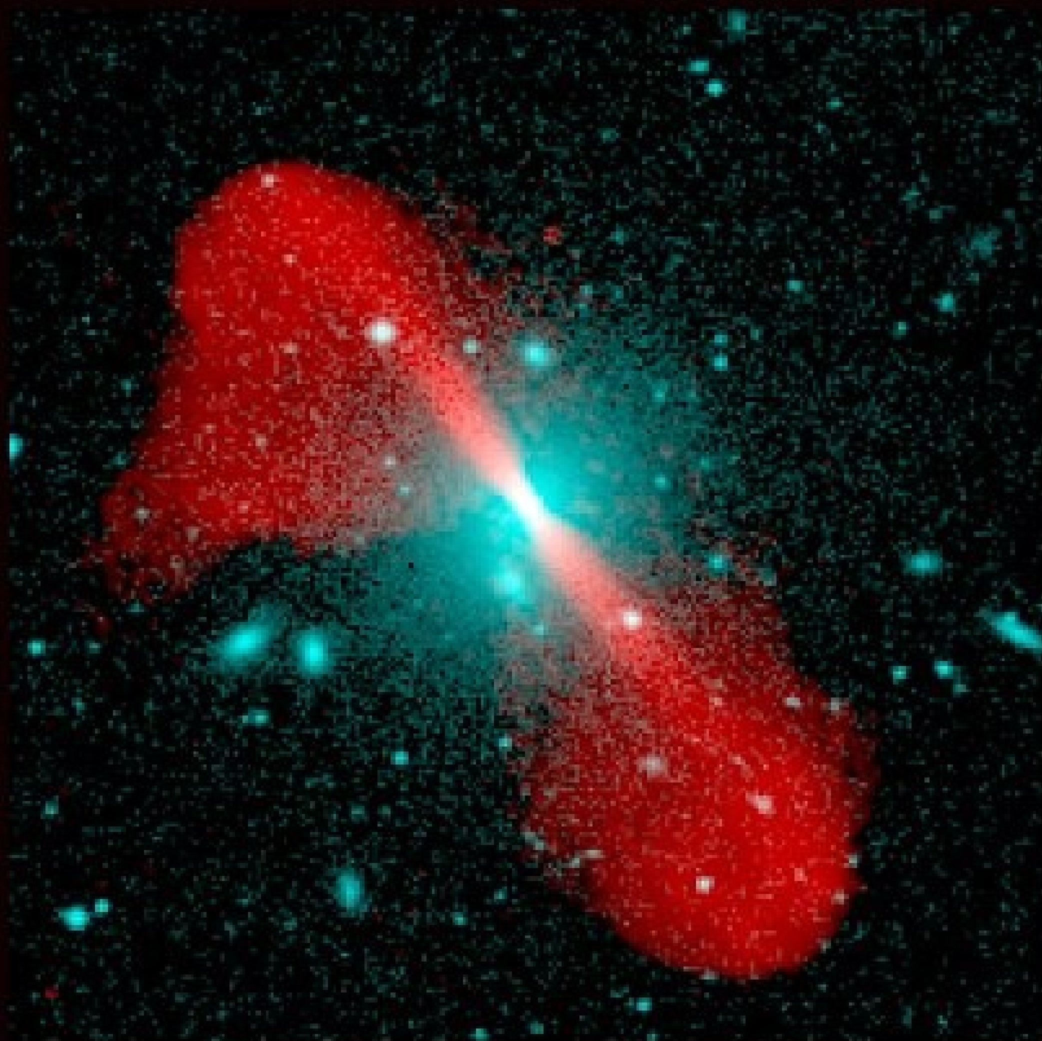
Jets

- Radio Galaxies
- Relativistic Jets
- Superluminal Motion

Radio Galaxies

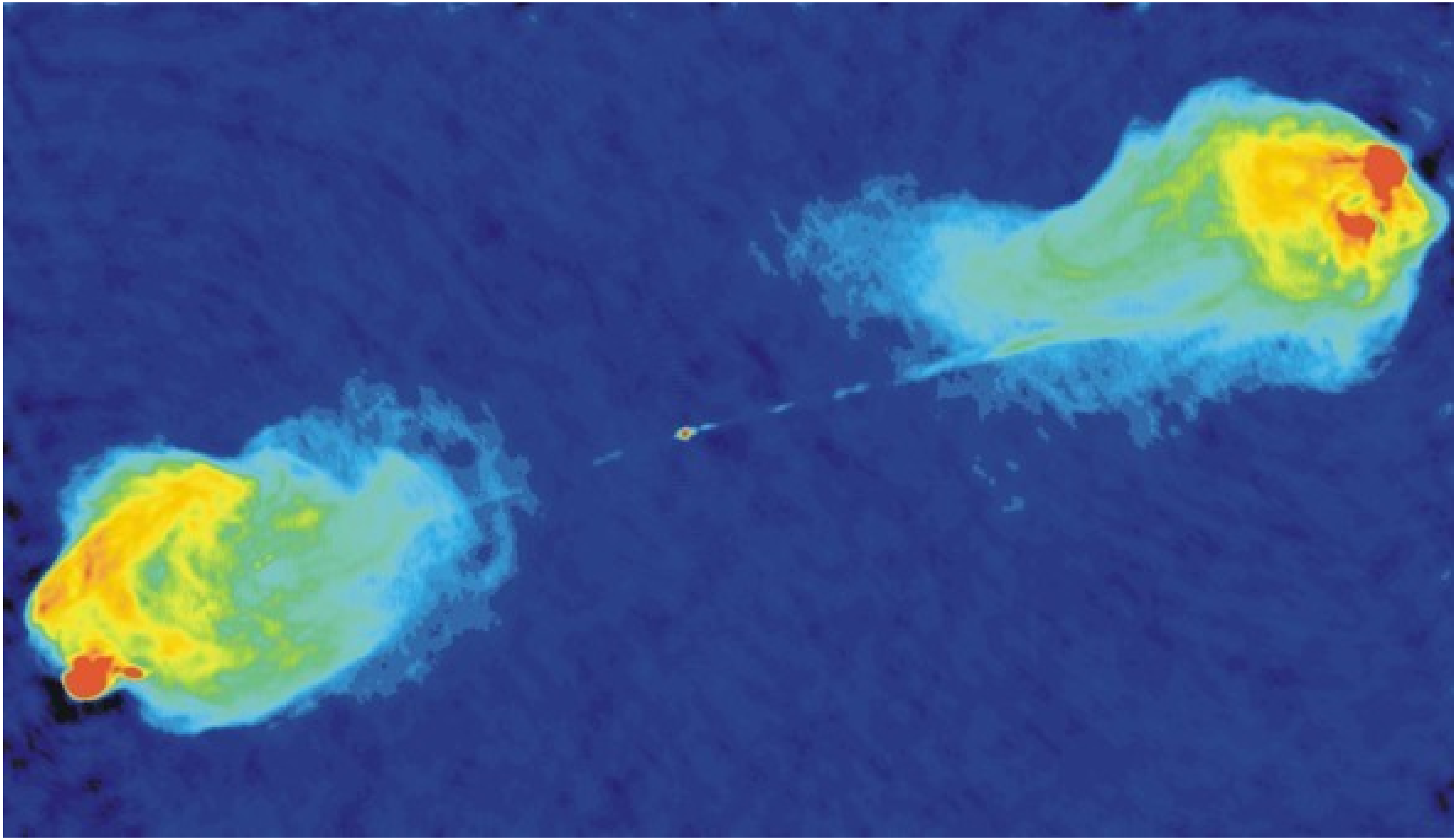
- A few galaxies are very strong radio emitters
- Often dominated by two enormous lobes
- These are located at distances up to 10 times the radius of the optical galaxy
- The central galaxy is located between the lobes and is usually a giant elliptical
- Jet originates from an AGN



