Multiwavelength Studies of Blazars BL Lac and 3C454.3

Ann E. Wehrle

Space Science Institute

Multiwavelength Collaborations

- **BL Lac: "Erratic Flaring of BL Lac in 2012-2013: Multiwavelength Observations"** Wehrle, Ann E.; Grupe, Dirk; Jorstad, Svetlana G.; Marscher, Alan P.; Gurwell, Mark; Baloković, Mislav; Hovatta, Talvikki; Madejski, Grzegorz M.; Harrison, Fiona H.; Stern, Daniel, 2016 ApJ 816, 53
- **3C454.3: "Multiwavelength Variations of 3C454.3 During the 2010 November to 2011 January Outburst"** Wehrle, A., Marscher, A., Jorstad, S., Gurwell, M., Joshi, M., MacDonald, N., Williamson, K., Agudo, I., and Grupe, D. 2012, ApJ 758, 72
- **3C454.3: "A Tight Connection between Gamma-Ray Outbursts and Parsec-Scale Jet Activity in the Quasar 3C454.3"** Svetlana G. Jorstad[1,2], Alan P. Marscher[1], Paul S. Smith[3], Valeri M. Larionov[2,4,5], Iván Agudo[1,6], Mark Gurwell[7], Ann E. Wehrle[8], Anne Lähteenmäki[9], Maria G. Nikolashvili[10], Gary D. Schmidt[11], Arkady A. Arkharov[4], Dmitry A. Blinov[2], Kelly Blumenthal[1], Carolina Casadio[6], Revaz A. Chigladze[10], Natalia V. Efimova[2,4], Joseph R. Eggen[12], José L. Gómez[6], Dirk Grupe[13], Vladimir A. Hagen-Thorn[2,5], Manasvita Joshi[1], Givi N. Kimeridze[10], Tatiana S. Konstantinova[2], Evgenia N. Kopatskaya[2], Omar M. Kurtanidze[10], Sofia O. Kurtanidze[10], Elena G. Larionova[2], Liudmilla V. Larionova[2], Lorand A. Sigua[10], Nicholas R. MacDonald[1], Jeremy D. Maune[12], Ian M. McHardy[14], H. Richard Miller[12], Sol N. Molina[6], Daria A. Morozova[2], Terri Scott[1], Brian W. Taylor[1,15], Merja Tornikoski[9], Ivan S. Troitsky[2], Clemens Thum[16], Gary Walker[17], Karen E. Williamson[1], Stephanie Sallum[17,18], Santina Consiglio[17,19], and Vladimir Strelnitski[17] ApJ 2013, 773, 147

Optical and radio brightening of BL Lacertae

ATel #4271; *Sh. A. Ehgamberdiev and D. O. Mirzaqulov (Ulugh Beg Astronomical Institute, Maidanak Observatory, Uzbekistan), C. S. Buemi, P. Leto, C. Trigilio and G. Umana (INAF, Osservatorio Astrofisico di Catania, Italy), C. M. Raiteri and M. Villata (INAF, Osservatorio Astrofisico di Torino, Italy), U. Bach (Max-Planck-Institut fuer Radioastronomie, Bonn, Germany) for the GASP Collaboration*
on *23 Jul 2012; 10:57 UT*

Near-infrared brightening of BL Lacertae

ATel #4277; *M. I. Carnerero (INAF, Osservatorio Astrofisico di Torino, Italy and Instituto de Astrofisica de Canarias, Spain and Depto. de Astrofisica, Universidad de La Laguna, Spain), A. I. Gonzalez (Depto. de Astrofisica, Universidad de La Laguna, Spain), J. A. Acosta Pulido (Instituto de Astrofisica de Canarias, Spain and Depto. de Astrofisica, Universidad de La Laguna, Spain), C. M. Raiteri and M. Villata (INAF, Osservatorio Astrofisico di Torino, Italy), for the GASP collaboration.*
on *26 Jul 2012; 14:09 UT*

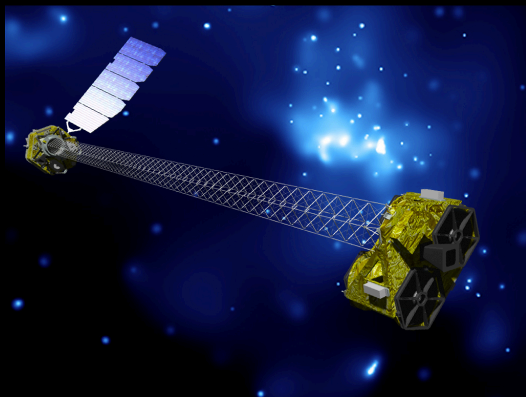
Gamma-ray blazar BL Lacertae: the highest recorded cm/mm radio flux over the past 30 years

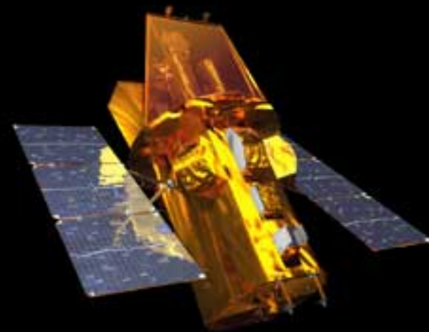
ATel #4349; *V. Karamanavis, I. Myserlis, L. Fuhrmann, E. Angelakis, I. Nestoras, T. P. Krichbaum, J. A. Zensus (F-GAMMA team, MPIfR, Bonn, Germany), H. Ungerechts, A. Sievers, D. Riquelme (IRAM, Granada, Spain)*
on *31 Aug 2012; 15:26 UT*

Gamma-Ray Blazar BL Lacertae at historic high brightness in millimeter, X-ray and far-infrared bands

ATel #4557; *Ann E. Wehrle (Space Science Institute), Dirk Grupe (Penn State), Mark Gurwell (CfA), Svetlana Jorstad (Boston University), Alan Marscher (Boston University)*
on *8 Nov 2012; 19:32 UT*

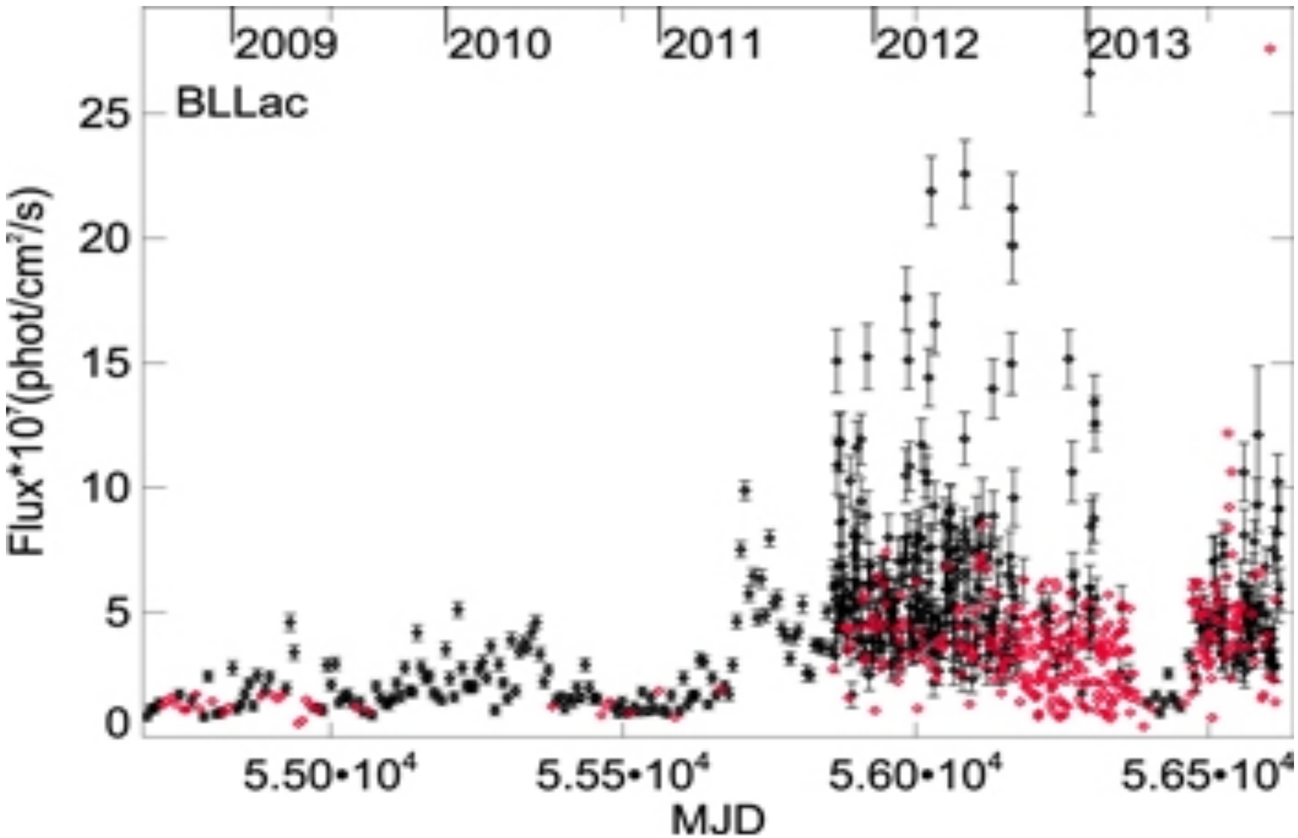
Goal: Study Evolving Flares with most densely sampled, broadest coverage for any blazar





