時空觀念的錯愕：黑洞

辜品高

師大地科系

中研院天文所

Black hole: metaphor of loss and despair?

藥價黑洞
高鐵黑洞
卡債黑洞
國防黑洞
退休金黑洞

Look out for the wording

金剛經：
所謂佛法者，即非佛法，是名佛法。

道德經：
道可道，非常道；名可名，非常名。

stellar evolution depends on mass

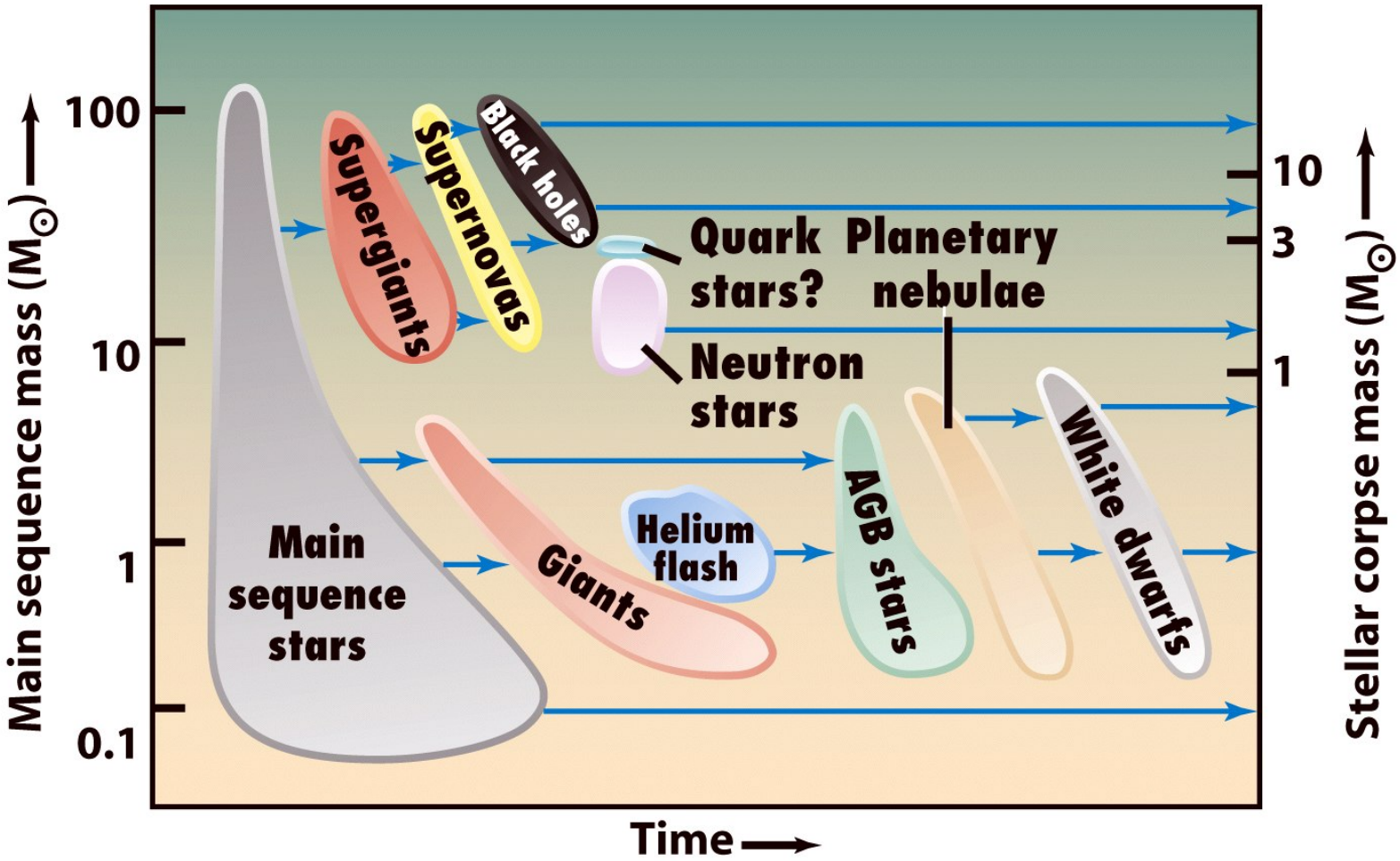

Figure 13-27a
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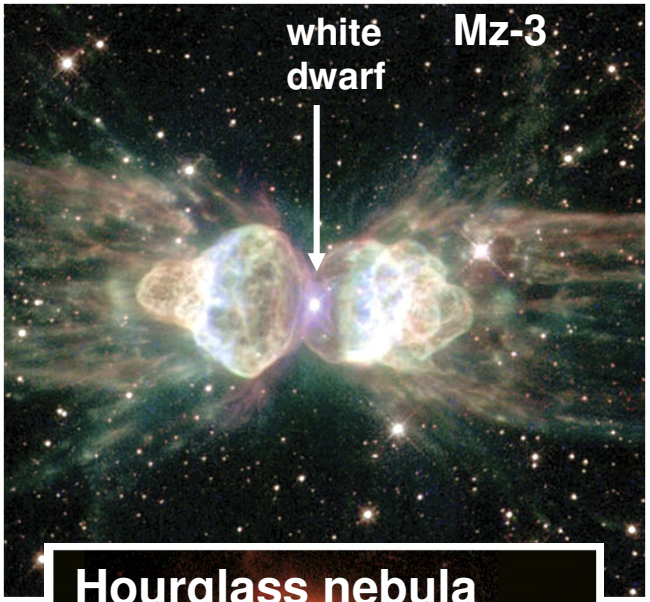
Planetary nebulae 行星狀星雲 leave a white dwarf behind



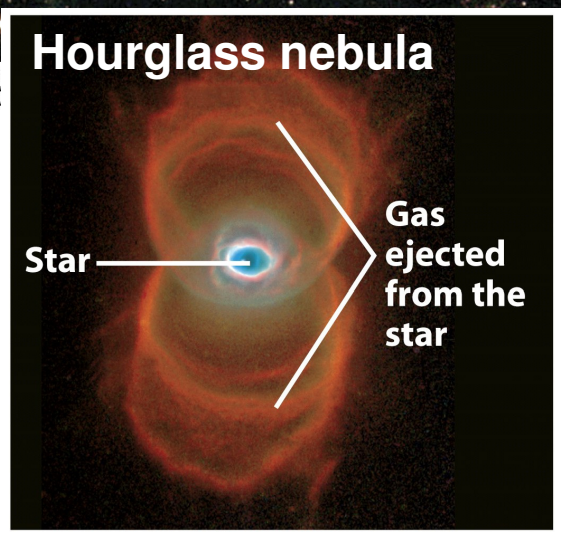


Figure 13-5c
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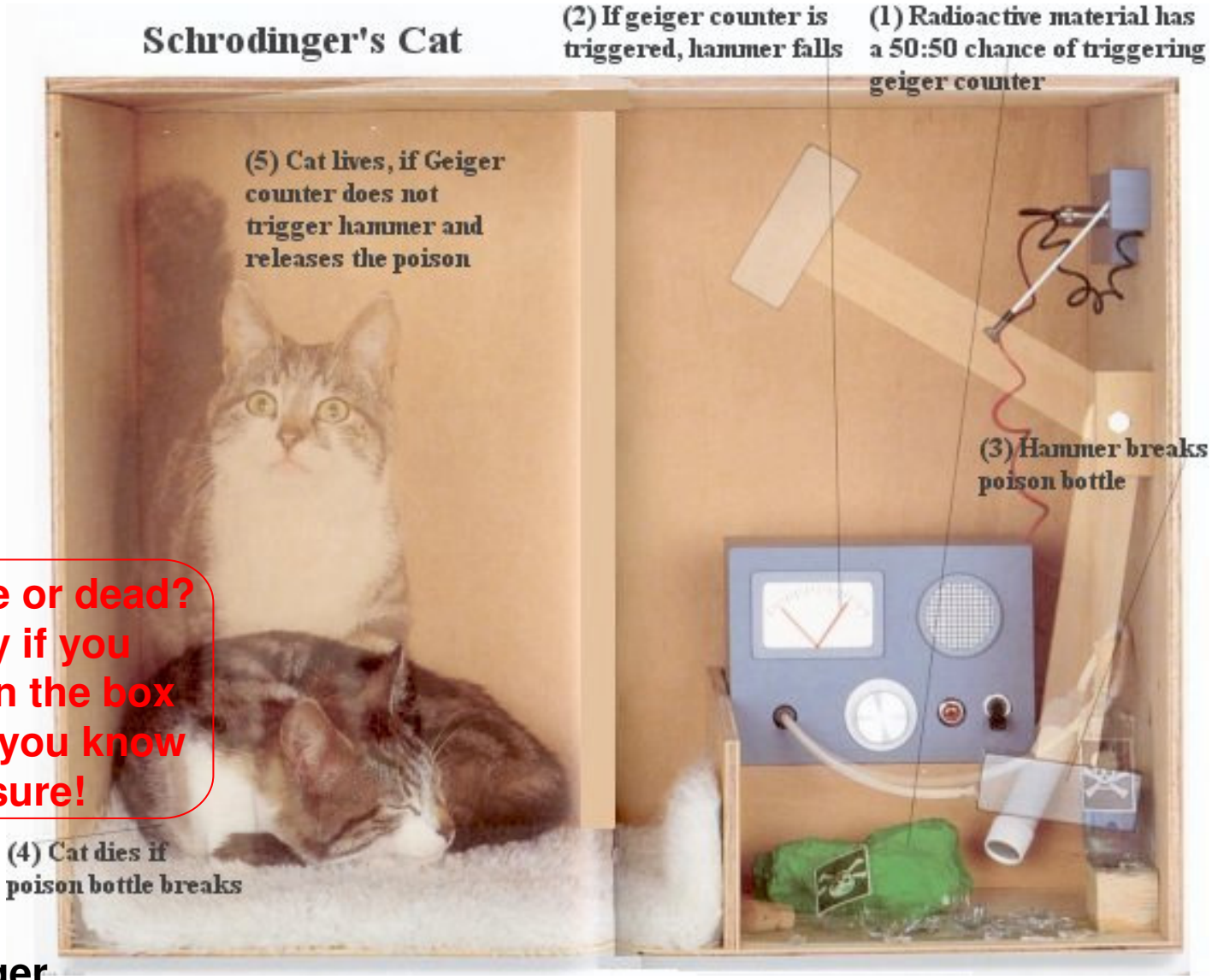
薛丁格之貓 (1935)

alive or dead?
Only if you
open the box
will you know
for sure!

Erwin Schrodinger
Nobel Prize in 1933



http://universe-review.ca/I12-21-cat.jpg

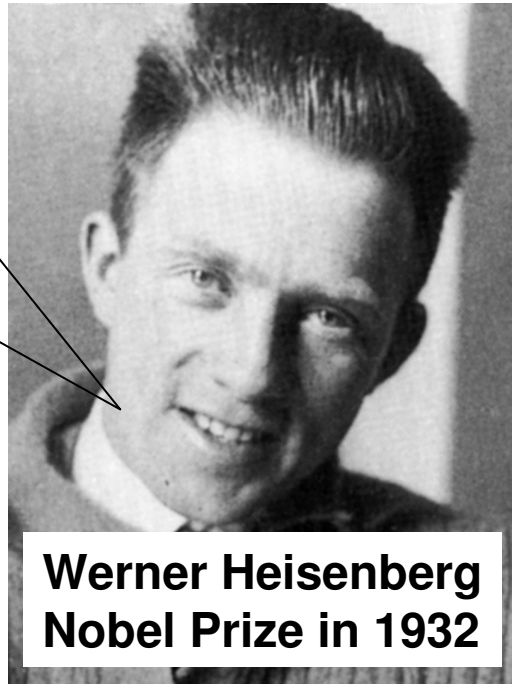
量子力學(quantum mechanics)的基石：測不準原理(uncertainty principle)

