Astronomy 150:
Killer Skies

This Class (Lecture 33):
Monsters at the Center of Galaxies

Next Class:
Aliens!

HW 11 due on Dec 10th

Final: Dec 15th, 1:30pm-4:30pm in classroom

Music: Until the End of the World – *U2*

Final

- In this classroom Dec15th, 1330-1630 (1:30pm-4:30pm).
- Will consist of
  - 18 question on Exam 1 material.
  - 18 question on Exam 2 material.
  - 35 questions from new material (Lect 23+).
  - +4 extra credit questions
- A total of 210 points graded out of 200 points, i.e. 5 points of extra credit.
- A normal-sized sheet of paper with notes on both sides is allowed.
- Exam 1and 2 are posted on class website (not Compass).
- I will post a review sheet

Grades

- I will endeavor to post grades for each topic as soon as I can.
- Remember, I will drop at least 5, probably more like 6, of the participation credits, AND 1 of the HWs.
- Running a little behind on the Night Labs and Asteroid Lab, but you try grading 500 reports!
- Nonetheless, medians of those are 100%, so most people doing quite well.

Online ICES

- ICES forms are available online, so far 87/244 students have completed it.
- I **appreciate** you filling them out!
  - Not just the happiest/disappointed of the class.
- **Please** make sure to leave written comments. I find these comments the most useful, and typically that's where I make the most changes to the course.
- This is a new course, so comments are especially welcomed. Keep in mind constraints of a gen-ed though.

Question

Are you going to fill out an ICES form before the deadline?

a) Yes, I did it already.
b) Yes, sometime today
c) Yes, this weekend
d) Yes, I promise to do it before the deadline of Dec 10th!
e) No, I don't want help you out (even after all you have done for me and my education) nor do I want to help out the large number of students who will come after me (I wish you a long life!). I prefer stagnation.

Question

Would you have preferred to have a book with this course instead of just my lecture slides? Keep in mind that color books will be on the expensive side.

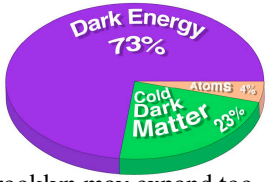
a) Yes
b) No
c) I don't care.

Outline

- The fate of the Universe
  - Big Crunch
  - Big Chill
  - Big Rip
- Quasars
  - Black holes feeding!
  - Watch out for the jets!

The Distant Future: The Big Rip

- Although this is not very popular, and the chances of it occurring is small, what if Dark Energy is not a cosmological constant?
- One extreme case is that it gets carried away, and rips the Universe apart.

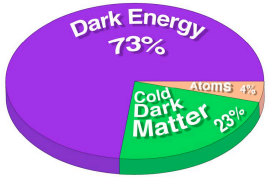


  - If repulsive force increases– Brooklyn may expand too.
  - Gravity/E&M forces can not hold Galaxies rip apart
  - Could rip the MilkyWay apart in ~1-100 billion years
  - Earth gets ripped apart soon after
  - You'd get ripped apart!

http://www.youtube.com/watch?v=oGVYG0ce1Ps

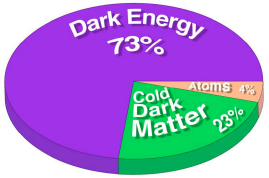
The Distant Future: The Big Crunch

- Another extreme case, is if the nature of Dark Energy changes and we re-collapse afterall.
- The entire Universe falls back to a point.
- All atoms smashed into particles, then pure energy—very hot again.
- Perhaps this has happened before?
- Would take more than 14 billion years.



The Distant Future: The Big Chill

- From what we know right now, we think that the Peter Out/Big Chill is more likely.
- It is less exciting and slow, but an effective way to end the human race.
- Let's play with the stages of the end of the Universe.
- For an interesting read of these, try "The Five Ages of the Universe" by Adams and Laughlin.



Stelliferous Age: 10^8 to 10^{15} years

- Last stars to form will happen in a few hundred billion years.
- Stars age and die
- In about trillion years all Sun-like stars are gone from the Universe forever.
- Only stars left are low-mass red dwarfs (~0.1 solar masses), which can live for trillions of years
  - Lots of these stars and they get brighter with age, so Galaxy brightness doesn't change too much

Stelliferous Age: 10^8 to 10^{15} years

- In 7-8 trillion years, in our Galaxy (Milkomeda), the last red dwarf stops fusing, becoming a white dwarf.
- These tiny white dwarfs will stay hot for quite some time.
- Wait another few trillion years and they fade.
- So when the Universe is 100 trillion years old, the Universe goes dark.

