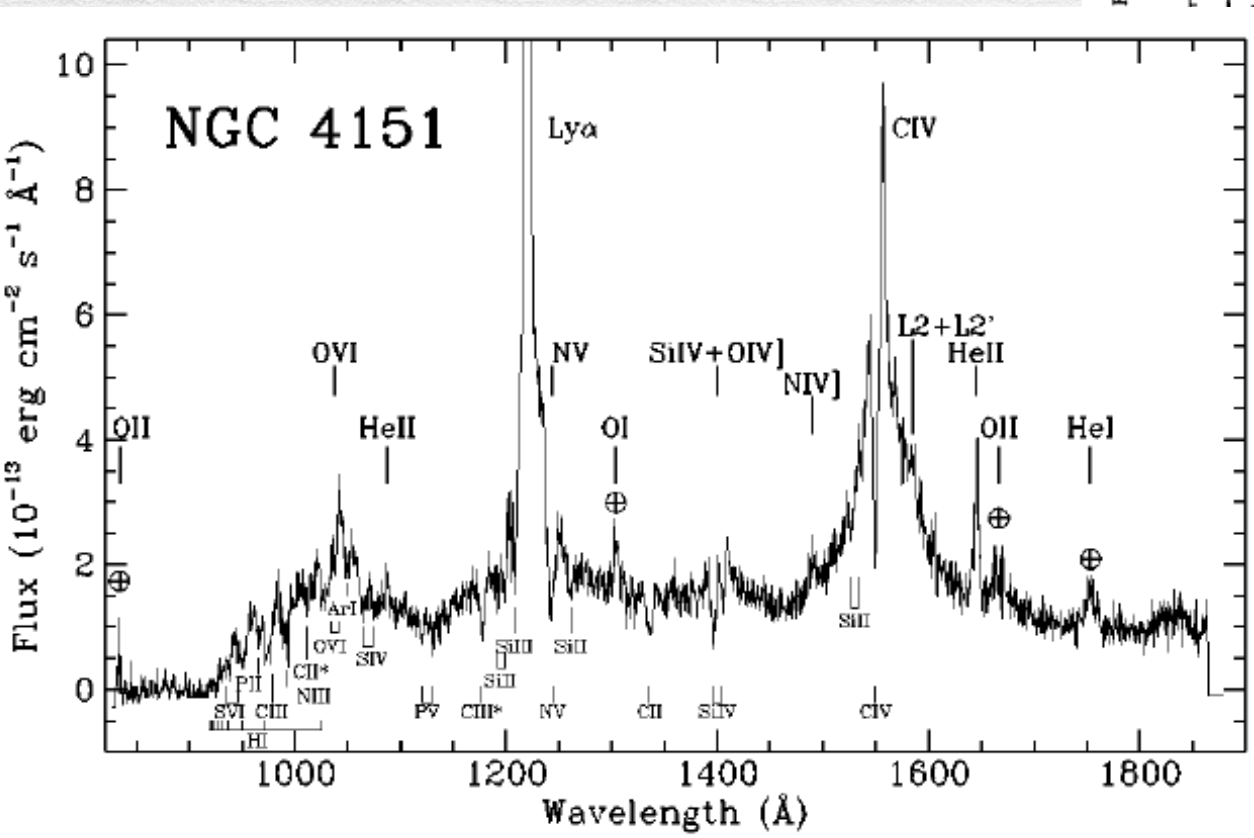
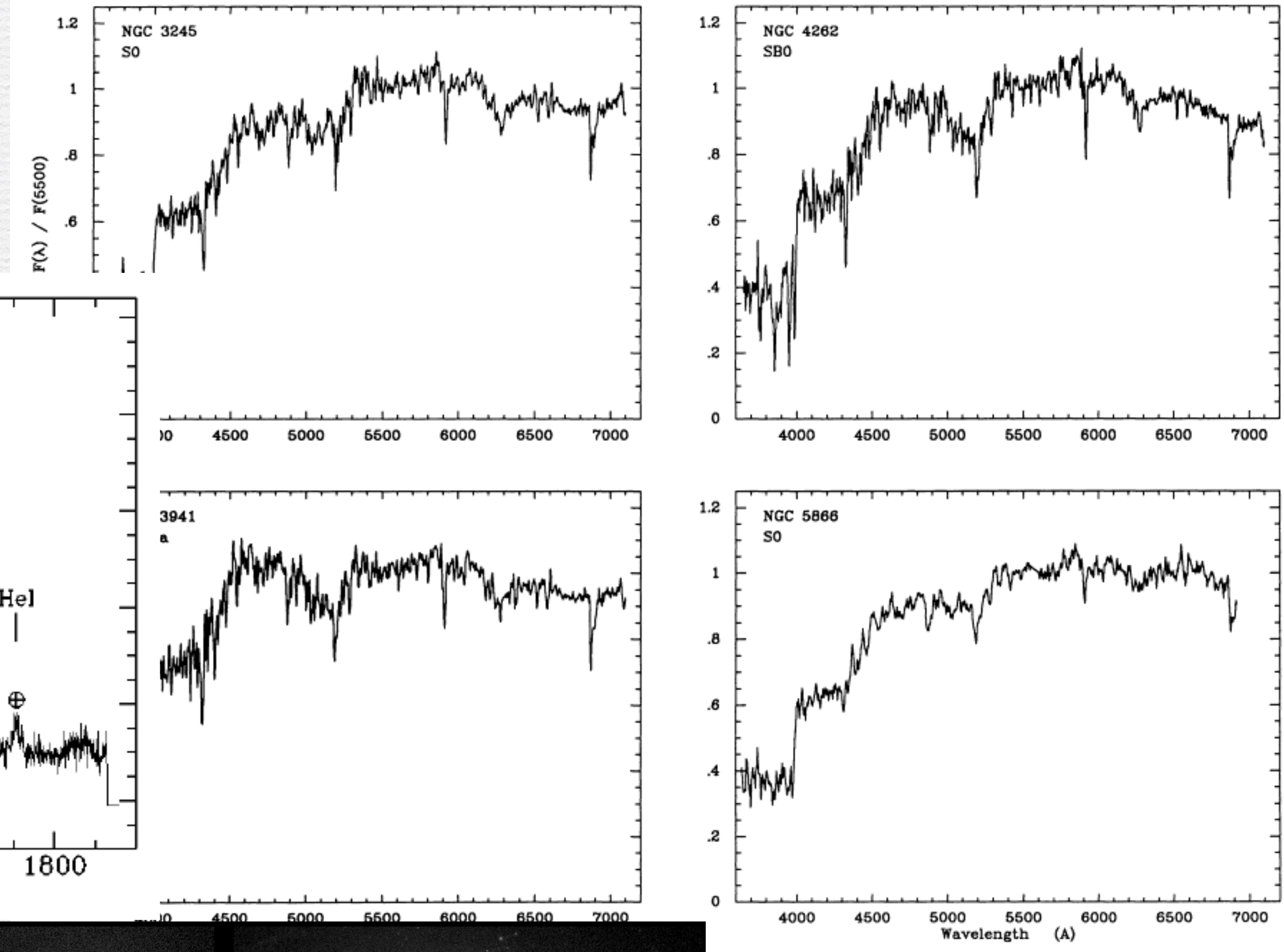
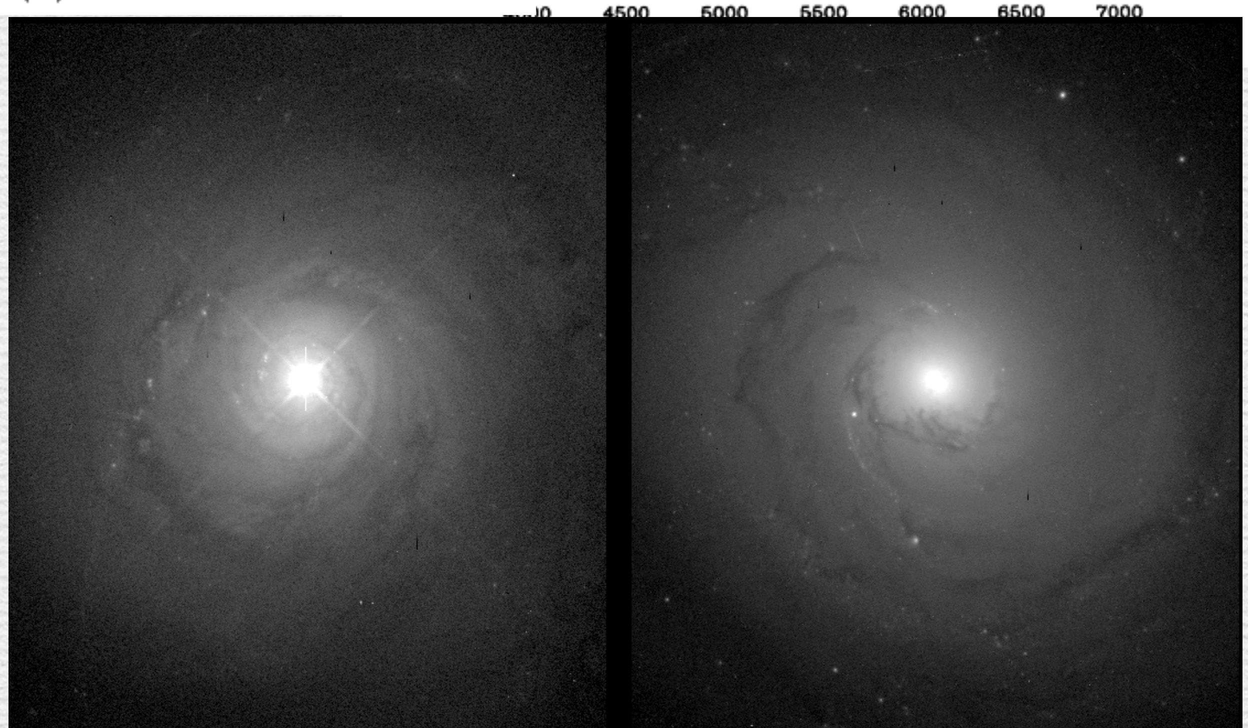
Active Galactic Nuclei with VLBI