Radio Galaxy 3C296
Radio/optical superposition

Relativistic Radio Jets

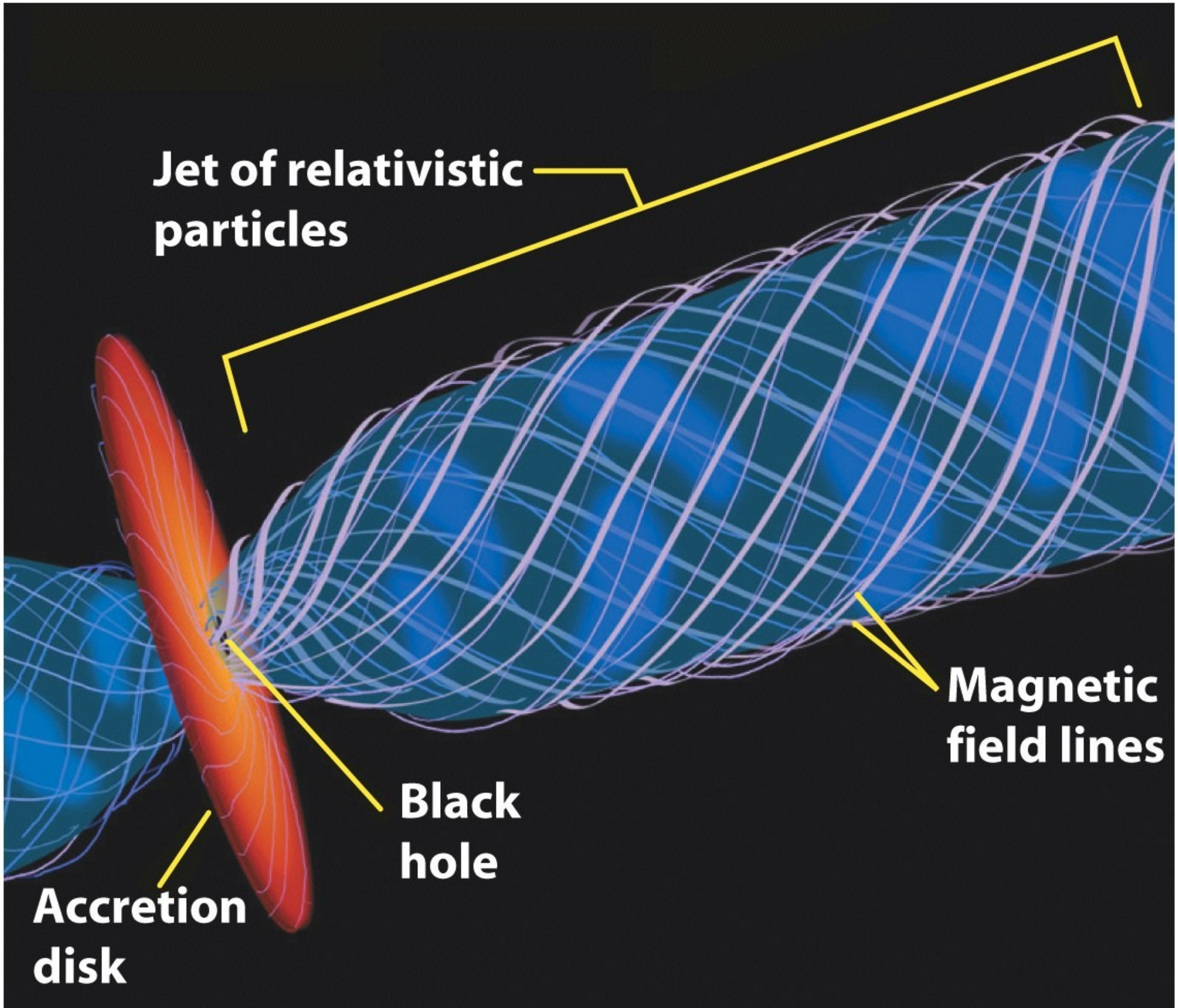
- Often a highly collimated radio jet is seen emanating from a compact nucleus
- Often this is only seen on one side and not the other (a relativistic beaming effect)
- Where the jet hits the lobe there is a hotspot