Really Dark

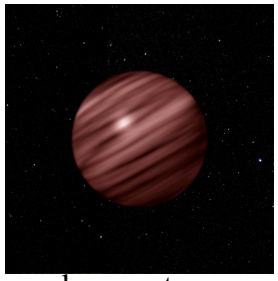
- If the Universe keeps expanding, it get worse for astronomers.
- The Galaxies we can see now, far away galaxies move out of our view.. Too far to see given the age of the Universe… out of our horizon.
  - The observable Universe is less and less
- The one giant elliptical galaxy (all that is left from our local group) is all that can be seen.
- The Universe appears empty!

Humans?

- We have 100 trillion years!
- Maybe longer, by smashing stars together to make fusion last longer.
- Won't last too long.
- When the Universe is slightly older than 100 trillion years old, the human race is out of fuel, out of stars, and out of luck.
- But the Universe isn't done!

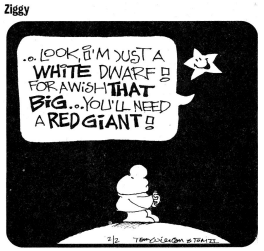
The Degenerate Era: 10^{15} to 10^{40} years

- Stellar corpses are all around the Galaxy.
- Every once in a while, a black hole will accrete a compact object, creating light again.
- Corpses may collide (remember we are talking 100 trillion years of time not the measly 13.7 billion of the Universe so far), and create new stars.
- Brown dwarfs, which did not have enough mass to fuse, can collide, making new stars.
- New life? Different Universe..



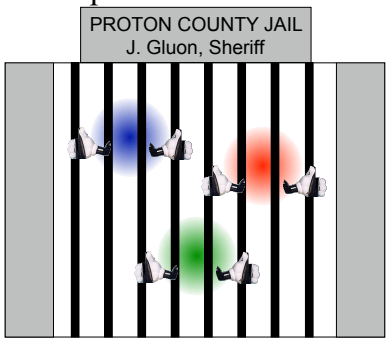
The Degenerate Era: 10^{15} to 10^{40} years

- But after a trillions, then quadrillions, and then quintillions of years, everything that can ever burn has happened.
- The Galaxy starts to lose weight.
  - Interactions with the stellar corpses, cause all the low-mass objects to be ejected from Galaxy.
  - High-mass objects fall to the center.
  - Supermassive Black Hole feeds!
- If the Earth still orbited the dead Sun (white dwarf) it is likely kicked out of the Sun and the Galaxy– a frozen dead planet in intergalactic space.



Proton Decay

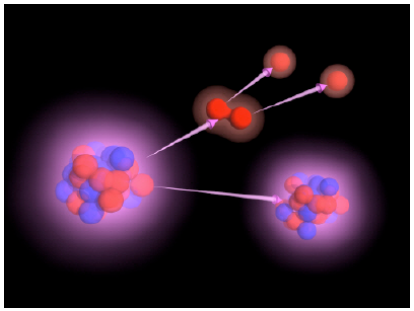
- Remember when quarks were imprisoned?
- We think that protons are radioactive.
- Except that they decay with a half-life of about 10^{37} years.
- Time is all that is left.



10^{31} years to life
Little chance of parole

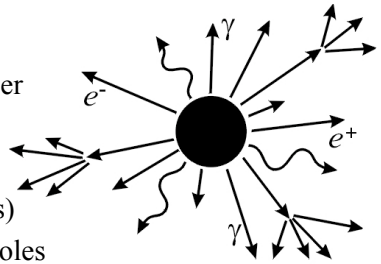
Proton Decay

- This proton decay creates heat again, feeble heat.
- What does non-proton life do?
- White dwarfs will evaporate
  - At -454 F, they are the hottest thing around!



