Detection of significant cm to sub-mm band radio and gamma-ray correlated variability in Fermi bright blazars

Stefan Larsson | Oscar Klein Centre, Stockholm University

L. Fuhrmann | MPIfR
J. Chiang | Stanford Univ.
E. Angelakis, J. A. Zensus | MPIfR

on behalf of the F-GAMMA & Fermi/LAT collaborations

Fuhrmann et al. 2007 – Angelakis et al. 2010

5th Fermi Symposium – Nagoya, Japan
20–24 October 2014
**F-GAMMA & Fermi synergy**

main scientific question

Where in AGN jets are the gamma-rays produced?

- close to the SMBH inside the Broad Line Region or further down the jet on pc-scales?

---

**F-GAMMA program:**

- monthly light curves at 11 radio bands between 2.6 and 345 GHz (11 cm – 0.8 mm)

**Fermi/LAT:**

- monthly light curves at 0.1 – 300 GeV energy range
- specific time boundaries to best match the radio light curves

---

**sample:**

- 54 AGN/blazars (1FGL)

**time period:**

- ~ 3.5 years: Aug. 15, 2008 to Jan. 26, 2012

---

5th Fermi Symposium– Nagoya, Japan – 20–24 October 2014
Correlating gamma-ray and radio light curves

Relative timing of flares
Correlating gamma-ray and radio light curves

The method in brief:

- **Use the DCCF to search for significant radio/γ-ray correlations** in the ~ 3.5 year light curves of 54 Fermi AGN/blazars
- **Test of statistical significance** via “mixed source correlations”
- **Single sources**: 9 cases significant where 1 expected by chance (prob 4 x 10^-6)

3 mm /γ-ray single source’ DCCFs:

- **J1504+1029** (PKS 1502+106, top left; red
eral flux monitoring conducted at the IRAM 30-m tele-
30-m (at Pico Veleta, PV) and APEX (Atacama Pathfinder
right).

- **B** and “C” SIS (until March 2009) and EMIR (Eight
tions were carried out with calibrated cross-scans using th

- **Fermi** 

- **Radio** 

- **DCCF**

- **90 and 99% significance**

DCCF stacking analysis (averaging over the whole sample)

Stacked 3 mm /γ-ray

Averaged over whole sample: we obtain highly significant correlations!

All stacked radio (11 cm to 0.8 mm) / γ-ray combinations
Radio lagging: lags close to 0 at mm/sub-mm bands & increasing towards lower frequencies

1) **Pos. delay**: gamma-rays from inside / upstream of “mm-core”

2) **Delay origin**: opacity/synchrotron self-absorption

3) **De-projected distance** between “gamma-origin” and radio $\tau=1$ surface:

$$\Delta r_{\gamma\gamma} = \frac{\beta_{\text{app}} c \tau_{\gamma\gamma}^{\text{source}}}{\sin \theta}$$

Jet speed $\beta_{\text{app}}$ from VLBI plus viewing angle $\theta$

42 sources:

- $\langle \tau \rangle_{\text{(sub-)mm}}$: ~ 24 to 7 days
- $\langle \tau \rangle_{\text{cm}}$: up to ~ 80 days

- $\langle \Delta r_{\gamma\gamma} \rangle_{\text{(sub-)mm}}$: ~ 3 to 0.9 pc
- $\langle \Delta r_{\gamma\gamma} \rangle_{\text{cm}}$: up to 10 pc
Locating the $\gamma$-ray emission

- radio/radio lags: “time delay core shifts” and VLBI proper motion
- “Königl type”, continuous jet
- absolute distance of gamma-ray emission region to the jet base:

$$r_{\text{base,\gamma}} = r_{\text{base,\nu}} - \Delta r_{r\gamma}$$

3C 454.3 @ 3 mm:

$$\Delta r_{r\gamma} = 1.0 \pm 0.5 \text{ pc}$$

$$r_{\text{base,\nu}} \sim 1.8 \text{ to } 2.6 \text{ pc}$$

$$r_{\text{base,\gamma}} \sim 0.8 \text{ – } 1.6 \text{ pc}$$

at the outer edge or outside the BLR!
Summary – Conclusions

- Highly significant averaged gamma – radio correlation

- Frequency dependent time lag.
  Consistent with opacity/synchrotron self-absorption

- Gamma-ray origin within or upstream of the mm-core.

- 3C454.3: Gamma-rays ~1-2 pc from the SMBH
CCF caveats

- The CCF is a useful tool but some information is lost. E.g. flare onset (see León-Tavares et al. 2011)

- Correlation significance as a function of data length for red noise
Whats next?

For $F_{\gamma}$

- Longer LC (5.2 years) and more sources (+10)
  Frequency dependent lag for more individual sources
- Dependence on source type & characteristics (e.g. FSRQs/BL Lacs)
- Flare onset (direct LC comparison)

In general

- Gamma - optical – radio correlation
- Systematic correlations with polarization in optical and radio
  (see poster by Hovatta et al, 8.13)

5th Fermi Symposium– Nagoya, Japan – 20–24 October 2014