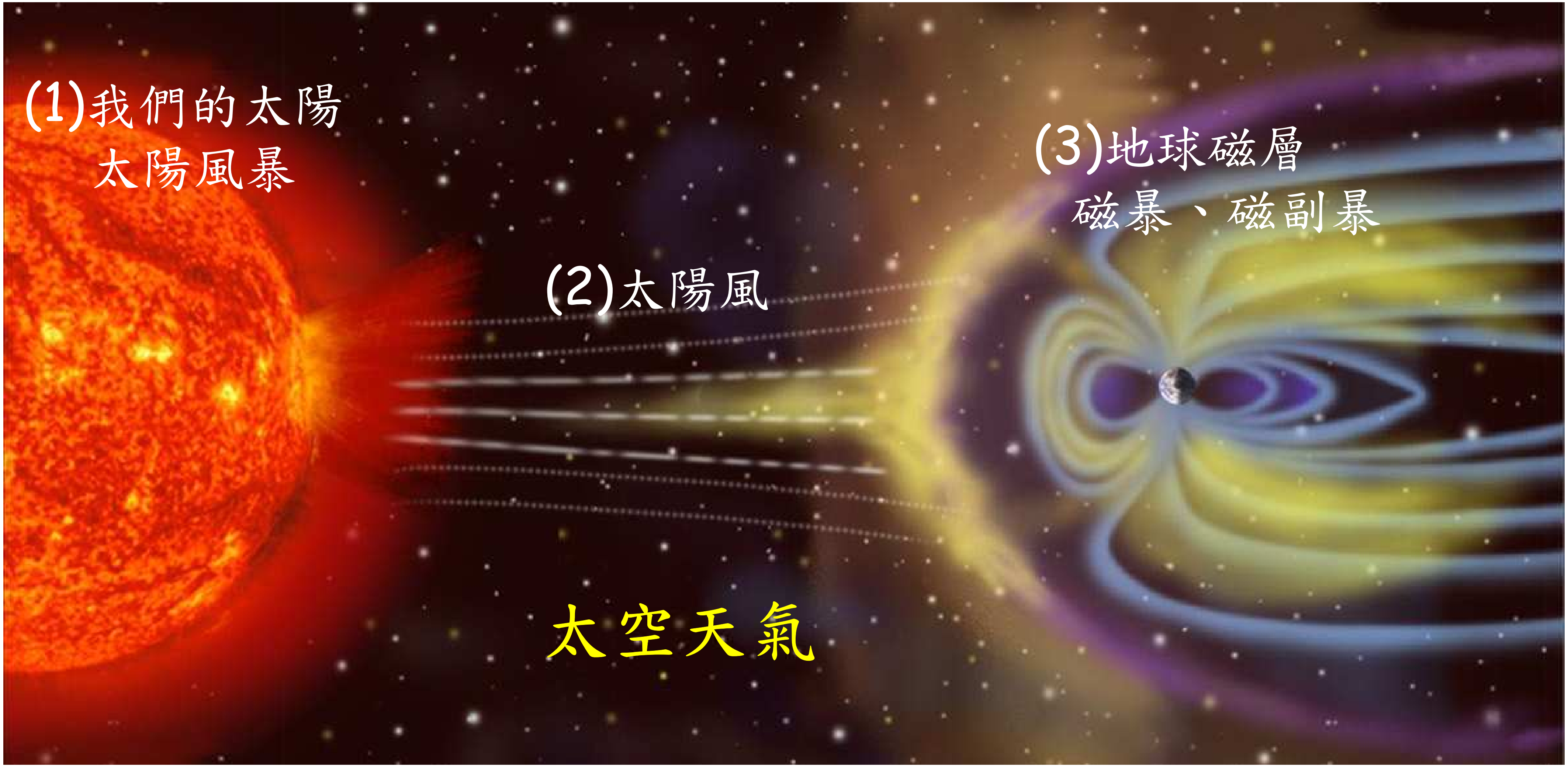
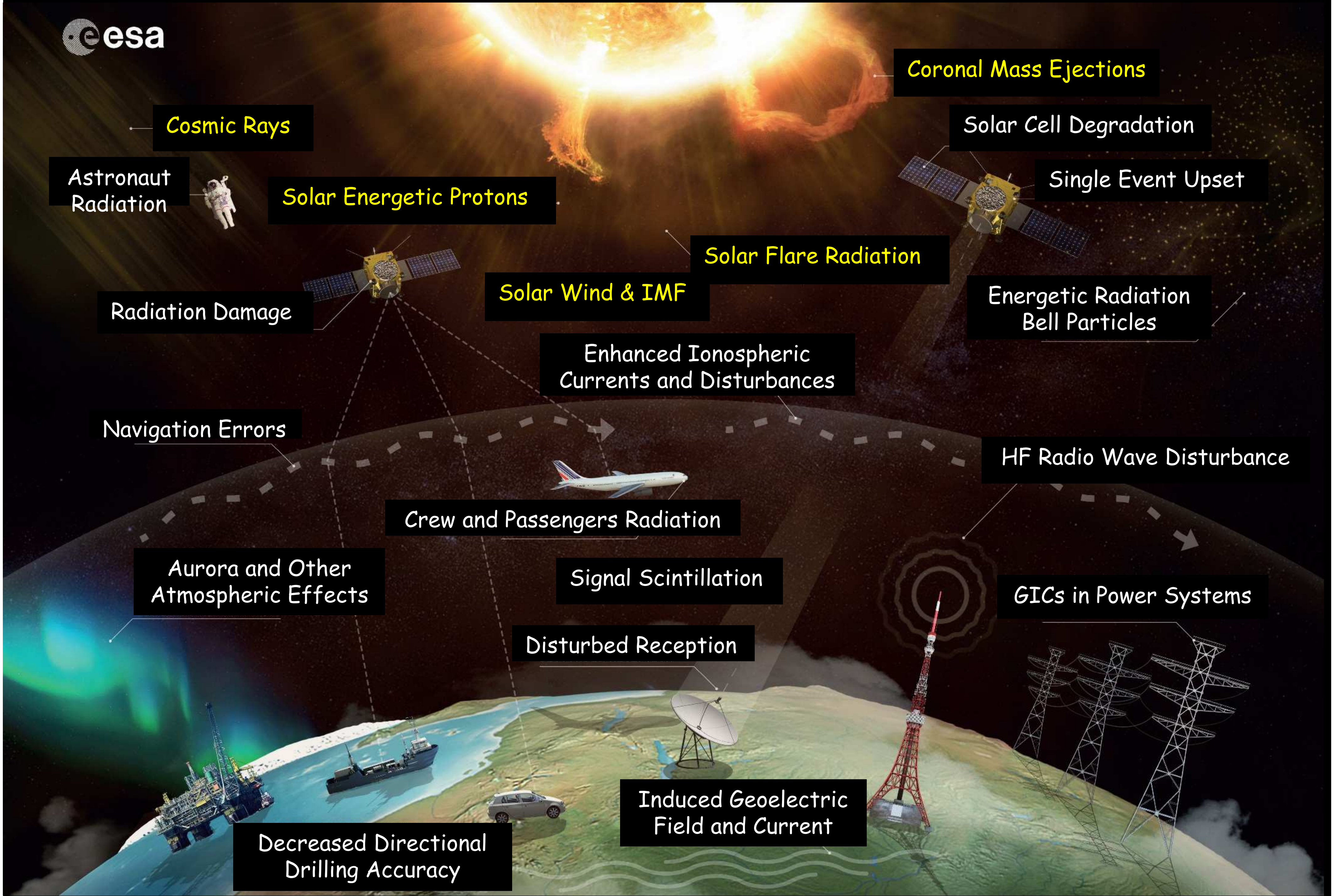
課程網址: http://www.ss.ncu.edu.tw/~yhyang/112-1/sei.html

期中考: 15%, 11/17

作業: 10%, 心得建議(一頁, 電子檔, 11/3), https://reurl.cc/QXQyWZ



http://g-ecx.images-amazon.com/images/G/01/askville/74139061_answers/1306272473581_magnetosphererendition.jpg



Credit: ESA/Science Office

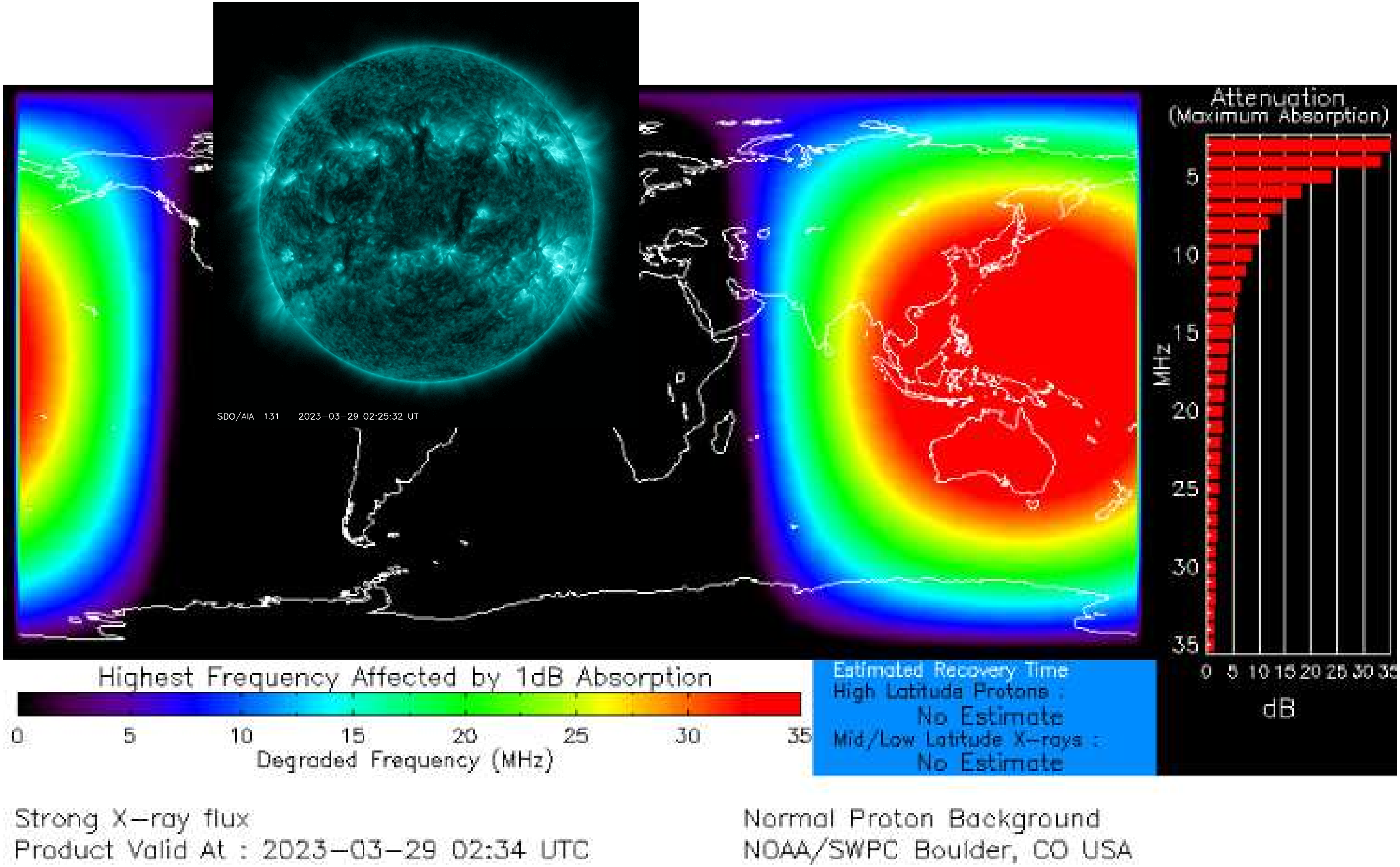
NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.