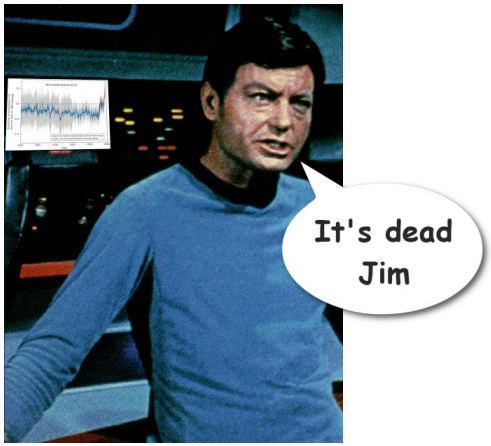
The Black Hole Era: 10^{40}-10^{92} years

- Black Holes survive.
  - Not made from matter, remember
- Galaxy is
  - The Supermassive Black Hole (1-10% of original Galaxy mass)
  - Trillions of stellar mass black holes
  - Lower mass stuff that was thrown out, so very far away.
- Hawking radiation is slow, but it will begin to evaporate the black holes
  - Slow, but lots and lots of time



The Dark Era: 10^{92}- Infinity

- 10^{92} is crazy!
- I mean really, really crazy!
- The weight of a single proton to the rest of the Universe is only 10^{79}!
- Still, at this point, the Universe is dead!
- Dead Jim!



The Dark Era: 10^{92}- Infinity

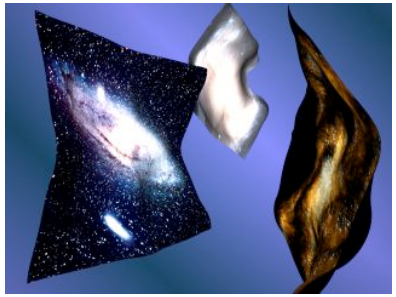
- Beyond this, two particles will once in a great while interact, but nothing will really happen.
- Universe is dead, randomized, and silent.
- Nothing really will ever happen again..
- Or will it?

The Dark Era: 10^{92}- Infinity

- Rebirth?
- We don't know what caused the Big Bang.
- Maybe it happens again?
- Maybe it already has?

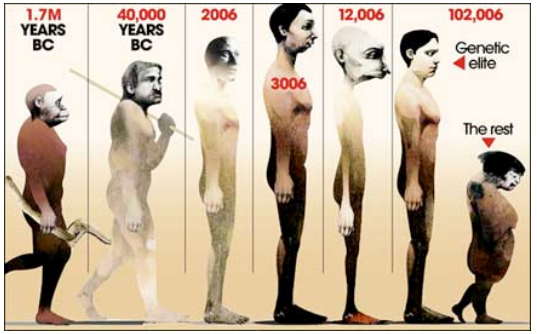
Branes, Branes!

- One idea is that the Universe has 11 dimensions
  - Our 4 dimensional Universe floats around in this space
  - Other universes float there too (called branes, short for membranes)
  - Sometimes they collide
  - Violently disturbed, energy/matter heat up, expanding space
  - Sounds familiar..



Mitigation

- Are you kidding me?
- If humans live this long, they won't be anything we'd recognize as human.



Imagine

- After getting flung a few billion years into the future in a British police box, everything seems normal.
- Humans must have moved the Earth.
- But something isn't right.
- Suddenly, the Earth rips apart..
- Then your body rips apart.
- As your body's atoms get ripped apart, you wonder why Leslie didn't mention how painful it would be.

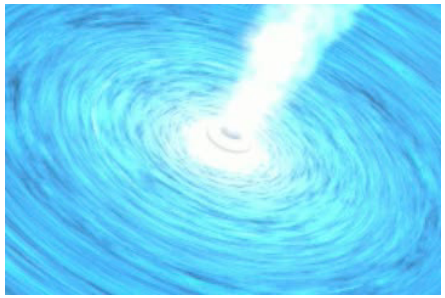
Top 10 Ways Astronomy Can Kill you or your Descendents

6. Rogue compact objects–White Dwarfs/Black Holes.
   Black Holes don't suck, but if they hit you it sucks.
7. Galaxy Collisions.
   Milky Way vs. Andromeda.
8. Cosmology!
   This is the way the Universe ends..
9. Quasars. The Monster in the Milky Way?
   It burnssss…

Top 10 Ways Astronomy Can Kill you or your Descendents

8. Quasars. The Monster in the Milky Way?

Right now, our supermassive black hole is quiet. But what if it starts to feed?



Imagine

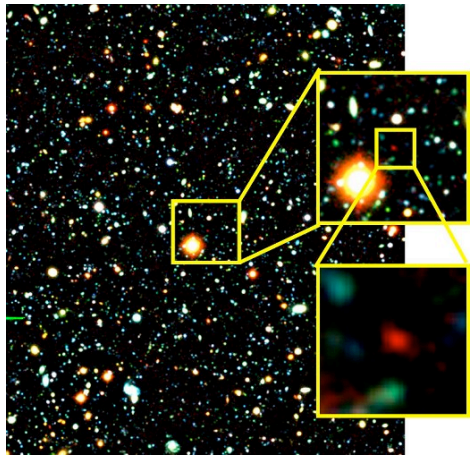
- Astronomers notice that the center of Andromeda is getting brighter. Something interesting is going on.
- Astronomers suggest that Andromeda's supermassive black hole is feeding for some reason.
- It is exciting as astronomers watch the formation of a large accretion disk, which is somewhat unexpectedly oriented perpendicular to our line of sight.

