



一小時搞懂天文 (Astronomy for Dummies)

辜品高
師大地科系
中研院天文所

remark : apparently I spent more than 1 hr giving this lecture...

古宇宙觀

玉琮
良渚文化晚期

代表帝王的權力

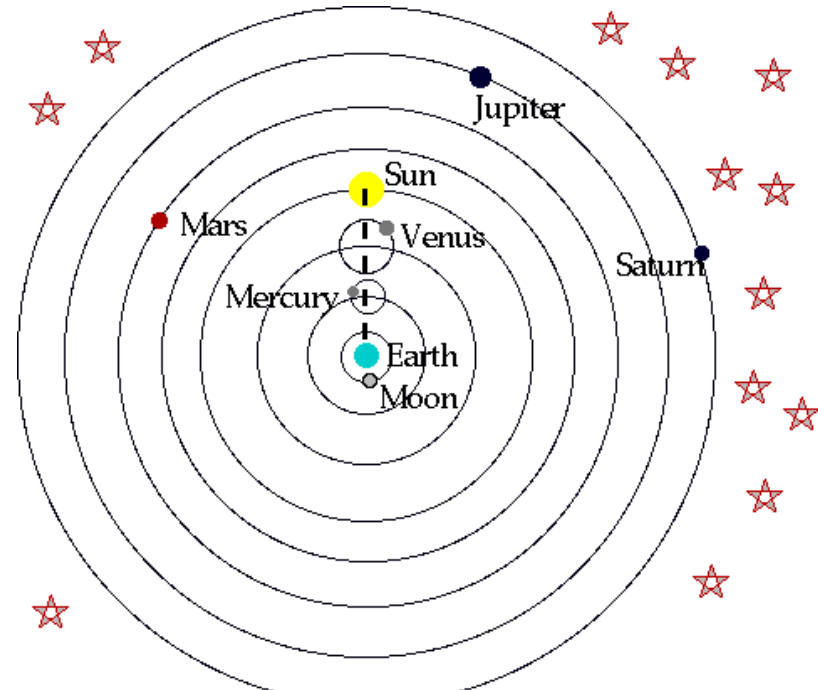


蓋天說：
天圓地方

渾天說：
蛋殼 - 天
蛋黃 - 地

A.D. 125?

Ptolemy's geocentric model



Planets (行星) wander
among stars (恆星)

For more info:

http://aeea.nmns.edu.tw/AEEA/contents_list/universe_concepts.html (天文教育資訊網)

科學精神

大膽假設（創意？哲學？八卦？）
→ 小心求證（建立模型解釋現象）

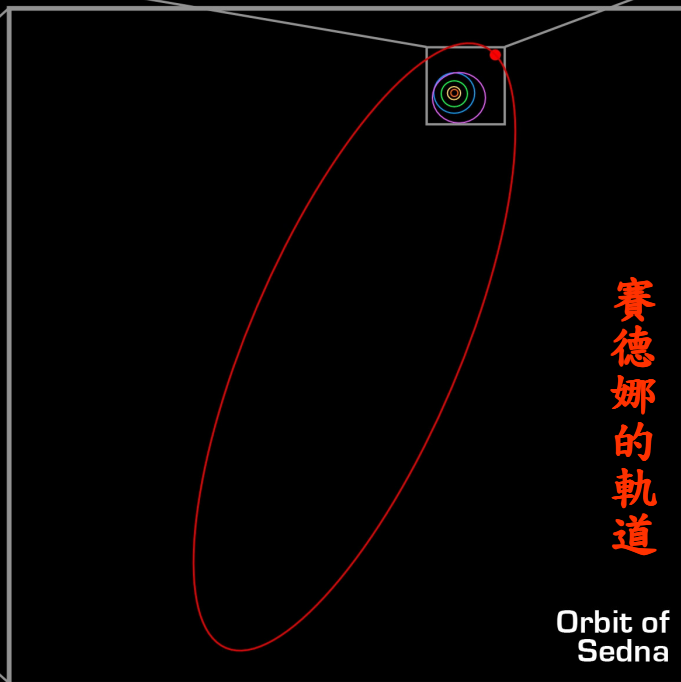
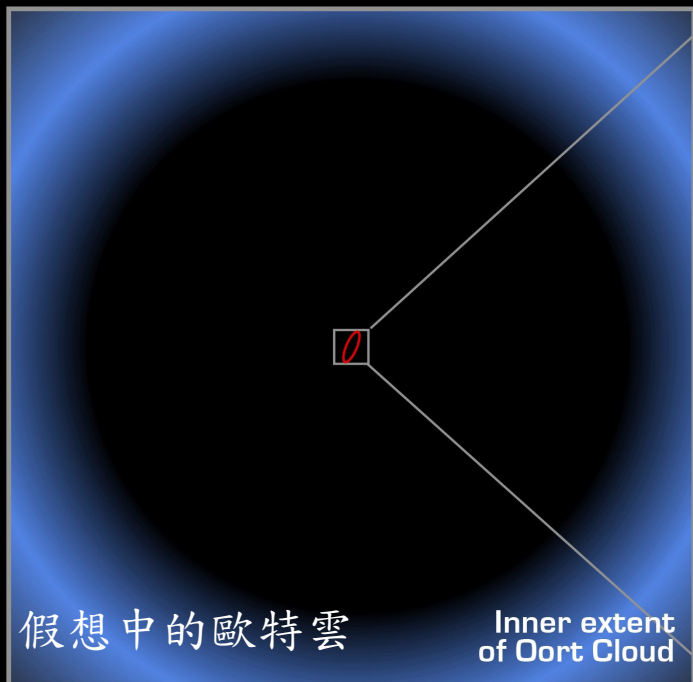
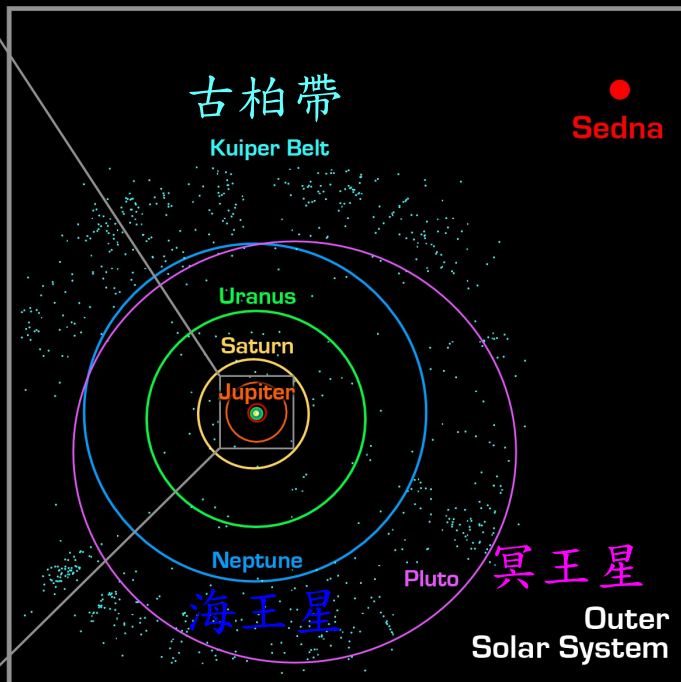
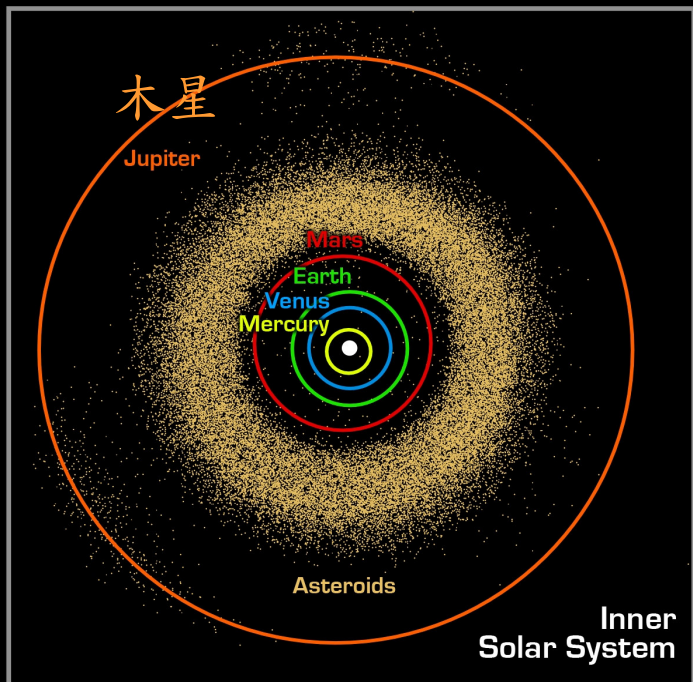
Models are not equivalent to truth though.

note

Ancient views of the cosmos might be born out of philosophical or even aesthetic ideas: for instance, the notions of harmony and symmetry sketched by a series of circles for the orbits of planets (for 玉琮, you may refer to 蔣勳 “美的沉思”). The geocentric model is certainly the most straightforward idea based on the perception that the Earth does not seem to move. In this model, the Sun is not a star but is more like a planet in the sense that it also orbits the Earth. I will tell you in one of the next lectures that ancient people did try to examine if the Earth is moving but they actually failed. After adding small circles on the big orbits around the Earth, Ptolemy's model did better explain the retrograde motion of planets (planets means wanderers in this regard) and predict the future position of planets. This is the spirit of science: making a model to fit to observational results. However, the error given from Ptolemy's model becomes larger and larger as observations are conducted for a longer time.

