

Long-term monitoring of blazars – the DWARF network

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Abstract. The variability of the very high energy (VHE) emission from blazars seems to be connected with the feeding and propagation of relativistic jets and with their origin in supermassive black hole binaries. The key to understanding their properties is measuring well-sampled gamma-ray lightcurves, revealing the typical source behavior unbiased by prior knowledge from other wavebands. Using ground-based gamma-ray observatories with exposures limited by dark-time, a global network of several telescopes is needed to carry out full-time measurements. Obviously, such observations are time-consuming and, therefore, cannot be carried out with the present state of the art instruments.

The DWARF telescope on the Canary Island of La Palma is dedicated to monitoring observations. It is currently being set up, employing a cost-efficient and robotic design. Part of this project is the future construction of a distributed network of small telescopes. The physical motivation of VHE long-term monitoring will be outlined in detail and the perspective for a network for 24/7 observations will be presented.

Keywords: Active Galactic Nuclei: individual; BL Lacertae objects: individual; gamma-rays: observations; gamma-rays: instrumentation

I. INTRODUCTION

According to the unification scheme for Active Galactic Nuclei (AGN), blazars are characterized by relativistic plasma outflows (jets) pointing towards the observer [1]. Thus, it is plausible that already for geometric reasons, observations of blazars probe deepest into the jets of AGN and, by this, carry most of the information about their central engine. Furthermore, the broadband spectral energy distribution (SED) of blazars is characterized by a purely non-thermal two hump structure spanning over more than 15 orders of magnitude in energy and showing variability on timescales from years down to minute scales [2].

The continuous spectra are subject of recent debates, just as the acceleration mechanisms causing these electro-magnetic spectra due to energy losses. Although the measured spectra can be explained quite well with reasonable models, it is still an unsettled question whether the acceleration processes within blazars are dominated by leptons or by protons.

Leptonic models, particularly the Synchrotron Self Compton (SSC) [3], are very successful in explaining most of the so far observed energy spectra as well as the temporal behavior of the sources. But for the Flat Spectrum Radio Quasar 3C 279 it has recently been shown that single zone leptonic models, even under the assumption of external photon fields (External Compton, EC), are not suited to explain the SED [4].

On the other hand, hadronic models, such as the Proton Blazar [5] or the Synchrotron Mirror Model (SMM) [6] are evenly well suited to explain the broad band SED measurements, but also predict the emission of high energy neutrinos. Besides this, they are capable of naturally explaining “orphan” gamma-ray flares without correlated X-ray flares as observed in 2002 for 1ES 1959+650 [7] and in 2004 for Mrk 421 [8], which is hardly possible in leptonic models.

II. BINARY BLACK HOLES IN AGN

Uninfluenced by the question for the predominant acceleration mechanisms, also the question for the central engine of AGN is under debate. In the recent bottom-up scenarios of galaxy formation, the big elliptical galaxies, which host most of the luminous, radio-loud AGN, are built up by the merging of smaller spirals. Additionally, modern surveys show that more or less every galaxy – like our own – hosts a central black hole (BH). By this, it is a natural expectation that especially the big elliptical galaxies contain more than one central black hole. This, in turn, leads directly to a model of Binary Black Holes (BBHs) [9], as it was shown that systems of more than one black hole are unstable except for binary systems [10].

Although widely separated binary black hole systems [11], [12] and recently a relatively narrow one [13] have been observed, it is still quite ambiguous whether BBHs enter the separation where gravitational wave emission becomes important and finally coalesce within a Hubble time. On the other hand, there are models connecting the activity state of AGN (like Seyfert or quasar type activity) to the separation of the internal BBH system [14], giving rise to the assumption that especially in blazars, the separation of eventual binary systems is such small that one will not be able to resolve them in the near future. Though, their detection is not quite impossible, but indirect. Due to the interaction of the secondary BH with either the accretion disc or the jet via tidal forces, a quasi periodic behavior should be observed in the emission of the sources, e.g. [15]. In fact, there are several observational evidences of such behavior (for an overview, see [16]): The best studied object, probably harboring a BBH, is OJ 287, where optical outbursts with a periodicity of 12 years are observed [17] and even period shortening due to gravitational wave emission is tested [18]. A similar periodicity of 10 years has recently been found in optical data of Mrk 501 [19]. This is especially interesting in the context of BBHs as based on an observed periodicity of 23 days in gamma-rays by HEGRA [20], the BBH interpretation of the source [21] predicted an optical periodicity of 6-14 years. Analyses of not only HEGRA gamma-ray but also Telescope Array gamma-ray and ASM X-ray data fortified the findings of a 23 day periodicity [22]. Recent studies confirm these results on MAGIC, VERITAS and Whipple gamma-ray and SWIFT and RXTE X-ray data, additionally finding 36 and 72 day periods in the RXTE lightcurve [23]. From this, it is both obvious that gamma-ray observations of the duration of weeks are much better suited to find periodic behavior of the sources than optical observations for decades, and that therefore gamma-ray monitoring observations are required on a long-term basis.

