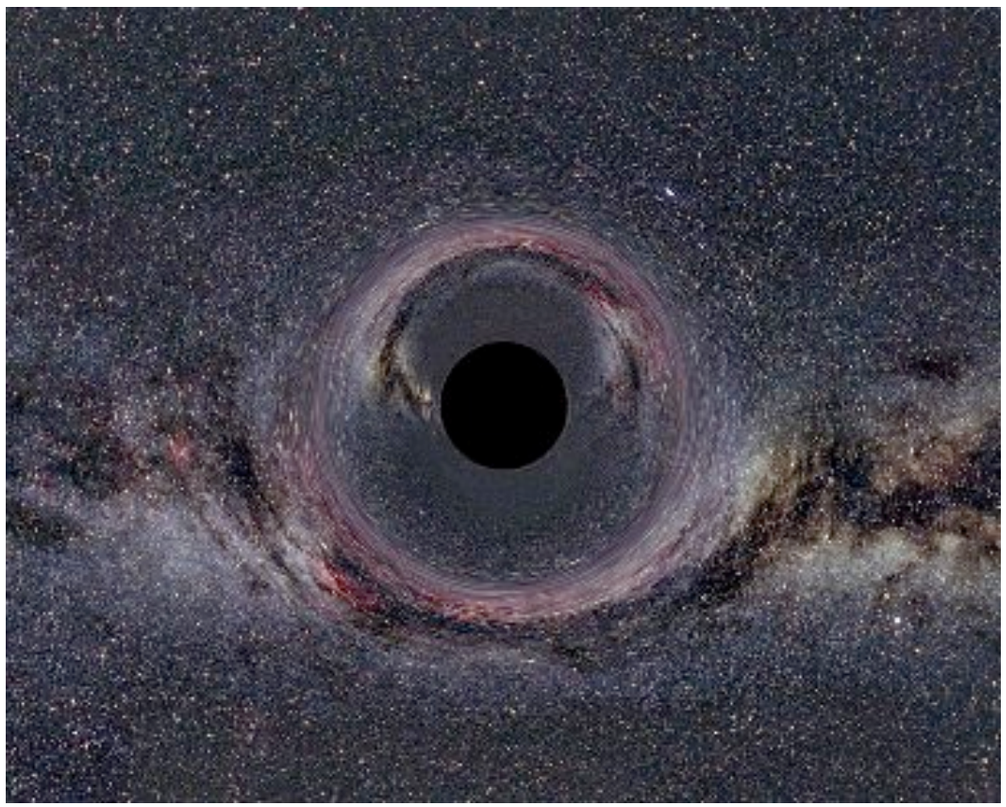
Astronomy 150: Killer Skies
Lecture 31, April 11

Assignments:

- HW9 due Friday
- Computer Lab 2 posted, due April 20
  - choose one of two assignments
  - if you do both, 2nd grade will count up to 20 points, can replace a low HW, Lab, or Observing score
- Solar Observing reports due Friday or before

Last time: Black Holes Everywhere

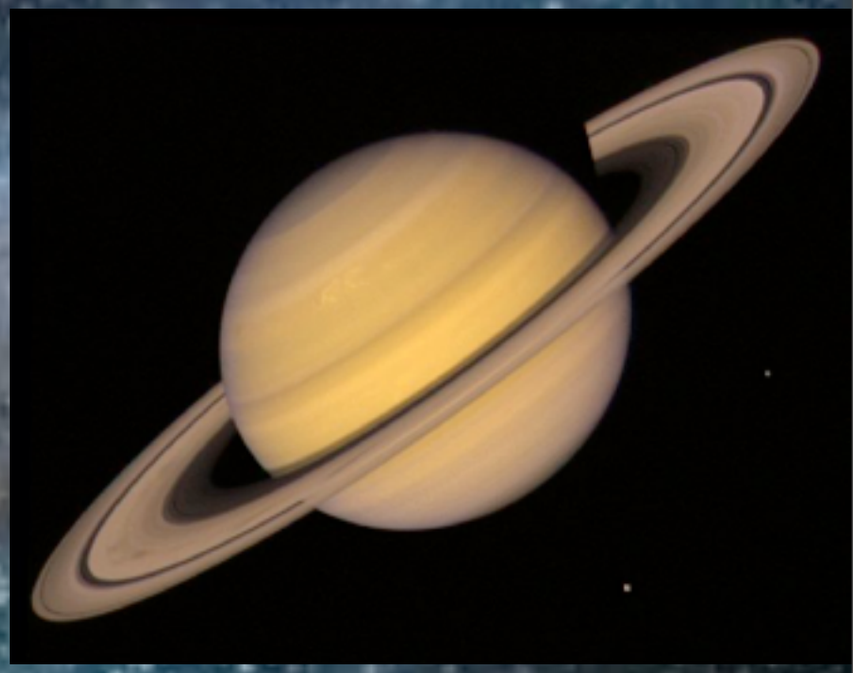
Today: Spaghettification

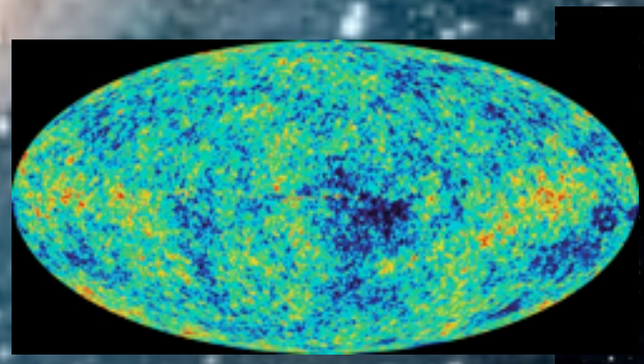


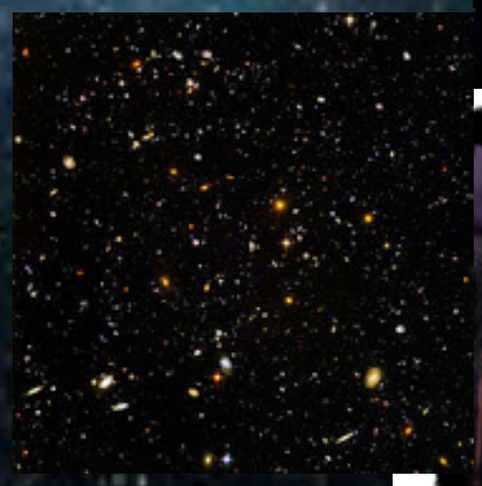
Online Astronomy 100

(Summer 100% online)

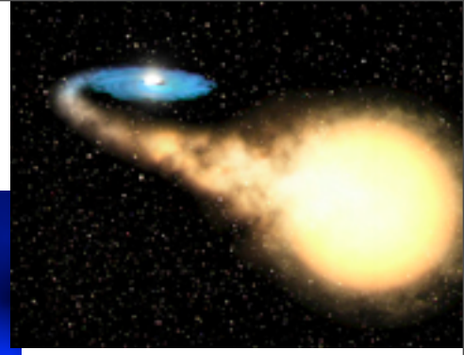
- Want more Astronomy?
- This summer, learn about the night sky, planets, stars, galaxies, and the beginning/end of the Universe by taking the 100% online Astronomy 100 summer course.
- As a self-guided narrative, you will learn astronomy while saving the Earth from alien enslavement by the evil Overlord. The Overlord is quizzing you to find out how much astronomy Earthlings know, and luckily for the Earth, you happened to have a thumb drive with your friend's Astro 100 lectures and notes from last semester. **Can you save the Earth?**
- Counts as a Physical Sciences course.

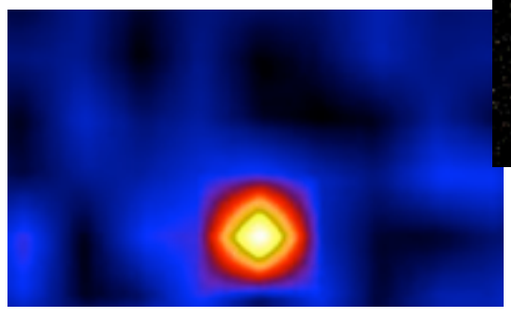






Recap: Living with Black Holes





Real Black Holes in the Cosmos

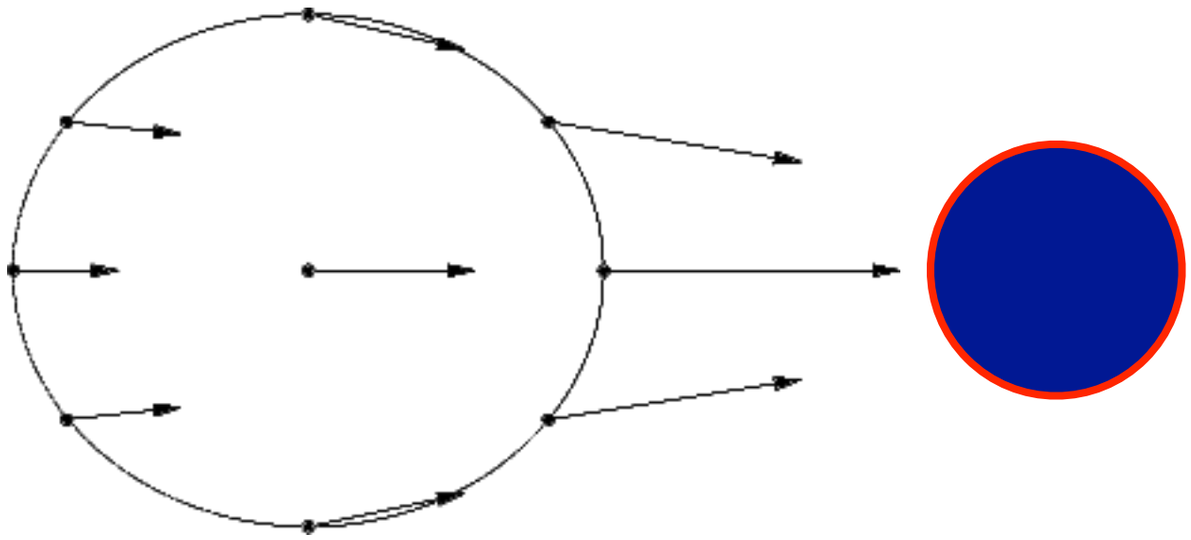
- black holes emit no light, so how do we see them?
- if black hole isolated with no nearby matter: totally dark
  - but does still have gravity, bends light
- can see a black hole swallowing nearby matter (accreting)
  - light can escape from material near horizon
  - infalling matter compressed, heated to high T
  - emits X-rays
  - we see: X-rays from massive object that isn't an ordinary star or neutron star
- Black Holes from supernova explosions (stellar mass BH)
  - found when in binary system: X-ray binary
  - companion star stripped by BH, see X-rays from accretion disk
- Supermassive Black Holes
  - at the center of our Milky Way Galaxy: stars orb unseen mass $4 \times 10^6 M_{sun}$
  - at centers of rare active galaxies: huge BH emits jet moving >99%c
  - at centers of all (?) galaxies: BHs found, mostly "quiet" like ours--not "feeding"

