Radio/gamma connection:

Study of cm/mm-band radio and gamma-ray correlated variability in Fermi bright blazars

Lars Fuhrmann

S. Larrson, J. Chiang, E. Angelakis, V. Pavlidou, I. Nestoras, J. A. Zensus et al.

on behalf of the F-GAMMA & Fermi LAT collaborations

Introduction

do gamma-ray flares usually have radio counterparts? what is the relative timing/delay?
where in the jet are the gamma-rays produced (close to BH or pc-scale jet, how far from BH etc.)?

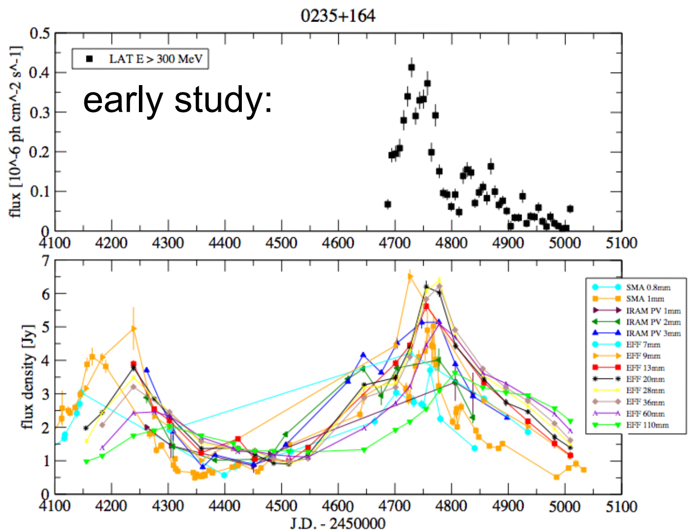
several approaches: VLBI studies, $flux_r$-$flux_\gamma$ studies, direct light curve analysis…

EGRET times - limited studies: "gamma-ray flares/activities appear to occur during the raising phase (i.e. after the onset) of high frequency radio flares" i.e. gamma-ray flares happen in the mm-shocks further out!

Now we have Fermi/LAT!

Many studies emerged

Long time baseline needed:
now 3 yrs of LAT LCs!



Project overview

The sample and data sets

Aim: a study focusing on the possible connection between radio and gamma-ray flares/activity periods in the 3 yr long-term light curves of about 60 *Fermi*-GST detected blazars through a detailed cross-band analysis

1) radio bands: F-GAMMA program since Jan. 2007:

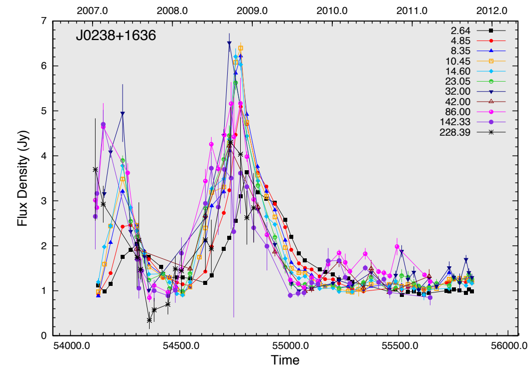
3-4.5 yrs of Effelsberg 100-m/IRAM 30-m monthly monitoring data at 10 different frequencies (110, 60, 36, 28, 20, 13, 9, 7, 3, 2, (1) mm)

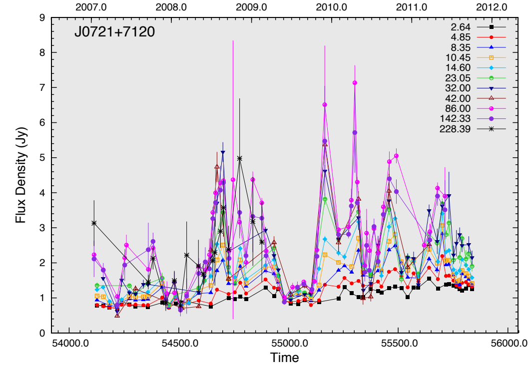
→ "the best suitable" 58 1FGL sources (best sampl., frequency & time coverage)

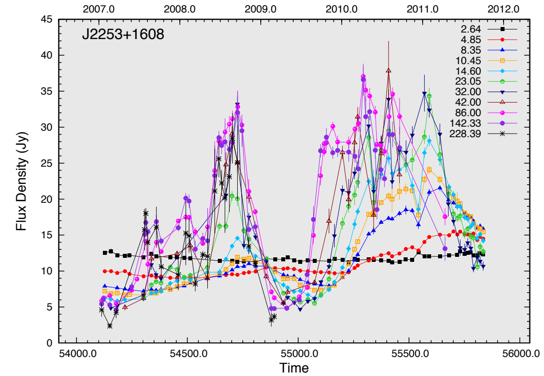
sample statistics:

Type	#
FSRQ	33
BL Lac	17
RG	2
Blazar	5
NLSy1	1

→ cross-band study: selection of 4 frequency bands (3, 9, 20, 60mm)







Project overview

The sample and data sets

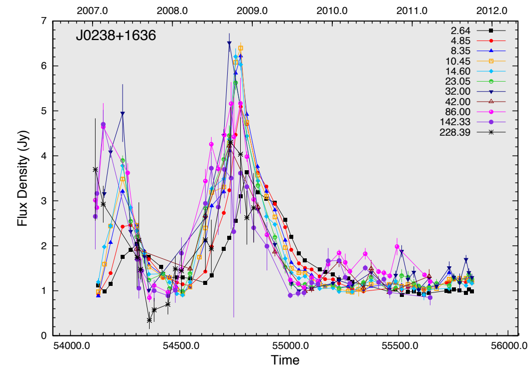
2) Fermi/LAT: 3 yr light curves starting in Aug. 2008

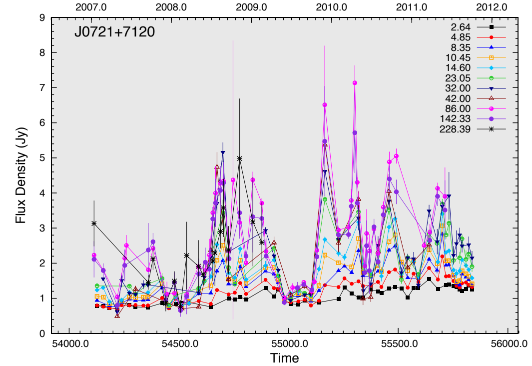
specific time boundaries to best match the radio light curves – start Aug. 15, 2008

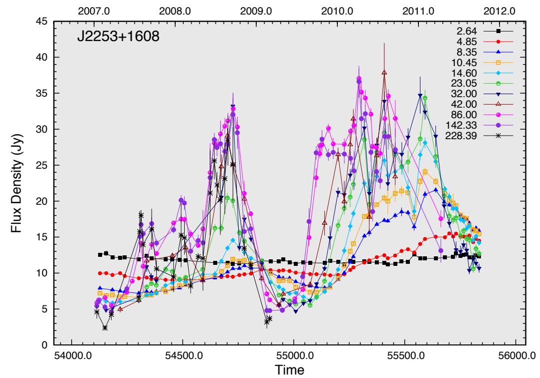
RSP pipeline, energy range 0.1 – 300 GeV using power law over that energy range

1FGL sources for ROI, ROI size etc.

future: switch to pass 7, 2 FGL sources, more careful spectral model for each source (e.g. broken power law for some etc.), LCs at different energy ranges etc.