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

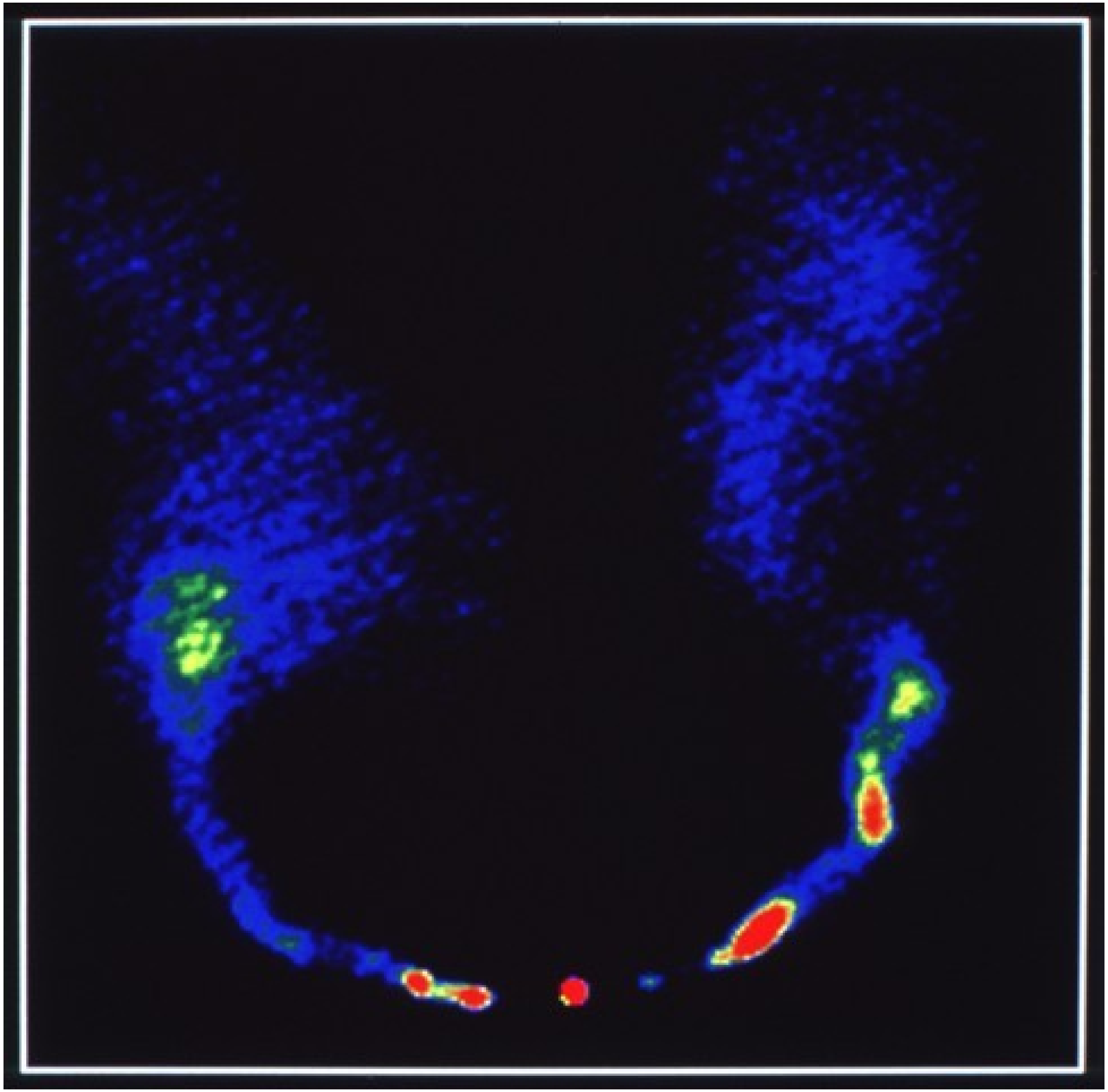
3C288
VLA,
NRAO/AUI

- 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


Jet of relativistic particles
Magnetic field lines
Black hole
Accretion disk

Head-Tail Galaxies

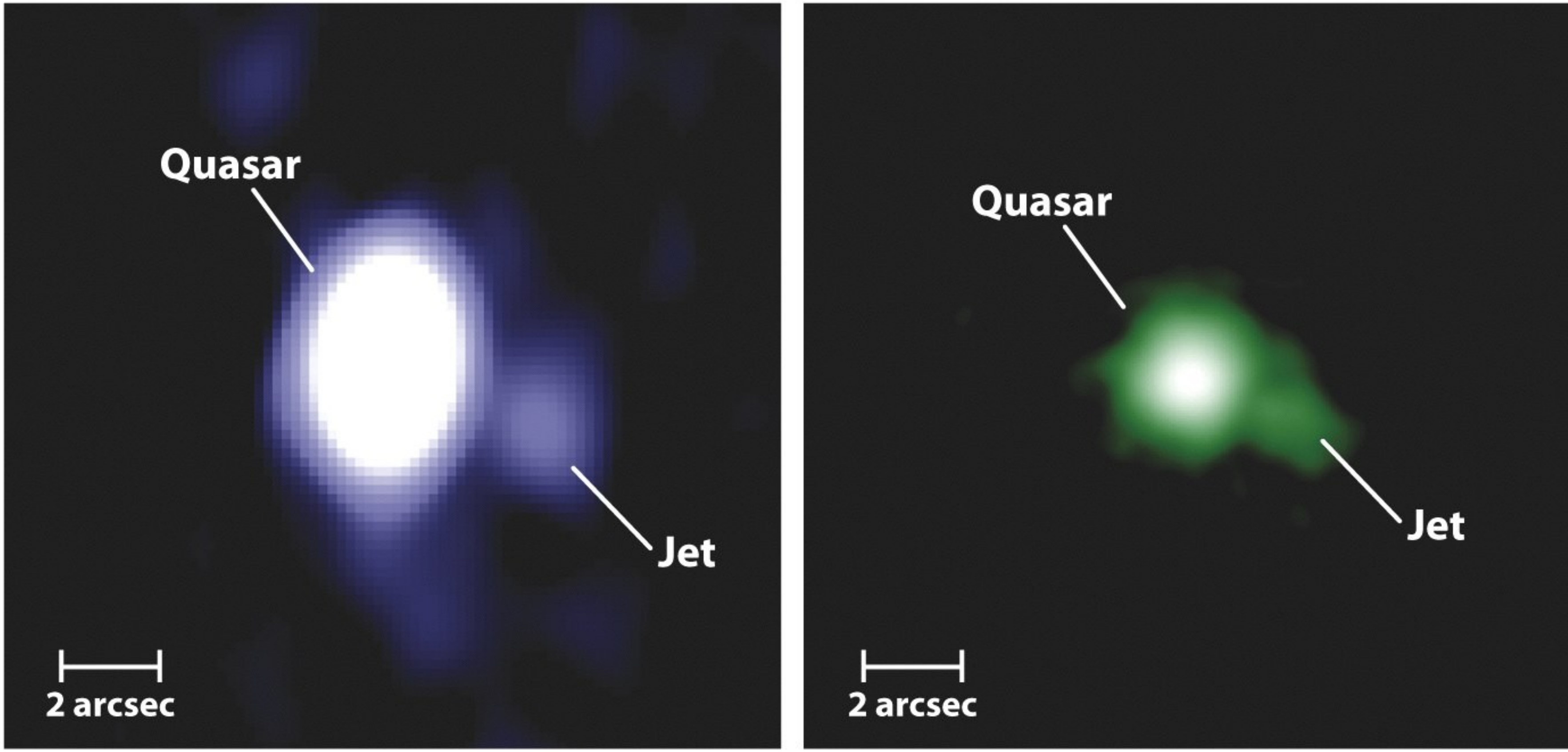
- Some radio galaxies have bent jets that give the appearance of motion through space
