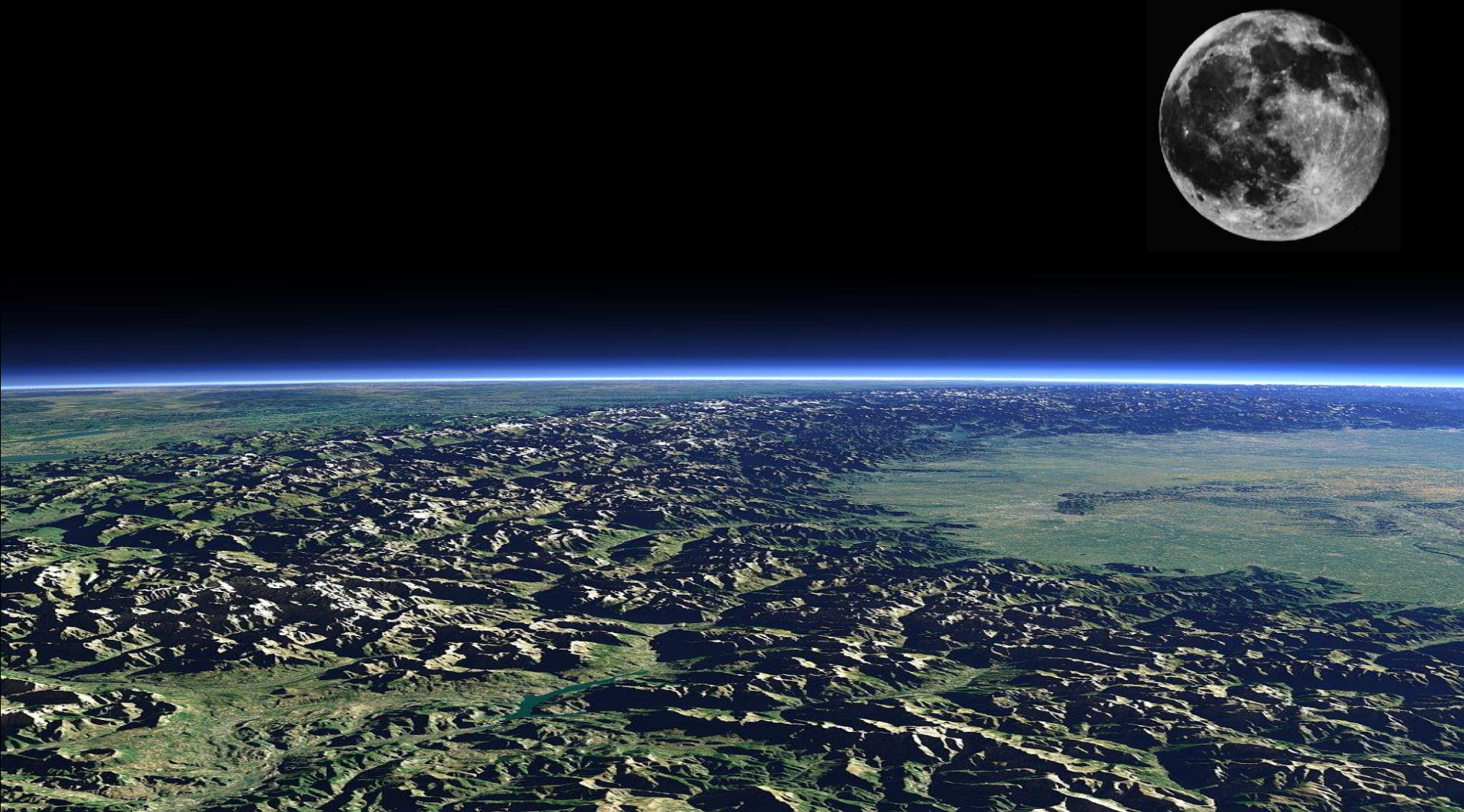


# THE EARTH-MOON SYSTEM





**Moon and Earth from Chang'e 5-T1 嫦娥五號 APOD**

# 地球 (Earth)

- 水的世界，孕育生命
- 活躍的地表（火山，地震等）
- 磁場與大氣層（80%氮 nitrogen, 20%氧 oxygen）的保護
- 永遠同一面向著我們的月球；  
潮汐 如果沒有月球會如何？

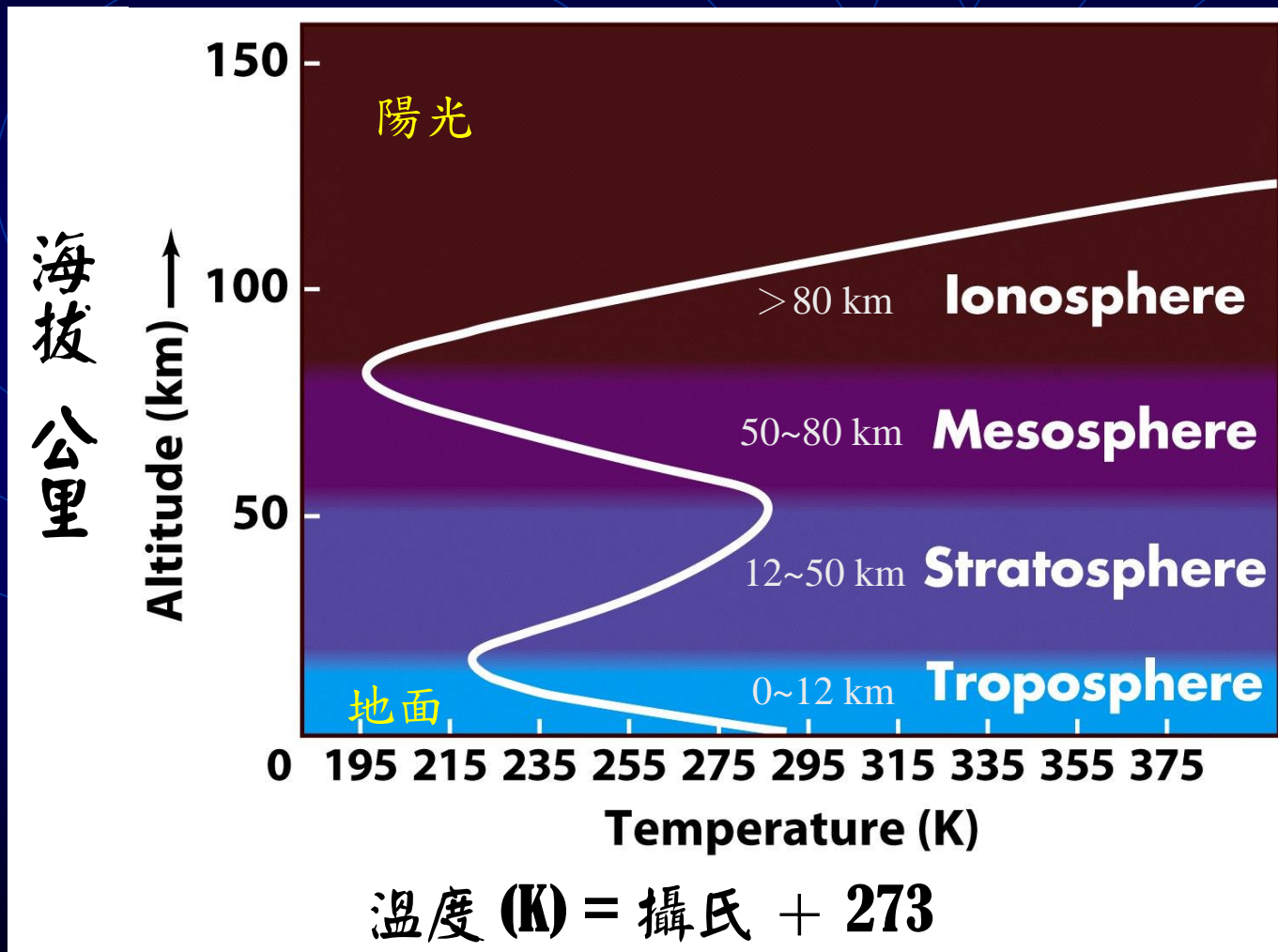


# Temperature variation with altitude

大氣壓力 = 大氣的重量

Atmospheric pressure drops with altitude.

