Universidad de Jaén

Grupo de Investigación
"Fuentes de Alta Energía en la Galaxia"
(FQM-322)

Searching for new gamma-ray binaries

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Universidad de Jaén (Spain)

Fuentes de Alta Energía en la Galaxia

(High Energy Sources in the Galaxy)

Andalusian Research Group FQM-322

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JUNTA DE ANDALUCIA
CONSEJERÍA DE ECONOMÍA, INNOVACIÓN Y CIENCIA

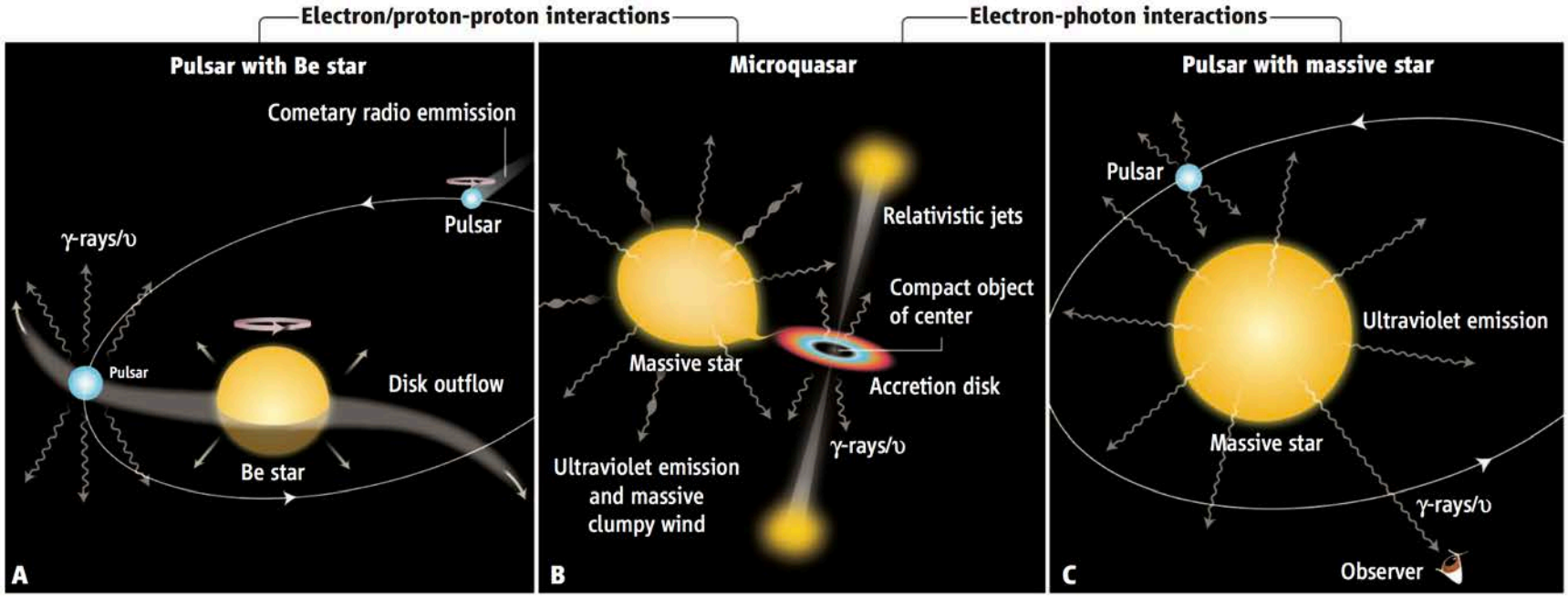
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Outline of the talk:

1. Introduction
2. Where to search?
3. Learning from previous failures
4. Unmasking hidden blazars
5. Conclusions and future perspectives

1. Introduction

Gamma-ray binaries and related systems are key sources in modern high and very high energy astrophysics …



Mirabel, I. F., Science 335, 175 (2012)

Gamma-ray binaries as of 2019 (Paredes & Bordas 2019)

γBs	PSR B1259–63 [4], LS 5039 [5], LS I +61 303 [6], HESS J0632+057 [7], 1FGL J1018.6–5856 [8], LMC–P3 [9], PSR J2032+4127 [10], HESS J1832–093 [11]

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Only a handful of systems are known!!!!!

