

Optical SETI with Imaging Cherenkov Telescopes

J. Holder^a, P. Ashworth^a, S. LeBohec^b, H.J. Rose^a and T.C. Weekes^c

(a) *School of Physics and Astronomy, University of Leeds, UK*

(b) *Dept. of Physics, University of Utah, USA*

(c) *Harvard-Smithsonian Center for Astrophysics, USA*

Presenter: J. Holder (jh@ast.leeds.ac.uk), uki-holder-J-abs3-og27-poster

The idea of searching for optical signals from extraterrestrial civilizations has become increasingly popular over the last five years, with dedicated projects at a number of observatories. The method relies on the detection of a brief (\sim few ns), intense light pulse with fast photon detectors. Ground-based gamma-ray telescopes such as the Whipple 10m, providing a large mirror area and equipped with an array of photomultiplier tubes (PMTs), are ideal instruments for this kind of observation if the background of cosmic-ray events can be rejected. We report here on a method for searching for optical SETI pulses, using background discrimination techniques based on the image shape.

1. Introduction

Schwartz and Townes [1] were the first to suggest the idea of searching for optical wavelength signals from extraterrestrial civilizations. The idea received little attention, with SETI projects choosing instead to focus on radio searches. Advances in laser technology have encouraged a re-evaluation of the potential of optical techniques for SETI. The most promising method is to search for intense pulses of optical photons from candidate star systems: Howard et al. [2] recently noted that, using current technology (10m reflectors as the transmitting and receiving apertures and a 3.7 MJ pulsed laser source), a 3 ns optical pulse could be produced which would be detectable at a distance of 1000 ly, outshining starlight from the host system by a factor of 10^4 .

A number of dedicated projects attempting to detect such a signal are now operating [2, 3, 4]. Typically, these consist of a \sim 1 m diameter reflector which is used to observe candidate stars. The collected photons are sent to a beam-splitter which redirects the signal to \sim 2 – 3 fast photo-detectors. The output pulse of the photo-detectors is passed to discriminators, and the signal is recorded if all discriminators trigger within a short time coincidence window. Howard et al. [2] recently published the results of a survey of 6176 stars made over five years with the 1.6 m Wyeth telescope at the Harvard/Smithsonian Oak Ridge observatory. They were sensitive to pulses with intensities greater than \sim 100 photons m^{-2} .

While diffraction limited resolution would be necessary for any potential transmitter in order to keep the beam width small, the optical properties of the receiver are less critical. Essentially all that is required is a large 'light bucket' with which to collect as many photons as possible, and fast photo-detectors in order to discriminate the pulsed signal from the steady background starlight and night-sky light. Similar requirements exist for ground-based gamma-ray telescopes. Covault [5] has suggested using the STACEE gamma-ray telescope for optical SETI studies. STACEE provides a mirror area of 2370 m^{-2} , enabling the detection of pulses down to 2 photons m^{-2} ; however, optical SETI observations would require a dedicated observing mode, and the discrimination of SETI signals from cosmic-ray signals is not trivial for this type of experiment. Eichler and Beskin [6] have also considered the use of ground-based gamma-ray telescopes for OSETI and note the importance of their relatively large fields-of-view and the use of more than one telescope for coincidence-based rejection techniques. Finally, the MAGIC collaboration have implemented a scheme to monitor for OSETI pulses at the hardware trigger level [7]. In this paper we present an analysis method for searching for optical pulses in archival data taken with the Whipple 10m ground-based gamma-ray telescope.

2. The Whipple 10m Telescope as an OSETI Detector

Imaging atmospheric Cherenkov telescopes use arrays of hundreds of PMTs to record the shape and orientation of the Cherenkov image in the focal plane due to particle showers in the atmosphere. Since 2000, the Whipple telescope has been equipped with a high resolution imaging camera of 379 PMTs with 0.12° spacing, giving a field of view of diameter 2.5° . The PMT camera is covered by light collecting cones which remove the dead area between PMTs. The telescope has a total mirror area of 90 m^2 , mounted on an altitude-azimuth positioner.

An optical laser pulse coming from the direction of a candidate star will appear as a point source in the camera of the Whipple telescope. If the optics of the telescope were perfect, such a signal would never trigger the telescope readout, since the photons would all fall within one PMT and the 3-PMT multiplicity trigger condition would never be satisfied; however, the optical requirements for Cherenkov telescopes are not strict, and the point spread function (PSF) for the Whipple telescope is comparable to the PMT spacing. We have performed a detailed simulation of the telescope response to point source light pulses, including a complete simulation of the telescope optics and the electronics chain [8]. Figure 1 shows the trigger efficiency as a function of pulse size for two values of the PSF and for two locations of the pulse in the field-of-view; one at the centre of the central PMT (corresponding to the worst case triggering scenario), the other offset to a position equidistant from three PMTs close to the centre (best case). The system has a trigger efficiency $> 80\%$ for all cases for pulses of $\sim 10 \text{ ph m}^{-2}$, implying a sensitivity a factor of 10 greater than that of the Harvard detector.

