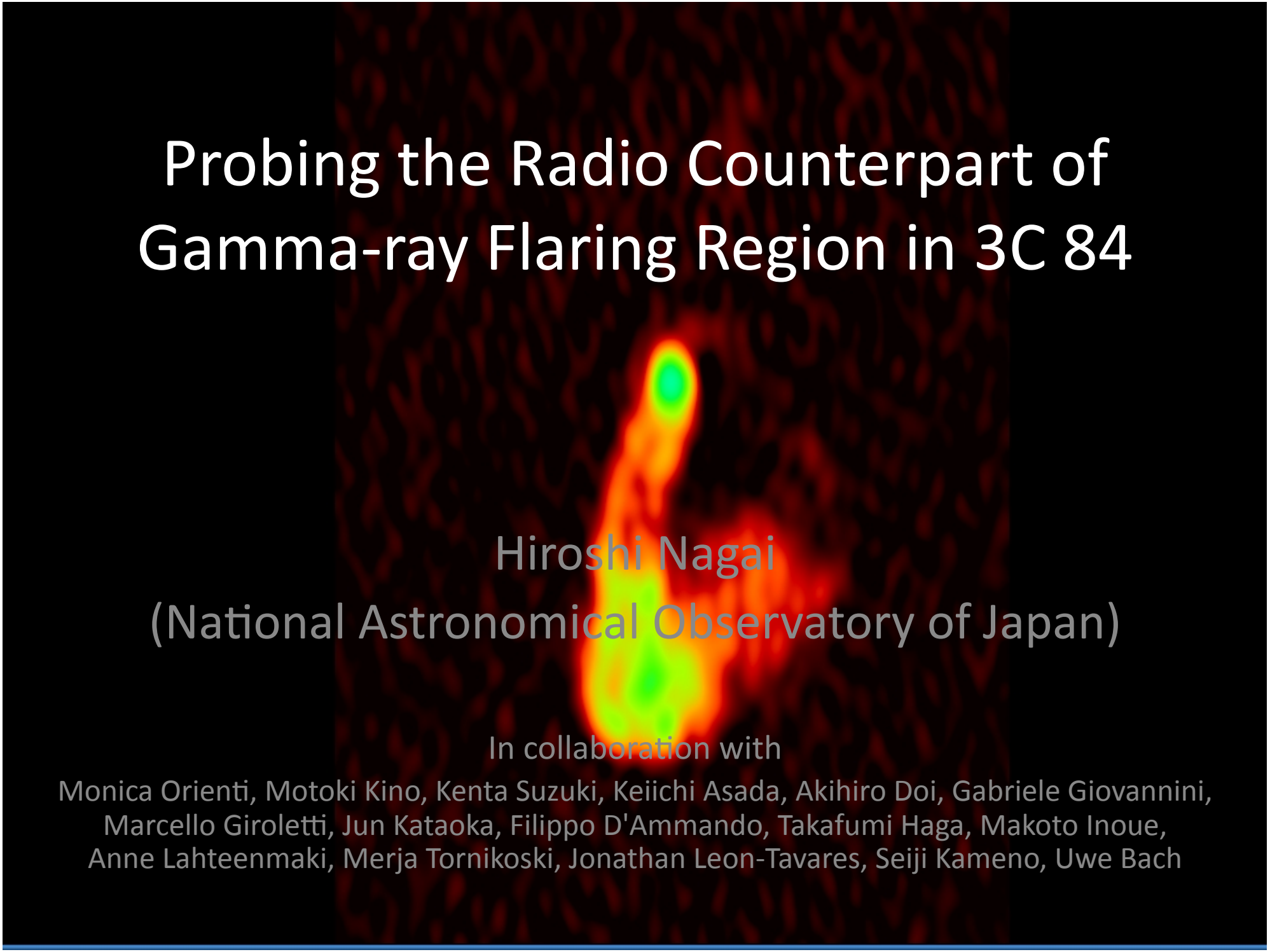
Probing the Radio Counterpart of Gamma-ray Flaring Region in 3C 84

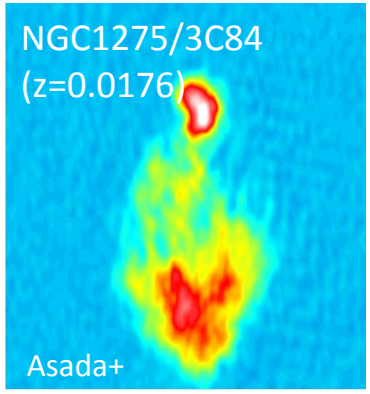


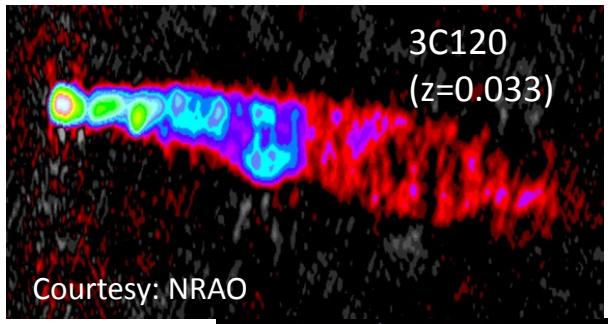
Hiroshi Nagai
(National Astronomical Observatory of Japan)

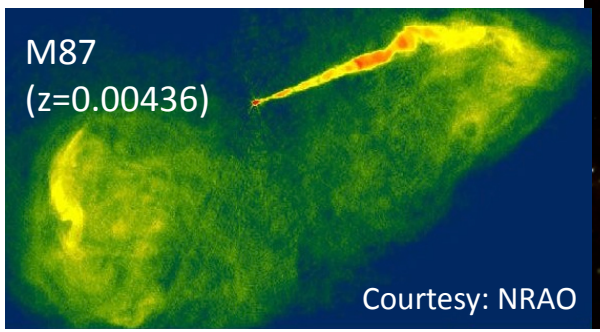
In collaboration with
Monica Orienti, Motoki Kino, Kenta Suzuki, Keiichi Asada, Akihiro Doi, Gabriele Giovannini, Marcello Giroletti, Jun Kataoka, Filippo D'Ammando, Takafumi Haga, Makoto Inoue, Anne Lahteenmaki, Merja Tornikoski, Jonathan Leon-Tavares, Seiji Kameno, Uwe Bach

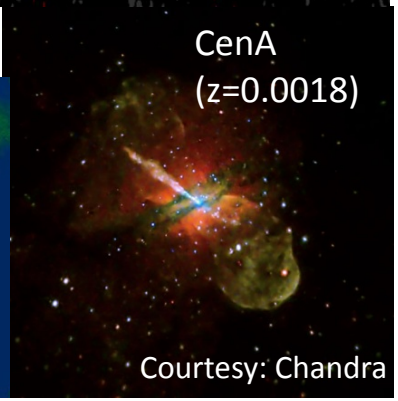
Gamma-ray bright RGs

- More than 10 RGs have been detected in GeV band by *Fermi*-LAT
- 3C84/NGC1275, M87, Cen A are also detected in VHE gamma-ray band
- The study of gamma-ray emission mechanism in RGs is important in the context of unification for the radio-loud AGN





