Counterpart candidates to unassociated γ-ray sources: the case of 3FGL J0133.3+5930

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Outline of the talk

1. Introduction

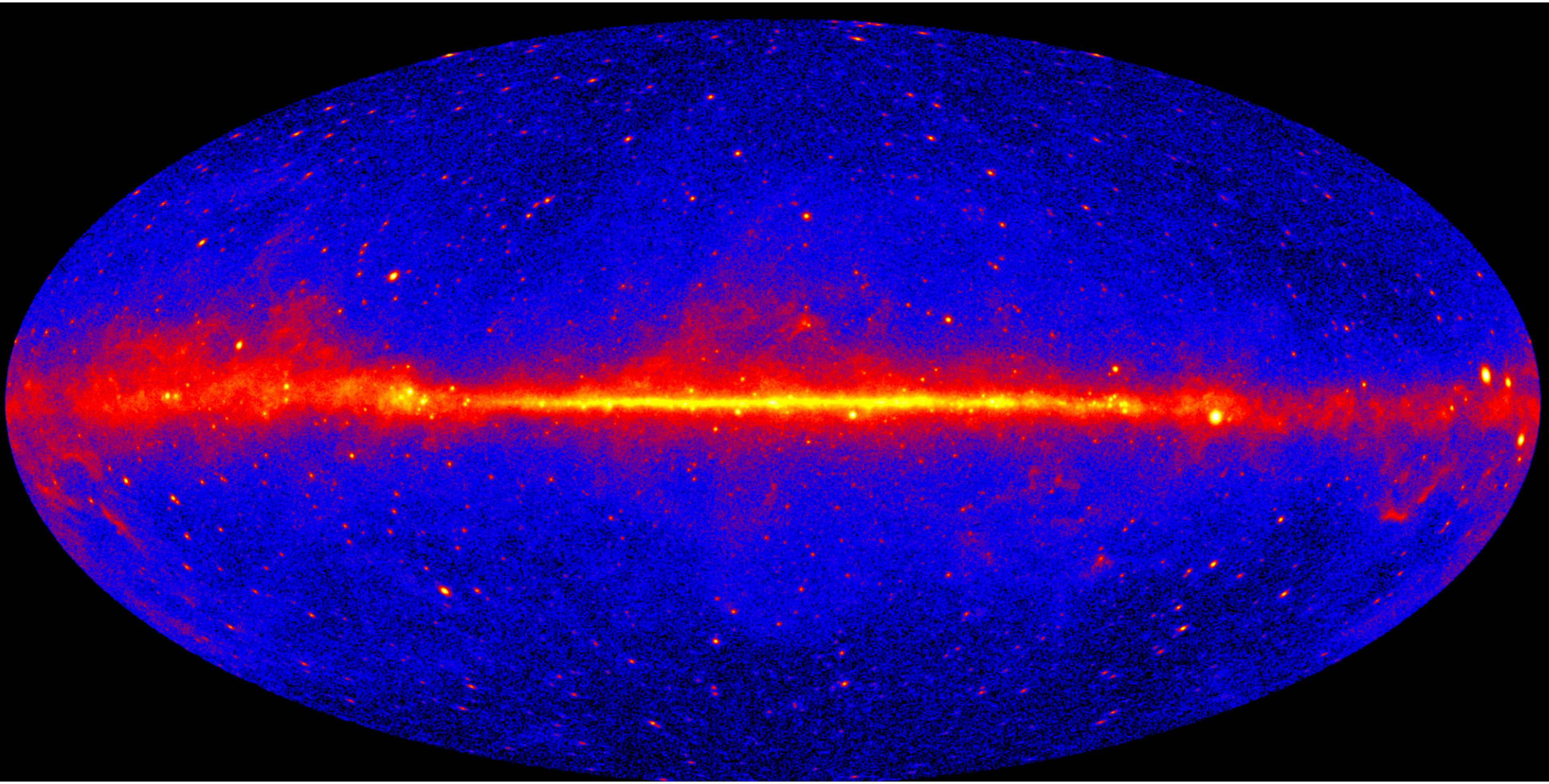
2. Our approach to the problem of unassociated gamma-ray sources

