Multi-wavelength observations of IC 310 following an extreme gamma-ray outburst

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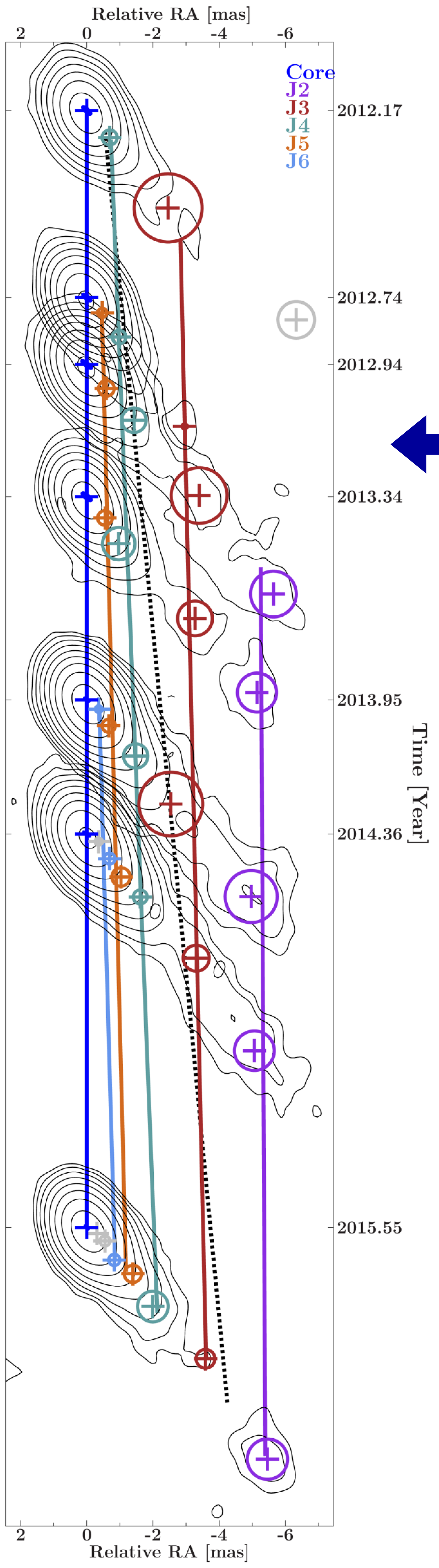
Abstract

IC 310, a one-sided radio galaxy in the Perseus Cluster, has repeatedly shown large amplitude and short time scale variability at TeV photon energies. The observed variability and hard spectrum of the minute-scale flare in November 2012 cannot be explained by shock acceleration in the jet, but instead by highly anisotropic particle beams at the base of the jet. The particle beams fire electromagnetic cascades, loading the jet with electrons and positrons. After passing through shocks further down the jet, the injected particles should lead to flux enhancements at radio frequencies.
In search of this afterglow, we carried out multi-wavelength follow-up observations, including the European VLBI Network and MOJAVE. Here, we report the first results of this campaign.

VLBI Monitoring

- Temporal evolution of the jet by MOJAVE monitoring at 15 GHz since early 2012
- No significant variability of the total flux density
- Results from kinematic analysis:

Comp. ID	N	$v_{app,est}$ [mas yr^{-1}]	$\beta_{app,est}$	$t_{inj,est}$ [yr]
J2	5	0.31±0.09	0.4±0.1	1980±20
J3	7	0.23±0.03	0.29±0.08	1980±10
J4	7	0.65±0.03	0.83±0.04	2010.4±0.2
J5	6	0.40±0.02	0.51±0.02	2011.0±0.2
J6	3	0.54±0.02	0.68±0.02	2013.0±0.1

