A wide and collimated radio jet in 3C84 on a scale of a few hundred gravitational radii

G.Giovannini, T.Savolainen, M.Orienti, M.Nakamura, H.Nagai, M.Kino, M.Giroletti, K.Hada, Y.Y.Kovalev, F.D'Ammando, R.Lico, B.W.Sohn, et al.

Nature Astronomy 2018

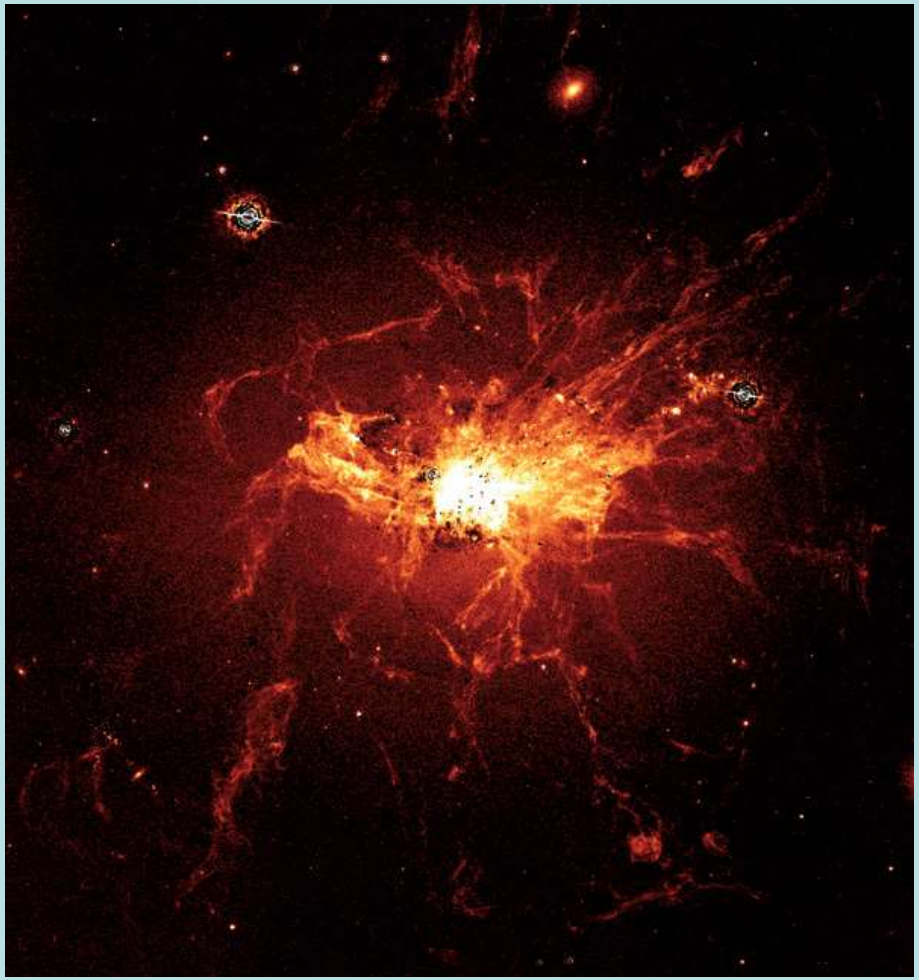
3C 84

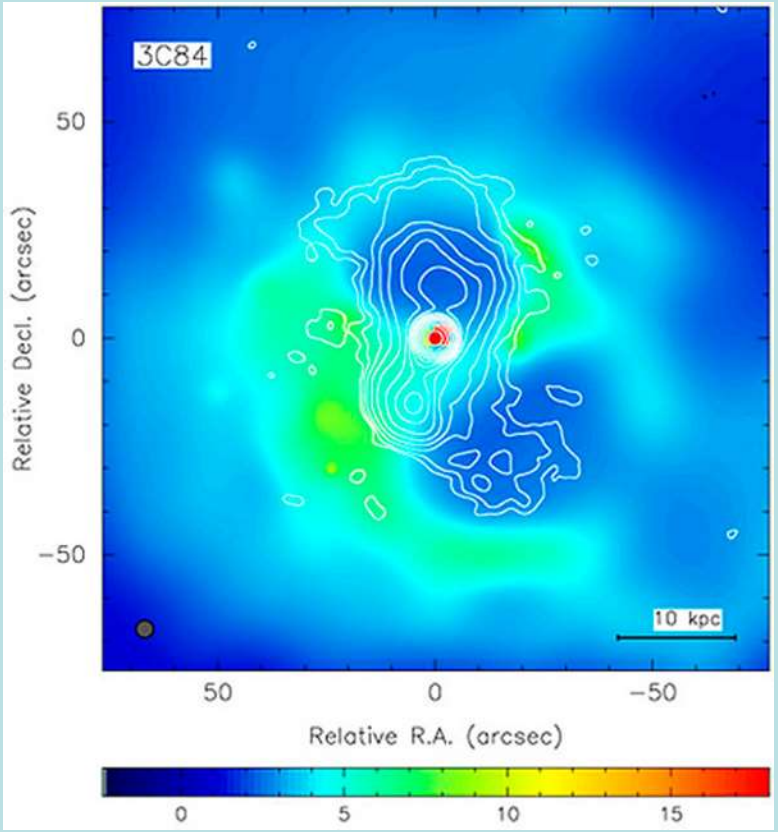
Nearby radio source (z = 0.0176)

cD galaxy at the center of the prototypical **cooling flow** Perseus cluster

Radio lobes fill the X-ray cavities

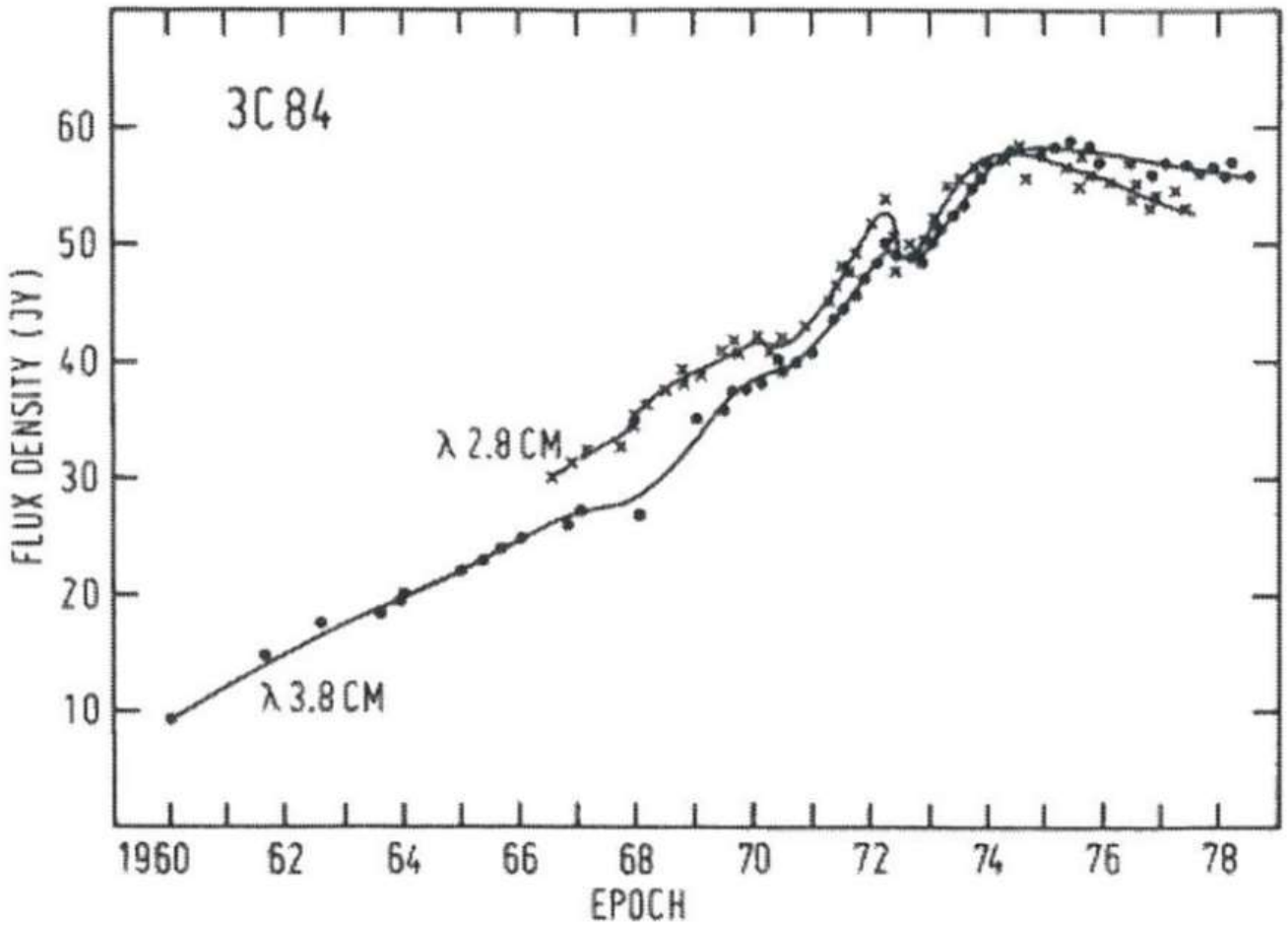
Chandra+VLA





HST image of NGC1275 – red filter + H alpha line (Fabian et al. 2008)

1979A&A....79..268P



History

1970

1982IAUS...97..291R

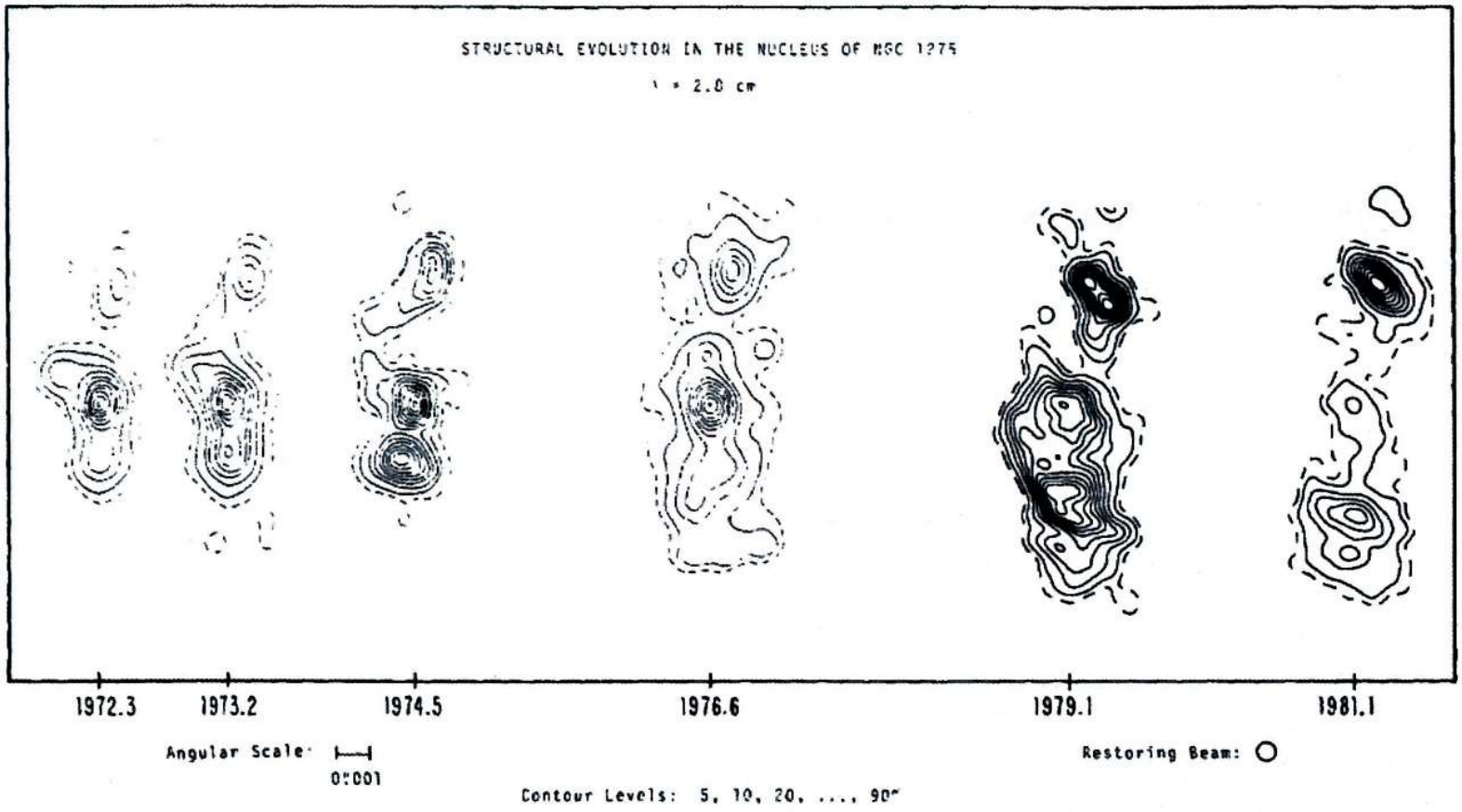
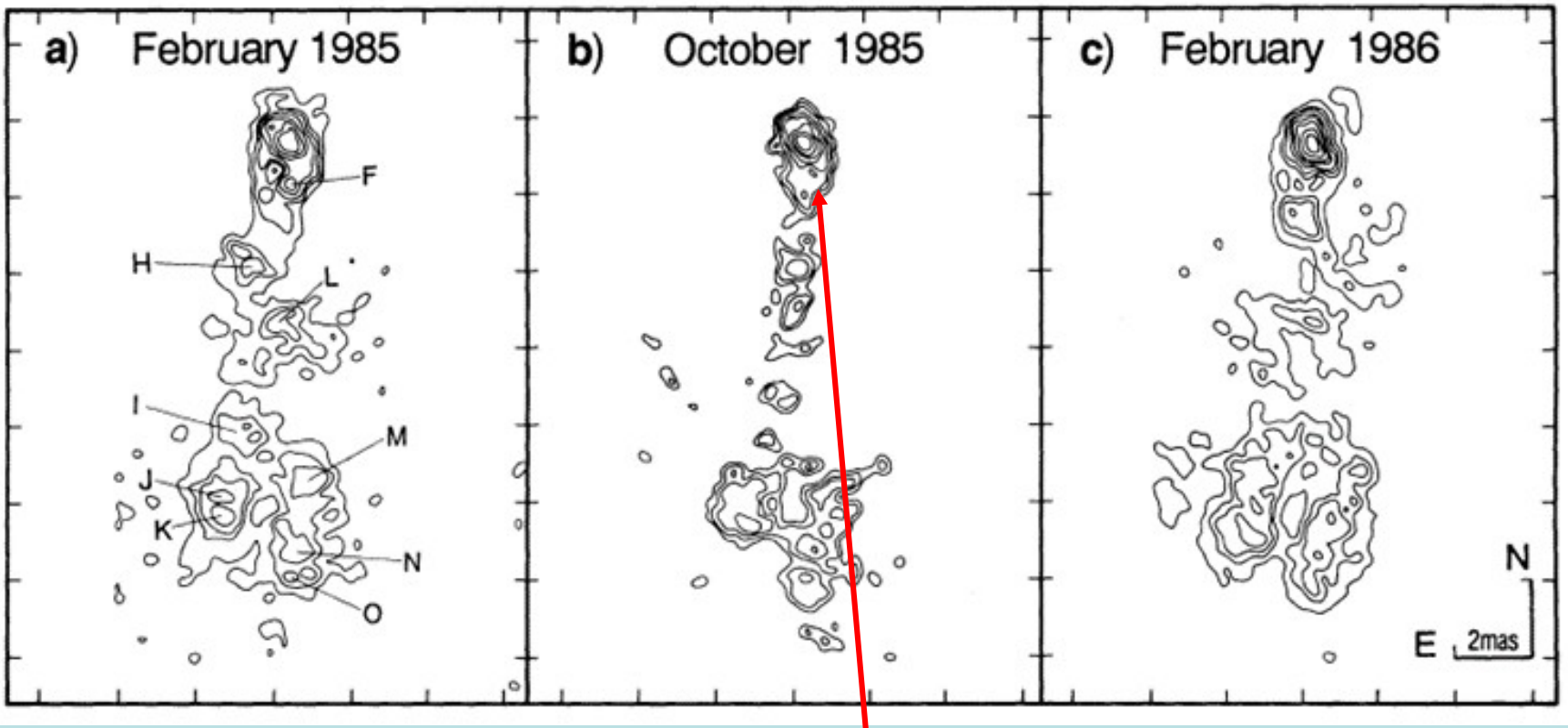


