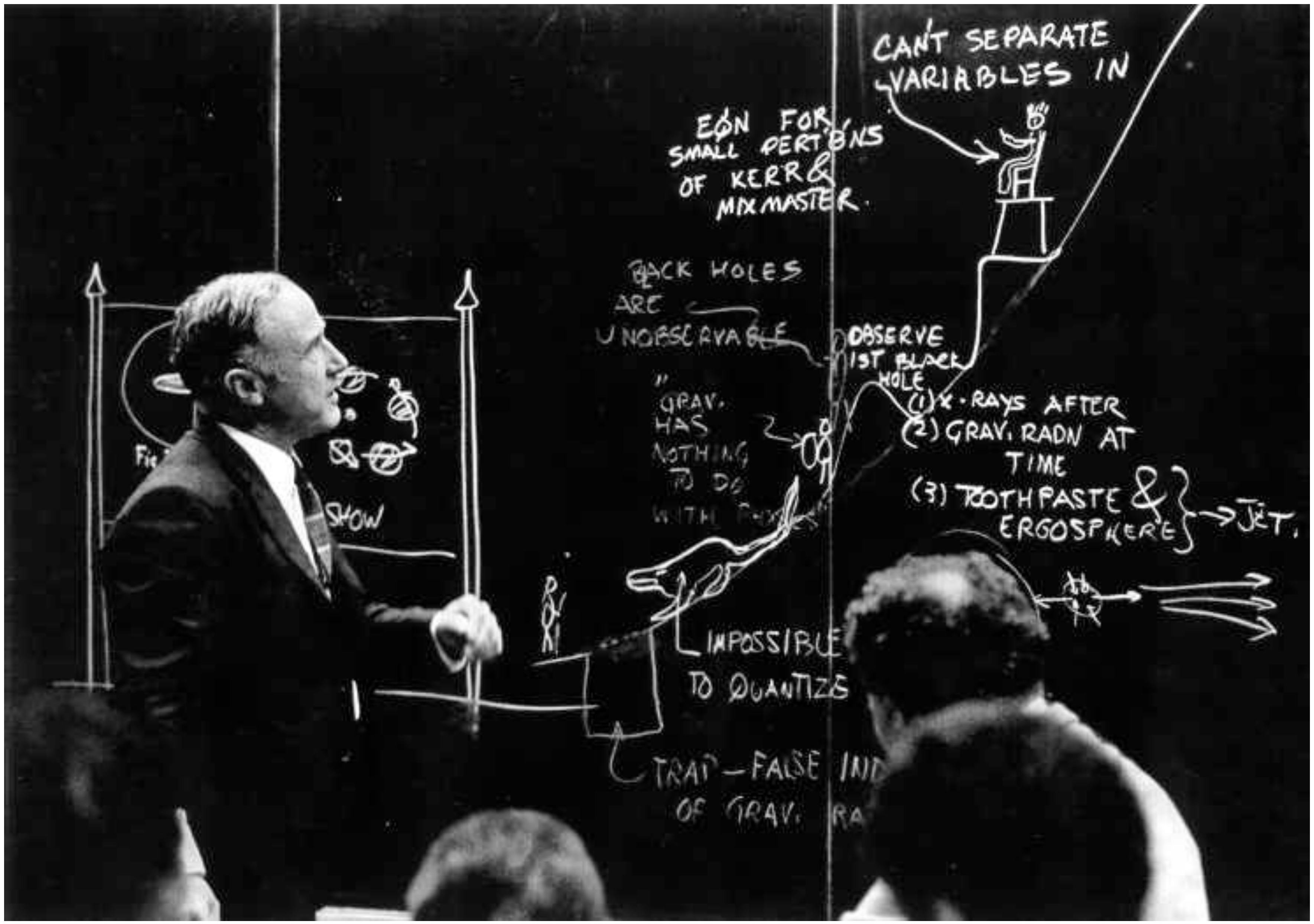
John Archibald Wheeler, 1952-1976: Black Holes and Geometrodynamics



Kip S. Thorne, Caltech

[relying heavily on Charles W. Misner, U. Md.]

American Physical Society, Denver, 2 May 2009

Relativity in 1952

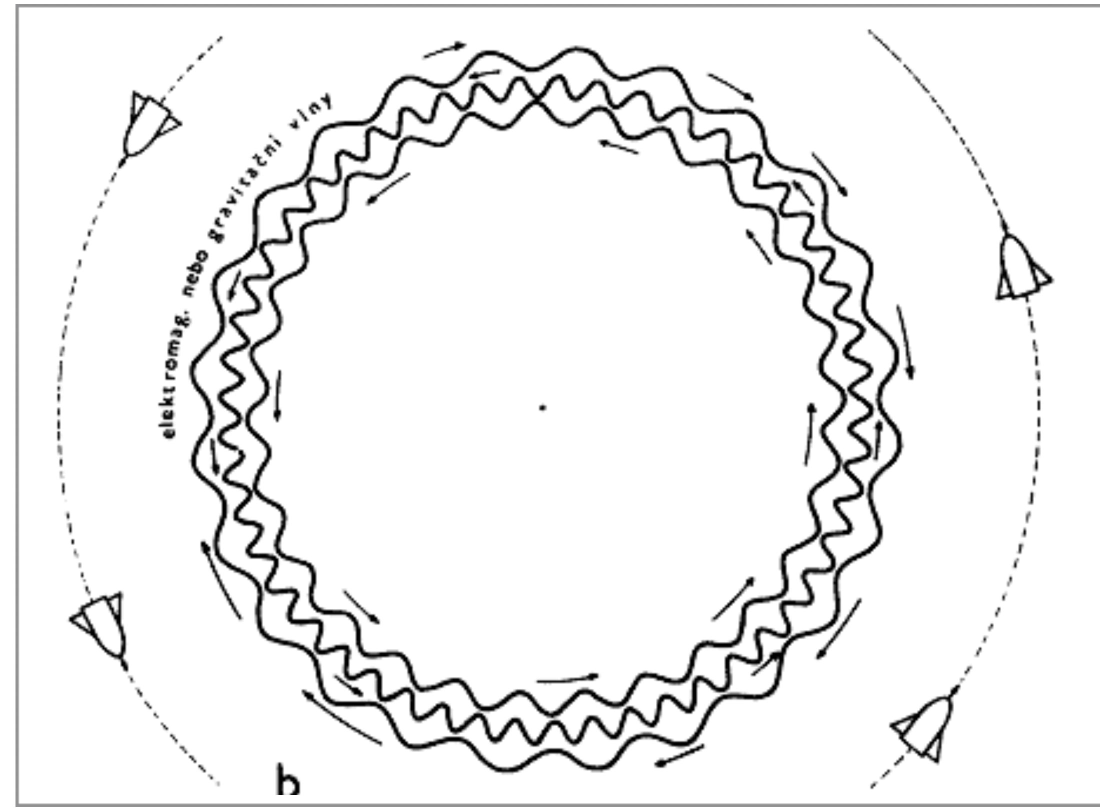
- A few exact solutions: Schwarzschild, Reissner-Nordstrom, Friedman, ...
- Linearized approximation: gravitational waves - skepticism over their physical reality
- Post-Newtonian equations of motion
- Contact with observation:
  - Expansion of universe
  - one precision test: perihelion shift of Mercury
  - two crude tests:
    light deflection, gravitational redshift
- Moribund; backwater of physics; little activity since 30s

Overview

- **1953**: Wheeler, emerging from H-bomb design work, embarked on quest to understand general relativity; curved spacetime
- First step: "If you would learn, teach"
- Wheeler led a "revolution"; ➔ major field of fundamental physics & tool for astrophysics