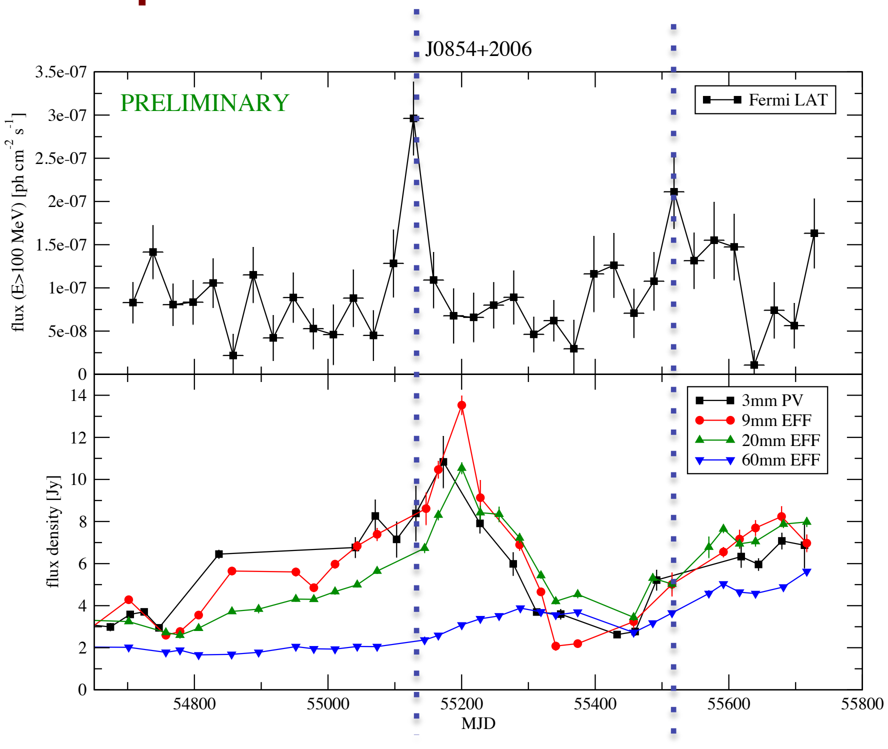
Project overview

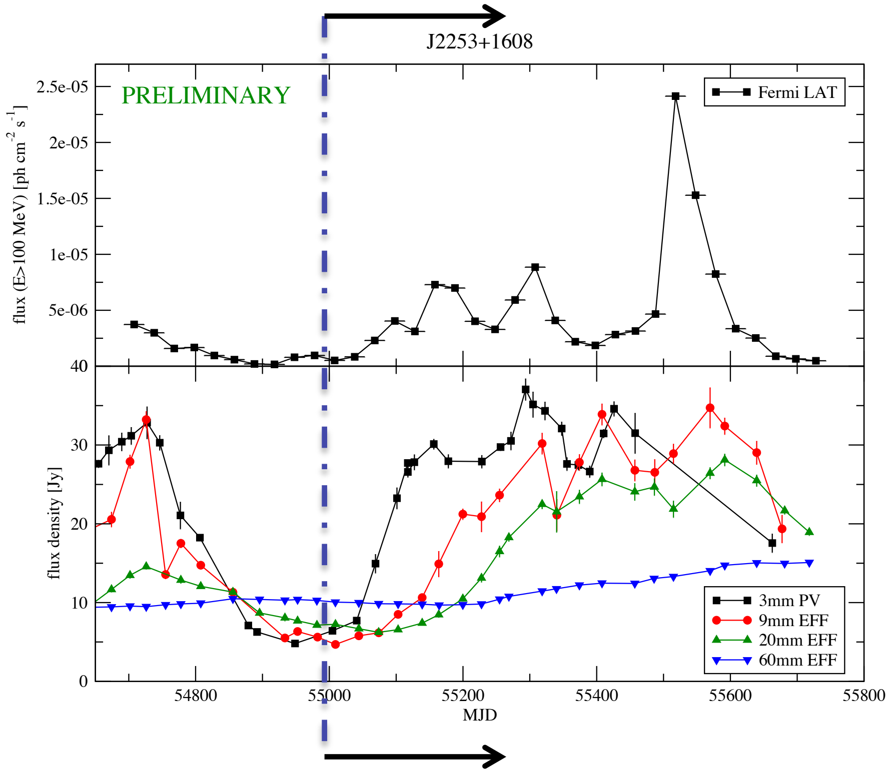
The light curves

Fermi Gamma-ray Space Telescope

F-GAMMA PROGRAM
Fermi-GST AGN Multi-frequency Monitoring Alliance

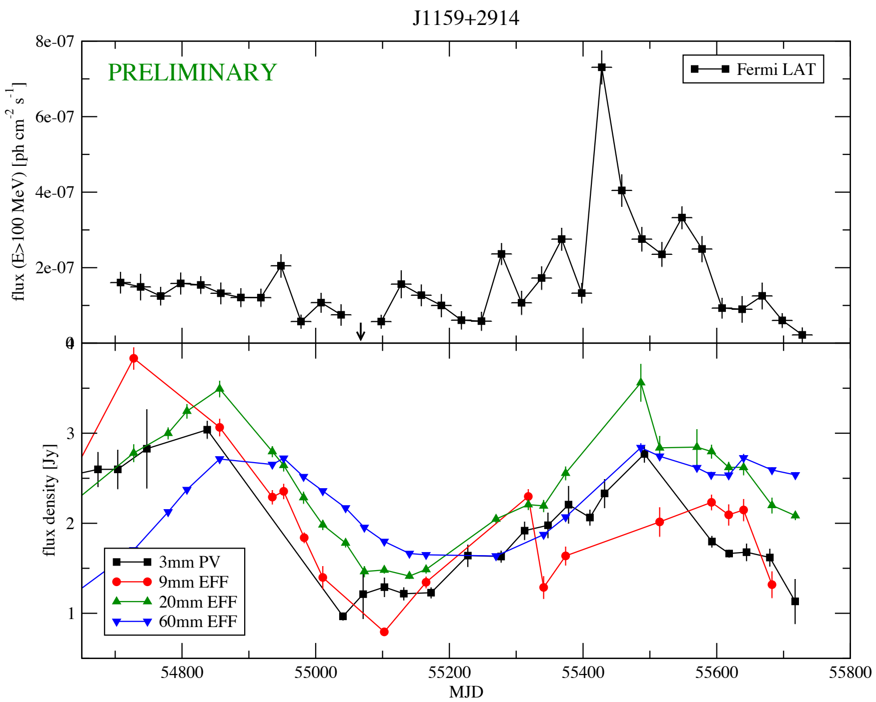
Examples:

