

Nobel Prize in Physics 2020

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The Nobel Prize in Physics 2020



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Fergus Kennedy

Roger Penrose

Prize share: 1/2



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Bernhard Ludewig

Reinhard Genzel

Prize share: 1/4



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Annette Buhl

Andrea Ghez

Prize share: 1/4

The Nobel Prize in Physics 2020 was divided, one half awarded to Roger Penrose "for the discovery that black hole formation is a robust prediction of the general theory of relativity", the other half jointly to Reinhard Genzel and Andrea Ghez "for the discovery of a supermassive compact object at the centre of our galaxy."

- ▶ Albert Einstein 1915, general relativity

$$R_{\alpha\beta} - \frac{1}{2}Rg_{\alpha\beta} = 8\pi T_{\alpha\beta}$$

- ▶ Karl Schwarzschild 1916, the Schwarzschild spacetime

$$g = -\left(1 - \frac{2m}{r}\right)dt^2 + \left(1 - \frac{2m}{r}\right)^{-1}dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2)$$

- ▶ white dwarfs and the Chandrasekhar mass

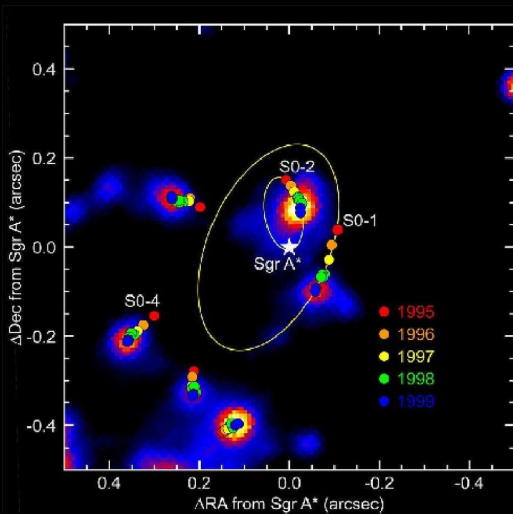
I think there should be a law of Nature to prevent a star from behaving in this absurd way!

Eddington, 1935

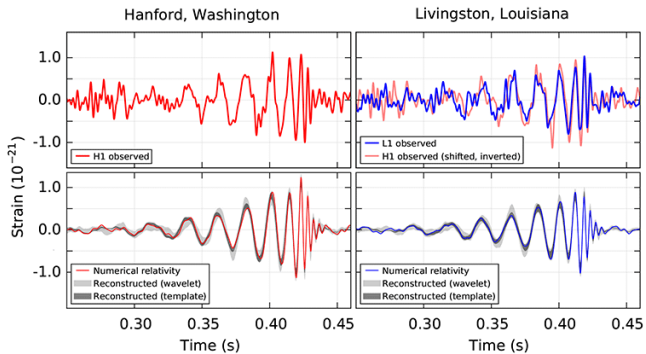
- ▶ Einstein, 1939, May 10

The essential result of this investigation is a clear understanding as to why “Schwarzschild singularities” do not exist in physical reality.

2000



2015, September 14, 9:50:45 UTC



2019



- ▶ Oppenheimer and Snyder, 1939, July 10

When all thermonuclear sources of energy are exhausted a sufficiently heavy star will collapse. Unless fission due to rotation, the radiation of mass, or the blowing off of mass by radiation, reduce the star's mass to the order of that of the sun, this contraction will continue indefinitely.

- ▶ the Schwarzschild solution as a final stage of the stellar evolution
- ▶ but: spherical symmetry, shortcomings of the matter model!

What is a singularity?

- ▶ infinities are not physical
- ▶ Newton's gravity: an evolution of a ball of dust with appropriate initial conditions may result in a finite mass in infinitesimally small volume \rightarrow singularity
- ▶ Einstein's gravity
 - ▶ coordinate singularities
 - ▶ a singularity does not belong to a spacetime
 - ▶ invariants
 - ▶ geodesic incompleteness — 'the detection of holes' method

- ▶ Albert Einstein dies, April 18, 1955
- ▶ the 'first' singularity theorem — Raychadhuri, published May 15, 1955
- ▶ singularities are not generic — Lifshitz, Khalatnikov, 1960 (*Classical Theory of fields*, Landau, Lifshitz, the section § 110 *The absence of singularities in cosmological solution* — removed in 1967)
- ▶ Penrose singularity theorem, 1965

If the space-time contains a non-compact Cauchy hypersurface and a closed future-trapped surface, and if $R_{\mu\nu}u^\mu u^\nu \geq 0$ holds for null u^μ , then there are future incomplete null geodesics.

