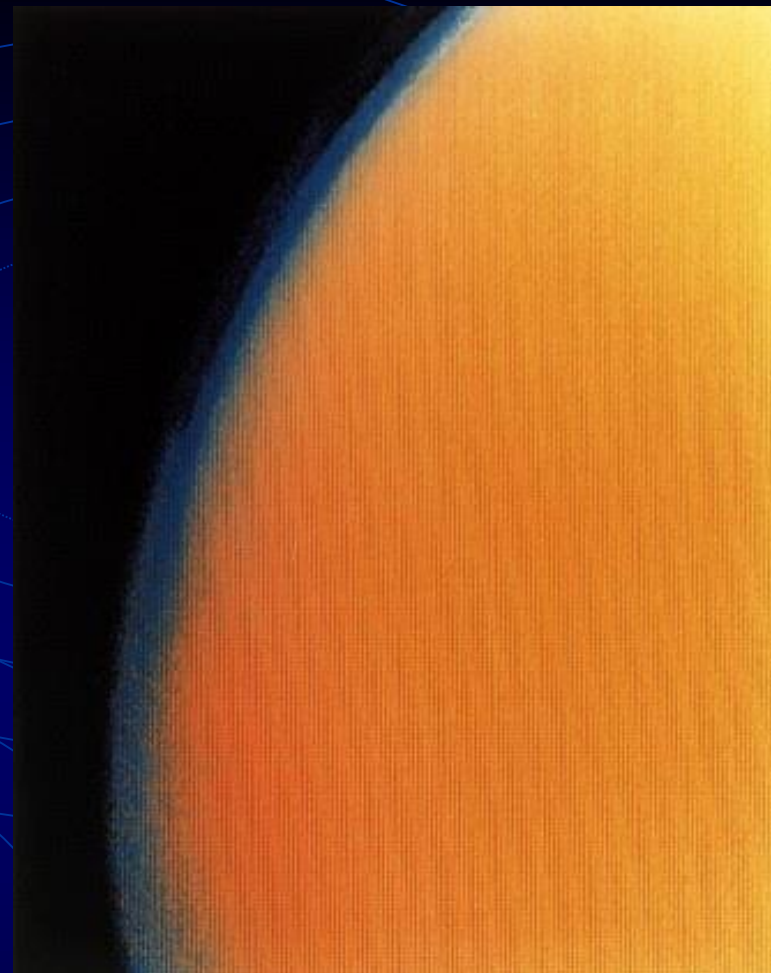
Each moon  
~ 50 km



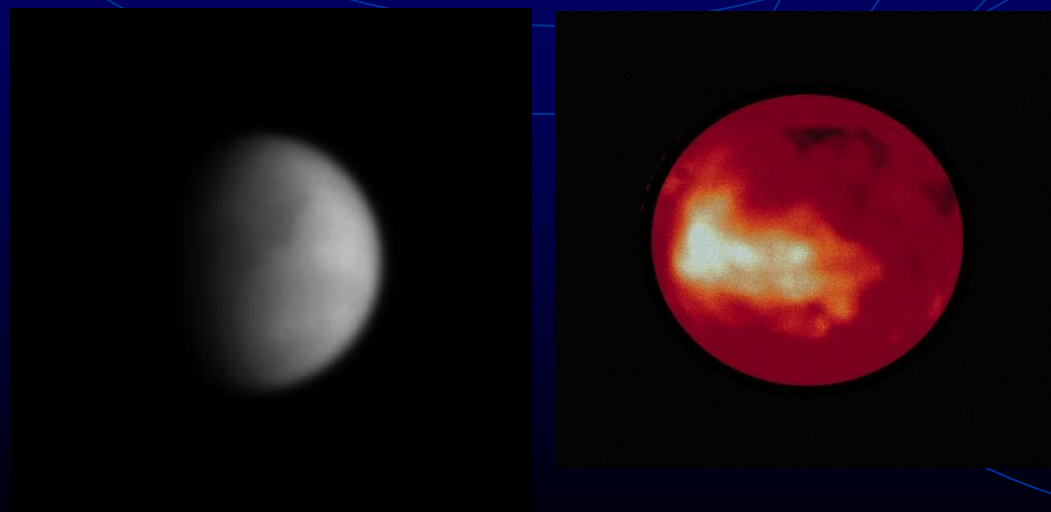
# 泰坦 (Titan) —— 土星的衛星

1655 年由 Christiaan Huygens 發現

擁有厚重的大氣層，充滿氮氣  
(90%)、甲烷，以及其他碳氫  
化合物



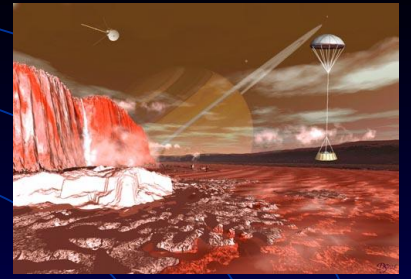
By Voyager 2



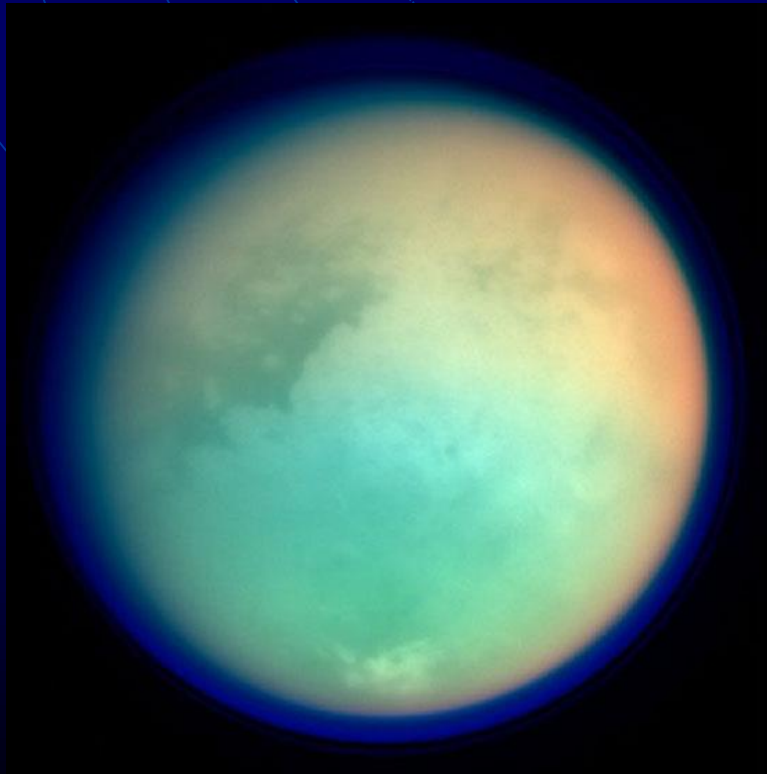
By HST in 1994

# Cassini-Huygens

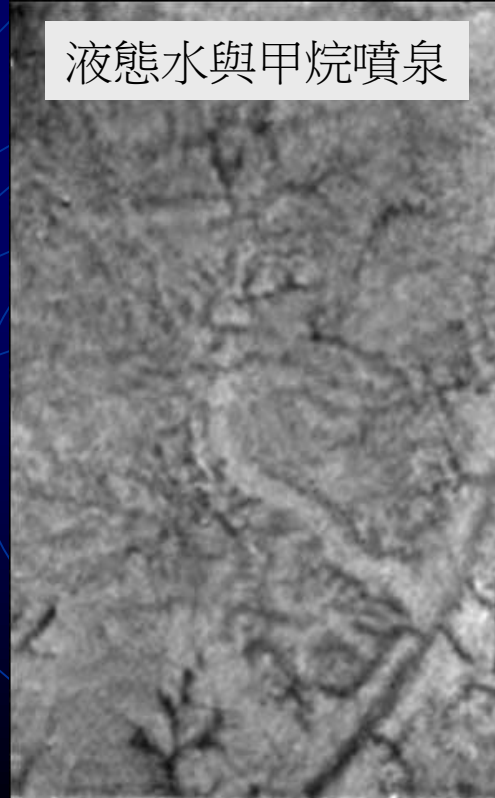
MISSION TO SATURN & TITAN



卡西尼任務：1997年發射，2005年抵達土星，釋放登陸艇到「泰坦」衛星



液態水與甲烷噴泉

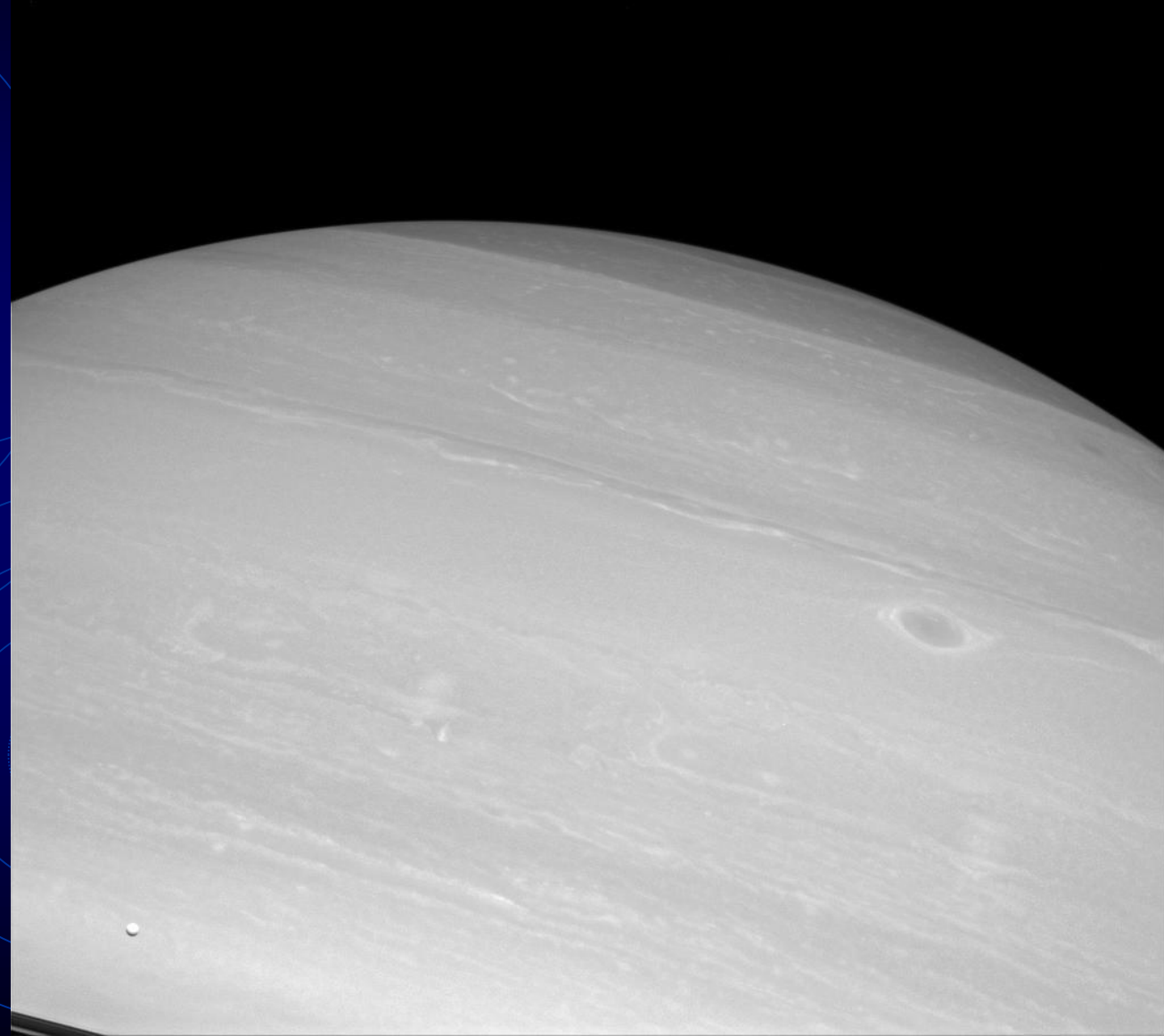


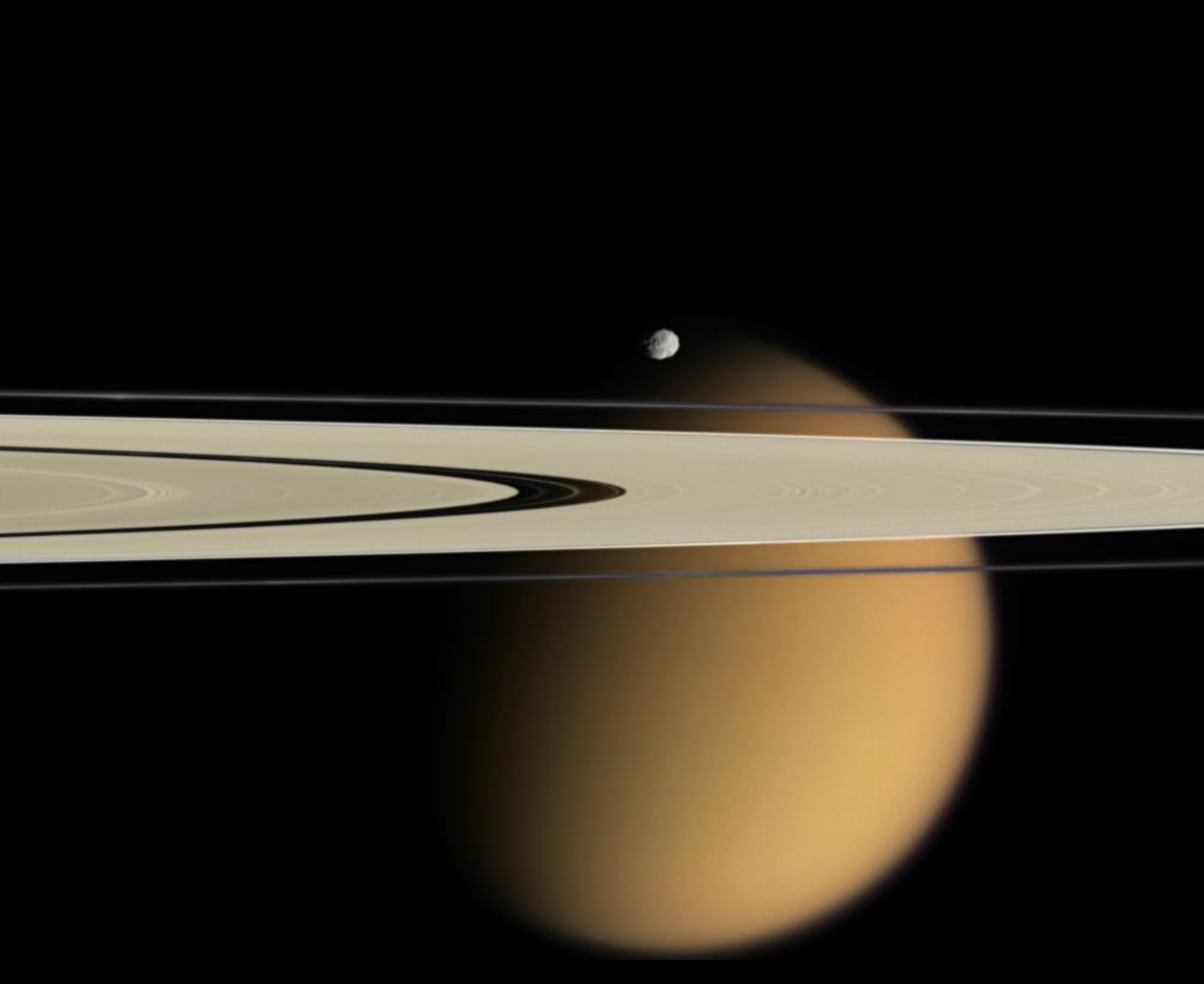
10幾cm的鵝卵石





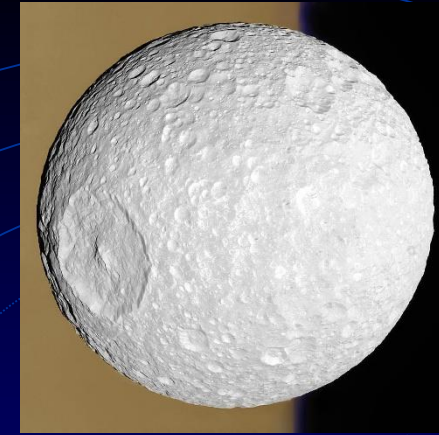
*Cassini* images of Saturn (clouds and rings)



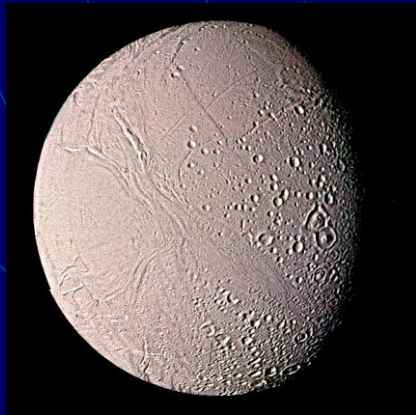


Saturn rings, Titan  
and the moon  
Epimetheus  
APOD 2014.11.02

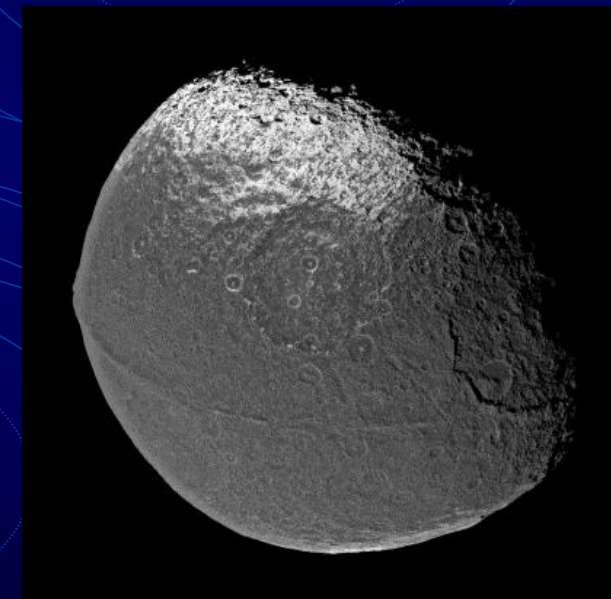
Mimas (D=392 km)  
Crater found by William  
Herschel, D=130 km



APOD  
2014.10.21



Enceladus  
(D=500 km)

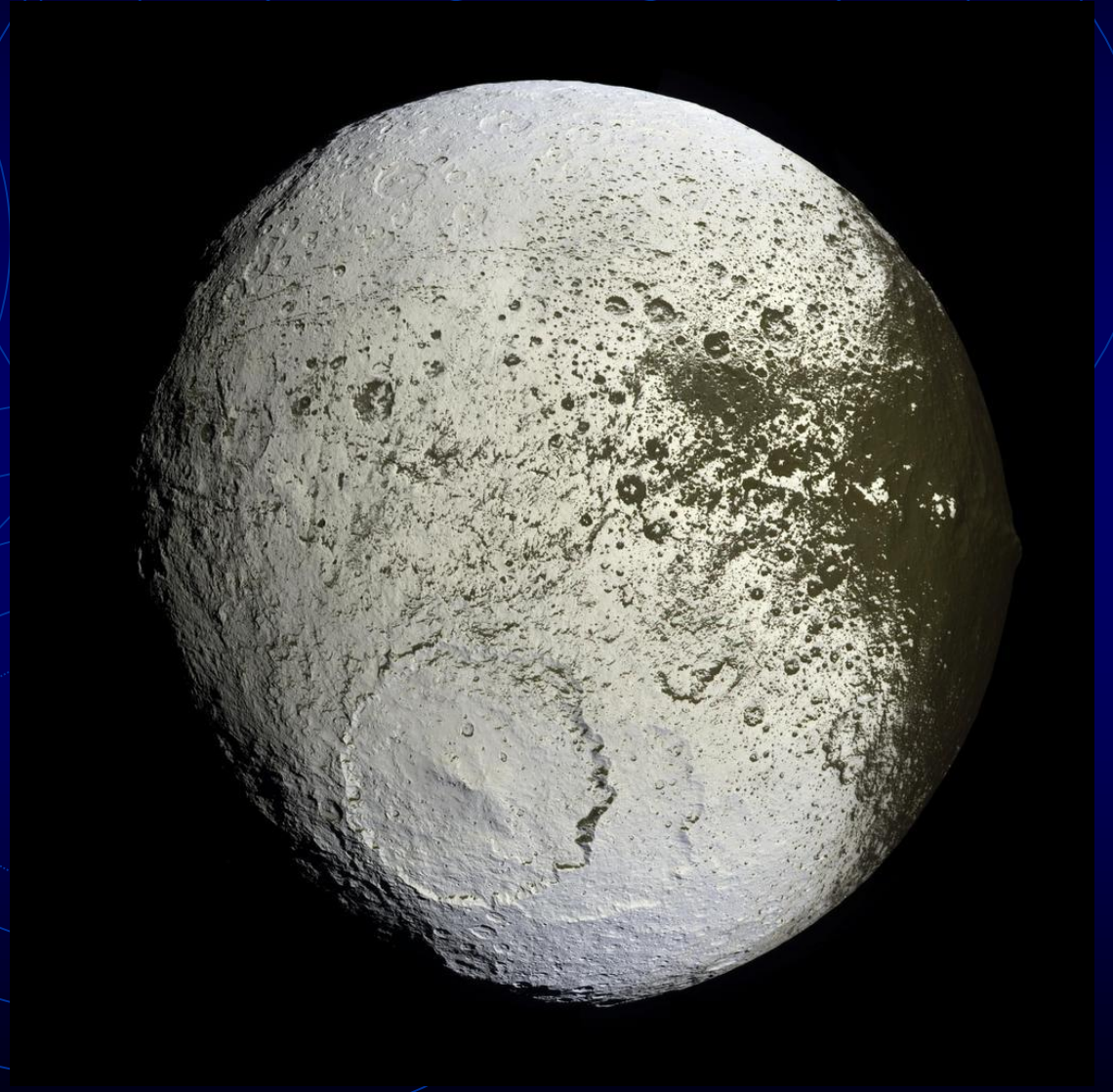


Iapetus  
(D=1460 km)

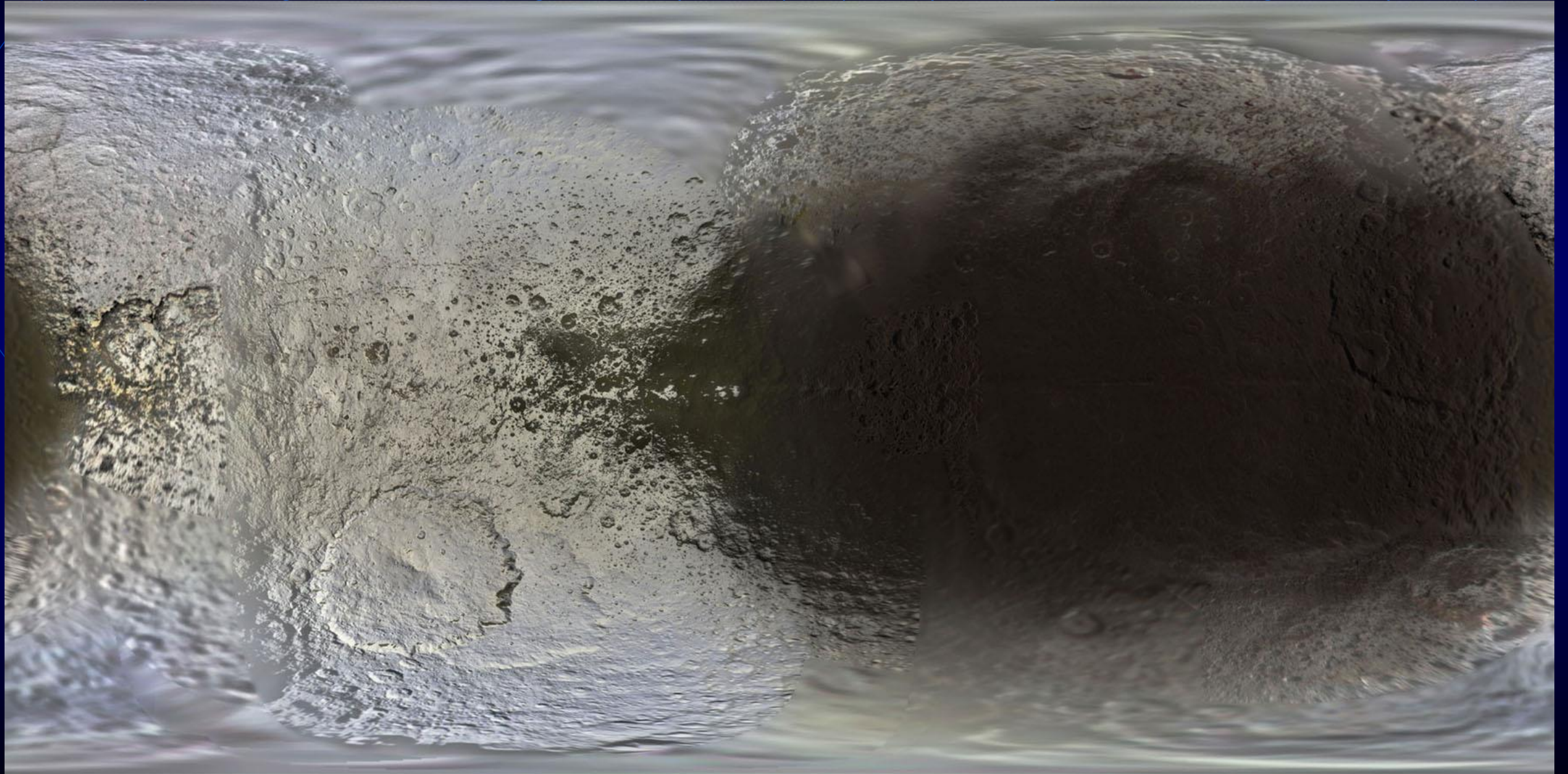


Dione  
(D=1120 km)