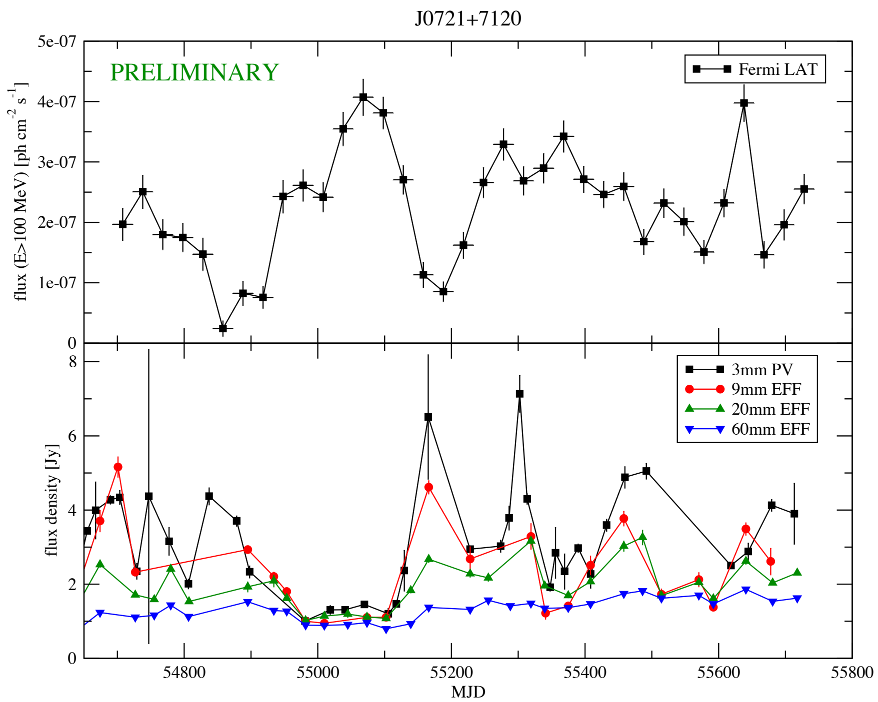




Project overview

Three different approaches





1) statistical Discrete Cross-Correlation Function (DCCF analysis)

2) flux_r – flux_γ analysis using simultaneous, monthly fluxes

3) direct LC analysis

1) DCCF analysis

The setup

compute DCCFs for each source: for all gamma-ray – radio (ν, ν = 86, 32, 15, 5 GHz) combinations following Edelson & Krolik (1988)

caveats: 3yrs – still small number of events, complicated flare structures (multiple sub-flares), “broad DCCFs”, what correlates?, “monthly smoothing” etc.

determine significances of correlations: test of chance correlations by mixing source’ gamma-ray LCs: e.g. source 1 (radio) with source 2 to N (gamma-ray), find “upper envelop” confidence levels

time lags with uncertainties are estimated by Monte Carlo simulations (Peterson et al.)

apply method to the whole sample plus sub-dividing according to FSRQs, BL Lacs, spectral type etc.

stacking of DCCFs: increasing the significance, study of averaged behavior of the sample

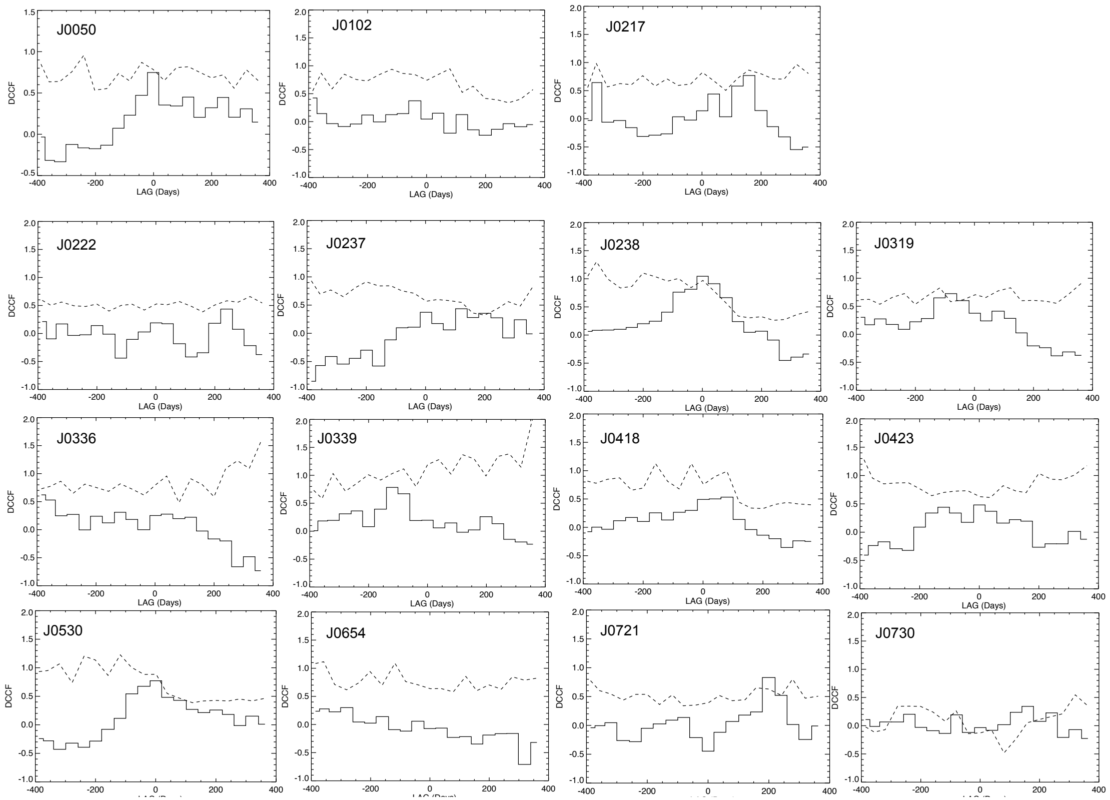
1) DCCF analysis

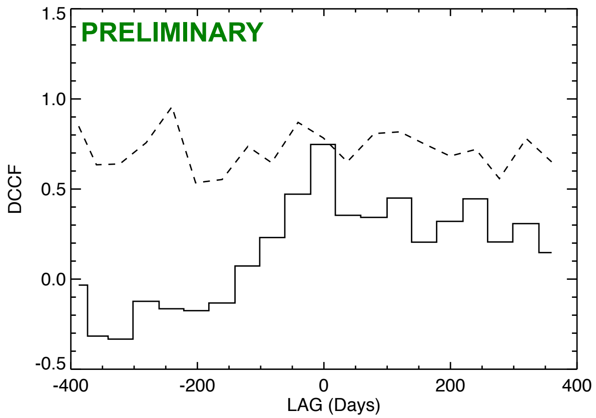
First results

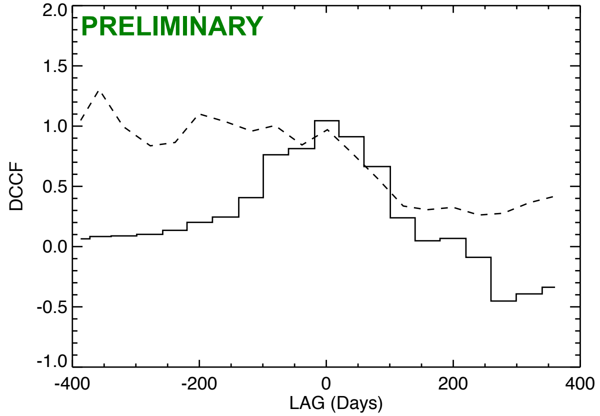
3mm vs LAT: examples of single source' DCCFs

-single source cases mostly not significant: "only" 18 out of 58 sources so far!
-no obvious, simple 1:1 correlation
-not yet long enough data trains
-conservative upper envelops

