Title: General Relativity 3 - Who's Who in the Story of Black Holes

Date: Aug 01, 2006 10:45 AM

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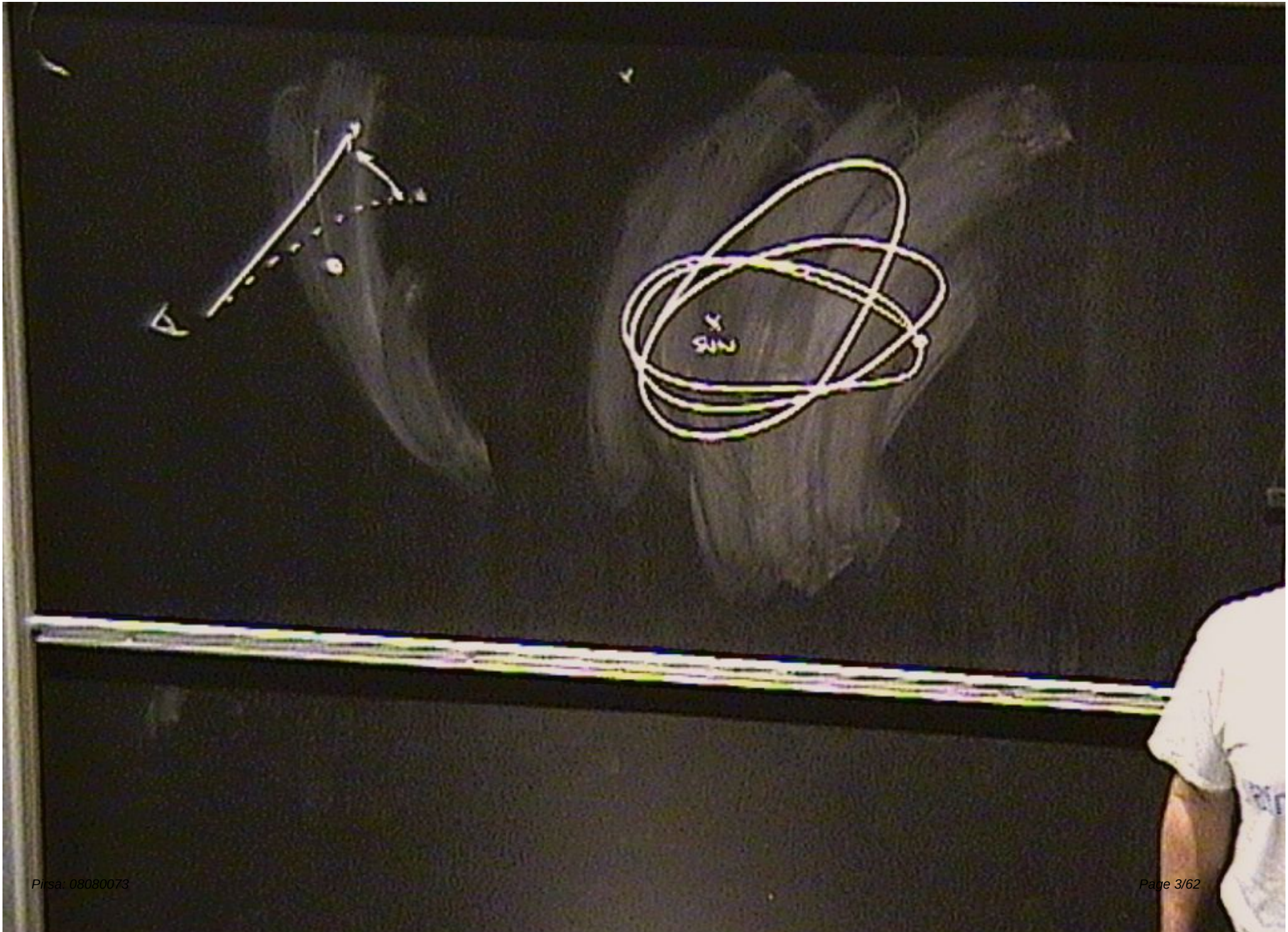
Abstract: An introduction to a few of the major scientists who applied Einstein's ideas to better understand the life cycle of various stars.
Learning Outcomes:
â€¢ How Subrahmanyan Chandrasekhar resolved the paradox of the white dwarf star, and how Walter Baade and Fritz Zwicky described the dynamics of neutron stars.
â€¢ Yakov Zel'dovich develops the nuclear chain reaction that is the engine that keeps stars burning.
â€¢ The roles Robert J. Oppenheimer , John Wheeler, and Roger Penrose played in moving the concept of a black hole from a object of pure theory to a physical object in the universe.

1919 Verification

The final proof: the small red line shows how far the position of the star has been shifted by the Sun's gravity.



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General Relativity Test (1976)

65
Excess Time Delay, Microseconds

Distance > 37 km

General Relativity Test (1976)