** Other frequencies may also be affected by these conditions.

Credit: NOAA/SWPC



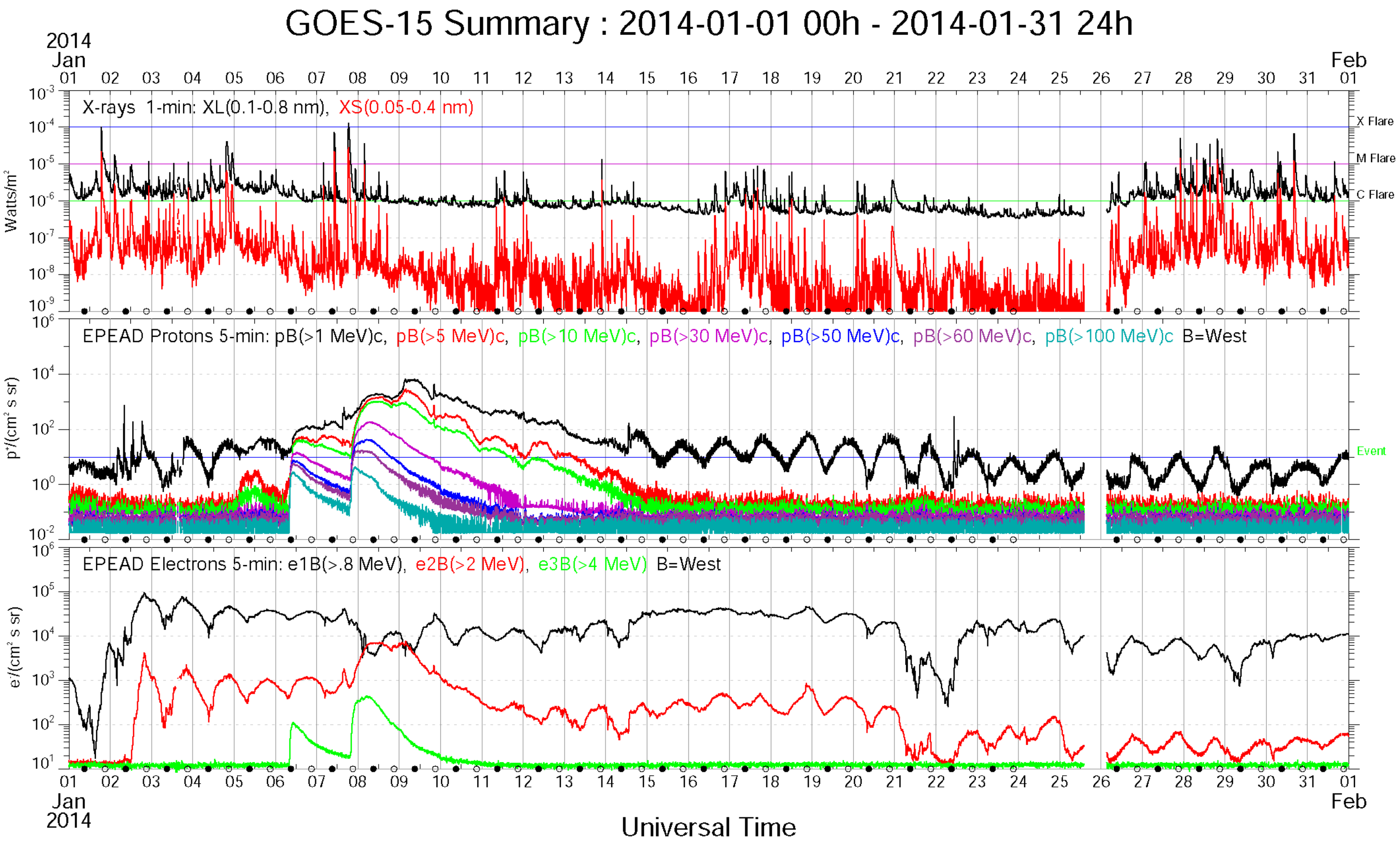
Credit: NOAA/SWPC, NASA/SDO

NOAA Space Weather Scales

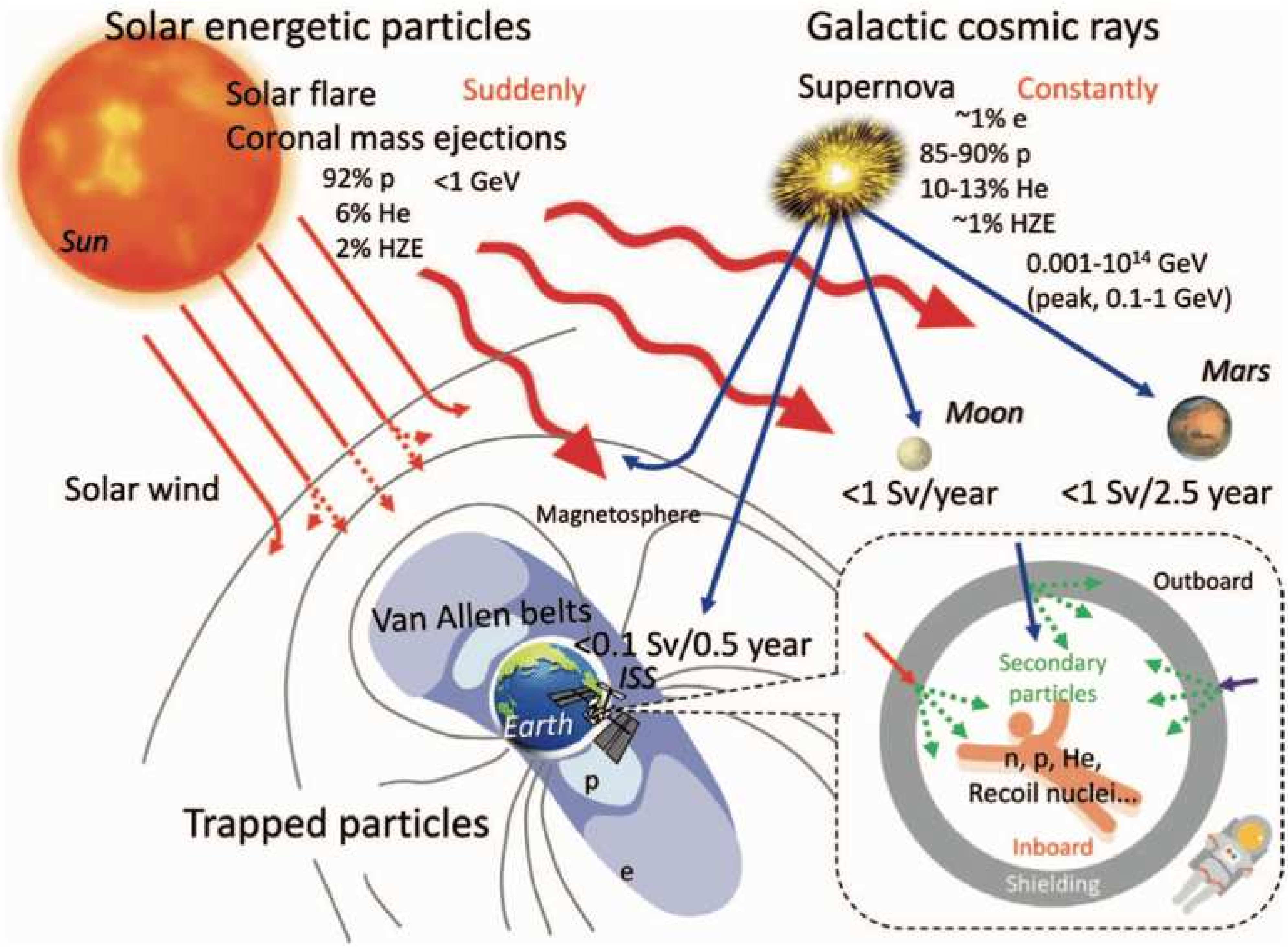
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews.. Pregnant women are particularly susceptible.

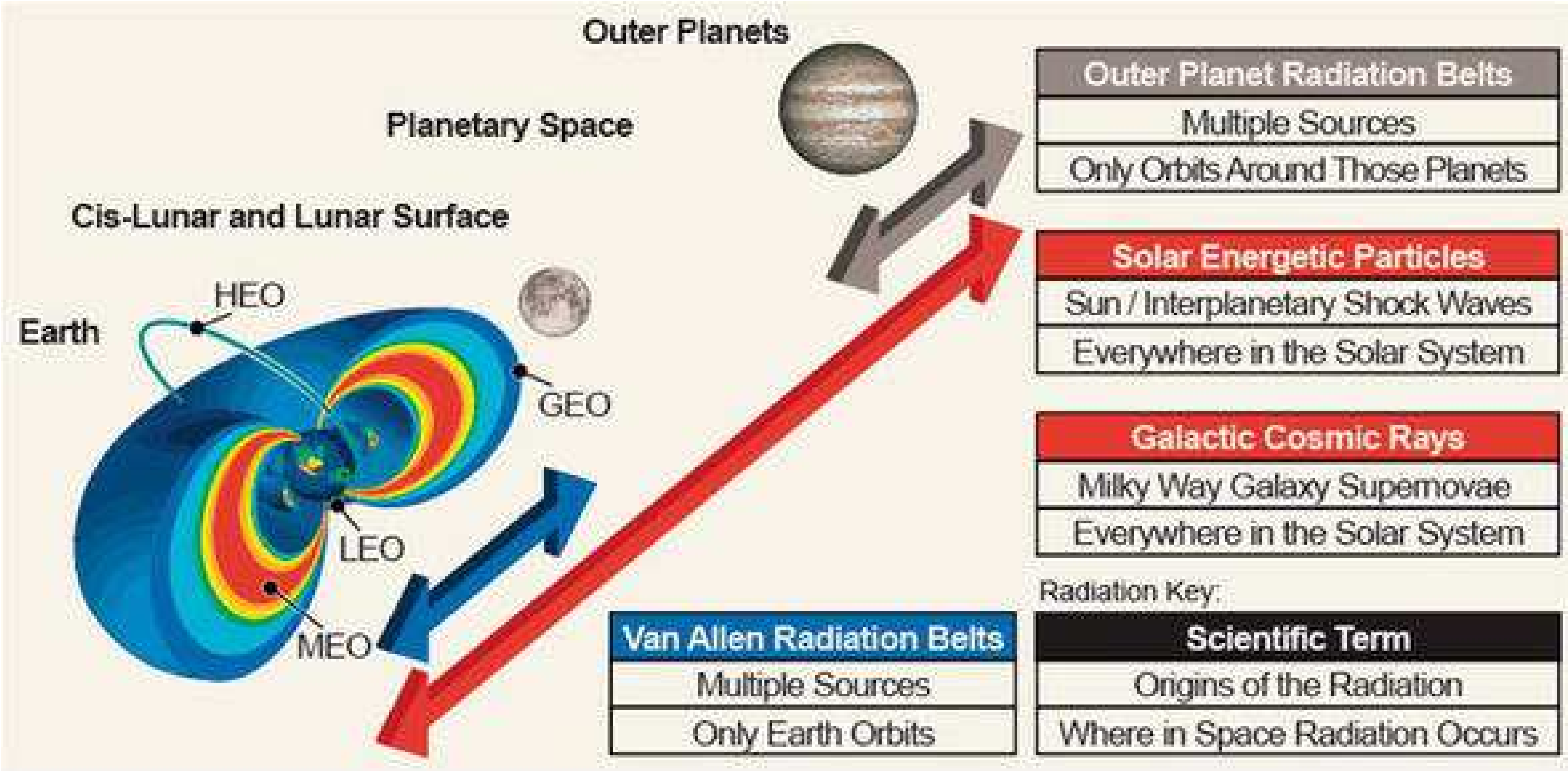
Credit: NOAA/SWPC



Credit: NOAA/NCEI/GOES



Credit: Chancellor et al. (2021)



Credit: Nwankwo et al. (2020)

NOAA Space Weather Scales

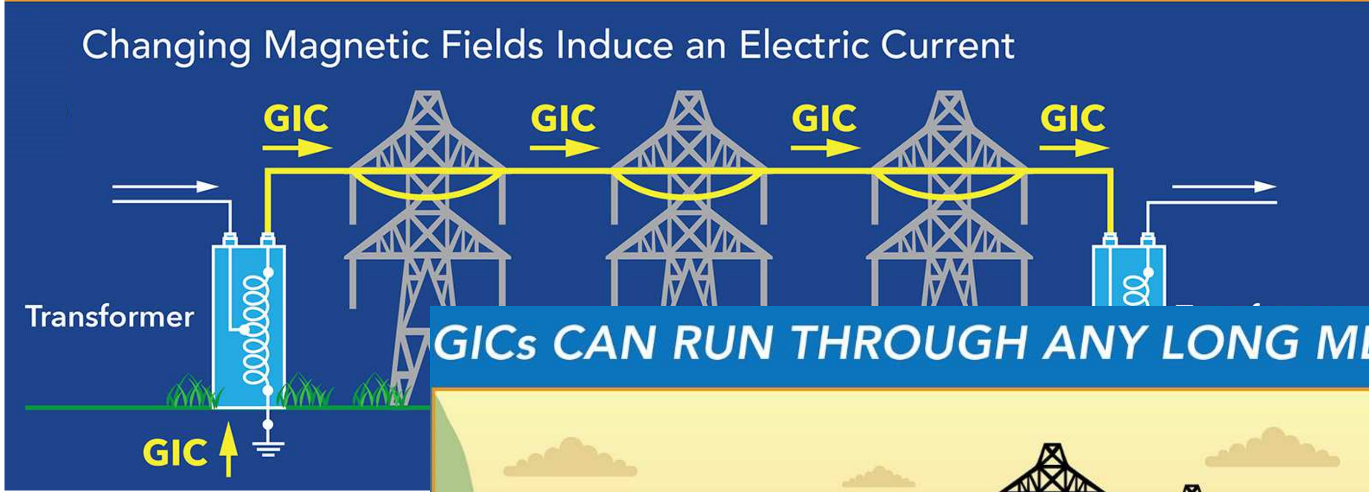
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).**	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).**	Kp=5	1700 per cycle (900 days per cycle)

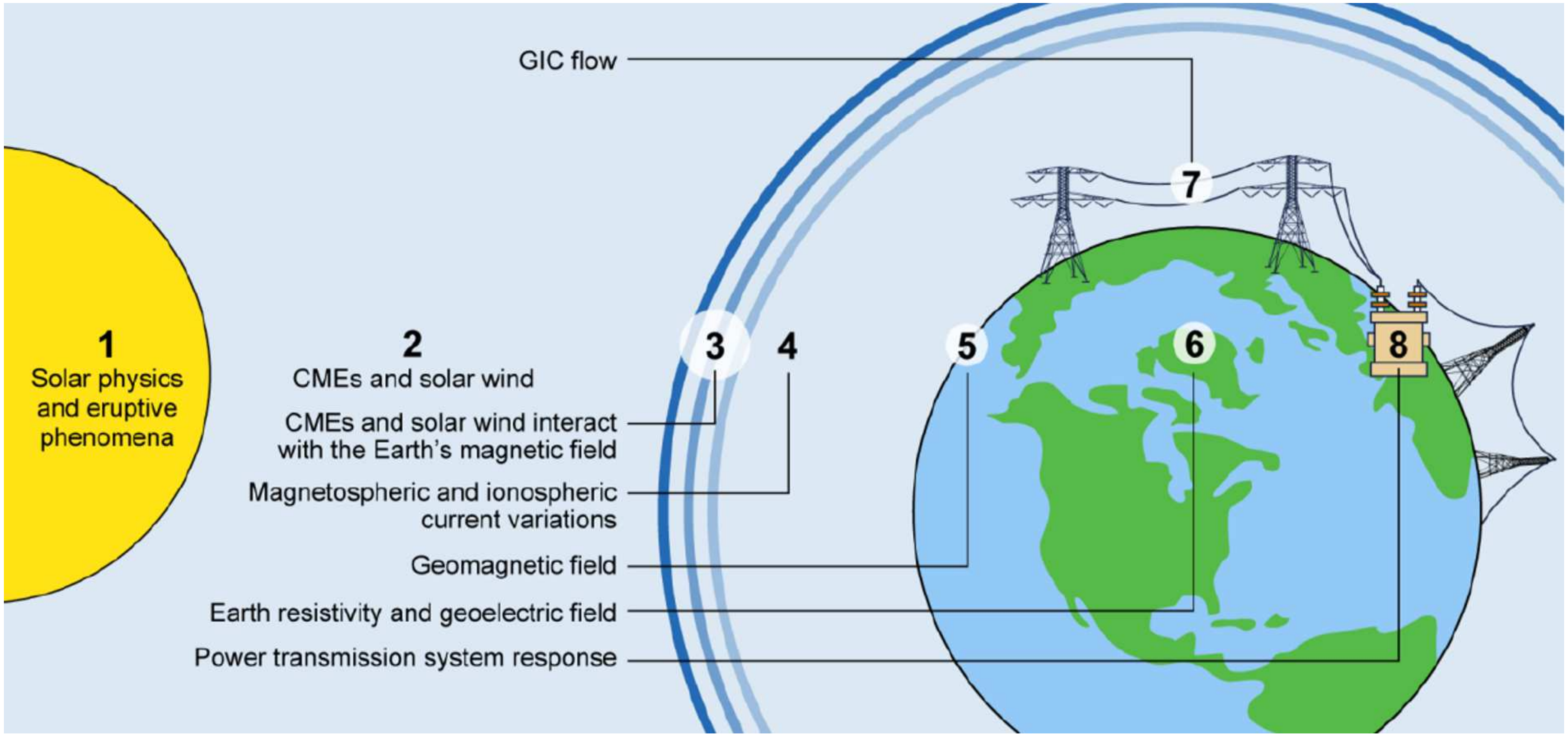
* Based on this measure, but other physical measures are also considered.

** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.swpc.noaa.gov/Aurora)

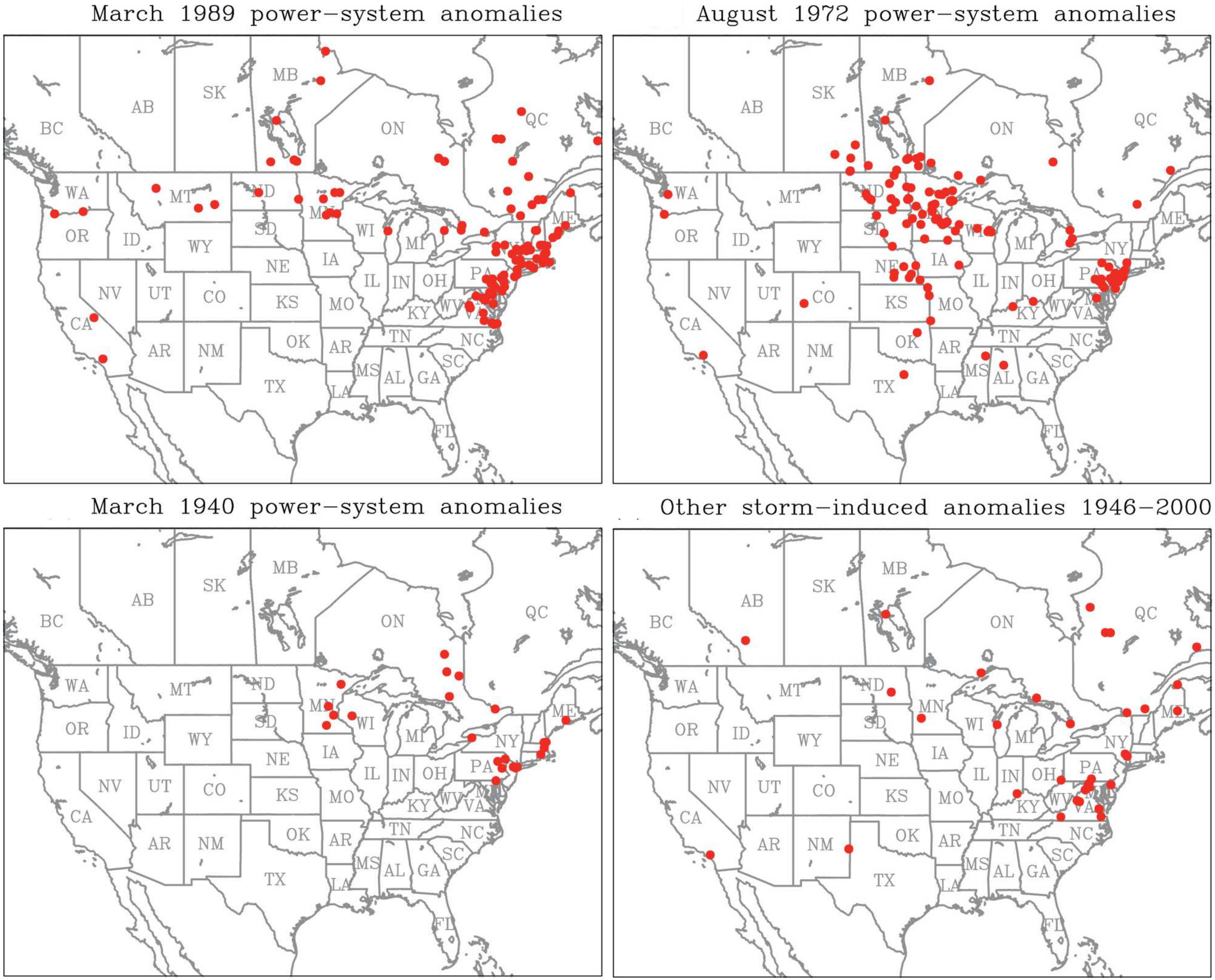
Credit: NOAA/SWPC

Geomagnetically induced current (GIC)





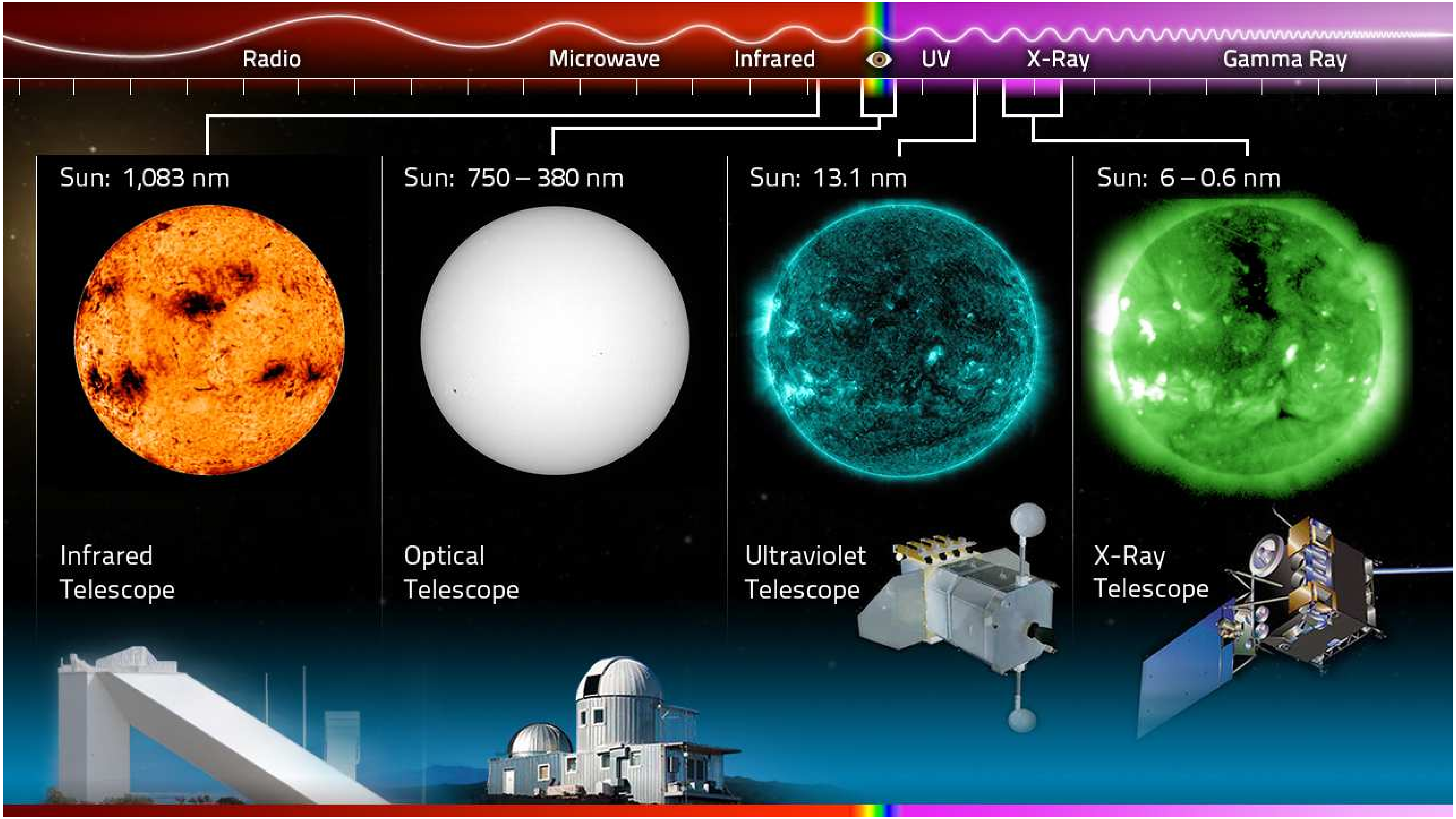
Credit: NASA, GAO



Credit: Love et al. (2022)

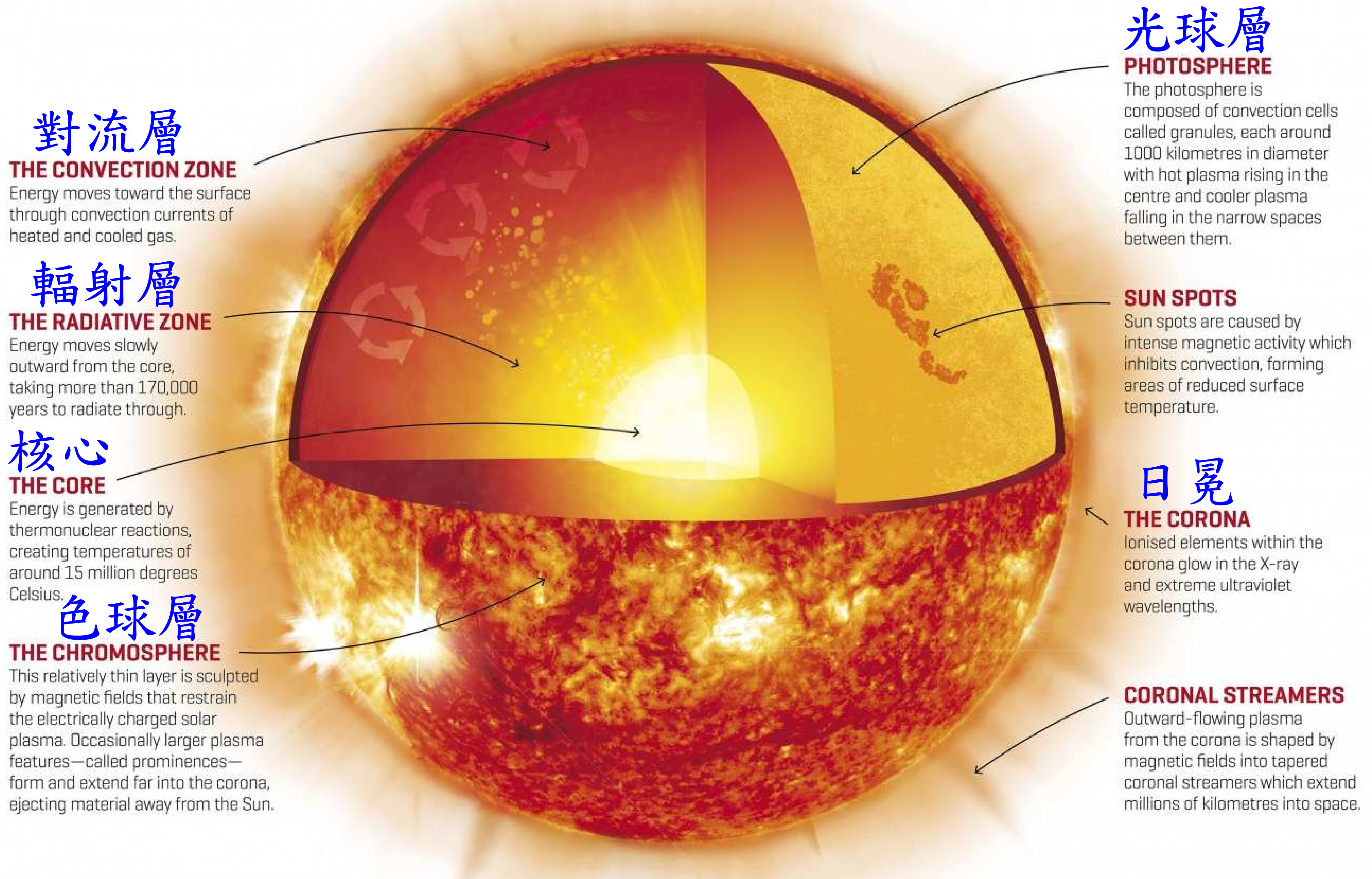
Credit: https://spaceweather.com/, NOAA/SWPC

多波段觀測



http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/images/astrophysics/Multiwavelength-Sun-and-Telescopes.jpg

