Blazar science with mm-VLBI

Marcello Giroletti, Monica Orienti, Filippo D'Ammando on behalf of the Fermi-LAT collaboration

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

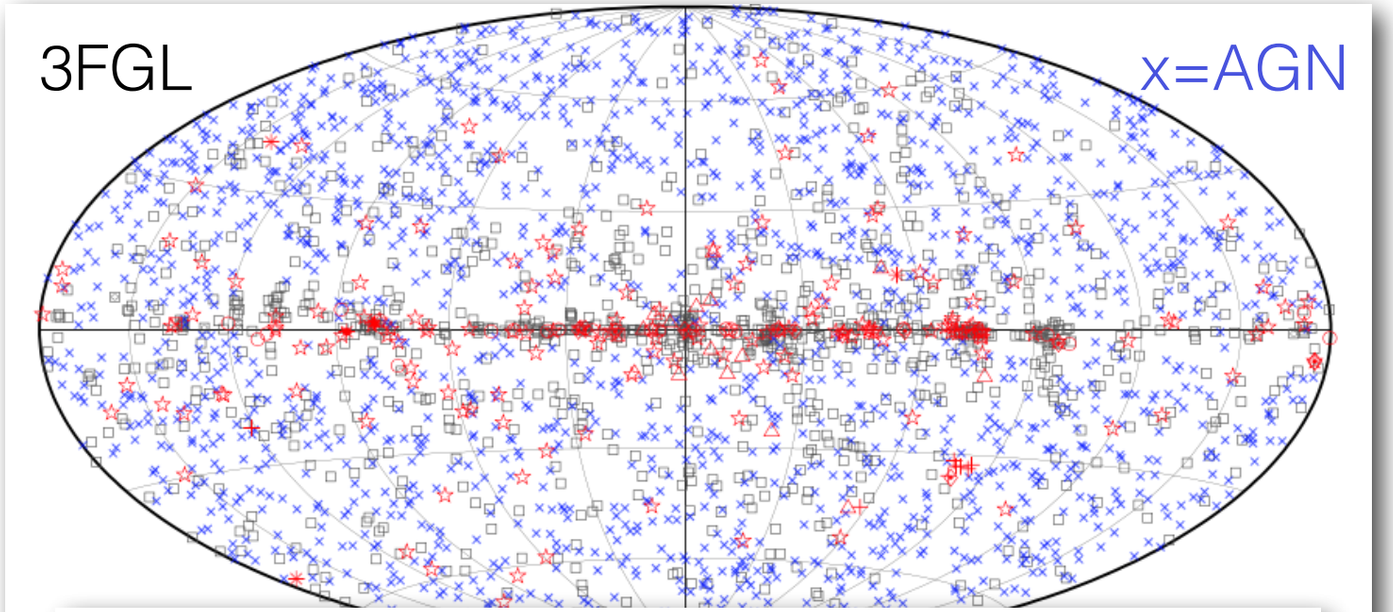
- ~1700 AGNs in the third *Fermi* catalog (**3FGL**), >1100 confirmed blazars

- bright and variable sources also at optical, UV, X-rays, VHE

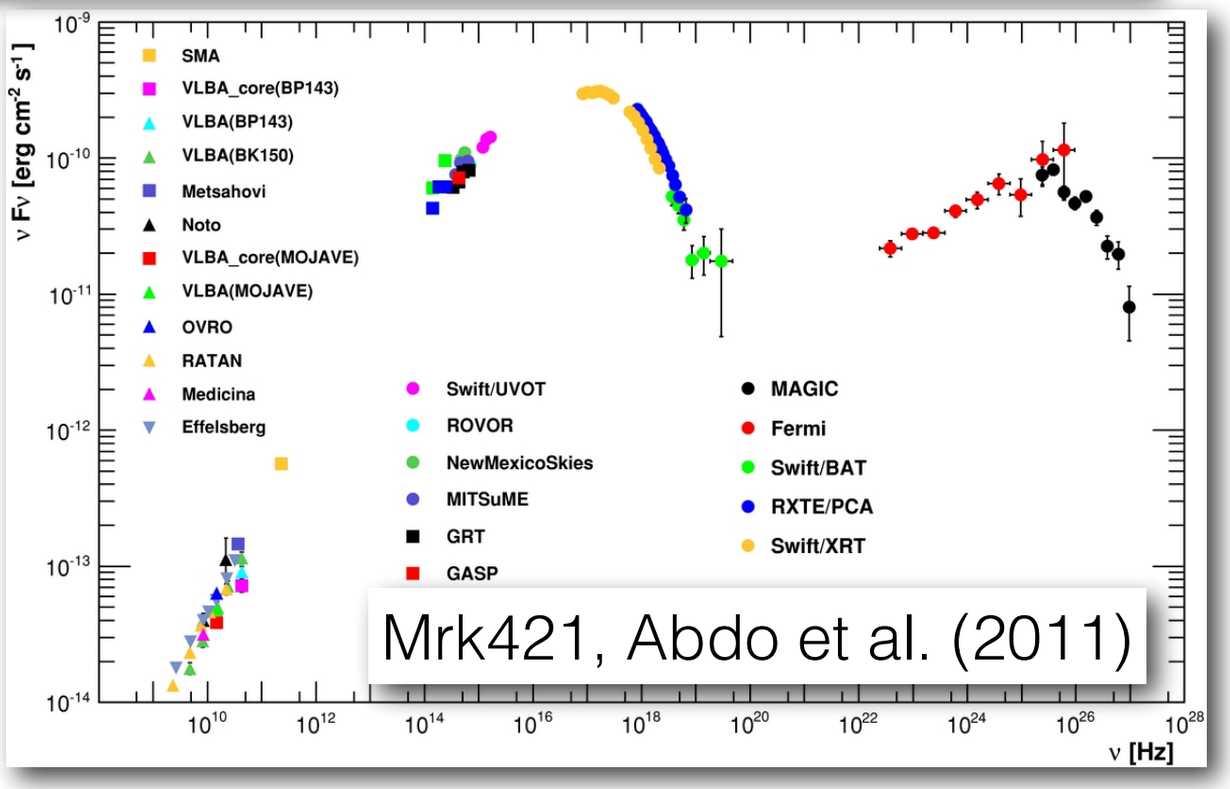
- SED modelling constrains emission region to very compact sizes (<~0.1pc)

- low energy emission: synchrotron

- high energy emission: inverse Compton (SSC, EC, multi-zone, layered jets), hadronic processes?



Fermi-LAT collaboration, arXiv:1501:02003



Mrk421, Abdo et al. (2011)

The connection between radio and gamma-ray emission in blazars

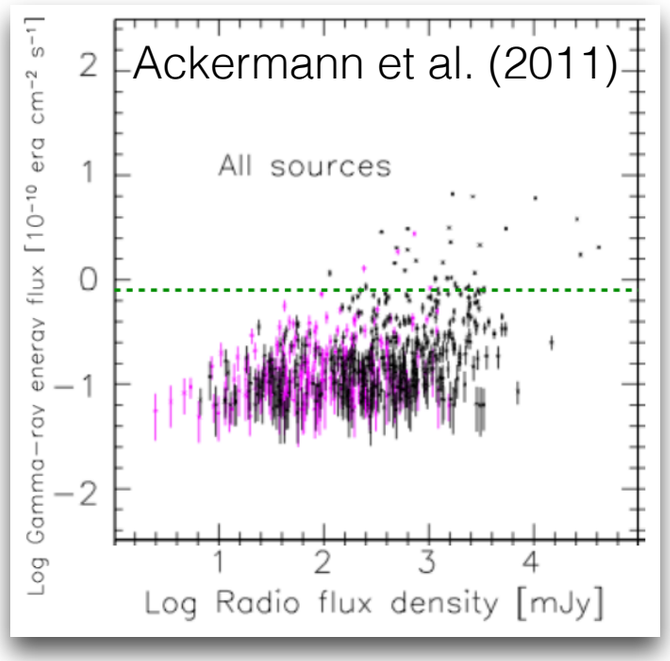
- a highly significant correlation between cm radio and gamma-ray emission is found on a sample of ~600 blazars (Ackermann et al. 2011)

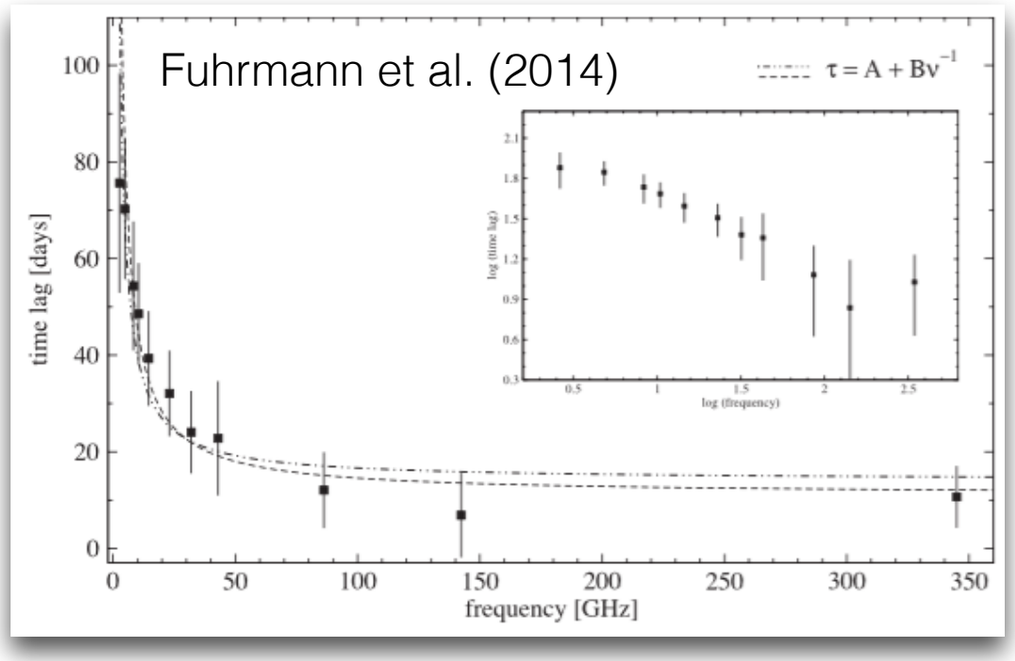
- yet, only one of 41 sources with high-quality light curves in both bands shows correlations with significance larger than 3σ (Max-Moerbeck et al. 2014)

- considering **3mm** data, Fuhrmann et al. (2014) find significant correlation for 9/54 sources

  - and the (stacked) radio-gamma lag decreases from 76±23d at 2.6 GHz to 7±9d at 142 GHz

- and we look forward to a statistical analysis with combined ***Fermi*+ALMA** data (PI Giroletti)