79
Excess Time Delay, Microseconds

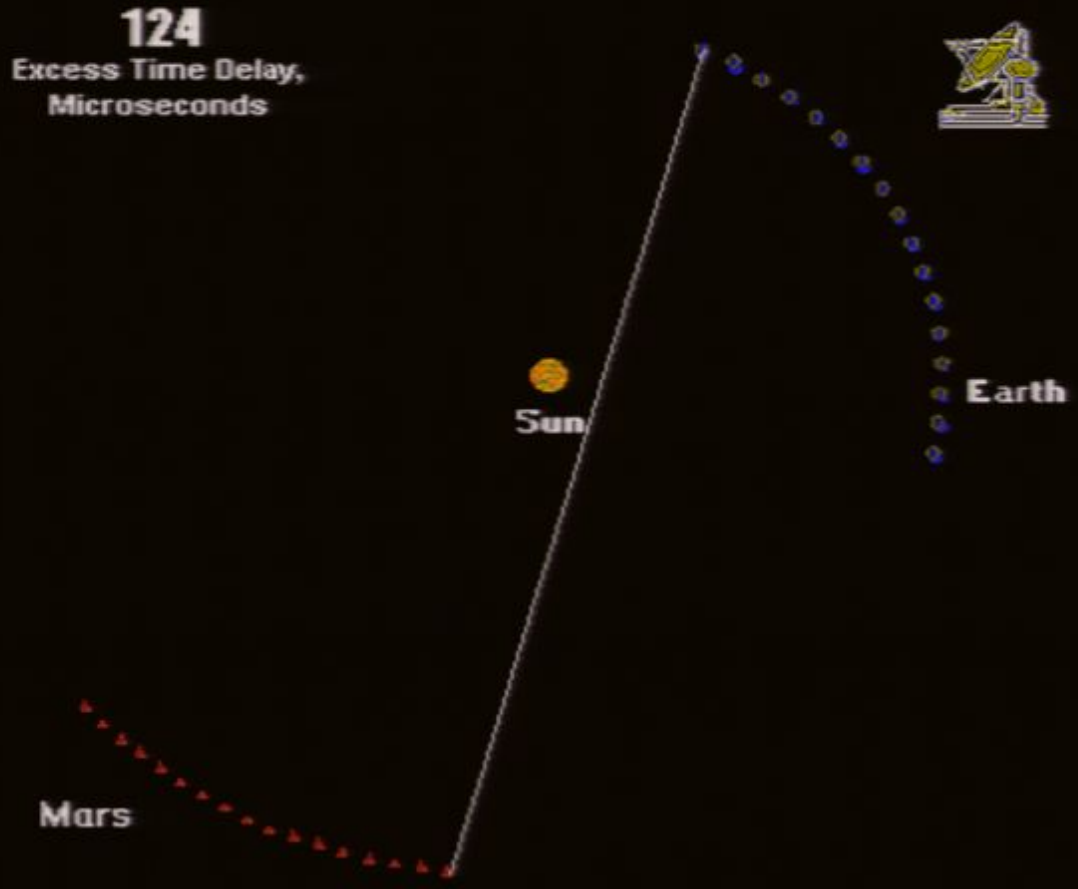
Distance > 37 km

General Relativity Test (1976)

96
Excess Time Delay,
Microseconds

Distance > 37 km

General Relativity Test (1976)



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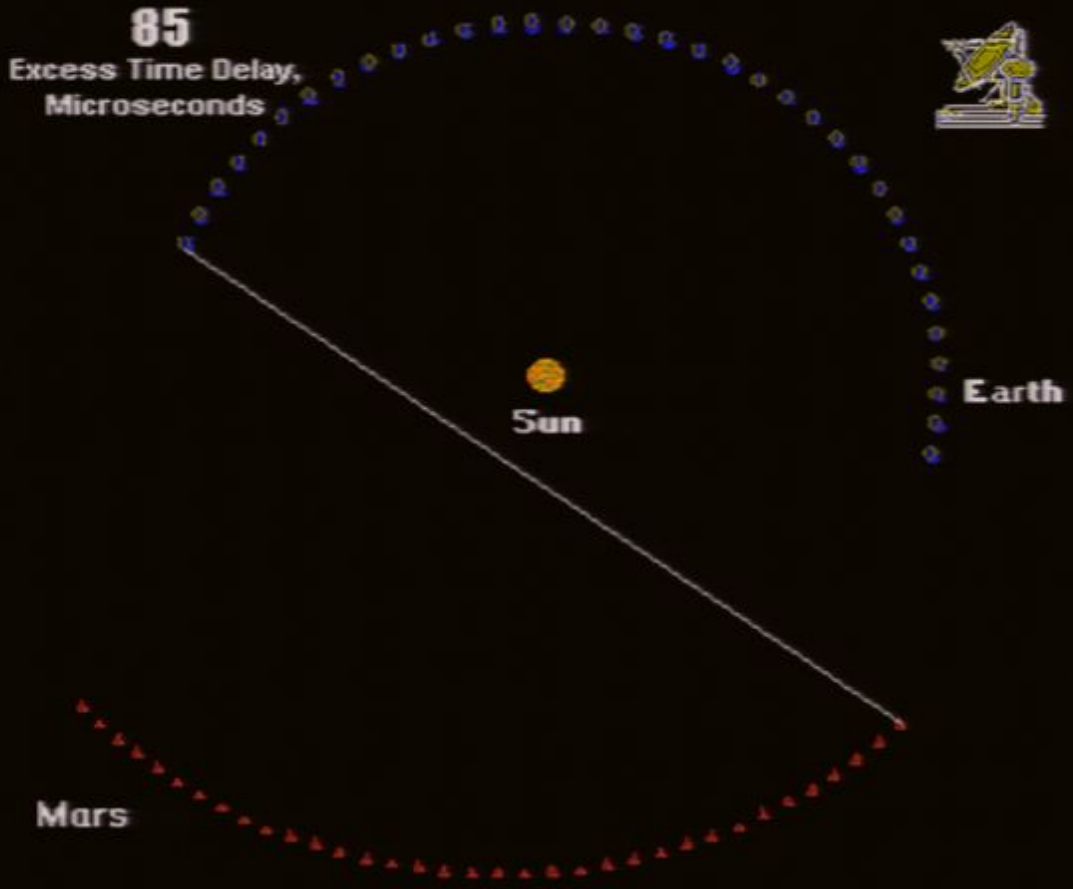