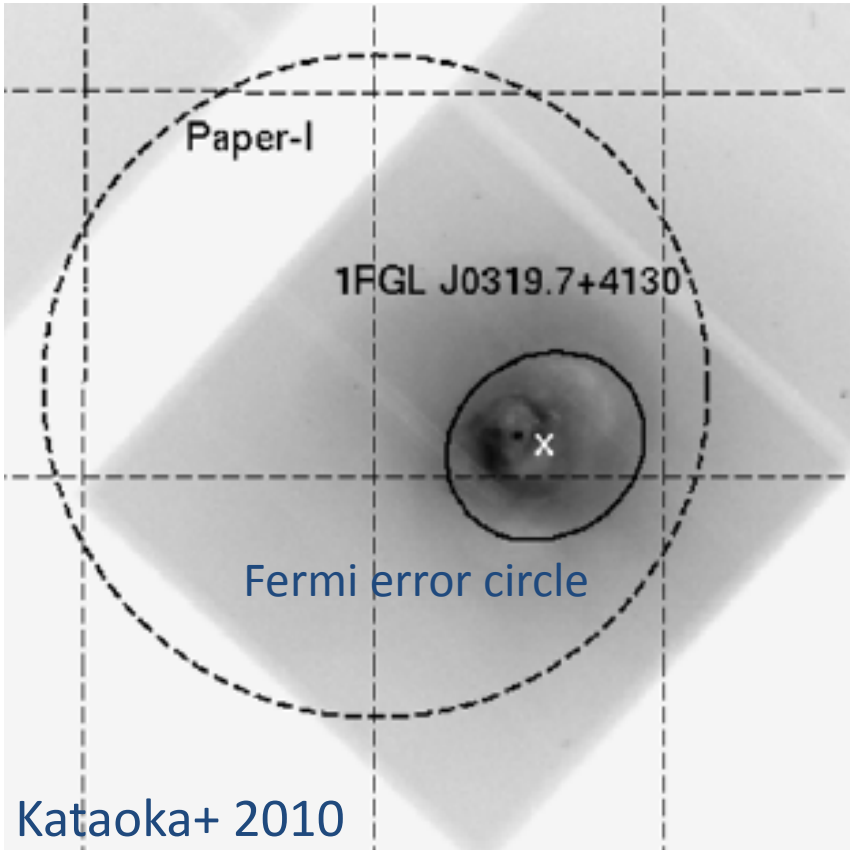




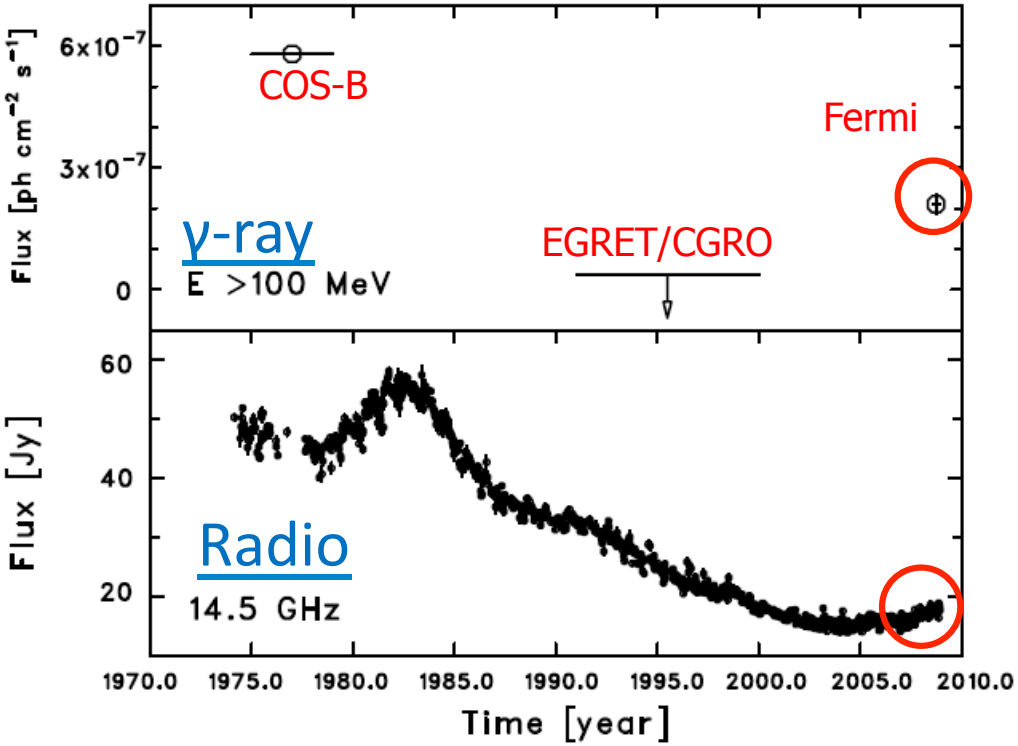
Object	1FGL Name	R.A. (J2000)	Decl. (J2000)	Redshift	Class		log (CD) at 5 (GHz)	Ref.	Cat.
					Radio	Optical			
3C 78/NGC 1218	1FGLJ0308.3+0403	03 08 26.2	+04 06 39	0.029	FRI	G	−0.45	1	3CR
3C 84/NGC 1275	1FGLJ0319.7+4130	03 19 48.1	+41 30 42	0.018	FRI	G	−0.19	2[a]	3CR
3C 111	1FGLJ0419.0+3811	04 18 21.3	+38 01 36	0.049	FRII	BLRG	−0.3	3	3CRR
3C 120		04 33 11.1	+05 21 16	0.033	FRI	BLRG	−0.15	1	3CR
PKS 0625−354	1FGLJ0627.3−3530	06 27 06.7	−35 29 15	0.055	FRI[b]	G	−0.42	1	MS4
3C 207	1FGLJ0840.8+1310	08 40 47.6	+13 12 24	0.681	FRII	SSRQ	−0.35	2	3CRR
PKS 0943−76	1FGLJ0940.2−7605	09 43 23.9	− 76 20 11	0.27	FRII	G	<−0.56	4	MS4
M87/3C 274	1FGLJ1230.8+1223	12 30 49.4	+12 23 28	0.004	FRI	G	−1.32	2	3CRR
Cen A	1FGLJ1325.6−4300	13 25 27.6	− 43 01 09	0.0009[c]	FRI	G	−0.95	1	MS4
NGC 6251	1FGLJ1635.4+8228	16 32 32.0	+82 32 16	0.024	FRI	G	−0.47	2	3CRR
3C 380	1FGLJ1829.8+4845	18 29 31.8	+48 44 46	0.692	FRII/CSS	SSRQ	−0.02	2	3CRR

Abdo+ 2010

Gamma-ray view of 3C 84

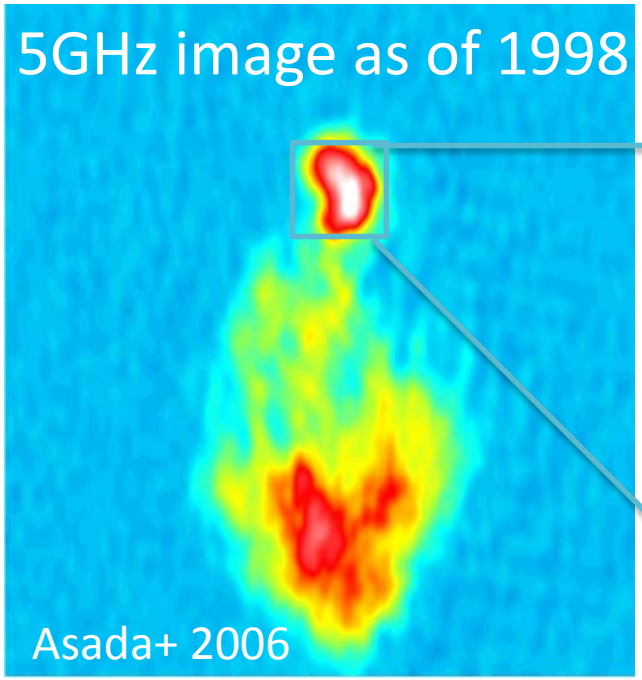


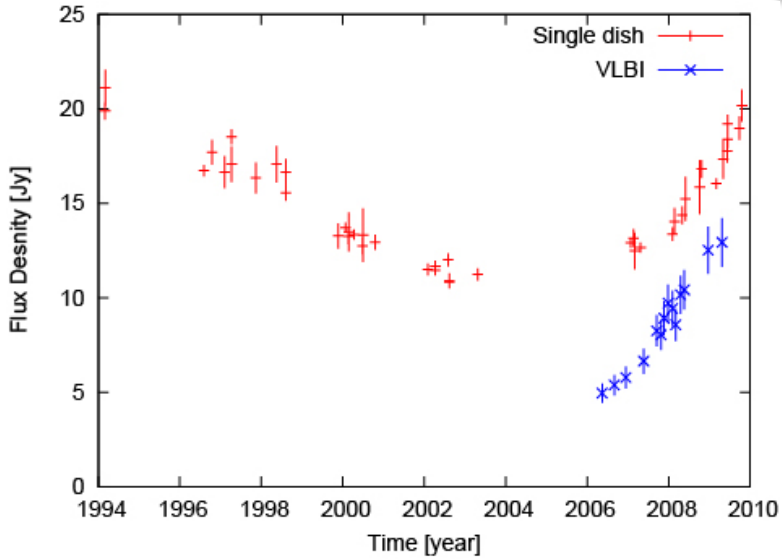
gamma-ray and radio lightcurve of 3C84



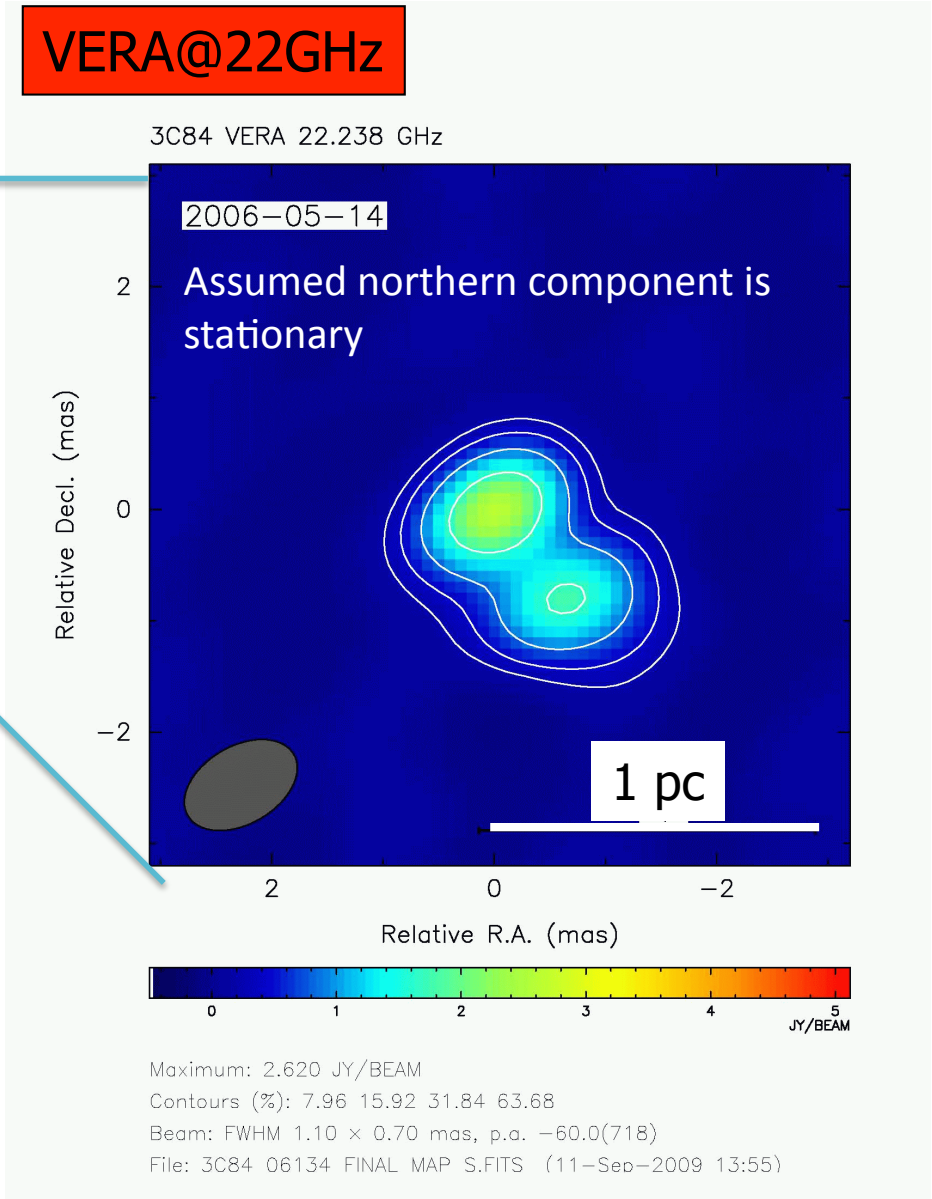
Abdo+ 2009 (Corresponding author: J. Kataoka)

