Stellar Evolution: Birth, Life, and Death of Stars
恒星的演化：诞生、生命与死亡

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Evolution of stars恒星的演化

The Ring Nebula, a dying star.
Source: NASA

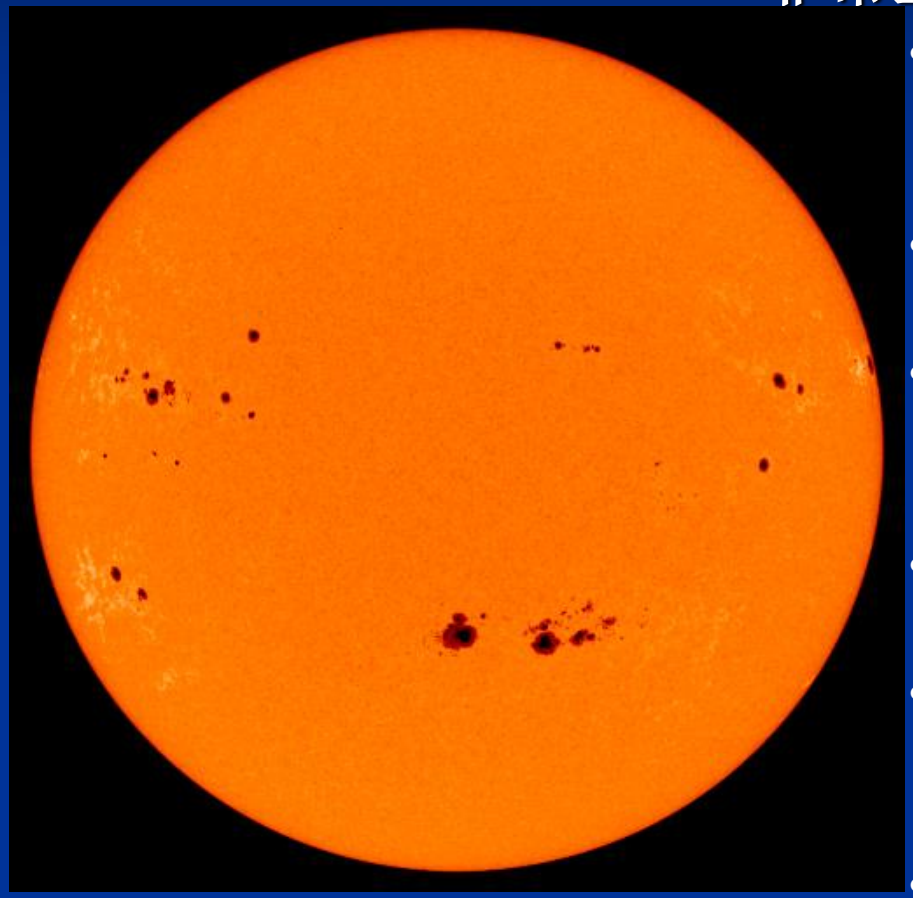
- When we talk about evolution of stars we mean to changes that occur in them as they consume "fuel", since birth through his long life, until his death.
- 我们所说的“恒星的演化”，是指恒星内部消耗“燃料” 时不断产生变化的过程，这一过程从其诞生开始一直伴随其走完漫长的一生。
- Understanding the evolution of stars help astronomers understand:
- 恒星演化过程的研究对天文学家来说有重要的意义：
- The nature and future fate of our Sun.
- 帮助我们认识太阳的相关特性及未来。

Evolution of stars恒星的演化

The Ring Nebula, a dying star.
Source: NASA

- The origin of our solar system.
- 帮助我们了解太阳系的起源。
- How we compare our planetary systems with other planetary systems.
- 帮助对比我们的行星系统与其他行星系统的各种异同。
- If there could be life elsewhere in the universe.
- 以及探寻在宇宙的深处是否还有其他生命存在。

Properties of the Sun: the nearest star and how astronomers decide it - important!
太阳的性质——距离最近的恒星以及天文学家如何测定，非常重要！



The Sun.
Source: NASA SOHO Satellite

- Distance: 1.5 x 10^{11} m, reflecting radar waves from Mercury and Venus
- 距离： ：1.5 x 10^{11} m，通过水星和金星反射雷达波测定
- Mass: 2 x 10^{30} kg, measuring the movement of the planets that orbit around the Sun
- 质量： 2 x 10^{30} kg，通过测量绕日运动行星的轨道计算得出
- Diameter: 1.4 x 10^{9} m, from apparent diameter (angle) of the Sun and its distance
- 直径： 1.4 x 10^{9} m，根据太阳的视直径（角度）以及距离计算得出

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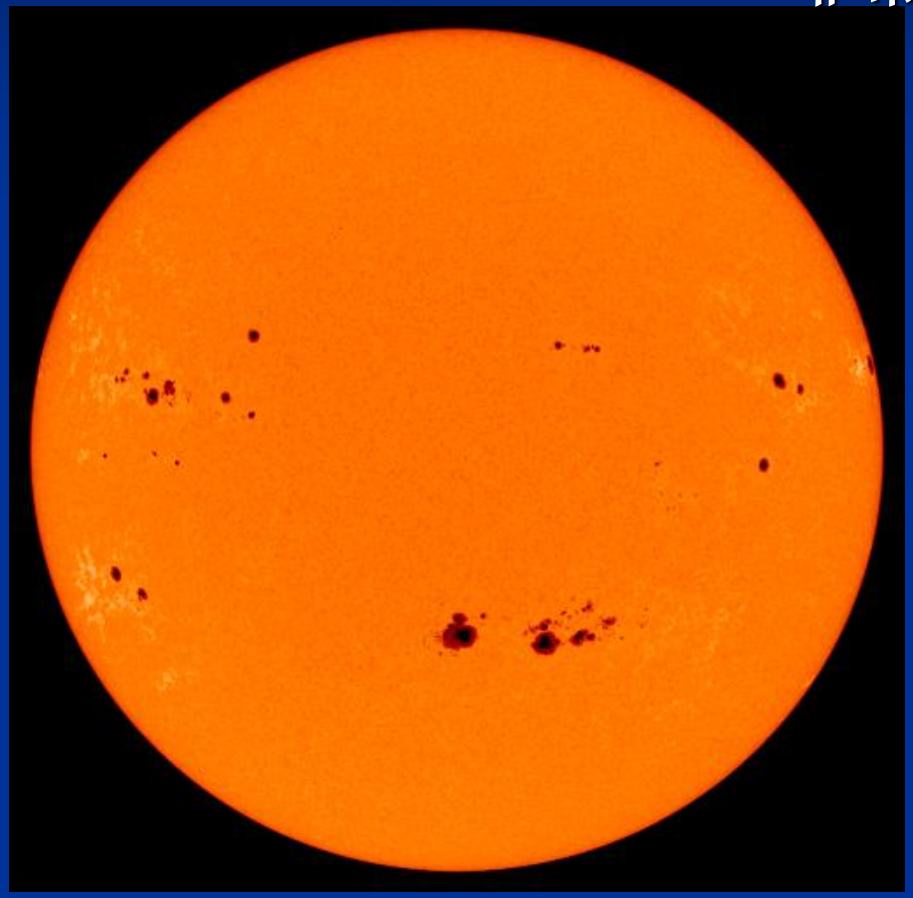


The Sun.
Source: NASA SOHO Satellite

- Power: 4 x 10^{26} W, from the distance and the measure power from Earth
- 辐射功率： 4 x 10^{26} W，根据日地距离以及地球上测得的功率得出
- Chemical composition: 98% hydrogen and helium, studying its spectrum.
- 化学组成：98%为氢和氦，通过分析太阳光谱得到

Properties of stars = distant Suns and how astronomers determine it-- important!
恒星的性质—遥远的太阳以及天文学家如何测定，非常重要

Orion Constellation.
Source: Besser Museum

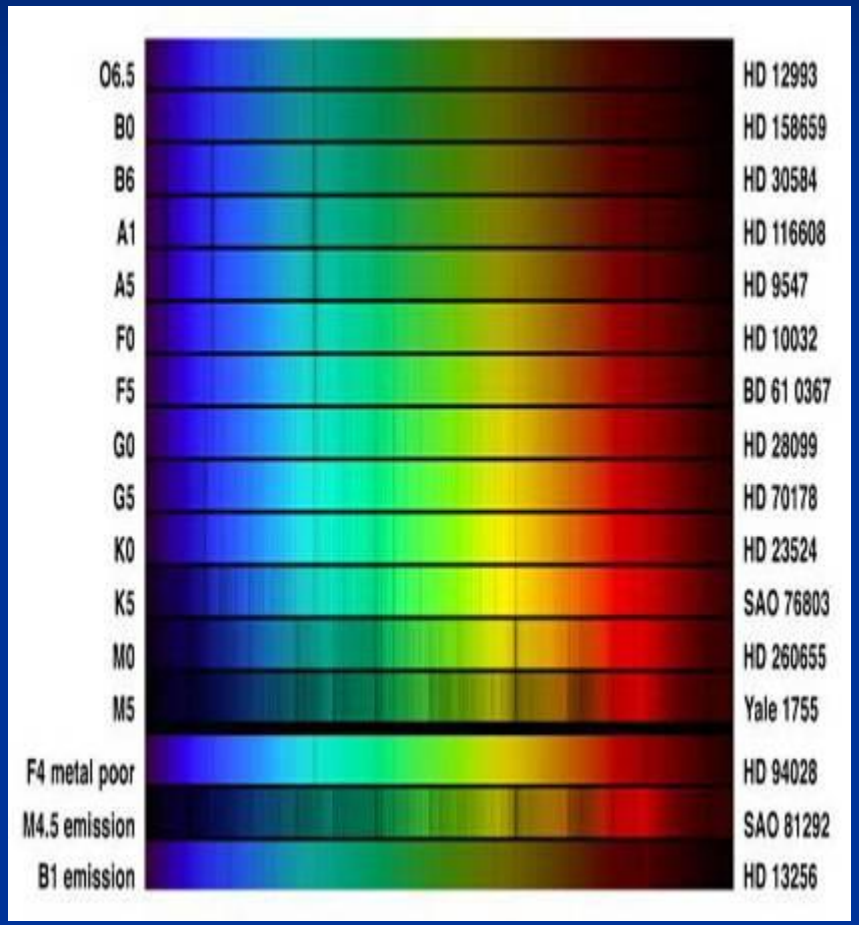
- Distance: from the parallax, or thanks to apparent brightness if the power is known.
- 距离：利用视差，或者已知功率以及视亮度信息求得
- Power: from the distance and apparent brightness
- 功率：利用距离以及视亮度求得
- Surface temperature: Due to the color or spectrum
- 表面温度：依据其颜色或者光谱求得
- Radio: Due to the power and temperature of the surface
- 半径：根据其辐射功率以及表面温度求得

Properties of stars = distant Suns and how astronomers determine it-- important!
恒星的性质—遥远的太阳以及天文学家如何测定，非常重要

Orion Constellation.
Source: Besser Museum

- Mass: Due to observations of binary stars
- 质量：通过观测双星的运动计算得到
- Chemical composition: from to the spectrum
- 化学组成：分析光谱得到