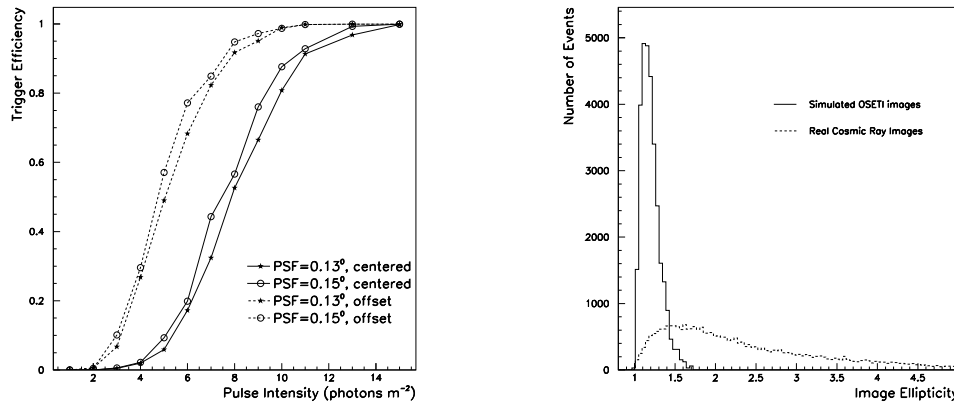


Figure 1. Left: The simulated trigger efficiency as a function of pulse intensity. The simulations were run for two values of the telescope point spread function; 0.13° and 0.15° . See text for details. **Right:** The distributions of *ellipticity* for simulated OSETI images and for real cosmic-ray data. The OSETI images were generated with an intensity of 20 ph m^{-2} .

3. Analysis and Simulations

The Whipple telescope is clearly able to trigger on low intensity, point-source optical pulses; however, to provide a useful measurement we must also be able to discriminate these pulses from the overwhelming background of cosmic ray images. The image shape and orientation provide powerful discrimination against cosmic rays for gamma-ray astronomy, and the same techniques can be used to select point-source optical flashes. PMTs which contain a signal above a threshold are selected, and the resulting image is parameterized with an ellipse; the parameters of the ellipse (*length*, *width*, etc.) can then be used to identify candidate events.

The image of a point source optical flash in the camera will be bright, compact, symmetrical and co-located with the position of a candidate star, as illustrated by the simulated OSETI flash shown in Figure 2. Figure 1 shows the *ellipticity* ($length/width$) of simulated OSETI flashes at the centre of the camera, compared to the *ellipticity* of cosmic rays for real data. Clearly, the OSETI images are more symmetrical than the majority of the background events; cutting events with ellipticity > 1.5 reduces the background by 81%, while retaining 97.5% of the OSETI images. Close to the edge of the camera many cosmic-ray images become highly elliptical due to truncation. We therefore restrict the field of view to images with an angular *distance* from the camera centre less than 1° .

The most distinctive property of the OSETI flashes is their compactness. We define the radius of the ellipse, $R = \sqrt{width^2 + length^2}$. Figure 3 shows R as a function of the *sum* over all the charge in the image for cosmic rays and for OSETI flashes simulated over a range of intensities, with the *ellipticity* and *distance* cuts applied. Bright OSETI flashes can be clearly discriminated from the cosmic ray background; if we select those events below and right of the line shown, only one of the original 30900 cosmic-ray events remains.

The discrimination provided by the *ellipticity*, *distance* and R vs *sum* cuts is good; however, the signal strength is completely unknown and may consist of just one flash. Further discrimination is possible if we assume a candidate source position, such as the location of a star in the field of view. The statistical error on the centroid position of the image is small; $\sim 0.01^\circ$ for flash intensities of $> 10 \text{ ph m}^{-2}$; however the tracking errors of the telescope add a systematic error of $\sim 0.05^\circ$. Selecting events which originate from within 0.05° of a stellar candidate reduces the remaining background by a factor of ~ 400 .

As an example, we have made a targeted observation of one star, HIP 107395, which was identified by Howard et al. [2] as their best candidate for an OSETI pulse. The 28 minute observation was made on November 12th 2004 beginning at 02:21 UTC. The right-hand side of figure 3 shows the result. Only 5 events remain after the selection cuts on *distance*, *ellipticity* and image location. No events pass these cuts and satisfy the R vs *sum* selection, hence we have no evidence for optical SETI signals from this candidate star during the observation, down to a sensitivity limit of 10 ph m^{-2} .

