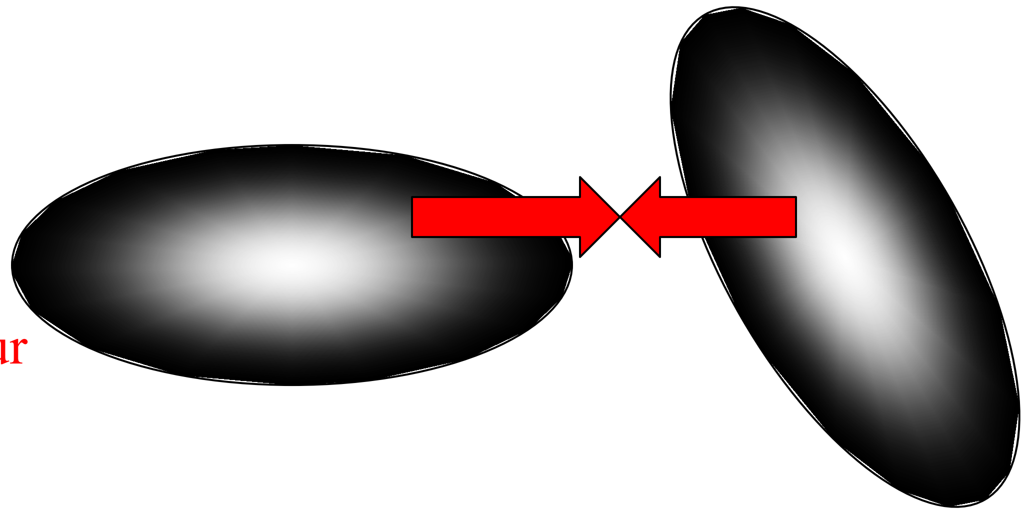
Galaxy Collisions and Active Galaxies

Galaxy Collisions

What Happens When Galaxies Collide?

When two galaxies collide or nearly collide, what happens?

- The stars do not collide with each other
  - The separation between them is very great
- But the clouds of gas in them *can* collide
- Also, the two galaxies can gravitationally influence each other
  - Even if they miss each other
- Galaxy collisions take *millions* of years to occur
  - We don’t see any change in real time
- But we can see galaxies in mid-collision
- And we can see galaxies that have already collided



Near Miss Collisions

Suppose a galaxy of mass M is passing by another galaxy

- As it passes, it pulls on each of the stars in the other galaxy

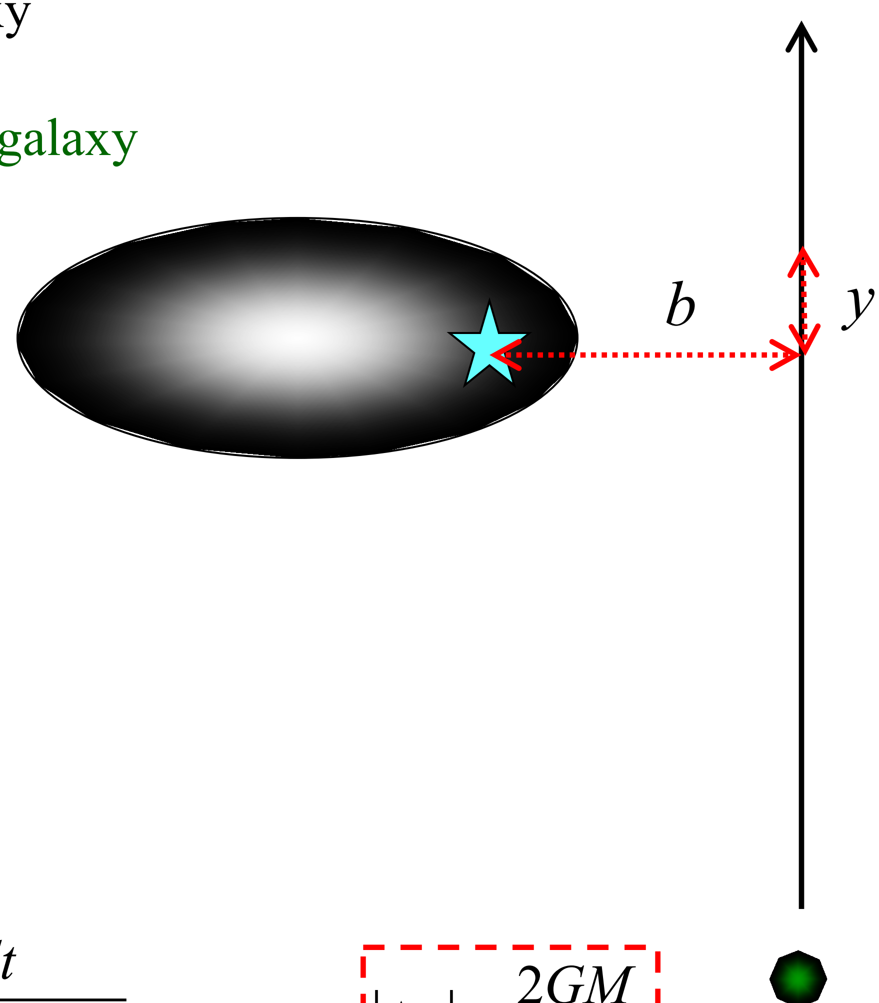
- Let's say it passes a star with an impact parameter b
- And it is currently y from its closest point

- The gravitational acceleration is

$$g = -\frac{GM\hat{\mathbf{r}}}{r^2} = -\frac{GM\mathbf{r}}{r^3} = -\frac{GM\left(b\hat{\mathbf{x}} + y\hat{\mathbf{y}}\right)}{\left(b^2 + y^2\right)^{3/2}}$$

- The position is continually changing $\quad y = vt$

- We need to integrate the acceleration over time



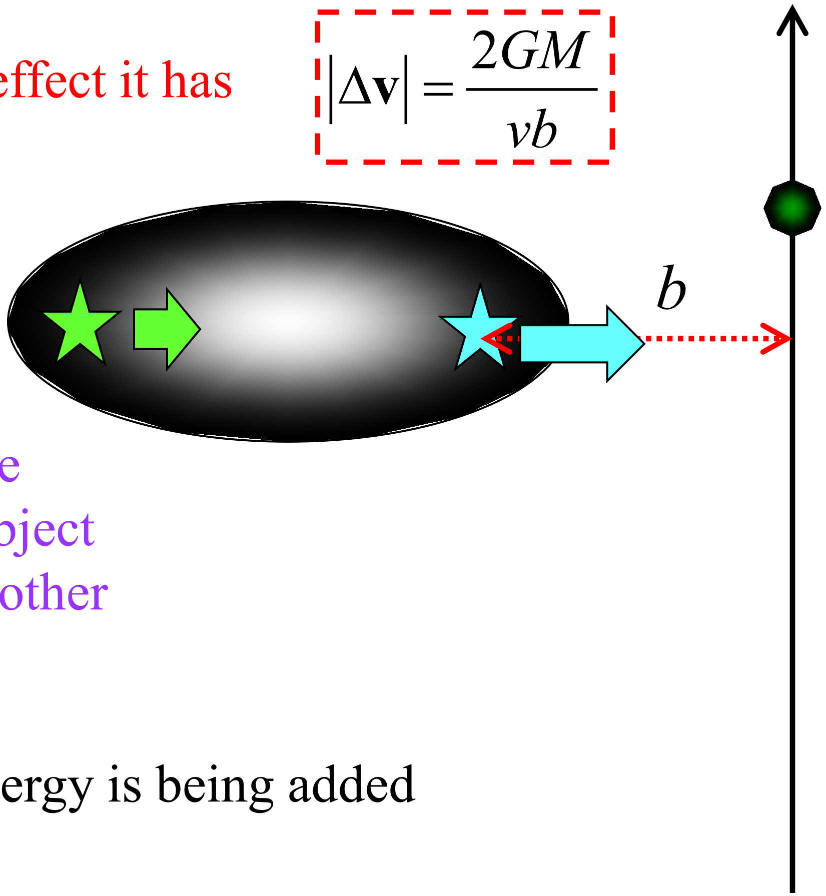
$$\Delta\mathbf{v} = \int \mathbf{g}\,dt = -GM\int \frac{b\hat{\mathbf{x}} + vt\hat{\mathbf{y}}}{\left(b^2 + v^2t^2\right)^{3/2}}dt = -GM\hat{\mathbf{x}}\int \frac{b\,dt}{\left(b^2 + v^2t^2\right)^{3/2}}$$

$$\left|\Delta\mathbf{v}\right| = \frac{2GM}{vb}$$

Tidal Friction

- Not surprisingly, the closer and more massive the impactor is, the more effect it has
- Perhaps surprisingly, the *slower* it moves, the more effect it has

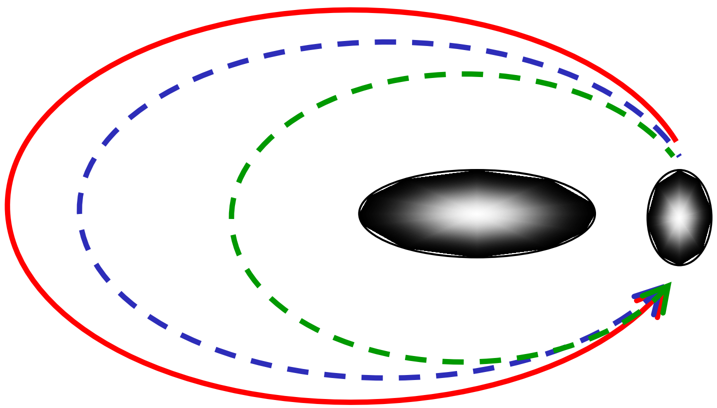
$$|\Delta \mathbf{v}| = \frac{2GM}{vb}$$



- Note that stars in different positions will have unequal accelerations
  - This effect is called *tidal forces*
- The *average* acceleration will simply cause the entire galaxy to accelerate in the direction of the passing object
  - The passing object also accelerates towards the other
  - This just causes them to orbit each other
- The *differences* in acceleration means that kinetic energy is being added to the internal motion of the stars in the galaxy
  - Causes the galaxy to expand
- This "heating up" of the internal energy of the galaxy is called *tidal friction*

Orbital Decay

- Suppose one galaxy is in orbit around the other
- Each time it goes around, kinetic energy goes into the internal energy of the galaxies
- This does disturb both galaxies a little
  - Not surprisingly the small galaxy is affected more
- Where does the energy come from?
- It must come from the kinetic energy of the overall motion
- The galaxy slows down – its orbit gets smaller
- Over several cycles, it gradually spirals towards the other galaxy
- Eventually, the two galaxies will undergo a true collision



True Galaxy Collisions

What happens depends on relative size of the two galaxies

Big + Small:

- Small galaxy is completely disrupted
- Stars enter large galaxy
- Over time, they get absorbed
  - Galactic cannibalism
- This is currently happening in our own galaxy
  - Sagittarius Dwarf and Canis Major Dwarf – currently being disrupted
  - Virgo Stellar Stream – a dead galaxy whose stars are being absorbed

Two comparable sized galaxies:

- At high speed, the galaxies can pass through each other
  - But gas clouds still collide
- At low speed, the galaxies will merge

Comparable Size Galaxy Collisions

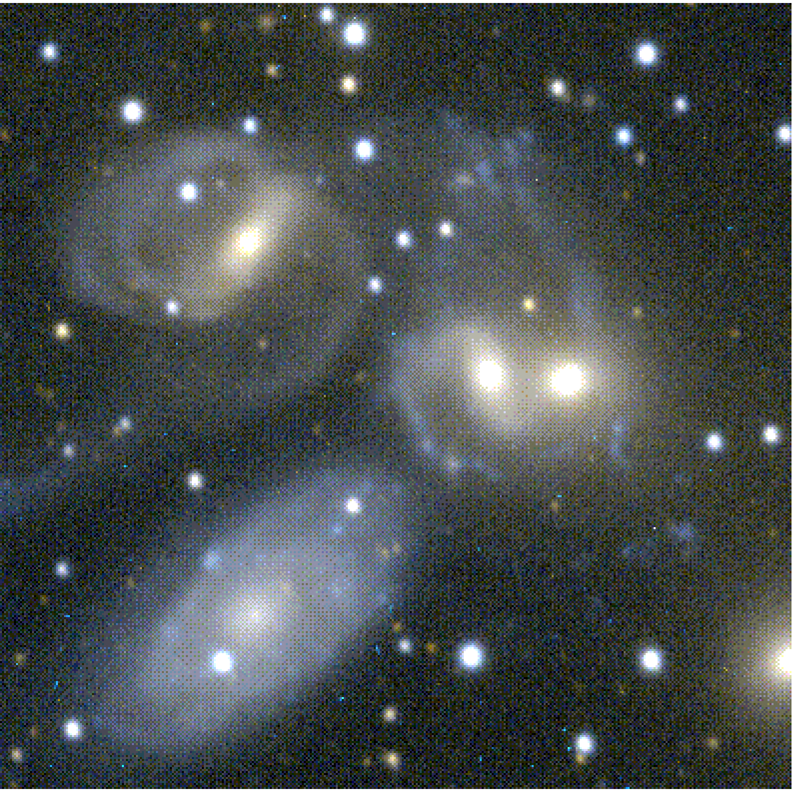
- When comparable size galaxies collide, there are major consequences
- Gas clouds collide
- Gas compresses – can cause a dramatic sudden increase in star production
  - A starburst galaxy
- Gas can get heated to high temperatures
- Gas may get completely knocked out of the galaxies
- If they collide at low speeds, the two galaxies will merge
- Initially, the galaxy will be irregular (probably SAm or SBm or Im)
- The energy converted to internal kinetic energy makes the resultant galaxy large in size
  - And, of course, increased mass
- Depending on whether there is any cool gas left, eventually galaxy settles down to a spiral or elliptical

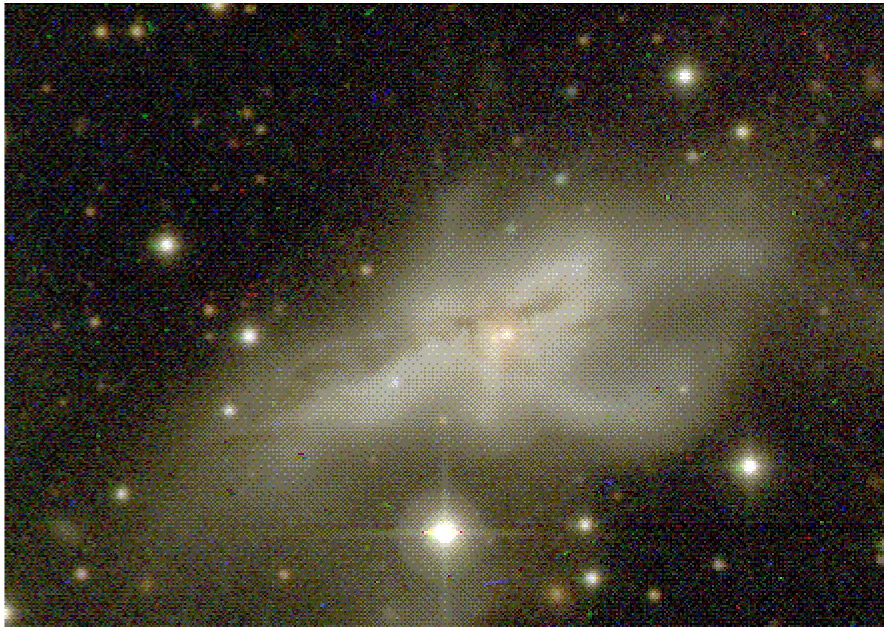
Starburst Galaxies

- Fast star formation
- Caused by compression of gas from recent galaxy collisions

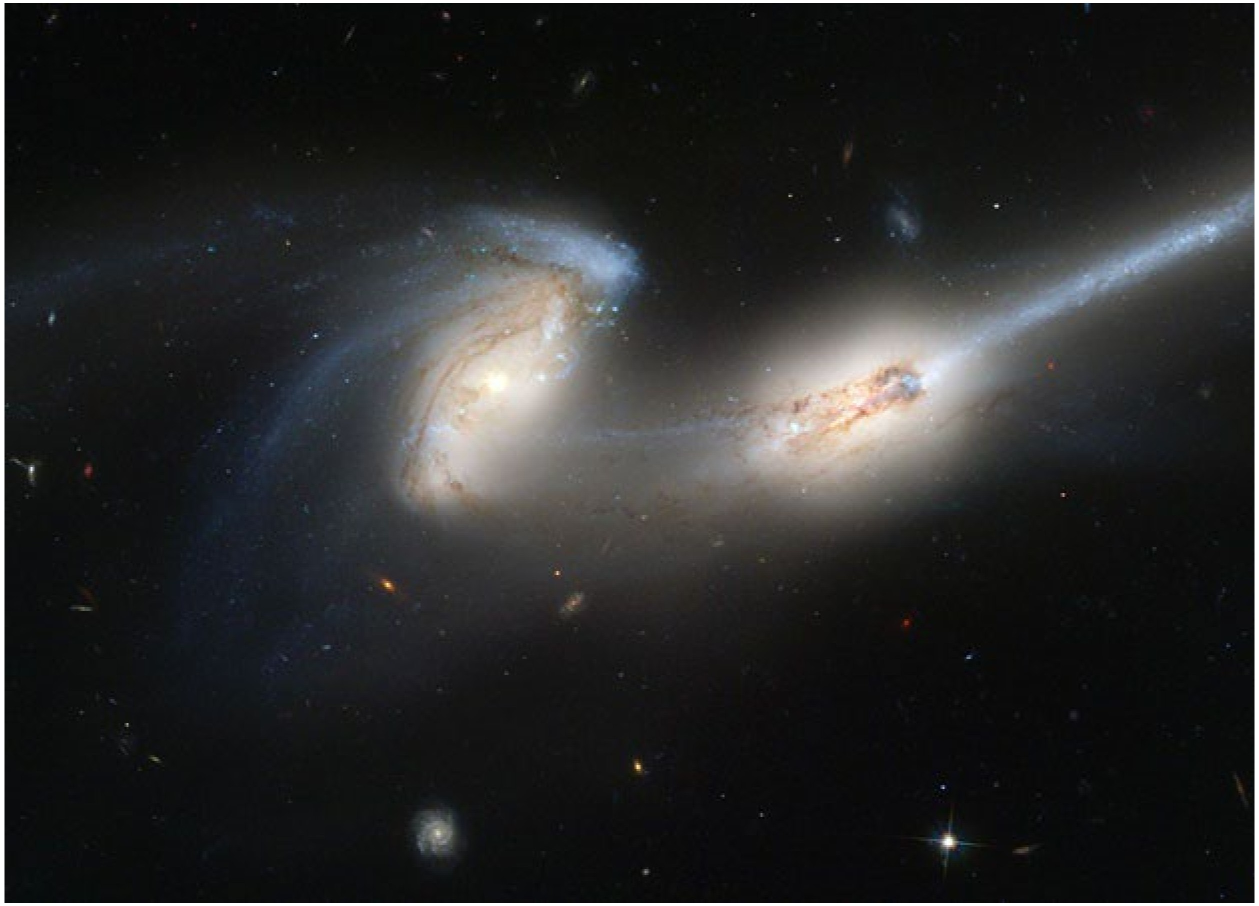
Colliding Galaxies – Images (1)

Colliding Galaxies – Images (2)





Colliding Galaxies – Images (3)

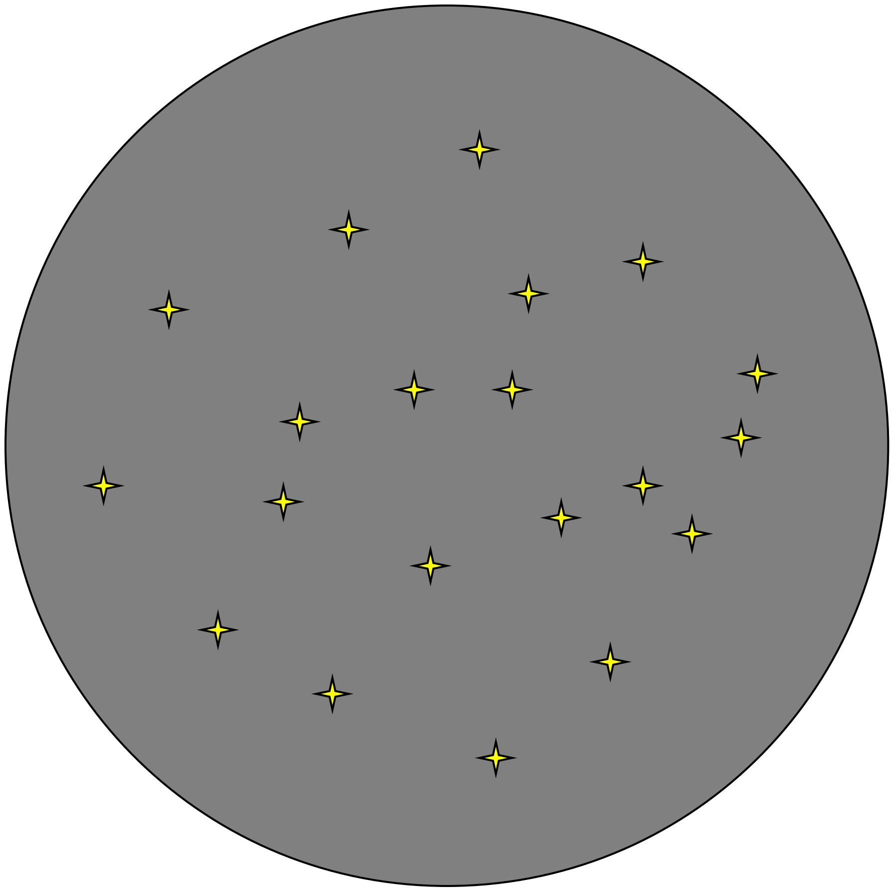


Milky Way Collision with Andromeda

- Our galaxy is currently headed towards Andromeda, the nearest large galaxy
  - Distance about 780 kpc
- Relative velocity measured by Doppler shift
  - Have to subtract Sun's velocity around our galaxy
  - About 110 km/s
- Transverse velocity measured recently by Hubble using proper motion
  - Very slow transverse motion
- Suggests the two will collide, or nearly collide about 4 billion years from now
- After initial encounter, two galaxies will probably merge "shortly" thereafter
  - MW - Andromeda Collision
- Best guess is that after that, they will merge to make a large elliptical galaxy

