Astronomy 353

(Spring 2007)

ASTROPHYSICS: From Black Holes to the First Stars

(Lecture 1: Introduction)

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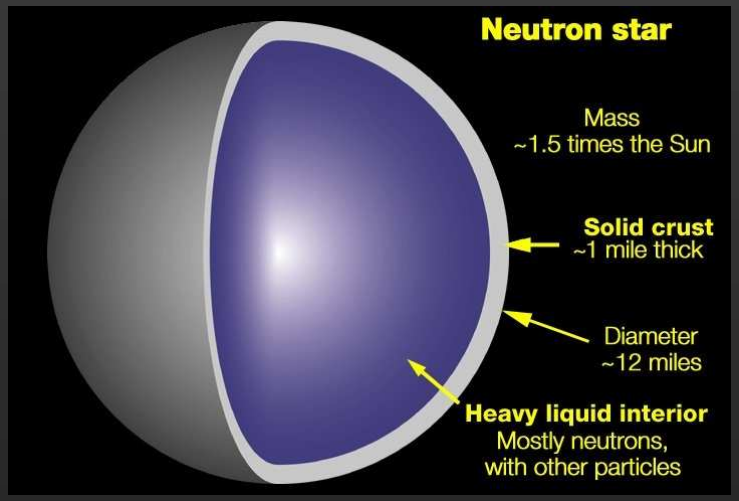
Physics of Stellar Remnants

White Dwarfs

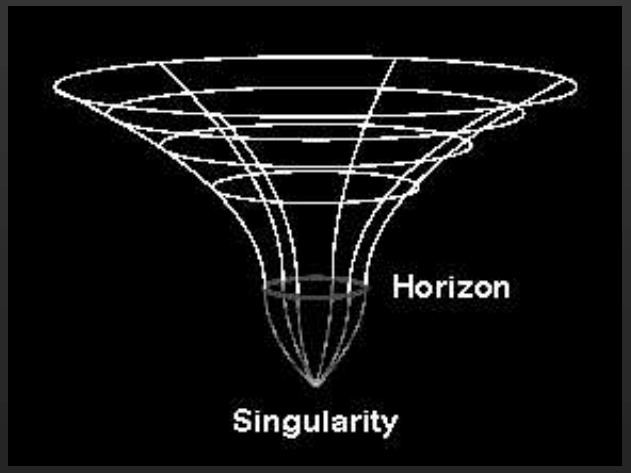
~ 10,000 km
(à Earth)