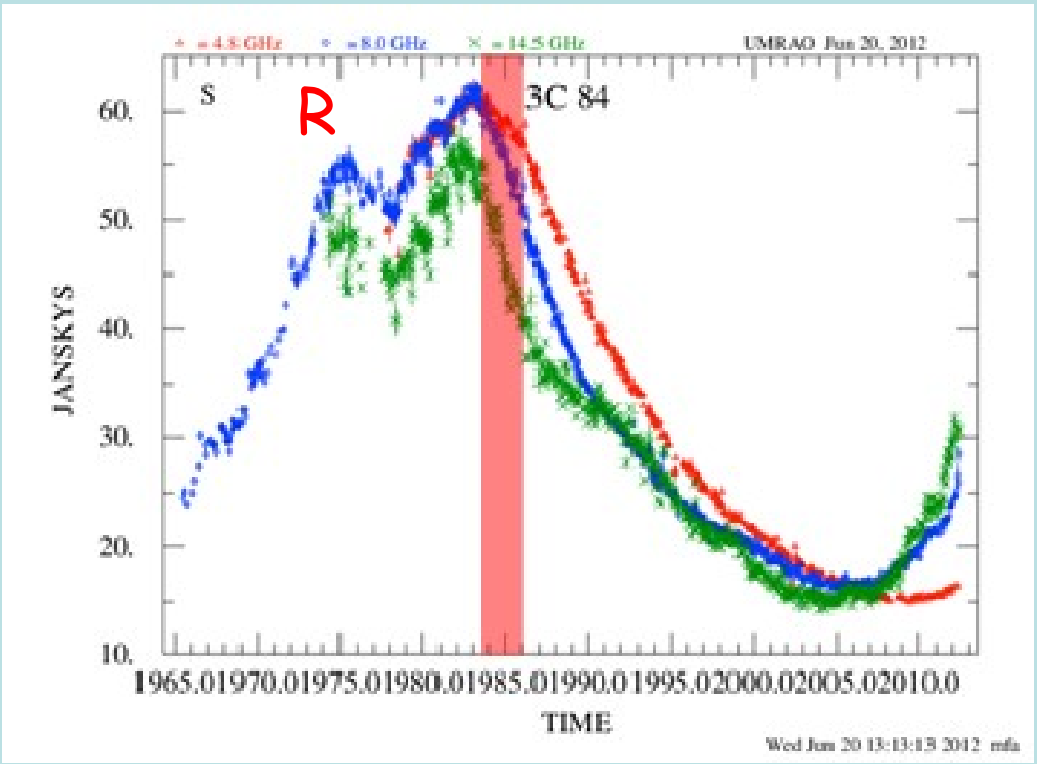
Fig. 1. Contour maps of the nucleus of NGC1275 at six epochs, aligned horizontally proportional to the epoch of observation.