基本粒子(質子、中子、電子…)是一種機率波

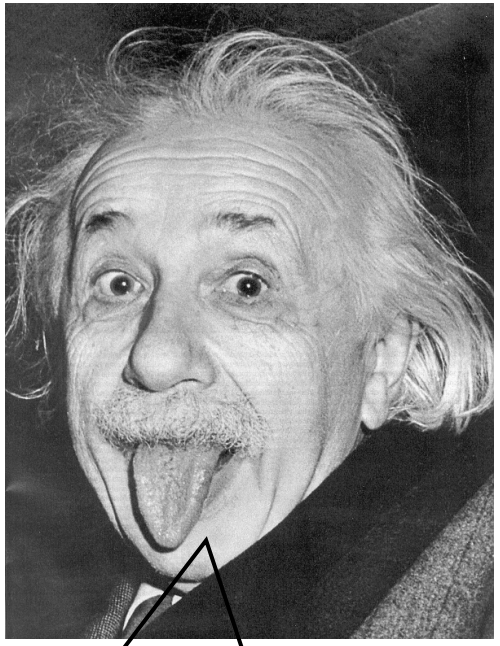
$$\Delta x \Delta p \geq \hbar / 2$$

$$\Delta E \Delta t \geq \hbar / 2$$

理工學院的同學可從
Fourier Analysis去了解



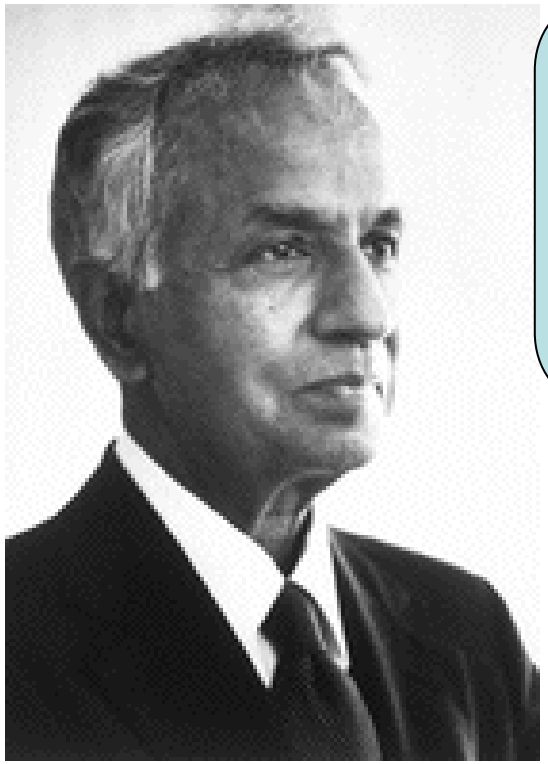
Werner Heisenberg
Nobel Prize in 1932



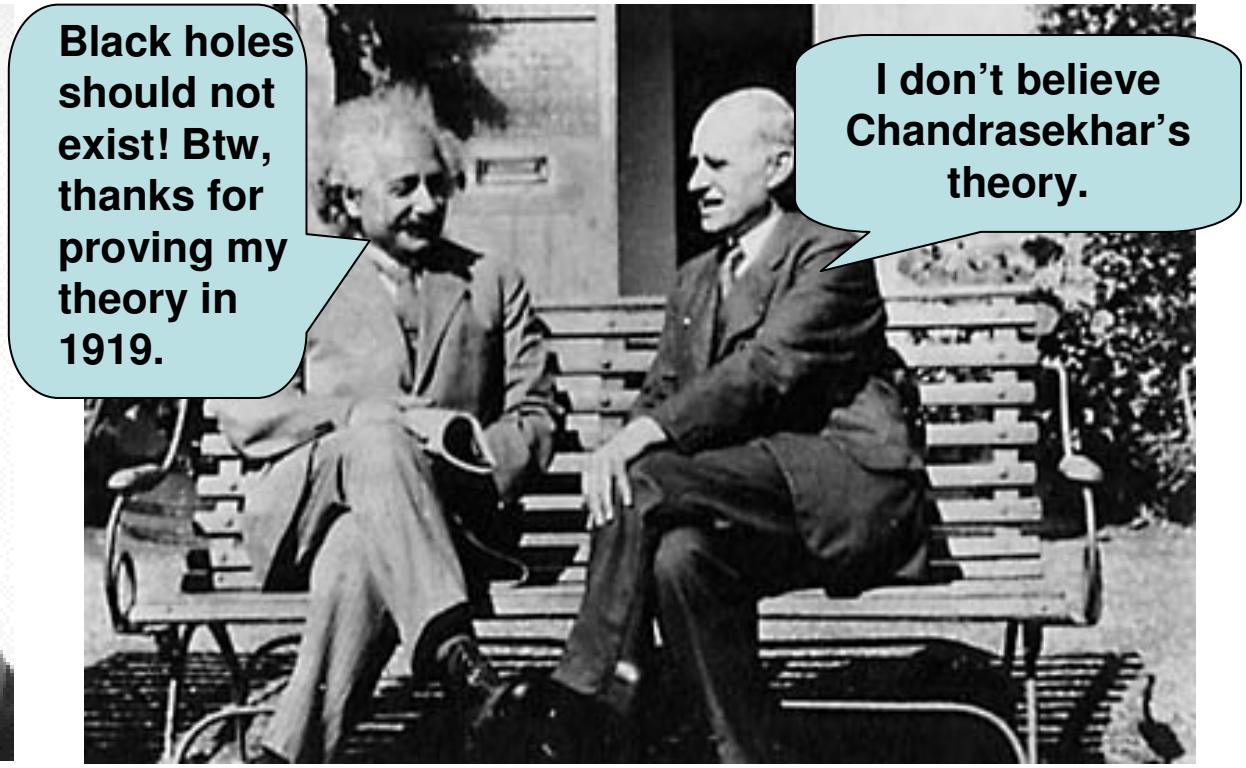
I don't believe it. God does not play dice!

阻擋重力塌縮的防線：Chandrasekhar Limit

當白矮星質量大於1.44太陽質量(Chandrasekhar Limit)，
電子簡併壓力將無法抵抗重力，於是開始重力塌縮。



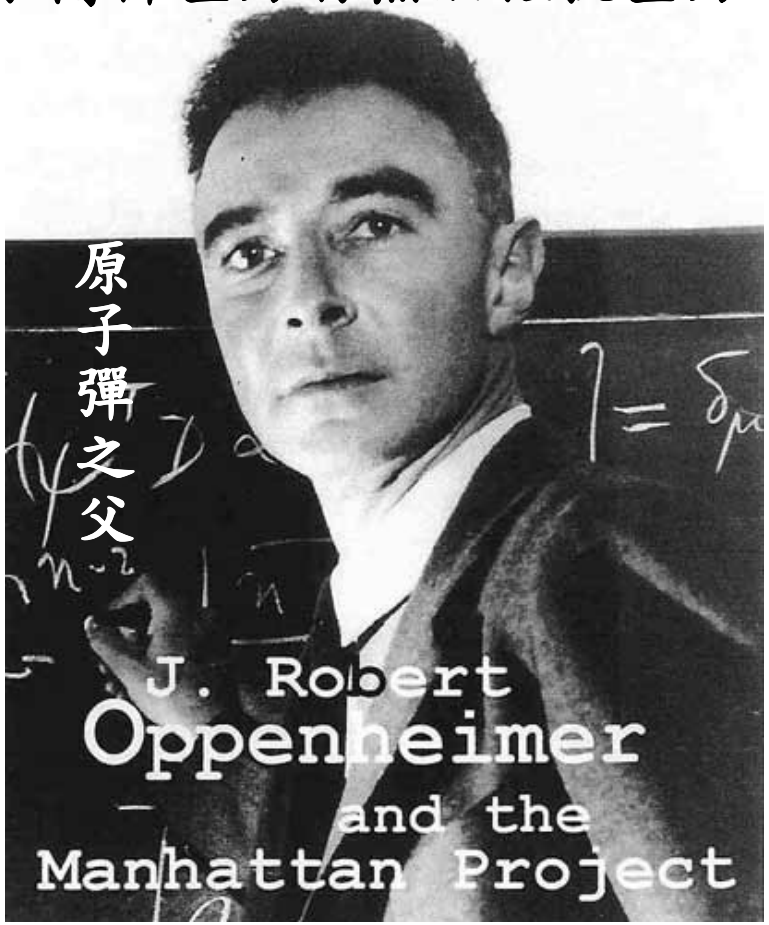
S. Chandrasekhar
Nobel Prize in 1983

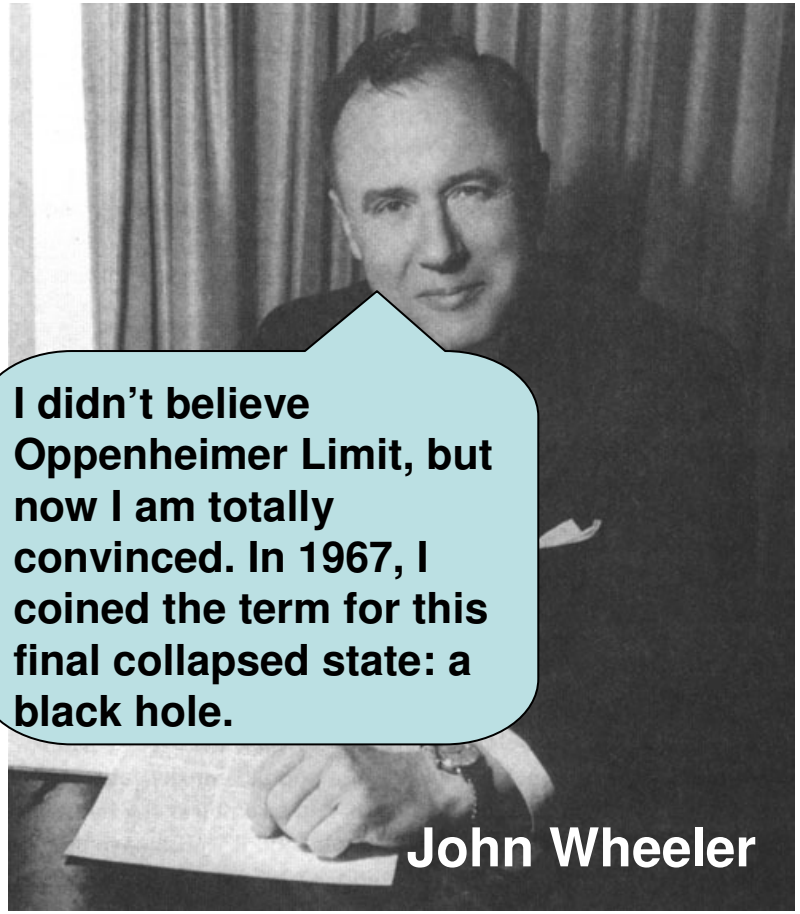


Albert Einstein & Sir Arthur Eddington
at Cambridge

阻擋重力塌縮的防線：Oppenheimer Limit

當中子星質量大於3個太陽質量(Oppenheimer Limit)，中子簡併壓力將無法抵抗重力，於是開始重力塌縮。





Old high-mass stars (>8 M_{sun})

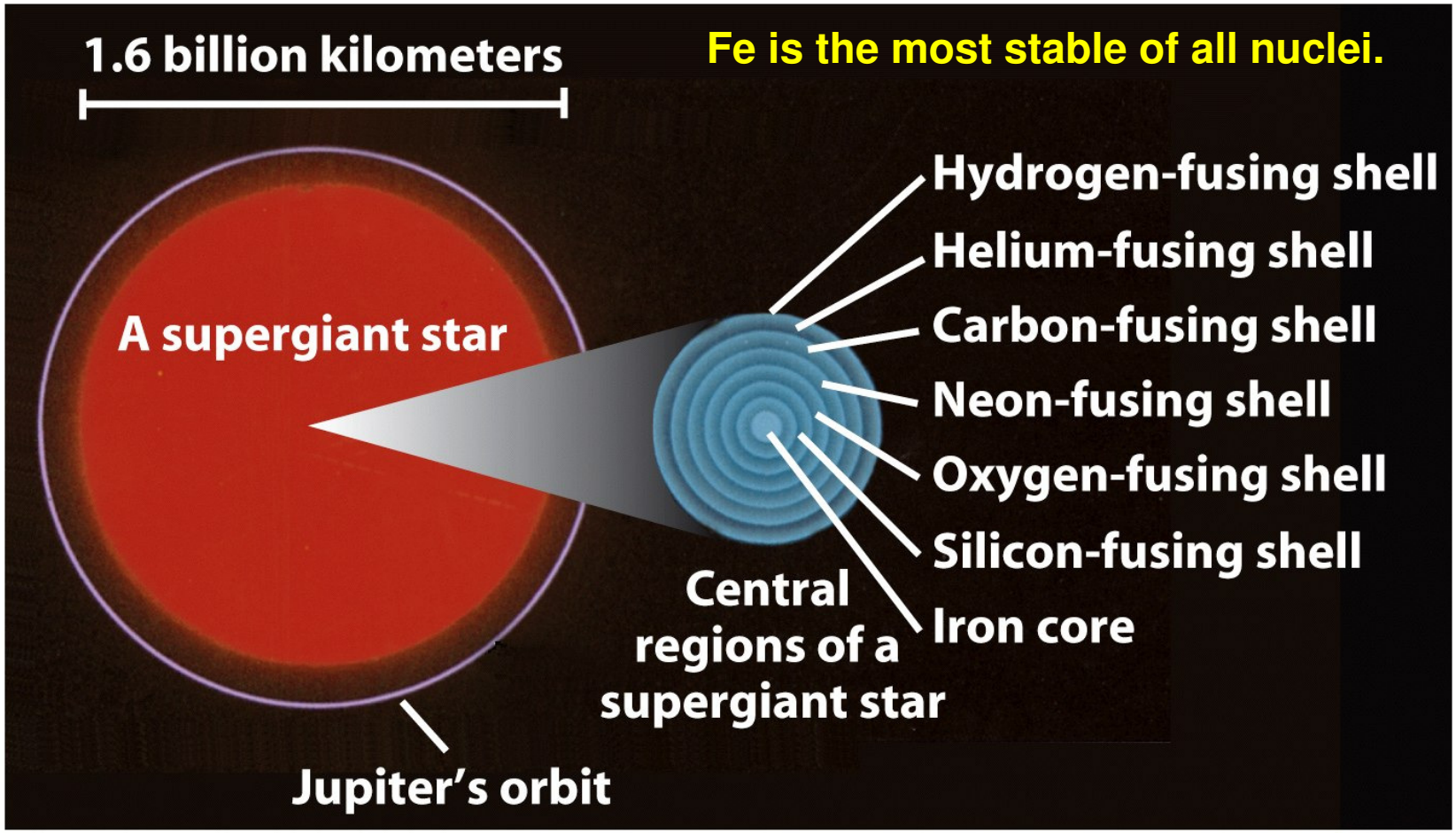


Figure 13-9
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Supernovae 超新星

core of a massive supergiant collapse → neutron star/black hole
outer layer hits the core and rebound → supernova

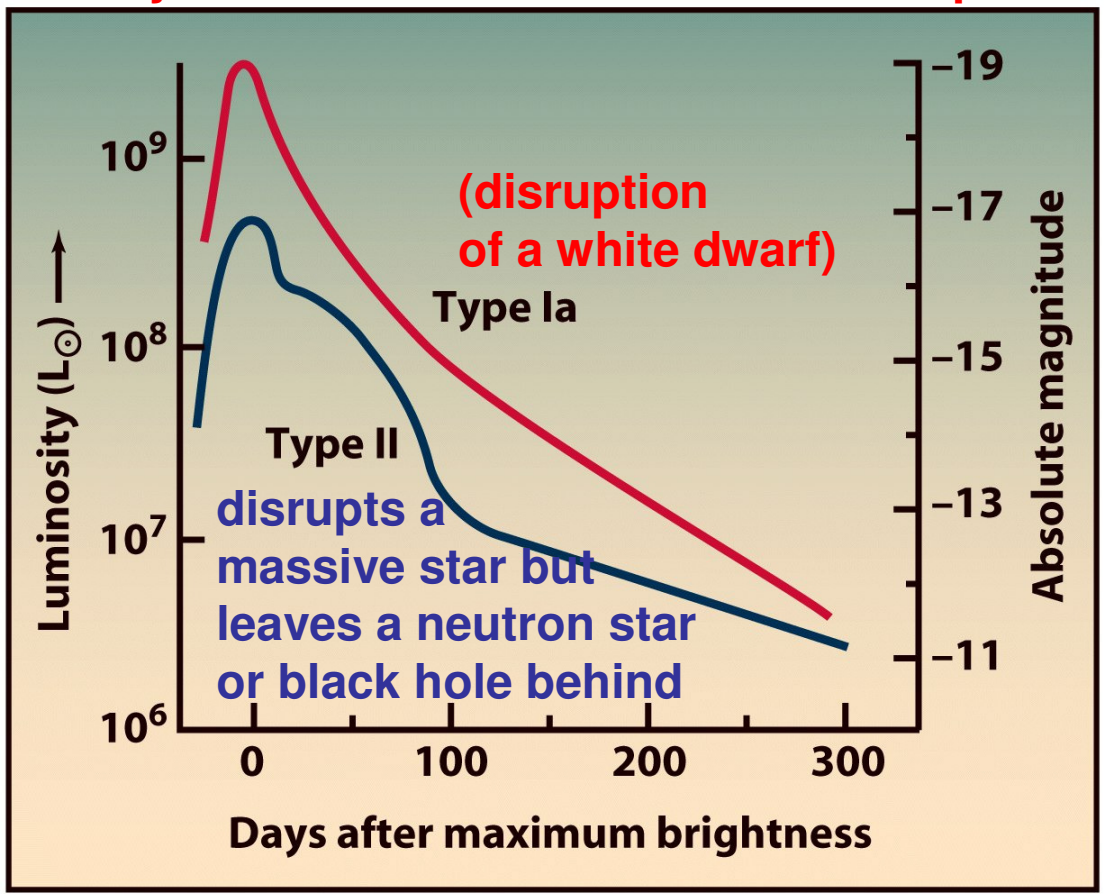

Figure 13-16
Discovering the Universe, Seventh Edition

Note that about 99% of released energy goes to neutrino!

supernova remnants

Figure 13-11
Discovering the Universe, Seventh Edition

Gum Nebular in Vela (visible)
Occurred about 11000 years ago
Size: 2300 ly in diameter