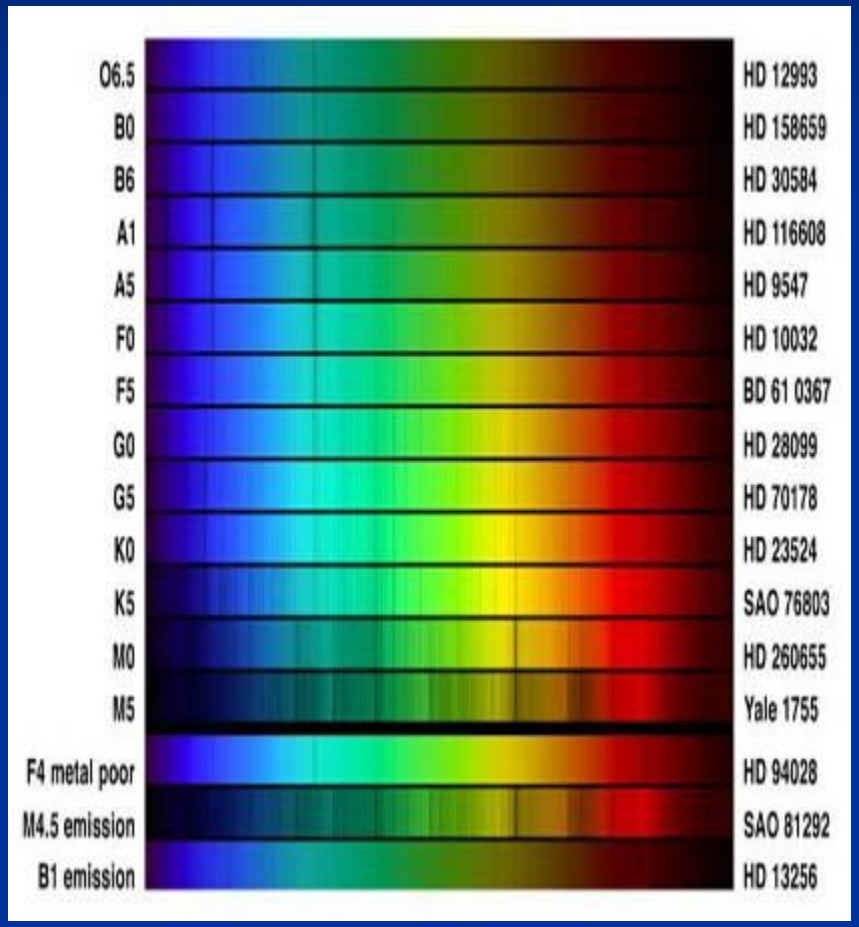
The spectra of the stars
starlight, decomposed into constituent colors
恒星的光谱：星光被分解成基本色



Stelar SApectra
Source: US National Optical Astronomy Observatory

- Astronomers learn about astronomical objects by light that they emit
- 天文学家通过研究天体辐射出的光来对其进行了解
- The spectrum provides information on the composition, temperature, and other properties of stars
- 光谱信息能为我们提供恒星的组成、温度以及其他的相关信息

The spectra of the stars
starlight, decomposed into constituent colors
恒星的光谱：星光被分解成基本色



Left: the first 13 spectra of stars of different temperatures (the highest on top), the three spectra at the bottom are from stars with peculiar properties

左图：从上至下的前13条光谱分别来自于温度不同的恒星（最顶端的温度最高），底下的3条光谱是来自于三颗性质特殊的恒星

Stelar SApectra
Source: US National Optical Astronomy Observatory

The Hertzsprung-Russell diagram

There is order in the properties of stars!

赫罗图：恒星的各项性质间存在相关性！

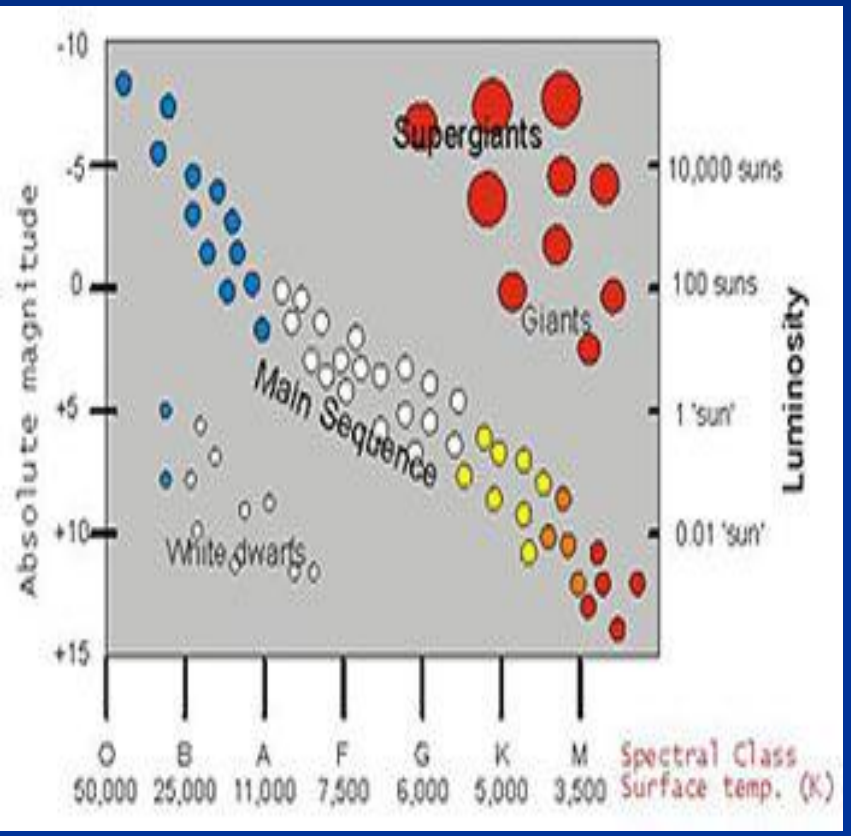


Diagram HR
Source: NASA

- The Hertzsprung-Russell (HR) diagram, draws the power (brightness) as a function of temperature (spectrum), the ordinate "absolute magnitude" is a logarithmic measure of power.
- 赫罗图（HR图）绘制出了功率（亮度）与温度（光谱型）的函数关系，纵轴“绝对星等”是功率的对数。
- Most of the stars are on the "main sequence": massive stars are hot stars and have high power, the small masses stars are cold and have low power (bottom right)
- 大部分恒星都处于“主序带”上：大质量恒星较热且辐射功率高（位于左上方），小质量恒星较冷且辐射功率低

The Hertzsprung-Russell diagram

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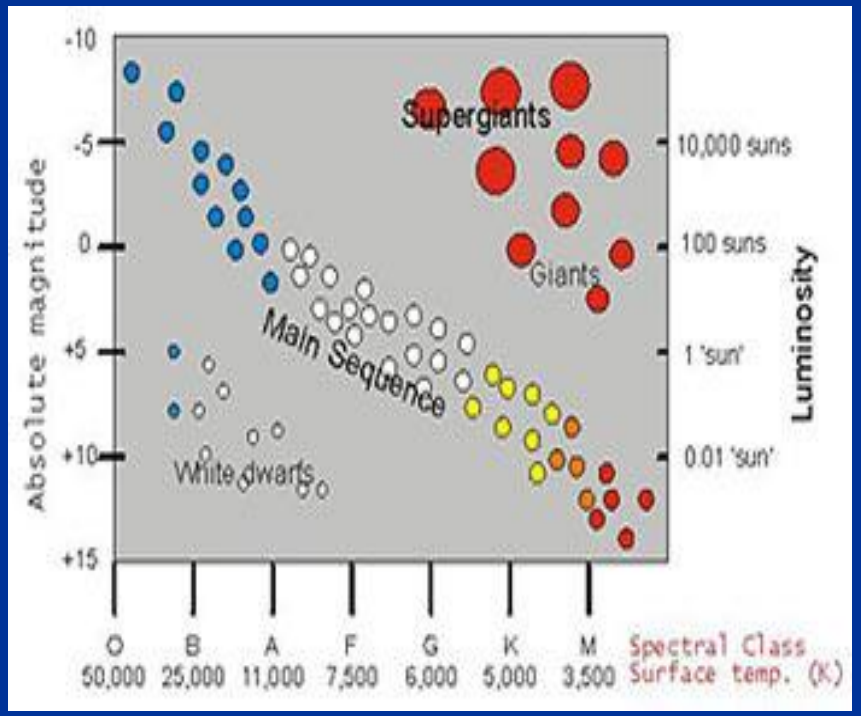
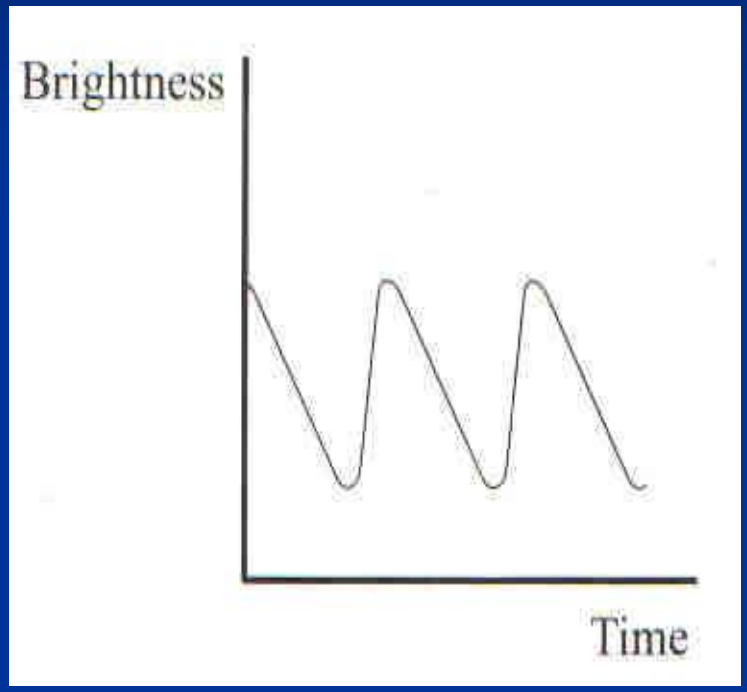
赫罗图：恒星的各项性质间存在相关性！



- The giant stars are on top at the right, and the white dwarf stars at the bottom left
- 巨星位于赫罗图的右上方，白矮星位于图中左下方

Diagram HR
Source: NASA

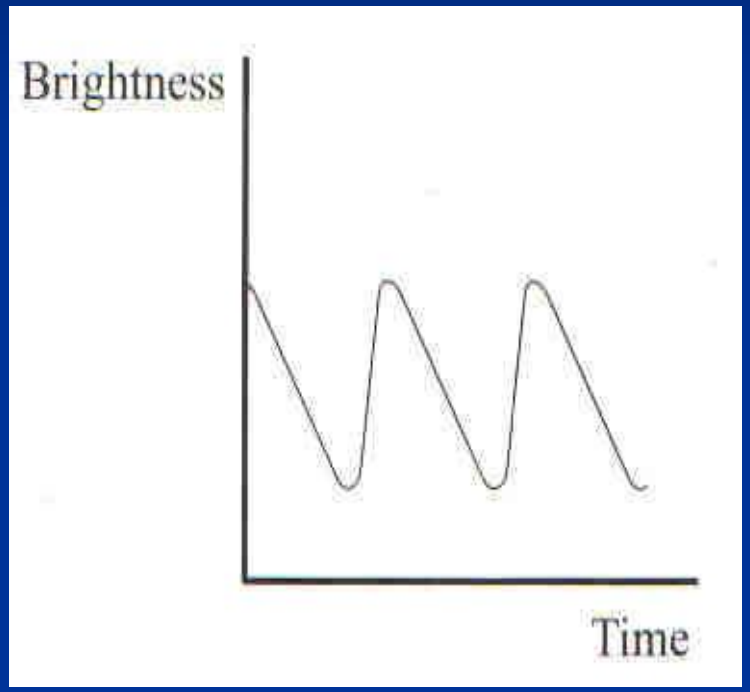
Variable Stars 变星



Light curve: a graph of brightness vs. time.

- Variable stars are stars that change their brightness with time
  变星：是指亮度会随时间发生变化的恒星。
- Most of the stars are variable; can vary because they vibrate, shine brightly, erupt or explode, or are eclipsed by a companion star or planet
  大多数恒星都是变星，这可能是因为恒星自身的震动、闪烁、喷发、爆炸，或者是受到伴星（恒星或行星）的掩食作用。

Variable Stars 变星

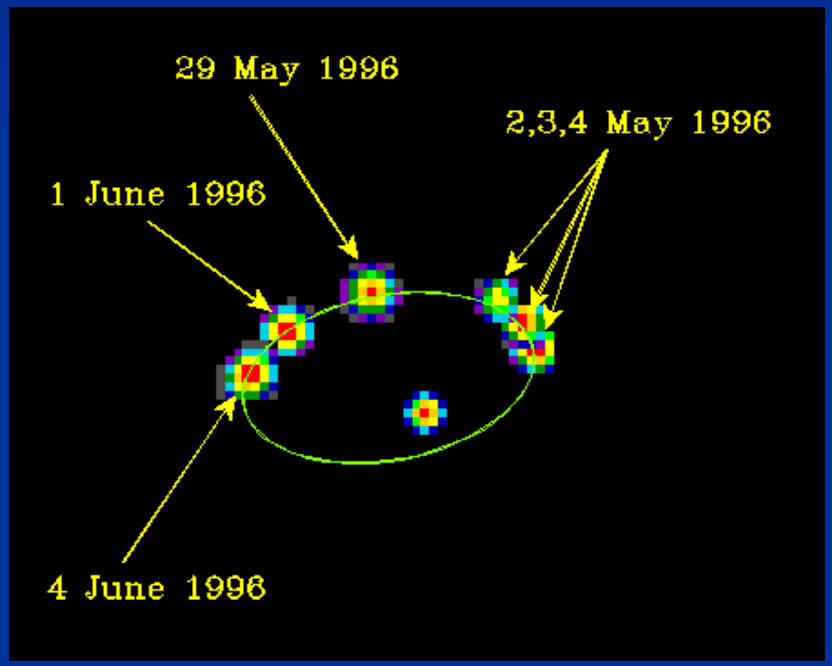


Light curve: a graph of brightness vs. time.

