The Whole Earth Blazar Telescope

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(INAF-Osservatorio Astrofisico di Torino)

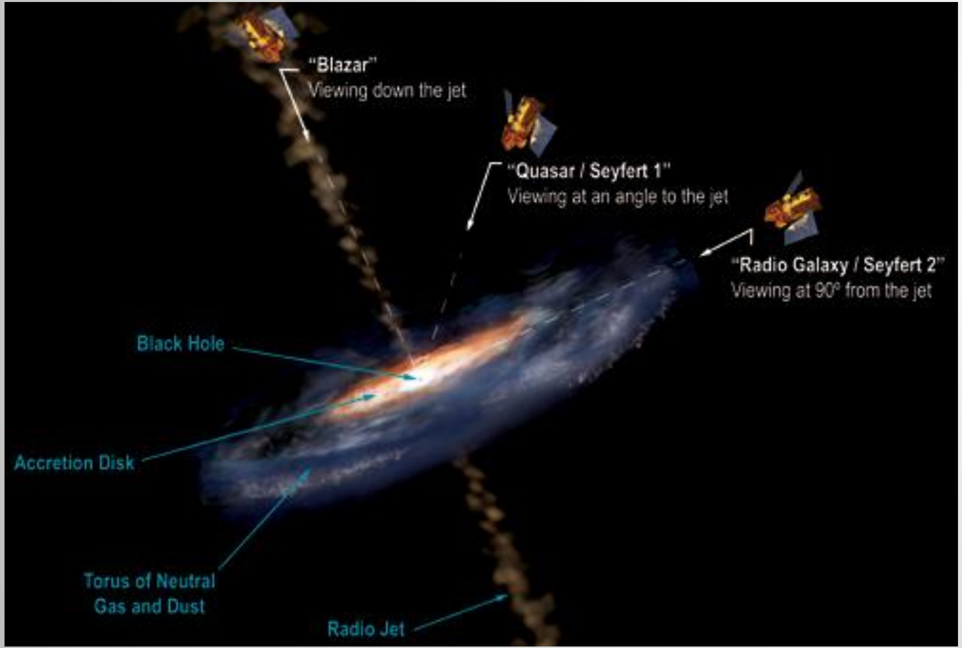
for the WEBT Collaboration

http://www.oato.inaf.it/blazars/webt/

What is a blazar?

➪ Active Galactic Nucleus (AGN) with one jet pointing toward us

➪ relativistic effects



Blazar emission properties:

- flux relativistically enhanced
- blue-shift of emitted frequencies
- contraction of variability time-scales

Blazar observed characteristics:

- unpredictable variability at all frequencies on all time-scales, from minutes/hours to months/years
- high polarization, with both the polarization degree P and angle (EVPA) very variable too

A brief outline of WEBT history

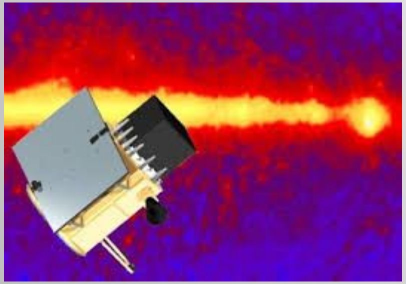
1991-2000 Compton Gamma Ray Observatory (CGRO)

➪ The extragalactic γ-ray sky is full of blazars

1997 birth of the WEBT - John Mattox (BU, USA) President ➪ support to the CGRO observations with continuous optical monitoring

2000 Massimo Villata (INAF-OATo, Italy) President ➪ +radio+near-IR

WEBT multiwavelength campaigns on specific objects



2007 birth of the GLAST-AGILE Support Program (GASP) in view of the launch of the AGILE and Fermi γ-ray satellites

➪ 14 BL Lacs + 14 FSRQs continuously monitored

Participation in the WEBT

~ 200 observers

~ 120 telescopes contributing to the WEBT campaigns
(~100 optical + 9 near-IR + 10 radio)

WEBT Products

- photometry + polarimetry + spectroscopy
- collaborations with other teams, in particular AGILE, Fermi, MAGIC
- archive, with data available one year after publication
- 247 papers by the WEBT in the NASA ADS, half refereed, including two papers on Nature, one of which led by the WEBT

Participation of the UBAI-Mt. Maidanak team in the WEBT

The collaboration started in 2000 with Mansur Ibrahimov and continued with Dovron Mirzaqulov and Shuhrat Ehgamberdiev

The UBAI team has been monitoring 27 blazars at Mt. Maidanak in the framework of the WEBT

Multiband photometry in *BVRI* bands

About 270 000 images acquired

Intraday brightness variability detected in more than 10 blazars (3 Astronomer’s Telegrams on 4C 38.41, BL Lacertae, and 3C 454.3)