Cassiopeia A (X-ray)

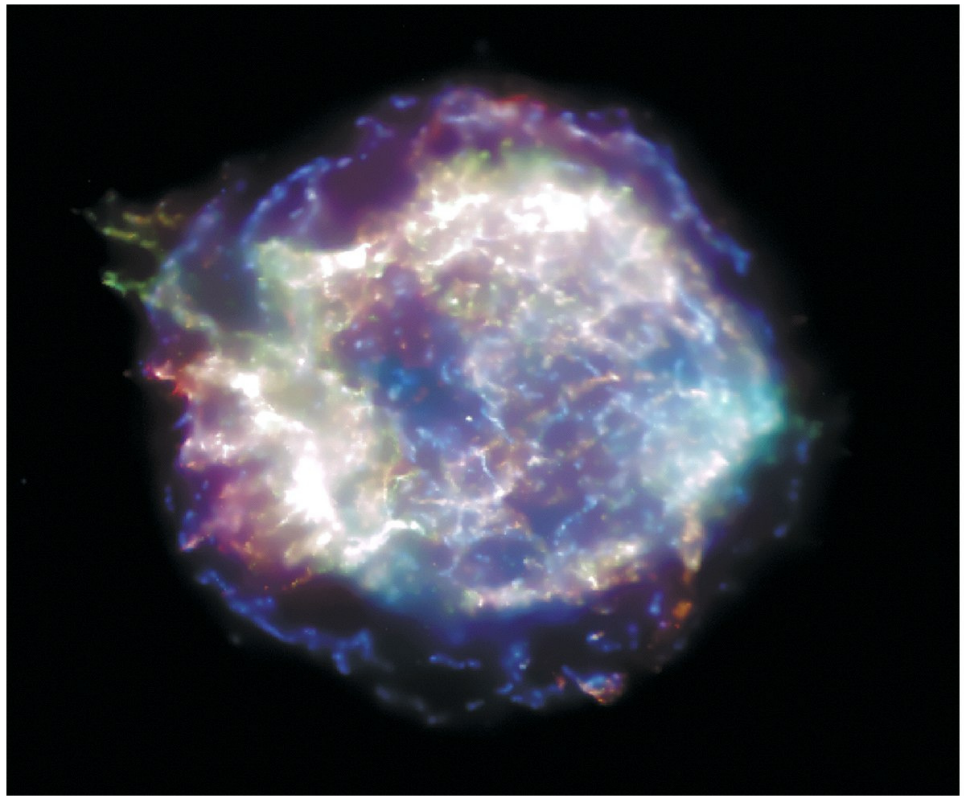

Figure 13-12a
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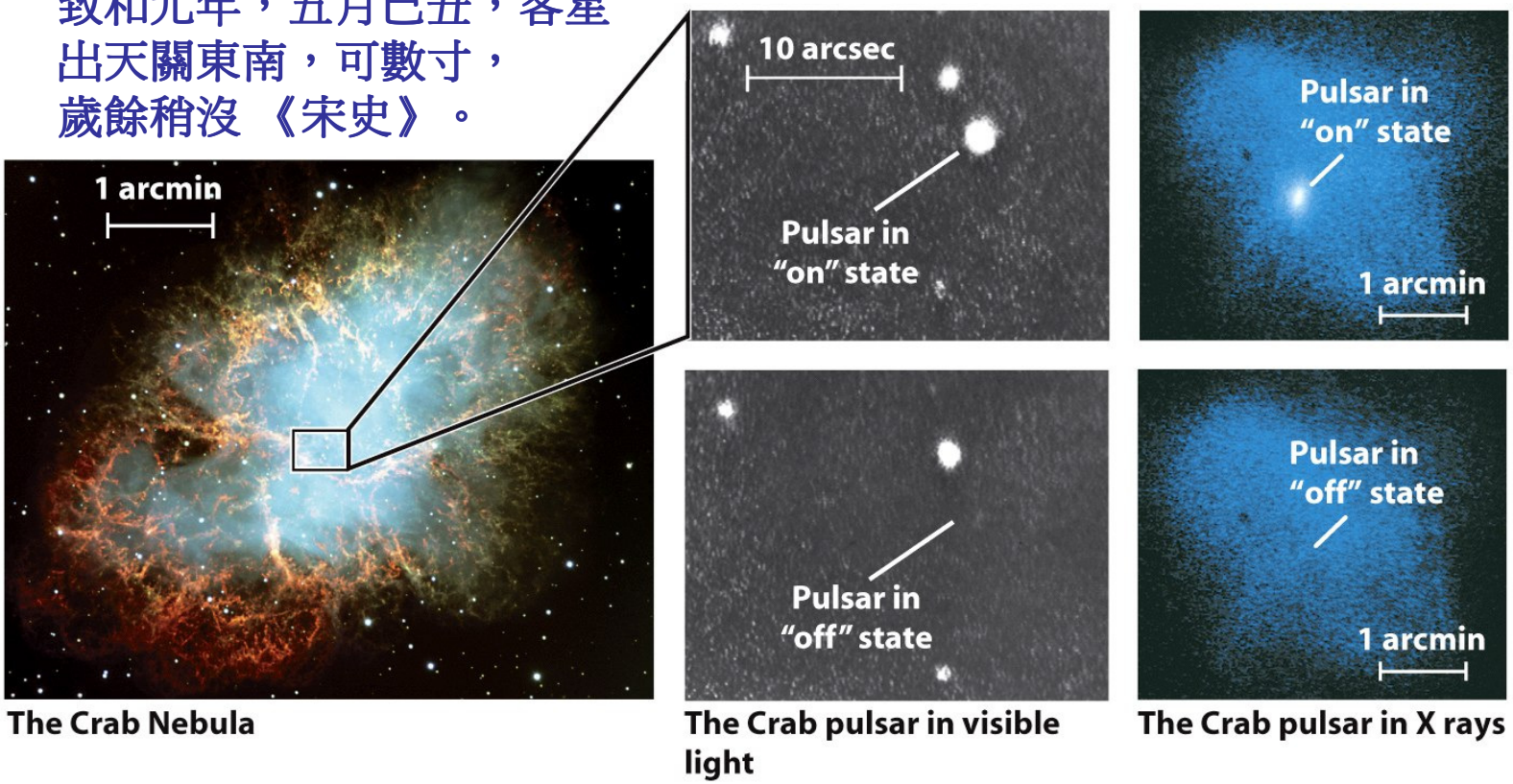
天津四
可能會變
成黑洞


天津四
Deneb
Kepler
Field of
View
Vega
織女星
LYRA
CYGNUS
Albireo
輦道增七
(雙星)
牛郎星
Altair
AQUILA

Crab Nebula (蟹狀星雲，M1)

致和元年，五月己丑，客星
出天關東南，可數寸，
歲餘稍沒 《宋史》。



The Crab Nebula

The Crab pulsar in visible light

The Crab pulsar in X rays

Figure 13-18b
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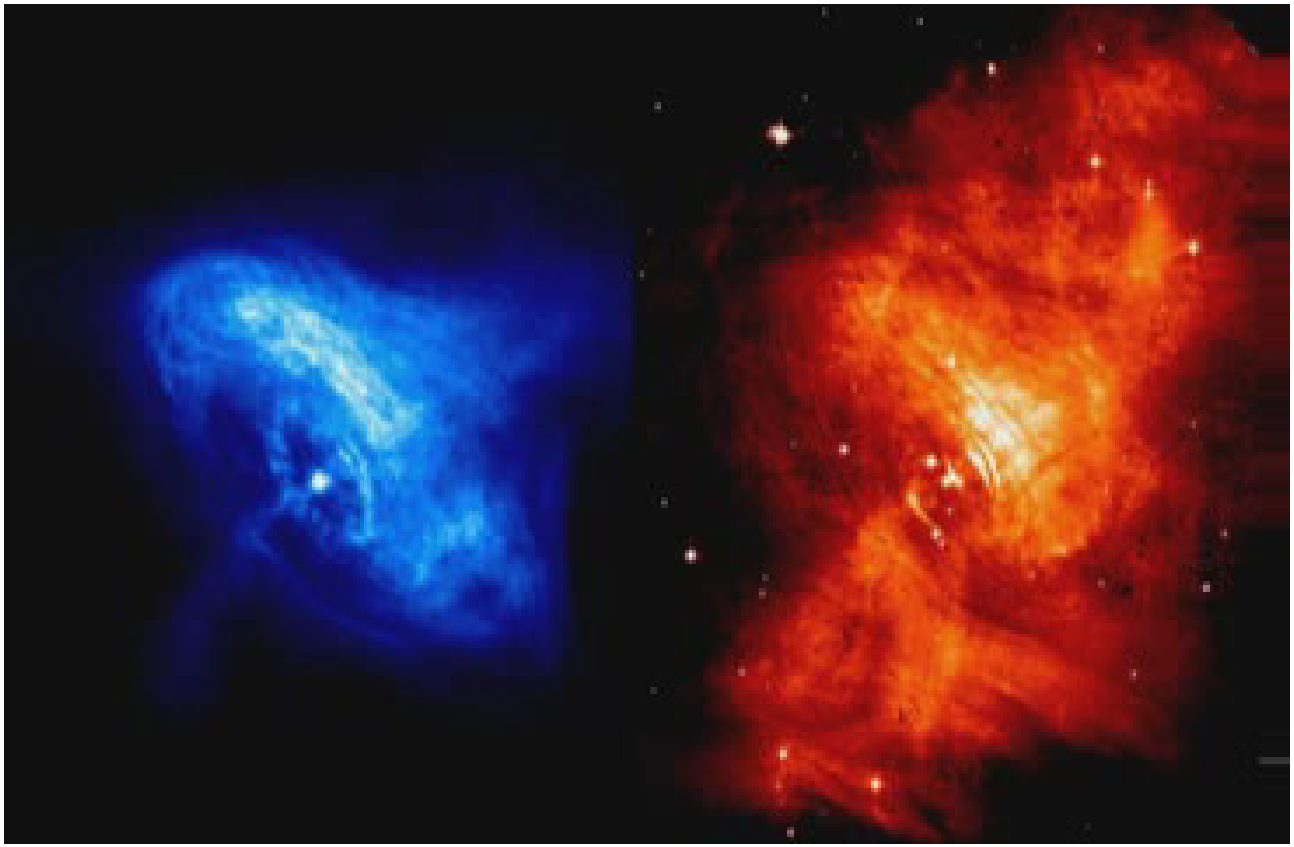
Pulsar (波霎) was thought to be a signal from an advanced alien civilization ☺

Crab Nebula

http://chandra.harvard.edu/photo/2002/0052/movies.html



X-ray (Chandra telescope) **visible (Hubble telescope)**

Pulsar (波霎) & Neutron star (中子星)

http://astronomy.swin.edu.au/pulsar/reduction/p2.html

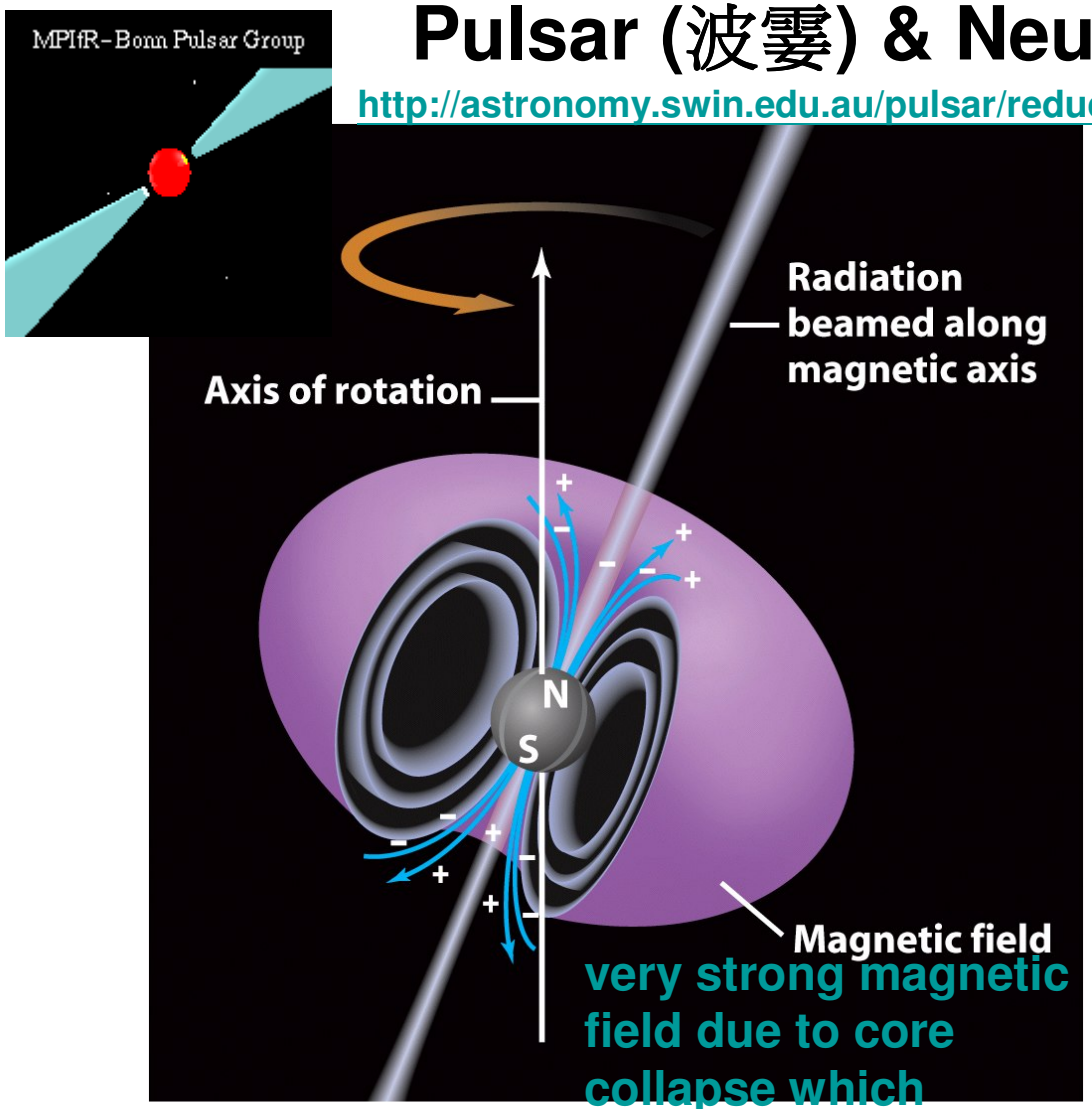


Figure 13-20
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very strong magnetic field due to core collapse which compresses magnetic fields.

White dwarf mass > 1.4 solar masses → p+ + e- → n + neutrino

Neutron star (a city-size dying star): Made of closely packed neutrons (density is as high as a nucleus!) →
gravity is balanced by the neutron degenerate pressure (the final defense against gravitational collapse)

Pulsar is the evidence of a neutron star!

