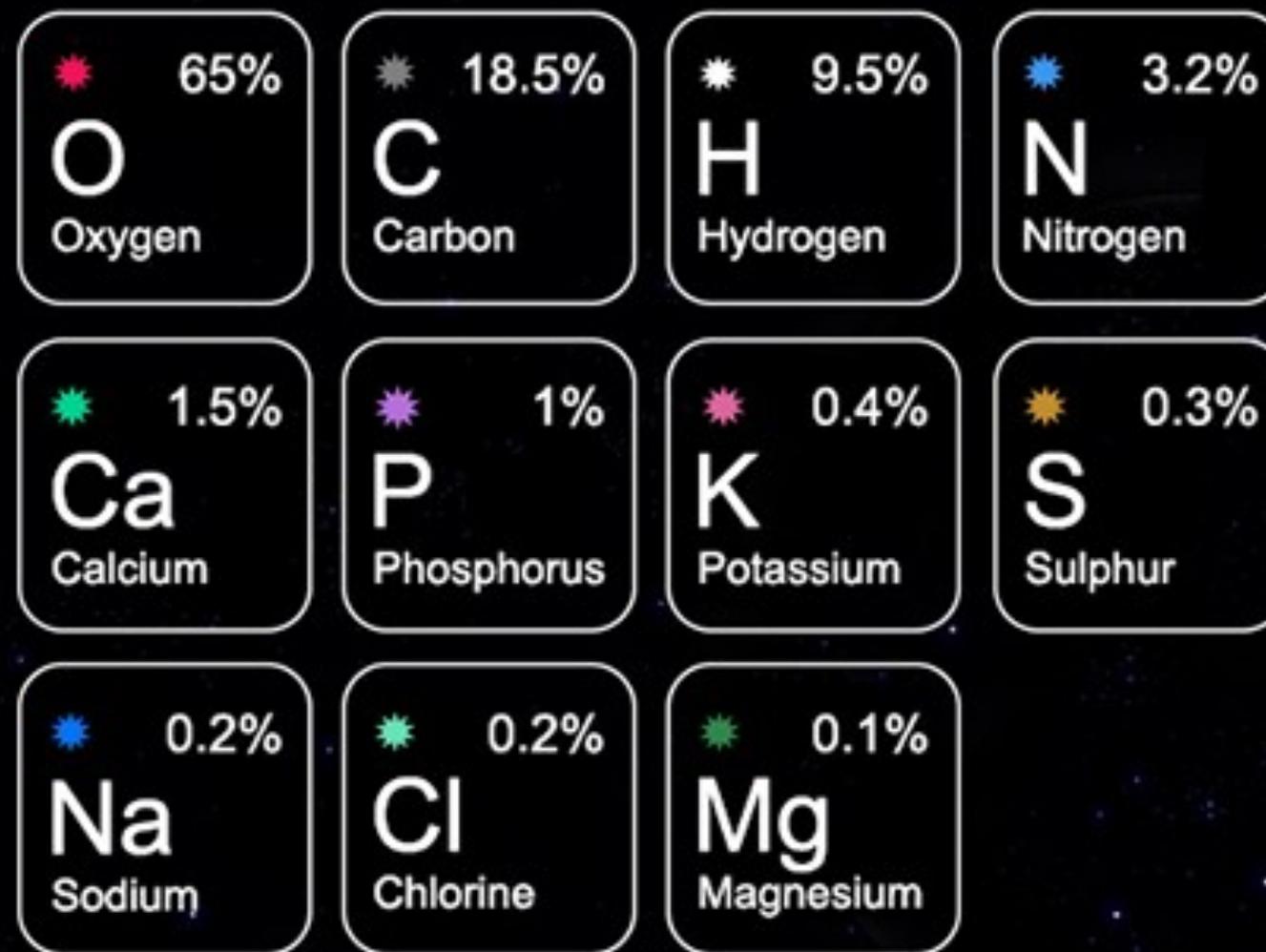




"WE ARE STARDUST"

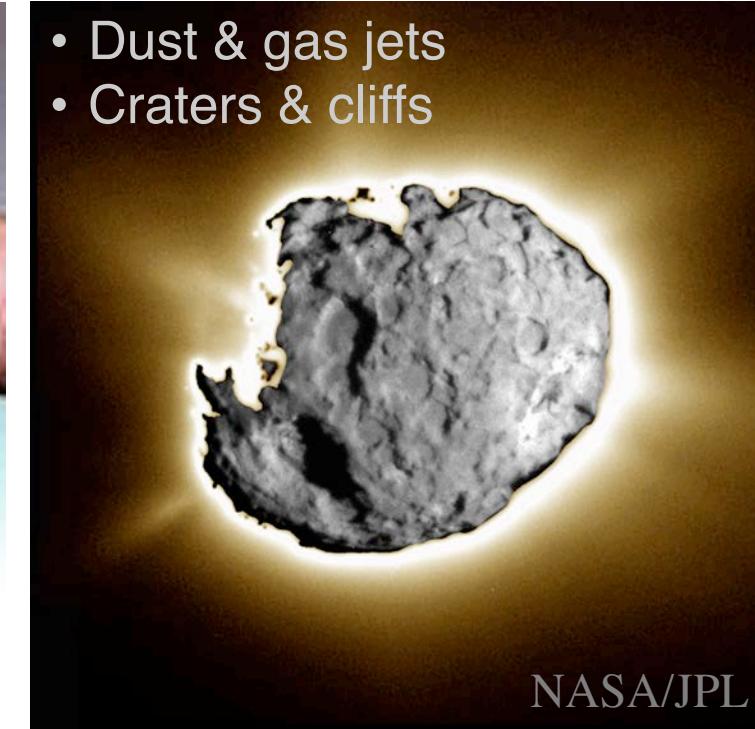
We are star dust, reaching out to the universe. The 15th Symphony of Science video featuring Neil DeGrasse Tyson, Richard Feynman and Lawrence Krauss.
From <https://www.youtube.com/watch?v=8g4d-rnhuSg>



Trace elements less than 1%: **B** Boron, **Cr** Chromium, **Co** Cobalt, **Cu** Copper, **F** Fluorine, **I** Iodine, **Fe** Iron, **Mn** Manganese, **Mc** Molybdenum, **Se** Selenium, **Si** Silicon, **Tin**, **V** Vanadium, **Zn** Zinc

星尘号(1999–2006)

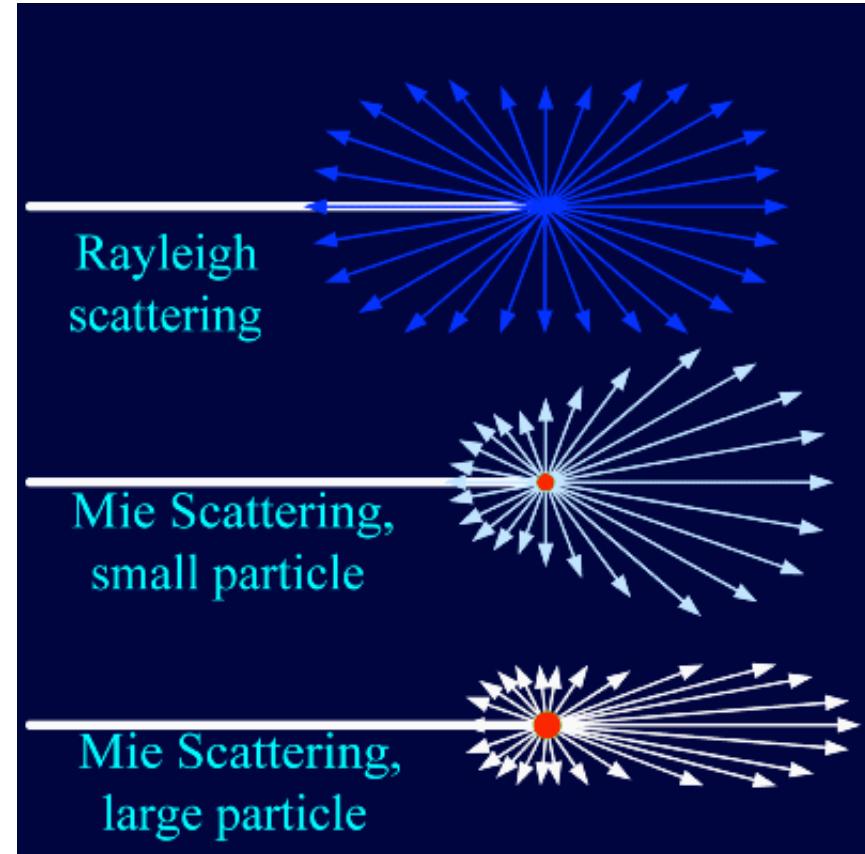
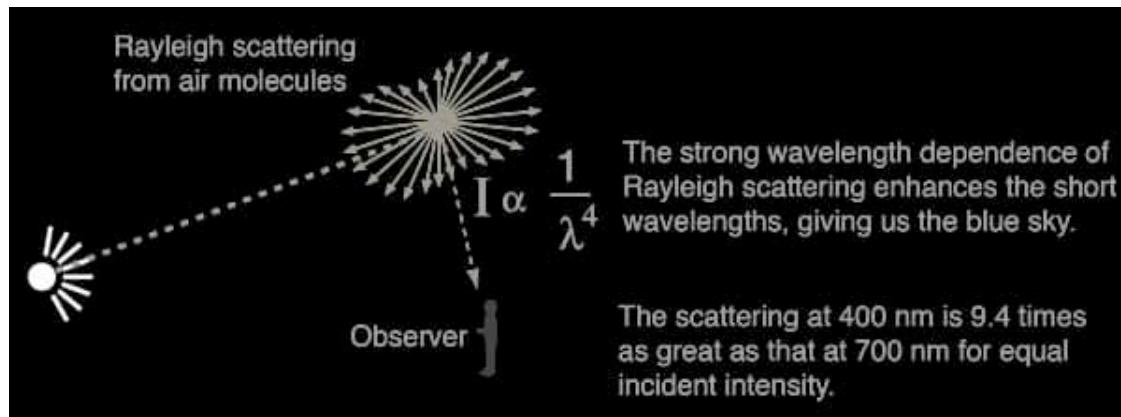
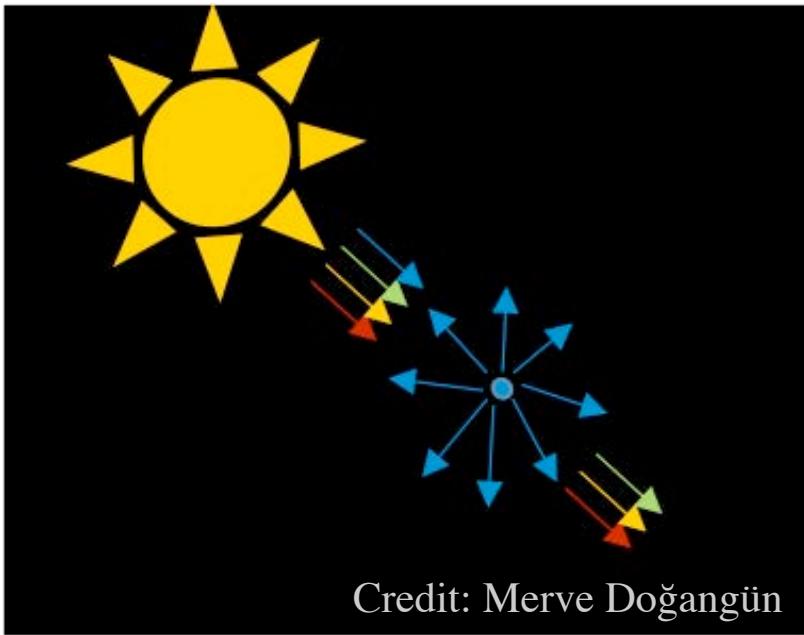
- 探测维尔特二号彗星 (comet Wild 2)。首次完成从彗星采样返回任务。



最轻的固体气凝胶“蓝烟”：當彗星微粒撞擊到氣凝膠時，會直接埋入其中，氣凝膠則會因為撞擊形成三角錐狀的長形洞穴，減緩微粒飛行的速度，使微粒停止運行，不會因為撞擊而遭破壞。並且在透明的氣凝膠中可直接進行觀測，以確定其飛行的方向。最後，再把微粒帶回地球做進一步的分析。From <https://scitechvista.nat.gov.tw/c/s9s0.htm>

Rayleigh Scattering – blue color

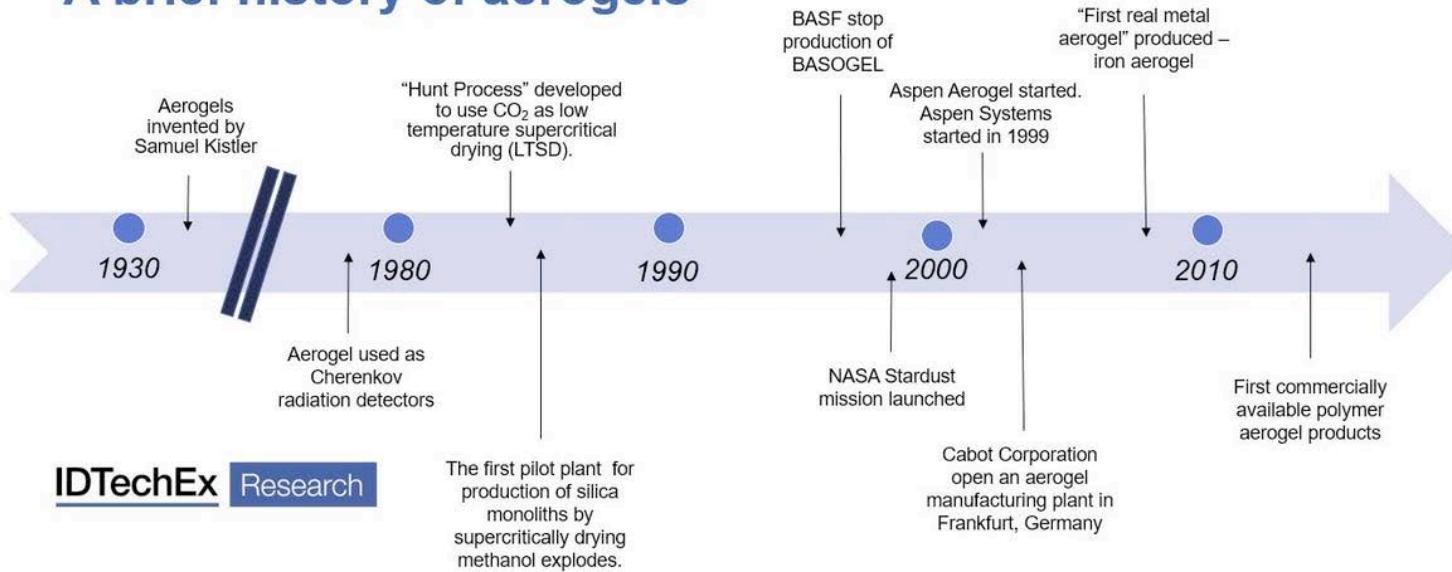
5



气凝胶 (from Wikipedia)