VLBI movie



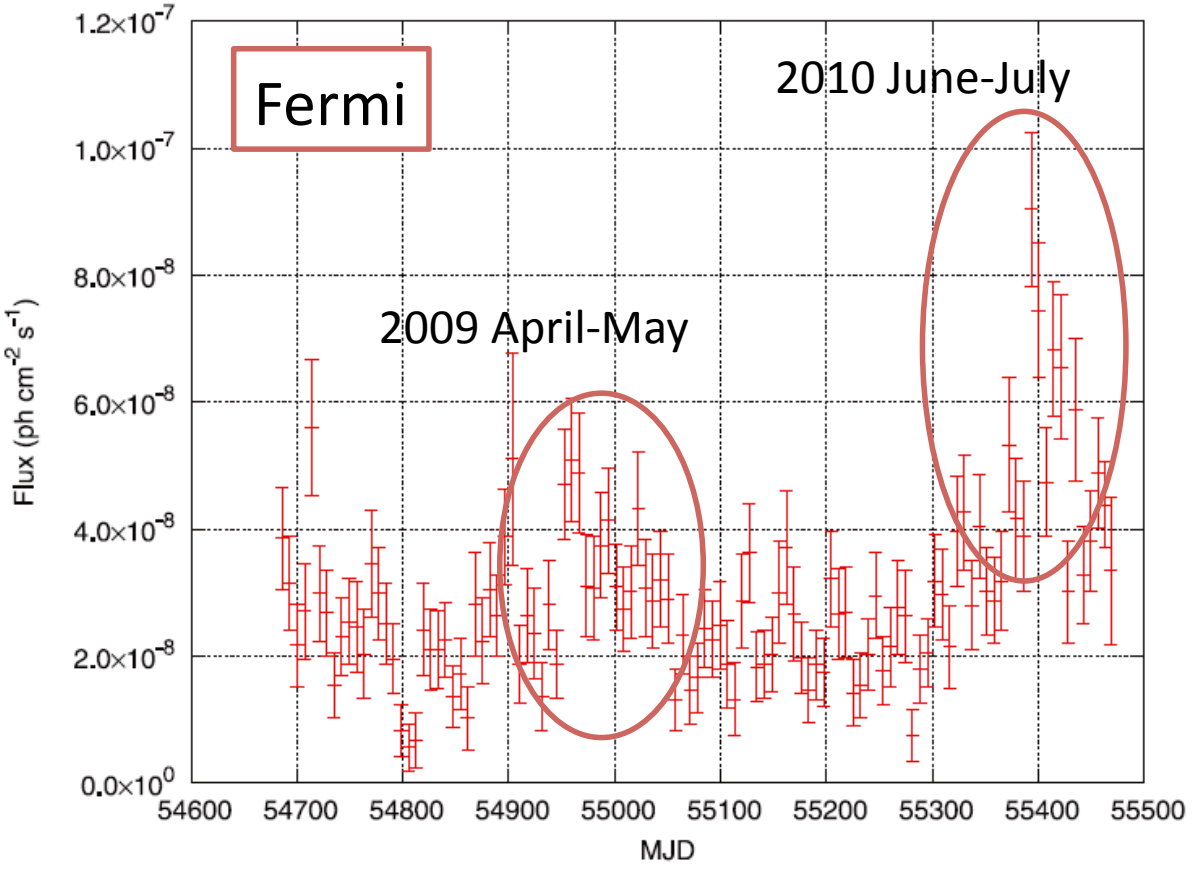


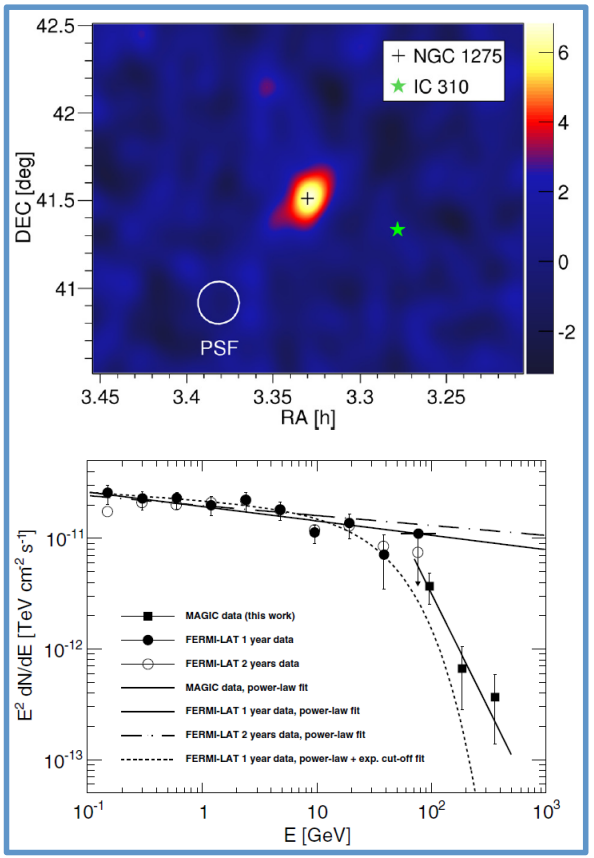
VERA@22GHz



Nagai et al. 2010

2-years light curve



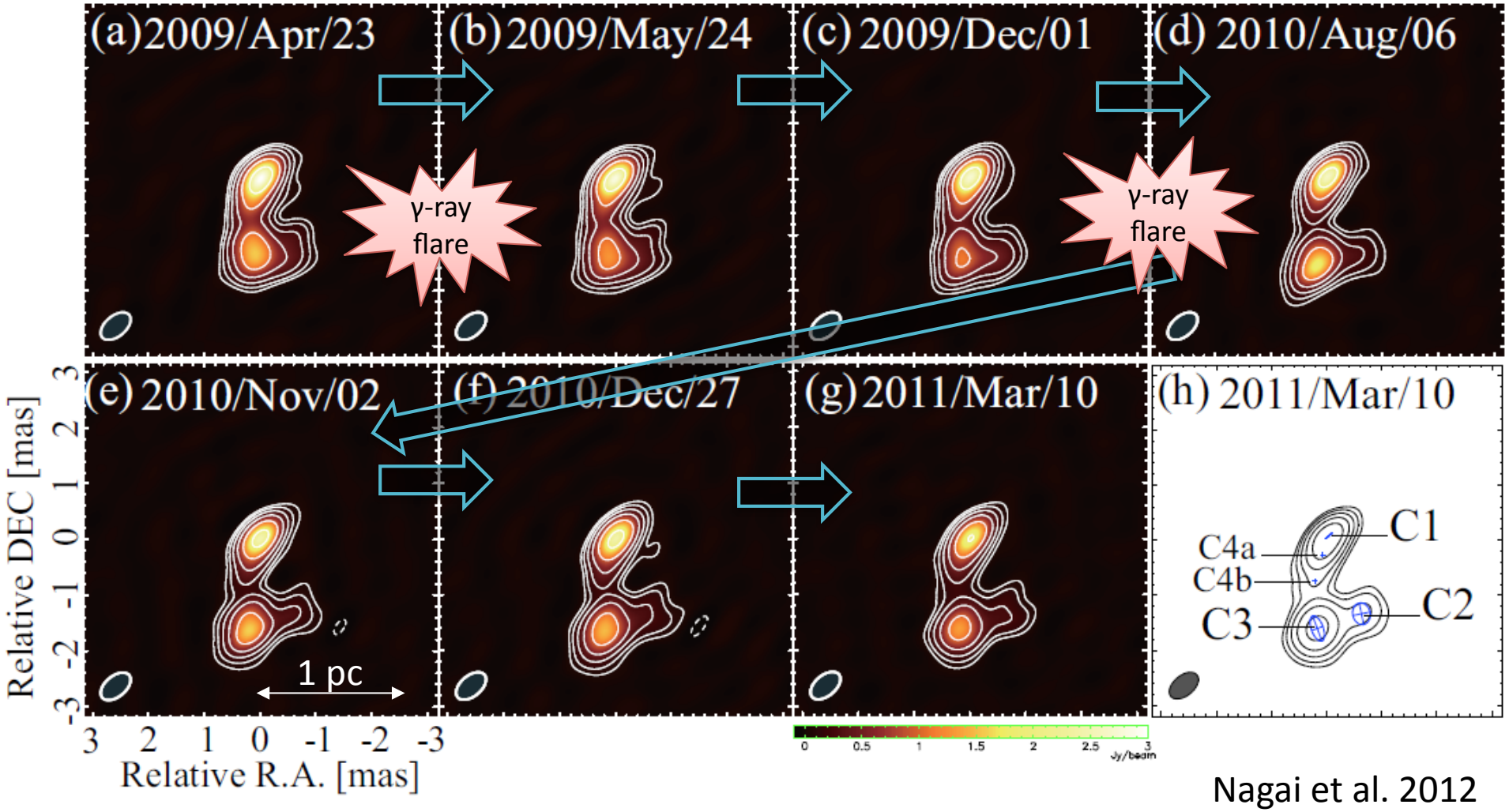


VHE gamma-ray by MAGIC (Aleksic+ 2012)