3. The case of 3FGL J0133.3+5930: gamma-ray binary or AGN?

4. Future prospects

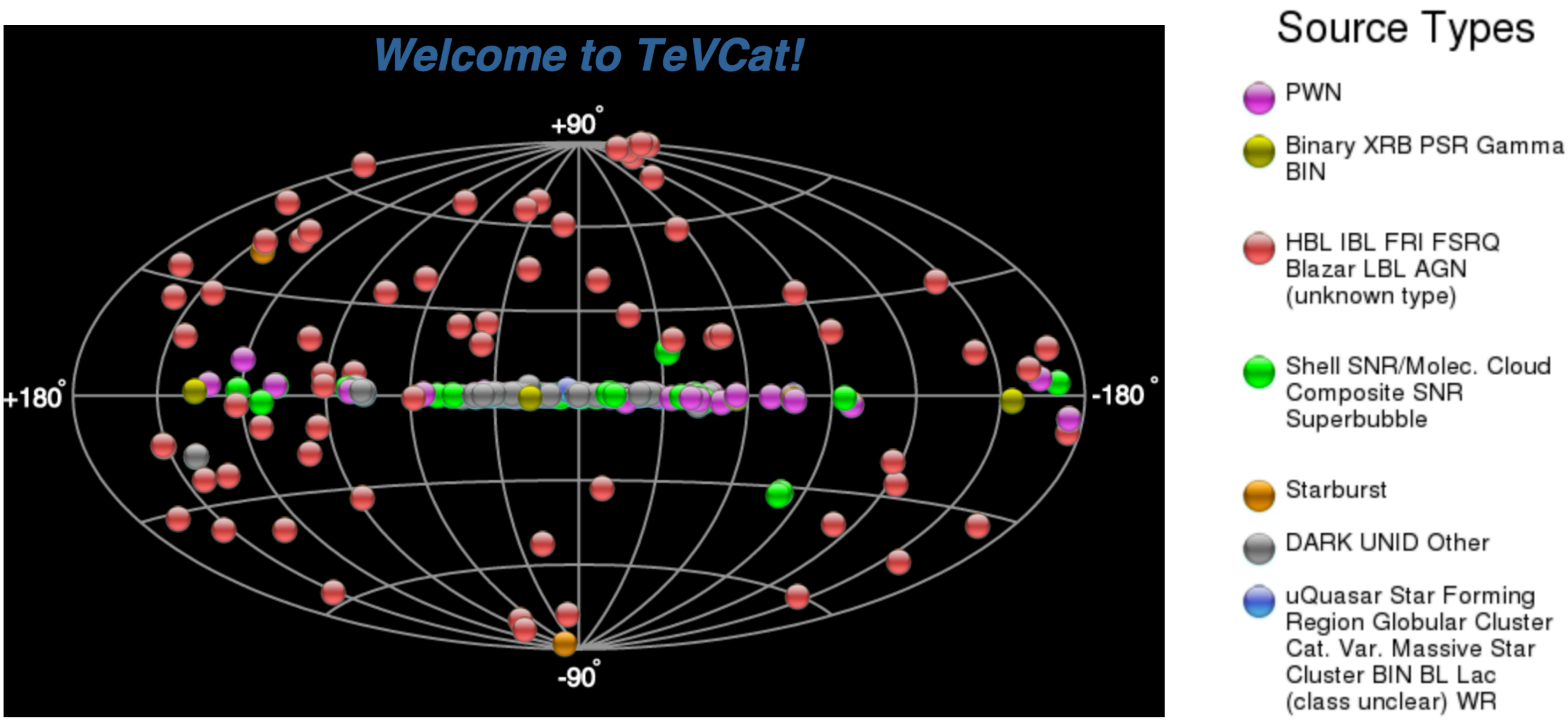
1. Introduction

http://fermi.gsfc.nasa.gov/ssc/Fermi_5_year.jpg



More than 30% of the approximately three thousand sources of GeV photons in the 3rd Fermi Large Area Telescope source catalogue (Acero et al. 2015) lack an associated counterpart at lower energies.

http://tevcat.uchicago.edu



About 20% of the TeV sources in the current version of the TeVCat catalogue also lack a lower energy counterpart.

2. Our approach to the problem of unassociated gamma-ray sources

We focus our attention on unassociated gamma-ray sources at **low galactic latitudes**. This is because they are more likely to be gamma-ray binaries and related systems (e.g. microquasars).

Not many of these stellar sources of gamma-rays are known, hence the interest of identifying new cases in order to enable statistically robust studies.

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ORIGINAL ARTICLE

In quest of non-thermal signatures in early-type stars

Josep Martí · Pedro L. Luque-Escamilla · Jorge Casares · Benito Marcote · Xavier Paredes-Fortuny · Marc Ribó · Josep M. Paredes · Jorge Núñez

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Abstract A reduced fraction of luminous, early-type stars in binaries has provided some of the most interesting sources in modern high-energy astrophysics. A fingerprint of the capability of these systems to accelerate particles up to TeV energies is the associated detection of non-thermal, synchrotron emission often in the radio domain. Here we aim to identify new early-type, luminous stars where energetic, non-thermal processes are at work to enable future comparative studies based on an extended sample. Moreover, gamma-ray observatories such as the Cherenkov Telescope Array. We have designed a methodology to search for new examples of these interesting sources in order to enlarge the extremely reduced population currently known. Our search procedure is described in this paper, together with a practical application using public databases and catalogues currently available (Luminous Stars in the Northern Milky Way, NRAO VLA Sky Survey, and Westerbork Northern Sky Survey). Optical and radio interferometric follow-up observa-

The Luminous Star (LS) catalogue pioneered by Hardrop et al. (1959)

Coordinates and identifications for Luminous Stars I
version: 15 Dec 2006, some corrections from Cameron Reed
          11 Dec 2006, slight amendments
          10 Dec 2006

source: 1959LS....C01....0H
         HARDORP J., ROHLFS K., SLETTEBAK A., and STOCK J.
         Hamburger Sternw., Warner & Swasey Obs., 1 (1959)
         Luminous stars in the Northern Milky Way. I.

position sources (column 's'):
c AC 2000.2 (1998AJ....115.1212U, I/275)
M 2MASS   (2006AJ....131.1163S, II/246)
T Tycho-2   (2000A&A...357..367H, I/259)
U UCAC2   (2004AJ....127.3043Z, I/289)

column 'r': when present, the spectrum appears strongly reddened

Name	RA (J2000)	Dec	s	Tyc2/GSC	UCAC2	HD	BD	V	spec	r	remarks
LS I +52 1	1 43 38.78	+52 53 08.8	T	3671-1086-1		10497	+52 420	6.7	A7II		NErn of 3" pair
LS I +52 2	2 13 52.70	+53 07 25.0	U	3686-1624-1	48326996	232618	+52 542	9.2	OB-e		
LS I +52 3	2 27 59.81	+52 32 57.6	T	3687-1024-1		15137	+51 579	7.9	OB		
LS I +53 1	1 46 08.59	+53 36 27.9	T	3671- 951-1		232525	+52 433	8.8	OBe		
LS I +53 2	1 49 21.10	+53 52 29.9	T	3684-1659-1		232537	+53 394	9.2	OB-		SErn of 12" pair
LS I +53 3	1 49 39.60	+53 54 52.8	T	3684- 577-1		232538	+53 395	9.1	OB-		NErn of 5" pair
LS I +53 4	2 13 51.83	+53 54 52.5	T	3686-2648-1		13544	+53 480	8.9	OB		
LS I +54 1	1 46 10.21	+54 45 33.1	T	3675-2348-1		232524	+54 373	9.3	OB-		
LS I +54 2	1 51 59.32	+55 08 50.6	T	3688-2149-1		11241	+54 396	5.5	OB-		
LS I +54 3	1 53 11.23	+55 07 24.7	T	3688-1766-1			+54 404	9.8	OB-		

Previous sucesses

Astron. Astrophys. 338, L71–L74 (1998)

ASTRONOMY
AND
ASTROPHYSICS

Letter to the Editor

The system LS 5039: a new massive radio emitting X-ray binary

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Abstract. We report the discovery of a bright and unresolved radio counterpart to the massive X-ray binary LS 5039. The optical position of this early type star is in excellent agreement with that measured in the radio. The observed spectrum is clearly of non-thermal synchrotron nature and some evidences of variability, although with moderate amplitude, have been detected at both radio and optical wavelengths. All the available data strongly support that LS 5039 is a new member in the reduced family of radio loud massive X-ray binaries.

ined the corresponding NVSS maps at the 20 cm wavelength in a search for possible radio counterparts. We find at least one interesting object in the M97 list that deserves special attention, namely LS 5039 ($l^{II} = 16\overset{\circ}{.}88$; $b^{II} = -1\overset{\circ}{.}29$).

