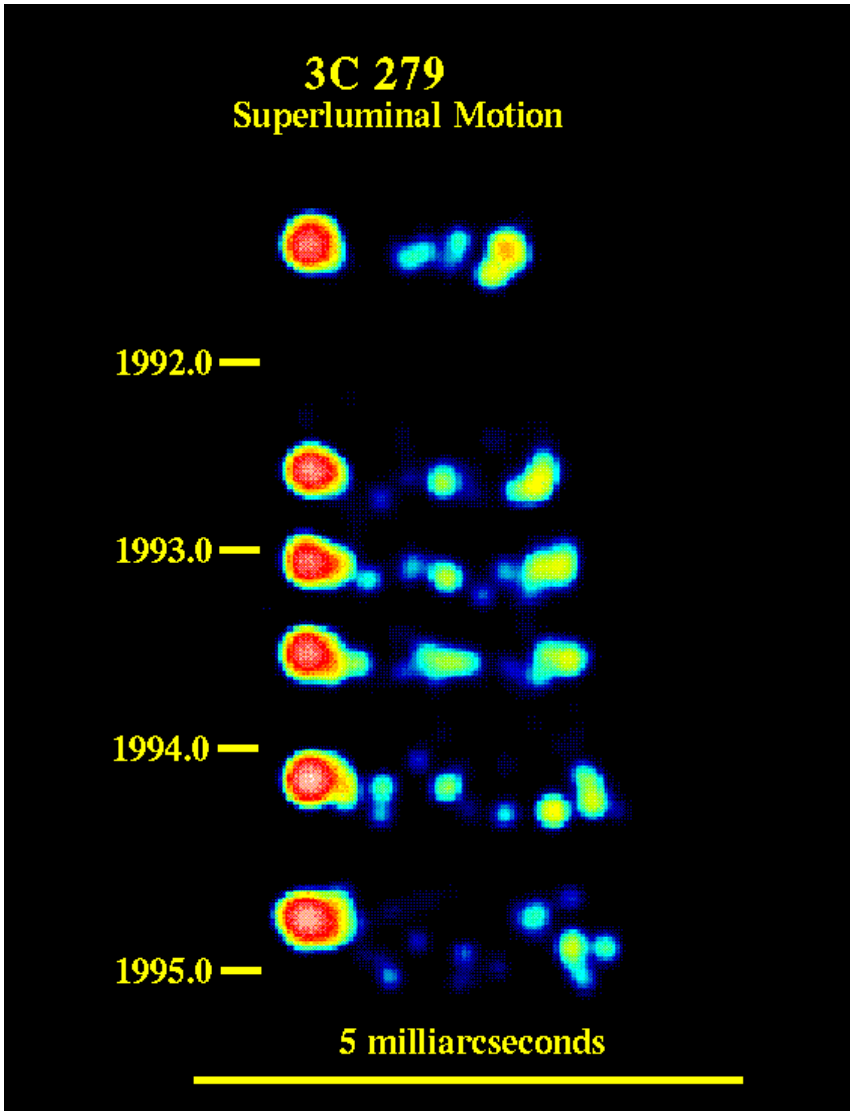
[21] Active Galaxies 2 (4/19/18)

Upcoming Items

1. Homework #5 due Tuesday.
2. Read Ch. 22.1 and do the self-study quizzes

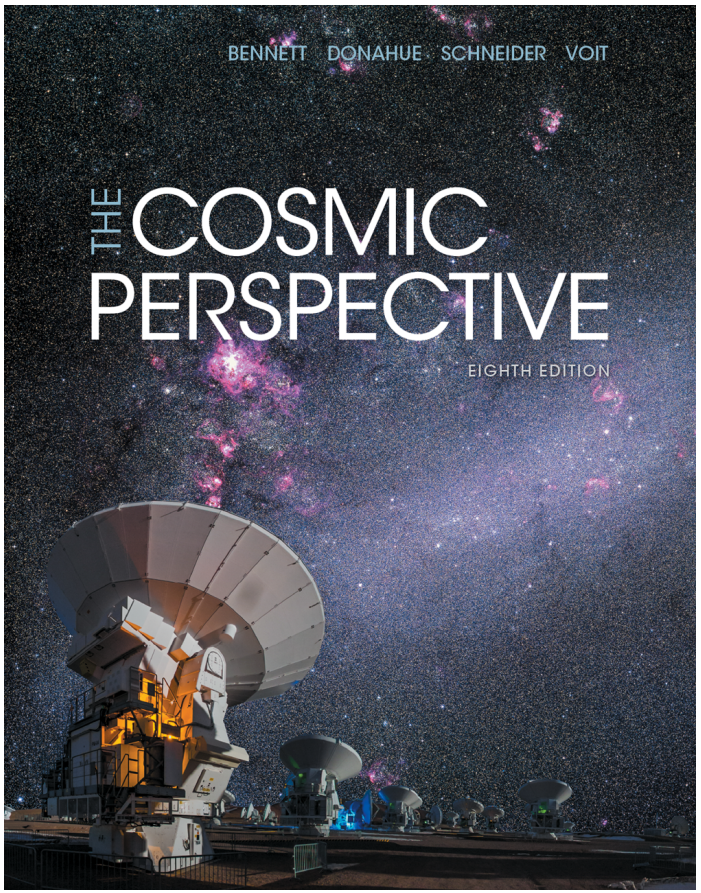


LEARNING GOALS

Ch. 21.3–21.4

For this class, you should be able to…

- … *relate the relative brightness in different wavebands (radio, visible) of a quasar or active galaxy to the viewing geometry and to whether the supermassive black hole is accreting material or not;*
- … *explain the evidence that AGN play a role in galaxy evolution.*



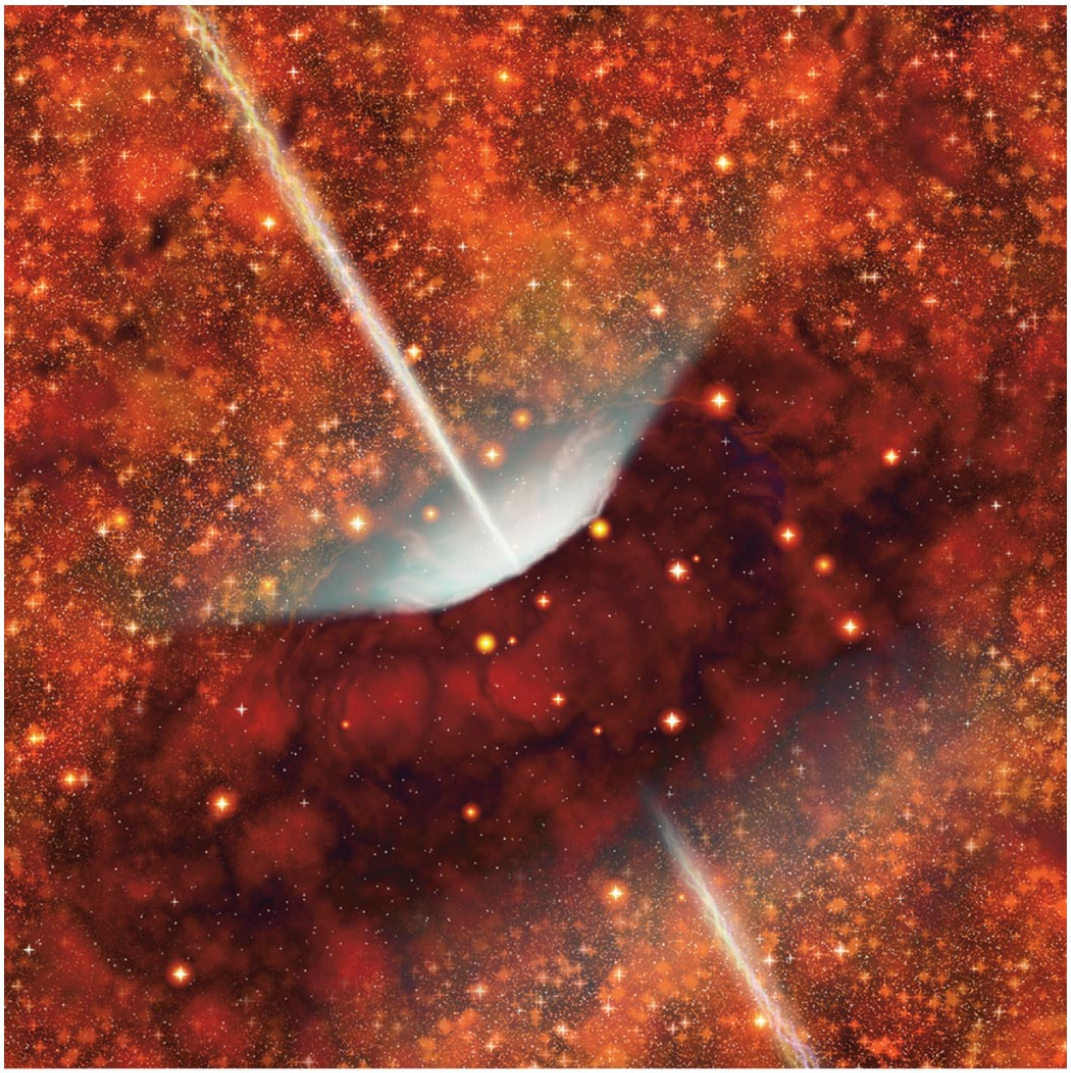
Any astro questions?

Active Galaxies 2

- Active galaxy/AGN types: quasars, Seyfert galaxies, radio galaxies, blazars. Unified model: all the same basic phenomena seen at different viewing angles (which sometimes make jets appear to be superluminal).
- M-sigma relation: all galaxies likely have a supermassive black hole, with mass proportional to galaxy bulge mass.
- AGN likely regulated the evolution of their host galaxies, in a process called AGN feedback.
- AGN were more active in the past; most nearby galaxies may contain dormant AGN.
- Gas in the universe can be measured by absorption of quasar light at intervening redshifts (the Lyman-α forest).