# Iapetus 特異的衛星 —— 只有黑白，沒有藍綠

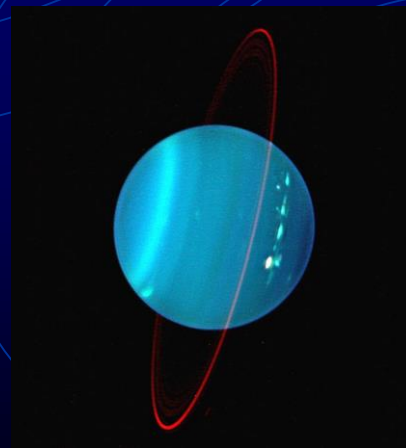


Iapetus by *Cassini*



# 天王星 (Uranus)

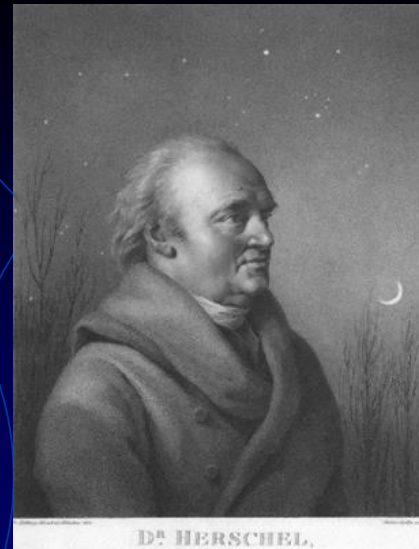
- 1781年由William Herschel以自製的望遠鏡（6.2吋）發現
- 自轉軸在公轉面上。原因未知，或許因為行星成形後經歷大撞擊造成
- 有環
- 看起來無彩色雲帶



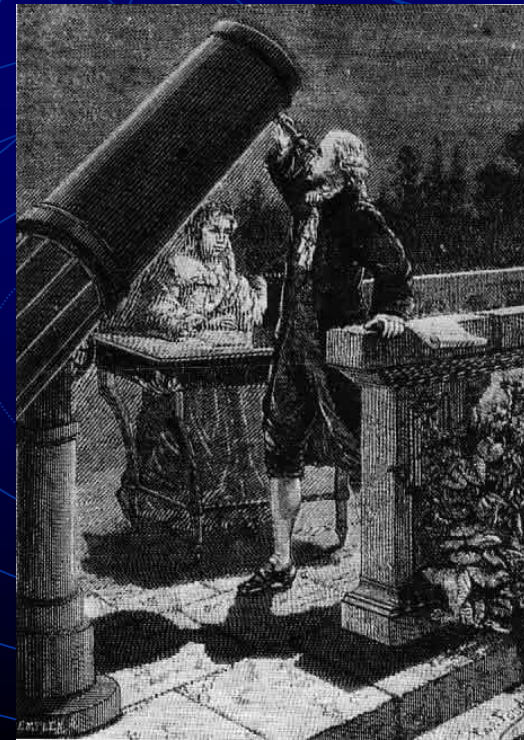
Uranus

© Copyright Calvin J. Hamilton

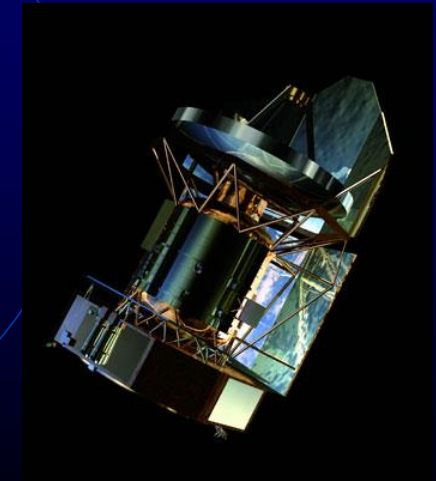
- William Herschel Musician, optician and astronomer; found Uranus
- Caroline Herschel, sister of William, became one of the pioneering woman astronomers in history; found 2500 nebulae and 8 comets before she died at an age of 97



<http://www.agnesscott.edu/Lriddle/women/herschel.htm>



Herschel Space Telescope



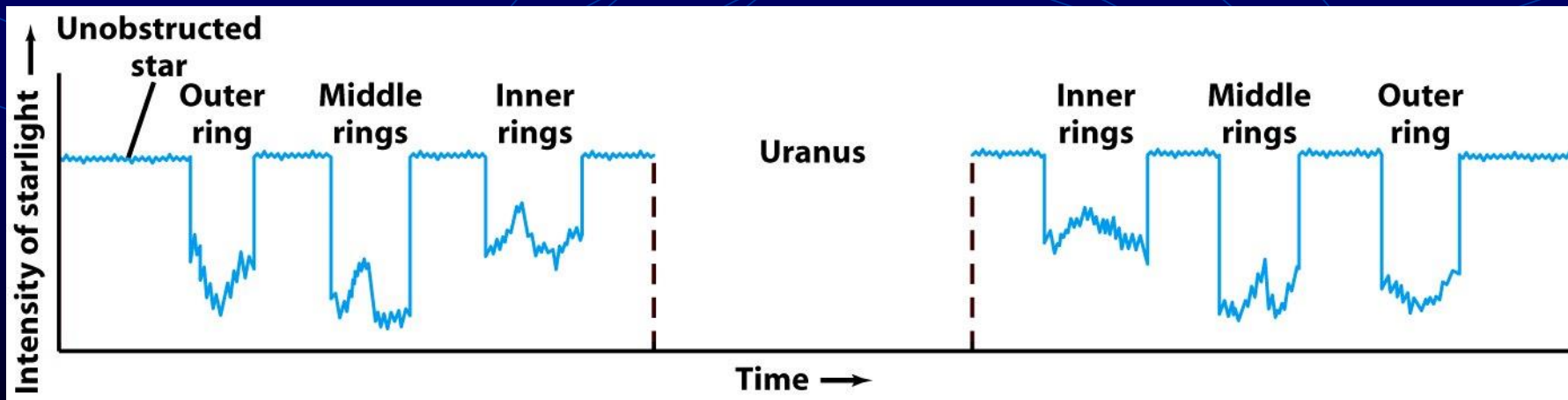
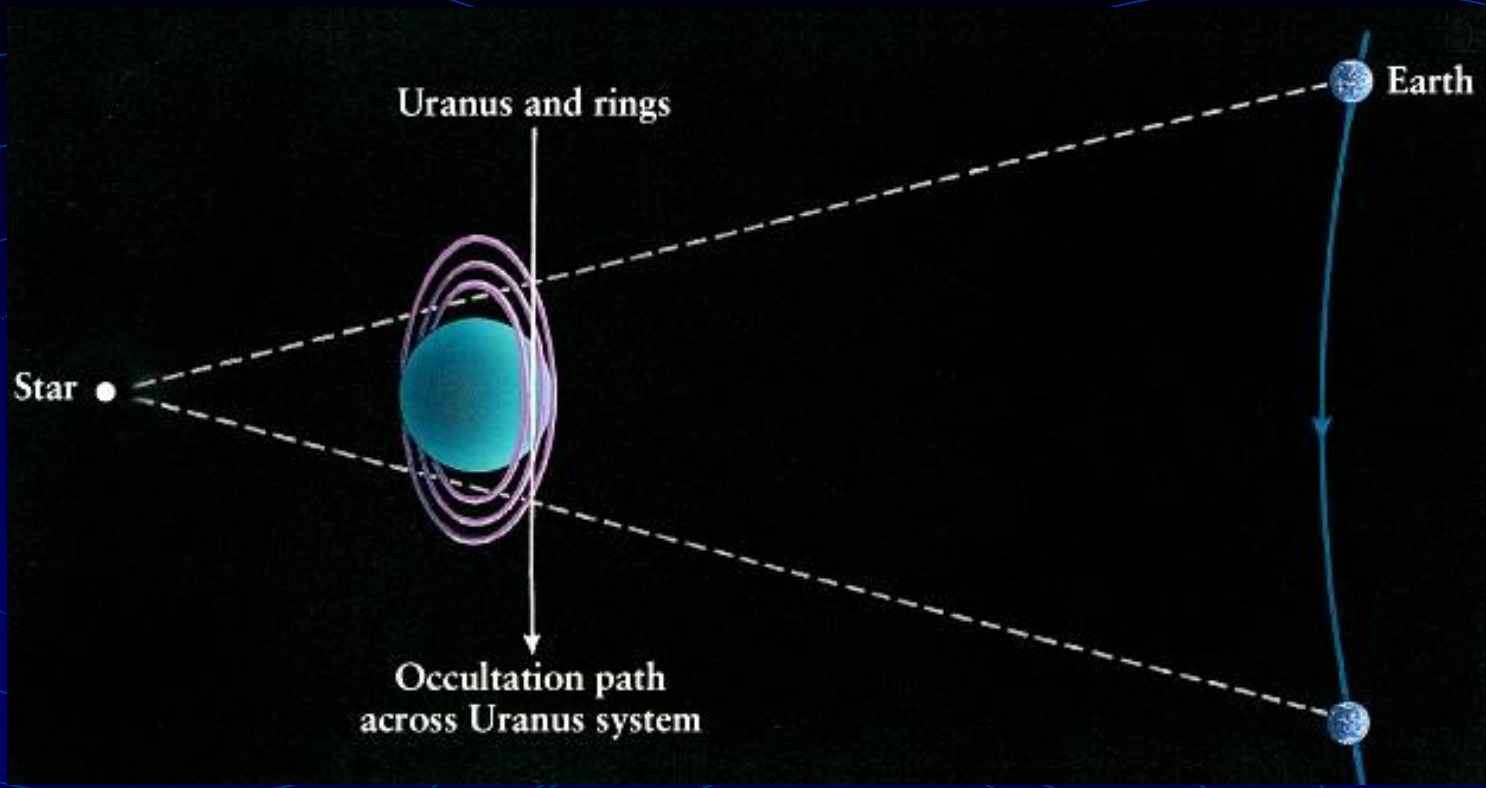
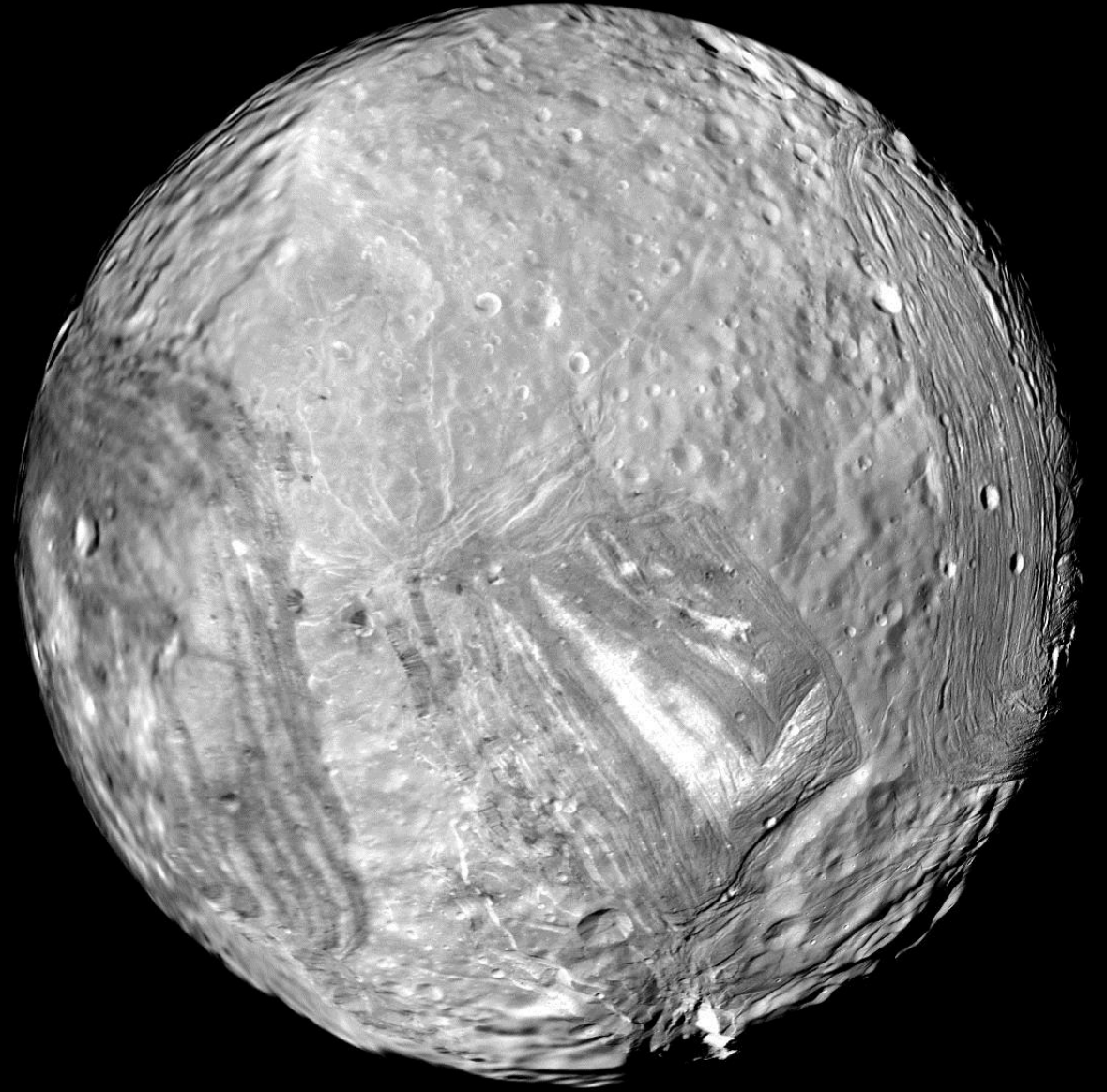


Figure 8-32b  
*Discovering the Universe, Seventh Edition*  
 © 2006 W.H. Freeman and Company

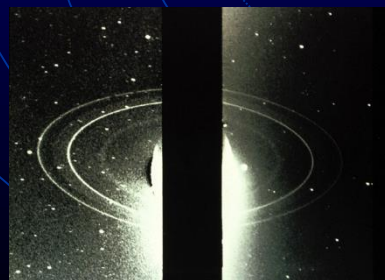
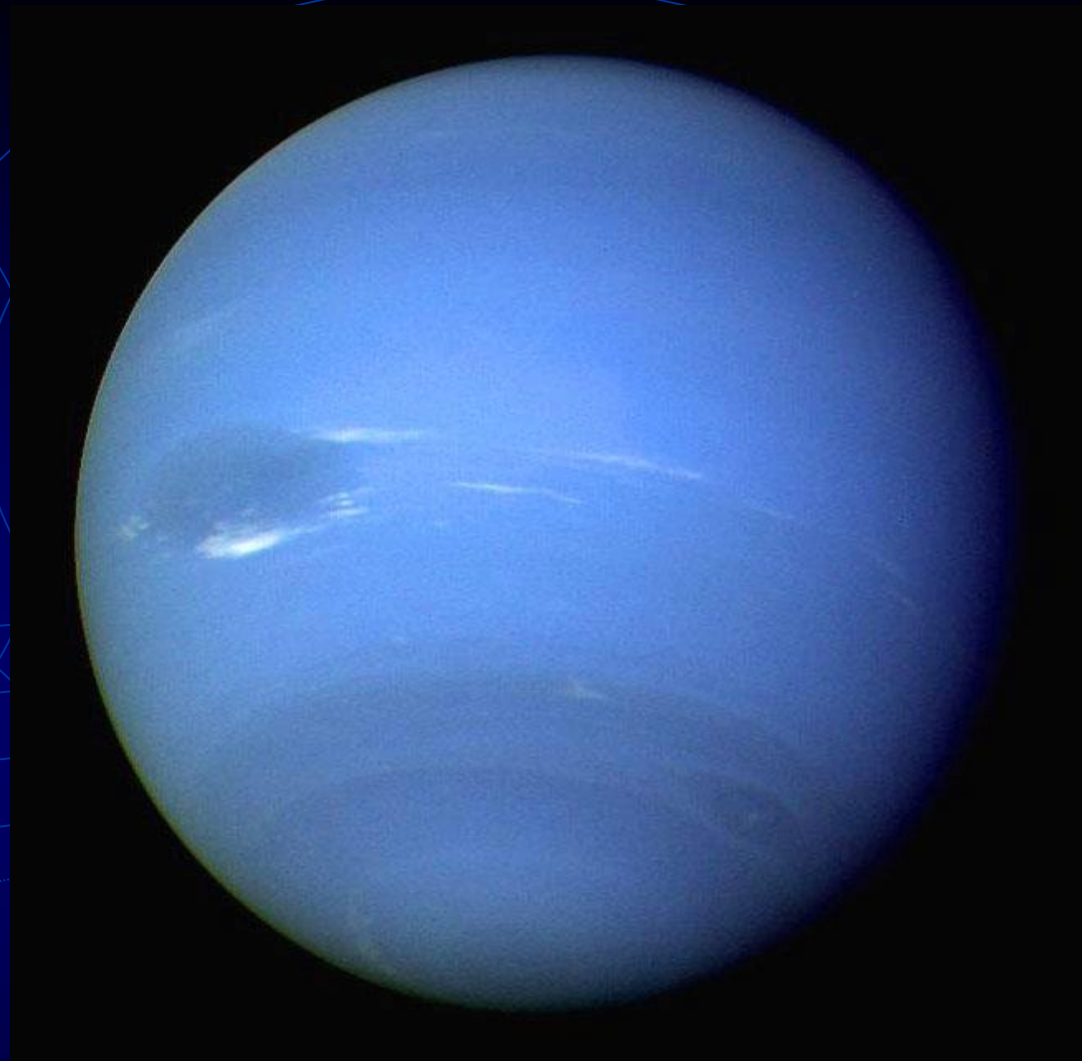


Miranda --- Uranus's moon



# 海王星 (Neptune)

- 1846年法國 Leverrier 由天王星不規則的軌道推算出海王星位置，由 Galle 尋獲
- 之前於1845年由英國 Adams 已有類似預測，但是...
- 天王星的發現為牛頓力學的一大勝利
- 大暗斑（們）
- 有環（石塊而非冰塊）

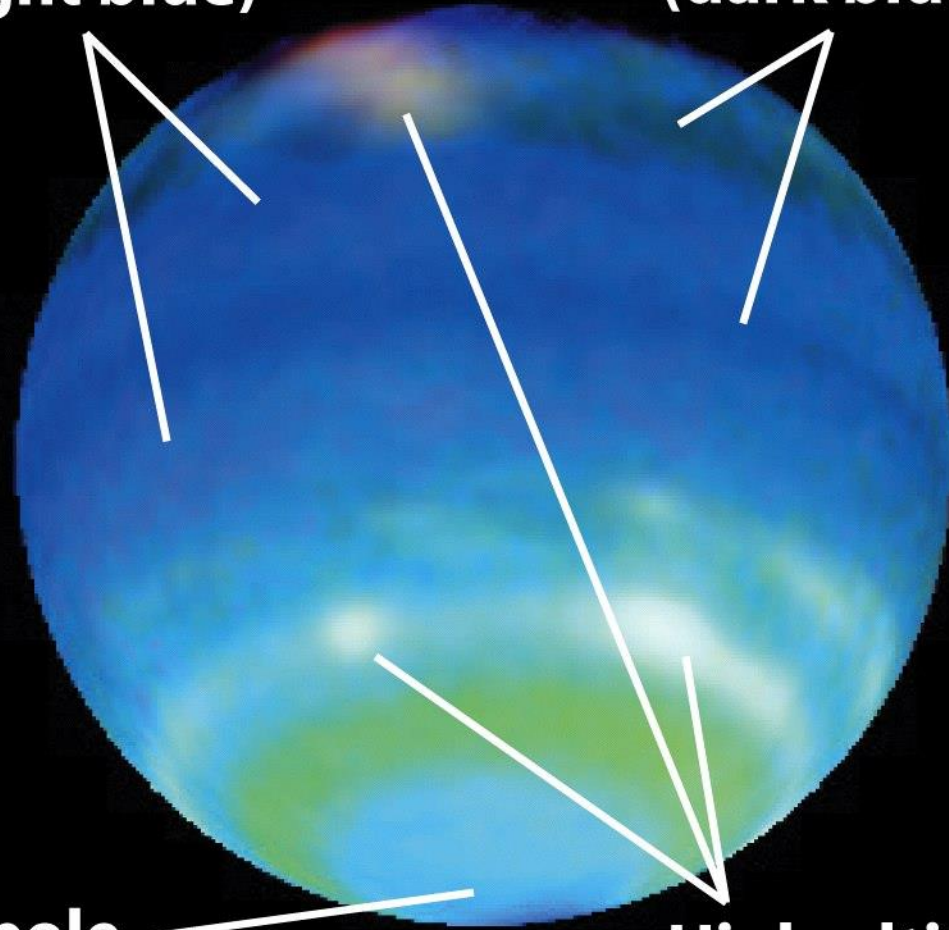


**Zones  
(light blue)**

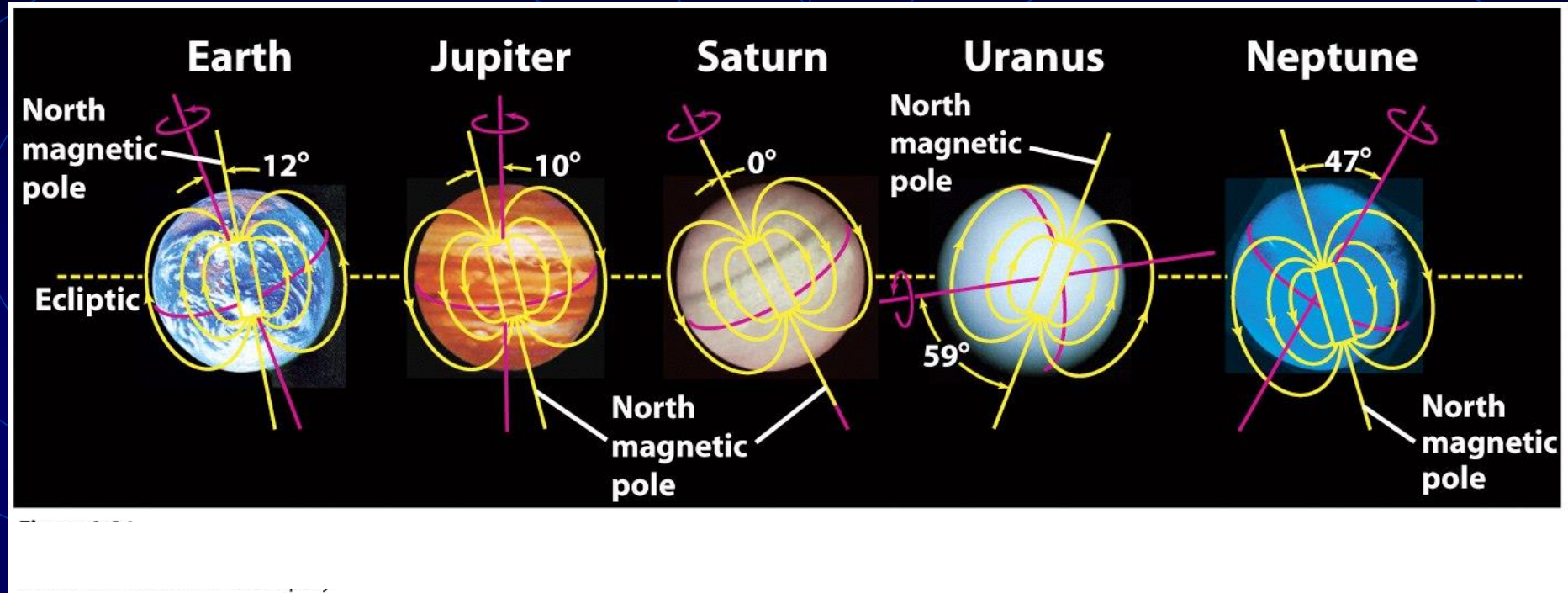
**Belts  
(dark blue)**

**South pole**

**High-altitude  
clouds**



# 行星的磁場



內部液態、帶電物質流動 → dynamo



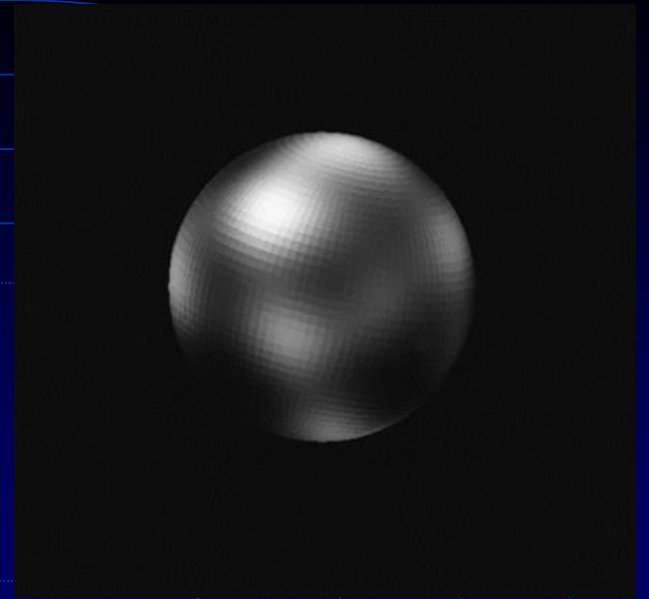
- 行星磁場 → 內部結構
- 很多太空船攜帶 magnetometers
- 水星有微弱磁場（～地球1%）→ 內部應該有小型液態核心
- 金星沒有磁場（因為自轉 243 天太慢？）
- 地球磁場（內部帶電物質流動）
- 木星具有強大磁場（～地球14倍），內部為液態金屬氫 (liquid metallic hydrogen)
- 土星也是一樣
- 天王星、海王星太小，內部沒有液態金屬氫 ...  
（游離的氨水？）

