Exam #2 is next class– November 14th!

Outline

- What happens when you approach a blackhole?
- Two types: rotating and not rotating
- Blackholes have mass, charge, and spin.
- Review

Exam #2

- **Date:** Friday, Nov 14th
- **Place and Time**: In class, at the normal 12:00-12:50 pm time.
- **Format**: 40 multiple choice problems and 2 bonus questions (extra credit).
- **Bring:**
  - Yourself, well-rested and well-studied
  - A #2 pencil
  - On the test you will be given numbers or equations (if any) that you will need. You may **not** use your book or your class notes.

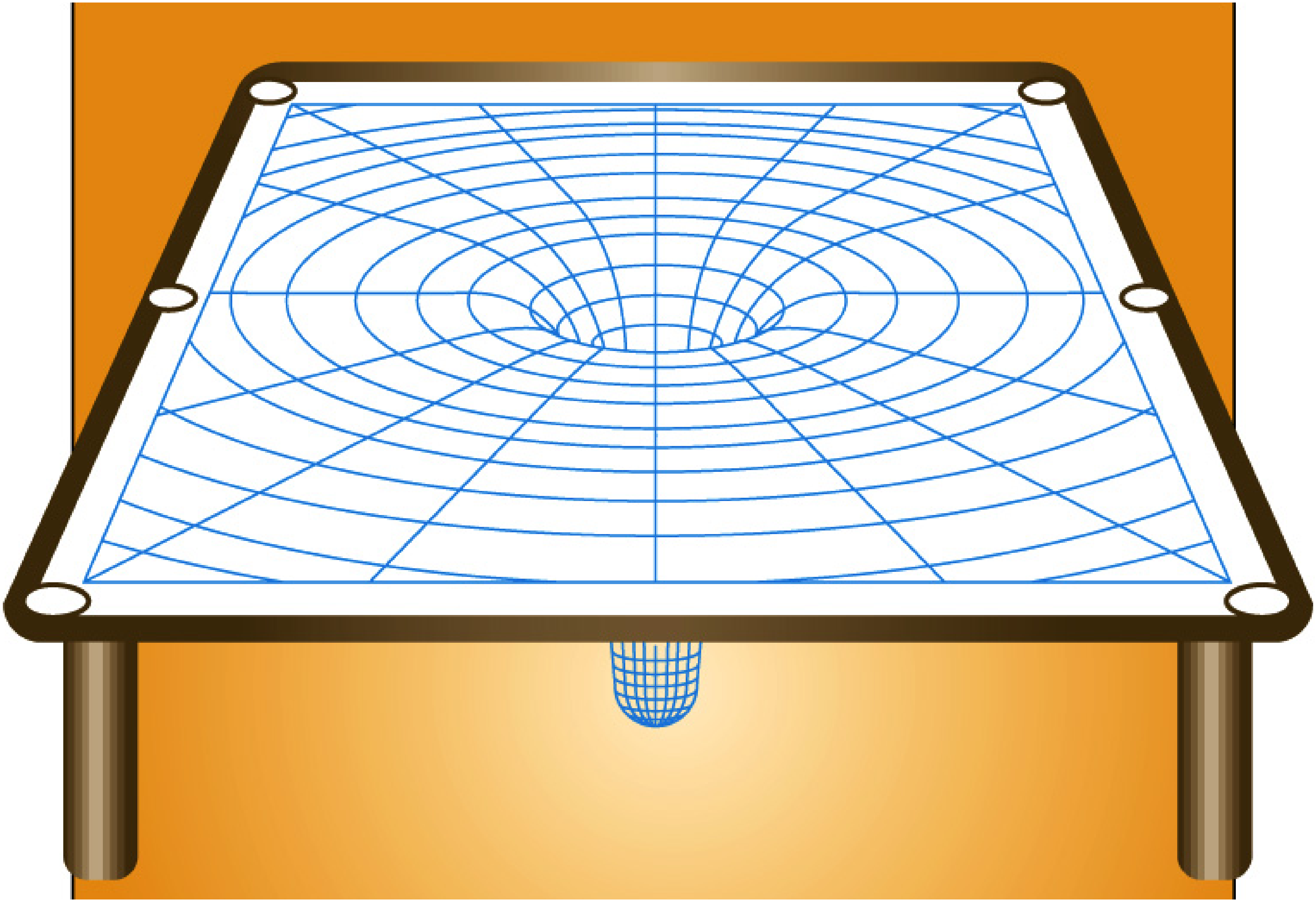
Exam #2

- **Topics included**: All material from the Sun through blackholes. Lecture and reading material are both included. My goal is to test for understanding of the concepts we have discussed, and how they fit together.
- **Study tips.** We have covered a lot of material in a short time, so here are some tips on how to approach your studies for the exam.
  - Topics covered in lectures should be stressed.
  - Homework questions have good examples of questions that may show up on the exam. An excellent way to begin studying is to review the homework problems, particularly those you missed (or got right but were not so sure about). Be sure you understand what the right answer is, and more importantly, **why** it is right.
  - You will need to understand and be able to use any equations that have been introduced in class. Calculations using these equations will be kept simple--it is possible to do the exam without a calculator, but you can bring one if you wish.

Exam #2

- **In-Class Q and A:** On Wed., Nov. 5th, some time will be allotted in class to ask questions about material on the exam. For example, if there are homework answers you do not understand, this would be an excellent time to ask. To get the most out of this time, you are strongly encouraged to begin studying prior to this class.
- **Out of Class Q and A:** On Thursday, Nov. 13th, I will have office hours from 10:30 to 11:30am and Justin will have TA office hours at 4:00 to 6:00pm. You should bring questions.

Curved Space



The Event Horizon

Where the escape velocity = the speed of light

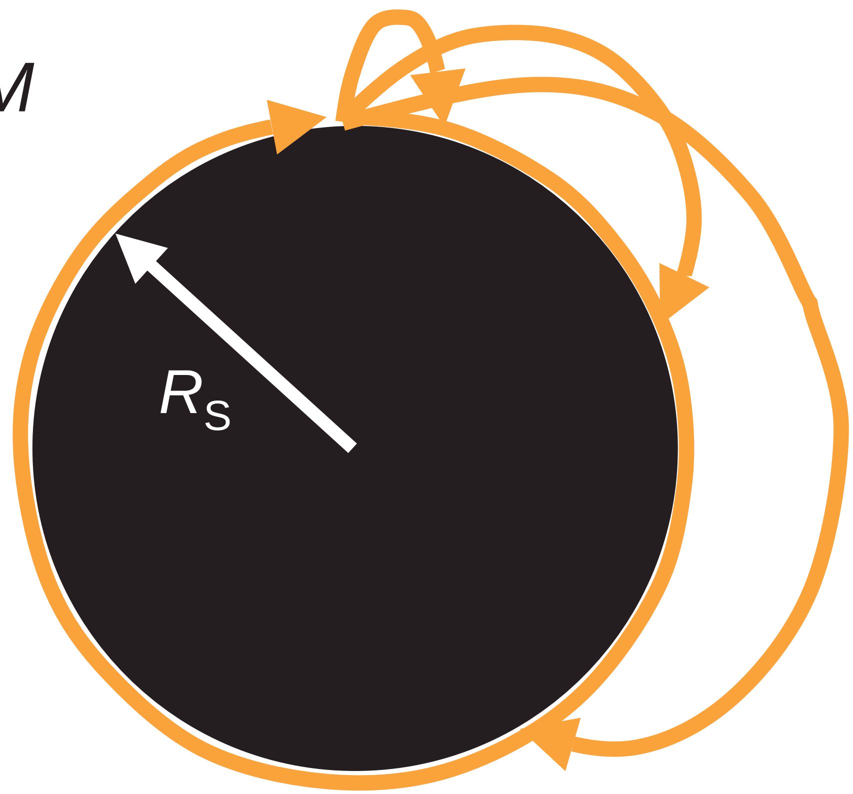
Nothing can escape from within that radius

