普通天文學 II — 2014/2015

教師：陳文屏 (S4-906) wchen@astro.ncu.edu.tw 或 03-422-7151 x 65960

上課時間：週一 1～2 pm；週四 10～12 am

上課地點：健雄館 S4-204

諮詢時間：週一 3～4 pm；週四 1～3 pm 或另約時間

課本："*Universe*" by Roger Freedman & William J. Kaufmann III (Freeman)
桂林書局：北市重慶南路一段 61 號 7 樓 716 室 電話：(02) 2311-6451

內容：這門課的第二學期繼續討論宇宙太空中的現象，探討如何應用目前所知道的知識解釋這些現象。探討的對象包括恆星、它們的誕生、演化與死亡、星際介質、本銀河系的組成、結構、其他的星系，以及這些種種所構成的宇宙本身的來龍去脈。上課方式以講授為主，配合課堂互動。主題天體尺度由小而大，距離由近而遠，進度非常快（比光速快），所以預習與複習很重要，也應避免缺課。

Part III --- **Understanding the Stars**

- Our Star, the Sun
- Nature of Stars
- Lives of Stars from Birth through Middle Age
- Deaths of Stars
- Compact Objects: Neutron Stars and Black Holes

期中考 — 04 月 23 日 週四上課時間

Part II --- **Understanding the Universe**

- Our Galaxy: The Milky Way Galaxy
- Galaxies
- Quasars and Active Galaxies
- Cosmology: The Origin and Evolution of the Universe
- Search for Extraterrestrial Life

期末考 — 06 月 25 日 週四上課時間

評分：期中考 (30%)；期末考 (35%)；作業、報告、其他 (35%)

課程網站：http://www.astro.ncu.edu.tw/~wchen/Courses/Ast101/index.htm

太陽 (The Sun)

學習目標

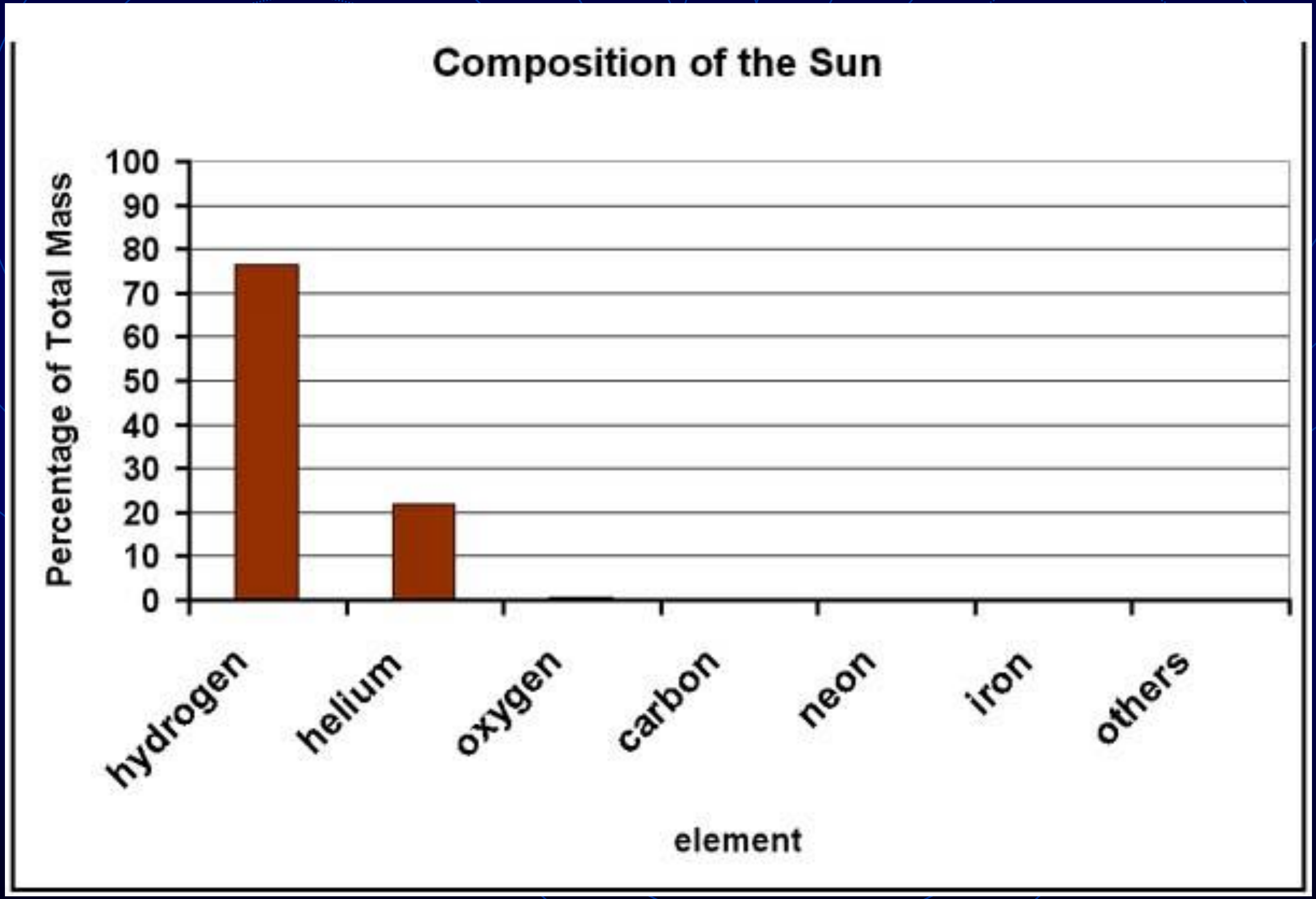
- 太陽的能量來源
- 太陽表面是什麼情形？內部結構呢？怎麼知道？
- 太陽黑子是什麼東西？
- 太陽為何會發光？可以維持多久？
- 太陽的生老病死如何影響地球？

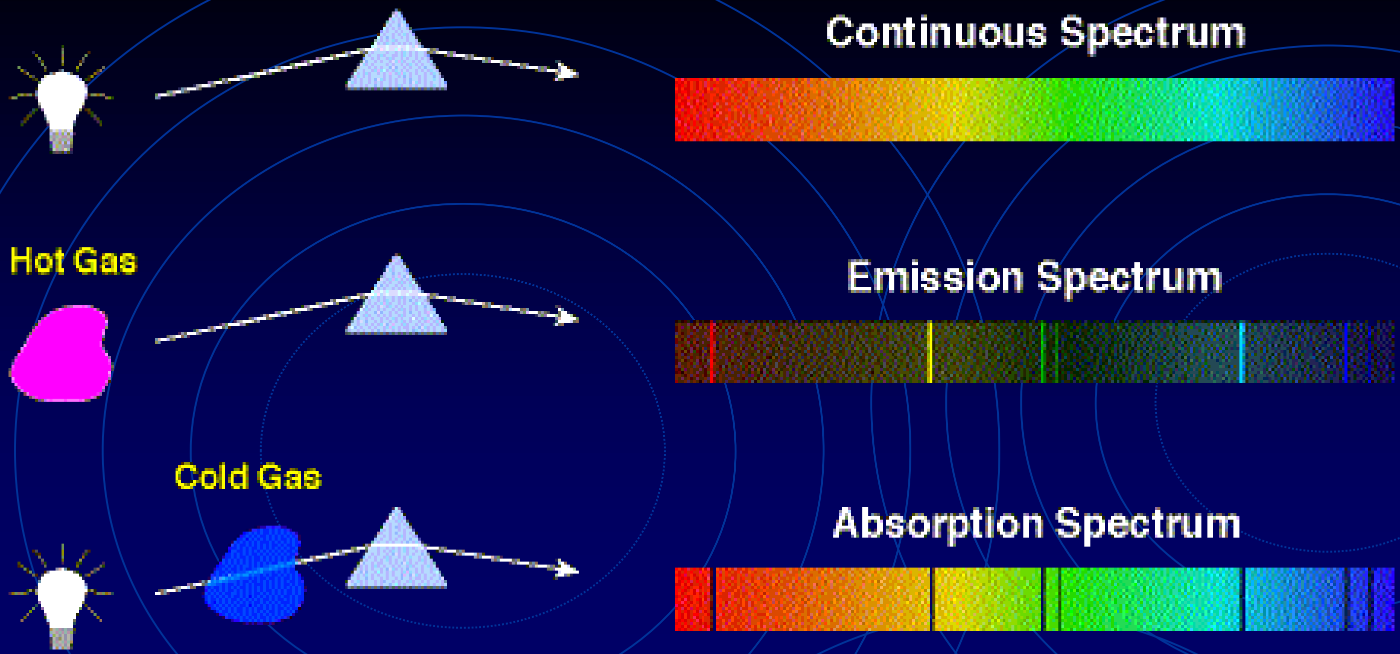
太陽的基本資料

- 表面溫度：5800 K（觀測）
- 核心：1.5×10^7 K （理論）
- 目視大小：32'
- 實際大小：7×10^5 km（70萬公里）
  = 約地球的100倍 = 約木星的10 倍
- 視星等：-26.74（c.f. 天狼星為 -1.45）
- 與地球距離： 1 AU （一億五千萬公里）
- 質量：$1\ M_{\odot}$ ＝ 2×10^{30} kg = 地球 33萬倍
  = 所有行星加起來的 700 倍 ＝太陽系總質量99.85％
- 密度：1.4 公克/立方公分（水是 1；地球是 6.4）
- 光度 (luminosity)： $1\ L_{\odot}$ ＝ 4×10^{26} W
- 赤道自轉一圈需時：約25天

太陽質量約74%是氫，25%是氦，其他元素(共1%) 都少得多

地球呢？

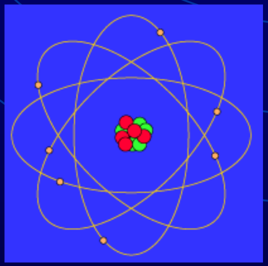


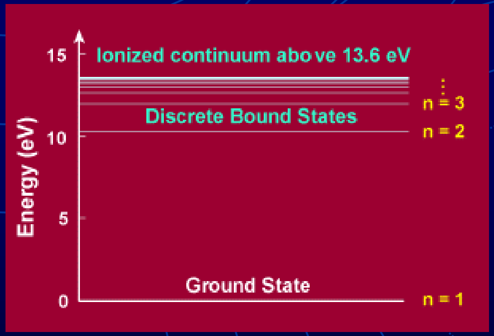


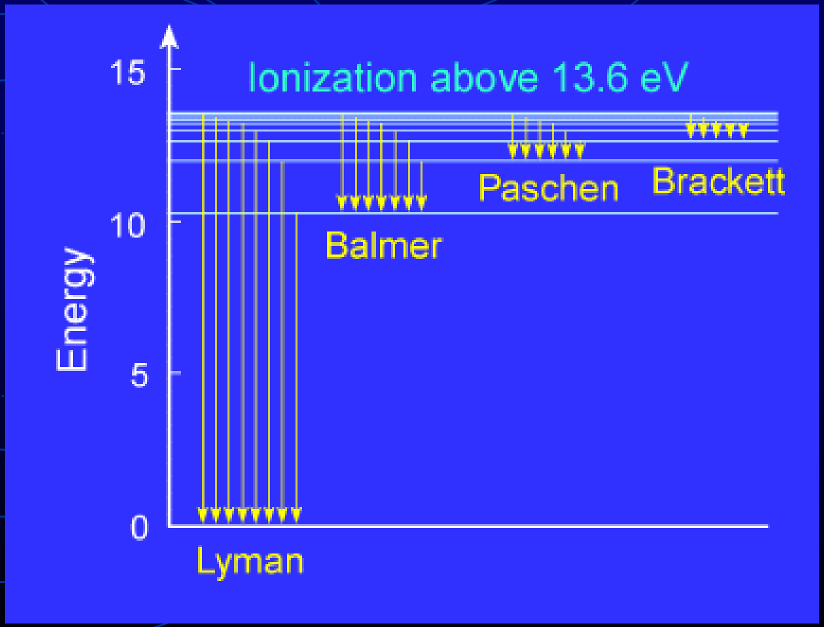
連續光譜

發射光譜

吸收光譜

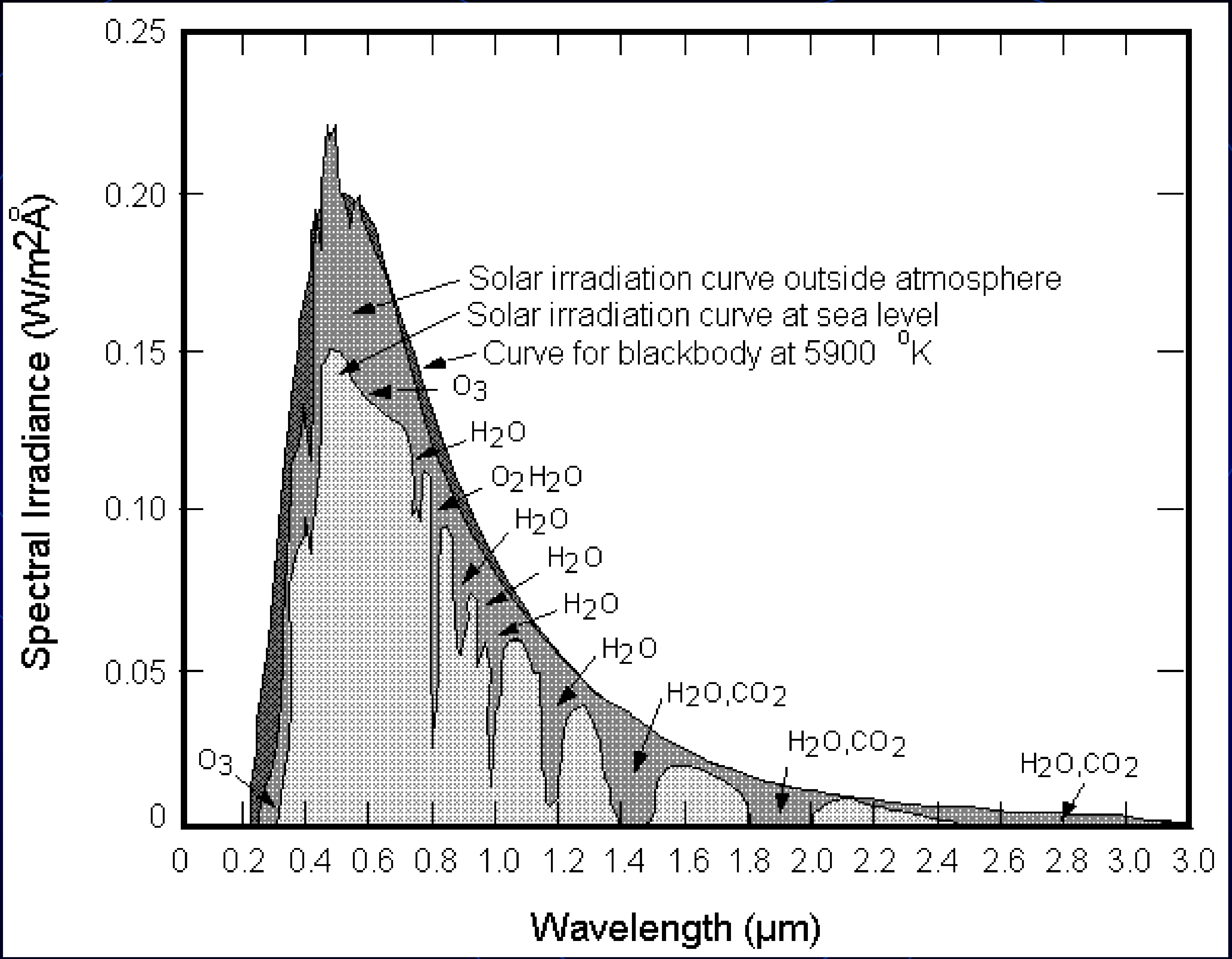




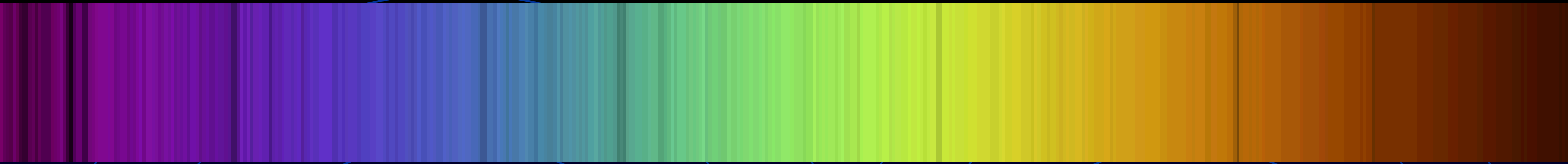


氫原子的電子躍遷能階

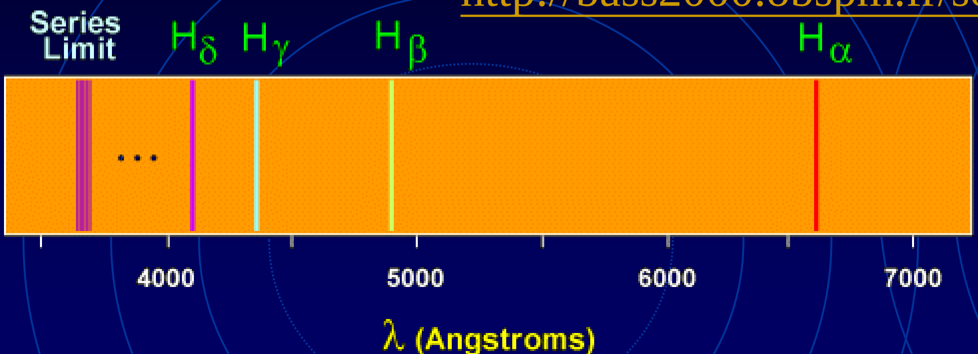
http://csep10.phys.utk.edu/astr162/lect/light/absorption.html



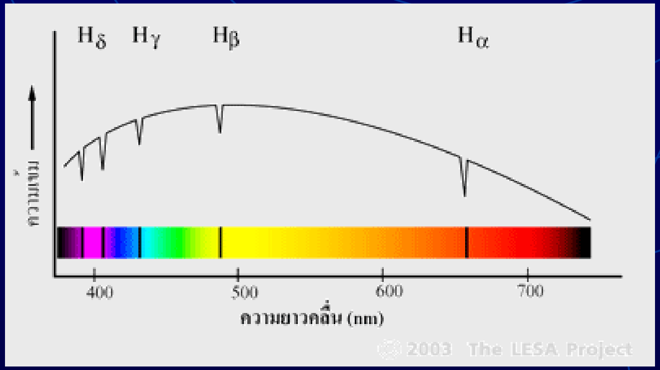
Spectral Irradiance (W/m2Å)
0.25
0.20
0.15
0.10
0.05
0
Solar irradiation curve outside atmosphere
Solar irradiation curve at sea level
Curve for blackbody at 5900 °K
O3
H2O
O2 H2O
H2O
H2O
H2O
H2O
H2O,CO2
H2O,CO2
H2O,CO2
O3
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.0
Wavelength (μm)

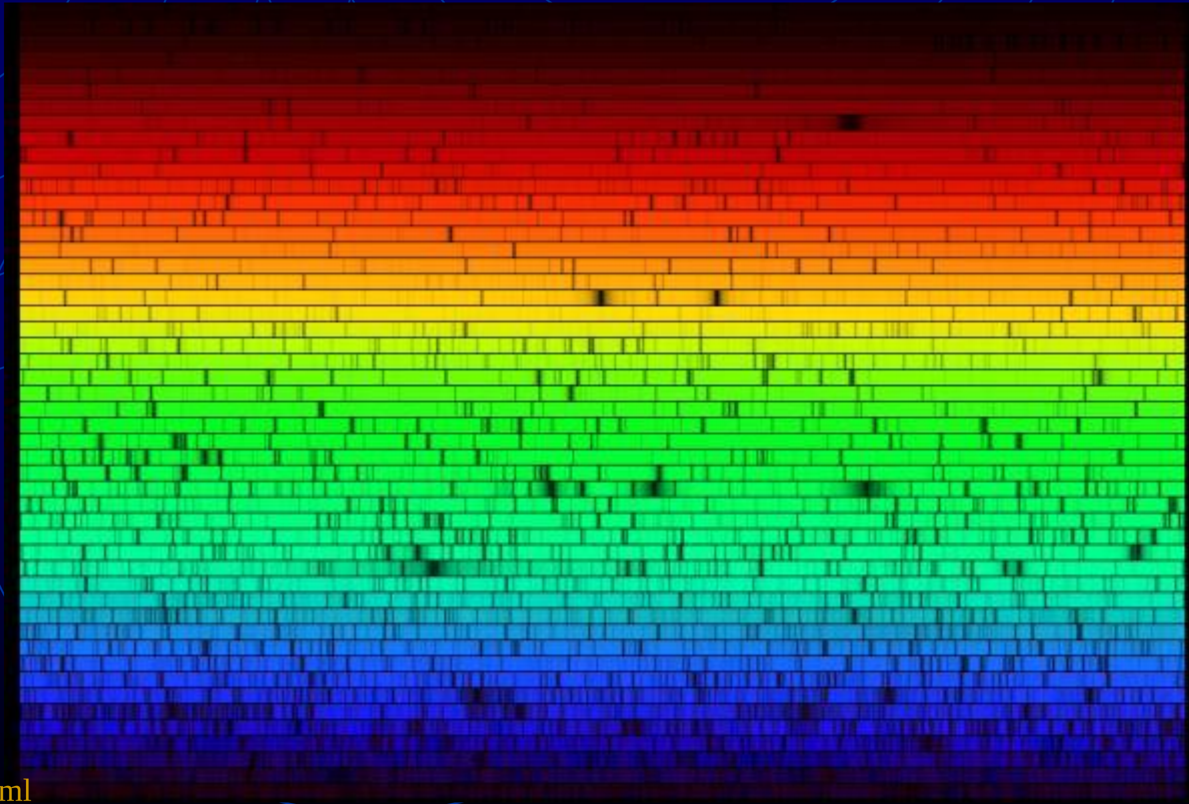


http://bass2000.obspm.fr/solar_spect.php 670-54000 Å



http://csep10.phys.utk.edu/astr162/lect/light/absorption.html





4000-7000 Å

http://www.noao.edu/image_gallery/html/im0600.html

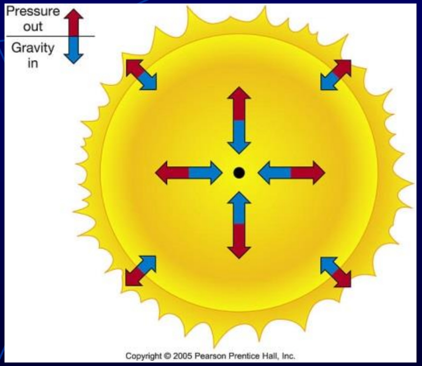
太陽由氣體組成，核心密度為水的150倍！

核心部分溫度高（百萬度），進行核子反應，產生能量向外以**輻射**方式傳送

氣體溫度高，分子運動快
→ 互相推擠 → 氣體壓力

向內萬有引力 ＝ 向外氣體壓力 → **平衡**

越向外溫度越來越低
外層改以**對流**方式傳送能量



太陽表面為翻騰的氣體
（有如煮沸的水）溫度超過攝氏5000度

太陽的能量來源 I

- **Chemical burning?**
  Typically 10^{-19} J per atom.
  How long can the Sun shine by chemical burning?

$1\ L_\odot = 4\times10^{26}$ W → 4 x 10^{45} atoms per second

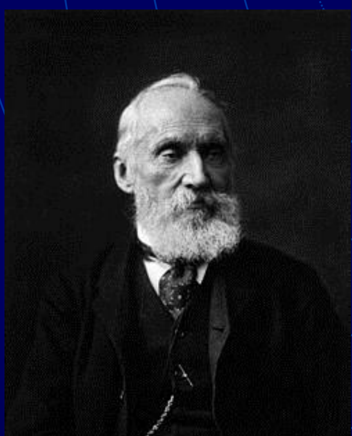
The Sun contains about 2×10^{30} kg/2 x 10^{-27} kg ~ 10^{57} atoms

→ 3 x 10^{11} s ~ 10,000 years

太陽的能量來源 II

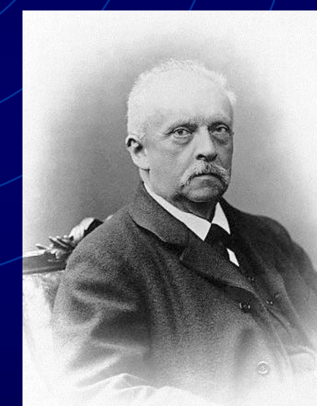
1800s 英國 Lord Kelvin and German Hermann von Helmholtz: contraction compresses interior gases → heat

Kelvin-Helmholtz contraction



William Thomson
(1824 – 1907)
British, first Baron Kevin

Hermann von Helmholtz
(1821 – 1921)
German



Gravitational energy ~ $GM^2/R \sim 4 \times 10^{41}$ J

$1\ L_{\odot} = 4 \times 10^{26}$ W → 3×10^{7} yr

但地質資料顯示地球年齡遠不止於此

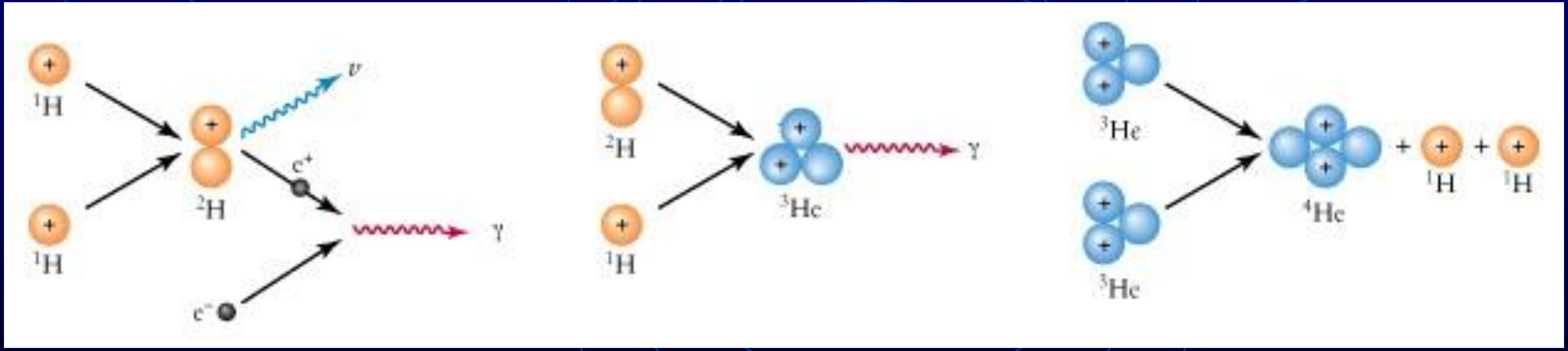
太陽的能量來源 III

簡單的原子核　結合 → 較複雜的原子核

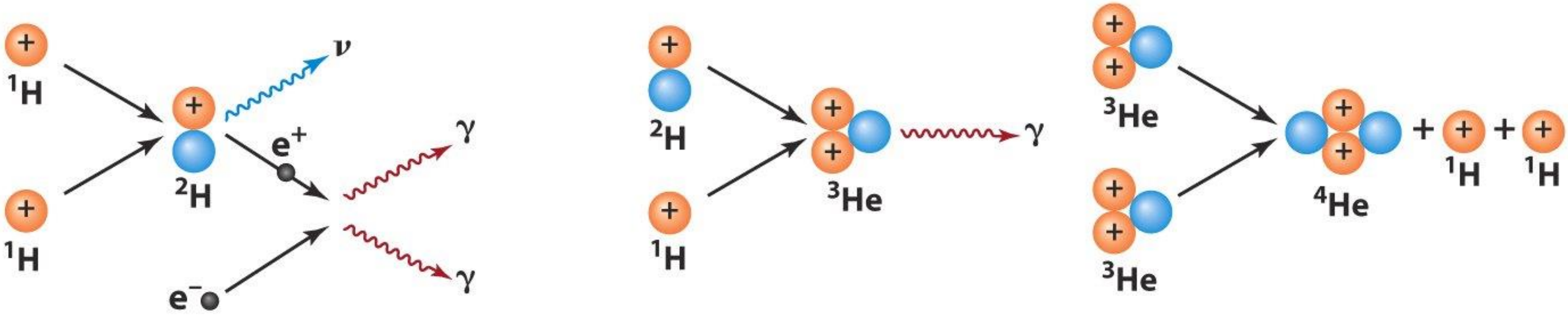
原子核強作用力把自己「抓得」比較緊

➔ 放出能量（γ射線、X射線、光）

例如：（4個）氫原子核　→　（1個）氦原子核



animation: cold gas　animation: hot gas　**Thermonuclear fusion**



(a) Step 1:

- Two protons (hydrogen nuclei, ^{1}H) collide.
- One of the protons changes into a neutron (shown in blue), a neutral, nearly massless neutrino (ν), and a positively charged electron, or positron (e^+).
- The proton and neutron form a hydrogen isotope (^{2}H).
- The positron encounters an ordinary electron (e^-), annihilating both particles and converting them into gamma-ray photons (γ).