LS 5039 has been proposed by M97 to be an X-ray binary system of the massive type with a high degree of confidence. The hardness of its X-ray spectrum is well consistent with a neutron star, or a black hole, accreting directly from the companion's wind. The unabsorbed X-ray luminosity in the 0.1–

Discovery of a High-Energy Gamma-Ray–Emitting Persistent Microquasar

Josep M. Paredes,[1]* Josep Martí,[2] Marc Ribó,[1] Maria Massi[3]

Microquasars are stellar x-ray binaries that behave as a scaled-down version of extragalactic quasars. The star LS 5039 is a new microquasar system with apparent persistent ejection of relativistic plasma at a 3-kiloparsec distance from the sun. It may also be associated with a γ-ray source discovered by the Energetic Gamma Ray Experiment Telescope (EGRET) on board the COMPTON–Gamma Ray Observatory satellite. Before the discovery of LS 5039, merely a handful of microquasars had been identified in the Galaxy, and none of them was detected in high-energy γ-rays.

The $V = 11.2$ magnitude star LS 5039 (*1*) has been recently identified as a nearby high-mass x-ray binary with spectral type O7V((f)) (*2*) and persistent radio emission (*3, 4*). Here, we report high-resolution radio observations with the Very Long Baseline Array (VLBA) and the Very Large Array (VLA) that reveal that LS 5039 is resolved into bipolar radio jets emanating from a central core.

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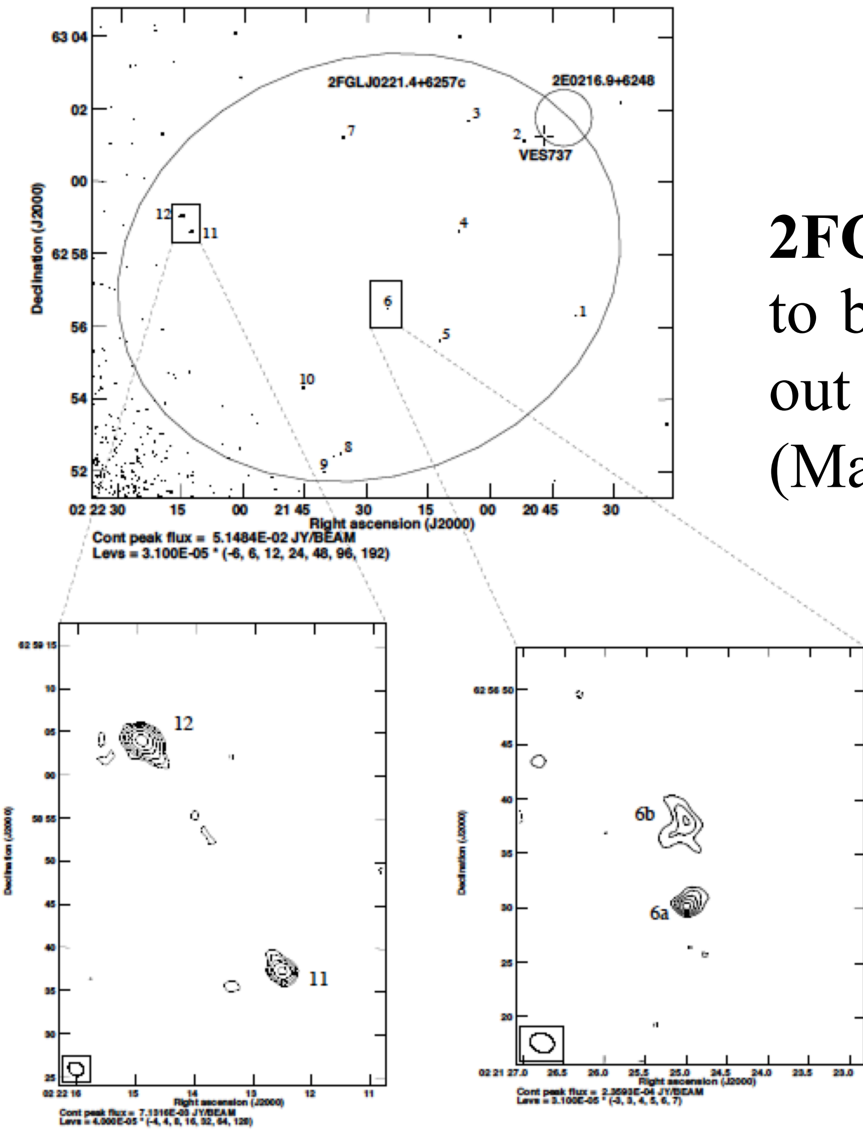
Because LS 5039 appeared unresolved (≤0.1″) to the VLA alone, we proceeded to study this object with milliarc sec resolution using the VLBA at the frequency of 5 GHz (6-cm wavelength) on 8 May 1999. The VLA in its phased array mode, equivalent to a dish of 115-m diameter, also participated as an independent station, providing sensitive baselines with the VLBA antennas. The source 3C345 was used as a fringe-finder, whereas J1733-1304 was the phasing source for the VLA. The data were calibrated using standard procedures in unconnected radio interferometry. The resulting pattern of the observed visibility amplitudes, decaying as a function of baseline length, indicated that LS 5039 had structure at milliarc sec scales.

The final synthesis map (Fig. 1) shows that bipolar jets emerge from a central core. A de-