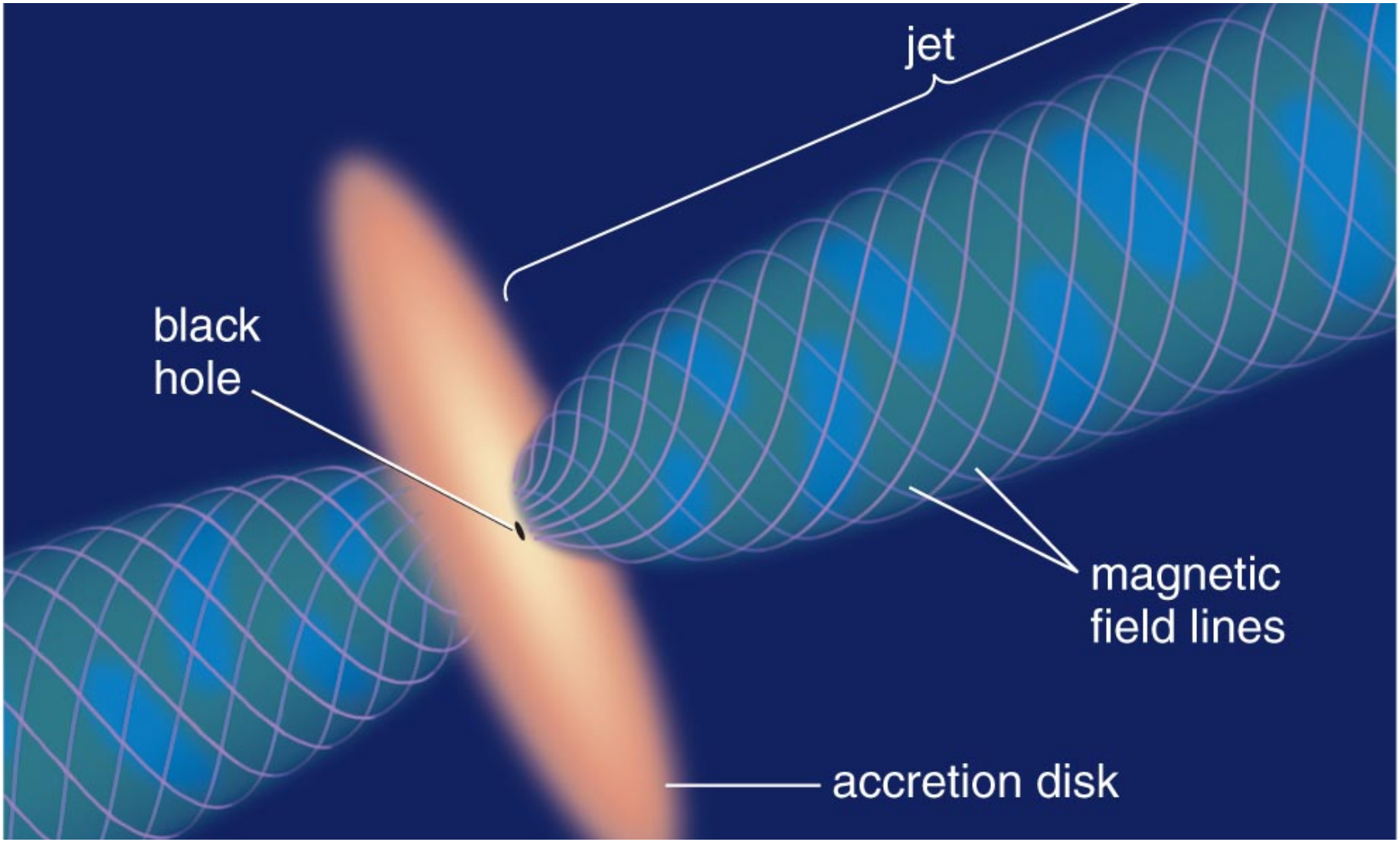
A Unified Model of AGN

- As gases spiral in toward the supermassive black hole, some of the gas may be redirected to become two jets of high-speed particles that are aligned perpendicular to the accretion disk.
- An observer sees a *radio galaxy* when the accretion disk is viewed nearly edge-on, so that its light is blocked by a surrounding torus.
- At a steeper angle, the observer sees a *radio-loud quasar*.
- If one of the jets is aimed almost directly at the Earth, a *blazar* is observed.



Artist's conception of an obscured *active galactic nucleus* (AGN).

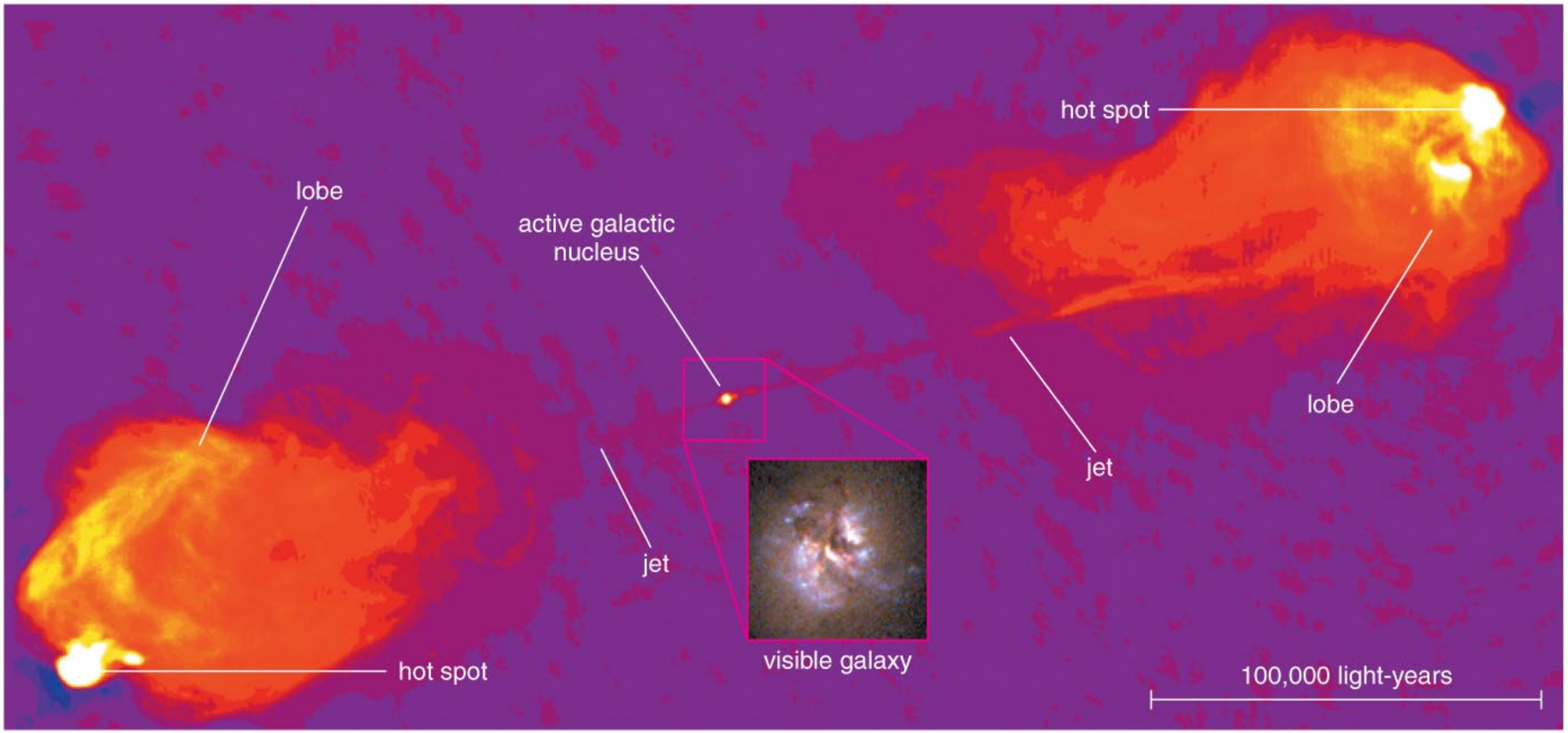
- Other AGN with jets look different because dusty gas clouds block our view of the central emitting region.
- We discovered them separately, so we do not call them quasars.
- Instead, these objects (host galaxy + AGN) are called *active galaxies*.



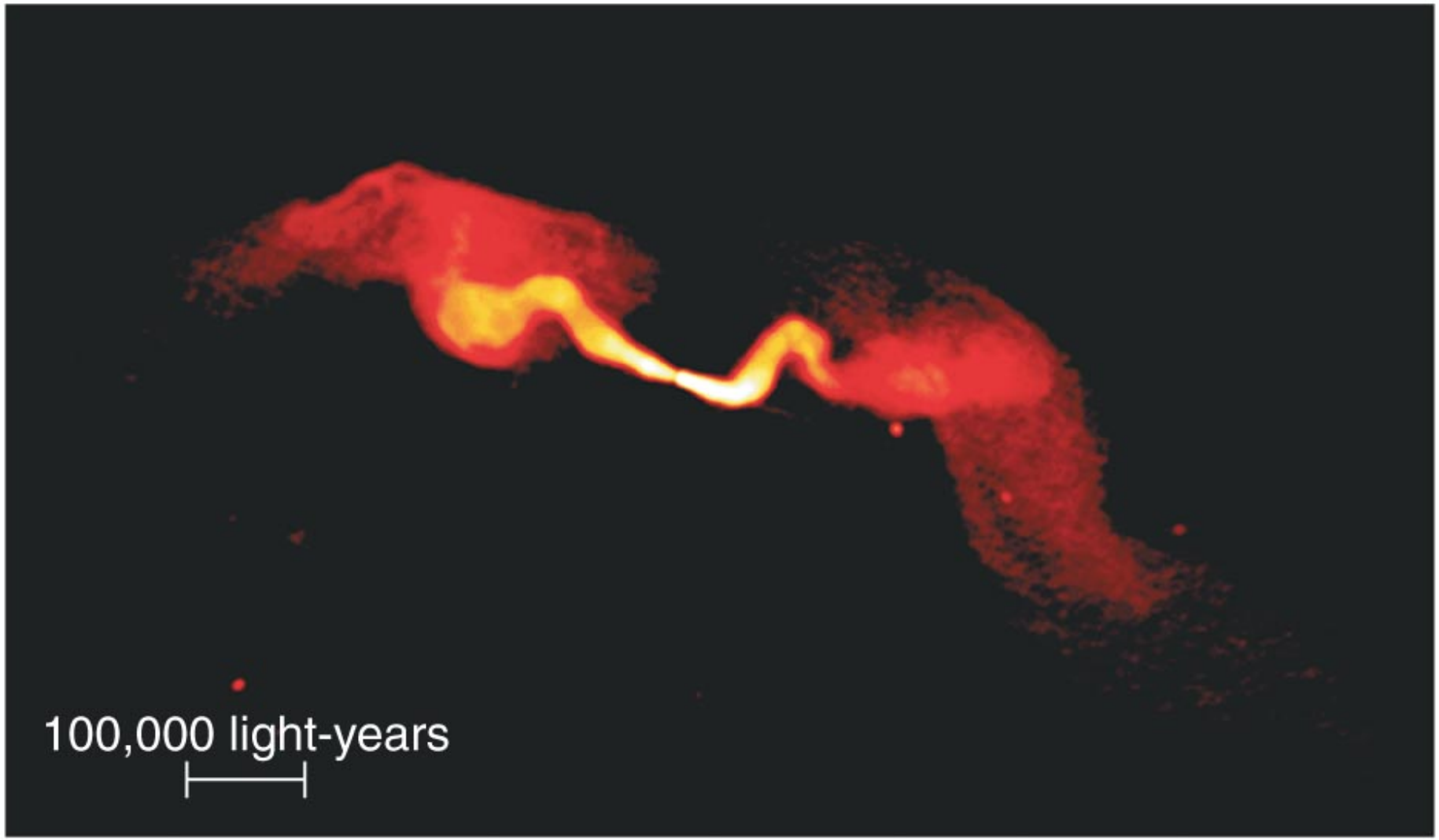
Jets are thought to come from twisting of the magnetic field in the inner part of the accretion disk. Details uncertain…