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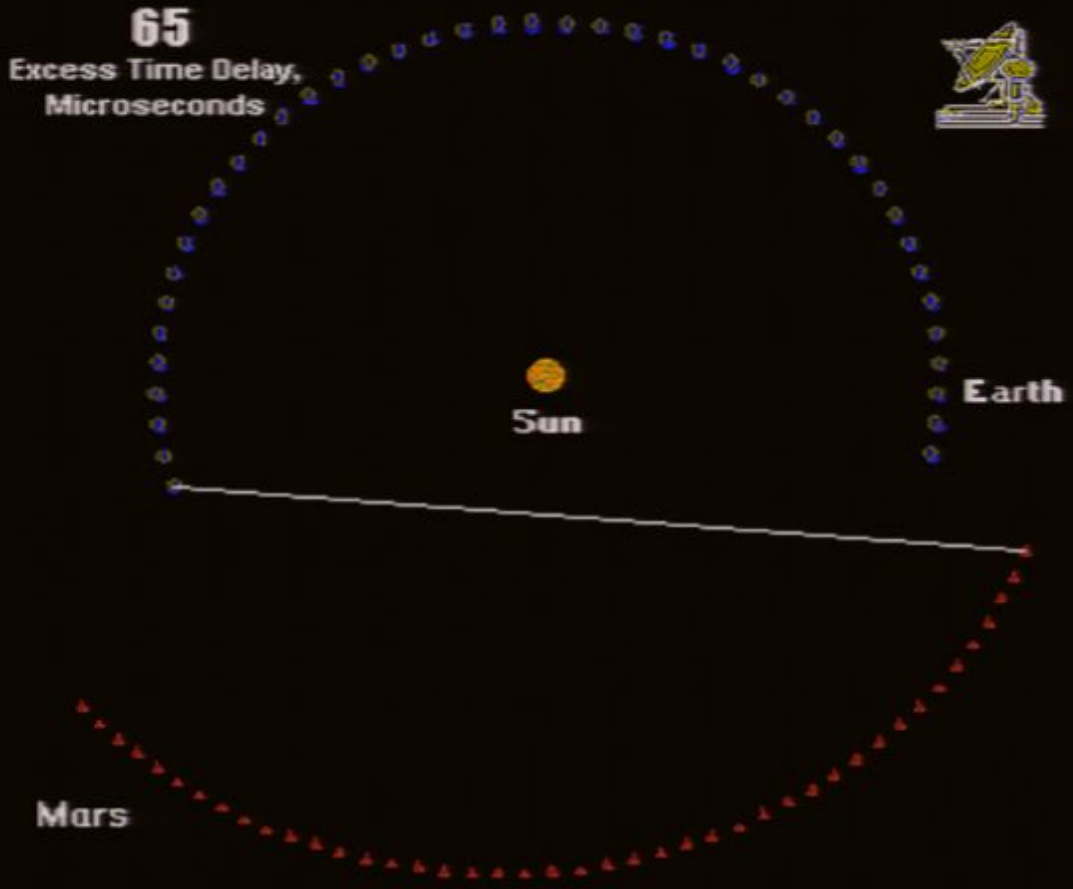

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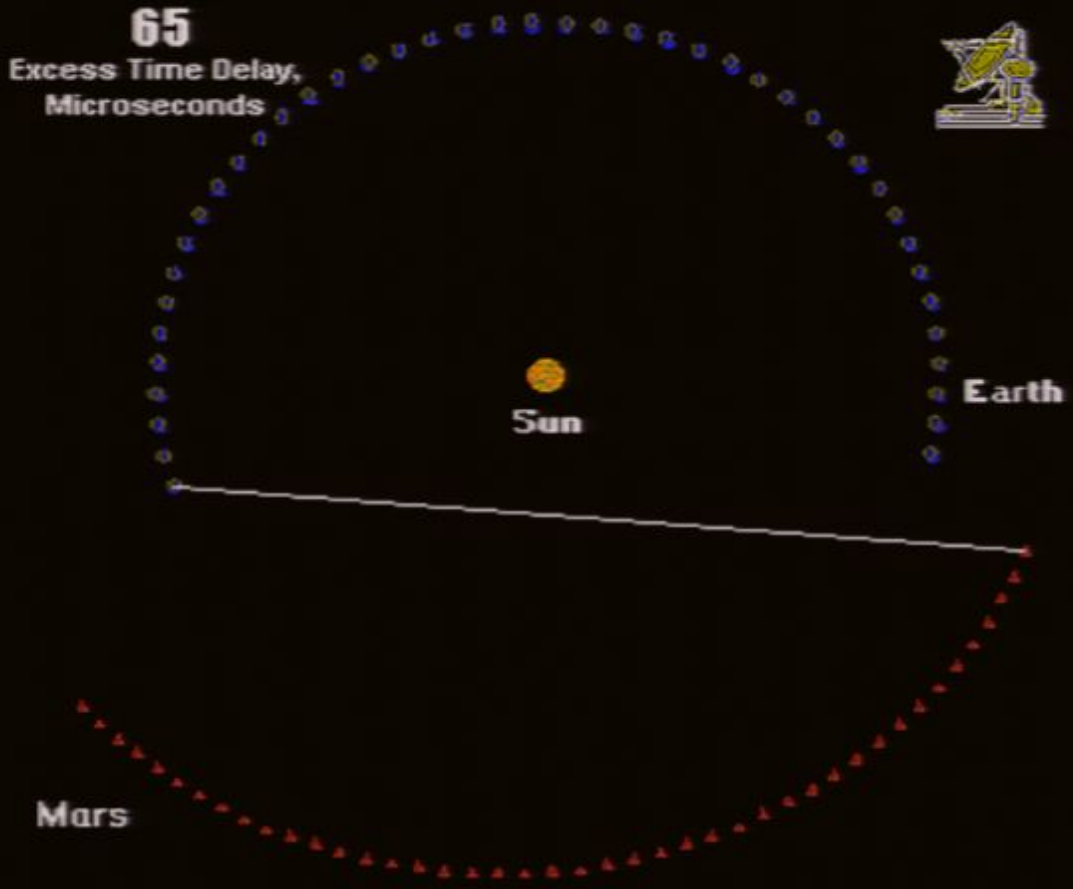