- The core of the galaxy (head) leads whilst the lobes trail behind (tail)



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

Other AGN Jets

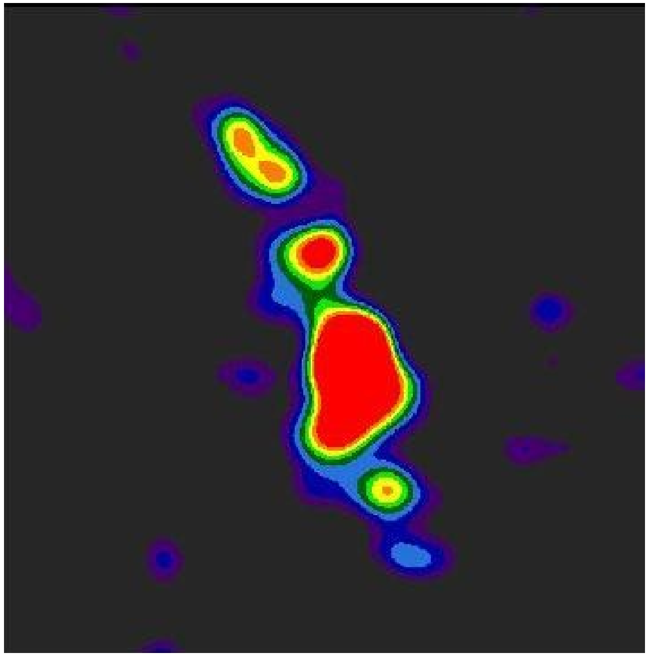
- Radio galaxies are not the only AGN to show jets
- Radio-loud quasars show, usually short, jets coming from the core in radio, optical and X-rays
- Seyfert galaxies show weak, compact radio jets