# Saturn, Rings and Aurora

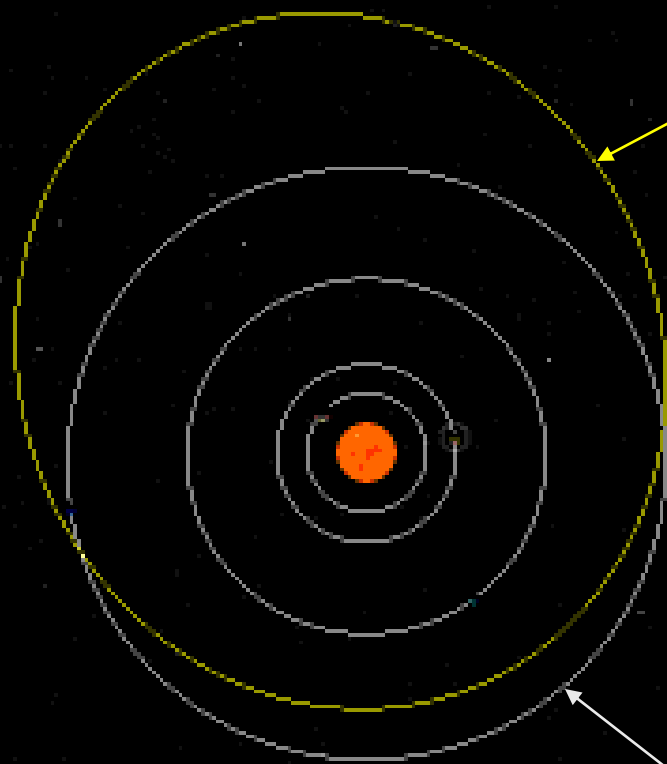


# 冥王星 (Pluto)

- 1930年Tombaugh 繼續 P. Lowell 未完志業，在 Lowell 天文台以海王軌道擾動尋找未知行星。乃幸運發現，因為 Lowell 預測未知行星應有7倍地球質量，但 Pluto 實際上只有0.002倍！根本不足以造成擾動
  - 離心率大 → 橢圓軌道，有時（例如 1979 至 1999 年間）比海王星更接近太陽
  - 公轉面與太陽系平面成17度
  - 稀薄大氣，表面（！）為氮化物與甲烷冰層
- 行星中的異數

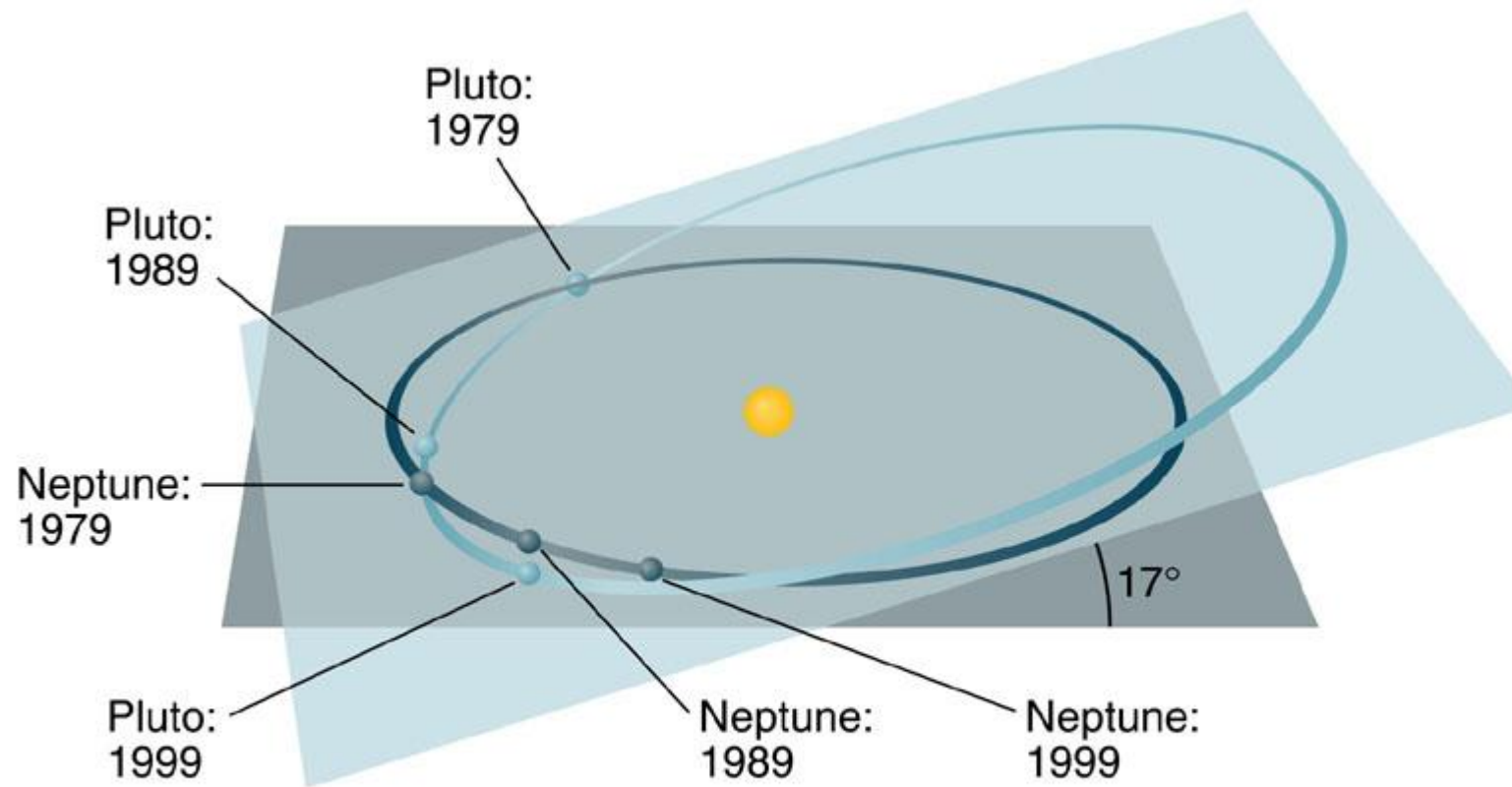


冥王星軌道



海王星軌道

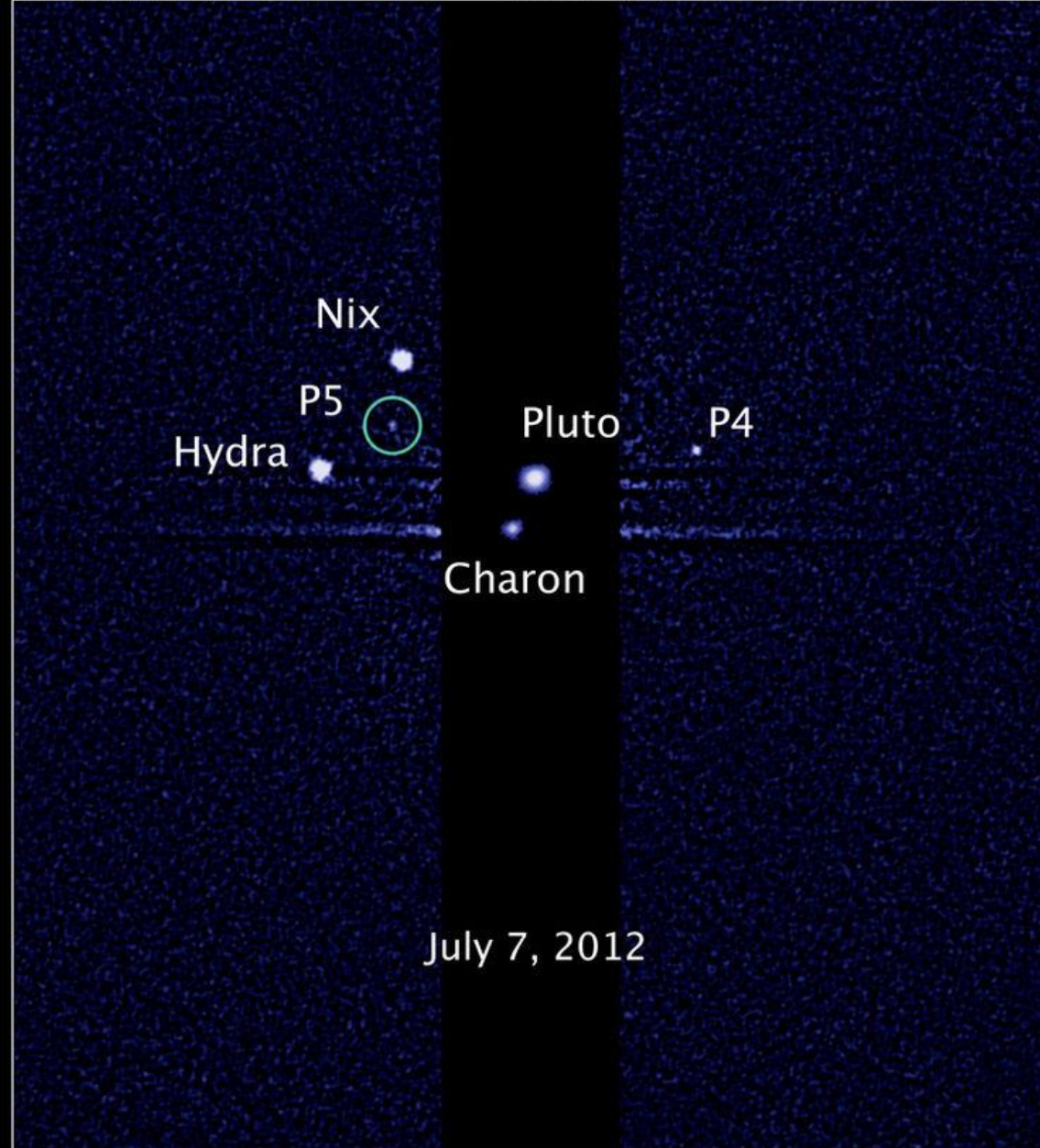




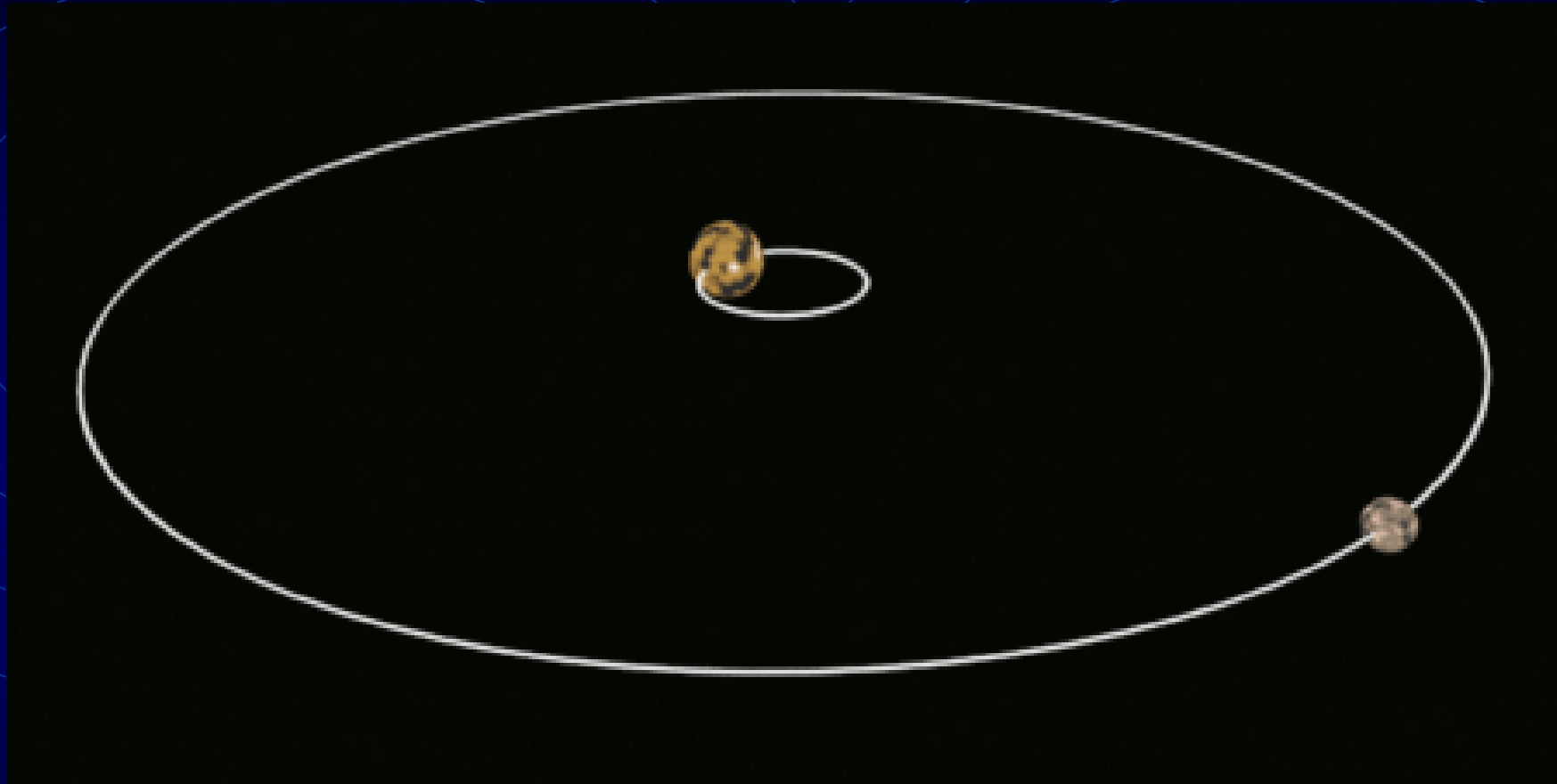
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Pluto System

Hubble Space Telescope • WFC3/UVIS



July 7, 2012



The Pluto-Charon system ... Note Pluto orbits outside itself .

[http://en.wikipedia.org/wiki/Charon\\_\(moon\)](http://en.wikipedia.org/wiki/Charon_(moon))

# 小行星 (asteroid; minor planets)



**Earth**

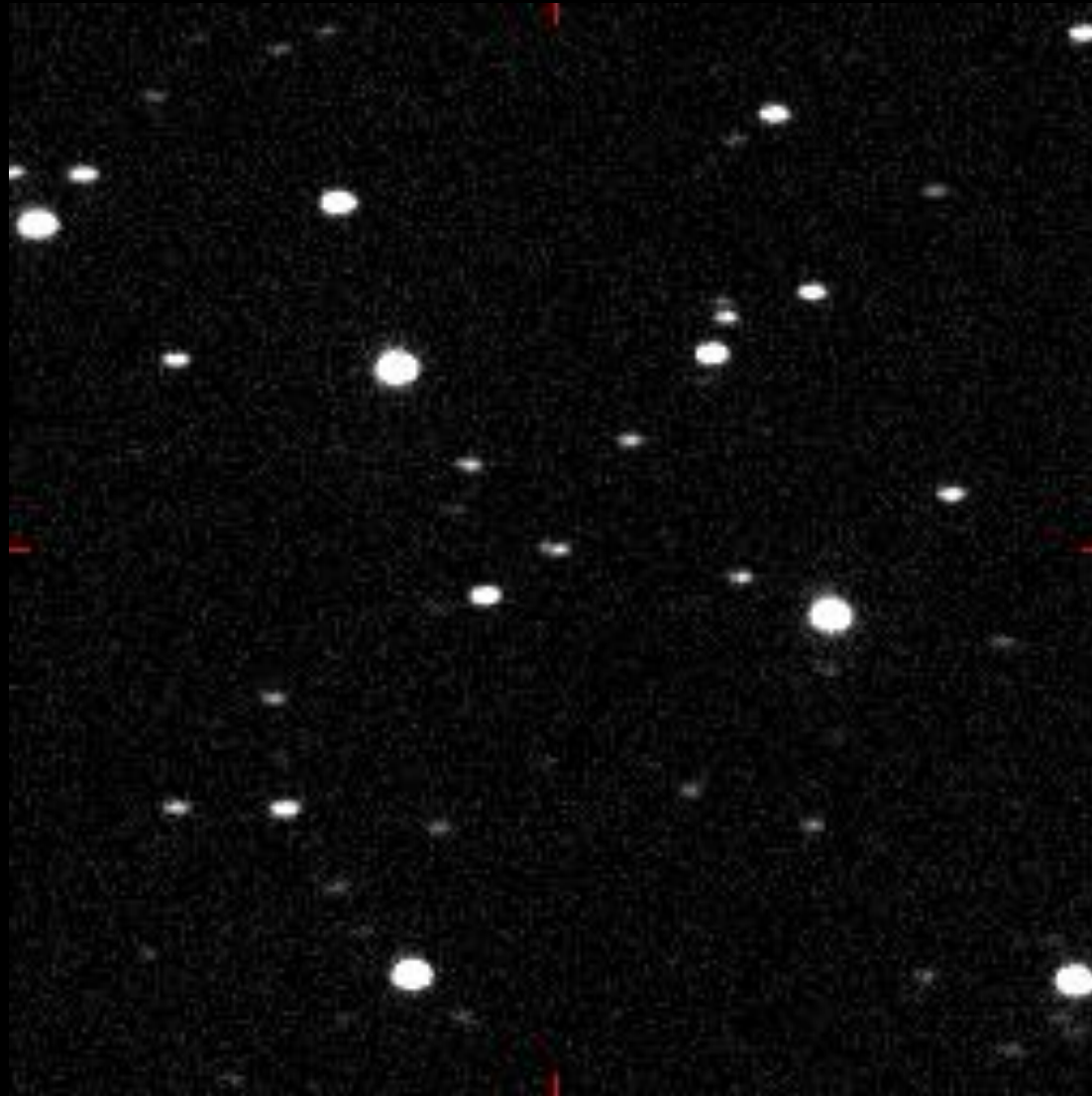


**Moon**



**Ceres**

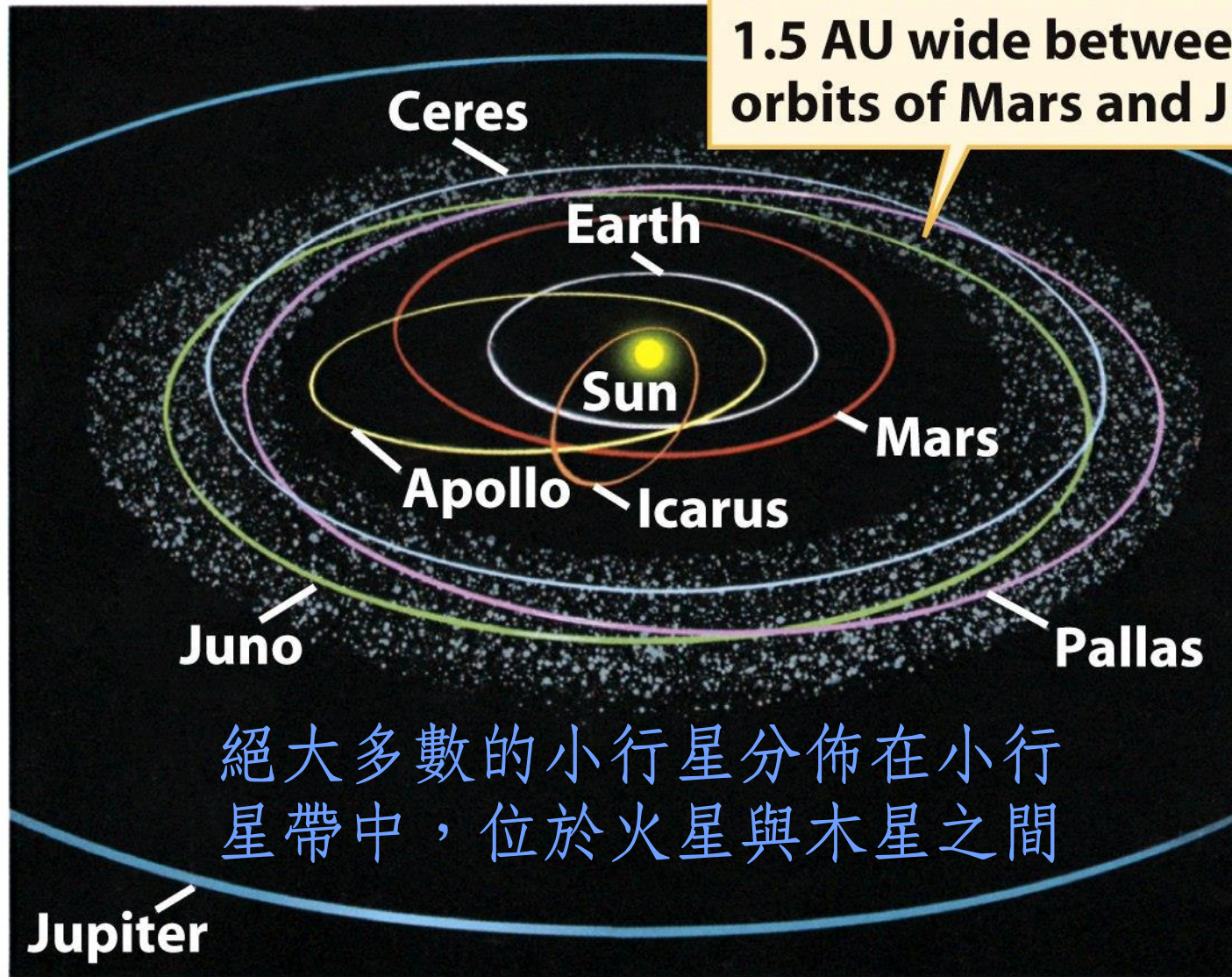
穀神星是最大  
的小行星



2004 FH is the center dot being followed by the sequence; the object that flashes by during the clip is an artificial satellite.

<http://en.wikipedia.org/wiki/Asteroid>

Most asteroids orbit the Sun in a belt about 1.5 AU wide between the orbits of Mars and Jupiter.



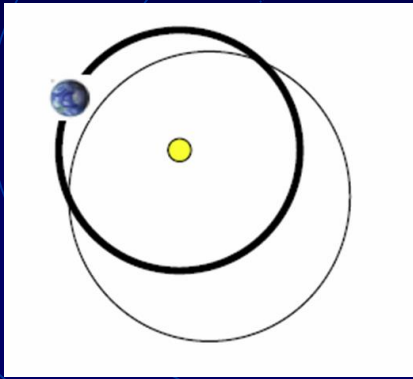
Apollo and Icarus asteroids have Earth-crossing orbits.