太陽結構



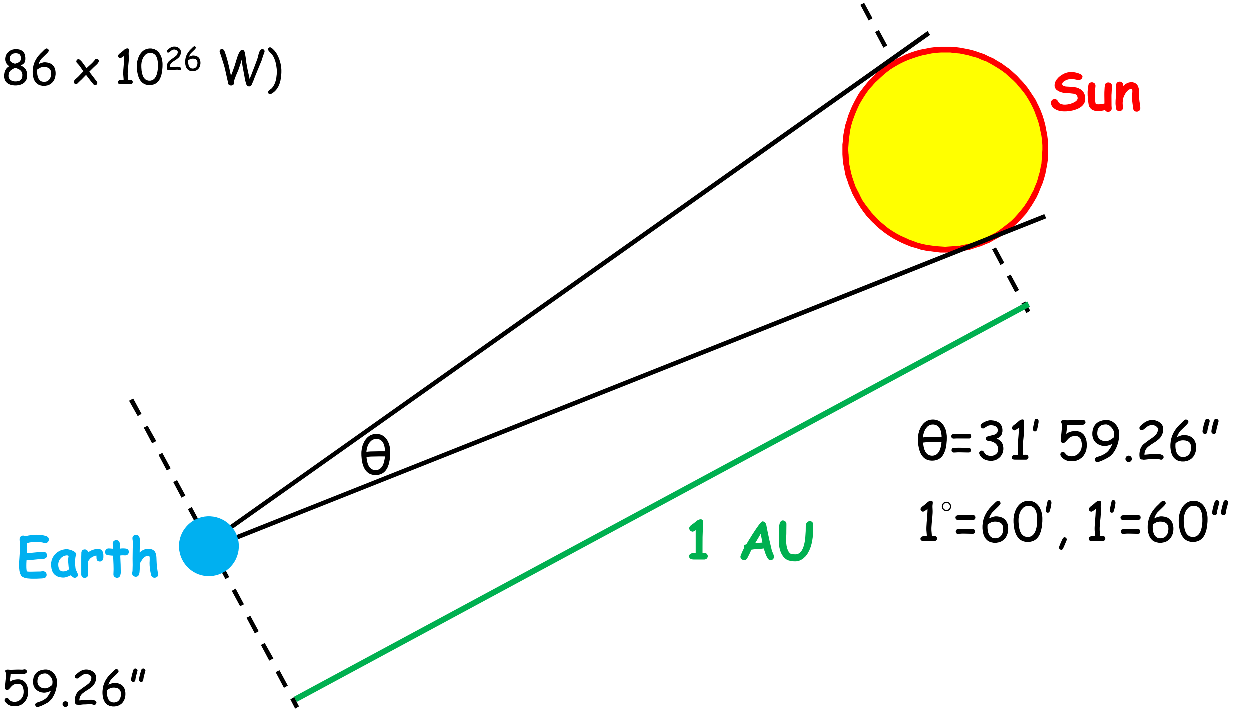
https://www.nzgeo.com/stories/the-end-of-days/

Basic Solar Parameters

Age: 4.5 x 10^9 years
Spectral type: G2V
Radius (R_S): 6.955 x 10^8 m ($1R_S$=0.004649 AU; ~109 radii of Earth)
Mass (M_S): 1.989 x 10^{30} kg (332 946 masses of Earth)
Volume: 1.41x10^{27} m^3 (1.3 million times the volume of Earth)
Mean density: 1.409 g/cm^3 (0.256 of mean density of Earth)
Effective temperature: 5770 K
Luminosity: 3.86 x 10^{33} erg/s (3.86 x 10^{26} W)

Sidereal rotation period:
At equator: 25.05 days
At poles: 34.4 days

Distance from the Earth:
Mean (1 AU): 1.496 x 10^8 km
In perihelium: 1.471 x 10^8 km
In aphelium: 1.521 x 10^8 km



Apparent diameter at 1 AU: 31′ 59.26″
1 arcmin (1′) at 1 AU: 43 520 km
1 arcsec (1″) at 1 AU: 725.3 km

Light travel time to the Earth: 8.32 min

http://en.wikipedia.org/wiki/Sun http://sob.nao-rozhen.org/content/basic-solar-parameters-and-information

Chemical composition of photosphere (by mass):

Hydrogen: 73.46%
Helium: 24.85%
Oxygen: 0.77%
Carbon: 0.29%
Iron: 0.16%

太陽質量約75%的成分是氫，25%是氦，及其他佔很小比例的重元素。

Density (water=1000):

Mean density of entire Sun: 1410 kg/m^3
Interior (center of Sun): 160000 kg/m^3
Surface (photosphere): 10^{-6} kg/m^3
Chromosphere: 10^{-9} kg/m^3
Low corona: 10^{-13} kg/m^3
Sea level atmosphere of Earth (for comparison): 1.2 kg/m^3

Temperature:

Interior (center): 15 000 000 K
Surface (photosphere): 6050 K
Sunspot umbra (typical): 4240 K
Penumbra (typical): 5680 K
Chromosphere: 4300 to 50 000 K
Corona: 800 000 to 3 000 000 K

Magnetic Field Strengths:

Sunspots: 3000 Gauss
Polar field: 1~2 Gauss
Prominences: 10~100 Gauss
Earth (for comparison): 0.3~0.6 Gauss

太陽常數(solar constant):

→每秒鐘太陽照射到地球每單位平方公尺面上的能量
→1%日照量的改變將使地球溫度有1~2℃的變化
→並非固定不變，一年當中的變化幅度約1%
→影響的是氣候的長期變化，而不是短期的天氣變化

Solar Radiation:

Entire Sun: 3.83×10^{23} kW
Unit area of surface of Sun: 6.29×10^{4} kW/m^2
Received at top of Earth's atmosphere: 1366 W/m^2

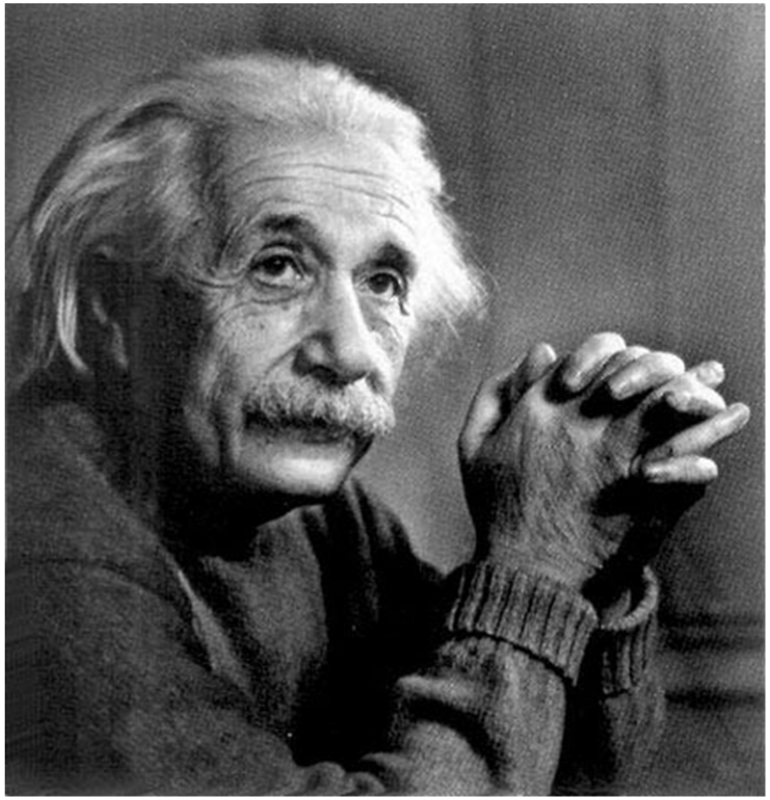
http://www.phys.ncku.edu.tw/~astrolab/e_book/sun/sun.html#solar_model
http://sob.nao-rozhen.org/content/basic-solar-parameters-and-information

太陽內部結構

→核心(0-0.25 R_s) ---太陽的能量來源

太陽核心溫度達$1.5*10^7$ K，壓力為地球大氣壓力的$2.5*10^{11}$倍，所以核心處的氫會發生核融合反應。

太陽的能量如何產生? ---質能轉換



$$\Delta E =(\Delta m)\ c^2$$

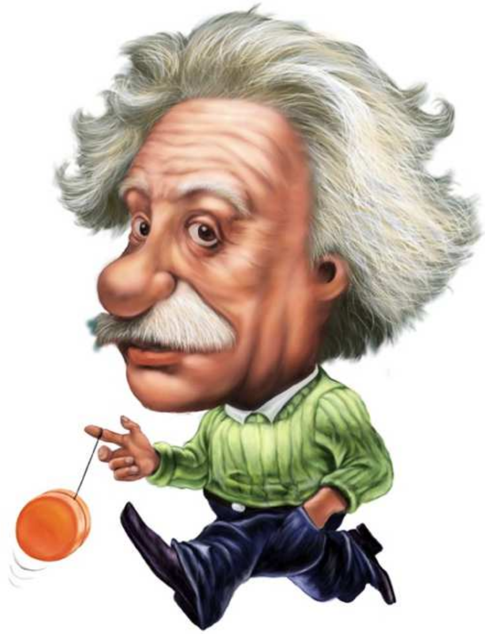
氫核融合反應可簡單總結為:

4個氫→1個氦+能量+2個微中子

一次氫核融合所釋出的能量有多大?

http://www.phys.ncku.edu.tw/~astrolab/e_book/sun/sun.html#solar_model http://web.fg.tp.edu.tw/~earth/learn/tasastro/ch081.htm

4個氫核的質量: m_{4H} = 6.693*10^{-27} kg
1個氦核的質量: m_{He} = 6.645*10^{-27} kg
在氫融合過程的質量損失:Δm = 0.048*10^{-27} kg



而一次氫核融合所釋出的能量為

$$\Delta E = (\Delta m)\, c^2$$
$$= (0.048 \times 10^{-27}\ \text{kg}) \times (3 \times 10^{8}\ \text{m/sec})^2$$
$$= 4.3 \times 10^{-12}\ \text{J}$$

即一次氫核融合反應用掉4個氫核產生4.3*10^{-12}J的能量

---------------------- 我是分隔線 ----------------------

這樣的能量其實非常小，所以必須有很多次反應才能獲得足夠維持一顆恆星的能量。例如對太陽而言，需要每秒約10^{38}次的這種反應(即約每秒五百萬噸的質量轉換成能量)，才能夠抵消太陽自身的重力收縮以維持穩定狀態。

http://www.phys.ncku.edu.tw/~astrolab/e_book/sun/captions/pp_chain.html

而兩個原子核必須要靠得夠近才可能融合，但因兩個原子核本身都帶正電會互相排斥。要克服此力，需要兩個原子核以高速互相碰撞。因為在高溫下粒子的運動速度才高，所以發生原子核融合反應的環境溫度要高達10^7 K。

融合反應除高溫外，氣體的密度也要很高。我們知道太陽需要每秒10^{38}次反應才能提供足夠的能量，但是在所有碰撞中只有少數百分之幾的碰撞能產生核融合，所以只有當氣體的密度夠高，碰撞的次數才能高到符合維持太陽能量所需。

氫核融合的主要過程有:質子-質子(proton-proton chain)與碳氮氧循環(CNO cycle)兩種。

http://www.phys.ncku.edu.tw/~astrolab/e_book/sun/sun.html#solar_model http://web.fg.tp.edu.tw/~earth/learn/tasastro/ch081.htm

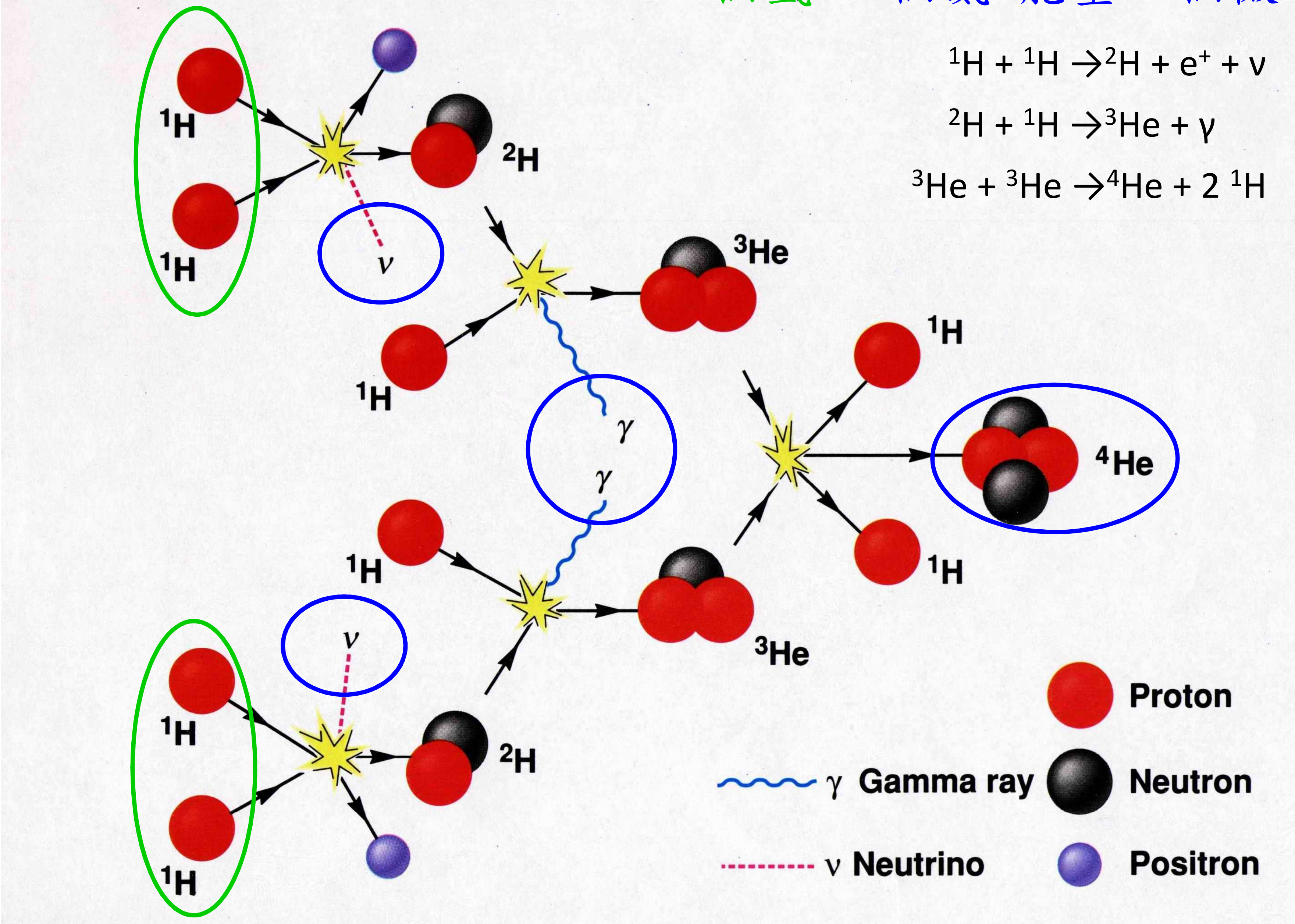
Proton-Proton Chain (PP Chain)---90%太陽能源的產生方式

