Proposal for VERITAS - 2022/2023

Proposal ID: 1234
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Title: Constraining the Unusual VHE γ-ray Emission of Blazar H 1722+119
Abstract: γ-ray blazars are a class of jetted AGN, where particles are accelerated to relativistic speeds along an axis coinciding with the Earth's line of sight. Detections of blazars in very high energy (VHE) γ-rays can help constrain the types of particles being accelerated as well as fit the models that allow blazars to exhibit flaring behaviour, high levels of flux occurring on short (~day) timescales. H 1722+119 is a blazar that has long been expected to be VHE γ-ray emitting due to its X-ray and high energy (HE) properties but remained undetected at VHE energies until a detection of 5.9 σ in 2013 by MAGIC (a ground-based imaging atmospheric Cherenkov telescope or IACT) over 12 hours in 2013, triggered by a high optical state of the source as detected by the KVA telescope. It is indicative that this source has an unusual γ-ray emission mechanism, since MAGIC was able to detect H 1722+119 so quickly in 2013, while it had remained undetected to VERITAS with regular monitoring from 2007-2008. We propose 12 hours of observations with VERITAS to reach at least a 5σ detection. VERITAS is an IACT of higher sensitivity than MAGIC that has archival data of H 1722+119 outside of MAGIC's observation period amounting to 4.6σ. Comparison of models fit to SEDs and light curves of VERITAS data with those of MAGIC's detection will help determine whether H 1722+119 exhibited unique behaviour during MAGIC's observation period.

Science Working Group: Blazar
Is this part of a Fermi-GI proposal? No
Target of opportunity observations? No
Multiwavelength requirement: No
Thesis: Yes
Analyzers: Samantha Wong will do the Event Display[1] analysis and XYZ will do the VEGAS analysis.

No	Target Name	R.A.	Dec	El	Tmax(Tmin)[2]	ObsMode[3]	Too	NTels[4]	Moon[5]	Sky[6]
1	H 1722+119			60	30(15)	Wobble (0.5)	No	3	N	B

[1] VERITAS data is analyzed by two independent analysis packages (Event Display and VEGAS) with slightly different event reconstruction and error estimation techniques. Detections are only confirmed if both packages agree.
[2] Maximum and minimum run durations, runs are typically 30 minutes long unless a source is extremely high priority (e.g., GRBs).
[3] Most sources are observed in 'wobble mode', where the source is placed off center (0.5 degrees for point sources) in order to gather both the counts of source photons and background photons in areas unaffected by the source. Wobble alternates between north, south, east, and west with each observing run to generate a ring of background regions from which the total significance is calculated.
[4] VERITAS is an array of 4 telescopes. For background estimation and event reconstruction reasons, it is typical that at least 3 telescopes are operating for normal observations (unless there are hardware issues, it's rare to observe with < 3 telescopes).
[5] Moonlight observations require a smaller input of high voltage to the camera's PMTs, which decreases sensitivity at lower energies (more detail in proposal).
[6] Sky grades correspond to cloud levels, with A weather being completely clear, and B weather being mostly clear with some small, wispy clouds. Usually, any weather worse than B gives data that is difficult to use.

Observing Proposal 2022/2023

Proposal Title : Constraining the Unusual VHE γ-ray Emission of Blazar H 1722+119
Science Group : Blazar[1]
Author : Samantha Wong

1. Introduction

Blazars are among the most prolific extragalactic very high energy (VHE) γ-ray sources in the observable universe (i.e., at energies between 100 GeV and 10 TeV), representing a class of active galactic nuclei (AGN) with their collimated jets pointed directly at Earth. These powerful sources act as *cosmic accelerators*, extreme astrophysical environments capable of accelerating particles to energies billions of times higher than any artifical laboratories built on Earth.

Though dozens of blazars have been detected as VHE sources, the mechanisms in which their jets produce and accelerate γ-rays are still uncertain. Furthermore, most blazars have been identified to be variable, meaning that they exhibit both high and low states of γ-ray flux, and are often undetectable in low states. Two hypotheses for flare origin are internal shock waves within the jet [2] or the ejection of relativistic plasma originating in the accretion disk or surrounding medium. [3].