Imagine

- Without warning, a beam of energy is unleashed from the center of Andromeda.
- The gamma-ray beam has less energy/time than a gamma-ray burst, but it doesn't turn off.
- As you are fried by gamma-rays, you wonder why you didn't pay more attention to Leslie during the last week of class and why you didn't fill out your ICES form online.

The Furthest Known Galaxy

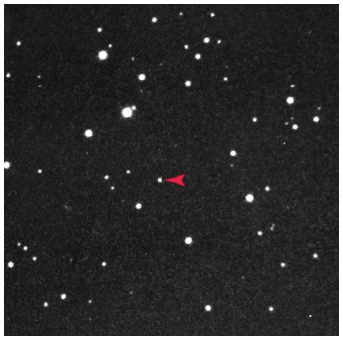
- IOK-1
- This galaxy is confirmed to be 12.88 billion light years away!
- That means only 750 Myrs after the Big Bang!
- If Universe had a human lifetime (say 80 years), this galaxy is from when the Universe was only 4 years old!



http://www.schoolsobservatory.org.uk/pic/news/iok1/iok1.jpg

A Very Strange Star !?!

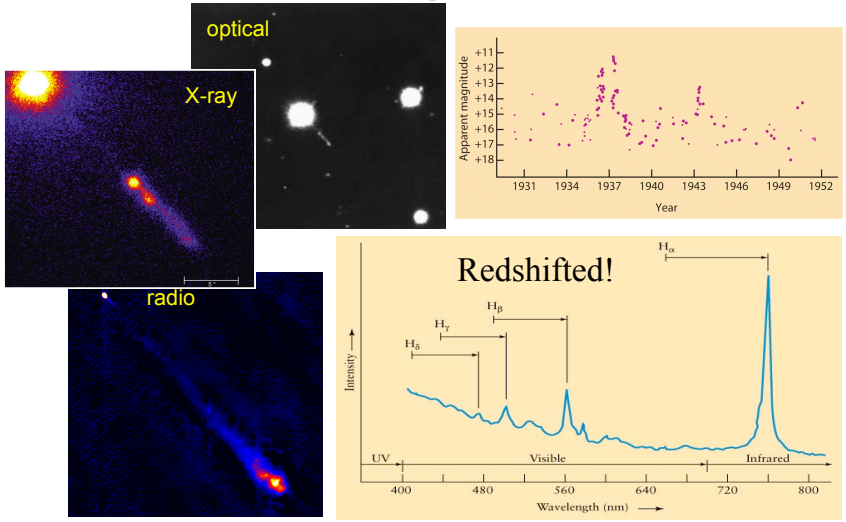
- The first most distant galaxy (while much closer) was a shock to astronomers: tracked down a bright radio source.
- Looked like a blue star, but had very odd spectrum.
- Turned out it was simply greatly redshifted.
- 2 billion light years away!
- It must be 100 times brighter than the entire Milky Way!
- **Not** a star



Quasars…

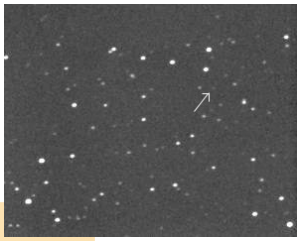
- These objects have a spectrum much like a dim star
  - But highly redshifted
  - Appear to moving away from us very fast!
- Dubbed **quasars** (quasi-stellar radio sources)
- Hubble's Law tells us that they are at "astronomical" distances
  - Up to 10 billion light years away!
- Great distances - must be very bright
  - Some 1 million times the brightness of our Galaxy!
- Highly variable
  - Emission region must be small - about the size of our Solar System

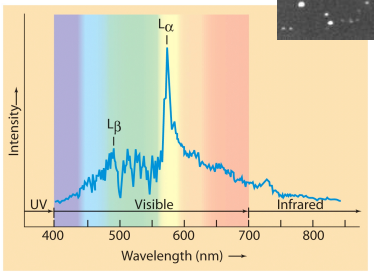
The First Quasar Discovered: 3C 273: z = 0.158