太陽系

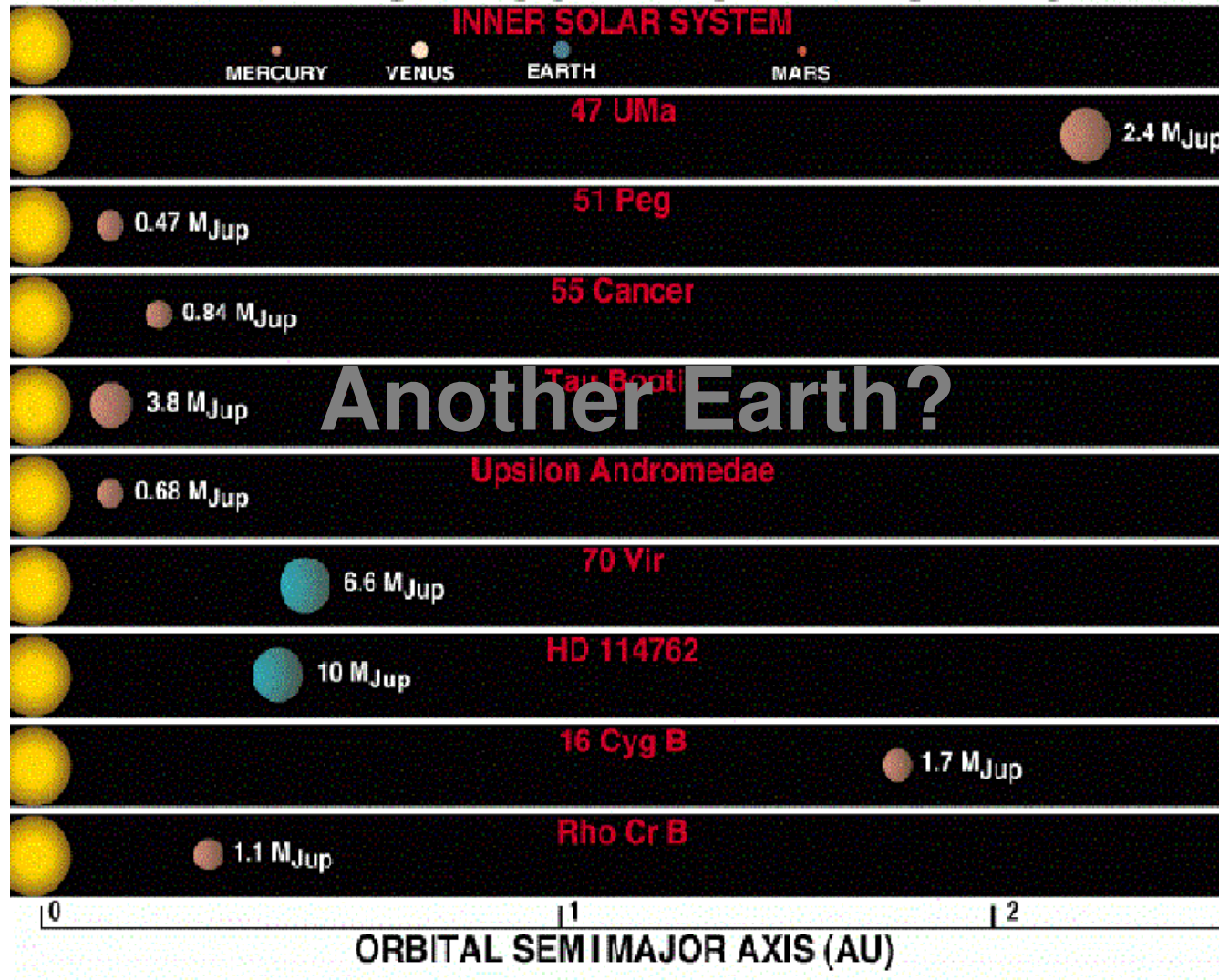
The Solar System



圖片來源:
<http://www.gps.caltech.edu/~mbrown/>

Is our solar system abnormal?

PLANETS AROUND NORMAL STARS



note

The Sun is not the only star having planets. Astronomers has discovered more than 150 extrasolar planets (planets outside of the Solar System). Many of these systems host a Jupiter-like planet (Jupiter is the most massive planet in the Solar System) which is extremely close to their Sun compared with our Jupiter. Is our Solar System abnormal? How did planets form in general? In addition to planets, can the asteroid belt and the Kuiper belt tell us about the formation of the Solar System?

The Sun as an example of a star

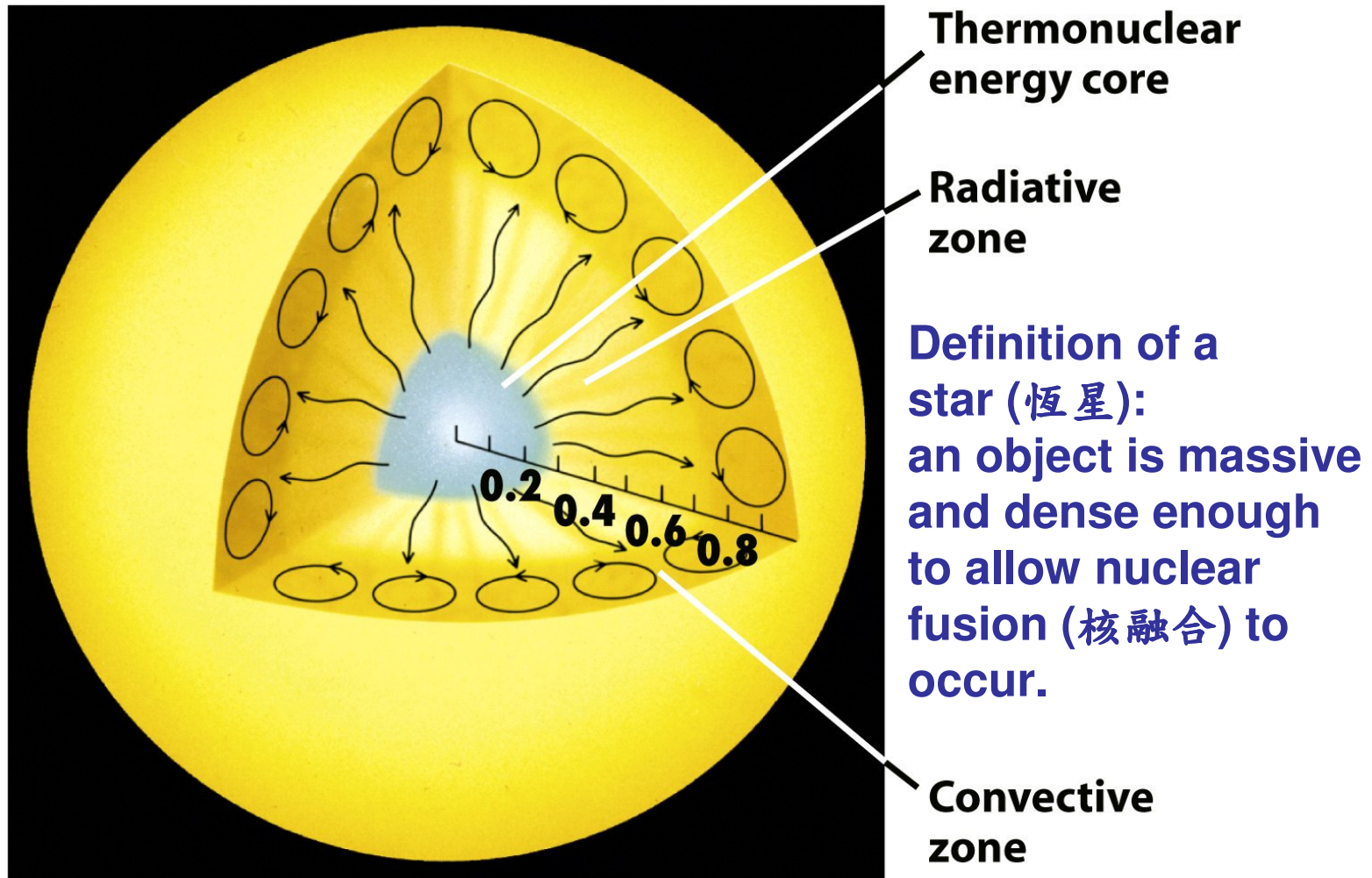


Figure 10-21a
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note

Nuclear fusion happens when two or more atomic nuclei get close enough down to the distance as small as its own size. This can occur at the center of a star (actually this is just the definition of a star) because the high temperature and high density environment brings them to collide together against the electrical repulsion force between protons. Within this extremely short separation, a strong nucleus attraction becomes dominant over the electric force, thereby fusing these atoms together and releasing a huge amount of energy.

