Long-term Radio and Gamma-ray Properties of 3C 84

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VLBA 43GHz (Nagai et al. 2014)
Since last GPS-CSS workshop...

- **Big change 1: re-started jet activity in 3C 84**
  - New prominent component shows a monotonic flux increase and subluminal motion
    - Consistent with “mini-lobe”-like properties
- **Big change 2: gamma-ray detection**
  - No clear radio counterpart associated with short-term gamma-ray flares
    - Stratified jet or flare region embedded in optically-thick radio core
  - Correlation between radio and gamma-ray light curves on the timescale of years
    - Gamma-ray emission from young radio source?
3C 84

- Bright radio source associated with giant elliptical/radio galaxy NGC1275
- Not GPS/CSS
  - But, central parsec radio structure shows GPS/CSO-like properties (as mentioned by Kino. M)
    - mini-lobes formed by re-started jet since 1959 (O’Dea+ 1984)
    - Strong absorption by accretion gas on counterjet (Walker+ 2000)
• Jet activity was decreasing after 1985
• Re-activated since ~2005
  – No one noticed this at the time of 4<sup>th</sup> GPS-CSS workshop!
3C 84

- VERA (Japanese VLBI array)
- AGN jet monitoring program: GENJI
  - by-weekly monitoring of 10 AGN jets (Nagai+ 2013)

Walker+ 2000
Nagai+ 2010
What is the nature of new component?

- Monotonic flux increase with optically thin spectrum
  - Need injection of fresh electrons

- Subluminal motion
  - Relative apparent speed $\sim 0.3c$
  - Comparable to CSO hotspot speed

Not blazar-like component, but mini-lobe/hotspot
High Resolution Image of 3C84

- Rare opportunity to study the lobe formation at very early stage ($t_{dyn} \sim 10$ yr)
- Important to do further monitoring

Nagai+ 2014

VERA@22GHz

VLBA@43GHz

C1

C2

C3

hotspot

Backflow?

Termination?
Radio – Gamma-ray connection

- Gamma-ray emitting region is likely to be associated with the site of radio brightening
Where is the gamma-ray emitting region?

- **Gamma-ray time variability**
  - $t_{\text{var}} \sim 1$ week at LAT band
  - $R < c t_{\text{var}} \delta \sim c \delta \times 10^{16}$ cm

- **SED modeling suggests $\delta = 2$-4** (e.g., Aleksic+ 2014)
  - Mildly relativistic mini-jet required

- **But, no core-brightening / jet ejection associated with short-term gamma-ray flares**

Aleksic+ 2014

VERA at 43GHz

Nagai+ 2012
Why no radio counterpart of short-term flare?

1. Gamma-ray emitting region embedded in the optically thick core

2. Multi-zone emitting model
   - e.g., spine-sheath
     - Radio: slow sheath
     - Gamma: slow sheath+fast spine
Long-term $\gamma$-ray variation

- Gamma-ray flux increases on the timescale of years
  - Composite of multiple mini-jet flares unlikely
  - Larger-sized emitting region favored
- C3 shows a radio flux increase on similar timescale
  - Signature of gamma-ray emission associated with C3 (mini-lobe/hotspot)
Gamma-ray emission model from YRS

- HE emission by IC of various surrounding photon fields by lobes’ electrons (Stawarz+ 2008)
  - $LS = 33\text{pc}, 100\text{pc}, 1\text{kpc}$

- If $L_j = 10^{45}$ erg/s, the model is accountable for the observed gamma-ray luminosity of 3C 84 ($\sim 10^{44}$ erg/s)
  - $\sim 10$-times higher than $L_j$ estimated from the kpc-scale radio bubble (Dunn & Fabian 2004)
  - Past jet power could be lower than at present?
Dependence of LS

LS=33 pc

LS=100 pc

LS=1 kpc

Stawarz+ 2008
Summary

• New radio component (C3) associated with recent restarted activity of 3C 84 shows mini-lobe/hotspot properties
  – Monotonic flux increase with optically-thin spectrum over 6 years
  – $V_{\text{app}} \sim 0.3c$

• Short-term and long-term gamma-ray variations are different origin
  – Short-term flare: probably blazar-like component, but no radio counterpart
  – Long-term flux variation: possibly associated with new component C3
    • 1st clear evidence of gamma-ray emission from YRS?