Open book Test 1 Reminder

Test 1: Wednesday Lecture slot : 10:00 am (one Hour test)

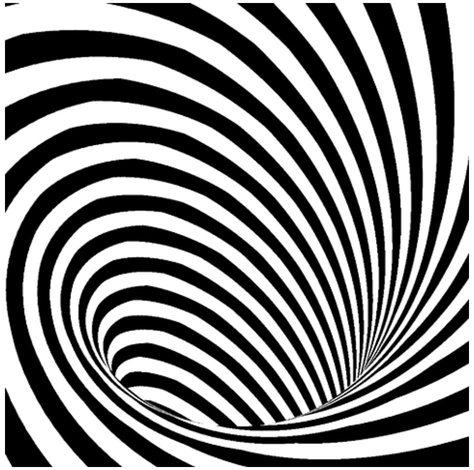
3rd March 2021 (7th week) : after one week-term break

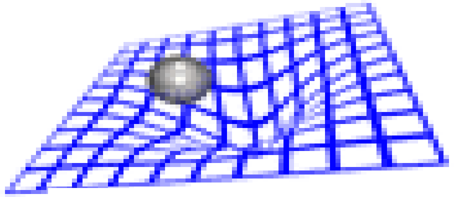
Instructions : Compulsory : need you to position your “PC or handphone” cameras on yourselves for the Zoom.

MCQ & short Questions : If you have participated in all the (Lecture Zero to where we stop today) lectures & Tutorial 1 and Tutorial 2, LumiNUS Forum and read the uploaded Relativity related essays/articles, it should be straightforward. (the pdf readings in LumiNUS should consolidate your learning).

Lecture 8

Blackhole Stars





SPACETIME

History of Black Holes

1784, John Michell (British), Philosophical Transactions of Royal Society of London.

1799, Pierre Laplace (French), Studied Newton’s works.

Both asked the possibility of an astronomical object whose mass and radius satisfy the criteria.

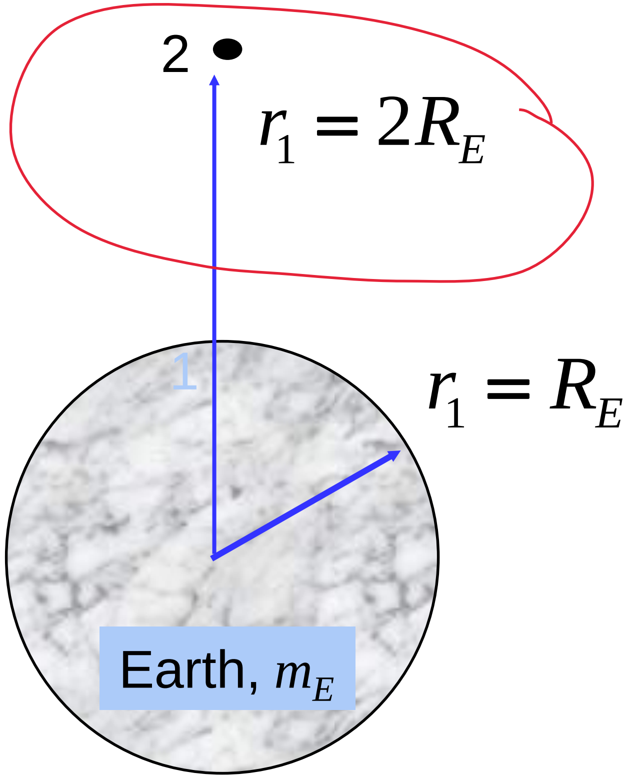
c is the speed of light.

R is the radius of Blackhole

$$R = \frac{2Gm}{c^2}$$

Simple Ideas (Newtonian)
Kinetic and Potential Energies

Project mass, m upwards



$$K_1 + V_1 = K_2 + V_2$$

$$\frac{1}{2}mv_1^2 + \left(-\frac{Gm_E m}{R_E}\right) = 0 + \left(-\frac{Gm_E m}{2R_E}\right)$$

Escape velocity
From the earth

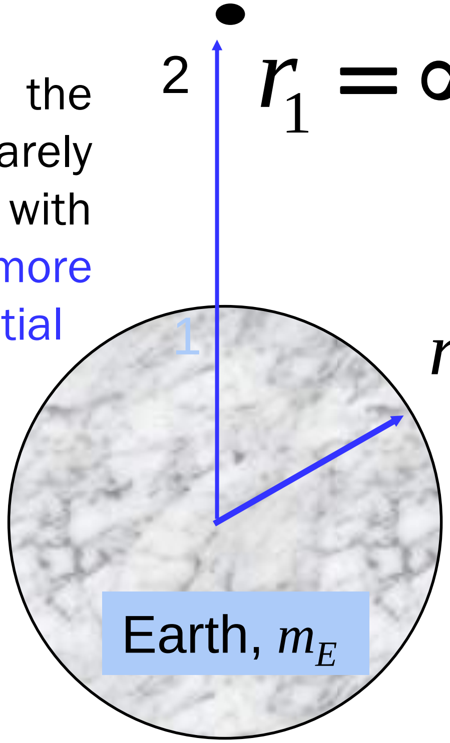
$$\boxed{v_1 = \sqrt{\frac{Gm_E}{R_E}}}$$

Escape Velocity (Newtonian)

Project mass, m upwards

We want the mass, m to barely reach infinity with no more Kinetic/Potential energy left.

$r_1 = \infty$



$r_1 = R_E$

$$K_1 + V_1 = K_2 + V_2$$

$$\frac{1}{2} m v_1^2 + \left(-\frac{G m_E m}{R_E} \right) = 0$$

Escape velocity
From the earth

$$v_1 = \sqrt{\frac{2 G m_E}{R_E}}$$

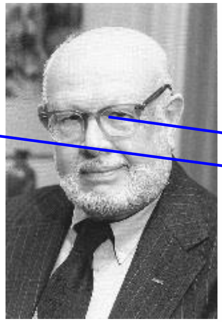
If $v = c$, limit of light.
This result does not depend on the mass, m.

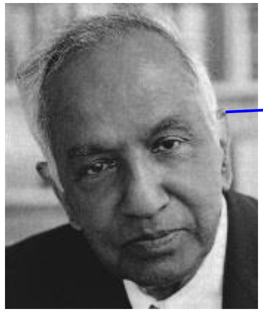
$$R = \frac{2 G m_E}{c^2}$$

Summary

Life Cycle of a Star

Really the only epistemic slide you need.





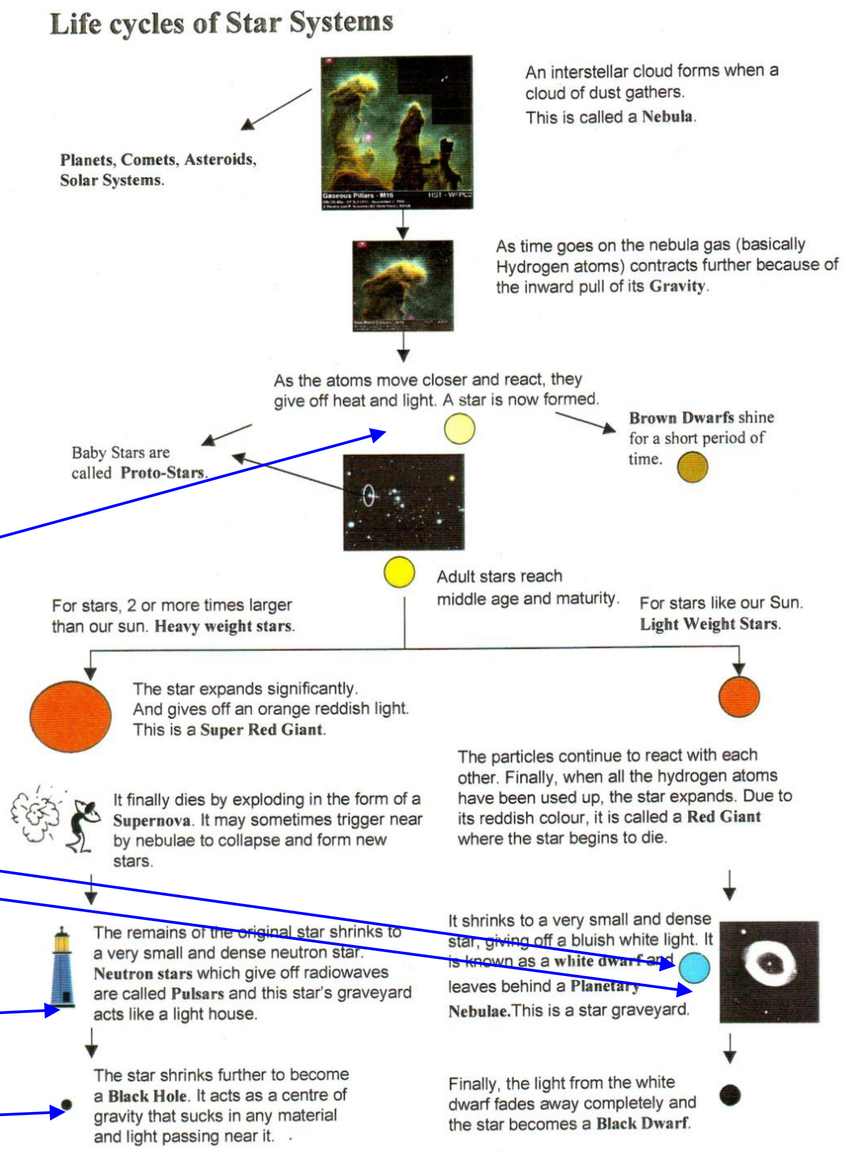
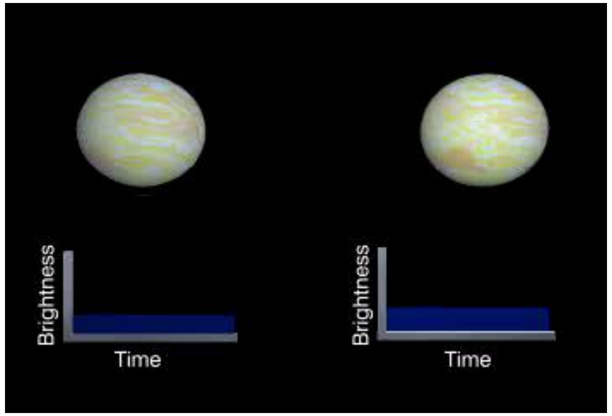


Figure [5] The participants of the ***stellar country*** and the life cycles of stars **in full glory**. But this is not the ultimate story, we will know more as we piece together more scientific ***jig-saw puzzles*** when they are available to mankind in future.

How are Black Holes Formed?

Recall Star Sequence (HR diagram)
Diffuse Nebulae (cloud), protostars (brown dwarfs)
Red Giant (it can be Super !)
White Dwarf (Degeneracy Pressure)
Planetary Nebulae
More than Chandrasekhar Limit, 1.4 ☉
Unstable ...(Super)nova to shed some mass
The Remnant is Neutron star ("strip of electrons)"
Black Hole (Einstein Relativity) say many ☉



There will be complete gravitational collapse and nothing can stop it. This massive object (extreme gravitational effects) will have a very much smaller radius. Stars can be black in colour.

Blackhole has a radius ?
… not just singularity ?

