VERA observation of flaring blazar TXS 0506+056: plausible counterpart of IceCube-170922A

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Introduction: high-energy neutrino from blazar TXS 0506+056

IceCube Collaboration et al. (2018a) recently reported the detection of a high-energy (HE) neutrino (IceCube-170922A) with the IceCube Observatory, for the first time coinciding spatially and temporally with a gamma-ray flaring blazar TXS 0506+056 (also known as 3FGL J0509.4+0541, Acero et al. 2015) at a confidence level of 3 sigma (Fig. 1 *left*). Following the alert of IceCube-170922A, intensive follow-up observations were conducted for TXS 0506+056 at electro-magnetic (EM) wave (see, Fig. 1 *right*). Several theoretical works have predicted that a flaring blazar is considered to be promising source as neutrino emitter (e.g., Dermer et al. 2014, Petropoulou et al. 2016, Gao et al. 2017). Therefore an EM observation is crucial to identify true origin of astrophysical neutrinos. Among the EM observations, the very long baseline interferometry (VLBI) is one of the most powerful techniques allowing us to identify the flaring component in response to the neutrino event with a sub-milli to milli-arcsecond (mas) scale because of its extremely high angular resolution.

VERA observation

In order to explore the unprecedented radio signature in blazar object related to the latest huge γ-ray flare, which is associated with the HE neutrino event, we performed four epochs of biweekly monitoring, which began eight days after the detection time of IceCube-170922A with VERA. Each observation was performed at 23GHz with a band width of 256MHz. The specific dates are 2017 Sep 30, Oct 13, Nov 1, and 13.

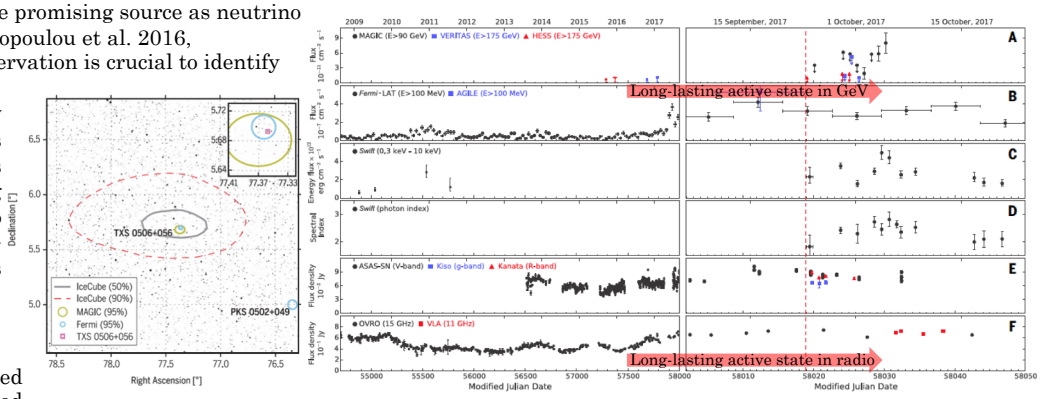

Fig. 1 *Left*: The 50% and 90% containment regions for the neutrino IceCube-170922A. *Right*: Time-dependent multiwavelength observations of TXS 0506+056 before and after IceCube-170922A (IceCube Collaboration 2018b)

Result

■ *VLBI images*

In Fig. 2, we show VERA and VLBA images of TXS 0506+056. The southward elongated structure can be clearly seen in these images. VLBI fluxes in 2017 have increased 1.6 times compared to the one in 2008. Also, no significant flux variability can be seen during our four epochs of VERA observations. These flux behaviors are consistent with the one seen in OVRO light curve at 15 GHz (Fig. 1).

