BLACK HOLES

Misconceptions,
and the Even More Startling Truth

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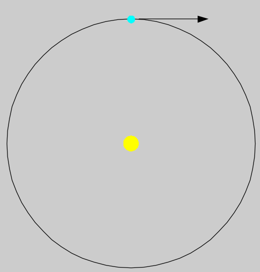
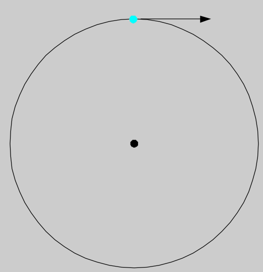
Myth #1 : Black holes are “cosmic vacuum cleaners” that suck in anything in the vicinity.

Truth: Gravity is just gravity.

Thought experiment : suppose we were suddenly to replace the Sun with a black hole of the same mass... what would happen to the orbits of the planets?

Earth Orbiting Sun	Earth Orbiting 1 $M_{\odot}$ Black Hole
	
Mass : 1 $M_{\odot}$ Radius : 700,000 km Orbit Radius : 150 million km Orbit Period : 1 year	Mass : 1 $M_{\odot}$ Radius : 2.9 km Orbit Radius : 150 million km Orbit Period : 1 year

Newton's Law of Universal Gravitation

$$F = \frac{G M_1 M_2}{d^2}$$

F = strength of the force between two bodies
G = Newton's Gravitational Constant
M_1 = mass of first body
M_2 = mass of second body
d = distance between bodies

Depends only on masses and distances,
not on what the bodies are!

Even works for Black Holes unless d is too small.

When is Newton's Gravity good enough?

Escape Velocity : $v_{esc} = \sqrt{\frac{2GM}{d}}$

If $v_{esc} \ll c$, Newton's Gravity is (usually) good enough!

$c = 3 \times 10^8$ m/s = 300,000 km/s = 670,000,000 mph

From Earth's Surface:	v_{esc} = 11 km/s = 25,000 mph
From Earth's Orbit:	v_{esc} = 42 km/s = 94,000 mph
From Sun's Surface:	v_{esc} = 620 km/s = 1.4 million mph
100 km from $M_\odot$ B.H.:	v_{esc} = 50,000 km/s = 100 million mph
From Black Hole:	$v_{esc} = c$

...a small caveat...

GPS (Global Positioning System)

Routinely must include general relativity corrections for gravitational redshift and gravitational time dilation!!

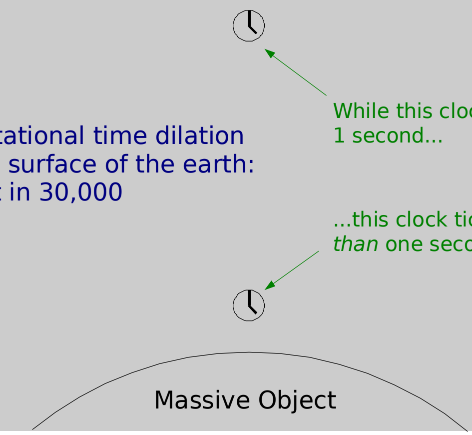
You can fall into a black hole, but you don't get sucked into a black hole.

It only matters that it's a black hole (as opposed to a normal star) if you get very close to it.

Myth #2 : It takes an infinite amount of time to fall into a black hole.

Truth: It doesn't! But there are calculations that seem to suggest this... but they are often interpreted incorrectly.

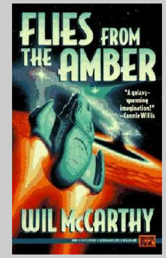
Gravitational Time Dilation



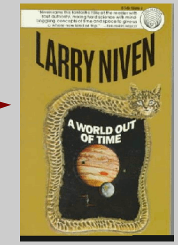
While this clock ticks 1 second...

Gravitational time dilation at the surface of the earth: 1 part in 30,000

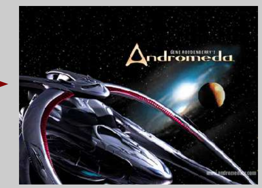
...this clock ticks *less than* one second!