TOO + long term -NuSTAR, Swift, Fermi, Herschel; VLBA, SMA, CARMA

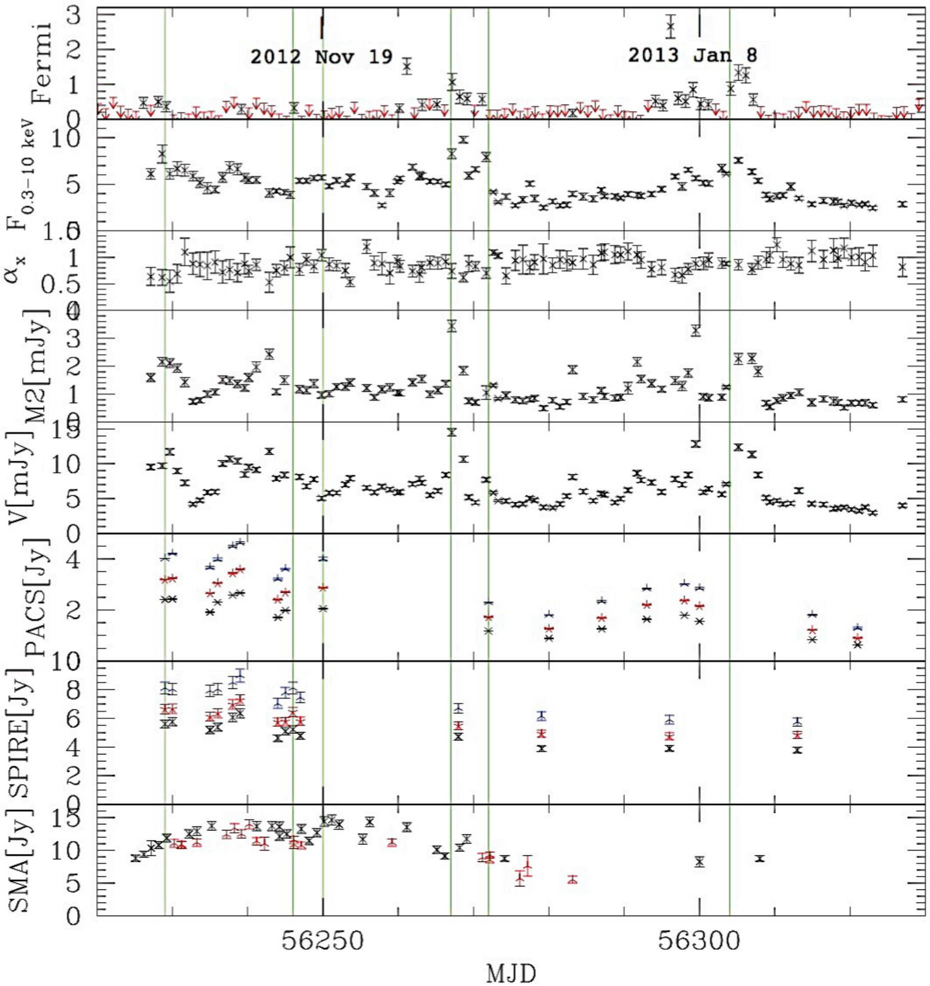
Multi-year Gamma-Ray light Curve



BL Lac: z= 0.0686, pointed at 6 degrees to our line of sight, 1 mas deprojected ~13 pc

Light curve of BL Lac from 2008 August 8 to 2013 October 31, as observed with the *Fermi* LAT. Black filled diamonds indicate detections, red filled diamonds indicate upper limits. A mixture of integration times is used: 7-day integrations when the source was faint, and 1-day integrations when the source was bright.

Light curves of BL Lacertae in 2012–2013



Fermi

Swift X-ray

Swift X-ray spectral index

Swift UV M2

Swift Optical V

Herschel 160, 100, 70 μm

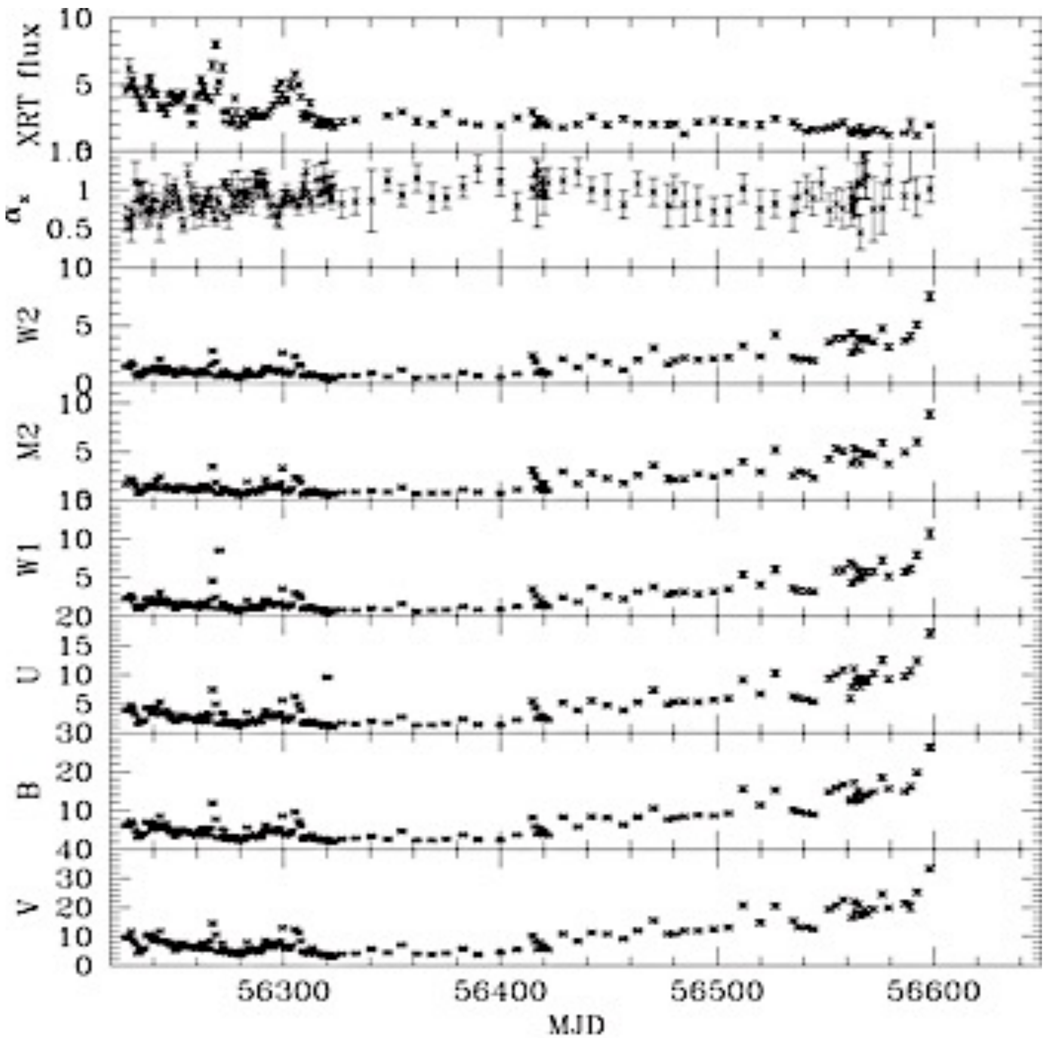
Herschel 500, 350, 250 μm

SMA 225 GHz, 345 GHz

95 SEDs on consecutive days

Vertical lines are drawn at MJDs 56229, 56246, 56250, 56267, 56272, and 56304, for SEDs models

Swift light curves of BL Lacertae from 2012 October 27 to 2013 October 31.

