

Black Holes

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History

- In 1939, J. Robert Oppenheimer and Hartland Snyder calculated the first models of neutron stars
- Proceeded to question what would happen when a star exhausted its sources of nuclear fusion
- What would happen if it collapsed due to massive gravity?
- By 1968, John A. Wheeler coins the term “black hole”

The Physics Behind It

Schwarzschild metric:

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

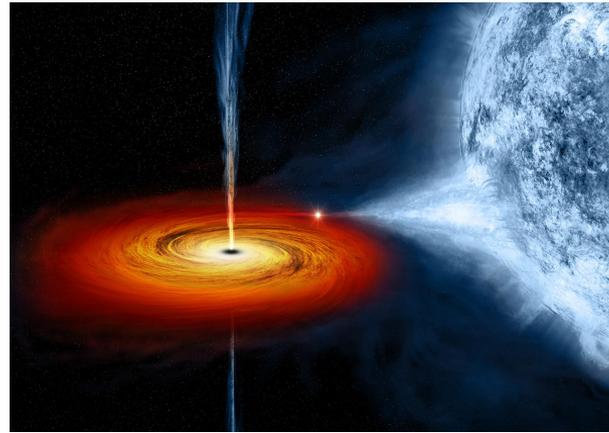
- Describes curved spacetime based on Einstein's theory of relativity

Schwarzschild Radius

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

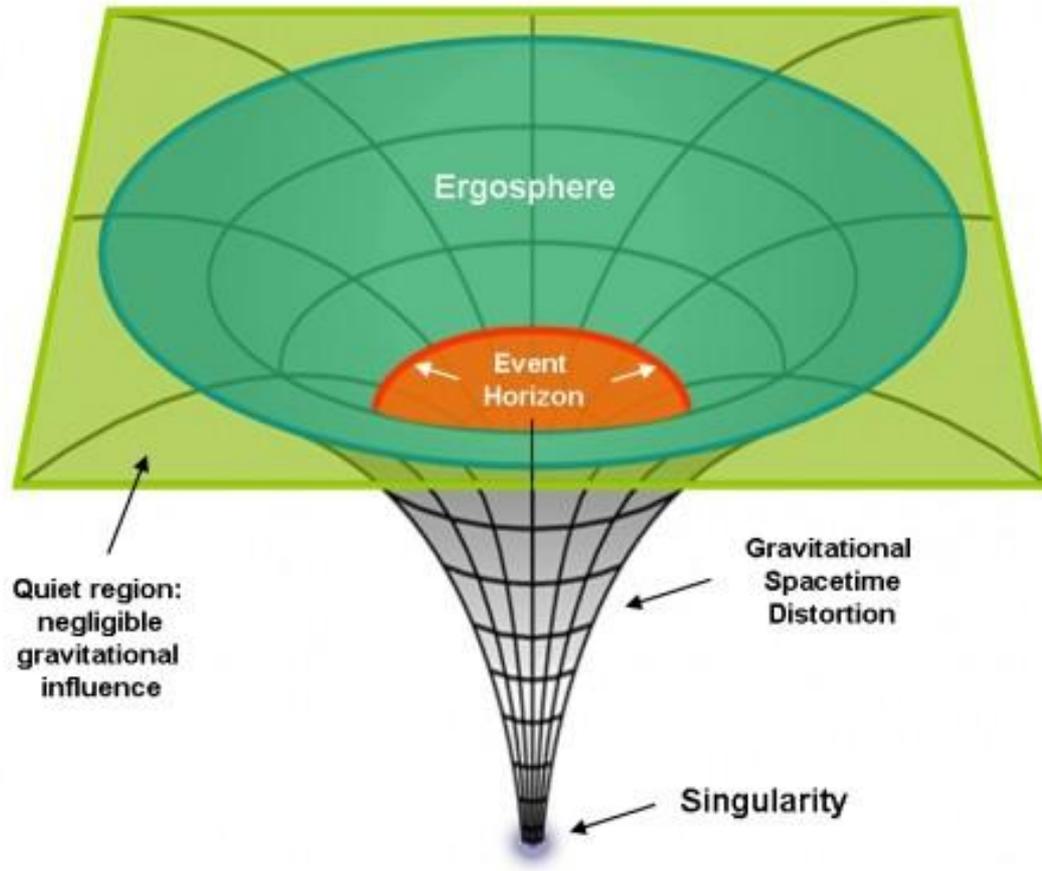
- This is the critical radius in which the Schwarzschild metric equals zero
- Escape velocity is the speed of light
- Therefore, light is frozen in time and cannot escape this region

