Looking for the first time into the heart of the blazar 2013+370

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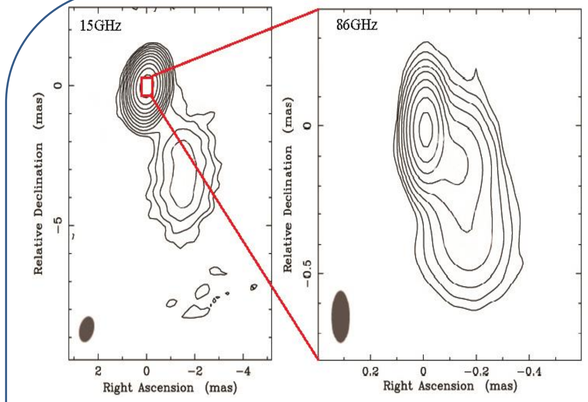
Abstract

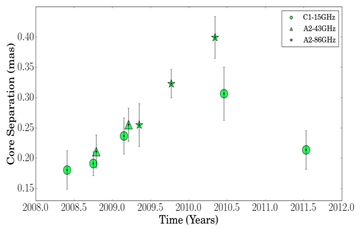
The compact radio source 2013+370 is a not yet well studied blazar which hosts a supermassive black hole of $M_{\odot} \cdot 10^8$ and is located at a redshift of z = 0.859. We observed the source with Very Long Baseline Interferometry (VLBI) at 15, 43 and 86 GHz and study the source's morphology and kinematics. The VLBI data are then combined with flux density variability measurements at 15 and 235 GHz and with the available γ-ray light curve in the period 2008-2017. A variability and cross-correlation analysis is used to check for possible correlations between the different bands. The analysis showed that the most prominent flares and maxima stem from the central VLBI region, namely the core, and most likely are physically connected with traveling shocks passing the core region. In the course of our analysis with present for the first time, 3mm (86 GHz) VLBI maps the innermost jet region (left panel).

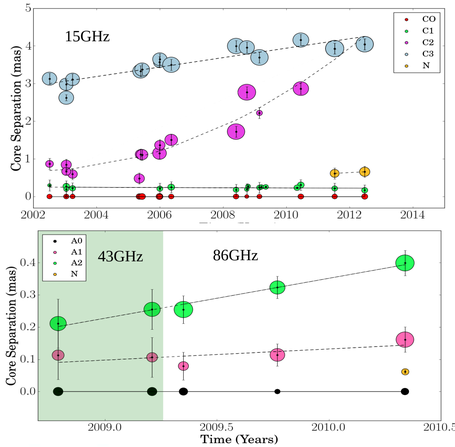


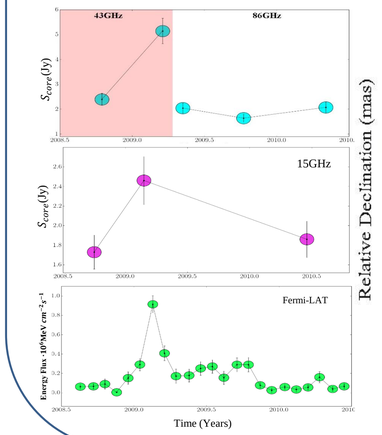
Imaging and Kinematic Analysis

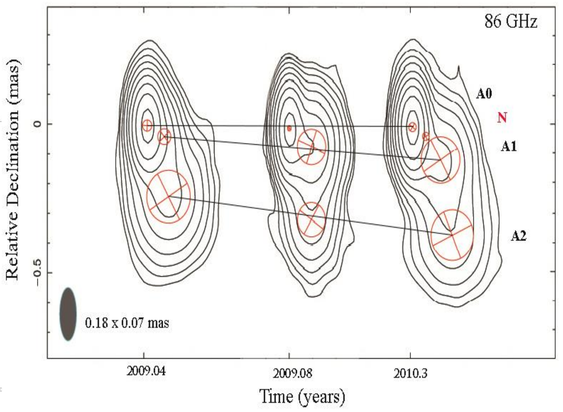
Source kinematics from the Mojave 15 GHz VLBA Monitoring Project (15 GHz, 15 epochs), 43 GHz VLBA (5 epochs) and from 86 GHz Global Millimeter VLBI (GMVA) observations (3 epochs) showed:

- Jet is described by 3-4 Gaussian components.
- Moving and stationary components are detected.
- New component around 2009-2010.
- Indications for the C1 quasi – stationary feature to be the same with A2 at 3mm (left panel).



