Hans Hofmann | Nulli Secundus (1964)

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Ultra-high resolution VLBI and broadband radio study of the flaring γ-ray blazar PKS 1502+106

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Extreme-Astrophysics in an Ever-Changing Universe
|
16 – 20 June 2014 | Ierapetra, Crete

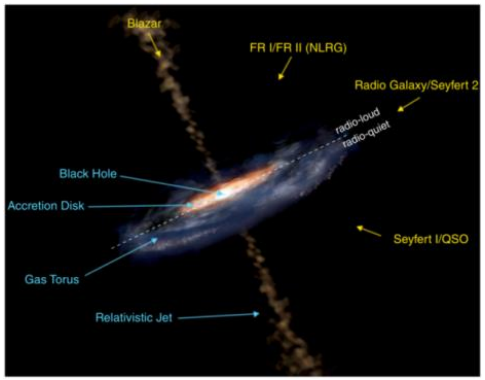
outline

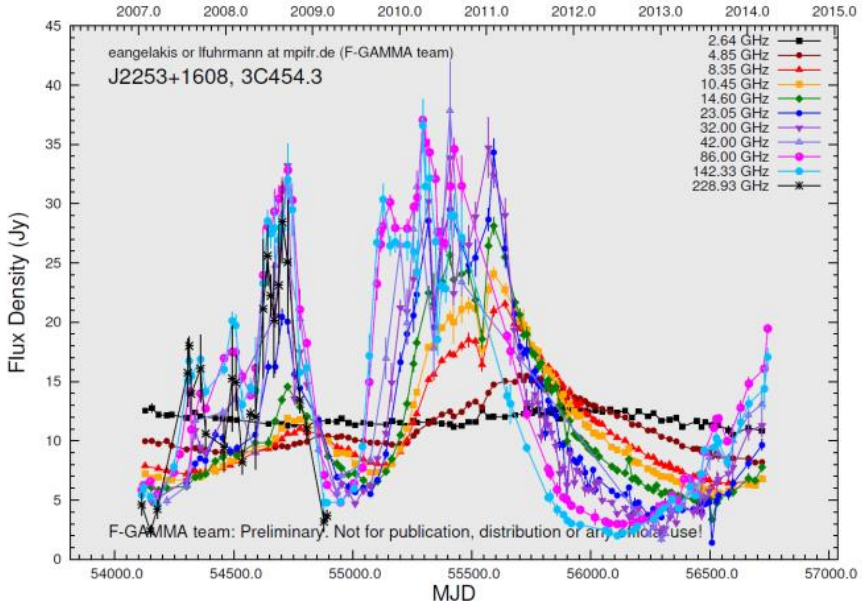
- Introduction
- The source
- Analysis and results
  - VLBI
    - Conclusions
  - Single dish
    - Conclusions
- Future work

blazars

- Highly variable at all frequencies with time scales from years down to even minutes → <u>Need for truly simultaneous MW data</u>
  - Good times: *Fermi* serves as a blazar monitoring machine filling the gap at γ-ray energies

- Extreme Δt imply extremely small emitting regions → <u>High resolution VLBI</u>





"F-GAMMA program"
Fuhrmann et al. 2007

understanding blazars - burning questions in blazar physics

1. Which mechanism(s) produce this outstanding variability?
    1. Shocks ?
    2. Helical / precessing jets
    3. Colliding plasma shells ?

2. Where in the jet are the γ rays produced?
    1. Within (near the SMBH) or without the BLR?

3. Addressing both here!

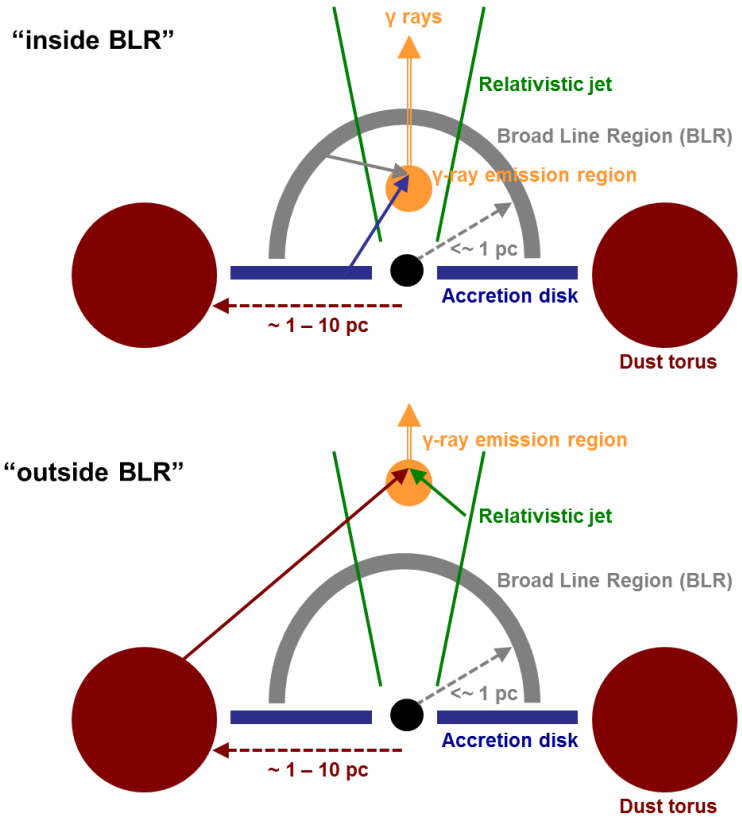
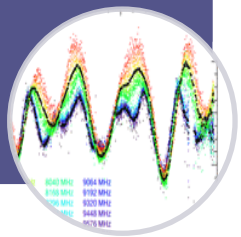


Image: L. Fuhrmann

tools of the trade

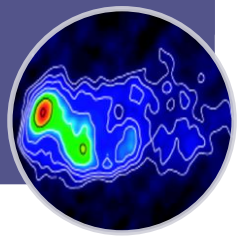
- Extract variability characteristics from LCs and spectra
  - e.g. Variability amplitudes, time lags, spectral evolution
- Compare with predictions in time and frequency domains
- Discriminate between competing variability models (Shock-in-jet?)

