Life of Stars
恒星的一生

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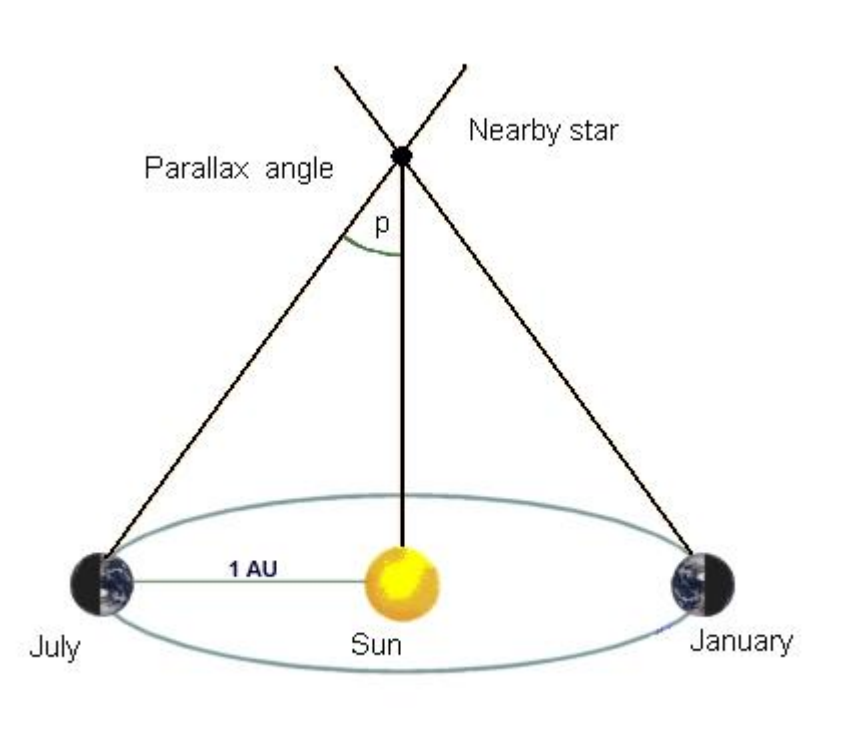
Goals
教学目标

- Understand the difference between apparent magnitude and absolute magnitude.
- 了解视星等和绝对星等的不同。
- Understand the Hertzsprung-Russel diagram
  - a color /magnitude diagram.
- 了解赫罗（颜色-星等）图。
- Understand concepts such as supernova, neutron star, black hole and pulsar.
- 知道什么是超新星、中子星、黑洞和脉冲星。

Activity 1: Simulating parallax
活动1：模拟视差

- Keep your thumb pointing upward to the distance of your own arm.
- 伸直手臂竖起一根手指
- Keep watching first only with your left eye open, then only with your right eye . What do you see?先只睁开左眼再只睁开右眼，你看到了什么？
- Now move your finger halfway up to your nose and repeat the observation. What do you see?将手指移动到之前一半的距离观测，你看到了什么？

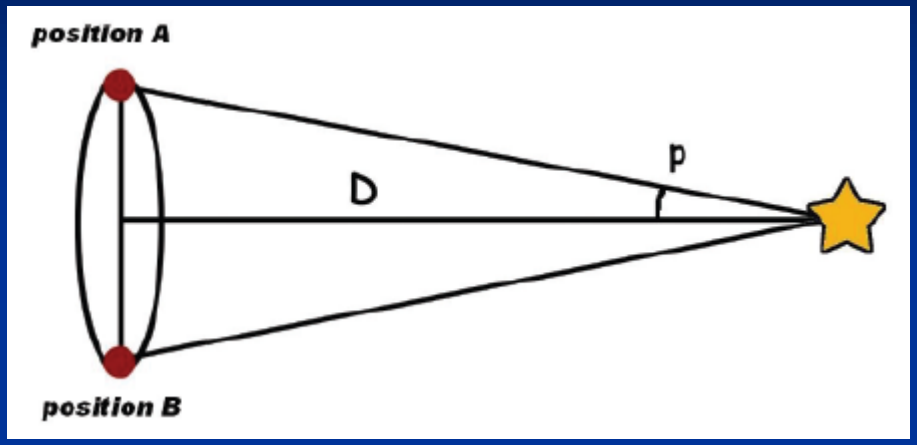
Parallax 视差



Source: Columbia University.
图片来源：哥伦比亚大学

- Parallax is the apparent difference in the position of an object when viewed from different locations.
- 视差是产生于观测地的不同
- The position of the nearby star on the sky appears to change when viewed from Earth now and six months later.
- 距离较近的恒星在地球上间隔半年的观测会产生明显的视差
- Thus we can measure the distance to nearby stars.
- 这用来估计较近恒星的距离

Parallax 视差



$$D = \frac{AB/2}{\tan p} = \frac{AB/2}{p}$$

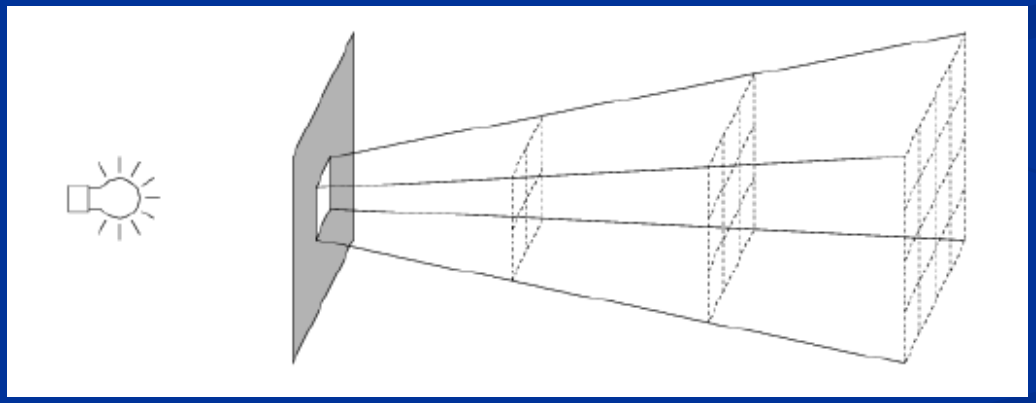
$$D \cong \frac{150\ 000\ 000}{2\pi/(360^{\circ}\text{x}60\text{x}60)} = 30\ 939\ 720\ 937\ 064\ \text{km} = 3{,}26\ \text{l.y.}$$

1 pc = 3.26 l.y.

d = 1/p

Activity 2: Law of inverse square
活动2：平方反比定律

A star emits radiation in all directions. The intensity that reaches a distance D is the luminosity L (power) divided by the area of a sphere centered on the star.
天体辐射光度L在距离D位置相当于分布在以D为半径的球面上



$$I = \frac{L}{4\pi D^2}$$

Activity 2: Law of inverse square
活动2：平方反比定律

When the distance becomes doubled, the corresponding area is four times larger, and the light intensity (the arriving light per unit area) will become four times smaller.
当距离增加1倍，辐射面积增加4倍，单位面积的能量为原来的1/4

The intensity of light is inversely proportional to the square of the distance from the source.
单位面积上的能量与光源距离的平方成反比

System of magnitudes星等

The stars show different brightness.

星星的亮度不同

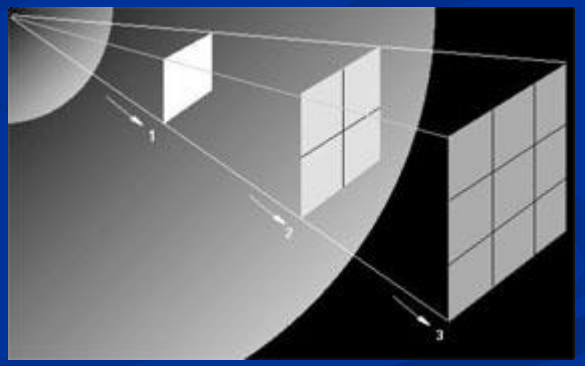
The brightest star may be small and close, or large and distant.

亮的恒星可能是很暗但距离较近，或者很亮但距离很远

The brightness could be defined as :

亮度（照度）被定义为：

$$B = F = \frac{L}{4\pi D^2}$$



System of magnitudes
星等系统

Hipparchus was born in Nicaea (now known as Iznik, Turkey) in 190 BC. It is believed that he died in Rhodes, Greece, in 120 BC.

