

太陽系家族

Our Solar System

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大綱 Outlines

- 類地行星 Terrestrial planets (or rocky planets)

水星 Mercury

金星 Venus

地球 Earth

火星 Mars

此類行星具有岩石外殼。岩石外殼上方或許有一層非常薄的大氣層（或完全沒有大氣層）

a planet with rocky surface, which is overlaid by a very thin atmosphere, or without an atmosphere.

- 類木行星 Jovian planets (or gas giants, or giant planets)

木星 Jupiter

土星 Saturn

天王星 Uranus

海王星 Neptune

此類行星之中央為岩石核心，核心外包裹著被壓縮成具有金屬特性的氫或液態物質，外圍再包著一層很厚的大氣

（金屬氫：氫原子核外面的電子，被壓成電子海，不屬於任何一個氫原子核）

A planet with a rocky core overlaid by a deep layer of metallic hydrogen, and/or liquid matter, then overlaid by a thick atmosphere

- 太陽系小星體

Small Solar System Body (SSSB)

矮行星 Dwarf Planets

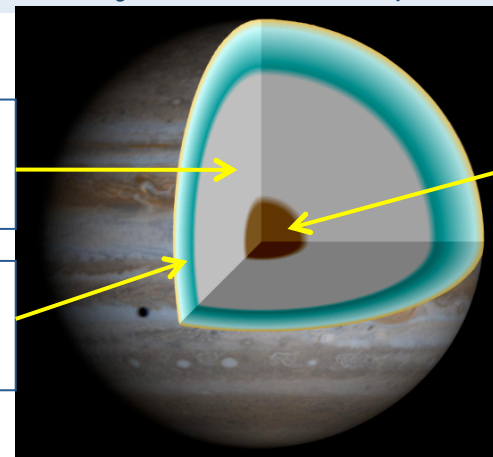
彗星 Comets

小行星 Asteroids

具有金屬特性的氫
metallic hydrogen

厚重的大氣層
A thick atmosphere

岩石核心
rocky core

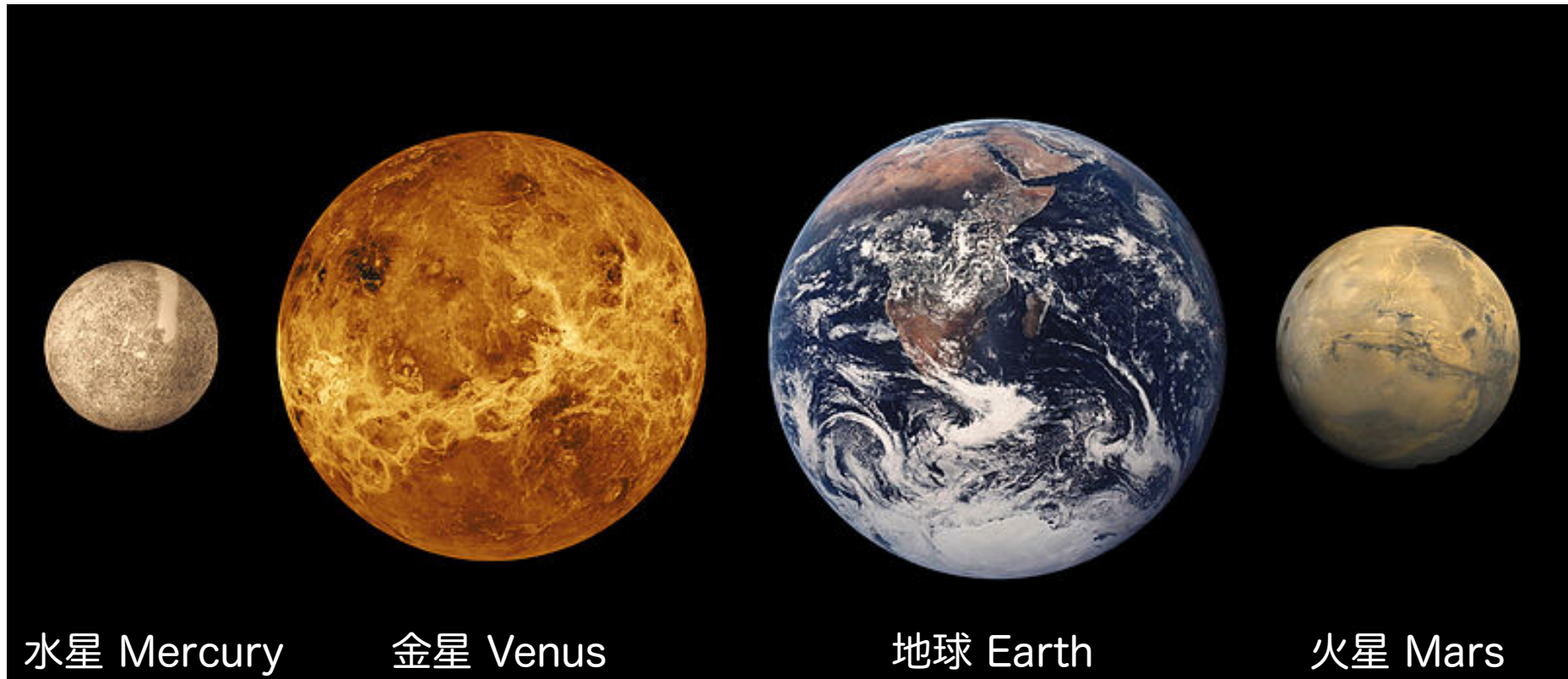


類似地球的行星（類地行星）

The “Earth-like” Planets

The Terrestrial Planets

The Rock Planets in the Solar System



水星 Mercury

金星 Venus

地球 Earth

火星 Mars

(雷達影像 SAR Image)

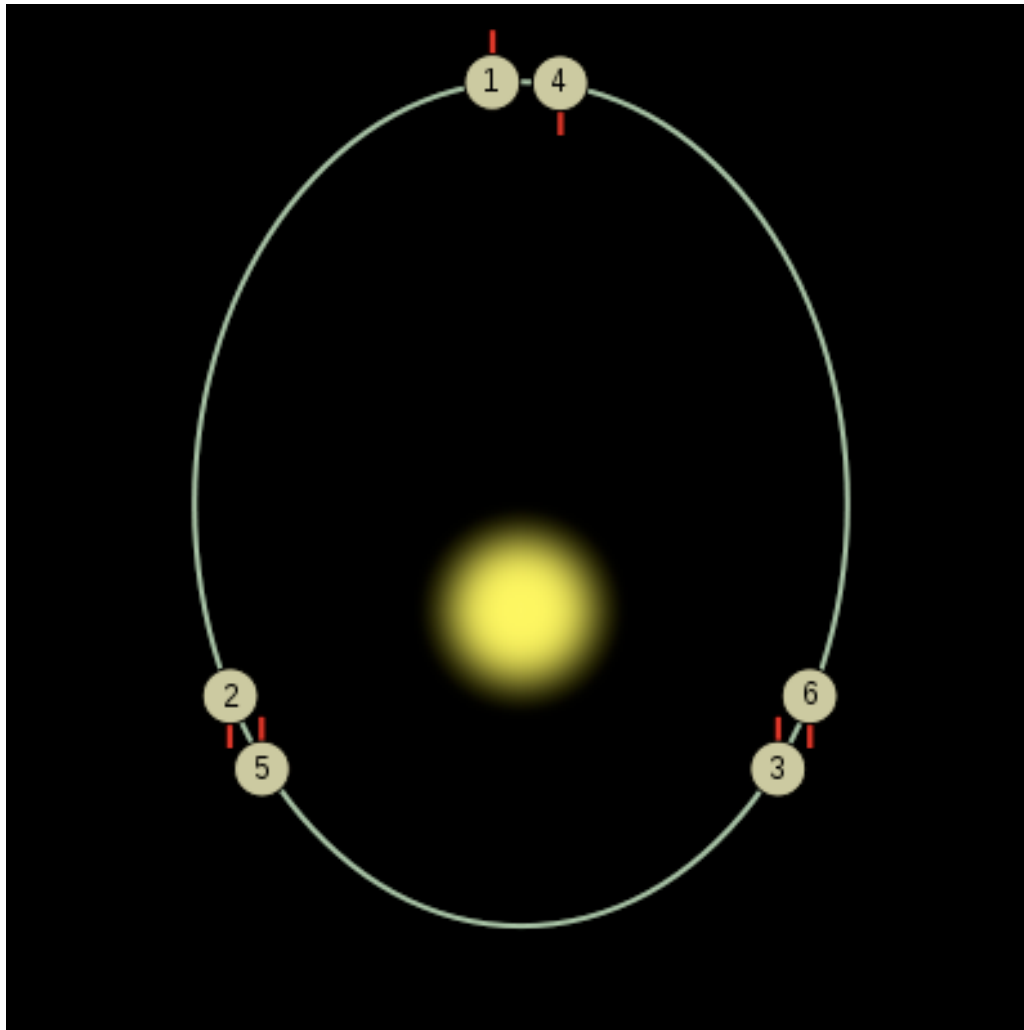
水星 Mercury

中國古書上稱“辰星”

- 向陽面表面溫度 Surface temperature $> 400^{\circ}\text{C}$
質量不夠大，抓不住高溫氣體 the gravitational force is not strong enough to hold the high temperature gas on the surface
 - 沒有大氣 no atmosphere
 - 沒有電離層 no ionosphere
 - 沒有電漿球層 no plasmasphere
- 有熔岩核心、富含鐵 iron-rich core
 - 有明顯的磁偶極場 dipole magnetic field
- 太陽風電漿吹過磁偶極場 solar wind pass by the dipole field
 - 形成磁層與磁尾 Formation of magnetosphere and magnetotail
- 自轉週期 spin period : 公轉週期 orbital period = 2 : 3

水星 自轉週期：公轉週期 = 2 : 3

Mercury Spin-Orbit Resonance



自轉週期 Spin period (1→2→3)
= 58.646 days (地球日)

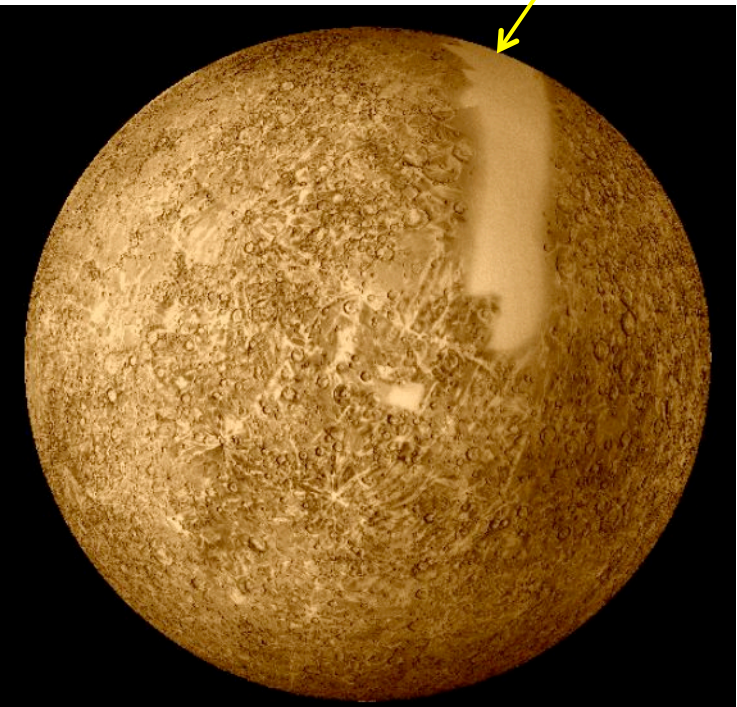
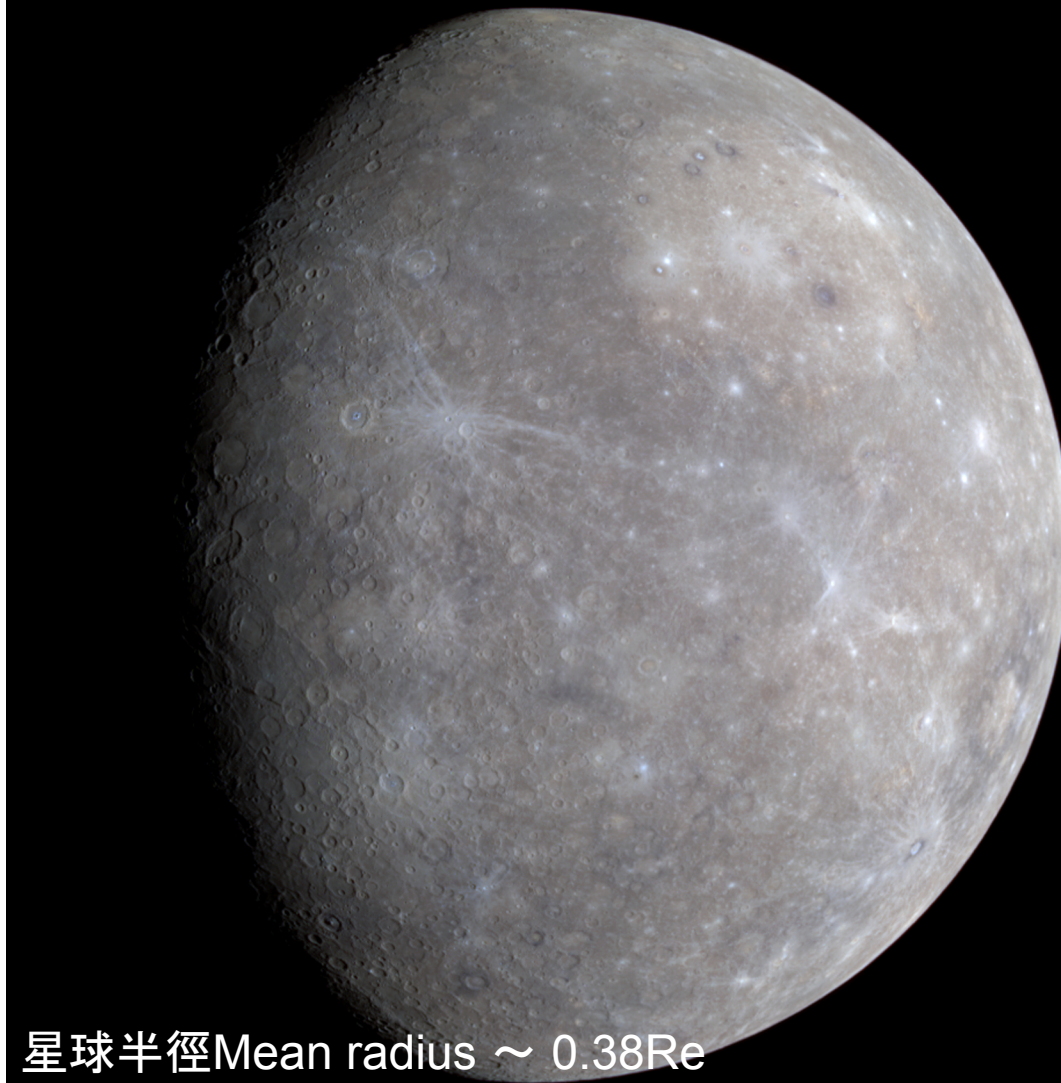
公轉週期 orbital period (1→2→3→4)
= 87.96 days (地球日)

恆星日 Sidereal day
= 自轉週期 Spin period (1→2→3)
= 58.646 days (地球日)

太陽日 Solar day
(1→2→3→4→5→6→1)
= 3x58.646 days = 2x87.96 days
= 175.938 days (地球日)

Mercury surface

缺觀測資料
Data gap



星球半徑 Mean radius $\sim 0.38R_e$
平均公轉半徑 Mean distance from the Sun $\sim 0.387\text{AU}$

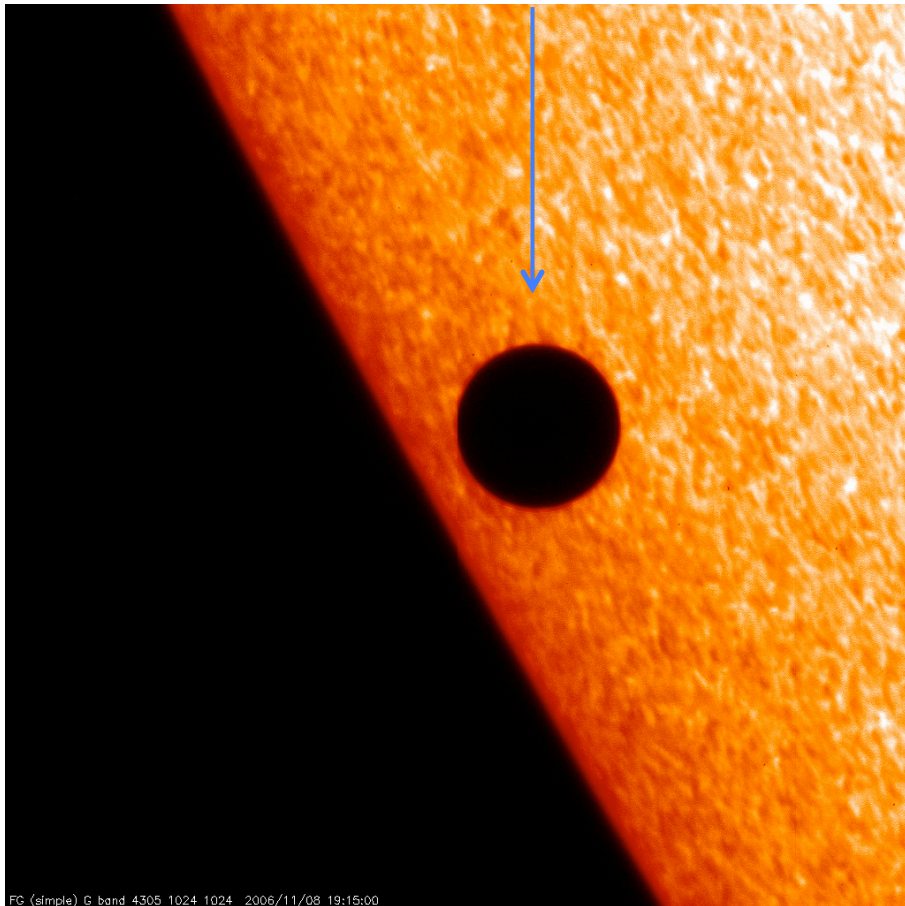
(1AU = 地日距 Mean distance between Sun and Earth)

水星凌日 Transit of Mercury

平均每七年才可見到一次

Average occurrence rate: every 7 years

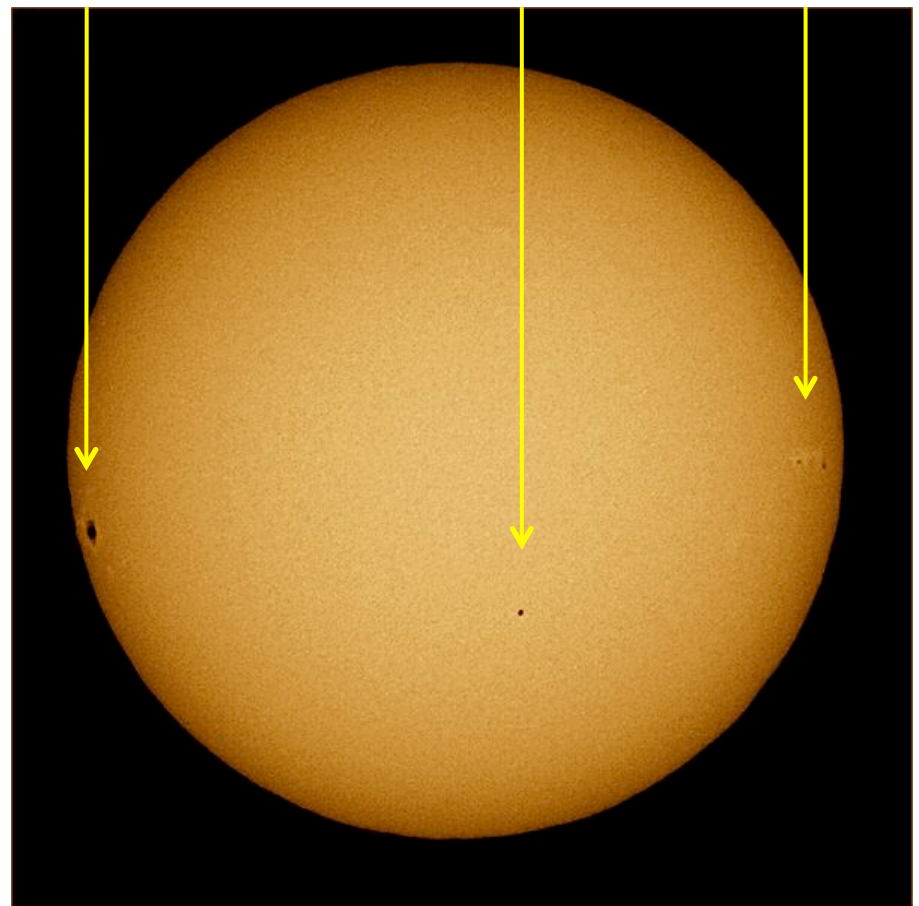
水星
Mercury



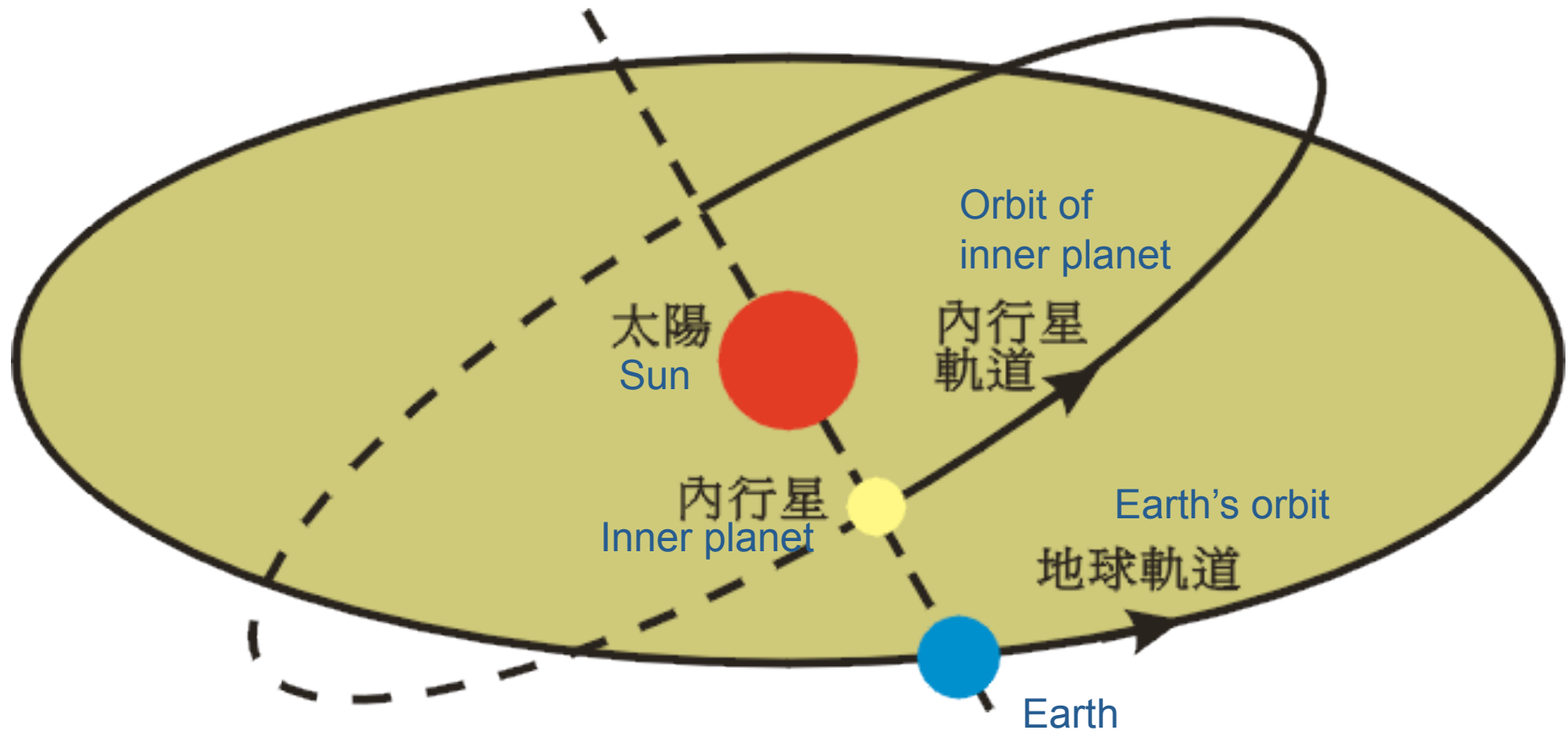
太陽黑子群
Sunspots

水星
Mercury

太陽黑子群
Sunspots



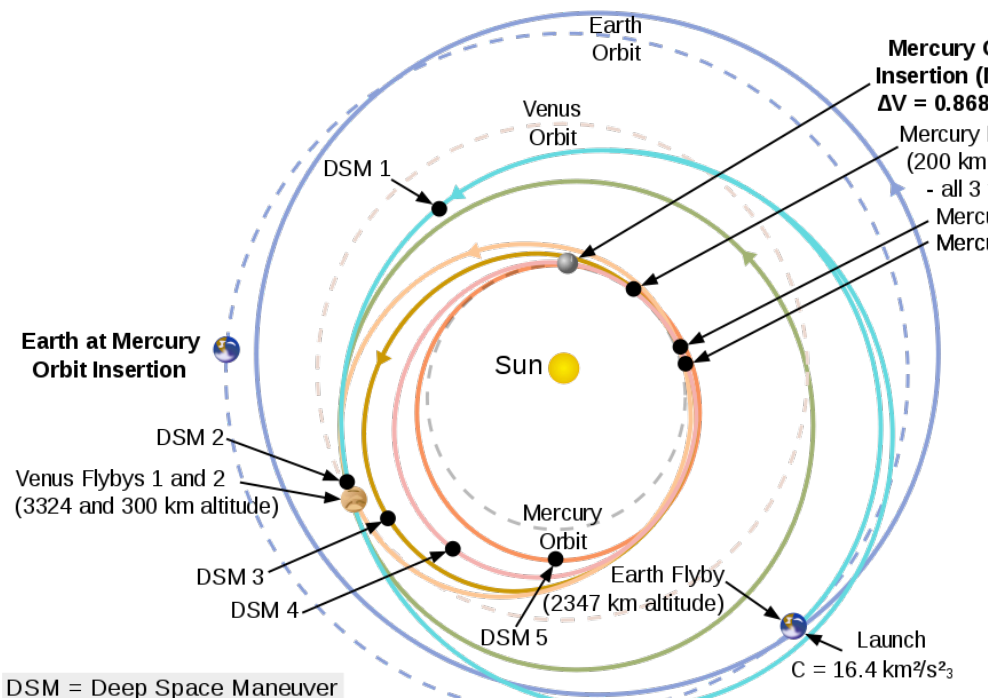
發生內行星凌日現象時 太陽、內行星及地球的相對位置 The cause of transit of inner planet