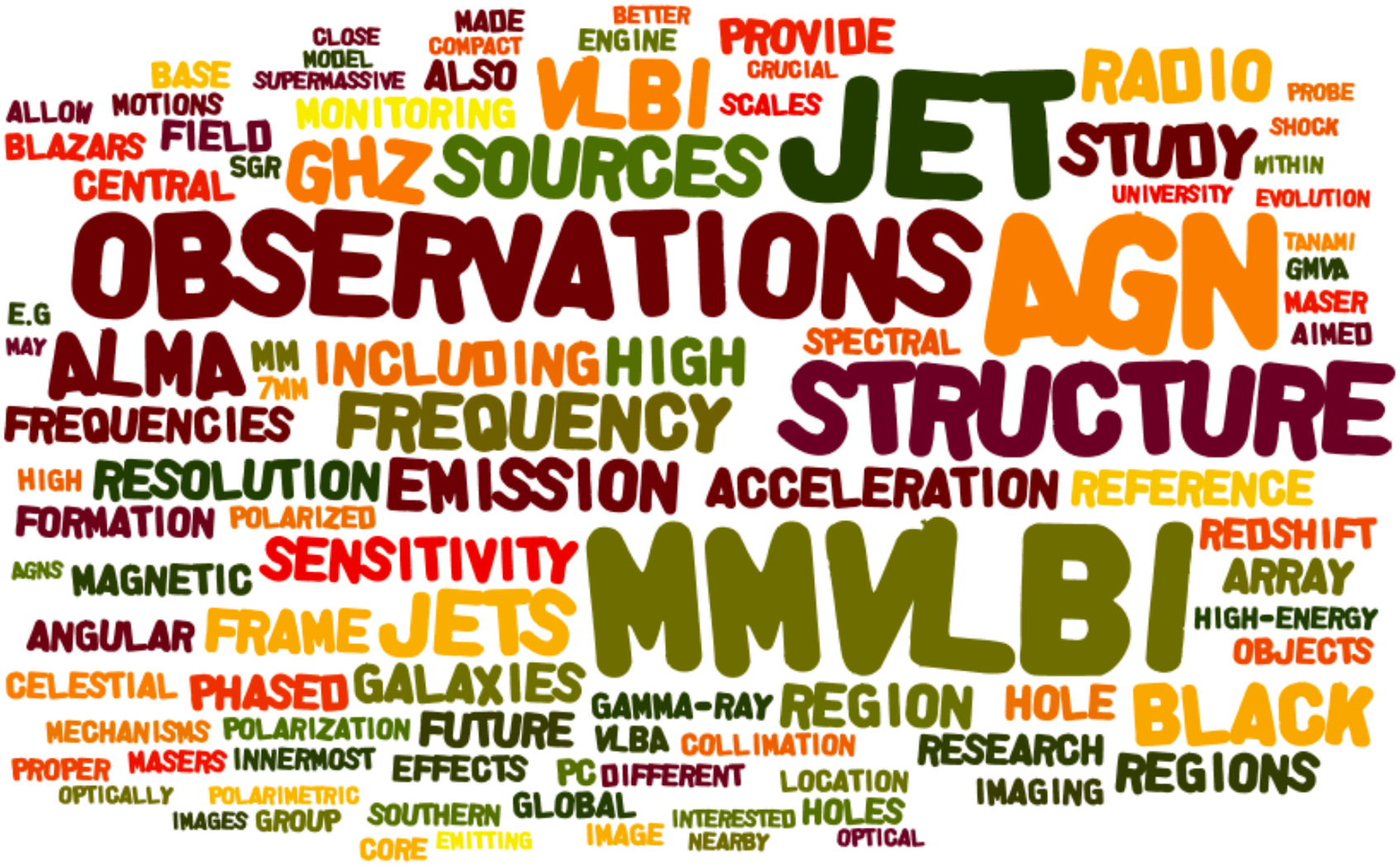




imaging the blazar region

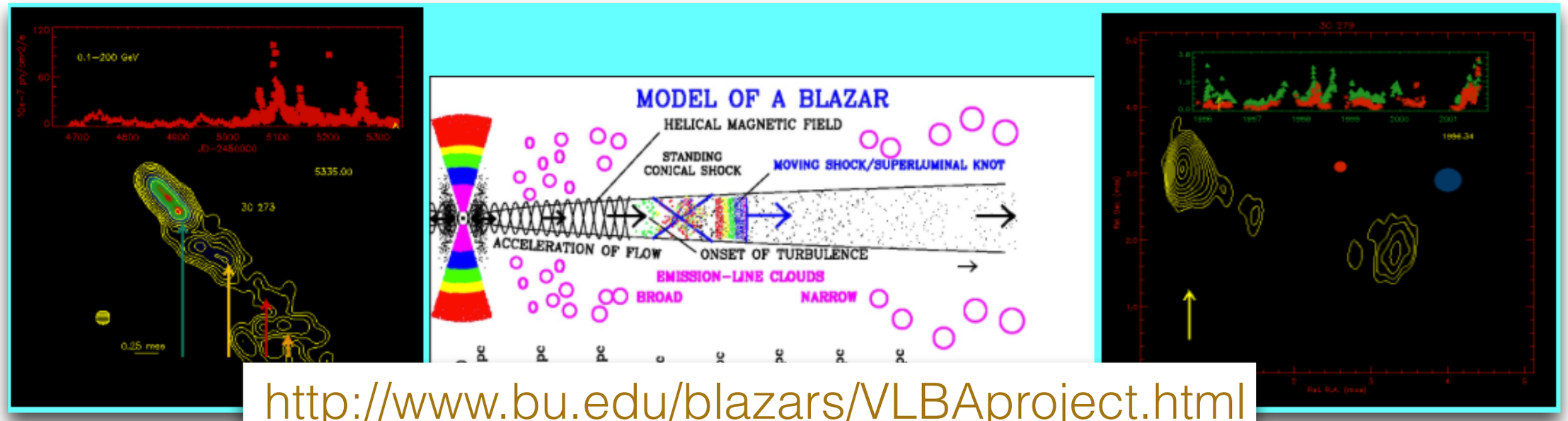
$$\nu_{\max} = e(\alpha)\, H^{1/5}\, \theta^{-4/5}\, S_{\max}^{2/5}\, (1+z)^{1/5}$$

- 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…



- 7mm: VLBA *(and global, some EVN, KaVA)*
- 3mm: GMVA *(and VLBA, KVN)*
- 1mm: towards EHT

