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Mid-infrared variability of the neutrino source blazar TXS 0506+056

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The IceCube instrument detected a high-energy cosmic neutrino event (IceCube_170922A) on 2017 September 22 (IceCube Collaboration 2018a). The electromagnetic follow-up campaigns associated the event with the flaring γ-ray blazar TXS 0506+056 (Padovani et al. 2018). Investigation of the archival data of the IceCube instrument revealed an excess of high-energy neutrinos in the direction of TXS 0506+056 compared to the atmospheric background between 2014 September and 2015 March (IceCube Collaboration 2018b) possibly also associated with the blazar (Padovani et al. 2018). Blazars are radio-loud active galactic nuclei where one of the synchrotron-emitting jets is pointed at small angle to line of sight, thus leading to relativistically boosted emission. They are thought to be promising sources of cosmic neutrinos (e.g., Mannheim 1995).

To investigate the mid-infrared (MIR) variability of TXS 0506+056, we analyzed the data collected by the *Wide-Field Infrared Survey Explorer* (*WISE*, Wright et al. 2010) satellite. *WISE* scanned the whole sky at four bands, at 3.4, 4.6, 12, and 22μm (W1, W2, W3, and W4, respectively) during 2010. After the end of the original mission, the survey continued as the NEOWISE (Near-Earth Object WISE, Mainzer et al. 2014) project, and after a 3-year hibernation gap as the NEOWISE Reactivation Mission. Since the cooling material required for the detectors W3 and W4 were depleted, latter measurements were conducted only at the W1 and W2 bands. We downloaded *WISE* single exposure data[1] of TXS 0506+056. To avoid potentially unreliable data, we followed the outline in the Explanatory Supplement[2] and discarded photometry associated with bad quality frames ('qual_frame'= 0). The observations of TXS 0506+056 were not performed too close to the boundary of the South Atlantic Anomaly, i.e., this issue does not affect us. With respect to the possible contamination by scattered moonlight, we examined the photometry of 63 *WISE* sources within $30'$ of TXS 0506+056 with similar brightnesses ($\pm 1^{\mathrm{m}}$) in W1 and W2 bands. We found that data points flagged due to this effect are well consistent with the neighbouring non-flagged data, thus we retained them for further analysis. The obtained light curves of TXS 0506+056 in W1 and W2 bands consist of 10 mission phases taken between 2010 March and 2017 September. Each mission phase covers $\approx 1-5$ days with a dozen measurement points.

TXS 0506+056 shows significant MIR variability during year-long time scale (Fig. 1) with more than a factor of 2.5 peak-to-peak variation in both bands. A brightening can be seen in the last two mission phases, which is concurrent with the γ-ray flare started in April 2017 and peaked around the IceCube_170922A event. No *WISE* observation is available during the previous excess neutrino event, however TXS 0506+056 became brighter in MIR after that period.

We used two indices, the correlation-based Stetson index (Stetson 1996) and the χ^2 test to assess the variability behavior on day-long time scales in each individual mission phase. The threshold values of these were determined based on *WISE* data of neighbouring sources with similar brightnesses (Gabányi et al. 2018). Two mission phases are found to show significant short time scale changes. In the first mission phase (at MJD 55258), a fading can be seen, reaching $\sim 10\,\%$ in W2. In the last mission phase preceding the IceCube_170922A event by a few days, a MIR brightening (Fig. 1 inset) as high as $\sim 30\,\%$ in both bands occurred during 4 days. Similar variability behaviour and intraday variability in MIR bands were found in γ-ray bright radio-loud narrow-line Seyfert 1 sources, which are thought to be blazar-like active galactic nuclei with a relatively small black hole mass ($10^6 - 10^8 M_{\mathrm{BH}}$, Yuan et al.

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[1] http://irsa.ipac.caltech.edu/Missions/wise.html
[2] http://wise2.ipac.caltech.edu/docs/release/allwise/expsup/sec3_2.html

2008). The short time-scale implies small emitting region indicating that instead of star formation in the host galaxy, or the torus of the active galactic nucleus, the jet is likely to be responsible for the variability (Jiang et al. 2012; Yang et al. 2018; Gabányi et al. 2018).

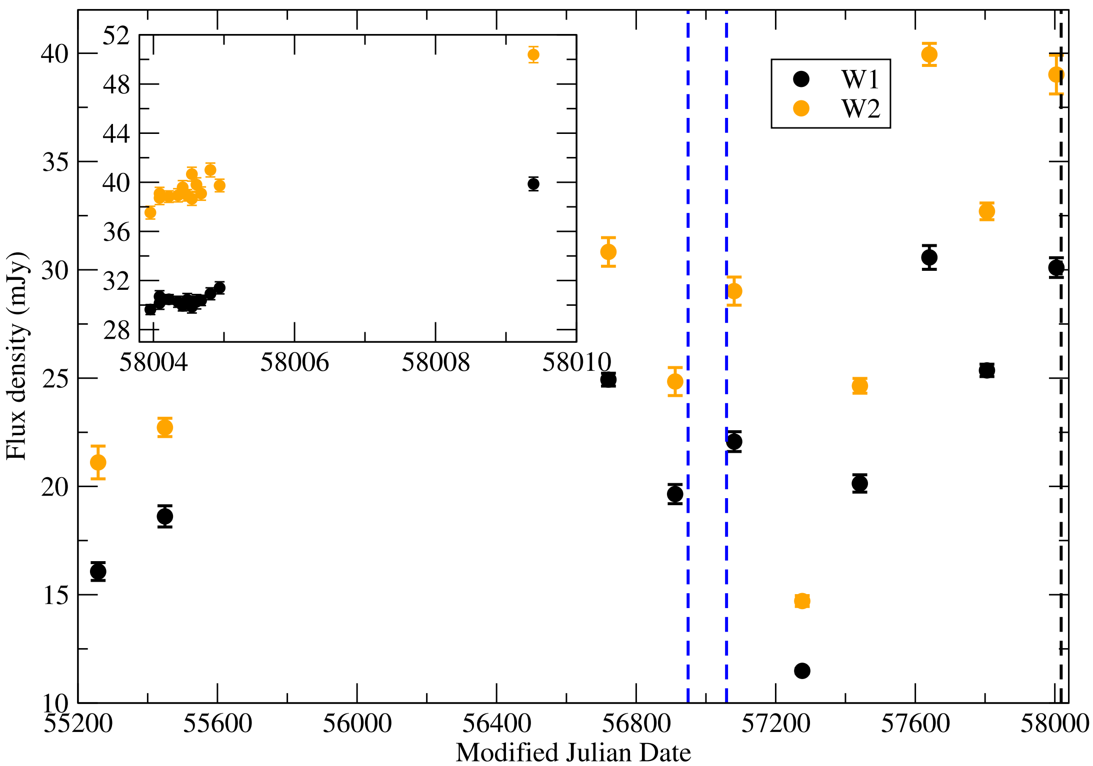

Figure 1. WISE light curve of TXS 0506+056, black and orange symbols are for band W1 and W2, respectively. Points are averages of each mission phases. The error bars represent the variability within the given phase. Blue vertical lines mark the excess neutrino phase reported in IceCube Collaboration (2018b). Black vertical line marks the IceCube_170922A event. The inset shows a zoom-in to the last mission phase. Here the error bars represent the formal errors of the single exposures.

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