# Search for Very High Energy candidate sources using South African observatories

**B van Soelen[1], L Klindt[1], IP van der Westhuizen[1], PJ Meintjes[1], M Böttcher[2], L Hanlon[3], M Topinka[3] and P Väisänen[4]**

[1]Department of Physics, University of the Free State, Bloemfontein, 9301, South Africa,
[2]Centre for Space Research, North-West University, Potchefstroom, 2520, South Africa,
[3]School of Physics, University College Dublin, Belfield, Dublin 4, Ireland, [4]South African Astronomical Observatory, PO Box 9, Observatory 7935, Cape Town, South Africa

E-mail: vansoelenb@ufs.ac.za

**Abstract.** The multi-wavelength South African observatories are ideally located to complement the very high energy (VHE) observations undertaken with the H.E.S.S. telescope located in Namibia. We are undertaking a long–term multi-wavelength campaign and a literature search to identify potential Very High Energy extra-galactic sources which may be observable with Imaging Air Cherenkov Telescopes such as the H.E.S.S. telescope. The early stages of this project have focussed on identifying candidate sources and undertaking optical photometric observations with the UFS/Boyden 1.5-m and Watcher telescopes located at the Boyden observatory, and optical spectroscopy observations with the South African Large Telescope (SALT) and the SAAO 1.9-m telescope located at the South African Astronomical Observatory (SAAO). We present an overview of the proposed observational programme, the different possibilities available for multi-wavelength observations and initial results from this project.

## 1. Introduction

Astronomy is currently in a special position as we are able to observe the universe from radio up to $\gamma$-ray energies. More and more, multi-wavelength astronomy is required to understand the physical processes occurring in a multitude of sources. This extends from, for example, $\gamma$-ray pulsars which show both radio and $\gamma$-ray pulsations [1], $\gamma$-ray binary systems which show varying multi-wavelength behaviour [2], Active Galactic Nuclei (AGN) which show variations over the entire spectrum of energies, including rapid $< 1$ day flaring in $\gamma$-rays (for example 3C 454.3 [3]) to $\gamma$-ray bursts (GRBs) and their afterglows spanning from GeV energies to radio [4]. All these examples point towards the importance of multi-wavelength support to complement the $\gamma$-ray observations at both GeV and TeV energies.

South Africa is in a good position to contribute towards multi-wavelength support of these observations. Given our similar geographical location to the H.E.S.S. $\gamma$-ray telescope in Namibia and the possibility that the southern station of the Cherenkov Telescope Array (CTA) may be placed in Namibia (currently the two candidate sites are Aar, Namibia and the European Southern Observatory, Chile), we would argue that South Africa should become more involved with the High Energy (HE) and Very High Energy (VHE; $E > 100$ GeV) sources and continue to contribute to multi-wavelength follow-ups and observations of HE/VHE sources.

Here we present a short overview of the proposed observational programmes we are undertaking. These have, thus far, focussed on optical spectroscopic observations of unclassified sources within the Second *Fermi*-LAT AGN Catalogue (2LAC) [5], as well as optical photometric monitoring of candidate blazar sources as part of multi-wavelength campaigns. It is intended that this will expand to include radio observations of these sources. Since this proceedings will focus mainly on AGN, below we briefly present an overview of AGN and our search strategy, before reviewing the available optical and radio observatories within South Africa. We conclude with a discussion of preliminary observations undertaken thus far, as well as some related observations of known VHE sources.

## 2. Active Galactic Nuclei

AGN represent some of the most energetic sources in the sky. They are power by accretion of material onto a supermassive black hole in the centre of the galaxy and often produce relativistic jets. The observed properties of AGN depend on the angle between our line of sight and the direction of flow of these jets. In sources where the direction of flow lies close to our line of sight the Doppler boosted non-thermal emission being produced in the jet can dominate over the thermal emission from the galaxy. Such sources are collectively known as blazars [6].

The non-thermal emission of blazars extends from radio to $\gamma$-rays and the Spectral Energy Distributions (SEDs) of these sources exhibit two different components: a low energy component extending from radio to UV/X-ray; and a high energy component extending from UV/X-ray to $\gamma$-rays. While the low energy component is produced through (leptonic) synchrotron emission, the high energy component could be produce through either leptonic or hadronic processes. In the leptonic scenario the high energy component is produced through inverse Compton scattering, either of external photons originating from, for example, the accretion disc or the broad line region, while in the hadronic scenario the emission could be produced through, for example, proton synchrotron or $\pi^0$ decay (see e.g. [7] and references therein).