Part I: 43 GHz blazar studies

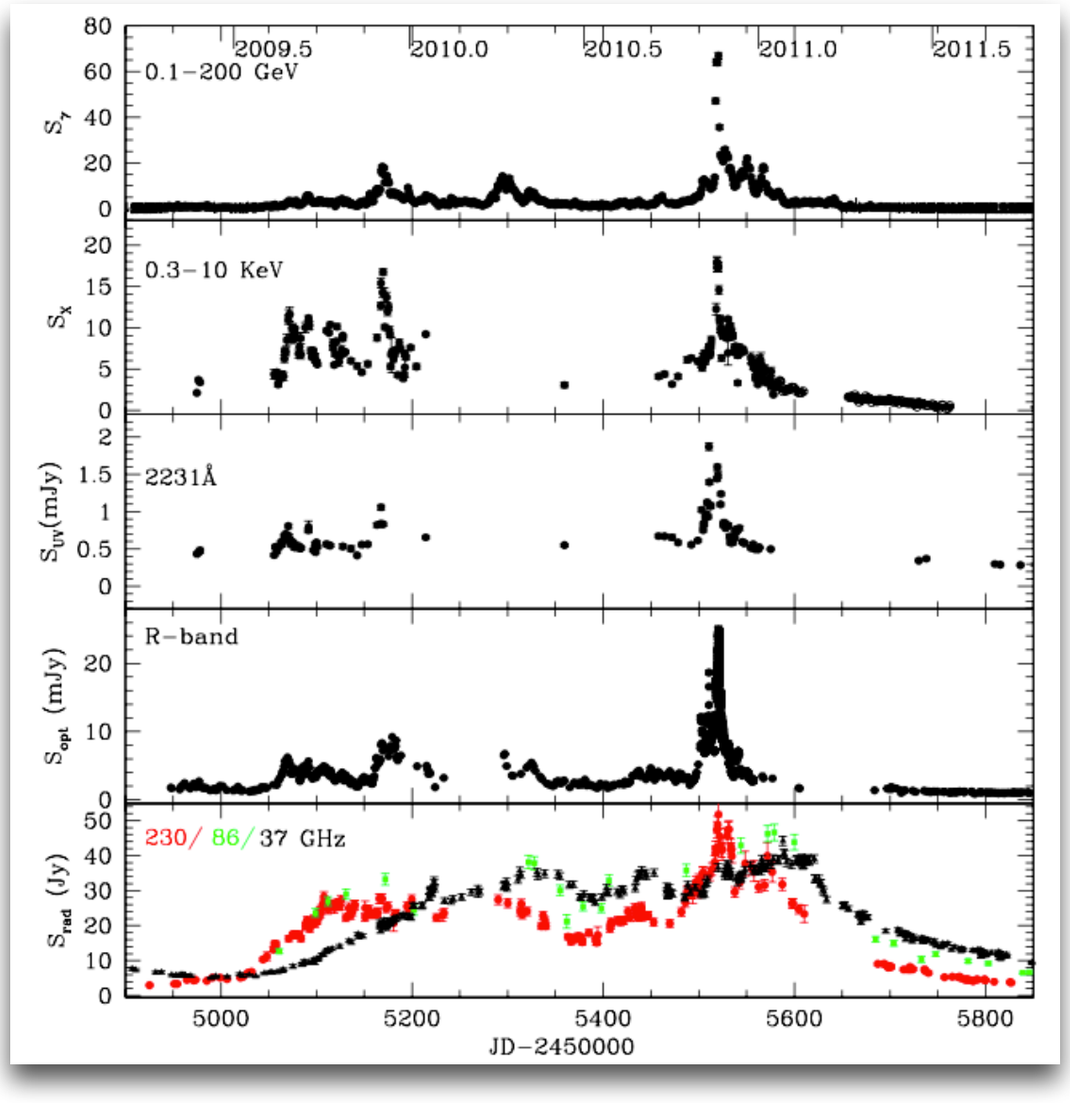


http://www.bu.edu/blazars/VLBAproject.html

- **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

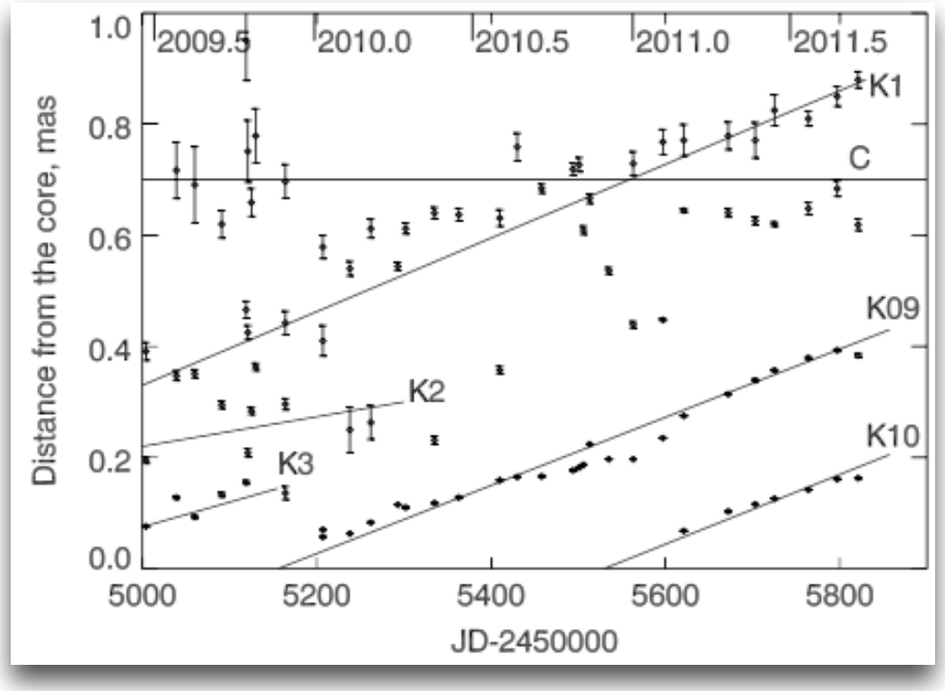


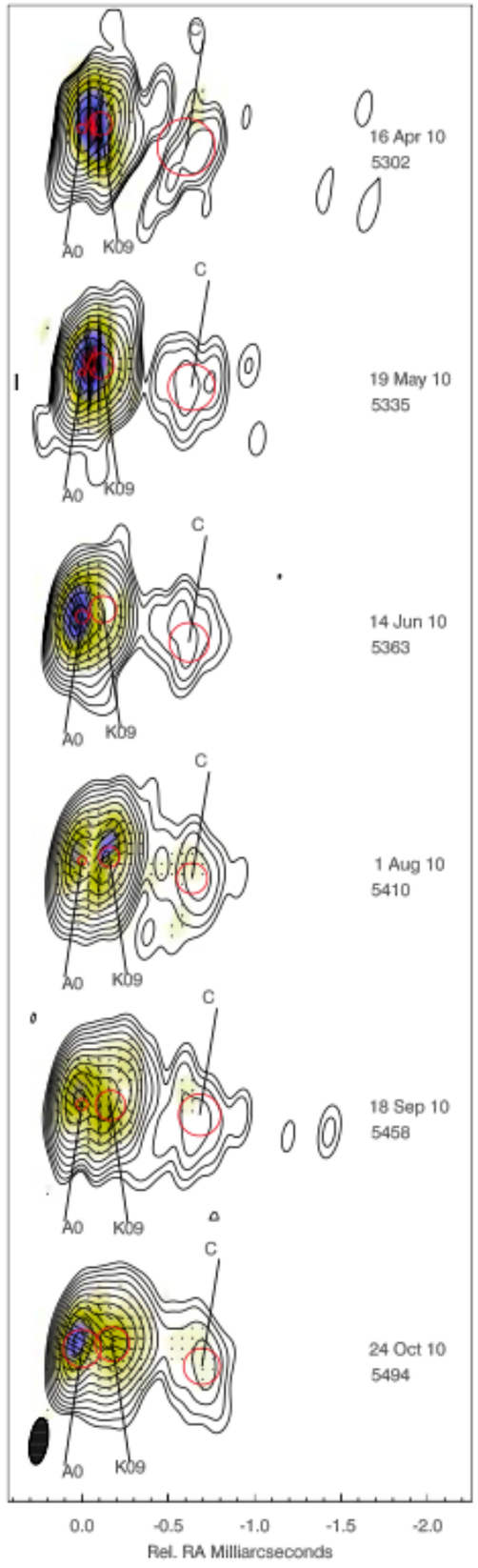
kinematics and high energy connection

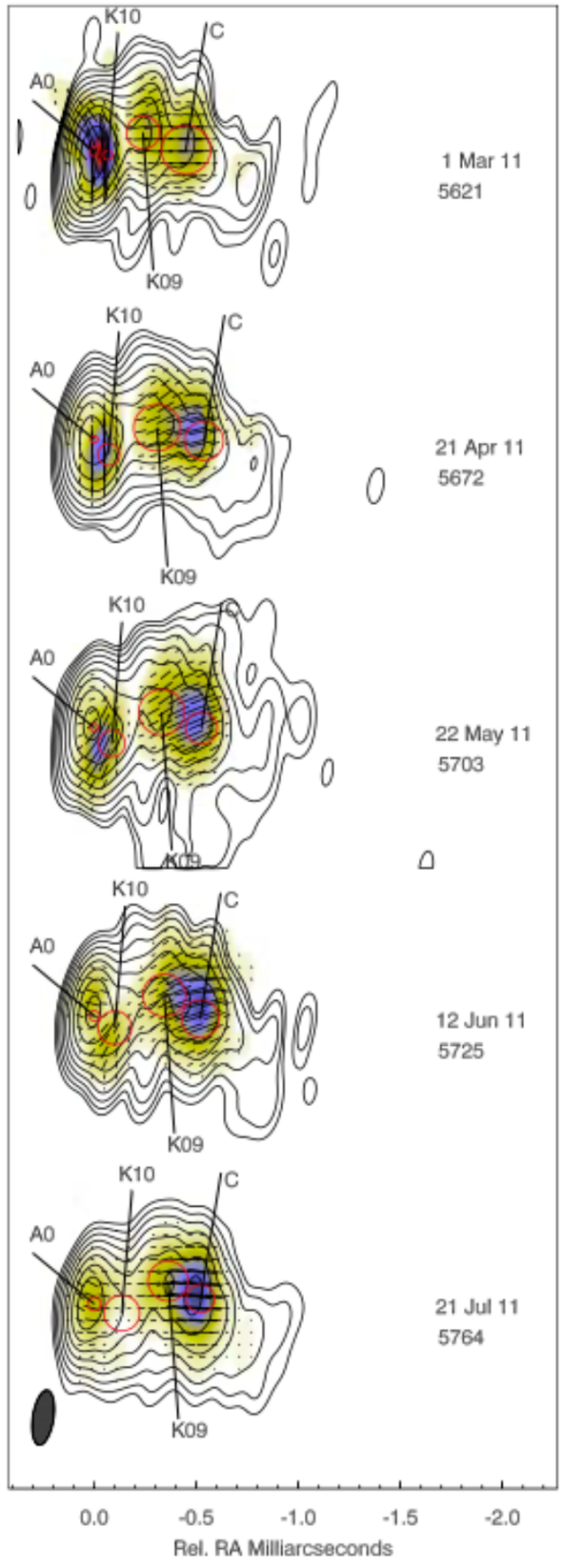
- stationary and “slow” (~3-4c) components