Not all AGN have jets…

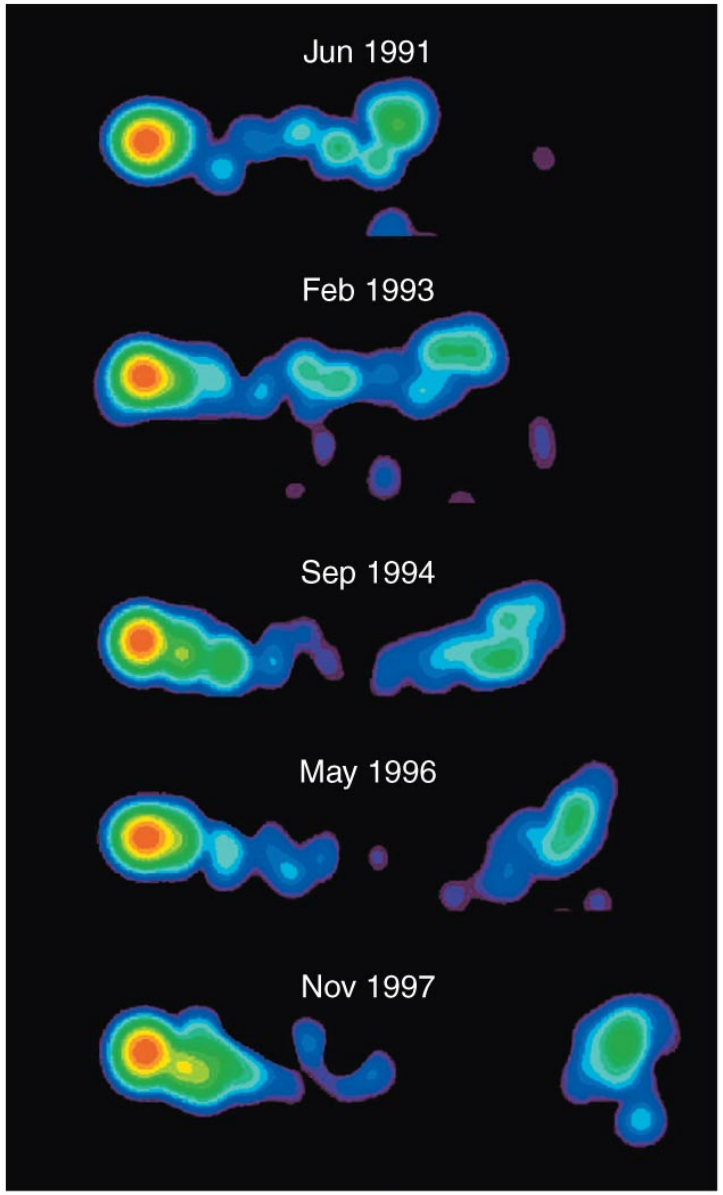
- In fact, most quasars (~90%) are not particularly strong radio sources!
- But all AGN emit copious radiation at most wavelengths from a central region.
- It is likely that AGN are powered by accretion onto supermassive black holes—different accretion rates and viewing geometries give rise to the different types of AGN.



- Radio galaxies contain active nuclei shooting out vast jets of plasma that emit radio waves coming from electrons that move at near light speed.



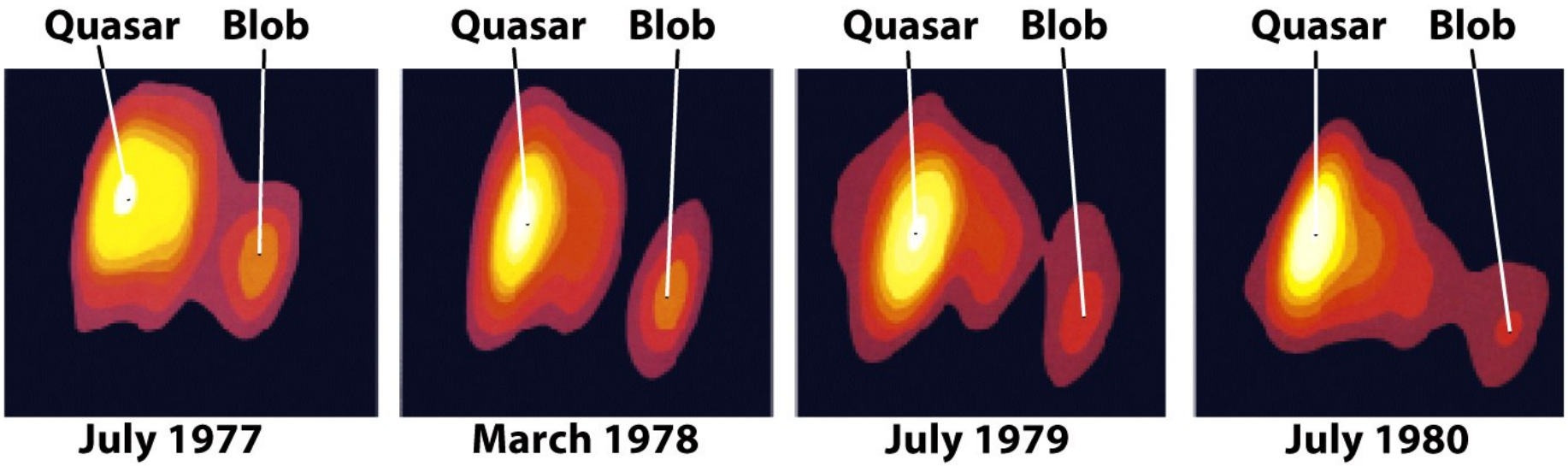
- The lobes of radio galaxies can extend over hundreds of thousands of light-years.



- An active galactic nucleus can shoot out blobs of plasma moving at nearly the speed of light.
- These ejection speeds suggest the presence of a black hole.

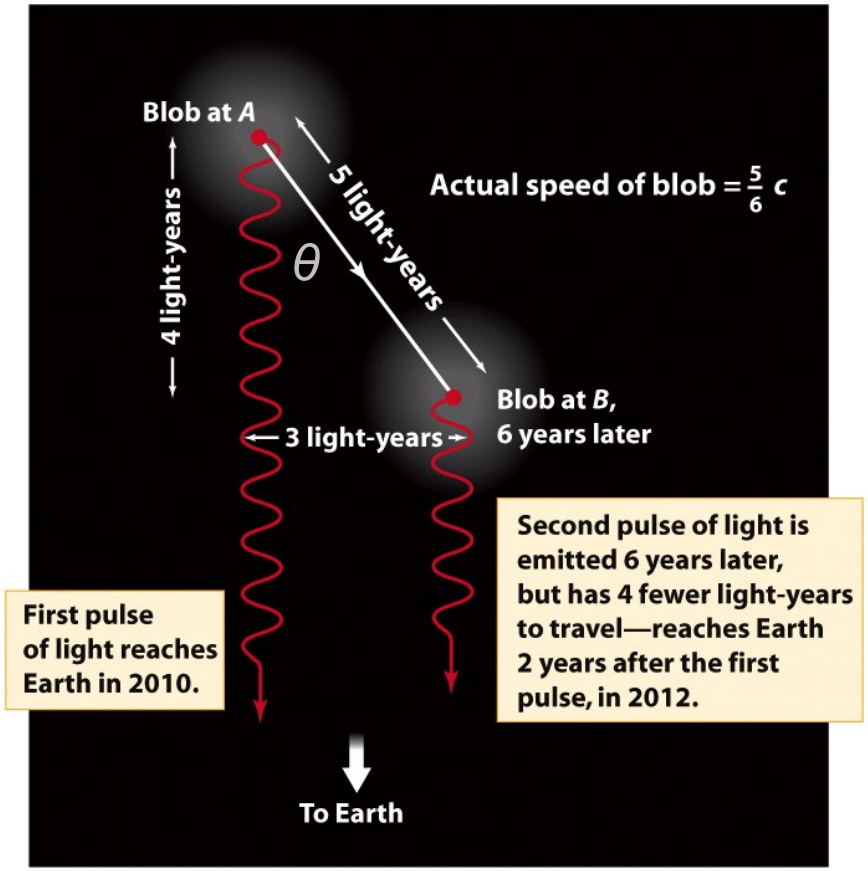
Some blobs seem to move *faster* than the speed of light…

3C 273 again…

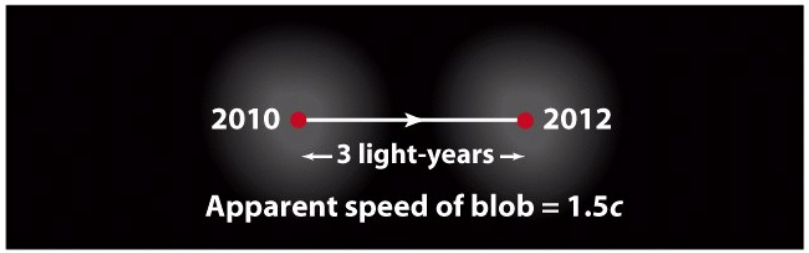


The blob seems to be moving at $10c$!