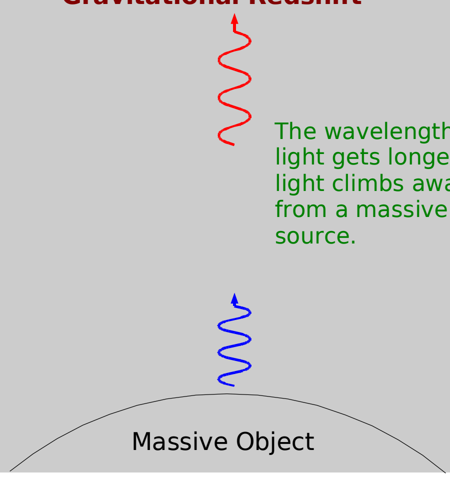
Good black hole time dilation in science fiction.



Bad black hole time dilation in science fiction....



Gravitational Redshift



The wavelength of light gets longer as light climbs away from a massive source.

Schwartzschild Coordinates

Describe space and time (e.g. time dilation, orbits, and so forth) for an observer outside a spherical star (including a black hole).

Indicate that $t \rightarrow \infty$ for an observer going into a black hole.

This is merely a coordinate singularity, not a real singularity! I.e., these are *bad coordinates* to describe somebody crossing the event horizon of the black hole!

Analogy : longitude at the North Pole

What really happens:

- Holediver falls into the B.H. in a finite time.
- After entering the event horizon, Holediver can no longer communicate with the outside... but *can* receive signals.
- Observer sees the very last light from Holdiver come out after infinite time, infinitely redshifted.

Thought Experiment : Observer watches Holediver falling into a black hole.

After waiting an arbitrary amount of time, can Observer decide to swoop down and rescue Holediver? (Ignore cost, engineering difficulties, etc; assume Observer has tremendous resources.)

If so, then it would be reasonable to say that for Observer, Holediver takes an infinite amount of time to fall in to the black hole.

Answer : NO!

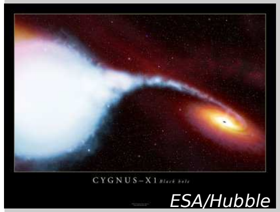
Even though Observer *sees* Holediver falling for the rest of eternity, eventually Observer has waited too long.

Myth #3 : Black holes are gateways to other universes, back in time, other dimensions, etc...

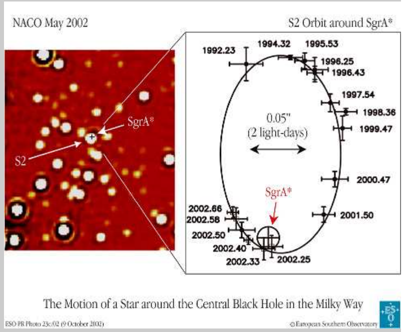
Truth : our Physics breaks down and can't describe the real singularity at the core of a black hole. Black holes are fun enough, and aren't necessarily connected to wormholes.

Myth #4 : Black holes exist only in theory, and haven't been observed.

Truth : we've seen the indirect effects of what can only be a black hole on surrounding matter.



Cygnus X-1
(Artist's Conception)



Milky Way B.H.
Mass : ~3.5 million Mo
Radius : 10 million km

Myth #5 : The Milky Way Black Hole is holding the Galaxy together.

Truth : the black hole's gravity is insignificant for all but the stars closest to the black hole.

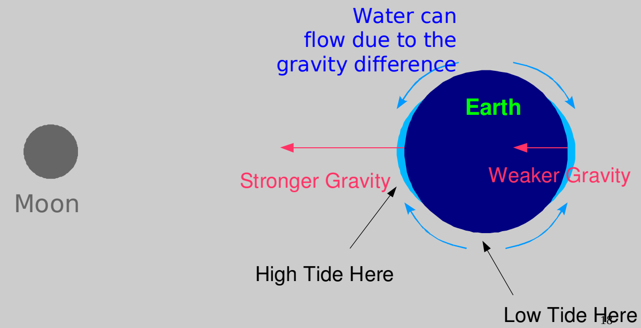
$M_{\bullet}$ = 10^6 solar masses

M_{gal} = 10^{12} solar masses

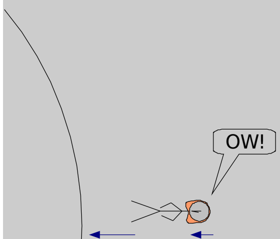
Spiral arms are *not* "down the drain"

Tidal Forces

...result from a *difference* in gravity from one side of an object to the other

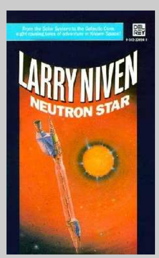


Cool B.H. Fact #1
YOU WILL BE PASTE!!!



