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# The BVIT: from Flare Stars to the Search for ET

INVITED TALK

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**Abstract.** The Berkeley Visible Image Tube (BVIT) has been a user instrument on the SALT 10-m telescope for the past six years. It can observe transient astrophysical phenomena occurring on time-scales of micro-seconds. This overview presented some recent observations of a dMe flare star, and discussed the recent results of our optical Search for Extraterrestrial Intelligence (OSETI) around nearby exoplanet-hosting stars.

**Keywords.** Stars: Flares, extraterrestrial intelligence: optical SETI.

## 1. Introduction

The Berkeley Visible Image Tube (BVIT) is a photon counting detector system operating at visible wavelengths ($\lambda$ 4000–7000Å), and has been a general user instrument attached to the 10-m Southern African Large Telescope (SALT) since 2011. Its operational characteristics can be found in Siegmund *et al.* (2008). At its core is a 25mm-diameter micro-channel plate sealed tube detector, whose SuperGen-2 photocathode converts incident visible photons into photoelectrons that are amplified by gains of up to $10^8$. The resultant charge cloud is accelerated onto a delay-line anode which enables an X, Y position and arrival time to be recorded. Similar detection schemes have been flown on the NASA *GALEX* and *HST*-COS space missions. The BVIT has been used to observe a wide range of astrophysical sources that are thought to have variable emission in sub-second time-frame, such as dMe flare stars (Welsh *et al.* 2012), soft X-ray transients (Pahari *et al.* 2017), ZZ Ceti stars (Kilkenny, *et al.* 2014) and cataclysmic variables (Potter *et al.* 2011).

This short review presented results from high time-resolution observations of dMe flare stars, and from the search for extraterrestrial intelligence on exoplanets in orbit around three nearby stars.

## 2. BVIT Observations of the dMe flare star CN Leo

M-type stars represent ~70% of all known stars in our Galaxy. The dMe dwarfs are magnetically active, so we can compare their flare activity with that of our Sun. Observations of such stellar flares recorded at high time-resolution can provide information on the time-scales of magnetic energy release into the corona, which can then be compared to current reconnection and particle acceleration models involving radiative hydro-dynamical considerations (RHD). An interesting by-product of such observations is the following: if these stars harbour exoplanetary systems, could they support life in such a seemingly harsh environment in which their orbits are tidally locked? Furthermore,

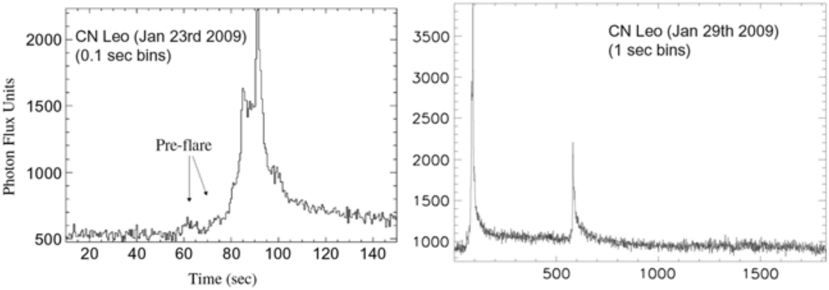

**Figure 1.** BVIT observations of flares on CN Leo on 2009 January 23 and 29.

if their surfaces are irradiated intermittently by harsh UV radiation, could it be of such intensity that they could lose any associated atmospheric gas?

dMe flares are separated broadly into three distinct types of shape, size and duration. G-type ('gradual') flares rise slowly in intensity with a typical duration of hours, I-type ('impulsive') flares rise and fall in intensity very quickly with typical durations of minutes, and T-type ('traditional') flares generally rise quickly in intensity and then fade gradually for hours to their pre-flare intensities. These three flare types detected in EQ Peg are shown in figure 1 of Kowalski *et al.* (2011); the observations were recorded with the ULTRACAM photometer. Fig. 1 of the present paper shows BVIT observations (on the 10-m SALT) of the dM6e flare star CN Leo, recorded through a B-band filter on two separate nights in 2009 January. The flare recorded on January 23 was a very fast, large-amplitude I-type flare with a rise-time to FWHM of only 3 seconds; the emission stayed elevated by 5% compared to its pre-flare continuum level for at least 50 seconds after the flare event. Such post-flare emission could come from Balmer emission lines. On 2009 January 29 we were fortunate to record a double flare on CN Leo: one of type I, the other of type T.