Neutron Stars



~ 10 km

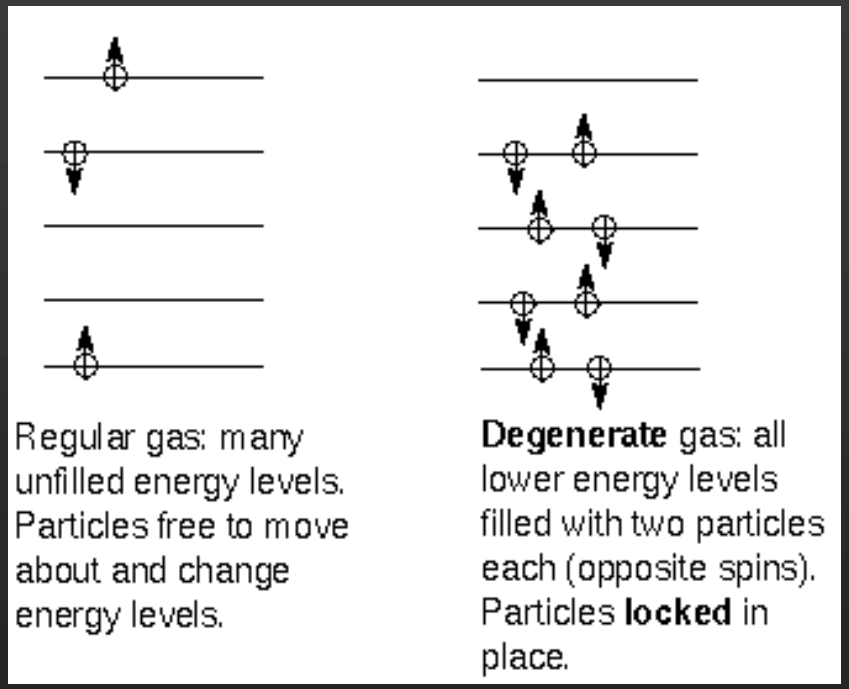
Black Holes

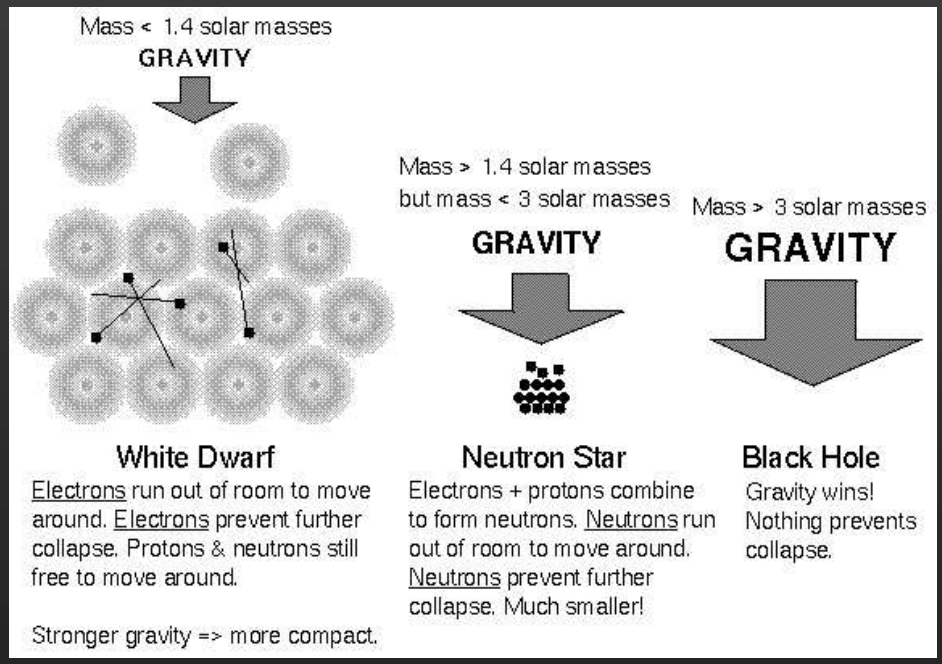


~ 3 km

Quantum Pressure in Stellar Remnants

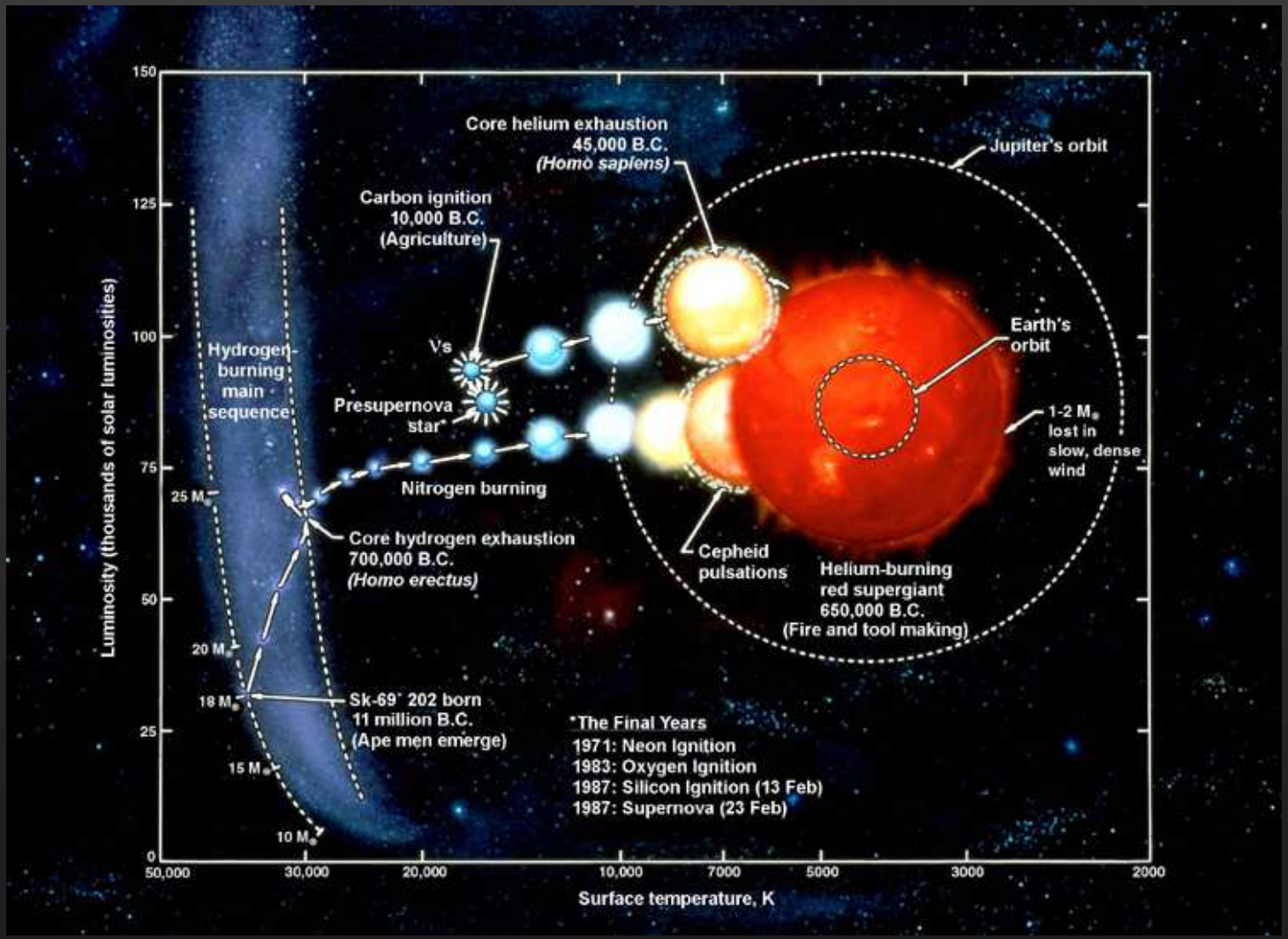
- often called: ``degeneracy pressure''





