Active galactic nuclei with GeV activities and the PeV neutrino source candidate TXS 0506+056

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ABSTRACT

On 2017 September 22 the IceCube neutrino observatory detected a track-like, very-high-energy event (IceCube-170922A) that is spatially associated with TXS 0506+056, a quasar at a redshift of \( z = 0.3365 \). This source is characterized by the increased activities in a very wide energy range (from radio to TeV) during these days. To investigate the possible connection of the PeV neutrino emission with the GeV activity of blazars, in this work we select 116 bright sources and analyze their lightcurves and spectra. We focus on the sources displaying GeV activities. Among these blazars, TXS 0506+056 seems to be typical in many aspects but is distinguished by the very strong GeV activities. We suggest to search for neutrino outburst in the historical data of IceCube, as recently done for TXS 0506+056, from the directions of these more energetic and harder blazars with strong GeV activities.

Keywords: galaxies: active – gamma rays: galaxies – blazars

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1. INTRODUCTION

The discovery of astrophysical neutrino flux around PeV energies by IceCube (Aartsen et al. 2017) is an important milestone in high energy astronomy (IceCube Collaboration 2013). The neutrino is an ideal astronomical messenger since they travel undistorted from the sources and are therefore a valuable probe of the innermost regions of the energetic and enigmatic objects in the cosmos. Since then, the accumulating observations of neutrino events from IceCube suggest that a significant fraction of the observed neutrinos are of extragalactic origin due to their isotropic distribution and reveal a flux of neutrinos with a total energy density comparable with that of the extragalactic γ rays observed by Fermi-LAT (Aartsen et al. 2014, 2015; Ackermann et al. 2016).

Blazars are an extreme subtype of Active Galactic Nuclei (AGNs), dominating the extragalactic γ-ray sky (Acero et al. 2015; Madejski & Sikora 2016). Emissions from their strong collimated jets are overwhelming due to relativistic beaming effects and hence blazars are characterized by the luminous and highly variable broadband continuum emissions (e.g., Blandford & Rees 1978; Ulrich et al. 1997). Blazars are traditionally divided into flat spectrum radio quasars (FSRQs) and BL Lacertae objects (BL Lacs) based on their optical spectra. Spectral energy distribution of these jetted AGNs generally exhibits a two-bump structure in logνF_ν−logν representation and the low energy bump is widely believed to be contributed by synchrotron emission. Therefore, blazars are also classified as low-synchrotron-peaked sources (LSPs, ν_{peak}^{syn} < 10^{14} Hz), intermediate-synchrotron-peaked sources (ISPs, 10^{14} Hz < ν_{peak}^{syn} < 10^{15} Hz), and high-synchrotron-peaked sources (ν_{peak}^{syn} > 10^{15} Hz)(Ackermann et al. 2015). However, the origin of the other bump extending to γ-ray regime is still under debate. On one hand, the leptonic radiation model (e.g., Maraschi et al. 1992; Dermer & Schlickeiser 1993; Sikora et al. 1994; Blażejowski et al. 2000) in which the γ rays are from inverse Compton scattering of soft photons by the same population of electrons that emit the synchrotron emission, can naturally describe the tightly connected multiwavelength variability of blazars (e.g., Abdo et al. 2010; Liao et al. 2014). On the other hand, observational phenomena, like the “orphan” γ-ray flare (e.g., Böttcher 2005), support the hadronic scenario that γ rays and neutrinos are produced via interactions of high-energy protons with gas (i.e., the pp-interactions) in the jets (Schuster et al. 2007).
or in interactions of protons with internal (Mannheim 1995) or external (Atoyan & Dermer 2001) photon fields (pγ-interactions).

Among the various possibilities of potential extragalactic sources of neutrinos (see Ahlers & Halzen (2015) for a review), including star-forming galaxies (e.g., Loeb & Waxman 2006), gamma-ray bursts (e.g., Waxman & Bahcall 1997), galaxy clusters (e.g., Berezinsky et al. 1997) and so on, blazars are believed to be promising sources (e.g., Tavecchio & Ghisellini 2015; Halzen & Kheirandish 2016). This kind of sources also contribute to the majority of extragalactic γ-ray background which is consistent with the measured neutrino flux level (Murase et al. 2013). Meanwhile, a correlation between cosmic neutrinos and blazar catalogs has been argued (Padovani et al. 2016). Moreover, since strong γ-ray flares of blazars have been frequently detected, a spatial association combined with a coincidence in time with a flaring blazar may represent a smoking gun for the origin of the IceCube flux. A coincidence between a 2 PeV neutrino event and the blazar PKS B1424−418 provides an interesting hint in this context (Kadler et al. 2016).

On 2017 Spetmber 22, the IceCube neutrino observatory (hereafter IceCube) detected a track-like, very-high-energy event with a high probability of being of astrophysical origin (Kopper & Blaufuss 2017). Inside the error region of the neutrino event, there is a Fermi-LAT source, TXS 0506+056 (Ajello et al. 2017). Interestingly, the GeV emission is found to be at high state (Tanaka et al. 2017). Enhanced emission are also found in radio, optical, X-ray and TeV bands (Tanaka et al. 2017; Fox et al. 2017; Franckowiak et al. 2017; Mirzoyan 2017). Therefore, TXS 0506+056 is a promising PeV neutrino source candidate (IceCube collaboration 2018; IceCube collaboration et al. 2018). Motivated by the coincidence of the GeV activity with the PeV neutrino emission, in this work we analyze the Fermi-LAT data (Atwood et al. 2009, 2013) of some bright AGNs and identify the GeV flares. We then compare the properties of these bright AGNs displaying strong GeV activities with TXS 0506+056 to look for possible indication of the high energy neutrino sources. This work is organized as follows: in Section 2 we introduce our sample and the data analysis. The results are reported in Section 3. We summarize our results with some discussions in Section 4.