喜帕恰斯公元前190年出生在土耳其的伊兹尼克，公元前120年逝世在希腊Rhodes

About 125 years before Christ defined the system of magnitudes.

在公元前125年定义了星等系统

System of magnitudes
星等系统

Hipparchus called stars of 1st magnitude stars at the brightest ones, 2nd those less bright , and continued so until the faintest, which he called 6th magnitude stars.
喜帕恰斯把最亮的星定为1等，肉眼可见最暗的星定为6等。

That system, slightly changed, is used also today: the larger is the magnitude, the star is fainter.
这样的分级方法沿用到今天，星等数值越大，星越暗。

Astronomers refer to the brightness of a star when talking about its magnitude.
天文学家将星等和亮度联系起来。

System of magnitudes
星等系统

In 1850, Robert Pogson suggested that a difference of 5 magnitudes should be exactly equal to the brightness ratio of 100/1.

1850年普森提出星等相差5等亮度相差100倍

This is the formal definition of the magnitude scale used by astronomers today.

这样的系统定义沿用至今

Pogson Law 普森公式

From the computational point of view , it is useful to use the logarithmic scale to write this relation:
亮度（照度）和星等的关系

$$2.5 \log (B_1/B_2) = m_2 - m_1$$

For example:例如

- Sirius, the brightest star on the sky, has a magnitude of -1.5全天最亮的天狼星是-1.5等
- The magnitude of Venus is-4,金星-4等
- The magnitude of the Moon -13 月球-13等
- The magnitude of the Sun -26.8 太阳-26.8等

Apparent and absolute magnitude
视星等和绝对星等

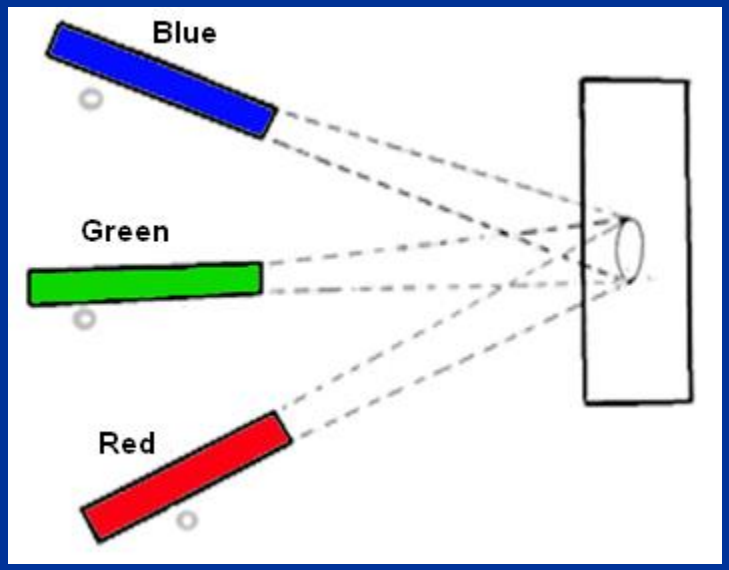
- However, a very powerful but distant star can have the same apparent magnitude, m, as another fainter star but closer.但m是视星等，不能代表星实际的亮度
- Astronomers have established the concept of absolute magnitude M that the star would have at the distance of 10 parsecs (32 l.y.) from us.天文学家引入绝对星等M，将星距离定义为10个秒差距的视星等
- With the absolute magnitude we can now compare the "real brightness" of two stars, or equivalent to it, its power or luminosity.
- 绝对星等反映星的真实亮度
- The mathematical relationship between m and M is: m和M的关系

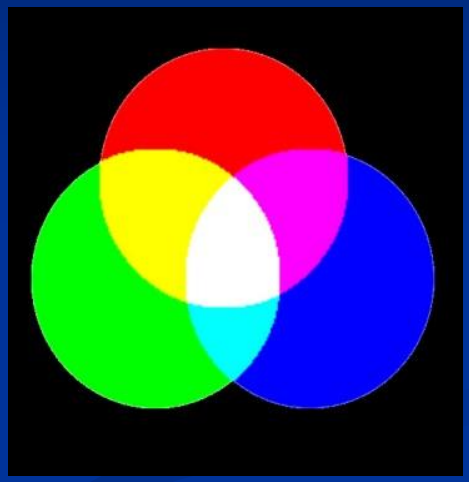
$$M = m + 5 - 5 \log d$$

where "d" is the real distance to the star

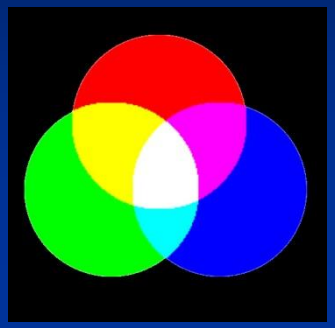
d是星到我们的距离

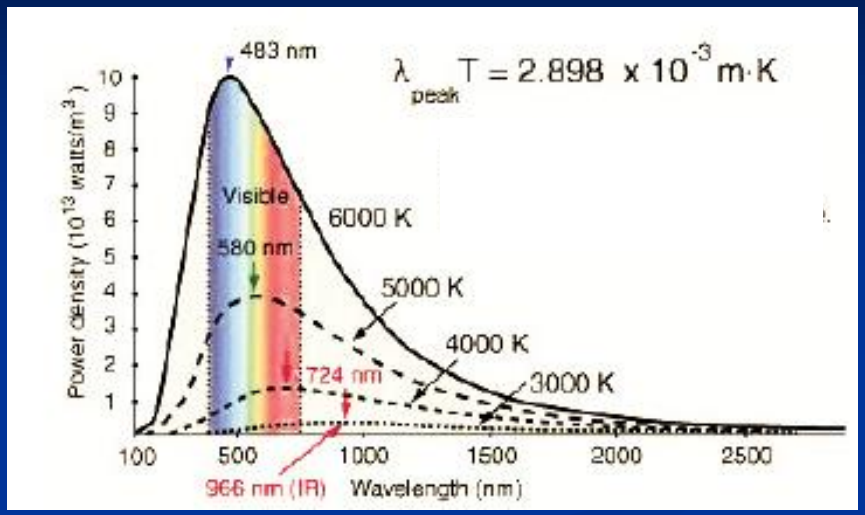
Activity 3: stellar colors
活动3：恒星的颜色





Activity 3: stellar colors
活动 3: 恒星的颜色





The stars show different colors according to their temperature

恒星的温度不同，呈现出的颜色也会不同。

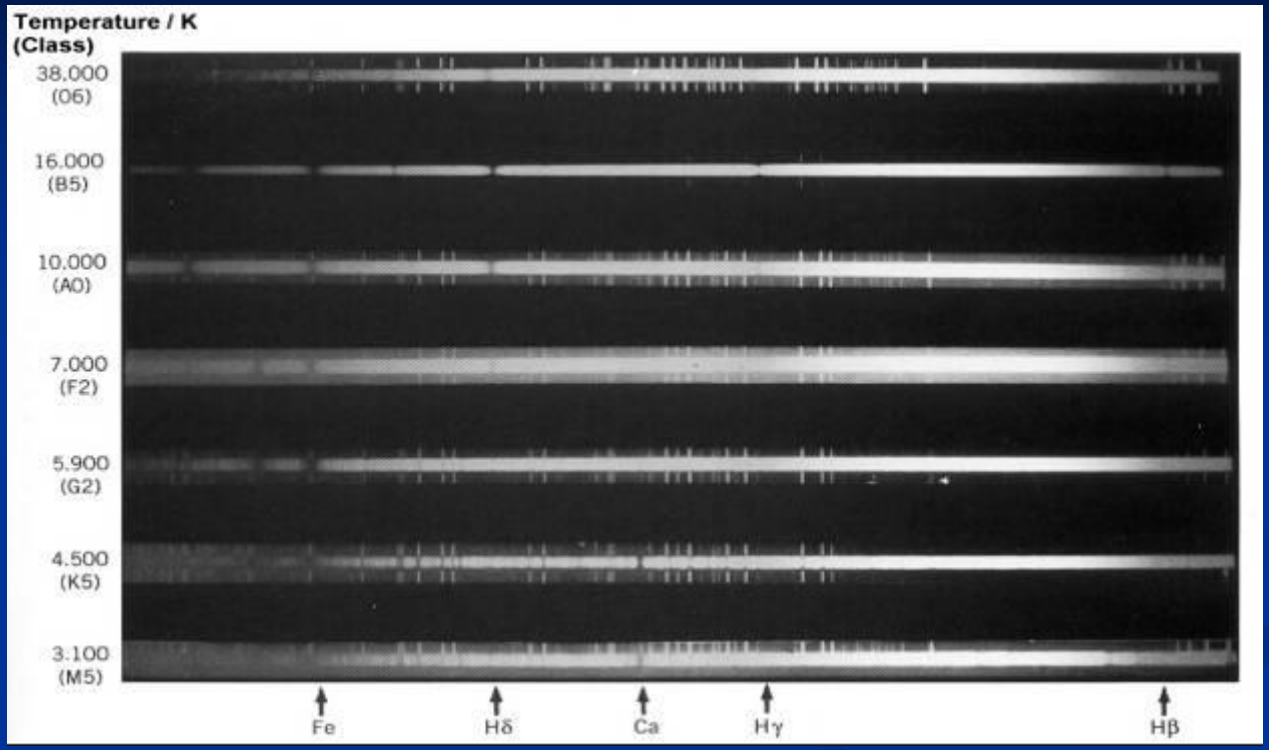
Intermediate temperature stars present maximum emission in green light, but they also emit a lot of red and blue light, the result is an average of the visible wavelengths and the sum of all the colors of the spectrum is white.