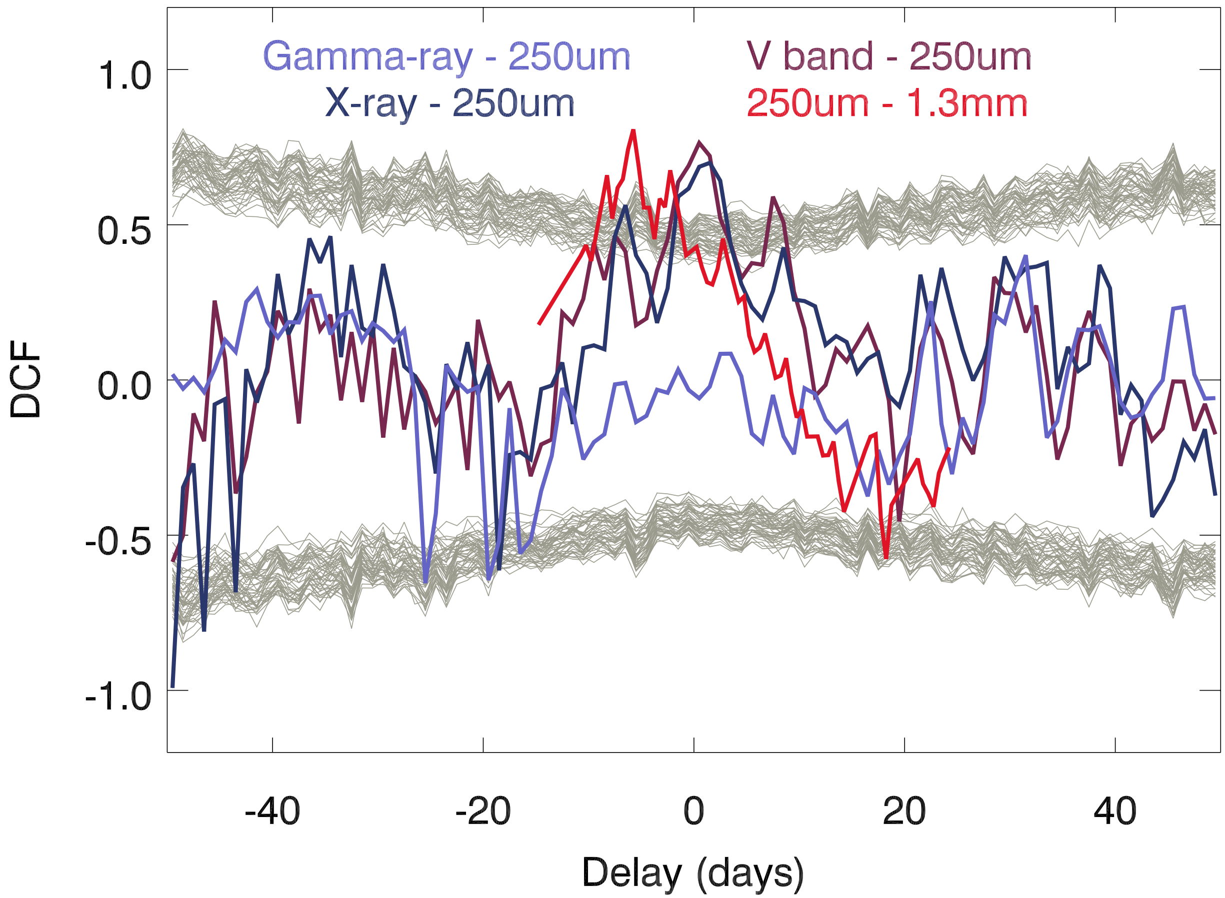


A rising tide lifts all ships: when the source is active, it is active at all bands.

But the source can be active in optical and not in X-ray bands.

Note that the optical and UV bands look exactly like each other, so the changing emission is coming from the same region.

Sample Light Curve Correlations



250 microns precedes 1.3mm by 5 days; other bands simultaneous to within 1 day.

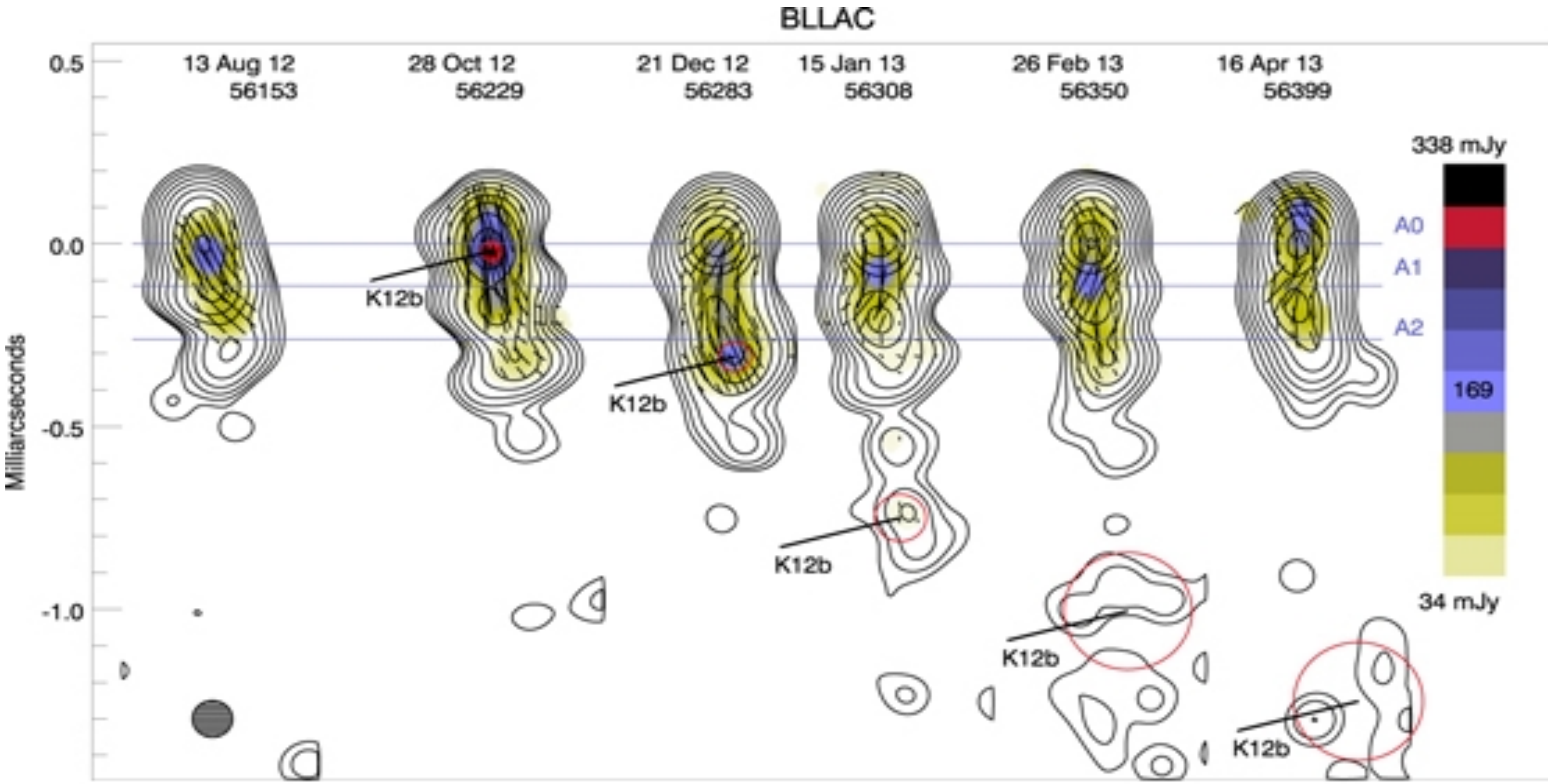
Correlations and Time Delays Between Events in the Light Curves

Assume the simplest model: If we correlate light curves, we always get the same delays between bands.

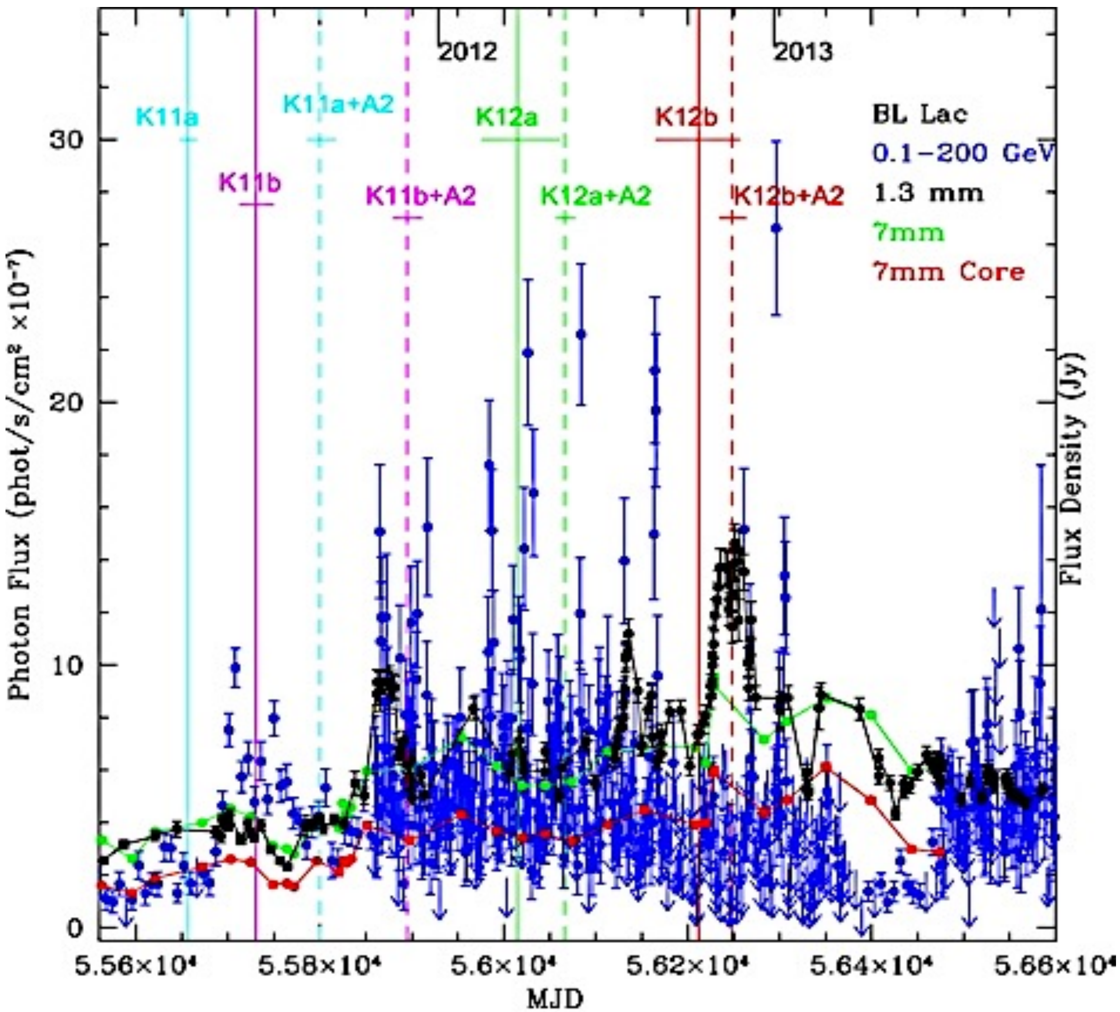
The new data tell us otherwise: Very long light curves allow study of multiple timescales: long, medium and short timescales have *different correlations between bands.*

Implications: We need *long, continous, well sampled* data trains to understand the source behavior- monitoring programs are time domain astronomy.