- **Variable stars provide important information about the stellar nature and evolution**

变星能为我们研究恒星的性质与演化提供非常重要的信息。

Binary stars (double) and multiple
双星和聚星



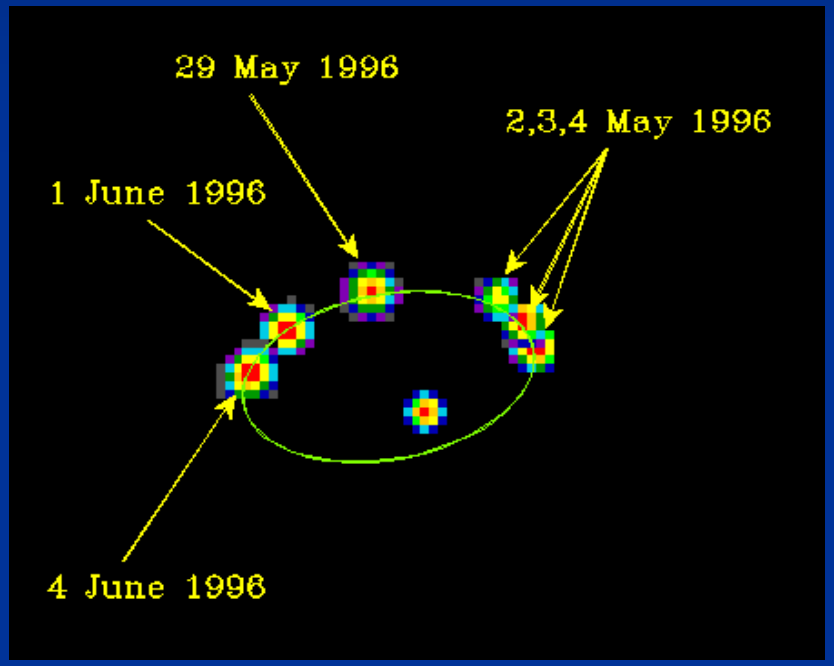
Orbital movement of Mizar, in Osa Major.
Source: NPOI Group, USNO, NRL

- Binary stars are pairs of stars that are close together due to gravity, and orbit around themselves. They can be visible directly (as in the image on the left), or detected by their spectra, or an eclipse between the stars.

双星是指两颗受到引力作用距离很近，互相绕转的恒星系统。

有些双星如左图所示是直接可见的，有些则是需要根据光谱发现，还有的可以通过恒星间的掩食[illegible]被发现

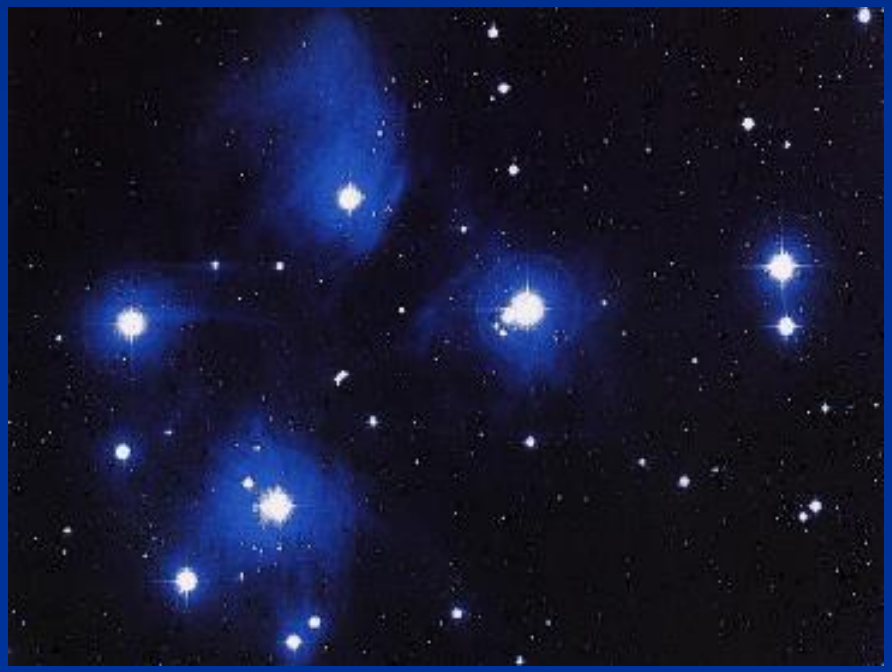
Binary stars (double) and multiple
双星和聚星



Orbital movement of Mizar, in Osa Major.
Source: NPOI Group, USNO, NRL

- They are the most important tool to measure the masses of stars
  双星系统是确定恒星质量非常重要的工具。
- Multiple stars are three or more stars that are bonded together due to gravity
  聚星系统是指三颗或三颗以上的恒星由于引力作用而聚集在一起的情况。

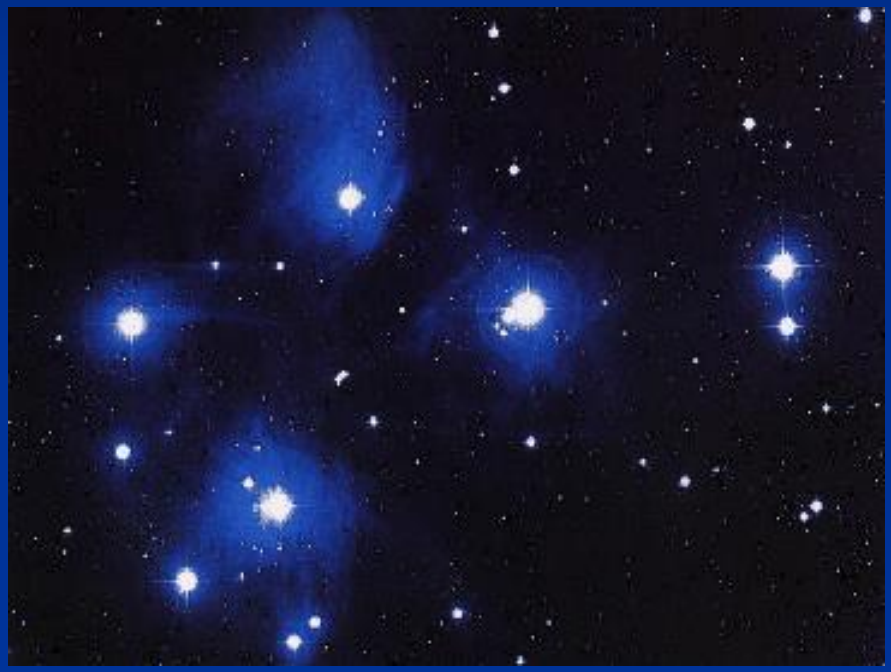
Star clusters “Experiments of nature”
星团 “大自然的实验”



Open Cluster The Pleiades.
Source: Mount Wilson Observatory

- Star clusters are groups of stars that are close each other due to gravity, and move all together through the space
  星团是指一群恒星受到引力作用而聚集在一起，并且在空间中一起移动。

Star clusters "Experiments of nature"
星团“大自然的实验”



Open Cluster The Pleiades.
Source: Mount Wilson Observatory

- They were formed at the same time and place, the same material, and are at the same distance, only differ in the mass
  它们形成于相同的时期和区域，具有相同的物质成分，并且在相同的距离处，不同的仅仅是各自的质量大小
- Clusters are samples of stars with different masses but with the same age
  星团中有着不同质量、年龄的大量恒星样本

What is it made the Sun and stars?
太阳和恒星由什么组成?

Abundances of chemical elements in the Cosmos: birdseed H (90%), rice He (8%), beans C, N, and O and a few of all the other elements (2%).

宇宙中的化学元素：

90%为氢，8%为氦，碳、氮、氧和其他元素占了2%。

What is it made the Sun and stars?
太阳和恒星由什么组成?

- **Using spectroscopy and other techniques, astronomers can identify the "prime materials" that stars are made of**

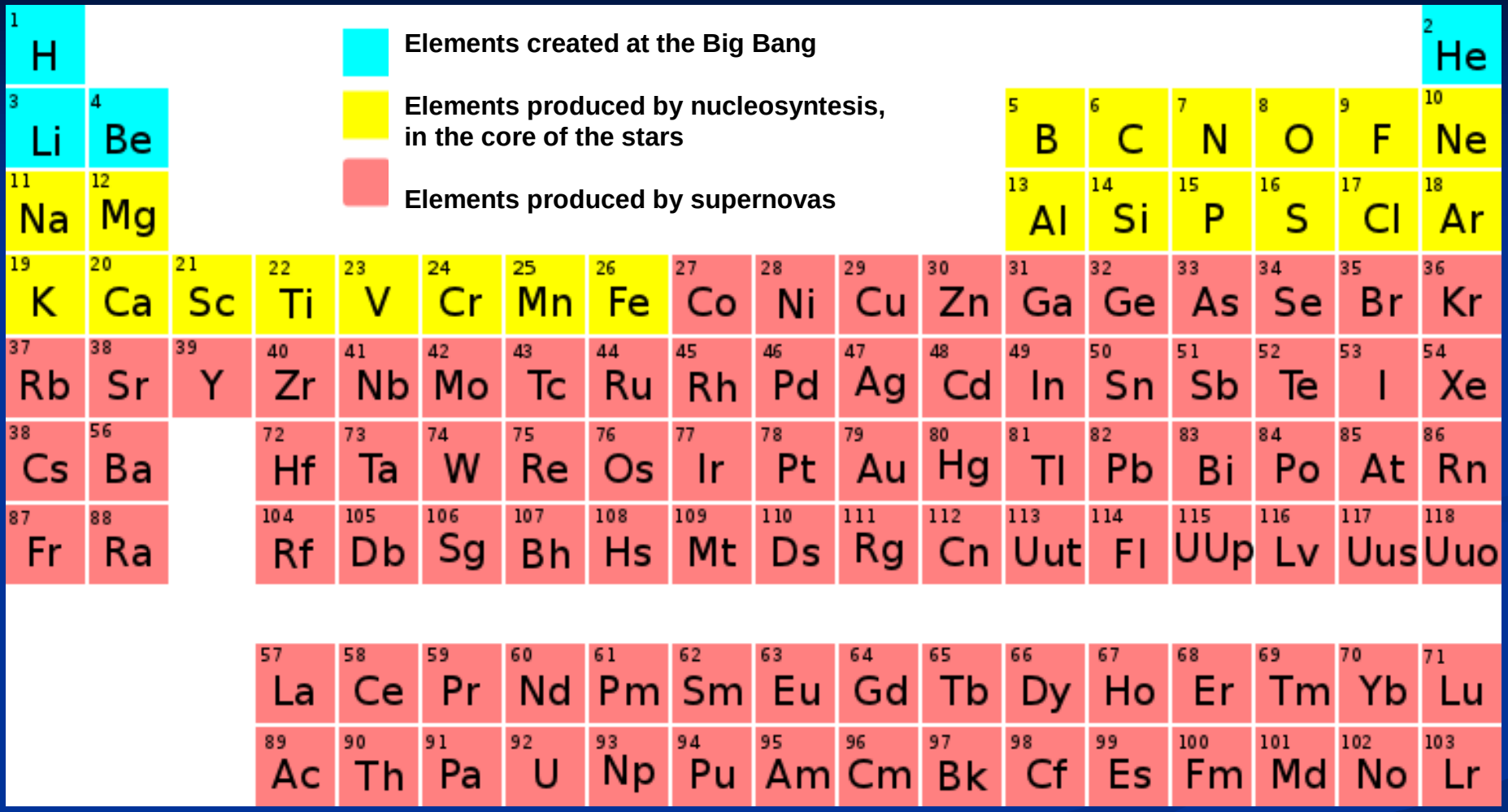
  利用光谱技术和其他技术，天文学家可以识别出组成恒星的"原材料"

- **Hydrogen (H) and helium (He) are the most abundant elements, and were formed with the formation of universe**

  氢和氦是宇宙中最丰富的元素，并且在宇宙形成早期就存在

- **Heavier elements are million or billion times less abundant. They were formed inside the stars through thermonuclear reactions**

  氢和氦的总量要比其他更重的元素多上百万或者十亿倍。较重的元素是通过恒星热核反应时在恒星中心形成的


Elements created at the Big Bang
Elements produced by nucleosyntesis, in the core of the stars
Elements produced by supernovas
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
38 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113 Uut
114 Fl
115 UUp
116 Lv
117 Uus
118 Uuo
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr

20

The laws of the star structure
恒星的结构

- **Inside the star, as we go deeper, the pressure increases due to the weight of upper layers.**

  由于恒星外层物质的重量，在恒星内部越深处，压力越大。

- **According with the laws of gases, temperature and density increase as the pressure increases.**

  根据气体定律可知，对于理想气体来说，压力越大，密度和温度也会越高。

The laws of the star structure
恒星的结构

- The energy will flow from the inside hotter part to the outside colder part, by radiation and convection.

