A decade of joint MOJAVE–*Fermi* AGN monitoring

Localisation of the gamma-ray emission region

Ivan Kramarenko

Moscow Institute of Physics and Technology
National Research University

Co-authors: A. B. Pushkarev, Y. Y. Kovalev, M. L. Lister, T. Hovatta, T. Savolainen

This study has been supported by the Russian Science Foundation grant 20-72-10078

γ-ray emission production

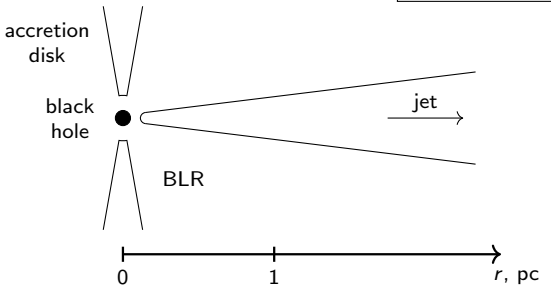
Inverse Compton

Possible sources of seed photons:

1. Up-scattered synchrotron photons (SSC)
2. External sources: from accretion disk, BLR, torus, CMB, ...

γ-ray emission localisation $\rightarrow$ limits on sources of seed photons

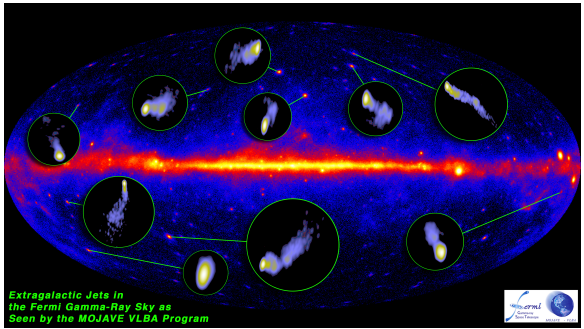
Inside ($\lesssim 0.1$ pc) or outside (few parsecs) the BLR?

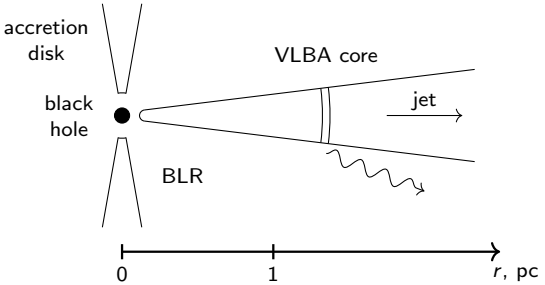


Problem statement

Fermi/LAT + MOJAVE (VLBA 15 GHz)

1. Whether gamma-ray photons originate within the **15 GHz VLBA core**
2. Whether gamma-ray emission zone is located within the **BLR**



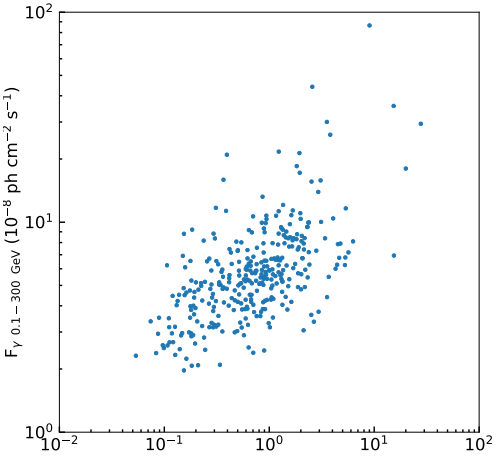


Source sample

331 MOJAVE AGNs that have positionally associated γ-ray counterparts from 4FGL-DR2

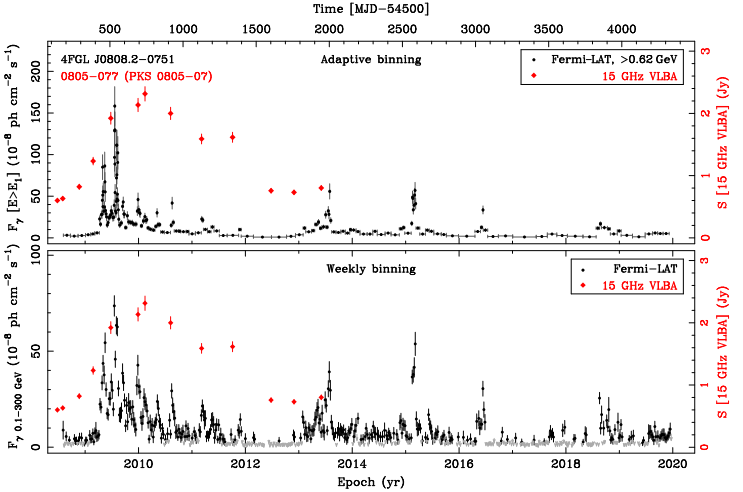
- ≥ 5 radio epochs
- galactic latitude $|b| > 10^{\circ}$

$> 3\sigma$ correlation



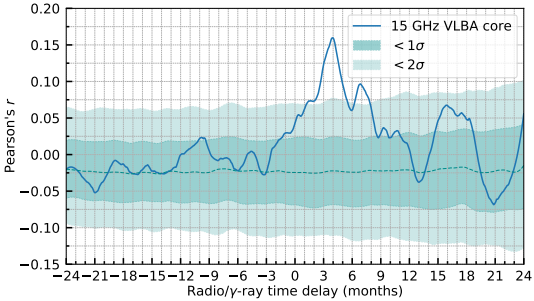
Gamma-ray data

- Adaptive (Lott et al. 2012) and weekly binning
- 4FGL-DR2
- August 4, 2008 – August 2, 2018
- 0.1 – 300 GeV

