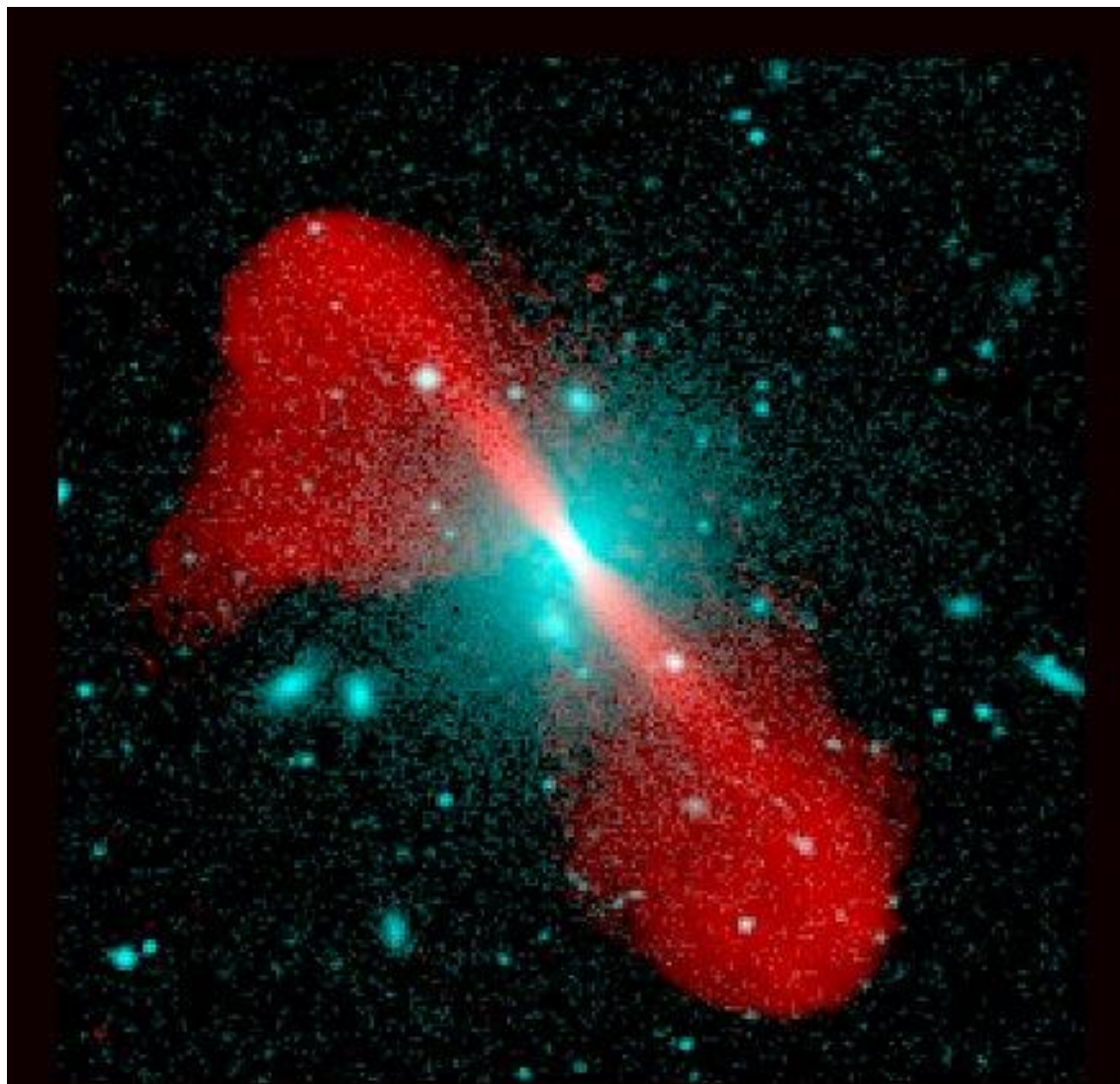


# Jets

- Radio Galaxies
- Relativistic Jets
- Superluminal Motion

# Radio Galaxies

- A few galaxies are very strong radio emitters
- Often dominated by two enormous lobes
- These are located at distances up to 10 times the radius of the optical galaxy
- The central galaxy is located between the lobes and is usually a giant elliptical
- Jet originates from an AGN