Broadband variability studies



- Monitoring the structural evolution of radio jets
- Their kinematical behavior (jet speed, ejected features)
- Get a handle on the mechanisms of launching and acceleration of jets

VLBI imaging



Pinpoint the γ-ray emitting region

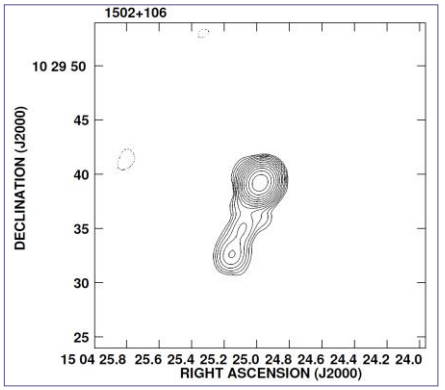
PKS 1502+106 | the blazar

PKS 1502+106 is a sub-GeV peaked, FSRQ, with $M_{BH} \backsimeq 10^9 M_\odot$ and z = 1.839

Straight kpc-scale jet

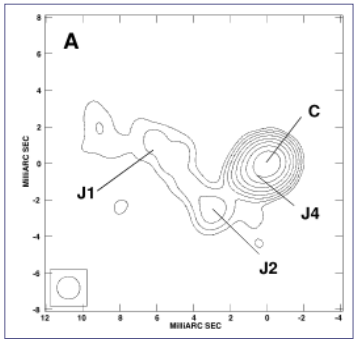
Bent jet morphology at pc scales and fast superluminal motions

VLA @ 1.4 GHz | 2004



Cooper et al. 2007

EVN @ 5 GHz | 1997.85



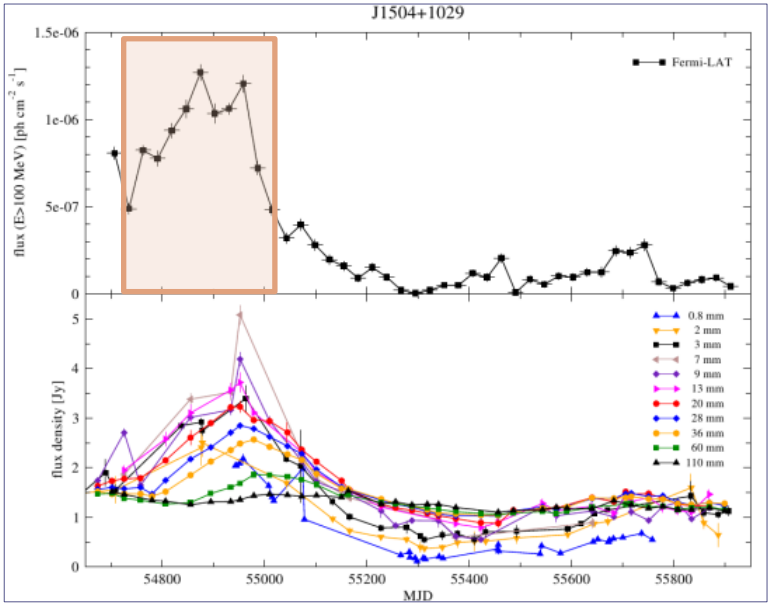
An et al. 2004

○ Why PKS 1502+106?

In August 2008 *Fermi* / LAT discovered a prominent, high energy (E >100 MeV) γ-ray outburst from PKS 1502+106

First *Fermi* multifrequency campaign (with the participation of F-GAMMA program)

