Black Holes: X-Rays and Sizes

• X-rays
• Black hole masses
• X-ray sources in other galaxies
• Beaming
• A nebula around a black hole
How do we know that quasars are no larger than the solar system?

A) The are too luminous to be very large.
B) The appear point like when viewed through a telescope.
C) The contain black holes.
D) The vary in brightness on time scales of days or weeks.
Black holes are invoked to explain quasars because

A) We can directly see matter falling across the event horizon
B) Quasars emit no light
C) Quasars are very distant
D) Black holes are very efficient and compact power generators
Black holes shine brightest in X-rays

Why?
Luminosity versus radius and temperature

\[ R = R_{\text{Sun}} \]
\[ T = T_{\text{Sun}} \]
\[ R = R_{\text{Sun}} \]
\[ T = 2T_{\text{Sun}} \]

Which star is more luminous?

The hotter star is more luminous.

Luminosity varies as \( T^4 \) (Stefan-Boltzmann Law)
Luminosity Law

\[
\frac{L_A}{L_B} = \frac{R_A^2 T_A^4}{R_B^2 T_B^4}
\]

If star A is 2 times as hot as star B, and the same radius, then it will be \(2^4 = 16\) times as luminous.
Eddington Luminosity

Gravity

X-rays
Black holes shine brightest in X-rays

- Take BH of one solar mass
- Event horizon is 3 km or 1/200,000 of Sun’s radius
- Luminosity can be 30,000 time the Sun’s luminosity
Black holes shine brightest in X-rays

\[
\frac{T_{BH}}{T_{Sun}} = \left( \frac{R_{BH}}{R_{Sun}} \right)^{-1/2} \left( \frac{L_{BH}}{L_{Sun}} \right)^{1/4}
\]

\[
\frac{T_{BH}}{T_{Sun}} = \left( \frac{1}{200,000} \right)^{-1/2} \left( 30,000 \right)^{1/4}
\]
Black holes shine brightest in X-rays

\[
\frac{T_{BH}}{T_{Sun}} = \left(\frac{1}{200,000}\right)^{-1/2} \left(30,000\right)^{1/4} = 6000
\]

\[
\frac{T_{BH}}{T_{Sun}} \approx 450 \times 13 \approx 5900
\]

\[
T_{BH} \approx 5900 \times 5800 \text{ K} \approx 30,000,000,000 \text{ K}
\]
A star’s color depends on its surface temperature.

- **a** This star looks red
- **b** This star looks yellow-white
- **c** This star looks blue-white
Black holes are so hot that they mainly produce X-rays.
In X-rays, the night sky glows with the light of black holes, not normal stars.
Accretion disks around black holes are extremely hot because

A) The spin rapidly
B) The black hole focuses light onto the disk
C) A large amount of energy is released in a small region
D) They're smoking
About how large is the radius of a 1 million solar mass black hole such as those which may exist at the centers of many galaxies?

A) a few km
B) a few thousand km
C) a few million km
D) a few billion km
Black hole masses

• Two types of black holes
• Stellar mass black holes are up to 30 solar masses, formed in collapse of stars
• Supermassive black holes are $10^6$-$10^9$ solar masses, found only in the nuclei of galaxies

• Is there anything in between?
Starburst galaxy – M82
Starburst galaxy M82 in X-rays

Green cross is center of galaxy
Bright X-ray source is 15,000,000 solar luminosities
From Eddington limit, looks like a 500 solar mass black hole
Beaming

Is the source really as luminous as it looks or are the X-rays in a beam pointing towards us?
Nebula surrounding a BH

• X-rays from the BH ionize Helium in the nebula which causes the Helium to emit one particular spectral line
• By counting the number of photons in this spectral line of Helium, we can count the number of X-rays and find the true X-ray luminosity in all directions
Nebula around a black hole

- Hγ
- HeII λ4686
- Hβ
- [OIII] λ4959
- [OIII] λ5007
Nebula around a black hole

Black hole is at least 750,000 solar luminosities.

Mass is at least 25 solar masses.
Review Questions

• Why do black holes shine brightest in X-rays?
• How can the luminosity of a black hole be used to estimate its mass? Why is this method sometimes uncertain?
• Are there medium-sized black holes in the Universe?