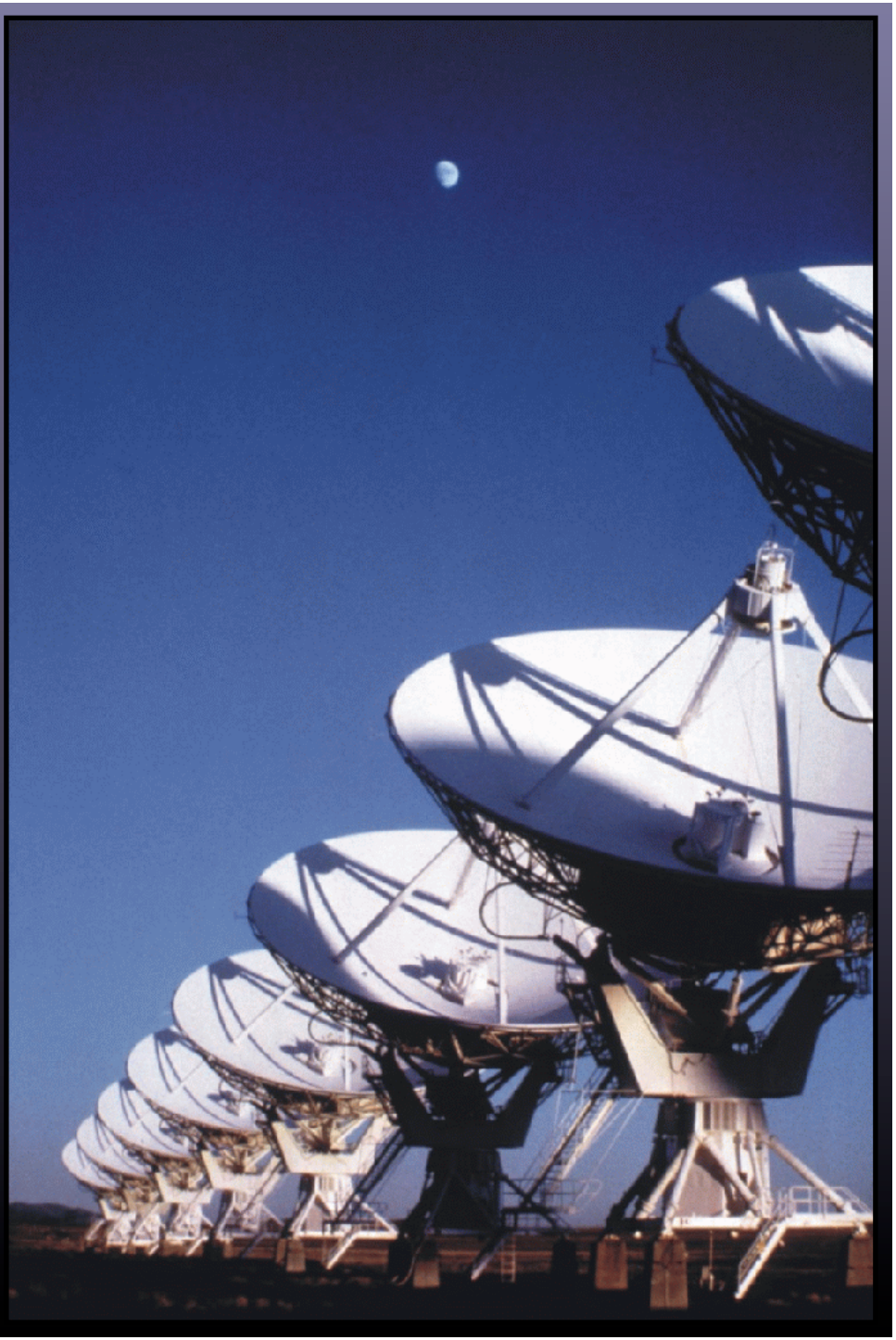
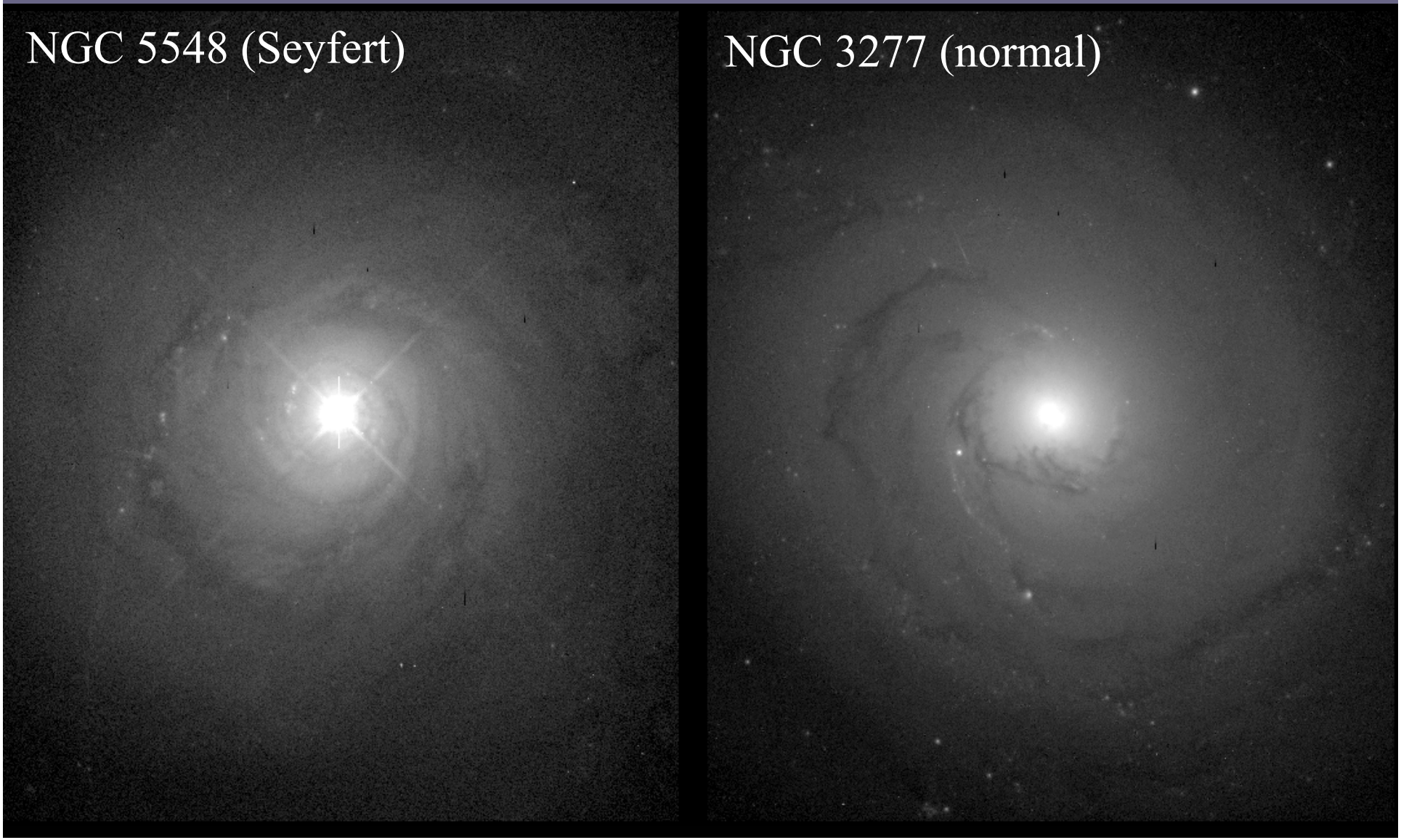
Active Galaxies



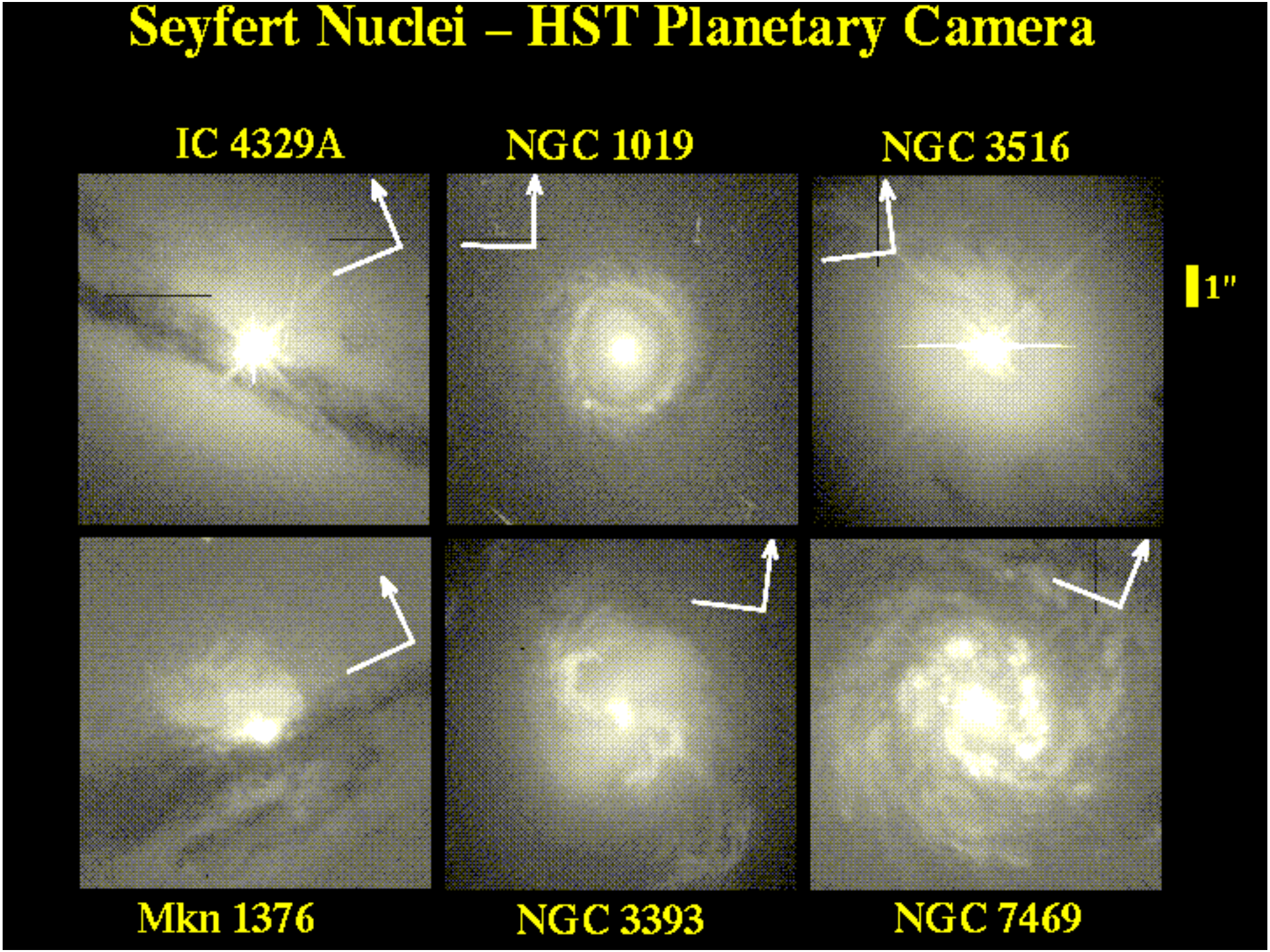
Outline

- Normal (boring) galaxies
- Active (fun) galaxies
- The extragalactic zoo: Quasars, Blazars, Radio Galaxies, BL Lacs, Seyferts, Optically Violent Variables, GHz Peaked Spectrum, Compact Symmetric Objects, ...
- Components of an active galaxy
  - Supermassive Black Holes
  - Jets
  - Hot spots and the evolution of radio galaxies

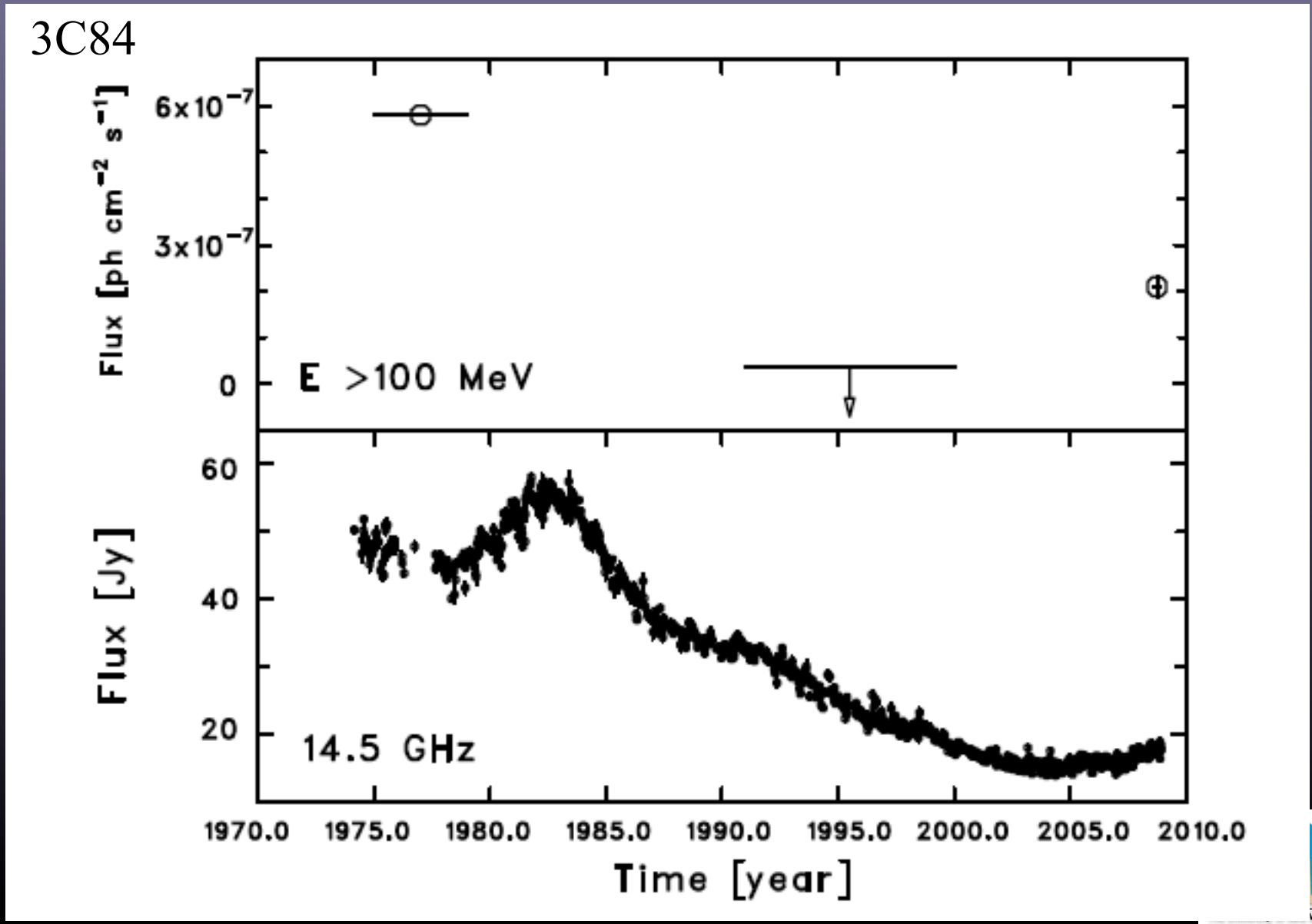
Seyfert vs Normal Galaxy



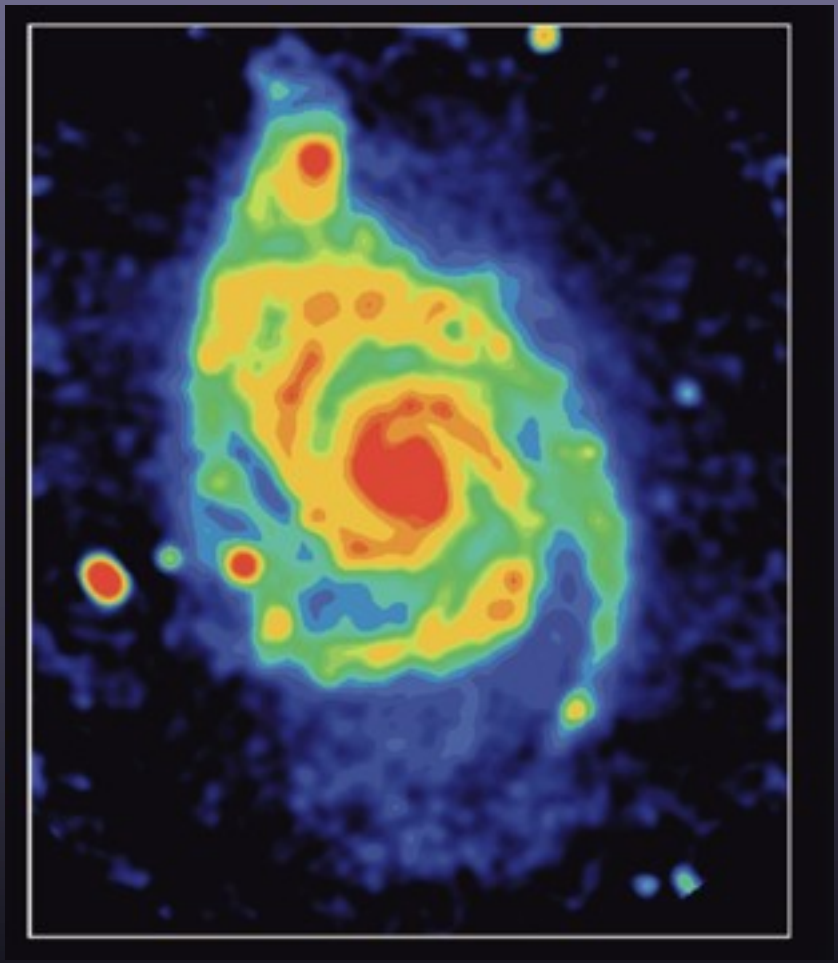
Seyfert Nuclei – HST Planetary Camera



Variability



Normal Galaxies in Radio Continuum



M51 - Beck et al.