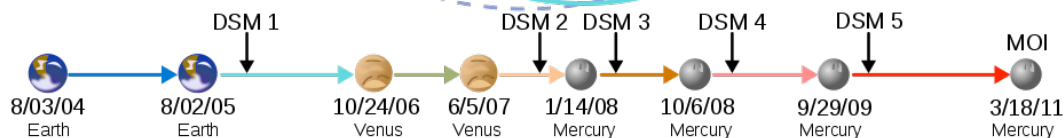
造訪水星的太空船

Mercury has been visited by spacecrafts:
Mariner 10 (1974-75) MESSENGER (2008-present)

Mariner 10 & MESSENGER 都是藉由金星的重力場飛到水星 using the gravity of Venus to adjust its route to Mercury. (The so called "gravitational slingshot")



DSM = Deep Space Maneuver



MESSENGER (MErcury Surface, Space ENvironment, GEOchemistry, and Ranging),

於2004年發射 launched on 2004

約一年後掠過地球，利用地球重力場轉向金星，
A fly-by of the Earth in 2005

在金星與地球軌道間做橢圓形運轉，第二次掠過金星時，利用金星重力場轉向水星

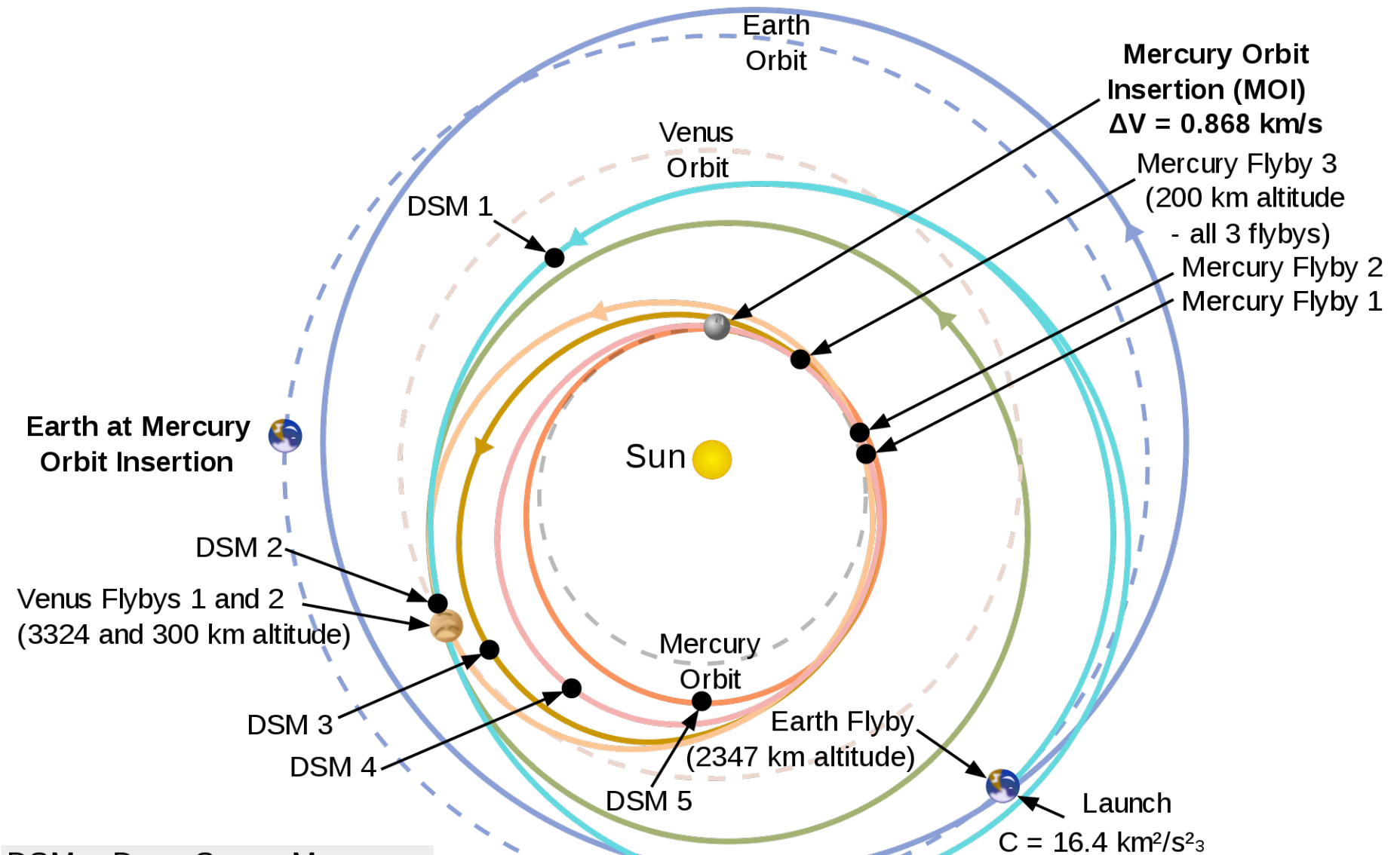
fly-by of Venus in October 2006 & June 2007

在逐漸接近水星的軌道過程中，一共掠過水星三次 (01/2008, 10/2008, 09/2009)，獲得許多影像

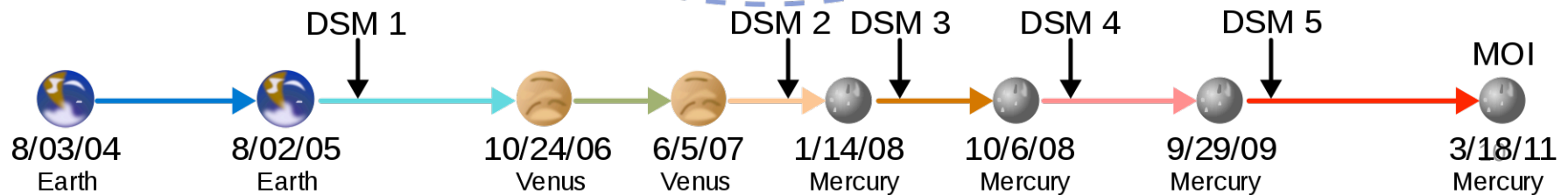
fly-by of Mercury on January 14, 2008, October 6, 2008, September 29, 2009.

終於在去年 2011年三月，進入水星軌道與水星一起運轉，從此可以好好觀測水星！

entered the orbit around the Mercury on March 18, 2011.

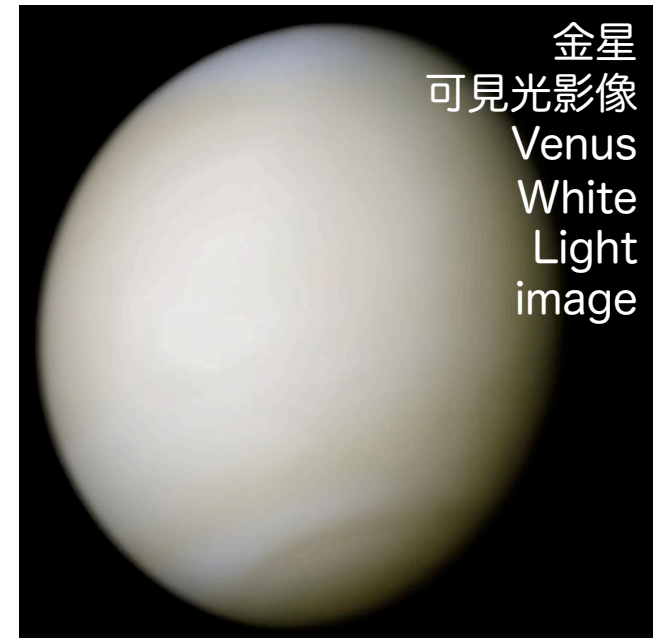


DSM = Deep Space Maneuver



金星 Venus

- 天上最亮的一顆星（只是偶爾會輸給客星）
the brightest object on the sky except Sun, Moon, and supernova, ...
 - 中國古書上稱“太白金星”
 - 傍晚出現時稱「長庚」，清晨出現時稱「啟明」
- 金星凌日 Transit of Venus：
 - 每隔一百多年發生兩次。上兩次金星凌日現象分別發生在1874年及1882年，2004年後下一次金星凌日將在2012年六月5-6日發生。
Occurrence: twice every 100s years.
For examples:
1874, 1882,
2004, 2012(June 5-6),
2117, 2125
- 平均公轉半徑 $\sim 0.72\text{AU}$
Mean distance from the Sun $\sim 0.72\text{AU}$
- 星球半徑 $\sim 0.95R_E$
Mean radius $\sim 0.95 R_E$

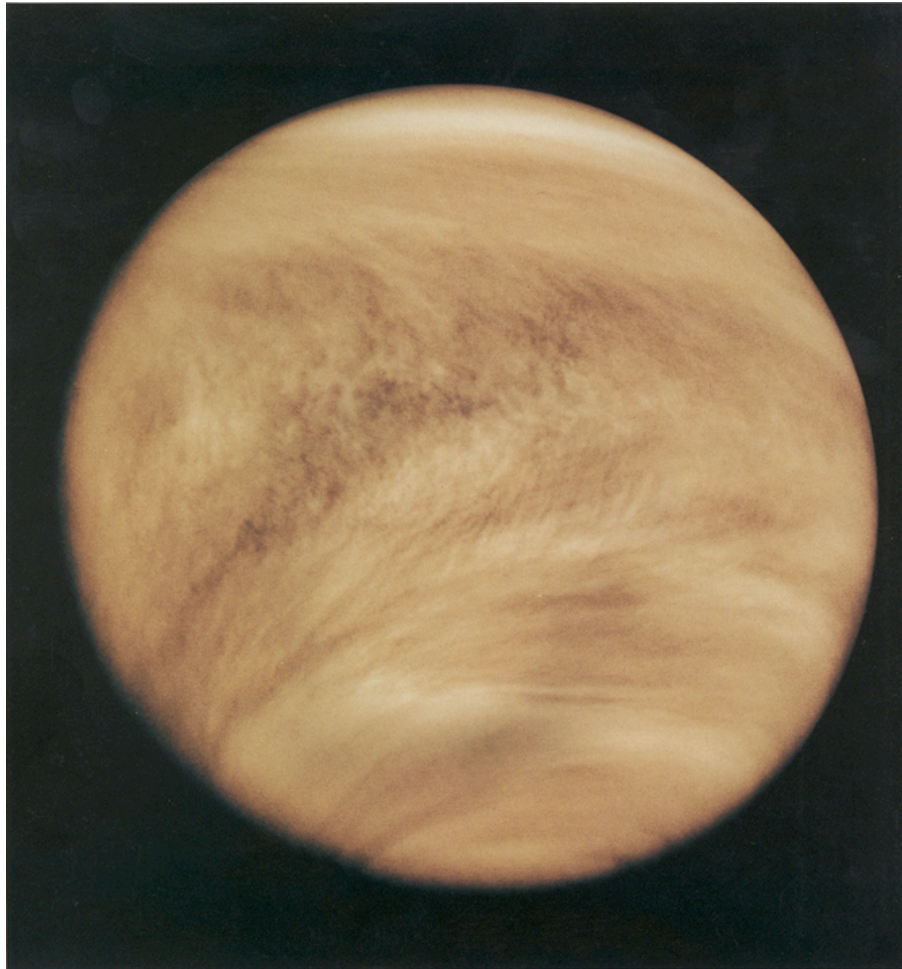


金星 Venus

UV image of Venus

SAR Obs. of Venus

SAR 觀測金星



利用“合成口徑雷達”(SAR), 可以測出地表微量的高低起伏變化, 也用來探測被雲遮蓋之金星地表結構。

SAR observations can see the surface of the Venus under the thick cloud.¹²

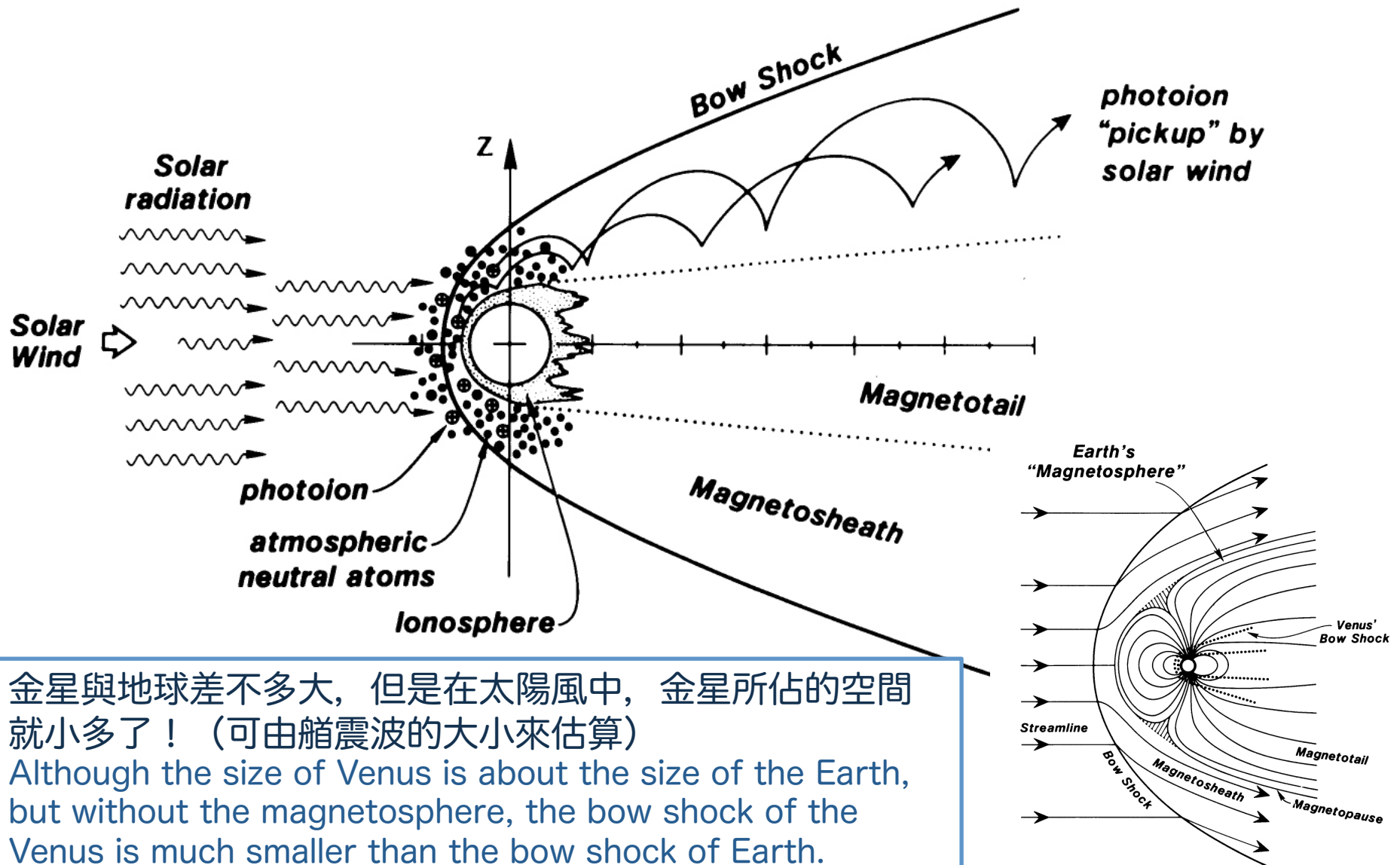
金星上可能的火山活動

Possible Volcanic Activity on Venus



- <http://www.visionsofthecosmos.co.uk/venus.htm>

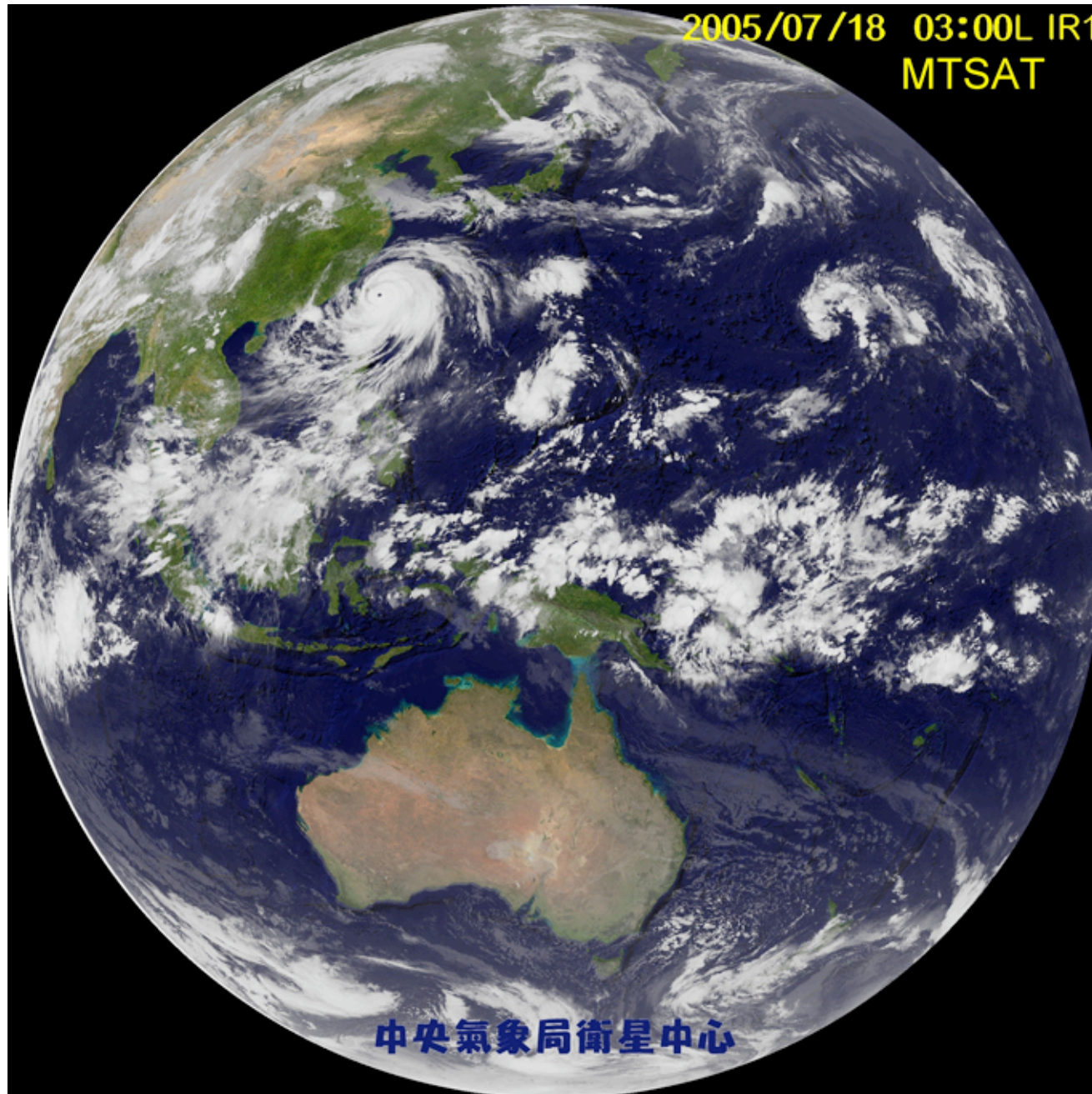
金星電離層 Venus ionosphere



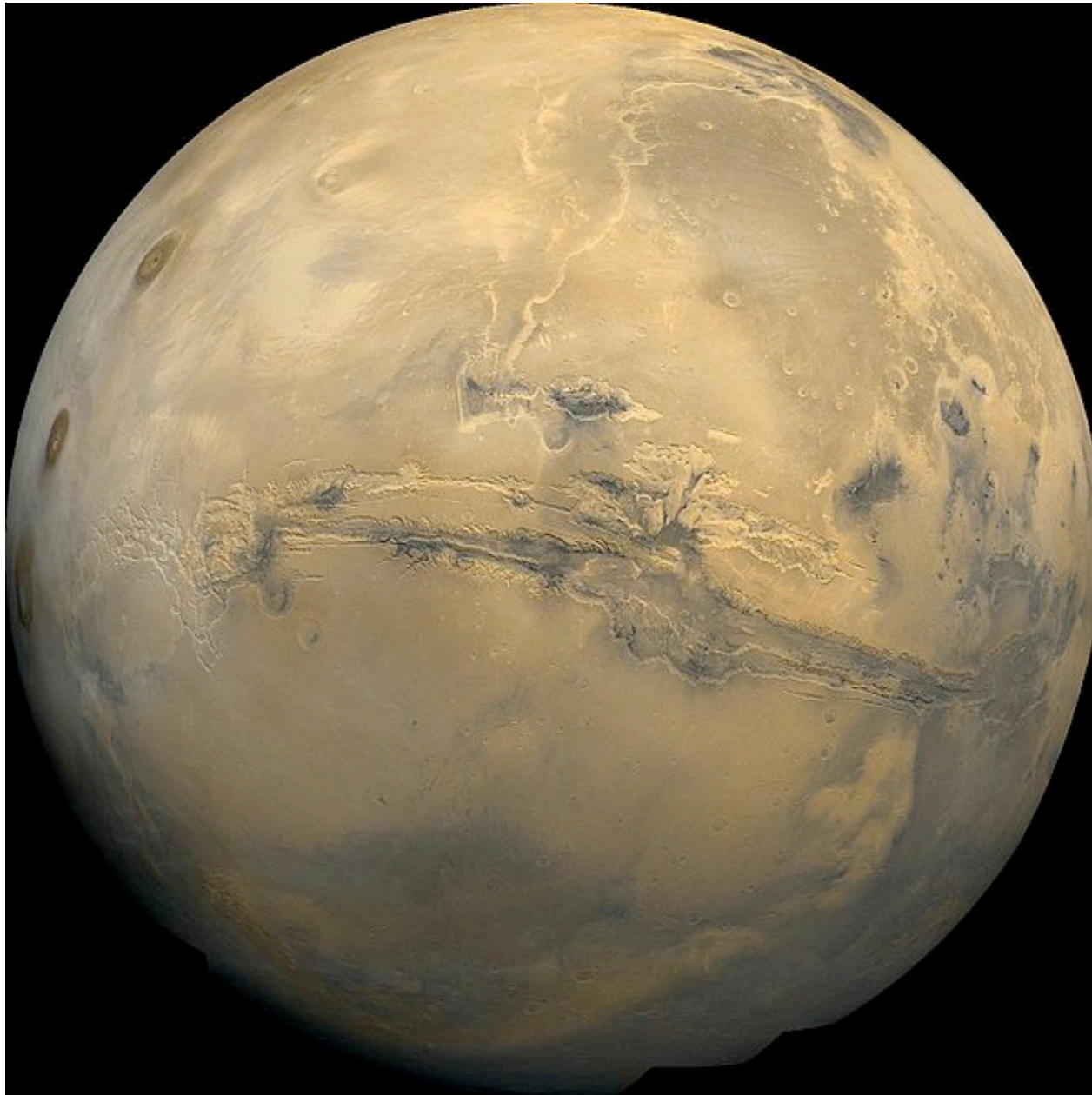
金星與地球差不多大，但是在太陽風中，金星所佔的空間就小多了！（可由船震波的大小來估算）

Although the size of Venus is about the size of the Earth, but without the magnetosphere, the bow shock of the Venus is much smaller than the bow shock of Earth.