2. THE SAMPLE AND DATA ANALYSES
2.1. The Sample

Blazars included in the Fermi-LAT monitored source list\(^1\) are chosen for this study, in which the sources are selected if their instantaneous weekly fluxes are above \(10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1}\). These sources represent the brightest and the most variable ones among the Fermi-LAT blazars. Another advantage is that the sources are randomly distributed in the sky since Fermi-LAT performs an all-sky survey. Several sources (e.g. Fermi J2007−2518) are excluded in our analysis because there are only a few flux data points in the preliminary weekly light curves provided by the Fermi collaboration. Meanwhile, two sources (i.e. NRAO 190 and B2 1144+40) are not considered due to the ambiguous association relationship between the \(\gamma\)-ray source and its low-frequency counterpart. Therefore, our sample consists of total 116 blazars, including 81 FSRQs, 22 BL Lacs and 13 sources with unknown optical spectral property (BZU), according to BZCAT\(^2\) (Massaro et al. 2009). Or alternatively, there are 96 LSPs, 10 ISPs and 8 HSPs, according to the third Fermi-LAT AGN catalog (3LAC, Ackermann et al. 2015), together with 2 sources lacking of relative information. The redshift distribution of our sample is between 0.031 (Mrk 421) and 2.852 (PKS 0438−43), and there are seven sources (either BL Lacs or BZUs) lacking redshift information. The basic information of the sources in our sample are listed in Table 1.

2.2. Fermi-LAT Data reduction

In the analysis, the latest Pass 8 version of the Fermi-LAT data (Atwood et al. 2013) with “Source” event class (\texttt{evclass = 128 & evtype = 3}) are selected, recorded from May 1, 2010 (Mission Elapsed Time 294364802; the time of the operation for the full IceCube detector) to May 1, 2018 (Mission Elapsed Time 546825605)\(^3\). We choose the events within a 10° region of interest (ROI) with energies between 100 MeV and 500 GeV in this analysis. In order to reduce the contamination from the Earth Limb, the events with zenith angles larger than 90° are excluded. In addition, the entire data set is filtered with \texttt{gtmktime} to obtain high-quality data in the good time intervals, with the expression

\(^1\) https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/
\(^2\) http://www.asdc.asi.it/bzcat/
\(^3\) Note there is \(~ 20\) day data gap for Fermi-LAT around March 2018.
recommended by the LAT team, namely \( (\text{DATA\_QUAL} > 0) \&\& (\text{LAT\_CONFIG} == 1) \). The data are analyzed with the standard LAT analysis software, \textit{ScienceTools} version v10r0p5\(^4\), available from the Fermi Science Support Center, and the “P8R2\_SOURCE\_V6” instrumental response functions are adopted. First, we perform the \textit{unbinned} likelihood analysis with \texttt{gtlike} to extract the global flux and spectral parameters of the target source. For the background subtraction, the Galactic diffuse emission and the isotropic diffuse emission are modeled by \texttt{gll\_iem\_v06.fits} and \texttt{iso\_P8R2\_SOURCE\_V6\_v06.txt}, which can be found from the Fermi Science Support Center\(^5\). Meanwhile, all sources in the preliminary LAT 8-year Point Source List (FL8Y\(^6\)) within a radius of 15° from the ROI center are included in the source model. For convenient comparison between different sources, the spectral template of each target source is set to a power-law function (i.e. \( dN/dE \propto E^{-\Gamma} \), where \( \Gamma \) is the spectral photon index). And during the fitting analysis, the normalizations and spectral parameters of all sources within a distance of 10° from the ROI center, together with the normalizations of the two diffuse backgrounds, are left free. The significance of the target source can be quantified by the test statistic (TS) value, which is defined as \( \text{TS} = -2 \ln(L_0/L) \) (Mattox \textit{et al.} 1996), where \( L_0 \) and \( L \) are the maximum likelihood values of the null hypothesis and the tested model including the target source. The fittings are demanded to converge (i.e. “fit quality = 3”) to make sure the results are valid. The best-fit results for all target sources in the sample are summarized in Table 1.

In the temporal analysis, we divide the data into 417 equal time bins and repeat the likelihood fitting for each time bin to extract a weekly light curve for each target. Considering the targets studied here are the brightest \( \gamma \)-ray sources in the extragalactic sky, we fix the spectral indexes of all background sources to the global fitting values, and only free the normalization parameters of background sources within 10° from the targets and two diffuse backgrounds. During the fitting analysis for each time bin, the weak background sources (i.e., TS < 5) are removed from the source

\(^4\) \url{http://fermi.gsfc.nasa.gov/ssc/data/analysis/software/}
\(^5\) \url{http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html}
\(^6\) \url{https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FL8y/}
model. Note that for any time bin in which the TS value of target source is smaller than 9, the 95% upper limit is calculated instead.

3. RESULTS

3.1. Global properties

The analysis results of the entire 8-year LAT data are summarized in Table 1 as well. We also plot the photon index versus the photon flux and the $\gamma$-ray apparent luminosity (from 0.1 to 500 GeV, with handled $k$-correction) diagrams, see Fig. 1. The average photon indexes of FSRQs, BL Lacs and BZUs in our sample are 2.40±0.17, 2.04±0.18 and 2.29±0.12, respectively, which are in agreement with the results in 3LAC (Ackermann et al. 2015). Note that there is only one FSRQ, VER 0521+211, whose photon index is smaller than 2. As shown in Fig. 1 and Fig. 2, FSRQs are generally brighter and more luminous than BL Lacs, and TXS 0506+056 appears to be typical among other BL Lacs. The spectra of FSRQs are softer than that of BL Lacs, which may lower the neutrino detection possibility.

3.2. Temporal Behaviors

3.2.1. TXS 0506+056

The weekly $\gamma$-ray light curve of TXS 0506+056 is presented in the left panel of Fig. 3. Before MJD 57855, the source maintains at a relatively quiescent state, with only a few bins whose fluxes reach roughly three times of the 8-year averaged flux, $9.8 \times 10^{-8}$ ph cm$^{-2}$ s$^{-1}$. However, since then, a strong $\gamma$-ray flare has appeared, with a peak flux of $(5.8 \pm 0.6) \times 10^{-7}$ ph cm$^{-2}$ s$^{-1}$ which is nearly 6 times of the 8-year averaged flux. The corresponding peak apparent $\gamma$-ray luminosity of the bin is $\sim 1.5 \times 10^{47}$ erg s$^{-1}$, adopting a redshift of 0.3365 (Paiano et al. 2018). Meanwhile, the photon index then is 2.05±0.07, suggesting no significant spectral variability than the average value, 2.07±0.01. The flare peaked on MJD 57981 (16th Aug. 2017), about a month before the arrival time of the IceCube neutrino event. A further 3-day $\gamma$-ray light curve (the right panel of Fig. 3) shows that several sub-flares constitute this activity phase. Maybe there is a weak flare coincident with the neutrino event, but the error bars are relatively large.
3.2.2. Comparison between TXS 0506+056 and Fermi-LAT bright blazars