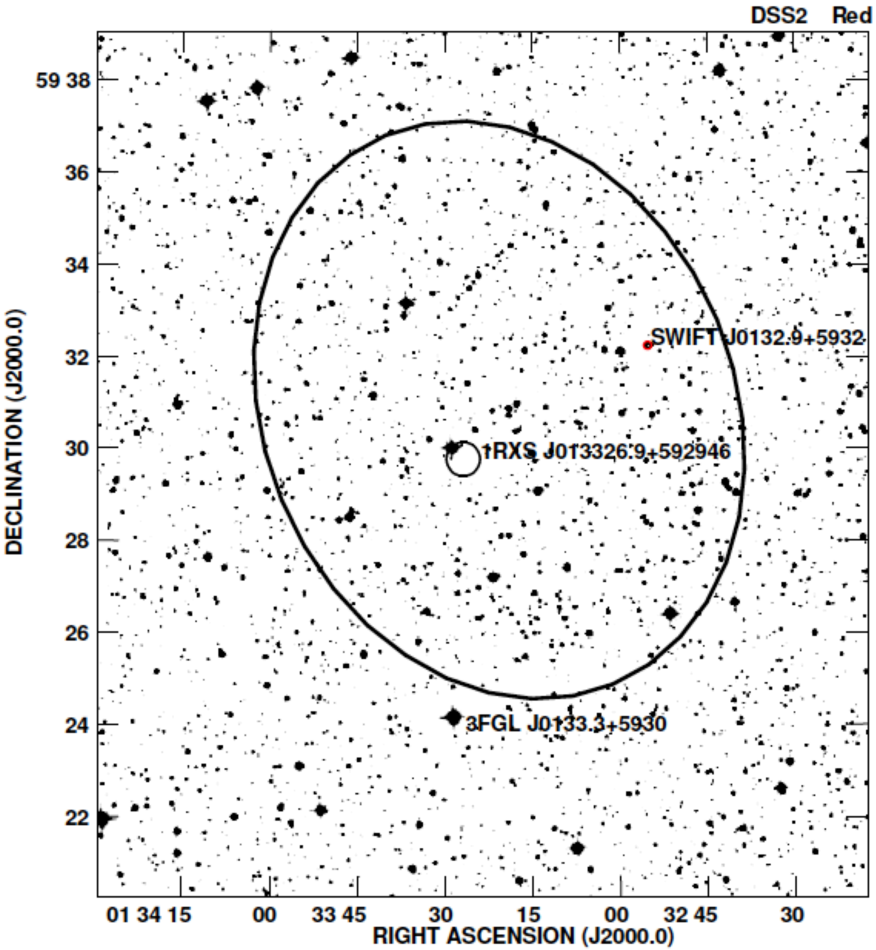
Previous "failures"

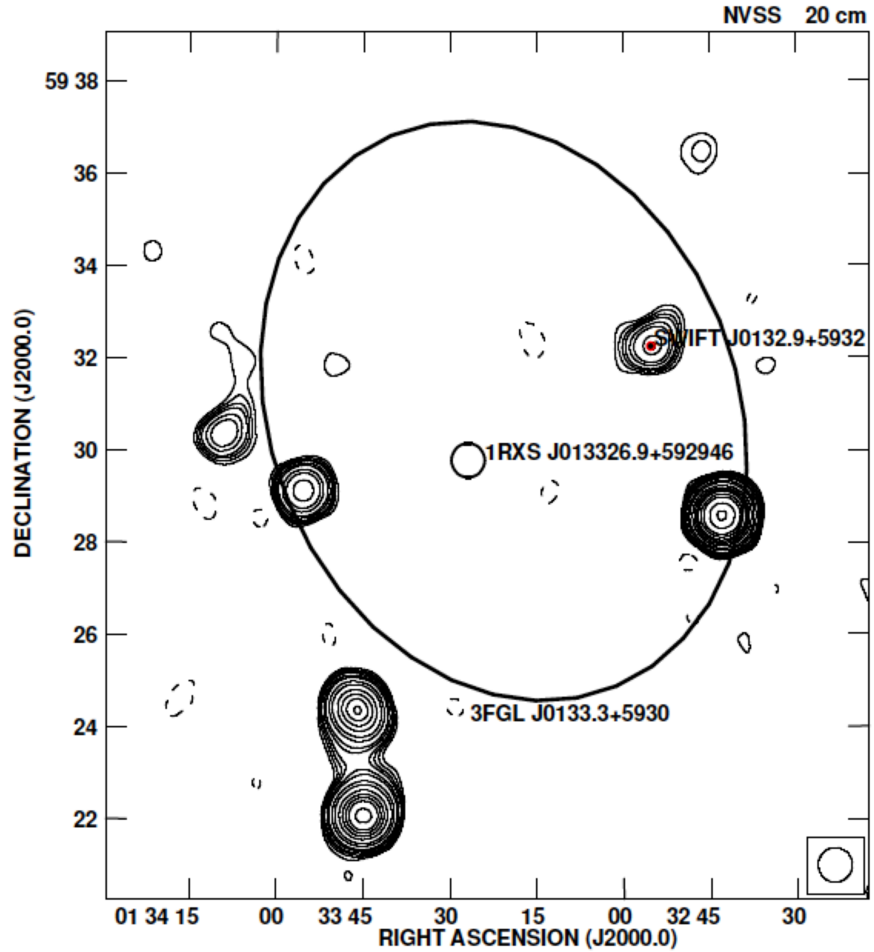


2FGL J0221.4+6257c, suspected to be a gamma-ray binary turned out to be most likely an AGN (Martí et al. 2014, BAJ, 21,3).

3. The case of 3FGL J0133.3+5930: gamma-ray binary or AGN?

The 95% confidence ellipse of the unassociated source 3FGL J0133.3+5930





Martí et al. 2016, A&A (in press) *https://arxiv.org/abs/1611.05609*

First suspicions about the peculiar nature of LS I 59 79

The Be star LS I 59 79 (a.k.a. TYC 3683-985-1) stands out inside the confidence ellipse of **3FGL J0133+5930**.

This bright star (V=10.7) is also consistent with the *ROSAT* X-ray source **1RXS J013326.9+592946**.

McCuskey et al. (1974) flagged LS I 59 79 as a possible **optical variable**!