$$1 \text{ atmosphere (atm)} = 1.01 \times 10^5 \text{ N/m}^2$$



$$[\text{Pressure}] = [\text{Force}] / [\text{Area}]$$

電離層

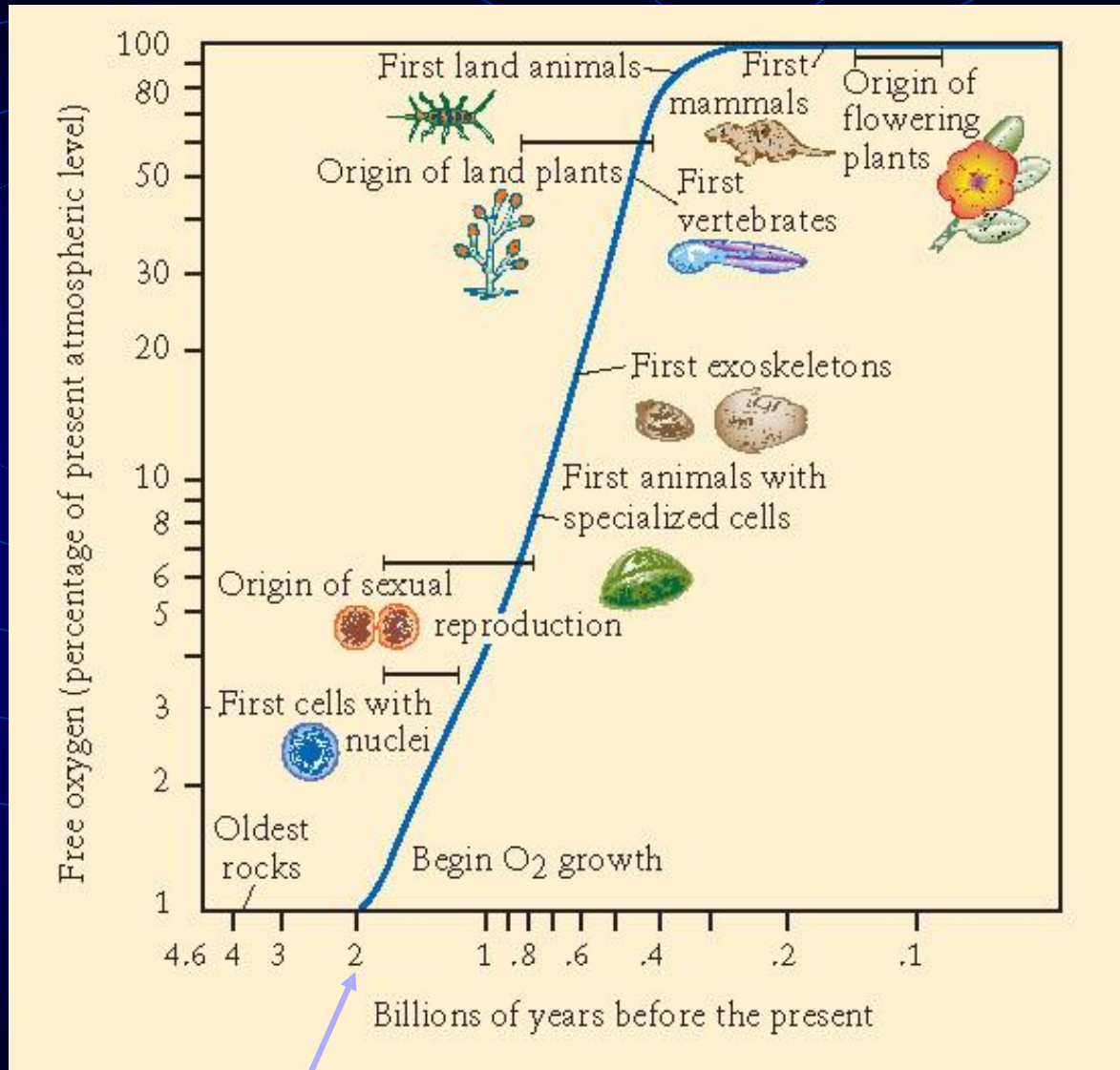
中氣層

同溫層

對流層

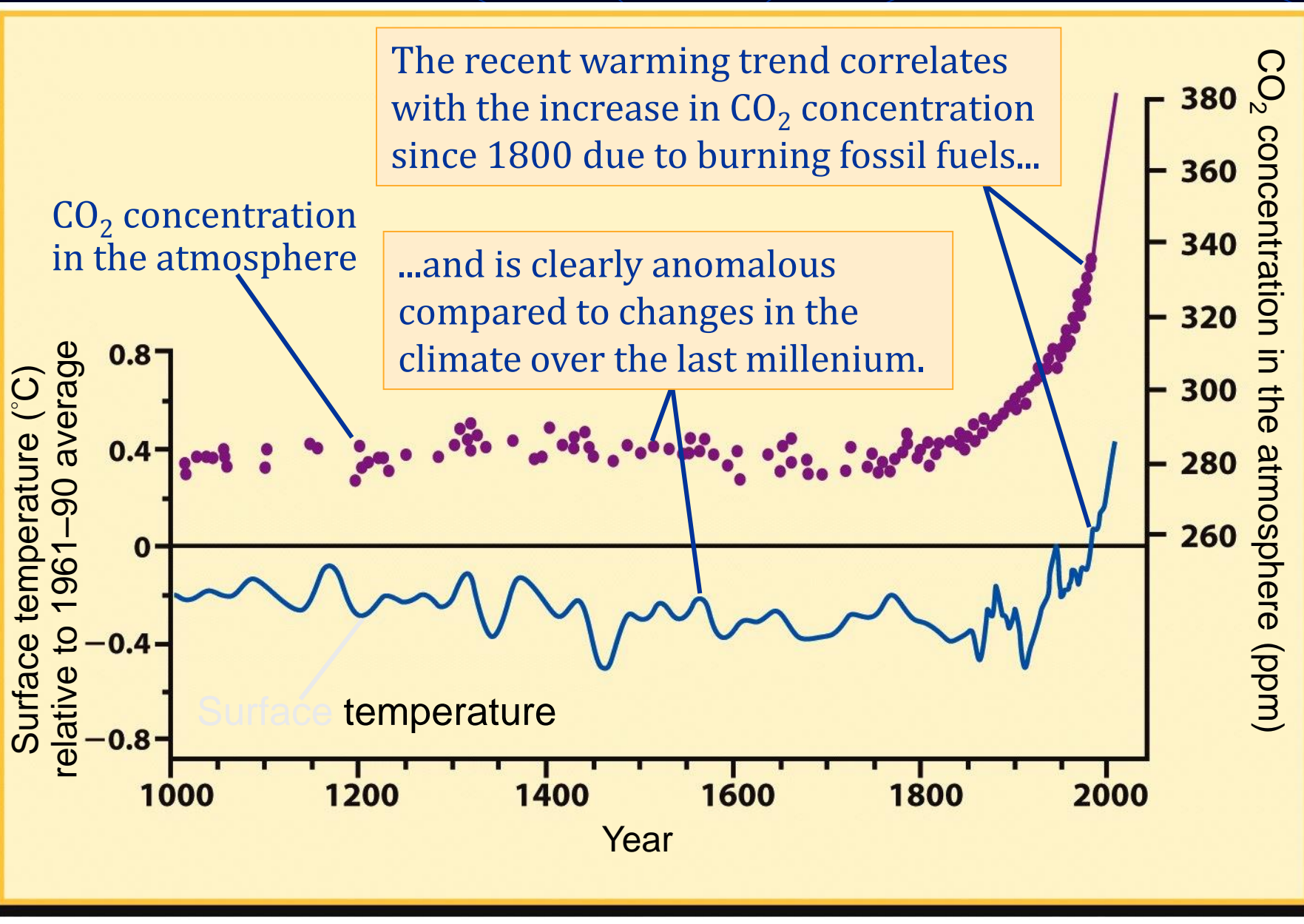
臭氧 (O<sub>3</sub>) 層 (ozone layer)  
吸收陽光紫外線

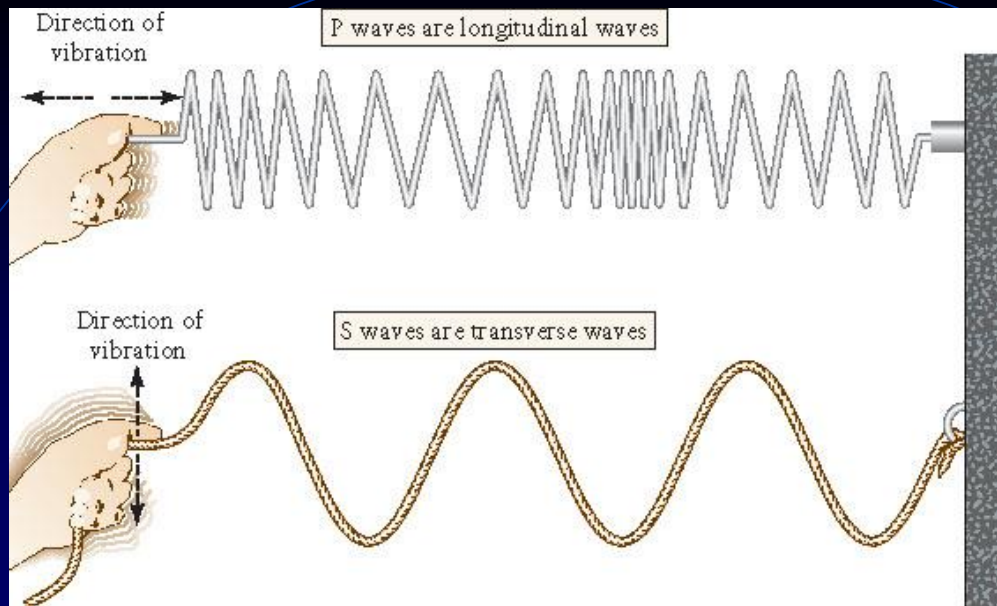
# Increase in Atmospheric Oxygen



Little oxygen until 2 billion years (20億年) ago

# Increase in Atmospheric CO<sub>2</sub>





# 地震波

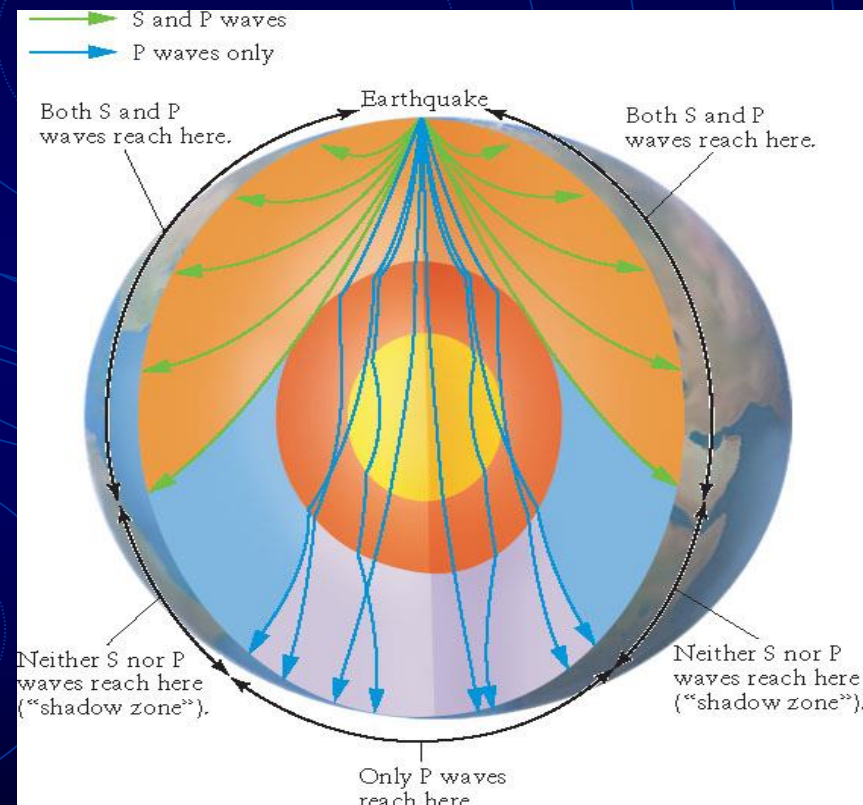
P 波 (縱波)

S 波 (橫波)

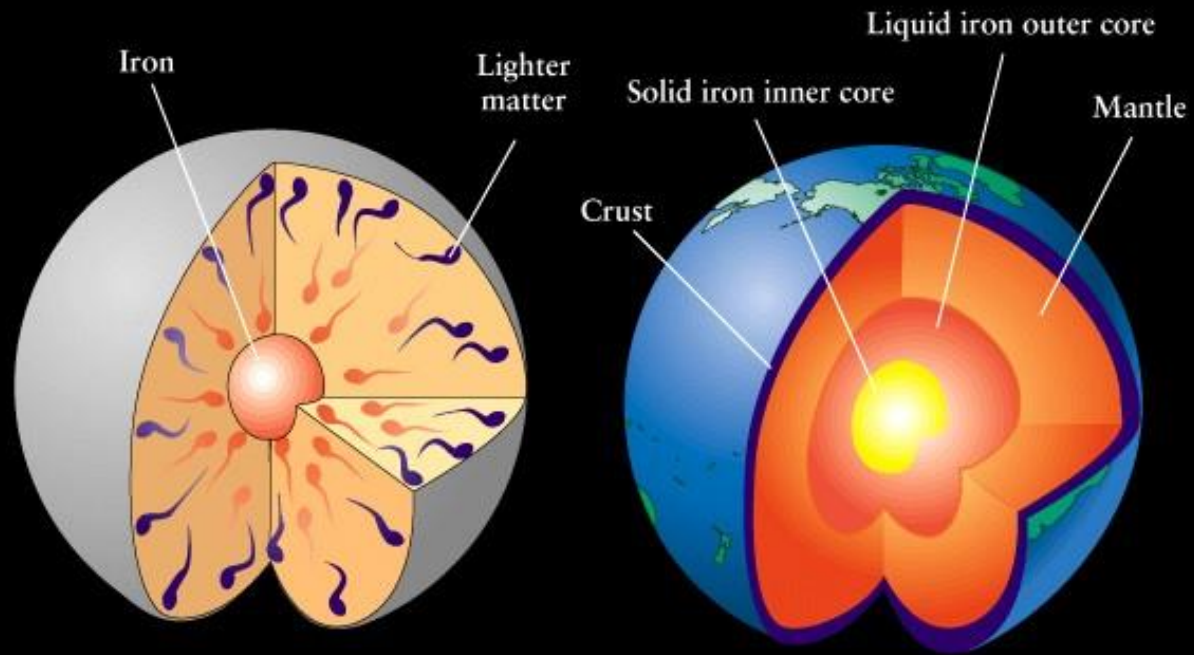
波動因為介質密度不同而折射

只有P波能夠穿越液態地心

→ 利用地震波探測地球內部結構



Paths of seismic waves → probing internal structure



地球中央有個鐵鎳 **核心**

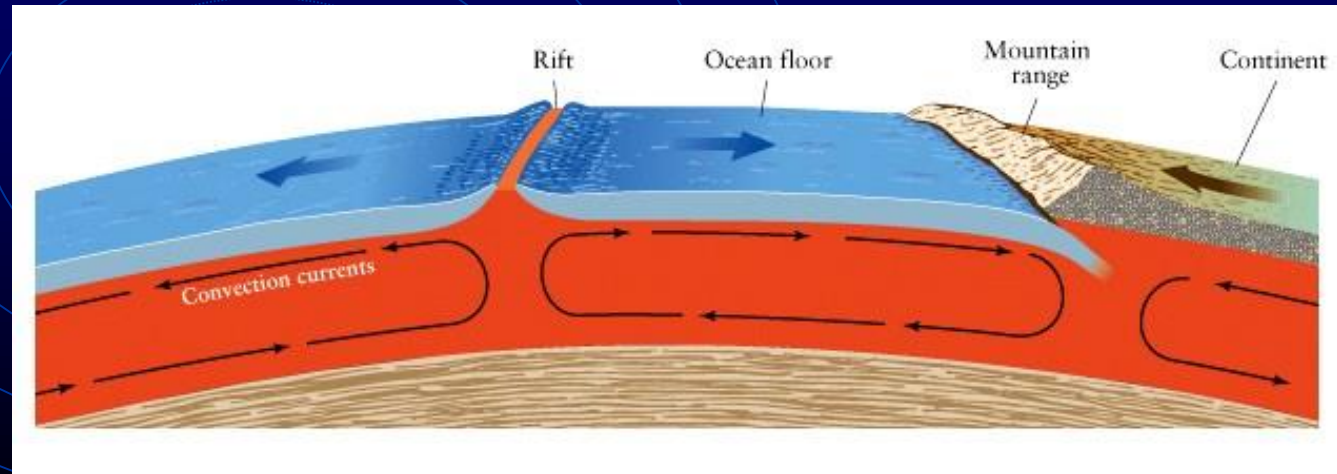
- inner solid core (< 1300 km)
- outer liquid core (1300~3500 km)

外面包覆著岩石  
**地函** (mantle)

最外面有**地殼** (crust)