Schwarzschild radius for mass *M*

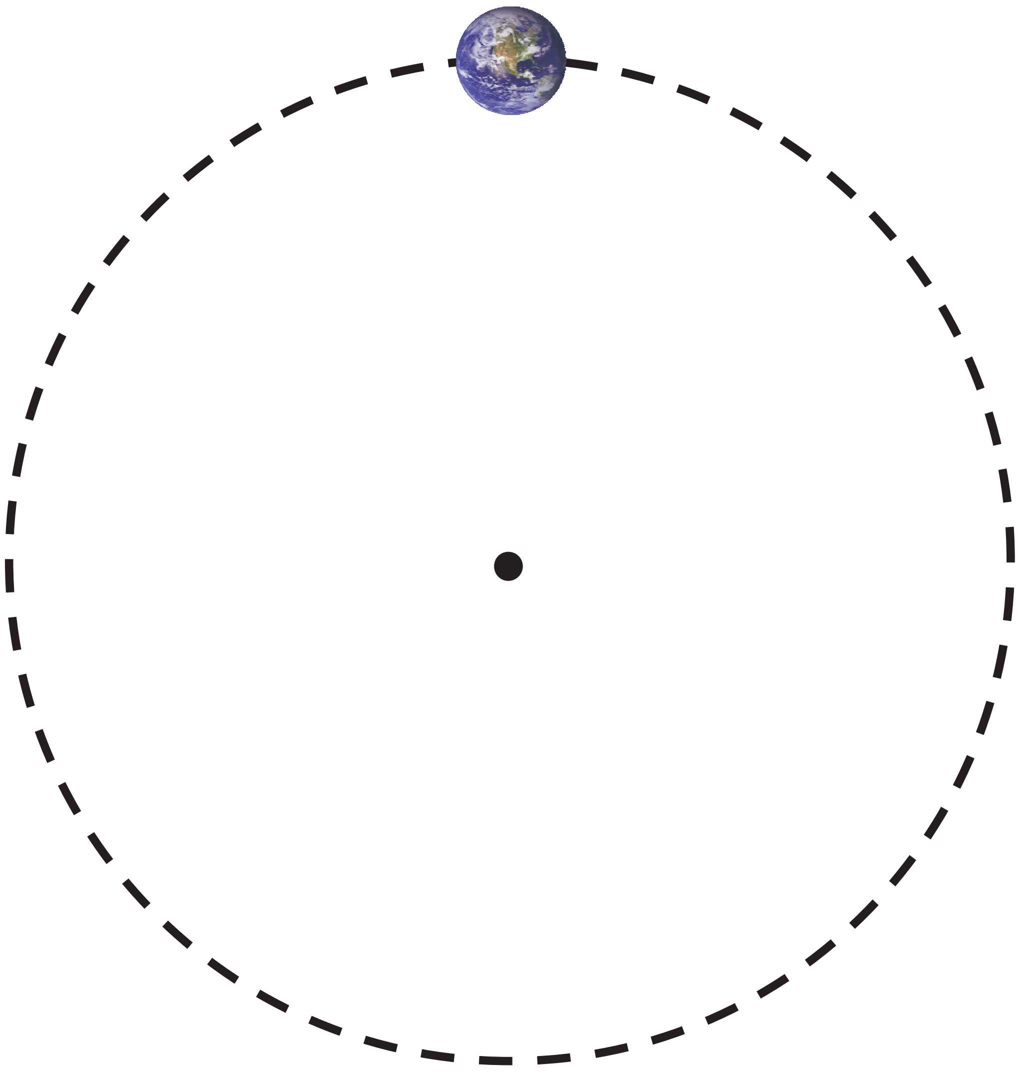
$$R_S = \frac{2GM}{c^2}$$

For the Sun, R_S = 3 km, so

$$R_S = 3(M/M_{Sun})\ \text{km}$$



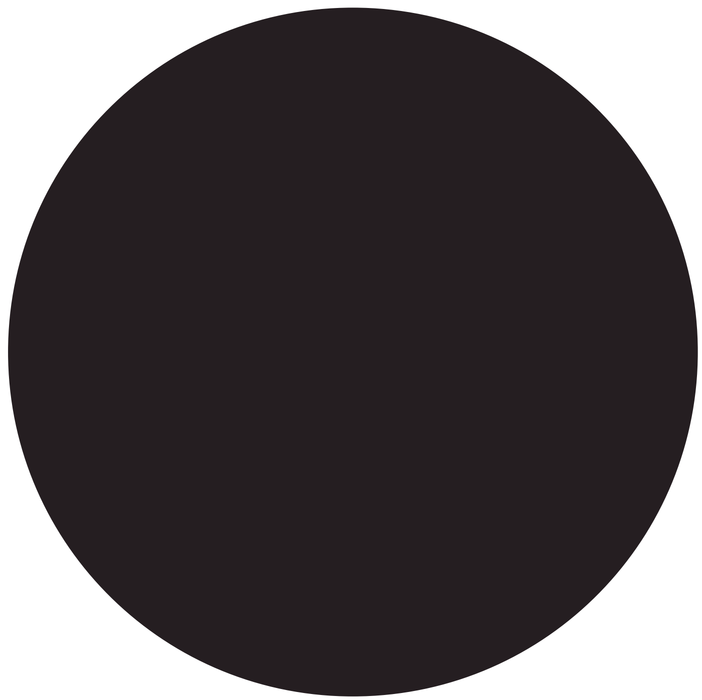
Well outside of a black hole –
It looks just like any other mass