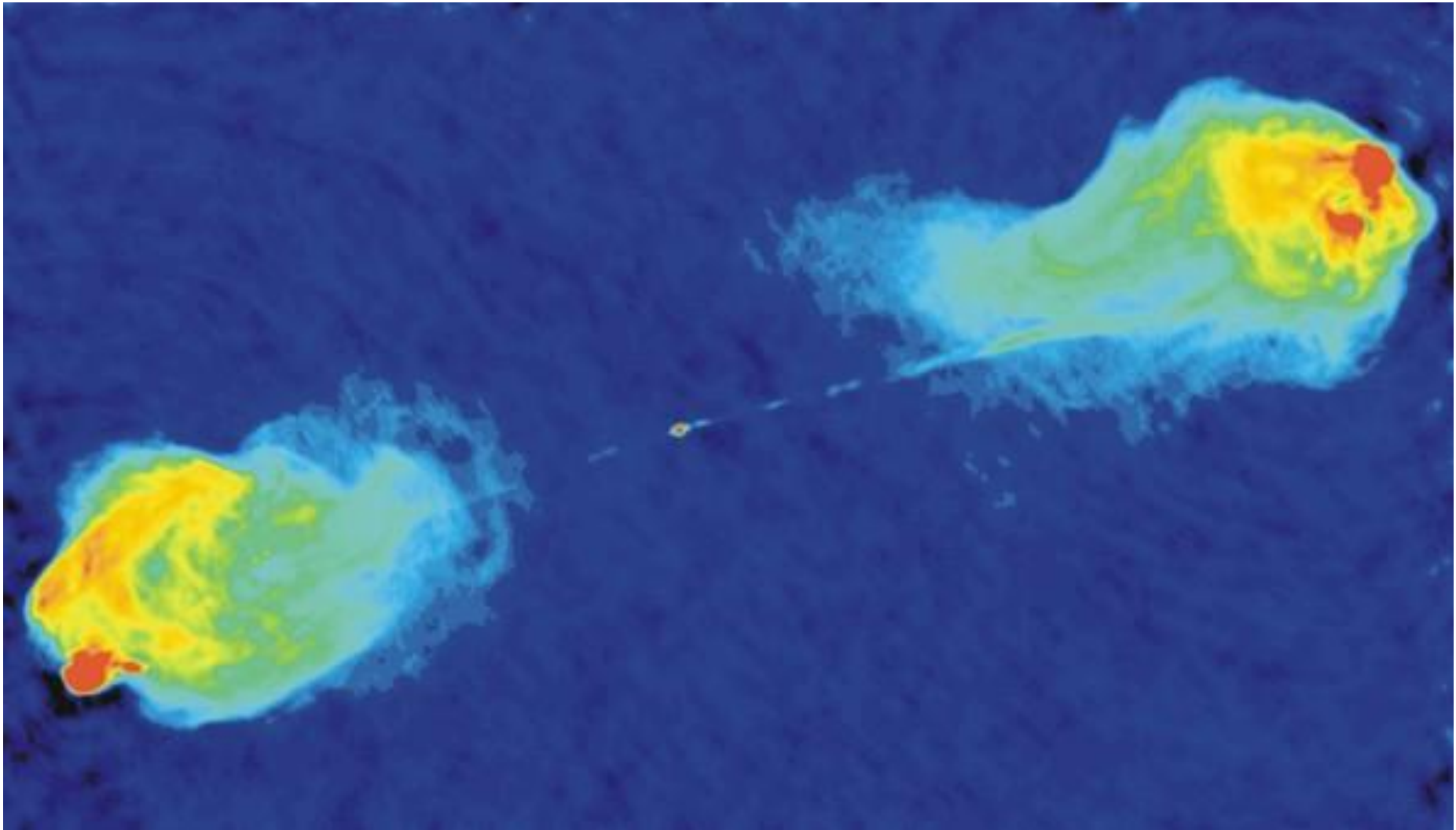


Radio Galaxy 3C296  
Radio/optical superposition

Copyright (c) NRAO/AUI 1999

# Relativistic Radio Jets

- Often a highly collimated radio jet is seen emanating from a compact nucleus
- Often this is only seen on one side and not the other (a relativistic beaming effect)
- Where the jet hits the lobe there is a hotspot

