

## Chapter 21 Galaxy Evolution



## Agenda

- Announce:
  - Test in one week
  - Part 2 in 2.5 weeks
  - Spring Break in 3 weeks
  - Online quizzes & tutorial are now on assignment list
- Final Exam questions
- Revisit “Are we significant question?”
- Ch. 21—Galaxy Evolution
- Balloon Lab

## Final Exam Essay Questions

- What’s the most exciting problem in astronomy that might get resolved within the next five years?
- Politicians often hide behind a “support our <blank>” (e.g. troops, president, ...). How does science depend on the opposite of this and give specific examples (discovery of neutrinos from the sun, determination that GRBs are outside the galaxy, big bang/dark matter/dark energy).
- We’ve seen stories of scientists who stuck with a position despite evidence to the contrary (e.g. neutrinos, GRBs, big bang). Were they being unscientific? In the end, the evidence came around to support them, so do the ends justify the means in science?

## Are We Significant?

## Are We Significant?

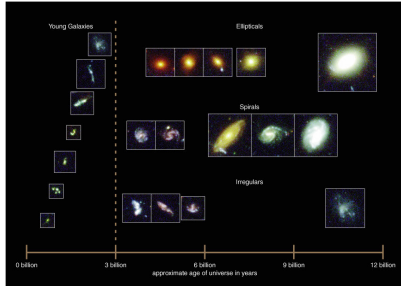
Cosmologists often refer to this possibility as “the ultimate Copernican revolution”: not only are we not at the center of anything; we’re not even made of the same stuff as most of the rest of everything. “We’re just a bit of pollution,” Lawrence M. Krauss, a theorist at Case Western Reserve, said not long ago at a public panel on cosmology in Chicago. **“If you got rid of us, and all the stars and all the galaxies and all the planets and all the aliens and everybody, then the universe would be largely the same. We’re completely irrelevant.”**

<http://www.nytimes.com/2007/03/11/magazine/11dark.t.html>

## 21.1 Looking Back Through Time

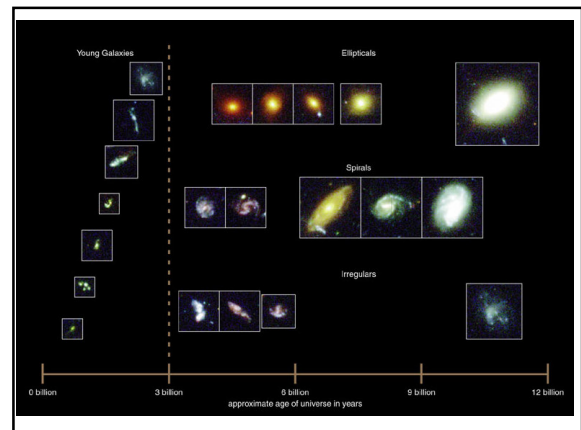
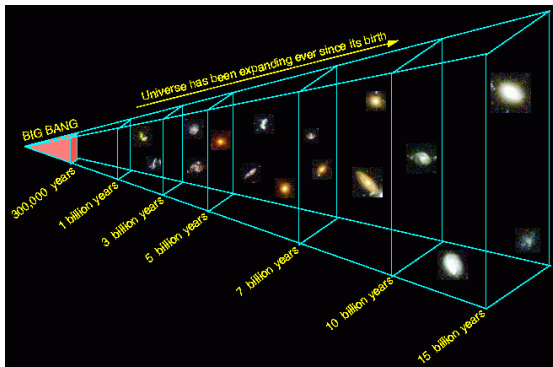
- Our goals for learning
- How do we observe the life histories of galaxies?
- How did galaxies form?