Recap: Living with Black Holes

Black Hole Threat

when **far away**:

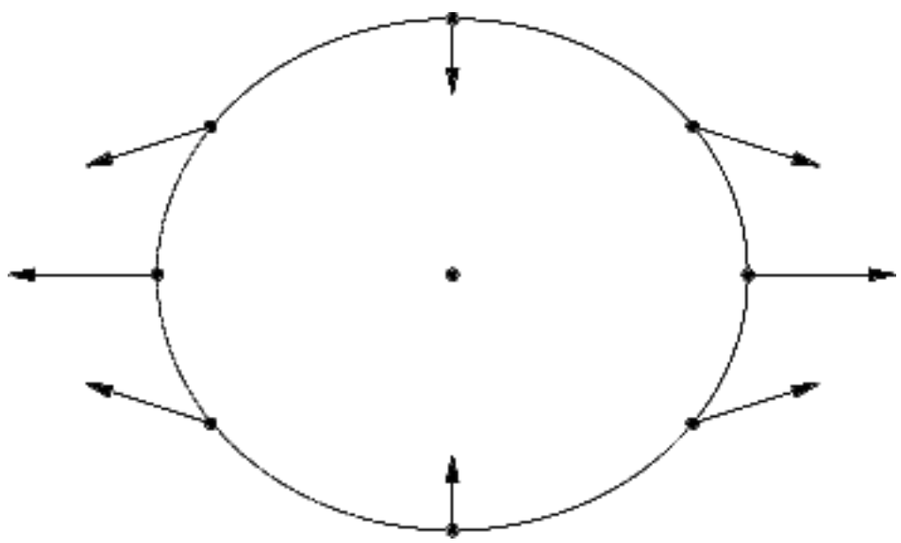
- gravity no stronger than star of same mass
- not particularly dangerous



pattern of gravity forces

when **near horizon**:

- gravity very strong
- tidal forces huge:
  - **stretching** along direction towards BH
  - **squeezing** perpendicular



force **differences** from average

Q: so if you fall onto a black hole, what happens?

Death by Black Hole

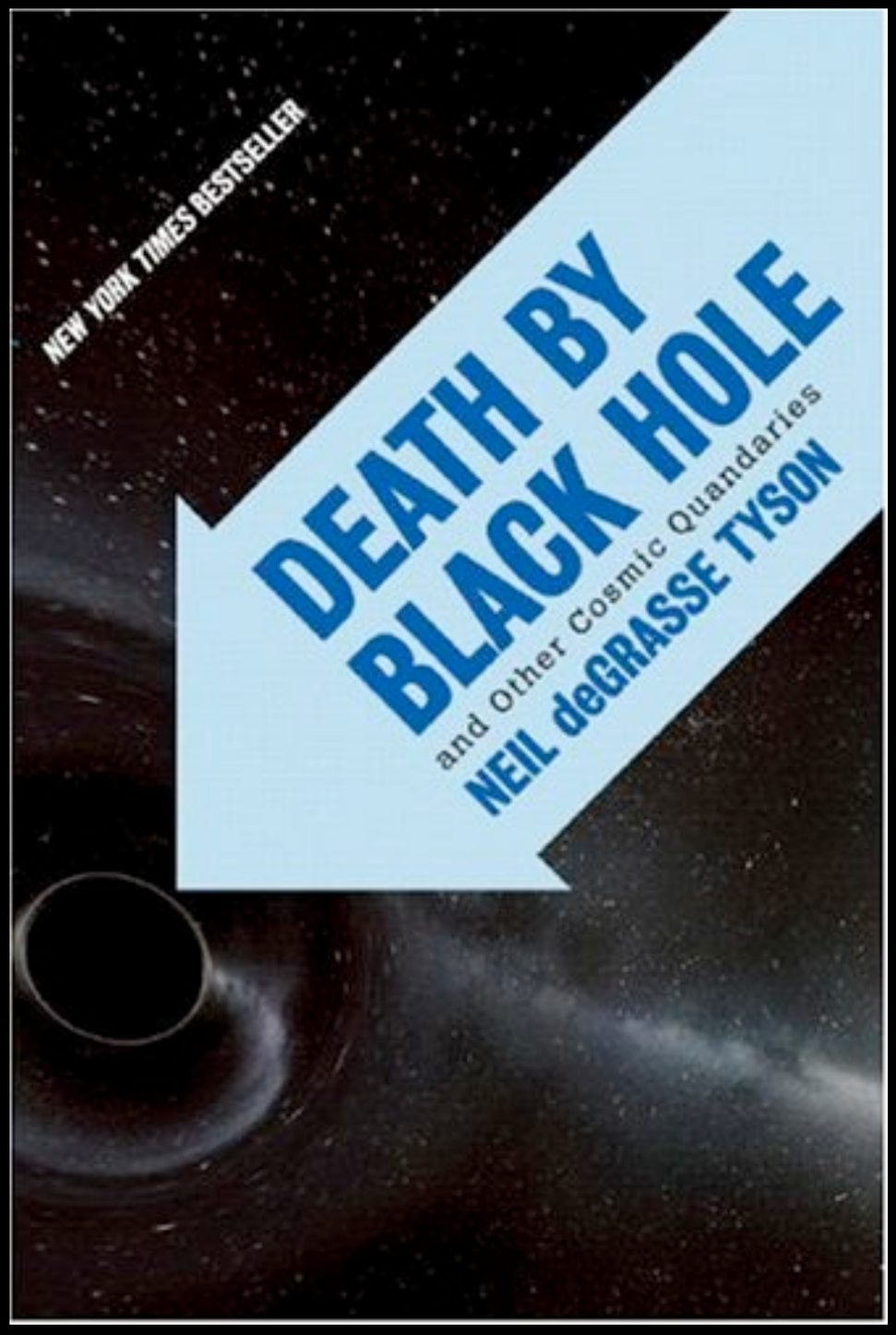
Overview: Neil de Grasse Tyson

http://www.youtube.com/watch?v=h1iJXOUMJpg

http://www.thedailyshow.com/watch/tue-january-30-2007/neil-degrasse-tyson-pt--2

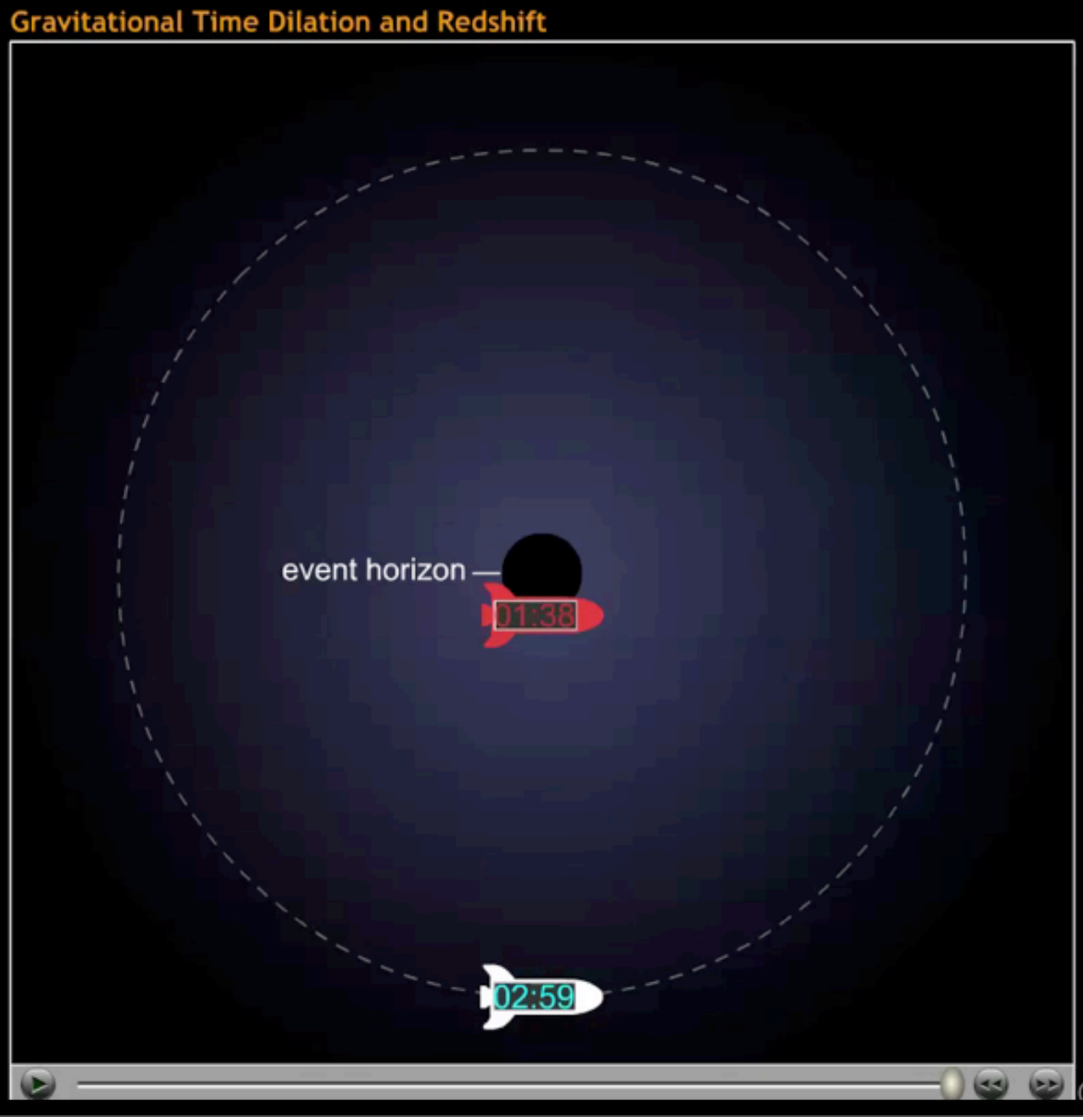
What would it be like to fall into a black hole?