Blazars are sub-divided based based on the frequency, $\nu_{\rm pk}$, at which the peak in the lower energy component of the SED occurs. These sources are classified as Low Synchrotron Peaked (LSP), Intermediate Synchrotron Peaked (ISP) and High Synchrotron Peaked (HSP) if $\nu_{\rm pk} \leq 10^{14}$ Hz, $10^{14}$ Hz $< \nu_{\rm pk} \leq 10^{15}$ Hz and $\nu_{\rm pk} > 10^{15}$ Hz, respectively. It can, to a first approximation, be assumed that HSP blazars are better candidates for VHE emission sources since, if both component are produced through leptonic processes, the high energy component should also peak towards higher energies. See for example [8], and references therein, for a discussion. Therefore, in our search for VHE sources we are establishing the multi-wavelength SED of these sources to determine whether there is an indication that the sources should have emission extending to VHE $\gamma$-rays.

The degree to which the Extragalactic Background Light (EBL) will attenuate any VHE emission must also be considered when searching for extra-galactic VHE candidates. VHE $\gamma$-rays emitted from AGN can interact with the EBL resulting in electron-positron pair production [9, 10]. This should introduce a redshift dependence on the opacity of AGN at VHE, and places a limited on the observability of blazars at VHE.

## 3. Search strategy

In order to identify new VHE candidate AGN, it is necessary to establish the SED of these sources, to classify them as LSP, ISP or HSP and to establish their redshift, as VHE $\gamma$-rays will be attenuated for high redshift sources. For the initial phase of this project we are focussing on multi-wavelength observations of a selection of unclassified extra-galactic HE sources identified in the *Fermi*-LAT catalogue in order to establish whether they present good candidates for VHE observations. Various factors were included in the selection of these candidate sources (as discussed in section 5.1).

In order to establish the SEDs a broad wavelength coverage from radio to $\gamma$-ray observations is required. While X-ray and $\gamma$-ray observations are available from archival data (e.g. *Fermi*), South African observatories can help to confirm/establish the radio and optical flux. Such observations, combined with initial modelling, can indicate sources which present good potential for VHE emission at a detectable flux. In addition we are undertaking optical spectroscopy to establish the redshifts of these targets as most detectable VHE sources lie at low redshifts, which therefore places a constraint on the observability of these sources at VHE.

In addition, photometric observations are being undertaken of the best candidate sources to search for short ($\sim$ 1 day) and long ($>$ 1 day) term variability. The detection of such variability will help to confirm the counter parts association with the $\gamma$-ray sources, particularly if optical/$\gamma$-ray correlation can be detected between the long-term photometric observations being undertaken with Watcher and data available with *Fermi*-LAT. Three of the candidate sources appear to exhibit $\gamma$-ray variability in *Fermi*-LAT observations since they have a variability test statistic $\mathrm{TS_{var}} \gtrsim 41.6$. Here, $\mathrm{TS_{var}}$ is a test statistic established in [5] and $\mathrm{TS_{var}} > 41.6$ indicates a 99% probability of variability over the 2 year period of the catalogue.

## 4. Optical and radio telescopes within South Africa

There are a number of telescopes available in South Africa and more detailed presentations are presented elsewhere at this meeting. Some of these telescopes have already been involved in multi-wavelength/TeV studies [11]. Here we only very briefly review the telescopes that we have used or are planning to use.

### *4.1. Optical telescopes*

*4.1.1. Boyden observatory.* The Boyden observatory is located approximately 25 km North-East of Bloemfontein, South Africa. The main science telescope at the Boyden observatory is the 1.5-m Boyden reflector. The telescope is in a Cassegrain configuration with photometry capabilities. The system is equipped with standard U, B, V, R, I filters and an Apogee U55 Back-illuminated CCD camera. The second science telescope on-site is the 40-cm Watcher Robotic Telescope [12]. This telescope is operated remotely and has the main science aim of observing GRB afterglows. However, non-alert time can be used for on-going monitoring of other systems and ,for example, [13] reported on on-going blazar monitoring.

Both the Boyden 1.5-m and Watcher telescopes focus on on-going long term photometric monitoring of candidate sources.

*4.1.2. South African Astronomical Observatory.* The South African Astronomical Observatory (SAAO) is host to a number of optical/near-infrared telescopes run both by the South African National Research Foundation (NRF) and external organizations. Here we mention only the Southern African Large Telescope (SALT) and the SAAO 1.9-m telescopes. Both systems are equipped for optical photometric and spectroscopic observations. The grating spectrograph on the SAAO 1.9-m telescope allows for low to medium spectral resolution. SALT, on the other hand, is a 10-m class telescope, which can undertake low to medium resolution spectroscopy ($R = \lambda/\Delta\lambda \sim 500 - 9000$) with the Robert Stobie Spectrograph (RSS) and high resolution spectroscopy with the High Resolution Spectrograph (HRS) which is currently being commissioned. In addition, both the SAAO 1.9-m telescope and SALT are capable of very rapid photometry with the Sutherland High Speed Optical Cameras (SHOC) and the Berkeley Visible Image Tube (BVIT), respectively.