Black Holes have no hair

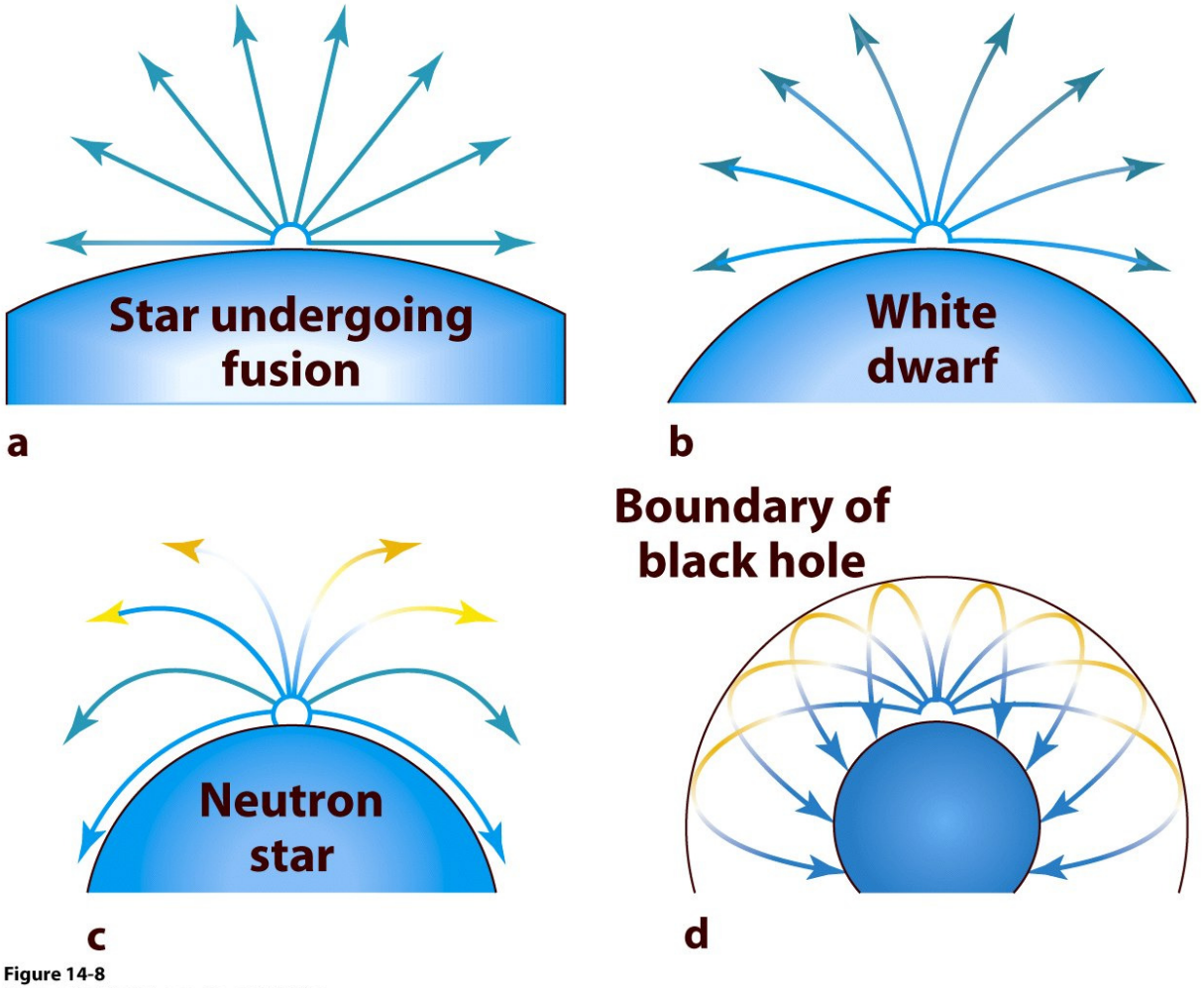


Figure 14-8
Discovering the Universe, Seventh Edition

If density is high enough → Very strong gravity → Event horizon: escape velocity = speed of light

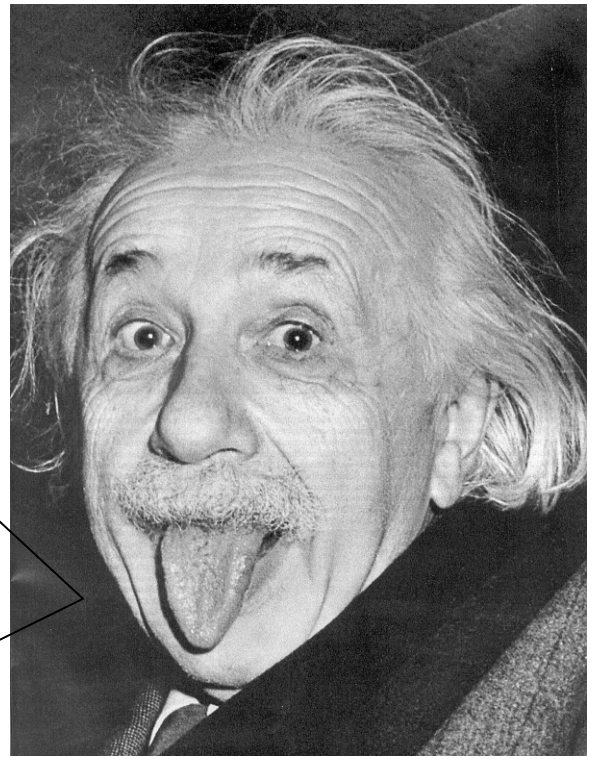
狹義相對論(special relativity)

相對中的絕對：

在互相做等速運動的觀測者來說，光速是一樣的。

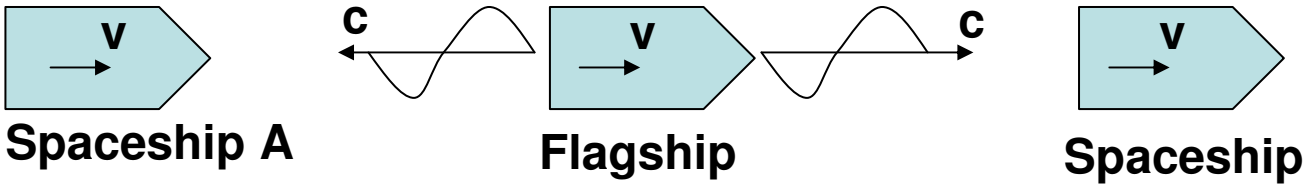
速度 = 距離/時間

如果「速度」這一個量出了問題，我大膽在此假設：我們傳統對距離與時間的觀念，可能在我們運動速度接近光速的時候，發生嚴重的謬誤。

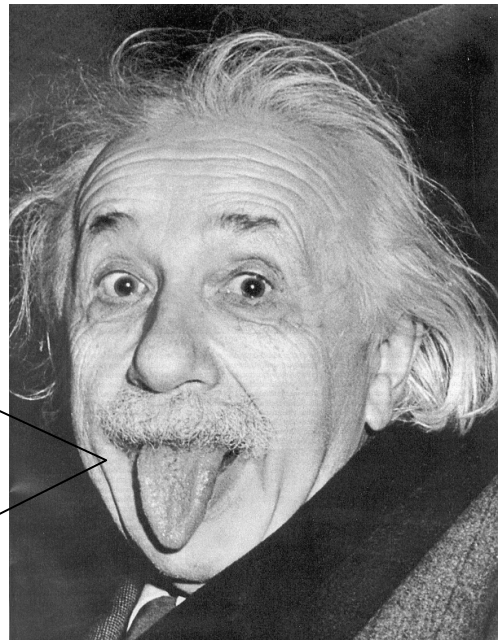


不同時性：時間是相對的

為了遷就光速是固定的，新的時間觀念產生了。



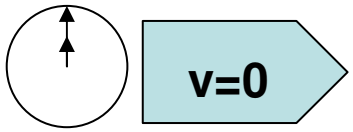
Flagship, Spaceship A, 和 Spaceship B 都相對我向右做等速移動。Spaceships A & B 都說同時接收到來自 Flagship 的無線電波訊號。但是我認為 Spaceship A 先收到 Flagship 的訊號！

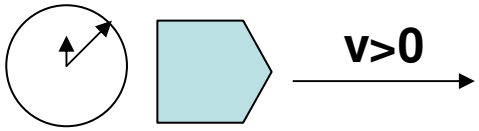


時間和空間是相對的

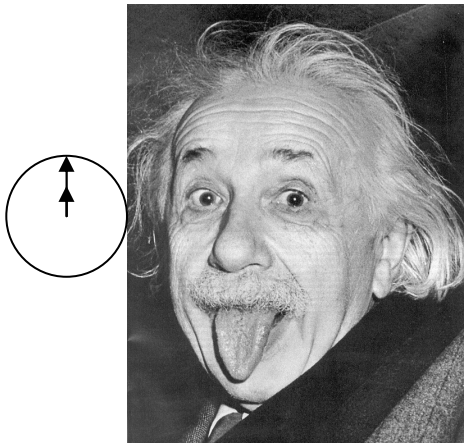
Time Dilation & Space Contraction

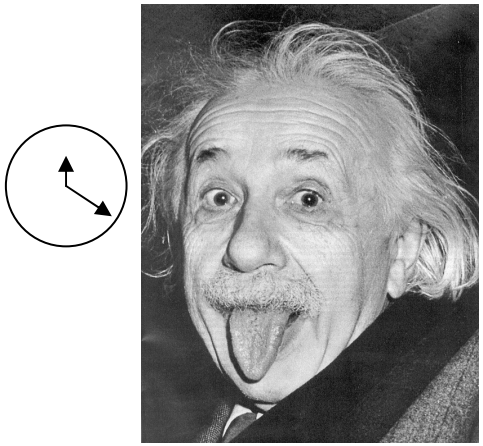
運動的鐘走得慢；運動的尺縮短了





When v=c (ie light),
剎那即永恆！





The twin paradox:
has been tested
using atomic clocks.

相對論的神話

人總是喜歡神話 …

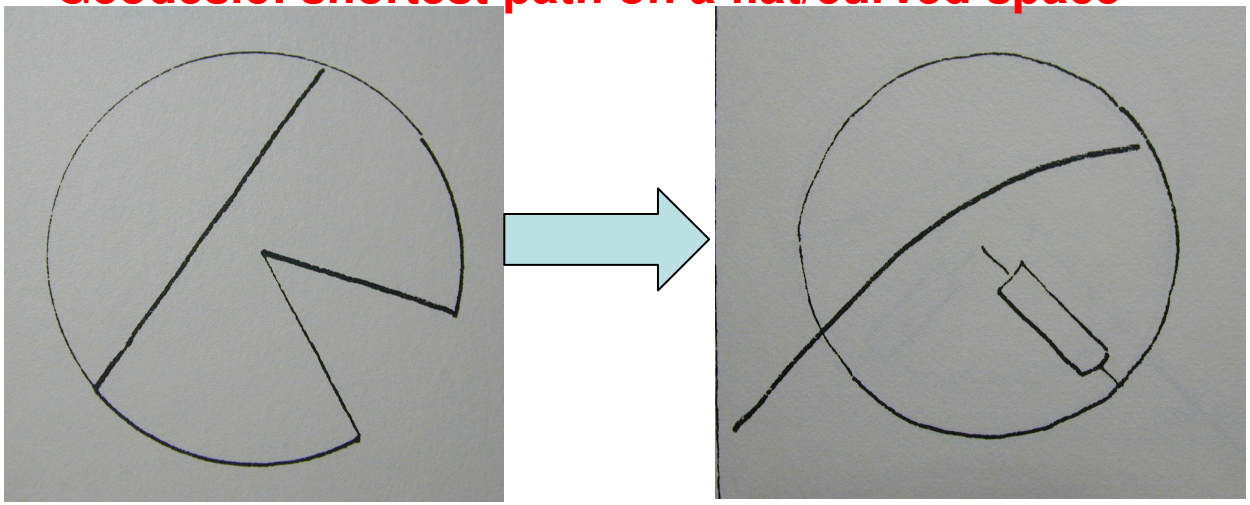
我們無時無刻都以光速在時空中運動。
所以靜止時，老得最快；
如光般運動的時候，剎那即永恆！

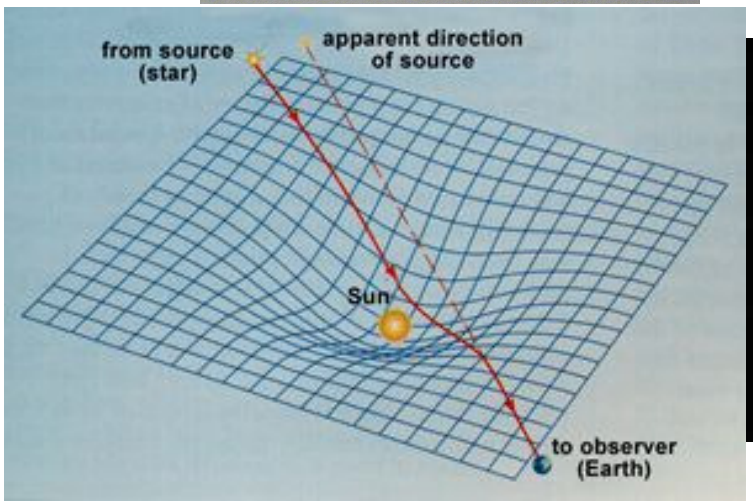
廣義相對論 General Relativity
(mass → time dilation)

重力紅移
Gravitational Redshift

廣義相對論 General Relativity
(mass → space warps)

Geodesic: shortest path on a flat/curved space





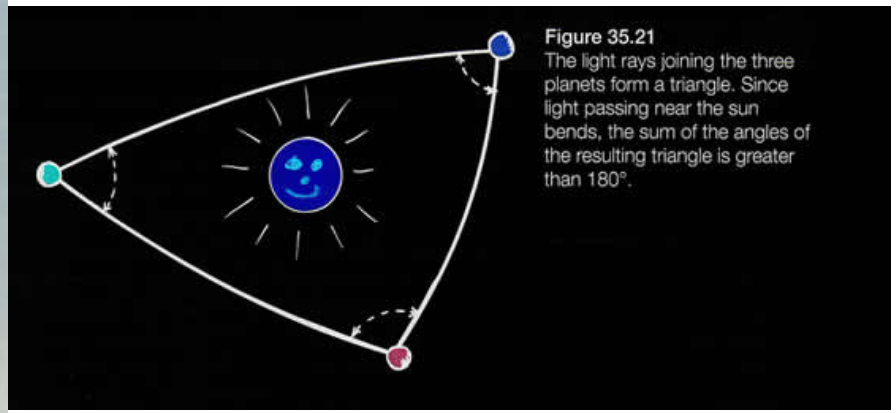
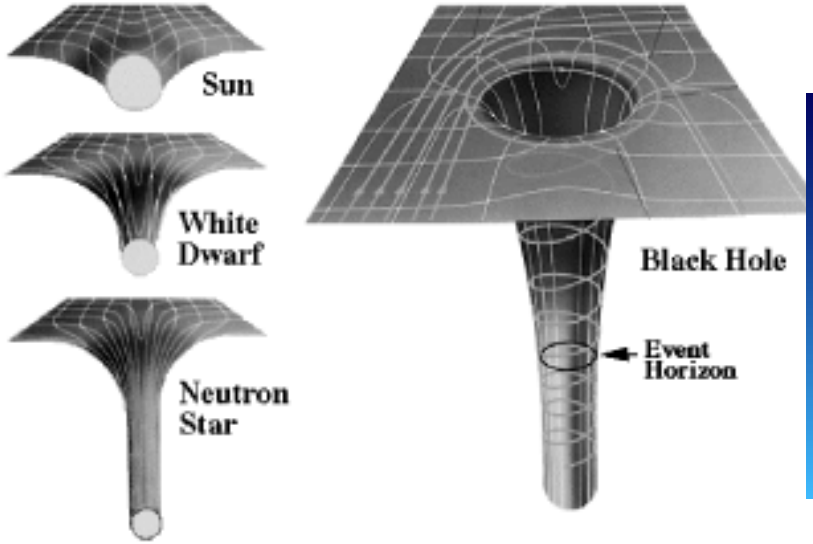
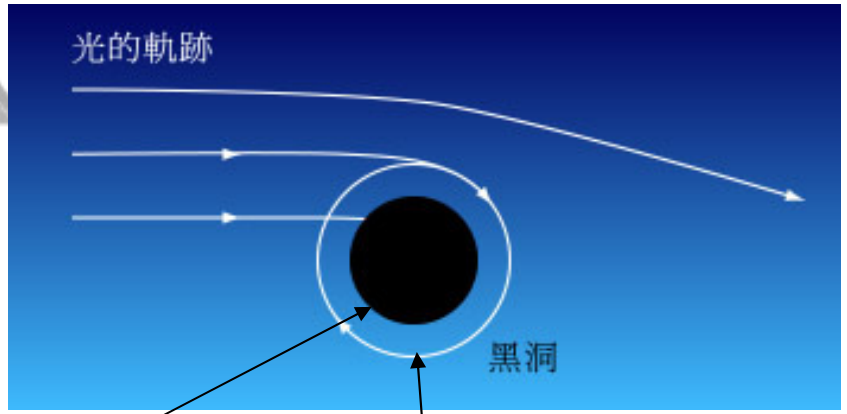


Figure 35.21
The light rays joining the three planets form a triangle. Since light passing near the sun bends, the sum of the angles of the resulting triangle is greater than 180°.

