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

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The compact radio source TXS 2013+370 is a γ-ray blazar which is located at a redshift of z = 0.859 in a galactic latitude b = 1.2^{o}. We observed the source with Very Long Baseline Interferometry (VLBI) at 15, 43 and 86 GHz and studied the morphology and the kinematic properties of the jet. The VLBI data were 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 cross-correlation analysis was performed to investigate the existence of a correlation between the variability observed in the different bands. The preliminary results of our study showed that the most prominent flares and maxima stem from the central VLBI region and most likely are associated with the nuclear region, namely the core, and are most likely caused by the passage of traveling shocks through the core region. In the course of our analysis, we present for the first time an 86 GHz GMVA image of the innermost jet region.

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1. Introduction

Blazars are among the most powerful and variable known astrophysical objects. Their extreme properties are due to the existence of a relativistic jet of matter ejected from the nuclear region and pointing towards the Earth at a very small viewing angle. This geometrical coincidence is a unique opportunity to investigate the structure and physical processes that take place in the innermost region of the jet. The γ-ray emitting blazar TXS 2013+370 is such a compact object. It is located at a redshift of $z = 0.859$ [10] and even though it is detected in γ-rays [4], it is not yet well studied due to its location close to the galactic plane (b = 1.2^o) [1]. By performing Very Long Baseline Interferometry (VLBI) observations at high frequencies, we can describe the morphology of the source, the kinematics on sub-parsec scales and probe how a change of the last can contribute to the high-energy emission. The combination of VLBI kinematics data and flux density variability measurements in the radio/mm/γ-rays often reveals correlations between them. The existence of such correlations can help us locate the γ-ray emission region and calculate its distance from the central engine.

2. Data Sample

To trace the inner jet properties of the source, we used VLBI observations at 43 GHz and 86 GHz of the Global Millimetre VLBI Array (GMVA) along with VLBI data from the MOJAVE program at 15 GHz [9]. We combine these with γ-ray data from Fermi Large Area Telescope (Fermi-LAT)[1] and light curves at 15 GHz from the Owens Valley Radio Observatory (OVRO) [12] and at 235 GHz from the Submillimeter Array (SMA) [13], covering the period 2002-2017.

3. Imaging and Kinematics Analysis

We performed the imaging and model fitting of the VLBI data within the DIFMAP package using the CLEAN and MODELFIT algorithms respectively. The component cross-identification over 15 epochs at 15 GHz and 5 epochs at 43 and 86 GHz showed that the jet's brightness distribution can be expressed by 4 (at 15 GHz) and 3 (at 43, 86 GHz) two-dimensional Gaussian components, which minimize the χ^2 fitting value, as described in [6]. Errors in each parameter of the Gaussian components are calculated based on the approach of [5]. A new component (N) was ejected between October 2008 and March 2009, after seeing the core brighten by 80%. The motion of the VLBI components is expressed by fitting polynomials to the radial separation from the core of each component (at each frequency) versus time. We find that a linear function is sufficient for fitting the trajectories of A1, A2 and C3. However, a second-order polynomial was needed to fit the trajectory of component C2 (Figure 1).
The linear and quadratic fit, provide us an average proper motion, a mean speed and acceleration for each component. Using the estimated angular rate μ we derived the apparent speed of each component, the fastest component being C2 with $\beta_{app} = 15.67 \pm 1.67$. Using the method of [11] we estimate the critical viewing angle of the jet to be $\vartheta_{crit} = 3.65^o$.

[1]https://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/LATDataQuery.cgi