Preeti Kharb
NCRA-TIFR

AGN

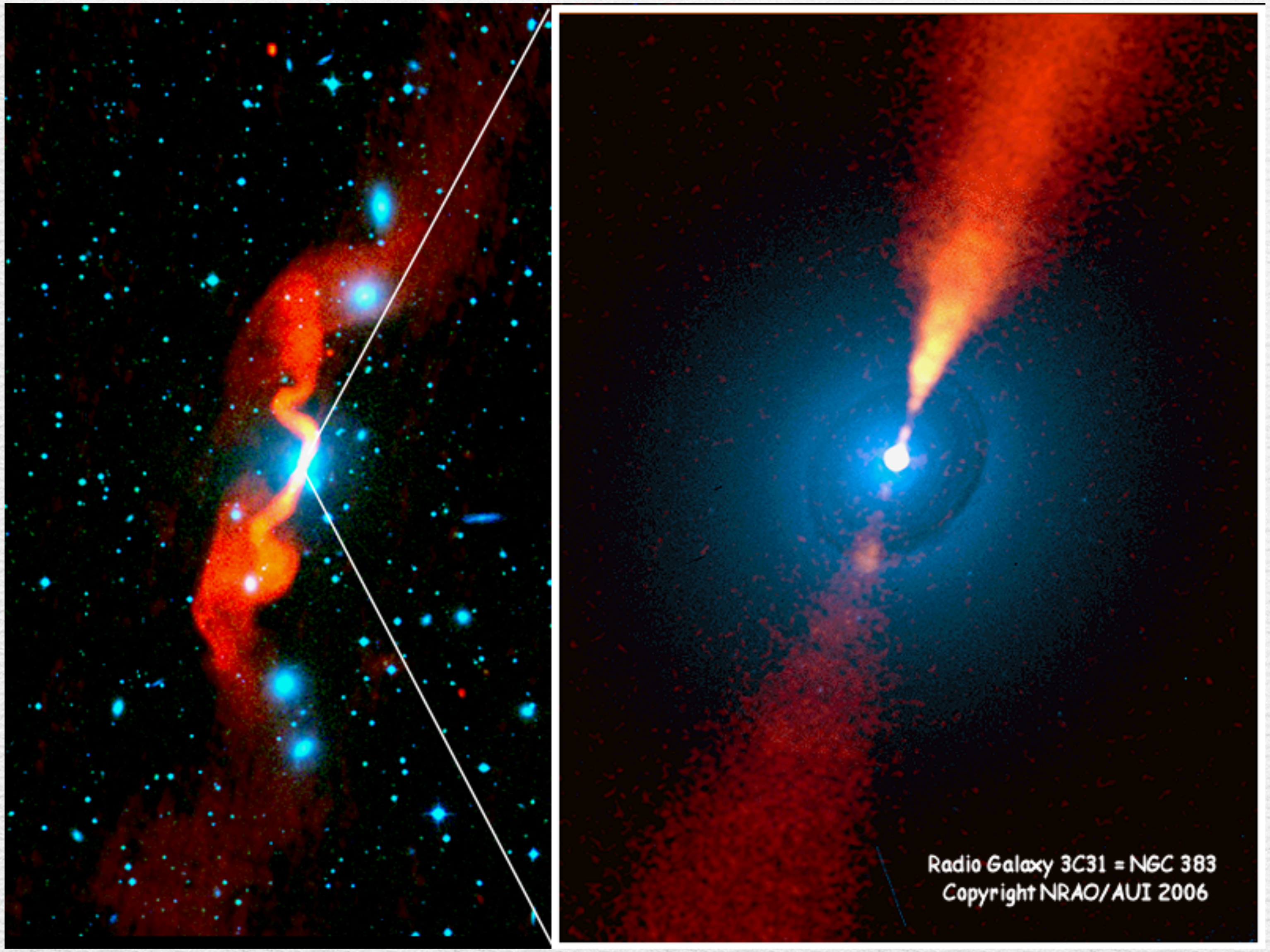




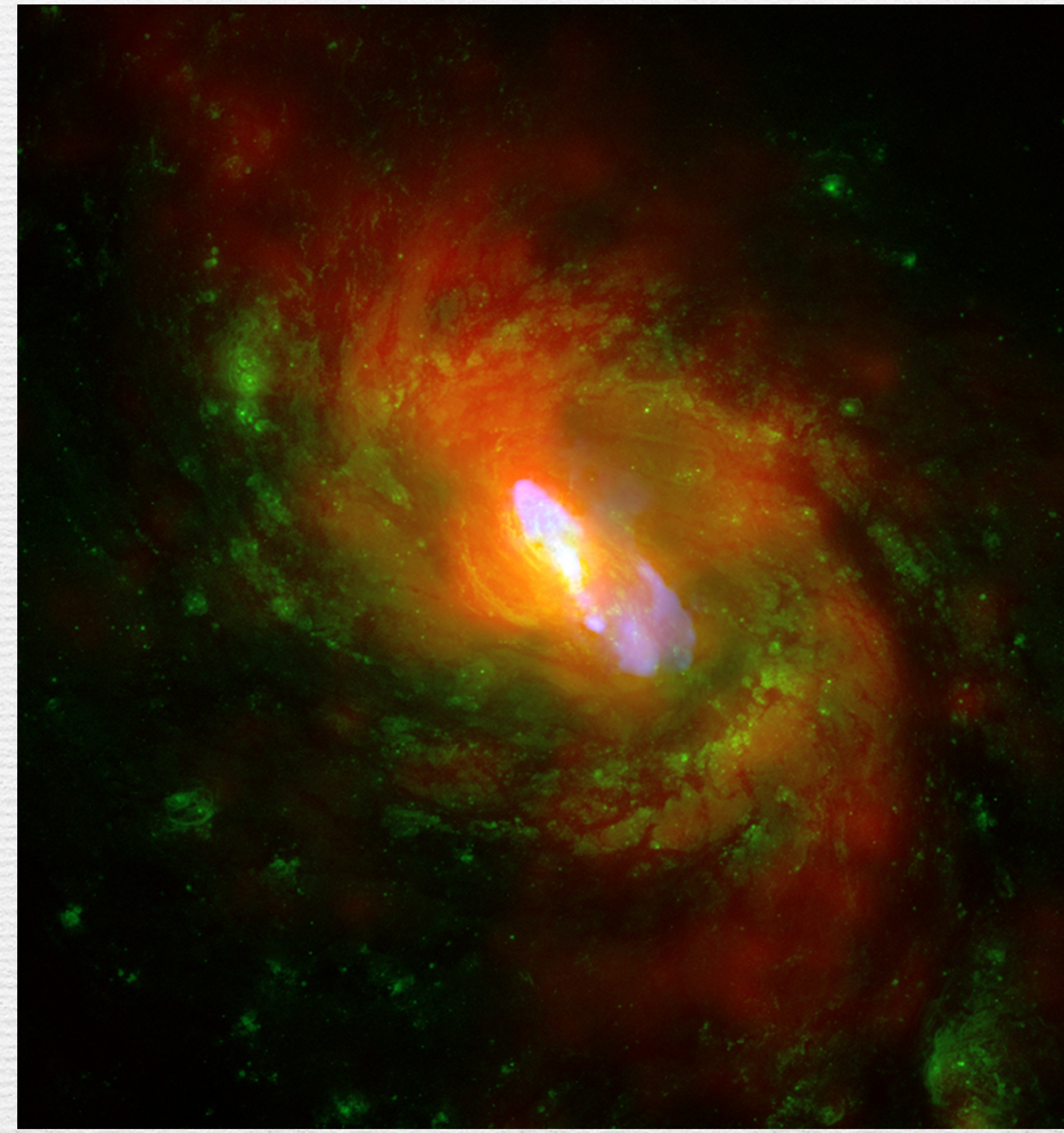


NGC5548 vs. NGC3277 — Carl Seyfert, 1943

Radio-loud vs. Radio-quiet AGN



Radio galaxy 3C31

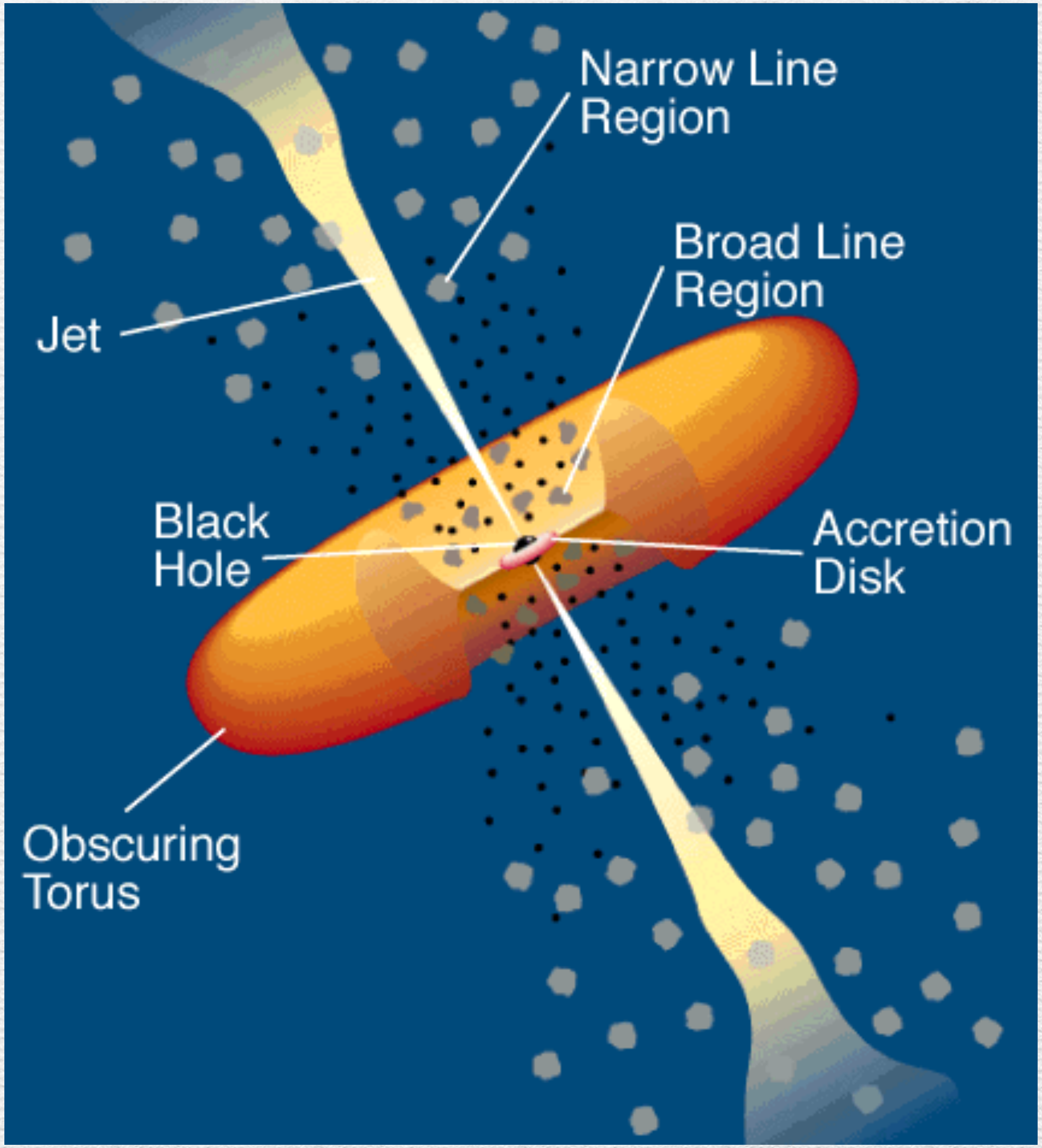


Seyfert galaxy NGC1068

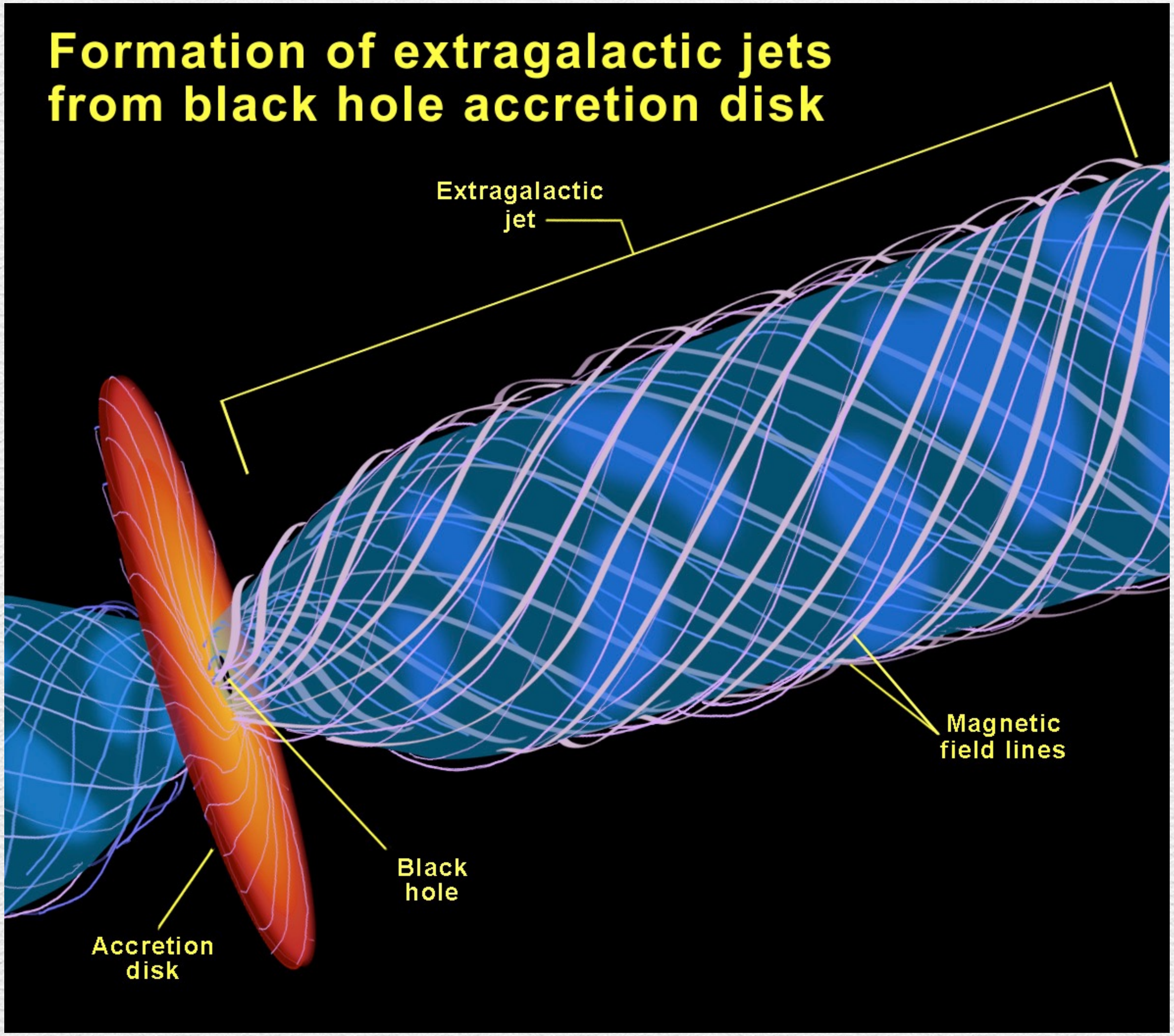
- Radio-loud AGN typically reside in elliptical galaxies
- Radio-quiet AGN typically reside in spiral galaxies
- Radio Jets emit incoherent synchrotron radiation

AGN model

- Supermassive blackhole (SMBH) $\sim 10^6$–10^9 $M_\odot$
- Accretion disk
- Broad-line region (BLR) line widths $\sim$1000 – 10,000 km/s, $n_e > 10^9$ cm^{-3}
- Narrow-line region (NLR) line widths $\leq$ 500 km/s, $n_e \sim 10^3$ cm^{-3}
- Dusty torus shields the BLR from some lines of sight
- Type 1s & 2s differ by orientation = Unification (Antonucci 1993, Urry & Padovani 1995)
- Relativistic Jets launched from Accretion disk - BH interface



Jet Formation in AGN



Blandford & Znajek (1977)

Energy & angular momentum extraction from a spinning black hole.

