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Kinematic study of the relativistic parsec-scale jet of the blazar TXS 0506+056 and its relationship to the high-energy neutrino IceCube170922A event

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Abstract. Blazars are a type of active galaxies that usually exhibit strong variability from radio up to TeV gamma-rays. In this work, we aim to study the blazar TXS 0506+056 (J0509+0541), which is thought to be the object that harbored the high-energy (HE) neutrino IceCube-170922A event. Here we present a kinematic study of the parsec-scale jet of TXS 0506+056 and examine a possible relationship between ejections of jet components and the occurrence of gamma-ray flares/HE neutrino emission. For this purpose, we have gathered existing VLBI data of TXS 0506+056 from the MOJAVE/VLBA Survey archive to apply our Cross-Entropy (CE) global optimization technique. Using this method, it is possible to model interferometric radio imagens of astrophysical jets and estimate a minimum number of discrete two-dimensional elliptical Gaussian components at each epoch. Up to now, we have identified at least seven jet components moving superluminally from the core, with apparent speeds greater than 1.3c. Besides, we have found a probable connection between the ejection of one of these jet components and the epoch of enhanced gamma-ray emission correlated to HE neutrino event in 2017.

Resumo. Blazares são núcleos ativos que geralmente exibem forte variabilidade, desde ondas de rádio até raios-gama de TeV. Neste trabalho, nosso objetivo foi estudar o blazar TXS 0506+056 (J0509+0541), considerado a provável fonte do evento de neutrino de alta energia IceCube-170922A. Apresentamos um estudo cinemático, em escalas de parsec, do jato do TXS 0506+056 e analisamos a possível relação entre as ejeções de componentes do jato e a ocorrência de flares de raios-gama/emissão de neutrinos de alta energia. Com este propósito, coletamos imagens VLBI do TXS 0506+056 do projeto MOJAVE para aplicar nossa técnica de otimização Cross-Entropy (CE). Ao utilizar esse método, foi possível modelar imagens interferométricas dos jatos astrofísicos e estimar um número mínimo de componentes Gaussianas elípticas bidimensionais discretas em cada época. Até o presente momento, identificamos ao menos sete componentes do jato, movendo-se superluminalmente a partir do núcleo, com velocidades aparentes superiores a 1,3 c. Além disso, descobrimos uma provável conexão entre a ejeção de uma dessas componentes e a época de emissão de raios gama correlacionada ao evento de neutrino de alta energia ocorrido em 2017.

Keywords. Galaxies: active – Galaxies: jets – BL Lacertae objects: individual: TXS 0506+056

1. Introduction

Blazars are a type of active galaxies whose jets direct close to our line of sight and have long been discussed in the literature as possible sources of high-energy neutrinos and cosmic-rays (Mannheim 1994; Padovani & Resconi 2014; Padovani et al. 2016; Gao, Pohl & Winter 2017; Rodrigues et al. 2018). They exhibit strong variability from radio up to TeV gamma-rays, presenting a non-thermal continuum and a superluminal jet. The subject of our study is the BL Lac TXS 0506+056 at redshift of 0.3365 ± 0.0010 (Paiano et al. 2018) and it is considered to be the probable counterpart of the IceCube neutrino event IC170922A.

2. Objective and methodology

The primary objective of this work consists of a kinematic study of the parsec-scale jet of the blazar TXS 0506+056. We have gathered existing VLBI data of TXS 0506+056 from the MOJAVE/VLBA Survey archive (Lister et al. 2013) (Fig.1) to apply the global optimization statistical technique Cross-Entropy (CE) (Rubinstein 1997).

Adapted by Caproni et al. (2011), this method, allows to model interferometric radio imagens of astrophysical jets and estimate a minimum number of discrete two-dimensional elliptical Gaussian components at each epoch (e.g., Caproni et al. 2014; 2017).

