Snowmass2021 - Letter of Interest

Surveying TeV Gamma-Ray Emission from Active Galactic Nuclei[*]

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

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Abstract: Very-high-energy gamma-ray photons (≥100 GeV) are expected from blazars and some radio galaxies— special sub-classes of Active Galactic Nuclei (AGNs). These gamma-ray photons can provide crucial information of fundamental physics around the intergalactic magnetic field, the radiative processes and acceleration mechanisms, multi-wavelength and multi-messenger observations, periodicity, and beyond-the-Standard-Model physics. The proposed Southern Wide-field Gamma-ray Observatory (SWGO) with a duty cycle near 100% will be one of the best gamma-ray instruments to study AGN phenomena at very-high energies.

[*]This Letter contains excerpts and material from White Papers submitted for the Astro2020 Decadal Survey [1;2]

Active Galactic Nuclei (AGNs) are one of the most luminous astrophysical objects in the Universe. Most of these sources are powered by accretion onto a supermassive black hole[3], leading to collimated relativistic ejecta that transport plasma with high Doppler factors[4]. AGNs present unique observational signatures that include very-high luminosities and short-variability time scales over the entire electromagnetic spectrum. Their broadband spectra, ranging from radio wavelengths to very-high-energy (VHE; $\geq 100\,\mathrm{GeV}$) gamma rays, are extensively studied through multi-wavelength campaigns. VHE gamma-ray observations play an important role in our understanding of the intergalactic magnetic field, the radiative processes and acceleration mechanisms in blazars, the multi-wavelength and multi-messenger observations, periodicity, and beyond-the-Standard-Model physics such as axion-like particles or Lorentz Invariance Violation. In particular, wide-field-of-view TeV gamma-ray observatories are capable of detecting several known VHE blazars at distinct time scales.

In recent years, increasing attention has been put on a sub-class of blazars known as extreme high-energy peaked BL Lacs, for which the low-energy peak is located at energies ≥ 1 keV[5] and the high-energy peak at energies ≥ 1 TeV[6]. The description of their broadband Spectral energy distribution in the framework of the synchrotron self-Compton model suggests an atypically low magnetic field ($\mathrm{B} < 10^{-2}\,\mathrm{G}$)[7] and a large minimum electron Lorentz factor ($\gamma_e \sim 10^5$)[8–10]. Hadronic scenarios are also possible where proton-synchrotron emission and secondary cascades inside the emitting region initiated by ultrarelativistic hadrons[11–14]. The study of jet phenomenology, together with ultra-high-energy cosmic-ray astrophysics, make these objects very interesting. At distances $z > 0.3$, the photon-photon absorption by the extragalactic background light becomes strong. These observations are therefore also particularly interesting for studies about radiative processes, acceleration mechanisms, the intergalactic magnetic field, and searches for physics beyond the Standard Model, such as axion-like particles or Lorentz Invariance Violation[15].

AGN science is also greatly enhanced by multi-messenger observations. The searches for transient high-energy gamma-ray emission correlated with high-energy neutrinos already revealed a first promising result: the detection of the flaring blazar TXS 0506+056 in coincidence with the high-energy neutrino event IceCube-170922A[16]. The significance of the temporal and spatial correlation between the neutrino event and the blazar, which at the time was flaring in high-energy gamma rays, is estimated to be at the 3σ level. The analysis of archival data from IceCube revealed an increase in the rate of neutrino events from the direction of TXS 0506+056 over the course of period of about 100 days in 2014–2015[17], providing further evidence that TXS 0506+056 is a potential neutrino source. An overview over the multi-wavelength observations of TXS 0506+056 and their relation to the neutrino data is given in Figure 1. This first evidence of a multi-messenger signal involving high-energy neutrinos opened a new window to the violent Universe and illustrates one of the likely paths to resolving the century old quest for the sources of cosmic rays.

On the other hand, this first event also raised many new questions and the need for follow-up studies and confirmations that can only be brought about by a next-generation wide-field-of-view TeV observatory, like the Southern Wide-field Gamma-ray Observatory (SWGO)[19]. Crucial is the need for long-term light curves of blazars at the highest energies. SWGO will have a wide field-of-view and will observe $\sim 2/3$ of the sky each day with a near-100% duty cycle. Therefore, SWGO[19] will be a unique instrument to provide these unbiased, quasi-continuous light curves for blazars in the Southern sky. Statistical analysis of light curves will allow the derivation of the frequency of occurrence of blazar flares in the TeV energy range, a crucial input to evaluate the significance of neutrino-blazar flare correlations. This is currently not available in the VHE regime. In addition, only a TeV observatory will monitor sources that are spatially consistent with the neutrino direction over a wide range of time scales (see Figure 2).

