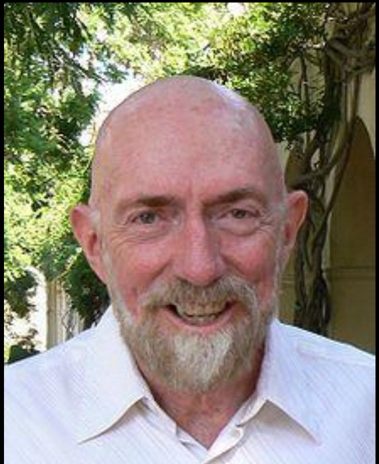
The Science of Interstellar

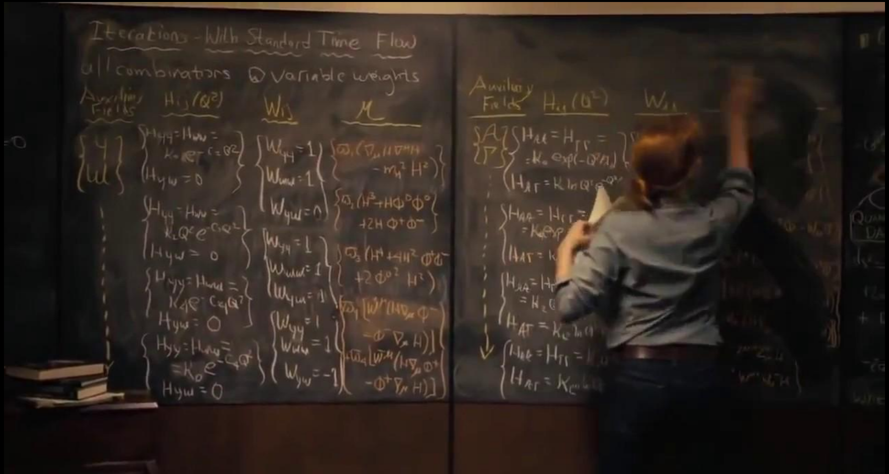
- Hawking Radiation

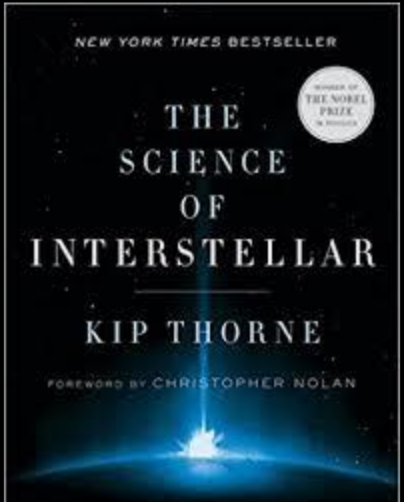
Gab and Max

Kip Thorne

- Caltech physicist, nobel prize winner, lead scientist for Interstellar
- The Science of Interstellar
- FREE HERE- https://www.scribd.com/document/338839584/The-Science-of-Interstellar-pdf