- 气凝胶 (Aerogel) 是目前已知密度僅次於全碳气凝胶的物质。它是由气体取代液体在凝胶中的位置製造而成。
- Samuel Stephens Kistler在1931年發明气凝胶。而這一切都是因為他與Charles Learned之間的賭注。他們二人當時正比賽誰先將凝膠裡的液体成分用气体取代卻不使發泡的間壁收縮崩塌。最後Kistler辦到了。
- 物理性质：易碎而坚固的固体、隔热性良好、吸湿

A brief history of aerogels



太阳和恒星光谱 内容介绍

1. 太阳结构，光谱，活动周期
2. 恒星 HR 图，恒星演化
3. 恒星核聚变，超新星爆发和元素起源

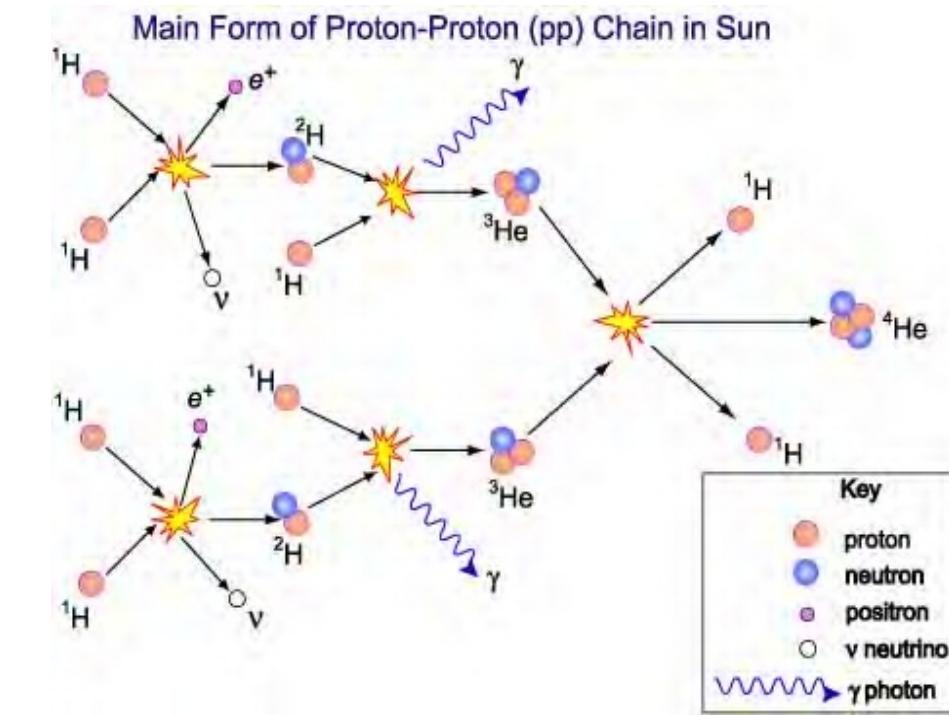
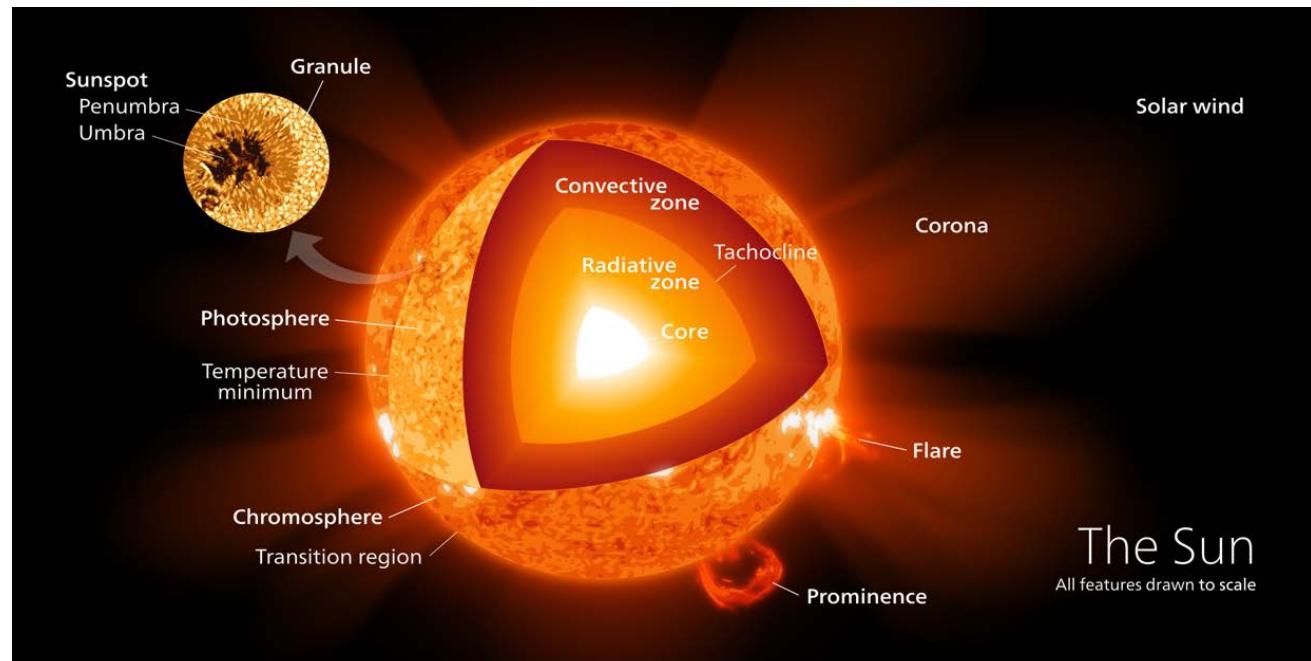
1. 太阳简介

- 太阳系位置：距离银河系中央大约2.5万光年，位于猎户臂，在人马臂和英仙臂之间
- 太阳光谱：G2 型主序星（表面温度 $5,505^{\circ}\text{C}$ ）



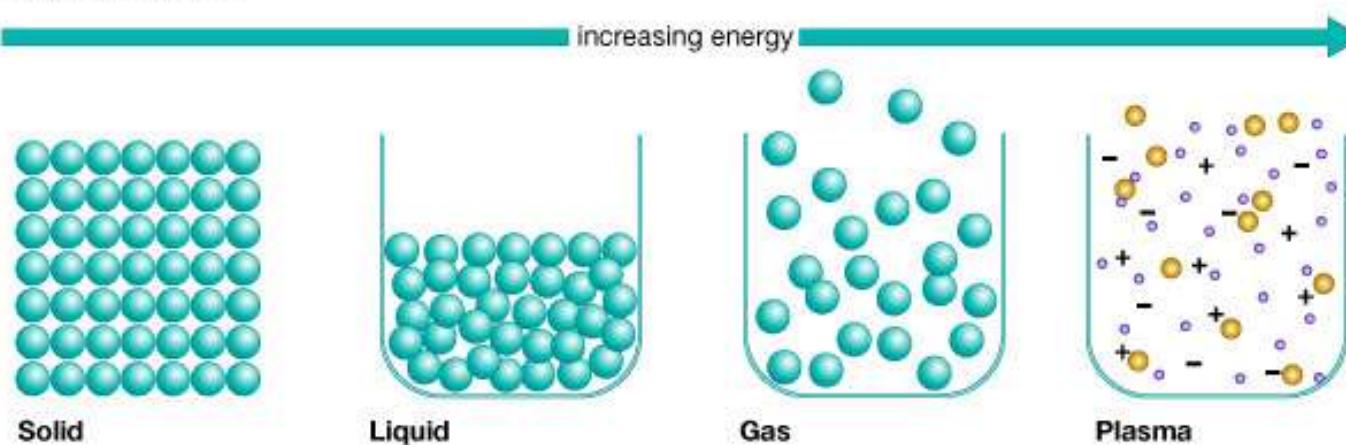
1. 太阳结构

- 化学组成 : 74% H + 25% He + 少量 O, C, Ne, Fe...
- 核 (1,500万K): 致密等离子体
 - 核聚变，产生99% 的太阳能: 功率密度较小，但总功率相当于每秒鐘产生 9.192×10^{10} 百万吨TNT炸药爆炸的能量
 - Hydrostatic state: gravity = Gas pressure
- 光球：太陽可見（对可见光不透明）的表面 ~10–100 km 厚.

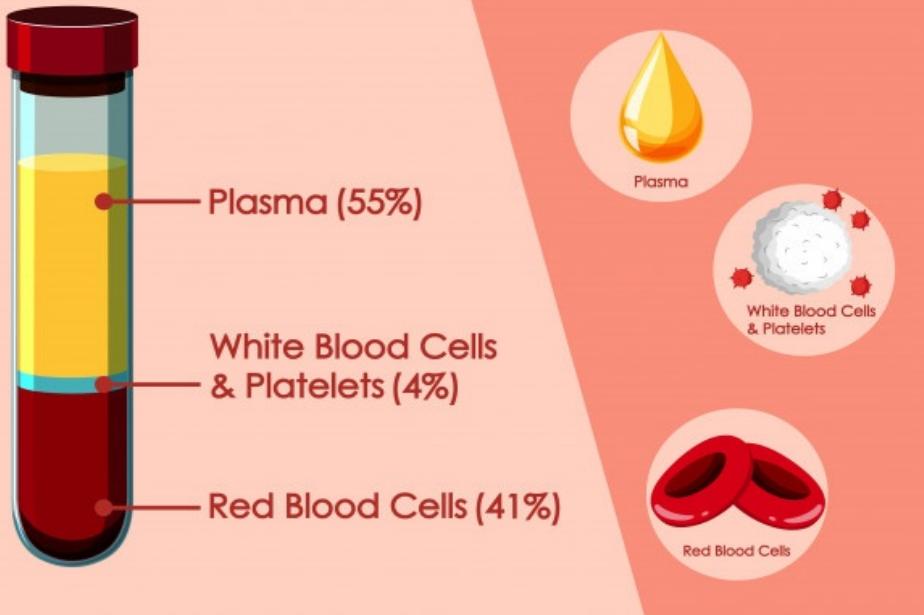


等离子体/电浆 (Plasma)