VLBA images obtained in 2012–2013 show the motion of fast superluminal knot K12b



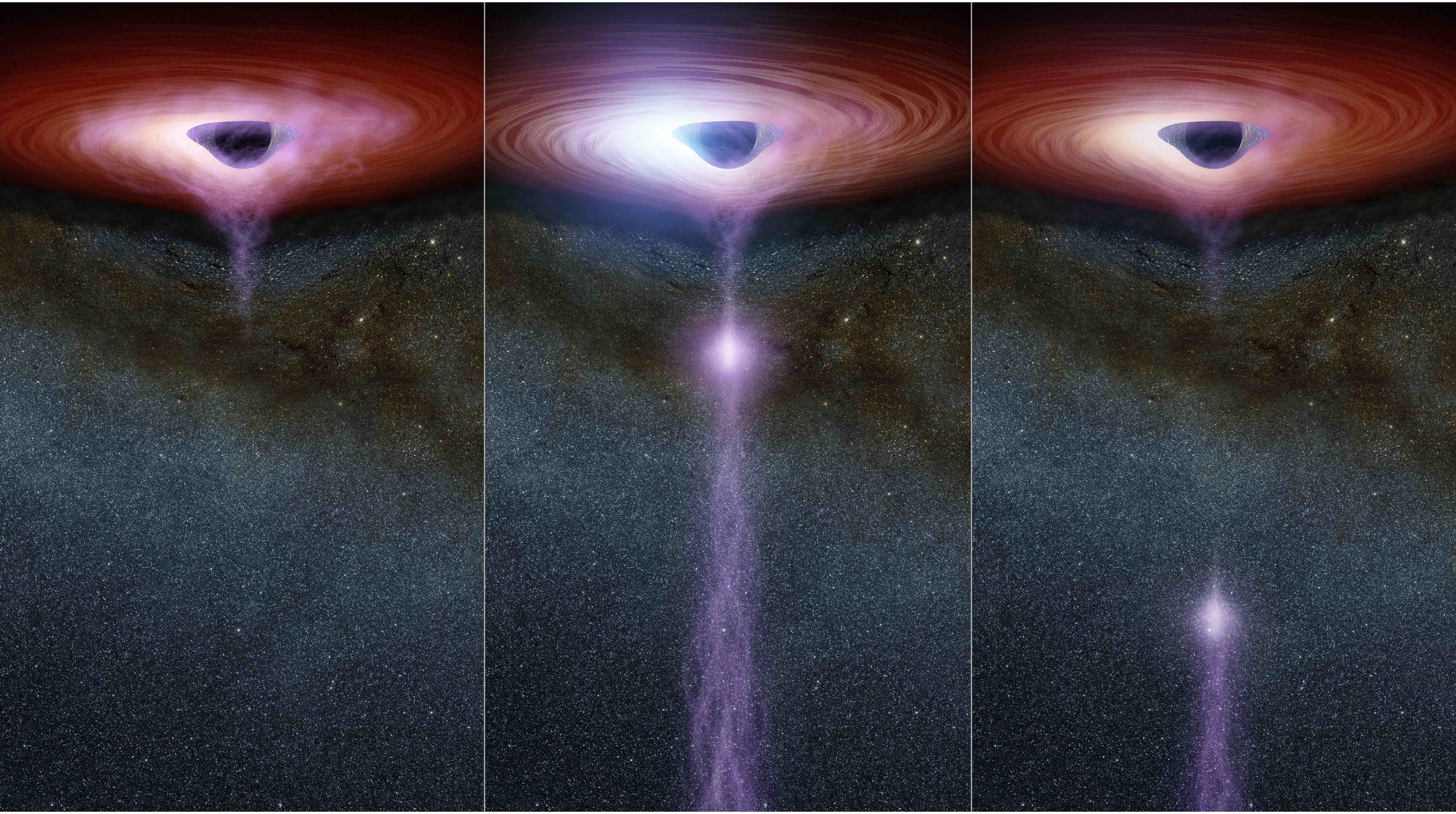
Zooming in on source with VLBI, we increased pace of coverage in the BU monitoring program for TOO. VLBI structure on 10-pc scale: core A0 is at top north, stationary knots A1 and A2 are to south, superluminal knot K12b was born in October 2012 and moved south along larger scale jet

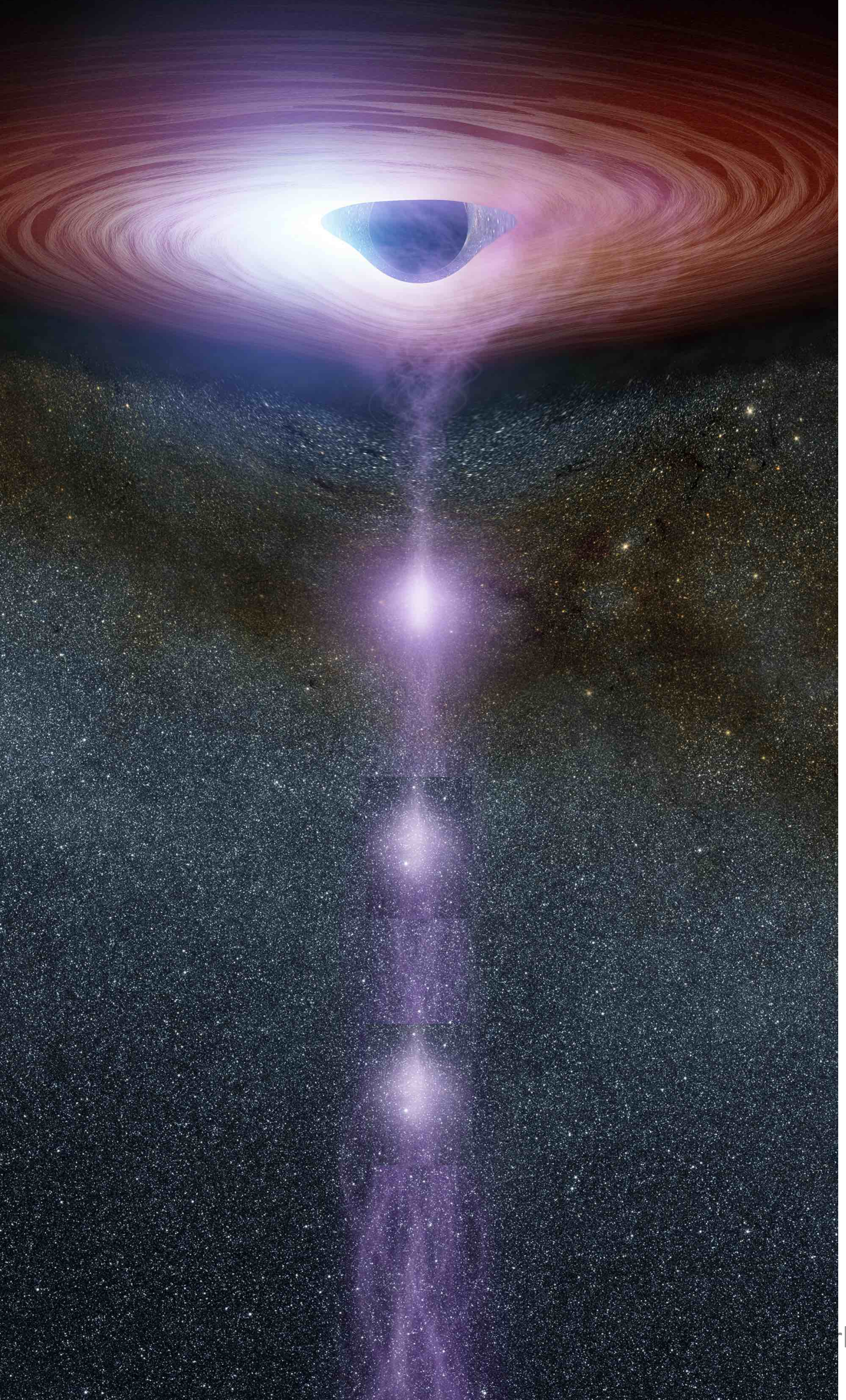


Light curves of BL Lac at γ-ray (blue), 1.3 mm (225 GHz; black) and 7 mm (43 GHz, green) wavelengths, and of the 7 mm core *AO* (red).