PRELIMINARY



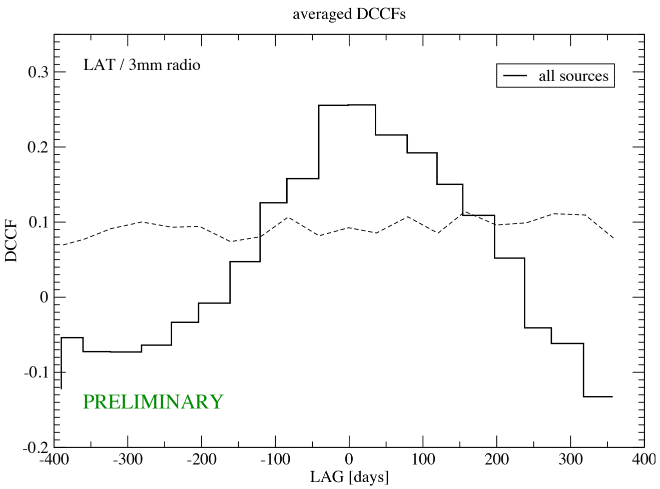


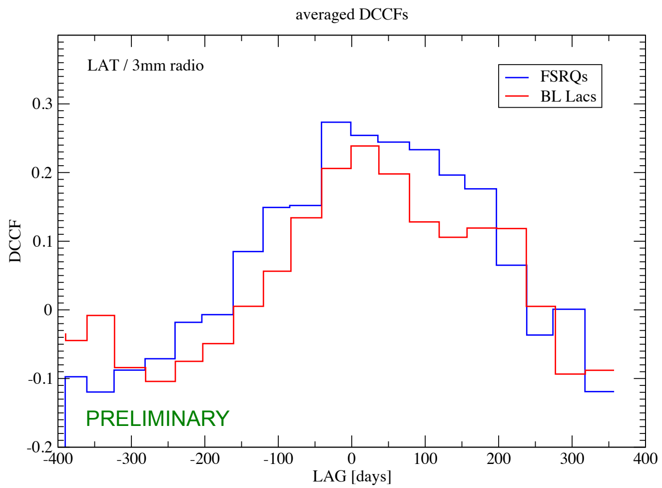


1) DCCF analysis

First results

3mm vs. LAT: stacking of DCCFs

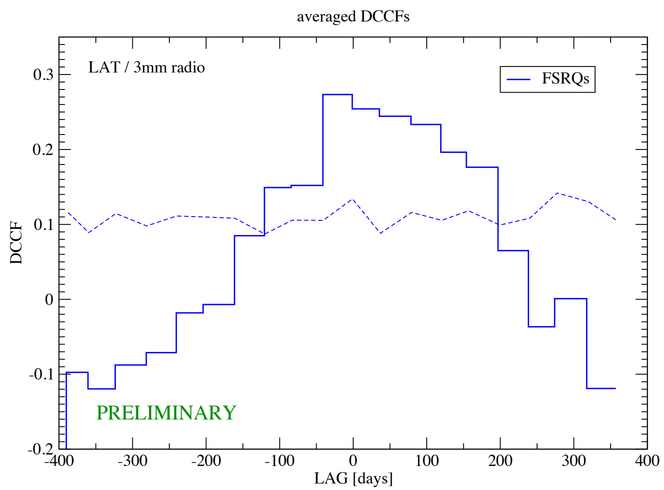


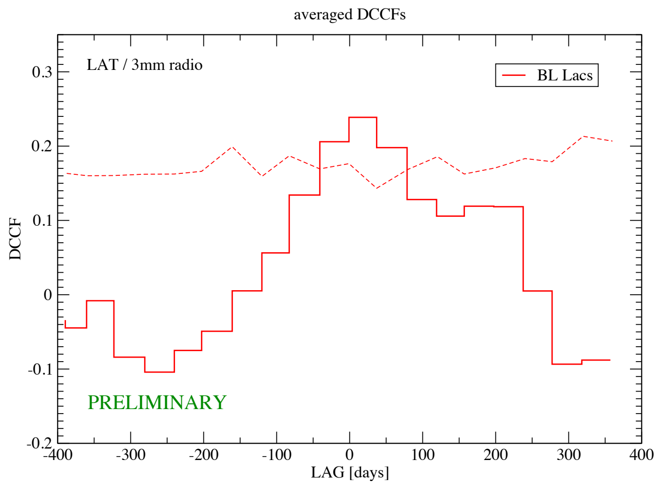


averaged over whole sample: we start seeing significant correlations !

99% confidence levels

asymmetry





All sources:
<lag>$_{3mm}$ = 36 days

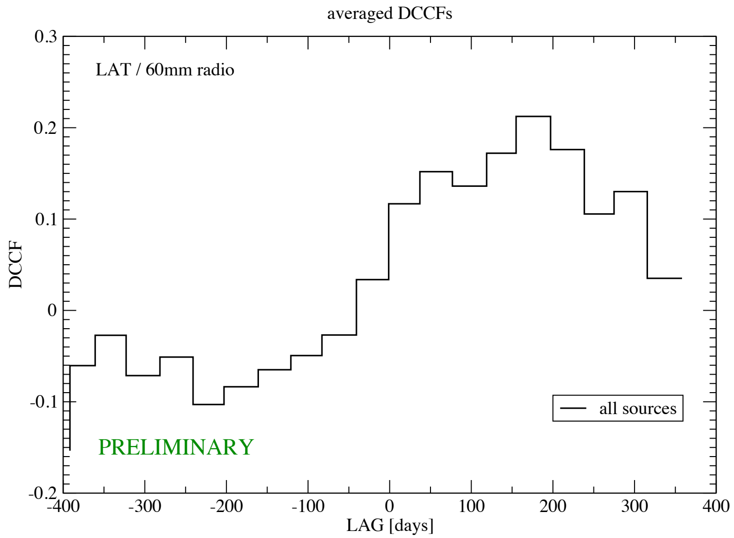
FSRQs:
<lag>$_{3mm}$ = -1 days

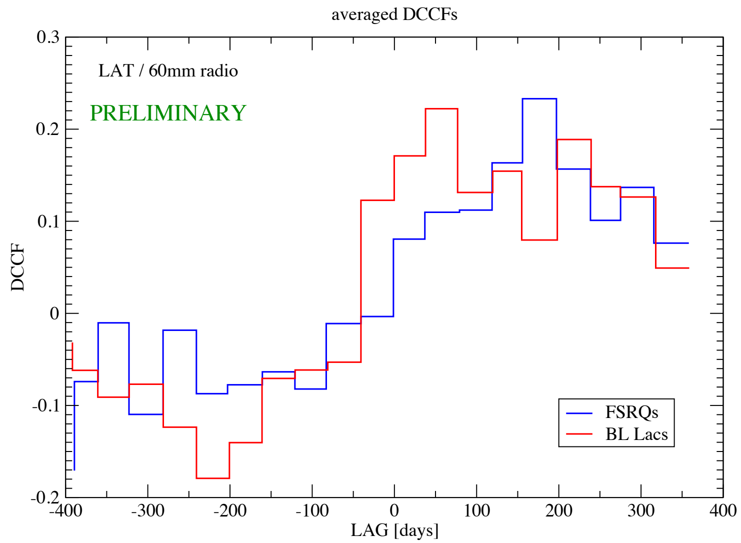
BL Lacs:
<lag>$_{3mm}$ = 37 days

1) DCCF analysis

First results

60mm vs LAT: stacking of DCCFs





All sources:

$\langle \mathrm{lag} \rangle_{60\mathrm{mm}}$ = 197 days

FSRQs:

$\langle \mathrm{lag} \rangle_{60\mathrm{mm}}$ = 197 days

BL Lacs:

$\langle \mathrm{lag} \rangle_{60\mathrm{mm}}$ = 77 / 239 days

delay origin: synchrotron self-absorption/opacity
(e.g. Pushkarev et al. 2010)

1) pos. delay: gamma from inside “3mm-core”

2) distance between “gamma-origin” and 86 GHz t=1 surface: $\Delta r \sim$ 0.8 pc (3mm), ~ 8 pc (60mm)

3) DCCF just sensitive to peaks/mins! which originates first?