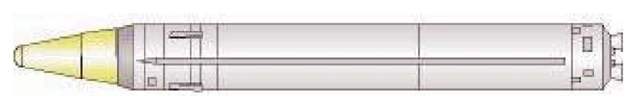


Black Holes Are Very Simple

They can have only

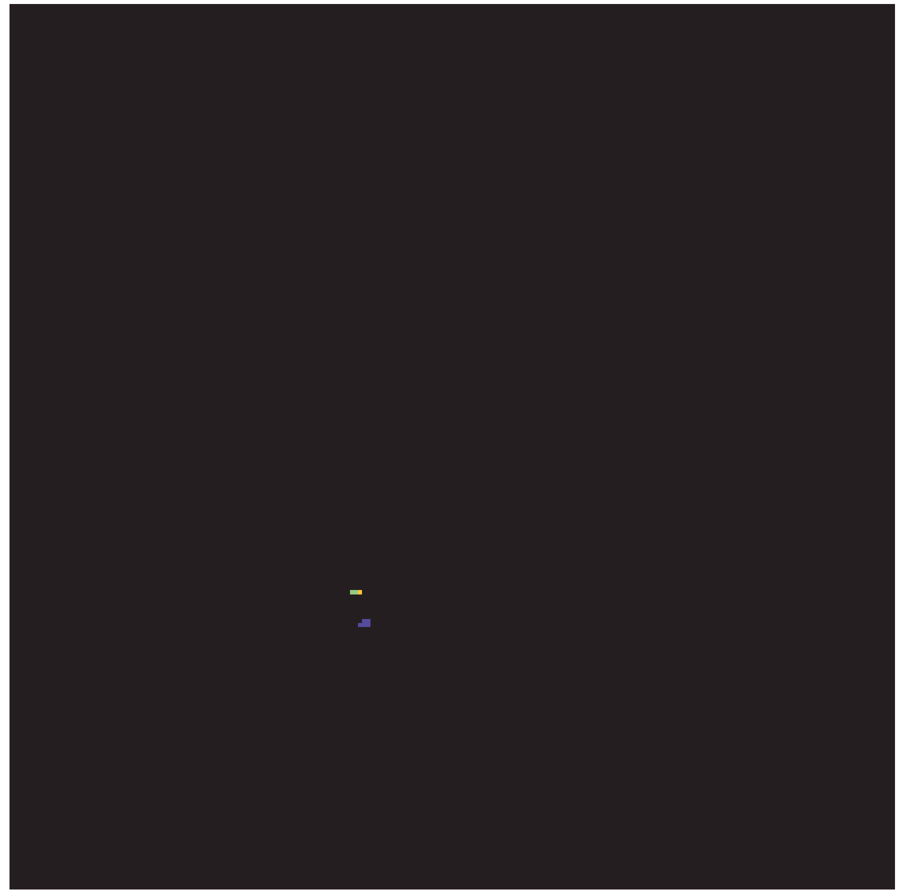
- Mass
- Electric charge
- Rotation (spin)





Visiting a Blackhole

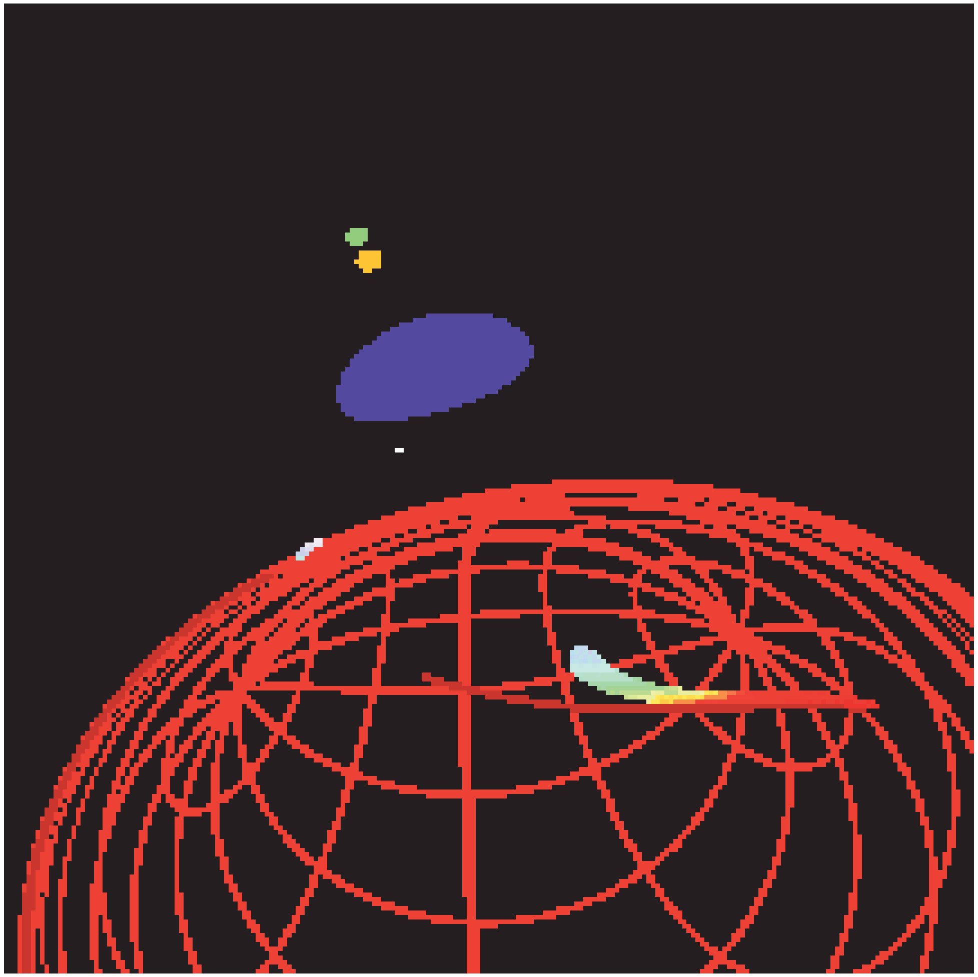
What if you approached a blackhole in a quadruple system? Gravitational bending to the extreme. Only when you get close do weird things start to happen.



http://origins.colorado.edu/~ajsh/schw.shtml

Visiting a Blackhole

What if you shot an orbital probe while in orbit.



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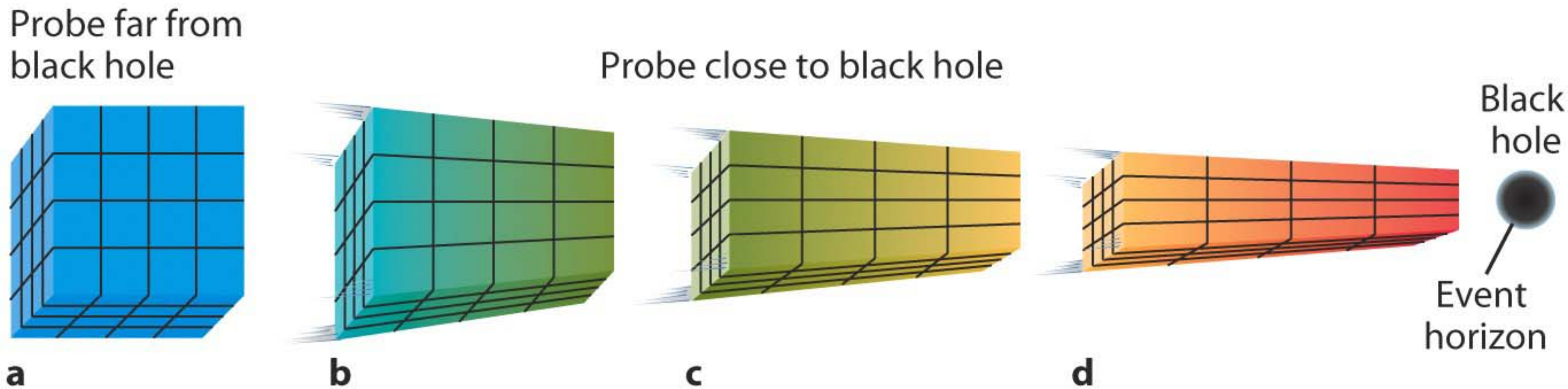
Falling In

- Observers far away see time slow down for you
- You see time proceeding normally
- Tidal forces stretch and squeeze you