(b) Step 2:

- The ^{2}H nucleus from the first step collides with a third proton.
- A helium isotope (^{3}He) is formed and another gamma-ray photon is released.

(c) Step 3:

- Two ^{3}He nuclei collide.
- A different helium isotope with two protons and two neutrons (^{4}He) is formed and two protons are released.

proton-proton (PP) chain 反應

步驟一：

兩個質子 (proton) 碰撞

其中一個變成中子（藍色），放出一個微中子(neutrino)，及一個正子 (positron)

質子與中子形成氘 (^{2}H)

正子與一般電子相互湮滅 (annihilate)，並放出迦瑪射線

步驟二：

步驟一的 ^{2}H 與另一個（第三個）質子碰撞，形成氦三 (^{3}He)

放出另一個迦瑪射線光子

步驟三：

兩個氦三 (^{3}He) 碰撞，形成氦四 (^{4}He)

放出兩個質子

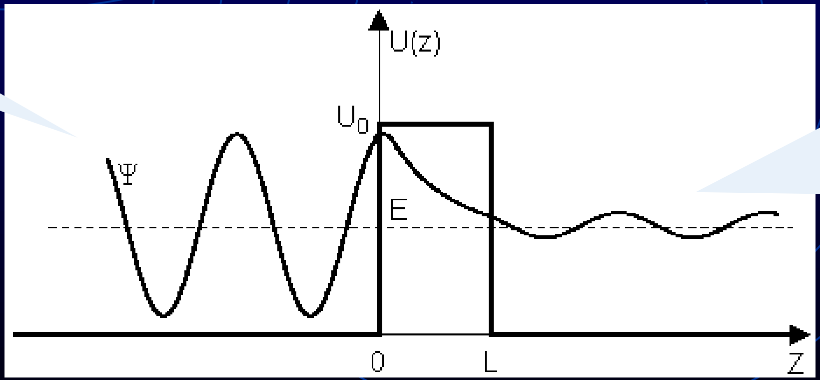
animation: pp chain

淨反應：4個質子產生1個氦四

Q: 原子核（質子）帶正電，彼此有庫侖排斥力，那麼它們如何融合呢？

A: **Quantum tunneling effect （量子穿隧效應）** → the particle can penetrate the potential barrier even with insufficient total energy

粒子有波動性



波動函數（也就是發現粒子的機率）能穿透到這個區域

Energy Gained in a PP Chain

- 4H → 1 He + neutrinos + energy
- $\quad$ Mass of 4 H $= 6.693 \times 10^{-27}$ kg

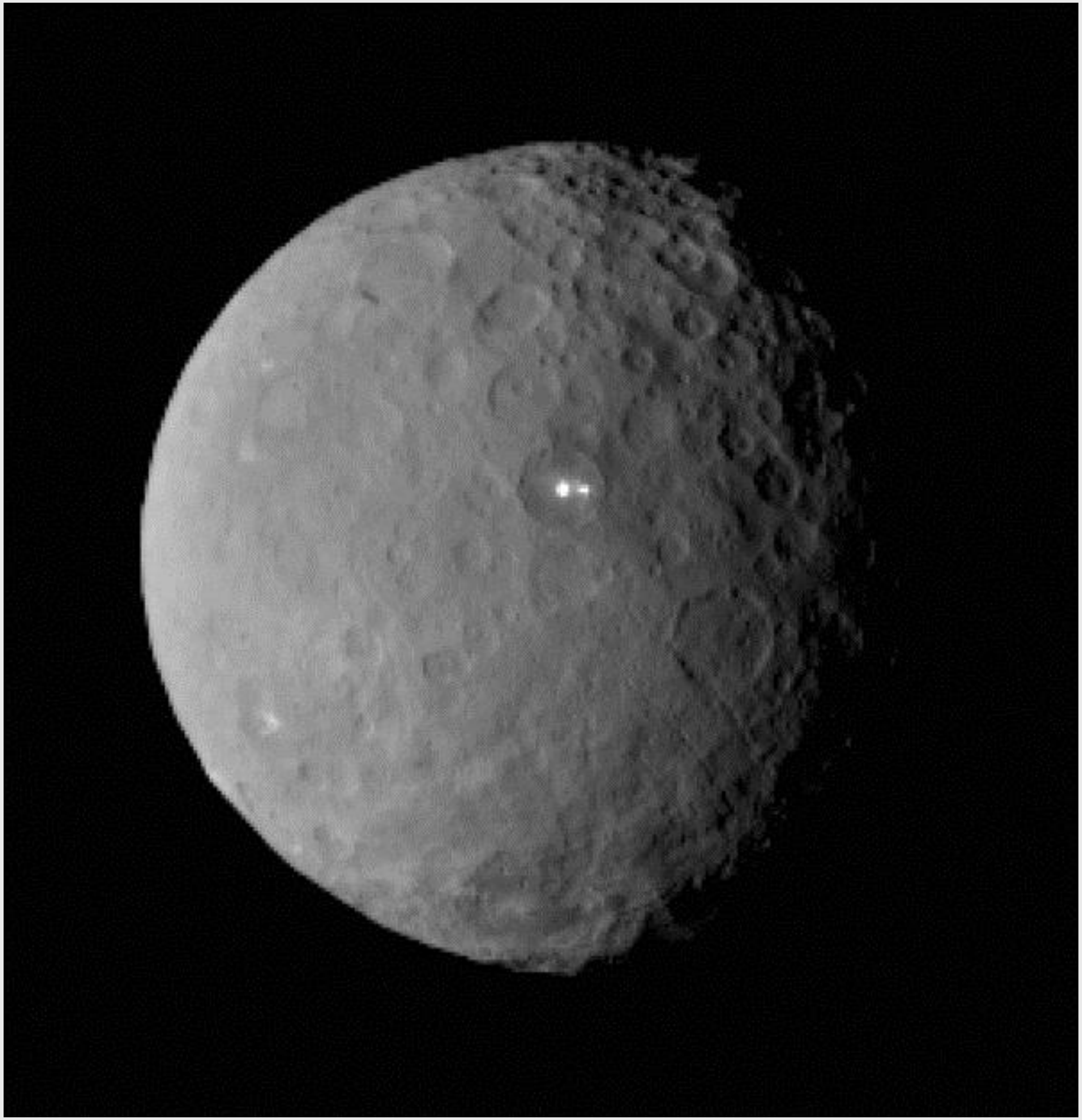
  — Mass of 1 He $= 6.645 \times 10^{-27}$ kg

  Mass deficit → 0.048×10^{-27} kg

- $E = mc^2 = (0.048 \times 10^{-27}\ \text{kg}) \times (3 \times 10^8\ \text{m/s})^2$

  $= 4.3 \times 10^{-12}$ J

- To generate $1\ L_\odot = 3.9 \times 10^{26}$ W, the sun needs to convert some **600 million tons** （六億公噸） of H into He in its core per second.

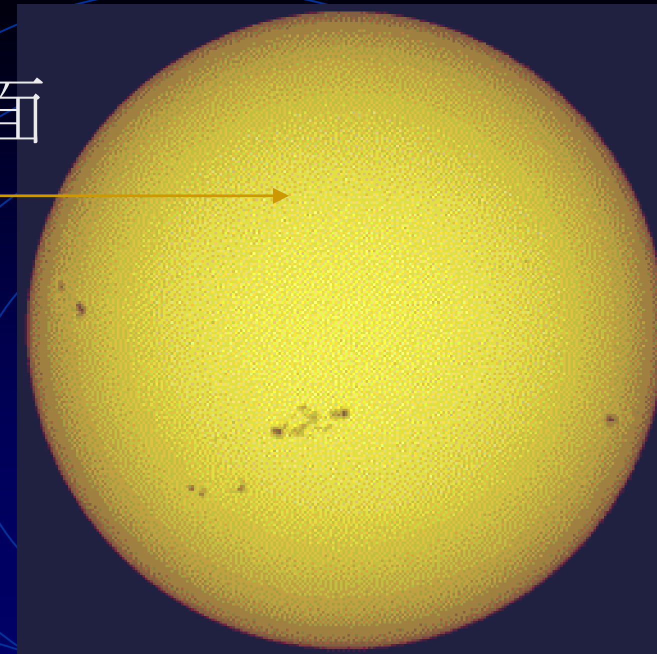


Dawn to arrive at Ceres on March 6, 2015

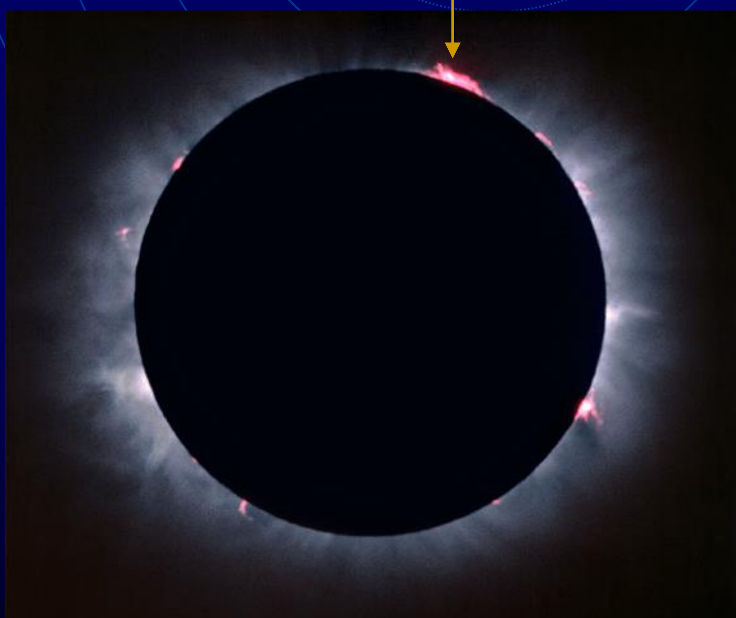
太陽表面

我們所見的日面

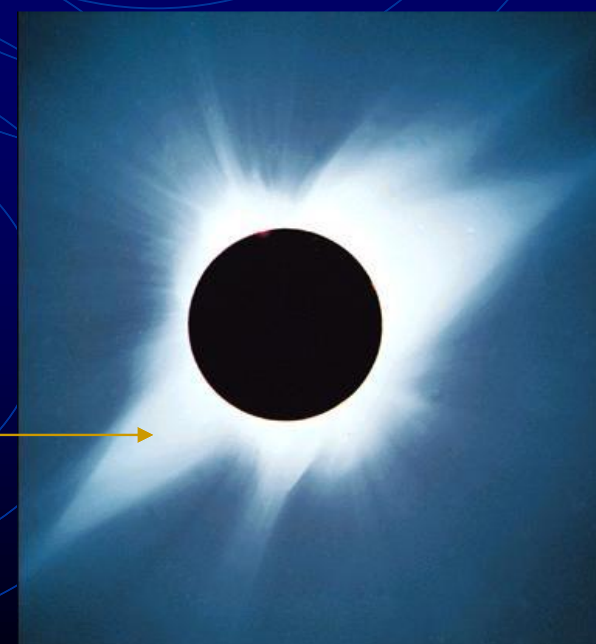
— 光球



色球



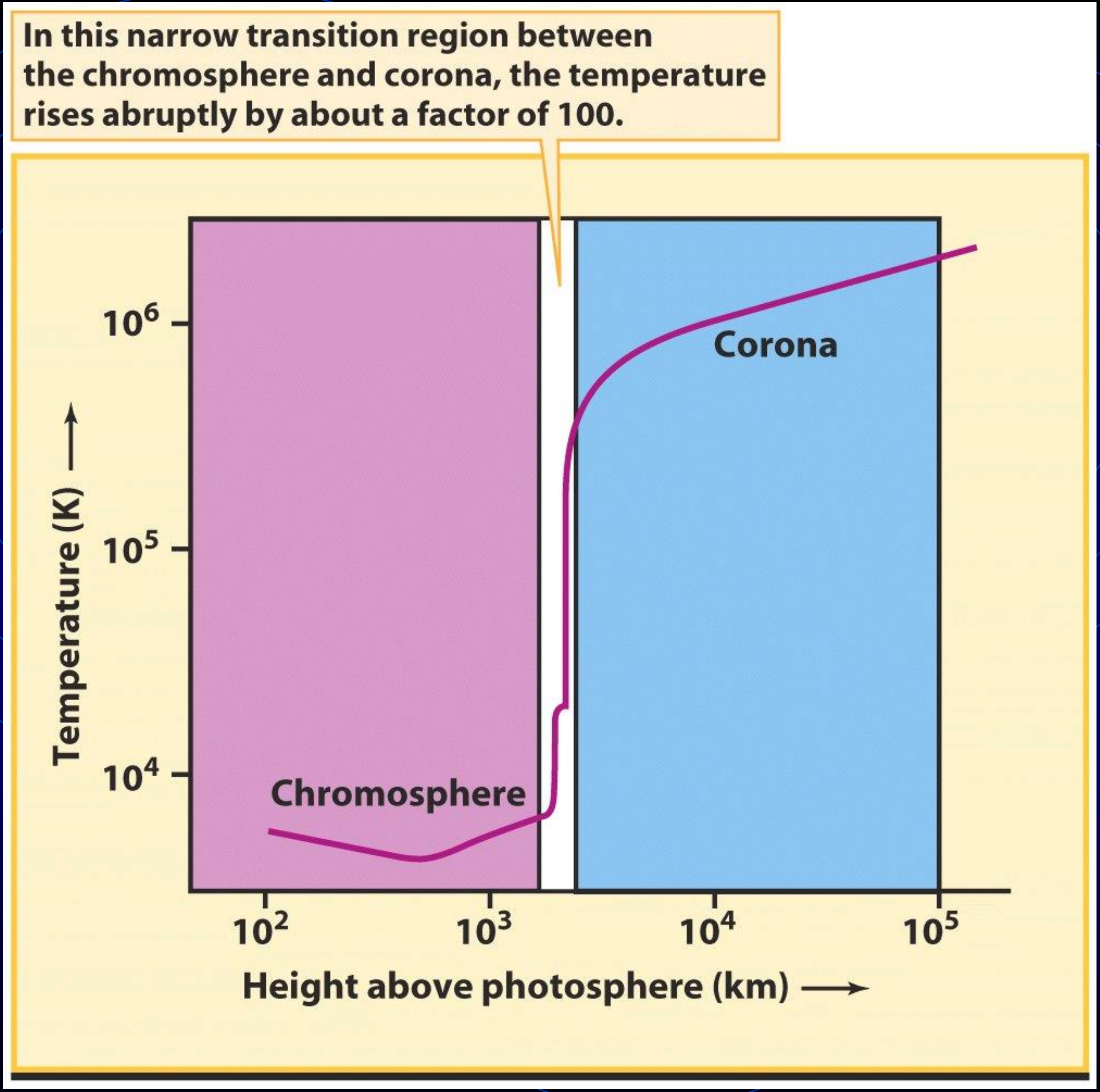
日冕



http://ircamera.as.arizona.edu/NatSci102/lectures/sun.htm

太陽大氣層

- **光球 (photosphere)**
  太陽大氣最低的一層；厚度約 400 km；是我們肉眼看到的太陽「盤面」
- **色球 (chromosphere)**
  比光球暗；密度也較低，只有在光球被擋住（如日全食）時，才見看得到色球。呈粉紅色；厚度約 500 km
- **日冕 (corona)**
  太陽大氣最外層；延伸數百萬公里；整個日冕在可見光的亮度，只相當於滿月，i.e., 只有 photosphere 的百萬分之一。只在日全食或利用日冕儀 (coronagraph) 擋住光球，才能看到 corona



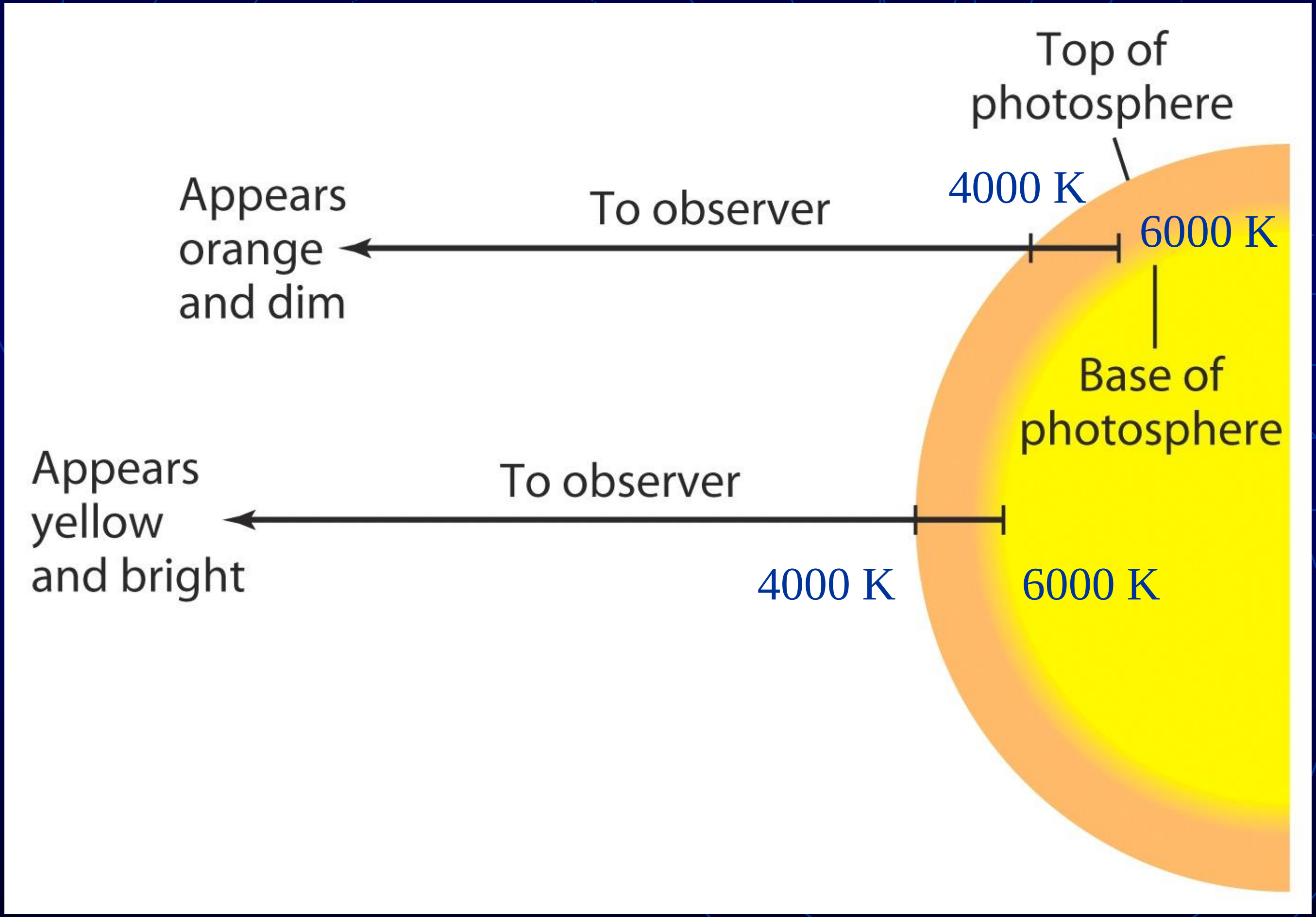
In this narrow transition region between the chromosphere and corona, the temperature rises abruptly by about a factor of 100.
Corona
Chromosphere
10⁶
10⁵
10⁴
Temperature (K)
10²
10³
10⁴
10⁵
Height above photosphere (km)

太陽外表特徵

- 緣暗現象 (limb darkening)
- 太陽黑子 (sunspots)
- 米粒組織 (granulation)
- 針狀結構 (spicules)