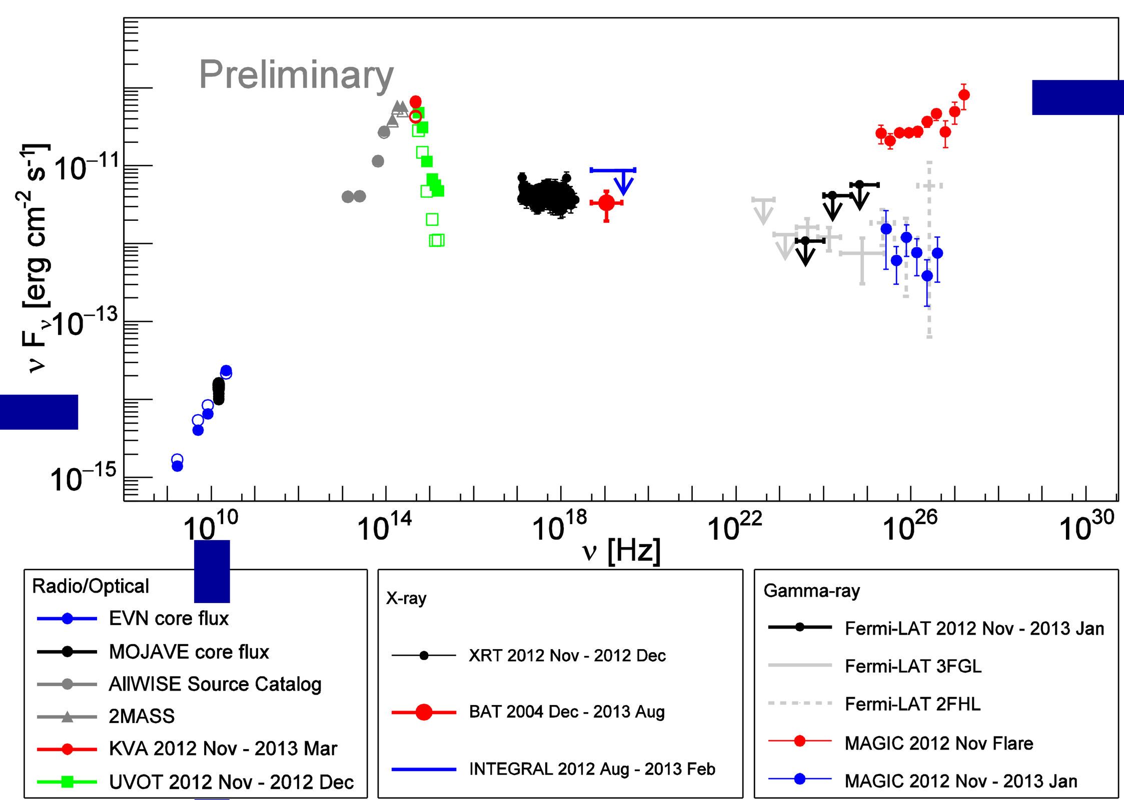


IC 310 in a nutshell

- Nearby galaxy of the Perseus Cluster of galaxies (S0, z=0.0189) exhibits an active nucleus with a mass of $3 \times 10^8\ M_{Sun}$ [1]
- Initially classified as head-tail radio galaxy based on kpc-scale radio morphology e.g. [2]
- Snap-shot VLBA observations showed pc-scale single-sided core-jet structure and same position angle of pc and kpc jet [3]
- Detected above 30 GeV with Fermi-LAT [4] and with the MAGIC Telescopes above 260 GeV [5]
- Shows a mixture of properties of a blazar or a radio galaxies in different frequency bands [6] → suggests classification as **misaligned blazar**

Spectral Energy Distribution

- **First extensive multi-wavelength** (MWL) **campaign** conducted in autumn 2012 until early 2013 to measure spectral energy distribution (SED)
- Hint for "harder-when-brighter" behavior in X-ray during Nov-Dec 2012
- Infrared/optical/UV range dominated by host galaxy



Black Hole Lightning

- **Extreme TeV flare** on Nov 12/13, 2012 detected with the MAGIC Telescopes during the MWL campaign [1]
- High state lasting for at least 3.5 h
- **Variability on time scales faster than ~4.8 min** in the frame of the jet (conservative)
- Very hard power-law spectrum up to ~10 TeV, no break
- No significant spectral variability during flare
- Observations afterwards until early 2013 showed low flux