Giant Elliptical Galaxies

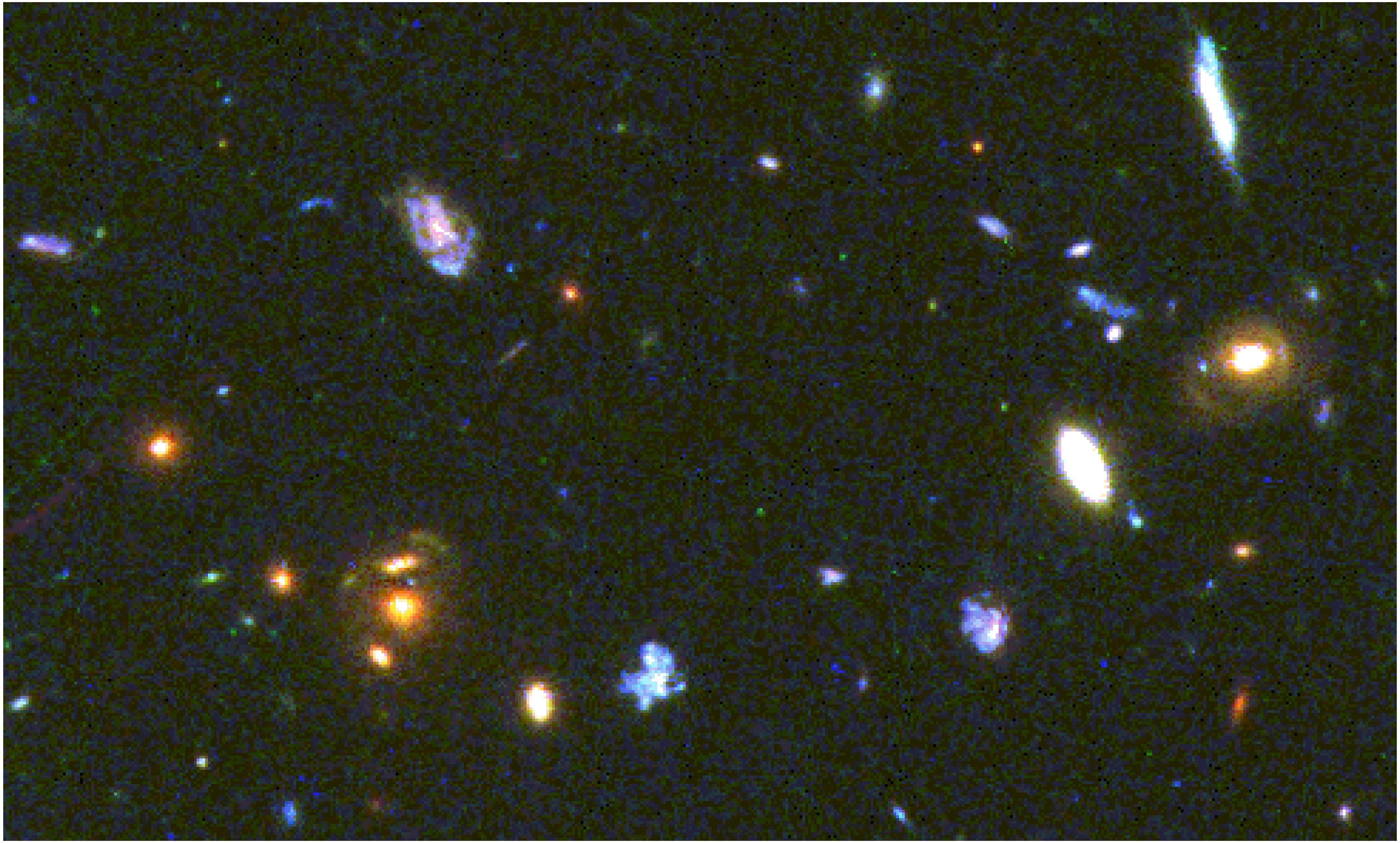
- In the centers of *clusters* of galaxies, many galaxies combine and merge
- Collisions pretty much *guarantee* all the cold gas will be heated
- It then will expand throughout the halo
- The kinetic energy transferred to the stars causes the galaxy to become very large
    - And of course, it is very massive too
- It will generally be almost spherical
- These galaxies are now giant elliptical galaxies
- The largest of these are the cD or central dominant galaxies
- They are *central* because they tend to be at the center of clusters of galaxies



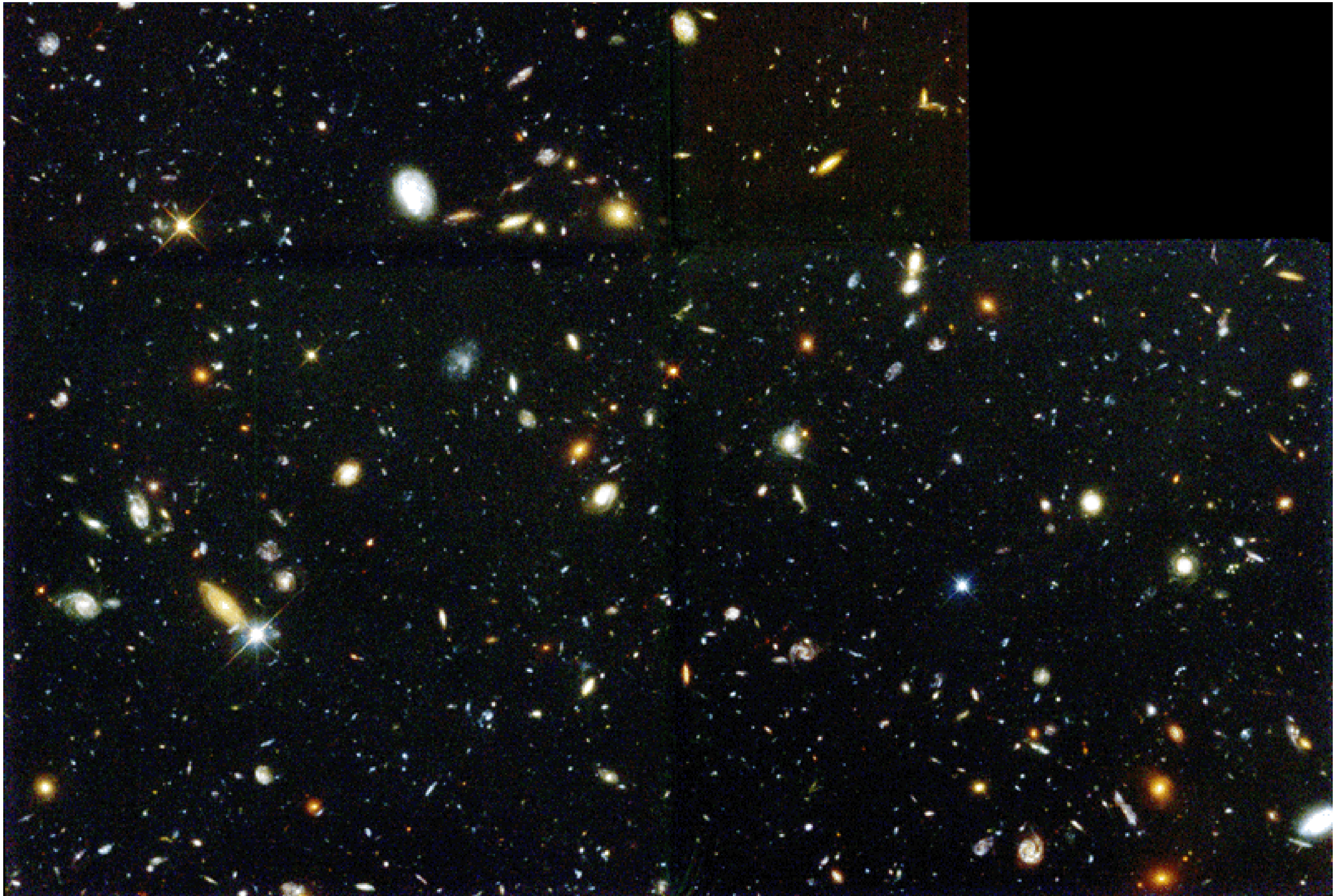
Looking Out = Looking Back

- Light travels at about 0.3 pc per year
- The farther away you are looking, the longer ago you are seeing
  - 1 kpc → 3.3 ky
  - 1 Mpc → 3.3 My
  - 1 Gpc → 3.3 Gyr
- You can see back almost to the beginning of the Universe!

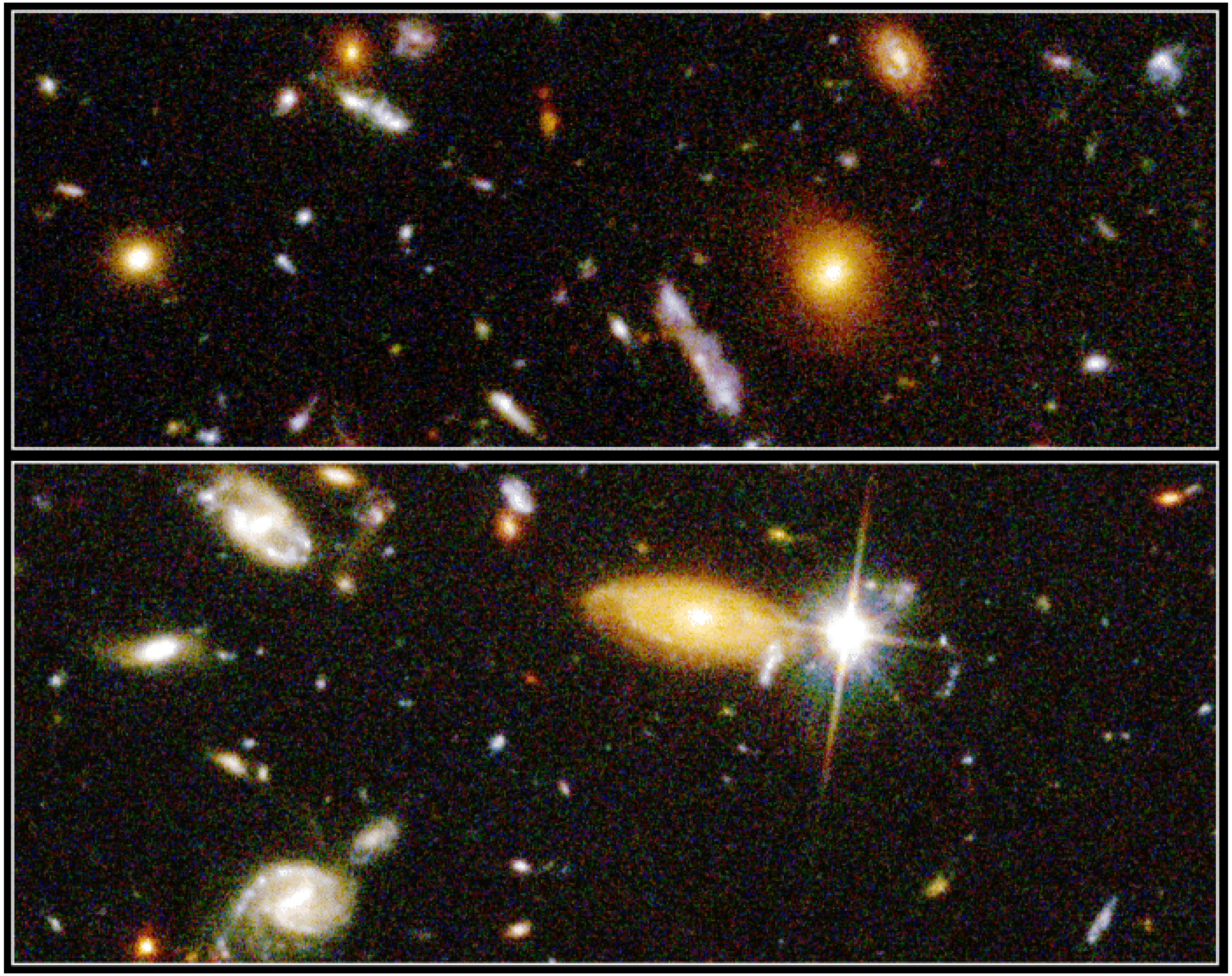
Galaxies Long Ago



Galaxies Long, Long Ago



Galaxies Long, Long Ago (Close Up)