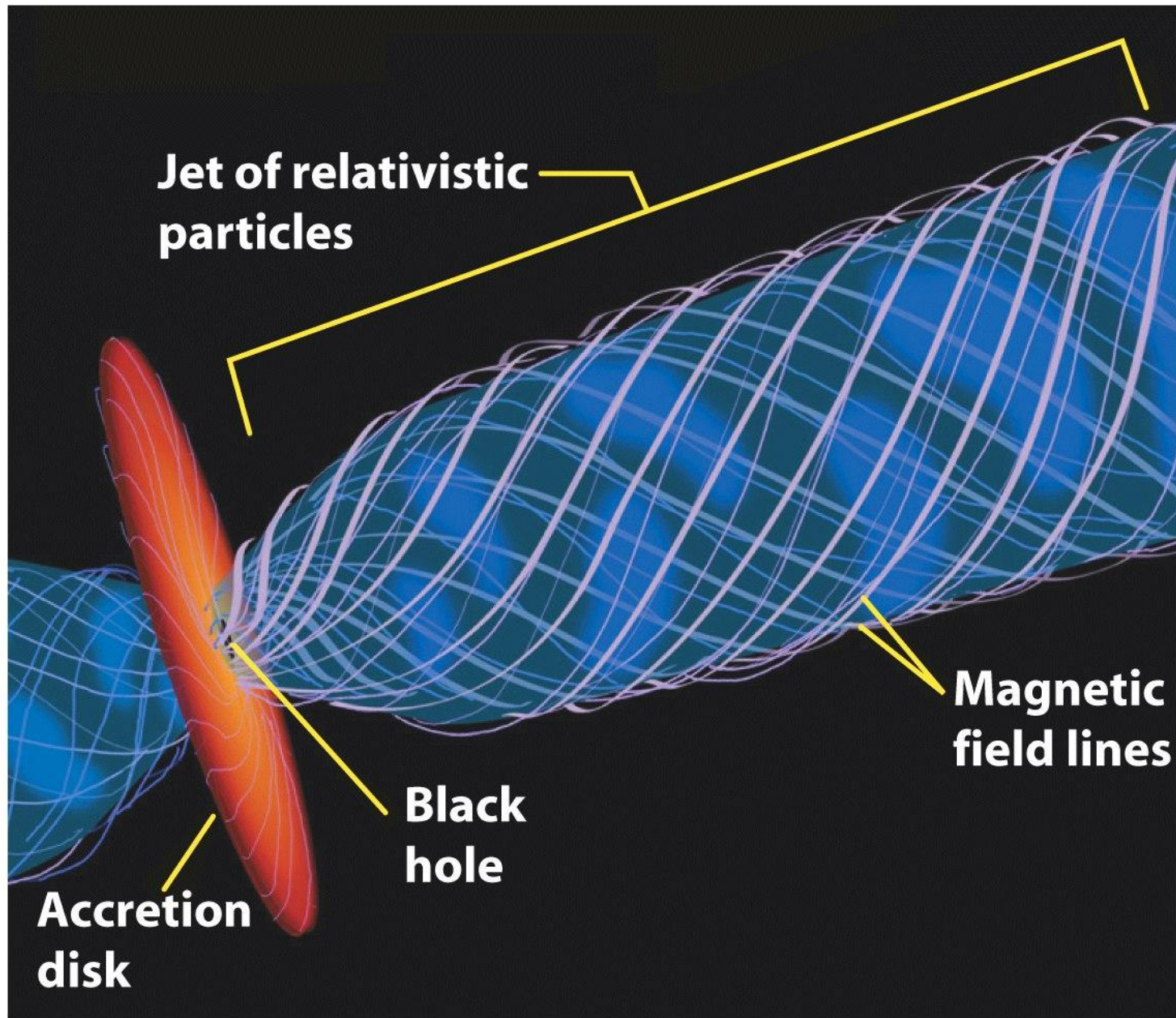


Radio image of the radio galaxy Cyg A. VLA courtesy of NRAO/AUI



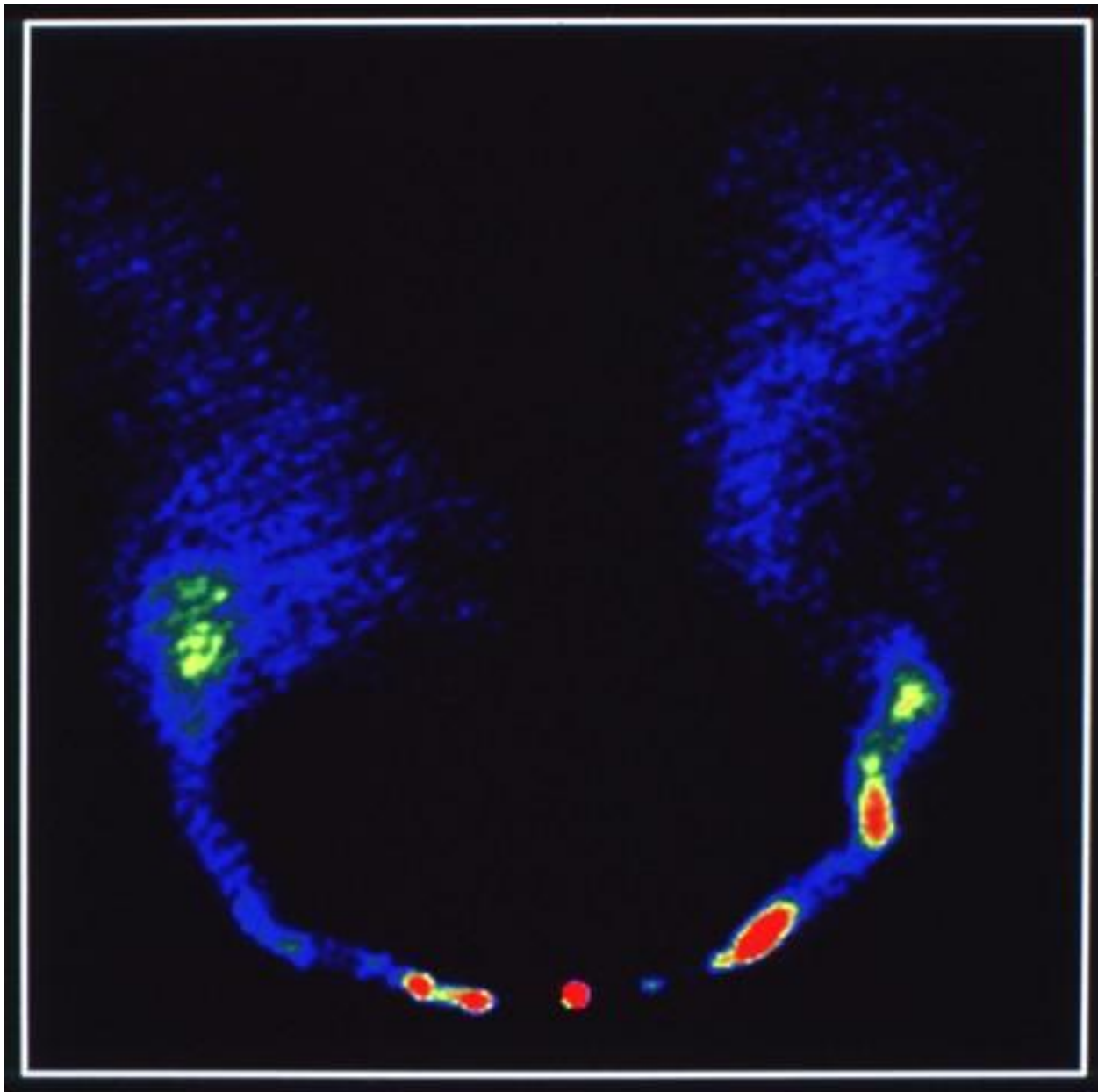
3C288  
VLA,  
NRAO/AUI

- The jet and the lobes both have non-thermal emission due to the synchrotron mechanism
- Relativistic electrons from the core travel up the jet
