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?

摘自鄭立三、錢誌恩：《宇宙的百慕達三角 -- 黑洞》

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
Planetary nebulae 行星狀星雲 leave a white dwarf behind

He\(^+\) (blue)  
O\(^{+2}\) (green)  
N\(^+\) (red)

Dust

Hourglass nebula

Gas ejected from the star

Mz-3 white dwarf
Schrodinger's Cat

(1) Radioactive material has a 50:50 chance of triggering Geiger counter

(2) If Geiger counter is triggered, hammer falls

(3) Hammer breaks poison bottle

(4) Cat dies if poison bottle breaks

(5) Cat lives, if Geiger counter does not trigger hammer and releases the poison

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

Erwin Schrödinger Nobel Prize in 1933

http://universe-review.ca/l12-21-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

\[ \Delta x \Delta p \geq \frac{\hbar}{2} \]
\[ \Delta E \Delta t \geq \frac{\hbar}{2} \]

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

I don’t believe Chandrasekhar’s theory.

Black holes should not exist! Btw, thanks for proving my theory in 1919.

2006/12/27
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。

I didn’t believe Oppenheimer Limit, but now I am totally convinced. In 1967, I coined the term for this final collapsed state: a black hole.

John Wheeler
Old high-mass stars (>8 $M_{\text{Sun}}$)

Fe is the most stable of all nuclei.

Hydrogen-fusing shell
Helium-fusing shell
Carbon-fusing shell
Neon-fusing shell
Oxygen-fusing shell
Silicon-fusing shell
Iron core

A supergiant star
Central regions of a supergiant star

1.6 billion kilometers

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

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

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

Cassiopeia A (X-ray)
天津四
可能會變
成黑洞
Crab Nebula (蟹狀星雲，M1)

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

致和元年，五月己丑，客星出天闕東南，可數寸，歲餘稍沒《宋史》。

Figure 13-18b
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Crab Nebula


X-ray (Chandra telescope)  visible (Hubble telescope)
Pulsar (波霧) & Neutron star (中子星)

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!

http://astronomy.swin.edu.au/pulsar/reduction/p2.html
Black Holes have no hair

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

Star undergoing fusion

Event horizon: escape velocity = speed of light

White dwarf

Neutron star
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」這一概念出了問題，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

\[ v=0 \]

\[ v>0 \]

When \( v=c \) (ie light),
刹那即永恆！

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！
General Relativity
(mass → time dilation)

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

Geodesic: shortest path on a flat/curved space
Space warps & density


Event Horizon (事件的穹界)

Photon Sphere (光子球層)
General Relativity
(mass → space warps)

水星椭圆轨道的长轴缓慢地朝公转运行的方向移动(进动)。

在19世纪，有大约10%的水星进动速度无法用牛顿力学来解释。
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
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 (ALS) or Lou Gehrig’s Disease, or in Taiwan called a slowly progressive paralysis.

Hawking was born 300 years to the day after Galileo died.

http://www.hawking.org.uk/about/mgallery3.html
Hawking Radiation: black holes are not so black 😊

Pairs of virtual particles made real by the black hole’s gravitational tidal force

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

- tidal force to separate particles
  - black hole loses energy
  - $t_{\text{evaporation}} \approx \left( \frac{M_{\text{blackhole}}}{M_{\odot}} \right) \times 10^{66} \text{ yr}$
  - too long to be observed for "normal" isolated black holes

Event horizon

Figure 14-23
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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

http://www.faculty.iu-bremen.de/course/fall02/GeneralGeoAstro1/students/BlackHoles/AmruthaMehta.html
How to find/see a black hole?

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

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 $\rightarrow$ collapse

\[
\text{released gravitational energy} \approx \frac{GMm}{R} \propto \frac{1}{R} \Rightarrow \text{heat (X-ray)}
\]
鐵原子x-ray線光譜的重力紅移


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

Fe Kα line: 6.4 kev

鐵原子正掉入超質量黑洞裏！
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 $\rightarrow$ “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

波霧(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 \times 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」！？

黑洞在发光的吸積盤中，產生比事件視界還大的「影子」！

no scattering

波長=0.6 mm

波長=1.3 mm

重力紅移

光在繞圈子

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
Mass-Velocity Dispersion Relation for Super-massive Black Holes

Kormendy 2000

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

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

天體在星系球核 (galactic bulge) 內的環繞速度
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”