

Astronomy 353 (Spring 2007)



ASTROPHYSICS: From Black Holes to the First Stars (Lecture 1: Introduction)

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## **Physics of Stellar Remnants**



## **Quantum Pressure in Stellar Remnants**

often called: ``degeneracy pressure''



Regular gas: many unfilled energy levels. Particles free to move about and change energy levels. **Degenerate** gas: all lower energy levels filled with two particles each (opposite spins). Particles **locked** in place.



# 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<sup>2</sup>
  - 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



#### **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'



#### COMPARING CHARACTERISTICS

Computer simulations have given scientists some indication of the possible masses, sizes and other characteristics of the earliest stars. The lists below compare the best estimates for the first stars with those for the sun.



SUN MASS: 1.989 × 10<sup>30</sup> kilograms RADIUS: 696,000 kilometers LUMINOSITY: 3.85 × 10<sup>23</sup> kilowatts SURFACE TEMPERATURE: 5,780 kelvins LIFETIME: 10 billion years

#### FIRST STARS

MASS: 100 to 1,000 solar masses RADIUS: 4 to 14 solar radii LUMINOSITY: 1 million to 30 million solar units SURFACE TEMPERATURE: 100,000 to 110,000 kelvins LIFETIME: 3 million years

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

## The First Supernova-Explosion

Gas density



## **The First Stars**

## forging the first heavy elements (beyond helium)



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



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announcments/updates

lecture notes

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