中等温度的恒星发射得最多的是绿光，但同时也会辐射大量红光、蓝光，结果最终就呈现为可见光波长的平均值，而光谱中所有颜色叠加后出现的就是白色。

That is why there are no green stars!

这就是为什么不存在绿色的恒星!

Spectral classes光谱分类



Relationship between spectral classification, temperature and color of stars
恒星温度和颜色的关系

Hertzsprung-Russell Diagram
赫罗图

The stars can be represented in an empirical diagram, using the surface temperature (or spectral type) and its brightness (or absolute magnitude).

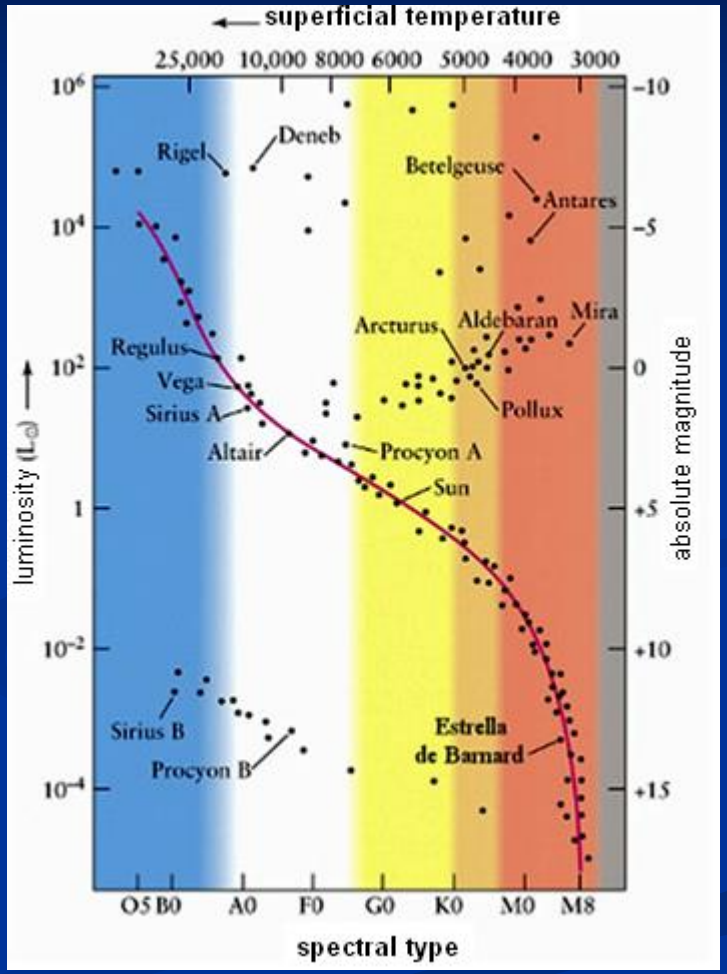
横坐标是温度或光谱型，纵坐标是亮度或绝对星等

In general, the stars occupy certain regions of the diagram.

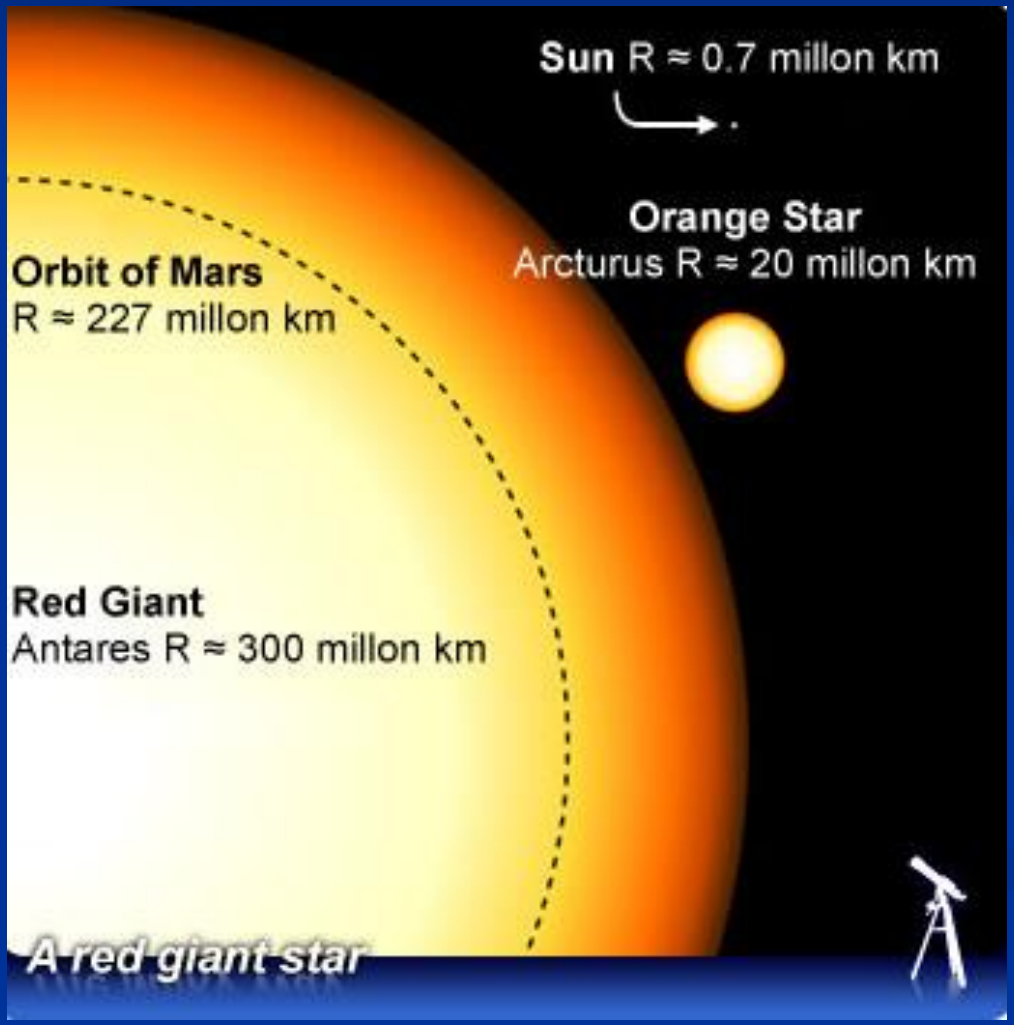
一般情况下星会在表中的某些区域

It is possible to know the type of star and its evolutionary stage.