Differential gravity can get huge...

Ironic Addendum : tidal forces near the event horizon become *less* extreme for larger black holes!



The most famous equation nobody understands:

$$E = m c^2$$

E = mass-energy in an object of mass m
c = speed of light = 3×10^8 m/s

Energy of a 83mph fastball : 100 J

Mass energy in a baseball: 1.3×10^{16} J

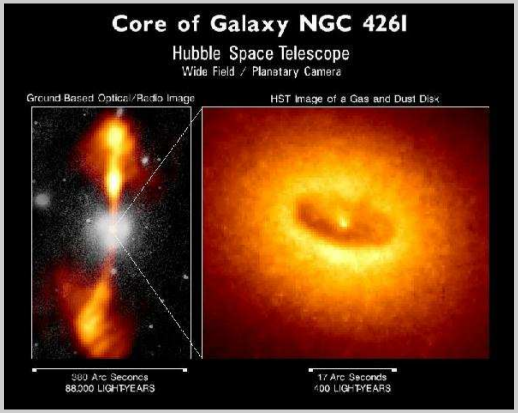
Cool B.H. Fact #2 : Power Generation

Power Generation "Efficiency": $eff = \frac{E_{\text{produced}}}{m_{\text{fuel}}\ c^2}$

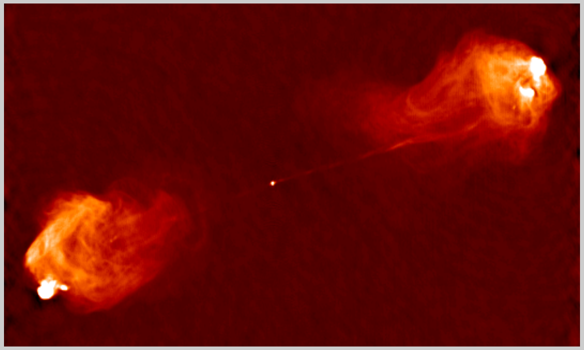
Process	Efficiency
Chemical Reactions	$\sim 10^{-10}$ - 10^{-9}
Nuclear Fusion	0.001 - 0.01
Dropping Mass on Earth	10^{-9}
Dropping Mass on the Sun	10^{-6}
Dropping Mass near the event horizon of a Black Hole	~ 0.5

Charles Sheffield,
Proteus Unbound

Cool B.H. Fact #3 : Active Galactic Nuclei



Radio Galaxy Cygnus A

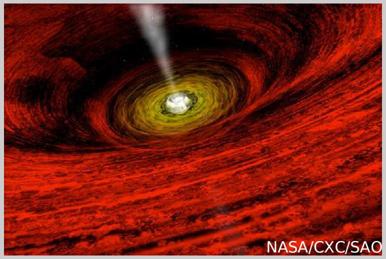


4.8 GHz VLA Radio Map

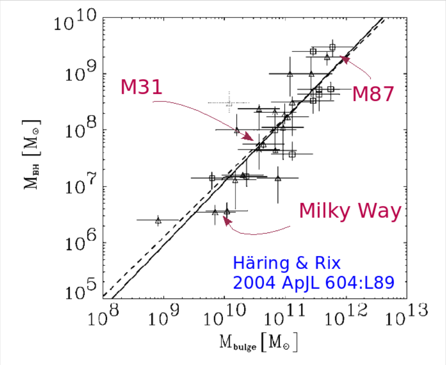
Quasars, Radio Galaxies, Seyfert Galaxies, etc.

Many non-active galaxies, including our own, harbor monstrous black holes.

More quasars are seen at higher redshifts— a long time ago, when the Universe was much smaller.



Cool B.H. Fact #4 :
Black Holes & Galaxy Growth?



$$\frac{M_\bullet}{M_{bulge}} = 0.0014 \pm 0.0004$$