Apparent superluminal motion is a geometric effect, not a violation of relativity!



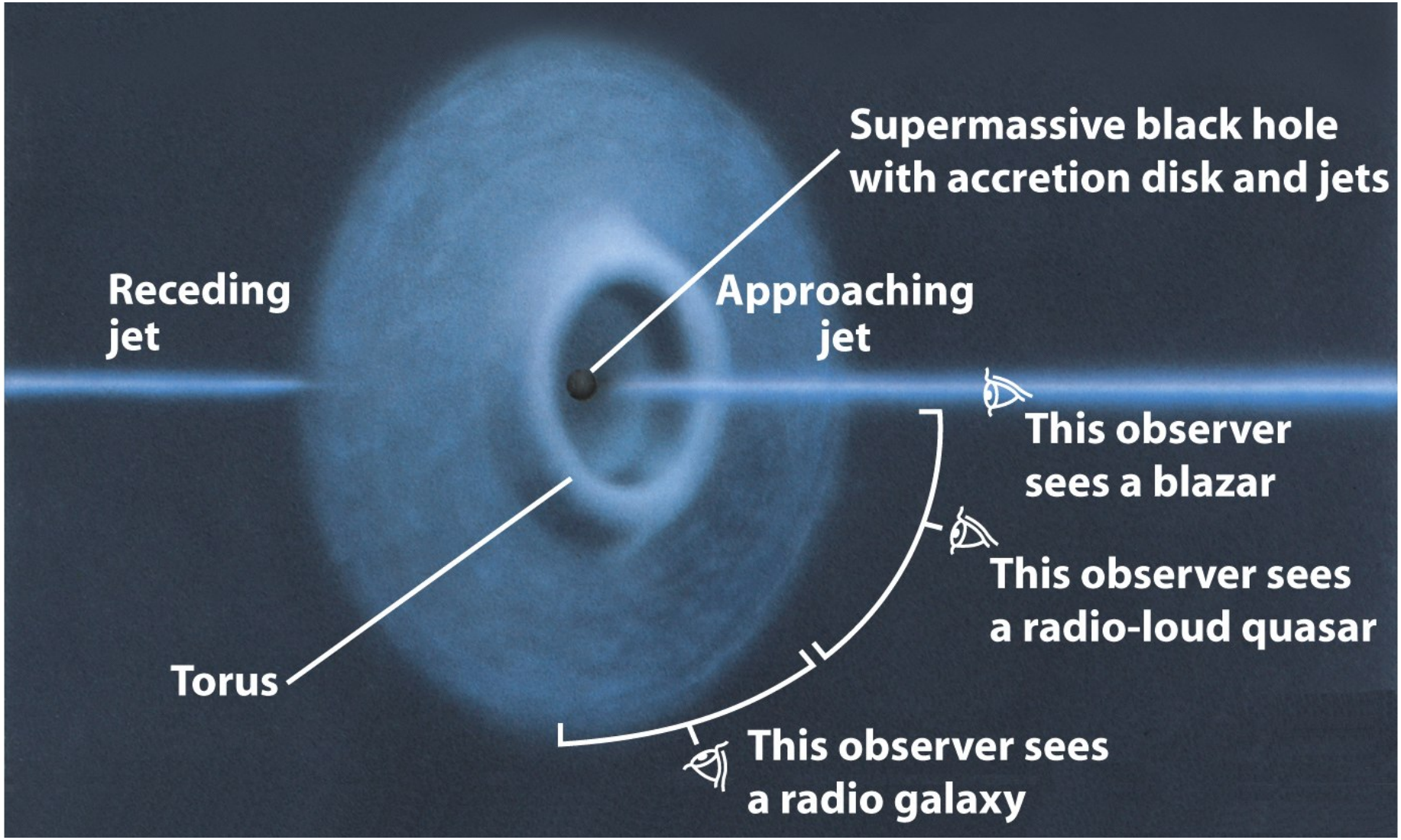
(a) View from above



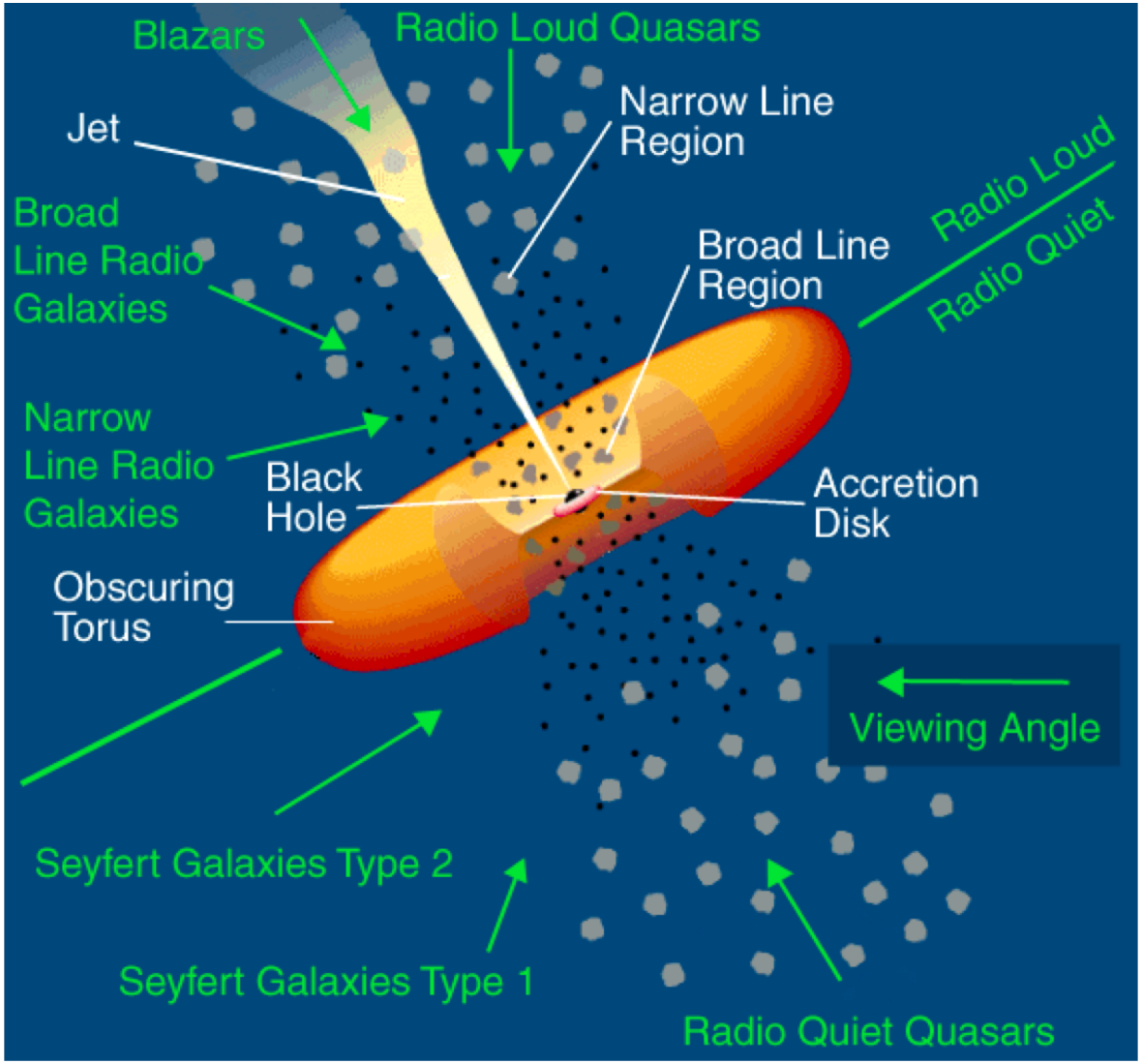
(b) View from Earth

$$v_{\text{app}} = \frac{v \sin\theta}{1 - \frac{v}{c}\cos\theta}$$

Radio-Loud AGN in the Unified Model

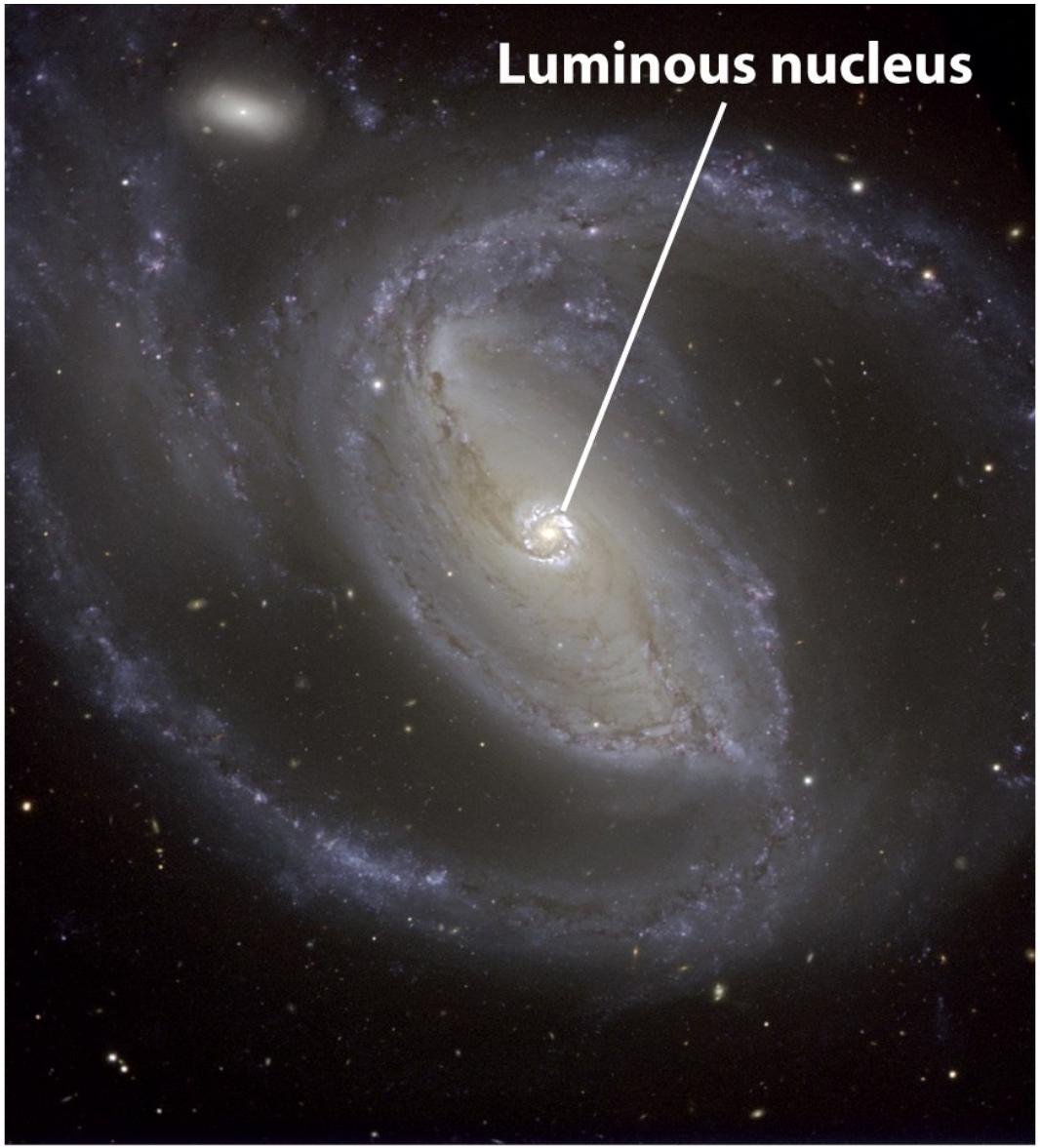


Schematic Unified Model of AGN

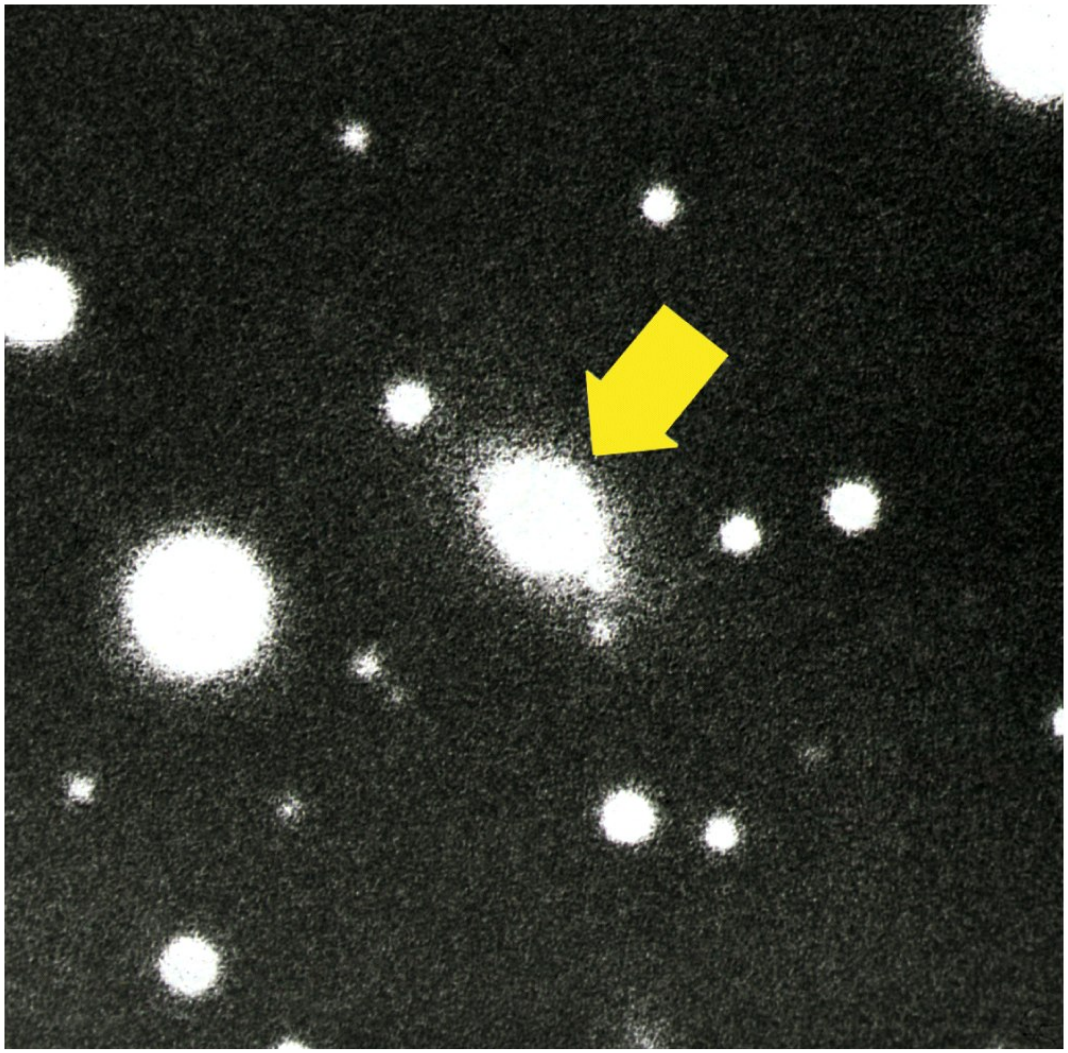


Types of Active Galactic Nuclei

- Note: unified picture is most important! Only if you're a specialist do you need to know all the names
- Quasars
  - Radio-loud (10%) and radio-quiet (90%).