45 WEBT publications signed by UBAI collaborators

Participation of the UBAI-Mt. Maidanak team to the WEBT: AO 0235+16

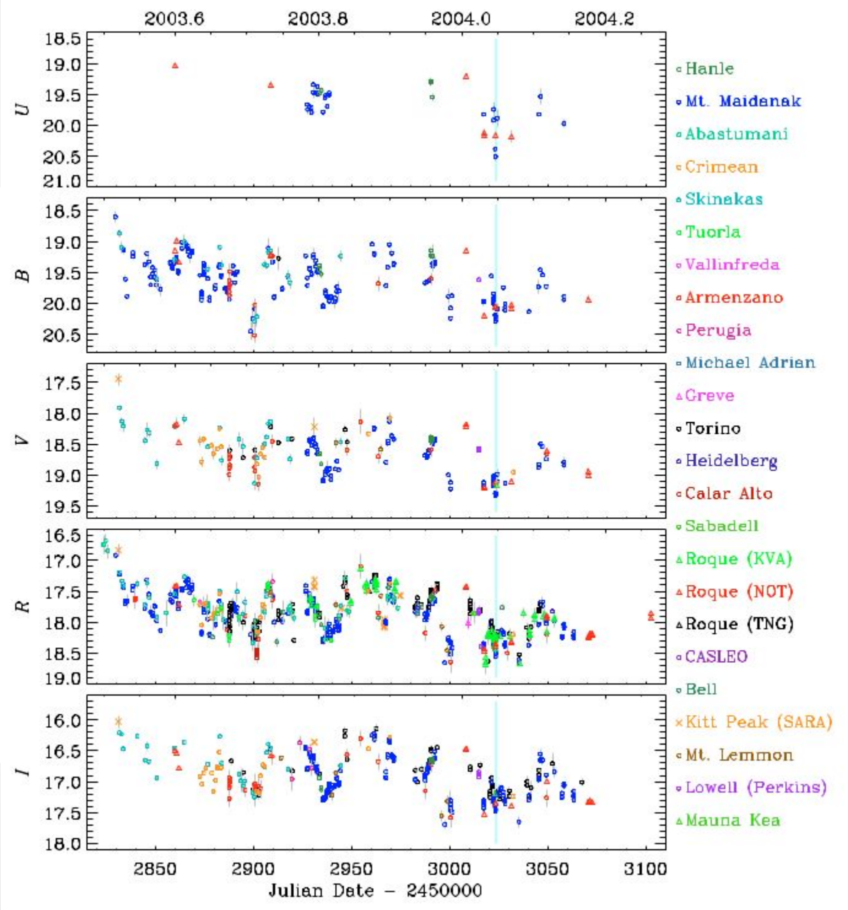
A&A 438, 39–53 (2005)
DOI: 10.1051/0004-6361:20042567

Astronomy & Astrophysics

The WEBT campaign to observe AO 0235+16 in the 2003–2004 observing season★

Results from radio-to-optical monitoring and XMM-Newton observations

C. M. Raiteri[1], M. Villata[1], M. A. Ibrahimov[2], V. M. Larionov[3,4], M. Kadler[5], H .D. Aller[6], M. F. Aller[6], Y. Y. Kovalev[7,8]★★, L. Lanteri[1], K. Nilsson[9], I. E. Papadakis[10,11], T. Pursimo[12], G. E. Romero[13], H. Teräsranta[14], M. Tornikoski[14], A. A. Arkharov[15], D. Barnaby[16], A. Berdyugin[9], M. Böttcher[17], K. Byckling[18], M. T. Carini[16], D. Carosati[19], S. A. Cellone[20], S. Ciprini[9], J. A. Combi[13,21], S. Crapanzano[1], R. Crowe[22], A. Di Paola[23], M. Dolci[24], L. Fuhrmann[1,5,25], M. Gu[26], V. A. Hagen-Thorn[3,4], P. Hakala[18], V. Impellizzeri[5], S. Jorstad[27], J. Kerp[5], G. N. Kimeridze[28], Yu. A. Kovalev[8], A. Kraus[5], T. P. Krichbaum[5], O. M. Kurtanidze[28], A. Lähteenmäki[14], E. Lindfors[9], M. G. Mingaliev[29], R. Nesci[30], M. G. Nikolashvili[28], J. Ohlert[31], M. Orio[1], L. Ostorero[32], M. Pasanen[9], A. Pati[33], C. Poteet[16], E. Ros[5], J. A. Ros[34], P. Shastri[33], L. A. Sigua[28], A. Sillanpää[9], N. Smith[35], L. O. Takalo[9], G. Tosti[25], A. Vasileva[3], S. J. Wagner[32], R. Walters[16], J. R. Webb[36], W. Wills[16], A. Witzel[5], and E. Xilouris[37]



More than 50% of the optical data from Mt. Maidanak

Participation of the UBAI-Mt. Maidanak team to the WEBT: 4C 38.41

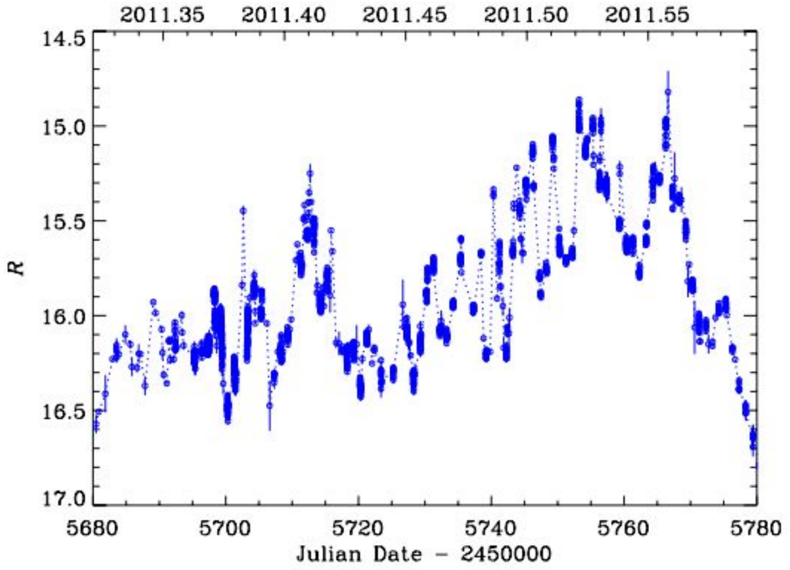


Fig. 3. The *R*-band light curve of 4C 38.41 in the most active period of 2011, showing noticeable intraday and interday variability episodes. The total number of data points is 2046, 1686 of which come from the Mt. Maidanak Observatory.