地球 Earth



火星 Mars



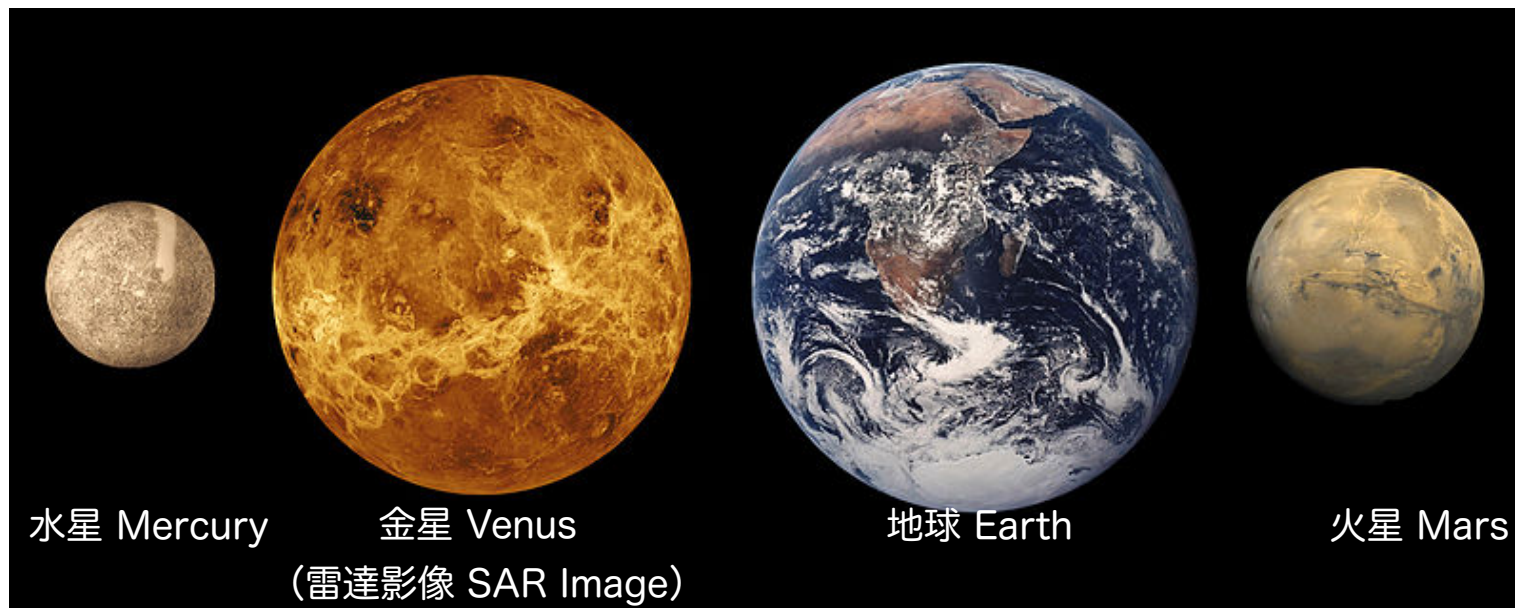
公轉週期、自轉週期(恆星日)、太陽日

Orbital Period, Spin Period (Sidereal day), Solar Day

	水星 Mercury	金星 Venus	地球 Earth	火星 Mars
平均公轉半徑 Mean distance from the Sun	~ 0.3AU	~ 0.72AU	1AU	~ 1.5AU
公轉週期 (地球日) Orbital period (days)	87.96	224.65	365	686.97
自轉週期 (地球日) Spin period (days) 恆星日 Sidereal day	58.646	-243	~ 1	1.025
太陽日 (地球日) Solar day (days)	175.938	116.73	~ 1	~ 1
金星自東向西轉 Venus rotates in the opposite direction 金星自轉的轉速非常慢，但是因為自轉反過來轉，所以金星的太陽日比水星太陽日還短				

類地行星 Terrestrial Planets

	水星 Mercury	金星 Venus	地球 Earth	火星 Mars	月亮 Moon
大氣層 atmosphere	No	Yes	Yes	No	No
電離層 ionosphere	No	Yes	Yes	No	No
磁層 magnetosphere	Yes	No	Yes	No	No
板塊上有殘存磁性 with crust magnetic field	should be	unknown	Yes	Yes	Yes



類似木星的行星（類木行星）

Jovian planets (or gas giants, or giant planets)

- 類木行星的共同特性：

Common features of the Jovian planets

- 有環、有大氣、有電離層、有磁層、有許多顆衛星、質量大所以表面大氣壓力大、自轉快，所以表面風暴多

rings, atmosphere, ionosphere, magnetosphere, numerous moons, fast rotation, and storms

- 類木行星包括： Jovian planets (or gas giants) in the solar system

木星 Jupiter

土星 Saturn

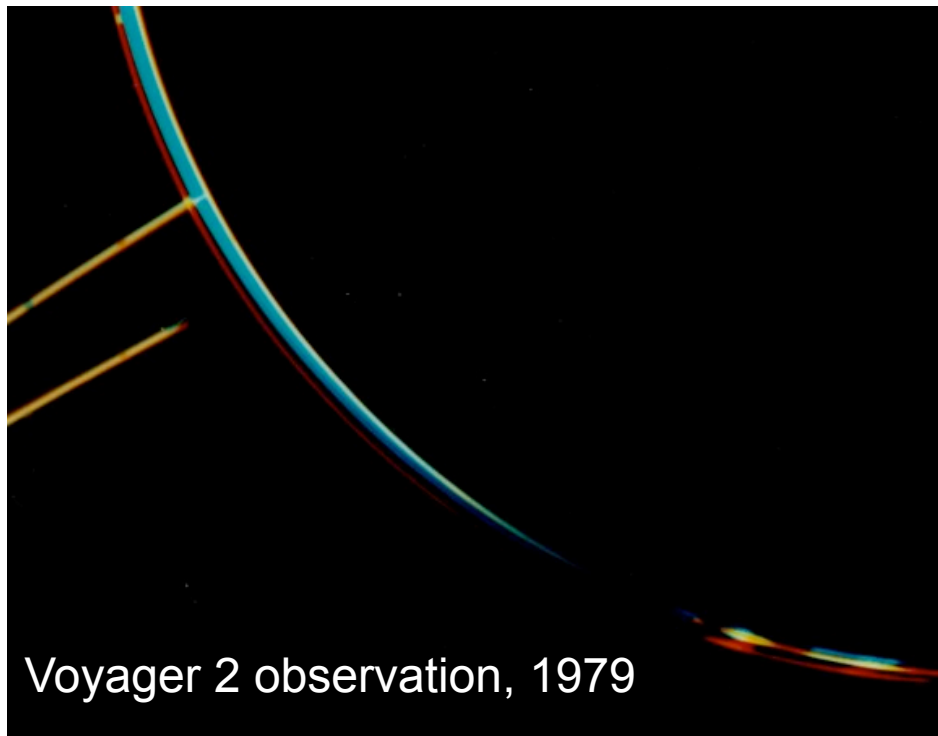
天王星 Uranus

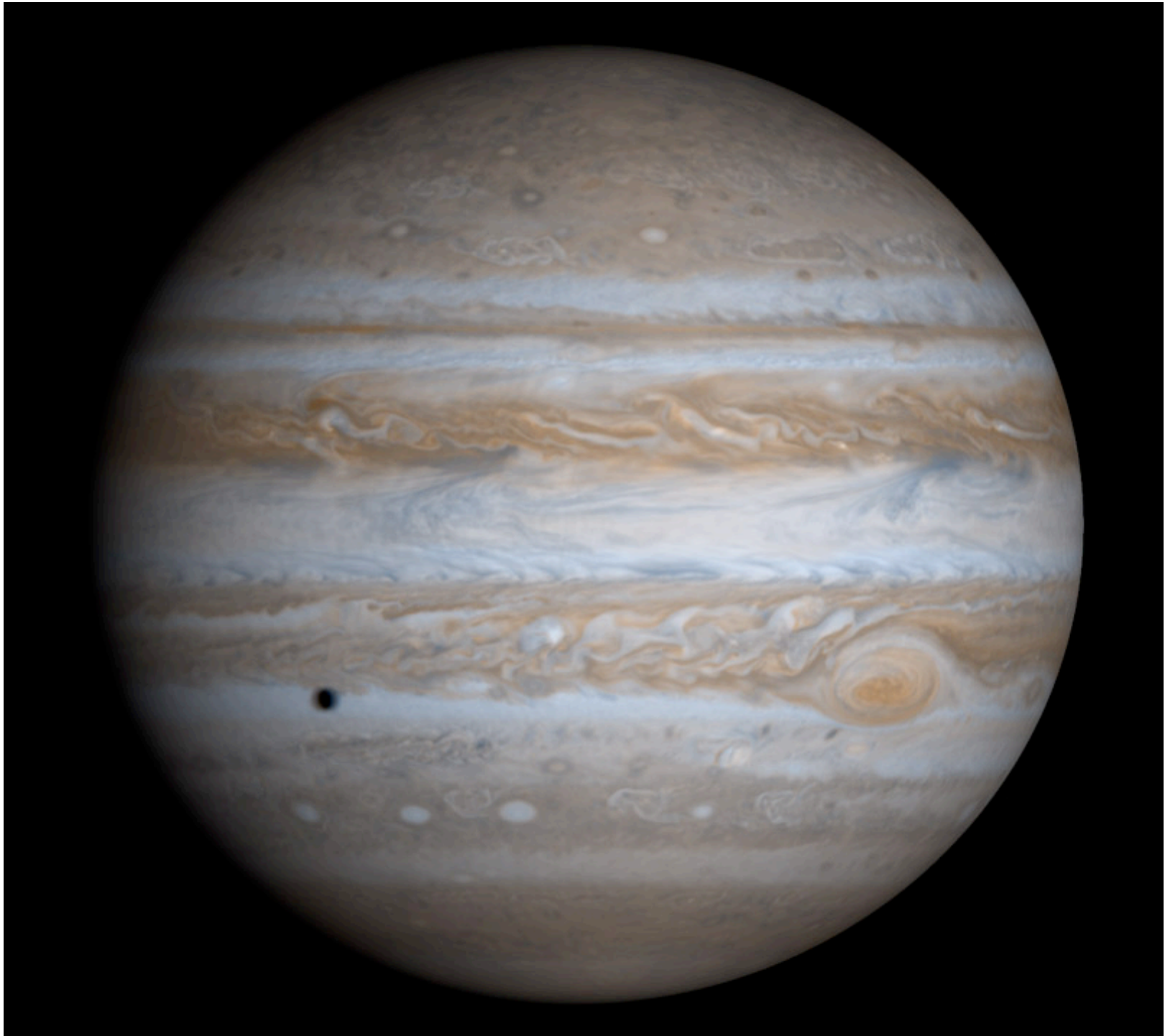
海王星 Neptune

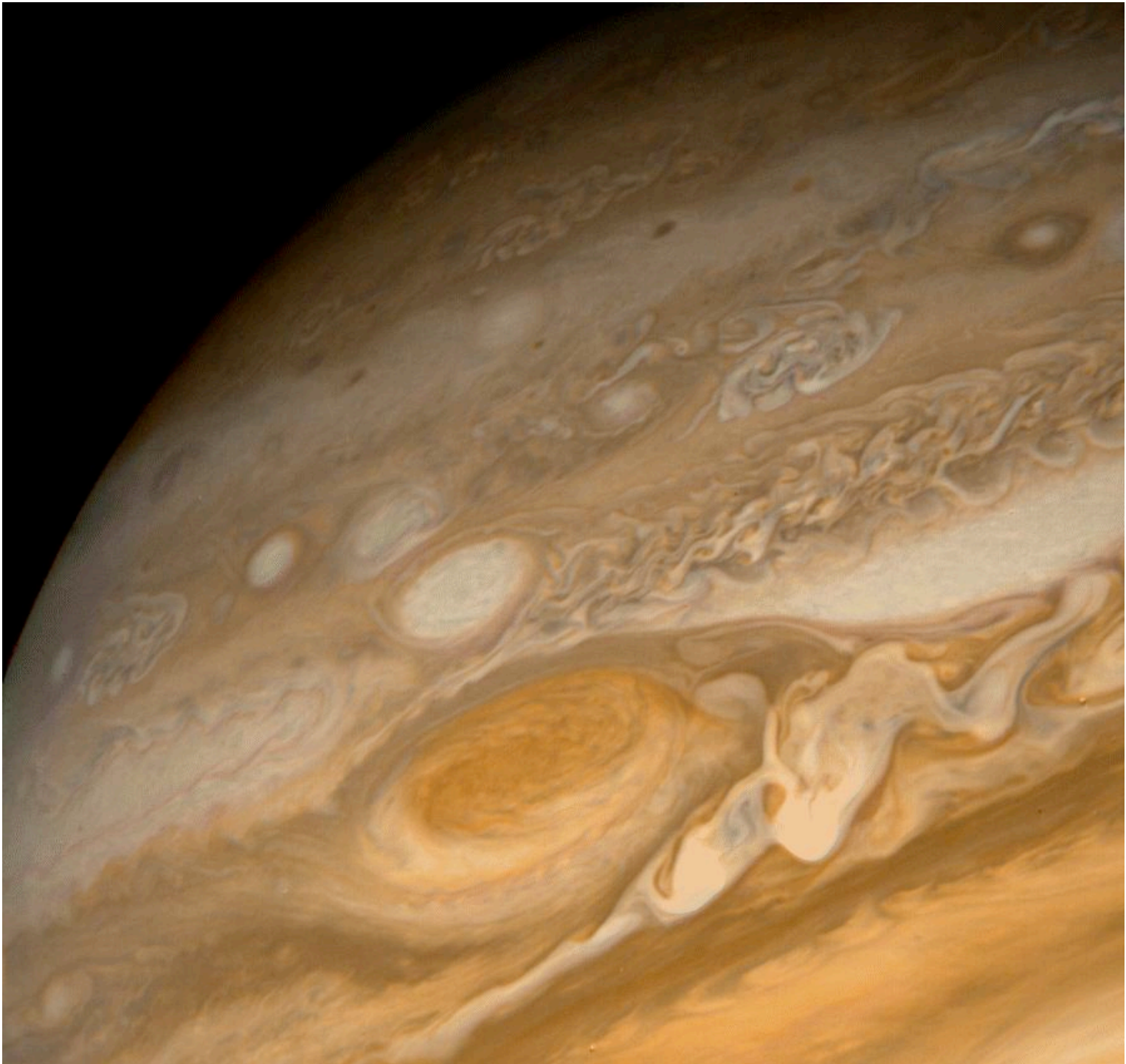
木星 Jupiter

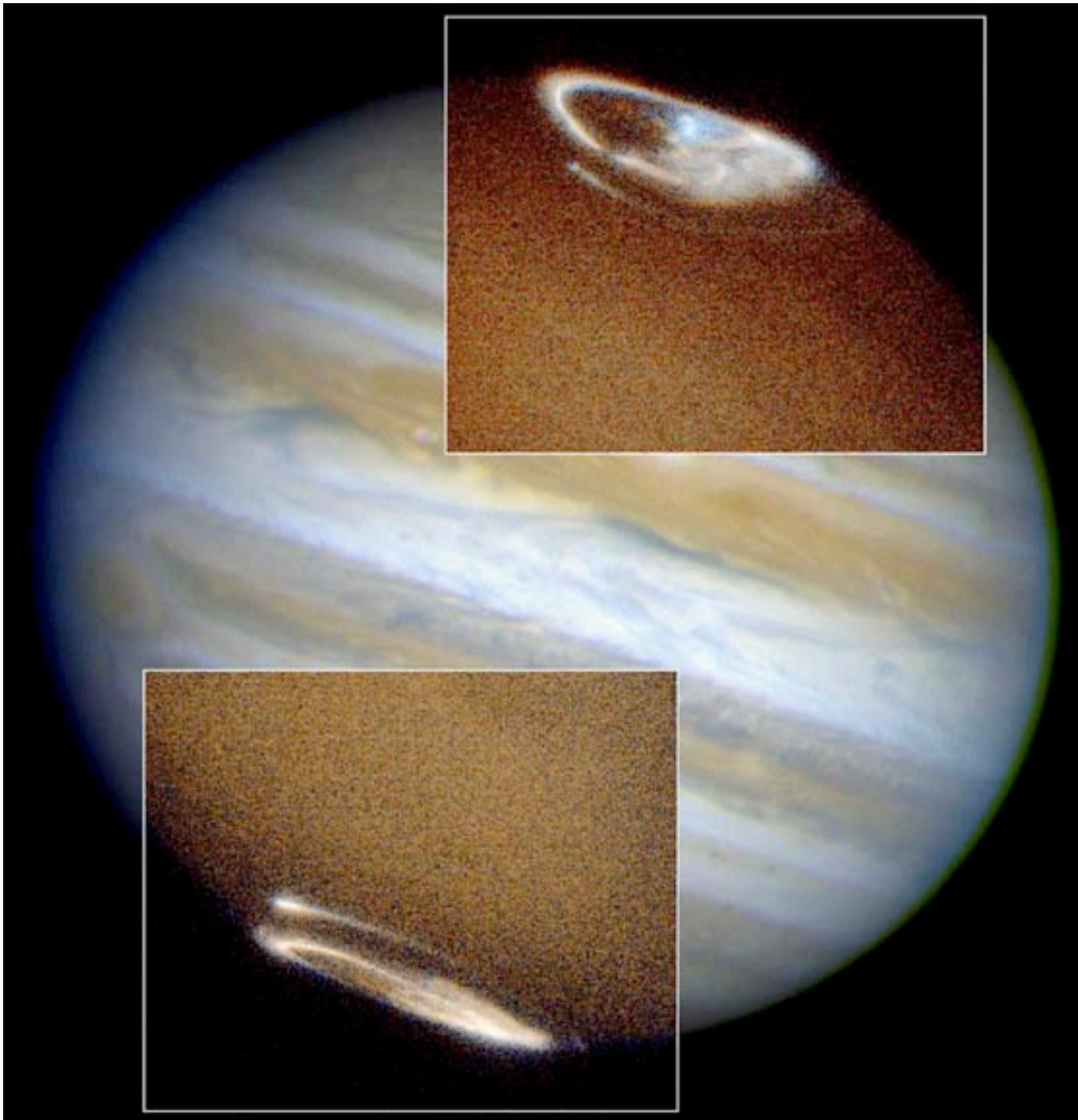
木星公轉一周，地球過12年
Orbital period of Jupiter : 12 years

- 特色：大紅斑(redspot)、極光(Aurora)、許多衛星(many satellites)，常有火山活動的依奧衛星(Volcanic activities on Io)，四顆主要衛星所通過的磁場線會造成極光橢圓圈外的極光活動現象(auroral brightening at the magnetic foot points along the paths of the four large satellites)
- http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-jupiter.html
- http://en.wikipedia.org/wiki/Rings_of_Jupiter
- <http://solarsystem.nasa.gov/planets/profile.cfm?Object=Jupiter&Display=Rings>





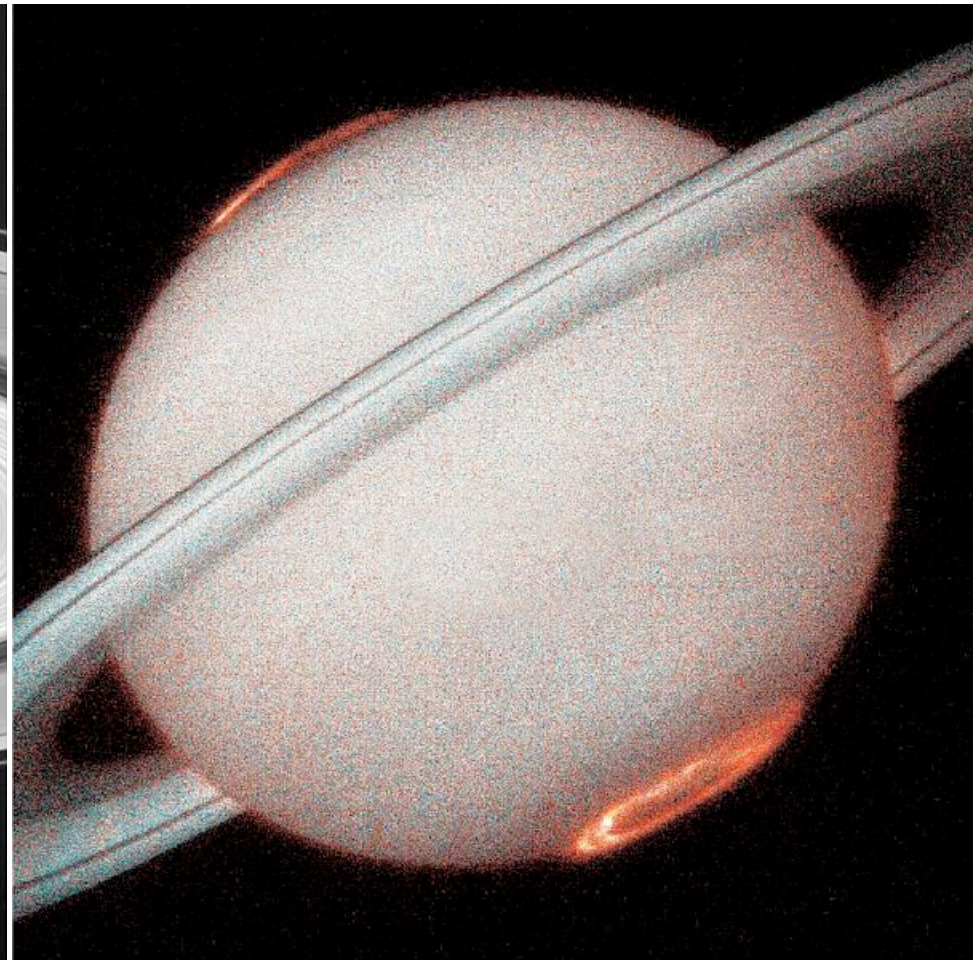
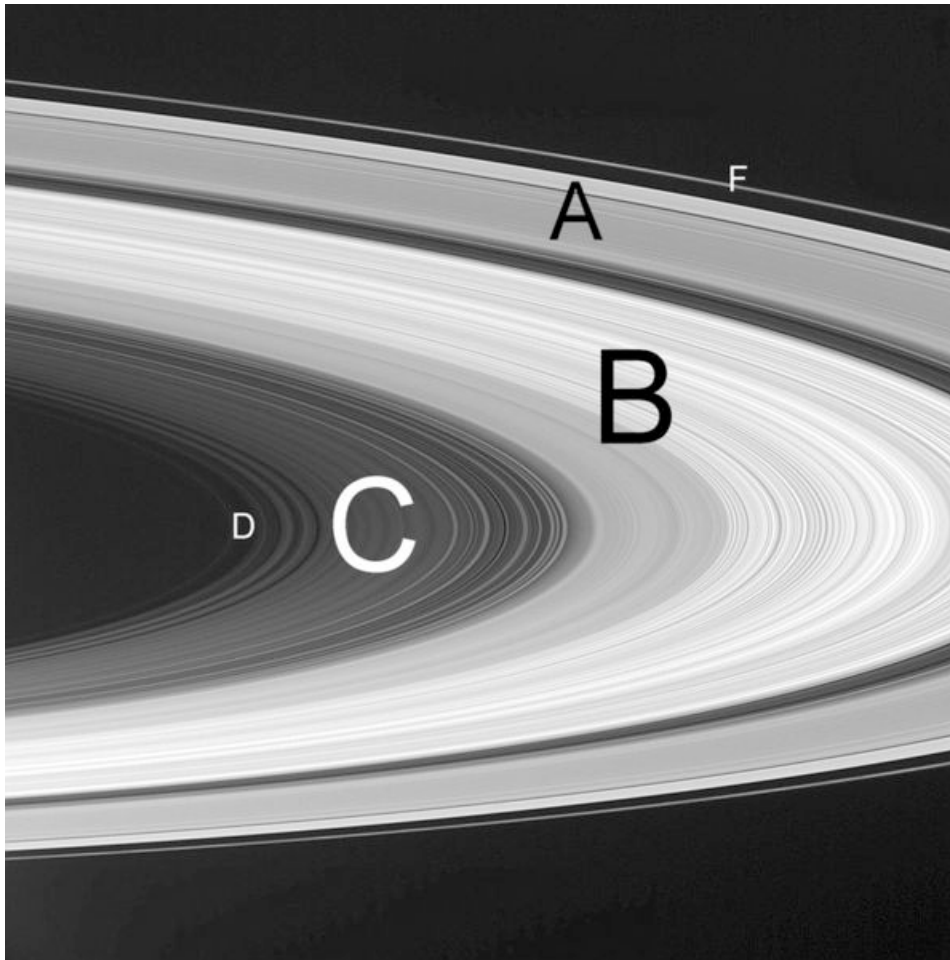




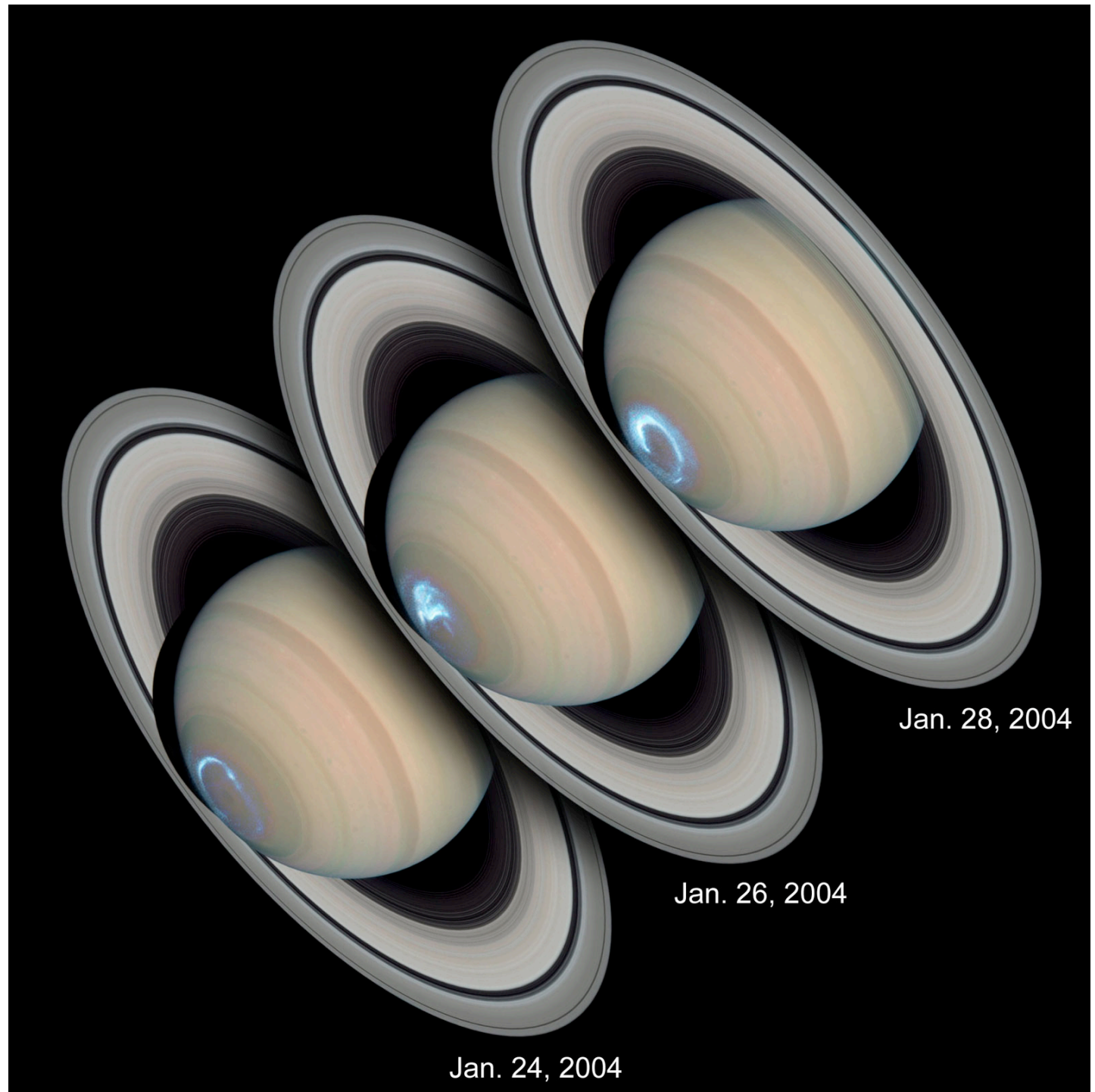
土星 Saturn

土星公轉一周，地球過30年
Orbital period of Saturn : 30 years

- http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-saturn.html
- 特色：環(Ring)，極光(Aurora)，偶而出現的風暴(Occasional Storm)，北極區六角形的駐波(Saturn's Hexagon standing wave at north pole)