Special Relativity

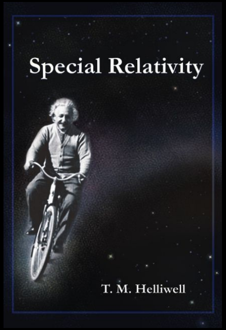
Special Relativity Example

- Actually from my textbook!
- Gamma= mathematical quantity NOT

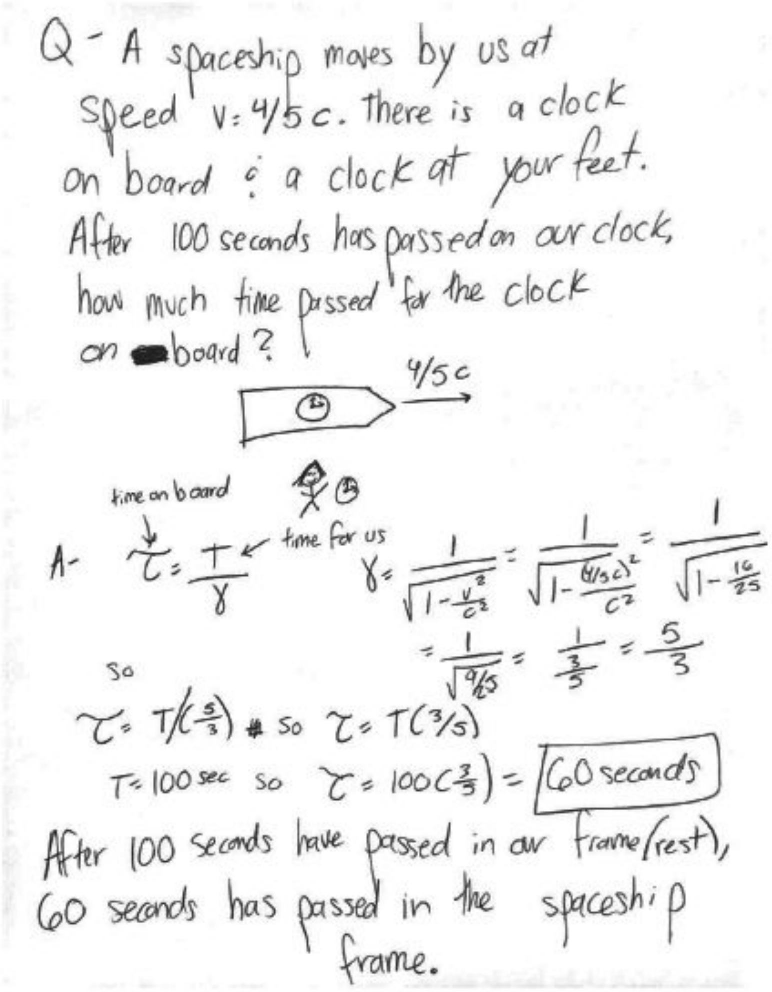
  physical, how it manipulates time

- Proof? Satellites have faster time

  than sea level



$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$



Q - A spaceship moves by us at Speed $v = 4/5c$. There is a clock on board & a clock at your feet. After 100 seconds has passed on our clock, how much time passed for the clock on board?

A- $\tau = \frac{T}{\gamma}$

time on board

time for us

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\frac{(4/5c)^2}{c^2}}} = \frac{1}{\sqrt{1-\frac{16}{25}}} = \frac{1}{\sqrt{9/25}} = \frac{1}{\frac{3}{5}} = \frac{5}{3}$$

So

$\tau = T/(\frac{5}{3})$ # so $\tau = T(3/5)$

$T = 100$ sec so $\tau = 100(\frac{3}{5}) = \boxed{60 \text{ seconds}}$

After 100 seconds have passed in our frame (rest), 60 seconds has passed in the spaceship frame.

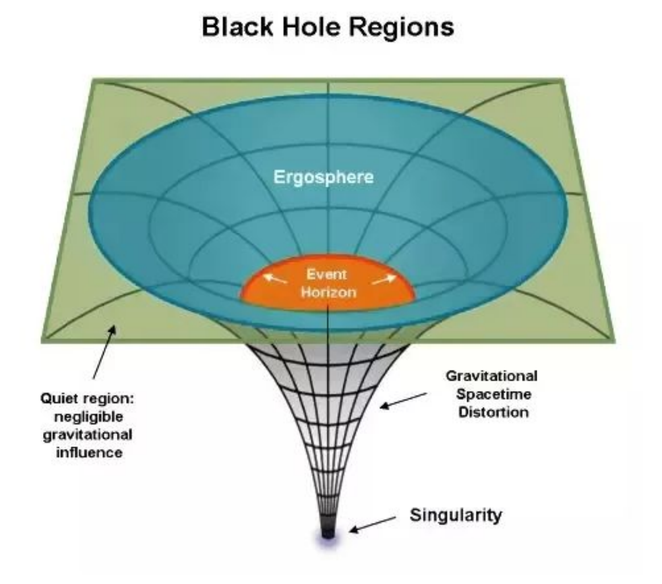
Questions?

Special Relativity

Basics of Special Relativity

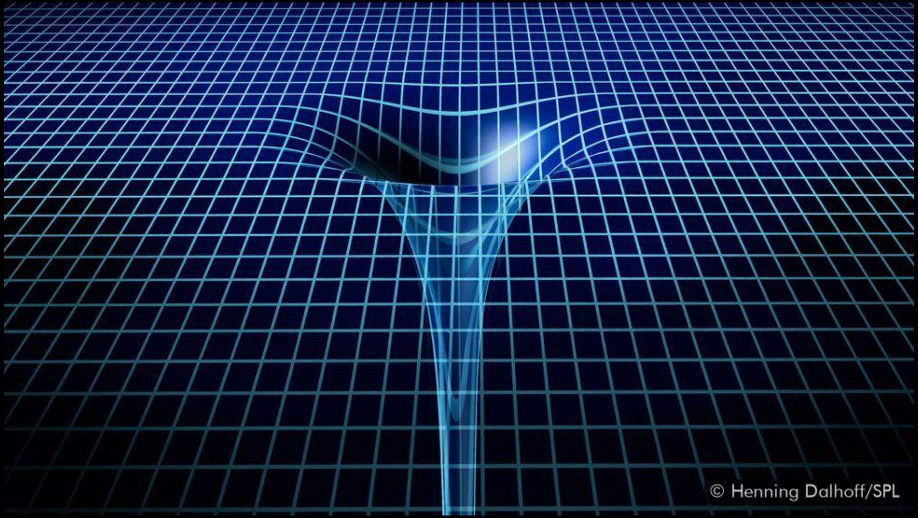
- Spaceship example, faster things move the less time passes
- Miller's Planet- gravity, at sea level you age less

  because of gravitational time dilation



Spec Rel Cont./Black holes

- Minkowski spacetime- space is flat! very far away vs. close
- Could you survive falling in? Matthew Mcconaughey did!
- 1. Infinite time 2. Redshift 3. Disappear