Space warps & density

http://imagine.gsfc.nasa.gov/docs/teachers/blackholes/imagine/page11.html





Event Horizon (事件的穹界)

Photon Sphere (光子球層)

General Relativity (mass → space warps)

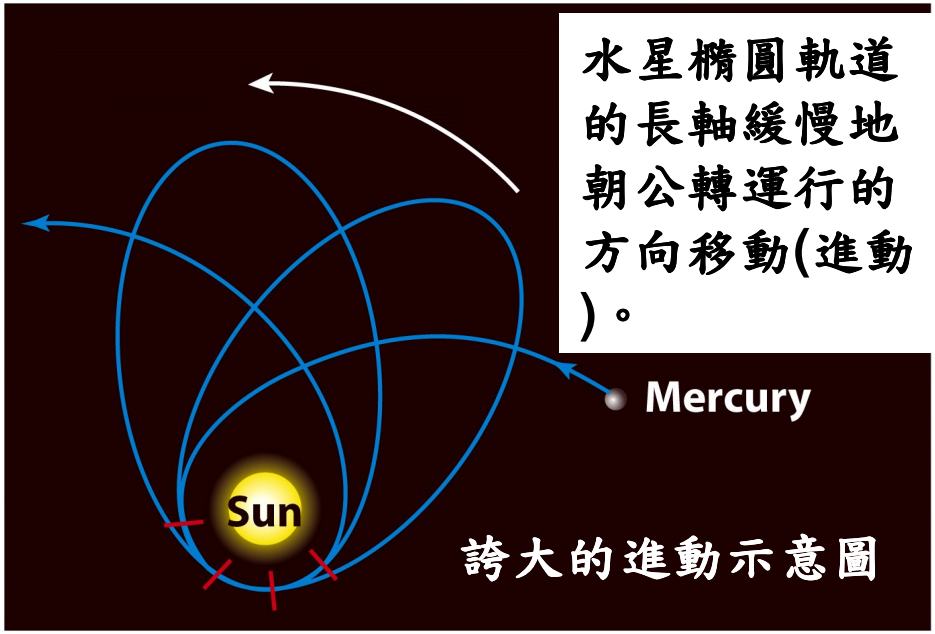
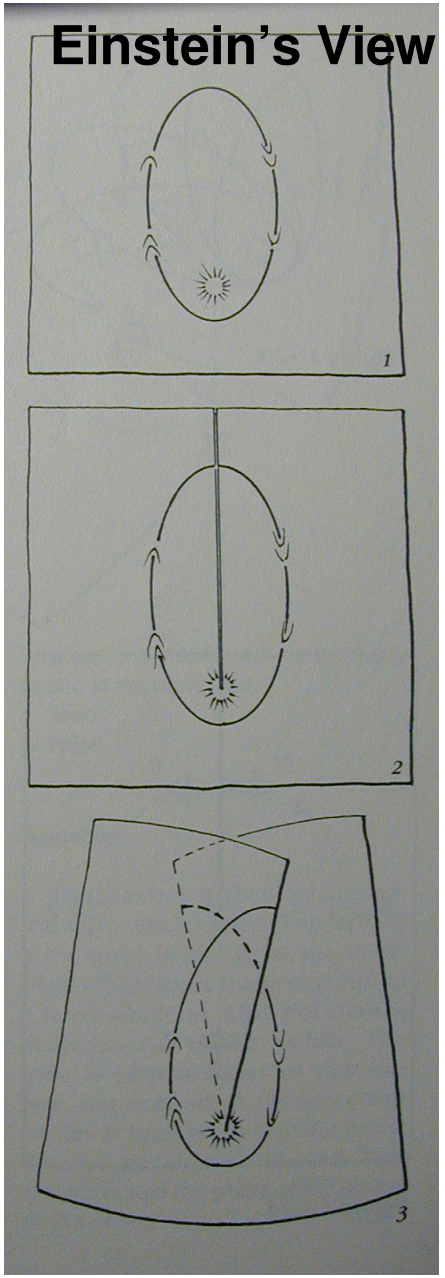


Figure 14-7
Discovering the Universe, Seventh Edition

在19世紀，有大約10%的水星進動速度無法用牛頓力學來解釋。



Strong tidal force

As an astronaut is falling Into a black hole, we (outside observers) will see

1) terrible tidal tearing

2) the astronaut falls more and more slowly (time dilation)

3) harder and harder to see the astronaut (gravitational redshift)

So my point about this is…

bloody but not very interesting

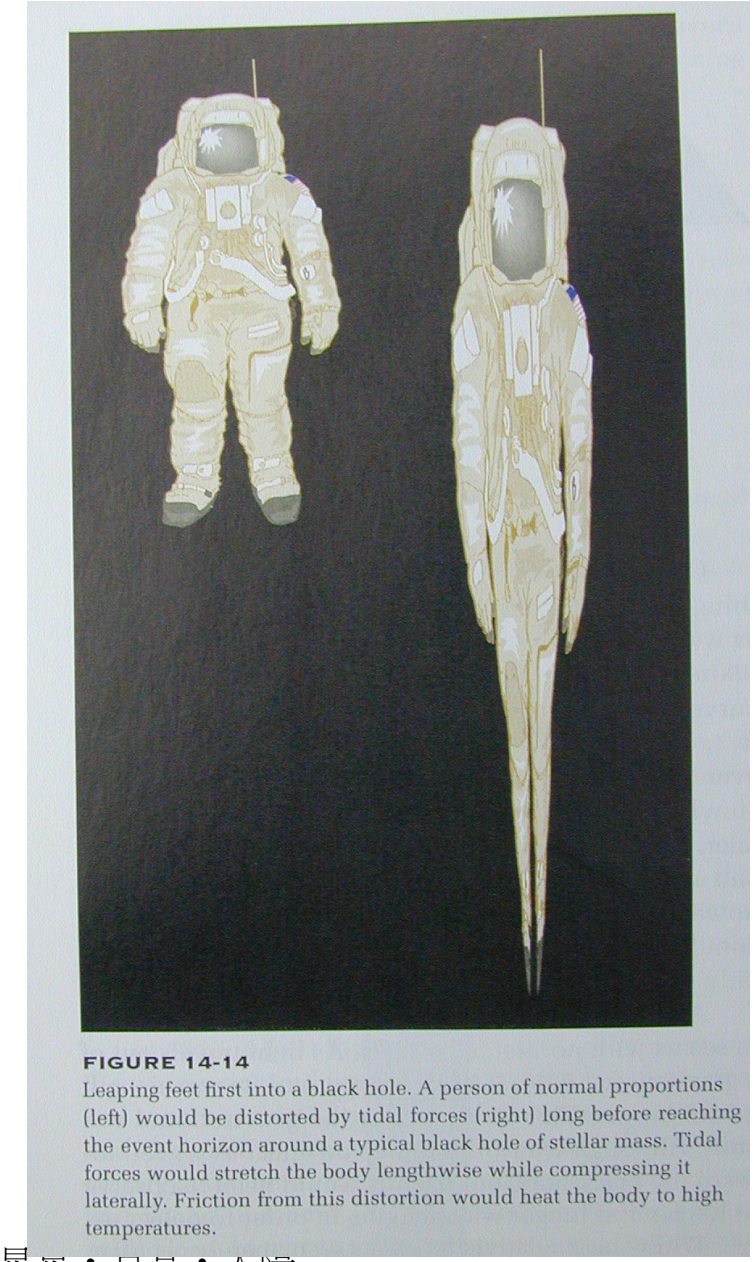


FIGURE 14-14
Leaping feet first into a black hole. A person of normal proportions (left) would be distorted by tidal forces (right) long before reaching the event horizon around a typical black hole of stellar mass. Tidal forces would stretch the body lengthwise while compressing it laterally. Friction from this distortion would heat the body to high temperatures.

Black Hole has no hair

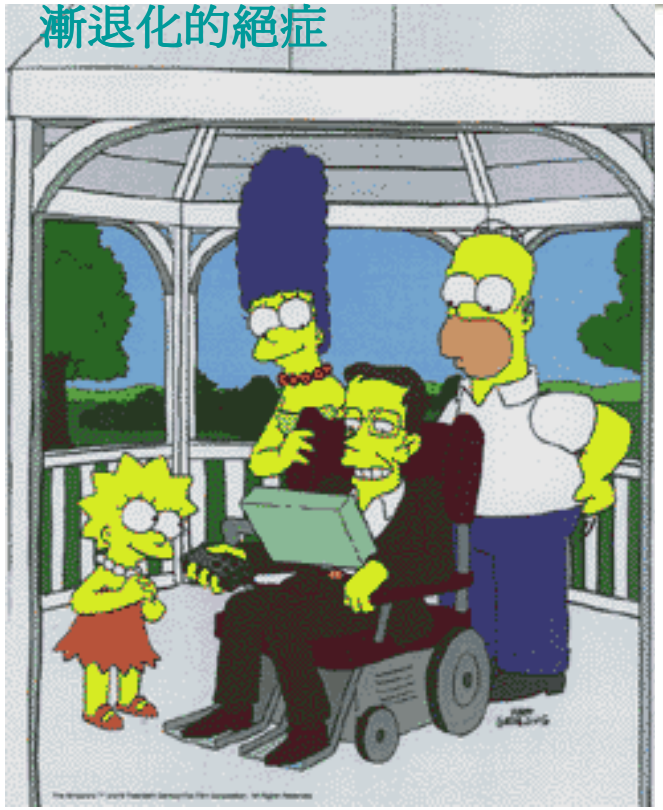
Price's theorem: whatever can be radiated is radiated. After collapsing to a black hole, there are only three properties left: mass, spin, & charge.

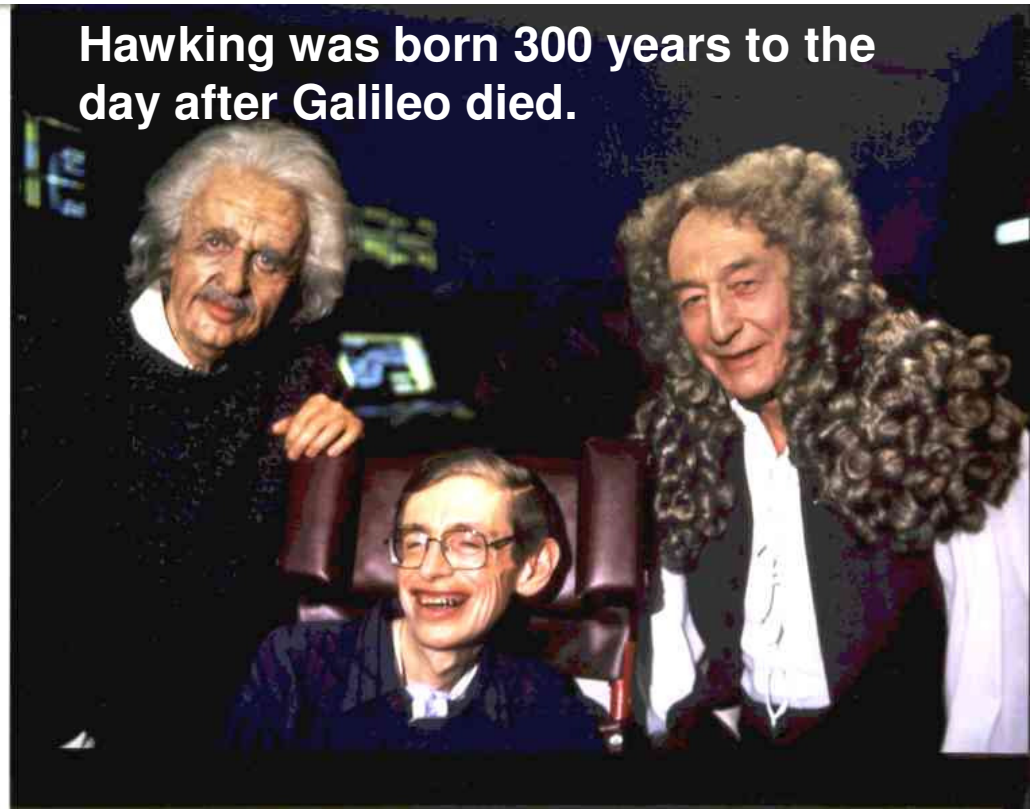
But a black hole can wear a toupee. ☺

Stephen Hawking (1942-)

