An AGN or a Be star as possible counterparts of 3FGL J0133.3+5930

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Abstract

We present recent results from our program for cross-identification of unassociated gamma-ray sources at low galactic latitudes. The main motivation for this work is the search for new members of the scarce class of gamma-ray binaries and microquasars. Here we report the case of the *Fermi* LAT source 3FGL J0133.3+5930. Two peculiar objects have been found inside the 95% confidence contour of this unassociated gamma-ray source. One of them is the optically bright Be star **TYC 3683-985-1, also** consistent with the *ROSAT* X-ray source 1RXS J013326.9+592946. In this work, we have discovered it to be a new eclipsing binary system. The other is the *Swift* X-ray source **SWIFT J0132.9+ 5932** whose radio, infrared and optical counterpart are still under study. Based on the observational evidence available, SWIFT J0132.9+ 5932 stands as the most likely counterpart to 3FGL J0133.3+5930. Although its spectral energy distribution appears to be consistent with a stellar system, a possible Active Galactic Nuclei nature cannot be yet ruled out.

The unassociated source 3FGL J0133.3+5930

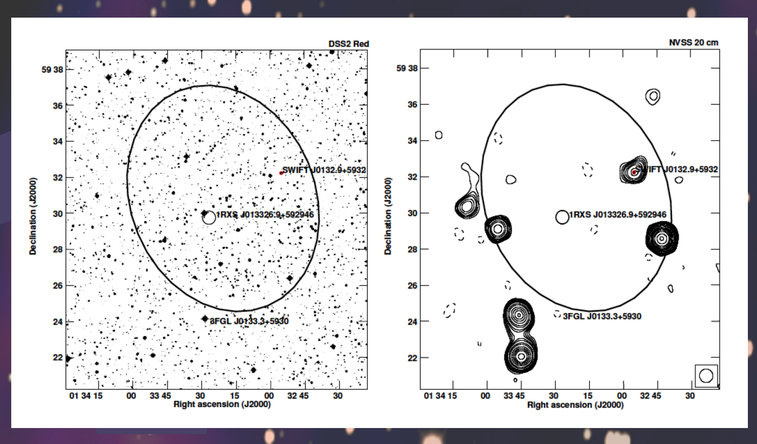

Figure 1. The 3FGL J0133.3+5939 field of view. The ellipse marks the 95% confidence region for the gamma-ray source location.

This gamma-ray source is included in the 3rd catalogue of the Large Area Telescope (LAT) on board NASA's *Fermi* Gamma-ray Space Telescope. Located at a galactic latitud of about -3º, it remains unidentified at lower energies. Fig. 1 displays the corresponding field of view at optical and radio wavelengths from the 2nd Digitized Sky Survey (red plate, McLean et al. 2000) and the NRAO VLA Sky Survey (NVSS, Condon et al. 1998), respectively. The *Fermi* LAT 95% confidence ellipse remarkably contains the Be star TYC 3683-985-1, whose position additionally matches that of the *ROSAT* X-ray source 1RXS J013326.9+592946. The region has been also covered during the *Swift* survey of *Fermi* unassociated sources (Stroh & Falcone, 2013), revealing the existence of another X-ray source undetected by *ROSAT*, namely SWIFT J0132.9+ 5932. Inspection of archival data shows that this 2nd X-ray emitter is also consistent with the radio source NVSS J013255+593217. Moreover, the *Swift* position (90% confidence radius 15") points to 2MASS 01325529+5932158 as its likely infrared counterpart in the Two Micron All Sky Survey (2MASS, Cutri et al. 2012). In the following we present more in detail the observational properties of both the Be star and the *Swift* X-ray source.

The discovery of TYC 3683-985-1 as a new eclipsging binary

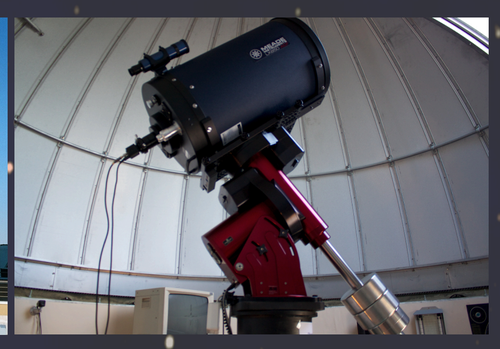

Figure. 2. Views of the Astronomical Observatory in the UJA campus.