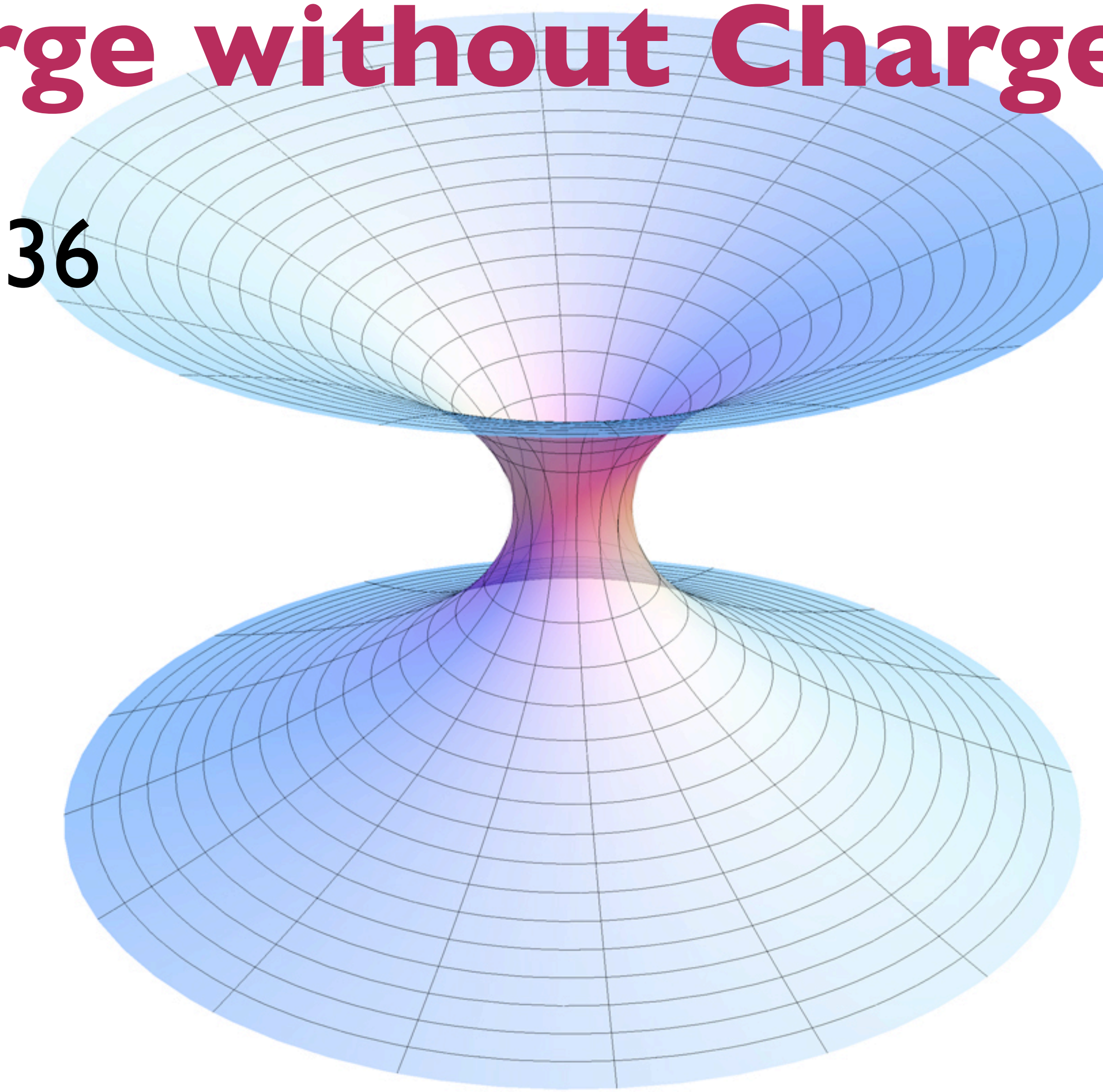
1955 - GEON: Mass without Mass

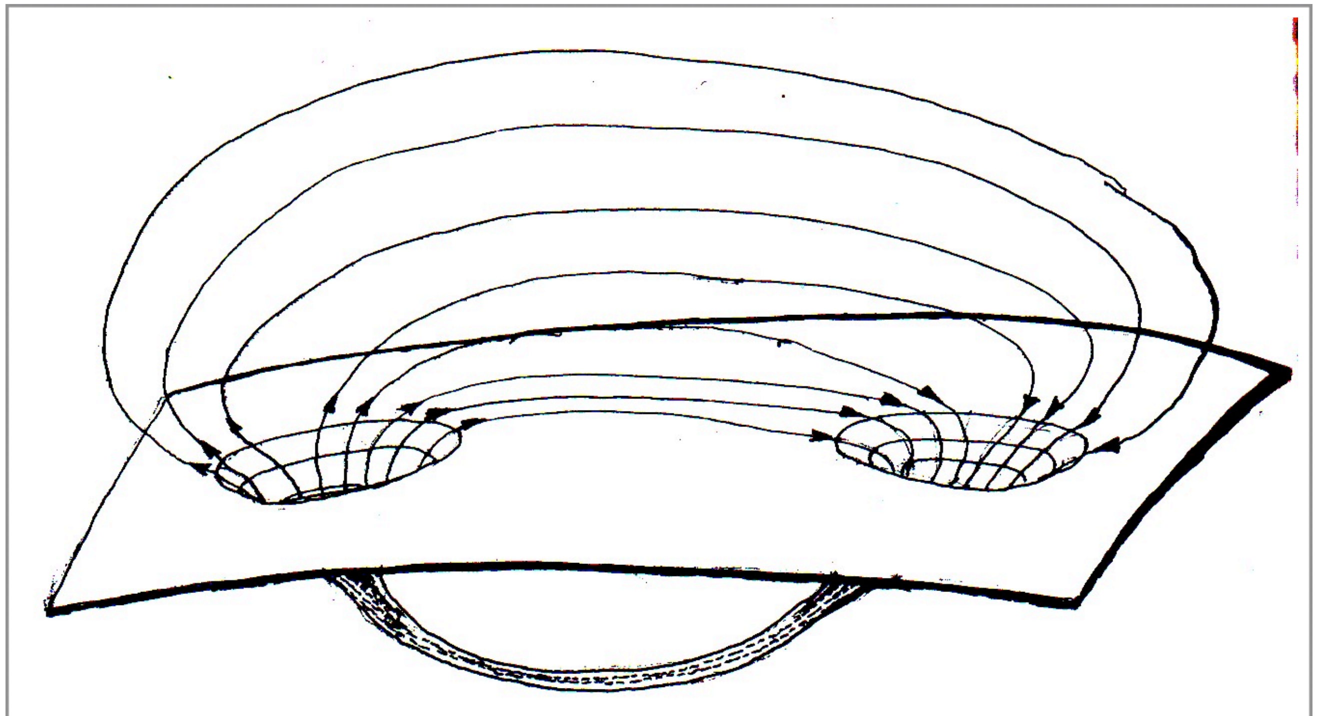
- **G**ravitational **E**lectromagnetic "particle"
- Leakage; collective instability so can't exist in Nature
- BUT:
  - Hinted at richness that nonlinearities can produce in curved spacetime
  - In hands of Wheeler's students ➔ powerful tools:
    - Brill & Hartle: 2-lengthscale expansions
    - Isaacson: Stress-energy tensor for Grav'l Waves



1957 - Wormhole: Charge without Charge

- Building on: Flamm 1916; Weyl 1924; Einstein&Rosen 1936
- "Radical Conservative-ism"
  - adhere to well-established physical law
  - follow it into the most extreme domains





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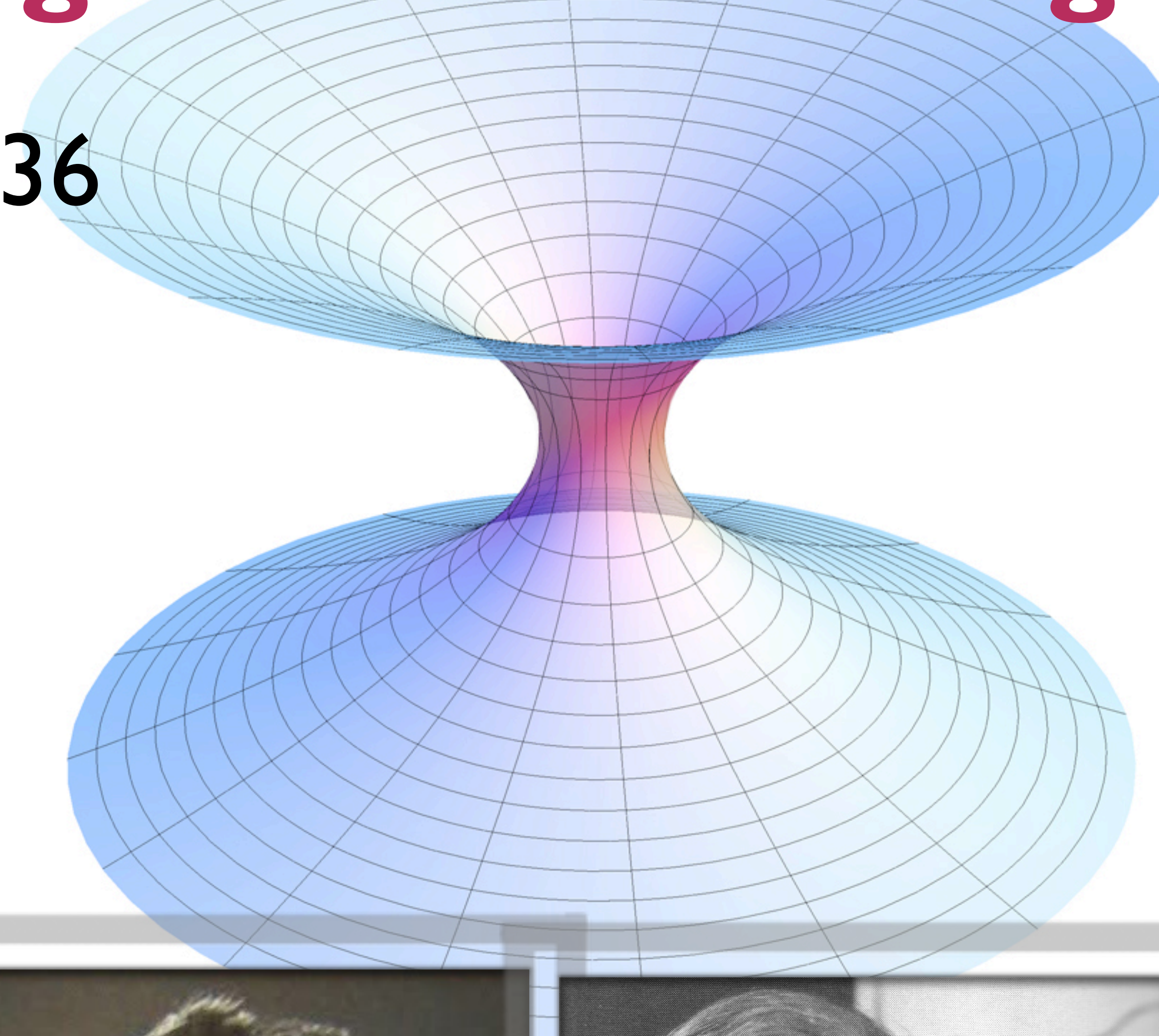

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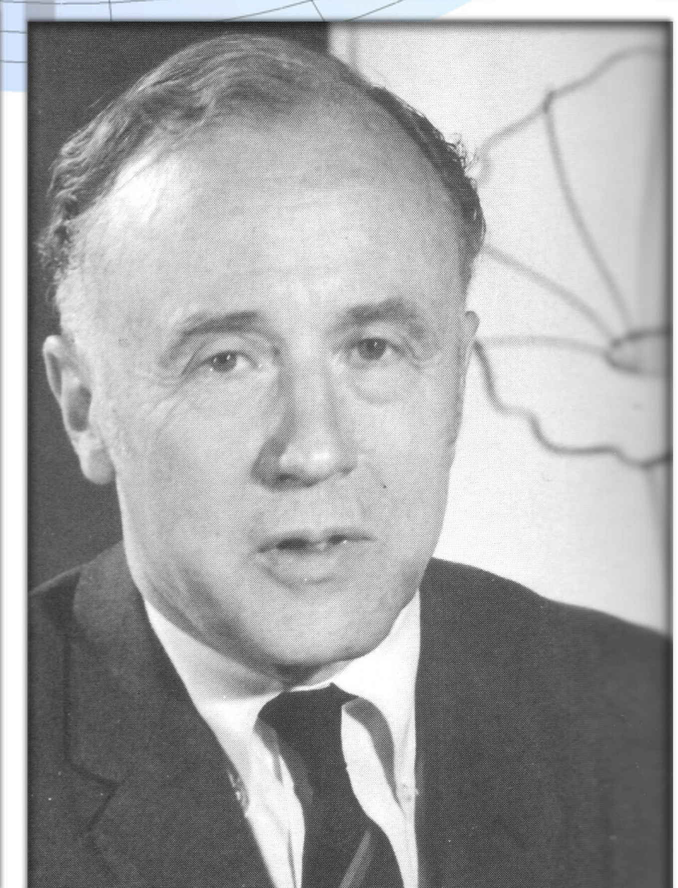
- Feynman’s remarks on Wheeler’s craziness
- Pinch-off (Kruskal, Wheeler)