A&A 545, A48 (2012)
DOI: 10.1051/0004-6361/201219492

Astronomy & Astrophysics

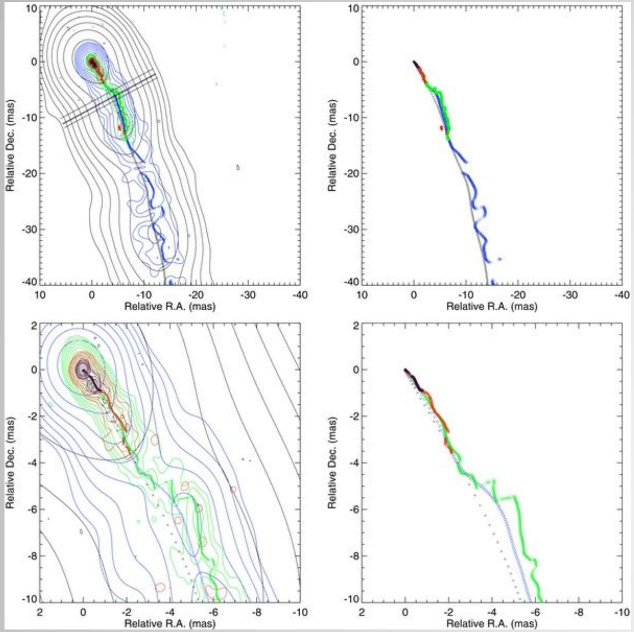
Variability of the blazar 4C 38.41 (B3 1633+382) from GHz frequencies to GeV energies★

C. M. Raiteri[1], M. Villata[1], P. S. Smith[2], V. M. Larionov[3,4,5], J. A. Acosta-Pulido[6,7], M. F. Aller[8], F. D'Ammando[9], M. A. Gurwell[10], S. G. Jorstad[11,3], M. Joshi[11], O. M. Kurtanidze[12,13,14,15], A. Lähteenmäki[16], D. O. Mirzaqulov[17], I. Agudo[18,11], H. D. Aller[8], M. J. Arévalo[6,7], A. A. Arkharov[4], U. Bach[19], E. Benítez[20], A. Berdyugin[21], D. A. Blinov[3], K. Blumenthal[11], C. S. Buemi[22], A. Bueno[6,7], T. M. Carleton[2], M. I. Carnerero[6,7,1], D. Carosati[23,24], C. Casadio[18], W. P. Chen[25], A. Di Paola[26], M. Dolci[27], N. V. Efimova[3,4], Sh. A. Ehgamberdiev[17], J. L. Gómez[18], A. I. González[7], V. A. Hagen-Thorn[3,5], J. Heidt[14], D. Hiriart[28], Sh. Holikov[17], T. S. Konstantinova[3], E. N. Kopatskaya[3], E. Koptelova[25,29], S. O. Kurtanidze[12], E. G. Larionova[3], L. V. Larionova[3], J. León-Tavares[16], P. Leto[22], H. C. Lin[25], E. Lindfors[21], A. P. Marscher[11], I. M. McHardy[30], S. N. Molina[18], D. A. Morozova[3], R. Mujica[31], M. G. Nikolashvili[12], K. Nilsson[32], E. P. Ovcharov[33], N. Panwar[25], M. Pasanen[21], I. Puerto-Gimenez[6,34], R. Reinthal[21], G. M. Richter[13], J. A. Ros[35], T. Sakamoto[36,37], R. D. Schwartz[38], A. Sillanpää[21], N. Smith[39], L. O. Takalo[21], J. Tammi[16], B. Taylor[11,40], C. Thum[41], M. Tornikoski[16], C. Trigilio[22], I. S. Troitsky[3], G. Umana[22], A. T. Valcheva[33], and A. E. Wehrle[42]

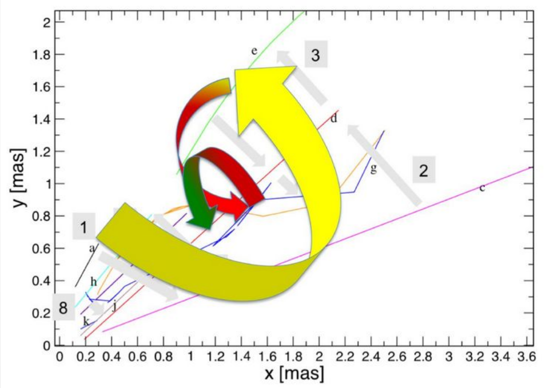
Exceptional contribution from Mt. Maidanak Observatory!

Long-term variability explained by a geometrical scenario, involving an inhomogeneous bent jet

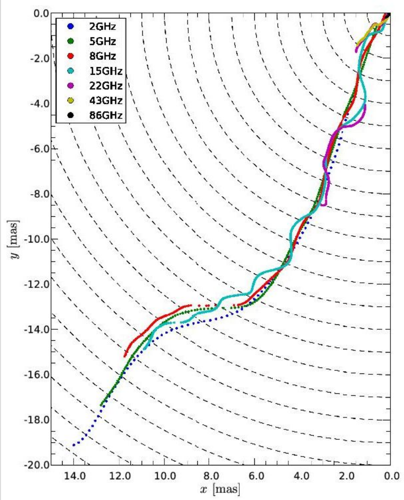
Geometrical scenario for the long-term variability: observational hints



Perucho et al. (2012, ApJ, 749, 55)
"*Anatomy of helical extragalactic jets: the case of S5 0836+710*"



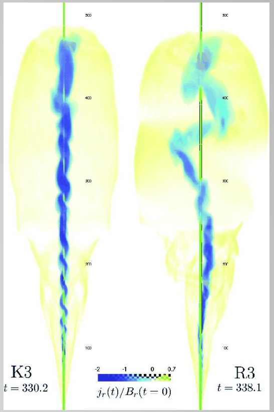
Britzen et al. (2017, A&A, 602, A29)
"*A swirling jet in the quasar 1308+326*"

