

Blazar science with mm-VLBI

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EUROPEAN ARC
ALMA Regional Centre || Italian



Outline

- Why are blazars interesting?
- mm-VLBI & blazar sampler
 - 7mm, 3mm, 1.3mm
- towards the future...

Foreword

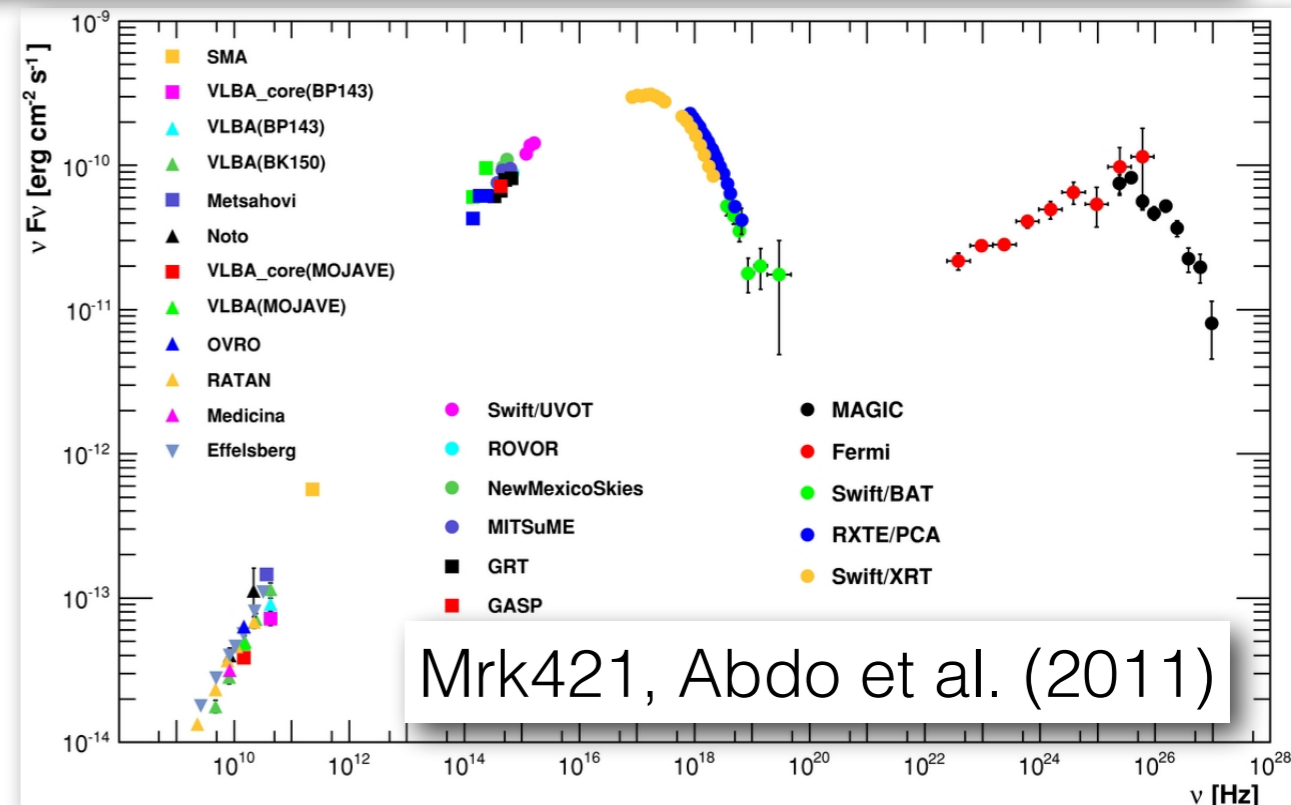
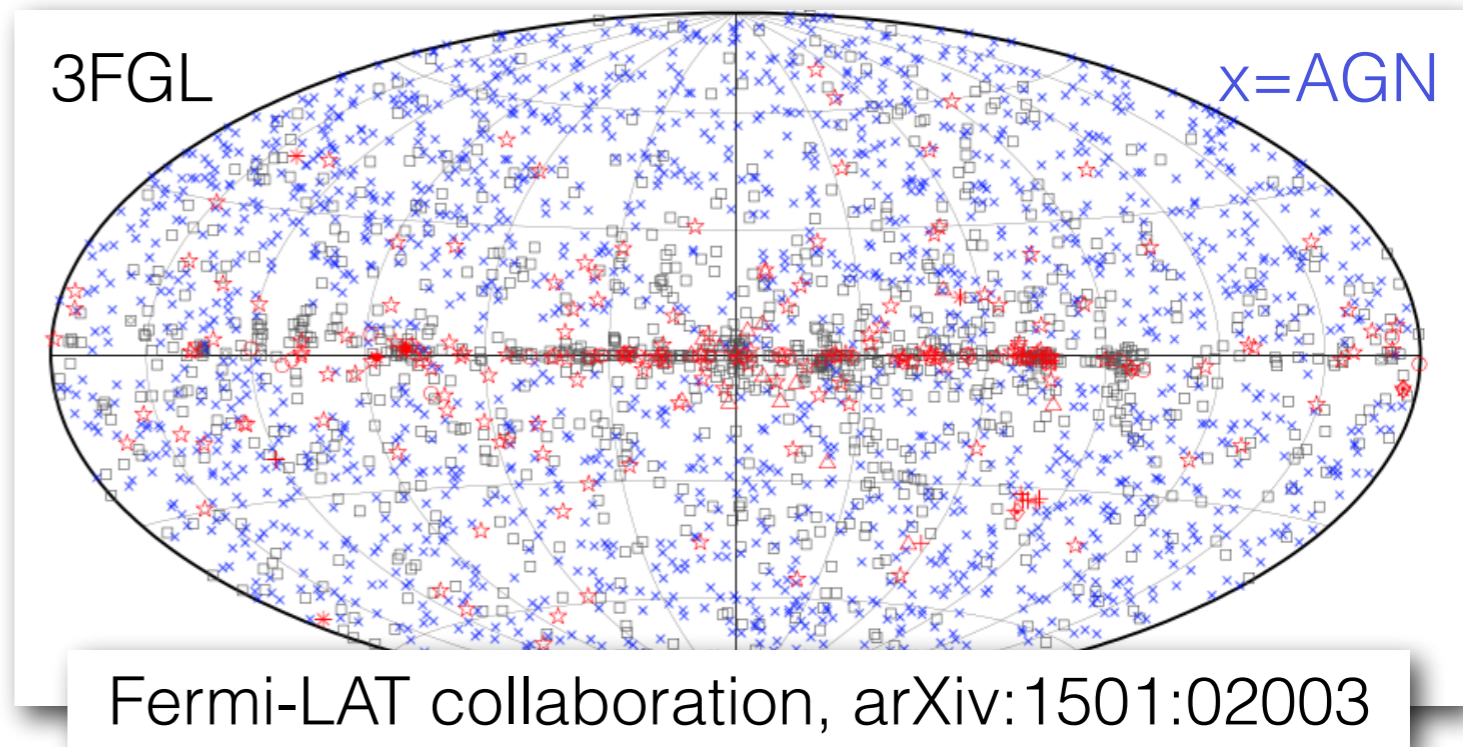
1. SgrA* is wonderful for event horizon studies...
 - ...but it does not launch a relativistic jet!
2. There is already **A LOT** of great blazar science with mm-VLBI, so this review will be certainly incomplete and biased
 - please pay attention to other talks, posters, references

Why do we care about blazars so much?

- luminous tracers of AGN activity
- SMBH-galaxy coevolution
- SMBH physics (eg spin)
- properties of relativistic jets
 - **accretion-ejection coupling, launch and acceleration mechanisms, particle acceleration processes, magnetic field role, jet composition**
- can't do it all only with M87!!!

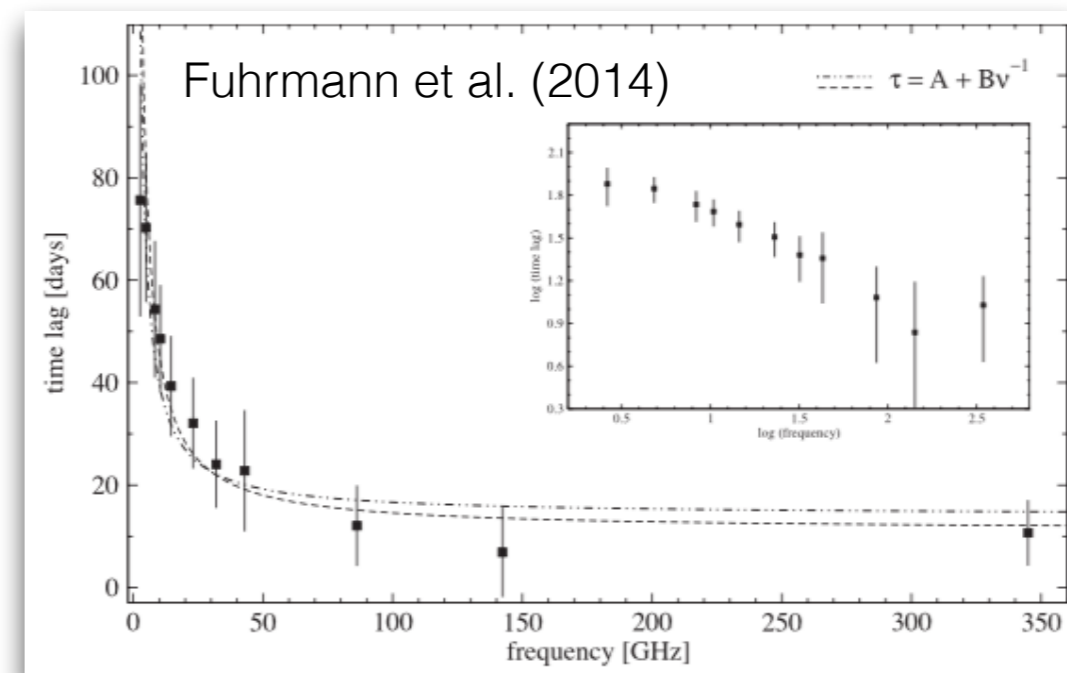
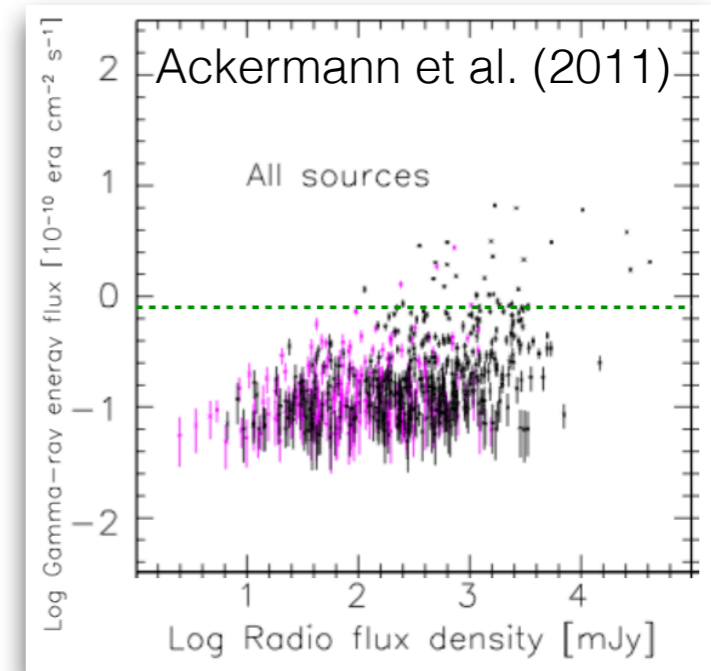
Blazars as broadband emission sources

- ~1700 AGNs in the third *Fermi* catalog (**3FGL**), >1100 confirmed blazars
- bright and variable sources also at optical, UV, X-rays, VHE
- SED modelling constrains emission region to very compact sizes (<~0.1pc)
- low energy emission: synchrotron
- high energy emission: inverse Compton (SSC, EC, multi-zone, layered jets), hadronic processes?



