The evolution of the nuclear structure of 3C84 at sub-mas resolution

Gabriele Giovannini (IRA/INAF and Bologna University)

T. Savolainen, M.Orienti, H. Nagai, M. Nakamura,, M.Giroletti, K.Hada, M.Honma, M.Kino, Y.Y.Kovalev, B.W.Sohn, J. Hodgson, S.-S. Lee, F. D'Ammando, R. Lico, et al.

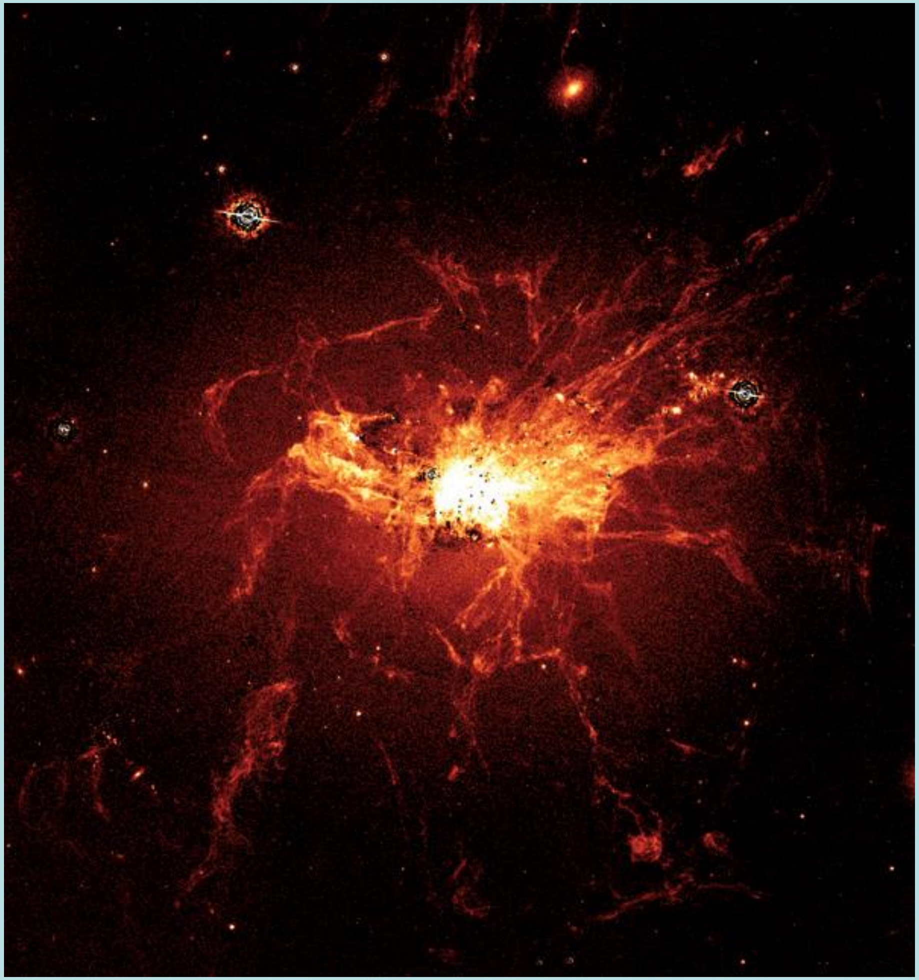
3C 84

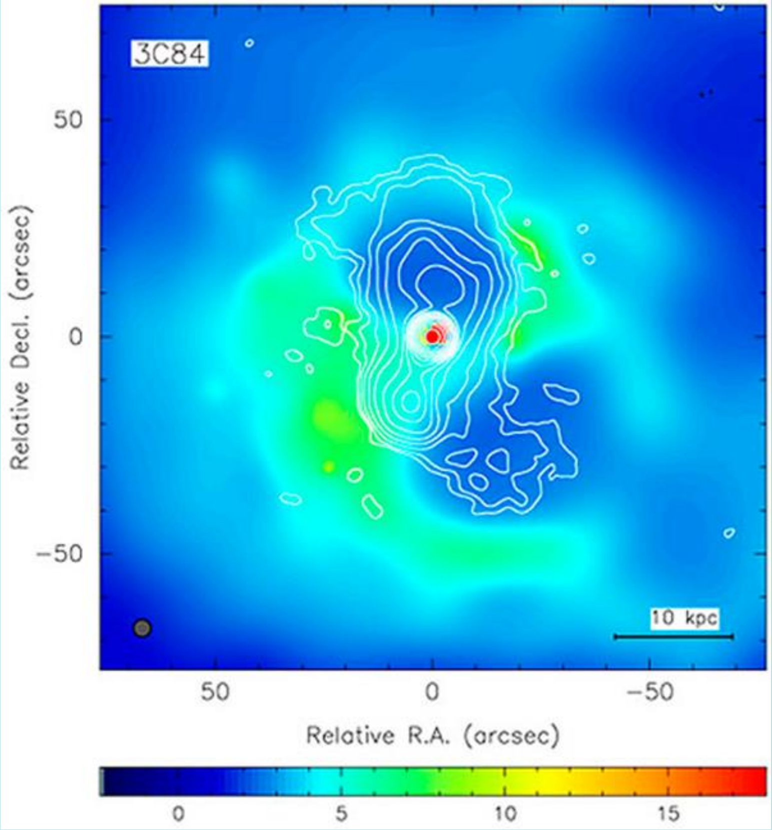
Nearby radio source (z = 0.0176)

Giant cD galaxy in the centre of the prototypical **cooling flow** Perseus cluster