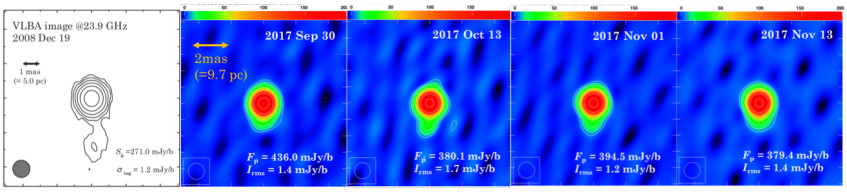

Fig. 2 VLBI images of TXS 0506+056. Contour image was obtained by VLBA on 2008 Dec 19, and color images were obtained by VERA in 2017. All images are restored with a synthesized beam of 1 mas in diameter, shown in the bottom-left corner. Peak fluxes and image rms are indicated in each image

■ *Proper motion of jet components*

In Fig. 3, we show the positional displacement of each jet component obtained by not only VERA but also VLBA at 15 GHz provided by MOJAVE project (from 2015 Jan to 2017 Jun). J_V is possibly the result of the mixture of J2, J3, J4 components in VLBA image as shown in Fig 3-(A) and 3-(B) because of not only insufficient angular resolution, but also less image dynamic range of VERA compared to VLBA observations.
As shown in Fig. 3-(C), all jet components seen in VLBA image show the proper motion within the positional error for recent two years, and J_V showed no systematic motion during follow-up observation. Also, no new-born jet associated with the HE neutrino event appeared by 2017 Nov 13.

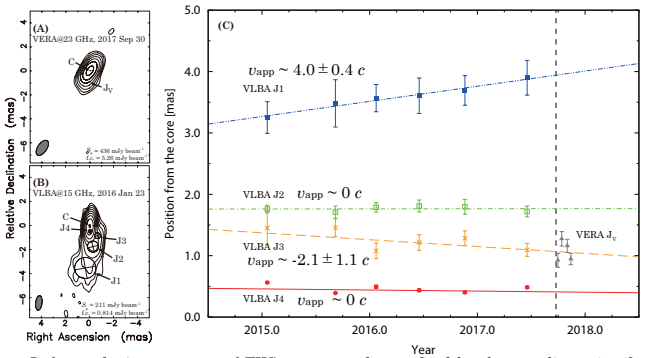

Fig. 3 Left panels: jet structure of TXS 0506+056 deconvolved by the two-dimensional circular Gaussian function. (A) shows 23 GHz VERA image reproduced by 2 components (C and JV) observed in 2017 Sep 30, and (B) shows 15 GHz VLBA image reproduced by 5 components (C, J1, J2, J3, and J4). (C): radial proper motion of each jet component with respect to the position of the VLBI core under the assumption of linear motion. Vertical dashed line indicates the time when IceCube-170922A was detected.

Discussion

- Neutrino event possibly occurred in the VLBI core of the flaring blazar, because both γ-ray and radio fluxes in recent long-lasting active state show gradual flux increase (i.e., γ-ray and radio activities in 2017 originate in the same location = VLBI core).
- If newly born jet is associated with the HE neutrino event, and to resolve it with VERA, the jet should move at least ~0.5 mas downstream from the positional center of the VLBI core. Based on observational facts and the assumption that the distance between the central engine and the VLBI core is ~10 pc as discussed in previous works (e.g., Orienti et al. 2013), and viewing angle of jet is 1 deg, we constrained its apparent velocity to less than ~60*c*.

Summary & Prospects

- We clarified the HE neutrino event possibly occurred in the VLBI core of flaring blzar, and no significant structural change related to the HE neutrino event was seen by 2017 Nov 13 (52 days after the detection of IceCube-170922A)
- Further VLBI observations at higher-frequency (i.e., millimeter wavelengths) and powerful interferometric observations at sub-millimeter wavelength (e.g., ALMA) will allow us to investigate the more optically thin part possibly reflecting the behavior of an upstream end of the blazar jet.
- To obtain new information on time evolutions of not only mm-fluxes and detailed structure but also opacity in the VLBI core, we will start higher quality VLBI imaging monitor with East Asia VLBI Network (EAVN: KaVA+Tianma+Nobeyama) at mm-wavelengths (both 23GHz and 43GHz quasi-simultaneously).

References: IceCube Collaboration et al., 2018a, Science, 361, 147; IceCube Collaboration et al., 2018b, Science, 361, eaat1378; Acero, F., et al., 2015, ApJS, 218, 23; Dermer, C. D., et al., 2014, Journal of High Energy Astrophysics, 3, 29; Petropoulou, M., et al., 2016, Astroparticle Physics, 80, 115; Gao, S. et al., 2017, ApJ, 843, 109; Orienti, M., 2013, MNRAS, 428, 2418