Global mm-VLBI Array (GMVA) observations @ 86GHz



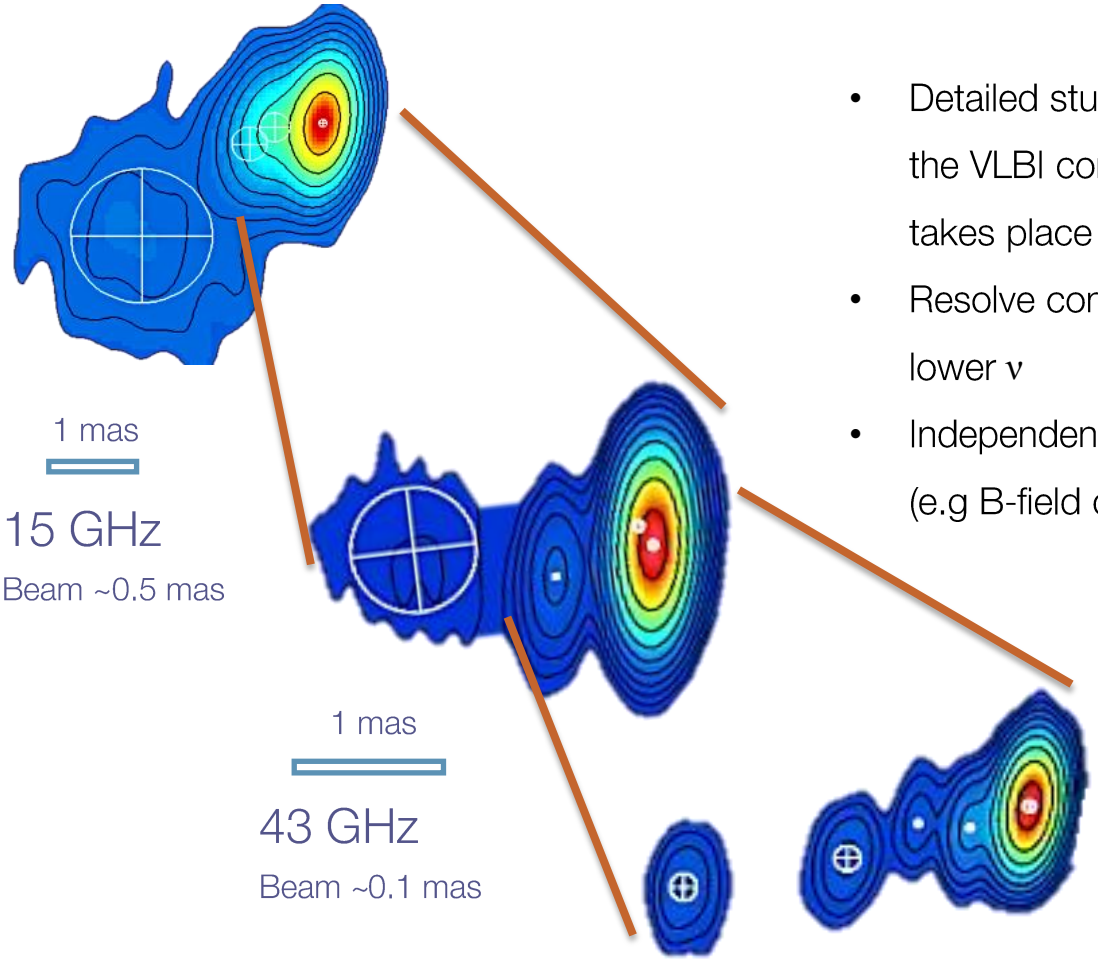
Fuhrmann et al. 2014

VLBI

- VLBI was invented in the quest for high angular resolution
- Correlating the output of a number of antennas, to synthesize an aperture with enhanced resolution
- … equivalent to a filled aperture with the diameter equal to the longest projected baseline
- Modern arrays capable of delivering μas imaging capability at mm wavelengths

VLBI | working at the highest resolutions

$$\theta = 1.22 \frac{\lambda}{b}$$



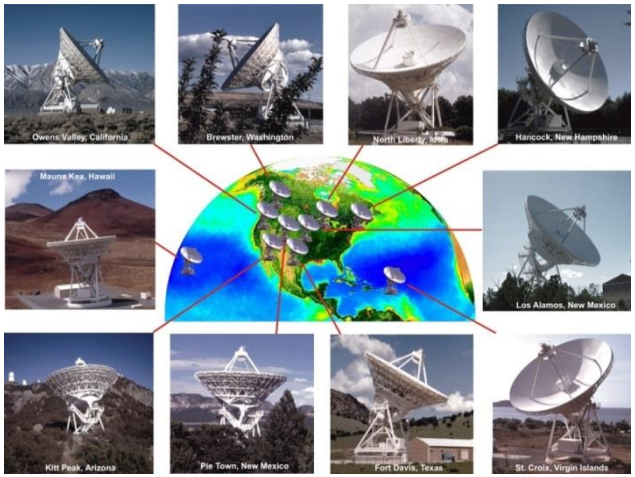
- Detailed study of self-absorption regions very close to the VLBI core (at each ν) where much of the activity takes place
- Resolve components that were blended together at lower ν
- Independent estimation of physical parameters of the jet (e.g B-field due to the core-shift effect)

z = 1.839
1 mas ≃ 8.5 pc

the VLBI dataset

Data set	Num. of epochs	Dates
3 mm GMVA	6	2009 May – 2012 May
7 mm VLBA	6	2009 May – 2012 May
20 mm VLBA (MOJAVE)	19	2002 Aug – 2011 Aug

http://www3.mpifr-bonn.mpg.de/div/vlbi/globalmm/
http://www.physics.purdue.edu/MOJAVE/



- A number of sensitive antennas in Europe
  - e.g. Effelsberg 100-m
  - Yebes 40-m
  - Plateau de Bure interferometer

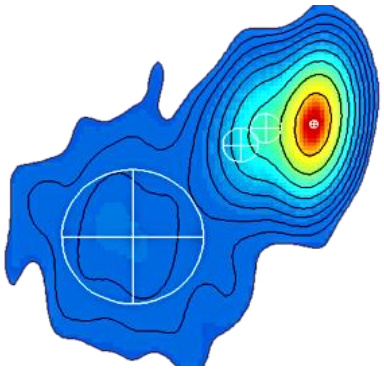
Global mm-VLBI array

(GMVA)

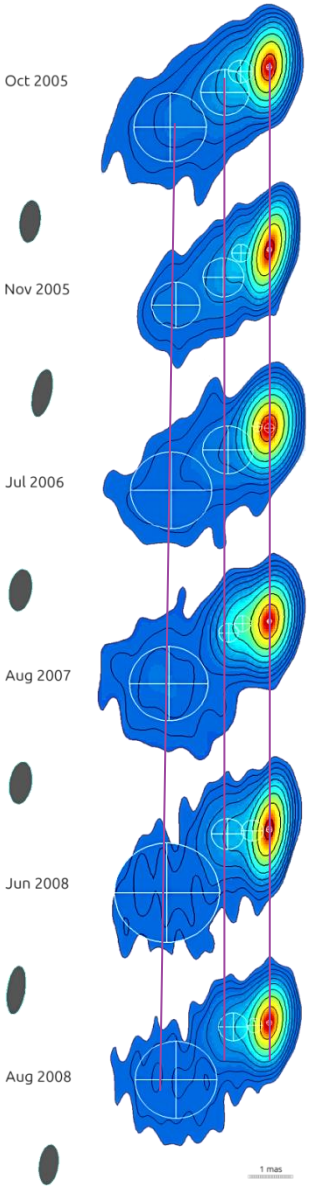
VLBI | What can we do with it?