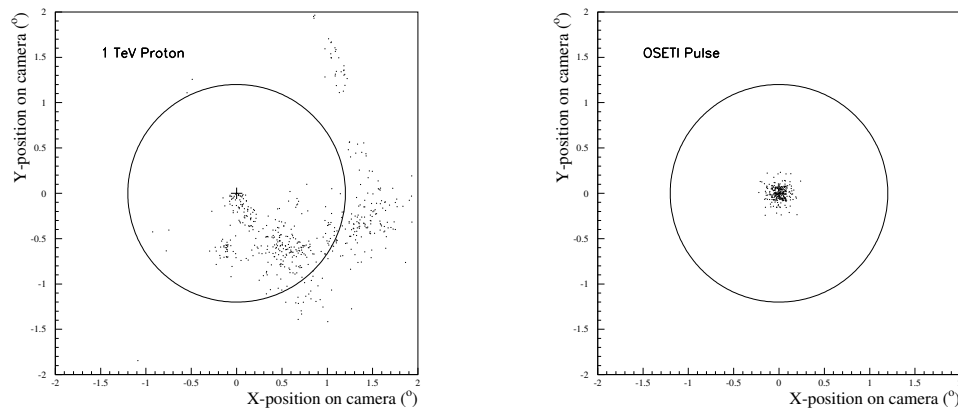


Figure 2. Photon positions in the focal plane for a simulated 1 TeV proton cascade (left) and a point source laser flash with the source at the centre of the field-of-view (right). The large circle shows the extent of the Whipple 10m camera.

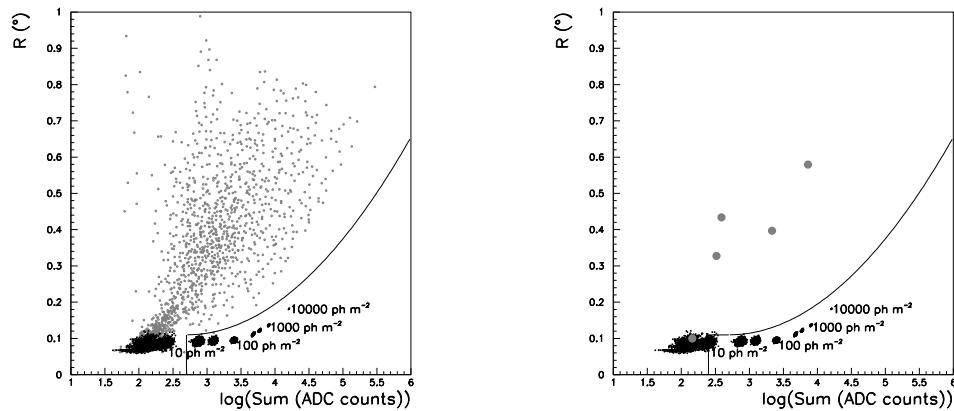


Figure 3. Left: The image radius, R , as a function of the image charge /textitsum for simulated OSETI flashes (black points) and background cosmic rays (grey circles). The OSETI flash intensities at the telescope are indicated. The line describes the selection criteria for OSETI images (see text). **Right:** The same for observations of HIP 107395, keeping only events from within 0.05° of the source location at the centre of the camera.

4. Conclusions

We have demonstrated that it is possible to search for optical SETI pulses using atmospheric Cherenkov telescopes with a sensitivity an order of magnitude better than dedicated experiments. While optical SETI observations are unlikely to form a major part of the observing schedule for these instruments, the large fields of view (from 2.5 to 5.0°) ensure that candidate stars are visible during gamma-ray observations. The Whipple telescope has been operating with an imaging camera for > 10 years. A search of this archive for OSETI pulses is currently underway. Other Cherenkov experiments also have large data archives which could be analysed similarly. The next generation of instruments (VERITAS, HESS, MAGIC, CANGAROO III) provide a further increase in sensitivity, and background rejection. Finally, we note that gamma-ray observations are not generally made when the moon is visible to avoid damage to the PMTs. Targeted optical SETI observations could be made during moontime with reduced sensitivity, increasing the scientific output from these instruments.

5. Acknowledgements

This research is supported by grants from the U.S. Department of Energy, the National Science Foundation, the Smithsonian Institution, by NSERC in Canada, Science Foundation Ireland and by PPARC in the UK. We thank the VERITAS Collaboration for the use of their dataset.

References

- [1] Schwartz, R. and Townes 1961 Nature 190, 205
- [2] Howard, A. W. et al. 2004 Ap. J., 613, 1270.
- [3] Lampton, M. 2000, in ASP Conf.Ser.213:Bioastronomy 99, 565
- [4] Wright, S. A. et al., 2001, in Proc. SPIE Vol. 4273, SETI in the Optical Spectrum III, 173
- [5] Covault, C. et al., 2001, in Proc. SPIE Vol. 4273, SETI in the Optical Spectrum III, 28
- [6] Eichler, D. & Beskin, G. 2001, Astrobiology, 1, 489
- [7] Armada, A., Cortina, C., Martinez, M. 2004, Proc. of the 14th Int. School of Cosmic Ray Astrophysics
- [8] Duke, C. & LeBohec, S., <http://www.physics.utah.edu/gammaray/GrISU>