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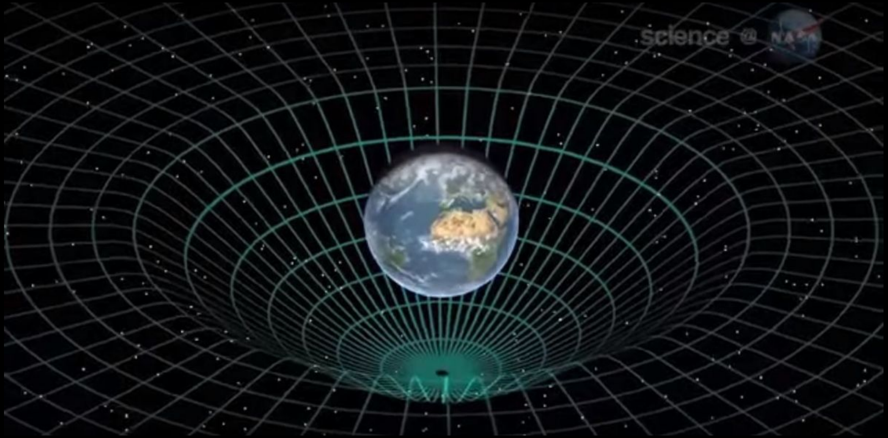


Questions?

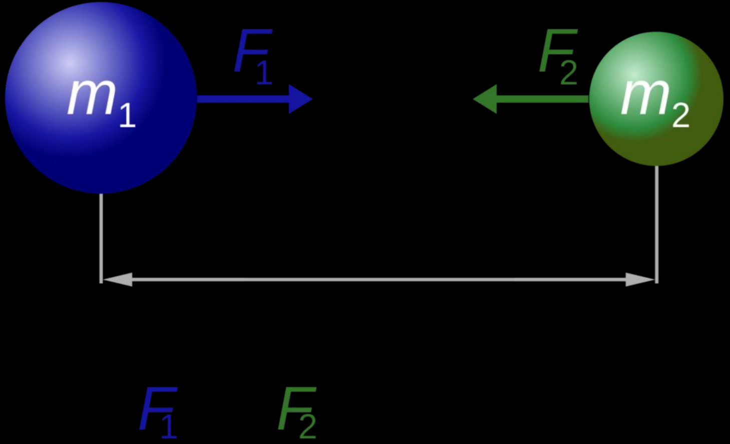
Wormholes

Can they exist?

Wormholes

Dark matter vs. Dark energy

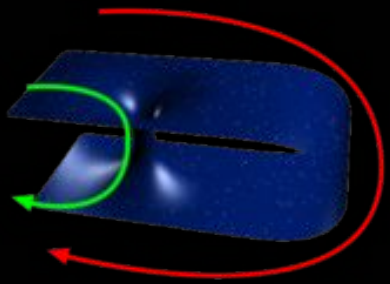
- Dark matter= 27% of the universe, we don't know (WIMPs and MACHOs)
- Dark Energy= repulsive force, 68% of the universe (Newton's law of gravitation)
- Can wormholes exist?

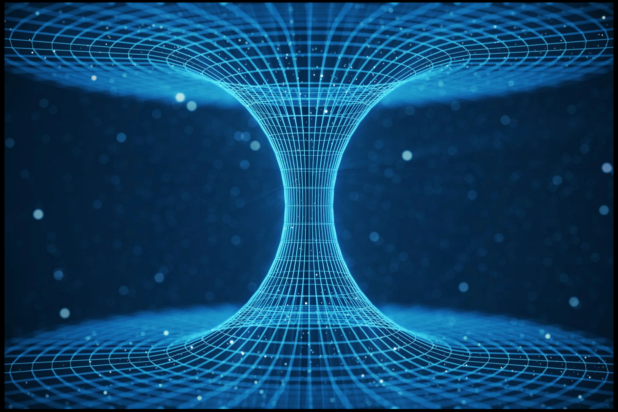


Wormholes cont.

Can’t exist w out being propped open

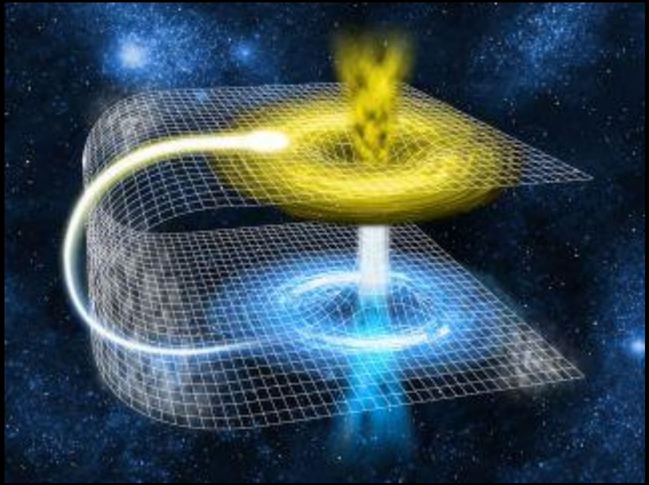
- Einstein–Rosen bridge
- White holes versus black holes
- Time travel?