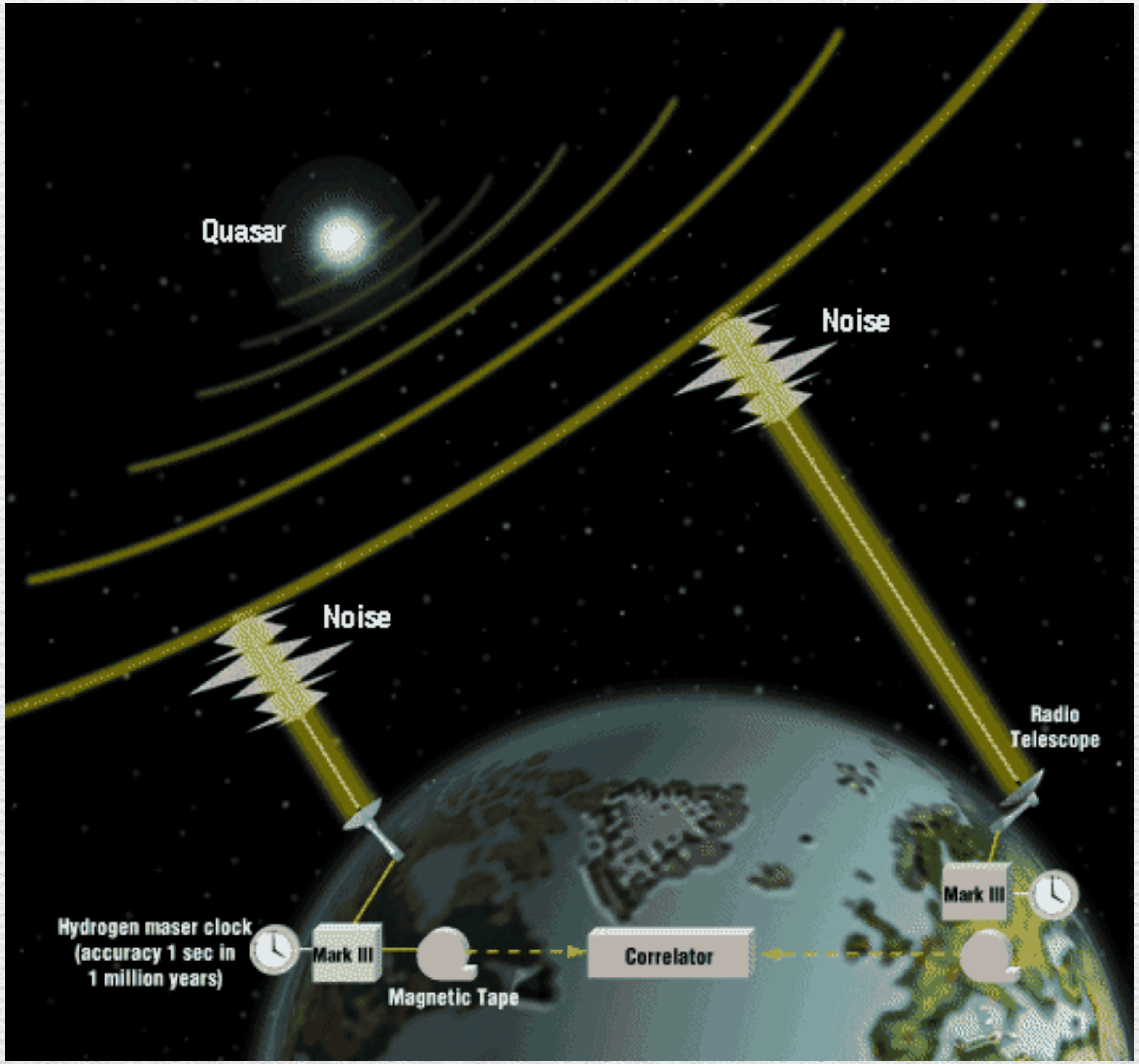
Strong poloidal magnetic field needed to begin with

Power extracted is proportional to B^2 & ω^2

B = magnetic field strength
ω = angular velocity

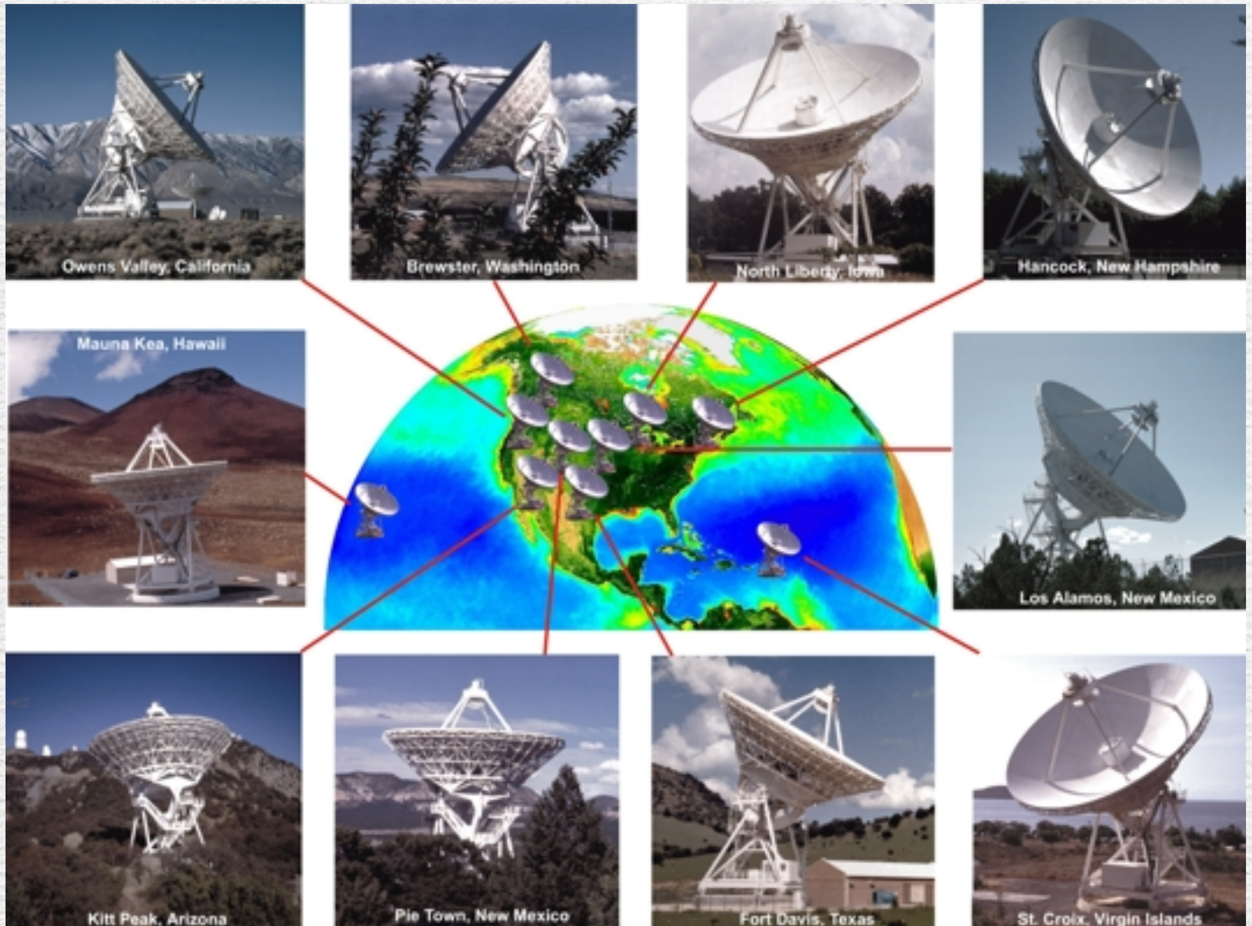
<u>VLBI needed, especially with polarisation</u>

Very Long Baseline Interferometry (VLBI)



- Widely separated antennas not connected by cables (unlike connected-interferometers like GMRT, VLA)
- Data recorded on magnetic tapes
- Recorded data is time-stamped by atomic clocks (e.g., hydrogen maser; sub-nanosecond time accuracy)
- Later, the tapes are played back with accurate time-stamps and correlated in a central location

