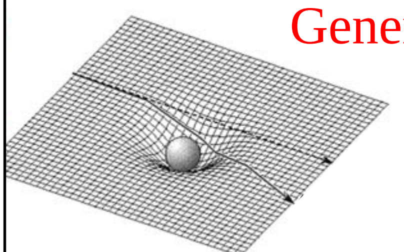
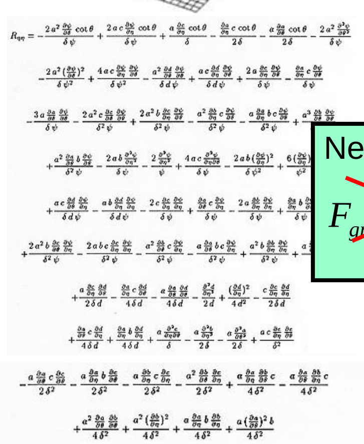
# Midterm 3

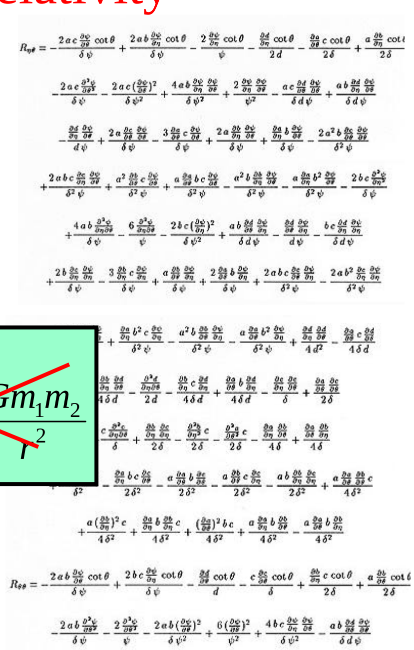
Homework 6 due late tonight.

- Sit in assigned rows, as for previous exams.
- Bring a photo-ID.
- Closed book, closed notes, no calculators etc.
- 34 multiple-choice questions *about the material covered in the lectures*.
- Suggestions for how to prepare:
  - Read study guide (on course web site).
  - Review lecture notes.
  - Then use textbook to reinforce what you know.
  - Use a few *relevant* sample questions to test your knowledge.

# General Relativity





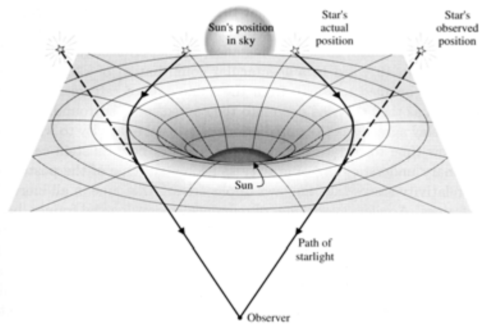


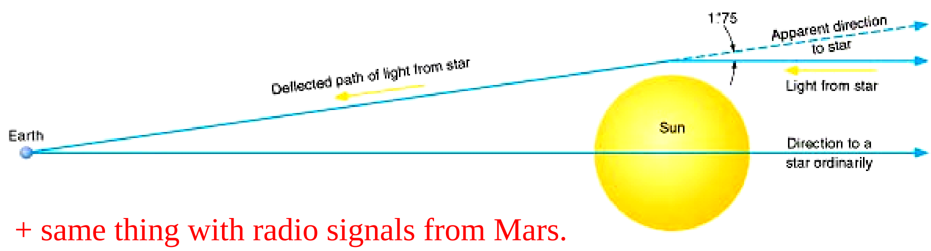
Newton:

$$F_{gravity} = \frac{Gm_1m_2}{r^2}$$

# Tests (Proofs) of General Relativity

- Bending of starlight in Sun's gravitational field.
  - Seen during 1919 eclipse



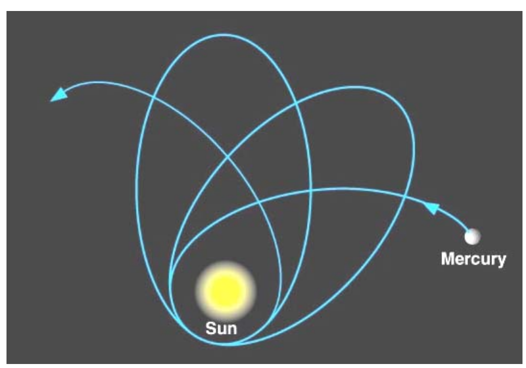

+ same thing with radio signals from Mars.