絕大多數的小行星分佈在小行星帶中，位於火星與木星之間

Jupiter

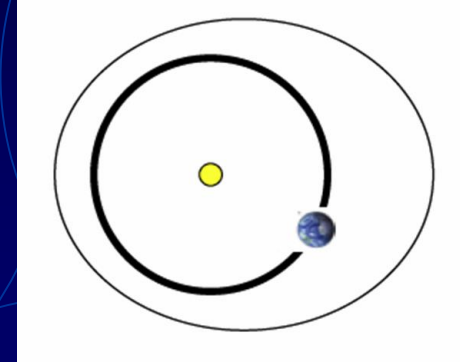
# 近地天體 (near-Earth objects, NEOs) 的種類

NEOs = near-Earth Asteroids (NEAs)



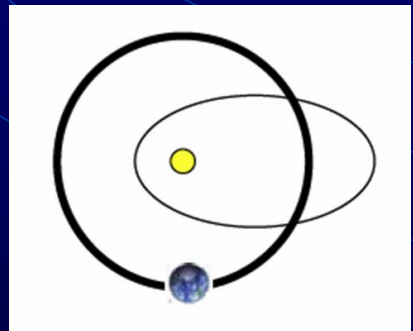
## Apollo 小行星

半長軸  $> 1.0$  AU  
近地點  $< 1.02$  AU  
與地球軌道交錯  
占已知 62%



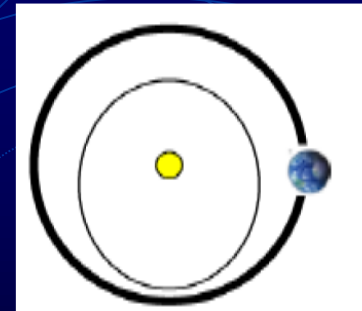
## Amor 小行星

近地點  $1.02 \sim 1.3$  AU  
32%



## Aten 小行星

半長軸  $< 1.0$  AU  
近地點  $< 1.0167$  AU  
與地球軌道交錯  
6%



## 地內小行星

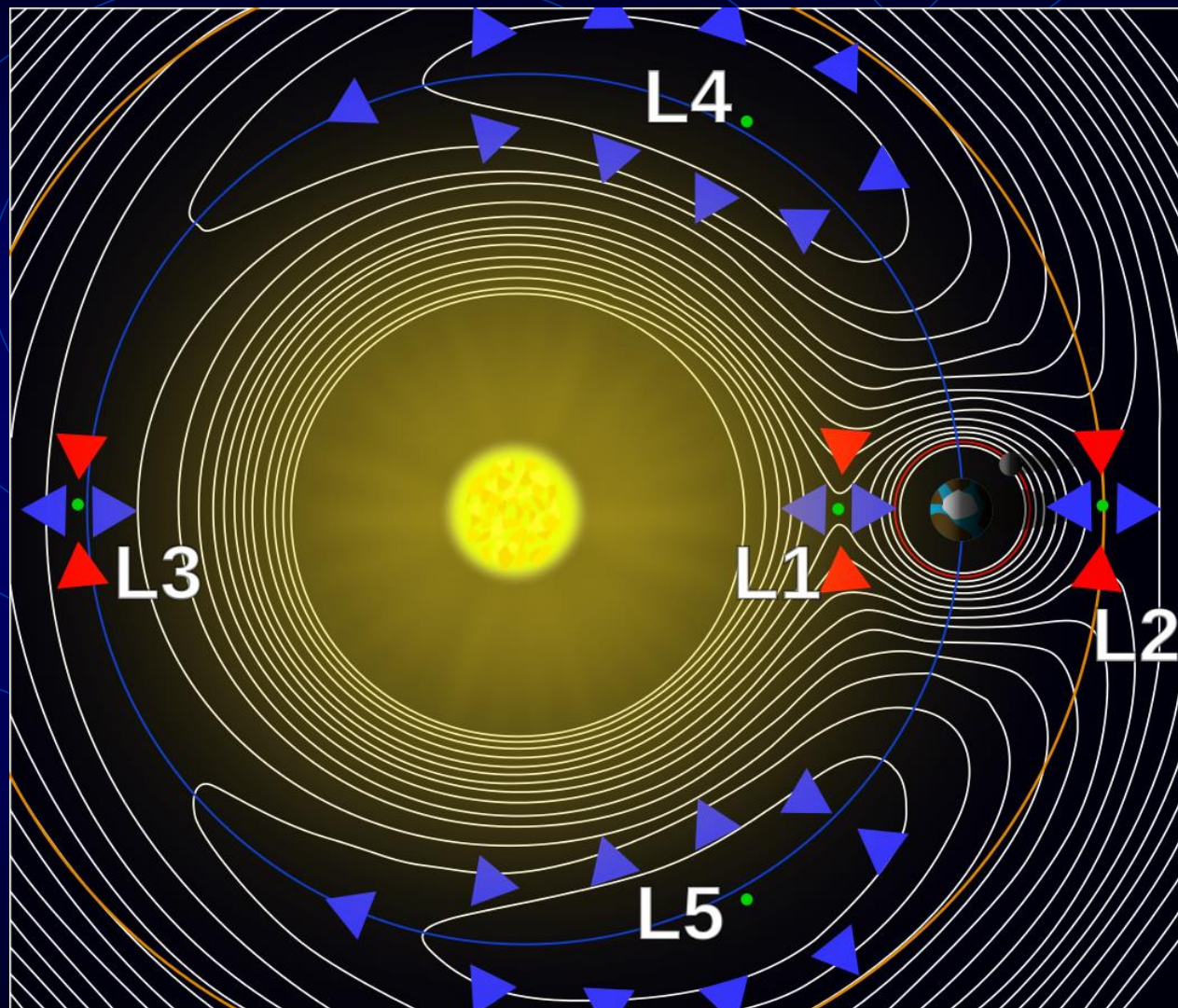
近地點  $< 0.983$  AU  
永遠在地球軌道之內  
Inner Earth (Apohele)  
已知13顆 (2014.02)

和地球最近距離  $< 0.05$  AU 且體積夠大

→ 潛在危險天體 (potentially hazardous objects, PHOs)

# Lagrange Points

受到兩大天體的引力，  
仍能保持穩定軌道



位於L2的望遠鏡：  
*Herschel, Planck,*  
*Eddington,*  
*GAIA, (JWST),*  
*(Darwin)*

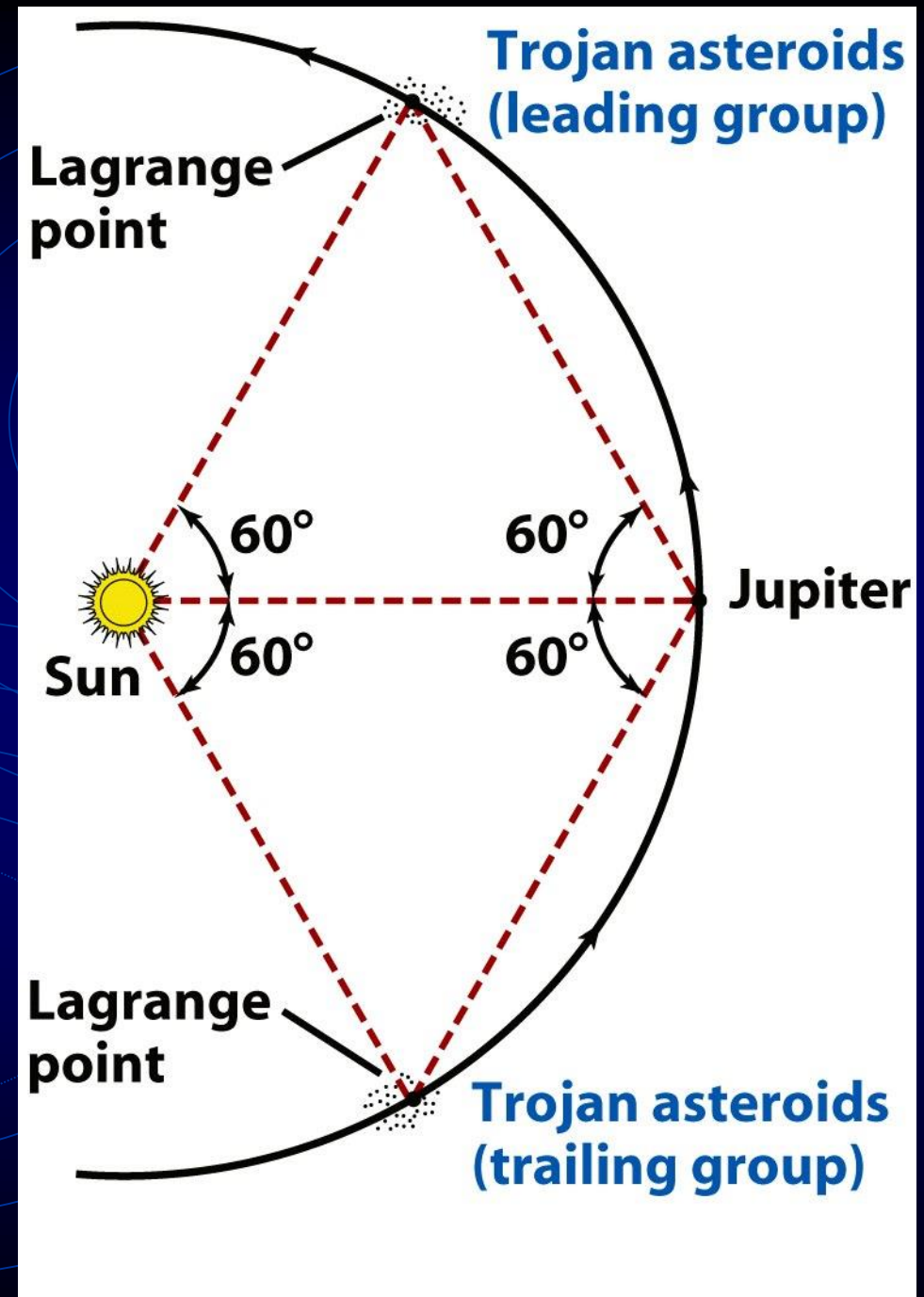
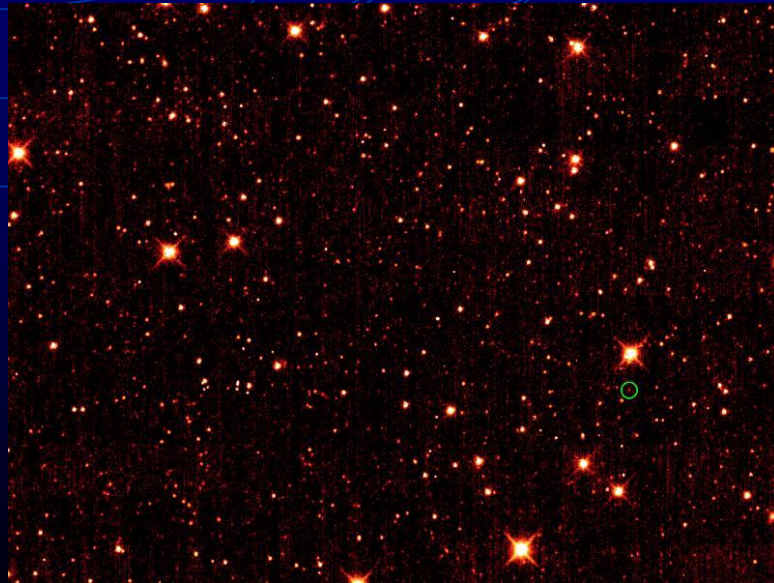


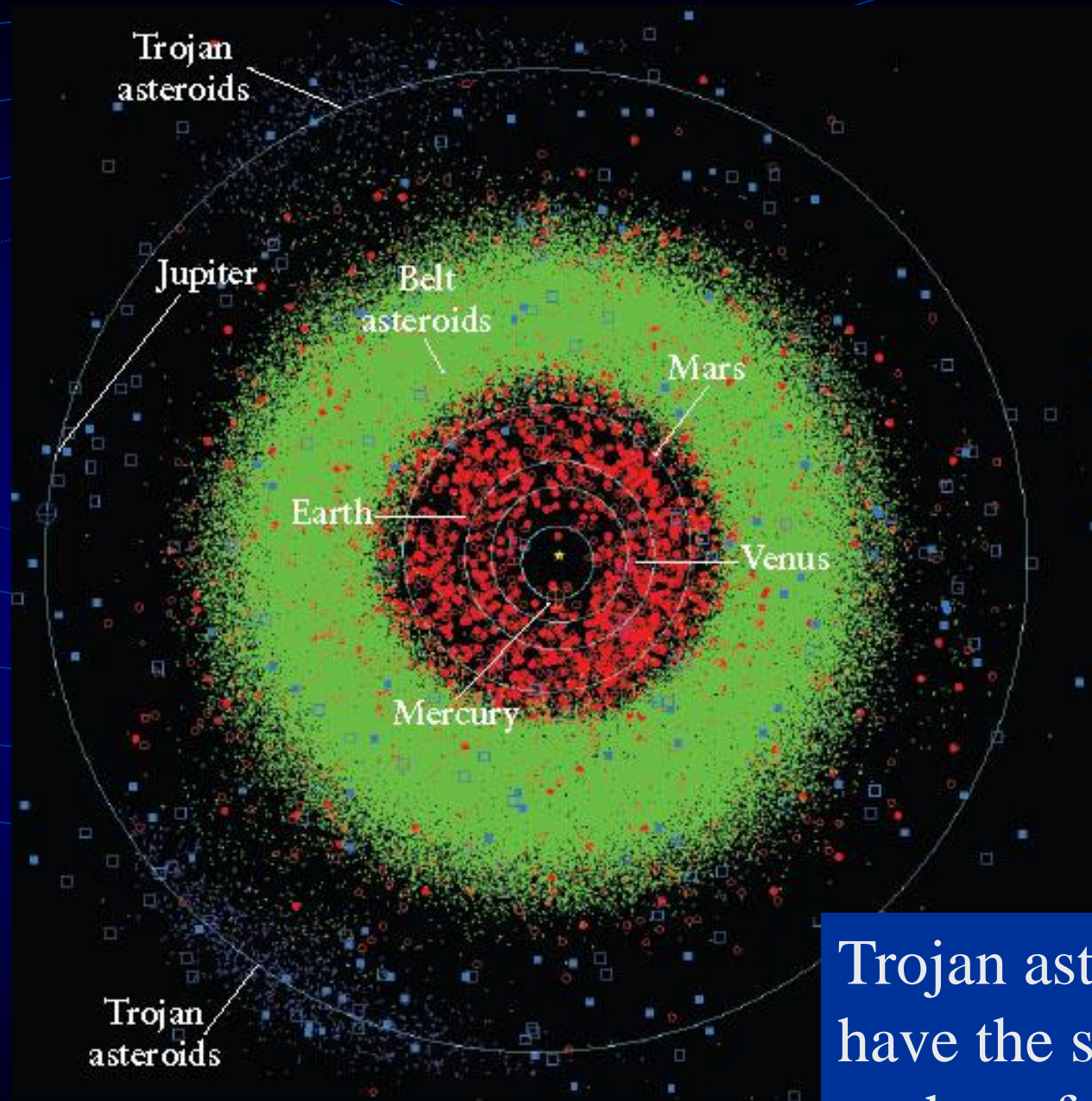
Stable Lagrange points (leading and trailing)

Some ~1700 Jupiter Trojans have been catalogued.

Neptune is known to have at least one Trojan asteroid.

Earth has one trojan asteroid known so far, 2010 TK<sub>7</sub>, at L4 (leading), D=300 m





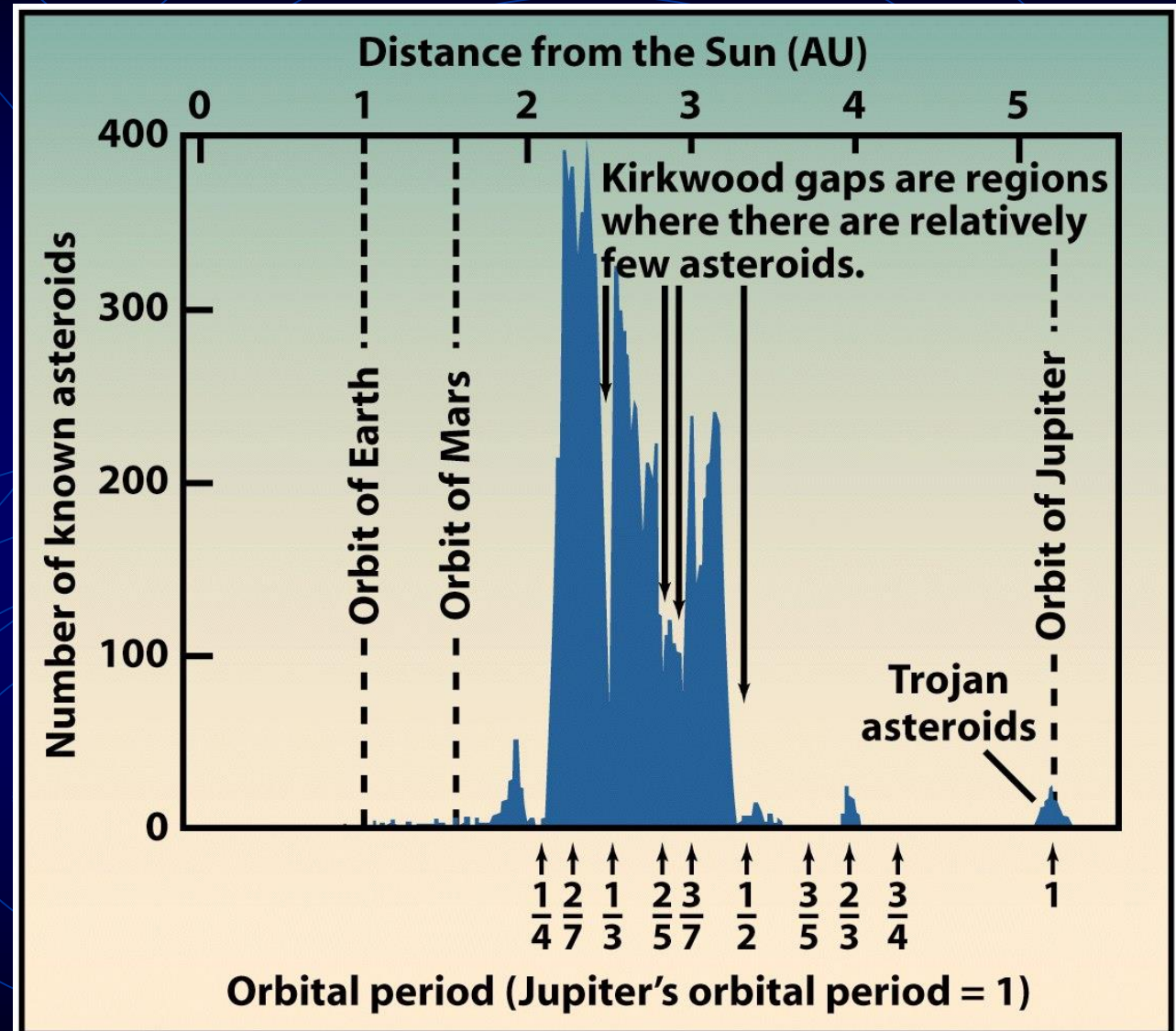
A map of all asteroids within Jupiter's orbit

Trojan asteroids have the same orbit as that of Jupiter.

**Kirkwood gap** --- simple fractions of Jupiter's orbital periods

→ harmonics/resonance

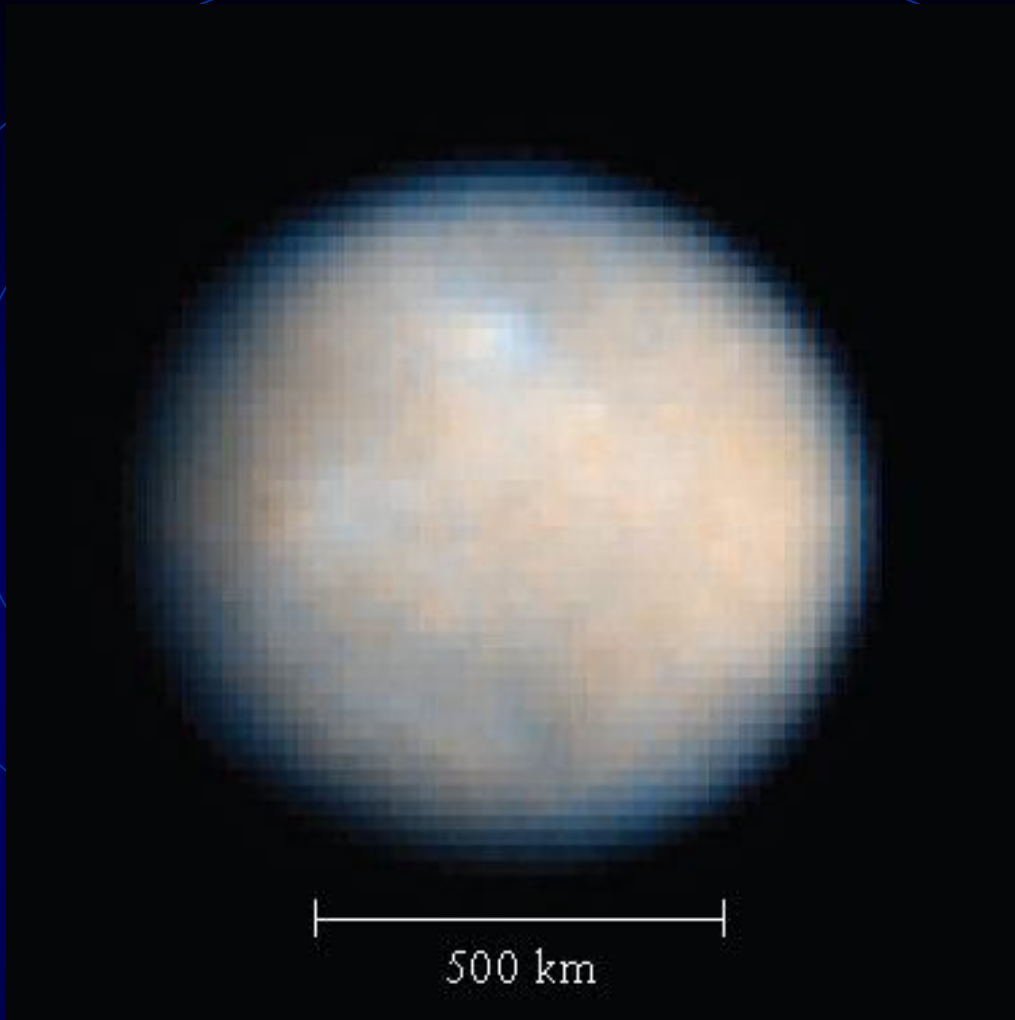
同樣的共振現象亦發生於  
土星光環中，由 Mimas  
所造成的 Cassini division



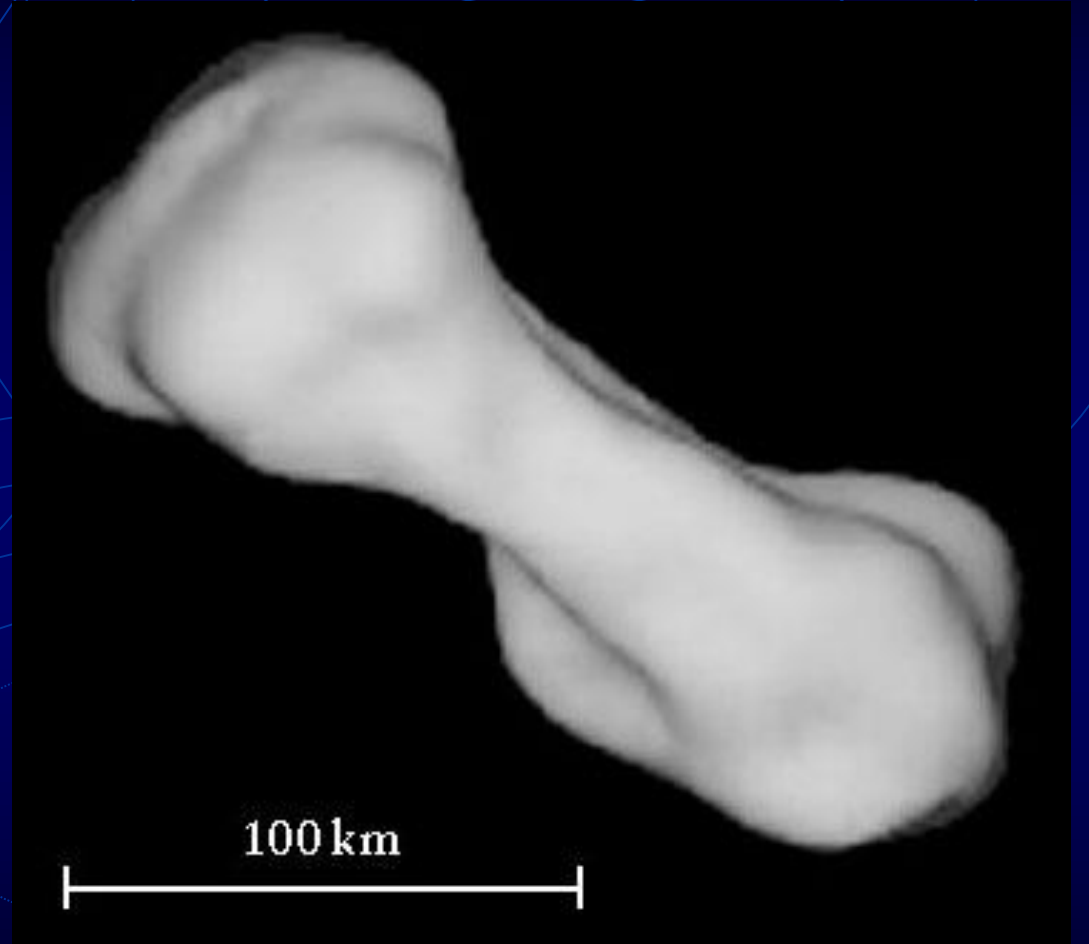


小行星 Ida 及其衛星 Dactyl  
Ida 的長度約 55 km





An HST view of a large  
(974.6 km) asteroid, 1 Ceres



A radar view of a medium-sized  
asteroid, 216 Kleopatra.