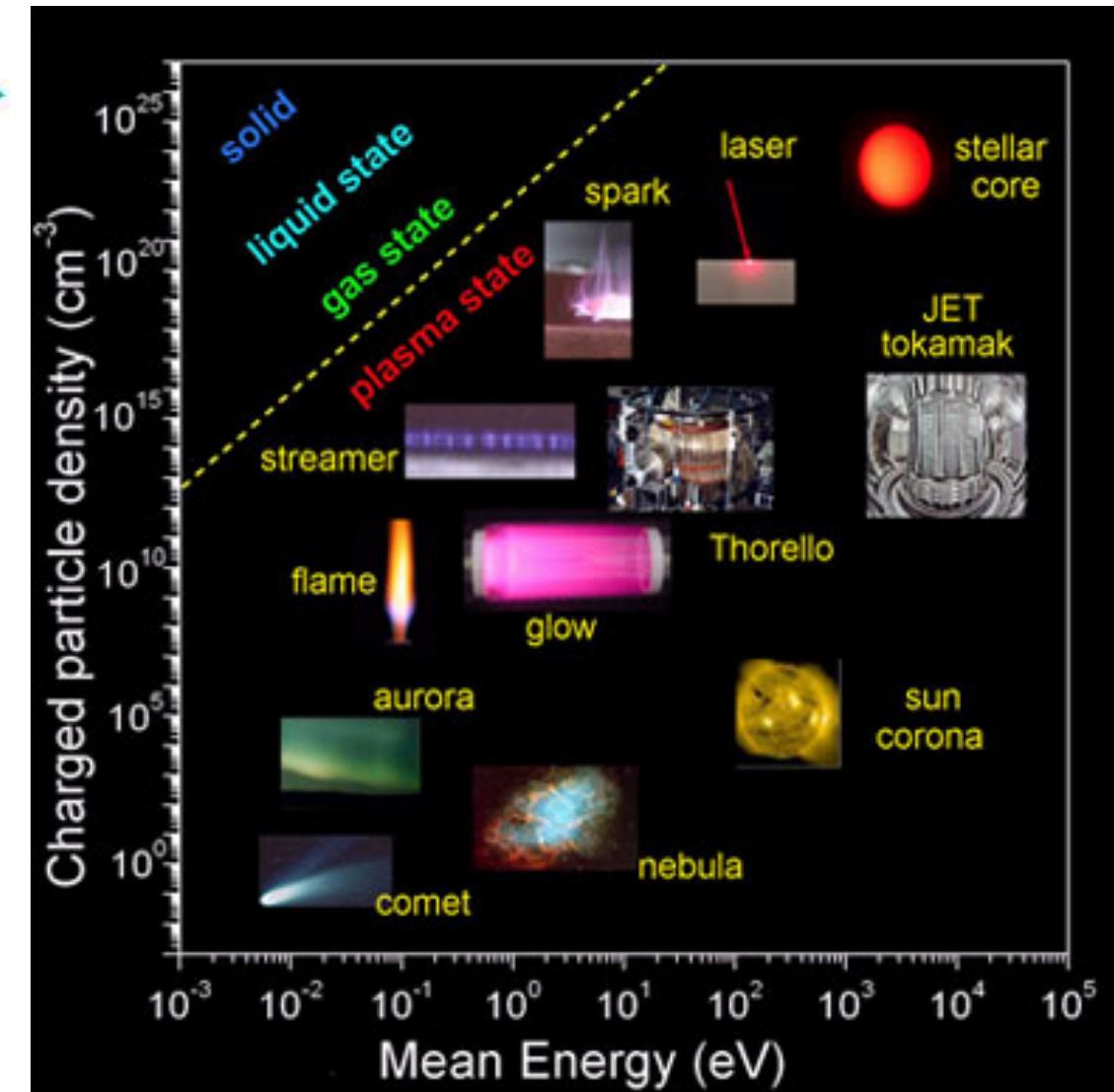
Physical states



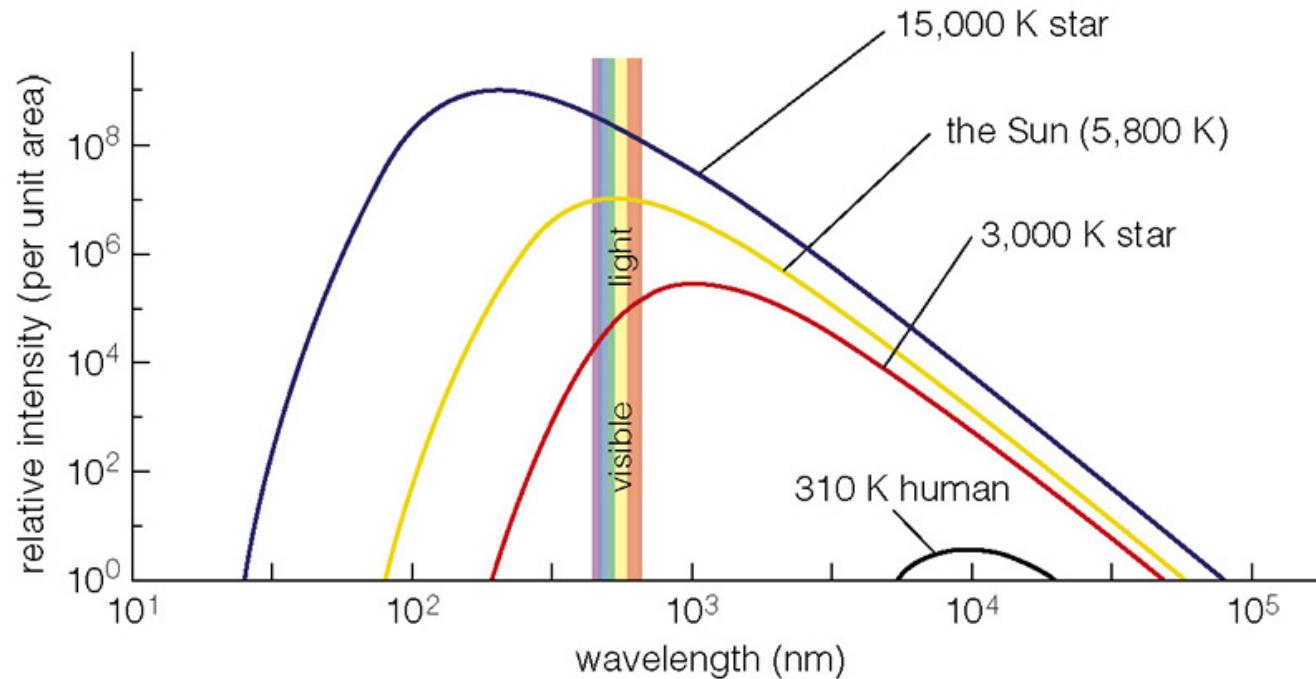
COMPOSITION OF BLOOD



At the very high temperatures of stars, atoms lose their electrons. The mixture of electrons and nuclei that results is the plasma state of matter.

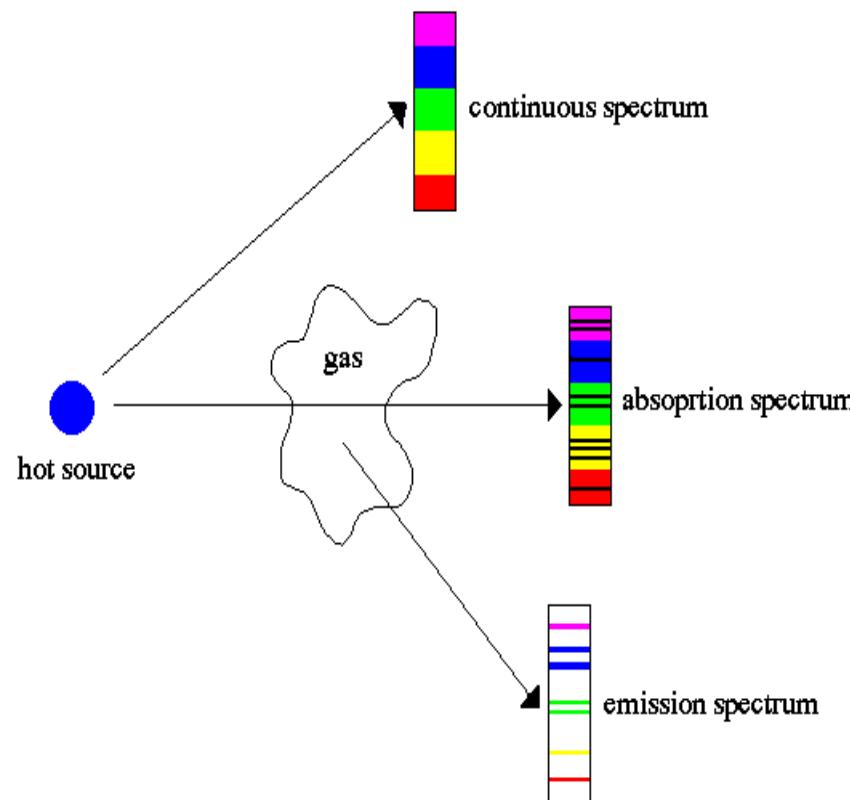
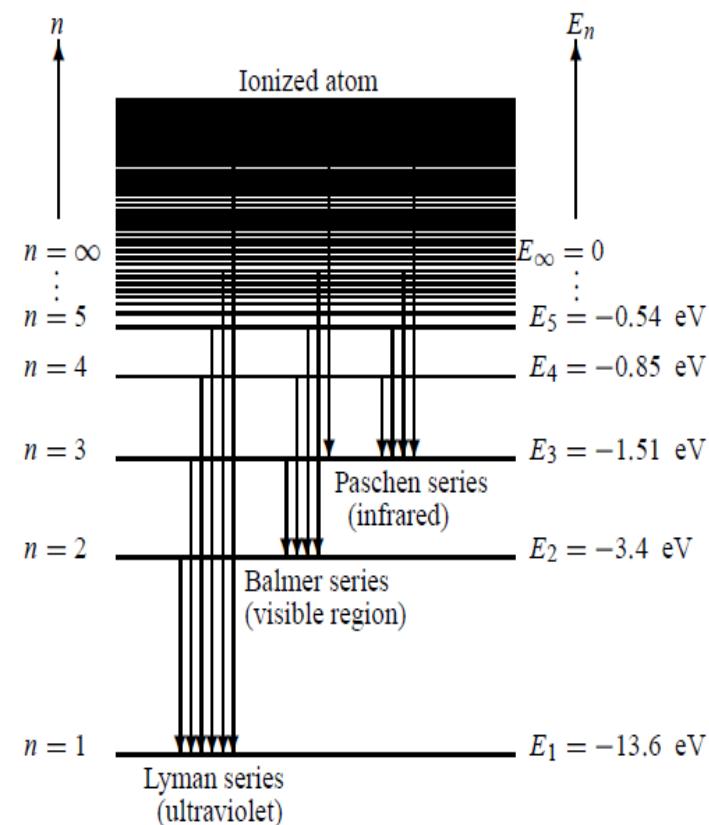


1. 太阳光谱

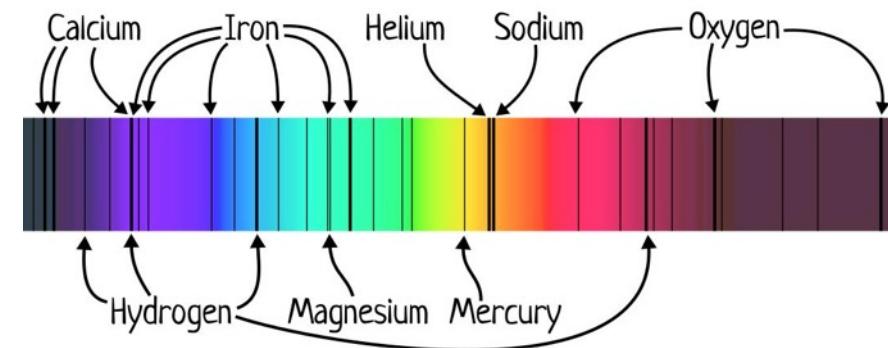


- 黑体：对任何波长的外来辐射完全吸收而无任何反射的物体
- 理想黑体可以吸收所有照射到它表面的电磁辐射，并将这些辐射转化为热辐射，其光谱特征仅与该黑体的温度有关，与黑体的材质无关。
- 普朗克(黑体)辐射定律： $I_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$ ；

1. 太阳光谱：吸收线、发射线以及He 的发现



In 1814, **Joseph von Fraunhofer** studied and measured the **dark lines** in the solar spectrum. 45 years later, it was noticed that the lines coincide with the **emission lines** in the spectra of heated elements. The discovery allows us to determine the **composition of the Sun**.



Flat-Earthers are often seen saying that it is impossible to determine the **composition of the Sun** because nobody has visited the Sun before. They are wrong. **Spectroscopy** allows us to study the **composition of the Sun** and other distant celestial bodies **without going there physically**.

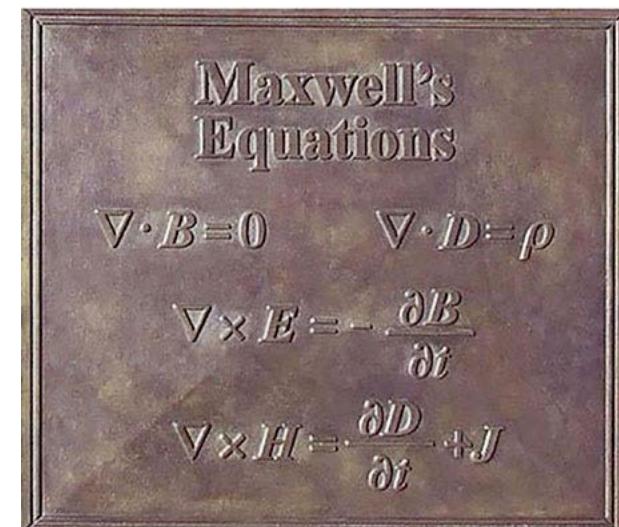
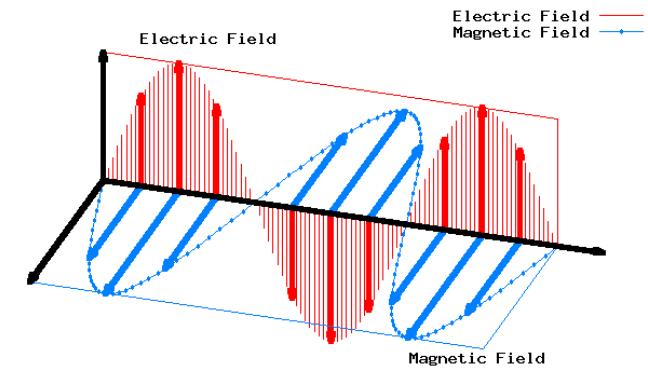
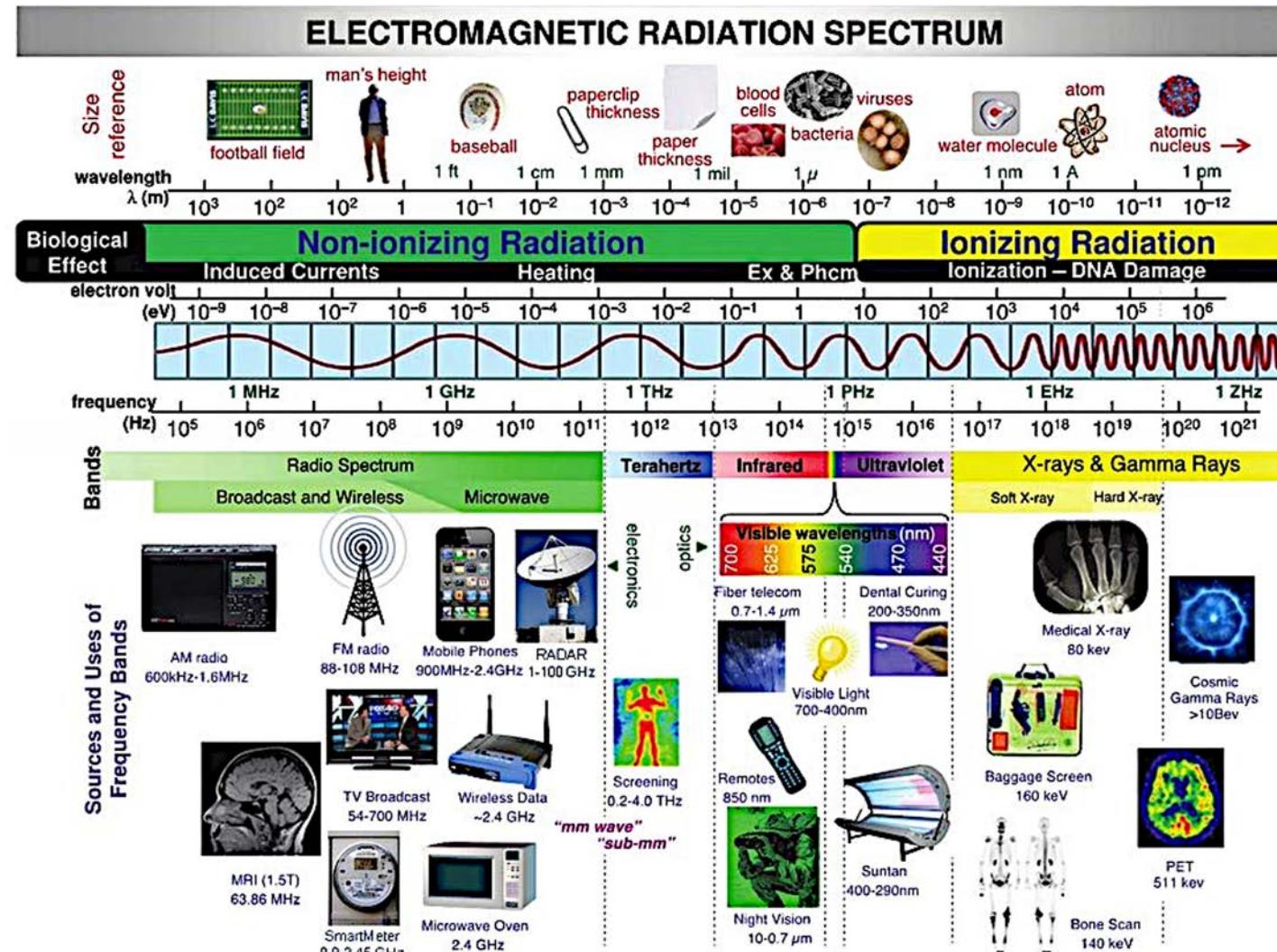