To better understand when emission should be expected from blazars, and more importantly, to constrain if and when emission of other relativistic particles, namely cosmic rays and neutrinos, should also be expected, detecting and modelling the multiwavelength and multimessenger emission from blazars is currently a priority in VHE fields.

2. Scientific Justification

H 1722+119 is a high-frequency peaked BL Lac (HBL) source[2] detected by MAGIC [7] at a significance[3] of 5.9σ in 2013 [5] after 12.5 hours of observations over 5 days, triggered by an optical high state seen by the Kungliga Vetenskapsakademien (KVA) optical telescope.

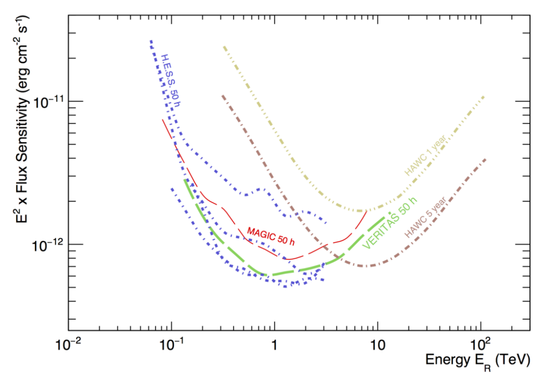

Figure 1: Sensitivity comparison of several VHE γ-ray observatories
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[1] VERITAS has three science working groups: Blazar, ATOMM (Astroparticle, transient, optical, multimessenger), and Galactic that each specialize in observing and analyzing different types of sources. Time allocations are approximately evenly distributed across the three groups.

[2] Blazars are characterized by a double hump shape in their spectral energy distributions (SEDs), with the first peak coming from synchrotron radiation, and the second from inverse Compton scattering. HBL means that inverse Compton scattering peaks at relatively high energies (usually in the X-ray or γ-ray bands).

[3] Significance in VHE γ-ray astrophysics is, by convention, defined as the ratio of the excess counts above background to its standard deviation [1]

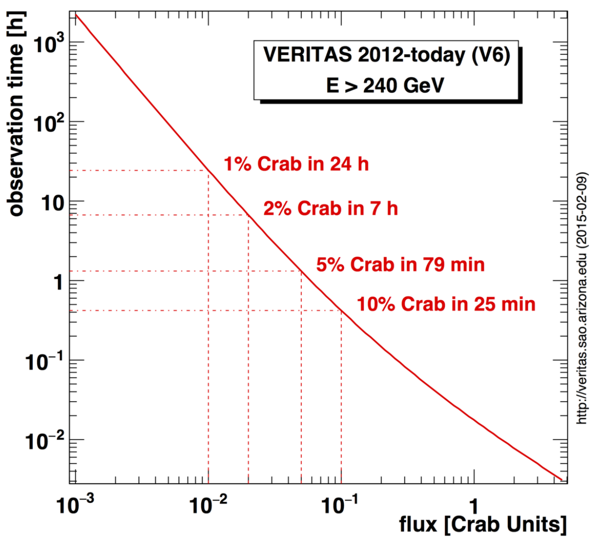

Figure 2: VERITAS observation time vs integral flux sensitivity (measured as a percentage of the Crab nebula's flux).

H 1722+119 did not exhibit any flux variability within the sensitivity of Fermi-LAT or MAGIC[6]. However, the MAGIC detection was attributed to a hardening of the Fermi-LAT spectrum[4]. Hardening usually occurs when there is increased flux from the source, which would imply that the source exhibited some small-scale variability in HE and VHE bands below the sensitivity of Fermi-LAT and MAGIC.

As seen in Figure 3, the MAGIC detection does not correspond to a region of especially high optical flux, though at the time it was a historical high point. VERITAS is more sensitive than MAGIC (see Figure 1), particularly at low energies, where emission from extragalactic sources is expected to be distributed. Early VERITAS observations occurred during a low state and resumed post-MAGIC detection. VERITAS took data during the very high optical state around MJD 85000 in Figure 3, but none of these resulted in a significant detection due to poor weather and bright moonlight conditions that decreased sensitivity.

