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IceCube neutrino generated in a jet-jet collision in TXS 0506+056?

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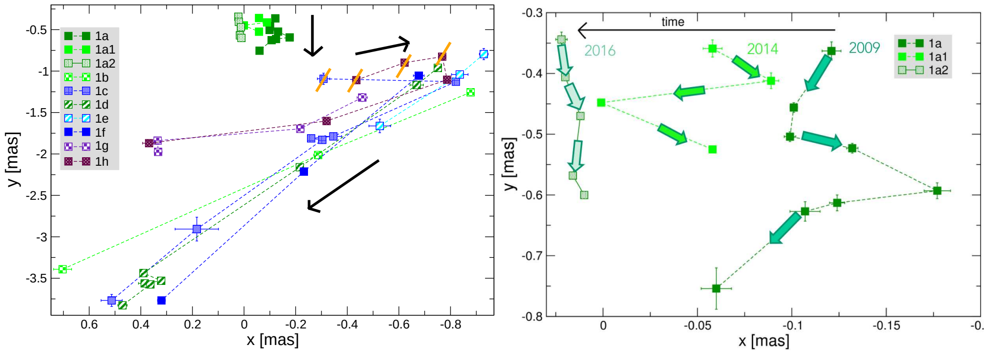
Abstract. The IceCube event IceCube-170922A appears to originate from the BL Lac object TXS 0506+056. Despite many other BL Lac objects showing similar properties as TXS 0506+056, such as multiwavelength variability or a curved jet, so far, only TXS 0506+056 has been identified as neutrino emitter. The pc-scale jet of TXS 0506+056 might thus reveal special properties. We performed a detailed study of radio images of the jet obtained at 15 GHz (16 VLBA observations between Jan. 2009 and May 2018). Our results suggest that the jet is extremely strongly curved and most likely observable under a very special viewing angle of close to zero. We might see interaction between jet features which cross each others' paths. An alternative, less likely scenario is, that we do not see the signature of one but of *two* jets. In both cases, we find evidence for a collision of jetted material. We propose that the enhanced neutrino activity during the neutrino flare in 2014 - 2015 and the single EHE neutrino IceCube-170922A were generated by a cosmic collision within TXS 0506+056. This seems to be the first time, that a collision within a jet is reported. And obviously, this is the first time that the detection of a cosmic neutrino can be traced back to a cosmic jet-collision.

Key words. black hole physics – techniques: interferometric – BL Lacertae objects: individual: TXS 0506+056

1. Introduction

Recently, the origin of the first cosmic neutrino has been linked to a BL Lac Object: TXS 0506+056 (IceCube Collaboration et al. 2018a) at a redshift of z=0.3365±0.0010 (Paiano et al. 2018). Multi-wavelength flaring (from radio to TeV) of TXS 0506+056, observable by many ground- and space-based telescopes (e.g., Padovani et al. 2018) enabled the identification.



(a) a (b) b

Fig. 1. [a]: The component paths in x and y for those features that could be traced reliably through the epochs. The orange lines mark the epochs where motion along a curve (or strongly bent structure) seems to be observed (one-jet scenario). We added black arrows to indicate the direction of motion in the case of the one-jet scenario. [b]: The paths of the three innermost components (as shown as well) in [a]. Arrows indicate the likely direction of motion.

The neutrino can be associated with the blazar TXS 0506+056 with chance coincidence being rejected at $\sim 3\sigma$ level (e.g., Ansoldi et al. 2018). In addition, an analysis of archival IceCube data revealed evidence for an enhanced neutrino activity between Sept. 2014 and March 2015 (IceCube Collaboration et al. 2018b).

Many other BL Lac Objects show similar properties as TXS 0506+056 but have not been identified as neutrino emitters so far. Multi-wavelength flaring, however, is a common phenomenon within the BL Lac blazar sub-class. To our knowledge, only one other flaring object, a Flat-spectrum Radio Quasar (FSRQ), has been discussed as a possible source of neutrino emission in combination with multi-wavelength flaring (PKS B1424-418, Kadler et al. 2016).