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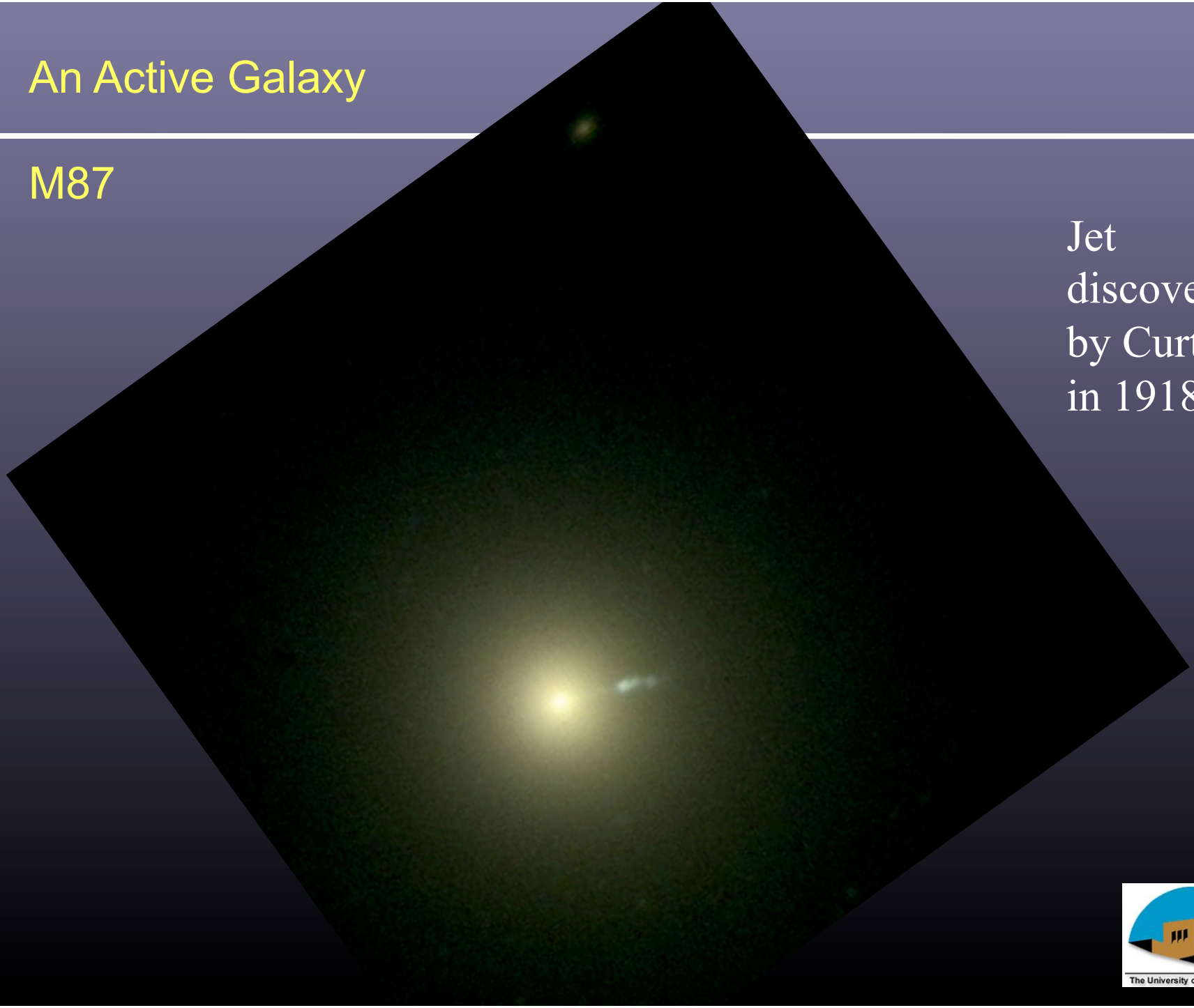
An Active Galaxy

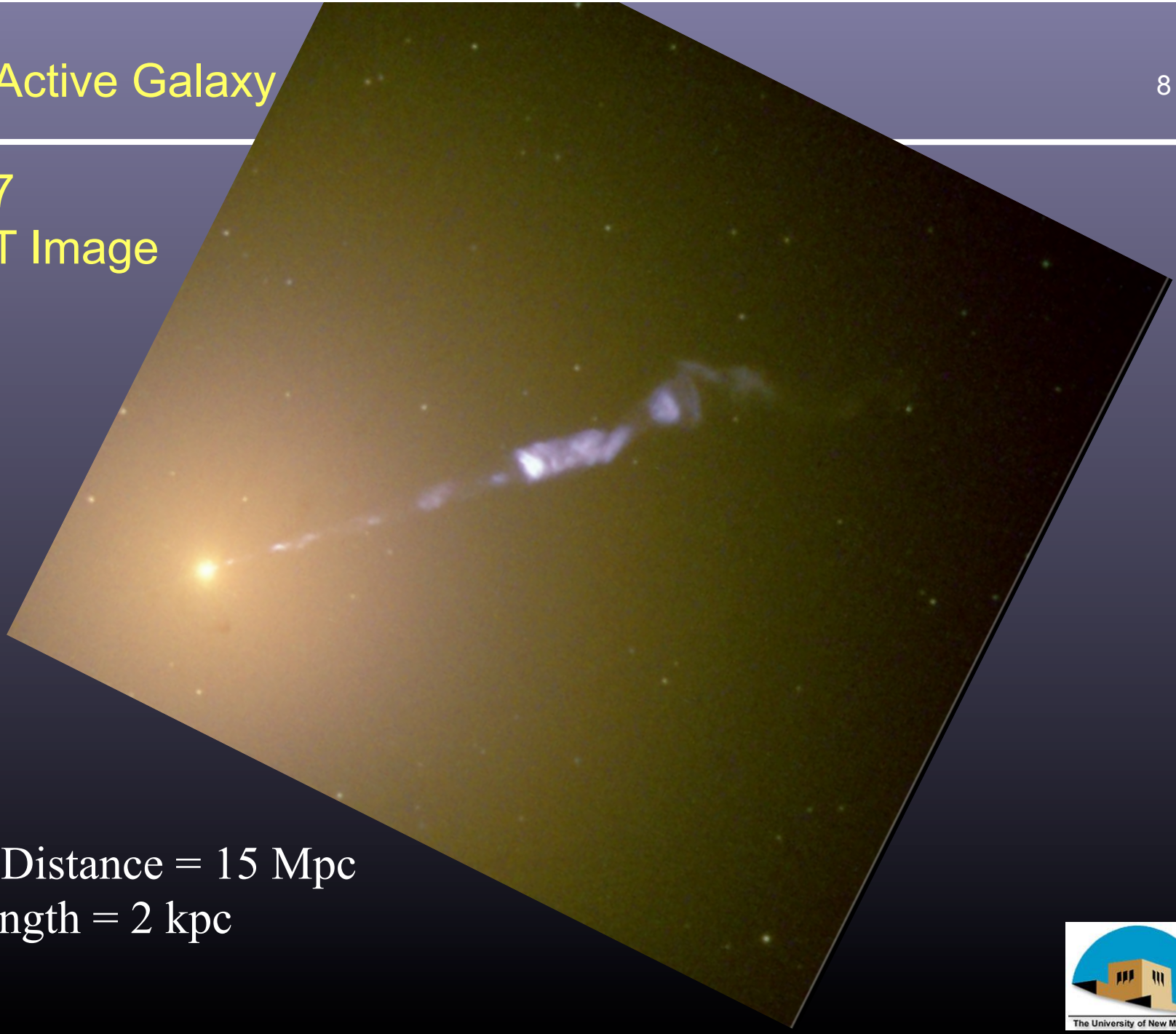
M87



Jet discovered by Curtis in 1918

An Active Galaxy

M87
HST Image



M87 Distance = 15 Mpc
Jet length = 2 kpc

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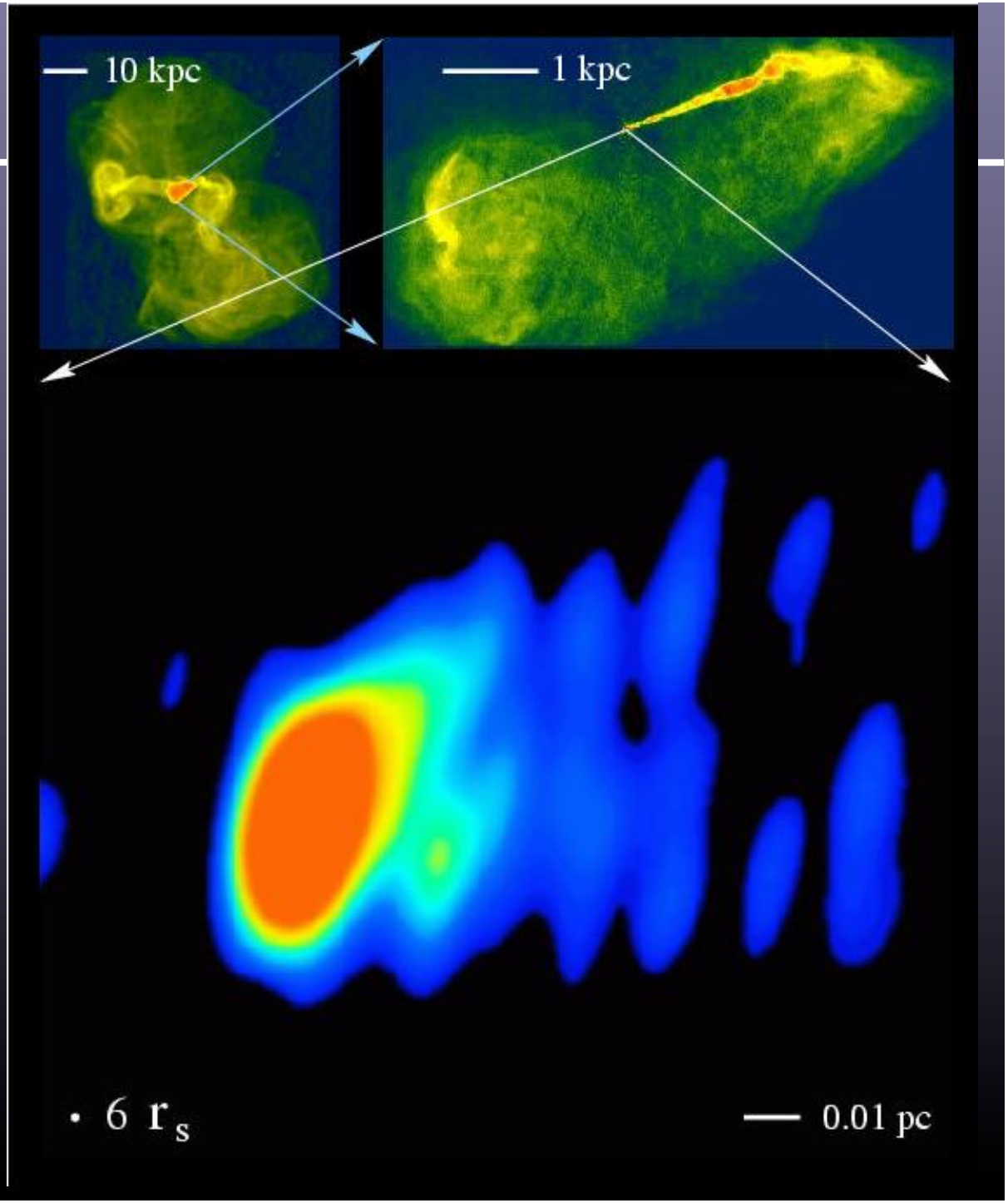
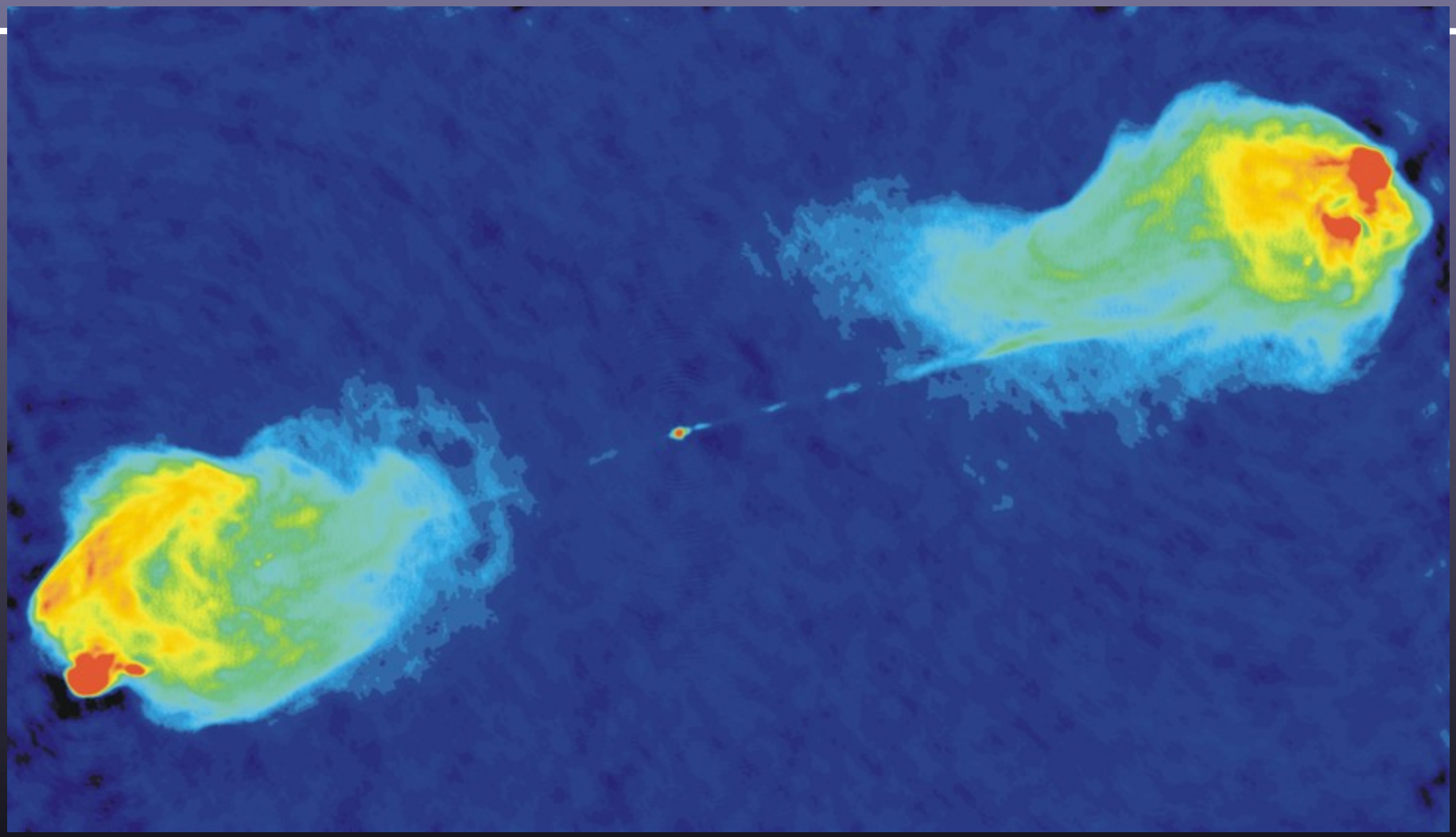
An Active Galaxy

M87
VLA and VLBA
Radio Images



Cygnus A – prototypical radio galaxy -- FR II



Carilli et al.