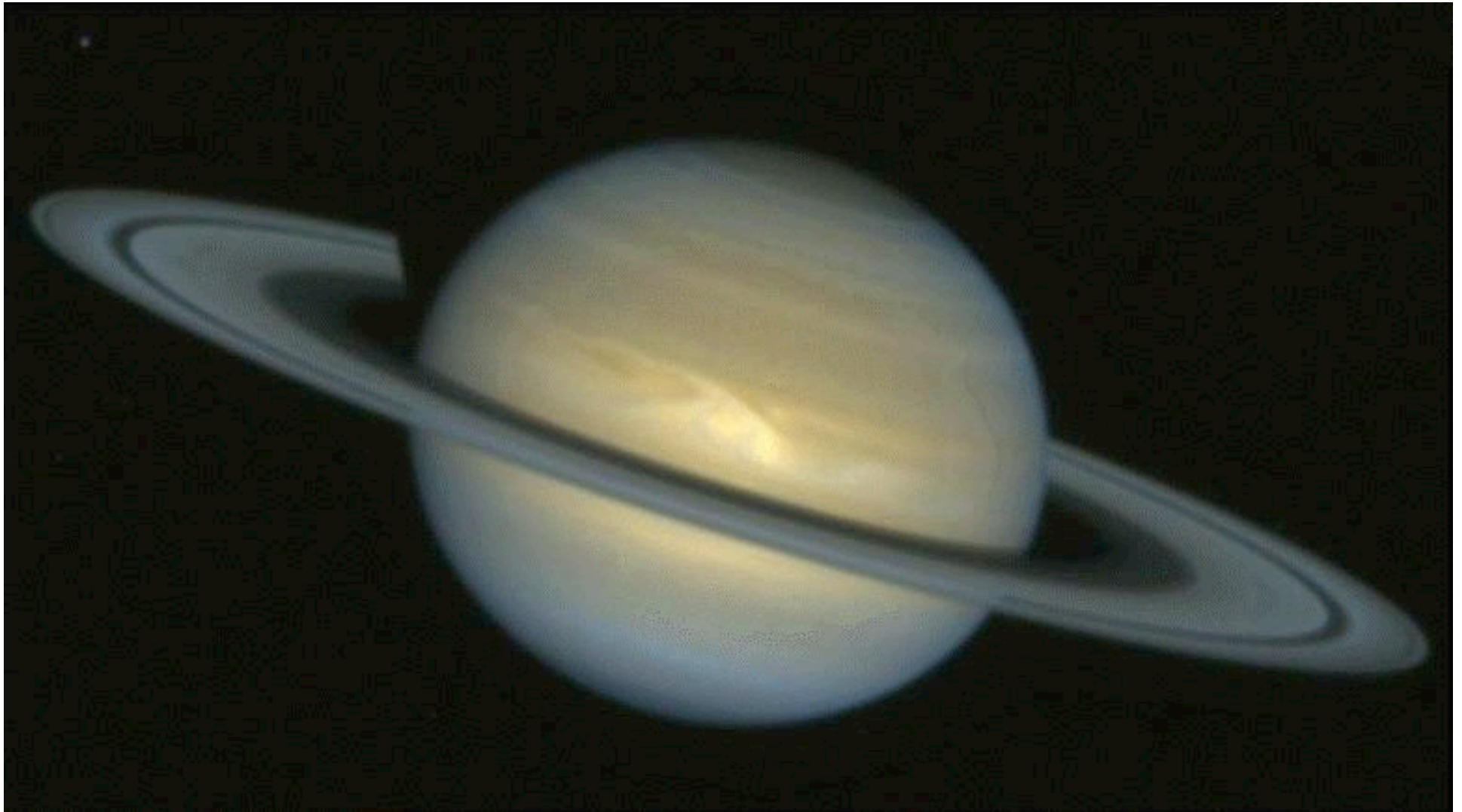


土星
Saturn
極光
Aurora

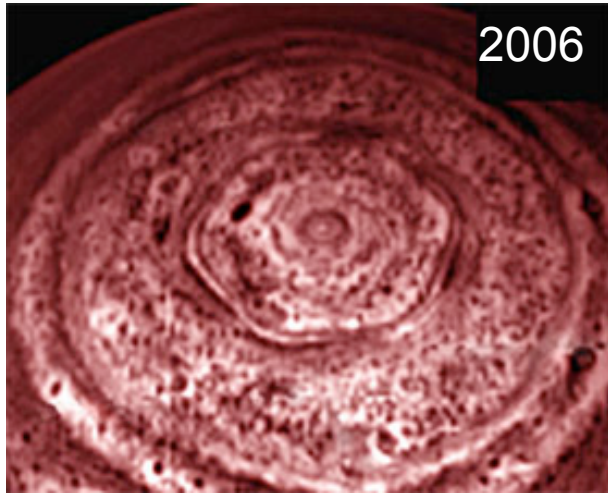


土星 Saturn

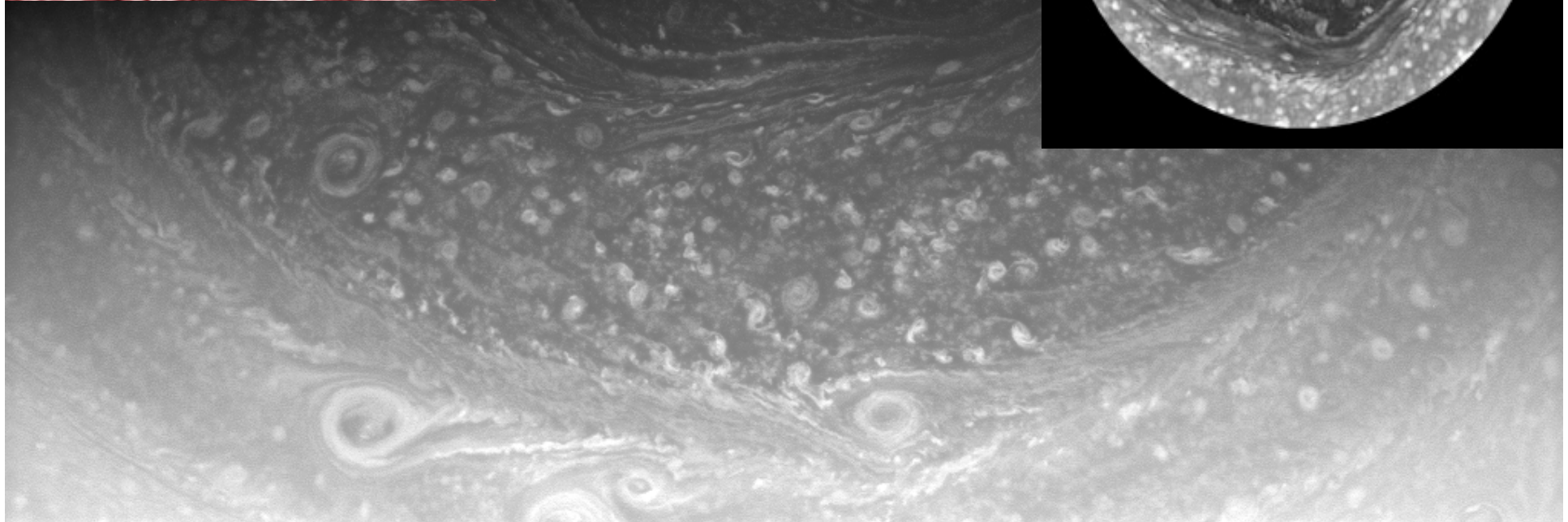
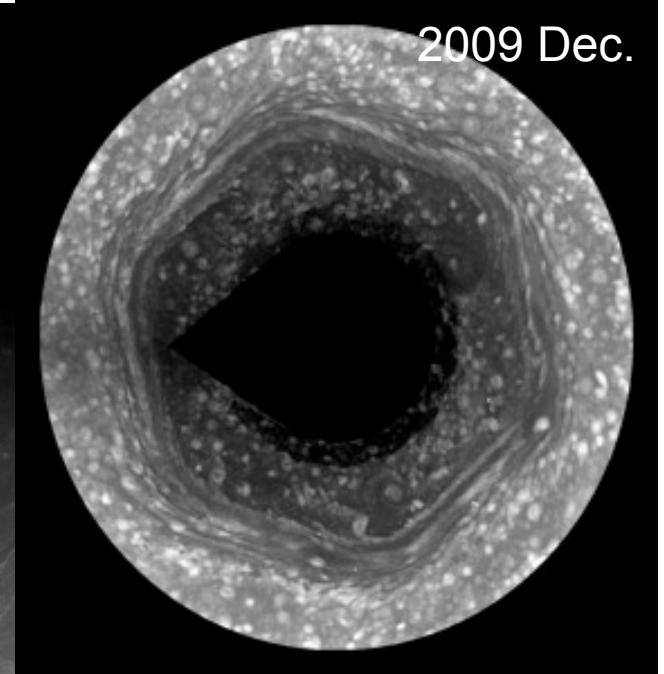
偶而出現的風暴 Storm on Saturn



Cassini Observation of Saturn's Hexagon at North Pole



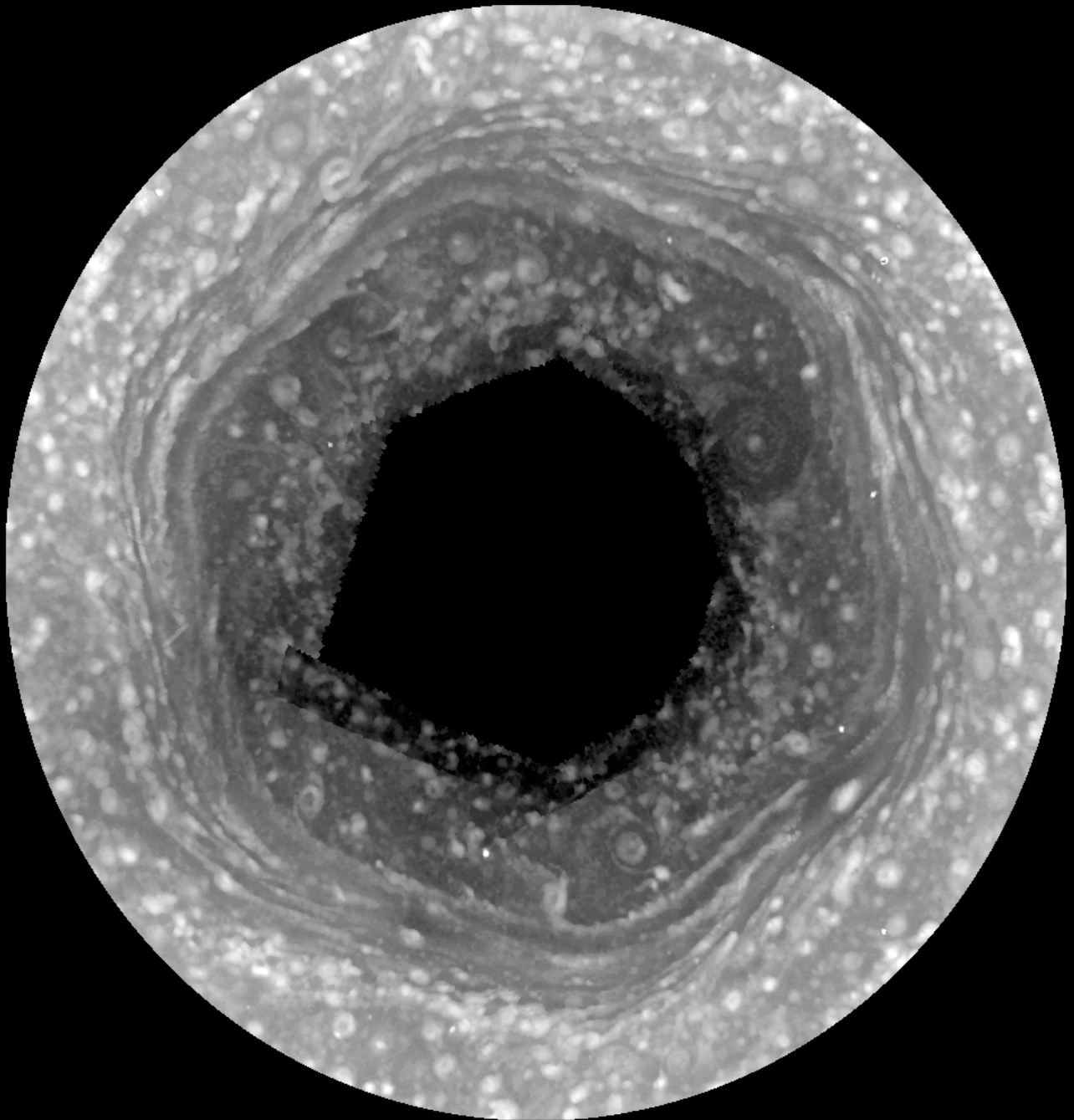
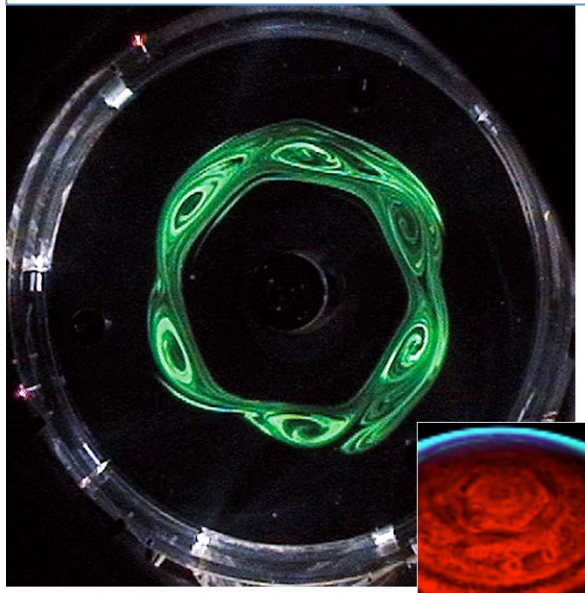
2009 Feb.



Saturn's Hexagon at North Pole 2009 Dec.

牛津大學學者做出八角
形環型駐波氣流結構
(2010/04)

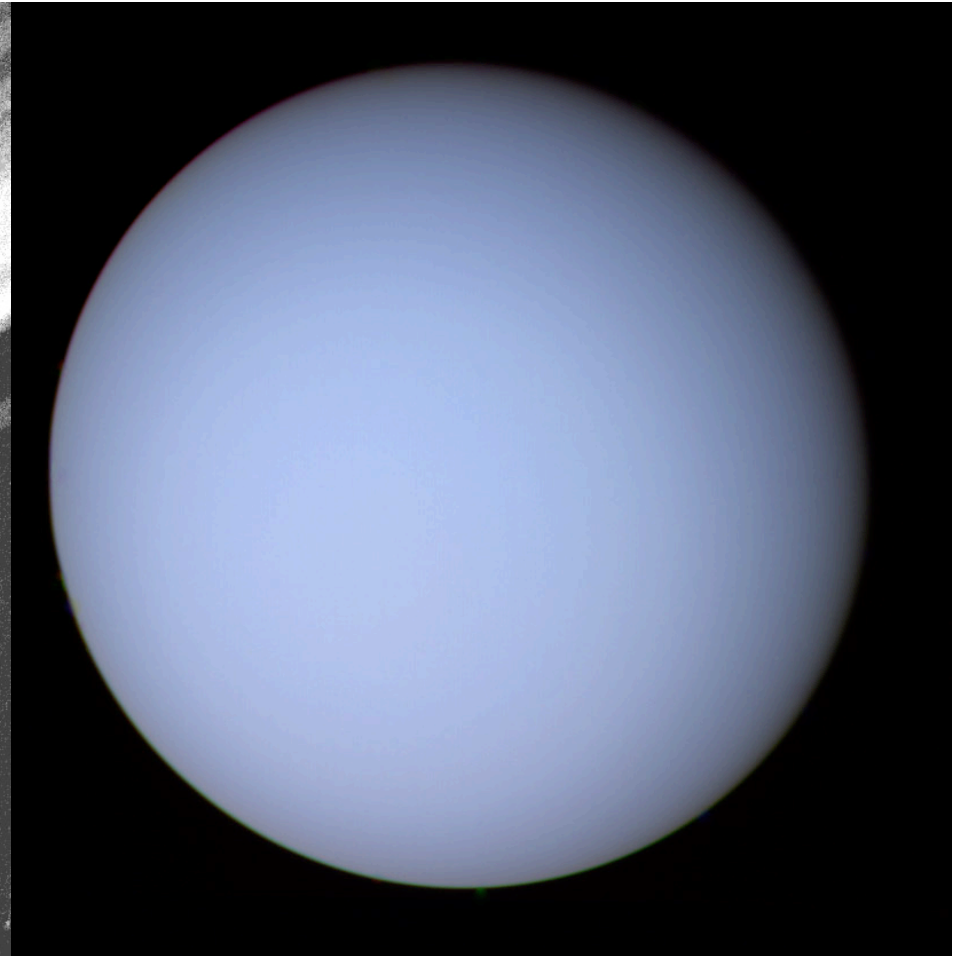
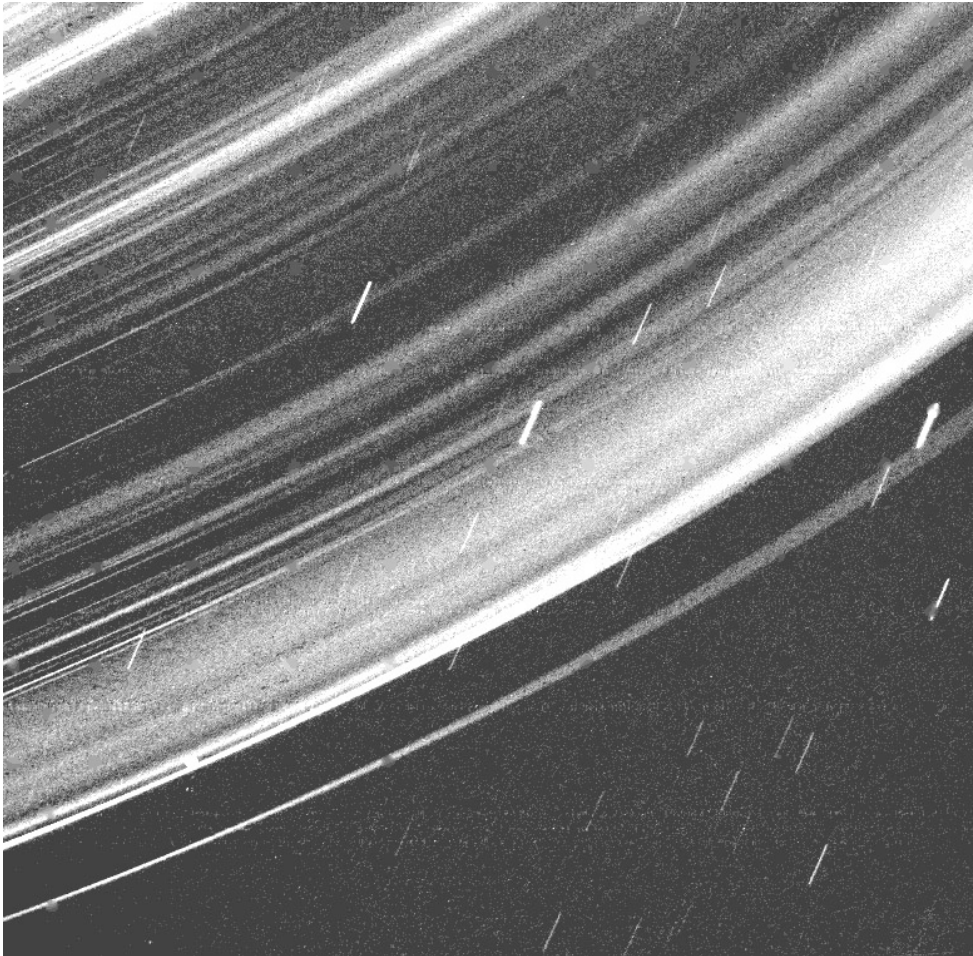
A hexagonal shaped flow
by Ana Claudia Barbosa
Aguiar and Peter Read



天王星 Uranus

天王星公轉一周，地球過85年
Orbital period of Uranus : 85 years

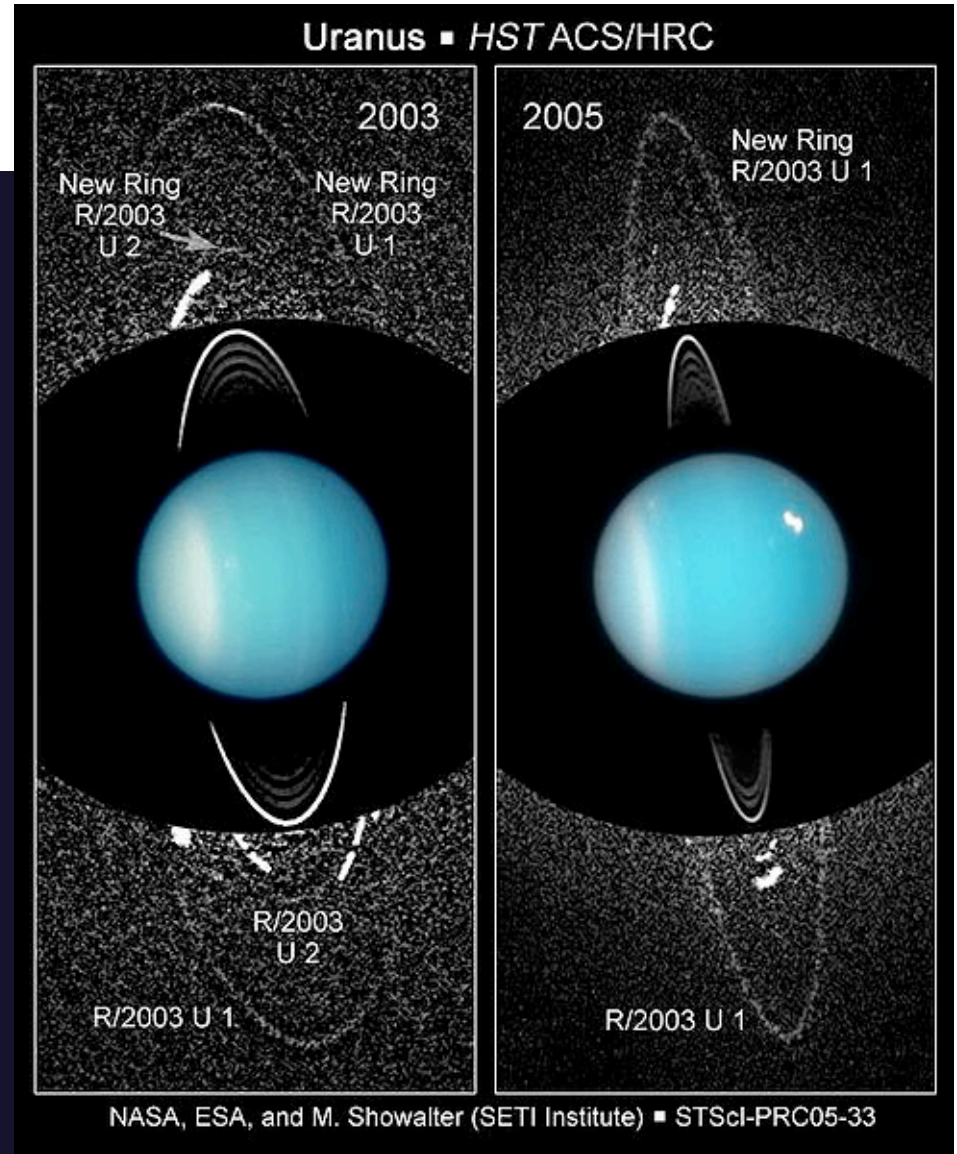
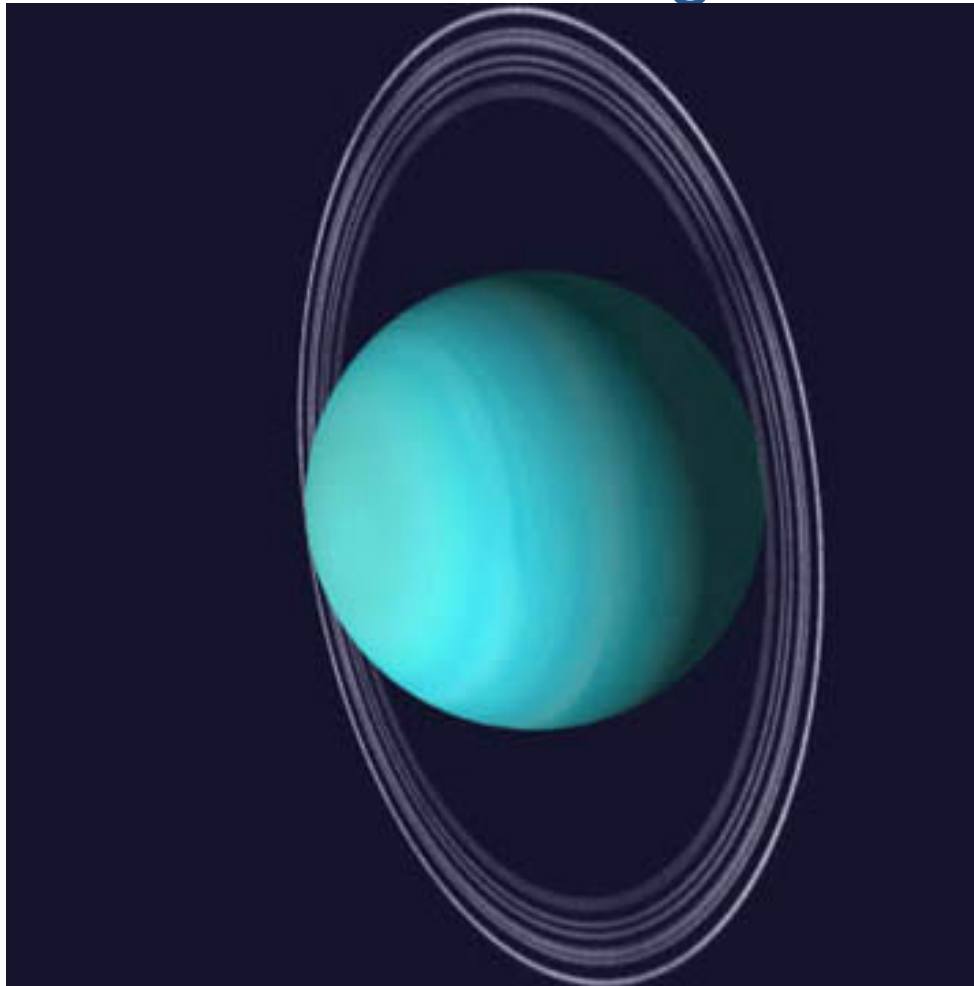
- http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-uranus.html
- 被打散後重新結合，躺著打轉 its axis of rotation is tilted sideways
- <http://nssdc.gsfc.nasa.gov/planetary/factsheet/uranringfact.html>



天王星 Uranus

- 被打散後重新結合? 躺著打轉
its axis of rotation is tilted sideways, nearly into the plane of its revolution about the Sun.
- 有多圈環 has rings