- two faster components (9c) associated to gamma ray flares

- similar average velocity but different trajectories and flux density evolution

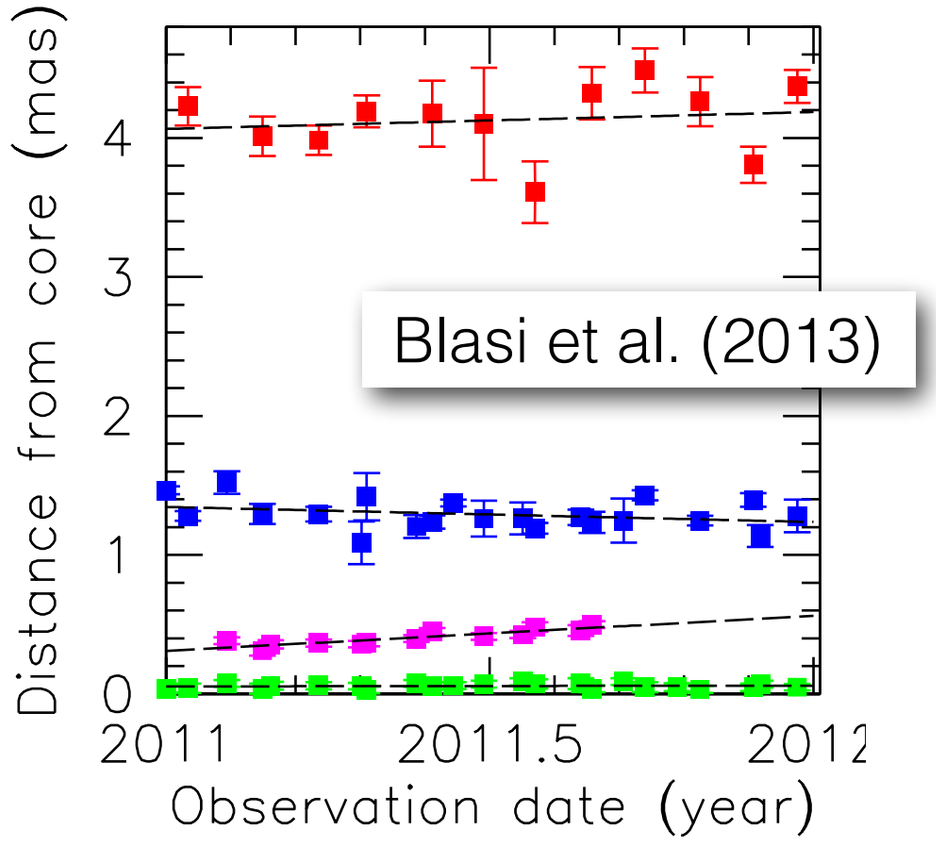




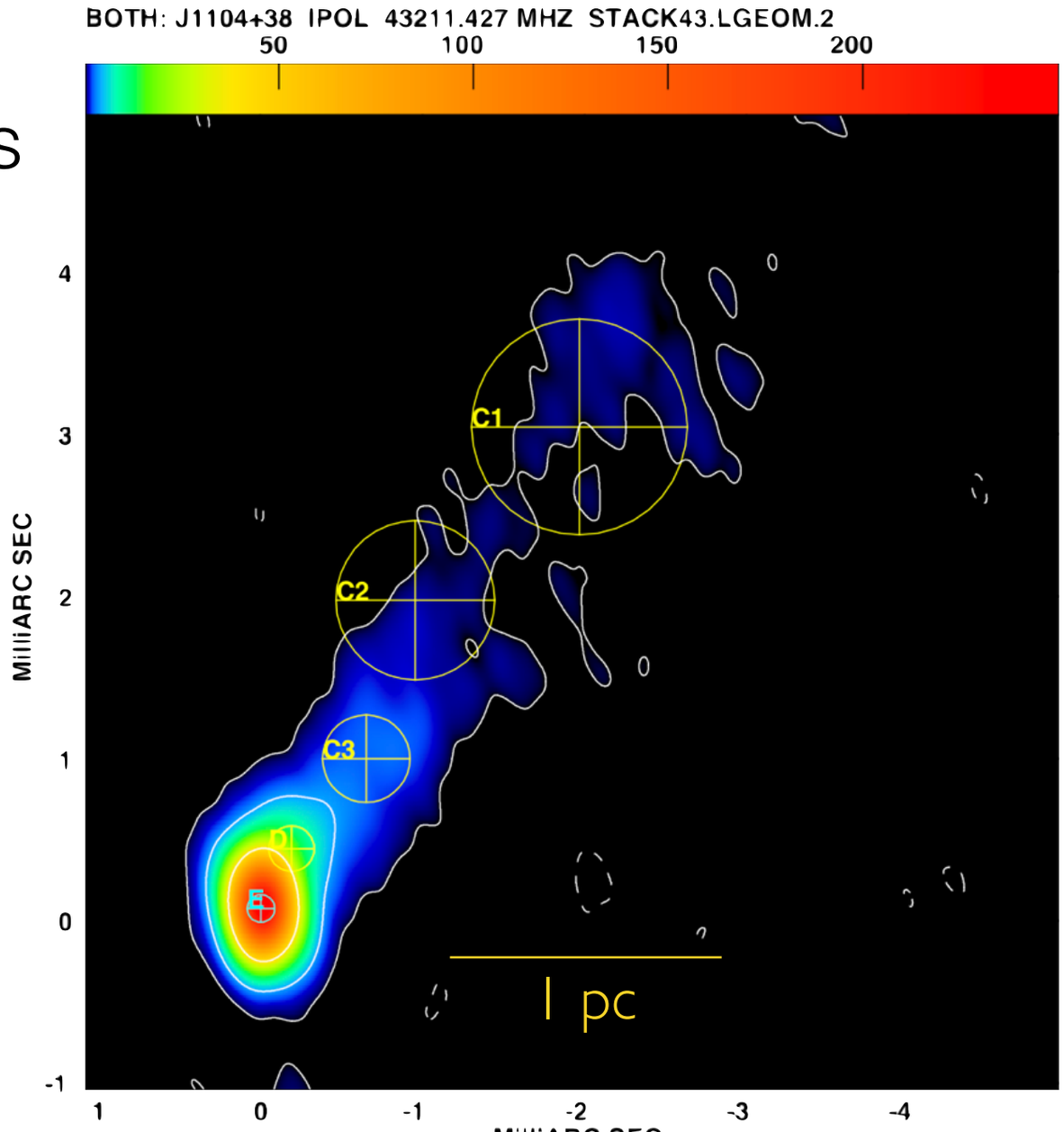


Mrk421, 2011 campaign

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

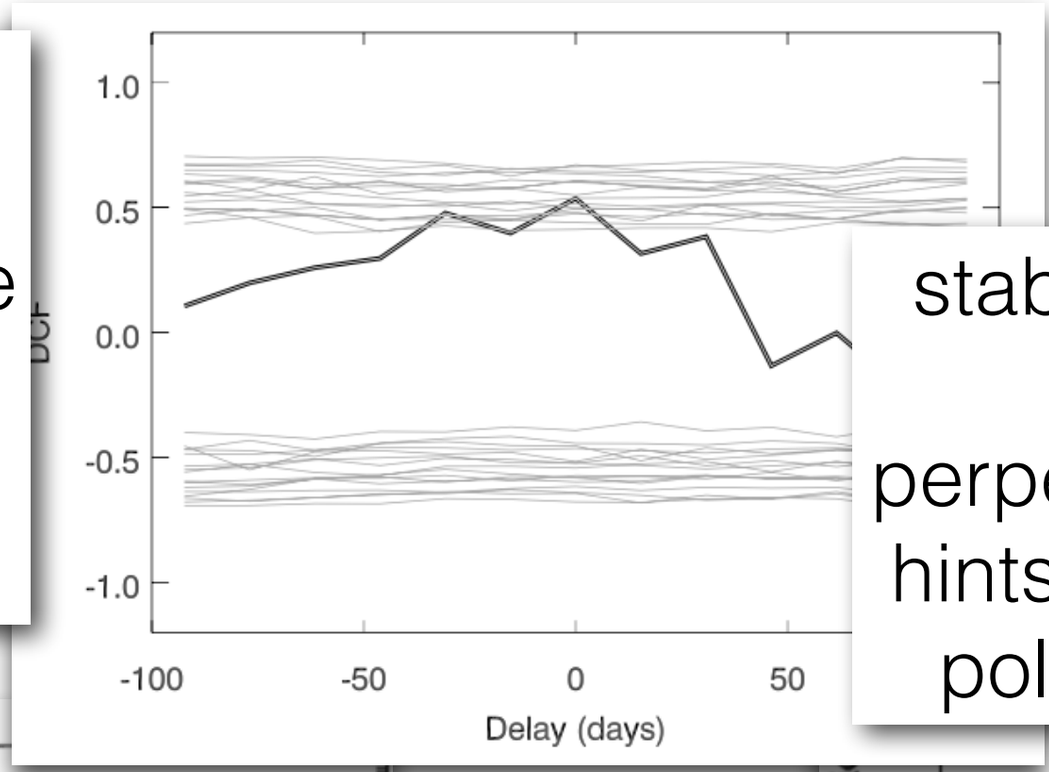


Blasi et al. (2013)

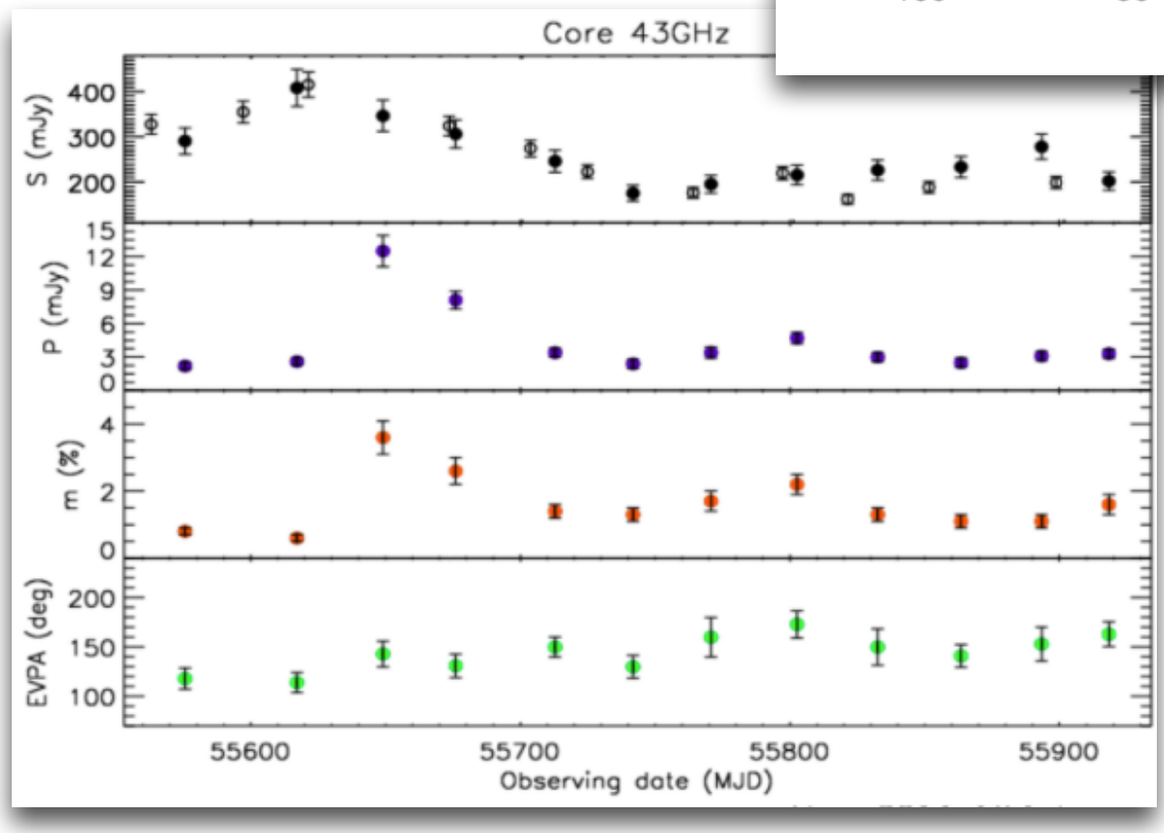


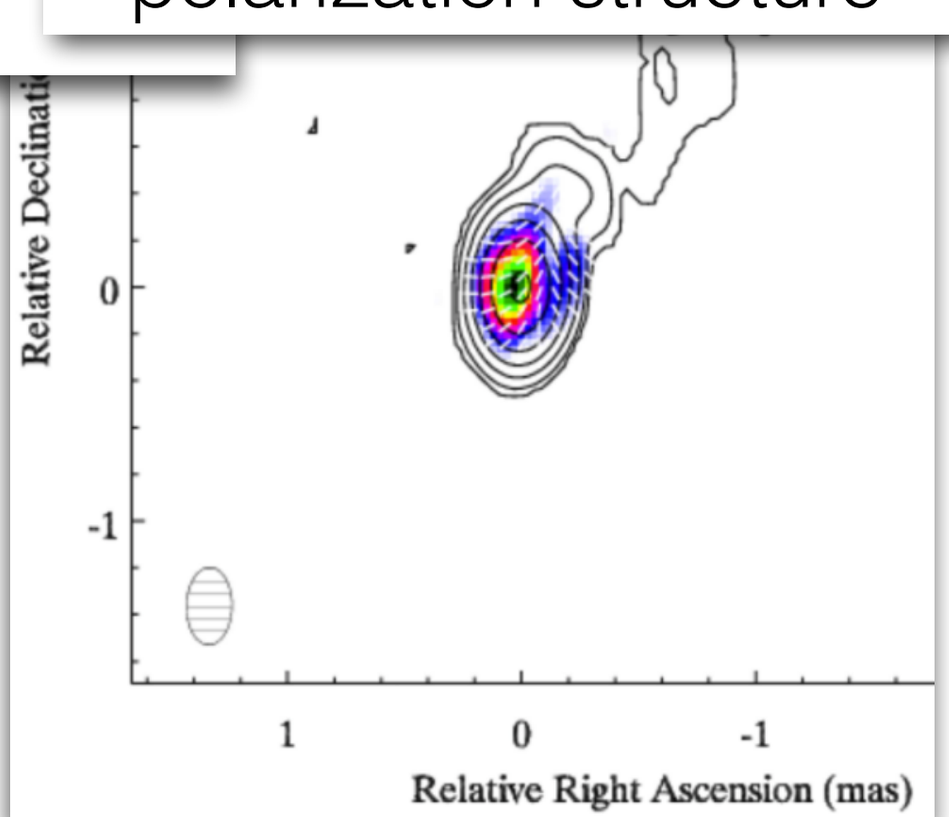
Mrk421, polarization and gamma rays *(Lico et al. 2014, A&A)*