In 3LAC, about 69% FSRQs are found to be significantly variable, however, this fraction is down to 23% for BL Lacs (Ackermann et al. 2015). Together with the fact that the former kind is generally brighter than the later one, it is not surprising that the vast majority of our sources are FSRQs. One famous case is CTA 102 (Becerra et al. 2016; Xu et al. 2016), whose daily LAT > 100 MeV flux is up to $10^{-5}$ cm$^{-2}$ s$^{-1}$, also see Fig. 4 for its weekly light curve. In addition to the brightness, its large variability amplitude is also remarkable. The weekly peak flux is more than one order of magnitude higher than the averaged flux. Examples of light curves of other subtypes are also shown in Fig. 4. Although most of our FSRQs are LSPs, there are several ISP FSRQs. No significant difference is found between their weekly $\gamma$-ray light curves. It is interesting to see that the variability amplitude for FSRQs is generally higher than HSP BL Lacs. However, for ISP BL Lacs and LSP BL Lacs, their $\gamma$-ray variability could be as violent as FSRQs. Worthy to note that there is one source, ON 246, which is also a ISP BL lac similar with TXS 0506+056. There is also a strong $\gamma$-ray flare with peak flux of $5 \times 10^{-7}$ ph cm$^{-2}$ s$^{-1}$ for ON 246.

Since the neutrino event IceCube-170922A arrived when TXS 0506+056 was flaring in GeV band, we adopt $f_{\gamma}^{\text{accu}}/f_{\gamma}^{\text{aver}}$ as an indicator to qualify the comparison between TXS 0506+056 and other Fermi bright blazars. $f_{\gamma}^{\text{accu}}$ is defined as an accumulated photon flux of the flares, which should have fluxes brighter than the average ($f_{\gamma}^{\text{aver}}$) by a factor of 3. The division of $f_{\gamma}^{\text{aver}}$ is to eliminate the influence caused by a wide distribution of flux level for different sources. Therefore, $f_{\gamma}^{\text{accu}}/f_{\gamma}^{\text{aver}}$ reflects the intensity of GeV activity of a source (a large $f_{\gamma}^{\text{accu}}/f_{\gamma}^{\text{aver}}$ arises if a few flares have fluxes much higher than $f_{\gamma}^{\text{aver}}$ or alternatively there are intense flare activities). If the neutrino is indeed tightly connected to the flare event of blazars, sources with high $f_{\gamma}^{\text{accu}}/f_{\gamma}^{\text{aver}}$ value and hard $\gamma$-ray spectra are preferred to be identified as neutrino sources. In the $f_{\gamma}^{\text{accu}}/f_{\gamma}^{\text{aver}} - \Gamma_{\gamma}^{\text{aver}}$ plot, as shown in Fig. 5, TXS 0506+056 is distinguished by the high $f_{\gamma}^{\text{accu}}/f_{\gamma}^{\text{aver}}$ (i.e., the very strong GeV activities). Together with the declination of TXS 0506+056 (as seen in Fig. 6; please note that the IceCube observatory has better sensitivity for sources with declination close to 0 (Aartsen et al. 2014)), it may help to explain why TXS 0506+056 is the first blazar associated with a significant neutrino excess.
We have also investigated the distribution of the accumulated isotropic-equivalent energy of the flare emission (i.e., $E_{\gamma}^{\text{accu}}$, with proper $k-$correction). In Fig. 7 we show the diagram of $E_{\gamma}^{\text{accu}} - \Gamma_{\gamma}^{\text{accu}}$, where $\Gamma_{\gamma}^{\text{accu}}$ is the powerlaw index of the spectrum of the accumulated flare emission. In such a plot, TXS 0506+056 is not distinct. Finally we study the change of the hardness of the blazar emission in the flare phase. We define a new parameter $\Delta \Gamma_{\gamma} = \Gamma_{\gamma}^{\text{aver}} - \Gamma_{\gamma}^{\text{accu}}$. In the plot of $E_{\gamma}^{\text{accu}} - \Delta \Gamma_{\gamma}$ (see Fig. 8), TXS 0506+056 is similar with other blazars, too. Therefore, TXS 0506+056 seems to be a normal blazar in many ways except for its very strong GeV activities. Dedicated neutrino searches in the directions of some bright blazars with strong GeV activities are encouraged, to check whether these sources are also important neutrino sources.