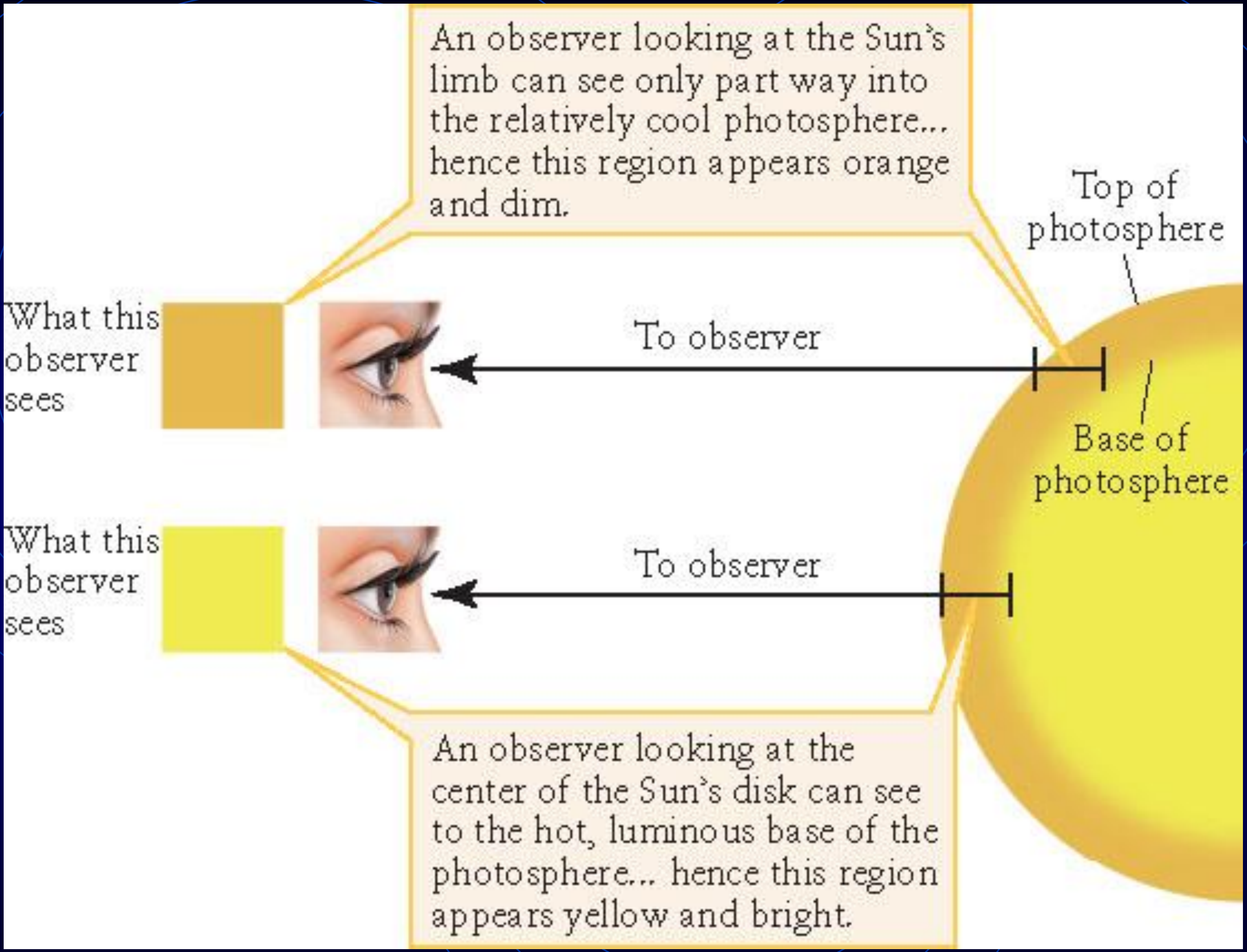
緣暗現象

視線透過等量的氣體

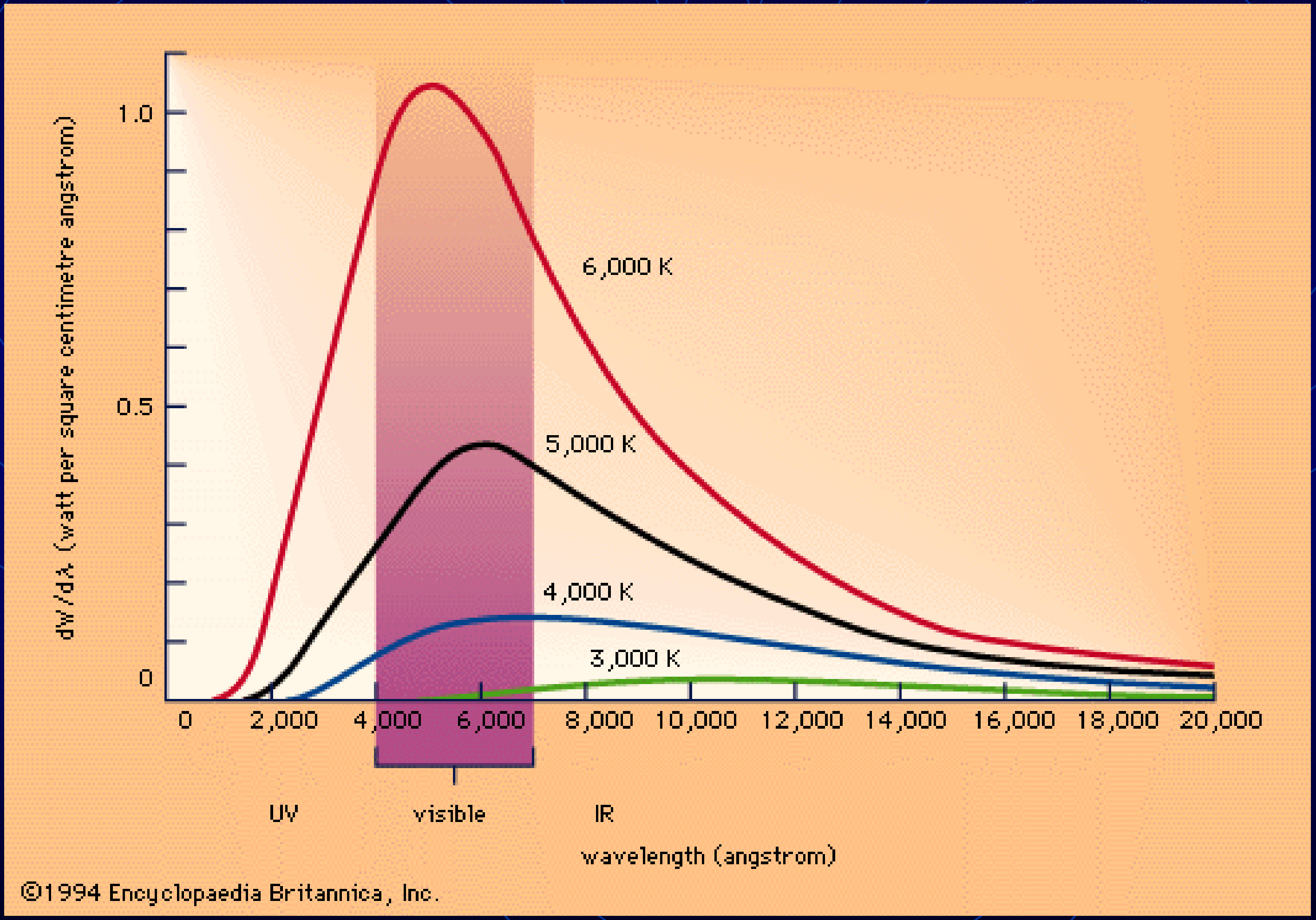


盤面邊緣透過較冷的高層大氣

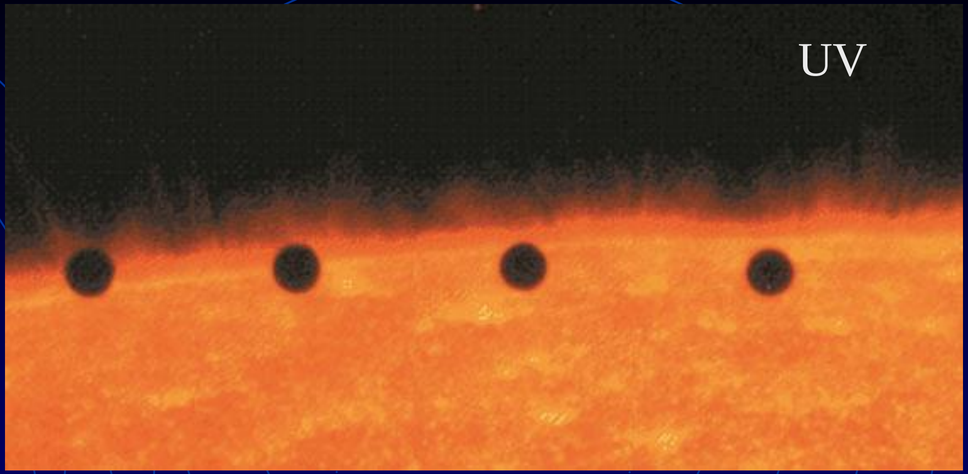
盤面中央透過較內部、較熱的氣體
➔比較明亮


An observer looking at the Sun's limb can see only part way into the relatively cool photosphere... hence this region appears orange and dim.
Top of photosphere
What this observer sees
To observer
Base of photosphere
What this observer sees
To observer
An observer looking at the center of the Sun's disk can see to the hot, luminous base of the photosphere... hence this region appears yellow and bright.

溫度低 → 輻射強度弱

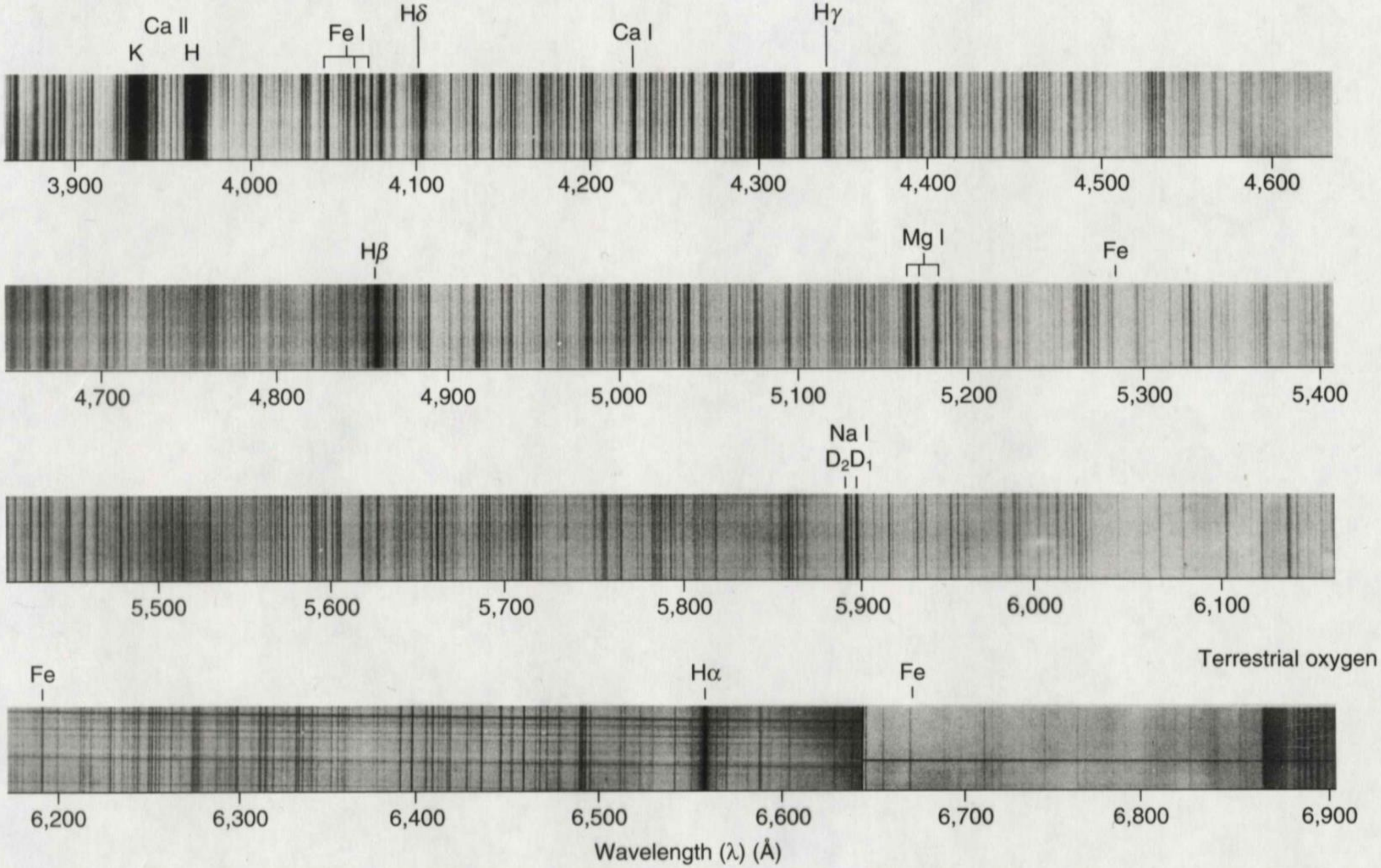

dW/dλ (watt per square centimetre angstrom)
1.0
0.5
0
6,000 K
5,000 K
4,000 K
3,000 K
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
UV
visible
IR
wavelength (angstrom)
©1994 Encyclopaedia Britannica, Inc.

- November 15, 1999, Mercury transited (passed in front of the Sun)
- Observed by the *TRACE* spacecraft
- The Sun appears larger in the ultraviolet image than in the visible-light image. Why?



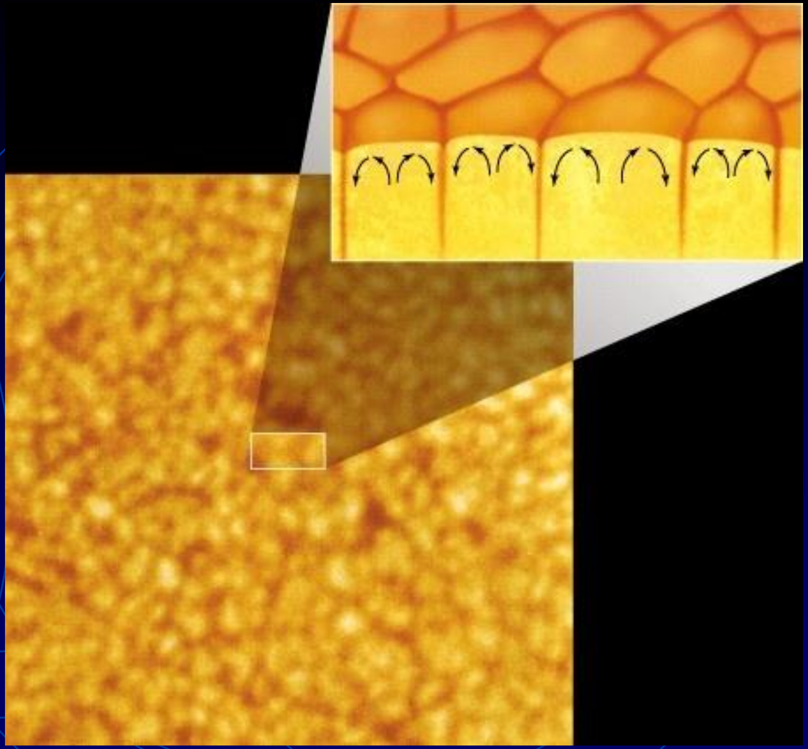
Every 6-9 min

Solar spectrum

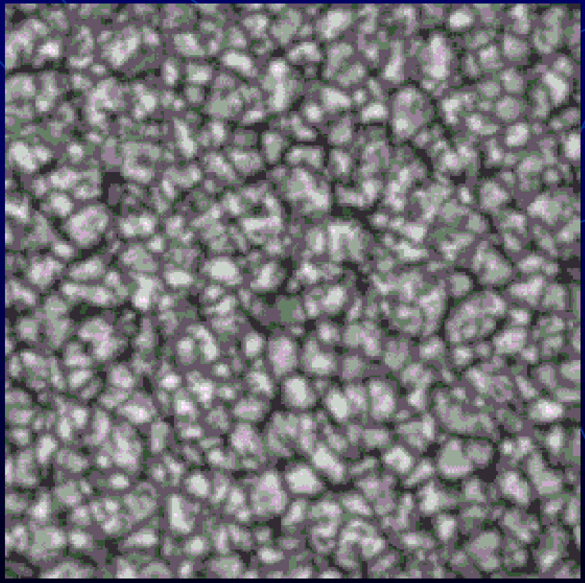


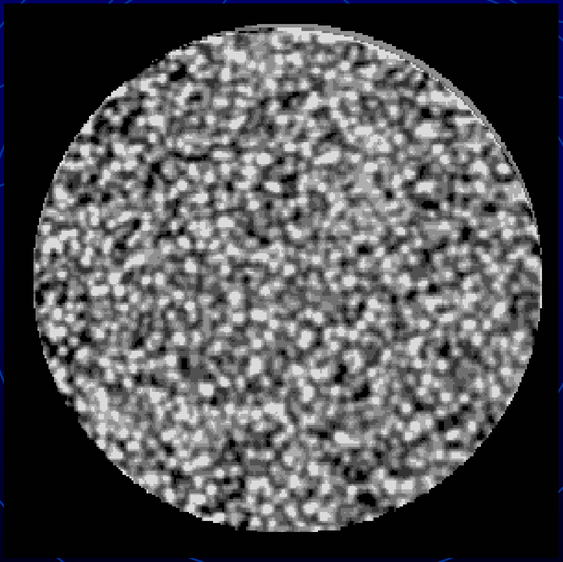
米粒組織 (granulation)

太陽氣體從內部到表面對流翻騰的證據

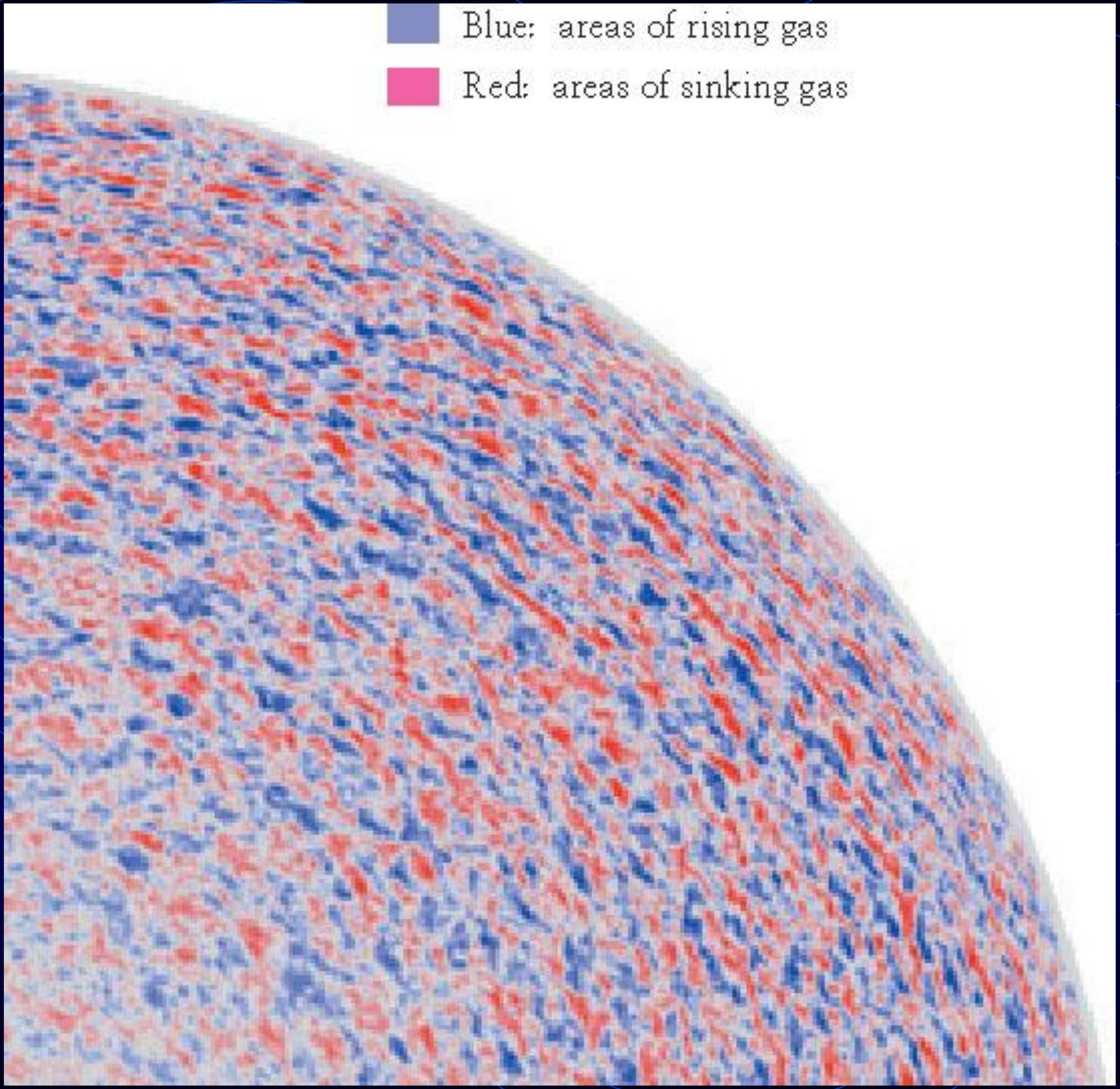


A granule: a hot, bright rising central part ＋ cooler, darker descending gas

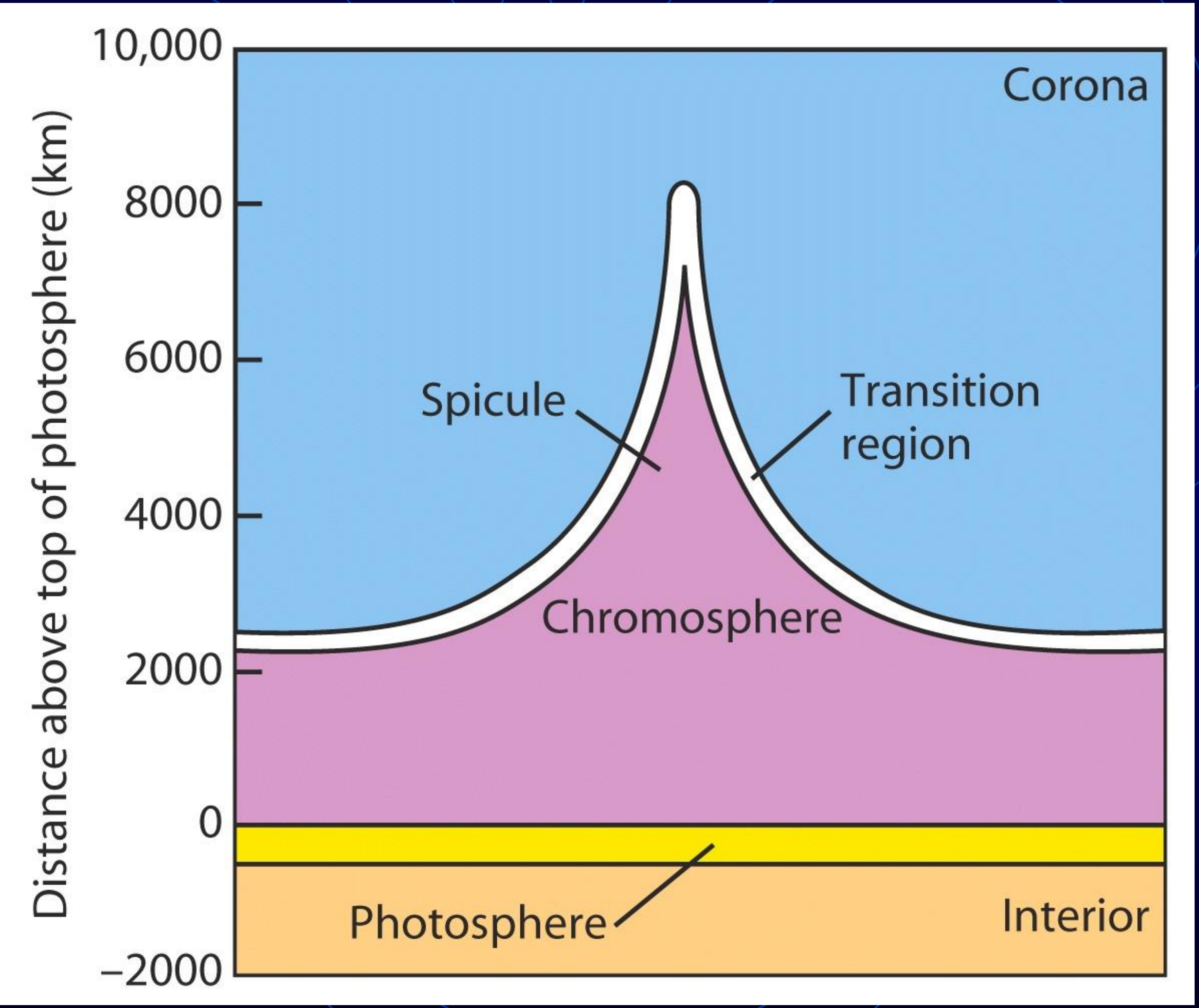


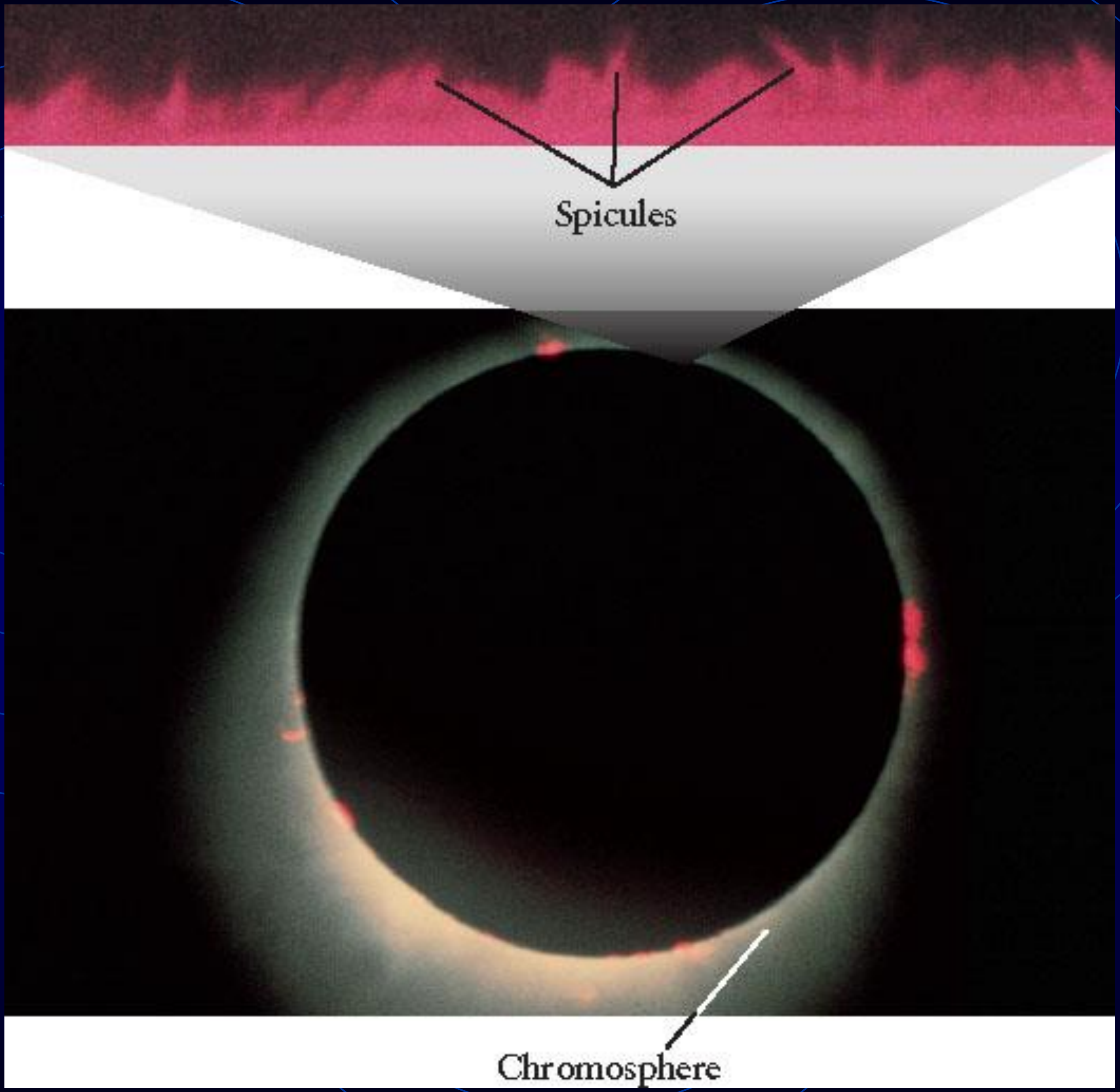


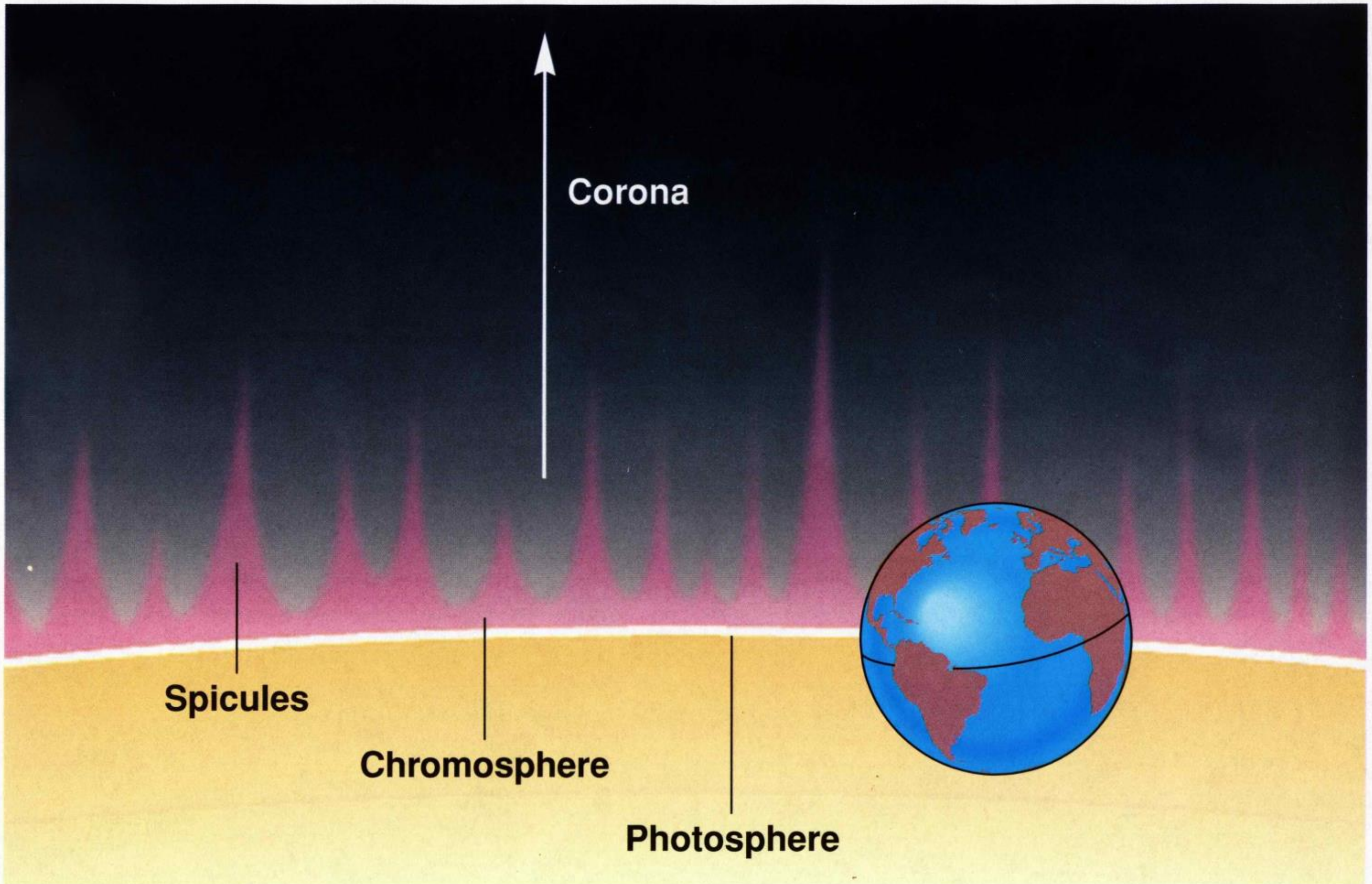
A typical granule ~ 1500 km in diameter, lasting for ~10 minutes


Blue: areas of rising gas
Red: areas of sinking gas

針狀組織 (spicule)




Spicules
Chromosphere



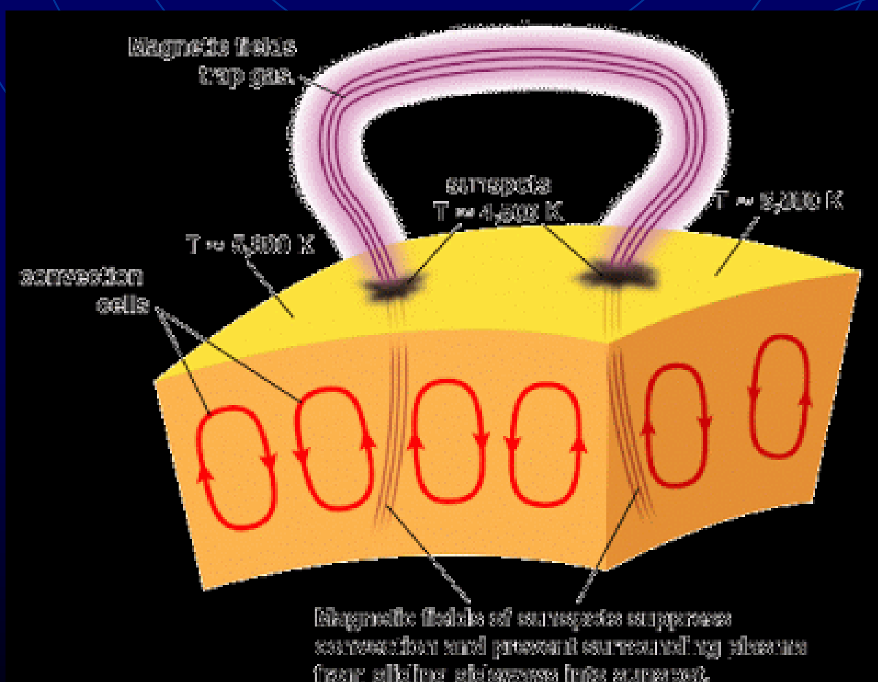
Cross section of photosphere.