  - Some emit synchrotron radiation: charged particles in mag. field.
- Seyfert Galaxies (~1% of nearby galaxies)
  - Spiral galaxies with bright nuclei, strong radiation.
  - Appear to be nearby, low-luminosity, radio-quiet quasars.
- Radio Galaxies
  - Elliptical galaxy located between lobes of double radio source.
  - Lobes are at endpoints of relativistic particle streams (jets).
- Blazars
  - Bright, star-like objects, rapidly varying.
  - Probably radio galaxies or quasars seen jet-on.



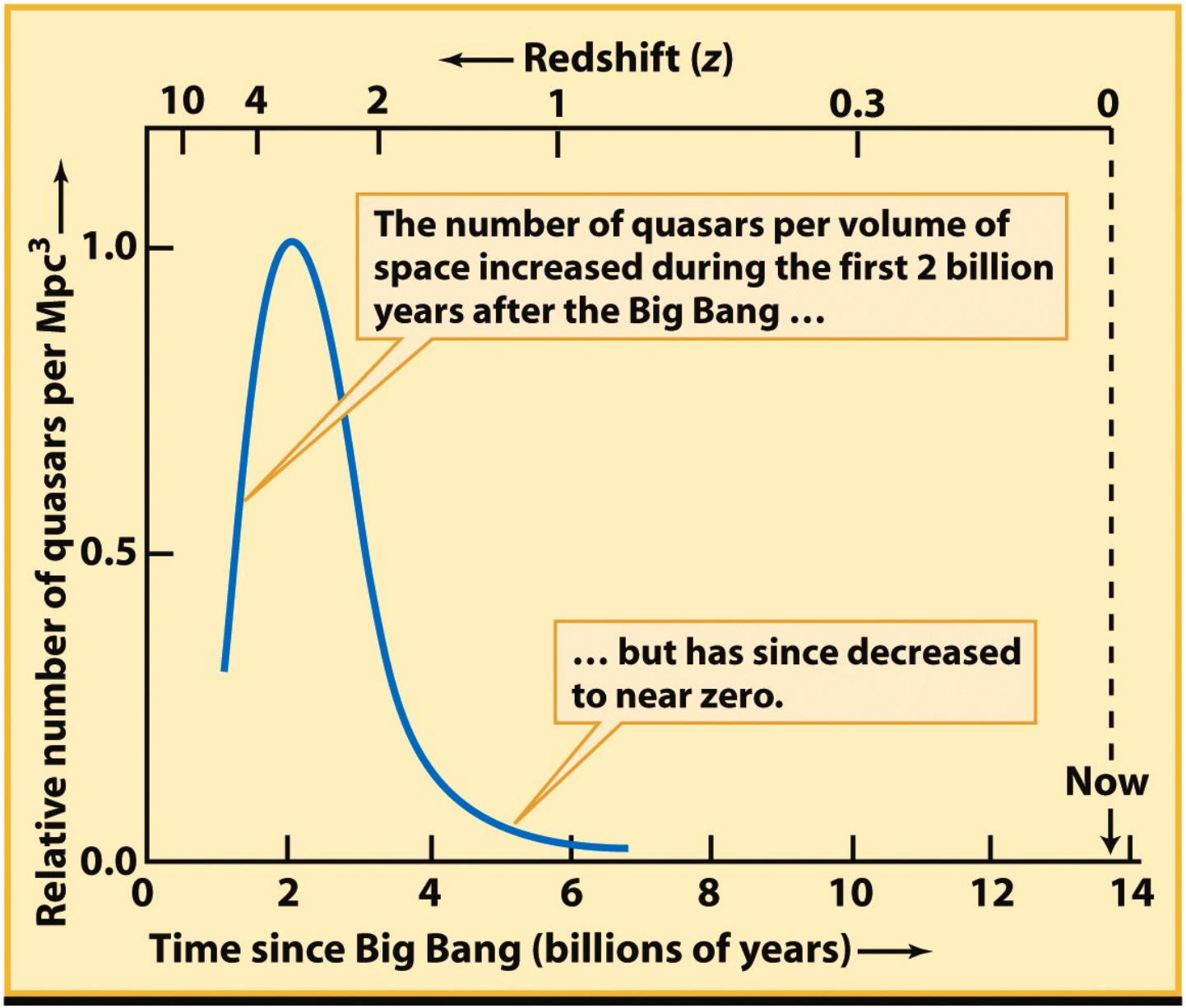
- NGC 1097, a Seyfert galaxy.
- Radio-quiet AGN tend to be found in spiral galaxies.