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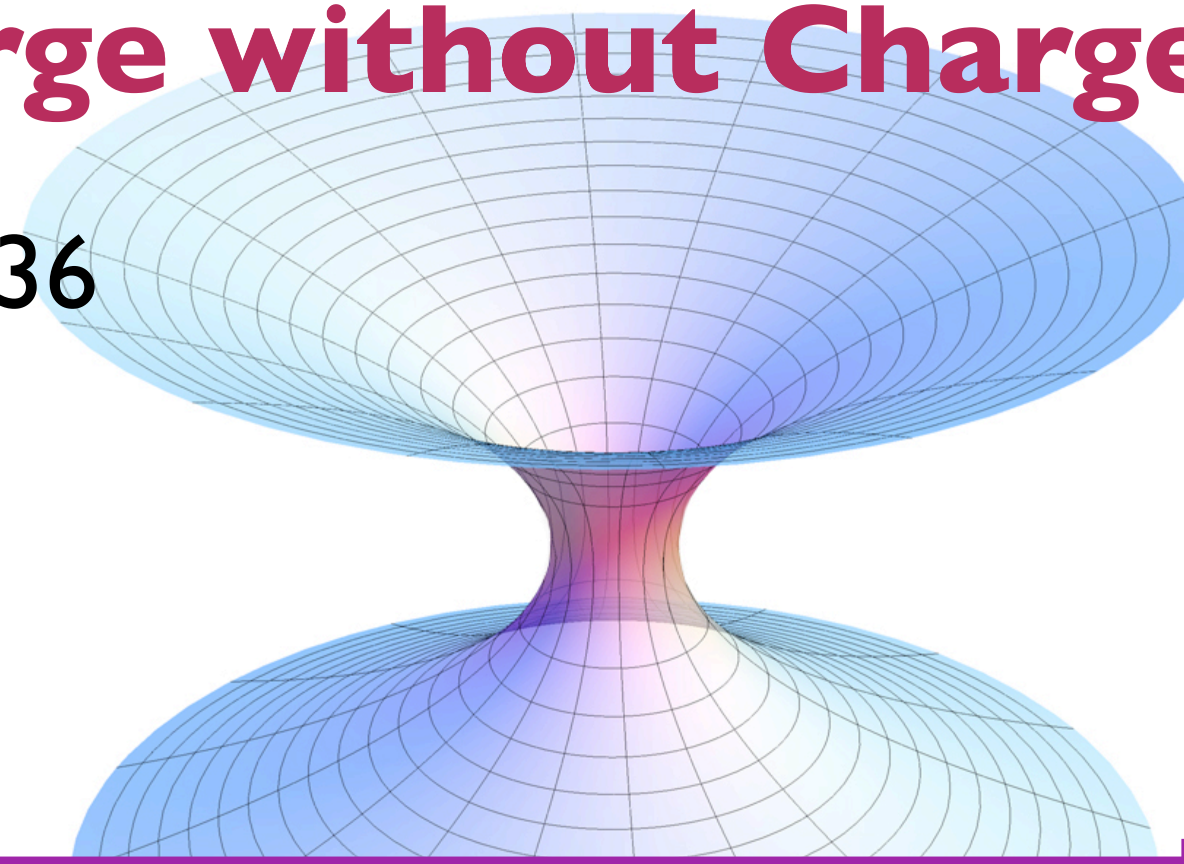

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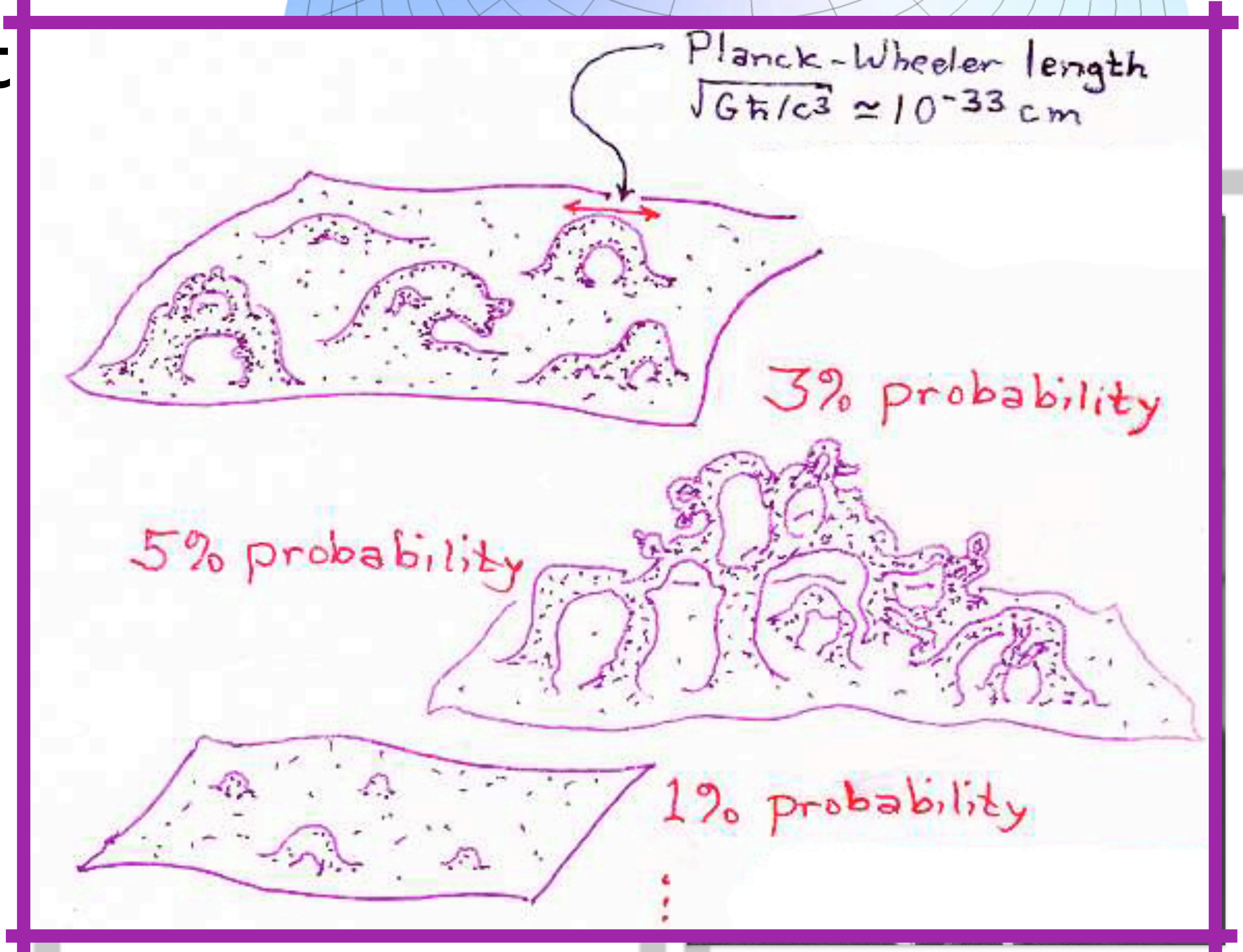
- Pinch-off
- Quantum foam
- Wheeler DeWitt Eqn

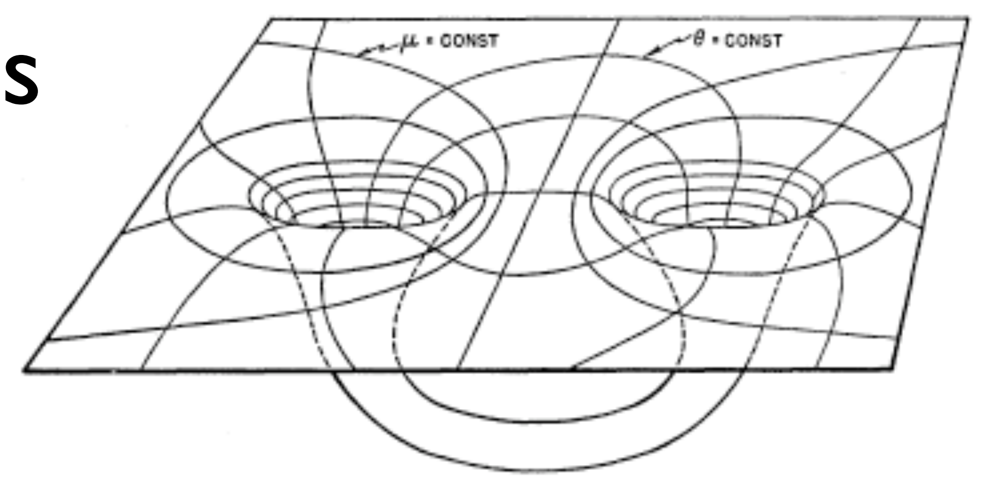


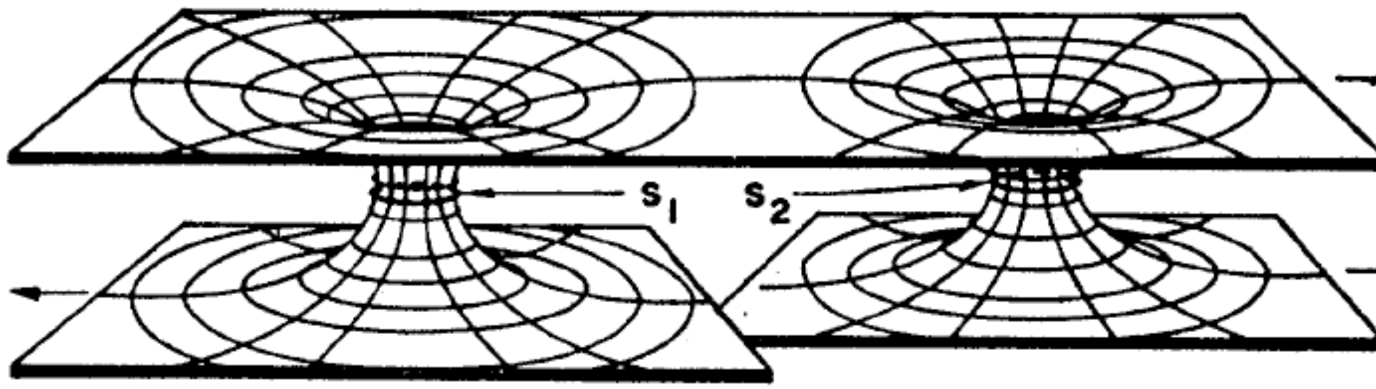
Gravitational Waves

- **1956:** Joseph Weber: Wheeler's "postdoc"
  - Weber & Wheeler, RMP (1957) - on the physical reality of gravitational waves