## How do we observe the life histories of galaxies?

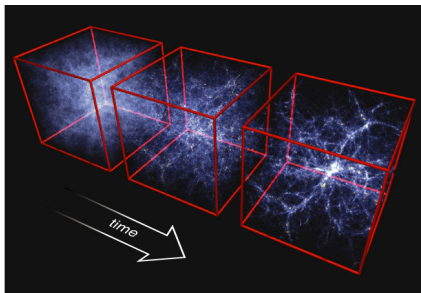


Deep observations show us very distant galaxies as they were much earlier in time

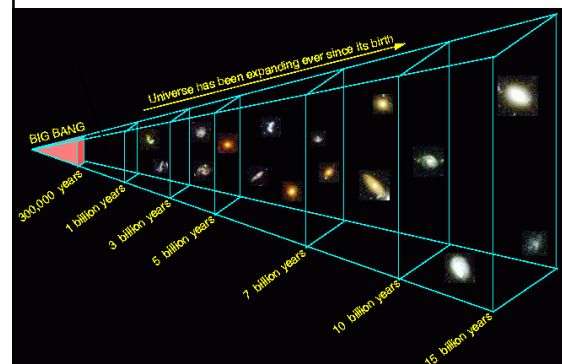
(Old light from young galaxies)

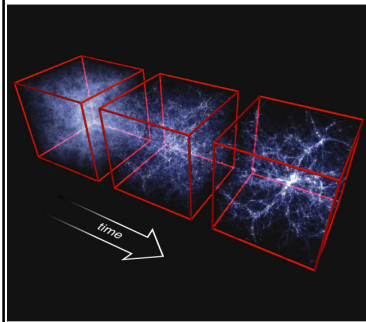


## How did galaxies form?



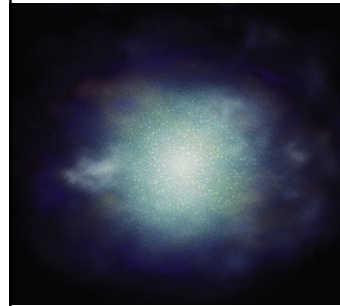
We still can't directly observe the earliest galaxies





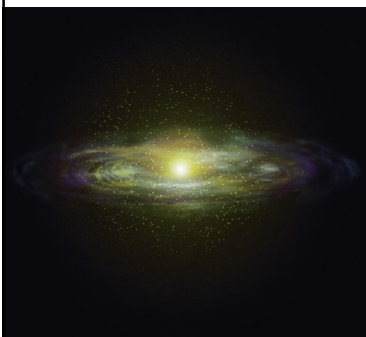
Our best models for galaxy formation assume:

- Matter originally filled all of space almost uniformly
- Gravity of denser regions pulled in surrounding matter



Denser regions contracted, forming *protogalactic clouds*

H and He gases in these clouds formed the first stars

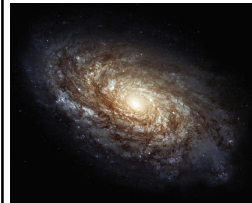


Supernova explosions from first stars kept much of the gas from forming stars

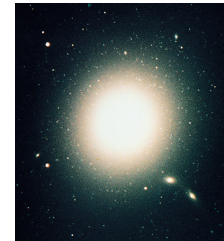
Leftover gas settled into spinning disk

*Conservation of angular momentum*

NGC 4414



M87



But why do some galaxies end up looking so different?

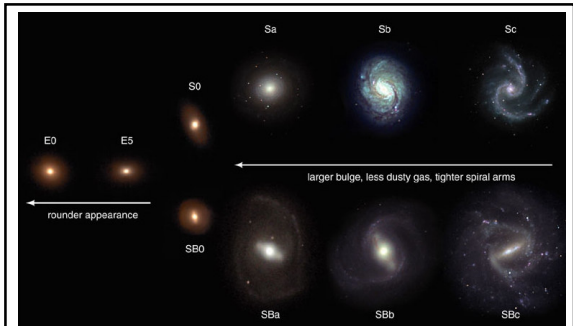
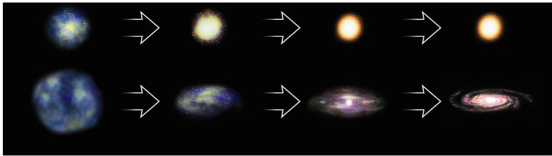
## What have we learned?

- How do we observe the life histories of galaxies?
  - Deep observations of the universe are showing us the history of galaxies because we are seeing galaxies as they were at different ages
- How did galaxies form?
  - Our best models for galaxy formation assume that gravity made galaxies out of regions of the early universe that were slightly denser than their surroundings

## 21.2 The Lives of Galaxies

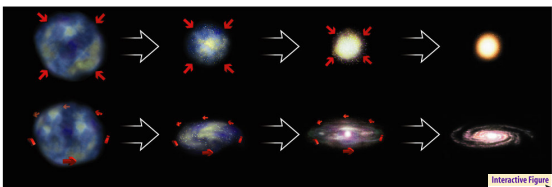
- Our goals for learning
- Why do galaxies differ?
- What are starbursts?