How Were Galaxies Different in the Past?

- Generally, galaxies were smaller
    - Because small galaxies combined a lot to make the galaxies we see today
- Generally, spirals were more likely to be unbarred (SA) than barred (SB)
    - Because bars take a lot of time to form
- There were more irregular galaxies back then
    - Because collisions were still building galaxies

Active Galaxies

General Description

- Most of the power of galaxies come from the stars
  - Almost all nearby galaxies

- Some galaxies have very bright sources right at the center
  - Can be as bright as a galaxy!
  - Or even much brighter
- Called *Active Galactic Nuclei* (AGN's)

- They can be incredibly bright
  - Up to $10^{15}\ L_{\mathrm{Sun}}$

- Their power comes out with different spectra
  - Visible
  - Radio
  - Infrared
  - Ultraviolet
  - X-rays

- Some of them vary their power in a day or less
  - This proves they are very, very small!

Fast Implies Small

- A large source will not – can not – change all at once
  - Roar from a stadium crowd
- Light (and other EM radiation) travels at *c*
- If it changes in a time *t* it must be no larger than $d = ct$
- If it changes in a day, its size is no bigger than

$$d = ct = \left(2.998\times10^{8}\ \text{m/s}\right)\left(86400\ \text{s}\right) = 170\ \text{AU} = \text{ size of solar system}$$

Types of Active Galactic Nuclei (AGN's)

- Seyfert Galaxies
  - Relatively dim as AGN's go
  - Emission lines – shows something exciting atoms to high temperature
  - Usually Spiral galaxies – with lots of gas in plane of galaxy
- Seyferts subcategorized as Seyfert 1 and Seyfert 2
  - Seyfert 1 – broad emission lines – shows source has high velocity, more than 10,000 km/s
  - Seyfert 2 – narrow emission lines – source is moving more slowly

- Radio Galaxies
  - Produce enormous amounts of radio energy
  - Often, the radio emission is mostly *not* from the nucleus

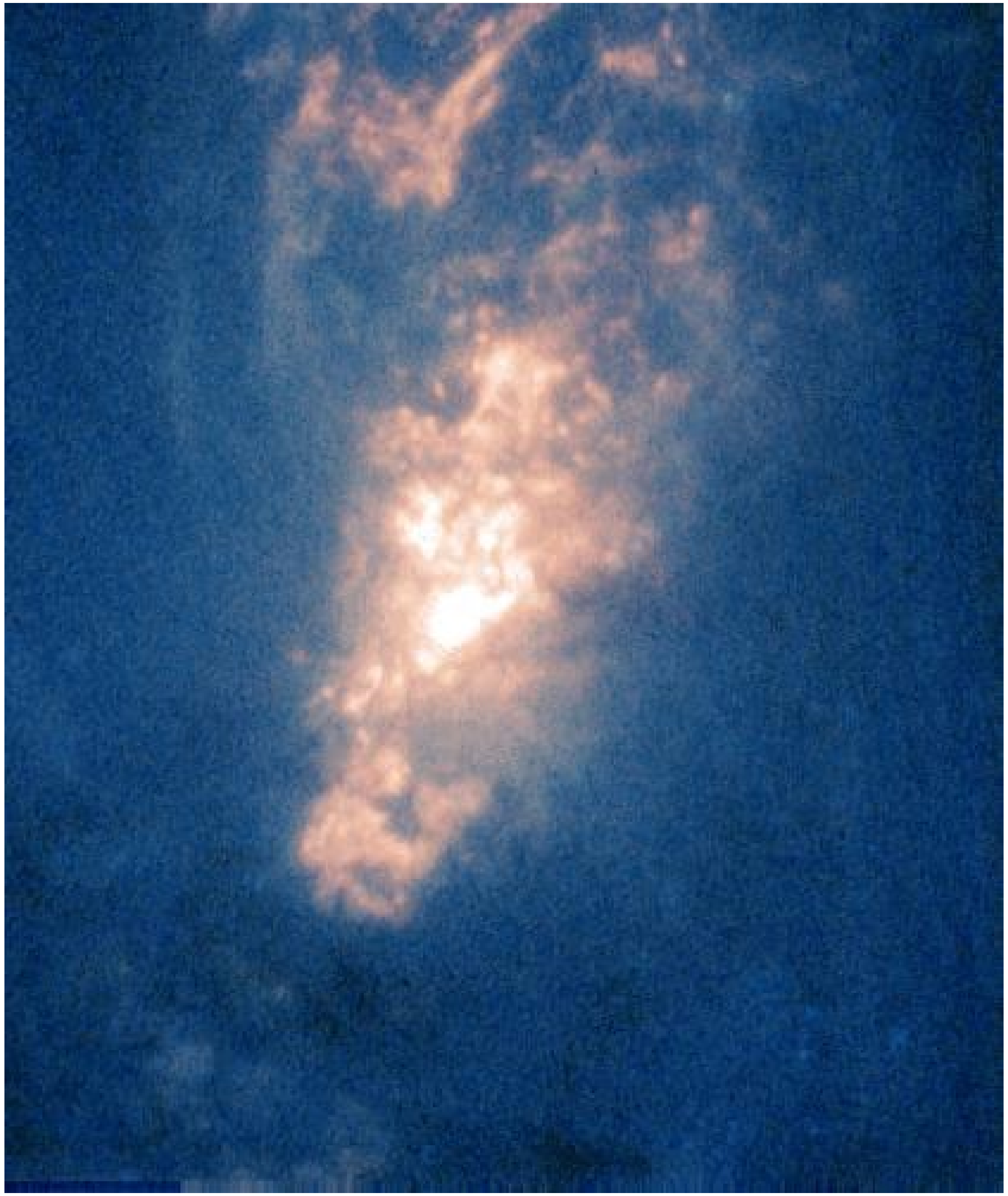
- Radio Quiet Quasars
  - Similar to Seyfert 1's, but <u>much</u> brighter

- Radio Noisy Quasar

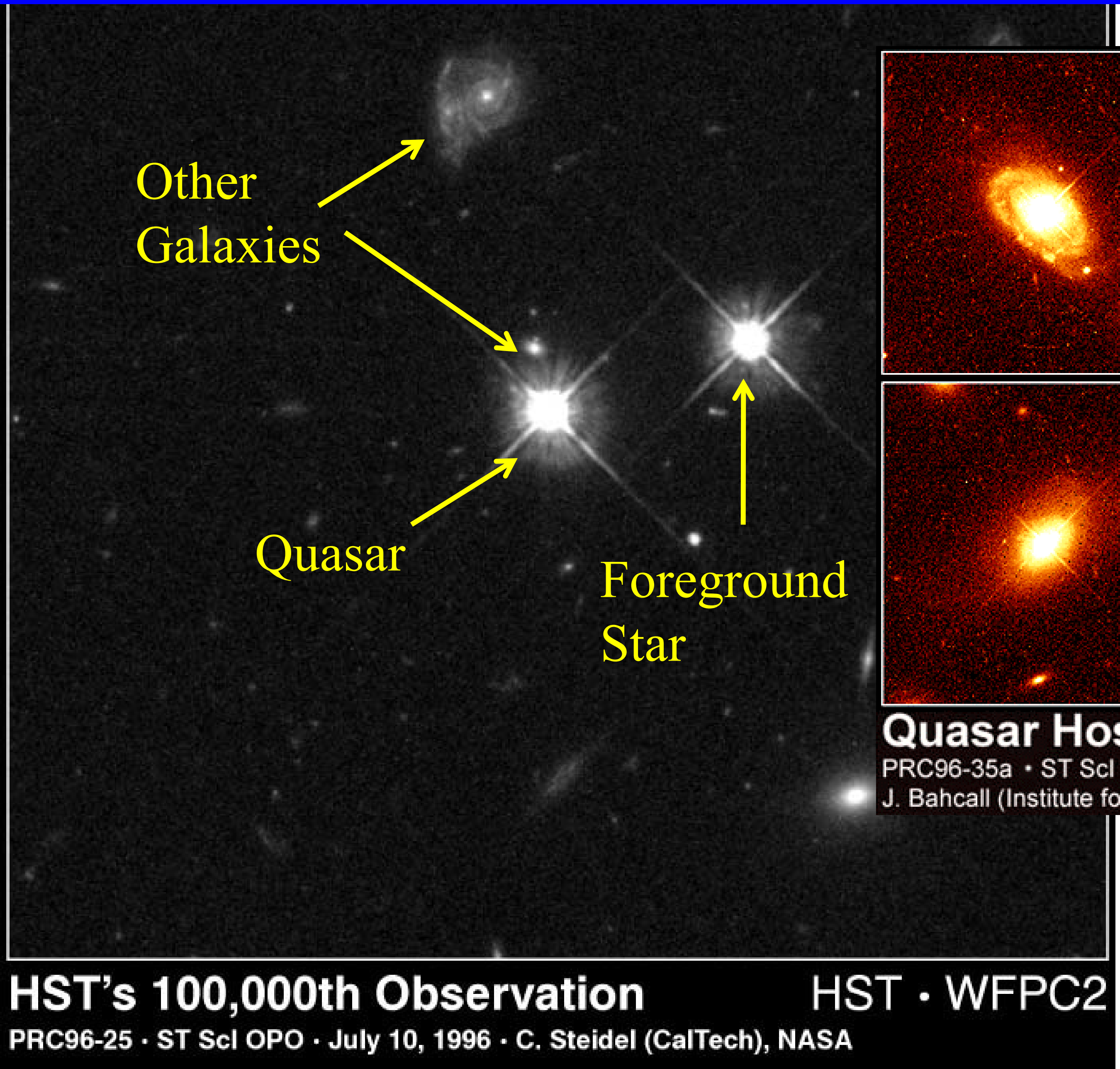
- Blazars / BL Lacartae Objects
  - Visible and radio signal can vary in as little as an hour