FlatEarth.ws/fraunhofer-lines
Debunking Flat Earth Misconceptions

1. 电磁波 $E = h\nu$

13

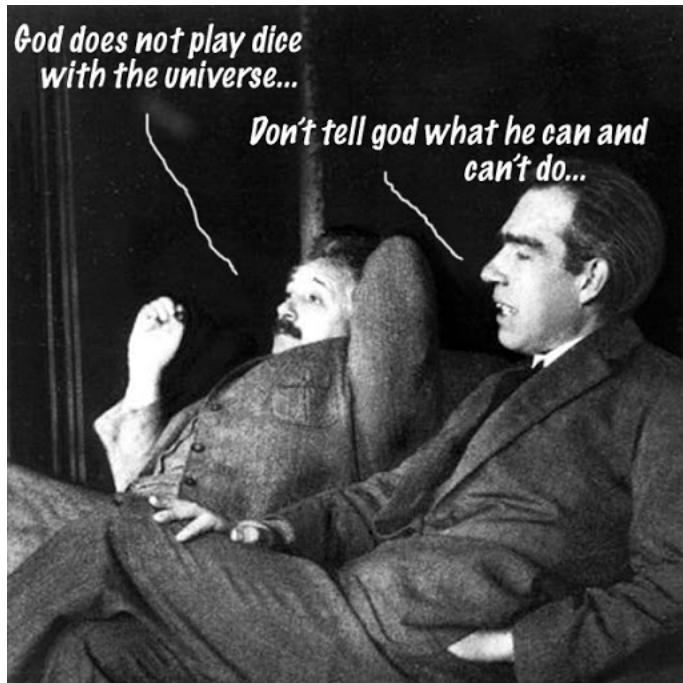
- 光既是一种高频的电磁波，又是一種由稱為光子的基本粒子組成的粒子流。因此光同时具有粒子性与波动性，或者说光具有“波粒二象性”



<https://steemit.com/steemstem/@alex18/need-for-electromagnetic-radiation-in-daily-life>

Great Einstein-Bohr Debate

14



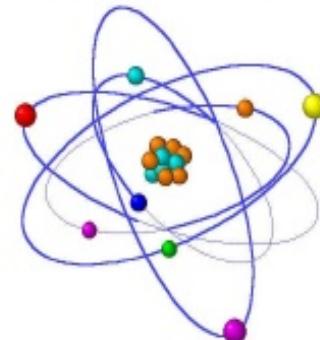
Copenhagen Interpretation

Developed by Niels Bohr in Denmark

Absolute division between scales

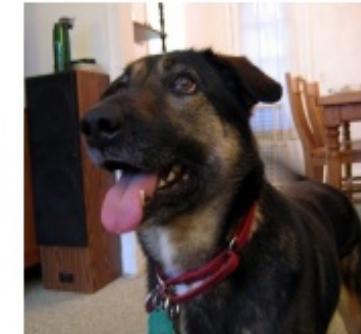


Microscopic:
electrons, atoms, molecules



Obey quantum rules
superposition states

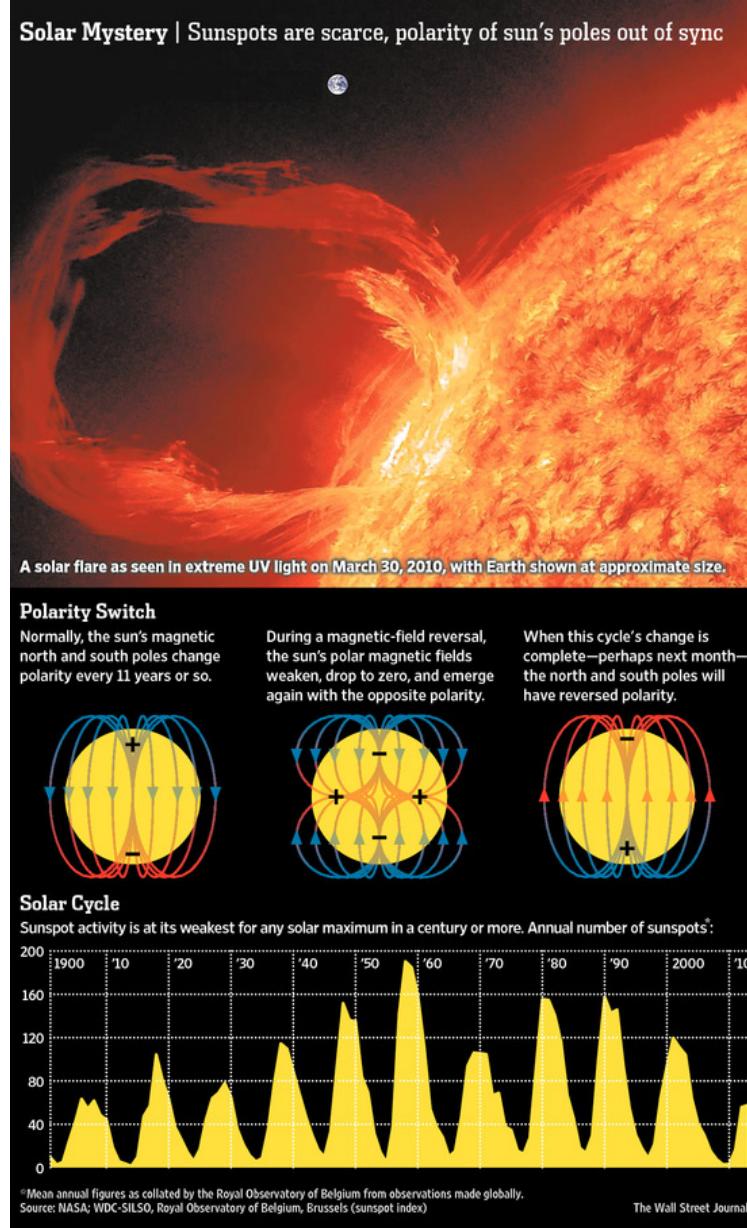
Macroscopic:
dogs, cats, physicists, steak



Obey classical rules
no superposition states

1. 太阳内部的光子运动

1. 太阳磁场倒转和太阳周期



Space Weather Impact Examples

- **1859 (Late August-early September):** The Carrington Event, named for astronomer Richard Carrington who observed the solar flare preceding an historic geomagnetic storm. The storm disrupted telegraph communications around the world and produced aurora seen as far south as Hawaii and Central America. ↗
- **1989 (March):** Quebec plunged into darkness for 9 hours as power grid overwhelmed by geomagnetic storm. ↗
- **2003 (October):** “Halloween Storms” resulted in a 30 hour outage of the Federal Aviation Administration’s Wide Area Augmentation System (WAAS), which provides GPS navigation support to aircraft. ↗
- **2005 (January):** United Airlines diverted 26 flights from polar routes to avoid radio blackout potential. ↗
- **2013 (March):** Three separate CME arrivals in March resulted in three separate satellite outages lasting from hours to days. ↗



<https://www.noaa.gov/explainers/space-weather-storms-from-sun>

Space Weather

日冕物质抛射

Sunspots
Sunspots are comparatively cool areas at up to 7,700°F and show the location of strong magnetic fields protruding through what we would see as the Sun's surface. Large, complex sunspot groups are generally the source of significant space weather.

太阳黑子

Coronal Mass Ejections (CMEs)
Large portions of the corona, or outer atmosphere of the Sun, can be explosively blown into space, sending billions of tons of plasma, or superheated gas, Earth's direction. These CMEs have their own magnetic field and can slam into and interact with Earth's magnetic field, resulting in geomagnetic storms. The fastest of these CMEs can reach Earth in under a day, with the slowest taking 4 or 5 days to reach Earth.

太阳风

Solar Wind
The solar wind is a constant outflow of electrons and protons from the Sun, always present and buffeting Earth's magnetic field. The background solar wind flows at approximately one million miles per hour!

太阳耀斑

Solar Flares
Reconnection of the magnetic fields on the surface of the Sun drive the biggest explosions in our solar system. These solar flares release immense amounts of energy and result in electromagnetic emissions spanning the spectrum from gamma rays to radio waves. Traveling at the speed of light, these emissions make the 93 million mile trip to Earth in just 8 minutes.

Earth's Magnetic Field
Earth's magnetic field, largely like that of a bar magnet, gives the Earth some protection from the effects of the Sun. Earth's magnetic field is constantly compressed on the day side and stretched on the night side by the ever-present solar wind. During geomagnetic storms, the disturbances to Earth's magnetic field can become extreme. In addition to some buffering by the atmosphere, this field also offers some shielding from the charged particles of a radiation storm.

Space Weather

Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space-based and ground-based technological systems, as well as endanger life or health. Just like weather on Earth, space weather has its seasons, with solar activity rising and falling over an approximate 11 year cycle.

Sun's Magnetic Field
Strong and ever-changing magnetic fields drive the life of the Sun and underlie sunspots. These strong magnetic fields are the energy source for space weather and their twisting, shearing, and reconnection lead to solar flares.

Solar Radiation Storms
Charged particles, including electrons and protons, can be accelerated by coronal mass ejections and solar flares. These particles bounce and gyrate their way through space, roughly following the magnetic field lines and ultimately bombarding Earth from every direction. The fastest of these particles can affect Earth tens of minutes after a solar flare.

Geomagnetic Storms
A geomagnetic storm is a temporary disturbance of Earth's magnetic field typically associated with enhancements in the solar wind. These storms are created when the solar wind and its magnetic field interacts with Earth's magnetic field. The primary source of geomagnetic storms is CMEs which stretch the magnetosphere on the nightside causing it to release energy through magnetic reconnection. Disturbances in the ionosphere (a region of Earth's upper atmosphere) are usually associated with geomagnetic storms.

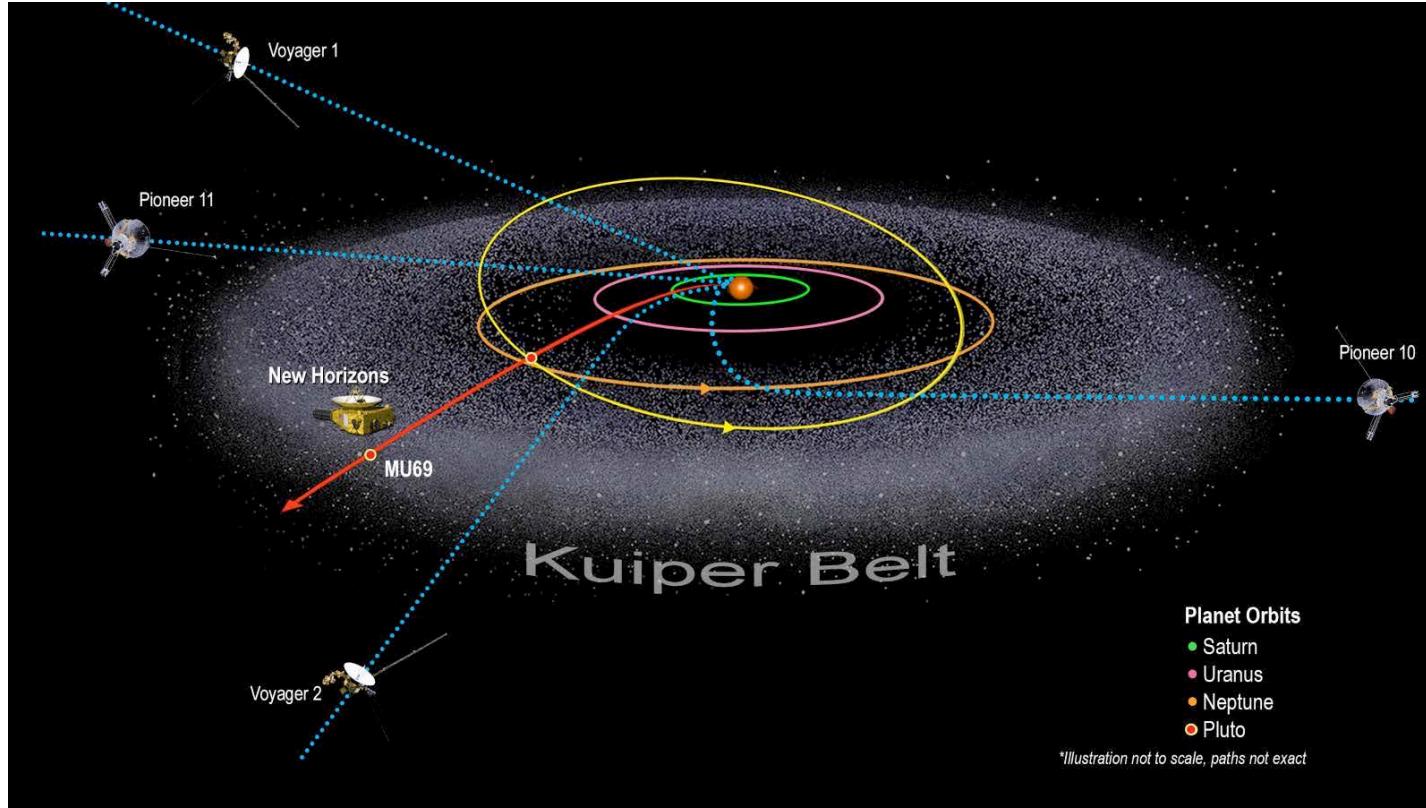
地磁爆

Source images: NASA, NOAA.