The connection between radio and gamma-ray emission in blazars

- a highly significant correlation between cm radio and gamma-ray emission is found on a sample of ~ 600 blazars (Ackermann et al. 2011)
- yet, only one of 41 sources with high-quality light curves in both bands shows correlations with significance larger than 3σ (Max-Moerbeck et al. 2014)
- considering **3mm** data, Fuhrmann et al. (2014) find significant correlation for 9/54 sources
 - and the (stacked) radio-gamma lag decreases from 76 ± 23 d at 2.6 GHz to 7 ± 9 d at 142 GHz
- and we look forward to a statistical analysis with combined **Fermi+ALMA** data (PI Giroletti)

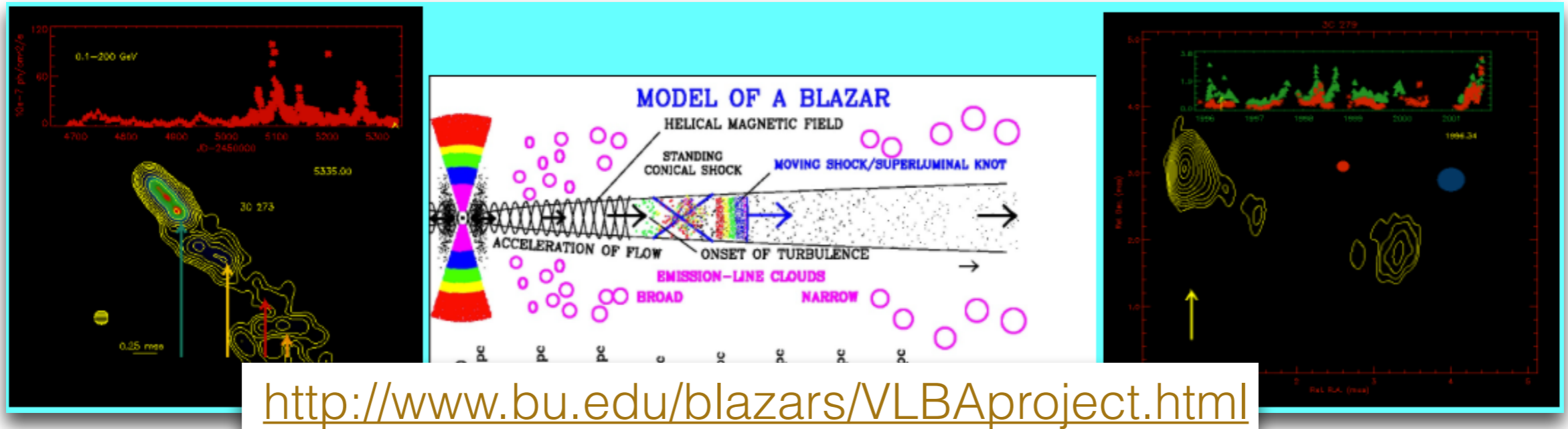


imaging the blazar region

$$\nu_{\max} = e(\alpha) H^{1/5} \theta^{-4/5} S_{\max}^{2/5} (1+z)^{1/5}$$

- to **probe** the radio emission from the compact blazar region, we need observations above the SSA turnover
 - blazar spectra turn over at ~8-80 GHz
- to **image** it, we need sub-parsec angular resolution
- **we need: mm-VLBI**
 - possibly with good image quality, sensitivity (jet), polarisation...

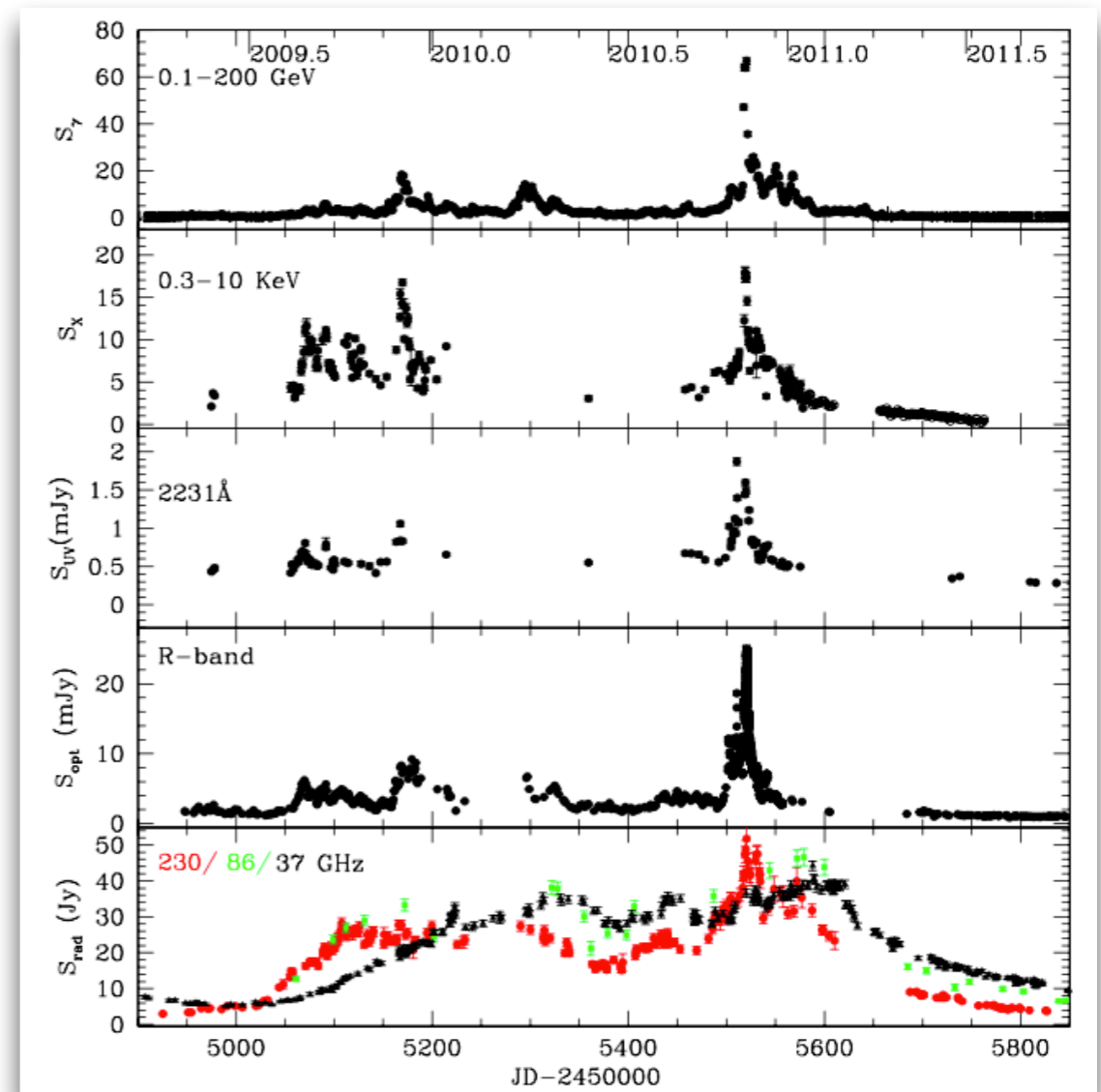
Part I: 43 GHz blazar studies



- **VLBA-BU-BLAZAR**, led by Alan Marscher and Svetlana Jorstad
- Data products: individual images in total intensity and polarized intensity, CLEAN model files, and calibrated visibility (uv) data files **for 37 sources**, with **monthly cadence**
- additional MWL monitoring
- ~40 papers since 2010

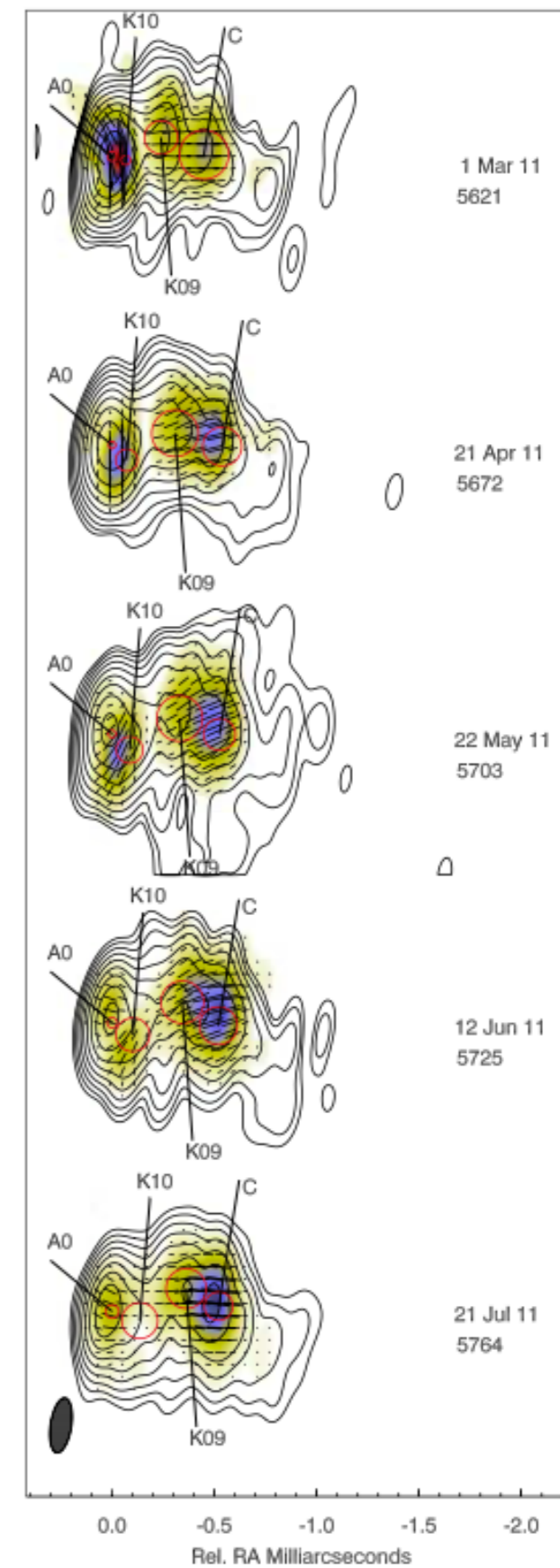
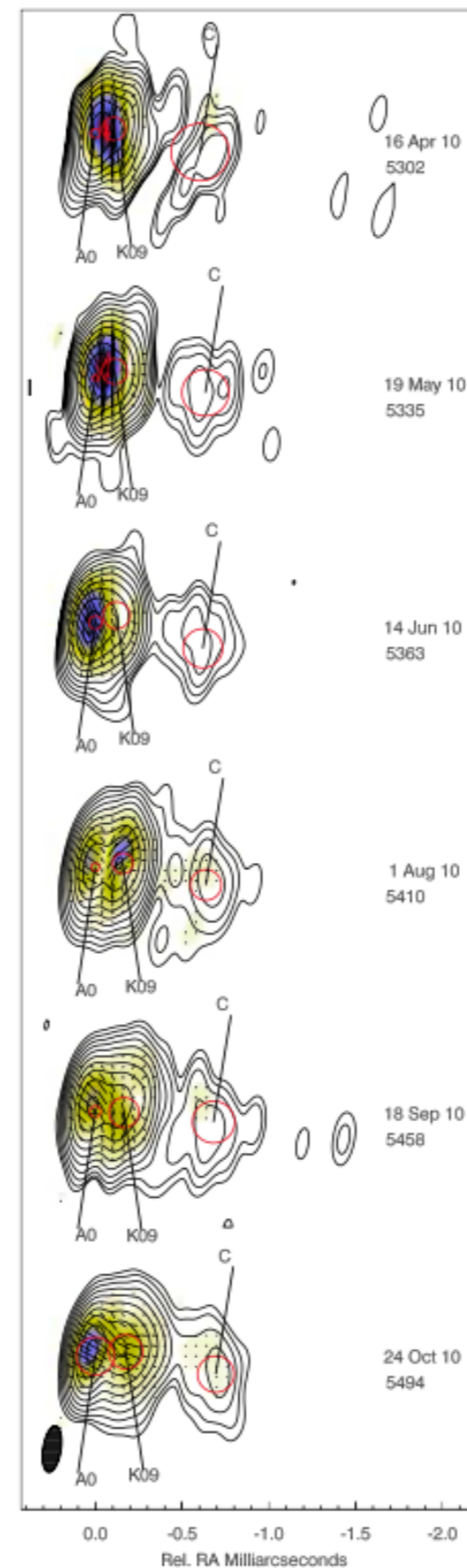
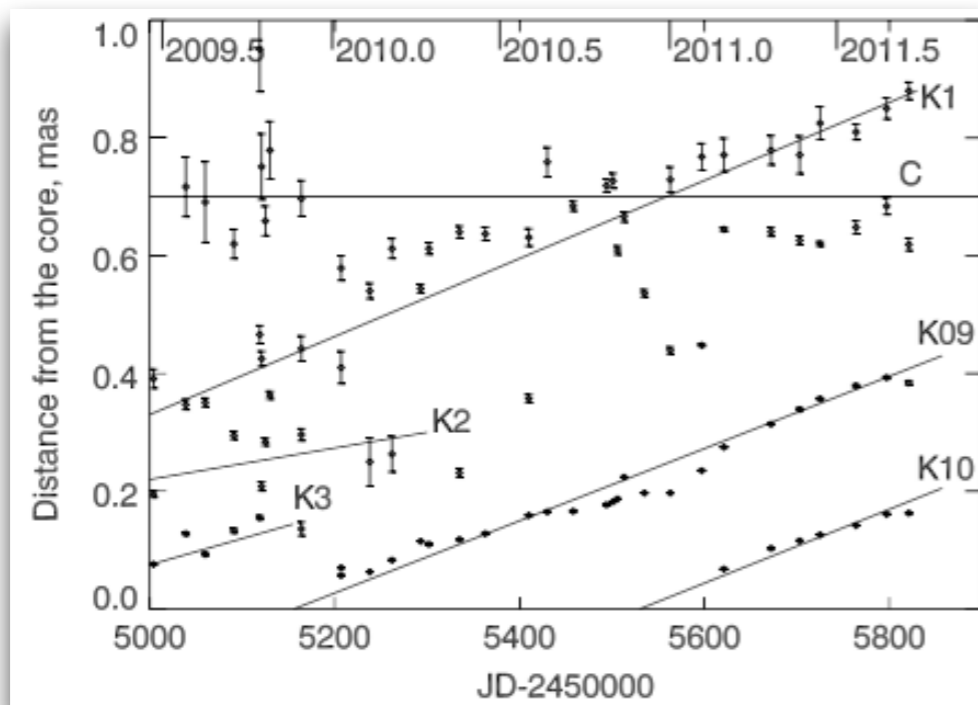
3C454.3 during three gamma-ray outbursts