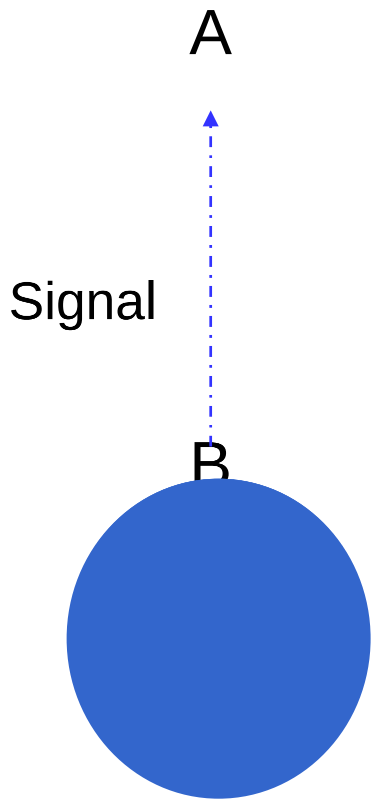
The Event Horizon

$$R = \frac{2Gm}{c^2}$$

Consider B on the surface of a very massive star.

B sends out signals every second to A

But the star starts to collapse.



As the star collapses, B experiences an increasing force of gravity.

Gravitational red shift comes into effect (also partly Doppler effect)

The event horizon defines the “size” of the blackhole.

The Event Horizon

$$R_s = \frac{2GM}{c^2}$$

Eventually, the star will approach the Schwarzschild radius. (1916 using Einstein's Field Equation)

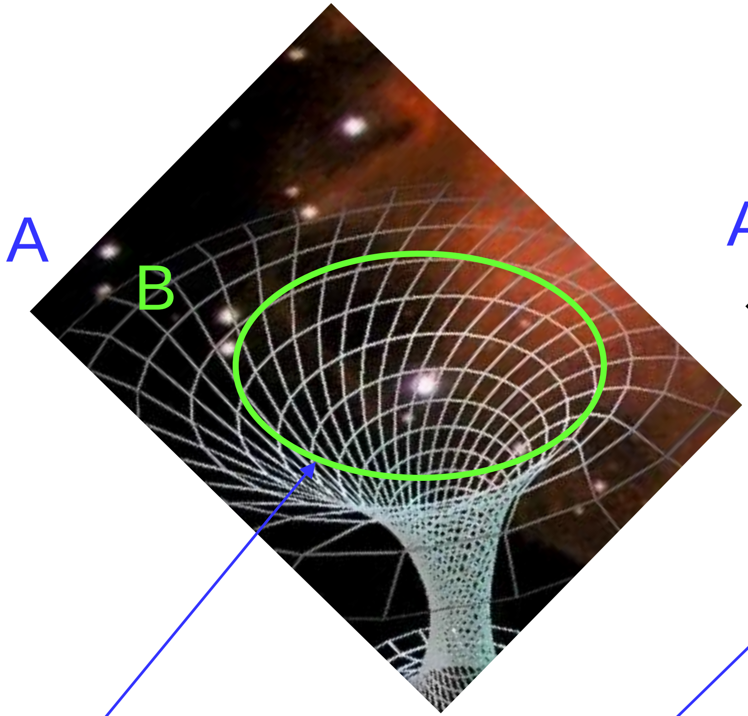
A will have to wait infinitely long for the next signal from B.

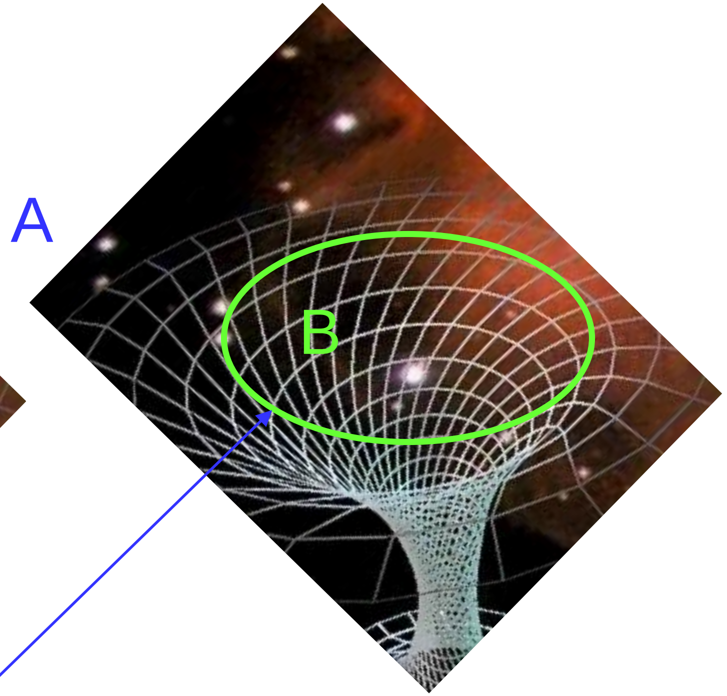
So when B crosses the sphere of Schwarzschild radius $R = R_s$, *no signals* from B will ever reach A.

R_s is called the Event Horizon. i.e. no events taking place within the event horizon will ever be observed by an outside observer like A.

Note: No mass can escape from a black hole not even light

The Event Horizon

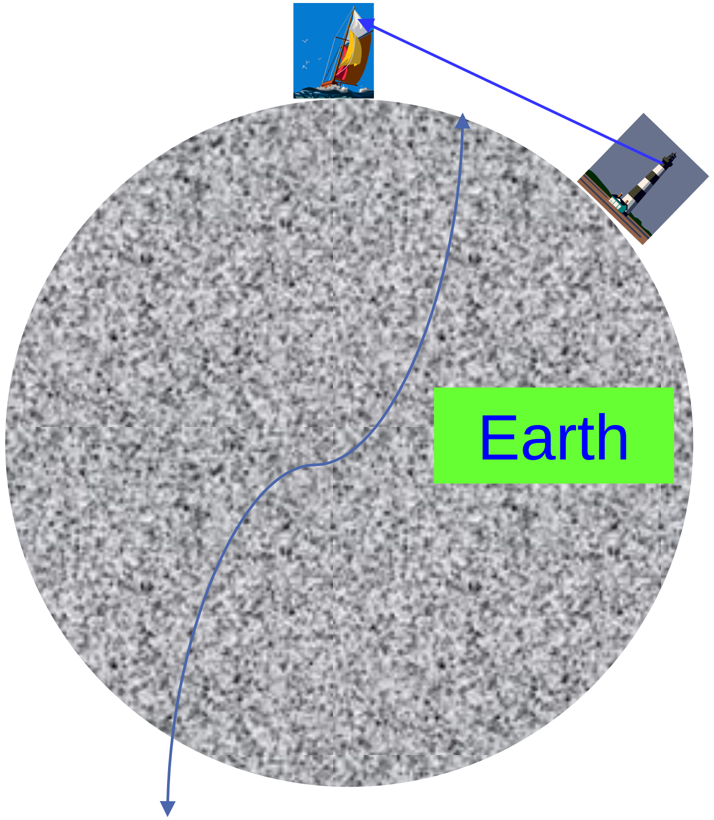


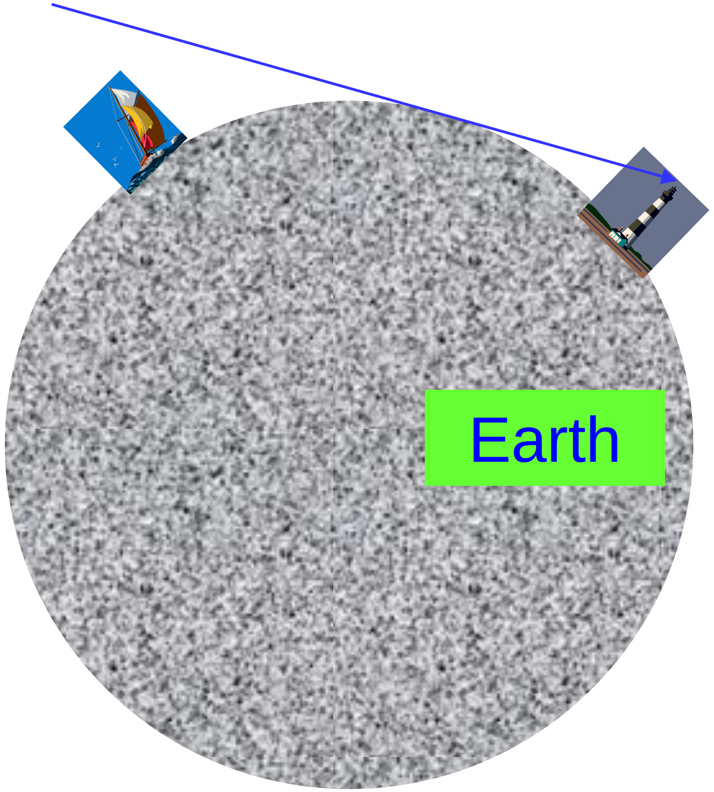


Schwarzschild Horizon (Radius)

Can you see what is a black hole like ?

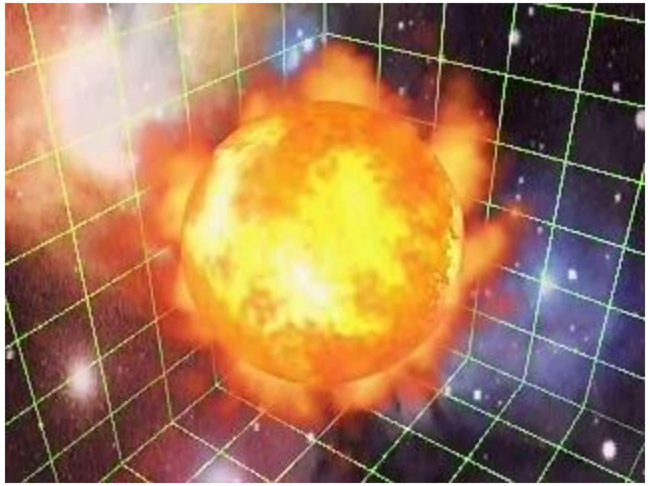
The Event Horizon





The Terrestrial Horizon

Gravitational Collapse

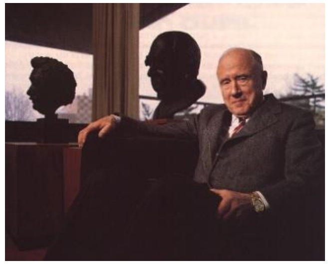


Schwarzschild Radii		Event Horizon
Star	$M = 10$	$R_s = 30$ km
Star	3 suns	9 km
Star	2 suns	6 km
Sun	1	3 km
Earth	0.000003	0.9 cm