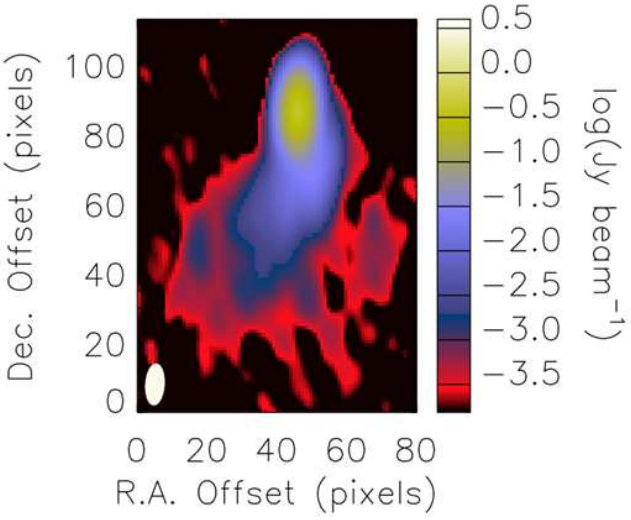

Figure 1. Interferometric radio map at 15 GHz obtained in 2013 June 2 by MOJAVE team (Lister et al. 2013).

3. Results

We identified seven components with apparent speeds greater than 1.3c, as it can be seen in Fig.2. These components were

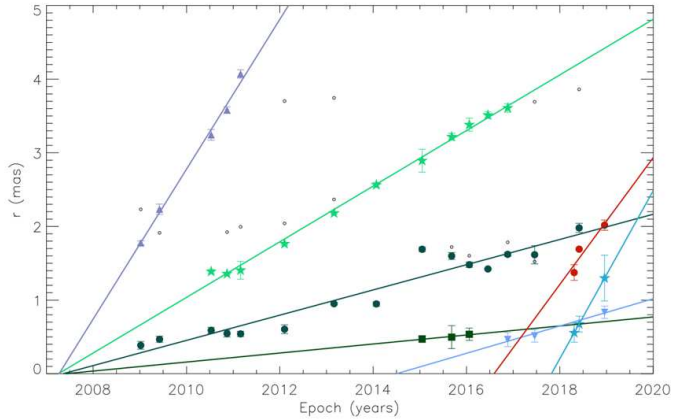

Figure 2. Core-component angular separation versus time for the jet components identified in this work.

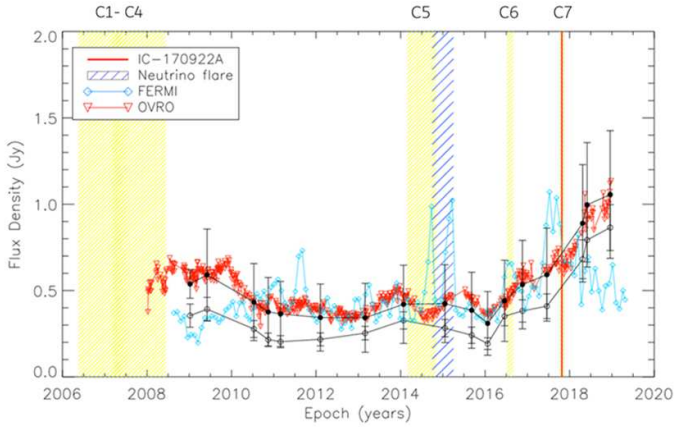

Figure 3. Flux density behavior between 2006 and 2020. The vertical red line shows the arrival time of IceCube-170922A and the hatched vertical blue bar shows the duration of the lower-energy neutrino flare. Red inverted triangles show the historical OVRO 40m 15-GHz light curve of TXS 0506+056. Fermi gamma-ray light curve is shown by blue diamonds. Black circles show the flux densities of core plus jet components. The unfilled circles represent core flux densities. The components ejected at different times are shown by hatched vertical yellow bars.

ejected at different times, and with different apparent speeds and directions in the plane of the sky.

The correlation between the OVRO 40m 15-GHz light curve, the Fermi-LAT gamma-ray light curve, the components ejected at different times, the 2014 neutrino flare and the IceCube-170922A event has shown in Fig.3.

4. Final remarks

From the analyses of seventeen 15-GHz interferometric images of the blazar TXS 0506+056, we could derive the structural parameters of the individual components (core and jet knots). We identified seven jet components receding ballistically from the core at superluminal apparent speeds (from 1.3c to 23.8c), and with slightly different trajectories in the plane of the sky (mean position angle of about -177 degrees).

We have found a probable connection between the ejection of the C5 and C7 component and the epoch of neutrino flare (2014/15) and enhanced gamma-ray emission correlated to HE neutrino event in 2017 respectively.

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