## Why do galaxies differ?



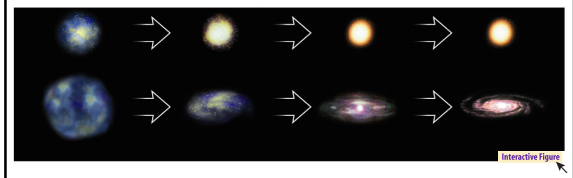
Why don't all galaxies have similar disks?

## Conditions in Protogalactic Cloud?



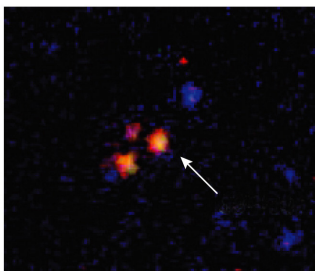
**Spin:** Initial angular momentum of protogalactic cloud could determine size of resulting disk

## Conditions in Protogalactic Cloud?

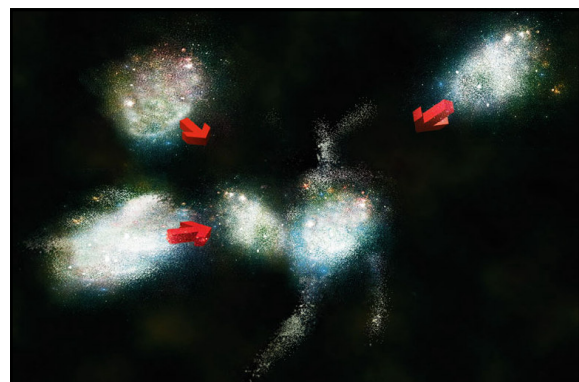


**Density:** Elliptical galaxies could come from dense protogalactic clouds that were able to cool and form stars before gas settled into a disk

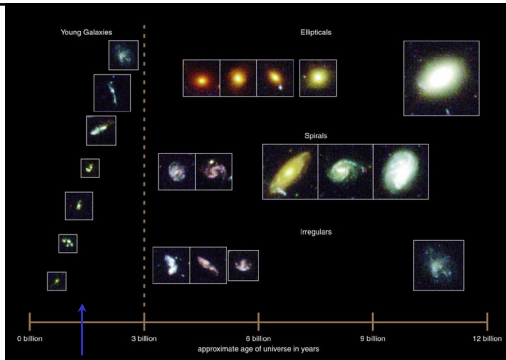
## Distant Red Ellipticals



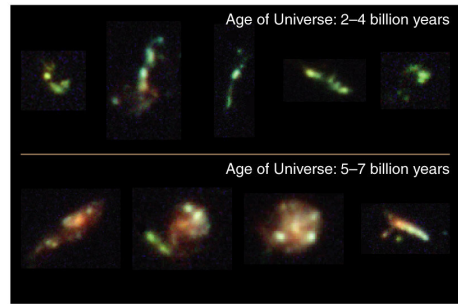
- Observations of some distant red elliptical galaxies support the idea that most of their stars formed very early in the history of the universe



We must also consider the effects of collisions



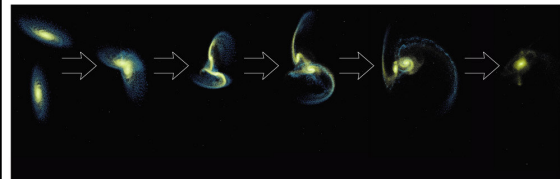
Collisions were much more likely early in time, because galaxies were closer together



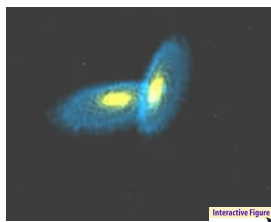
Many of the galaxies we see at great distances (and early times) indeed look violently disturbed



