

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) They are too luminous to be very large.
- B) They appear point like when viewed through a telescope.
- C) They contain black holes.
- D) They vary in brightness on time scales of days or weeks.

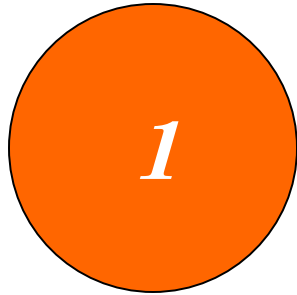
Black holes are invoked to explain quasars because

- 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

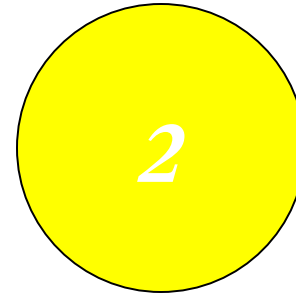
Why?

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.

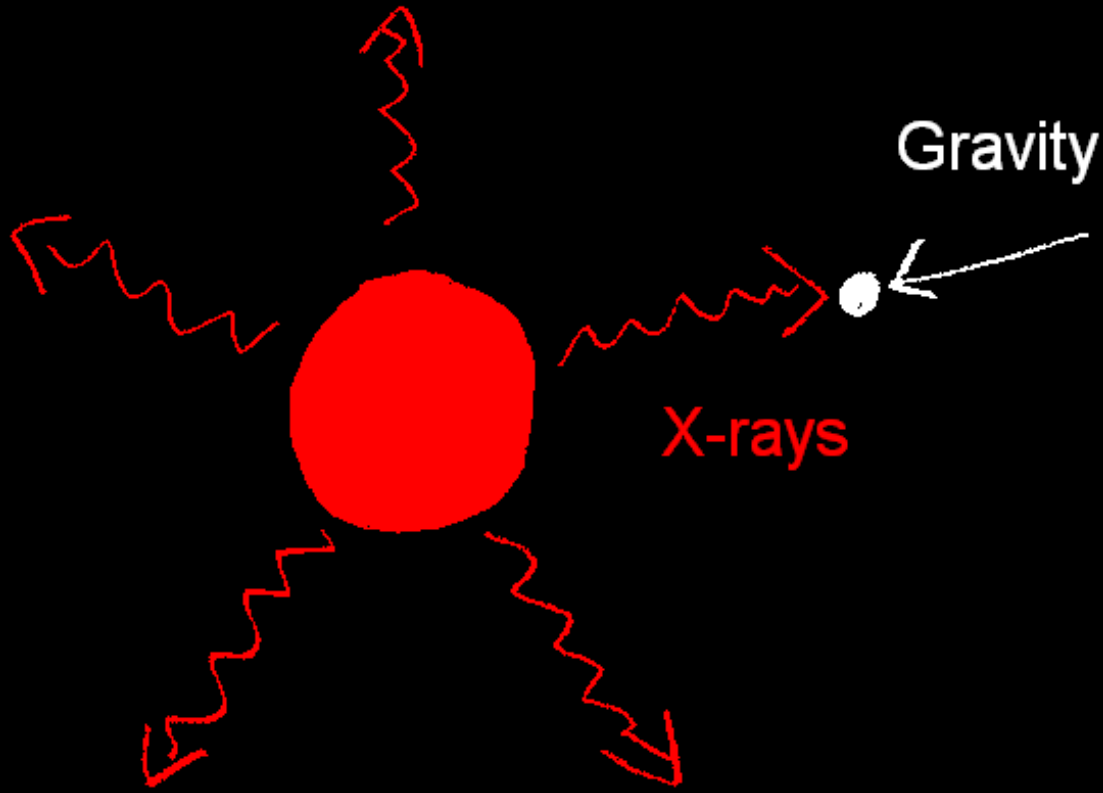
Luminosity varies as T^4 (Stefan-Boltzmann Law)