Martí et al. 2016, A&A (in press) *https://arxiv.org/abs/1611.05609*

Confirmation of the Be nature

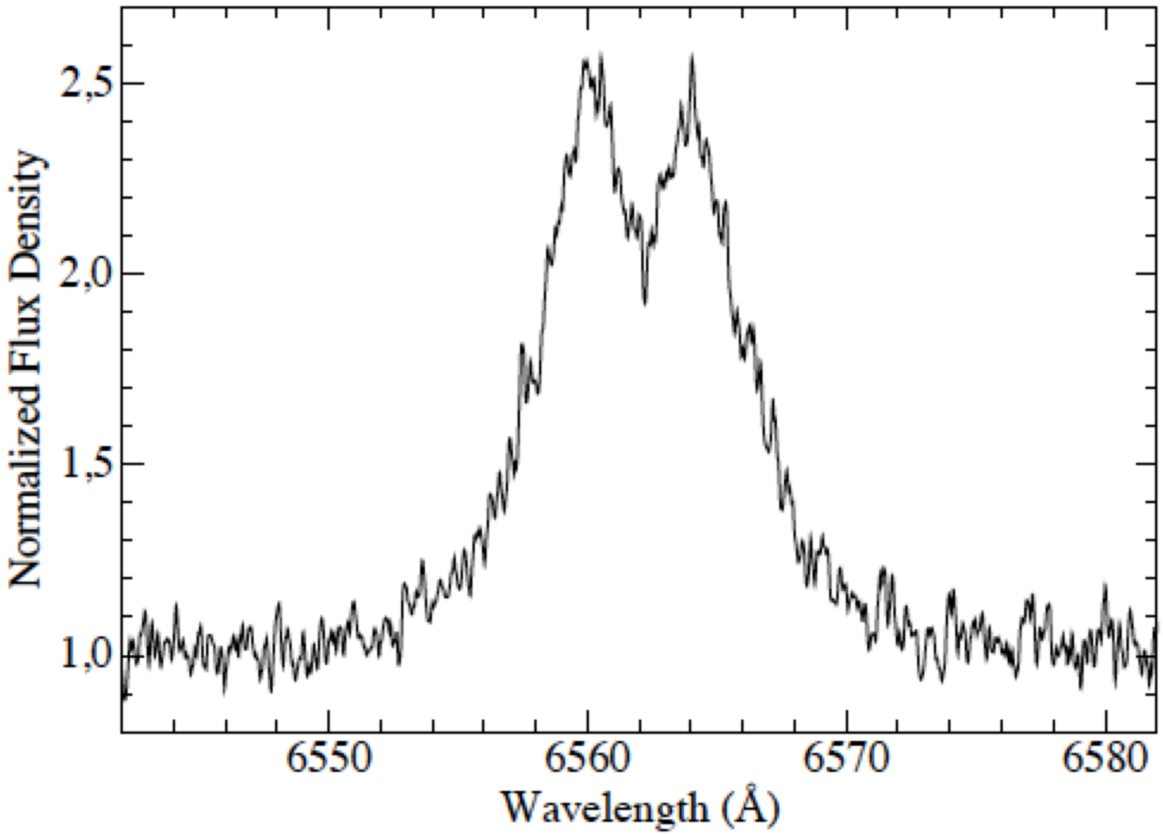


Fig. 4. Optical spectrum of TYC 3683-985-1 in the Hα region as observed with the NOT telescope and the FIES instrument.

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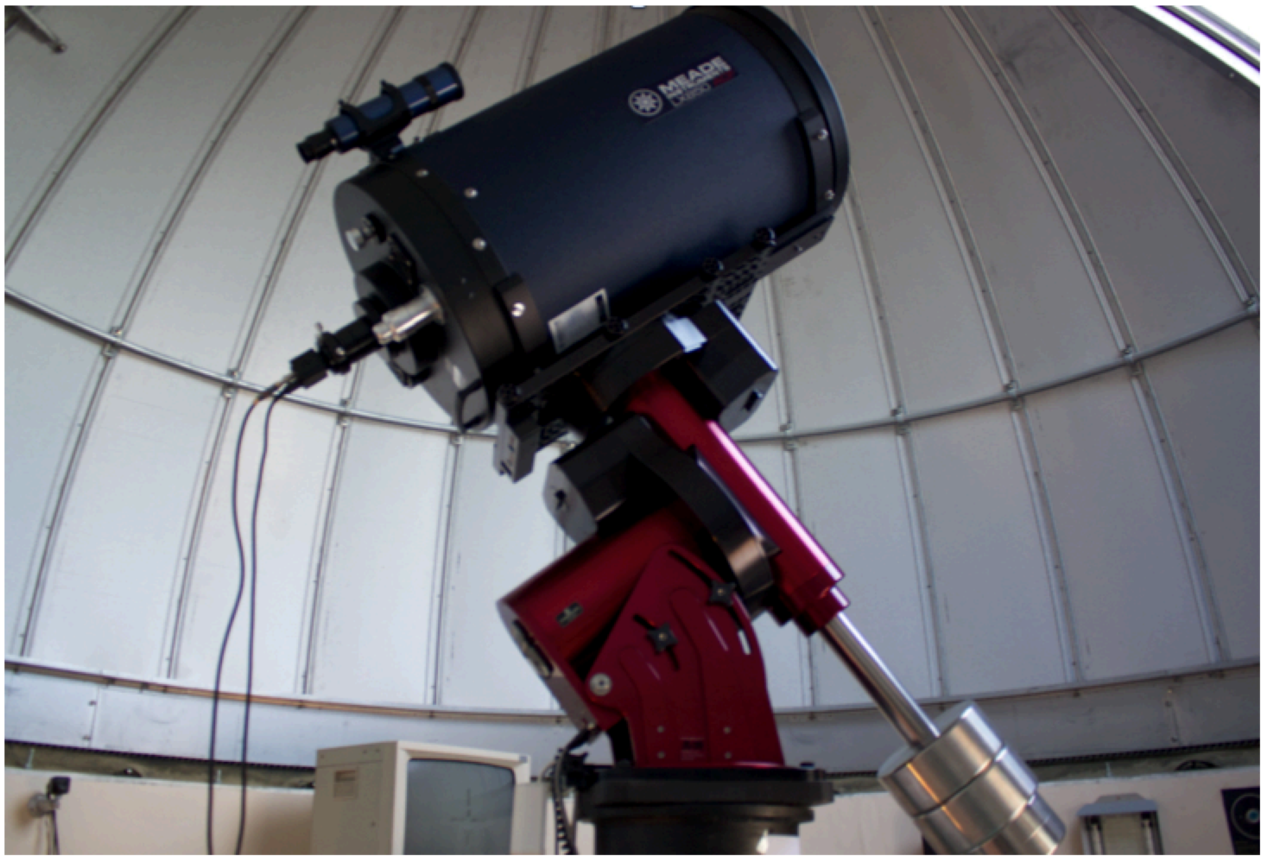
Confirmation of the binary nature of LS I 59 79 using the University of Jaén 41 cm telescope



Martí et al. 2016, A&A (in press) *https://arxiv.org/abs/1611.05609*

Confirmation of the binary nature of LS I 59 79 using the University of Jaén 41 cm telescope