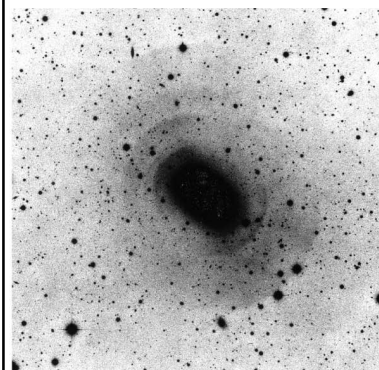
The collisions we observe nearby trigger bursts of star formation



Modeling such collisions on a computer shows that two spiral galaxies can merge to make an elliptical



Modeling such collisions on a computer shows that two spiral galaxies can merge to make an elliptical

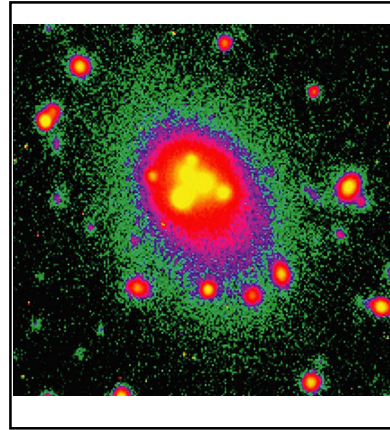


Shells of stars observed around some elliptical galaxies are probably the remains of past collisions



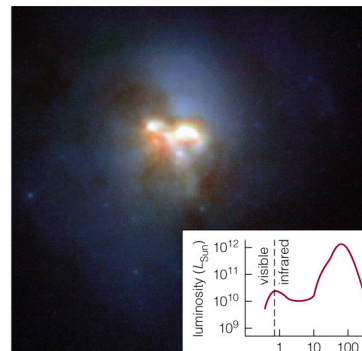


Collisions may explain why elliptical galaxies tend to be found where galaxies are closer together



Giant elliptical galaxies at the centers of clusters seem to have consumed a number of smaller galaxies

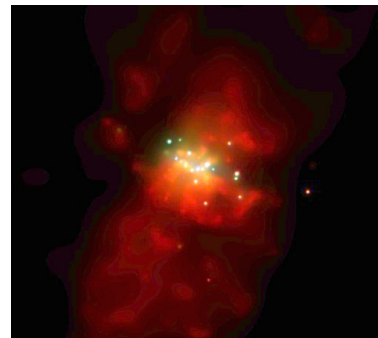
### What are starbursts?



Starburst galaxies are forming stars so quickly they would use up all their gas in less than a billion years

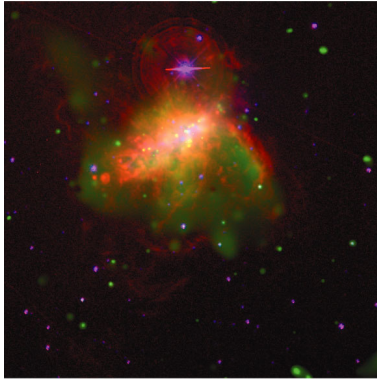


Intensity of supernova explosions in starburst galaxies can drive galactic winds



X-ray image

Intensity of supernova explosions in starburst galaxies can drive galactic winds



A galactic wind in a small galaxy can drive away most of its gas

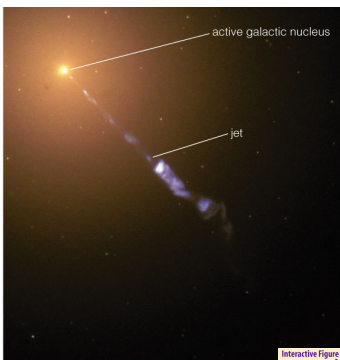
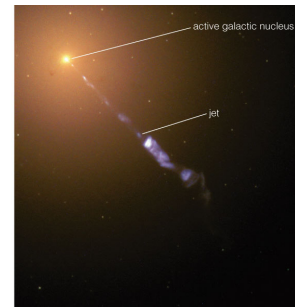
## What have we learned?

- **Why do galaxies differ?**
  - Some of the differences between galaxies may arise from the conditions in their protogalactic clouds
  - Collisions can play a major role because they can transform two spiral galaxies into an elliptical galaxy
- **What are starbursts?**
  - A starburst galaxy is transforming its gas into stars much more rapidly than a normal galaxy

## 21.3 Quasars and other Active Galactic Nuclei

- Our goals for learning
- What are quasars?
- What is the power source for quasars and other active galactic nuclei?
- Do supermassive black holes really exist?
- How do quasars let us study gas between the galaxies?