- The FSRQ 3C454.3 had three big gamma-ray flares in 2009-10 (Ackermann et al. 2010, Abdo et al. 2011)
 - $L \sim 10^{49}$ erg s $^{-1}$, $\delta > 15$
- Jorstad et al. (2013) report on 35 observations between 2009 April and 2011 August, with VLBA @43 GHz
 - 0.3 mas x 0.1 mas



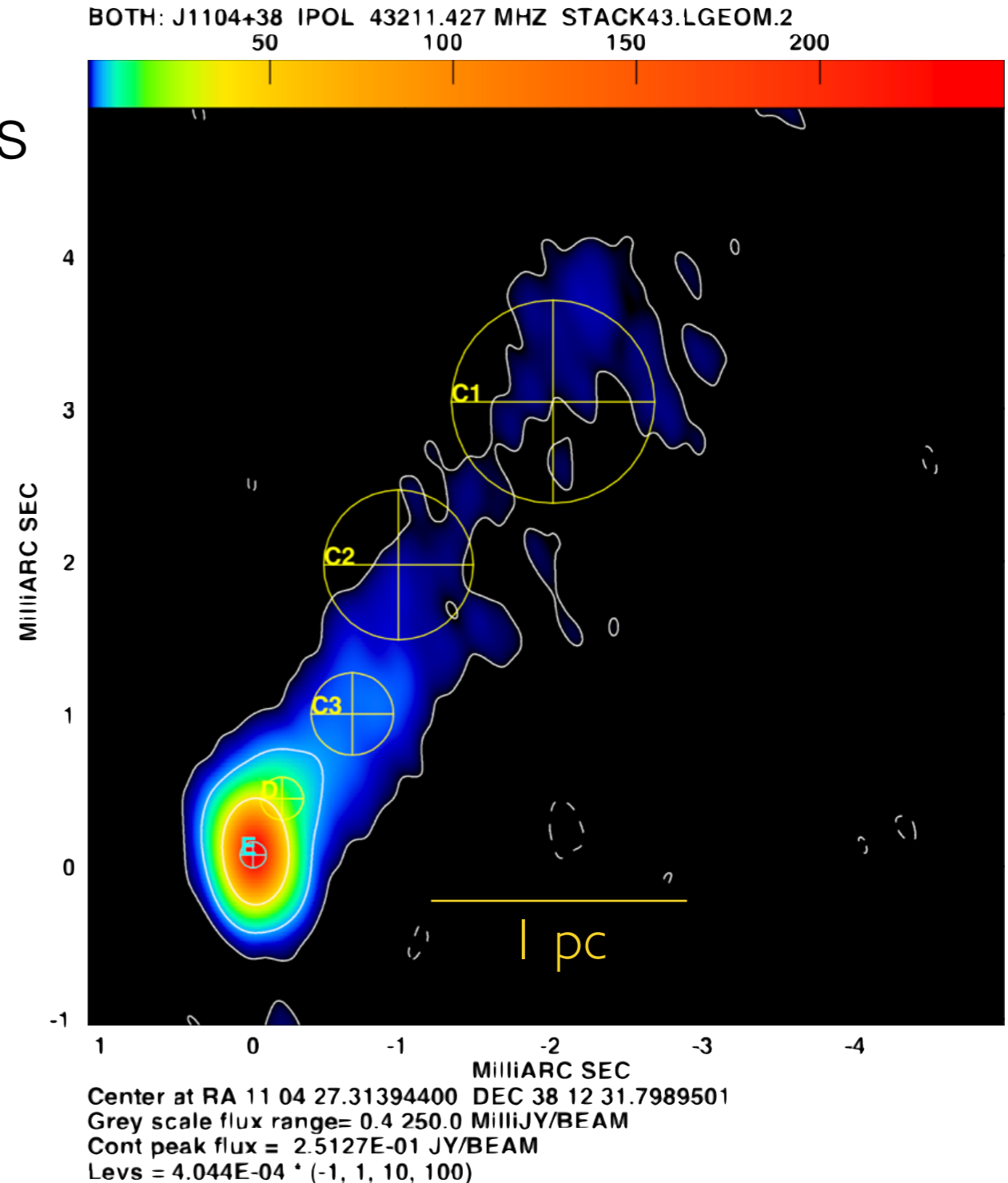
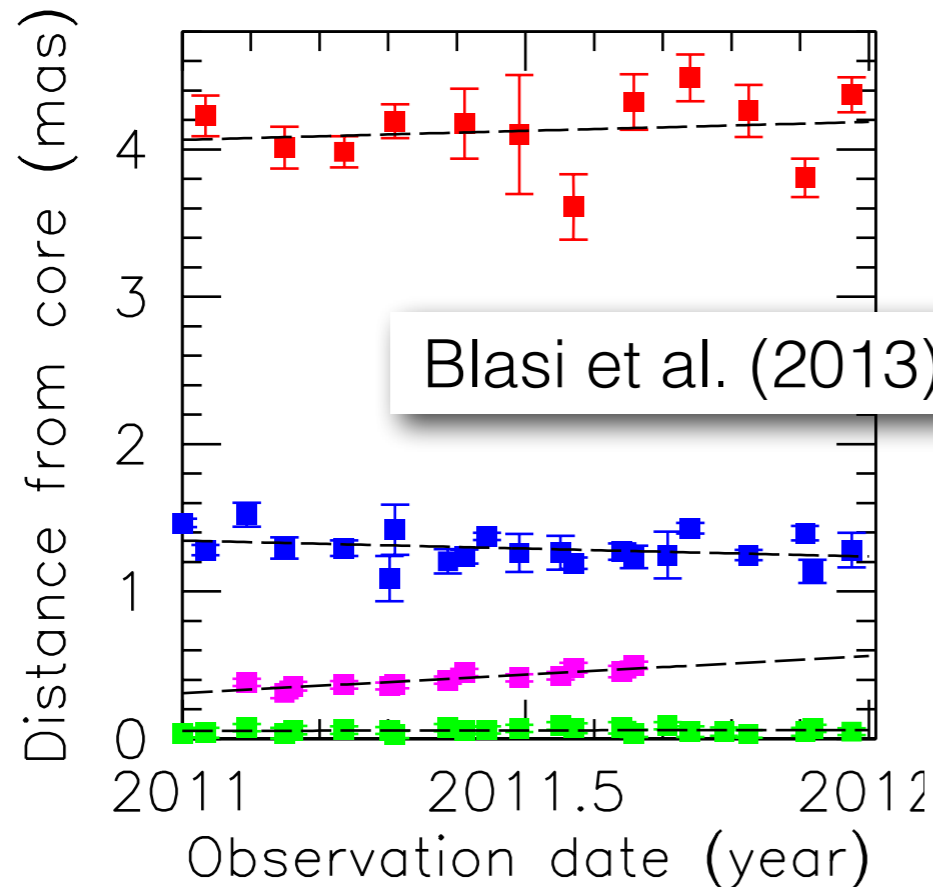
kinematics and high energy connection

- stationary and “slow” ($\sim 3-4c$) components
- two faster components (9c) associated to gamma ray flares
- similar average velocity but different trajectories and flux density evolution