Geometrodynamics

- The dynamics of curved spacetime
- Give initial 3-geometry of space, subject to constraints.
- Evolve the geometry forward in time
- Mathematical formulation: Arnowitt, Deser & Misner - 1959, 1960; York 1971 ff
- Wheeler's vision: numerical relativity
  - solutions to constraint equations for multiple wormholes: Misner 1960; Brill & Lindquist 1963





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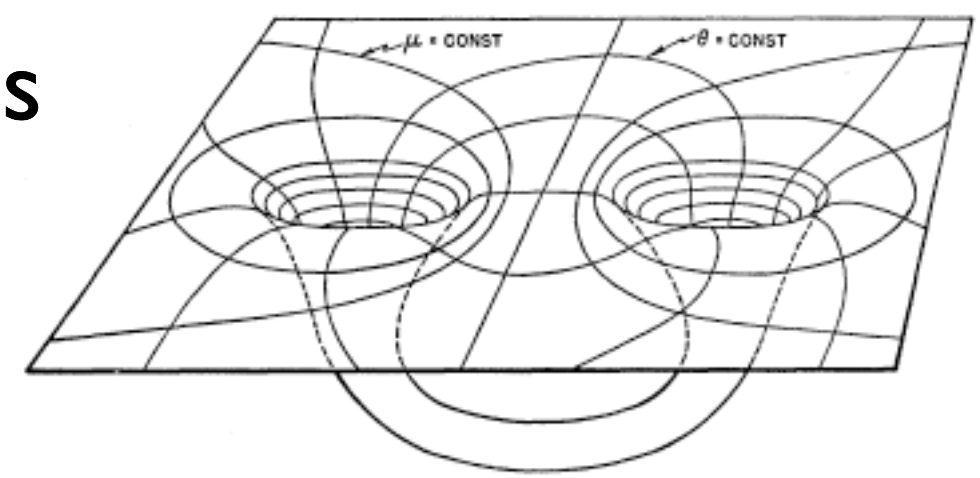
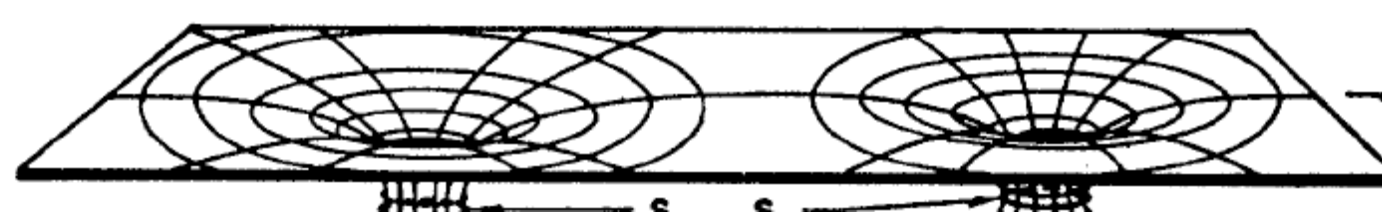
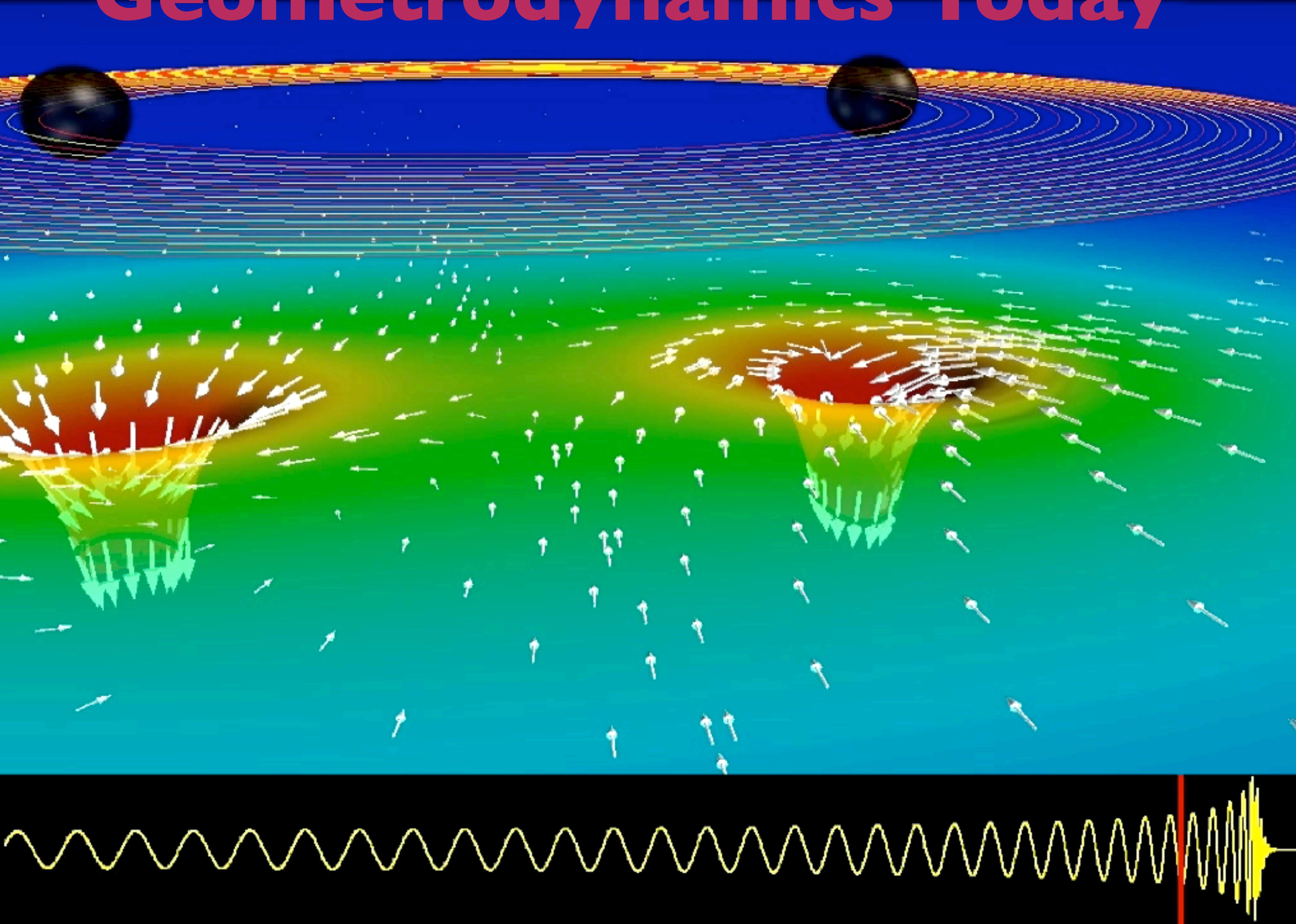