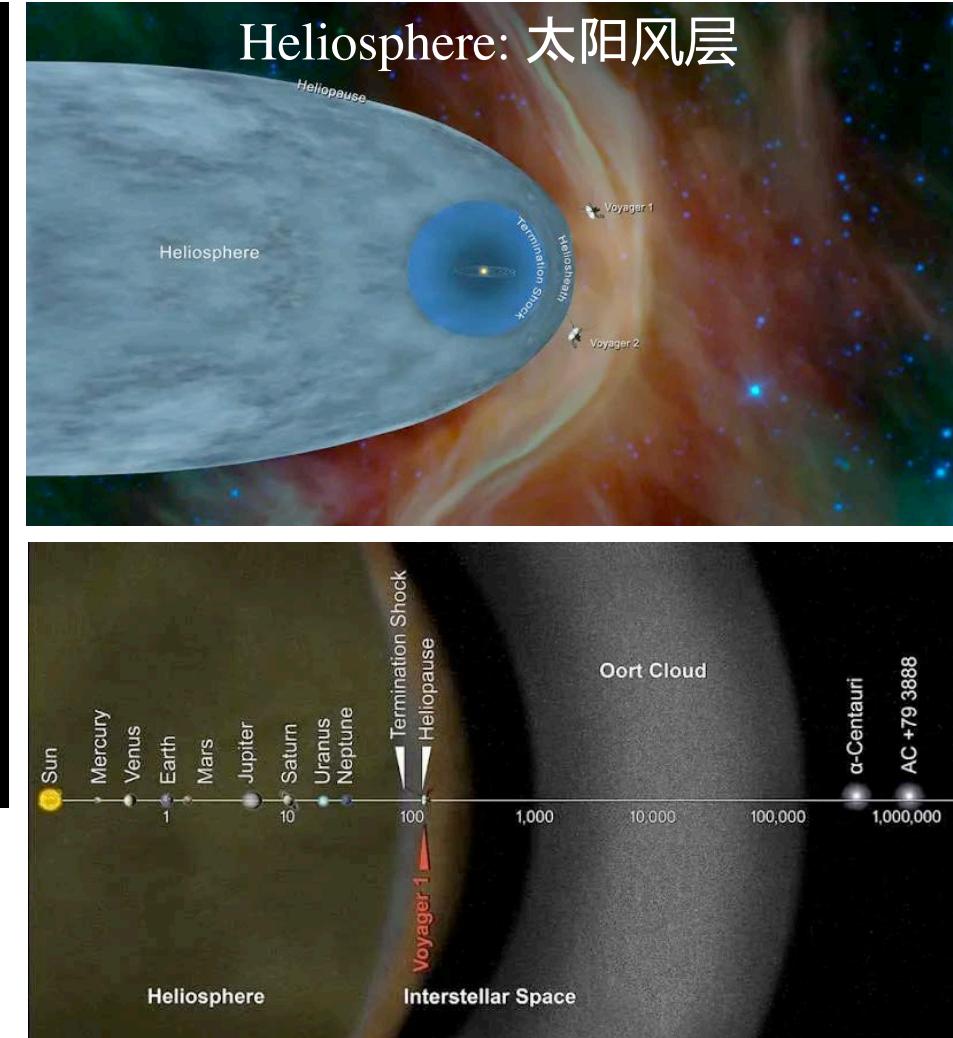
NOAA Space Weather Prediction Center - www.spaceweather.gov

星际空间探测

18



- Five space probes leaving the solar system,
<https://ourplnt.com/space-probes-leaving-solar-system/>



2. 恒星的种类和演化

恒星是一种天体，由引力凝聚在一起，核心正在进行核聚变的一颗球型发光等离子体



恒星分类：HR 图-光度

- 光度 L ：恒星单位时间辐射出的总能量
- $L = 4\pi r^2 \sigma T^4$
- 绝对星等 M ：假定把恒星放在距离地球 32.6 光年的位置测得恒星亮度。
- 视星等/视亮度

$$M_{\text{bol},*} - M_{\text{bol},\odot} = -2.5 \log_{10} \left(\frac{L_*}{L_\odot} \right)$$

该式逆变换得到：

$$\frac{L_*}{L_\odot} = 10^{0.4(M_{\text{bol},\odot} - M_{\text{bol},*})}$$

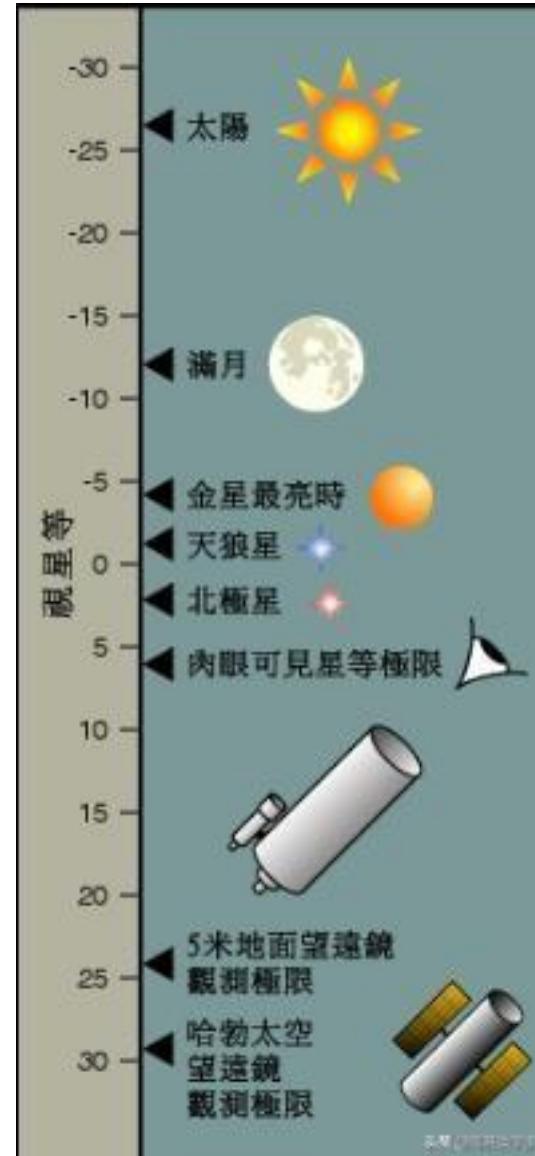
此處

L_\odot 是太陽的光度（全波段光度）

L_* 是恒星的光度（全波段光度）

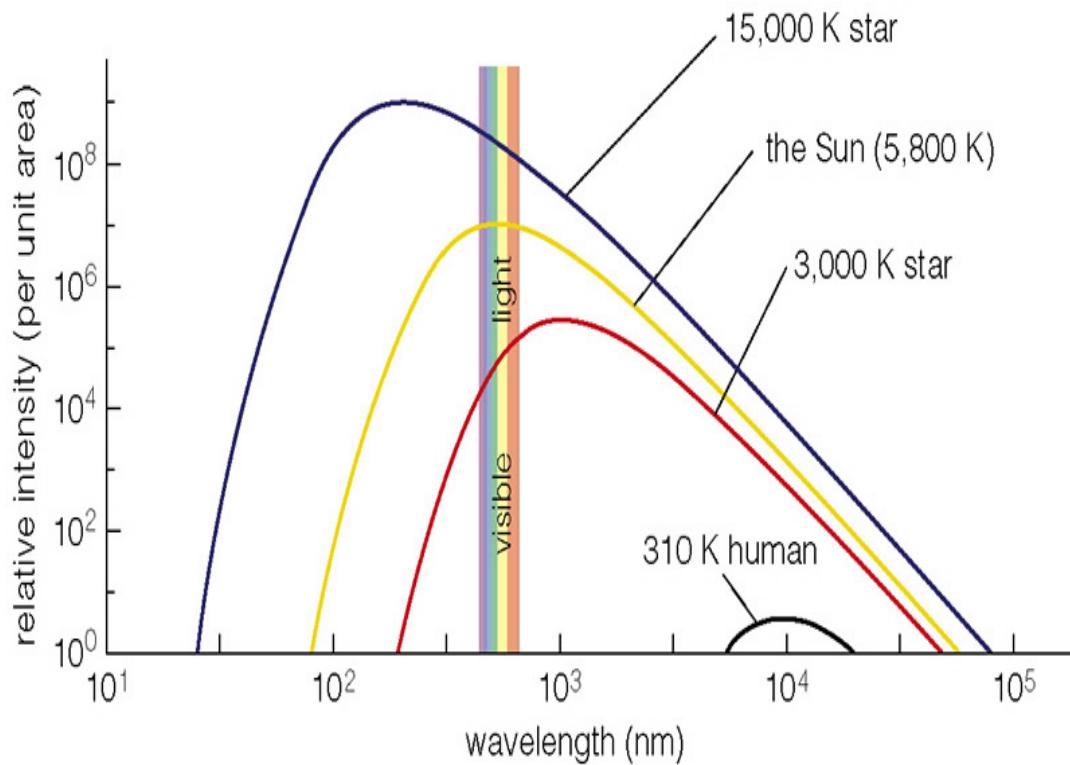
$M_{\text{bol},\odot}$ 是太陽的全波段星等

$M_{\text{bol},*}$ 是恒星的全波段星等。



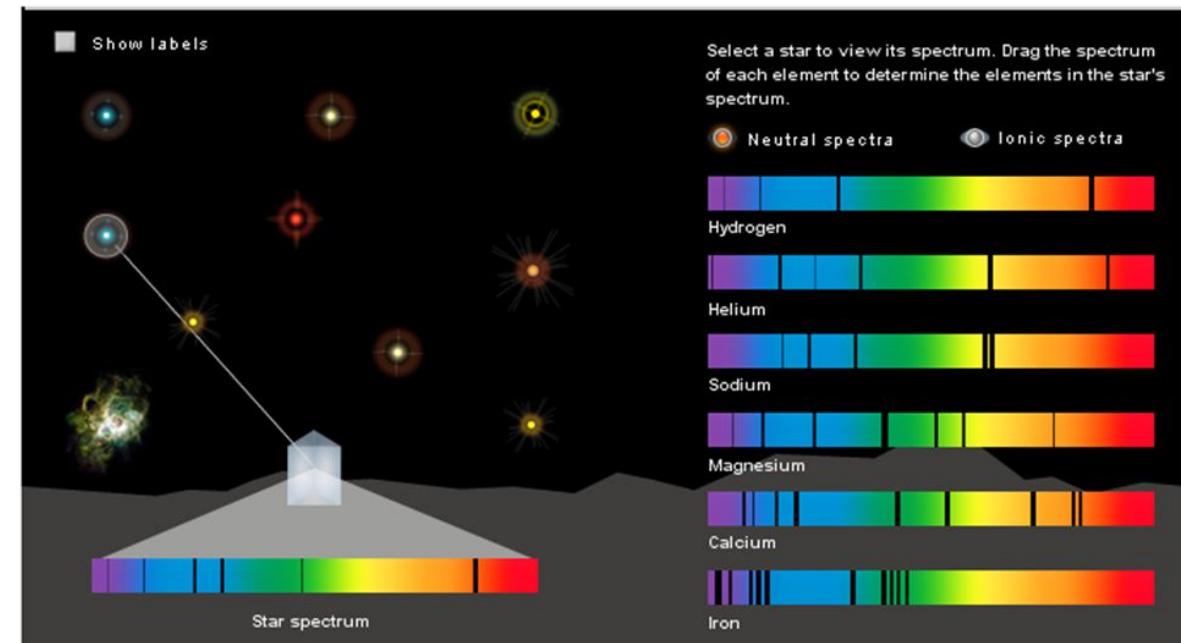
恒星分类：HR 图-表面温度

- Black-body thermal radiation spectrum
- Or use spectrum of the star



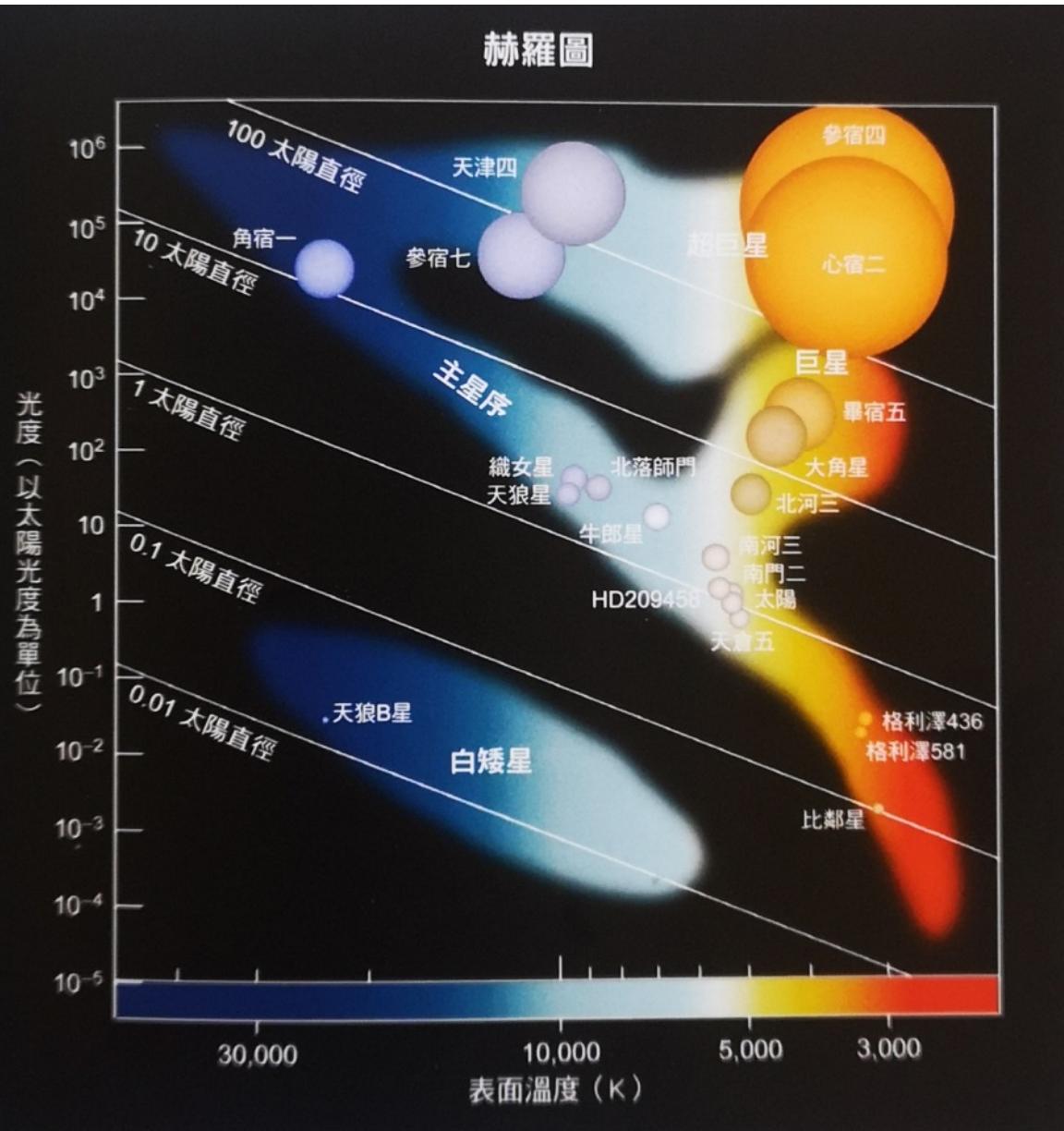
Star Spectrum

- Star spectra contain specific spectral lines. These provide evidence of the elements in the star



