Active Galactic Nuclei = AGNs

- **Seyfert Galaxies & Radio Galaxies & Quasars**
- Fornax A (Radio & Visible

Seyfert Galaxies

- Carl Seyfert 1943 cataloged
- Spiral galaxies
- Small bright nuclei which changed brightness in months
- Spectra: emission lines
- Bright in Radio, X-rays etc.

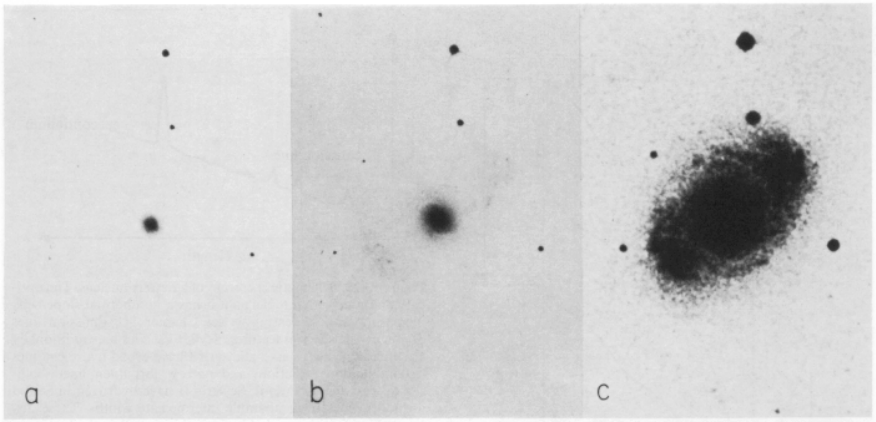
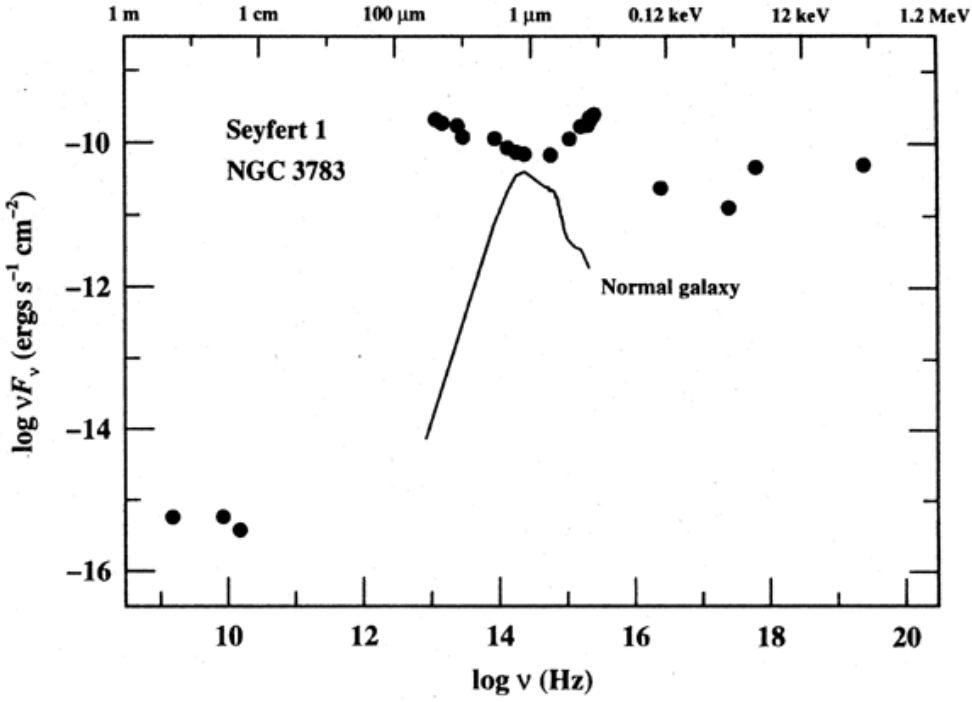
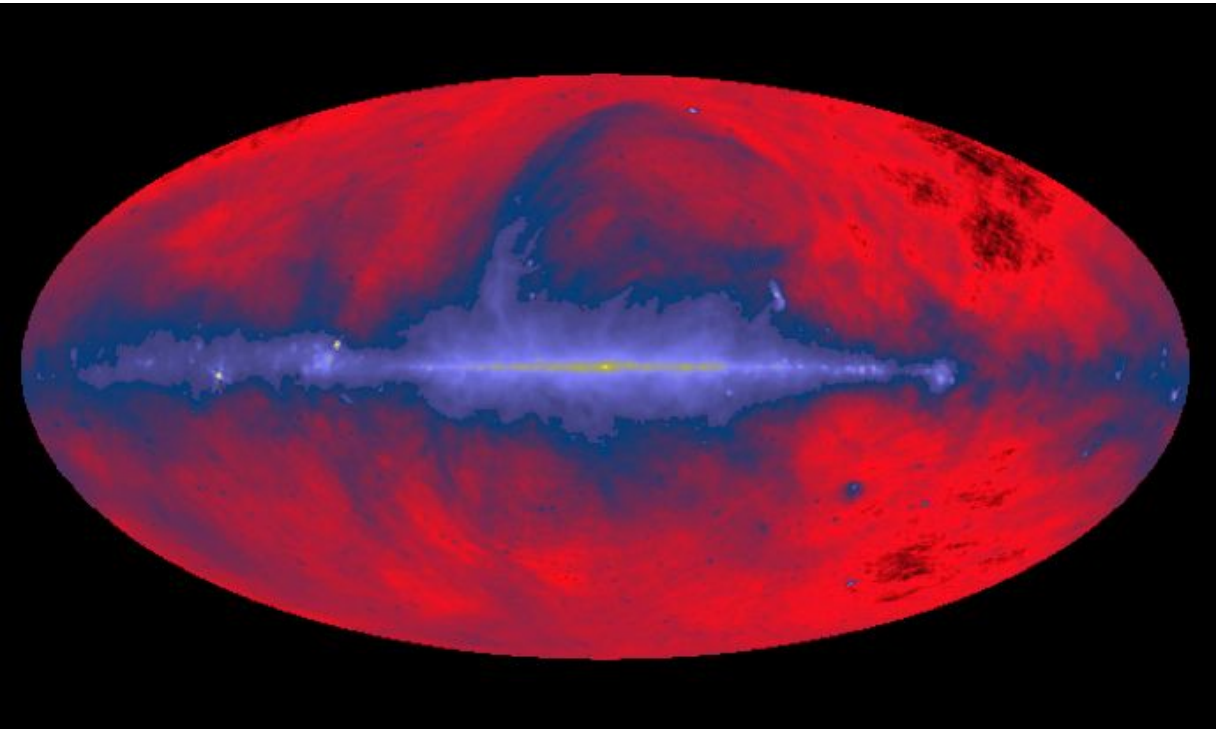


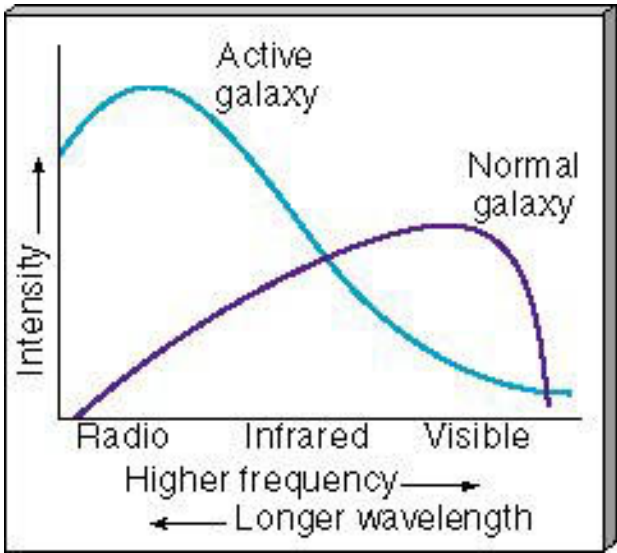
Figure 13.20. Negative prints of various exposure lengths of the Seyfert galaxy NGC4151. (a) A short exposure shows only the



Radio Galaxies

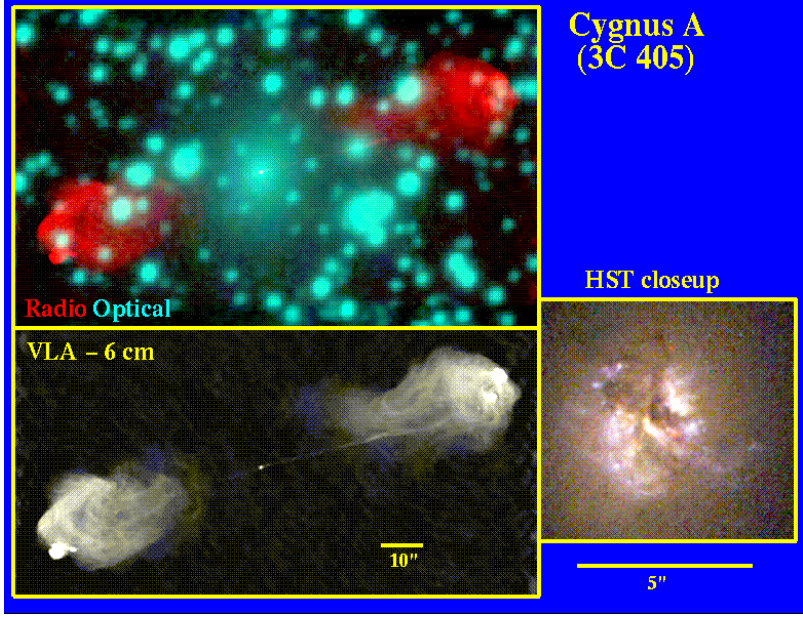
- Third Cambridge Radio Source Catalog
- Scanned the sky in 1960
- Found some sources that emitted radio noise = **Radio Galaxies**

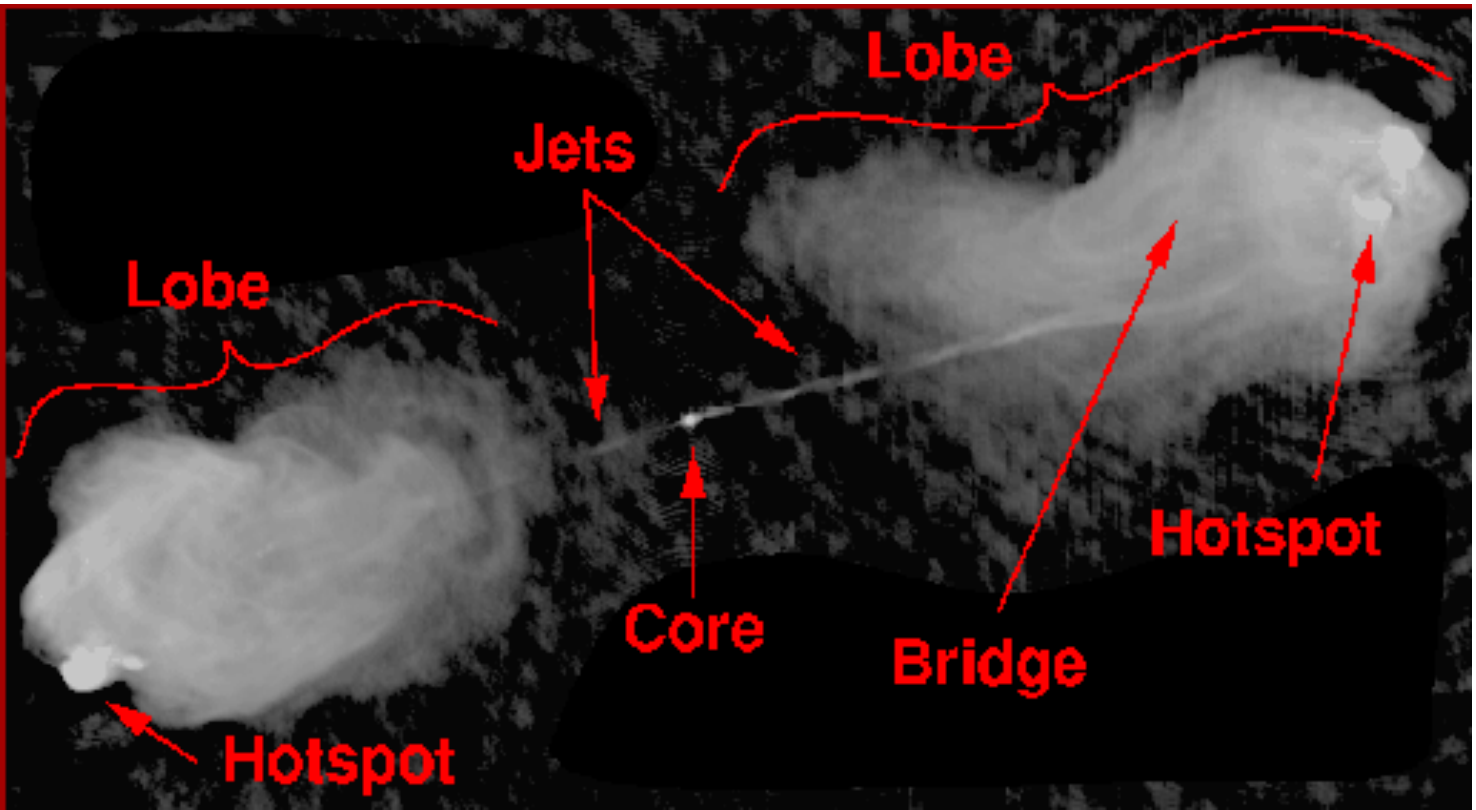




Radio Lobes

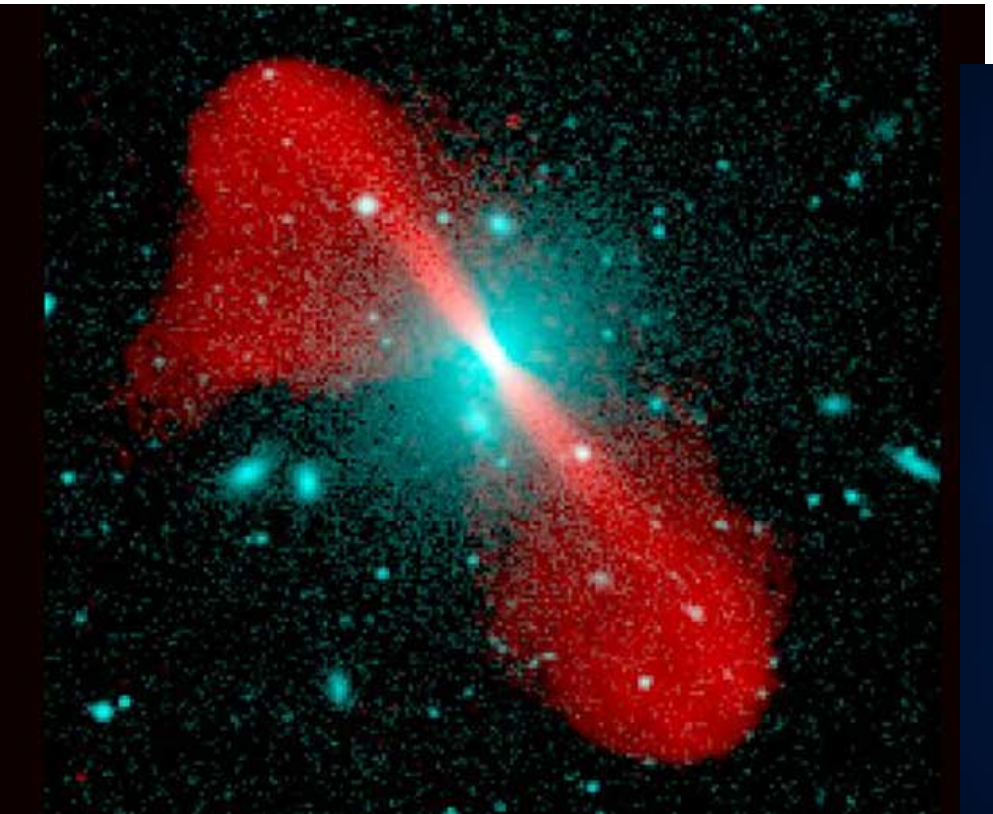
- Cygnus A; elliptical galaxy; 800Mpc; compact core, collision?
- **E**nergy in lobes is 10^{60} ergs = a million solar **M**asses times $\mathbf{C}^2$

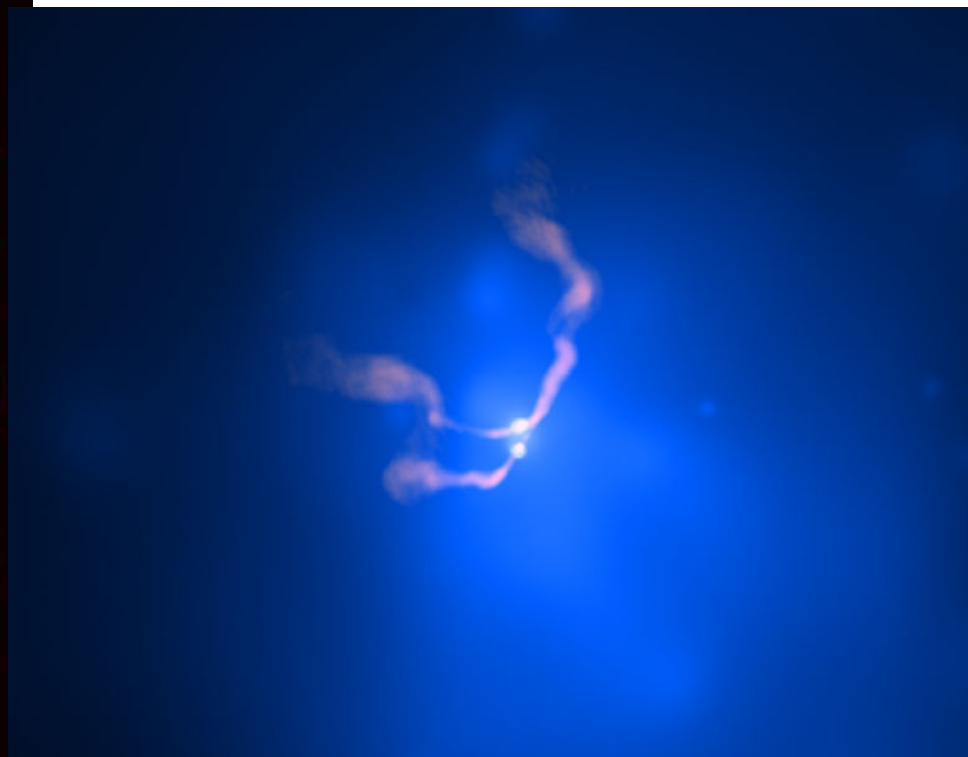




Double Lobed Radio Source

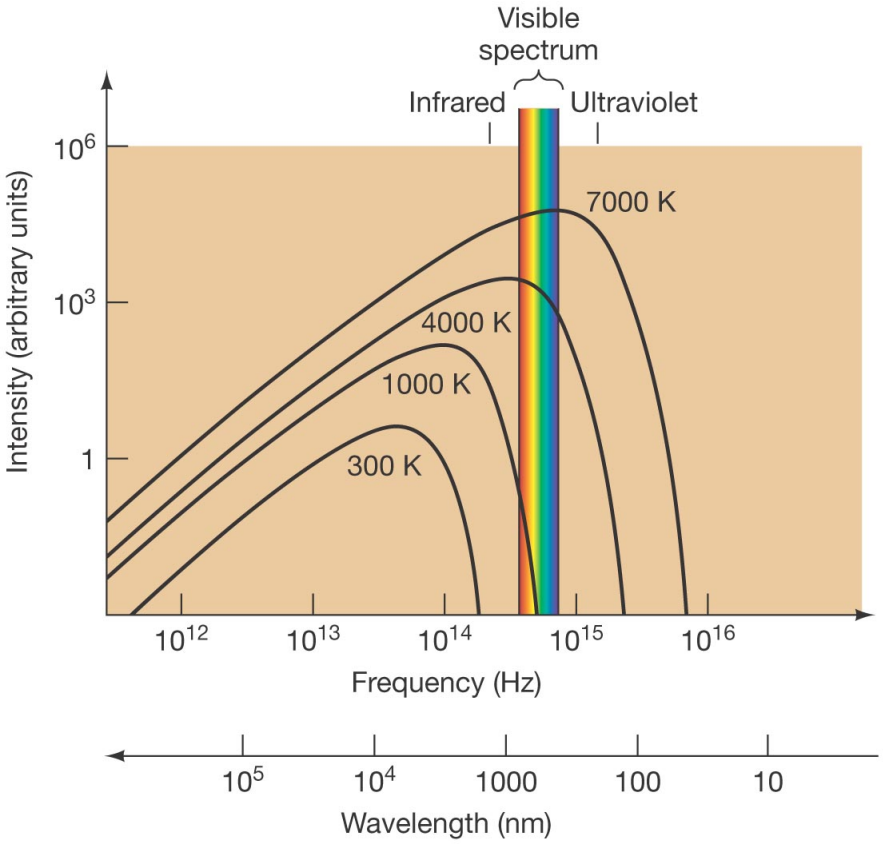
- Visible light in blue and radio observations in red
- Jets much bigger than visible galaxy – 5Mpc long & 20kpc lobes
- So must remain collimated and stay aligned for millions of years
- 3C75 shows 2 radio galaxies in X-rays and with Radio jets