Time travel

- If wormholes are possible, time travel is too! Only backwards tho
- Faster than the speed of light! Yes and no
- Grandfather paradox bootstrap paradox

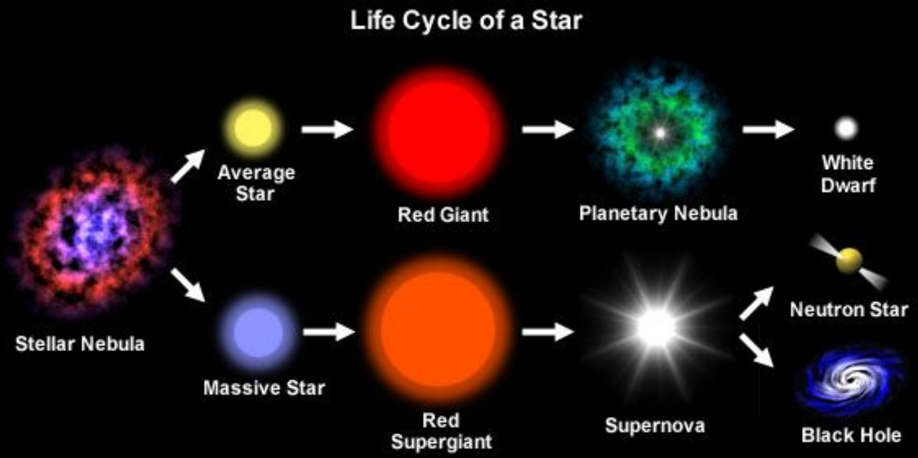


Questions?

Black Holes

Black Hole Formation

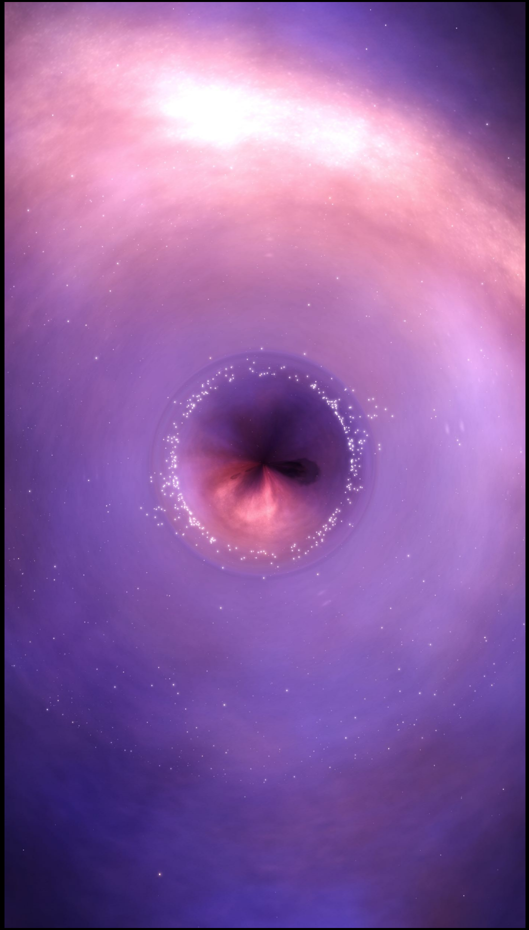
- When a star runs out of fuel, its core begins to gravitationally collapse under the weight of the heavier elements (iron)
- NO FORCE able to prevent the core collapse of stars with cores that weigh > 3 solar masses.
- all of the mass of the star to shrink and condense to a single point, known as a *singularity*



Singularity

- Singularity = a point with 0 radius that has infinite density (and infinite gravity at the singularity)
- Surrounded by a region of space where the speed of light isn't fast enough to prevent gravity from pulling objects into the singularity
- This region has a radius known as the *Schwarzchild* radius

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



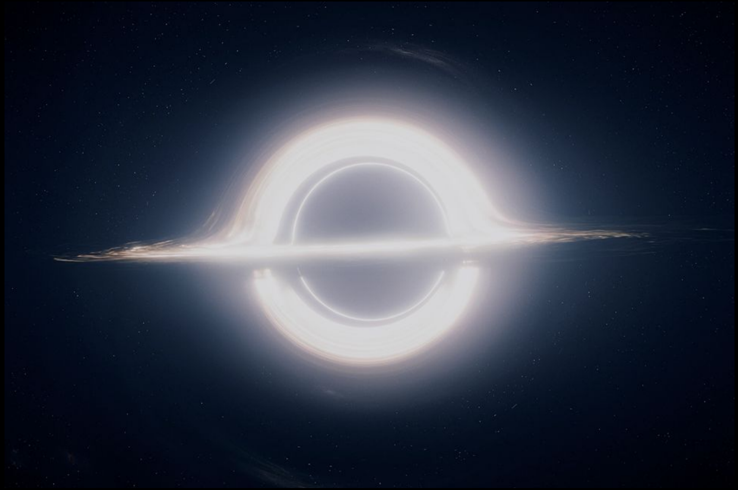
Schwarzchild Radius

$$r = 2GM/c^2$$

- The Schwarzchild radius= radius where the speed of light is < the escape velocity of the object
  - It can be determined by rearranging the escape velocity equation to solve for radius, and replacing escape velocity with the fastest possible velocity, which is the speed of light.
- This is known as the event horizon, where not even light can escape the gravitational pull of the black hole (when they aren't rotating)
- So how do we know they exist?