Note: No mass can escape from a black hole not even light

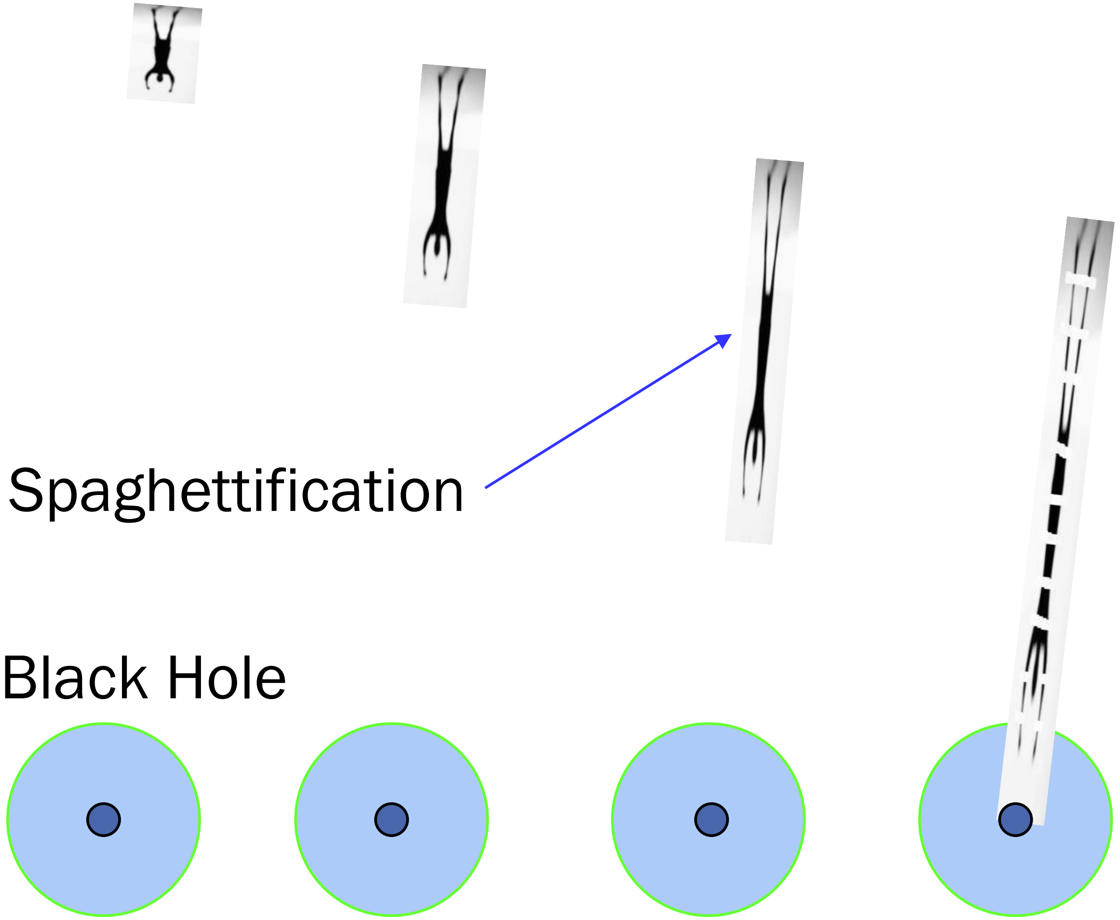
Examine things outside the blackhole ?

Spacetime Spaghettification



Wheeler

... time would appear to have stopped (due to GR) at the surface of the Black Hole



due to intense gravitation effects

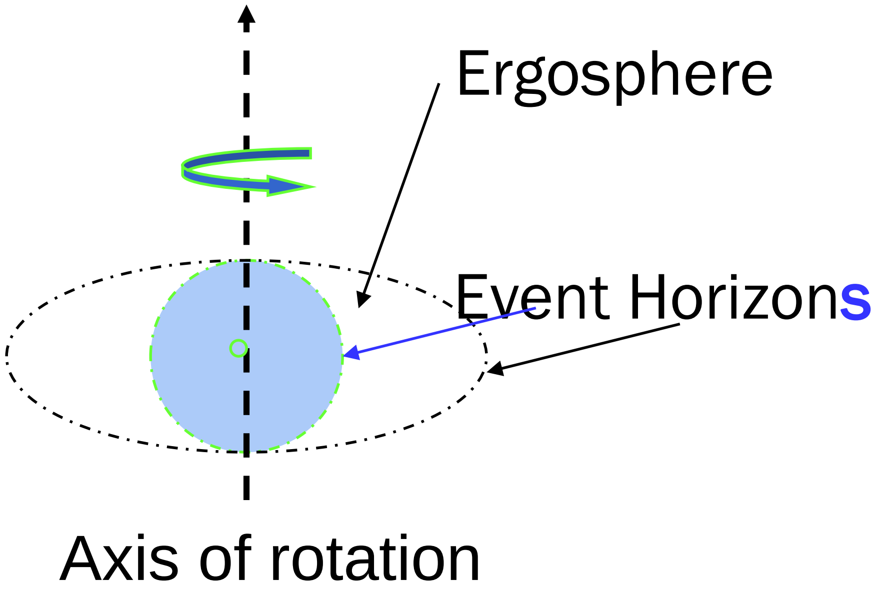
Wait a minute, where is the famous Black Hole Singularity ?

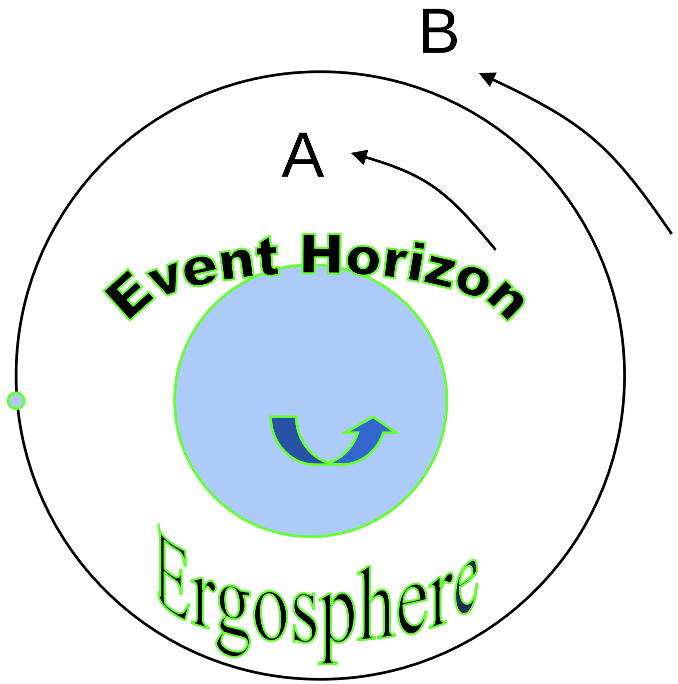
Spinning Black Holes

a) Schwarzschild (no spin & no charge)

b) Reissner - Nordstrom (no spin but charged)

c) Kerr (spin but no charge)



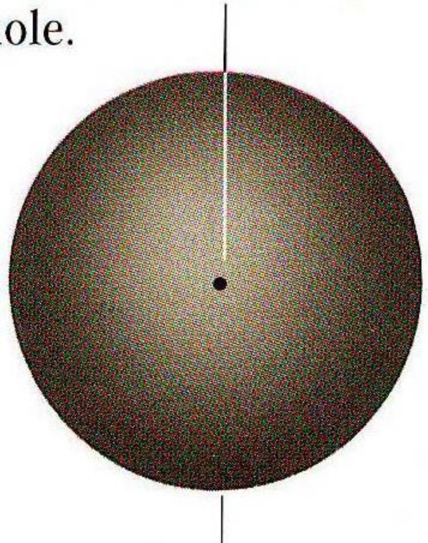


Spinning Black Hole Stars

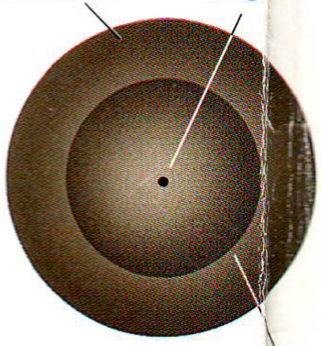
THE BLACK HOLE FAMILY

All black holes have the same basic structure: an event horizon surrounding a central singularity. But there are different types of holes – stationary, spinning, and those that have an electric charge. And each has different characteristics. While one may be deadly, another may allow a journey into another universe.

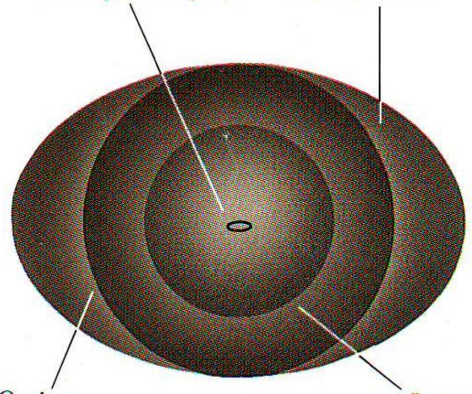
The simplest is a Schwarzschild black hole. With no spin and no charge, it consists of just a singularity surrounded by an event horizon. Anything crossing the event horizon will be forced toward the singularity.



In a Reissner–Nordstrøm black hole, which has charge but no spin, there are two event horizons. The region between them is a one-way zone where matter is forced to moved inward. Once inside the inner event horizon, matter is no longer sucked inward.

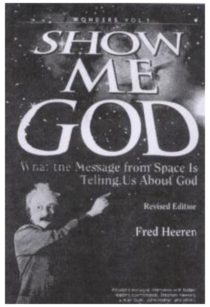


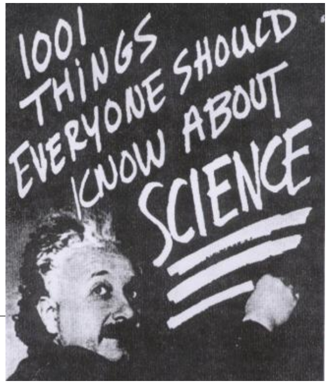
In a Kerr black hole, which has spin, the singularity is elongated into a ring. It, too, is surrounded by two event horizons. Beyond the outer one is the ergosphere – a region like a cosmic whirlpool, where matter is not only dragged inward but also swirled around.



How do we know so much about blackholes ?

Recall Previous Lectures:

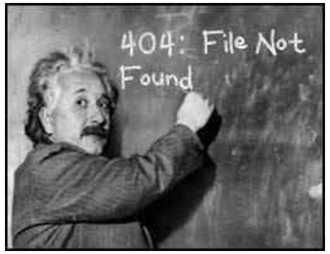




Recall Einstein Field Equation

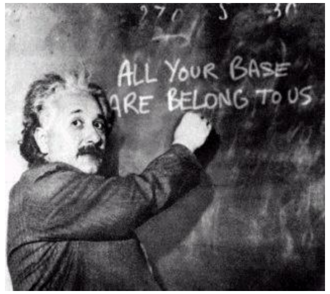
$$R = g^{\alpha\beta} R_{\alpha\beta}$$

$$R_{\alpha\beta} - \frac{1}{2} g_{\alpha\beta} R = 8\pi G T_{\alpha\beta}$$



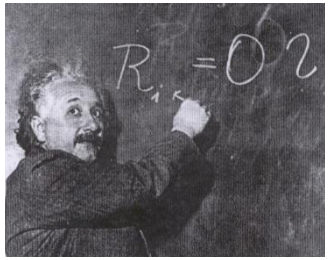
A measure = A measure

(spacetime curvature) = (matter/momentum energy density)



Note: Hard to solve ? Nonlinear terms
Use weak field and static approximation

$$R_{ik} = 0\ ?$$



He pondered over this for pure geometry for the last few decades of his life !

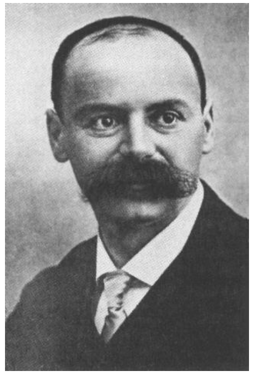
Einstein's Field Equation

$$R_{\alpha\beta} - \frac{1}{2} g_{\alpha\beta} R = 8\pi G T_{\alpha\beta}$$

Do not worry about your difficulties in mathematics. I assure you, mine are still greater. A. Einstein

I had not expected that the exact solution to the problem could be formulated, your analytic treatment of the problem appears to me splendid. A. Einstein (GR completed in 1915)

Einstein's field equations themselves are not "derived" anymore than Newton's laws of motion are derived. Taylor and Wheeler



Schwarzschild, 1916

Schwarzschild Solution (1916)

Within a month from the battle field,

$$ds^2 = -(1+\frac{2V}{c^2})(cdt)^2 + (1-\frac{2V}{c^2})(dx^2 + dy^2 + dz^2)$$

Change to more convenient co-ordinates

$(ct, x, y, z) \curvearrowright (ct, r, \phi, \theta)$

$$ds^2 = -(1-\frac{2GM}{c^2 r})(cdt)^2 + (1-\frac{2GM}{c^2 r})^{-1} dr^2 + r^2 d\phi^2 + r^2 \sin^2\theta d\theta^2$$

Recall dual roles for gs and Vs,

$$V = -\frac{GM}{r}$$

Notice :

you cannot divide by a zero.