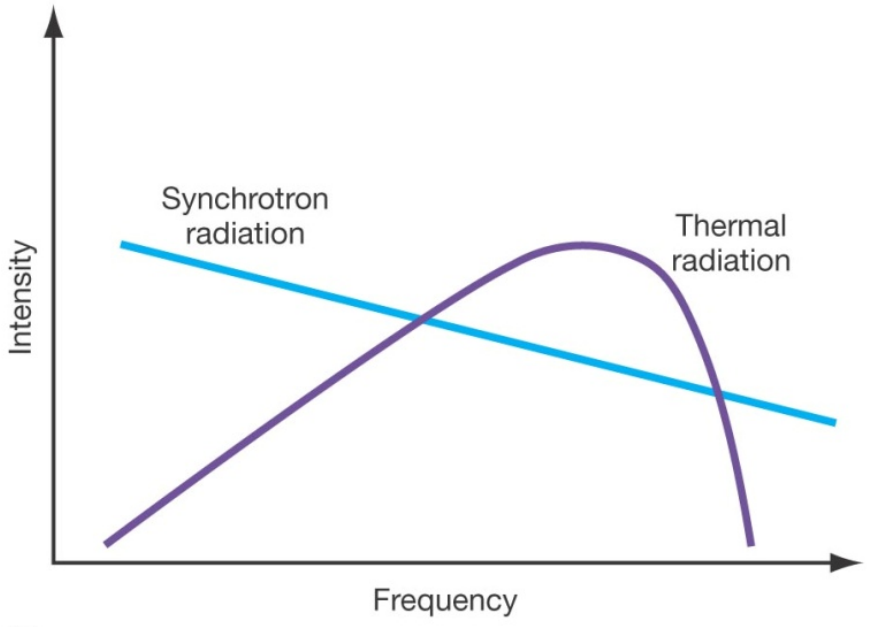




Thermal and **Nonthermal Spectrum**

- Thermal radiation - hot opaque objects = stars
- Nonthermal radiation independent of temperature = synchrotron radiation

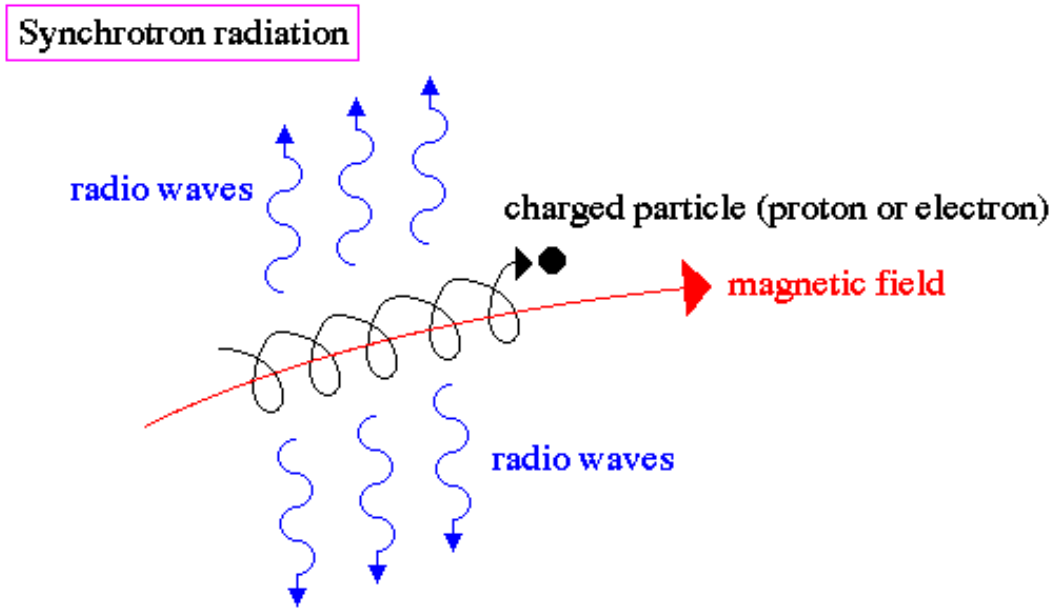




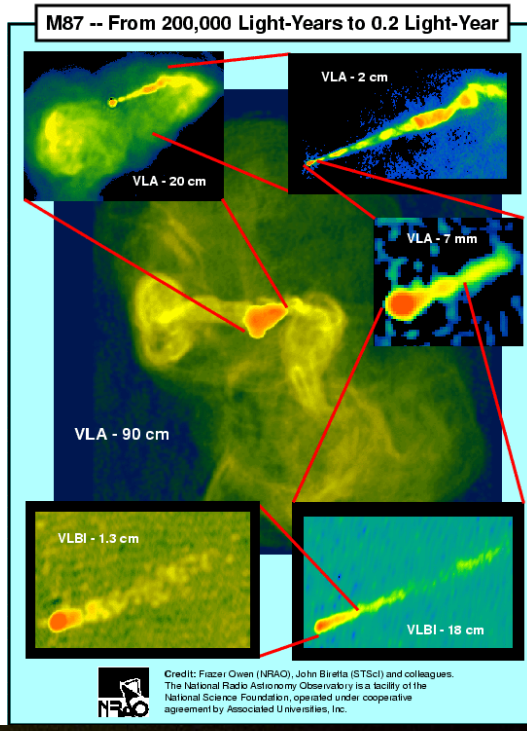
(b)

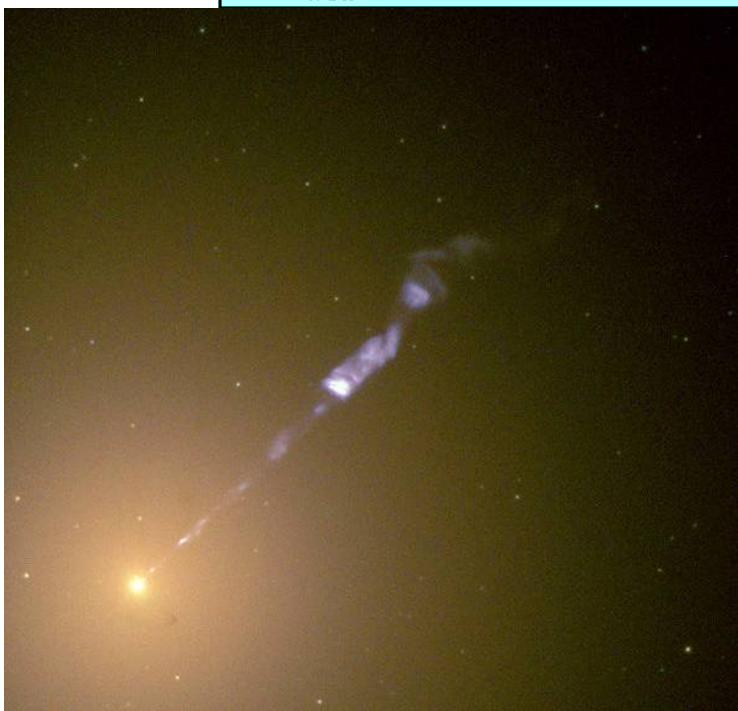
Synchrotron Radiation

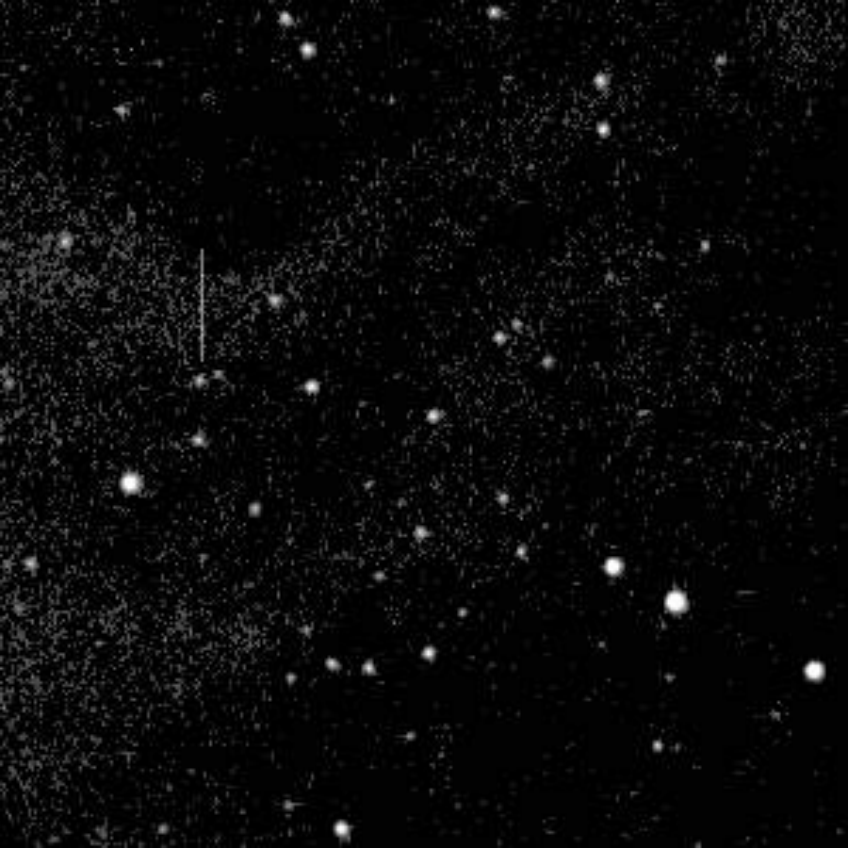
- Relativistic electrons spiral in magnetic field and acceleration causes emission of photon as polarized radiation/light

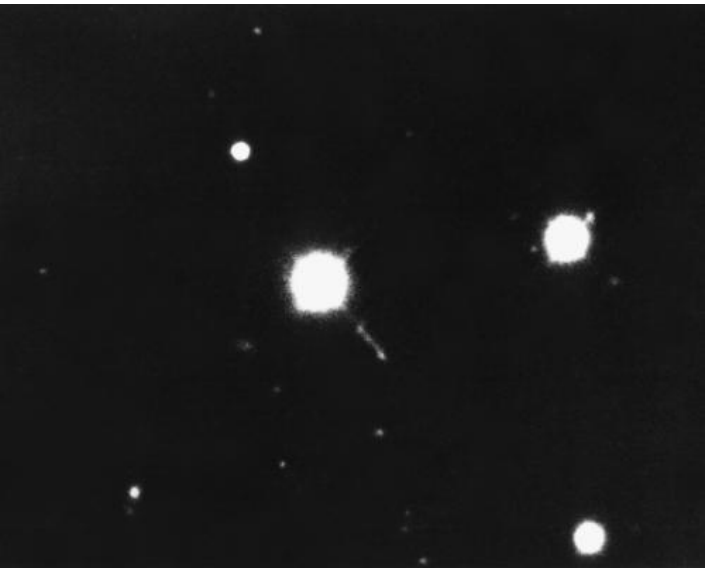


synchrontron radiation occurs when a charged particle encounters a strong magnetic field – the particle is accelerated along a spiral path following the magnetic field and emitting radio waves in the process – the result is a distinct radio signature that reveals the strength of the magnetic field









Quasars

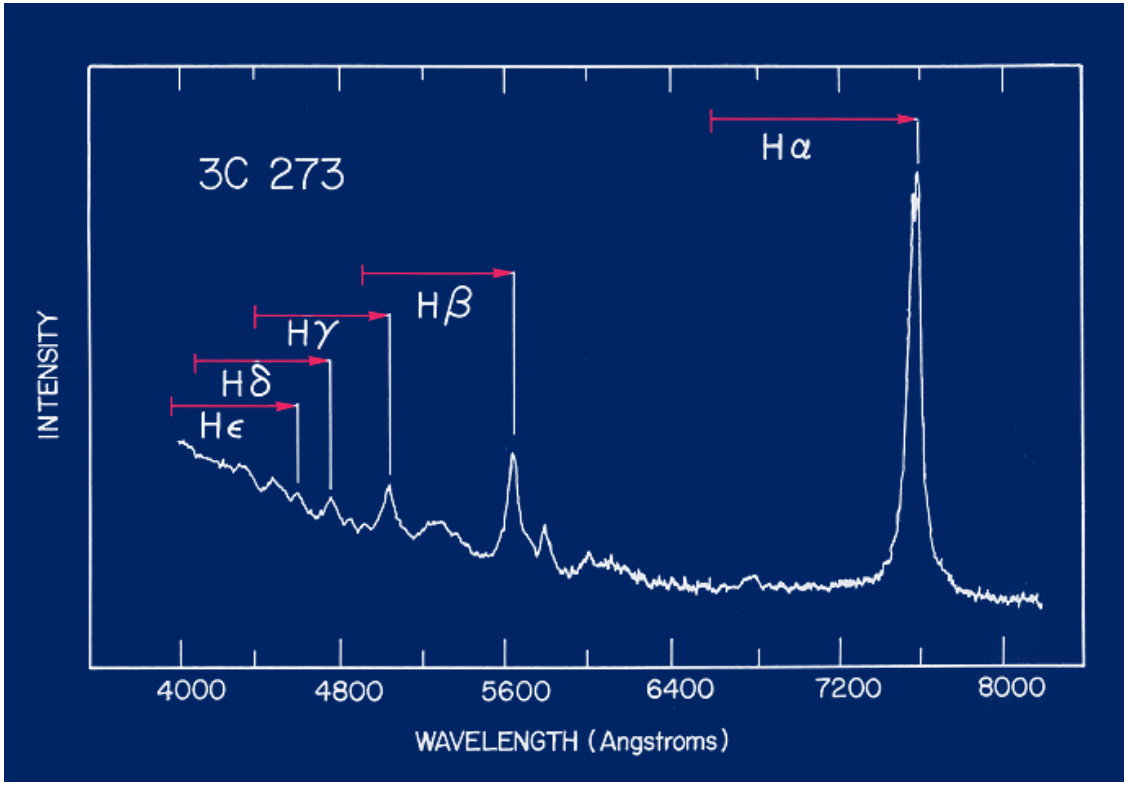
- Some of the brightest radio sources were not identifiable (3C273 for example)
- Quasi-Stellar Radio Source = quasar
- Active Galactic Nuclei =AGN
- Of the 200,000 quasars only 10% are radio loud

Parkes Radio Telescope

- A lunar occultation of 3C273
- In 1962
- Resolved two sources
- Gave precise position
- Movie of Apollo 11 moon landing “The Dish”

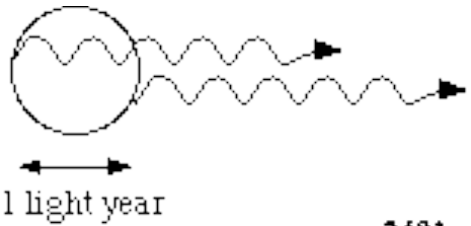
3C273 Spectrum

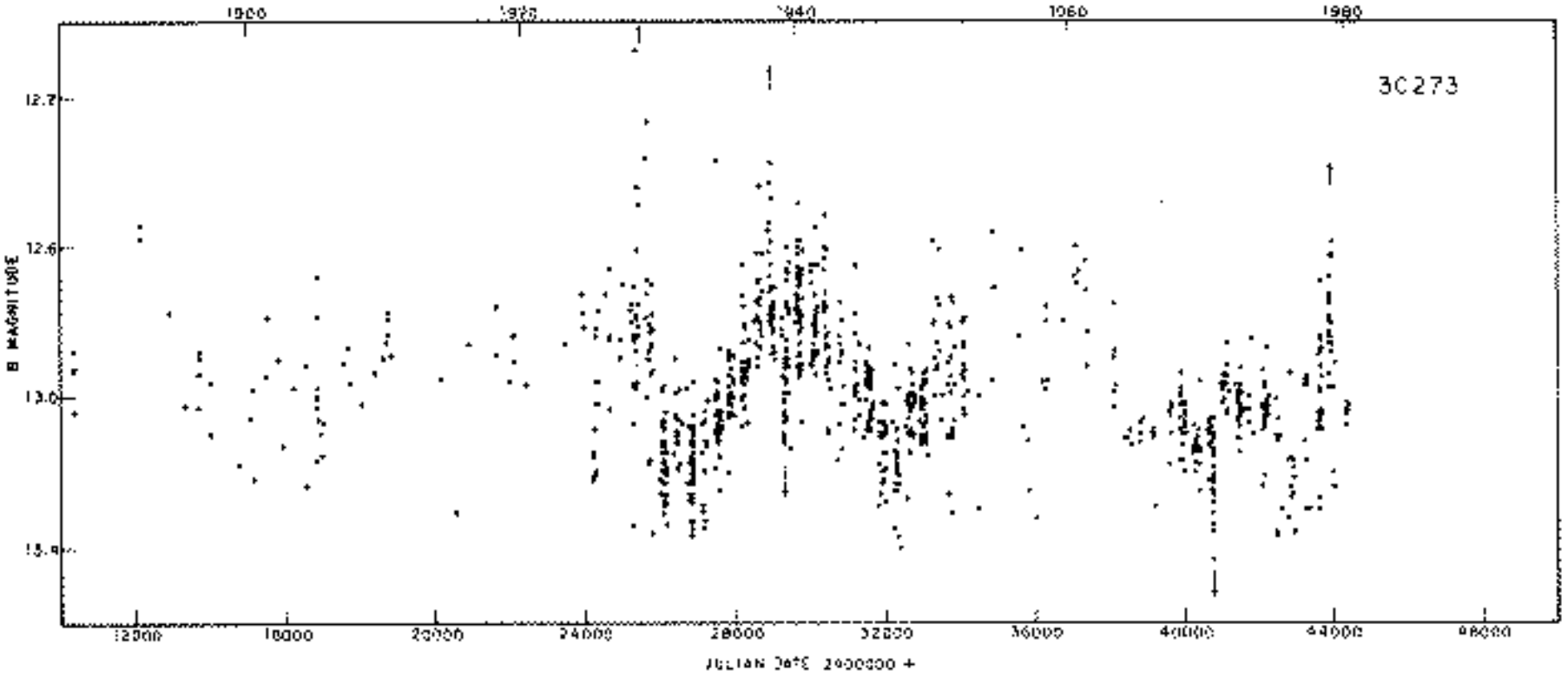
- Spectra show emission lines so not optically opaque
- Redshift z=0.16 = v/c so v = 48,000km/sec
- More than the escape velocity of galaxy
- Hubble constant of 72km/sec/Mpc = distance of 2 billion light years
- Wide lines indicate fast internal motions