Ejection dates of new components and dates of their passage through the quasi-stationary knots are indicated by vertical bars.

Fast Superluminal blob moves away from central supermassive black hole, through 43 GHz core about 1 pc away

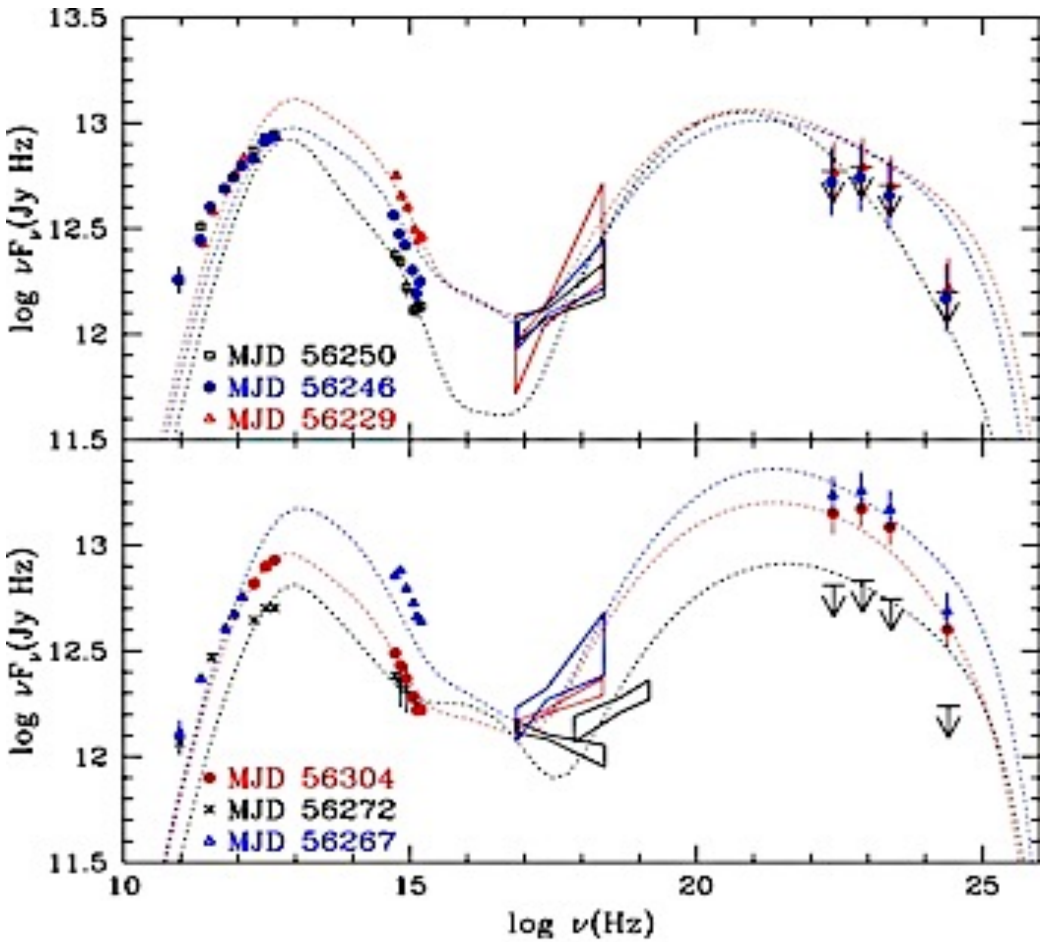




Fast superluminal blob lights up the core and two stationary knots as it passes through them.

Brightening seen at various bands, directly with VLBI and inferred from light curves at other wavebands

Comparison of Observed Spectral Energy Densities With Turbulent Extreme Multi Zone Models

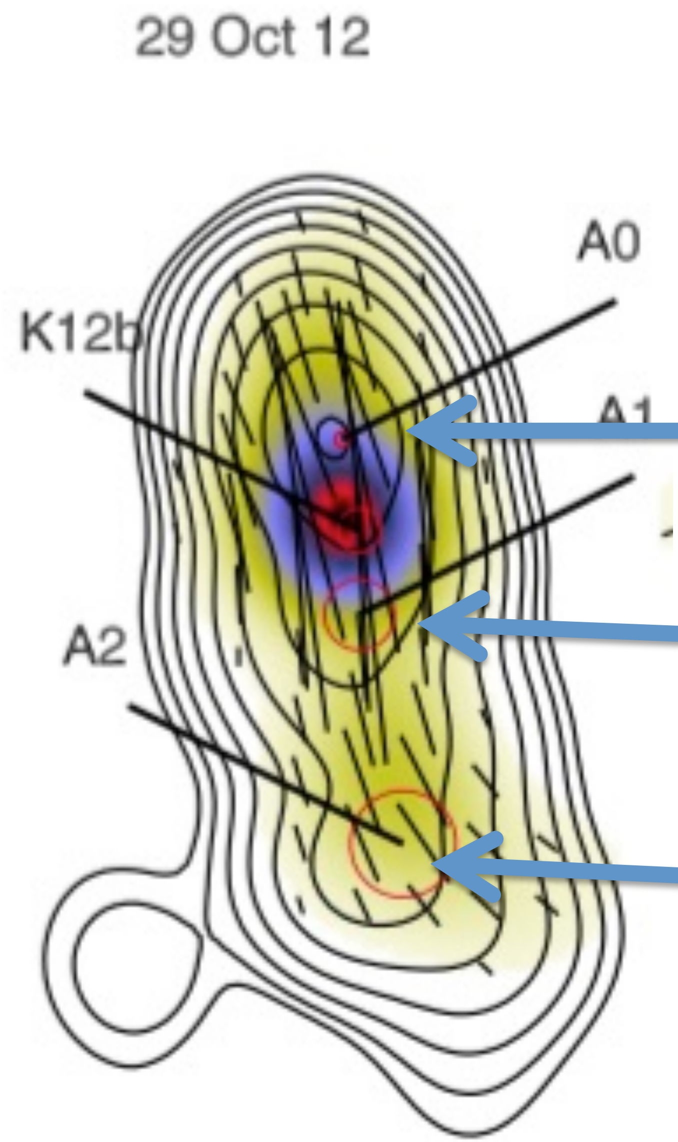


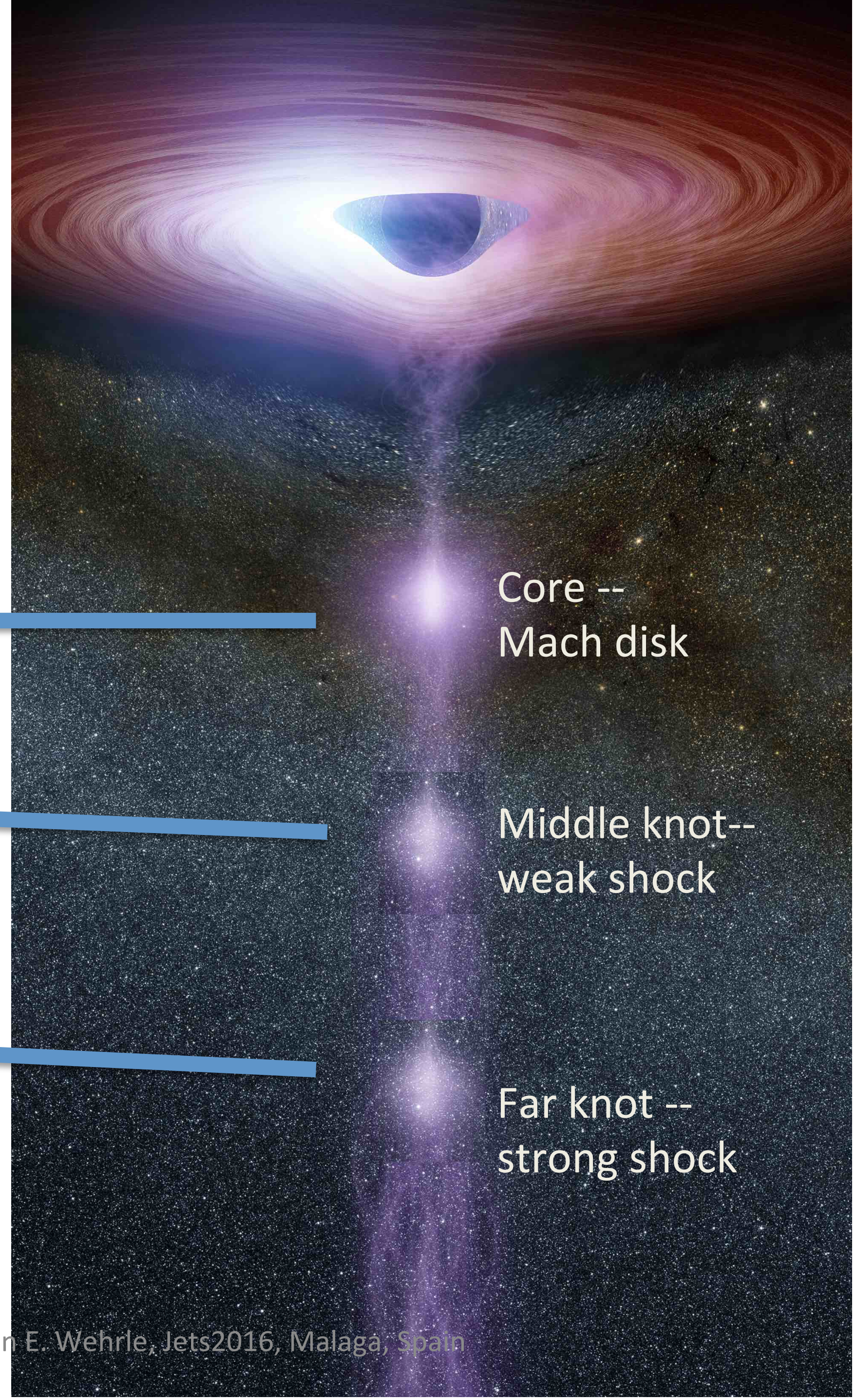
SEDs at six epochs (out of 95 available).