It is unclear why MAGIC was able to detect H 1722+119 so quickly in 2013, when it had previously remained undetected. MAGIC reported a flux of 2% Crab[5], which would be detected in 7 hours of VERITAS observations, according to Figure 2. VERITAS took good quality data on H 1722+119 for 17 hours between 2007 and 2008 but did not yield a detection, implying that it must have been emitting in VHE at a higher flux level in 2013.

3. Observation Details

Note: Since VERITAS is an instrument that typically only receives proposals from within the collaboration, I've provided details about the instrument in the following three paragraphs to clarify how observations work.

We request observations with the Very Energetic Radiation Telescope Array System (VERITAS), an imaging atmospheric Cherenkov telescope (IACT) located near Tucson, Arizona. IACTs are VHE γ-ray detectors that indirectly detect γ-rays. As VHE γ-rays enter the Earth's upper atmosphere, they interact with atmospheric particles to create electron-positron pairs. As these particles travel through the atmosphere, they emit new photons, which will go on to make more electron-positron pairs. This creates a shower-like effect, aptly named an air shower. Since the incident γ-ray was very energetic, the particles produced in its air shower will travel faster than the speed of light in the atmosphere, creating an effect called Cherenkov radiation. Cherenkov radiation can be observed as rapid (ns duration) flashes of blue optical light on the ground.

[4]Hardening implies a higher spectral index, i.e., higher energy radiation.

[5]The Crab nebula (M1) is a bright and steady VHE source, which is often used as a point of comparison for flux levels.

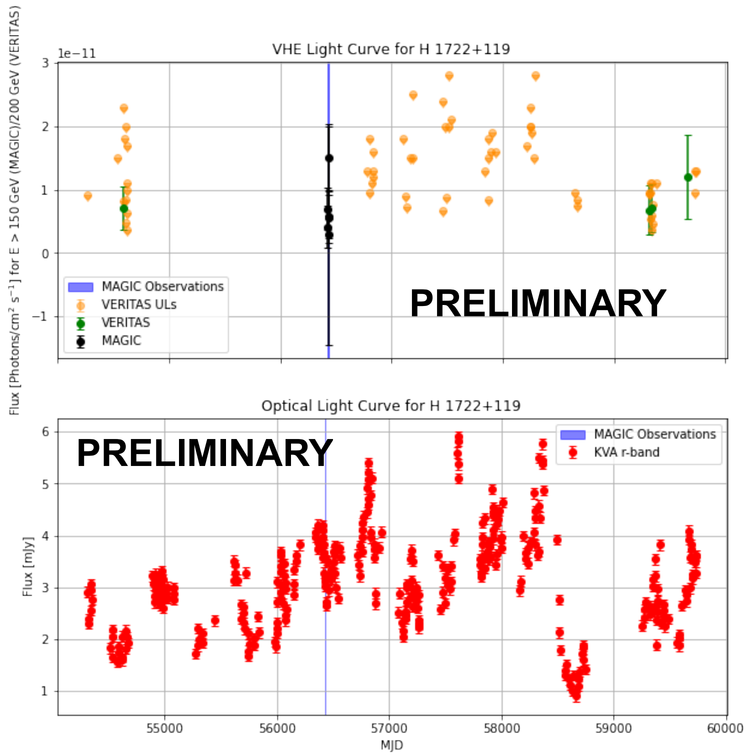

Figure 3: Light curve of H 1722+119 during all VERITAS observations. Energy thresholds of 200 GeV and 150 GeV for VERITAS and MAGIC fluxes, respectively, correspond to the instrument sensitivities. VERITAS upper limits (orange) are calculated at the 95% confidence level (green VERITAS flux points correspond to nightly-binned significance $> 2\sigma$).