The I-type flare was one of the most impulsive moderate-energy flares ever observed (Kowalski, private communication), having an in-band flare energy of $\sim 2\times 10^{29}$ erg, which is nearly 10 times the energy of a typical flare. 35% of that energy was emitted in the impulsive phase. The enlargement of the January 23 flare (Fig. 2) suggests the presence of substructure in the flare. A best-fit to the actual flare and the remaining flux, shown in the lower part of Fig. 2, suggests the presence of a sinusoidal substructure (albeit with a significance of only $2.5\sigma$). Such substructure has been predicted by several RHD theoretical models (Kowalski *et al.* 2013).

## 3. An Optical Search for Extraterrestrial Intelligence

Over the past 50 years much effort has gone into searching for signals originating in an extraterrestrial (ET) civilization. Such searches have almost exclusively been carried out in the radio band. However, as early as the 1960s it was proposed that if an advanced ET civilization were to possess a high-powered diffraction-limited optical laser in orbit about its planet, then that could be an effective means of signalling its presence via a large-aperture telescope through spatially coherent light (Schwartz & Townes 1961). On Earth, those laser pulses would appear as fast bright flashes with a far greater photon flux than any background star (though only for very short durations like nanoseconds). Clearly the existence of such pulses is highly speculative since their origin relies on the reality of ET intelligent life-forms.

However, we have carried out a new and unique detection methodology using the BVIT on SALT to search for ET laser pulses originating on three nearby Earth-like planets.

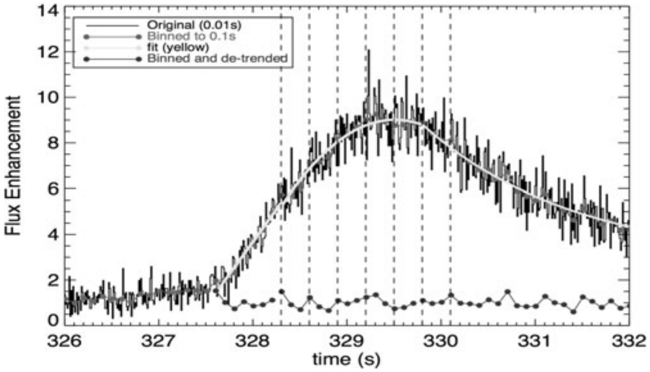

**Figure 2.** The flare of 2009 January 23 on CN Leo, showing indications of weak sinusoidal substructure after the onset of the impulsive flare.

Observations of that nature can act as a technology demonstration that could be implemented on future 30-m-class telescopes. Although several thousand exoplanets have been discovered thus far in the solar neighbourhood, the search for any bio-signatures from potential life-forms is still in its infancy. The ET signature we are currently attempting to discern is one that has a very, very low probability of occurrence in the BVIT photon-counting detector. In practice it would amount to recording a far higher count rate than one might expect from random fluctuations in the Gaussian or Poisson statistics coming from a constant source of stellar and background photons.

For a laser-generated ET signal to be detected in the optical regime, the signal must be much brighter than its parent star/galaxy but only lasting for a very short time, like a nanosecond. Natural sources of nanosecond flashes of significant optical intensity are absent in the sky, so any signal spike in that time domain is a candidate for the presence of an ET-generated signal. The BVIT micro-channel plate detector (MCP) is a photon-counting device that records the position (X,Y) and time (t) of arrival of each incident photon with a 'pulse height' corresponding to the size of the electron avalanche in the MCP. If multiple photons arrive together within a narrow time window (for example the 5-ns readout binning of the BVIT), then the pulse height will scale with the number of detector-generated photoelectrons. In order to identify ET-generated signals, we turn down the normal operating high voltage of the BVIT detector by $\sim 300$V, thereby making BVIT most sensitive to photons with a high value of pulse height. The observational key is thus to operate the BVIT at a sufficiently low voltage that photons originating from the stellar source are just still just visible at a low value of pulse-height bin (i.e., a low gain event), while photons generated by an ET source on the orbiting exoplanet would be detected at a high pulse height bin value. The operation is shown schematically in Fig. 3 for the case of a bright laboratory lamp positioned next to a He-Ne laser. In the normal high-voltage operation of the BVIT detector, the photon pulses emitted from the laser are of a pulse-height distribution that is difficult to separate from the large number of photons generated by the adjacent lamp. However, when the BVIT high voltage is decreased, a clear separation of laser-generated and lamp-generated photons is apparent. The laser-generated photons can then be isolated and examined numerically to plot both their times of arrival at the detector and their associated X,Y positions. That experiment corresponds directly to the astrophysical case of a bright parent star plus an ET laser signal originating on an exoplanet orbiting on a line-of-sight that is physically close.