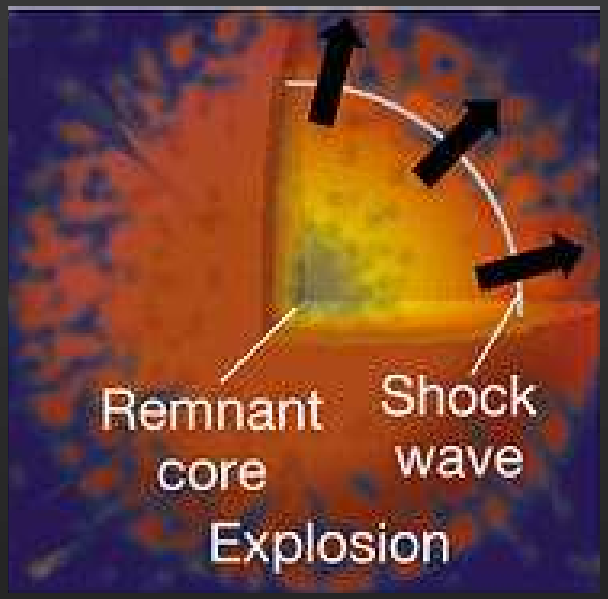
How are Compact Objects born?

à Brief Overview of Stellar Evolution



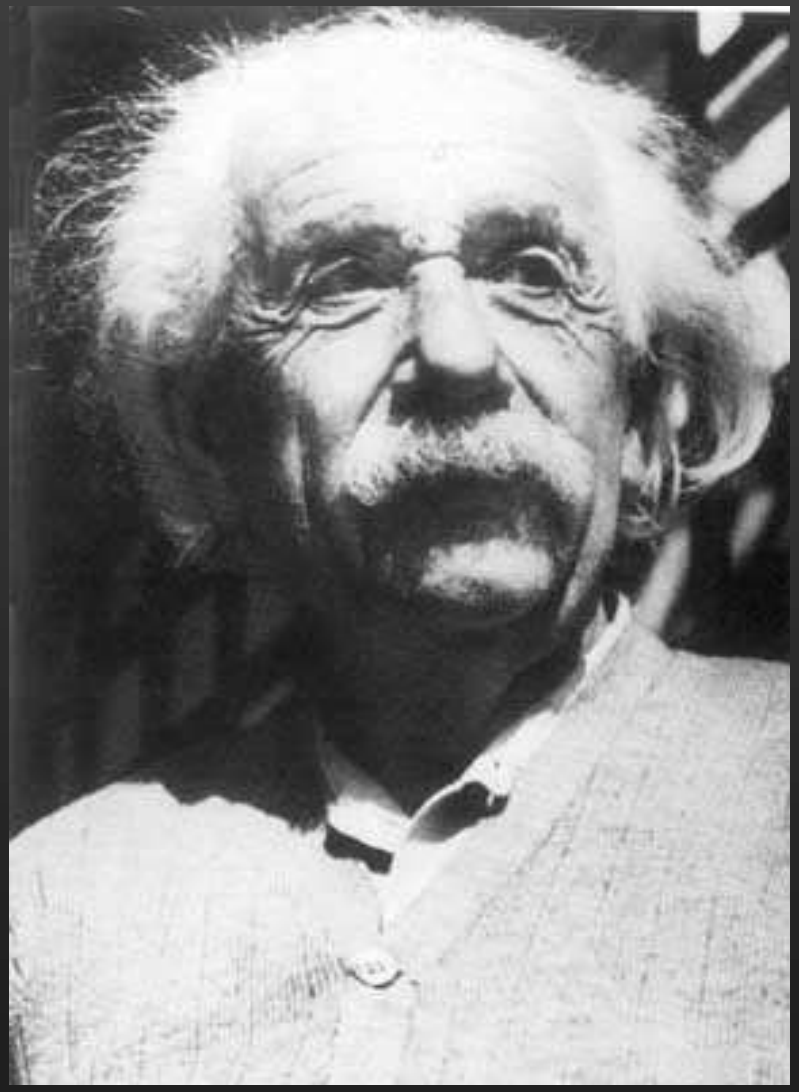
Supernova (SN) Explosions

- extremely energetic and violent events



SN Remnants (e.g., Crab Nebula)