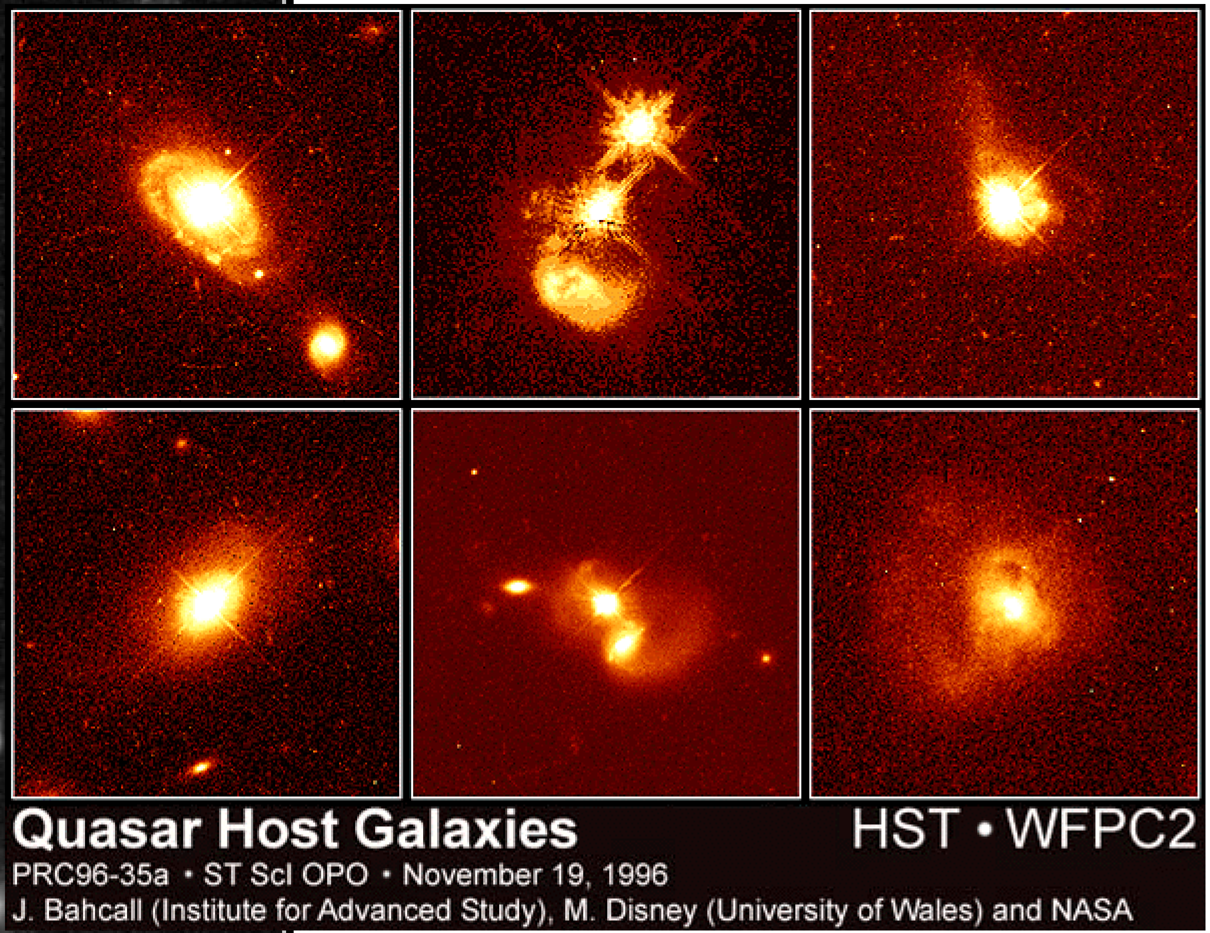
Seyfert Galaxies – Images

Core of a Seyfert Galaxy

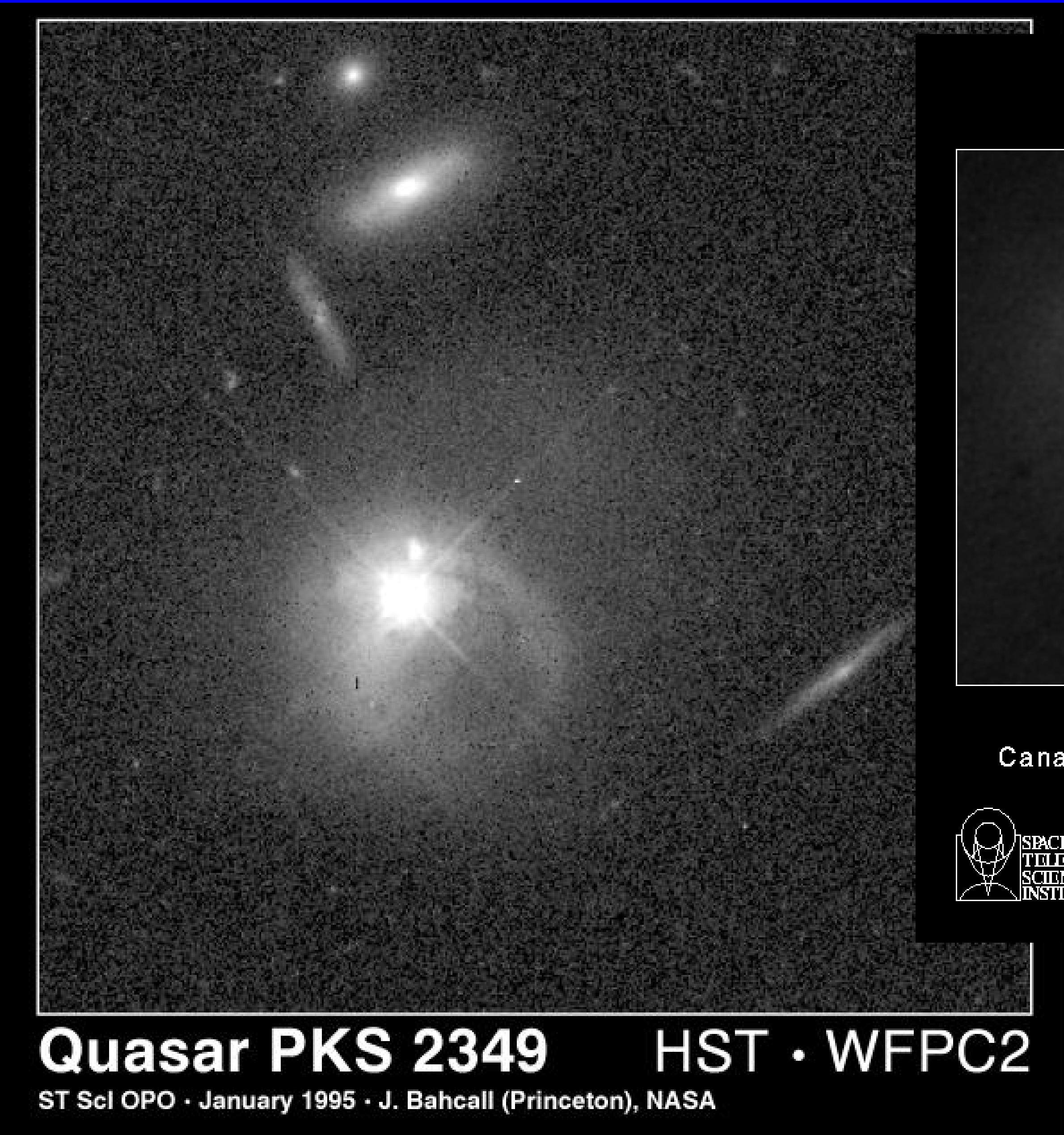


Quasars (1)

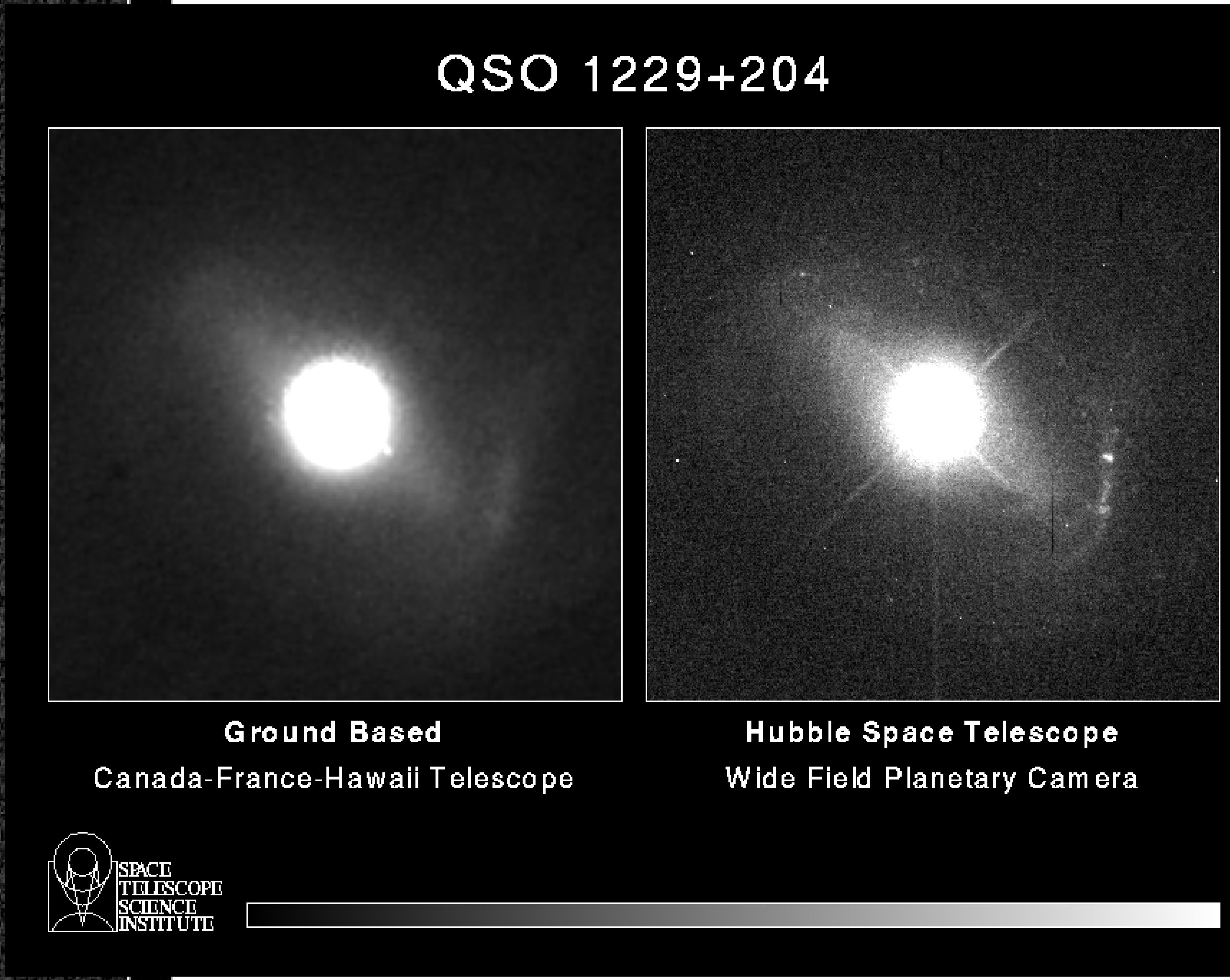

Other
Galaxies
Quasar
Foreground
Star
HST's 100,000th Observation
HST • WFPC2
PRC96-25 • ST ScI OPO • July 10, 1996 • C. Steidel (CalTech), NASA