- BL Lac, a blazar (the fuzz is the surrounding giant elliptical galaxy).
- Radio-loud AGN tend to be found in elliptical galaxies.

Black Holes in Galaxies

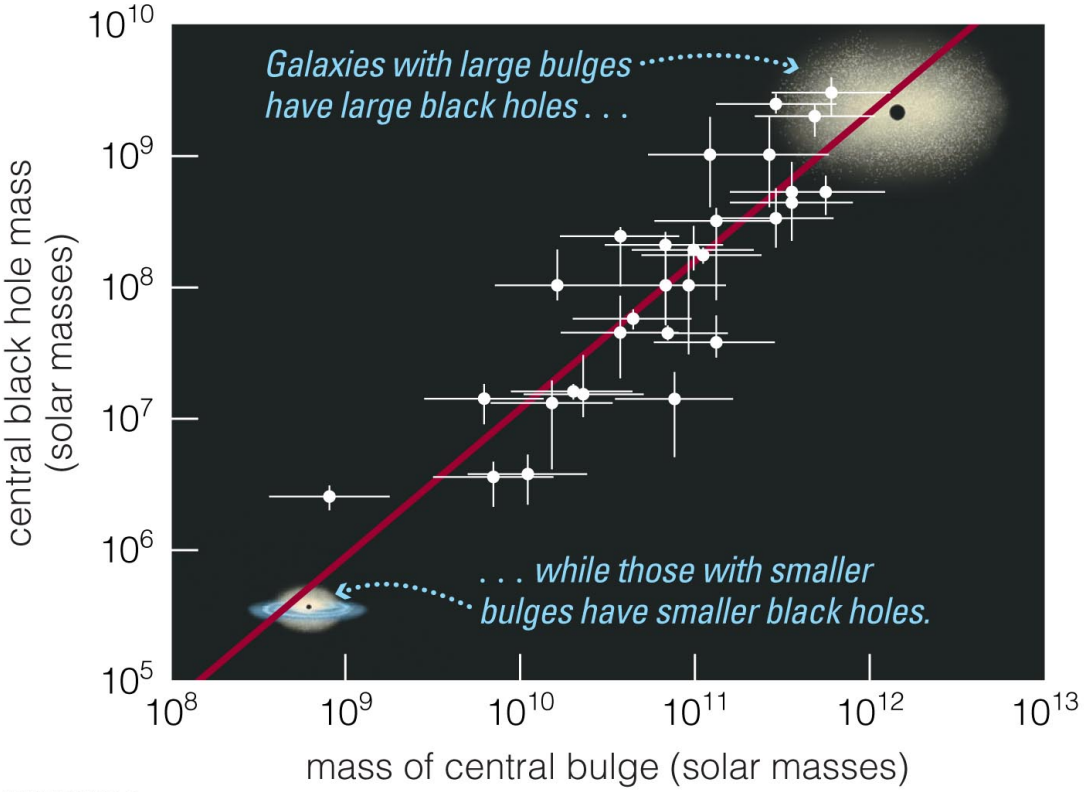
- Many nearby galaxies—perhaps all of them—have supermassive black holes at their centers.
- These black holes seem to be dormant active galactic nuclei.
- All galaxies may have passed through a quasar-like stage earlier in time.


Redshift (z)
10
4
2
1
0.3
0
Relative number of quasars per Mpc³
1.0
0.5
0.0
The number of quasars per volume of space increased during the first 2 billion years after the Big Bang …
… but has since decreased to near zero.
Now
0
2
4
6
8
10
12
14
Time since Big Bang (billions of years)

Black Holes and Galaxy Evolution

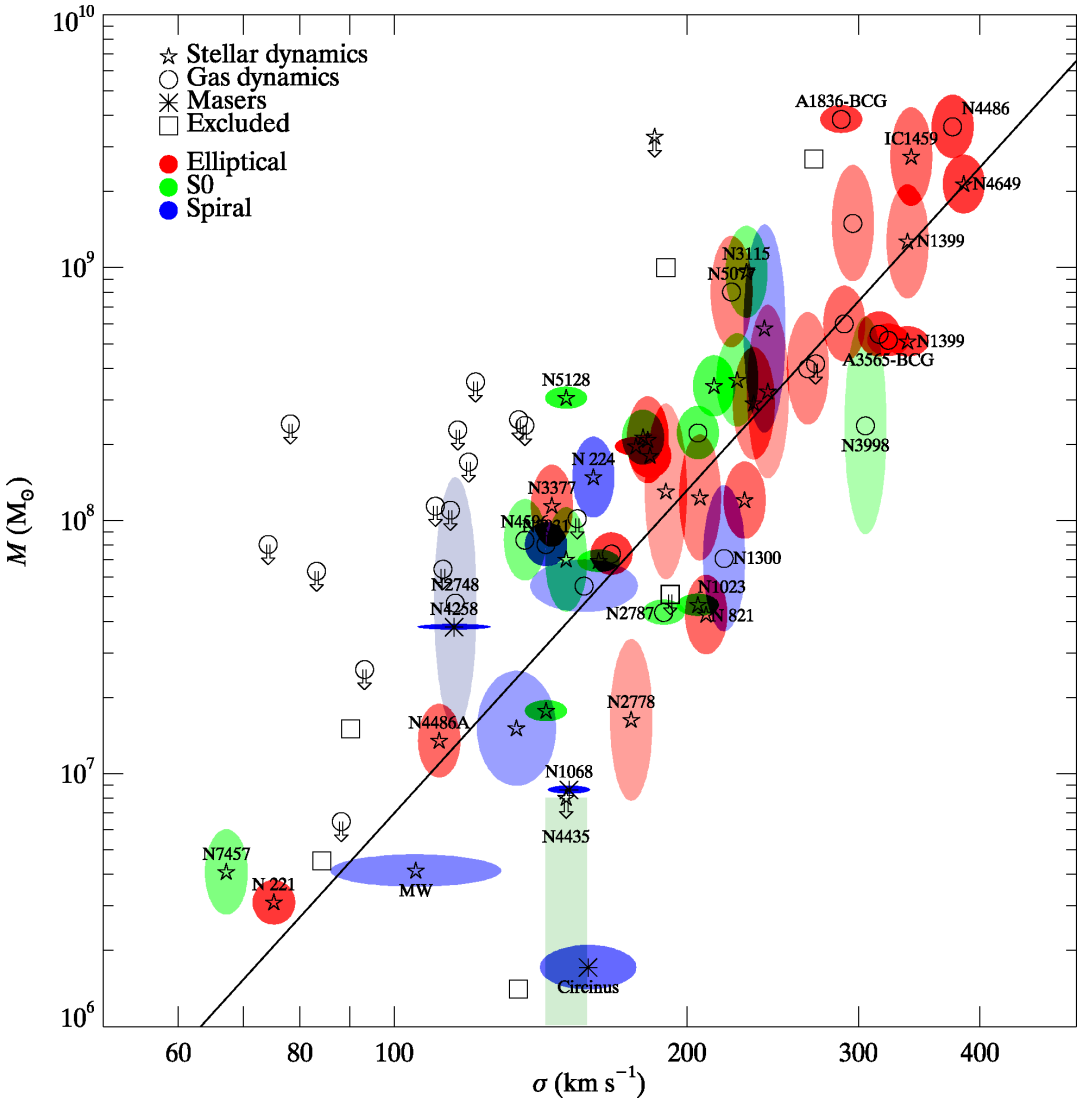
- **Remarkable discovery of past ~decade: black holes have significant effect on evolution of whole galaxies!**
- Evidence…
  - Correlation between galaxy properties and black hole properties.
  - Inability of galaxy evolution models to reproduce observed properties of galaxies without invoking powerful “energy source.”
  - Detailed observations of nearby galaxy clusters.
- How does this work?
  - Still subject of research…
  - Powerful radiation field of quasars and powerful jets of radio galaxies may both be important.

Galaxies and Black Holes



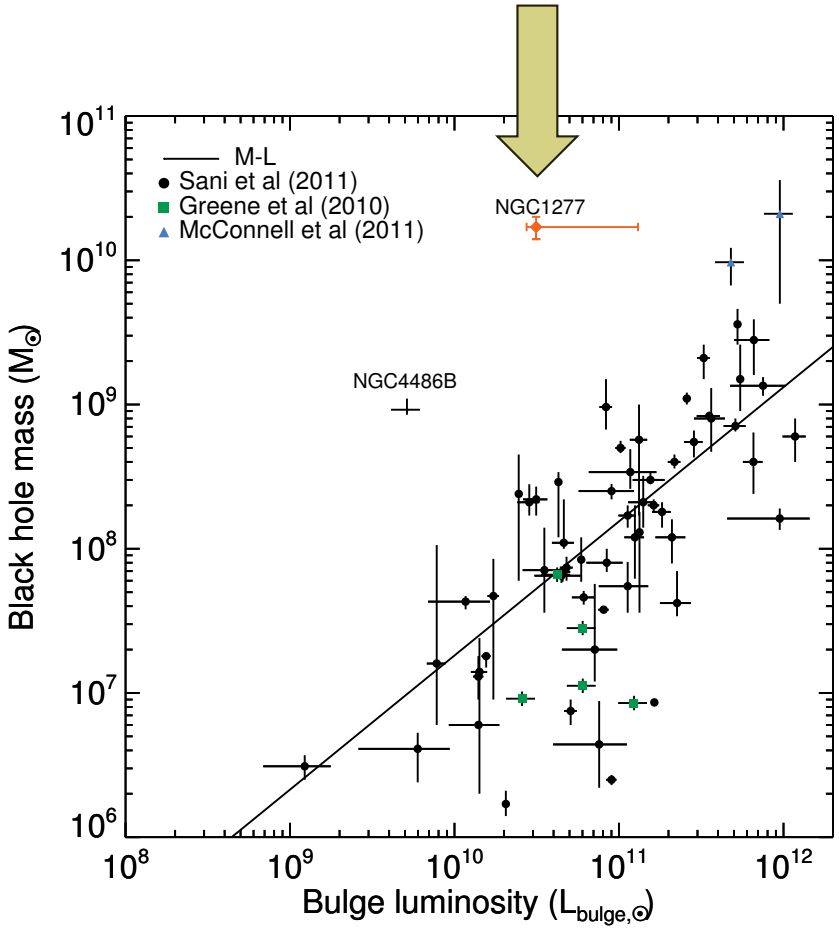
- The mass of a galaxy's central black hole is closely related to the mass of its bulge.
- The development of the central black hole must be somehow related to galaxy evolution.