Existence and Detection of Black Holes

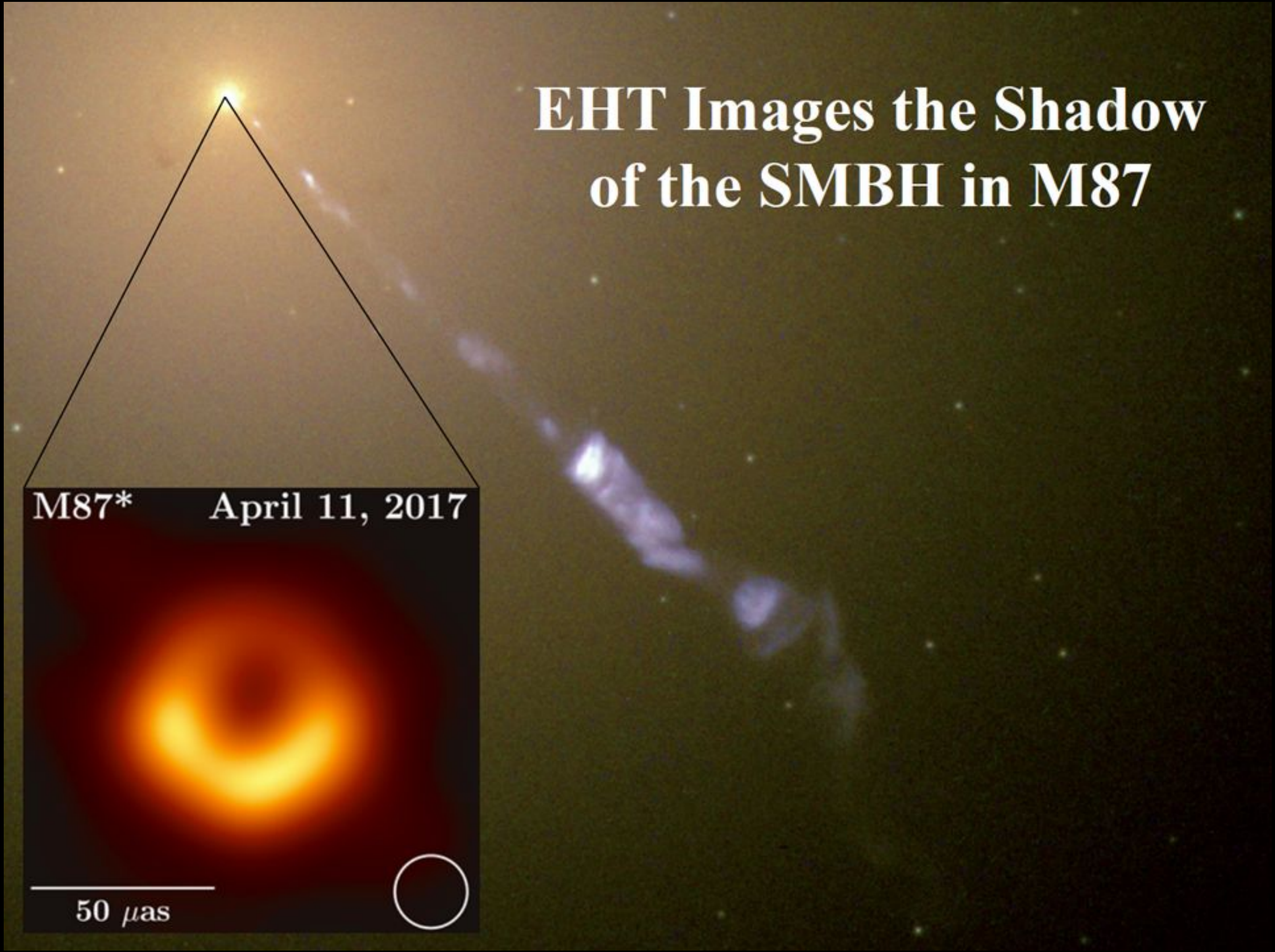
- Matter is continuously falling into a black hole, and the energy of this matter is radiated away in the form of X-Rays
  - The accretion disk of a black hole is composed of matter that is being pulled into the event horizon
  - 100 days to render every second black holes to be on screen



Existence and Detection of Black Holes

- The strongest evidence for black holes is the existence of gravitational waves detected by LIGO

EHT Images the Shadow of the SMBH in M87



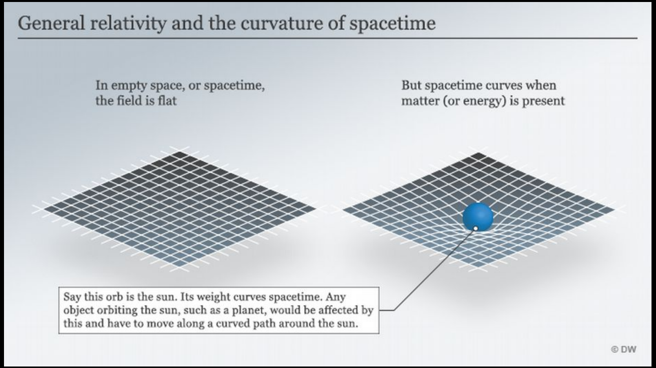
Lifetime of a Black Hole

- It seems as though a Black Hole is permanent, but Stephen Hawking theorized that black holes not continuously consuming matter will actually evaporate.
- This theory has been called Hawking Radiation

Questions?