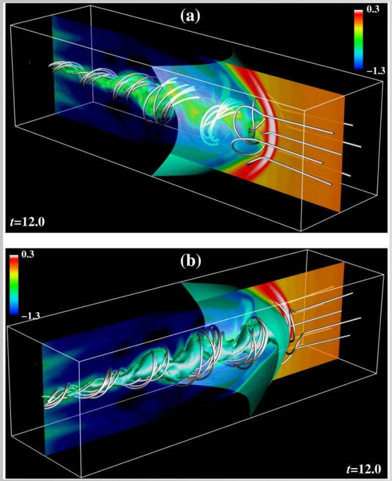


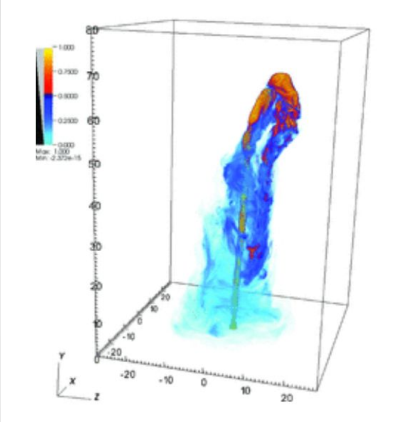
Fromm et al. (2013, A&A, 557, A105)
"*Catching the radio flare in CTA 102*"

Geometrical scenario for the long-term variability: numerical simulations hints

Moll et al. (2008, A&A, 492, 621)
“ *Kink instabilities in jets from rotating magnetic fields*“



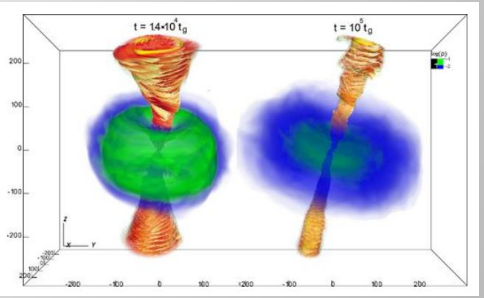




Mignone et al. (2010, MNRAS, 402, 7)
“*High-resolution 3D relativistic MHD simulations of jets*”

Nakamura et al. (2001, New Astronomy, 6, 61)
“*Production of wiggled structure of AGN radio jets in the sweeping magnetic twist mechanism*”

Liska et al. (2018, MNRAS, 474, L81)
“*Formation of precessing jets by tilted black hole discs in 3D general relativistic MHD simulations*”



GEOMETRICAL interpretation proposed in many WEBT works:

long-term VARIABILITY = variation of the VIEWING ANGLE θ

of the emitting jet regions

➪ variation of the DOPPLER FACTOR δ

$\delta=[\Gamma(1-\beta\cos\theta)]^{-1}$ with $\Gamma=(1-\beta^2)^{-1/2}$ bulk Lorentz factor

When δ increases:

- flux density increases as $F_\nu(\nu) = \delta^{2+\alpha} F'_{\nu'}(\nu)$ (for a continuous jet)
- variability time scale decreases as $\Delta t = \Delta t'/\delta$
- variability amplitude of intrinsic flux changes increases as $\Delta F \propto \delta^{2+\alpha}$

But can we see the effects of Doppler factor changes in the blazar light curves?

YES!

NATURE, VOL 552, DECEMBER 2017, 374

LETTER

doi:10.1038/nature24623

Blazar spectral variability as explained by a twisted inhomogeneous jet

C. M. Raiteri[1], M. Villata[1], J. A. Acosta-Pulido[2,3], I. Agudo[4], A. A. Arkharov[5], R. Bachev[6], G. V. Baida[7], E. Benítez[8], G. A. Borman[7], W. Boschin[2,3,9], V. Bozhilov[10], M. S. Butuzova[7], P. Calcidese[11], M. I. Carnerero[1], D. Carosati[9,12], C. Casadio[4,13], N. Castro-Segura[3,14], W.-P. Chen[15], G. Damljanovic[16], F. D'Ammando[17,18], A. Di Paola[19], J. Echevarría[8], N. V. Efimova[5], Sh. A. Ehgamberdiev[20], C. Espinosa[8], A. Fuentes[4], A. Giunta[19], J. L. Gómez[4], T. S. Grishina[21], M. A. Gurwell[22], D. Hiriart[8], H. Jermak[23], B. Jordan[24], S. G. Jorstad[21,25], M. Joshi[25], E. N. Kopatskaya[21], K. Kuratov[26,27], O. M. Kurtanidze[28,29,30,31], S. O. Kurtanidze[28], A. Lähteenmäki[32,33,34], V. M. Larionov[5,21], E. G. Larionova[21], L. V. Larionova[21], C. Lázaro[2,3], C. S. Lin[15], M. P. Malmrose[25], A. P. Marscher[25], K. Matsumoto[35], B. McBreen[36], R. Michel[8], B. Mihov[6], M. Minev[10], D. O. Mirzaqulov[20], A. A. Mokrushina[5,21], S. N. Molina[4], J. W. Moody[37], D. A. Morozova[21], S. V. Nazarov[7], M. G. Nikolashvili[28], J. M. Ohlert[38,39], D. N. Okhmat[7], E. Ovcharov[10], F. Pinna[2,3], T. A. Polakis[40], C. Protasio[2,3], T. Pursimo[41], F. J. Redondo-Lorenzo[2,3], N. Rizzi[42], G. Rodriguez-Coira[2,3], K. Sadakane[35], A. C. Sadun[43], M. R. Samal[15], S. S. Savchenko[21], E. Semkov[6], B. A. Skiff[44], L. Slavcheva-Mihova[6], P. S. Smith[45], I. A. Steele[23], A. Strigachev[6], J. Tammi[32], C. Thum[46], M. Tornikoski[32], Yu. V. Troitskaya[21], I. S. Troitsky[21], A. A. Vasilyev[21] & O. Vince[16]