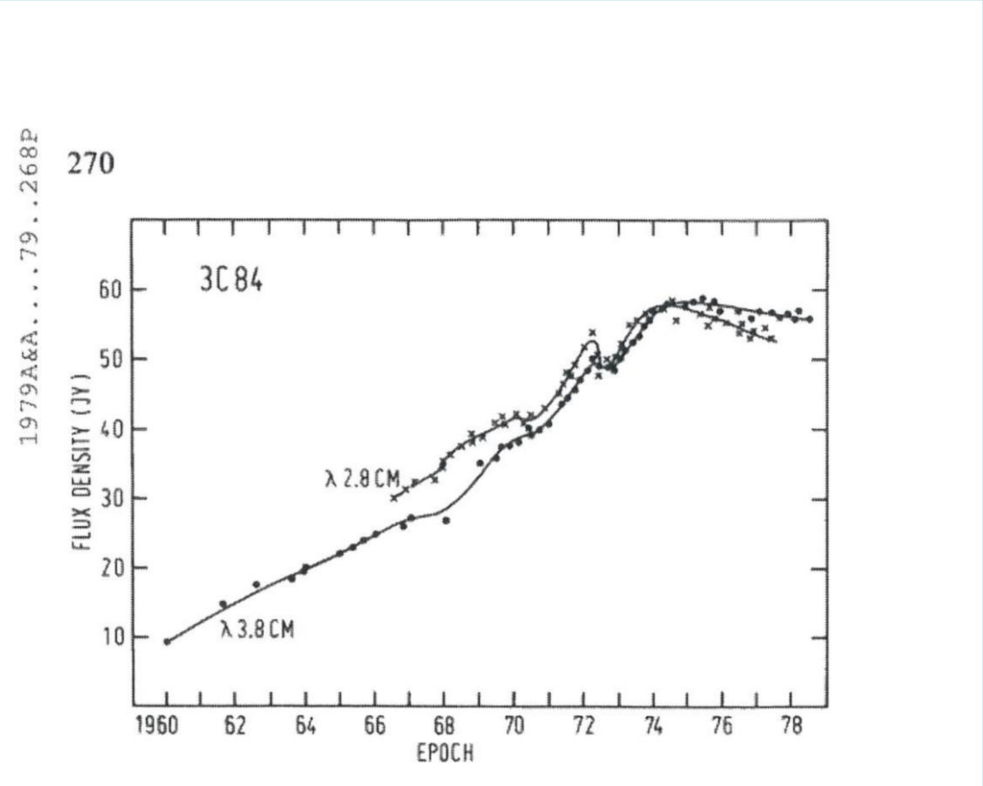
Radio lobes fill the X-ray cavities

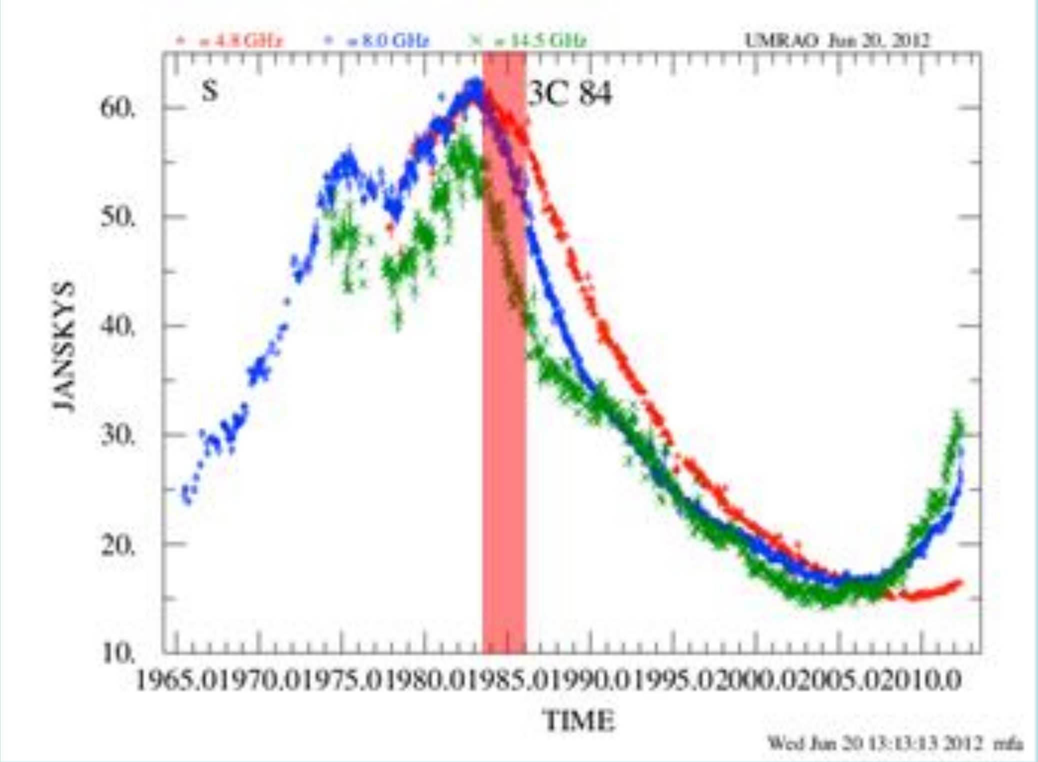
Chandra+VLA





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



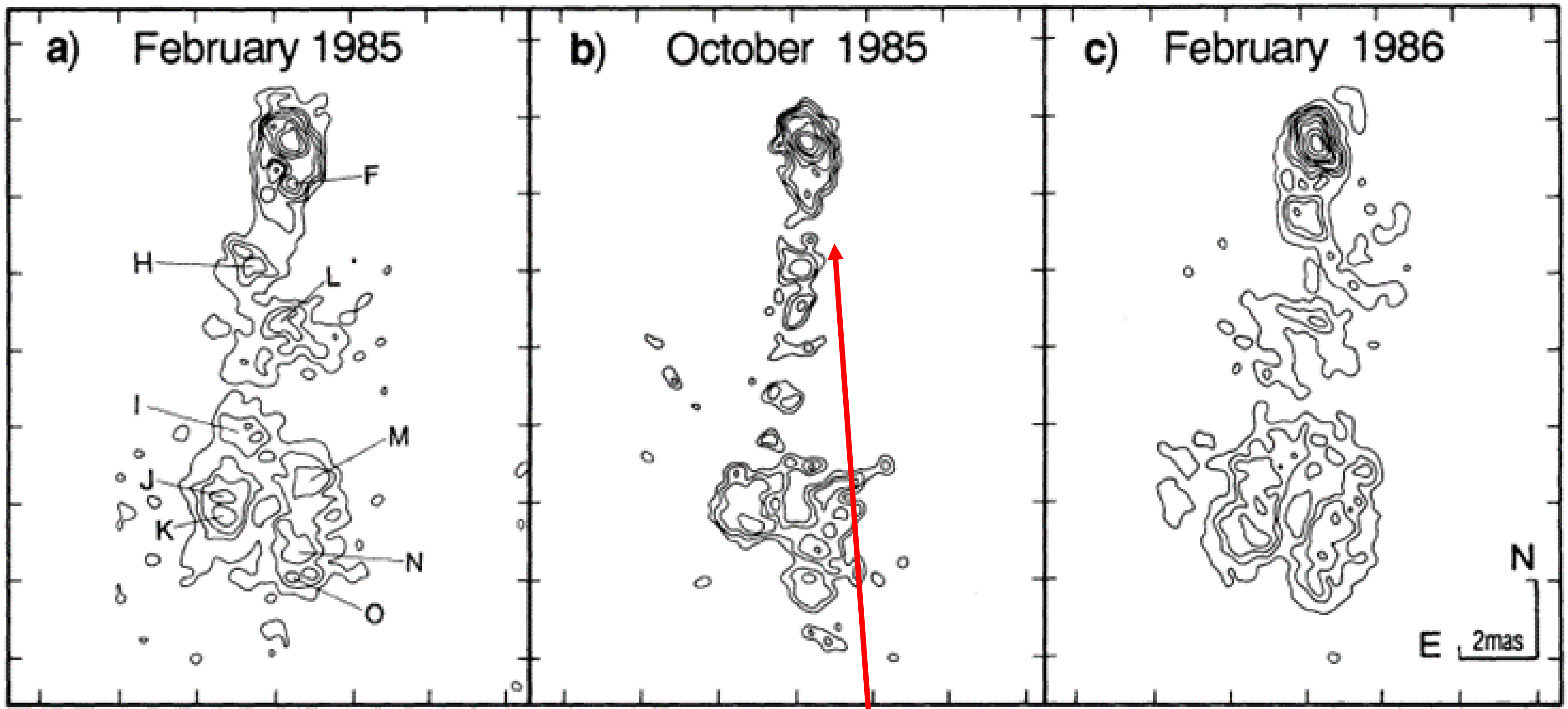


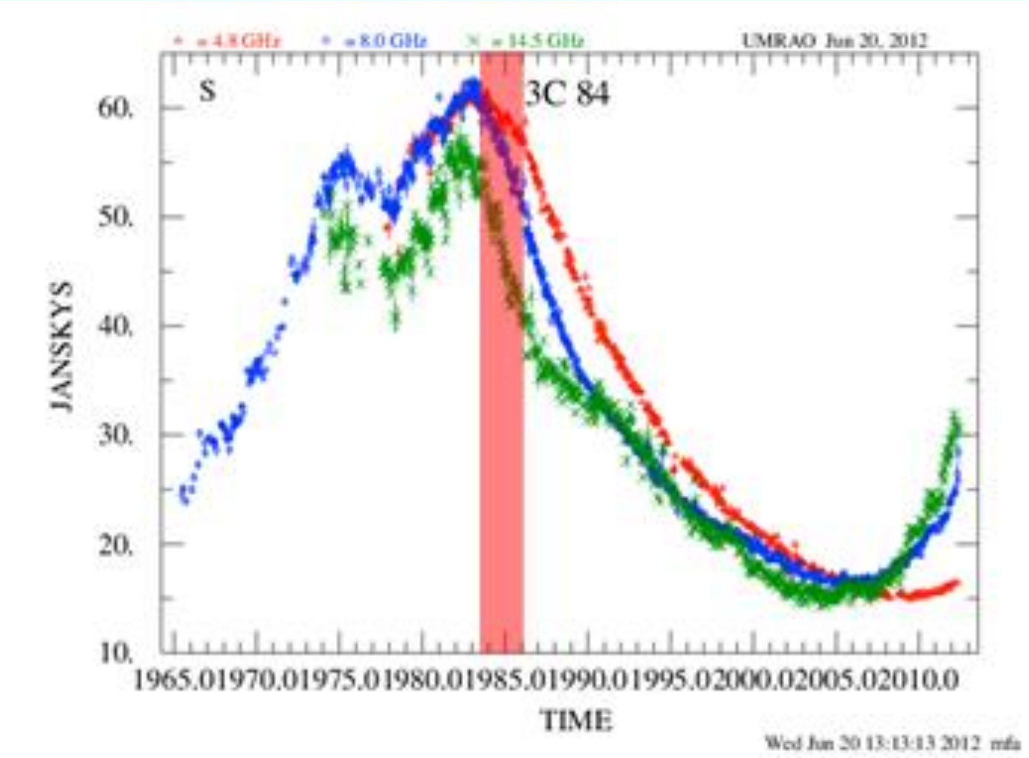
Long term variability

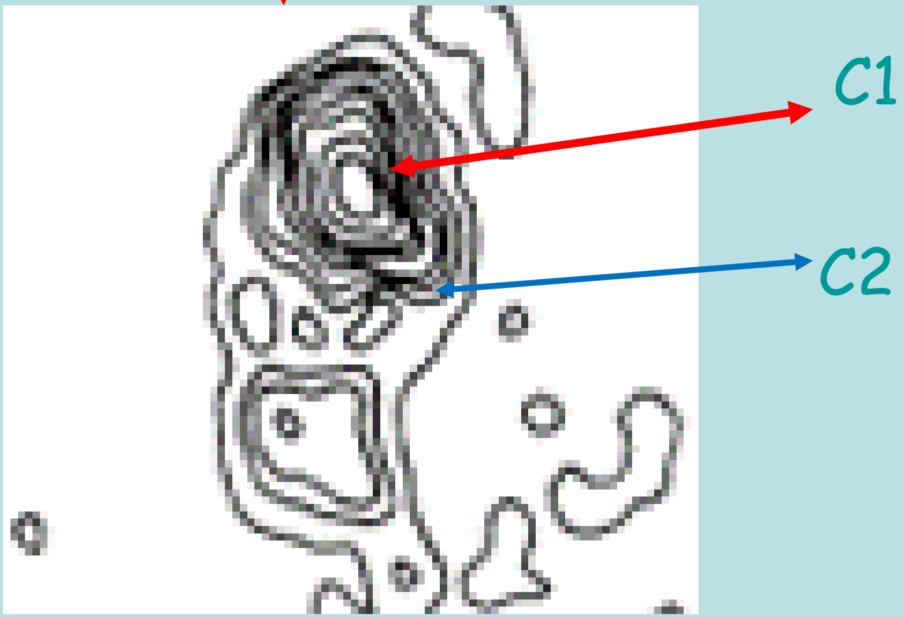
Recurrent activity

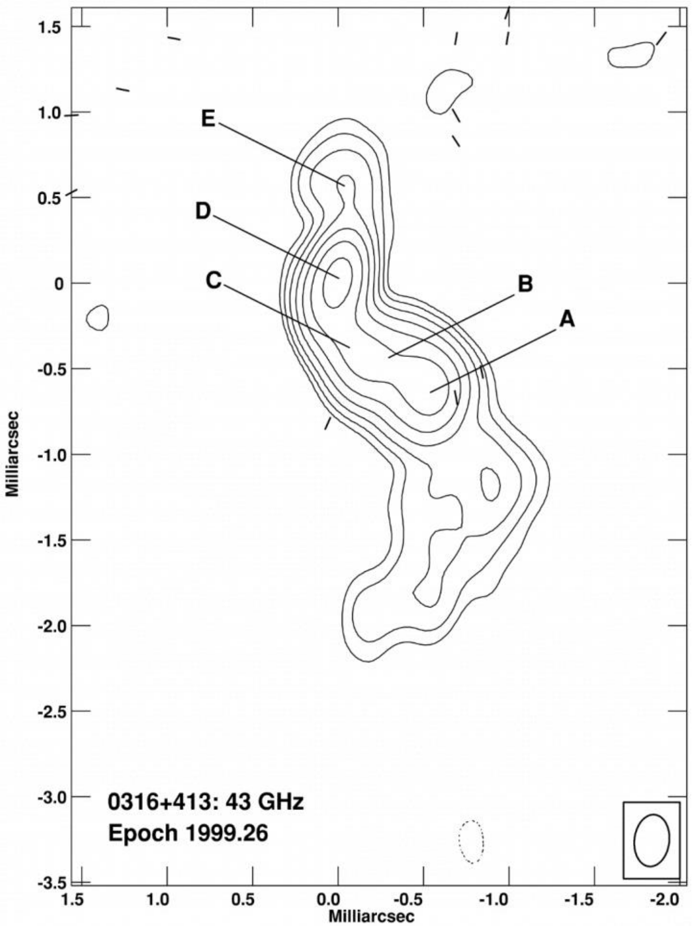
1985

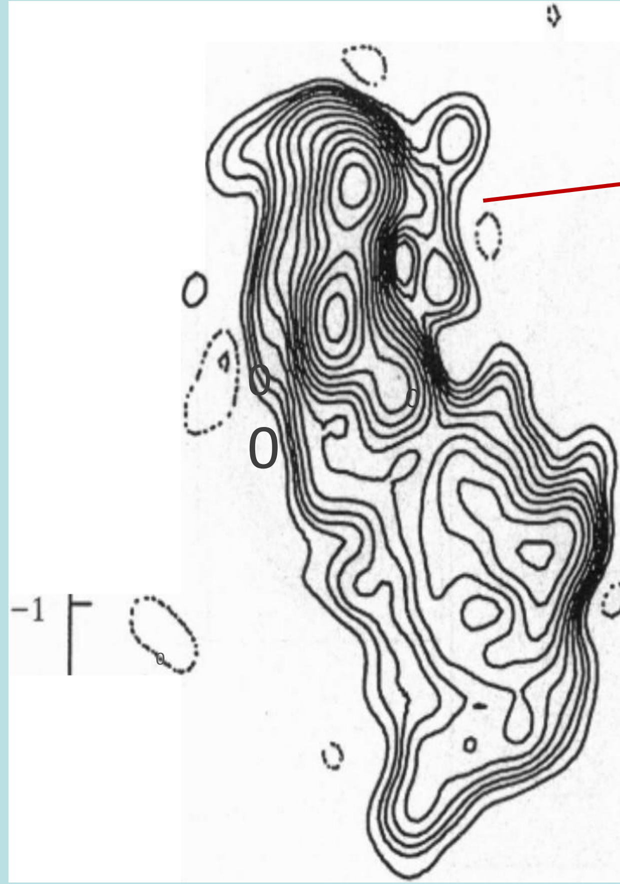
Venturi et al. 1993







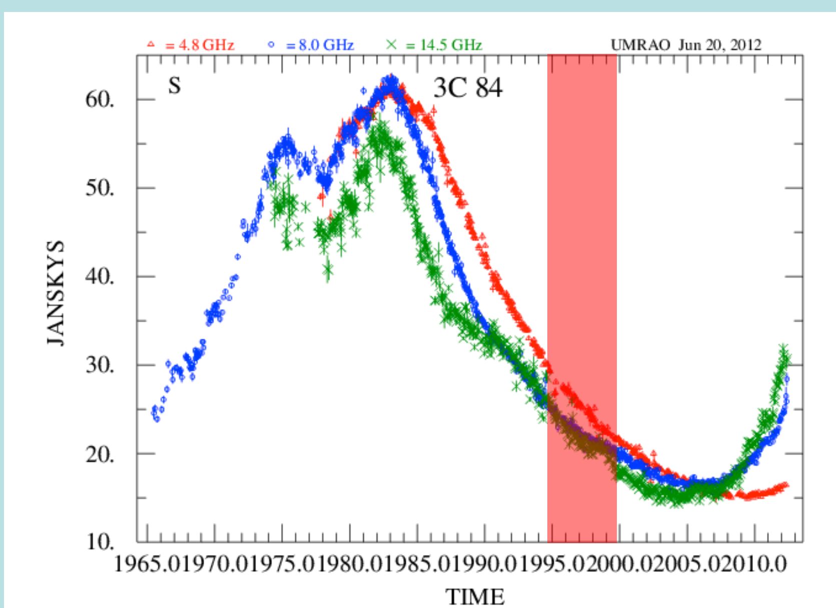




Core C1

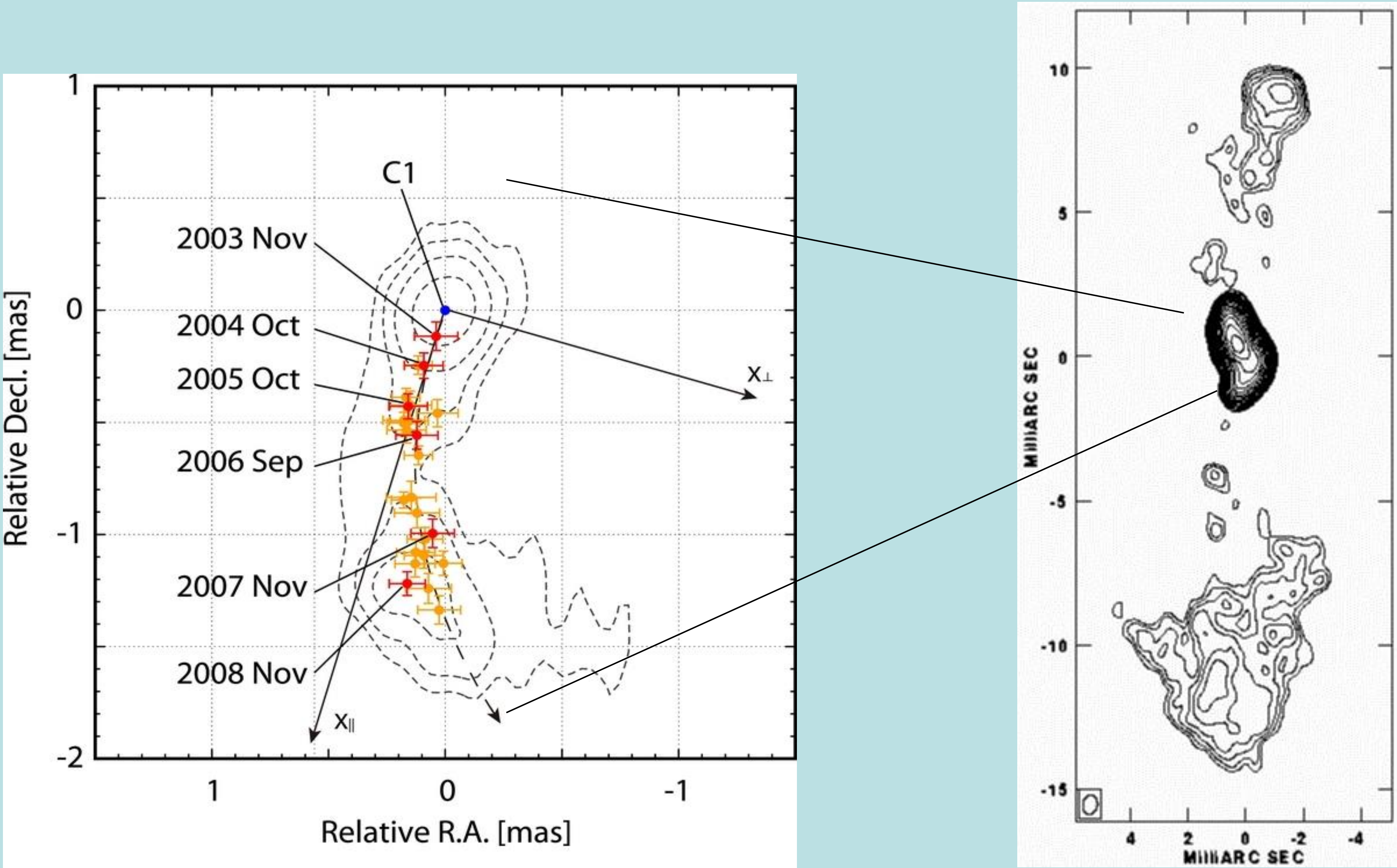
C2

Romney et al. 1995