Lucasian Professor of Mathematics, University of Cambridge

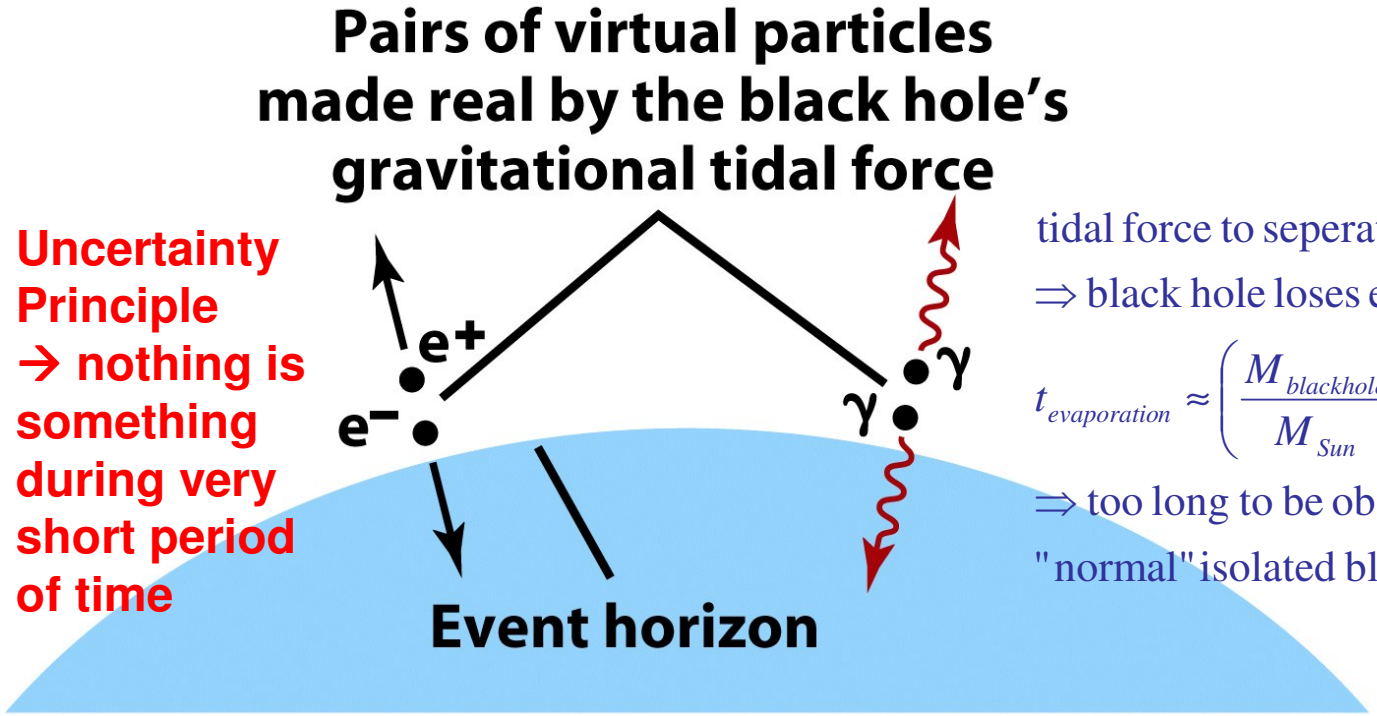
Amyotrophic Lateral Sclerosis肌肉萎縮側索硬化症(ALS)又叫Lou Gehrig's Disease，或在台灣稱爲漸凍人，是控制自主運動的神經細胞逐漸退化的絕症





http://www.hawking.org.uk/about/mgallery3.html

Hawking Radiation: black holes are not so black ☺



Uncertainty Principle → nothing is something during very short period of time

tidal force to seperate particles

$\Rightarrow$ black hole loses energy $\Rightarrow$

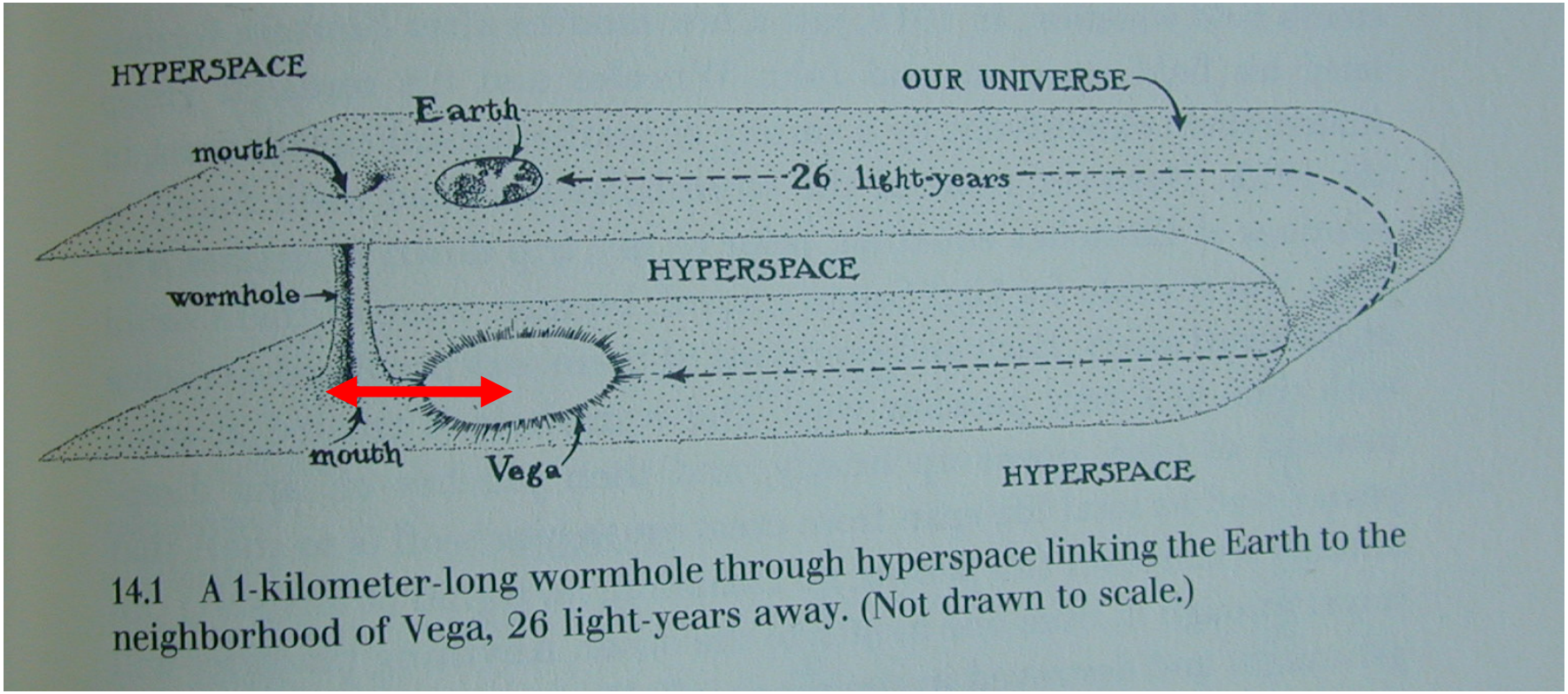
$$t_{evaporation} \approx \left(\frac{M_{blackhole}}{M_{Sun}} \right) \times 10^{66} \text{ yr}$$

$\Rightarrow$ too long to be observed for "normal" isolated black holes

Figure 14-23
Discovering the Universe, Seventh Edition

蟲洞(wormhole) & Time Machine

摘自於 Kip Thorne: Black Holes & Time Warps

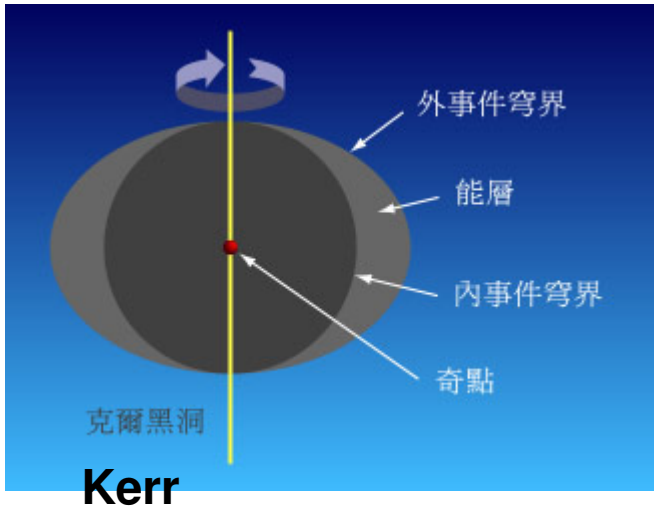


14.1 A 1-kilometer-long wormhole through hyperspace linking the Earth to the neighborhood of Vega, 26 light-years away. (Not drawn to scale.)

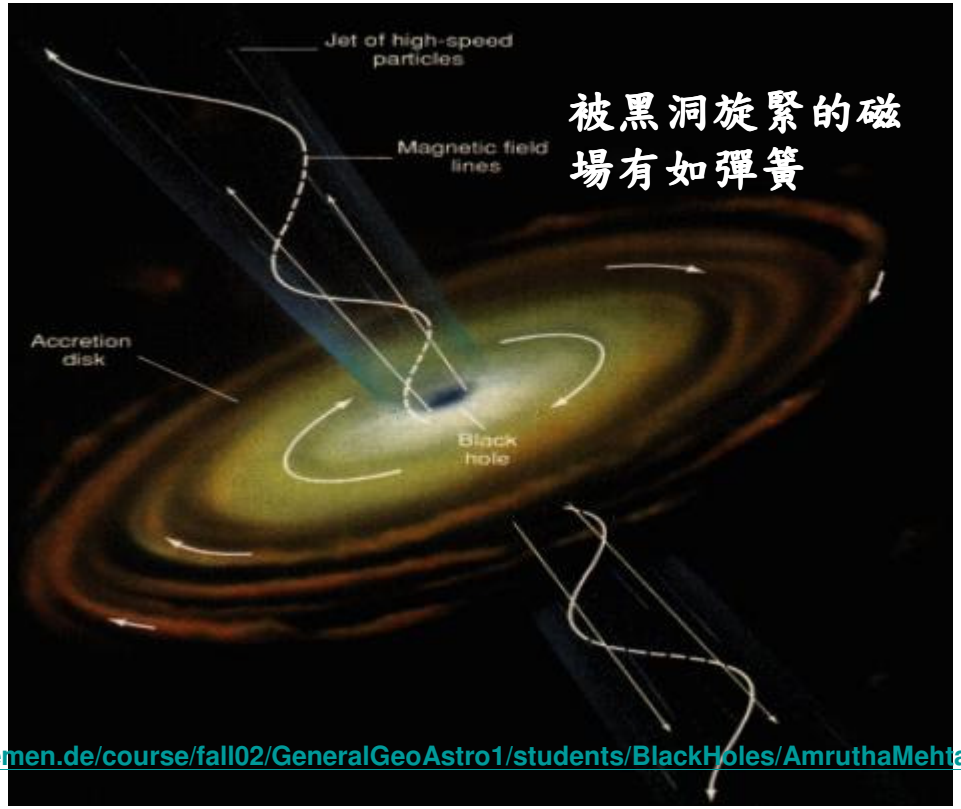
Three puzzles need to be explained:
1) tidal disruption (to survive),
2) "anti-gravity" energy (to open the wormhole),
3) Causality (to make us feel better!)

Kerr Black Hole & Ergosphere (能層)

- Frame-dragging (空間跟著黑洞轉), tap black hole's rotational energy



Kerr Black Hole



被黑洞旋緊的磁場有如彈簧

http://www.faculty.iu-bremen.de/course/fall02/GeneralGeoAstro1/students/BlackHoles/AmruthaMehta.html

讓我們務實一點吧
How to find/see a black hole?

我們無法在黑暗中找一隻黑貓…

1. **Hawking radiation is no use: too weak (no Nobel Prize for him ☹).**
2. **If a black hole is not alone, we may observe its influence on its nearby objects to imply its existence.**

- **stellar-mass black holes (collapsed stars)**
- **super-mass black holes (at the center of a galaxy)**

X-ray from an accretion disk (吸積盤) around a neutron star/black hole in a binary system

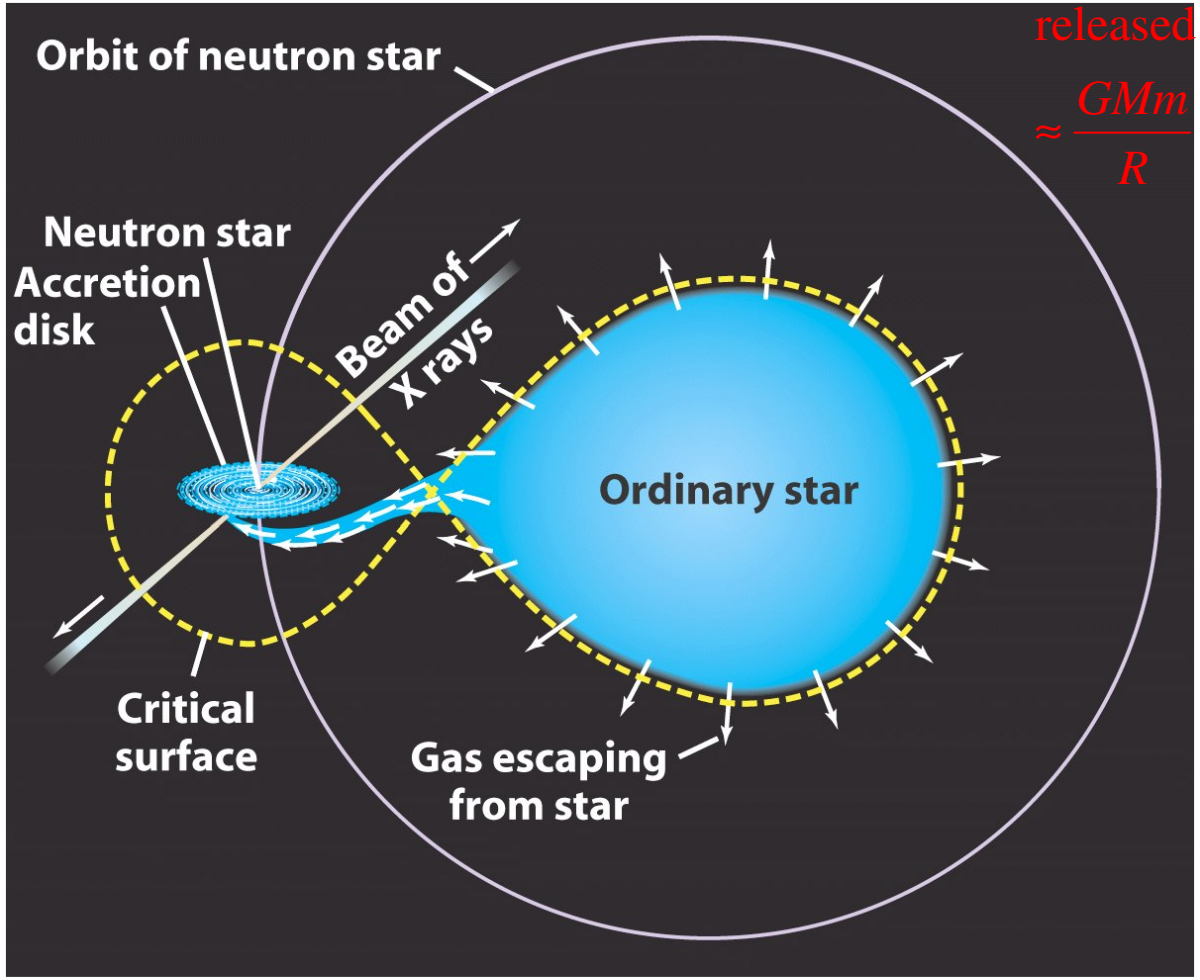


Figure 13-25
Discovering the Universe, Seventh Edition

$$\text{released gravitational energy} \approx \frac{GMm}{R} \propto \frac{1}{R} \Rightarrow \text{heat(X-ray)}$$