Differentiation → dense materials sink → layered structure

地球內部對流造成  
**板塊運動 (plate tectonics)**







## 中洋脊

大西洋當中的海底山脈 (the Mid-Atlantic Ridge)，乃是地球內部岩漿冒出而成

海洋板塊仍持續向外擴張

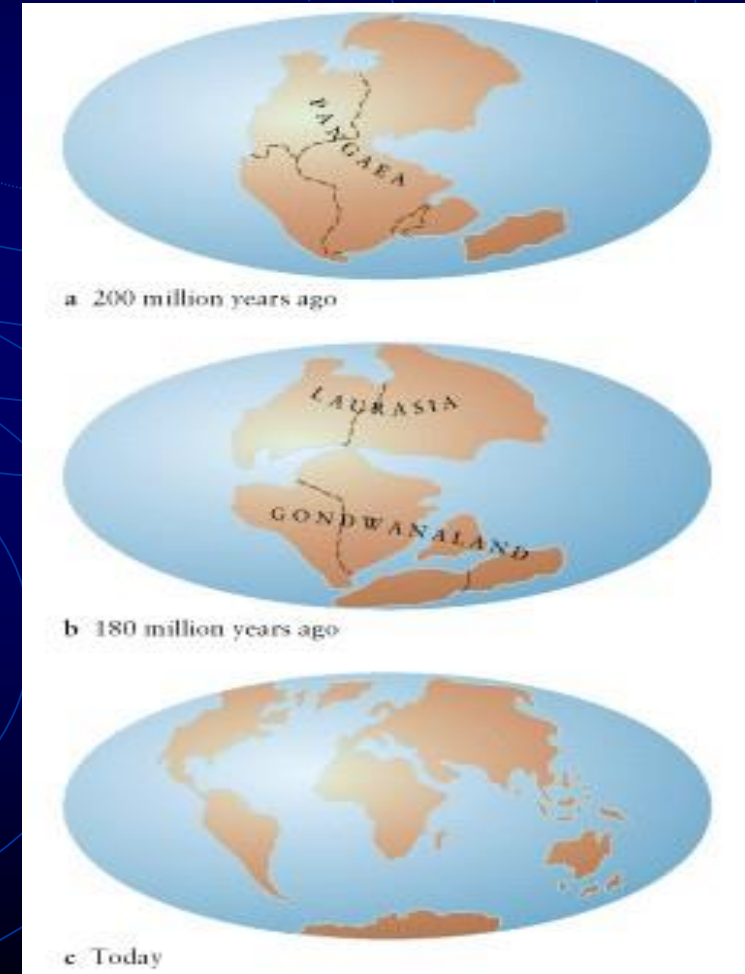
大陸邊緣吻合

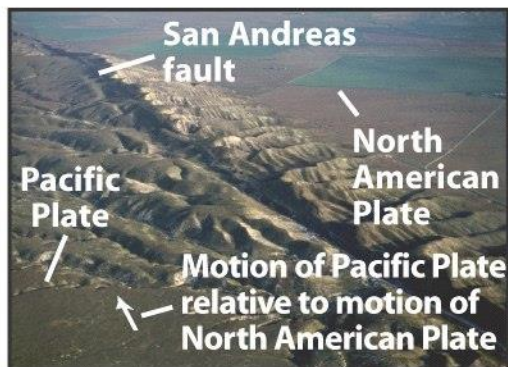
→ 以前連在一起

Alfred Wegener：  
大陸飄移學說  
(continental drift)



Pangaea  
盤古大地

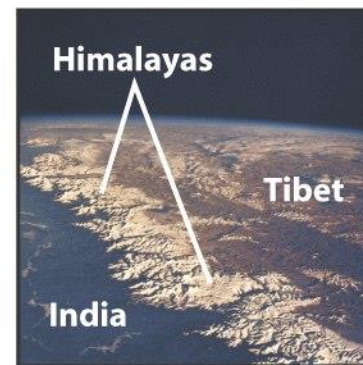




b

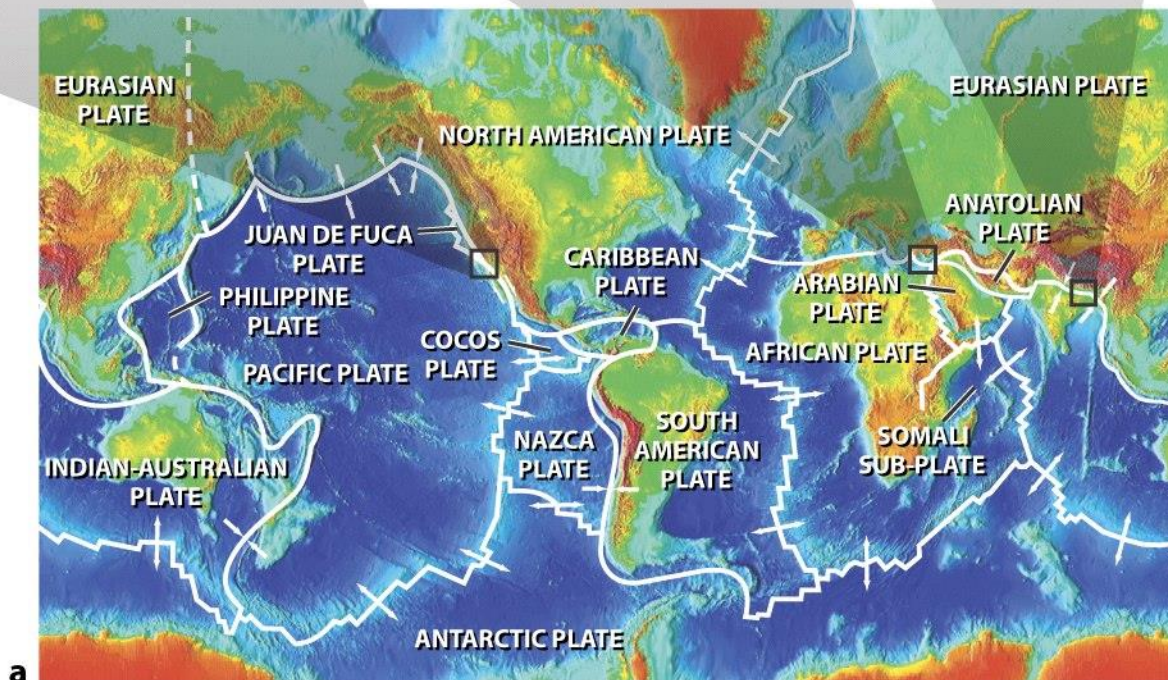


c

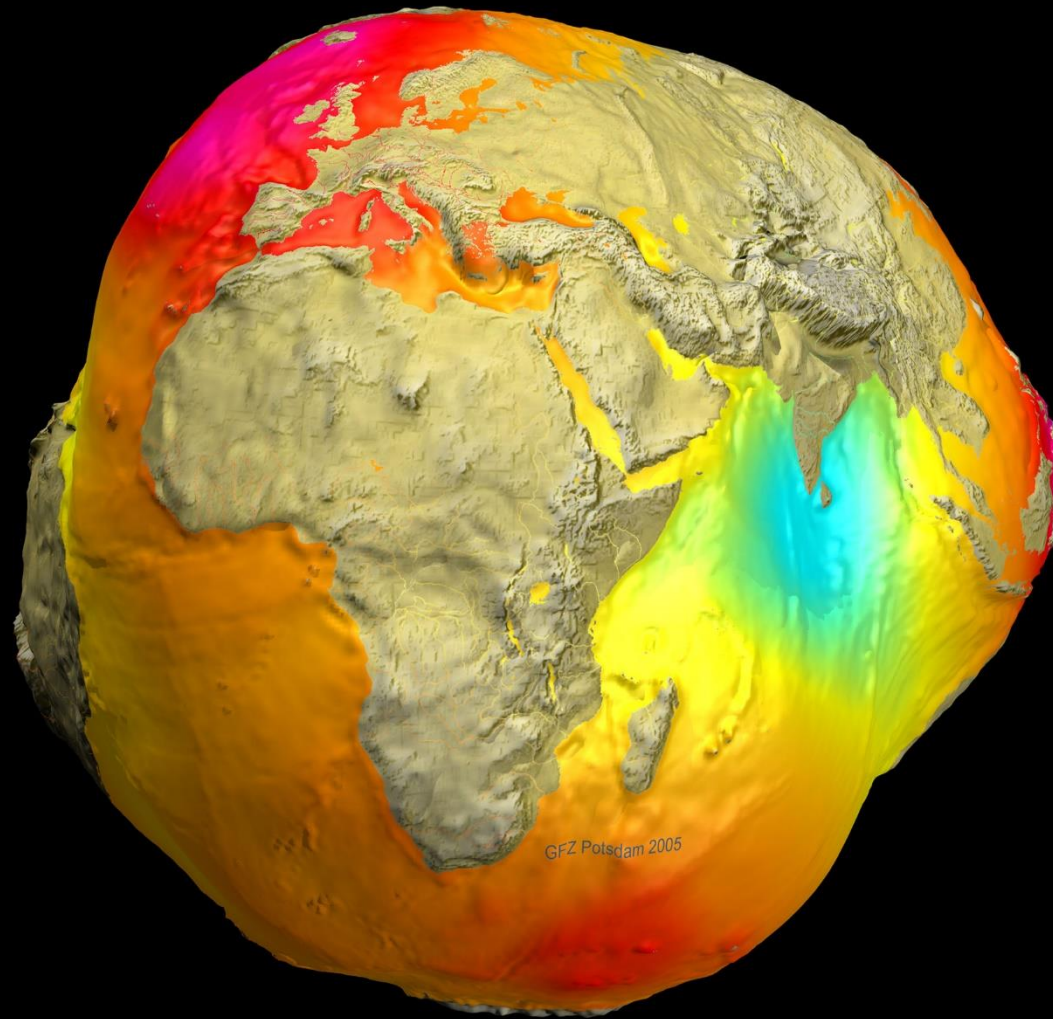


d

地表主要板塊  
(tectonic plates)



a



Red: gravity stronger  
Blue: weaker

APOD 2014.12.15

## Potsdam Gravity Potato

[http://apod.nasa.gov/apod/image/1412/geoid2005\\_champgrace\\_2362.jpg](http://apod.nasa.gov/apod/image/1412/geoid2005_champgrace_2362.jpg)



動態的海洋

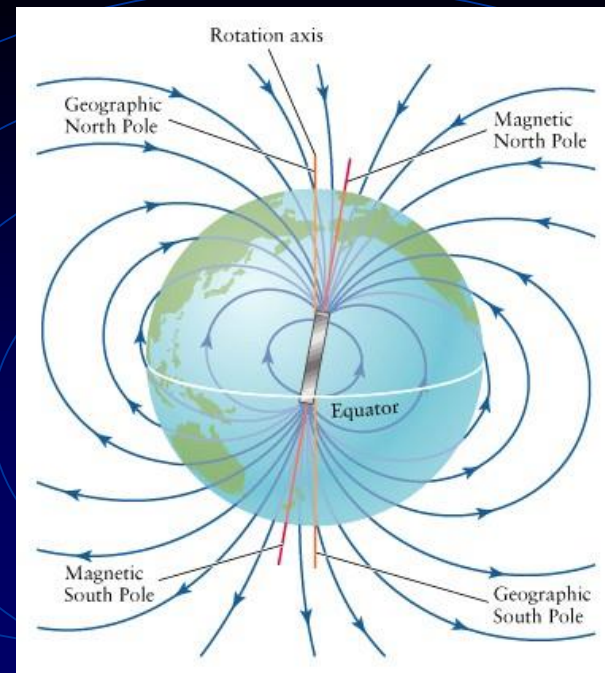
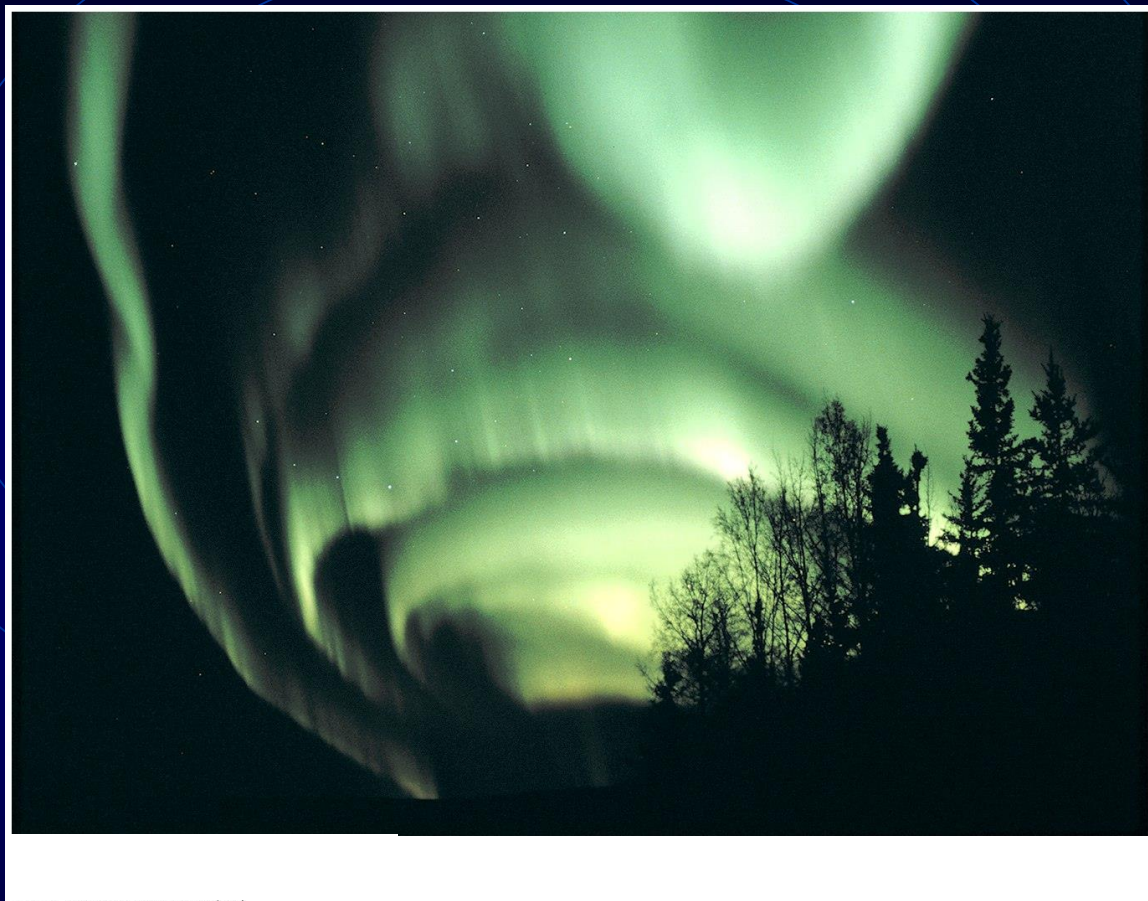


