Calorimetric neutrino expectations from bright blazar flares

Michael Kreter[1], Matthias Kadler[2], Felicia Krauss[3], Roopesh Ojha[4], Sara Buson[2], for the *Fermi*/LAT Collaboration
Joern Wilms[5], Markus Böttcher[1]

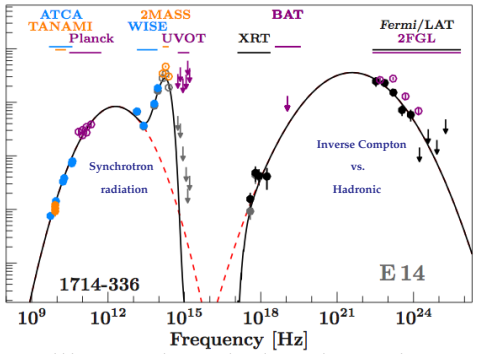
[1]Centre for Space Research, North-West University, Private Bag X6001, Potchefstroom 2520, South Africa
[2]Lehrstuhl für Astronomie, Universität Würzburg, Emil-Fischer-Strasse 31, 97074 Würzburg, Germany
[3]GRAPPA & Anton Pannekoek Institute for Astronomy, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands
[4]NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[5]Dr. Remeis Sternwarte & ECAP,Universität Erlangen-Nürnberg, Sternwartstrasse 7, 96049 Bamberg, Germany.

Email: michael@kreter.org

Abstract

Blazar jets are extreme environments, in which relativistic proton interactions with a UV photon field could give rise to photopion production. High-confidence associations of individual high-energy neutrinos with blazar flares could be achieved via spatially and temporally coincident detections. Recently, the track-like, extremely high energy neutrino event IceCube-170922A was found to coincide with increased gamma-ray emission from the blazar TXS 0506+056, leading to the identification of the most promising neutrino source candidate so far. We test the chance coincidence of such events by calculating the expected number of neutrinos that can be detected by IceCube, based on a broadband parametrization of bright short-term blazar flares that were observed in the past 8-years by Fermi/LAT. We find that the integrated keV-to-GeV fluence of most individual blazar flares is far too small to yield a substantial Poisson probability for the detection of one or more neutrinos with IceCube. We show that the association of the IC170922A neutrino with TXS 0506+056 is energetically plausible at a significance level of about 3.5 sigma and discuss strategies to search for more significant associations in future data unblindings of IceCube and KM3NeT.

AGN as promising neutrino sources



Typical blazar spectral energy distribution showing a characteristic double-hump structure. For the high-energy hump, both leptonic and hadronic models can describe the observed radiation. Credit: Krauss et al. 2014

Jets from Active Galactic Nuclei (AGN) are among the best candidates for the recently detected extraterrestrial neutrino flux (IceCube Collaboration 2013, IceCube Collaboration et al. 2018). Hadronic AGN jet-emission models like e.g. Mannheim 1993 and Mannheim 1995 predict a tight correlation between the neutrino flux and the (time-variable) gamma-ray emission, while model calculations for the integrated signal of all gamma-ray blazars (e.g. Krauß et al. 2014, Kadler et al. 2016 are predicting a cumulative neutrino signal exceeding the atmospheric background above energies of 100 TeV.

Previous calorimetric blazar correlation studies (e.g. Kadler et al. 2016) have found a correlation between the 2 PeV neutrino event "BigBird" and a long-lasting outburst period of the blazar PKS 1424−418 on the order of 5%. **In this work, we want to use this calorimetric approach to study the maximum neutrino prediction of bright daily blazar flares and track-like neutrino events.**

Maximum calorimetric neutrino output

The maximum calorimetric neutrino output of a single source can be estimated based on Monte Carlo simulations performed by Mücke et al. 2000. In this sense, the dominant neutrino production channel is pion photoproduction. This leads to a 1:1 balance between gamma-rays F_γ and neutrinos F_ν:

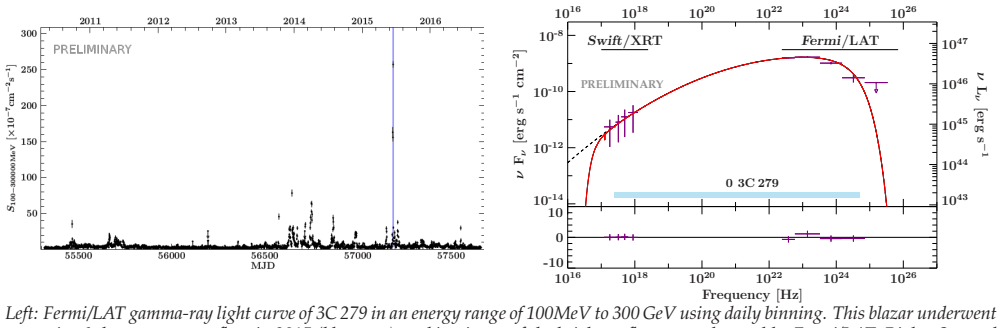
$$F_\gamma = F_\nu$$

In this 'maximal case', the integrated keV-to-GeV gamma-ray fluence yields the maximum-possible neutrino output. **The best candidate sources show bright keV-GeV emission on time scales from days to months.**