Historically, the FAEG group in collaboration with UB colleagues contributed initially with the identification of one of the prototypical GB systems: **LS5039**

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

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

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

J. Martí[1,2], J.M. Paredes[3], and M. Ribó[3]

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[2] DAPNIA/Service d'Astrophysique, CEA/Saclay, F-91191 Gif-Sur-Yvette, France
[3] Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, E-08028 Barcelona, Spain

Received 28 July 1998 / Accepted 25 August 1998

The non-thermal radio counterpart of **LS 5039** was first noticed after inspection of archival survey data (NVSS).

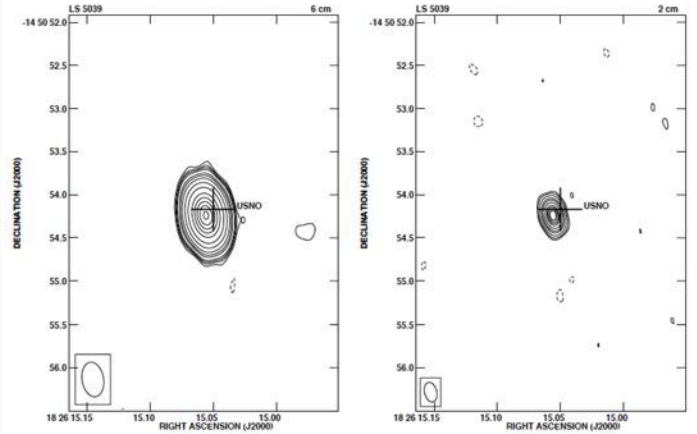
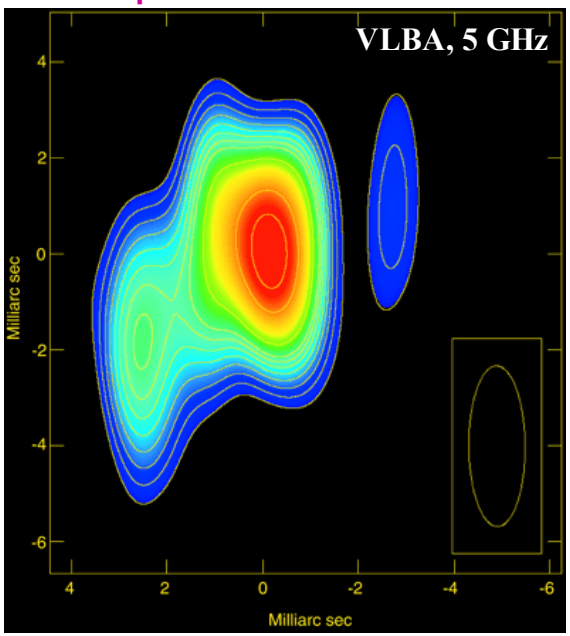


Fig. 1. Left. Self-calibrated map of LS 5039 at the 3.5 cm wavelength obtained from the concatenation of all our VLA data in the A configuration. Natural weight of the visibilities was used. The thick cross indicates the optical position of LS 5039 as listed in the USNO-A1.0 catalogue. Contours are $-3, 3, 5, 7, 10, 20, 30, 50, 100, 200, 400, 600, 800, 1000$ and 1200 times 0.015 mJy beam^{-1}, the rms noise. The synthesized beam is shown at the bottom left corner and corresponds to $0\overset{''}{.}40 \times 0\overset{''}{.}25$, with position angle of $9\overset{\circ}{.}1$. **Right.** The same at the 2.0 cm wavelength. Contours are $-3, 3, 5, 10, 20, 30, 50, 80, 100, 120$ and 140 times 0.082 mJy beam^{-1}, the rms noise. The 2.0 cm synthesized beam is $0\overset{''}{.}23 \times 0\overset{''}{.}14$, with position angle of $13\overset{\circ}{.}4$.