# Tests (Proofs) of General Relativity

- Precession of Mercury
  - 1/90 degree per century in excess of amount expected from Newton's laws.
    - Easy to observe because of long time span of observations.
  - GR predicts this.
  - Need extra planet to explain it with Newton's laws.

Orbits in strongly curved spacetime

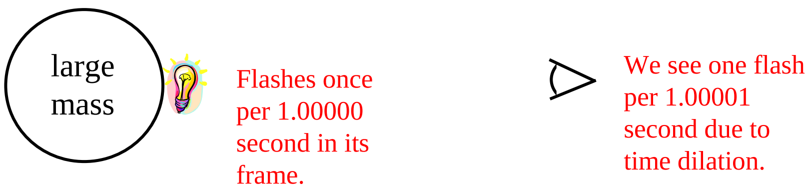
GR vs Newtonian orbits



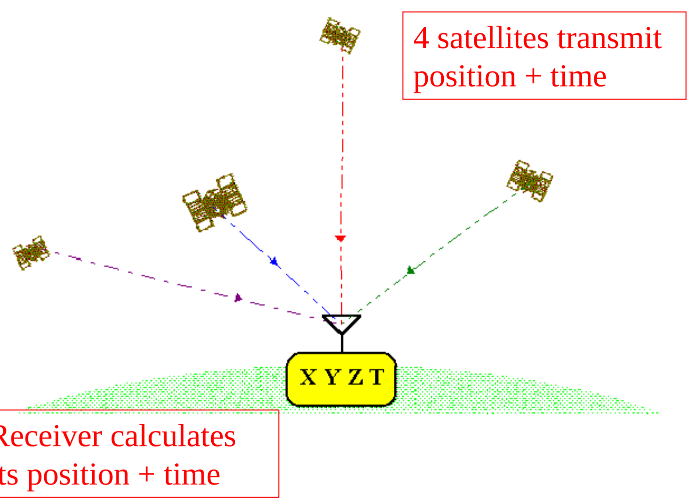
# Tests (Proofs) of General Relativity

- Time runs slower in stronger gravitational field
  - *General relativistic time dilation .*

- ➔ gravitational redshift: light waves emitted at different frequency than we receive them.
  - Observed from surface of white dwarfs.




# GPS Navigation





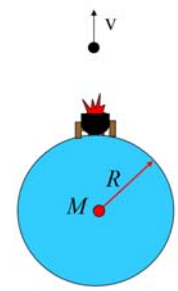
- General Relativity ➔ time runs faster in the satellites.
- If no correction applied, 6 mile position error after only 1 day!

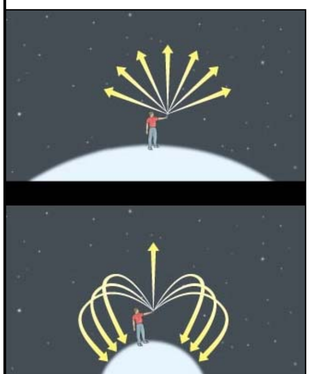
## Stars - Possible ending #3: a black hole

For M > 3M$_\odot$: Further collapse

➔ black hole

Mass is so concentrated that light cannot escape.



$$v_{escape} = \sqrt{\frac{2GM}{R}}$$

becomes greater than speed of light.

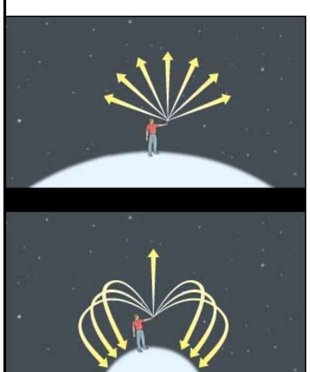
➔ photons can't escape.