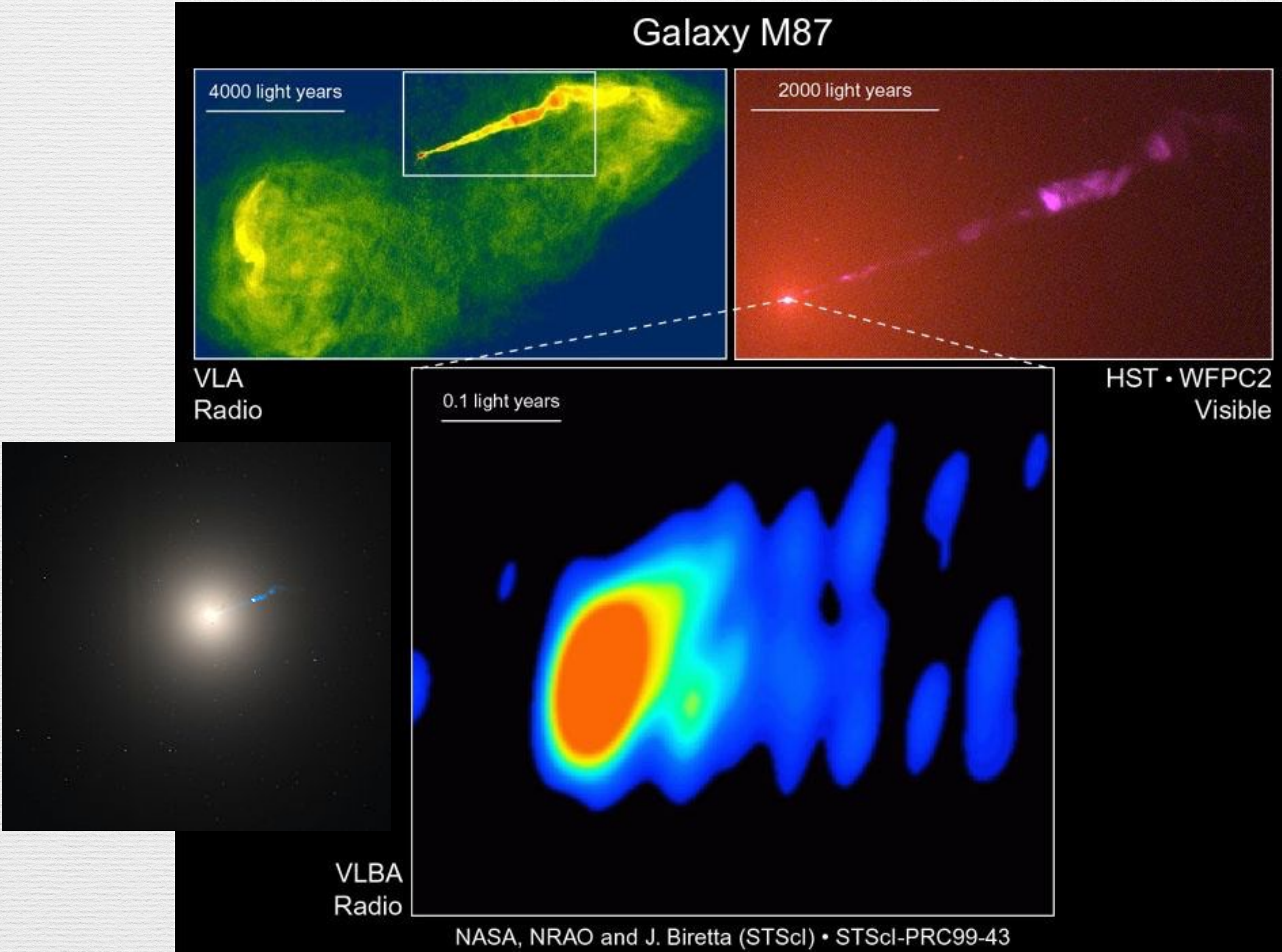
VLBI Arrays



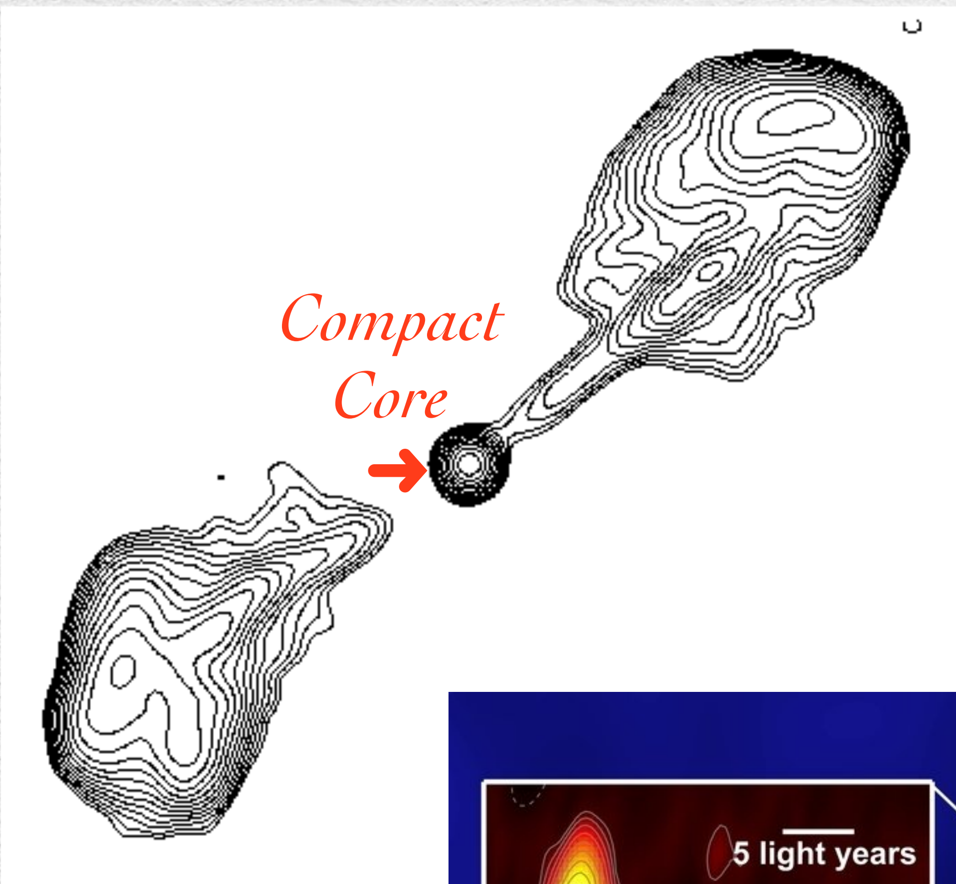
VLBA, USA

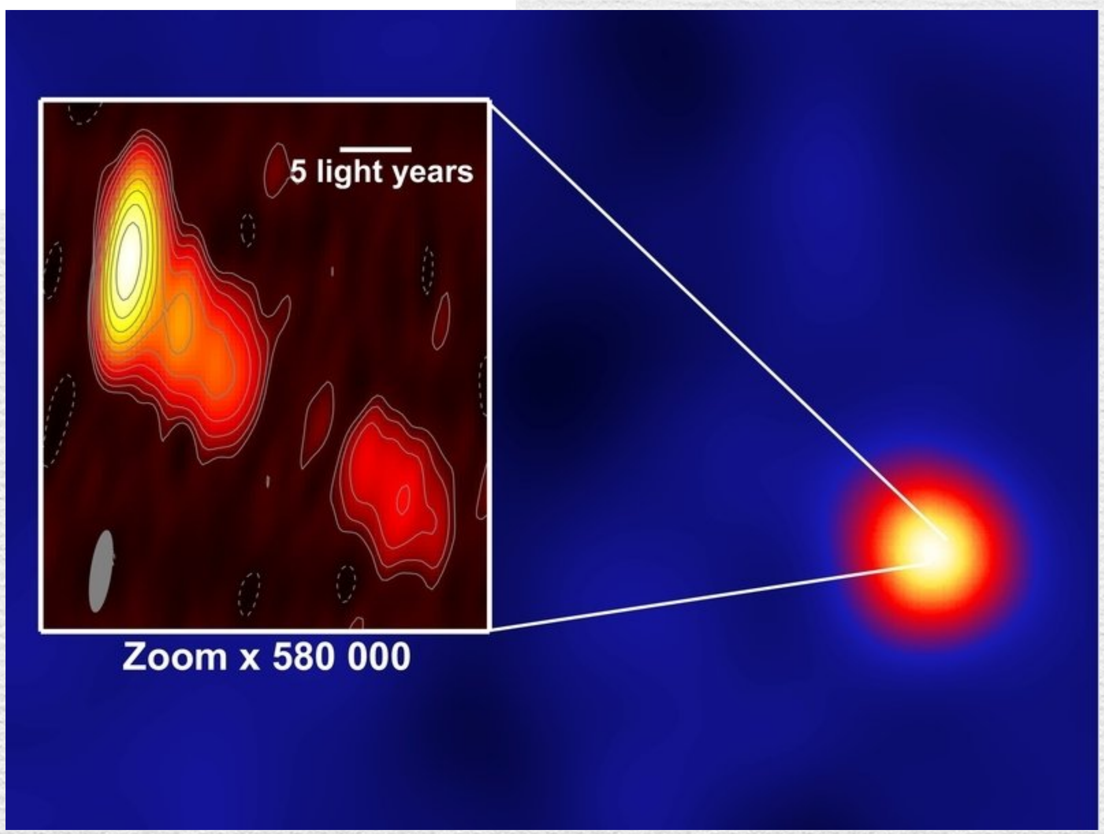
EVN, Europe

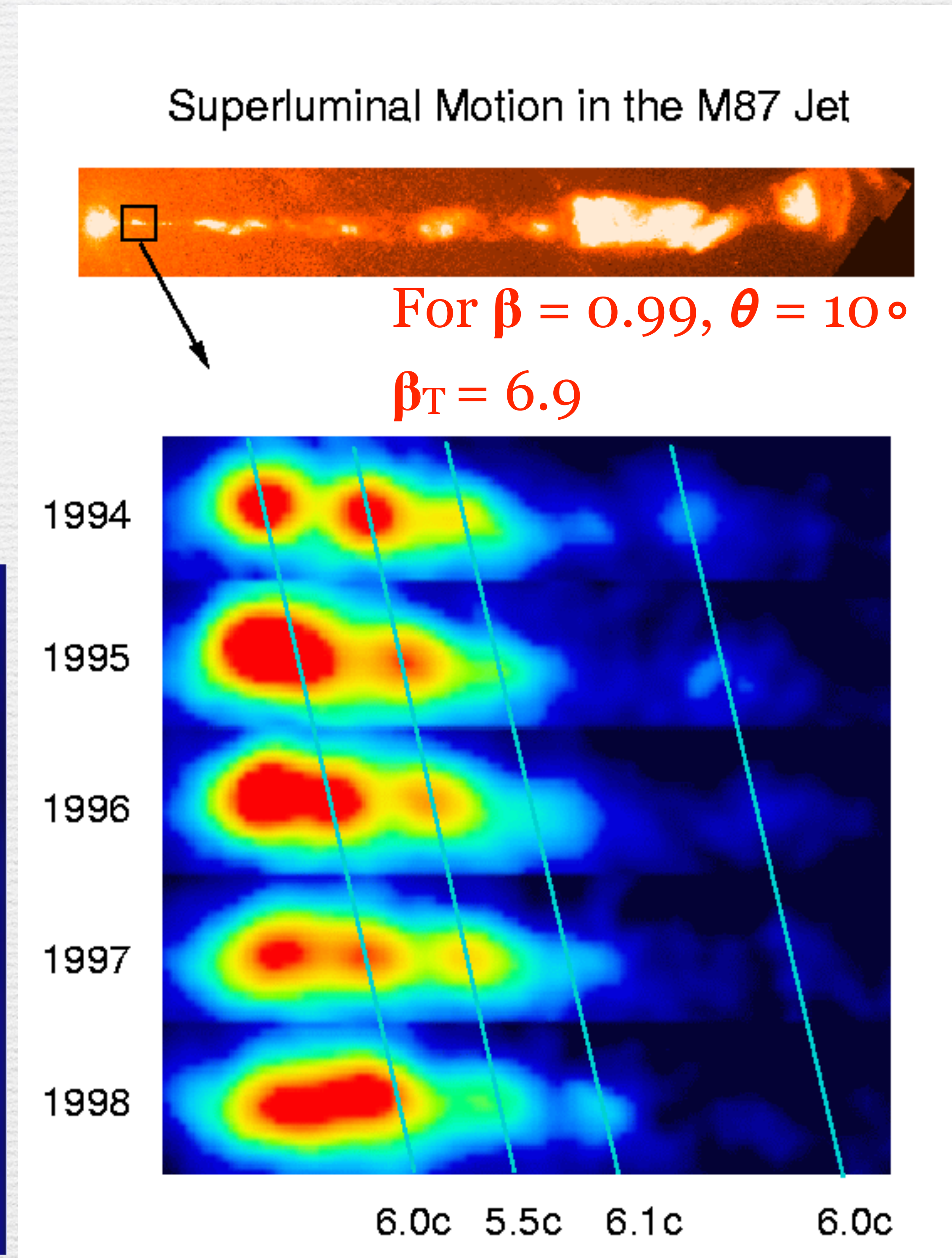
Global VLBI: VLBA+EVN


Galaxy M87
4000 light years
2000 light years
VLA
Radio
HST • WFPC2
Visible
0.1 light years
VLBA
Radio
NASA, NRAO and J. Biretta (STScI) • STScI-PRC99-43