恒星分类

22



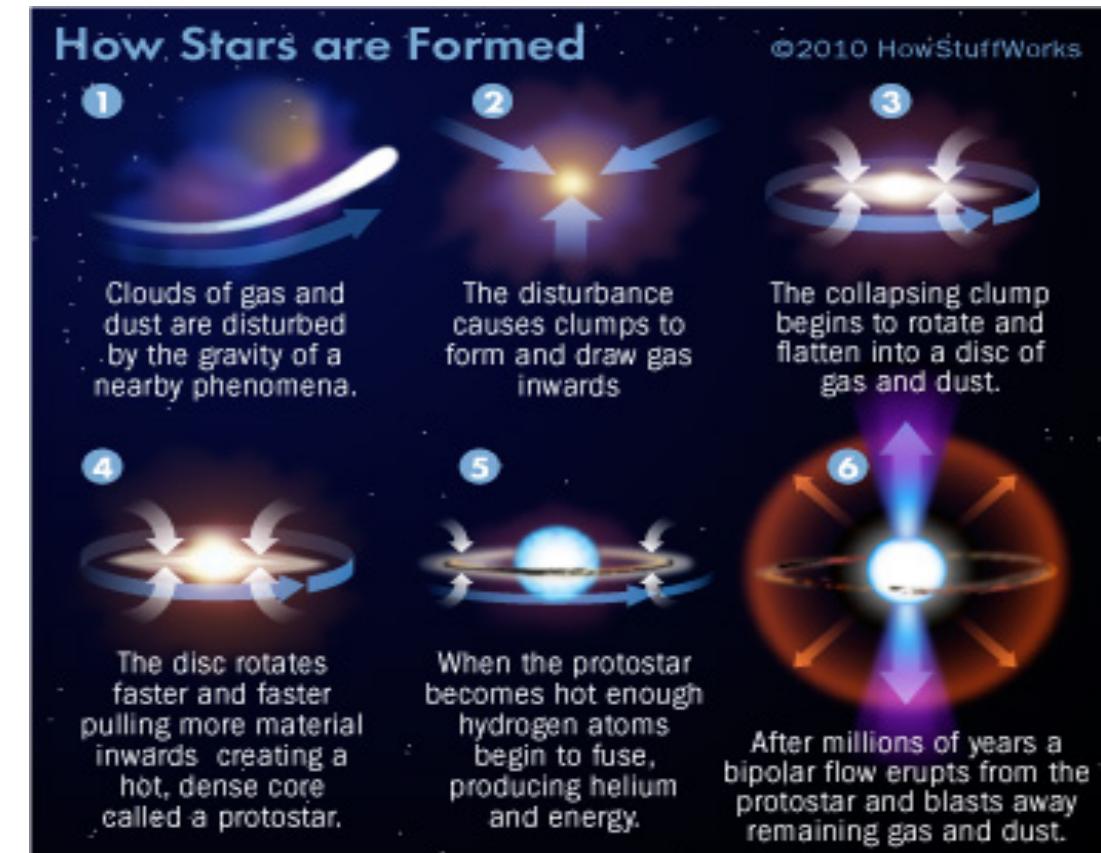
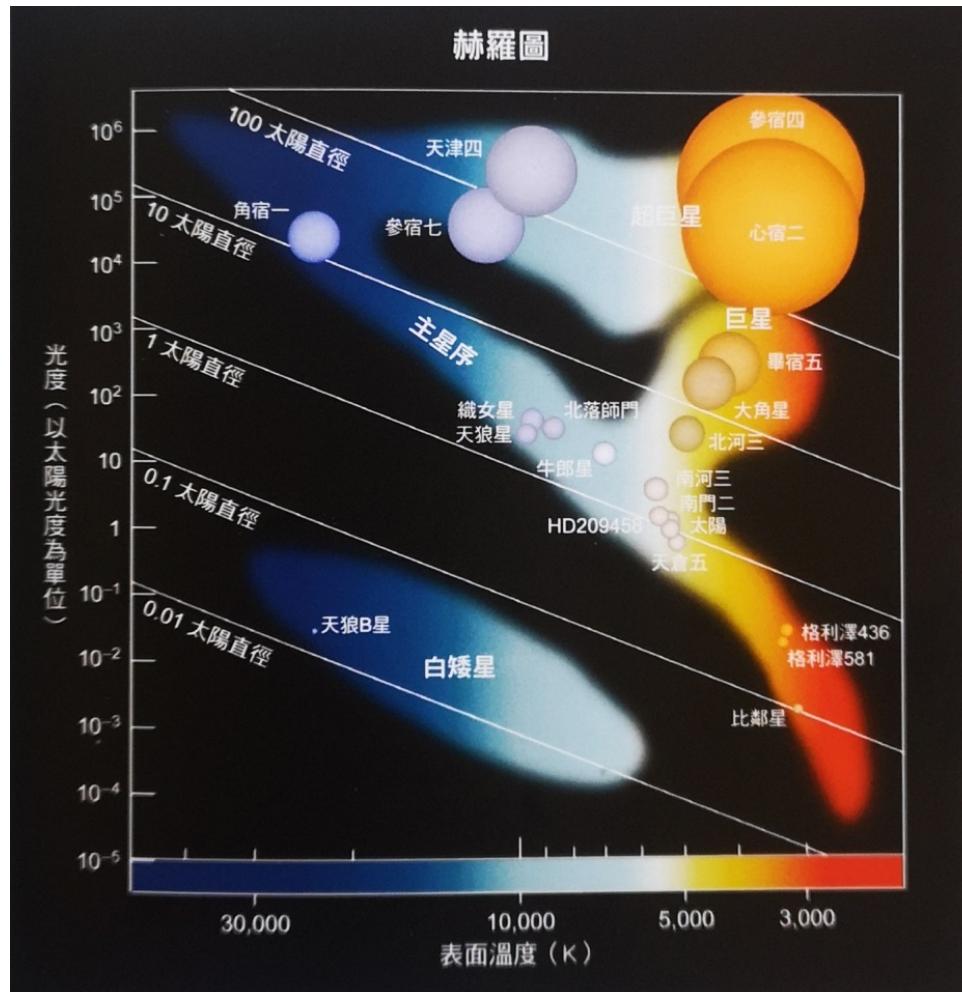
Spectral Type	Color	Temperature (K)*	Spectral Features
O	Blue	28,000-50,000	Ionized helium, especially helium
B	Light Blue	10,000-28,000	Helium, some hydrogen
A	White	7,500-10,000	Strong hydrogen, some ionized metals **
F	Yellow	6,000-7,500	Hydrogen and ionized metals such as calcium and iron
G	Yellow-Green	5,000-6,000	Both metals and ionized metals, especially ionized calcium
K	Orange	3,500-5,000	Metals
M	Red	2,500-3,500	Strong titanium oxide and some calcium

* To convert approximately to Fahrenheit, multiply by 9/5.
** Astronomers regard elements heavier than helium as metals.

$$\bullet L = 4\pi r^2 \sigma T^4$$

主星序和恒星的产生

- 在赫羅圖上的恆星絕大多數都位於主序帶的曲線上
- 以氫燃燒為主
- 恒星的生命活躍期幾乎都耗費在這個階段



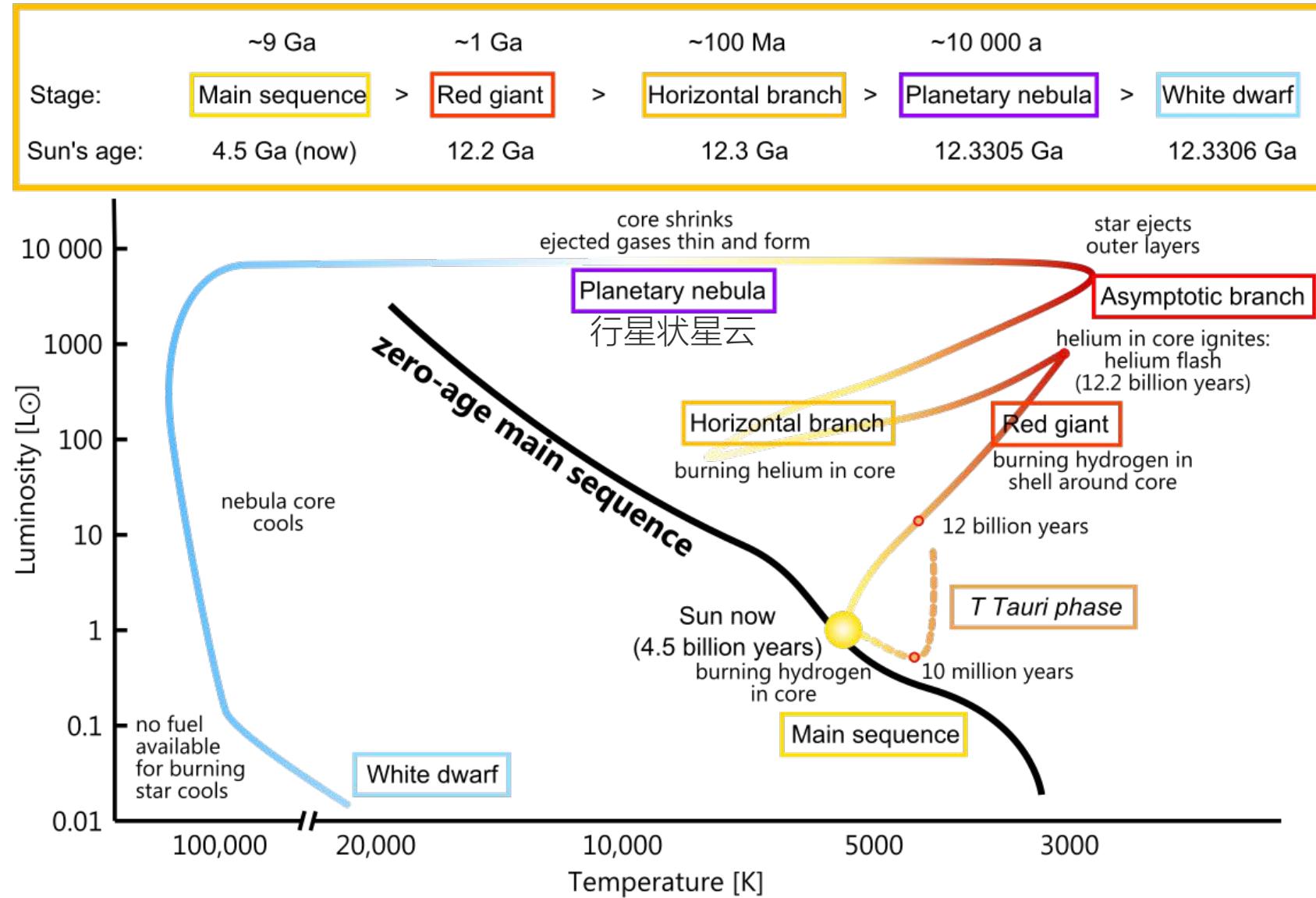
主序星寿命

估计恒星寿命 T

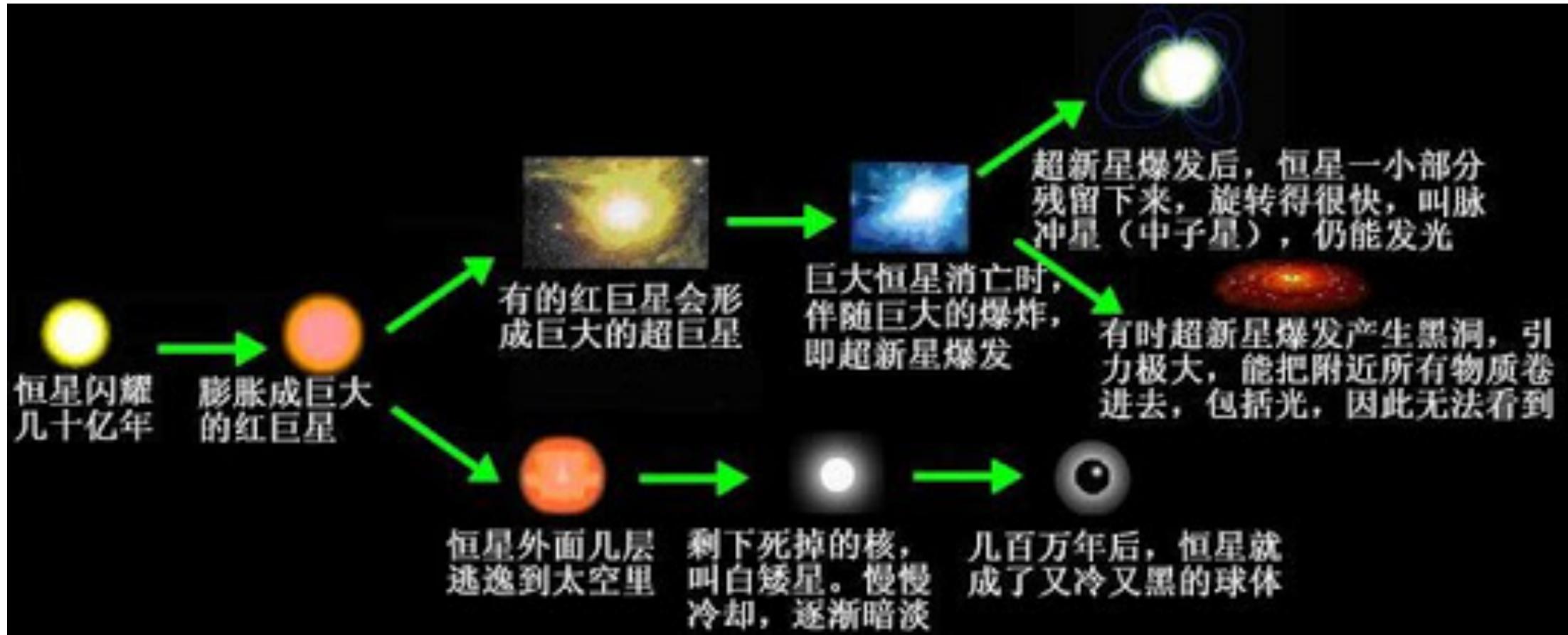
- 燃料是恒星质量 : M
- 消耗燃料的速度 : 光度 L
- 已知恒星质光关系 : $L \propto M^{3.5}$
 $\rightarrow T = M/L \propto M^{-2.5}$