Romney et al. 1982

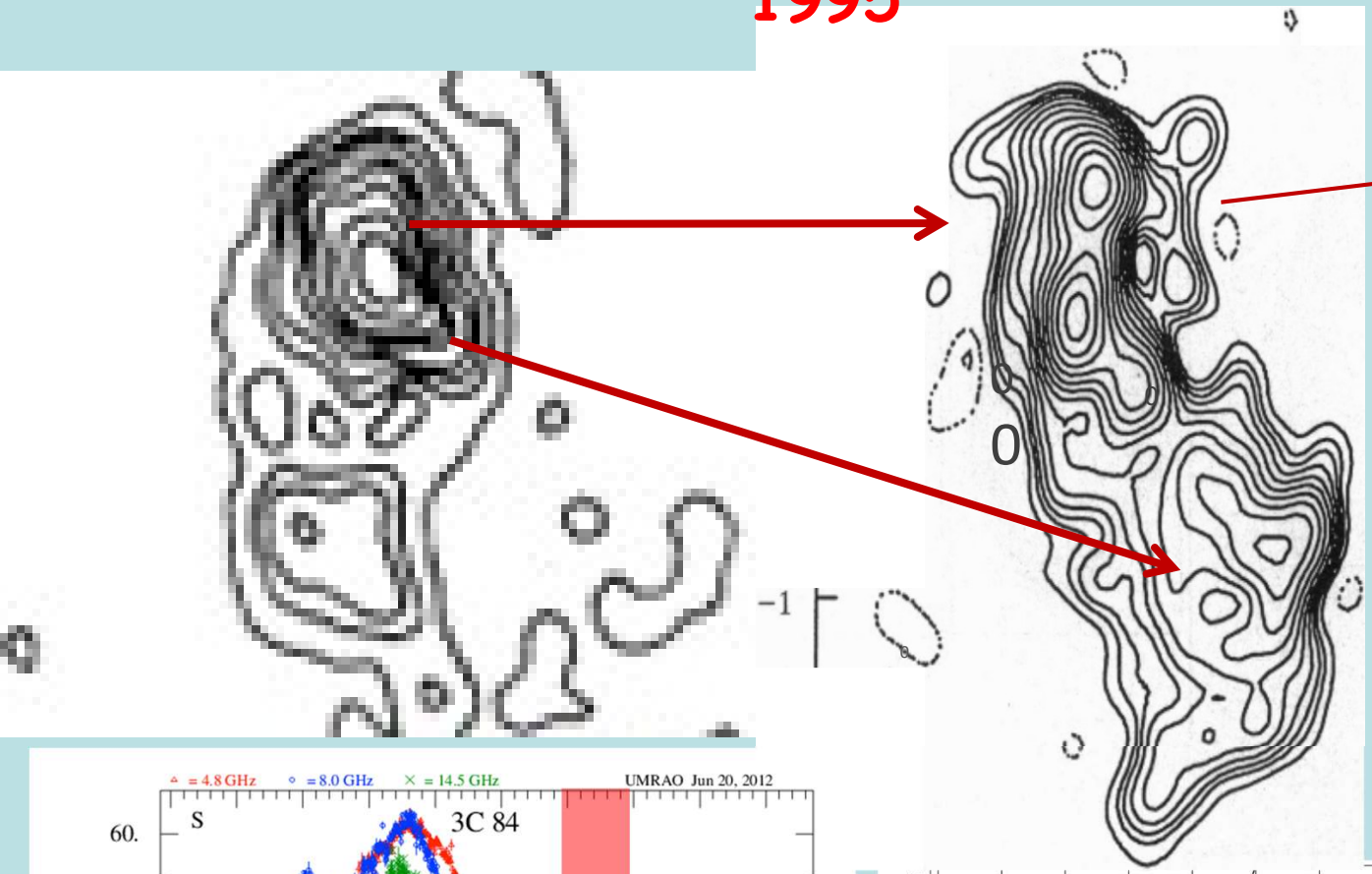
1985

Venturi
et al. 1993





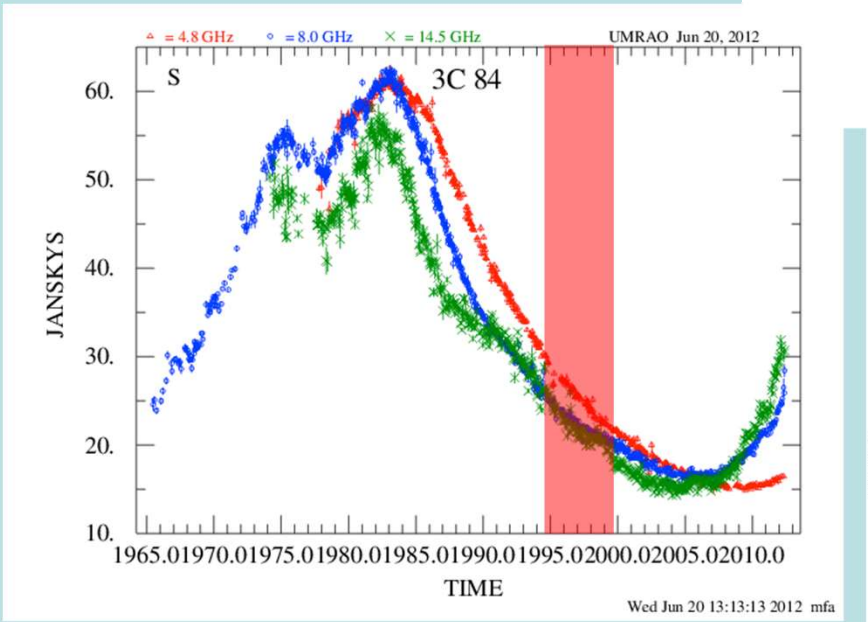
1995

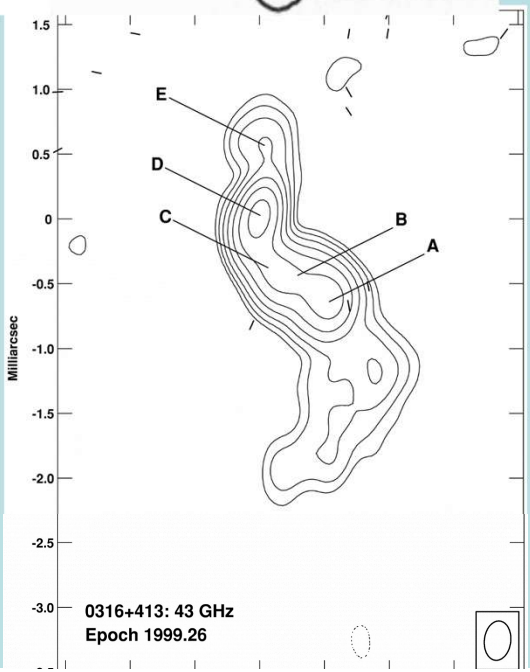


Core C1

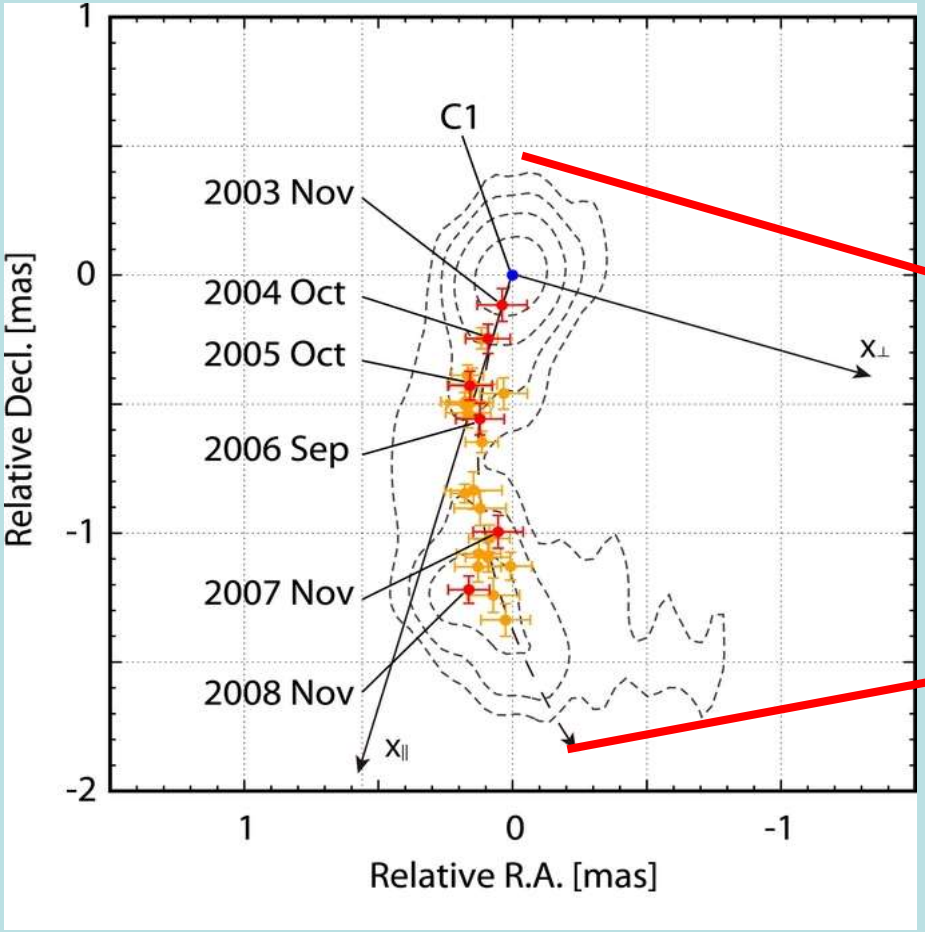
C2

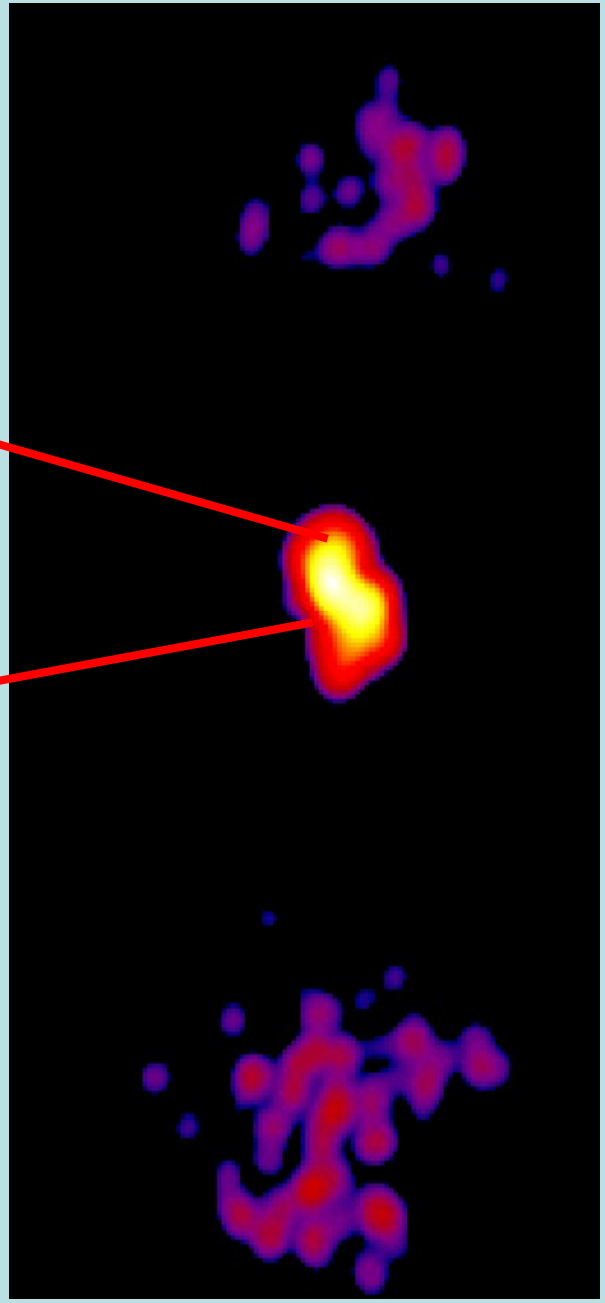
Romney et al. 1995
Epoch: 1995.1





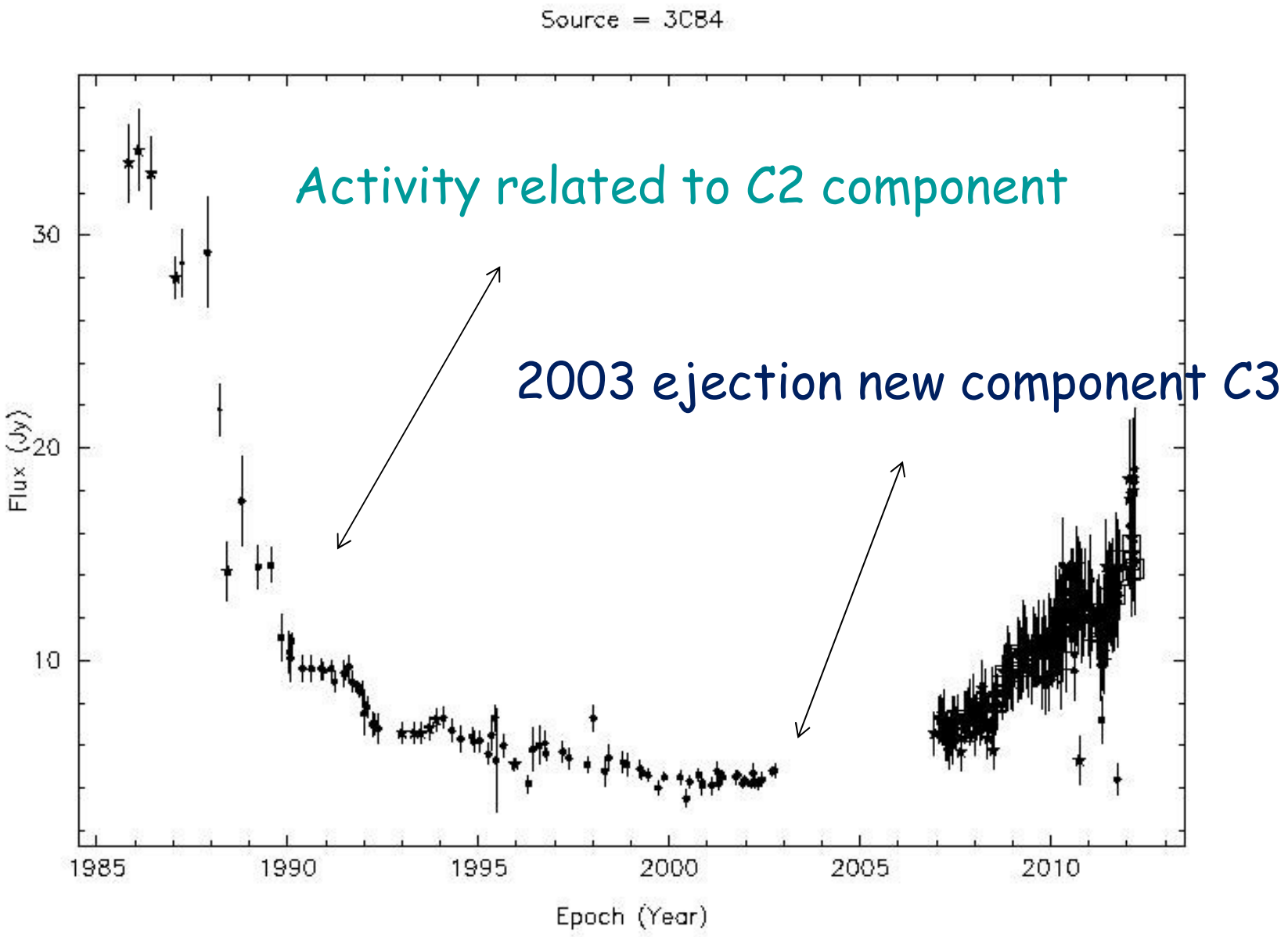
Recent activity

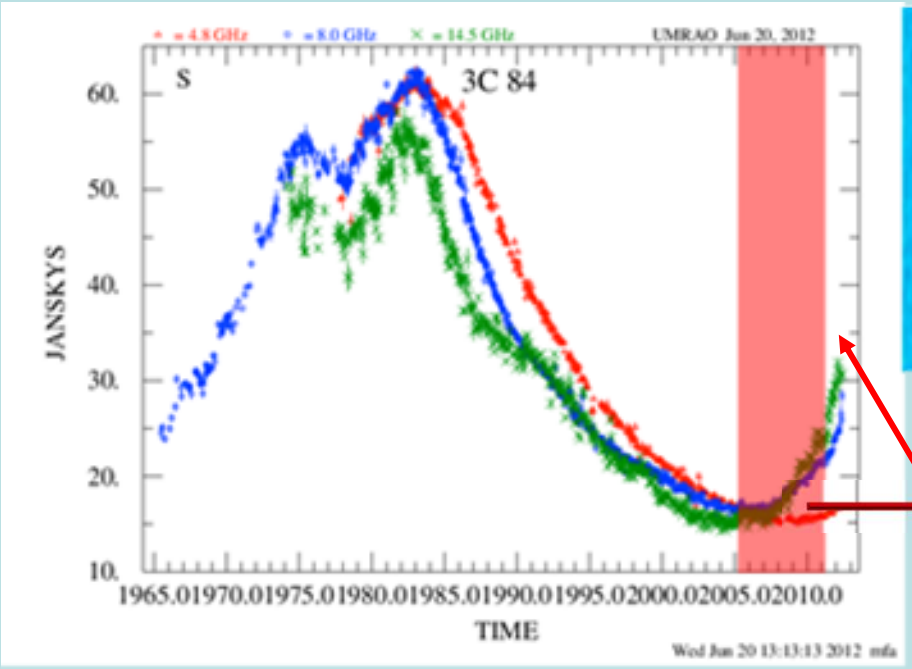


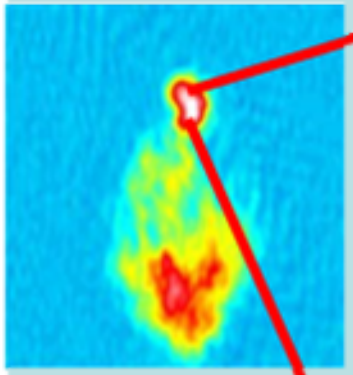


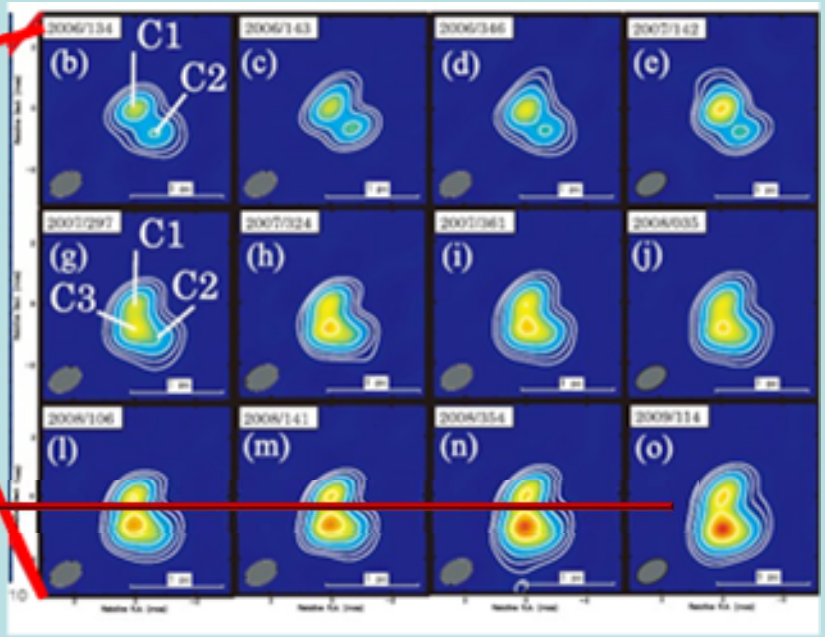
VLBA at 43 GHz in the period of 2003–2008. New component C3
Kenta Suzuki et al. 2012

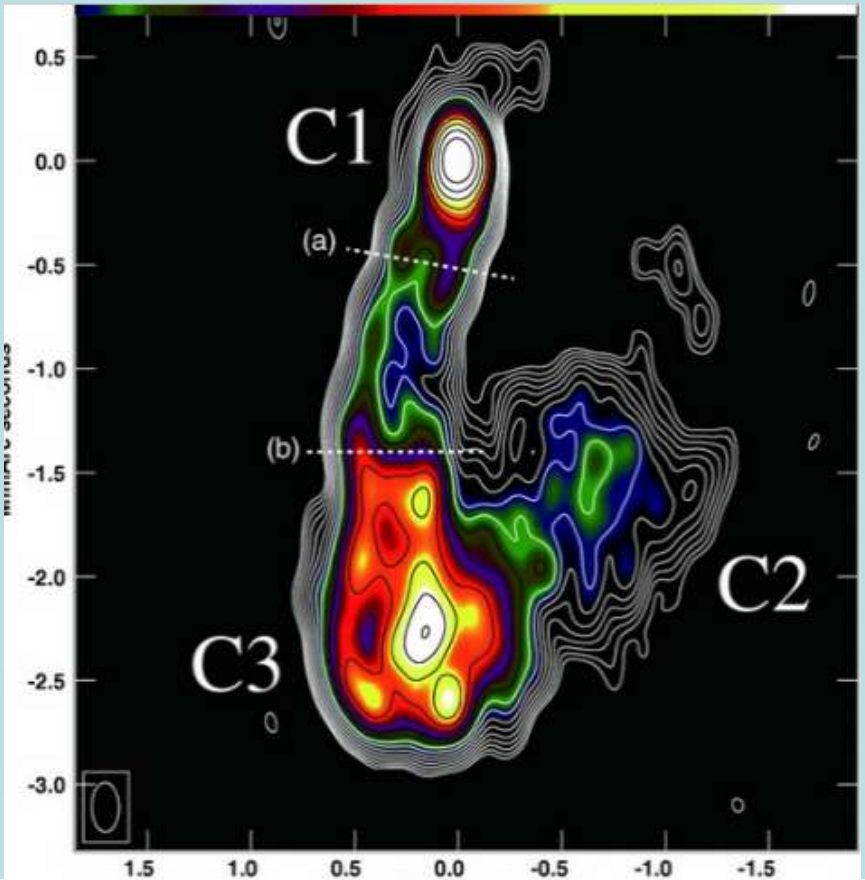
MOJAVE Program 2003-03 epoch


Source = 3C84
Activity related to C2 component
2003 ejection new component C3
Flux (Jy)
30
20
10
1985
1990
1995
2000
2005
2010
Epoch (Year)