"One-sided" Jets, Superluminal motion







For $\beta = 0.99$, $\theta = 10°$

$\beta_T = 6.9$

Observed Luminosity versus Intrinsic Luminosity

$$L_{obs} = \delta^{3+\alpha} L_{int}$$

Jet-to-Counterjet Intensity Ratio

$$R = \left(\frac{1 + \beta cos\theta}{1 - \beta cos\theta} \right)^{3+\alpha}$$

Apparent Speed of Jet

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

where,

Beta, $\beta = v/c$

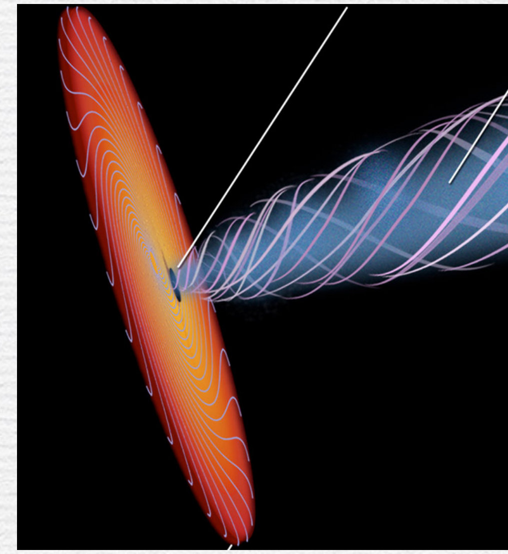
Doppler factor, $\delta = \frac{1}{\gamma(1-\beta cos\theta)}$

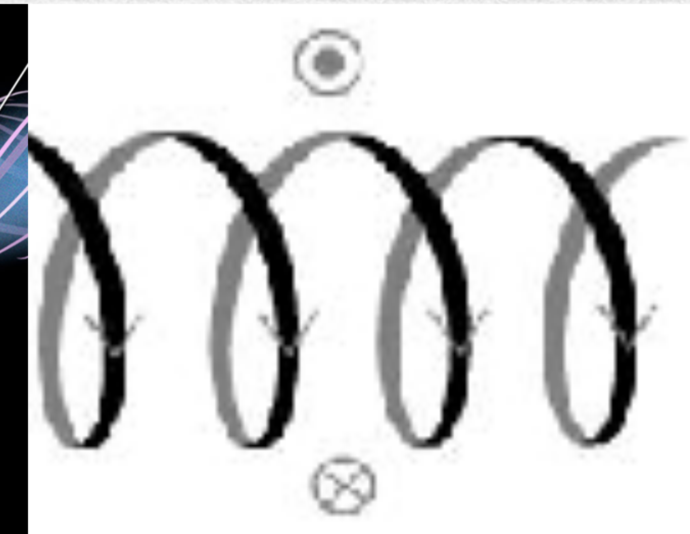
Lorentz factor, $\gamma = \frac{1}{\sqrt{1-\beta^2}}$

