Fuhrmann et al. 2007 – Angelakis et al. 2010

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

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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 ?

sample:
54 AGN/blazars (1FGL)

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

F-GAMMA program:

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

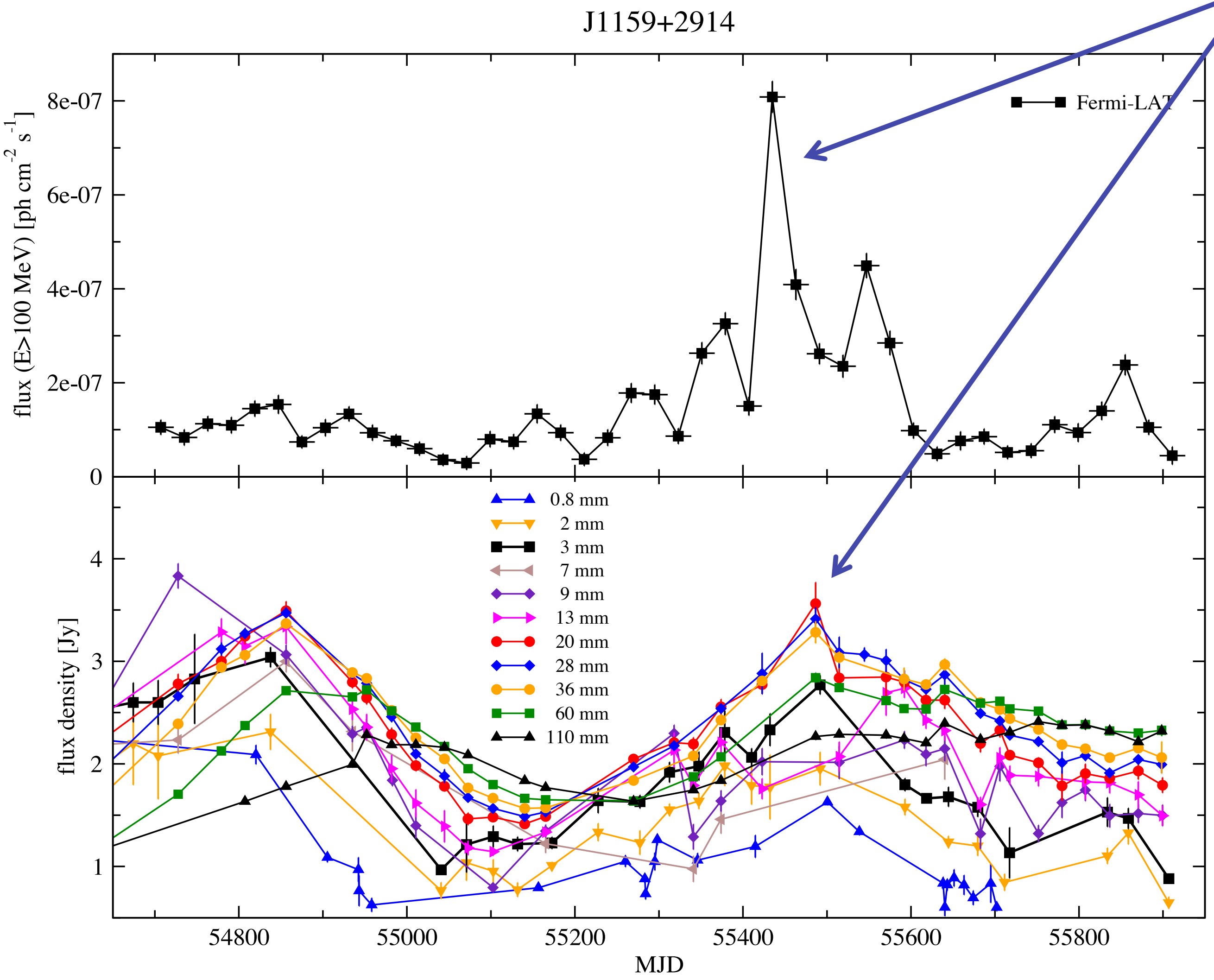
Fermi/LAT:

monthly light curves at 0.1 – 300 GeV energy range

specific time boundaries to best match the radio light curves

Correlating gamma-ray and radio light curves

relative timing of flares

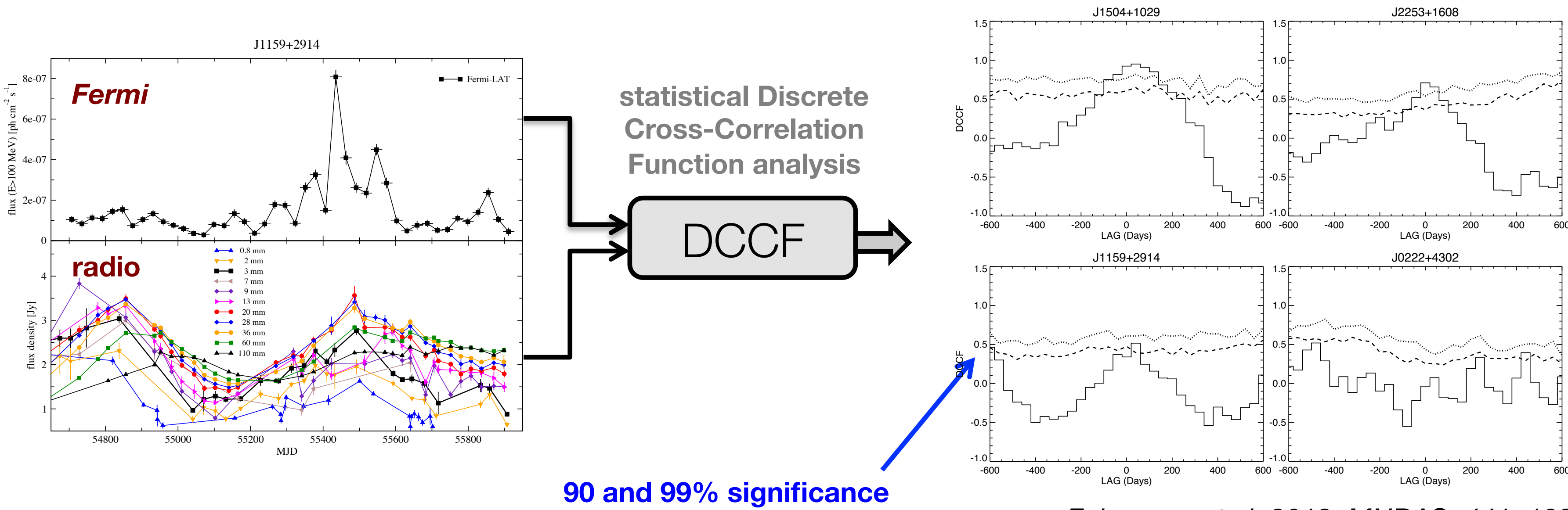


Correlating gamma-ray and radio light curves

3 mm /γ-ray

The method in brief:

single source' DCCFs:

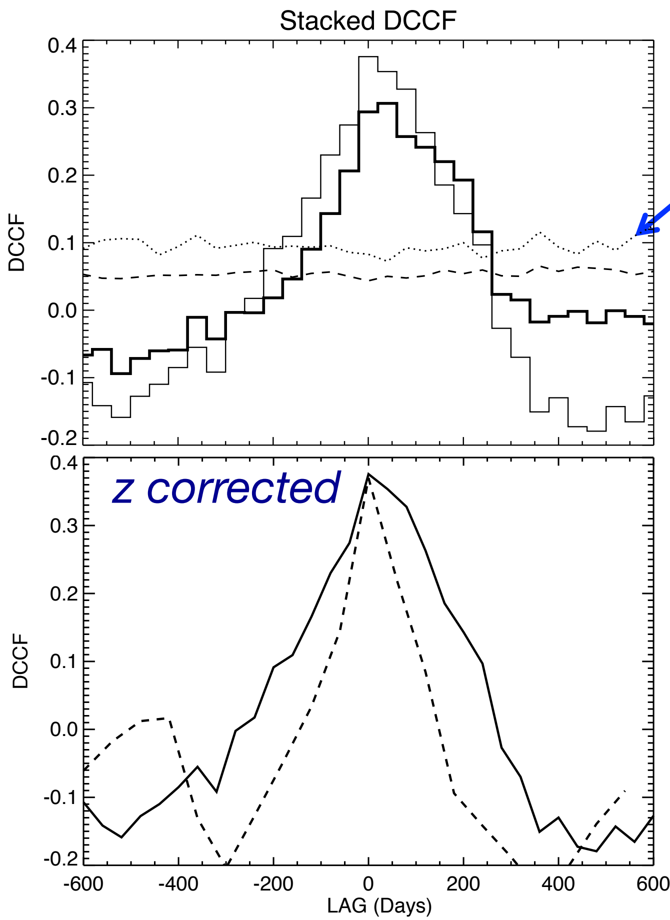


Fuhrmann et al. 2013, MNRAS, 441, 1899

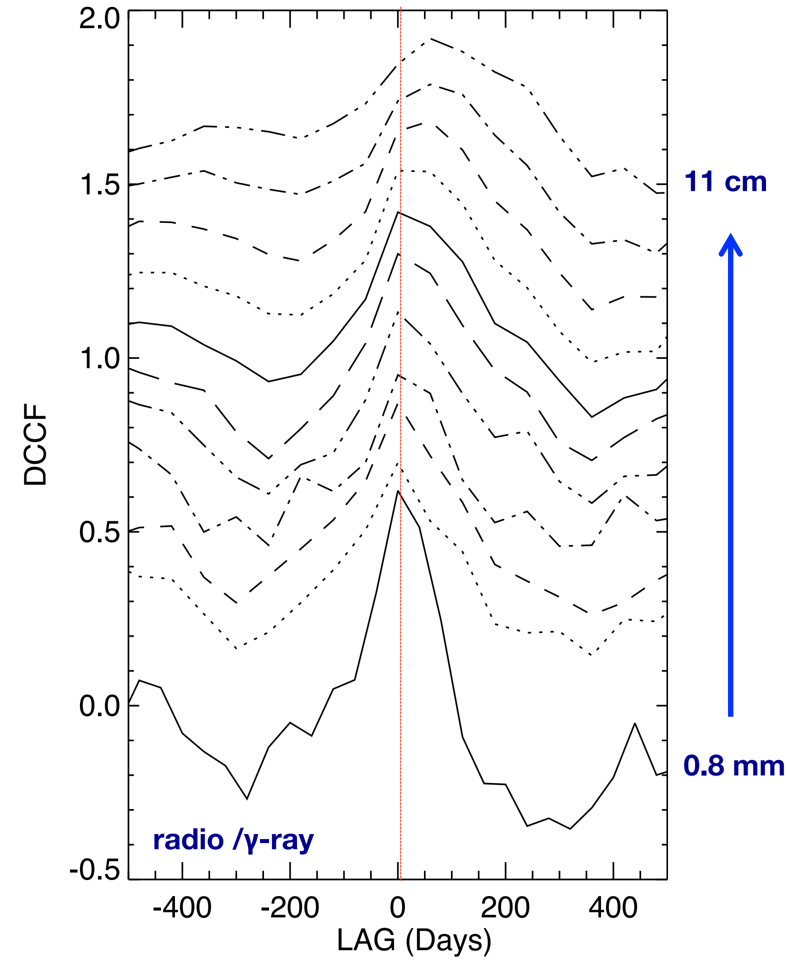
- **Use the DCCF to search for significant radio/γ-ray correlations** in the ~ 3.5 year light curves of **54 Fermi AGN/blazars**
- Test of **statistical significance** via "mixed source correlations"
- **Single sources:** 9 cases significant where 1 expected by chance (prob 4 x 10^{-6})

DCCF stacking analysis (averaging over the whole sample)

Stacked 3 mm /γ-ray



99% signif.



⇨ Averaged over whole sample: we obtain highly significant correlations !

All stacked radio (11 cm to 0.8 mm) / γ-ray combinations

Time lag vs. freq.

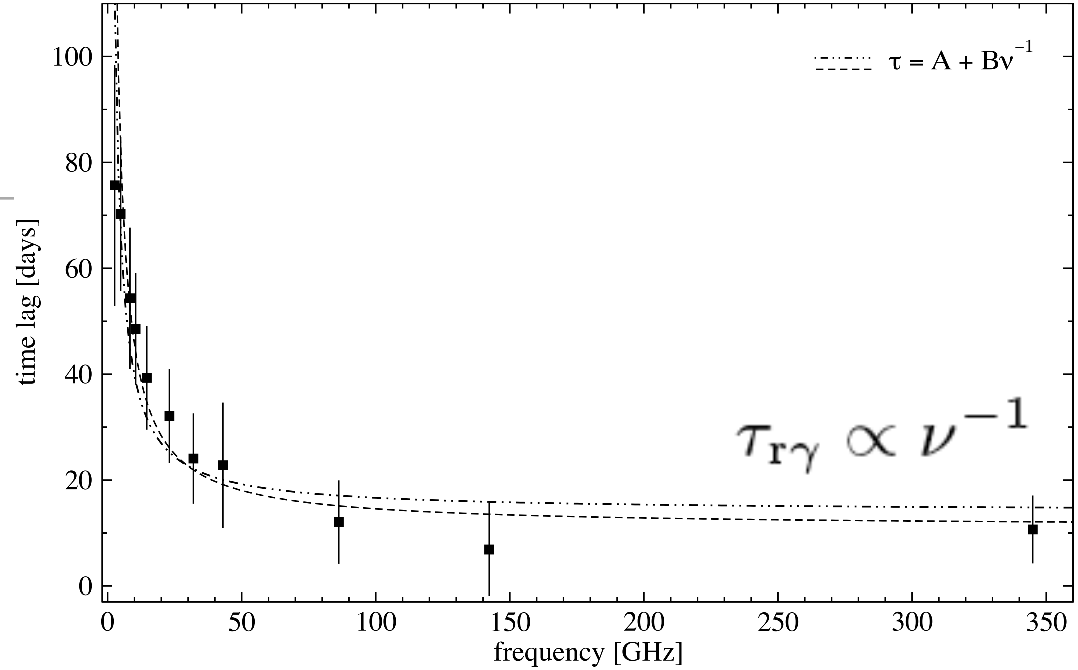
Opacity

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 τ=1 surface:

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

jet speed β_{app} from VLBI
plus viewing angle θ



$<\tau>_{(sub-)mm}$: ~ 24 to 7 days
$<\tau>_{cm}$: up to ~ 80 days

42 sources:

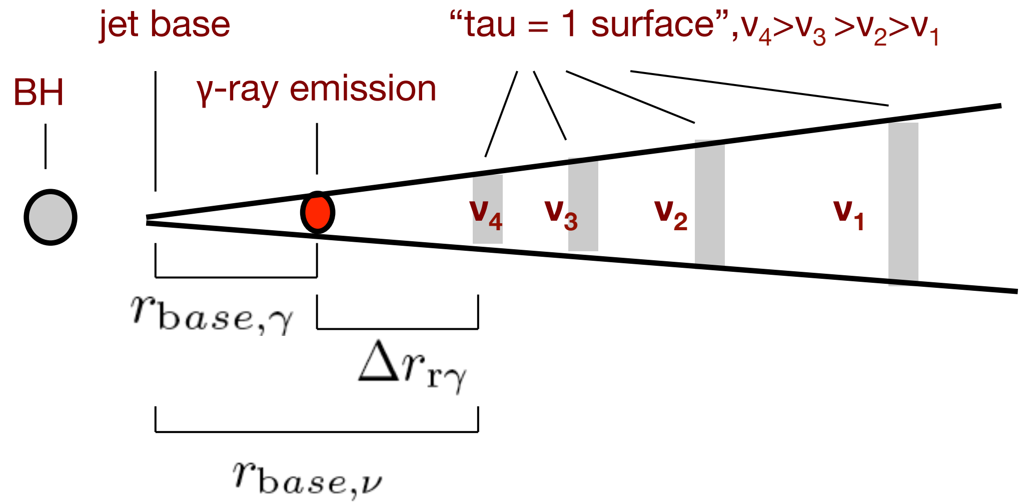
$<\Delta r_{r\gamma}>_{(sub-)mm}$: ~ 3 to 0.9 pc
$<\Delta r_{r\gamma}>_{cm}$: up to 10 pc

Fuhrmann et al. 2013, MNRAS, 441, 1899

Locating the γ-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:

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

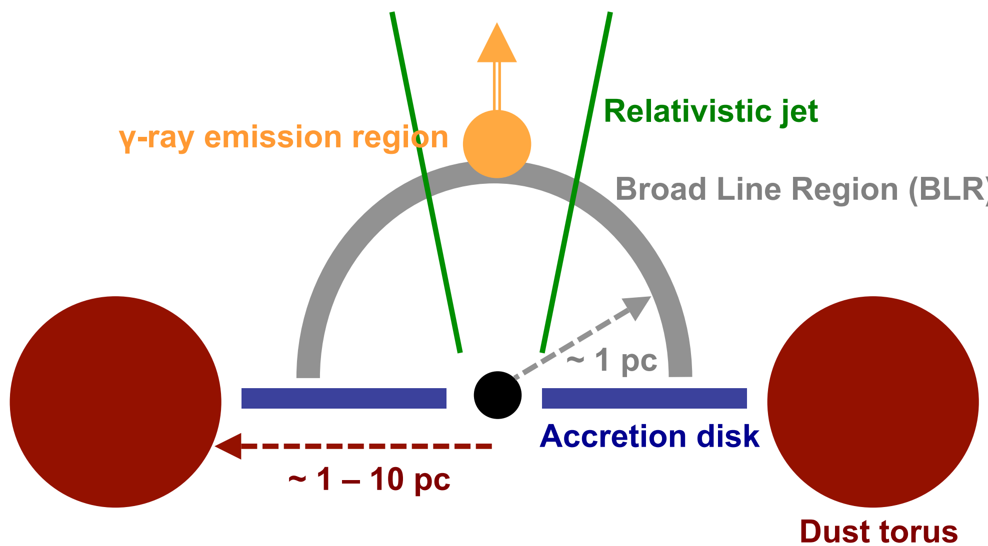


3C 454.3 @ 3 mm:

$\Delta r_{\text{r}\gamma}$ = 1.0 +/- 0.5 pc

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

⇒ $r_{\text{base},\gamma}$ ~ 0.8 – 1.6 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 Fgamma

- 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)