The "M-Sigma" Relation



Plot from a paper led by my first graduate student, Kayhan Gultekin (now an assistant professor at the University of Michigan)

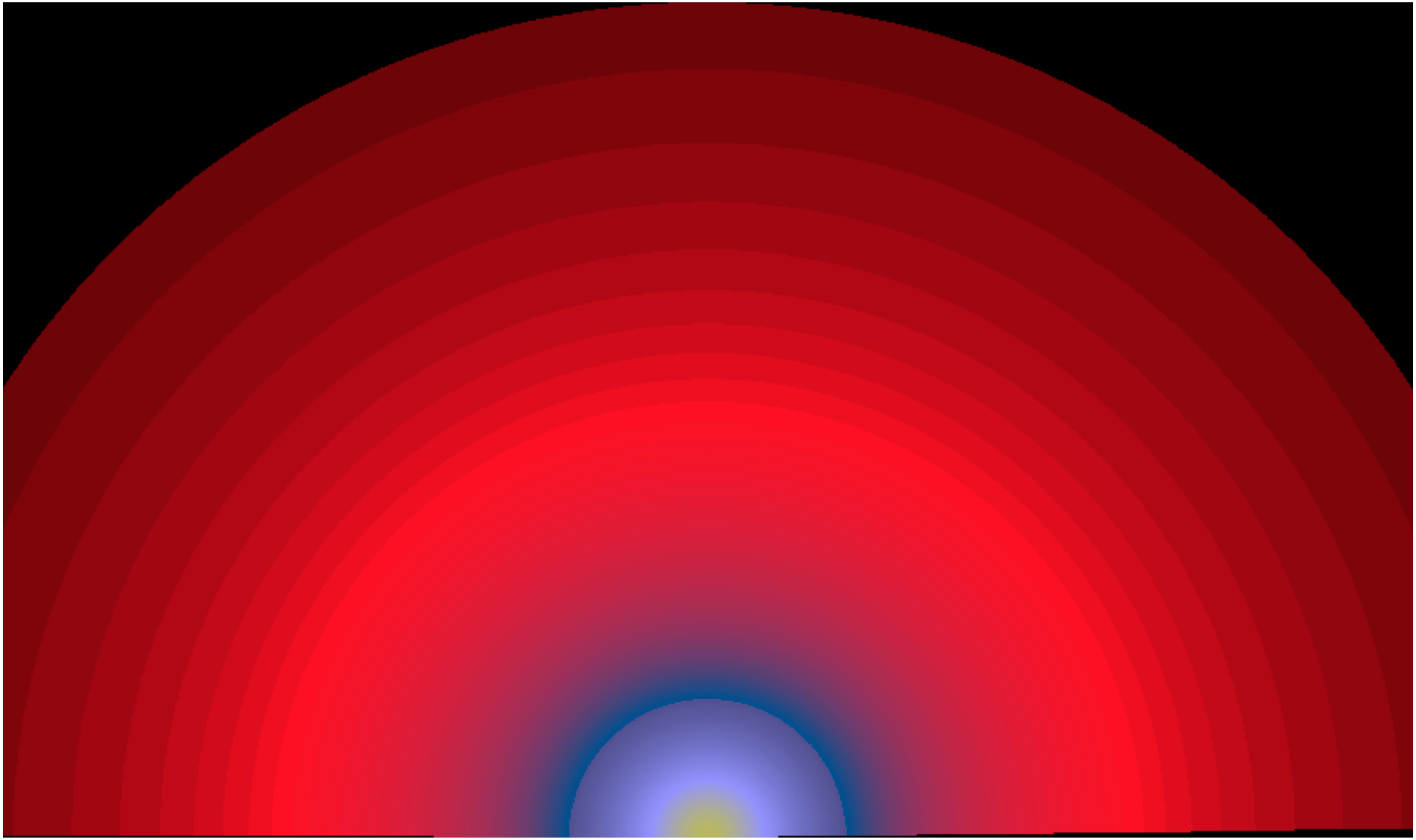
Special Case: An Over-Massive Black Hole

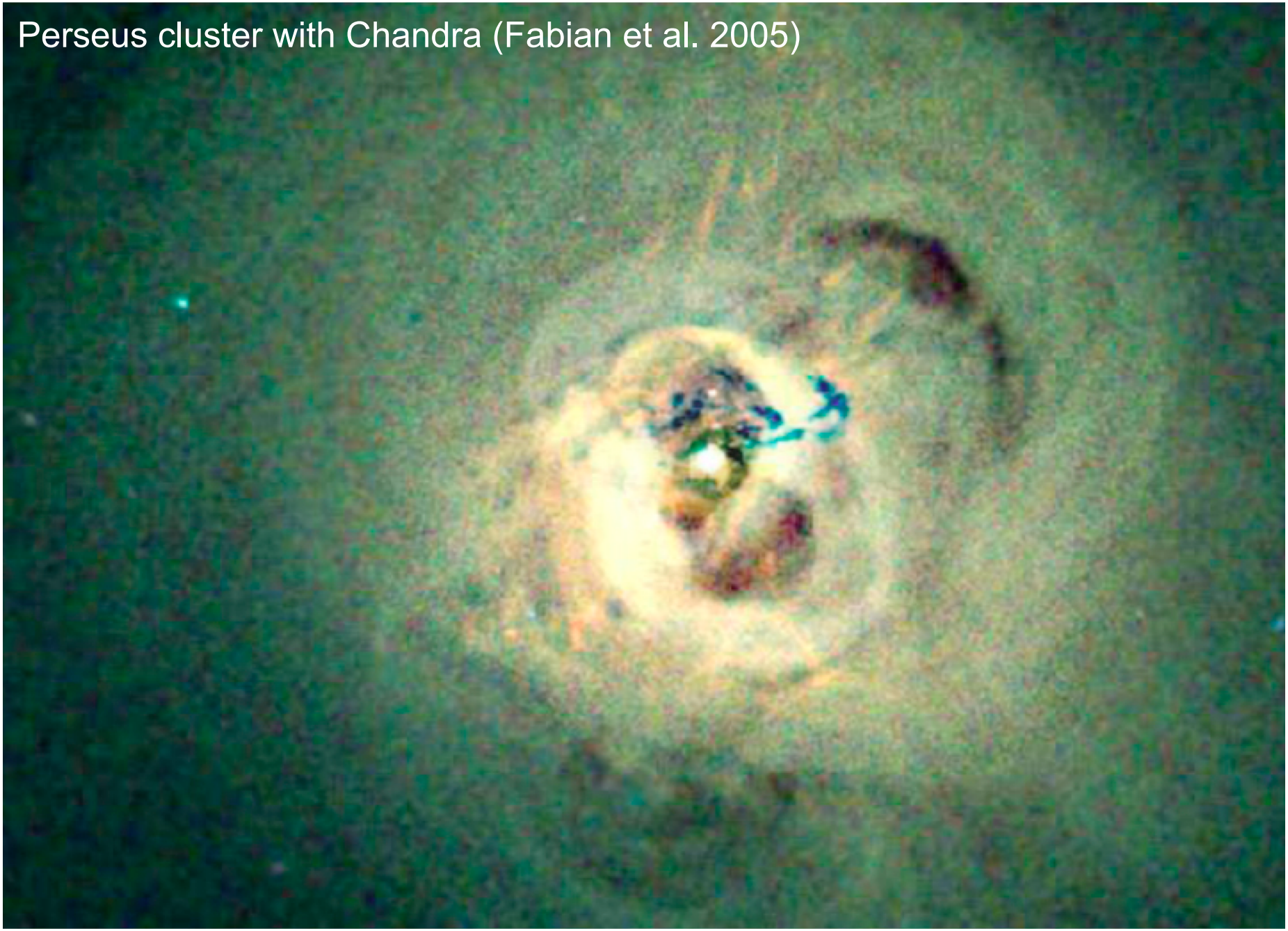


- In late 2012, van den Bosch et al. discovered one of the largest supermassive black holes in a compact lenticular galaxy.
- It is ~7 times larger than the M-sigma relation predicts! But lots of uncertainty in estimate...