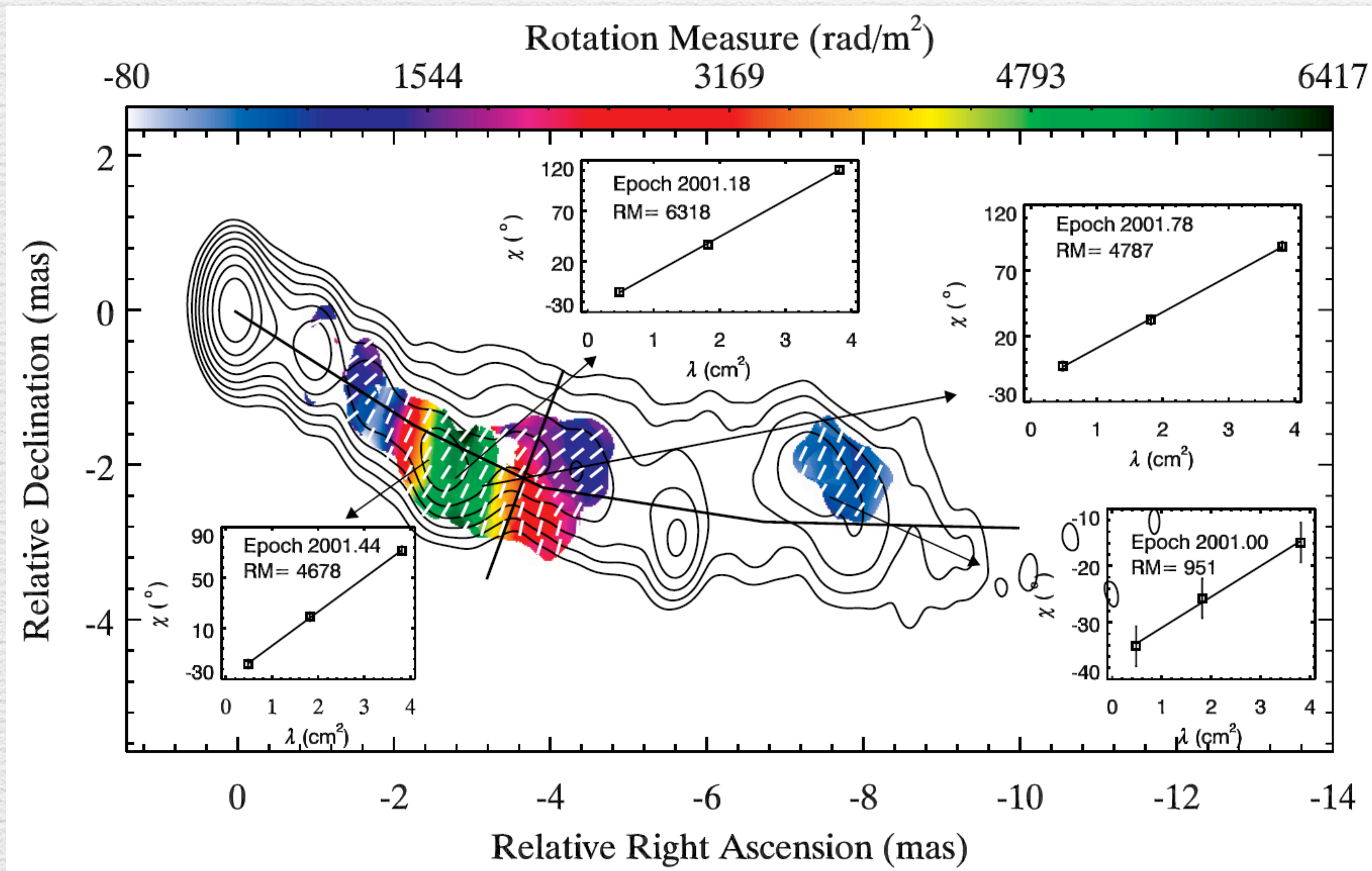
Rybicki - Lightman Book

https://ned.ipac.caltech.edu/level5/Urry1/UrryP_contents.html

VLBI Polarization: Rotation Measure Gradients







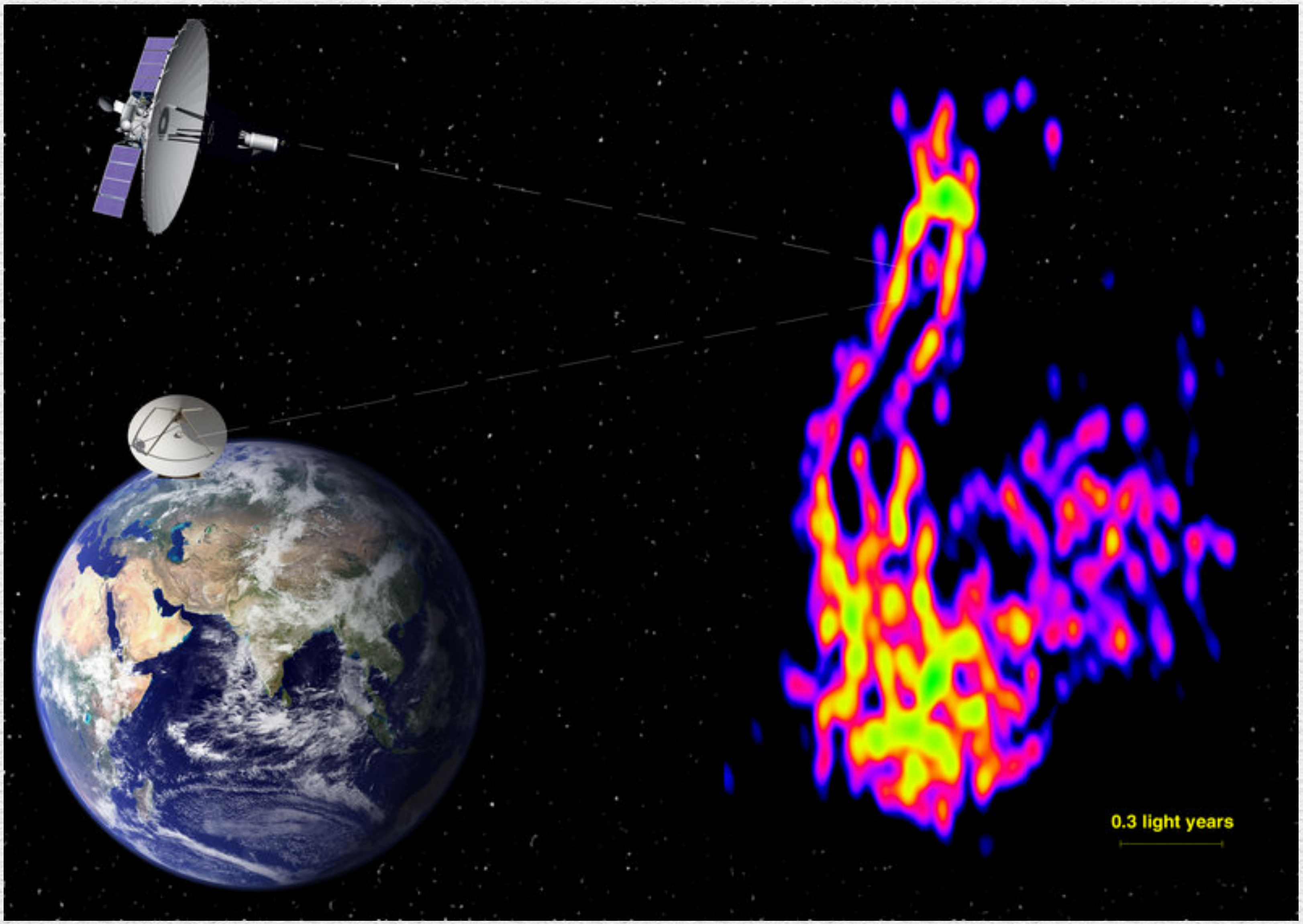
$$\chi(\lambda^2) = \chi_0 + \lambda^2\,\mathrm{RM},$$

$$\mathrm{RM} = \frac{e^3}{2\pi m_e^2 c^4} \int_L n_e \boldsymbol{B} \cdot d\boldsymbol{s}$$

Signature of **helical magnetic fields** wrapping the jets (Blandford 1993)

3C120 – VLBA @ 15, 22, 43 GHz (Gómez+ 2008)