Quasar Host Galaxies
HST • WFPC2
PRC96-35a • ST ScI OPO • November 19, 1996
J. Bahcall (Institute for Advanced Study), M. Disney (University of Wales) and NASA

Quasars (2)

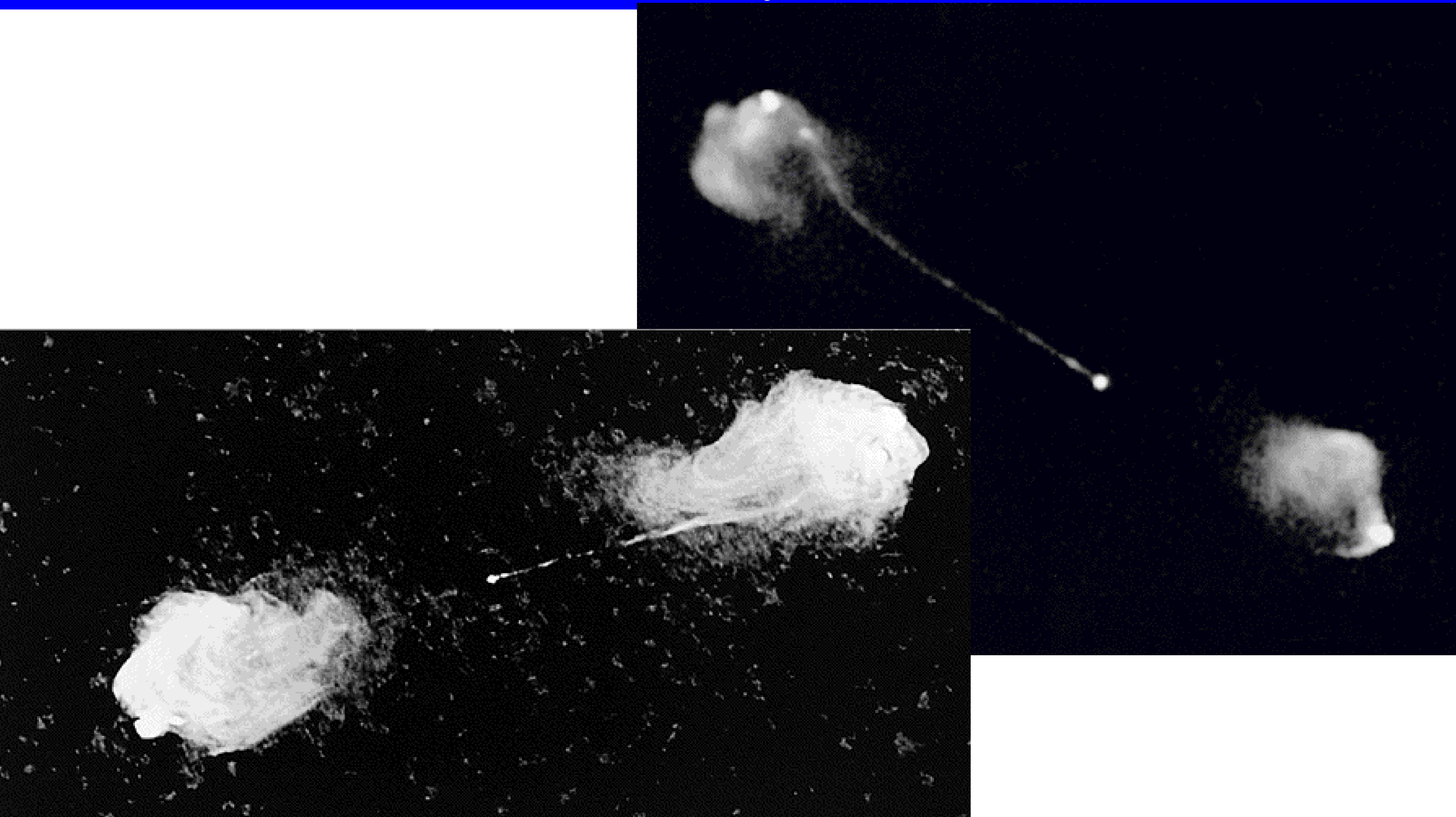


Quasar PKS 2349
HST • WFPC2
ST ScI OPO · January 1995 · J. Bahcall (Princeton), NASA

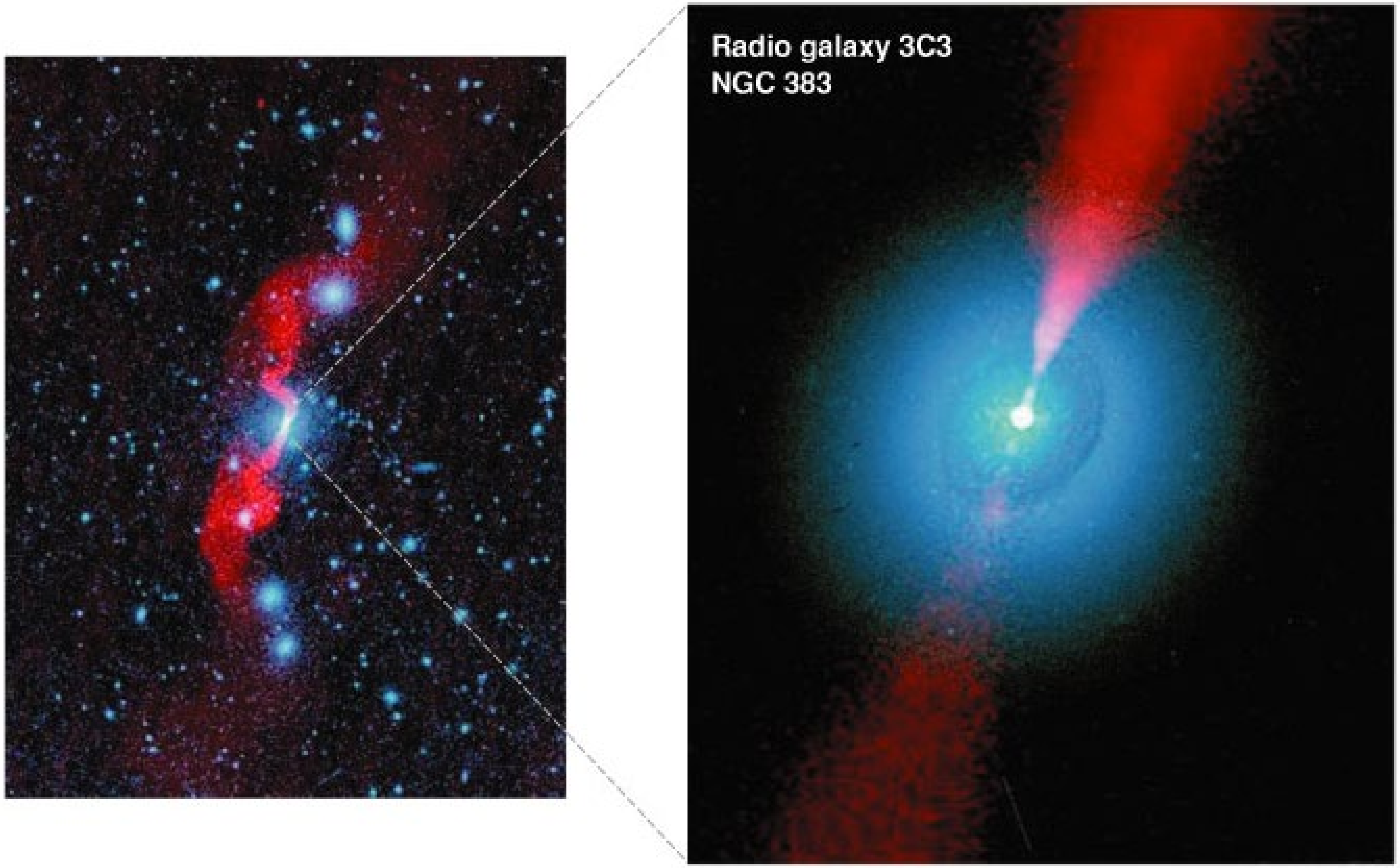


QSO 1229+204
Ground Based
Canada-France-Hawaii Telescope
Hubble Space Telescope
Wide Field Planetary Camera
SPACE TELESCOPE SCIENCE INSTITUTE