- astrobites.org/2012/12/05/introducing-the-over-massive-black-hole/

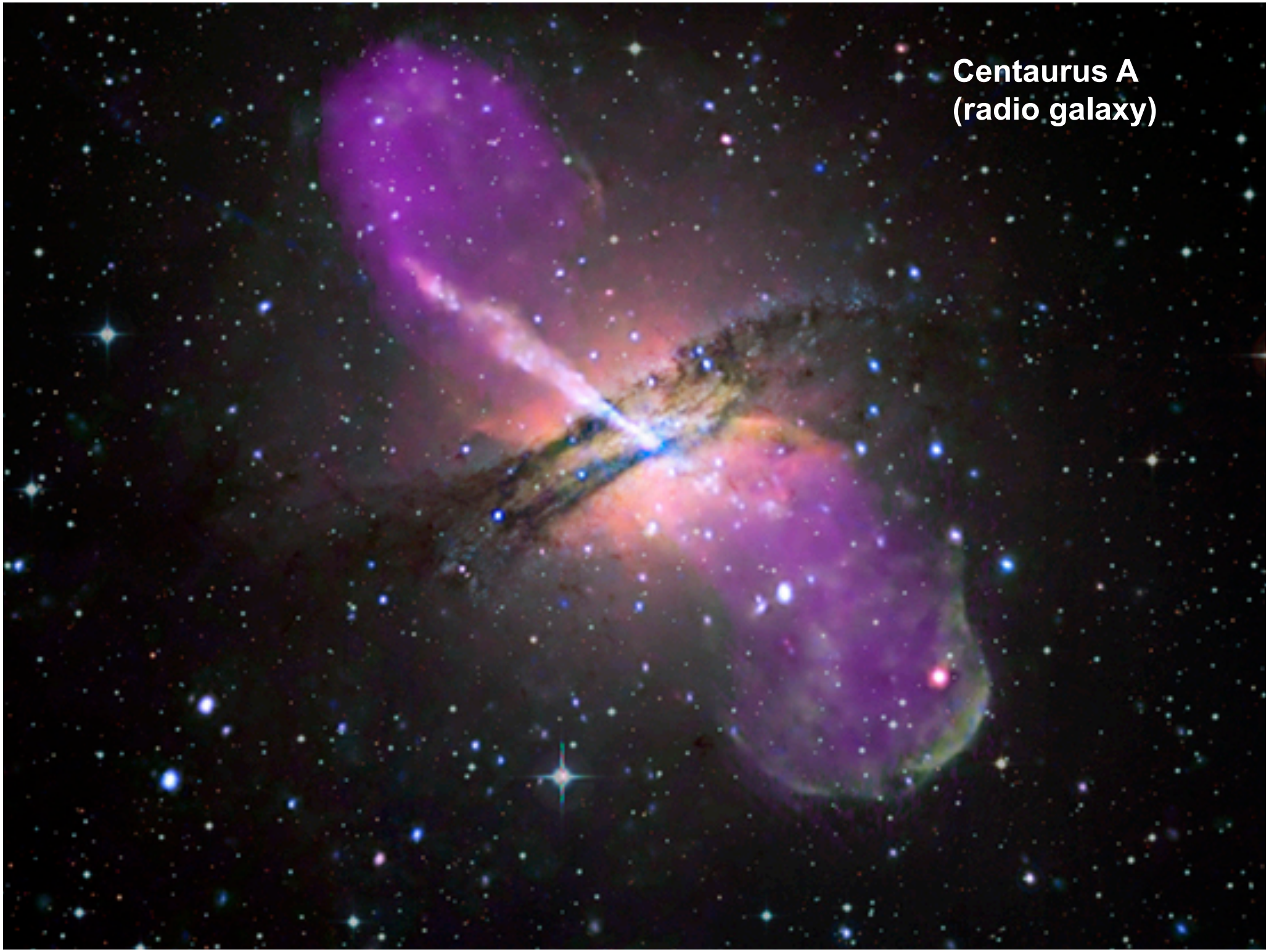
AGN Feedback

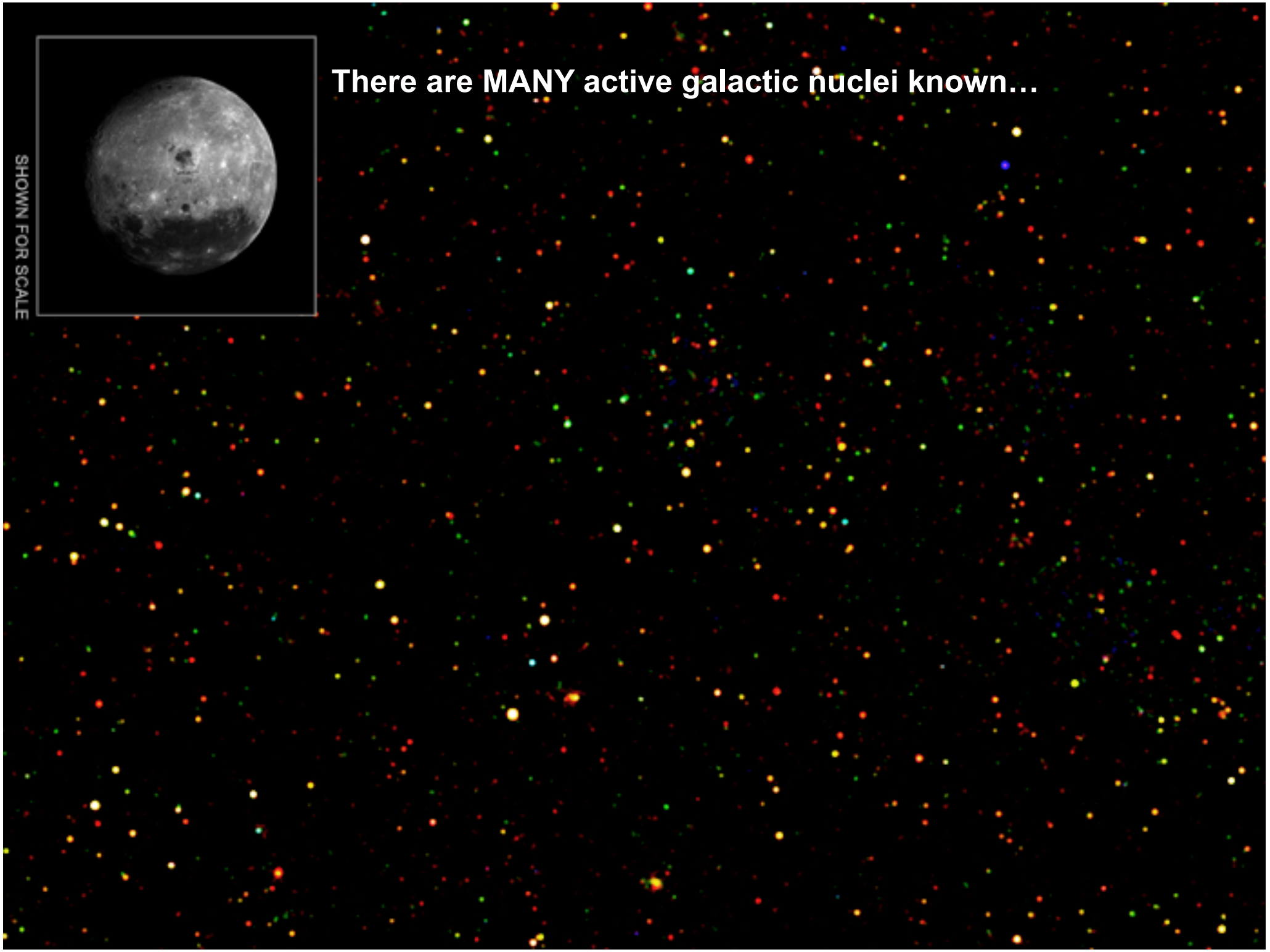


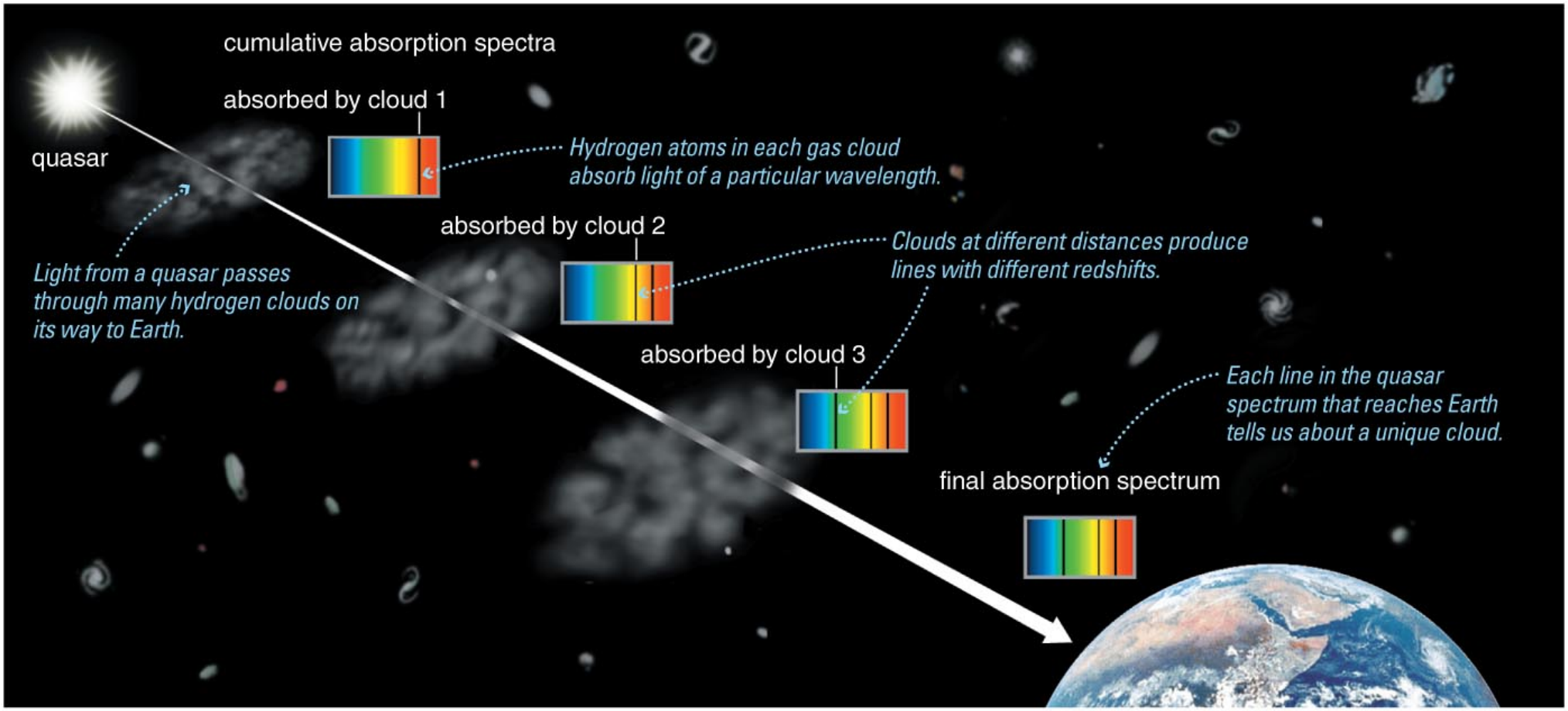

Perseus cluster with Chandra (Fabian et al. 2005)

AGN Evolution

- As a quasar runs out of nuclear material, the central luminosity decreases.
- Eventually the host galaxy can be seen, resulting in a relatively quiescent supermassive black hole.
- The Milky Way may once have had an AGN.
- Collisions/mergers can briefly reactivate AGN by driving more gas into the central black hole (e.g., Centaurus A).


Centaurus A
(radio galaxy)


There are MANY active galactic nuclei known…
SHOWN FOR SCALE



- Gas clouds between a quasar and Earth absorb some of the quasar's light.
- We can learn about protogalactic clouds by studying the absorption lines they produce in quasar spectra.