- Imagine you and a ~~friend~~ *enemy* are orbiting a black hole at a safe distance
- He jumps out of the airlock on a trajectory to fall into the black hole
- What would happen to him?
-



What you observe

- As your “friend” falls toward the black hole:
- His clock slows down
- Light from his clock becomes **dim** and **red**
- You never see him cross the **event horizon!**



What happens to your ~~friend~~ enemy - from his perspective

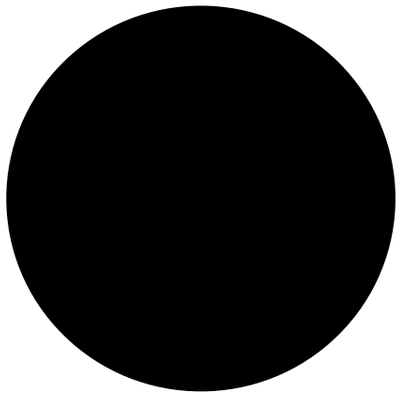
- His clock keeps ticking, stays bright and blue
- You appear to speed up! Light from your clock is blueshifted!
- He crosses the event horizon when his clock reads 1:39
- No barrier - the event horizon is not a physical boundary

Uh Oh.

- Unfortunately, he does not live to experience crossing the event horizon
- Near the event horizon, gravity would act more strongly on his feet than his head
- Tidal forces become strong
  - stretching in direction towards center
  - squeezing in direction perpendicular

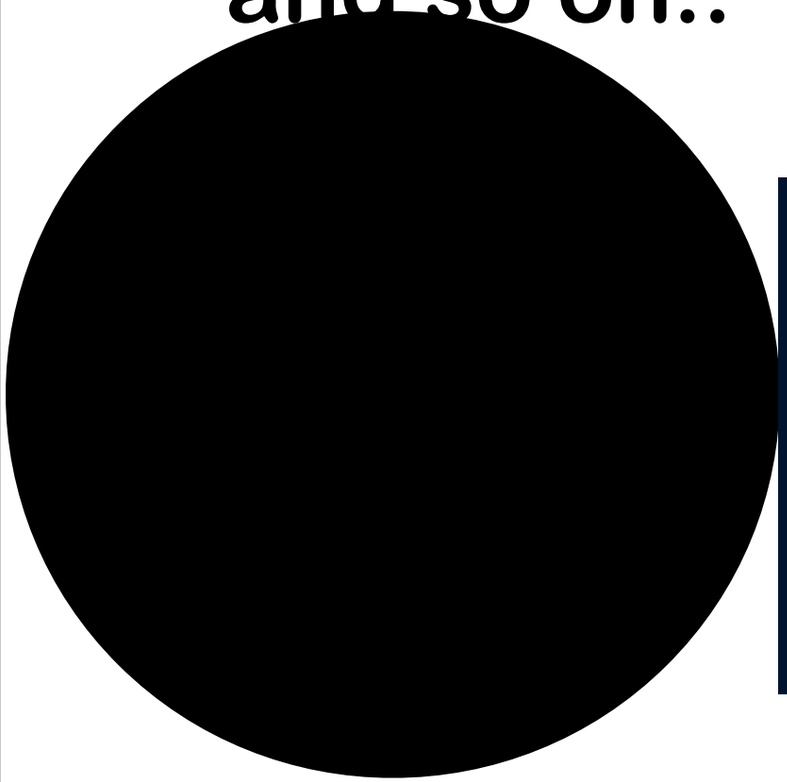
Death by Black Hole

- At first you would not feel a thing….
- Microgravity… standard situation for an astronaut.
- But as you get closer, the pull of gravity on your feet is stronger than the pull on your head– tidal forces.



Death by Black Hole

- The tidal pull…
- If you were made out of rubber, this would not be bad, but humans are made out of bones, muscles, etc.
- Molecular bonds are overcome, you snap in 2 at the midsection. Those pieces snap in two, and so on..



The Ultimate Rack

- The shreds of organic molecules headed toward the center of the black hole begin to feel that stretching feeling.. getting ripped into atoms
- Then, the atoms rip apart…
- Now we have an unrecognized stream of subatomic particles that use to be you only minutes ago.
- All of these parts are moving toward the black hole center, extruding through the fabric of space-time.. Like toothpaste squeezed through a tube..

Spaghettification

- If someone falls into a black hole, they will get pulled apart.
- They turn into a stream of sub-atomic particles.
- Human into spaghetti.

- And all of this is still outside the event horizon!

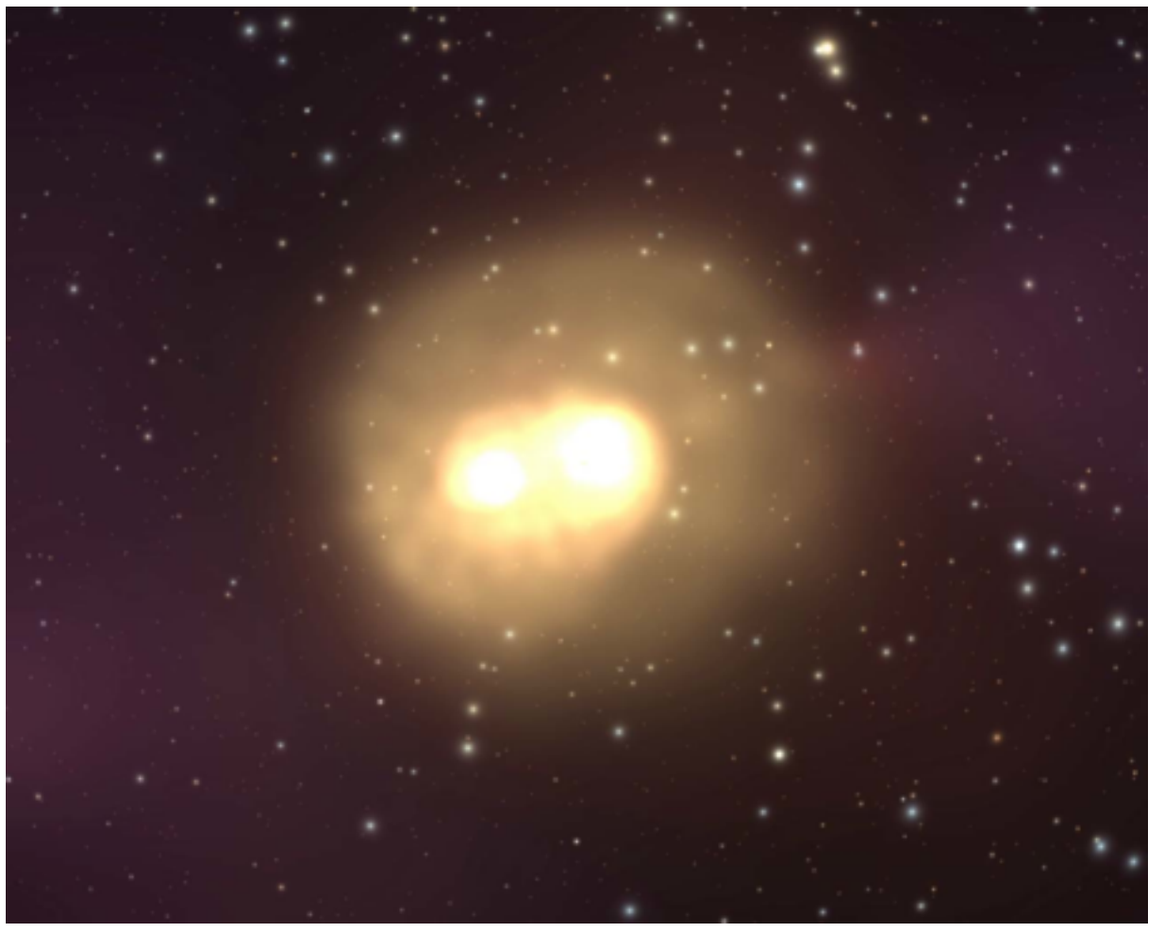
http://www.youtube.com/watch?v=hliJXOUMJpg

Rogue Black Holes?

- Might we expect a black hole to enter our Solar System?
- If so what might happen?

Stars Collide?

- Chance of interacting with another star is very, very unlikely.
- Star comes within 3.26 light years every 100,000 years.
- Chances for a star to influence planets in Solar System?
- You would have to wait more than the age of the Universe!



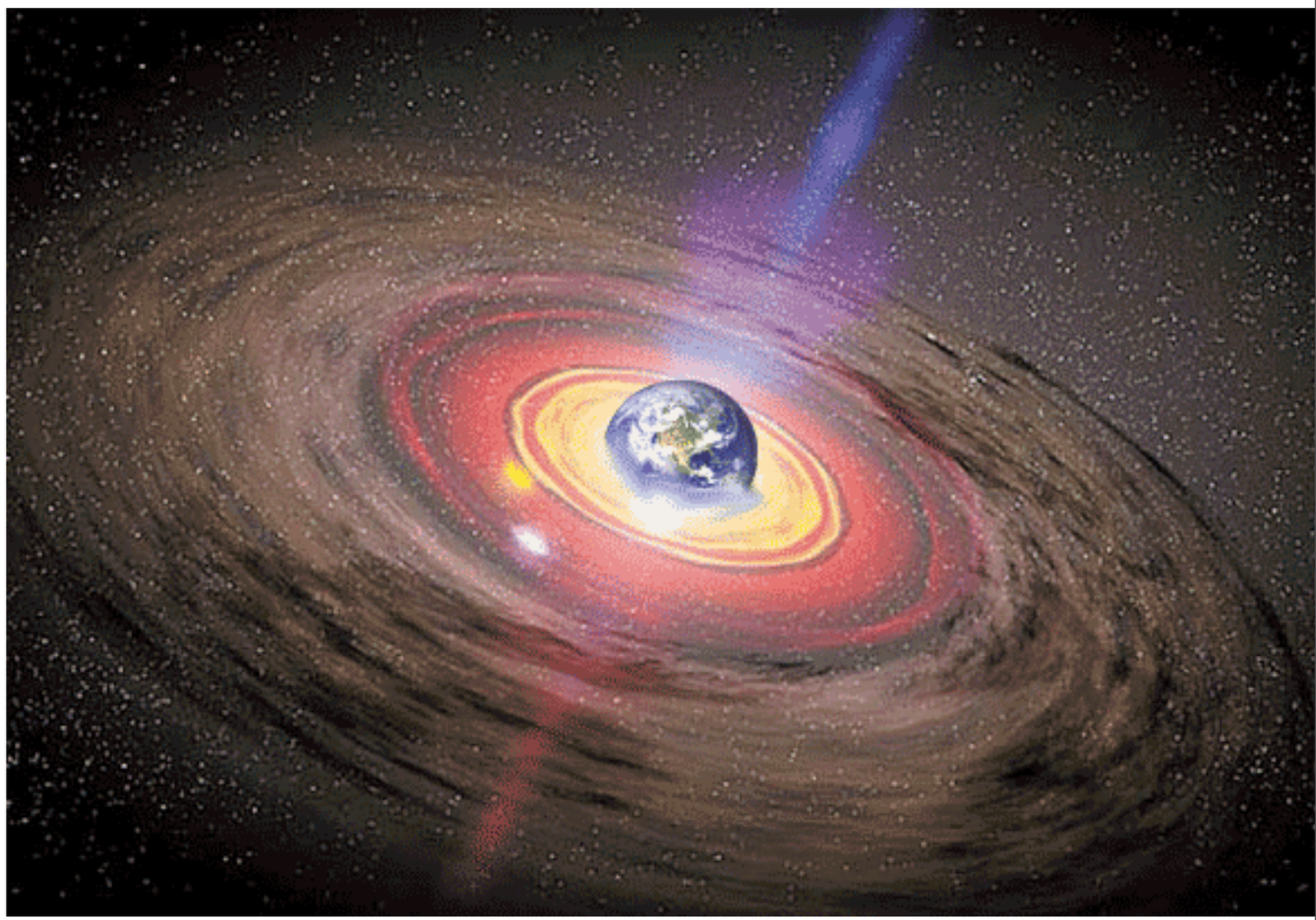
But What If?