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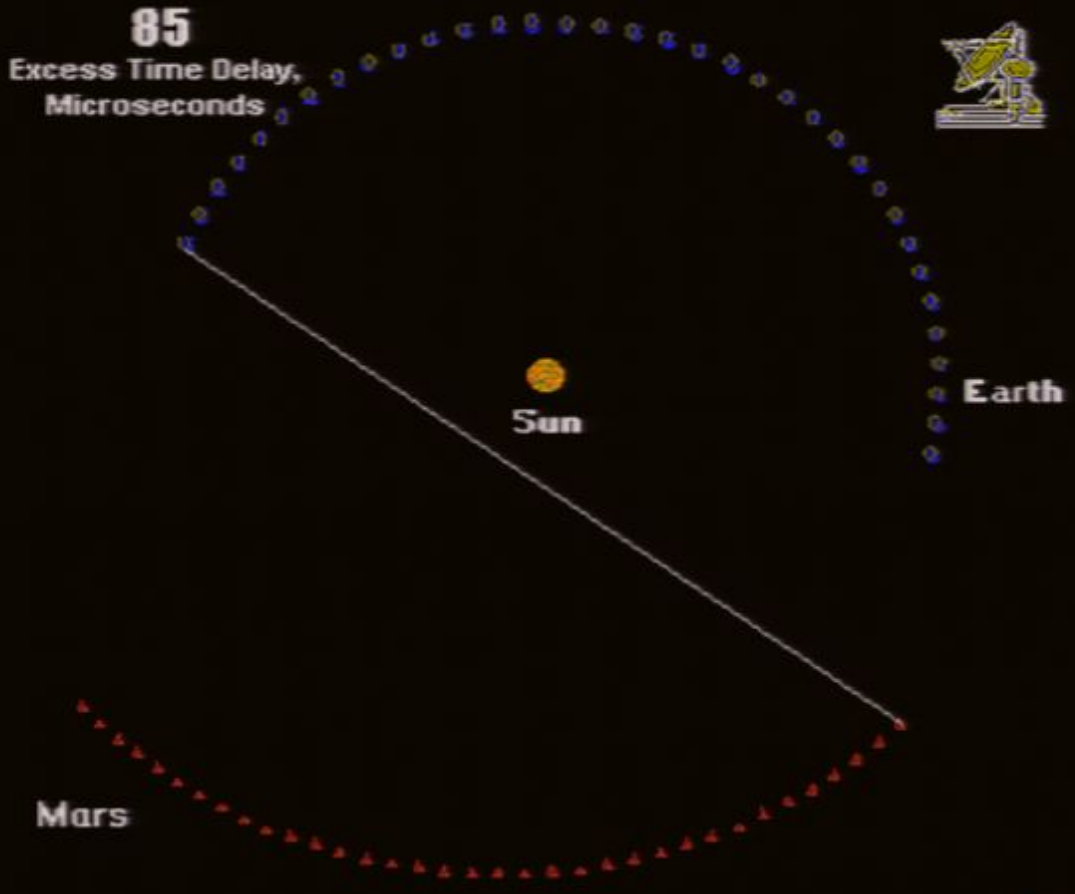

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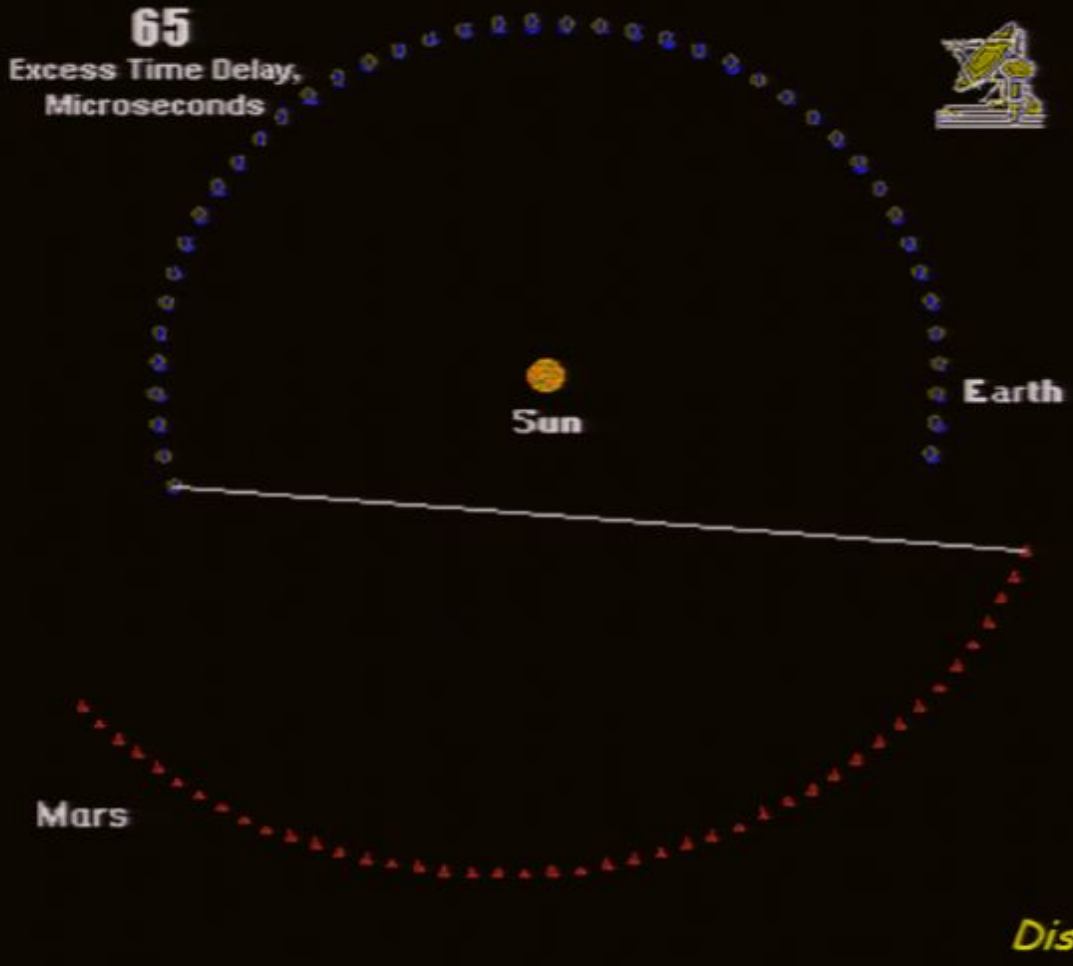

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Karl Schwarzschild (1876-1916)

Calculation of Schwarzschild radius

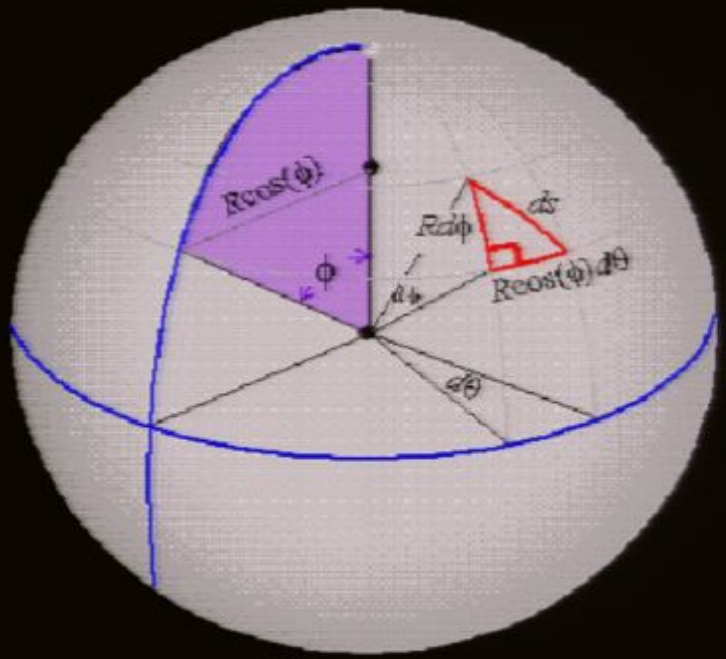
- ***In 1916 Karl Schwarzschild discovers a solution of the Einstein field equation, which describes a nonspinning, uncharged spherical body.***
- ***Did this when serving in the German Army on the Russion front of World War I***
- ***Only required a few days to solve equation and describe spacetime curvature.***
- ***Einstein presented solution on behalf of Shwarzschild to the Academy of Sciences.***
- ***Schwarzchild was killed 4 months later.***