Albert Einstein: Revolutionary of Physics



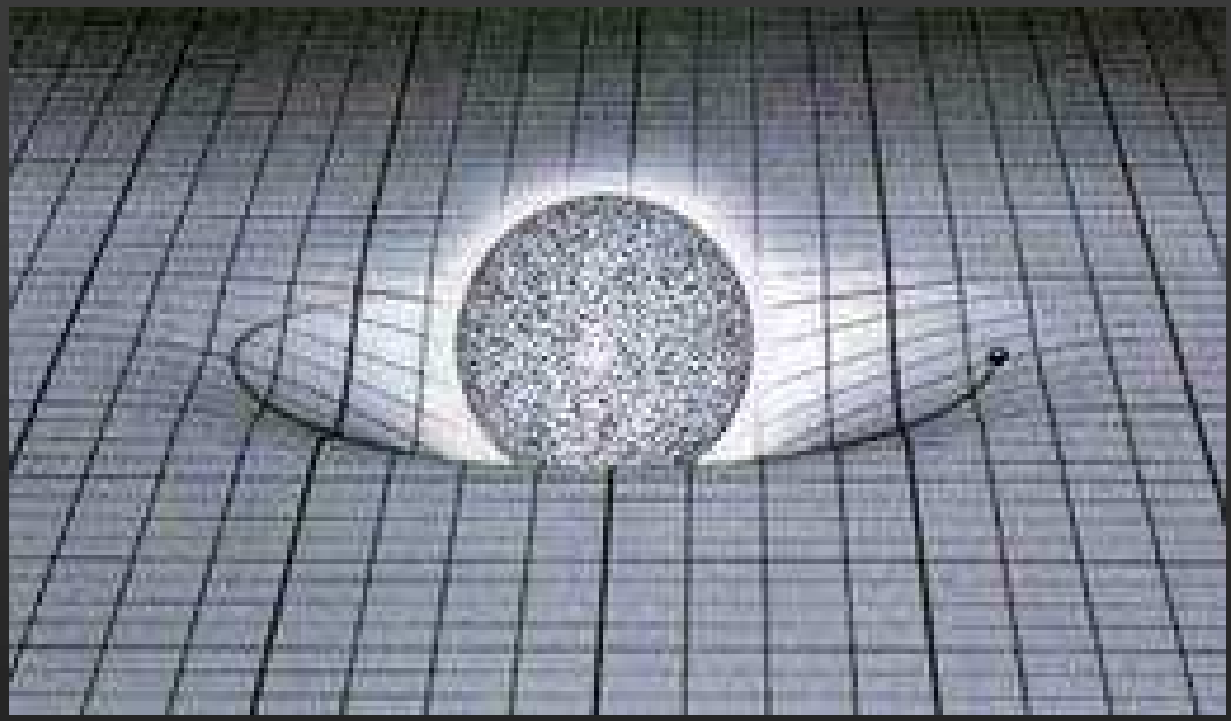
- 1879 (Ulm) – 1955 (Princeton)

- revolutionized concepts of space, time, and gravity
  - Special Relativity (1905):
    à $E=mc^2$
  - General Relativity (1915):
    à new theory of gravity

- co-founder of quantum theory
  à photons

General Theory of Relativity (1915-16)

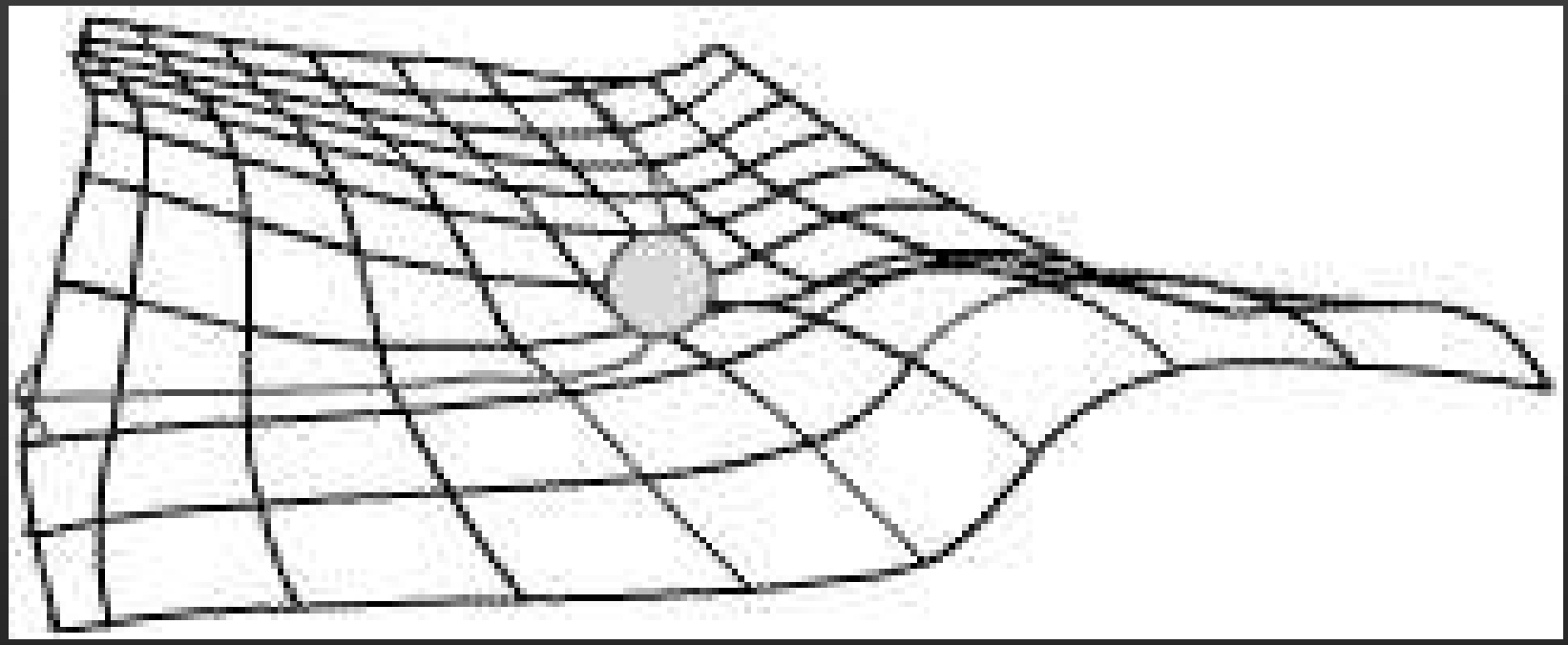
- Principle 1: “Matter tells space how to curve”