  能量通过辐射和对流的方式，从内部温度较高的部分传递到外部温度较低的部分。
- If the energy flows out of the star, this is will cool - unless energy is created inside.

  如果热量由恒星内部传出，则其内层会因此变冷，除非其内部还能产能。
- *The stars are governed by these simple and universal laws of physics*

  恒星都遵循着这些简单而普适的物理规律。

Example: Why does not collapse or contracts the Sun?
例：为什么太阳没有塌缩或者收缩？

- Inflate a balloon as shown on the left
  如左图所示吹个气球
- The atmospheric pressure is "pushing" the balloon inward. It does not shrink because the gas pressure is "pushing" the balloon outward.
  大气压会将这个气球向内“挤压”，但由于内部气体向外的压力，所以没有发生收缩。
- Inside the Sun, gravity, pushing the material inward, is balanced by the gas pressure.
  在太阳内部，向内挤压物质的引力与向外的大气压力形成平衡。

The energy source for the Sun and Stars
太阳和恒星的能量来源

- Chemical combustion of gas, oil or carbon?
  天然气、石油或碳这类化学燃料？
- This process is so inefficient that bring energy to the sun for only a few thousand years
  这种方式效率很低，仅能点燃太阳几千年而已
- Slow gravitational contraction?
  缓慢的引力收缩？
- This could bring energy to the Sun during millions of year but the Sun is billions years old

这种能量来源足以维持数百万年。不过，太阳的年龄长达数亿年了。

The energy source for the Sun and Stars
太阳和恒星的能量来源

- Radioactivity (nuclear fission)?

  放射性（核裂变）？

- Radioactive isotopes are almost non-existent in the Sun and stars

  太阳和其他恒星上的放射性元素极为稀少

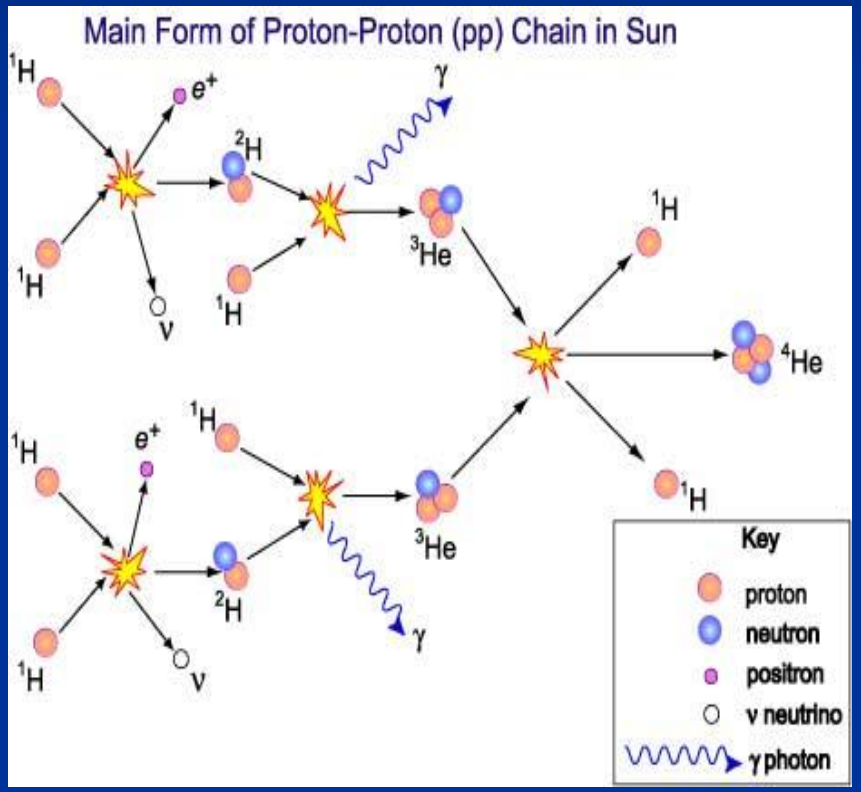
- Nuclear fusion of light elements into heavier ones?

  较轻元素核聚变为较重元素？

- Yes! This is a very efficient process, and light elements such as Hydrogen and Helium represent 98% of the Sun and stars

  正是如此！这种过程效率非常高，而且例如氢、氦这些较轻元素在太阳及其他恒星上的含量高达98%。

Chain Proton-Proton is the main process of fusion in the Sun
太阳上的主要聚变反应——“PP链”



Proton-proton cycle
Source: Australia National Telescope Facility

- At high temperature and density, in stars like the Sun protons (in red) overcome the electrostatic repulsion between them, and permeate to form ² H (deuterium), and a neutrino (ν)

在类似于太阳的恒星中，高温且高密度，质子（红色）会克服静电斥力形成² H （氘）和中微子ν。

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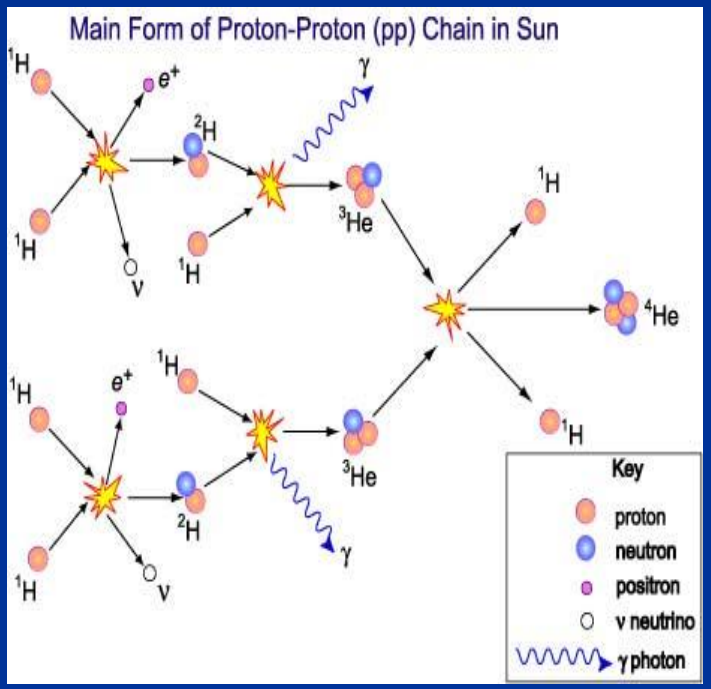
太阳上的主要聚变反应——“PP链”



Proton-proton cycle
Source: Australia National Telescope Facility

- Later, another proton is coupled with deuterium to form ^3He

然后，另一个质子会和氘一起形成^3He。

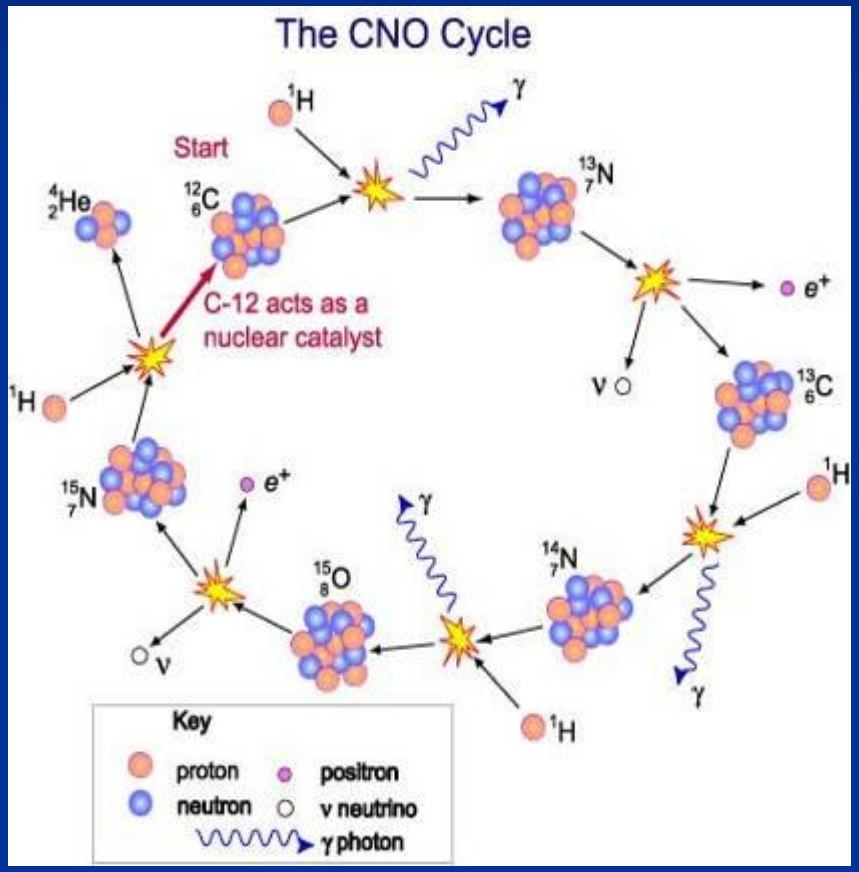
- Later, the ^3He nuclei are coupled with each other to form a ^4He nucleus, releasing two protons.