- They interact with the intergalactic medium to produce the lobes
- The jet and lobes must have strong magnetic fields



# Head-Tail Galaxies

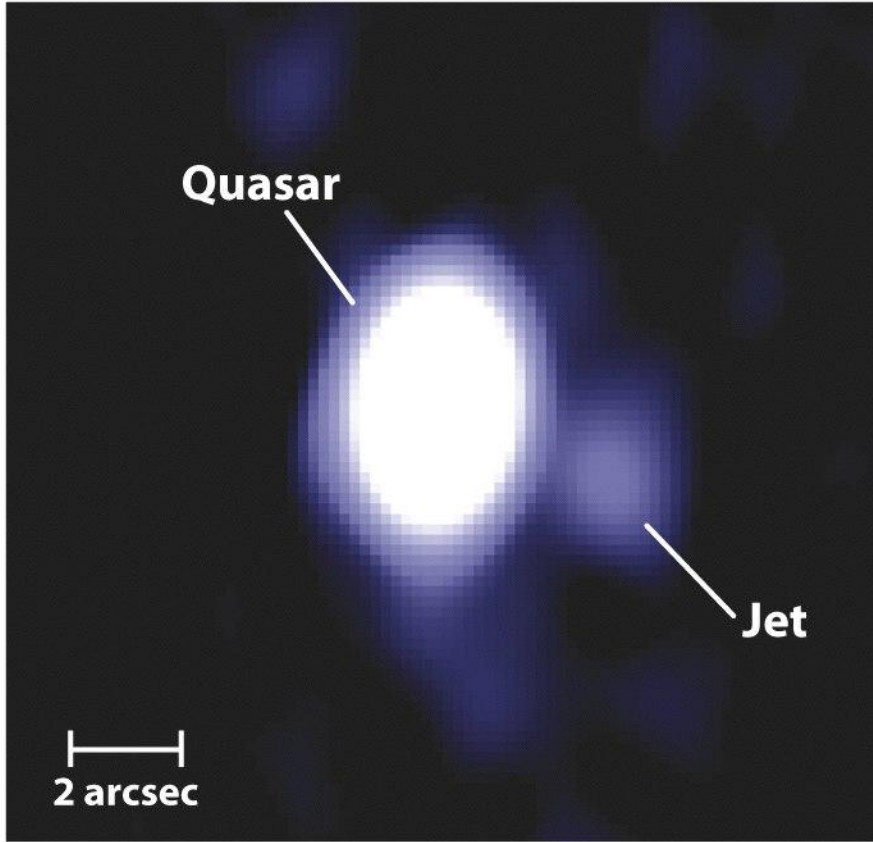
- Some radio galaxies have bent jets that give the appearance of motion through space
- The core of the galaxy (head) leads whilst the lobes trail behind (tail)



