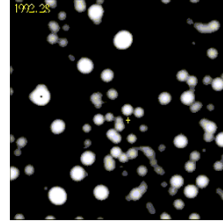


Black Holes & Quasars—19 Nov

- Test 3: Mon
- Missouri Club
 - Mon, 8:00-9:00am, 1420BPS
- No class on Wed, 11/24
- No pre-class questions for 11/29

- Black hole
 - Mass is so concentrated that nothing escapes
- Einstein's gravity
- Quasar
 - Black holes in the center of galaxies that is lit by material falling in toward the black hole.
- Evidence for black hole in center of Milky Way.



BH in center of Milky Way



Jet in galaxy M87

Objectives

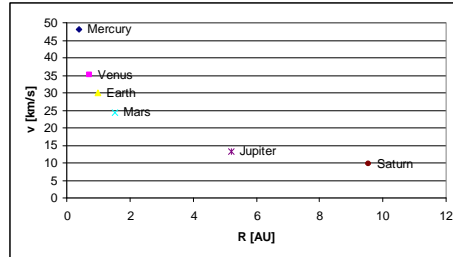
- What is a black hole?
- How does Einstein's theory of gravity modify ideas about space and time?

Laplace's argument for black holes (1796)

- The rotational speed at distance R from a mass M is

$$v^2 = GM/R$$

- Important Principle: Speed of light c is maximum speed.
 - If a signal can go faster than c , then you affect the past. You can kill your mom before your birth so that you were never born.
- For $M = M_{\text{sun}}$, $R = 1.5\text{km}$.
- If the sun were squeezed to be smaller than 1.5km, nothing can escape from it—not even light.



Black hole in Einstein's Gravity

- Event horizon: Regions outside the event horizon can send light to distant observers. Inside the event horizon, no signal can be sent.
- The Schwarzschild radius is the radius of the event horizon.

$$R_S = GM/c^2$$

- For a solar mass, $R_S = 3\text{km}$.

Space is curved near a black hole

- You learned that the circumference of a circle is $2\pi R$.
- The presence of a black hole modifies this.
 - There is extra distance along a radial line.
- The circumferences of circles at R_S and at $2R_S$ are $2\pi R_S$ and at $4\pi R_S$.
- 1. If there were no black hole nearby, the radial distance between these two circles is
 - A. 0
 - B. R_S .
 - C. $2R_S$.
- The actual radial distance is $2.296R_S$.

Time is distorted near a black hole

- Joe is at $1.007R_S$ and Colin is at $2R_S$. Joe's mom and Colin's mom send them birthday emails every year.
- The presence of a black hole modifies this.
 - Less time passes near the black hole.
- 1. If there were no black hole nearby, Joe & Colin receive emails
 - A. every year.
 - B. More often than every year.
 - C. Less often than every year.
- Joe gets a birthday email every month. Colin gets one every 8.5mo.

Time and space are distorted by gravity

- Einstein's Law of Gravity: an object feels the distortion of time and space and changes its direction and speed.
- Einstein's theory using distortion is equivalent to Newton's theory if $GM/(rc^2)$ is small.
- In solar system, E's theory shows orbit of Mercury is not exactly an ellipse. Perihelion of ellipse rotates once every 3.2Myr.
- Gravity bends path of light.

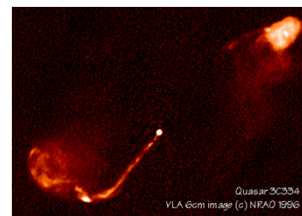
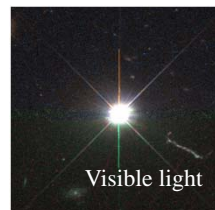


Objectives

- How was the first quasar discovered?
- What supplies the energy of a quasar?

Discovery of quasars (quasi-stellar objects)

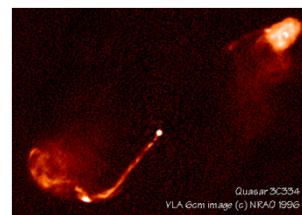
- Some sources of radio waves are coincident with stars.
- Stars do not emit light at radio wavelengths.
- Are they some kind of weird star within the Milky Way Galaxy?



Radio light

Discovery of quasars (quasi-stellar objects)

- Maarten Schmidt gets a spectrum.
 - “Star” was moving at 40,000 km/s. (Hwk 7)
 - Fastest stars in Milky Way move at 200km/s.
- 1. Why is it moving so fast?
 - A. It is in a distant galaxy.
 - B. It was shot out of the MW.



Radio light

Energy source of quasars

- A quasar is brighter than a whole galaxy with billions of stars radiating.
- When hydrogen fuses into helium, 0.7% of the mass turns into energy. In the sun, 10% of the mass is fused, and it takes 10Byr.
- When mass falls towards a black hole to radius R,

$$v^2 = GM/R$$
- If $R=1.1R_s$, v is 95% speed of light.
 - Temperature is hot. Hot enough to emit x-rays.
- Energy creation is efficient. About 10% of the mass can be converted into energy. Time is very short.