然后，两个氦3原子核会彼此结合形成一个氦4原子核，同时释放出两个质子。

Result: 4 protons together to form helium and energy (gamma-rays and kinetic energy)

结果就是，四个质子一起形成了氦并释放能量（以伽马射线和原子核动[illegible]式）

The carbon – oxygen cycle
CNO循环

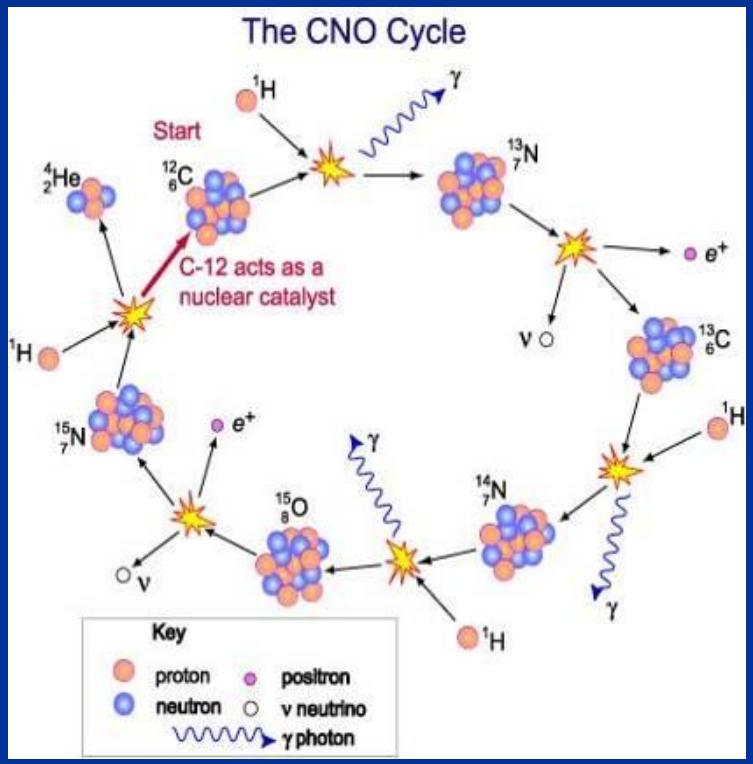


- In massive stars, with very hot nucleus, protons (red) will put togheter with a ^{12}C (carbon) nuleus (top left)

  在大质量恒星中，核内温度极高，质子（红色）将与^{12}C（碳）在一起（图中左上）

CNO cycle
Source: Australia National Telescope Facility

The carbon – oxygen cycle
CNO循环



CNO cycle
Source: Australia National Telescope Facility

- This begins a circular sequence of reactions in which four protons fuse to form a Helium nucleus (top left)

  这时会发生循环反应——四个质子融合成一个氦原子核（图中左上）。

- A ^{12}C nucleus is recovered, therefore the ^{12}C neither be created nor destroyed; acts as a nuclear catalyst

  在反应过程中^{12}C仍会保留，既没产生也没消失，它只是作为催化剂参与了整个过程。

Making stellar “models”
建立恒星“模型”

- The laws of the structure of the stars are expressed in equations, and are resolved by means of a computer

  恒星结构遵循的原则可以通过方程表达出来，然后利用计算机给出计算结果。

Making stellar “models”
建立恒星“模型”

- The computer calculates the temperature, density, pressure, and the power at each point of the Sun or the star. This is called a model

  计算机会给出温度、密度、压强和太阳（或其他恒星）中某处的辐射功率。这就是构建的模型。

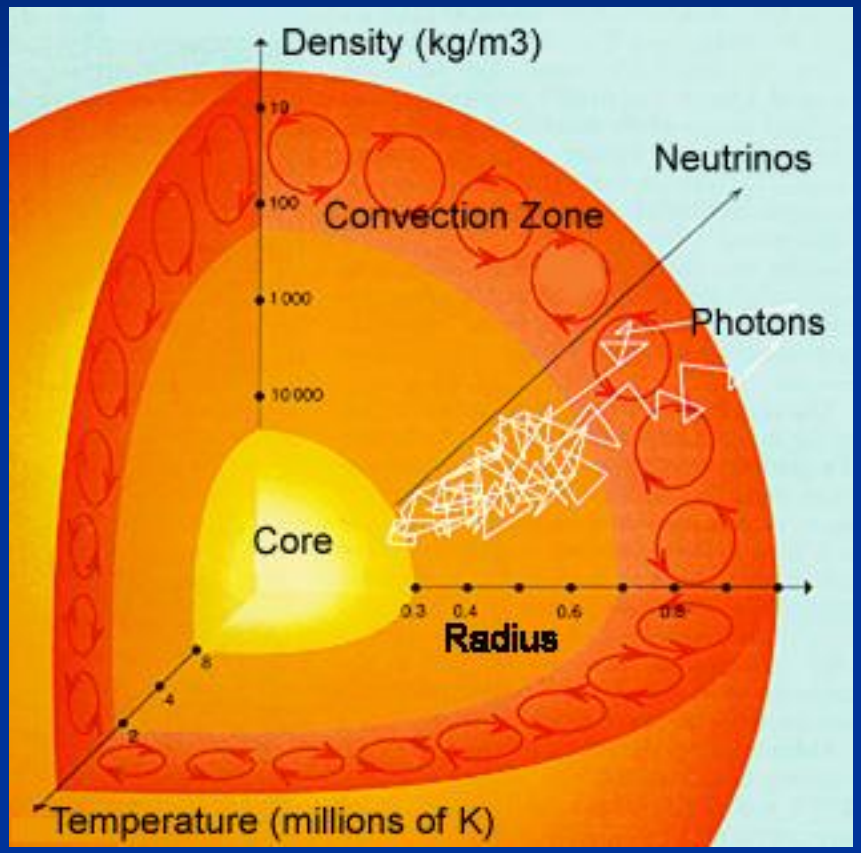
- In the center of the Sun, the density is 150 times that of water, and the temperature is 15,000,000 K!

  在太阳中心的密度是水密度的150倍，温度高达15,000,000 K!

In the interior of the Sun

Based on a “model” of the Sun made with computer

太阳内部：基于计算机给出的“模型”



Solar model

Source: Institute of Theoretical Physics, University of Oslo

- Inside the hot core, nuclear reactions produce energy by fusing hydrogen into helium

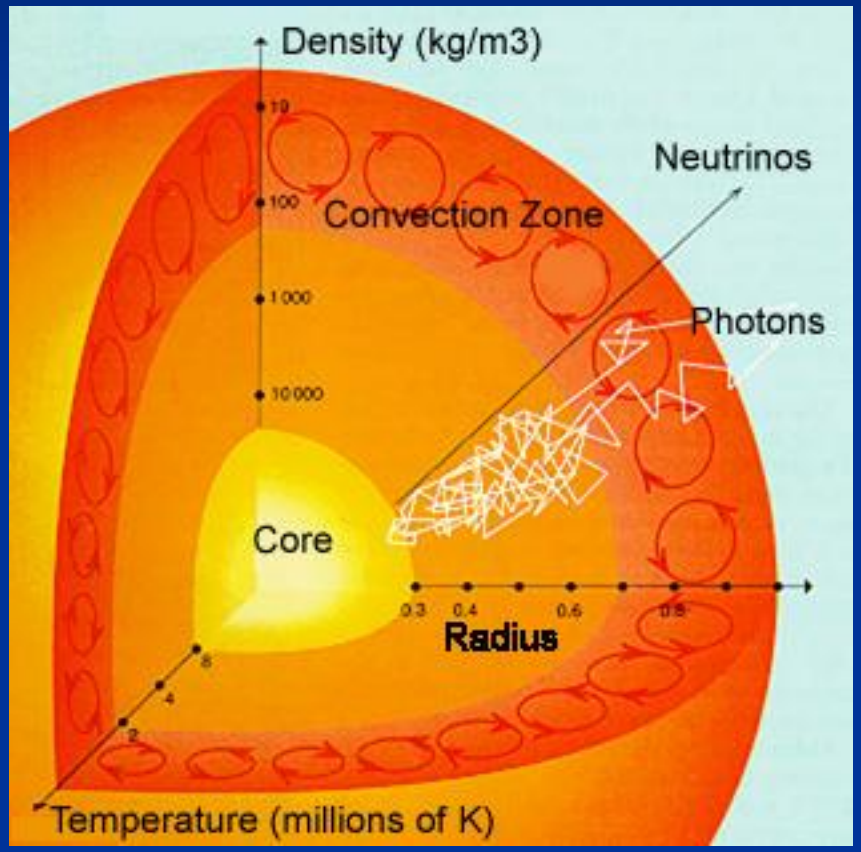
  在太阳炽热的核心区里，通过氢聚变成氦的核聚变反应正不断向外释放能量

- In the radioactive zone, above the nucleus, the energy flows out through the mechanism of radiation

  在核心区外层的辐射区，能量通过辐射的方式向外传导

In the interior of the Sun

Based on a "model" of the Sun made with computer



Solar model
Source: Institute of Theoretical Physics, University of Oslo

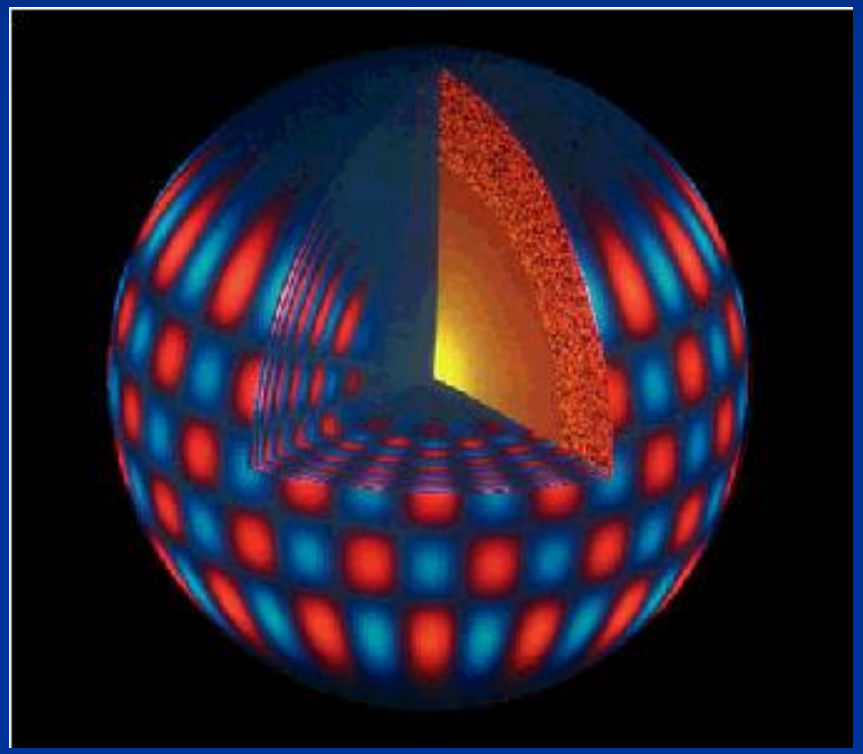
- In the convective zone, between the radioactive area and the surface area, the energy flows out by convection

  在太阳辐射区与表面之间的对流区，能量通过对流的方式向外传导

- The photosphere, on the surface, is the layer where the star becomes transparent

  太阳表面是光球层，至此恒星变得较为透明

Testing helioseismology model
日震模型的检验



Artistic conception of the solar vibration. Source: US National Optical Astronomy Observatory

- The Sun vibrates gently in thousands of ways (patterns). One of them is shown in the image on the left

  太阳及其他恒星在以上千种模式轻微震动，其中一种就如左图所示。

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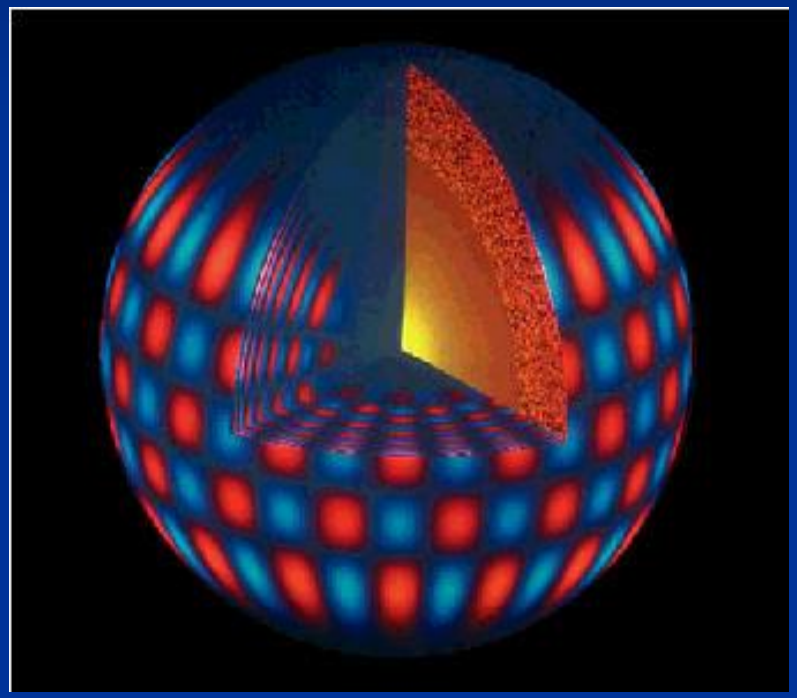
Testing helioseismology model
日震模型的检验



Artistic conception of the solar vibration. Source: US National Optical Astronomy Observatory

- They can be observed; This data is used to deduce the internal structure of the Sun, and this, review models. This process is known as helioseismology