4個氫→1個氦+能量+2個微中子

$^1H + ^1H \rightarrow ^2H + e^+ + \nu$

$^2H + ^1H \rightarrow ^3He + \gamma$

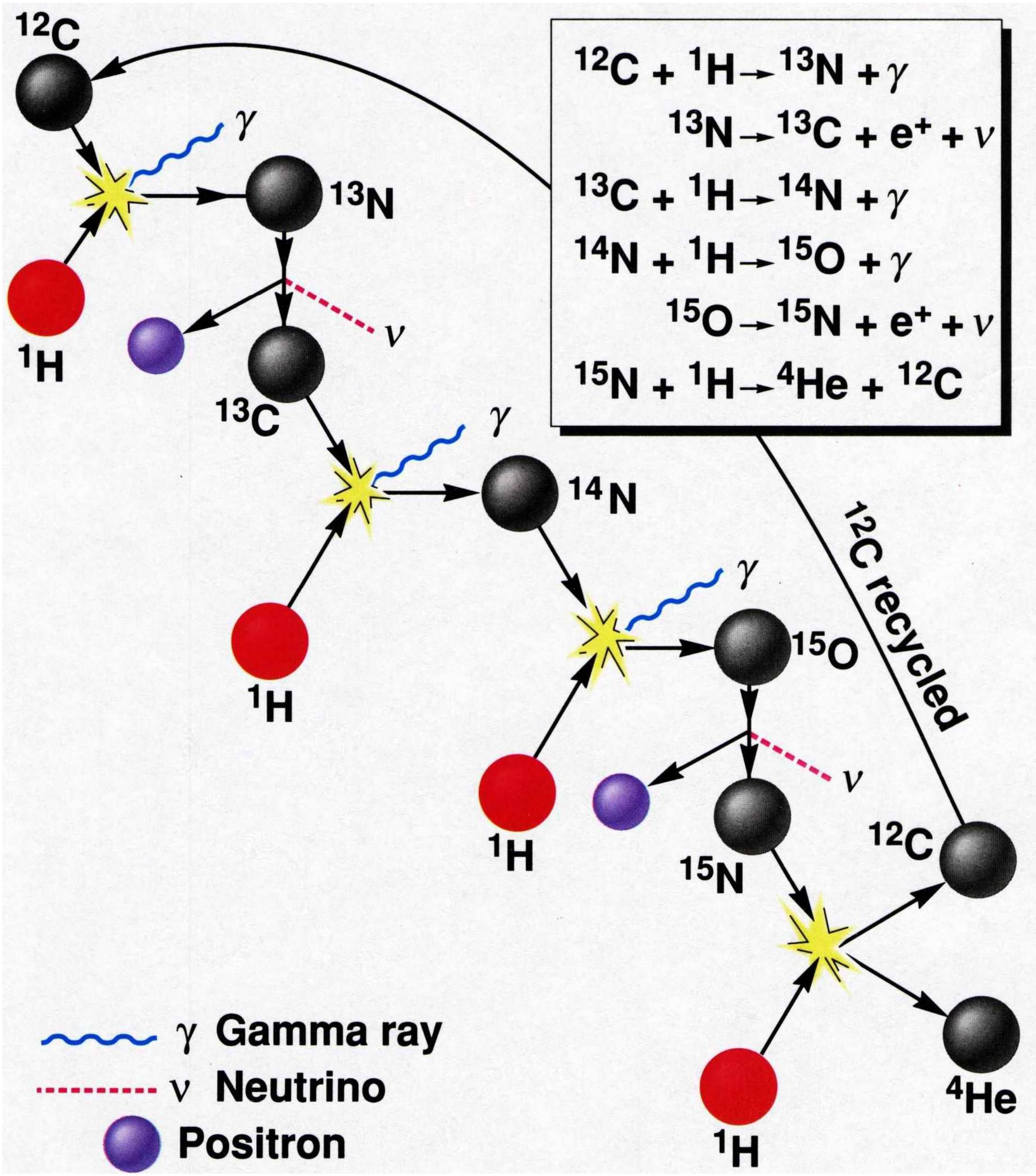
$^3He + ^3He \rightarrow ^4He + 2\ ^1H$



Proton-proton chain.

http://crab0.astr.nthu.edu.tw/~hchang/ga1/f1803-PP_1.JPG

CNO Cycle (Carbon-Nitrogen-Oxygen)



http://crab0.astr.nthu.edu.tw/~hchang/ga1/f1803-CNO_1.JPG

→輻射層(0.25-0.7 R_s) ---能量以輻射形式傳出

能量以輻射形式傳出，也就是以電磁波的形式傳遞，因為此層的溫度和壓力不如核心，所以無法產生氫核融合反應

溫度從7百萬K降至2百萬K，密度從20 g/cm^{3}降至只有0.2 g/cm^3

γ射線(高能光子):不斷與輻射層內的物質粒子碰撞，被物質粒子吸收再以較低能量輻射出來，約花百萬年的時間才能穿過輻射層，光子的能量由γ射線減低到可見光與紫外光的能量

微中子:幾乎不與太陽內部任何物質起反應，以光速或近光速的速度，離開核心向外傳播。

http://en.wikipedia.org/wiki/Sun http://content.edu.tw/senior/earth/tp_ml/sun/index.htm

→ Tachocline(差旋層: 0.7 +0.04 R_s)

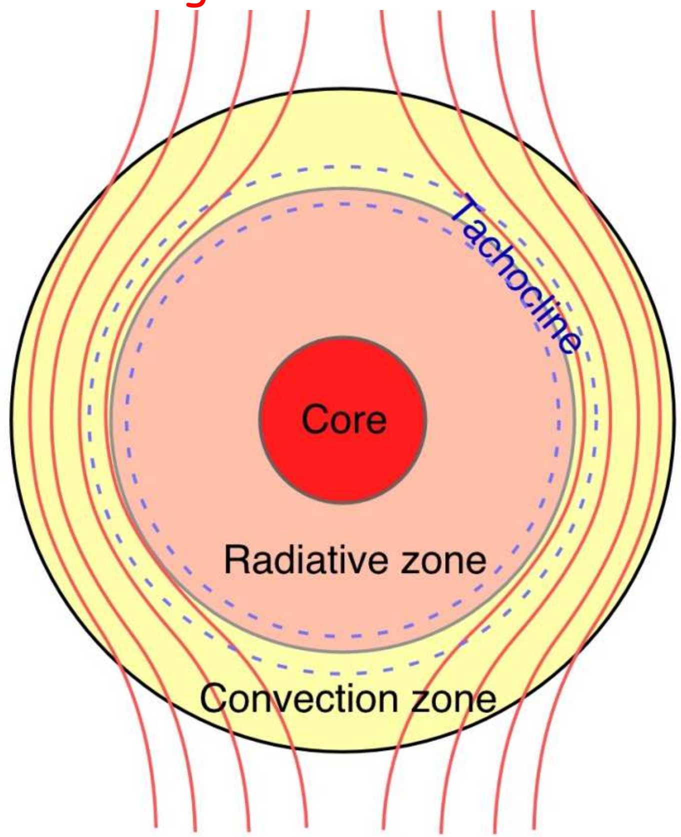
均勻旋轉的輻射層與差動自轉的對流層之間的過渡區域，即意味著此過渡區有很大的剪切剖面，這是一種可以形成大規模磁場的方法

→ 對流層(0.7-1 R_s) ---能量以對流形式傳出

此層電漿已經不夠稠密或不夠熱，由輻射層傳來的能量，不再能經由傳導作用有效的將內部的熱向外傳送

溫度向外遞減率非常大，在可見的太陽表面溫度已經降至5800 K，造成對流不穩定而發生對流

此層電漿呈現差動自轉(Differential Rotation)現象

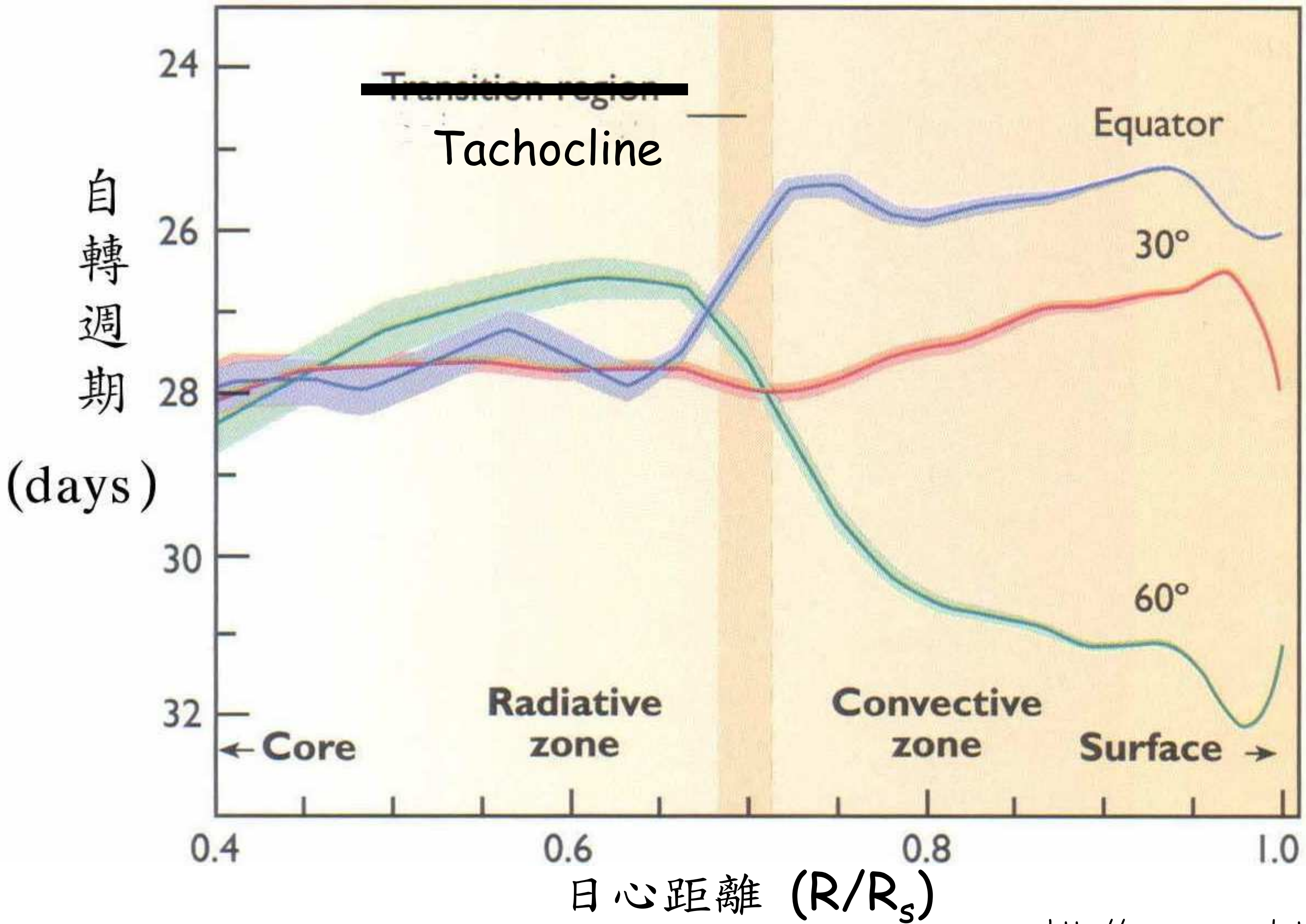


http://en.wikipedia.org/wiki/Sun

http://www.ss.ncu.edu.tw/~lyu/lecture_files

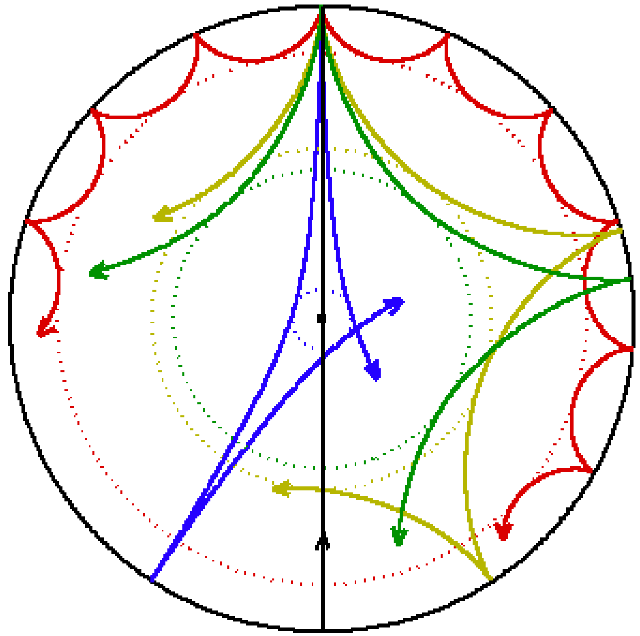
差動自轉

太陽平均約27天自轉一周，赤道區自轉速率較快約需25天，高緯區自轉速率較慢約需30天。太陽的核心和輻射層並無差動自轉。



http://www.ss.ncu.edu.tw/~lyu/lecture_files

日震學(Helioseismology)