4. SUMMARY

The sources of PeV neutrinos and ultra-high-energy cosmic rays are still in debate in the literature. Thanks to the successful performance of IceCube and Fermi-LAT and the quick follow-up observations in optical, radio and X-ray, significant progresses have been made. The most exciting findings are the possible IceCube-170922A/TXS 0506+056 association (IceCube collaboration et al. 2018) and the the coincidence between a 2 PeV neutrino event and the blazar PKS B1424−418 (Kadler et al. 2016), which favors the hypothesis that blazars are important sources of PeV neutrinos and ultra-high-energy cosmic rays. Motivated by the possible connection between the GeV activity and the neutrino IceCube-170922A, in this work we have analyzed the Fermi-LAT data of a group of bright AGNs and identify strong GeV flares. We have compared the properties of these bright AGNs displaying strong GeV activities with TXS 0506+056 to look for indication of the ultra-high-energy cosmic ray sources. It turns out that TXS 0506+056 appears to be similar to other bright blazars studied in this work (see Fig.1, Fig.2, Fig.7 and Fig.8), except its very strong GeV activities (i.e., the high value of $f_{\gamma}^{\text{accu}} / f_{\gamma}^{\text{aver}}$ shown in Fig.5). We suggest to carry out dedicated searches for (weak) neutrino outburst in the historical data of IceCube, as recently done for TXS 0506+056 (IceCube collaboration 2018), from the directions of these more energetic and harder sources with strong GeV activities. If null results are turned out, new indicator rather than the GeV activity should be identified for the neutrino sources.
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Facilities: Fermi (LAT)
Aartsen, M. G., Ackermann, M., Adams, J., et al. 2014, Physical Review Letters, 113, 101101
Aartsen, M. G., Abraham, K., Ackermann, M., et al. 2015, Physical Review Letters, 115, 081102
Aartsen, M. G., Ackermann, M., Adams, J., et al. 2017, Journal of Instrumentation, 12, P03012
Abbott, B. P., Abbott, R., Abbott, T. D., et al. 2016, Physical Review Letters, 116, 131103
Abdo, A. A., Ackermann, M., Ajello, M., et al. 2010, Nature, 463, 919
Acero, F., Ackermann, M., Ajello, M., et al. 2015, ApJS, 218, 23
Ackermann, M., Ajello, M., Albert, A., et al. 2016, Physical Review Letters, 116, 151105
Ackermann, M., Ajello, M., Atwood, W. B., et al. 2015, ApJ, 810, 14
Ahlers, M., & Halzen, F. 2015, Reports on Progress in Physics, 78, 126901
Ajello et al., arXiv:1702.00664
Atoyan, A., & Dermer, C. D. 2001, Physical Review Letters, 87, 221102
Becerra. J., et al., 2016, ATel No.8722
Berezinsky, V. S., Blasi, P., & Ptuskin, V. S. 1997, ApJ, 487, 529
Blandford, R. D., & Rees, M. J. 1978, in Pittsburgh Conference on BL Lac Objects, ed. A. M. Wolfe (Pittsburgh, PA: Univ. Pittsburgh Press), 328
Błażejowski, M., Sikora, M., Moderski, R., & Madejski, G. M. 2000, ApJ, 545, 107
Böttcher, M. 2005, ApJ, 621, 176
Dermer, C. D., & Schlickeiser, R. 1993, ApJ, 416, 458
Fox, D. B., et al. 2017, ATel No.10845
(Access URL http://www.astronomerstelegram.org/?read=10845)
Franckowiak, A., et al. 2017, ATel No.10794
(Access URL http://www.astronomerstelegram.org/?read=10794)
Halzen, F., & Kheirandish, A. 2016, ApJ, 831, 12
Kadler, M., Krauß, F., Mannheim, K., et al. 2016, Nature Physics, 12, 807
Kopper, C., & Blaufuss, E. 2017, GCN Circ. 21916
(Access URL https://gcn.gsfc.nasa.gov/gcn3/21916.gcn3)
Madejski, G., & Sikora, M. 2016, ARA&A, 54, 725
Mannheim, K. 1995, Astroparticle Physics, 3, 295
Maraschi, L., Ghisellini, G., & Celotti, A. 1992, ApJL, 397, L5
Massaro, E., Giommi, P., Leto, C., et al. 2009, A&A, 495, 691
Mattox, J. R., Bertsch, D. L., Chiang, J., et al. 1996, ApJ, 461, 396
Mirzoyan, R. 2017, ATel No.10817
(Access URL http://www.astronomerstelegram.org/?read=10817)
Murase, K., Ahlers, M., & Lacki, B. C. 2013, PhRvD, 88, 121301
IceCube Collaboration 2013, Science, 342, 1242856
Liao, N. H., Bai, J. M., Liu, H. T., et al. 2014, ApJ, 783, 83
Loeb, A., & Waxman, E. 2006, JCAP, 5, 003
Padovani, P., Resconi, E., Giommi, P., Arsioli, B., & Chang, Y. L. 2016, MNRAS, 457, 3582
Paiano, S., Falomo, R., Treves, A., & Scarpa, R. 2018, ApJL, 854, L32
Schuster, C., Pohl, M., & Schlickeiser, R. 2002, A&A, 382, 829
Sikora, M., Begelman, M. C., & Rees, M. J. 1994, ApJ, 421, 153
Tanaka, Y. T., Buson, S., & Kocevski, D. 2017, ATEL No.10791 (http://www.astronomerstelegram.org/?read=10791)
Tavecchio, F., & Ghisellini, G. 2015, MNRAS, 451, 1502
The IceCube Collaboration. 2018, Science, 361, 147
The IceCube Collaboration et al. 2018, Science, 361, eaa1378
Ulrich, M.-H., Maraschi, L., & Urry, C. M. 1997, ARA&A, 35, 445
Waxman, E., & Bahcall, J. 1997, Physical Review Letters, 78, 2292
Atwood, W. B., Abdo, A. A., Ackermann, M., et al. 2009, ApJ, 697, 1071
Atwood, W., Albert, A., Baldini, L., et al. 2013, ArXiv e-prints, arXiv:1303.3514
Xu, Z. L. et al., 2016, ATEL No.9901 (http://www.astronomerstelegram.org/?read=9901)
Aartsen, M. G., Ackermann, M., Adams, J., et al. 2014, ApJ, 796, 109
Figure 1. TXS 0506+056 in the $L^{\text{aver}}_\gamma - f^{\text{aver}}_\gamma$ (left) and $L^{\text{aver}}_\gamma - \Gamma^{\text{aver}}_\gamma$ (right) diagrams. The superscript $\text{aver}$ means that they are average quantities for the whole 8-year data. The red circles, green squares and blue triangles represent the FSRQs, BL Lacs and the blazars of unknown type (BZU), respectively. TXS 0506+056 is marked as a green pentagram.
Figure 2. TXS 0506+056, marked as the green pentagram, in the $L_{\gamma} - f_{\gamma}$ diagram. The legends are as the same of Fig 1.
Figure 3. The weekly $\gamma$-ray light curve from MJD 55317 to MJD 58239 (left) and the 3-day time bin $\gamma$-ray light curve from MJD 57888 to MJD 58239 (right) of TXS 0506+056. For any time bin in which the TS value of TXS 0506+056 is larger than 25, the photon flux is derived by free the spectral index of TXS 0506+056, which is shown as the green dot. The blue dots are for the time bin with $9 < \text{TS} < 25$, and the fluxes in these bin are derived by keeping spectral indexes of all sources including TXS 0506+056 fixed. The red triangles are the 95\% upper limits for the time bins with TS values of TXS 0506+056 smaller than 9. The gray dashed line is the average flux of TXS 0506+056 and the three-time average flux is shown as the black dotted line. The black solid line denotes the arrival time of the neutrino event detected by IceCube.
Figure 4. Same as Fig. 3 but for different target sources. The name of the source and its type are marked as the title of each panel.
Figure 5. The $\frac{f_{\text{accu}}}{f_{\text{aver}}} - \Gamma_{\text{aver}}$ diagram, where $f_{\text{accu}}$ represents the photon flux accumulated over the time bins with flux at least three times larger than $f_{\text{aver}}$. TXS 0506+056 is marked as the green pentagram (same legend as for Fig. 1).
Figure 6. The Declination – $f_{\gamma}^{\text{aver}}$ diagram. TXS 0506+056 is marked as the green pentagram (same legend as for Fig. 1).
Figure 7. The $E^\text{accu}_\gamma - \Gamma^\text{accu}_\gamma$ diagram, where $E^\text{accu}_\gamma$ and $\Gamma^\text{accu}_\gamma$ represent the accumulative equivalent energy and the averaged spectral index for the time bins in which the energy flux is three times larger than $f^\text{aver}_\gamma$, respectively. The legends are as the same of Fig. 1.
Figure 8. TXS 0506+056, marked as the green pentagram, in log $E^{\text{accu}}_\gamma - \Delta \Gamma_\gamma$ diagram (same legend as for Fig. 1).
Table 1. Model parameters of all target sources in the sample