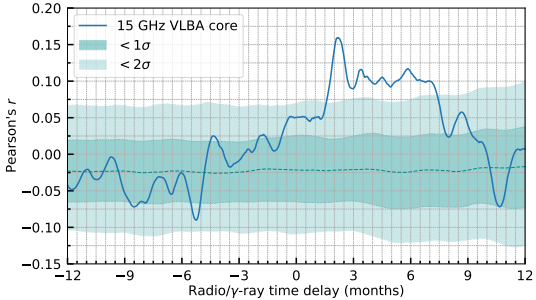


Radio/γ-ray time delay

Observer's frame



Source frame: $(1+z)^{-1}$ correction

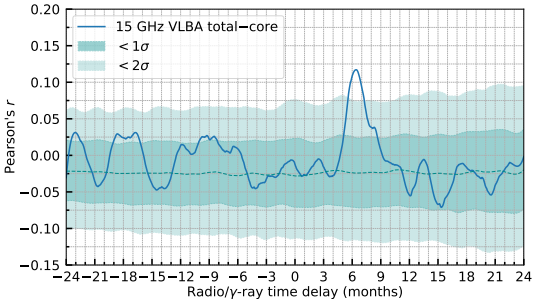


γ-ray emission precedes radio

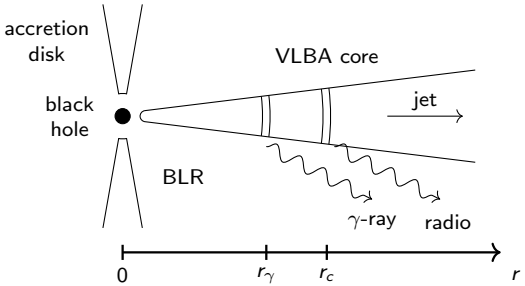
typical delay: 3-5 months (obs. frame), 2-3 months (source frame)

$r_c \propto \nu^{-1} \rightarrow$ time delay

Radio/γ-ray time delay

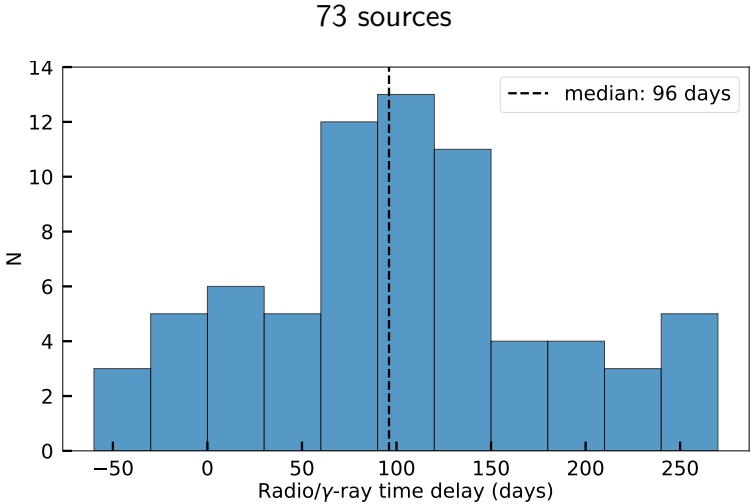


"External" VLBA components:
correlation at greater time lags!



γ-ray emission is produced within the 15 GHz VLBA core region

Time delays of individual sources



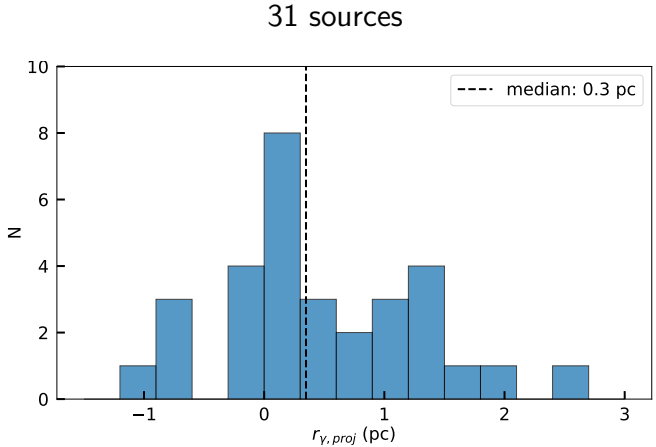
$r_{\gamma,\mathrm{projected}}$

$r_{\gamma,\mathrm{proj}}$ = distance between the BH and the place of the γ-ray emission production (in projected scale)

De-projected scale: $\sim$3 pc

16 sources: $r_{\gamma,\mathrm{proj}} > 0$ (1σ)

Outside the BLR!



Summary

1. There is a significant correlation between gamma-ray photon flux and VLBA core flux density (3-5 months delay in the observer's frame; 2-3 months in the source frame).
2. Gamma-ray emission is likely to be produced within the compact region of the 15 GHz VLBA core.
3. Gamma-ray emission is likely to be produced at parsec distances from the BH (outside the BLR).

Extra material: correlation method

z-transformed discrete correlation function (zDCF, Alexander 1997)

- $\geq$ 11 data points (42% of the sample)
- Monte Carlo simulations for errors accounting
- Stacked correlation curves: median correlation coefficient in each bin

Extra material: weekly binned LC