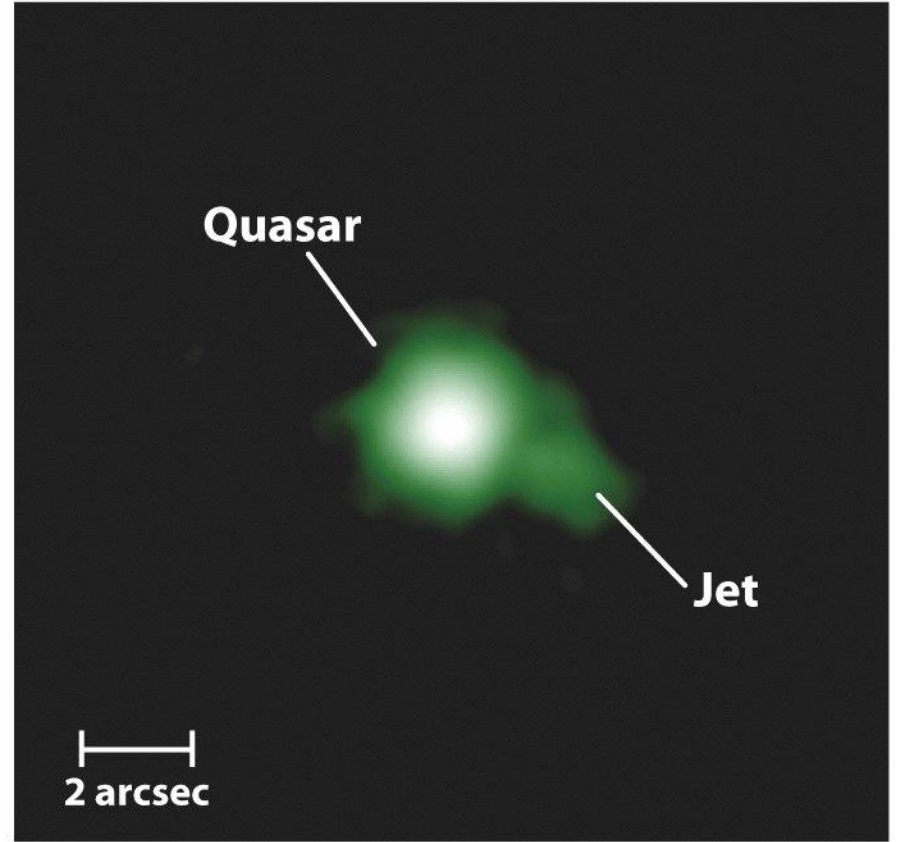
Radio image of the head-tail radio galaxy 3C83.1. VLA courtesy of NRAO/AUI

# Other AGN Jets

- Radio galaxies are not the only AGN to show jets
- Radio-loud quasars show, usually short, jets coming from the core in radio, optical and X-rays
- Seyfert galaxies show weak, compact radio jets

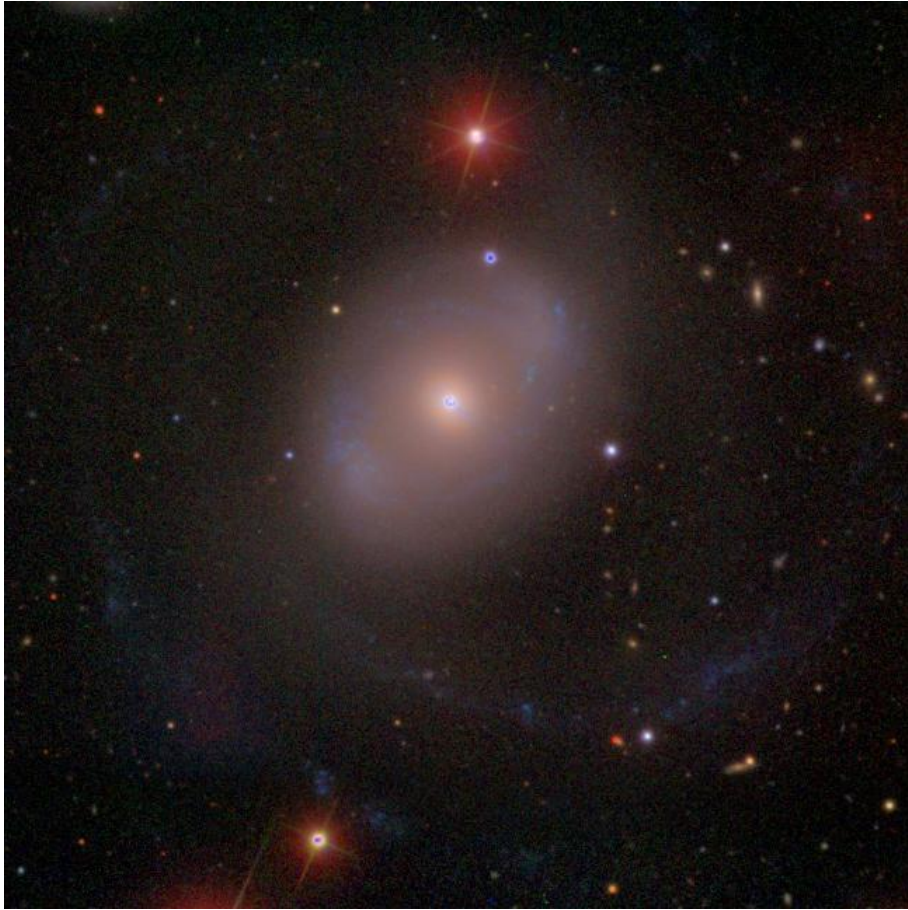
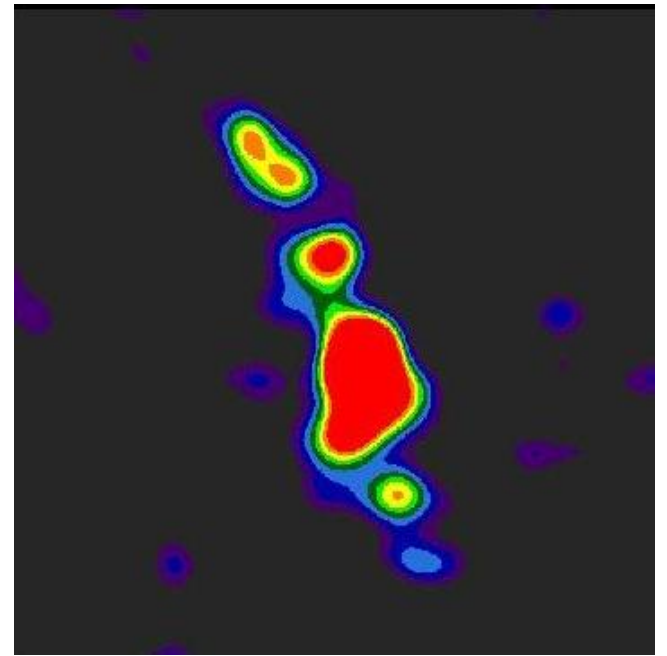