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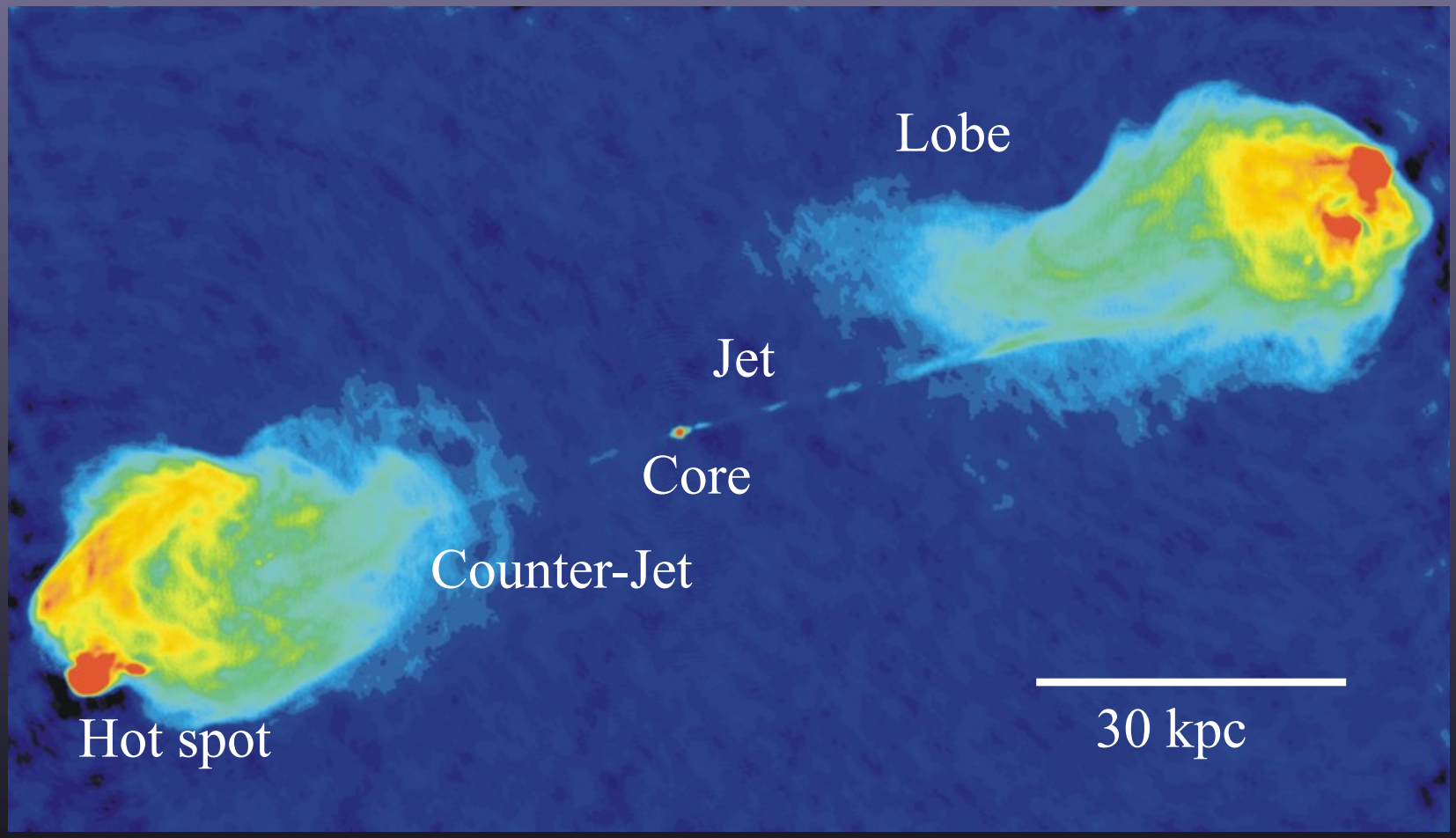
Components of an AGN



"core" contains the central engine

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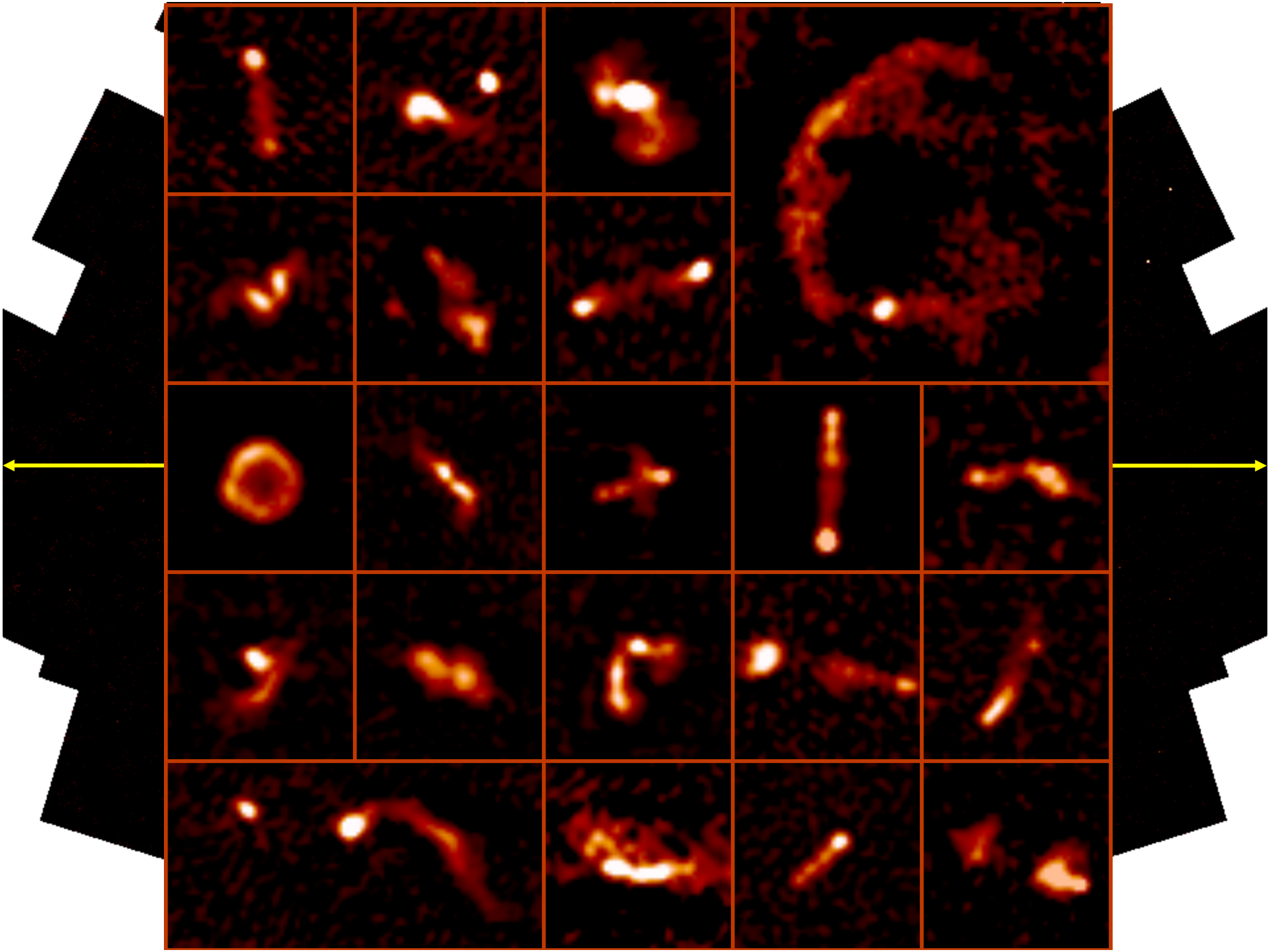
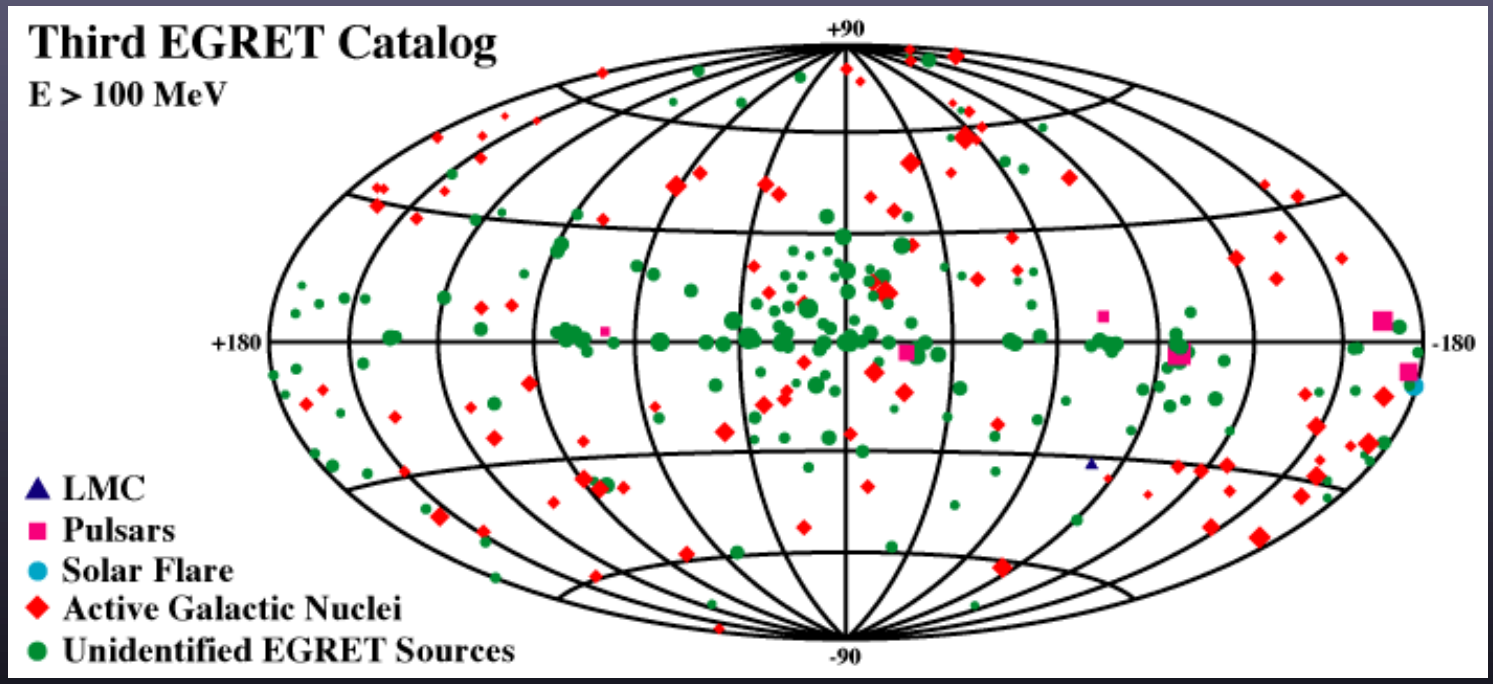


The EGRET Era

AGN dominate the extragalactic high-energy sky

- 67 Blazars
- marginal detection of a couple of radio-galaxies



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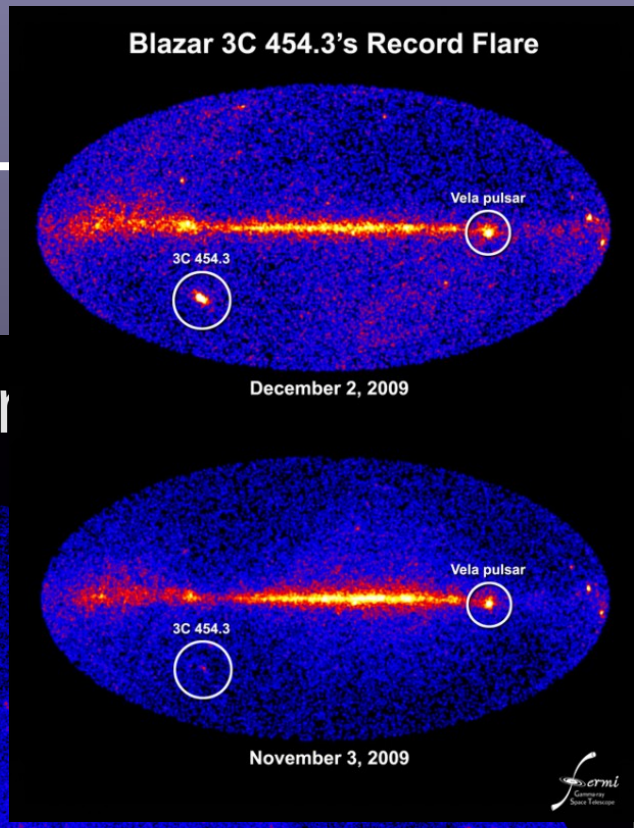
The Fermi Era

1000 Blazars + Many radio-galaxies



Fermi two-year all-sky

Credit: NASA/DOE/Fermi/LAT Collaboration

Clicker Question:

What is the ultimate energy source in an Active Galaxy?

A: Nuclear fusion in stars.

B: Nuclear fission in stars.

C: Accretion of material onto a supermassive black hole.

D: Direct conversion of matter into energy in the hot spots.

Clicker Question:

The end of the Jet in a radio galaxy is usually marked with a:

A: hot spot.

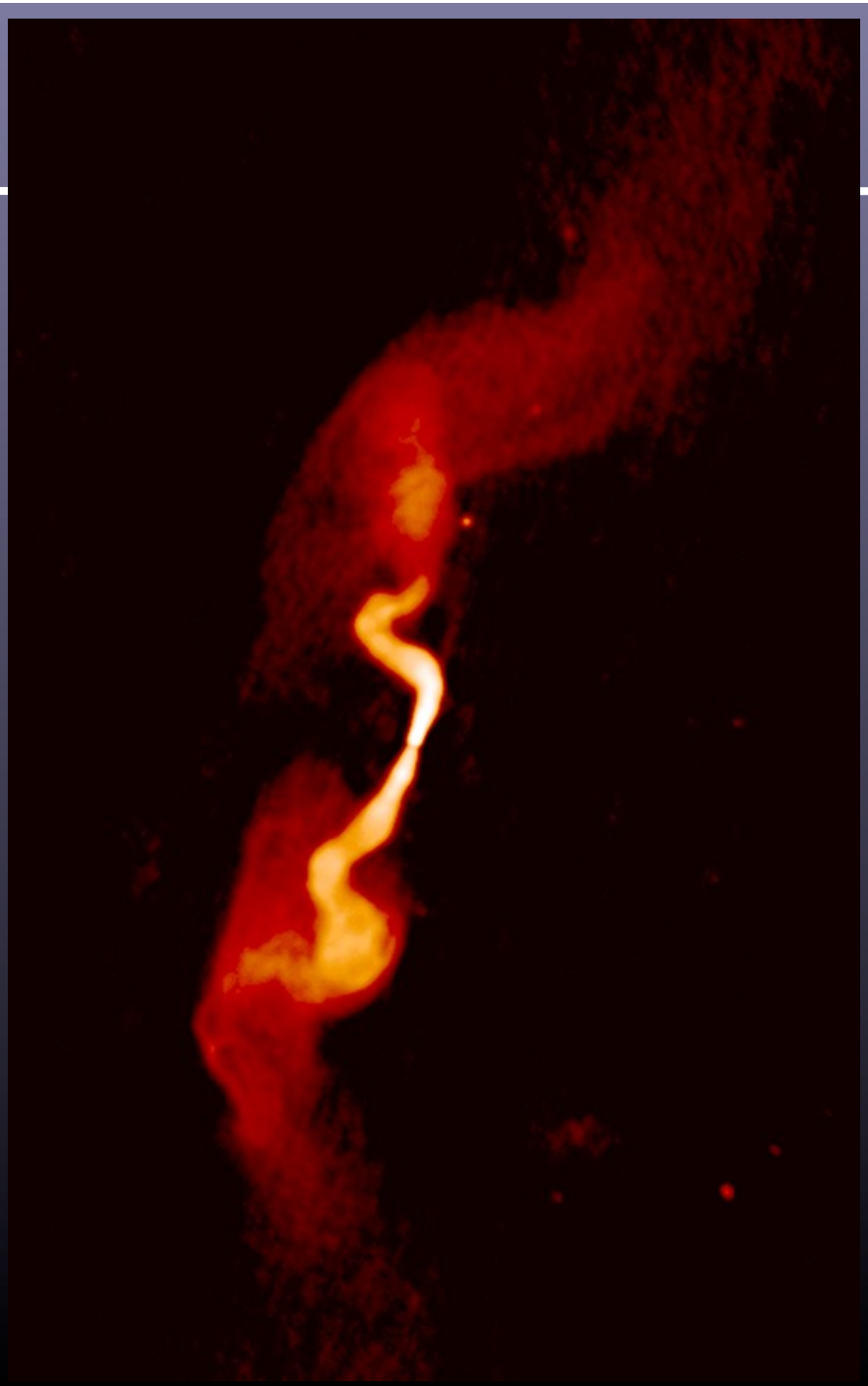
B: lobe.