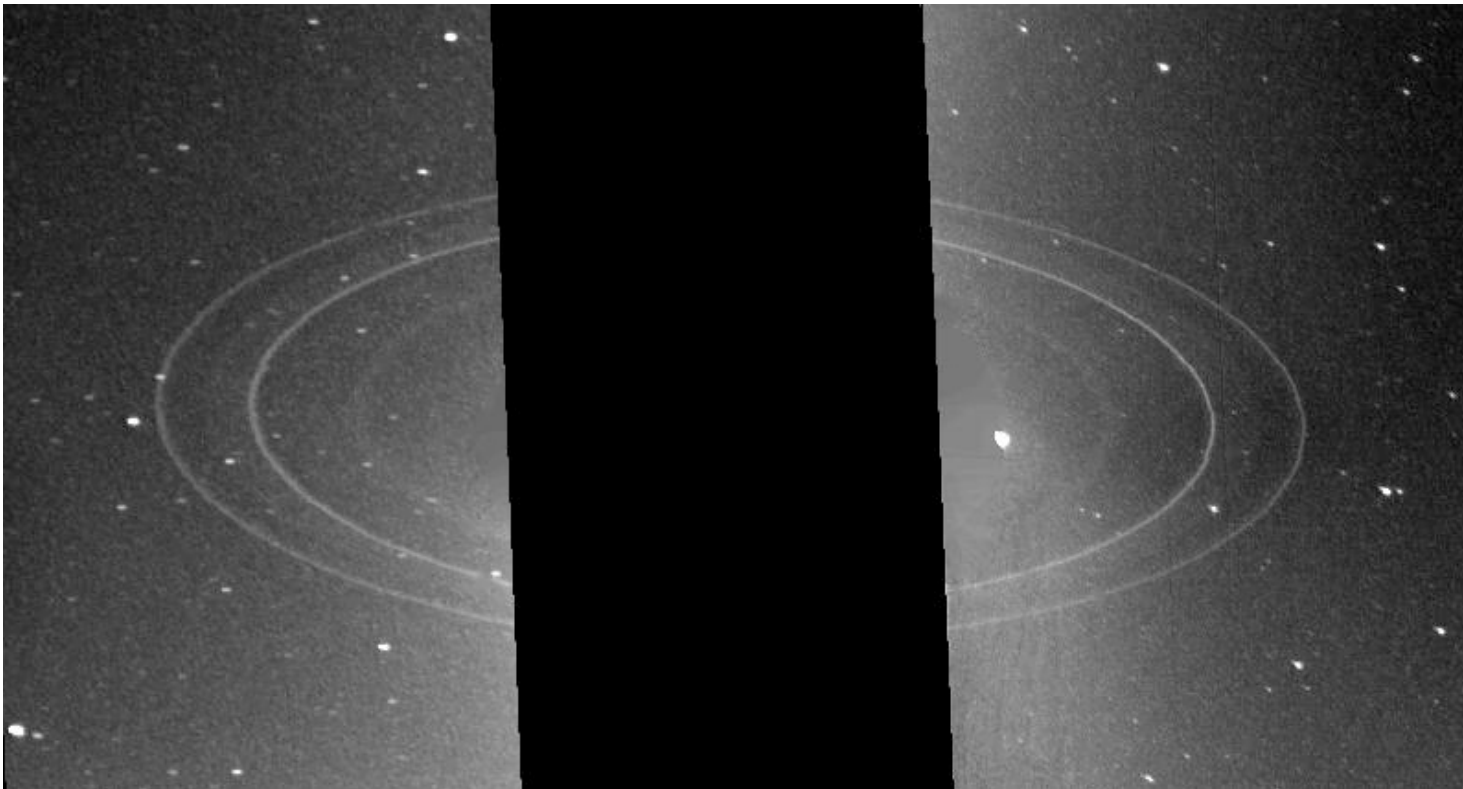
http://en.wikipedia.org/wiki/Rings_of_Uranus



海王星 Neptune

海王星公轉一周，地球過165年
Orbital period of Neptune : 165 years

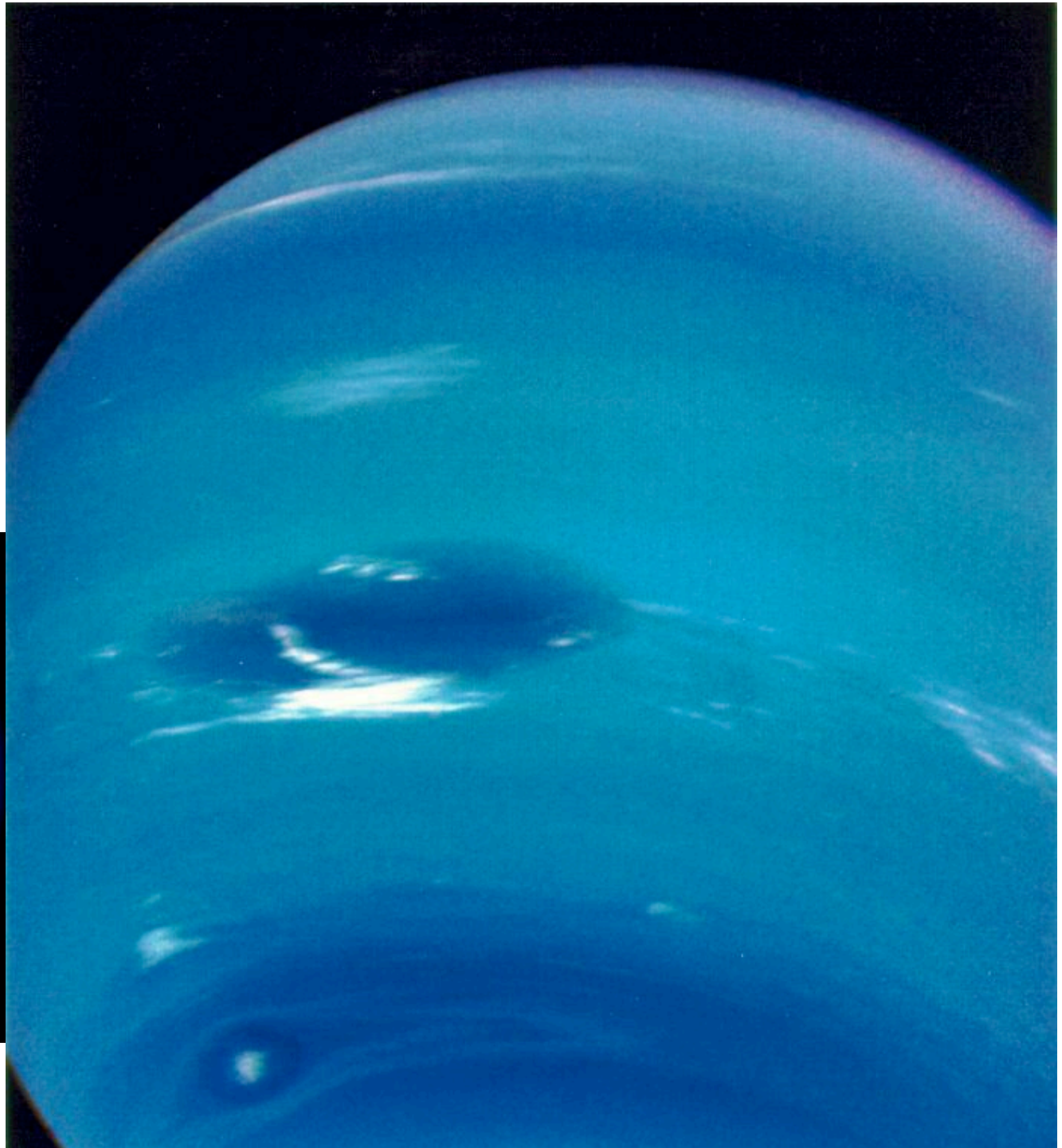
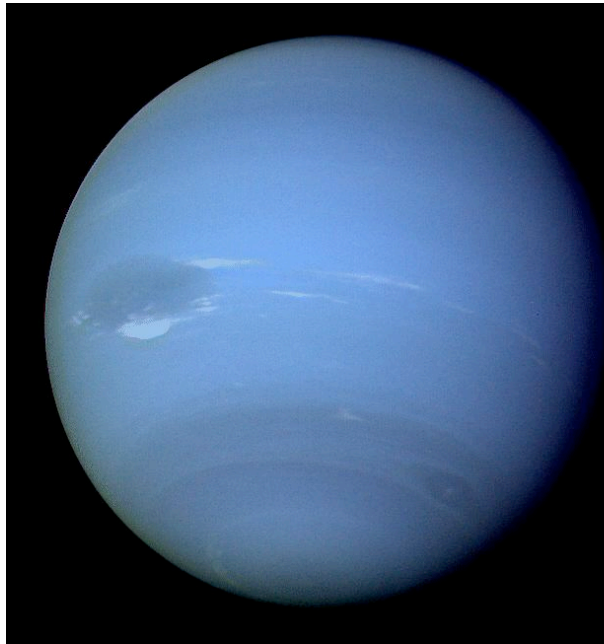
- http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-neptune.html
- http://en.wikipedia.org/wiki/Rings_of_Neptune
- 特色：環(Rings)、出現過一段時間的風暴(Storm shown as a dark spot)、衛星(Satellites)



海王星

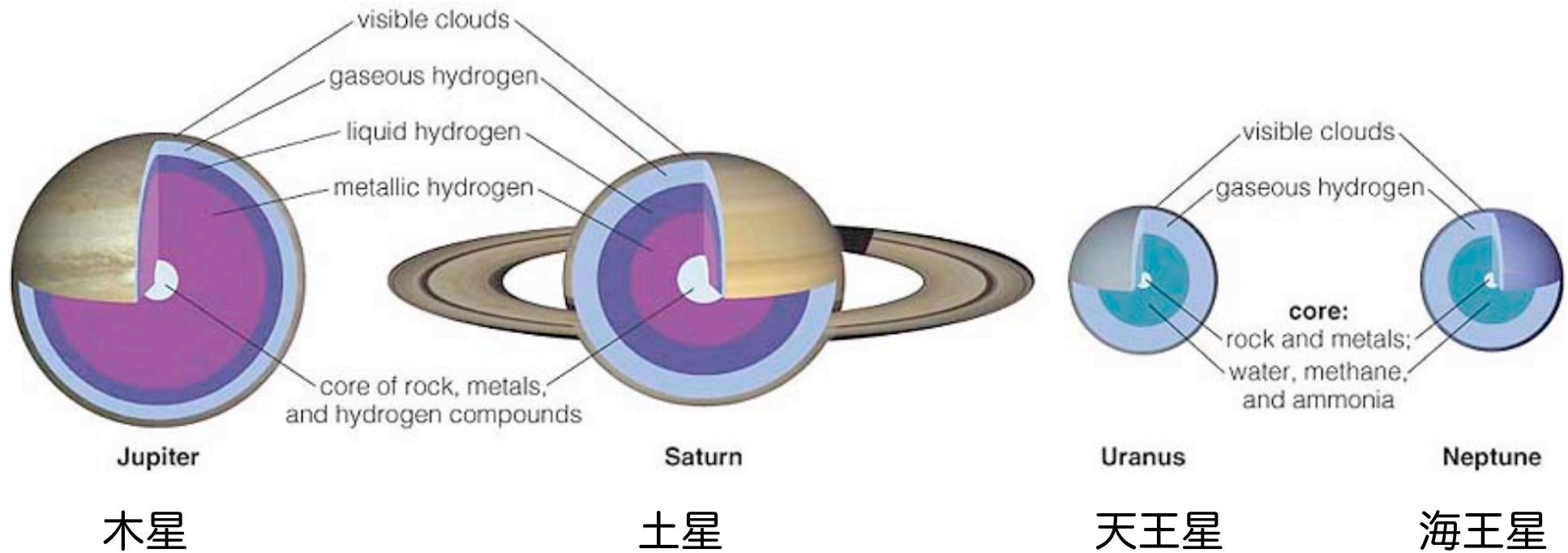
Neptune

- 大小風暴
dark-spot storms
- 雲層結構 clouds



類木行星的內部結構

Interior of Jovian Planets

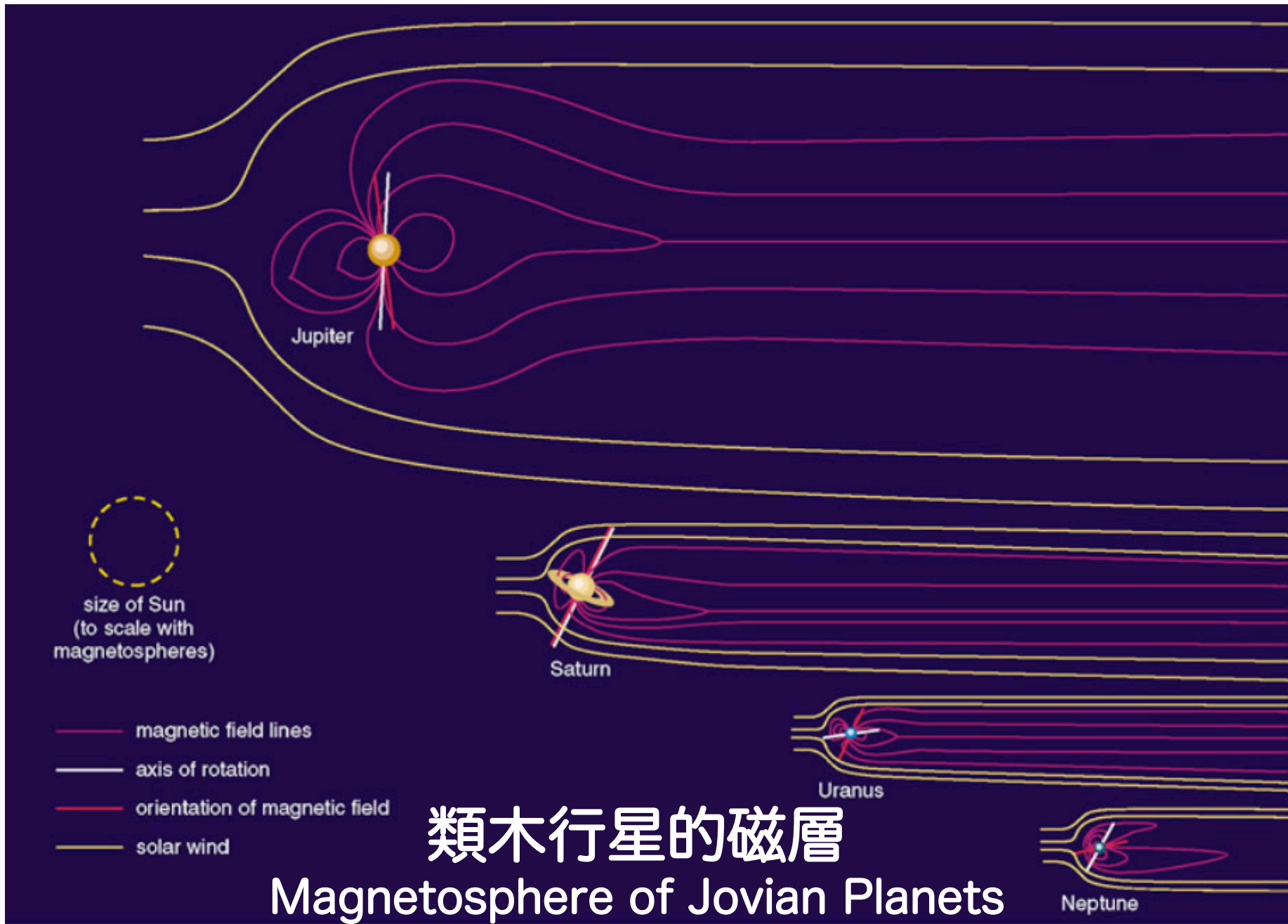


類木行星的磁層與衛星

Magnetosphere and Moons of Jovian Planets

- 木星 Jupiter：極光(aurora)、63顆衛星(63 moons)
 - 南向磁場強度 Southward dipole field strength: 4.28 Gauss at $R_j = 71,398$ km
- 土星 Saturn：極光(aurora)、62顆衛星 (62 moons)
 - 南向磁場強度 Southward dipole field strength: 0.21 Gauss at $R_s = 60,330$ km
- 天王星 Uranus：自轉軸與公轉軸夾角97.77度、27顆衛星(27 moons)
 - 磁軸與自轉軸夾角 58.6度 The angle between the dipole axis and rotation axis is 58.6°
 - 磁軸偏移中心約 0.3 R_u The dipole axis is offset by 0.3 R_u from the center of Uranus
 - 南向磁場強度 Dipole field strength: 0.228 Gauss at $R_u = 25,000$ km
- 海王星 Neptune：可能正在快速反轉中的磁極、13顆衛星(13 moons)
 - 磁軸與自轉軸夾角 46.9 度 The angle between the dipole axis and rotation axis is 46.9°
 - 磁軸偏移中心約 0.55 R_n The dipole axis is offset by 0.55 R_n from the center of Neptune
 - 磁場強度 Dipole field strength: 0.142 Gauss at $R_n = 24,765$ km

比較：地球磁場強度 0.3 Gauss at $R_e = 6,378$ km
Dipole field strength of the Earth: 0.3 Gauss at $R_e = 6,378$ km

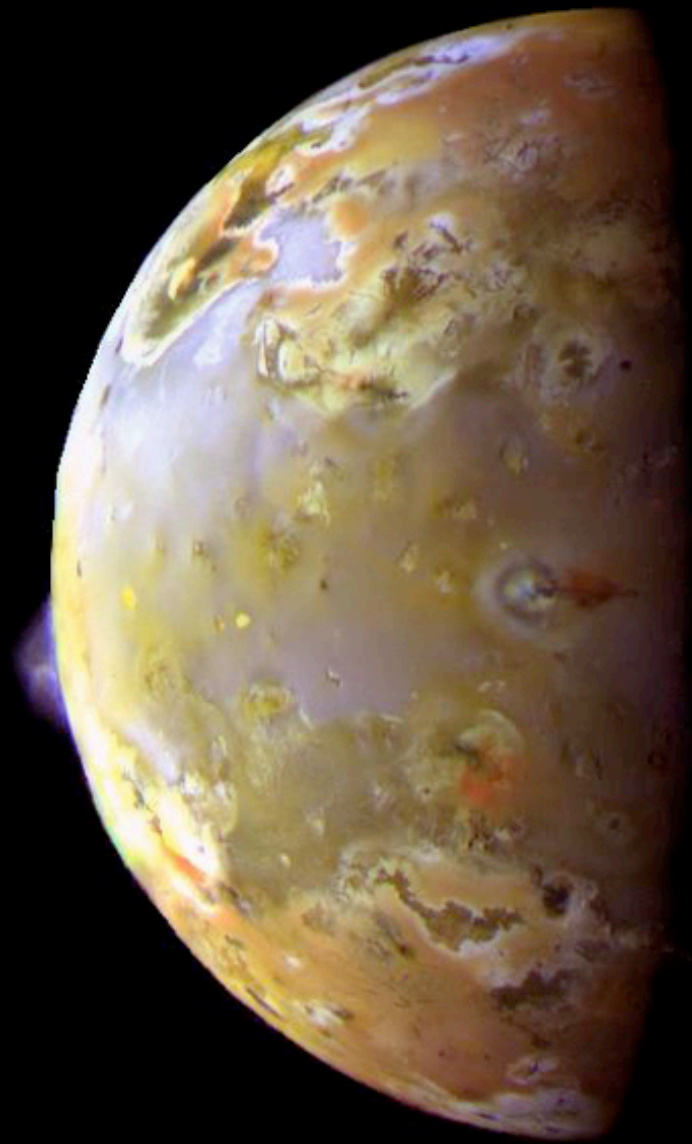




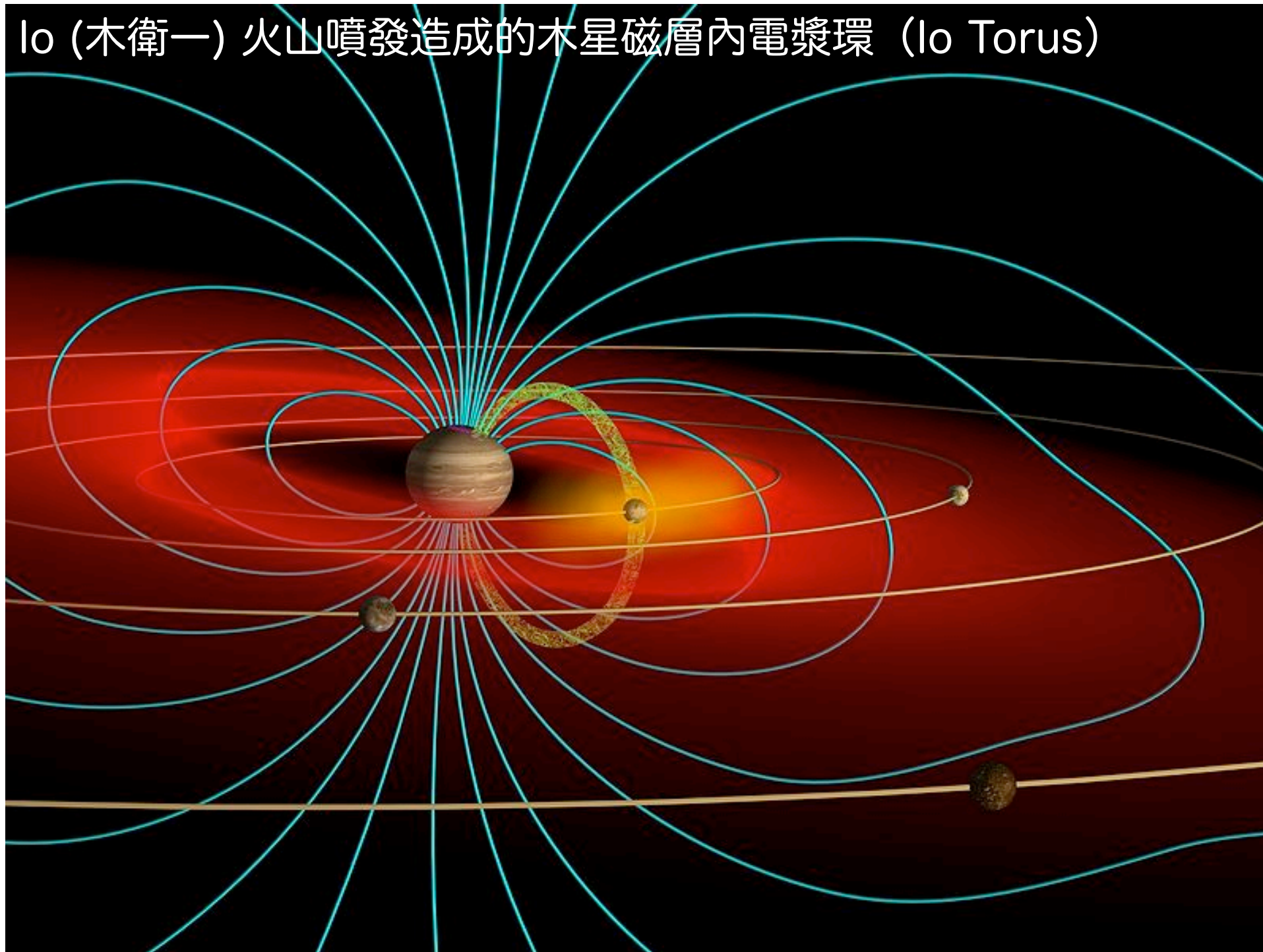
由於木星的衛星依奧有火山，有大氣，因此可提供電漿，在木星磁層中，形成一個甜甜圈餅一般的電漿環，因此木星的磁層結構與地球磁層結構不太相同。

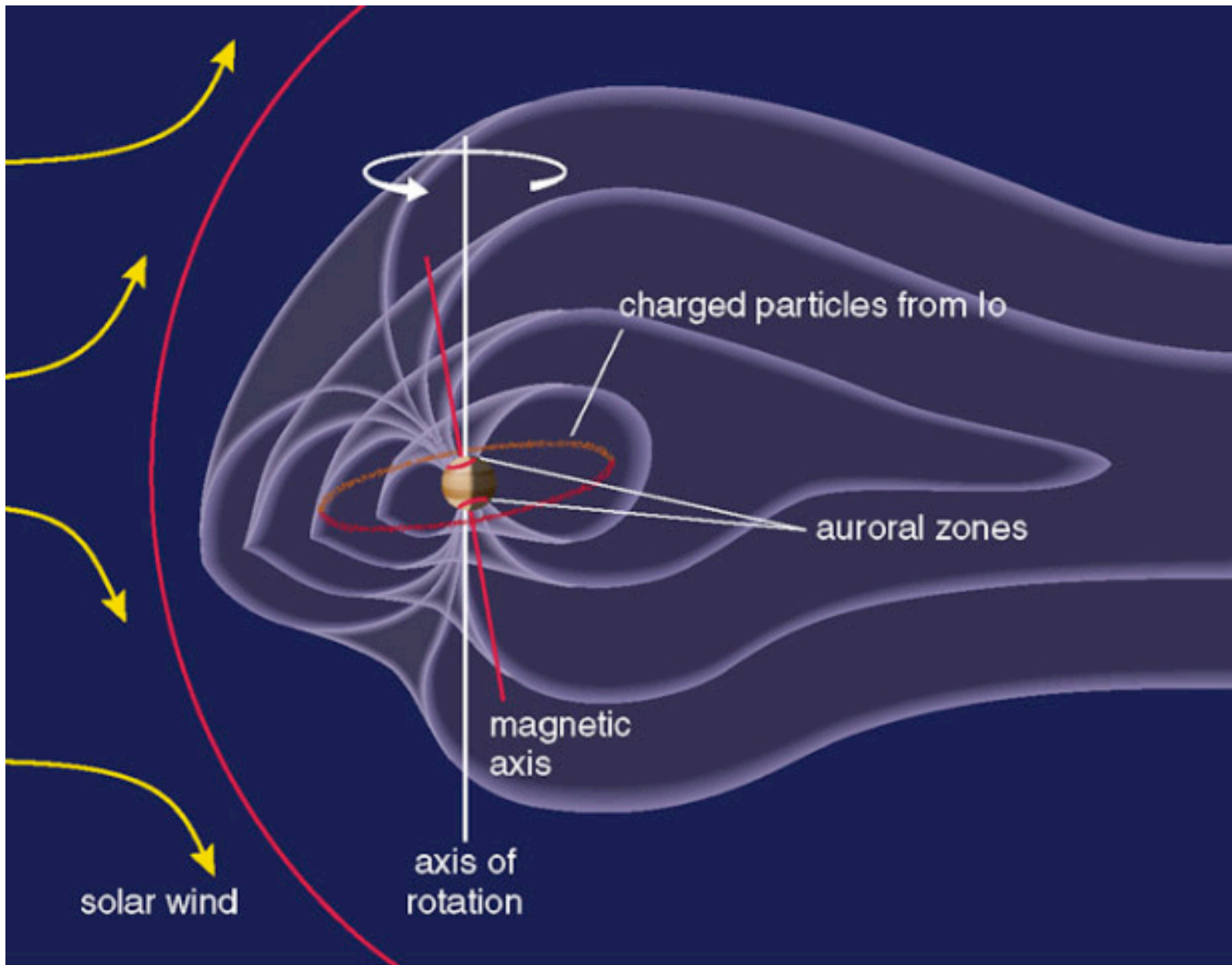
天王星的磁層結構示意圖。
天王星的自轉軸幾乎平行於黃道面。

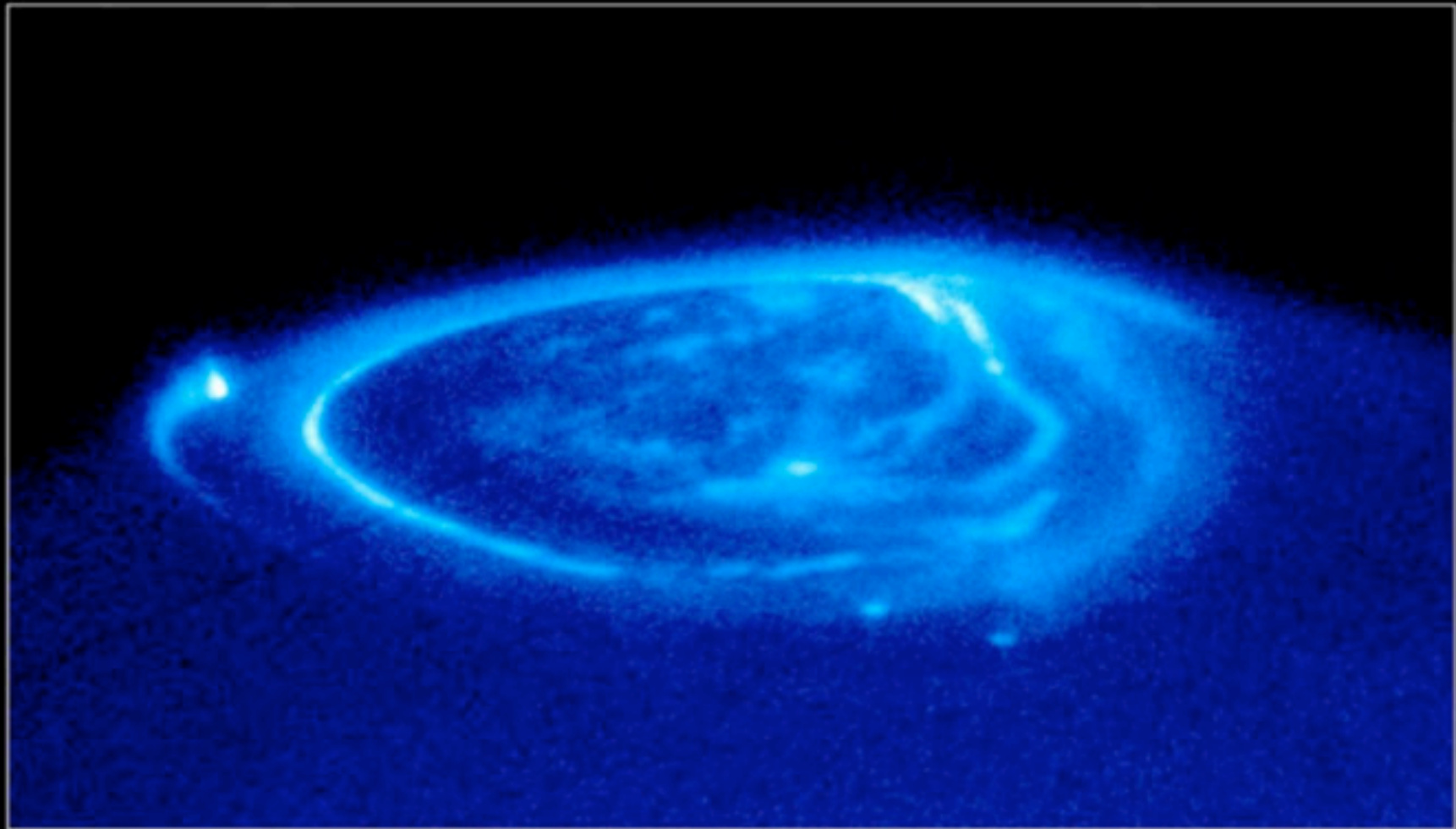
Io (木衛一)受潮汐力影響造成的火山噴發Volcano eruptions



Io (木衛一) 火山噴發造成的木星磁層內電漿環 (Io Torus)







