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GAMMA-RAY AND NEUTRINO ASTROPHYSICS CONNECTION

Dario Gasparrini
INFN - Roma Tor Vergata Via della Ricerca Scientifica, 1. I-00133 Rome - Italy
ASI Space Science Data Center Via del politecnico, snc. I-00133 Rome - Italy
Sara Buson
University of Würzburg, Emil-Fischer-Str. 31 D-97074 Würzburg - Germany
on behalf of Fermi-LAT Collaboration

Abstract

The recent discovery of a diffuse neutrino flux of astrophysical origin by IceCube started the search to identify the cosmic sources of the emission. Synergy with other experiments could be a useful mean of investigation and in particular, the combination of neutrino/gamma-ray information is motivated by the fact that both radiations may be produced in the same astrophysical particle-cascade scenario, arriving us undeflected from the source. With these assumptions, we can place limit on the known astrophysical source classes contribution to the diffuse neutrino flux. Another ground of discovery in this field is the search for transients and variable neutrino/ electromagnetic sources, in which case the atmospheric neutrino and the muon background can be reduced by taking time- and space-coincidence.

1 Introduction

The detection of a diffuse high-energy neutrino flux of cosmological origin in the range from 30 TeV to 2 PeV [1] by the IceCube observatory has prompted the quest for the identification of of the astrophysical sources responsible of it. The observed signal is consistent with an isotropic distribution, suggesting that the majority of the contribution is from extragalactic origin [2]. The production of high energy neutrinos involves the acceleration of cosmic rays. Two main categories of high-energy neutrino / cosmic rays production models have been proposed: "cosmic-ray accelerators", where neutrino are produced within the cosmic ray source and mesons are typically produced by interactions of cosmic rays with radiation, and "cosmic-ray reservoirs", where neutrinos are produced by inelastic hadronuclear collisions while confined within the environment surrounding the cosmic ray source (for more details see e.g. [3]). For instance, the former models have been suggested for relativistic jets of gamma-ray bursts and blazars, while the second one for starburst galaxies, galaxy clusters and active galactic nuclei (AGN).

2 AGN as Multi-Messenger Sources

AGN with relativistic jets, powered by accretion of mass onto the central massive black hole (SMBH), have long being endorsed and, in turn, neutrino emitters [4]. Blazars, AGN with jet pointing close to the line of sight of the observer are the most numerous sources in the extragalactic GeV-TeV γ-ray sky (e.g., [5]). Their powerful jets are capable of accelerating electrons to relativistic energies, and their electromagnetic emission is often explained within the framework of leptonic scenarios.

However, it is reasonable assuming that in such environments hadrons are present too and, at least at some extent, accelerated as well. the idea has fostered the development of lepto-hadronic scenarios, where emission by hadrons interactions contribute to the electromagnetic radiation observed at the highest energies. In hadronic interactions, high energy photon / pairs and neutrinos are produced in equal powers making gamma-ray blazars plausible source candidates of the observed high-energy neutrinos.. It has been shown that one-zone blazar emission models, where neutrinos are produced in photo-hadronic interactions, typically predict the peak of neutrino spectra at or beyond PeV-energies [6].

2.1 A promising hint

In literature, several studies claim a hint for connection between gamma-ray blazars and high energy neutrino events, although with marginal correlation significance. One example is the blazar PKS 1424-418 which flare was found correlated at 2-3σ of significance with a 2 PeV neutrino [7].

To date, the most compelling correlation is in the observation of IceCube event IceCube-170922A in spatial and time coincidence with the flaring gamma ray blazar [8]. Information about its sky localization were reported by the IceCube collaboration to the astrophysical community almost in real time and prompted an extensive multi-messenger campaign to pinpoint the potential counterpart. High energy gamma-ray emission from the candidate neutrino counterpart, the blazar TXS 0506+056, was first reported by the *Fermi*-Large Area Telescope [9], and further confirmed by the MAGIC and VERITAS Cherenkov detectors [10], [11]. At the time of the neutrino detection TXS 0506+056 was undergoing an enhanced activity state (see fig. 1). Assuming a direct correlation between the gamma-ray and neutrino emission, a spatial chance coincidence of the neutrino and blazar was disfavored at 3 σ significance. The rich multiwavelenght dataset collected enabled an avalanche of theoretical efforts directed to model the neutrino emission in coincidence with electromagnetic blazar flare (see e.g [10])

A subsequent follow up analysis of the IceCube arrival data evidenced the presence of additional neutrinos positionally coincident with TXS0506+056 [2]. The neutrino excess was constituted by 13 low-energy events clustered in a four months time interval, between October 2014 and March 2015. The energy of the events was on average 10 TeV, and the most energetic one had a deposited energy of 20 TeV. The spatial coincidence and previous gamma-ray/neutrino connection had motivated the idea that the blazar could be responsible also for these observed neutrinos. Intriguingly, during this period of time, the source did not show remarkable activity over the gamma ray spectrum and its emission is compatible with a quiescent state (green shaded area in fig.1).