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

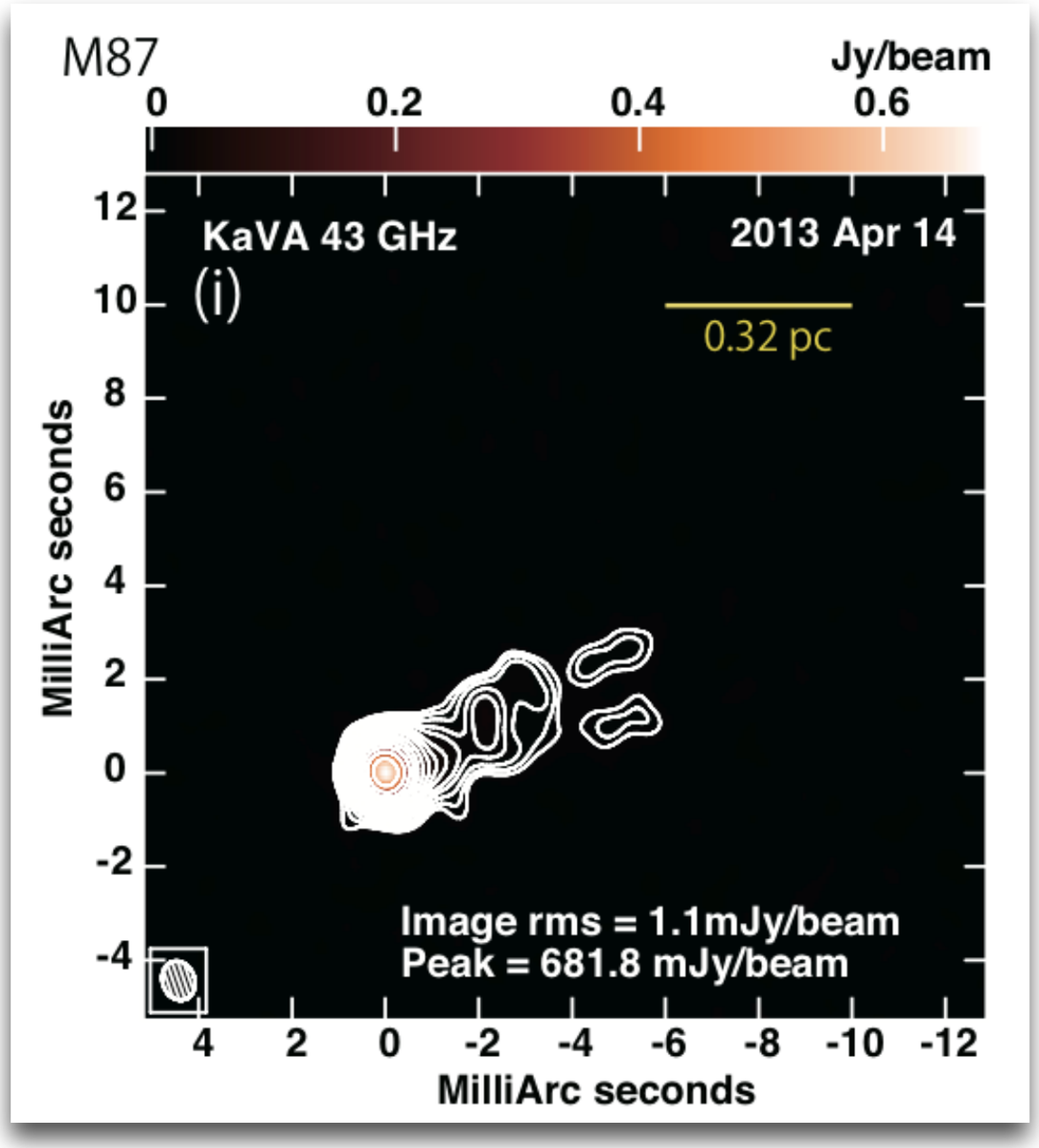


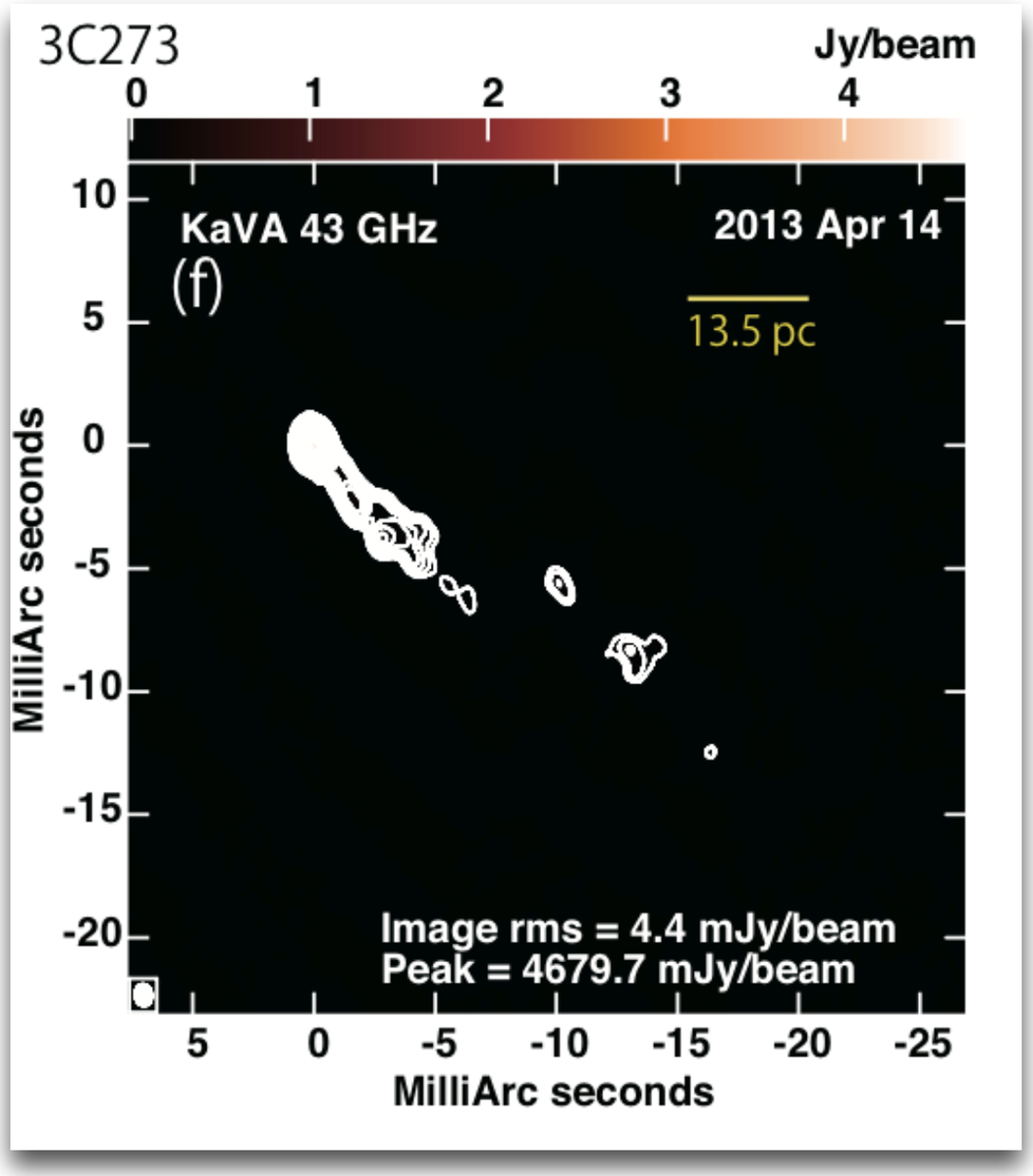
stable EVPA, with core magnetic field perpendicular to jet axis; hints of limb brightened polarization structure





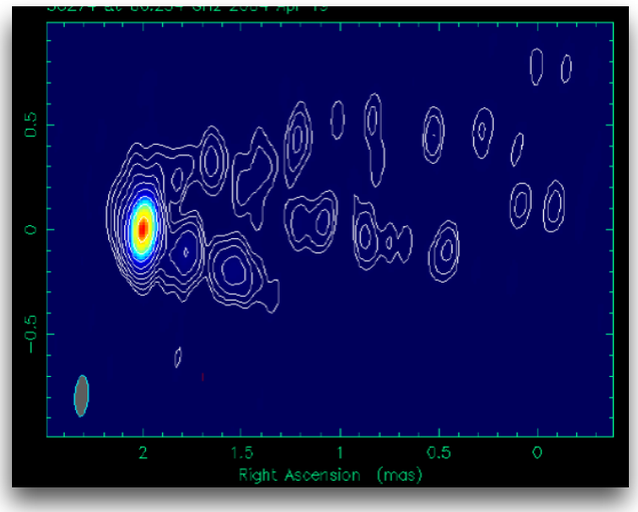
…and more!



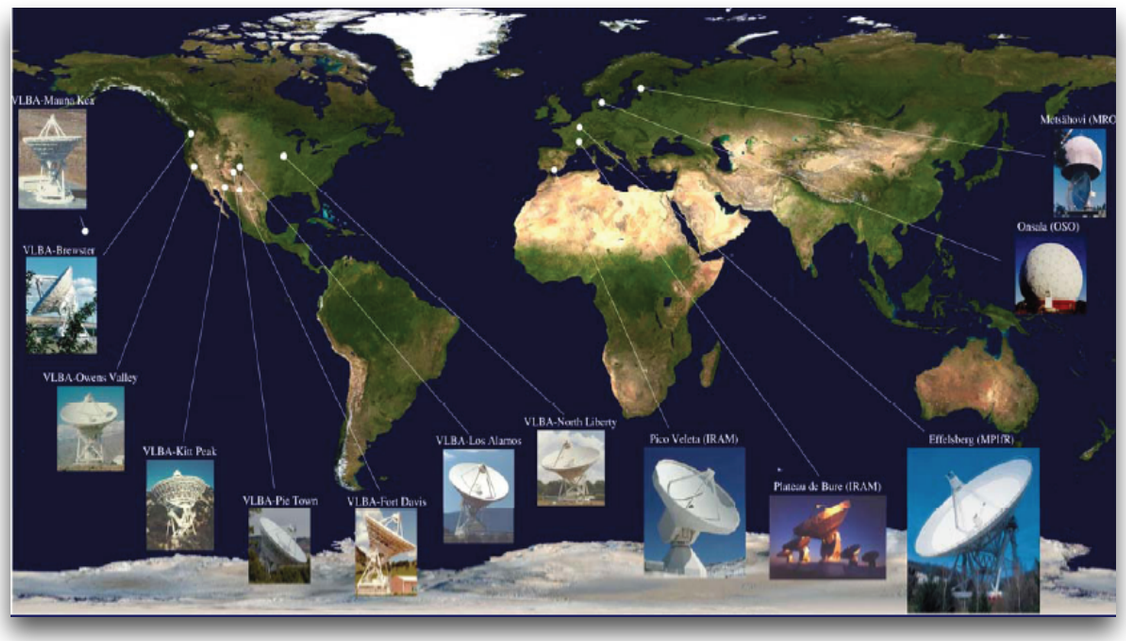


- KVN+VERA is providing excellent imaging capabilities (Niinuma et al.)

Part II:
86 GHz blazar studies

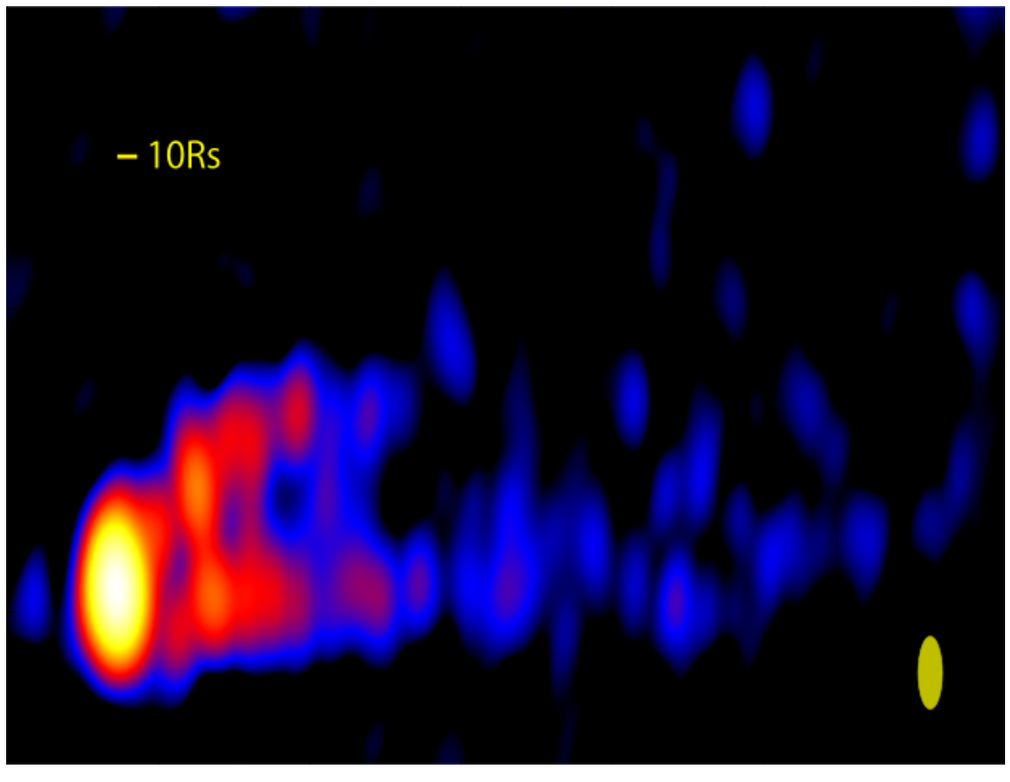


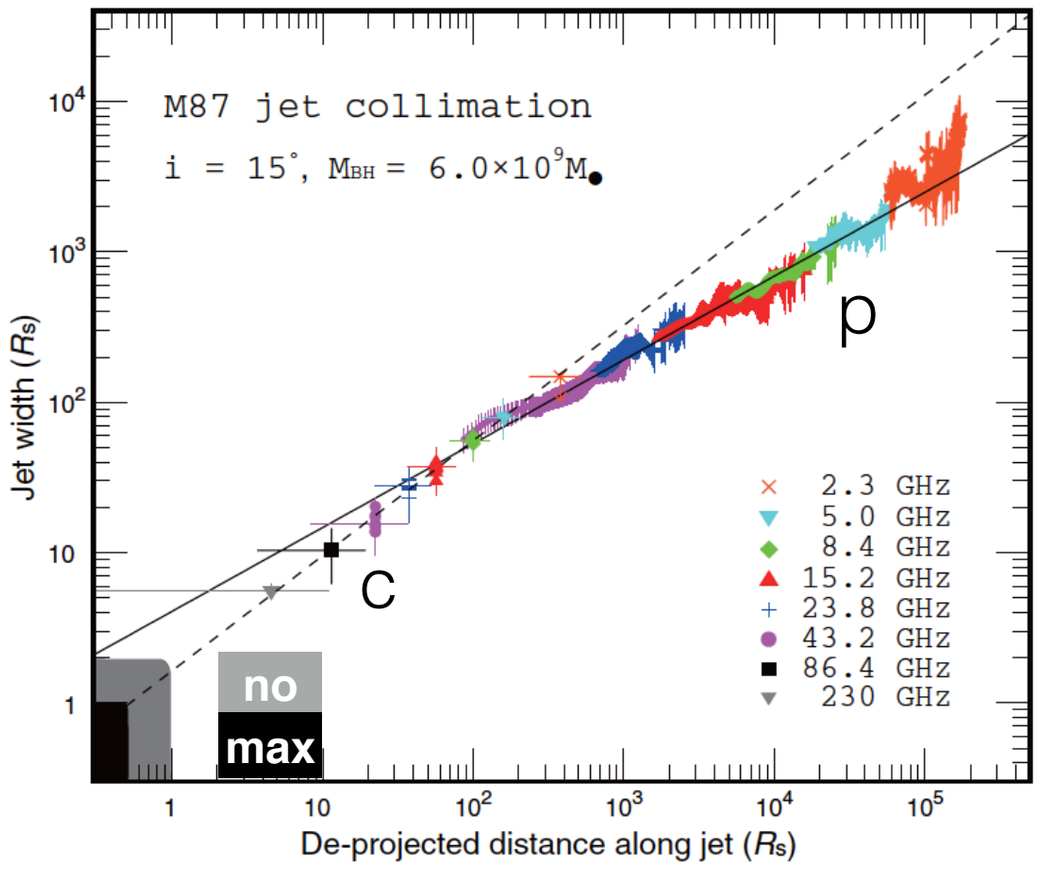
- Science becomes potentially even more interesting
- Challenging conditions (atmospheric stability and telescope accuracy) affect observations