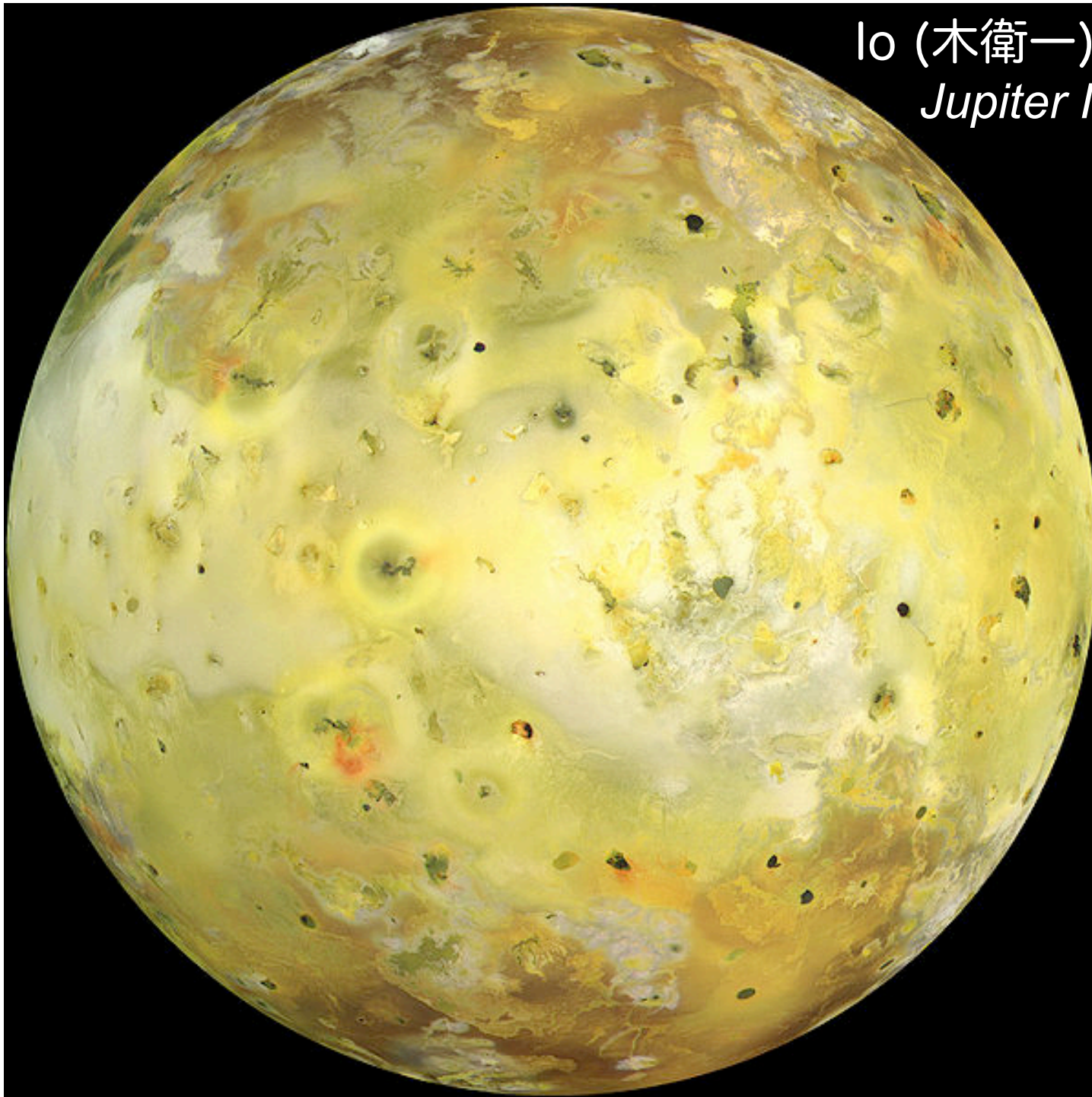
Jupiter Aurora
Hubble Space Telescope • STIS

NASA and J. Clarke (University of Michigan) • STScI-PRC00-38

著名的衛星(有水？有氣？)

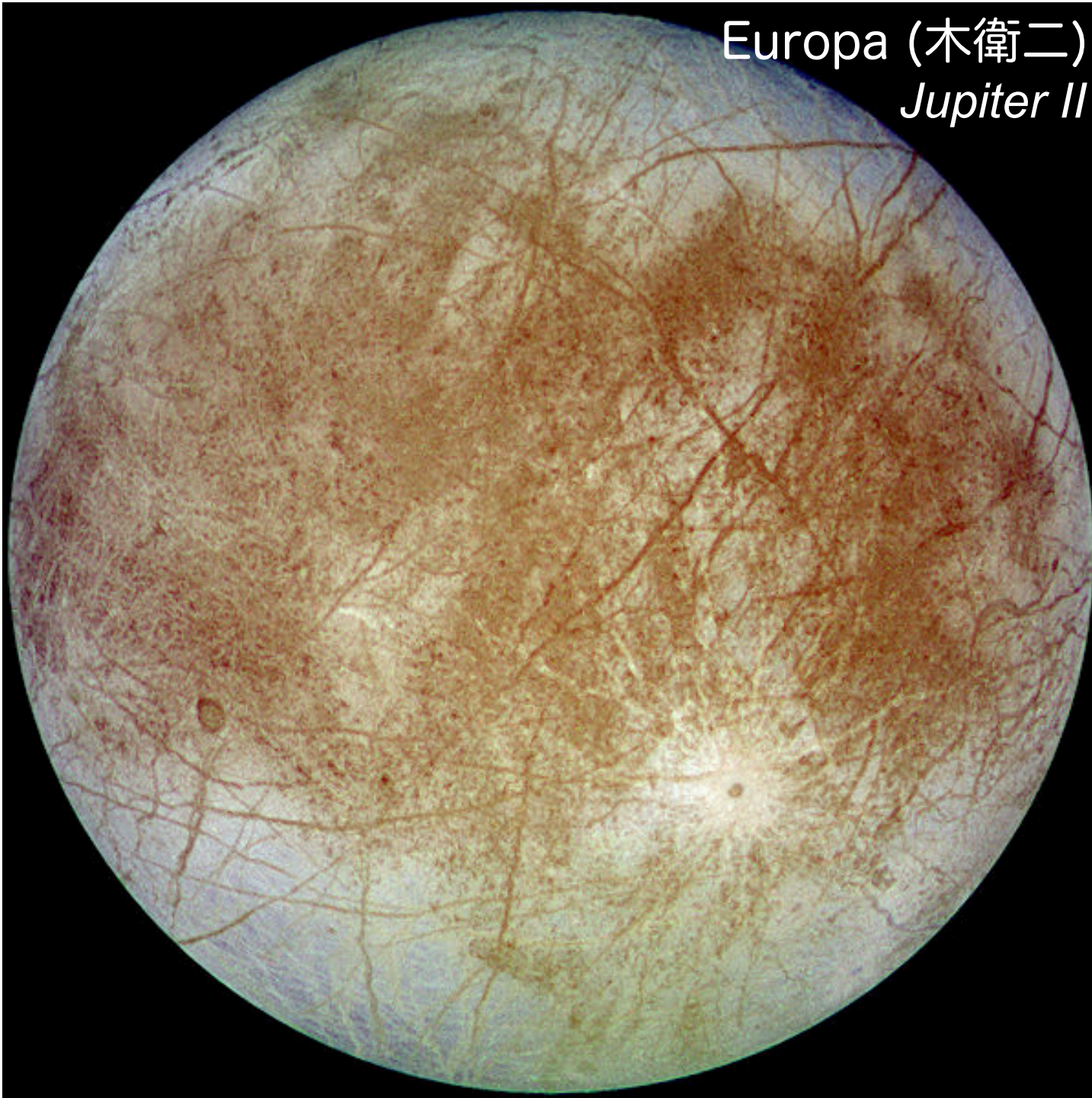
The Most-Studied Satellites in the Solar System (with either water or atmosphere)

- 木星的衛星 Moons of Jupiter (伽利略四大衛星) (Galilean moons) :
 - Io 埃歐(木衛一)潮汐力，導致常常火山爆發 (Volcano & atmosphere)
 - Europa 歐羅巴(木衛二)冰殼下有海洋？ (Ocean under ice?)
 - Ganymede (木衛三)有磁層？冰殼下有海洋？ (Ocean under ice?)
 - Callisto 卡利斯多(木衛四)冰殼下有海洋？ (Ocean under ice?)
- 土星的衛星 Moons of Saturn :
 - Titan 泰坦 (土衛六) 具有非常濃厚的大氣 (thick atmosphere)
 - Enceladus (土衛二) 為了觀測泰坦，送卡西尼太空船去土星。結果無意中發現Enceladus 正在噴水蒸汽呢！ (water vapor)
- 海王星的衛星 Moons of Uranus :
 - Triton 崔頓 (海衛一) 公轉軌道逆行，一個被捕獲的衛星？
(with a retrograde orbit: an orbit in the opposite direction to its planet's rotation.)
- 地球的衛星 Moon of Earth :
 - 月亮 (our moon) 水、冰存留於極區隕石坑的陰暗處？
(Water and ice kept in the shadow of the polar craters?)

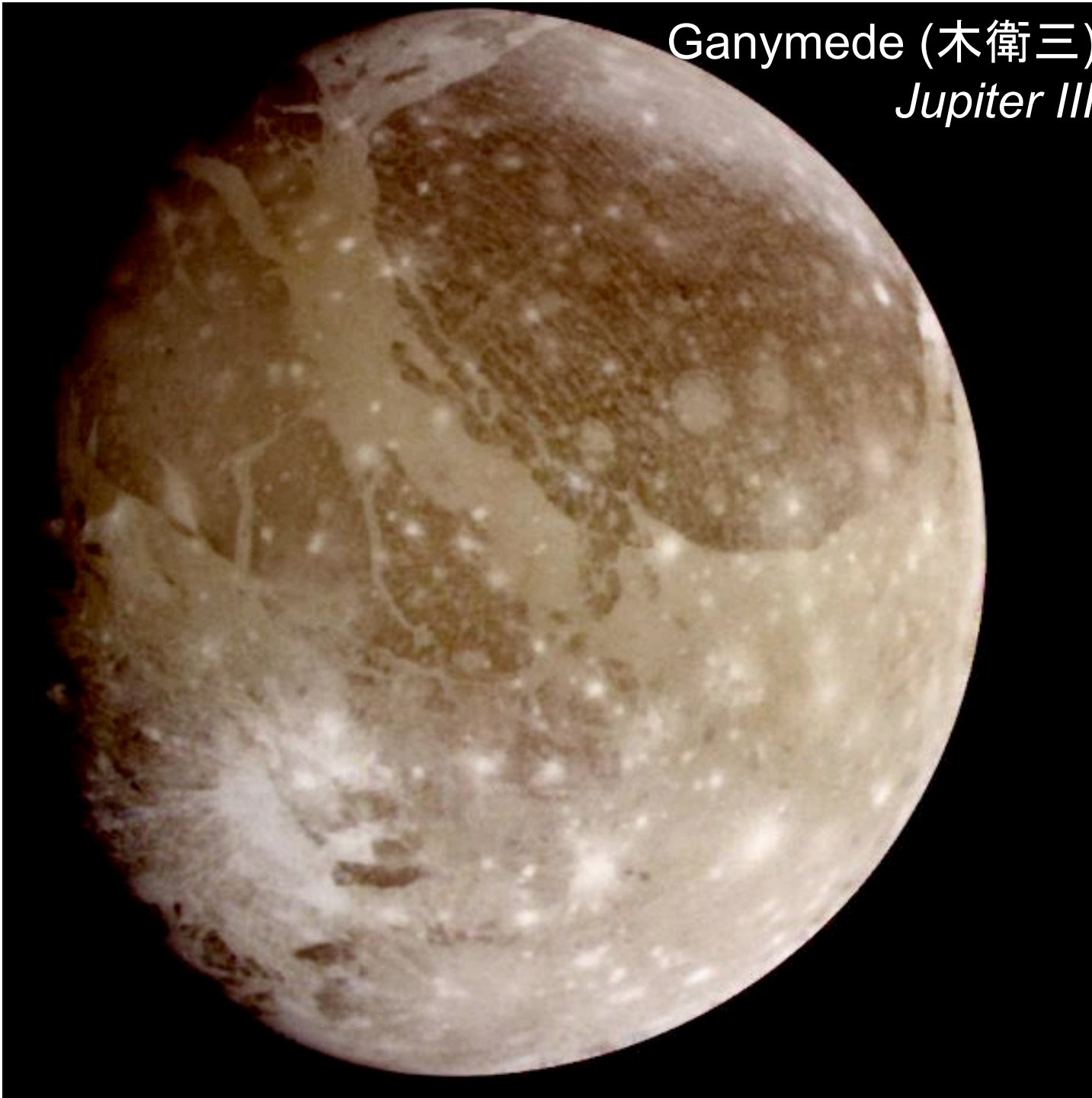


Io (木衛一)
Jupiter I

Europa (木衛二)
Jupiter II



Ganymede (木衛三)
Jupiter III

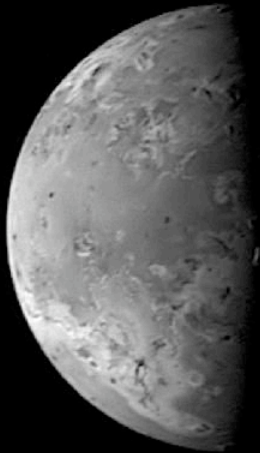


Callisto (木衛四)
Jupiter IV

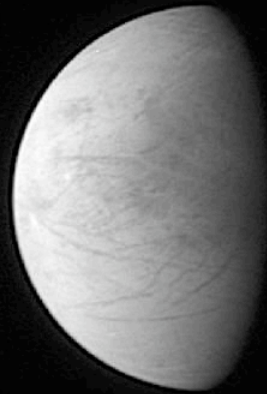


伽利略四大衛星 Galilean moons

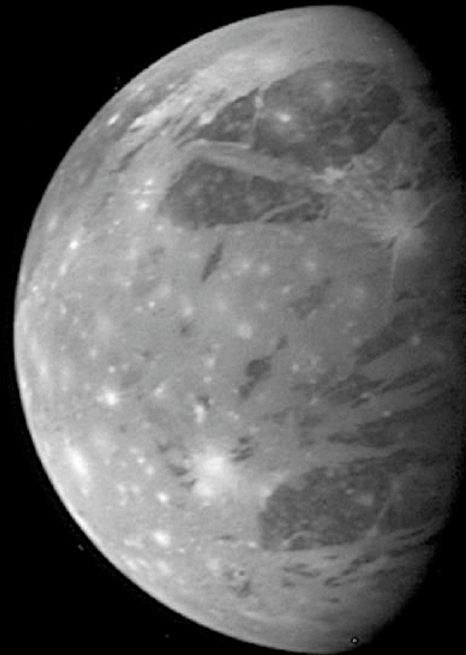
Io (木衛一)



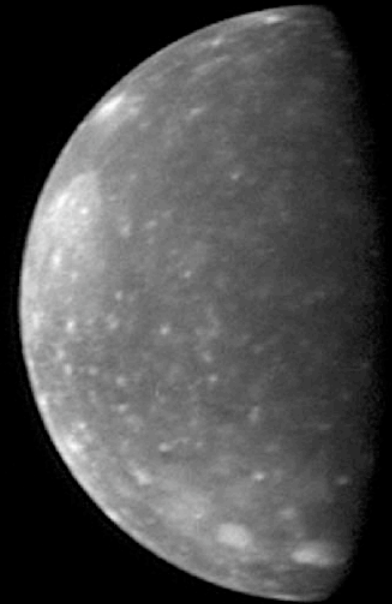
Europa (木衛二)



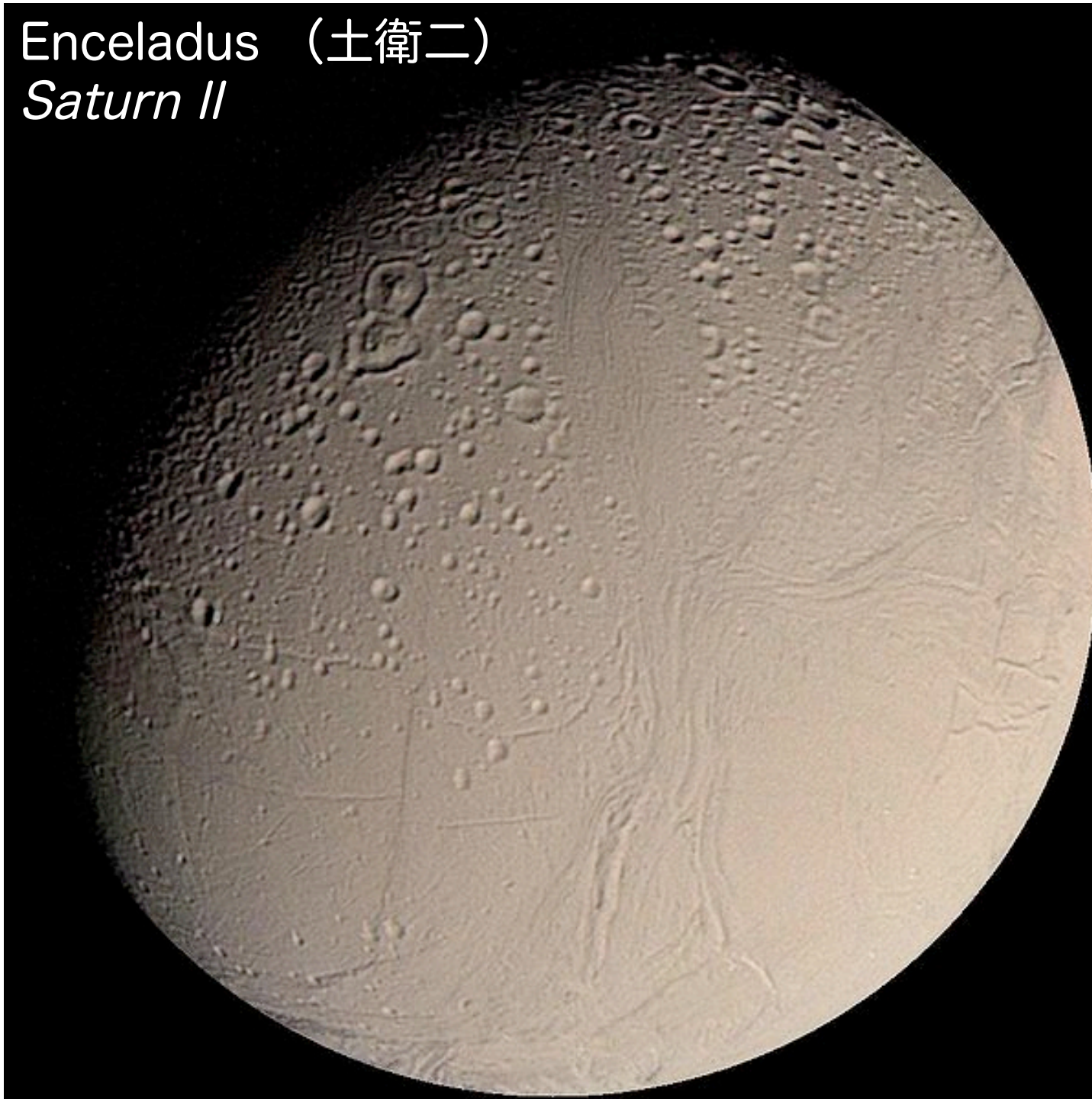
Ganymede (木衛三)



Callisto (木衛四)



Enceladus (土衛二)
Saturn II

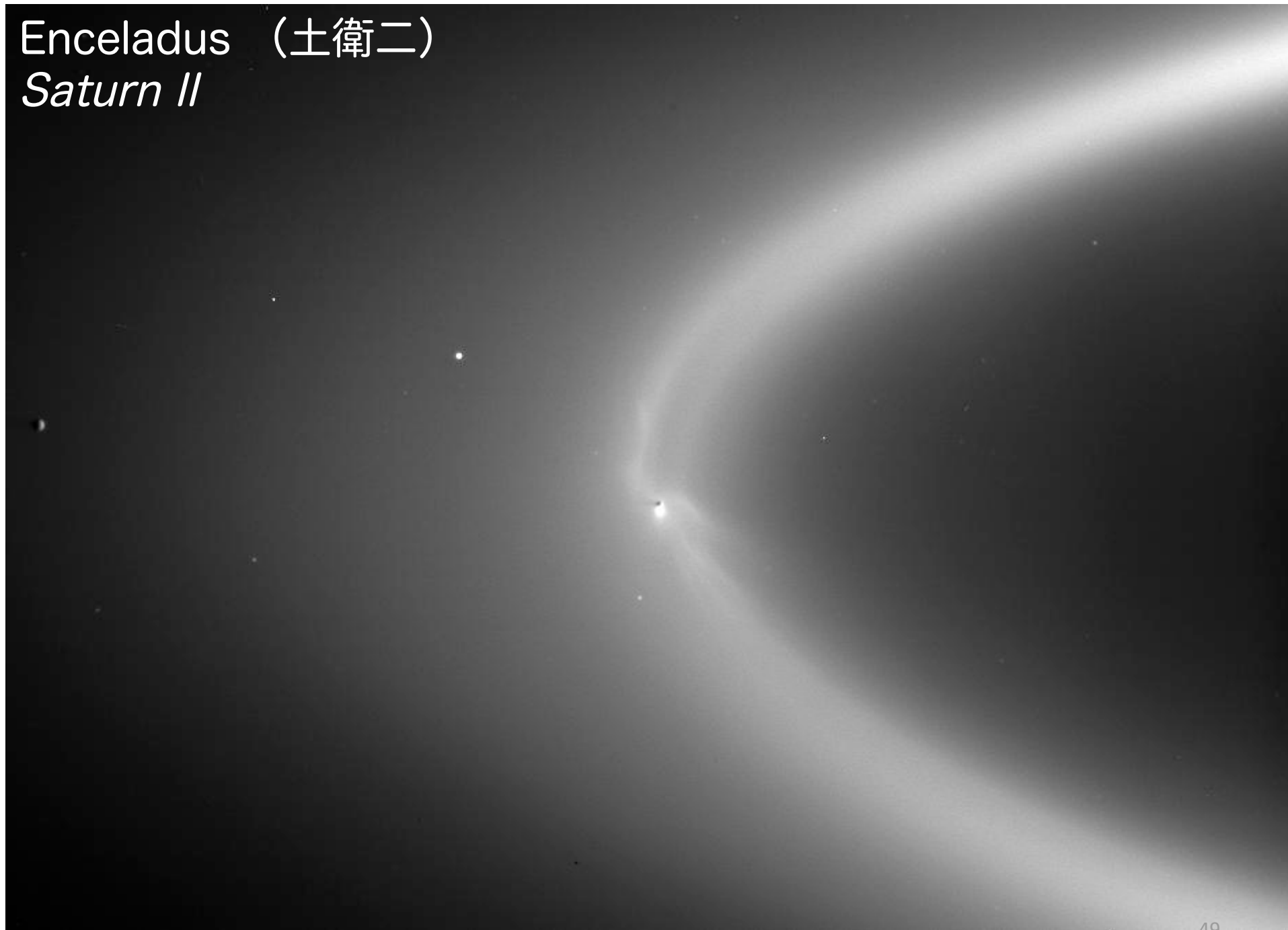


Enceladus (土衛二)
Saturn II

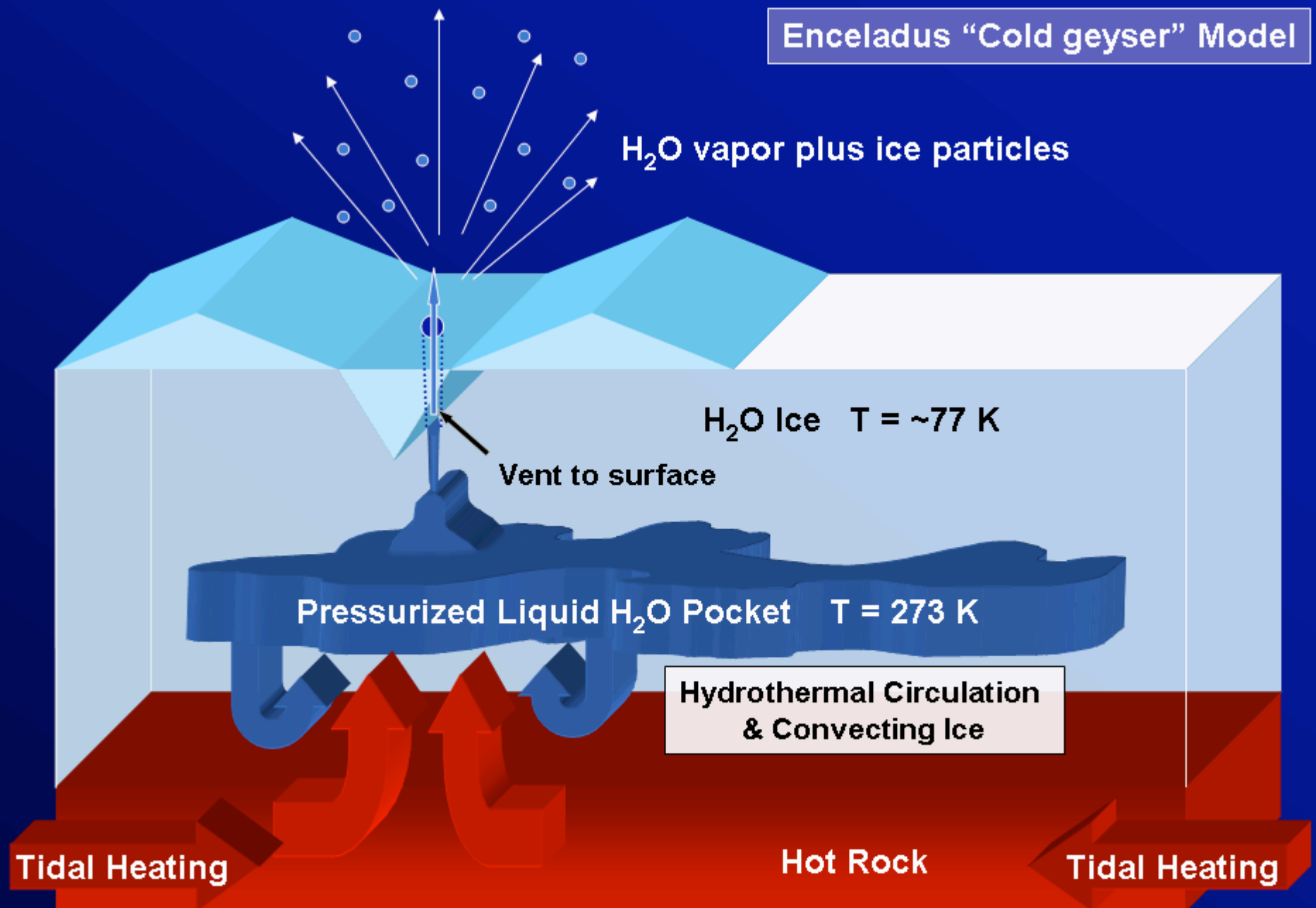


Enceladus (土衛二)