A factor of ~2-3 flares in 2009-2010 periods

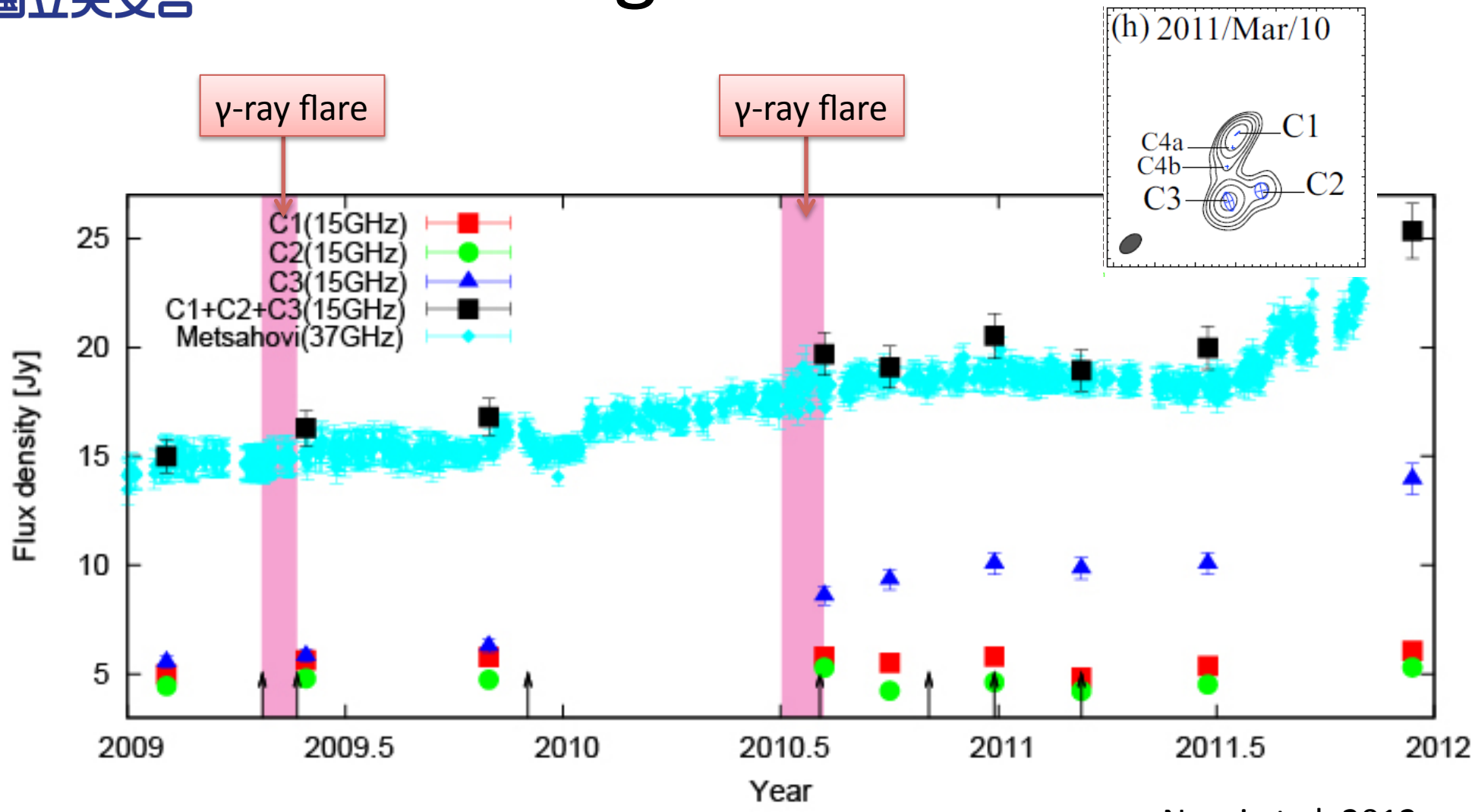
Structural change

VERA 43GHz images



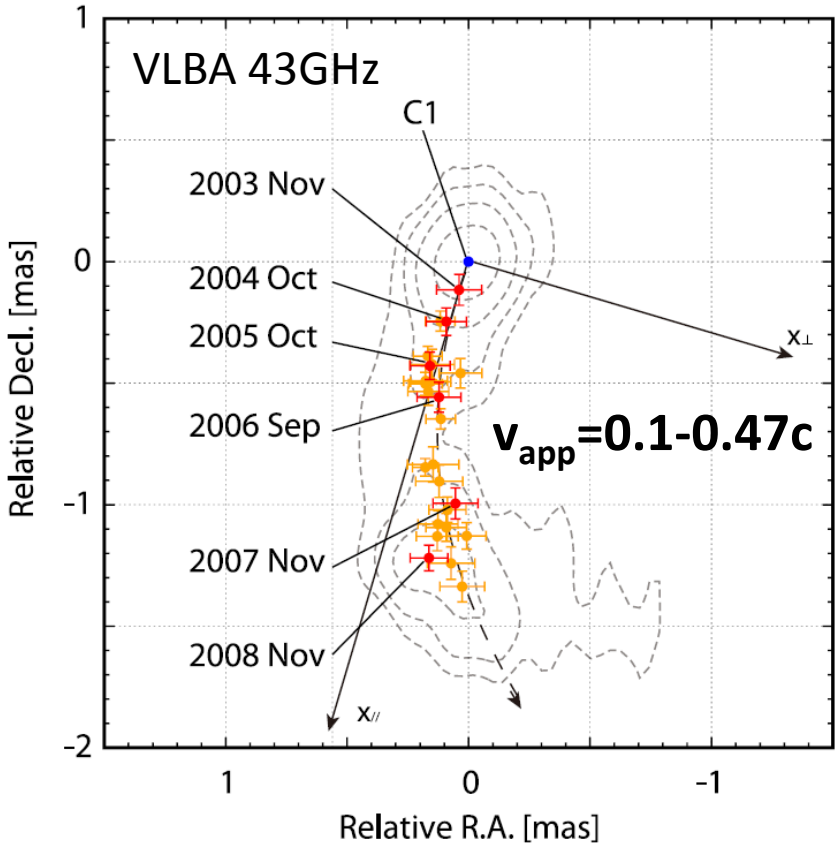
Nagai et al. 2012

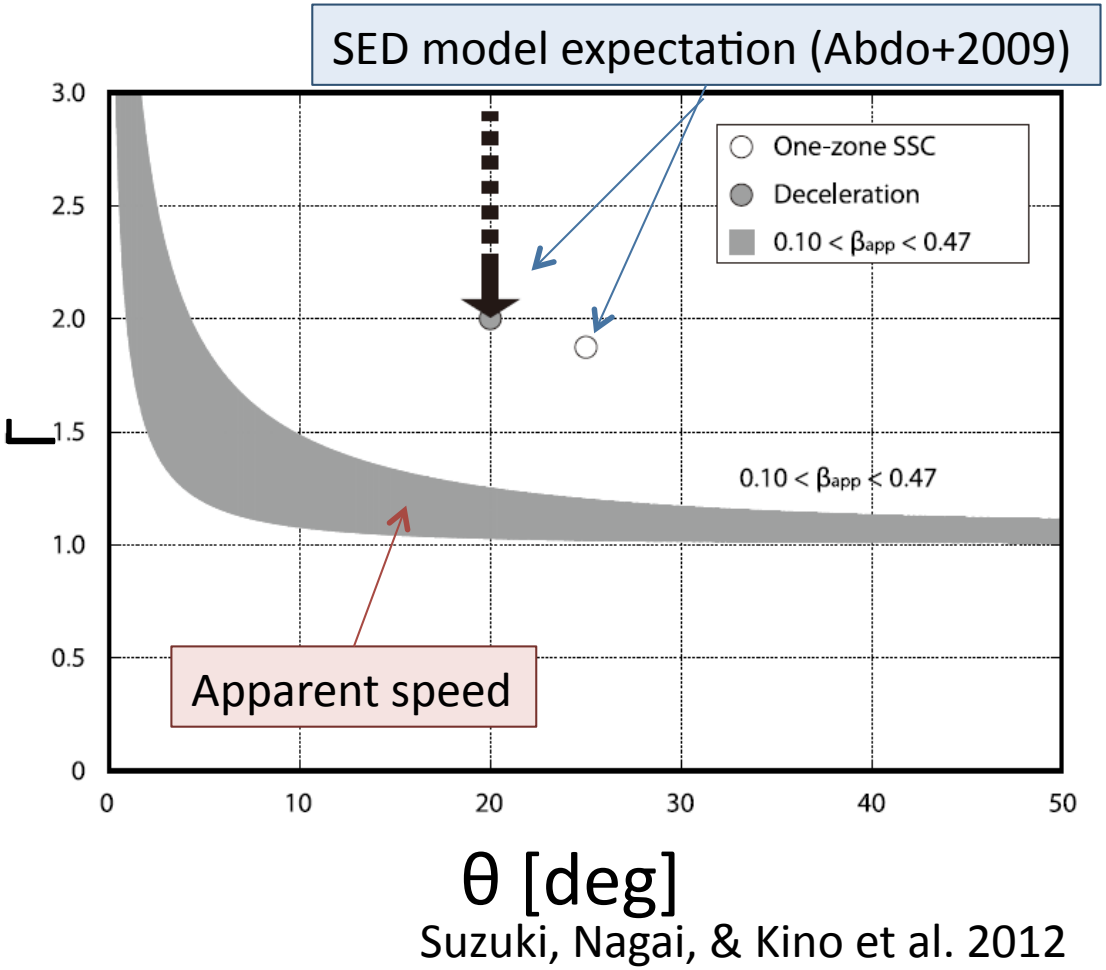
Light curve



Nagai et al. 2012

Apparent motion





Suzuki, Nagai, & Kino et al. 2012

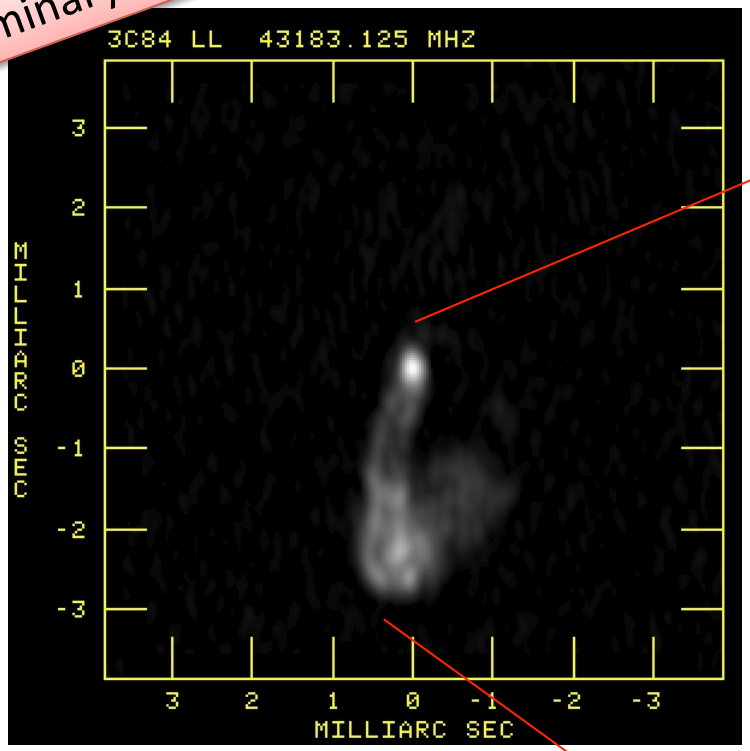
- v_{app}=0.1-0.47c
- Slower than the jet speed predicted from gamma-ray emission by Abdo+ 2009

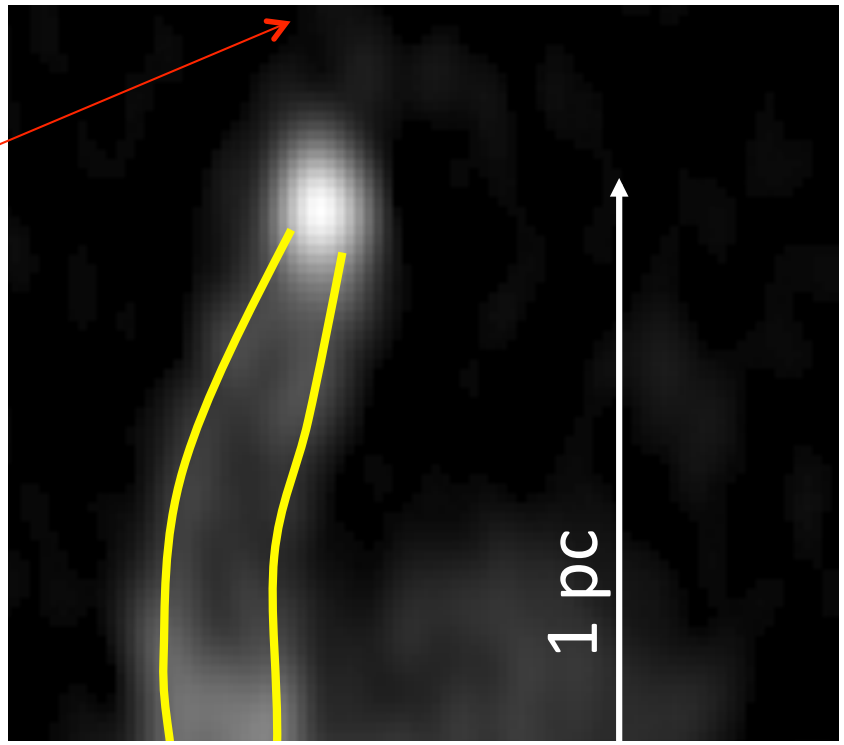
Summary, so far…

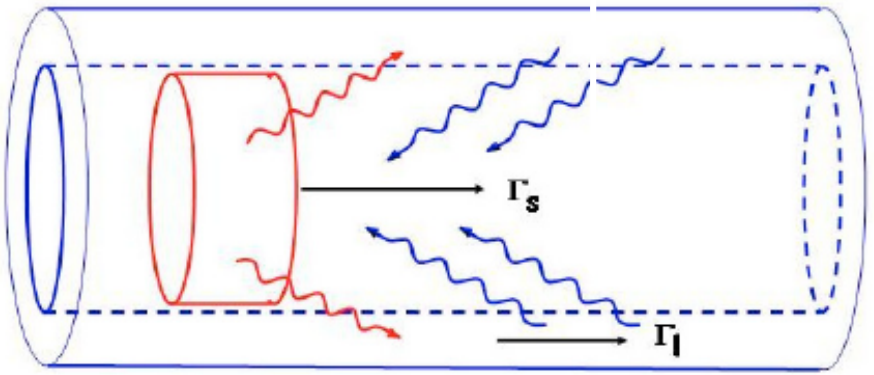
- No clear correlation between radio and gamma-ray light curves