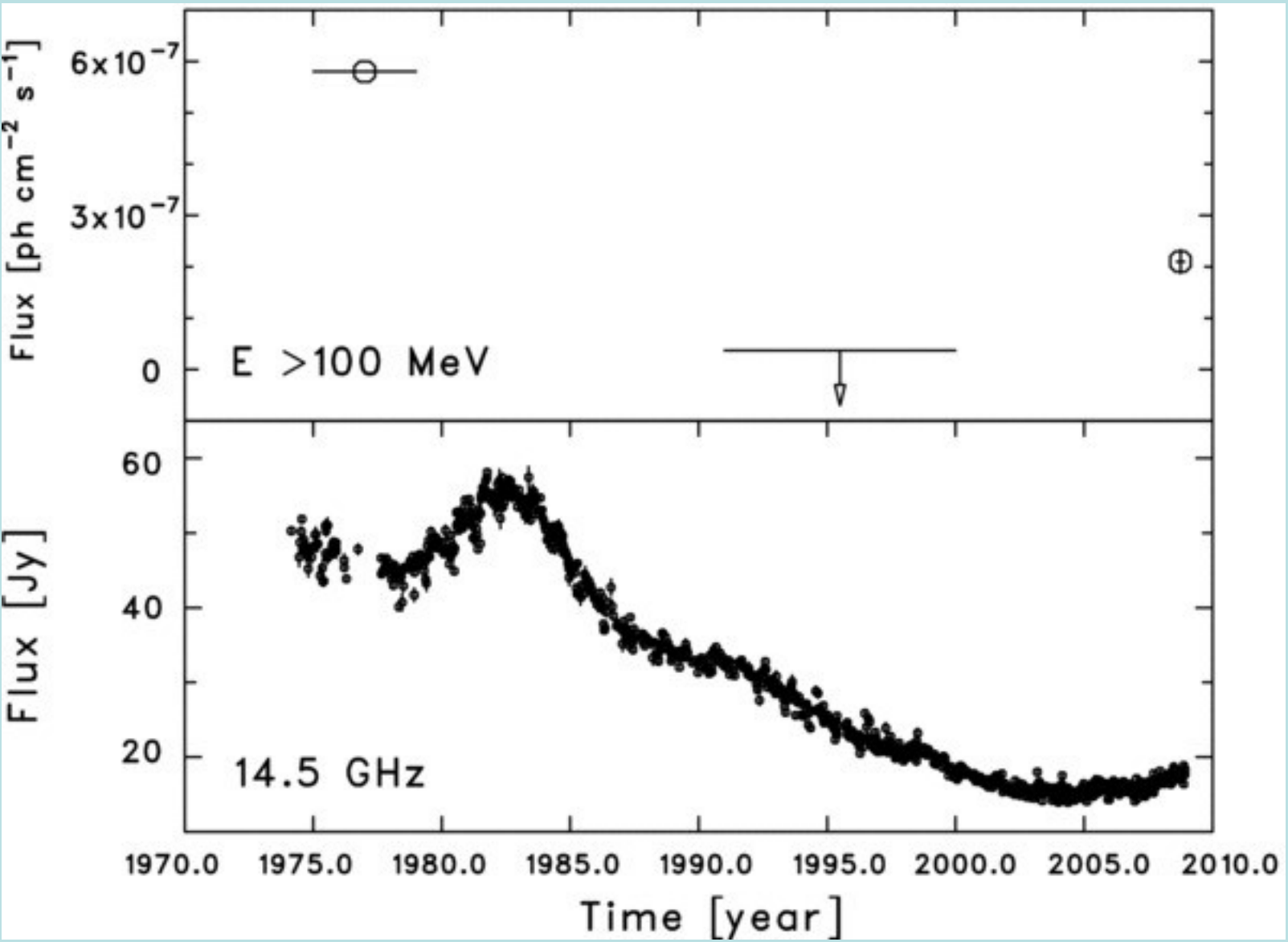






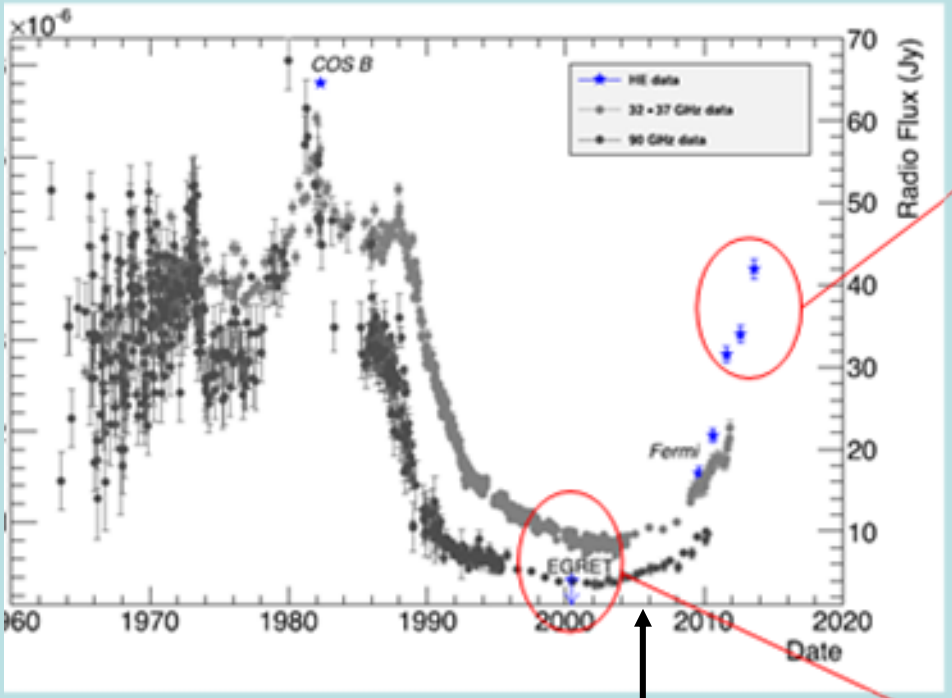


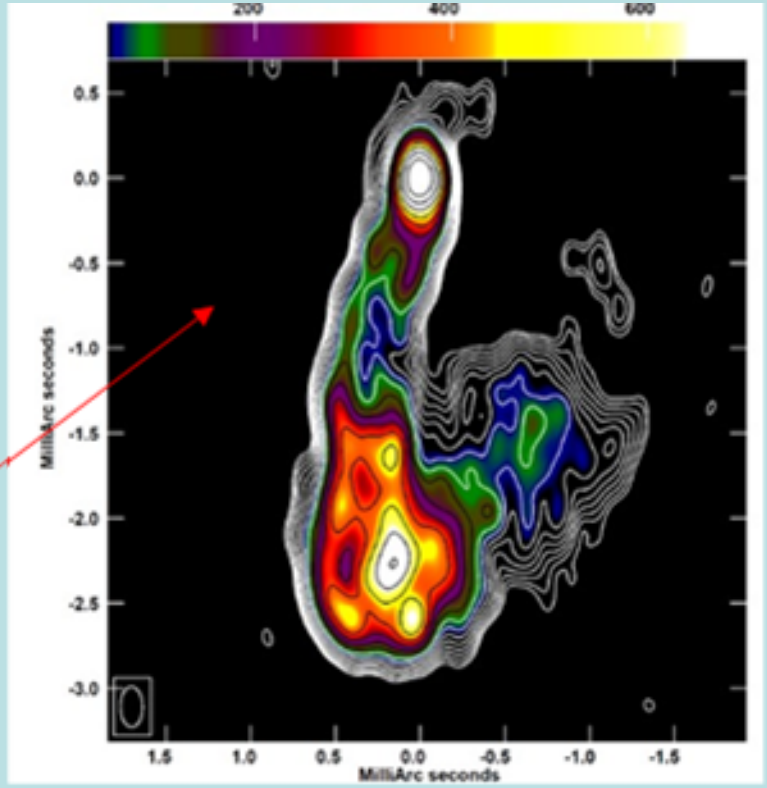
Nagai et al. 2014

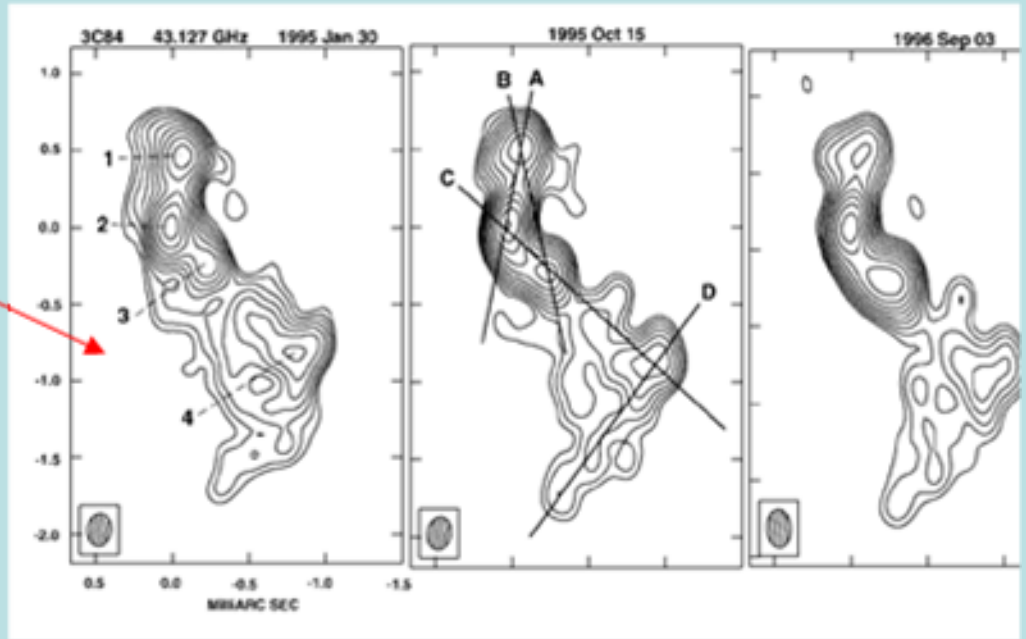


2009 August detected by Fermi-LAT
Abdo et al. 2009

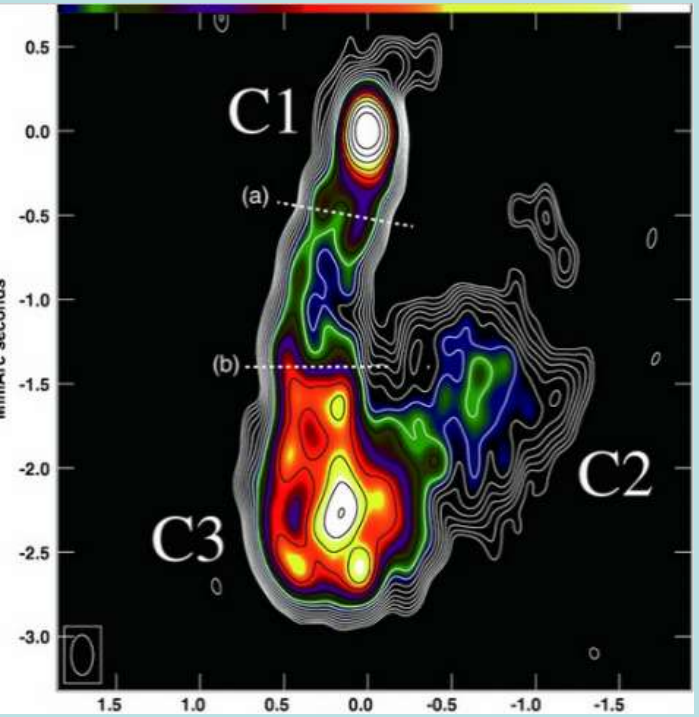
Gamma ray different properties:



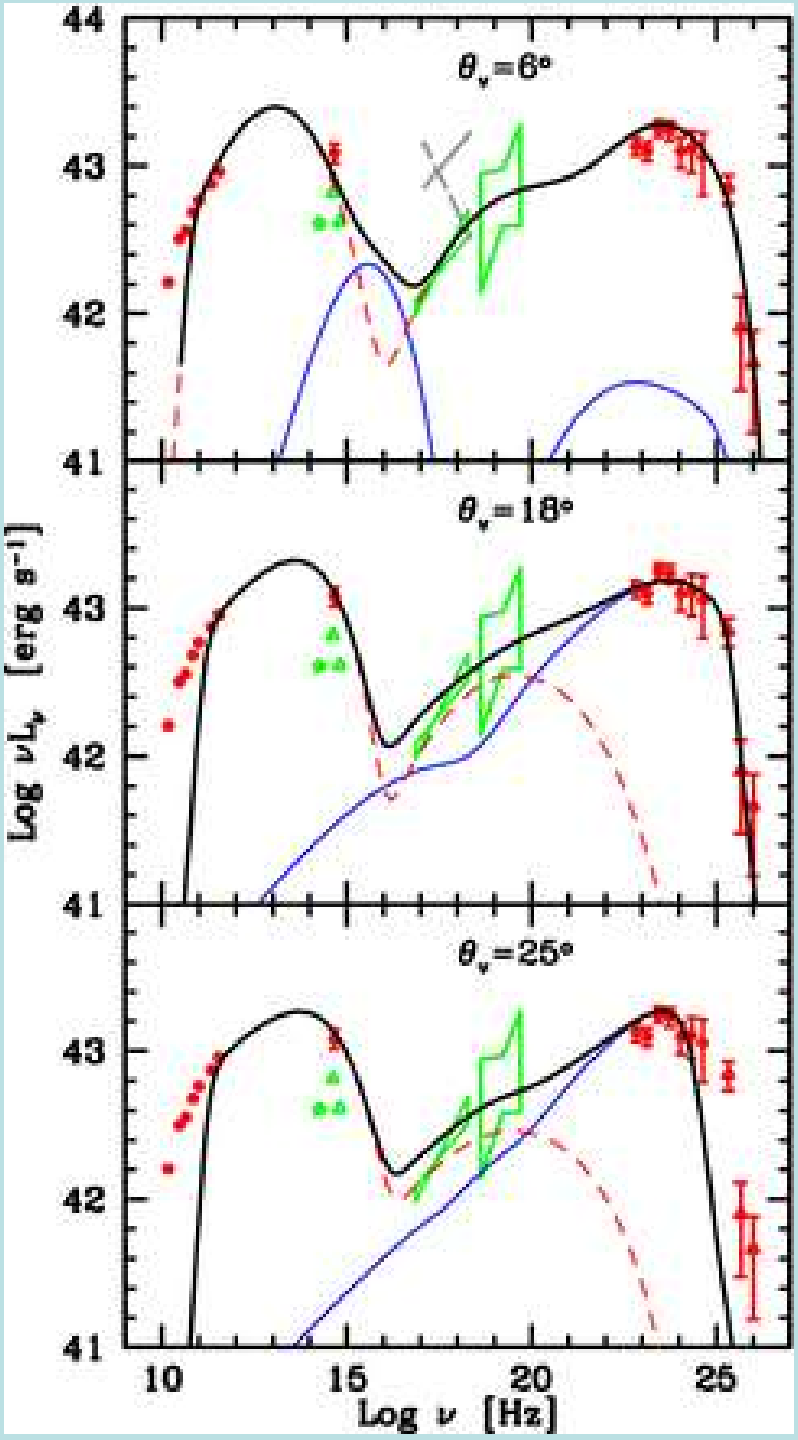




C3 starts



Tavecchio&Ghisellini 14



One-zone SSC implies unreliable high Doppler factor.

Small angle: spine dominated, not in agreement with radio

Spine-layer model well reproduces the SED with theta ~ 18 degree

theta > 20 unllikely due to strong internal absorption.