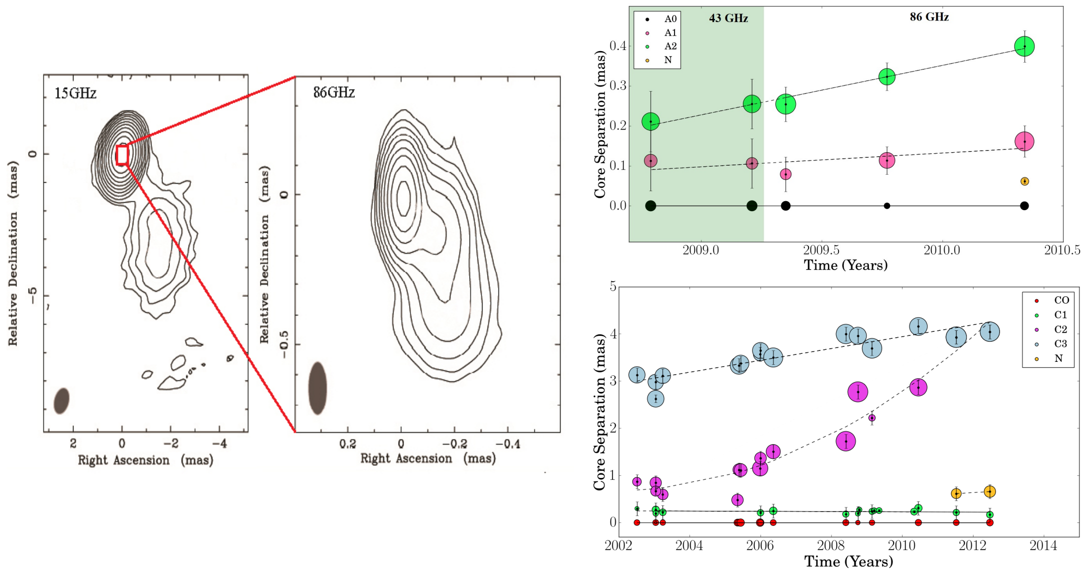

Figure 1: Left panel: A synthesis of an 15 GHz image of TXS 2013+370 (beam size 0.9×0.6mas at -17.8^{o}) and at the 86 GHz (beam size 0.18×0.07mas at 0^{o}). Top right: Components radial separation from the core versus time at 43 and 86 GHz. A new component, labeled N, is visible in May 2010. Bottom right: Components radial separation from the core versus time at 15 GHz during period 2002-2012.

For all calculations, we adopted a cosmology with: $\Omega_M = 0.27, \Omega_\Lambda = 0.23, H_o = 71 kms^{-1} Mpc^{-1}$, $D_L = 17.903$ Gly[9]. Particularly interesting is the case of knot C1 which appears quasi-stationary, but there are some indications that it follows an oscillating trajectory. It is reported that bending jets often present quasi-stationary shocks [2]. Numerous studies have shown that when a moving shock passes through a stationary, the latter could be displaced in position for a short time and then return to its initial position [8]. In our case, components C1 and A2 may exhibit such behaviour. Another possible explanation is that we observe some motion of the $\tau = 1$ opacity surface that we use as a reference point, after the ejection of a new component. In this scenario, when the core moves upstream (towards the supermassive black hole) the distance of all secondary components slightly increase, until the new component is well separated and the core moves back to its initial position. More observations are needed in order to explain the path of the C1 component.

4. Light Curve Analysis

We searched for possible correlations between the radio and γ-rays variability. Using the Discrete Cross-Correlation function (DCCF) we found evidence for a positive correlation between the γ-rays and 235 GHz lightcurve. The DCCF analysis [3] revealed that the radio activity lags behind the γ-rays by (91 ± 24) days and between γ-rays and 15 GHz, also radio reach our antennas (103 ± 30) days after the high energy activity. This indicates that the gamma-ray emission originates in the region upstream of the compact core. The time delays can be converted to linear distances between the regions of the radio synchrotron opacity barrier and the γ-ray emission region [7]. Converting the aforementioned time lags into linear distances, we determine also the distance between the γ-ray production region and the VLBI core, to be (10.11 ± 2.7) pc at 86 GHz and (11.56 ± 3.3) pc at 15 GHz.

5. Conclusions

In this paper, we present for the first time the innermost structure of the blazar TXS 2013+370. Based on multi band variability curves our preliminary results revealed a correlation between the γ-ray emission and the radio properties, especially at the highest radio frequencies. We have cross-identified superluminally moving knots on subparsec scales and we report the ejection of a new component, which is associated with prominent flare events in the millimeter and high energy bands. Tracing the peculiar motion of the jet component C1 and overlaying it with A2, we conclude that it is a shock, which first moves downstream and then returns back to its original position. We created for the first time high resolution images of the source at 86 and 43 GHz. Our variability analysis showed that the high energy activity is strongly correlated with the 15 GHz and 235 GHz variability, with radio lagging behind γ-rays. This behaviour is consistent with synchrotron self-absorption in the VLBI jet and suggests that the γ-rays stem from a region which is located almost 10 pc upstream to the VLBI core.

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