M87 with VLBA+GBT *(courtesy of K. Hada, NAOJ)*

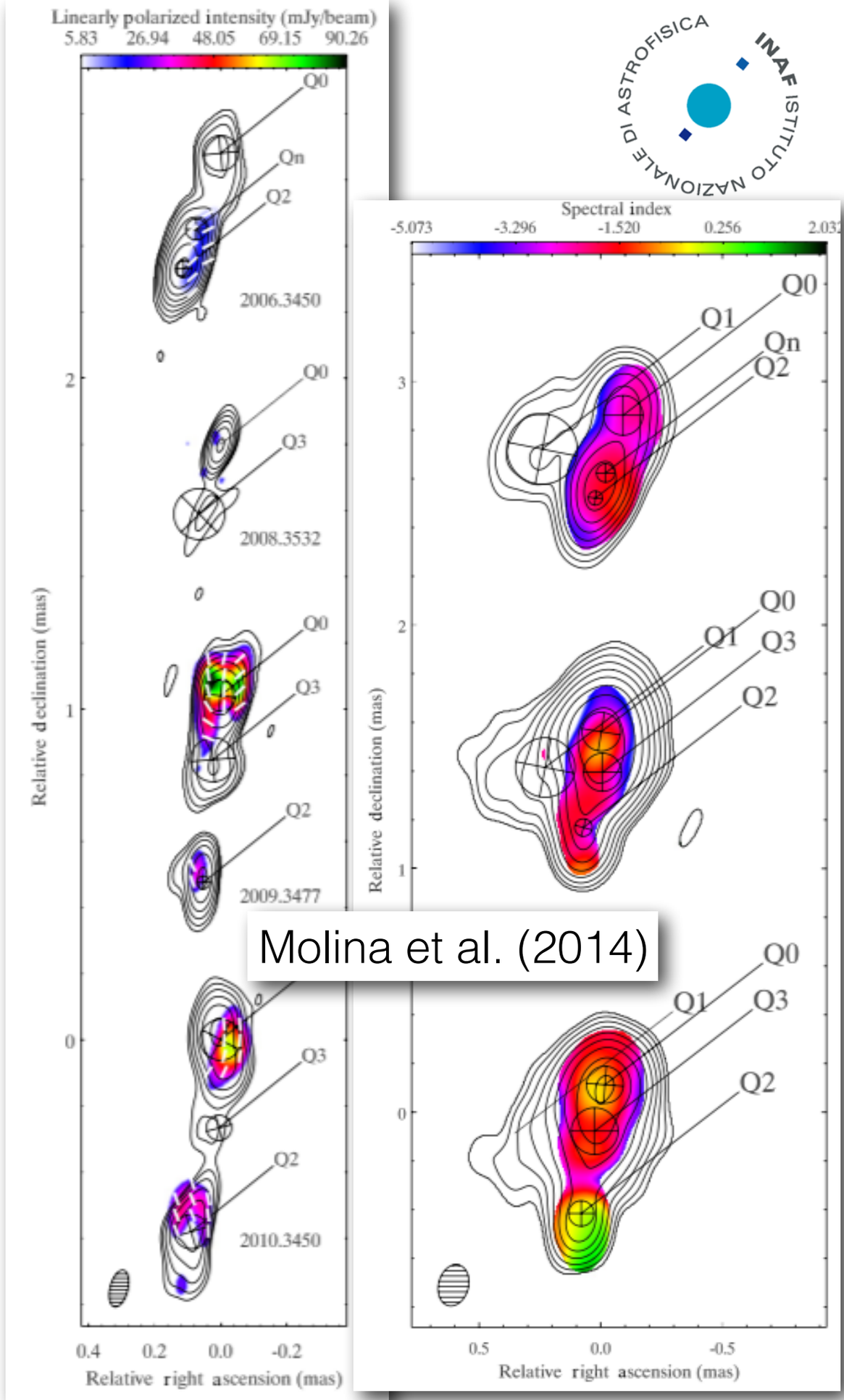
- location of black hole, through astrometry (Hada et al. 2011)
- discriminate between conical or parabolic jet width profile and max or no spinning black hole (Hada et al. 2013)
- role of magnetic field in jet launch, though polarisation (in progress)





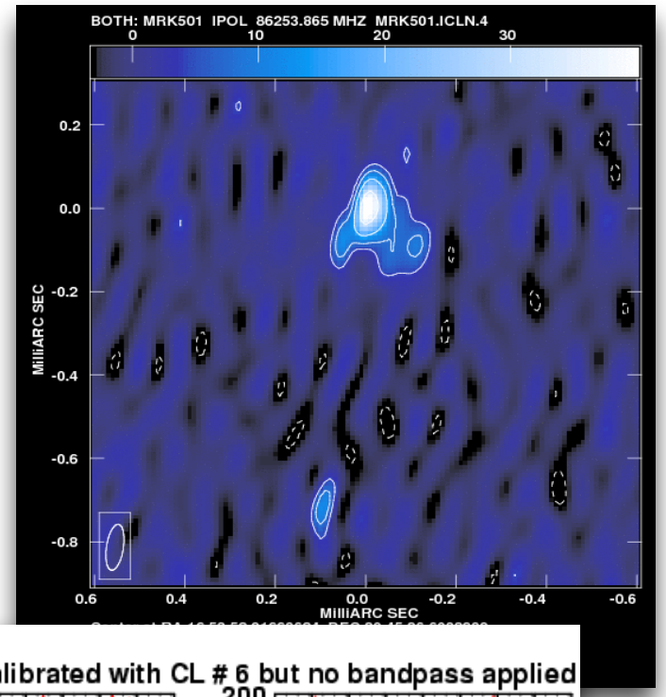
NRAO 150

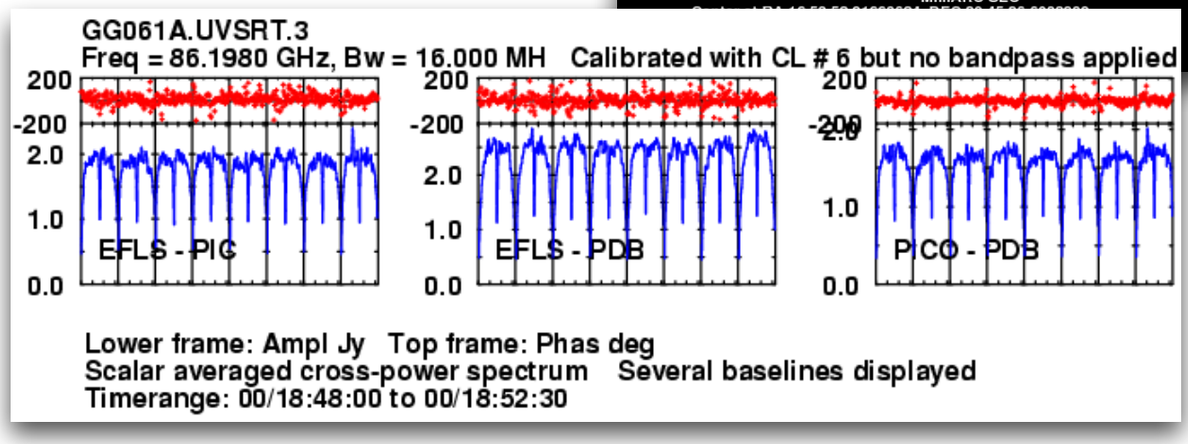
- z=1.52 quasar with fast CCW inner jet rotation (Agudo et al. 2007)
- 8-86 VLBA+GMVA campaign permit to study evolution of structure, linear polarisation, and spectral index
- jet rotating, and seen at very small angle
- no clear core feature
- toroidal magnetic field



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?