- matter creates `dimples’ in otherwise flat spacetime!

General Theory of Relativity (1915-16)

- Principle 2: “Curved space tells matter how to move”



- particles move through spacetime along paths of least resistance (technically: `geodesics’)!

General Theory of Relativity (1915-16)

- Einstein's Field equations:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

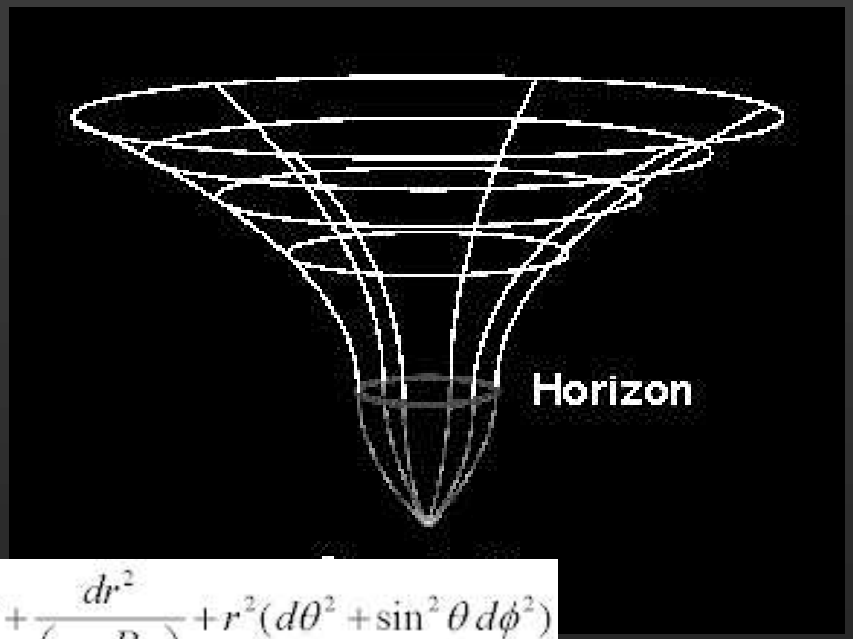
(curvature of space) **(matter content)**

- a `tensor equation' à *quite* complicated (10 coupled non-linear differential equations)

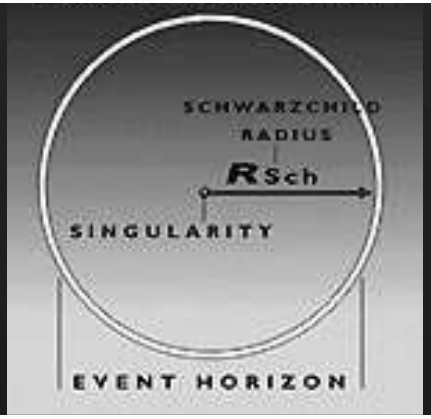
Solving Einstein's Equations of GR

- 1916: Karl Schwarzschild predicts black holes

Karl Schwarzschild (1873-1916)