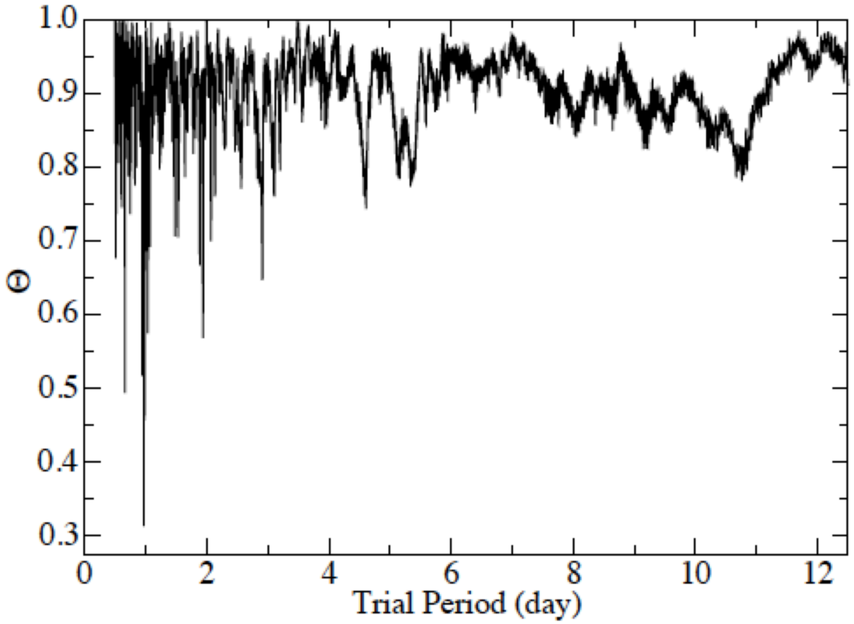


Fig. 2. PDM periodogram of the *V*-band observations of TYC 3683-985-1 where the statistic Θ displays a very deep minimum for a trial period of 0.97 d, which we interpret as half the true orbital period of the system.

Clear **period detection** using PDM method at 0.9701± 0.0003 d. This has been later interpreted as half the orbital cycle.

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Multi-colour folded light curves

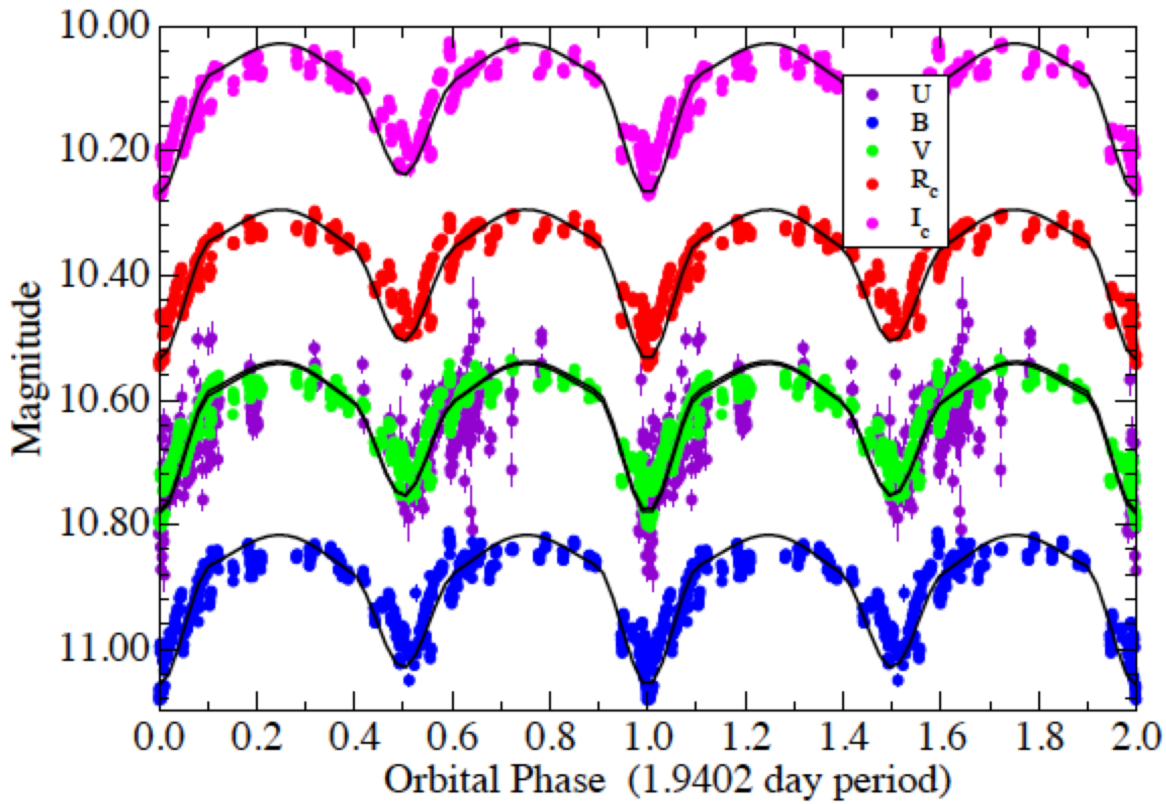

Fig. 3. $UBVR_cI_c$ light curves of TYC 3683-985-1 as observed with the UJT and folded using the orbital period value of 1.9402 d reported in this work. The continuous lines correspond to the synthetic light curves generated using the PHOEBE software packages with the physical parameters listed in Table 1. HJD 2457378.306 has been adopted as phase origin. All points are plotted twice for easier display.

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PHOEBE modelling: an eclipsing system!!!

Table 1. Values of the main PHOEBE parameters for TYC 3683-985-1

Parameter	Value	Comments
Eccentricity	$e = 0.000$	fixed
Semimajor 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 second Lagrangian point	$\Omega_{L_2} = 3.02$	computed

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

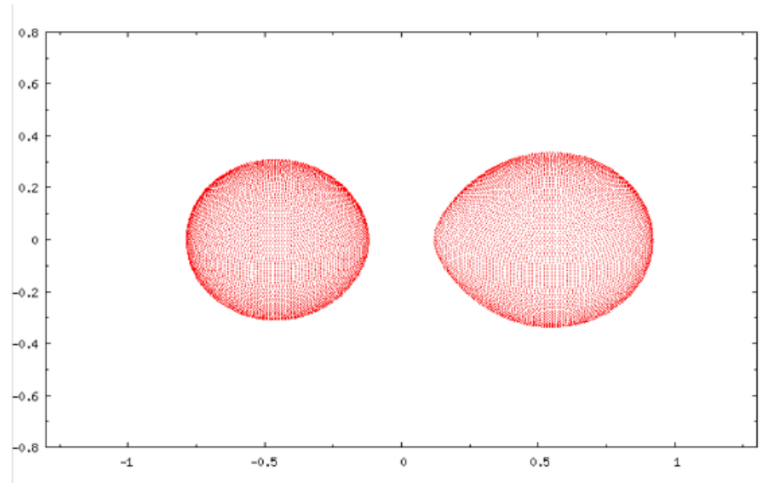

Fig. 8. Shape of the TYC 3683-985-1 stellar components resulting from the PHOEBE parameters in Table 1. The primary and secondary stars are located at the left and right side of the plot, respectively. The secondary star is practically filling its Roche lobe. Axes labels are given in units of the semimajor axis.