EGRET candidate: LS 5039

Orbital phase 0.2



Jet parameters:

$\beta > 0.15$, $\theta < 81°$

$T_B = 9.4 \times 10^7$ K

Equipartition:

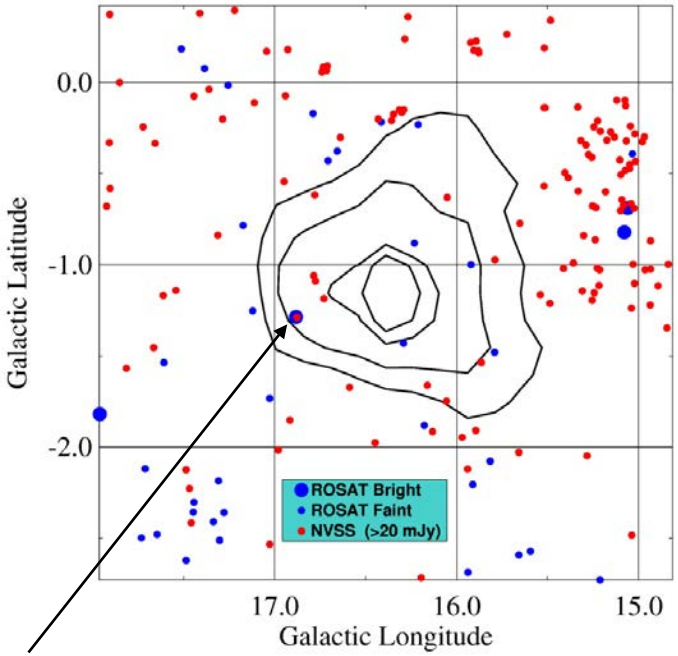
$E_e = 5 \times 10^{39}$ erg

B = 0.2 G

The photon spectral index is steeper than the $\alpha < 2$ values usually found for pulsars

Merk et al.1996, A&ASS 120, 465

LS 5039 could be related to the high energy gamma-ray source 3EG J1824-1514



It is the only simultaneous X-ray/radio source within the 3EG J1824-1514 statistical contours.

Paredes, Martí, et al. 2000, Science 288, 2340

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.

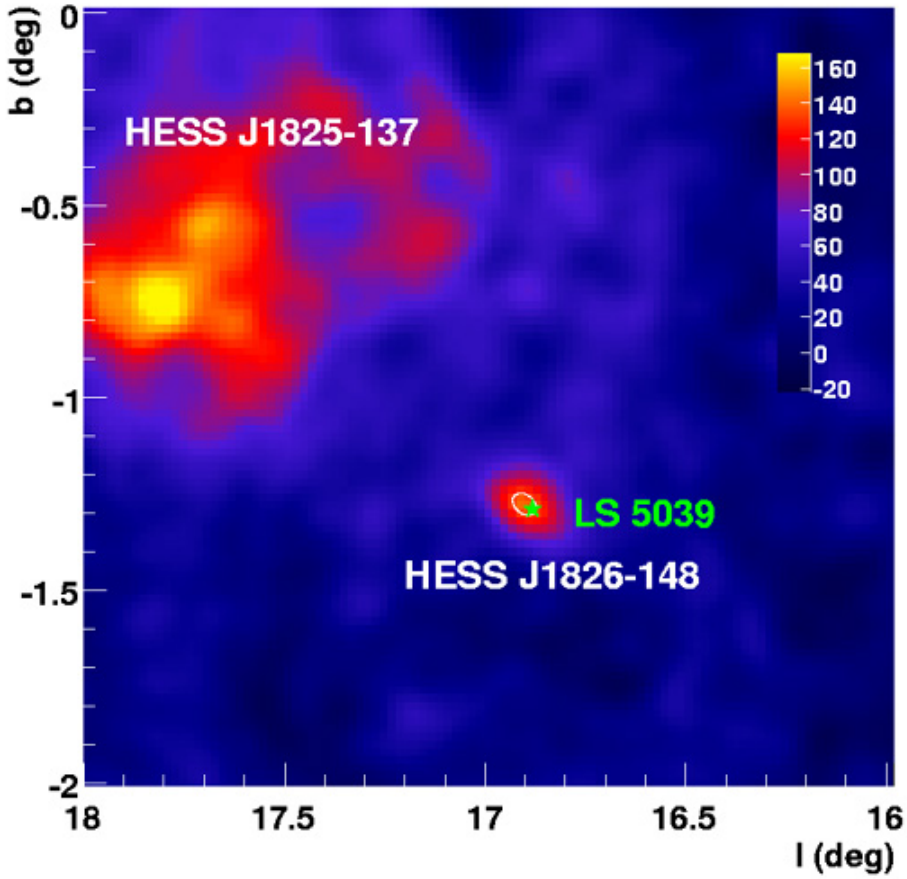
The $V = 11.2$ magnitude star LS 5039 (*1*) has been recently identified as a nearby high-mass x-ray binary with spectral type O7V((f)) (*2*) and persistent radio emission (*3, 4*). Here, we report high-resolution radio observations with the Very Long Baseline Array (VLBA) and the Very Large Array (VLA)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

[1]Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, E-08028 Barcelona, Spain. [2]Departamento de Física, Escuela Politécnica Superior, Universidad de Jaén, Calle Virgen de la Cabeza 2, E-23071 Jaén, Spain. [3]Max Planck Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany.