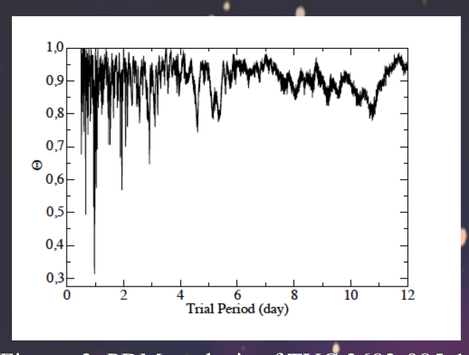

Figure. 3. PDM analysis of TYC 3683-985-1 photometry in the *V*-band showing a clear minimum at 0.9701 ±0.0003 d, i.e., half the orbital period.

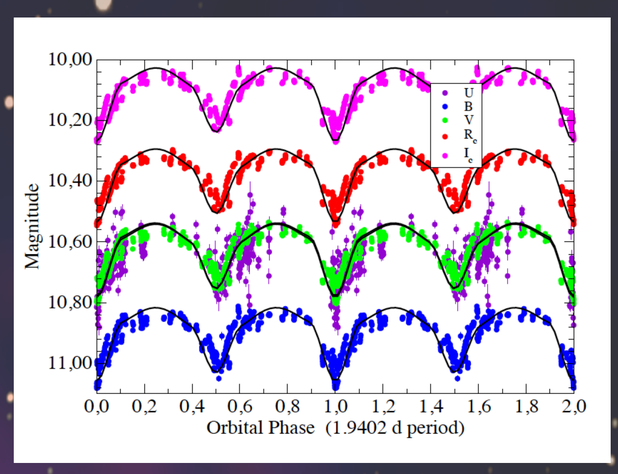

Figure 4. Results of multi-color photometry of TYC 3683-985-1 with the UJA telescope and the PHOEBE model fits overplotted. HJD 2457378.306 has been adopted as phase origin.

We first focused our attention on the bright (V≈10.7)Be star TYC 3683-985-1, suspected to be a possible gamma-ray binary. This star was orignally classified as of B1/2Vnne spectral type by McCuskey et al. (1974). An intensive campaign (45 nights) of UBVR$_c$I$_c$ CCD photometry was carried out using the new 41 cm telescope in the University of Jaén (UJA) observatory (see Fig. 2). Despite being located in a light polluted urban area, this educational instrument performed remarkably well, and allowed us to discover a clear photometric period of 0.9701±0.0003 d. This value was soon interpreted as half an orbital cycle. The Phase Dispersion Minimization (PDM) analysis is shown in Fig. 3. The light curves, folded according to an orbital period of 1.9402±0.0006 d and modelled using the PHOEBE software package (Prša & Zwitter 2005), are presented in Fig. 4. Stellar shapes at orbtial phase 0.25 and physical parameters obtained are displayed in Fig. 4 and Table 1, respectively. The fact that the light curves are consistent with TYC 3683-985-1 hosting two non-degenerated early-type stars renders now difficult to attribute it the origin of gamma-rays. At this point, we turned back out attention towards the other peculiar object inside the *Fermi* LAT ellipse.

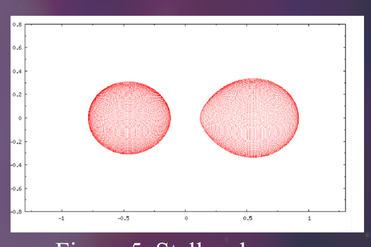

Figure 5. Stellar shapes. Secondary star fills its Roche lobe.

Parameter	Value	Comments
Eccentricity	$e = 0.000$	fixed
Semi-major axis	$a = 13.1 \pm 0.4\ R_\odot$	
Mass ratio	$\frac{M_2}{M_1} = 0.845 \pm 0.004$	
Inclination	$i = 65.9 \pm 0.1°$	
Primary effective temperature	$T_1 = 19000 \pm 500$ K	
Secondary effective temperature	$T_2 = 21000 \pm 600$ K	
Primary star surface potential	$\Omega_1 = 4.1 \pm 0.1$	(a)
Secondary star surface potential	$\Omega_2 = 3.55 \pm 0.05$	(a)
Potential value at the Inner Lagrangian point	$\Omega_{L_1} = 3.49$	computed
Potential value at the 2nd Lagrangian point	$\Omega_{L_2} = 3.02$	computed

(a) Kopal modified potential as defined in Kopal (1959).