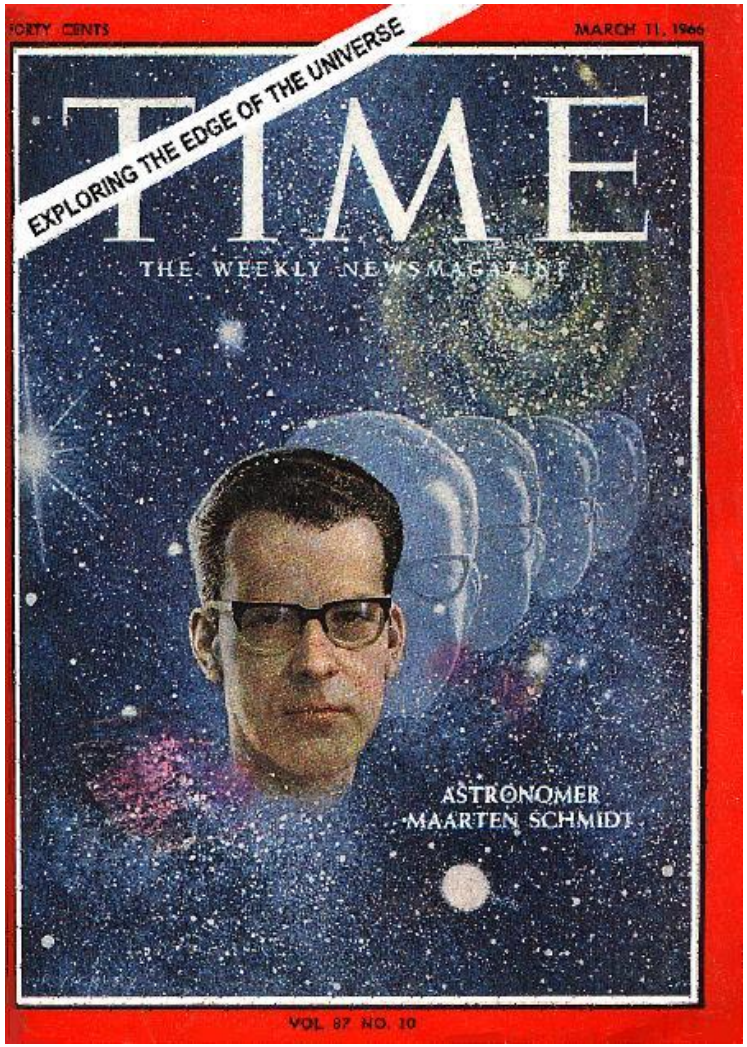
Brightness Variations of 3C273

- Harvard Patrol plates from <1900-1980
- Shows brightness can double in a year
- Size must be less than light year





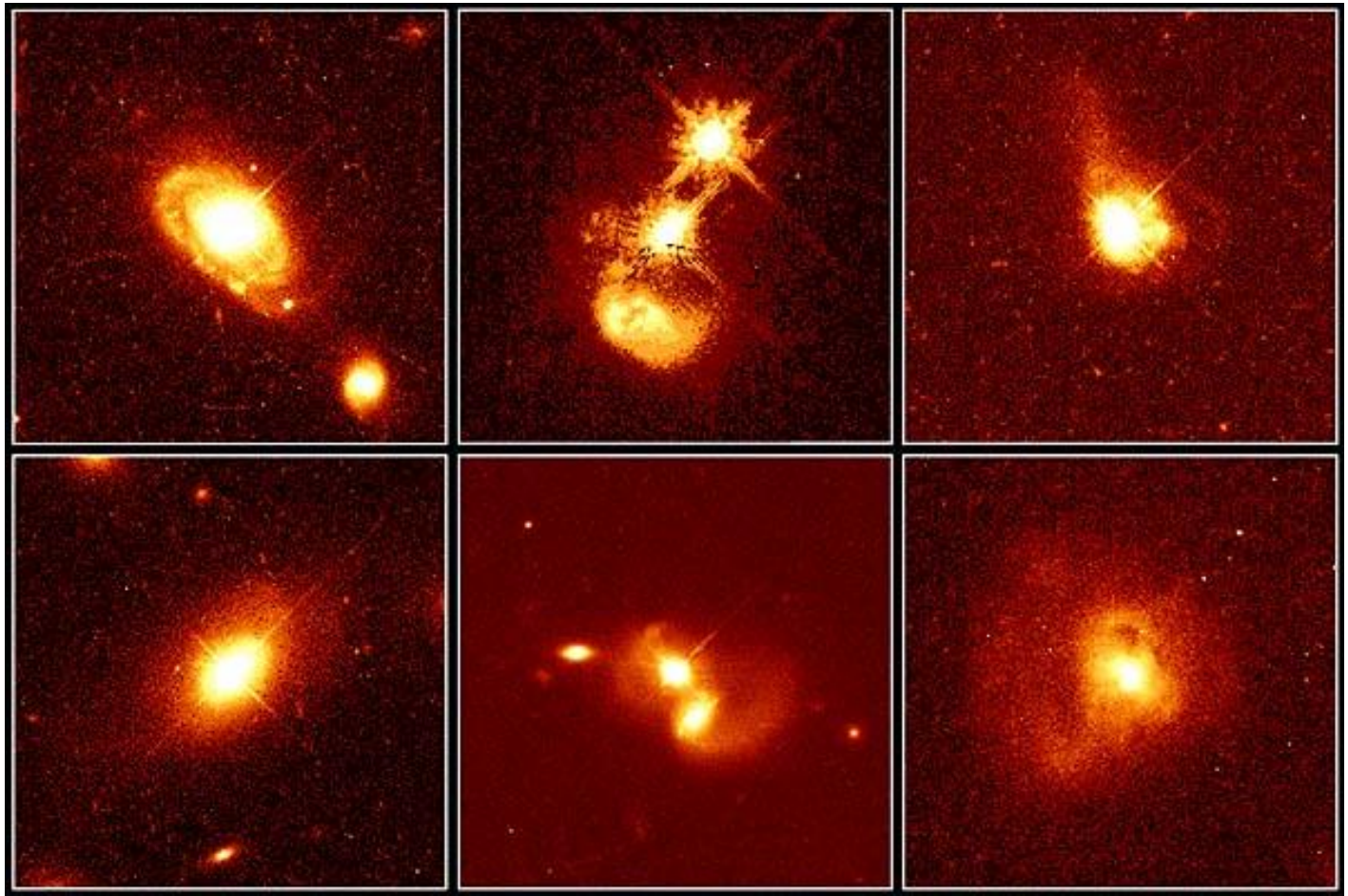
Maarten Schmidt 1963



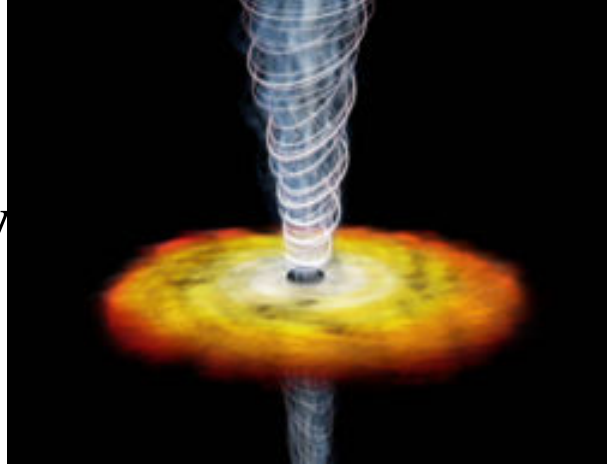
- Star with m_v=12 & 2Billion lys
- Intrinsic Brightness M_v = -26
- =100 Milky Ways
- Width of lines ~10,000km/sec
- Brightness varies in a year
- Velocity & size gives mass of Billions of Solar Masses

HST Quasar Portrait Gallery

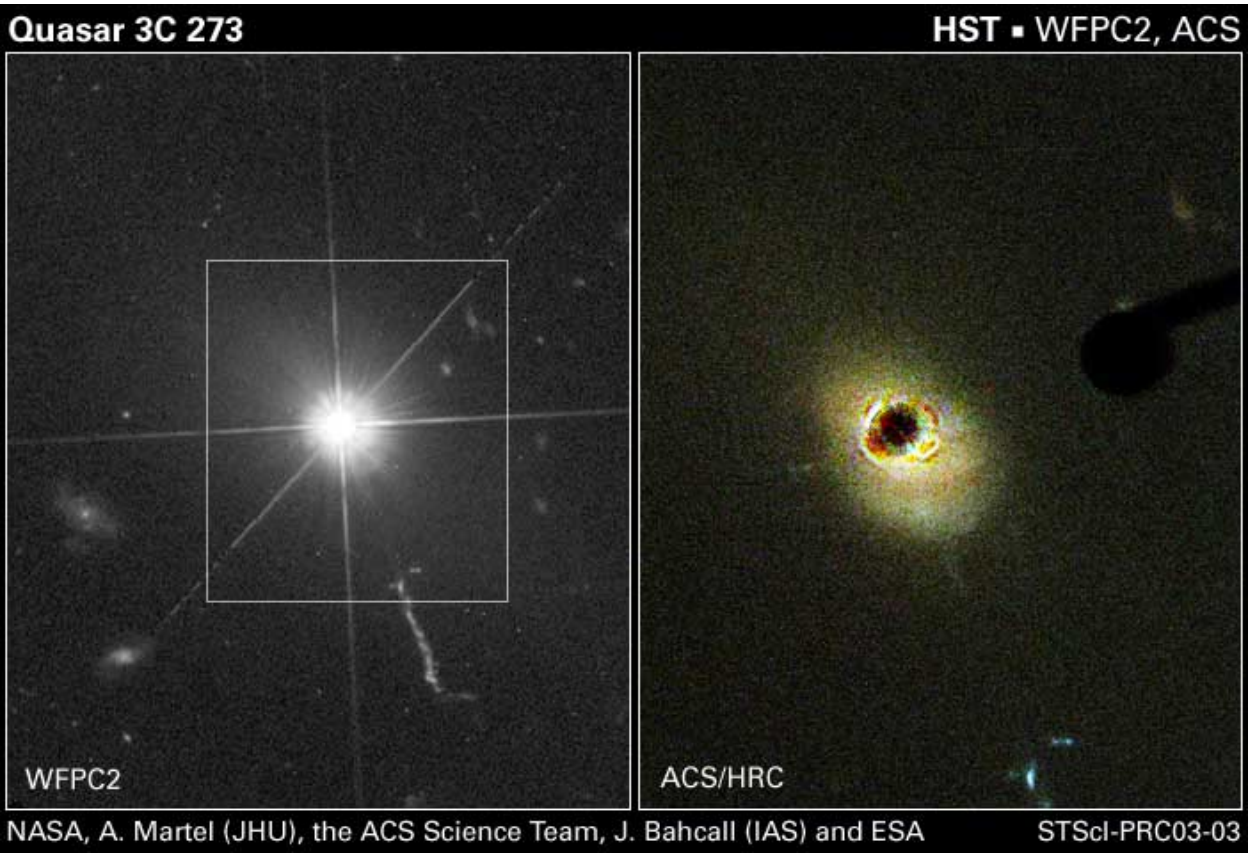
- Other galaxies nearby with same redshift=distance as quasar
- Quasar host galaxies appear distorted/merging

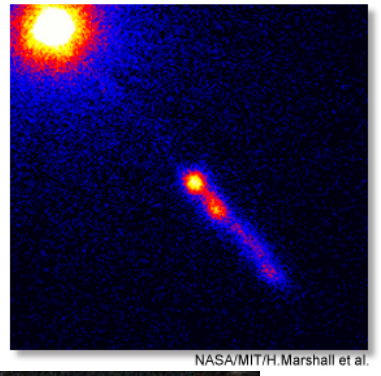


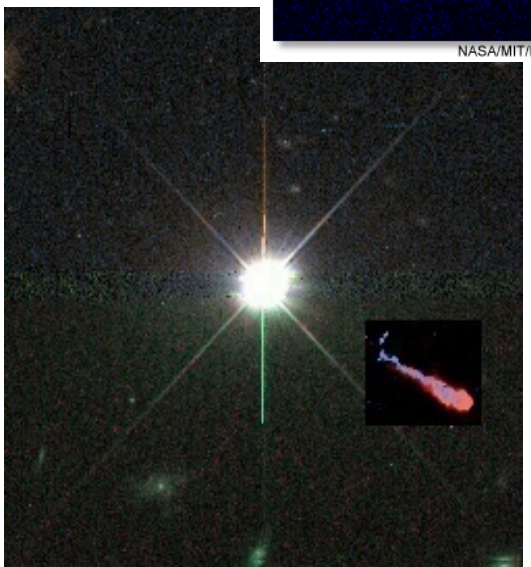
3C273's Jet



- Jet can be seen in visible, radio and x-ray
- Synchrotron emission from relativistic electrons
- HST/ACS is coronagraph image; shows galaxy

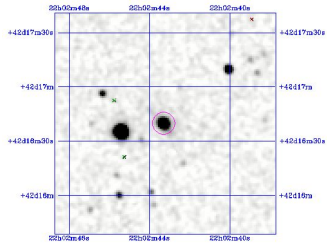


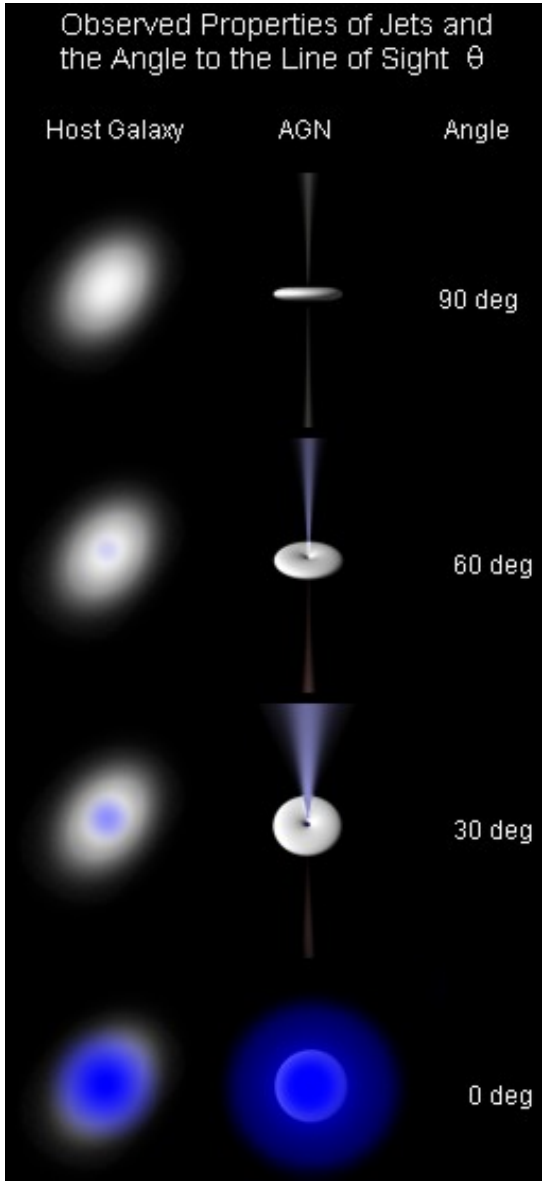


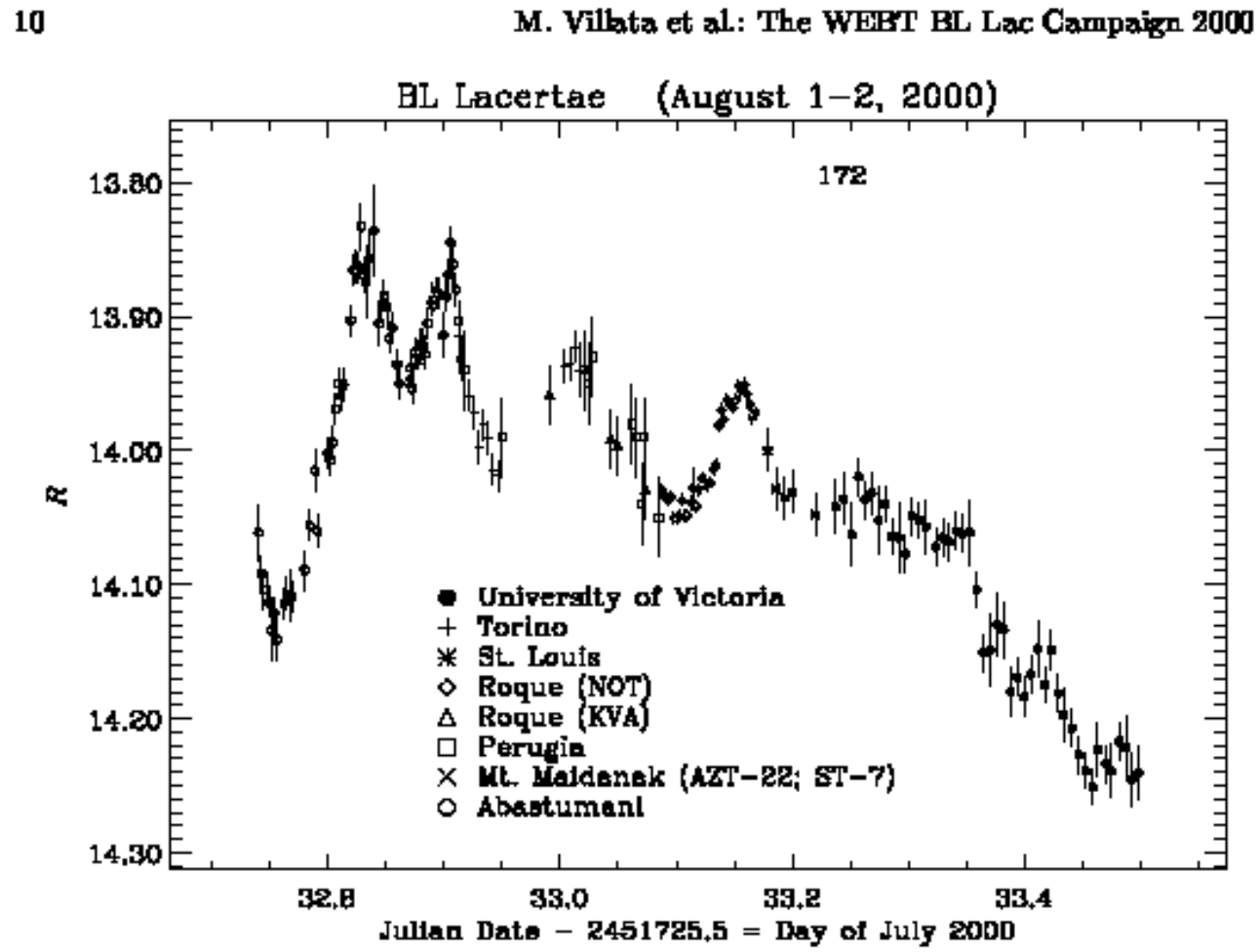


BL Lac = Blazars

- No emission or absorption lines in spectra
- Rapid variations in brightness
- BL Lac is where we are looking down the jet







Hubble Deep Field Fly Thru

- Look back 10 billion years

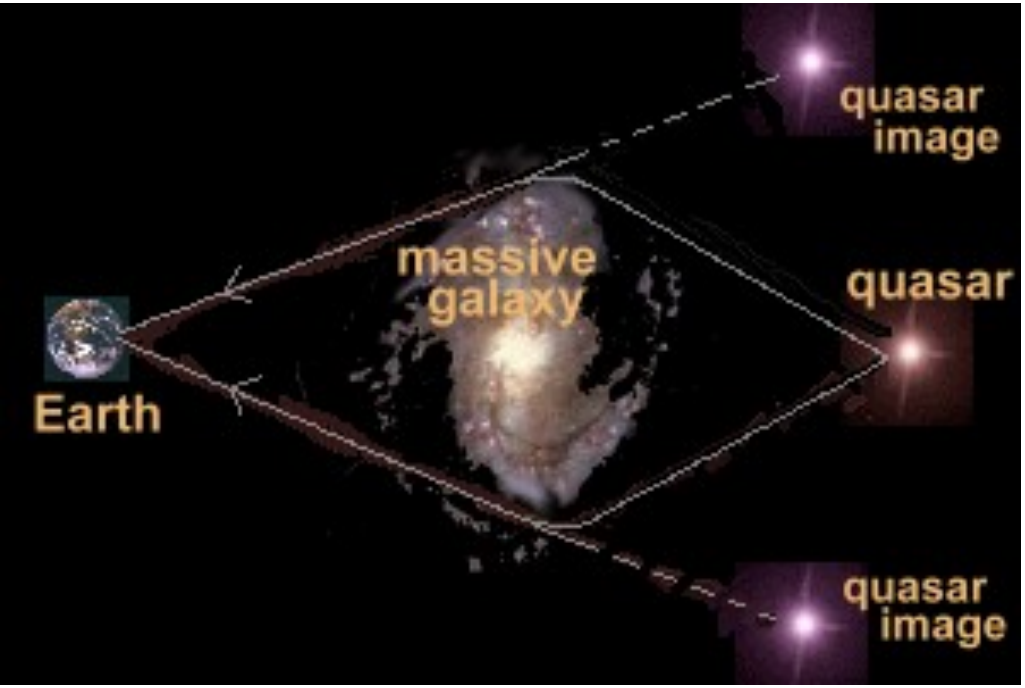
Characteristics of an AGN
Active Galaxy Nuclei / Quasar