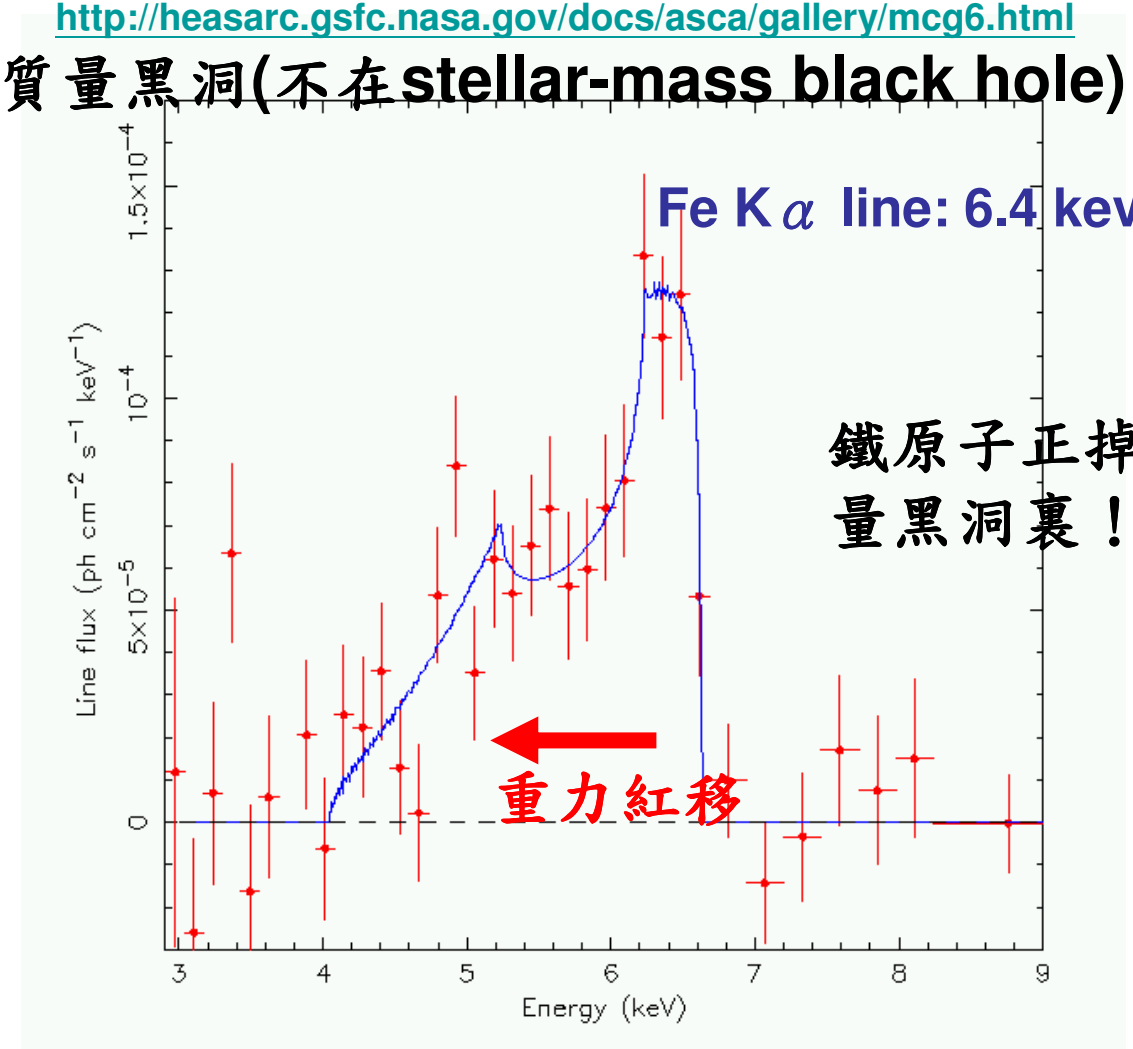
Neutron stars and black holes have a small radius *R*.

An indirect way to find a black hole (black holes have no hair).
neutron star mass > 3 Solar masses → collapse

鐵原子x-ray線光譜的重力紅移

http://heasarc.gsfc.nasa.gov/docs/asca/gallery/mcg6.html

只會在超質量黑洞(不在stellar-mass black hole)附近發生



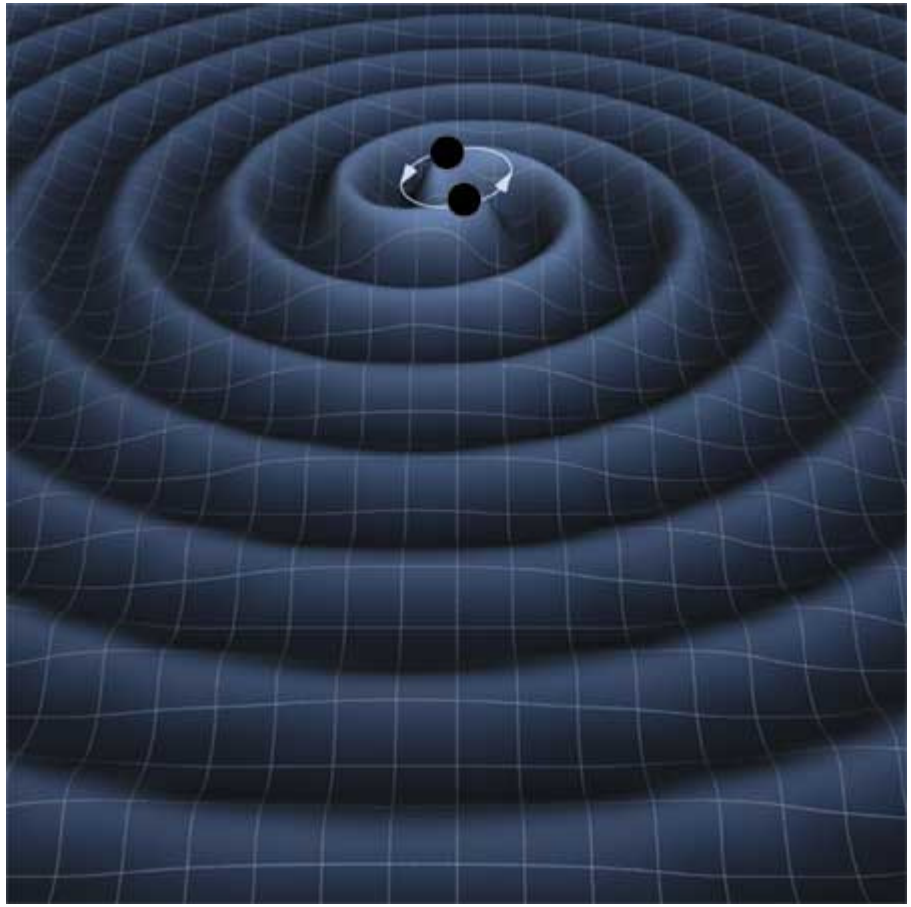
NGC 6240: two galaxies are merging

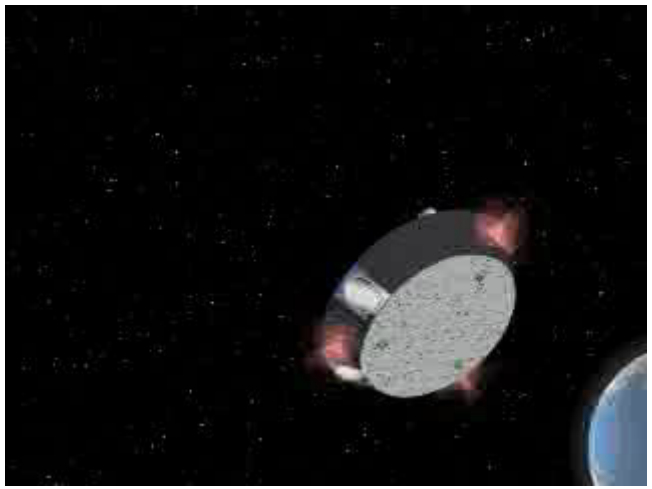
http://chandra.harvard.edu/photo/2002/0192/animations.html

Chandra X-ray image: two black holes?

Merging black holes →
“strong” gravitational waves (重力波)

http://lisa.jpl.nasa.gov/

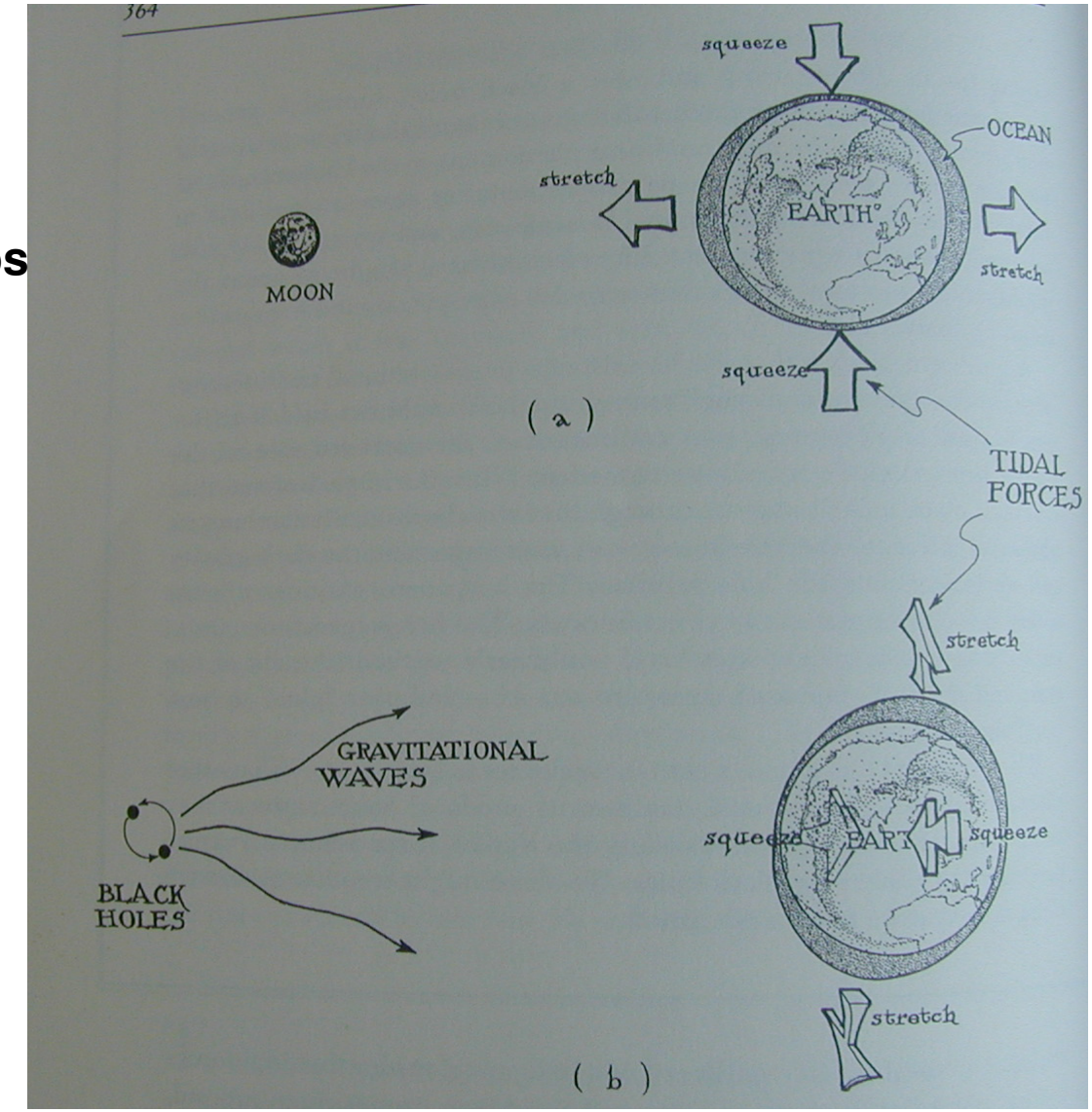




Gravitational wave is still a million times less energetic than that in the cosmic microwave background radiation which, itself, is a billion times weaker than that in a household oven .
As the gravitational waves pass by, the change in distance between two detectors will be as small as a size of proton!