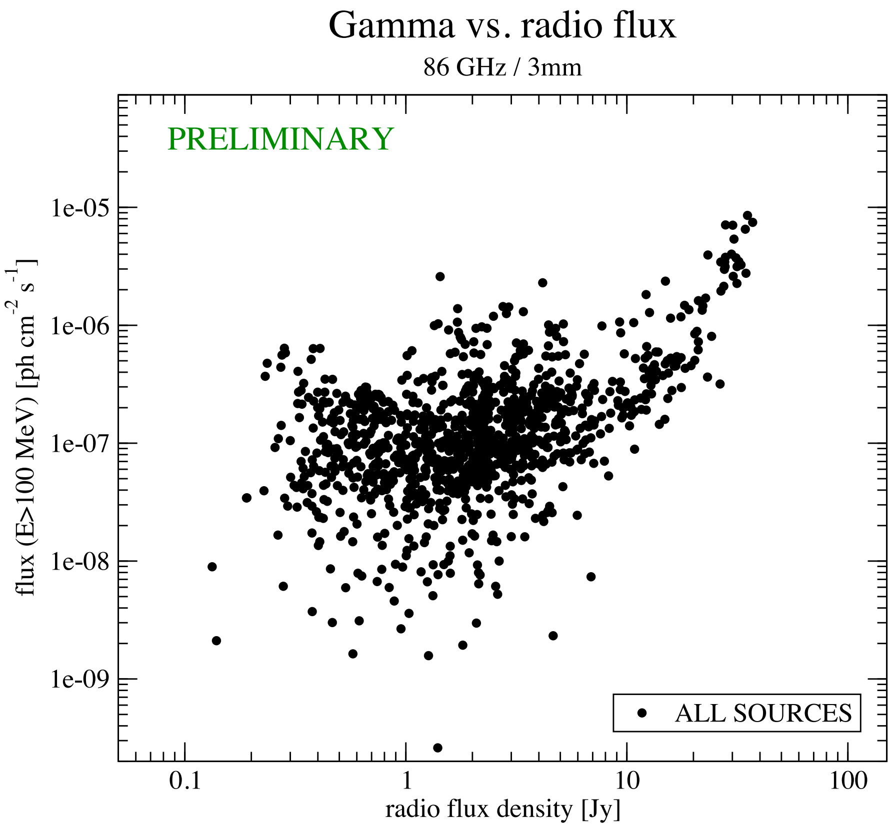
2) flux-flux analysis

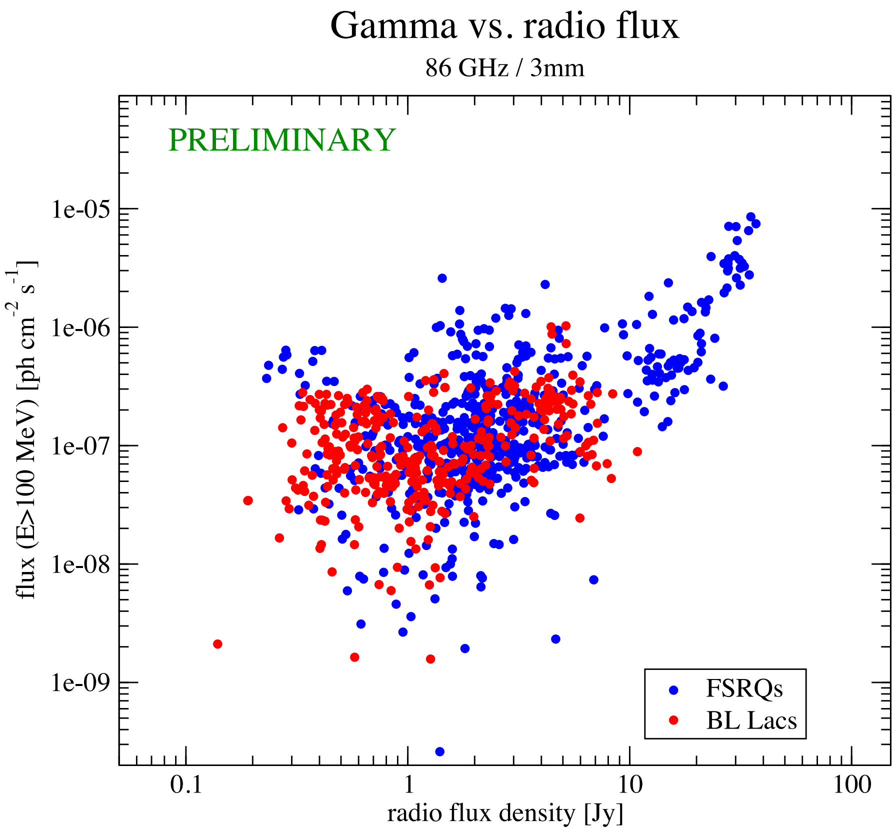
The setup + first results

Fermi Gamma-ray Space Telescope

F-GAMMA PROGRAM Fermi-GST AGN Multi-frequency Monitoring Alliance

~ monthly, multi-frequency simultaneous fluxes over 3 years: interpolated LAT fluxes for each radio flux measurement
86 GHz: total number of data points: 1017 (FSRQs: 499, BL Lacs: 359, other: 8)