**(a)** A quasar jet at radio wavelengths...



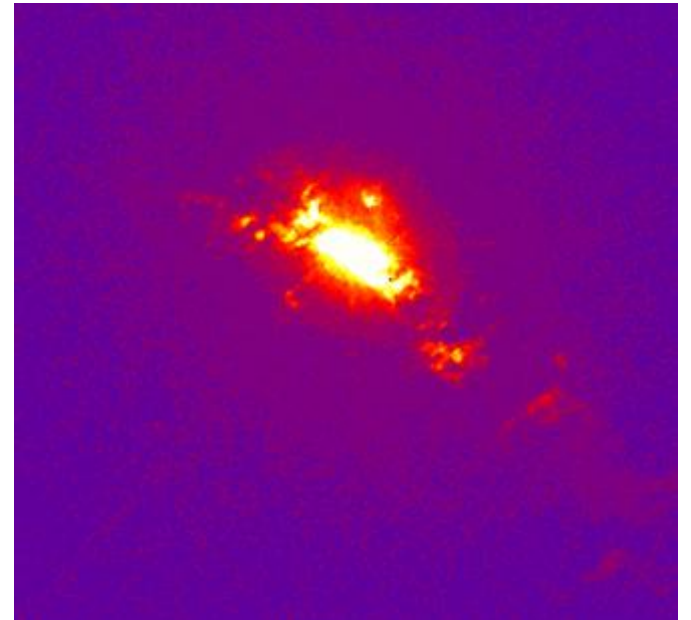
**(b)** ...and at X-ray wavelengths

Radio VLBA  
NRAO/AUI



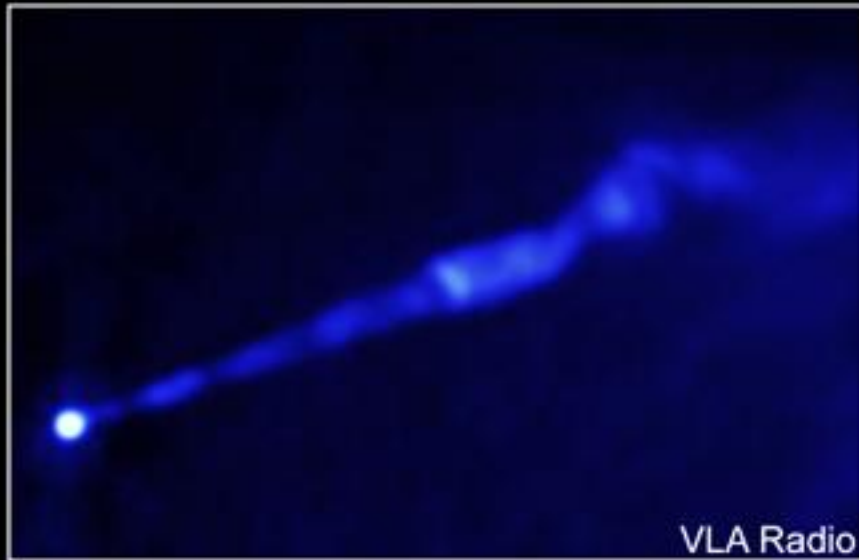
NGC 4151 Seyfert  
galaxy, optical

Optical HST

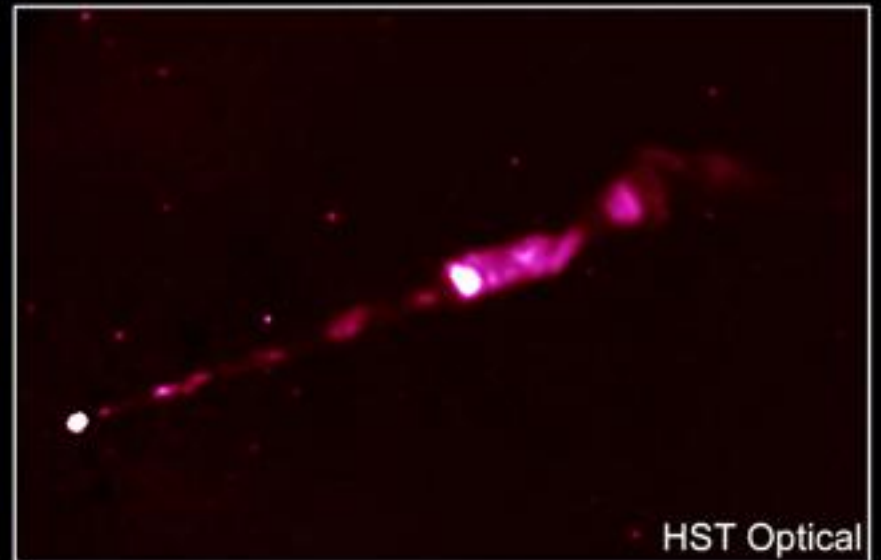




Chandra X-Ray

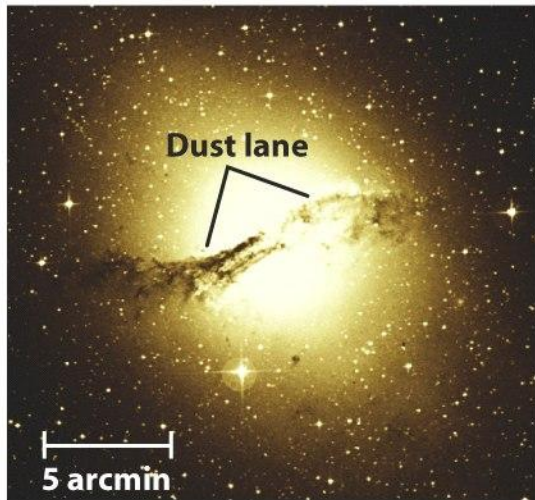


VLA Radio

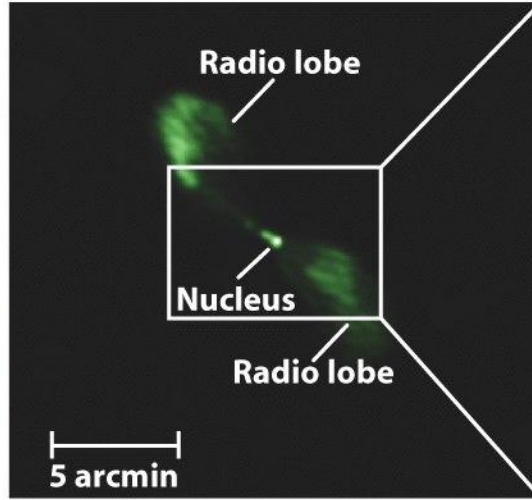


HST Optical

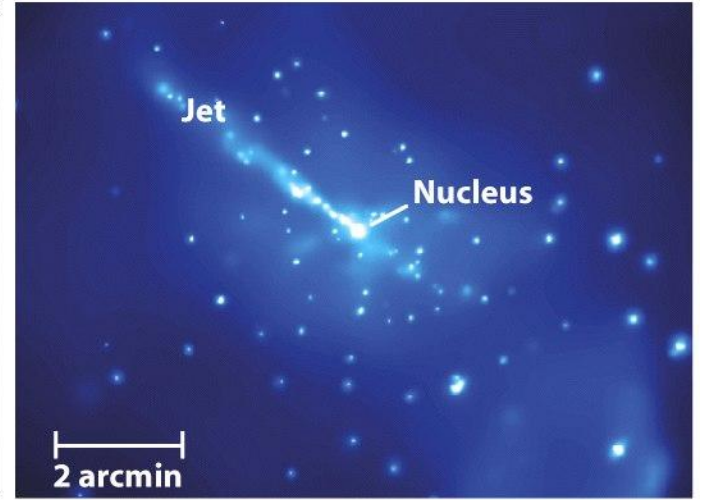
M87 Jet



(a) Centaurus A: light from stars