| FLSY Name       | Alias Name     | R.A. \(^{\circ}\) | Dec. \(^{\circ}\) | Photon Flux \([10^{-5} \text{ ph cm}^{-2} \text{ s}^{-1}]\) | Spectral Index | Energy Flux \([10^{-5} \text{ MeV cm}^{-2} \text{ s}^{-1}]\) | TS Value |
|-----------------|----------------|------------------|-----------------|---------------------------------|---------------|---------------------------------|--------|
| FLSY J001.4+2112| TXS 2358+209   | 0.385            | 21.227          | 8.747 ± 0.237                   | 2.715 ± 0.024 | 2.090 ± 0.048                   | 3238   |
|                 |                |                  |                 |                                 |               |                                 | 1.106  |
| FLSY J0108.6+0135| 4C +01.02     | 17.162           | 1.583           | 28.651 ± 0.326                  | 2.369 ± 0.008 | 10.163 ± 0.113                  | 37684  |
| FLSY J0112.8+3208| 4C 31.03      | 18.210           | 32.138          | 4.876 ± 0.183                   | 2.392 ± 0.025 | 1.667 ± 0.050                   | 2526   |
| FLSY J0133.1−5201| PKS 0131−522  | 23.274           | −52.001         | 3.652 ± 0.155                   | 2.287 ± 0.026 | 1.495 ± 0.053                   | 2705   |
| FLSY J0210.7−5101| 0208−512      | 32.693           | −51.017         | 10.342 ± 0.196                  | 2.343 ± 0.014 | 3.825 ± 0.071                   | 12026  |
| FLSY J0211.2+1051| CGRaBS J0211+1051 | 32.805       | 10.860          | 7.334 ± 0.201                   | 2.130 ± 0.015 | 4.267 ± 0.121                   | 7080   |
|                 |                |                  |                 |                                 |               |                                 | 0.2    |
| FLSY J0221.1+3556| S3 0218+35    | 35.273           | 35.937          | 14.846 ± 0.283                  | 2.280 ± 0.011 | 6.157 ± 0.100                   | 18551  |
| FLSY J0222.6+4302| 3C 66A         | 35.665           | 43.035          | 11.196 ± 0.224                  | 1.954 ± 0.010 | 11.119 ± 0.260                  | 24508  |
| FLSY J0237.9−2848| 4C+28.07       | 39.468           | 28.802          | 21.721 ± 0.198                  | 2.308 ± 0.007 | 8.554 ± 0.097                   | 27262  |
| FLSY J0238.6+1637| 0235+164       | 39.662           | 16.616          | 11.963 ± 0.272                  | 2.175 ± 0.013 | 6.214 ± 0.120                   | 13023  |
| FLSY J0246.0−4650| PKS 0244−470   | 41.500           | −46.855         | 5.902 ± 0.167                   | 2.419 ± 0.021 | 1.941 ± 0.048                   | 4355   |
| FLSY J0252.8−2219| PKS 0250−225   | 43.200           | −22.324         | 8.124 ± 0.183                   | 2.353 ± 0.016 | 2.959 ± 0.065                   | 7095   |
| FLSY J0303.4−2407| PKS 0301−243   | 45.860           | −24.120         | 3.780 ± 0.119                   | 1.879 ± 0.016 | 4.948 ± 0.214                   | 7982   |
| FLSY J0324.7+3411| 1H 0323+342   | 51.172           | 34.179          | 6.654 ± 0.332                   | 2.871 ± 0.037 | 1.426 ± 0.061                   | 1169   |
| FLSY J0339.5−0146| PKS 0336−01    | 54.873           | −1.777          | 15.226 ± 0.262                  | 2.346 ± 0.012 | 5.611 ± 0.091                   | 13820  |
| FLSY J0348.5−2750| PKS 0346−27    | 57.159           | −27.820         | 4.332 ± 0.158                   | 2.261 ± 0.023 | 1.865 ± 0.061                   | 3685   |
| FLSY J0359.6+5057| 4C+50.11       | 59.874           | 50.964          | 8.821 ± 0.342                   | 2.593 ± 0.027 | 2.351 ± 0.076                   | 1246   |
| FLSY J0403.9−3605| PKS 0402−362   | 60.974           | −36.084         | 18.047 ± 0.235                  | 2.539 ± 0.011 | 5.097 ± 0.061                   | 21108  |
| FLSY J0428.6−3756| PKS 0426−380   | 67.168           | −37.939         | 26.287 ± 0.276                  | 2.090 ± 0.006 | 17.024 ± 0.231                  | 70329  |
|                 | PKS 0438−43    | 70.072           | −43.552         | 2.221 ± 0.237                   | 2.626 ± 0.060 | 0.573 ± 0.044                   | 426    |
| FLSY J0457.0−2324| PKS 0454−234   | 74.263           | −23.414         | 24.695 ± 0.238                  | 2.189 ± 0.007 | 12.408 ± 0.162                  | 49810  |