18 luglio 2011

RadioAstron observations on 21-22/Sept. 2013

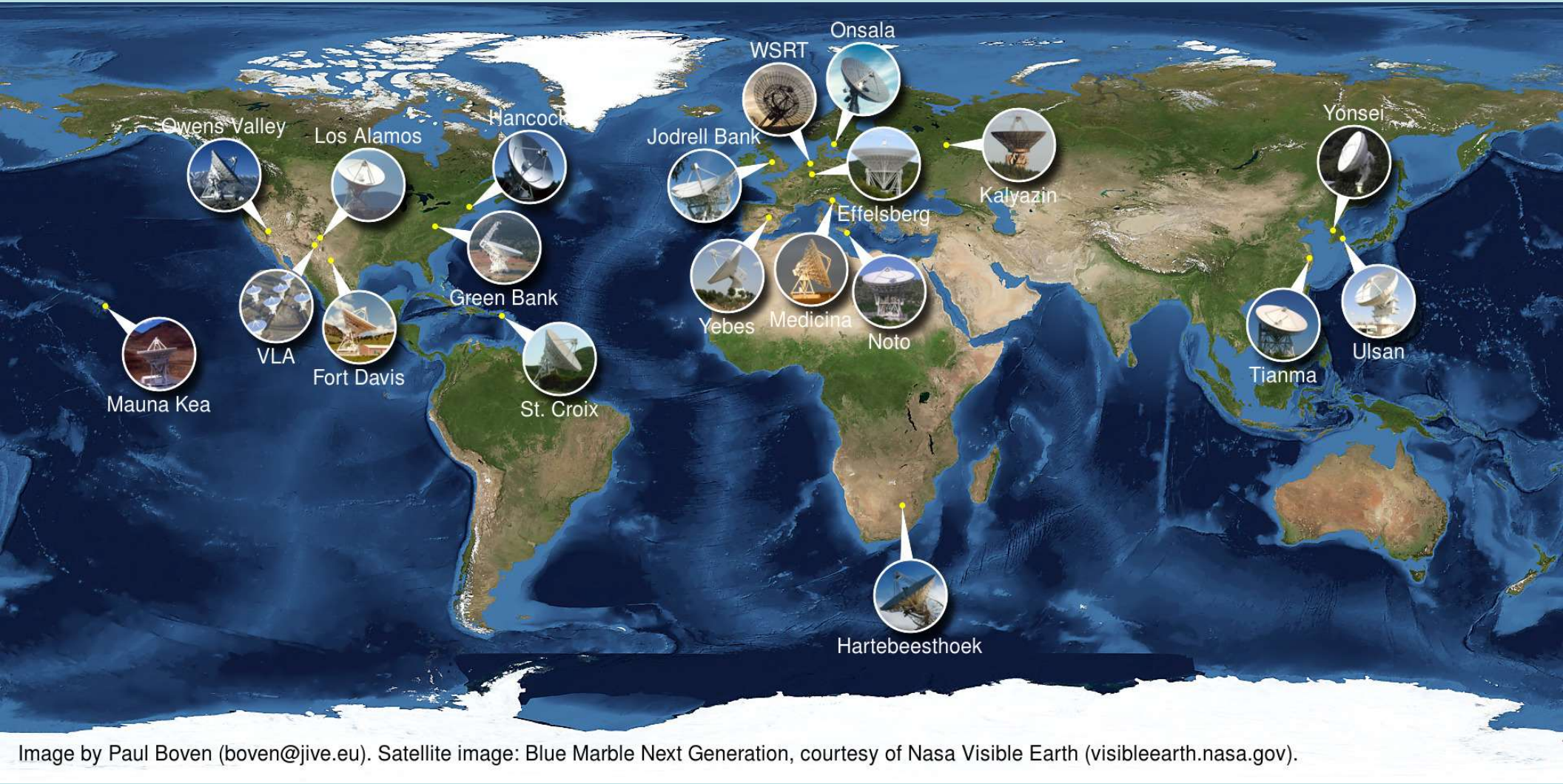
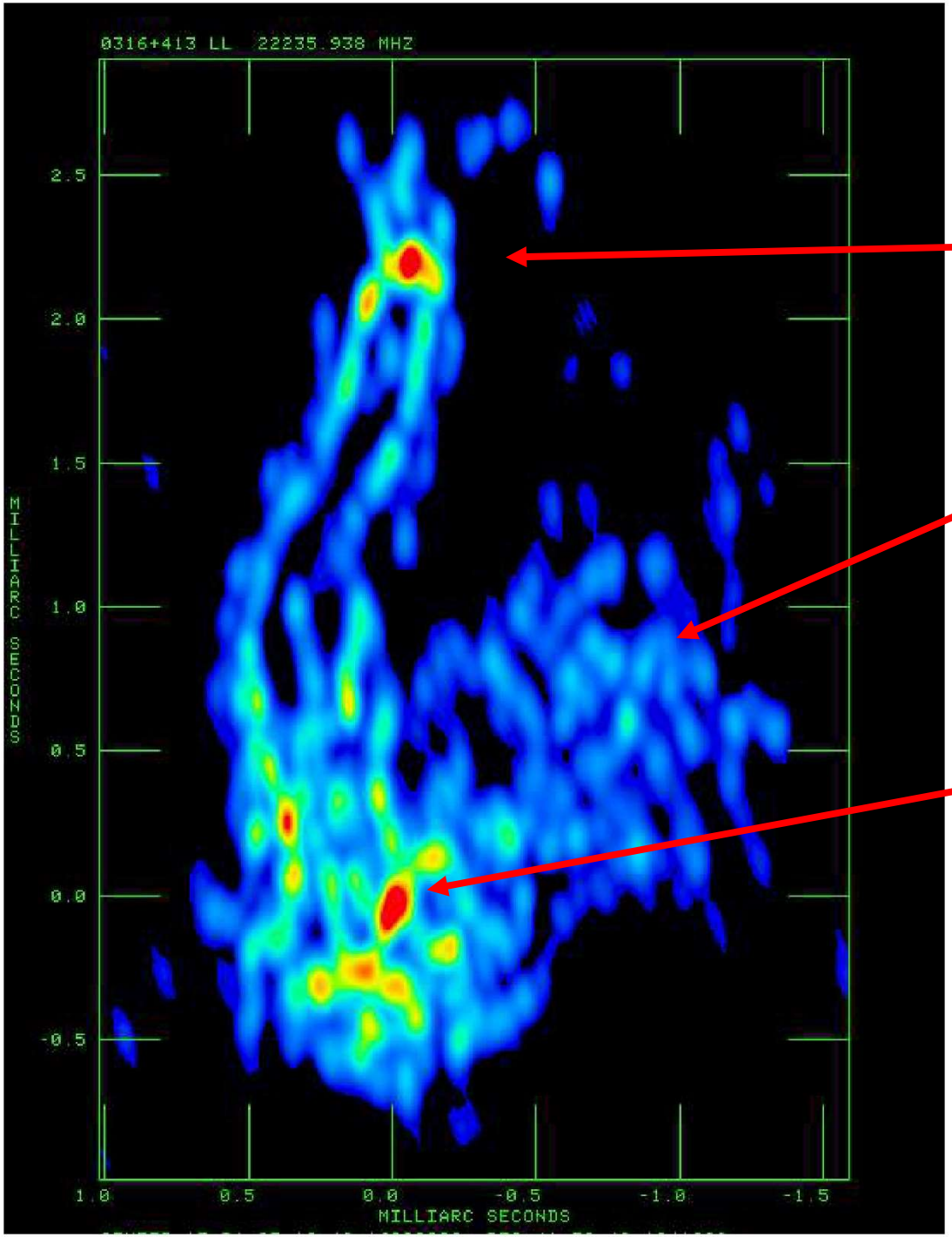


Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Ground array: 29 radio telescopes, of which 24 produced data successfully correlated



22 GHz

Core

C2

C3

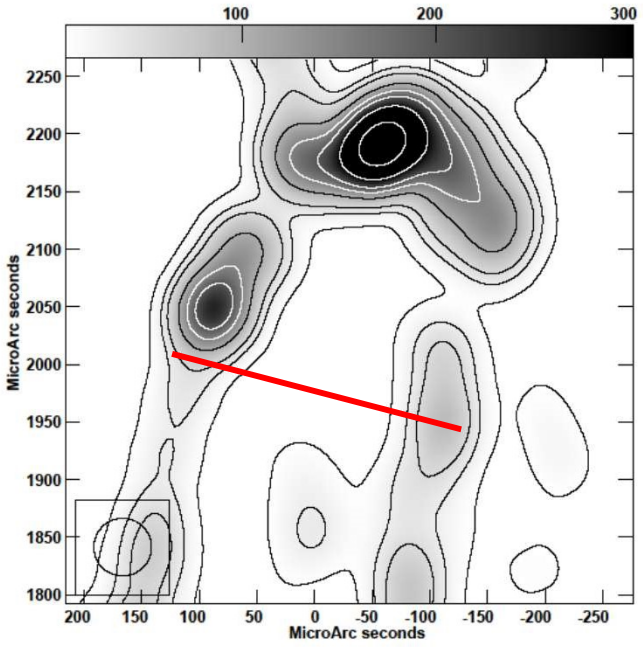
HPBW 0.10 x 0.05 mas

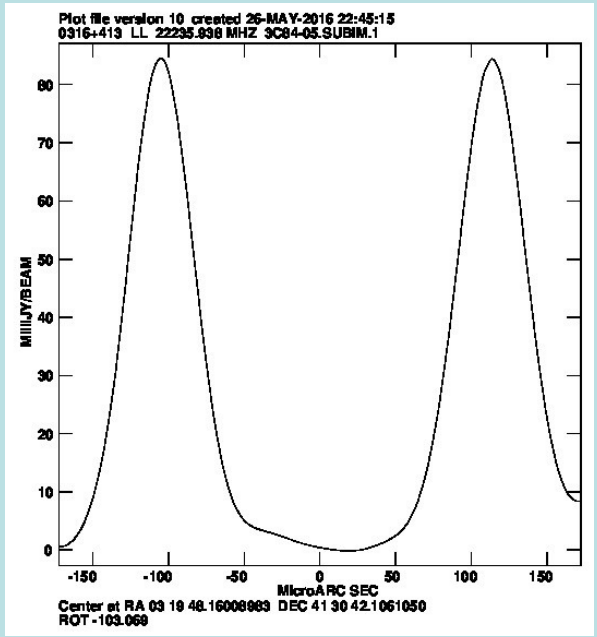
RadioAstron results at 22 GHz

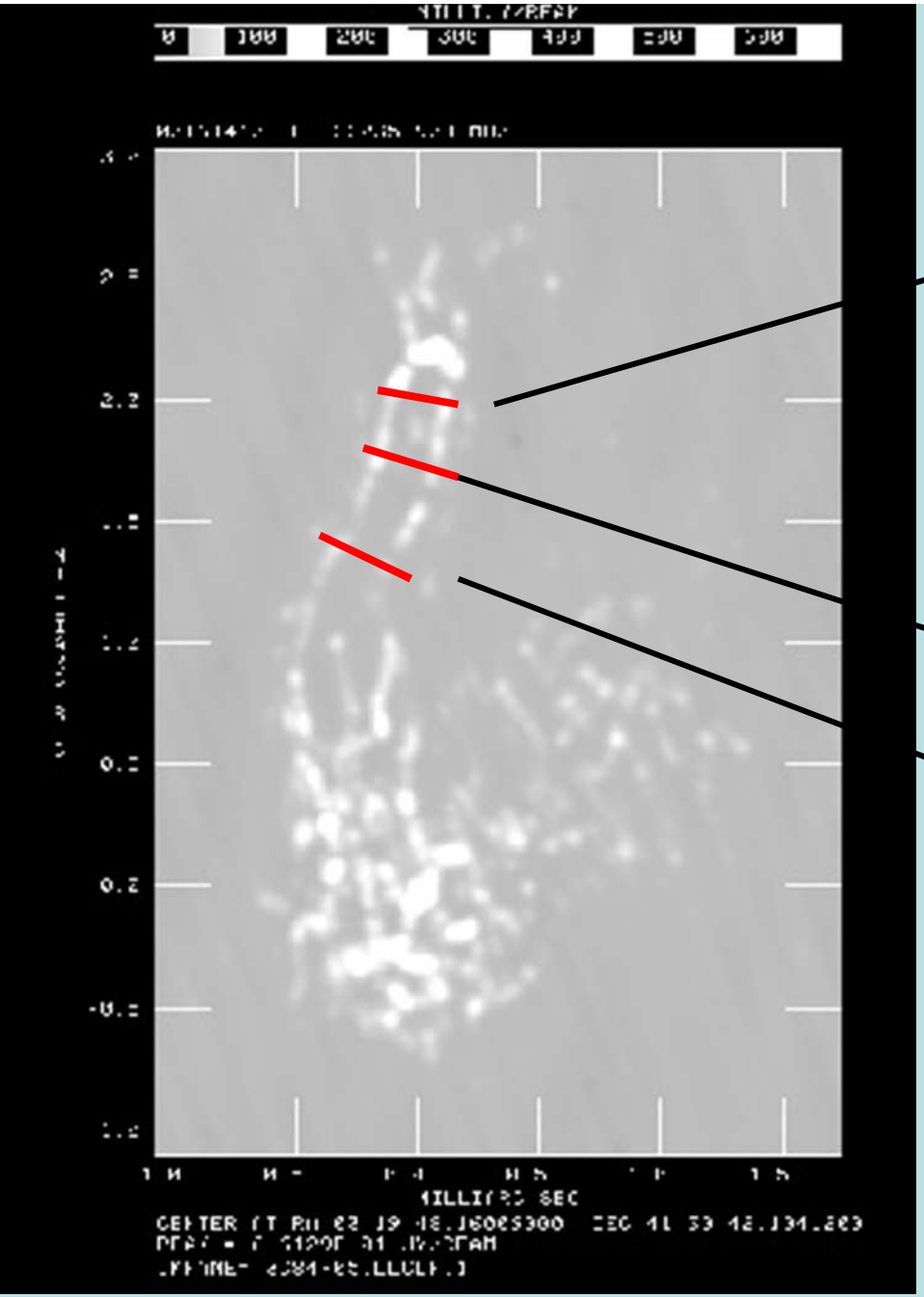
See Giovannini et al. 2018 Nature Astr
arXiv: 1804.02198

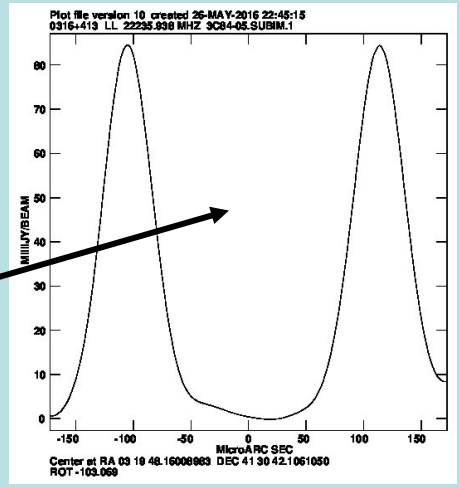
1) Edge brightened jet at 30 microarcseconds from the core corresponding to 350 r_g de-projected