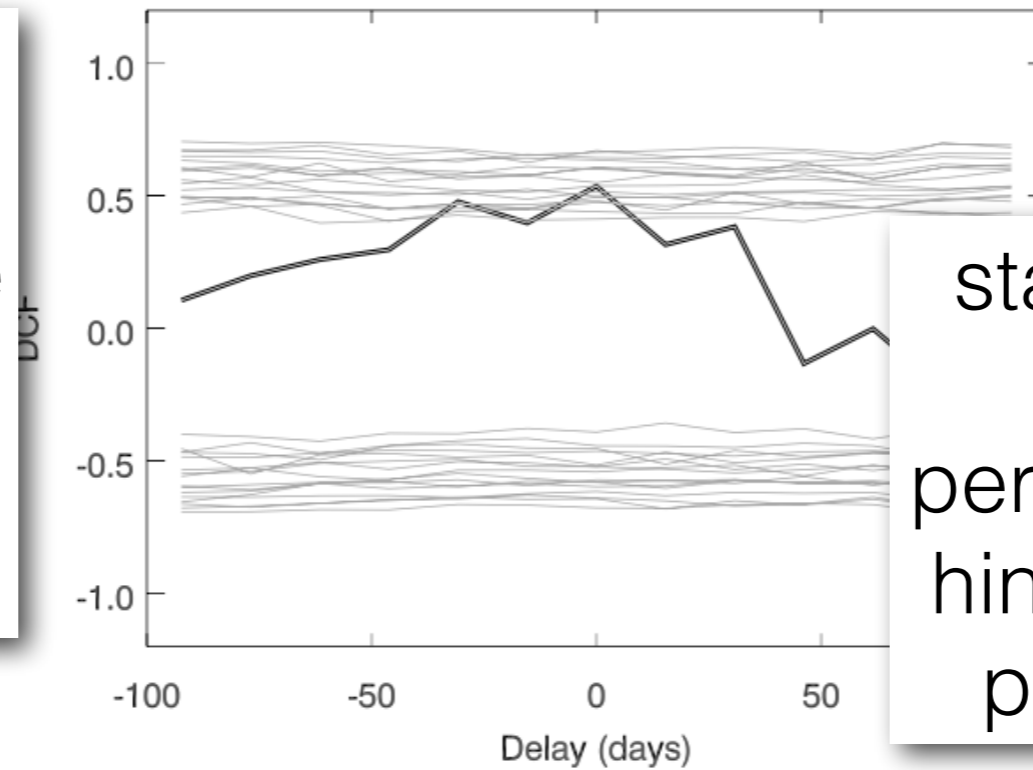
Mrk421, 2011 campaign

- 23 epochs (12 dedicated, plus 11 from VLBA-BU), w. full stokes
- simultaneous gamma-ray study
- variable core, stationary jet

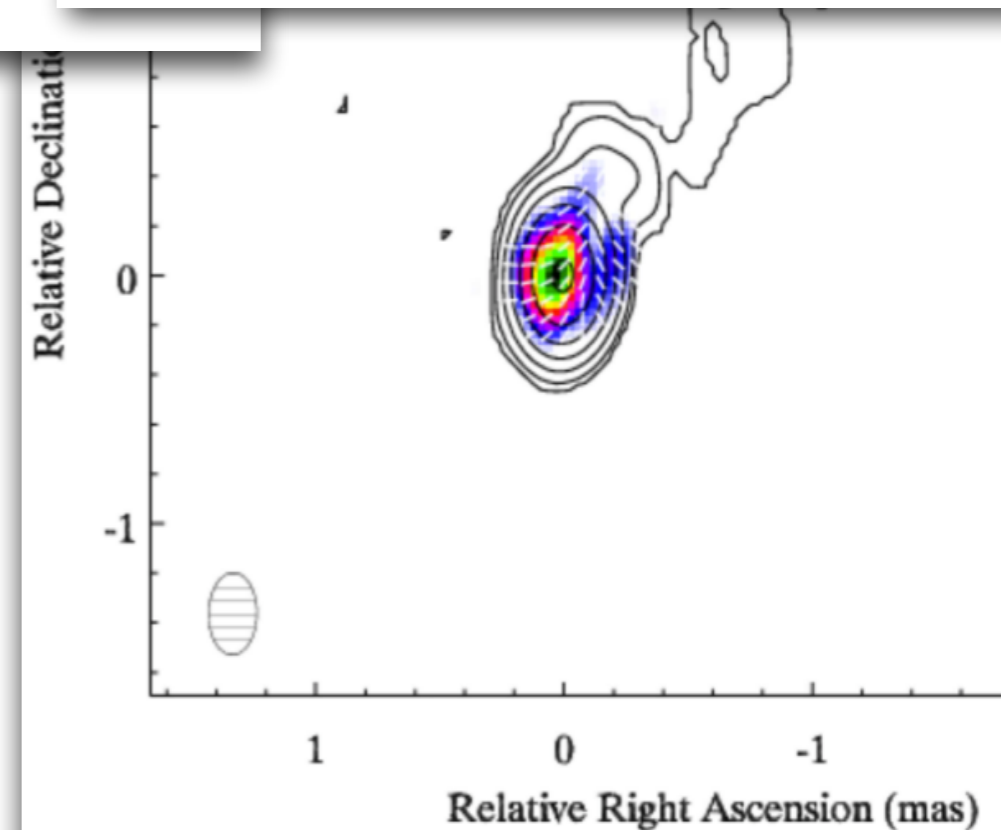
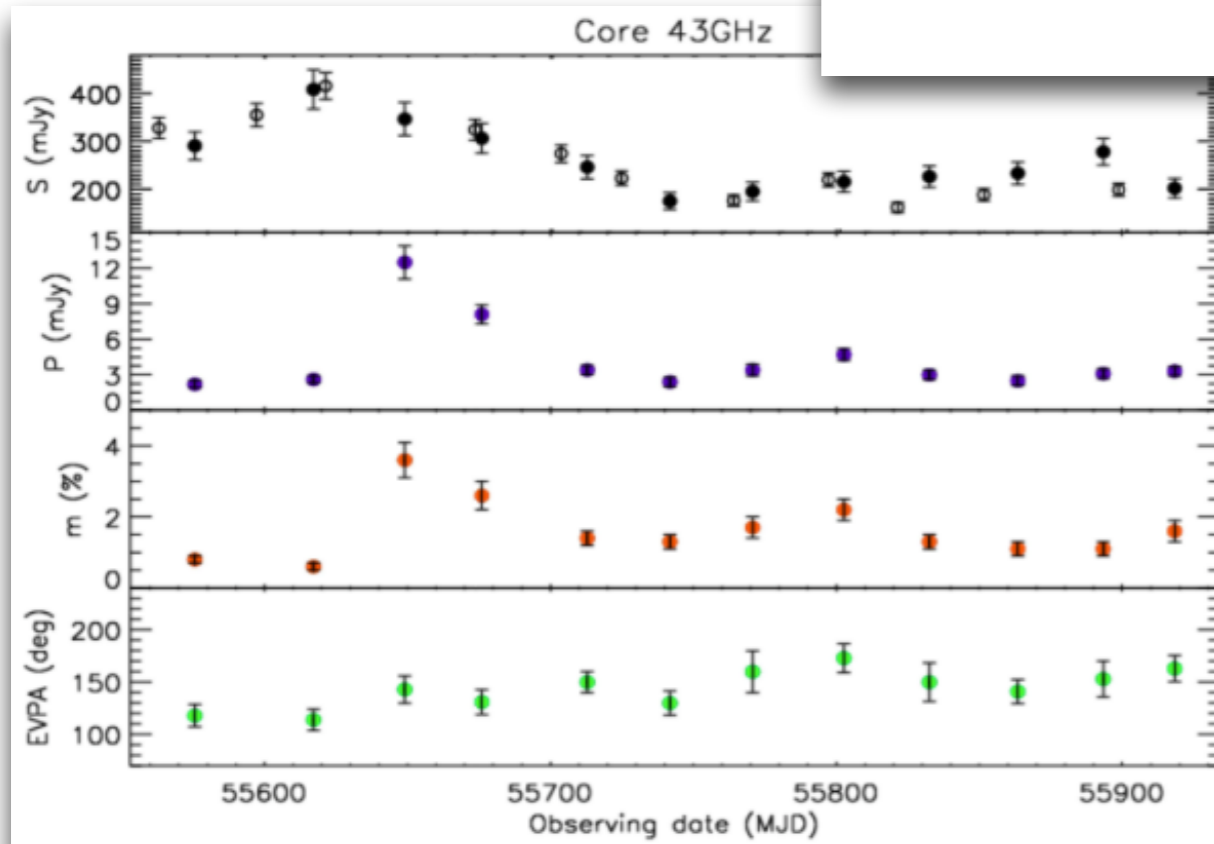


Mrk421, polarization and gamma rays (Lico et al. 2014, A&A)

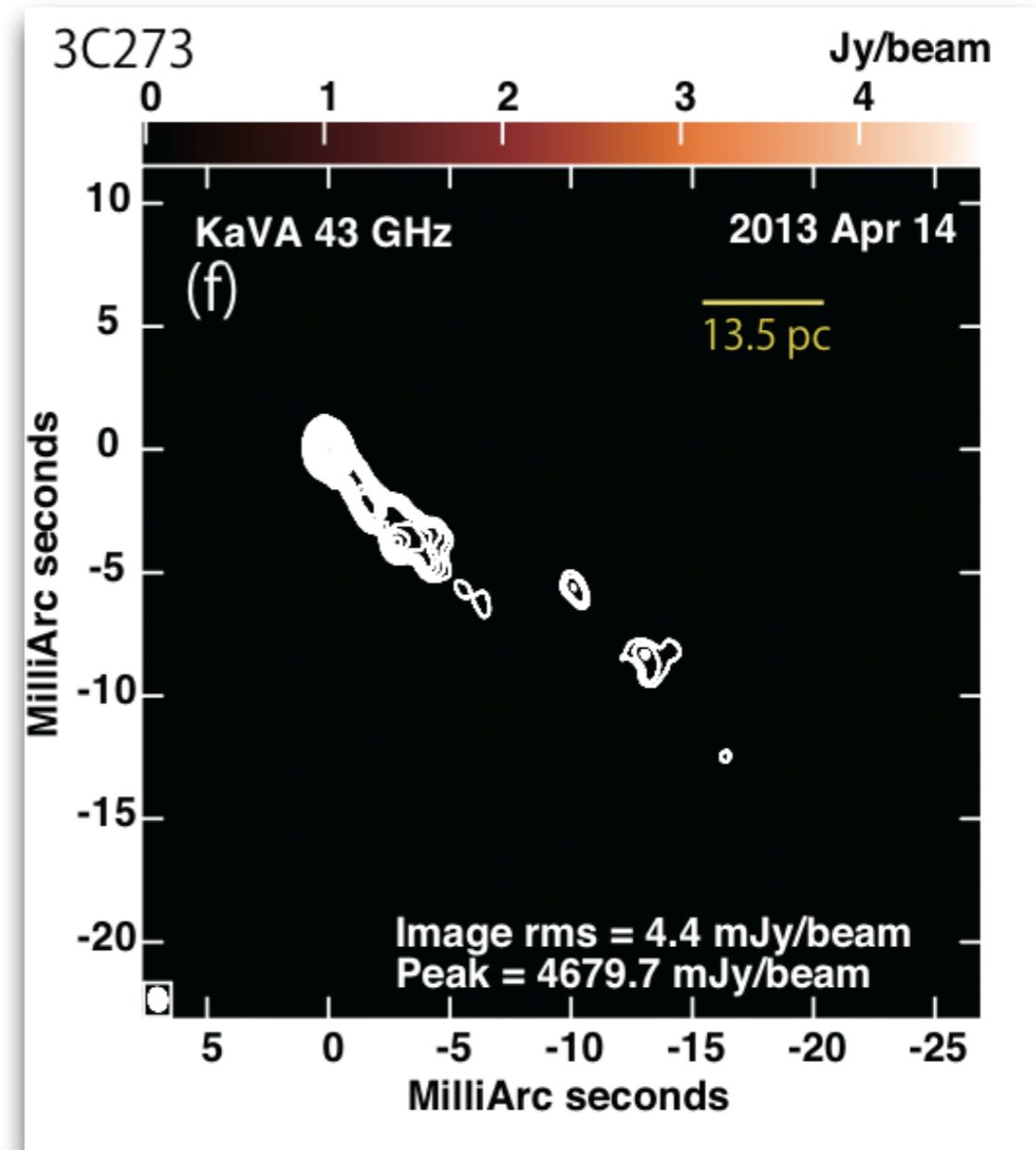
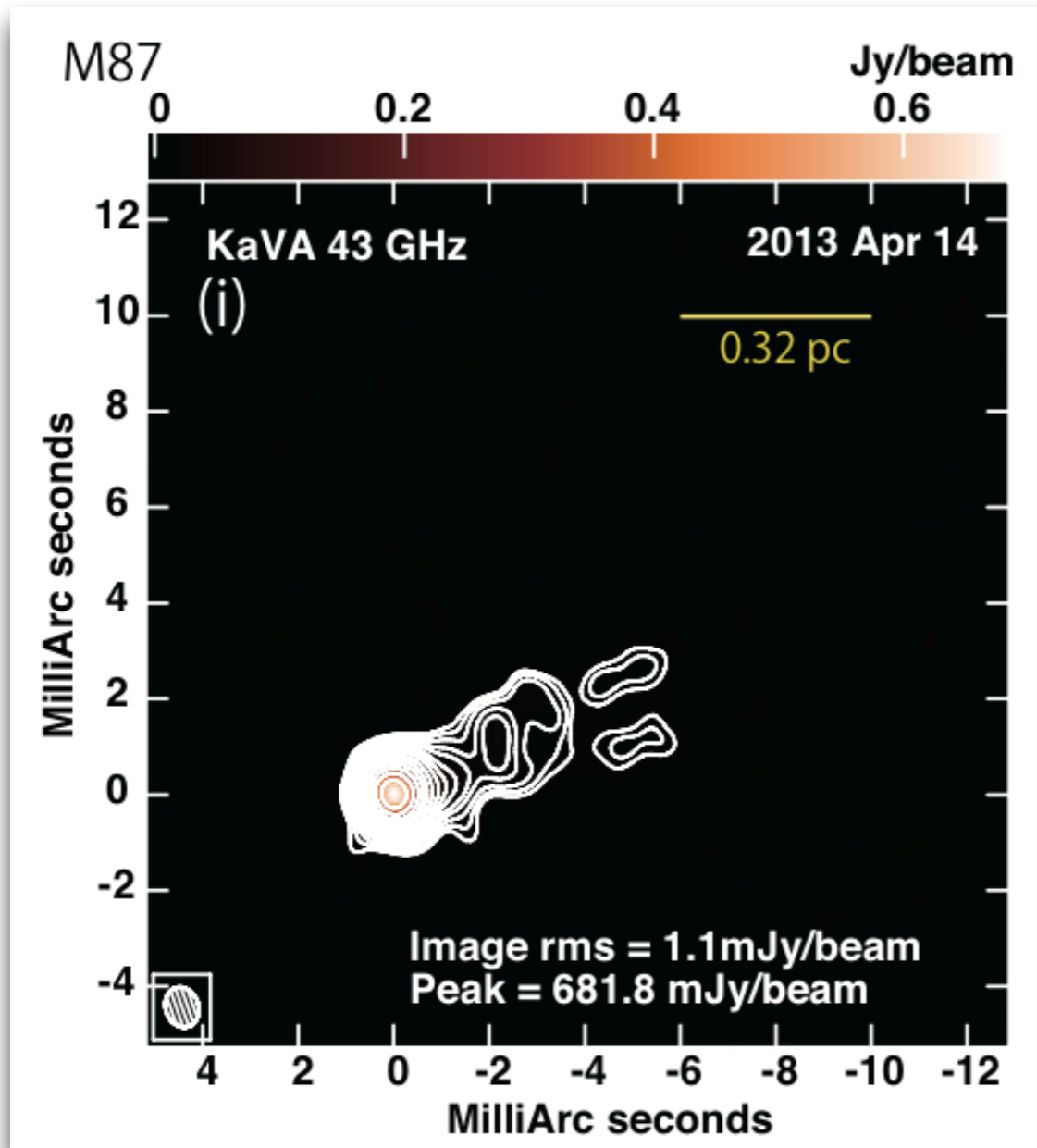
gamma-ray
enhanced emission
simultaneous to core
total intensity peak
and polarization
jump