- Average distance to a black hole should be ~100 light years!
- That's less common than stars, but sounds close!
- Black hole colliding with the Earth would of course be a disaster.
- At the end, Earth is destroyed by tidal forces, ripped apart.
- Or even if black hole misses, it could throw Earth out of our nice orbit, which is still bad.

http://www.intute.ac.uk/hottopics/spotlight/images/SPT59-smallest-black-hole-birds-eye-view.jpg

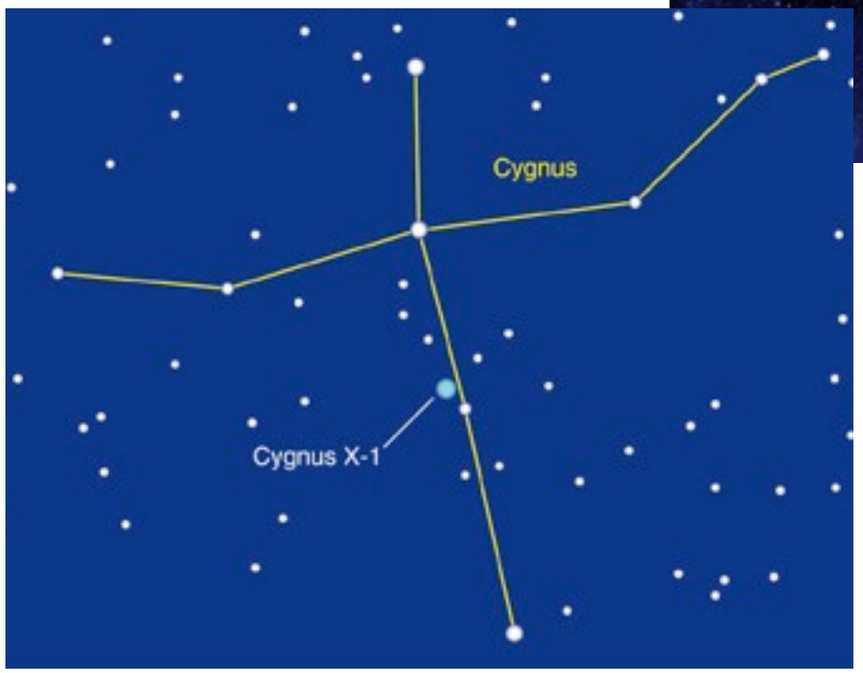
But What If?

- Remember unless it is feeding, it will be hard to detect a nearby black hole.
- What if a run away stellar black hole (~10 solar mass) was heading right for the Earth?
- What would be the effects?



Stars Collide?

- The Galaxy may have a lot of black holes.
- But, Space is Freaky Big!
- Closest known black hole is Cygnus X-1, which is 6500 lyrs away
- Stars still are much, much, much more common than black holes.



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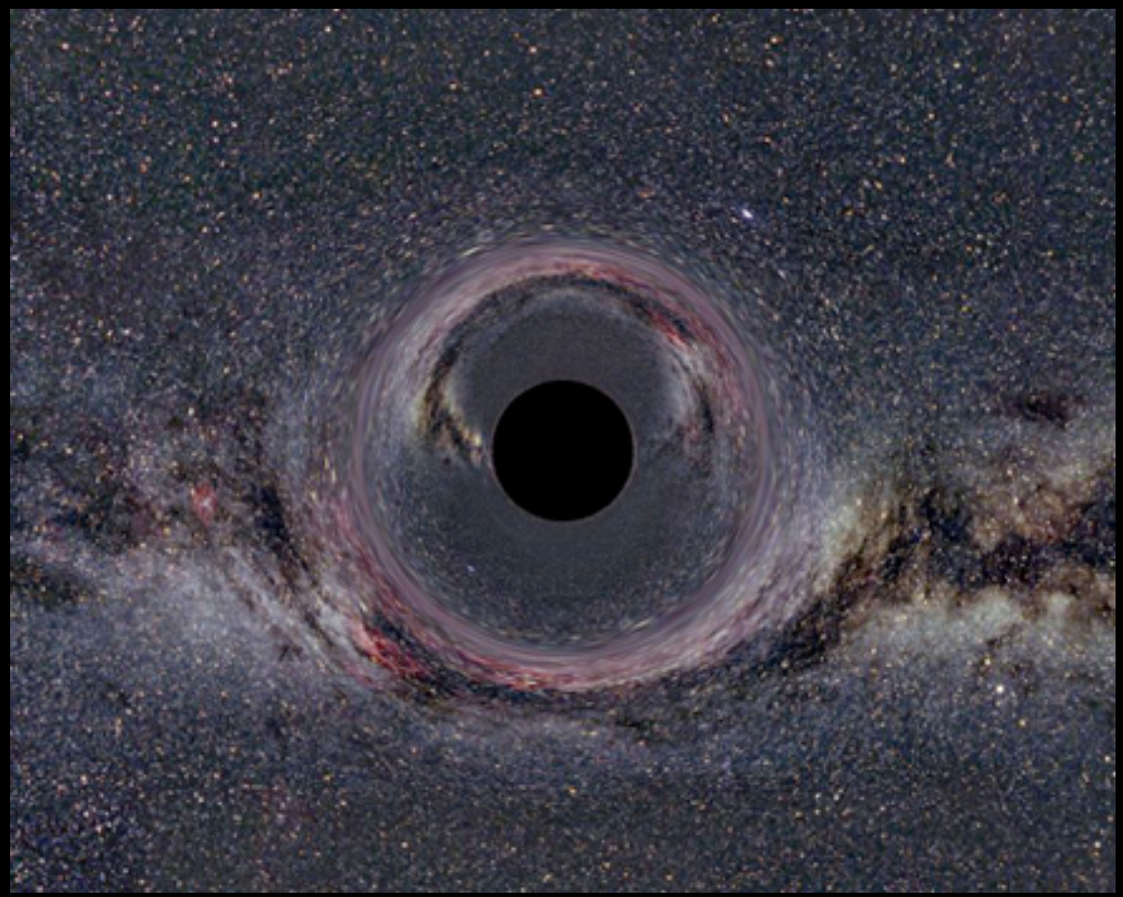
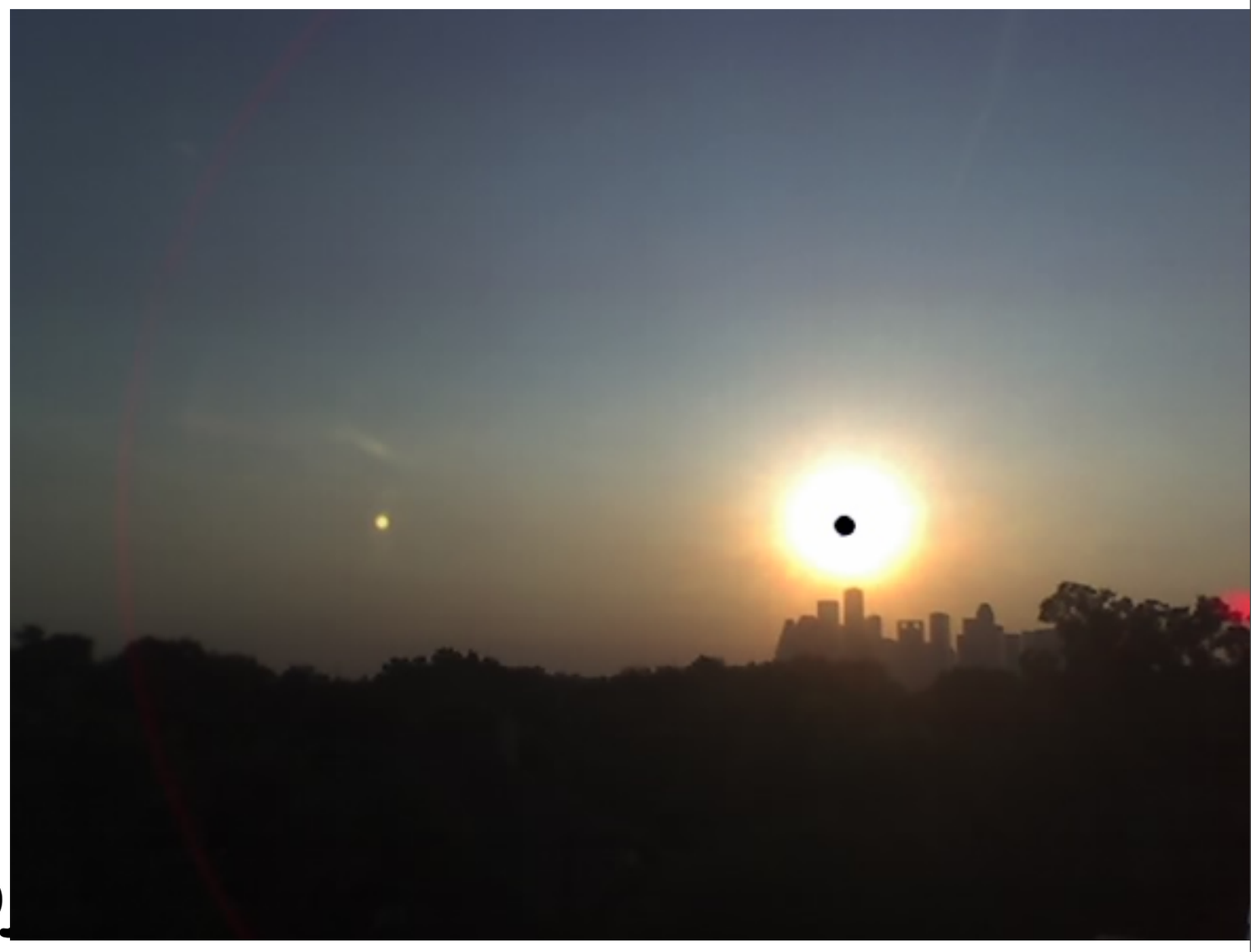


If a black hole ten times more massive than our Sun were lurking just beyond Pluto's orbit, we'd have no way of knowing it was there.