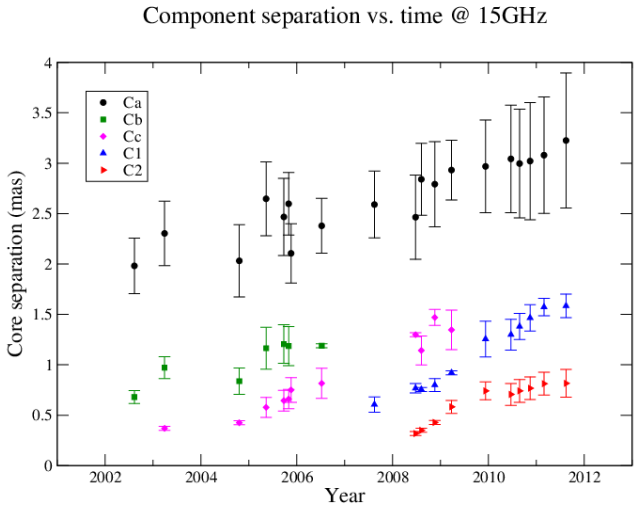
1. Calibration
2. Imaging
3. Model fitting

(representation of the source)



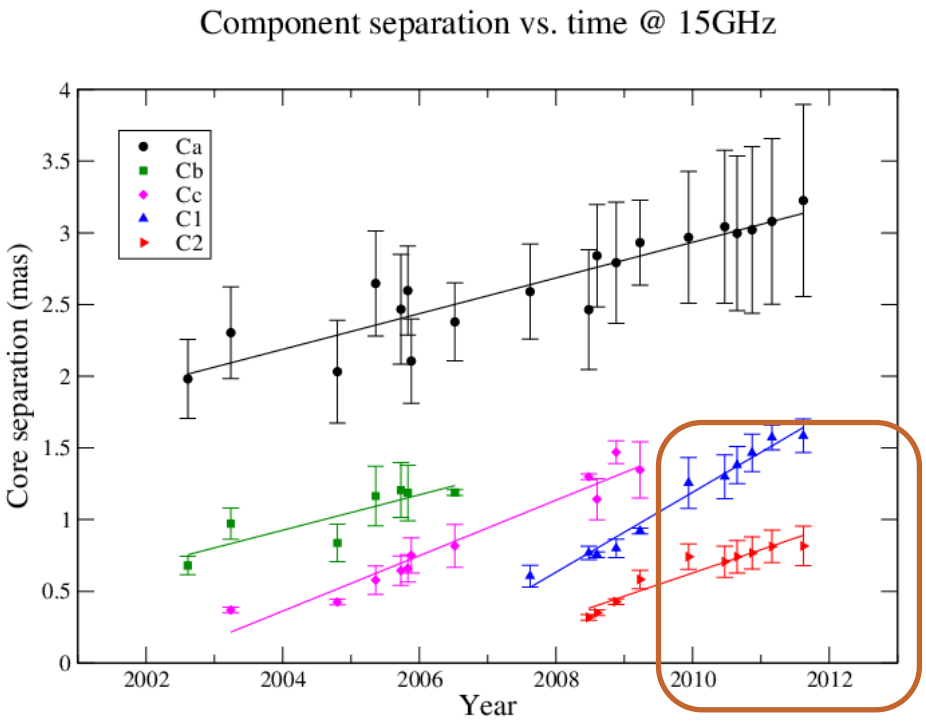
Aug 2007





- Putting together Model fits to obtain ejection times and speeds

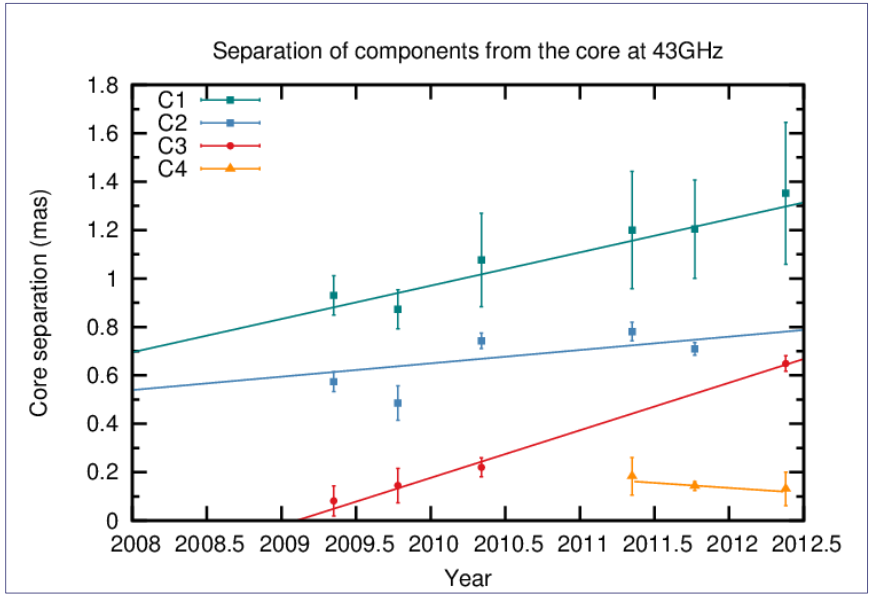
VLBA 15 GHz | MOJAVE survey

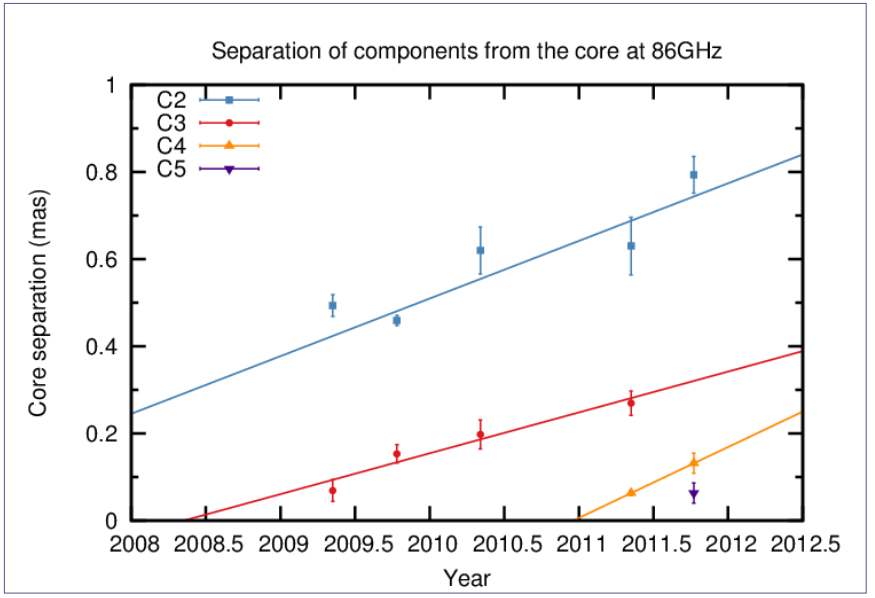


Comp. ID	mas/y	β_{app} (c)	t_{ej}
Ca	0.12	10	2002.1 +/- 2.4
Cb	0.12	10	2002.1 +/- 2.3