Recall Sec. School Pythagoras Theorem

$$dr^2 = dx^2 + dy^2 \qquad (dr)^2 = (dx)^2 + (dy)^2$$

Lazy to write !

$$dr^2 = dx^2 + dy^2 + dz^2$$

$$ds^2 = -dt^2 + dx^2 + dy^2 + dz^2$$

Sometimes + / - unity

$$\begin{aligned} ds^2 = \\ &+ g_{tt}d(ct)d(ct) &+ g_{tx}d(ct)dx &+ g_{ty}d(ct)dy &+ g_{tz}d(ct)dz \\ &+ g_{xt}dxd(ct) &+ g_{xx}dxdx &+ g_{xy}dxdy &+ g_{xz}dxdz \\ &+ g_{yt}dyd(ct) &+ g_{yx}dydx &+ g_{yy}dydy &+ g_{yz}dydz \\ &+ g_{zt}dzd(ct) &+ g_{zx}dzdx &+ g_{zy}dzdy &+ g_{zz}dzdz \end{aligned}$$

May be it is a number or some function g

$$ds^2 = \sum_{\mu=0}^{3}\sum_{\nu=0}^{3} g_{\mu\nu}dx^\mu dx^\nu$$

Notational Nightmare !

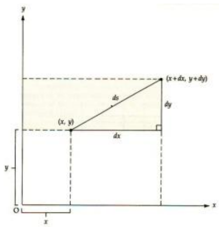
$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

$$(ct, x, y, z) \longrightarrow (x^0, x^1, x^2, x^3)$$

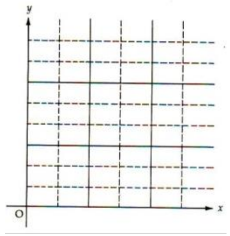
Recall: Why and what ?

g turns out to be the potentials, V.

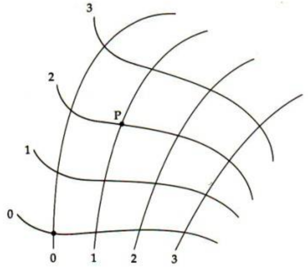
In fact, Newtonian potential turns out to be one of the terms in Einstein's Theory. But the *gs* are also the coefficients in *the "Pythagoras Theorem"*. This matrix is called Metric Tensor.



$$dr^2 = dx^2 + dy^2$$



$$ds^2 = \left(\tfrac{1}{3}\right)^2 dx^2 + \left(\tfrac{1}{3}\right)^2 dy^2$$



$$\begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} \quad \text{or} \quad \begin{pmatrix} V_{11} & V_{12} \\ V_{21} & V_{22} \end{pmatrix}$$

$$ds^2 = g_{11}dx^2 + g_{12}dxdy + g_{21}dydx + g_{22}dy^2$$

In short, gravitation does not cause the curvature. It is the curvature ...

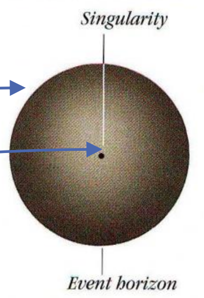
Gravity is Geometry ! Voi la ! B. Hoffmann

Pythagoras (Metric)

c set to 1 for convenience

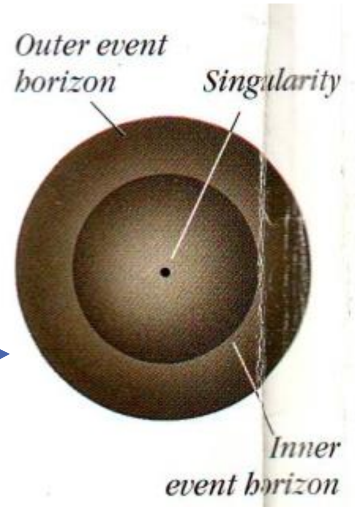
Schwarzschild (no charge and no spin)

$$ds^2 = -\left(1-\frac{2M}{r}\right)dt^2 + \frac{1}{\left(1-\frac{2M}{r}\right)}dr^2 + r^2 d\phi^2$$



Reissner-Nordstrom (charged but non spinning)

$$ds^2 = -\left(1-\frac{2M}{r}+\frac{Q^2}{r^2}\right)dt^2 + \frac{1}{\left(1-\frac{2M}{r}+\frac{Q^2}{r^2}\right)}dr^2 + r^2 d\phi^2$$

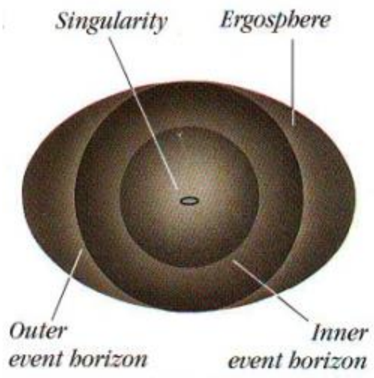


Q : charge parameter

Kerr Metric (spinning but not charged)

a : spin parameter

$$ds^2 = -\left(1-\frac{2M}{r}\right)dt^2 - \frac{4Ma}{r}dtd\phi + \frac{1}{\left(1-\frac{2M}{r}+\frac{a^2}{r^2}\right)}dr^2 + \left(1+\frac{a^2}{r^2}+\frac{2Ma^2}{r^3}\right)r^2 d\phi^2$$



A General Relativity Failure ?: Black Hole Singularity:

However it was discovered after long study that this singularity in the metric is due to the choice of co-ordinates and is not real. On the other hand, the singularity at r = 0, appears to be real. … Any way, nature has hidden away the singularity inside $r = 2M$, so we cannot find out while remaining outside … all real singularities are "clothed".

That is, anything falling to the center of a black Hole is crushed to zero volume … to a single point … quantum theory predicts that nothing … not even a single electron … can be confined to a point.

What is the truth ? Nobody knows … need a quantum gravity theory that combines quantum mechanics and general relativity. Taylor and Wheeler

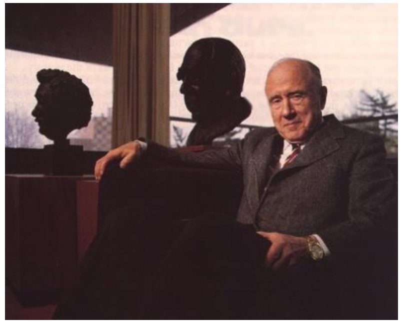
General Relativity brings about its own downfall by predicting singularities. S. Hawking

“No force” Concept in General Relativity Theory
A paradigm shift … in *Time*

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$

Many not close to his work of Einstein as a man who could only make headway by dint of pages of complicated mathematics. The truth is the direct opposite. As the great mathematician of the time, D. Hilbert, put it, “Every school boy in the streets of Gottingen understands more about 4 dimensional geometry than Einstein”.

Yet … Einstein did the work and not the mathematicians” the amateur grasped the simple central point that had eluded the expert …



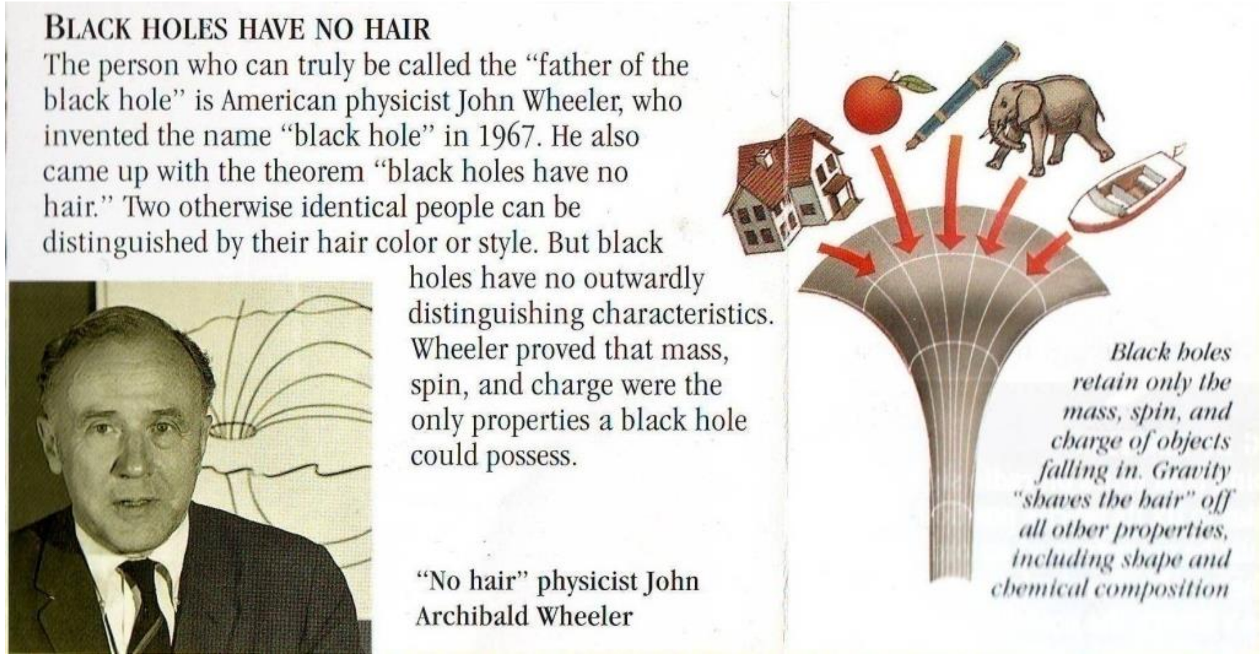
J. A. Wheeler

Some Properties of Blackholes

Black Holes have no Hairs

What other information can we get from the black hole ?

- Mass
- Angular Momentum (Spin)
- Electric Charge



BLACK HOLES HAVE NO HAIR

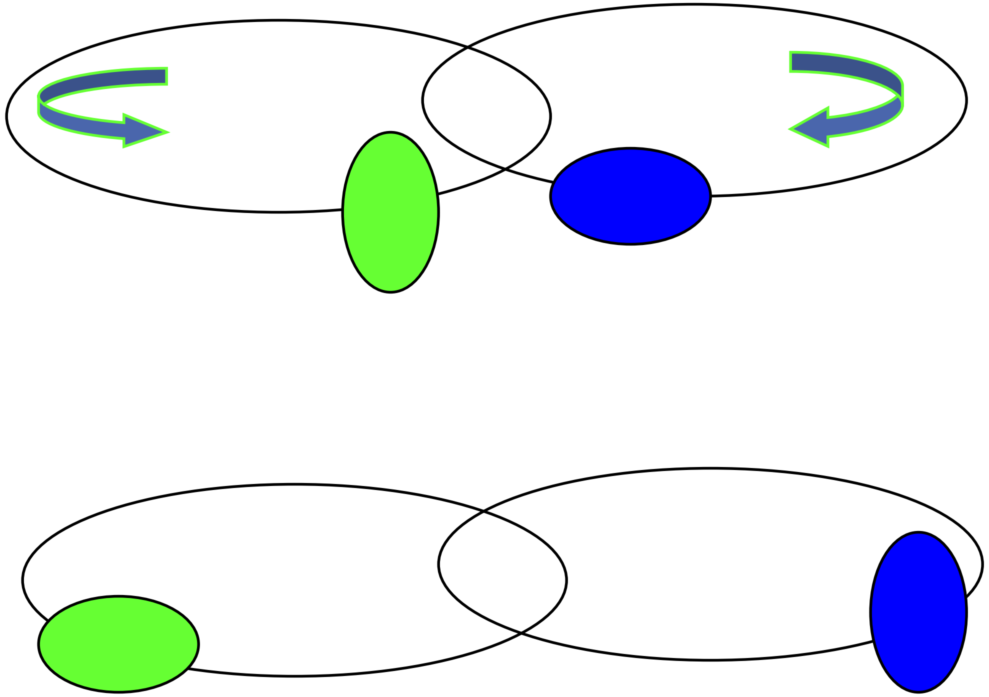
The person who can truly be called the "father of the black hole" is American physicist John Wheeler, who invented the name "black hole" in 1967. He also came up with the theorem "black holes have no hair." Two otherwise identical people can be distinguished by their hair color or style. But black holes have no outwardly distinguishing characteristics. Wheeler proved that mass, spin, and charge were the only properties a black hole could possess.