C: core.

D: 'X'

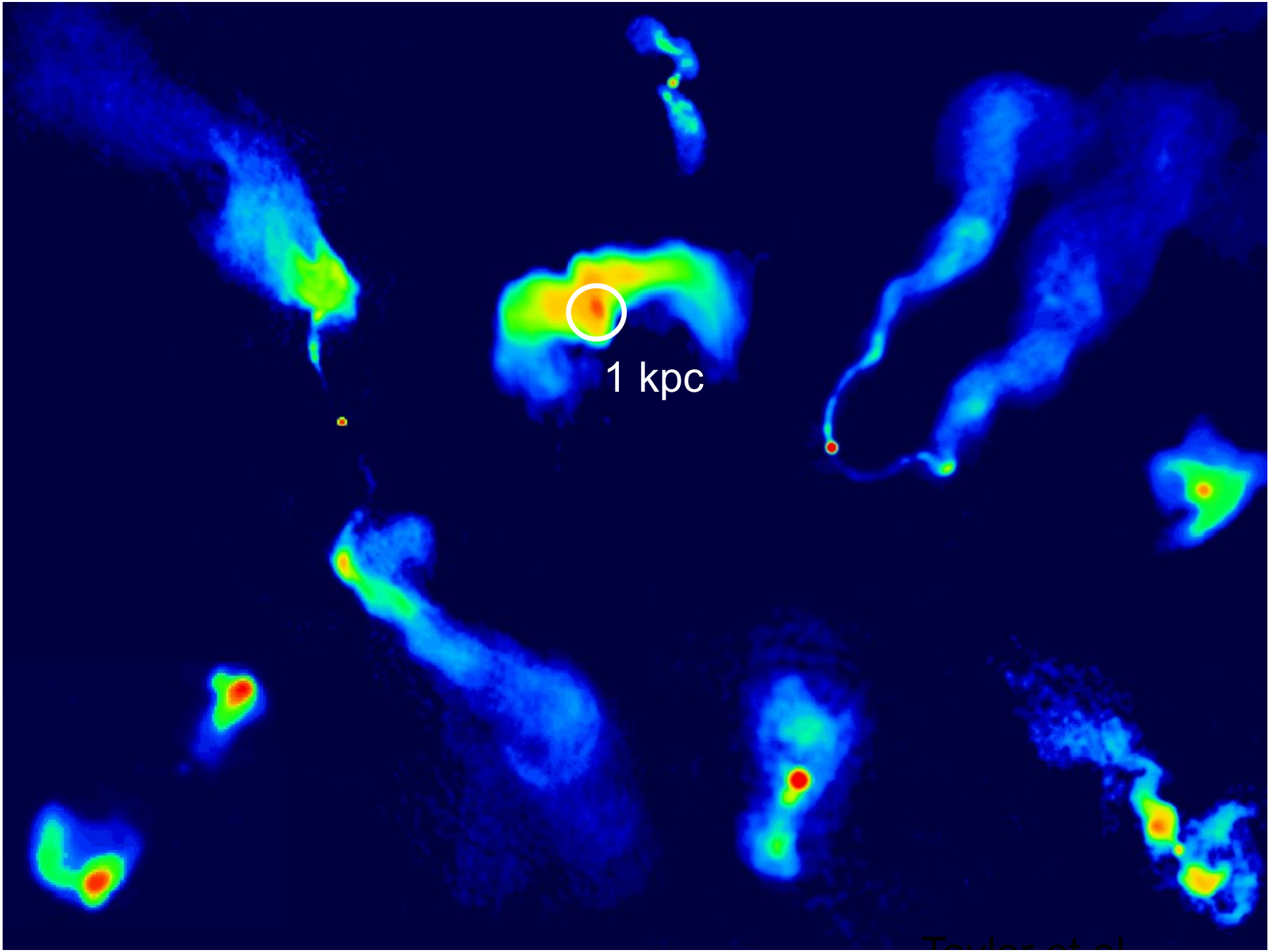
An Active Galaxy

3C31
FR I

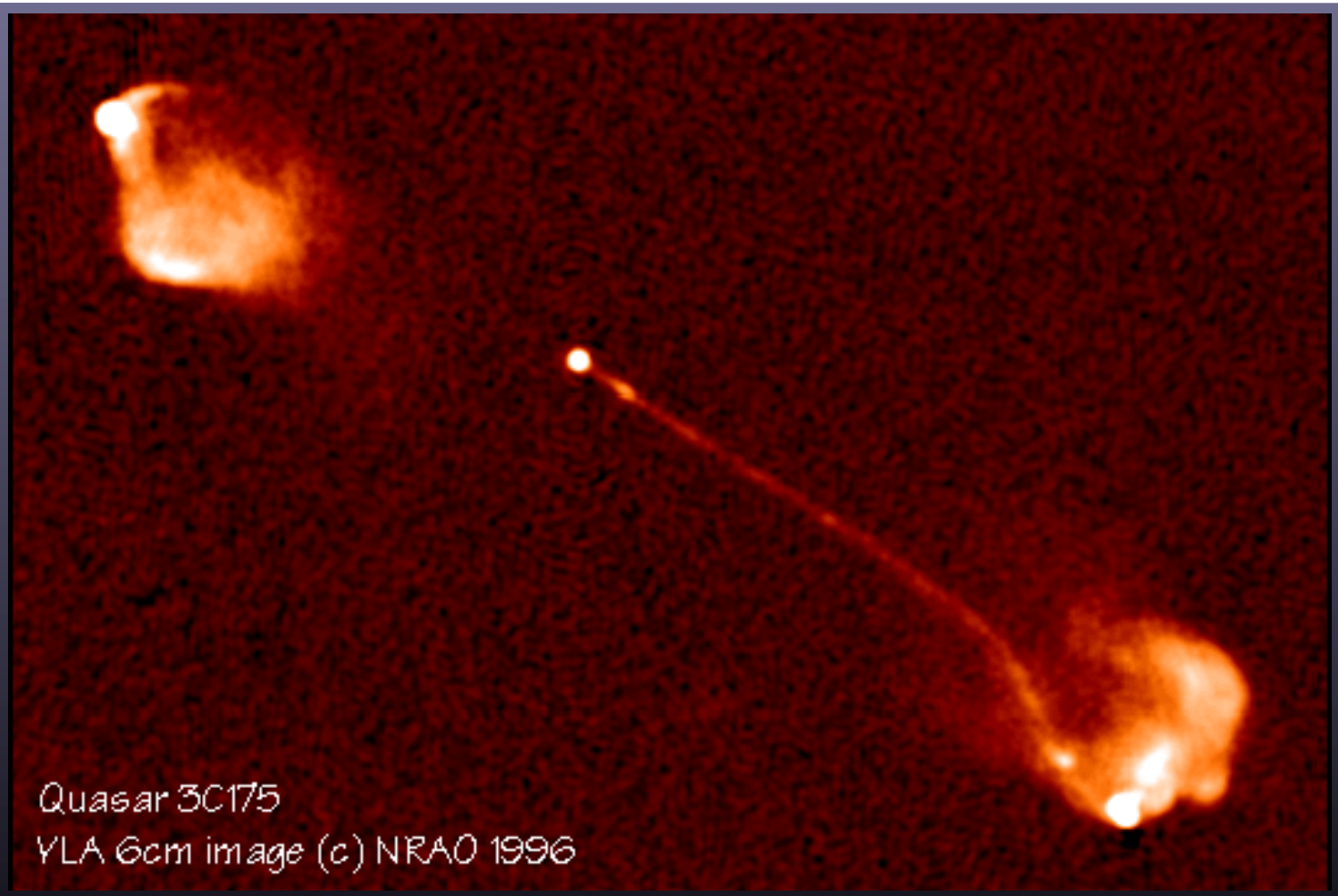


Laing et al.