2.2 A complicated interplay

Many theoretical models that have been applied to the spectral energy distribution (SED) of TXS0506+-56 successfully explain the multi wavelength emission and the neutrino detection from the blazar. However, the detection of one single neutrino event makes it difficult to derive robust estimates on the neutrino spectrum. The latter is a necessary ingredient to anchor any theoretical model. The archival neutrino

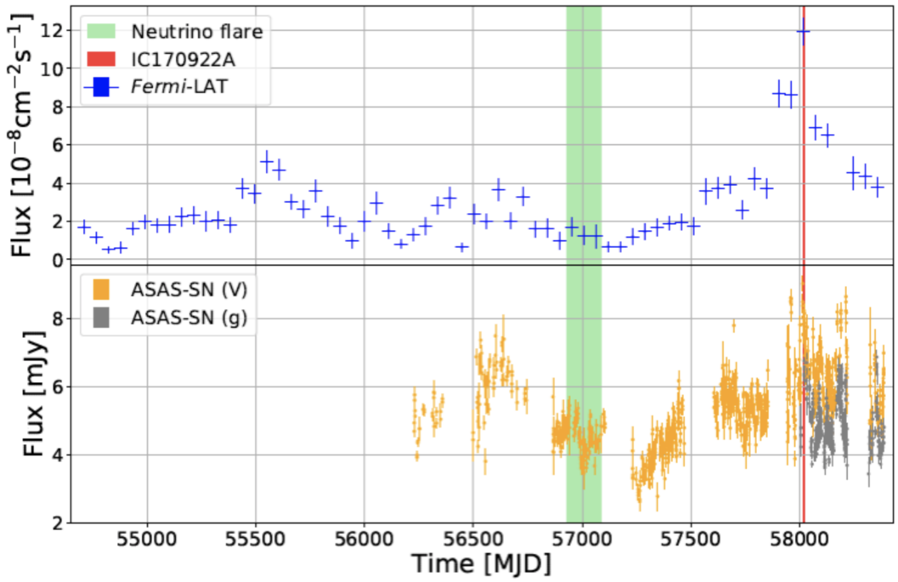

Figure 1: *Light curve of TXS 0506+056 in the-gamma-ray (top, Fermi-LAT) and optical band (bottom, ASAS-SN). The vertical red line indicates the arrival time of IceCube-170922A, The green shaded area highlights the period if time when in 2014-15 IceCube observed an excess of low-energy neutrinos ("neutrino flare"). From* [12]

excess observed in 2014-15 offers an ideal opportunity in this case; it includes a sufficient statistics to derive special constrains and thus allows us to test predictions for photo-hadronically produced neutrinos from TXS 0506+056 and place constrains on the associated broad-band electromagnetic SED.

In the photo-hadronic scenario of a jetted AGN, the high energy photons and electron-positron pairs accompanying the neutrino emission are expected to develop electromagnetic cascades. It can be shown that the efficiency is directly linked to the observed neutrino production rate and the observable photon radiation is theoretically expected to be shifted in the keV to MeV band.

Efforts have been directed into comparting the contemporaneous neutrino and electromagnetic observations for October 2014/March 2015 dataset. During the archival neutrino flare only sparse observations in optical, X-rays, and gamma-rays are available. Nevertheless, this limited information accessible are yet remarkably constraining for photon-hadronic predictions.

3 Future perspective

The progress made in the past years have turned neutrino astrophysics into a promising ground for future discoveries. the Possible TXS 0506+056 / IceCube-170922A association is a tantalizing clue in support of hadronic acceleration in blazar, and the identification of the first neutrino emitter. Nevertheless, detailed investigation of the 2014/2015 blazar/neutrino dataset suggest that a correlation between gamma-ray flaring activity and neutrino emission is not straightforward and needs further investigation. The signature of the expected cascade electromagnetic emission accompanying the neutrino production are likely encoded in X-ray - soft gamma-ray band, making the keV band and above the crucial energy range to solve the multi messenger case. Current wide-field instruments such like INTEGRAL [13] and

MAXI/GSC [14] provide larger sky coverage offering a good complement to more sensitive instruments like *Swift* and *NuSTAR*. Significant progress are expected in the future, when instruments like IXPE [15] and hopefully AMEGO [16] will provide the first X-ray/gamma-ray polarimetry results and coverage of the sub MeV band helping to disentangle leptonic and hadronic contribution in the blazar SED. New neutrino observatories planned for the upcoming decade, such as KM3NeT [17] and GVD [18] in the northern hemisphere and the upgrade of IceCube in the South Pole will have a sensitivity similar or improved by a factor of two to the current IceCube detector. These next generation observatories promise to shed the light in the identification of hadronic sources, providing the first definite clues into Universe PeV accelerators.

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