III. MONITORING OBSERVATIONS

The key to obtain answers to the questions raised above lies in the combination of single deep observations of different source states with long-term monitoring observations providing information about the long-term behavior of the sources. A wide multi-wavelength coverage is mandatory for both kinds of observations. In contrary to the recent deep observations of known sources, which are mostly triggered by information on the source state from different wavebands, e.g. X-ray satellites, monitoring observations scheduled independent of prior knowledge of the source state offer the possibility of both, detecting “orphan” gamma-ray flares as well as statistical analyses. Investigations on the flux state probability [24] might open the opportunity of cross-correlating gamma-ray observations with those of the neutrino telescope IceCube, but statistically significant conclusions can only be drawn from cross-correlating

complete data samples from both, the gamma and the neutrino astronomy. Such a cross-correlation would be the smoking gun of hadronic acceleration processes in the sources and would immediately settle this outrageous question of modern high energy astrophysics. Although there are ongoing monitoring programs of bright blazars with MAGIC [25], [26], [27] and Whipple [28], those observations – which are especially in the case of MAGIC only of about 30 min duration – are far from being complete and thus can complement the full-time IceCube observations only in a very limited way. But as the latest generation Cherenkov telescopes, such as MAGIC, H.E.S.S., VERITAS and CANGAROO-III are overbooked with discovery observations at their sensitivity limit or deep multi-wavelength observations of known sources, it is obvious that no more precious observation time of these instruments can be assigned to time-consuming monitoring observations – this is the starting point for the DWARF network, first proposed in [29].

IV. THE DWARF NETWORK

To overcome the disadvantages of biased sampling and of time series analyses dominated by gaps rather than by observations, we intend to initiate a global network of Cherenkov telescopes, operated in a coordinated way for monitoring observations of nearby blazars – the DWARF (Dedicated Worldwide AGN Research Facility) Network. The aim is to distribute several Cherenkov telescopes around the globe to be able to do 24/7 monitoring, preferably with temporal overlap and redundancy to account for weather and duty cycle constraints. The monitored sources will be the brightest TeV blazars: Mrk 501, Mrk 421, 1ES 1959+650, 1ES 2344+514, H 1426+428, and PKS 2155-304. This initiative is led somehow by the Whipple and TACTIC telescopes which have been dedicated to monitoring observations for several years on the one hand, and on the other by the authors, building the DWARF telescope right now and having starting to coordinate those monitoring activities. Fig. 1 depicts the distribution of the Cherenkov telescopes contributing to the DWARF network, so far. The following sections will give an overview of the involved instruments.

A. The DWARF Telescope

At the Roque de los Muchachos on the Canary island of La Palma, the mount of the former HEGRA CT3 is located beside the MAGIC telescopes at 2200m a.s.l. and is still operational. After a complete refurbishment it will be operated with an enlarged mirror area, a micro-controller-based motion system similar to the one of both MAGIC telescopes [30], and with a robotic design. For details see [31], [32]. Additionally, a completely new camera is being developed [33], [34], based on Geiger-mode Avalanche Photodiodes (G-APDs) [35]. Together with newly developed non-imaging light guides (see [36]), this will significantly lower the energy

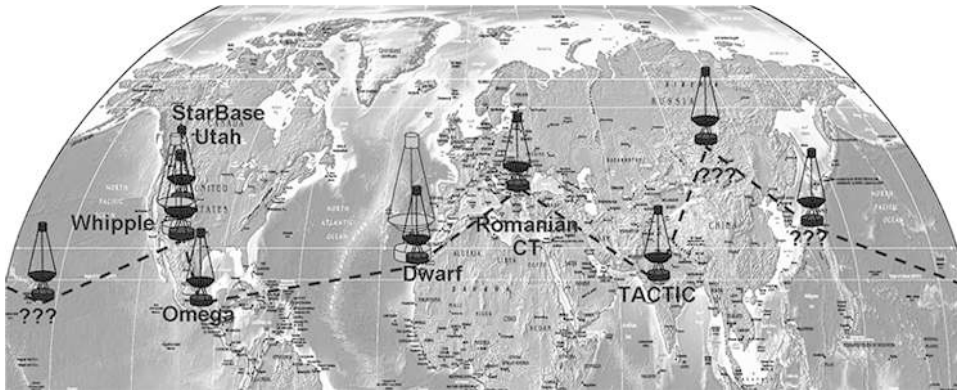


Fig. 1: The (nearly) worldwide DWARF network, so far.