重力波的作用有點兒像潮汐作用

Kip Thorne:
Black holes
& time warps

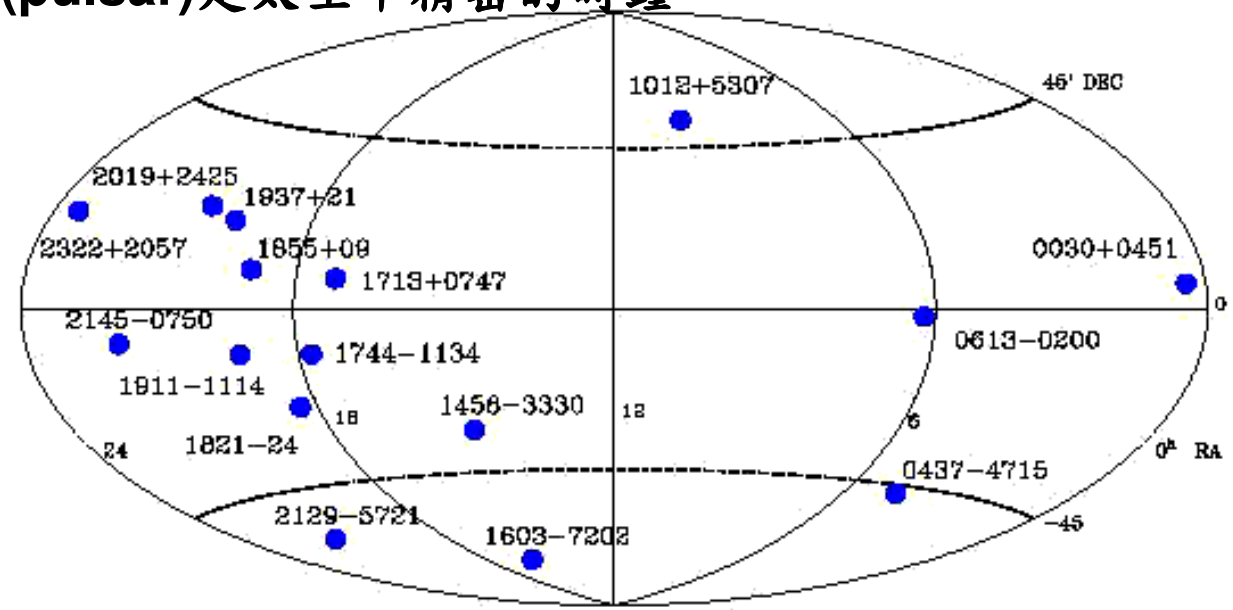


不必花$$$就可以偵測到重力波 ☺

http://www.berkeley.edu/news/media/releases/2002/01/07_array.html

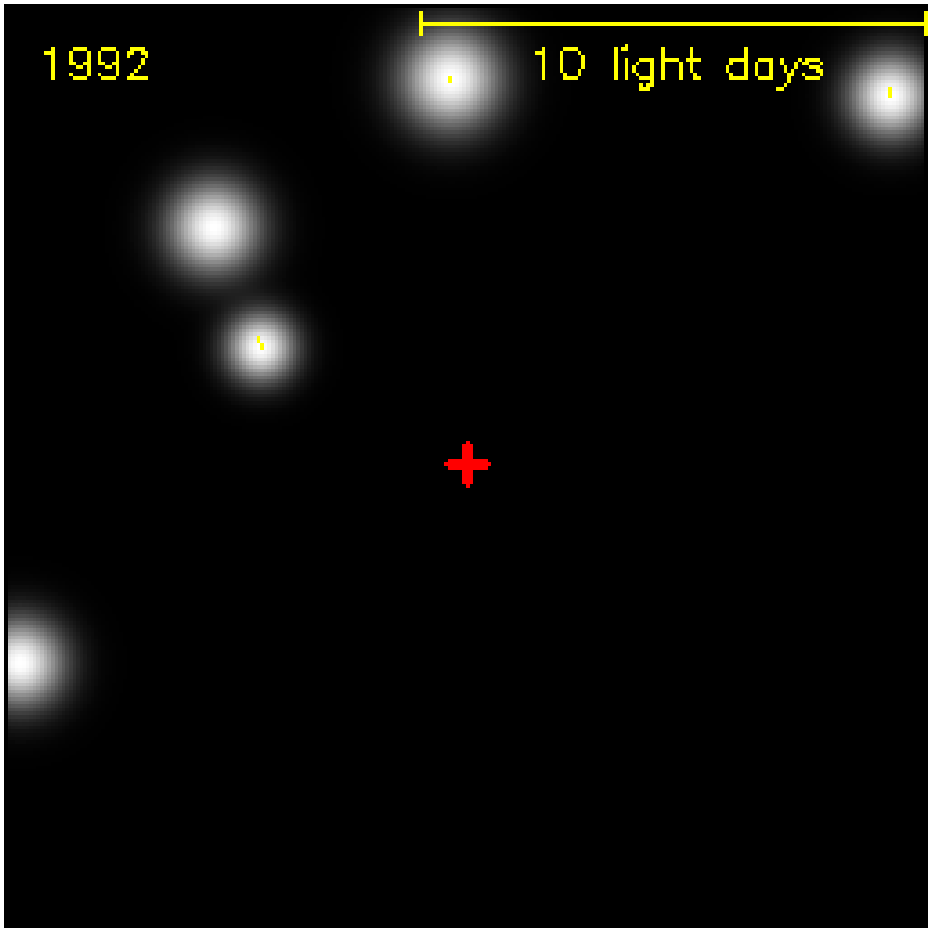
MILLISECOND PULSAR TIMING ARRAY – 2001

波霎(pulsar)是太空中精密的時鐘



Measuring the mass of a super massive black hole at the center of the Milky Way

http://www.cfa.harvard.edu/~narayan/NJP/

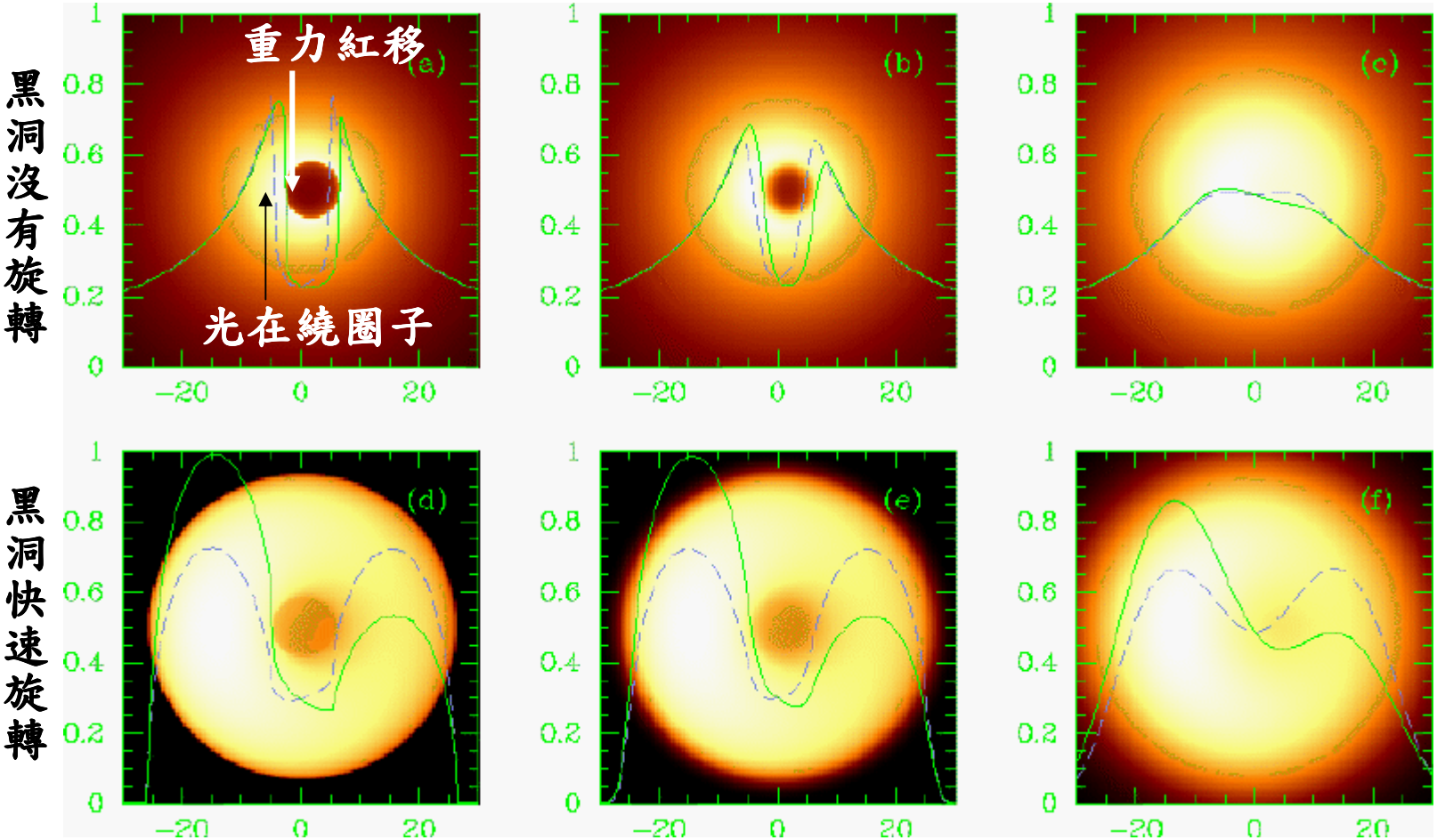


Fast motion of stars
→ Mass of Sagittarius A*
≈ 2.5 x 10^6 solar masses
→ Impossible to be stars
→ the only known object we know of to explain this is…
Supermassive black hole! (c.f. stellar-mass black hole resulting from a collapsed a massive star)

是否能真的看到黑洞：「黑洞的影子」！？

http://www.mpifr-bonn.mpg.de/staff/hfalcke/bh/sld14.html

黑洞在發光的吸積盤中，產生比事件穹界還大的「影子」！




scattering (散射): street lamp in the rain
同理，星際物質會散射黑洞
旁邊吸積盤的光，使得黑洞
的「影子」看不清楚。

The closest region to Sagittarius A* we can see so far

廣設10座望遠鏡 不眠不休觀測10年

台中美科學家掌黑洞實證

研究團隊繪製的黑洞圖像

次經度 等高線 黑洞 次緯度

≈1AU

■圖為根據望遠鏡看到影像所繪製的黑洞位置圖。

■圖為經電腦計算、調整後較接近實體的黑洞繪圖。

Wide-Field VLA Radio Image of the Galactic Center (λ = 90 cm)

Sgr D Hll
Sgr D SNR
SNR 0.9+0.1
Sgr B2
Sgr B1
SNR 0.3+0.0
Threads
Arc
The Cane
Background Galaxy
Threads
Sgr A
Sgr C
The Pelican
Snake
Coherent structure?
Mouse
Sgr E
SNR 359.0-0.9
SNR 359.1-0.5
Tornado (SNR)

240光年的範圍

■台中美研究團隊利用特長基線干涉陣列望遠鏡，發現在人馬座A*強烈無線電波發射的地方（強烈光源處），中間有一個超大質量黑洞。 中研院提供

■賀曾樸對此次發現銀河系中心存在超大質量黑洞的證據，相當高興。 廖瑞祥攝

國際研究學者團隊成員

隸屬	學者	曾任中研院職稱
中研院天文所籌備處	賀曾樸	現任主任
中國科學院上海天文台	沈志強	天文所籌備處副教授
美國國家電波天文	魯國鏞	天文所籌備處主任
美國加州理工學院	梁茂昌	天文所籌備處研究助理
美國哈佛史密松天文物理中心	趙軍輝	天文所籌備處客座學人

資料來源：中研院

黑洞形成過程示意圖

黑洞小檔案

資料來源：中央大學天文所副教授孫維新

定義 黑洞是擁有強大引力的物體，引力之大即使是宇宙中速度最高的光線也不能逃離黑洞

起源 1907~1915年愛因斯坦發展廣義相對論，預測該天體之存在；1960年代則由美國科學家約翰惠勒創立黑洞一詞

天文發現

（高琇芬、張馨芳／台北報導）天文科學界在二、三十年前提出銀河系中心藏匿著大質量黑洞的推論，最近由台灣、中國、美國五名天文科學家合作，透過對銀河系中心人馬座A*（即人馬座A位置光源處）神秘電波源的高解析度觀測，終於找出支持這項觀點的最有力證據。

這是天文學家首次看到距離黑洞中心如此近的區域，並可做為檢驗「廣義相對論」的工具。這項重大發現刊登於本月三日出刊的英國自然科學權威期刊《自然（Nature）》。

台中美研究團隊五名成員都曾是中研院天文所的教授或客座學人，包括來自中國科學院上海天文台研究員沈志強、美國國家電波天文台長魯國鏞、美國加州理工學院的梁茂昌、中研院天文所特聘研究員兼主任賀曾樸、心副研究員趙軍輝。

中研院天文所籌備處昨表示，根據愛因斯坦的廣義相對論，超大質量黑洞的強引力場會使經過邊緣的光線發生彎曲，一九七四年二月發現位於銀河系中心的人馬座A*因距地球最近，被公認為是研究黑洞物理的最佳目標。中央大學天文所副教授孫維新則說，人馬座A*是人馬座天體上類似茶壺造型的尖嘴處，至於A*則是當中強烈無線電波發射處。

刊於權威期刊《自然》

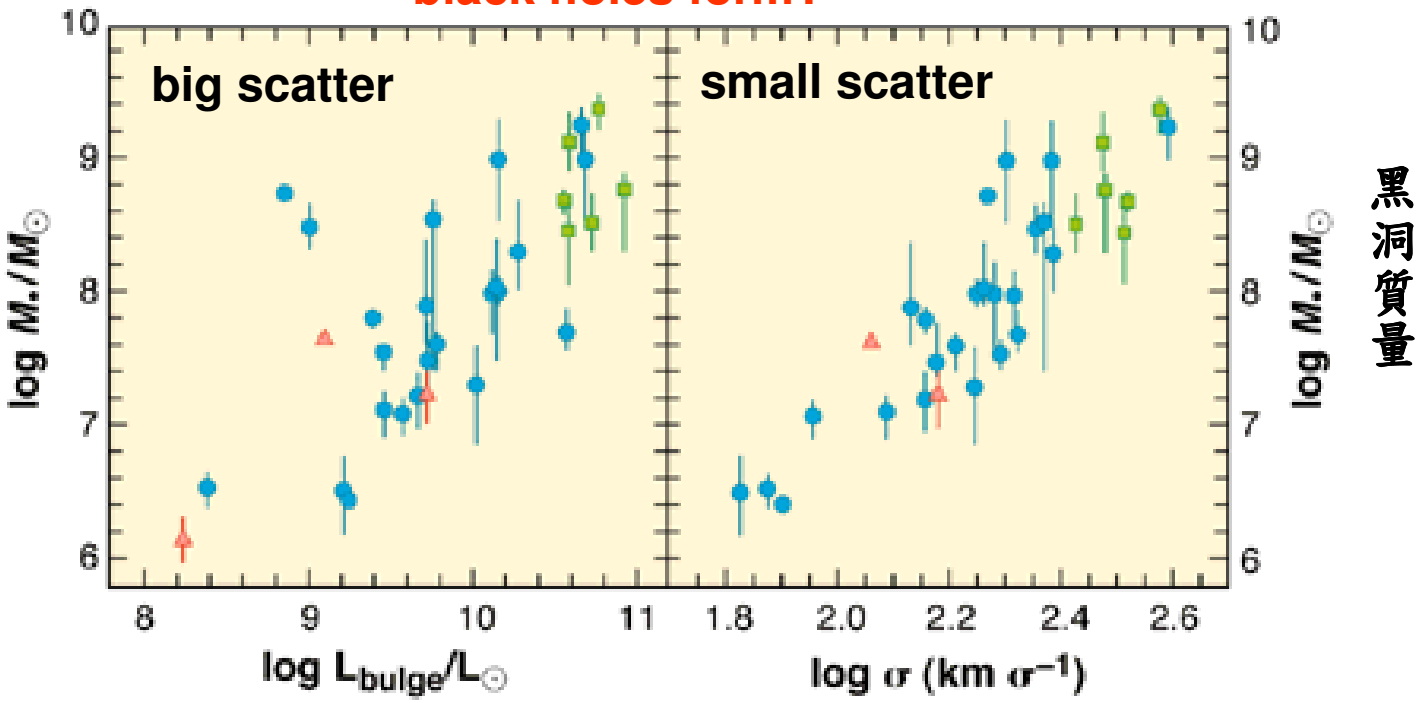
該小組利用國際先進的特長基線干涉陣列（簡稱VLBA）天文望遠鏡，在二〇〇二年十一月首次獲得人馬座A*在三點五毫米波長上的影像，由此推斷出的最小質量密度比目前任何已知可能的黑洞密度都要大一萬億倍以上，強烈支持人馬座A*的超大質量黑洞本質。這項發現經兩年多的驗證，至今年才在權威期刊《自然》公布成果。

賀曾樸受訪時說，五名研究成員十年來在美國夏威夷、加州、華盛頓州、愛荷華州、新墨西哥州

Mass-Velocity Dispersion Relation for Super-massive Black Holes

Kormendy 2000

Tell us about how galaxies & super-massive black holes form?



黑洞質量

天體在星系球核(galactic bulge)內的環繞速度

circle: stellar dynamics
square: ionized gas dynamics
triangle: maser disk dynamics

有中等質量的黑洞(intermediate-mass)嗎？

Can the mass of a black hole be between stellar mass (3-20 solar masses) and super-mass (>10^6 solar masses)?

X-ray intensity → mass

Some x-rays sources seem to imply their mass lies in the intermediate mass range. For instance, an X-ray source in the starburst galaxy "M82 X-1"
http://www.nasa.gov/centers/goddard/news/topstory/2005/new_blackhole.html