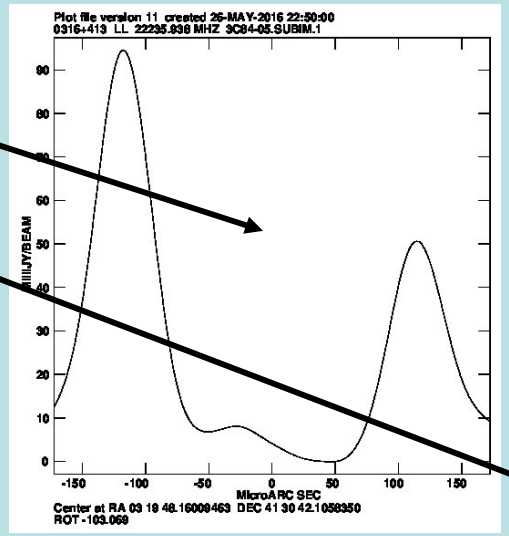
HPBW: 0.05 x 0.05 mas

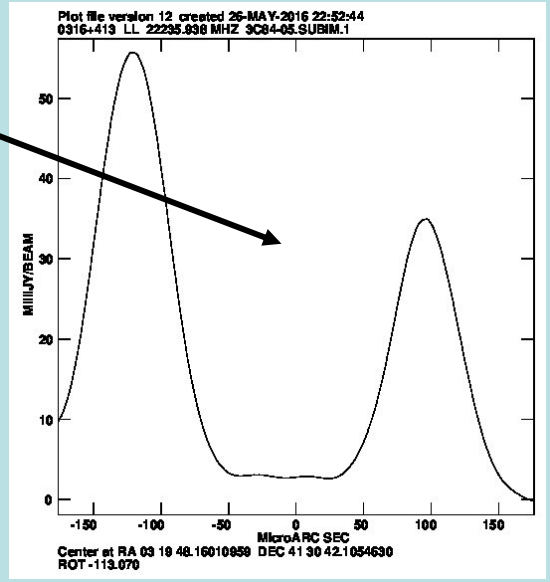










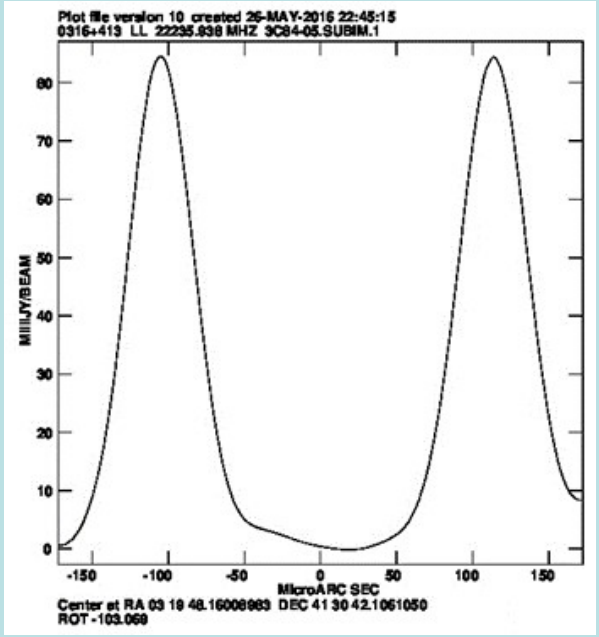


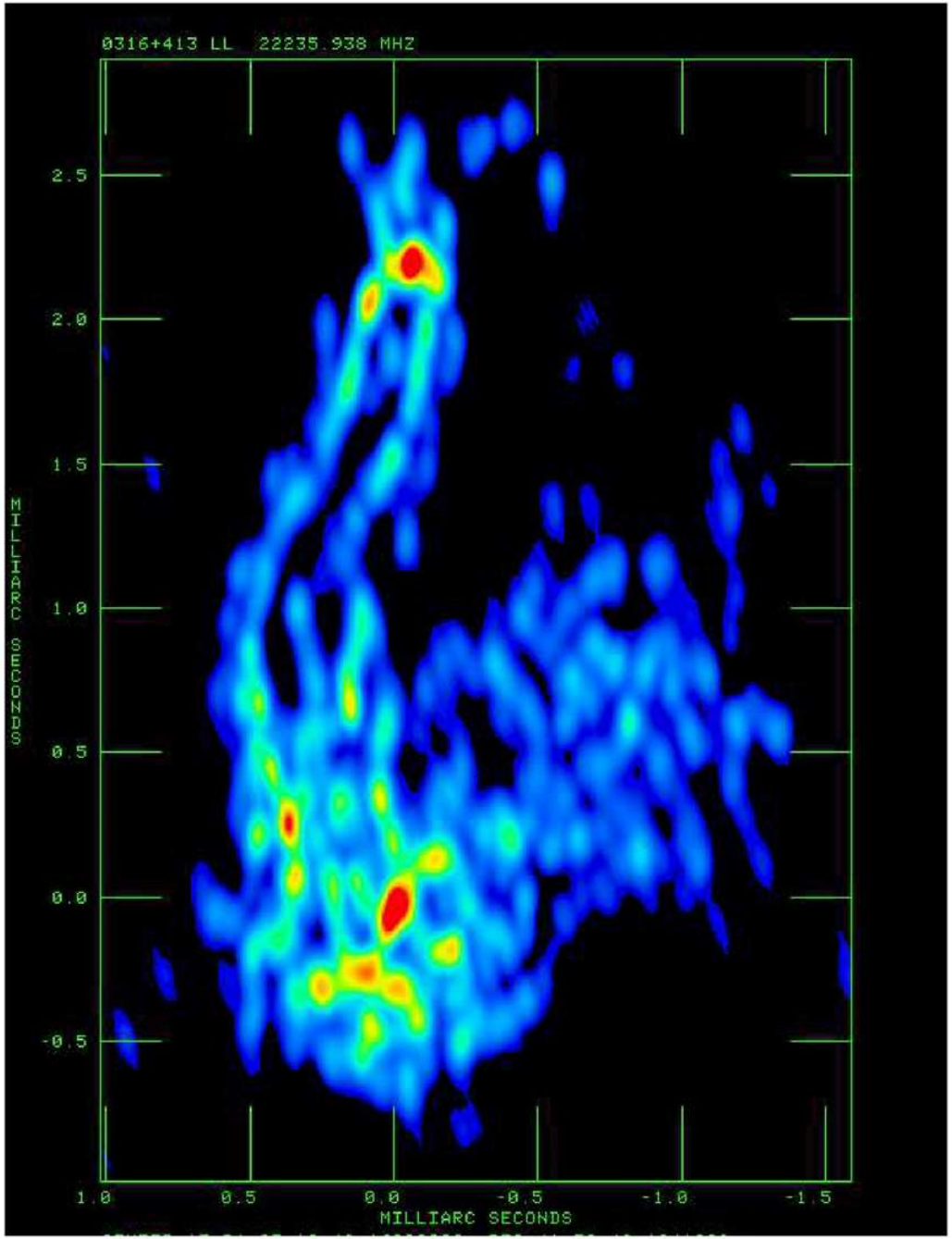
The jet structure Sept. 2013

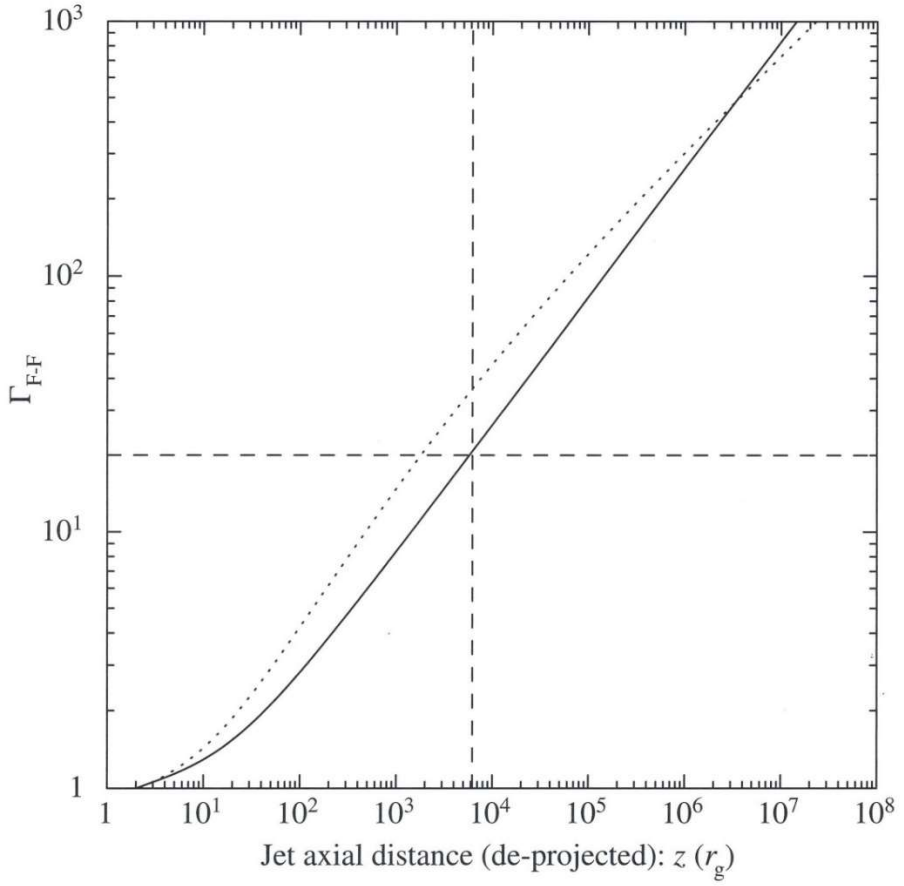
Shear (external jet region) collimated,
≈ unresolved: deconvolved size is < 15 microarcsec at the beginning and about 40 ± 8 microarcsec at 1 mas

Hollow jet or velocity structure?
Brightness ratio between the shear and the spine is ≥ 20 ➔ transverse velocity structure or intrinsic emissivity differences or both

We see the spine brightening as the jet approaches C3







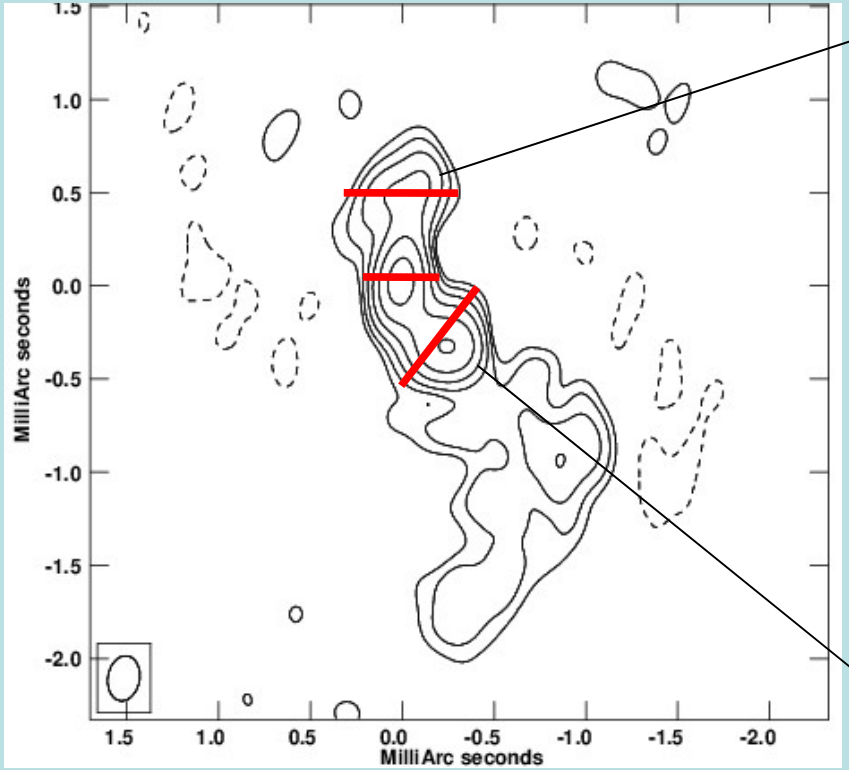
A major problem is the jet limb-brightened very near to the core. Even with an efficient acceleration we expect at a deprojected distance of 500 rg $\Gamma = 10$, we need at least 20.
A rapid more efficient acceleration (semi-parabolic spine –dotted line) is better but at $z = 500$ we have $\Gamma = 10$ too low.
We need also an intrinsic brightness difference.

Punsly et al. 2018(arXiv:1801.03541v2) discussing the hollow jet with a forked morphology in M87 discuss new models where the spine is not an invisible powerful jet, but an intrinsically weak jet.

A powerful ghost jet is not required to power the large scale jet.

