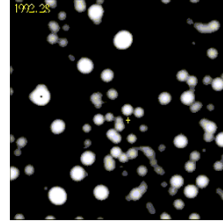


Black Holes in Galactic Center—29 Nov

- Schedule for the rest of the semester
 - “Recombination,” Universe at 400,000 years
 - Weighing the universe
 - How much matter is there in a 1m box?
 - Surprising answer: The gravity of the dominant matter repels.
- Evidence for black hole in center of Milky Way.
- Black hole in M87, the biggest galaxy in the Virgo cluster.
- Every galaxy has a massive black hole.



BH in center of Milky Way



Jet in galaxy M87

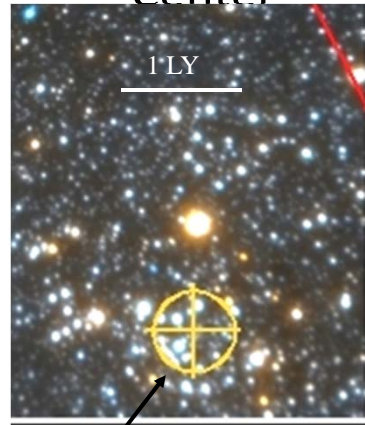
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Objectives

- How do astronomers measure the mass of black holes?
- What is the evidence for a black hole in the center of Milky Way Galaxy? In the center of M87?

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Infrared Images of the Galactic Center



Galactic Center
(Sagittarius A*)

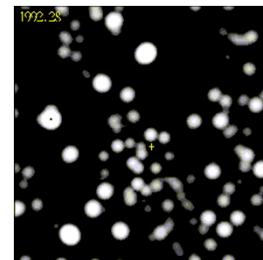
Using
“adaptive
optics”
technique on
Gemini 8m
telescope.

Density of stars is 300,000 x
that in vicinity of Sun

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The center of the Milky Way

- Movie was made by taking pictures over a 4 year span of time.
- Stars in the center move because they are in orbit around a black hole.
- 1. What have you already learned about the orbit of stars around a black hole? L1: The shape of the orbits. L2: The orbital speed vs. distance. L3: The relationship between period and semi-major axis.
 - A. L1 does not apply
 - B. L2 does not apply.
 - C. All three apply.
 - D. L3 does not apply.
- If the mass is a point compared with the distance of closest approach, then Kepler’s Laws apply.
- If Kepler’s Law are violated, then the mass is not a point. It is spread out.



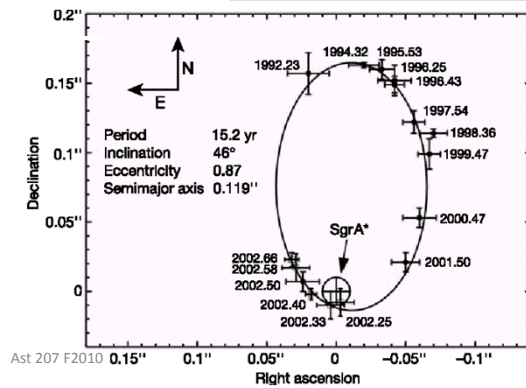
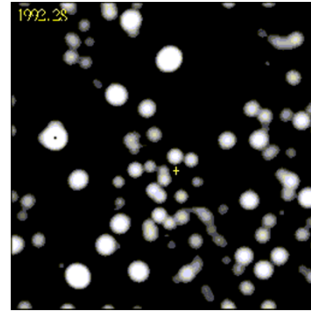
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Black Hole at the Center of the Milky Way Galaxy

- From 2002.25 to 2002.40 (0.15yr), star moved same as it did from 1995.53 to 1996.43 (0.9yr).