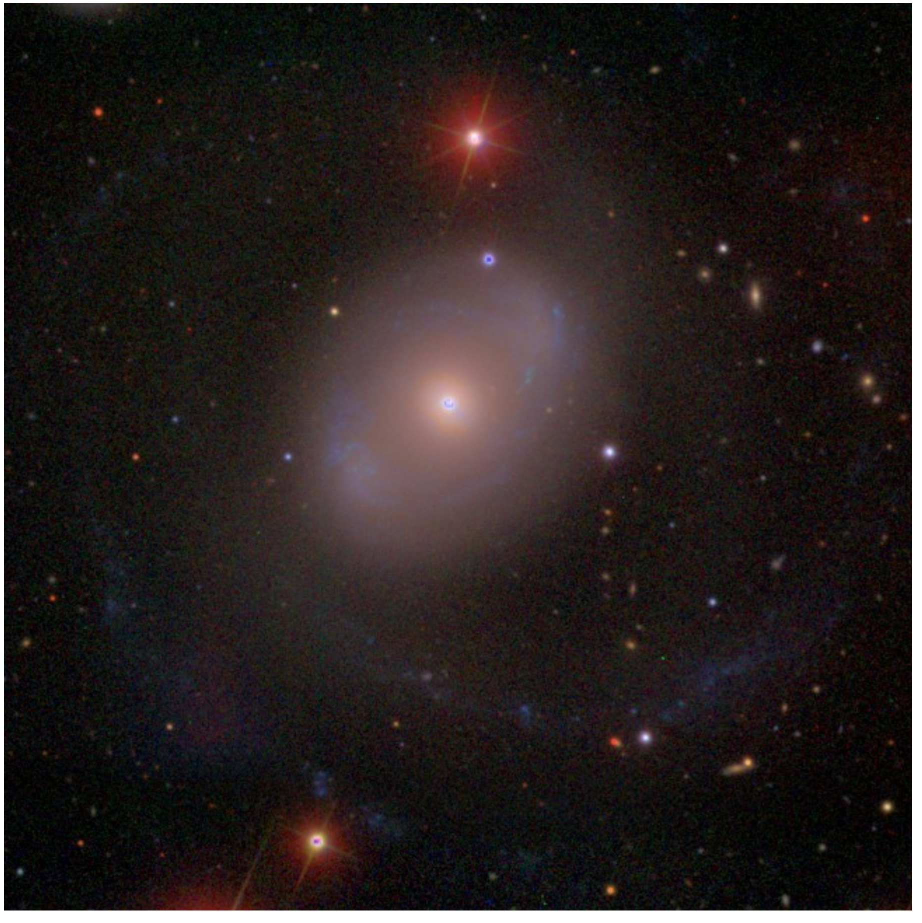


(a) **A quasar jet at radio wavelengths…** **(b)** **…and at X-ray wavelengths**

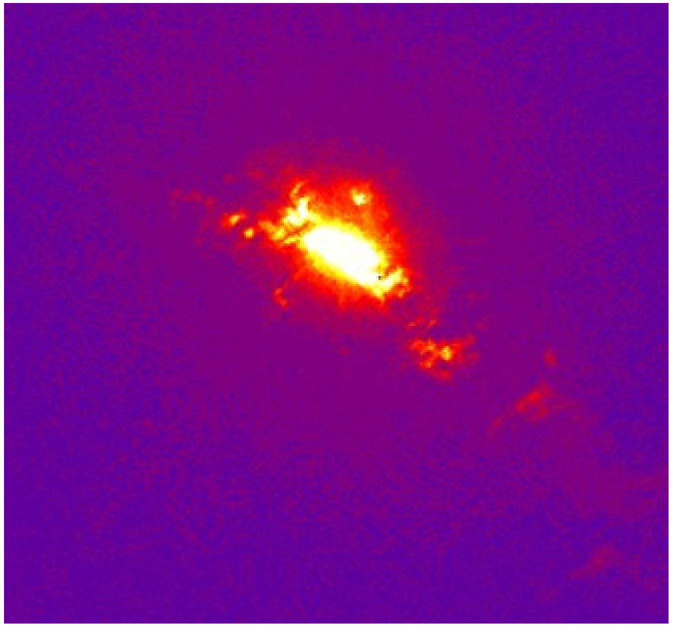
Radio VLBA