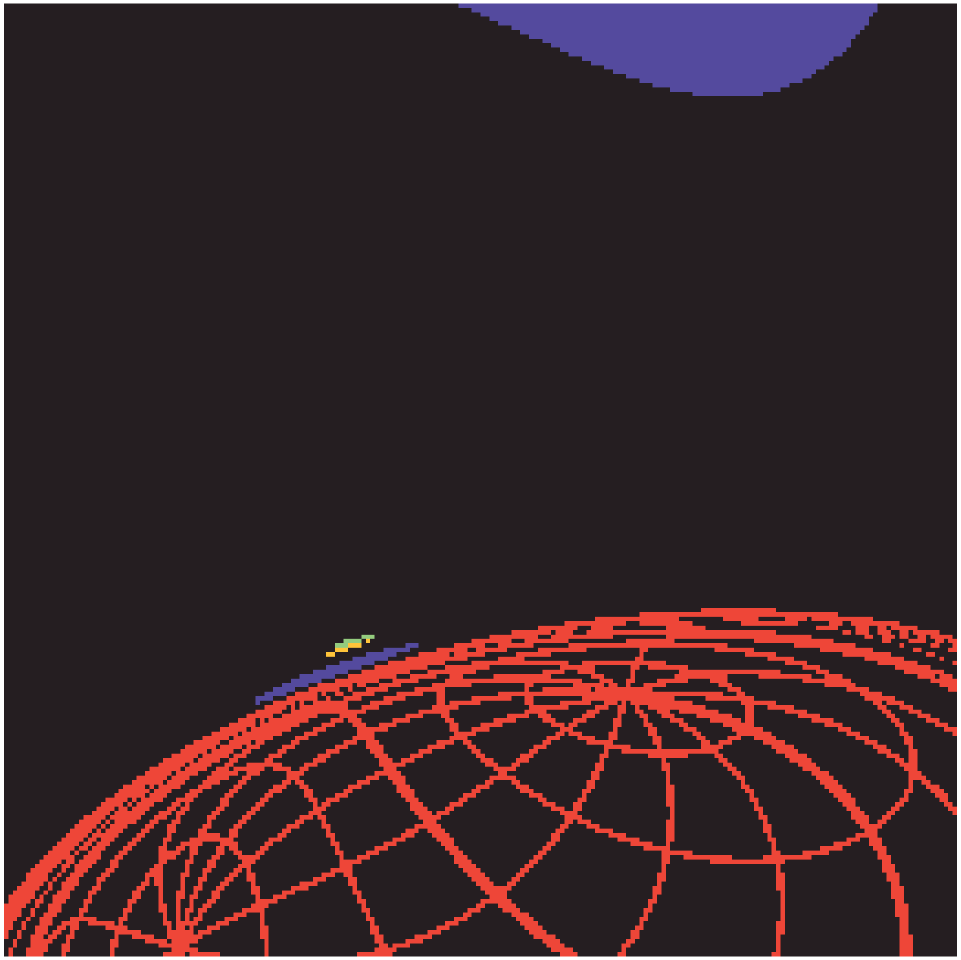


About 100 R_s

About 2-3 R_s

Visiting a Blackhole

Now go inside the event horizon onto the singularity.



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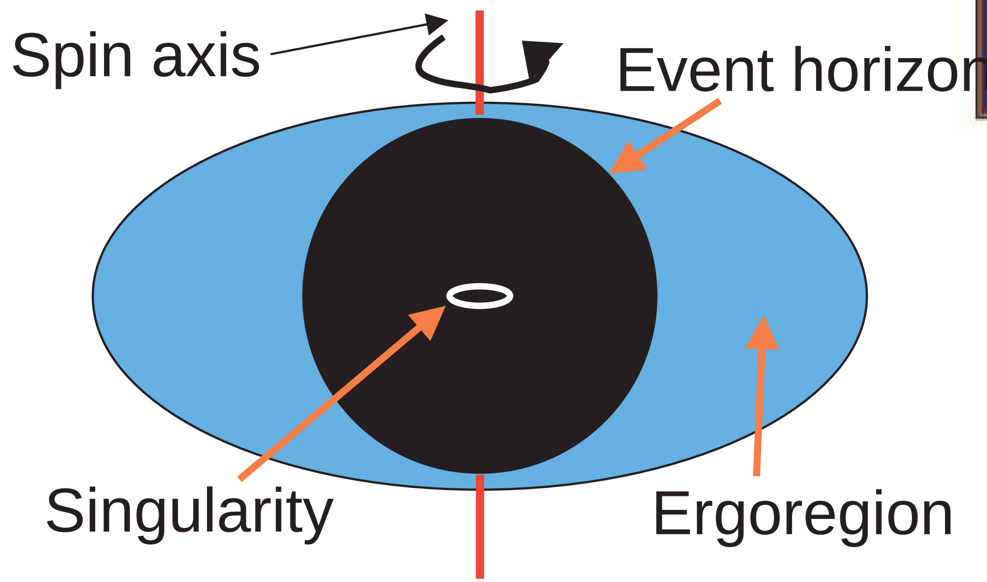
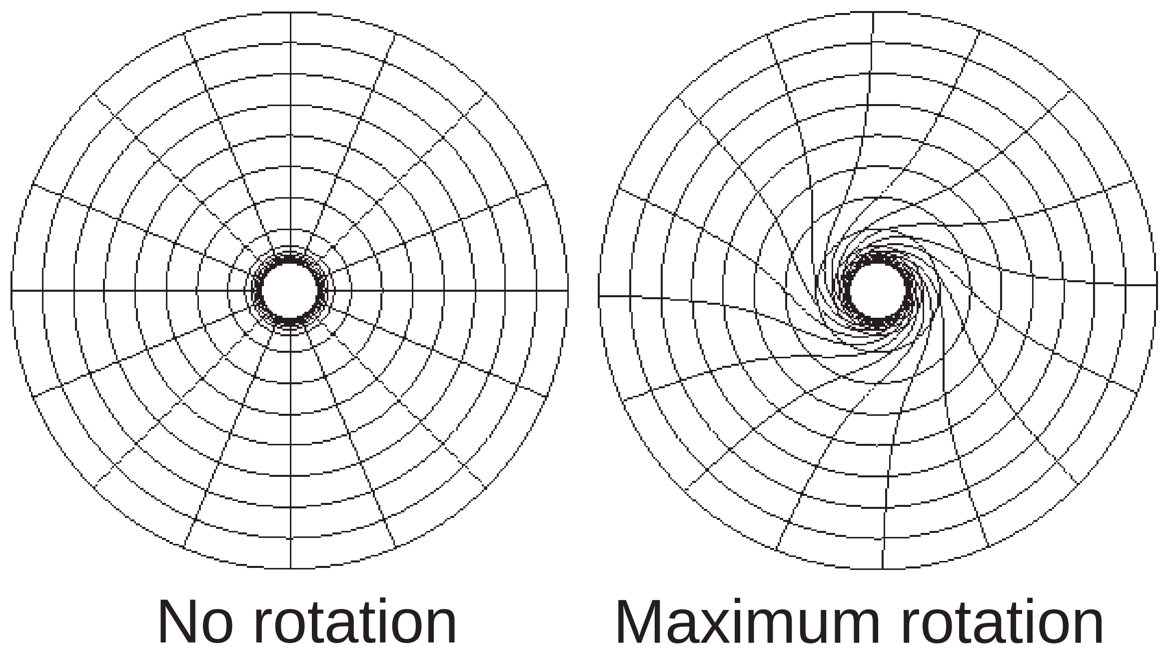
Rotating Black Holes