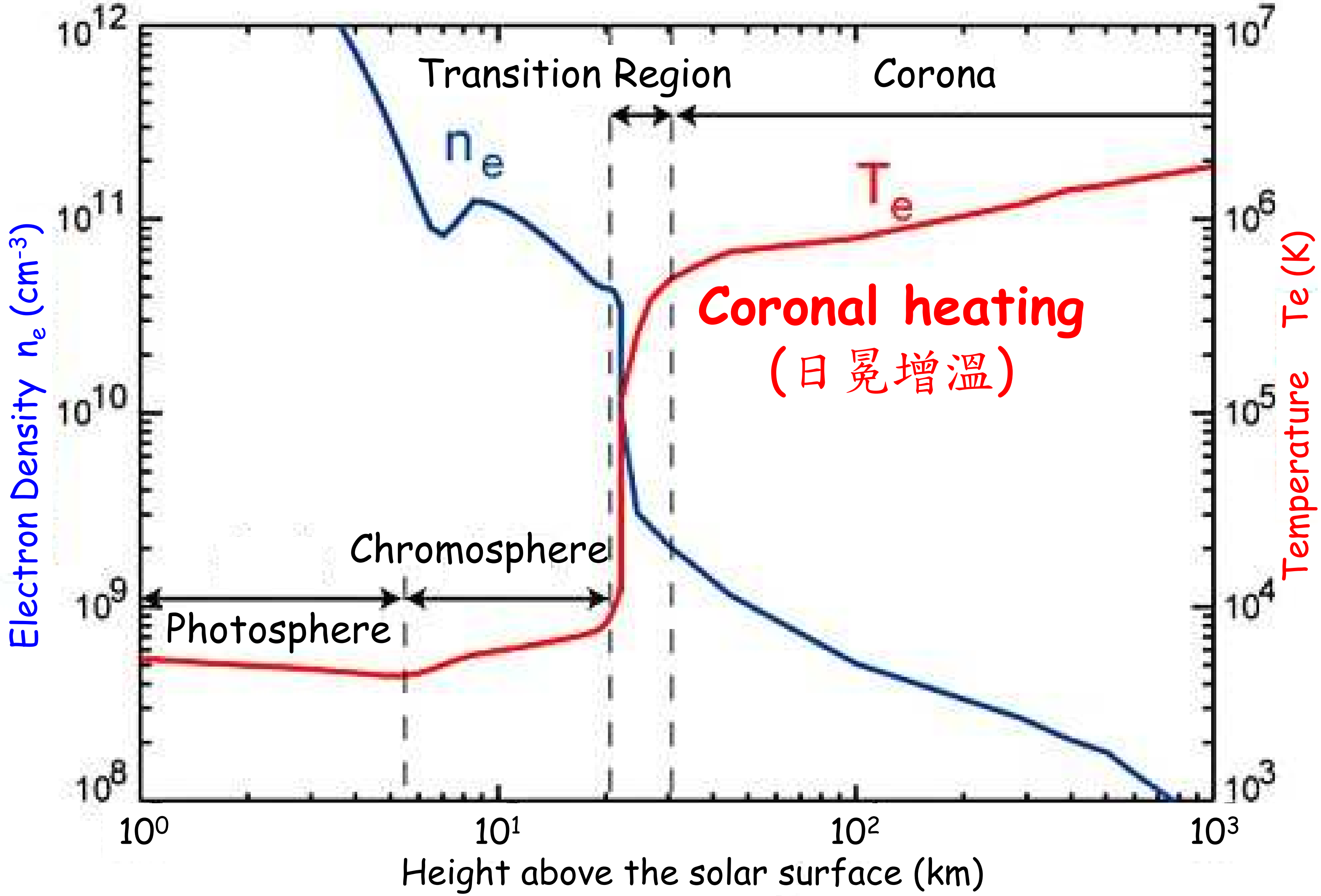
太陽內部的結構原本是以恆星理論預測的，並無法觀察到。類似地震波在地球內部反射與傳遞來推測地球的內部結構，科學家利用日震現象來推演太陽的內部結構，雖無法在太陽放置探測器，但是當太陽內部震動時，震波會傳到表面的光球層，造成複雜的上下運動。雖然表面震動很小，但可從都卜勒位移得到震動的頻率。將這些觀測結果與模擬太陽內部的模型比較，便可推斷出太陽內部的結構與運動。

日震學的結果發現太陽內部的溫度比以往想像的要高，排除了太陽微中子問題是由於太陽內部模型不正確的可能性，氦的成分也比原本認為的多，並瞭解對流層和輻射層以不同的速度旋轉，兩者的交界面處是太陽產生磁場及與太陽活動週期相關的地方。

http://web.fg.tp.edu.tw/~earth/learn/tasastro/ch081.htm

https://www-n.oca.eu/grec/rays2.gif

太陽大氣層

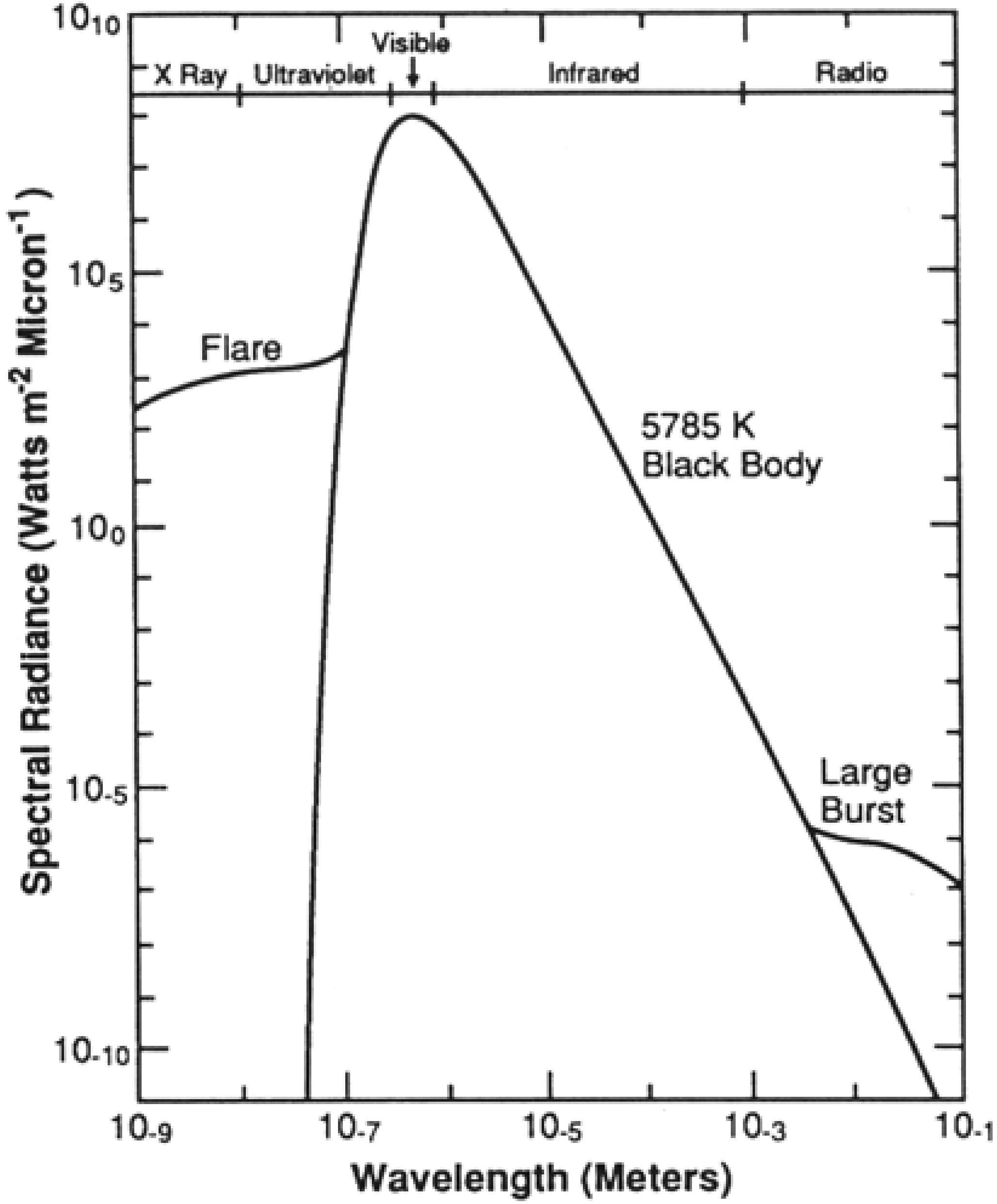


http://ase.tufts.edu/cosmos/print_images.asp?id=28

→光球層(Photosphere)

厚度約500 km，溫度約5800 K，為我們所能看到的太陽表面。地球所見太陽光譜主要來自光球層，譜型與5800 K 的黑體輻射相近。光球層以下的太陽對可見光是不透明的，而在光球層上方的氣體密度又太低，無法放出足夠的光。只有光球層它的溫度密度恰當，既能輻射出較多的光，又能讓光子逃離太陽表面。