它反映了恒星的演化



Stellar Evolution恒星的演化
Formation of a Red Giant红巨星的形成



The stars evolve in different ways depending on their mass

恒星的质量不同

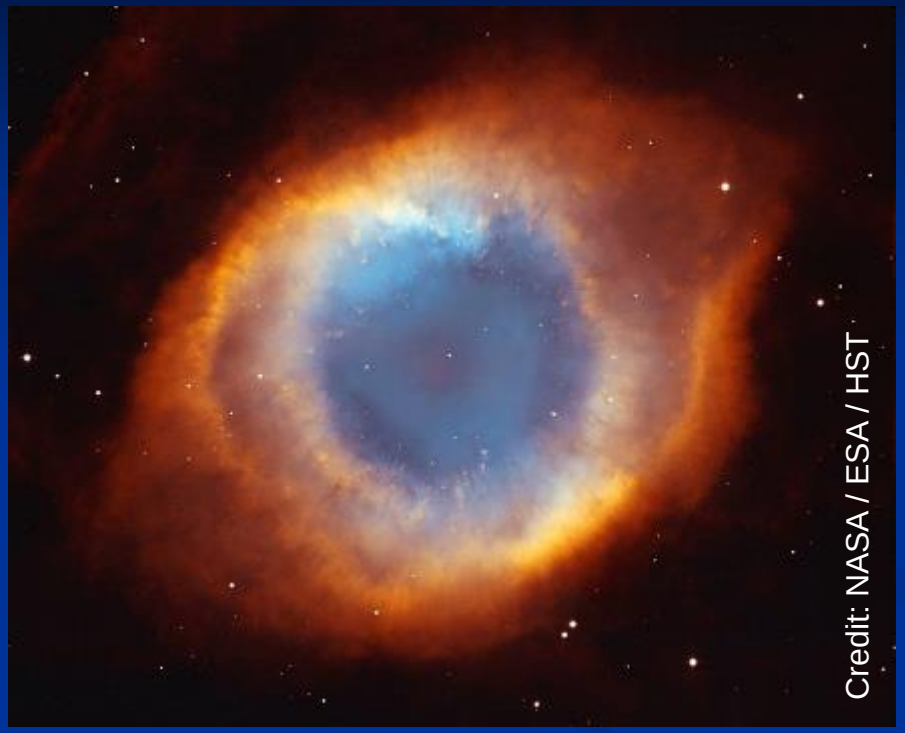
演化方式不同

Stellar Evolution
Formation of the white dwarf
白矮星的形成

A star of low or intermediate mass, as the Sun, evolves into a white dwarf, a form of non-catastrophic stellar death.

像太阳一样的小质量恒星，演化的结果是白矮星

Helix Nebula螺旋星云



The central object, small and white is a white dwarf, the dead star, which no longer produces energy by fusion and is visible due to its very high temperature.

中心就是很小的白矮星，还可以持续辐射能量的时间不会持续太长，看起来呈白色是因为温度很高

Cat‘s Eye Nebula猫眼星云

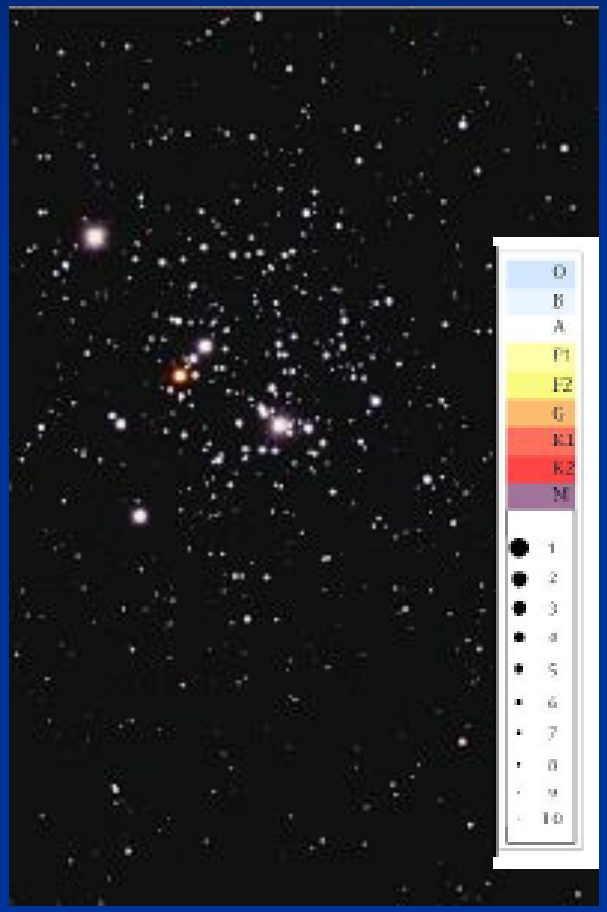
The Cat's Eye Nebula is a planetary nebula of great beauty. Here you see the photo in the visible region (HTS) and X-ray (Chandra).

猫眼星云是非常美丽的行星状星云，左图是哈勃空间望远镜的可见光波段照片，右侧来自钱德拉X射线望远镜

Activity 4: The age of the open clusters
活动4：疏散星团的年龄

You can determine the age of a cluster comparing a HR diagram with the other diagrams clusters whose ages are known.
通过与赫罗图上一些已知恒星的年龄进行对比，我们可以确定一个星团的年龄。

Activity 4: The age of the open clusters

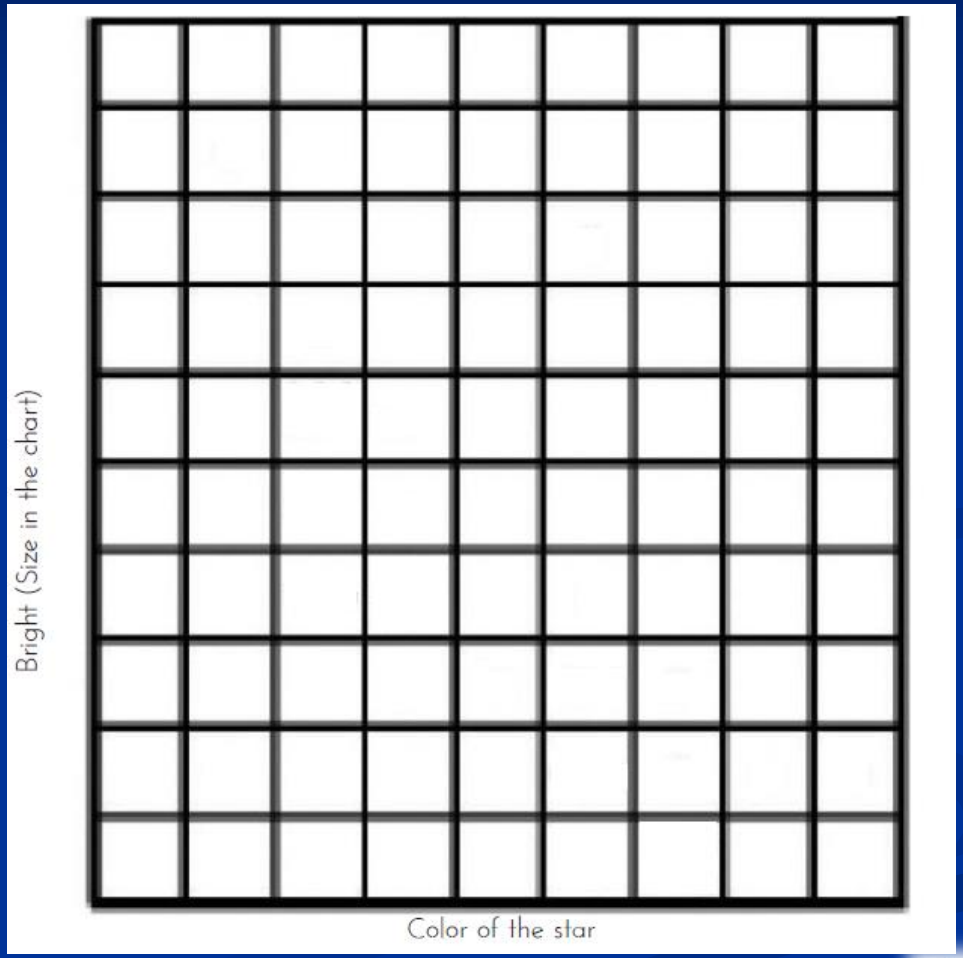


Kappa Crucis

- Draw a square of 4 cm of side centered in the cluster.
- 在星团中画一个4厘米的方框
- Measuring the brightness of the star comparing it with the points in the guide.
- 根据标尺测出亮度
- Estimate the color of the star using the color guide for comparison.
- 根据标尺估计星的颜色