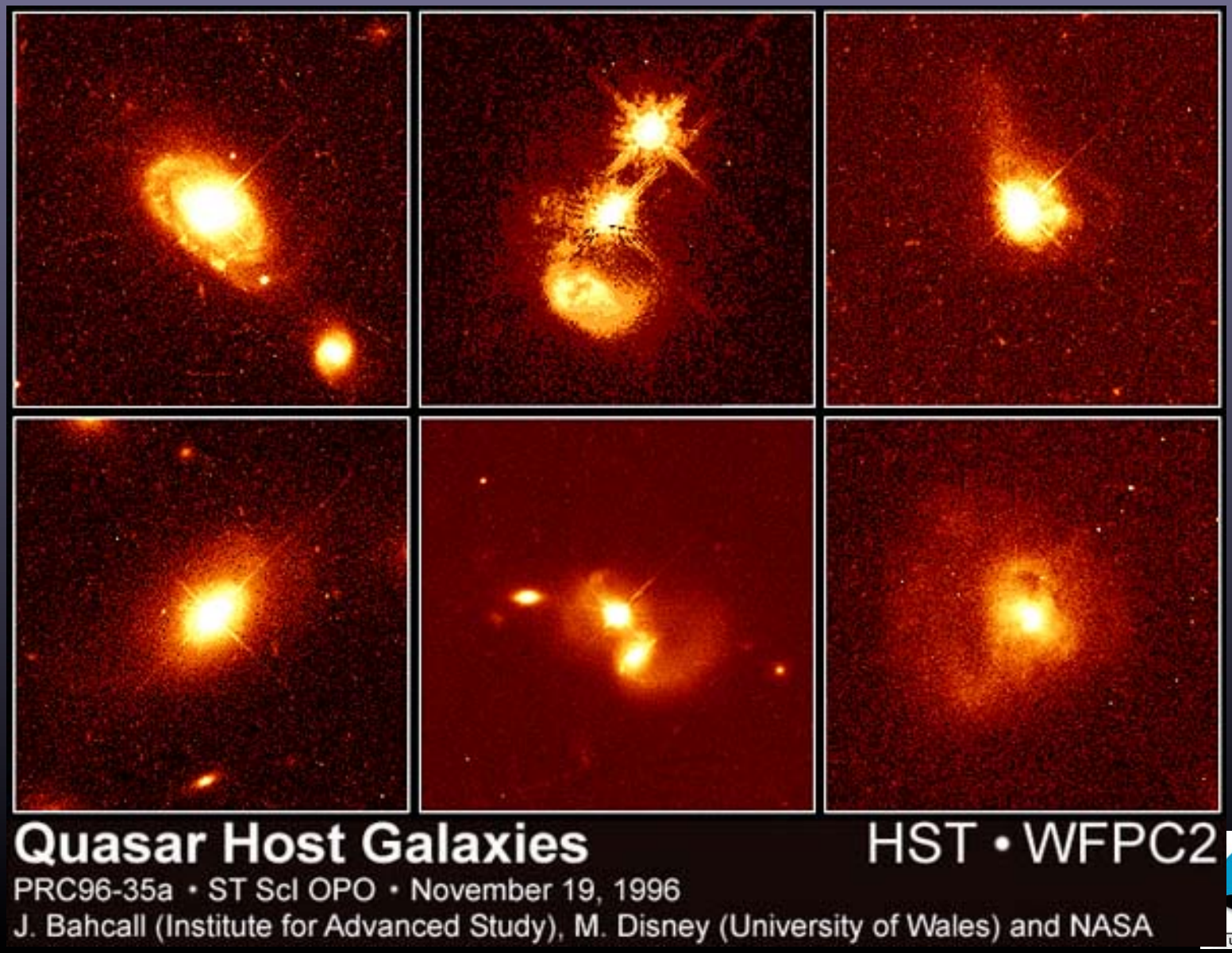
The University of New Mexico


1 kpc

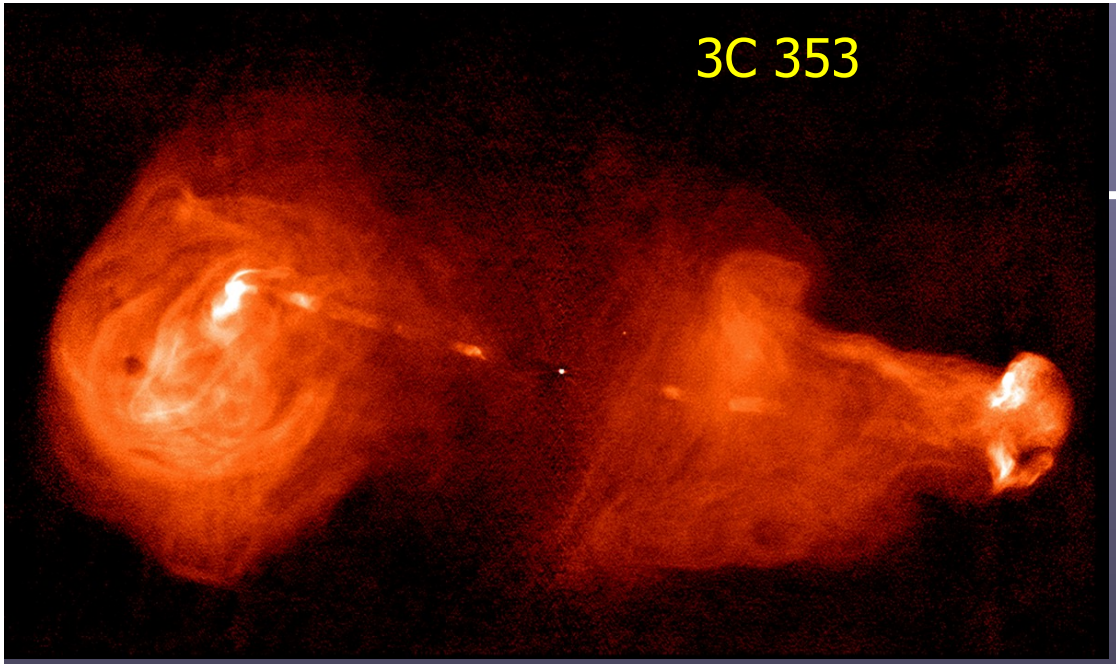
Quasar

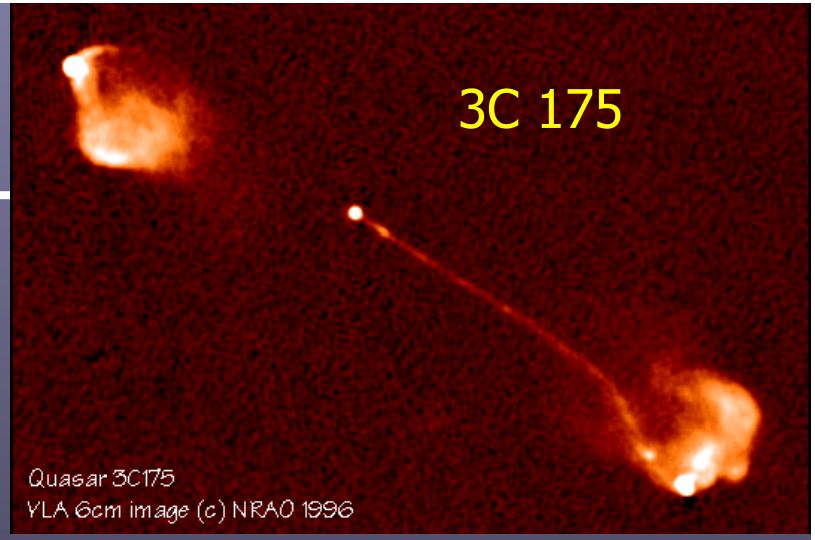


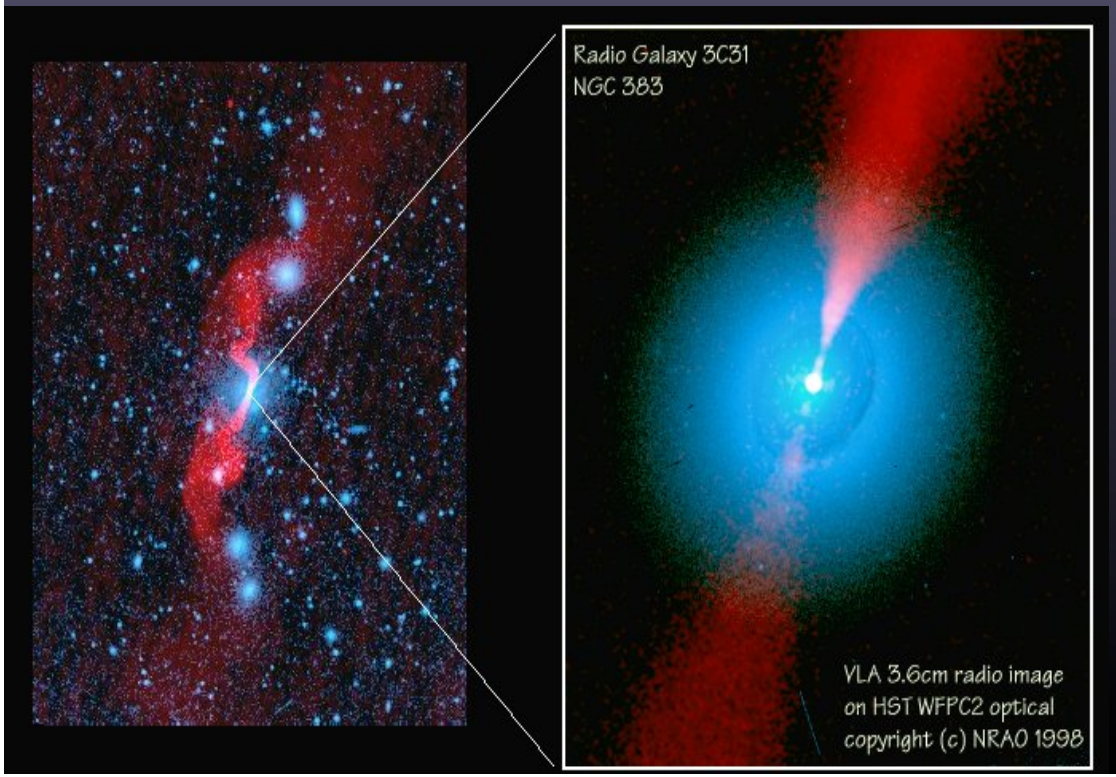
Quasar Host Galaxies

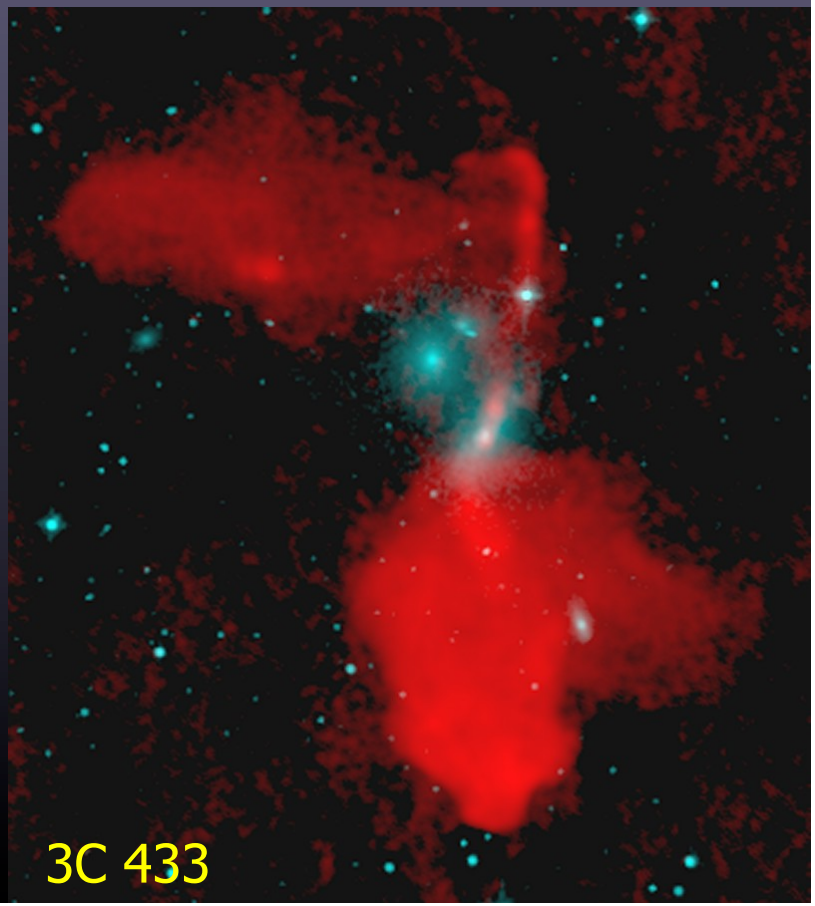


University of New Mexico


3C 353

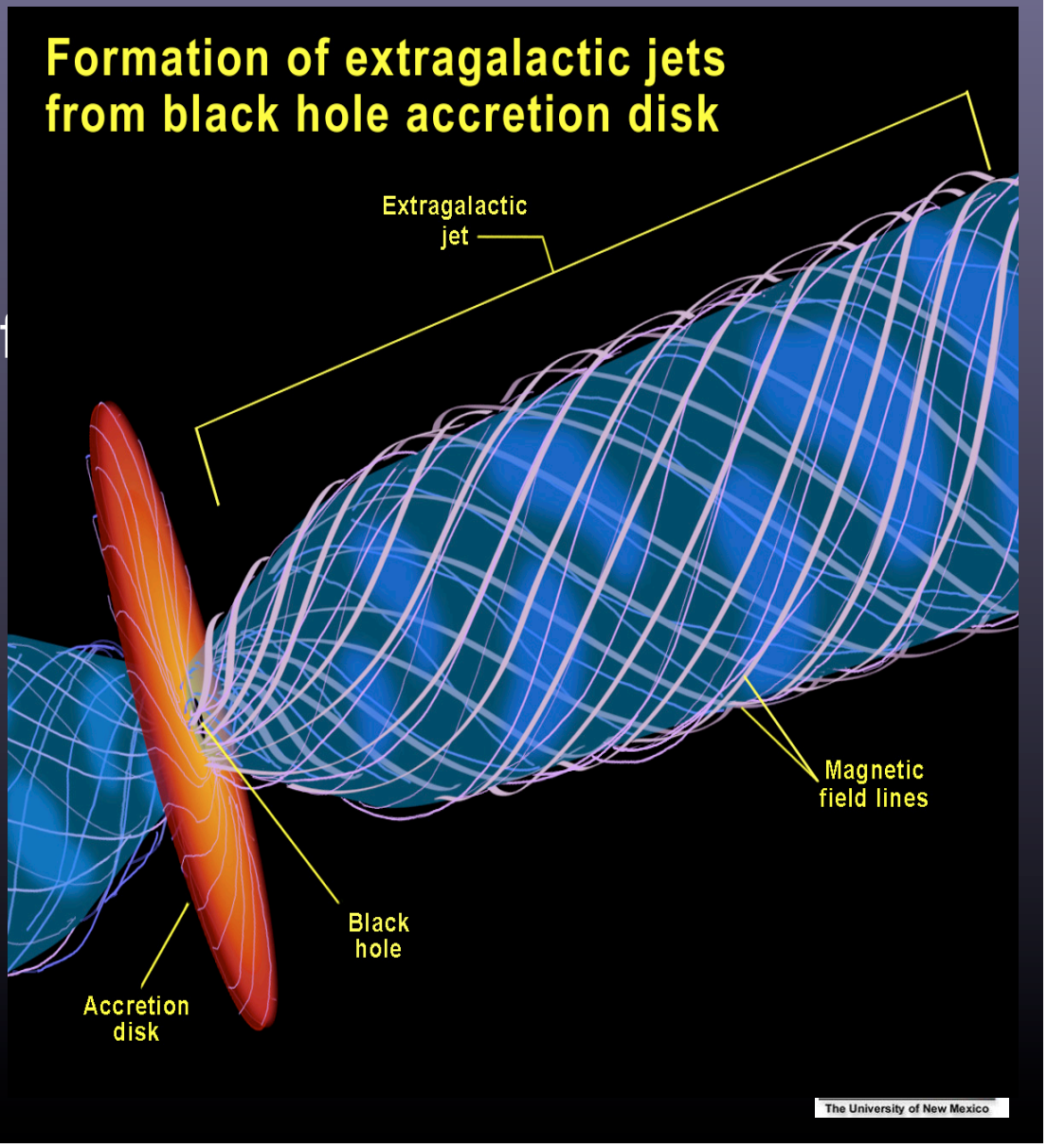

3C 175
Quasar 3C175
VLA 6cm image (c) NRAO 1996


Radio Galaxy 3C31
NGC 383
VLA 3.6cm radio image
on HST WFPC2 optical
copyright (c) NRAO 1998

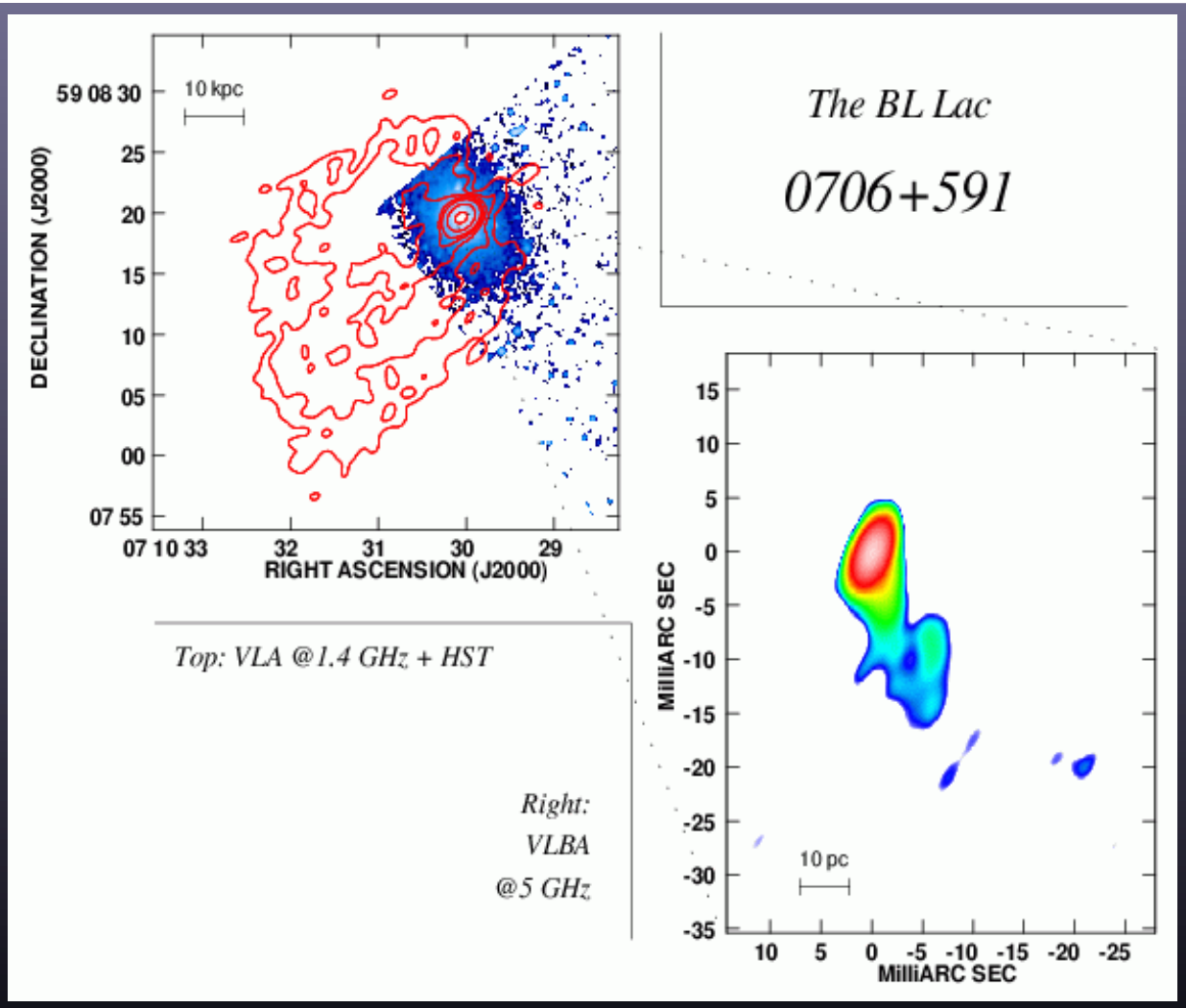

3C 433

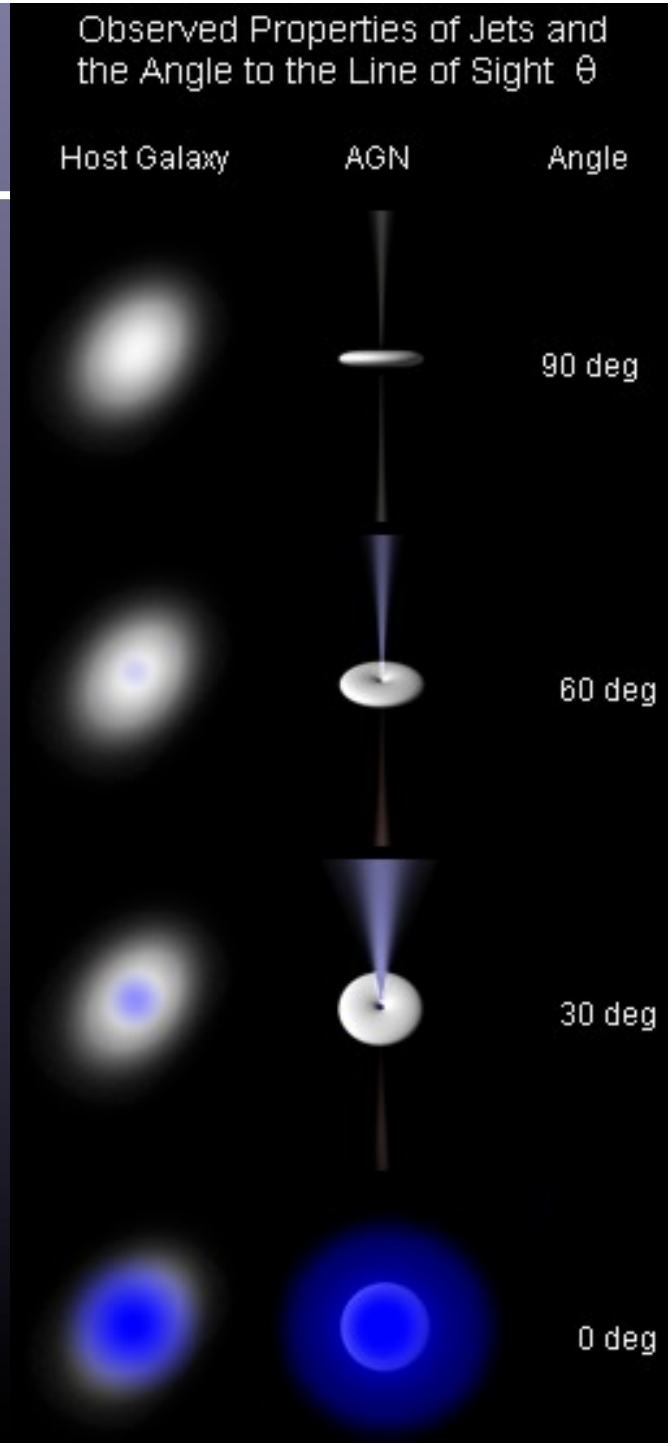
Radio Jets - Theory

- Accretion of gas onto a massive central black hole releases tremendous amounts of energy
- Magnetic field collimates outflow and accelerates particles to close to the speed of light