  - Monotonic increase in radio flux density
  - Gamma-ray flare on the timescale of days-weeks
- No significant change in VLBI-scale structure before and after the gamma-ray flares
- Apparent motion is relatively slower than the ones predicted from one-zone SSC and deceleration jet model

New VLBA 43GHz image

Preliminary!!!



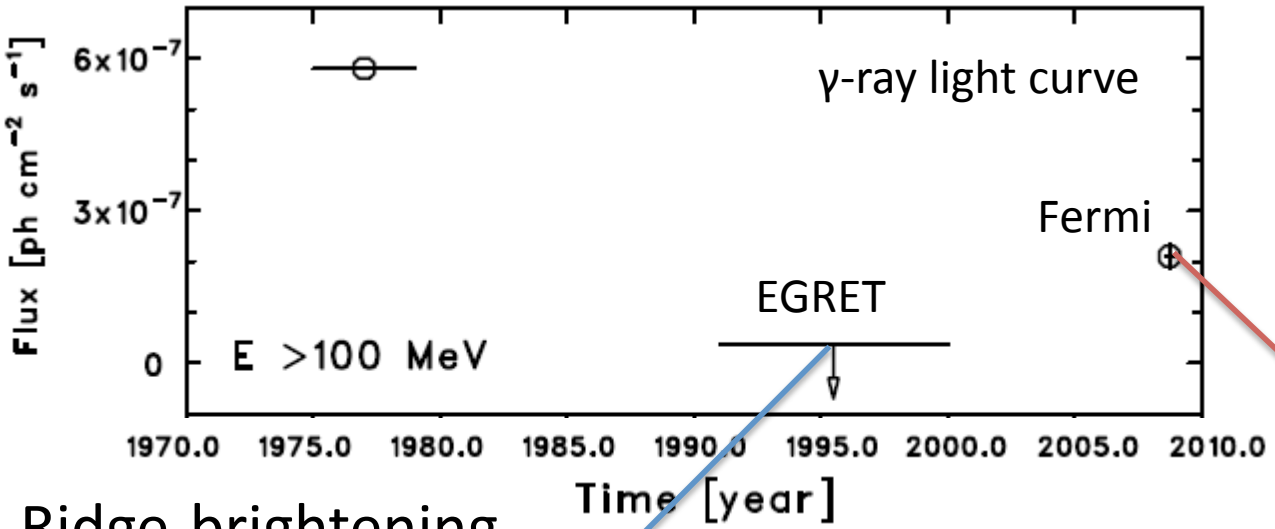




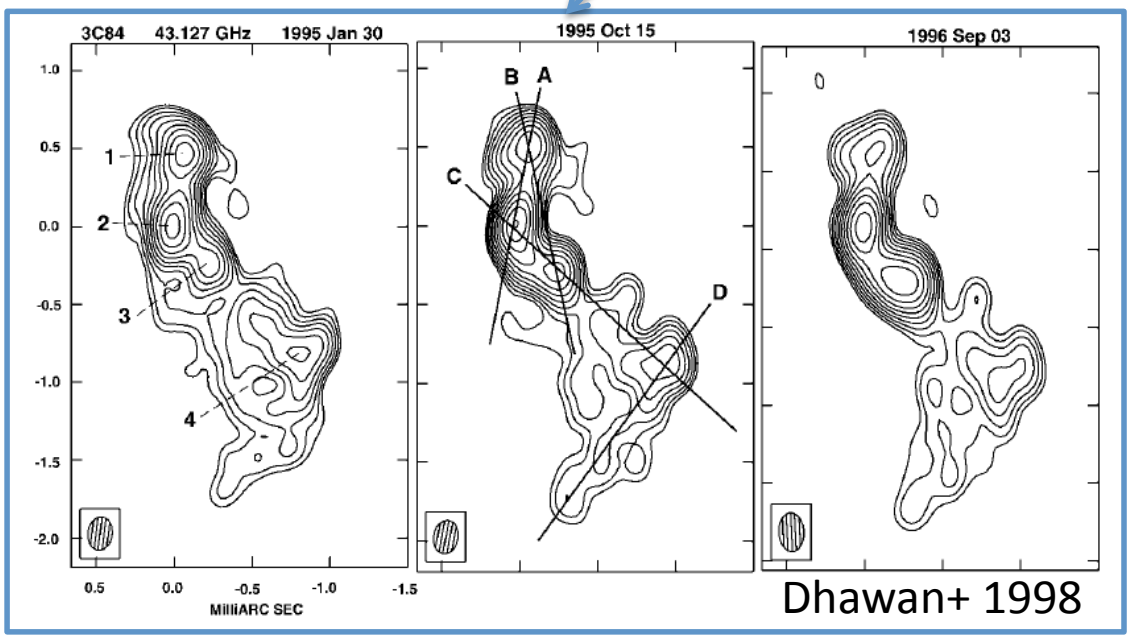
Ghisellini+ 2005

- Data as of 2013 Jan (PI: T. Haga)
- **Clear limb-brightening as expected from the spine-sheath scenario (Ghisellini+ 2005)**
  - **Velocity gradient across the jet?**

Ridge-brightening -> limb-brightening?