Table 1 continued on next page
|                  |                  |                  |                  |                  |                  |
|------------------|------------------|------------------|------------------|------------------|------------------|
| FLSY J0501.2−0158 | PKS 0458−02      | 75.303           | −1.987           | 11.826 ± 0.198   | 2.383 ± 0.012    | 4.105 ± 0.069    | 8876             | 2.285998         |
| FLSY J0505.3+0459 | PKS 0502+049     | 76.347           | 4.995            | 15.895 ± 0.390   | 2.360 ± 0.014    | 5.720 ± 0.103    | 11563            | 0.954            |
| FLSY J0510.0+1800 | PKS 0507+17      | 77.510           | 18.012           | 6.096 ± 0.306    | 2.184 ± 0.019    | 3.002 ± 0.118    | 4128             | 0.416            |
| FLSY J0515.5−4556 | PKS 0514−459     | 78.939           | −45.945          | 3.155 ± 0.227    | 2.410 ± 0.038    | 1.051 ± 0.047    | 1358             | 0.194            |
| FLSY J0521.7+2112 | VER 0521+211     | 80.442           | 21.214           | 9.696 ± 0.361    | 1.945 ± 0.018    | 9.594 ± 0.373    | 12723            | 2.218            |
| FLSY J0522.9−3628 | PKS 0521−36      | 80.742           | −36.459          | 12.144 ± 0.241   | 2.461 ± 0.014    | 3.572 ± 0.064    | 11505            | 0.056546         |
| FLSY J0530.9+1331 | PKS 0528+134     | 82.735           | 13.532           | 3.921 ± 0.321    | 2.513 ± 0.035    | 1.183 ± 0.064    | 706              | 2.06             |
| FLSY J0532.0−4827 | CRATES J0531−4827 | 82.994          | −48.460          | 4.598 ± 0.242    | 2.134 ± 0.018    | 2.501 ± 0.094    | 6265             | None             |
| FLSY J0532.7+0733 | OG 050           | 83.162           | 7.545            | 10.355 ± 0.337   | 2.340 ± 0.016    | 3.729 ± 0.090    | 6004             | 1.254            |
| FLSY J0538.8−4405 | PKS 0537−441     | 84.710           | −44.086          | 15.656 ± 0.225   | 2.072 ± 0.008    | 11.445 ± 0.195   | 39101            | 0.894            |
| FLSY J0622.9+3326 | B2 0619+33       | 95.718           | 33.436           | 5.735 ± 0.260    | 2.244 ± 0.020    | 2.475 ± 0.093    | 3162             | None             |
| FLSY J0713.9+1935 | MG2 J071354+1934 | 108.482          | 19.583           | 2.252 ± 0.239    | 2.595 ± 0.057    | 0.613 ± 0.032    | 348              | 0.54             |
| FLSY J0721.9+7120 | 0716+714         | 110.430          | 71.350           | 22.819 ± 0.215   | 2.044 ± 0.005    | 14.510 ± 0.242   | 94091            | 0.3              |
| FLSY J0725.3+1425 | 4C 14.23         | 111.320          | 14.420           | 4.887 ± 0.217    | 2.252 ± 0.020    | 2.039 ± 0.072    | 3421             | 1.038            |
| FLSY J0730.3−1141 | PKS 0727−11      | 112.580          | −11.687          | 17.450 ± 0.360   | 2.303 ± 0.011    | 6.586 ± 0.124    | 12549            | 1.591            |
| FLSY J0739.2+0137 | PKS 0736+01      | 114.825          | 1.618            | 12.472 ± 0.331   | 2.410 ± 0.014    | 3.997 ± 0.081    | 9398             | 0.18941          |
| FLSY J0742.6+5443 | BZU J0742+5444   | 115.666          | 54.740           | 3.954 ± 0.181    | 2.324 ± 0.023    | 1.464 ± 0.055    | 3314             | 0.72             |
| FLSY J0752.0+3318 | B2 0748+33       | 117.974          | 33.222           | 3.561 ± 0.167    | 2.412 ± 0.030    | 1.183 ± 0.043    | 1552             | 1.935716         |
| FLSY J0808.2−0751 | PKS 0805−07      | 122.065          | −7.853           | 7.687 ± 0.229    | 2.304 ± 0.018    | 2.443 ± 0.067    | 4439             | 1.837            |
| FLSY J0808.7+2410 | 0827+243         | 127.490          | 24.220           | 3.856 ± 0.270    | 2.516 ± 0.032    | 1.160 ± 0.053    | 1747             | 0.9414           |
| FLSY J0841.5+7053 | S5 0836+71       | 130.352          | 70.895           | 15.342 ± 0.253   | 2.859 ± 0.014    | 3.286 ± 0.046    | 15186            | 2.172            |
| FLSY J0852.5−5755 | PMN J0852−5755   | 133.161          | −57.925          | 3.874 ± 0.208    | 2.212 ± 0.027    | 1.851 ± 0.075    | 1637             | None             |
| FLSY J0854.8+2006 | OJ 287           | 133.704          | 20.109           | 8.843 ± 0.251    | 2.214 ± 0.014    | 3.943 ± 0.115    | 10848            | 0.3056           |
| FLSY J0904.9−5735 | PKS 0903−57      | 136.222          | −57.585          | 7.483 ± 0.249    | 2.266 ± 0.019    | 3.187 ± 0.086    | 3829             | 0.695            |
| FLSY J0909.1+0121 | PKS B0906+015    | 137.292          | 1.360            | 5.209 ± 0.302    | 2.515 ± 0.030    | 1.494 ± 0.065    | 1909             | 1.024905         |
| FLSY J0921.6+6216 | OK +630          | 140.401          | 62.264           | 5.385 ± 0.192    | 2.334 ± 0.019    | 1.954 ± 0.061    | 5830             | 1.446            |
Table 1 (continued)