Cc	0.19	15	2002.1 +/- 0.4
1	0.28	22	2005.7 +/- 0.2
2	0.16	13	2006.0 +/- 0.5

- 19 epochs, max jet speed ~22c
- Most recent ejection event in 2006
- Difficulty to associate a component with the flare since the resolution is a limiting factor

mm-VLBI imaging | 43 & 86 GHz Kinematics



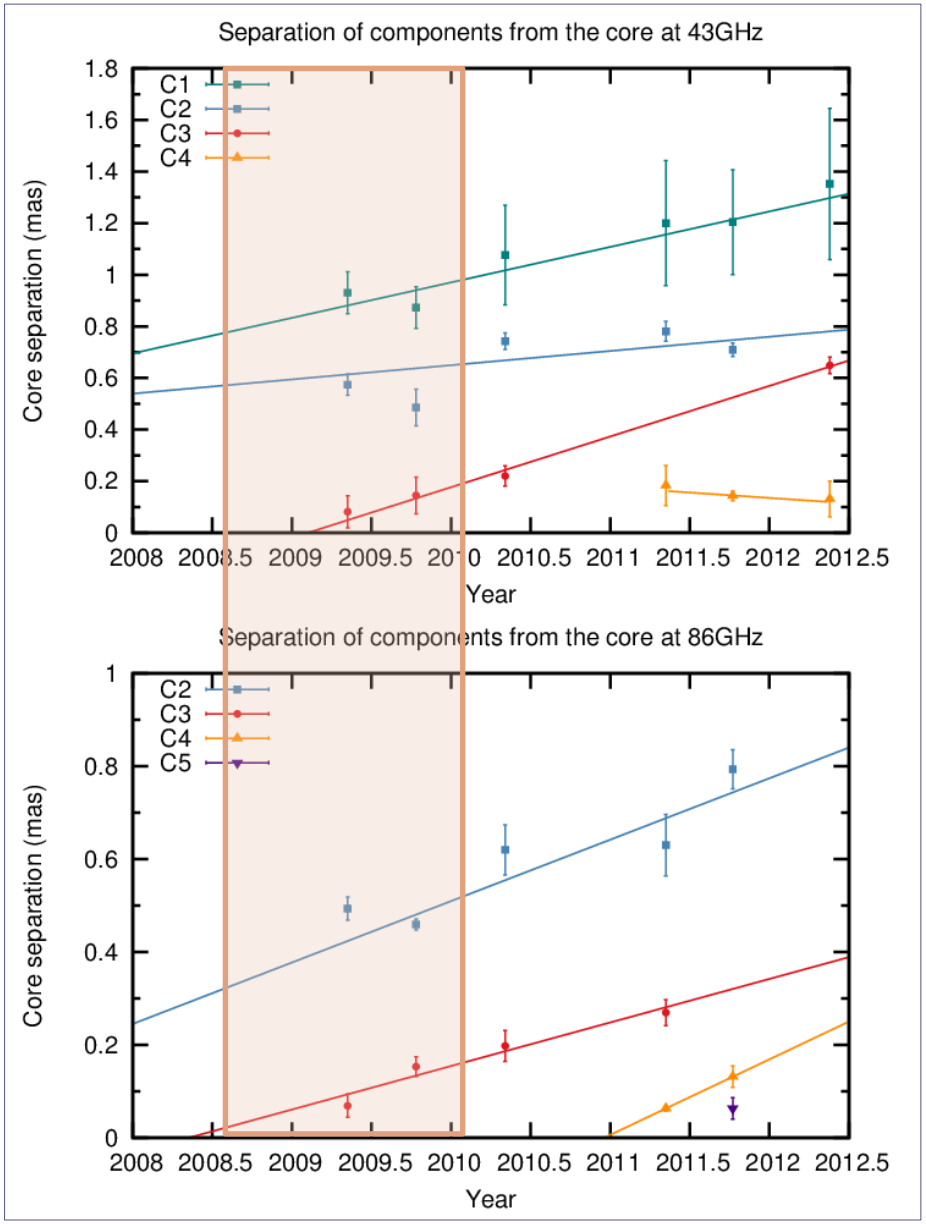


Comp. ID	mas/y	β_{app} (c)	t_{ej}
1	0.14	19	2002.94 +/- 1.87
2	0.05	4	1998.21 +/- 9.21
3	0.20	16	2009.1 +/- 0.12