PKS 2000-330

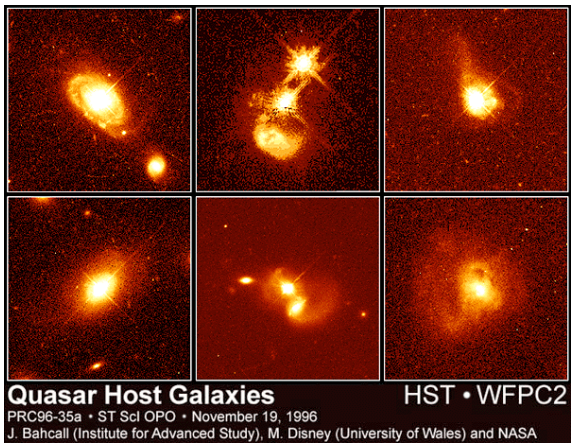
- Redshifted so much that UV emission can be seen in the optical
- This quasar appears to be moving away from us at 92% of the speed of light!



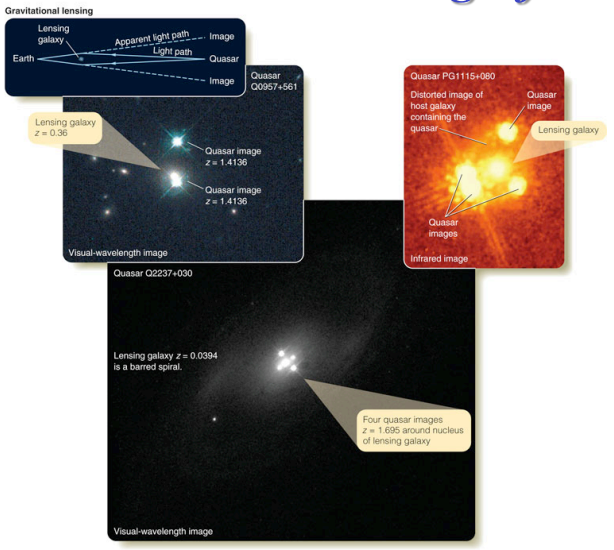


Quasar Host Galaxies

- Quasars live in distant galaxies
- They are *galactic nuclei!*
- *But why are these nuclei so bright?*



Gravitational Magnified



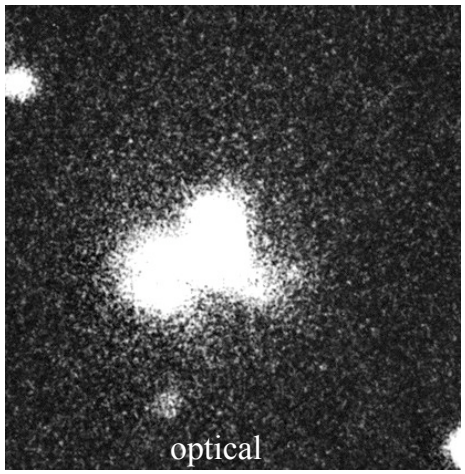
Question

So what is a quasar?

a) The nucleus of a galaxy far away.
b) A tasty treat.
c) A star with high velocity.
d) A quasi-static nebula that is bright in the radio.

Are there quasars in the nearby Universe?

The Cygnus A Galaxy



- Looks like a star
- But bright in the radio
- And it's moving away from us fast!
- Moving away at 14,000 km/s.
- That's about 5% the speed of light!
- 635 million light years away!
- Similar to a quasar??

Active Galaxies

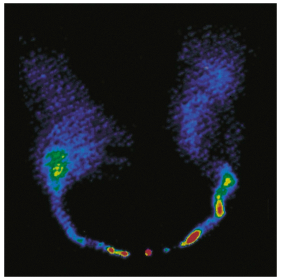
- There are no quasars in the nearby Universe *now*
- But there are some very energetic galaxies (about 1% of all galaxies)
  - Very bright, star-like nuclei
  - Often, energetic outflows of matter from the nucleus
- Called **active galaxies**
- Types of active galaxies
  - **Seyfert galaxies**
  - **Blazars**
  - **Radio galalxies**
- Like quasars, but not as energetic