Hawking Radiation - QFT Background

- Spacetime is flat
- Quantum Field Theory tells us space is filled with intersecting quantum fields with vibrational modes corresponding to their direction in time
- QFT states that these waves have quantized energy that can be interpreted as "virtual particles"
- Quantum fields cancel out in vacuum, modes interfering destructively
    - The annihilation of virtual particle-antiparticle pairs



General relativity and the curvature of spacetime

In empty space, or spacetime, the field is flat

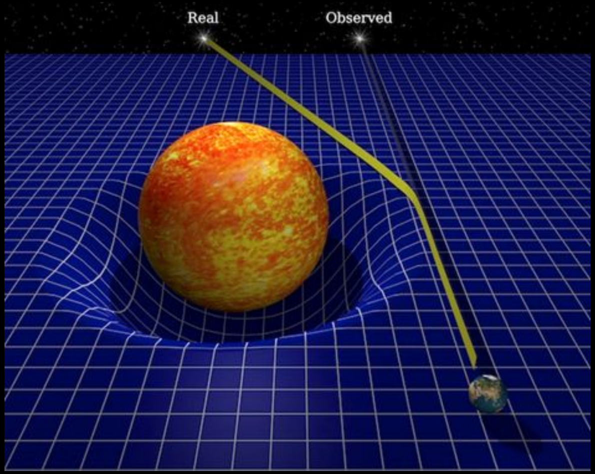
But spacetime curves when matter (or energy) is present

Say this orb is the sun. Its weight curves spacetime. Any object orbiting the sun, such as a planet, would be affected by this and have to move along a curved path around the sun.

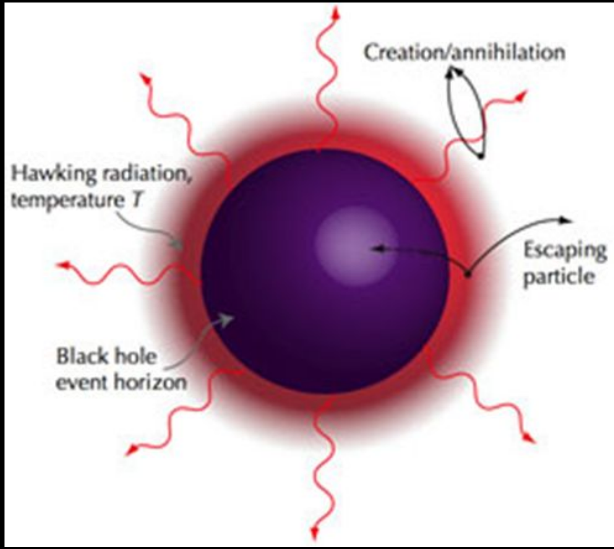
https://www.dw.com/en/10-or-so-things-you-should-know-about-albert-einstein-and-his-theories-of-relativity/a-18875068

Hawking Radiation - QF Disruption

- Massive objects exert a gravitational field that can be thought of as curvature in spacetime
    - follows from general relativity, and contributes to the “gravitational lensing” of light around massive object
- Black Holes cause spacetime curvature dependent on their mass
- Quantum fields crossing this curved region in space for a Black Hole will be disrupted at the event horizon, and unable to cancel out like they do in perfect vacuum



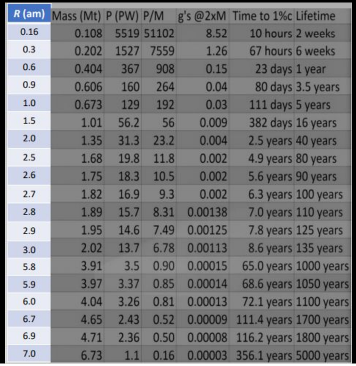
Hawking Radiation - Particle/Antiparticle Annihilation



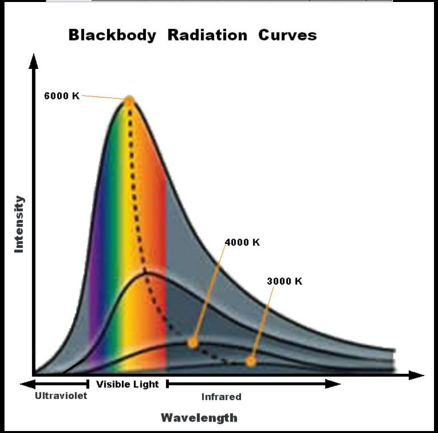
- The virtual particle-antiparticle annihilation that defines “normal” vacuum is disrupted at the event horizon, and the modes of the quantum field will be scattered
    - Since these modes/particles are lost to the black hole, the remaining “scattered” modes must annihilate outside the surface of the event horizon to maintain vacuum
- The energy produced from this annihilation is called Hawking Radiation, and comes at the expense of the black hole’s mass/energy