| Name         | RA      | Dec     | J2000 RA   | J2000 Dec | E2000 RA  | E2000 Dec |
|--------------|---------|---------|------------|-----------|-----------|-----------|
| FLS J0948.9+0022 | PMN J0948+0022 | 147.239 | 0.374 | 11.425 ± 0.274 | 2.630 ± 0.018 | 2.938 ± 0.061 | 5600 | 0.58384 |
| FLS J0958.7+6533 | S4 0954+65 | 149.607 | 65.565 | 6.304 ± 0.140 | 2.219 ± 0.014 | 2.962 ± 0.068 | 8226 | 0.367 |
| FLS J1006.7−2159 | PKS 1004−217 | 151.693 | −21.989 | 4.570 ± 0.179 | 2.320 ± 0.024 | 1.759 ± 0.058 | 2556 | 0.331 |
| FLS J1033.9+6050 | S4 1030+61 | 158.464 | 60.852 | 7.498 ± 0.234 | 2.197 ± 0.016 | 3.699 ± 0.090 | 11691 | 1.40995 |
| FLS J1048.4+7143 | S5 1044+71 | 162.115 | 71.727 | 17.398 ± 0.240 | 2.246 ± 0.009 | 7.715 ± 0.105 | 37461 | 1.15 |
| FLS J1058.4+0133 | 4C +0128 | 164.623 | 1.566 | 9.918 ± 0.266 | 2.229 ± 0.015 | 4.558 ± 0.104 | 9457 | 0.18516 |
| FLS J1104.4+3812 | Mrk 421 | 166.114 | 38.209 | 21.273 ± 0.226 | 1.776 ± 0.005 | 42.327 ± 0.699 | 117751 | 0.031 |
| FLS J1153.4+4930 | 1150+497 | 178.352 | 49.519 | 3.330 ± 0.166 | 2.392 ± 0.031 | 1.139 ± 0.040 | 2047 | 0.33364 |
| FLS J1159.5+2914 | Ton 599 | 179.883 | 29.246 | 18.036 ± 0.223 | 2.172 ± 0.008 | 9.452 ± 0.148 | 36503 | 0.72475 |
| FLS J1224.9+2122 | PKS B1222+216 | 186.227 | 21.380 | 36.327 ± 0.297 | 2.390 ± 0.007 | 12.475 ± 0.113 | 65284 | 0.43383 |
| FLS J1229.0+0202 | 3C 273 | 187.278 | 2.052 | 21.798 ± 0.364 | 2.864 ± 0.016 | 4.692 ± 0.065 | 12020 | 0.158339 |
| FLS J1230.2+2517 | ON 246 | 187.559 | 25.302 | 5.045 ± 0.162 | 2.076 ± 0.018 | 3.404 ± 0.117 | 6680 | 0.135 |
| FLS J1239.5+0443 | J123939+04400 | 189.900 | 4.700 | 14.912 ± 0.273 | 2.421 ± 0.013 | 4.887 ± 0.077 | 12355 | 1.761 |
| FLS J1246.7−2547 | PKS 1244−255 | 191.695 | −25.797 | 13.740 ± 0.263 | 2.323 ± 0.013 | 5.264 ± 0.089 | 12886 | 0.638 |
| FLS J1256.1−0547 | 3C 279 | 194.047 | −5.789 | 80.799 ± 0.428 | 2.303 ± 0.004 | 32.109 ± 0.209 | 196753 | 0.5362 |
| FLS J1312.6+4828 | GB6 B1310+4844 | 198.181 | 48.475 | 1.938 ± 0.129 | 2.261 ± 0.038 | 0.834 ± 0.041 | 1205 | 0.501 |
| FLS J1316.1−3338 | PKS 1315−333 | 199.033 | −33.650 | 4.870 ± 0.238 | 2.344 ± 0.027 | 1.799 ± 0.061 | 2066 | 1.21 |
| FLS J1332.0−0509 | PKS 1329−049 | 203.019 | −5.162 | 7.418 ± 0.327 | 2.538 ± 0.026 | 2.096 ± 0.066 | 3105 | 2.15 |
| FLS J1345.5+4453 | B3 1343+451 | 206.388 | 44.883 | 17.004 ± 0.194 | 2.252 ± 0.008 | 7.449 ± 0.107 | 34551 | 2.534 |
| FLS J1427.9−4206 | PKS 1424−41 | 216.985 | −42.105 | 64.429 ± 0.369 | 2.172 ± 0.008 | 33.733 ± 0.556 | 168531 | 1.522 |
| FLS J1504.3+1029 | PKS 1502+106 | 226.104 | 10.494 | 24.391 ± 0.250 | 2.254 ± 0.008 | 10.654 ± 0.135 | 40353 | 1.83928 |
| FLS J1506.1+3731 | B2 1504+37 | 226.540 | 37.514 | 6.272 ± 0.179 | 2.482 ± 0.021 | 1.893 ± 0.045 | 4379 | 0.674 |
| FLS J1512.8−0906 | 1510−089 | 228.170 | −8.830 | 79.200 ± 0.455 | 2.534 ± 0.004 | 28.760 ± 0.187 | 150184 | 0.36 |
| FLS J1517.7−2422 | AP Lib | 229.420 | −24.370 | 9.333 ± 0.407 | 2.161 ± 0.014 | 5.015 ± 0.092 | 8952 | 0.049 |
| FLS J1522.1+3144 | B2 1520+31 | 230.540 | 31.740 | 27.550 ± 0.162 | 2.459 ± 0.002 | 8.570 ± 0.037 | 45252 | 1.4886 |
| FLS J1532.7−1319 | TXS 1530−131 | 233.160 | −13.350 | 8.117 ± 0.083 | 2.213 ± 0.004 | 3.870 ± 0.024 | 6019 | None |