"No hair" physicist John Archibald Wheeler

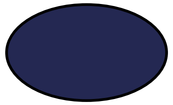
Black holes retain only the mass, spin, and charge of objects falling in. Gravity "shaves the hair" off all other properties, including shape and chemical composition

No Hair Theorem

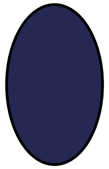
Tidal Binary Spheroid Dance



Oblate spheroid

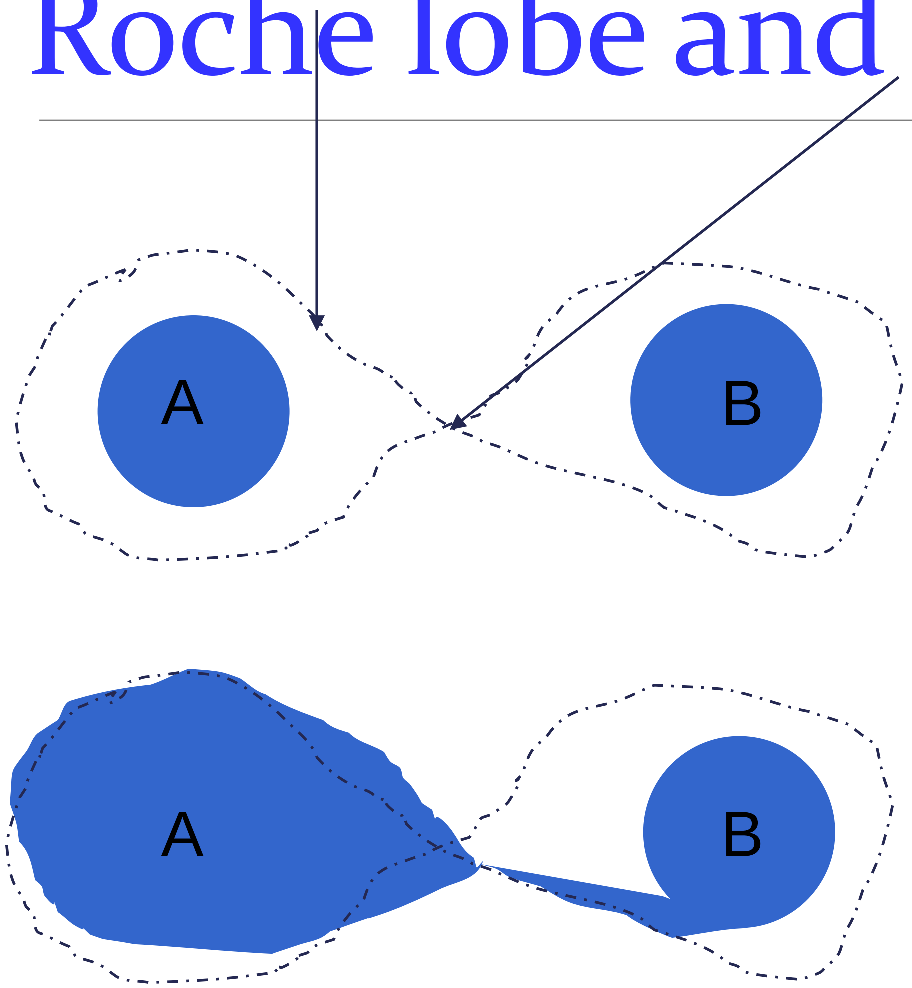


Prolate spheroid



A Standard Binary System (Distortable shapes)

Roche lobe and Lagrangian points



If a satellite comes too close to a planet, the tidal force may become so enormous that it destroys the satellite.

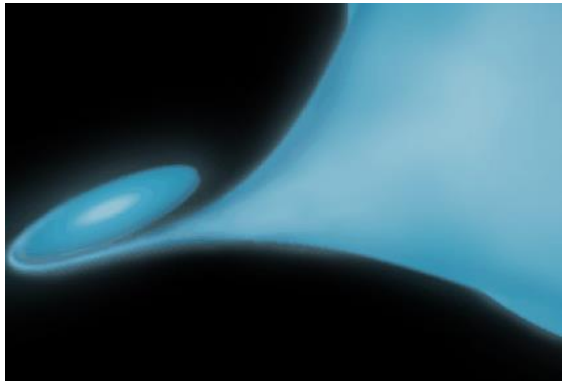
Roche Limit.

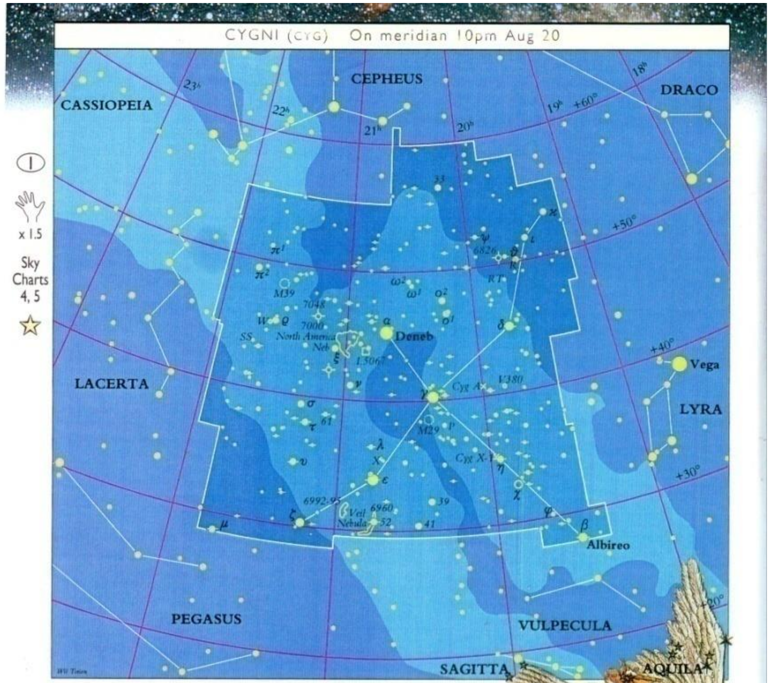
How close can a planet be to a parent star ?

Cynus X-1

How to detect a Black Hole?

- Gravitational Lensing
- Gravitational Waves
- Binary Systems





Cygnus

(SIG-nus) The Swan

Cygnus is the Northern Hemisphere's answer to Crux. Looking like a large cross, Cygnus straddles the northern Milky Way, which is at its best in this part of the sky. If you are under a dark sky you may be able to see the Milky Way divide into two streams in Cygnus. A dark nebula between us and the more distant stars causes this apparent divergence.

Since the time of the Chaldeans, many civilizations have seen this constellation as a bird of some sort. One story claims that Cygnus is Orpheus, the great hero of Thrace, who sang and played his lyre so beautifully that wild animals and even the trees would come to hear him. It is said that Orpheus was transported to the sky as a swan, so that he could be near his cherished lyre. Another myth claims that Cygnus is Zeus in the disguise of a swan—the form he took to seduce Leda of Sparta.

Deneb (Alpha [α] Cygni): Deneb means "tail" in Arabic, which is where this star is positioned on the swan. On a par with Rigel in Orion, it is one of the mightiest stars known—25 times more massive and 60,000 times more luminous than the Sun. About 1,500 light years away, Deneb is by far the most distant star of the famous Summer Triangle, which it forms with Vega and Altair. Vega is 25 light years away and Altair only 16.

Albireo (Beta [β] Cygni): Whether you are observing this star from the dark of the country or from the middle of a city, Albireo, at the foot of the cross, is one of the prettiest sights in the sky. Without a telescope it is seen as a single star; a telescope transforms it into a spectacular double with a separation of 34 arc seconds. One member is golden yellow with a magnitude of 3, and the other is blueish with a magnitude of 5.

Urania's Mirror (1825) places brilliant Deneb between the feet of the swan.

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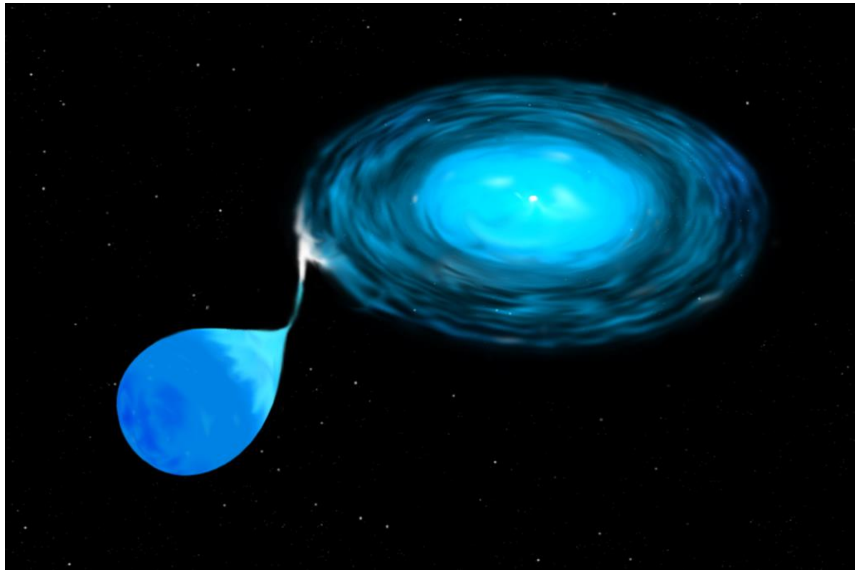
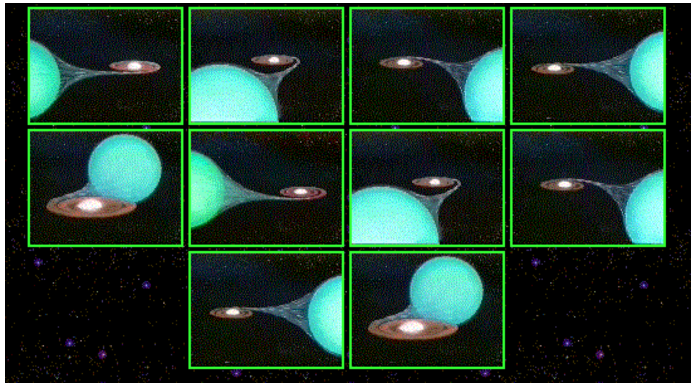
Cynus constellation is also called Northern Cross