stable EVPA, with core
magnetic field
perpendicular to jet axis;
hints of limb brightened
polarization structure



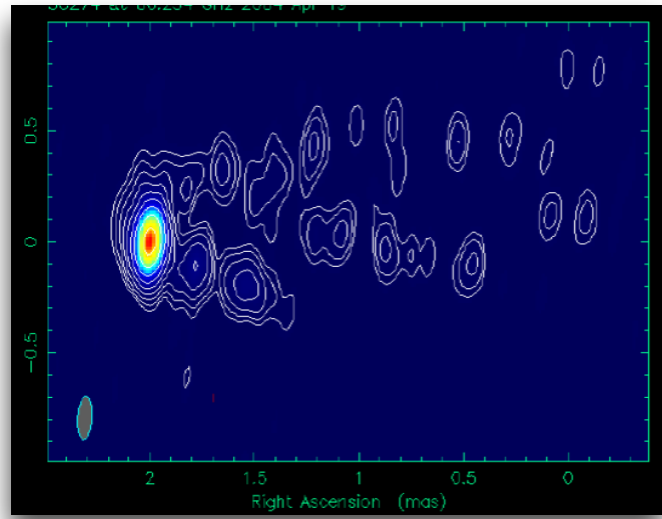
...and more!



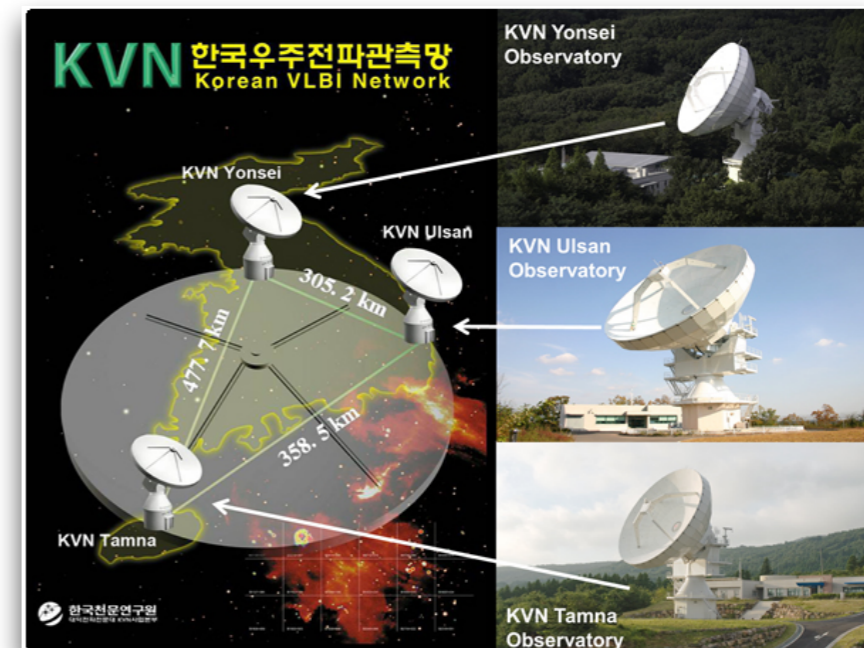
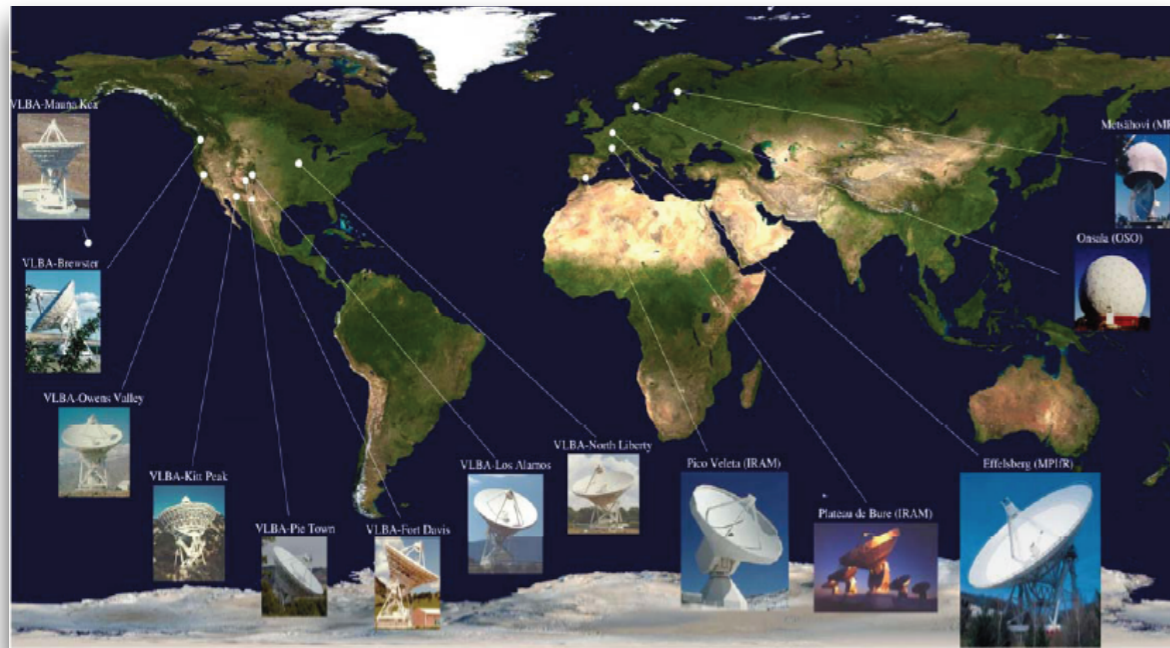
- KVN+VERA is providing excellent imaging capabilities (Niinuma et al.)

Part II:

86 GHz blazar studies



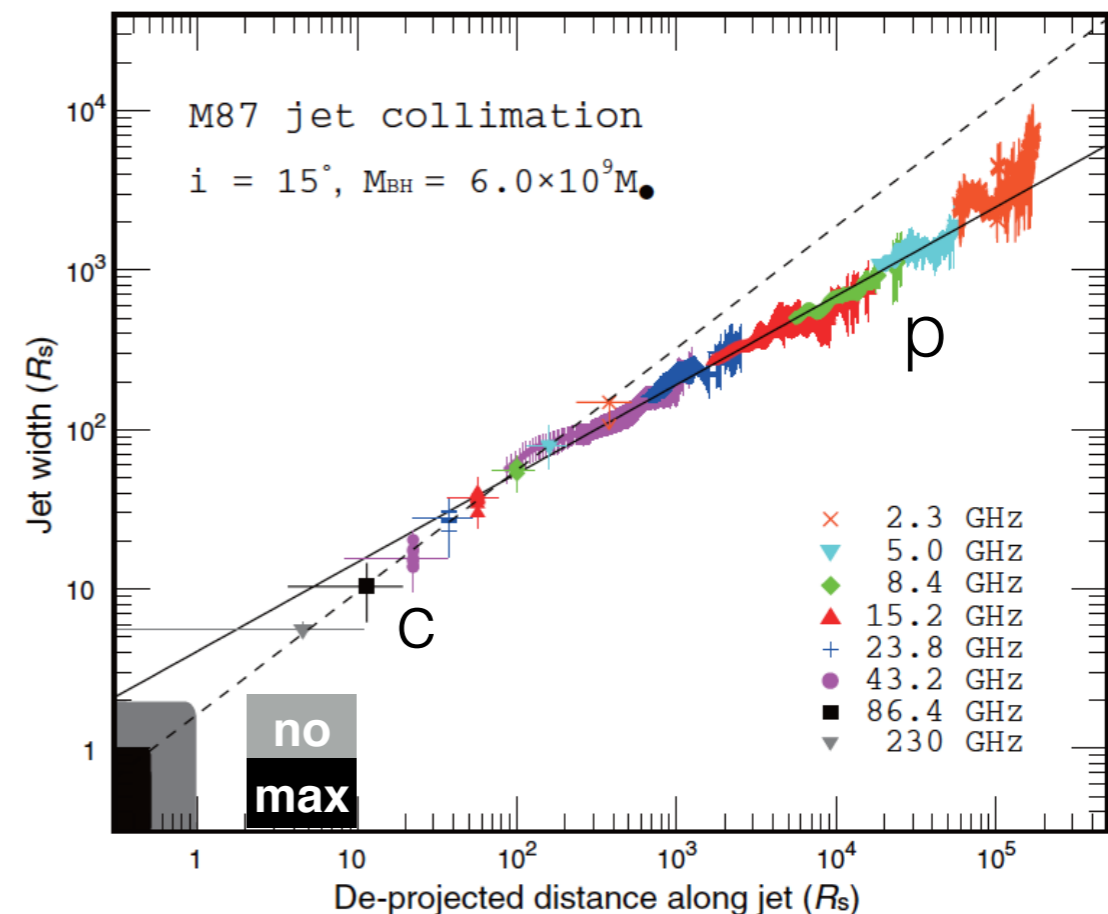
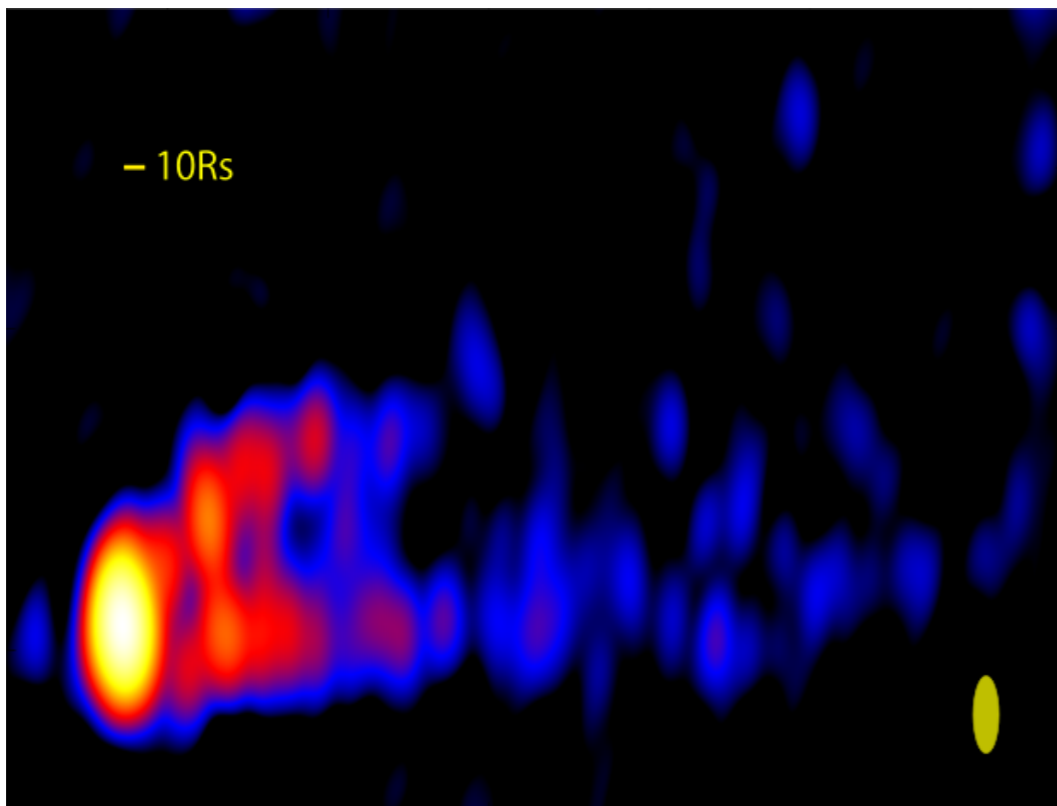
- Science becomes potentially even more interesting
- Challenging conditions (atmospheric stability and telescope accuracy) affect observations



M87 with VLBA+GBT

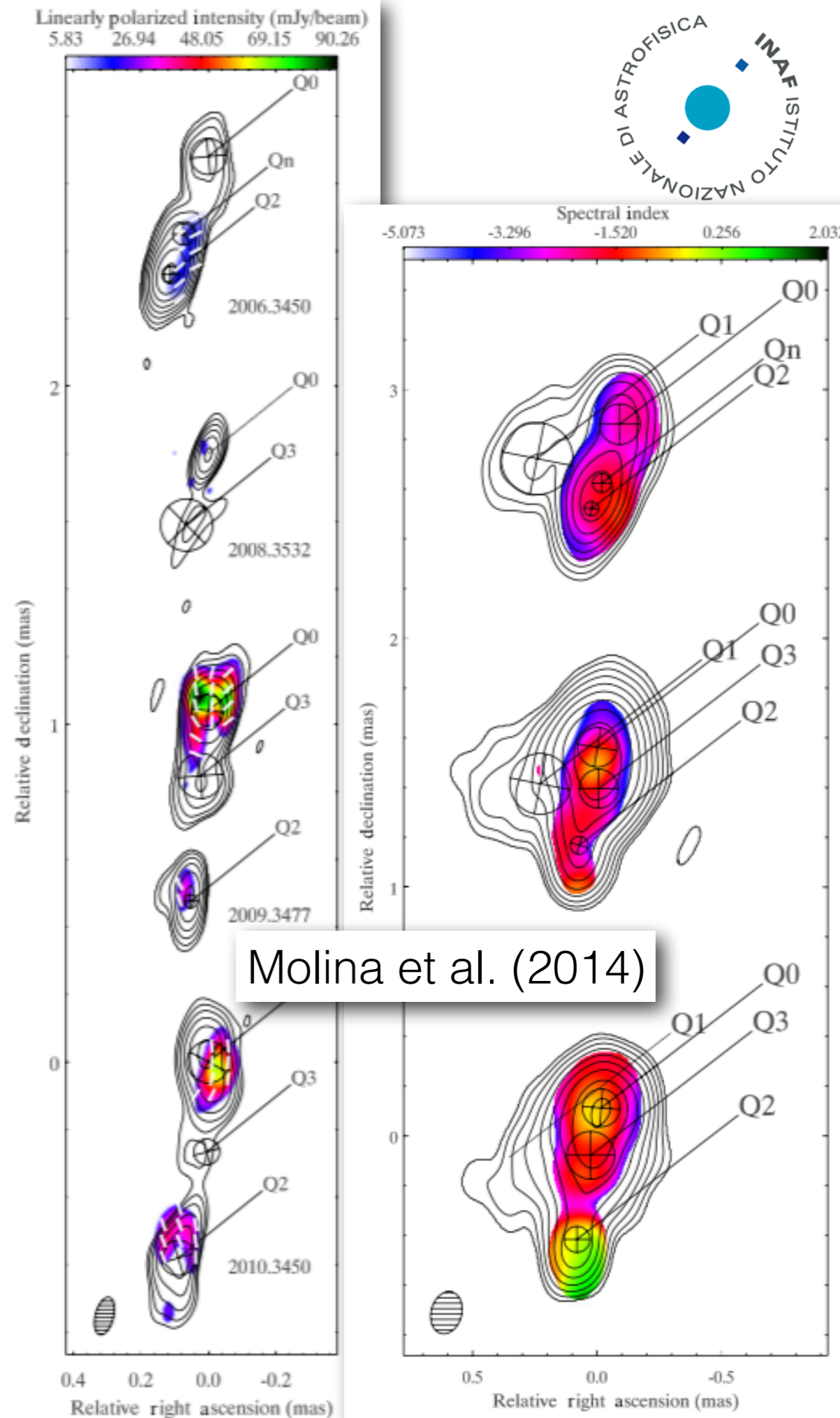
(courtesy of K. Hada, NAOJ)

- location of black hole, through astrometry (Hada et al. 2011)
- discriminate between conical or parabolic jet width profile and max or no spinning black hole (Hada et al. 2013)
- role of magnetic field in jet launch, though polarisation (in progress)



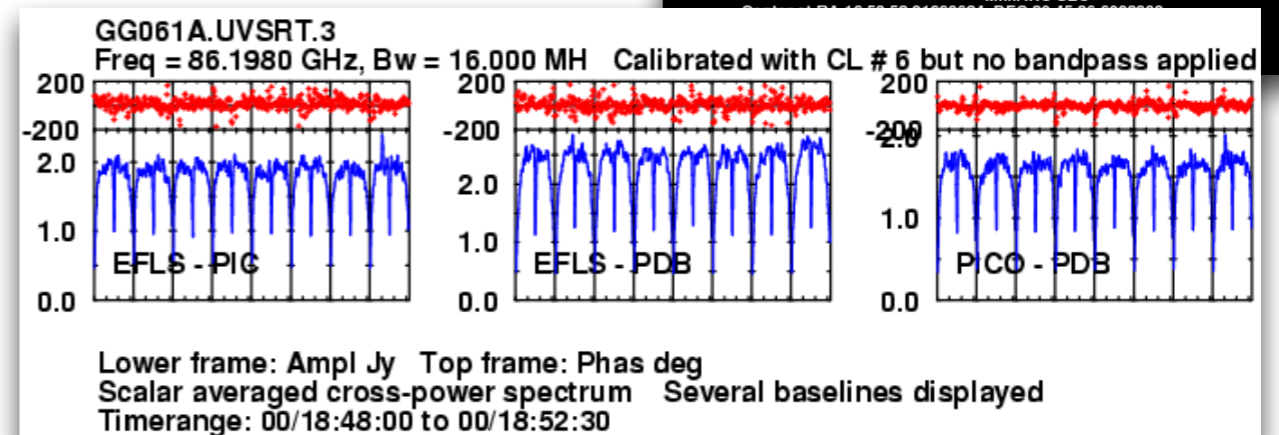
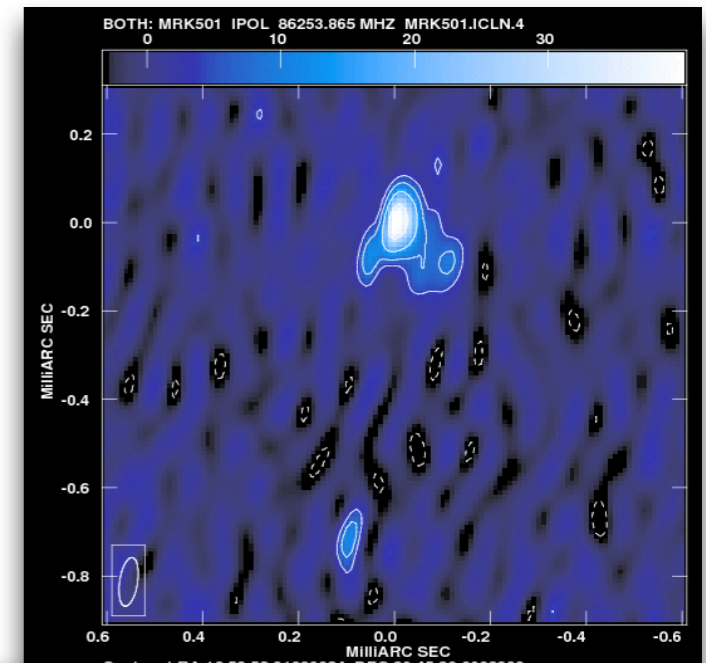
NRAO 150

- $z=1.52$ quasar with fast CCW inner jet rotation (Agudo et al. 2007)
- 8-86 VLBA+GMVA campaign permit to study evolution of structure, linear polarisation, and spectral index
- jet rotating, and seen at very small angle
- no clear core feature
- toroidal magnetic field



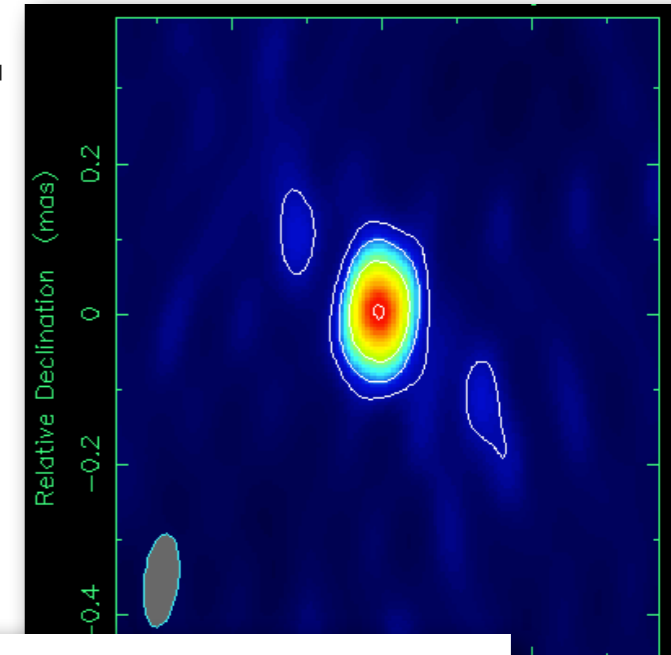
TeV blazars, e.g. Mrk501

- TeV blazars ~ high synchrotron peaked, radio faint, BL Lac type objects: **high linear resolution** (near), **difficult detection and imaging** (faint)
- Lorentz factor crisis: jet velocity structure?
- In good observing conditions, we find hints of limb brightening and position angle changes in Mrk501 (Giroletti et al. 2008)
- can we confirm it?