- Why did the star move so fast when it was near Sgr A*?
 - Kepler's law of equal areas
 - It got sucked in by the black hole.
 - The black hole spit it out.
 - There is mass near the black hole

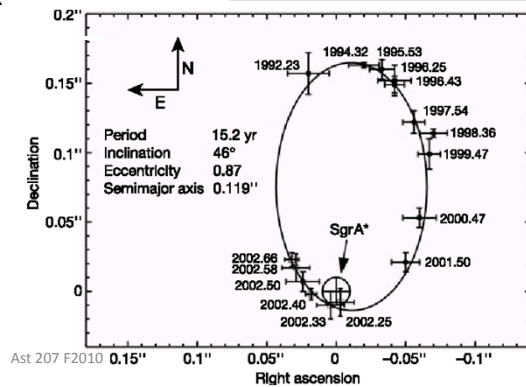
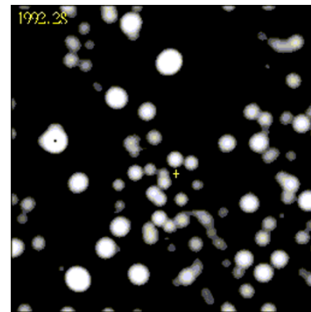
Infrared observations over 6 years.



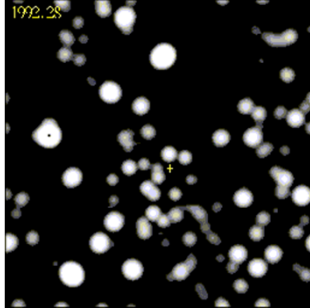
Black Hole at the Center of the Milky Way Galaxy

- Orbit is an ellipse tilted by 46°.
- Data from 2002 goes within 60AU from black hole. [Orbit of Pluto is 40AU.]
- Within 60AU, the mass at SgrA* acts like a point.
- Orbit is consistent with Sag A being a black hole.

Infrared observations over 6 years.



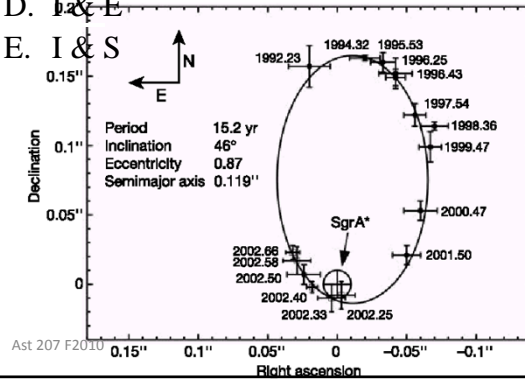
The Black Hole at the the Galactic Center



Measure orbits of stars in very center.

1. To deduce the mass, what quantities do you need from the figure?

- A. Period & inclination
- B. P & eccentricity
- C. P & semi major axis
- D. I & E
- E. I & S



Mass of the black hole in the center of our galaxy

- A star orbits Sgr A in an elliptical orbit with a period of 15 yr. The semi major axis of the orbit is 950AU. Show how to find the mass of Sgr A. Give the numerical answer for the mass. (It is easiest to express the mass in solar mass, rather than in kg.)
- 1. What is the key big idea needed to figuring out the mass from the observations?
 - A. Kepler's 3rd Law
 - B. Orbit is an ellipse.
 - C. Period is expressed in years.
 - D. Semi major axis is expressed in AU.
- Use Newton's version of Kepler's Third Law: $P^2 = R^3/M$, where the period P is in years, the semi major axis R is in AU, and the mass M in solar masses.