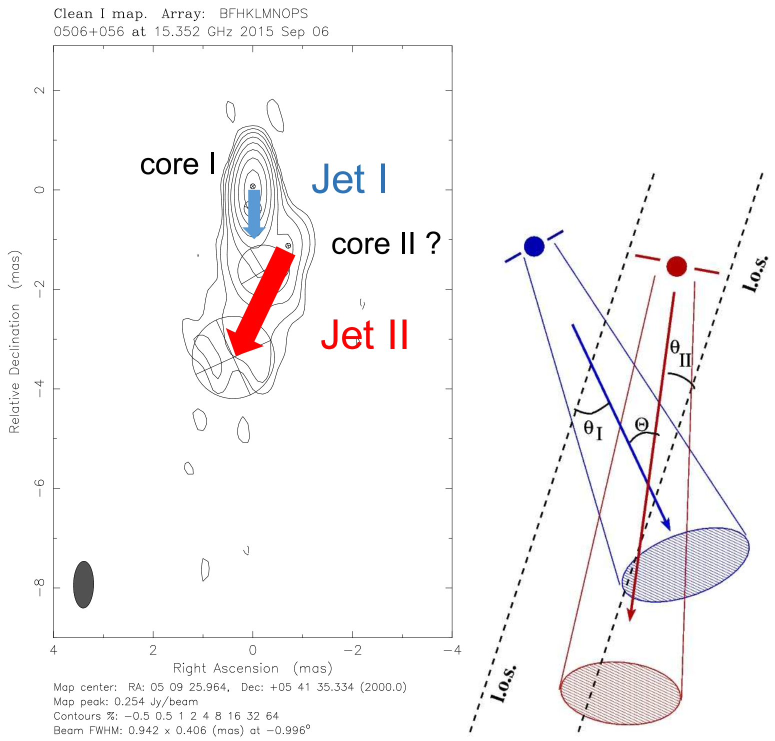
We have performed a detailed study of the kinematics of the pc-scale jet of TXS 0506+056 in an attempt to better understand what is special about this blazar and how it is able to produce high-energy neutrinos. We argue, that the enhanced neutrino activity in 2014-15 as well as the extremely high energy (EHE) neutrino were generated in a collision within the jet.

The work presented in this article is an excerpt of a complete study presented in Britzen et al. (2019).

2. Data analysis

We re-modeled and re-analyzed 16 VLBA observations (15 GHz, MOJAVE[1]) obtained between Jan. 2009 and Mar. 2018. Gaussian circular components were fit to the data to obtain the optimum set of parameters within the *difmap*-modelfit program (Shepherd 1997). The model fits for each individual epoch were obtained independently so as not to introduce a bias in the jet direction. Since the unique neutrino detection we expected TXS 0506+056 might reveal special properties. Without knowing what these peculiar properties would be – we re-modeled all the available MOJAVE data in a way to allow also very faint components. Any unusual morphologies and morphological changes should appear in the model-fitting process. The excellent data quality of the MOJAVE program allows such a deep analysis. More details concerning the modelfitting are described in Britzen et al. (2019).

[1] `https://www.physics.purdue.edu/MOJAVE/`



(a) a (b) b

Fig. 2. [a] An image with the difmap modelfit components superimposed (circles). In addition, we highlight (in colour) two potential jet directions in the two-jet scenario (see Britzen et al. (2019) for a detailed description). [b] Model geometry of the proposed jet interaction. The two jets are labeled in red (jet II) and blue (jet I) color. Note that in addition to the relative inclination indicated in this (2D) sketch, there is also an inclination in the third dimension. The viewing angles of the jets with respect to our line of sight (l.o.s.) are denoted by Θ_I and Θ_{II}.

3. Results concerning the pc-scale jet kinematics & discussion

We find clear evidence for extreme curvature in the pc-scale jet of TXS 0506+056 (see Fig.1 [a]). This is most likely due to an extreme viewing angle which might be close to zero. As a consequence, the jet emission is likely to be highly Doppler beamed in our frame.

We also find clear evidence for changes in the paths in the inner jet (Fig.1 [b]) which we suggest to be connected to precession of the jet source(s). Precession is to be expected in a binary system of supermassive black holes and has been observed in several AGN-jets (e.g., Britzen et al. 2018, for OJ 287). Precession naturally causes a change in the jet direction and speed (see e.g., Jorstad et al. (2004); Abraham & Carrara (1998) for 3C 279). We find evidence for different apparent velocities for those components closer to the core (slower, at about 1-2*c*) compared to those at larger core separations (faster, at about 6*c*).

Two model scenarios are able to account for the observed jet kinematics: (1) a strongly curved jet (one-jet scenario), (2) a structure comprised of two jets (see Fig. 2 [a] and [b], two-jet scenario). Jetted material within the source obviously moves in different directions so that interactions between the jet material seems unavoidable. In both physical scenarios that we consider (i.e., a single strongly curved jet or two interacting jets) the paths of individual plasma components within the plasma flow seem to collide. These collisions may then lead to the generation of high energy emission and in particular to the generation of a high energy neutrino.

Based on the above kinematic analysis and discussion we conclude that an interaction of jetted material, which to our knowledge has in this form not been observed before, provides a plausible scenario to explain the observed neutrino emission. We describe in Britzen et al. (2019) how a radiative interaction of two jets in TXS 0506+056 or in a strongly curved one-jet scenario can provide a target photon field for photo-hadronic production of IceCube neutrinos (Reimer et al. 2018).

4. Conclusions

We conclude that TXS 0505+056 is an atypical AGN and might not be representative of the blazar class of AGN at large. This source seems to provide the proper set-up for an interaction of jetted material under a dramatic viewing angle. We have presented a viable scenario where the collision of jetted material can produce the IceCube neutrinos via photo-hadronic interaction. This could, in the future, produce further high-energy events.

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[2] Any opinion, finding and conclusion or recommendation expressed in this material is that of the authors and the NRF does not accept any liability in this regard.

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