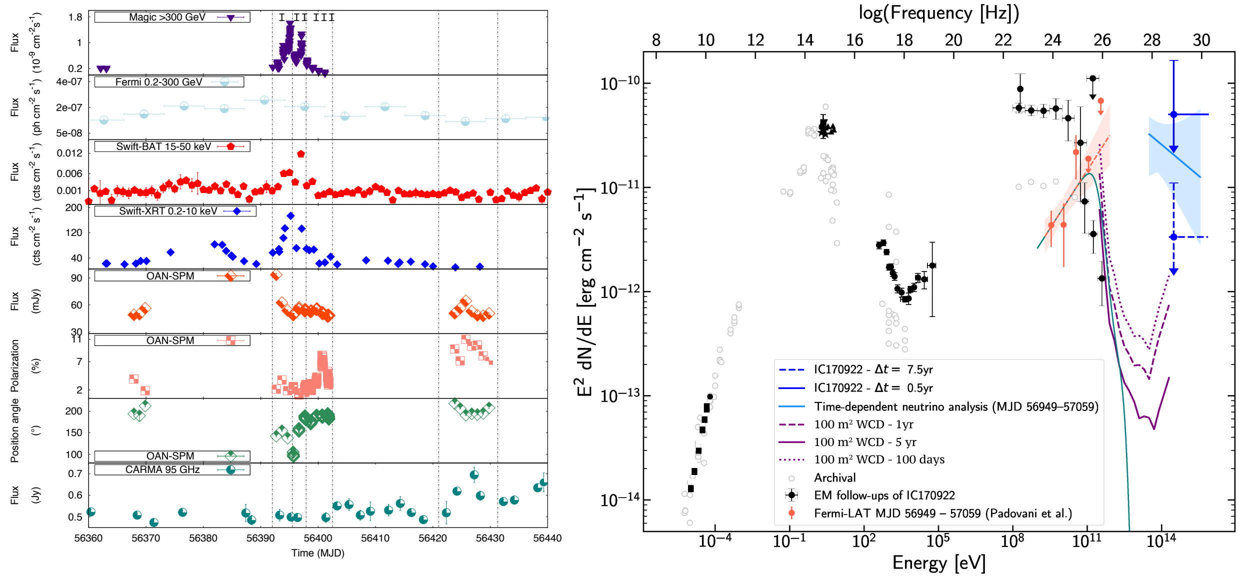

Figure 1: Multi-wavelength of Mrk 421[18] and multi-messenger observations of TXS 0506+056 illustrating the crucial energy and sensitivity range the Southern Wide-field Gamma-Ray Observatory (SWGO) will cover. Modified from Refs. 16;17.

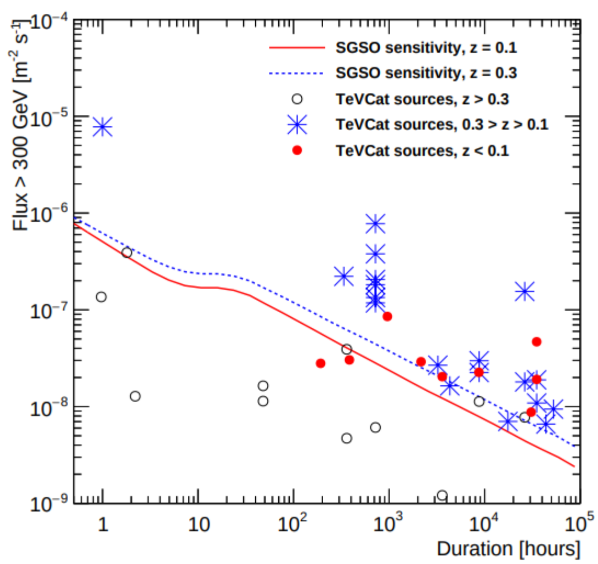

Figure 2: Integral flux above 300 GeV versus duration (see text) for TeVCat sources with published spectra[19]. The plot shows sources in the declination range from -54° to $+6^{\circ}$ (lying within 30° of one of the potential SWGO (previous named SGSO) sites, i.e. $\sim 24^{\circ}$ S latitude), along with the assumed SWGO sensitivities. The sources are divided into three redshift ranges, as indicated.

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