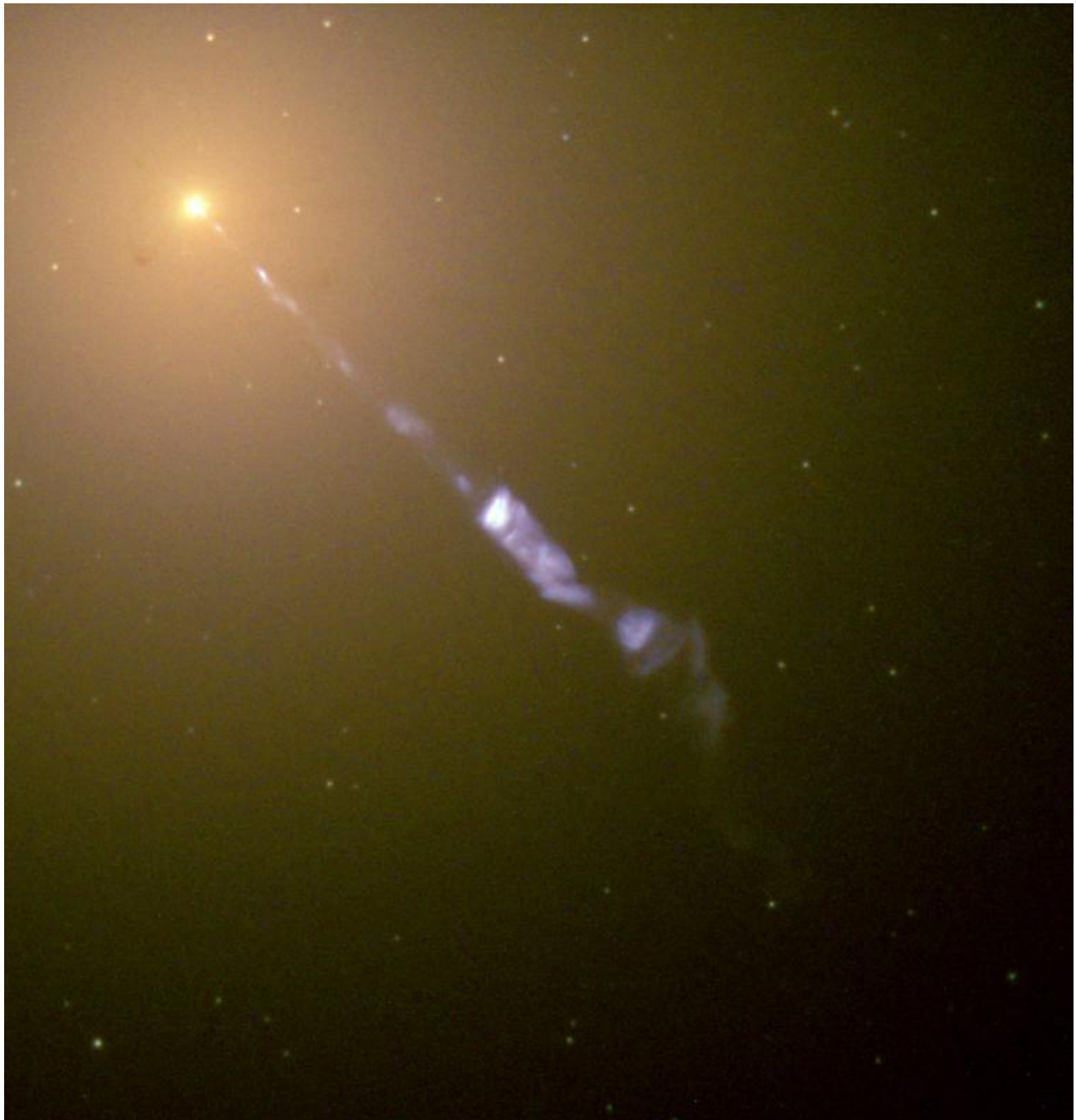
(b) Centaurus A: radio lobes



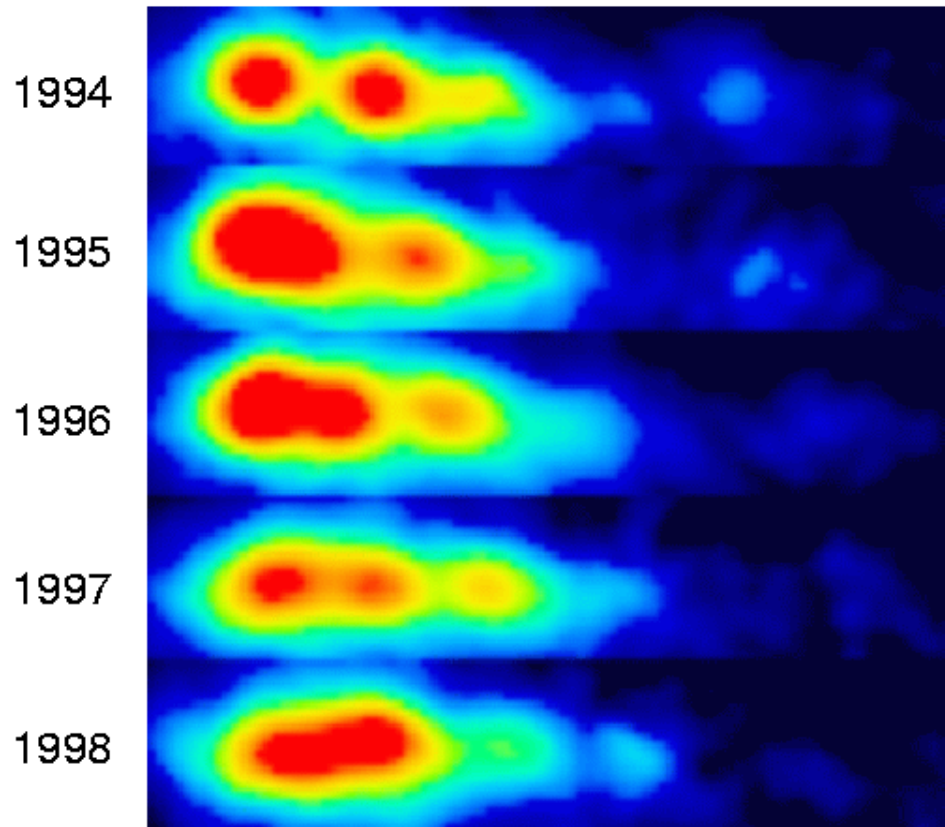
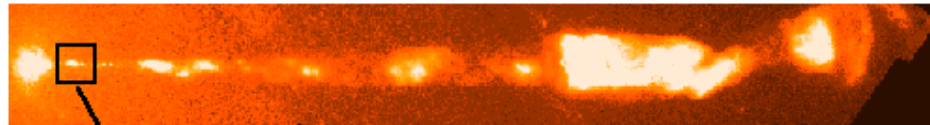
(c) An X-ray-emitting jet emanates from the nucleus

# Superluminal Motion

- Many jets have blobs or knots in them
- These can be seen to move over time
- This 'proper motion' can be used to measure the velocity of the jet
- Sometimes this velocity appears to be larger than the speed of light
- A result of the jet being close to our line of sight