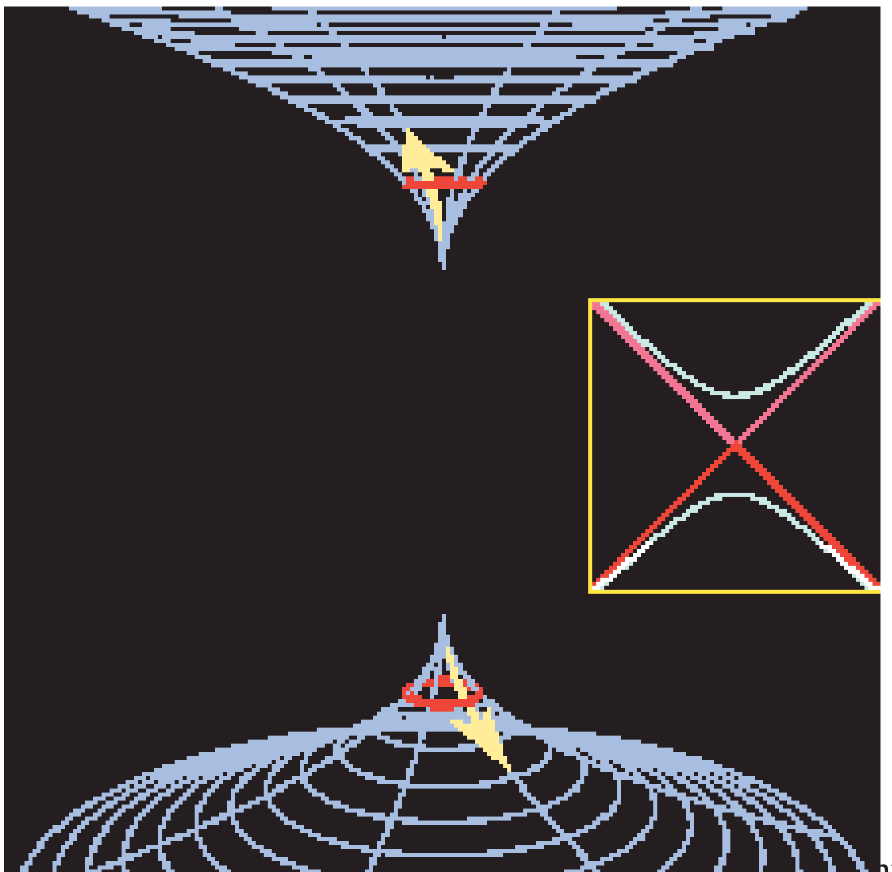
- First studied by Roy Kerr in the early 1960s
- Region just outside horizon where you are dragged along by spacetime
- Can't stand still in ergoregion without falling in
- Singularity is a torus





Wormholes

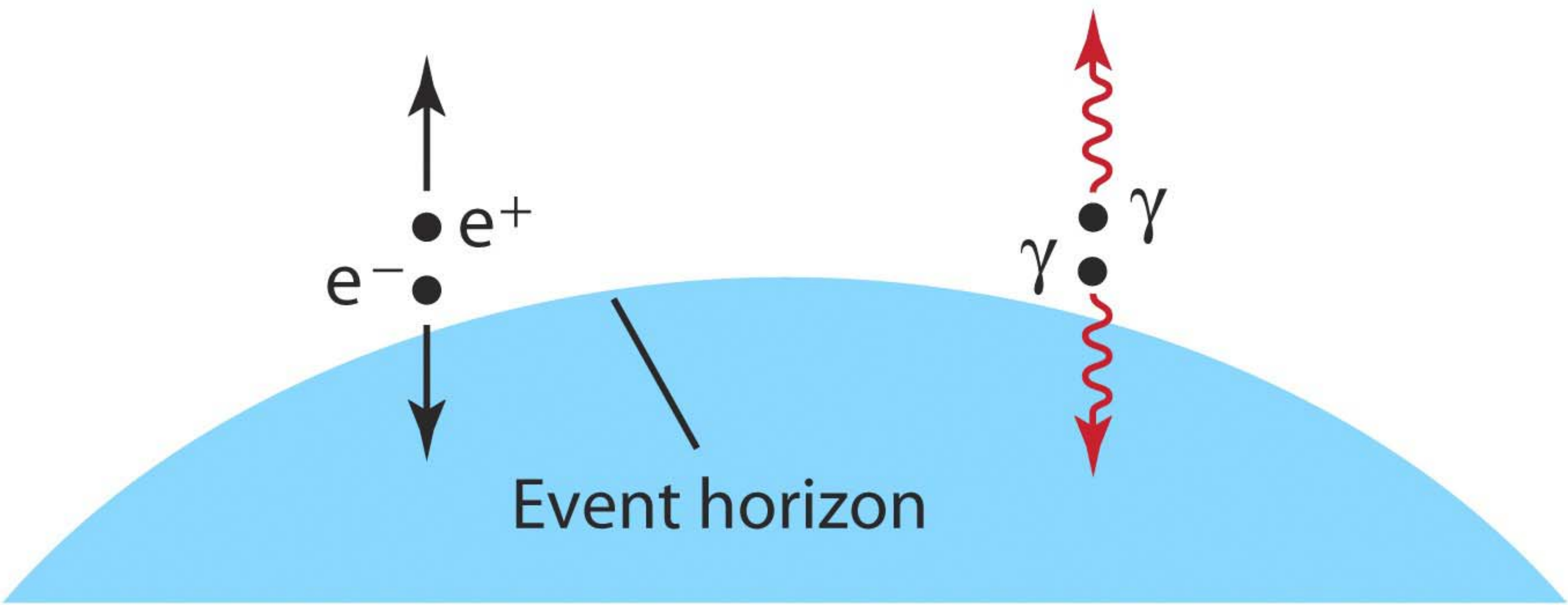
- Tunnel to another universe, or another part of our own?
- **No:**
  - Wormhole throat is unstable, and pinches off
  - Once you fall through one horizon, you can't come out through another
- **Also:** Stellar collapse to a black hole does not produce a wormhole
- **So:** mathematically allowed, but unphysical in general relativity