Optical observations with SALT and SAAO 1.9-m telescope focus on obtaining spectroscopic observations to establish the distance to these sources (redshift).

*4.2. Radio telescopes*

*4.2.1. HartRAO.* The Hartebeesthoek Radio Astronomy Observatory (HartRAO) is located near Hartbeespoort, South Africa and operates (among others) a 26-m single-dish radio telescope which operates between 1.67 to 23 GHz. The system is regularly involved with Very Long Baseline Interferometry (VLBI) observations and contributes to AGN monitoring observations. Radio observations of our candidate sources will be proposed to establish and/or confirm the radio brightness of these sources as well as searching for variability. These observations will be, in general, limited to bright ($> 100$ mJy) sources.

*4.2.2. KAT and SKA.* The expansion towards the development of Square Kilometre Array (SKA) in South Africa (see e.g. [14]) has lead to the development of Karoo Array Telescope (KAT) which currently consists of 7 dishes (KAT-7) which also regularly contributes towards the AGN monitoring and scientific observations. The next phase of development is the construction of the MeerKAT 64 dish array (see e.g. [15]). The first telescope was installed in March 2014 with a planned completion by 2017. The development of KAT-7/MeerKAT opens new possibilities for observing fainter radio sources, which may increase the number of candidate sources which can be investigated.

## 5. Initial results

*5.1. Classification of AGU within the 2LAC catalogue*

The Fermi/2LAC catalogue contains 886 identified sources in the "clean sample", classified as extragalactic due to their location $10°$ above the galactic plane, of which 157 had no clear classification ("AGU" sources) [5]. Follow-up observations reported by, for example [16], have classified a number of these sources, but a large number remain unclassified. We have begun a processes to identify sources we wish to follow-up with South African telescopes from this sample. This is an extension of previous work undertaken to identify the unknown sources included within the 3rd EGRET catalogue by [17, 18], where 13 candidate sources were investigated. The main aim is to search for sources which could be TeV emitters. Furthermore, only (in general) bright radio sources ($> 100$ mJy) were selected to allow us to undertake radio observations with the HartRAO 26-m telescope. Follow-up optical spectroscopic observations were undertaken with the SAAO 1.9-m telescopes for two weeks during during the end of May 2014. Preliminary analysis shows, mainly featureless spectra as expected from blazars. This is an ongoing analysis and higher signal to noise observations are proposed for SALT. Please see [19] for a detailed discussion.

Long term observations of the blazar candidates identified as part of this project are being undertaken with the Watcher Telescope, to search for variability. In addition, observations to search for short term variability with SHOC on the SAAO 1.9-m telescope have been submitted.

## 6. Observations of known VHE sources

In addition to the campaign to investigate new VHE candidates we have also undertaken observations of known VHE sources. Two such campaigns are briefly mentioned below.

*6.1. Optical monitoring of Blazars candidates with Watcher*

The Watcher Robotic Telescope has been used as part of monitoring of campaigns of blazars and blazar candidates. Optical monitoring of the BL Lac 1ES 0229+200 was undertaken with the Watcher Robotic Telescope during October 2013 as part of a multi-wavelength campaign which coincided with NuSTAR and H.E.S.S. observations. Further observations were undertaken with the Boyden 1.5-m telescope, but the low altitude of the source made observations difficult as the telescope was very near its visibility limits.

### 6.2. PSR B1259-63

We have undertaken optical spectroscopic observations of the $\gamma$-ray binary system PSR B1259-63 during April-June with SALT and the SAAO 1.9-m telescope around the time the system went through periastron. This binary star system consists of a Be star and 48 ms radio pulsar and has been detected at TeV energies during previous periastron passages by H.E.S.S. (see e.g. [20]). The optical results may have important consequences as this can be used as an indication of the size and strength of the Be stars circumstellar disc. The disc will influence the shock which forms between the pulsar and stellar winds which is believed to be the production site of the non-thermal emission. The disc is known to vary around periastron and a disruption of the disc will influence the bow shock which will in turn influence the non-thermal emission. Variations in the optical spectrum have previously been reported by [21] who also suggested that the change in the disc mass may be responsible for the GeV flare report during 2011 [22].

## 7. Conclusion

South Africa is well placed to offer multi-wavelength support to complement TeV observations, in particular the H.E.S.S. $\gamma$-ray telescope located in Namibia and potentially CTA. Such multi-wavelength observations have already been undertaken. Here we briefly presented our on-going project to identify potential TeV emitting sources among the Fermi/2LAC catalogue as well as ongoing observations focussed on optical observations of known TeV sources. We have identified a subset of *Fermi* 2LAC AGU for which multi-wavelength SED are being constructed and optical spectroscopic and photometric observations are being undertaken, using the SAAO 1.9-m, SALT and Watcher Robotic Telescopes. Preliminary redshift distance have been established for 4 of these sources [19]. Further follow-up observations are planned.

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