動態的大氣



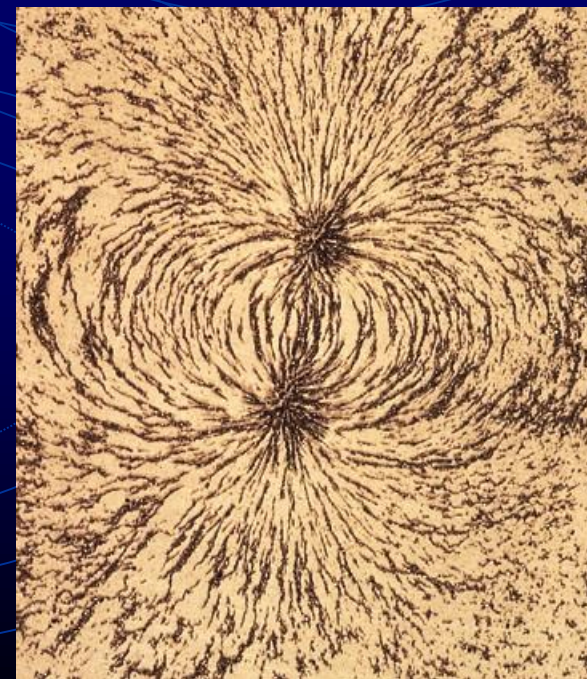
動態的地表

# 極光 (aurora)

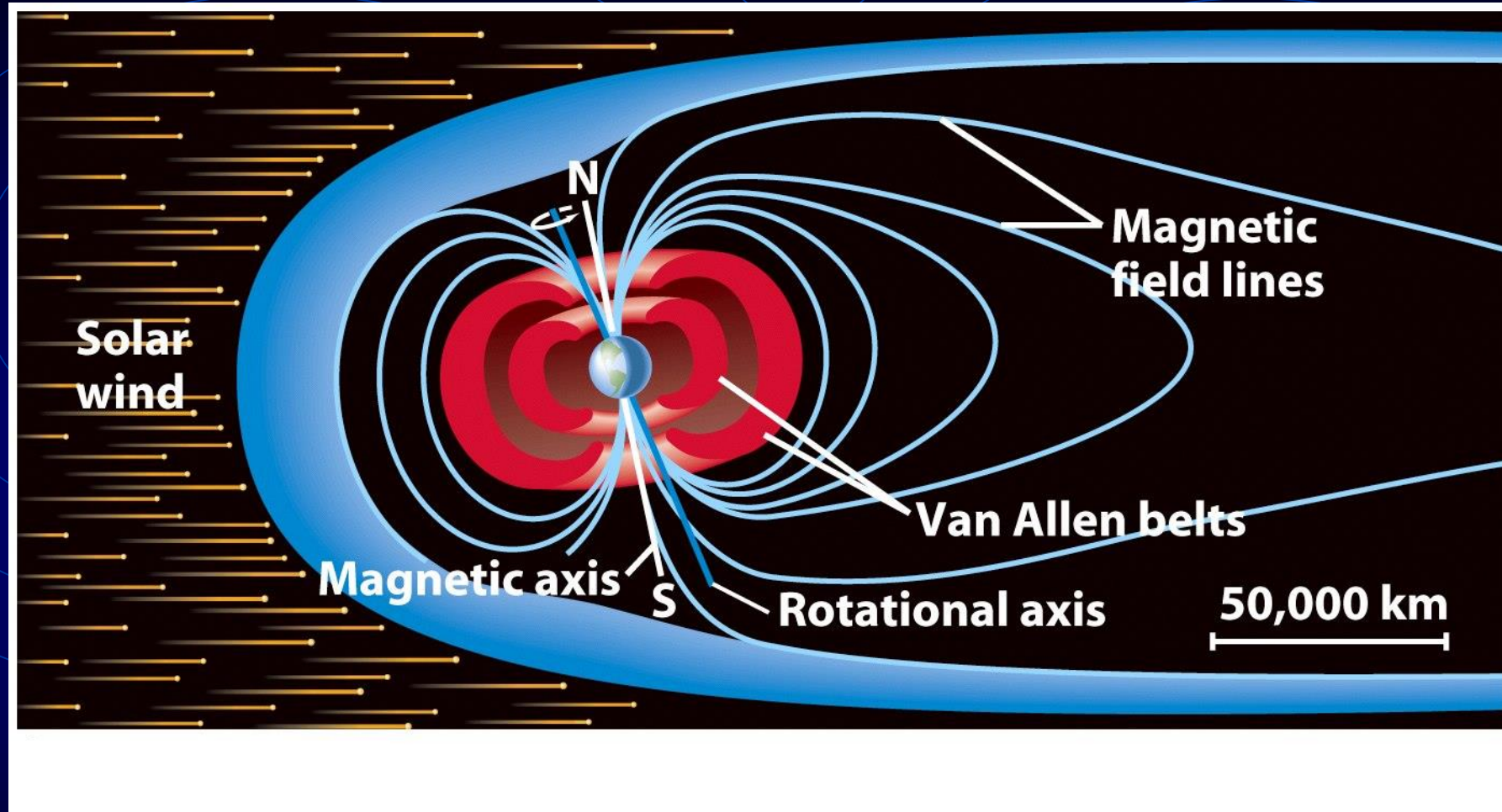


磁偶極

地球本身有磁場，保護地表與生物免於受太空帶電粒子（宇宙射線）侵襲



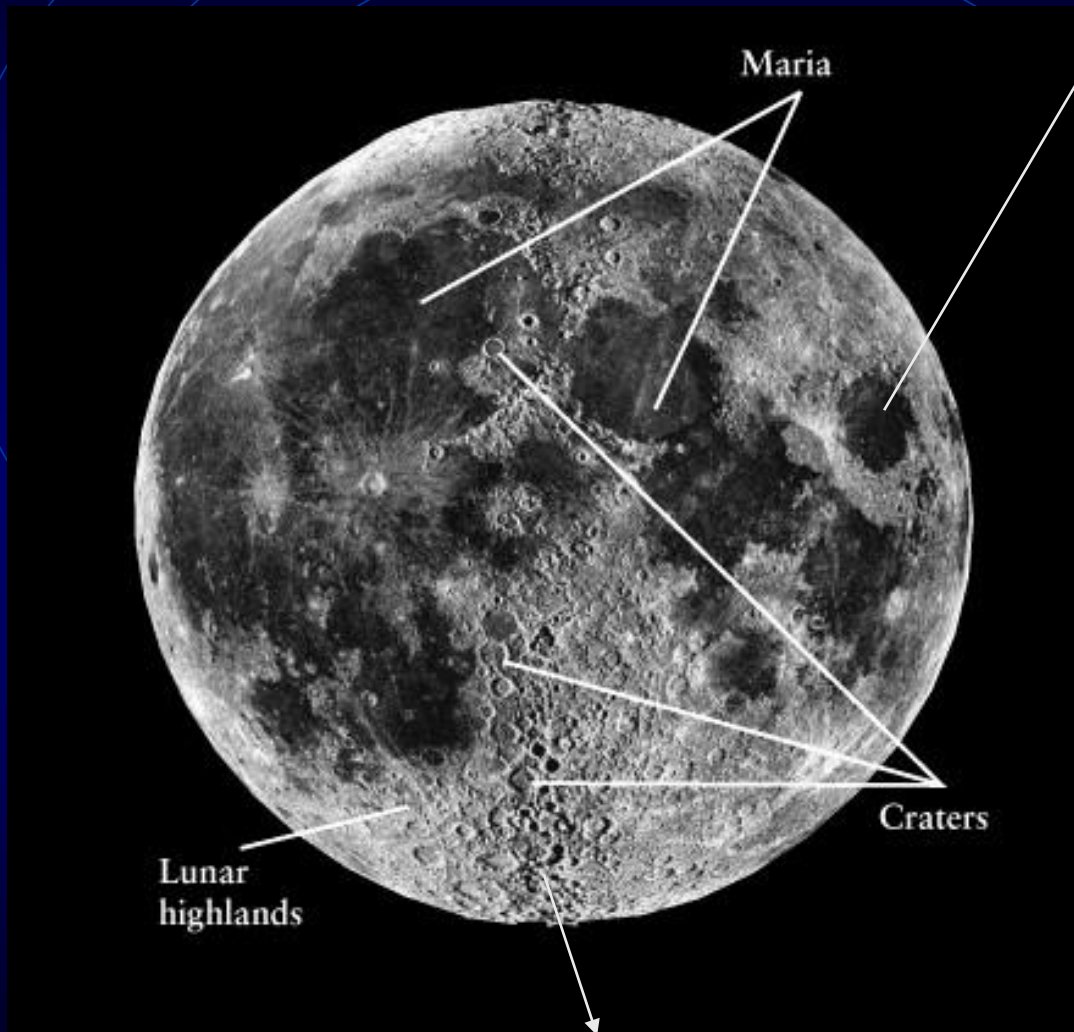
# Magnetosphere (磁層)



**Van Allen radiation belts:** 地球周圍兩個如泳圈狀區域，乃太陽風帶電粒子集中之處

# 月球 (Moon)

「月海」(mare) = 顏色灰暗；低窪地區



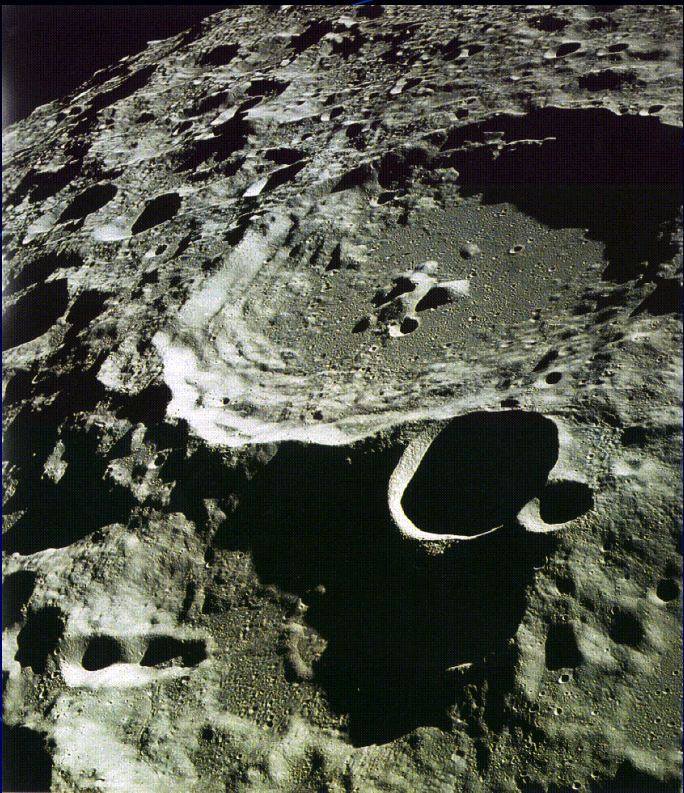
highland 高地，佔月面 83% 面積



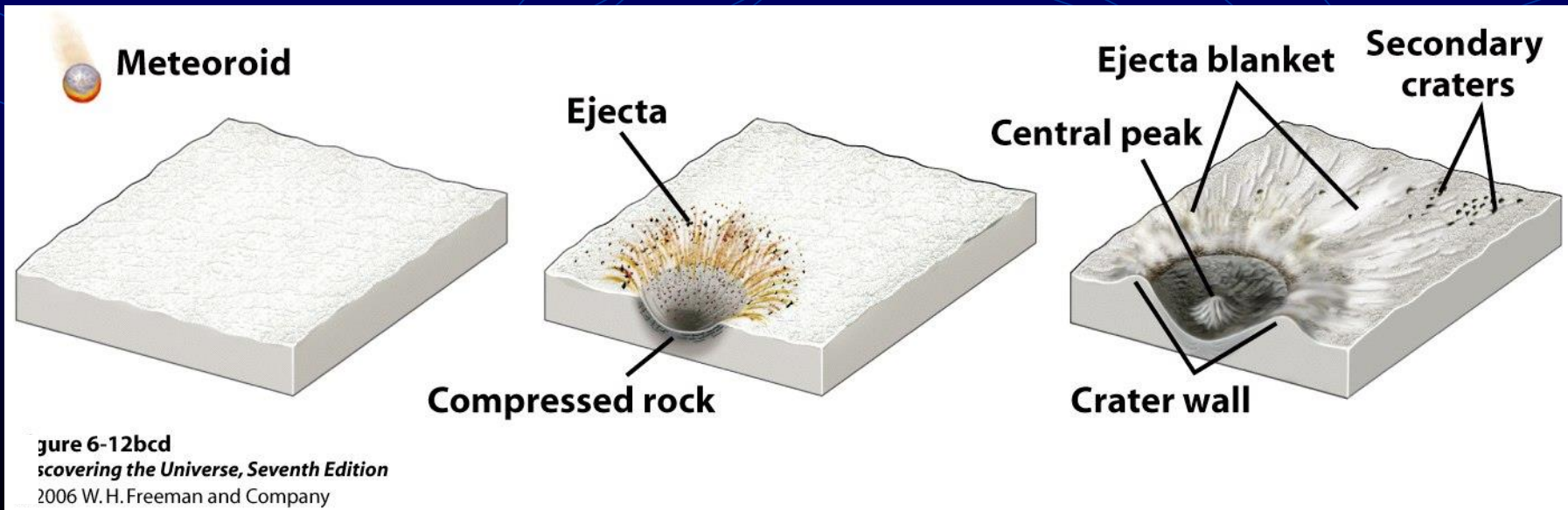
# Earth, Moon and Hubble Space Telescope