Sorry… not any time soon

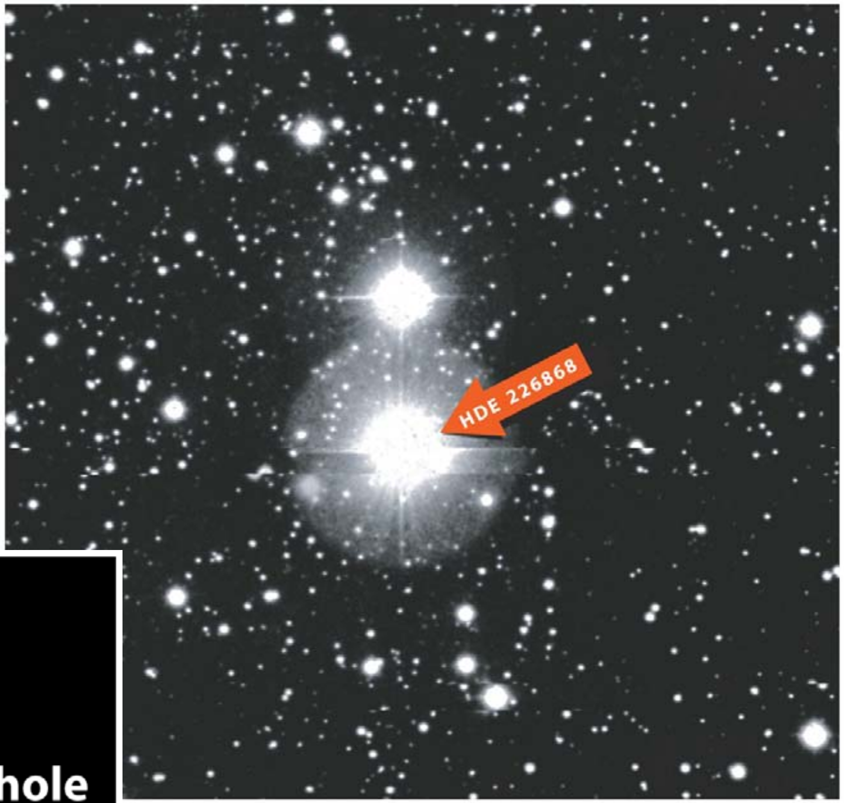
Hawking Radiation

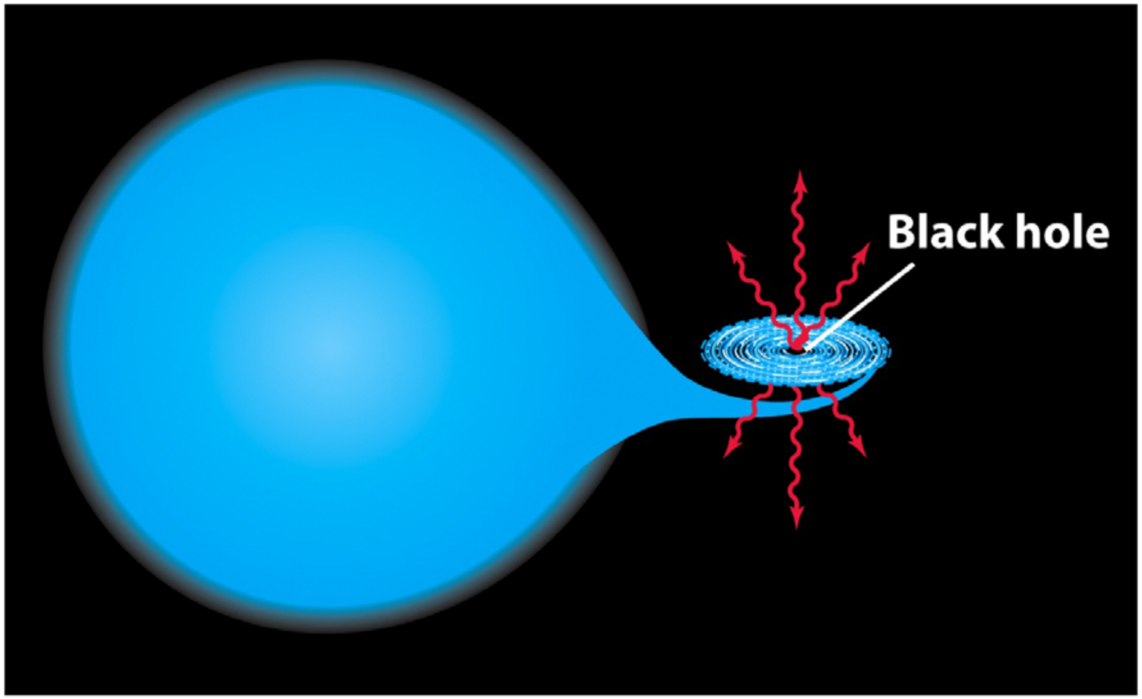
- Black holes are not truly black!
- Quantum mechanical effects near event horizon cause them to produce blackbody radiation
- Temperature **increases** as mass **decreases**
- Too dim/cool to see for stellar-mass black holes



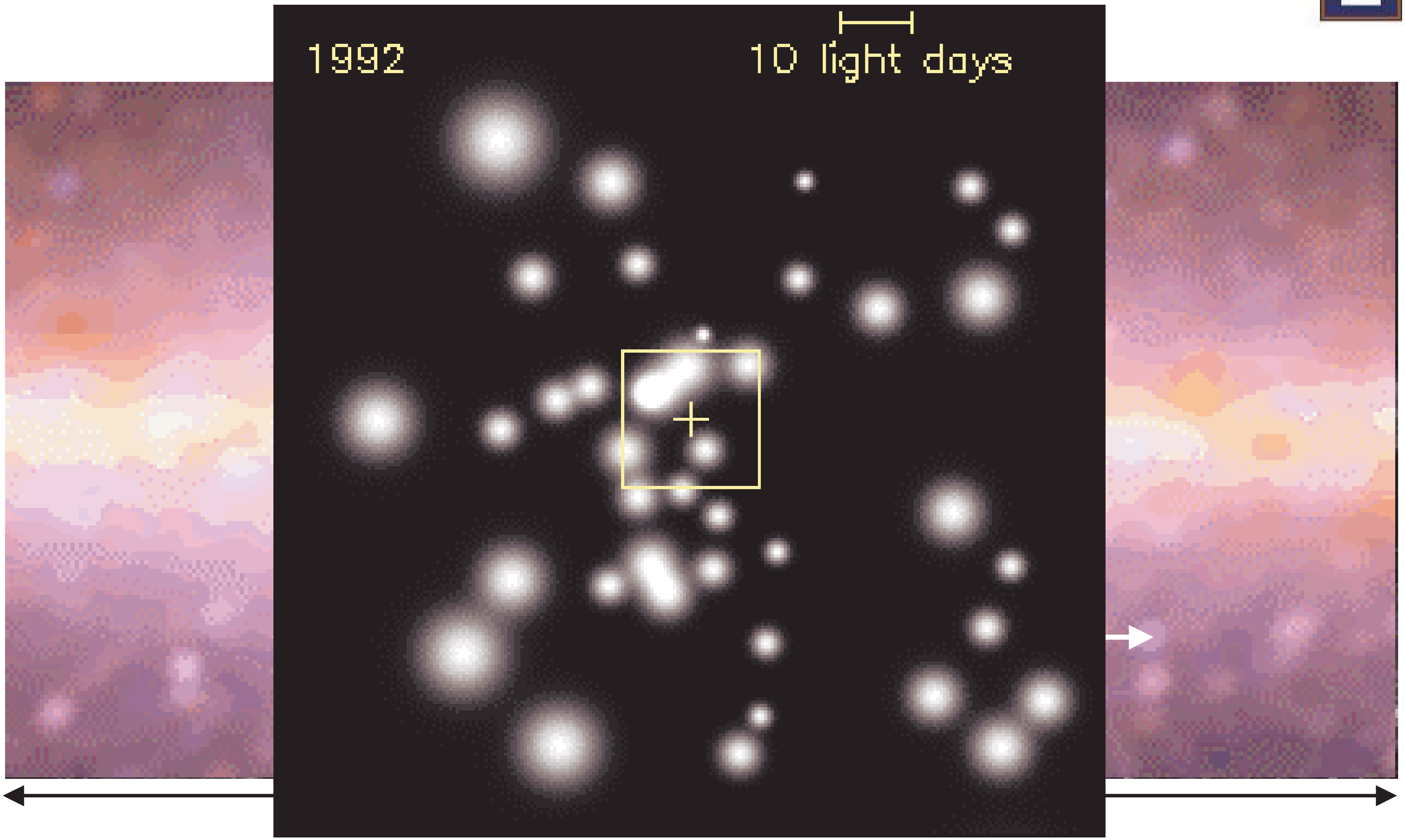
Cygnus X-1

- Binary system with $7M_{Sun}$ unseen companion
- Spectrum of X-ray emission consistent with that expected for a black hole
- Rapid fluctuations consistent with object a few km in diameter