即恒星的质量越大，消耗约快（光度越大，表面温度越高），其主序星寿命越短。

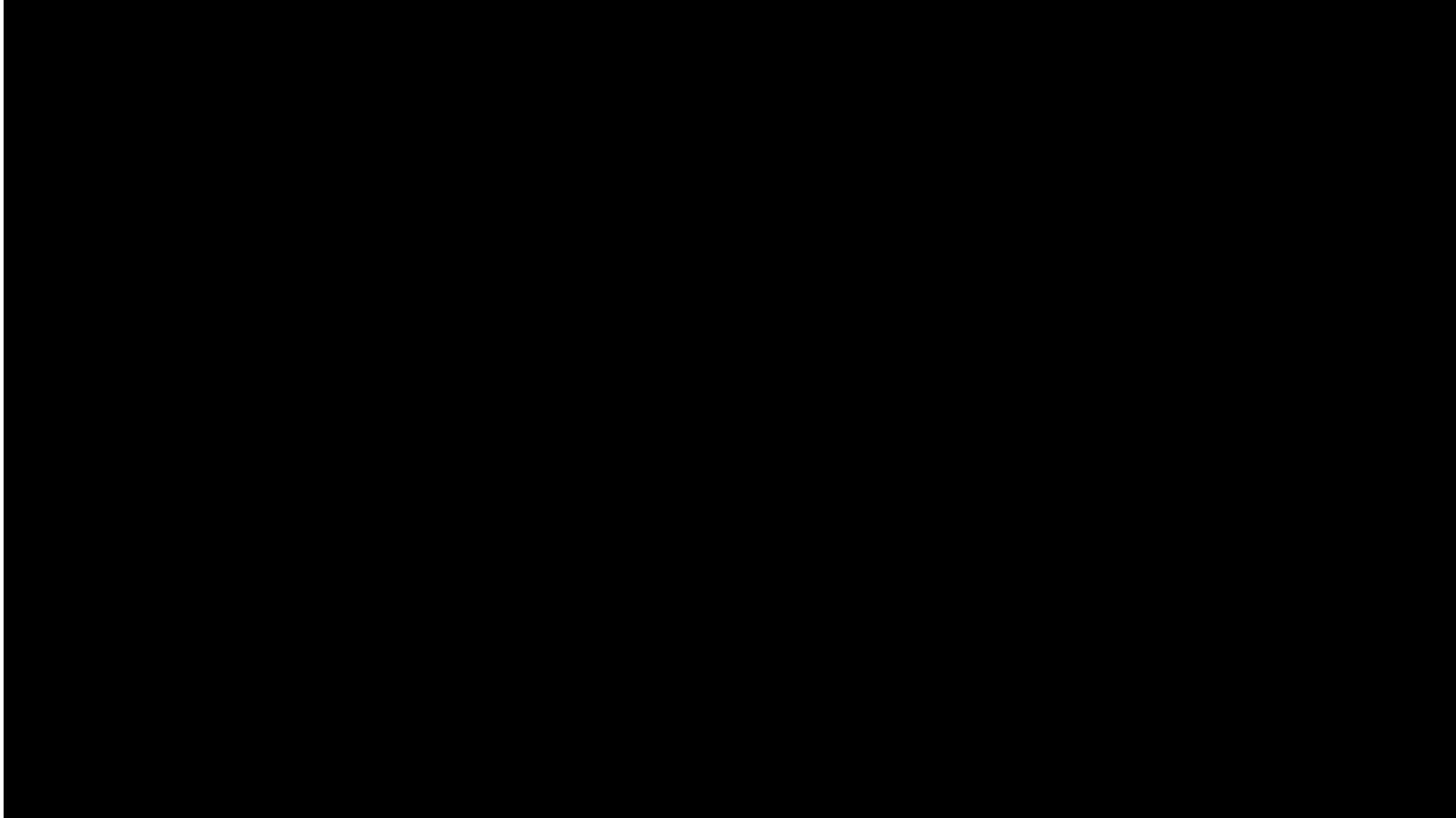
恒星的演化: 太阳的演化



恒星演化



恒星演化



恒星演化周期：从星尘到星尘

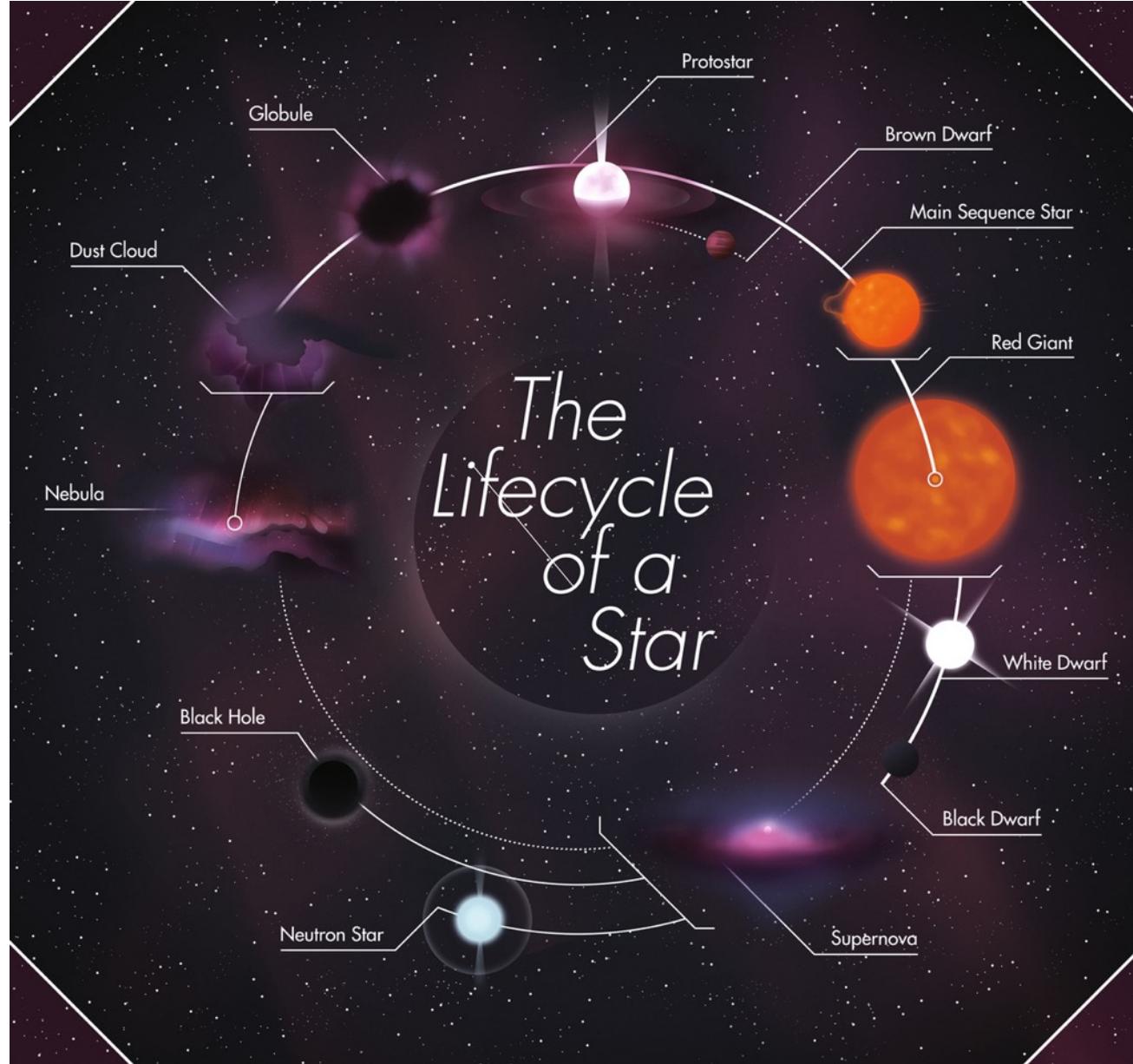
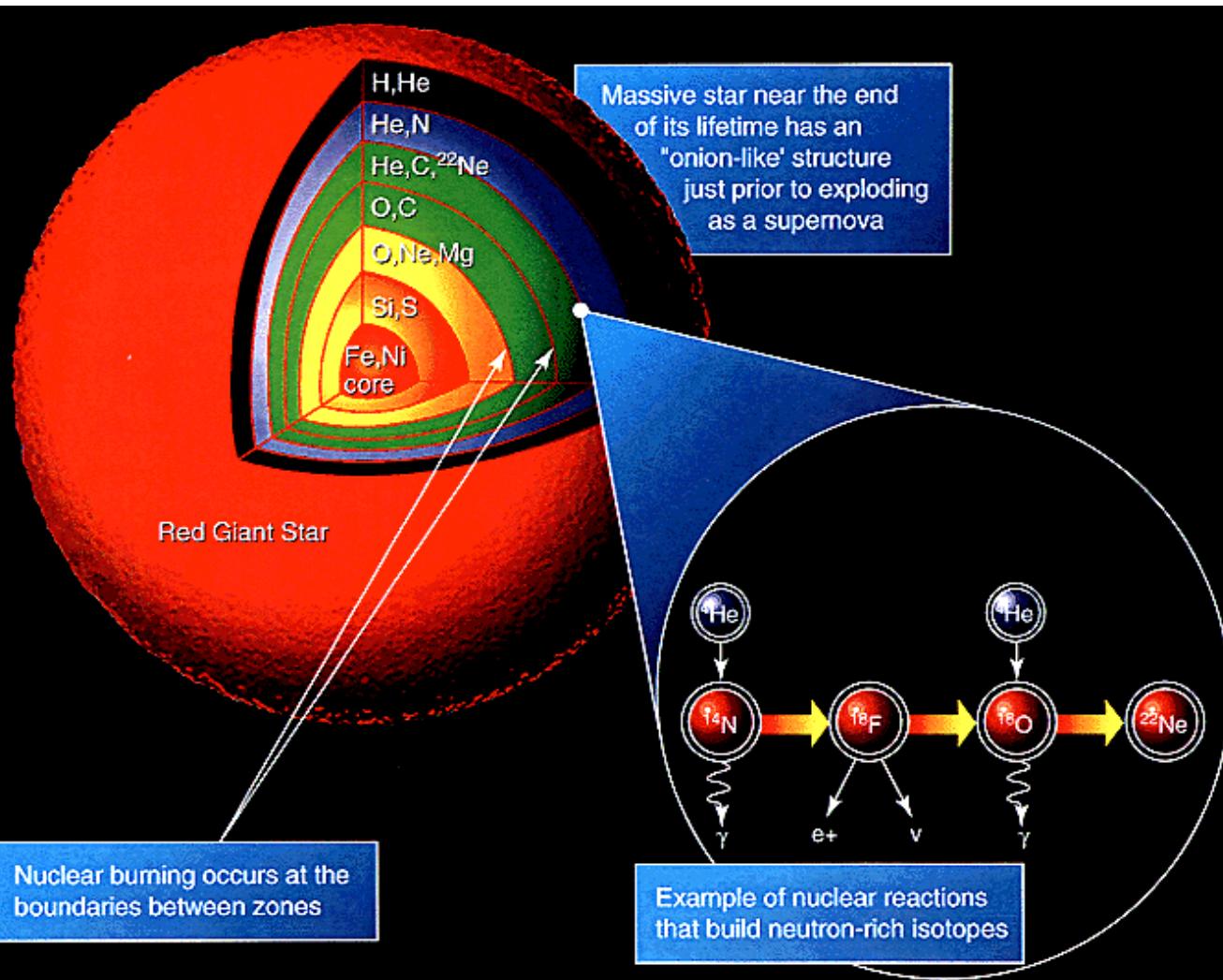


Image: [Jack Hughes](#)
Twitter:
[@jackmrhughes](#)