Why is it a black hole?



- Since the light cannot travel anywhere, it appears to be a “black hole”
- The center of a black hole is a singularity, which has zero volume and infinite density
- This singularity is cloaked by the event horizon, called the “Law of Cosmic Censorship”
- Must be larger than $3 M_{\odot}$ to overcome both electron and neutron degeneracy

Black Hole Regions



Into the Rabbit Hole

- A photon will slow down until it stops at the event horizon in the infinite future
- So an observer would never see the light get there, much less return
- As light travels toward the black hole, we'd see redshifted light waves since the signal is slowing down
- The rate and energy of the photons decreases as well, so the light gets dimmer
- The light is quickly redshifted and dimmed into invisibility

“Black Holes Have No Hair”

- Only described by its mass, angular momentum, and electric charge
- Resulted in this odd phrase
- Maximum angular momentum:

$$L = (GM^2)/c$$

- If this limit were exceeded, there wouldn't be an event horizon, which is impossible

Black Hole Sizes

Stellar-Mass Black Holes

- Has a mass ranging from 3 to 15 M_{\odot}
- Formed in the destruction/core collapse of a massive supergiant star
- Can also be formed by binary neutron star system stealing mass

Intermediate-Mass Black Holes

- Has a mass ranging from 100 to 1000 M_{\odot}
- More mysterious than SMBHs
- Believed to be formed by the merging of stars in globular clusters for supermassive stars which would then collapse or collisions between Stellar-Mass Black Holes

Black Hole Sizes (cont'd)

Supermassive Black Holes

- Has a mass ranging from 10^5 to $10^9 M_{\odot}$
- Exist at the center of galaxies (believed to be at the center of every galaxy)
- Speculation is that they are formed due to collisions between galaxies or Intermediate-Mass Black Holes

Primordial Black Holes

- Has a mass ranging from 10^{-8} to $10^5 M_{\odot}$
- Formed in the earliest points of the creation of the universe
- Only requirement is that all mass must lie in the Schwarzschild Radius.