*To whom correspondence should be addressed. E-mail: josepmp@am.ub.es

Because LS 5039 appeared unresolved ($\leq 0.1''$) 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-



Confirmation of LS5039 as a TeV source by the H.E.S.S. collaboration

(Aharonian et al. 2005, Science).

Historically, the FAEG group in collaboration with UB colleagues contributed initially with the identification of one of the prototypical GB systems: **LS5039**

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This finding was prompted thanks to the availability of public **data archives and catalogues**, mainly NVSS and EGRET.

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Could this early finding be emulated again?

2. Where to search?

Interestingly, some of the currently known gamma-ray binaries and new additions to this class correspond to objects already present in **ancient catalogues** of peculiar stars. For example:

- Catalogue of Luminous Stars in the Northern Milky Way (Hardorp + 1959-1965): LS I+61303, HESS J0632+057 (LS VI+05 11), …
- Catalogue of Luminous Stars in the Southern Milky Way (Stephenson & Sanduleak 1971): LS 5039, PSR B1259-63 (LS 2883) …
- Catalogue of Early-Type Stars Whose Spectra Have Shown Emission Lines (Wackerling 1970): HESS J0632+057 (MWC 656), AGL J2241+4454 (MWC 656) …

Are there any more similar systems waiting for discovery in the archives?

Systematic searches could still provide interesting results here in parallel to serendipitous discoveries.

The Luminous Star (LS) catalogue series 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-		

Astrophys Space Sci (2014) 355:2157
DOI 10.1007/s10509-014-2157-7

ORIGINAL ARTICLE

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

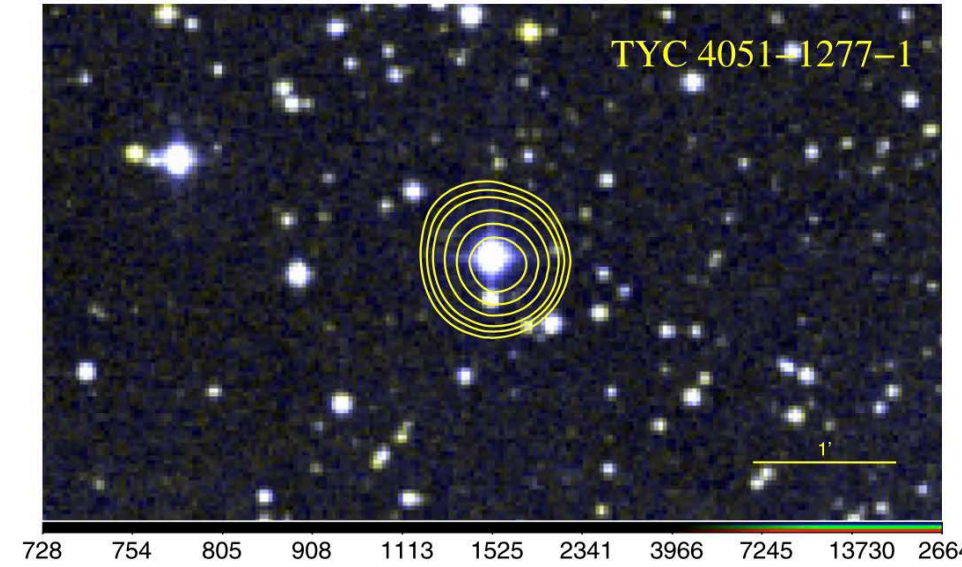
Josep Martí · Pedro L. Luque-Escamilla · Jorge Casares · Benito Marcote · Xavier Paredes-Fortuny · Marc Ribó · Josep M. Paredes · Jorge Núñez