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



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 times the Sun's luminosity

Black holes shine brightest in X-rays

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

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

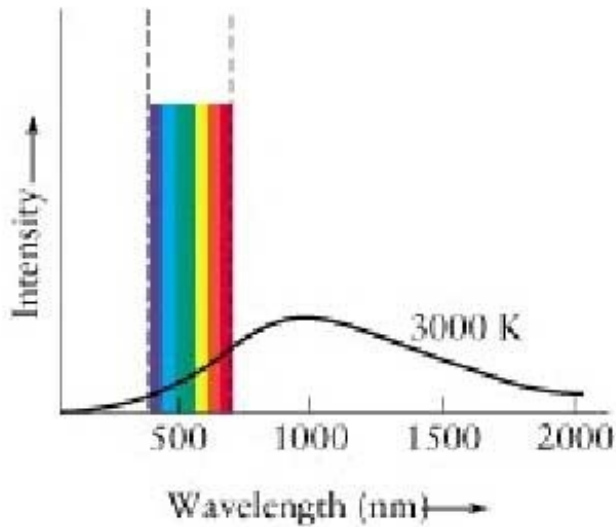
Black holes shine brightest in X-rays

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

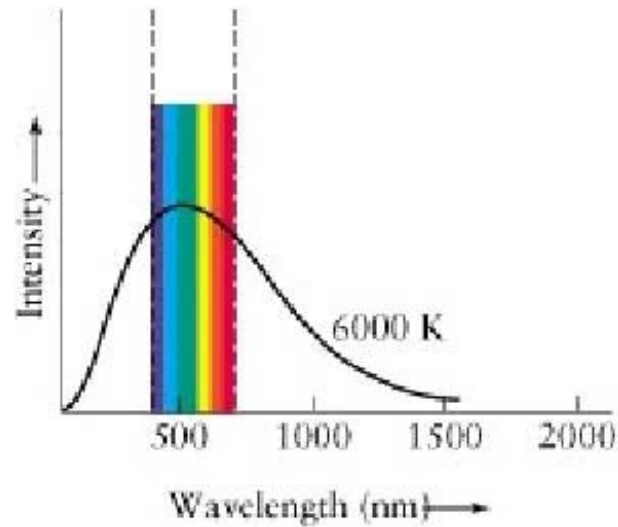
$$\frac{T_{BH}}{T_{Sun}} \approx 450 \times 13 \approx 5900$$

$$T_{BH} \approx 5900 \times 5800 \text{ K} \approx 30,000,000 \text{ K}$$

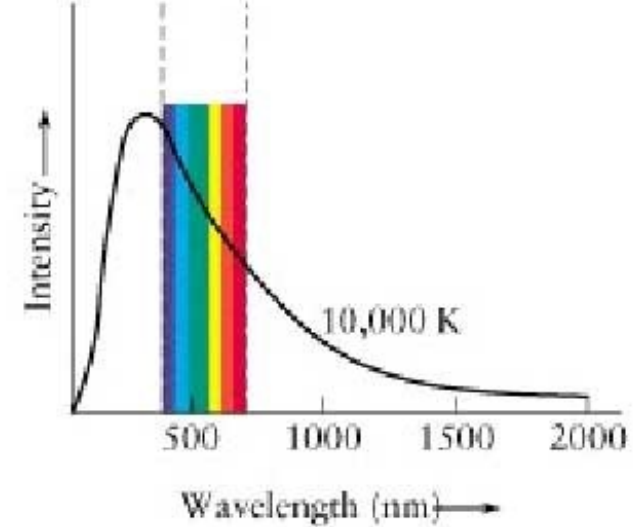
A star's color depends on its surface temperature