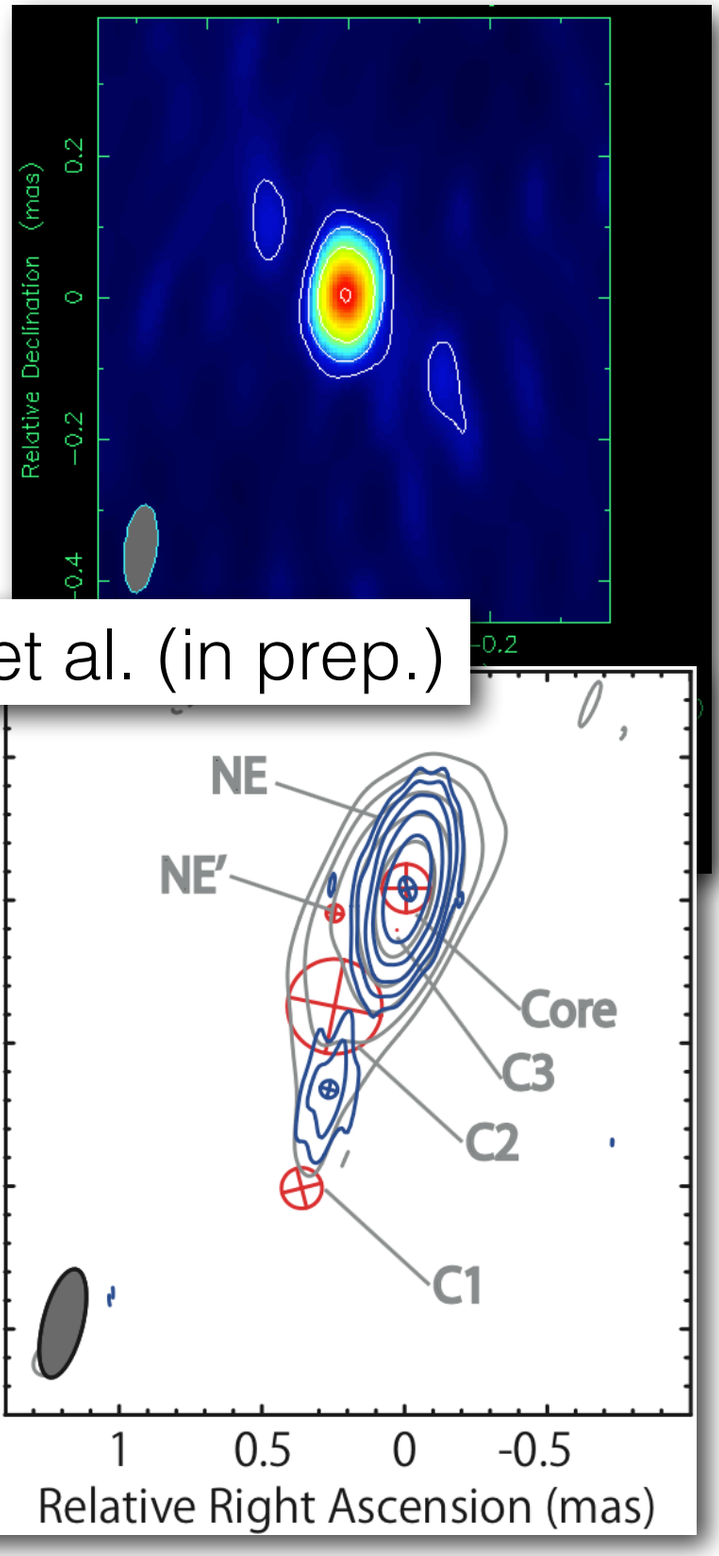




on the importance of sensitive stations…

- 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



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

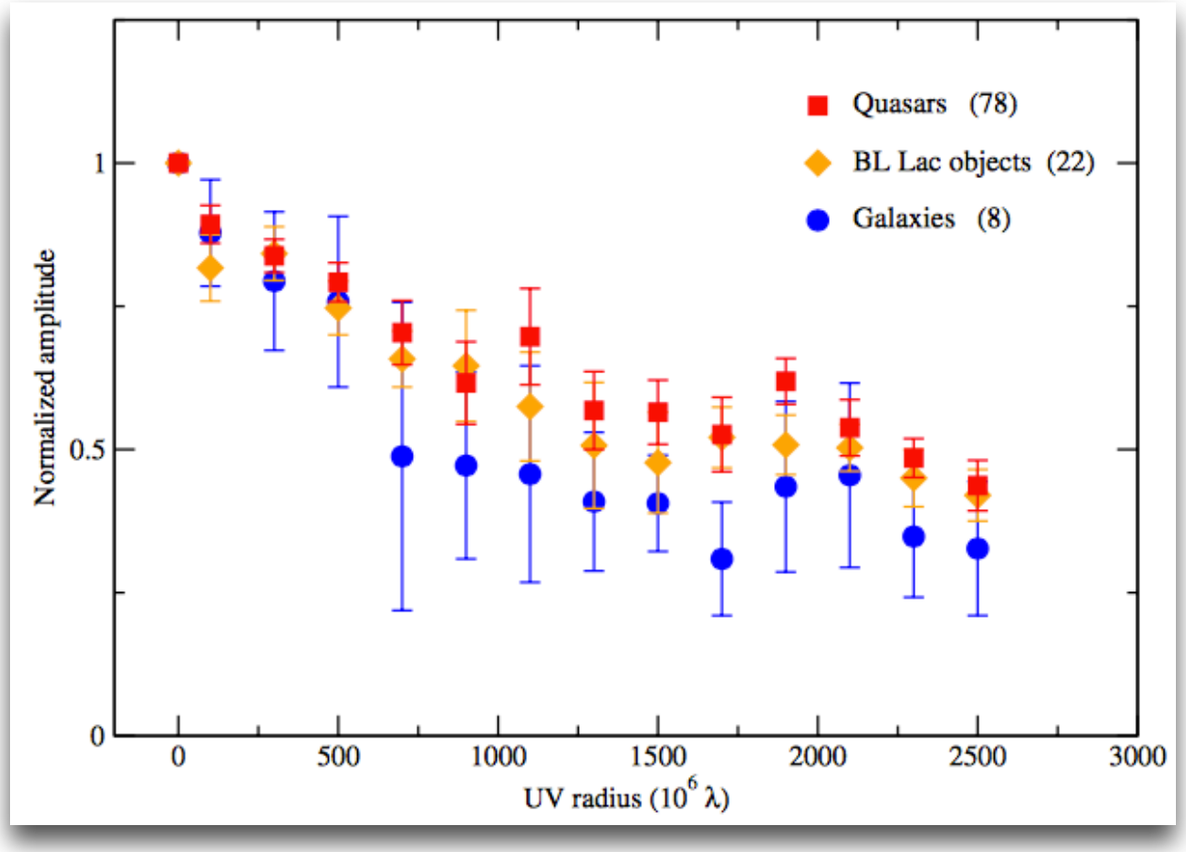
- snapshot mode, single baseline sensitivity of ~0.1 Jy; image sensitivity <10 mJy beam^{-1}

- 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=7x10^{10}K



…and more!

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **418,** 2260–2272 (2011) doi:10.1111/j.1365-2966.2011.19537.x

High-frequency very long baseline interferometry studies of NRAO 530

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Accepted 2011 July 29. Received 2011 July 14; in original form 2010 I

ABSTRACT

NRAO 530 is an opticall
frequency high-resolutio
was monitored with the
86 GHz) on 10 consecu

Detecting supermassive binary black holes with VLBI - discovery of a ring-structure in 3C454.3

S Britzen[1], M Zamaninasab[1], M Aller[2], H Aller[2], O Kurtanidze[3], S Vercellone[4], G M Richter[5], A Witzel[1], TP Krichbaum[1] and JA Zensus[1]

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Sternwarte 16, 14482 Potsdam, Germany

rst VLBI ring-structure around the core of an
.3. This ring-structure starts being visible in
n apparent velocity between 0.11±0.01mas/yr

THE ASTROPHYSICAL JOURNAL, 665:232–236, 2007 August 10

SEARCH FOR ELECTRON-POSITRON ANNIHILATION RADIATION FROM THE JET IN 3C 120

ALAN P. MARSCHER,[1] SVETLANA G. JORSTAD,[1,2] JOSÉ L. GÓMEZ,[3] IAN M. MCHARDY,[4] THOMAS P. KRICHBAUM,[5] AND IVÁN AGUDO[3,5]

Received 2006 July 13; accepted 2007 May 1

ABSTRACT

npt to detect the electron-positron annihilation line from the radio galaxy 3C 120, in which the
with interstellar clouds. Such interactions should cause most of the jet plasma to mix with the gas
will thermalize the majority of any positrons in the jet, leading to continuous annihilation with
We derive the number density of the combined electron-positron population in the core and com-
of 3C 120 using ultrahigh-resolution observations with the Global millimeter-VLBI Array at

2005 November 10
ed. Printed in U.S.A.

AND 86 GHz VERY LONG BASELINE POLARIMETRY OF 3C 273

M. ATTRIDGE,[1] JOHN F. C. WARDLE,[2] AND DANIEL C. HOMAN[3]

2005 June 21; accepted 2005 September 28; published 2005 October 26

ABSTRACT

nd resolution total intensity and linear polarization VLBI images of 3C 273, using
ata taken with the Very Long Baseline Array in 2002 May. The structure seen in
we have fortuitously caught the jet in the act of changing direction. The polarization
is unpolarized (fractional polarization ≲1%) at 86 GHz, but also show well ordered
the inner jet, at a projected distance of 2.3 pc from the core. In this strongly
measure changes across the jet by ~4.2 × 10^4 rad m^{-2} over an angular width of
about 0.3 mas. If the lack of polarization in the core is also attributed to a Faraday screen, then a rotation measure
dispersion ≳5.2 × 10^4 rad m^{-2} must be present in or in front of that region. These are among the highest rotation

A&A 544, A89 (2012)
DOI: 10.1051/0004-6361/201218852

Astronomy & Astrophysics

The parsec-scale jet of PKS 1749+096★

R.-S. Lu[1,2,3,4], Z.-Q. Shen[1,5], T. P. Krichbaum[3], S. Iguchi[6], S.-S. Lee[7], and J. A. Zensus[3]

A&A 571, L2 (2014)
DOI: 10.1051/0004-6361/201424796

Astronomy & Astrophysics

LETTER TO THE EDITOR

utflow and gamma-ray emission correlations in S5 0716+714★

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eived 12 August 2014 / Accepted 30 September 2014

ABSTRACT

ng millimeter very long baseline interferometry (VLBI) observations of the BL Lac object S5 0716+714 from August 2008 to
tember 2013, we investigate variations in the core flux density and orientation of the sub-parsec scale jet, i.e. position angle. The
y data obtained by the *Fermi* Large Area Telescope are used to investigate the high-energy flux variations over the same time
od. For the first time in any blazar, we report a significant correlation between the γ-ray flux variations and the position angle
ations in the VLBI jet. The cross-correlation analysis also indicates a positive correlation such that the mm-VLBI core flux density
ations are delayed with respect to the γ-ray flux by 82 ± 32 days. This suggests that the high-energy emission is coming from a
on located ≥(3.8 ± 1.9) parsecs upstream of the mm-VLBI core (closer to the central black hole). These results imply that the
erved inner jet morphology has a strong connection with the observed γ-ray flares.

Research in Astronomy and Astrophysics > Volume 9 > Number 2

Periodicity of the ejection of superluminal components in 3C345

Shan-Jie Qian[1], A. Witzel[2], J. A. Zensus[2], T. P. Krichbaum[2], S. Britzen[2] and Xi-Zhen Zhang[1]
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Shan-Jie Qian *et al* 2009 *Res. Astron. Astrophys.* **9** 137. doi:10.1088/1674-4527/9/2/003
Recei

Research in Astronomy and Astrophysics > Volume 10 > Number 1

A new three-stage evolution model for millimeter to centimeter wavelength outbursts in BL Lacertae

Shan-Jie Qian[1,2], T. P. Krichbaum[2], A. Witzel[2], J. A. Zensus[2], Xi-Zhen Zhang[1], H. Ungerechts[3], H. D. Aller[4] and M. F. Alle
Show affiliations

Shan-Jie Qian *et al* 2010 *Res. Astron. Astrophys.* **10** 47. doi:10.1088/1674-4527/10/1/005
Received 25 November 2008, accepted for publication 7 May 2009.

Abstract

The multi-frequency light curves of BL Lacertae during 1997.5–1999.5 have been modeled by four outbursts, each having
evolution in the (S_m, ν_m) plane with distinct rising-plateau-decaying phases. It is shown that the observed light curves can
fitted for the eight frequencies from 350 GHz to 4.8 GHz. The main characteristics of the model-fitting are: (1) the outburst

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Oxford Journals › Science & Mathematics › MNRAS › Volume 436, Issue 4 › Pp. 3341-3356.

Evidence for a large-scale helical magnetic field in the quasar 3C 454.3

M. Zamaninasab[1,★], T. Savolainen[1], E. Clausen-Brown[1], T. Hovatta[2], M. L. Lister[3], T. P. Krichbaum[1], Y. Y. Kovalev[1,4] and A. B. Pushkarev[1,5,6]
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Received 2013 September 23.
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First published online October 28, 2013.

Abstract

Most current theoretical models link the launching of relativistic jets from active galactic nuclei to the presence of twisted magnetic fields close to

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=1.2x10^{11} K, lower than cm
  - viewing angle change, accelerating jet, truly different jet part