CTA 102 (2230+114)

FSRQ @ $z = 1.037$

WEBT optical+near-IR+radio monitoring

In 2013-2017:

39 telescopes in 28 observatories

Mt. Maidanak: 3014 data in BVRI @ T-60

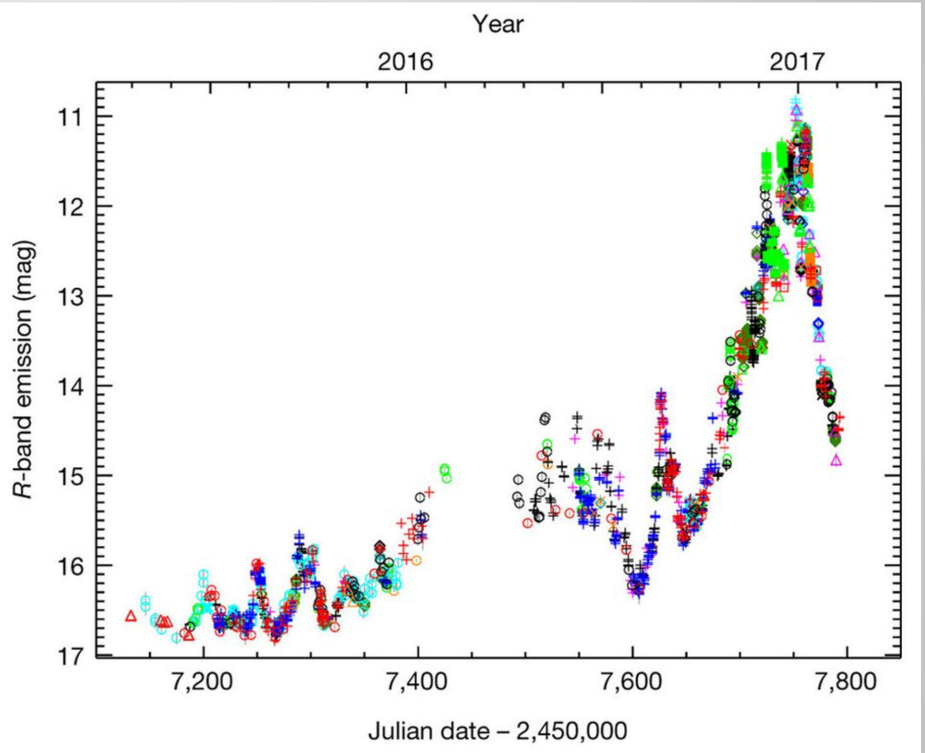
Late 2016: jump of 6-7 mag

Peak: 28 December 2016

➪ $R = 10.82 \pm 0.04$

➪ $\log \nu L_\nu = 48.12$ (erg/s)

➪ unprecedented



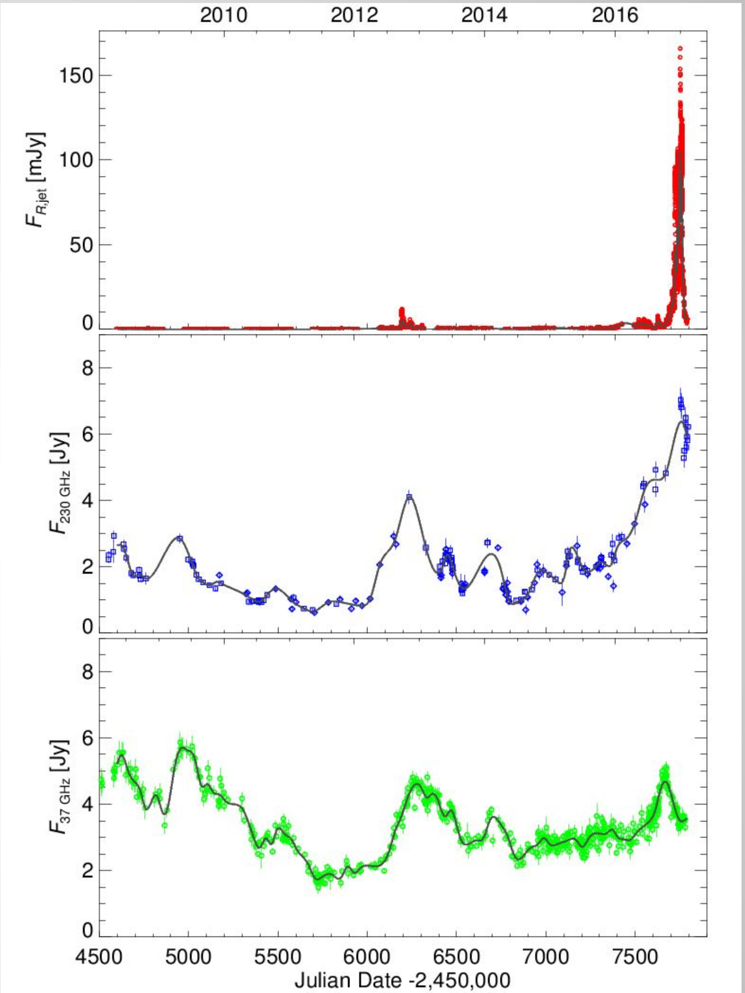
Optical, mm, and radio behaviour different