Basic model is that jet is composed of turbulent cells that encounter Mach disk and stationary shocks in jet, with ensuing flares of inverse Compton emission.

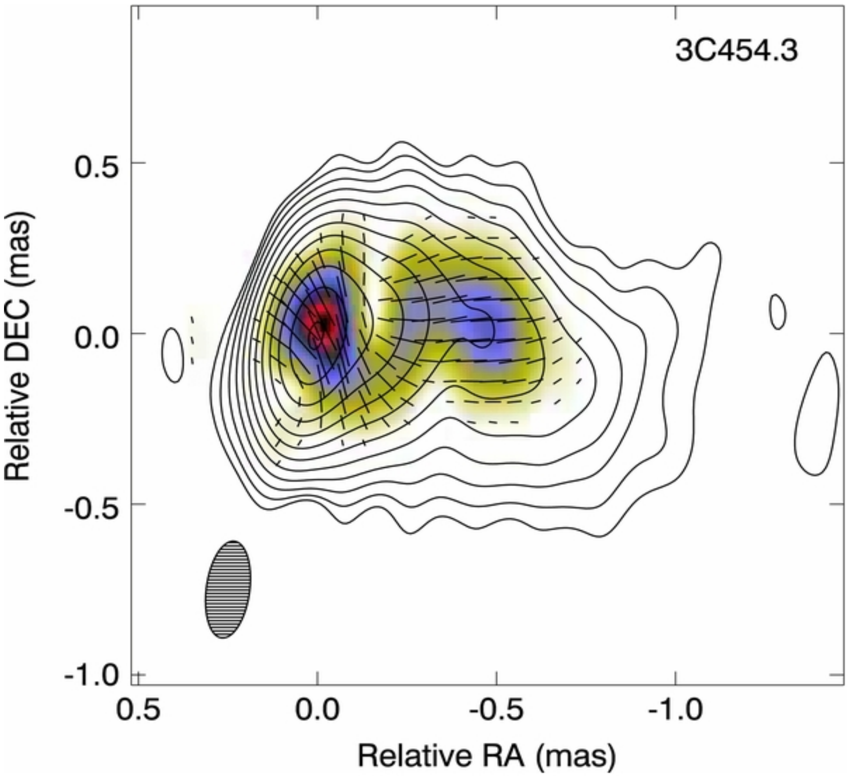
Good Matches: Dotted curves correspond to SEDs from different time steps from a simulation with the TEMZ model, selected such that they are similar to the observed SEDs drawn with the same colors. (TEMZ – Marscher 2014 ApJ 780, 87)

What do we deduce about the jet structure?



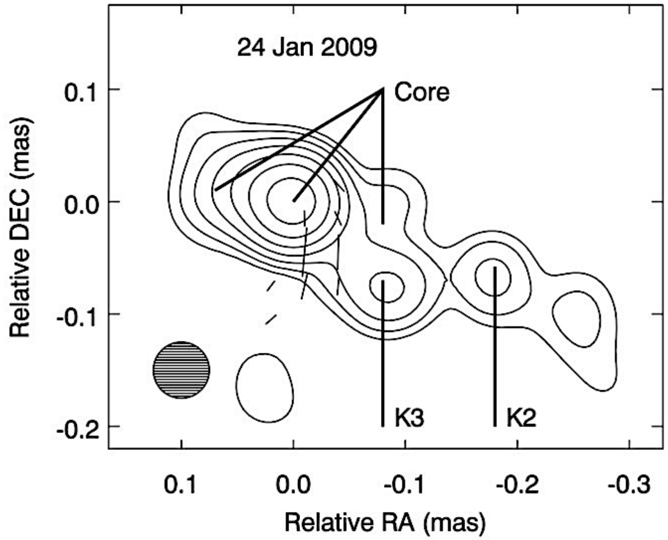


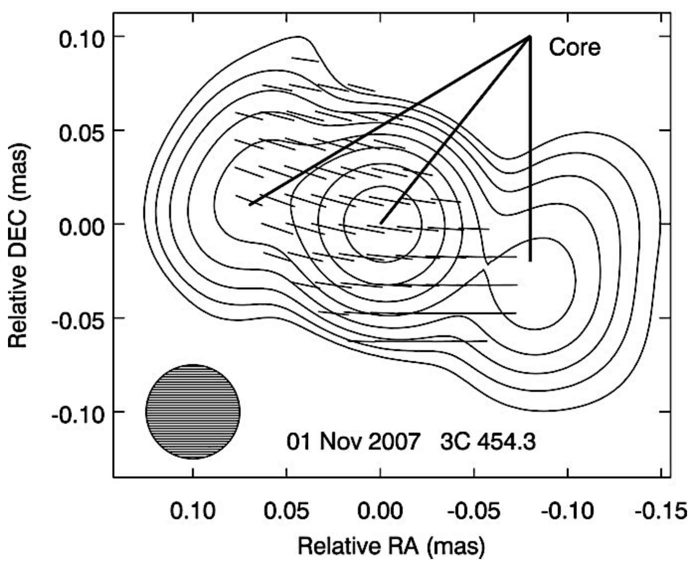
Have we seen similar behavior before?



Composite total (contours) and polarized (color) intensity image of 3C 454.3, which is the average of all 35 epochs of VLBA data at 43 GHz from 2009 April to 2011 August contours represent intensity; line segments show direction of polarization.

from "A Tight Connection between Gamma-Ray Outbursts and Parsec-scale Jet Activity in the Quasar 3C 454.3" Svetlana G. Jorstad et al. 2013 ApJ 773, 147



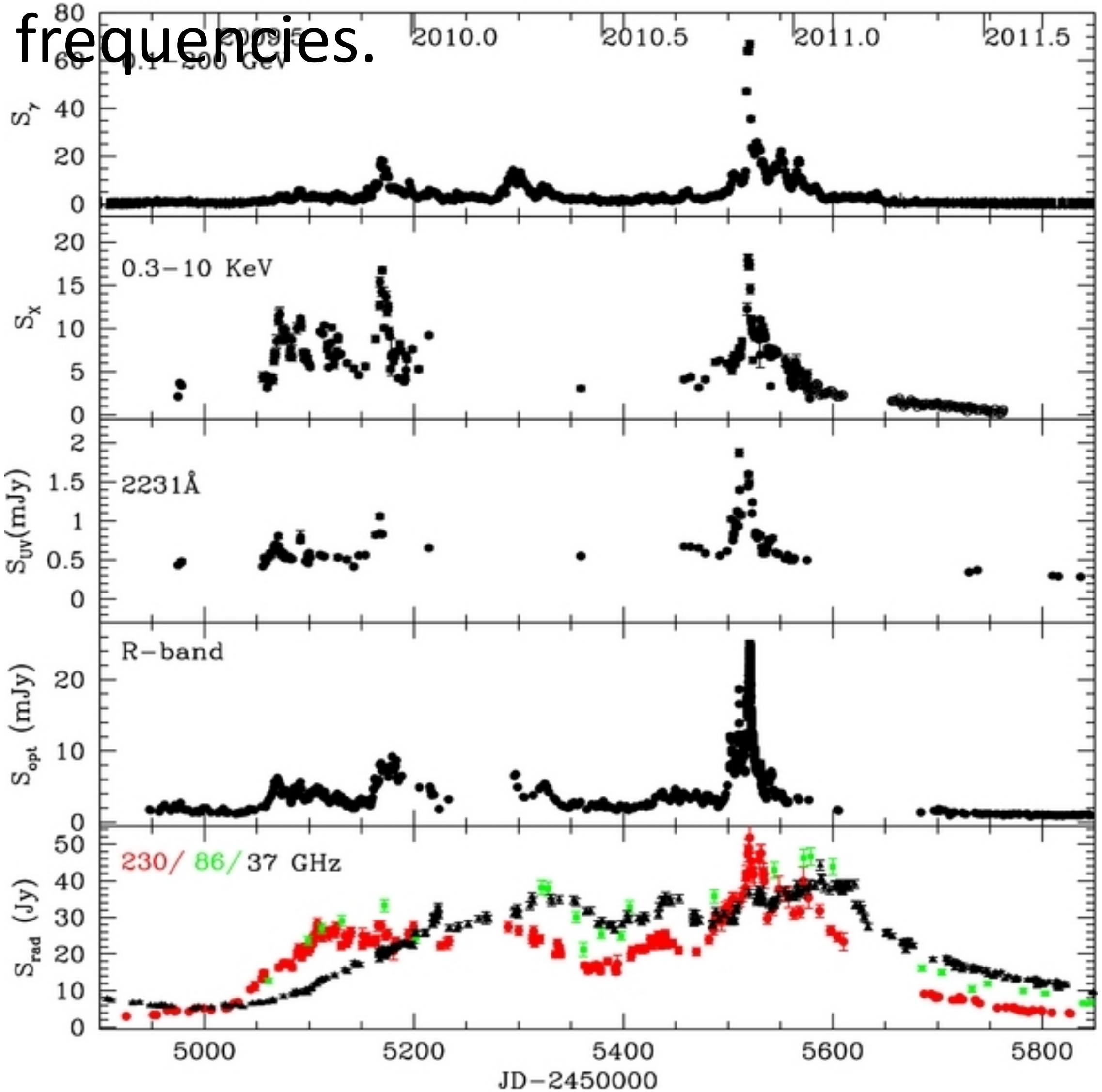


VLBI Core of 3C454.3

43 GHz VLBA Monitoring Program (Jorstad et al. 2010 ApJ 715, 362)

Superresolved images show three knots within the core – structure is persistent over time

Light curves of the quasar 3C 454.3 at different frequencies.