NRAO/AUI

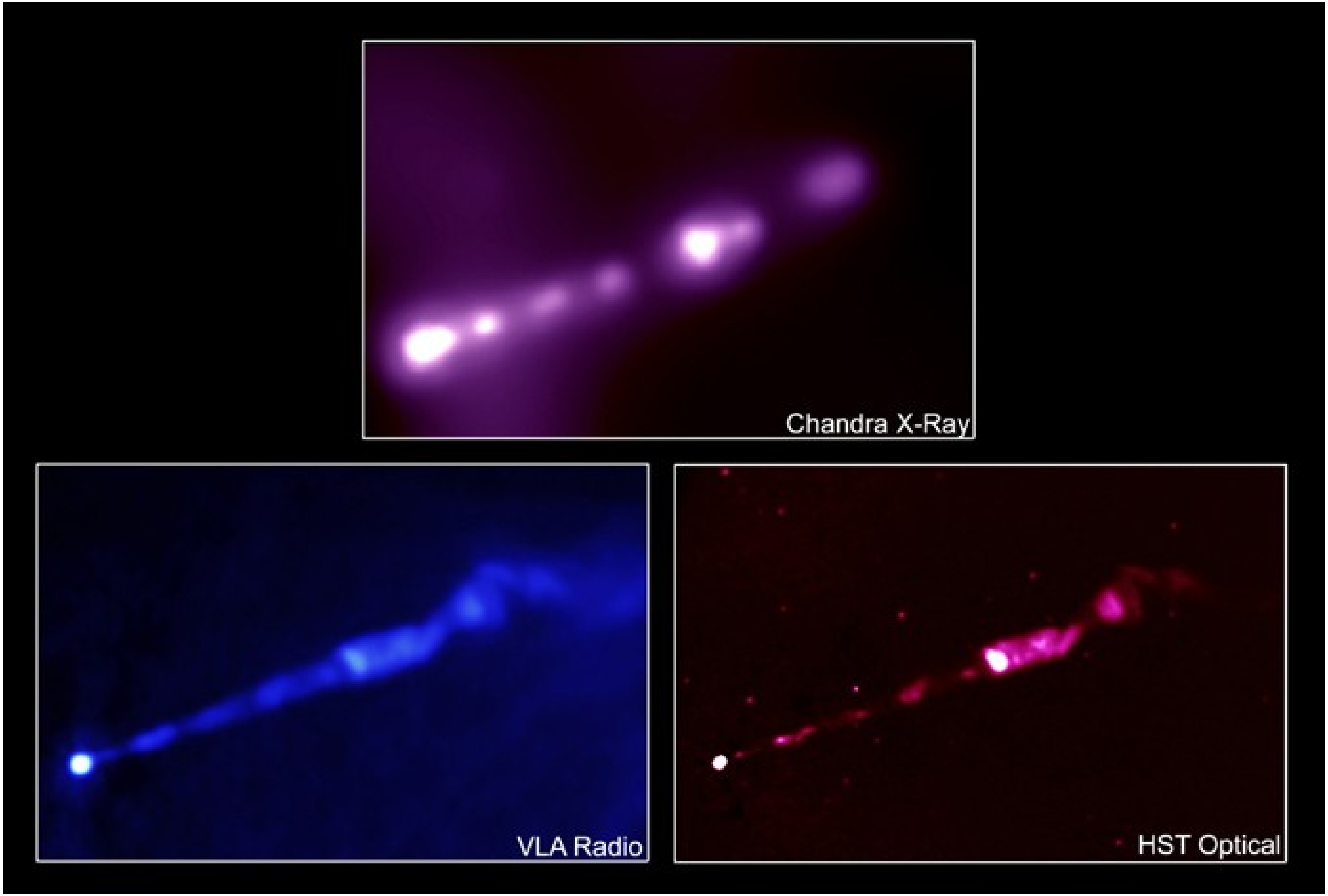




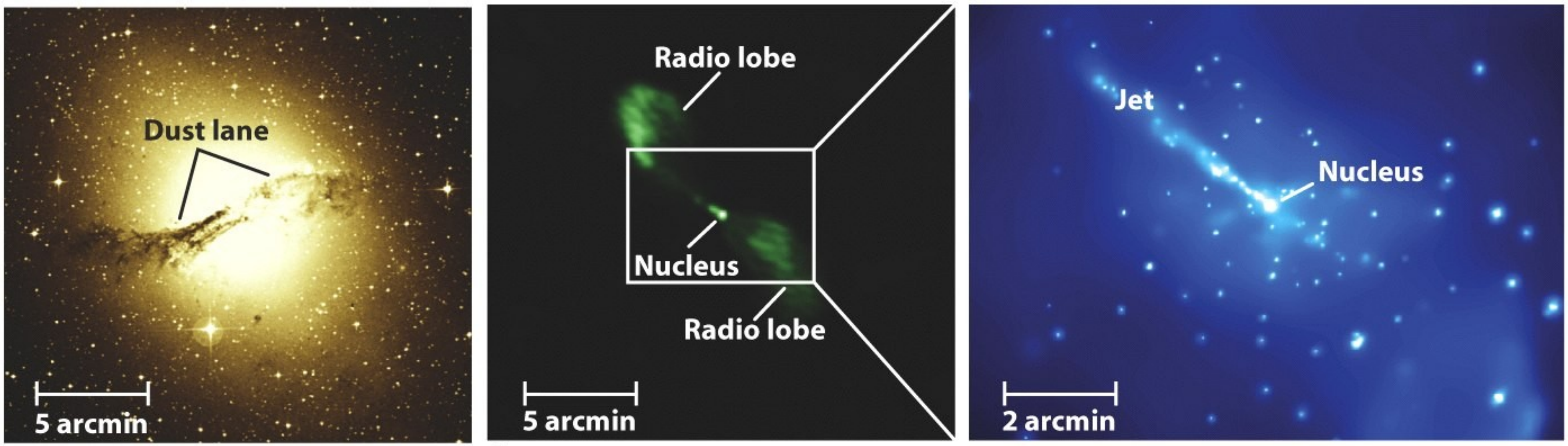
NGC 4151 Seyfert galaxy, optical



Optical HST



M87 Jet



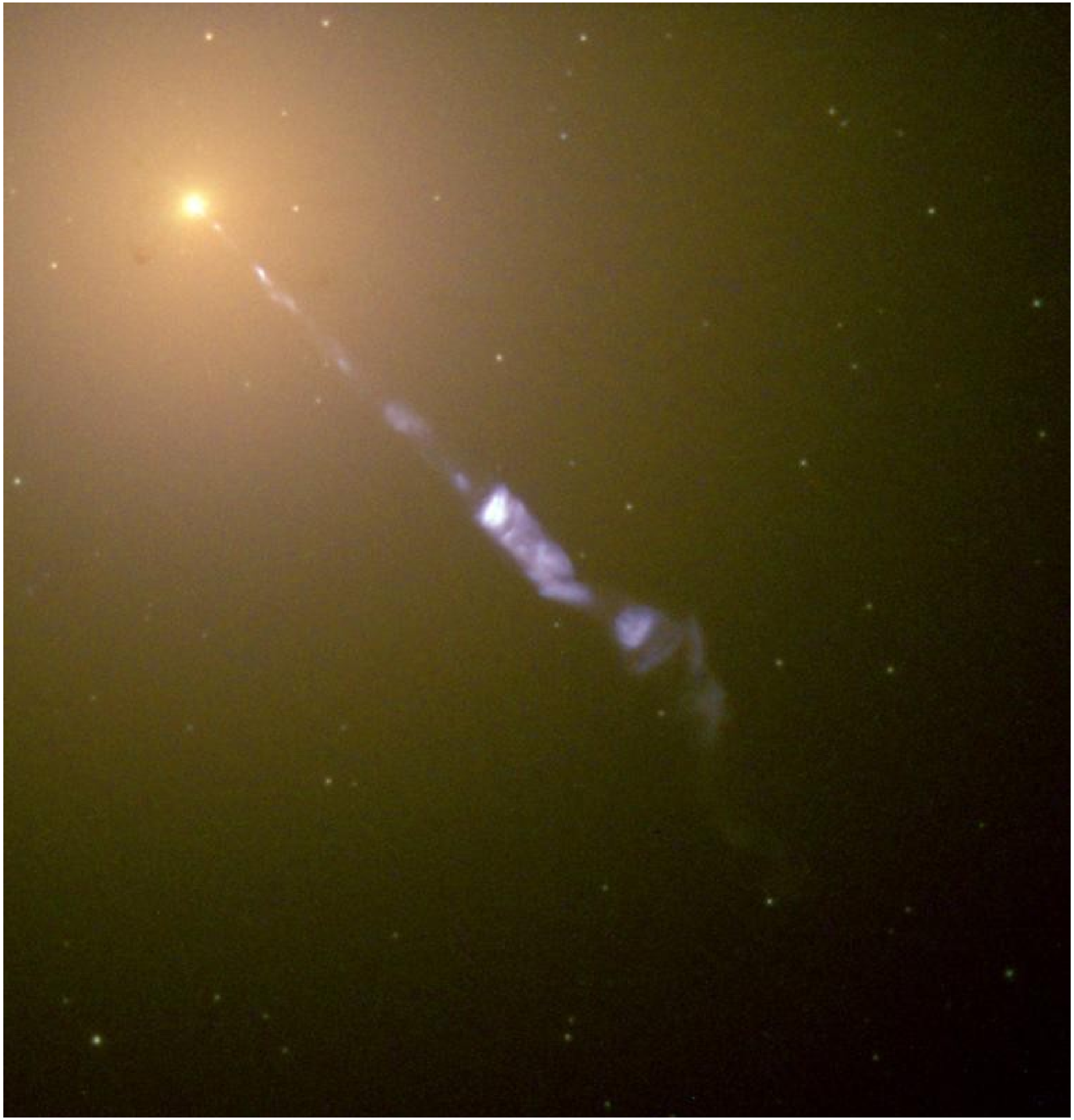