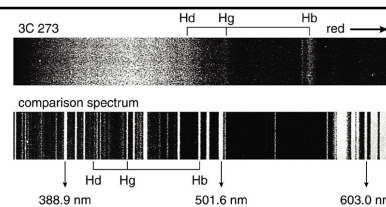
## What are quasars?



If the center of a galaxy is unusually bright we call it an **active galactic nucleus**

Quasars are the most luminous examples

Active Nucleus in M87



The highly redshifted spectra of quasars indicate large distances

From brightness and distance we find that luminosities of some quasars are  $>10^{12} L_{\text{Sun}}$

Variability shows that all this energy comes from region smaller than solar system

### Thought Question

What can you conclude from the fact that quasars usually have very large redshifts?

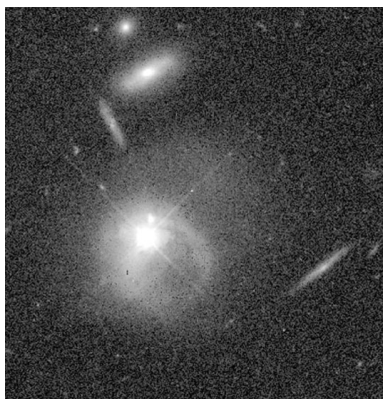
- A. They are generally very distant
- B. They were more common early in time
- C. Galaxy collisions might turn them on
- D. Nearby galaxies might hold dead quasars

### Thought Question

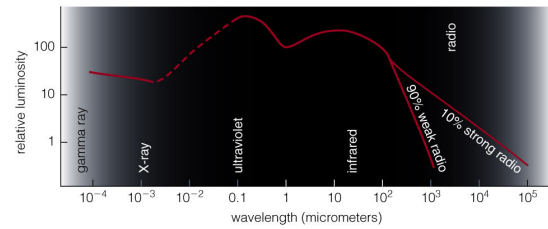
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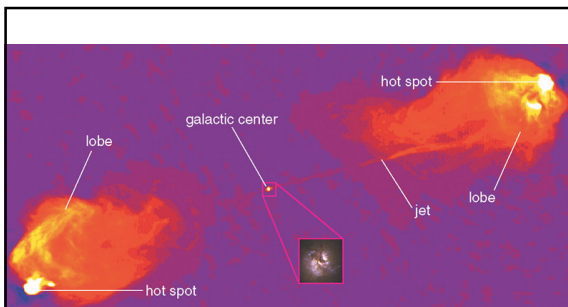
*All of the above!*



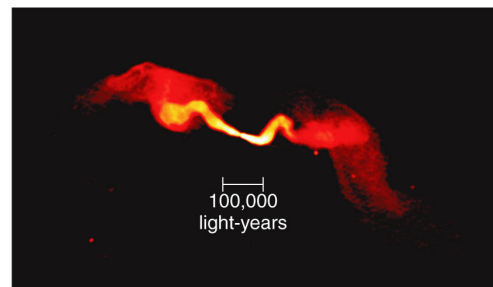
Galaxies around quasars sometimes appear disturbed by collisions



Quasars powerfully radiate energy over a very wide range of wavelengths, indicating that they contain matter with a wide range of temperatures

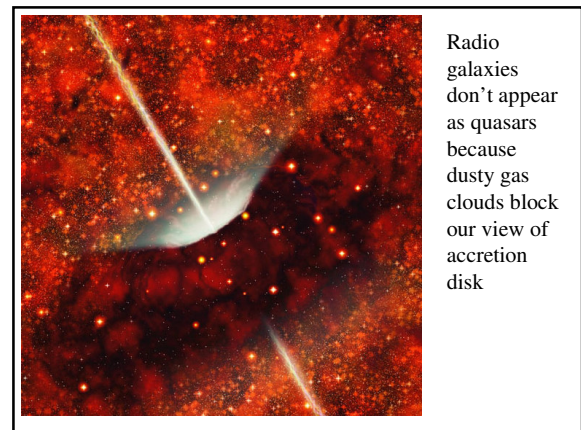
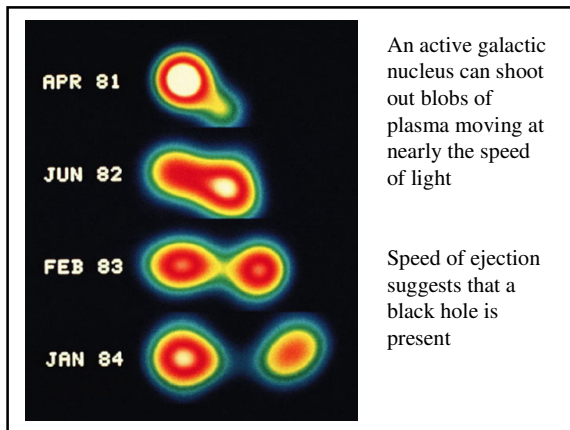