Fermi LAT γ-ray flux with 1 day binning interval in units of 10^{-6} photons cm^{-2} s^{-1}

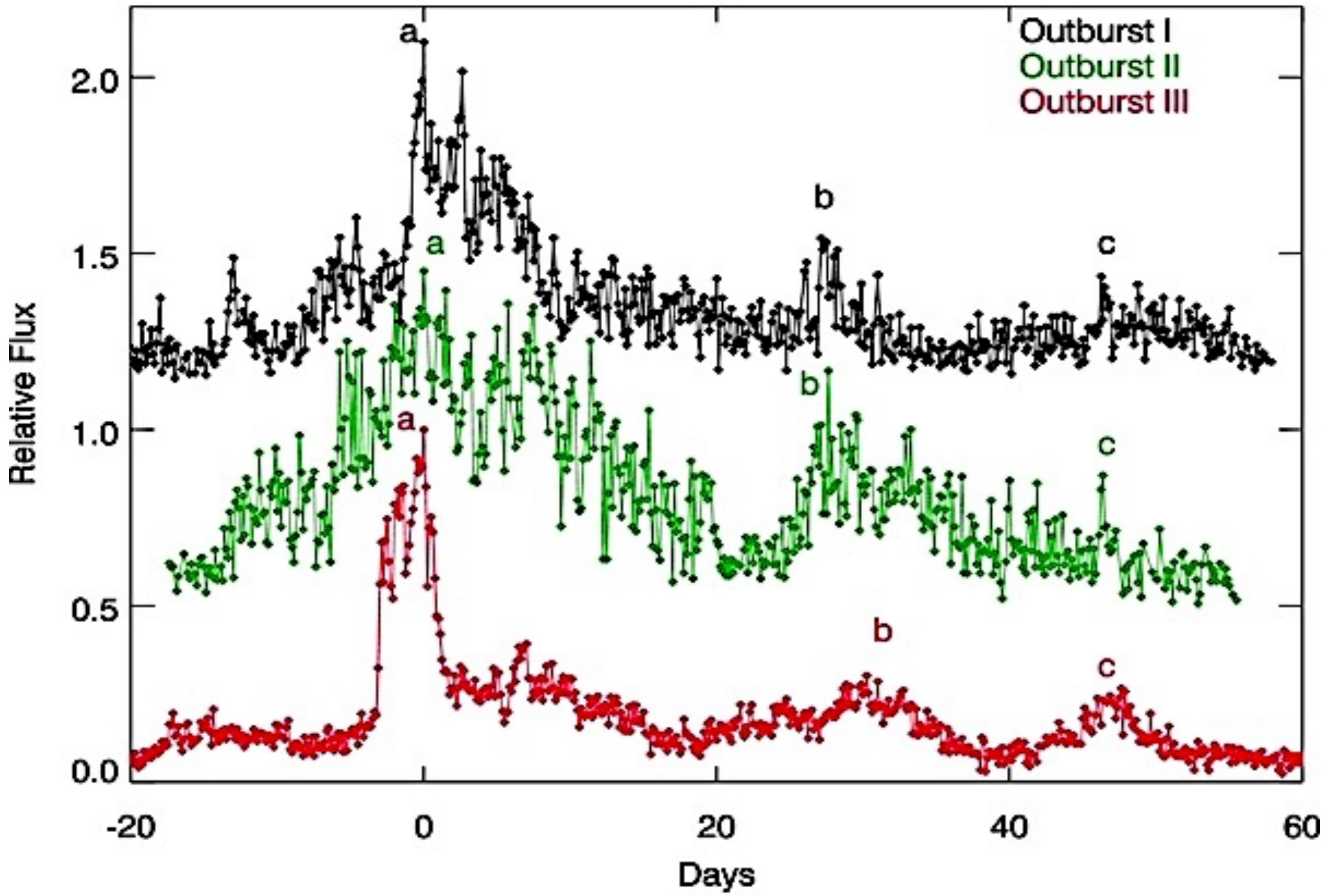
Swift X-ray flux in units of 10^{-11} erg cm^{-2} s^{-1};

Swift UV flux measurements at 2231 Å;

optical light curve in *R* band;

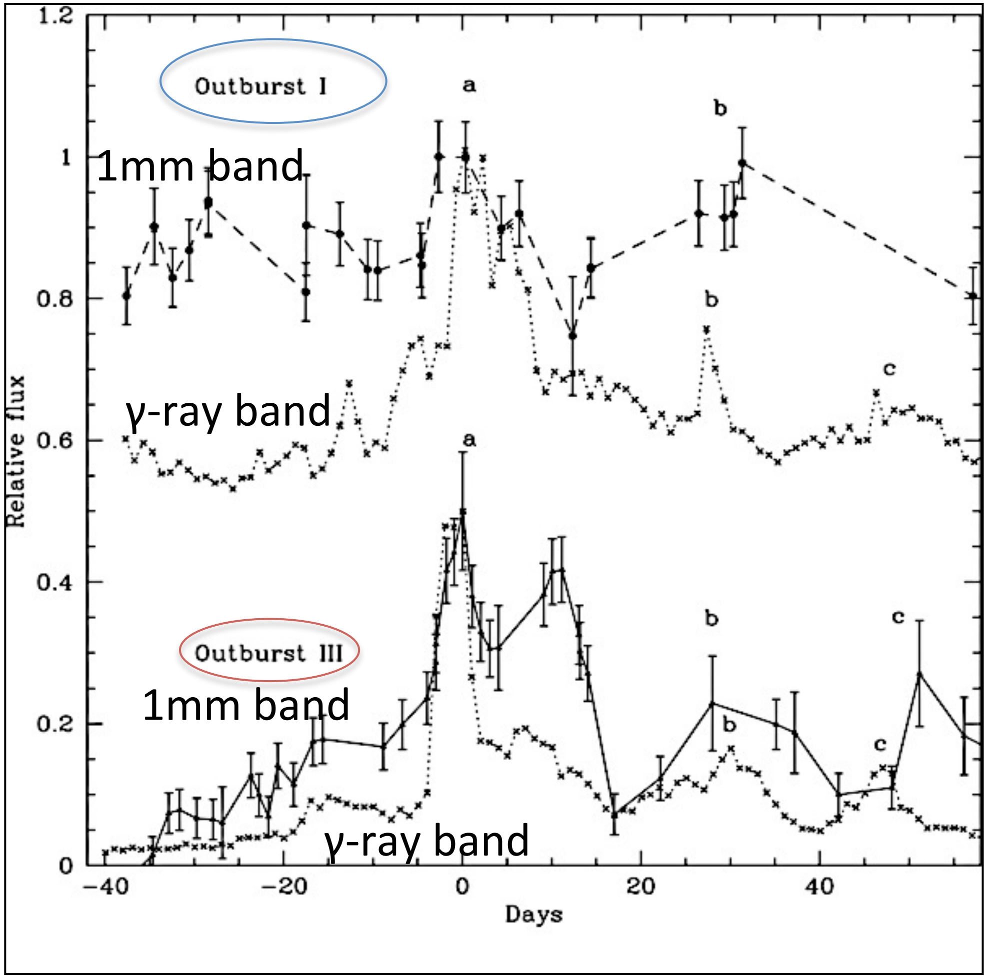
flux densities at 230 GHz (1.3 mm, red circles), 86 GHz (3 mm, green squares), and 37 GHz (8mm, black triangles)

Three Gamma-Ray Outbursts Have Remarkably Similar Secondary Flares



The three main flares during each outburst are designated as a, b, and c.

Light curves at 1 mm during outbursts I and III and superposed with the corresponding γ-ray light curves.