BL Lac object

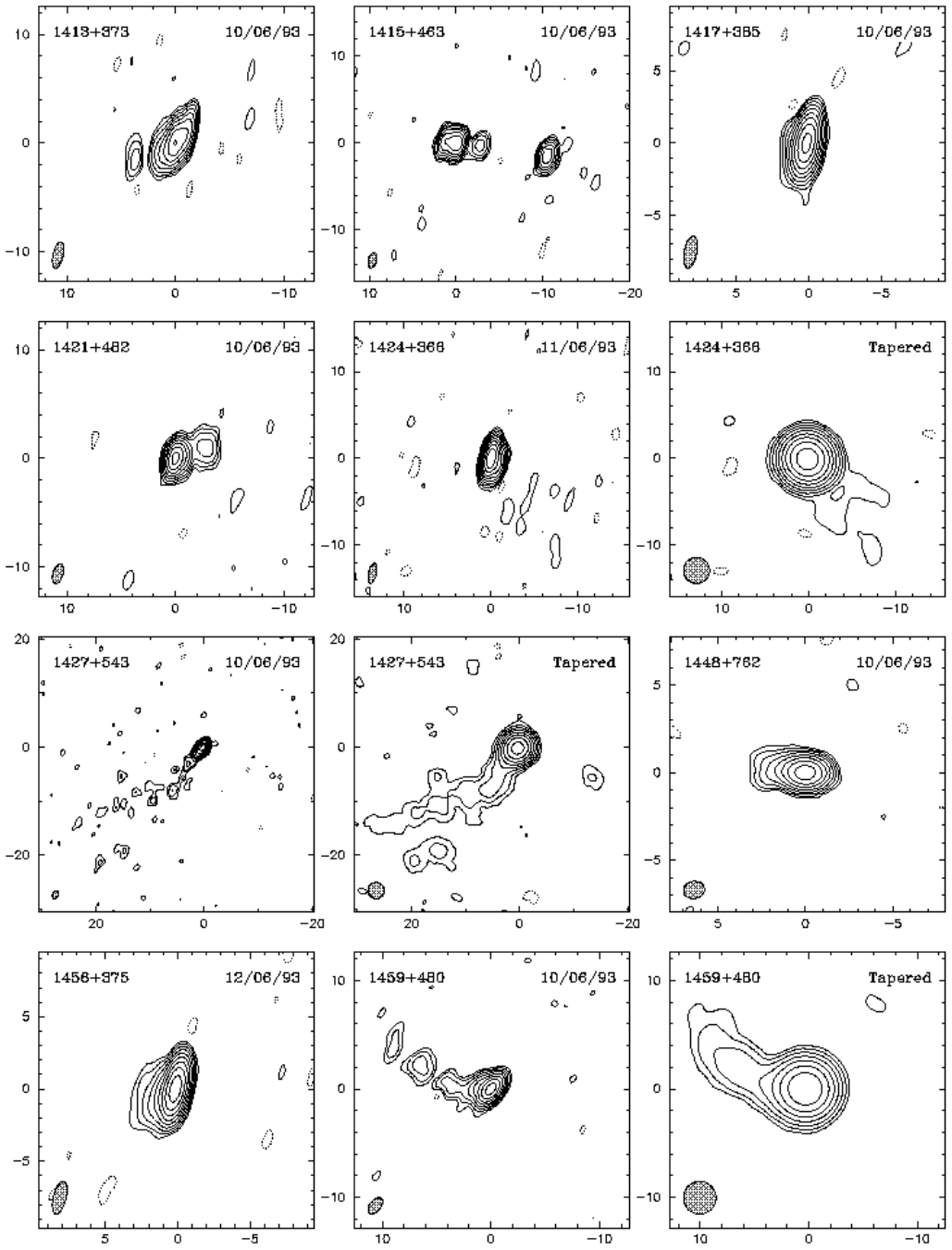




Giroletti et al 2004

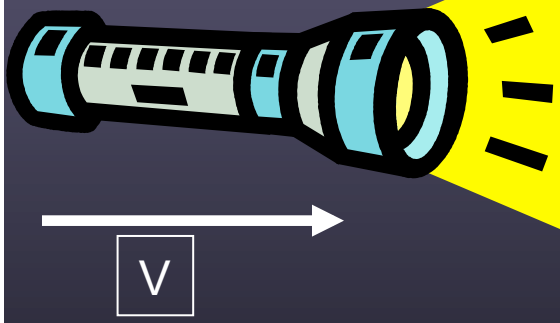
VLBA Images At 5 GHz

Taylor et al. 1994



30 pc

Headlight effect



- Beam becomes focused.
- Same amount of light concentrated in a smaller area
- Flashlight appears brighter!

Superluminal motion

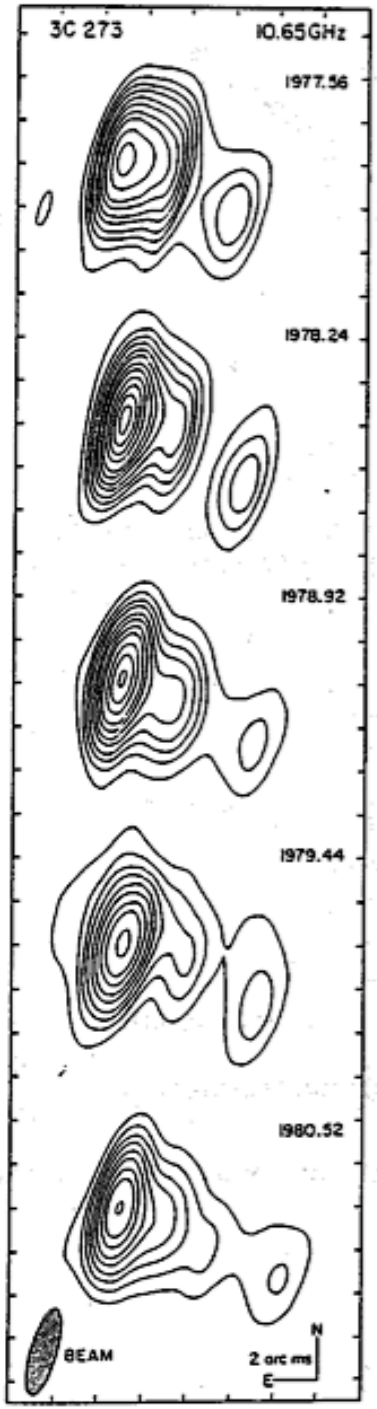
Pearson et al. 1981

Constant expansion observed for 3C273 at
Rate = 0.76 +/- 0.04 milliarcseconds/year

Redshift z=0.158 so D = 704 Mpc
Assuming H_0 = 75 km/s/Mpc

1 milliarcsecond = 2.5 pc at 704 Mpc

Velocity = 2.5 pc/mas * 0.76 mas/y
= 2 pc/year * 3.26 light-year/pc
= 6.5 light-year/year
= 6.5 c !!!



Clicker Question:

Most compact jets are one-sided because:

A: The jets are intrinsically one-sided (like a jet from a hose).

B: The jets are strongly beamed and one side is pointing closer to us.

C: On one side they are compressed as they run into material in the interstellar medium.

D: Gravitational lensing by the supermassive black hole.

Clicker Question:

Some extragalactic jets have components that appear to move faster than light (superluminal motion). This happens because:

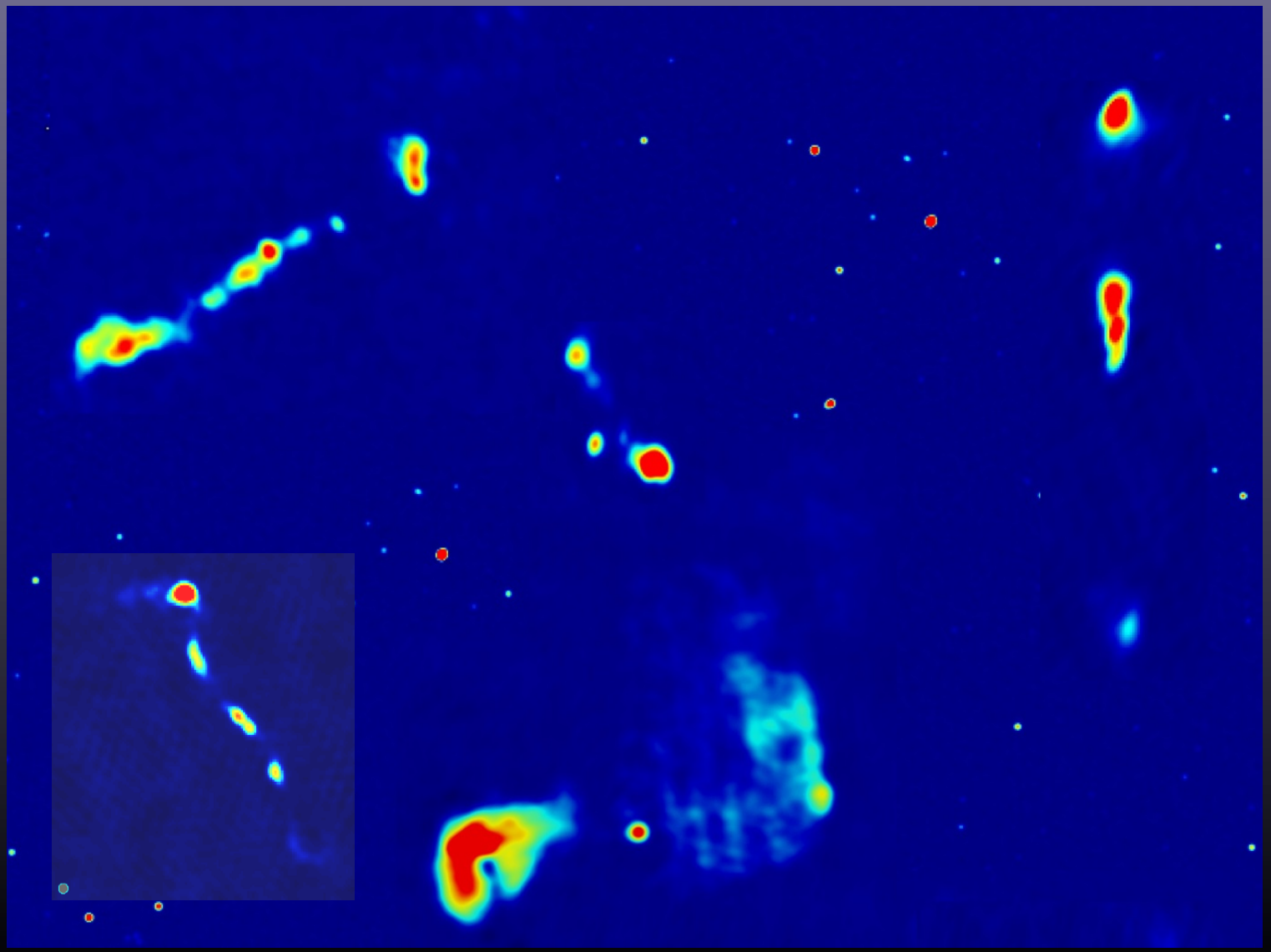
A: Its an illusion because the jets are pointed at us and moving close to the speed of light.

B: The jets come out of a black hole.

C: The jets are very light.

D: The jets are made of tachyons.

Compact Symmetric Objects (CSOs)



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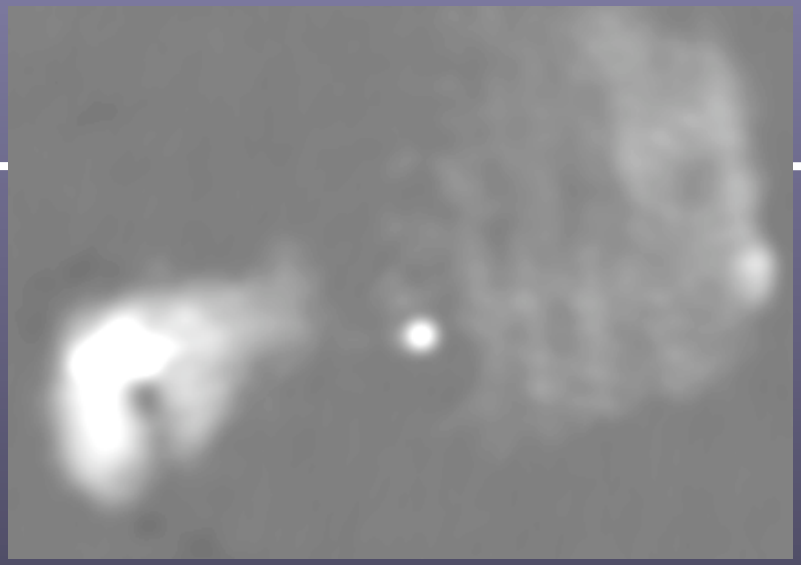
Evolution



100 pc

4C31.04

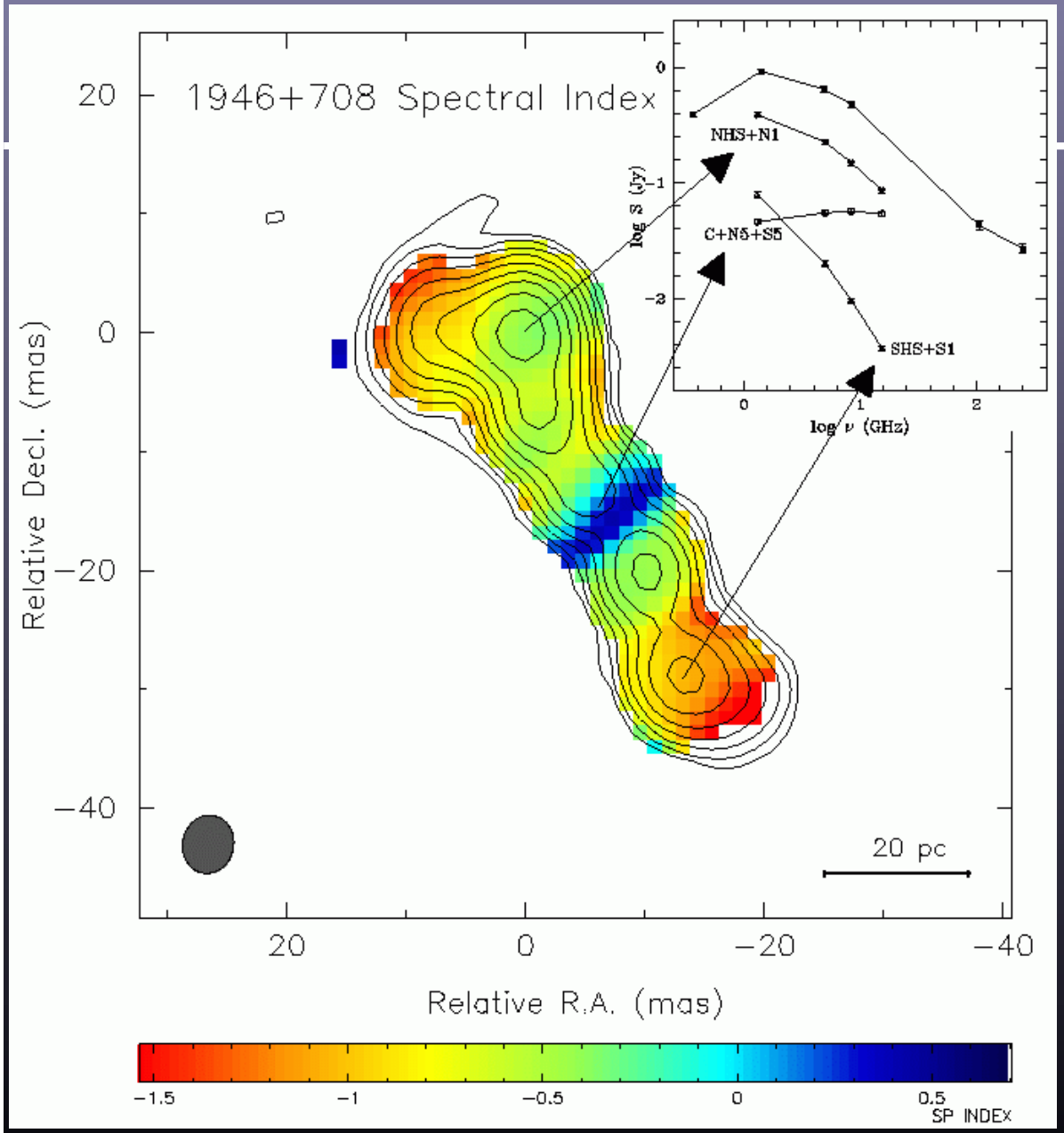
?