Stellar Mass, Color, & Luminosity

notice that mass spread vs luminosity spread

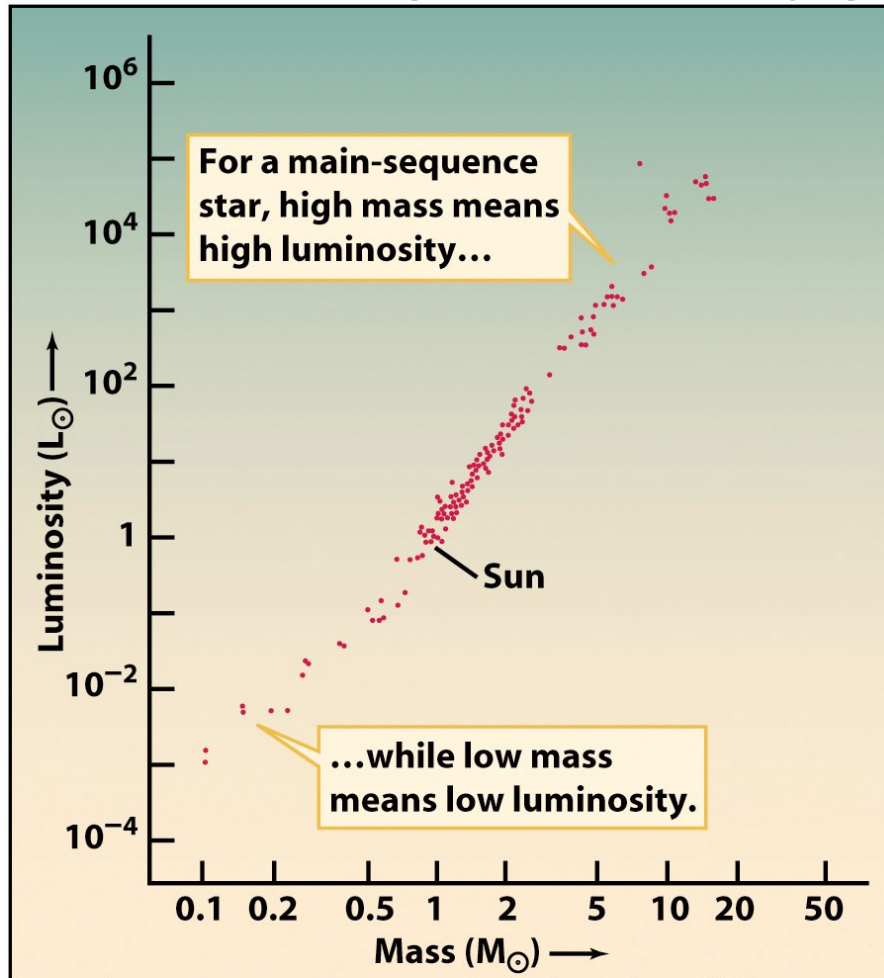


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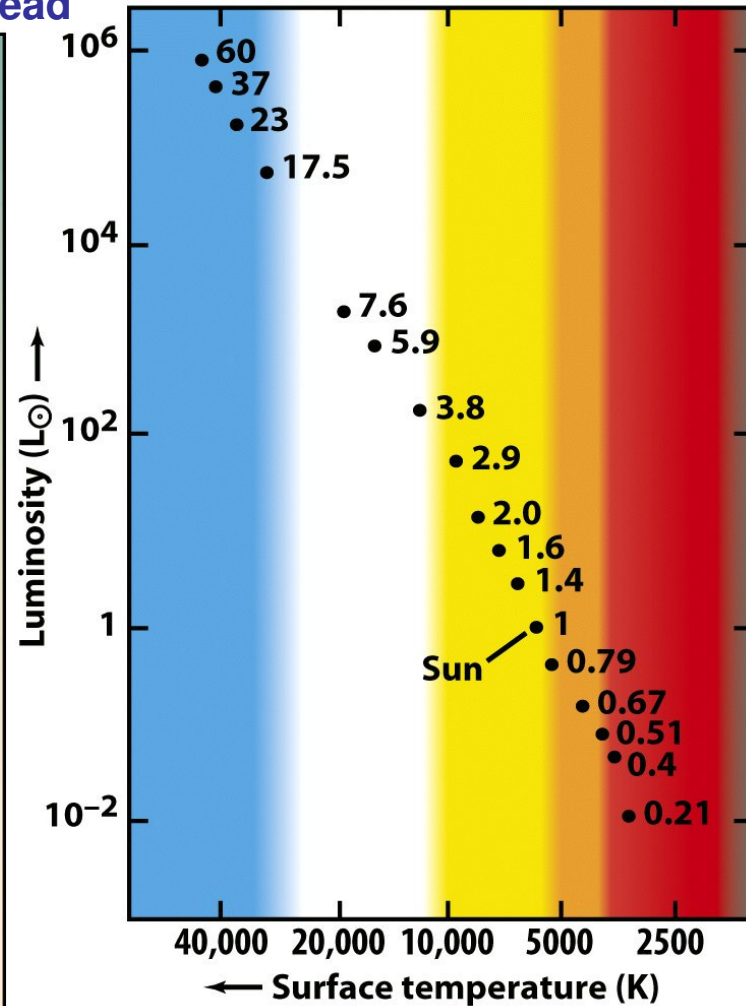
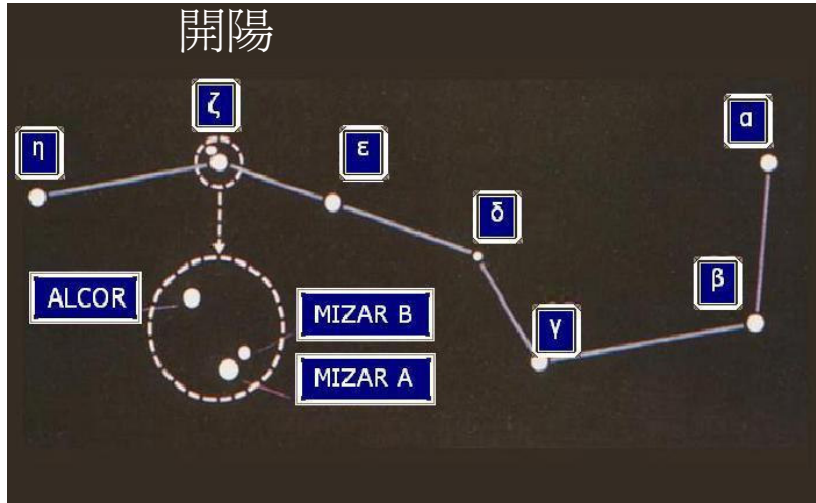


Figure 11-12b
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Binary Stars (雙星)



北斗七星

In fact, Mizar is a quadruple system!

Roughly speaking,
50% of stars are
binaries.

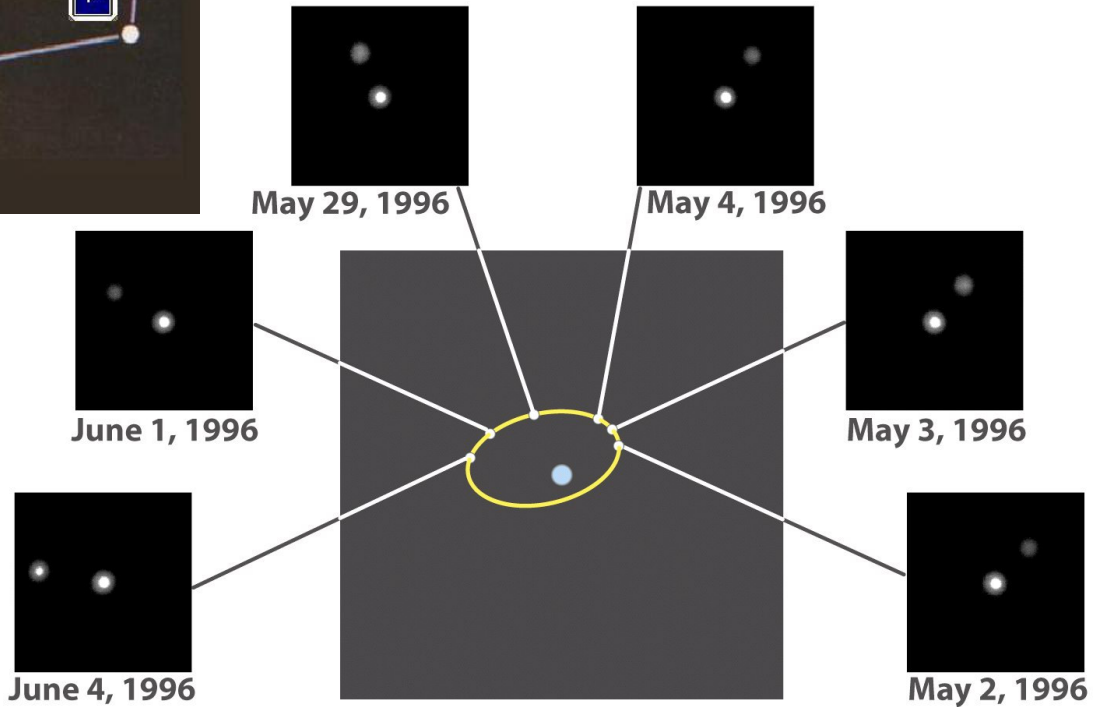


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Star Formation

Rosette Nebula (NGC 2237) 薔薇星雲:
gravitational collapse (重力塌縮) → stars form in cluster

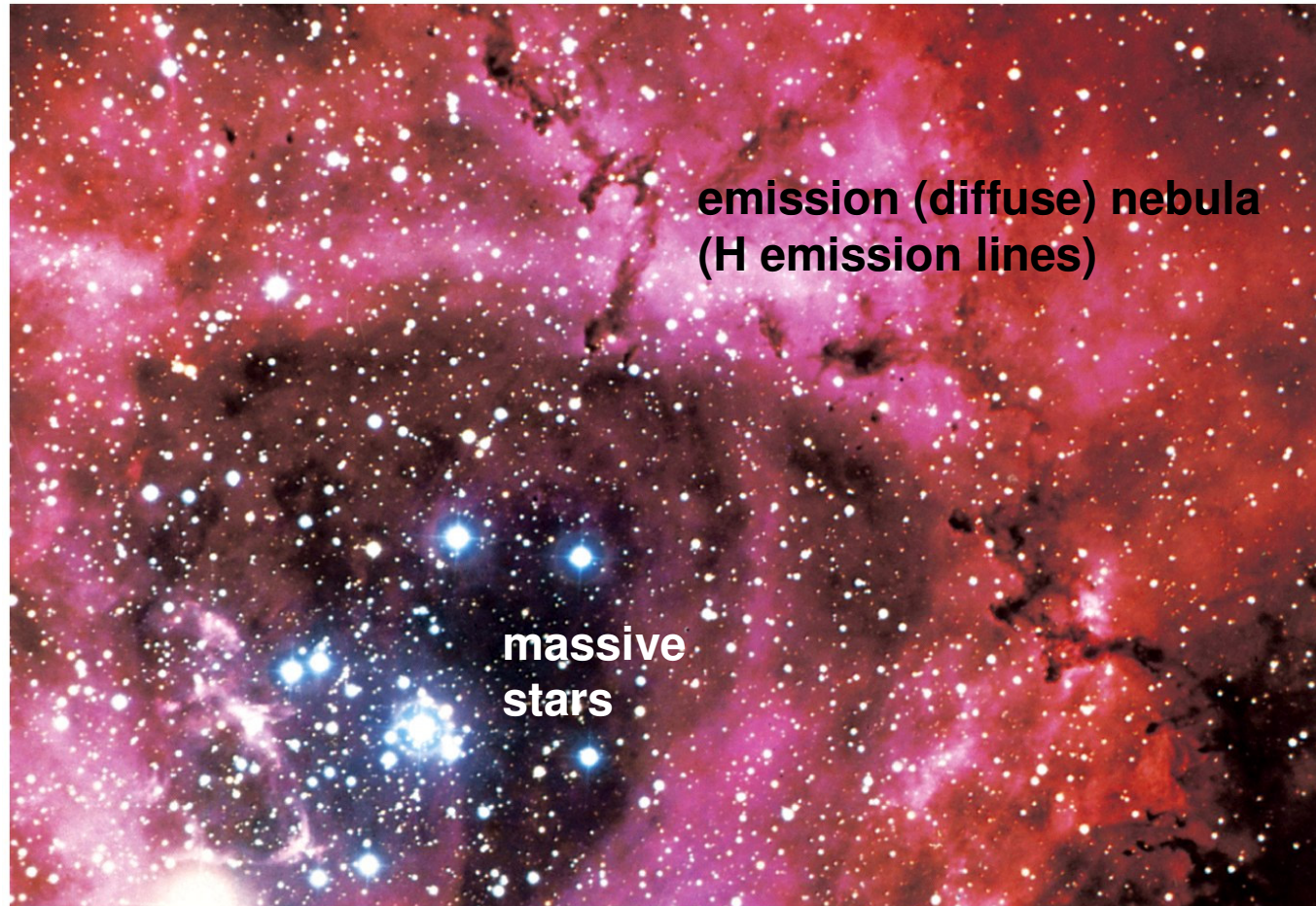


Figure 12-8
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note

Stars form in cluster. A huge and dense cloud of hydrogen gas for some reasons collapses due to the pull of its own gravity. As a result, some of the cloud fragments into smaller and even denser clouds, each of which may further collapses by the pull of its own gravity and finally become a star. These new born stars, especially massive ones, can light up the ambient gas cloud. Then the ambient gas becomes the emission nebula (the name “emission” just means that the gas emits light) beautifully shining in the sky.