Epoch: 1995.1

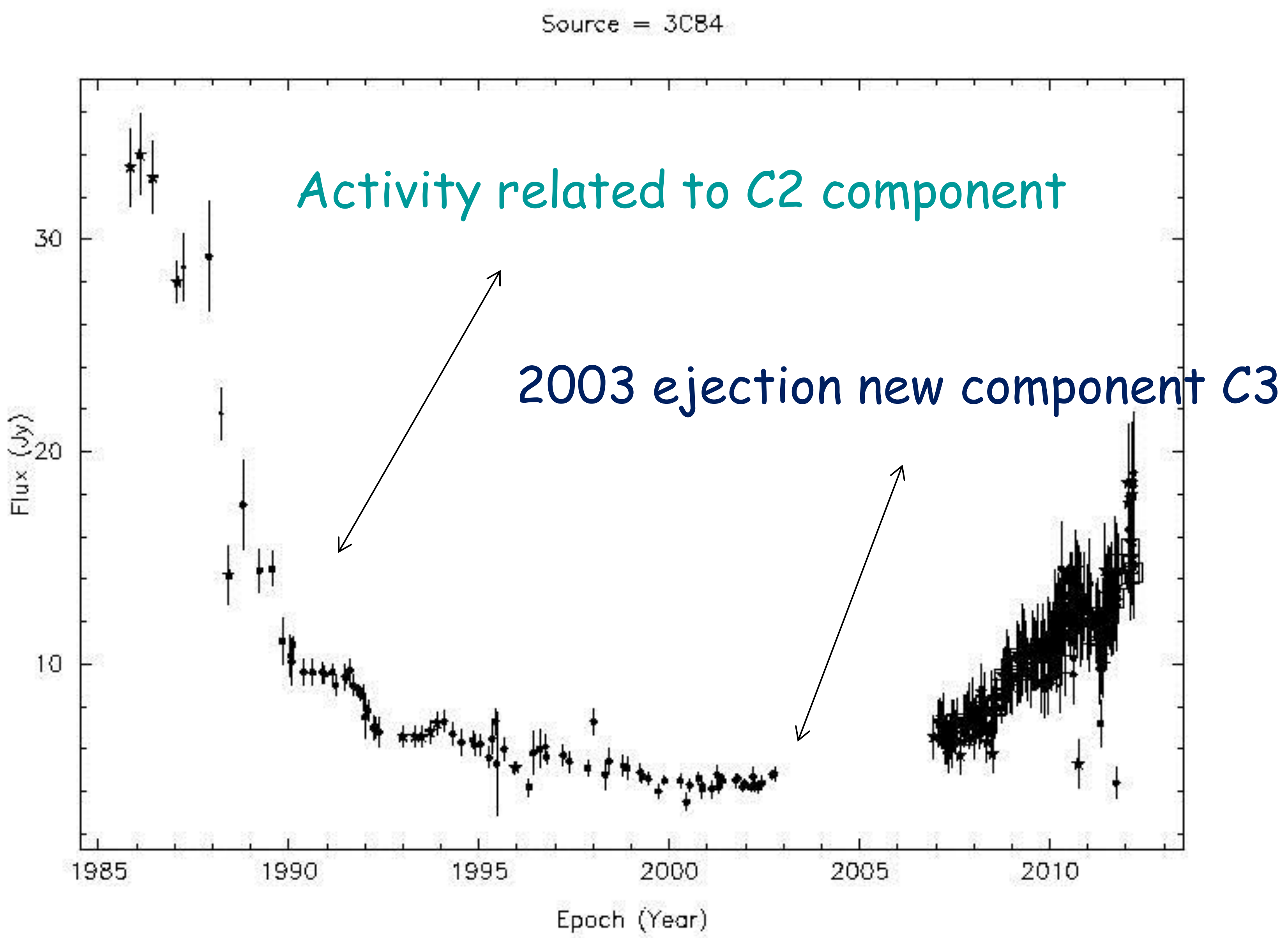


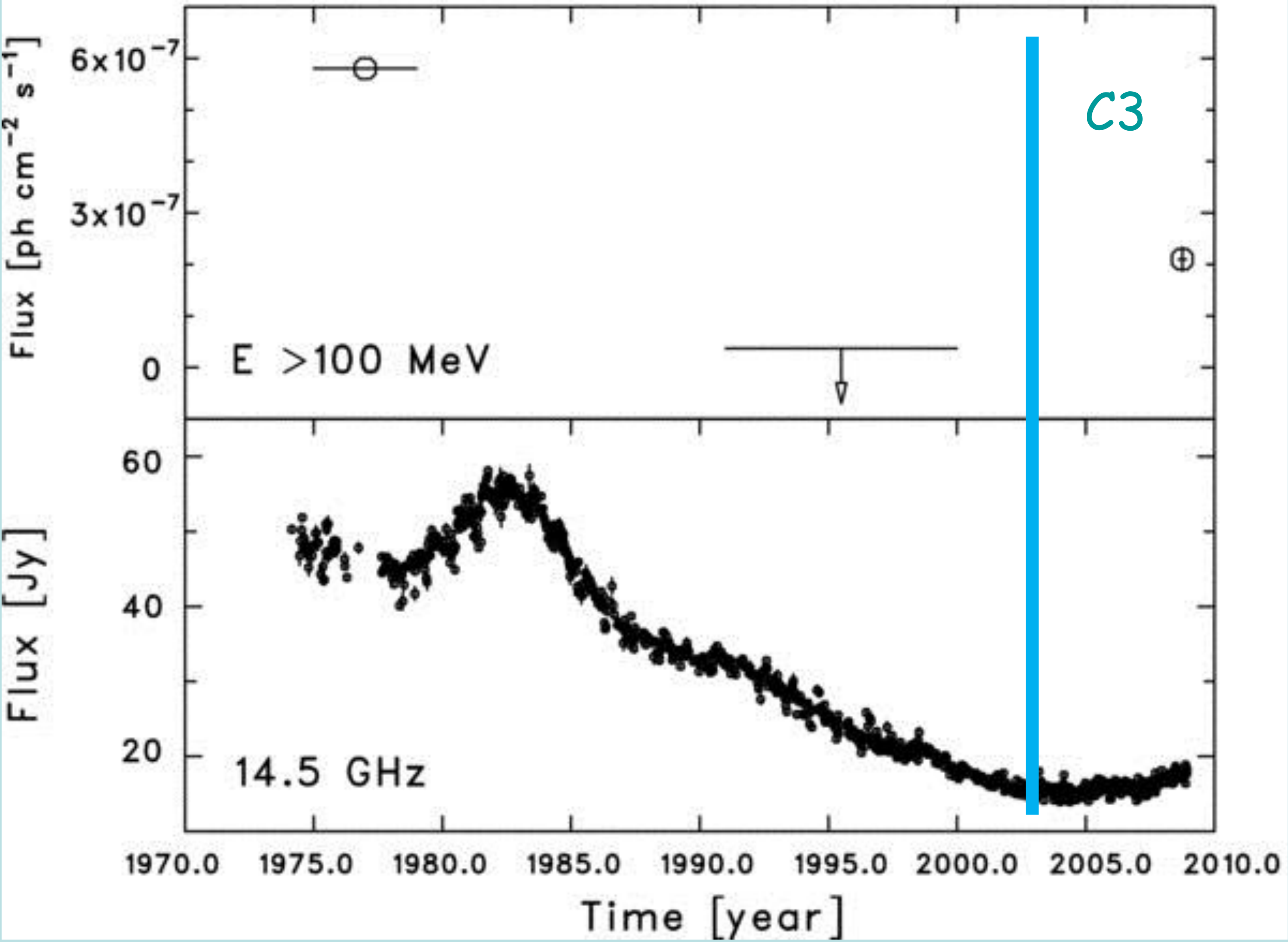
1995

New component C3
Nagai et al. 2010
Kenta Suzuki et al. 2012



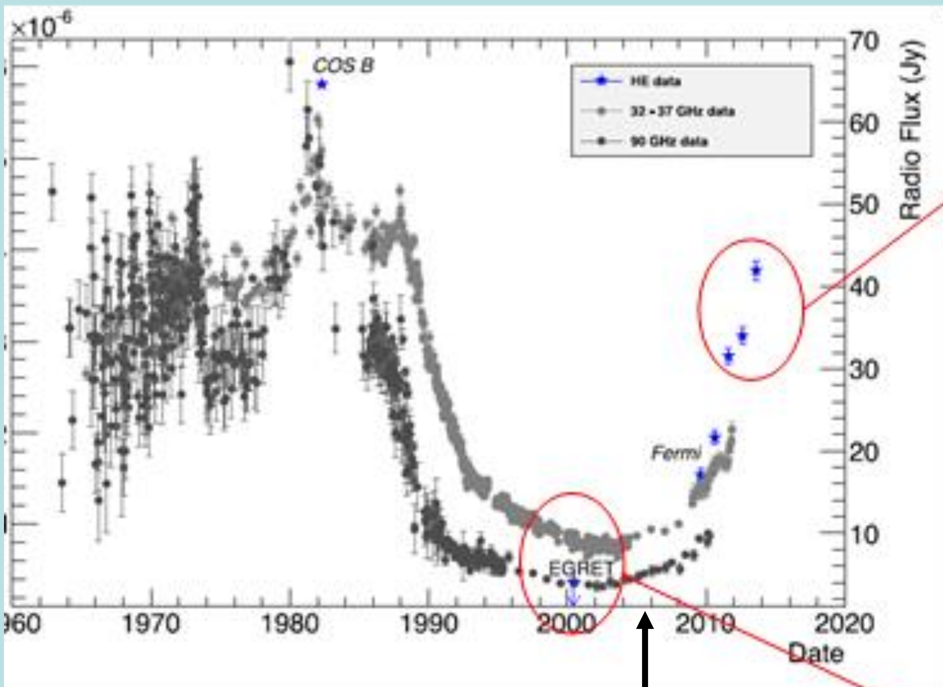
Peak position of C3

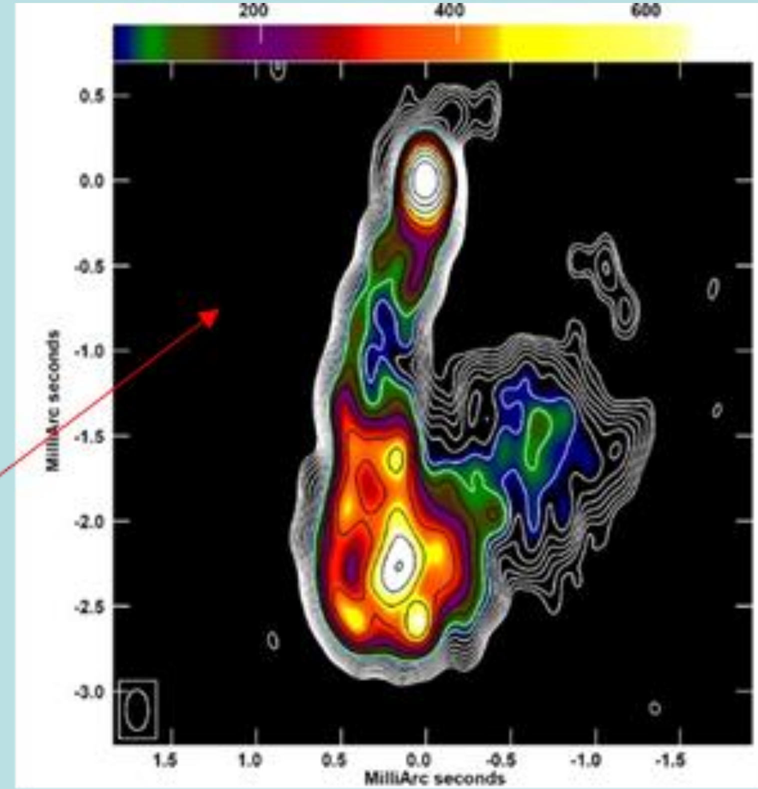

Source = 3C84
Activity related to C2 component
2003 ejection new component C3
Flux (Jy)
30
20
10
1985
1990
1995
2000
2005
2010
Epoch (Year)

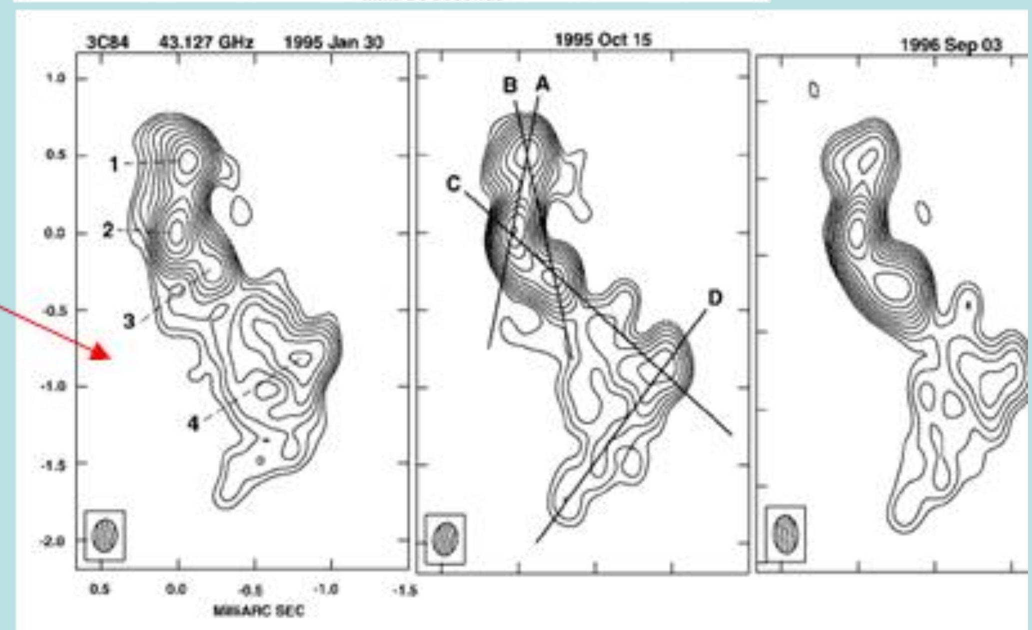


2009 August detected by Fermi-LAT
Abdo et al. 2009

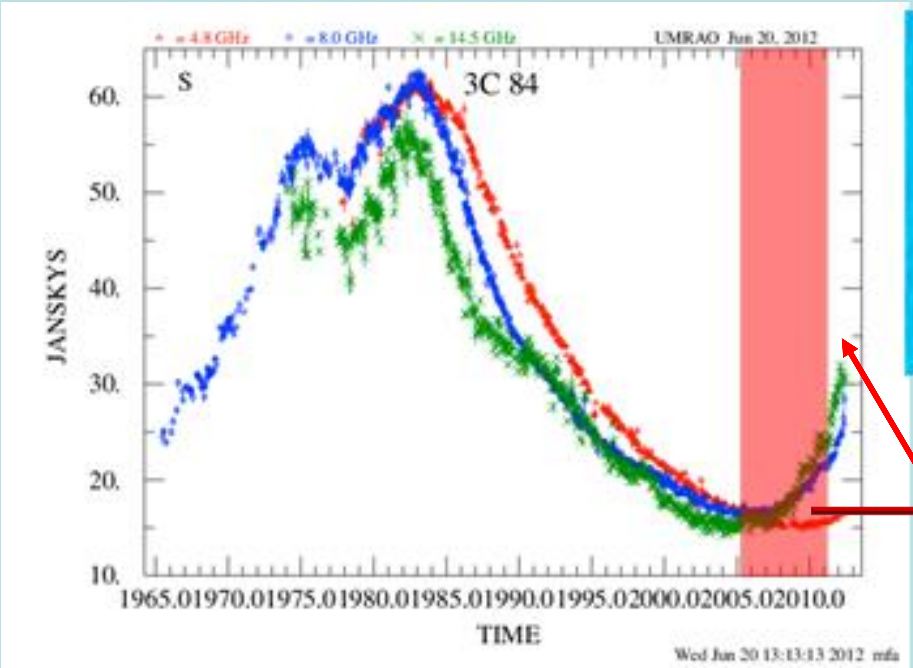
Gamma ray different properties:

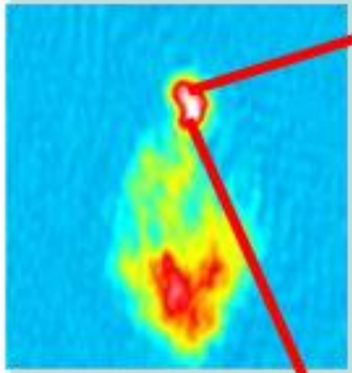


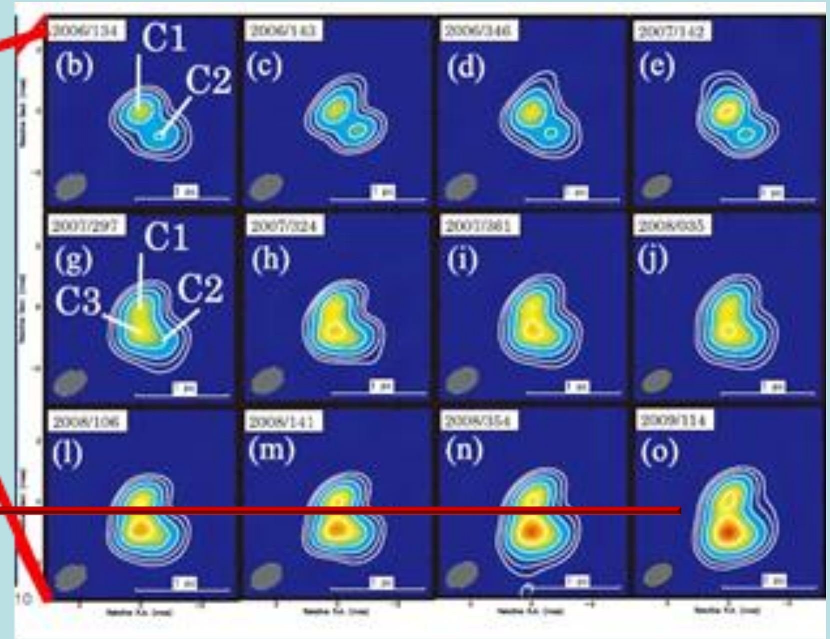


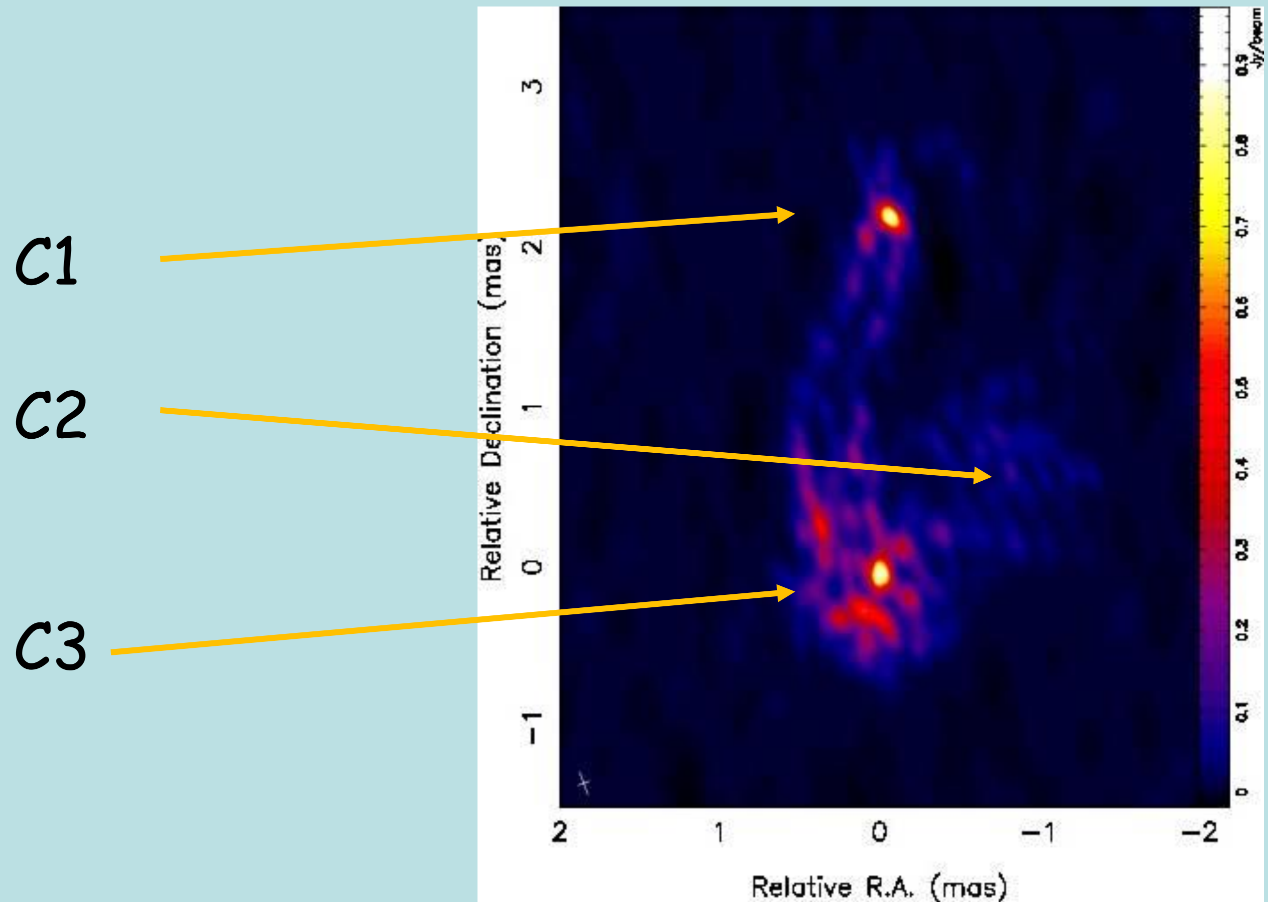


C3 starts







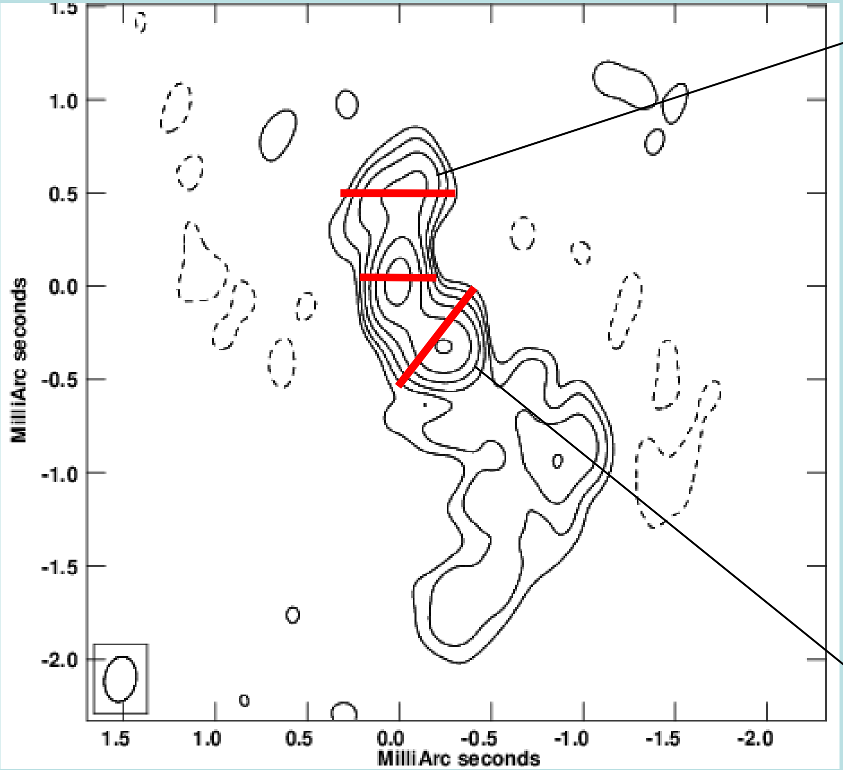


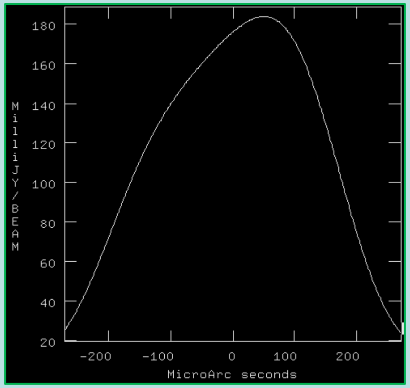
2013-Sept. 21

➔ 10 yrs old

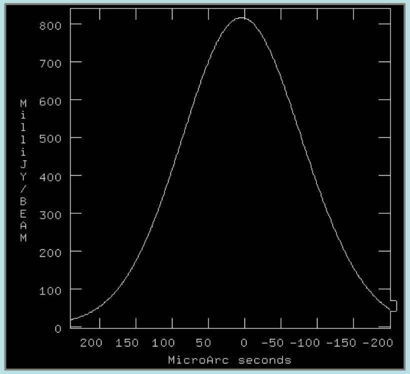
1: The jet structure

43-GHz VLBA image

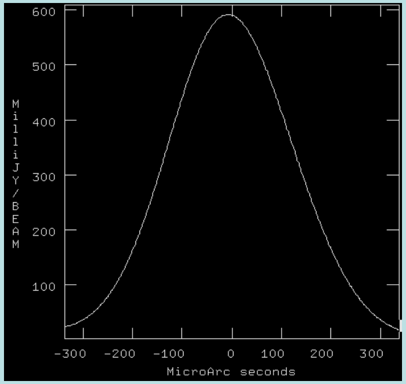




Peak ~ 0.2 Jy/b
D ~ 0.5 mas



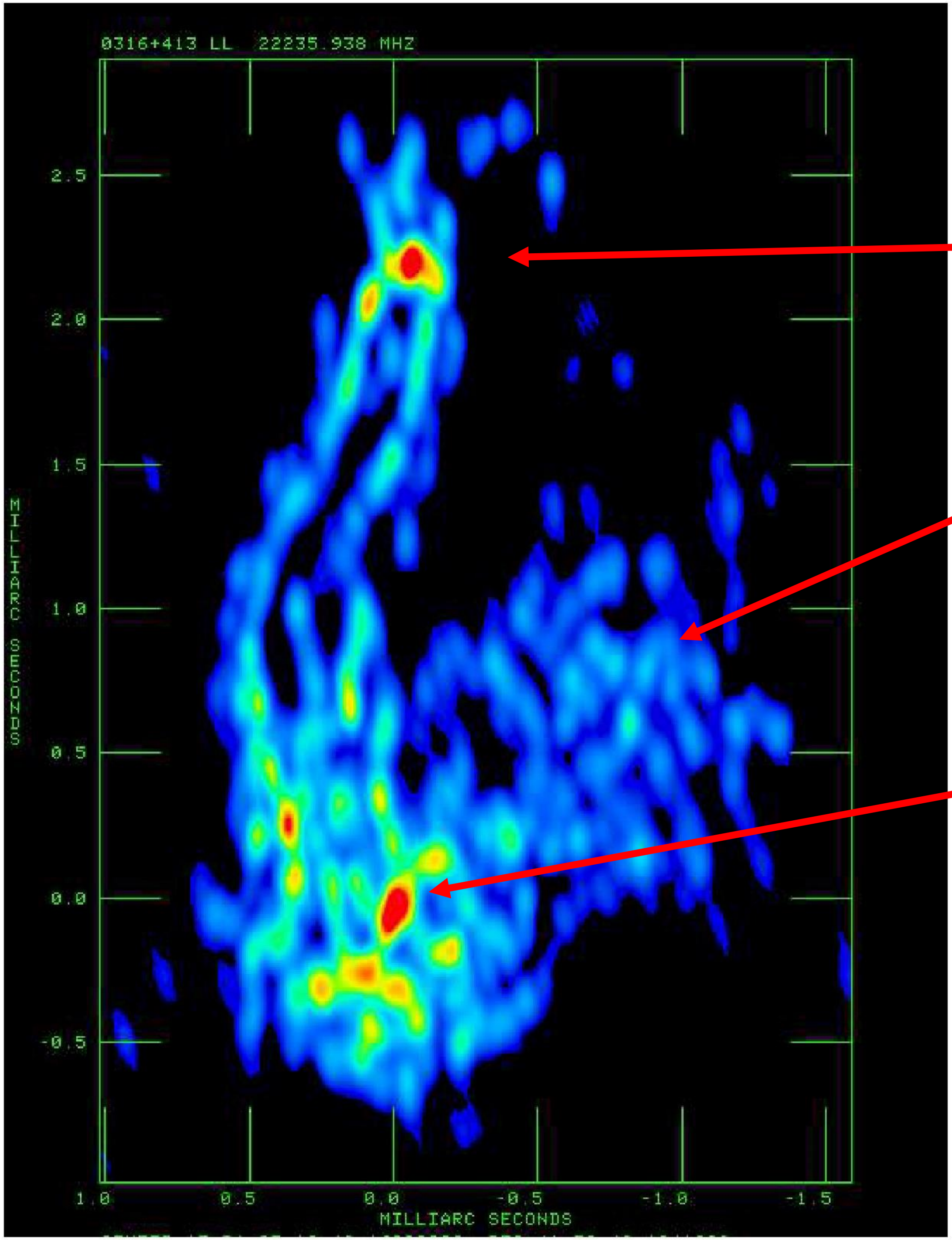
Peak ~ 0.8 Jy/b
D ~ 0.5 mas



Peak =0.6 Jy/b
D ~ 0.4 mas

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

FWHM ~ 0.24 x 0.17 mas



Core C1

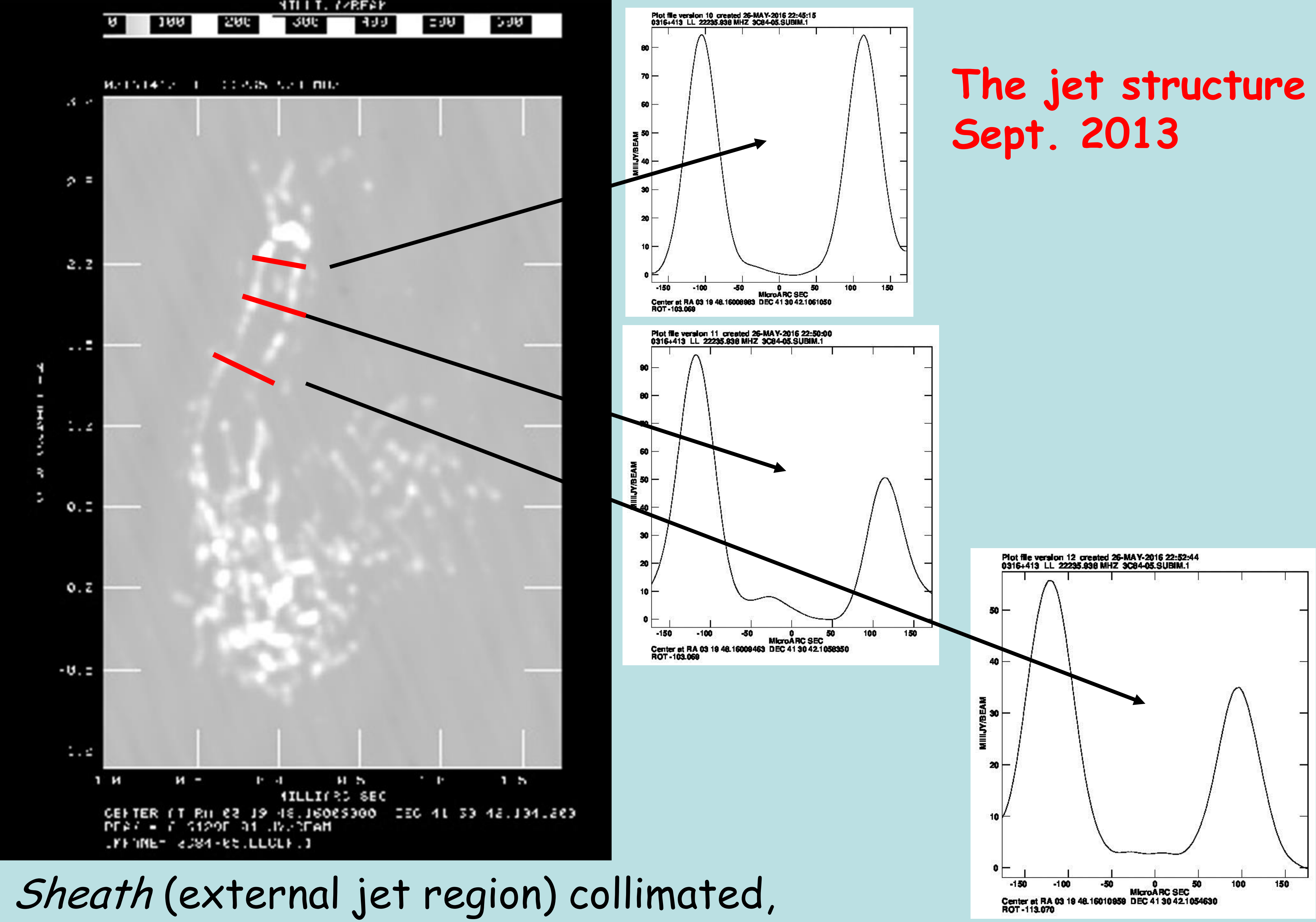
C2

C3

HPBW: 0.10 x 0.05 mas

1mas = 3.58×10^3 r_g

The jet structure Sept. 2013



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

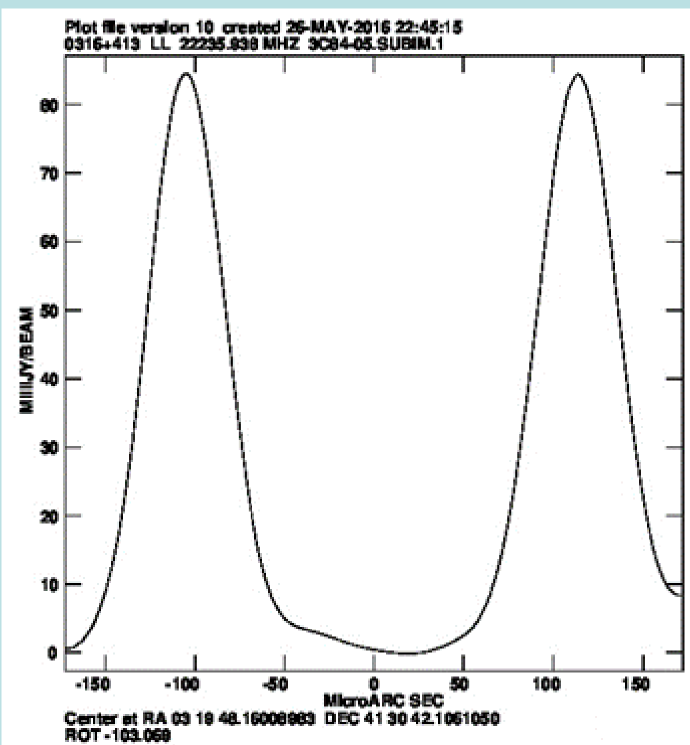
Hollow jet or velocity structure?