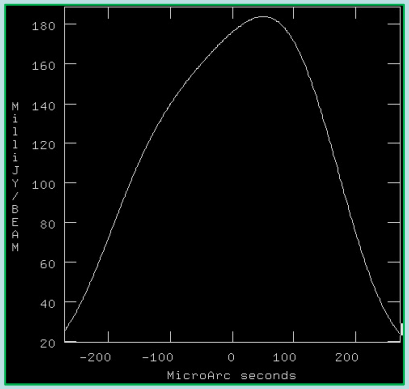
The jet structure: 1995

43-GHz VLBA image

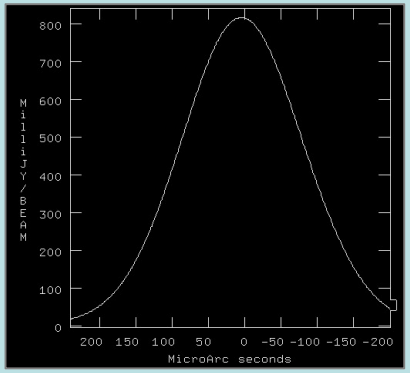


p ~ 0.8 Jy/b; f.c. ~ 18 mJy/b

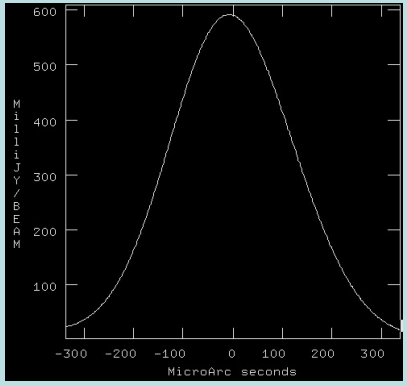
FWHM ~ 0.24 x 0.17 mas



Peak ~ 0.2 Jy/b
D ~ 0.5 mas



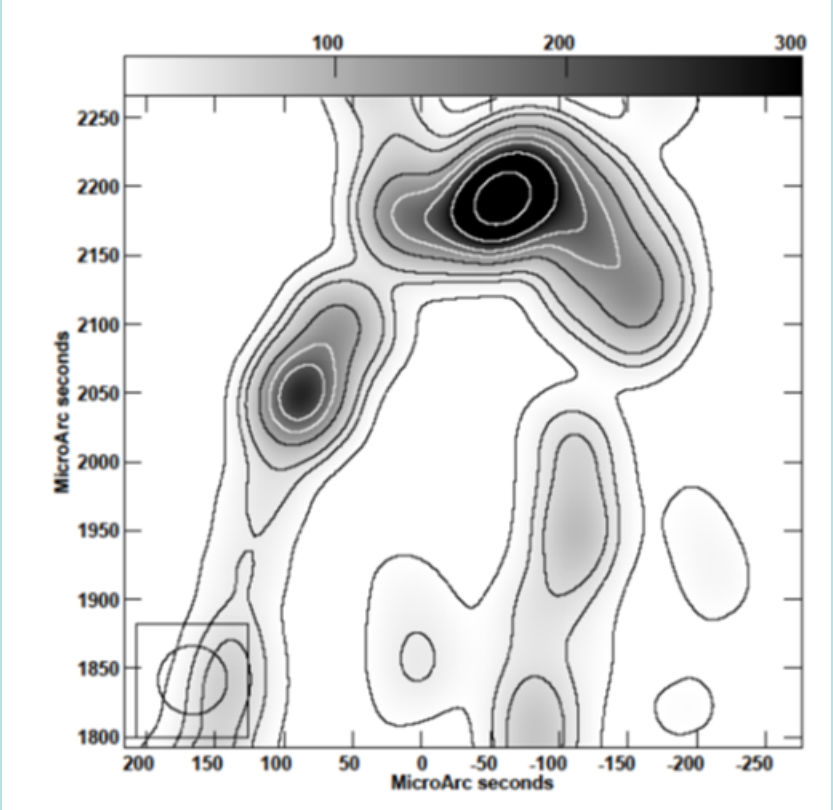
Peak ~ 0.8 Jy/b
D ~ 0.5 mas

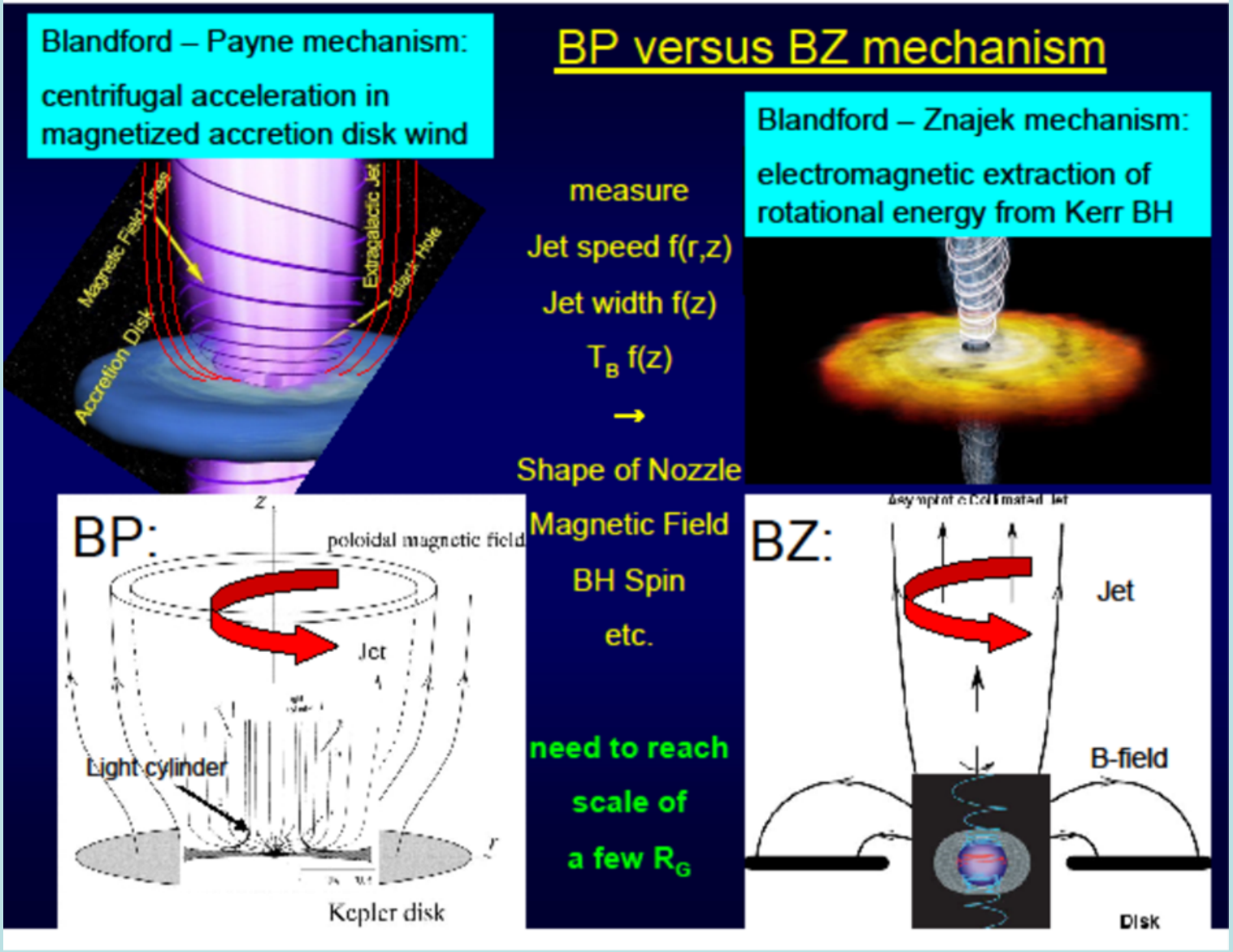


Peak =0.6 Jy/b
D ~ 0.4 mas

2) Large opening angle followed by almost cylindrical jet profile

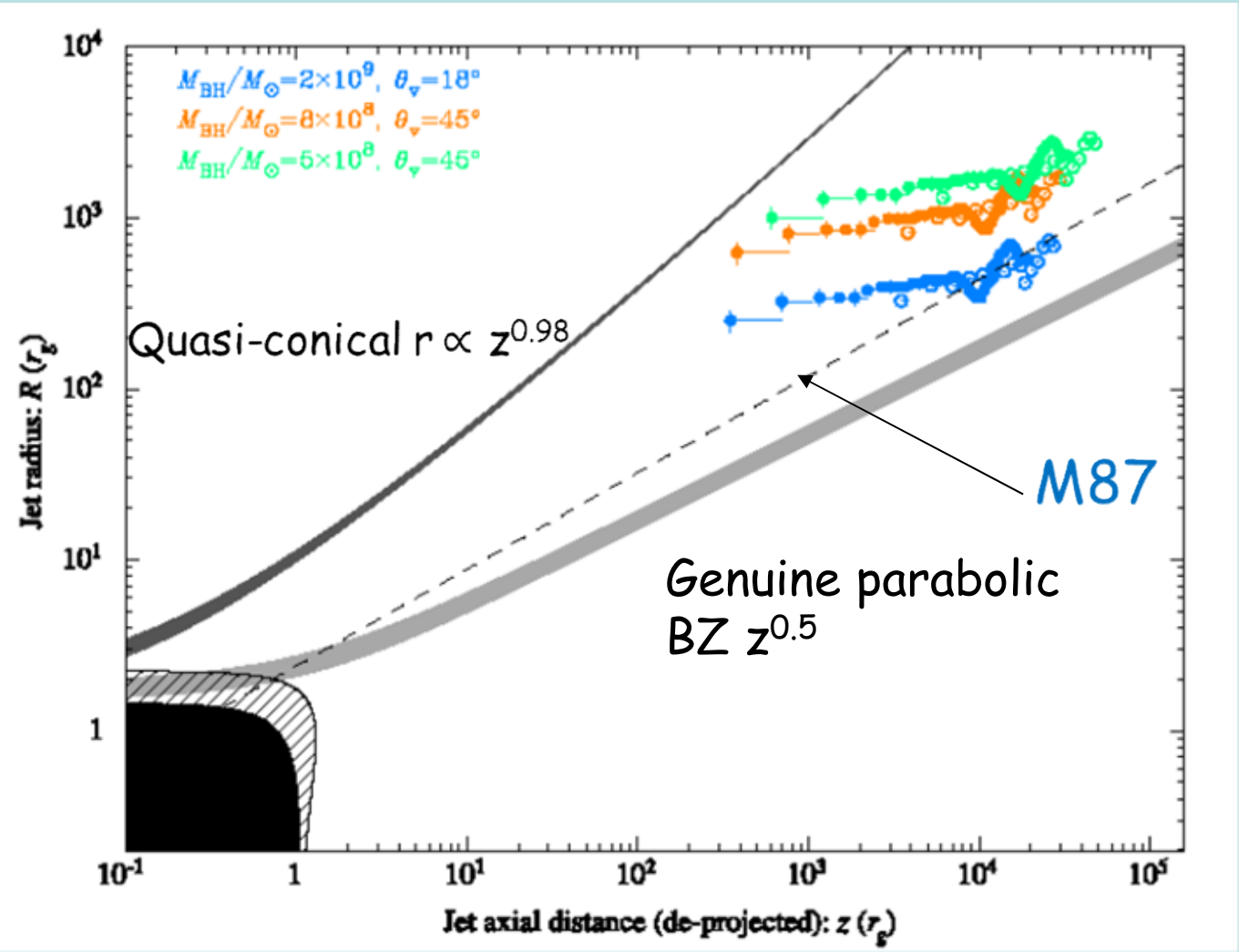
We find a broad jet with a tranverse radius ≥ 250r_g at only 350 r_g from the core.
If the bright outer jet layer is launched by the BH ergosphere, it has to rapidly expand laterally followed by an almost cylindrical collimation. If this is not the case ➔ the jet sheath is likely launched from the accretion disk.





From Krichbaum, 2014

Theoretical arguments and computer simulations favour BZ model especially in thick radiatively inefficient accretion flows (RIAFs) as is considered 3C84.

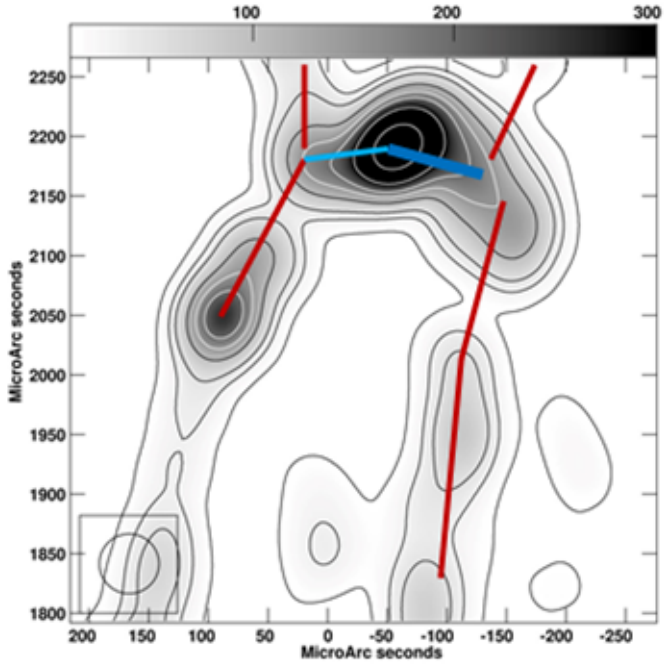


Measured jet width is between 2 streamlines hence an ergosphere-launched jet is possible

$r \propto z^{0.56}$

Problems.
Core shift
BH mass:
Scharwachter + 2013
Using different orientation angle

Streamlines of the jet sheath may in principle to connect to the horizon if a rapid lateral expansion is present. If such a rapid expansion does not occur on scales below 100 r_g the jets sheath is launched from the accretion disk.



We see a rapid collimation at ≤ 400 r_g
The quasi-cylindrical jet structure
Between 400 and 8000 r_g is in contrast with the jet collimation profiles in M87 and Cygnus A (nearly parabolic). Since the jet outline is determined by confinement by external medium, this difference implies a very different ISM where the jets propagate (see next talk: Savolainen)

Differences between M87 and 3C 84 can be:

- 3C 84 is a gas rich galaxy at the center of a strong cooling flow. M87 is a gas poor galaxy

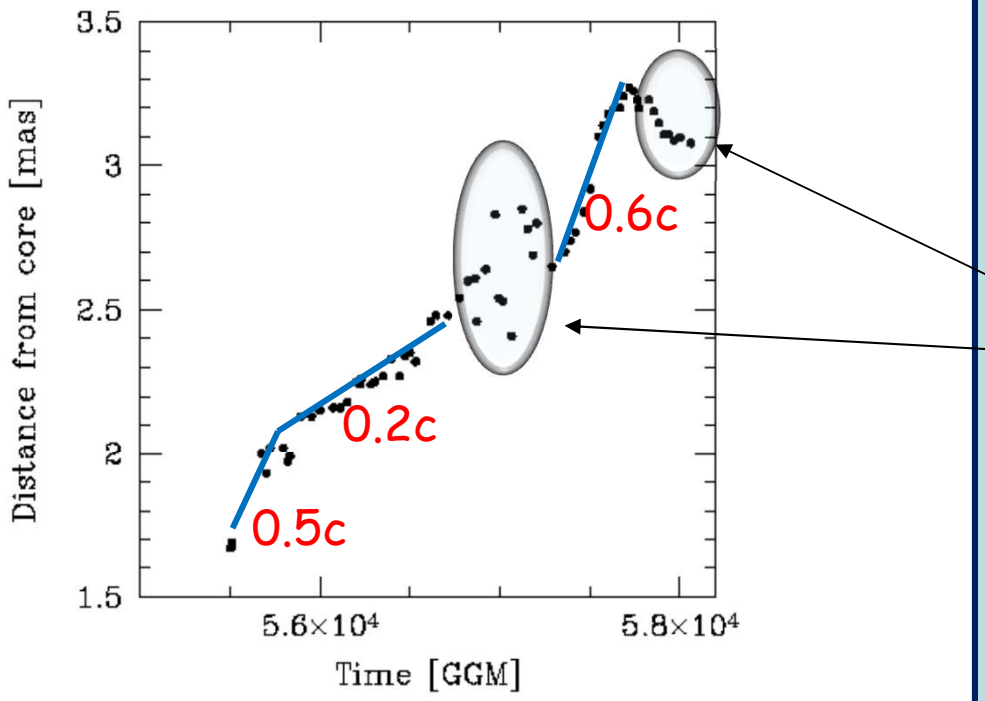
- 3C 84 jet is a young jet originated by a restarted activity. The 3C84 jet could be not yet shaped by the underlying stratified ISM but by the shocked surrounding medium. 3C 84 jet it is not yet in an equilibrium condition with the surrounding ISM