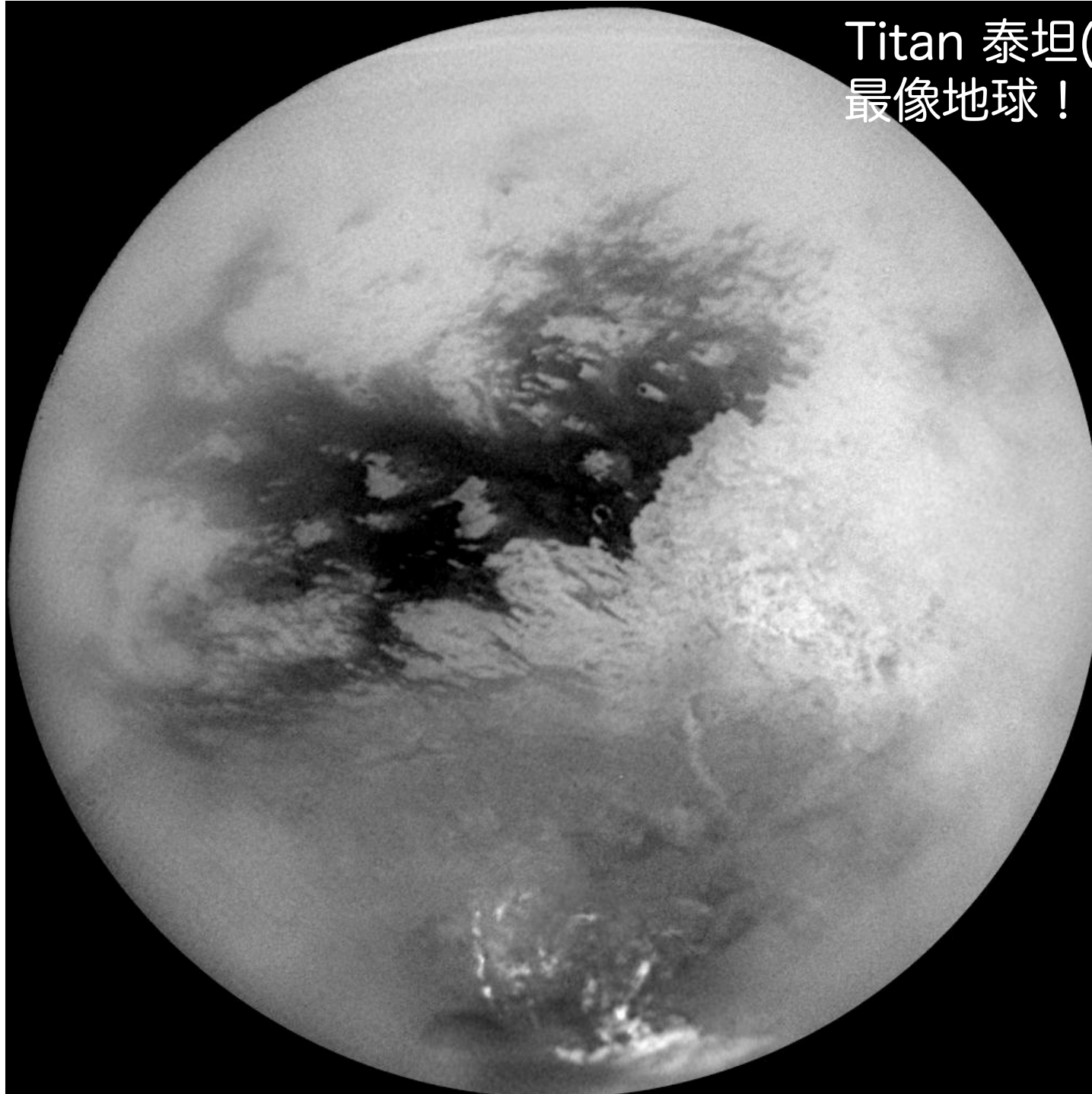
Saturn II



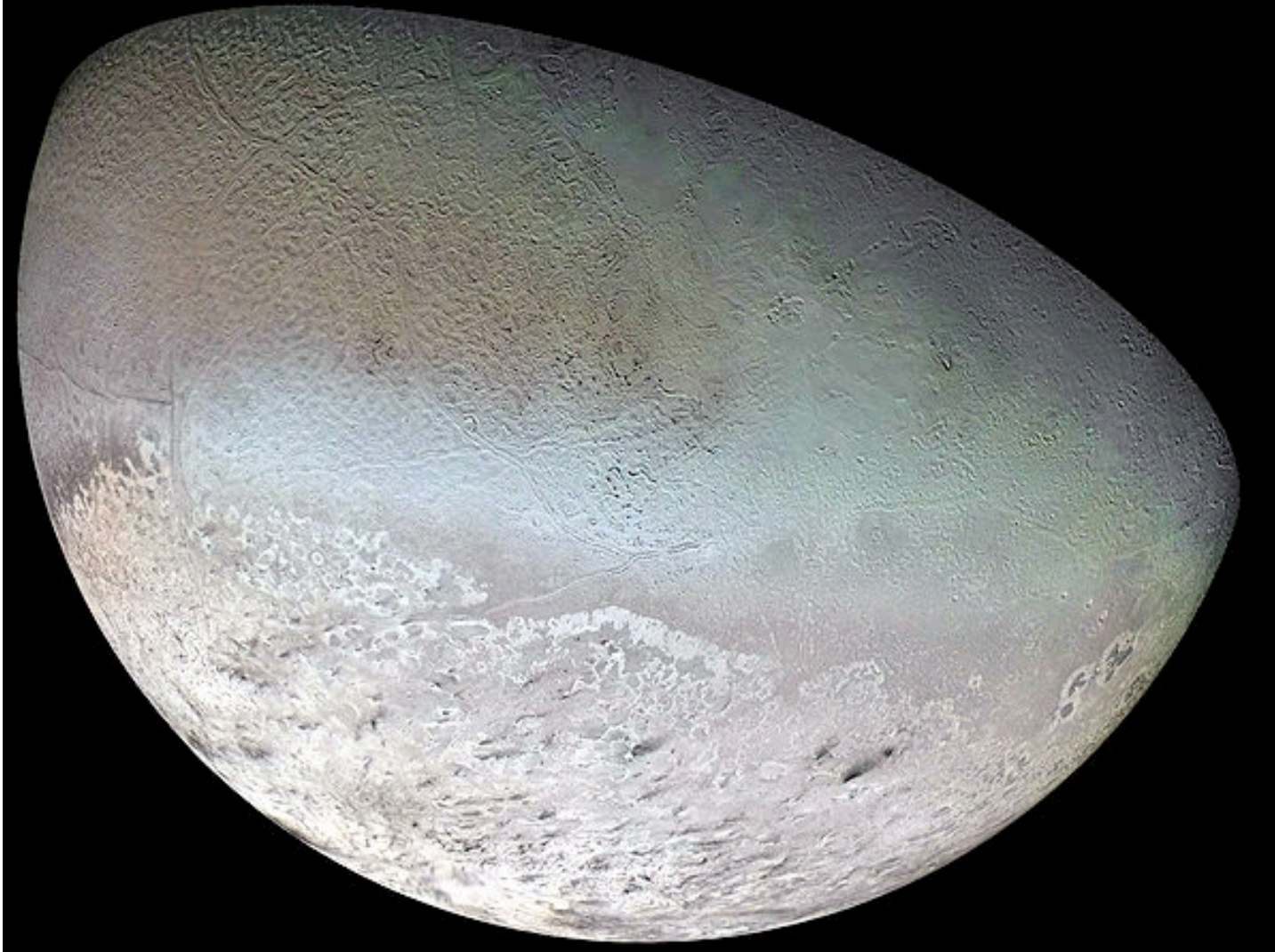
Enceladus "Cold geyser" Model



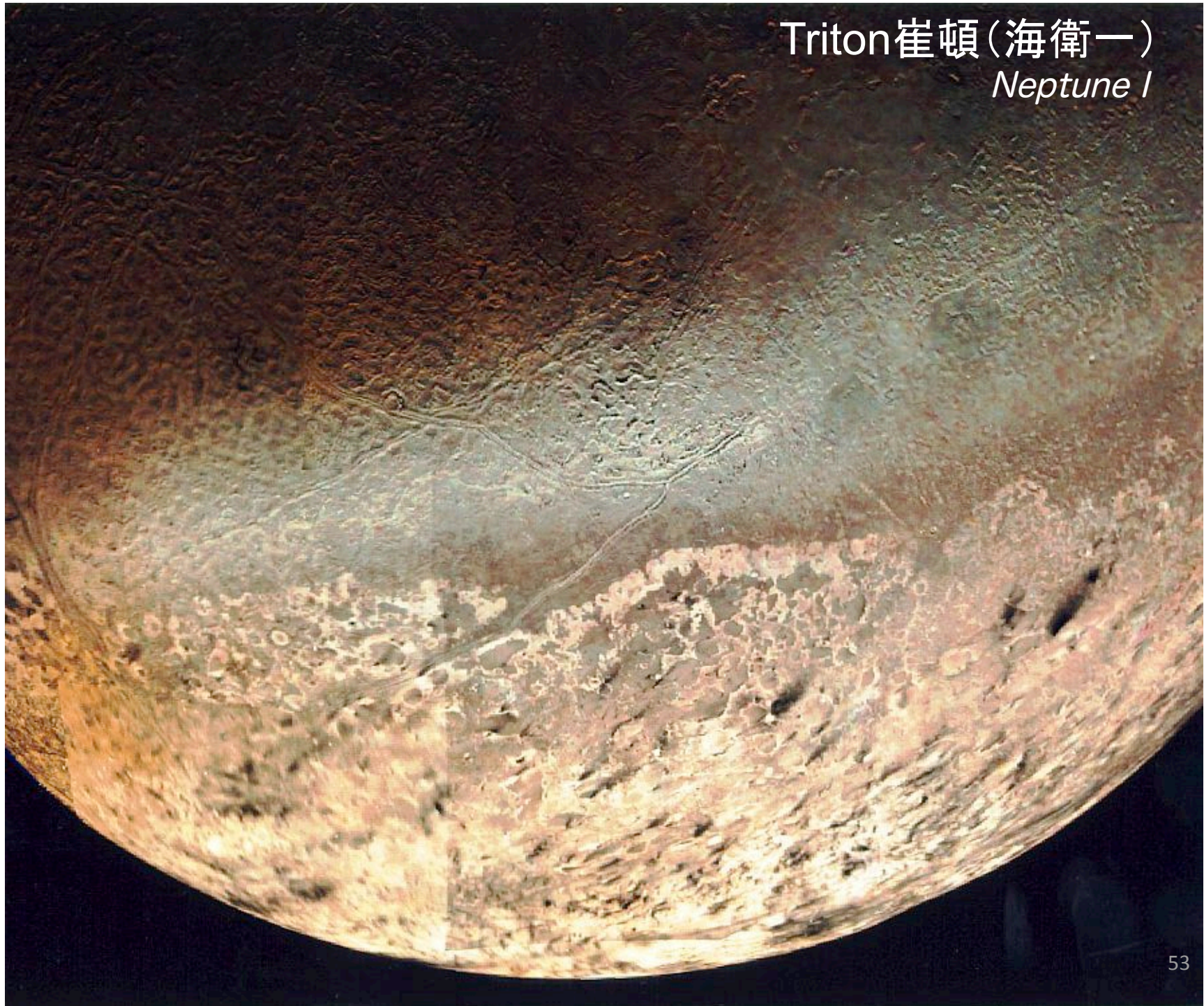
Titan 泰坦(土衛六)
最像地球！ *Saturn VI*



Triton 崔頓 (海衛一)
哈密瓜皮！ *Neptune I*



Triton 崔頓 (海衛一)
Neptune I



地球的衛星：月亮 A:向地面, B:背地面

John D. Fix, *Astronomy: Journey to the Cosmic Frontier*, 2nd ed. © 1999 The McGraw-Hill Companies, Inc. All rights reserved.

The near side and far side of the Moon.



A Near Side



B Far Side

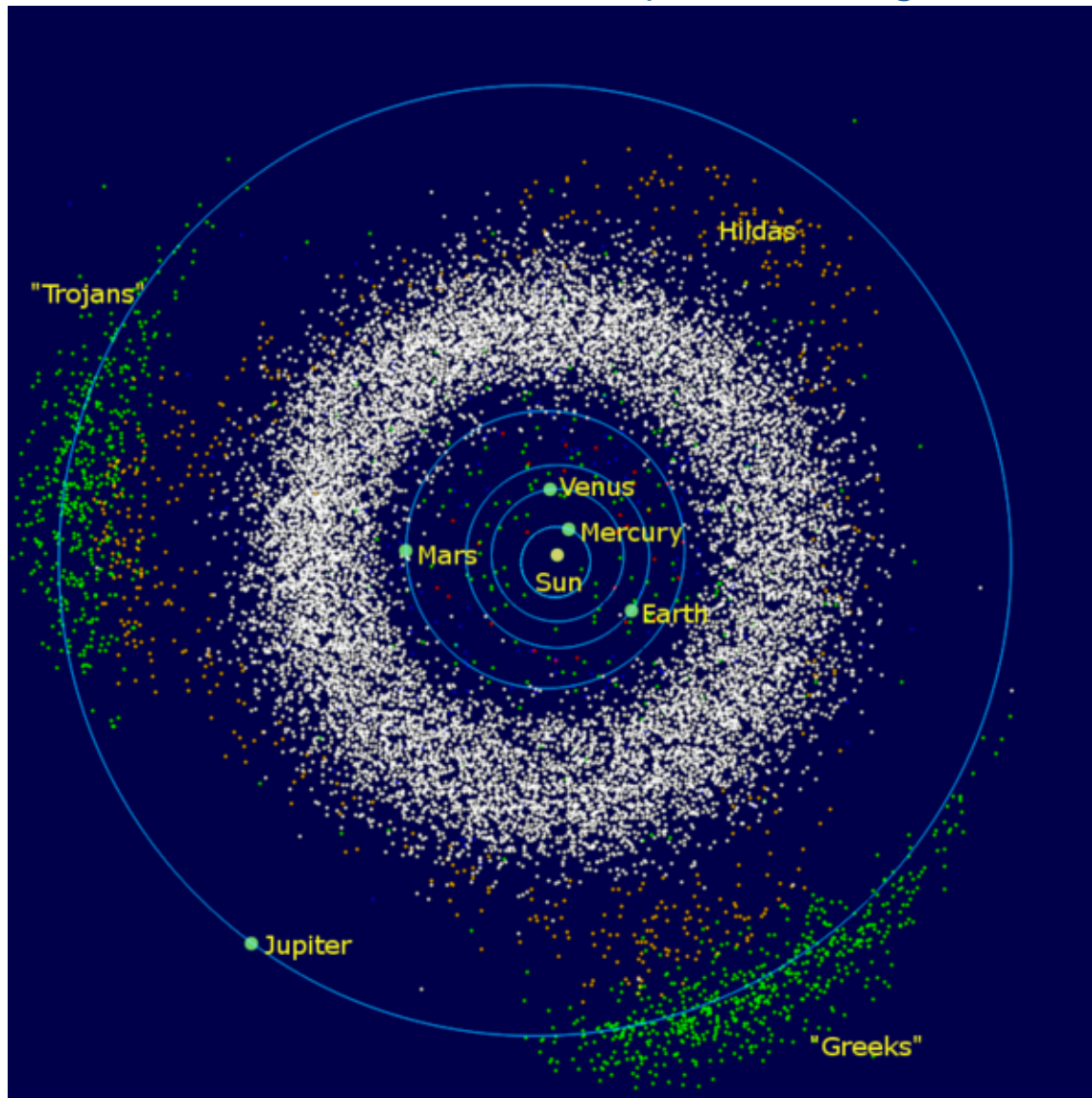
太陽系小星體 Small Solar System Body

矮行星、彗星、小行星、？流星體

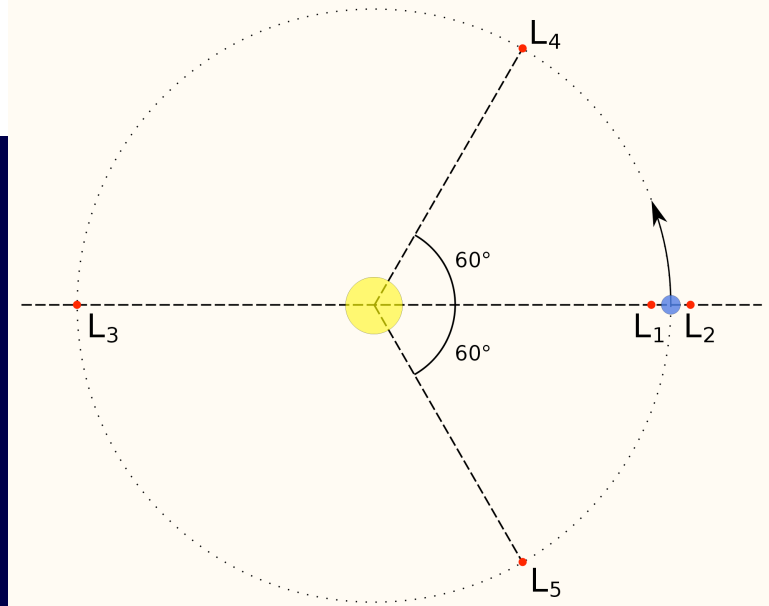
Dwarf Planets, Comets, Asteroids, ? Meteoroids

- 小行星帶 *Asteroid Belt* : 介於火星 與 木星之間 *between Mars and Jupiter*
- 古柏帶 *Kuiper belt* : 位於海王星外 (*trans-Neptunian objects*)
- 矮行星 Dwarf Planets: 體積比較大, 具有圓形外觀, *regular shape*
 - 古柏帶中的大星體 *Large object in the Kuiper belt* 例如: 冥王星 *Pluto*
 - 小行星帶中的大星體 *Large object in the asteroid belt* 例如: 穀神星 *Ceres*
- 彗星 *Comet*: 有彗髮 *Comet hair*、彗尾 *Comet tail*
 - 分為長週期彗星 *Long-Period Comets*、短週期彗星 *Short-Period Comets*
- 小行星 *Asteroids*: 無彗髮 *no comet hair*、無彗尾 *no comet tail*, 外觀不規則 不夠圓 *irregular shape*
- ? 流星體 *Meteoroid* : *size smaller than an asteroid*
 - 流星雨 *Meteor shower*: 地球軌道與彗星軌道接近時彗星殘留物, 落入地球大氣燃燒, 呈現流星
 - 隕石坑 *Meteor Crater* : *meteorite impact crater*
 - 隕石 *Meteorite* : 落入地球沒有燒完之的流星、小行星、或其他類似的天體
 - A portion of a meteoroid or asteroid that survives its passage through the atmosphere and impact with the ground without being destroyed.

火星與木星之間的小行星帶 & 木星的特洛伊小行星帶 Asteroid Belt & Jupiter Trojans



五個拉格朗日點 The five Lagrangian points



L4 and L5 又稱為特洛伊點 Trojan points.

Trojan moons:

- 土星有三顆特洛伊衛星

Saturn has 3 Trojan moons

Trojan asteroids:

- 木星有多顆特洛伊小行星 Numerous Jupiter Trojans have been found.

- 火星軌道上有3顆特洛伊小行星

Three Mars Trojans have been found.

- 海王星軌道上有8顆特洛伊小行星

Eight Neptune Trojans have been found.

- 地球軌道上已經發現了1顆特洛伊小行星

One Earth Trojan at L4 has been found in 2011

彗星 Comets

- 根據彗星週期進行彗星分類：

Classification of comets based on the length of their orbital periods :

- 短週期彗星 (Short-Period Comets)

- 木星族彗星 Jupiter-Family Comets

週期短於20年(軌道小於10AU) $\text{period} < 20 \text{ years}$

- 哈雷族彗星 Halley-Family Comets

週期介於20-200年之間 $20 \text{ years} < \text{period} < 200 \text{ years}$

- 古柏帶 Kuiper belt

週期略短於200年 $\text{period slightly less than } 200 \text{ years}$

- 長週期彗星 Long-Period Comets (e.g. Comet West, Comet McNaught)

週期長於200年 $\text{period} > 200 \text{ years}$

- Oort Cloud (歐特雲) 位在約 50000 AU 到一光年 (50000AU~1 light year)

- 出現一次的彗星

Single-apparition comets (lying beyond the outer Oort cloud)

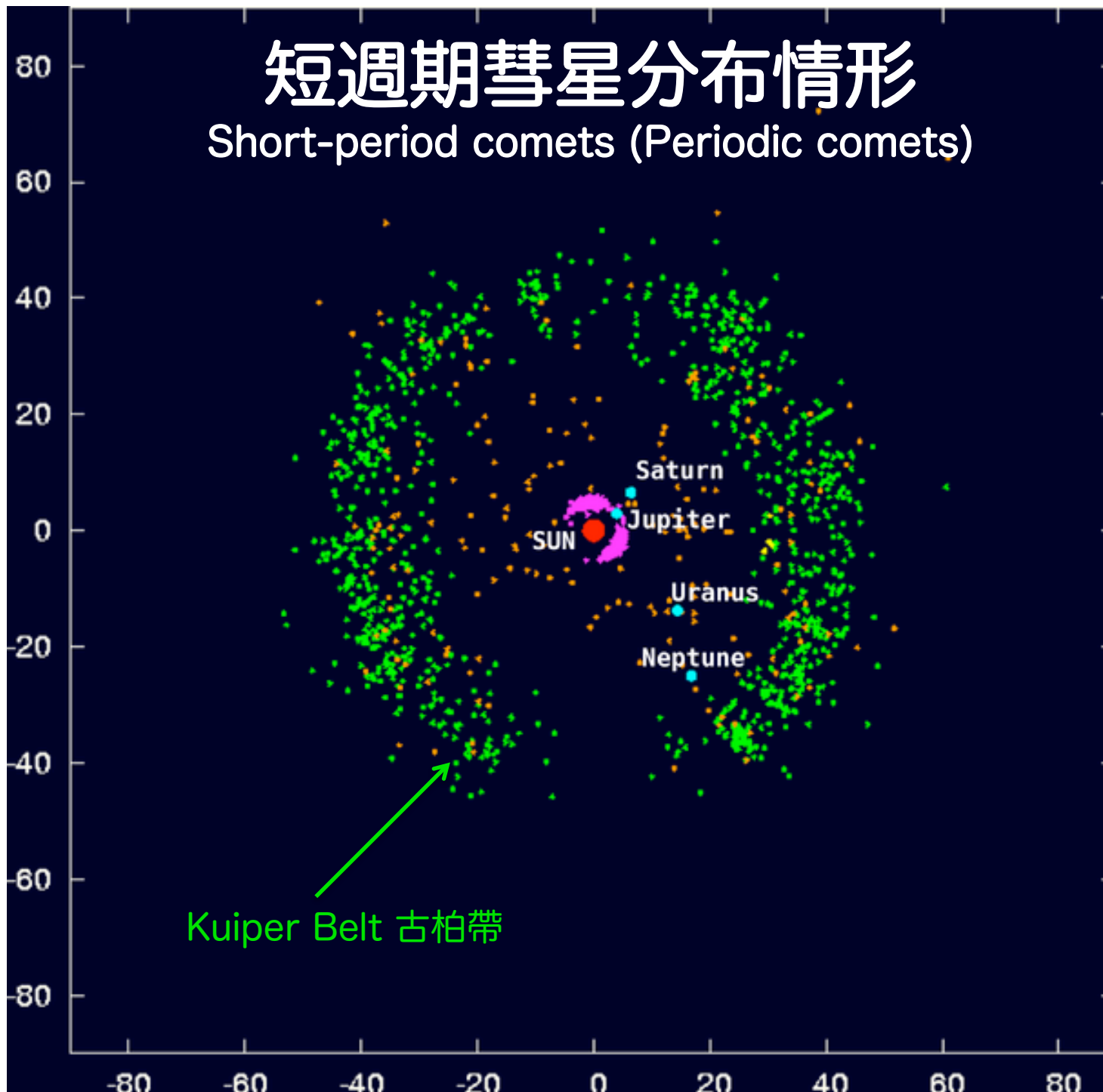
- 彗星結構 (Structure of comets) :