➪ coming from different jet regions

➪ the jet is inhomogeneous

Radio and mm changes smoother

➪ coming from more extended (outer) regions



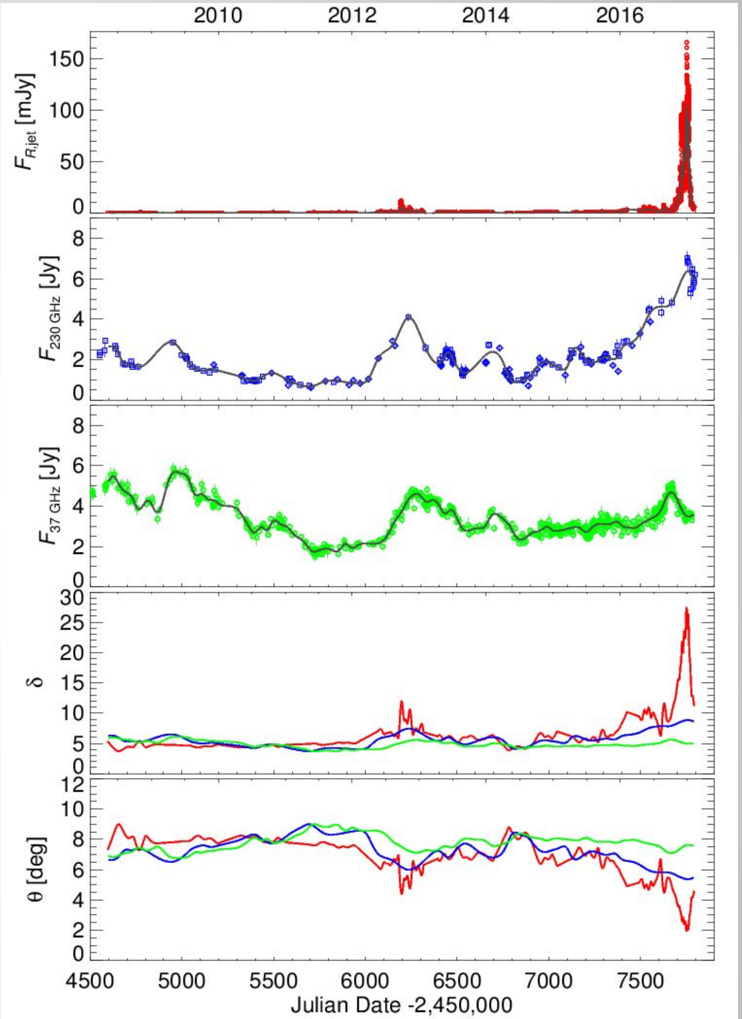
In optical, fast flares are more rapid and pronounced when the source is brighter