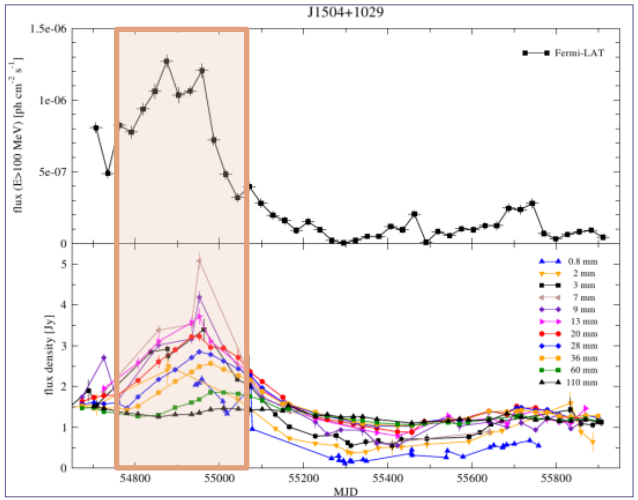
Comp. ID	mas/y	β_{app} (c)	t_{ej}
2	0.13	11	2006.15 +/- 1.17
3	0.09	7	2008.35 +/- 0.38
4	0.16	13	2010.96 +/- 0.00

- Is component 3 connected to the γ flare?

VLBI imaging | Conclusion

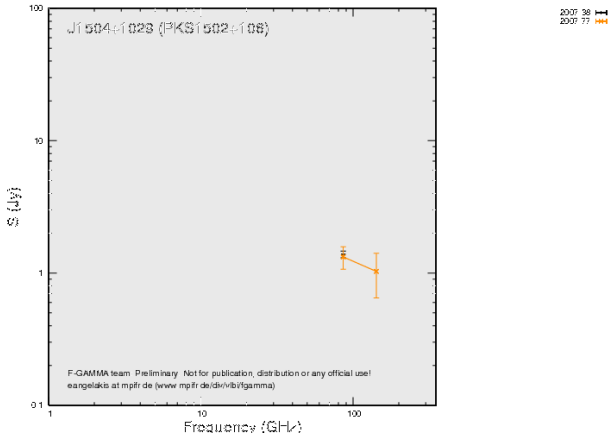


- Component 3 is the only one that can be associated with the γ-ray flare
- Component at a mean projected distance of 0.7 pc from the core at the time of the γ-ray flare
- Do some of the components follow helical trajectories ? (at least near the core)

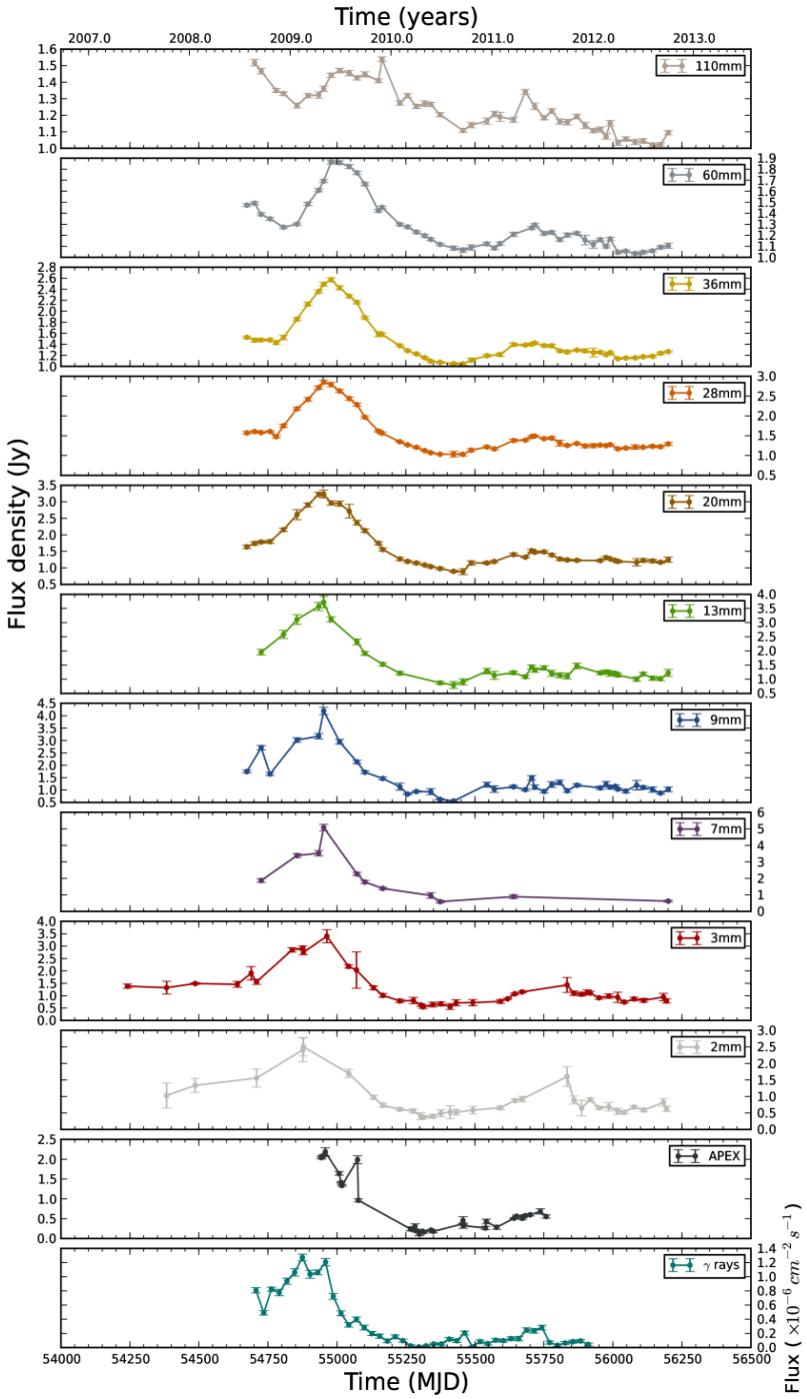


the broadband data set

- Monthly monitoring of ≃ 60 blazars, since 2007
- Main instruments: Effelsberg 100-m, IRAM 30-m (PV)
- 11 frequencies in the range 2 – 345 GHz
- Products: LCs and broadband radio spectra



band	Instrument
X-rays	Swift – XRT
UV	Swift – UVOT
Optical phot + pol	Steward & Kanata