a This star looks red

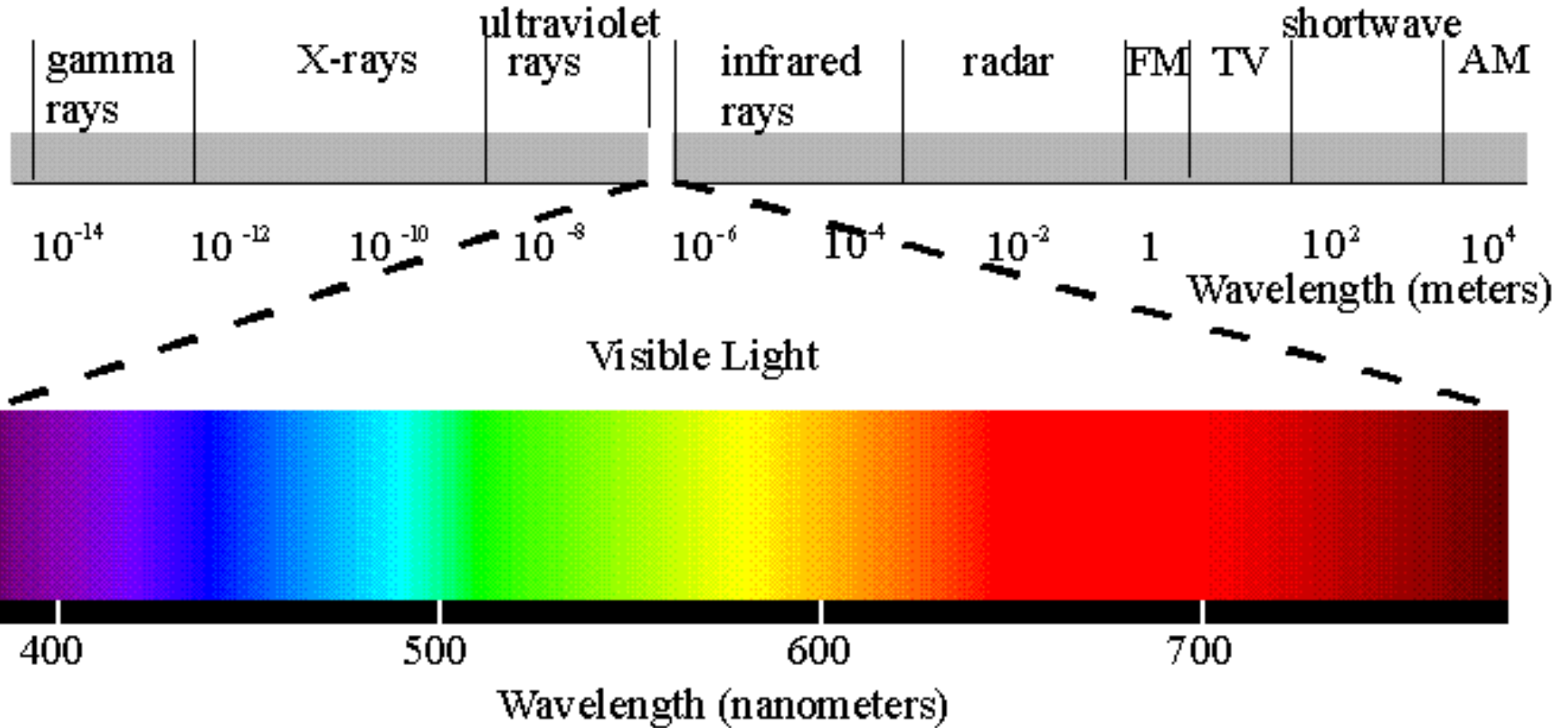


b This star looks yellow-white



c This star looks blue-white

Electromagnetic spectrum



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

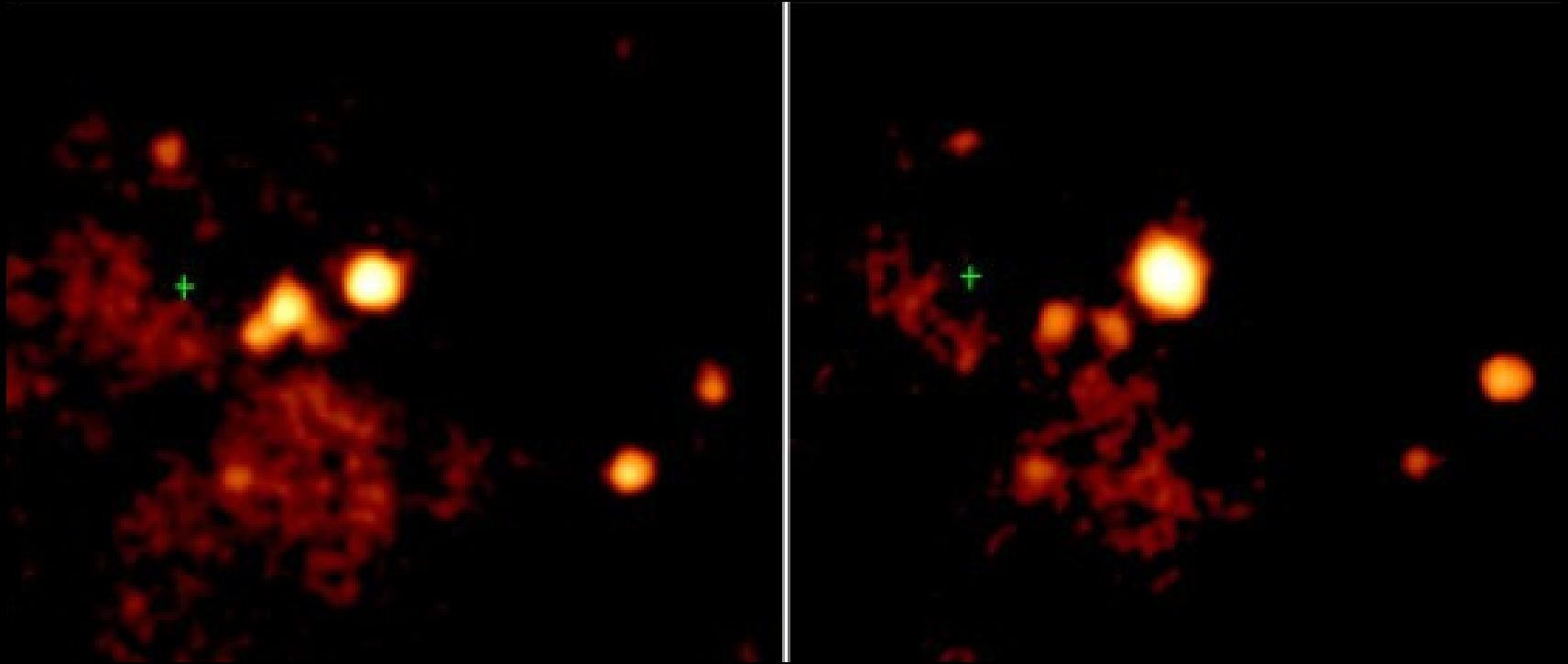