Supergiant & Element Factory

Very strong stellar wind due to low gravity & high luminosity

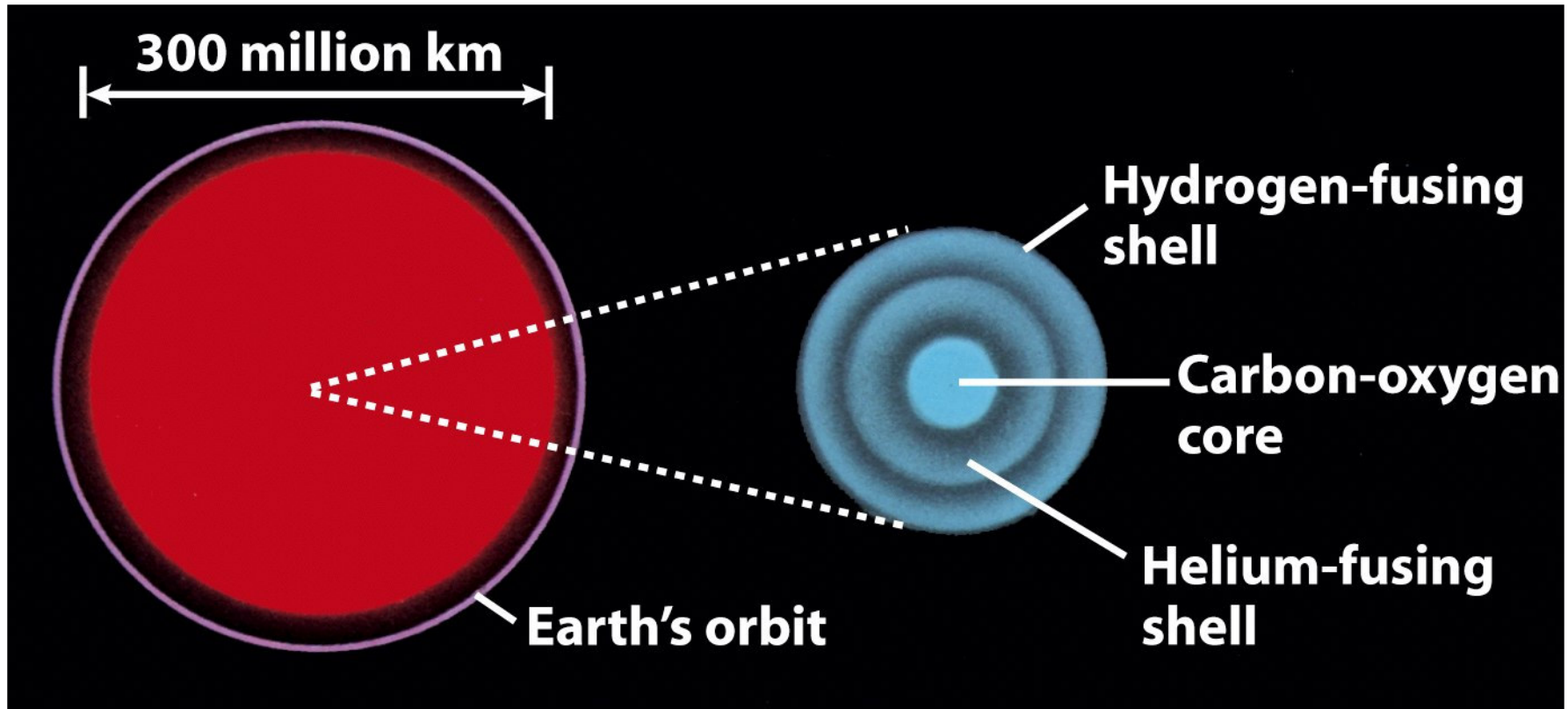


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We are all star dusts!

Planetary nebulae: fate of low mass stars

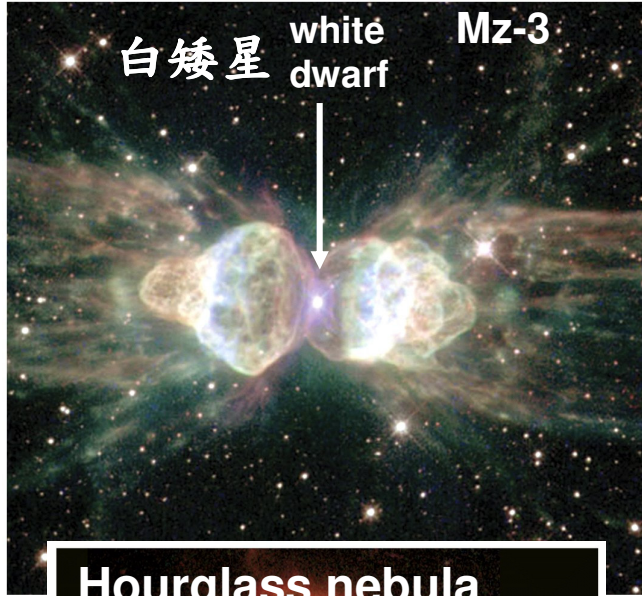


Figure 13-5c
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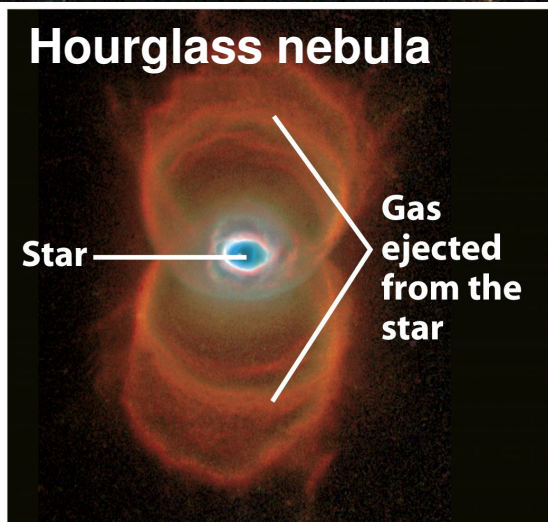


Figure 13-5c
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2006/9/27

...nce tell us that their radi...
...n 0.2 to 3 light-years.
...nce of emission
...eir spectra
...s they are
...w-density
...ler shifts
...y are
...g at
...m/s. If
...radius
...y, we find
...nebulae
...ore than
...ars old.
...etary
...vidently
...nixed into
...stellar

...out 1500
...nebulae in our
...se planetary
...re short-lived
...s, we can conclude
...must be a common
...llar evolution. All stars
...n, up to a mass of about
...asses, are destined to die
...g planetary nebulae.

...cess that produces planetary
...e involves two stellar winds. First,
...aging giant, the star gradually
...away its outer layers in a slow
...e of low-excitation gas that is not
...visible. Once the hot interior of the
...exposed, it ejects a high-speed
...that overtakes and compresses the
...f the slow wind like a snowplow,
...ultraviolet radiation from the hot
...ins of the central star excites the
...s to glow like a giant neon sign.

IC3568 Visual

This nearly spherical planetary nebula has a low-luminosity outer envelope and a highly excited inner region.

He⁺ (blue)
O⁺ (green)
N⁺ (red)

white dwarf

dust

Hubble Heritage Team, AURA/STScI/NASA

Visual

Slow stellar wind from a red giant

Fast wind from exposed interior

The gases of the slow wind are not easily detectable.

We see a planetary nebula where the fast wind compresses the slow wind.

The Ring Nebula is in the constellation Lyra and is visible even in small telescopes. Note the hot blue star at its center and the radial texture in the gas, suggesting outward motion.

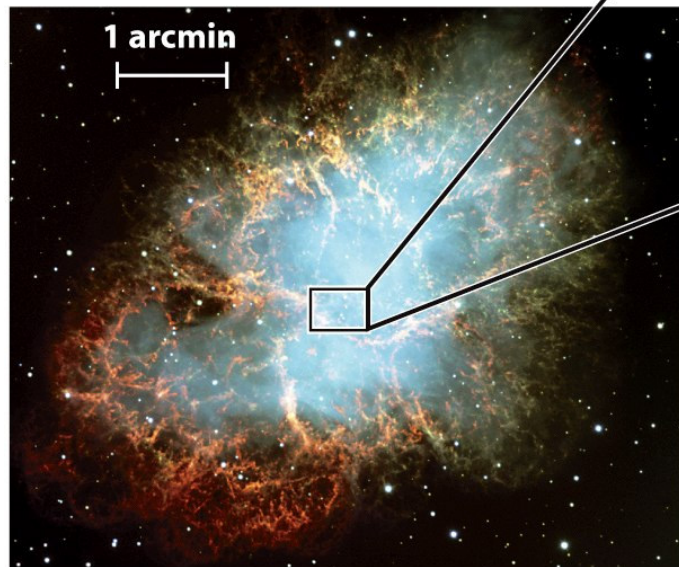
星... 行星... 天体...

note

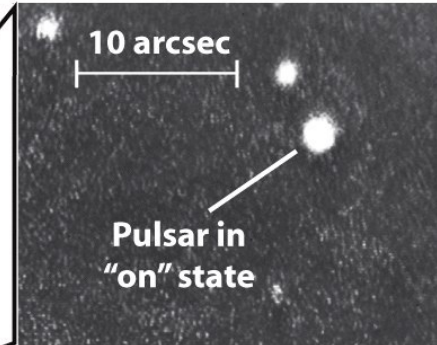
A star like our Sun will convert hydrogen to helium and then to heavier elements such as carbon and oxygen at its center. At this stage, the star will inflate to a huge size and become a supergiant. The stellar surface now is far from the stellar center and therefore experiences very small gravitational pull. The gas on the surface can then easily escape and forms strong stellar winds. The heavy elements such as carbon and oxygen manufactured at the stellar center can be brought away by the winds to the interstellar space where new stars and/or planets may form. This is why stars are element factories and we are all star dusts. Soon after the supergiant phase, lots of stellar gas has gone and becomes planetary nebula, leaving a very dense stellar core at the center. This dense core is a white dwarf.

Supernova 超新星: fate of high mass stars

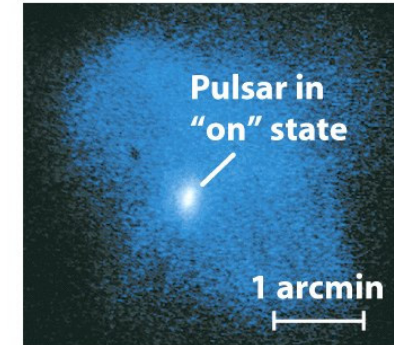
致和元年(A.D.1054), 五月己丑,
客星出天關東南, 可數寸,
歲餘稍沒 《宋史》。



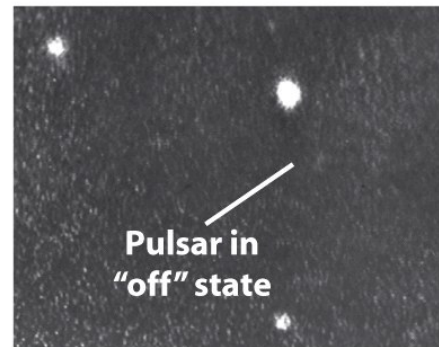
The Crab Nebula 蟹狀星雲



The Crab pulsar in visible light



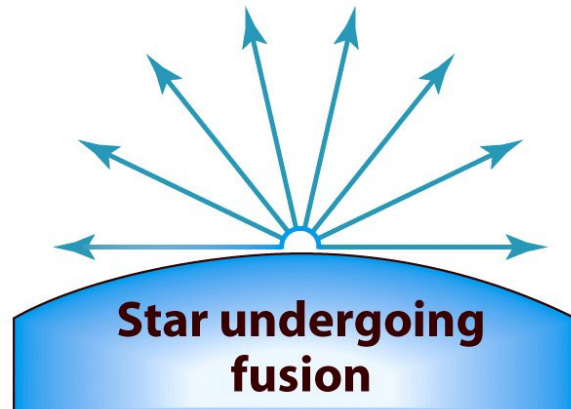
The Crab pulsar in X rays



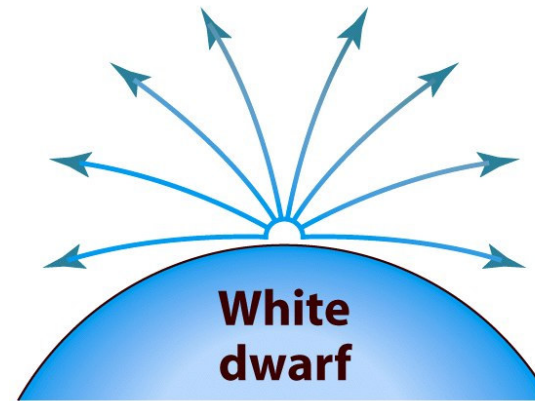
Pulsar (脈衝星) was thought to be a signal from an advanced alien civilization 😊