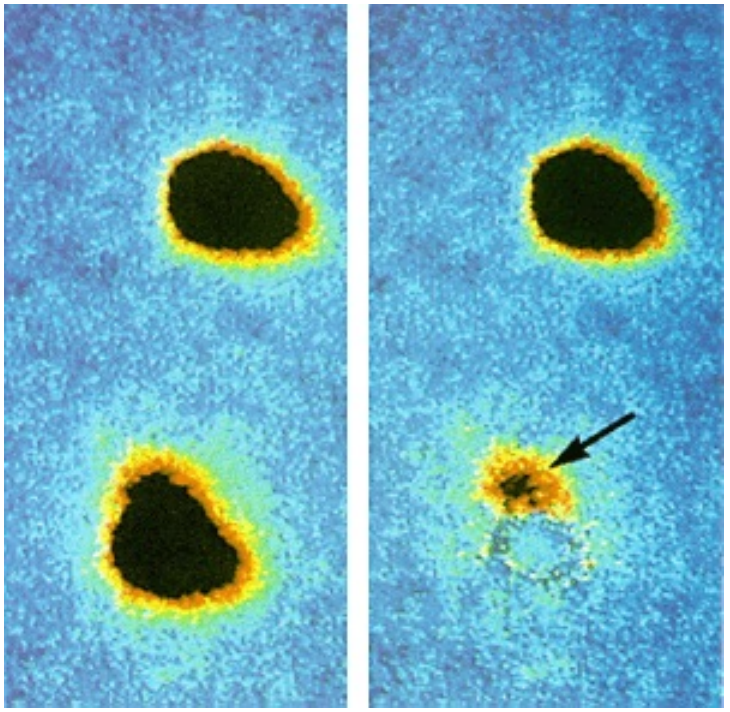
1. Brighter than normal galaxy
2. Radio source; nonstellar
3. Highly variable
4. May have jets
5. Rapid internal motion
6. Interacting with other galaxies

- Large redshift = large distance

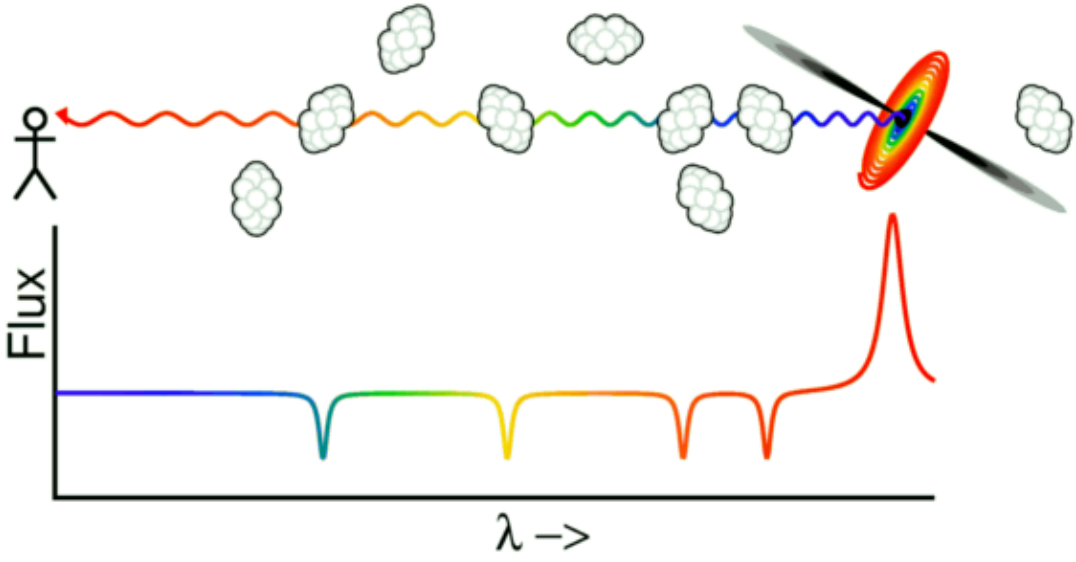
Very Distant: 1.Gravitational Lensing

- Two quasar images form from foreground galaxy's gravity
- Subtract top image from the bottom
- Reveals the foreground elliptical galaxy

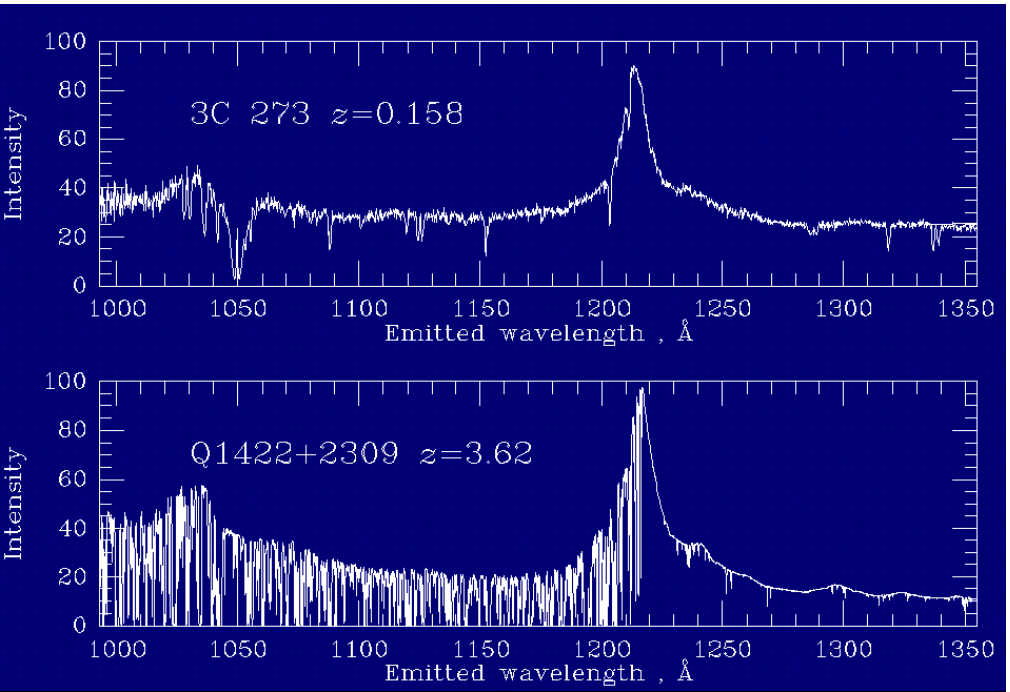


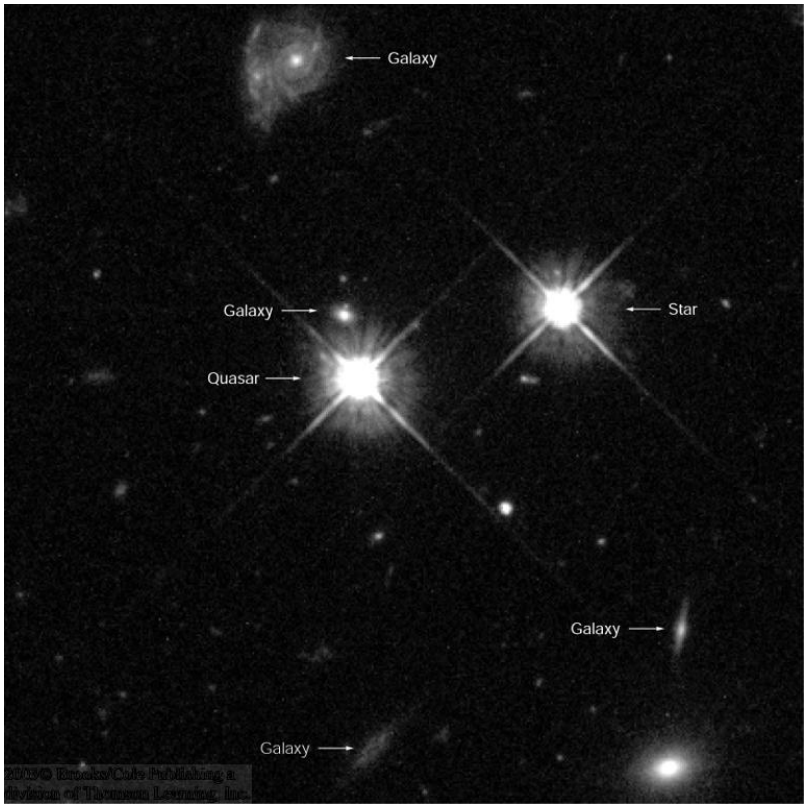


Very Distant: 2.Absorption Lines in Quasar Spectra

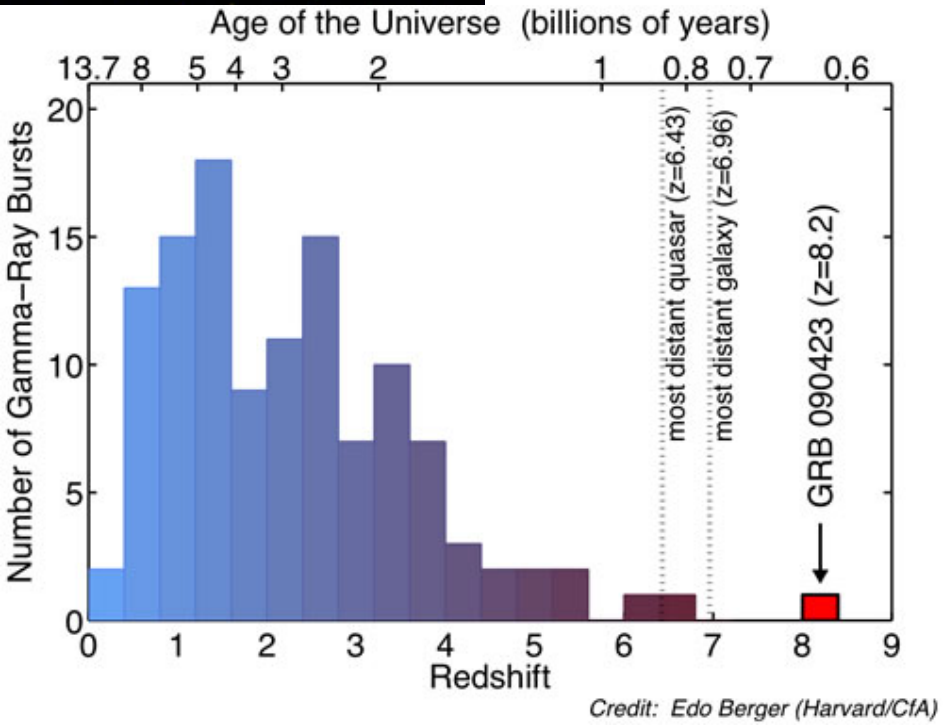


- Galaxies must be closer than the quasar if they
- Make absorption lines with smaller redshift





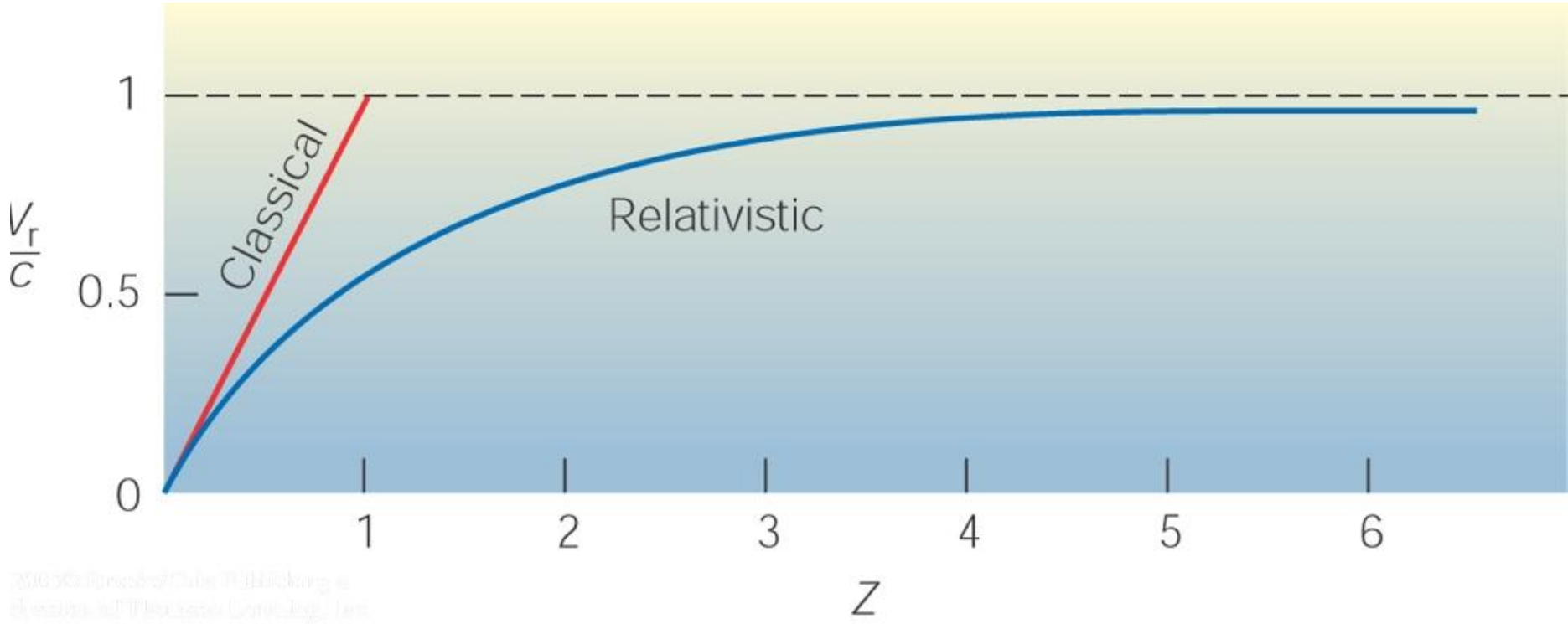
Very Distant: Relativistic Redshifts



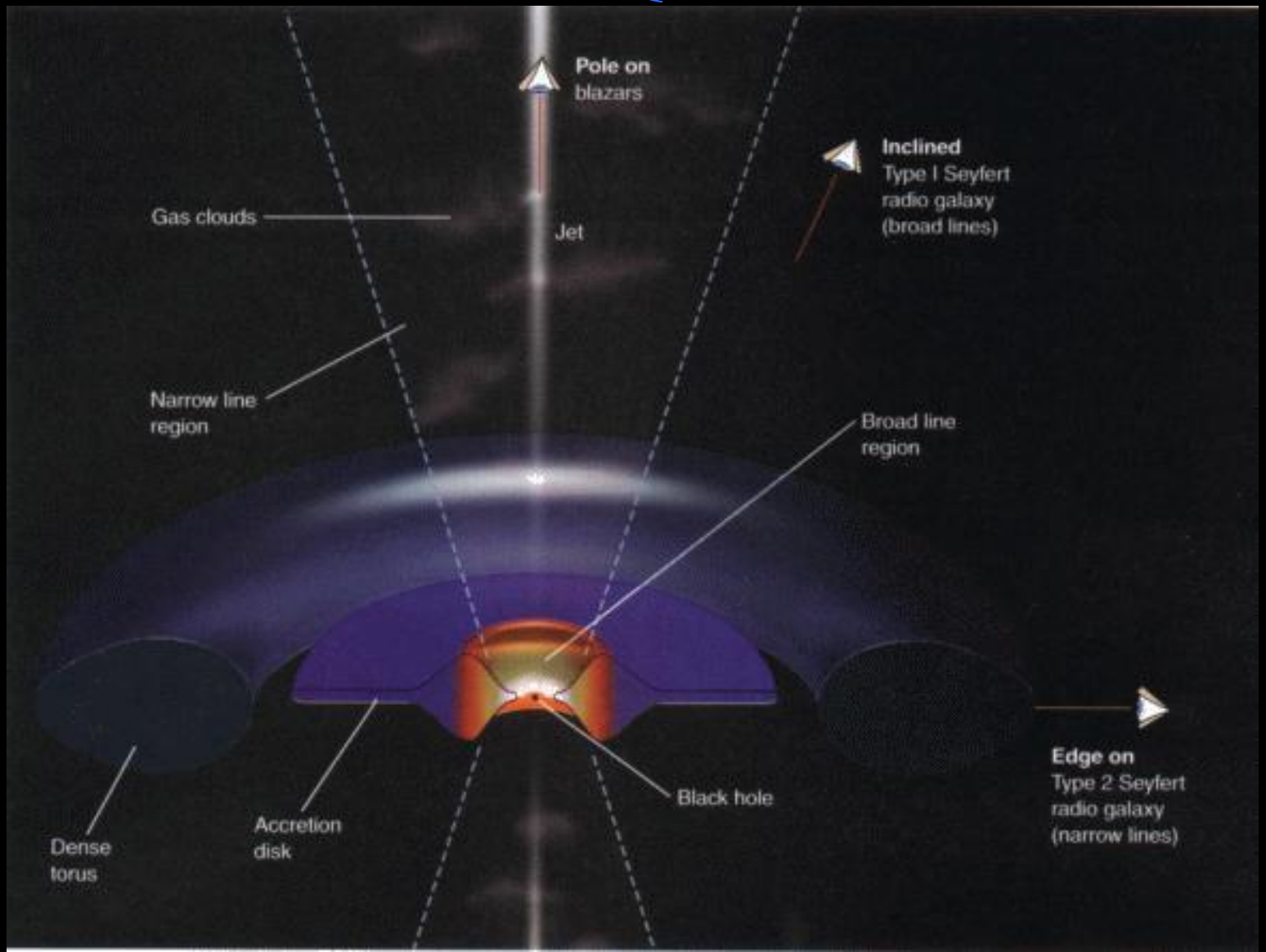
- Most distant=J1120+0641
- Z=velocity/c=7.085
- Red dot beside white star
- 2billion solar mass black hole
- Grew in a few hundred million years after Big Bang????