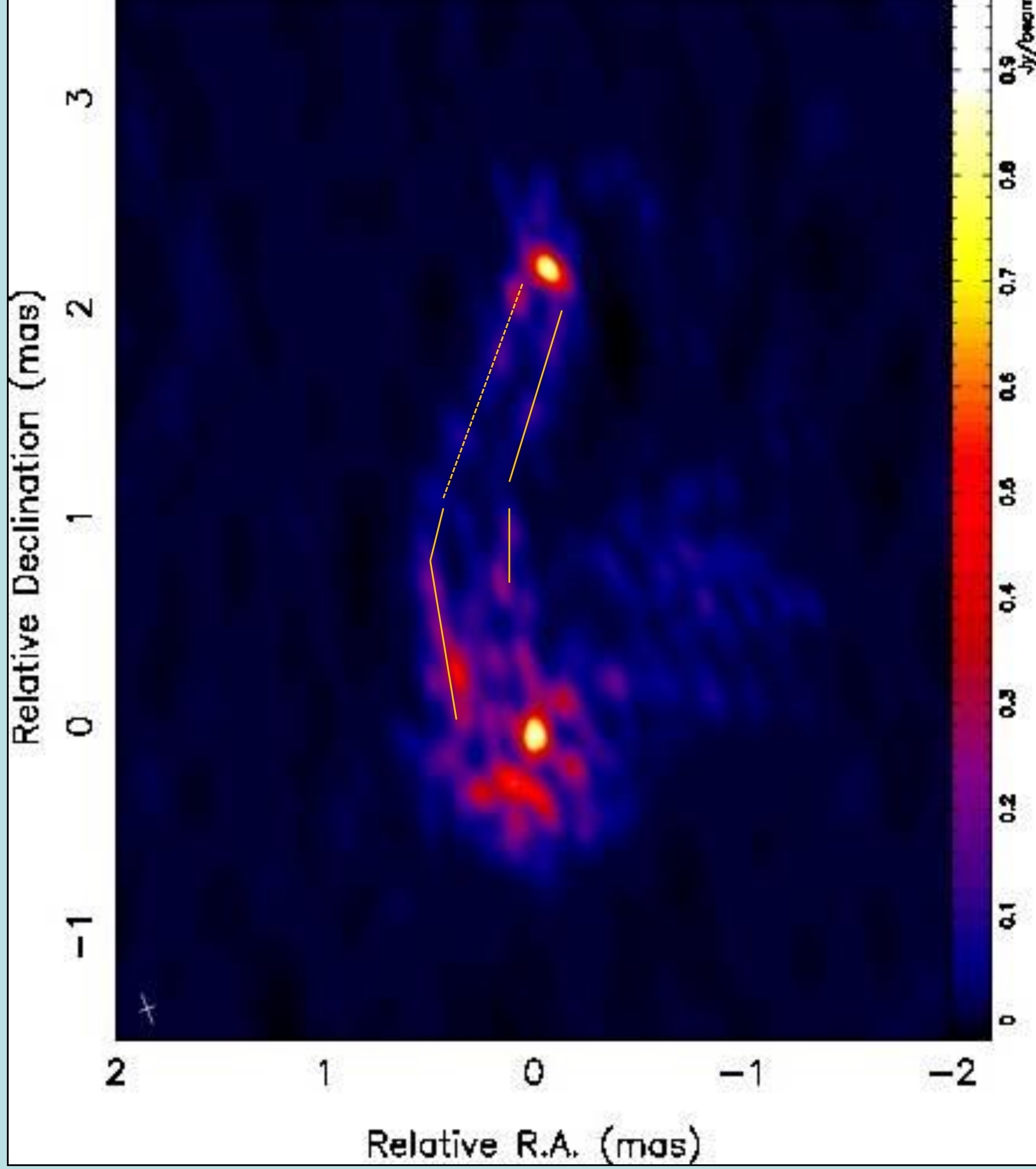
Brightness ratio between the sheath and the spine is about a factor 20.

Assuming intrinsic same brightness with $\theta = 18$ degree

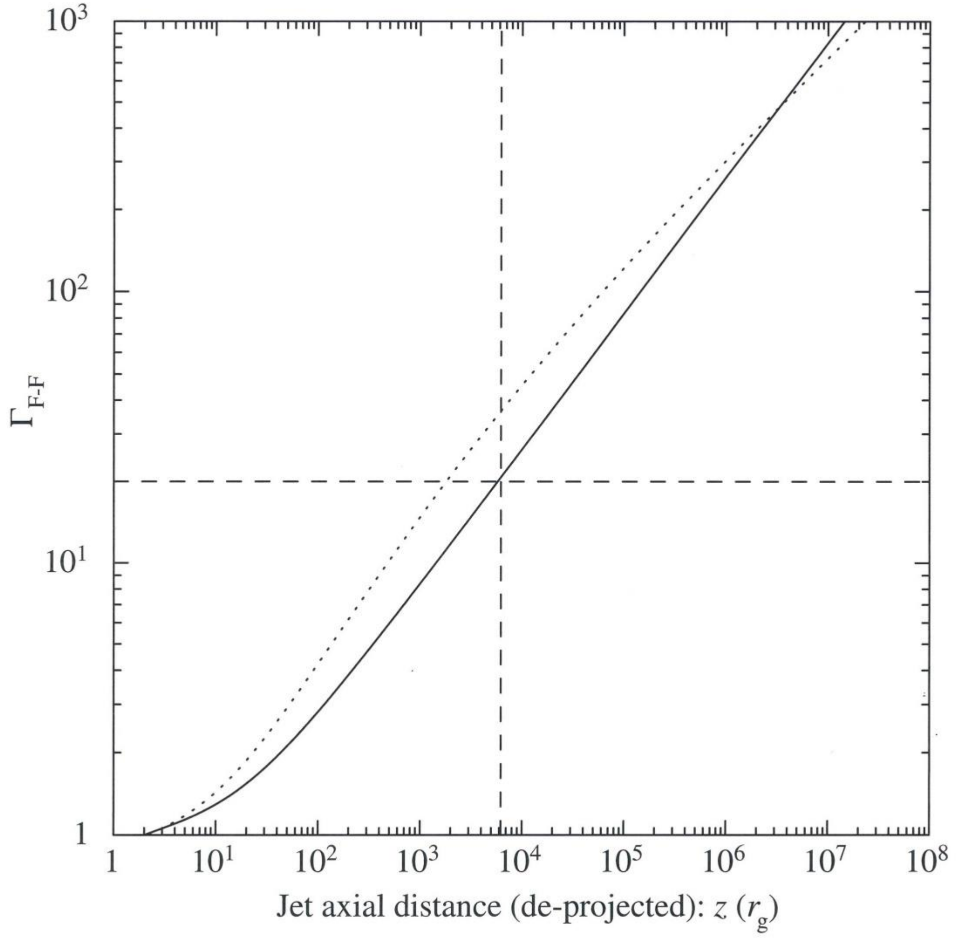
Sheath $\Gamma = 3$ $\delta = 3.23$

Spine $\Gamma = 20.5$ $\delta = 0.97$





Alternatively inner structure intrinscally fainter: higher mass loading of the sheath due to interaction with the ISM



M. Nakamura

Problem: we see the jet structure (hollow jet) already at about 400 r_g

Short distance to have a density structure

Γ = 20 + BZ77 model and z propto r^2 (solid lane) is expected at about 6000 r_g

A rapid more efficient acceleration (semi-parabolic spine (dotted line) is better but at z = 500 we have Γ = 10, too low.

Velocity structure and density structure at the same time could relax above problems

2: The jet structure

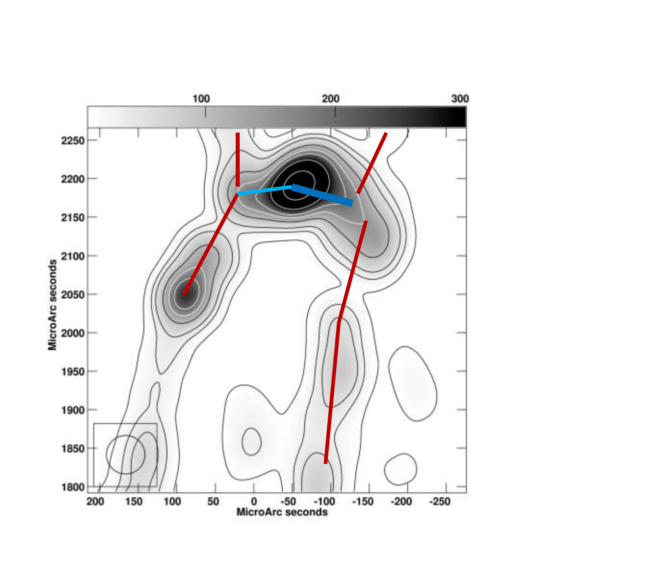
The jet in 3C 84 starts out very broad

Opening angle is the largest measured
then collimates to an almost cylindrical profile (few hundreds gravitational radii)

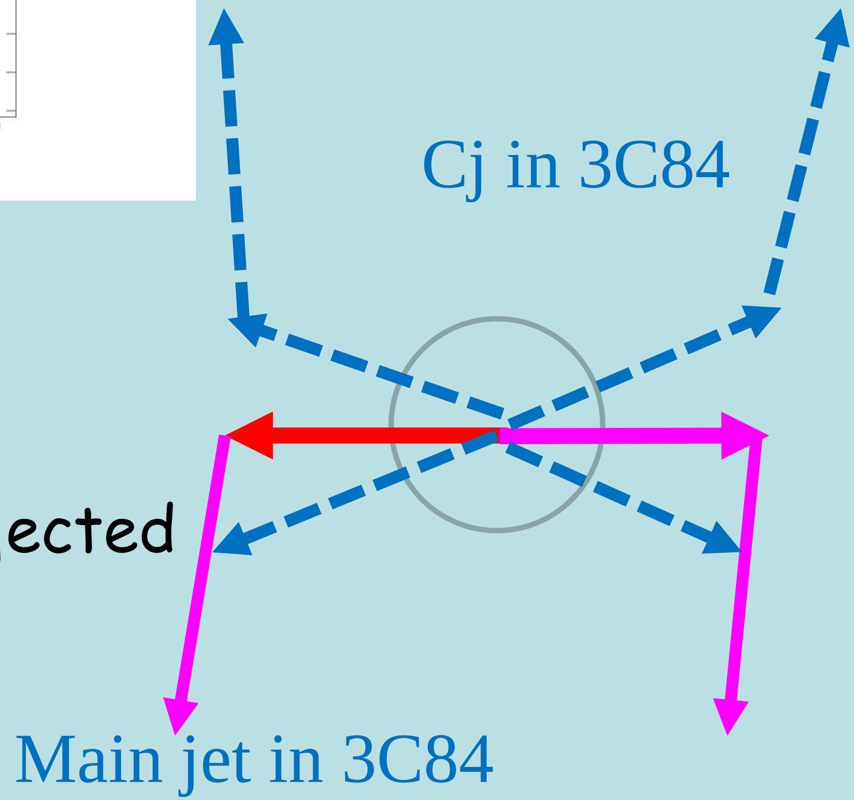
A strong expansion is present between 200 – 350 rg
Somewhere inside 400 rg we need a wall to re-shape the jet in a quasi-cylindrical form and to maintain the almost cylindrical shape From 350 to about 8000 rg

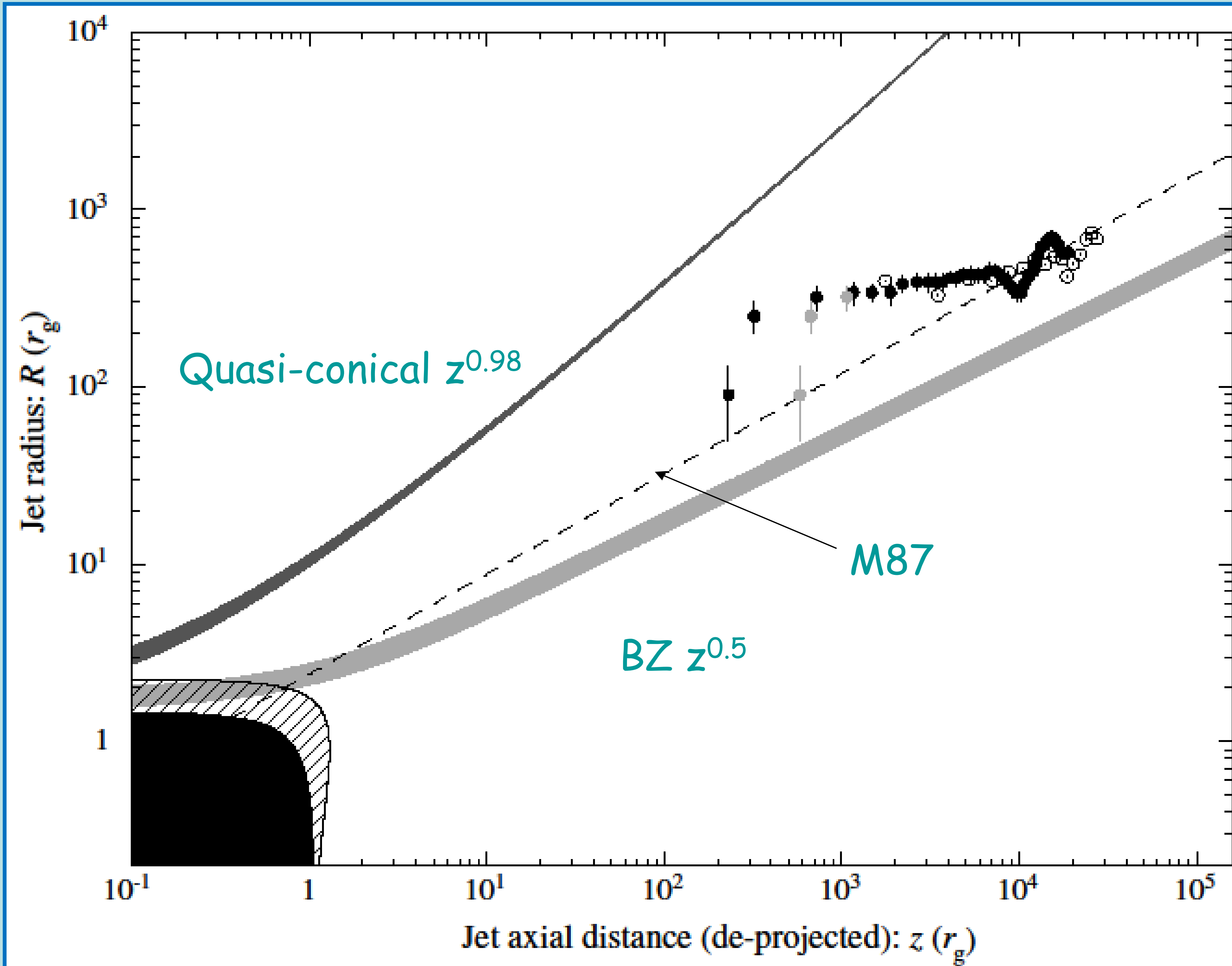
Wall: non uniform dense medium – disk wind – cocoon ???

This jet may be is in a transition phase (young). It is not yet in a Final equilibrium with the ambient



0.03 mas
350 r_g deprojected





Quasi-conical $z^{0.98}$
M87
BZ $z^{0.5}$
Jet radius: R (r_g)
Jet axial distance (de-projected): z (r_g)
10^{-1}
1
10^1
10^2
10^3
10^4
10^5

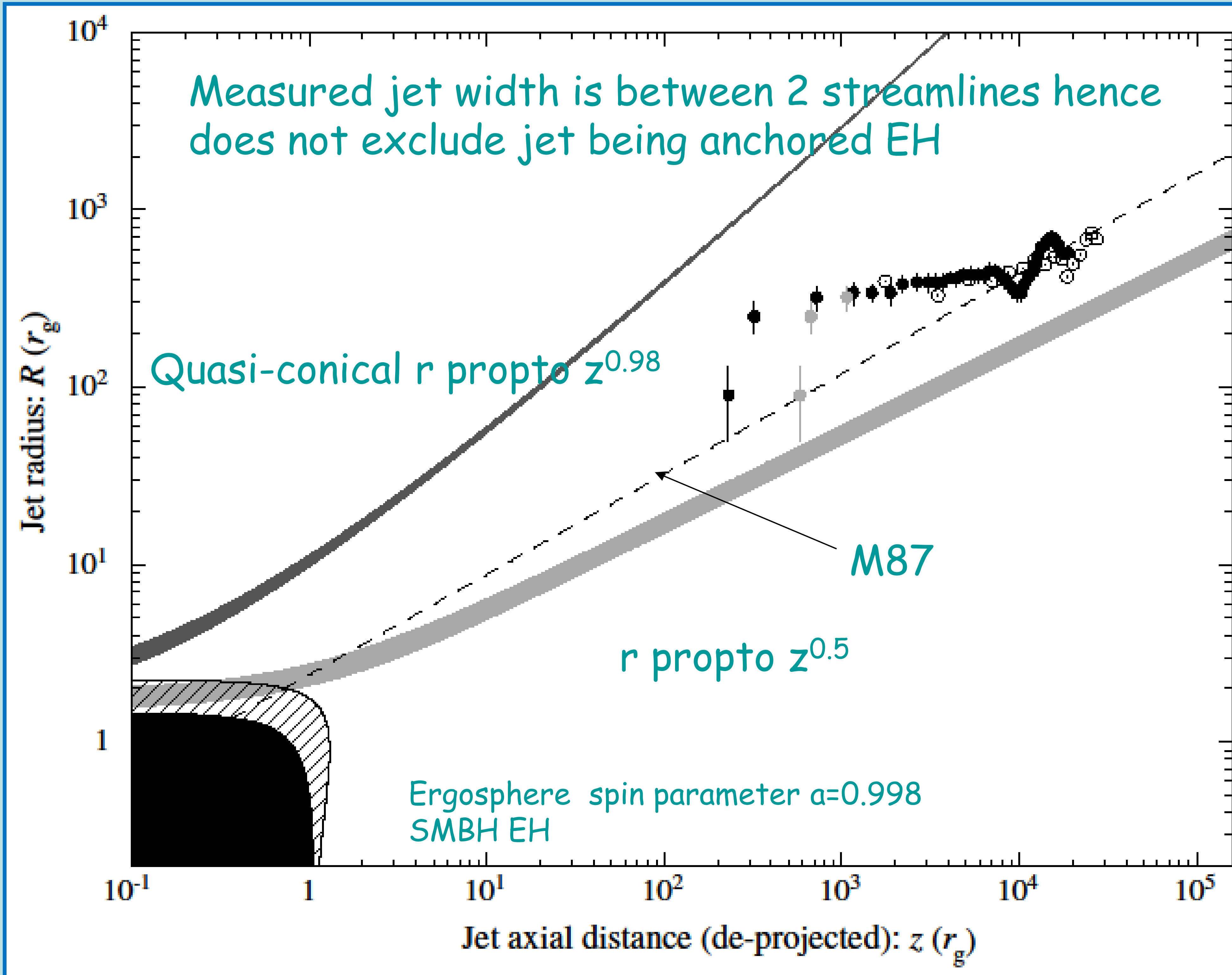
3: The jet trend

Light gray curve: genuine parabolic BZ-type streamline
R propto $z^{0.5}$ at $r \gg r_g$

Dark gray: quasi-conical streamline R propto $z^{0.98}$ at $r \gg rg$

a= 0.1 – 0.998 considered in both cases

The jet collimation in 3C 84 differs from nearly parabolic collimation in M87 and Cygnus A



Measured jet width is between 2 streamlines hence
does not exclude jet being anchored EH
Quasi-conical r propto z0.98
M87
r propto z0.5
Ergosphere spin parameter a=0.998
SMBH EH
Jet radius: R (rg)
Jet axial distance (de-projected): z (rg)

The jet appears to be very wide (250 rg) already at 350 rg from the core.