- as bright as the Milky Way
- once per century in our galaxy

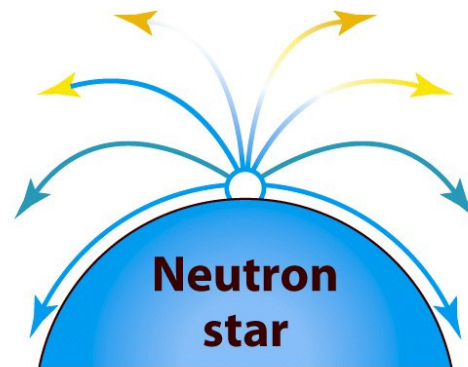
Black Holes (黑洞) have no hair



a

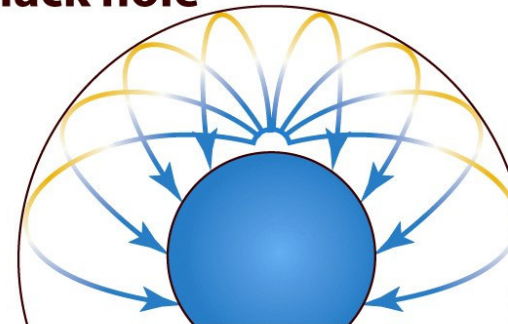


b



c

Boundary of
black hole



d

If **density**
is high
enough

→ Very
strong
gravity

→

Event
horizon:

escape
velocity
= speed of
light

Figure 14-8
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note

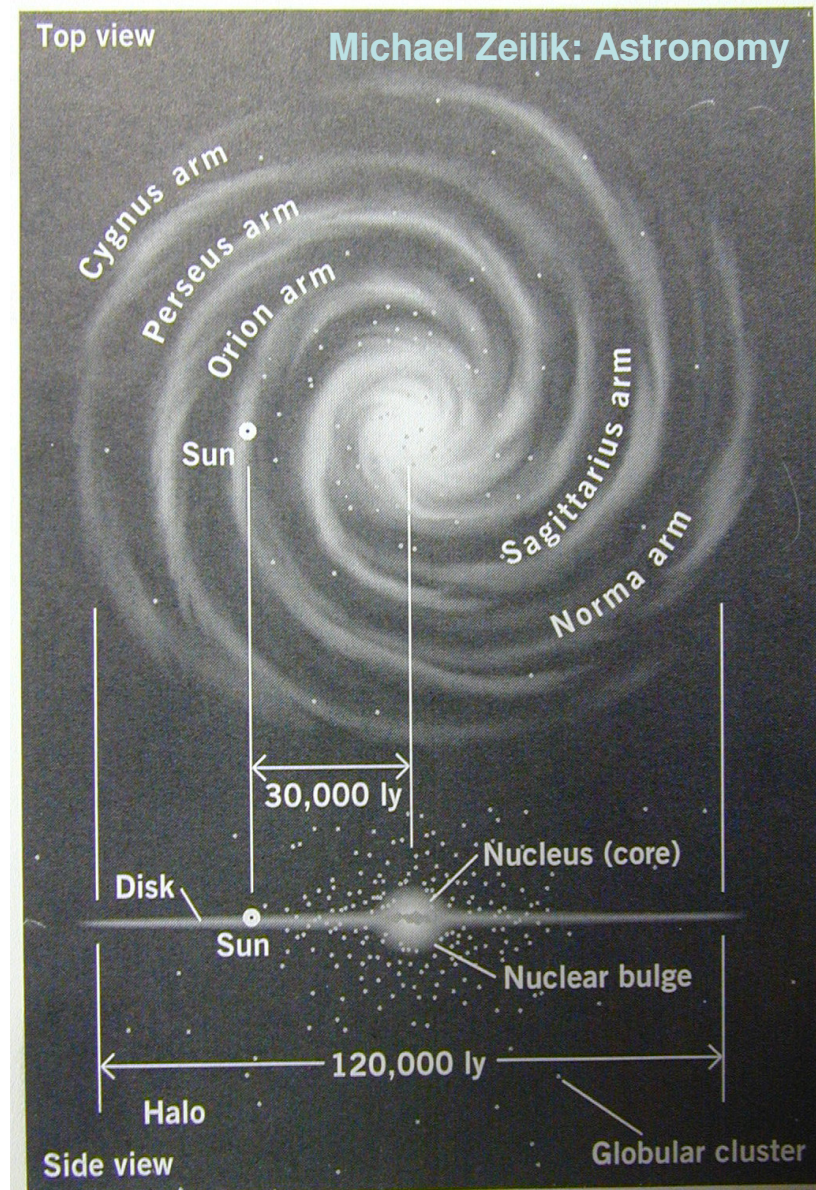
Rather than turning to a planetary nebula and a white dwarf, the final fate (i.e. the final expanding phase) of a massive star (more than 7-8 masses of the Sun) ends up with a more energetic expansion: an explosion with the luminosity comparable to the luminosity of the Milky Way galaxy. This is a supernova. In this case, the stellar core exposed to the outside world after the catastrophic explosion is even denser than a white dwarf. This core is called a neutron star. A neutron star manifests itself as an on-and-off light emitter just like a light house but with extremely high precision. This is why a neutron star acquires another name “pulsar” (I guess you know what “pulse” means) and has been regarded as an accurate clock in nature.

An even more massive star would conclude its life with a supernova too, but leaves an even denser “core” at its center: a black hole forms. One of the most important properties of a black hole (or I should say the definition of a black hole) is that it is dense enough to possess a space boundary called the “event horizon”. Inside the “event horizon”, even light cannot escape and therefore there is no way to know any “events” happening in there. This is why we call it a “black hole”.

Structure of the Milky Way 銀河系

Spiral galaxy 螺旋星系：
most of forming stars (+gas & dust) lie in the spiral arms (旋臂) and around the center.
Most of the old stars are located in the galactic halo (星系暈).

Gravity of the Milky Way is stronger than that contributed from the stars: dark matter (暗物質). So far we do not know the nature of dark matter.



47 Tuc

Globular Cluster 球狀星團

Number density of stars at the center is about 10^5 higher than that in the solar neighborhood.

<http://spider.ipac.caltech.edu/staff/jarrett/papers/LGA/LGA.htm> (2MASS)

Active Galactic Nuclei (AGN)

活躍星系核

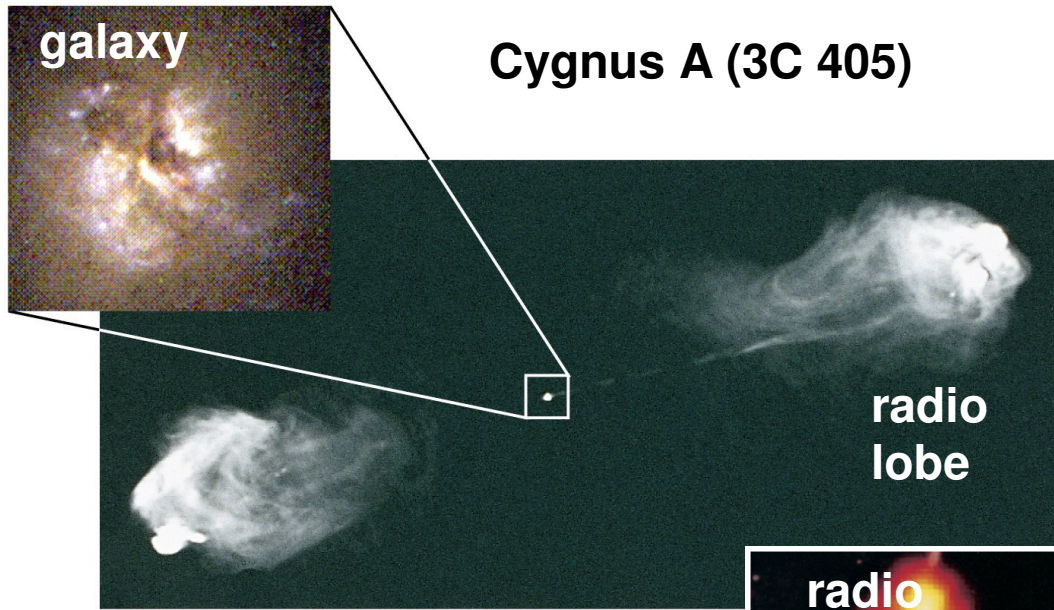


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A supermassive black hole ($10^6 - 10^9$ solar masses) “fed” by an accretion disk lies at the center of most galaxies.