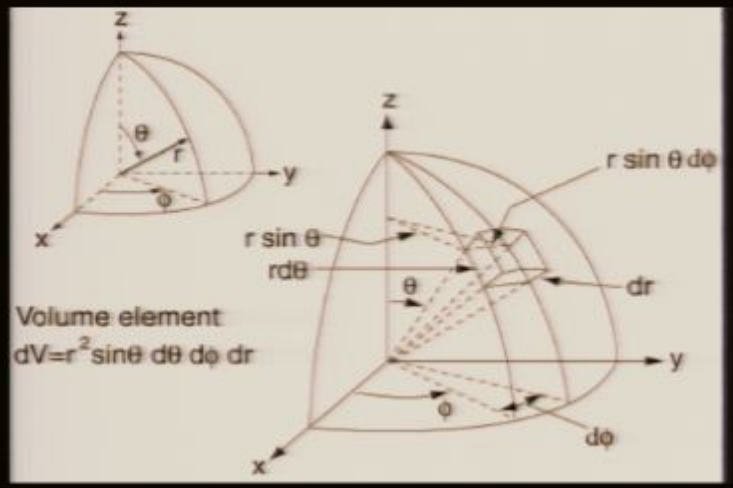
The Schwarzschild Radius

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

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

r, θ, ϕ *are the polar coordinates*





Schwarzschild Metric

Schwarzschild Metric

$\tau^2 = t^2 - s^2$ ⟸ *Timelike Spacetime Metric*

Schwarzschild Metric

$$d\tau^2 = dt^2 - dx^2 - dy^2$$ ⟸ *2D flat Spacetime in Cartesian*

Is the square of the wristwatch time between two events as marked by x, y, t

Schwarzschild Metric

$$(d\tau)^2 = (dt)^2 - (dr)^2 - (r d\phi)^2$$ ⟸ *2D flat Spacetime in Polar*

Schwarzschild Metric

$$d\tau^2 = \left(1 - \frac{r_s}{r}\right) c^2 dt^2 - \frac{dr^2}{\left(1 - \frac{r_s}{r}\right)} - r^2 d\phi^2$$

⟸ *Curvature added, now Schwarzschild timelike Spacetime Metric*

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

Schwarzschild Metric

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

The metric describes the shape of spacetime outside of matter. Once you hit matter, be it some gas, a star, a planet, or a rock, this metric no longer applies.

You can see that, if r = 2M, dt term would be zero. That is to say that at the event horizon there would be no change in time. Makes sense; you can look at the event horizon as being the place where time "stops." The dr factor deals with how close to something you are. You'll notice that it "blows up" when r = 2M.

Schwarzschild Metric

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⟸ *Spacelike Form*

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Timelike Form

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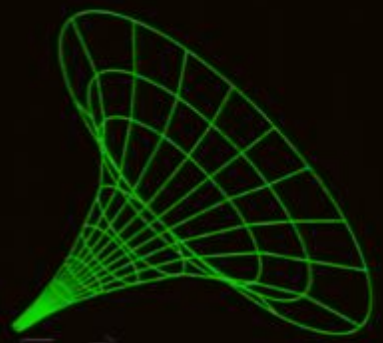
Schwarzchild radii for different objects

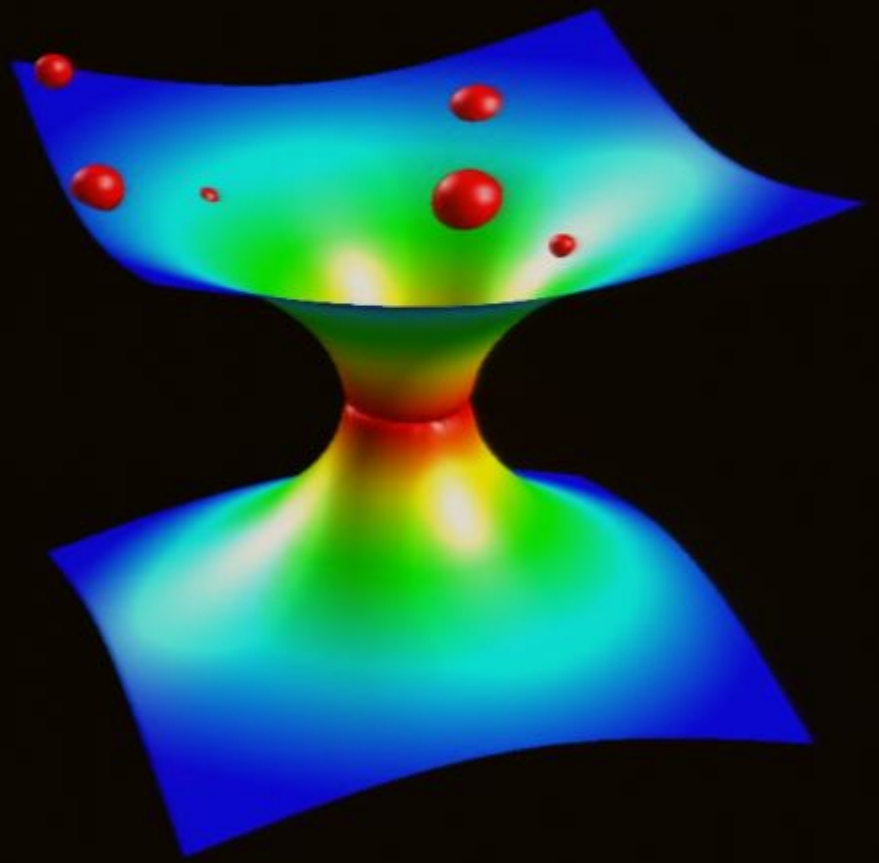
Object	Mass	R_S
Atom	10^{-26} kg	10^{-51} cm
Human Being	70 kg	10^{-23} cm
Earth	6.0×10^{24} kg	0.89 cm
Sun	2.0×10^{30} kg	3.0 km
Galaxy	$10^{11}\ M_S$	10^{-2} l.y.
Universe (if closed)	$10^{23}\ M_S$	10^{10} l.y.