Table 1 continued on next page
| Source     | RA      | Dec     | $V$      | $A_V$   | $B_{1.4}$ | $B_{6}$ | $B_{2}$ | $B_{0.8}$ | $B_{0.5}$ | $B_{0.3}$ |
|------------|---------|---------|----------|--------|-----------|--------|--------|-----------|-----------|-----------|
| FLSY J1555.7+1111 | 238.930 | 11.190  | 7.017 ± 0.072 | 1.689 ± 0.005 | 20.460 ± 0.316 | 25725  | 0.36    |
| FLSY J1625.7−2527  | 246.440 | −25.460 | 10.310 ± 0.140 | 2.301 ± 0.003 | 4.112 ± 0.042 | 3581   | 0.786   |
| FLSY J1626.0−2950  | 246.530 | −29.860 | 11.320 ± 0.274 | 2.549 ± 0.014 | 3.161 ± 0.061 | 3426   | 0.815   |
| FLSY J1635.2+3808  | 248.810 | 38.130  | 31.600 ± 0.334 | 2.360 ± 0.007 | 11.370 ± 0.117 | 56527  | 1.813   |
| FLSY J1640.5+3945  | 250.350 | 39.670  | 5.175 ± 0.004 | 2.441 ± 0.007 | 1.650 ± 0.021 | 1930   | 0.5948  |
| FLSY J1653.8+3945  | 253.470 | 39.760  | 6.222 ± 0.123 | 1.750 ± 0.009 | 13.840 ± 0.412 | 24831  | 0.033   |
| FLSY J1700.0+6830  | 255.040 | 68.500  | 5.295 ± 0.083 | 2.399 ± 0.007 | 1.792 ± 0.020 | 4206   | 0.301   |
| FLSY J1709.7+4318  | 257.420 | 43.310  | 5.185 ± 0.067 | 2.350 ± 0.005 | 1.898 ± 0.016 | 3997   | 1.027   |
| FLSY J1733.0−1304  | 263.260 | −13.080 | 14.390 ± 0.164 | 2.359 ± 0.004 | 5.184 ± 0.039 | 6130   | 0.902   |
| FLSY J1734.3+3858  | 263.590 | 38.960  | 5.558 ± 0.188 | 2.378 ± 0.023 | 1.943 ± 0.051 | 3761   | 0.975   |
| FLSY J1748.6+7005  | 267.140 | 70.100  | 3.986 ± 0.057 | 1.951 ± 0.006 | 3.999 ± 0.046 | 8077   | 0.77    |
| FLSY J1751.4+0938  | 267.890 | 9.650   | 8.703 ± 0.057 | 2.264 ± 0.002 | 3.727 ± 0.017 | 5388   | 0.322   |
| FLSY J1800.7+7828  | 270.190 | 78.470  | 8.541 ± 0.057 | 2.240 ± 0.003 | 3.839 ± 0.017 | 13318  | 0.68    |
| FLSY J1801.4+4404  | 270.380 | 44.070  | 4.301 ± 0.078 | 2.389 ± 0.007 | 1.509 ± 0.019 | 2457   | 0.663   |
| FLSY J1829.1−5814  | 277.300 | −58.230 | 10.160 ± 0.049 | 2.593 ± 0.002 | 2.707 ± 0.010 | 4883   | 1.531   |
| FLSY J1833.6−2103  | 278.420 | −21.060 | 45.950 ± 0.001 | 2.543 ± 0.003 | 12.910 ± 0.001 | 27416  | 2.507   |
| FLSY J1848.4+3217  | 282.090 | 32.320  | 5.727 ± 0.019 | 2.401 ± 0.001 | 1.933 ± 0.005 | 1841   | 0.8     |
| FLSY J1848.5+3242  | 282.140 | 32.730  | 7.474 ± 0.023 | 2.541 ± 0.001 | 2.104 ± 0.005 | 2339   | None    |
| FLSY J1849.2+6705  | 282.320 | 67.090  | 7.127 ± 0.057 | 2.320 ± 0.003 | 2.747 ± 0.014 | 7111   | 0.657   |
| FLSY J1911.2−2006  | 287.790 | −20.110 | 10.440 ± 0.204 | 2.537 ± 0.008 | 2.953 ± 0.044 | 3856   | 1.119   |
| FLSY J1958.0−3845  | 299.499 | −38.752 | 7.108 ± 0.204 | 2.369 ± 0.019 | 2.522 ± 0.064 | 3783   | 0.63    |
| FLSY J2000.0+6508  | 300.000 | 65.149  | 6.514 ± 0.159 | 1.801 ± 0.011 | 11.660 ± 0.345 | 19361  | 0.047   |
| FLSY J2025.6−0735  | 306.419 | −7.598  | 14.490 ± 0.234 | 2.257 ± 0.011 | 6.293 ± 0.109 | 15463  | 1.388   |
| FLSY J2035.4+1056  | 308.843 | 10.935  | 13.090 ± 0.318 | 2.362 ± 0.014 | 4.693 ± 0.091 | 8410   | 0.601   |
| FLSY J2126.3−4606  | 321.628 | −46.097 | 3.336 ± 0.185 | 2.535 ± 0.038 | 0.946 ± 0.040 | 953    | 1.67    |
| FLSY J2141.6−6410  | 325.003 | −64.026 | 7.776 ± 0.197 | 2.381 ± 0.018 | 2.708 ± 0.063 | 5834   | None    |
| Source             | RA       | Dec      | RA Error | Dec Error | V       | V Error  | Source Error |
|--------------------|----------|----------|----------|-----------|---------|----------|--------------|
| FL8Y J2143.5+1743  | 325.898  | 17.730   | 0.261    | 0.014     | 4.543   | 0.075    | 9425         |
| FL8Y J2147.2−7536  | 326.803  | −75.604  | 0.214    | 0.012     | 4.293   | 0.062    | 10384        |
| FL8Y J2151.9−3027  | 327.981  | −30.465  | 0.276    | 0.025     | 2.169   | 0.051    | 3662         |
| FL8Y J2158.8−3013  | 329.717  | −30.226  | 0.194    | 0.008     | 19.940  | 0.445    | 45844        |
| FL8Y J2201.8+5048  | 330.431  | 50.816   | 0.301    | 0.017     | 3.864   | 0.068    | 5089         |
| FL8Y J2202.7+4216  | 330.680  | 42.278   | 0.297    | 0.006     | 19.470  | 0.216    | 64653        |
| FL8Y J2232.5+1143  | 338.152  | 11.731   | 0.427    | 0.003     | 45.470  | 0.267    | 292708       |
| FL8Y J2236.5−1433  | 339.142  | −14.556  | 0.196    | 0.014     | 5.088   | 0.136    | 9629         |
| FL8Y J2244.2+4057  | 341.053  | 40.954   | 0.232    | 0.012     | 6.178   | 0.151    | 11734        |
| FL8Y J2250.7−2806  | 342.498  | −12.855  | 0.451    | 0.012     | 6.902   | 0.175    | 15991        |
| FL8Y J2253.9+1608  | 343.491  | 16.148   | 0.554    | 0.003     | 67.980  | 0.273    | 563863       |
| FL8Y J2258.0−2759  | 344.525  | −27.973  | 0.325    | 0.019     | 3.062   | 0.079    | 6130         |
| FL8Y J2311.0+3425  | 347.772  | 34.420   | 0.203    | 0.016     | 3.113   | 0.068    | 6329         |
| FL8Y J2323.5−0317  | 350.883  | −3.285   | 0.255    | 0.017     | 3.880   | 0.098    | 6797         |
| FL8Y J2329.3−4956  | 352.337  | −49.928  | 0.231    | 0.007     | 10.850  | 0.141    | 48780        |
| FL8Y J2345.2−1555  | 356.302  | −15.919  | 0.254    | 0.010     | 8.955   | 0.180    | 2311         |

**Note**—

a: The coordinate (R.A., Dec.) of each source is adopted from the *Fermi*-LAT monitored source list.

b: Two sources have no counterparts in the FL8Y catalog which marked as “NONE” due to they are in a relatively quiescent state during the first eight years.

c: Several source marked as “None” have no redshift values due to the non-detection of optical spectral lines for them.

https://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/