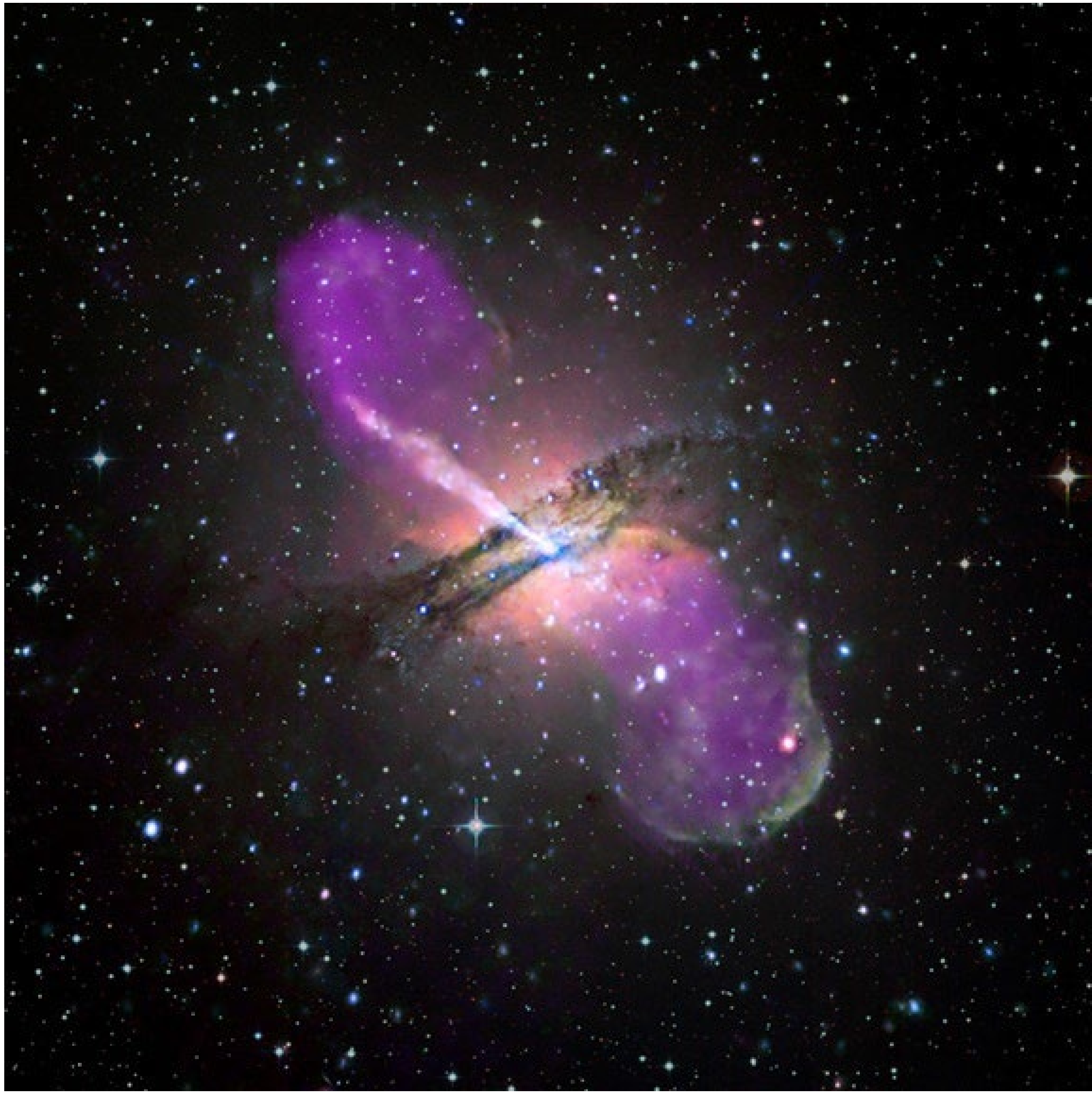
Radio Galaxy in Radio



Radio Galaxy in Visible and Radio

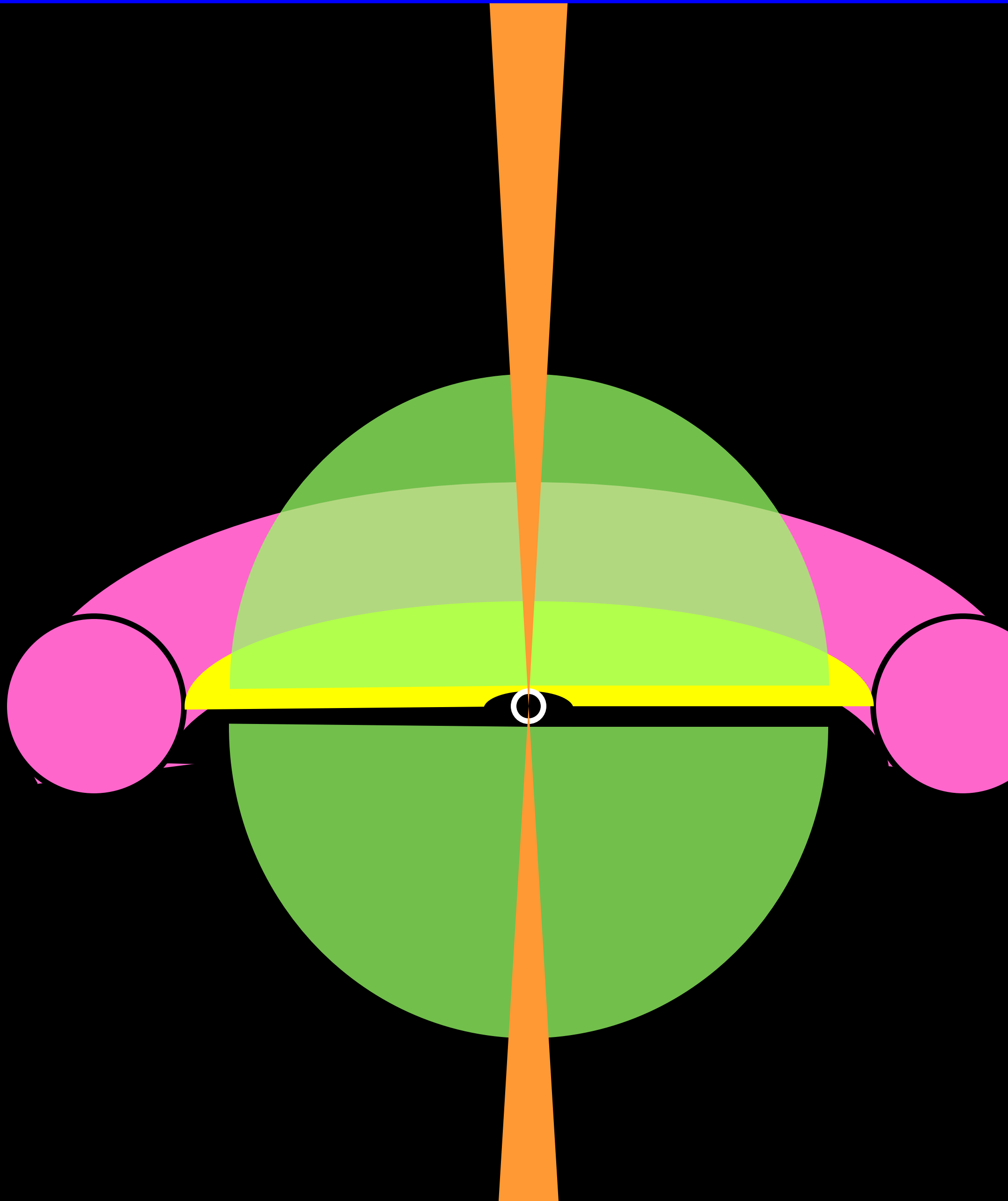


Centaurus A, a Radio Galaxy



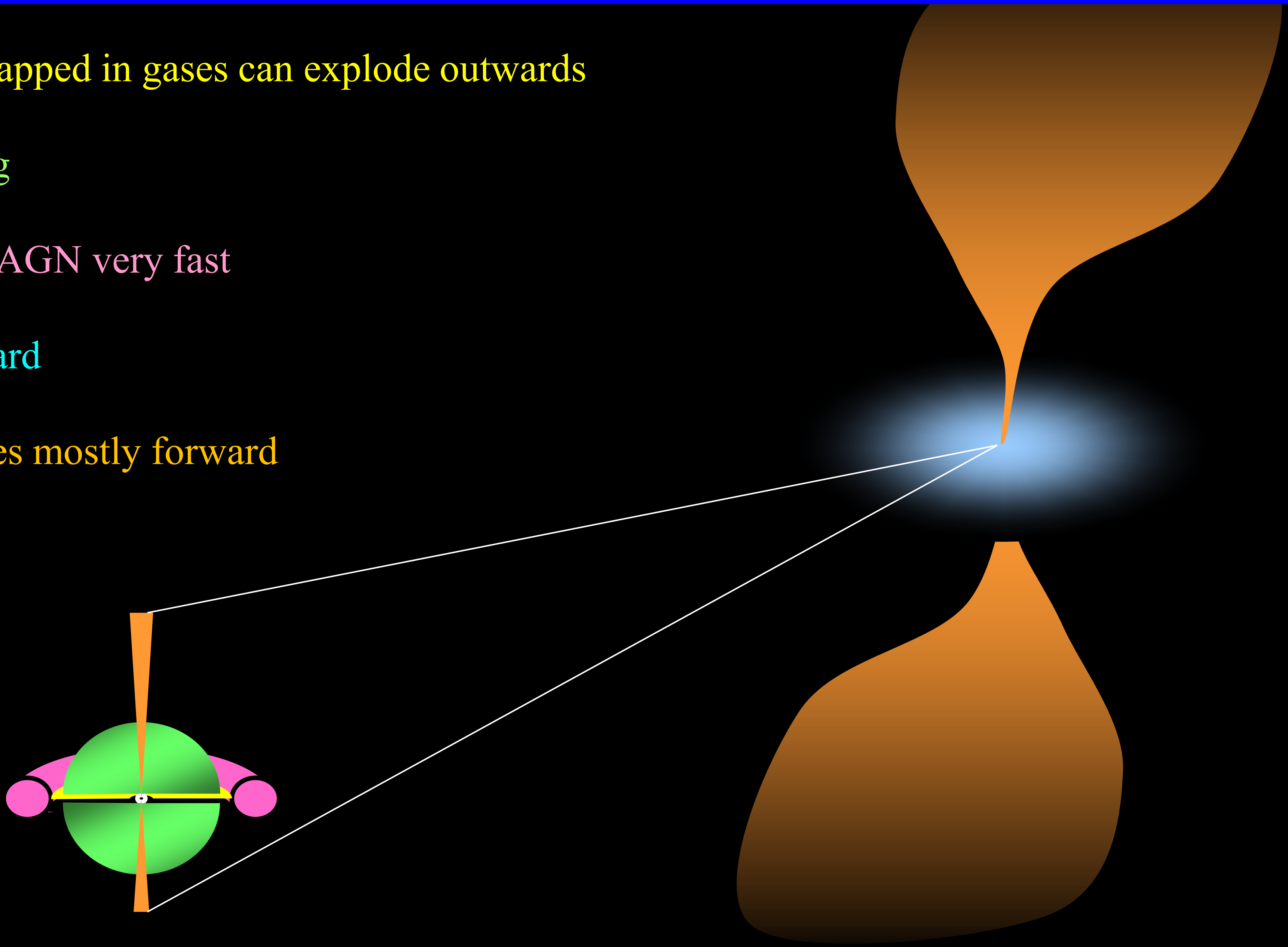
What Causes an AGN?