Space VLBI



<u>First mission (1997-2003)</u>

HALCA 8m dish
Best resolution ≈ 0.1 mas

Freq: 1.6 & 5 GHz

<u>New mission (2011)</u>

RadioAstron - 10m dish Max. Baseline = 350,000 km

Freq: 0.325, 1.6, 5, 22 GHz

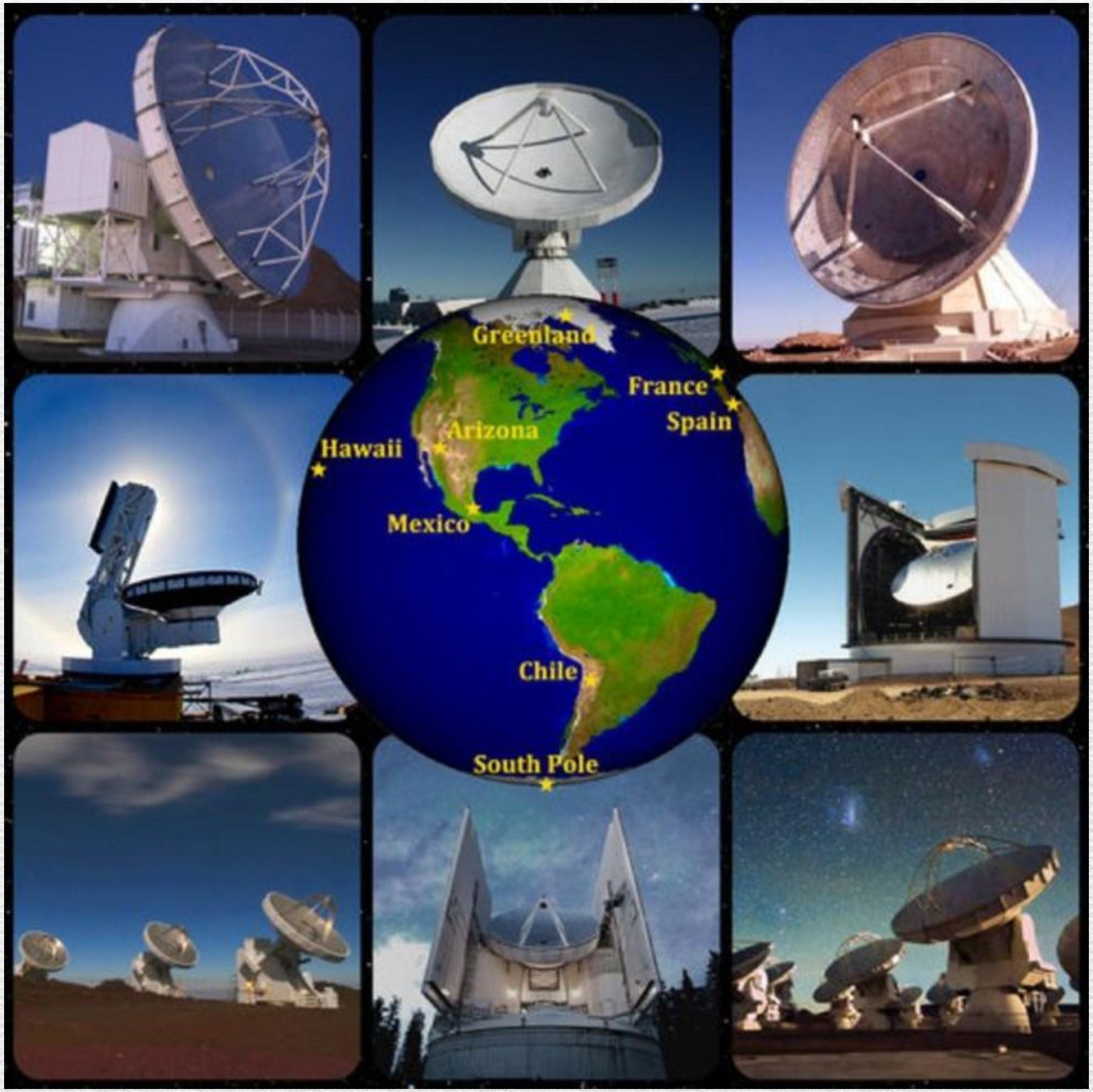
Perseus A = 3C84 at ~50 **μ**as

≥250 r_g wide - from accretion disk

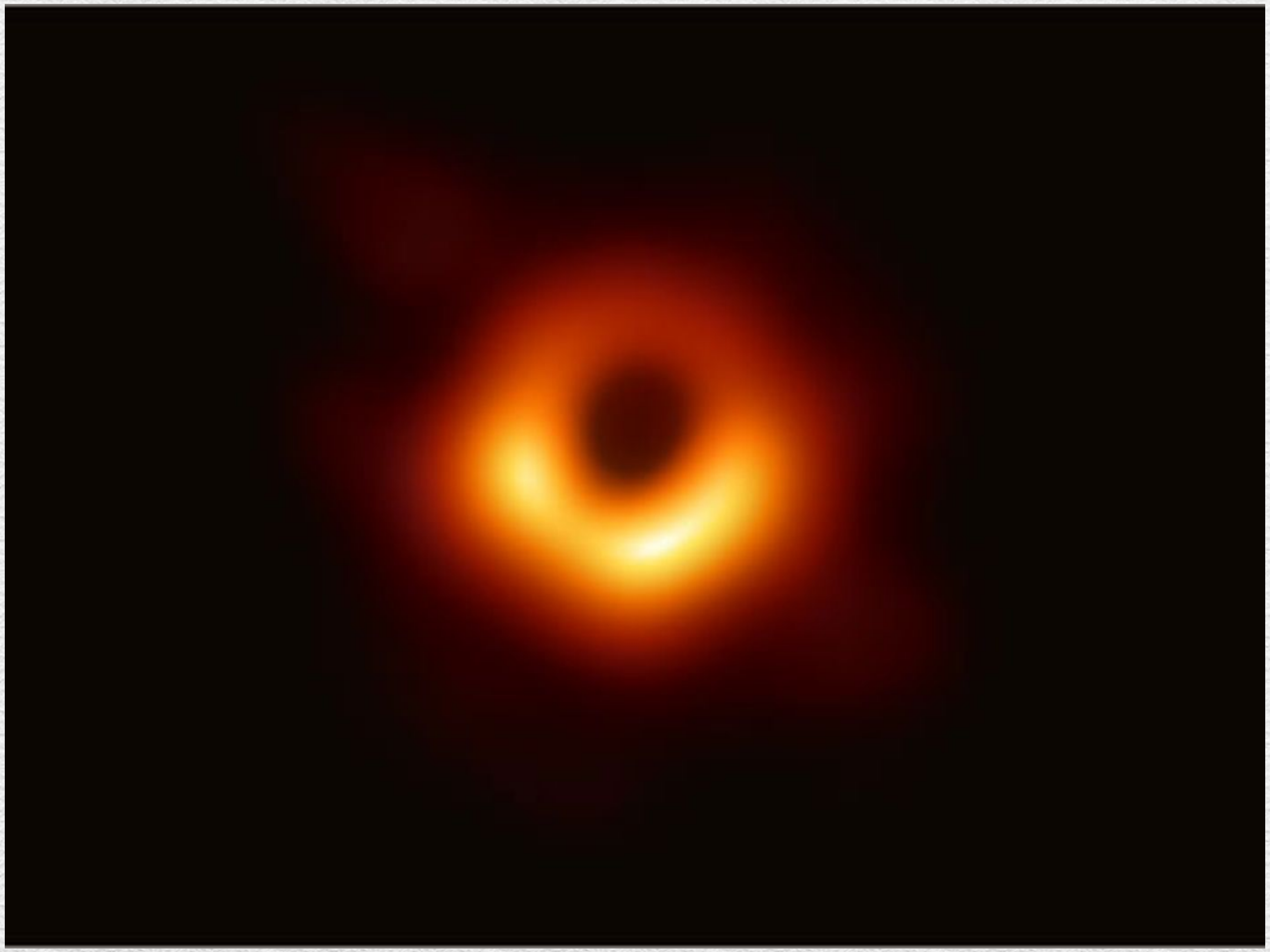
Giovannini+ 2018, Nature Astronomy

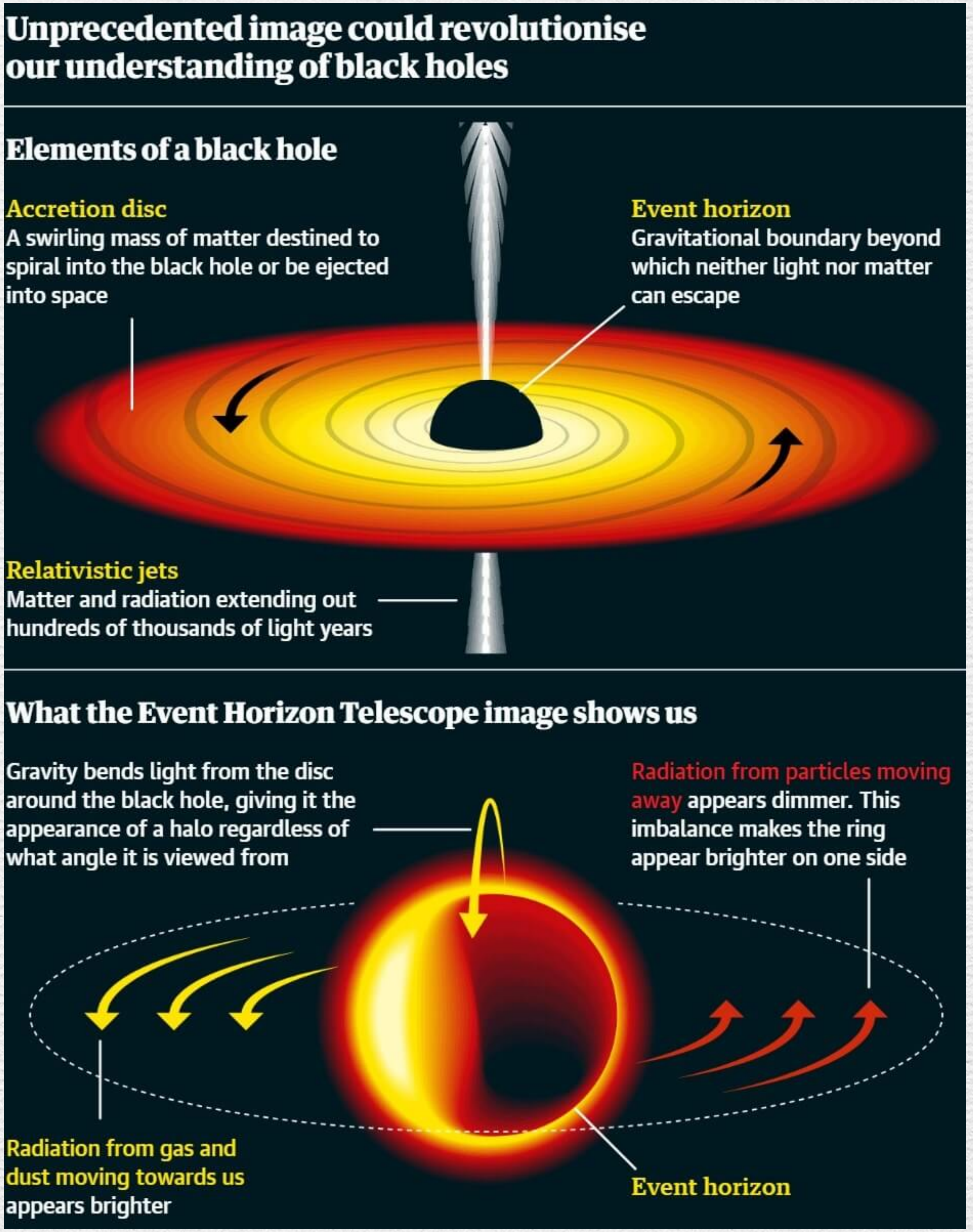
The Event Horizon Telescope (EHT)

- mm-wave VLBI
- Resolution <60 μas at 230 - 450 GHz
- Looked at M87
- Data from 8 telescopes acquired in April 2017 — Press Release April 2019
- Milky Way SMBH gravitational radius ~ 10 μas



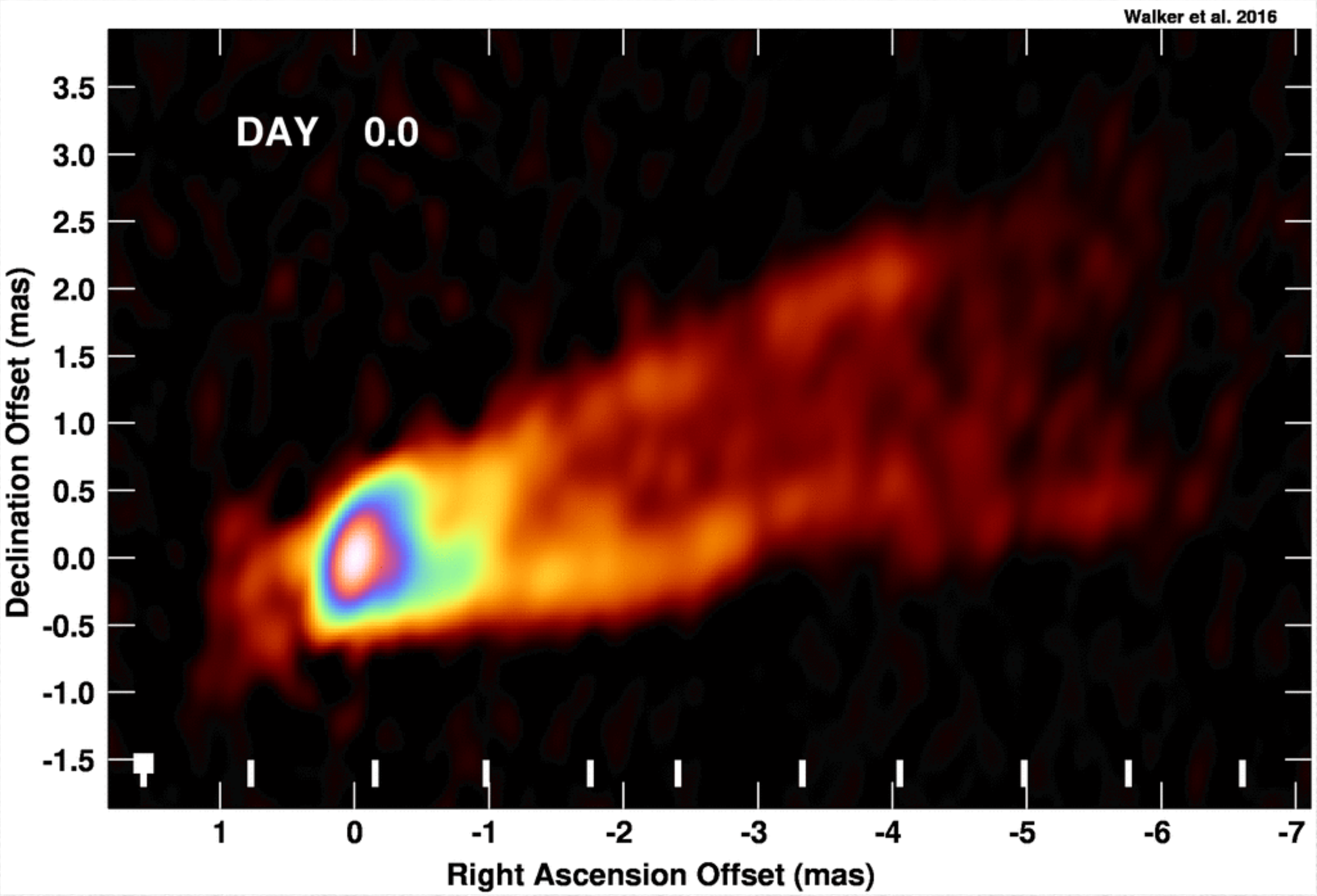
The Blackhole Shadow in M87





The EHT Collaboration, 2019, ApJL
VLBI image at 1.3 mm (230 GHz)

VLBI Jet Movies



https://www.aoc.nrao.edu/~cwalker/M87/

https://www.physics.purdue.edu/MOJAVE/movies.html