A. Correct. Black holes do not emit light so they cannot be detected.
B. Correct. Such a low mass black hole would have no influence on the solar system unless it impacted a planet.
C. Incorrect. Such a black hole would measurably affect the orbits of the planets.
D. Incorrect. X-ray observations would reveal its presence as it sucked in material around it.
E. Incorrect. It would be readily apparent as a pulsating radio source in the outer solar system.

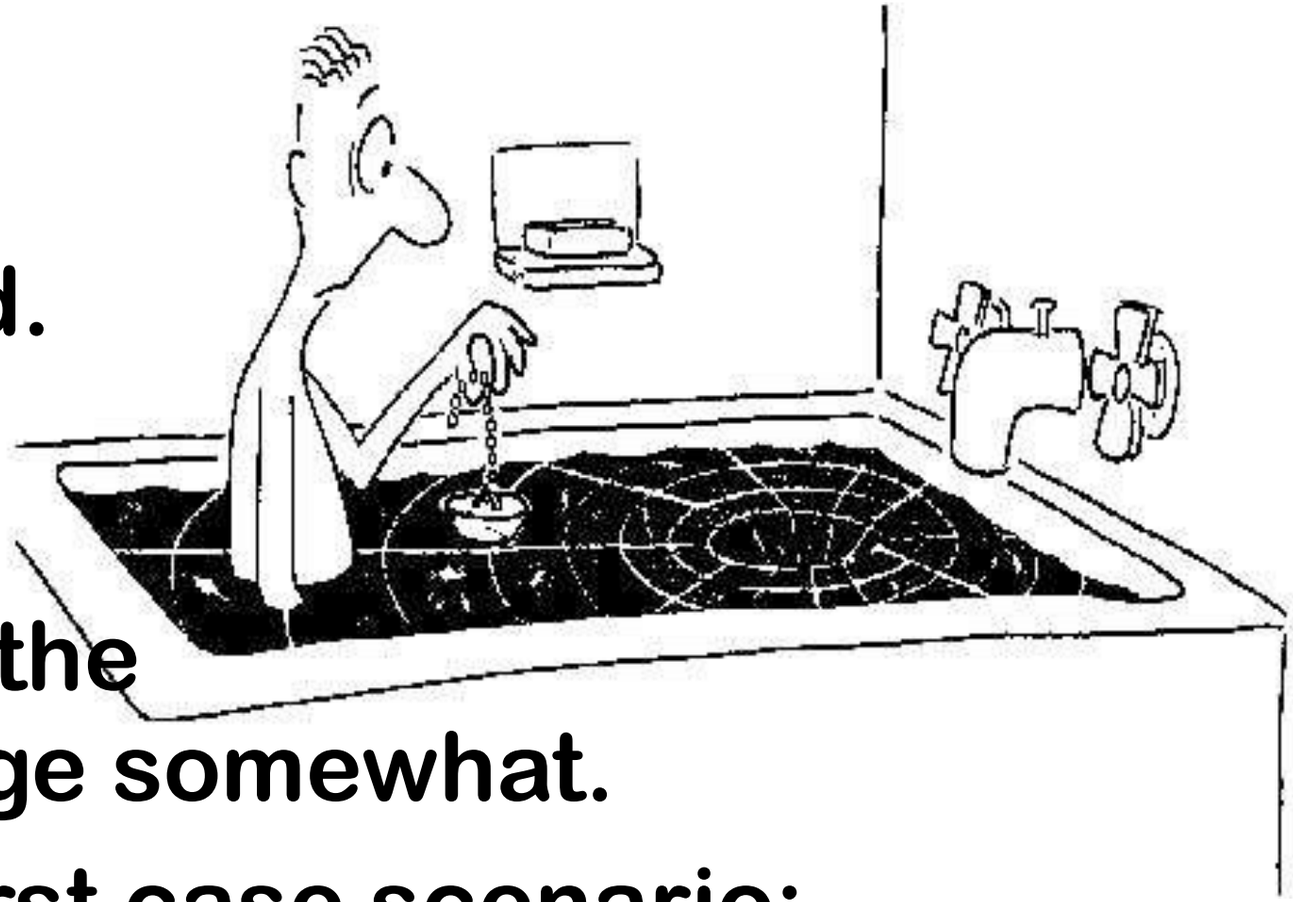
But What If?

- Many of the early effects of a nearby blackhole would be the same as a nearby star.
- We could go from a single star system to a binary system.
- Planets would be pulled two ways, orbits will change.
- At some point the farther out planets will be pulled harder by the new ob



But What If?

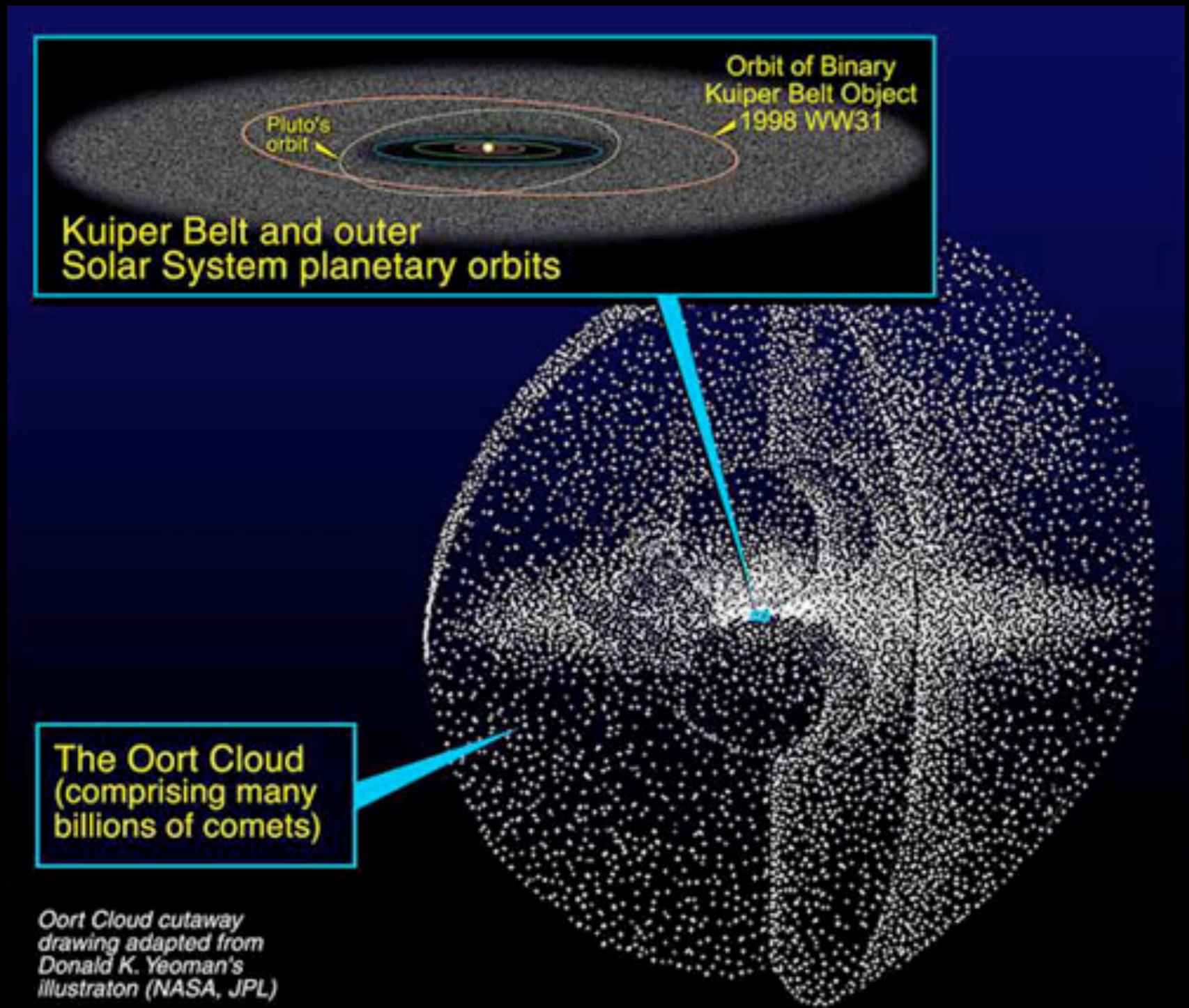
- Planets may orbit the black hole or be flung from the Solar System.
- For two massive object interaction, lower mass objects will often be ejected.
- At first, people won't notice too much, even though the orbit starts to change somewhat.