Rapid collimation at < 400 rg

Collimation profile between 350 and 8000 r_g is almost cylindrical R propto $z^{0.17}$ Jet oscillations at > 8000

quite different from M87 ($z^{0.56}$ between 200 and 400000 r_g and Cygnus A $z^{0.55}$ between 500 and 10000 $r_{g)}$

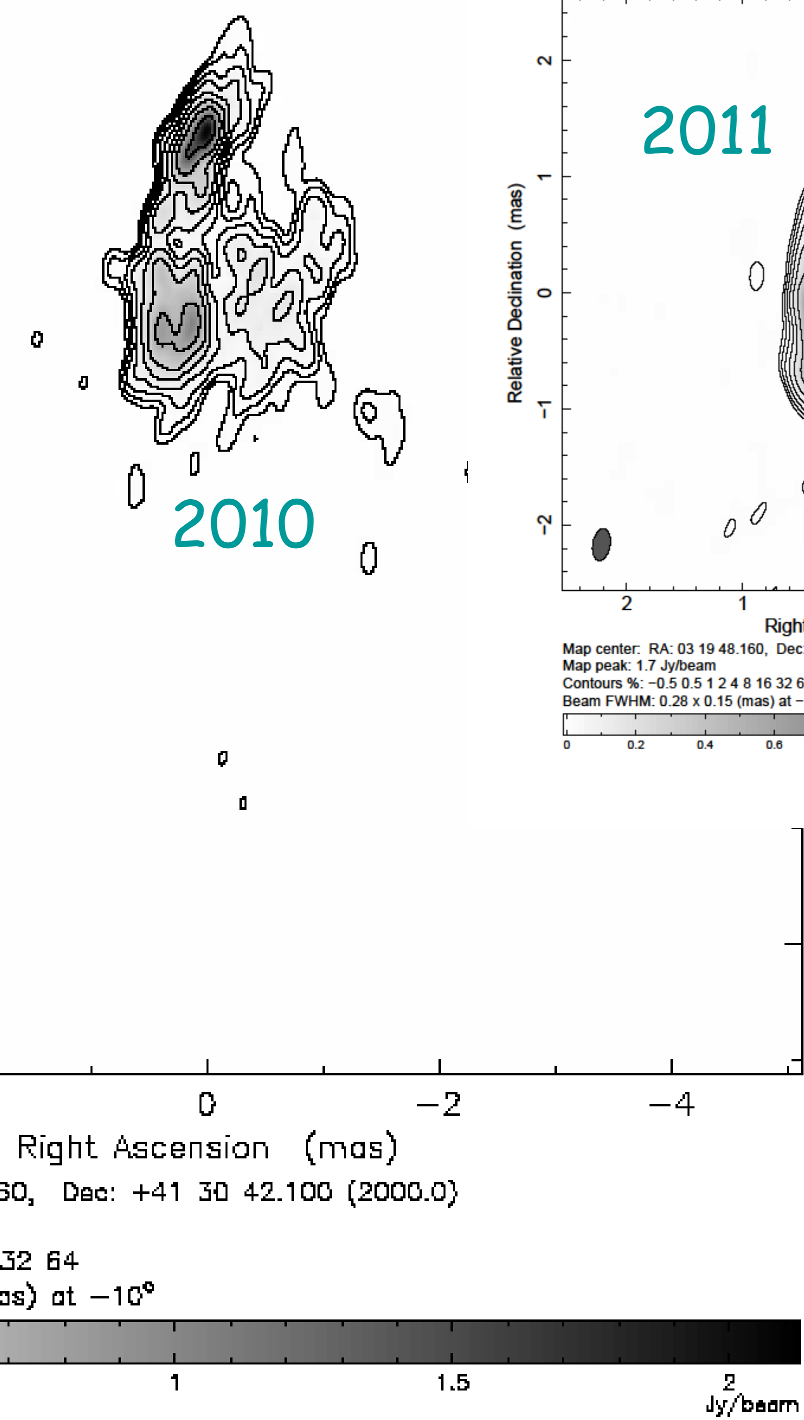
Jet streamlines anchored at the EH

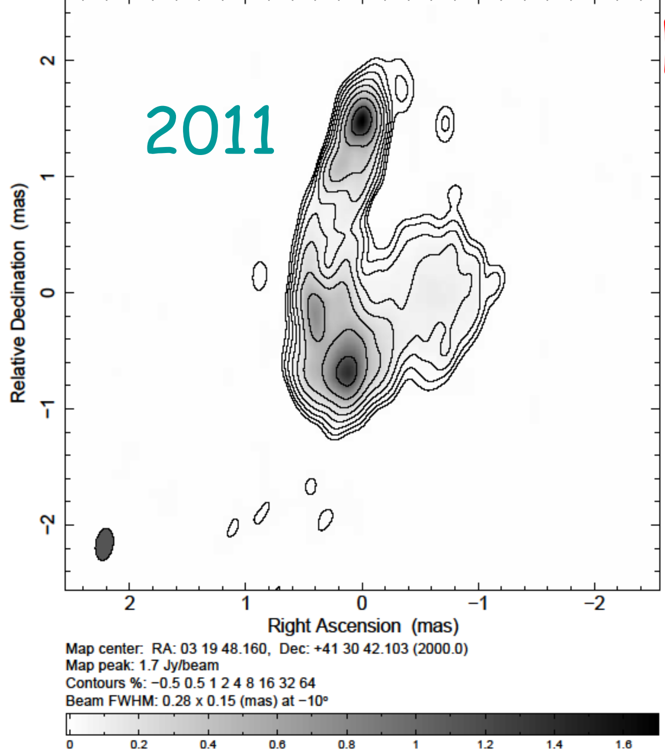
Jet launching from SMBH ergosphere (BZ) works very efficiently
In GRMHD simulations of RIAFs 80% BZ 20% in disk
➔Jet streamlines anchored at the EH

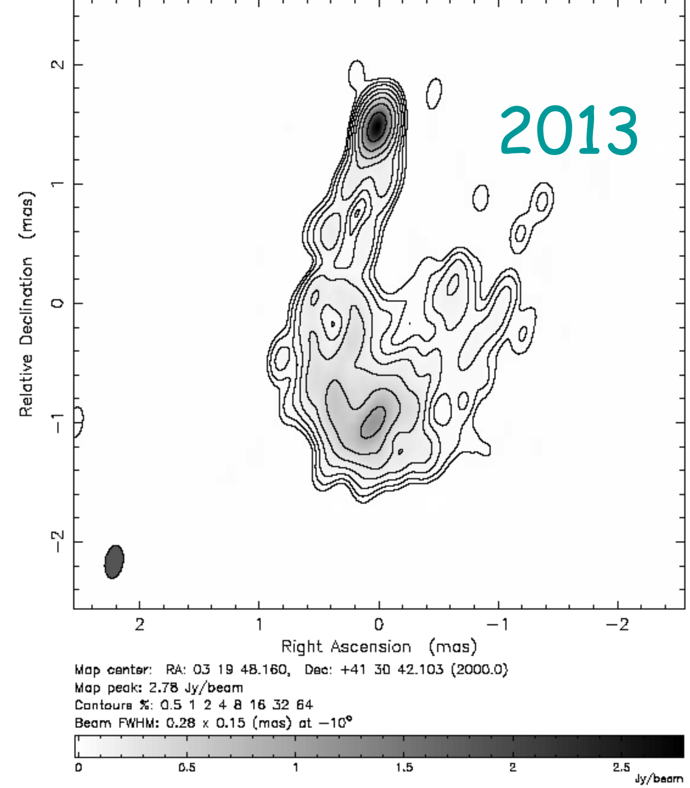
Difference between 3C 84 and M 87

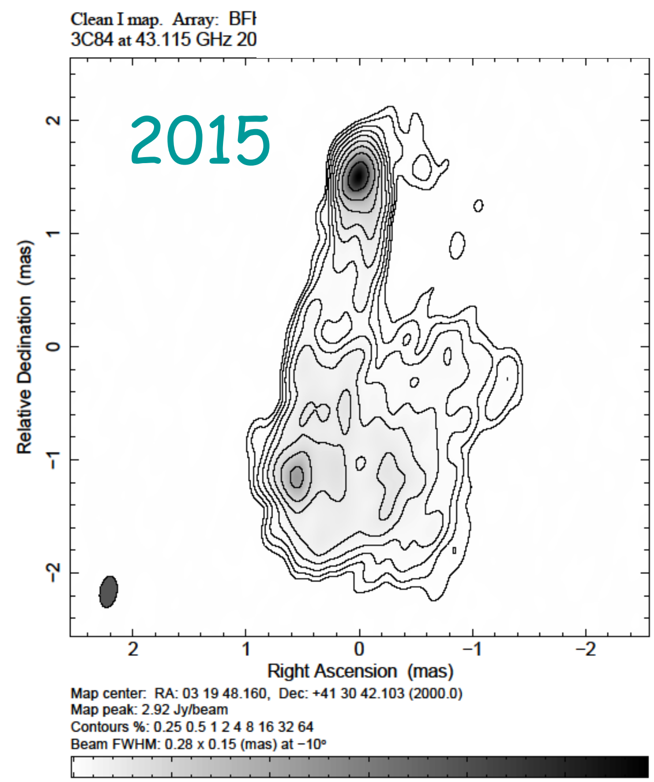
3C 84 cooling a lot of cold gas
3C 84 restarted 10 yrs ago

Next

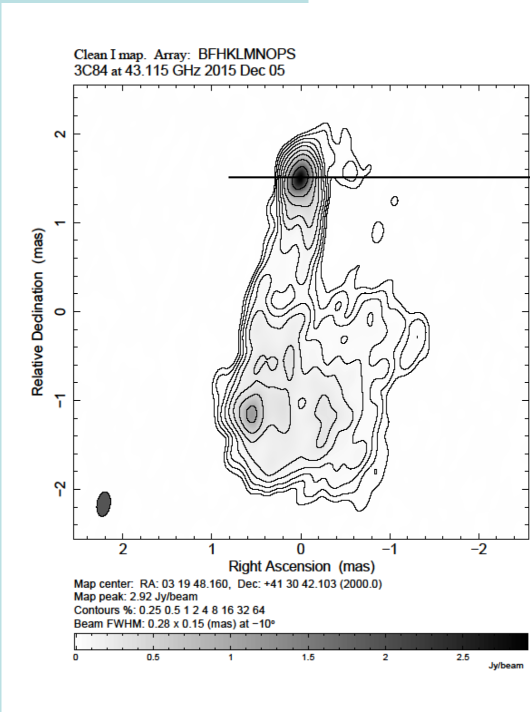




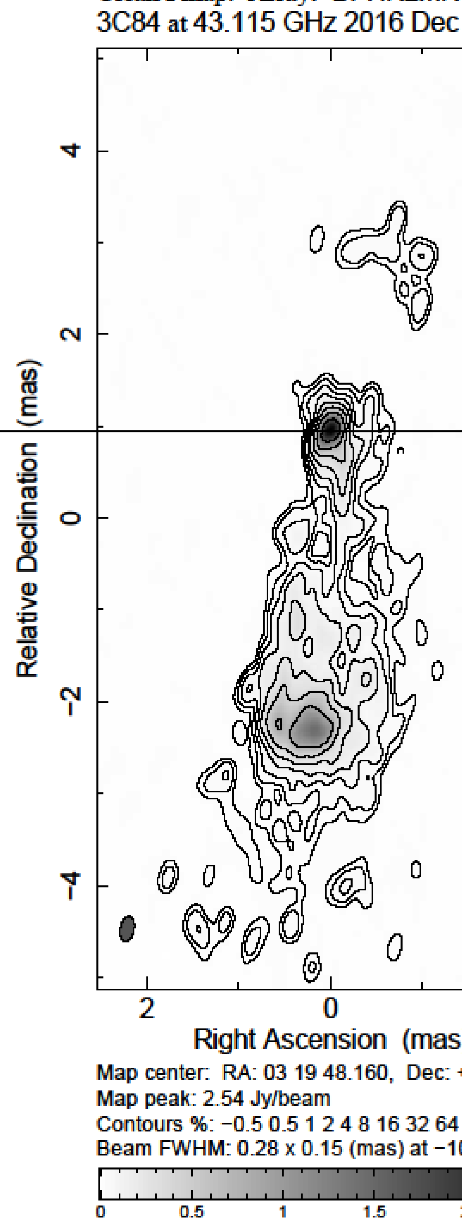




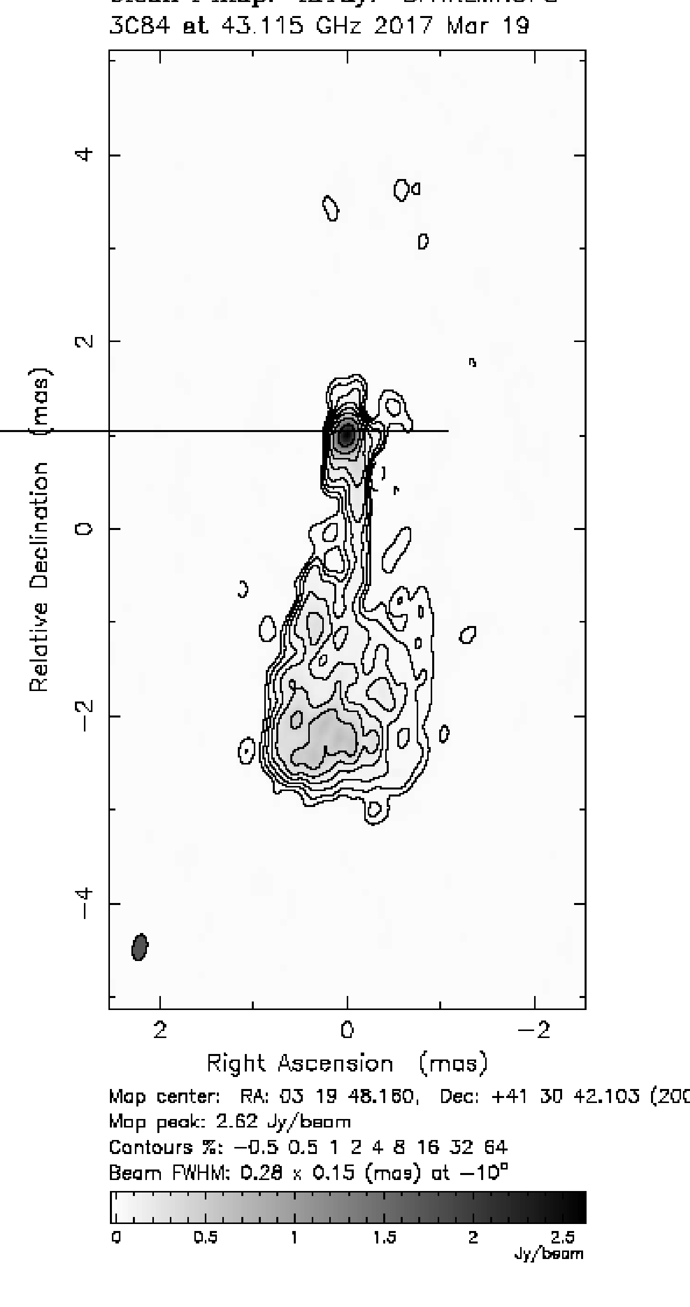
See Nagai + 2017



2015.12



2016.12



2017.3

Conclusions

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

2)Large difference in brightness between the jet sheath and spine ➔ different Doppler factor and Lorentz factor or different electron density -- problem: too near to the core
Structured jet different properties and origin????