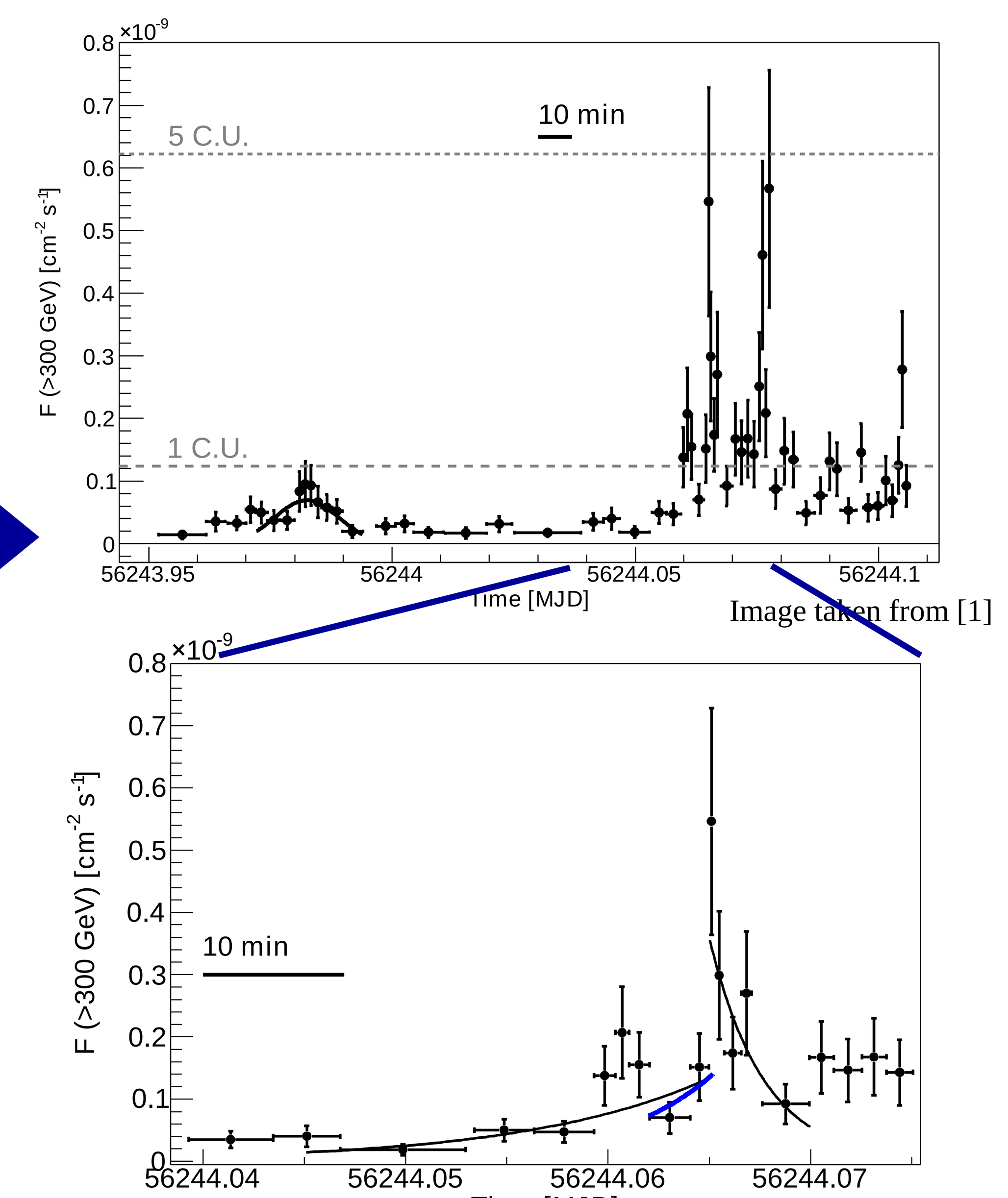


Image taken from [1]