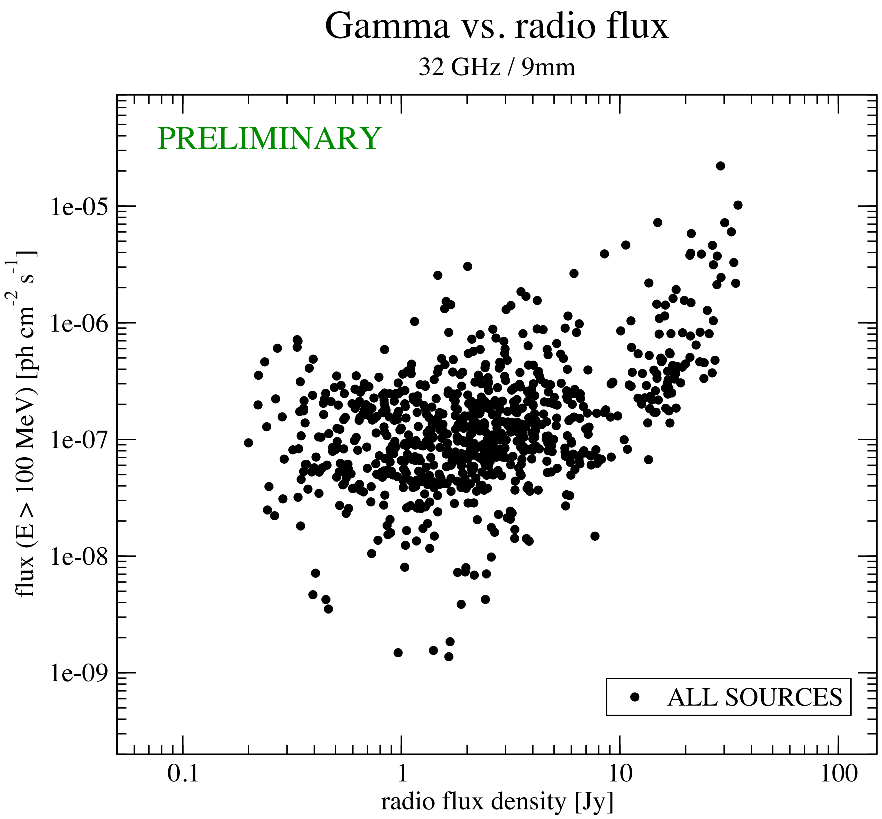


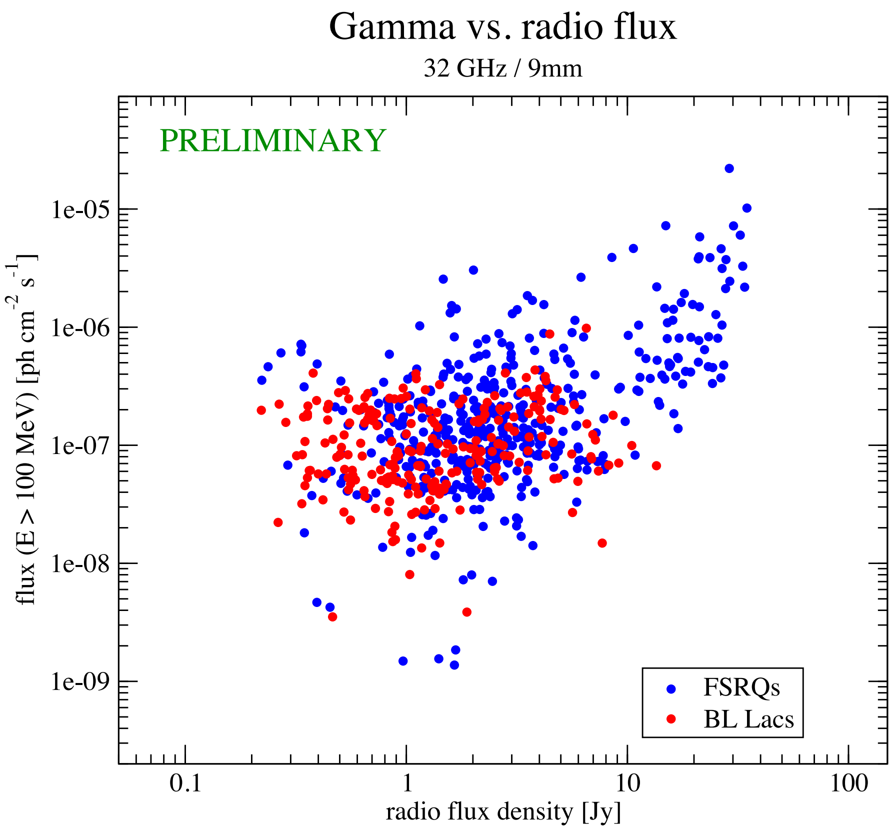


2) flux-flux analysis

The setup + first results

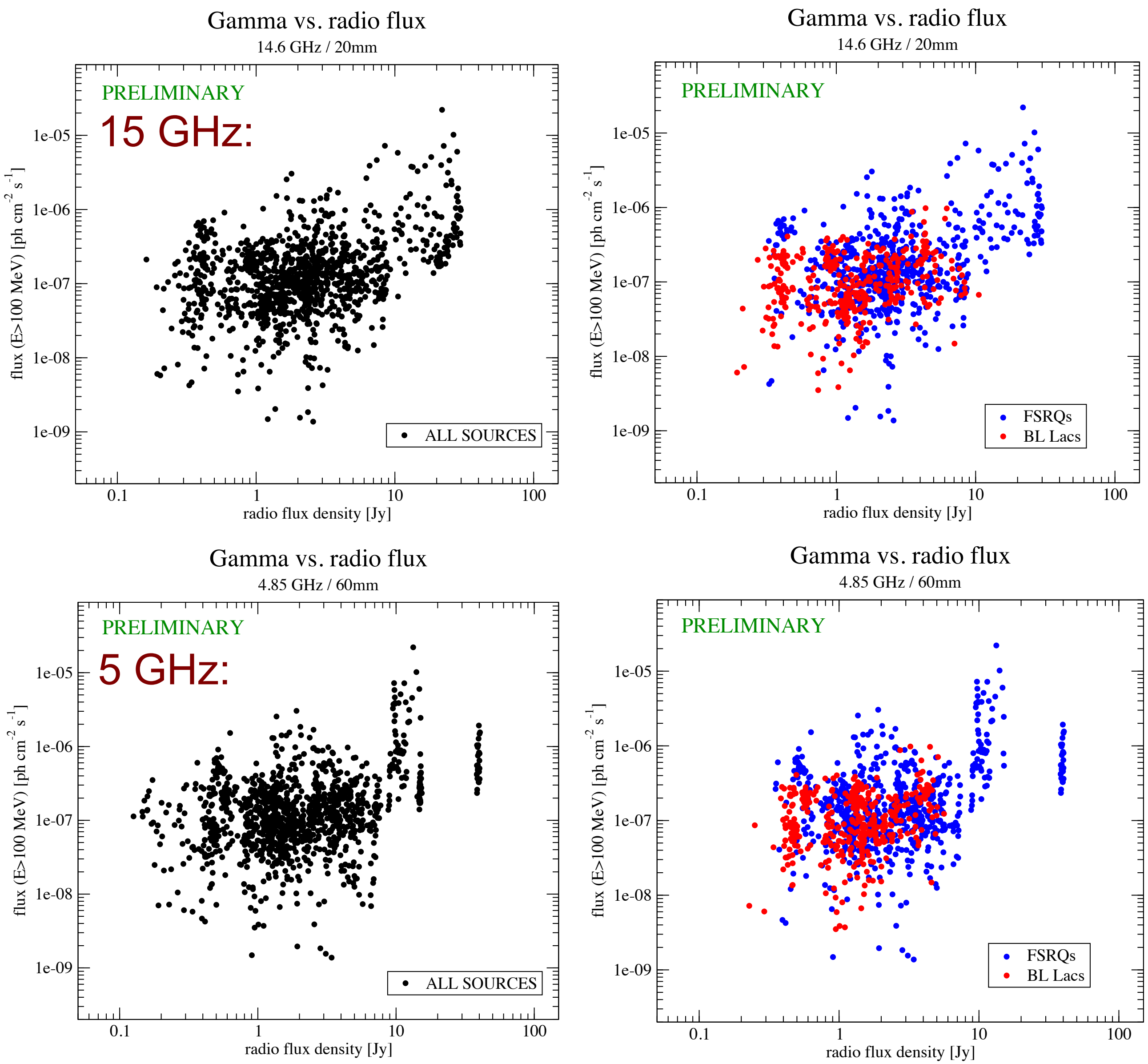
32 GHz:





2) flux-flux analysis

The setup + first results



highest frequencies: prominent *apparent* correlation

apparent correlation vanishes towards lower radio bands

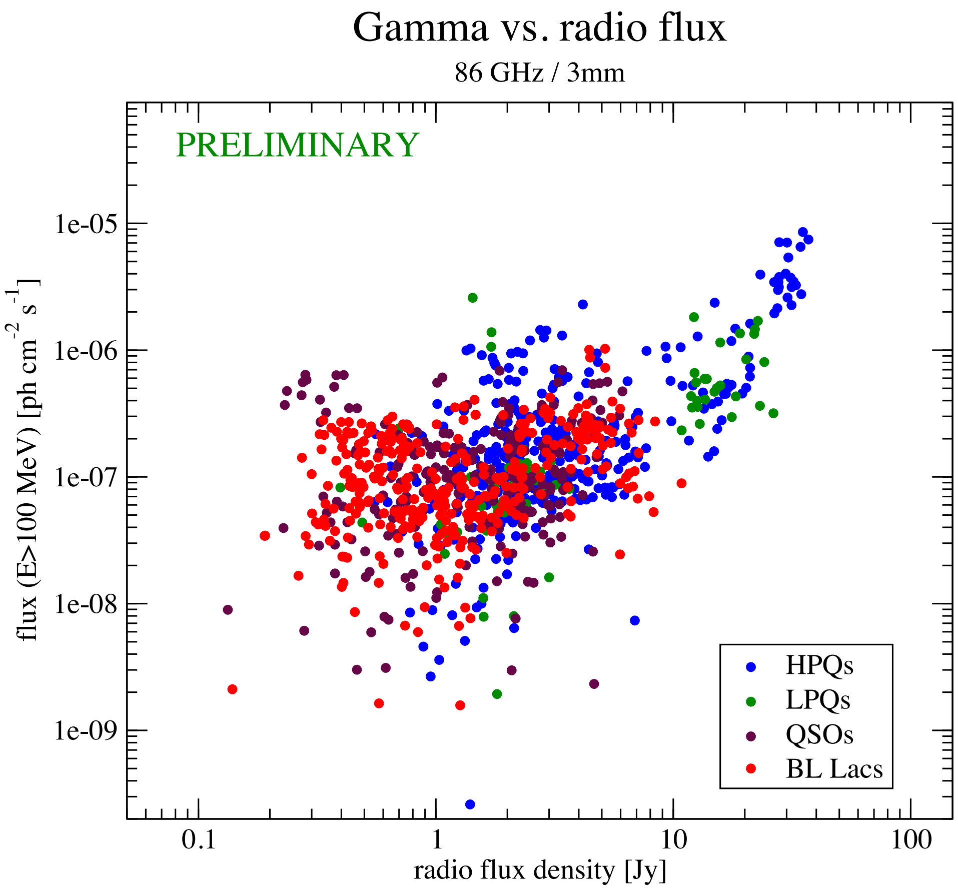
opacity, core+jet, mm: more co-spatial!

BL Lacs appear mostly uncorrelated !

2) flux-flux analysis

The setup + first results

BL Lacs different? also at single flux-flux evolutions!



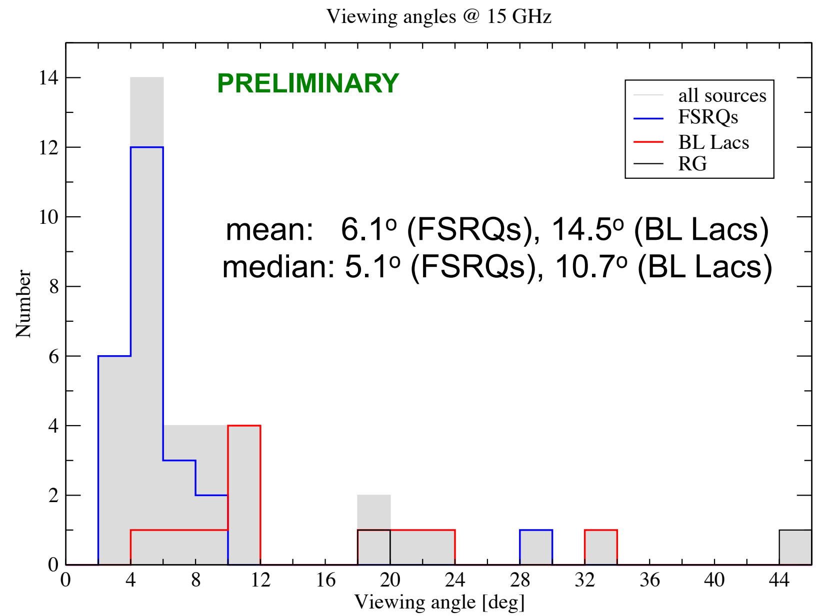
•Leon-Tavares et al. (2011): BLLacs → QSOs → LPQs → HPQs

•sequence in correlation strength

→larger viewing angles? lower D?

•sample: $\theta_{BLLacs} > \theta_{FSRQs}$?

D_{var} (F-GAMMA) and β_{app} (VLBI kinematics) → θ_v



2) flux-flux analysis

The setup + first results

BUT:

common distance bias! **simultaneous LC fluxes: increasing (flux) statistics without extending the luminosity dynamical range !**

statistical analysis (Pavlidou et al. 2011, Ackermann et al. 2011)

3mm:
BL Lacs: r-value (Pearson product-moment): 0.377, significance: $<10^{-5}$
FSRQs: r-value: 0.474, significance: 0.047

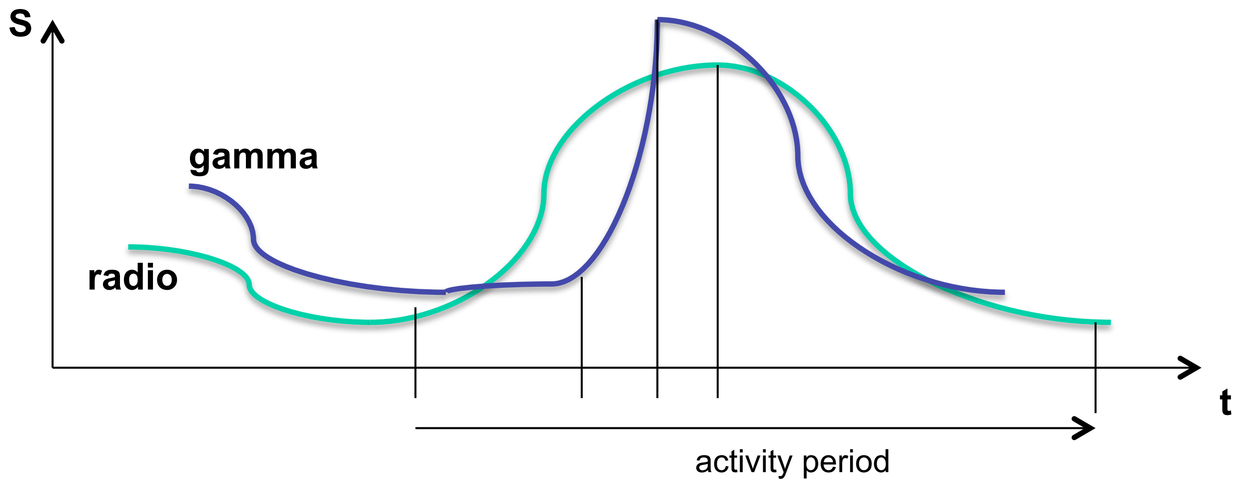
60mm,
BL Lacs: r-value: 0.2, significance: 0.006
FSRQs: r-value: 0.32, significance: 0.99

no significant *intrinsic* correlation sequence !

but frequency dependence significant!