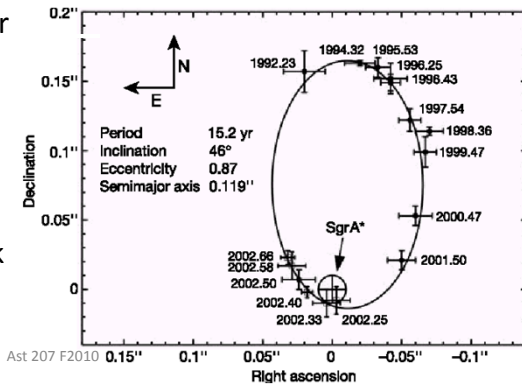
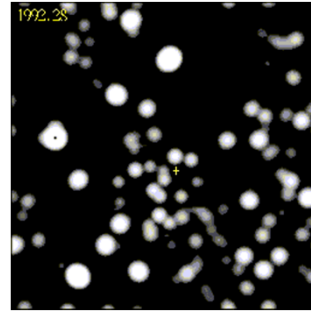
$$M = R^3/P^2 = 950^3/15^2 = 4 \times 10^6 M_{\text{sun}}$$

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Black Hole at the Center of the Milky Way Galaxy

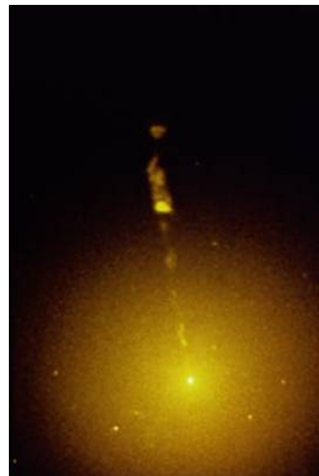
- Orbit is an ellipse. Data from 2002 goes within 60AU from black hole. [Orbit of Pluto is 40AU.]
- Within 60AU, the mass at SgrA* acts like a point.
- Orbit is consistent with SgrA* being a black hole.
- If SgrA* is made of stars, there would be a million stars packed within the size of the solar system. The stars would collide.
- Therefore SgrA* is a black hole.

Infrared observations over 6 years.



Measurement of Mass of Black Hole in M87

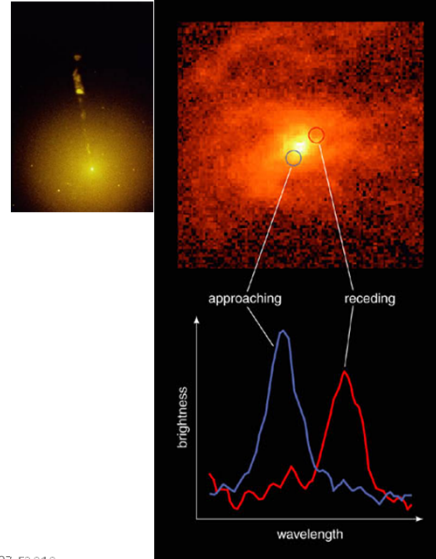
- M87 is the biggest galaxy in the Virgo Cluster
 - The bright center may be a dense concentration of stars.
1. What must you measure to find the mass of the black hole in M87, a big elliptical galaxy?
 - a. Luminosity of nucleus
 - b. Distance to M87
 - c. Size of orbit & speed of something in orbit
 - d. Speed of ejected material



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Measurement of Mass of Black Hole in M87

- To find the mass of black hole in M87, a big elliptical galaxy, use Kepler's 3rd Law.
 - Mass = $R^3/P^2 = RV^2$
 - R = 60ly
 - V = 800km/s
 - M = 3Billion M_{\odot}
 - (1000 times mass of the black hole in center of Milky Way.)
- If the mass were stars, density is 15,000 times that in sun's neighborhood.



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Every galaxy has a massive black hole in the center

- There is a 3Billion M_{\odot} black hole in the center of M87, and a 4Million M_{\odot} black hole in the center of Milky Way.
- Karl Gebhardt (and others) found that the mass of the black hole is proportional to the mass of the galaxy. (Karl was an MSU graduate student; now a prof. at U Texas.)
 - Every galaxy has a massive black hole in the center.
 - The mass of the black hole (tiny in size) is related to the mass of the galaxy (big in size).
- Summarizing questions
 - What is the evidence for a massive black hole at the center of the Milky Way Galaxy?

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