(a) Centaurus A: light from stars

(b) Centaurus A: radio lobes

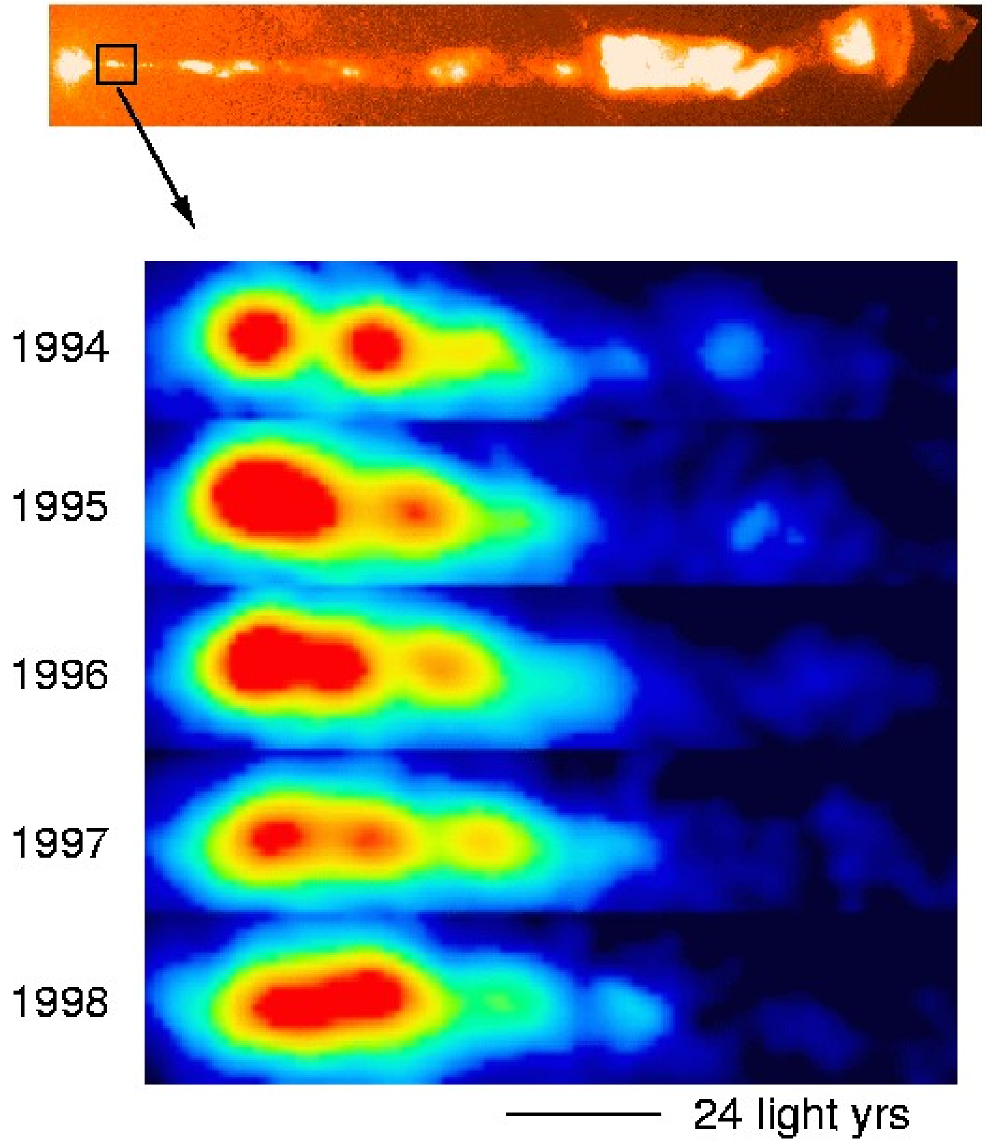
(c) An X-ray-emitting jet emanates from the nucleus