**Radio galaxies** contain active nuclei shooting out vast jets of plasma that emits radio waves coming from electrons moving at near light speed



The lobes of radio galaxies can extend over hundreds of millions of light years

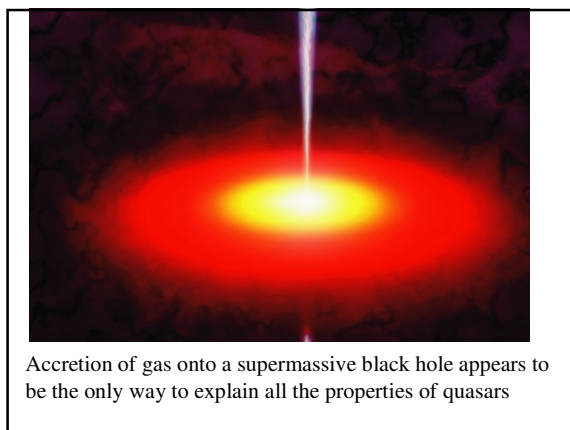
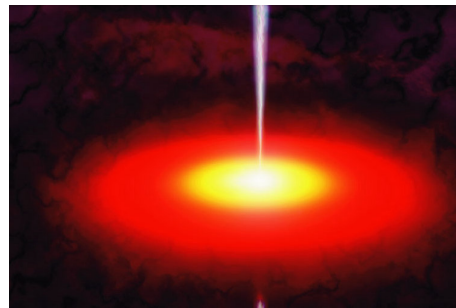




### Characteristics of Active Galaxies

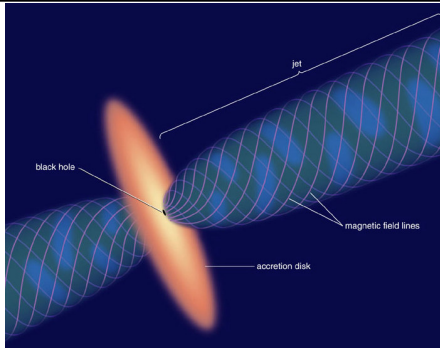
- Luminosity can be enormous ( $>10^{12} L_{\text{Sun}}$ )
- Luminosity can rapidly vary (comes from a space smaller than solar system)
- Emit energy over a wide range of wavelengths (contain matter with wide temperature range)
- Some drive jets of plasma at near light speed

### What is the power source for quasars and other active galactic nuclei?



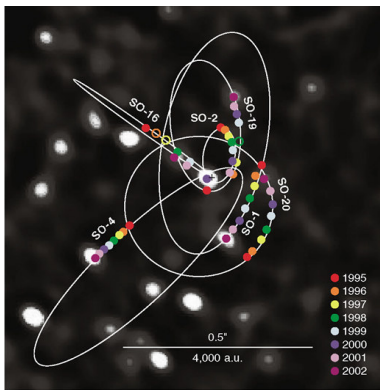
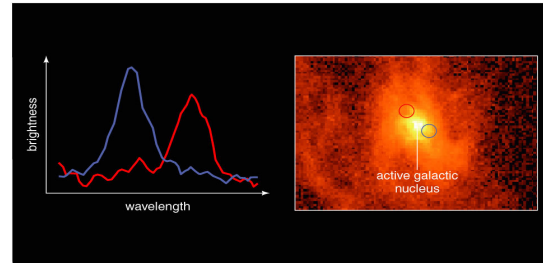
### Energy from a Black Hole