Hawking Radiation - BH Size vs. Energy

- Hawking Radiation is inversely proportional to Black Hole size
    - Larger Black Holes disrupt longer wavelengths, which have lower energy
- The energy released by Hawking radiation would have the same frequency distribution spectrum as a black body, or an object at high temperature
    - The larger the black hole, the longer its lifetime, and the slower its evaporation
    - The evaporation accelerates over time, smaller black holes radiate more energy faster



R (am)	Mass (Mt)	P (PW)	P/M	g's @2xM	Time to 1%c	Lifetime
0.16	0.108	5519	51102	8.52	10 hours	2 weeks
0.3	0.202	1527	7559	1.26	67 hours	6 weeks
0.6	0.404	367	908	0.15	23 days	1 year
0.9	0.606	160	264	0.04	80 days	3.5 years
1.0	0.673	129	192	0.03	111 days	5 years
1.5	1.01	56.2	56	0.009	382 days	16 years
2.0	1.35	31.3	23.2	0.004	2.5 years	40 years
2.5	1.68	19.8	11.8	0.002	4.9 years	80 years
2.6	1.75	18.3	10.5	0.002	5.6 years	90 years
2.7	1.82	16.9	9.3	0.002	6.3 years	100 years
2.8	1.89	15.7	8.31	0.00138	7.0 years	110 years
2.9	1.95	14.6	7.49	0.00125	7.8 years	125 years
3.0	2.02	13.7	6.78	0.00113	8.6 years	135 years
5.8	3.91	3.5	0.90	0.00015	65.0 years	1000 years
5.9	3.97	3.37	0.85	0.00014	68.6 years	1050 years
6.0	4.04	3.26	0.81	0.00013	72.1 years	1100 years
6.7	4.65	2.43	0.52	0.00009	111.4 years	1700 years
6.9	4.71	2.36	0.50	0.00008	116.2 years	1800 years
7.0	6.73	1.1	0.16	0.00003	356.1 years	5000 years



Blackbody Radiation Curves

Theoretical power generation of antiproton annihilation caused by micro black holes and its potential applications to propulsion engineering

Max Adang

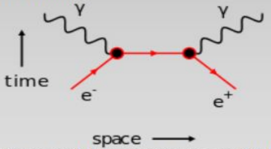
Abstract

The prospect of using antiproton annihilation—the annihilation of a proton and its antiparticle pair—as a power source is a concept that holds promise, but is complicated by quantum effects on the power generating system. Hawking radiation and micro black holes play an integral role in this system as the source of the antiproton and proton pairs. However, these concepts are heavily dependent on quantum theory, the physics of which becomes theoretical at small enough sizes.

A synthesis of the concepts that would allow antiproton annihilation to occur from Hawking Radiation generated from a micro black hole with an emphasis on the relativistic attributes of the system and its components is what this poster is focused on. This synthesis will be then used to address whether harnessing the power of a micro black hole would allow for propulsion at near relativistic speeds.

Antiparticle Annihilation

- When an electron (e^-) and positron (e^+) collide, they produce two gamma ray photons with the energy of the positron and electron distributed between them



V

- Electron and positron each have a rest energy of 8.187122e-14 Joules
- Provided $KE_{antiparticle} << 8.187122e\text{-}14$ J the rest energy will appear as the photon energy of the radiated gamma rays

Hawking Radiation

- Black holes are defined as regions of spacetime where matter and energy can enter, but nothing can leave
- By performing calculations under the assumption that the observer is very far away from the black hole, gravity and its currently unknown effects on quantum mechanics, quantum field theory in curved spacetime (around a massive body like a BH) quantum effects show that black holes should emit black body radiation
- This temperature can be calculated as:

$$T = \frac{hc}{4\pi kR}$$

- This blackbody electromagnetic radiation is explained as the effect of antiparticle pairs colliding at the event horizon, radiating a pair of subatomic particles, one into the BH, and one outward
- Due to conservation of energy, one of these subatomic particles has negative energy with respect to the observer, thus the black hole system emits blackbody radiation and loses mass, and energy is conserved.

Micro-Black Holes' Power, Life Expectancy, and Size

- The power that a BH would emit through Hawking Radiation has been shown as:

$$P = \frac{af(T)}{R^2}$$

- *R* is the effective radius of the BH and is directly proportional to BH mass
- f(*T*) is a function that describes the energy contribution of possible emitted particles from a BH
- *a* is a constant calculated to have a value of 1.06×10^{-20}Wxm^2
- Because of this small value, the blackbody radiation BHs detected in nature is almost unnoticeable
- Thus, micro black holes must be considered for creating a theoretical BH powered starship

- Due to the loss of mass predicted by Hawking Radiation, BHs will decrease in size as energy is emitted
- This "Lifespan" (L) can be described through the below equation:

$$L = \int_0^{R_0} \frac{c^2R^2}{2Gaf(t)}\,dR$$

- Because small black holes radiate power at a substantially greater rate, a balancing act must be struck between BH size and the amount of power emitted

- The below chart indicates the mass of a BH, its power output in PetaWatts, its power to mass ratio, and how many g's of acceleration would result from this power output, and the time it would take to accelerate to 1% the speed of light