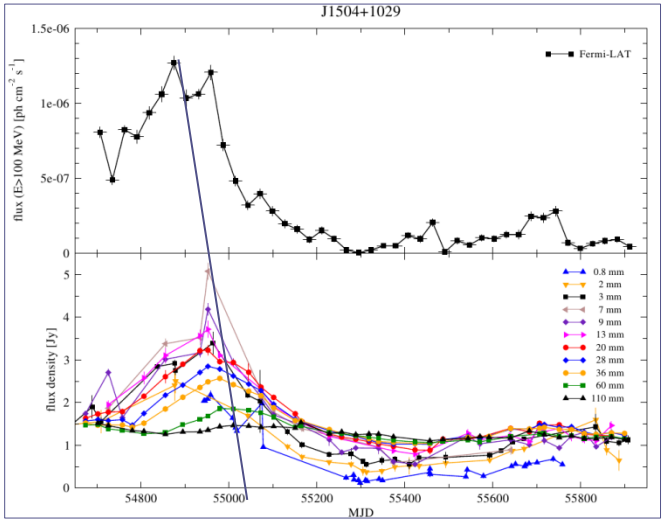


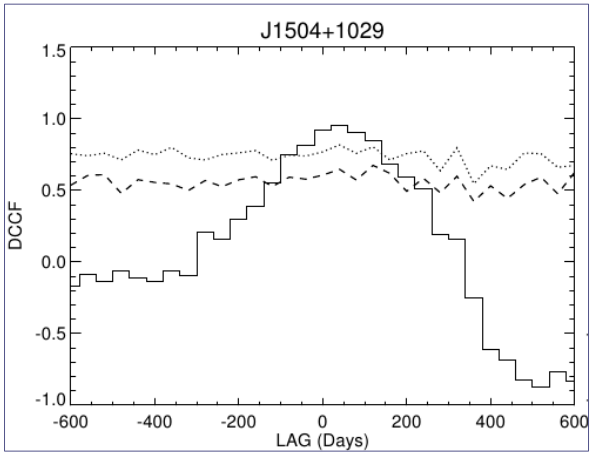
broadband analysis

Statistical analysis with the Discrete Cross Correlation Function (DCCF) between γ-rays and 3mm

- Statistically significant lag = 14 +/- 11 days

(Fuhrmann et al. 2014)



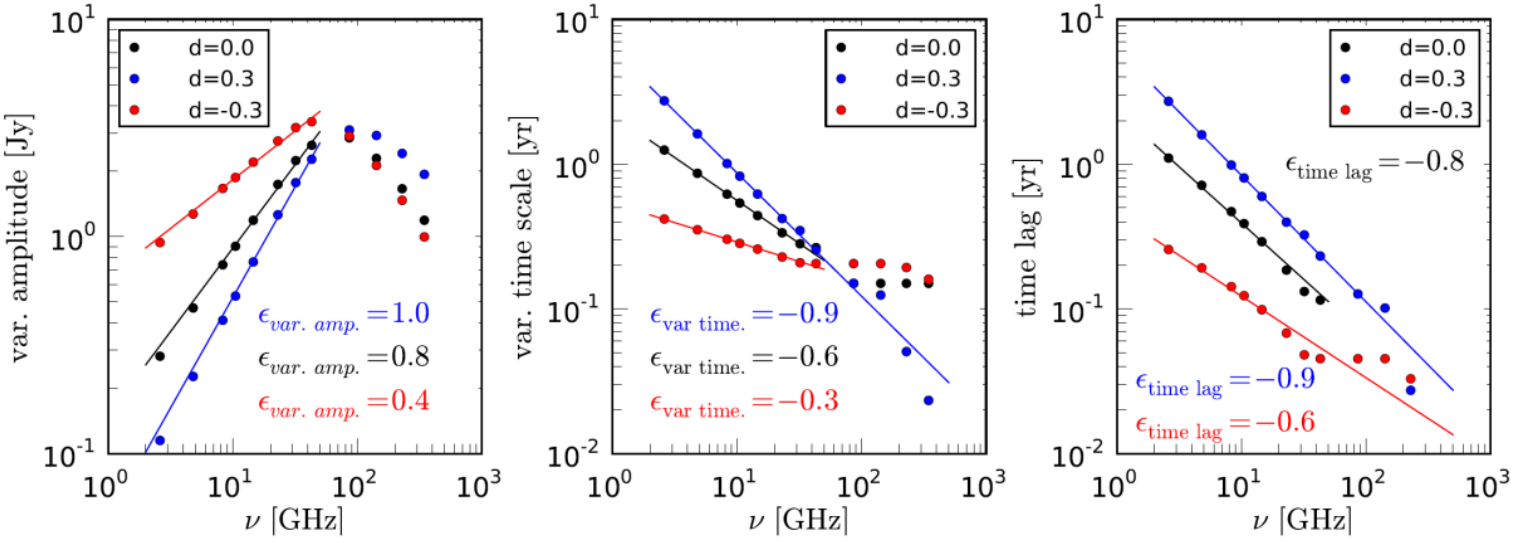


Fuhrmann et al. 2014

Shock modeling

- Based on the Shock-in-jet model Fromm et al. (2014, in prep.) produced synthetic LCs :
  - At different radio frequencies (2 – 345 GHz, matching F-GAMMA coverage)
  - For different physical conditions (B-field, Doppler factor)
  - In a conical jet