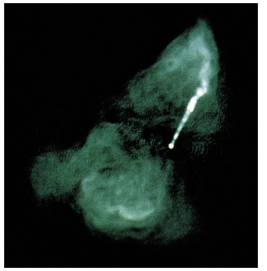
Seyfert Galaxies

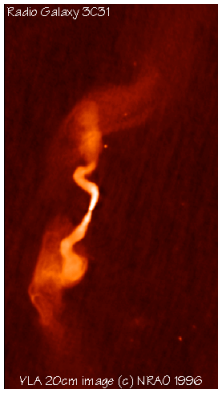
- Look like normal spiral galaxies, but with incredibly bright nuclei
- Potentially as bright as a trillion Suns!
- Brightness varies tremendously
- Over a few weeks it's brightness can change by the ENTIRE brightness of the Milky Way

Radio Galaxies

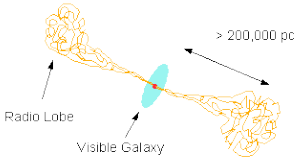
- There are varying types of radio galaxies
- Called *radio loud* as they can be 10 million times as bright as the Milky Way at radio wavelengths

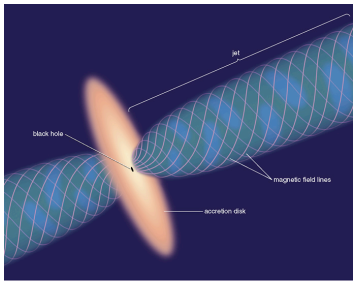


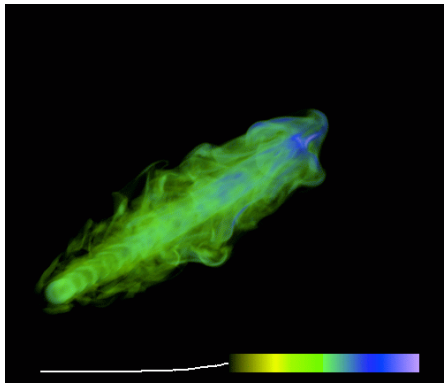




Radio Galaxy Jets

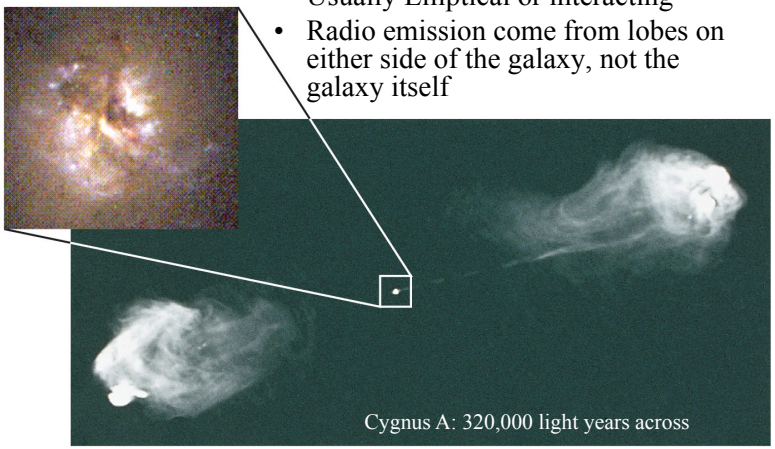




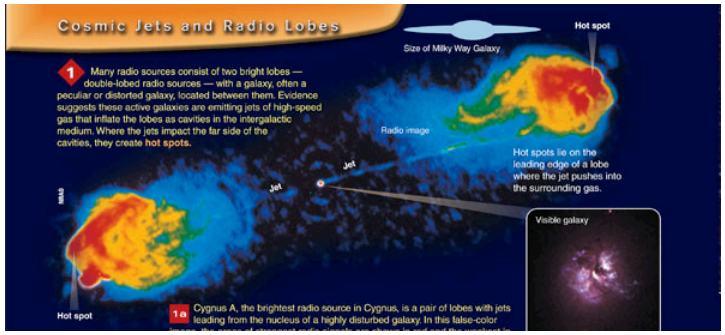


Radio Galaxies

- Galaxies that emit large amounts of radio waves
- Usually Elliptical or interacting
- Radio emission come from lobes on either side of the galaxy, not the galaxy itself

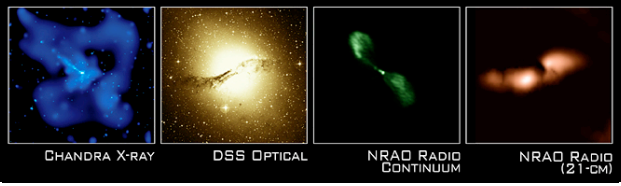


Huge



Radio Galaxies: Centaurus A

If you could see the lobes of the jet with your naked eyes, it would be 10 times bigger than a full moon!