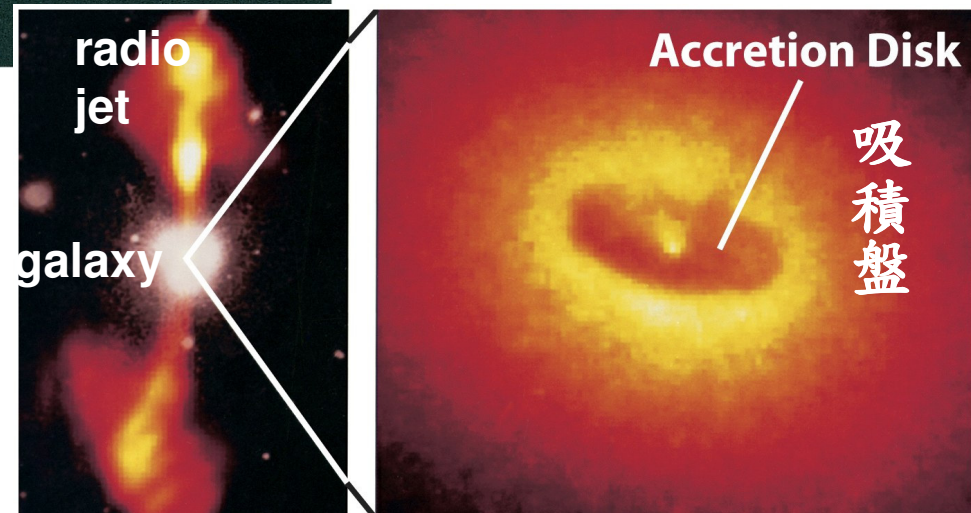
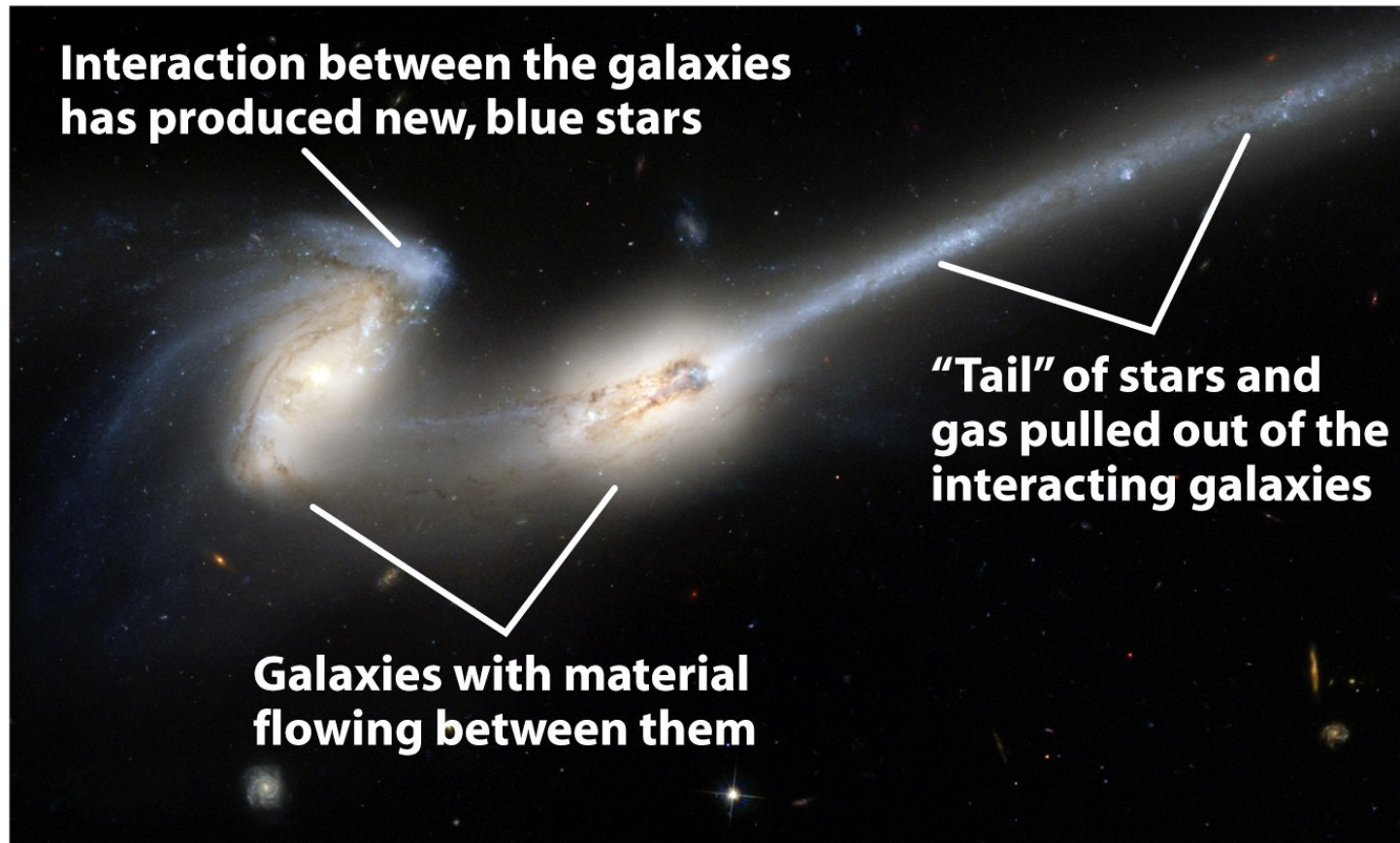


Figure 17-15b
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Interacting Galaxies



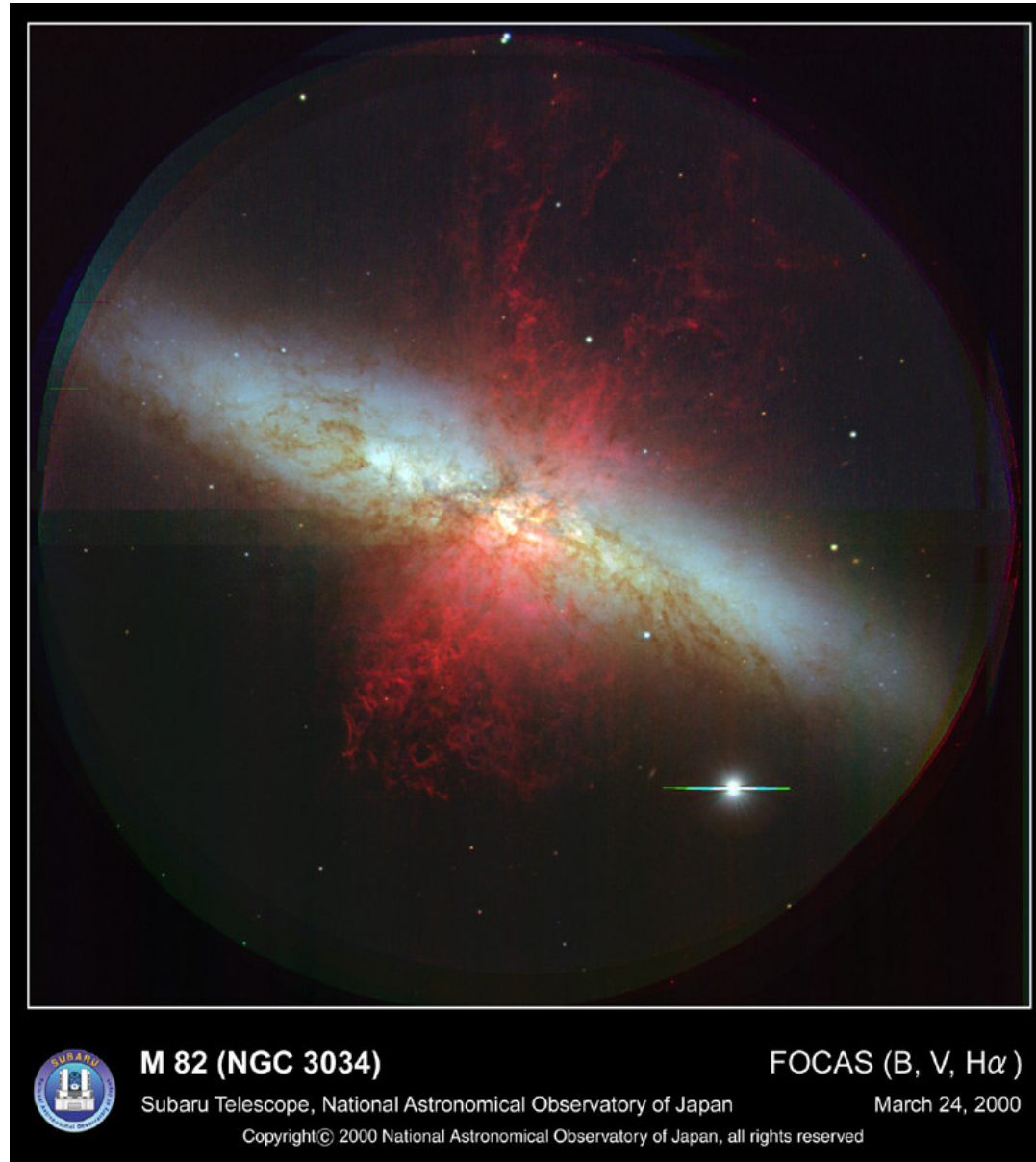
NGC 4676

Figure 16-25a
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Starburst Galaxy

Stars are forming
at a rapid rate in
the “starburst”
galaxy, generating
lots of dust and
gas outflow.

lots of **dust** &
very strong
outflows from
supernovae



M 82 (NGC 3034)

Subaru Telescope, National Astronomical Observatory of Japan

Copyright © 2000 National Astronomical Observatory of Japan, all rights reserved

FOCAS (B, V, H α)

March 24, 2000

note

Unlike the collimated jets from the very small central region of an “active” galaxy (a.k.a. AGN), the outflow from the center of a starburst galaxy is not collimated but spreads out in a wide angle. Astronomers believe that the collimated jet from an AGN is driven by a supermassive black hole. The wide outflow from the center of a starburst galaxy is the explosive gas and dusts from many supernovae. The occurring rate of supernovae in a starburst galaxy is certainly much higher than that in the Milky Way, implying that the star formation rate is much higher in a starburst galaxy. This is what “starburst” means.

Clusters of galaxies (galaxy clusters)