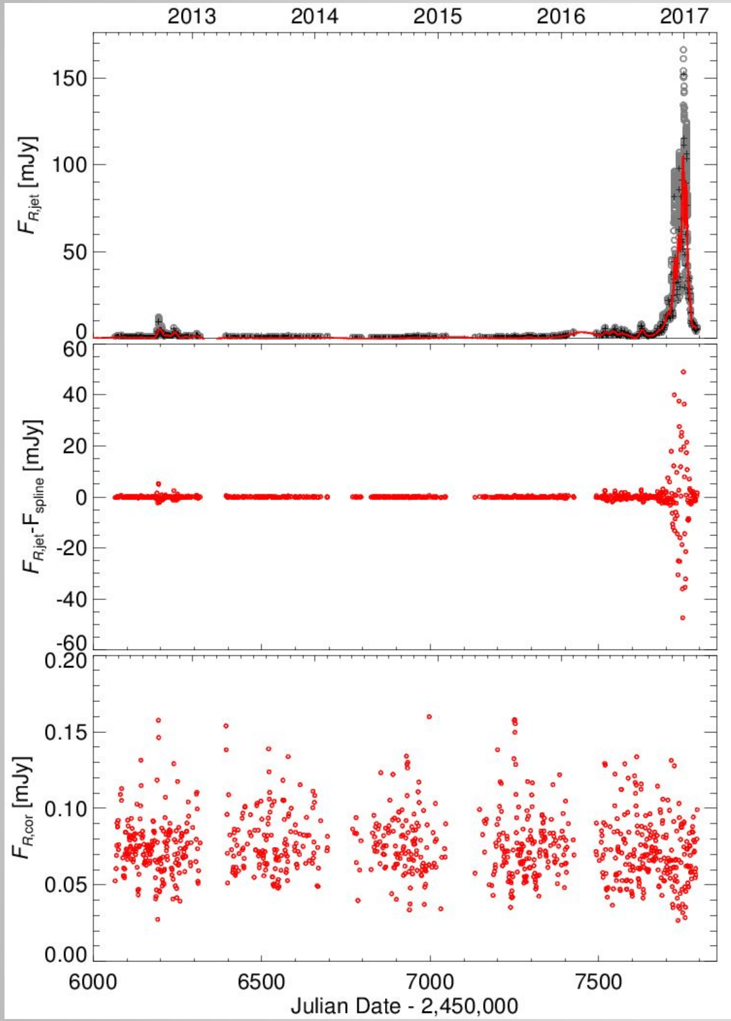
➪ Doppler beaming effect

Assume that long-term variability is due to changes of δ because of changes of θ

➪ From the long-term trends derive δ(t) and θ(t) at different ν

➪ the jet is curved and twisting



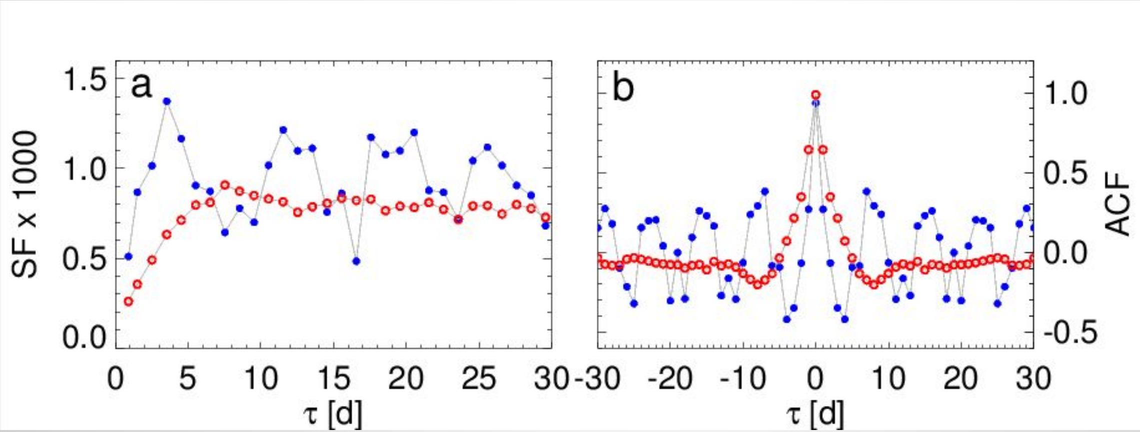


Verify increased variability amplitude for higher δ

Oscillations around the long-term trend represented by the spline

Small-amplitude fast variations due to intrinsic processes after correcting for δ(t)
(= fixed δ_{base})

Verify time contraction



Blue: high brightness state

Red: low brightness state

➪ $\tau_{blue} = \tau_{red}/2$

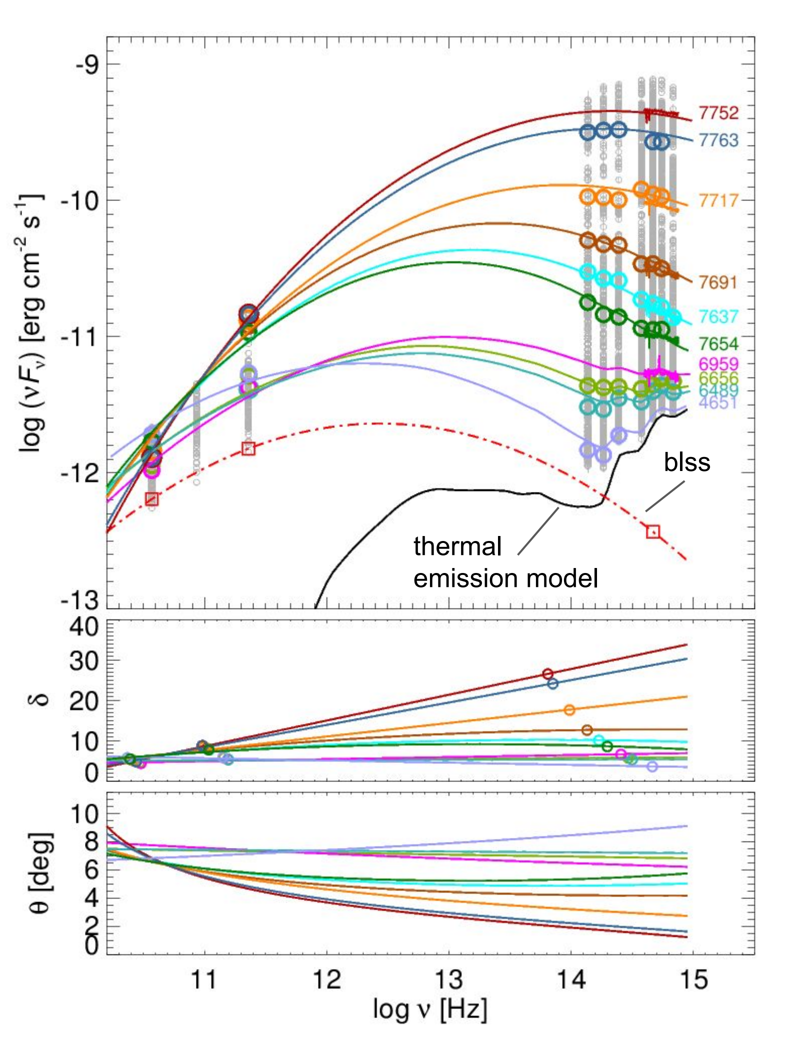
SED modelling

- build thermal emission model
- build a base-level synchrotron spectrum (blss)
- ∀ epoch build $\delta(\nu)$ and $\theta(\nu)$
- derive the predicted synchrotron SED as Doppler enhancement of the blss