$$R = \frac{2GM}{v_{escape}^2}$$

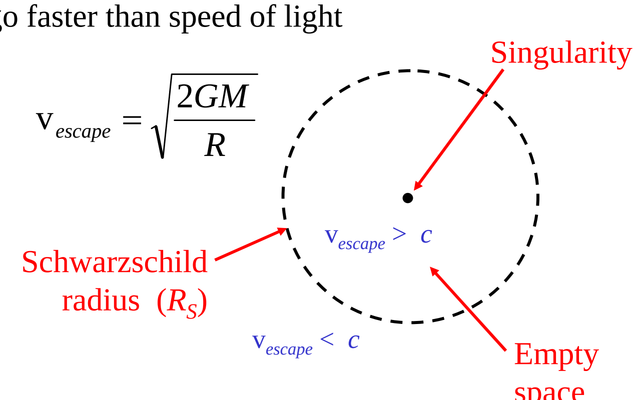
$$R_S = \frac{2GM}{c^2}$$ = *Schwarzschild radius*

## Schwarzschild Radius = $R_S$

- Light follows distorted paths slightly outside $R_S$.
- No wave phenomenon (*i.e.* no light) escapes from inside Schwarzschild radius.
  - Would have to go faster than speed of light



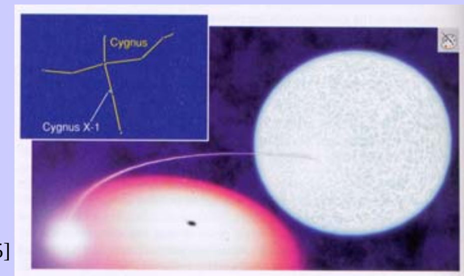
$$v_{escape} = \sqrt{\frac{2GM}{R}}$$



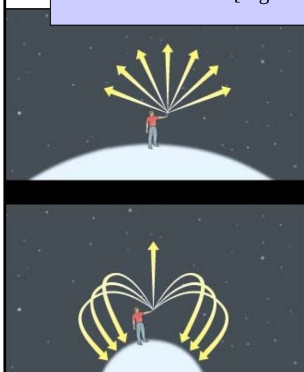

But gravity *does* escape.

X-ray binary:
Luminous star orbiting a black hole.
Cygnus X-1

[Fig 13.15]




- 
- m inside



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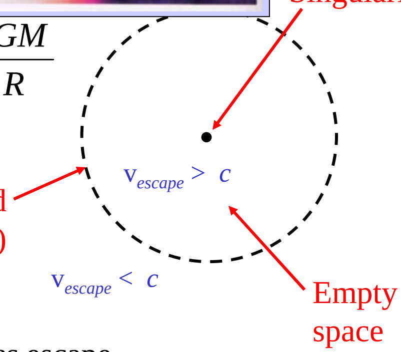
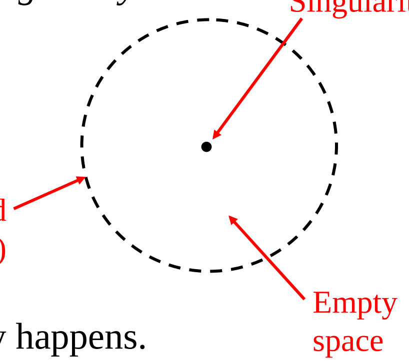



But gravity *does* escape.

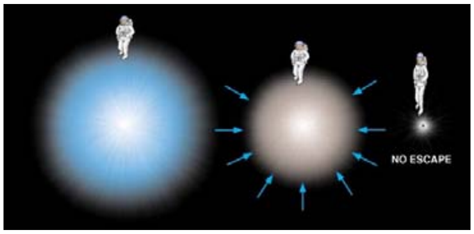
# What's Inside?

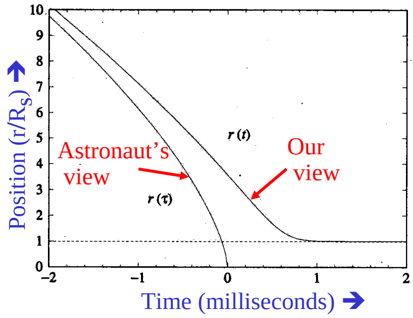
- Only known mathematical solutions are for free space.
- All mass concentrated at *singularity*.
  - Radius = 0
  - ➔ density = ∞ (infinity)




- We don't know what really happens.

# Falling into a Black Hole




## Astronaut's view:

- Tidal forces become stronger & stronger.
- Time runs normally.
- Nothing special happens at Schwarzschild radius.
- But singularity is real. *Splat!*

## Our view:

- Tidal forces become stronger & stronger.
- Time runs slower & slower.
- Astronaut never quite reaches Schwarzschild radius.
- No knowledge about interior.