  这些震动是可以观测的，利用这些数据可以研究太阳的内部结构并检验模型。这种过程就称为日震。

- Similar vibrations can be observed in other stars: astroseismology

  在其他恒星中也存在类似的，称为：星震。

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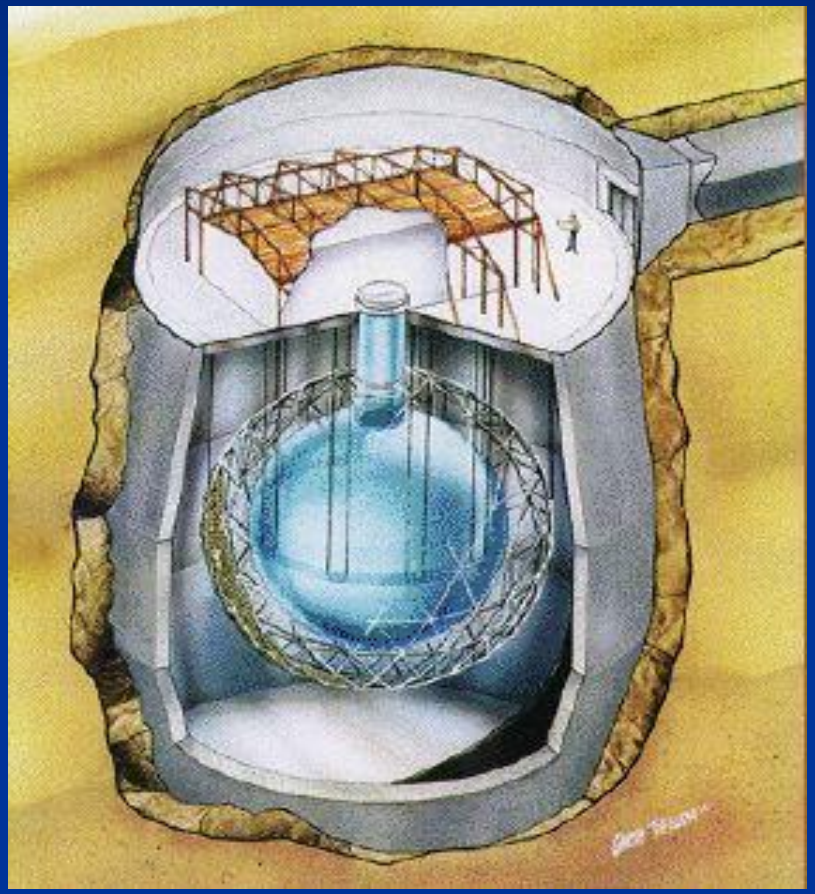
Testing the solar neutrino model
检验太阳中微子模型



Observatory of neutrino, Sudbury
Source: Sudbury Neutrino Observatory

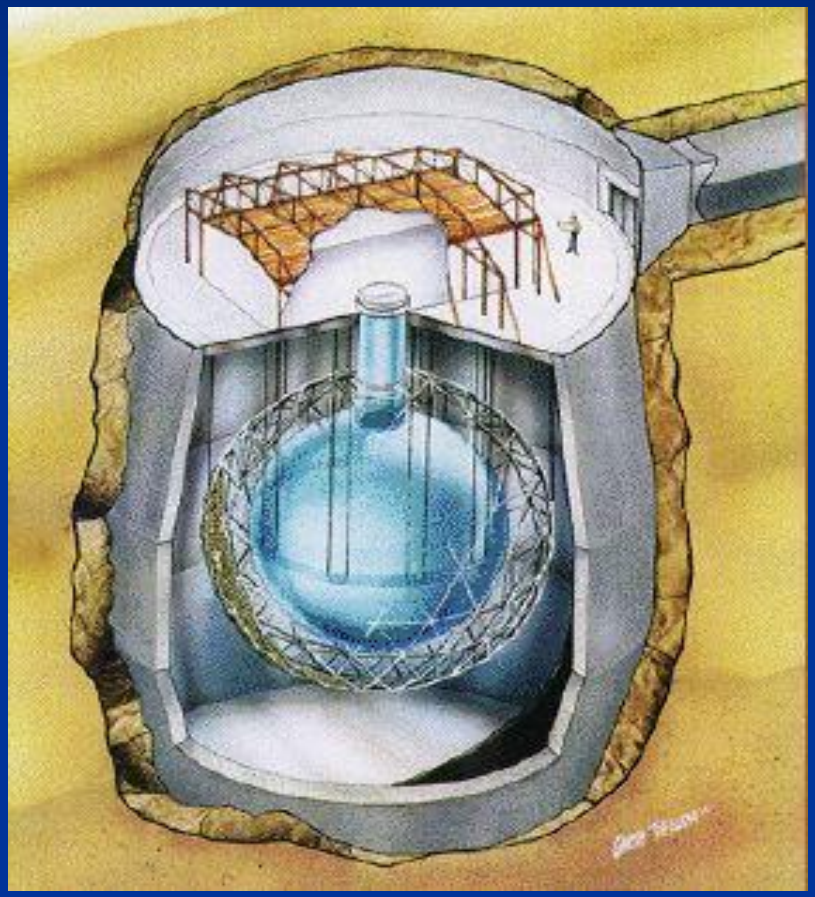
- Nuclear fusion reactions produce elementary particles called neutrinos.

  核聚变的反应过程中会产生大量的亚原子粒子——中微子。

- They have very low mass, and rarely interact with matter.

  它们仅有非常小的质量，极少与物质相互作用。

Testing the solar neutrino model
检验太阳中微子模型



Observatory of neutrino, Sudbury
Source: Sudbury Neutrino Observatory

- Their mass was detected and measured thanks to special observatories, such as the Sudbury Neutrino Observatory (left). The results are consistent with the predictions obtained in models

得益于特殊的观测装置，比如，加拿大萨德伯里中微子天文台（SNO，左图），我们才得以探测并对其数量进行计量。其观测所得数量与模型预言的相一致。

The duration of the life of the stars
恒星的一生

- The duration of the life of a star depends on how much nuclear fuel has (Hidrogen), and how fast consume it (power)

  恒星的生命能延续多久，取决于它拥有多少核燃料（氢），以及其消耗速率有多快（功率）

- The stars less massive than the Sun are the most common. They have less fuel, but much smaller powers, so they have longer lives

  其实，大多数常见的恒星质量一般要比太阳小，它们的燃料也较少，但辐射功率也相应较小，所以它们的寿命反而更长。

The duration of the life of the stars
恒星的一生

- The stars more massive than the Sun are very rare. They have more fuel, but powers much higher, therefore have shorter lives

  仅有少数恒星的质量会比太阳质量大，它们拥有更多燃料，但辐射功率也更大，所以寿命反而较短。

How astronomers learn about the evolution of stars
天文学家如何研究恒星的演化

- Observing the stars in various stages of their lives, and putting them in a sequence of logical evolution.

  观测夜空中处于不同演化阶段的天体，将其罗列在符合逻辑顺序的“演化序列”上。

- Making models using computers, using the laws of physics, and accounting for changes in the composition of the stars that occur because of nuclear fusion.

  根据物理规律，通过计算机建立模型，并考虑随着核反应的发生恒星内部物质成分的变化。

How astronomers learn about the evolution of stars
天文学家如何研究恒星的演化

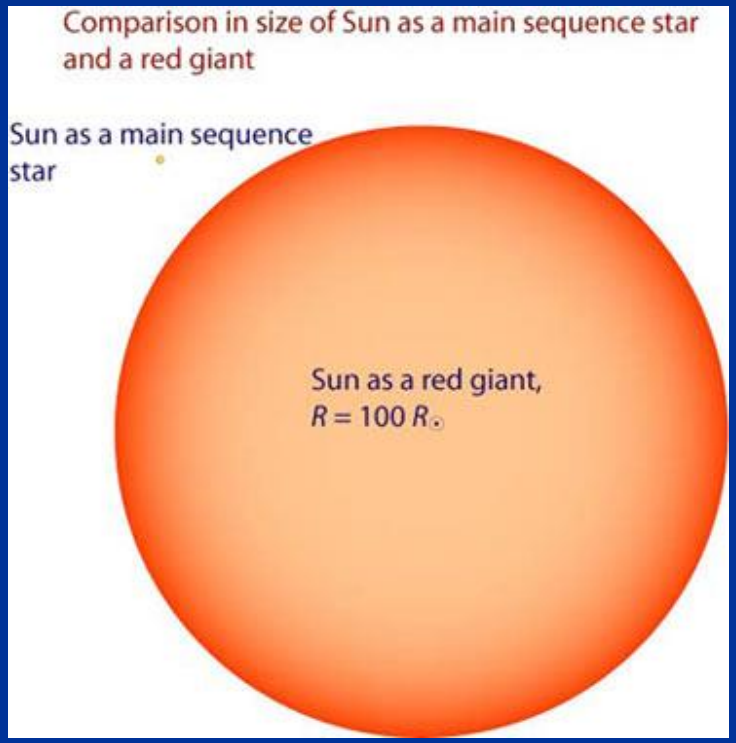
- Studying the stellar clusters and/or groups of stars with different masses, but with the same age.

  研究星团和恒星群，这些恒星基本都同时产生，但质量却各异。

- Studying the fast and strange phases in stellar lives (e.g. supernovae and novae).

  研究在恒星演化过程中快速、奇特的阶段，比如超新星。

The evolution of Sun-like stars
类太阳恒星的演化



Comparison of size: Sun - red giant
Source: Australia National Telescope Facility

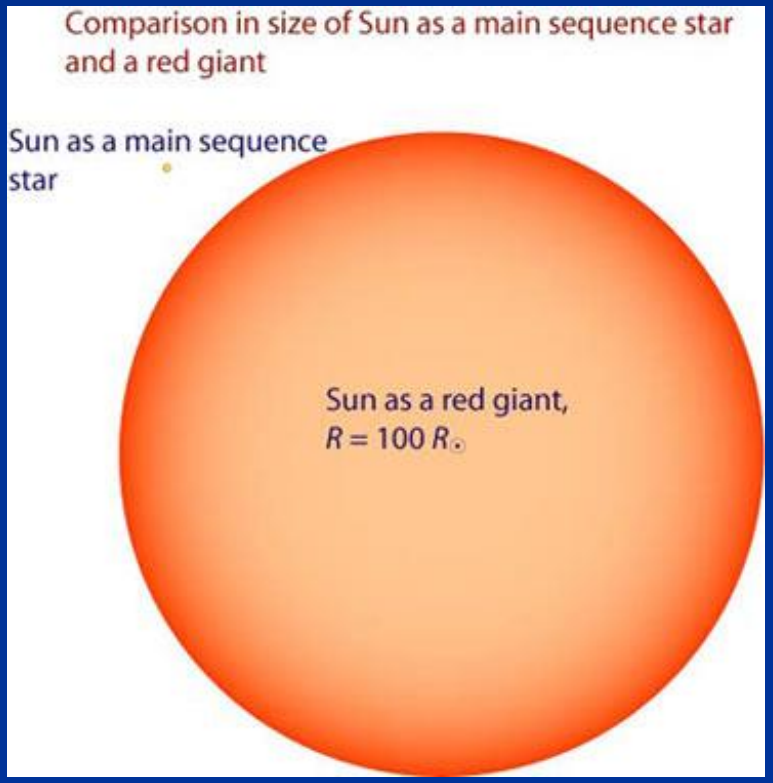
- The Sun-like star does not change much during the first ~90% of its life, as far as it has enough fuel (hydrogen) to continue with thermonuclear reactions. We call it a main sequence star.

  在类太阳恒星的一生中，90%的时间里并不会发生变化，期间只是在消耗其燃料：氢。这就是一颗主序星。

- When its fuel, Hydrogen, exhausts, it expands into a red giant star.

  当其燃料——氢耗尽时，它就会膨胀成一颗红巨星。

The evolution of Sun-like stars
类太阳恒星的演化



Comparison of size: Sun - red giant
Source: Australia National Telescope Facility

- Inside the core, the temperatures can increase enough to start to produce the energy through the fusion of helium into carbon.

  其核心足够高温，能够迅速将氦聚变成碳。

- When the Helium fuel is exhausted, again swells into a red star giant wholesale, hundreds of times bigger than the Sun

  当氦耗尽时，它会再度膨胀，更大，将比太阳大上百倍。

The death of Sun-like stars
类太阳恒星的死亡

- When the star becomes a red giant, begins the pulsation (vibration). It is called a Mira star.