3) jet size trend does not exclude jet being anchored to EH

4)Collimation profile between 350 and 8000 r_g is almost cylindrical R propto $z^{0.17}$. Jet oscillations at > 8000. Strong confinment

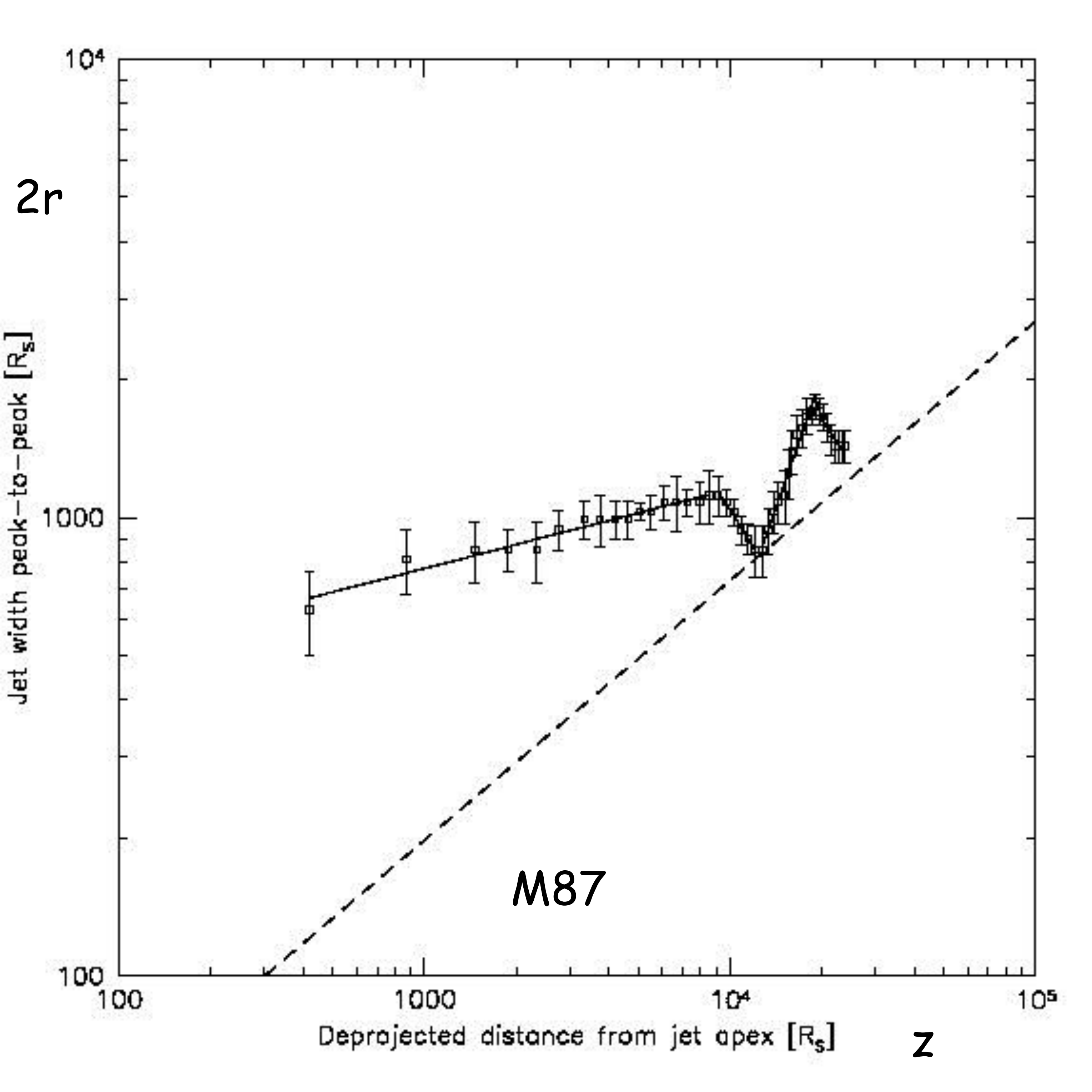
5) 3C 84 different from M87 and Cygnus A: BCG in a strong cooling flow cluster + young


Thanks
15/11/2014 07:29

Opening angle:

Observed 134

Intrinsic 41



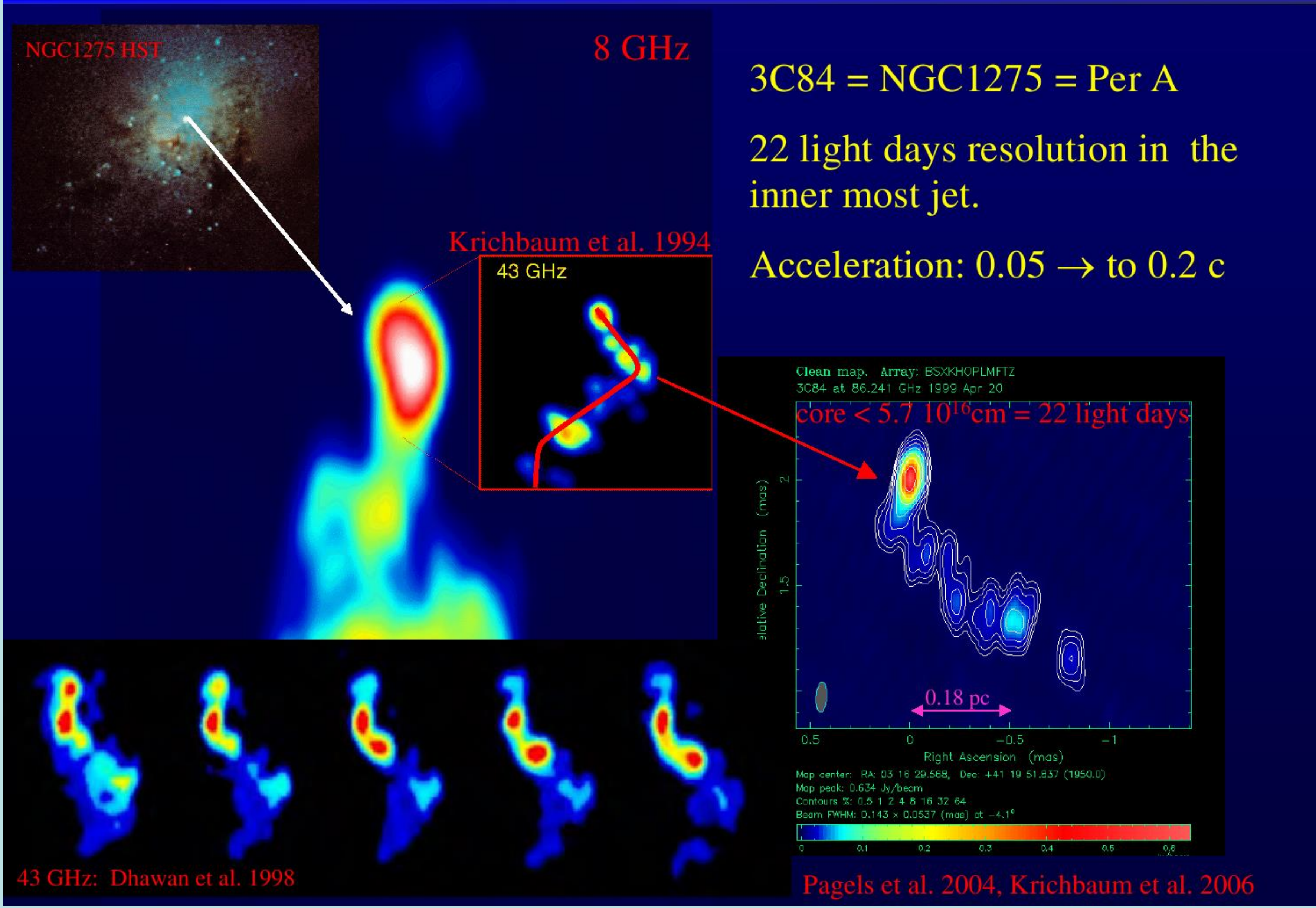
1990 – 2000: source in a low flux density phase
centrally peaked jet
no VHE emission

C2 now relatively steep spectrum: 1990 – 2000 activity
no connection with 1959 lobes – dying structure

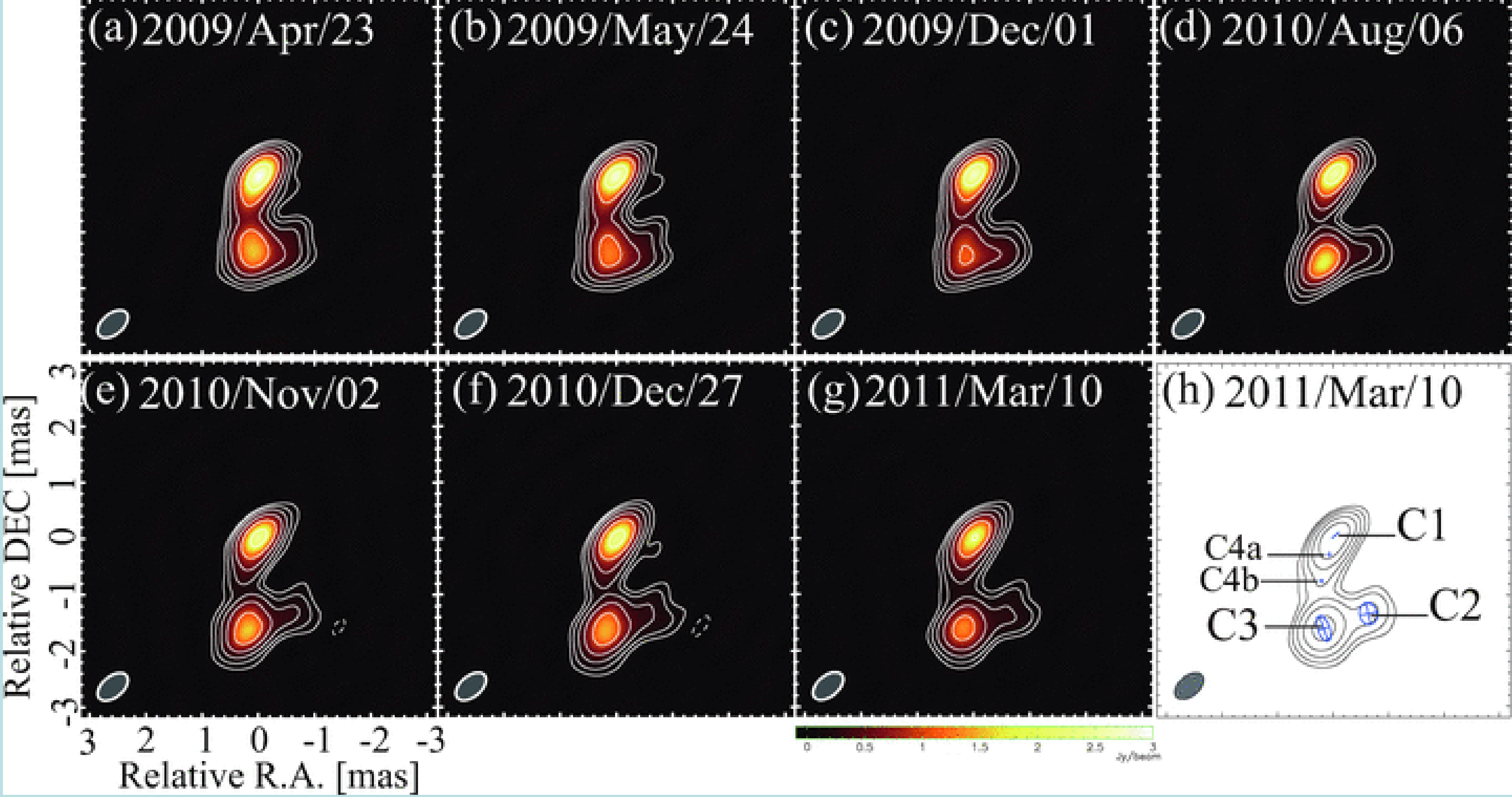
After 2005: nuclear activity + C3 ➔ increasing flux density
new jet orientation
limb-brightened jet
VHE activity: 2009, 2010, 2013 Jan. (GeV)

C3 complex – new ejection - connection with 1959 lobes?
Recollimation? Hot spot?

Tavecchio and Ghisellini 2014: the overall SED of 3C84 can be reproduced in the framework of the «spine-shear» model.



Precession confirmed by X-ray holes analysys by Dunn et al. 2005
Precession timescale estimated to be around 3.3×10^7 yrs

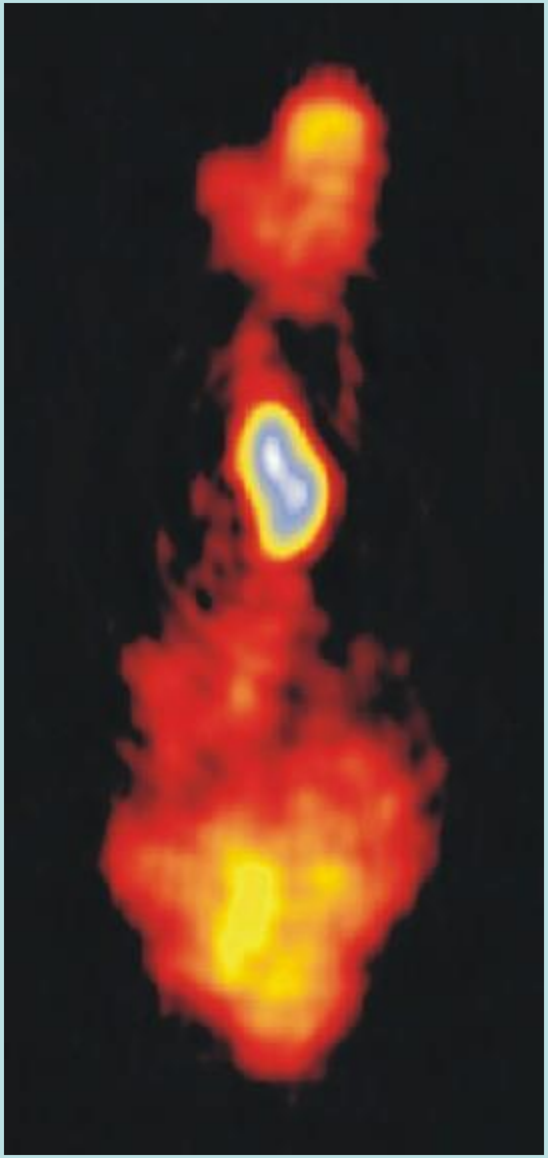


VERA 43 GHz images from Nagai et al. 2012

New ejection C3, flux density increase

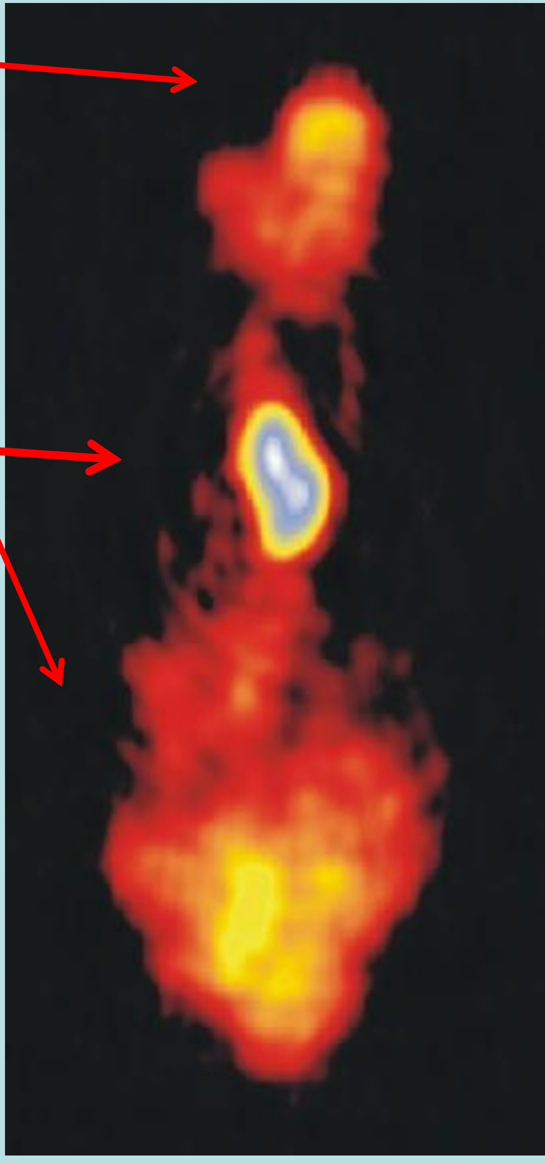
3C84: A gamma-ray bright misaligned AGN

- **BCG of the Perseus Cluster**
- **Prototypical cooling core cluster**
- **One of the strongest compact radio sources**
- **Extensively studied up to 87 GHz (radio)**
- **Nearby: z=0.0176 1 mas = 0.344 pc**
- **Central mass 3.4 x 10^8 solar masses**
- **0.1 mas = 10^3 r_g**