\+ thermal emission model

= total SED to be compared with observed SED

➪ excellent reproduction of both flux level and spectral slope

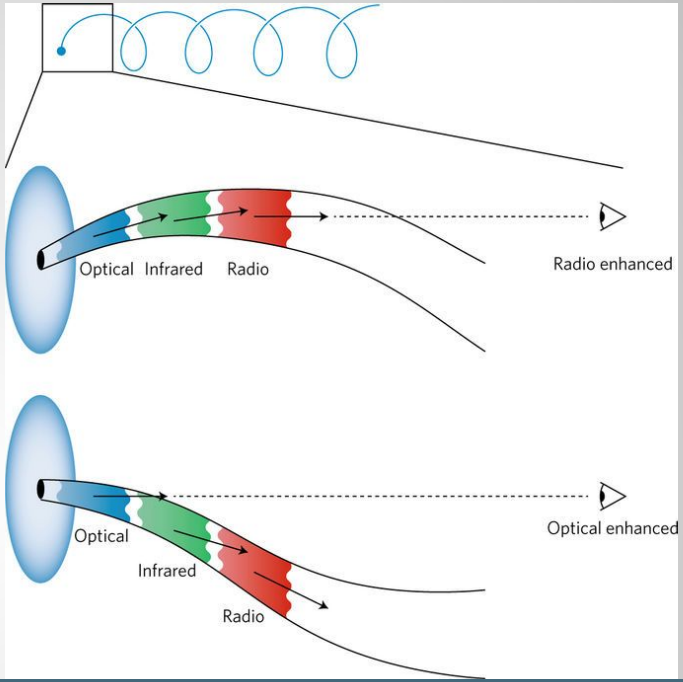


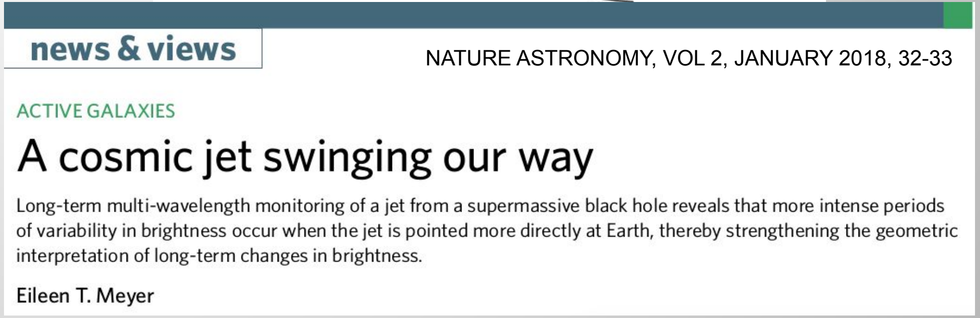
As a result the jet is:

- inhomogeneous different frequencies emitted from different regions

- curved different regions have different viewing angles

- twisting/swinging/swirling/ snaking/meandering/wiggling
  the viewing angle varies in time
  because of internal (instabilities)
  or external (orbital motion, precession)
  reasons





news & views

NATURE ASTRONOMY, VOL 2, JANUARY 2018, 32-33

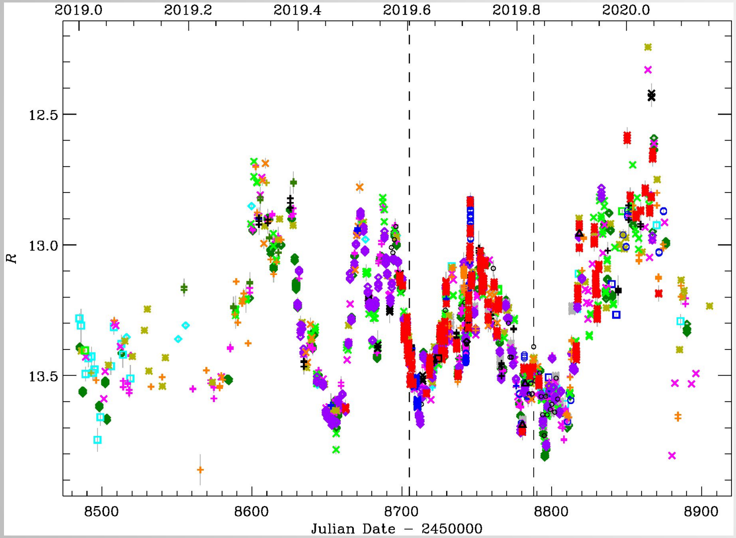
ACTIVE GALAXIES

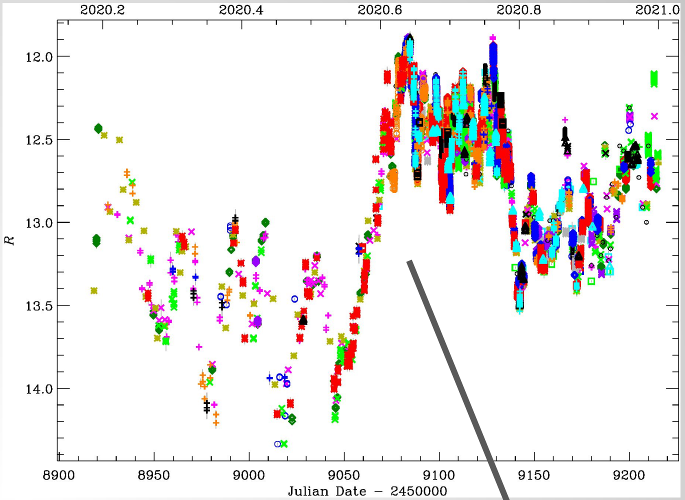
A cosmic jet swinging our way

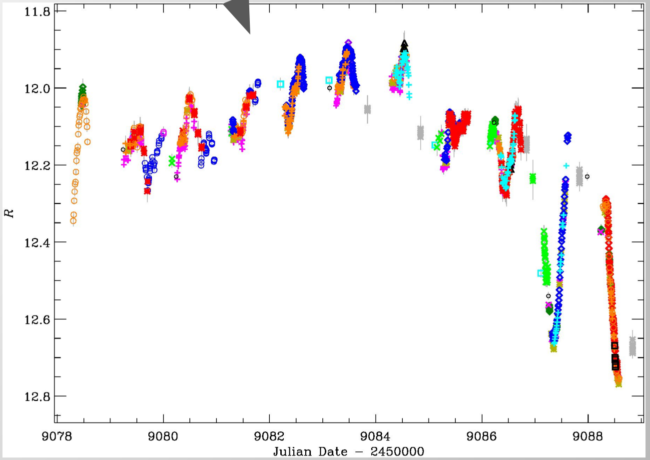
Long-term multi-wavelength monitoring of a jet from a supermassive black hole reveals that more intense periods of variability in brightness occur when the jet is pointed more directly at Earth, thereby strengthening the geometric interpretation of long-term changes in brightness.

Eileen T. Meyer

Undergoing project:
BL Lacertae 2019-2021







Thank you