  - cut off at throats - get black holes

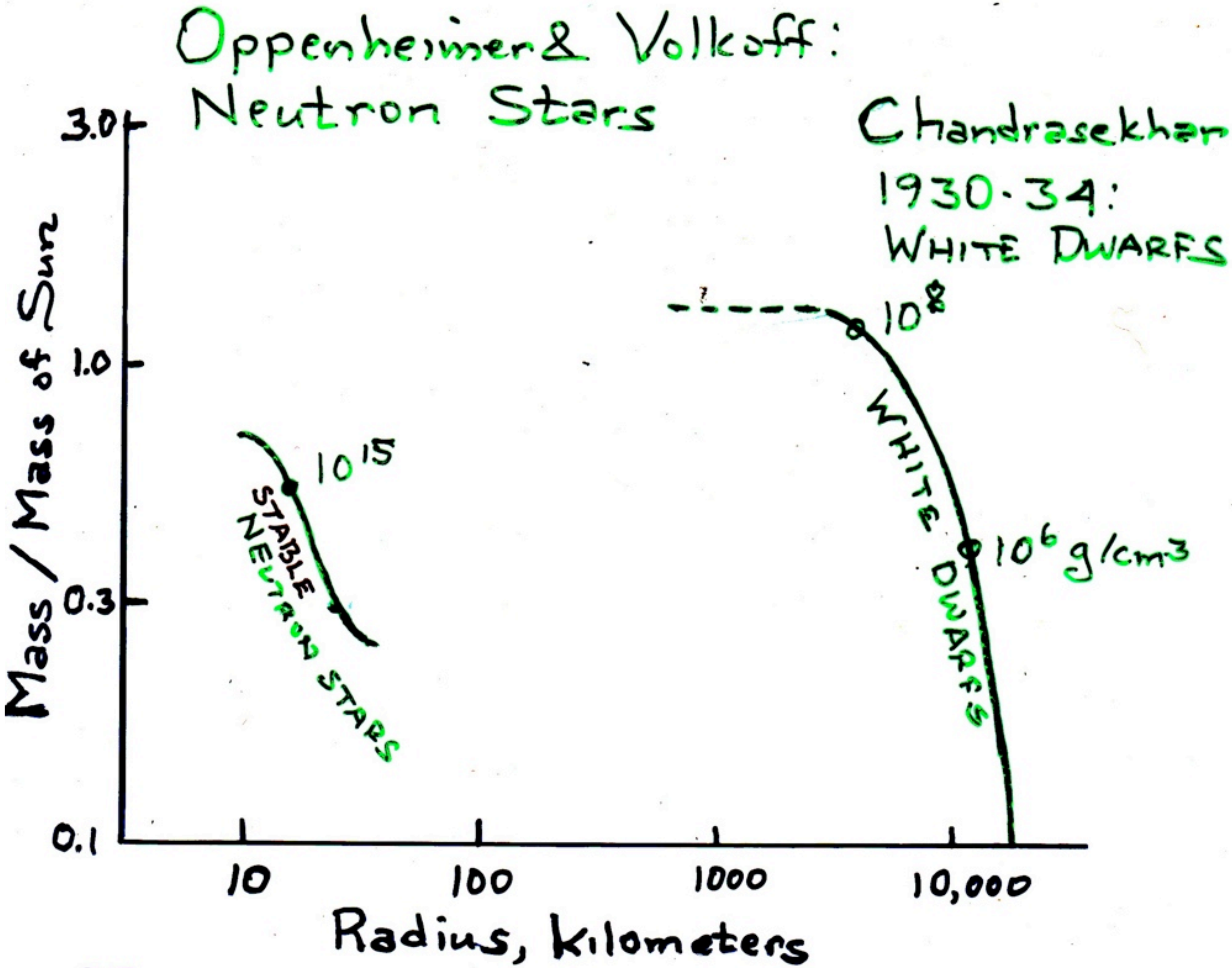


  - 111 citations since 2000

Geometrodynamics Today



The Final Graves of Stars



John Wheeler & students (Harrison, Wakano) 1956-57

What else? What between neutron stars & white dwarfs?

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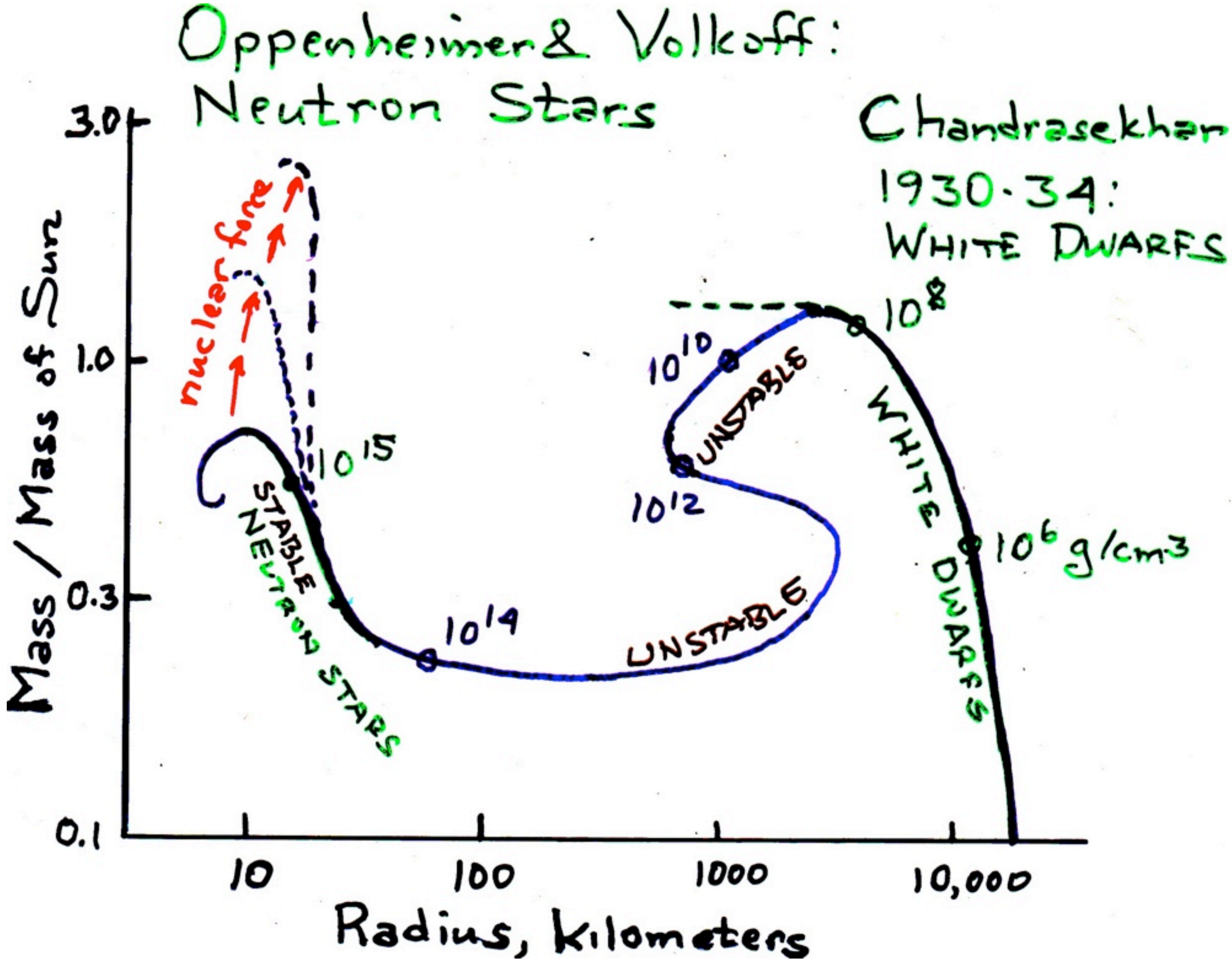

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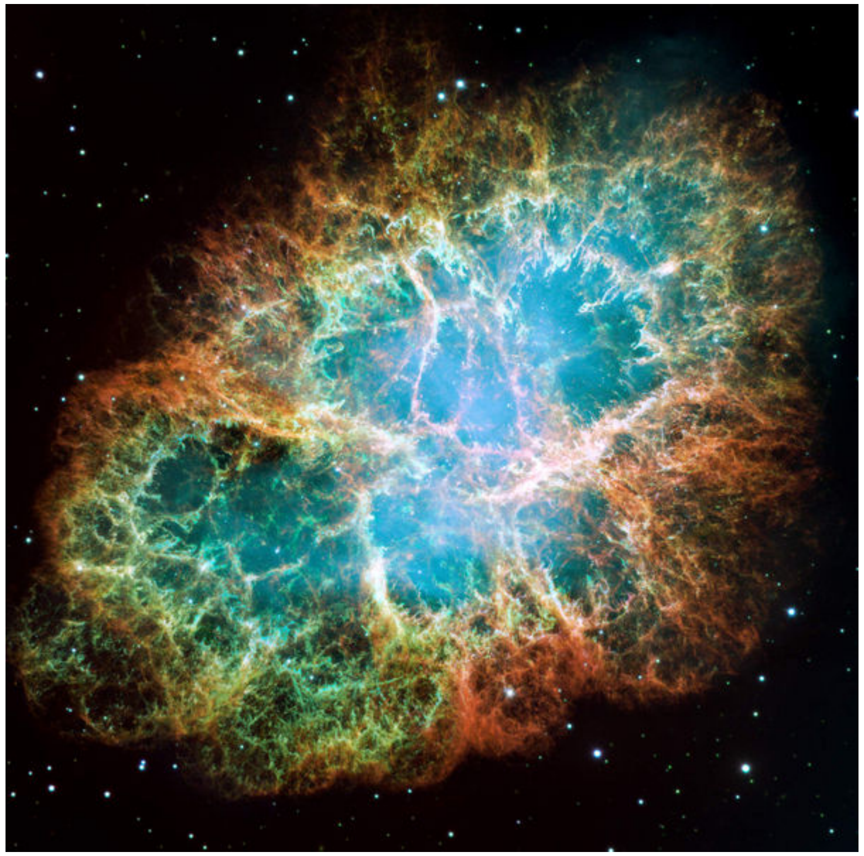
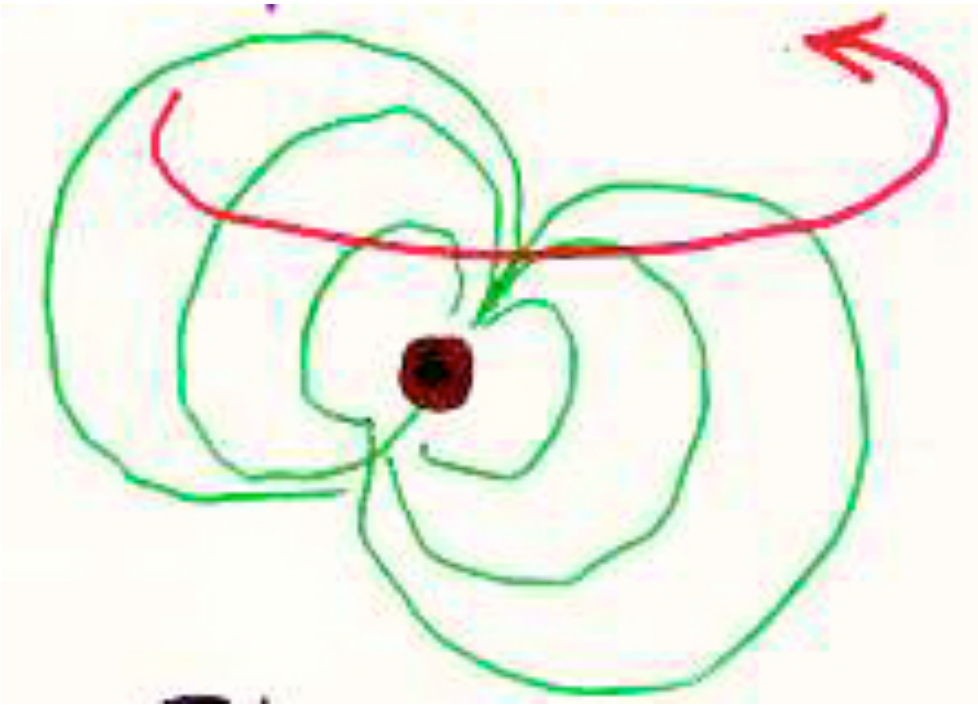
How to Discover a Neutron Star?