R (am)	Mass (Mt)	P (PW)	P/M	g's @2xM	Time to 1%c	Lifetime
0.16	0.108	5519	51102	8.52	10 hours	2 weeks
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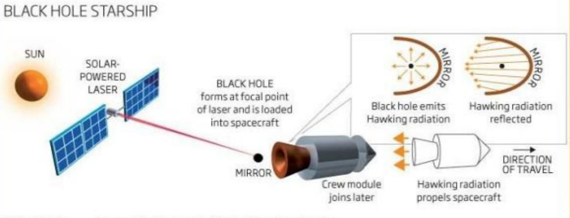
7.0	6.73	1.1	0.16	0.00003	356.1 years	5000 years

VII

Applications to Propulsion Engineering

- Theoretical interstellar starships would be incredibly massive, on the order of hundreds to thousands of tons, excluding the BH
- A BH of several attometers is at the upper limit of the range of BHs that would provide enough energy for propulsion while still being small enough to allow for the capture and use of the emitted energy to propel the ship



● TOP SPEED: Approaching the speed of light within a few decades
● WEIGHT: 1 million tonnes (including black hole)
● ADVANTAGES: Technologies better developed
● DISADVANTAGES: Immense long-term effort required

VI

- Above is a diagram representing a theoretical BH Starship
- The key components of such a vehicle would be the means of containing a BH that emits such high levels of energy and heat

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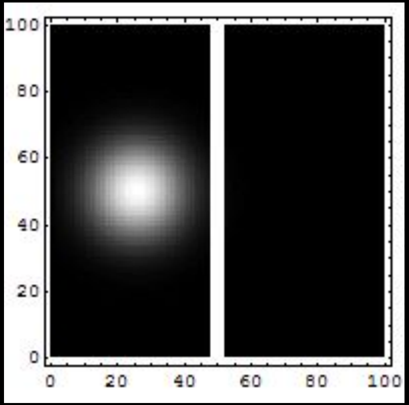
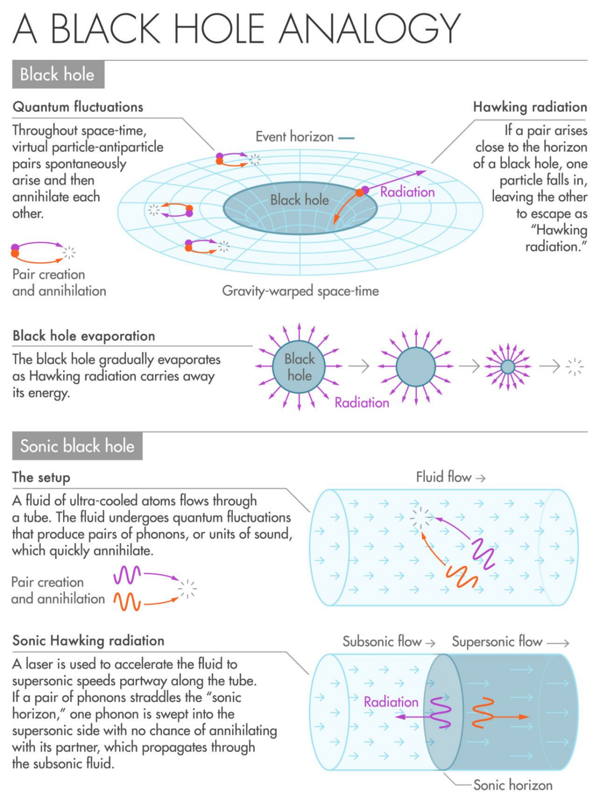
Hawking Radiation - Realistic Theory?

- This radiation is *not localized* however, and hasn't been observed yet
- Source of Hawking Radiation is also controversial
  - Scientists have formed theories that arrive at similar results with a different source of the radiation, such as quantum tunneling.



Hawking Radiation - Realistic Theory?

- It is experimentally unfeasible to create small black holes in a lab that would radiate extremely brightly and be easy to detect
- However, some experiments with sound wave event horizons have shown *similar* optical analogues to this effect, characterized as phonons, but it is unknown if this is the same effect



A BLACK HOLE ANALOGY

Black hole

Quantum fluctuations

Throughout space-time, virtual particle-antiparticle pairs spontaneously arise and then annihilate each other.

Hawking radiation

If a pair arises close to the horizon of a black hole, one particle falls in, leaving the other to escape as "Hawking radiation."

Black hole evaporation

The black hole gradually evaporates as Hawking radiation carries away its energy.

Sonic black hole

The setup

A fluid of ultra-cooled atoms flows through a tube. The fluid undergoes quantum fluctuations that produce pairs of phonons, or units of sound, which quickly annihilate.

Sonic Hawking radiation

A laser is used to accelerate the fluid to supersonic speeds partway along the tube. If a pair of phonons straddles the "sonic horizon," one phonon is swept into the the supersonic side with no chance of annihilating with its partner, which propagates through the subsonic fluid.

https://www.quantamagazine.org/philosophers-debate-new-sonic-black-hole-discovery-20190625/