- Black hole in center
  - $10^4 - 10^{10}\ M_{sun}$ (possibly higher)
  - Size of Earth up to size of Solar system
- Source of gas - a gas torus (doughnut)
  - Gas getting dumped into the center
- An accretion disk of gas falling in
  - Rotating very fast
  - Friction makes it hot – X-rays
  - Very efficient – 50% mass → energy
- Thin gas surrounding the center
  - Heated by X-rays from the accretion disk
- Sometimes, jets shooting out

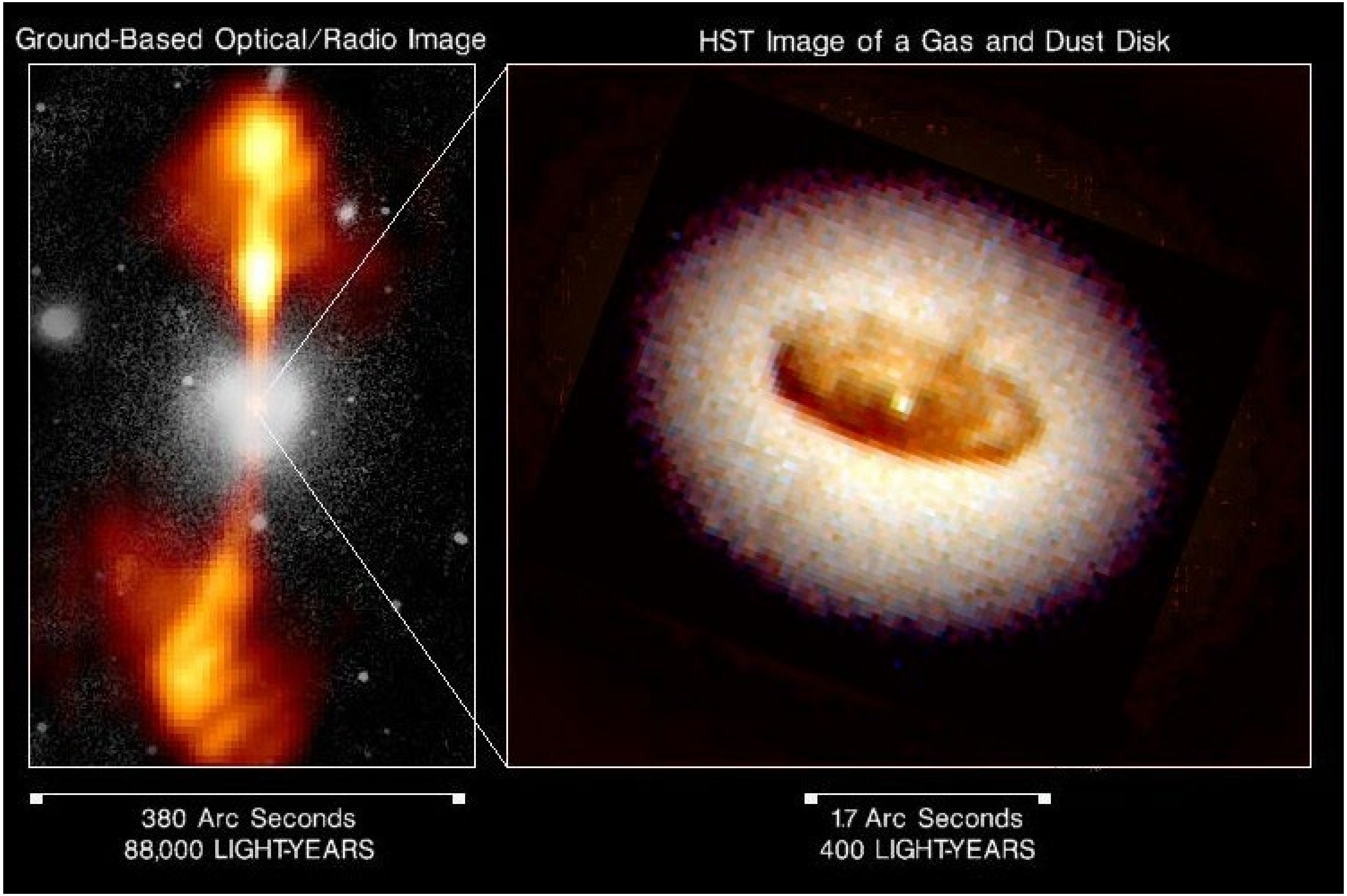


Jets and Lobes

- Magnetic fields trapped in gases can explode outwards
- Gases swept along
- Flung away from AGN very fast
- Beams light forward
- Beams radio waves mostly forward

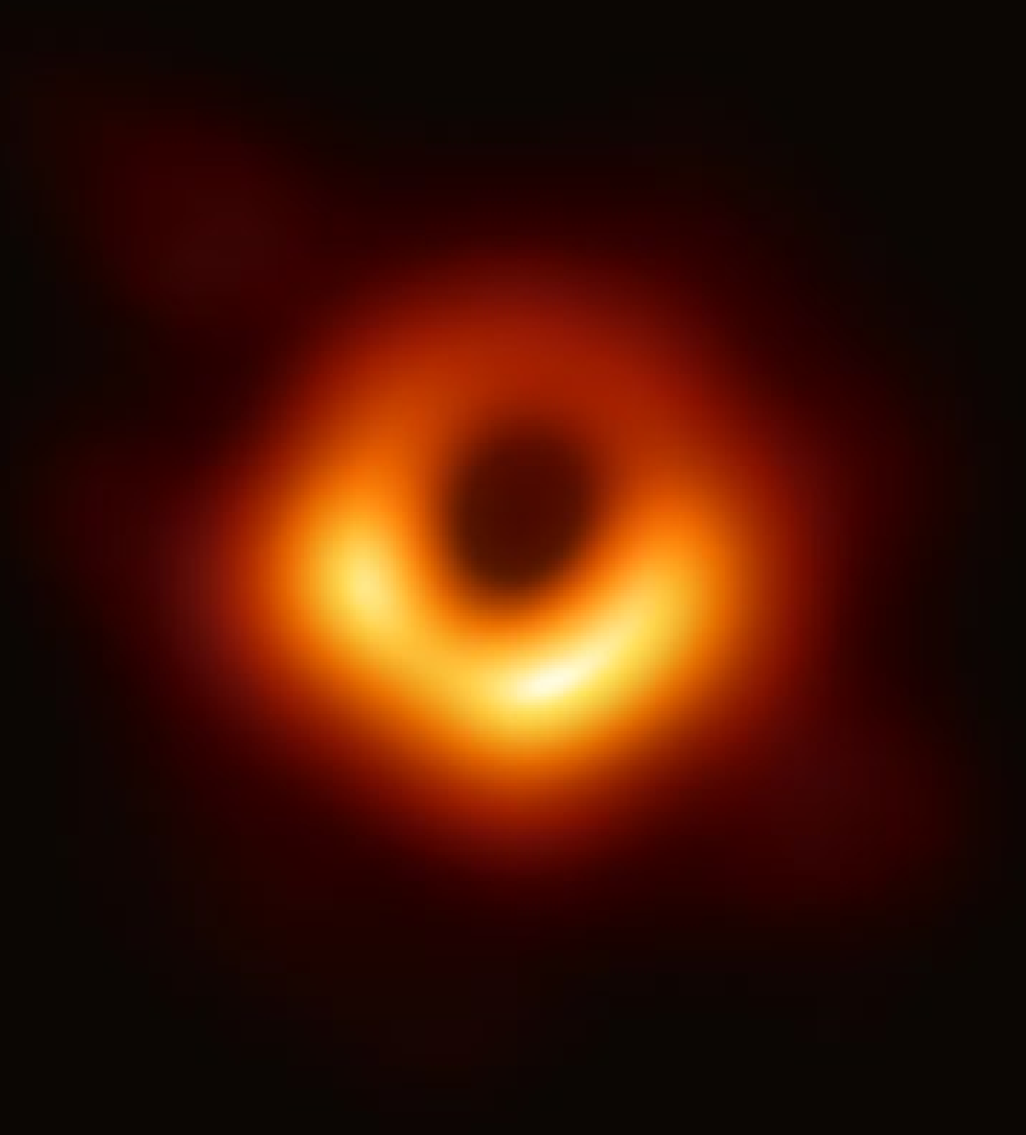


Core of an Active Galaxy



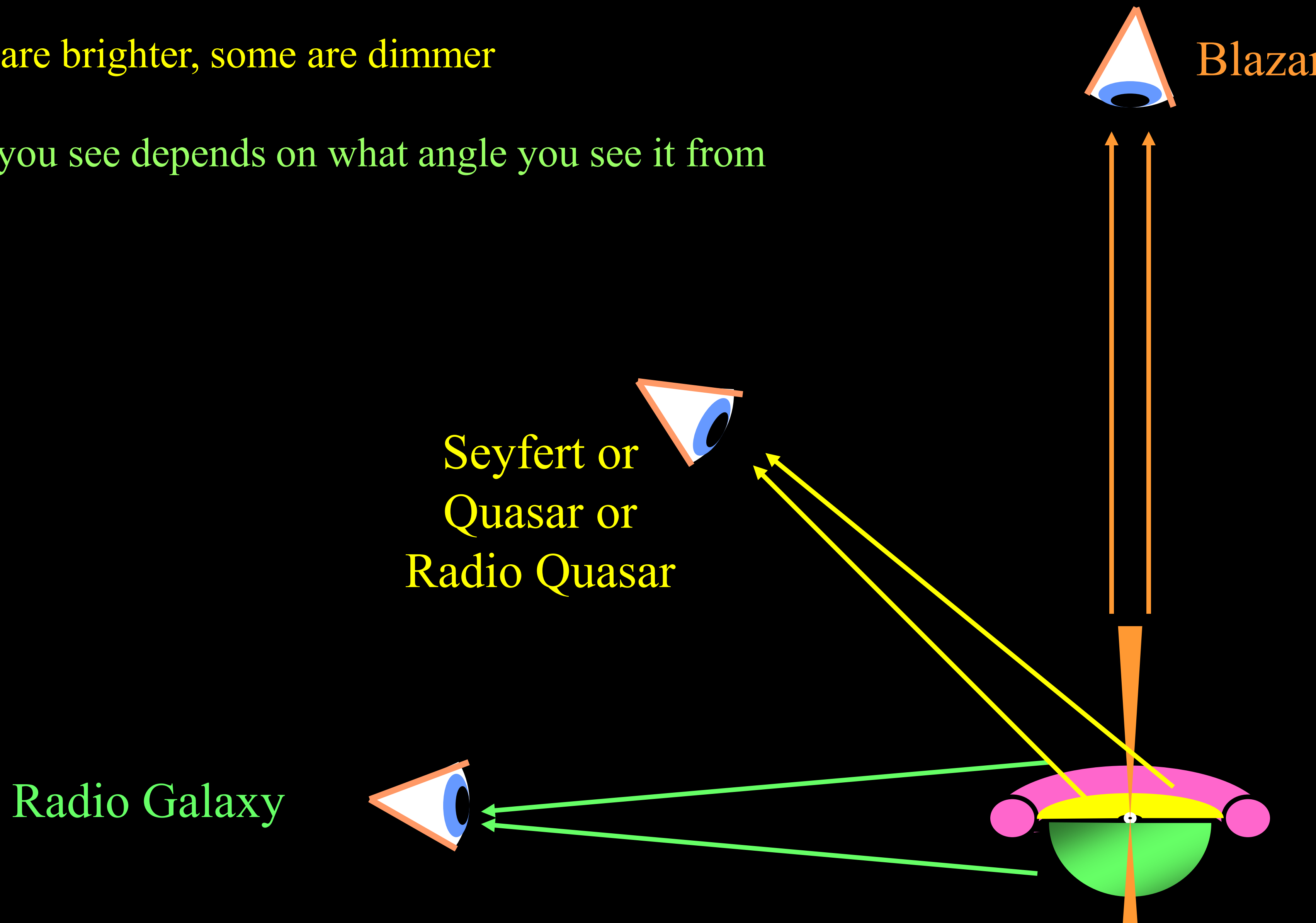
Black Hole in M87 Galaxy in Radio

- Image released April 10, 2019
- First image of black hole
- 6.5 billion solar masses
  - Compare: Ours is 4.3 million



Unified Picture of Active Galaxies

- Some are brighter, some are dimmer
- What you see depends on what angle you see it from



Active Galaxies Used to be More Common

- Active galaxies, especially bright ones, are rare now
  - But common in the past

Why?

- Active galaxies require fuel to be fed into the black hole

- Colliding galaxies allow gas to flow to center

- Galaxy collisions were much more common in the past