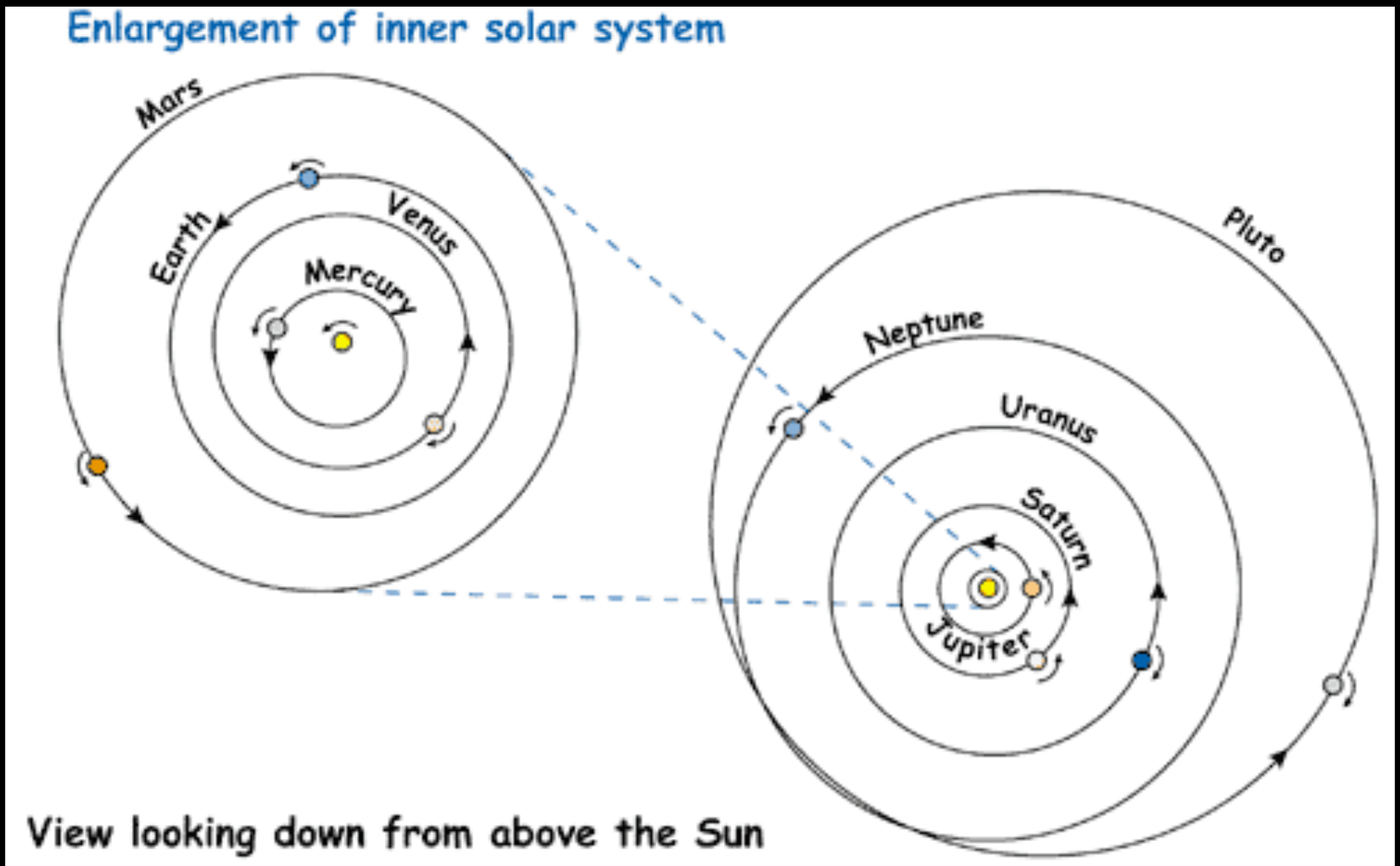
- But imagine the worst case scenario:
  - the black hole is headed straight for the Earth and the Sun

First encounter: Oort Cloud

The black hole's gravity will first affect the Oort Cloud



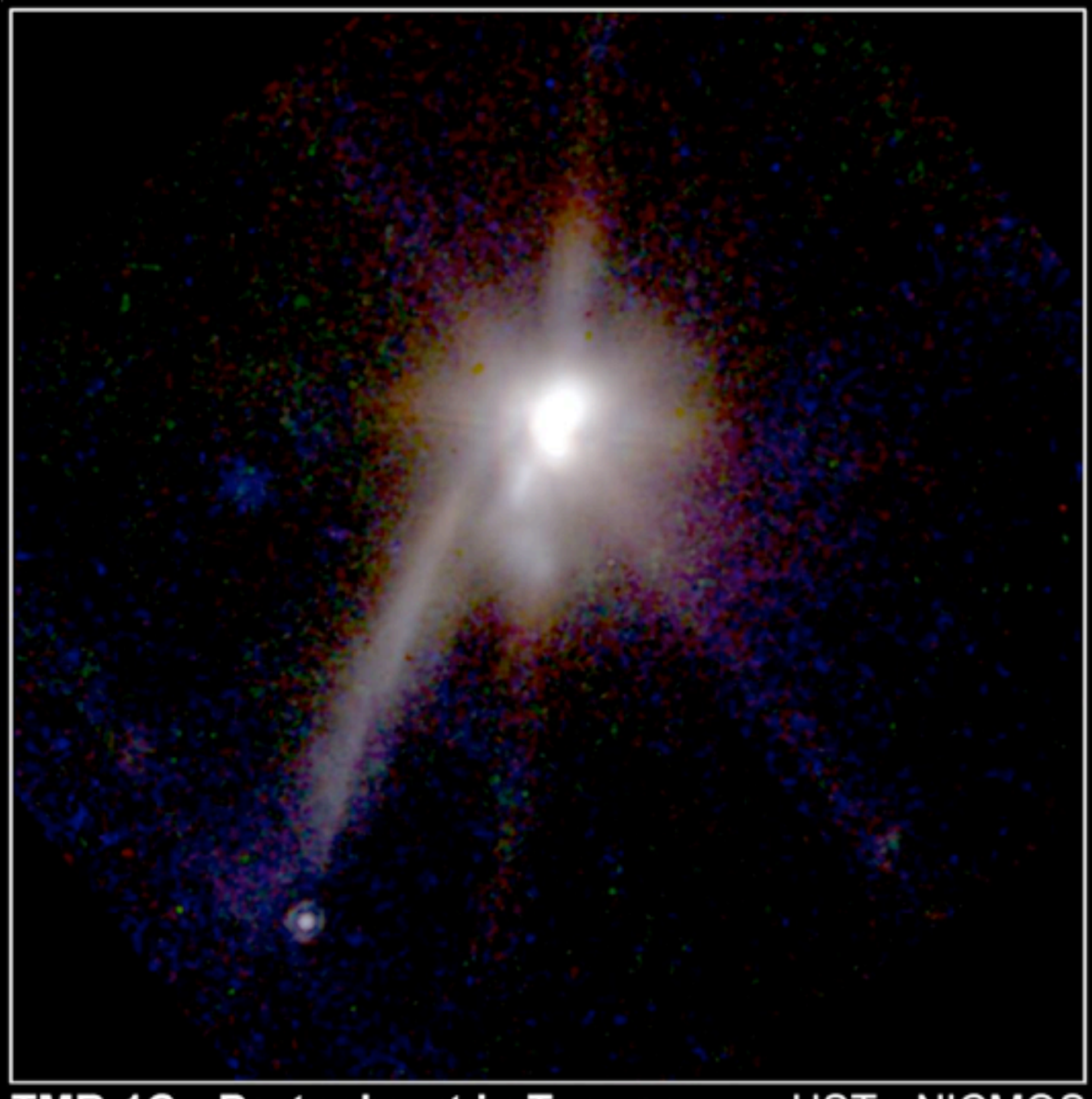
Oort Cloud comets are scattered into the inner solar system, creating an impact threat



Planets' orbits will be altered by the black hole's gravity

Ejected Planets?

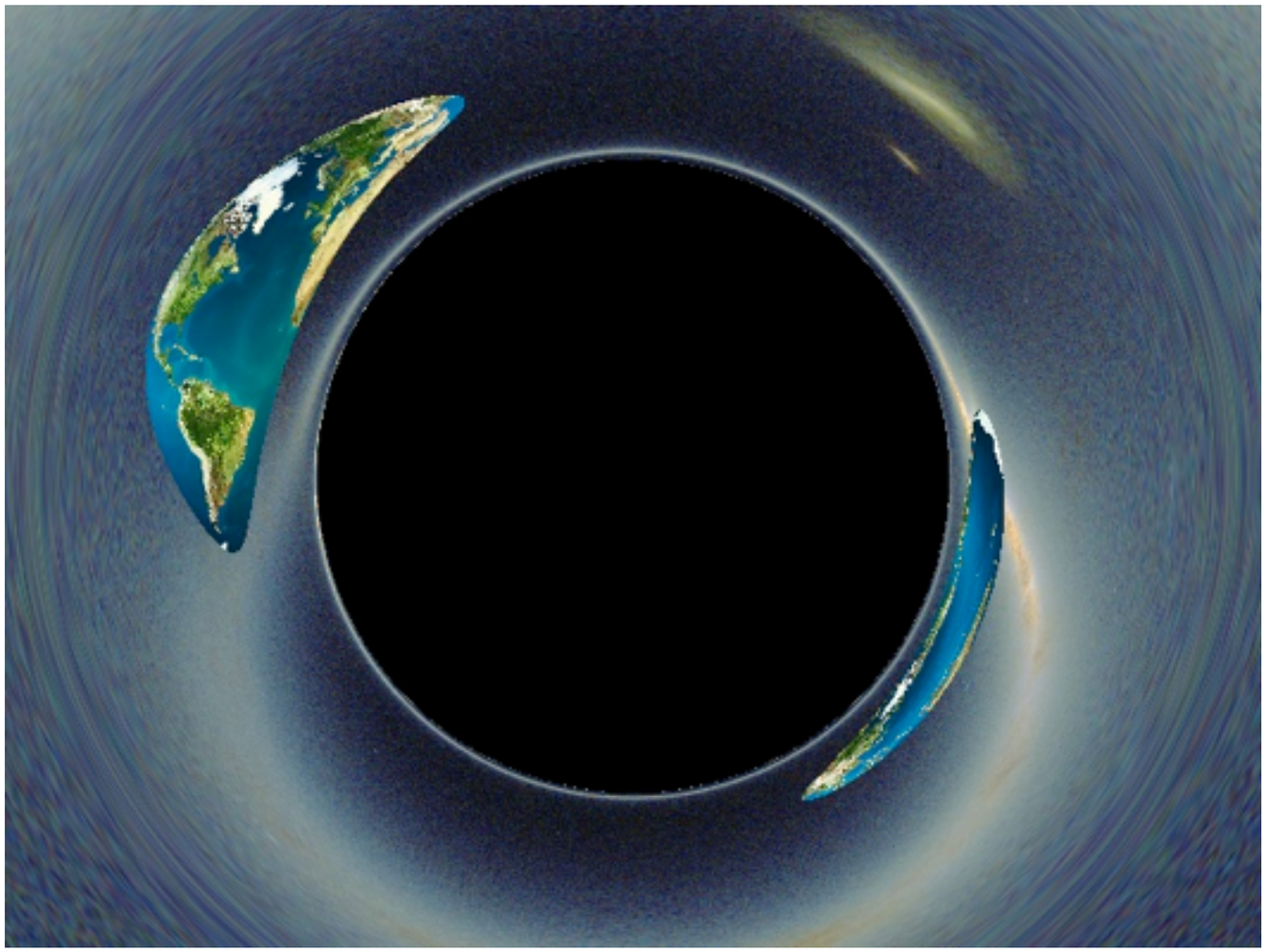
- Planets may orbit the black hole or be flung from the Solar System
- In a two massive object interaction (Sun & black hole), lower mass objects (planets) will often be ejected



TMR-1C • Protoplanet in Taurus HST • NICMOS
PRC98-19 • ST ScI OPO • May 28, 1998
S. Terebey (Extrasolar Research Corp.) and NASA

But What If?