‘Relativistic’ Redshift $z=\Delta\lambda/\lambda=v/c$

- $\frac{V}{C} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$ V=recession velocity
- c=speed of light
- As **cosmological redshift** increases lookback time increases
- Distance between galaxies=Radius of universe is ~1/(1+z)
- Age as fraction of age of universe is ~1/(1+z)

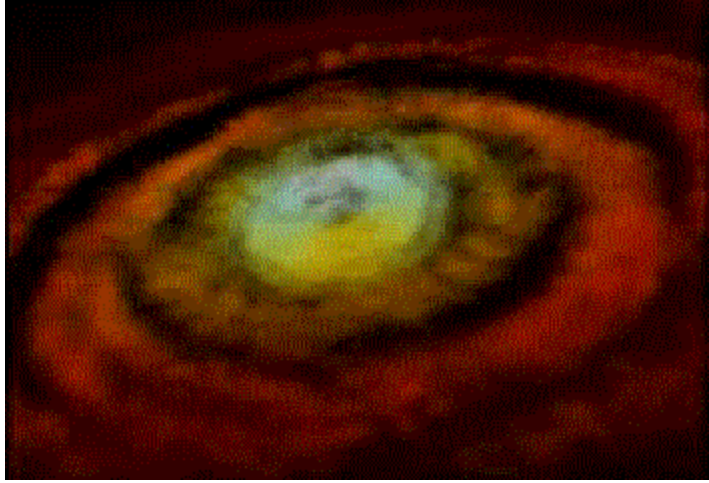


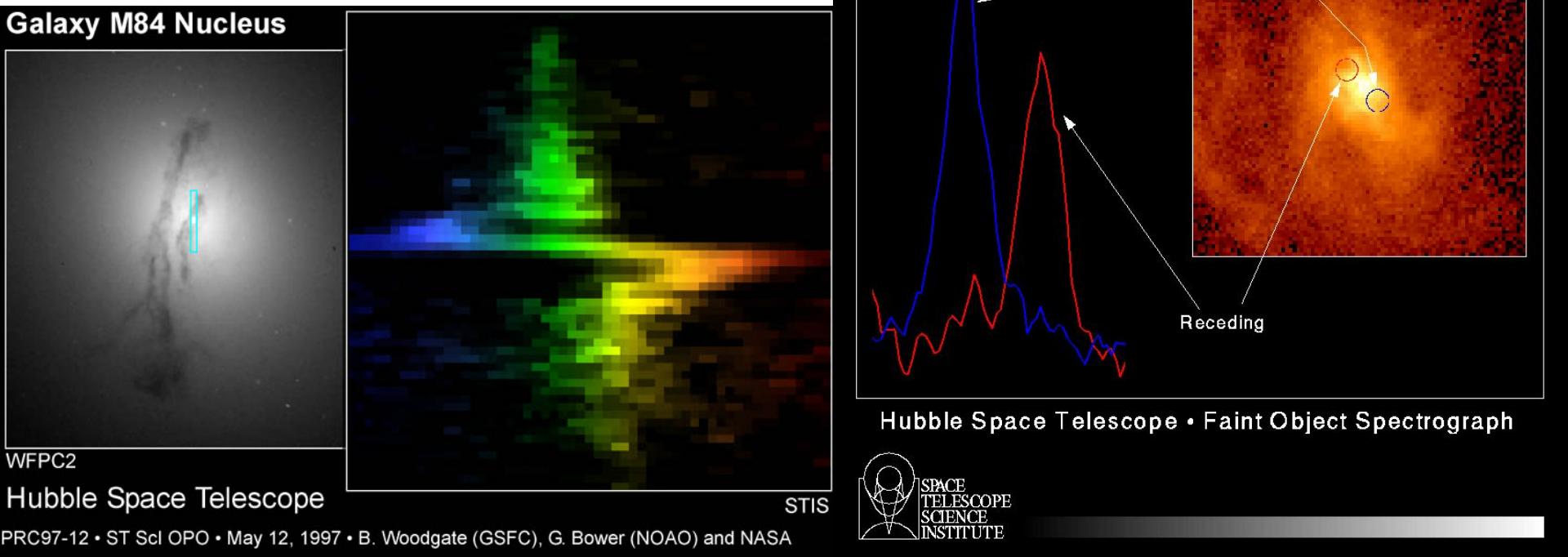
Central Engine of an Active Galaxy / Unified Quasar Model



Supermassive Black Holes

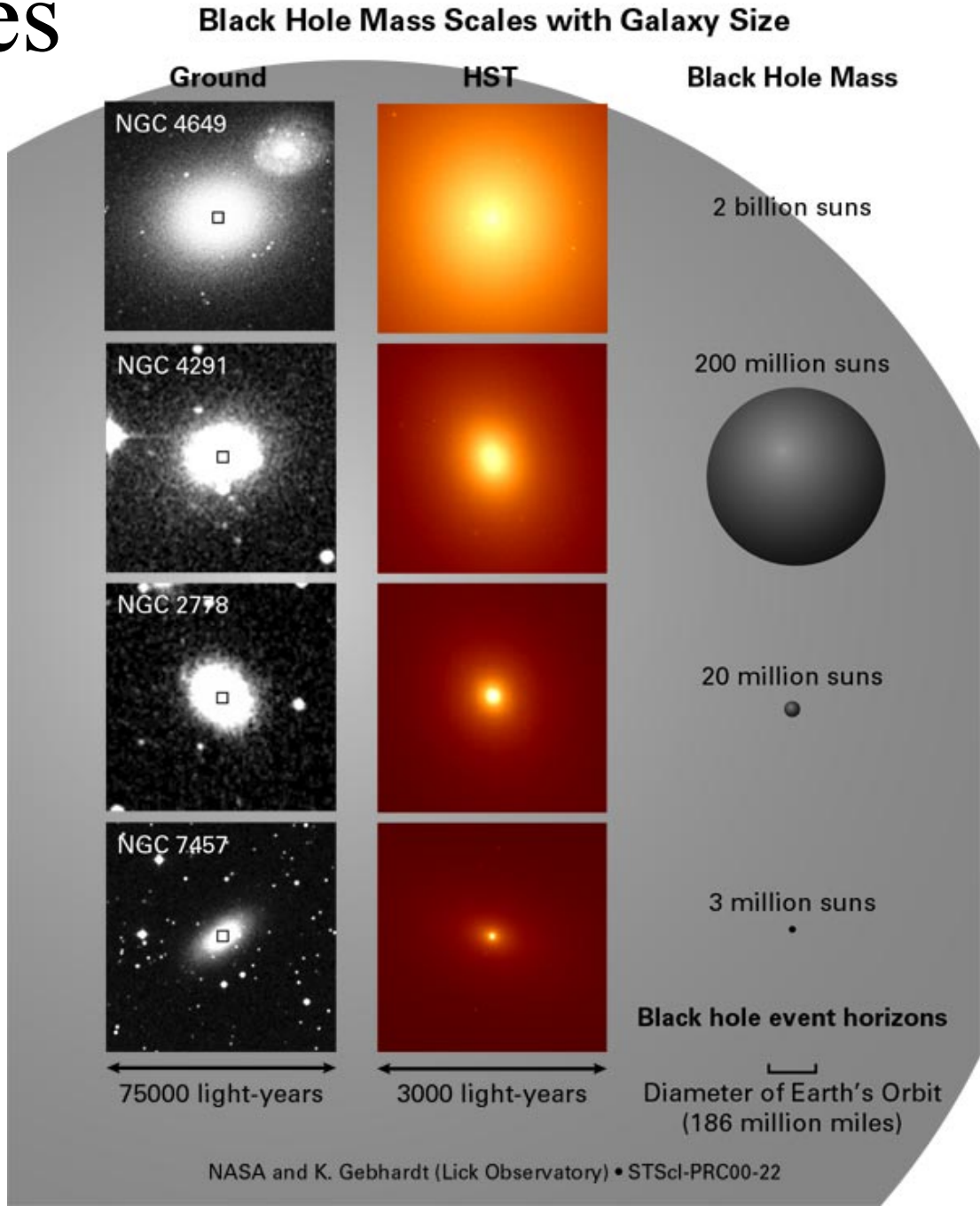
- Large velocities of gas in nuclei of galaxies give mass of supermassive black holes





Black Hole Sizes

- The size of the black hole sets the size of the accretion disk and the time scale of variations

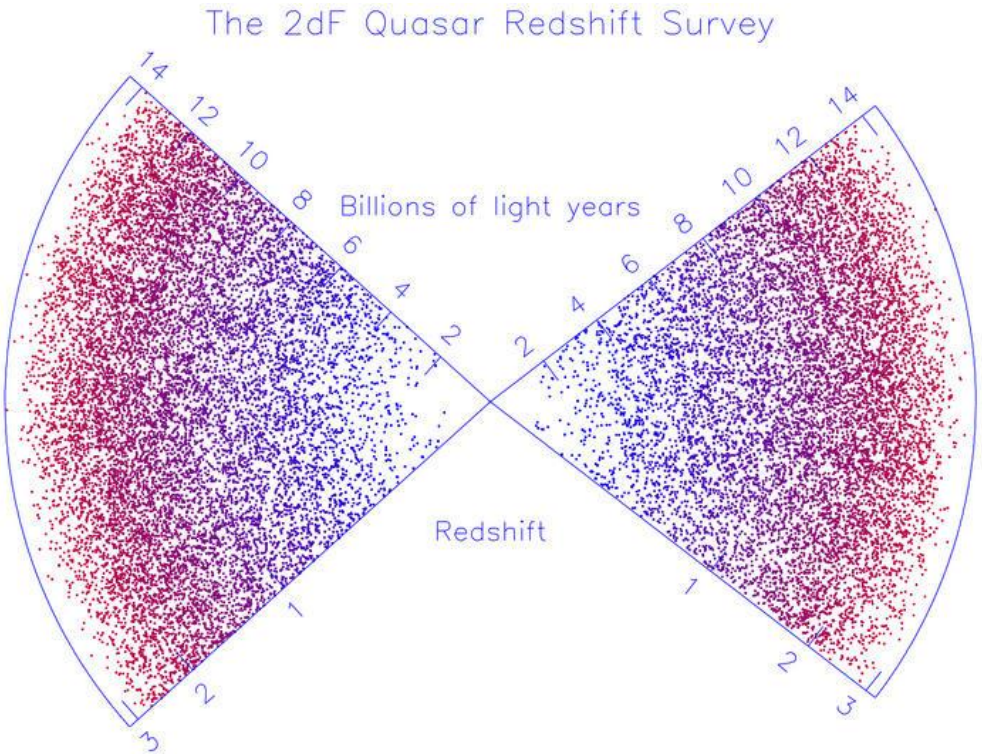


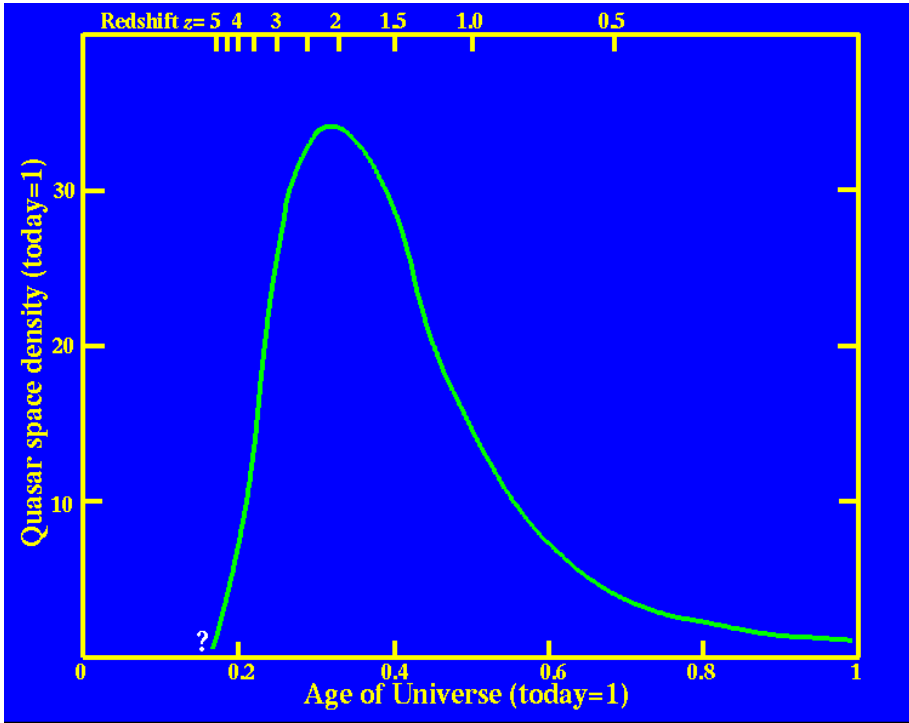
Energy Production = Growth

- $M_v+E=mc^2$ Quasar needs to accrete ~ one solar mass/year
- Star gets too close to black hole and is tidally disrupted
- Millions of years to make million solar mass black hole
- Billions of years to make a billion solar mass black hole?

Space Density of Quasars

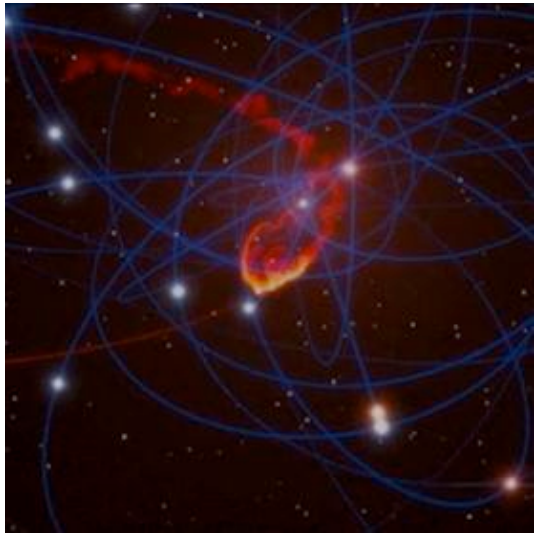
- 2dF survey found thousands of quasars
- Plotted according to distance from Earth shows most at z=2
- Universe 1/1+z=1/3 the present size; age is 1/3 = 4 billion years
- Galaxies closer together, more mergers, more gas falling into nucleus

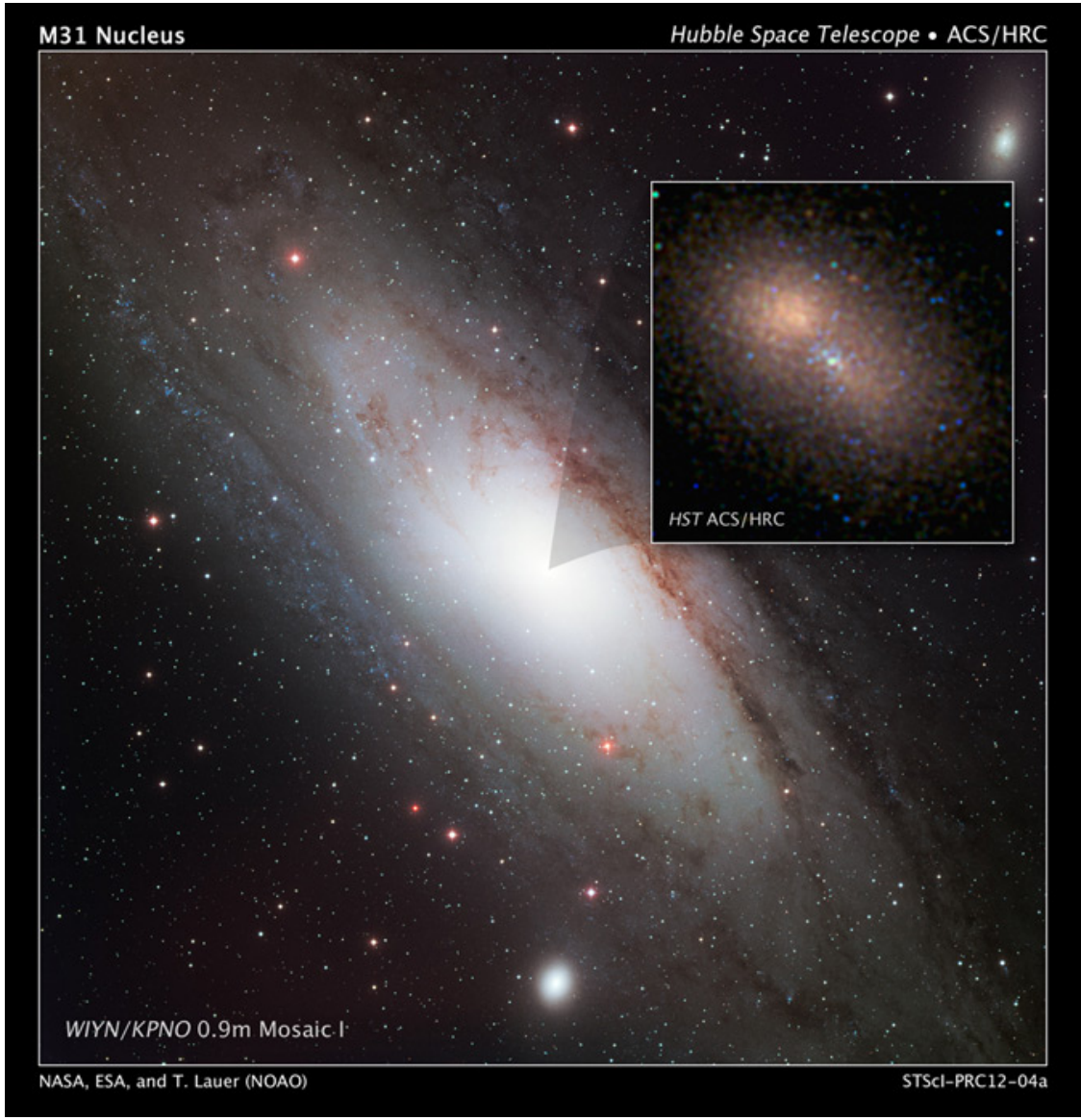




Where are the Quasars Now?

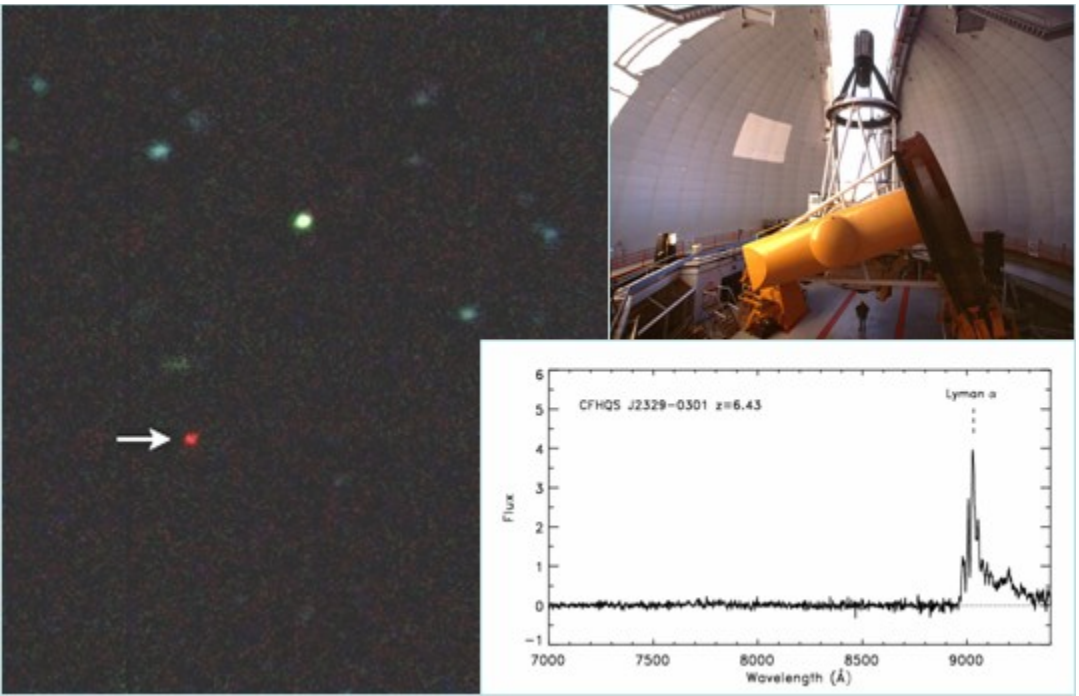
- Supermassive black holes do not disappear
- Just quietly waiting for a passing star or cloud or galaxy to reactivate them
- Cloud heading toward SGR A* Is that bad?