  当恒星演化成红巨星，就会开始脉动，也被称为刍藁型星。

- The pulsation causes the separation of the outer layers of the star, producing a beautiful planetary nebula (on the left)

  这种脉动会使恒星外部壳层分离，形成左图中美丽的行星状星云。

- The core of the star is a dense, white, small, dwarf without fuel

其中心处将剩下一个致密、白色体积较小、耗尽燃料的白矮星

Helix Planetary Nebula.
Source: NASA

White dwarf白矮星

The white dwarf companion of Sirius (below). Source: NASA

- A white dwarf presents a dead core of a Sun-like stars.

  类太阳恒星死亡后就会变成白矮星。

- A white dwarf star has a mass similar to the Sun, a volume similar to the Earth, and a density million times greater than that of the water.

  白矮星的质量与太阳接近，体积与地球相似，其密度是水的百万倍。

White dwarf 白矮星

The white dwarf companion of Sirius (below). Source: NASA

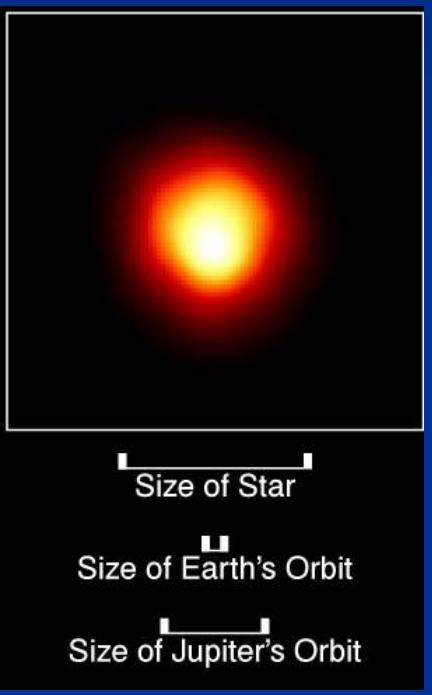
- In a white dwarf, the centripetal gravitational force is balanced by the external quantum pressure of the electrons in its interior.

  在白矮星中，其向内的引力与向外的电子压力相平衡。

- Many nearby stars, including (left) Sirius (left) and Procyon, have white dwarf companions.

  我们周围许多近邻恒星，包括左图中的天狼星和南河三这样的明亮恒星周围，都有白矮星在围绕着它们运动。

The evolution of a massive star
大质量恒星的演化



Betelgeuse.
Source: NASA/ESA/HST

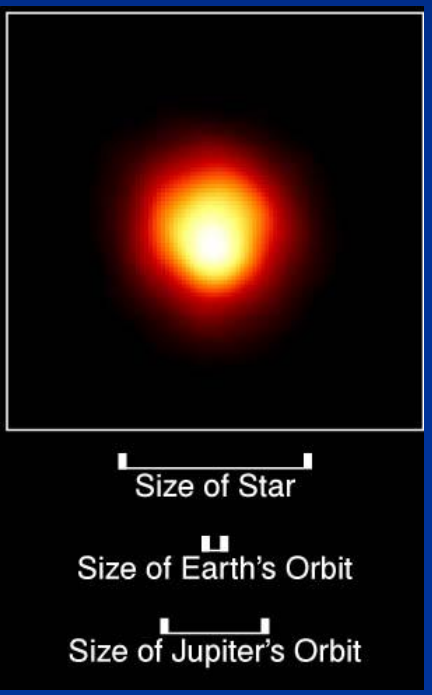
- Massive stars are rare, powerful and consume their fuel very quickly - in a few million years.

  大质量恒星辐射功率强大，消耗燃料速度极快，但却较为罕见。它们寿命较短，仅有几百万年。

- When they spent their fuel, they swell and become red supergiant stars

  当其用尽燃料时，会发生膨胀演化成红超巨星。

The evolution of a massive star
大质量恒星的演化



Betelgeuse.
Source: NASA/ESA/HST

- Their core are very hot, enough to melt heavy elements as Iron .

  其核心非常炽热，足以熔化铁这类的重元素。

- Betelgeuse (left), in Orion, is a bright red supergiant. It is larger than the Earth's orbit

  猎户座参宿四（左图），是一个明亮的红巨星。它比地球的轨道还要大。

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The death of a massive star
大质量恒星的死亡

- When the core of a massive star disintegrates Iron, has no more nuclear fuel and can no longer remain hot.

  在其生成的铁核后，它将无法在进行聚变或裂变，也就没有可用的能量来源。至此，已没有能量去维持铁核的炽热。

- Gravity crushes the nucleus in a neutron star, releasing enormous amounts of gravitational energy, and leading the star to an explosion of a supernova (left).

  重力会将其挤压成一颗中子星，同时释放出巨大的引力能，使得恒星的外层发生爆炸形成超新星（左图）。

The crab nebula, the remnant of an explosion of supernova observed in 1054 AD.
Source: NASA

The death of a massive star
大质量恒星的死亡

The crab nebula, the remnant of an explosion of supernova observed in 1054 AD.
Source: NASA

- Supernovae produce elements heavier than Iron, and expel these and other elements to the space, which become part of new stars, planets and life

  超新星会产生比铁更重的元素，并连同其他物质一起抛向宇宙中，这些将会成为新的恒星、行星和生命的组成部分。

Neutron stars中子星

Pulsar, neutron star in the heart of the Crab Nebula
The rotational energy that emits energized Nebula.
Source: NASA/ESA/HST

- The stellar cores with masses between 1.5 and 3 times the mass of the Sun collapse to become neutron stars at the end of the life of the star.

  质量为1.5~3倍太阳质量的恒星在其生命完结之时，其中心部分将会塌缩成中子星。

- They have diameters of about 10 km and densities trillions of times bigger than water.

  它们的半径大约为10km，密度要比水高数万亿倍。

Neutron stars中子星

Pulsar, neutron star in the heart of the Crab Nebula
The rotational energy that emits energized Nebula.
Source: NASA/ESA/HST

- They are made of neutrons and more exotic particles.

  中子星由中子以及其他更奇特的粒子组成。
- Young neutron stars rotate rapidly and emit regular pulses of radiation of radio, they are known as pulsars.

  年轻的中子星高速旋转，并周期性对向外发出射电辐射脉冲，也被称为脉冲星。

Black holes 黑洞

Artistic conception of Cygnus X-1, a visible Star (left) with a black hole (right) in a disk accretion. Source: NASA.

- A black hole is an astronomical object whose gravity is so strong that nothing can escape, not even light.

黑洞这类天体是指，密度高到没有任何物质可以逃离其引力的控制，就连光线也无法逃脱。

- The nuclei of the uncommon massive stars (more than 30 times the mass of the Sun) become black holes when them the fuel runs out.

在那些罕见的大质量恒星（超过30倍的太阳质量）耗尽燃料时，就会变成黑洞。

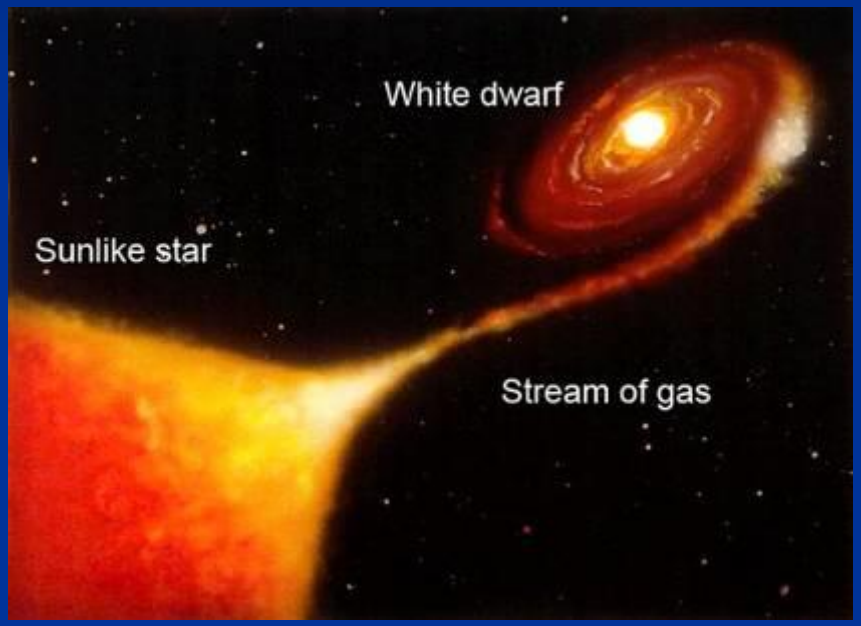
Black holes 黑洞

Artistic conception of Cygnus X-1, a visible Star (left) with a black hole (right) in a disk accretion.
Source: NASA.

- One way of black hole detection: when a visible star is orbiting around them (left).

探测黑洞一种的办法：当黑洞周围有可观测恒星在绕其运动（左图）。

Cataclysmic variable stars
激变变星



A star with a normal cataclysmic variable (left) and a white dwarf star on an accretion disc (right).
Source: NASA

- Many stellar corpses - white dwarfs, black holes or neutron stars - have a normal visible star orbiting around it.

  许多恒星的“尸体”——白矮星、黑洞或者中子星周围都会有一颗普通的可观测恒星在进行绕转。

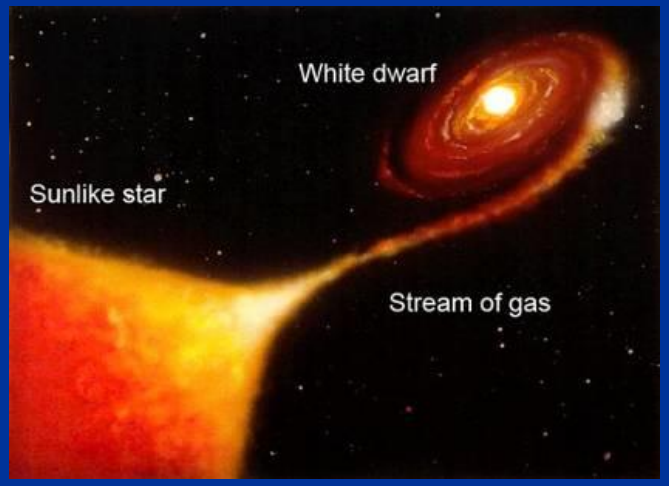
Cataclysmic variable stars
激变变星

- If the gas from the normal star falls to the stellar remnant, the accretion disk can be formed around it (left).

如果从普通恒星上喷出的气体物质掉落到恒星“尸体”附近，那么就会在其周围产生吸积盘（左图）。

- When gas falls on the stellar corpse, it can burst, erupt, or exploit, this is a cataclysmic variable star

当气体物质掉向恒星“尸体”时，会发生喷发、爆炸，这就被称为激变变星。



A star with a normal cataclysmic Variable (left) and a white dwarf star on an accretion disc (right).
Source: NASA

The birth of stars
恒星的诞生

Orion Nebula
Source: NASA

- Stars are formed inside the molecular clouds (nebulae), made of cold gas and dust. 恒星诞生于分子云（星云）之中，主要由冷气体和尘埃构成。
- Interstellar dust and gas is about 10% of the matter in our Galaxy.在我们的银河系物质中，10%左右的是星际尘埃和气体。

The birth of stars
恒星的诞生

- The young stars can generally be found inside or near the nebula from which they arose.年轻的恒星一般都在诞生所在地的星云内部或者附近。
- The closer and clear example of a "stellar nursery" is the Orion Nebula (left), around 1500 light years away.

  离我们较近的典型例子就是左图中的“恒星托儿所”——猎户座星云，大约距离为1500光年。

Orion Nebula
Source: NASA

Interstellar gas
The gas between the stars
星际气体——恒星间的气体

- The interstellar gas (atoms or molecules) can be activated by ultraviolet light from a nearby star, producing an emission Nebula (left).

  星际气体（原子或分子）会被附近恒星的紫外辐射激发，形成发射星云（左图）。

The Orion Nebula. The gas is energized by ultraviolet light from the stars in the Nebula. Source: NASA

Interstellar gas
The gas between the stars
星际气体——恒星间的气体

The Orion Nebula. The gas is energized by ultraviolet light from the stars in the Nebula. Source: NASA

- Cold gas between the stars, produces radio waves that can be detected by radio telescopes.