Singularities are not artifacts of symmetries or the special conditions on matter assumed in the Openheimer-Snyder example!

Raychaudhuri

$$u^\nu \nabla_\nu \underbrace{\nabla_\mu u^\mu}_{\Theta} = - \underbrace{S_{\mu\nu} S^{\mu\nu}}_{\geq 0} - \underbrace{R_{\mu\nu} u^\mu u^\nu}_{\geq 0}$$

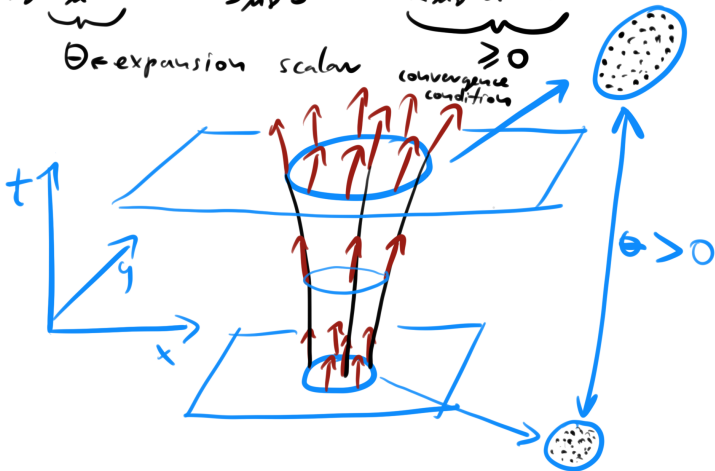
Θ ← expansion scalar

Ricci tensor

convergence conditions ≥ 0

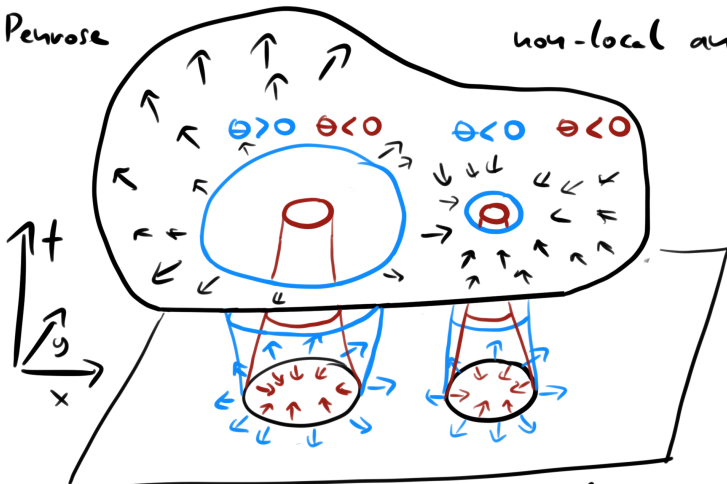
local analysis

tunnel or null



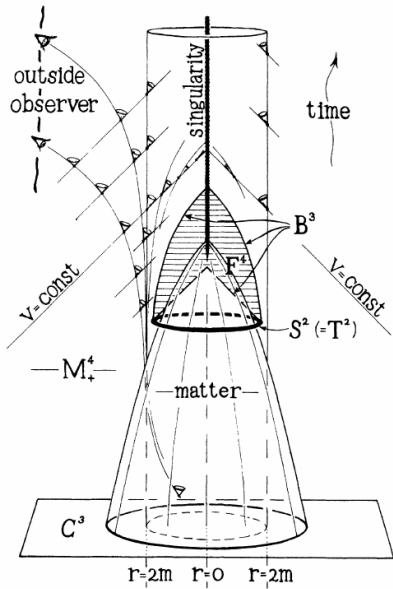
Penrose

non-local analysis



non-trapped surface

trapped surface



- ▶ Hawking, Ellis, 1965 — cosmology
- ▶ Hawking–Penrose singularity theorem, 1970
- ▶ trapped null surfaces → apparent horizon → event horizon
- ▶ the cosmic censorship hypothesis, Penrose, 1969
singularities → black holes

- ▶ Penrose diagrams, 1963
- ▶ singularity theorem, 1965
- ▶ twistor theory, 1967
- ▶ cosmic censorship, 1969
- ▶ Penrose tilings, 1970
- ▶ spin network, 1971
- ▶ Penrose inequality, 1973

$$m \geq \sqrt{\frac{A}{16\pi}}$$

- ▶ Weyl curvature hypothesis, 1979
- ▶ Penrose–Lucas argument, 1989
- ▶ conformal cyclic cosmology, 2010
- ▶ ...