Table 1. PHOEBE fit.

SWIFT J0132.9+5932: gamma-ray binary or AGN?

SWIFT J0132.9+5932, likely associated with NVSS J013255+593217, stands out as our favourite counterpart candidate to 3FGL J0133.3+5930. Analysis of X-ray archives shows that it is a highly variable source on time scales of weeks and years. With a photon index Γ=2.5±0.5, it is seen across a $N_H = (6.7 \pm 2.2) \times 10^{21}$ cm^{-2} column density. Only a K_s=14.0 near infraed source, 2MASS 01325529+5932158, is consistent with the few-arcsec accurate *SWIFT* position. This source is also visible at optical wavelengths (*R*=17.0) as illustrated in Fig. 6. A service time proposal for optical spectroscopy using the NOT telescope and its ALFOSC instrument has been recently accepted. Meanwhile, we can only infer conclusions from the spectral energy distribution (SED). A stellar or extragalactic nature remains yet to be established, although a B-type star template appears to better fit the observed SED (see Fig. 7). This fact supports a more likely gamma-ray binary interpretation, but an extragalactic origin cannot be strictly ruled out at present. In any case, we are confident to be narrowing on the right suspect because of the non-thermal nature of the NVSS radio source. SWIFT J0132.9+ 5932 is the only object displaying all these peculiarities inside the 95% confidence ellipse provided by the *Fermi* LAT.

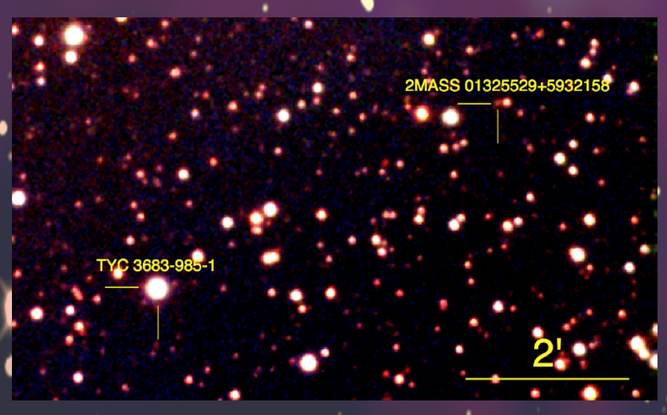

Figure 6. Deep image of the 2MASS 01325529+5932158 and TYC 3683-95-1 field as observed with the UJA telescope at optical wavelengths. North is up and East is left.

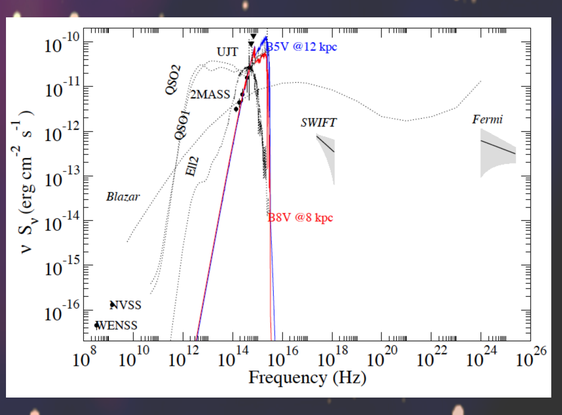

Figure 7. De-reddened SED of the X-ray source SWIFT J0132.9+5932 tentatively compared against different spectral templates. The best fit is obtained for a B8V star at a distance of 8 kpc.

Conclusions

1) We have identified the X-ray source **SWIFT J0132.9+5932** as a promisng canditate for the origin of gamma-ray emission from the unassociated source **3FGL J0133.3+5930**. An optical, infrared and radio counterpart is also proposed. The true nature of the *SWIFT* source remains yet to be established by future spectroscopic observations in progress. Nevertheless, a stellar interpretation appears to be highly conceivable based on SED considerations.

2) In our search, we have also discovered **TYC 3683-985-1** as a new eclipsing binary of semi-detached nature hosting two early-type stars. It is remarkable that this system has been found using a small educational telescope, and that it escaped detection in modern automated surveys. The fact that its half orbital period is close to one integer sidereal day is likely the main reason that rendered it difficult to find in blind surveys with a daily sampling of the sky.

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