Activity 4: The age of the open clusters

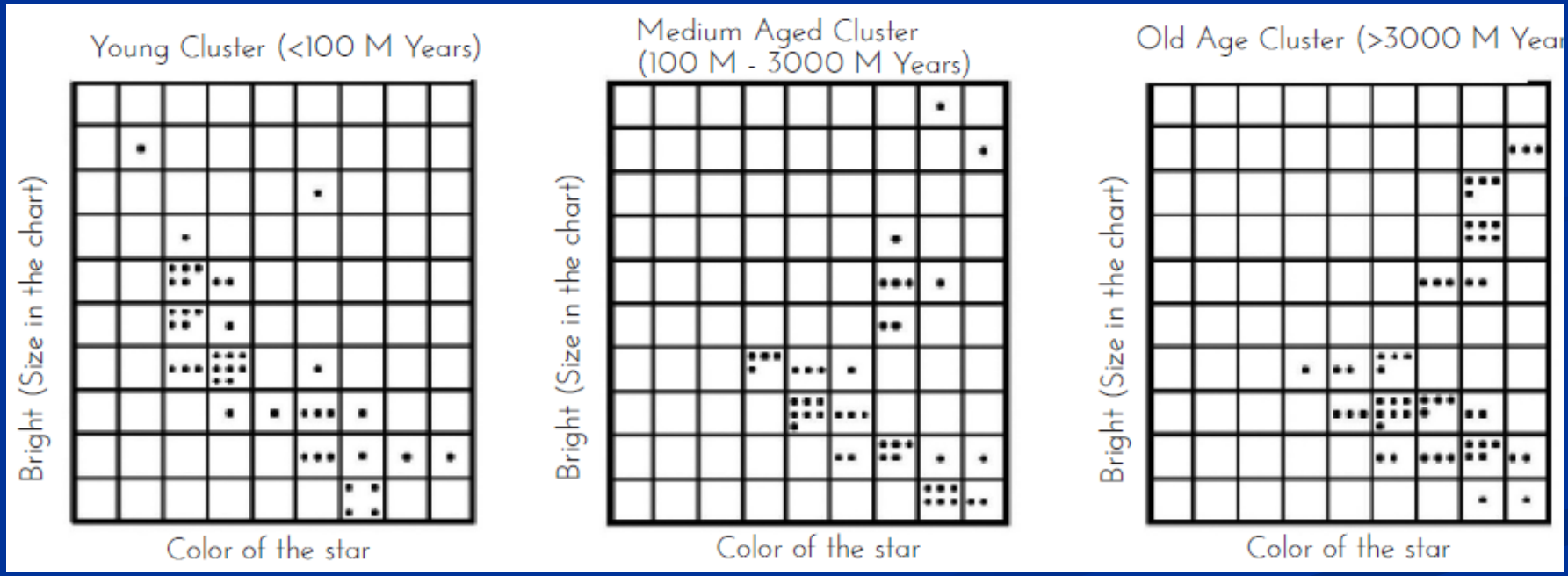
- Locate that star in the grid on the right.将星标在右侧相应的格子里
- Repeat the same with other stars.
- 其他的星用同样的方式处理



Activity 4: The age of the open clusters

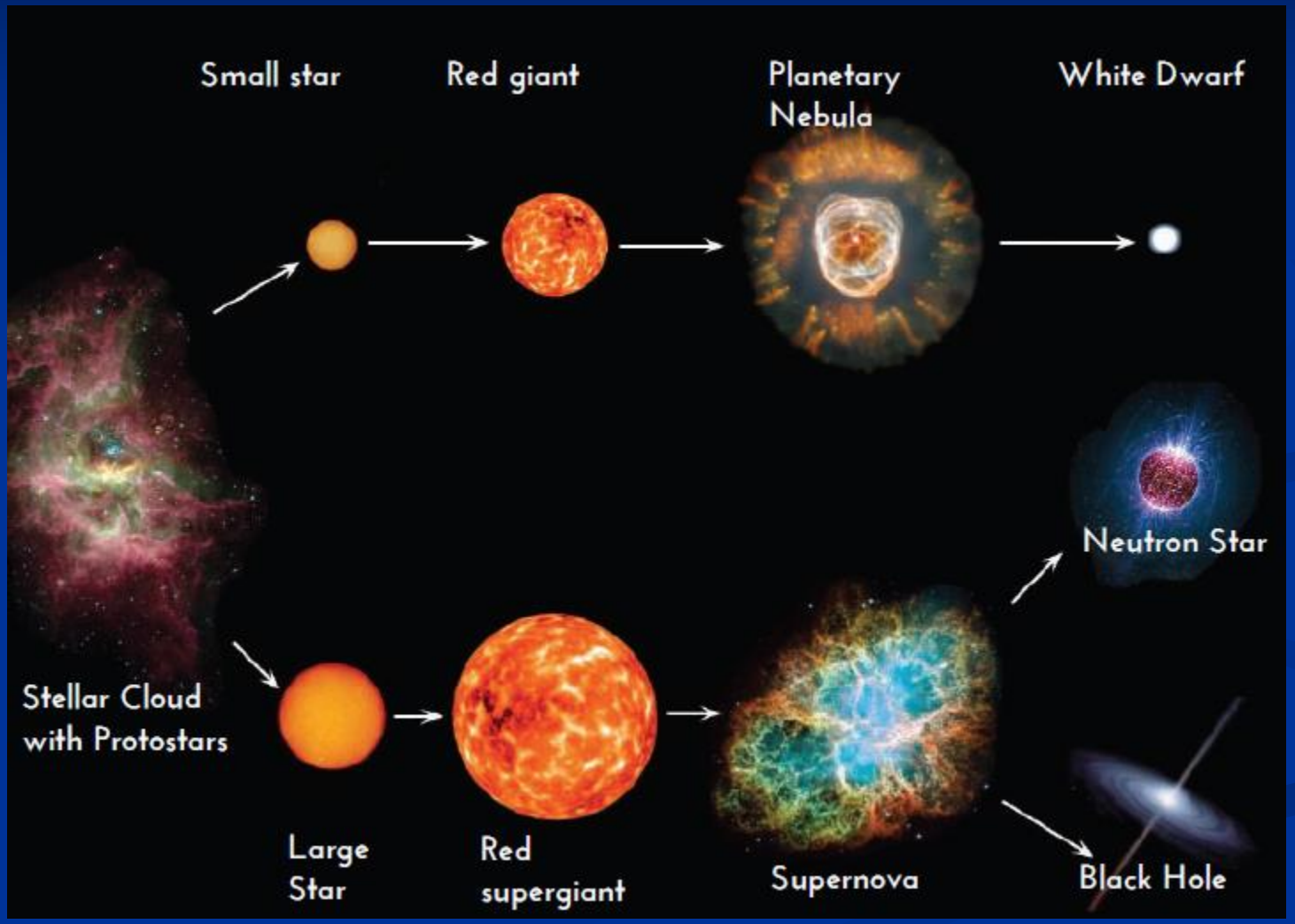
Compare the obtained diagram with the ones below. How old is it?