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Are there modern X-ray observations?

Yes, the *Swift* satellite has covered the 3FGL J0133.3+5939 field (**5ks**, Stroh & Falcone 2013).

The old *ROSAT* soource is **not detected**!!!! Variable? Spureous?

In contrast, another X-ray source appears in the field located several arc-minutes away from LS I 59 79 and detected at the **8σ level**.

The *Swift* source, **SWIFT J0132.9+5932**, is variable on time scales of days and consistent with 2MASS 01325529+5932158 at infrared wavelengths.

Deep UJA telescope view

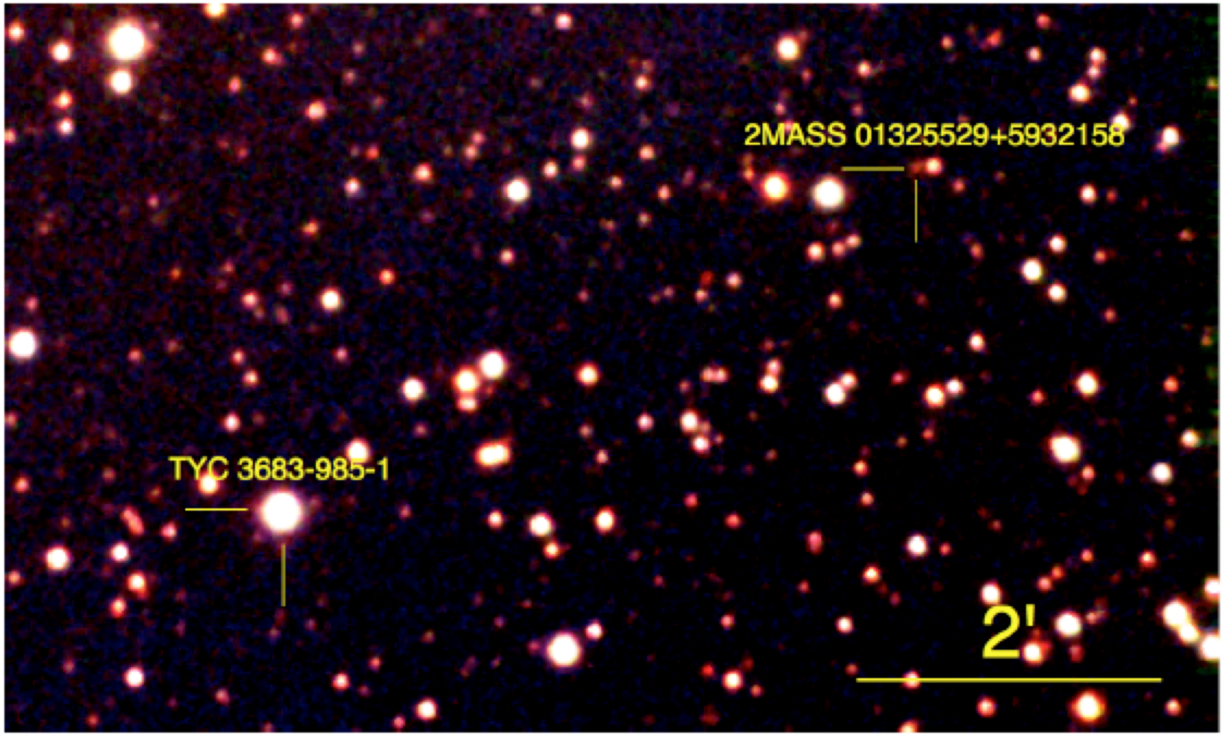

Fig. 6. Combined view of the TYC 3683-985-1 field as observed with the UJT in the VR_cI_c bands (blue, green and red filters, respectively). The total integration time is about 1 h in each photometric band. The locations of TYC 3683-985-1 and the faint 2MASS object consistent with the SWIFT J0132.9+5932 X-ray source are marked by yellow lines. The horizontal bar sets the angular scale. North is up and east is left.