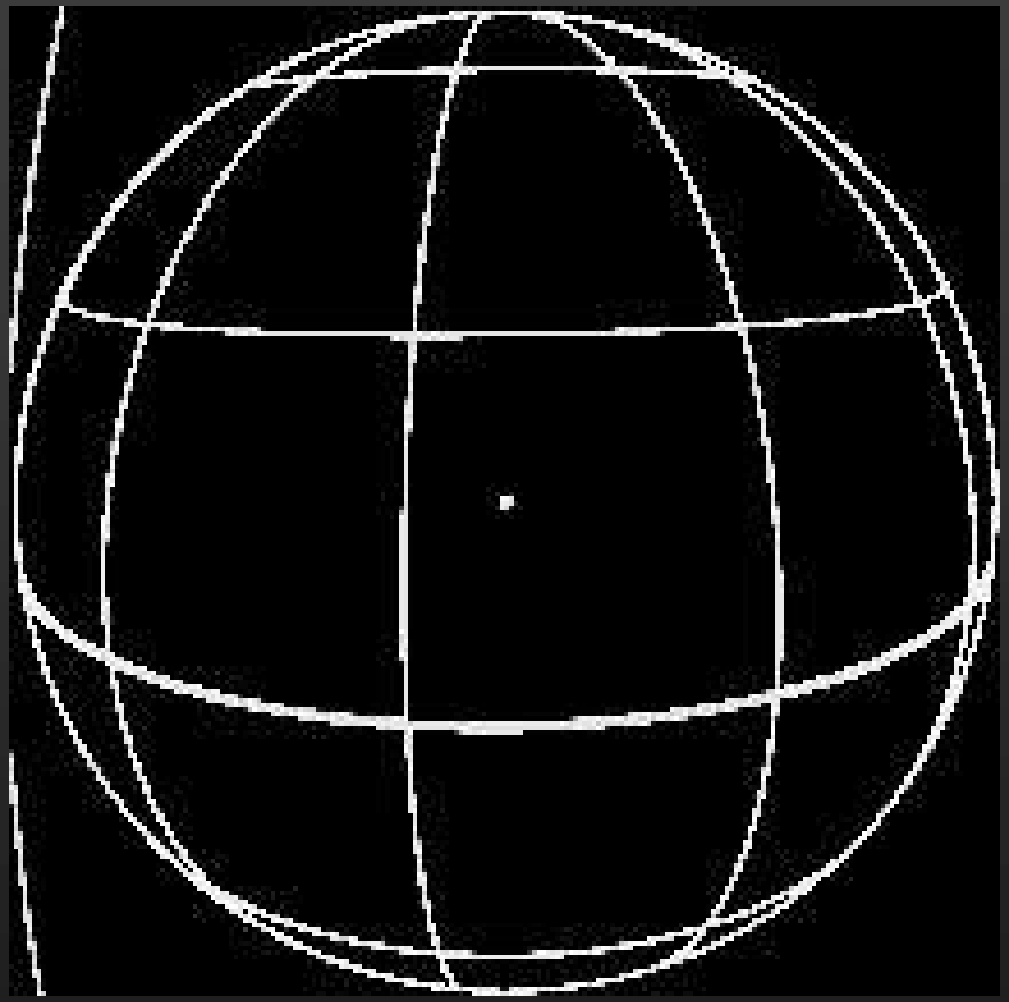
$$ds^2 = -\left(1 - \frac{R_G}{r}\right) dt^2 + \frac{dr^2}{\left(1 - \frac{R_G}{r}\right)} + r^2 (d\theta^2 + \sin^2\theta \, d\phi^2)$$



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

`Schwarzschild radius'

Gravitational Collapse of Massive Star



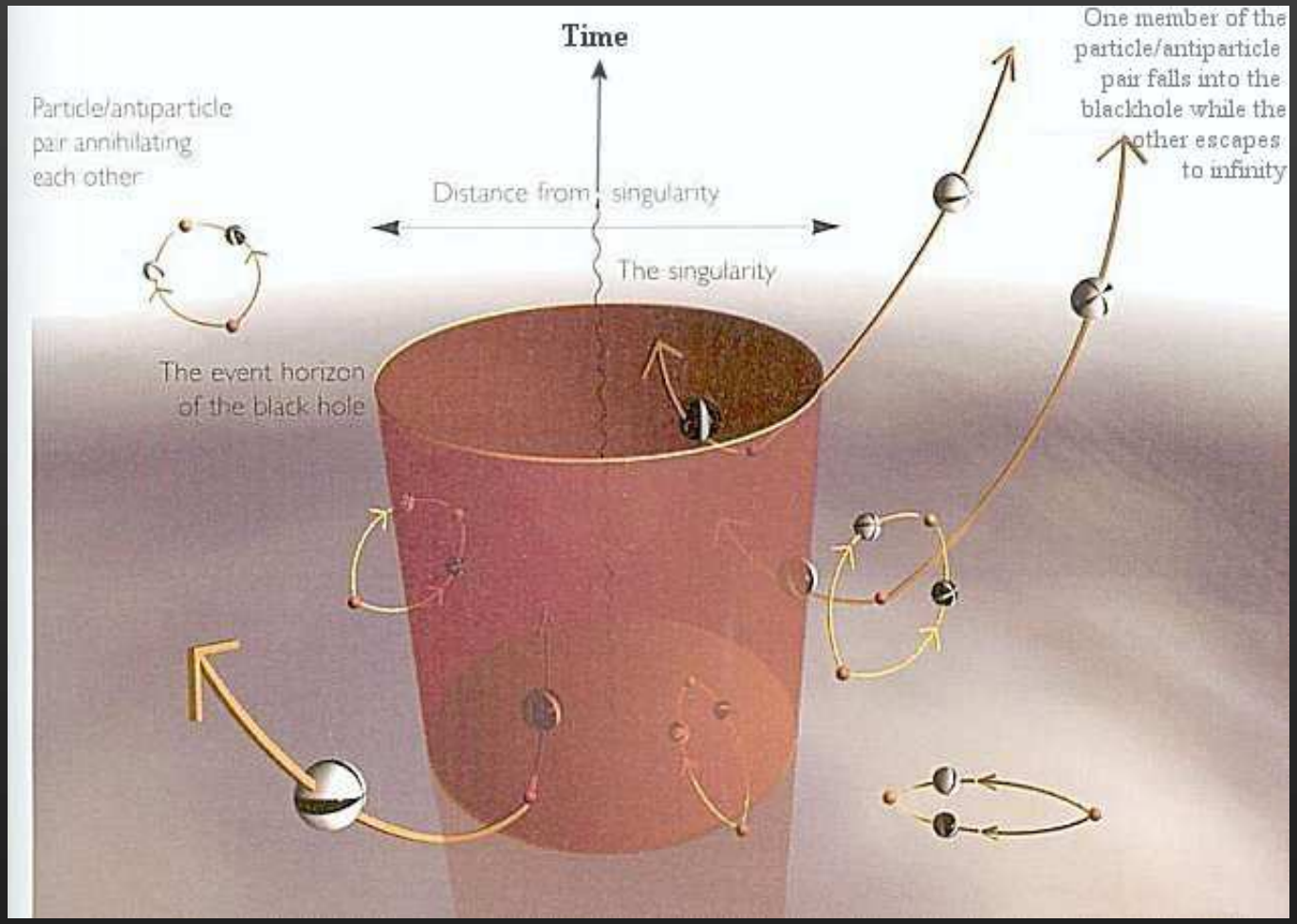
- surprising result:
  for far-away observer,
  star's surface `freezes'
  at event horizon
  (i.e., never crosses over)