**Kuiper Belt**

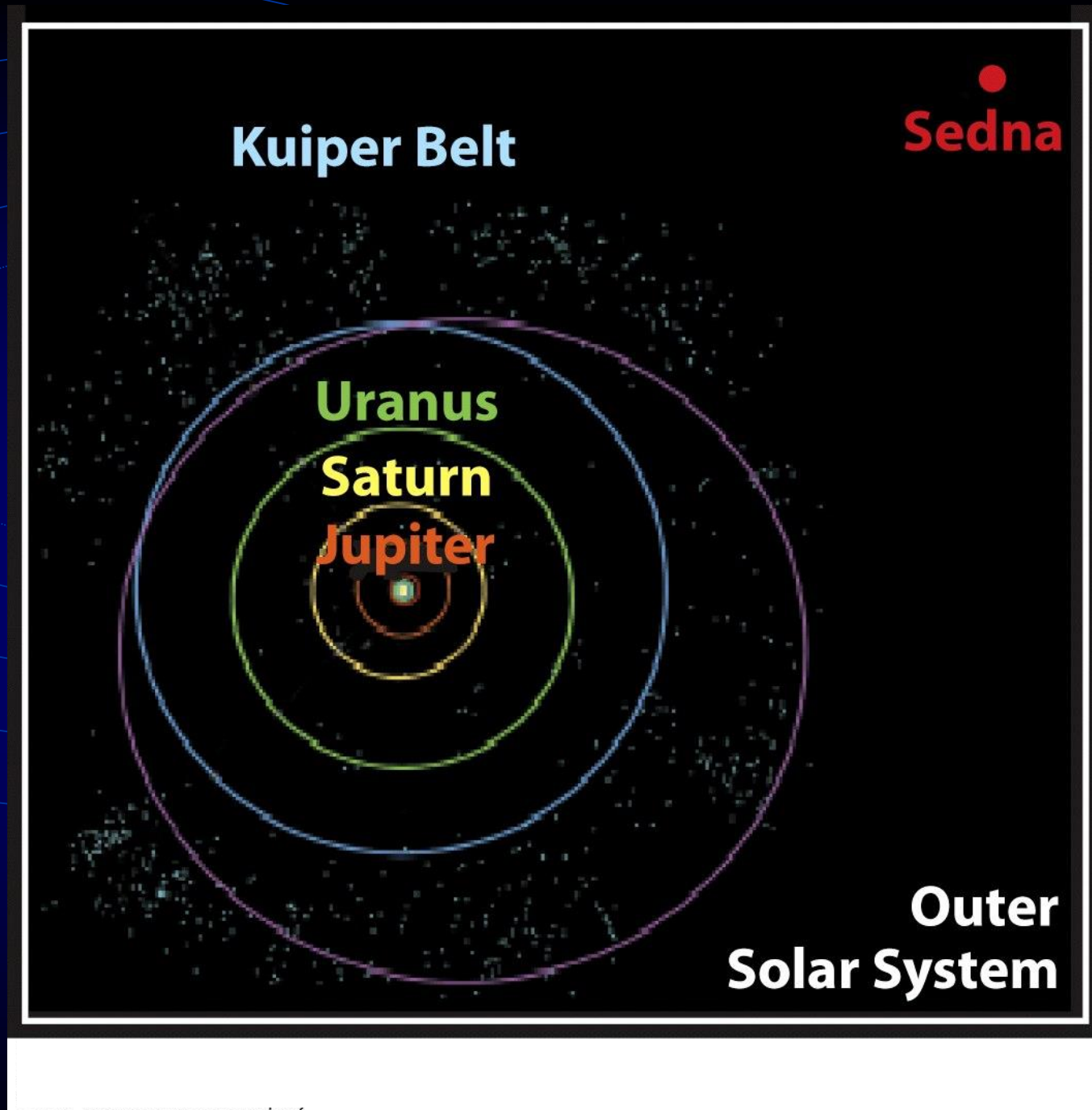
**Sedna**

**Uranus**

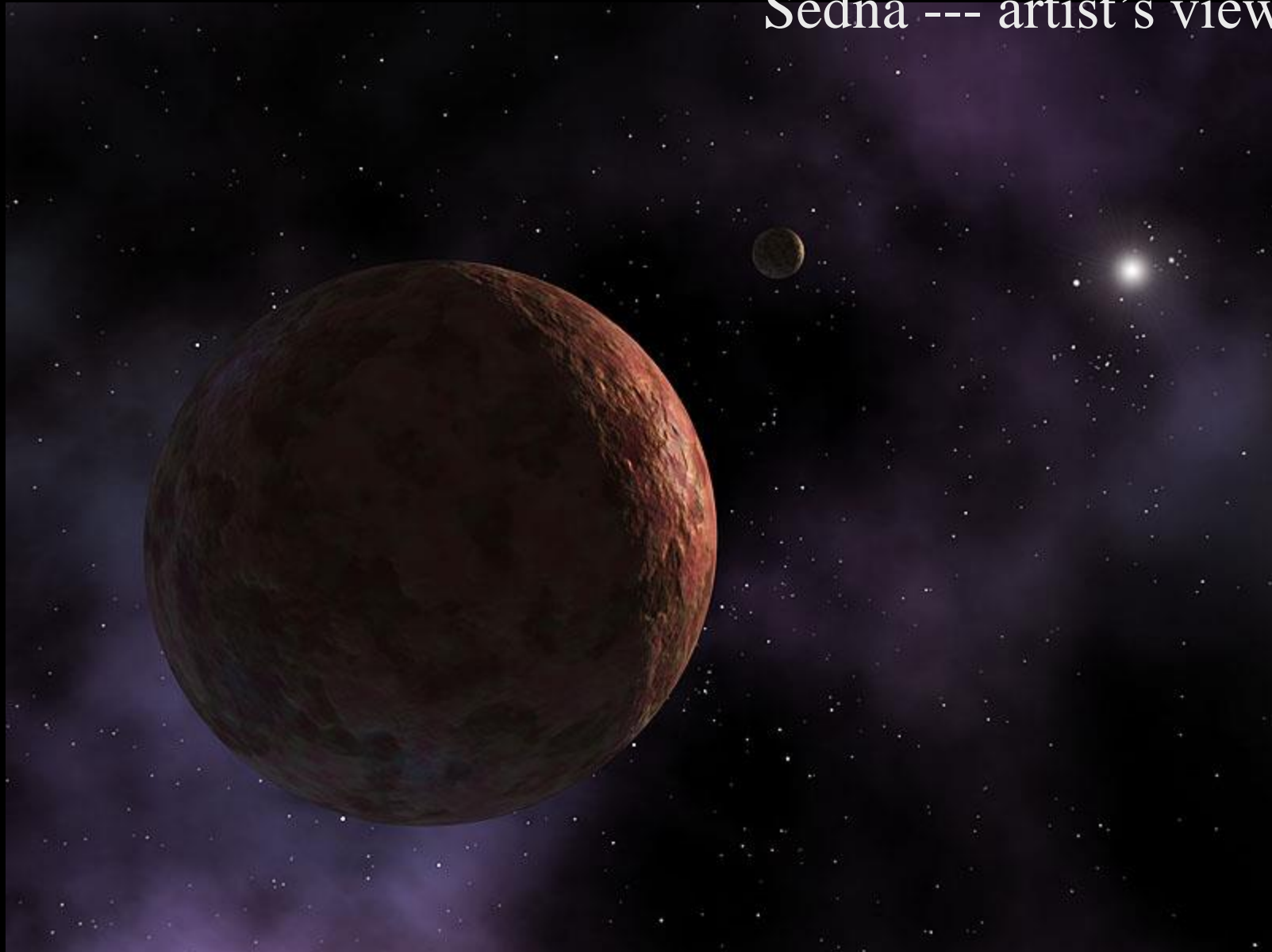
**Saturn**

**Jupiter**

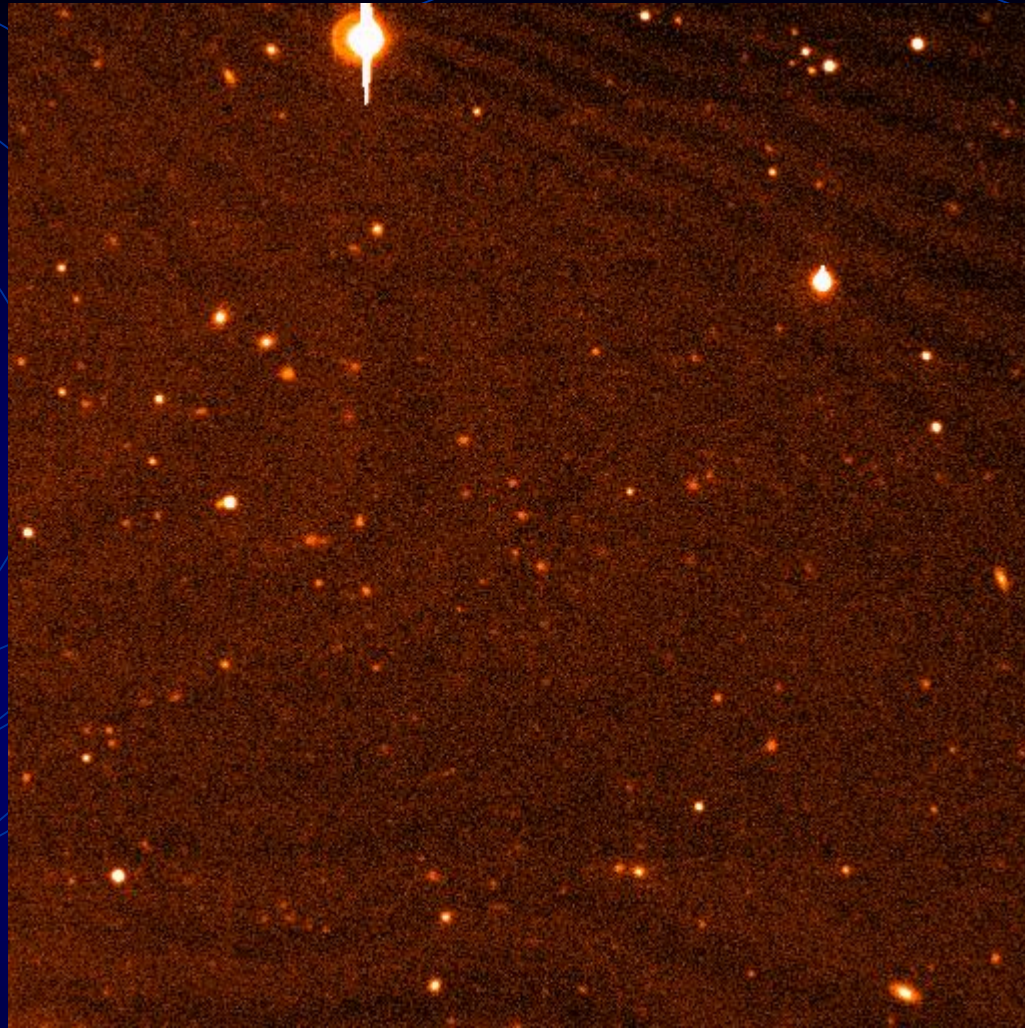
**Outer  
Solar System**



Sedna --- artist's view



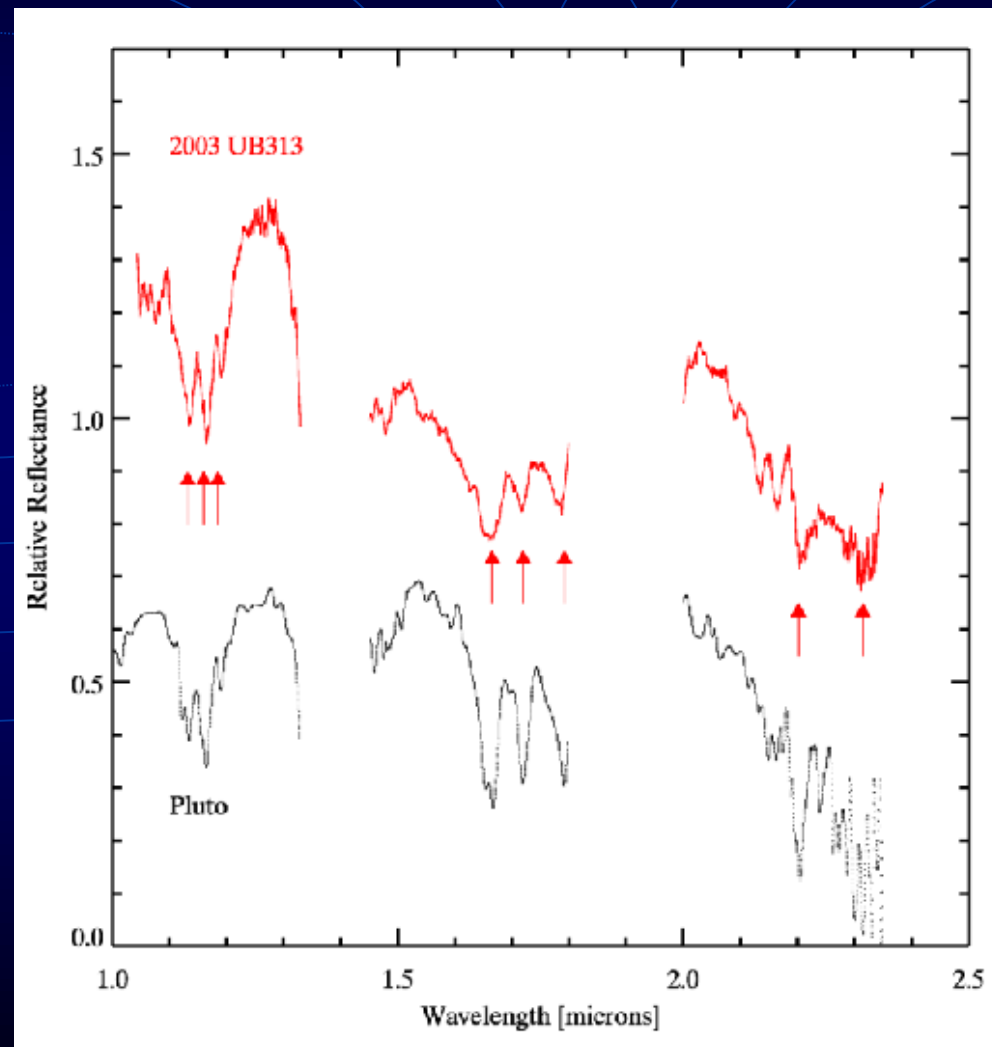
Discovery images of 2003  
UB<sub>313</sub> ( 閼神星 );  
tracked since October 2003;  
planetary nature determined  
January 2005



閼神星 or 136199 **Eris** 歸類於矮行星



Eris 的紅外光譜與冥王星非常類似，  
箭頭標示者乃甲烷 (methane) 吸收線



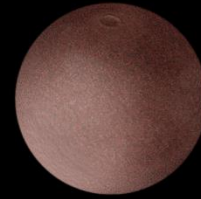
# Largest known trans-Neptunian objects (TNOs)



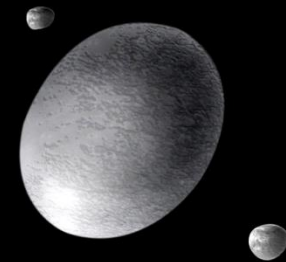
**Eris**



**Pluto**



**2005 FY<sub>9</sub>**



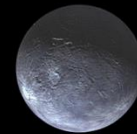
**2003 EL<sub>61</sub>**



**Sedna**



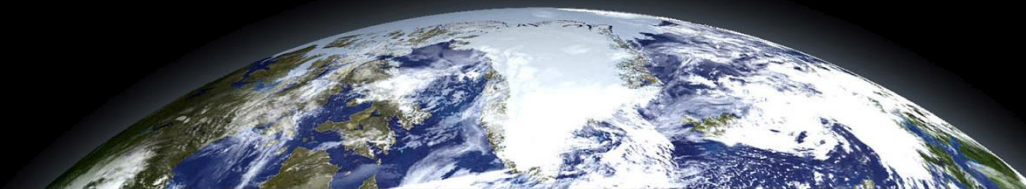
**Orcus**



**Quaoar**

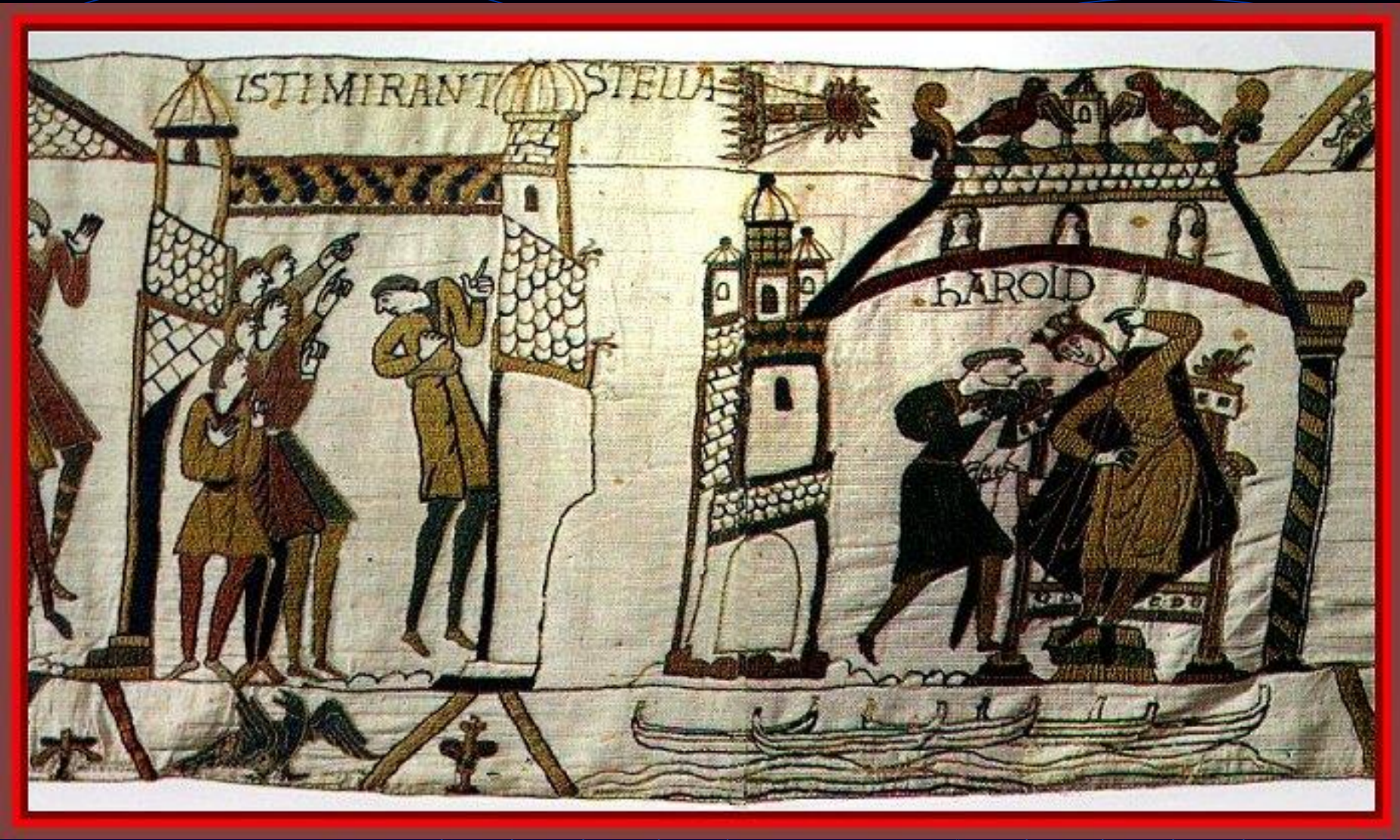


**Varuna**



# 彗星 (comet)





哈雷彗星最早歷史紀錄 (1066年4月24日)，哈洛德王一世在戰役前被告知彗星出現，被薩克森人認為乃不祥預兆 (Bayeux Tapestry)



Donati's Comet as seen over Paris above the Palais du Justice, the Conciergerie and the Seine on Oct. 5, 1858, from a plate in The World of Comets, 1877, Amédée Guillemin.

1664年10月28日看到彗星接近角宿與常陳

Giotto di Bondone, "Adoration des mages" (1301-1305),



Comet of Caricature in 1811



長沙馬王堆出土，西漢帛畫中的彗星圖



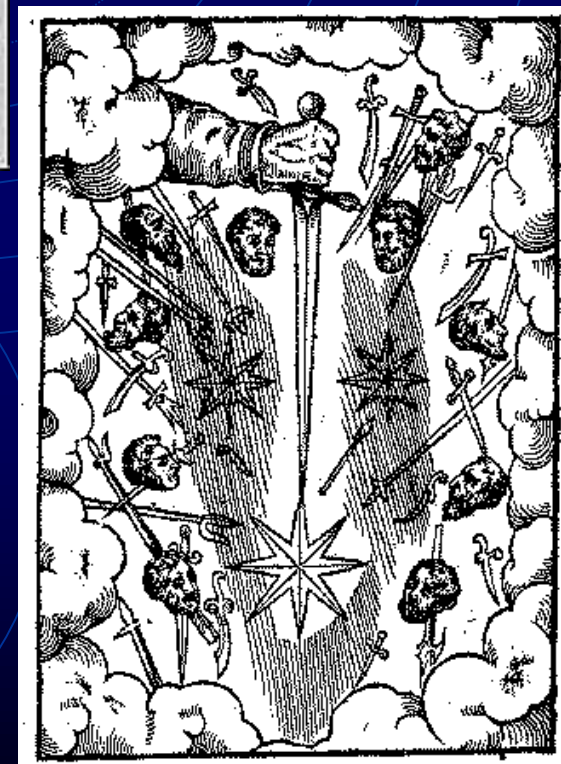
古人對於「來無影、去無蹤」的彗星，尤其是變化多端的尾巴，感到畏懼



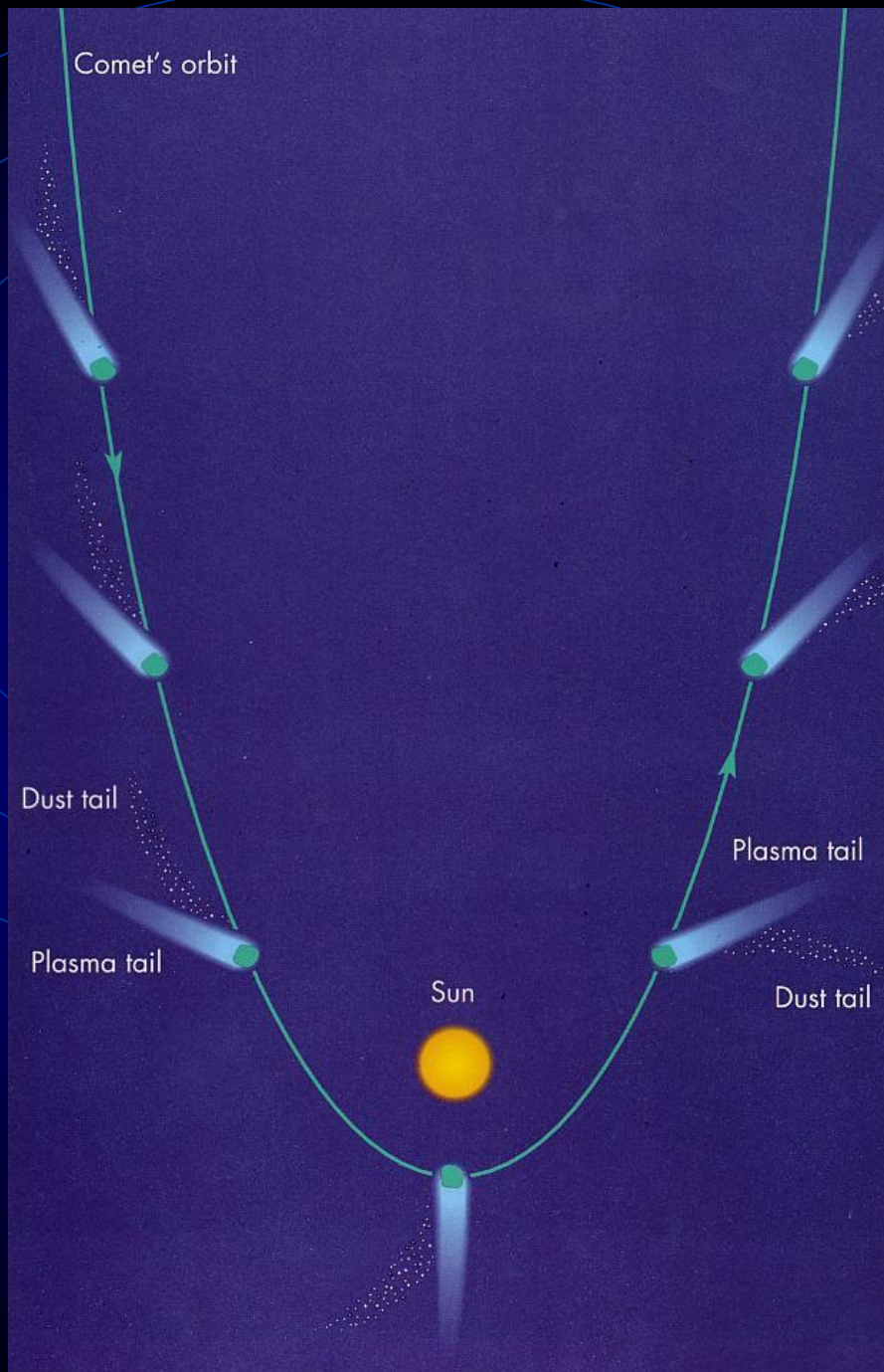
Comet 1857



Thomas Nast 所繪 “The Comet of Chinese Labor” (1870) 以彗星比喻中國勞工入侵



The comet of Ambroise Paré (1528)



太陽風

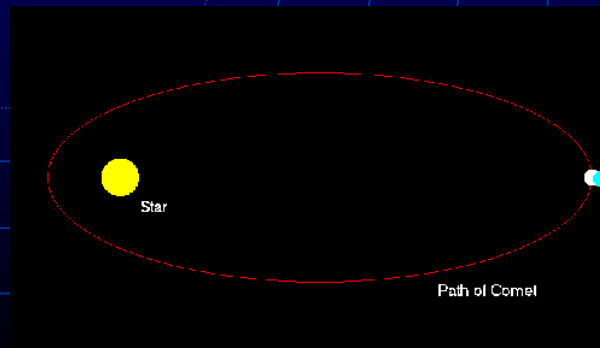
... 離子尾 (氣體發光)

太陽輻射壓

... 塵埃尾 (塵埃反光)