星系團

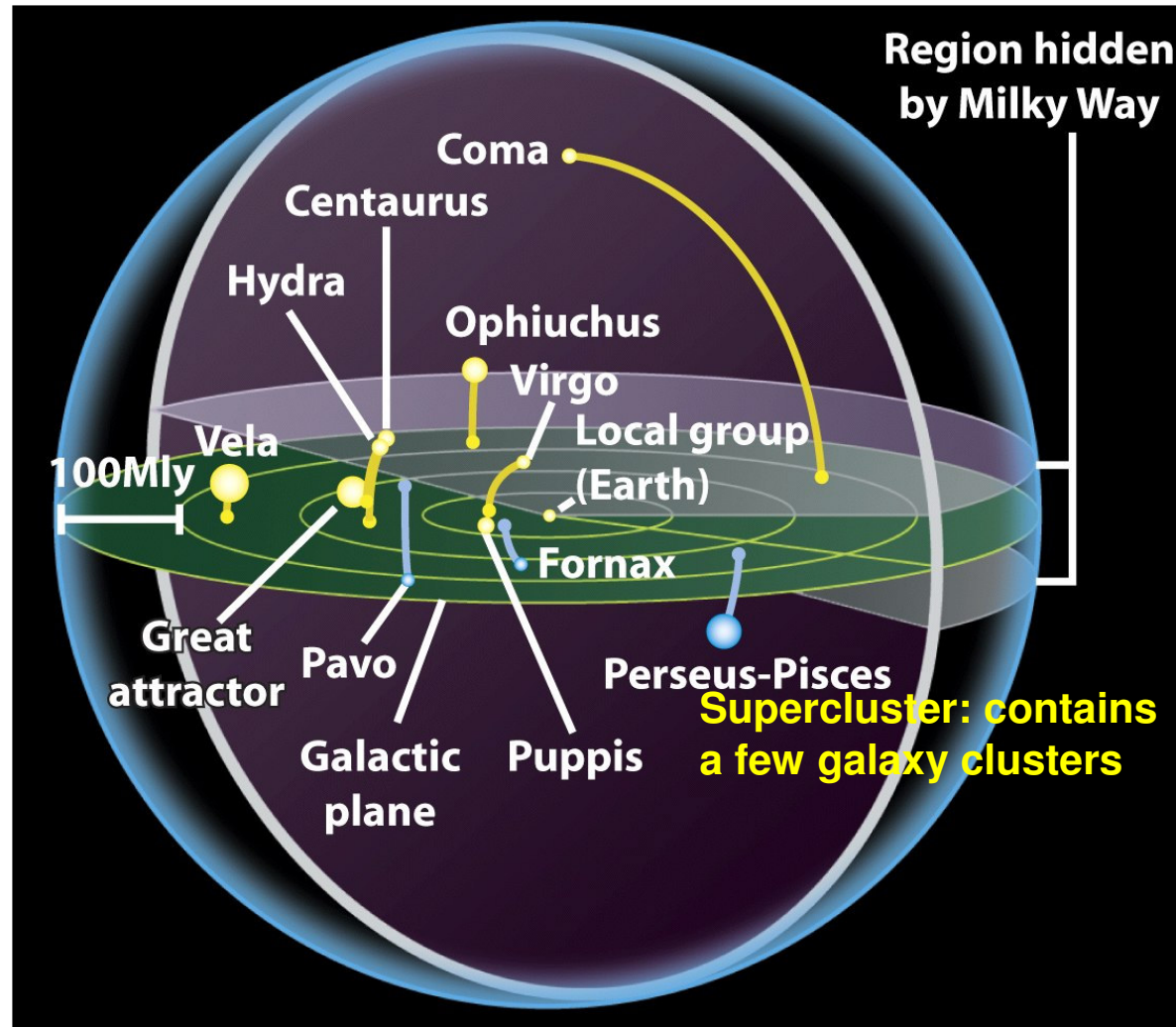


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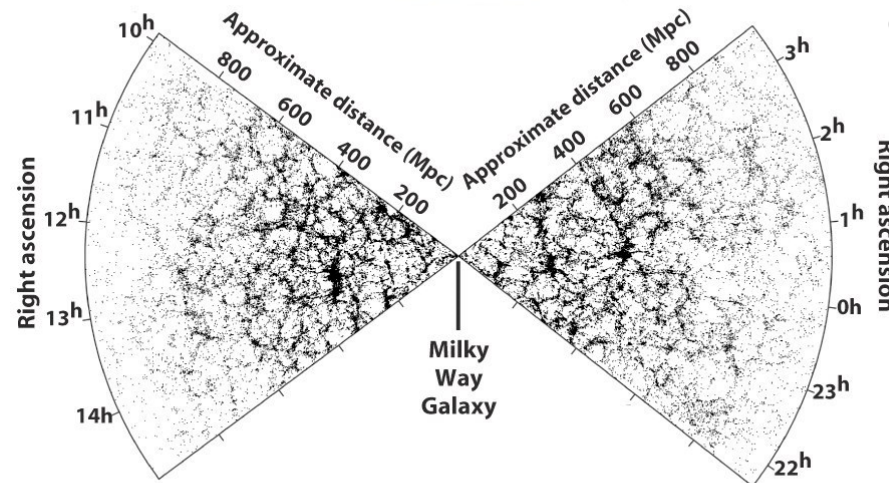
Large-scale structure

**filamentary
structure:
wall & void**



**Since light
takes time
to get to us,
a very distant
object is very
young.**

**Each small
dot is a galaxy!**



The 2dF galaxy survey

Figure 16-16
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Hubble Flow: expanding Universe

紅位移 → 離開速度 (有點像 Doppler effect 都卜勒效應)

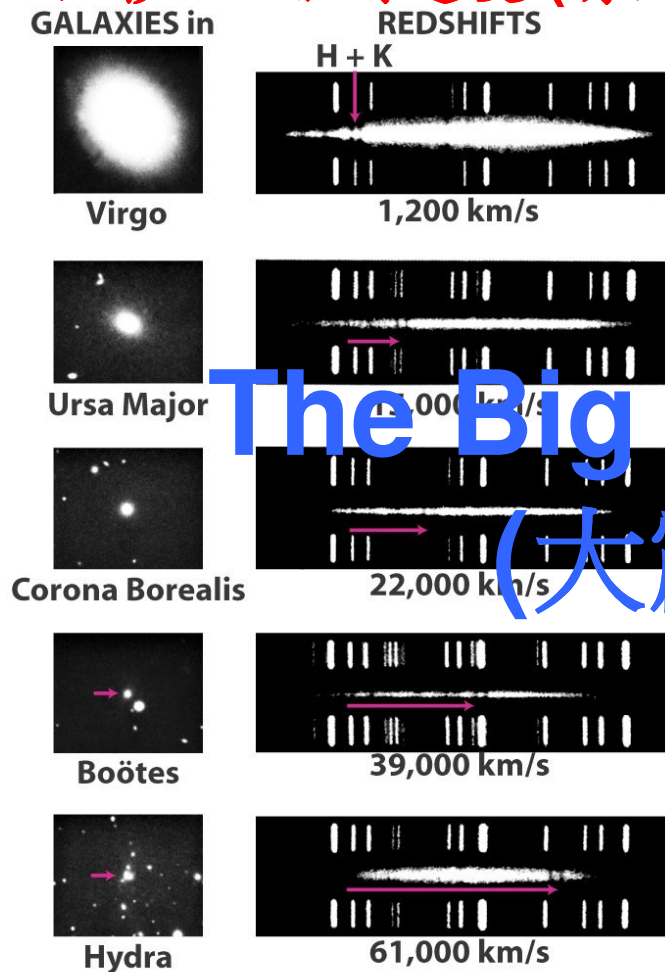


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The Big Bang Model
 (大霹靂說)



note

The nearby galaxies do not serve a good indication of the expansion of the Universe. It is because the flying-away speeds of the nearby galaxies are small compared with their local movement due to their mutual gravitational interactions. The farther away a galaxy is, the faster a galaxy is moving away from us. Hubble observed the light spectra of distant galaxies. He found the red shift of the spectral lines and concluded that the Universe is expanding. This concept of the Universe is called “the Big Bang” model. The Big Bang is referred to the extremely early phase of the Universe when the Universe was tiny and hot.

Catch the Ancient Light!

Cosmic Microwave Background (CMB)

宇宙微波背景輻射

Isotropic temperature: 2.726 K



Robert Dicke

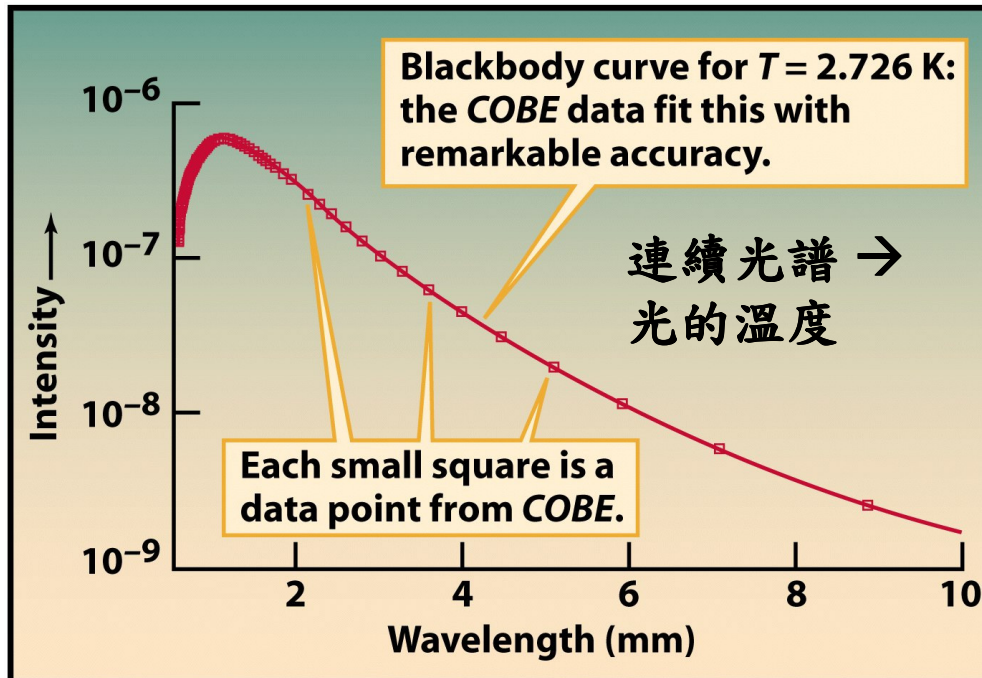


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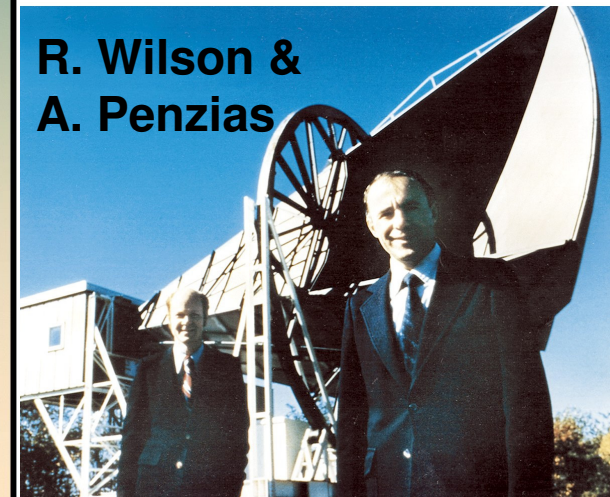