- When a 10 solar mass black hole gets about 3 AU away, it will have more pull than the Sun.
- The Earth will then no longer be bound to the Sun.
- It will either be ejected out of the Solar System, fall into the Sun, or fall into the black hole.



- No matter which, all options are bad for us.

http://www.naturalbuy.com/wp-content/uploads/2009/10/earth-orbiting-black-hole.jpg

But What If?

- When the black hole is 7 million miles away, it's force on you is greater than the Earth's.
- Moon already ejected from system.
- Tides are 20,000 times worse.
- You are weightless.
- With a small kick you can fly upward.
- Earthquakes, continents torn apart.

http://home.vicnet.net.au/~hmwkhelp/images/tidal.wave1.jpg

But What If?

- Final tides are too much for Earth to handle.
- Earth is torn apart like astronaut from before.
- You are killed from either suffocating or if you grabbed a spacesuit spaghettification or from the accretion disk radiation.

- Adding the Earth doesn't really make it any bigger, still about 40 miles across.

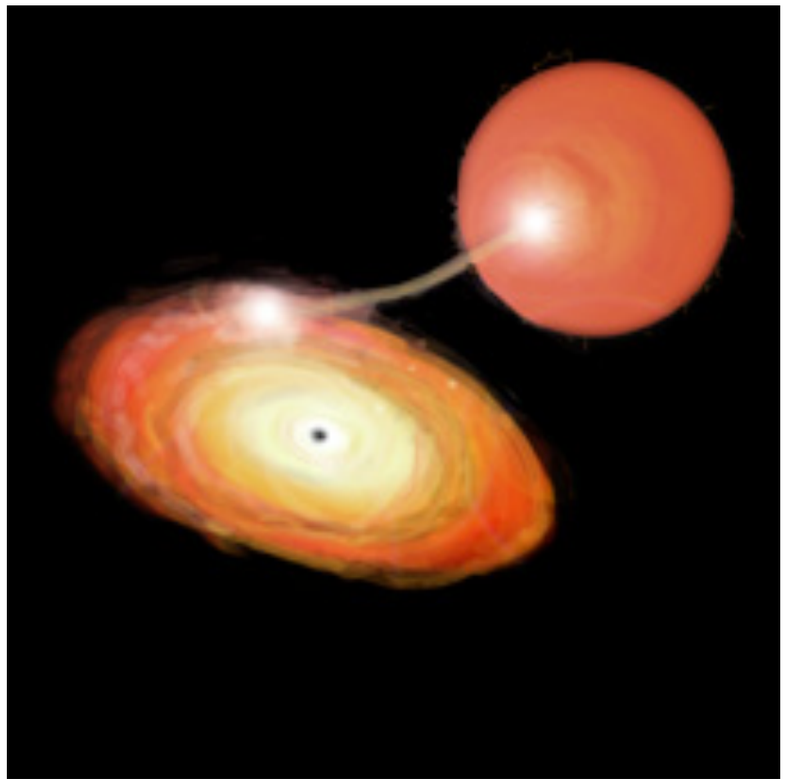
But What If?

- For the rest of the Solar System, it will depend on the orbits.
- If the black hole doesn't ge close to the Sun, it will be fine, otherwise, it may get torn apart too.
- Then, the black hole likely moves on.

http://www.intute.ac.uk/hottopics/spotlight/images/SPT59-smallest-black-hole-birds-eye-view.jpg

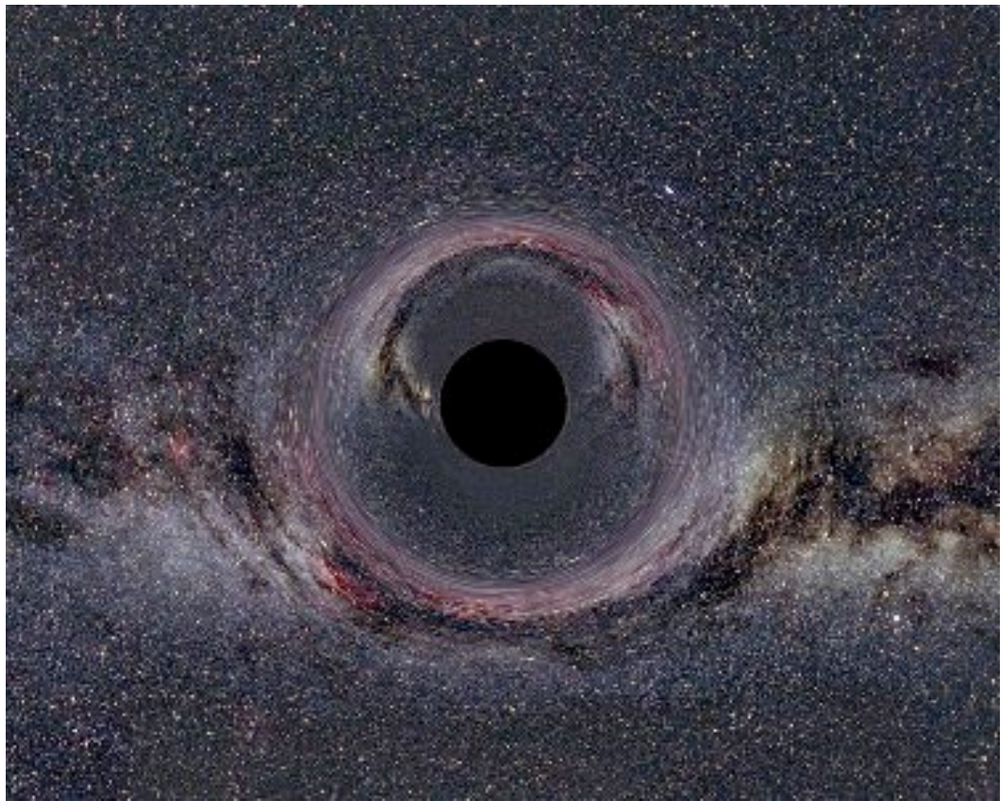
Other Compact Objects?

- There are a lot of white dwarfs or other non-black hole compact objects in the Galaxy.
- Still not very likely to interact with one.
- Collision is very unlikely, but could eject us or destroy the Sun.
- Very, Very unlikely, but probably more likely than a black hole.



Mitigation

- None or very little warning for some objects.
- For some objects much more warning.
- Try to play general relativity engineer?
- Can we predict accurately enough the orbits?
- Leave the Solar System.



Imagine

An amateur astronomer trying to see Uranus is the first to notice. It's in the wrong place!

Later, Jupiter is in the wrong place, then Mars!

Even the Sun has moved!

What is happening?! Oh, the Earth has moved.

Panic spreads as scientist realize that a compact object has entered the Solar System and its mass is throwing off the orbits!

Once the orbit was fixed for the object, telescopes looked for the object, but nothing– a black hole!

Imagine

A black hole coming right at us at 500 miles/ sec.

As it gets closer tidal effects– floods, earthquakes, and tsunamis.

As the 10 solar mass black hole reaches 7 million miles away, its gravitational pull equals that of Earth, everything on Earth is weightless.

Then, the pull of the black hole is more than Earth.

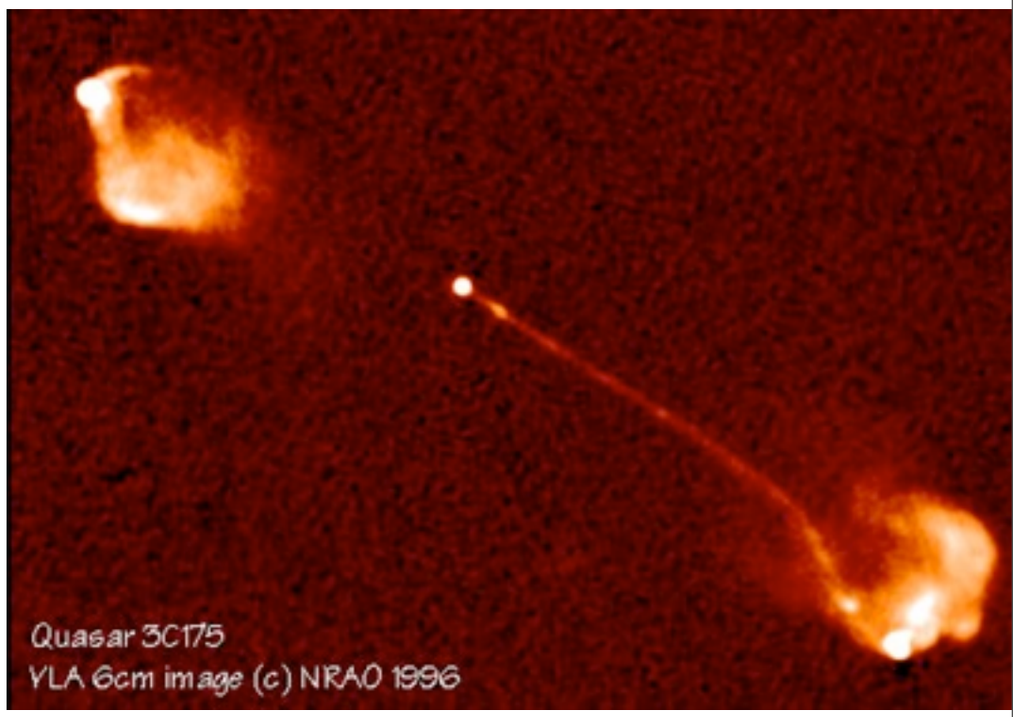
As the Earth gets shredded, you try to remember what Brian said about black holes!

Supermassive Black Hole Jets
Cosmic Blowtorches

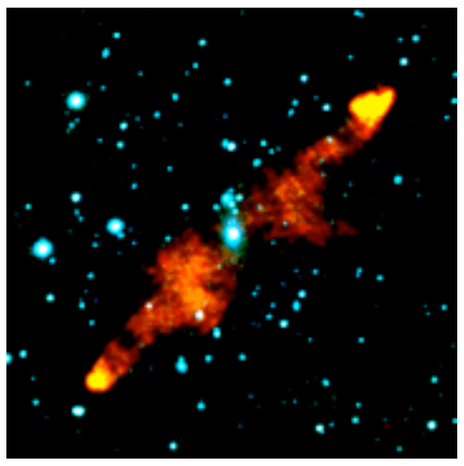
- We have seen that black holes are messy eaters
- undigested matter ejected at high speed

  can be deadly even from "small" stellar mass black holes

  this was the Gamma-Ray Burst threat



- but supermassive black holes also eject huge amounts of matter
- What if we are in the beam?