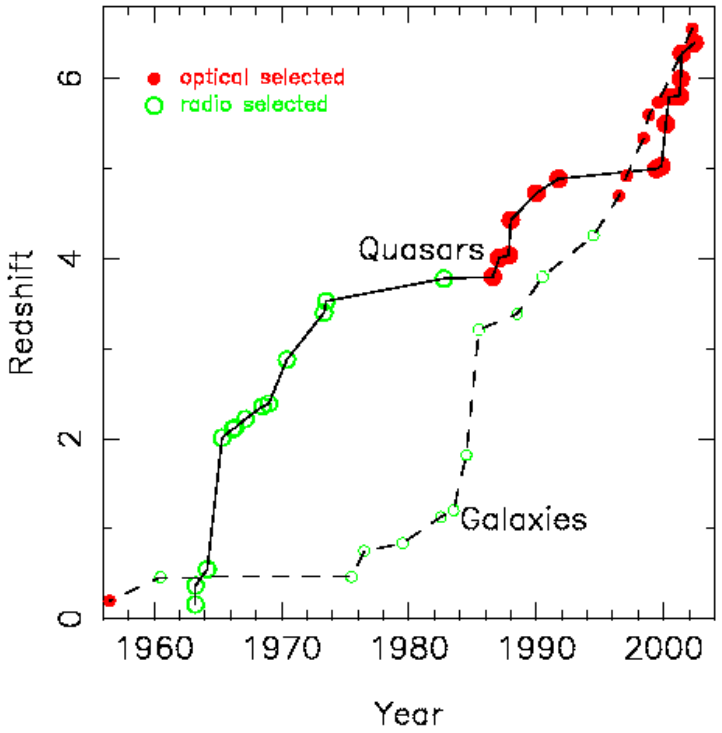




2nd most Distant Quasar z=6.43

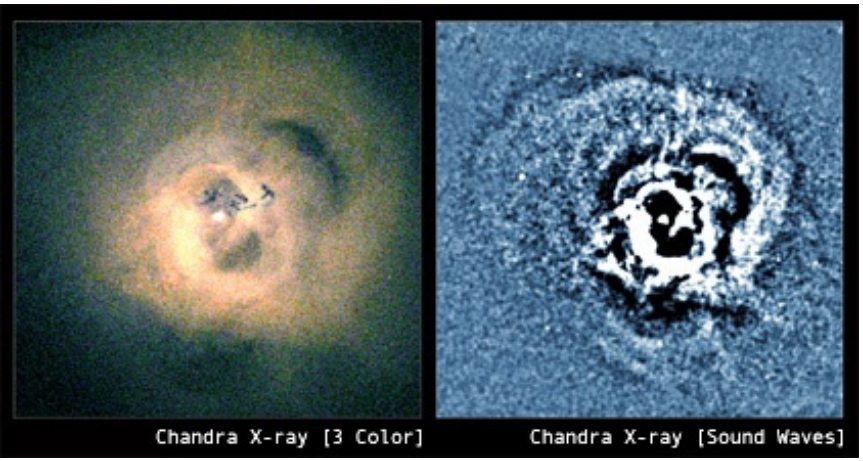
- Announced 9Jun07 by CFHT – Chris Willott ex-DAO
- Formed 800 Million years after Big Bang so supermassive black holes had formed by that time

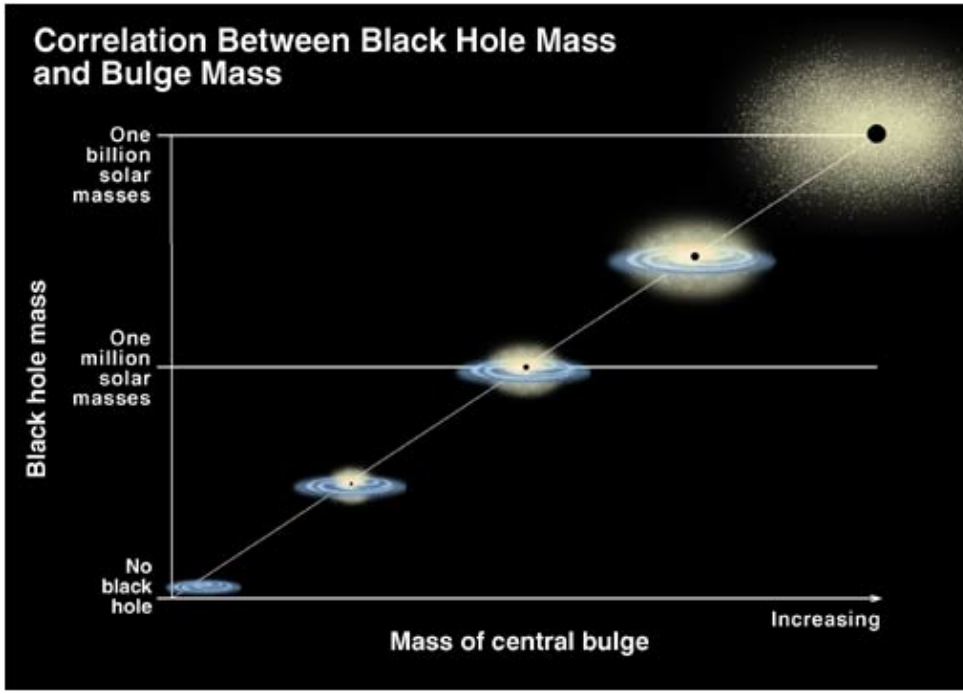




Black Hole-Bulge Relation=
Quasar Feedback

- The X-ray gas should cool and fall into galaxy forming more stars and making black hole bigger, but
- The supermassive black hole in the middle of the Perseus galaxy cluster emits jets & radio lobes heat X-ray gas
- This limits the size of the galaxy/bulge



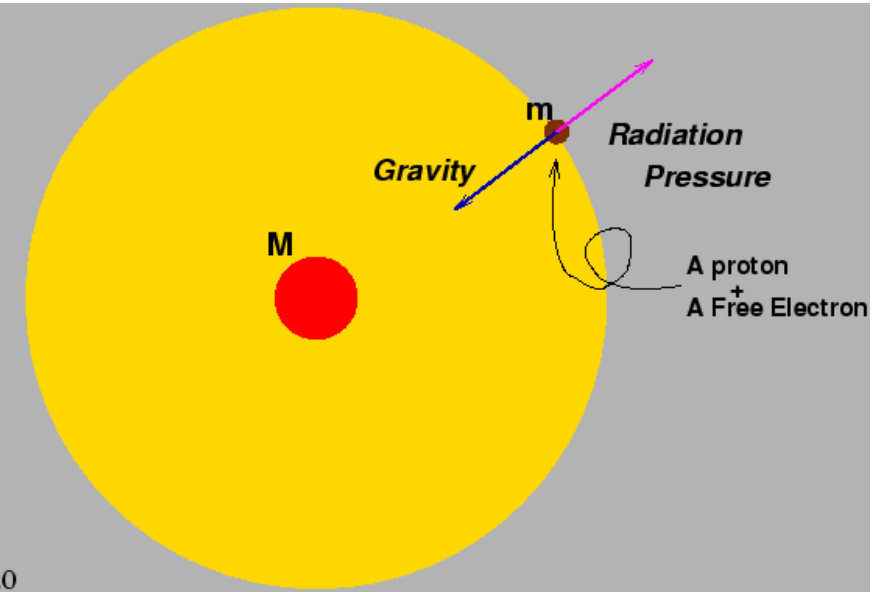


Size of Object Limits Variations

- If band starts with drum beat from left
- It takes half a second for sound to travel to far end of field
- And they will be half a second behind
- You can tell if band is spread across field or in small group

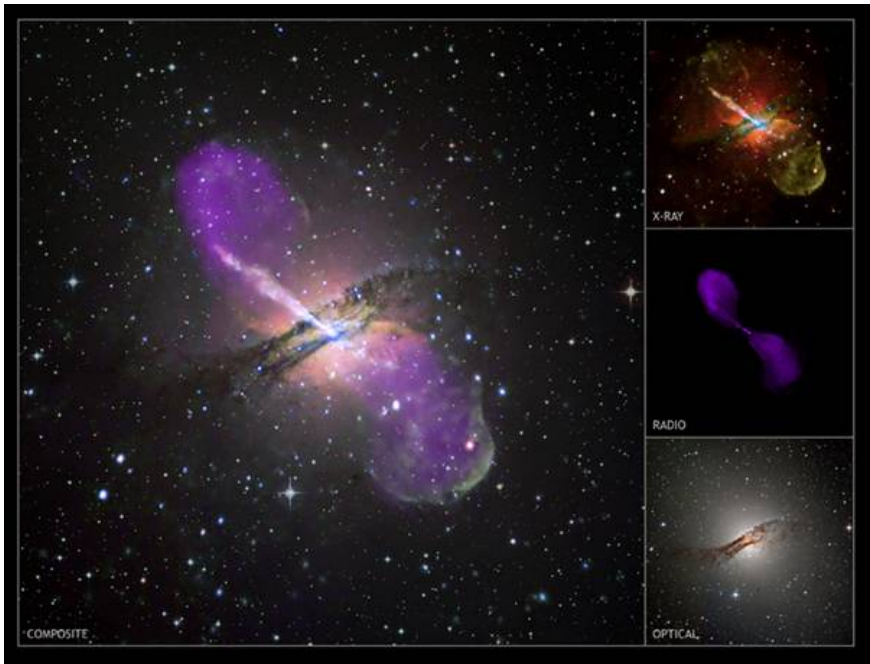
Eddington Limit

- Radiation pressure equals gravity
- Star or accretion disk produces so much light it blows away any gas falling in



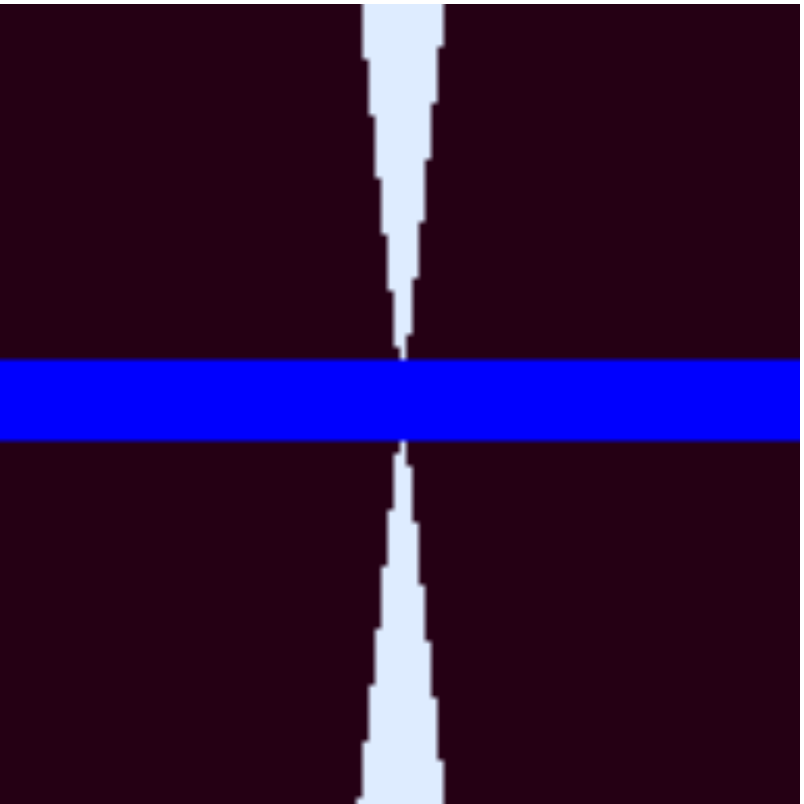
Head-Tail Source

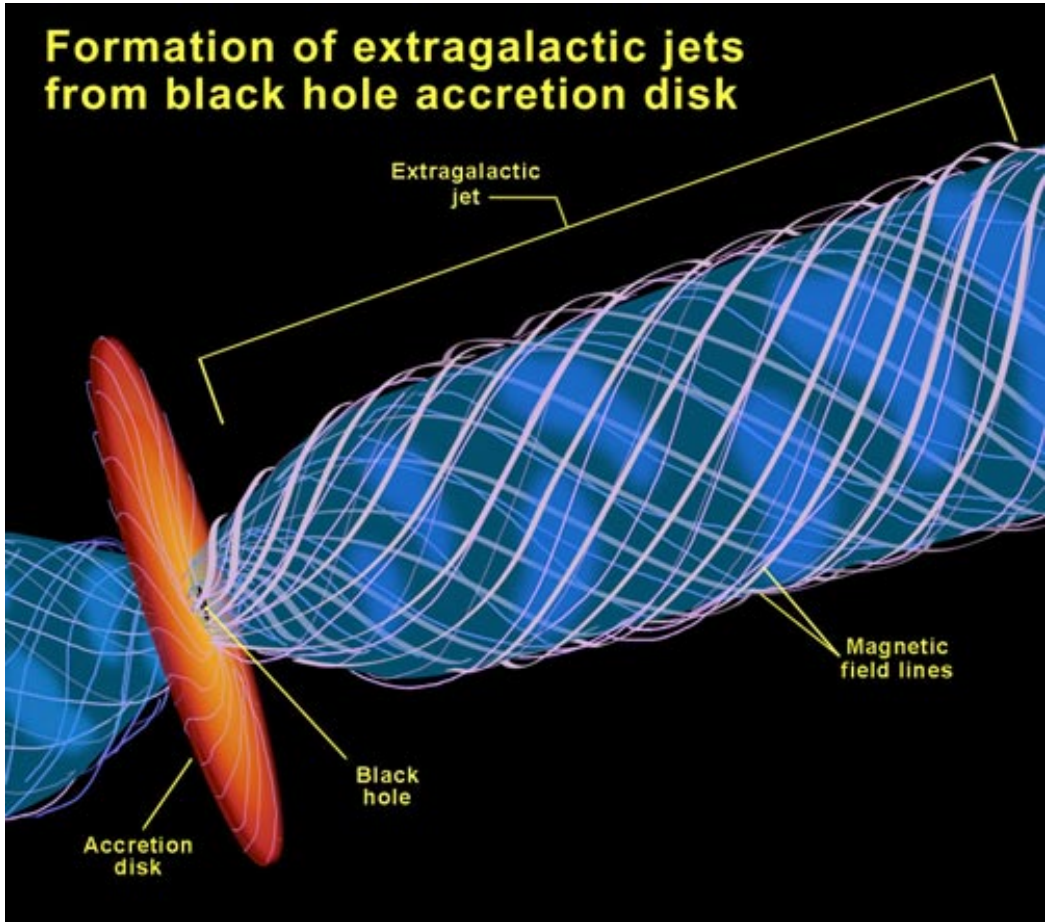
- Jets are swept back
- Synchrotron emission from relativistic electrons
- Corkscrews from precession of jets/Black Hole



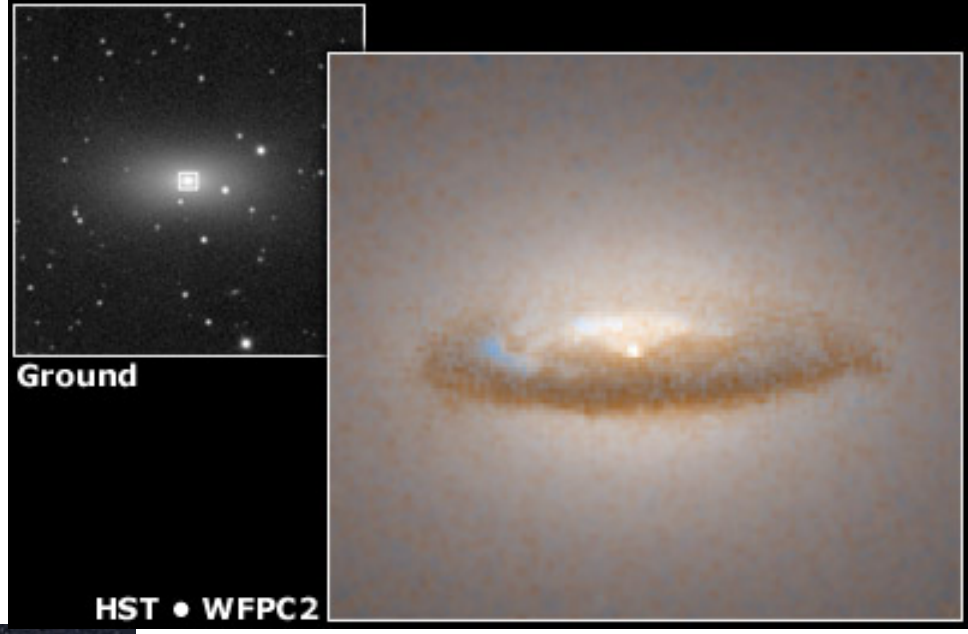
Accretion Disk and Jet

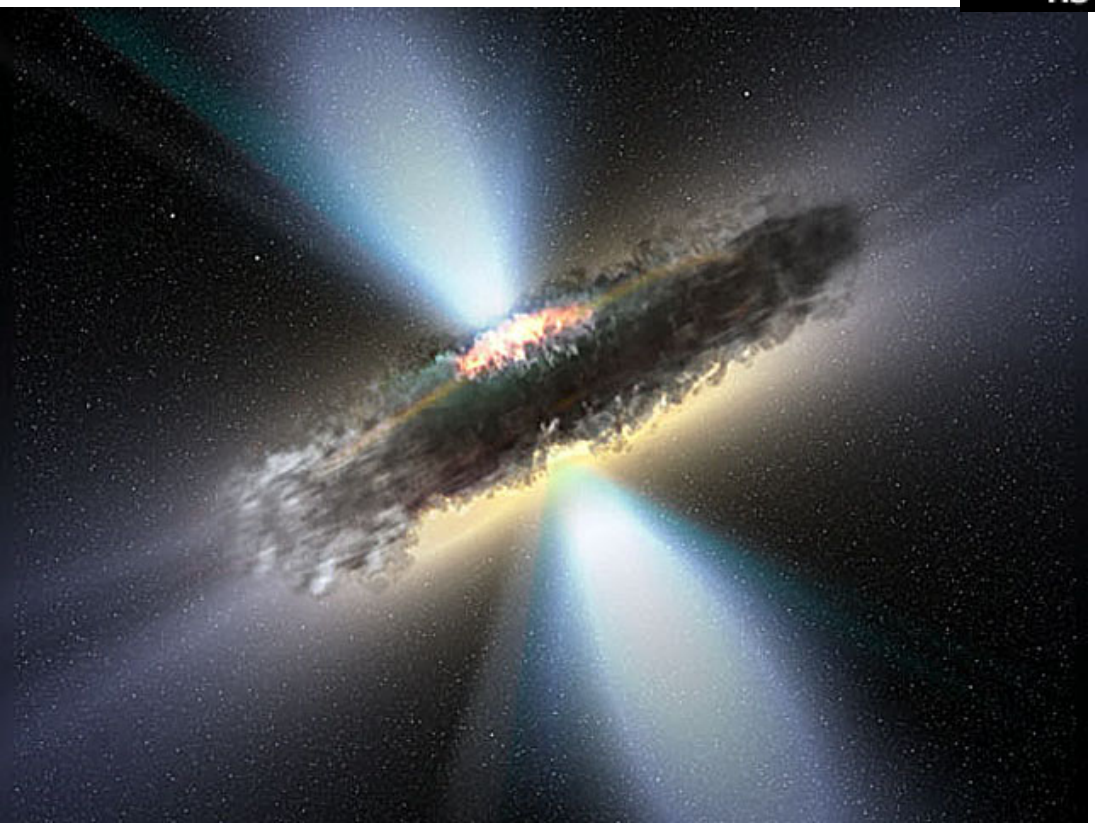
- A few light days across – Black hole ~1AU radius
- Produces X-ray, UV, and visible light from accretion disk
- Jet of relativistic particles





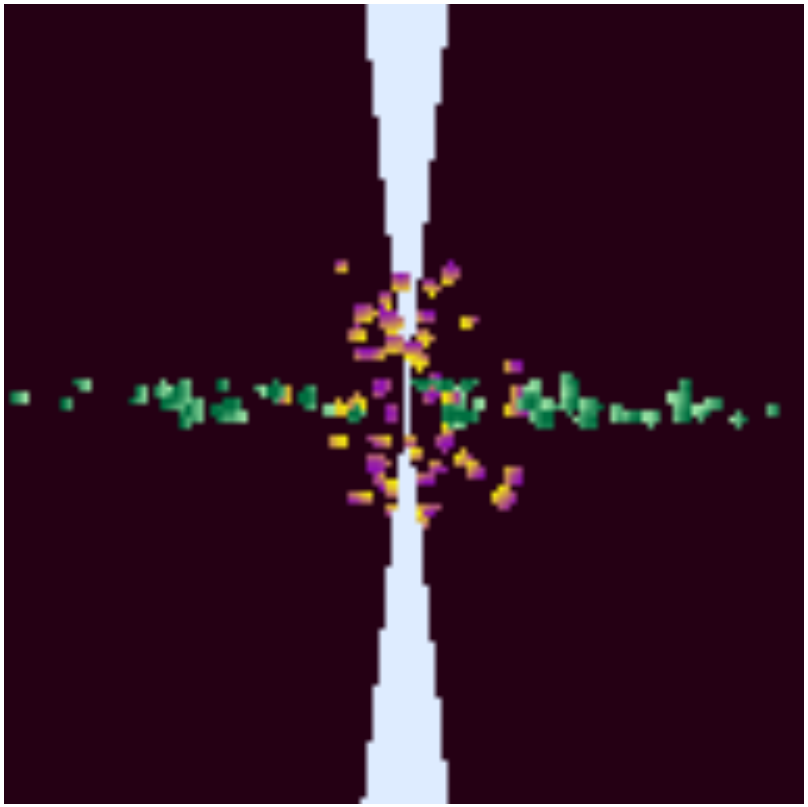
Molecular Torus





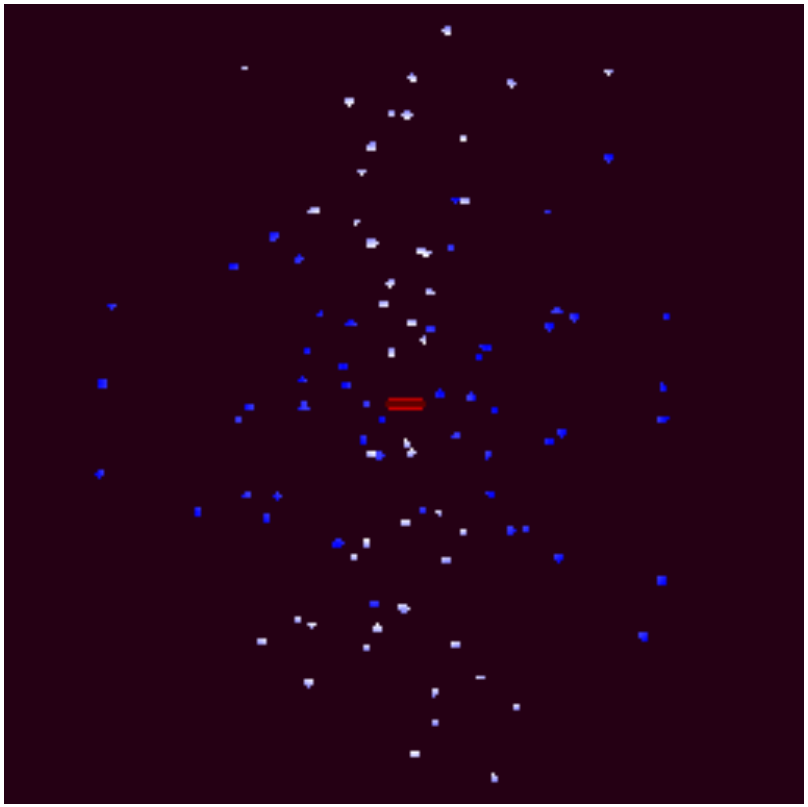
- 200 light years
- Thick opaque dust and molecular gas
- Rotates at 150 km/sec
- Gives mass of 300 million solar masses