S103E5252 1999:12:22 13:51:46



從地球使用望遠鏡可看到超過 3 萬個隕石坑，一般大型隕石坑以天文學家、物理學家、數學家、哲學家命名，例如凱卜勒、哥白尼、畢達哥拉斯 (Pythagoras)、柏拉圖 (Plato)、亞里斯多德 (Aristotle)



# 月海 (mare; 複數為 maria)

- 拉丁文「海」之意。十七世紀觀察月球者以為是「海」
- 現在我們知道這些並非水，而是月面岩漿往低窪地區流動構成的盆地區域
- 有名的月海：
  - Mare Imbrium (Sea of Showers 雨海) 最大月海，直徑1100 km
  - Mare Tranquillitatis (Sea of Tranquillity 寧靜海)
  - Mare Nebium (Sea of Clouds 雲海)
  - Mare Nectaris (Sea of Nectar 酒海)
  - Mare Serenitatis (Sea of Serenity 澄海)

柏拉圖  
隕石坑

哥白尼  
隕石坑

雨海

澄海

風暴洋

危海

雲海

寧靜海

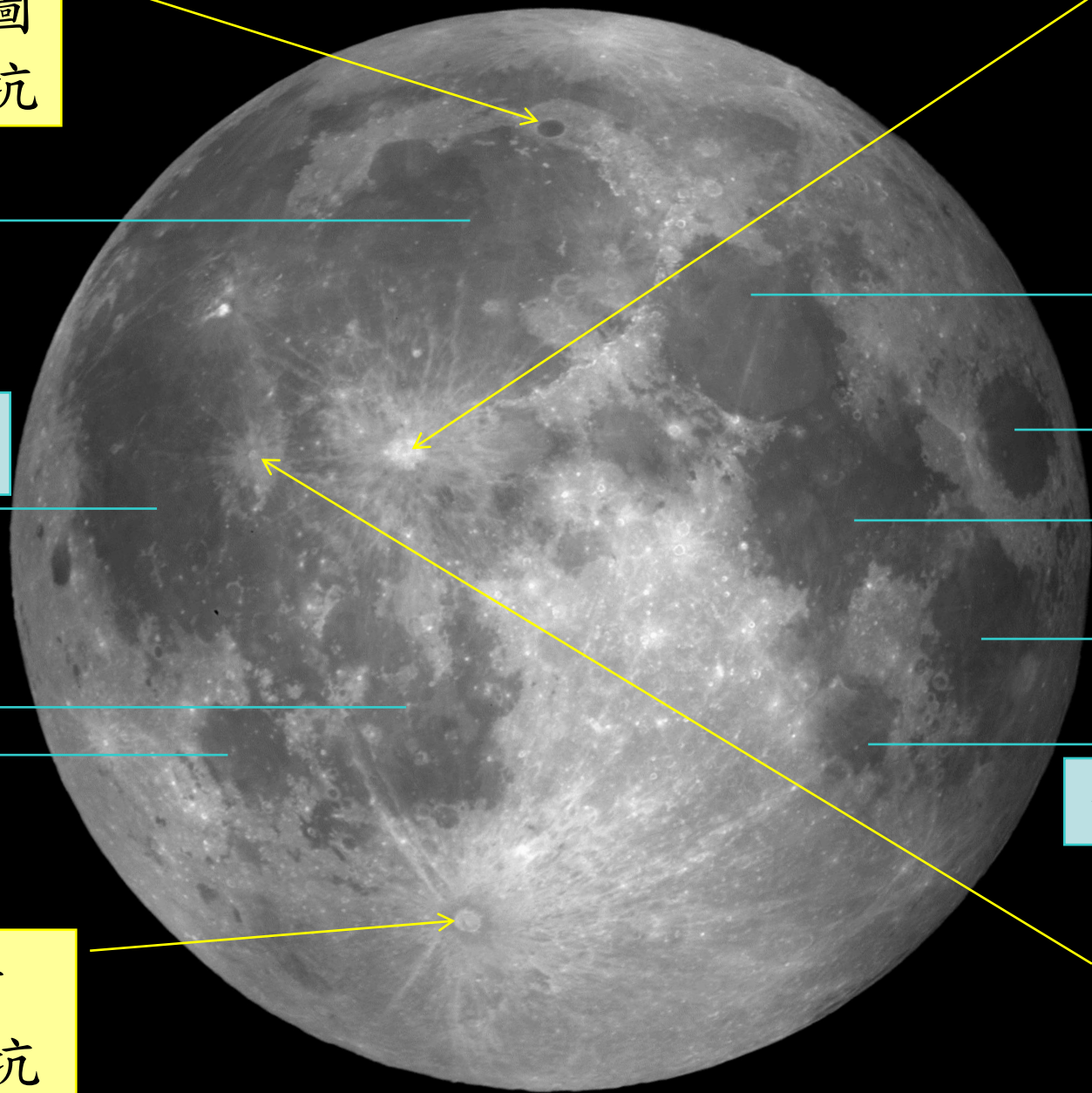
濕海

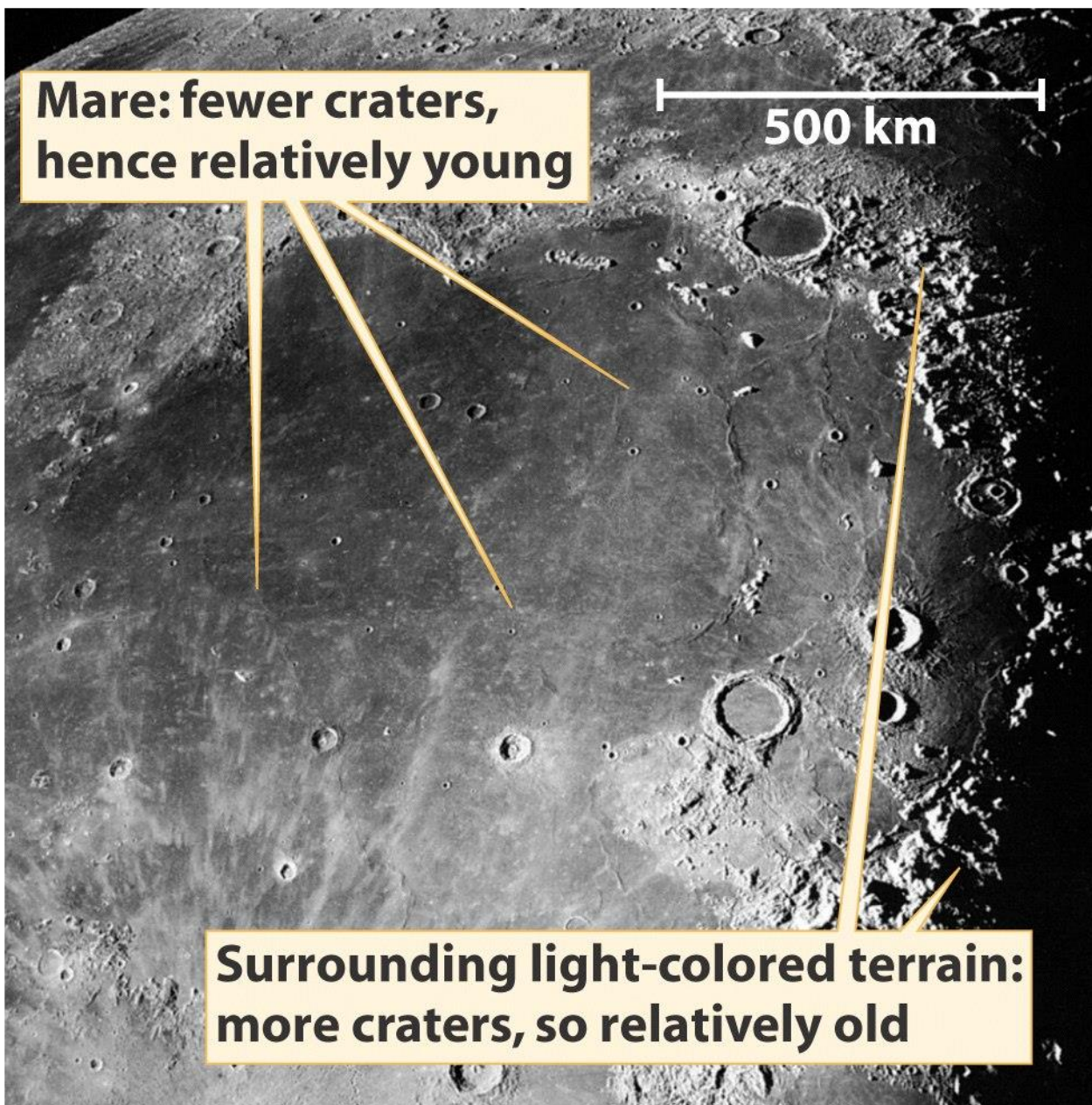
豐海

酒海

第古  
隕石坑

刻卜勒  
隕石坑





**Mare: fewer craters,  
hence relatively young**

500 km

**Surrounding light-colored terrain:  
more craters, so relatively old**

Figure 6-14

covering the Universe, Seventh Edition

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# Mare Imbrium (雨海)



Figure 6-13

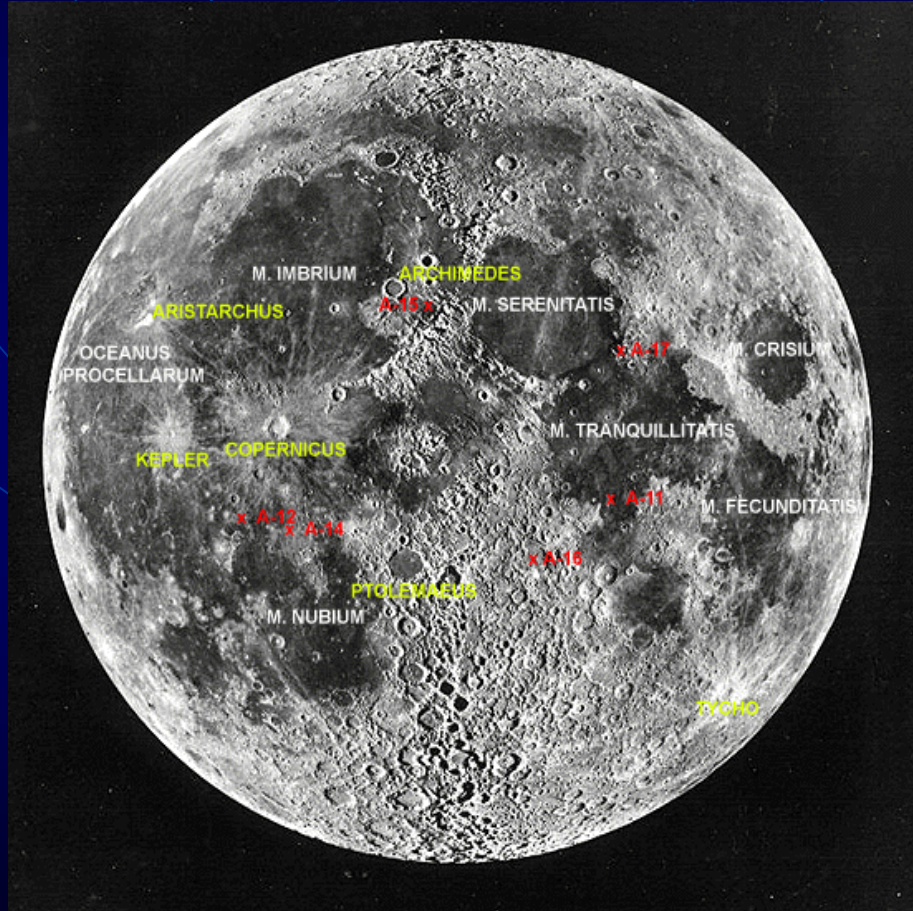
*Covering the Universe, Seventh Edition*