Tidal Disruption

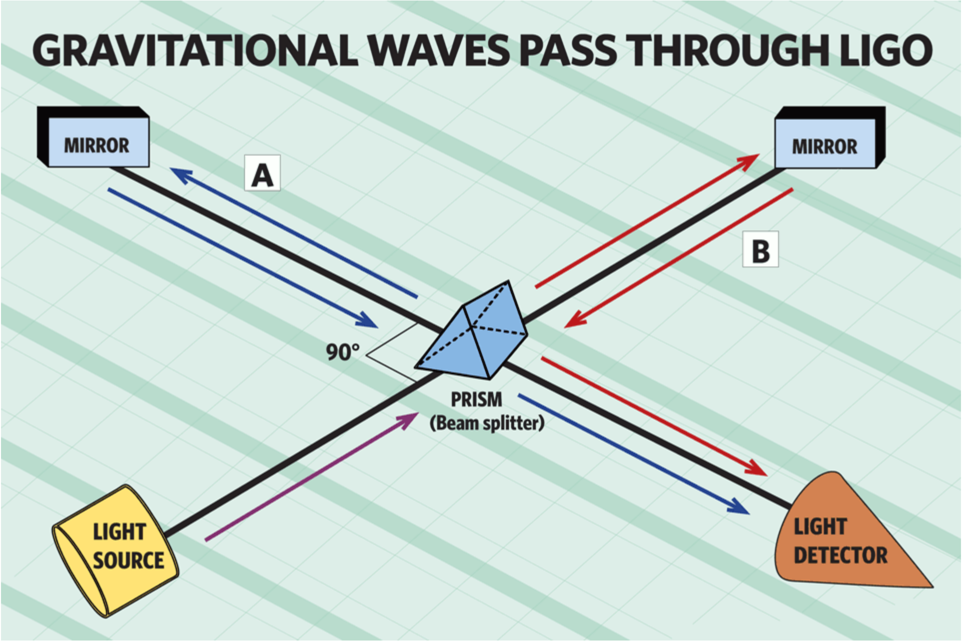
Blackholes Scenario





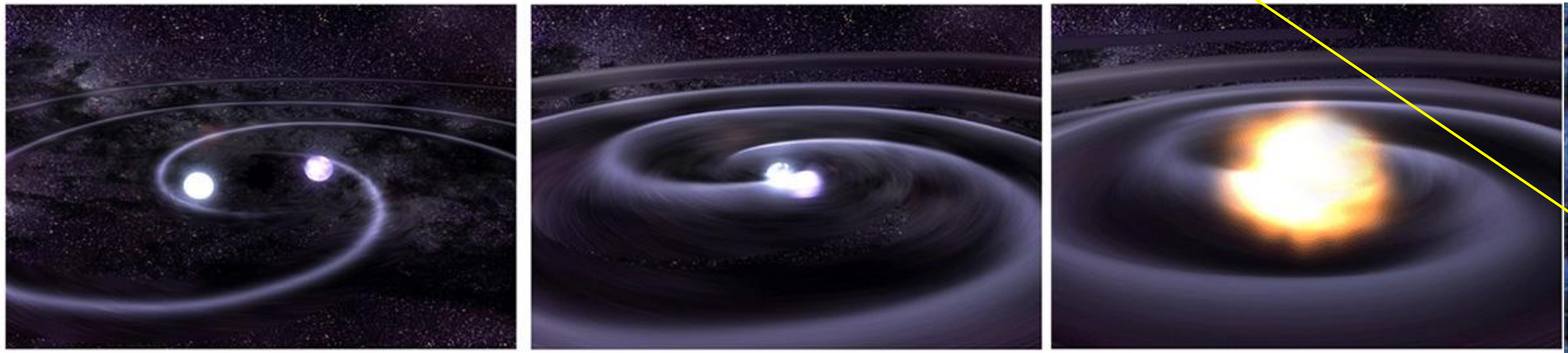
Recently More Evidences

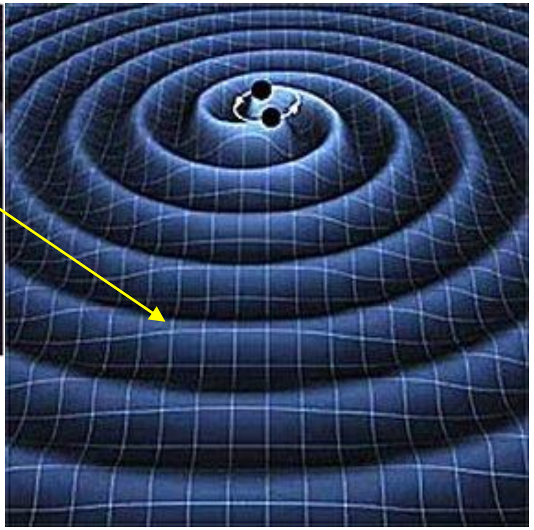
LIGO “Telescopes” (2015)



[LIGO Collaboration]

Recent Gravitational Waves





14th September 2015 discovery

Binary Blackholes & Gravitational Waves

Comments on Black Holes

... Credence given to black Holes is somewhat exaggerated ! ... J.V. Narlikar

Black Holes cannot be directly observed, their existence must be inferred from indirect measurements.

Some feel inference of the existence of black holes rests on insufficient evidence.

J.V. Narlikar

Black Hole Comments

Skepticism of black holes: So far all the evidence in active galactic nuclei, quasars, etc. shows outward rather than, inward motion of particles and radiation.

So in the black hole picture it is presumed that the inward motion generated by the black hole's attraction is somehow converted into outward motion.

J.V. Narlikar

Some Ideas about whiteholes ?

White Holes

So implosion into singularity is now replaced by an explosion from a singularity.

Also the final state of collapse has now become the initial state of explosion.

Einstein's general theory of relativity is a time-symmetric theory, it permits the explosive situation.

J.V. Narlikar

White Holes

As an alternative to black holes; what are white holes ?

Recall the gravitational red shift, we now has blue shift. Why ?

White Hole is the time reversed version of Black Hole.

J.V. Narlikar 

White Holes

Why consider white holes when we are uncertain of black holes?

The basic laws of physics – whether the laws of gravity, electricity, magnetism or the interactions in the interior of the atomic nucleus are all time symmetric.

This means that any event taking place according to these laws has a time reversed version that can also take place according to the same laws.

J.V. Narlikar

White Holes as Particle Accelerators

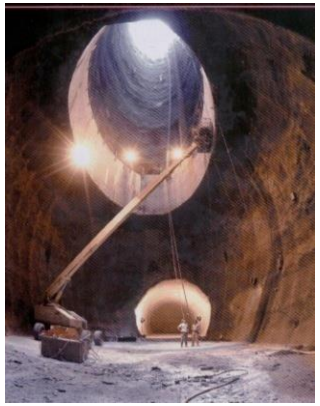
High Energy particles from outer space.

10^{20} GeV or hundred billion times the energy of the proton at rest.

What mechanism caused say the proton to move with such high speed?

X rays and gamma rays burst over very short intervals.

White holes could exist in astronomical objects displaying signs of explosion.



Demised Super Conducting Super Collider, Texas

Can White Hole Exit ?

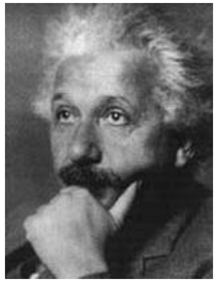
Some candidates : Quasars, radio galaxies and nuclei of Seyfert galaxies are likely sites for white holes.

In spite of these questions regarding white holes of a limited size, astronomers have paradoxically given an uncritical acceptance to the hypothesis of the biggest white hole of them all : The Universe

J.V. NarLikar

So The Big Bang spills out The Universe .

Exploring Black Holes



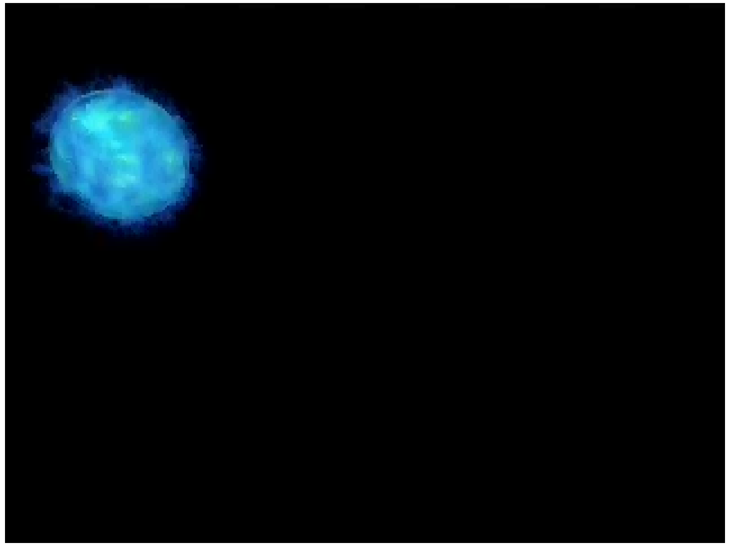
… Einstein and Eddington were not. Blackholes just didn't smell right … we are so accustomed to the idea of blackholes today that it is hard not to ask, 'How could Einstein be so dumb ? How could he leave out the very thing, implosion, that makes the blackhole …

Kip Thorne

Supermassive Black Holes

Galactic Nuclei

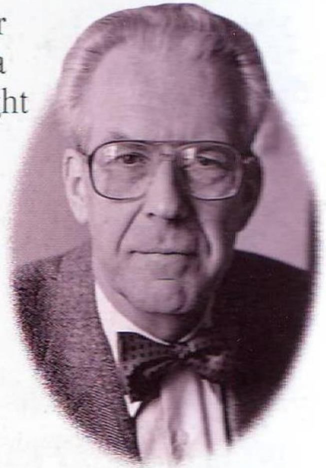
Quasi-Stellar Radio Sources (Quasars)

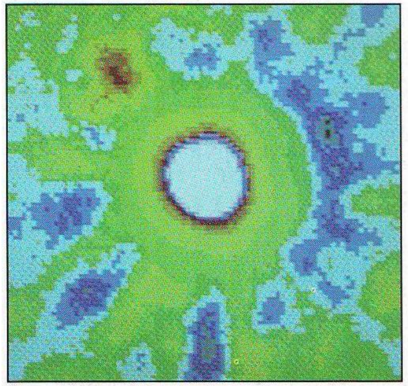


At the edge of the Universe

DISCOVERY OF QUASARS

In 1963, Dutch-American astronomer Maarten Schmidt was puzzling over a "star" called 3C 273 that gave out light and radio waves. When he analyzed the light, it didn't make sense. Then he realized: 3C 273 is farther away than most galaxies and the expansion of the Universe stretches the wavelength of its light. 3C 273 was called a "quasi-stellar radio source," soon shortened to "quasar."