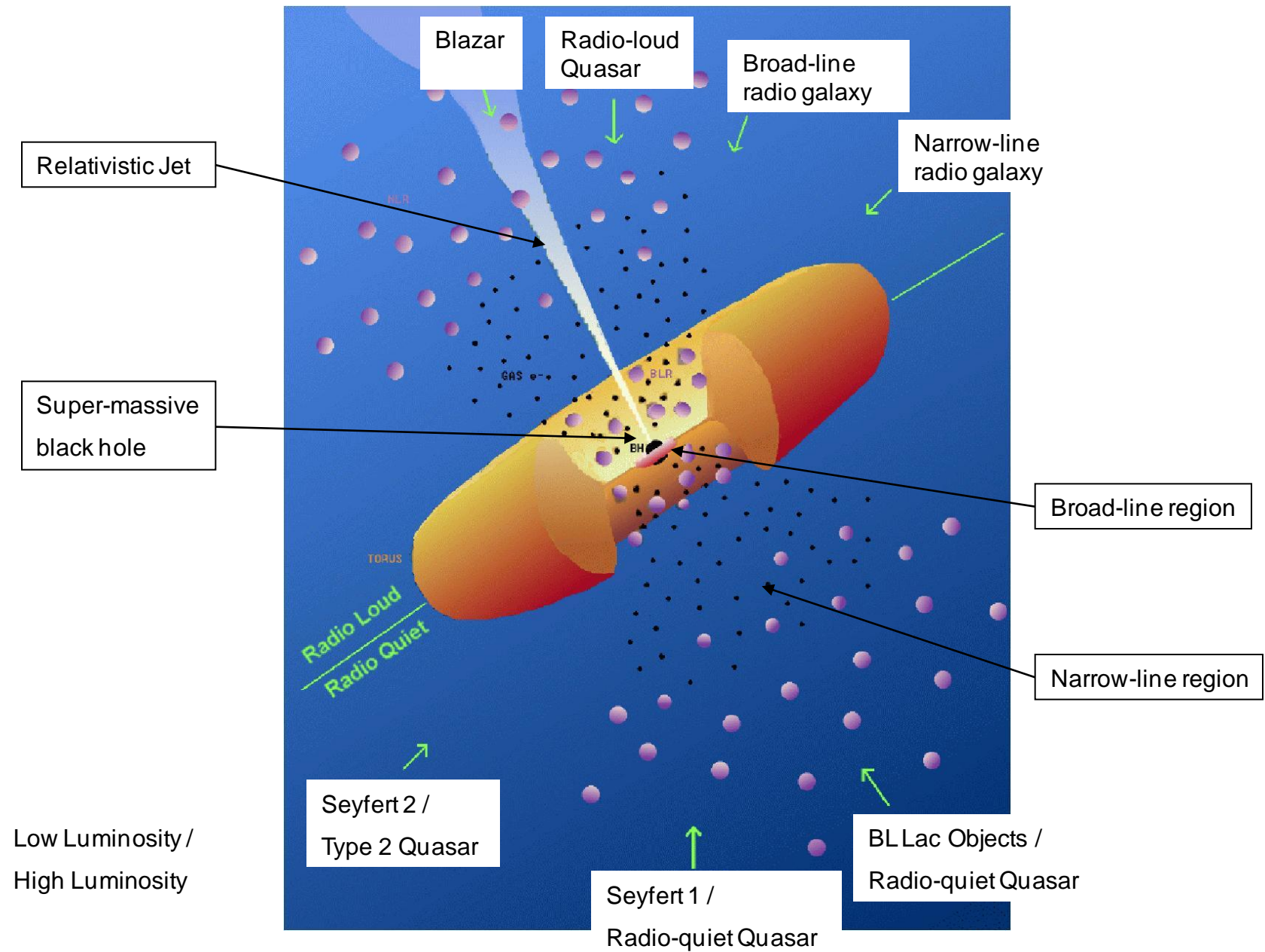
# Superluminal Motion in the M87 Jet



————— 24 light yrs

# Unified Model for AGN

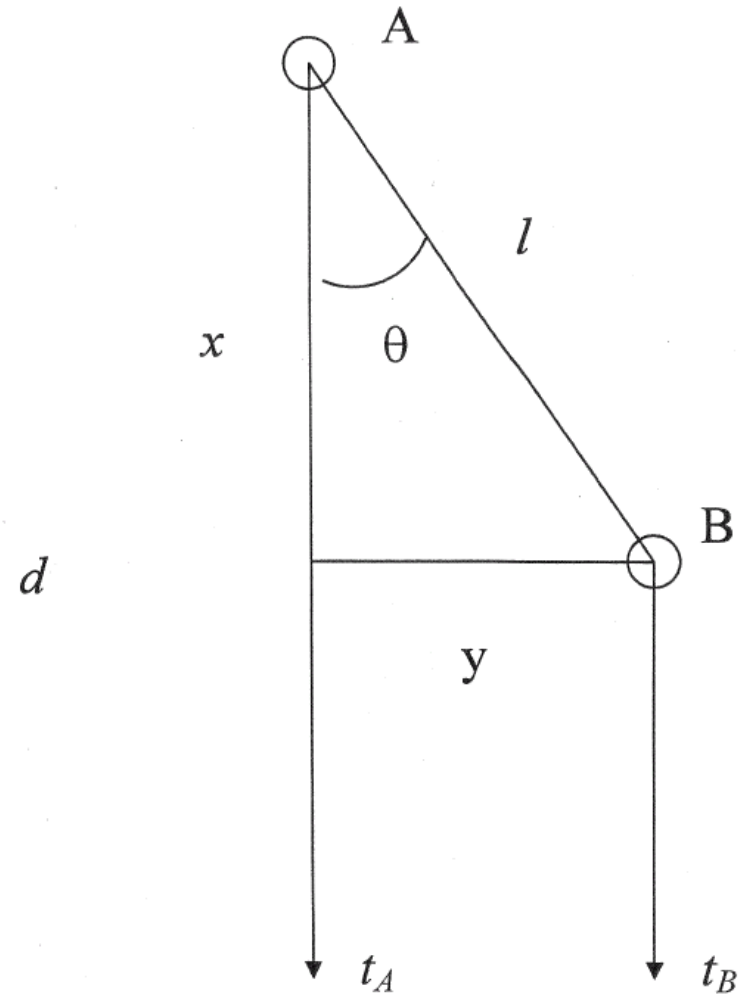
- Currently thought that all the different types of AGN can be understood as the same phenomena, but with different viewing angles and nuclear luminosities



# Summary

- Relativistic jets are associated with all AGN activity
- In radio loud galaxies they are the most obvious sign of activity
- The non-thermal emission from jets can be seen across all wavelengths

- Consider an AGN jet a distance  $d$  away
- A blob is observed from Earth at time  $t_A$  in the core (A)
- A time interval  $t_{int}$  later the blob has moved to B and this is observed from Earth to occur at time  $t_B$
- The blob is moving at a speed  $v = \beta c$  where  $\beta < 1$  at an angle  $\theta$  to the line of sight



- Apparent velocity on sky is

$$v_{app} = \frac{y}{t_B - t_A}$$

- arrival time at Earth from A is

$$t_A = \frac{d}{c}$$

- arrival time at Earth from B is

$$t_B = t_{int} + \frac{(d - x)}{c}$$

- from geometry

$$l = vt_{int} = \beta ct_{int}$$

$$y = l \sin \theta$$

$$x = l \cos \theta$$

- So

$$\begin{aligned}v_{app} &= \frac{l \sin \theta}{\left(t_{\text{int}} + \frac{(d-x)}{c}\right) - \frac{d}{c}} \\&= \frac{l \sin \theta}{t_{\text{int}} - \frac{x}{c}} \\&= \frac{\beta c t_{\text{int}} \sin \theta}{t_{\text{int}} - \frac{\beta c t_{\text{int}} \cos \theta}{c}} \\&= \frac{\beta \sin \theta}{1 - \beta \cos \theta} c\end{aligned}$$