© 2006 W. H. Freeman and Company

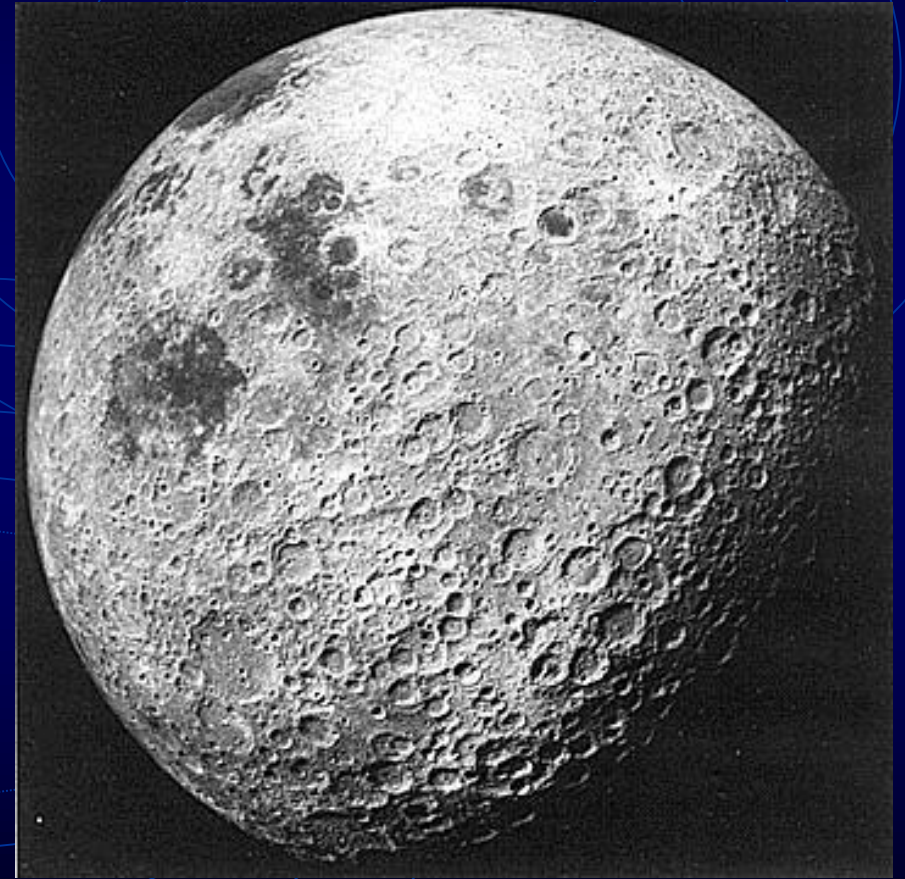
Microscopic Lunar Crater < 1 mm

# 月球永遠以同一面對著地球

## 我們看到的月球表面

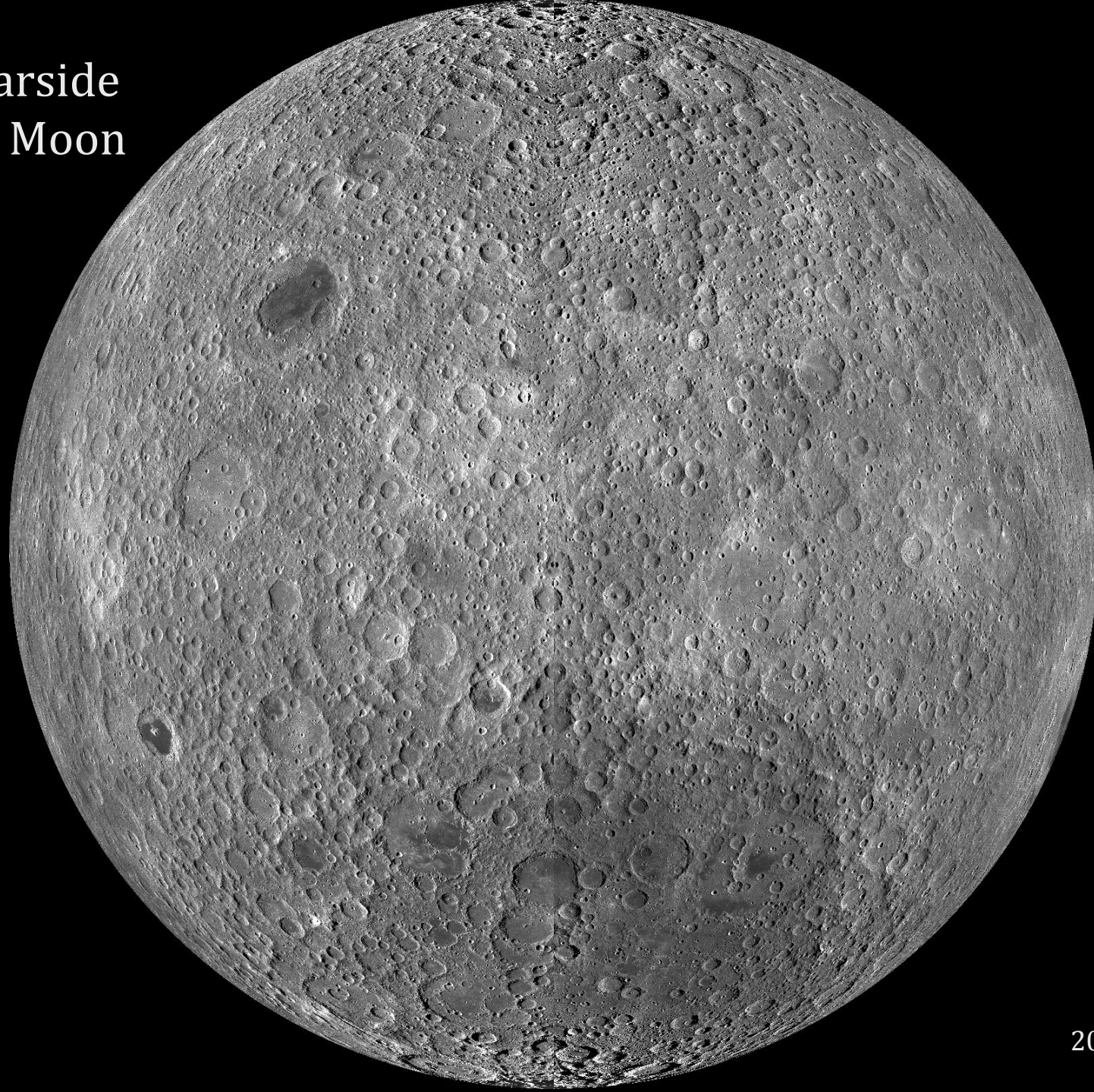


## 月球背面 (farside)



月球引力只有地球1/6，無法抓住大氣 灰暗（低窪）區域少→ 高地居多

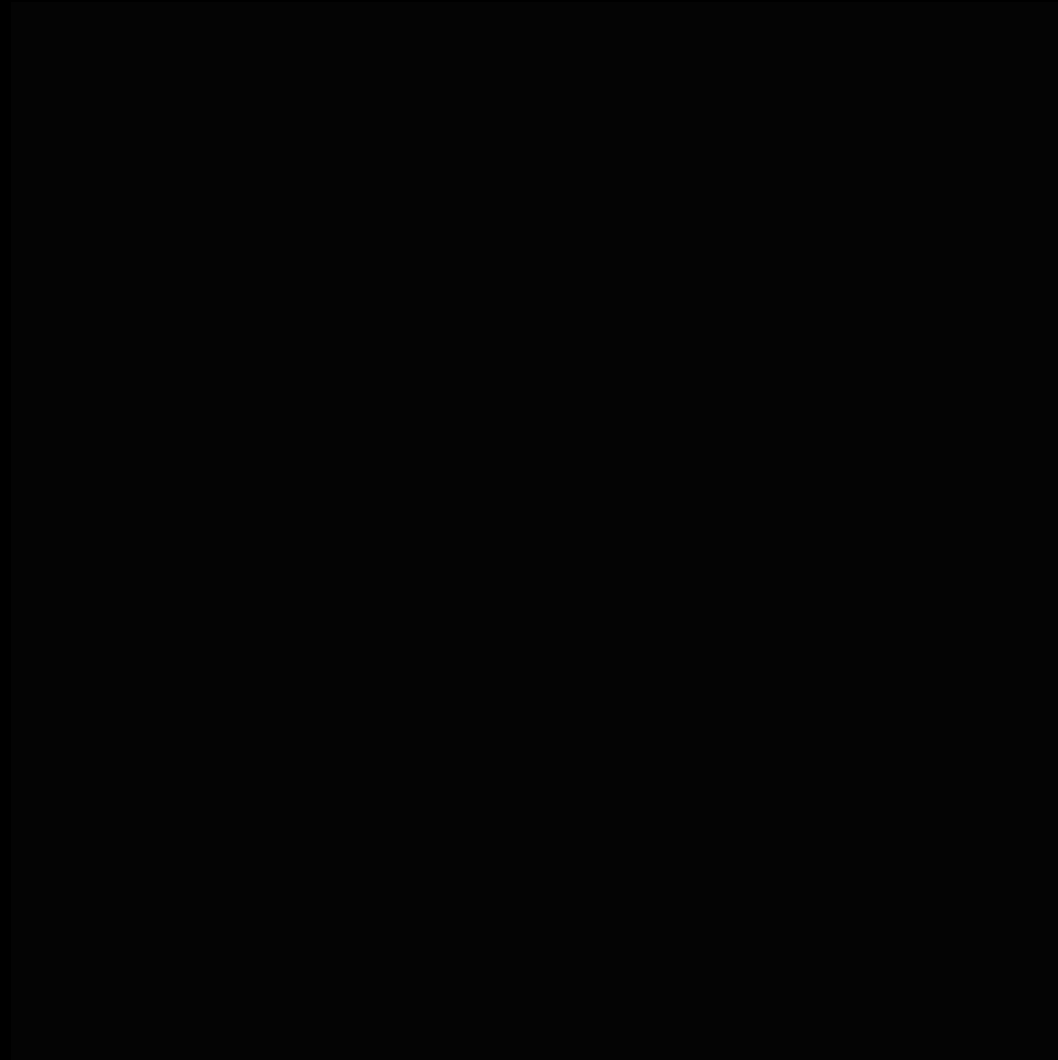
The farside  
of the Moon

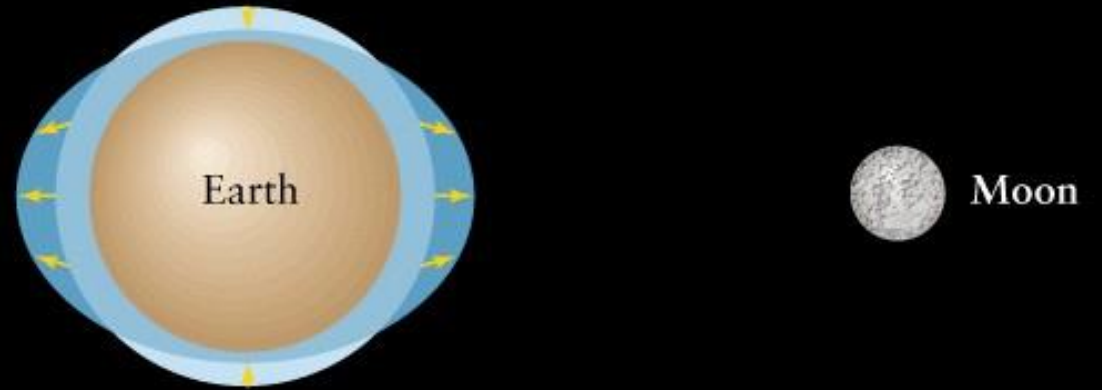
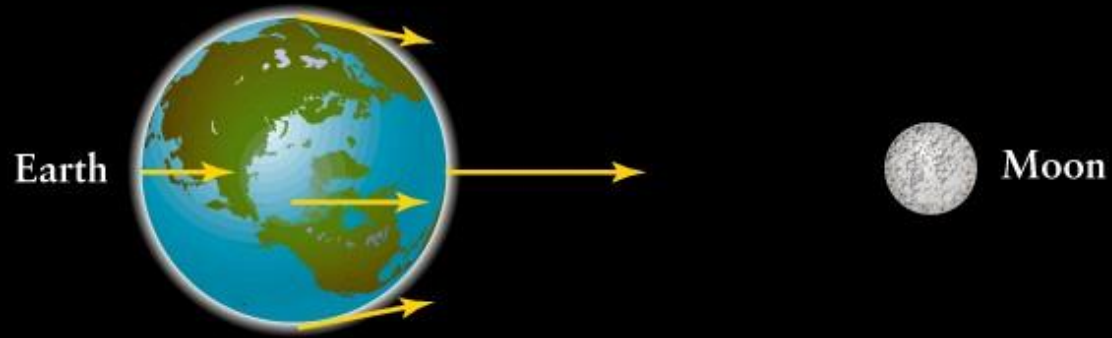