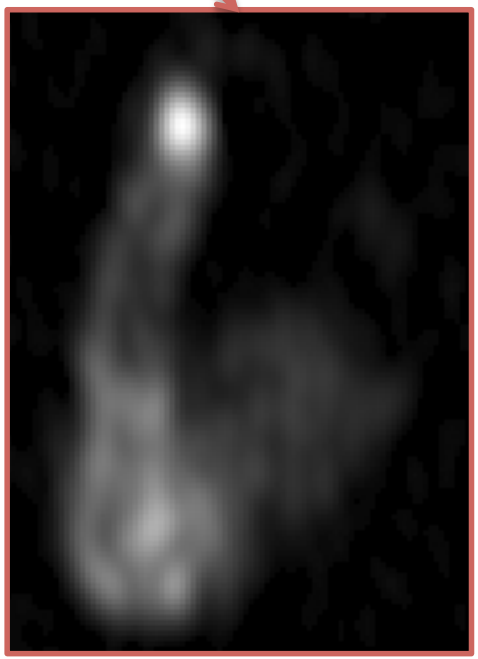


Ridge-brightening



Dhawan+ 1998

Limb-brightening

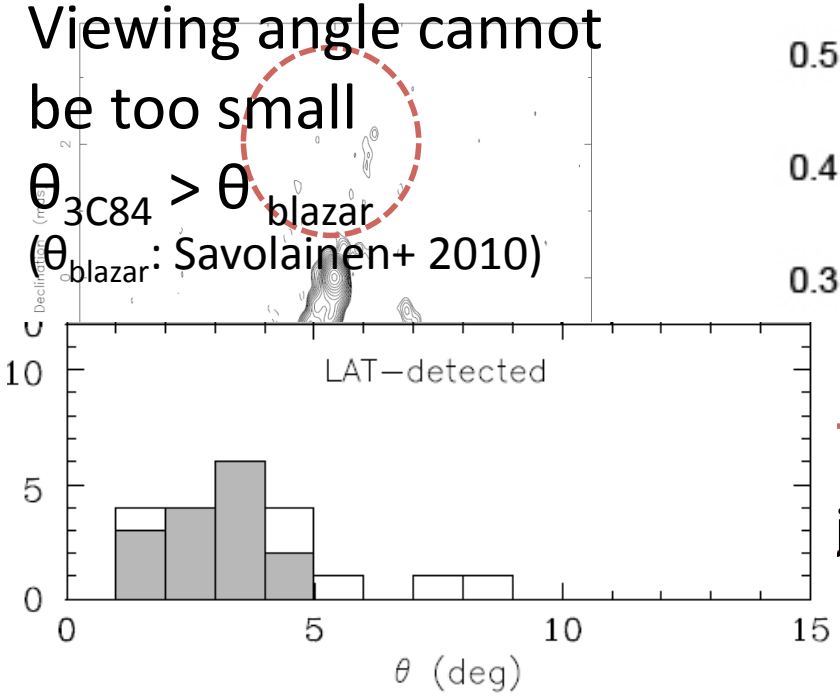


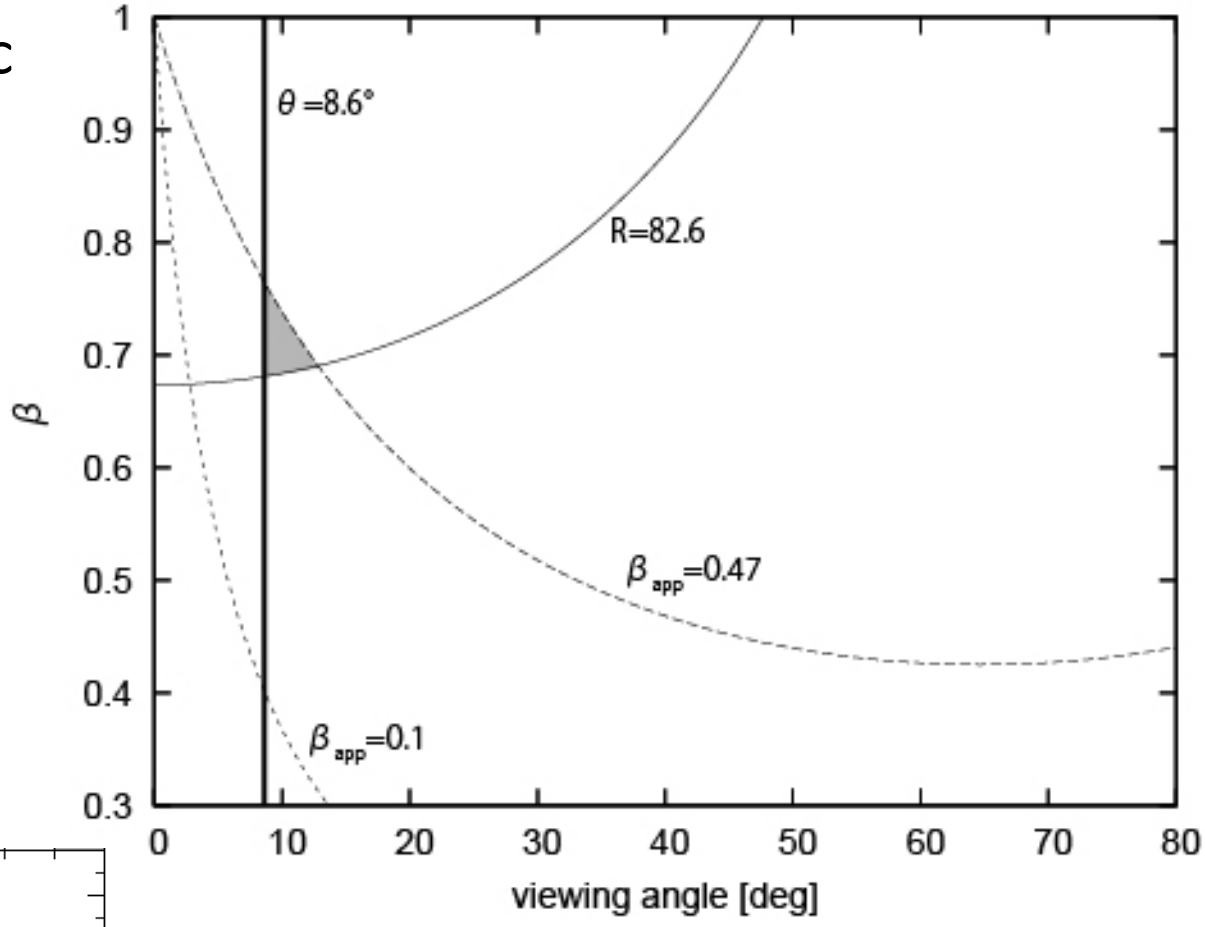
Constraint on v_{jet} and θ_{jet}

Apparent speed 0.1-0.47c
Suzuki+ 2012

Jet-counter-jet ratio
lower limit#: 82.6
#: Absorption corrected using
Walker+ 2000

Viewing angle cannot
be too small
$\theta_{3C84} > \theta_{blazar}$
(θ_{blazar}: Savolainen+ 2010)