100 kpc

Cygnus A

The University of New Mexico

Free-free absorption in 1946+708



Peck & Taylor (2001)

Spectral index map from 1.3/5 GHz VLBI observations

The University of New Mexico

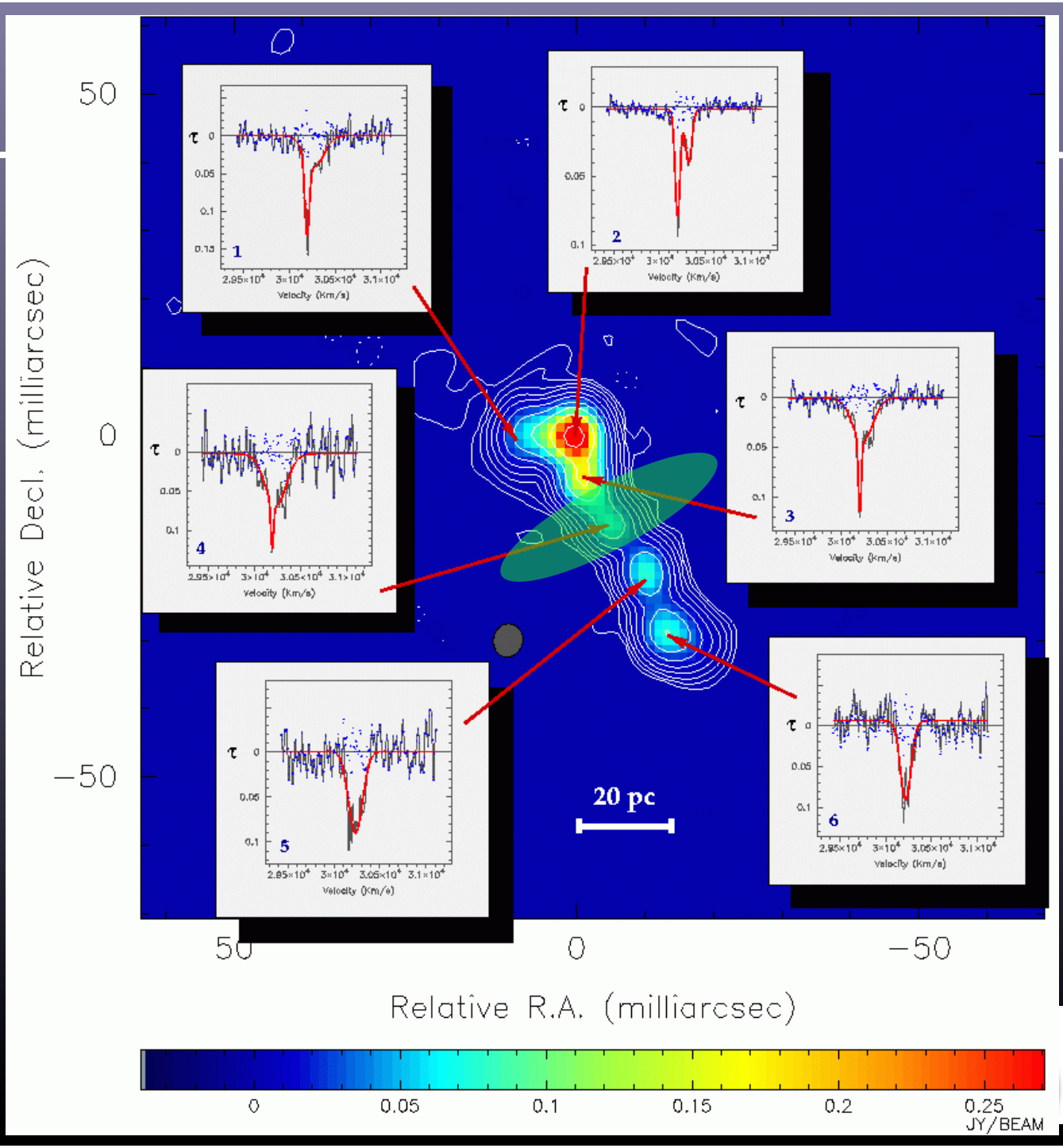
HI absorption in 1946+708

Peck & Taylor (2001)

"Global" VLBI observations

core:

M ~ 10^8 M_{sun}

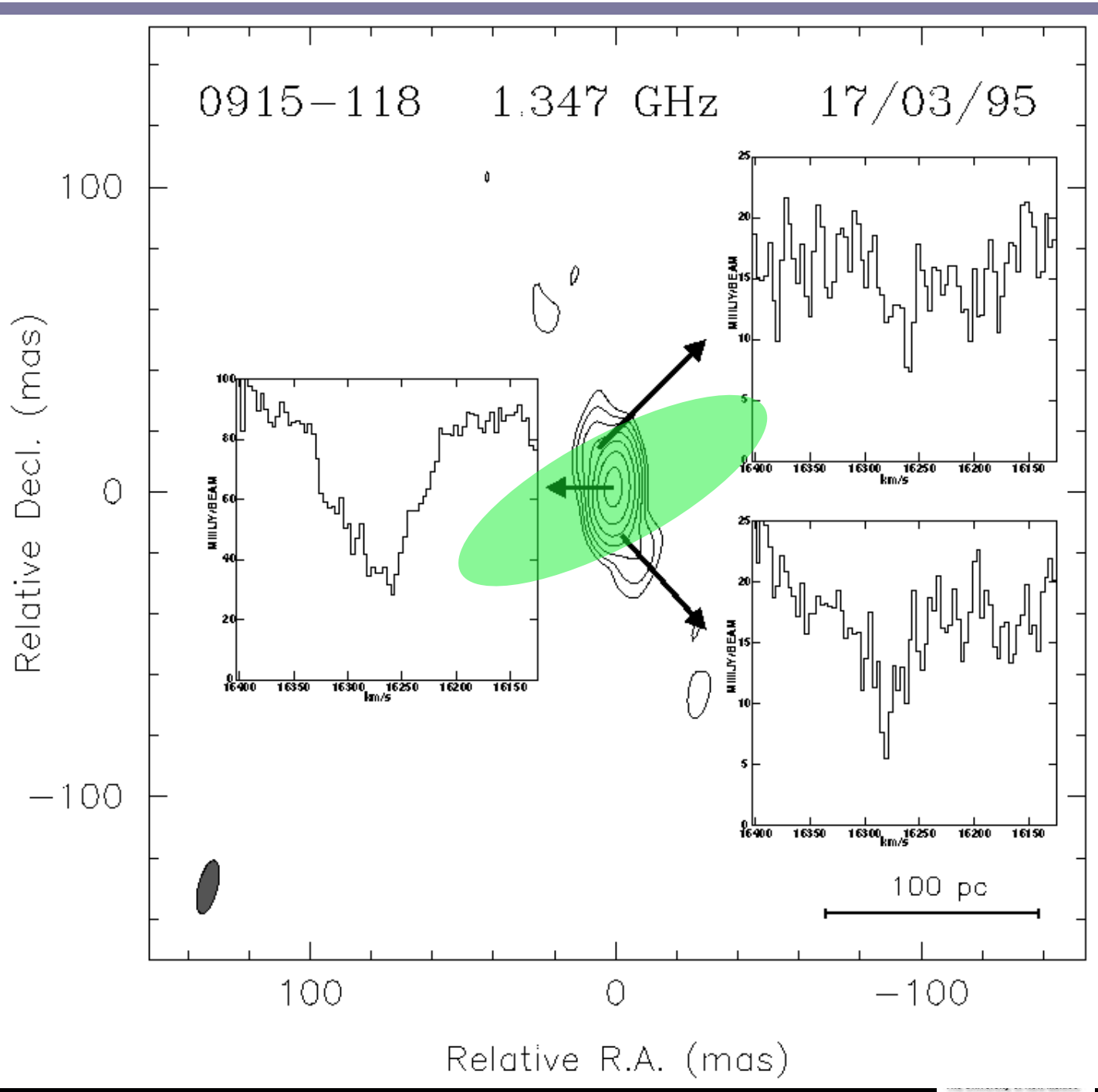


Hydra A

Taylor (1996)

core:

$M \sim 2 \times 10^7 M_{sun}$



NGC 4258

- Considered best evidence of a supermassive black hole
- Can estimate central mass
- Can estimate distance to host galaxy

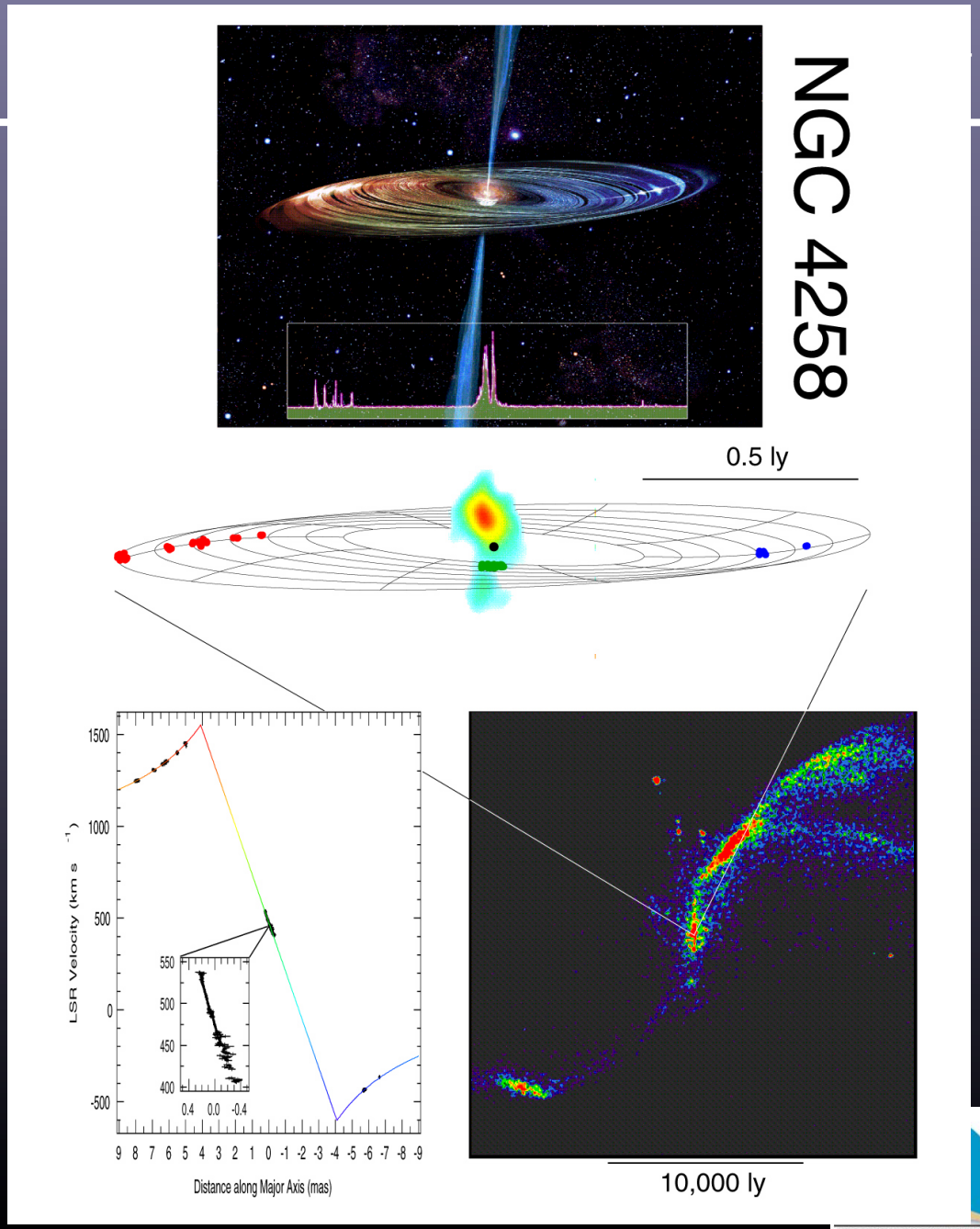
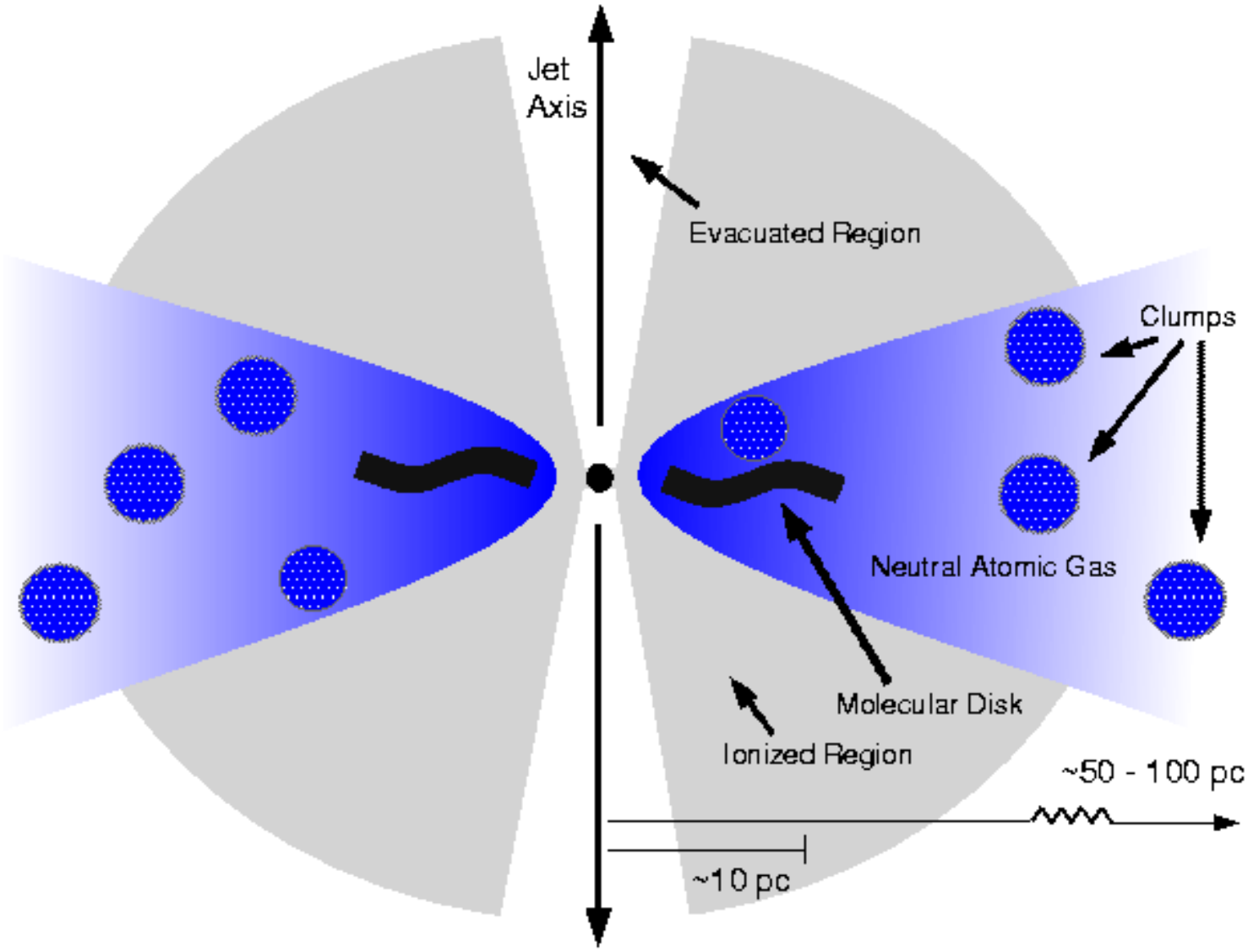
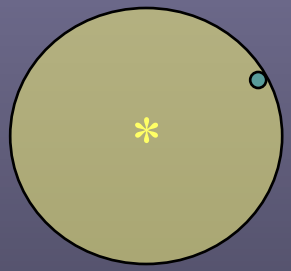


image courtesy Lincoln Greenhill
(see Miyoshi et al 1995
Herrnstein et al 1999)


Jet
Axis
Evacuated Region
Clumps
Neutral Atomic Gas
Molecular Disk
Ionized Region
~50 - 100 pc
~10 pc