Imagine

Radio and X-ray astronomers notice something odd

Sagittarius A* is getting brighter

And bigger: appears as an expanding blob

High-energy gamma rays turn on next, along with high-energy neutrinos

The blob starts to appear in visible light

Doppler shifts show that it is made of matter travelling at huge speeds >99% c

Eventually it fills half of the night sky

Imagine

The UV, X-rays and gamma-rays become ever more intense

The Earth's ozone layer is totally stripped clean

The Sun's UV rays destroy the food chain and initiate a mass extinction

Finally, the solar system is engulfed in the blast of a plasma filled with positrons

The blast pushes back the solar wind, possibly inside 1 AU

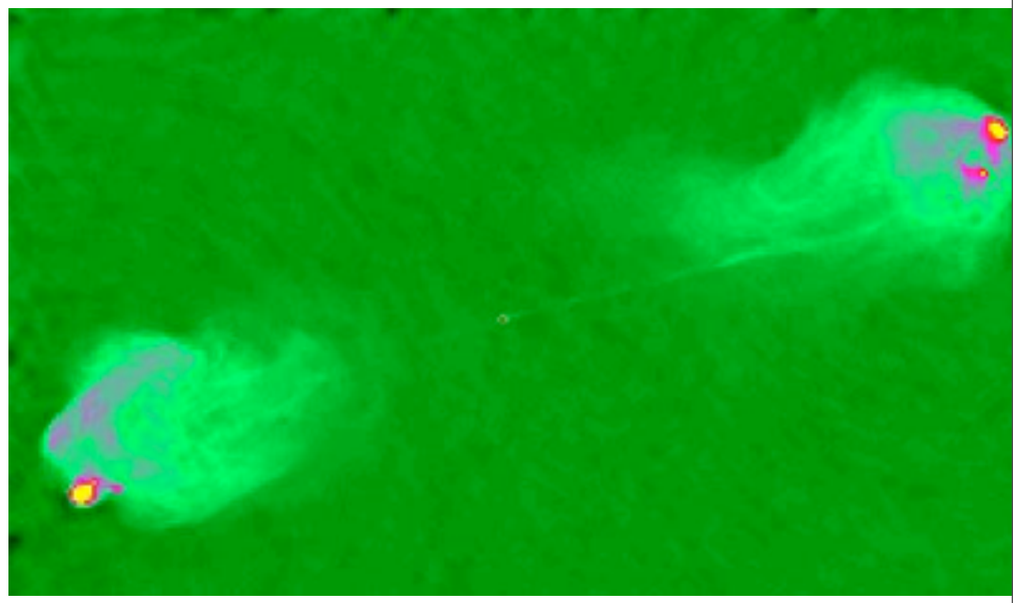
The Earth will be bathed by intense cosmic rays for thousands of years

As you slather on Sunblock 2000, you wonder if this is what Brian meant by a relativistic jet

Supermassive Black Hole Jets

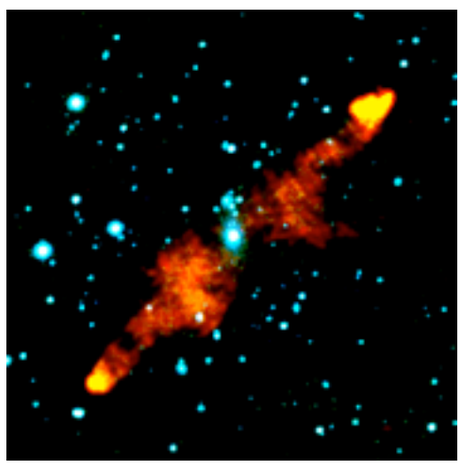
Every (?) galaxy has a supermassive black hole at its center

- most on a diet, not feeding, not dangerous (except nearby)
- when they do feed, not all matter falls in
- some matter ejected at speeds >99% c
- forms back-to-back "jets"

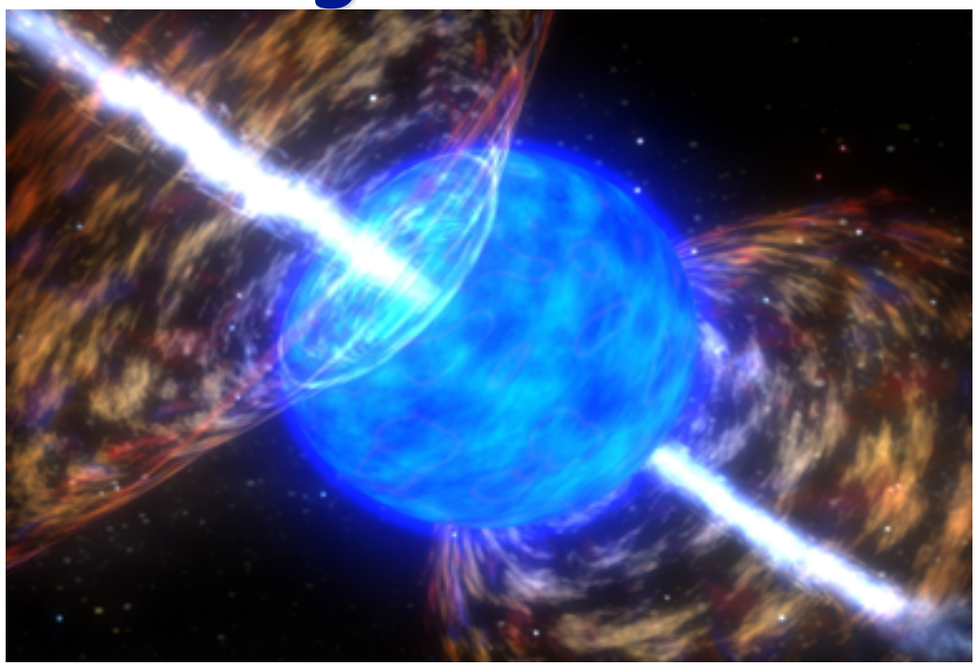


Relativistic Jets from Active Galactic Nuclei

- stretch from black hole to far beyond the host galaxy
- Jets are among largest structures in the Universe
- carry enormous energy
- but many open questions are under study:
  - how exactly is the jet created by the BH?
  - what is the jet made of?
  - what determines the amount of time the jet is "on"?



AGN Jets vs Gamma-Ray Bursts

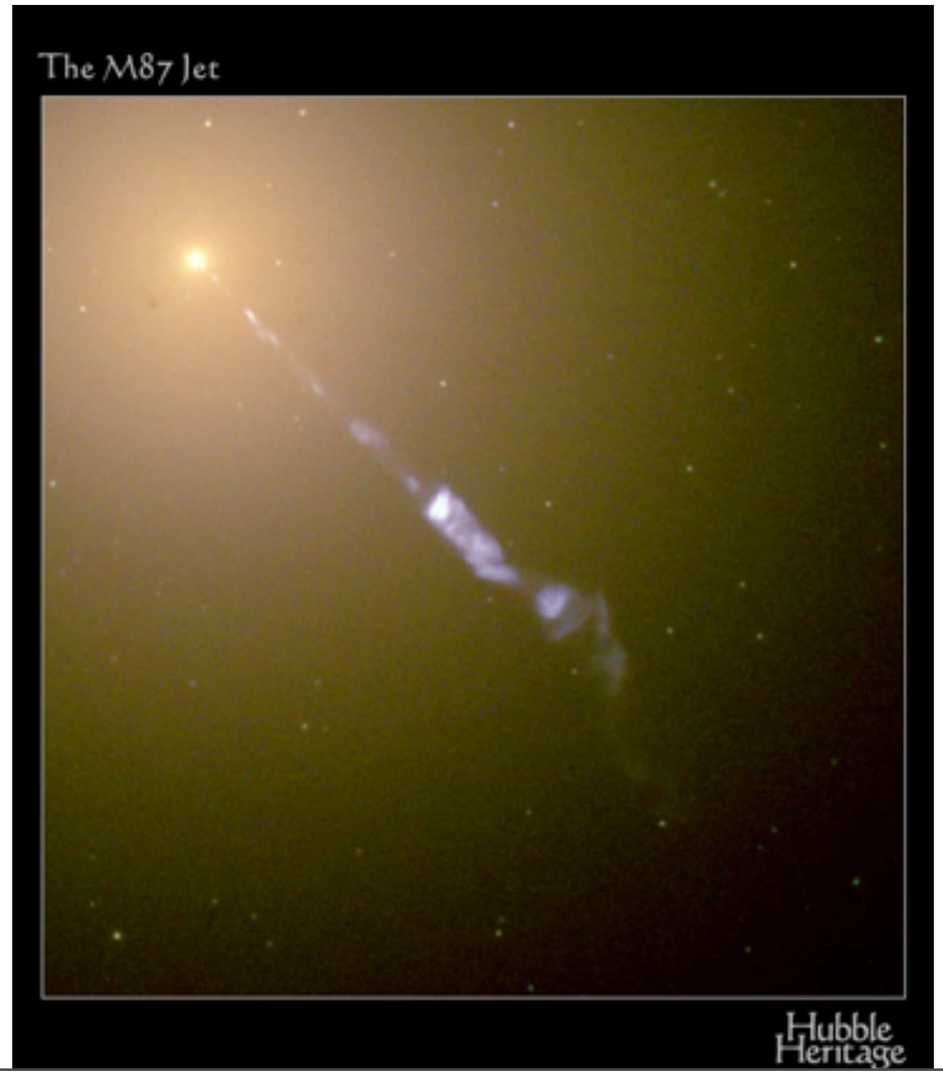


In many ways, AGN jets are similar to GRBs

- both are created by black holes
- both are material ejected at huge speeds
- both eject matter in a narrow beam
- both are directed along the poles of a spinning black hole
- both generate ionizing radiation which is very dangerous if you are in the beam

but note important differences

- GRB outflows
  - created by stellar-mass black holes, say 1-10M_{sun}
  - ejected matter has small mass, <M_{earth}
  - blast is very short-lived, dies off in days
  - blast material stopped well within galaxy hosting the GRB
- AGN outflows
  - created by supermassive black holes >$10^6 M_{sun}$
  - ejected material unknown, but carries huge energy
  - bast sustained for possibly millions of years
  - blasts stretch far beyond host galaxy



Lesson: AGN jets are GRBs on steroids!