不同顆粒受力不同，抵銷部分太陽引力，以不同軌道繞行太陽，呈現扇形

➔ 彗尾指向太陽反方向

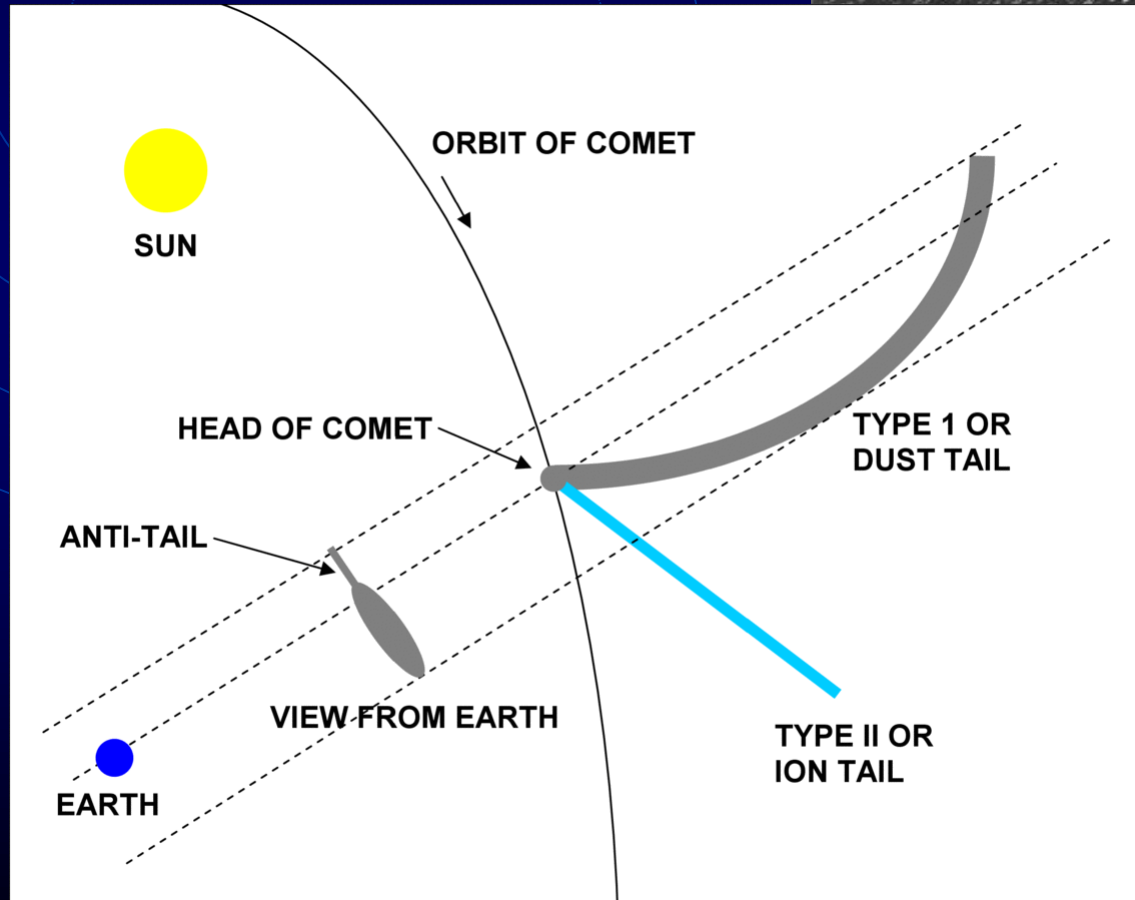
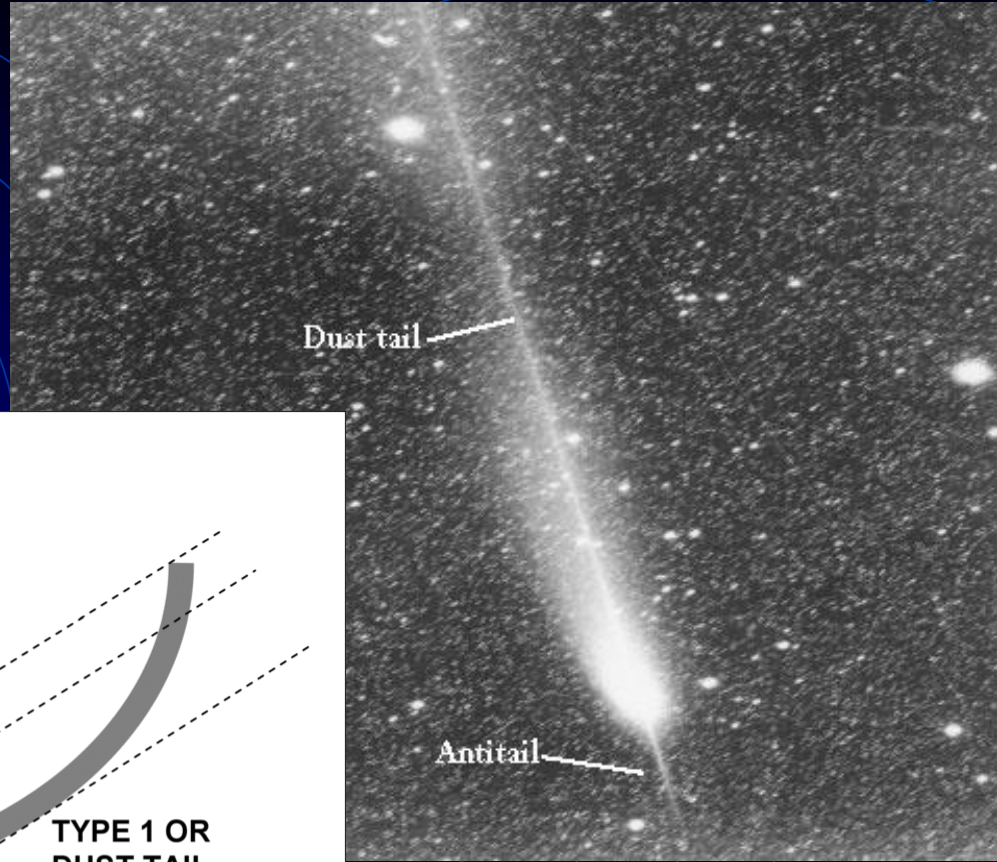


冰體受熱 → 蒸發、昇華 → 彗星（現象）





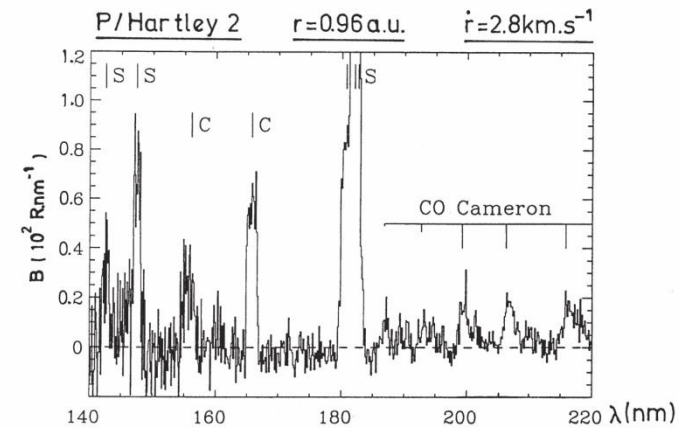
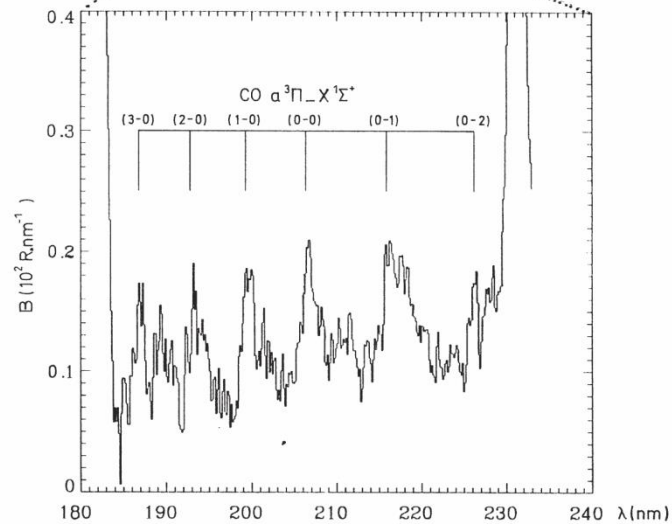
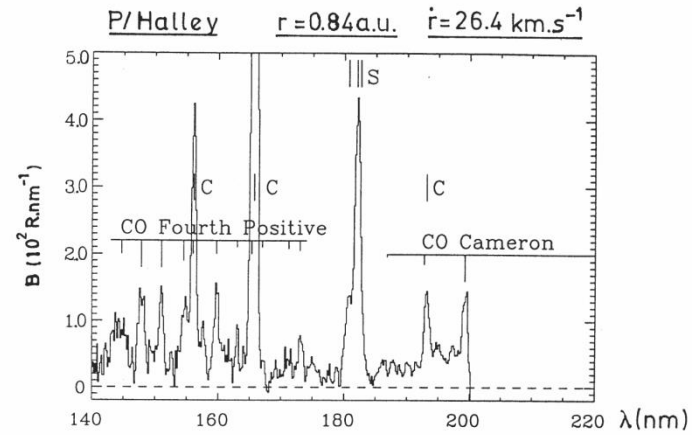
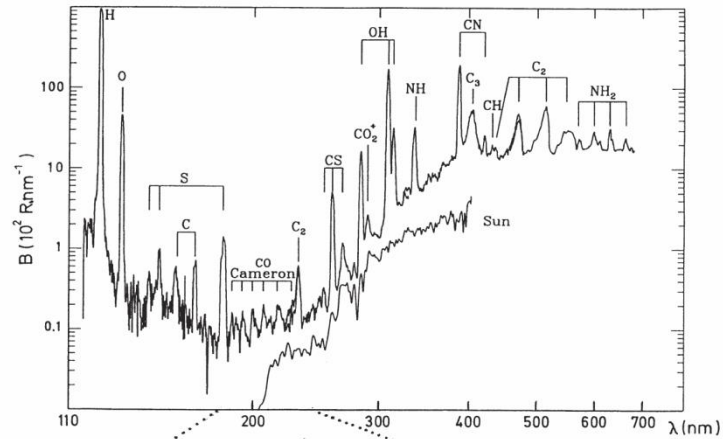
彗星的尾巴背向太陽  
而非地球  
→ 有時可見 antitail

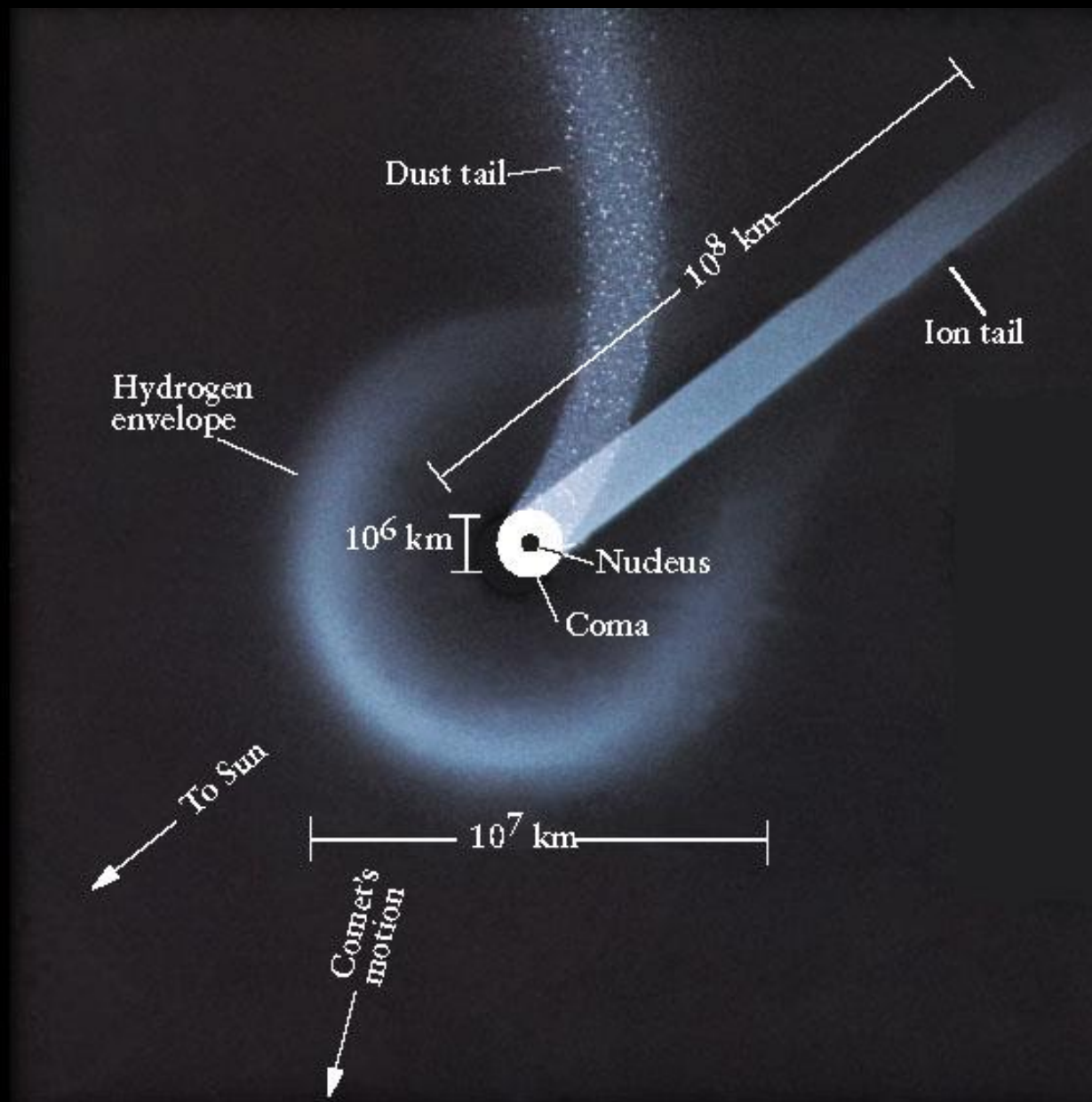


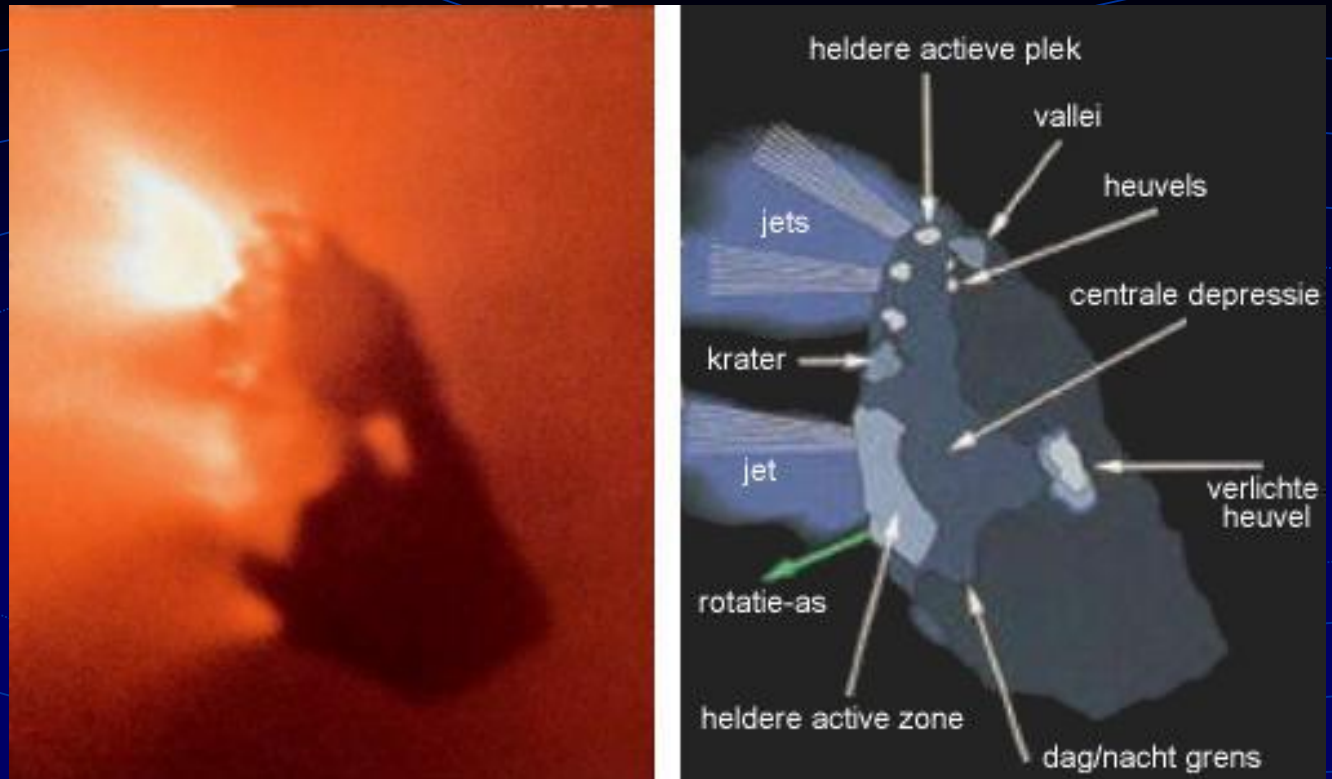
彗星的逆尾

# Complex molecules in comets

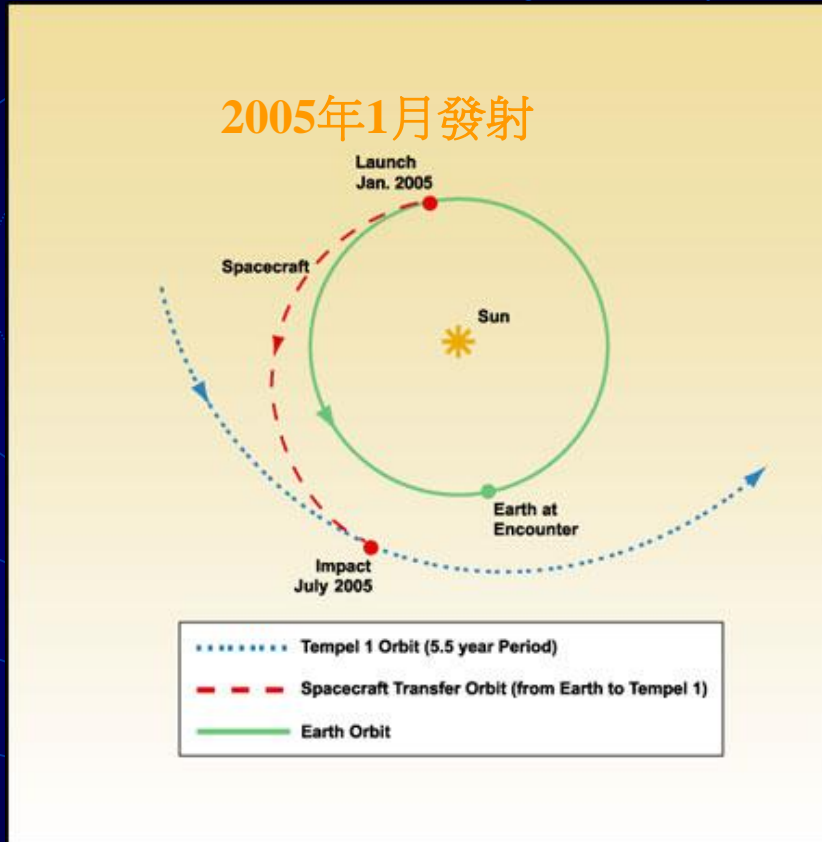
Comet P/Hartley 2 (1991 XV)  $r=0.96$  a.u.







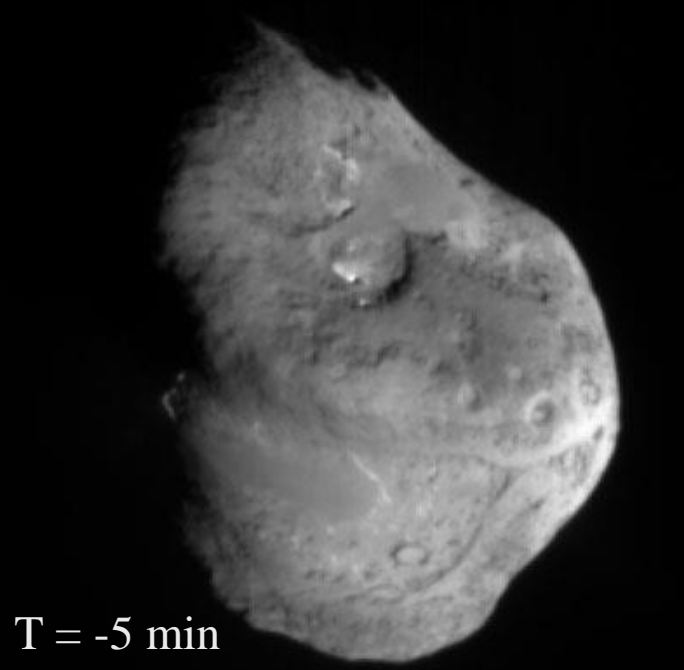
哈雷彗星每76年繞行太陽一圈。這張照片是1986年哈雷彗星接近太陽時，太空船前往近距離拍攝，可看到形狀不規則的彗核正噴發氣體。



2005.7.4 抵達譚普一號  
(Temple 1) 彗星，釋放370 kg  
子船「撞擊號」(impactor) 自  
行導引以時速36000公里撞向  
彗星。預期產生大小、深度達  
十幾公尺到幾十公尺的坑洞，  
藉此研究彗星表面塵埃、氣體  
噴出，以及內部結構。

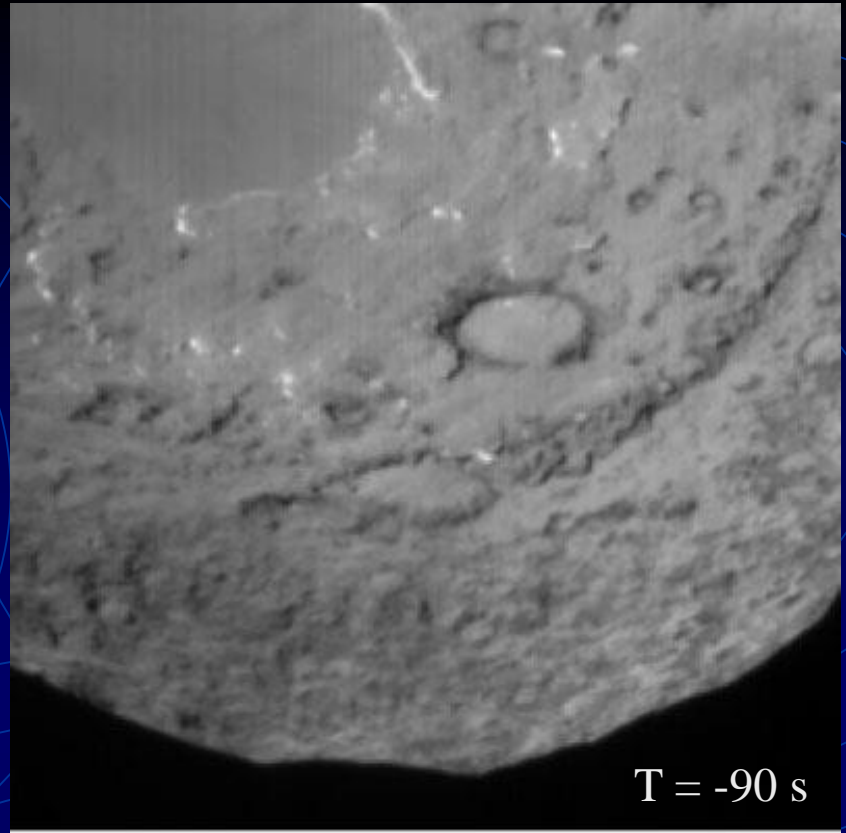
母船「飛掠號」(flyby spacecraft)  
撞擊後改變軌道，以500 km近距  
離觀察撞擊結果，並將結果傳回  
地面 NASA Deep Space Network



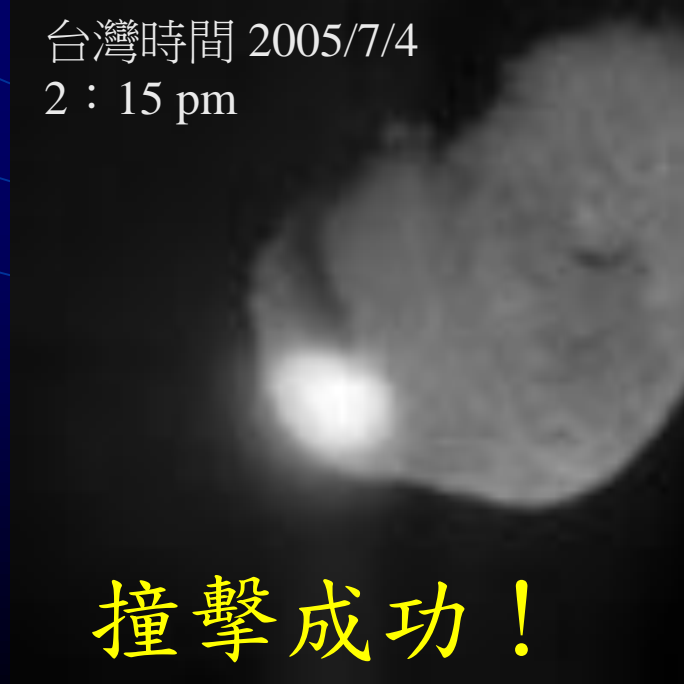


T = -5 min

台灣時間 2005/7/4  
2 : 15 pm



T = -90 s

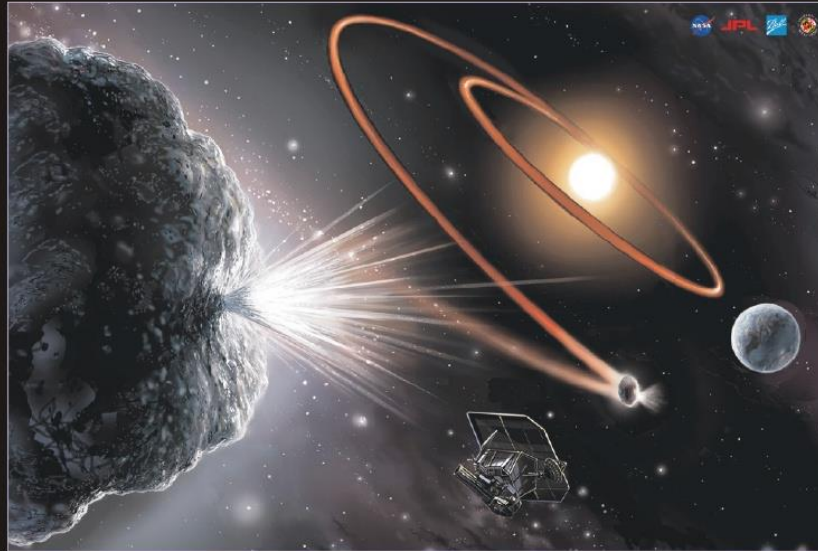


撞擊成功！



**DEEP IMPACT** FIRST LOOK INSIDE A COMET  
IN **TAIWAN** MAY 28, 2004

INSTITUTE OF ASTRONOMY, NATIONAL CENTRAL UNIVERSITY



BEIJING ASTRONOMICAL OBSERVATORY



LULIN ONE-METER TELESCOPE



MAIDANAK OBSERVATORY



KISO OBSERVATORY

**INVITED SPEAKERS:**

**K. MEECH** (HAWAII)

**S. SUBITA** (TOKYO)

**T. KADONO** (JAMSTEC)

**X. ZHOU** (BAO/NADD)

**J. WATANABE** (NADJ)

**Z.Y. LIN/ W.H. IP** (NGU)

**W.H. SUN** (NGU)

**W.P. CHEN** (NGU)

AND MORE...