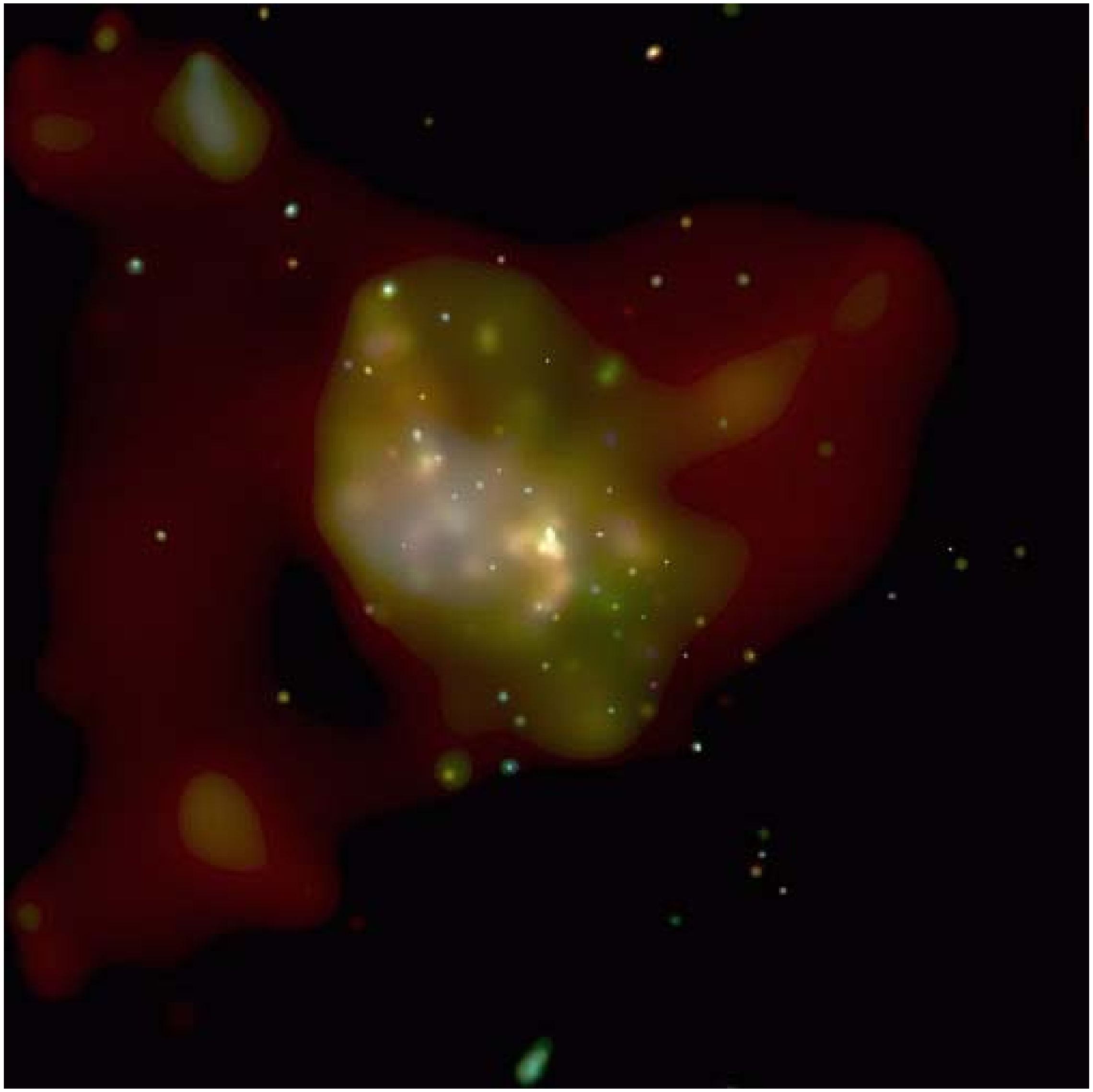


The Monster at the Center of the Galaxy



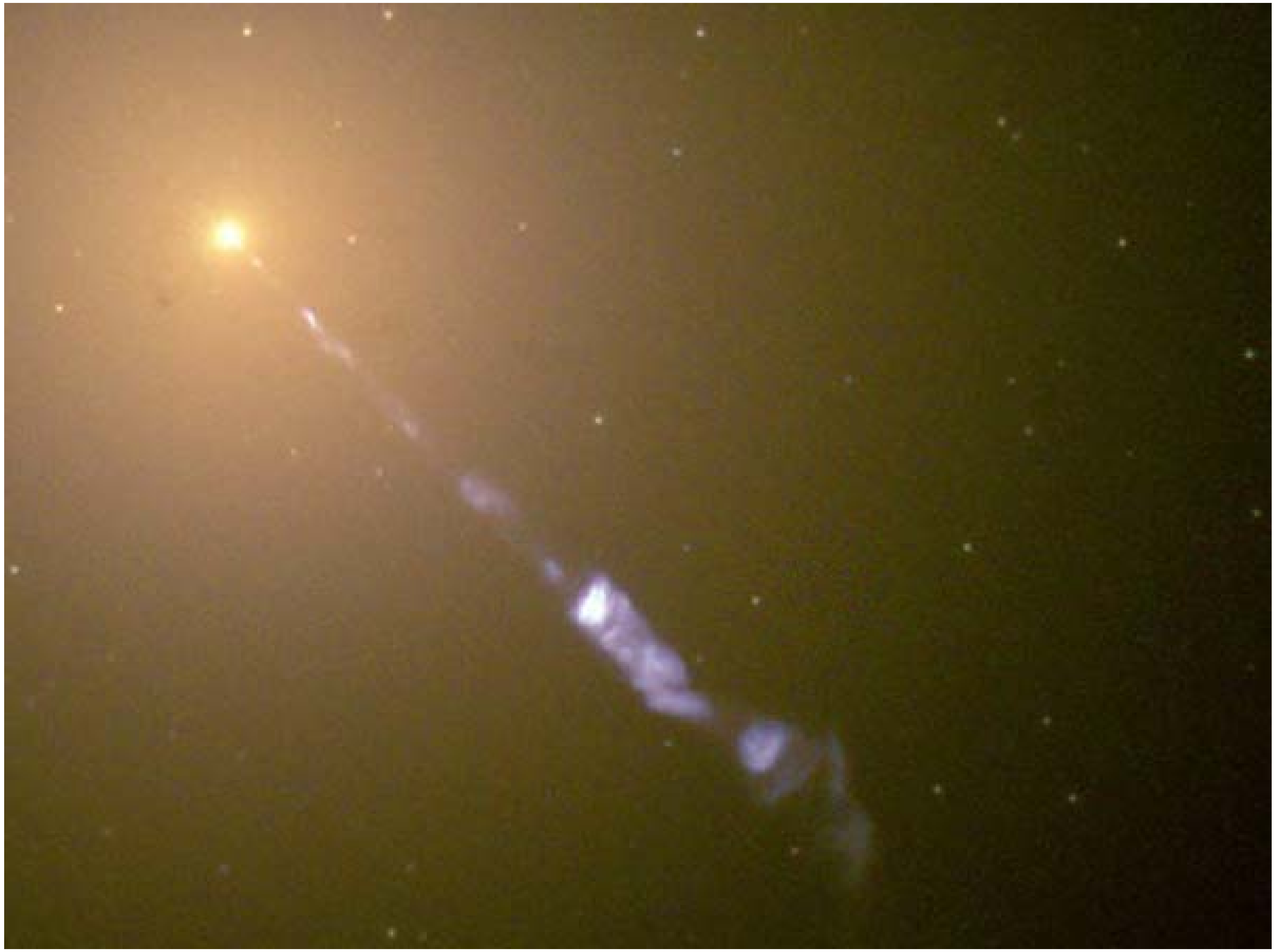
The Monster at the Center of the Milkyway