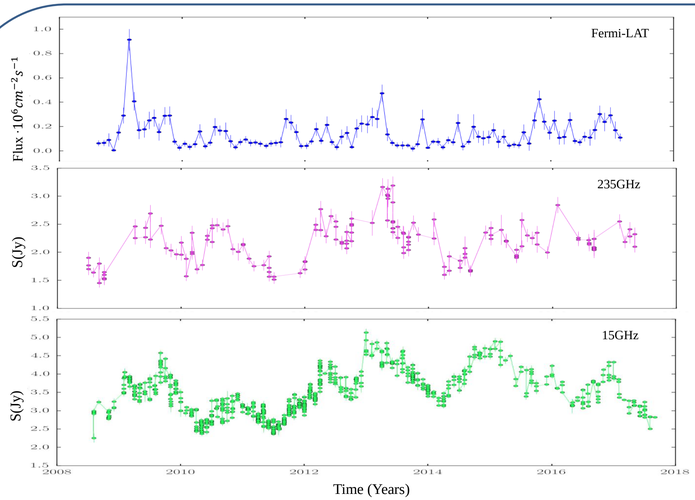






2009 Flare – Shock Ejection

The 86 GHz GMVA images shown on the left the ejection of a new jet component between 2009.01 - 2010. The ejection of N might be related to an enhanced gamma-ray flux, peaking in 2009.01 (left, bottom plot) as well as a rising the VLBI core flux at 15-86 GHz (left upper and middle panels).



Flux evolution of mm and γ-ray bands

Comparison in time scale among Fermi-LAT γ-ray light curve (upper panel), 235GHz Submillimeter Array (SMA) (middle panel) and 15GHz Owens Valley Radio Observatory (OVRO) (bottom panel) of 2013+370 indicates an quasi-simultaneously flux variability in the most prominent events during the period 2008 to 2017. Such behavior implies the possibility that those events are associated and produced by the same processes.

DCCF Analysis

The DCCF analysis showed correlated variability between gamma-rays and the 235 GHz light curve (top left) . No significant correlation is seen between the gamma-rays and 15 GHz (bottom left). Namely:

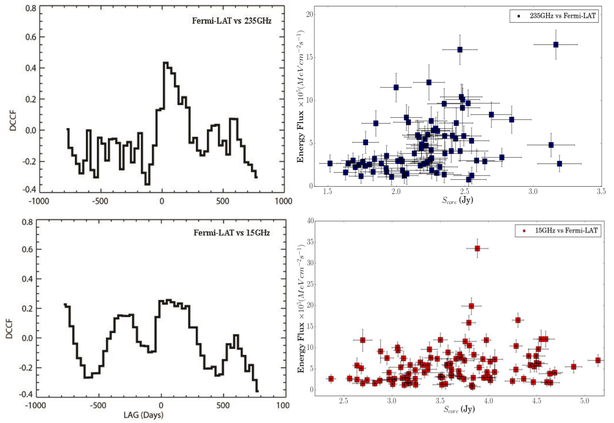
- *γ-rays–235GHz*

$\boldsymbol{\tau_{DCCF} = 91 \pm 24.3\ days}$

- *γ-rays–15GHz*

$\boldsymbol{\tau_{DCCF} = 103.2 \pm 30\ days}$

The aforementioned differences in time implies that the emission process originates upstream of the radio core.



Flux-Flux Relation

Comparison between γ-ray flux and radio flux indicates some quasi-simultaneous flux variations during the activity period of 2008-2017. Spearman's rank correlation test showed :

- *γ-rays–235GHz* :

$\boldsymbol{\rho = 0.43\ ,\ P_{value} = 9.44 \cdot 10^{-5}}$

- *γ-rays–15GHz :*

$\boldsymbol{\rho = 0.25\ ,\ P_{value} = 0.01}$

The apparent correlation of the light curves suggest that radio/mm and gamma-rays are co-located within the inner VLBI jet.

Locating the γ -ray emission region

The time lags derived from the DCCF analysis can be converted into linear distances, adopting a jet speed of β_{app}=15.67 c and a jet viewing angle of θ_{crit}= 3.65^o.
From this we derive the following linear dimensions:

$\boldsymbol{\Delta r_{235GHz-\gamma} = 10.11 \pm 2.7(pc)}$ **away of the** $\boldsymbol{\tau_{235GHz} = 1}$

$\boldsymbol{\Delta r_{15GHz-\gamma} = 11.56 \pm 3.3(pc)}$ **away of the** $\boldsymbol{\tau_{15GHz} = 1}$

This knowledge combined with future VLBI observations can help to understand the mechanism that dominates the γ-ray production in 2013+370.