Wheeler: 1966, *Annual Reviews of Astronomy & Astrophysics*



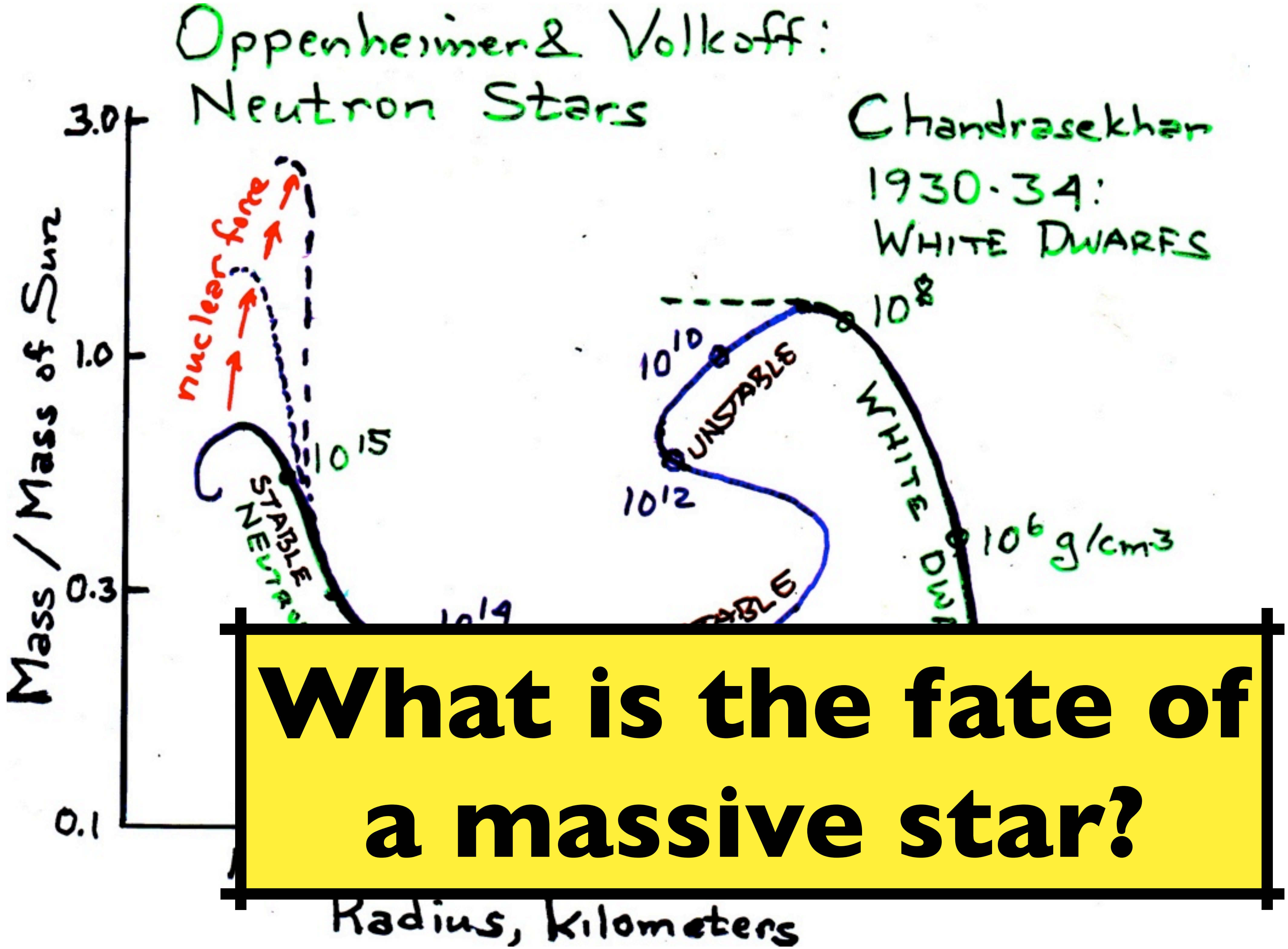
- Crab Nebula: remnant of a supernova explosion
- Should be a Neutron Star inside
- How is the Crab energized?
- Wheeler's speculation: a spinning, magnetized neutron star!



The Discovery of Neutron Stars

Anthony Hewish and Jocelyn Bell, 1968

The Final Graves of Stars



What is the fate of a massive star?

John Wheeler & students (Harrison, Wakano) 1956-57

What else? What between neutron stars & white dwarfs?

The Fate of Massive Stars

Wheeler's Conclusion, 1957

- Unacceptable answer!   CRISIS for physics!!
- Speculation: Perhaps a "fiery marriage" of general relativity and quantum theory (Quantum Gravity) will take over, and replace the singularity by something else
- The Issue of the Final State

Principle of Radical Conservative-sm

The Fate of Massive Stars

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Oppenheimer: Endpoint is hidden

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The Fate of Massive Stars

Oppenheimer:
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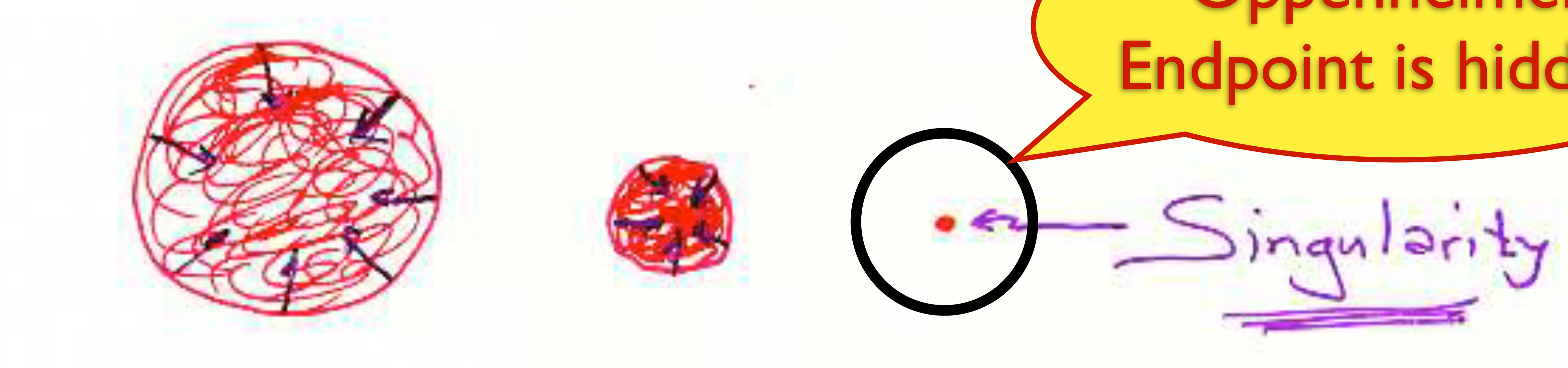
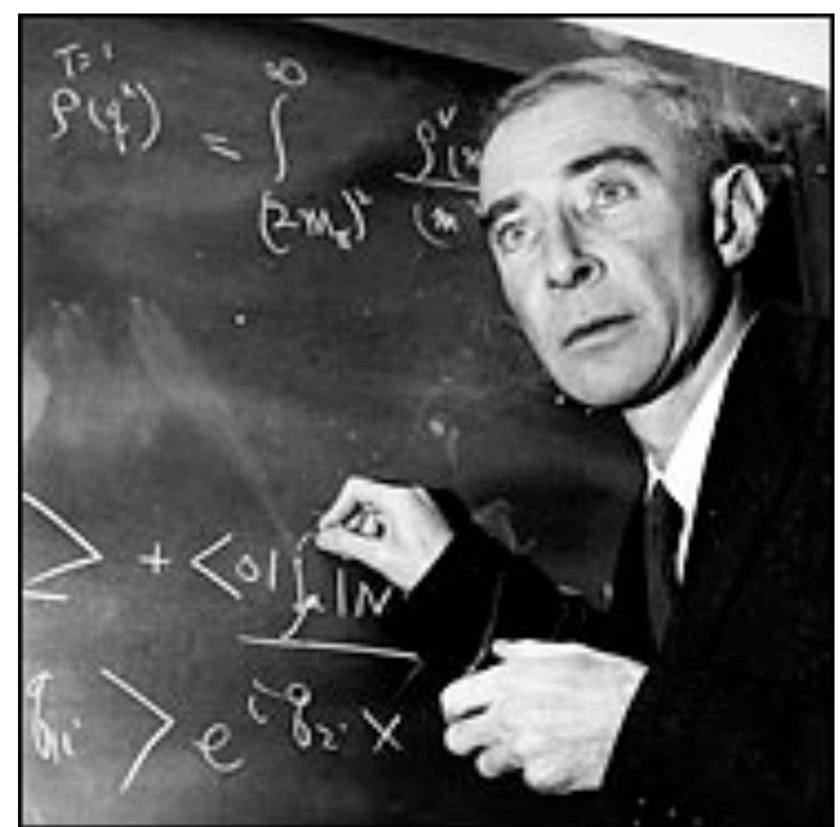