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

Embedding Diagram

Emphasis on Spatial rather than temporal interpretations

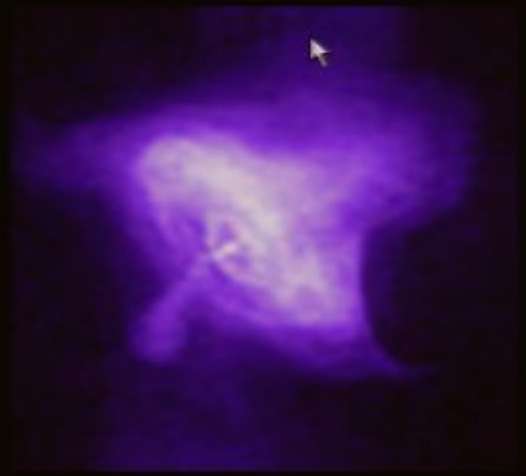




Sir Arthur Eddington

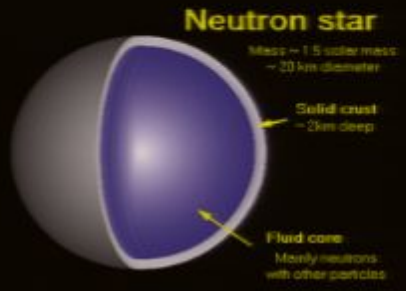
- 1926 Book – The internal constitution of the Stars
- Early proponent of Einstein's Theory of General Relativity (next to Einstein best expert on General Relativity)
- Poses the mystery of white dwarfs and attacks the reality of black holes predicted by Schwarzschild.
- Believed White Dwarf was last state in a stars life (rock Star)
- Paradox with White Dwarf

Subrahmanyan Chandrasekhar

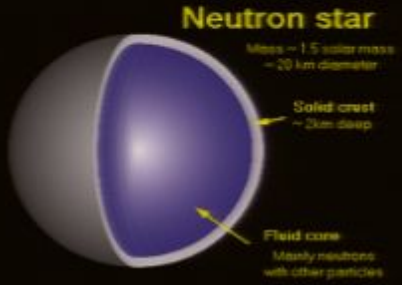


- *Idolized Eddington, resolved Eddington;s paradox*
- *In 1930 he showed that there is a maximum mass for White Dwarfs*
- *1935 Eddington attacks his work. "Chandra" left the field of Blackholes until 1970's*
- *Nobel Prize in Physics 1983*

Walter Baade and Fritz Zwicky



- *Identifies the process of a supernovae, predicted that this collapse strips the atoms of their electrons, packing the nuclei together as a neutron star .*
- *Neutron stars would not be verified observably until 1968.*
- *Identified the galaxies associated with cosmic radio sources.*
- *Still something was missing that took a star from fusion to supernovae.*

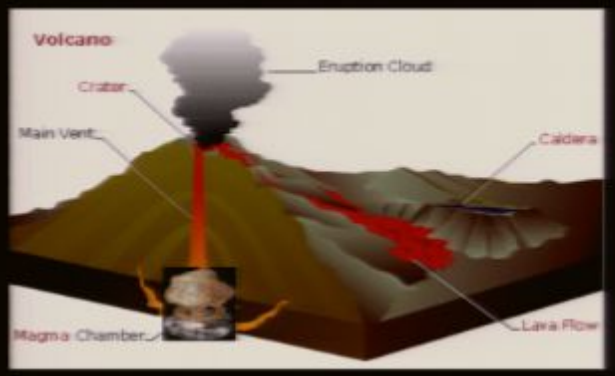


Robert J. Oppenheimer

- *Showed that there is a maximum mass for a neutron star from 1.5 to about 3 solar masses (1938).*
- *In a highly idealized calculation, showed that an imploding star forms a black hole.*
- *Led the American atomic bomb project.*
- *Which provided the opportunity to experimentally verify and test theories (too expensive for the universities) and the development of the atomic bombs which mimic the power source for the sun to come up with the mathematics and understanding of stellar mechanics*
- *Major battle with Wheeler.*

Yakov Zel'dovich

- *Soviet counterpart to Oppenheimer.*
- *Developed the theory of nuclear chain reactions. (1939)*
- *Lead theorist on USSR atomic bomb (1945)*
- *Creates black hole research team (1962).*
- *Super massive black holes power Quasars (1960's).*



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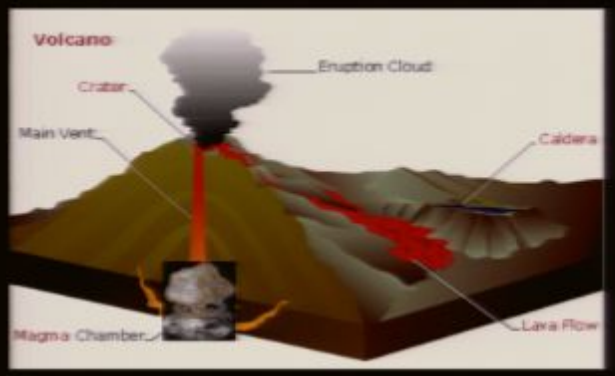

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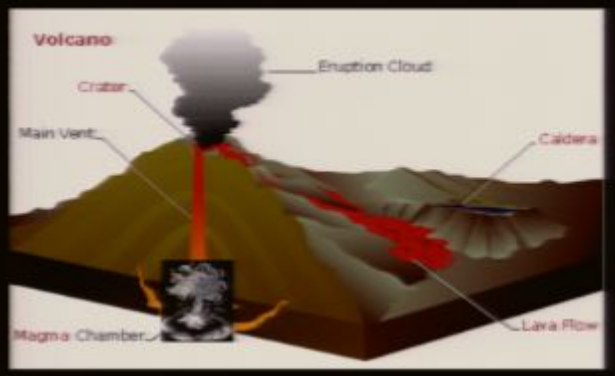