3) Direct LC analysis

The setup + first results



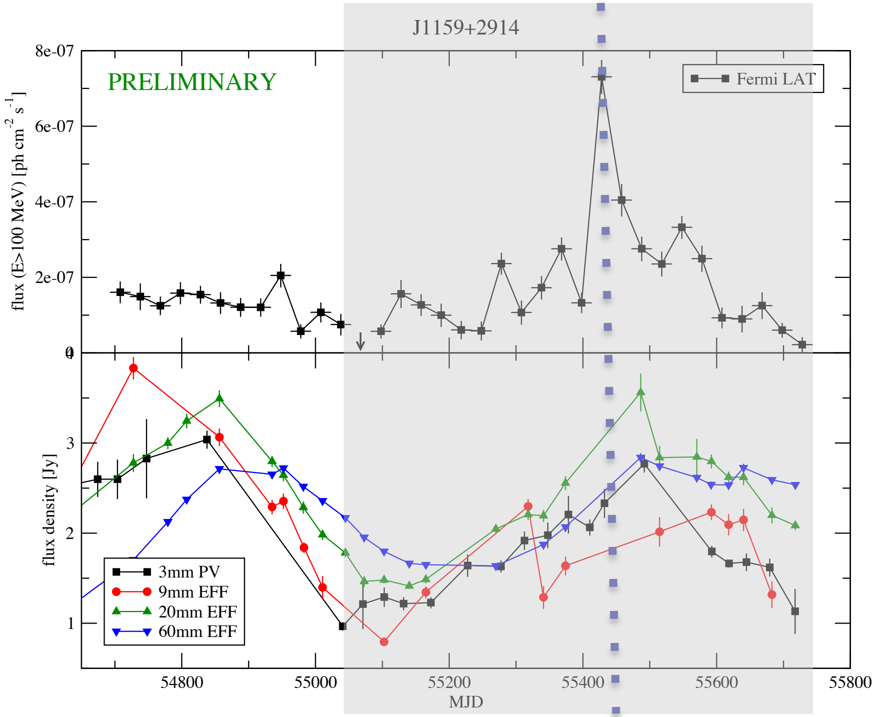
DCCF analysis: timing of radio/γ−ray peaks/minima, opacity in the core etc.

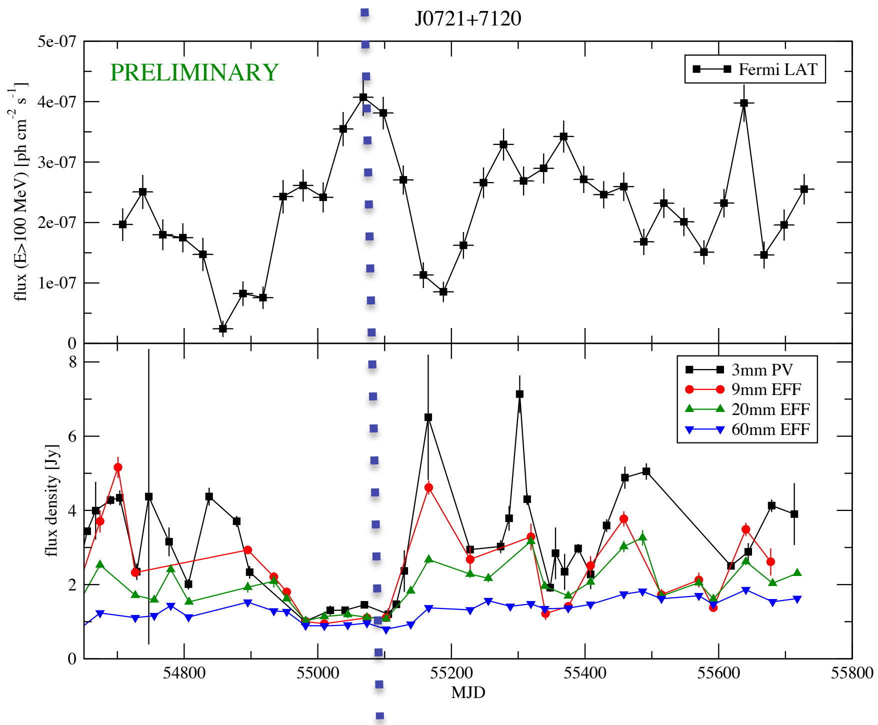
additional LC information: relative timing/occurrence/onset of radio/γ−ray events to constrain location (e.g. Leon-Tavares et al. 2011)

“time delays”: distance of max. γ –ray production region from radio/mm shock onset downstream of radio core

3) Direct LC analysis

The setup + first results





mm-flux often already raising during γ−ray flares

machinery to obtain LC parameters

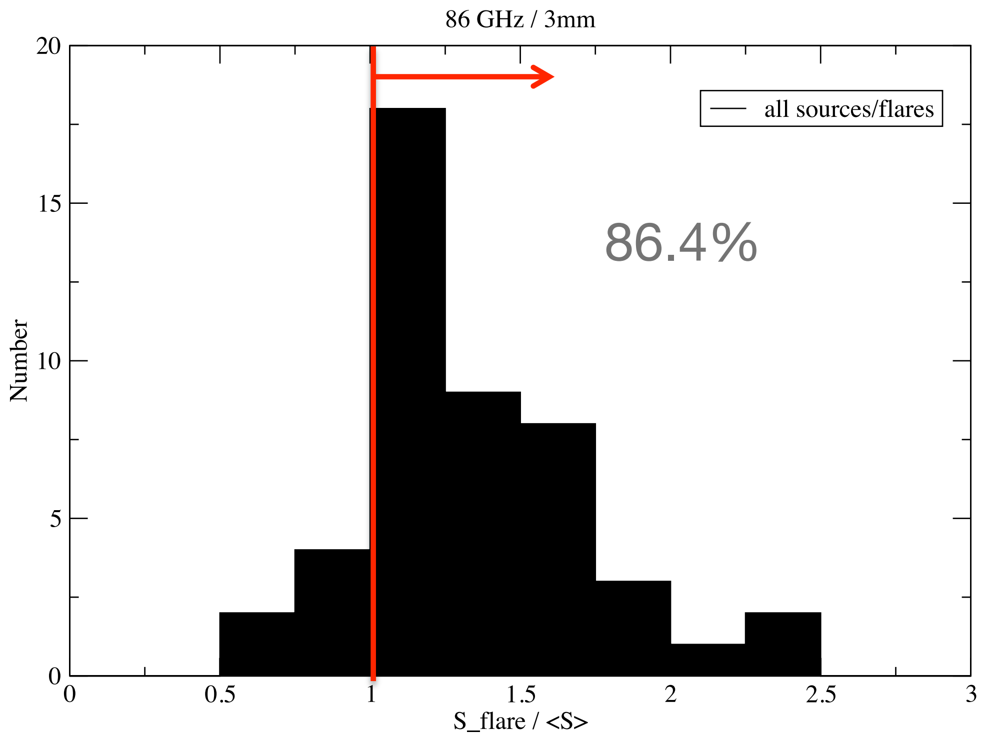
difficult task!

3) Direct LC analysis

The setup + first results

# of prominent γ-flares: 44

S_{3mm}[γ-peak] / <S_{3mm}>



Conclusion

1) statistical Discrete Cross-Correlation Function (DCCF analysis)

single sources: often DCCFs still not significant! 18 cases so far!
but stacking: significant correlations, radio lagging (3mm: 36 days, 60mm: 197 days), opacity: $\Delta r \sim 0.8$ pc (3mm), ~ 8 pc (60mm)

2) flux$_r$ – flux$_\gamma$ analysis using simultaneous, monthly fluxes

possible flux-flux correlations mostly apparent due to distance bias!
but frequency dependence robust!

3) direct LC analysis

difficult task to obtain proper LC parameters/values
mm-flux high during γ-ray flares for ~ 90 % of the cases!