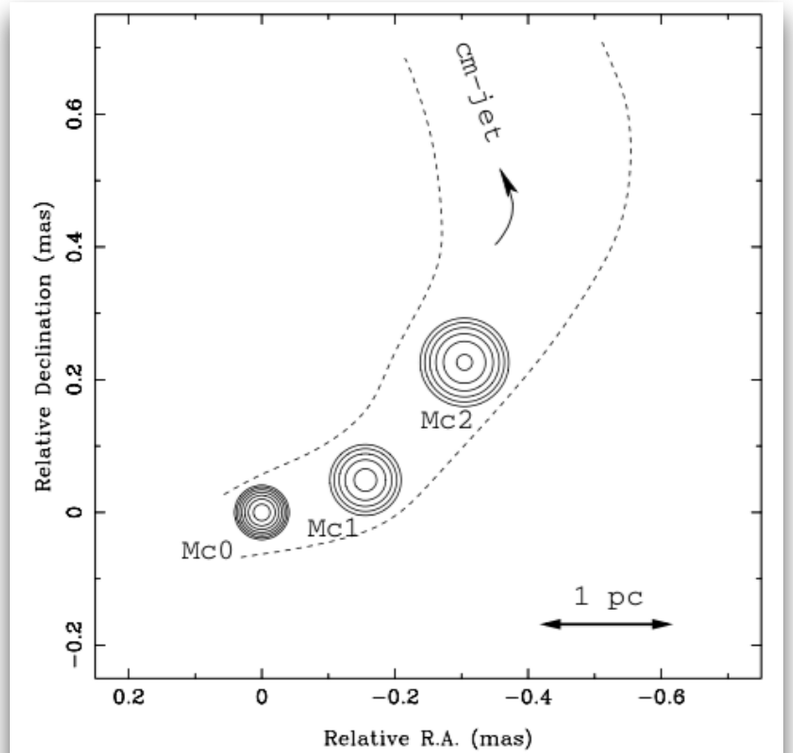
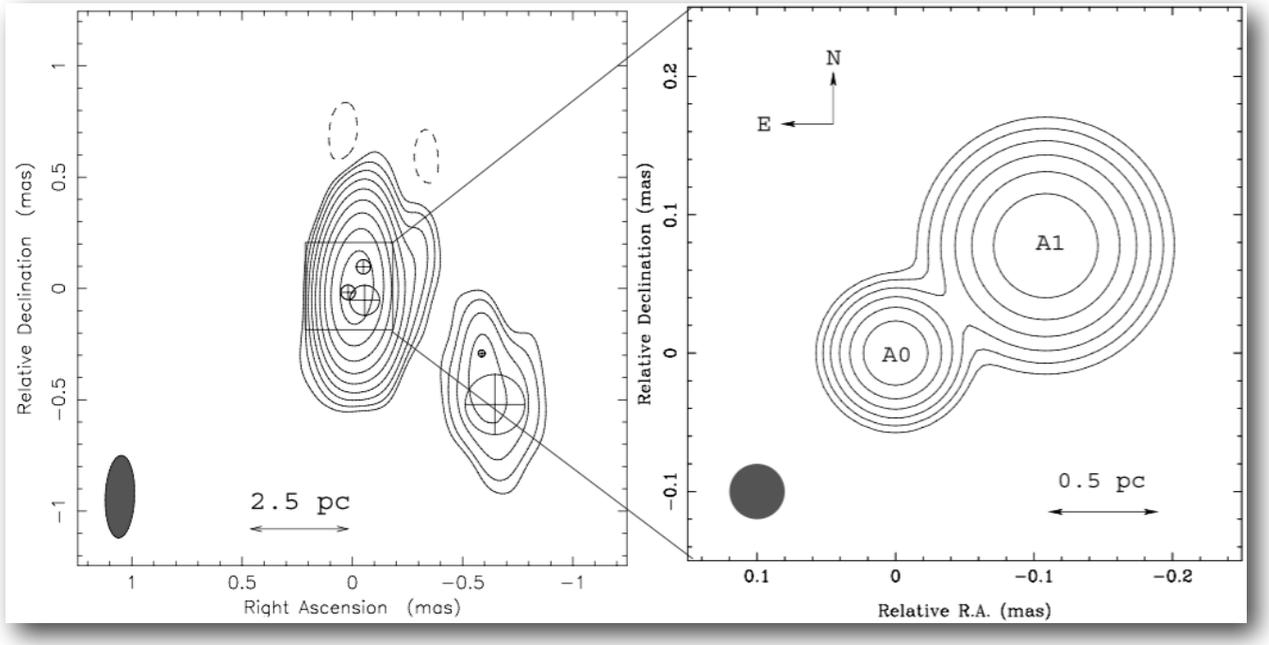


Figure 4. Model image of 1924-292. Contours are drawn at 1%, 2%, 4%, . . ., 64% of the peak brightness. The two dashed curves indicate (schematically) how the inner jet is bent toward the cm-jet.

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

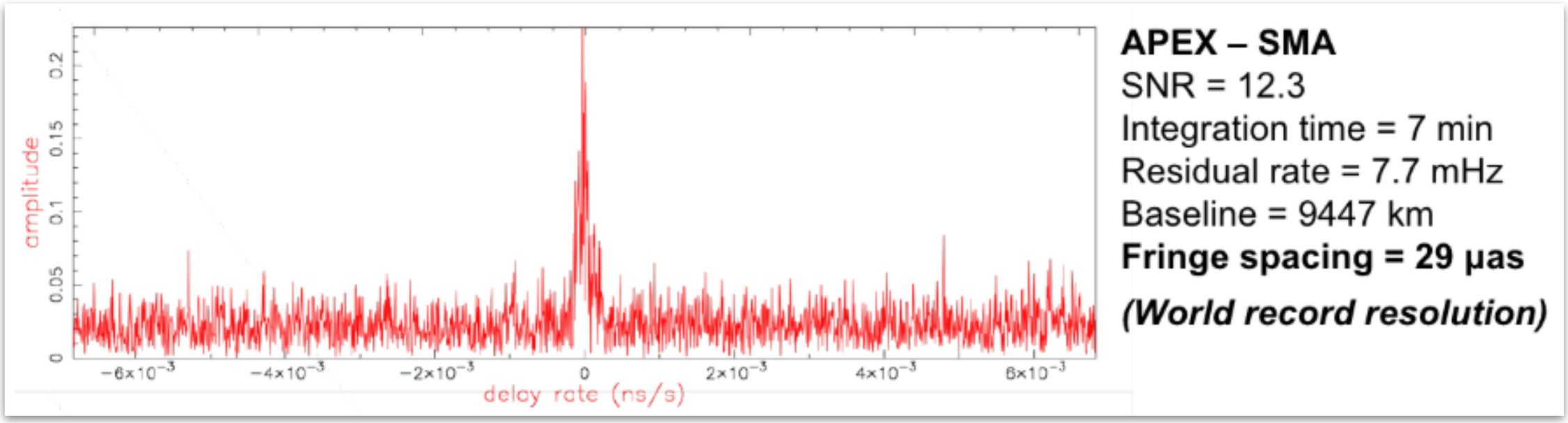
- z=0.536 quasar, 1 mas=0.6 pc, 0.1 mas yr^{-1}=3.2*c*
- seven stations/three sites (Hawaii/JCMT-CSO-SMA, CARMA, SMT)
- 5 nights between 2011 days 88-94, with other sources, at 1.3 mm
- 2-comp fit looks good, 3-comp maybe better but difficult to constrain
- good match in comp. position and size to ~simultaneous 7mm VLBA data
- T_b=8x10^{10} 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, SMTO, 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

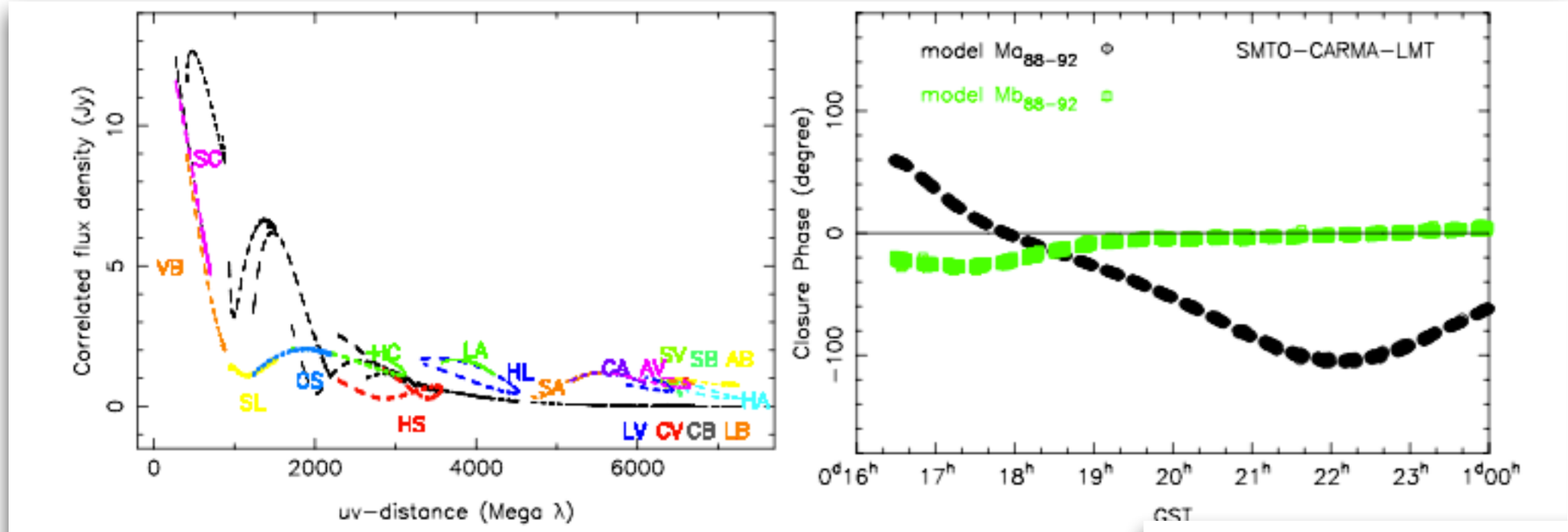
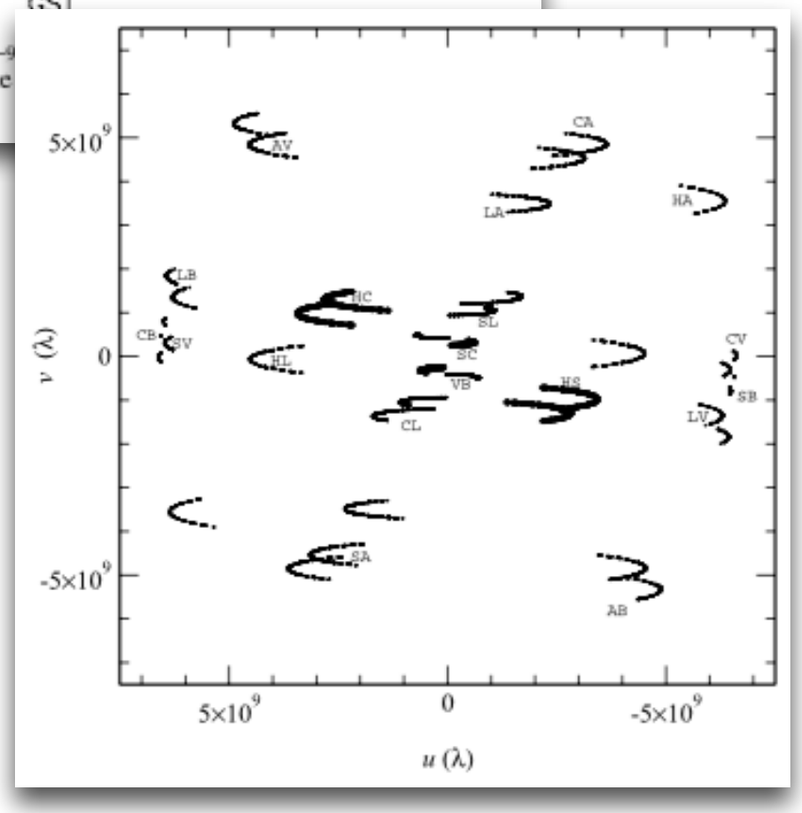


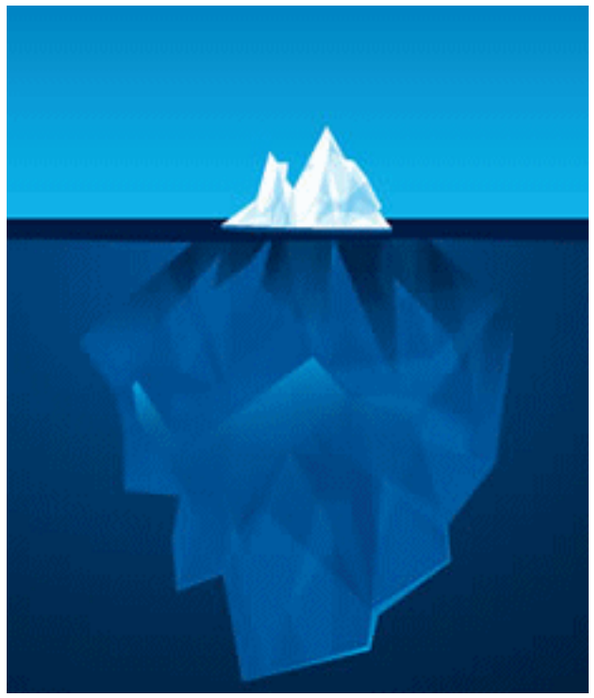
Figure 7. Left: correlated flux density as a function of *uv* distance for the two models of days 88–92 (Ma_{88-92} and Mb_{88-9} color coded and labeled by baseline (same as in Figure 6). Right: plot of the predicted closure phase for the shown time Simulated data were coherently averaged into 10 s bins.

- 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**