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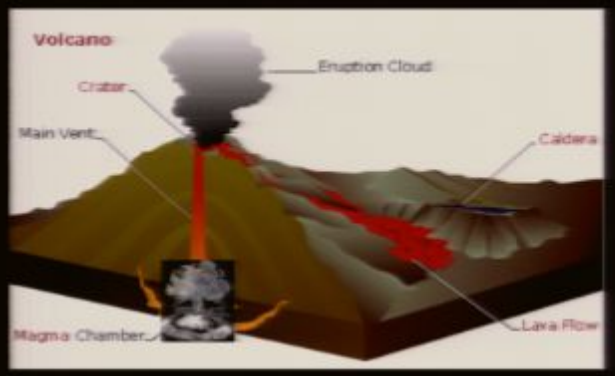

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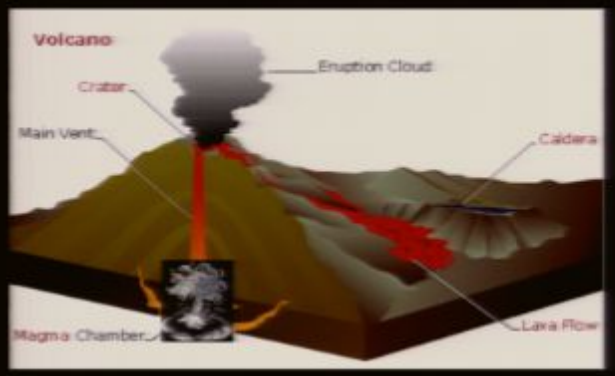

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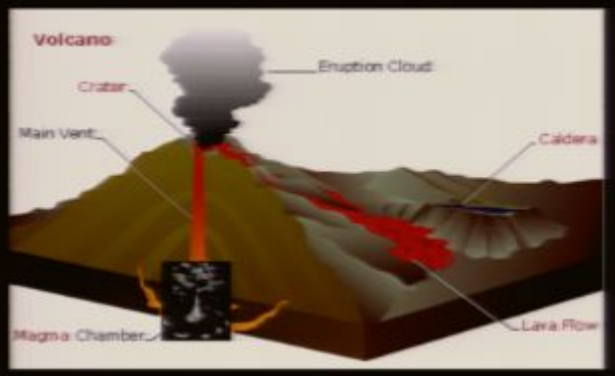

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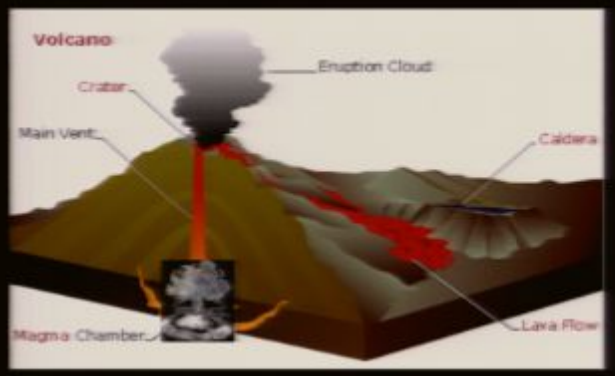

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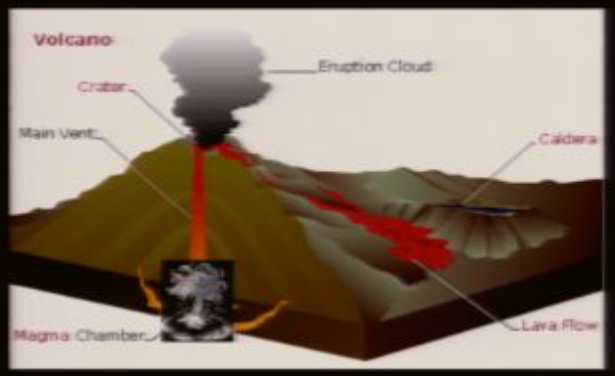

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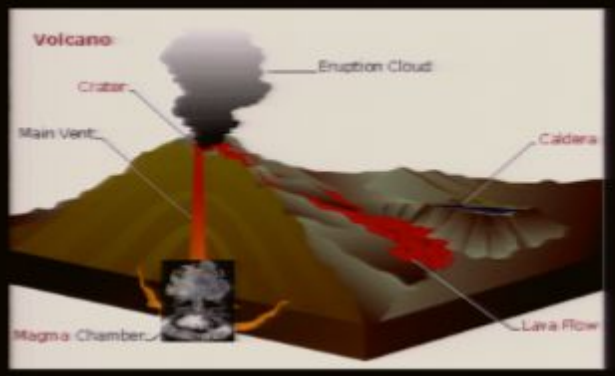

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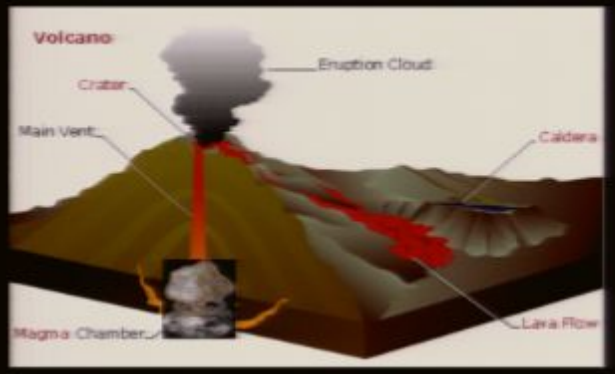

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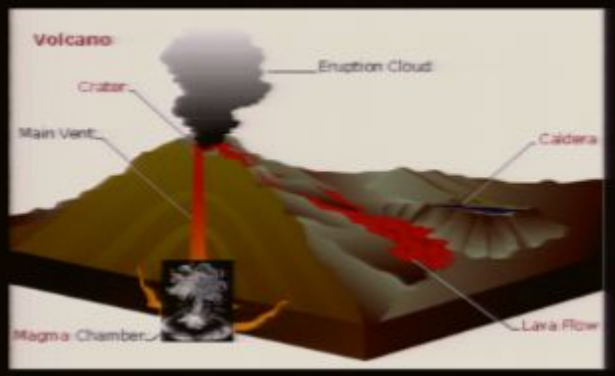