和下面的表格比较，你测量的星团的年龄是多少？

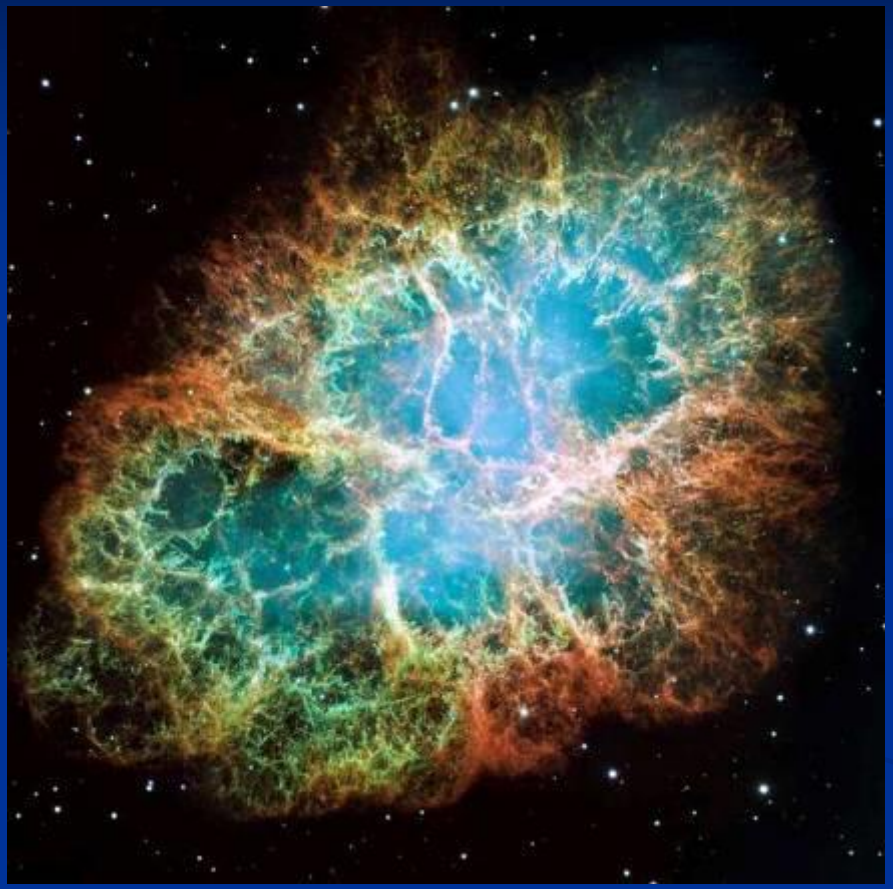


Relation between the mass and the death of stars

不同质量恒星的结局

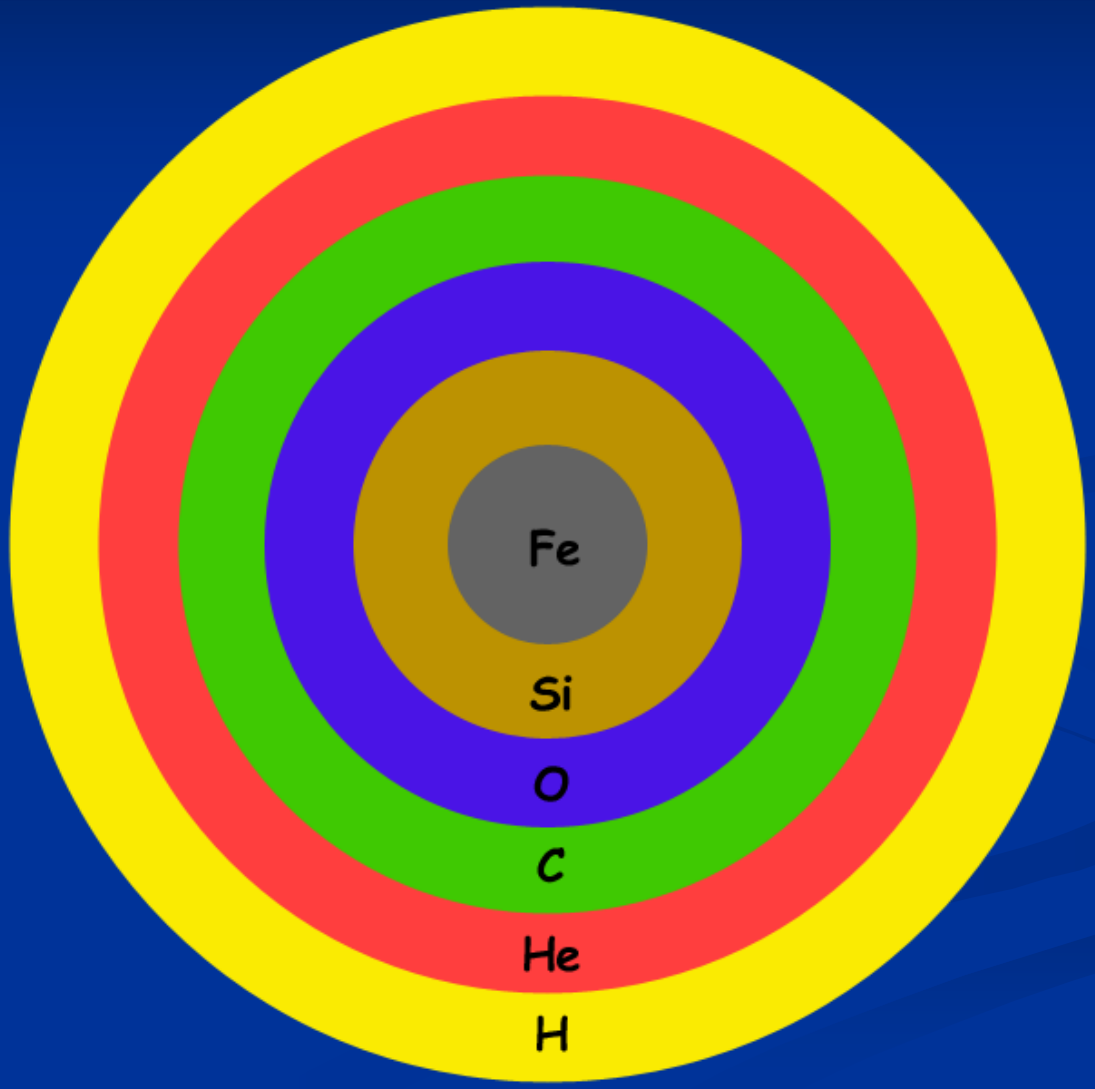


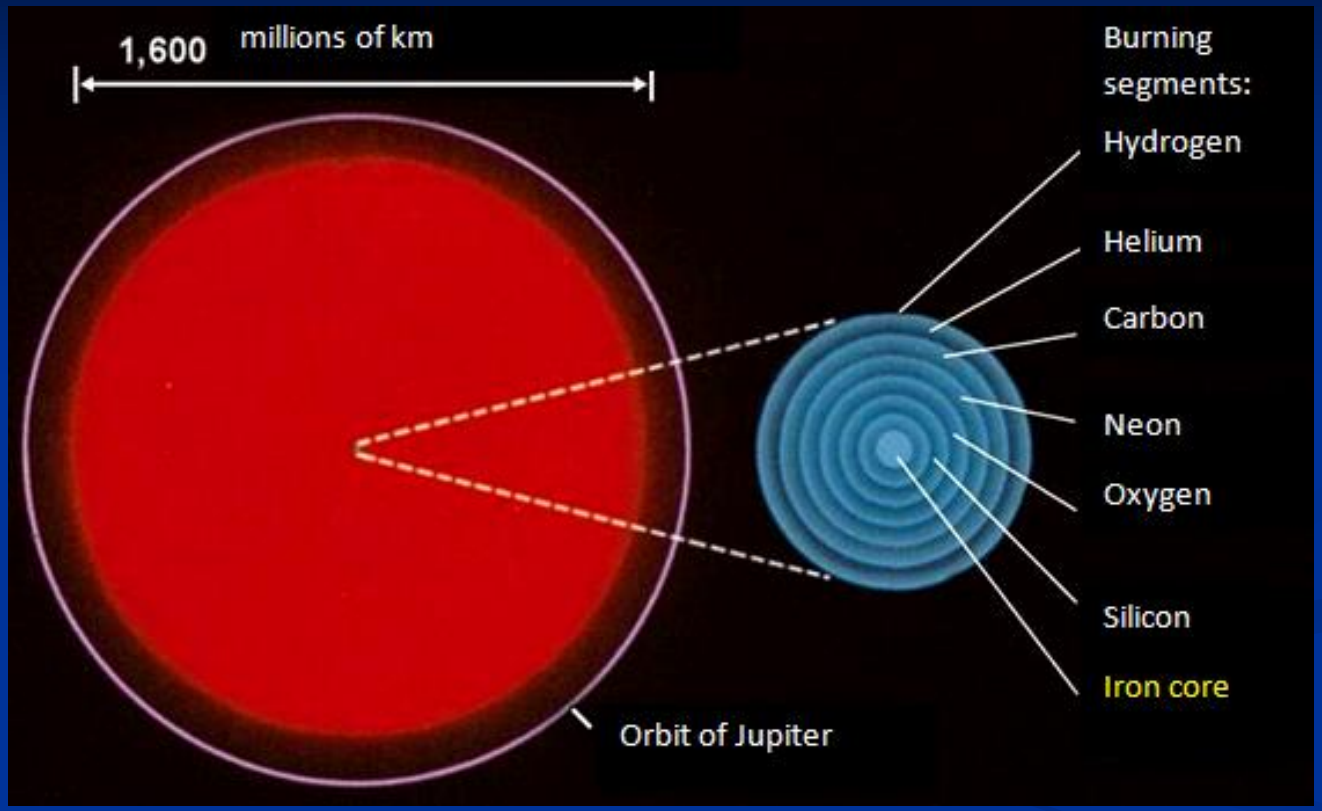
The death of massive stars
大质量恒星的死亡



M1: The Crab Nebula in Taurus, is the supernova remnant observed in 1054.
金牛座蟹状星云M1，1054年被观测到的超新星

Star ready to explode as a supernova
一颗即将爆发成为超新星的恒星





Characteristics of a star ready to explode as a supernova

一颗即将爆发成为超新星的恒星

A star of 20 solar masses lasts:
20倍太阳质量恒星的最终归宿

- 10 million years burning hydrogen inside its core (main sequence).