APOD  
2014.04.05



# Lunar Phases 月相



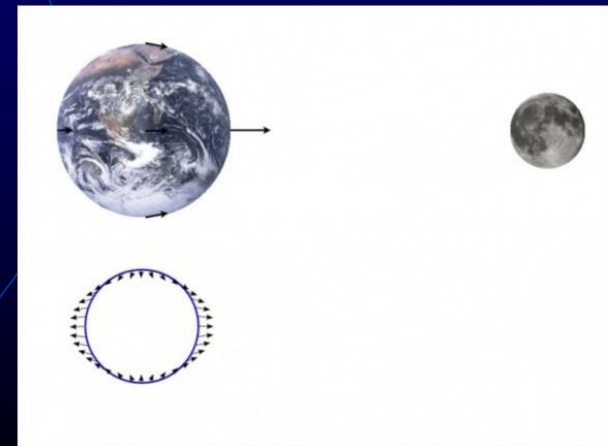


潮汐來自月球與太陽的萬有引力差

月球雖然小，但是距離地球近，影響較大

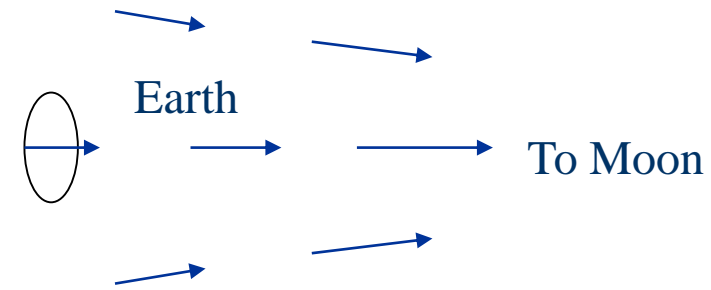
滿月、新月 → 大潮

上弦、下弦 → 小潮



# Tidal Force 潮汐力 = 萬有引力差

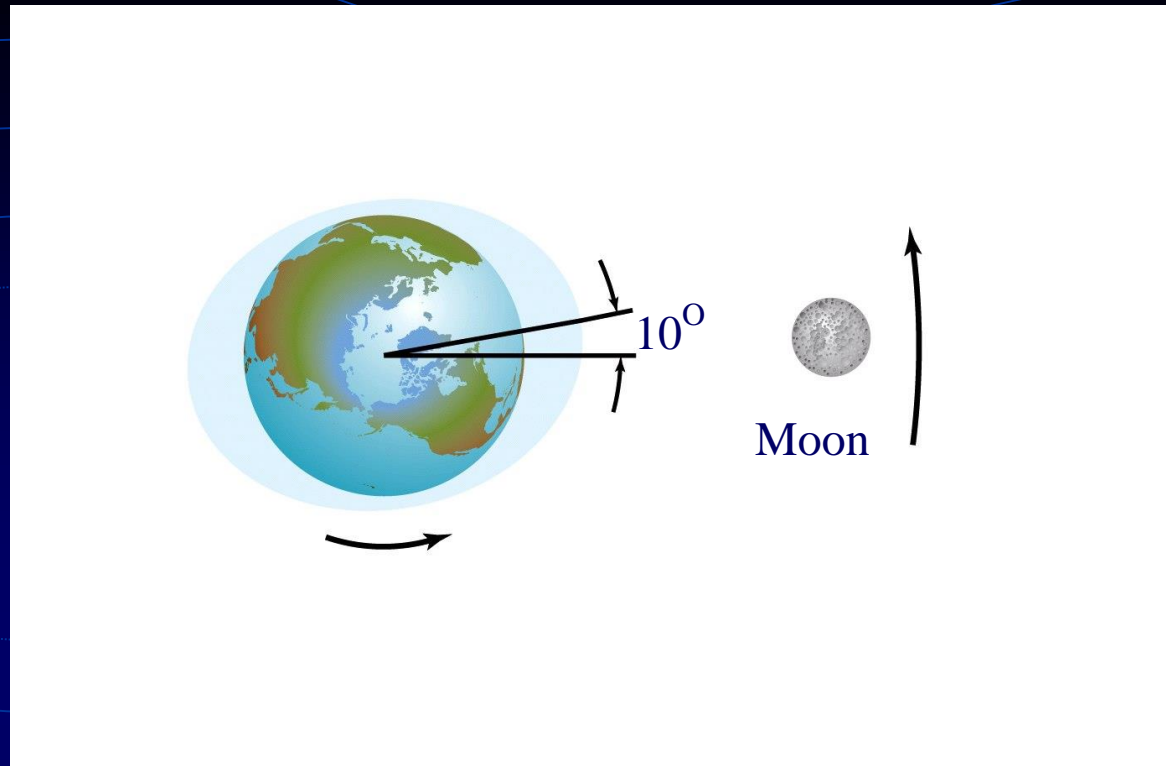
$$dF/dR = -2GM_{\text{moon}}/R^3$$



$dF$  is the differential gravitational force directed along  $R$ , and  $dR$  is the diameter of a single solid body or the separation between two bodies being acted upon by the tidal forces.

驗證：

The tidal force of the Sun relative to that of the Moon is  $\approx 5/11$ .



地球自轉比月球公轉快

→ 地球的海洋突起指向月球「前方」約 $10^\circ$ 處

→ (1) 地球自轉越來越慢 (每世紀 0.002 秒)

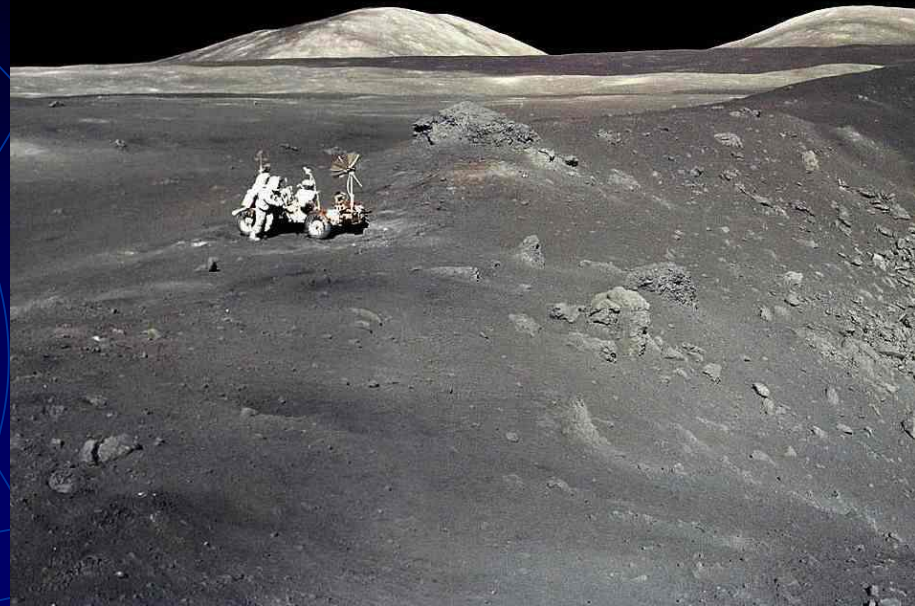
地球剛誕生時可能每6~10小時轉一圈

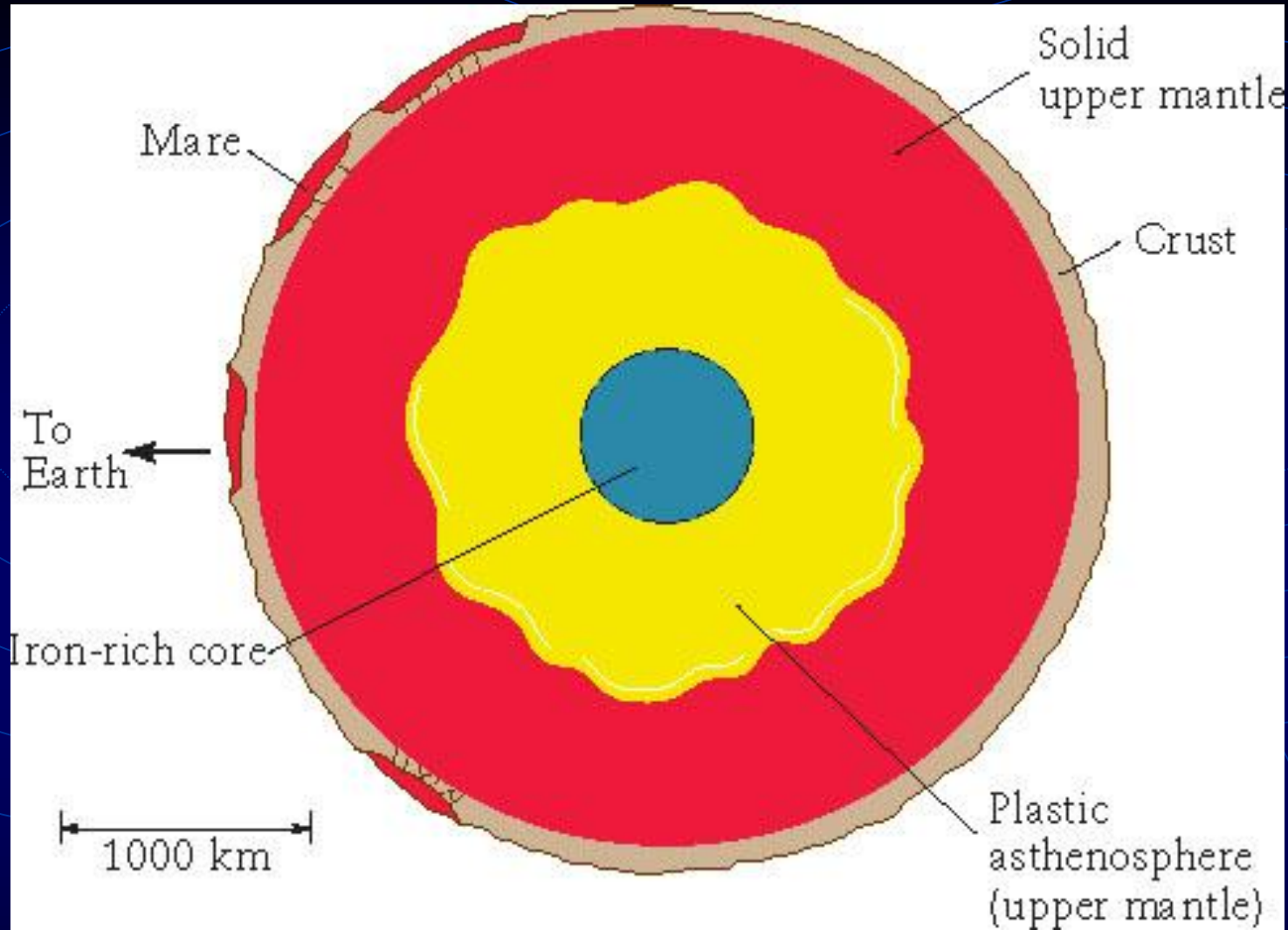
(2) 月球越來越遠 (每年 3.8 公分)



近來對月球的探測的重點之一，在於月球是否有水…

水不但可以提供生活所需，  
分解後也可以提供氫（燃料）  
及氧（生命所需）



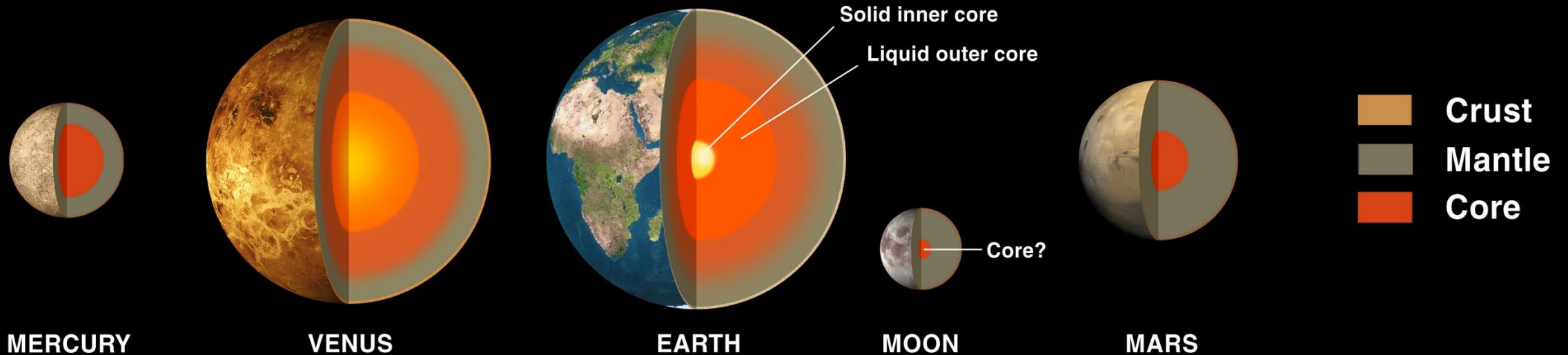


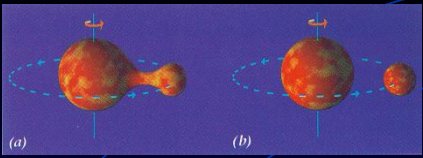
Lunar crust thicker than that of the Earth (thickest on the far side of the Moon), 80% of the Moon's radius, with a small iron core.