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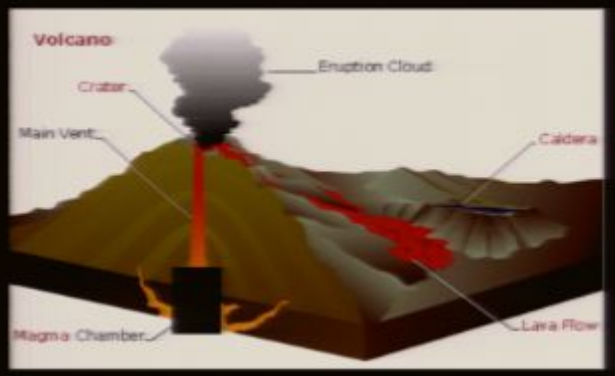

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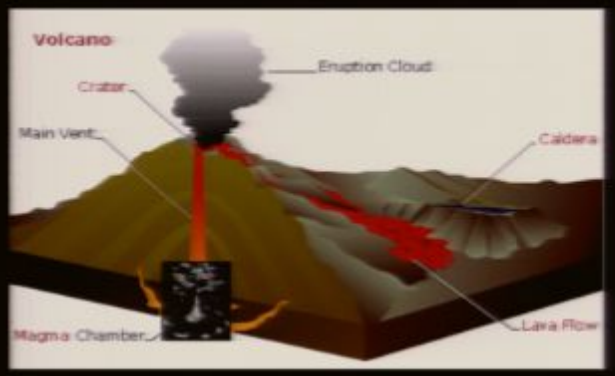

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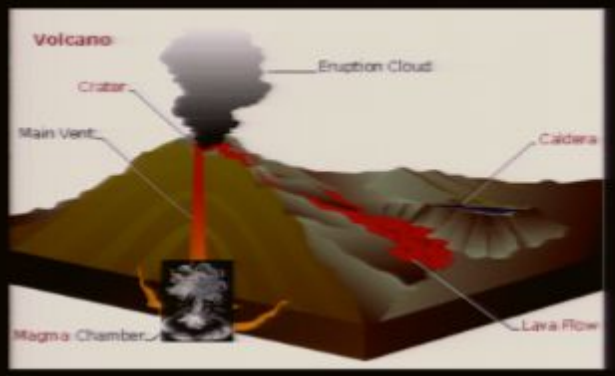

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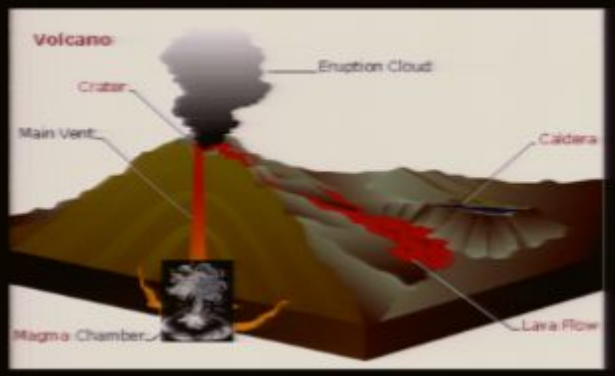
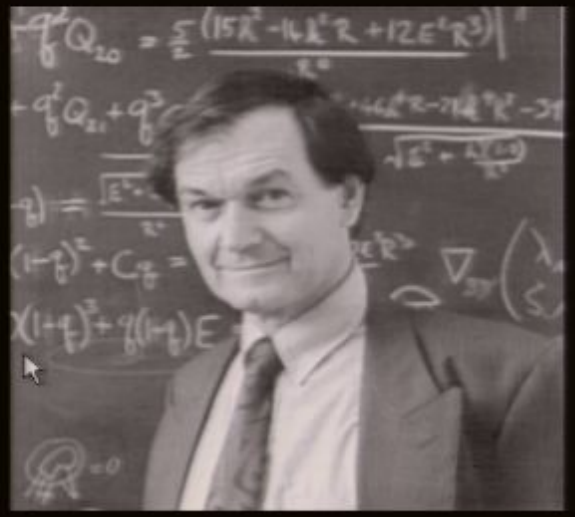


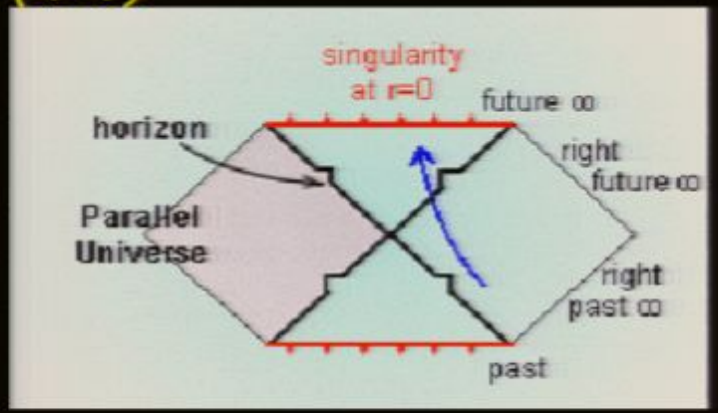
John Wheeler

- *With Bohr develops the theory of nuclear fission.*
- *Completes a catalog cold, dead stars firming up evidence of destiny of dead stars. (1957)*
- *Major battle with Oppenheimer about existence of black holes. (1957)*
- *Retracted argument and became the leading proponent of black hole. (1960)*
- *Coined the phrase "Black Hole" (1967).*
- *Coined the phrase "a Black Hole has no hair" (1968).*

Roger Penrose



- *Speculated black holes loose their hair by radiating it away.*
- *Discovered that spinning black holes store energy in space outside their horizon (1969).*
- *Discovered surface area of black holes must increase.*
- *Proved that black holes must have singularities at their core (1964).*
- *Proposed cosmic censorship conjecture (1969).*



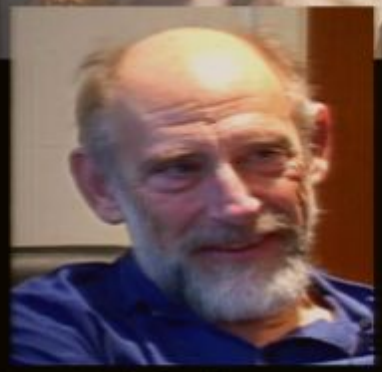
Topology

The Blackhole Stars Today

Hawking

Bekenstein

Thorne



Susskind

Werner Israel

Robert Wald