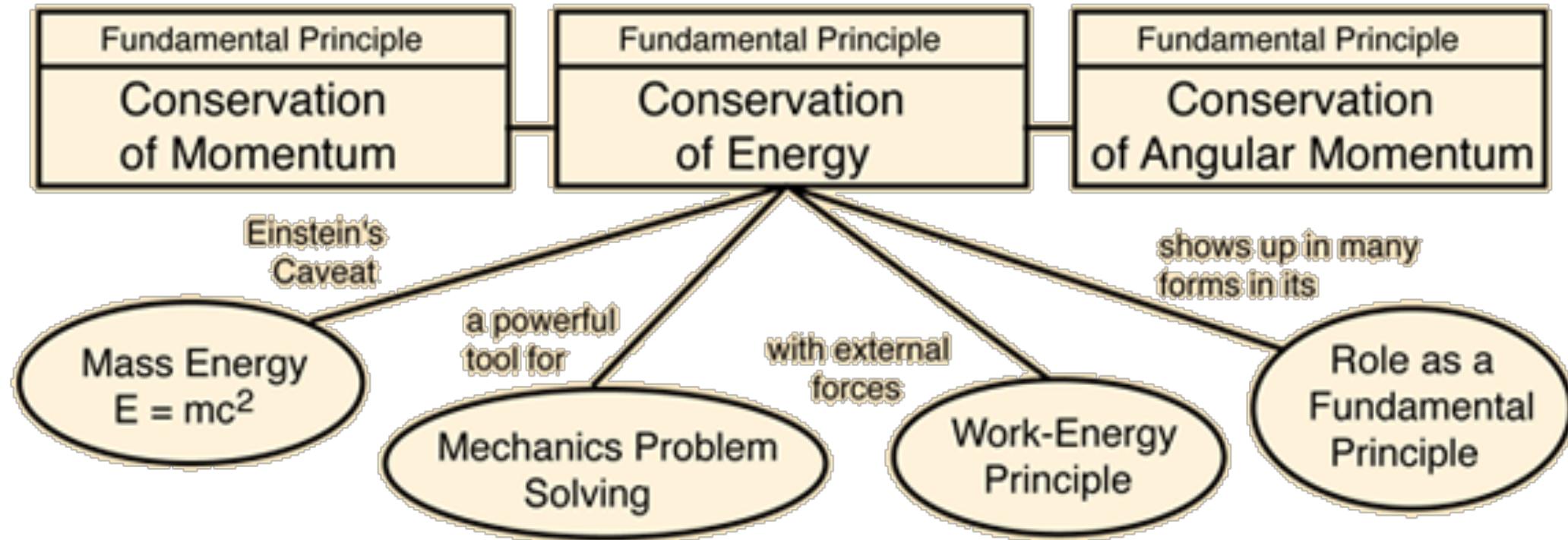
恒星核聚变



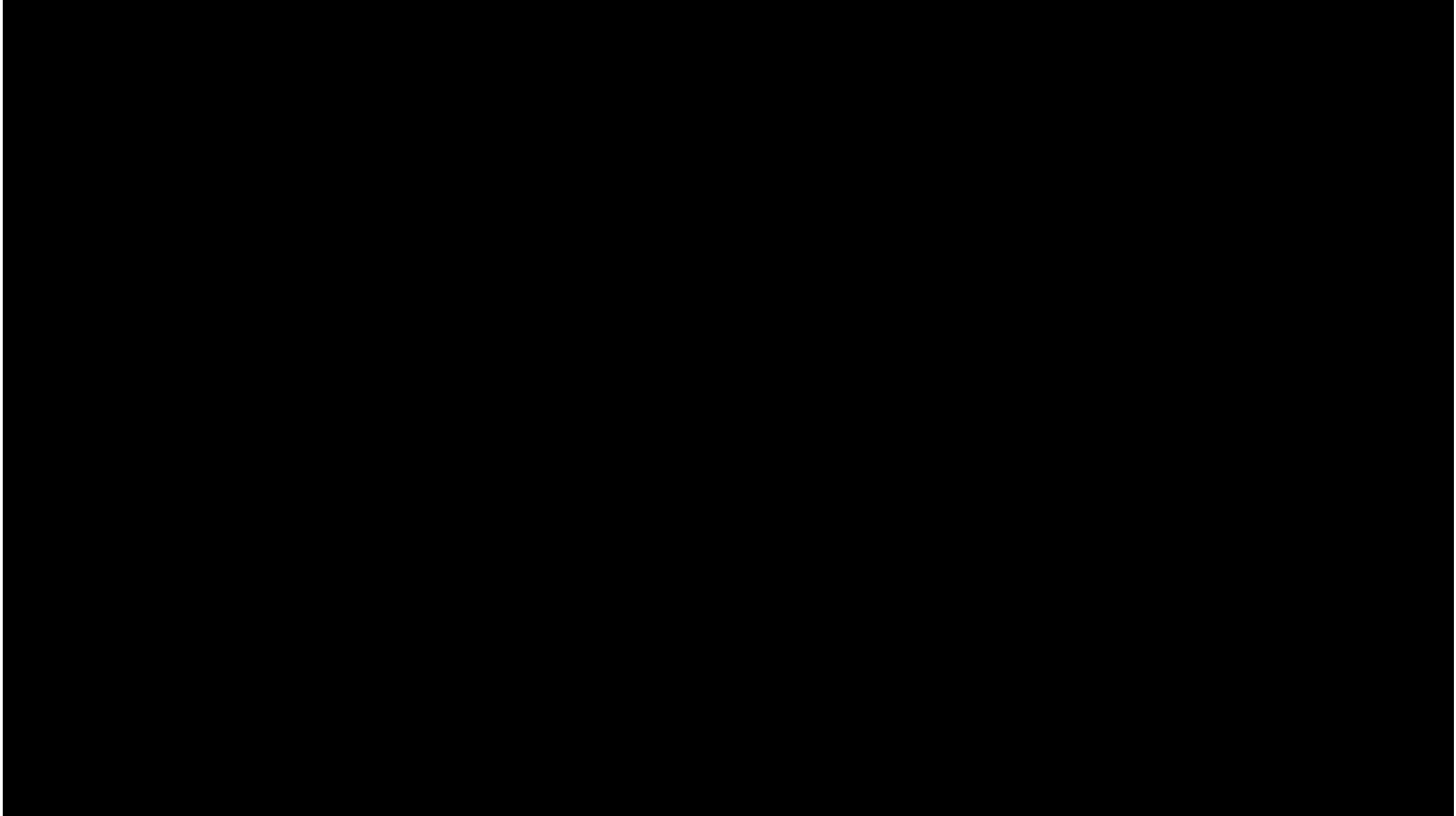
恒星演化时发生的核反应种类与其质量的关系

质量	发生的核反应
0.08个太阳质量	不发生
0.3个太阳质量	氢燃烧
0.7个太阳质量	氢、氦燃烧
5.0个太阳质量	氢、氮、碳燃烧
10个太阳质量	发生所有的核反应

<https://www.slideserve.com/patch/agb>

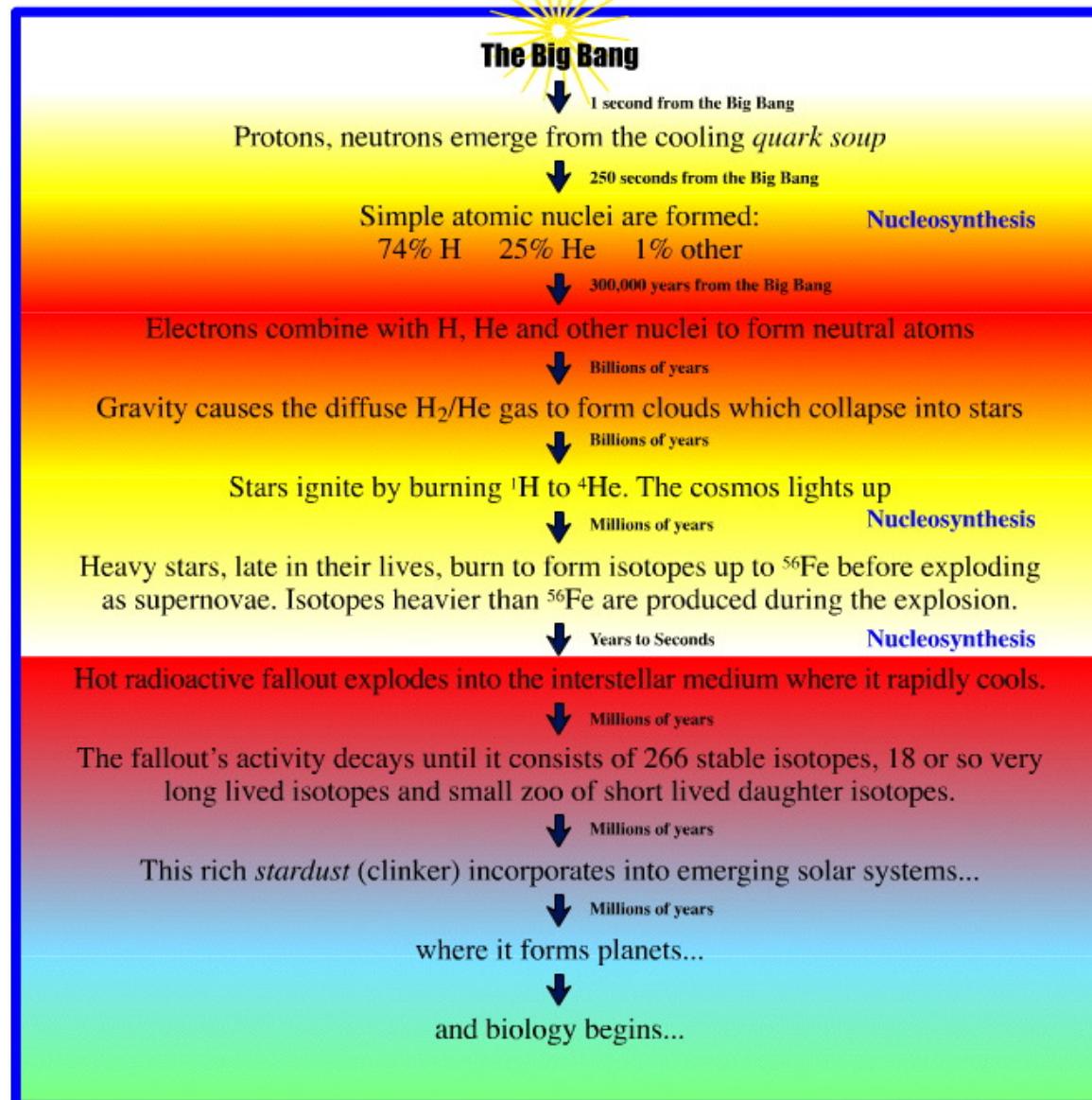


超新星爆发



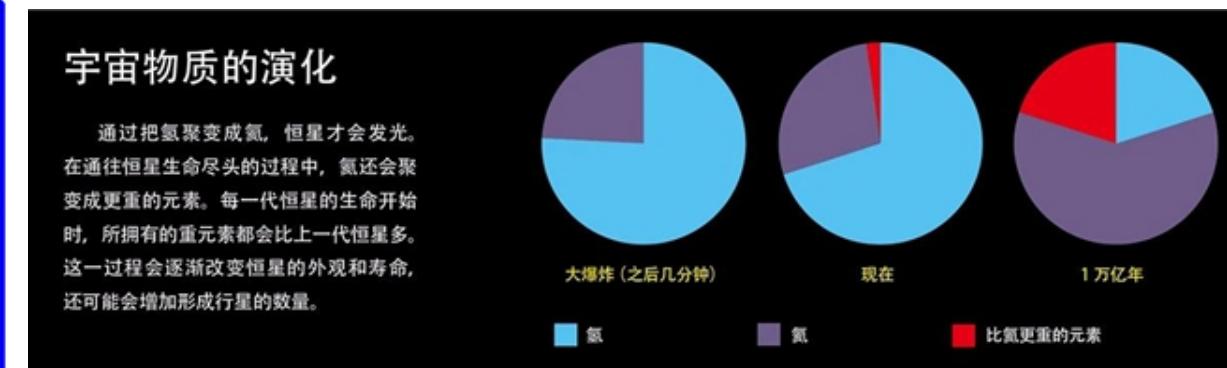
宇宙元素的来源

Nucleosynthesis



宇宙物质的演化

通过把氢聚变成氦，恒星才会发光。在通往恒星生命尽头的过程中，氦还会聚变成更重的元素。每一代恒星的生命开始时，所拥有的重元素都会比上一代恒星多。这一过程会逐渐改变恒星的外观和寿命，还可能会增加形成行星的数量。



https://www.meta-synthesis.com/webbook/32_n-synth/nucleosynthesis.html

Conclusion: We Are Stardust

33

ORIGINS: SOLAR SYSTEM ELEMENTS



Periodic Table of Elements. Credit: NASA/CXC/K. Divona; Reference: [SDSS blog](#), J. Johnson

Conclusion: 你我皆星尘

- "*The amazing thing is that every atom in your body came from a star that exploded. And, the atoms in your left hand probably came from a different star than your right hand. It really is the most poetic thing I know about physics: You are all stardust. You couldn't be here if stars hadn't exploded, because the elements - the carbon, nitrogen, oxygen, iron, all the things that matter for evolution - weren't created at the beginning of time. They were created in the nuclear furnaces of stars, and the only way they could get into your body is if those stars were kind enough to explode. So, forget Jesus. The stars died so that you could be here today.*" — Lawrence M. Krauss *『A Universe from Nothing』*

Home Activities

35

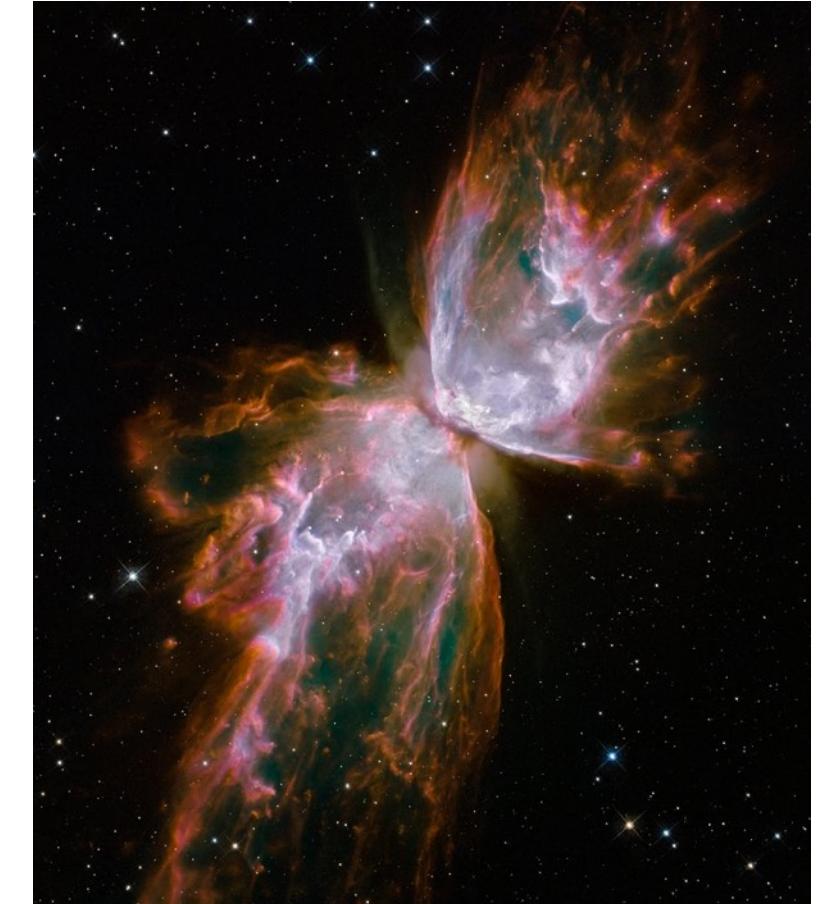
- **Citizen Science:**

<https://www.zooniverse.org/projects?discipline=astronomy&page=1&status=live>

- **Apollo 13 in Real Time:** <https://apolloinrealtime.org/13/>



Credit:NASA, ESA and the Hubble Heritage Team (STScI/AURA)-ESA/Hubble Collaboration



Butterfly emerges from stellar demise in planetary nebula NGC 6302
Credit:NASA, ESA and the Hubble SM4 ERO Team

References

1. 未注明出处图片来自 Wikipedia
2. Welcome to the Universe: An Astrophysical Tour, by Neil deGrasse Tyson, Michael Strauss, J. Richard Gott

Videos

1. 科学交响曲 我们都是星尘 We Are Star Dust
<https://www.bilibili.com/video/av15393792/>
2. Sunlight is older than you think, <https://www.youtube.com/watch?v=Z-UO-RZBQ3U>
3. 【天文17】氦闪是什么？太阳的宿命会是黑洞吗？恒星的演化过程
<https://www.youtube.com/watch?v=w93inHZt32I>
4. 【天文18】什么是超新星爆发？重元素从何而来？消失的中子星之谜
<https://www.youtube.com/watch?v=qResw4tuqns>
5. 薛定谔的猫：量子力学里的理想试验
https://www.ted.com/talks/chad_orzel_schrodinger_s_cat_a_thought_experiment_in_quantum_mechanics/transcript?language=zh-cn#t-145764