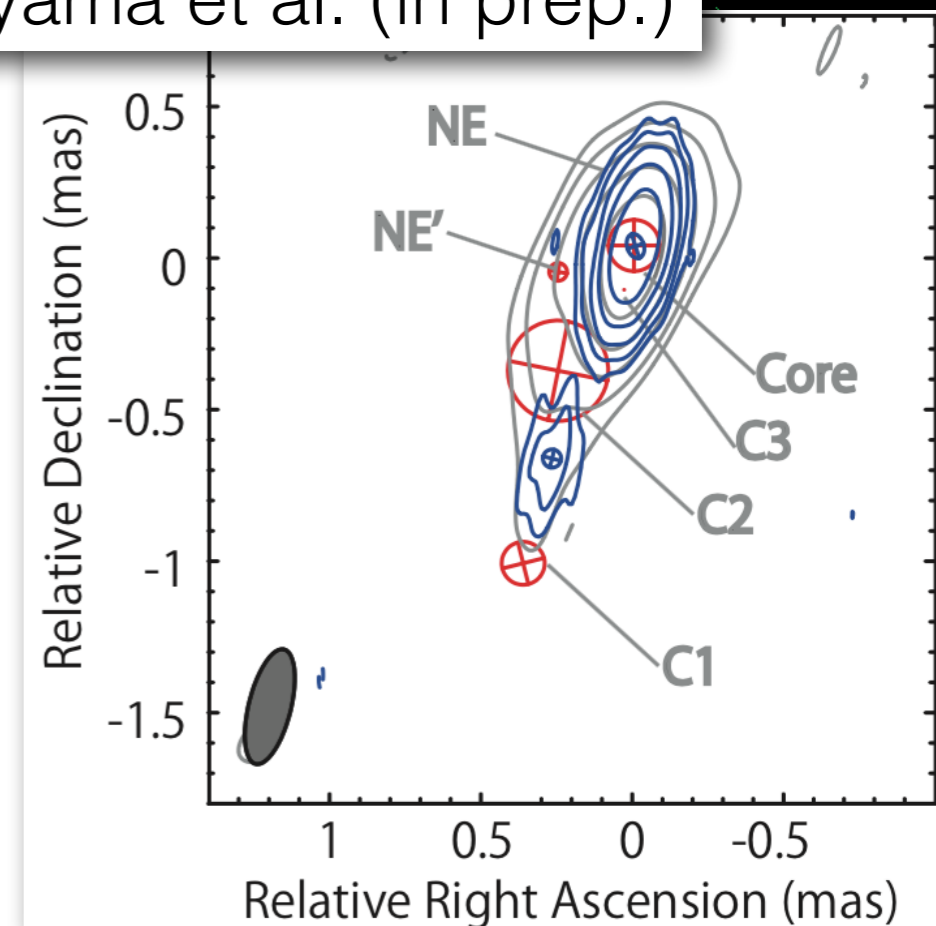


on the importance of sensitive stations...

- two more attempts (2010, 2012) to observe Mrk501 with GMVA did not encounter favorable observing conditions
- the source is detected on shorter baselines, but transatlantic fringes are very difficult when sensitive stations are missing

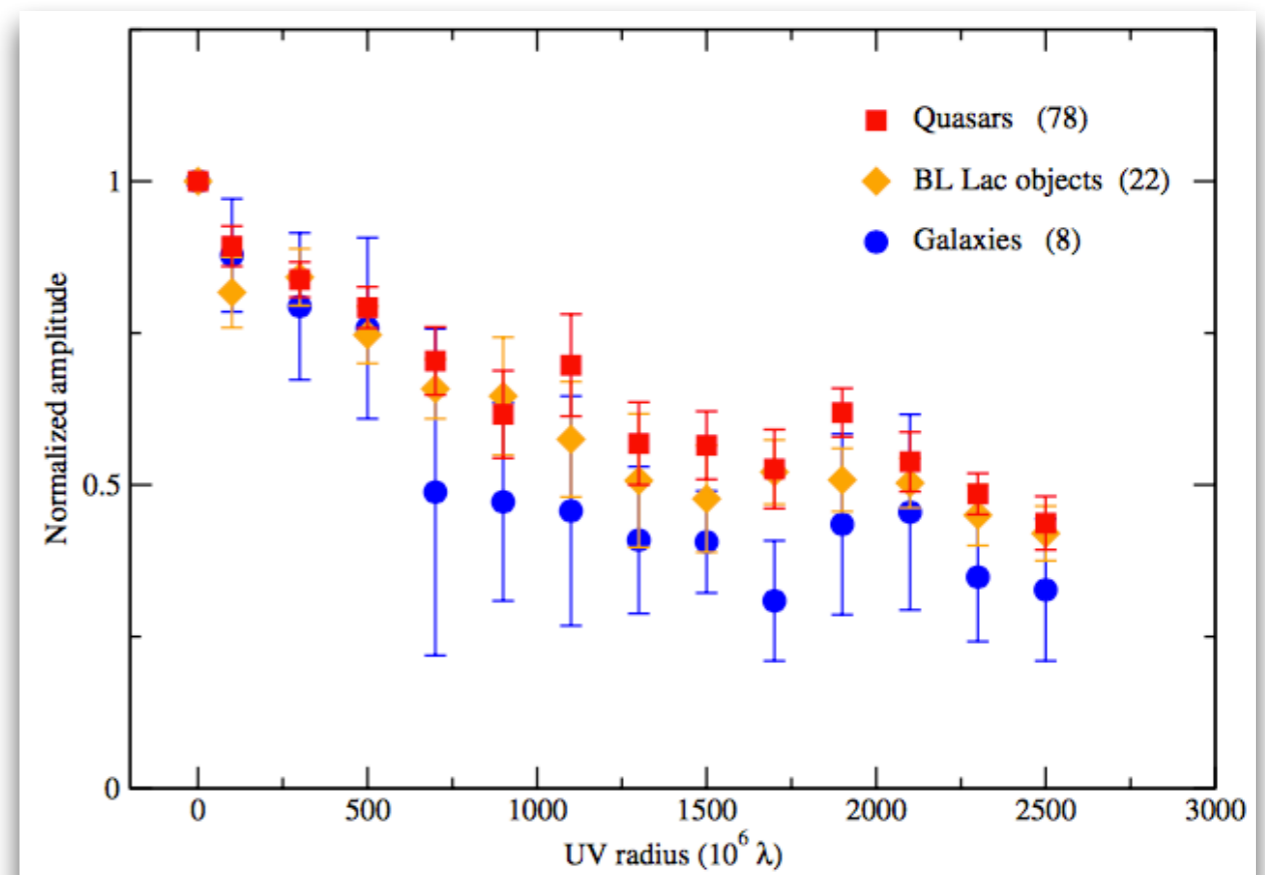


Koyama et al. (in prep.)



86 GHz VLBI survey (*Lee et al. 2008*)

- snapshot mode, single baseline sensitivity of ~ 0.1 Jy; image sensitivity < 10 mJy beam $^{-1}$
- 127 radio sources (88 quasar, 25 BL Lacs, 11 radio galaxies); 109 images, 90 of which first timers
- 77 resolved cores, 32 unresolved
- blazars more compact than radio galaxies
- median $T_b = 7 \times 10^{10}$ K

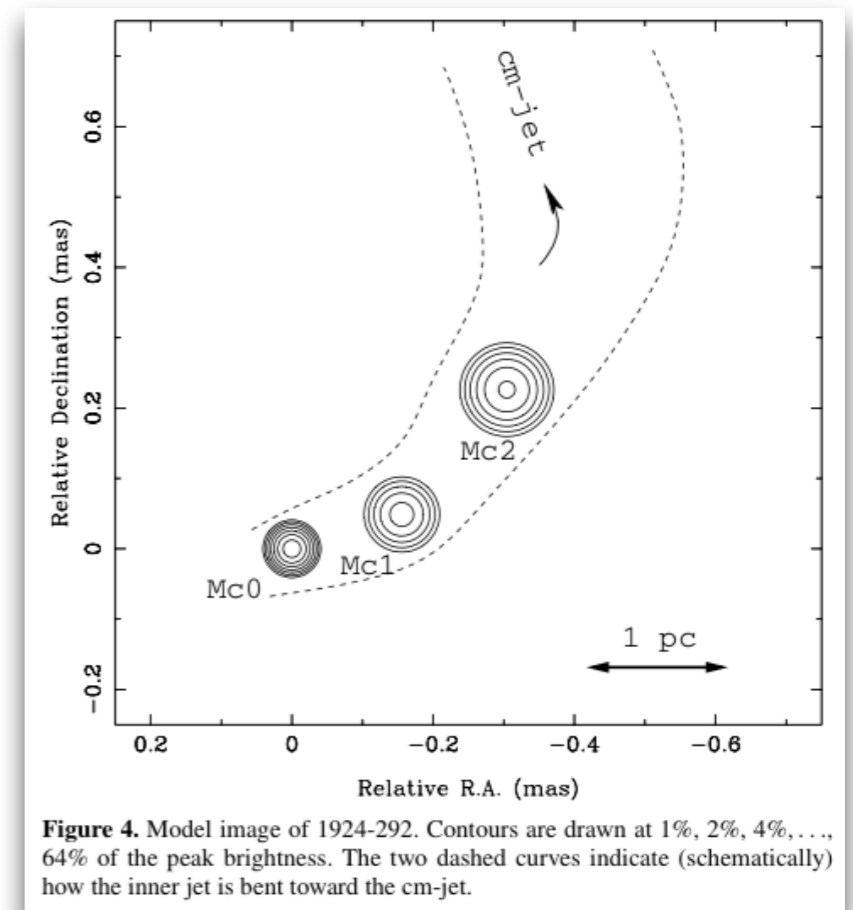


Part III:

230 GHz blazar studies

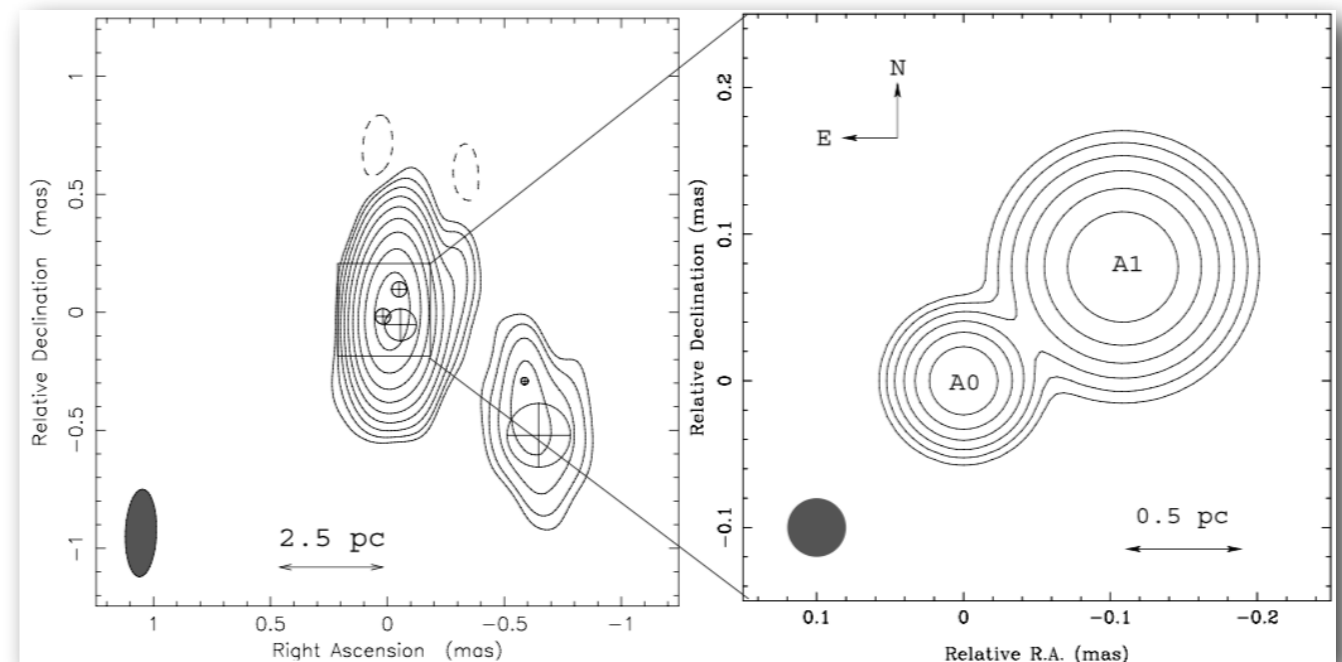
Resolving the inner jet structure of 1924-292 with the EHT (*Lu et al. 2012, ApJL*)

- First 1.3 mm VLBI **model image** of a blazar jet using closure phase technique
- four element array (JCMT, SMT, 2xCARMA), 2009 April 5-7, ~50 min on source per day
- 0.26mas x 0.06mas beam, coherence time 3-5s
- model with 2 or 3 Gaussian components
- 0.15 pc core, $T_b = 1.2 \times 10^{11}$ K, lower than cm
- viewing angle change, accelerating jet, truly different jet part



Fine-scale structure of the quasar 3C 279 measured with 1.3 mm VLBI (*Lu et al. 2011, ApJ*)

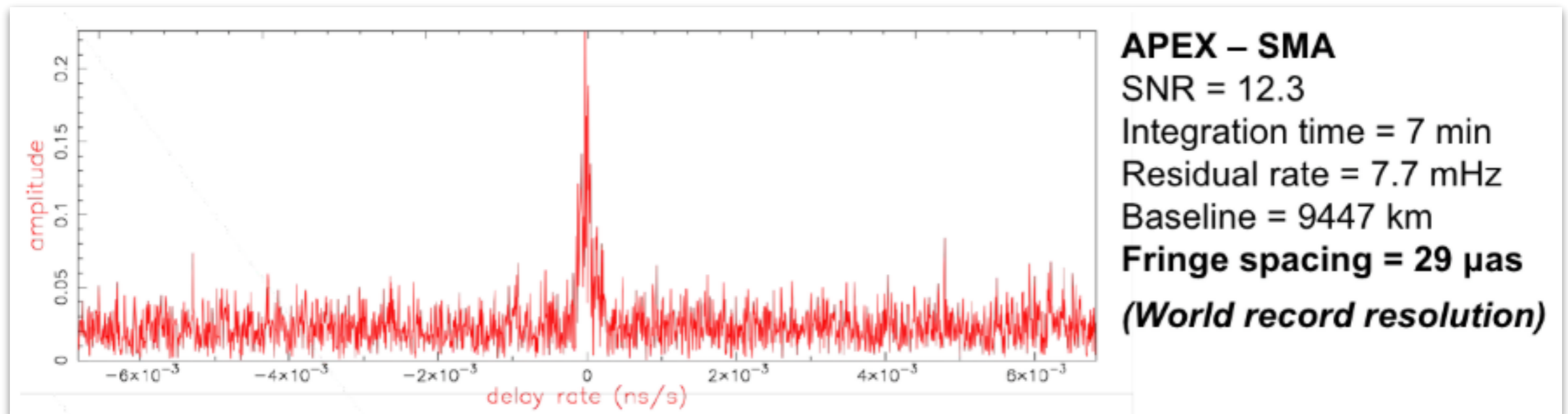
- $z=0.536$ quasar, $1 \text{ mas}=0.6 \text{ pc}$, $0.1 \text{ mas yr}^{-1}=3.2c$
- seven stations/three sites (Hawaii/JCMT-CSO-SMA, CARMA, SMT)
- 5 nights between 2011 days 88-94, with other sources, at 1.3 mm
- 2-comp fit looks good, 3-comp maybe better but difficult to constrain
- good match in comp. position and size to \sim simultaneous 7mm VLBA data
- $T_b=8 \times 10^{10} \text{ K}$, lower than cm
- jet PA different from cm- λ data, possibly because of precession
- closure phase on d94 significantly different from dd88-92



...includes simulations, more later...

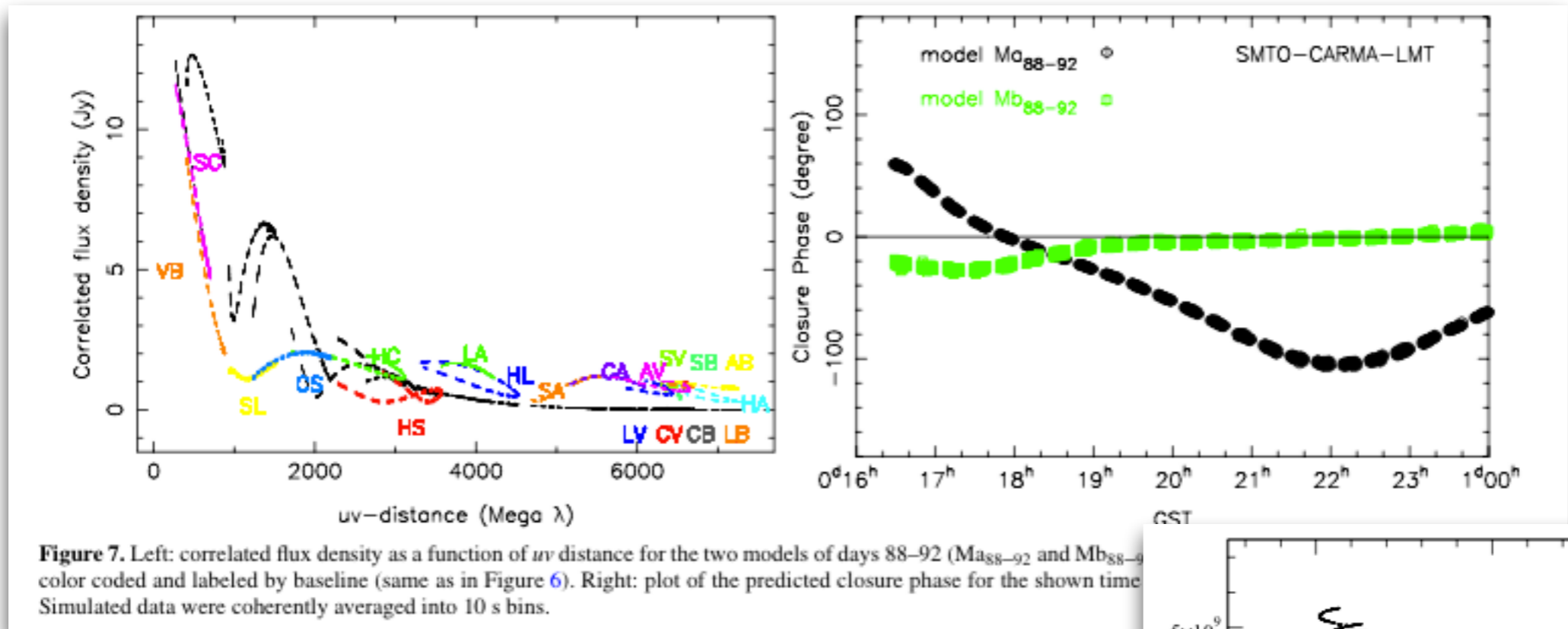
more on blazars @1mm

- Roy et al. (PoS 11thEVN) report on SMA, SMT0, APEX observations of 3C279
 - fringes are detected to APEX in May 2012, with good SNR and surprisingly long coherence time

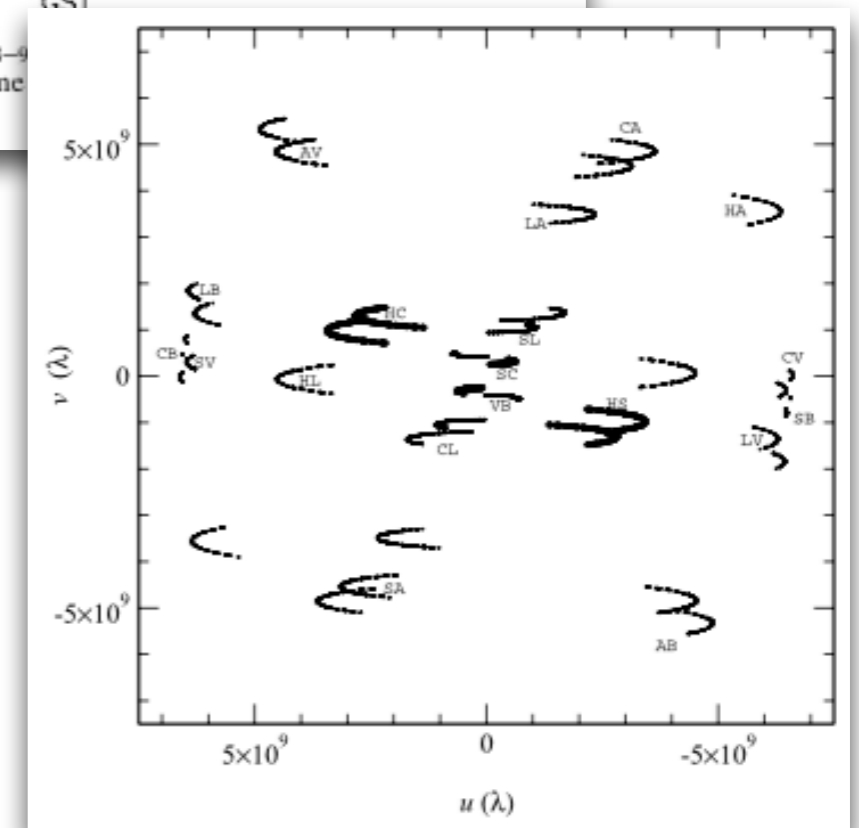


- Krichbaum et al. (2004) report 1mm detection of transatlantic fringes at 1.3 mm in two blazars (3C 454.3, 0716+714)
- *Krichbaum talk for more 1mm VLBI with APEX*

...and beyond



- In the 3C279 EHT paper, Lu et al. show that an improved uv-coverage would unambiguously discriminate among source image models



Take home notes

- at present, #of observed sources, operating stations, and published papers decreases with increasing frequency
- this really is just the tip of the iceberg
- key observables: **brightness temperatures**, **transverse structures**, **polarization**