3C84 – The BCG of the Perseus cluster: A gamma-ray bright misaligned AGN

At mas resolution 3C84 shows two symmetric 'lobes' with evidence of absorption in the Northern one



At sub-mas 3C84 appears one-sided with slow proper motion (sub-luminal) : 0.1 – 0.5 c in contrast with the sidness asymmetry and the high jet velocity required by the gamma-ray emission

➔large deceleration expected because of jet interaction with a dense ISM (cooling cluster, Liuzzo et a. 2010)

Preuss
E.
Kellermann
K. I.
Pauliny-Toth
I. I. K.
Witzel
A.
Shaffer
D. B.
1979
, A&A
 , 79
, 268
Scanner flussi pg 270 fig 2

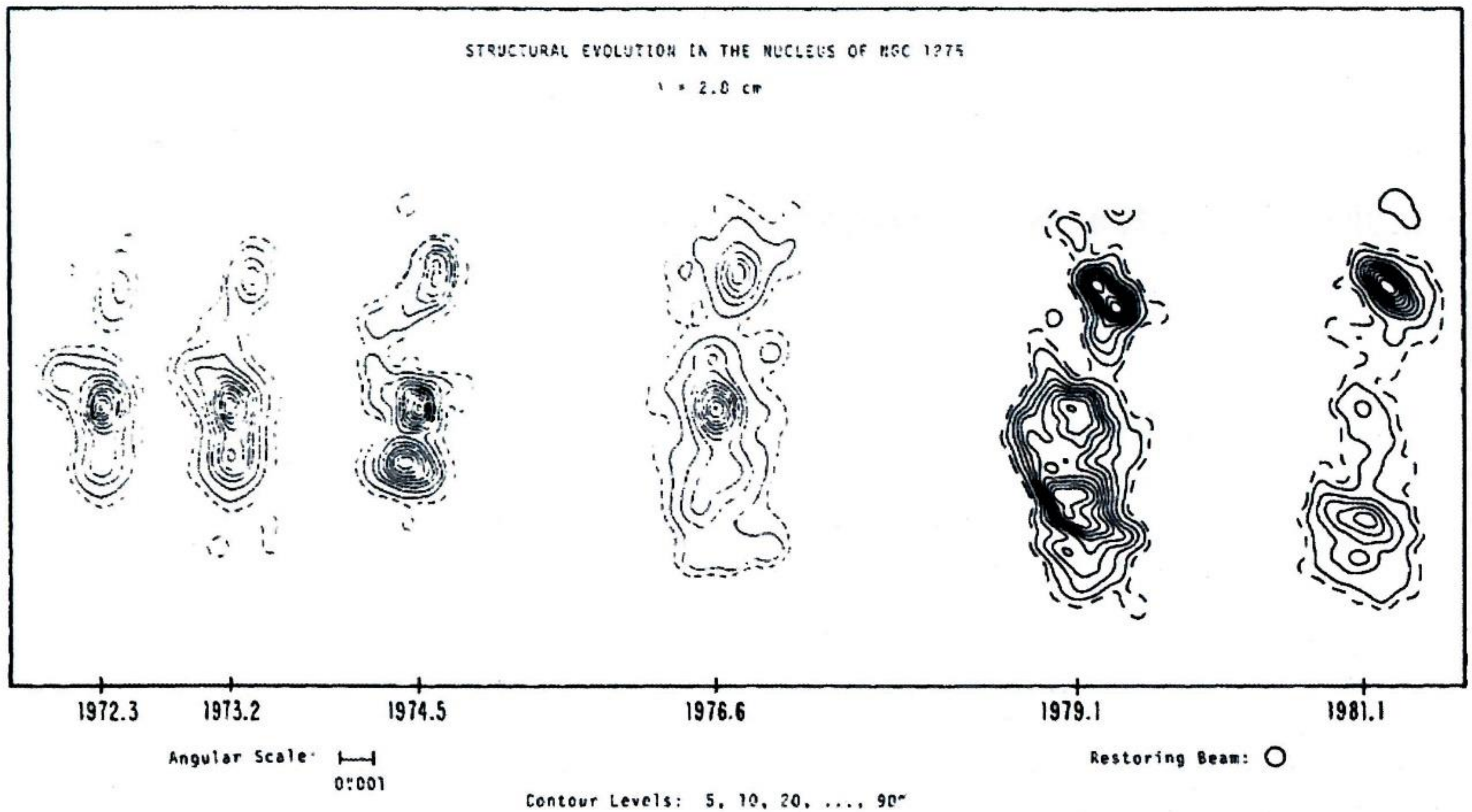
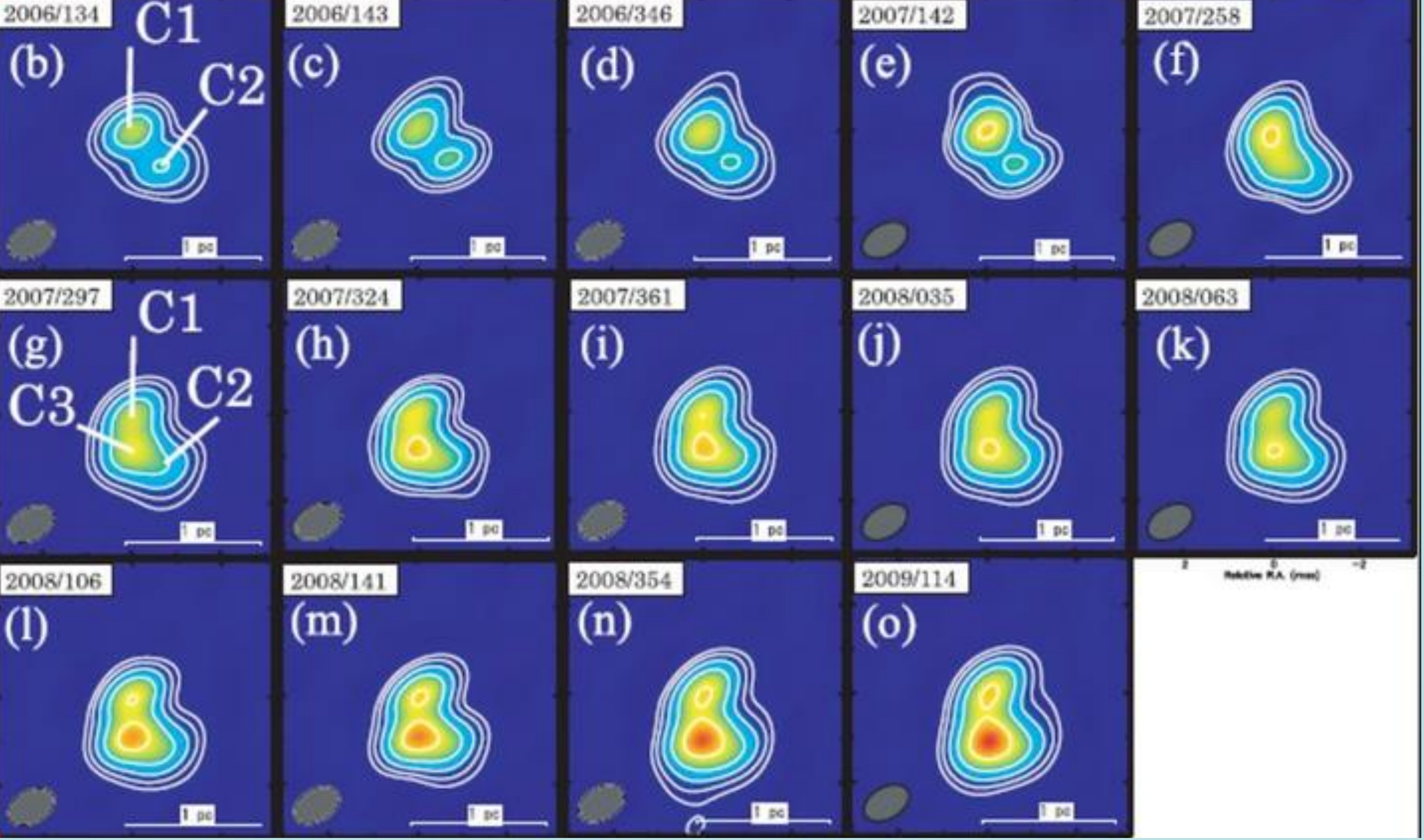
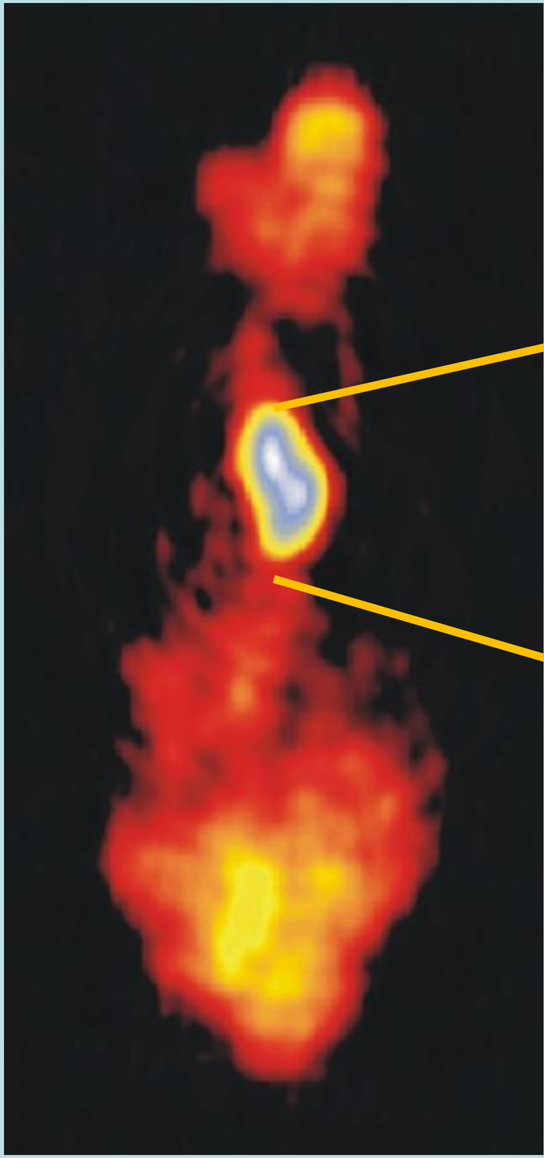


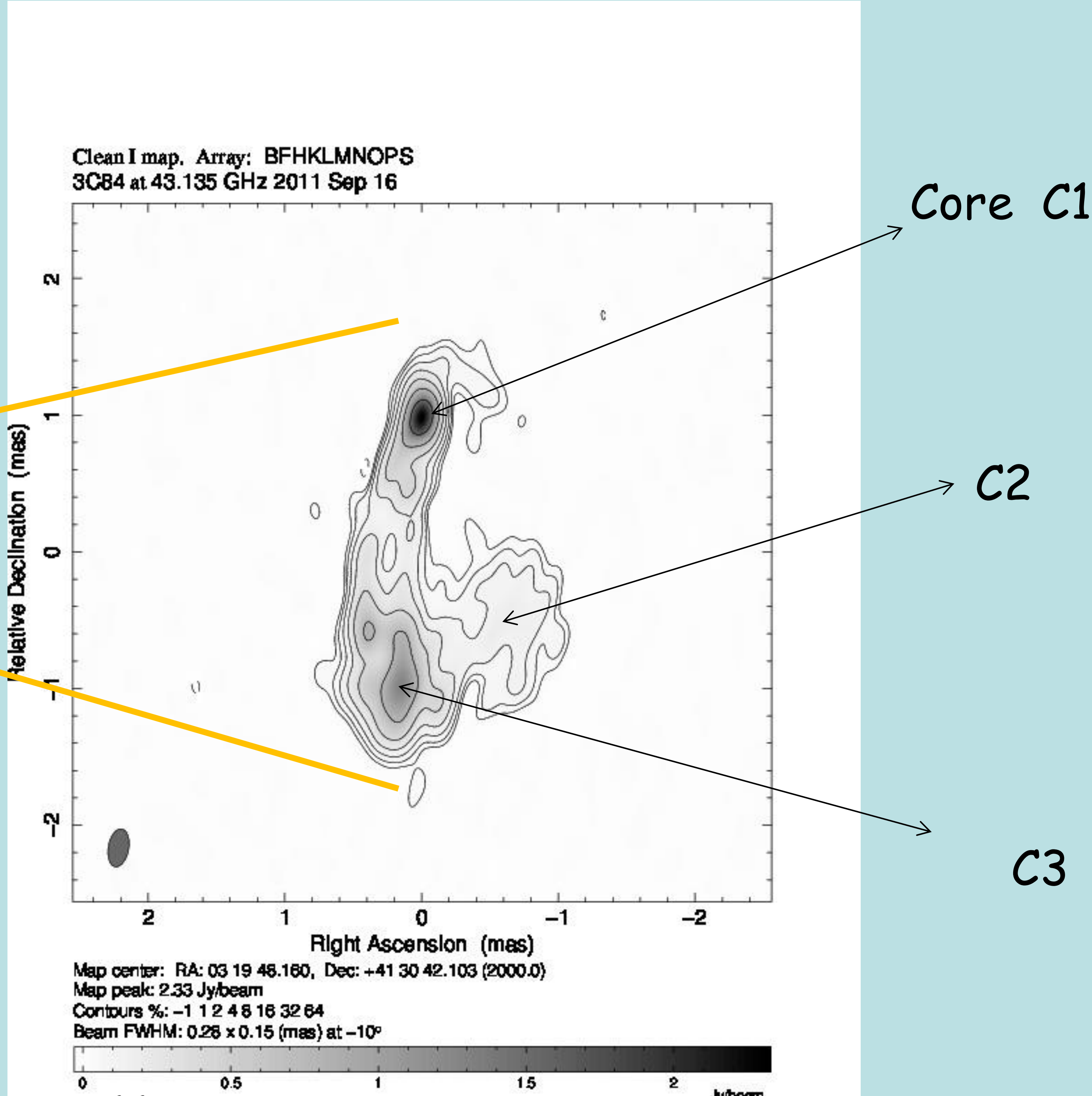
Fig. 1. Contour maps of the nucleus of NGC1275 at six epochs, aligned horizontally proportional to the epoch of observation.



2006/134
(b)
C1
C2
1 pc
2006/143
(c)
1 pc
2006/346
(d)
1 pc
2007/142
(e)
1 pc
2007/258
(f)
1 pc
2007/297
(g)
C1
C3
C2
1 pc
2007/324
(h)
1 pc
2007/361
(i)
1 pc
2008/035
(j)
1 pc
2008/063
(k)
1 pc
2008/106
(l)
1 pc
2008/141
(m)
1 pc
2008/354
(n)
1 pc
2009/114
(o)
1 pc

1 mas= 3.58×10^3 r_g





SMBH = 2×10^9 solar mass