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Swift X-ray light curve

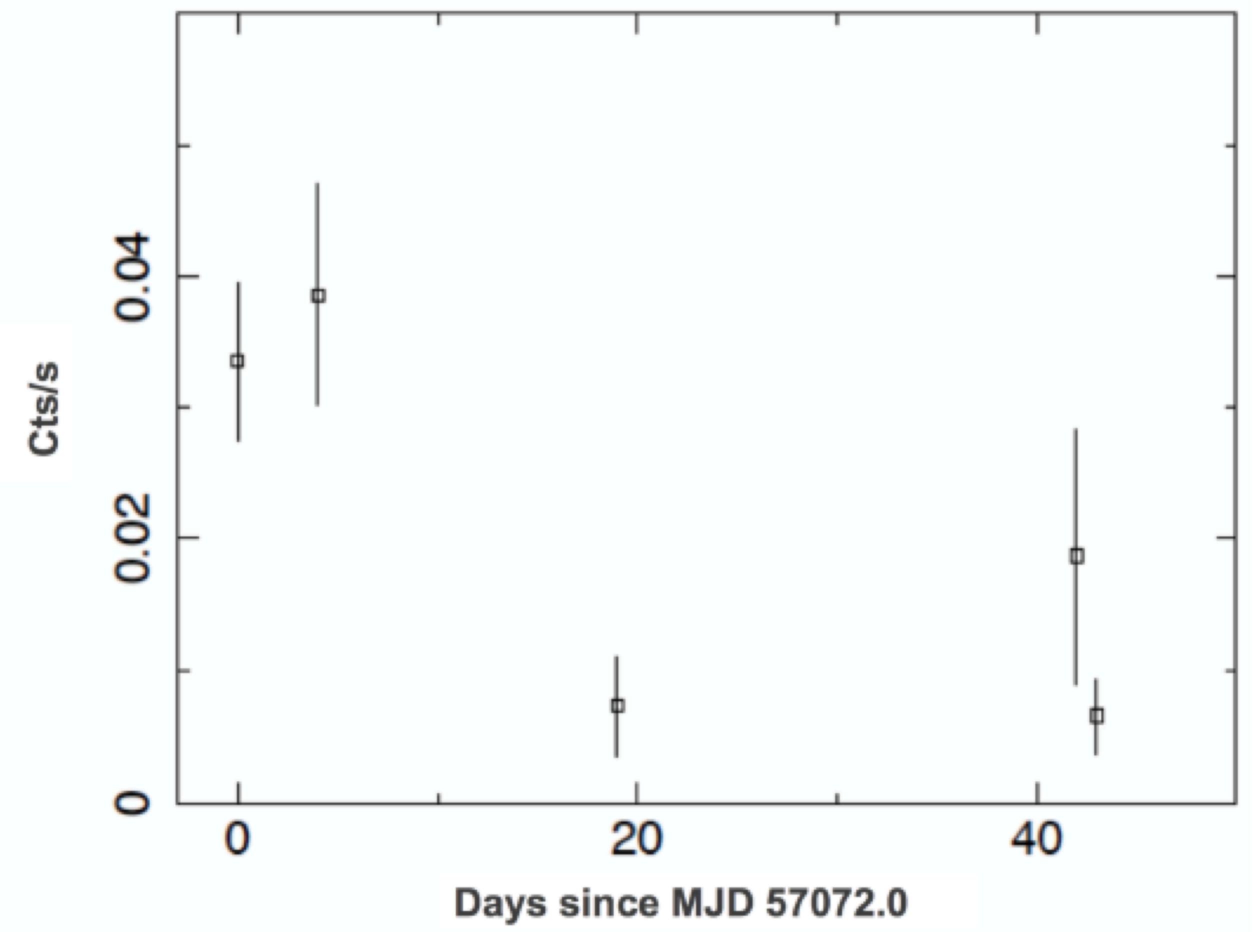

Fig. 5. Light curve of the X-ray source SWIFT J0132.9+5932 inside the 3FGL J0133.3+5930 ellipse showing a clearly variable behaviour on timescales of weeks in the 0.2–10 keV energy range.

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NOT optical spectrum

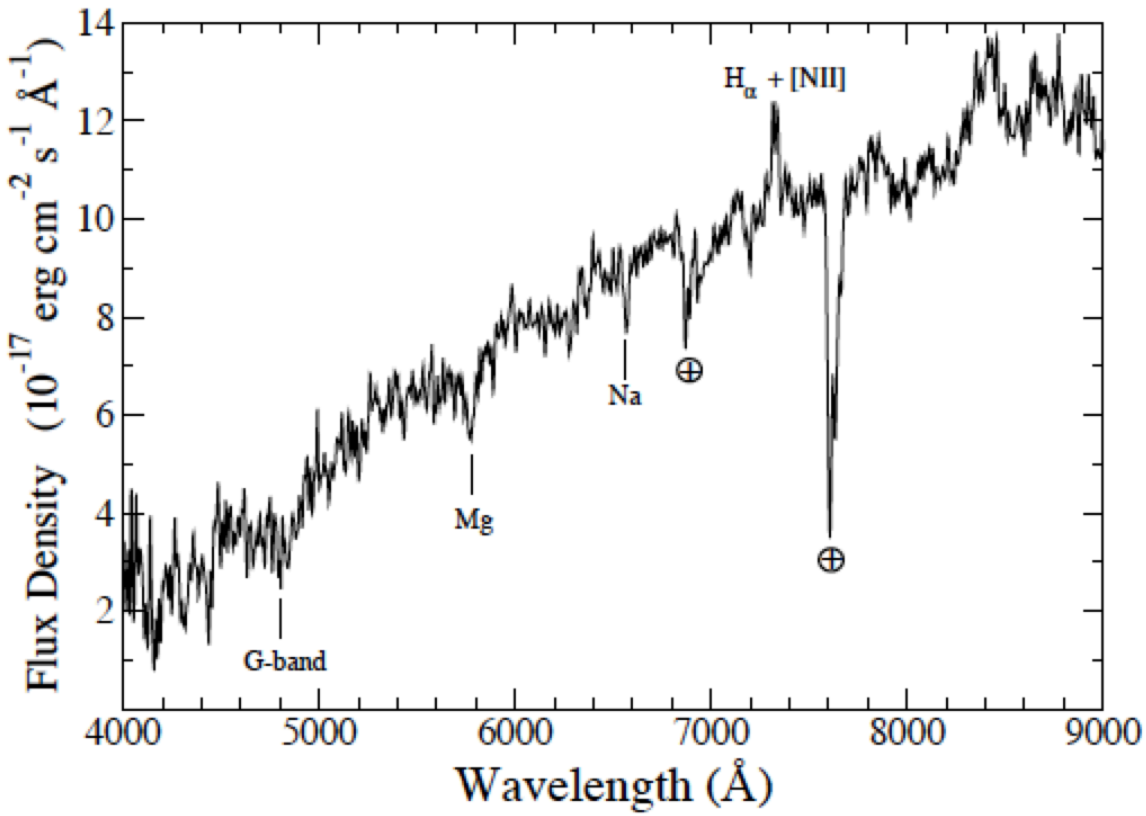

Fig. 7. Optical spectrum of 2MASS 01325529+5932158 obtained with the NOT telescope and its ALFOS instrument on 21 September 2016. The most prominent absorption and emission features are identified. All of them are consistent with the redshift value stated in the text.

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G-band, Mg, Na, Hα + [NII] lines
all consistent with the same redshift:

$$z = 0.11430 \pm 0.0002$$

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Two counterpart candidates

LS I 59 79: a confirmed Be eclipsing binary, but a gamma-ray emitting scenario is challenging with two non-degenerate stars. However, our knowledge of the system is yet uncomplete due to the lack of radial velocity data. A compact stellar companion cannot be yet excluded.

2MASS 01325529+5932158: could be a blazar, but a normal AGN unable to account for the *Fermi* emission cannot be ruled out.

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4. Future prospects

Radial velocity monitoring of LS I 59 79 using the Canary islands telescopes in order to meaure the mass function(s).

Proceed with the study of other gamma-ray candidate stars from the LS and *Fermi* catalogues.