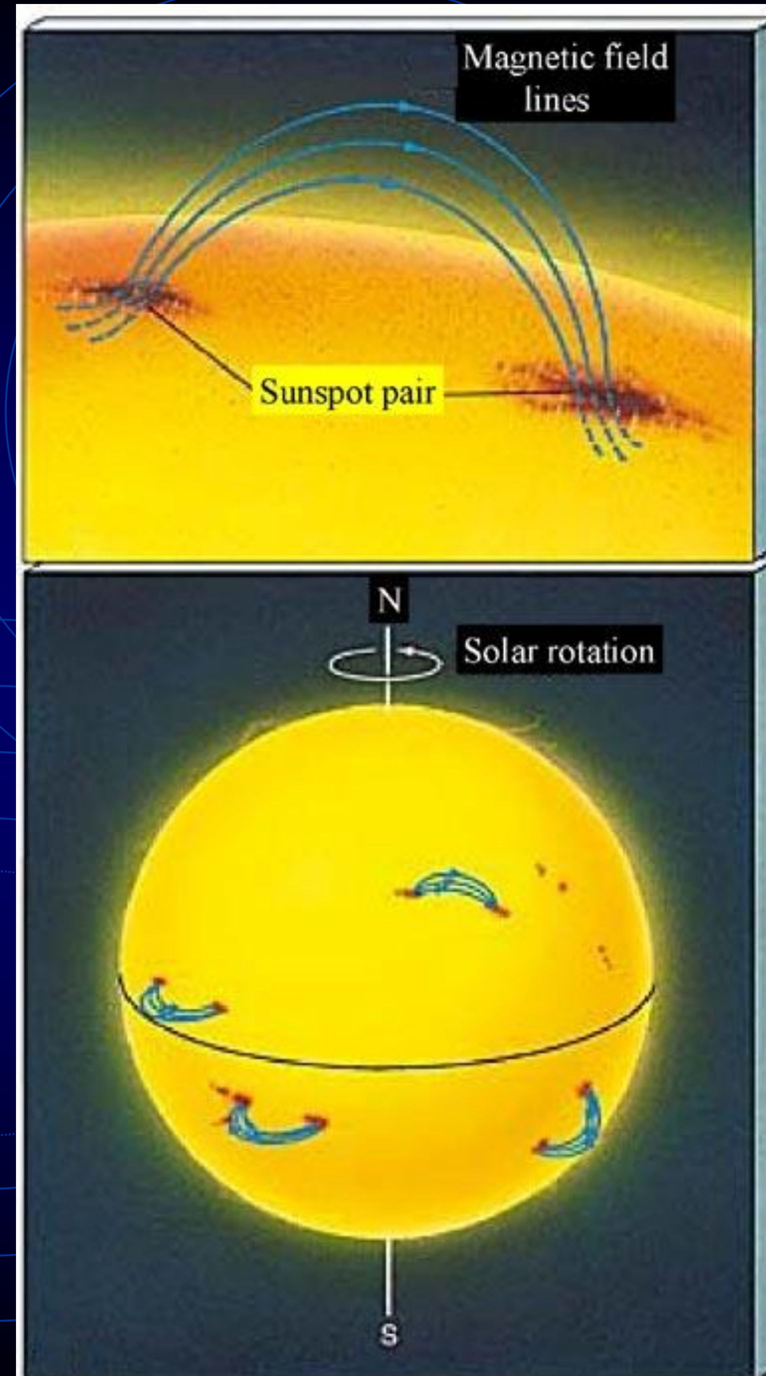
http://crab0.astr.nthu.edu.tw/~hchang/ga1/f1801-atmosphere1.JPG

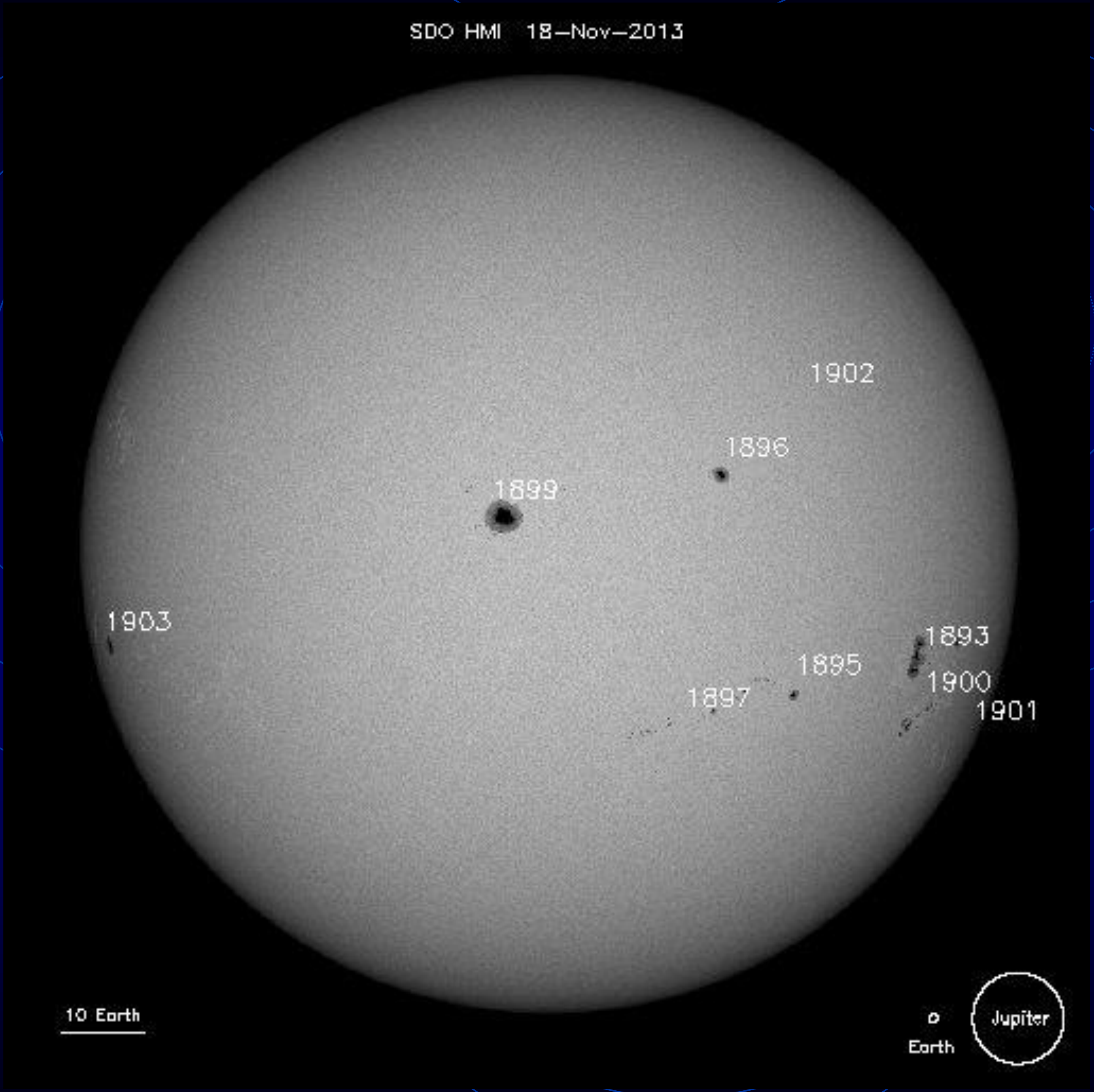
太陽黑子 (sunspots)

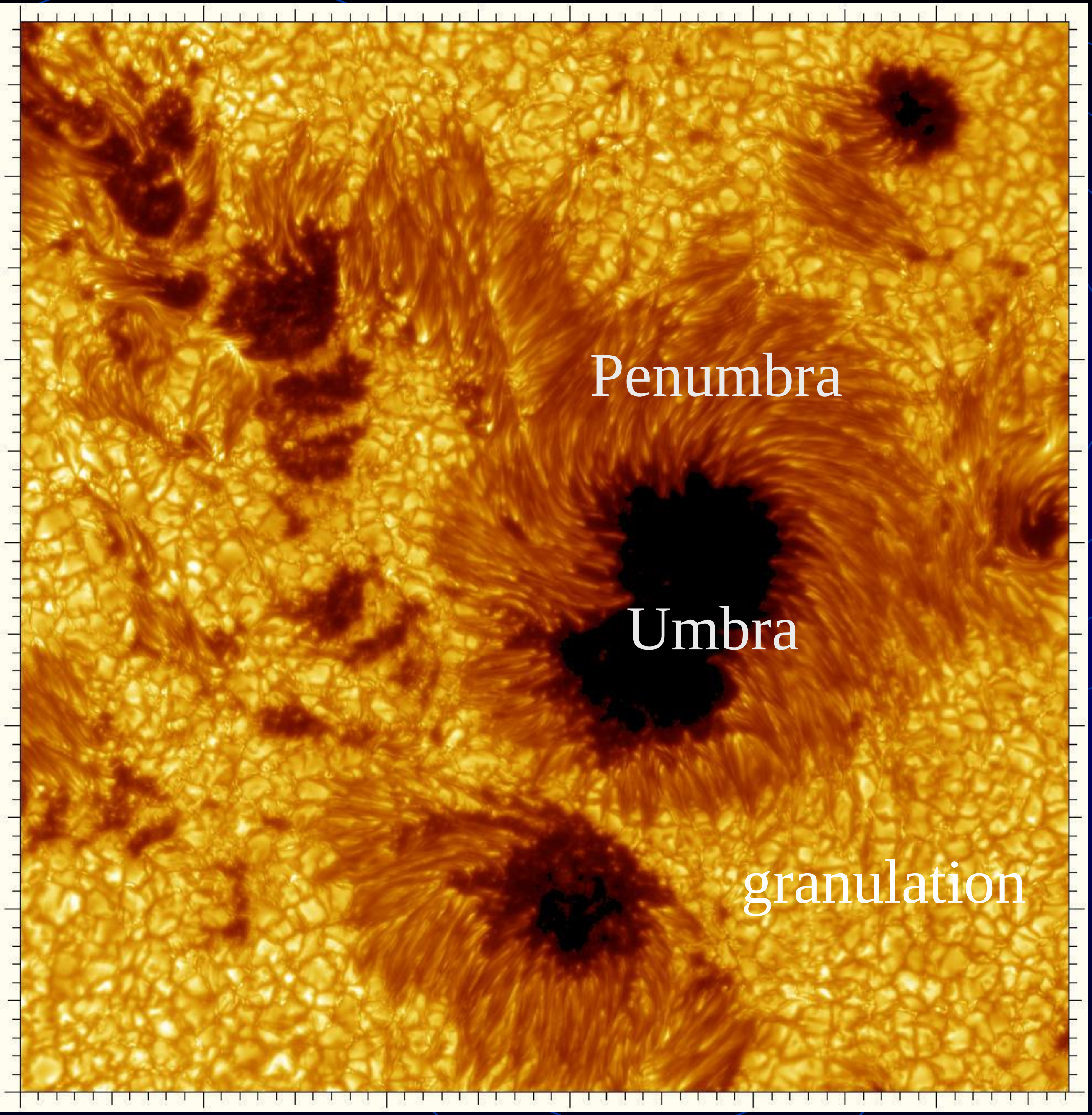
為表面低溫地區，
「看起來」比較暗

該處磁場強，抑制了內部傳遞出來的能量



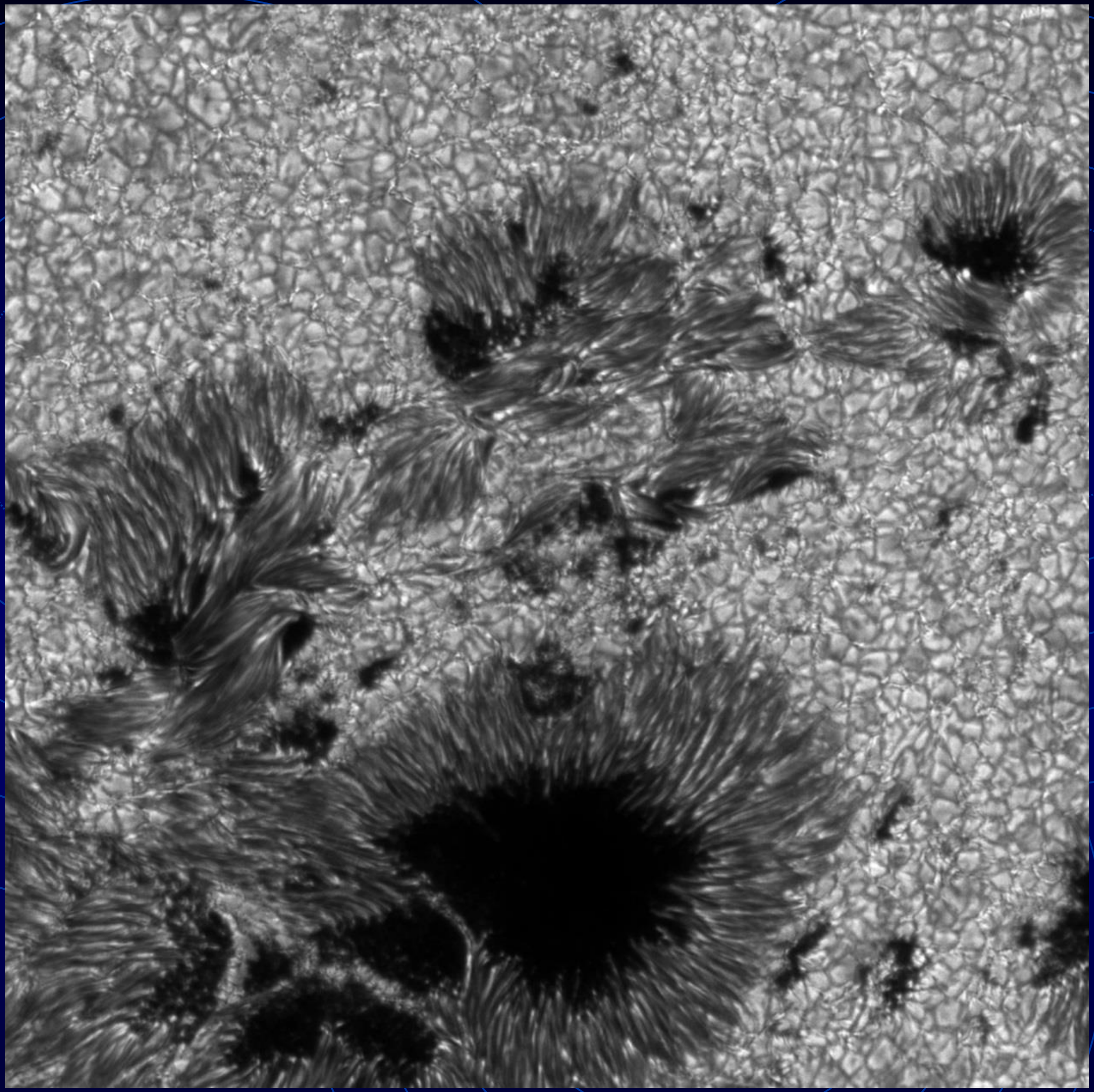



SDO HMI 18-Nov-2013
1902
1896
1899
1903
1893
1895
1900
1897
1901
10 Earth
Earth
Jupiter

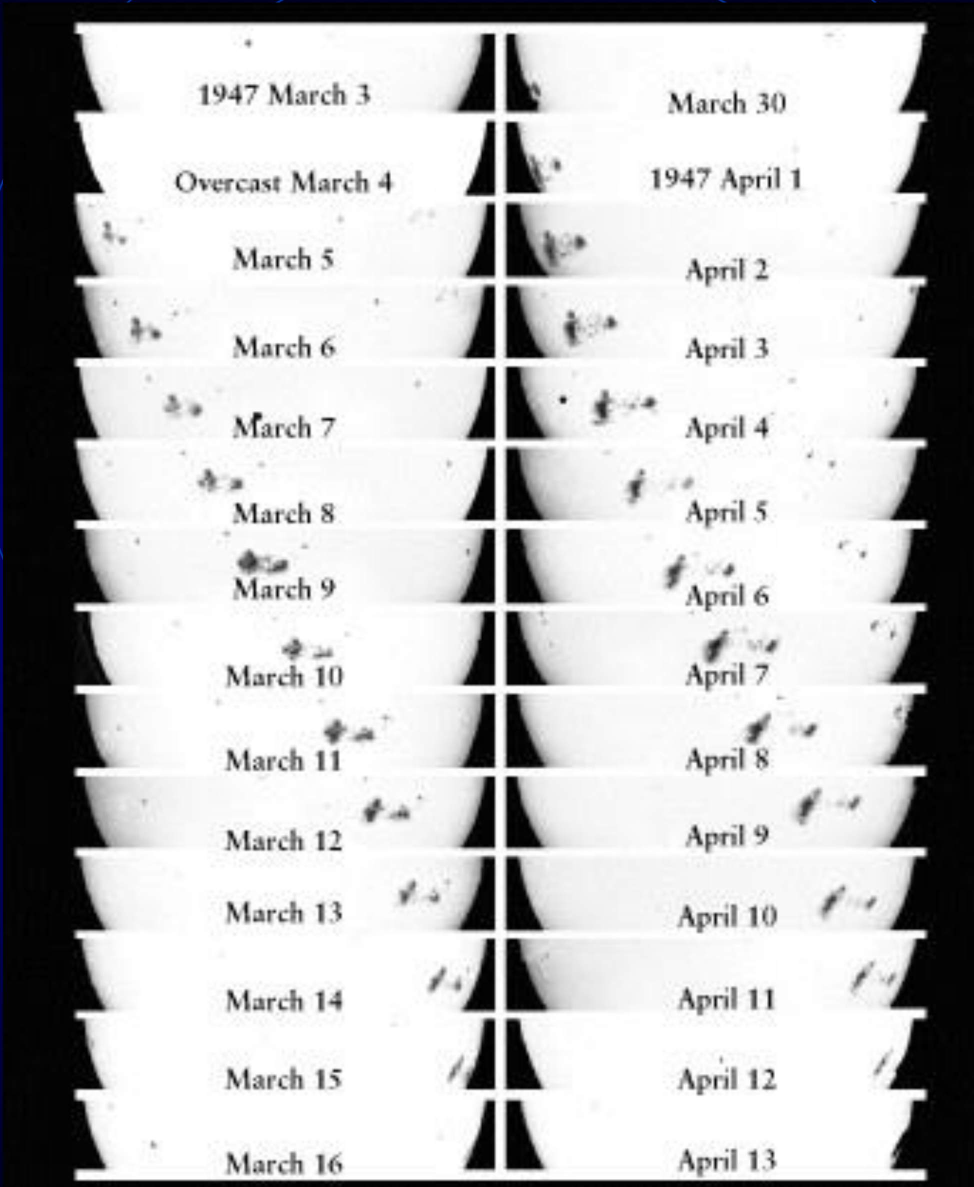


movie

http://www.solarphysics.kva.se/NatureNov2002/



中國雲南　撫仙湖　太陽望遠鏡拍攝



黑子會有消長

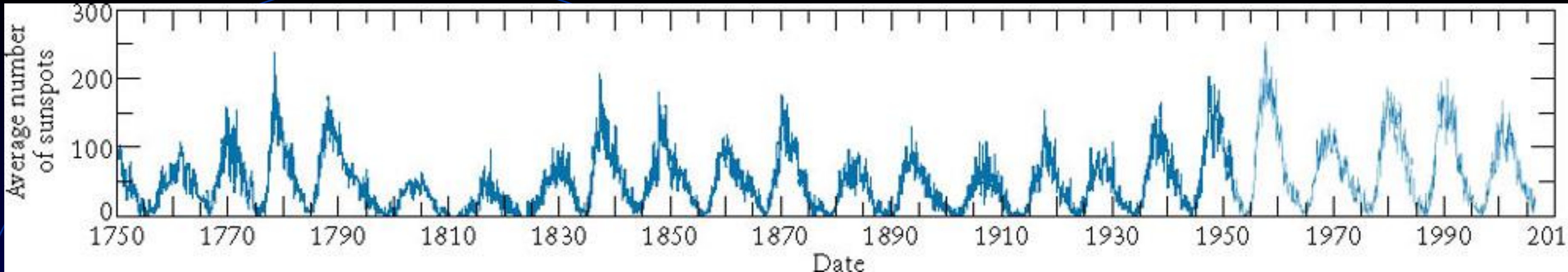
藉由同一個黑子群在太陽盤面的運動可以研究太陽轉動

赤道附近轉一圈~25 d

緯度30度附近轉一圈約需時 27 天

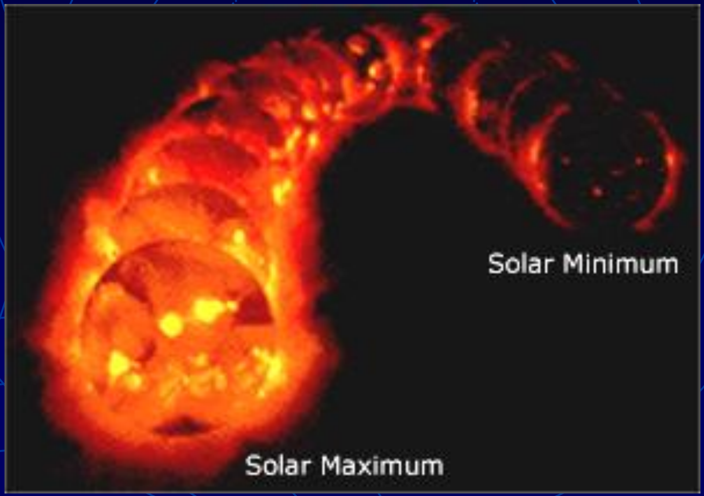
兩極附近約35天

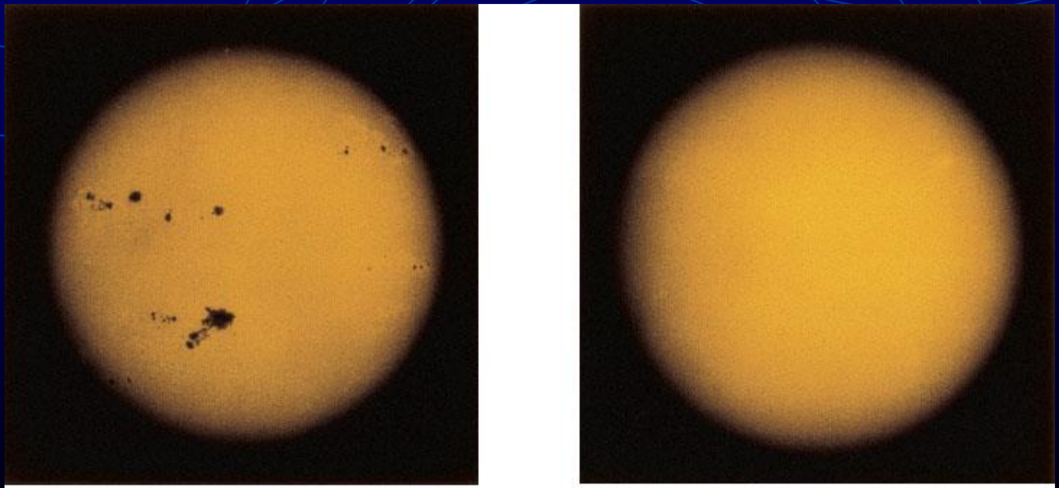
➔ 差動自轉 (differential rotation)



太陽黑子數目呈現11年週期變化 (solar cycle)