**THE DEEP IMPACT MISSION**

**IMPACT FLASH IN THE LAB**

**CRATERS & PROJECTILE PENETRATION**

**BAO PROGRAM**

**ISHIGAKI ASTRON. OBS. PROGRAM**

**LULIN PROGRAM**

**KENTING PROGRAM**

**MAIDANAK PROGRAM**

For more information, please contact: [tracy@astro.ncu.edu.tw](mailto:tracy@astro.ncu.edu.tw)

**Rosetta**

Credit: ESA

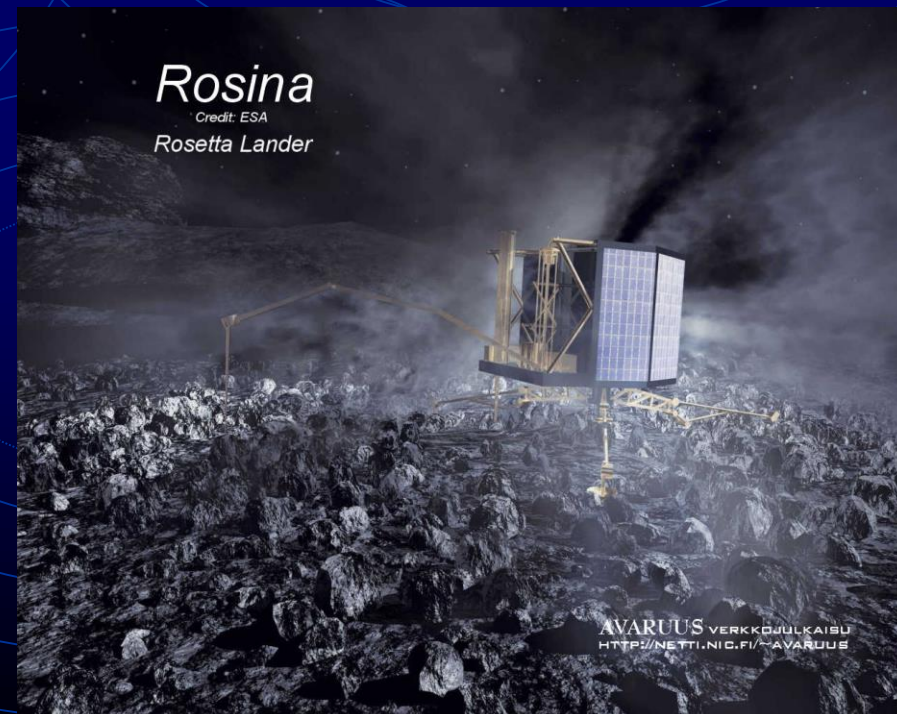


AVARUUS VERKKOJULKAISU  
[HTTP://NETTI.NIC.FI/~AVARUUS](http://netti.nic.fi/~AVARUUS)

**Rosina**

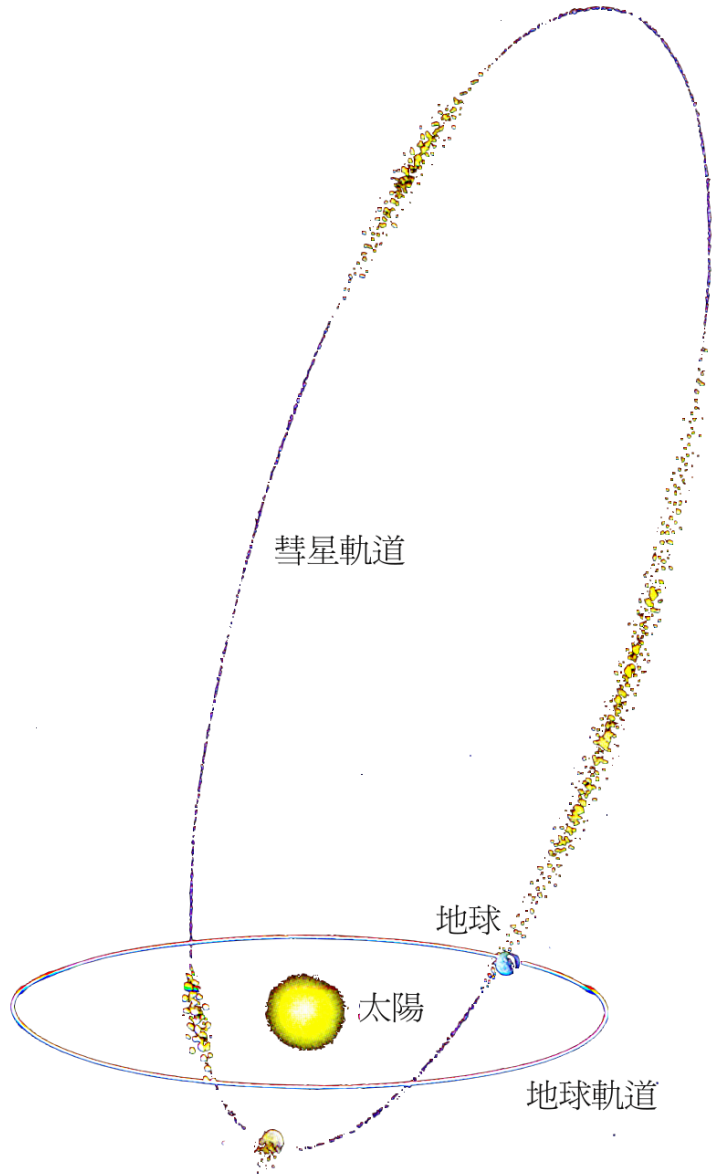
Credit: ESA

Rosetta Lander



AVARUUS VERKKOJULKAISU  
[HTTP://NETTI.NIC.FI/~AVARUUS](http://netti.nic.fi/~AVARUUS)

# 一年當中著名的流星雨



流星雨 (輻射點星座)	大約 極大期	每小時 流星數	可能母彗星
象限儀座	01/03	40	C/1490 Y1?
天琴座	04/22	15	Comet Thatcher
寶瓶座 Eta	05/04	20	1P/Halley (P=75 a)
寶瓶座 Delta	07/30	20	96P/Machholz + family
英仙座	08/12	80	109P/Swift-Tuttle (P=133 a)
獵戶座	10/21	20	1P/Halley
金牛座	11/04	15	2P/Encke
獅子座	11/16	15	55P/Tempel-Tuttle (P=33 a)
雙子座	12/13	50	3200 Phaethon (P=1.43 a)
小熊座	12/22	15	8P/Tuttle





<http://www.astronomy.com.cn/bbs/thread-285933-1-1.html>

# Radiant (converging) Point (輻射點)





APOD  
2014.04.24



母彗星剛回歸  
地球通過彗星殘渣聚集處

大規模流星雨 → 流星暴

Leonids in 1833?

<http://star.arm.ac.uk/leonid/Meteor-Shower.jpg>

# 太陽系中各式天體

雲氣收縮、中央溫度升高、點燃核子反應 → 太陽

雲氣縮成扁盤狀、盤中灰塵凝集 → 小行星

✓ 繼續凝集 → 行星

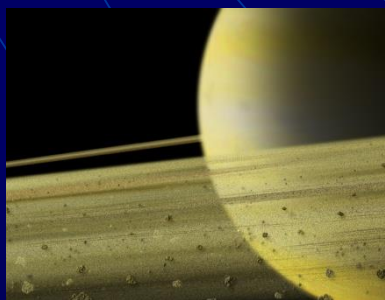
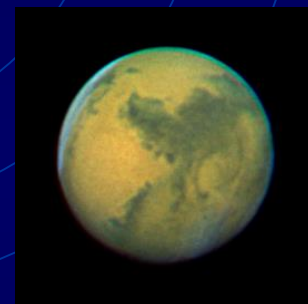
❖ 旁邊扁盤中的灰塵繼續凝集 → 衛星

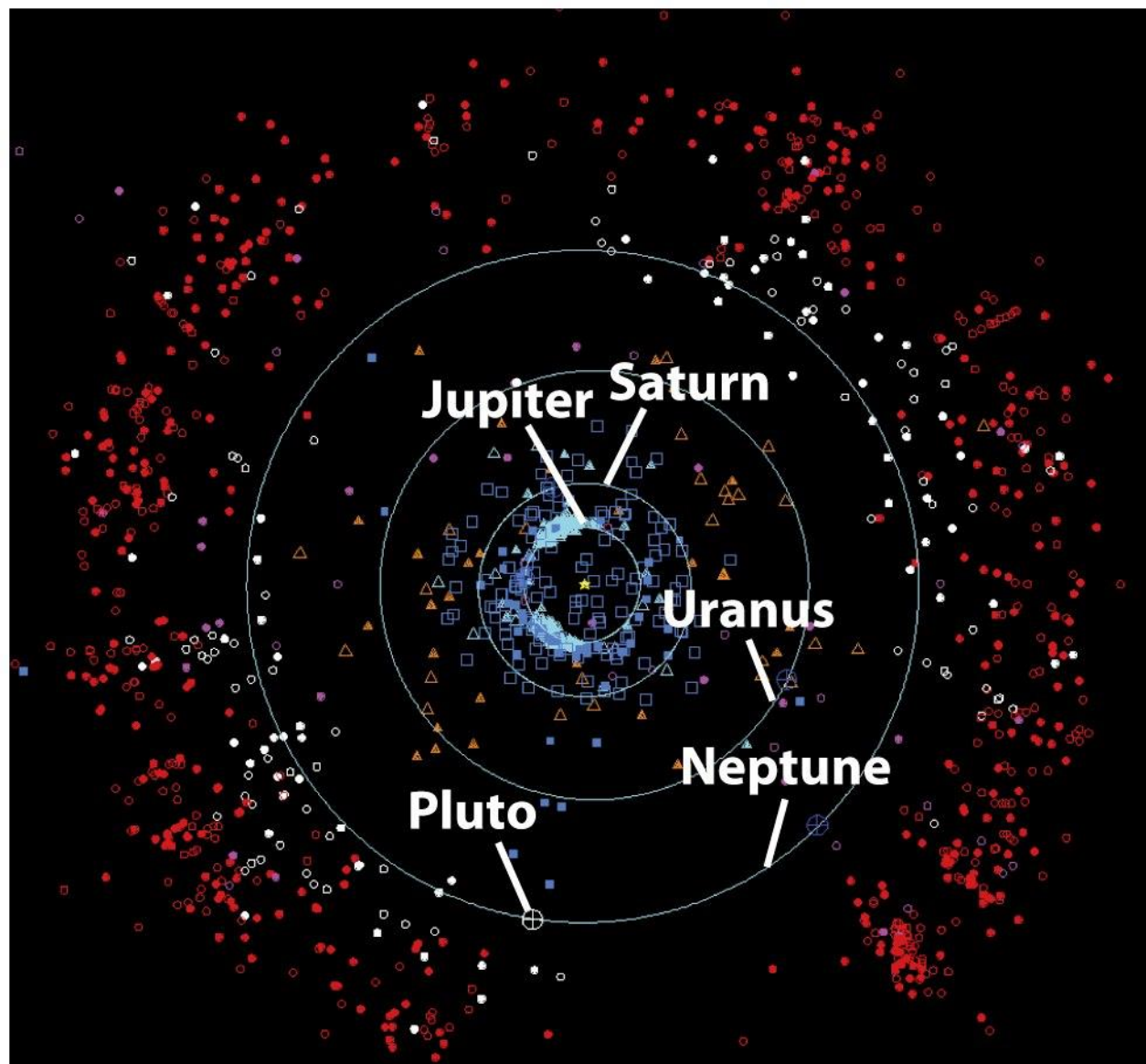
❖ 不成形的 → 外行星的環

✓ 不成形的 → 留在原地，例如小行星帶

→ 被拋到遠方 → 歐特雲中的彗星核

不小心進入太陽系內圍 → 彗星

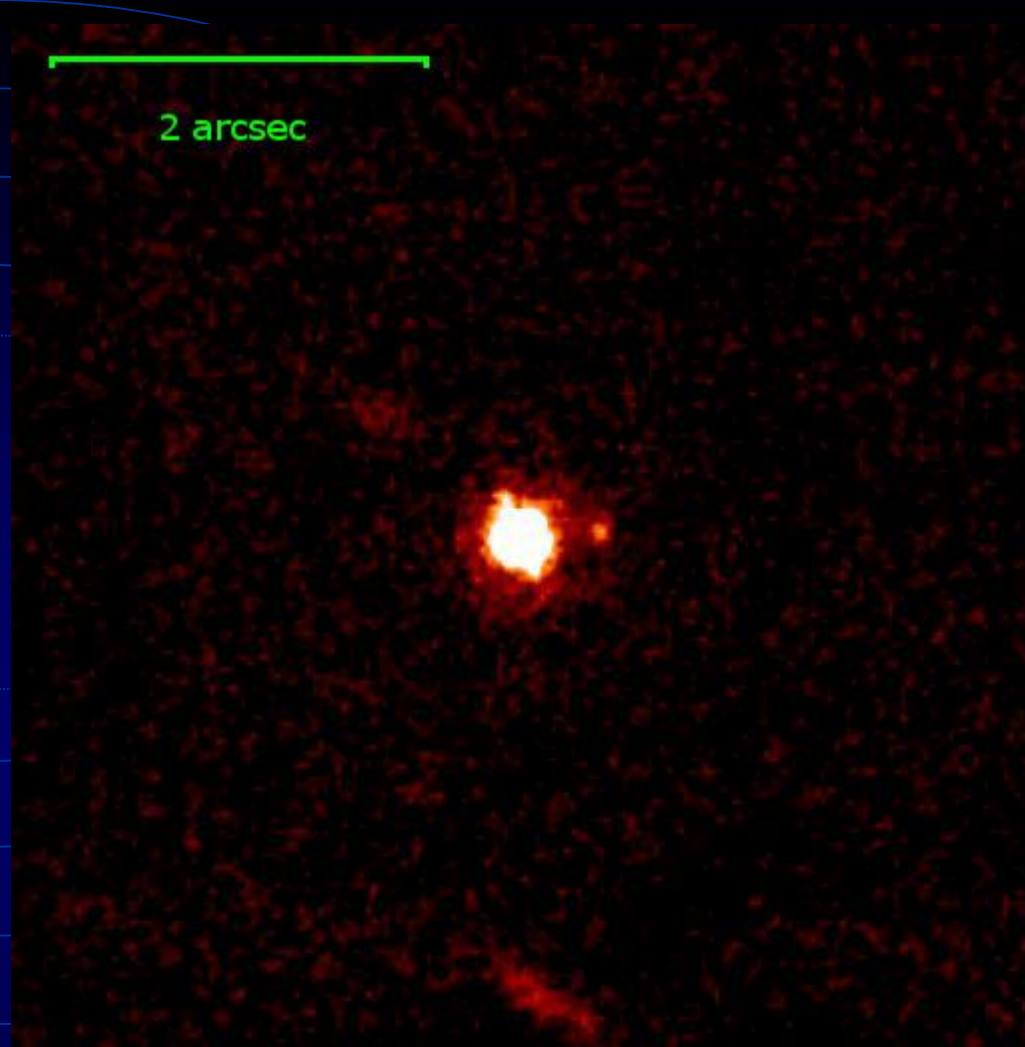




古柏帶 (Kuiper belt) 是製造行星剩下的小天體所在 目前已知超過數千顆



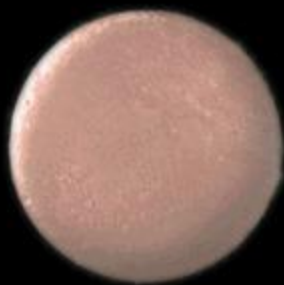
## 古柏帶中的小型天體



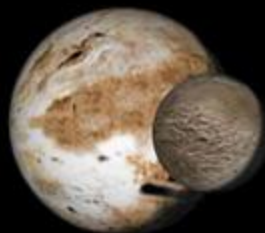
Keck Telescope image of **Eris** (2003 UB313, dwarf planet 矮行星) and its moon Dysnomia. The pair had been tentatively nicknamed "Xena and Gabrielle" at the time the picture was taken.



**UB 313**  
3000 km

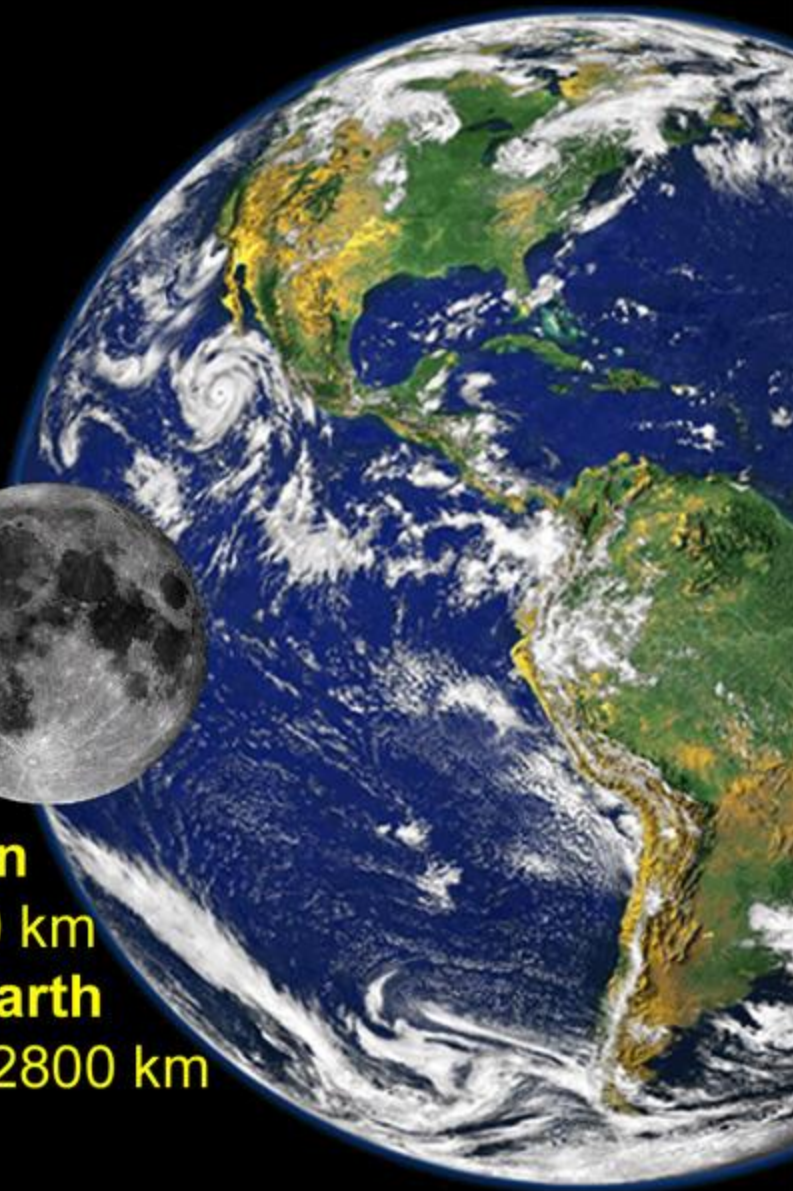


**Pluto/Charon**  
2300/1200 km



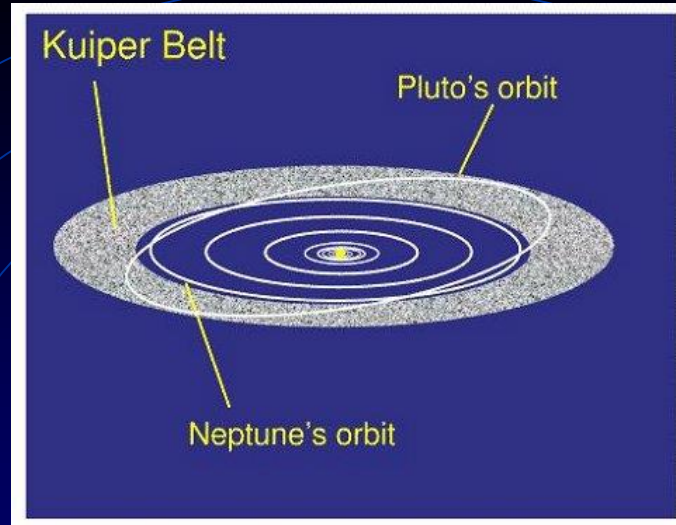
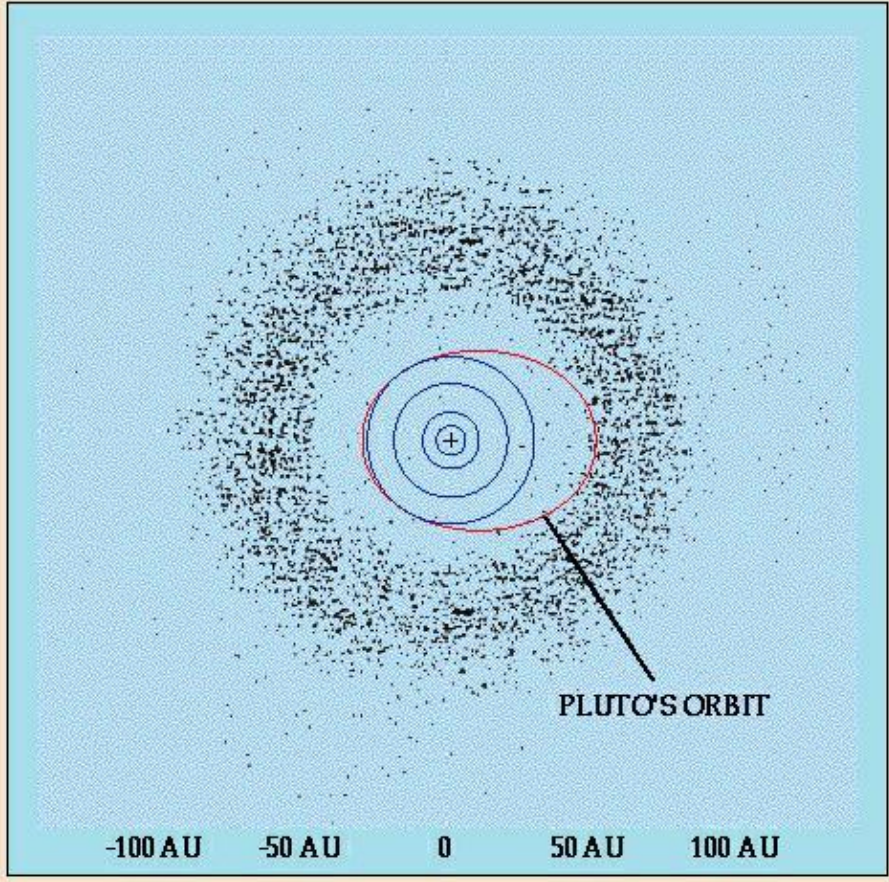
**Moon**  
3500 km  
**Earth**  
12800 km

第十顆行星？



**The surplus material and planetesimals become the Kuiper disk or Kuiper belt.**

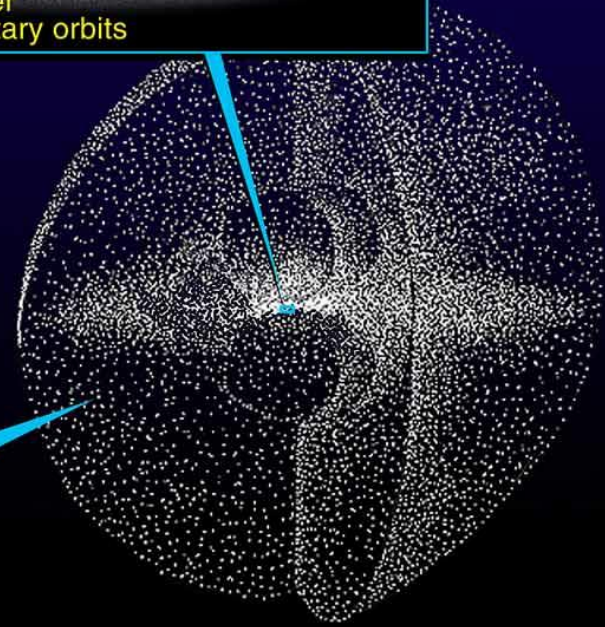
### THE OUTER PLANETS AND THE KUIPIER DISK

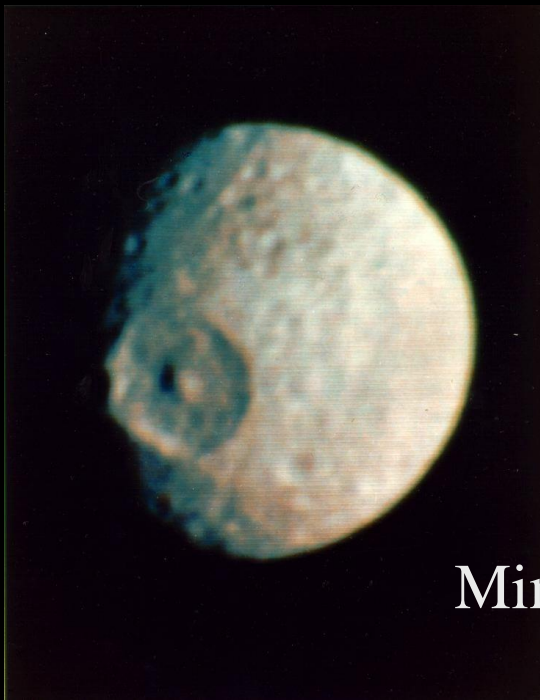


### 歐特雲 (Oort cloud)

The Oort Cloud  
(comprising many billions of comets)

*Oort Cloud cutaway drawing adapted from Donald K. Yeoman's illustration (NASA, JPL)*