- 彗髮、彗尾 (塵埃尾、離子尾或電漿尾)

comet hair, comet tail (dust tail, ion tail)

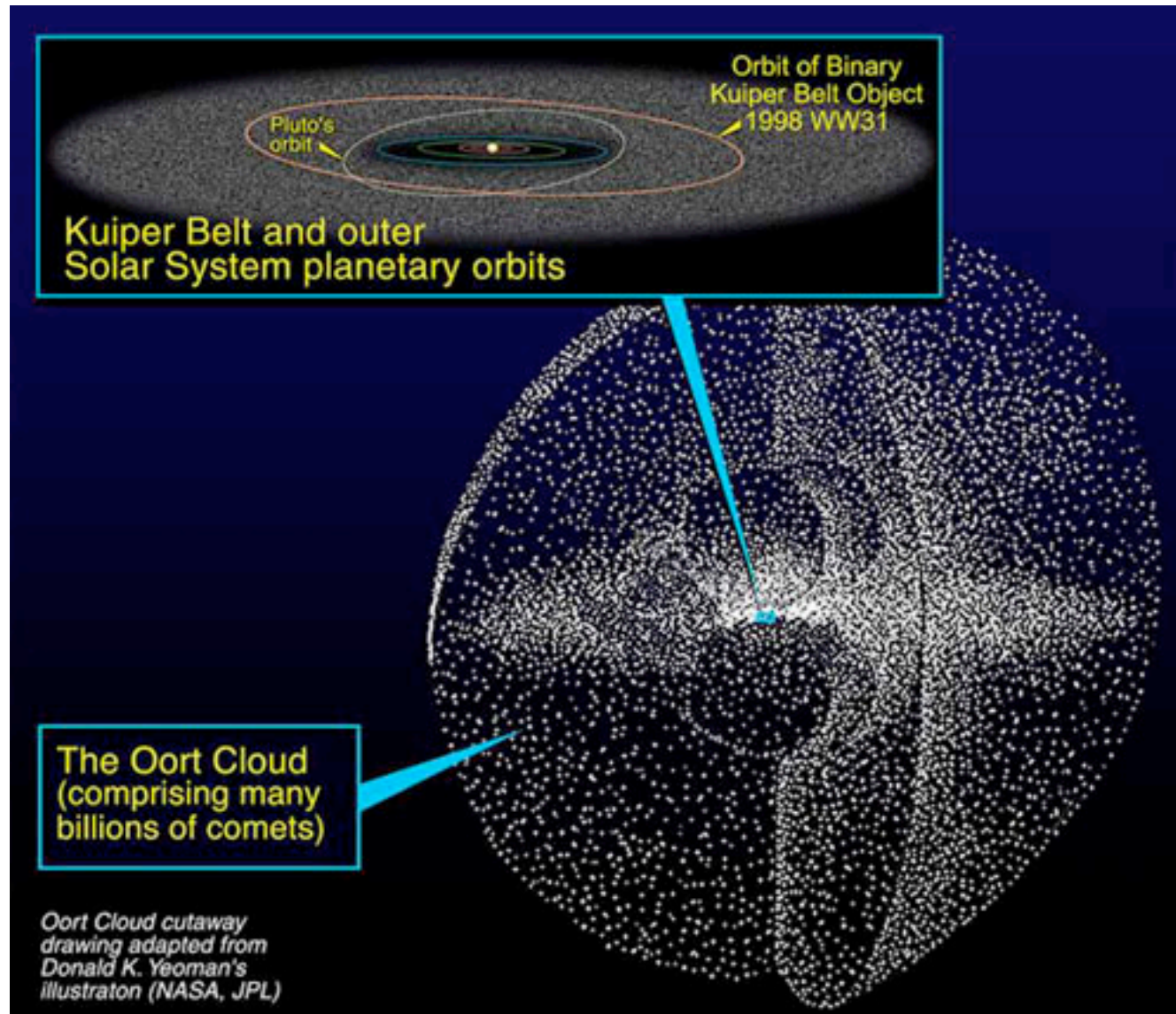
短週期彗星分布情形

Short-period comets (Periodic comets)



Kuiper Belt & Oort Cloud

古柏帶 & 歐特雲

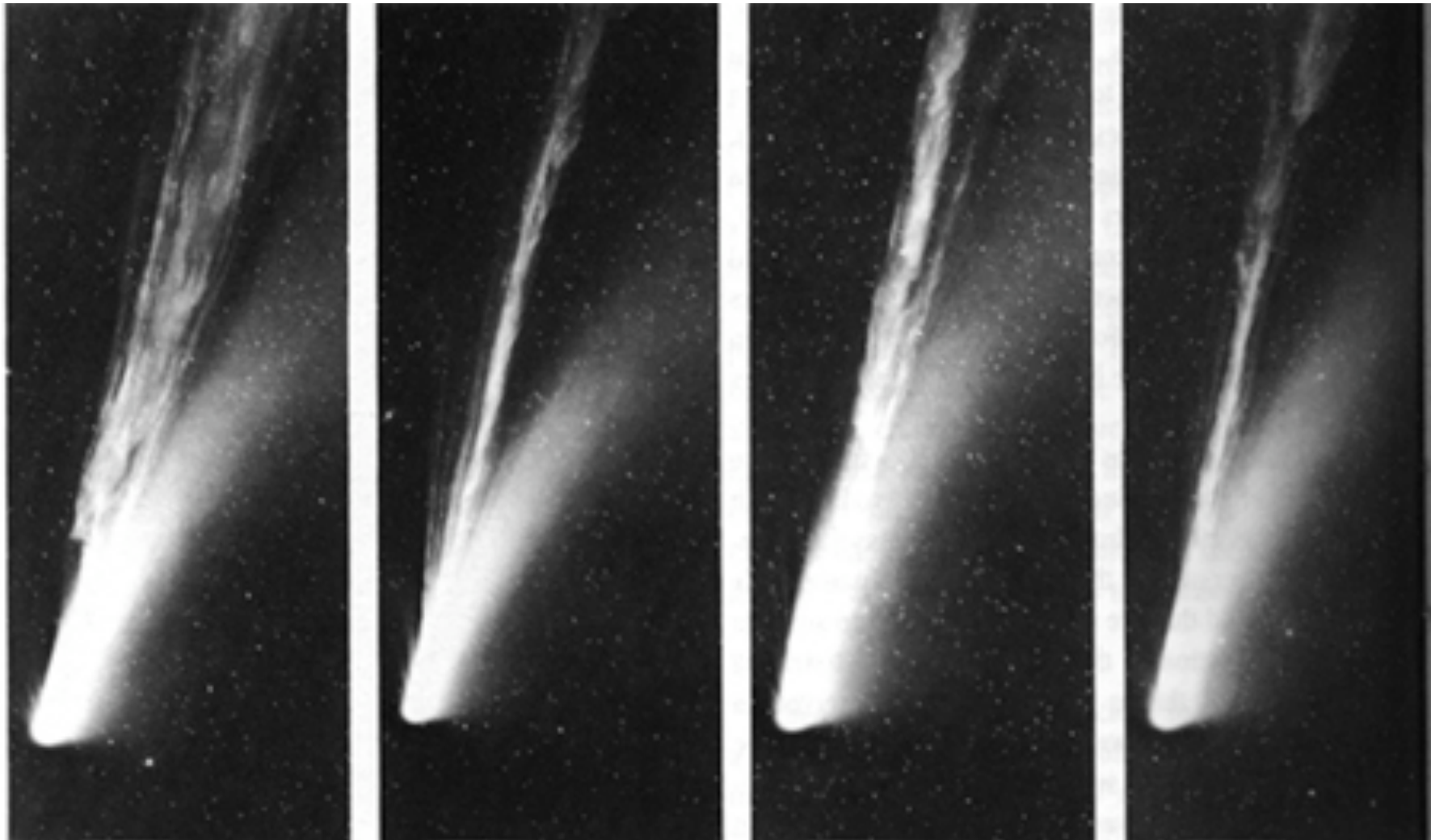


彗尾：塵埃尾、離子尾(或電漿尾)

Comet tails: Dust tail and ion tail

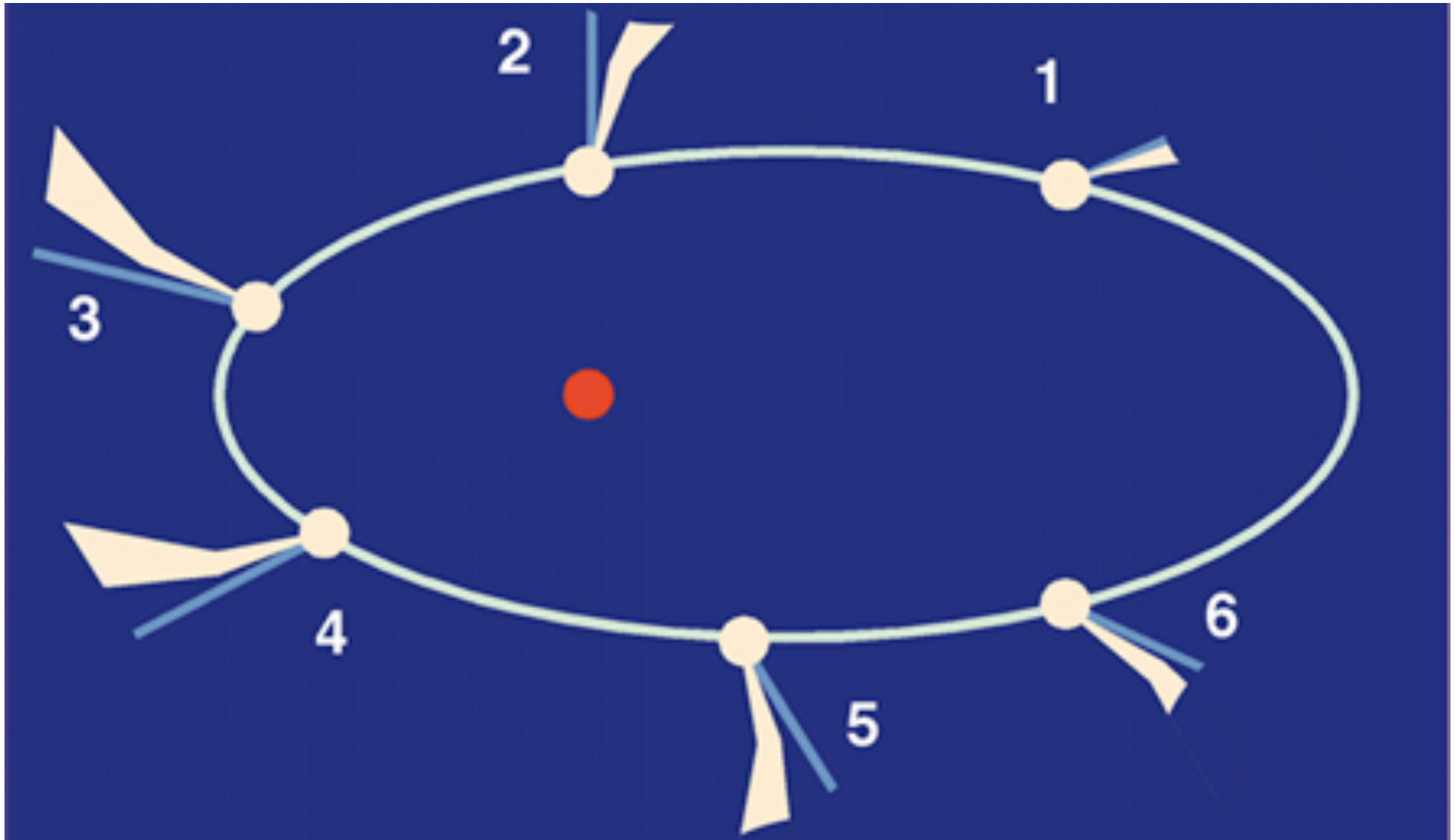
太陽風中磁場方向改變會影響離子尾的結構

Variations of ion tail after interaction with current sheets in the solar wind



彗尾分布會沿著彗星軌道而變化

Distribution of comet tails along the comet orbit



不同角度看到的
塵埃尾與離子尾

Comet tails:
Dust tail and ion tail

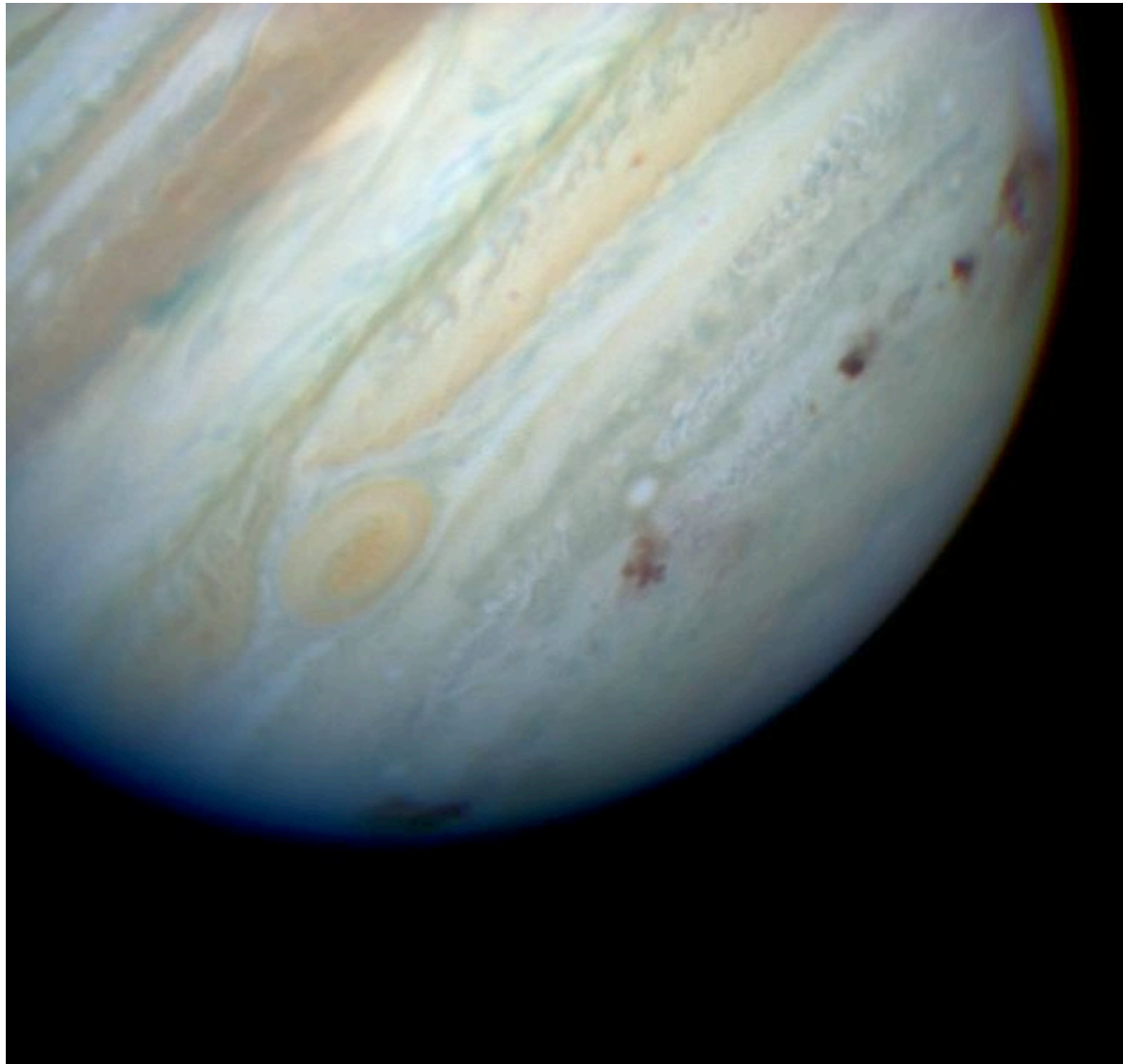


鹿林彗星 (Lulin comet)



西元1994年 SL-9 彗星被扯裂後撞木星

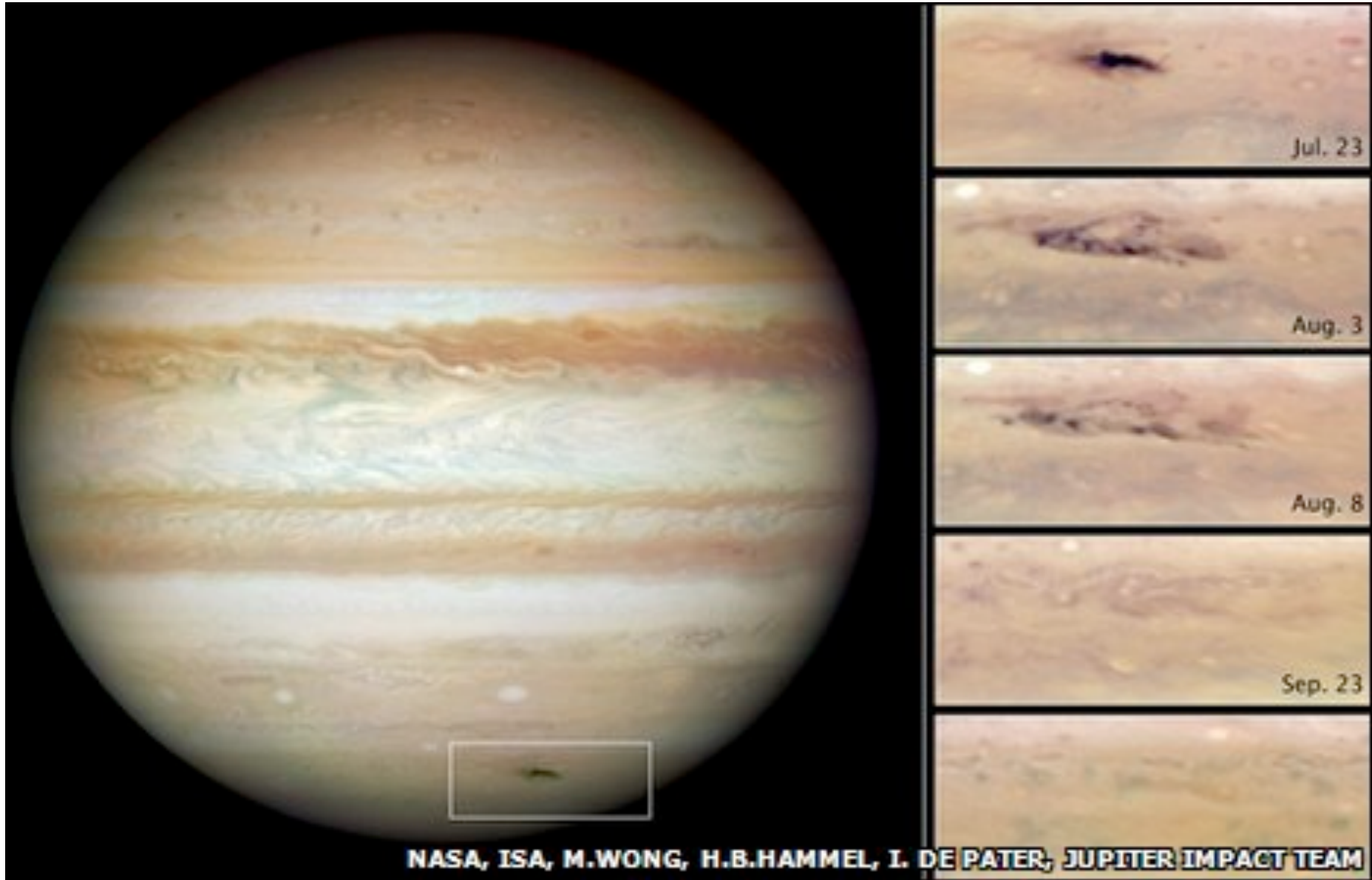
Comet Shoemaker–Levy 9 broke apart and collided with Jupiter in July 1994



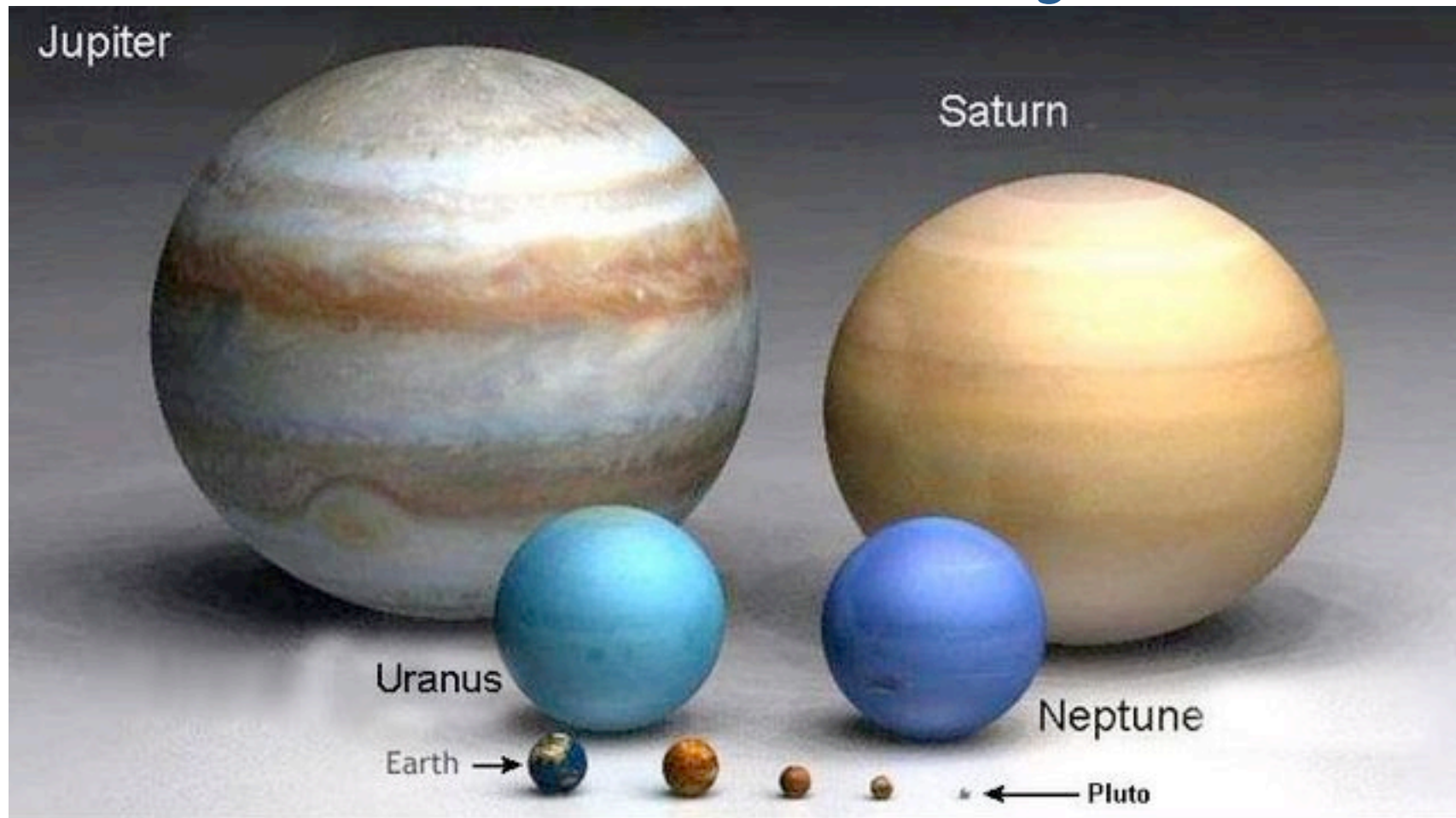
如果地球被撞，最大的災難，就是海嘯。其次的問題就是地磁反轉。要重新建立一個穩定的磁偶極場要花1000多年。缺乏穩定的磁偶極場，地球上的生物將暴露於高濃度的宇宙射線中，導致基因突變更加頻繁。生命期較長的物種，勢必將面臨絕種的危機。

If the impact occurred on the Earth, the worst problem would be the Tsunami, the second worst problem would be the flipping of the Earth dipole field. In that case, life on the Earth will be exposed to high dose of cosmic-ray radiation for more than 1000 years before a stable dipole field can be established. The damage from the radiation shall increase with increasing lifetime of the species.

西元2009年小行星在木星上留下的疤痕？ 'Scar' after the 2009 Jupiter impact event



總結 Summary



1. List of Solar System Objects by size

http://en.wikipedia.org/wiki/List_of_Solar_System_objects_by_size

2. 泛星計畫(Pan-STARRS)利用多台望遠鏡, 運用干涉法巡天, 企圖找出更多目前不知道的古柏帶天體與各行星的特洛伊天體, 以預防可能的地球撞擊。

影片介紹 Movies

水星的一般特性

<http://www.5min.com/Video/Learn-About-Mercury-38356766>

水星的太空環境

<http://www.5min.com/Video/Learn-about-The-Planet-Mercury-117571336>

探測水星的困難度

<http://www.5min.com/Video/Sending-the-Spacecraft-Messenger-to-Mercury-311434946>

隕石撞及火星，導致火星物質墜落地球南極

<http://www.5min.com/Video/What-a-Martian-Meteorite-Can-Tell-Us-About-the-Earth-311863129>

生命來自隕石

<http://www.5min.com/Video/The-Importance-of-Studying-Meteorites-311435042>

Enceladus - Saturns moon

<http://www.youtube.com/watch?v=rBhAPz5pqYg>

Salt in Enceladus

<http://www.youtube.com/watch?v=-yGsg9sggNM&NR=1>

The Mystery Hexagon on SATURN

<http://www.youtube.com/watch?v=qzL194jiTyY>

The Bizarre Hexagon on Saturn

<http://www.youtube.com/watch?v=FOiV1RSfMnQ>

NASA Discovers Giant Ring Around Saturn

<http://www.youtube.com/watch?v=-9LbL0QjxdU&NR=1>

相關圖片連結 URLs

仙人掌月 (Saguaro Moon)

<http://www.phys.ncku.edu.tw/~astrolab/mirrors/apod/ap070926.html>

月亮的向地面與背地面

<http://www.mhhe.com/physsci/astronomy/fix/student/images/09f19.jpg>

木星極光

http://lasp.colorado.edu/education/outerplanets/images_giants/big/jupiter_aurora.jpg

木星磁層

http://lasp.colorado.edu/education/outerplanets/images_giants/big/jupiter_magnetosphere.jpg

類木行星內部結構

http://lasp.colorado.edu/education/outerplanets/images_giants/big/interior.jpg

類木行星磁層結構

http://lasp.colorado.edu/education/outerplanets/images_giants/big/magnetospheres.jpg

Io Volcano

http://www.nasa.gov/multimedia/imagegallery/image_feature_758.html

THE IO TORUS

http://en.wikipedia.org/wiki/File:Jupiter_magnetosphere_schematic.jpg

鹿林彗星

<http://www.phys.ncku.edu.tw/~astrolab/mirrors/apod/ap090207.html>