1千万年燃烧氢

- 1 million years burning helium
- 1百万年燃烧氦
- 300 years carbon
- 300年燃烧碳
- 200 days the oxygen
- 200天燃烧氧
- 2 days in consuming silicon: the explosion of the supernova is imminent.

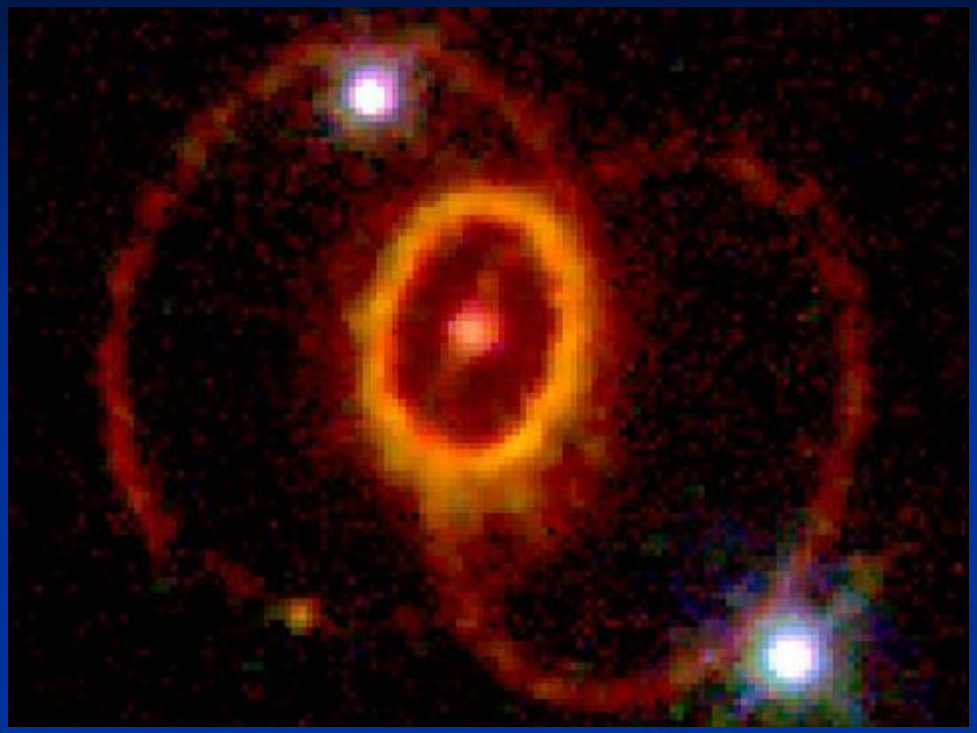
2天燃烧硅，之后超新星爆发

Supernova 1987A 超新星1987A

The supernova 1987 A was observed in 1987 in the Large Magellanic Cloud. The cloud is at 168,000 l.y.: the light needed this time to reach the Earth

1987年观测到的大麦哲伦星云中的超新星，距离16.8万光年

Supernova 1987A 10 years after



The material ejected after the explosion moves away at high speed away from the star.
爆发后物质高速喷发
This photo of SN 1987A was taken by Hubble Space Telescope in 1997.
这是1997年哈勃空间望远镜拍摄到的超新星1987A

Example of supernova in one distant galaxy. In average, in each galaxy one supernova forms per century.

平均**每个世**纪在每个星系中会有一次超新星爆发

In the Milky Way, there are no detections of supernova over the last 400 years.

但在银河系已经有400年没有超新星爆发了

Activity 5: Simulation of the supernova explosion

活动5：模拟超新星爆发

When a star explodes as a supernova, the light atoms of the outer layers fall over inner heavier atoms, and they bounce off the solid core.

超新星爆发时较轻的原子会向内侧较重的原子塌缩，它们一起向固态核心塌缩。

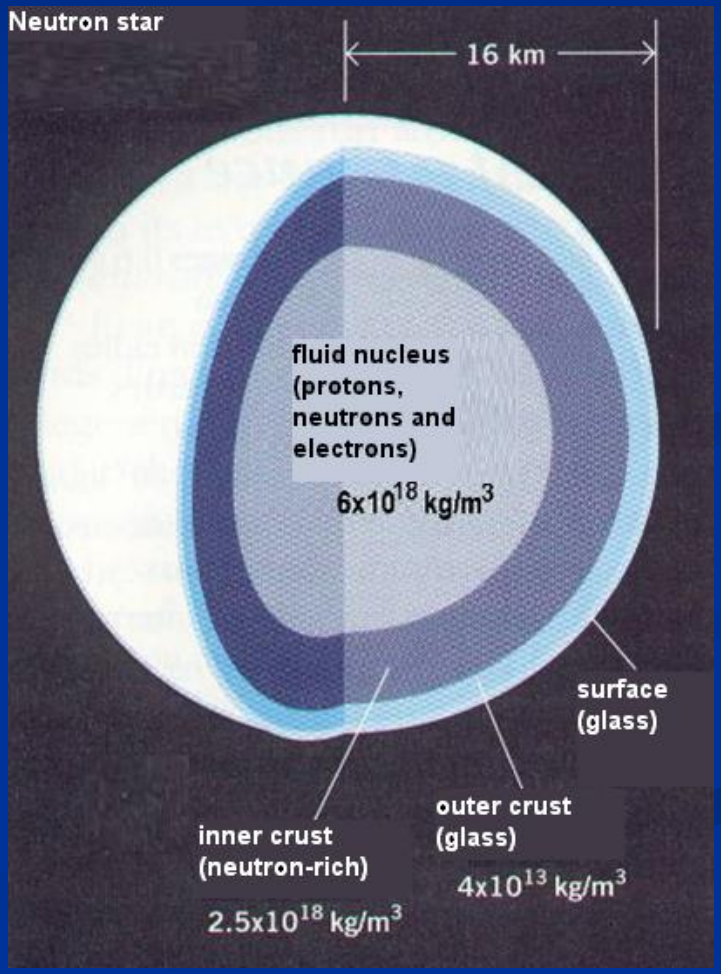
In this model, the floor represents the solid core of the neutron star, the basketball would be a heavy bouncing atom, which pushes the light atom that comes behind, represented by the tennis ball.