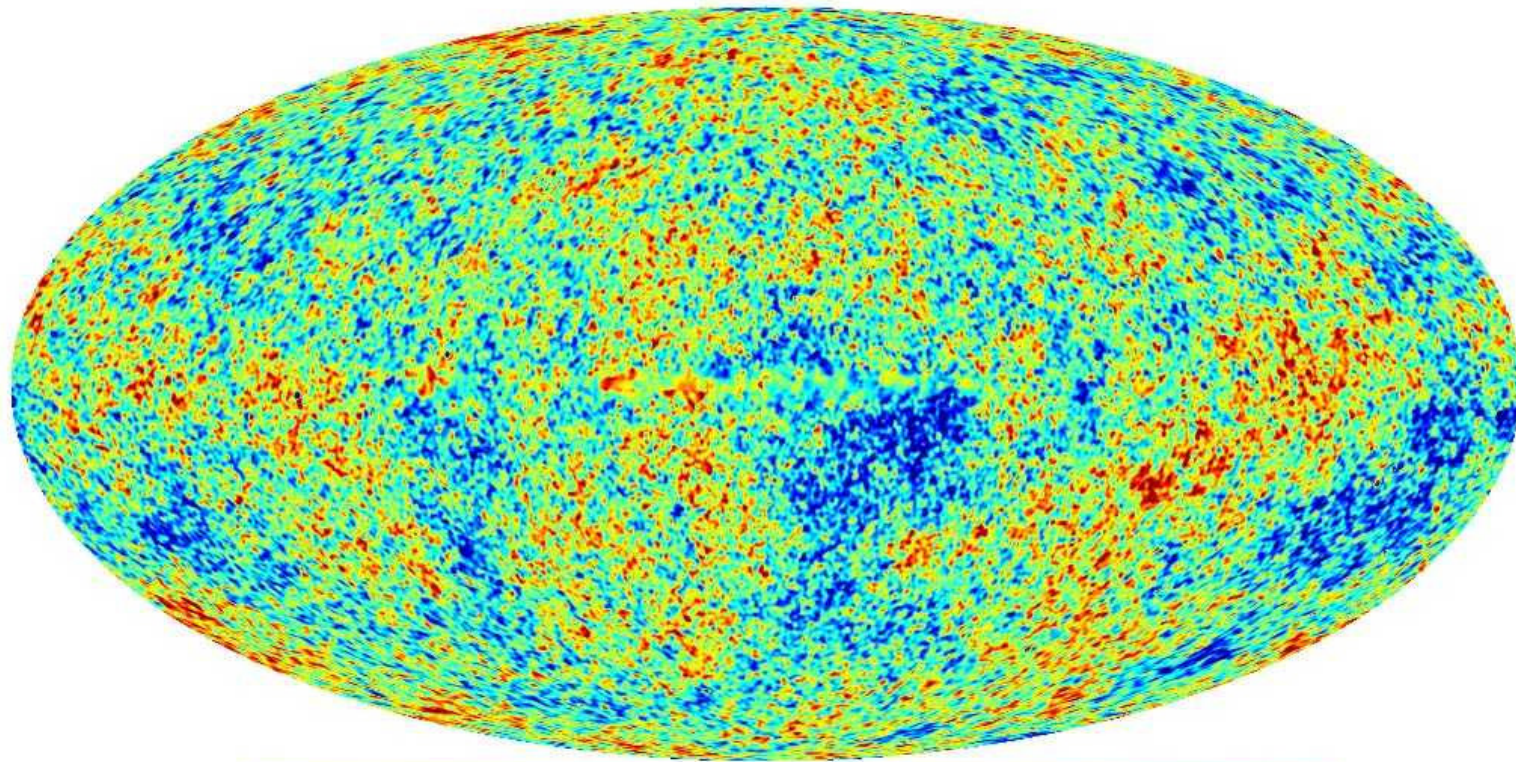
Figure 18-2
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note

CMB radiation is coming from all directions from the sky (i.e. isotropic). Since the energy of the radiation peaks at the microwave range, this indicates that the radiation is cold now (2.726K). Astronomers have modeled the radiation and believe that the CMB radiation is the ancient light from the Big Bang. As the Universe expands and therefore cools and becomes less dense, the ancient light can travel freely with little interaction with matters. This is why the light can preserve the ancient history of the Universe. The cold temperature of the radiation today is a result of the expansion of the Universe (analogy: expanding hot gas gets colder and colder just because energy spreads out in a bigger volume).

Ancient Light is not 100% isotropic!

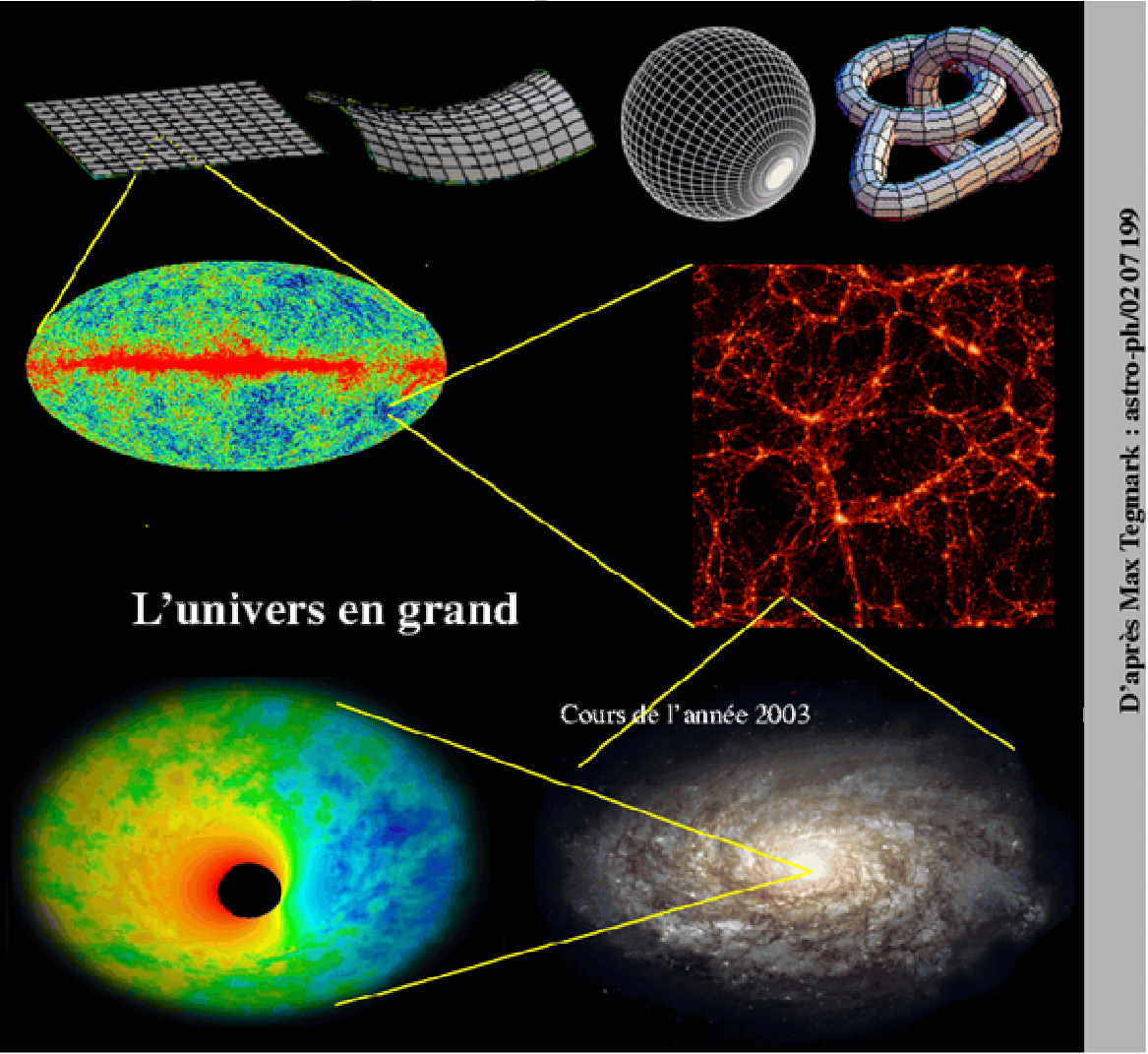
CMB anisotropy 不均向性



-200 μ K  200 μ K

WMAP (Wilkinson Microwave Anisotropy Probe)

density fluctuations in the Big Bang & galaxy formation



note

Tiny temperature anisotropy in the uniform CMB radiation actually imprints the information of how the large-scale structure forms and distributes. The slightly hot region is the site of collapsing matter (most of them are dark matters) due to its own gravity pull (contracted gas becomes hotter). This gravitational collapse form galaxies and clusters of galaxies which exhibit a filamentary structure as we observe today in the large-scale.

Cosmic Timeline

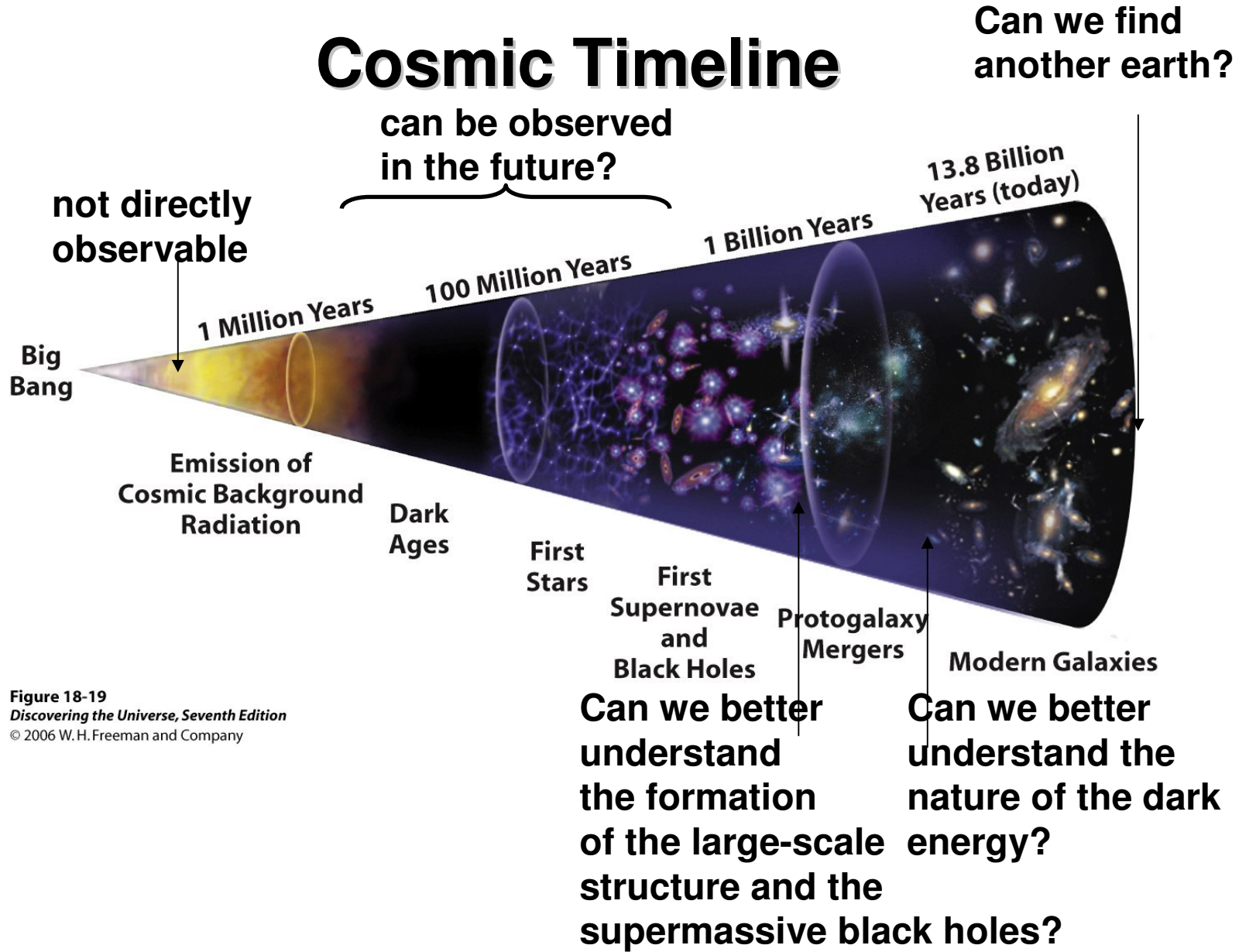


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