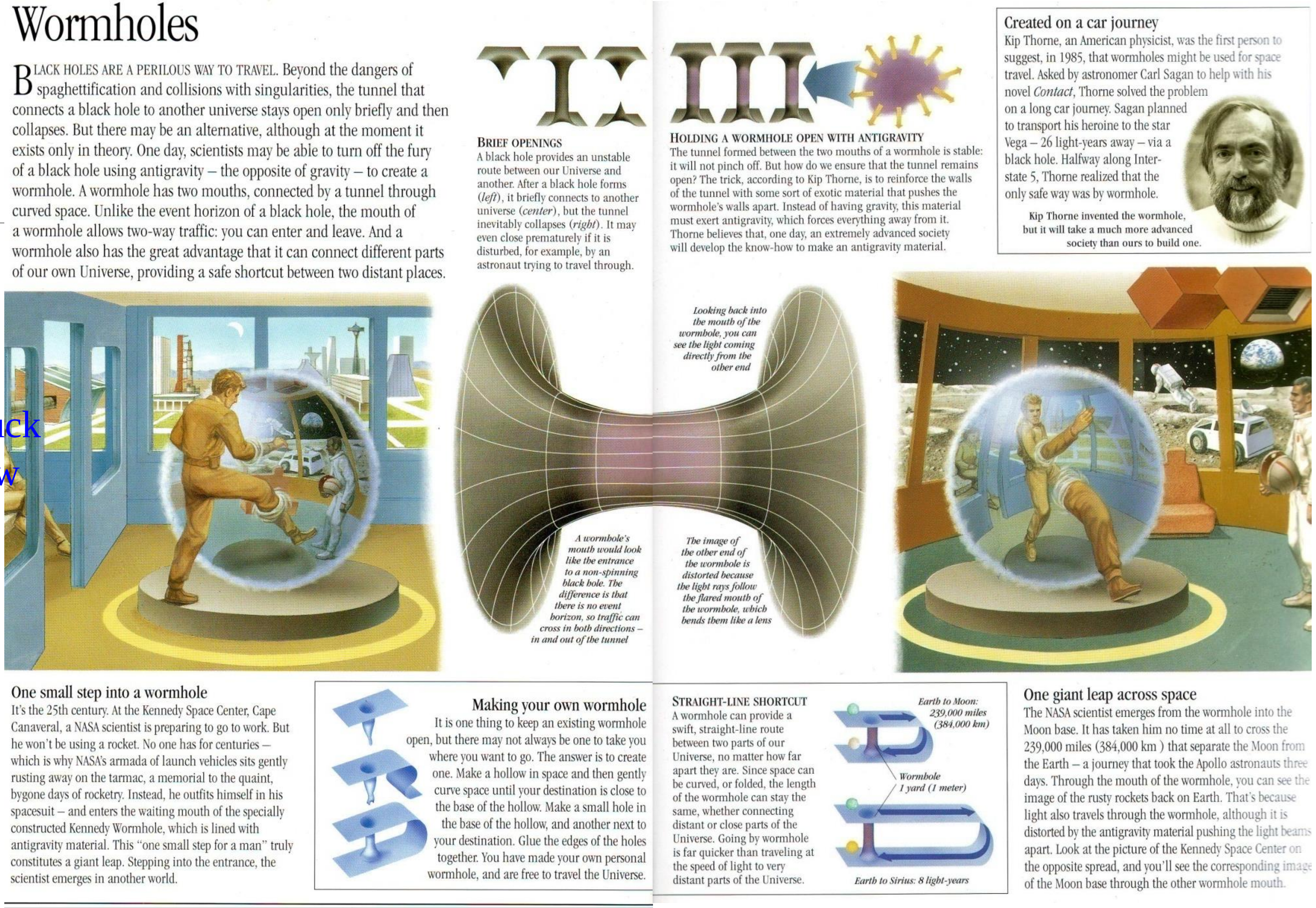
The first of thousands of quasars to be discovered, 3C 273 is imaged here by X rays. It is one of the nearest quasars, just 2 billion light-years from us. The average quasar is no bigger than our Solar System, but brighter than a trillion Suns.

Other Ideas about Blackholes !

Worm

Holes

Because, blackhole suck in and whitehole throw out



Wormholes

BLACK HOLES ARE A PERILOUS WAY TO TRAVEL. Beyond the dangers of spaghettification and collisions with singularities, the tunnel that connects a black hole to another universe stays open only briefly and then collapses. But there may be an alternative, although at the moment it exists only in theory. One day, scientists may be able to turn off the fury of a black hole using antigravity – the opposite of gravity – to create a wormhole. A wormhole has two mouths, connected by a tunnel through curved space. Unlike the event horizon of a black hole, the mouth of a wormhole allows two-way traffic: you can enter and leave. And a wormhole also has the great advantage that it can connect different parts of our own Universe, providing a safe shortcut between two distant places.

BRIEF OPENINGS
A black hole provides an unstable route between our Universe and another. After a black hole forms (*left*), it briefly connects to another universe (*center*), but the tunnel inevitably collapses (*right*). It may even close prematurely if it is disturbed, for example, by an astronaut trying to travel through.

HOLDING A WORMHOLE OPEN WITH ANTIGRAVITY
The tunnel formed between the two mouths of a wormhole is stable: it will not pinch off. But how do we ensure that the tunnel remains open? The trick, according to Kip Thorne, is to reinforce the walls of the tunnel with some sort of exotic material that pushes the wormhole's walls apart. Instead of having gravity, this material must exert antigravity, which forces everything away from it. Thorne believes that, one day, an extremely advanced society will develop the know-how to make an antigravity material.

Created on a car journey
Kip Thorne, an American physicist, was the first person to suggest, in 1985, that wormholes might be used for space travel. Asked by astronomer Carl Sagan to help with his novel *Contact*, Thorne solved the problem on a long car journey. Sagan planned to transport his heroine to the star Vega – 26 light-years away – via a black hole. Halfway along Interstate 5, Thorne realized that the only safe way was by wormhole.

Kip Thorne invented the wormhole, but it will take a much more advanced society than ours to build one.

Looking back into the mouth of the wormhole, you can see the light coming directly from the other end

A wormhole's mouth would look like the entrance to a non-spinning black hole. The difference is that there is no event horizon, so traffic can cross in both directions – in and out of the tunnel

The image of the other end of the wormhole is distorted because the light rays follow the flared mouth of the wormhole, which bends them like a lens

One small step into a wormhole
It's the 25th century. At the Kennedy Space Center, Cape Canaveral, a NASA scientist is preparing to go to work. But he won't be using a rocket. No one has for centuries – which is why NASA's armada of launch vehicles sits gently rusting away on the tarmac, a memorial to the quaint, bygone days of rocketry. Instead, he outfits himself in his spacesuit – and enters the waiting mouth of the specially constructed Kennedy Wormhole, which is lined with antigravity material. This "one small step for a man" truly constitutes a giant leap. Stepping into the entrance, the scientist emerges in another world.

Making your own wormhole
It is one thing to keep an existing wormhole open, but there may not always be one to take you where you want to go. The answer is to create one. Make a hollow in space and then gently curve space until your destination is close to the base of the hollow. Make a small hole in the base of the hollow, and another next to your destination. Glue the edges of the holes together. You have made your own personal wormhole, and are free to travel the Universe.

STRAIGHT-LINE SHORTCUT
A wormhole can provide a swift, straight-line route between two parts of our Universe, no matter how far apart they are. Since space can be curved, or folded, the length of the wormhole can stay the same, whether connecting distant or close parts of the Universe. Going by wormhole is far quicker than traveling at the speed of light to very distant parts of the Universe.

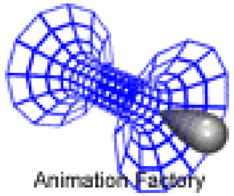
Earth to Moon: 239,000 miles (384,000 km)

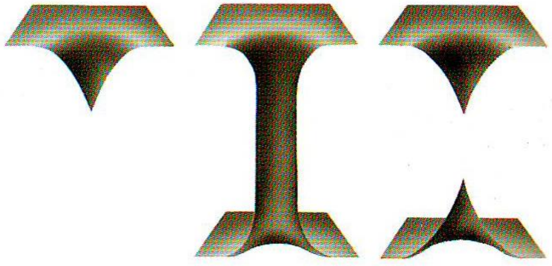
Wormhole 1 yard (1 meter)

Earth to Sirius: 8 light-years

One giant leap across space
The NASA scientist emerges from the wormhole into the Moon base. It has taken him no time at all to cross the 239,000 miles (384,000 km) that separate the Moon from the Earth – a journey that took the Apollo astronauts three days. Through the mouth of the wormhole, you can see the image of the rusty rockets back on Earth. That's because light also travels through the wormhole, although it is distorted by the antigravity material pushing the light beams apart. Look at the picture of the Kennedy Space Center on the opposite spread, and you'll see the corresponding image of the Moon base through the other wormhole mouth.

Wormholes (Space Travel !)





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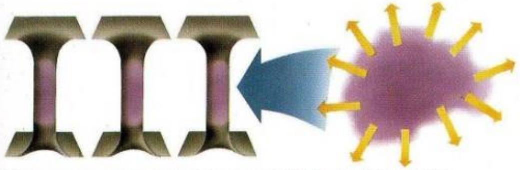

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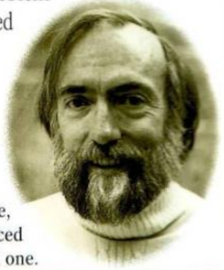

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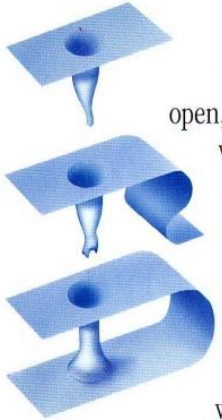

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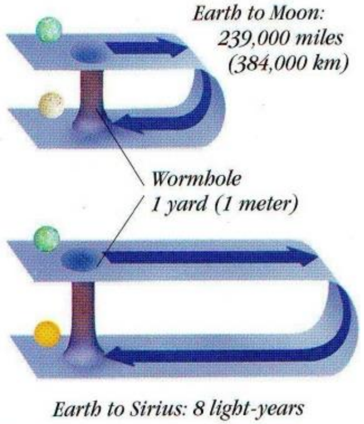
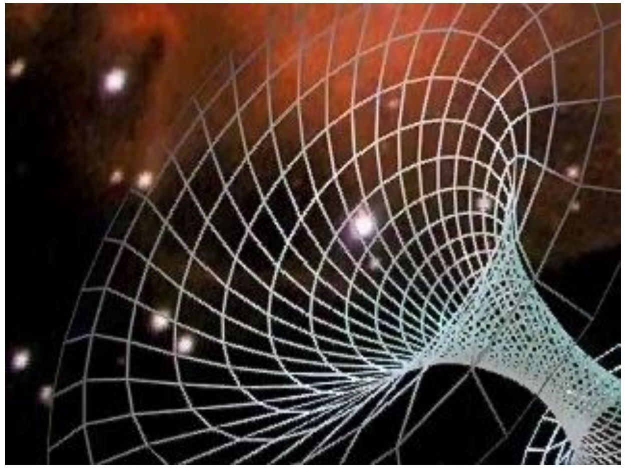
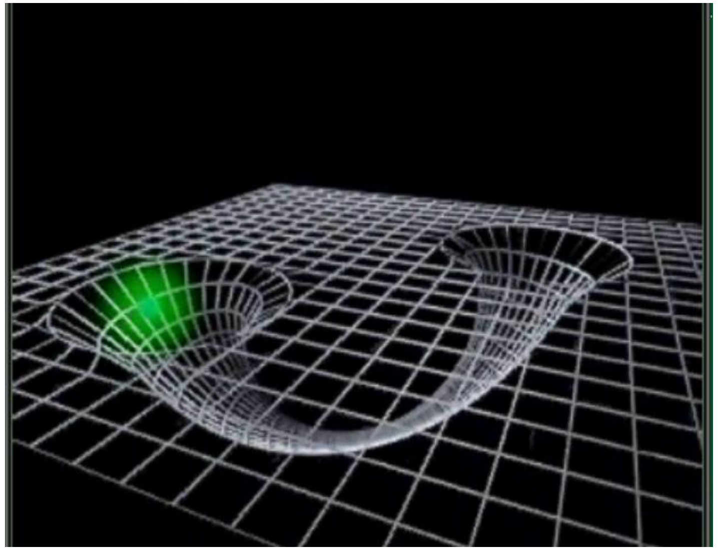


Time Travel and Parallel Universes



Einstein-Rosen Bridge

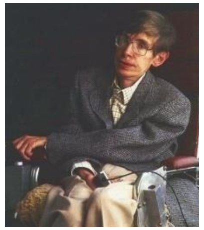
Notice that the wormhole opens up as it rotates.