Accretion



$v = (2GM/R)^{1/2}$
$= c\,(R_g/R)^{1/2}$

$L = 0.5\ \dot{M}\ c^2\ (R_g/R)$

$L = \varepsilon\ \dot{M}\ c^2$

c = speed of light
v = velocity
R = object radius
R_g = gravitational radius
ε = efficiency

$\varepsilon = 3 \times 10^{-4}$ for a white dwarf, 0.15 for a neutron star
ε up to 0.5 for a rotating black hole
Compared to 7×10^{-3} for hydrogen fusion

Accretion is a very efficient energy source

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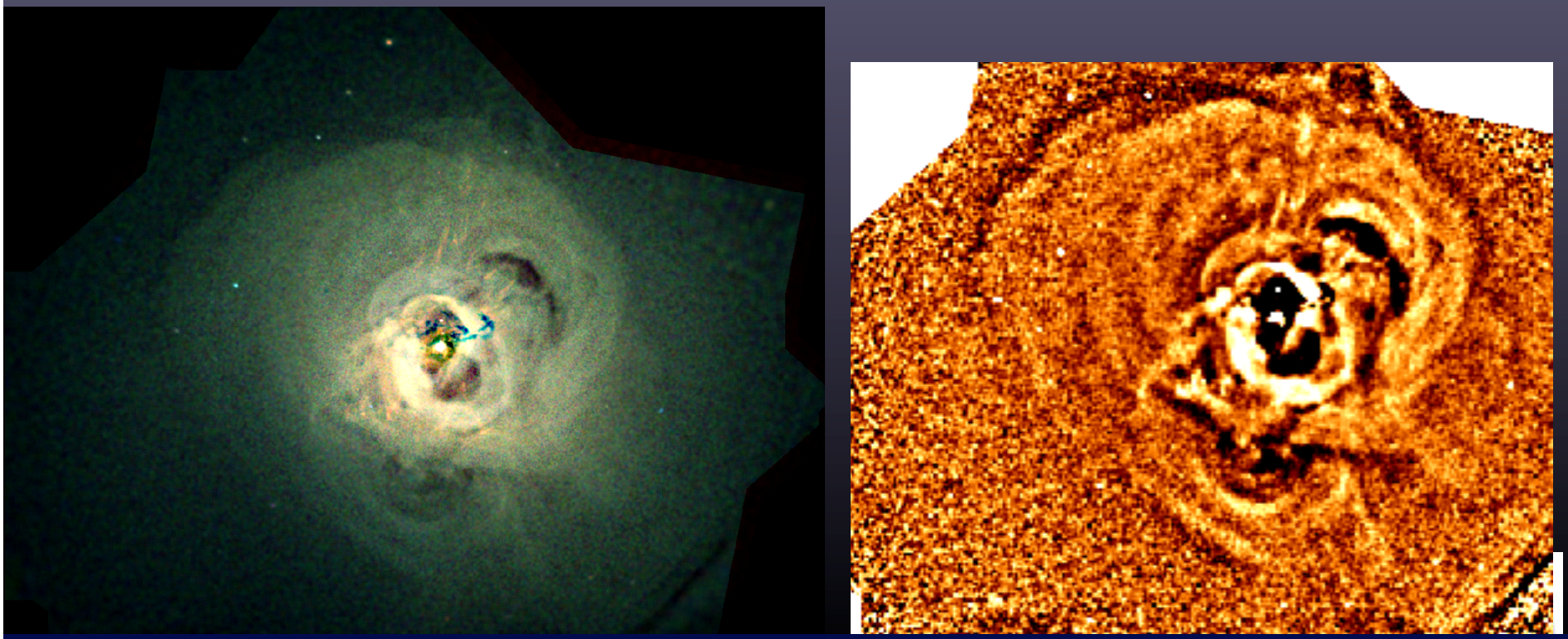
AGN Feedback

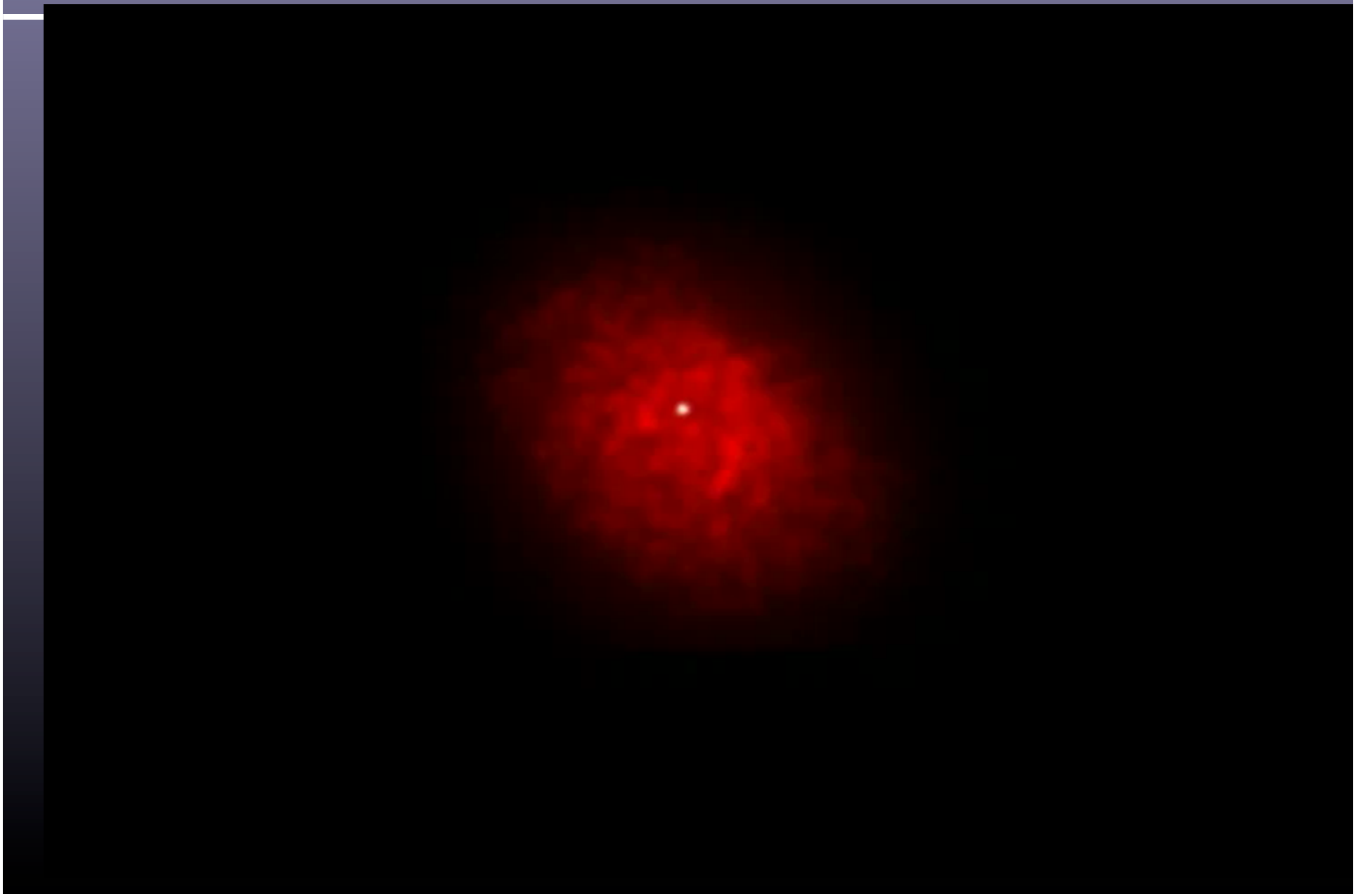
AGNs feedback energy to the cluster gas, prevent further cooling

Fabian, Forman: studies of nearby clusters ⇒ In Perseus and in M87, directed energy from jets is being redistributed via bubbles blown, compression waves …



Chandra 900 ks image of Perseus cluster, unsharp-masked at right (Fabian et al. 2006)

NASA animation of sound waves produced by 3C84



Clicker Question:

What is the most efficient energy source in the Universe?

A: Fusion of hydrogen

B: Accretion onto a black hole

C: Coal-fired power plants

D: Wind turbines.

Clicker Question:

What sources dominate the sky at radio wavelengths?

A: Stars

B: Active Galaxies

C: Normal Galaxies

D: Globular clusters

The Radio Sky

5 GHz
300 ft telescope

5 GHz image from 300 ft,Condon et al.

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FOOD FOR THOUGHT

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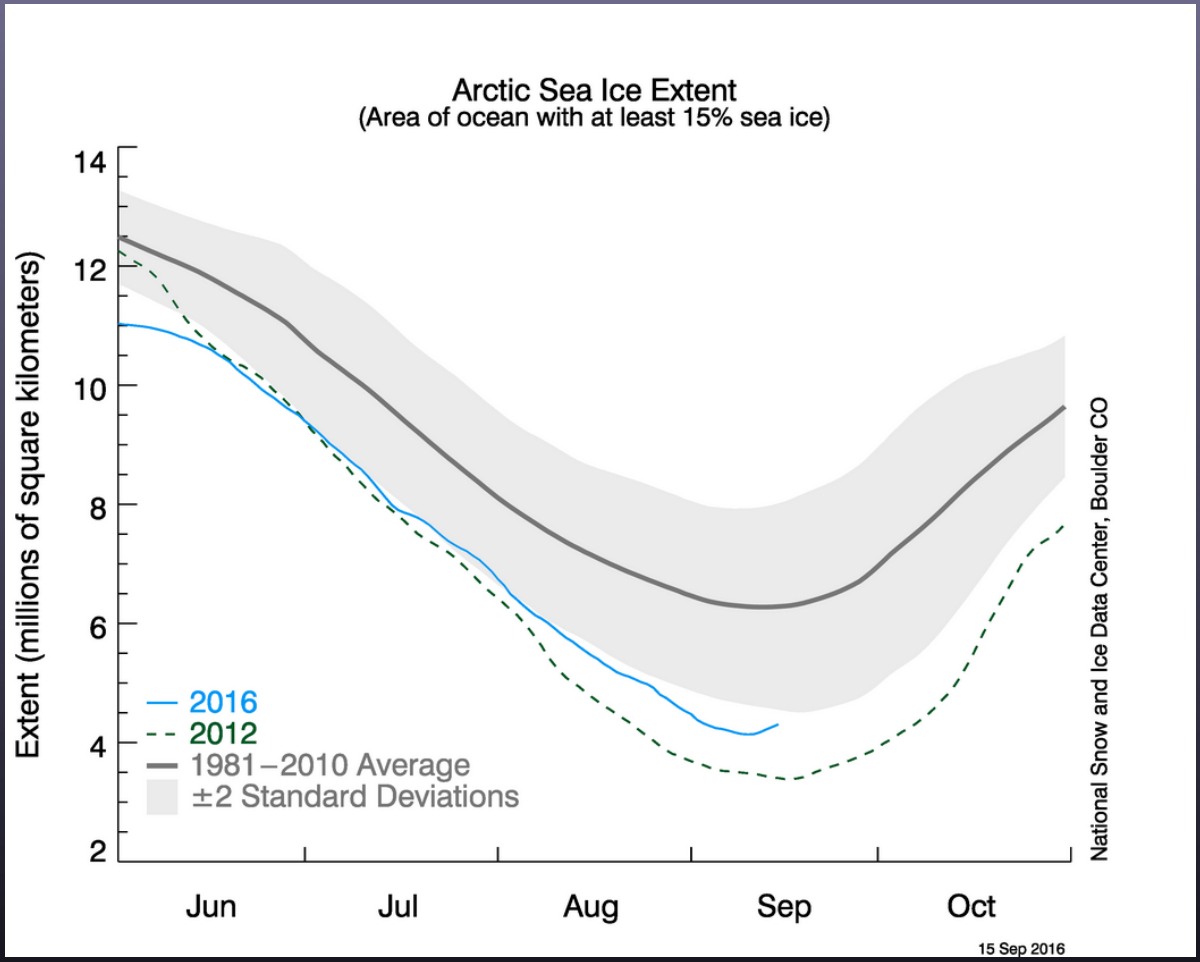
Melting Sea Ice



- An area twice the size of Texas has melted away since 1979 (over 50% decrease).
- Ice 40% thinner. (Rothrock,D.A, et al. 1999)
- Ice free summer in 20 years?
- Bering Sea Ice Sheet also retreating (Science 3/10/06).

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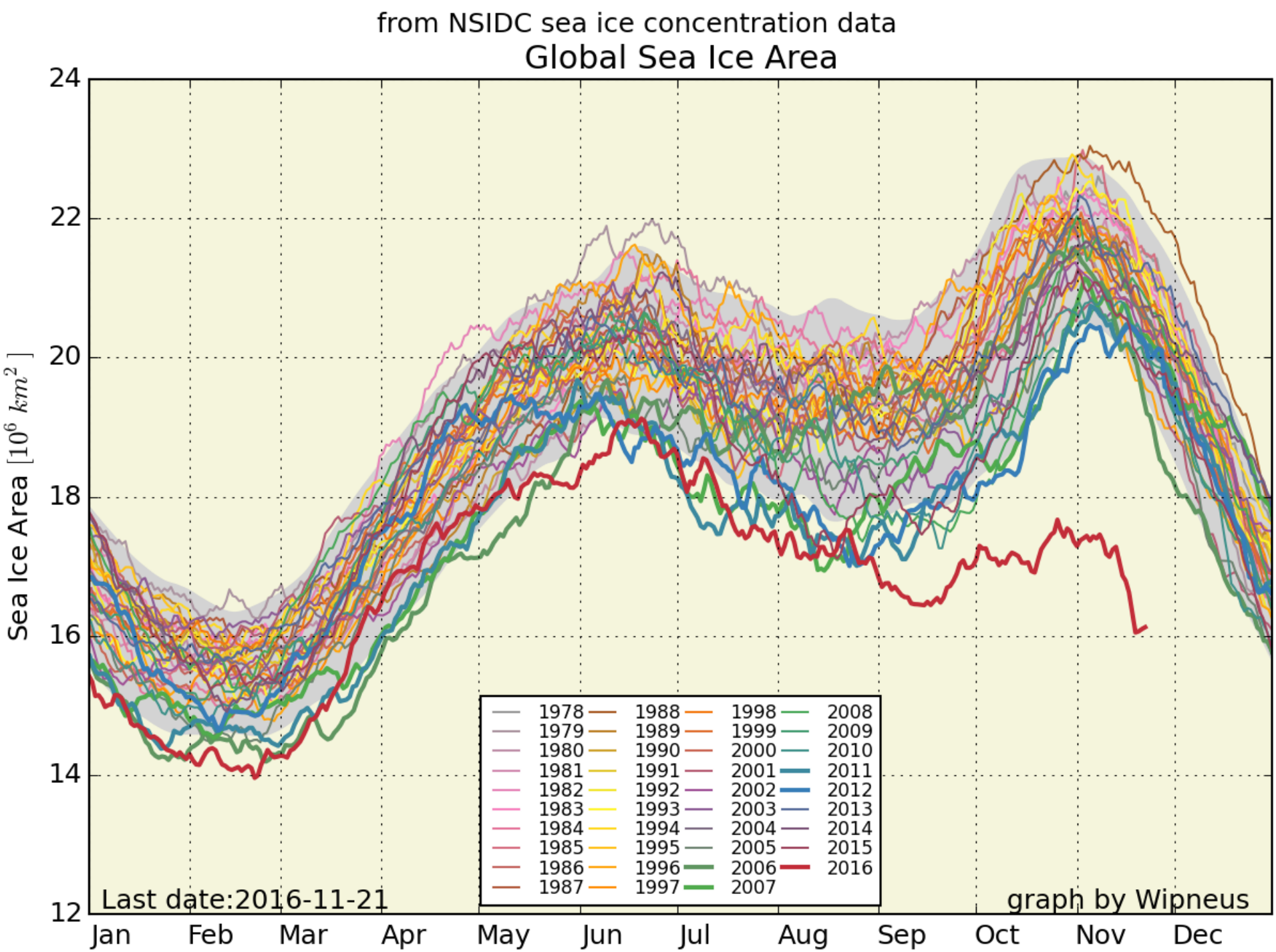
from NSIDC sea ice concentration data
Global Sea Ice Area
Sea Ice Area [10^6 km^2]
24
22
20
18
16
14
12
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1978
1979
1980
1981
1982
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2016
Last date:2016-11-21
graph by Wipneus