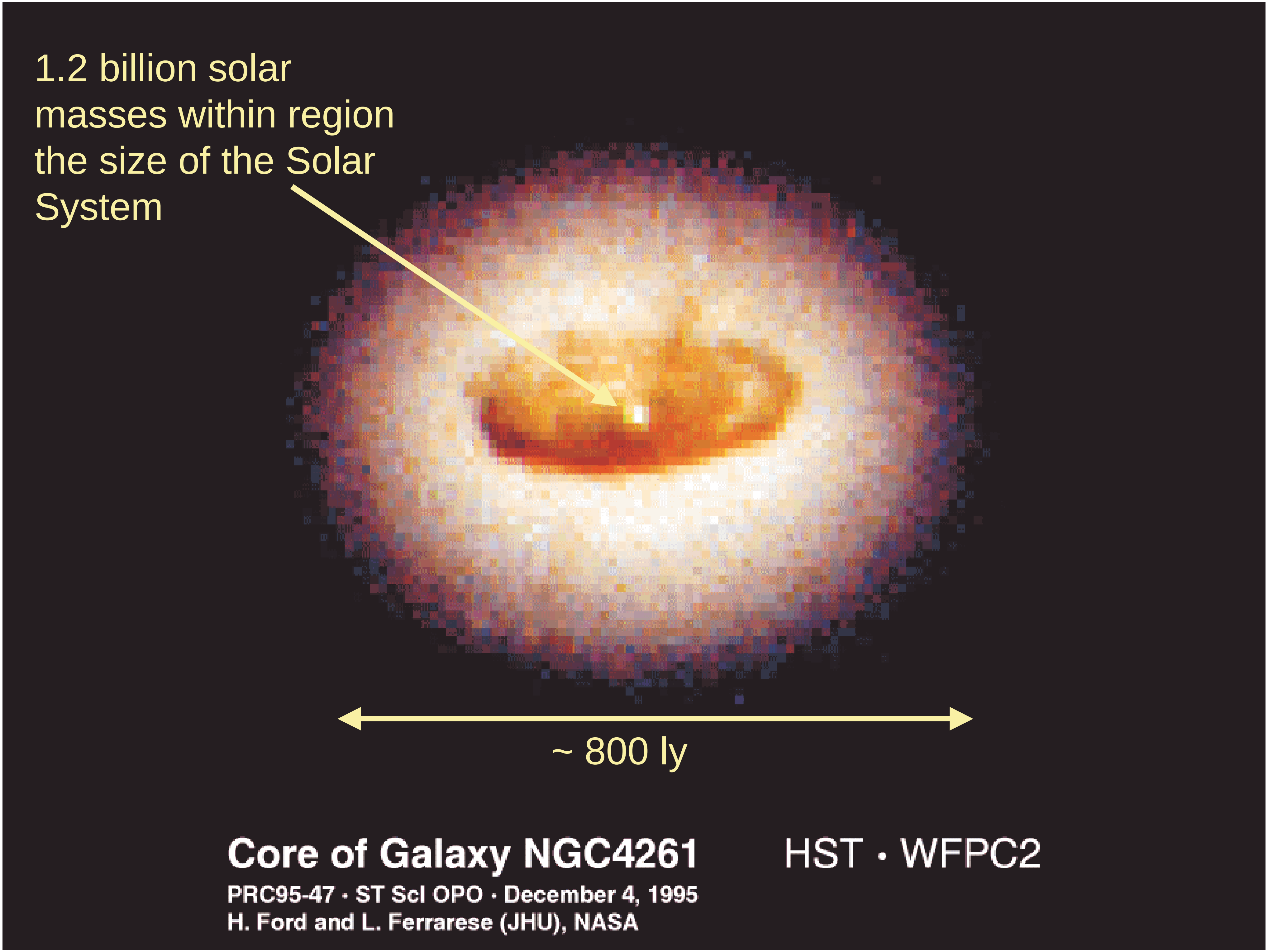
- X-ray image of a flare at the location of our blackhole.
- Lunch?



Other Galaxies

- Jet of M87
- Probably from the disk of the blackhole at the center.
- 5000 light year blow torch
- Only 50 million light years away




1.2 billion solar masses within region the size of the Solar System
~ 800 ly
Core of Galaxy NGC4261
HST • WFPC2
PRC95-47 • ST ScI OPO • December 4, 1995
H. Ford and L. Ferrarese (JHU), NASA

Review

- The Sun
  - Photosphere: granules
  - Chromosphere: supergranules, spicules
  - Corona: CMEs
- Auroras
- Limb darkening– Why?
- Sunspots– why?
- What makes the Sun shine?
  - How do we know?
  - How much longer?
- What makes the Sun stay up?

Review

- Light– particle or wave?
- Color of light– speed, energy, wavelength
- Why is the sky blue? Reflection nebula blue? And the setting Sun red?
- Blackbody emission– continuous spectrum
  - Wein's Law
  - Stefan-Boltzmann
- Intrinsic brightness compared to relative brightness
- What does a telescope do?
  - Light gathering, resolution, and magnification
  - BIMA and SOFIA
- Reflecting vs. refracting

Review

- Doppler shift– toward (blue) and away (red)
- Quantum mechanics– electrons can be wave-like
  - Electrons around nucleus have certain orbits– defines emission and absorption of each atom
  - When excited, atoms emit certain lines (like in class)– fingerprint or barcode of atom
- What is parallax?
- HR diagram– why?
  - Where are the main sequence, the white dwarves, giants, supergiants, red dwarves?
  - Where are most stars?
- Spectral class (O, B, A, F, G, K, M)
- Where do massive stars live on the HR diagram? What is the Mass-Luminosity relation?

Review

- Star formation– stars form in clouds, condense from dust.
- A star's life on the main sequence.
- How does a star's demise vary?
- How do giants and supergiants differ from MS stars?
- Star < 0.08 solar masses– Brown Dwarf (nothing)
- From 0.4 to 0.08 solar masses– Red Dwarf (long life)
- From 0.4 to 4 solar masses– Low mass star (white dwarf)
  - What is a planetary nebula?
  - What keeps a White Dwarf up?
- From 4 to 8 solar masses– Intermediate mass star (white dwarf)
  - How does their demise differ from that of low mass stars?

Review

- From 8 to 25 solar masses– High mass star (supernova and neutron star)
  - Why does nuclear burning stop at iron?
  - What is a supernova? What's left behind?
  - What is the source of most of Earth's heavy elements?
- > 25 solar masses – black hole
- What is a white dwarf?
- What is a neutron star?
  - What is a Pulsar?
- What is a blackhole?
- What is the deal with special relativity?
  - What is the speed of light measured on a spaceship?
  - Distance contraction and time dilation
- What is general relativity?