  恒星间的较冷气体还会产生射电波，能利用射电望远镜探测到。

- 98% of the interstellar gas is made of hydrogen and helium

  98%的星际气体是氢和氦。

Interstellar dust
Dust between the stars
星际尘埃——恒星间的尘埃

- Interstellar dust near the bright stars can be detected in the visible part of spectra 靠近亮星的星际尘埃可以在光谱的可见光波段被观测到
- Dust can block the light from the stars and gas behind (left). The stars are formed in these clouds.

  尘埃能够遮挡住背后恒星和气体的光线（左图）。而恒星正在这些云块中诞生。

M16
Soruce: NASA/ESA/HST

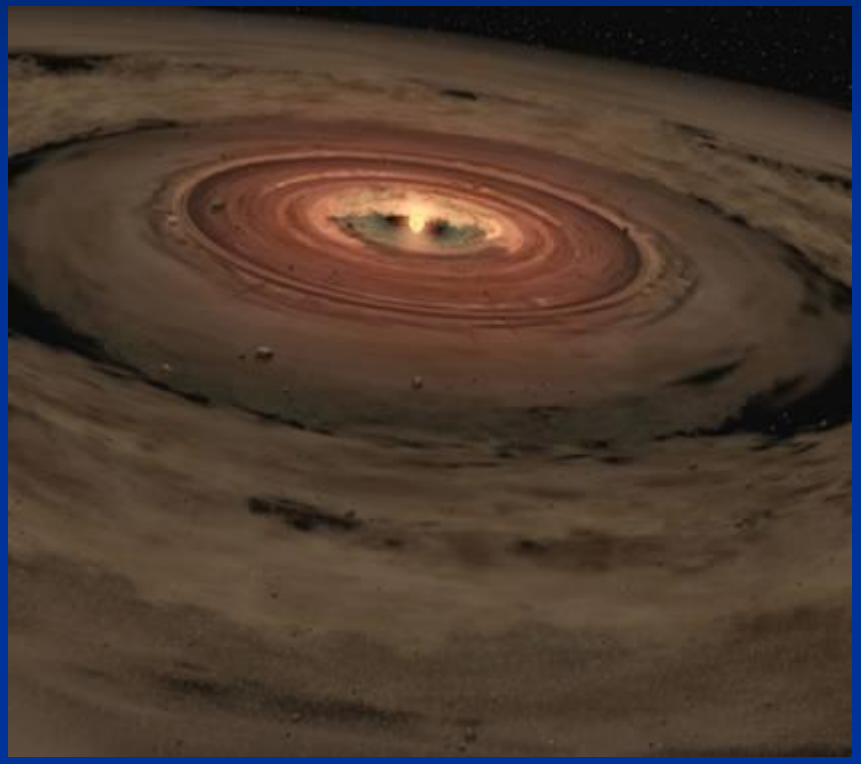
Interstellar dust
Dust between the stars
星际尘埃——恒星间的尘埃

- Only 1% of the material between the stars is dust. The dust particles are a few hundred nm in size, and are mostly silicates or graphite

在恒星间仅有1%的物质是尘埃。这些尘埃颗粒的大小只有几百纳米，主要是硅酸盐和石墨。

M16
Soruce: NASA/ESA/HST

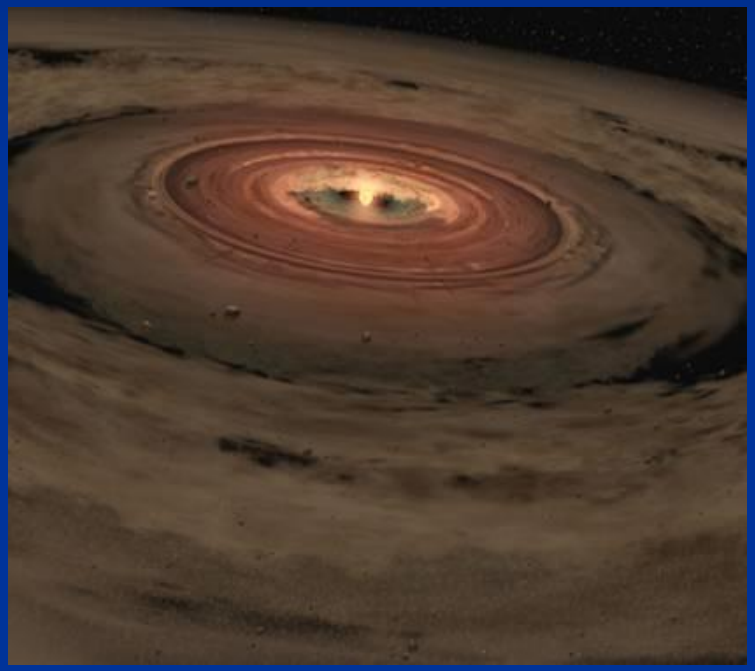
Star formation
恒星形成



Artistic conception of a planetary system in the formation process.
Source: NASA

- The stars are formed from parts of a nebula called nuclei, which are dense or compressed. 恒星产生自星云中的致密部分，云核。
- Gravity is responsible for attraction of nuclei. 引力作用不断压缩核心区域。

Star formation
恒星形成



Artistic conception of a planetary system in the formation process.
Source: NASA

- The conservation of angular momentum increases the rotation of the nuclei, which become flattened and finally convert into the discs. 由于角动量守恒，随着核心的转动不断加速，核心会变得扁平，最终变成盘状。
- Stars are formed in the center of disks. The planets are formed in the colder outer parts of the disk.
  恒星就产生自盘的中心。行星产生自盘外圈较冷的部分。

Protoplanetary disks: Proplyds
Planetary Systems in the process of formation
原行星盘：形成行星系统的过程

- Protoplanetary disks have been observed in the Orion Nebula (left)

在猎户座星云中发现原行星盘（左图）

- The star can hardly be visible in the center of the disc.

很难看清在盘中心的恒星。

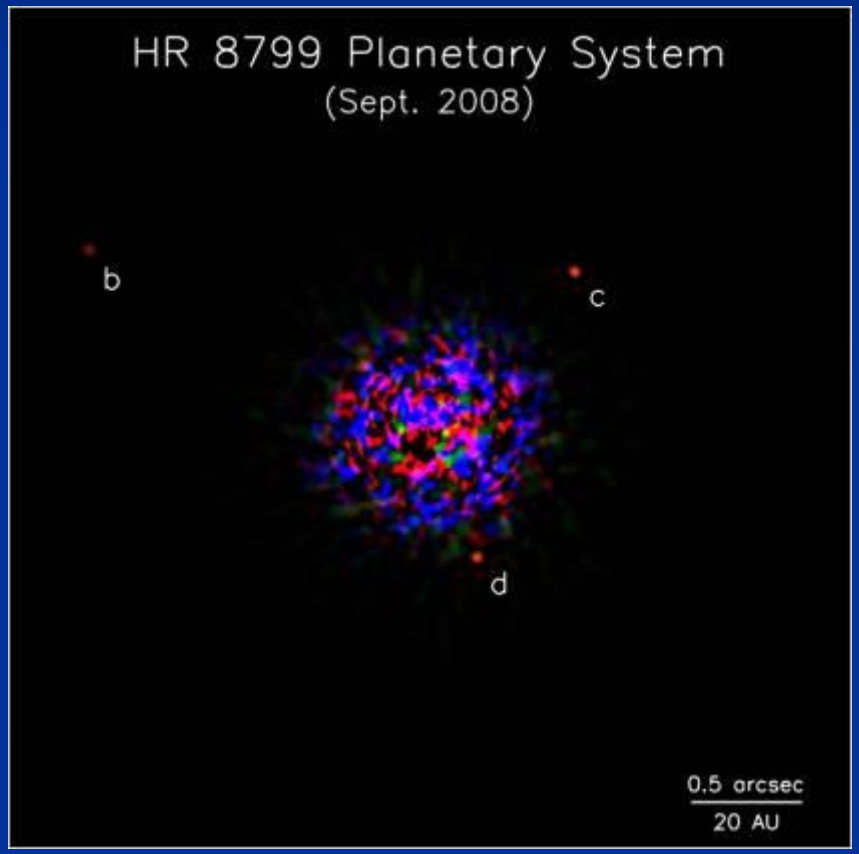
Proplyds
Source: NASA/ESA/HST

Protoplanetary disks: Proplyds
Planetary Systems in the process of formation
原行星盘：形成行星系统的过程

Proplyds
Source: NASA/ESA/HST

- The disk of dust blocked the light that is behind.
  盘中的尘埃挡住了其身后的光线。
- These and other observations provide a direct evidence of the formation of planetary systems.
  很多观测都为行星系统的形成提供了直接证据。

Exoplanets = extrasolar planets
Planets around other stars
系外行星=太阳系外的行星
围绕其他恒星的行星



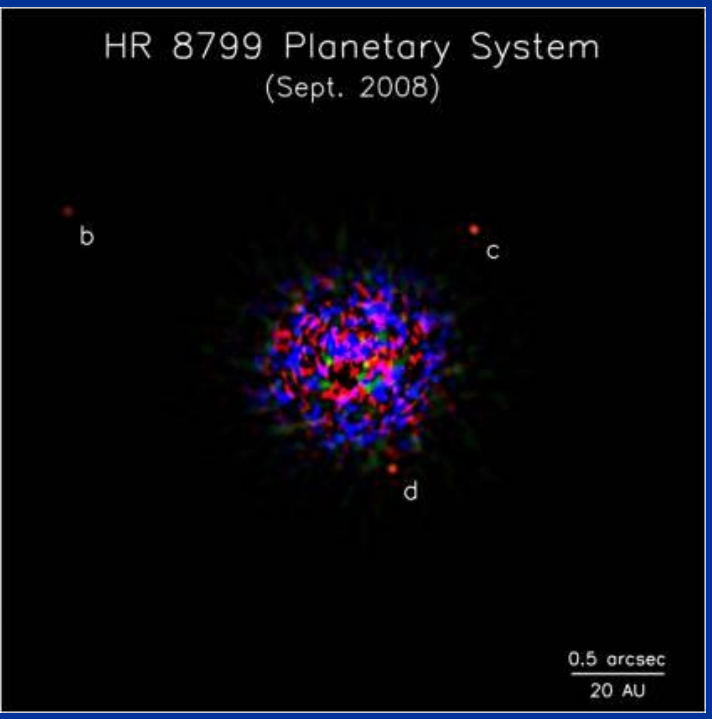
System exoplanet HR 8799
Source: C. Marois et al., NRC Canada

- The exoplanets are usually discovered and studied through gravitational effect they have on the star, or through the light dimming of its star if transit occur.

  系外行星一般都是通过对恒星的引力效应或者由于掩食现象造成恒星亮度变暗等被发现并进行研究的。

Exoplanets : extrasolar planets around other stars

系外行星：围绕其他恒星的行星



System exoplanet HR 8799
Source: C. Marois et al., NRC Canada

- Very few have been directly captured (left).

只有很少能被直接拍摄到（左图）。

- Unlike the planets in our Solar System, many exoplanets are huge and very close to its star. This allows the astronomers to modify/correct their theories of how planetary systems formg.

与我们太阳系中的行星不同，许多系外行星非常巨大而且紧靠恒星。这就需要天文学家进一步修正恒星系统形成的理论了。

Final considerations
结语

- “Gravity drives the formation, life and death of stars” [Professor R.L. Bishop]

  “引力驱动着恒星一生的诞生、演化及死亡”

- The birth of a star explains the origin of our Solar System and other planetary systems.

  恒星的诞生解释了我们太阳系和其他行星系统的起源

- The life of the star explains the energy source that makes life on Earth possible.

  恒星的一生说明了有能源存在地球上就有可能存在生命

Final considerations
结语

- The life and death of the stars produce chemical elements heavier than hydrogen, that stars, planets and life are made of.

  恒星的演化和死亡产生出了重于氢的其他元素，这也是恒星、行星和生命的组成元素。

- During the death of a star, gravity produces the more stranger objects in the universe: white dwarfs, neutron stars and black holes.

  在恒星的死亡过程中，引力又为宇宙创造出了更加奇特的天体：白矮星、中子星和黑洞。

Many Thanks
for your attention!
谢谢！