# Terrestrial planets: crust, mantle and core

silicates

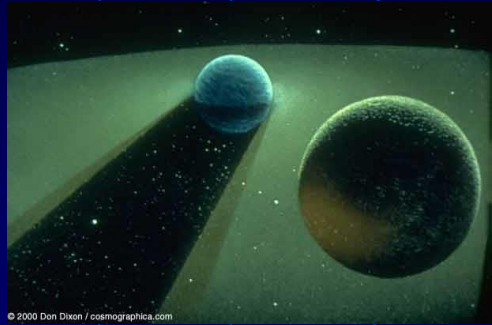
iron and nickel



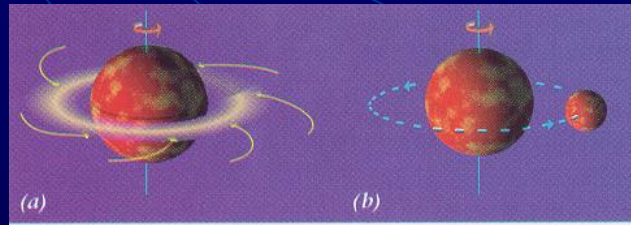


**Fission Theory** --- Moon pulled out from a rapidly rotating proto-Earth. Moon is receding from us.  
*But* lunar samples showed no water in the rocks

[animation](#)



**Capture Theory** --- Moon formed elsewhere, but drawn into orbit about the Earth  
*But* the Moon and Earth's surface have similar geochemistries



**Accretion Theory** --- Moon and Earth formed near each other at the same time  
*But* the Moon has less of the denser elements (e.g., iron) compared to the Earth

[animation](#)



**Giant Impact Theory** --- young Earth struck at an angle by a Mars-sized asteroid. Earth's surface layer → orbit → Moon

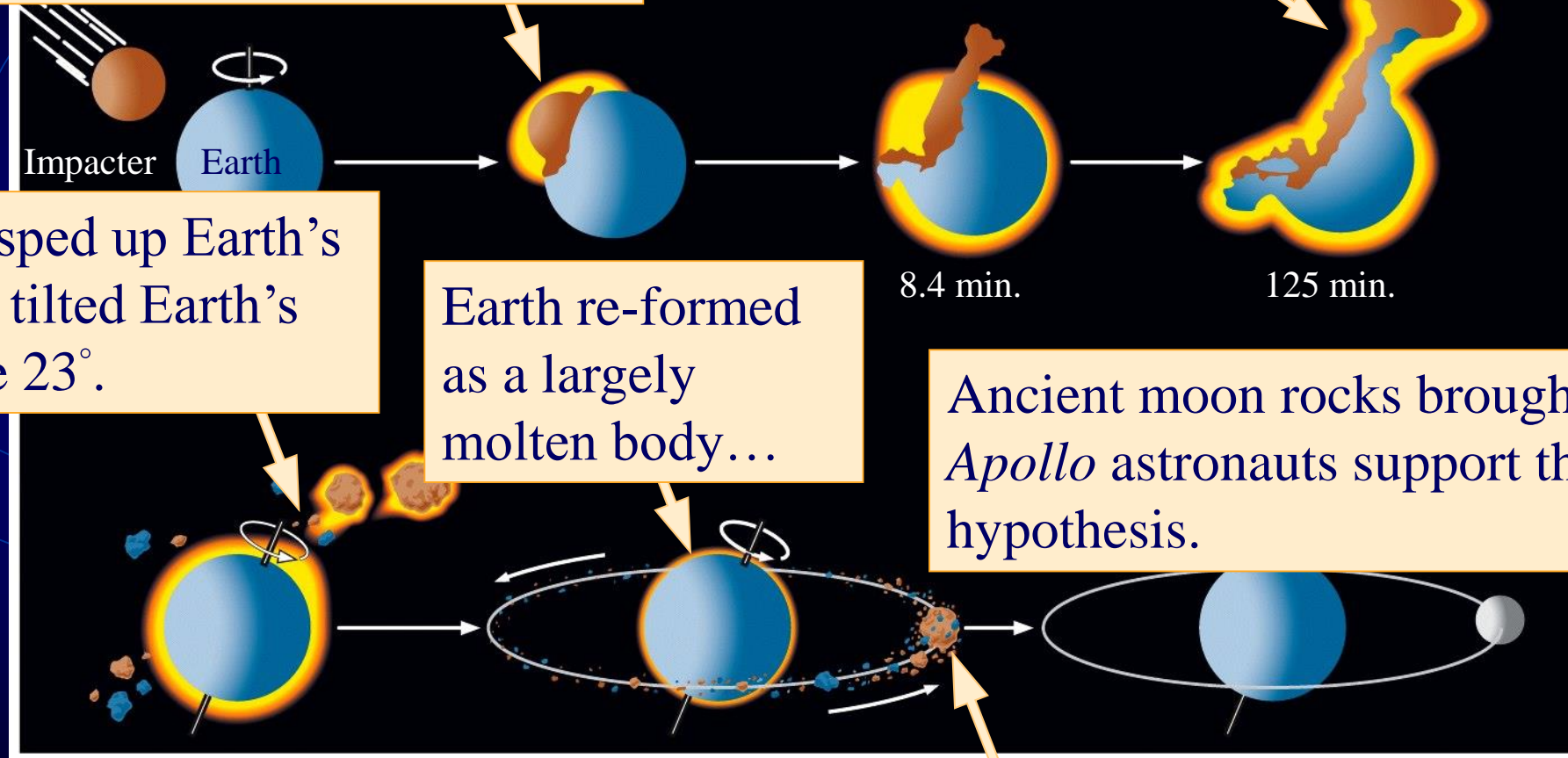
[animation 1](#)

[animation 2](#)



During middle to late stages of Earth's accretion, about 4.5 billion years ago, a Mars-sized body impacted the Earth...

...and the giant impact quickly propelled a shower of debris from both the impactor and Earth into space.

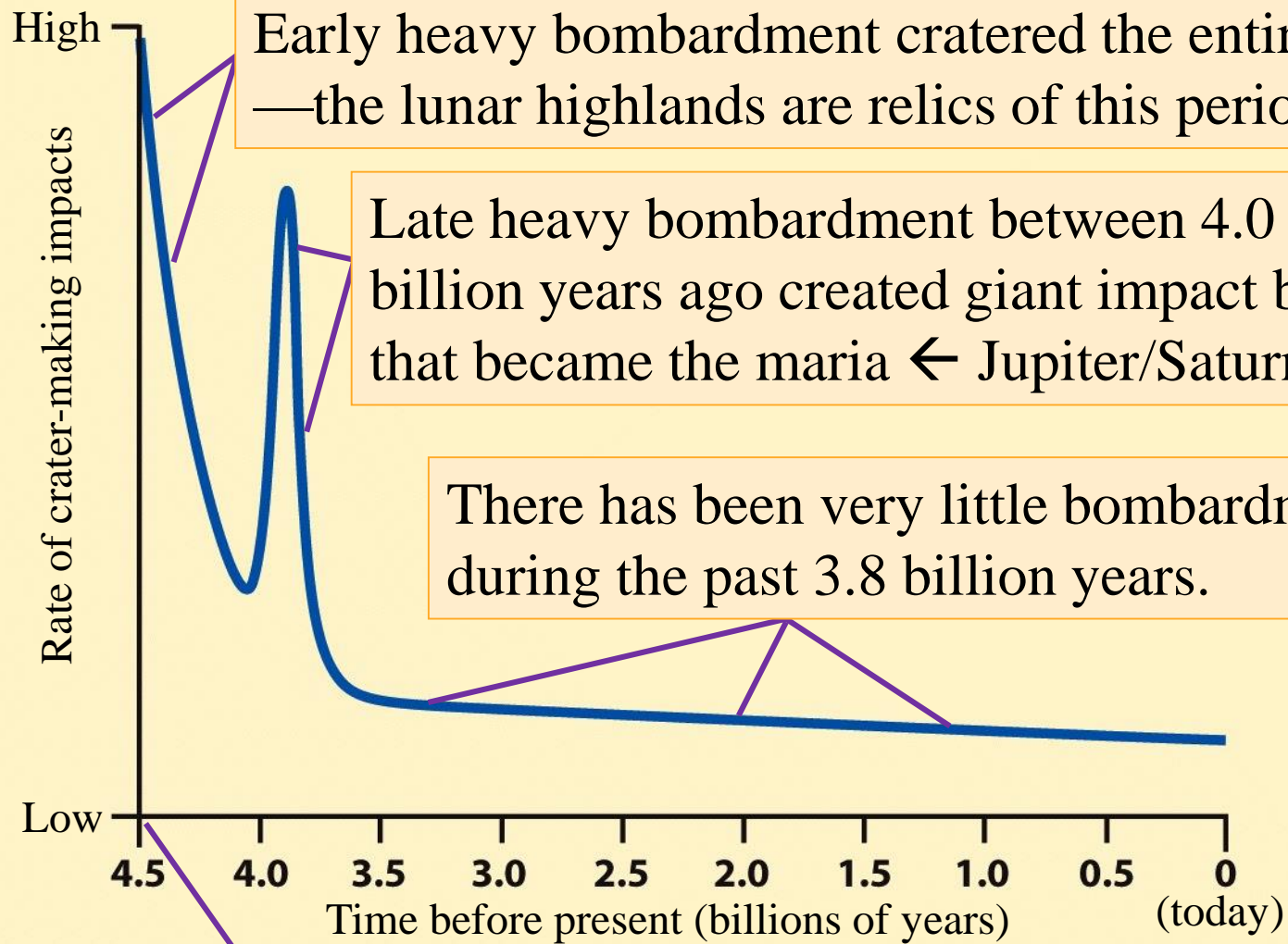


The impact sped up Earth's rotation and tilted Earth's orbital plane 23°.

Earth re-formed as a largely molten body...

Ancient moon rocks brought back by the *Apollo* astronauts support this impact hypothesis.

...and the Moon aggregated from the debris.



Early heavy bombardment cratered the entire Moon —the lunar highlands are relics of this period.

Late heavy bombardment between 4.0 and 3.8 billion years ago created giant impact basins that became the maria ← Jupiter/Saturn migration?

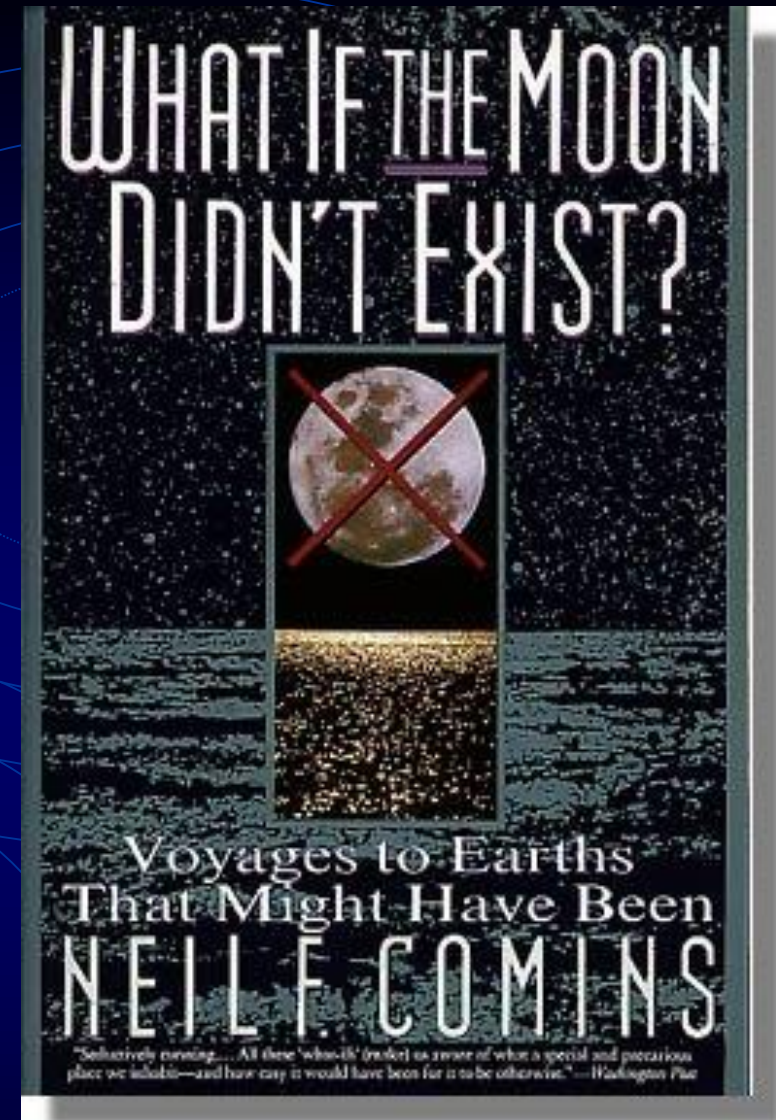
There has been very little bombardment during the past 3.8 billion years.

4.47 billion years: age of the oldest Moon rocks

月球表面隕石坑形成率

# 如果沒有月亮...

- 沒有中國農曆年，沒有中秋節
- 沒有 lunatics
- 沒有 Moon River, 沒有 honeymoon
- 床前沒有明月光
- 潮汐規模小得多；地球自轉會比較快  
(一天不到10小時)
  - 強風、強磁場
  - 生物演化過程可能非常不同
  - 連「上課」方式都會不同...



如果地球離太陽稍微近一點 ...

如果沒有木星 ...

如果太陽質量稍微大一點 ...

如果我昨天沒有 ...

如果我剛才做了 ...

**What If ...**

# WHAT IF the Moon Didn't Exist?

- Delayed Origins 生命可能不會這麼快誕生
- Harsh Conditions 地球環境可能更惡劣
- Rush Hours 一天6小時
- Tumbling Earth 自轉軸指向不穩定

AST101 2014 Fall