Broad Line Region



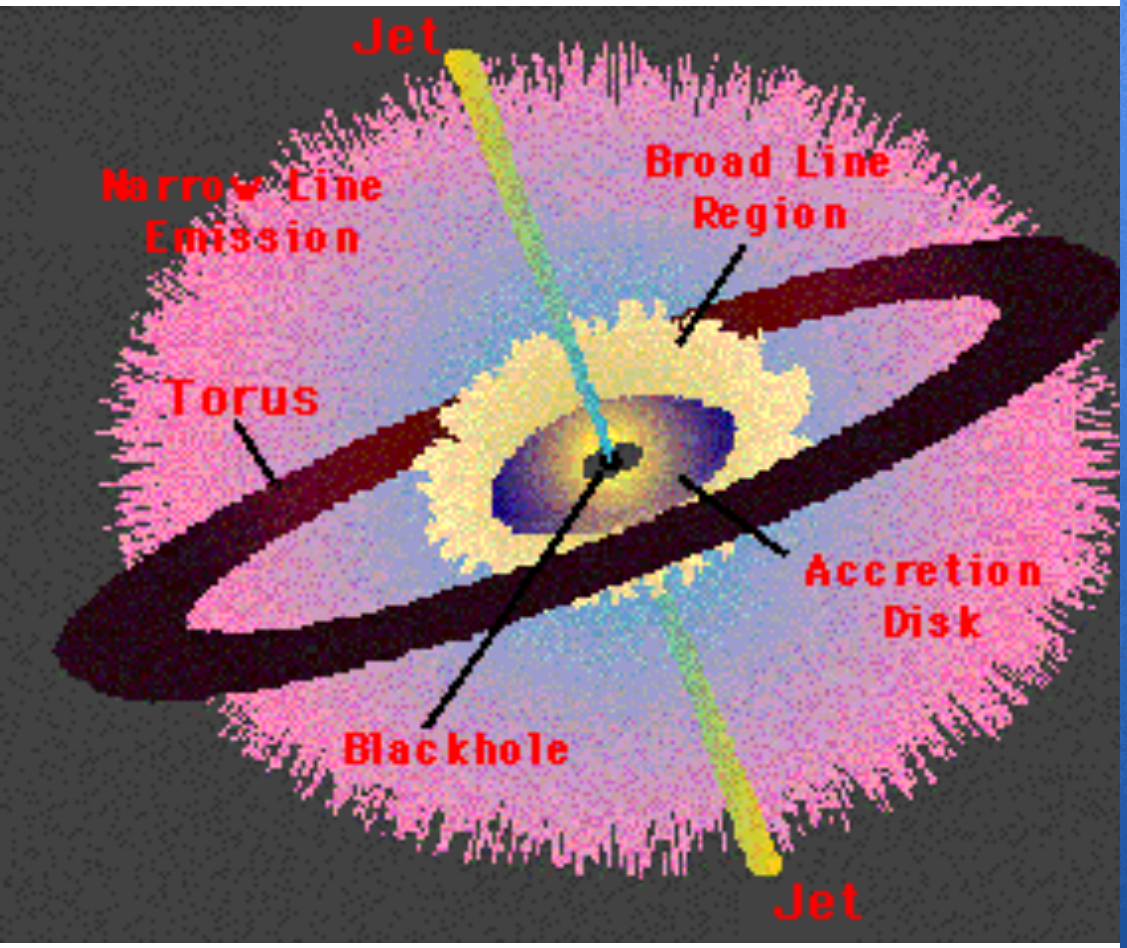
- 100 light days
- HII clouds close to black hole
- Orbiting rapidly

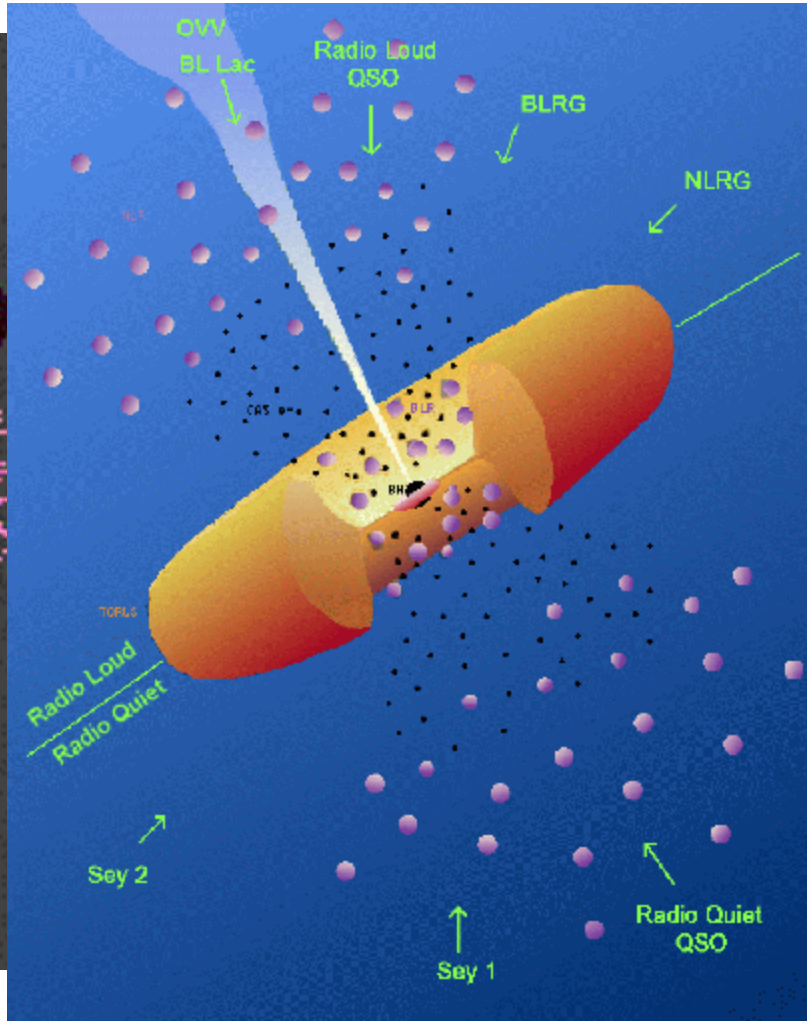
Narrow Line Region

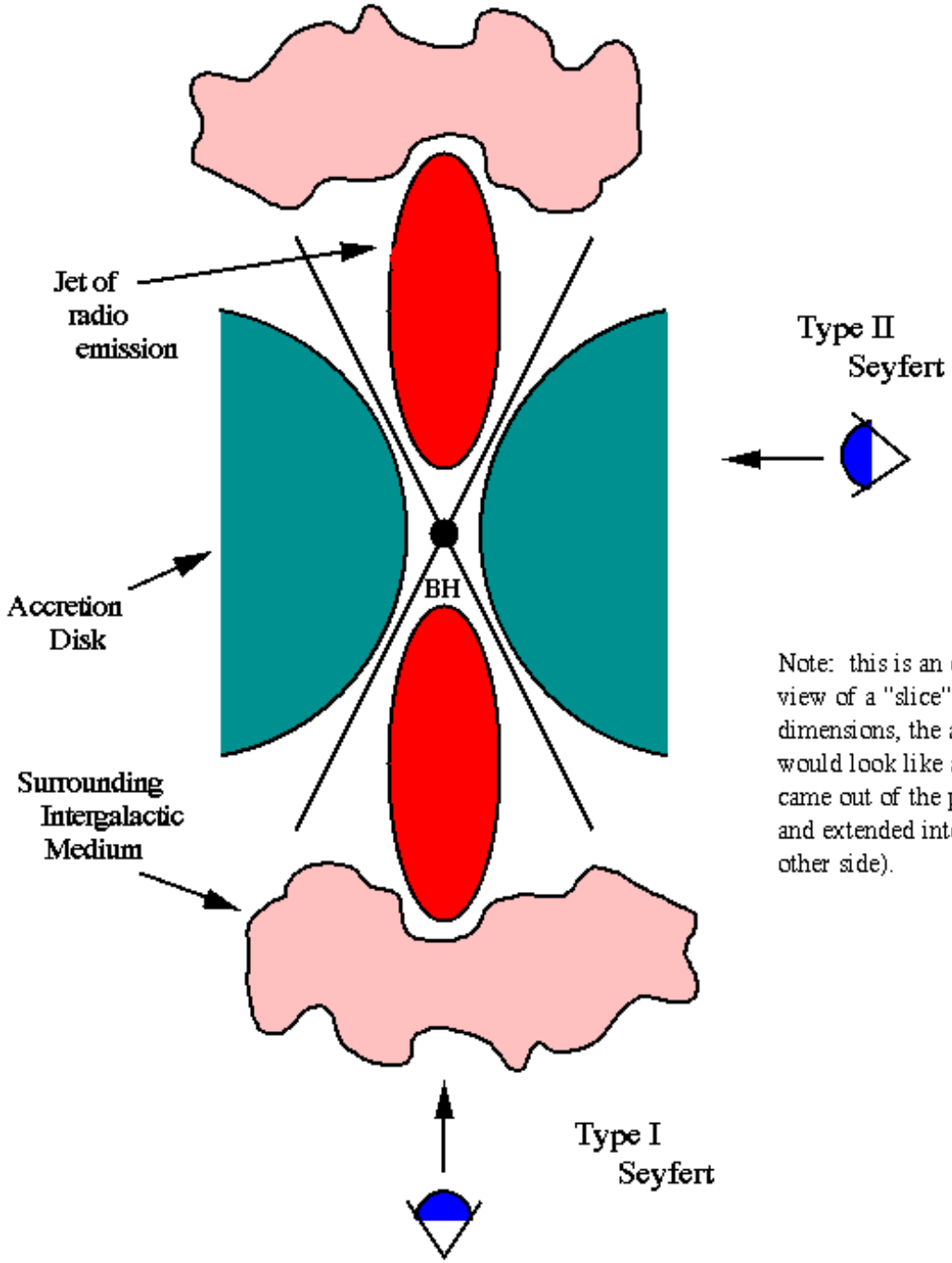


- Low density = forbidden lines
- Low velocity
- Thousands of light years across

Unified Model: Monster in the Middle







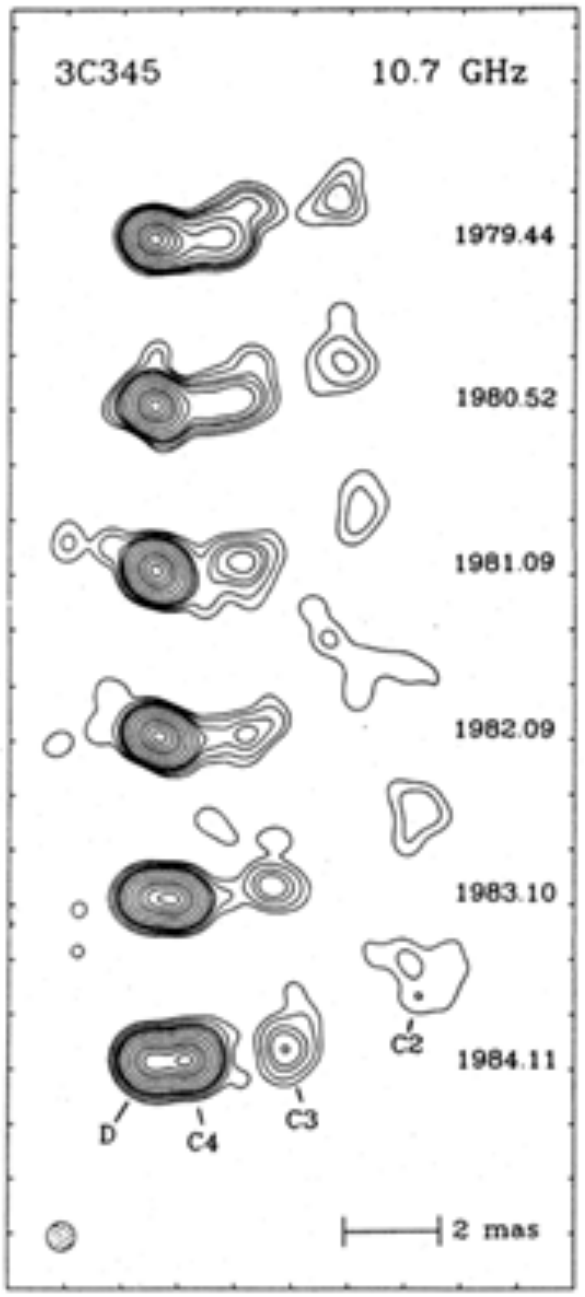
Note: this is an edge–on view of a "slice" of the system. In 3 dimensions, the accretion disk would look like a donut which came out of the page (towards you) and extended into the page (on the other side).

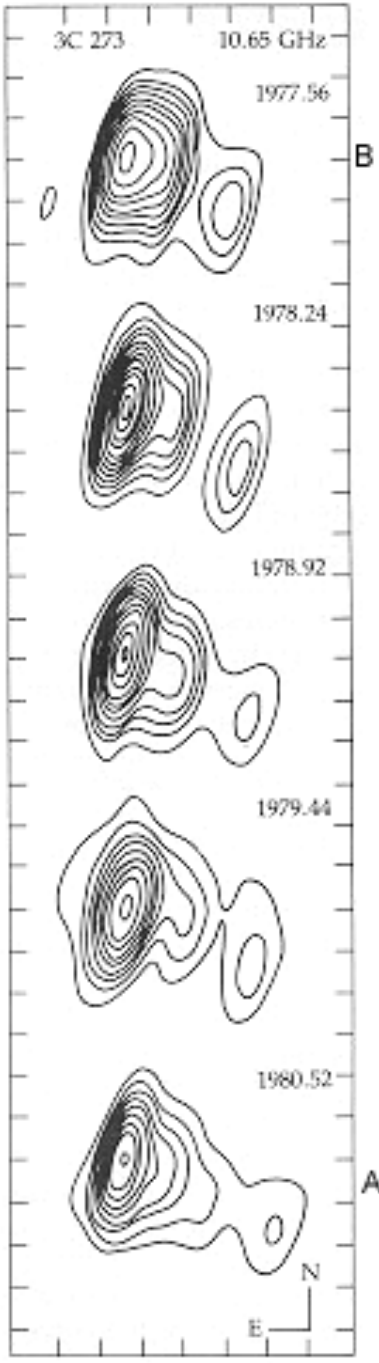
Seyfert Galaxies Type I & II

- Type I – X-ray, UV, broad emission lines
- Type II – narrow emission lines
- 2% of spiral galaxies are Seyfert type

Jets That Go Faster than Light? **Superluminal**

- 3C273 Jet has blobs
- VLBI resolves 0.002”
- Blob moves 0.0008”/yr
- At 1000 Megaparsecs
- S=1X10^{9}X0.0008/206265
- s=4pc/year
- s=12 light years/year



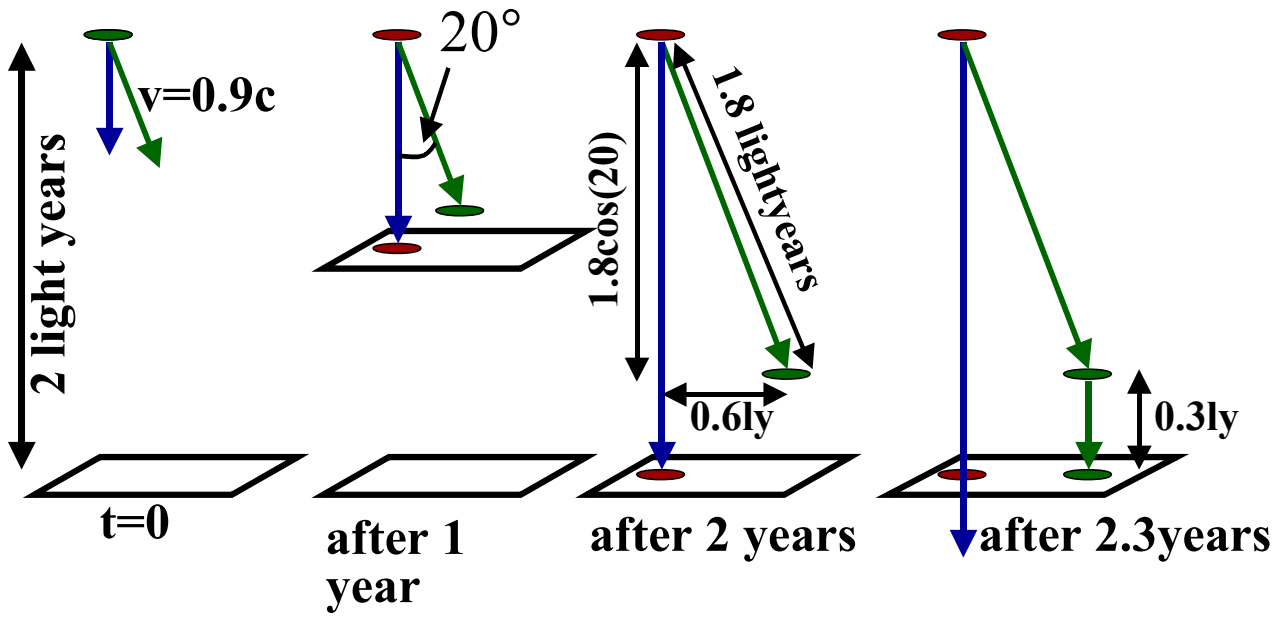


Superluminal Motion

- What we see happen 0.3 years later really was 2.3 years later

Radio superluminal expansion

Features appear to move at v>c!