Contact Information

Michael Kreter
Centre for Space Research
North-West University,
Potchefstroom, South Africa
Email: michael@kreter.org

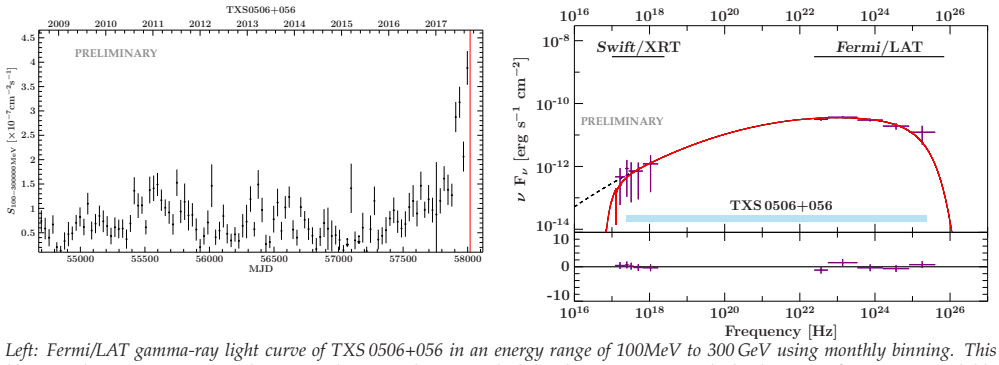
Neutrino expectation from short-term gamma-ray flares



Left: Fermi/LAT gamma-ray light curve of 3C 279 in an energy range of 100MeV to 300 GeV using daily binning. This blazar underwent a massive 6-day gamma-ray flare in 2015 (blue area), making it one of the brightest flares ever detected by Fermi/LAT. Right: Spectral energy distribution of the 2015 flare, using simulations Swift/XRT and Fermi/LAT data. The calorimetric neutrino expectation of this flare can be derived from an integration over the total keV to GeV emission.

We performed a systematic study of the calorimetric neutrino prediction of bright blazar flares with durations of days, using *Fermi*/LAT gamma-ray light curves and multiwavelength measurements of the highly dynamic spectral energy distribution. We used the method introduced in Krauß et al. (2014) and Kadler et al. (2016) to scale these maximum-possible values down to realistic predicted numbers taking into account their fluence, duration and position in the sky. We studied the detection potential for flare-associated neutrino searches, defined as the neutrino prediction value divided by the flare duration, and performed a systematic analysis of the 50 blazars with the highest detection potential for IceCube. The largest neutrino prediction of $N_\nu = 0.02$ shower-like PeV neutrino events is provided by the massive flare of 3C 279 in 2015. The neutrino prediction of individual short-term flares has to be well below unity, as otherwise the sky would already be populated with numerous neutrino point sources. **The Poisson probability for a direct neutrino association of bright short-term blazar flares is small, even for the most promising source candidates.**

Calorimetric neutrino prediction from TXS 0506+056



Left: Fermi/LAT gamma-ray light curve of TXS 0506+056 in an energy range of 100MeV to 300 GeV using monthly binning. This blazar underwent a massive outburst period since early 2016, which has been consistent with the detection of a 290 TeV track-like neutrino event by IceCube (red line). Right: Spectral energy distribution of the outburst period from early 2016 to September 2017, using simulations Swift/XRT and Fermi/LAT data. The calorimetric neutrino expectation of this flare can be derived from an integration over the total keV to GeV emission.

On 22 th September 2017, IceCube detected a 290 TeV neutrino-induced, track-like event (called IceCube-170922A) from a direction spatially and temporally consistent with enhanced gamma-ray activity from the blazar TXS 0506+056. This event is of particular interest, since for the first time, a high energy track-like neutrino event with an angular uncertainty of only $\sim 1°$ was found from the direction of a flaring blazar (IceCube Collaboration et al. 2018). We performed a calorimetric neutrino prediction for a 3-day period around the arrival time of the neutrino event, as well as a correlation analysis between IceCube-170922A and the outburst period which was ongoing since early 2016. An association between the track-like neutrino event and a 3-day flaring period of this blazar is calorimetrically very unlikely ($N_\nu \sim 10^{-5}$ events), while for the long-term association we derived a significance of $3.5\,\sigma$. **Future neutrino point source searches should concentrate on a correlation between long-term blazar outburst and track-like neutrino events.**