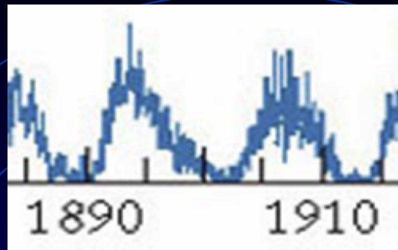
整個太陽的活動亦然，包括日冕大小



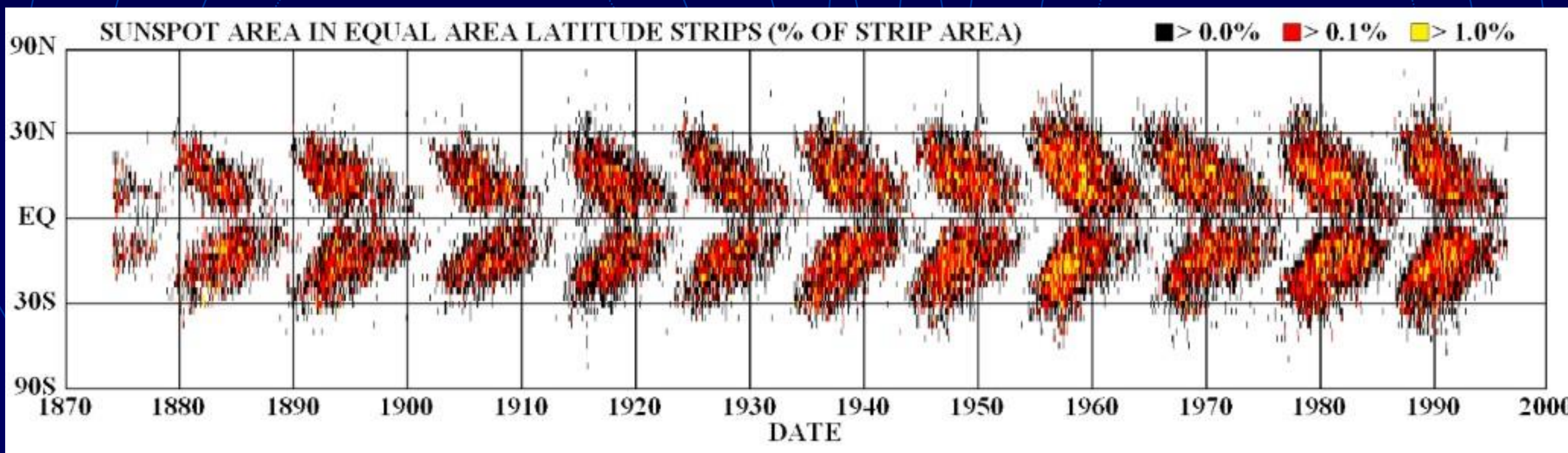


(b) Near sunspot maximum (c) Near sunspot minimum

Max



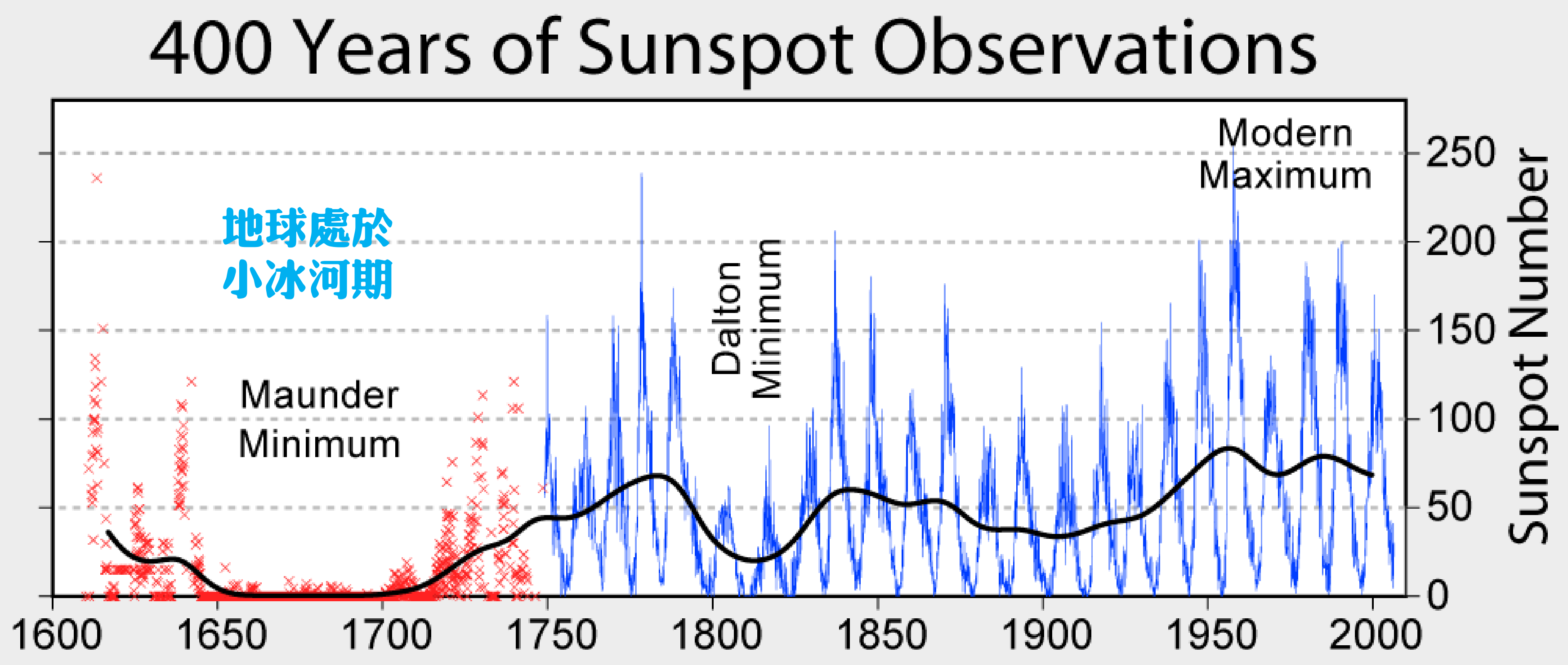
Min



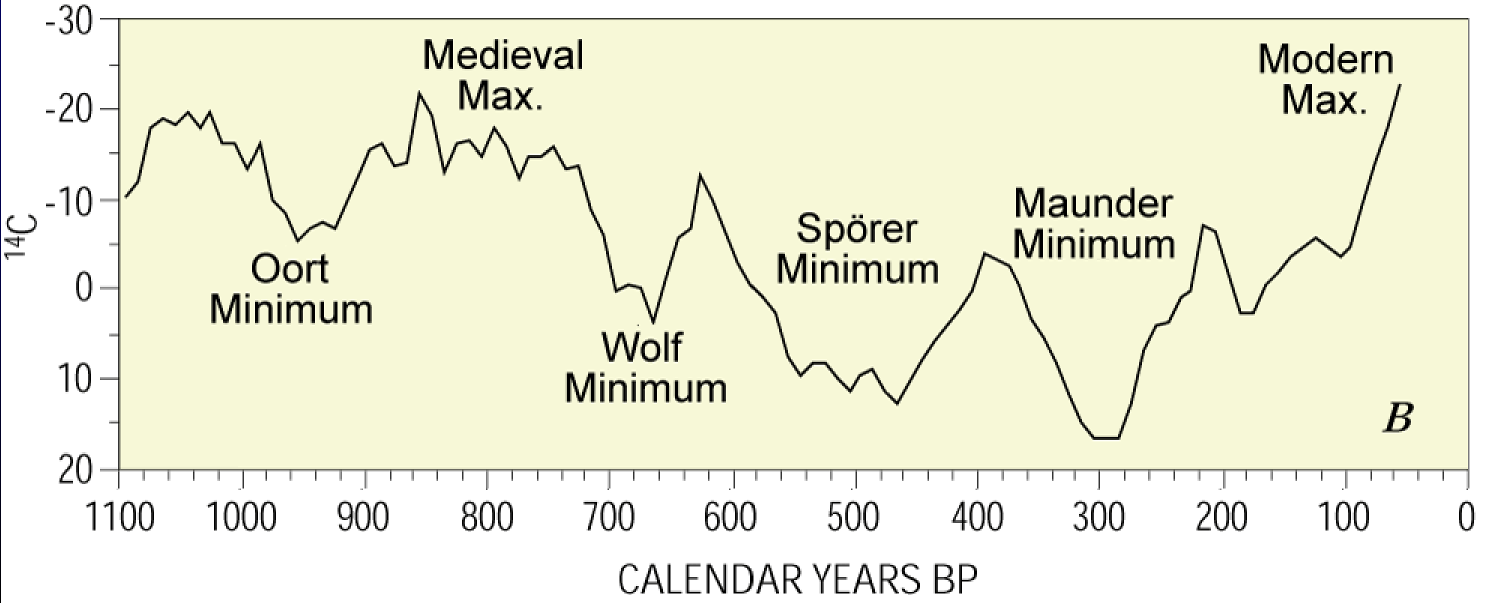
每個太陽週期之初，黑子多半在約緯度30度附近出現，隨後黑子出現的緯度越來越接近赤道

蒙氏蝴蝶圖 Maunder (butterfly) diagram

太陽極大時期發出的能量比極小時期多0.1%

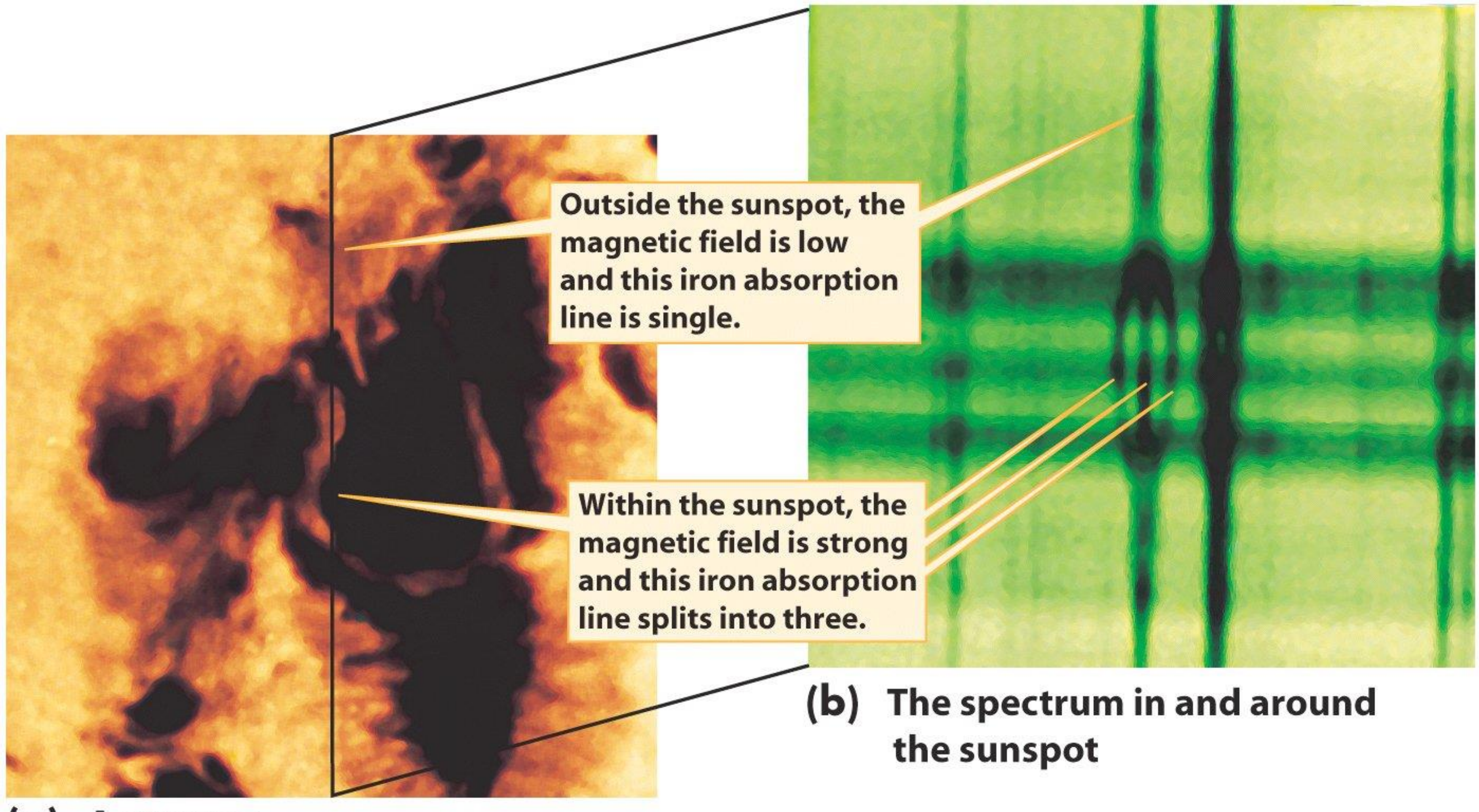


400 Years of Sunspot Observations
地球處於
小冰河期
Maunder
Minimum
Dalton
Minimum
Modern
Maximum
Sunspot Number
250
200
150
100
50
0
1600
1650
1700
1750
1800
1850
1900
1950
2000



Medieval
Max.
Oort
Minimum
Wolf
Minimum
Spörer
Minimum
Maunder
Minimum
Modern
Max.
B
^{14}C
-30
-20
-10
0
10
20
1100
1000
900
800
700
600
500
400
300
200
100
0
CALENDAR YEARS BP

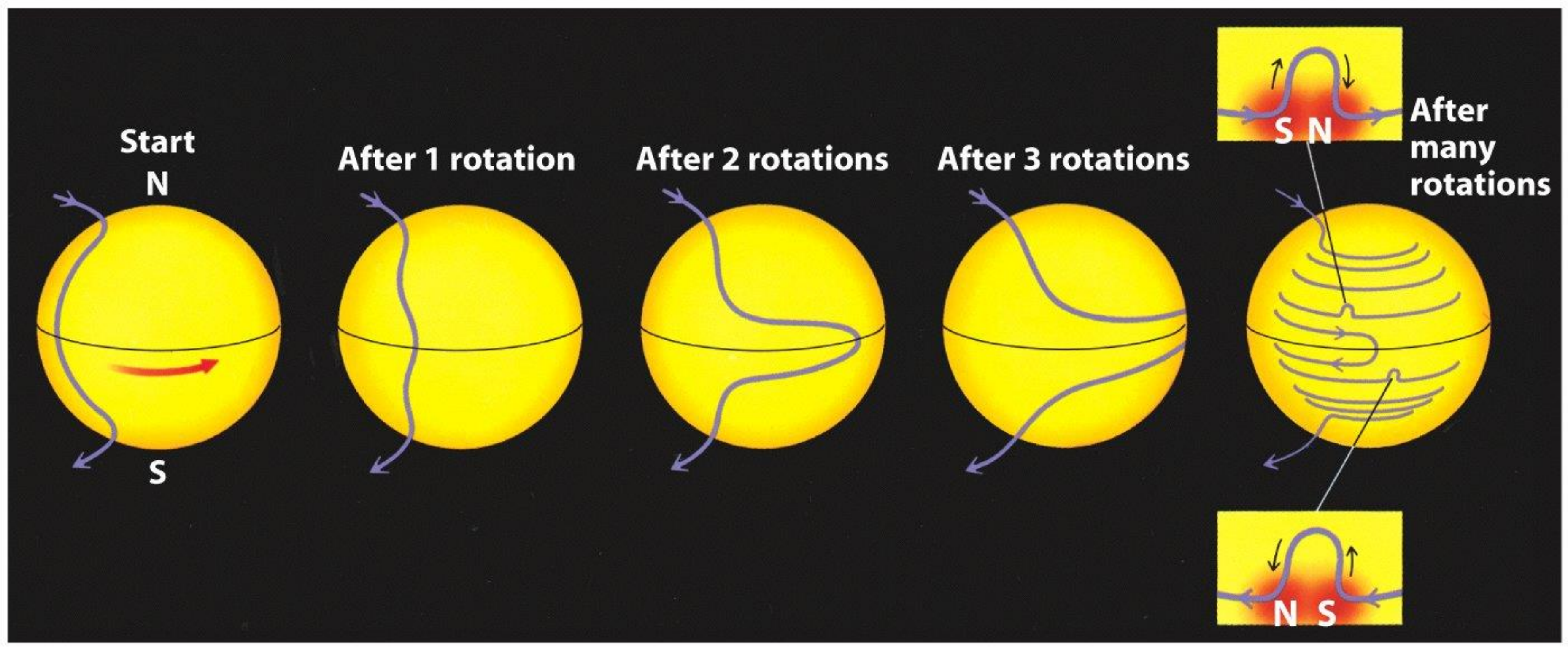
測量太陽磁場 **Zeeman Effect** --- splitting of a spectral line by magnetic field



(a) A sunspot

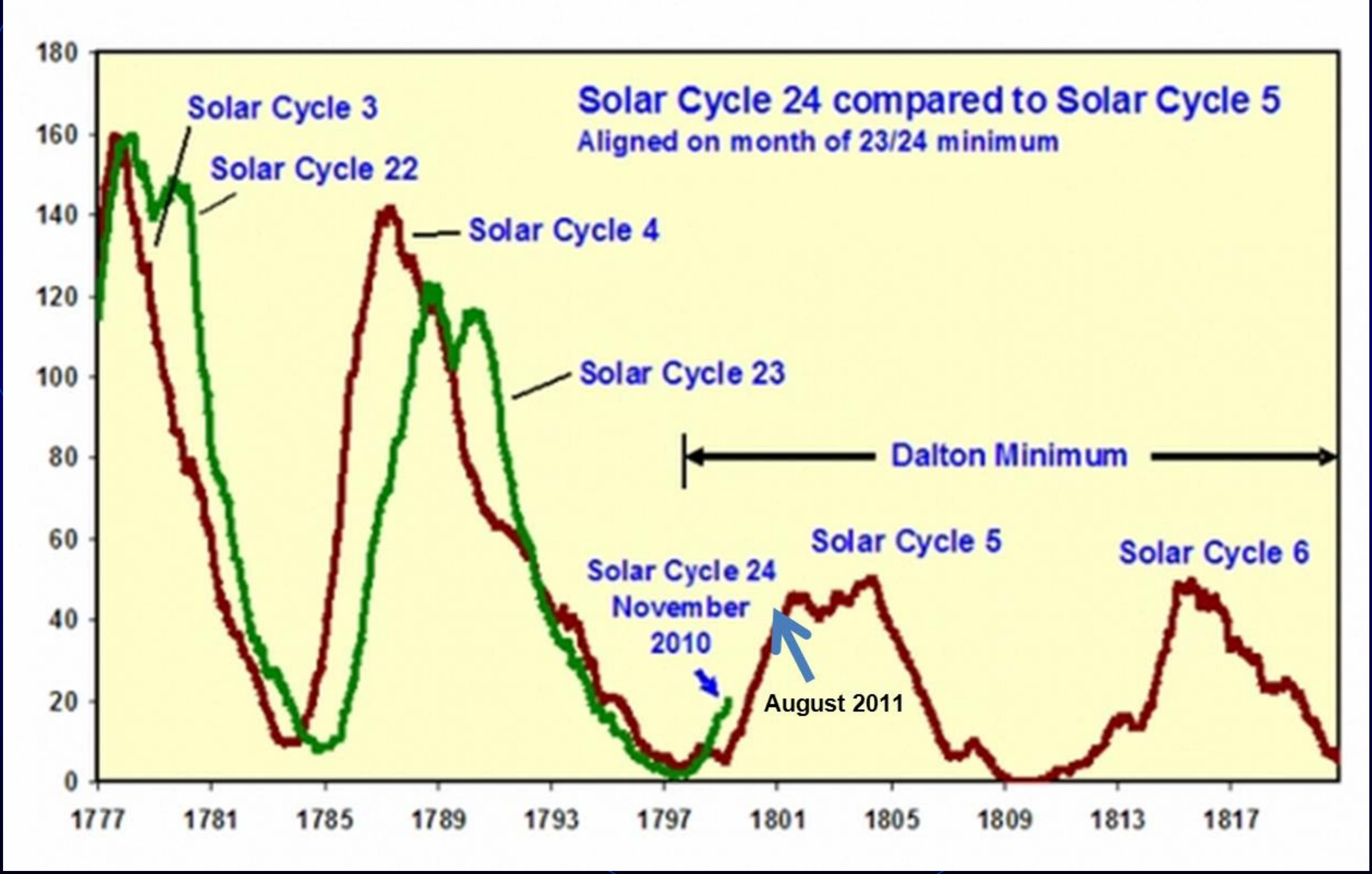
(b) The spectrum in and around the sunspot

The magnetic field gets increasingly tangled because of the differential rotation. The field breaking through the surface is parallel to the surface and suppresses upward convection → cooler and lower elevation