- however: for observer
  riding on top of
  collapsing surface, this
  only takes a finite time!

- Q: How can both perspectives be right?

Quantum Mechanics of Black Holes

- Hawking radiation



à Black Holes slowly evaporate!

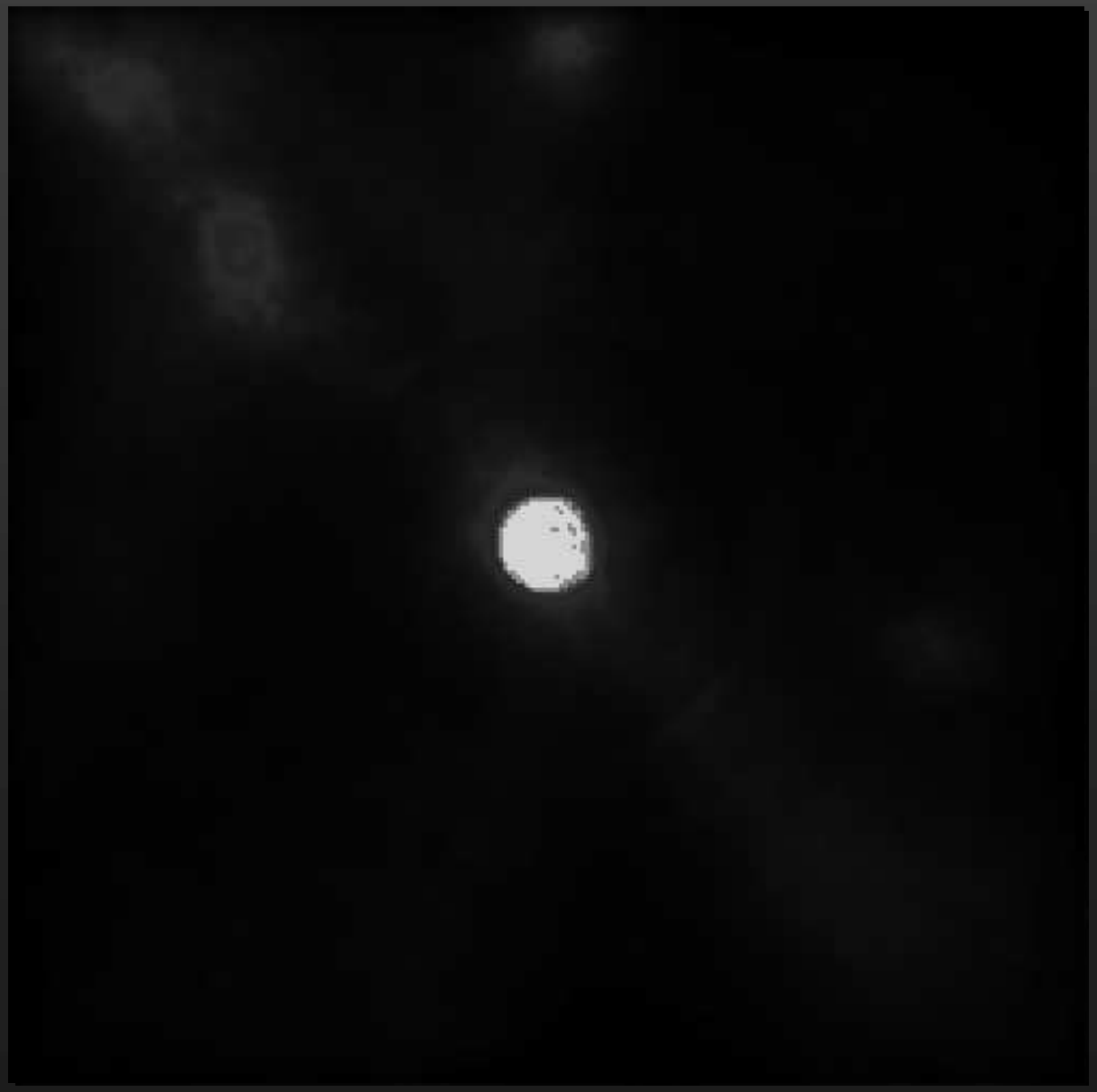
The First Stars

- formed at the end of the `Cosmic Dark Ages'

à First stars are predicted to be much more massive than stars today!