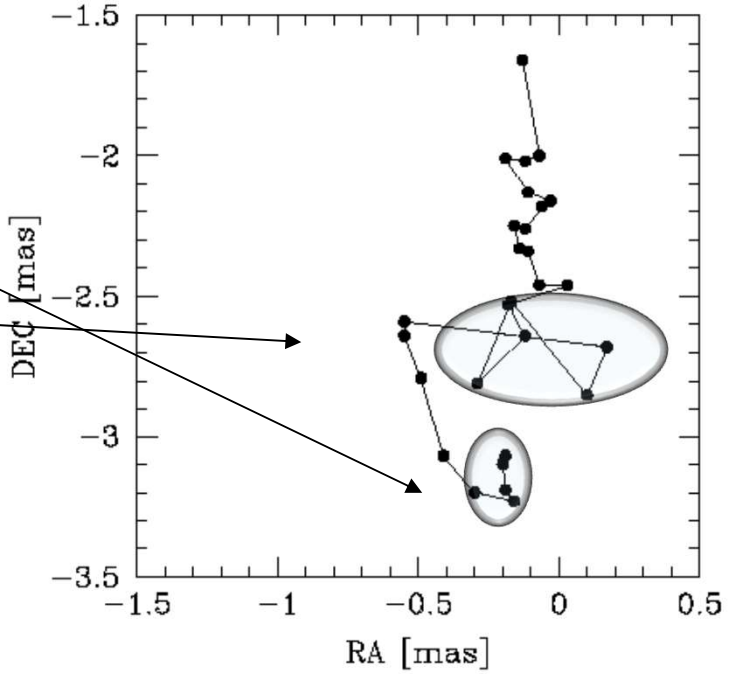
A still in evolution scenarium is supported by the C3 properties:

- Nagai et al. 2013 discussed C3 polarization and interaction with the ambient

- Kino-Nagai poster (here) discuss the flip of the jet head position (C3) of 3C 84 in 2015 as an evidence of a jet propagation in clumpy ambient

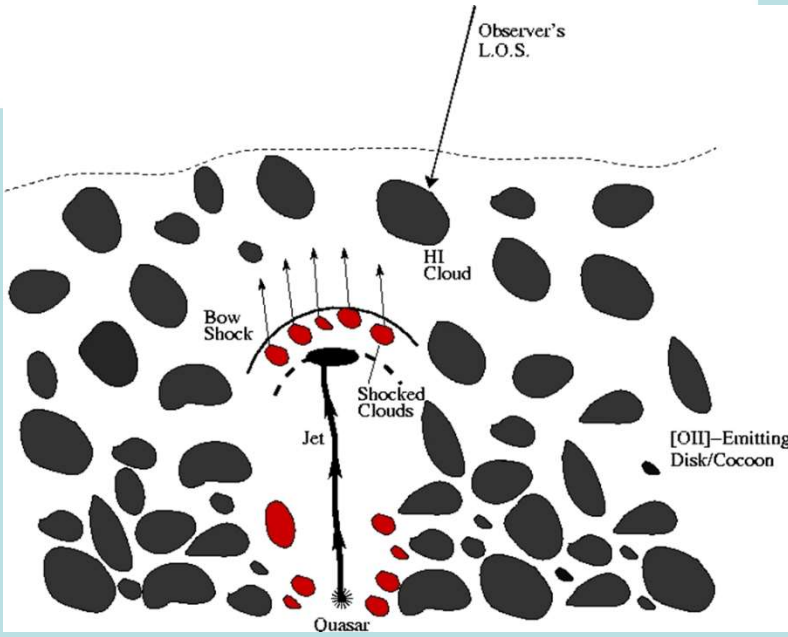
- Hiura et al. 2018 in press present VERA monitoring of the radio jet in 3C 84 during 2007-2013 with a strong evidence of a non linear motion.

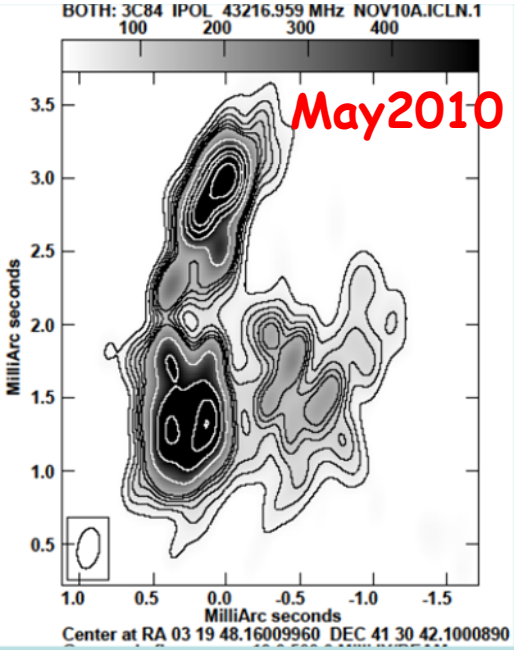


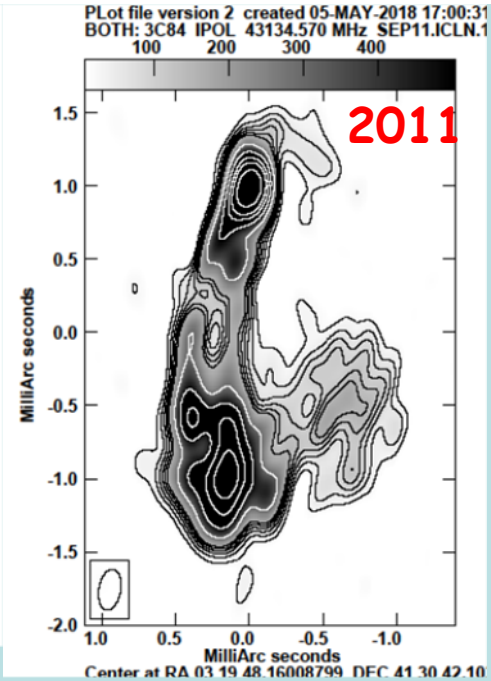


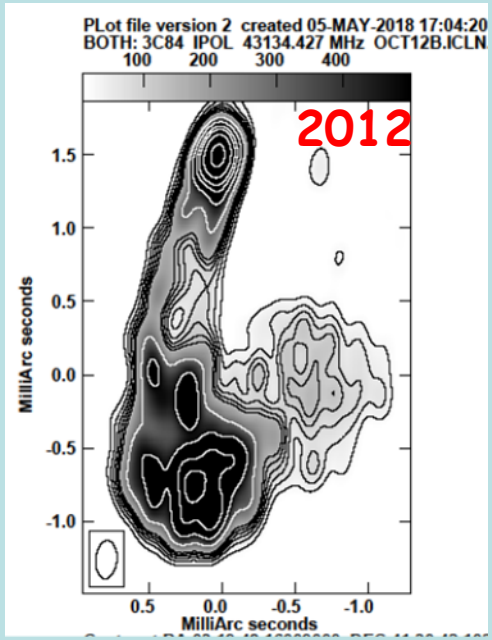
43 GHz VLBA data from the VLBA-BU Blazar Monitoring Program from November 2010 to November 2017

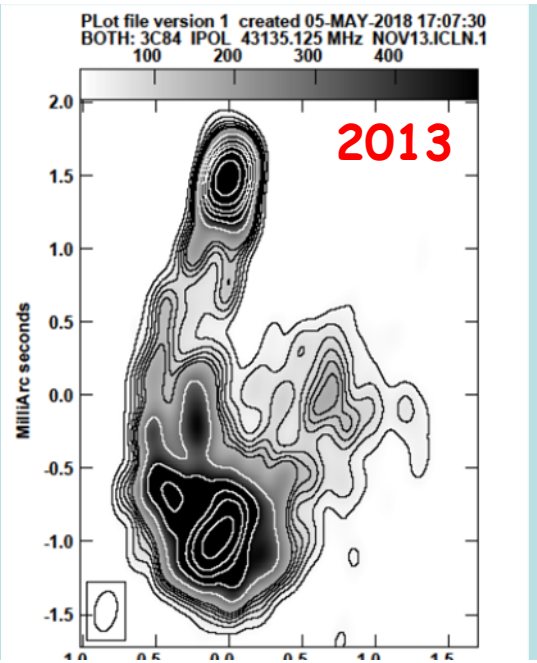
3C 84 jet still evolving: unique opportunity to study early evolution of a restarted jet in an active rich gas galaxy

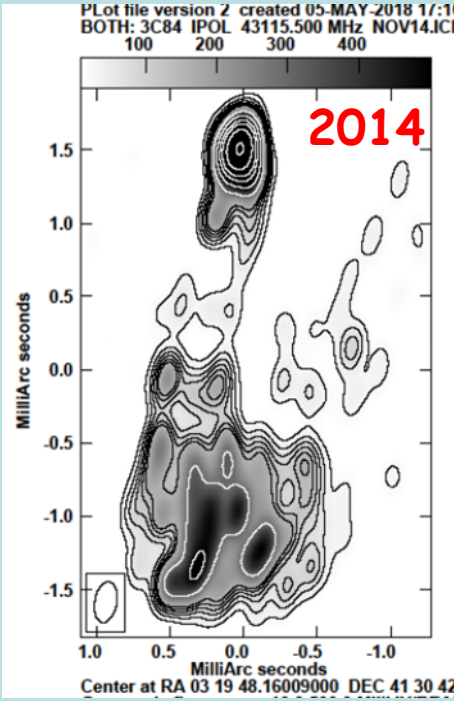


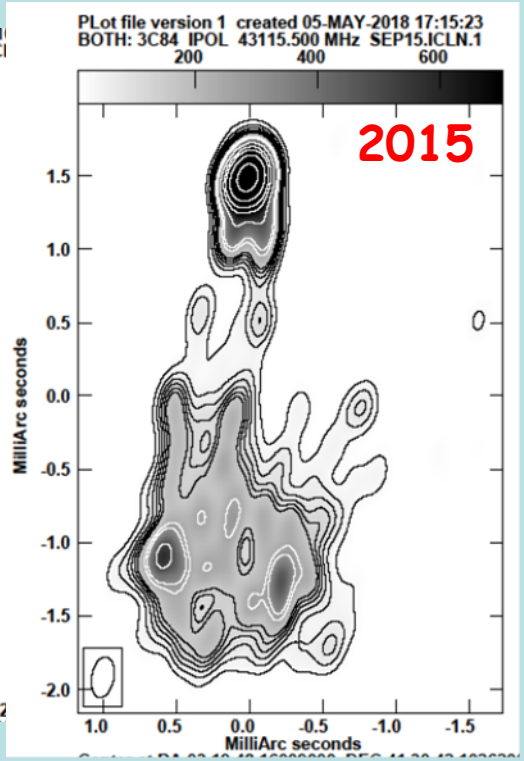


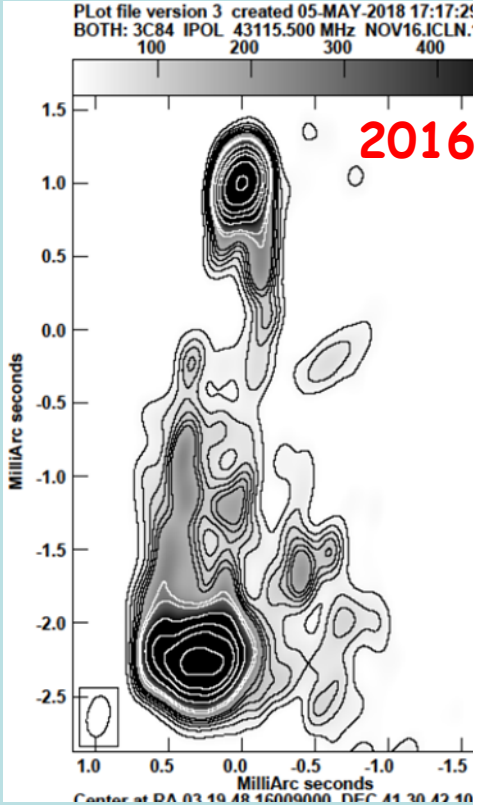


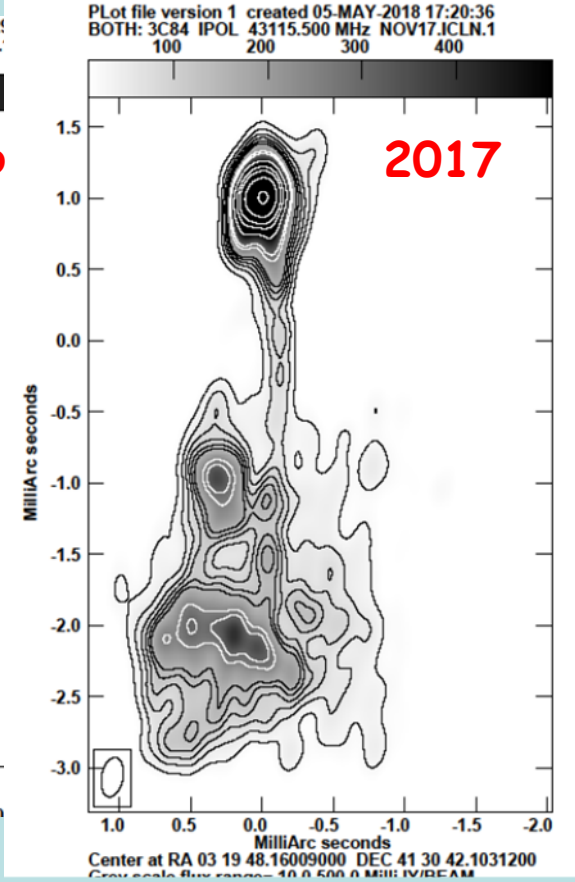












Preliminary

conclusions

1) 3C 84 core: complex edge brightened jet with large opening angle near the core

2) Large difference in brightness between the jet shear and spine ➔ different Doppler factor and/or electron density problem: too nearby to the core

3) The shear is well defined and collimated: strong confinment by the external medium

4) An ergosphere launched jet is possible but we cannot exclude that the jet sheath is launched from the accretion disk

5) 3C 84 different from M87 and Cygnus A: 3C 84 is a BCG in a strong cooling flow cluster + young jet

6) Unique opportunity to study in detail the evolution of a young jet


Thank You
18/07/2011 04:48