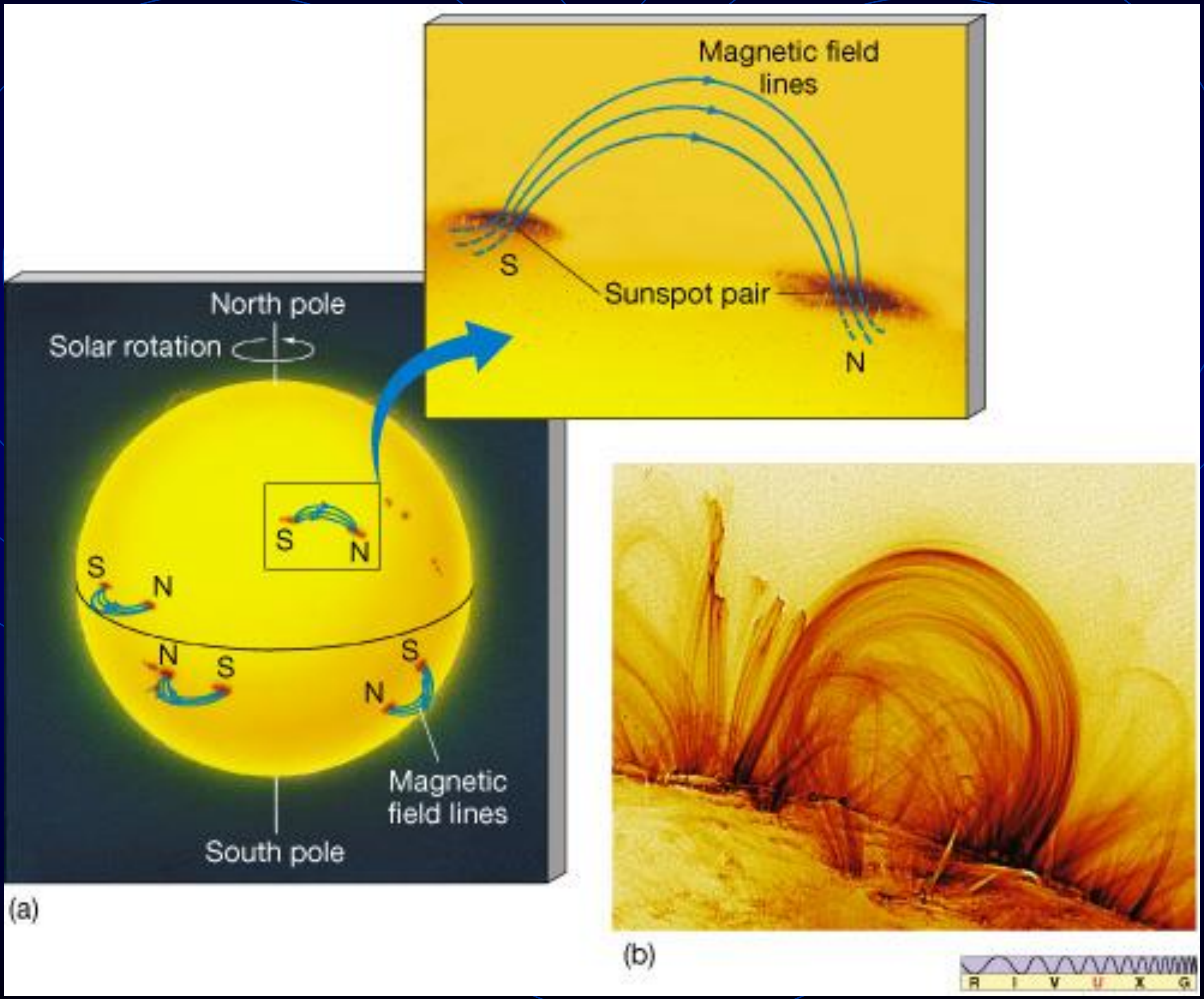


Bobcock's magnetic dynamo model

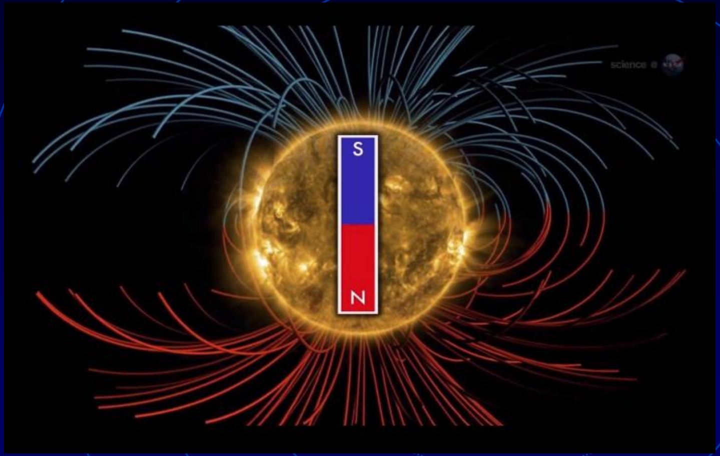
以太陽黑子11年週期計算，目前為第24期

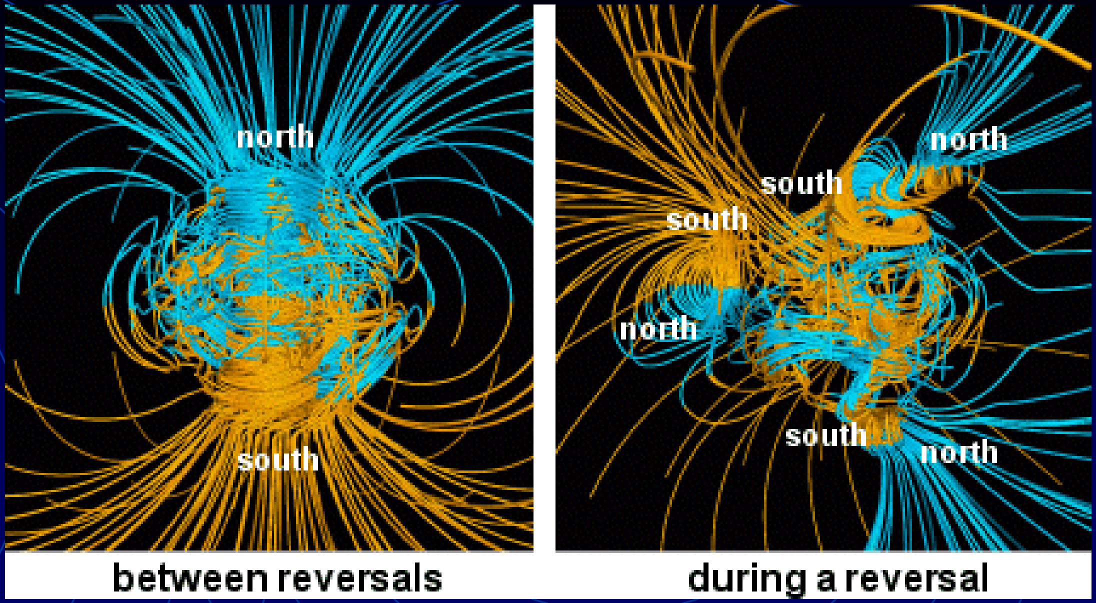


太陽南北半球磁極性相反

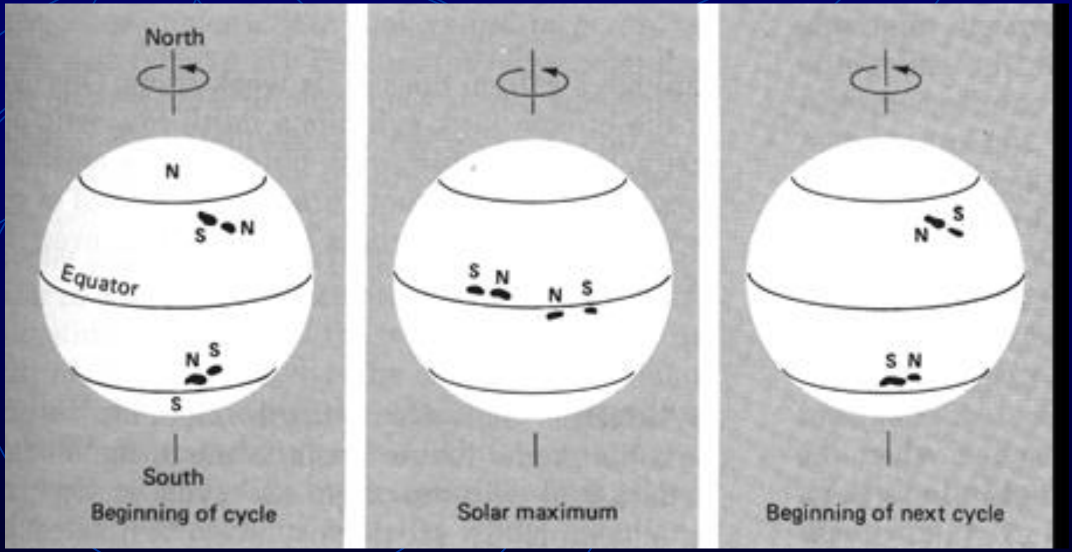


太陽磁場逆轉

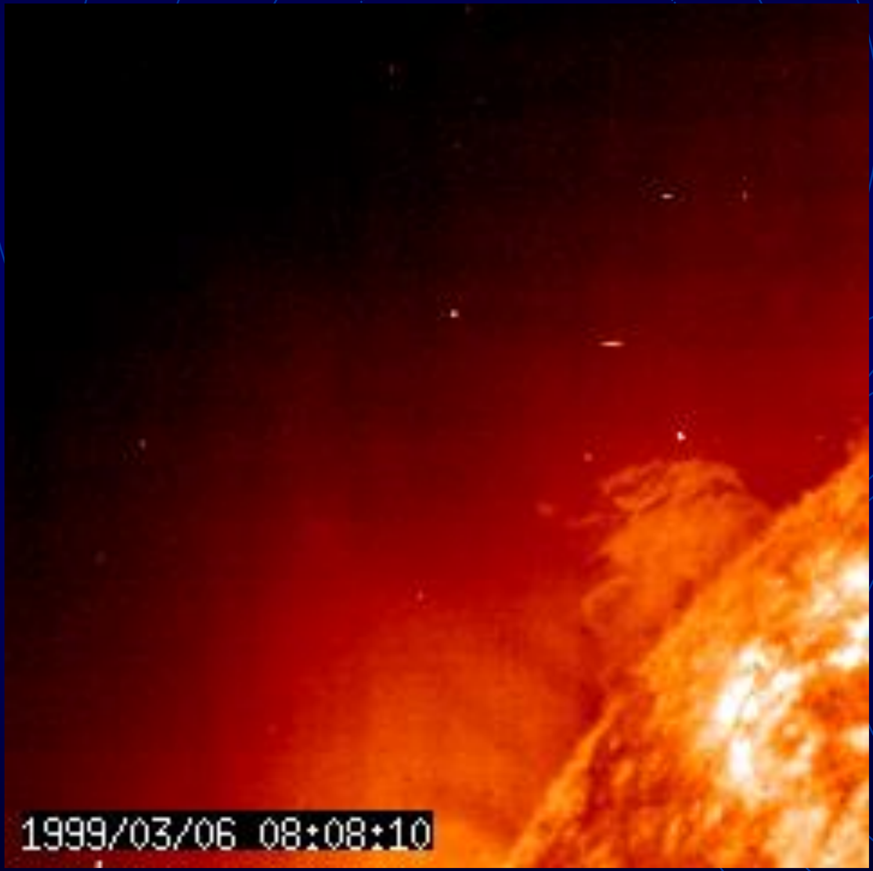


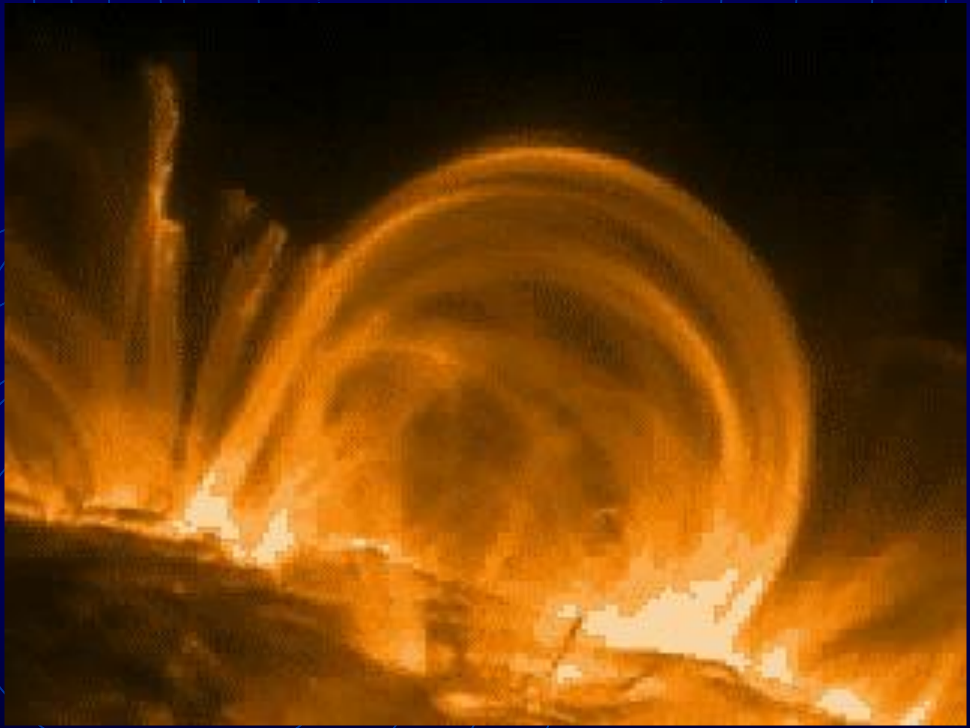


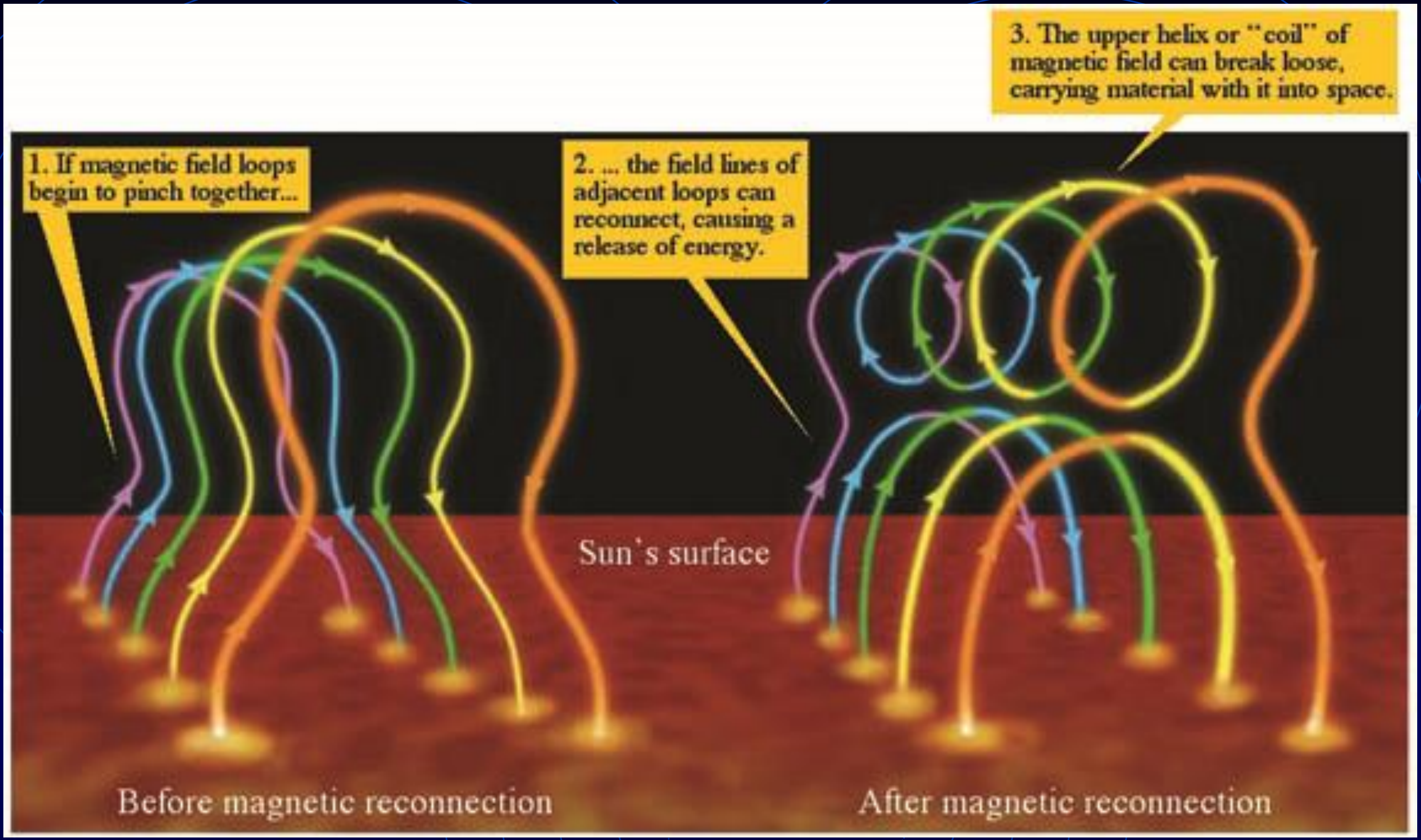
兩次太陽週期南北極性互換，例如上個週期北半球N極前導，S極跟隨（同時南半球則S極前導），那麼下個週期則北半球S極前導 → 如果考慮磁場變化，完整的太陽變化週期為22年



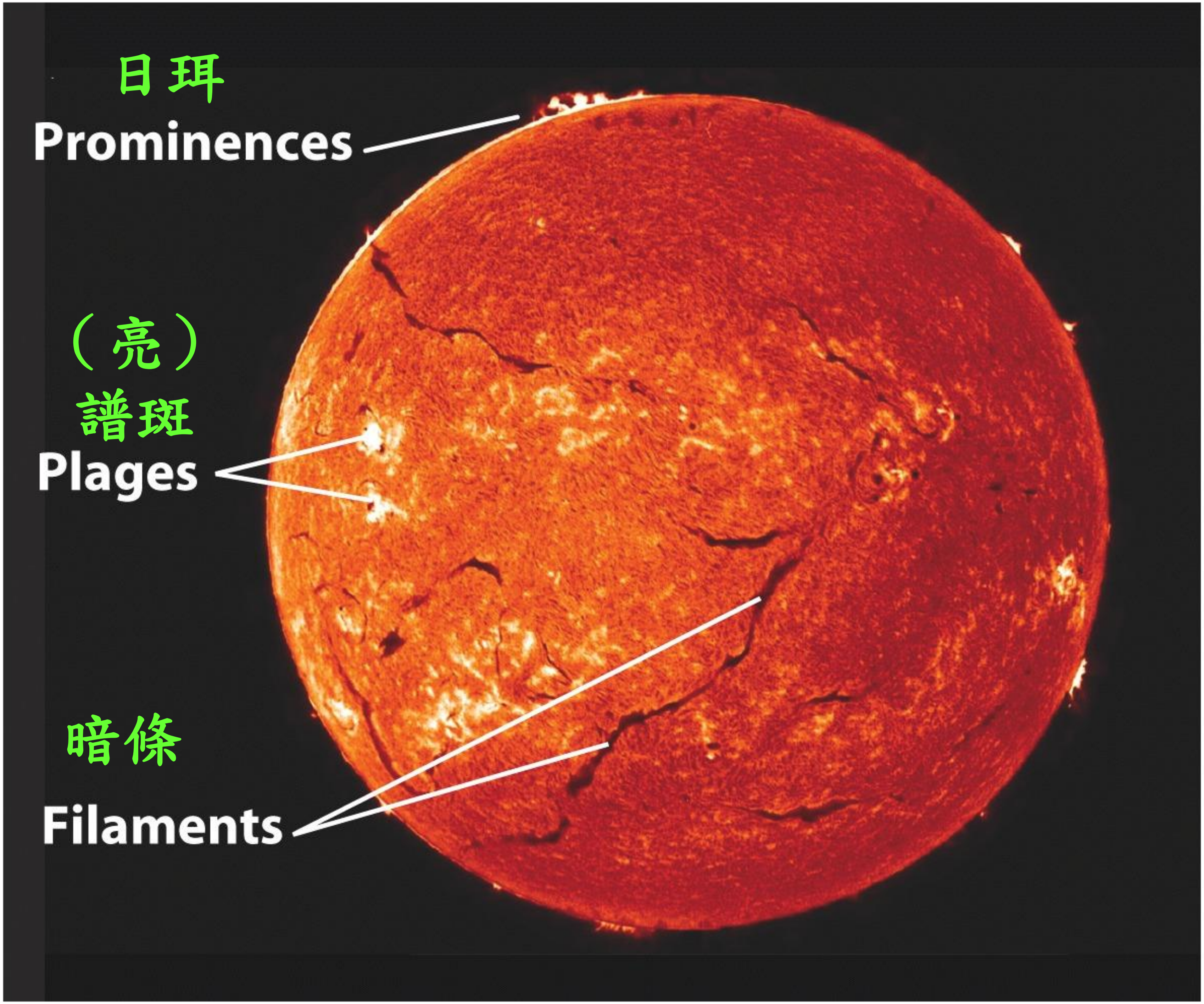
太陽表面常有劇烈活動，物質高速噴發，常看得出磁場結構

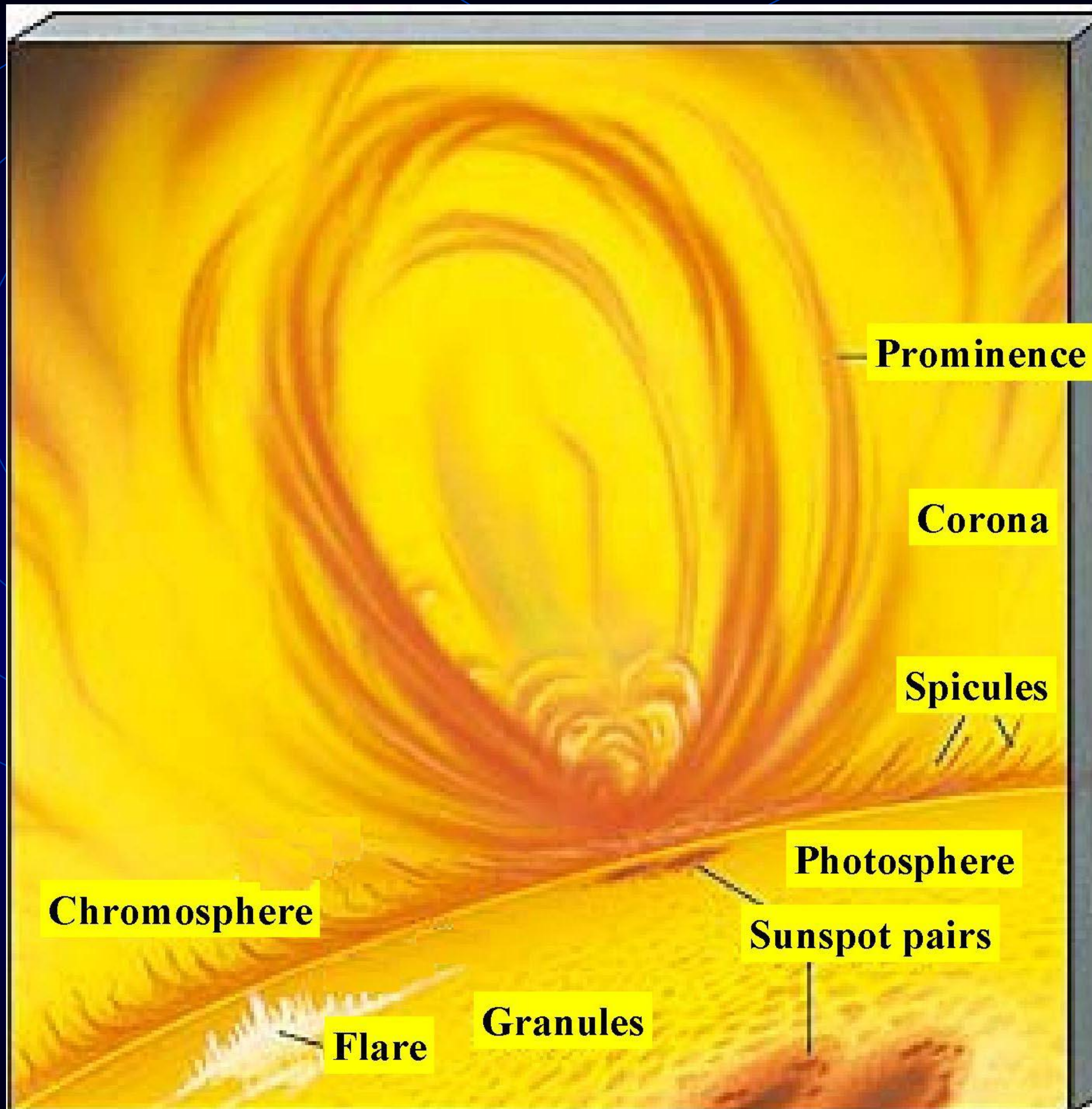


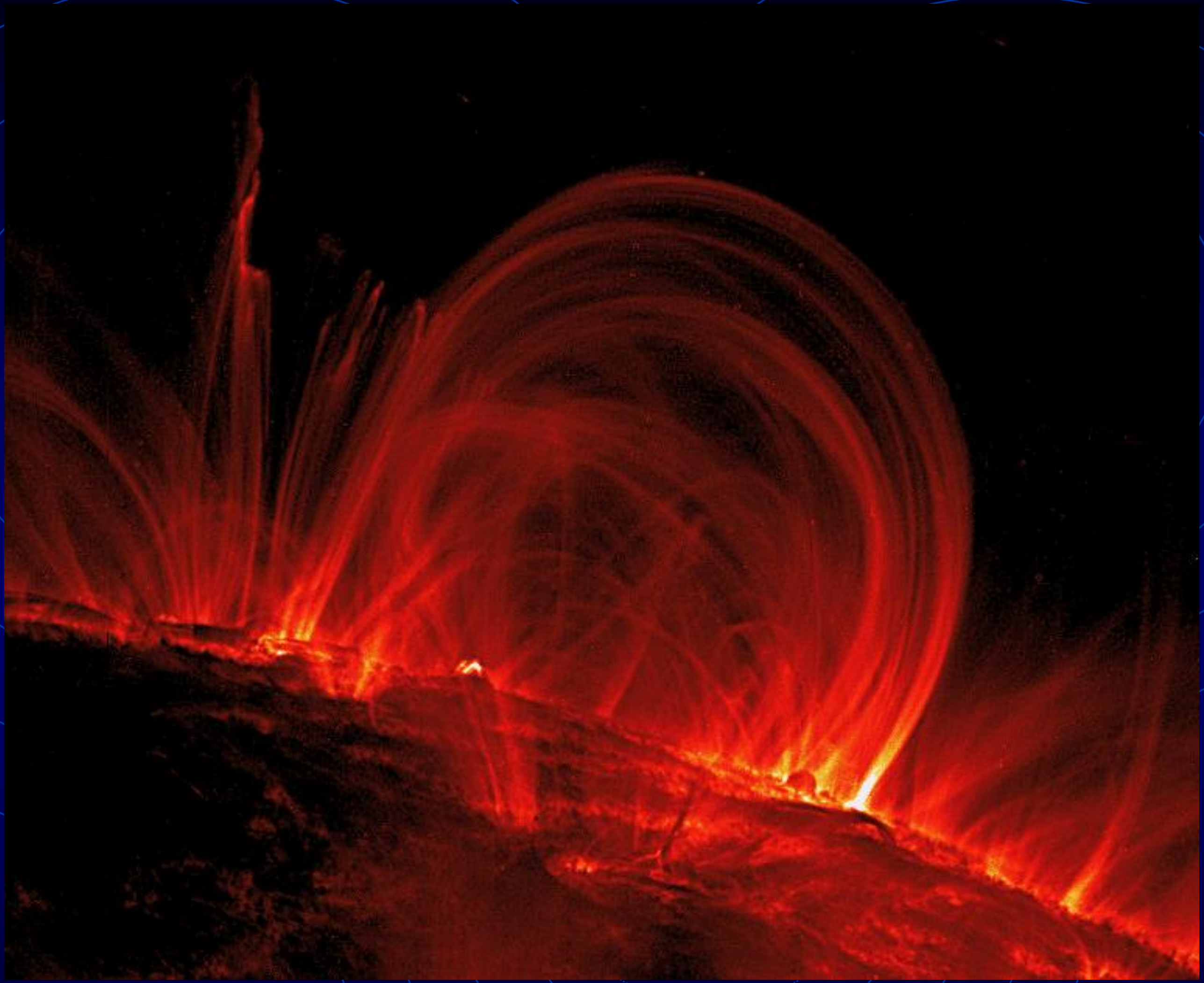




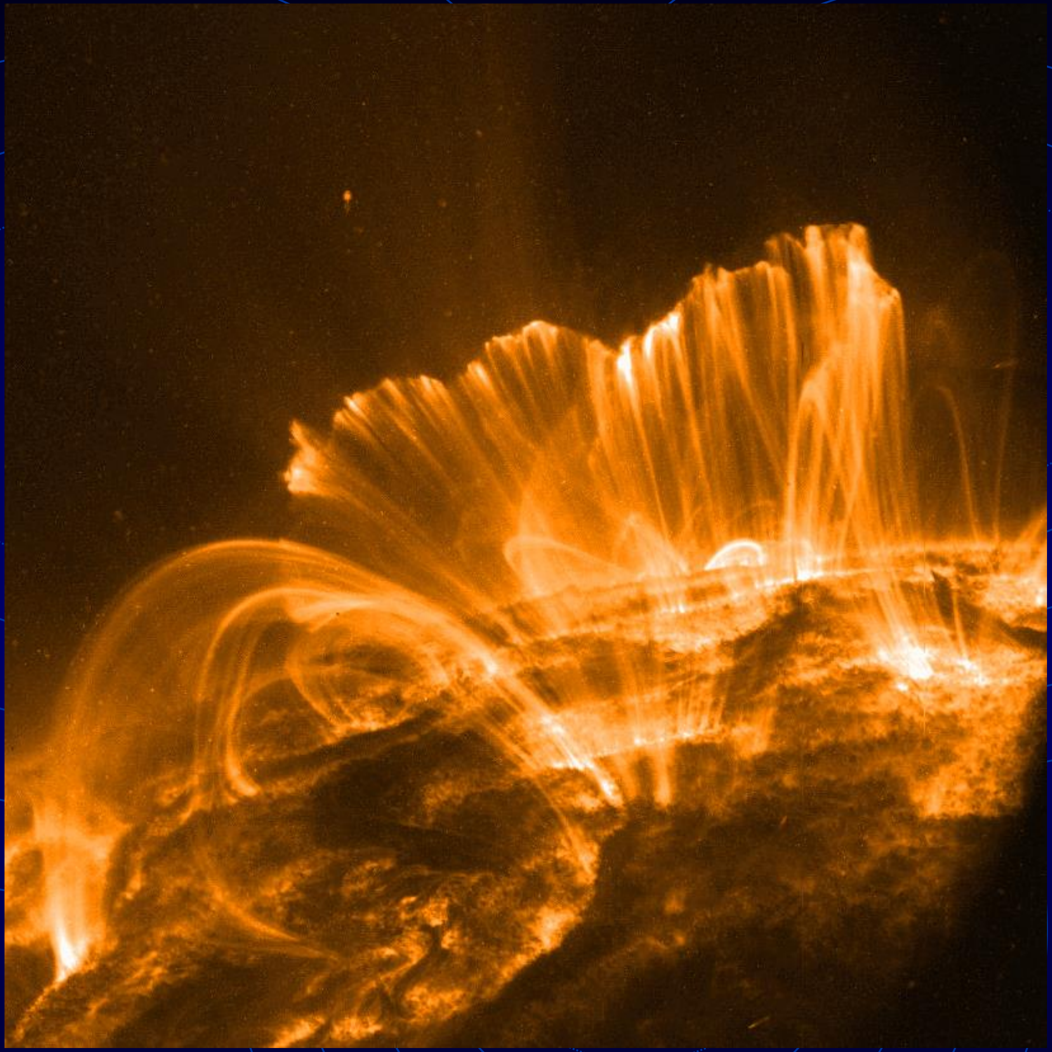
Magnetic field reconnection causes release of energy and ejection of material upward.