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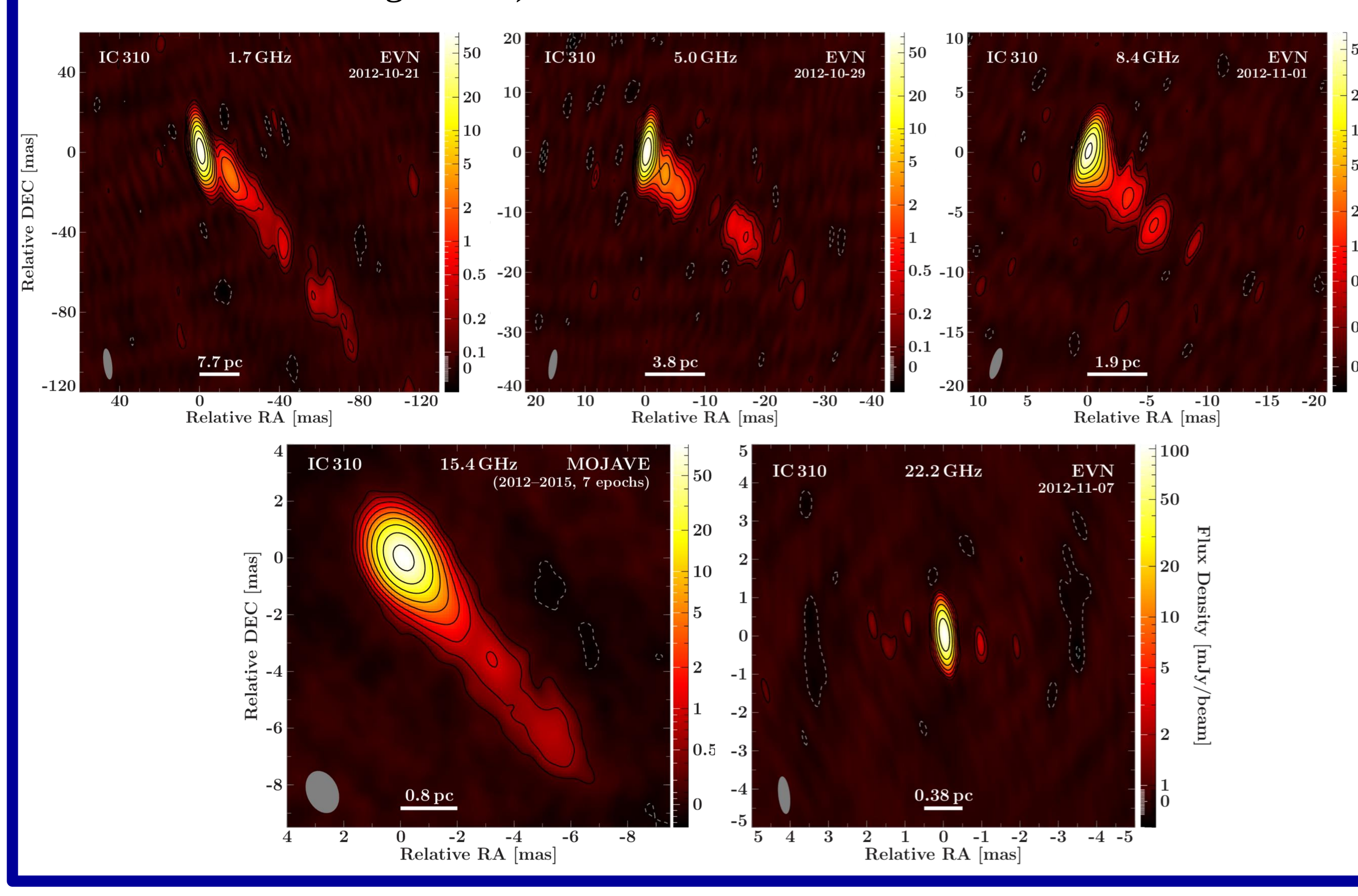
Multifrequency VLBI Imaging

- Observation with the EVN at different frequencies [7] and the VLBA (MOJAVE)
- EVN observations show flat spectrum due to dominating VLBI core
- Intrinsic half opening angle of ≲ 4.3° (assuming a conical jet)
- Magnetic field strength from core shift measurements following [8]:
  - at 1pc ≳ 0.07 G
  - at $1R_S \gtrsim 2.5\times10^3$ G (extrapolated assuming a purely toroidal field configuration)



Conclusion

- Intermediate angle of the jet to the line of sight: $\mathbf{10° \lesssim \theta \lesssim 20°}$ [1]
- VLBI measurements yield $1.4 \lesssim \Gamma_b \lesssim 1.8$ and $1.7 \lesssim \delta \lesssim 3.1$
  → **no strong** (blazar-like) **boosting**
- Kinematic analysis of MOJAVE data shows $\beta_{app} < 1$, similar to TeV detected BL Lac objects and radio galaxies
- High magnetic fields of above 2.5×10^3 G at the jet launching region
- Size of gamma-ray emission region $R < \delta \cdot 0.2\ R_G$ from TeV variability
  → $\delta \gtrsim 10$ required to avoid γγ-pair production
- **TeV variability can not be explained with standard shock-in-jet model** [4]
- **Magnetospheric model** similar to "aligned magnetic rotator model " works (e.g. [9], [10]):
  - Electromagnetic cascades and particle acceleration in vacuum gaps
  - Gamma-ray emission due to inverse Compton and curvature radiation

Contact

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