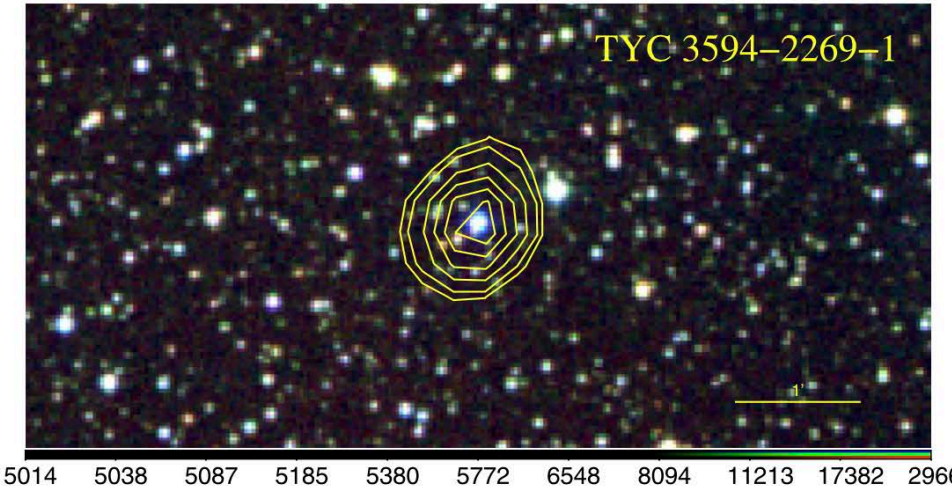
Received: 14 August 2014 / Accepted: 19 September 2014

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-

3. Learning from previous failures

Two fomer LS-GB candidates that initially looked very promising (Martí et al. 2014)





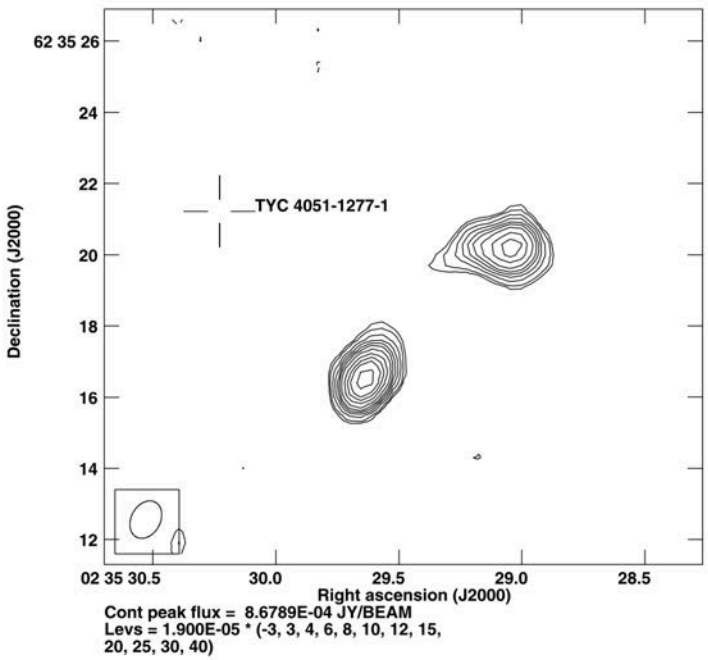


Fig. 8 Contour radio map of the TYC4051-1277-1 position in the C-band as observed with the VLA. The *cross with a gap* indicates the star position. This map has been computed with a 0 value of the Robust parameter in the CASA clean task. Then *bottom left ellipse* represents the synthesized beam equivalent to $1\overset{''}{.}11 \times 0\overset{''}{.}82$, with position angle of $-28\overset{\circ}{.}7$