在这个演示中地板代表中子星的硬核，篮球代表重原子网球代表较轻的原子。

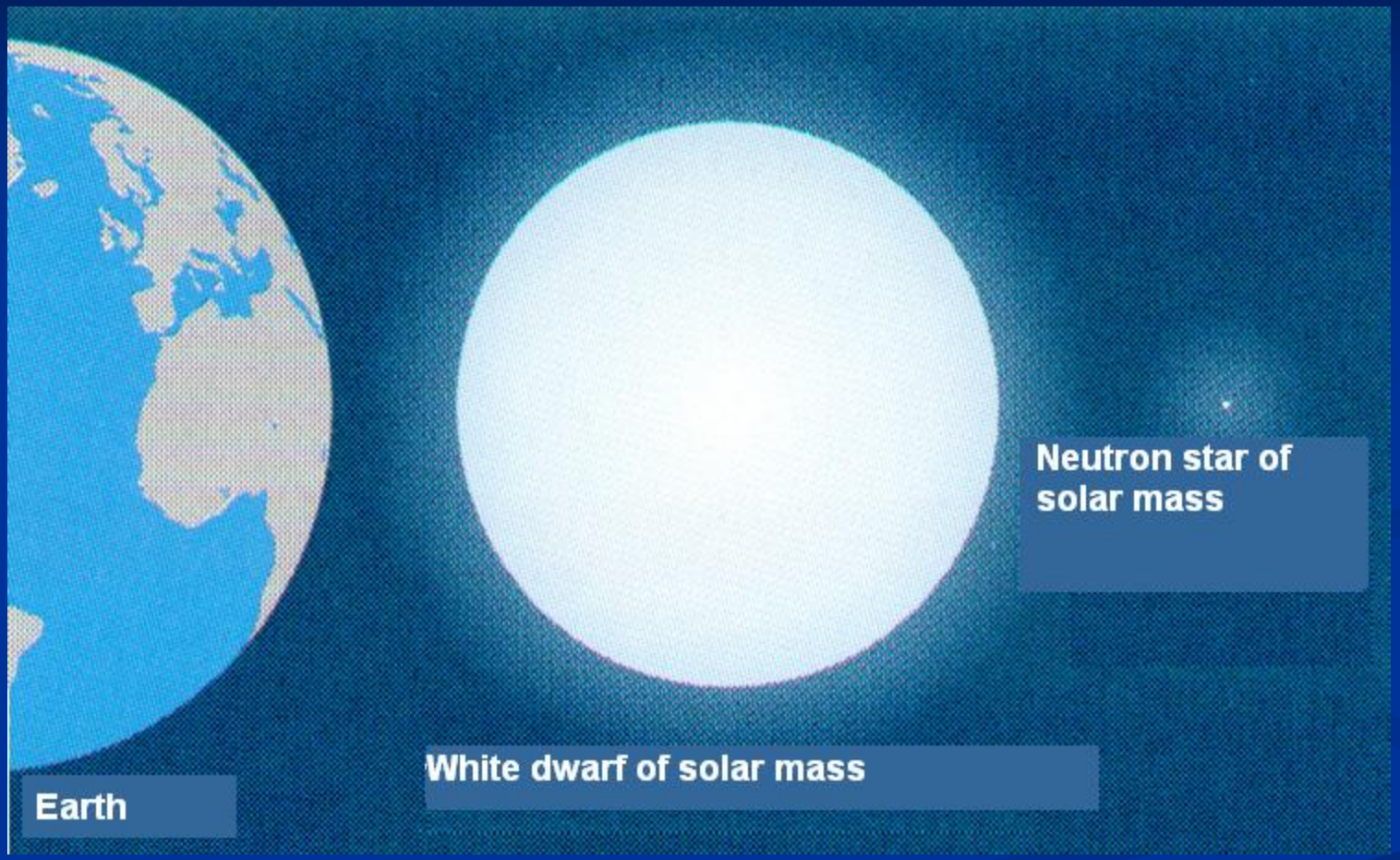
Neutron Stars
中子星

Another form of stellar death are neutron stars or pulsars

另一种恒星的归宿是中子星或脉冲星

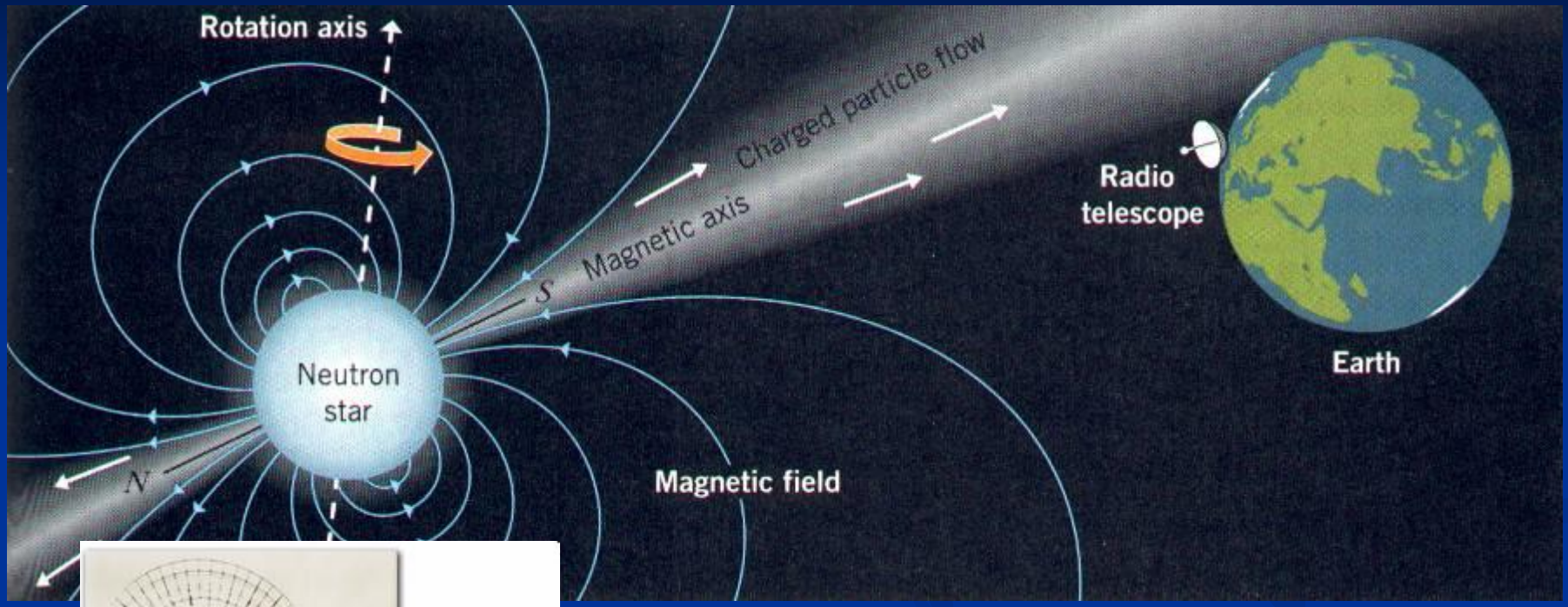


Neutron Stars 中子星



Size Comparison 大小对比

Pulsars脉冲星



How the radiation emitted by a pulsar is seen from the Earth.
在地球上看脉冲星的辐射
Jocelyn Bell, the discoverer of pulsars.
乔瑟林·贝尔发现了脉冲星

Activity 6: Simulation of a pulsar
活动6：模拟脉冲星

A pulsar is a neutron star, very massive, and rapidly rotating. It emits radiation but the source is not fully aligned with the axis of rotation, so that the emission spins as a lighthause.

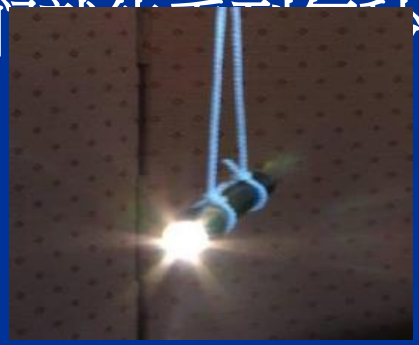
脉冲星就是高速旋转的中子星，自转轴和辐射轴并不重合

If it is oriented towards the Earth, what we see is variable radiation with a period of several times per second.

如果辐[illegible]我们[illegible]几个周期的光变

Mounting演示设备

Turning
旋转



3rd form of stellar death: Black Holes
第三种恒星的归宿：黑洞

John Mitchell and Simon Laplace proposed the possibility for the gravitational collapse of supermassive objects at the end of their life.
米歇尔和拉普拉斯率先率先提出了大引力场天体的假设。

They called these objects black holes, being invisible in the optical range, since their gravitational force is so big that nothing can escape from them, not even the light.
他们称其为黑洞，是因为它的引力巨大以至于光都无法逃脱。

Stellar Evolution: Black Holes
恒星演化：黑洞

There are supermassive black holes at the centers of galaxies

星系中心存在大质量黑洞

Activity 7: Simulation of the curvature of space and of a black hole
活动7：模拟黑洞产生的空间弯曲

It is possible to simulate the space curvature determined by a black hole using a piece of elastic fabric (Lycra) and a water balloon.
用弹力布和水球模拟空间弯曲和黑洞

The path of the tennis ball is not in a straight line but a curve.
网球不走直线而是弯曲的路径。

Activity 7: Simulation of the curvature of space and of a black hole
活动7：模拟空间弯曲和黑洞

The elastic net, sold in pharmacies, can be also used.
还可以用有弹力的网。

If we loosen the elastic net, the well is greater and it simulates a black hole.
如果我们放松网，势阱就会更大，这样就可以模拟黑洞了。

Thank you very much
for your attention!
谢谢！