For our BVIT observations we selected three K and M-type stellar candidates from the list of stars with potentially habitable exoplanets and having Earth Similarity Indices $>0.75$. The sources selected were Trappist-1, Wolf-1061 and GJ 422b. If a star with

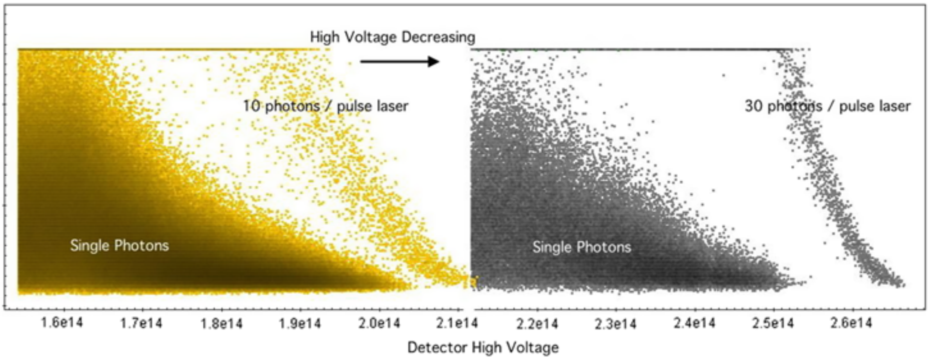

**Figure 3.** Pulse height (P.H.) distributions of photons emitted from a laboratory lamp and adjacent He-Ne laser, as a function of decreasing high voltage of the BVIT-detector.

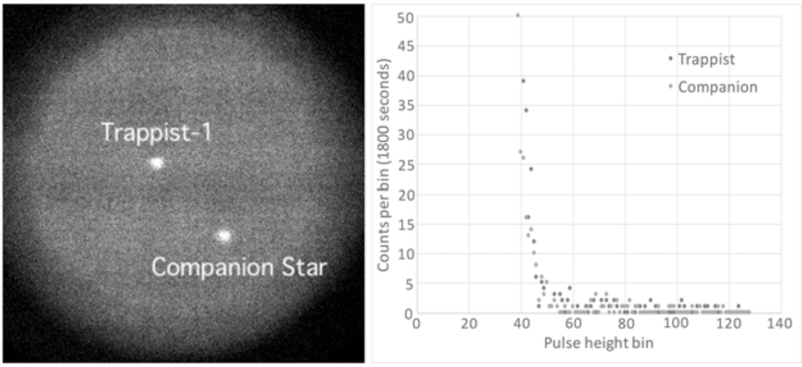

**Figure 4.** Left panel: BVIT image of the 1′.5 field of view around the star Trappist-1. Right panel: Pulse-height distribution of photon events recorded at the sky position of Trappist-1, with the BVIT-detector high-voltage reduced by 300V. Photons with pulse-height bins <60 are of stellar origin. Photons with an ET origin would have bin numbers >60.

$B = 11.0$ mag has a stellar photon count rate of ∼2.45MHz at normal detector gain, then by lowering the gain by a factor 30 we would expect to detect $1.6 \times 10^{-8}$ triggers from false alarm events originating from the star at a location X, Y on the BVIT detector over a 1000 sec integration period on the SALT 10-m telescope. Hence, any detection of significant numbers of photon events at X,Y with a high pulse-height bin would indicate a non-stellar (perhaps ET?) origin. In the left-hand plot of Fig. 4 we show the image on the BVIT detector of a 1′.5 field of view around the star Trappist-1, which has at least 7 known exoplanets. The field also contains a comparison star (of similar visual magnitude) which was used to test whether any photons recorded within the Trappist-1 image during two 1800-sec observations on 2017 July 22 were of stellar or ET origin, as determined by their pulse-height bin recorded at a lowered high voltage on the BVIT detector.

In our observations the number of photon events >6 photoelectrons (>bin 60) numbered 35, as opposed to 40 events predicted by our non-optical background rate based on cosmic rays and natural radioactivity in the MCPs. The comparison star showed 29 measured events as opposed to 31 predicted by background considerations. We could therefore conclude that our observations of Trappist-1 resulted in a non-detection of ET signals and they were consistent with the number of background radiation events. Similar results were found for observations of both the Wolf-1061 and GJ 422b exoplanet systems. These null results indicate that if ET had a diffraction-limited 10-m telescope in orbit around Trappist-1 and it had a 5-ns pulsed laser pointed at the Earth, then the associated laser-pulse energy must be <700 joules per pulse. Lasers of this power are presently easily obtainable by several manufacturers on Earth. Our future observational goal is to observe exoplanets whose orbital planes are pointed more directly towards Earth, thus improving the detection limits of ET-generated photons.

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