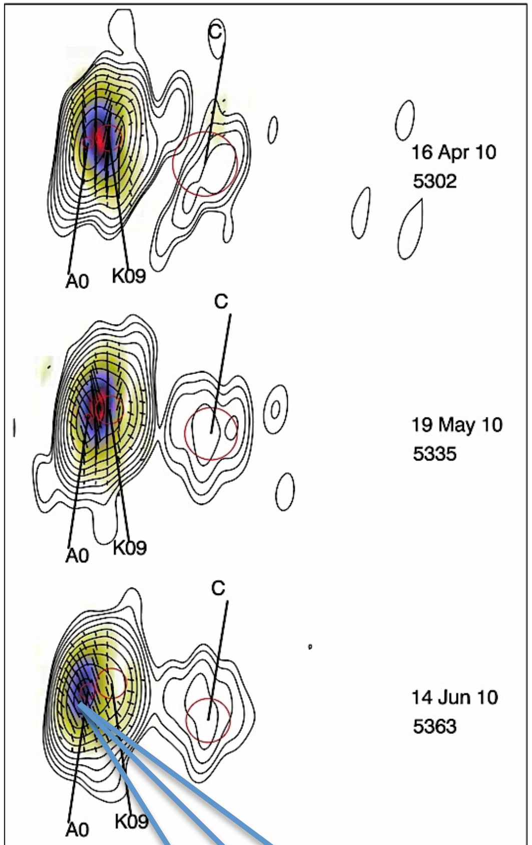


Light curves at 1 mm during outbursts I (circles, dash line) and III (triangles, solid line), normalized to the corresponding maximum and superposed with the corresponding γ-ray light curves (crosses, dotted lines).

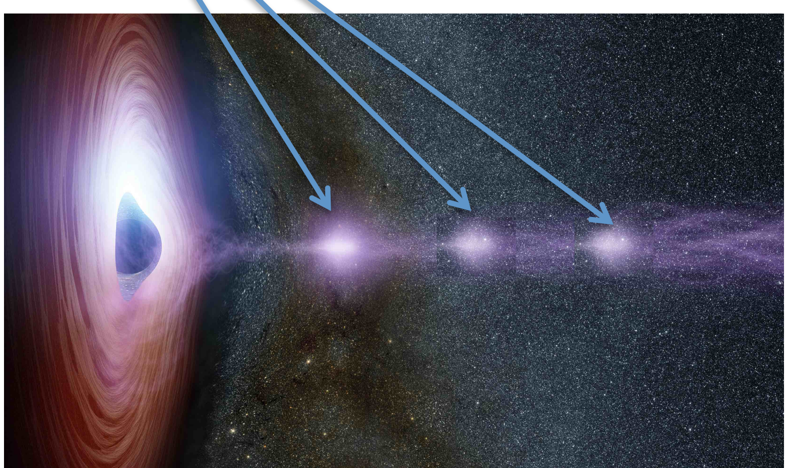
The γ-ray light curves are normalized to twice the value of the corresponding maximum.

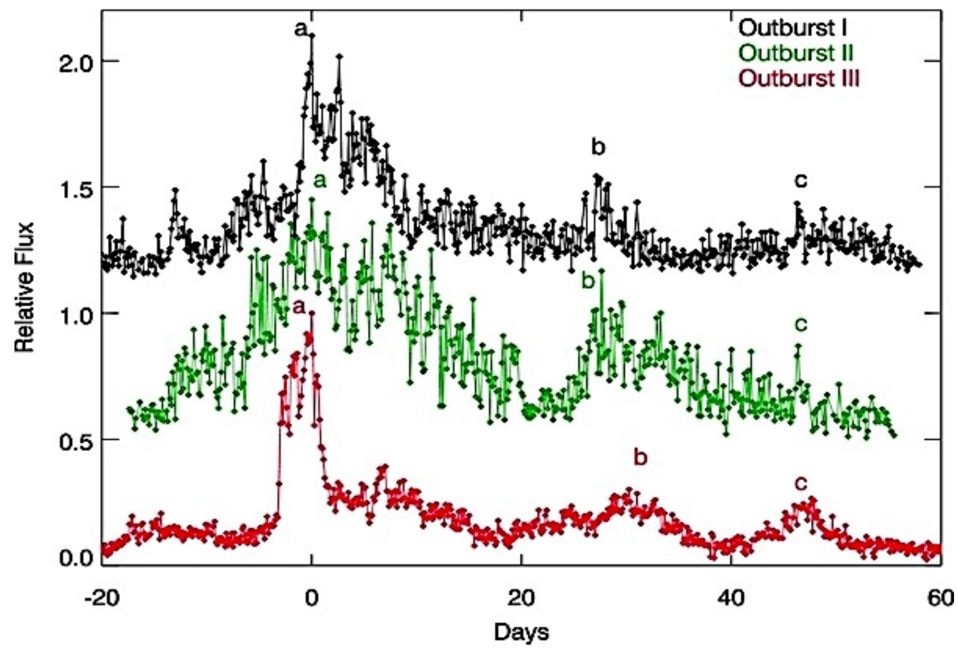
All light curves are centered with respect to the corresponding peak of the γ-ray outbursts.

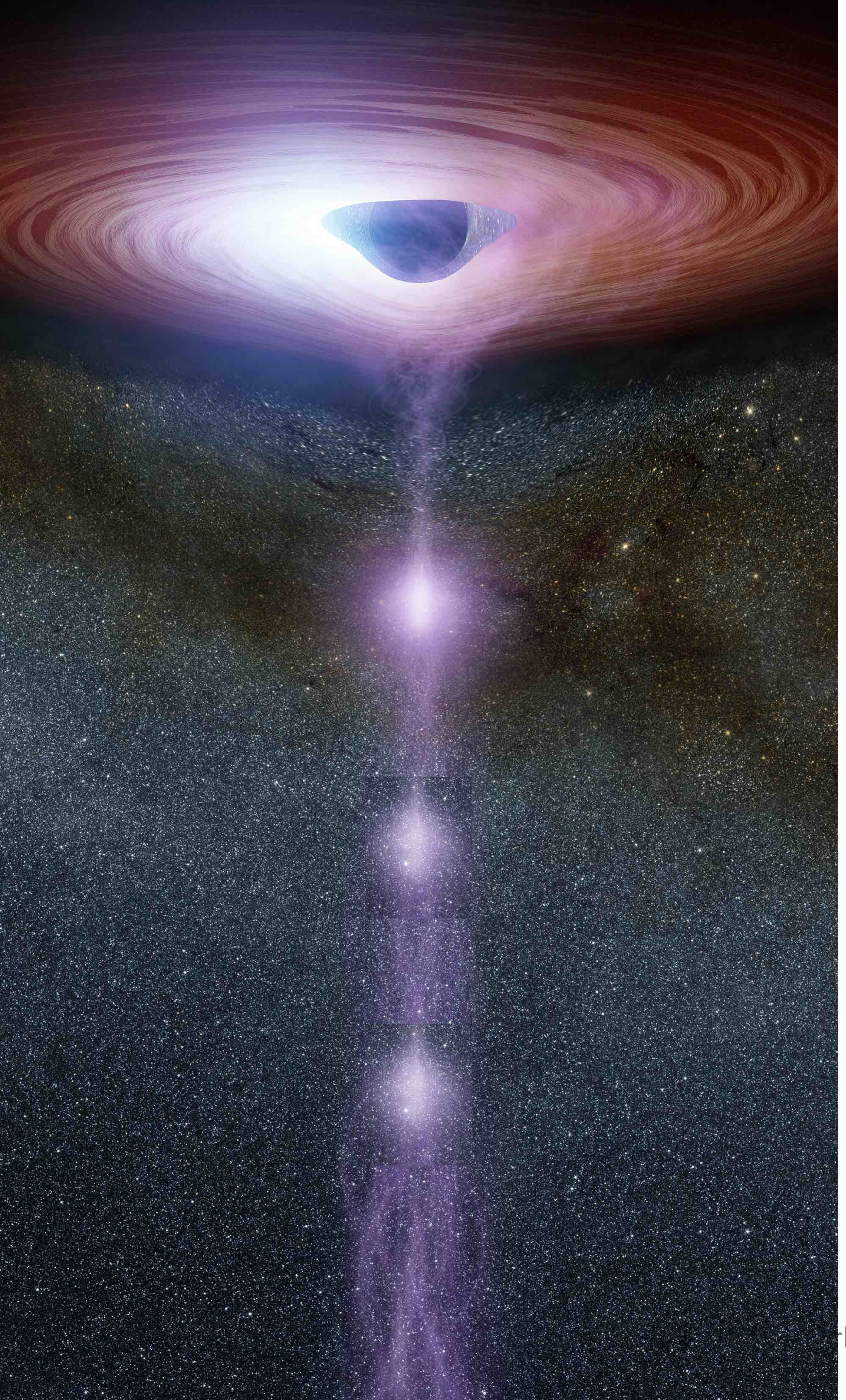
The three main flares during each outburst are designated as *a*, *b*, and *c*.



Analysis of 3 VLBI blob motions shows that the gamma-ray triple flare events in 3C454.3 occurred within the VLBI core A0 before the new superluminal blobs emerged. Timing consistent with the three super resolved knots.







Conclusions & Future

- Historic flaring in BL Lac and 3C454.3
  - -BL Lac when 4 superluminal blobs moved through core and 2 stationary knots within 4 pc of supermassive black hole
  - -3C454.3 when 3 superluminal blobs moved through 3 knots inside the core, within 5 pc of supermassive black hole
- *Shocks light up in turn when blobs pass through them- "what lights up when" depends on the physical nature of the shock and the moving superluminal blob*
- Model the evolution of flares and derive physical characteristics of the jet using the rich sequence of light curves and spectral energy distributions with the Turbulent Extreme Multi-Zone model.

- Future: Kepler K2 observations of 3C273 starting July 6, 2016: 2 months, 1-minute