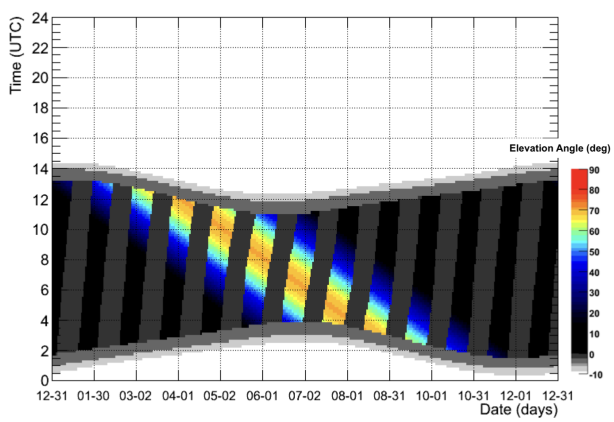

Figure 4: Visibility plot of H 1722+119 to VERITAS. Horizontal grey bands mark the beginning and end of night, while the vertical grey bands mark periods of bright moonlight.Orange/red colours are optimal elevation for observations. Generated using the TeVCat online source catalog[4]

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VERITAS is an array of four 12-m IACTs that images Cherenkov light using cameras each consisting of 499 photomultiplier tubes (PMTs). PMTs are optimal for γ-ray astronomy (as opposed to other detectors, such as CCDs), because they are capable of ns readout times and have a combination of high gain and low noise, optimizing them for faint flashes of Cherenkov light. The duty cycle is limited by the summer monsoon season, where weather prohibits observations from late June to mid-September. Additionally, observations are stopped when the moon is $> 75\%$ illuminated ($\sim$8 days/month) to avoid damage to the PMTs and due to the high levels of background.

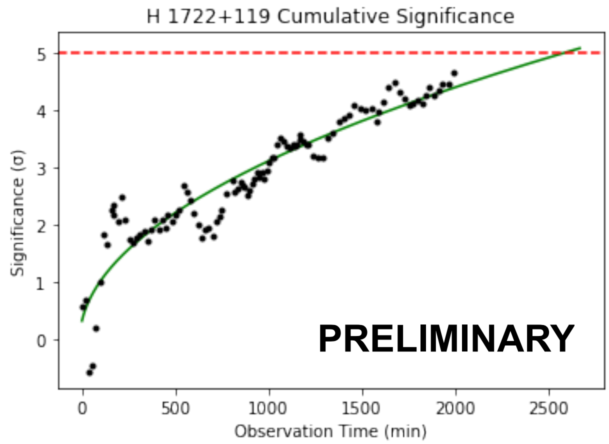

Figure 5: Cumulative significance of H 1722+119 for all VERITAS observations. Following Poissonian statistics, $\sigma \propto \sqrt{t}$, the expected time to reach 5 σ is calculated by fitting a square root function to significance calculated using equation 14 in Li & Ma [1] (the convention in VHE astrophysics).

We request 10 hours of observations with VERITAS. This is calculated by Figure 5, which shows VERITAS's current sensitivity to persistent Crab-like sources[6] and padded by an hour to account for sub-optimal weather conditions and slewing time. These observations should be performed at an elevation above 60°[7] and during dark time ($<$ 30 % moon illumination). Figure 4 shows that H 1722+119 is visible at elevations $> 60°$ from April until the end of the observing season. The duration of single observations for most sources with VERITAS is typically 30-60 minutes per night, spread out over several nights during the visibility window[8]. We will not request changes to this standard cadence, since flares typically occur on nightly timescales, with rare cases of intra-night variability. Light curves can then be binned either nightly (default) or on smaller timescales for flux and spectral studies. Furthermore, it is useful to have observations spread throughout the visibility window so that we can monitor any changes to flux.

4. Relation to Previous Observations

H 1722+119 has been detected in VHE by MAGIC in 2013. VERITAS currently has 33 hours of data on the source, with more regular observations following the MAGIC detection in 2013 but no overlapping window with the detection.

Current VERITAS archival data from 2007 through 2022 gives a significance of 4.6σ, which is just below the detection threshold of 5σ.

The source is currently part of the reduced high voltage (RHV) snapshot program. This program surveys most known blazar sources (primarily those who do not have dedicated observations) that are likely to be VHE γ-ray emitting during periods of moonlight[9]. These sources usually only get a few observations per year, but some sources are not observed at all. Moonlight observations decrease sensitivity to lower energy photons ($<$ 300 GeV), this is particularly relevant to blazar studies, since at extragalactic distances, most of the highest energy VHE photons are absorbed and scattered by the extragalactic background light[10], so most of the energy observed is at the energies that suffer sensitivity loss during RHV observations. In order to get significant flux points for light curves or spectral studies, it is important to take dedicated observations of H 1722+119 in optimal conditions.