Black hole masses

- 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

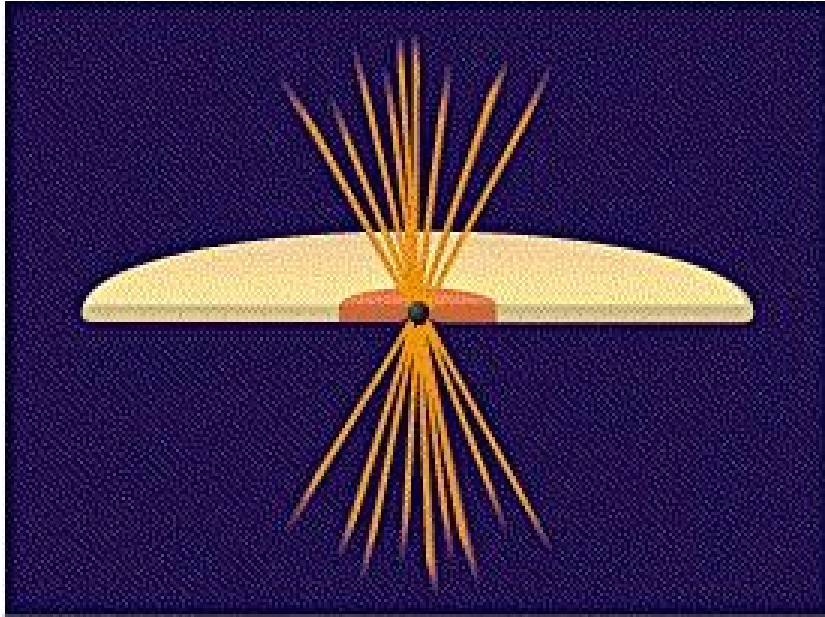


Green cross is center of galaxy

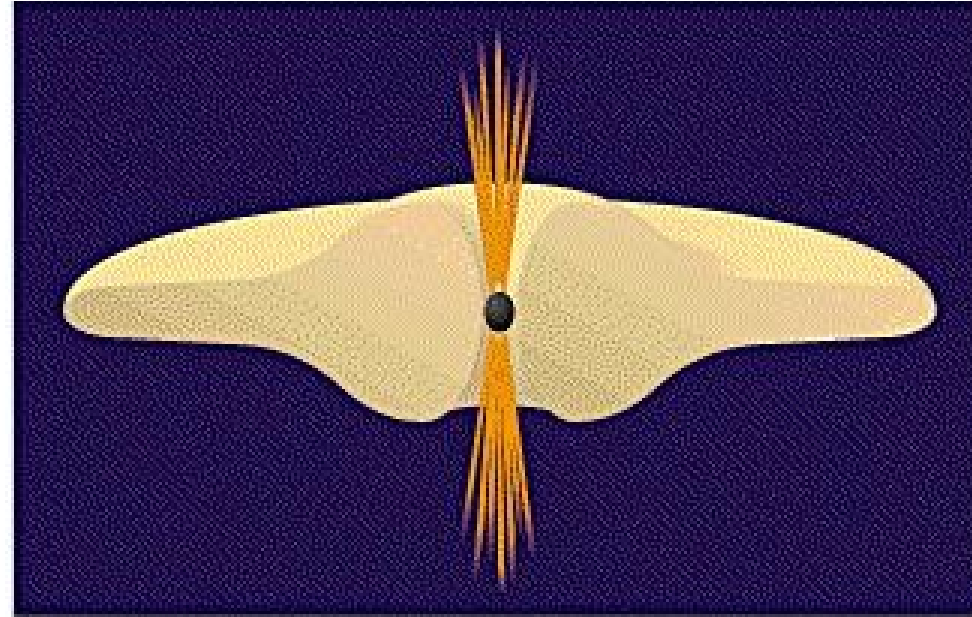
Bright X-ray source is 15,000,000 solar luminosities