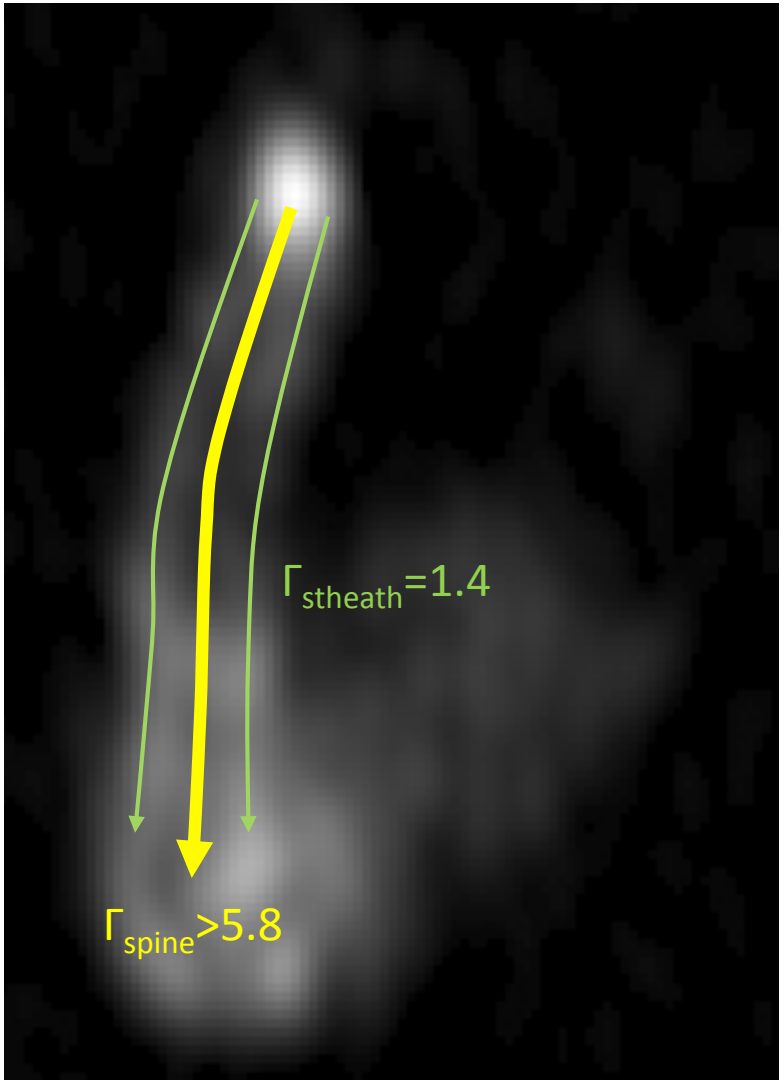




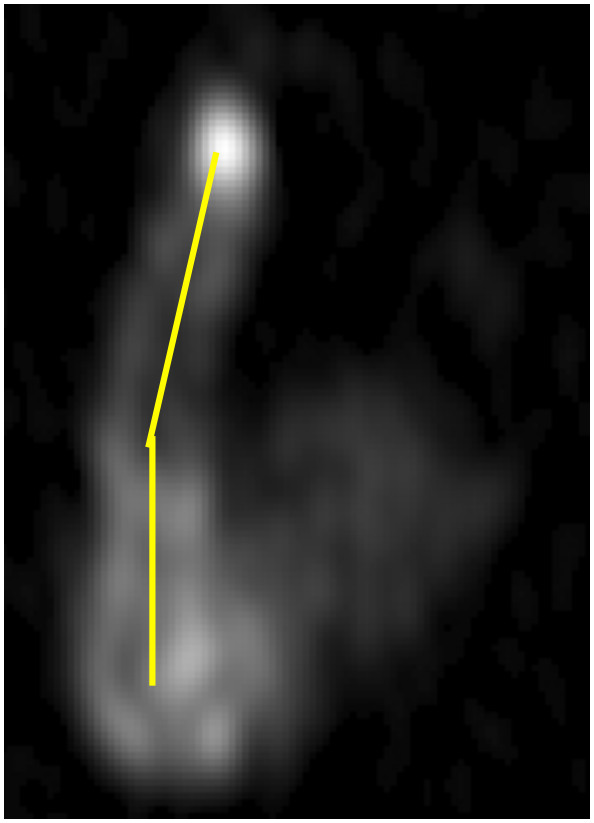
v_{jet}~0.7c (Γ=1.4) , θ_{jet}~ 10 deg

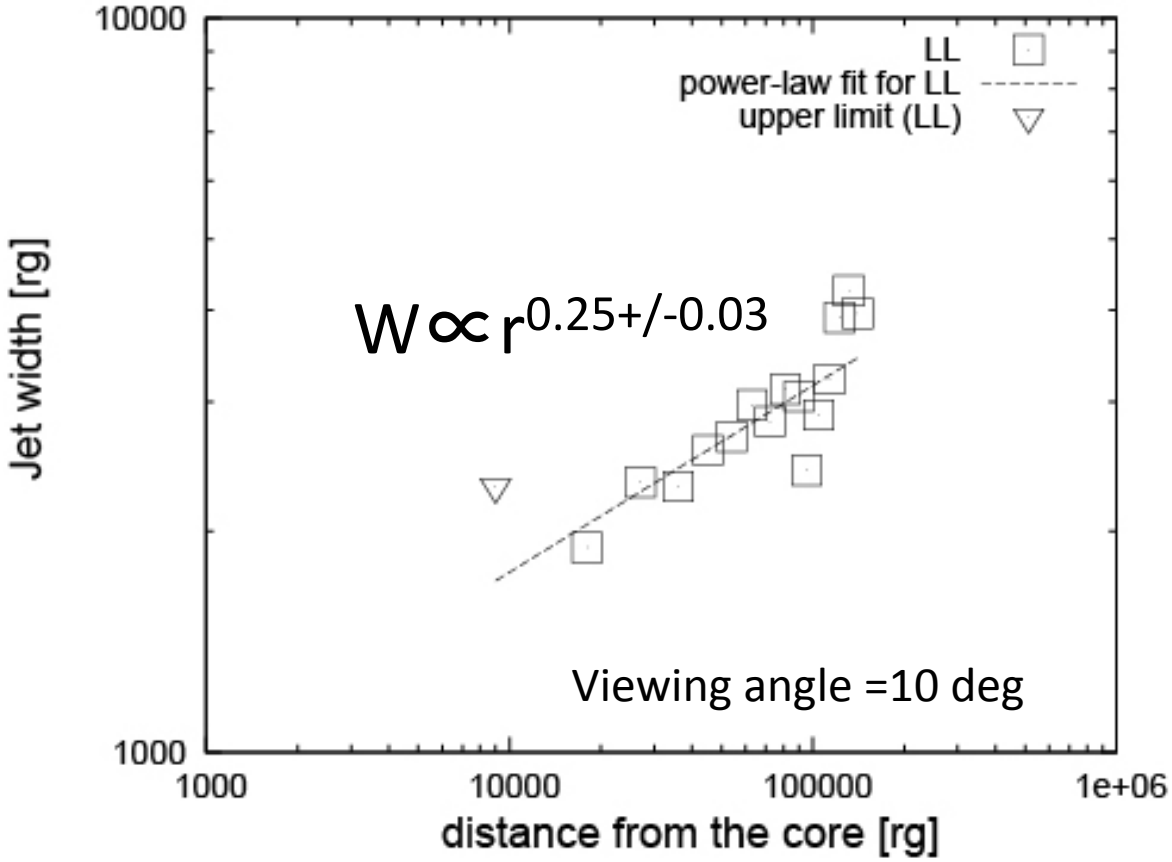
Constraint on the spine flow

- If the limb-brightening results from the velocity gradient across the jet,
  $\theta_{jet} > \theta_{beaming} = \sin^{-1}(1/\Gamma_{spine})$
- $\Gamma_{spine} > 5.8$



Jet width profile





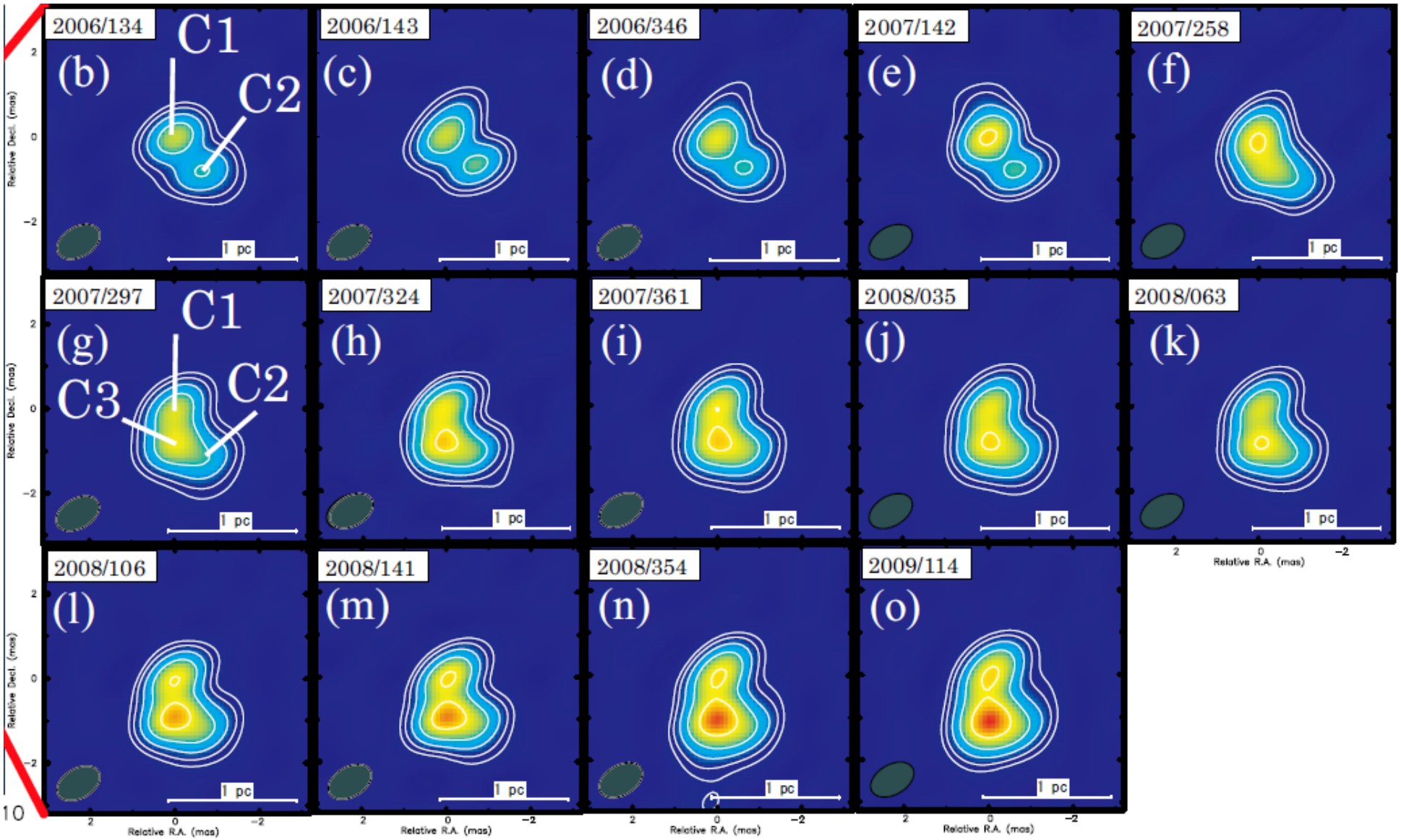
- Power-law index is flatter than that of M87
  - α=0.58-1.04 (Asada & Nakamura 2012)
- Due to different circumnuclear environment ??