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

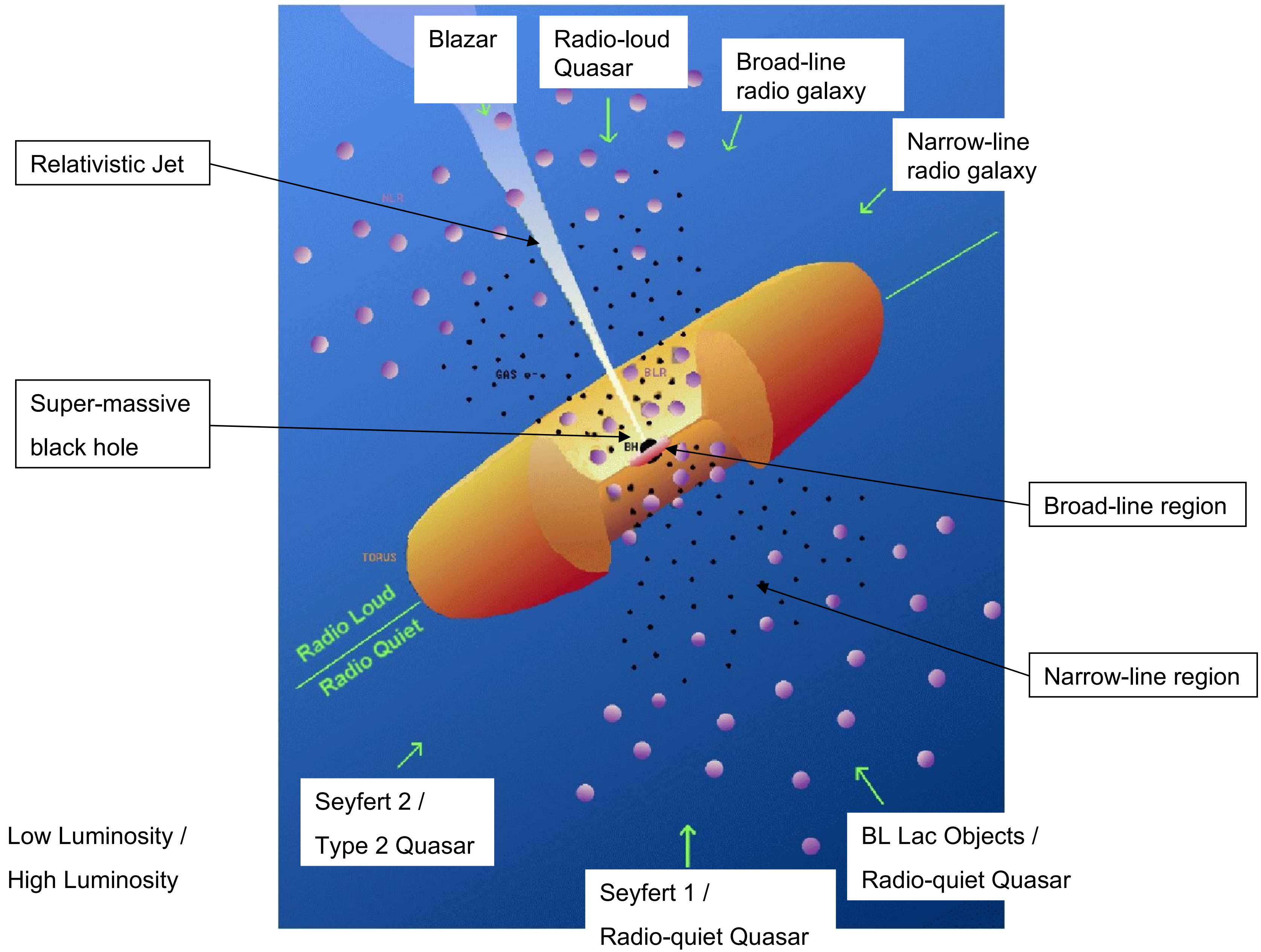


Superluminal Motion in the M87 Jet



Unified Model for AGN

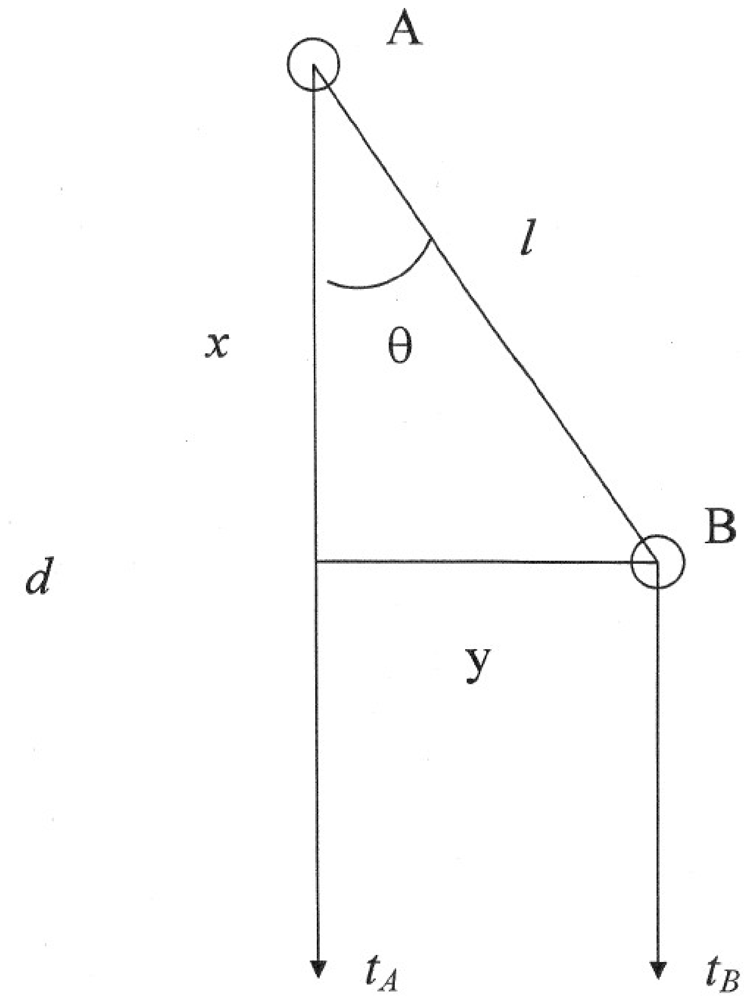
- Currently thought that all the different types of AGN can be understood as the same phenomena, but with different viewing angles and nuclear luminosities


Blazar
Radio-loud Quasar
Broad-line radio galaxy
Narrow-line radio galaxy
Relativistic Jet
Super-massive black hole
Broad-line region
Narrow-line region
GAS e-
BLR
BH
TORUS
Radio Loud
Radio Quiet
Seyfert 2 / Type 2 Quasar
Seyfert 1 / Radio-quiet Quasar
BL Lac Objects / Radio-quiet Quasar
Low Luminosity / High Luminosity

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 θ 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

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

- from geometry

$$l = vt_{\text{int}} = \beta c t_{\text{int}}$$

$$y = l \sin\theta$$

$$x = l \cos\theta$$

- So

$$v_{app} = \frac{l \sin\theta}{\left(t_{\text{int}} + \frac{(d-x)}{c}\right) - \frac{d}{c}}$$

$$= \frac{l \sin\theta}{t_{\text{int}} - \frac{x}{c}}$$

$$= \frac{\beta c t_{\text{int}} \sin\theta}{t_{\text{int}} - \frac{\beta c t_{\text{int}} \cos\theta}{c}}$$

$$= \frac{\beta \sin\theta}{1 - \beta \cos\theta} c$$