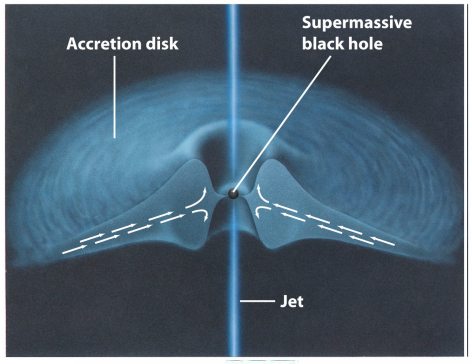


Centaurus A

What is the power source for quasars and other active galaxies?

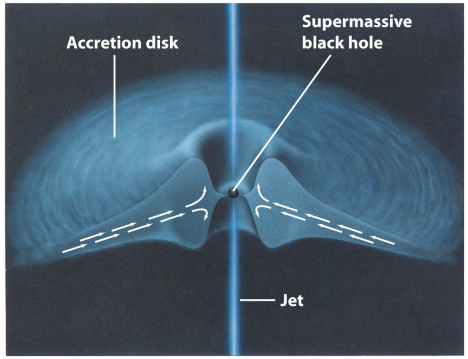
Driving Active Galaxies: The Monster Within

- A scary blue monster?
- Probably not



Driving Active Galaxies: The Monster Within

- Most likely - the energy source is a supermassive black hole
- Accretion disk emits tremendous amounts of energy as it falls onto the black hole
- Active nuclei are the largest reservoirs in the Universe, lasting millions of years or longer.



Quasars and Active Galaxies

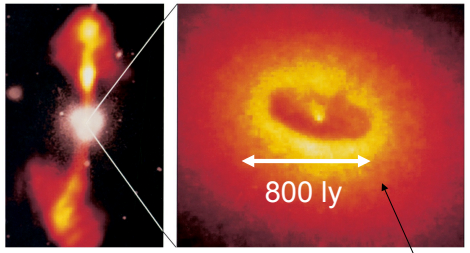
- Supermassive black holes probably exist in most if not all galaxies' cores
- In the past, active galaxies were more common then now
- Were very powerful active galaxies at one time quasars?
- As the Universe evolved, the quasars calmed down
  - Turned off?
  - Became today's active galaxies?
  - Why?

TABLE 16-1 Galaxy and Quasar Luminosities

Object	Luminosity (watts)
Sun	4×10^{26}
Milky Way Galaxy	10^{37}
Seyfert galaxies	$10^{36} - 10^{38}$
Radio galaxies	$10^{36} - 10^{38}$
Quasars	$10^{38} - 10^{42}$

The Central Engine – Supermassive Black Holes

- Energy source for active galaxies
- Only thing compact enough and energetic enough



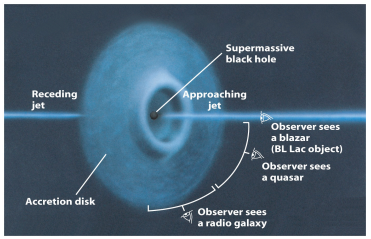
NGC 4261 in the Virgo Cluster

- Material falling into the black hole compresses and heats up
  - Emits tremendous amounts of energy
  - Some gas escapes via high-speed jets

From velocities, 1.2 billion solar masses!

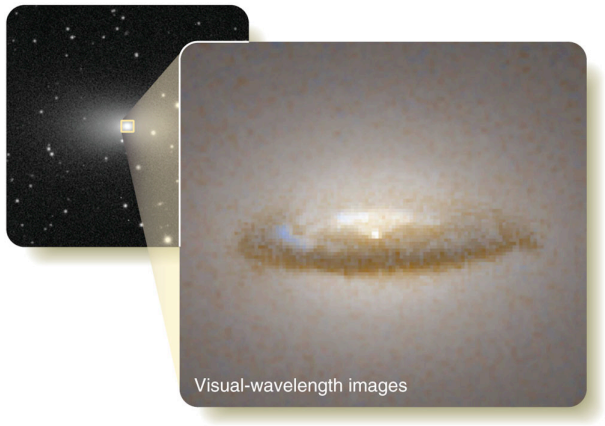
Origin of Supermassive Holes?