Conclusion

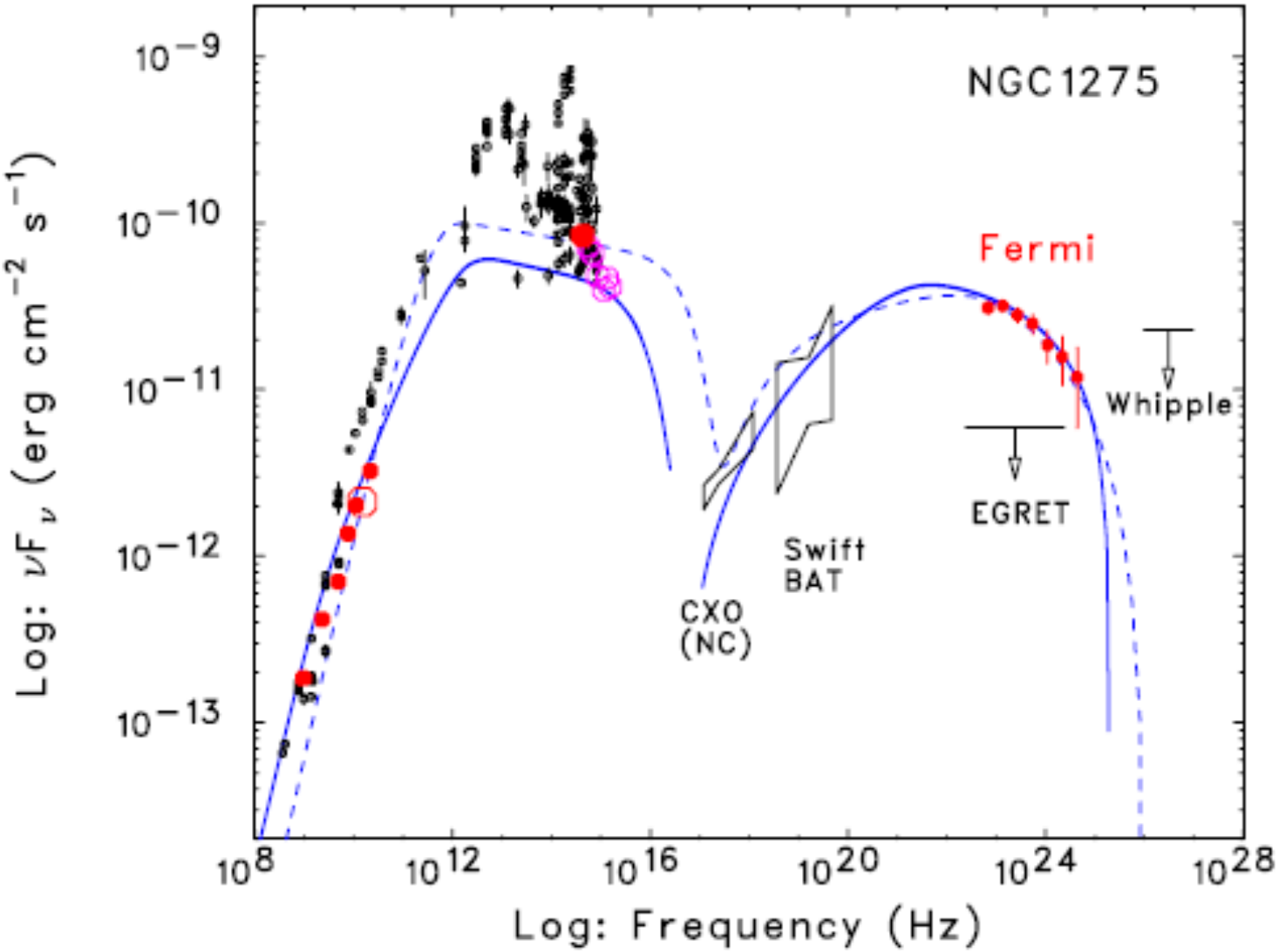
- No clear correlation between radio and gamma-ray light curves
- VLBI-measured apparent speed is relatively slower than the one expected from the SED modeling
  - Gamma-ray emission is more beamed than the Lorentz factor as indicated by the VLBI motion?
- Clear Limb-brightening as expected from the spine-sheath model

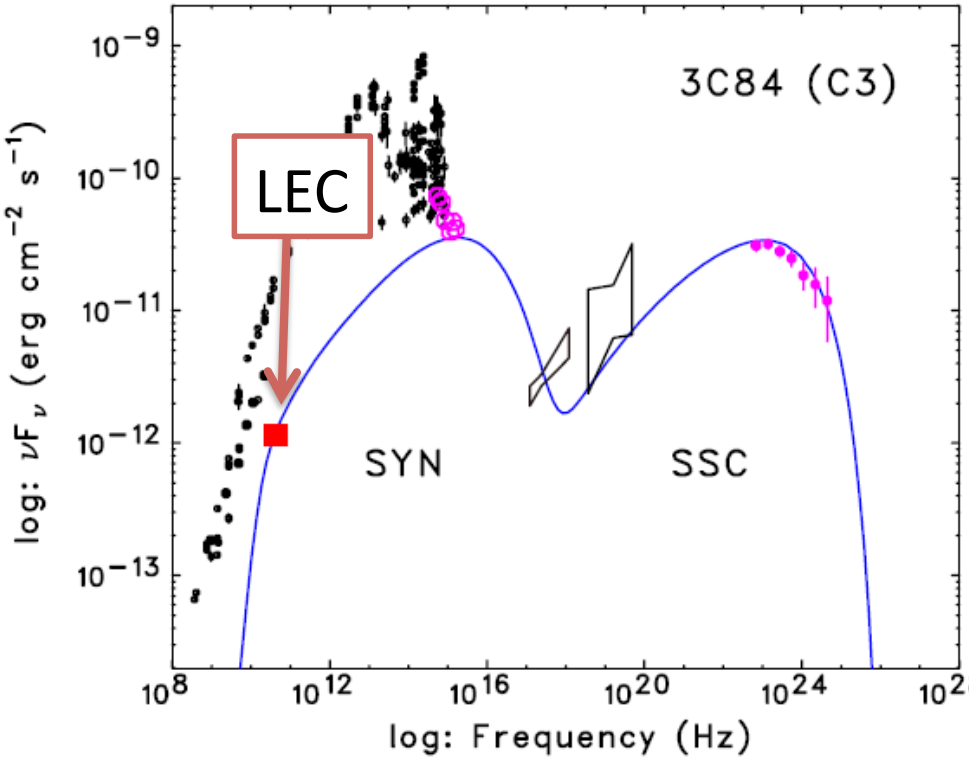
Are we seeing slower sheath of jet at radio wavelengths?

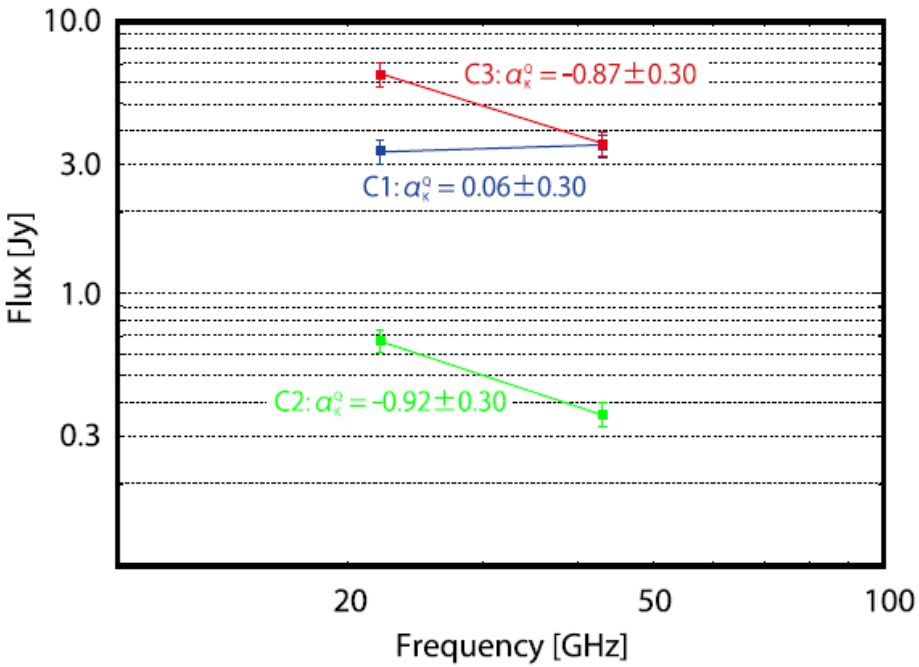
appendix


2006/134
C1
C2
(b)
2006/143
(c)
2006/346
(d)
2007/142
(e)
2007/258
(f)
2007/297
C1
C3
C2
(g)
2007/324
(h)
2007/361
(i)
2008/035
(j)
2008/063
(k)
2008/106
(l)
2008/141
(m)
2008/354
(n)
2009/114
(o)
1 pc
Relative Decl. (mas)
Relative R.A. (mas)
2
0
−2

SED model bby Abdo+ 2009







- 43GHz data lies below the low energy cutoff (α~1/3)
- Observed spectral index of C3 disagree with α=1/3

- What is the bridging structure between C1 and C3?
- Equipartition magnetic field of C3 is ~0.3G.
- t_{syn}~1.5 yr (at 43GHz)
  - Bridging structure is probably not a “remnant” of C3
- Subsequent jet ejection from C1