- Wheeler resisted. Confrontation at June 10, 1958 - Solvay Conference, Brussels

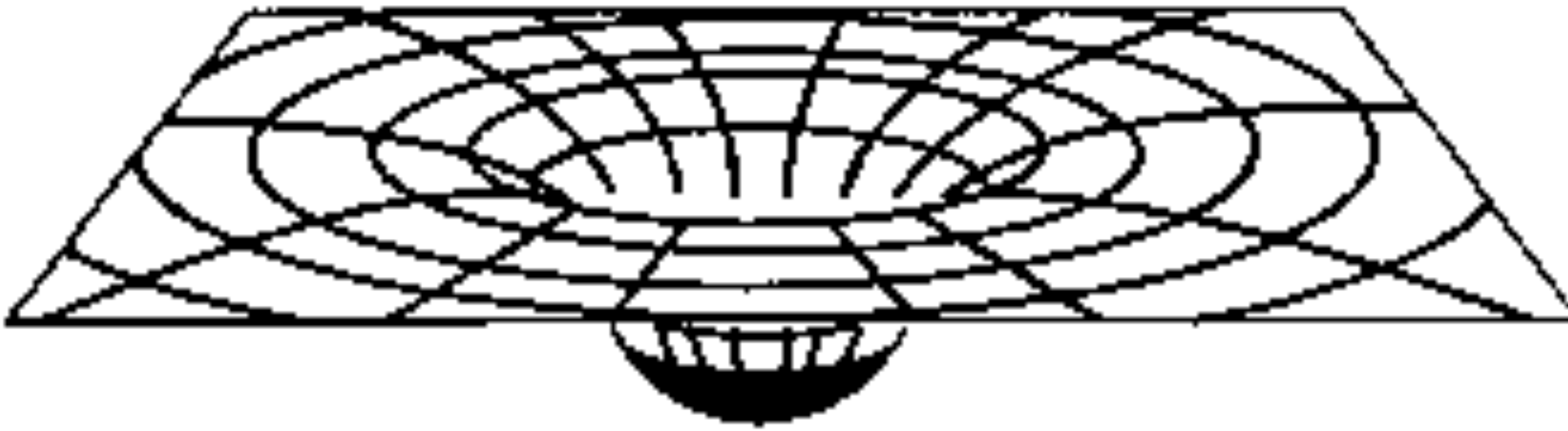


The Fate of Massive Stars

Oppenheimer:

★ Gradually (1958 - 1962) Wheeler became convinced.

★Perhaps most of all: Beckedorff & Misner elucidate Oppenheimer & Snyder



The Fate of Massive Stars

Oppenheimer:

- ★ Gradually (1958 - 1962) Wheeler became convinced.
  - ★perhaps most of all: Beckedorff & Misner elucidate Oppenheimer & Snyder
- ★1963: Quasars Discovered
- ★ First Symposium on Relativistic Astrophysics
- ★ Wheeler adopted the name ***Black Hole*** (1968)
- ★Continued to focus on the mystery of the singularity
- ★Until 1964, speculated information leaks out

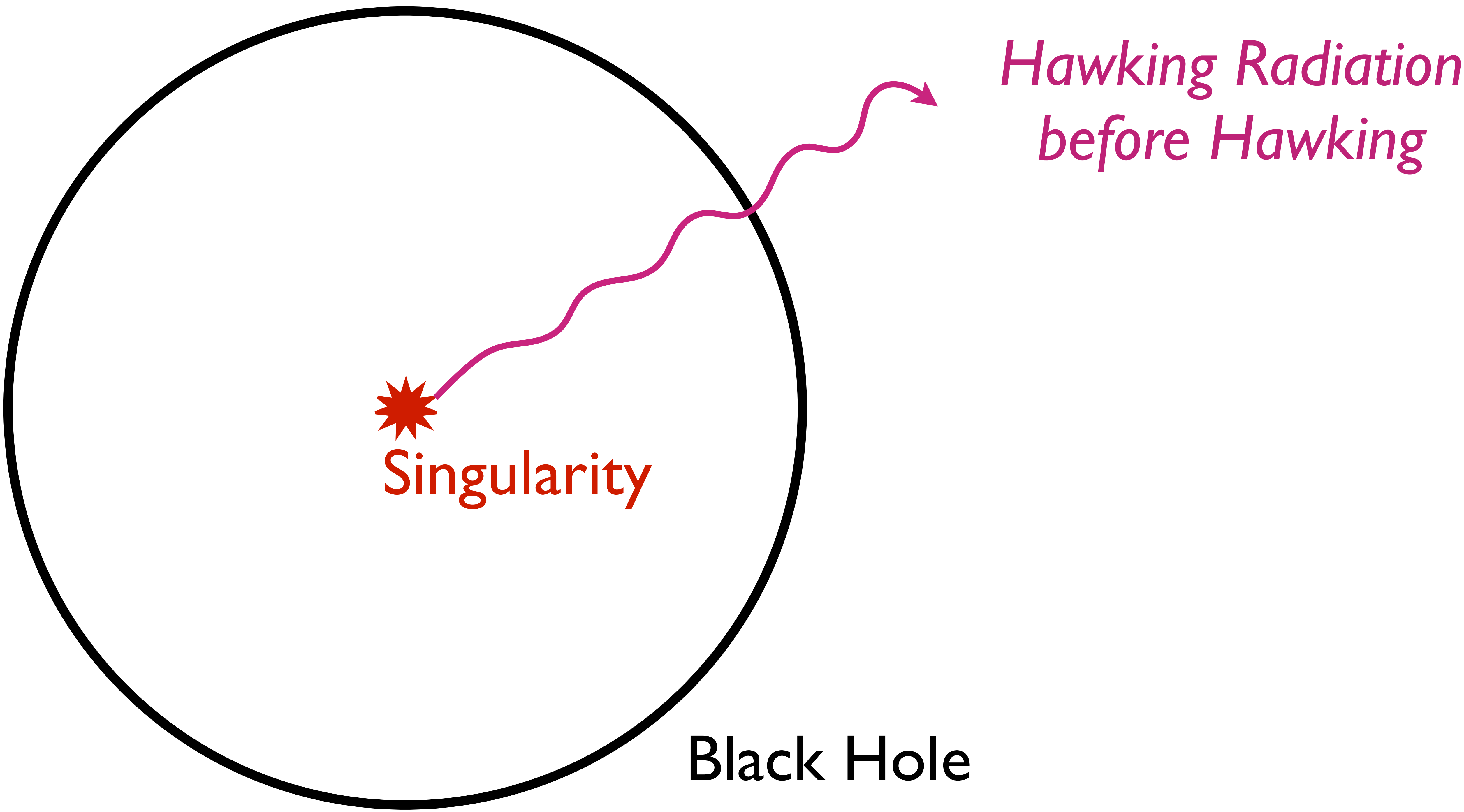
1964: Information Leaking Out of a Black Hole

John and Kip - Writing

Gravitation Theory and Gravitational Collapse

High Island, Maine

1964: Information Leaking out of Black Hole



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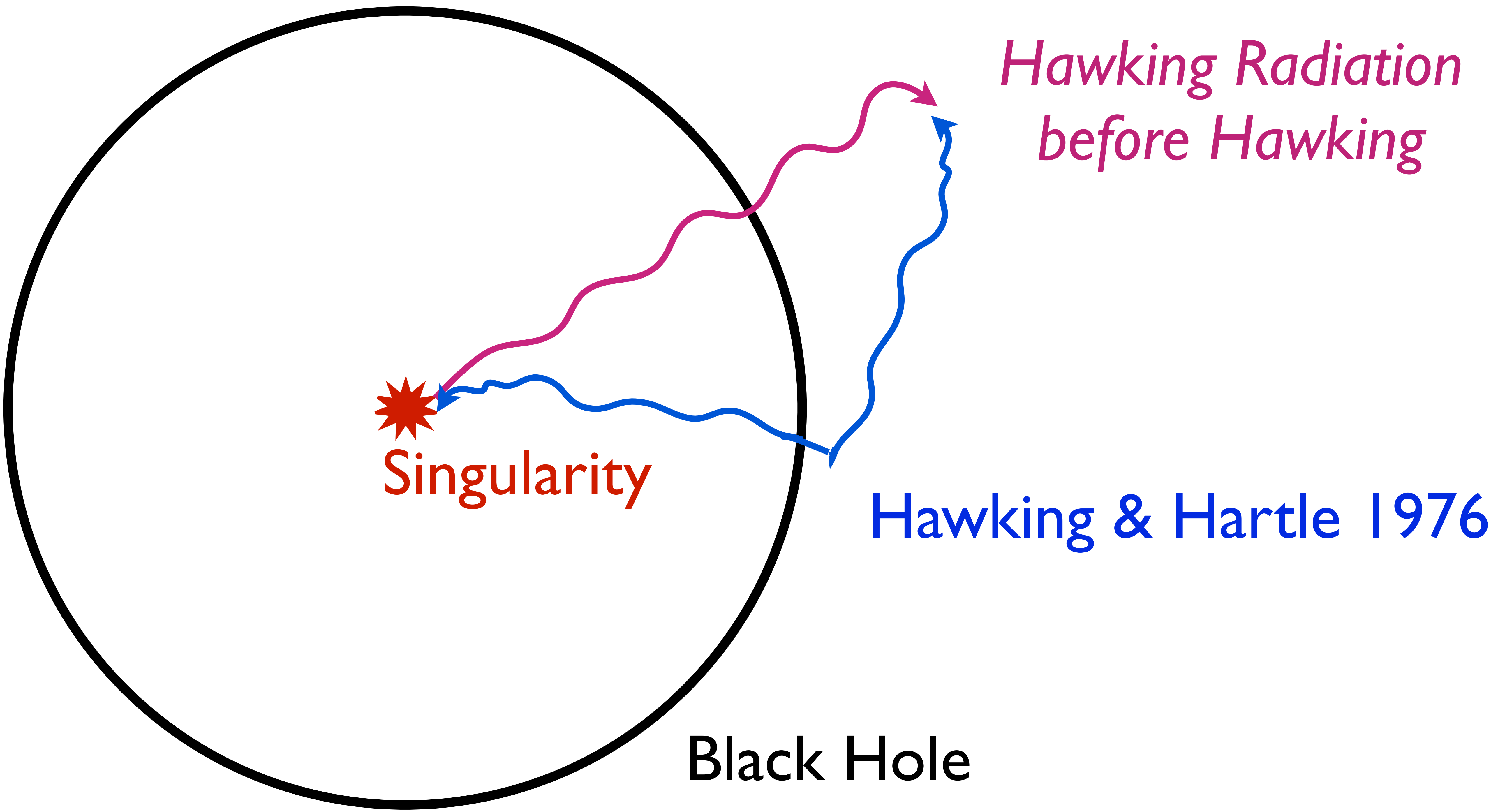


The Stability of Black Holes

- 1956: Tullio Regge and John Wheeler

PHYSICAL REVIEW VOLUME 108, NUMBER 4 NOVEMBER 15, 1957

Stability of a Schwarzschild Singularity

TULLIO REGGE, *Istituto di Fisica della Università di Torino, Torino, Italy*

AND

JOHN A. WHEELER, *Palmer Physical Laboratory, Princeton University, Princeton, New Jersey*

(Received July 15, 1957)

It is shown that a Schwarzschild singularity, spherically symmetrical and endowed with mass, will undergo small vibrations about the spherical form and will therefore remain stable if subjected to a small nonspherical perturbation.