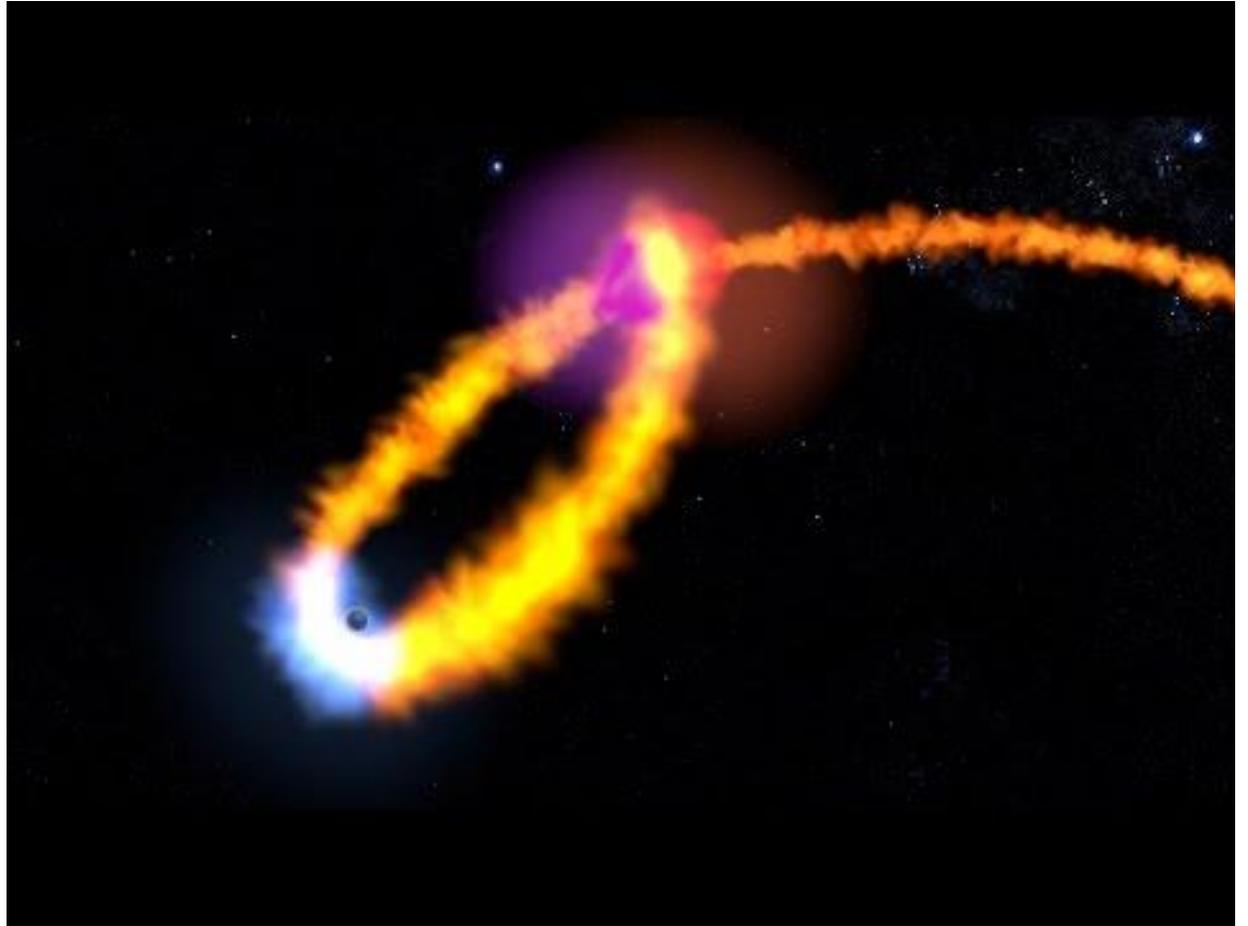
An illustration of an astronaut in a white and blue spacesuit floating in space. The astronaut is positioned above a large, swirling black hole with purple and blue accretion disks. The background is a dark purple space filled with stars. A teal banner at the bottom contains the text 'BLACK HOLES'.