Possible mathematical Construction of different surfaces

More wormhole action

Hawking Radiation



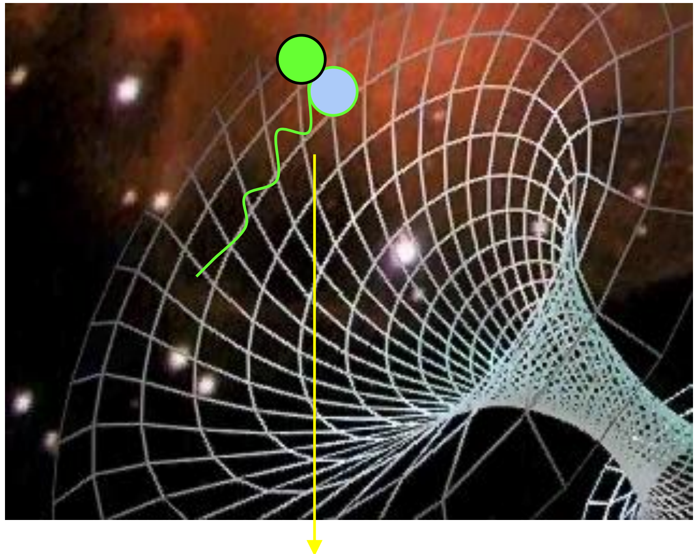
The theory states that virtual particle-antiparticle pairs are sometimes created outside the event horizon of a black hole. Three things can happen to a pair of particles just outside the event horizon:

A) Both particles are pulled into the black hole.

B) Both particles escape from the black hole.
C) One particle escapes while the other is pulled into the black hole.

For the third possibility, the particle that has escaped becomes real and can therefore be observed from Earth. The particle that was pulled into the black hole remains virtual and must restore its conservation of energy by giving itself a negative mass-energy. The black hole absorbs this negative mass-energy and as a result, loses mass and appears to shrink. The rate of power emission is proportional to the inverse square of the black hole's mass.

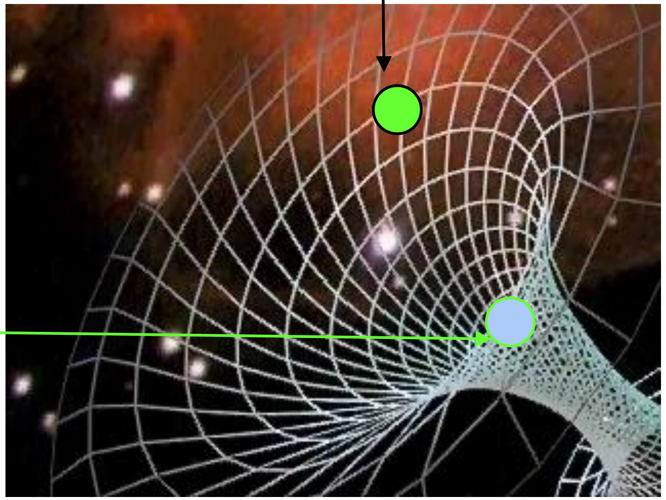
Hawking Evaporation



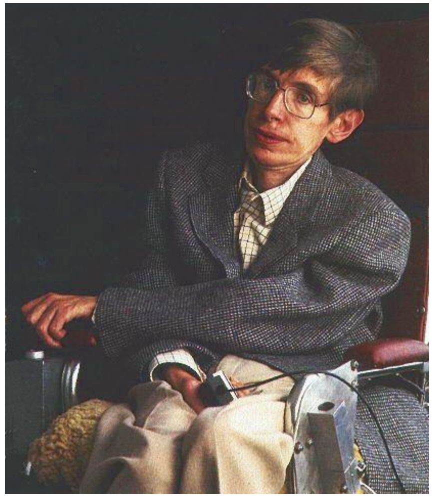
Quantum Fluctuation

Negative Energy particle

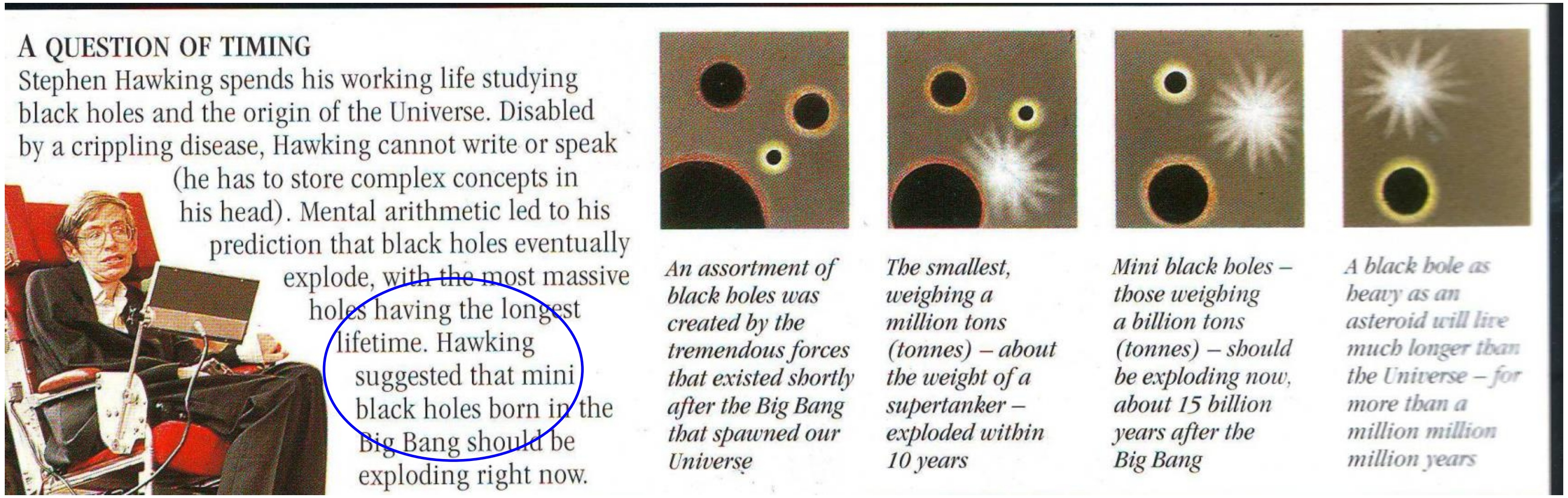
Real particle



Blackhole is not black ... Surprise !



Mini Black holes (Primordial)



A QUESTION OF TIMING

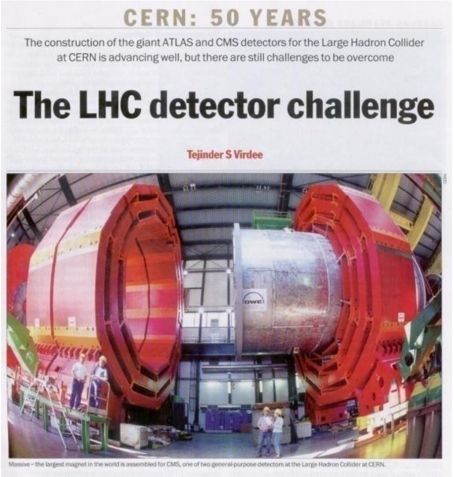
Stephen Hawking spends his working life studying black holes and the origin of the Universe. Disabled by a crippling disease, Hawking cannot write or speak (he has to store complex concepts in his head). Mental arithmetic led to his prediction that black holes eventually explode, with the most massive holes having the longest lifetime. Hawking suggested that mini black holes born in the Big Bang should be exploding right now.

An assortment of black holes was created by the tremendous forces that existed shortly after the Big Bang that spawned our Universe

The smallest, weighing a million tons (tonnes) – about the weight of a supertanker – exploded within 10 years

Mini black holes – those weighing a billion tons (tonnes) – should be exploding now, about 15 billion years after the Big Bang

A black hole as heavy as an asteroid will live much longer than the Universe – for more than a million million million years



CERN: 50 YEARS

The construction of the giant ATLAS and CMS detectors for the Large Hadron Collider at CERN is advancing well, but there are still challenges to be overcome

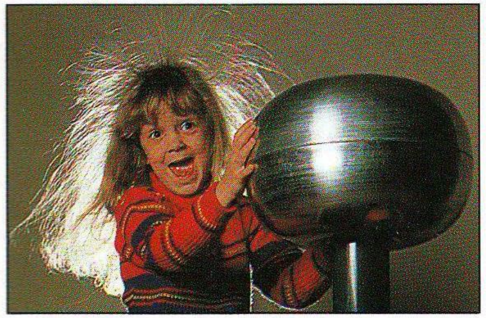
The LHC detector challenge

Tejinder S Virdee

Large Hadron Collider, LHC 2005–202?, Highest Energy: 14 TeV
Discovery of Hawking Temperature.
Smaller Black Holes have shorter lifetime (reverse of stars)
When an unexpected result makes such links, they must be fundamental !

http://www.youtube.com/watch?v=BXzugu39pKM

Naked Singularity Possibility

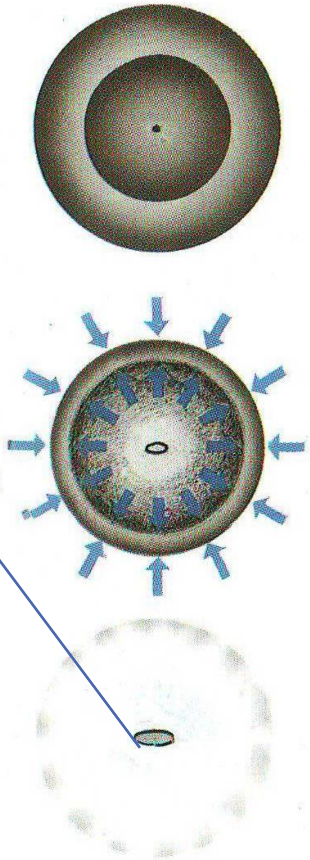


Electric forces can make your hair defy gravity…

…while rapid spin can hurl you outward

How to make a naked singularity

The trick is to overcome the forces of gravity that would otherwise create an event horizon. Two forces can achieve this: spin and electric charge. If a body collapsing to become a black hole is spinning very fast or has a strong electric field, the opposing force creates an inner event horizon. Increasing the spin or charge will bring the inner and outer event horizons closer together. If there is enough spin or charge, the two horizons merge and disappear completely, leaving the singularity exposed. In the real Universe, a collapsing star cannot build up enough electric charge to counteract gravity, but a very rapidly spinning star might end up as a naked singularity.



A spinning black hole has an inner and outer event horizon, with a one-way zone between the two where things can only move inward.

A more rapidly spinning black hole has a larger inner event horizon and a smaller outer event horizon. The one-way zone is thinner.

If the hole spins fast enough, the two horizons may merge. The one-way zone disappears, and the singularity becomes visible – and accessible.

References

1) E. Taylor and J. Wheeler, Black Holes, Addison Wesley (2003)

2) H. Couper and N. Henbest, *Black holes* (DK Publishing, New York)

3) J.P. Luminet, *Black holes* (Cambridge University Press, UK)

4) K. Ferguson, *Prisons of light* (Cambridge University Press, UK)

5) J. B. Hartle, *Gravity,* Addison Wesley (2003)

"It's black, and it looks like a hole. I'd say it's a black hole."