日珥
Prominences
（亮）
譜斑
Plages
暗條
Filaments

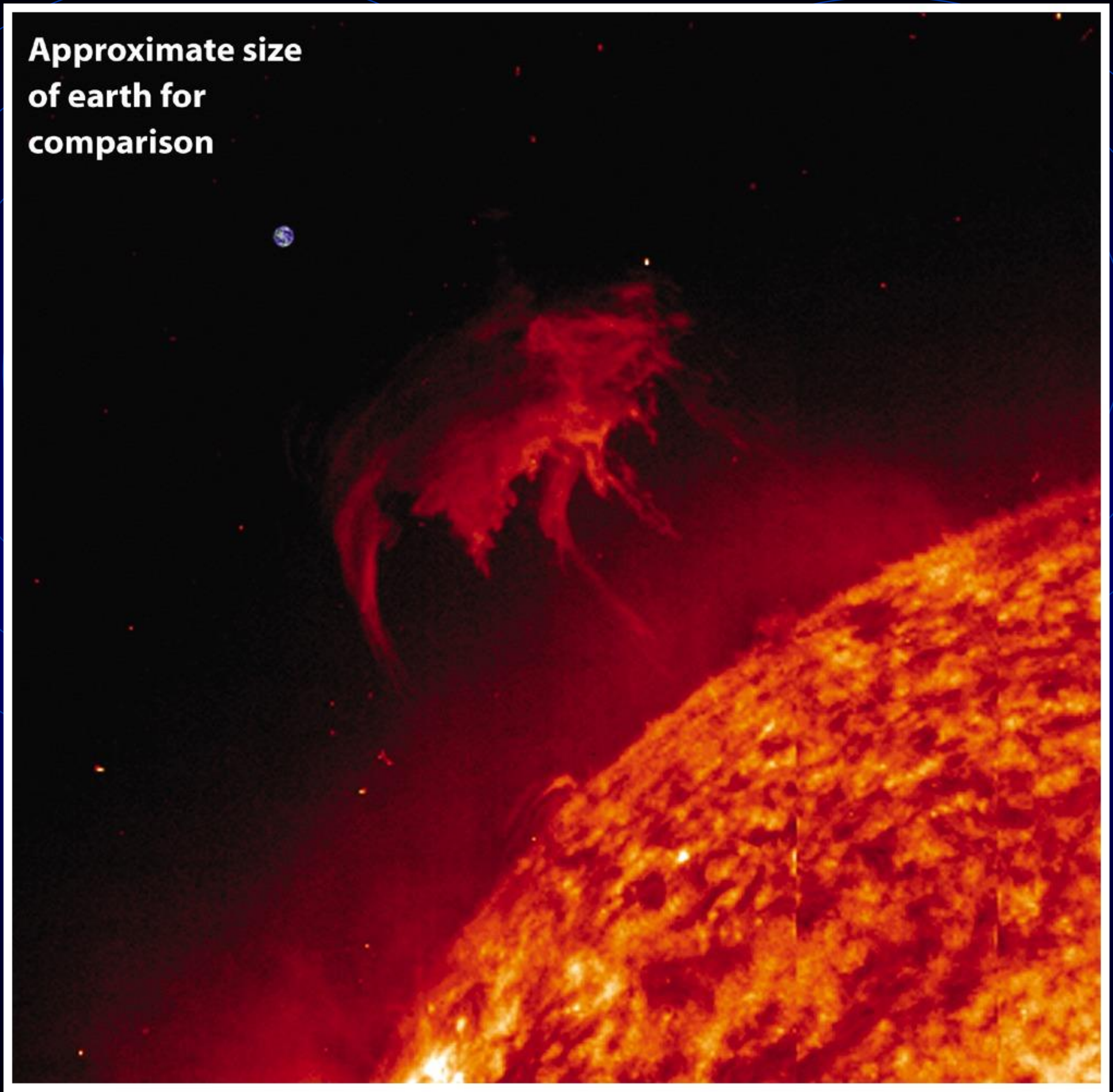

Prominence
Corona
Spicules
Photosphere
Chromosphere
Sunspot pairs
Granules
Flare



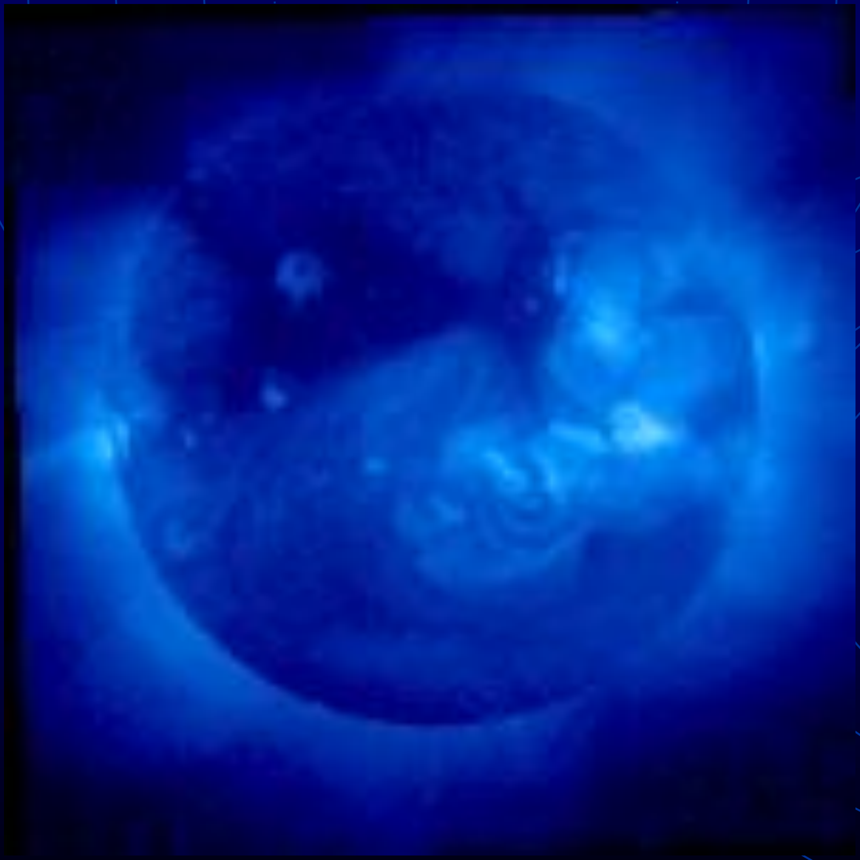
http://soi.stanford.edu/results/SolPhys200/Schrijver/images/TRACE171_991106_023044.gif

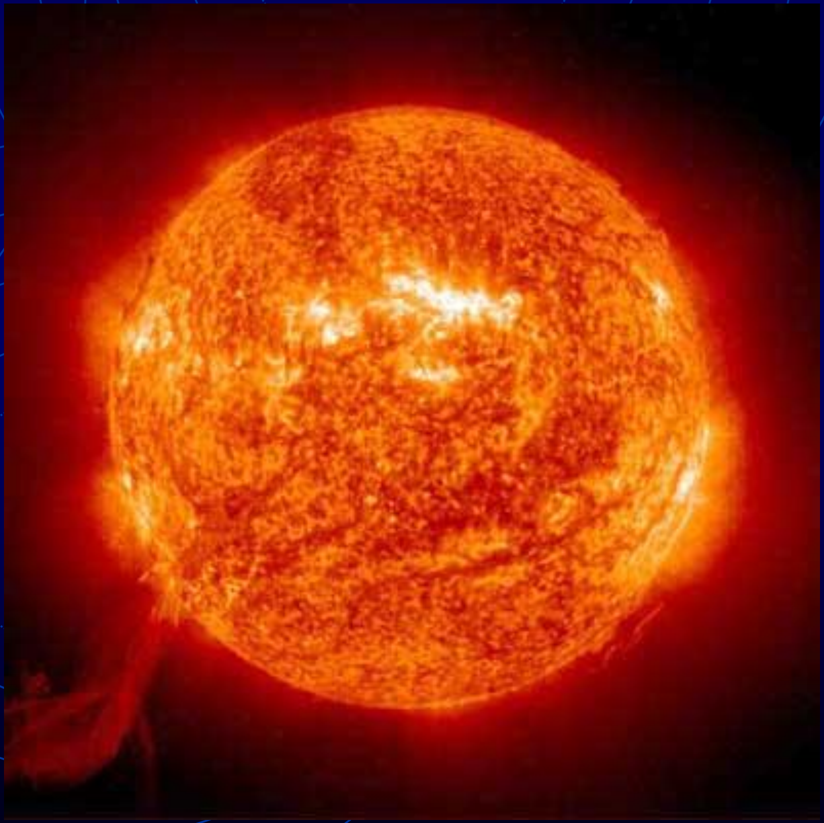


http://soi.stanford.edu/results/SolPhys200/Schrijver/images/arcade_9_nov_2000.gif

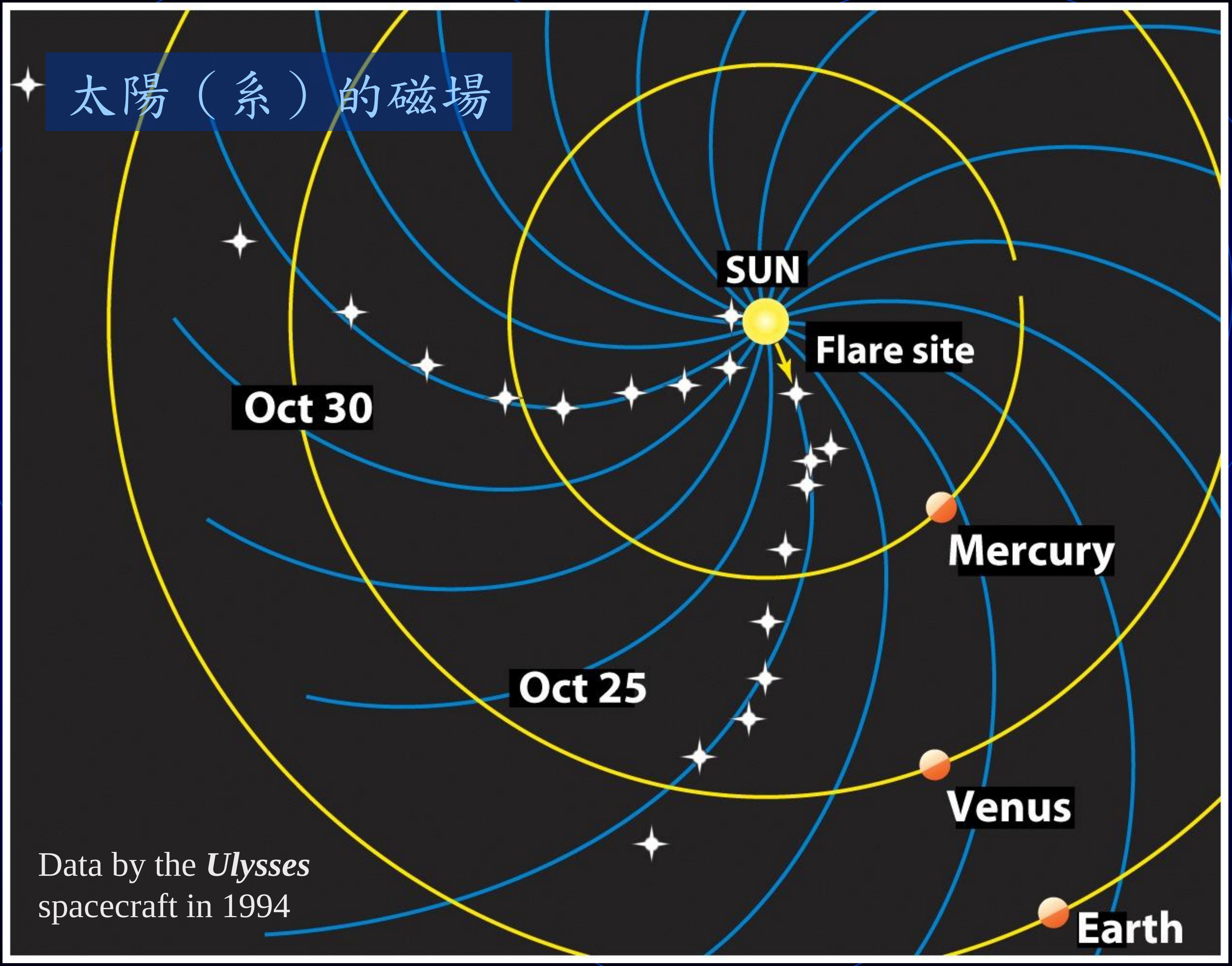

Approximate size
of earth for
comparison

日冕氣體溫度非常高，達數百萬度，因此在X光波段很明亮。corona 中的氣體以高速（時速百萬公里）逃逸到太空，形成**太陽風** (solar wind)；每秒拋出百萬噸的物質（主要成分為質子、電子）



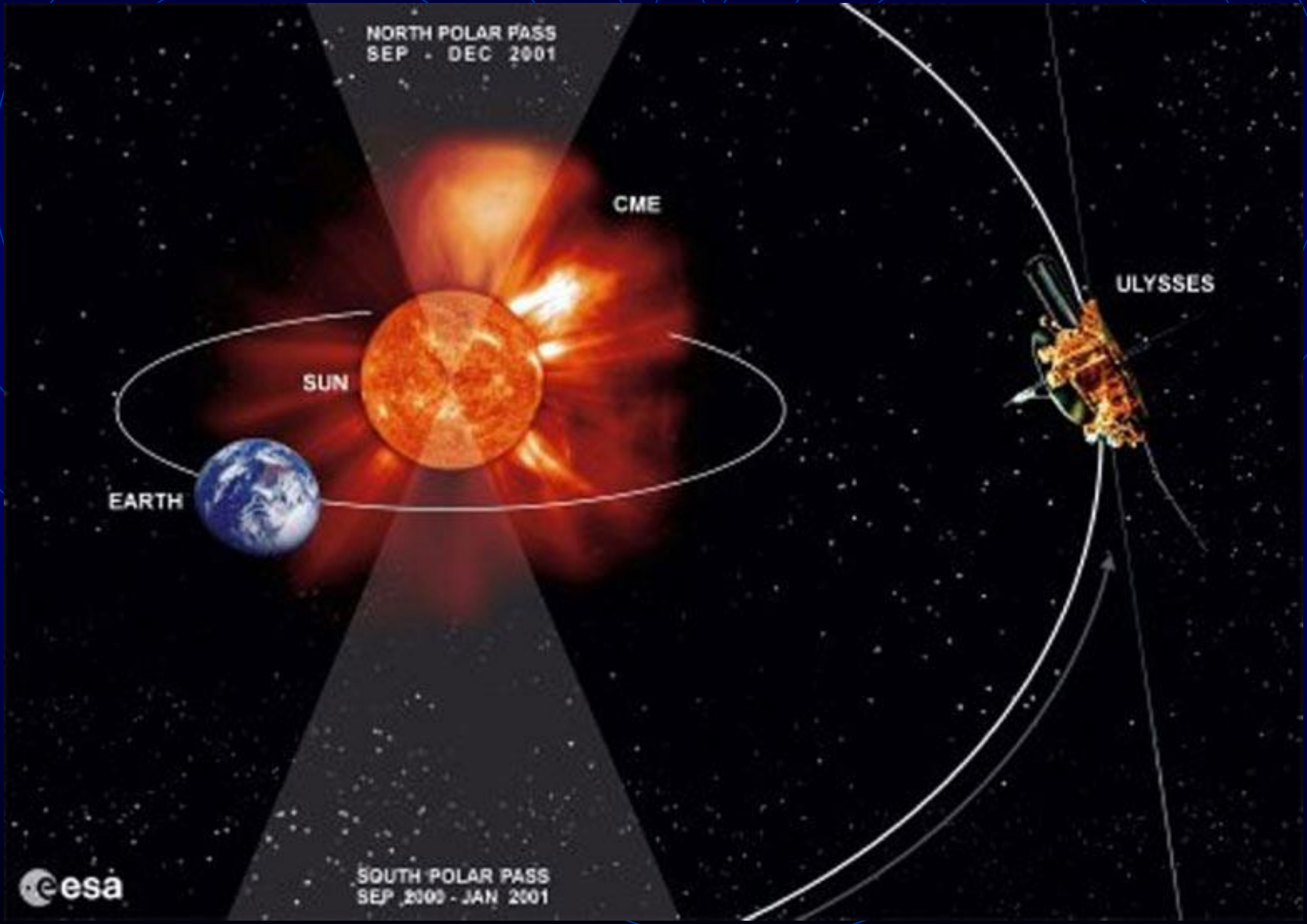


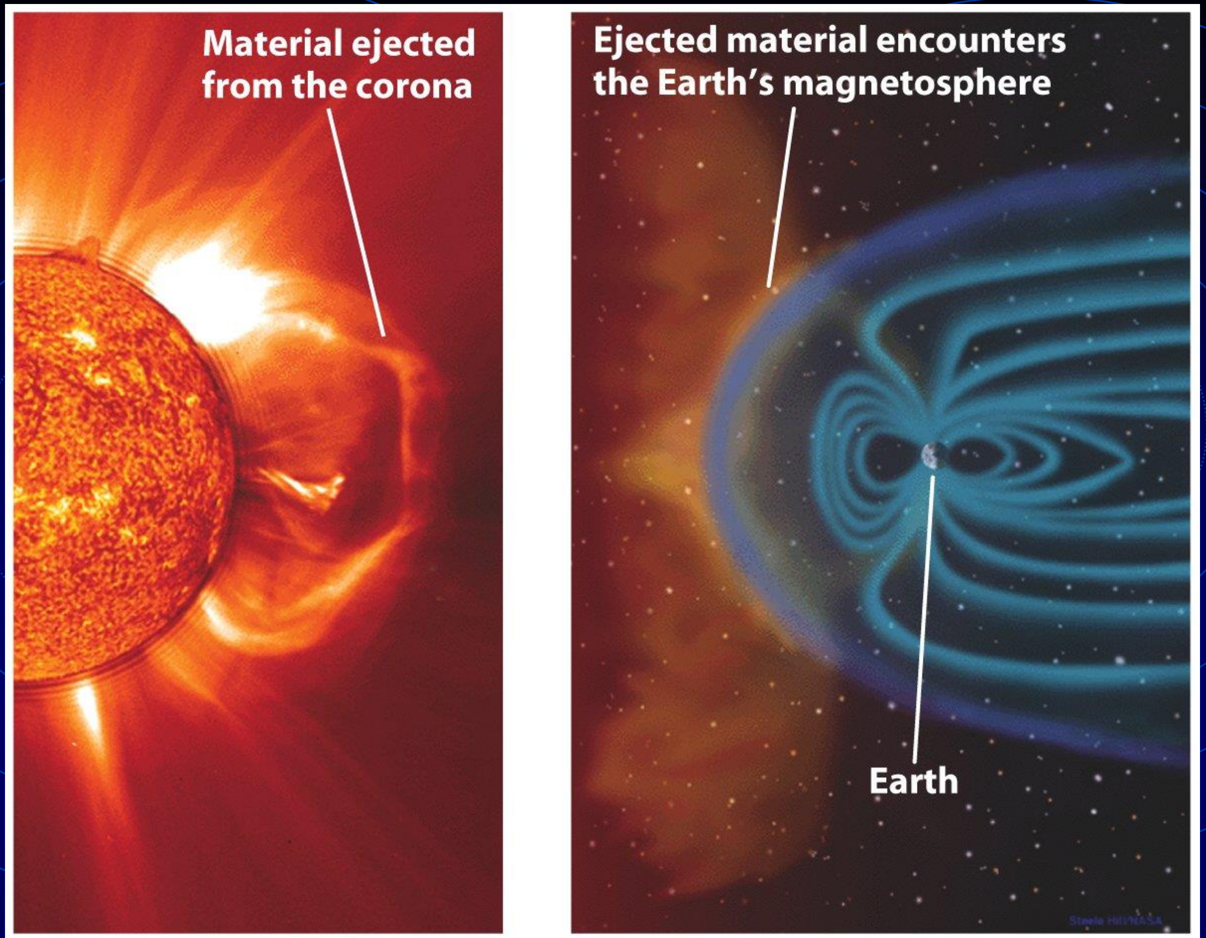
太陽（系）的磁場



Data by the ***Ulysses*** spacecraft in 1994

尤力西斯 (Ulysses) 是第一架從黃道面上方研究星際空間的太空船





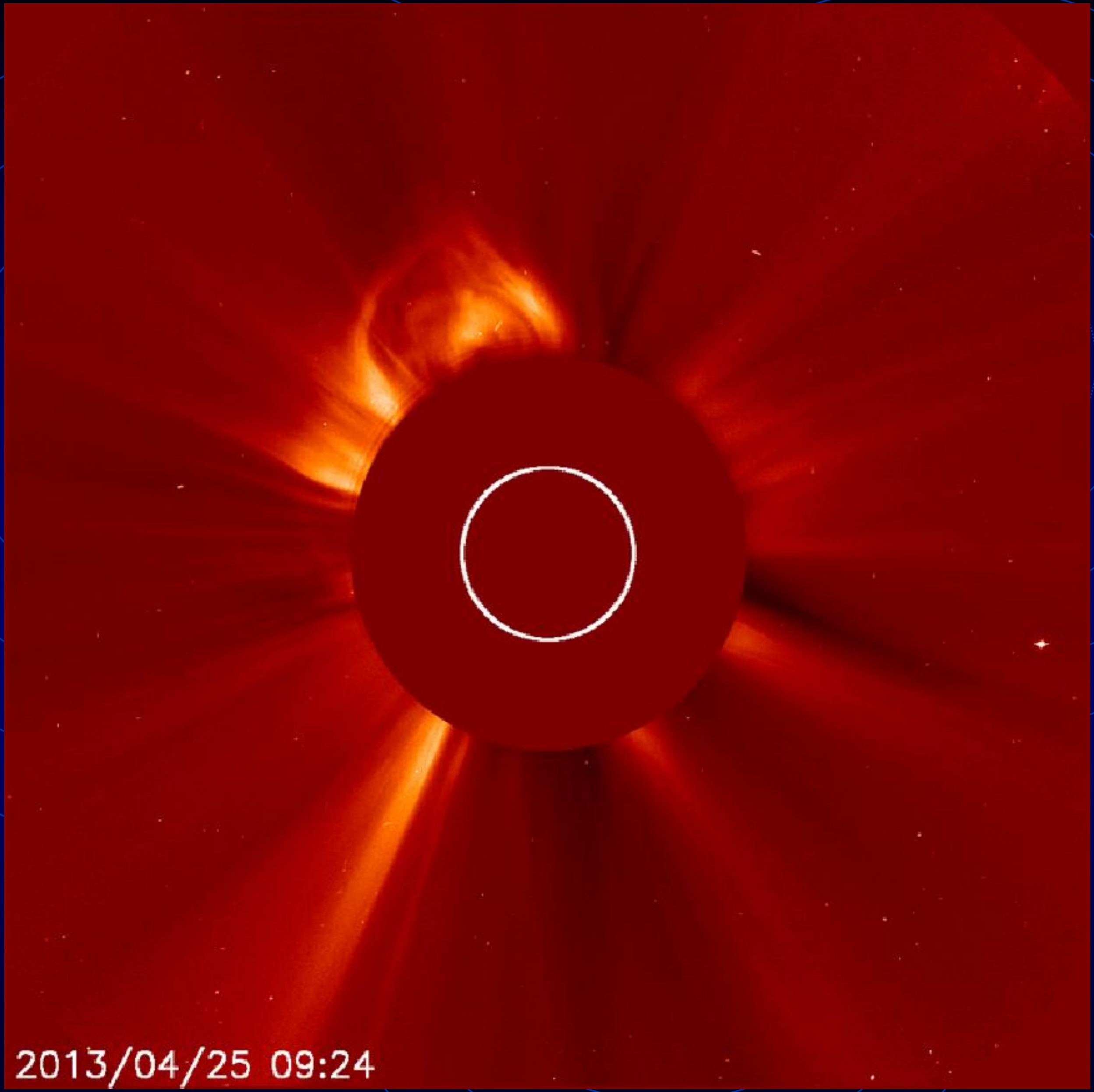
(a) A coronal mass ejection (b) Two to four days later

CME animation

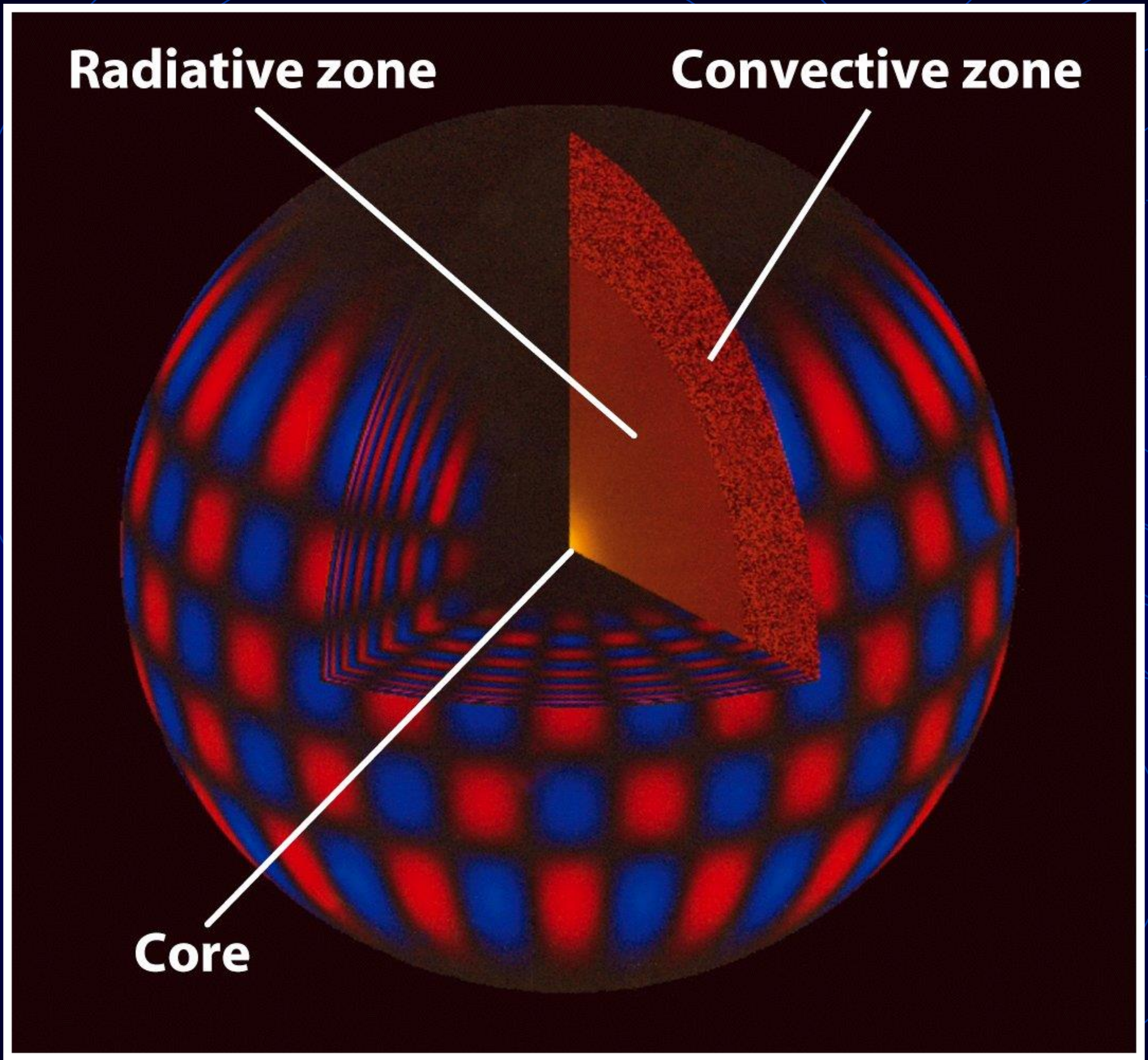
2-4天以後

SOHO 太空船所拍攝太陽 coronal mass ejection 的 X 射線影像

最高能量的氣體粒子到達地球，多半被地球磁場偏折離去，但仍有少數衝向地球，造成極光、中斷通訊與電力供應、損害衛星



Solar Heliospheric Observatory (SOHO)