From Eddington limit, looks like a 500 solar mass black hole

Beaming



A Thin disk: Slow accretion of matter

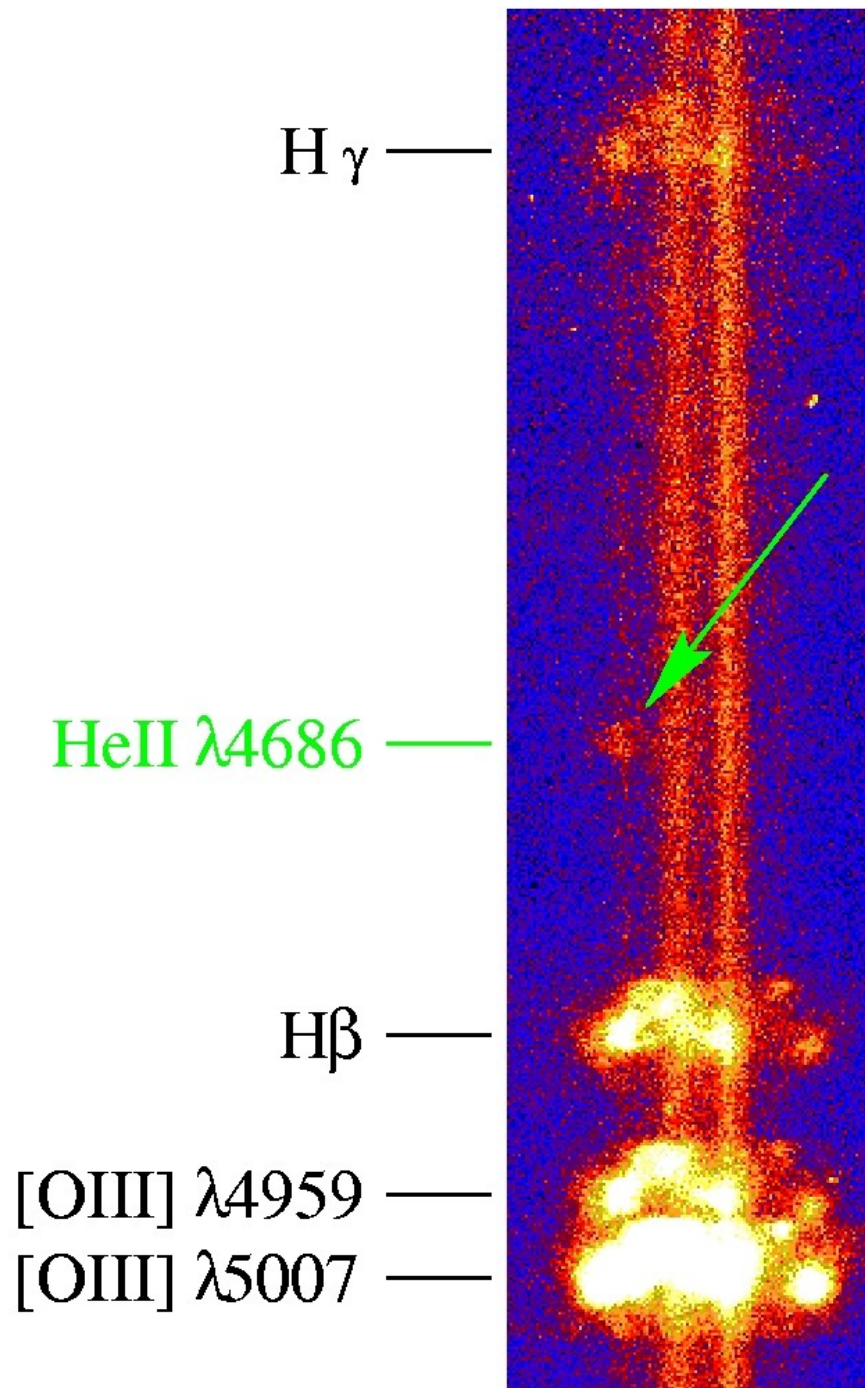


B Thick disk: Rapid accretion of matter

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

Nebula surrounding a BH

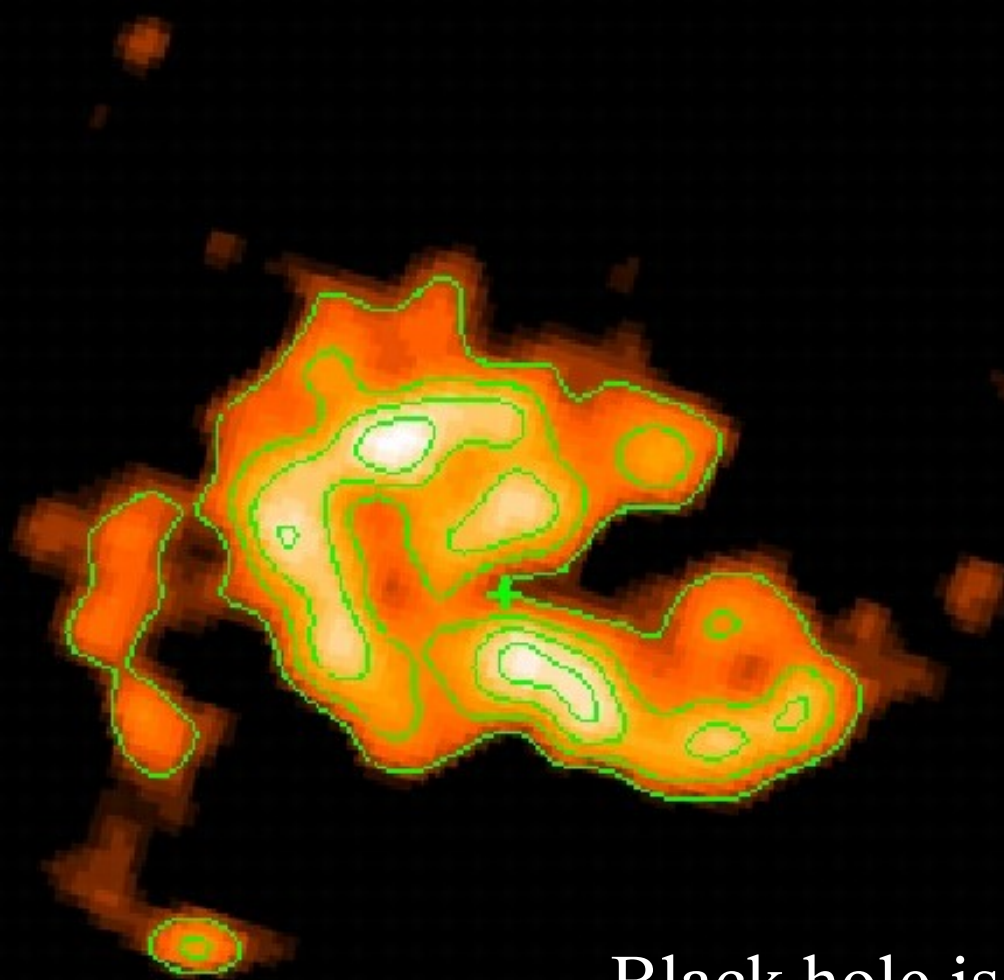
- X-rays from the BH ionize Helium in the nebula which causes the Helium to emit one particular spectral line
- By counting the number of photons in this spectral line of Helium, we can count the number of X-rays and find the true X-ray luminosity in all directions



Nebula
around a
black
hole

Nebula around a black hole

N



HeII

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?