- Gravitational potential energy of matter falling into black hole turns into kinetic energy
- Friction in accretion disk turns kinetic energy into thermal energy (heat)
- Heat produces thermal radiation (photons)
- This process can convert 10-40% of  $E = mc^2$  into radiation

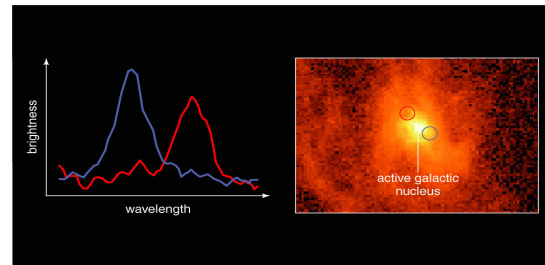


Jets are thought to come from twisting of magnetic field in the inner part of accretion disk

## Do supermassive black holes really exist?



Orbits of stars at center of Milky Way stars indicate a black hole with mass of 4 million  $M_{\text{Sun}}$

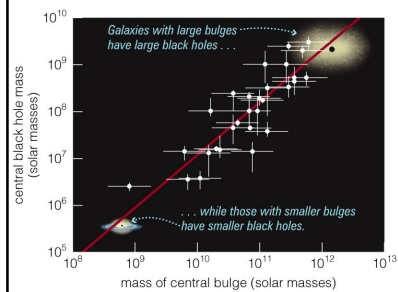


Orbital speed and distance of gas orbiting center of M87 indicate a black hole with mass of 3 billion  $M_{\text{Sun}}$

## Black Holes in Galaxies

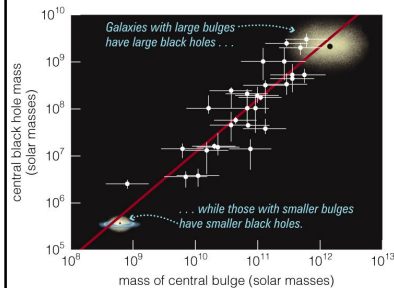
- Many nearby galaxies – perhaps all of them – have supermassive black holes at their centers
- These black holes seem to be dormant active galactic nuclei
- All galaxies may have passed through a quasar-like stage earlier in time

## Galaxies and Black Holes



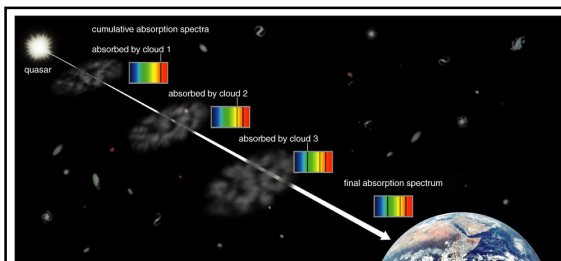
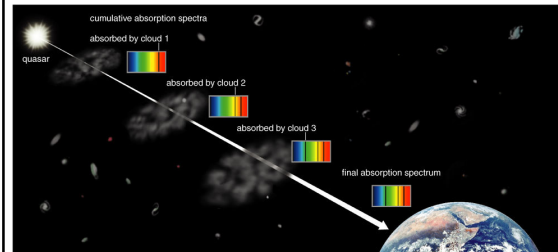
- Mass of a galaxy's central black hole is closely related to mass of its bulge

## Galaxies and Black Holes



- Development of central black hole must be somehow related to galaxy evolution

## How do quasars let us study gas between the galaxies?



Gas clouds between a quasar and Earth absorb some of a quasar's light

We can learn about protogalactic clouds by studying the absorption lines they produce in quasar spectra

## What have we learned?

- What are quasars?
  - Active galactic nuclei are very bright objects seen in the centers of some galaxies, and quasars are the most luminous type
- What is the power source for quasars and other active galactic nuclei?
  - The only model that adequately explains the observations holds that supermassive black holes are the power source

## What have we learned?

- Do supermassive black holes really exist?
  - Observations of stars and gas clouds orbiting at the centers of galaxies indicate that many galaxies, and perhaps all of them, have supermassive black holes
- How do quasars let us study gas between the galaxies?
  - Absorption lines in the spectra of quasars tell us about intergalactic clouds between those quasars and Earth