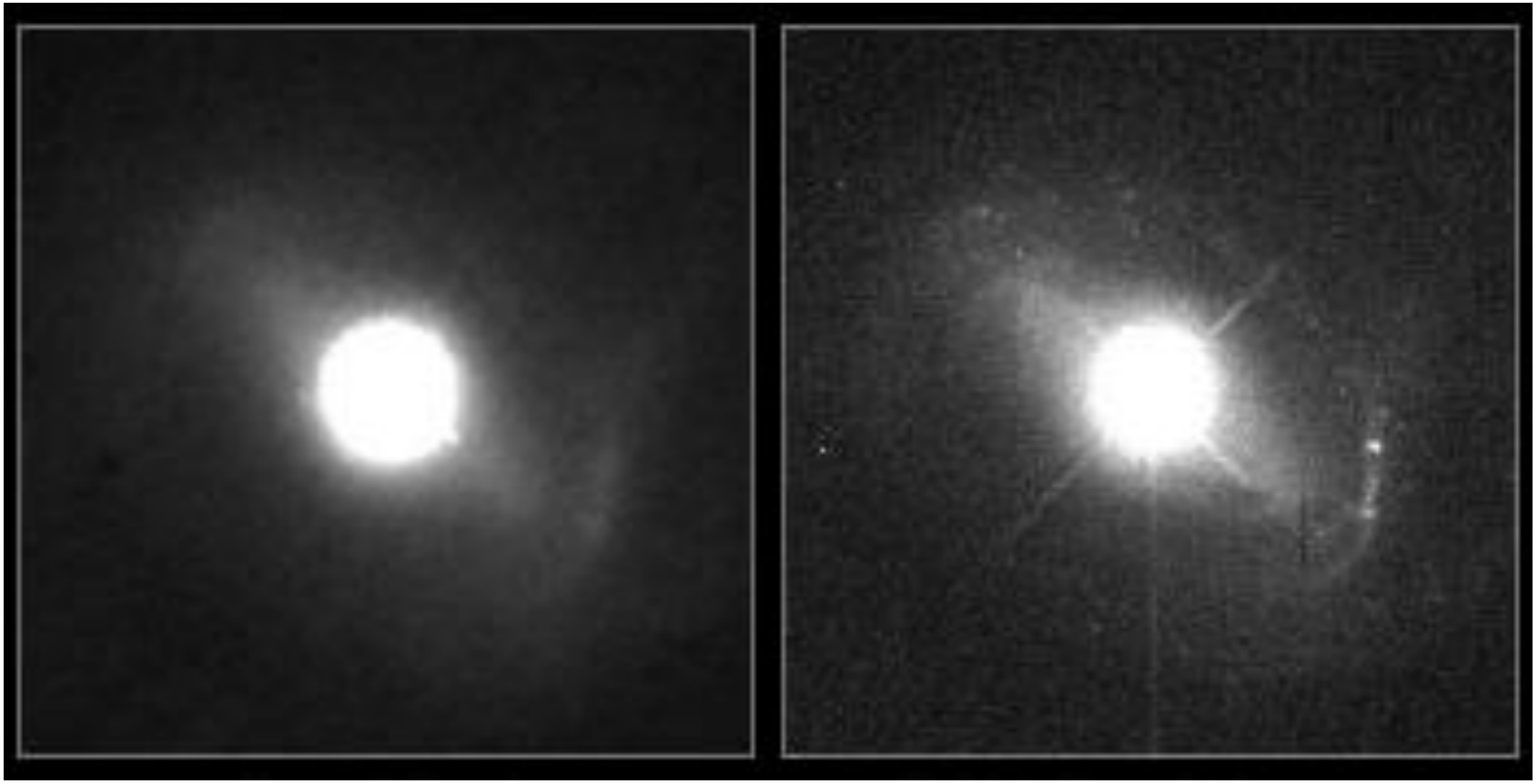


Halton Arp

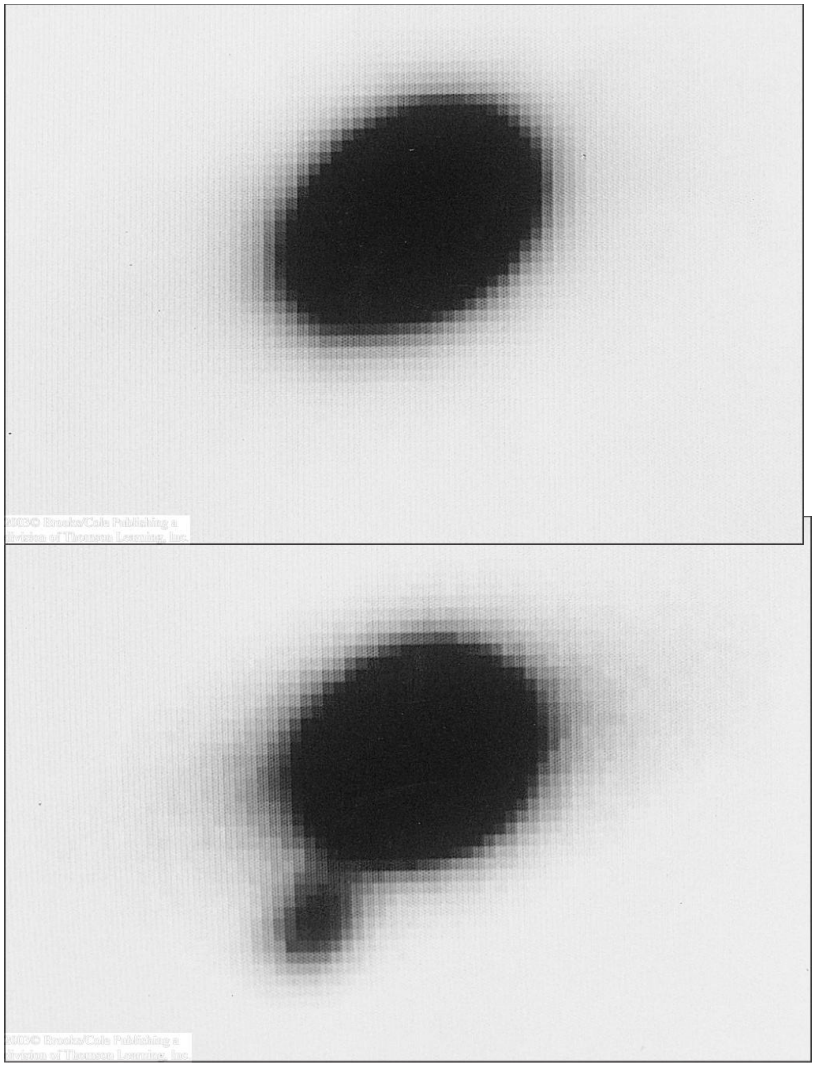
- Redshift not cosmological
- Gravitational?- not with emission lines
- Doppler? – no blue shifts
- Quasars aligned with disturbed galaxies
- Bridges between quasar and galaxy

Evidence for Quasar Distance: =Fuzz

- Left picture is from a ground based telescope
- Right picture is from HST by J. Hutchings (DAO)
- Right picture shows host galaxy that has right redshift and brightness for distance



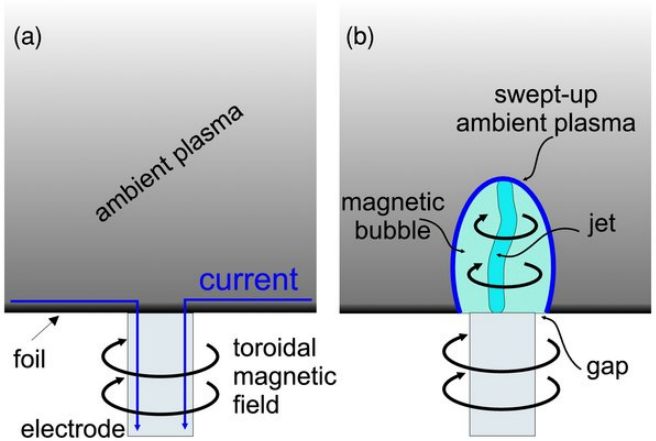
Supernova in Quasar/Galaxy

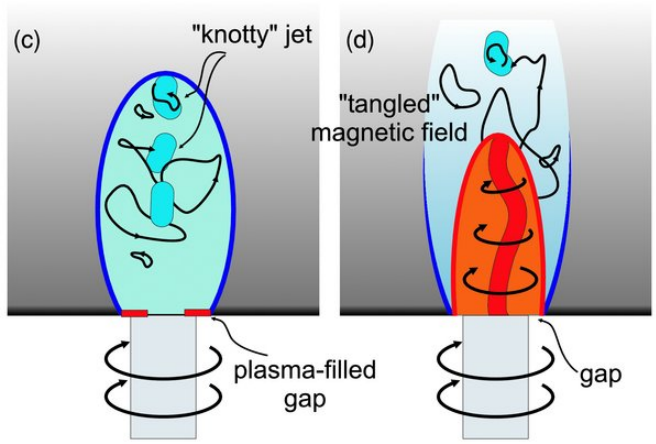


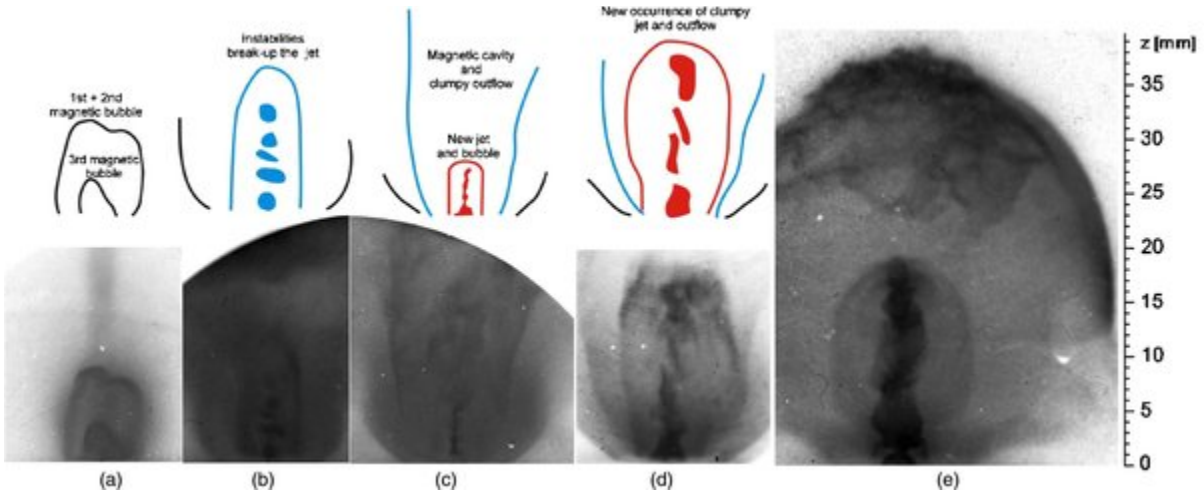
- Bruce Campbell discovered a supernova beside a quasar
- Shows quasars at cosmological distances
- Shows there are stars around quasars

Jets in the Lab

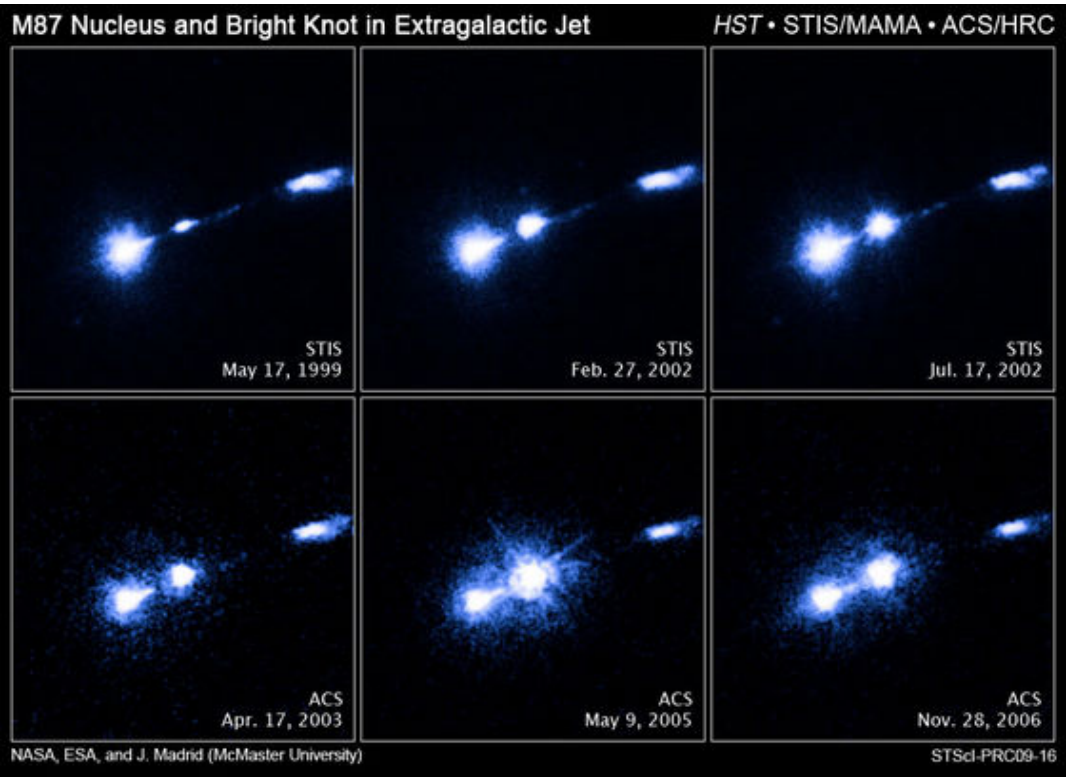
- Recently A. Ciardi has created a jet in a plasma that lasted a microsecond and was an inch long, but ~200km/sec = correct for bipolar flows!





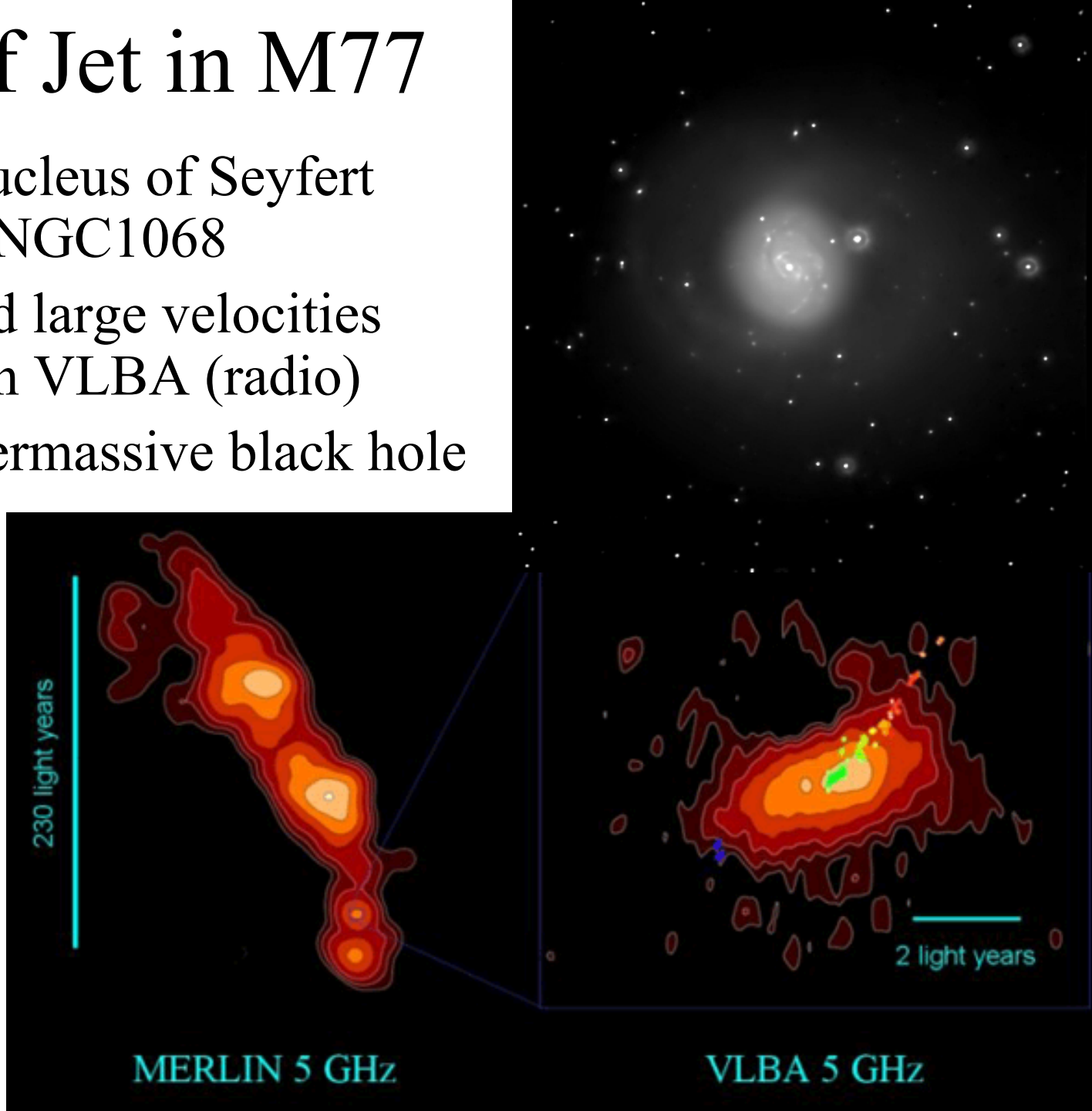


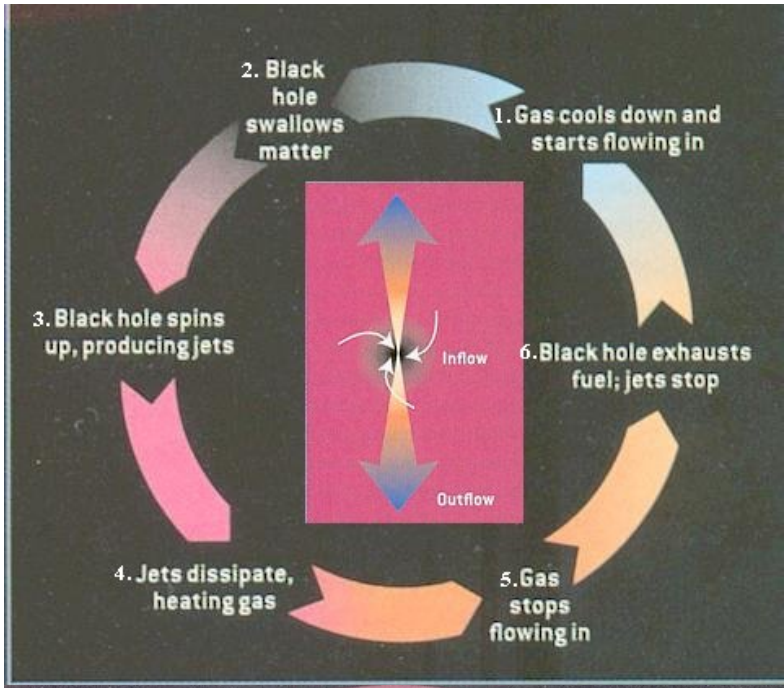
Jets in M87

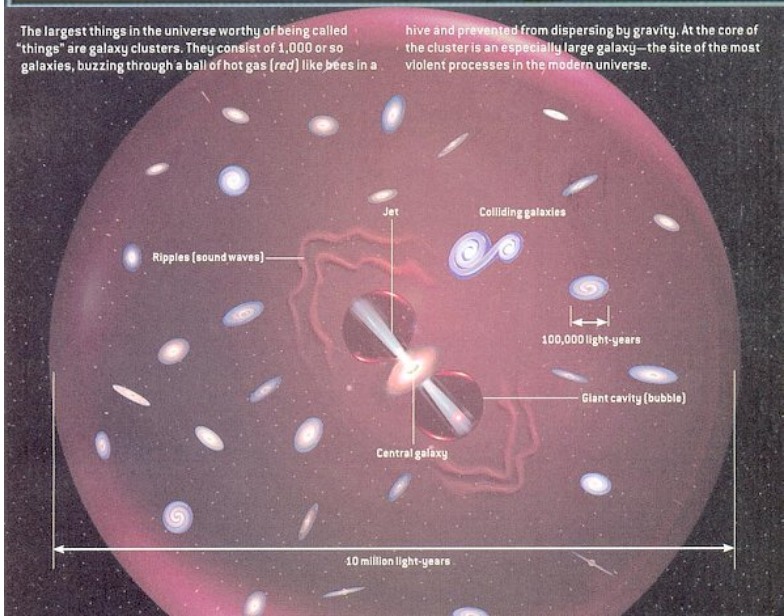

M87 Nucleus and Bright Knot in Extragalactic Jet
HST • STIS/MAMA • ACS/HRC
STIS
May 17, 1999
STIS
Feb. 27, 2002
STIS
Jul. 17, 2002
ACS
Apr. 17, 2003
ACS
May 9, 2005
ACS
Nov. 28, 2006
NASA, ESA, and J. Madrid (McMaster University)
STScI-PRC09-16

Origin of Jet in M77

- Jet starts in nucleus of Seyfert galaxy M77=NGC1068
- Small size and large velocities measured with VLBA (radio)
- Indicates supermassive black hole




2. Black hole swallows matter
1. Gas cools down and starts flowing in
3. Black hole spins up, producing jets
Inflow
6. Black hole exhausts fuel; jets stop
Outflow
4. Jets dissipate, heating gas
5. Gas stops flowing in


The largest things in the universe worthy of being called "things" are galaxy clusters. They consist of 1,000 or so galaxies, buzzing through a ball of hot gas (*red*) like bees in a hive and prevented from dispersing by gravity. At the core of the cluster is an especially large galaxy—the site of the most violent processes in the modern universe.
Jet
Colliding galaxies
Ripples (sound waves)
100,000 light-years
Giant cavity (bubble)
Central galaxy
10 million light-years

AGN / Seyfert Galaxy Spectra

- Type 1 has broad (10,000km/sec) +forbidden lines
- Type 2 have narrow (400km/sec) + forbidden lines