threshold to less than 450 GeV and greatly enhance the sensitivity of the telescope [32]. The autonomous robotized approach of the DWARF telescope keeps the man power demand on the low side and additionally, the construction costs per telescope are quite affordable. This concept is especially attractive for countries having smaller budgets for scientific developments but wanting to contribute to the high-technology spearhead of astrophysics. As such, this telescope will hopefully act as a prototype of many more telescopes being built to contribute to the monitoring network DWARF. For multi-wavelength observations, there are already agreements with the Mesähoivi Radio Observatory and the optical KVA telescope of the Tuorla Observatory, which will simultaneously complement the DWARF telescope observations.

B. The Whipple 10m-Telescope

Since 2005, the Whipple 10 m-telescope [37], located on Mt. Hopkins in Arizona, USA, is dedicated to nightly monitoring observations of the five northern hemisphere blazars [28]. With the 10 m diameter mirror dish focusing the Cherenkov light on the 499 photo multiplier tube camera, it reaches an energy threshold of about 400 GeV. Due to the long history of monitoring observations with this telescope there are lots of multi-wavelength partners providing quasi-simultaneous data from nearly all other wavebands, as demonstrated in [38]. Already in 2007, it was decided that Whipple observations will dovetail with those of the DWARF telescope and by this, both groups made the first move into the direction of a full time monitoring network of TeV bright blazars.

C. TACTIC

The TACTIC gamma-ray telescope [39] on Mt. Abu (1300 m a.s.l.), India, has been in operation since 2001. With its 9.5 m² mirror area and its 349 pixel camera it has a similar performance as a single HEGRA telescope, reaching an energy threshold of 1.2 TeV. By this, it is capable of establishing a 3σ signal of a Crab Nebula like source within one night. The TACTIC telescope is dedicated to monitoring observations on a long-term

basis and is perfectly suited to be part of the DWARF network.

D. OMEGA

Beside the HAWC detector on the Volcano Sierra Negra, two of the former HEGRA telescopes (8.5 m² mirror, 271 pixel camera, each) will be installed under the name of OMEGA [40]. Due to the higher altitude of 4100 m a.s.l. (instead of 2200 m a.s.l. at the HEGRA site), the energy threshold is expected to be lower than 500 GeV which will raise the source detection rate compared to a former two telescope HEGRA system. All hardware and software have been checked at UNAM, Mexico, and will be installed at the HAWC site, soon. After installation, the primary scientific goal of OMEGA will be to monitor nearby blazars.

E. Star Base Utah

Star Base Utah [41] consists of two telescopes of the former Telescope Array, each one having a reflector of 3 m diameter with $f/D=1$ Davis-Cotton optics. The telescopes are built less than 50 miles western of Salt-Lake-City on a 23 m East-West baseline. They were constructed as a testbench for gamma-ray astronomy instrumentation and for intensity interferometry. After Cherenkov cameras will have been built, Star Base Utah will join the monitoring efforts with a stereoscopic system.

F. Romanian CT

Lead by the Institute for Space Science, Bucharest, a Romanian consortium has started two projects to prepare the construction of a Cherenkov telescope in their homeland [42]. The first one is engaged in the construction of a dedicated instrument to measure the light of the night sky and the second one will carry out the site search, based on meteorological, astronomical and social/infrastructural conditions. After the completion of those projects, a Cherenkov telescope will be built and operated within the DWARF network for blazar monitoring.

V. CONCLUSION

In this paper we presented the physical motivation of long-term monitoring observations of bright AGN with the ambitious goals of the detection of binary black holes through temporally modulated gamma-ray emission and the detection of hadronic acceleration processes in AGN through cross-correlation of full-time gamma-ray and neutrino observations. Furthermore, we presented the status and the perspective of a distributed monitoring network of Cherenkov telescopes for long-term 24/7 observations – the DWARF network.

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