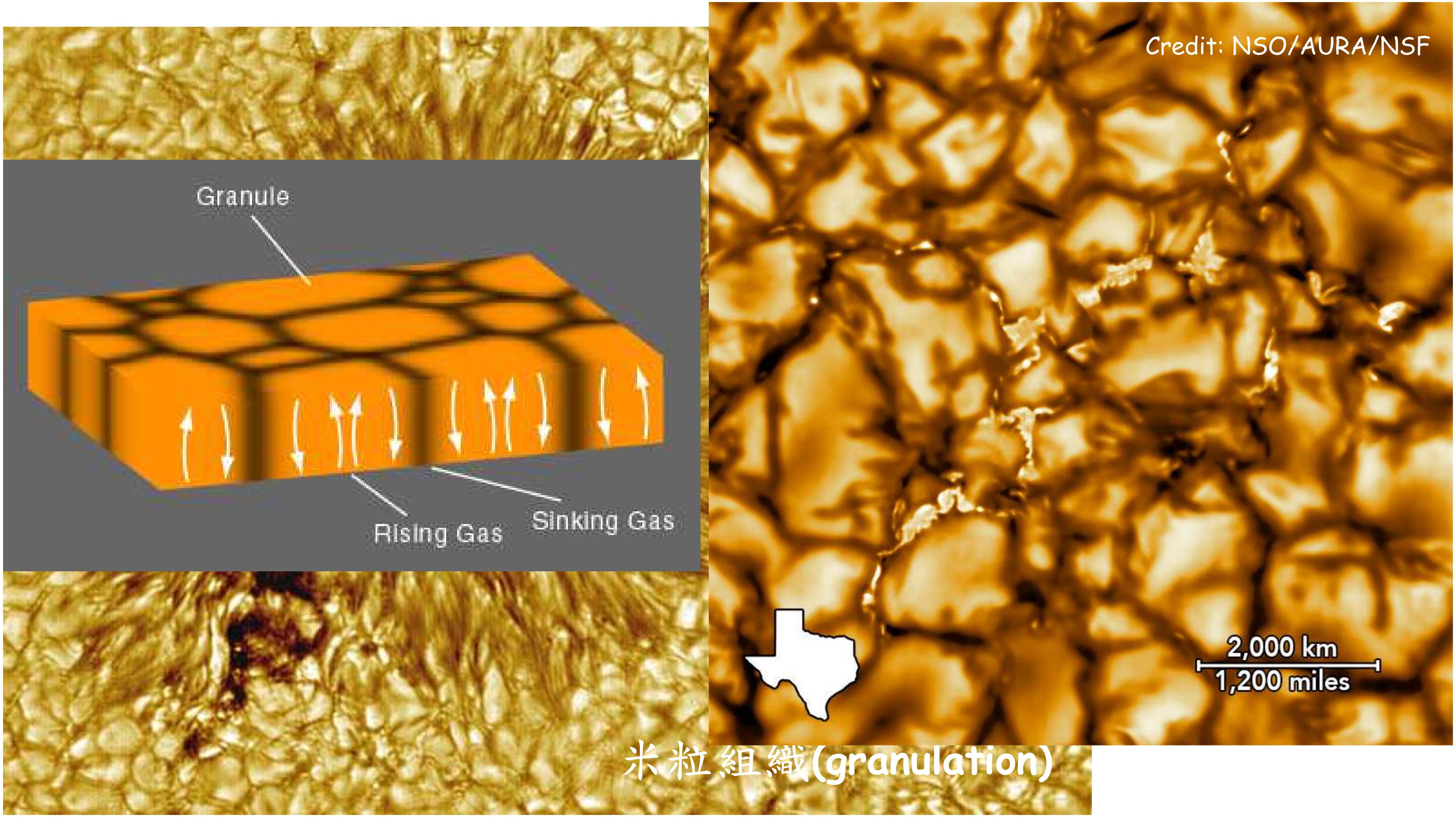
主要現象為:黑子(sunspots)，米粒組織(granulation)。



http://web.fg.tp.edu.tw/~earth/learn/tasastro/ch082.htm

http://www.ss.ncu.edu.tw/~lyu/lecture_files/

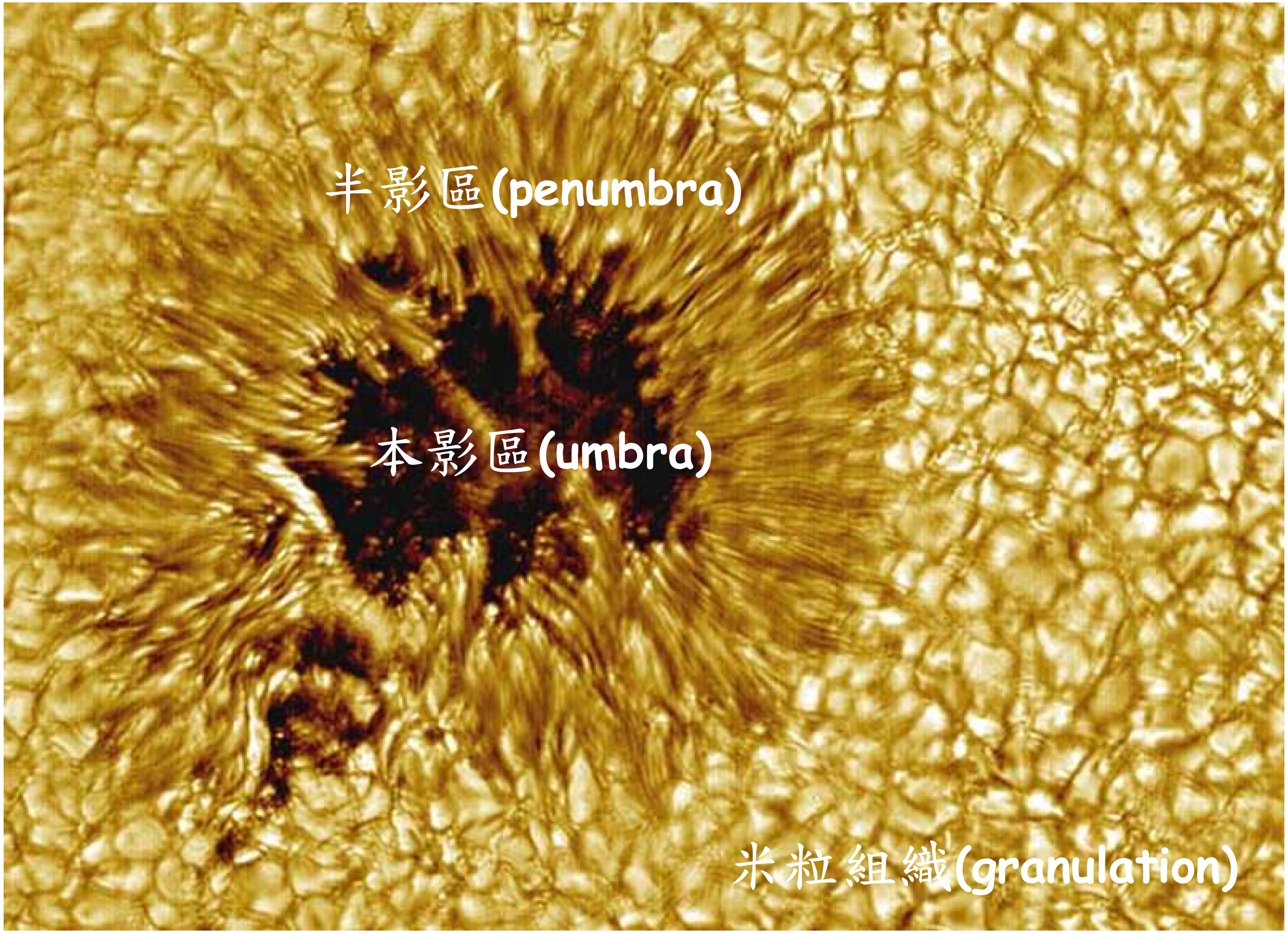
每個米粒組織的大小約1500公里，生命週期約10分鐘，中央部份比四周溫度約高300 K，故較為明亮。由都卜勒位移發現，米粒組織的中心是向上湧升而周圍是下沉，是由對流所造成的結構。



米粒組織(granulation)

https://www.noao.edu/outreach/press/9808image.html
https://www.nso.edu/telescopes/dkist/first-light-cropped-image/
https://www.lcsd.gov.hk/CE/Museum/Space/archive/EducationResource/Universe/framed_e/lecture/ch11/ch11.html

黑子經常成群成對出現。黑子處的溫度約比光球層其他區域低1000-1500 K，中心溫度約4000 K，故對比之下呈黑色，但實際上單一黑子的照度與滿月相去不遠。

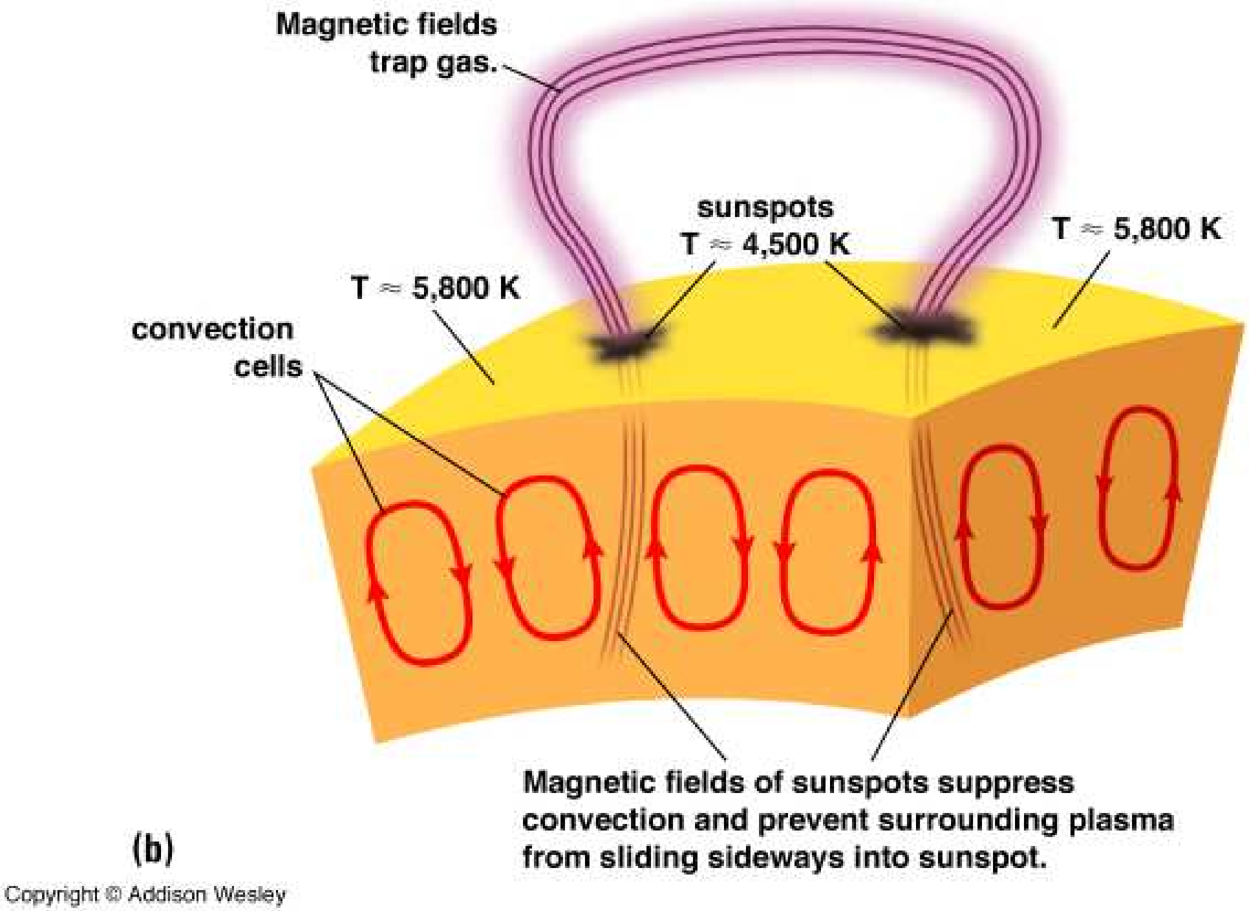


https://www.noao.edu/outreach/press/9808image.html

http://www.ss.ncu.edu.tw/~lyu/lecture_files/IntroSpace.html

黑子處的磁場約為太陽表面平均磁場的數百倍，本影區的磁場強度可能介於1000至4000高斯之間。

黑子為強磁低溫區域。

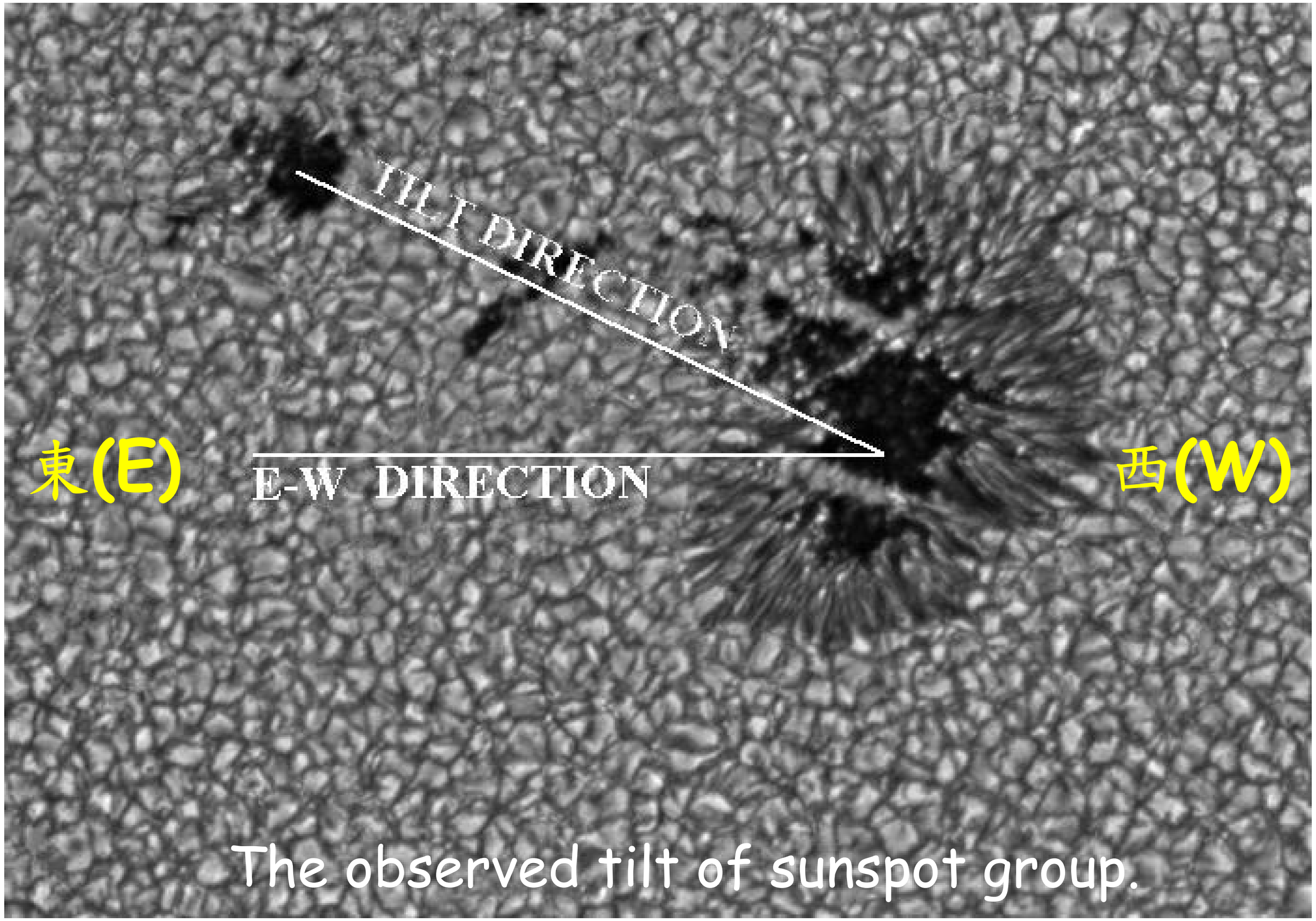


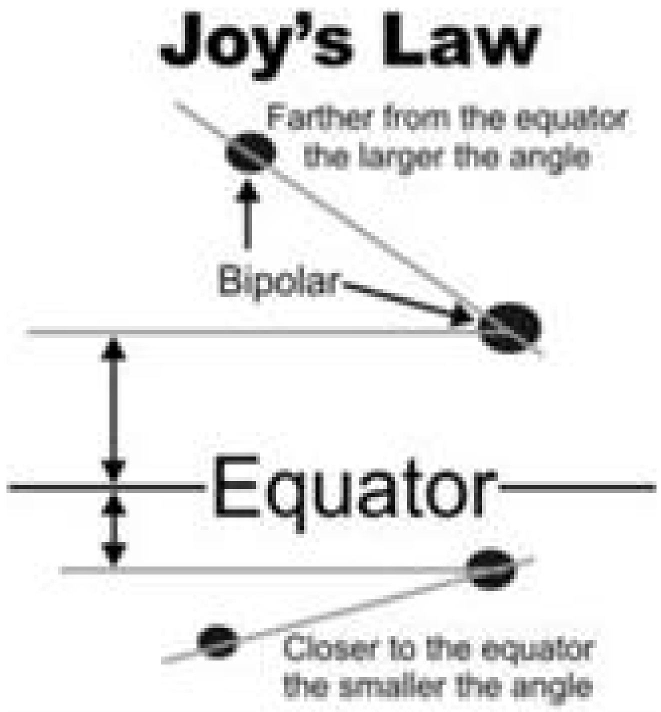
1908年美國天文學家George Ellery Hale發現黑子附近的磁場比太陽平均磁場高出約1000倍(地球平均磁場約0.5 Gauss，太陽平均磁場約1.0 Gauss，黑子則高達約1000 Gauss)，解釋了太陽黑子是由強磁場抑制對流能量傳輸所造成。

由於黑子區內的磁場抑制了來自光球層下方對流能束的能量傳輸，因而較少能量能傳至光球層，造成黑子區內溫度較低，對比上也較光球層暗。

http://ircamera.as.arizona.edu/NatSci102/NatSci102/lectures/suninterior.htm
http://content.edu.tw/junior/earth/tn_gz/astro/sumsite/sun3a.htm#黑子的成因