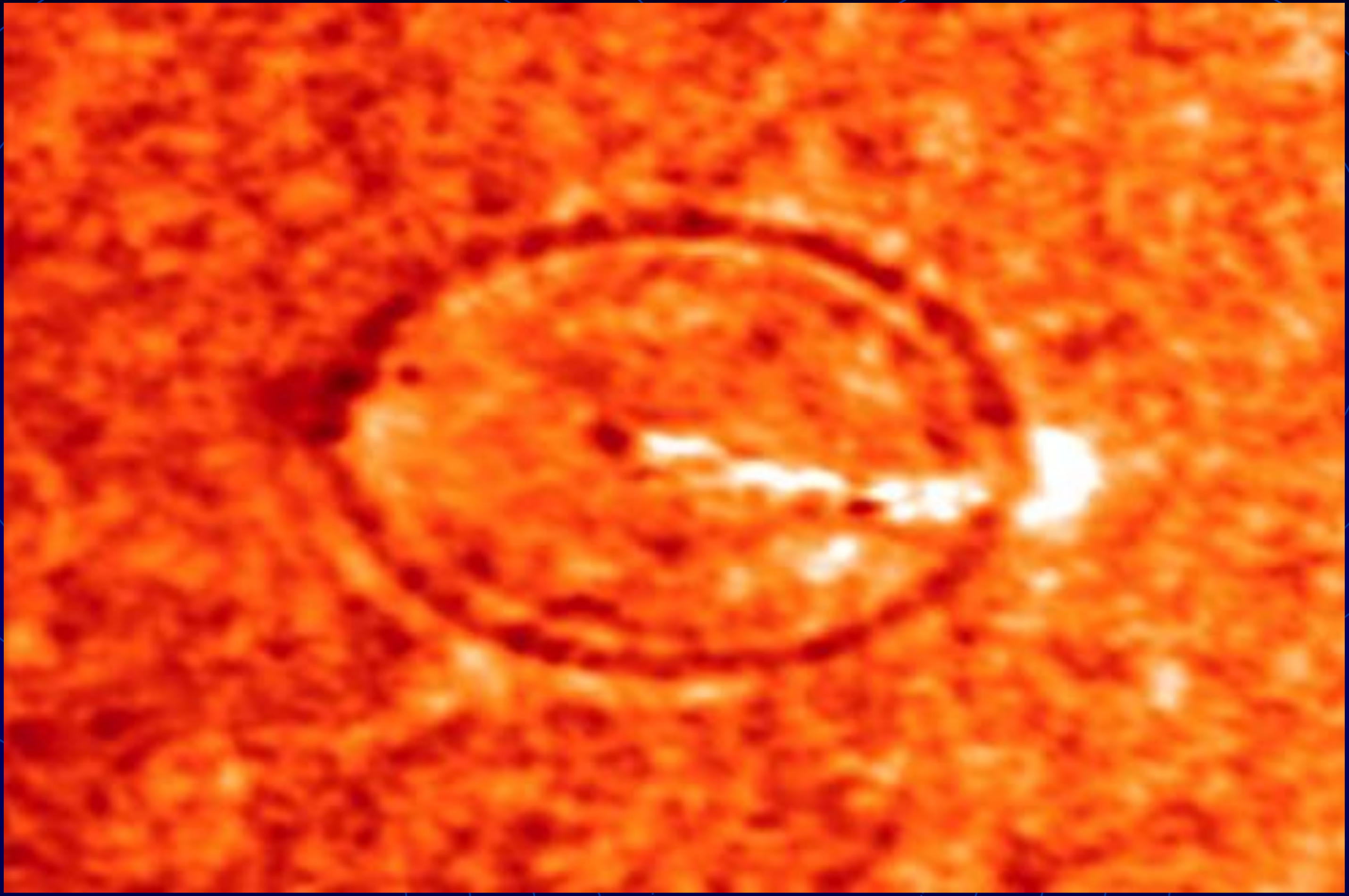


買西瓜時，
敲一敲，
聽一聽！

到底敲什麼，
聽什麼？

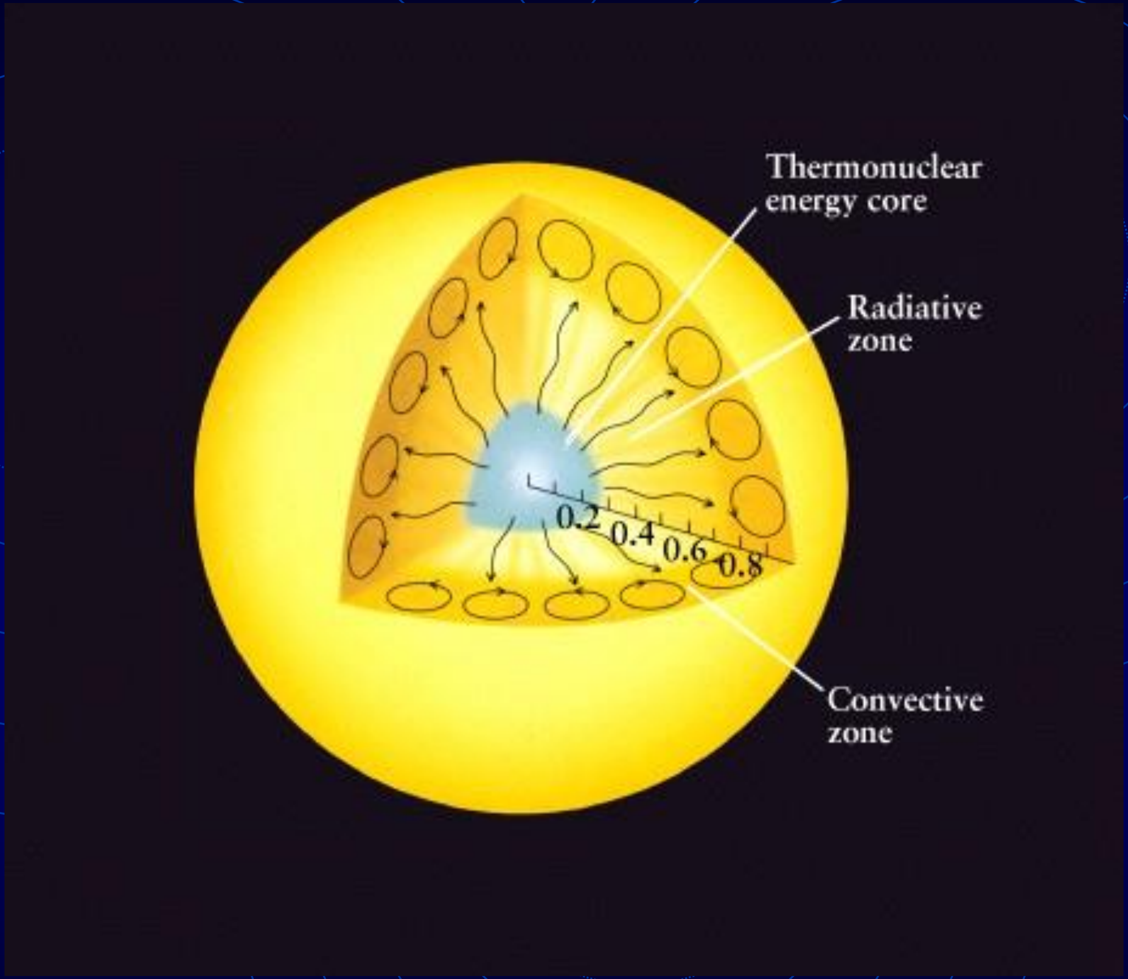
觀測震動情形
藉以研究星球
內部結構

和理論建構的
模型比較



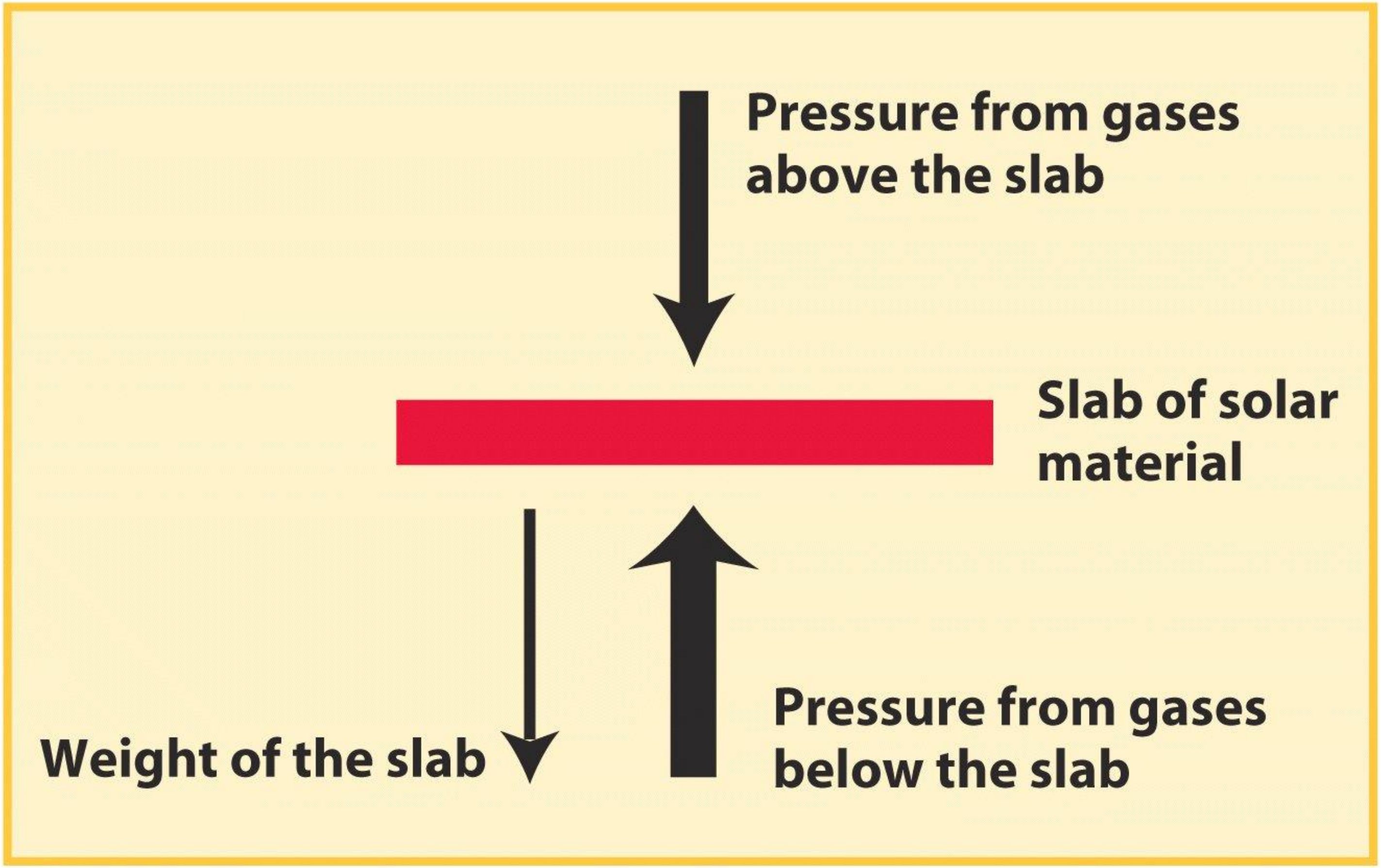
Solar Flares Cause Sun Quakes APOD 1998.06.01

太陽內部結構



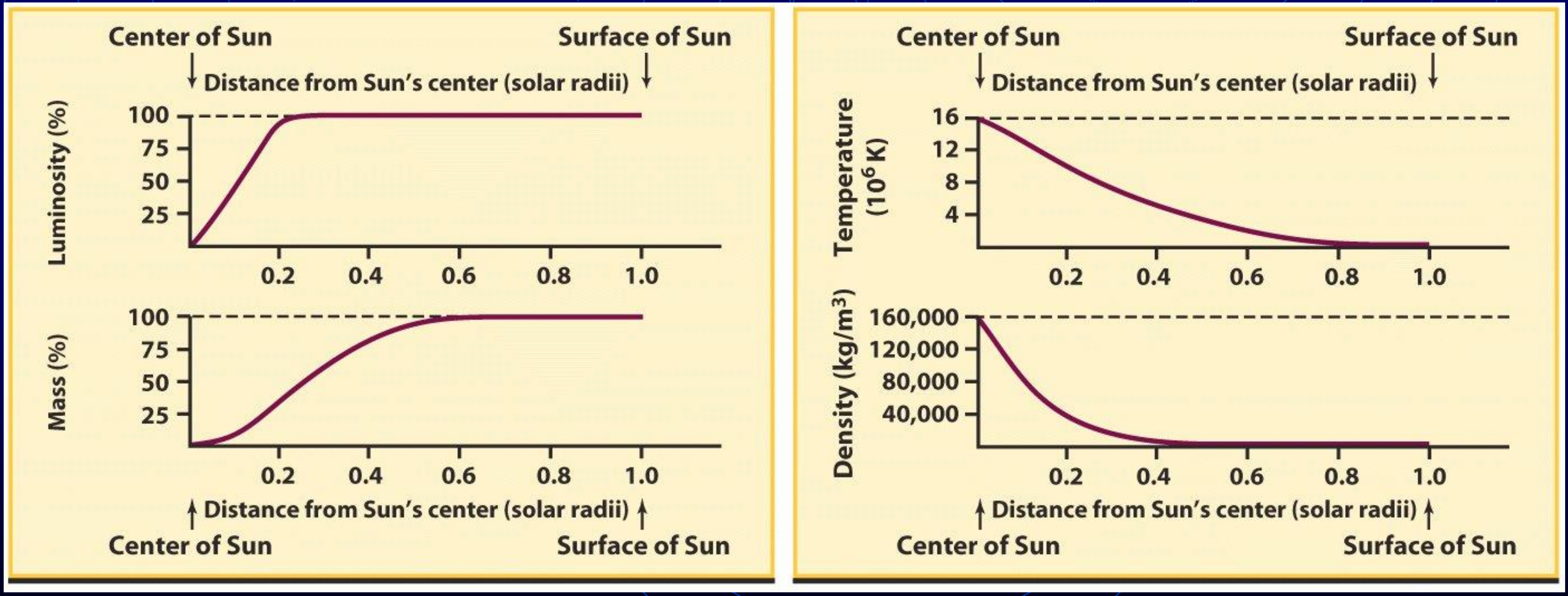
半徑1/4之內的核心進行核反應，釋放的能量藉輻射與對流方式傳到表面，然後輻射到太空

太陽各部分處於**靜力平衡 (hydrostatic equilibrium)**

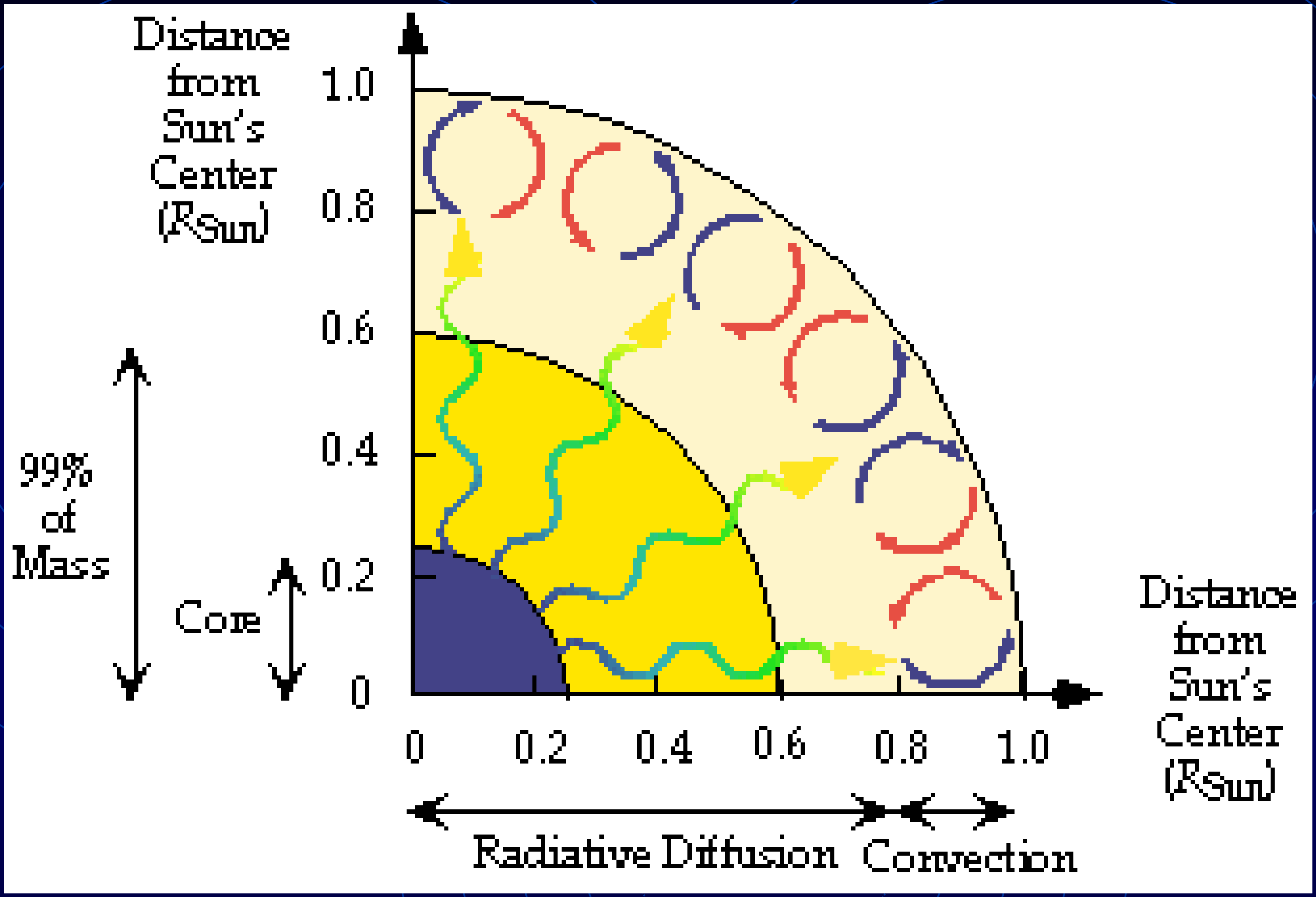


Material inside the sun is in hydrostatic equilibrium, so forces balance

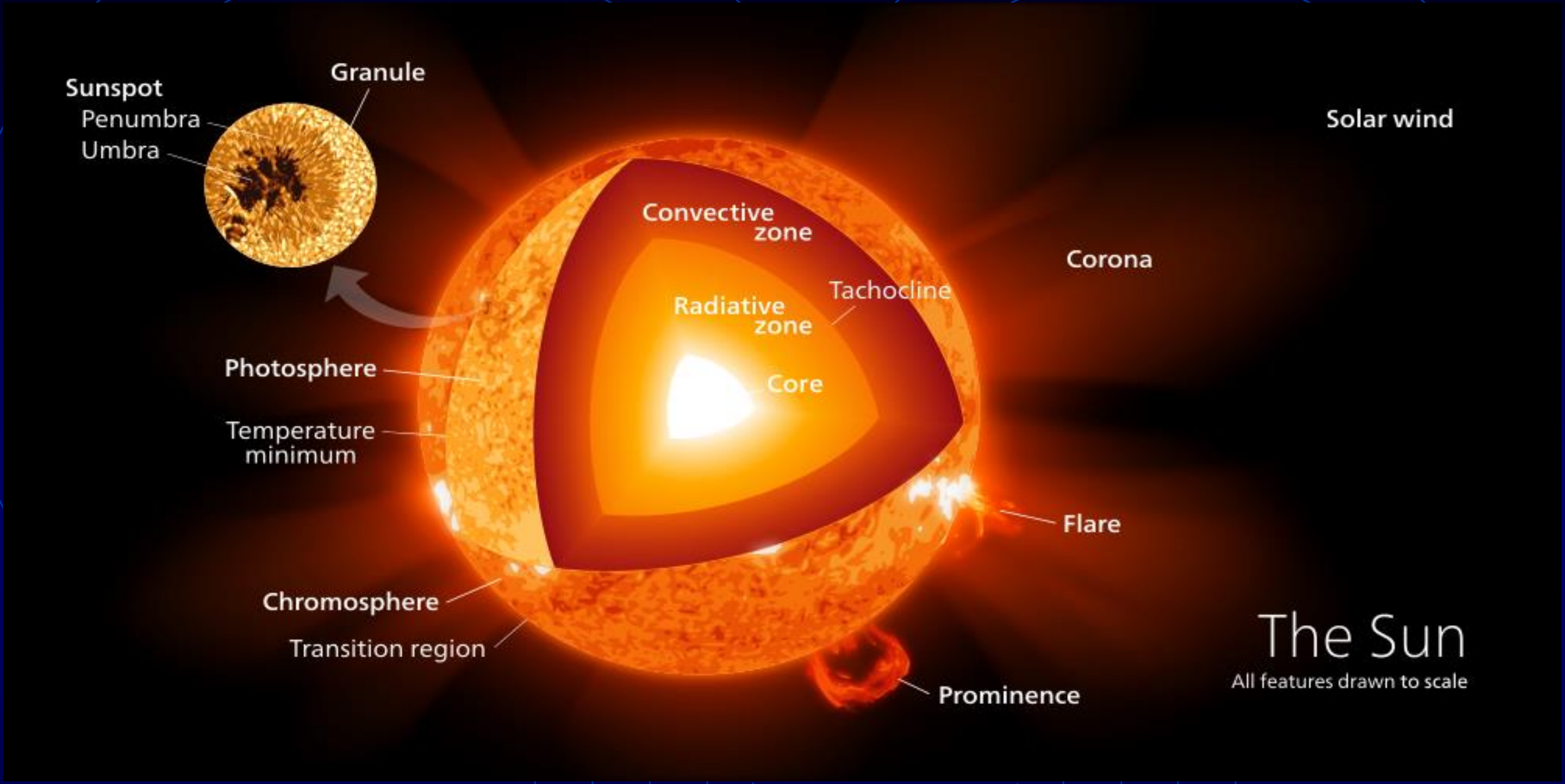
太陽的結構模型



Center of Sun
Surface of Sun
Distance from Sun's center (solar radii)
Luminosity (%)
100
75
50
25
0.2
0.4
0.6
0.8
1.0
Mass (%)
100
75
50
25
0.2
0.4
0.6
0.8
1.0
Distance from Sun's center (solar radii)
Center of Sun
Surface of Sun
Center of Sun
Surface of Sun
Distance from Sun's center (solar radii)
Temperature (10^6 K)
16
12
8
4
0.2
0.4
0.6
0.8
1.0
Density (kg/m^3)
160,000
120,000
80,000
40,000
0.2
0.4
0.6
0.8
1.0
Distance from Sun's center (solar radii)
Center of Sun
Surface of Sun



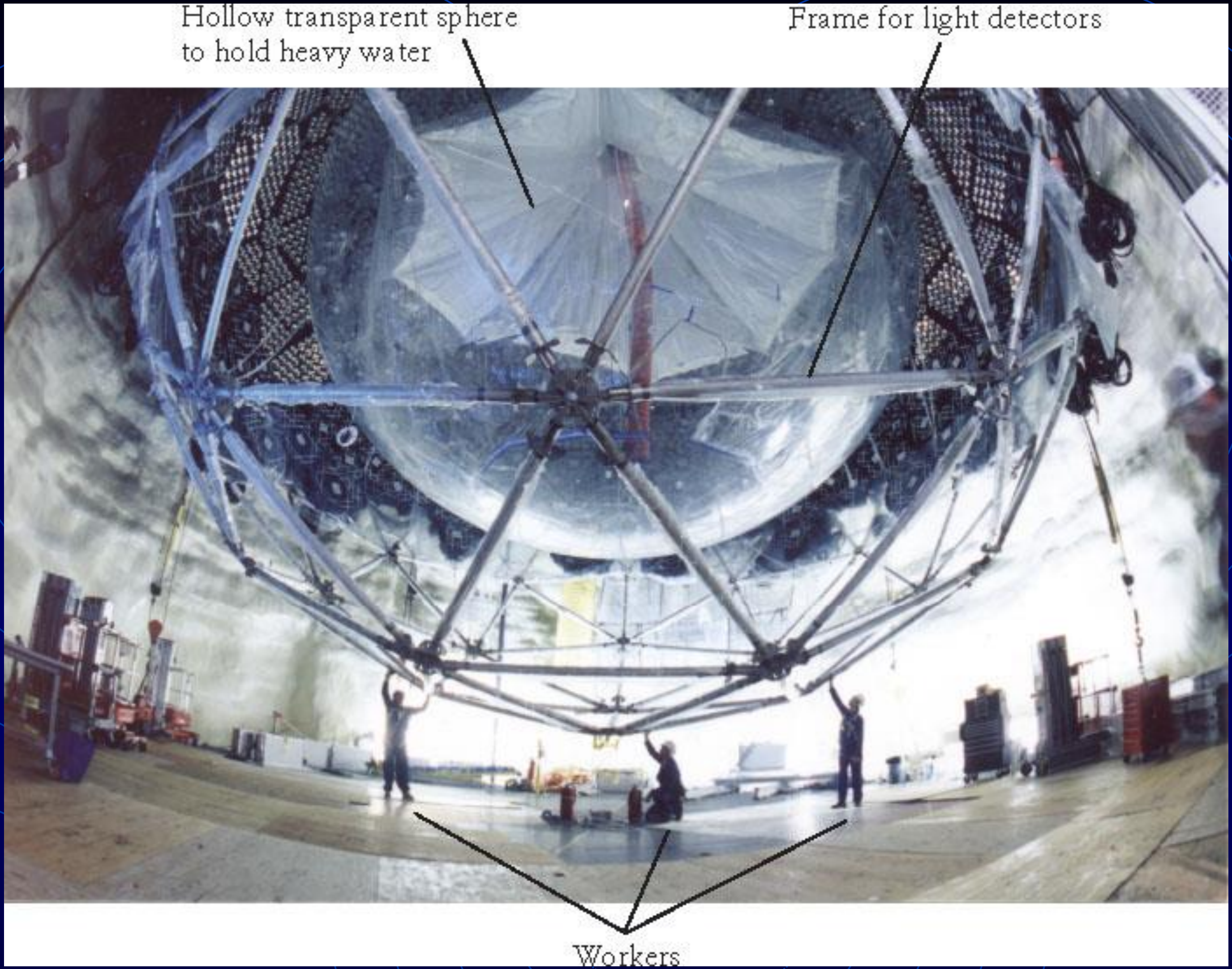
Distance
from
Sun's
Center
(RSun)
1.0
0.8
0.6
0.4
0.2
0
99%
of
Mass
Core
0
0.2
0.4
0.6
0.8
1.0
Distance
from
Sun's
Center
(RSun)
Radiative Diffusion
Convection



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

The Solar Neutrino Problem

- Thermonuclear reactions produce neutrinos （微中子）; 10^{38} neutrinos per second!
- This amounts to 10^{14} solar neutrino per m^2 on the Earth's surface
- Neutrinos react with matter very weakly; but they do interact with matter occasionally, e.g., *neutrino + neutron → proton*
- But in various solar-neutrino experiments, only a fraction has been detected of the expected flux.
- What happened? **neutrino oscillation**



The Sudbury Neutrino Observatory (Canada)
with 1000 tons of heavy water