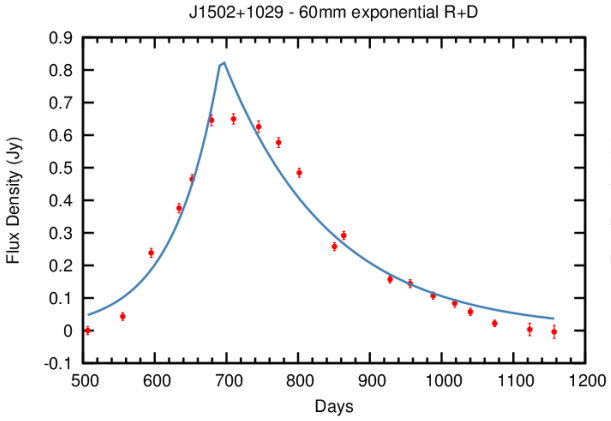
Frequency dependence of amplitude, var. time scale and cross-band delay

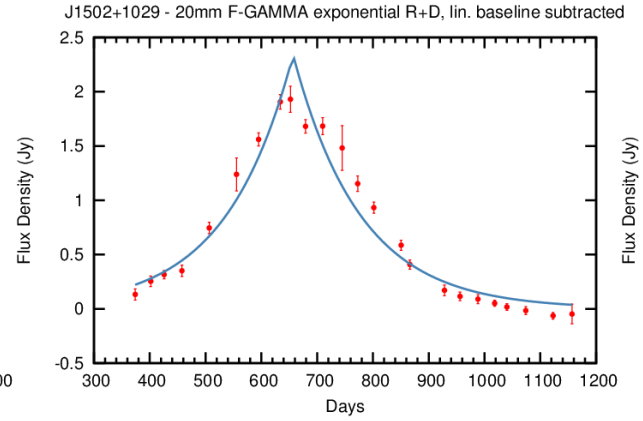


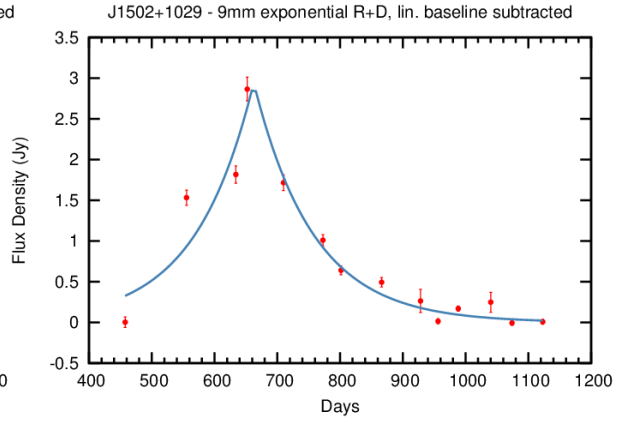
Fromm et al. 2014, in prep.

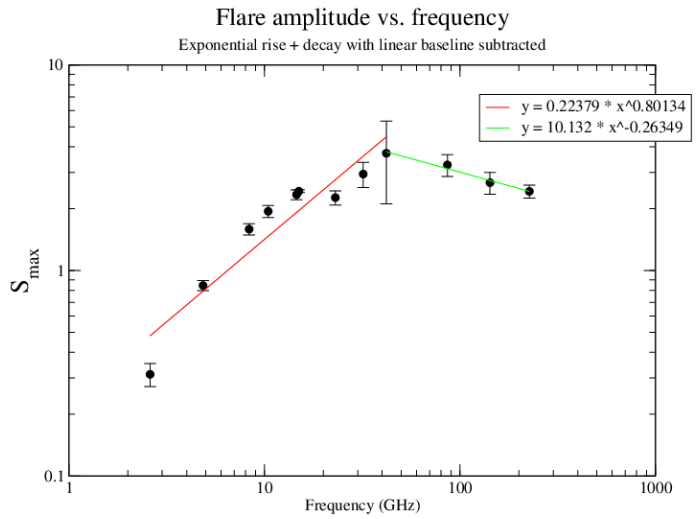
radio LC analysis

Preliminary

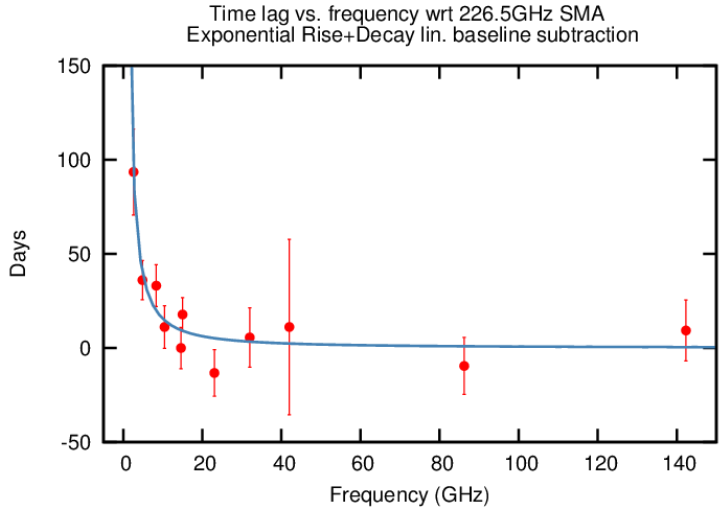








$\epsilon_{var\ amp} = 0.8 +/- 0.1$



$\epsilon_{time\ lag} = -1.3 +/- 0.3$

radio LC analysis | Conclusions

- Overall frequency dependencies for amplitude and time lag are consistent with expectations from shocks

- whereas the physical parameters of the shock will be obtained from detailed comparisons of the fitted slopes with the analytical model simulations

future

VLBI

- Spectral analysis of the VLBI data
- Core shift analysis for estimation of B-field

Single dish

- Completion of radio LC analysis (extraction of variability timescales)
- Perform the DCCF analysis between γ-rays and all other available bands
- A more sophisticated approach to obtain the relevant LC parameters

Hans Hofmann I Nulli Secundus (1964)

Thank you !