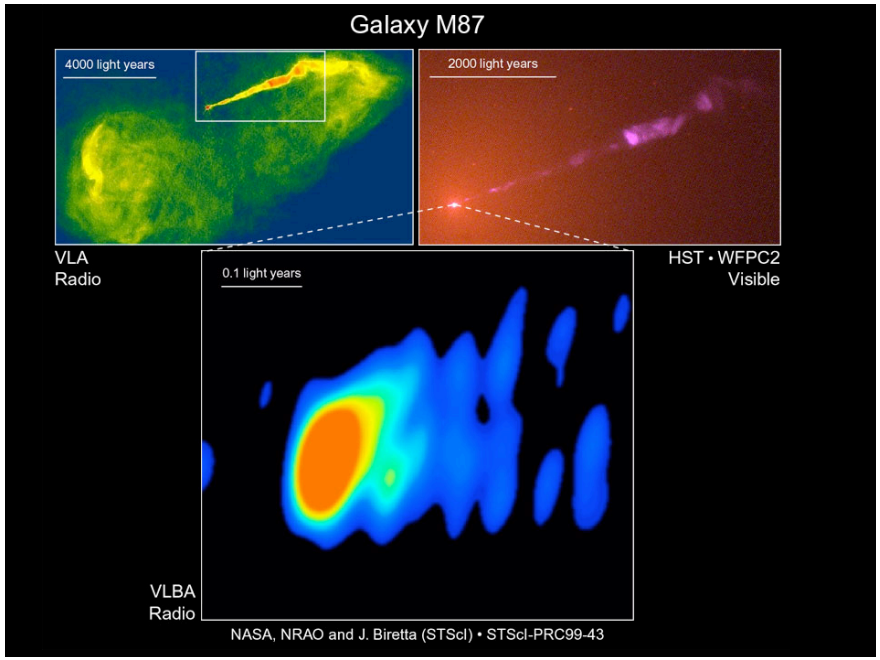
- There is a correlation between the mass of the central black hole and the bulge of the galaxy.
- Not the disk component, only the bulge.
- About 0.5% of the bulge.
- Suggests that the black hole formed earlier in the bulge formation process.



The Central Engine – Supermassive Black Holes

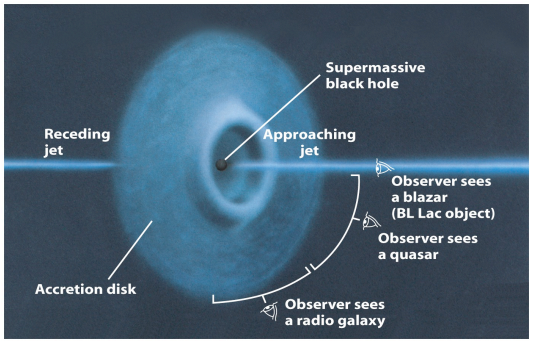
NGC 7052



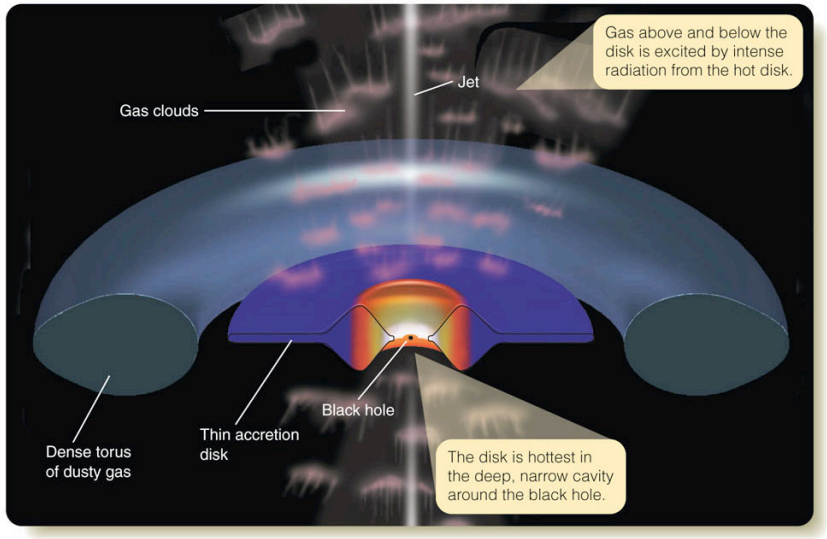


A Unified Model

- Active galaxies and quasars have the same energy source (supermassive black holes)
- Orientation matters!



Torus



Question

What would happen to our Galaxy if the supermassive black hole at the center were "fed"?

a) Nothing
b) Something