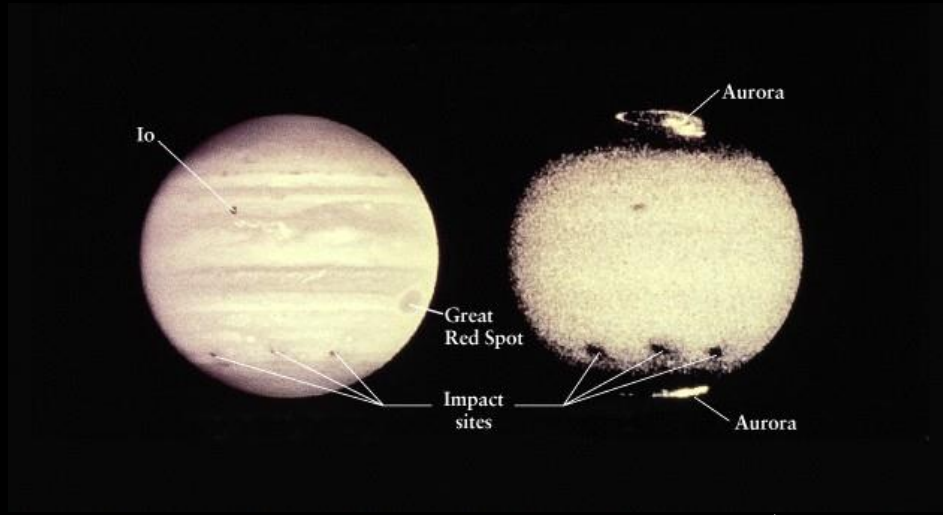


Mimas

月球表面有大量撞擊的痕跡



Gaspa 小行星表面也有很多撞擊痕跡



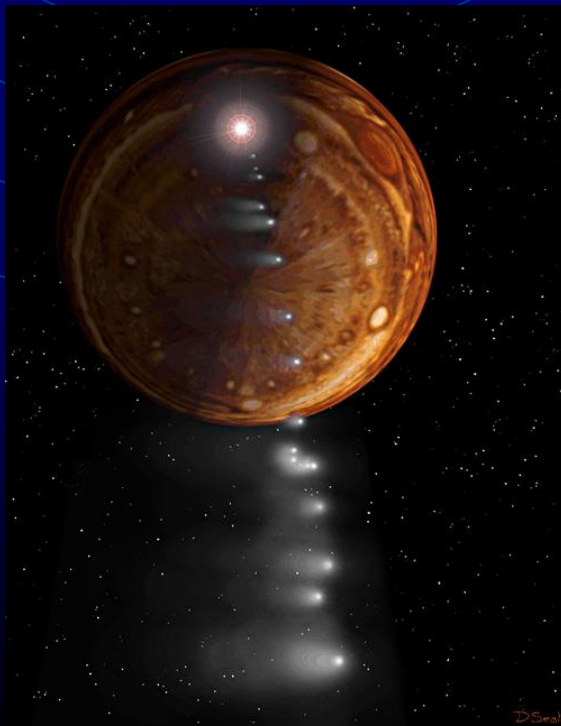
木星也曾被撞得鼻青臉腫

Shoemaker-Levy9 彗星分裂成21碎塊

彗星為什麼會分裂呢？

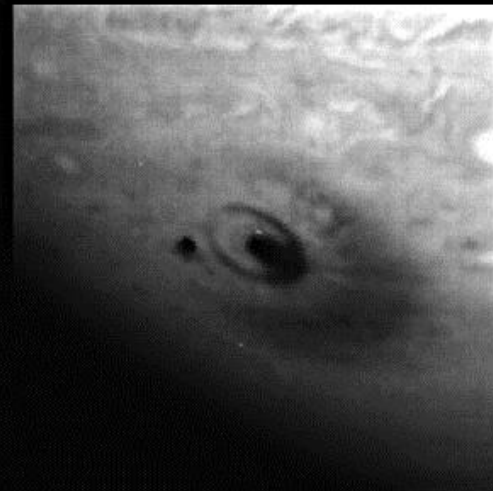


1994 年夏天彗星撞木星

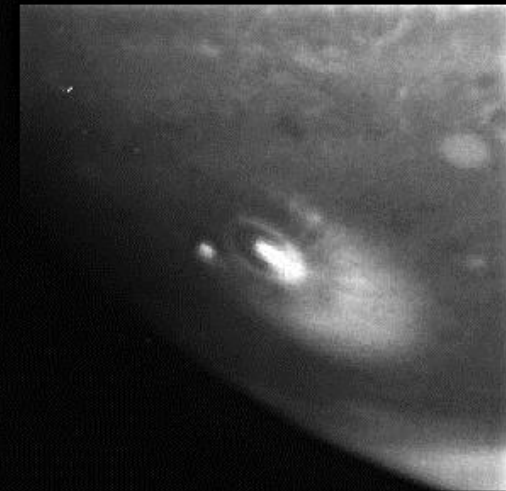


G Impact Site

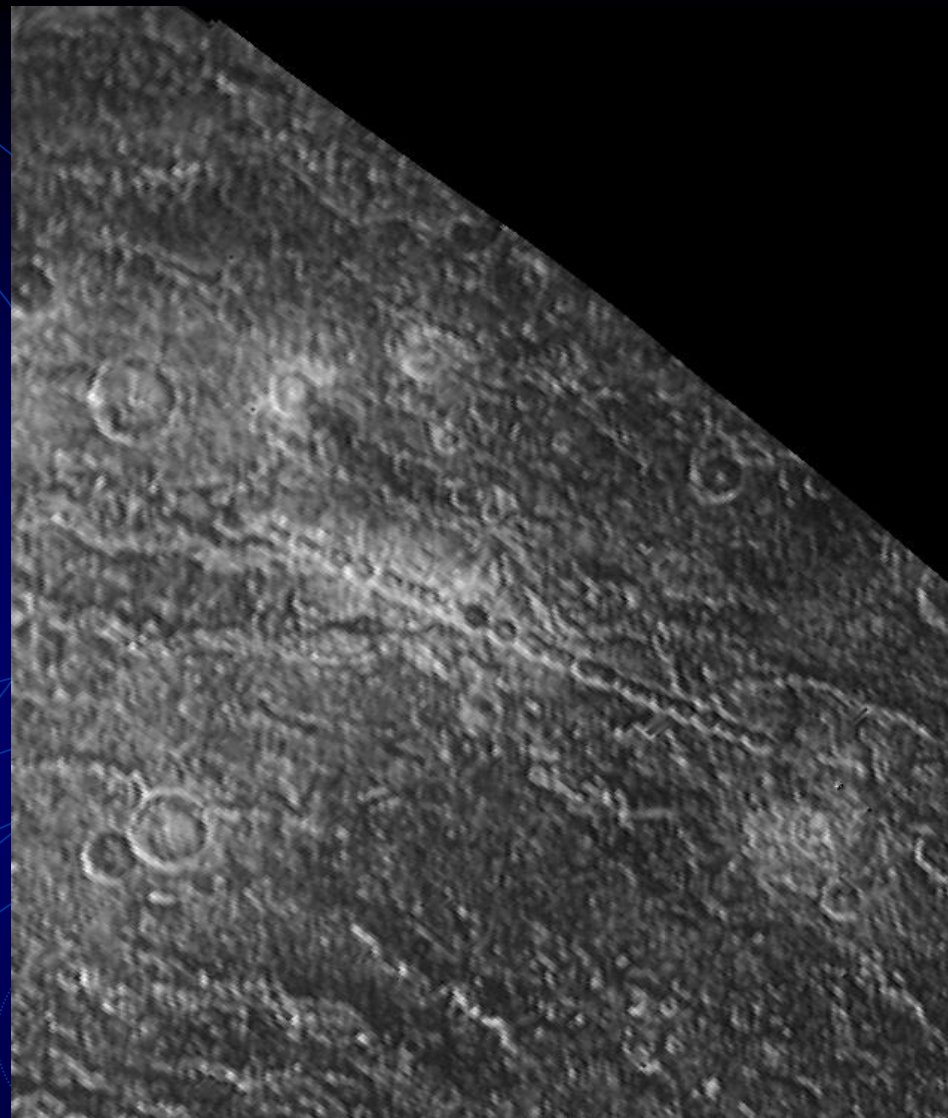
Green



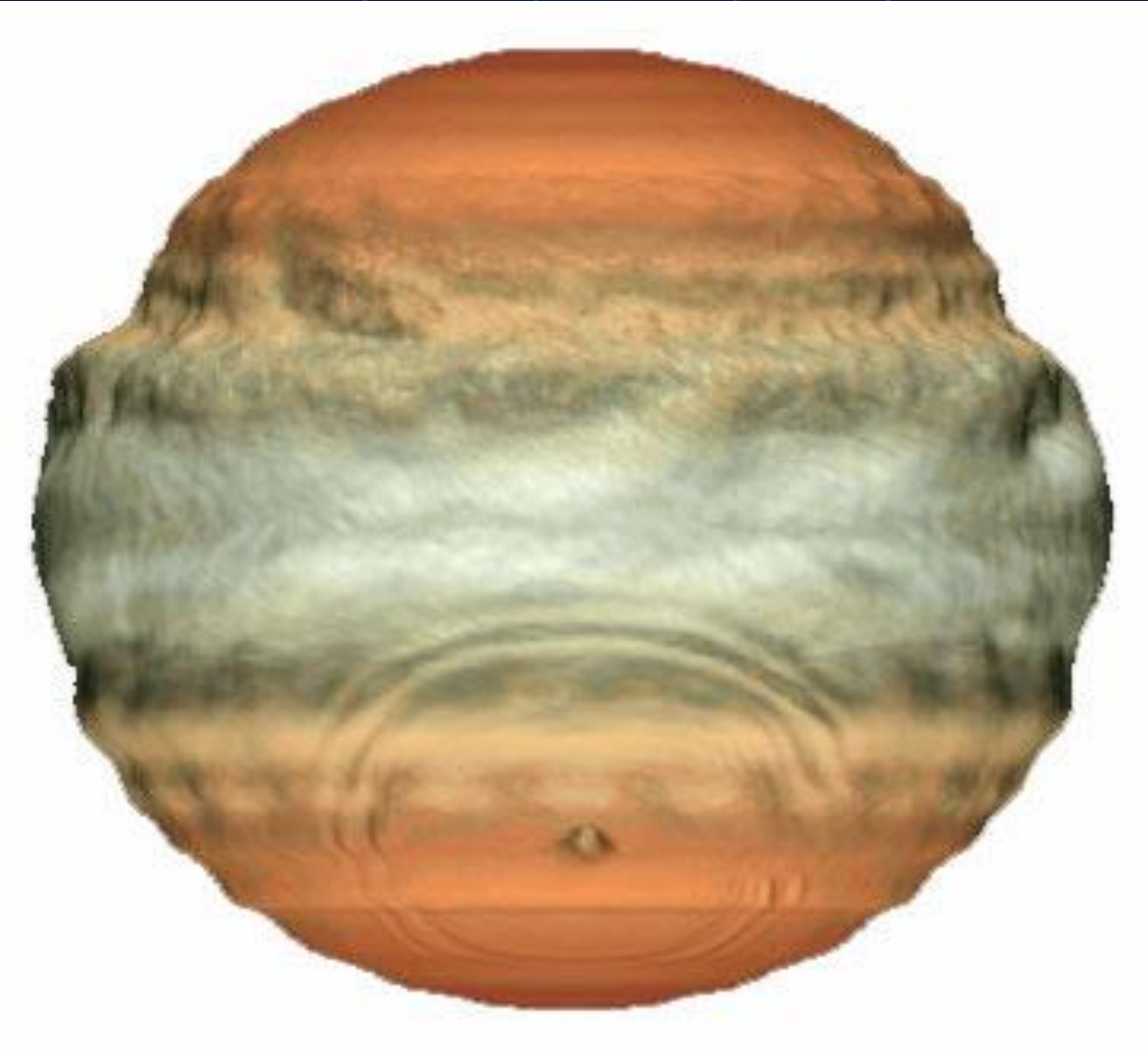
Methane



18 July 1994



木星的衛星 Callisto  
表面的串狀隕石坑



*Earth 100 minutes after a G-Sized impact*



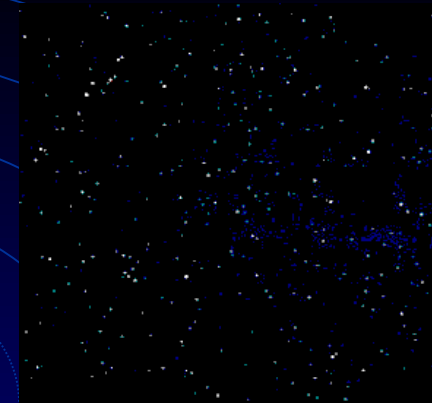
*G impact scar reprojected onto Earth, to scale*

如沙粒般的碎渣掉入地球大氣 → **流星**

• 地球撞向彗星留在軌道上的殘渣 → **流星雨**

• 大一點的如小石，燃燒剩餘部分落到地面 → **隕石**

• 再大一點的呢？

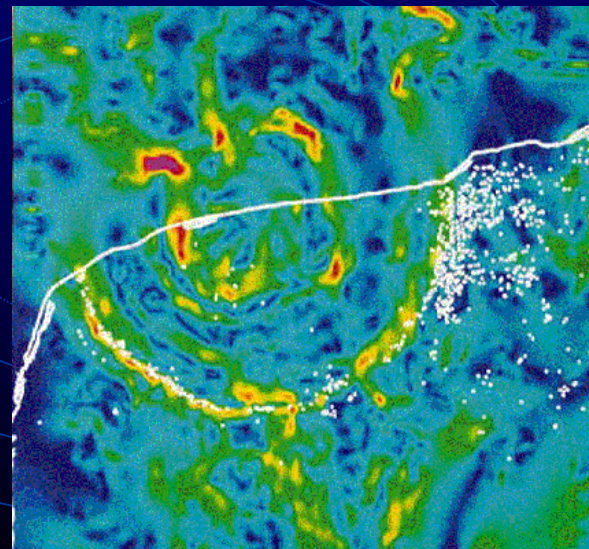
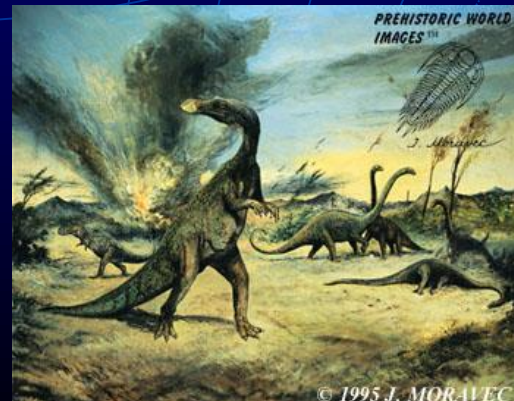


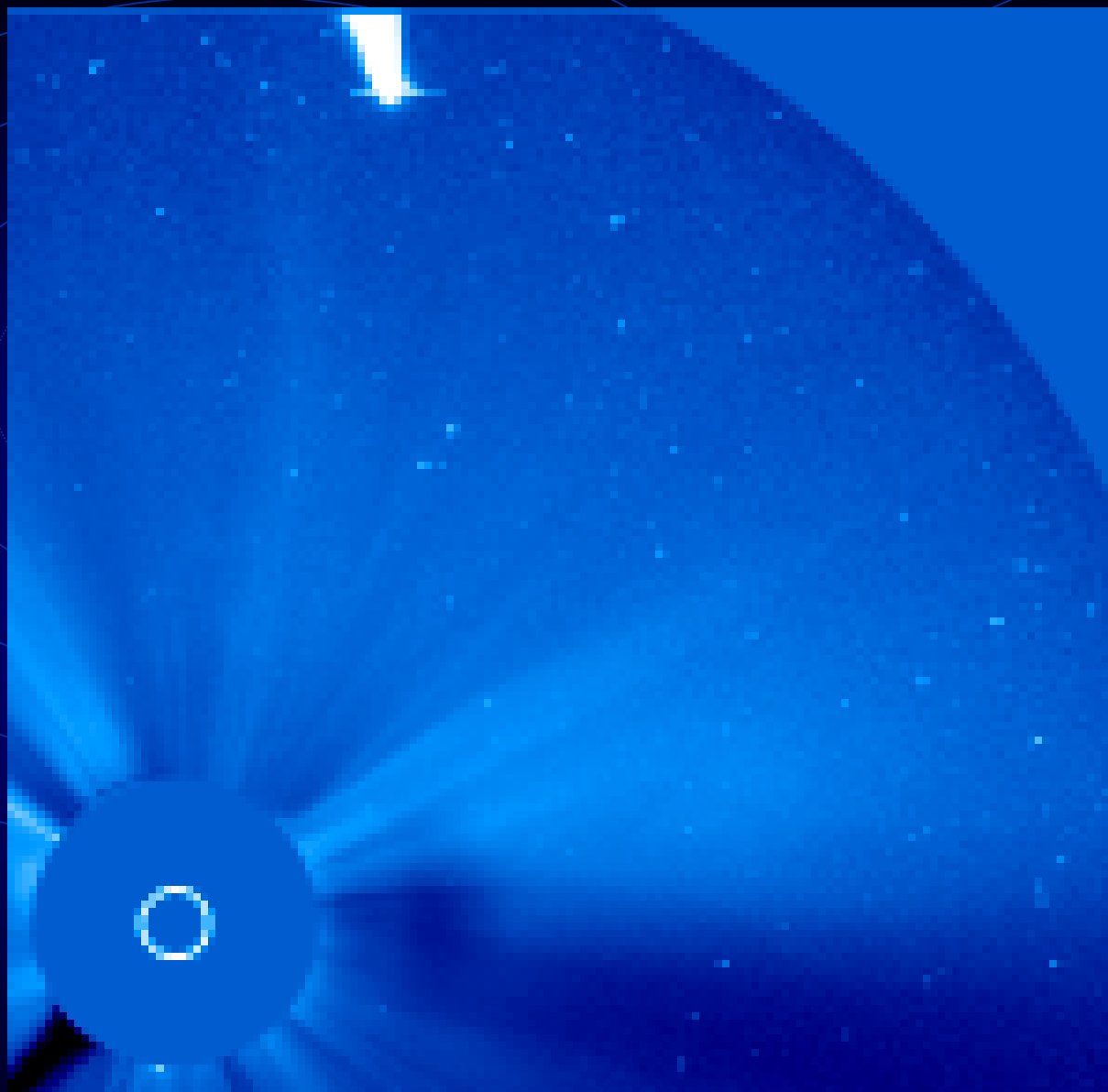
Barringer Meteor Crater, Arizona, USA

1927 年所攝「通古斯加地方」  
(Tunguska) 離爆炸點約20公里的森林



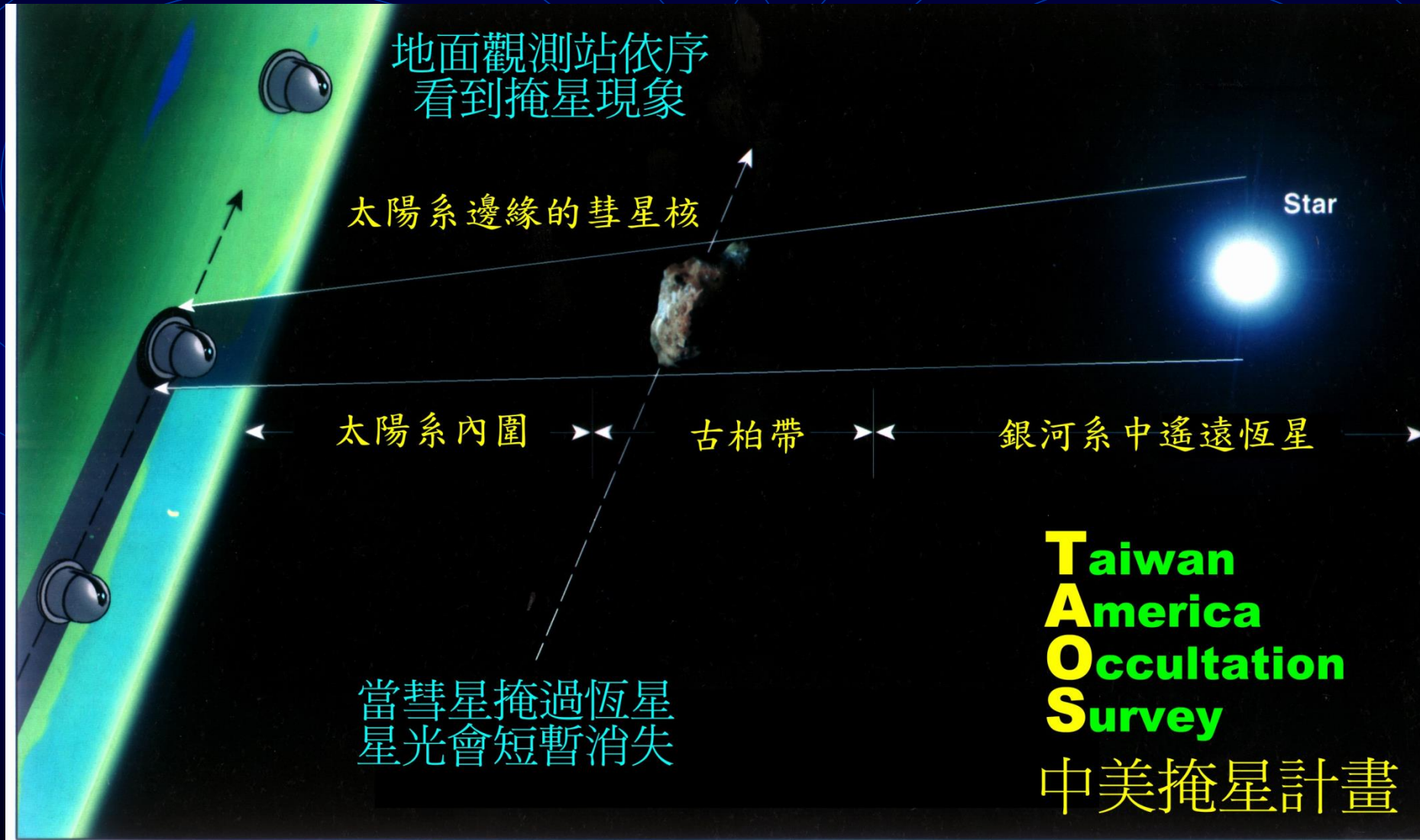
# 恐龍怎麼滅種的？ 6500萬年前的撞擊！





彗星撞太陽

# 中美掩星計畫 (TAOS)





# Panoramic Survey Telescope And Rapid Response System

泛星



- ❑ To patrol the entire observable sky ( $3\pi$ ) several times a month
- ❑ An array of 4 telescopes, located in Hawaii, each of  $D=1.8$  m, equipped with a 1.4 Gpix camera of an Orthogonal Transfer Array CCD detector (= 40 cm square focal plane)  $\rightarrow$  7 square-degree FOV with 0.26" pixels
- ❑ Detection of moving, transient, and variable objects down to faint limits
- ❑ Very deep cumulative sky images
- ❑ Wide-Field Imaging
- ❑ Short Duty Cycle
- ❑ Efficient Operations

**鹿林彗星**是在2007年7月11日，由大陸廣州中山大學葉泉志，以及中央大學天文研究所觀測助理林啟生，使用鹿林天文台41公分望遠鏡進行鹿林巡天計畫 (Lulin Sky Survey, LUSS) 時共同發現。發現當時位在寶瓶座，亮度僅19等。

國際彗星組織按其身為非週期彗星、2007年7月上半月發現的第三顆新彗星的特性，將其編號為C/2007 N3，並以發現的天文台為其命名為「鹿林 (Lulin)」。鹿林彗星是臺灣本土所發現及被命名的第一顆彗星，也是海峽兩岸合作發現的第一顆彗星。



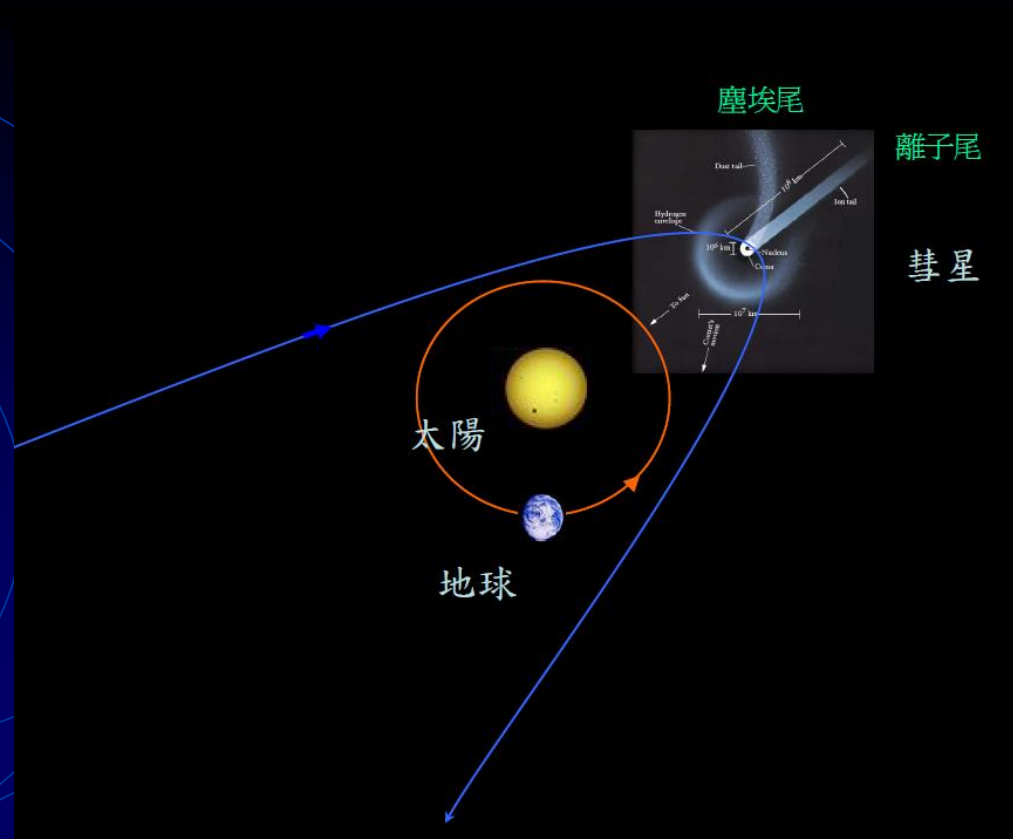
C/2007 N3  
原始發現影像



# 鹿林彗星的尾巴 與逆尾



An antitail and 3 ion tails







APOD 2009-02-21 *Swift* Gamma-ray OH emission 每秒鐘3釋放3200公升的水