The First Supernova-Explosion

Gas density



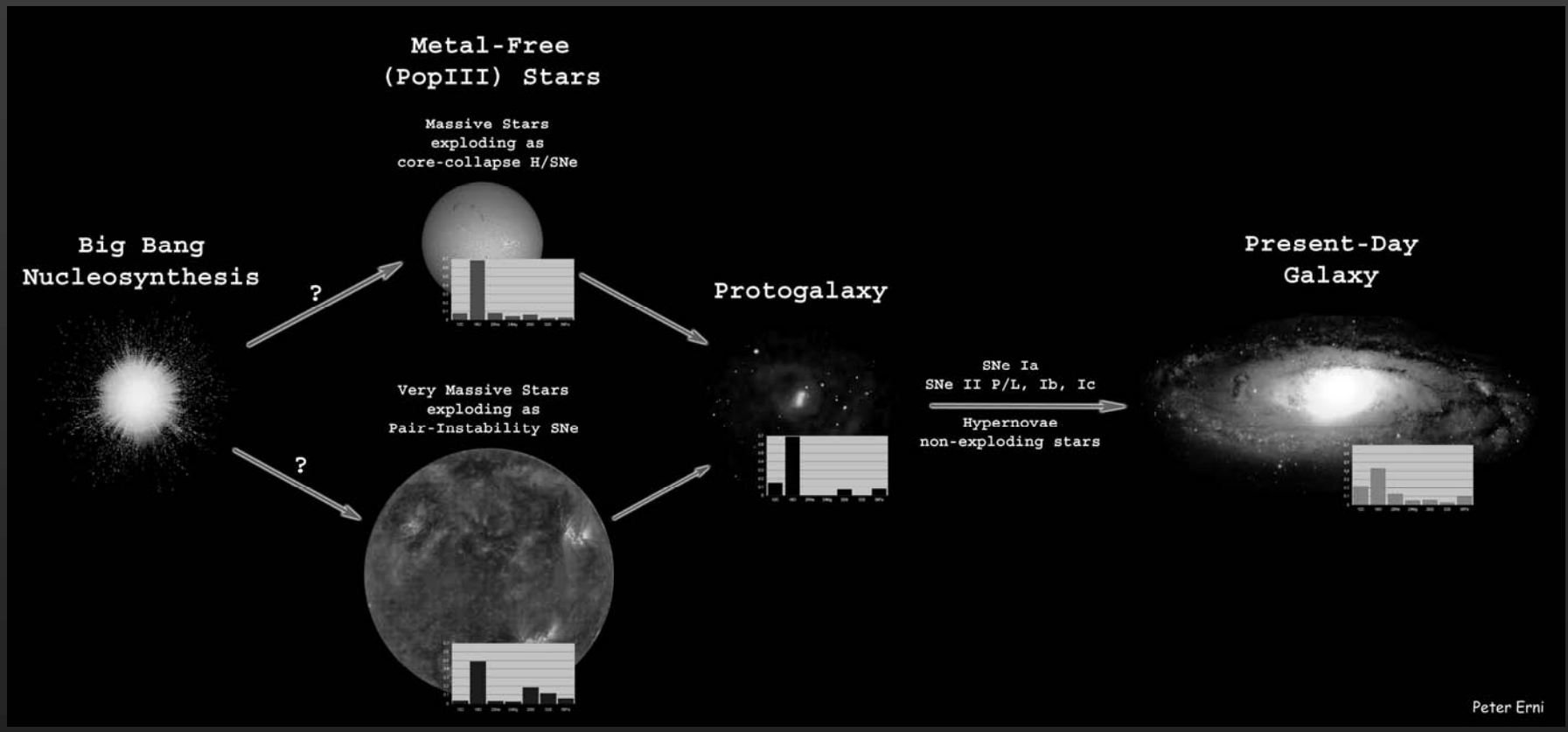
~ 1 kpc

- $E_{SN} \sim 10^{53}$ergs

- Complete Disruption (PISN)

The First Stars

- forging the first heavy elements (beyond helium)



à **Possibly unique kind of supernova:**
Pair-instability Supernova

COURSE WEBSITE:

www.as.utexas.edu/astronomy/education/spring07/bromm/353.php

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