I. INTRODUCTION AND SUMMARY

SCHWARZSCHILD found long ago the solution of the Einstein equations for the metric around a fixed spherically symmetrical center-of-mass:

$$ds^2 = -(1-2m^*/r)dT^2 + (1-2m^*/r)^{-1}dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2) = g_{\mu\nu}dx^\mu dx^\nu, \quad (1)$$

with $x^0 = T$, $x^1 = r$, $x^2 = \theta$, $x^3 = \varphi$. Here the quantity

$$m^*(\text{cm}) = Gm/c^2 = (0.74\times 10^{-28}\ \text{cm/g})m(\text{g}) \quad (2)$$

field in the usual way of writing these equations. However, the equations can be rearranged[3] in such a way as to bring into evidence an additional production of gravitational field by the stress energy tensor *of* the gravitational field. On this account the geometrized mass, m^*, is not uniquely determined by the geometrized charge, q^*; it only follows that m^* is no less than q^*. (5) One can therefore think of the field energy—or the mass and stress that goes with it—as in equilibrium under its own gravitational attraction.

We have equilibrium, but is it stable? A sphere of

Wheeler As Mentor and Teacher

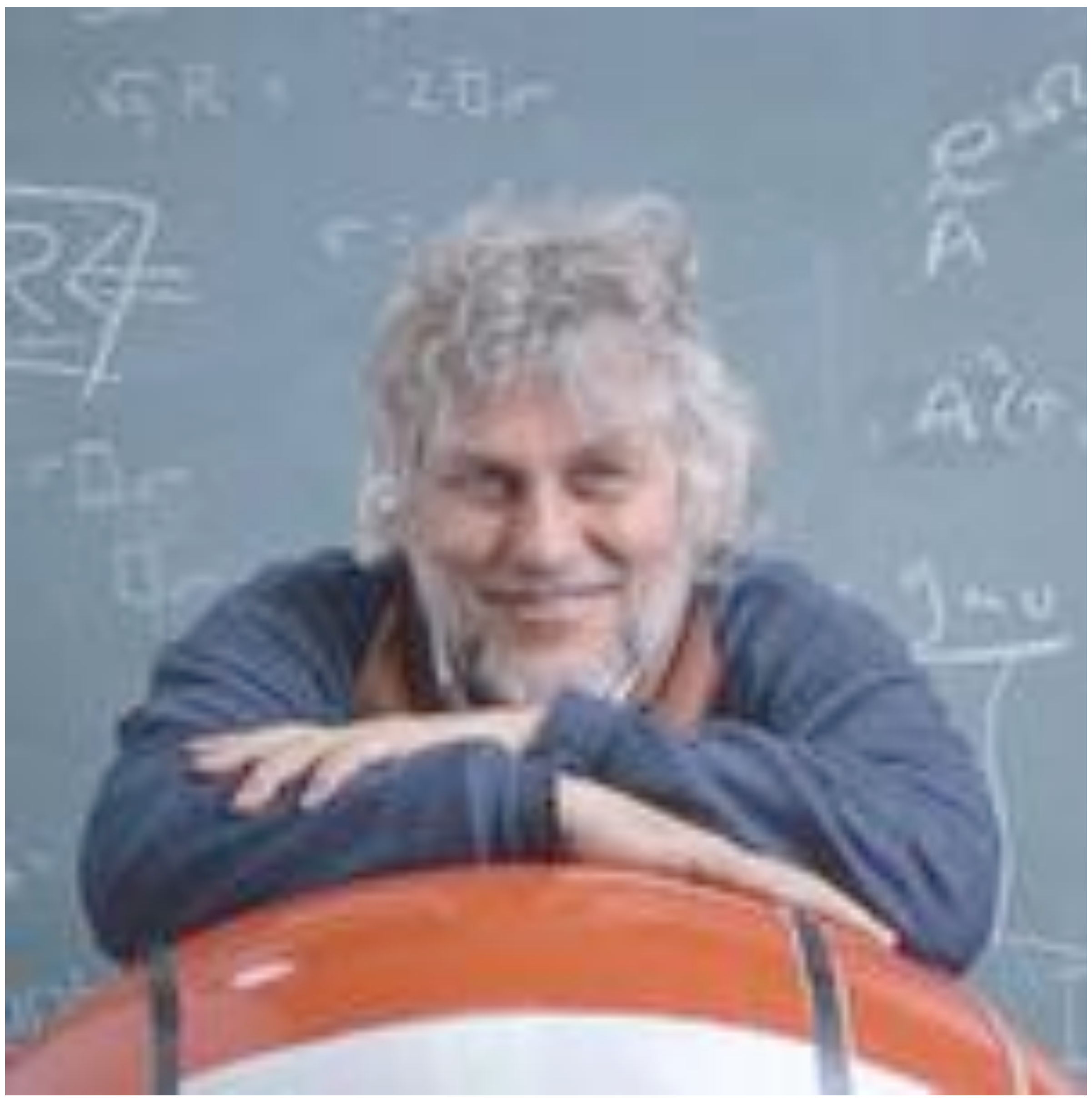
- My first meeting with Wheeler: June, 1962
- Wheeler's mentoring style

Wheeler As Mentor and Teacher

- Lectures: Tours de Force

Wheeler As Mentor and Teacher

- Bill Unruh's recollections



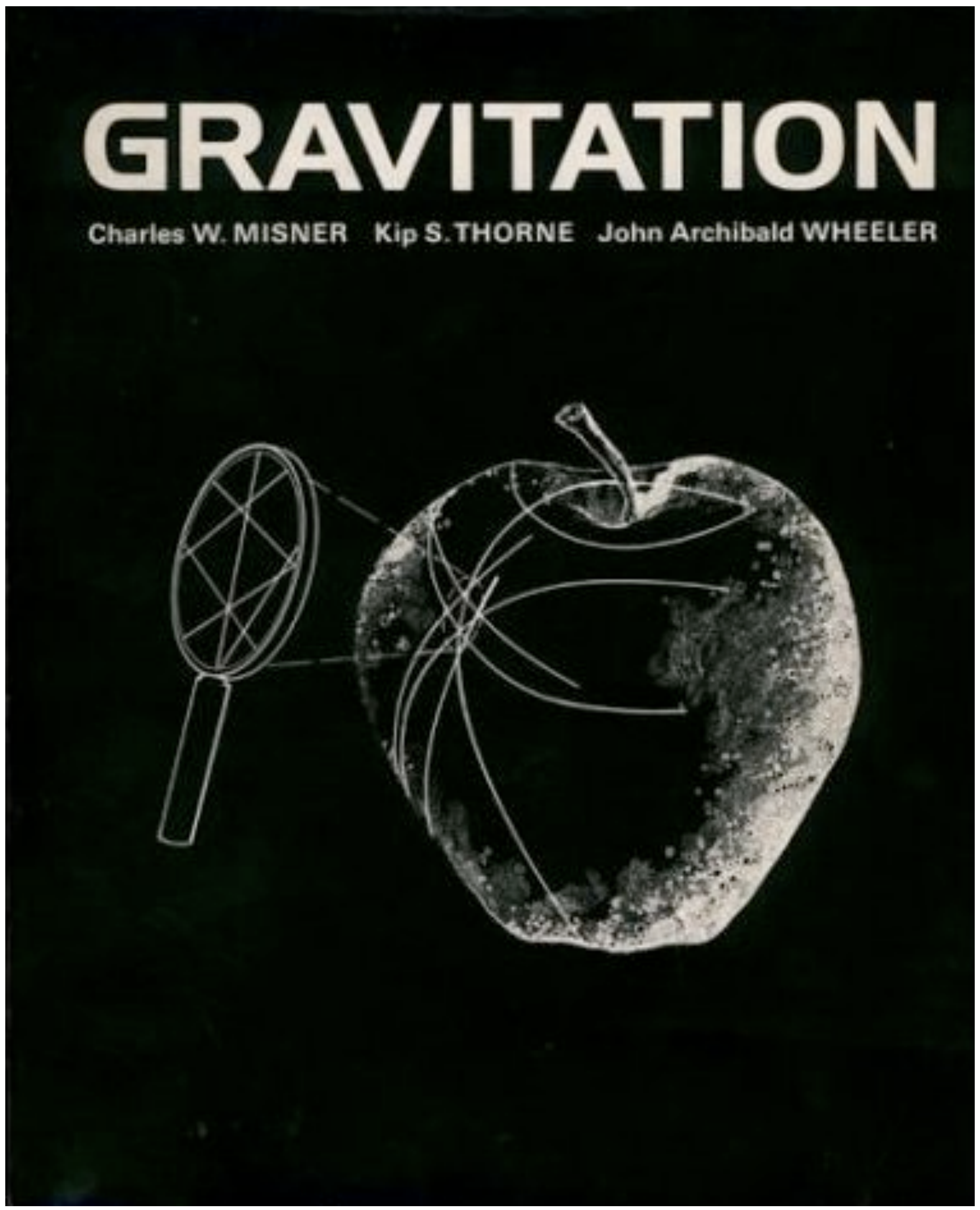
Wheeler As Mentor and Teacher

- Bob Geroch's recollections

Wheeler As Mentor and Teacher

- David Sharp recollections

Misner, Thorne & Wheeler



1973