5. Quantitative Description of Expected Outcome

A 5σ detection is expected after 9 more hours of observations of H 1722+119 (see Figure 5). A detection will likely provide us with several more flux points and a VHE SED that can be com-

[6] If a source is variable, detection time will vary, so this is an estimate based on no variability, consistent with VERITAS' observations of H 1722+119 so far.

[7] γ-ray flux is low, so observations $> 60°$ are necessary to get sufficient photon counts for a flux point determination.

[8] This is partly because sources are only above the minimum required elevation for a few hours each night but also so that time can be given to many sources in each RA band while they are visible.

[9] Due to the faint nature of Cherenkov light, PMTs are very sensitive and large non-astrophysical backgrounds will appear when exposed to a bright sky. For this reason, VERITAS reduces the voltage applied to PMTs while observing during moonlight

[10] isotropic accumulated radiation from star formation and AGN

pared with that of MAGIC's 2013 detection.

We will continue to monitor the optical state of H 1722+119 through KVA's Tuorla Observatory blazar monitoring program [11] to determine if the source is optically in a 'very high' (similar to the highest optical flux around MJD 85000), 'high' (similar to the 2013 optical flux), or 'low' (quiescent) state. This will allow us to fit a model either for the quiescent state of H 1722+119 to which we can compare the MAGIC SED and determine if any variability is present, or to 'high' or 'very high' states to determine the level of variability of the source. Any of these outcomes will allow for SED modelling of the blazar, which will constrain its emission mechanism and source of variability.

6. Publication Plans

A detection of the source, along with modelling and any multiwavelength data, will be published as a letter in *MNRAS*. This will include discussion about any constraints we have been able to place on the source's variability and any observed changes from MAGIC's 2013 detection.

References

[1] T. -P. Li and Y. -Q. Ma. "Analysis methods for results in gamma-ray astronomy." In: 272 (Sept. 1983), pp. 317–324. DOI: 10.1086/161295.

[2] Martin J. Rees. "Black Hole Models for Active Galactic Nuclei". In: *Annual Review of Astronomy and Astrophysics* 22.1 (1984), pp. 471–506. DOI: 10.1146/annurev.aa.22.090184.002351. eprint: https://doi.org/10.1146/annurev.aa.22.090184.002351. URL: https://doi.org/10.1146/annurev.aa.22.090184.002351.

[3] M. Boettcher, H. Mause, and R. Schlickeiser. *Gamma-ray emission and spectral evolution of pair plasmas in AGN jets*. 1996. DOI: 10.48550/ARXIV.ASTRO-PH/9604003. URL: https://arxiv.org/abs/astro-ph/9604003.

[4] S. P. Wakely and D. Horan. "TeVCat: An online catalog for Very High Energy Gamma-Ray Astronomy". In: *International Cosmic Ray Conference* 3 (2008), pp. 1341–1344.

[5] Juan Cortina. "Discovery of Very High Energy Gamma-Ray Emission from BL Lac object H1722+119 by the MAGIC Telescopes". In: *The Astronomer's Telegram* 5080 (May 2013), p. 1.

[6] M. L. Ahnen et al. "Investigating the peculiar emission from the new VHE gamma-ray source H1722119". In: *Monthly Notices of the Royal Astronomical Society* 459.3 (Mar. 2016), pp. 3271–3281. DOI: 10.1093/mnras/stw689. URL: https://doi.org/10.1093%2Fmnras%2Fstw689.

[7] J. Aleksić et al. "The major upgrade of the MAGIC telescopes, Part II: A performance study using observations of the Crab Nebula". In: *Astroparticle Physics* 72 (Jan. 2016), pp. 76–94. DOI: 10.1016/j.astropartphys.2015.02.005. URL: https://doi.org/10.1016%2Fj.astropartphys.2015.02.005.

[11] https://users.utu.fi/kani/1m/