Joy's Law



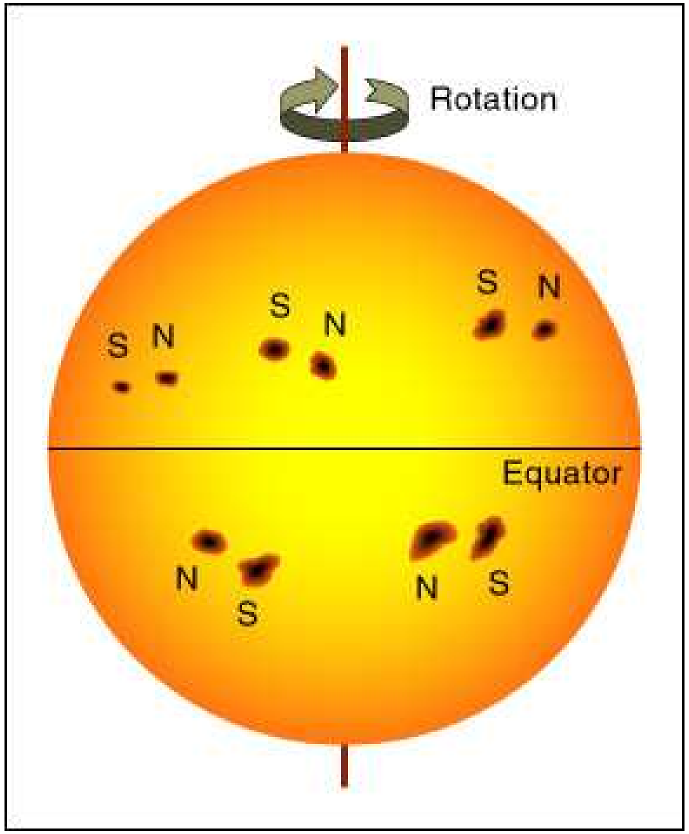


太陽黑子群因前導黑子較尾隨黑子靠近赤道而傾斜，傾斜角度隨緯度增加而增加，該傾斜現象稱之。

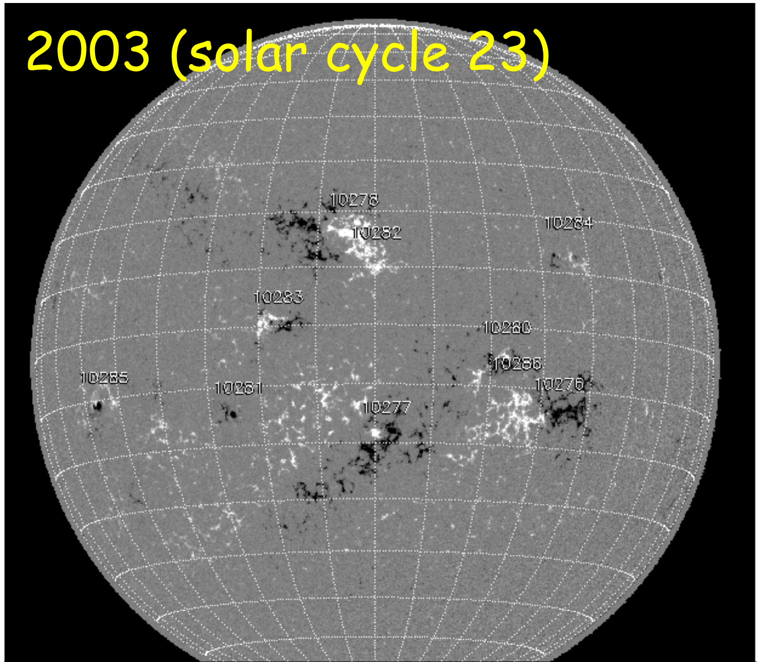
http://solarscience.msfc.nasa.gov/images/joys_law.jpg

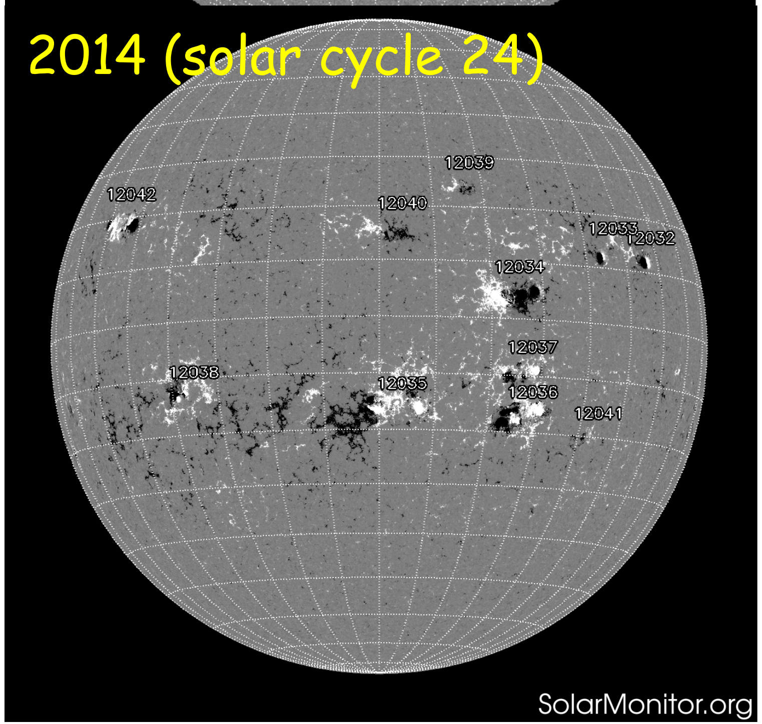
http://www.e-huh.com/chapter%207%20the%20sun/chapter%207%20a%20new%20model%20of%20the%20sun_files/image004.jpg

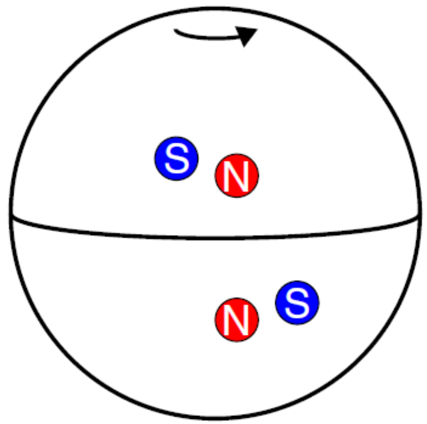
Hale's Polarity Law



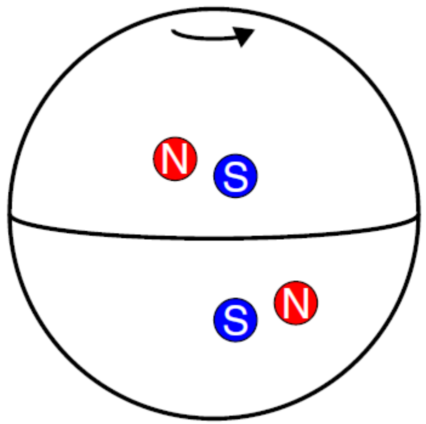
在同一週期中，北半球前導黑子的極性與南半球前導黑子的極性相反，下一週期南北半球黑子的極性會反轉。







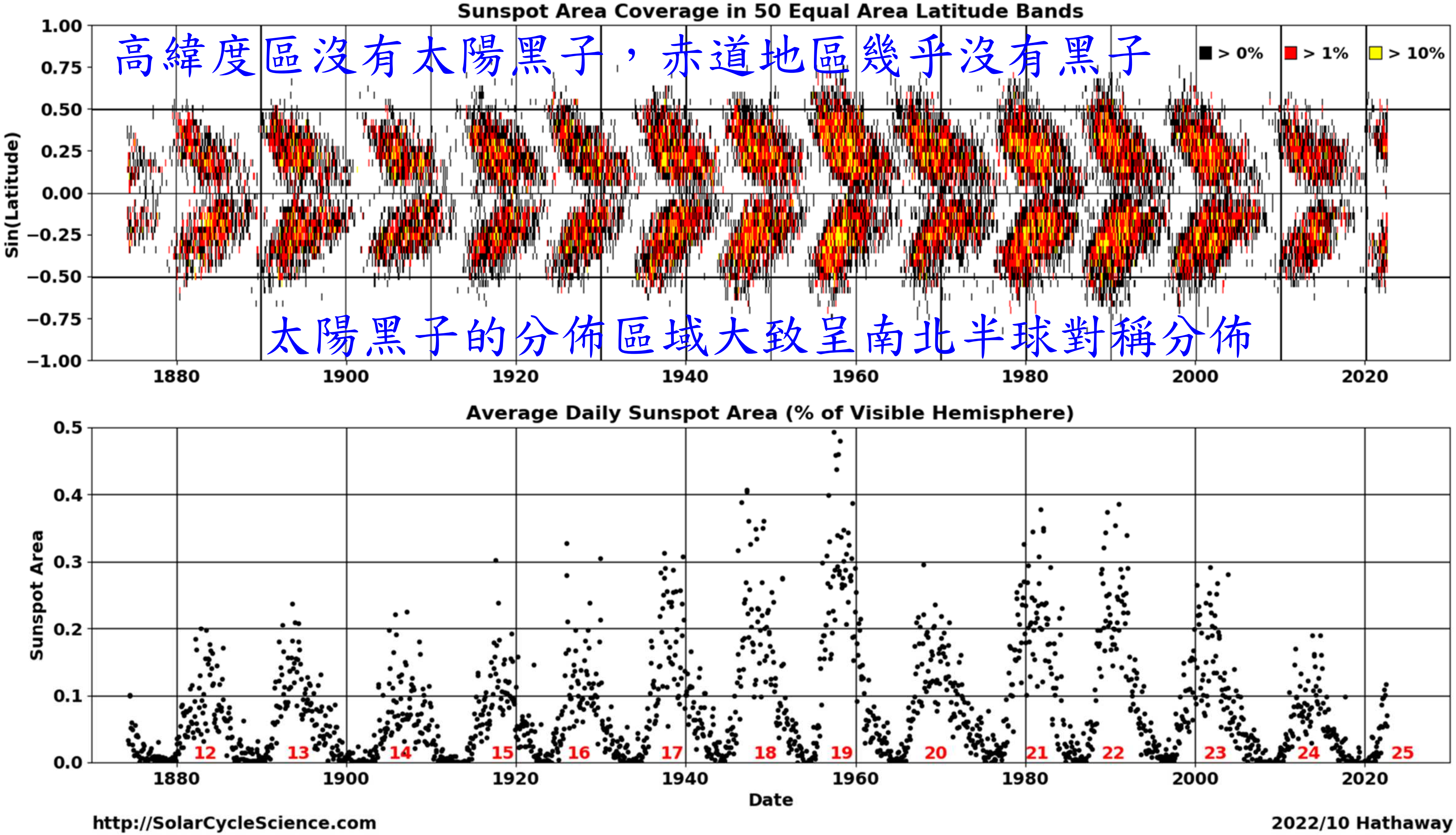
Odd cycles



Even cycles

https://doi.org/10.1007/s41116-019-0019-7

蝴蝶圖(butterfly diagram)

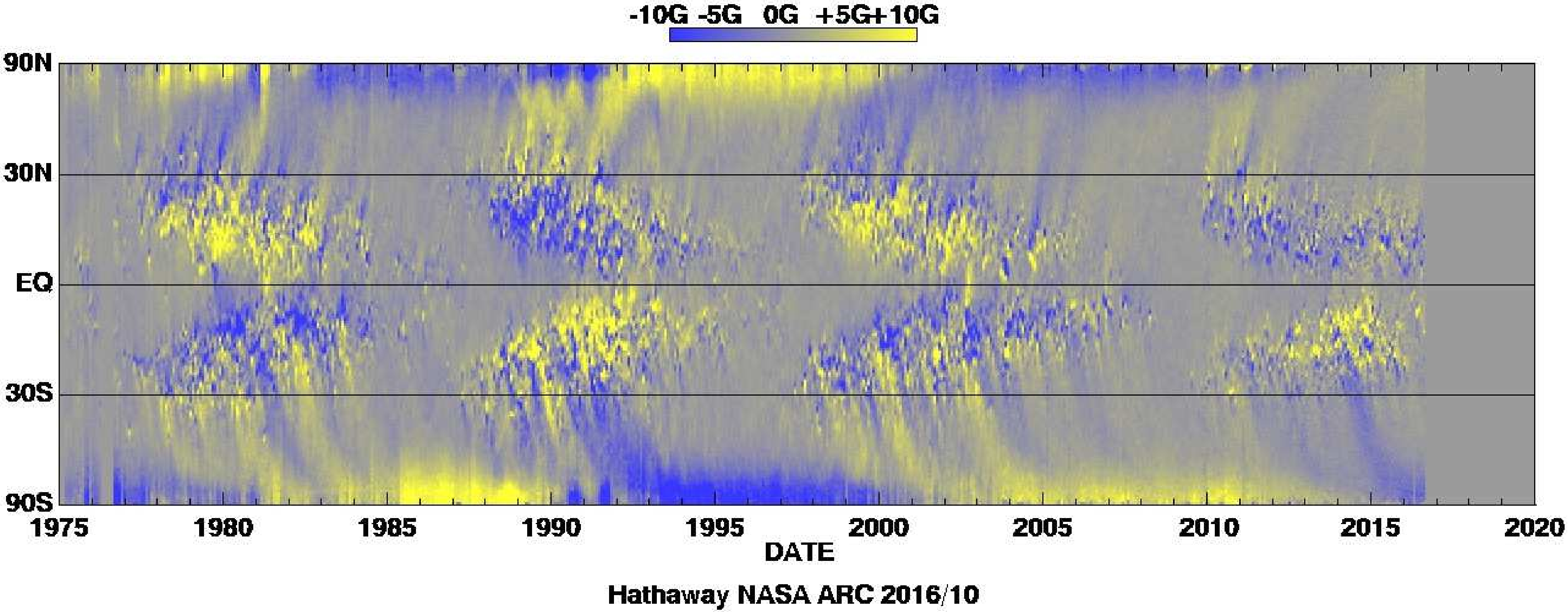


高緯度區沒有太陽黑子，赤道地區幾乎沒有黑子

太陽黑子的分佈區域大致呈南北半球對稱分佈

太陽黑子週期開始時，黑子主要出現在南北緯約35°處，而在週期結束時，黑子通常出現在南北緯約5°處

Magnetic Butterfly Diagram



https://solarscience.msfc.nasa.gov/images/magbfly.jpg