BLACK HOLES

Star Collapse

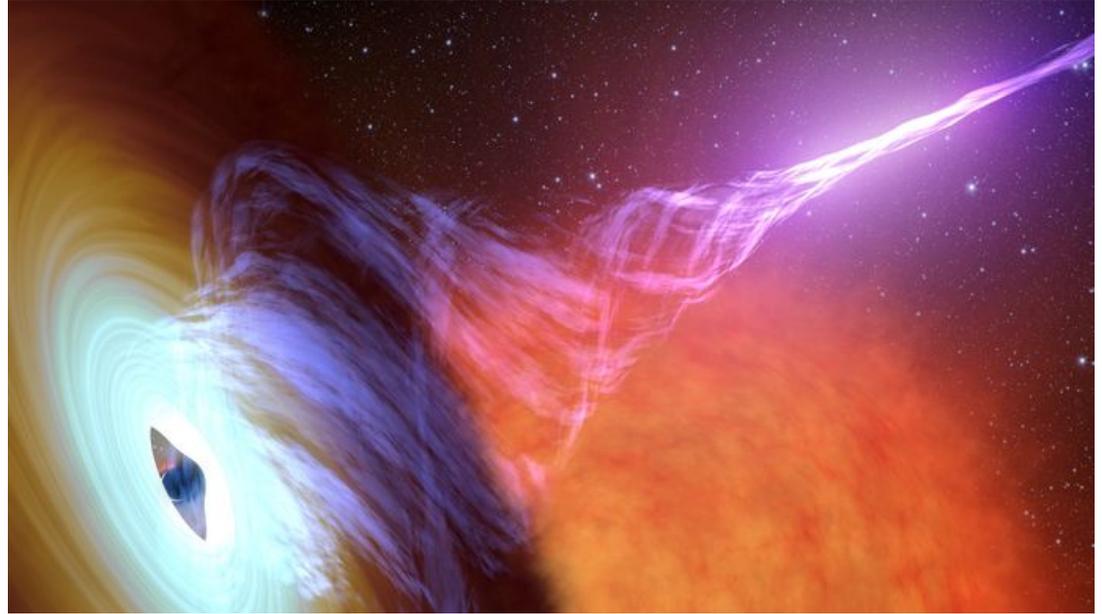
Event-ASASSN-14li

Solar mass star debris approaches a 3 million solar mass black hole (similar to center of the Milky Way)

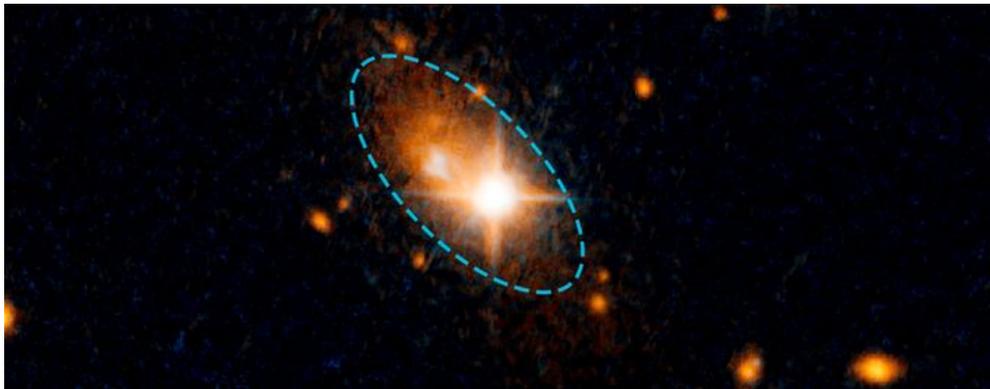


Plasma Jets (Fuel for new stars?)

Black holes are not all powerful celestial objects which destroy and absorb everything. Some material is released as plasma which is extremely hot and energized, thus causing it to become a source of light. This was observed in V404 Cygni and GX339-4.



MOVING A BLACK HOLE?!



Merger between galaxy 3C 186 and another unknown.

Tidal tails found by gravitational pull when supermassive black hole was back tracked.

Would require the energy of more than 100 million supernovas.

35000 light-years away from its home.

Moved by the merger between two galaxies (ie their central black holes).

Fun facts

- Black holes do not suck up everything in sight.
- You will never see one.
- Time gets warped near the black hole.
- You can fall forever (sort of).
- Black holes can die (10^{67} years).
- Black holes are not infinitely small (Planck Wavelength).
- They make the elements that make life possible.
- Physics breaks down in a black hole (tiny with infinite density)



Bibliography

- Crash Course Astronomy video
- Ostlie textbook p. 609 - 646
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<https://science.nasa.gov/astrophysics/focus-areas/black-holes>
- Black Holes: Facts, Theory & Definition, Nola Taylor Redd, Space.com,
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