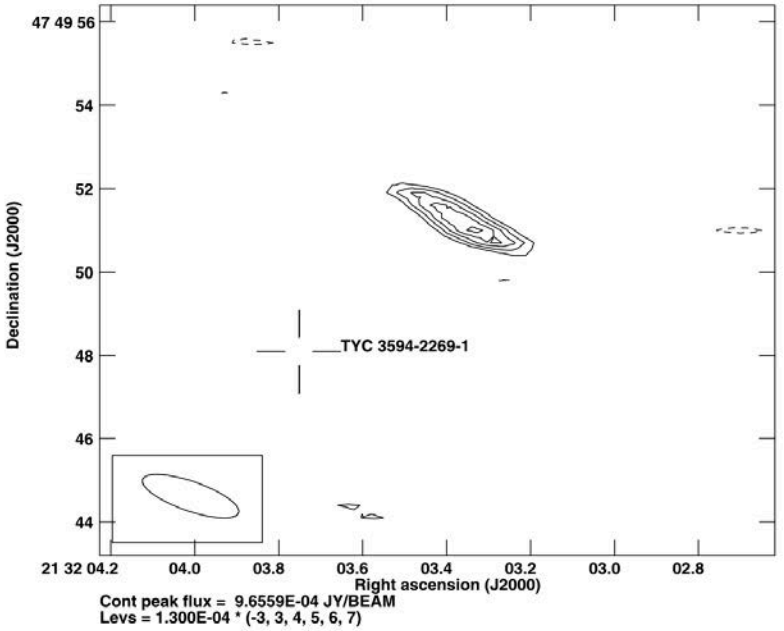
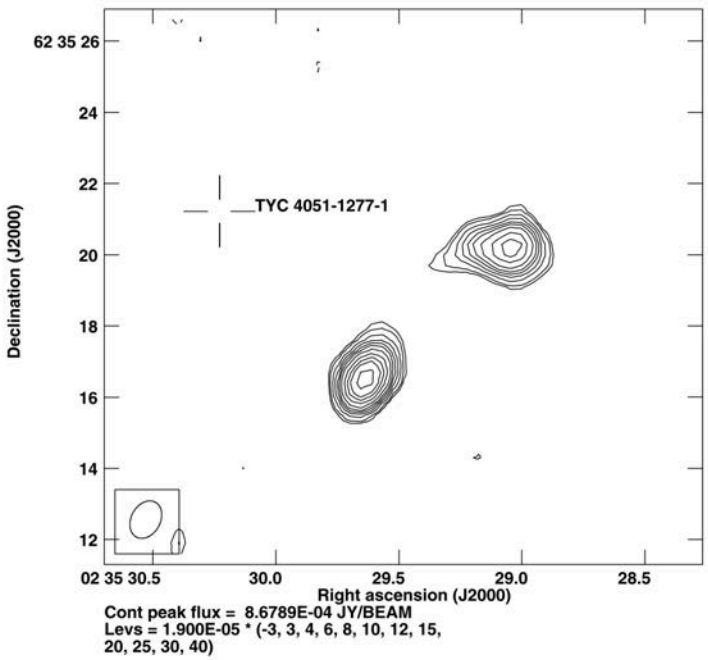


Fig. 9 Contour radio map of the TYC3594-2269-1 position in the C-band as observed with the VLA. The *cross with a gap* indicates the star position. This map has been computed with a 5 value of the Robust parameter in the CASA clean task. Then *bottom left ellipse* represents the synthesized beam equivalent to $2\overset{''}{.}44 \times 0\overset{''}{.}71$, with position angle of $70\overset{\circ}{.}8$

Martí et al. (2014)



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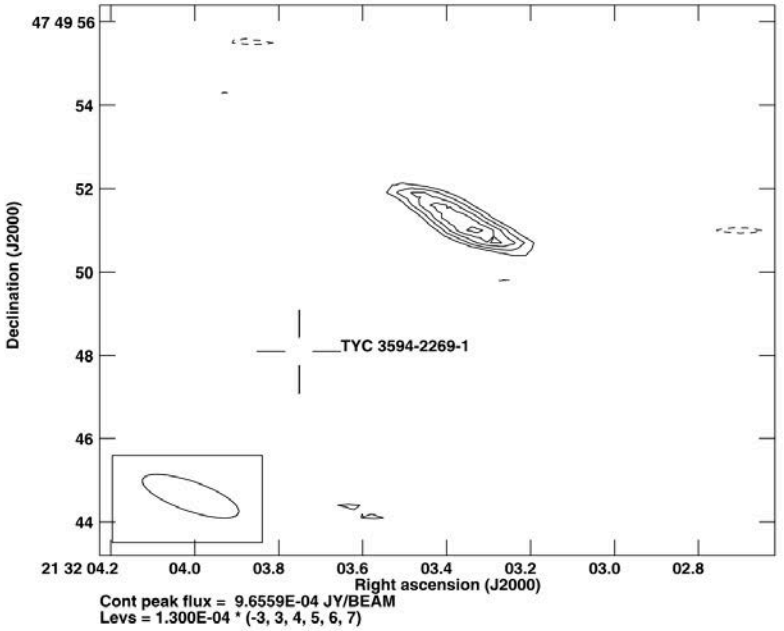

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No astrometric optical-radio coincidence!!!!!

Martí et al. (2014)

The case of 3FGL J0133.3+5930 and LSI +5979 (Martí et al. 2017)

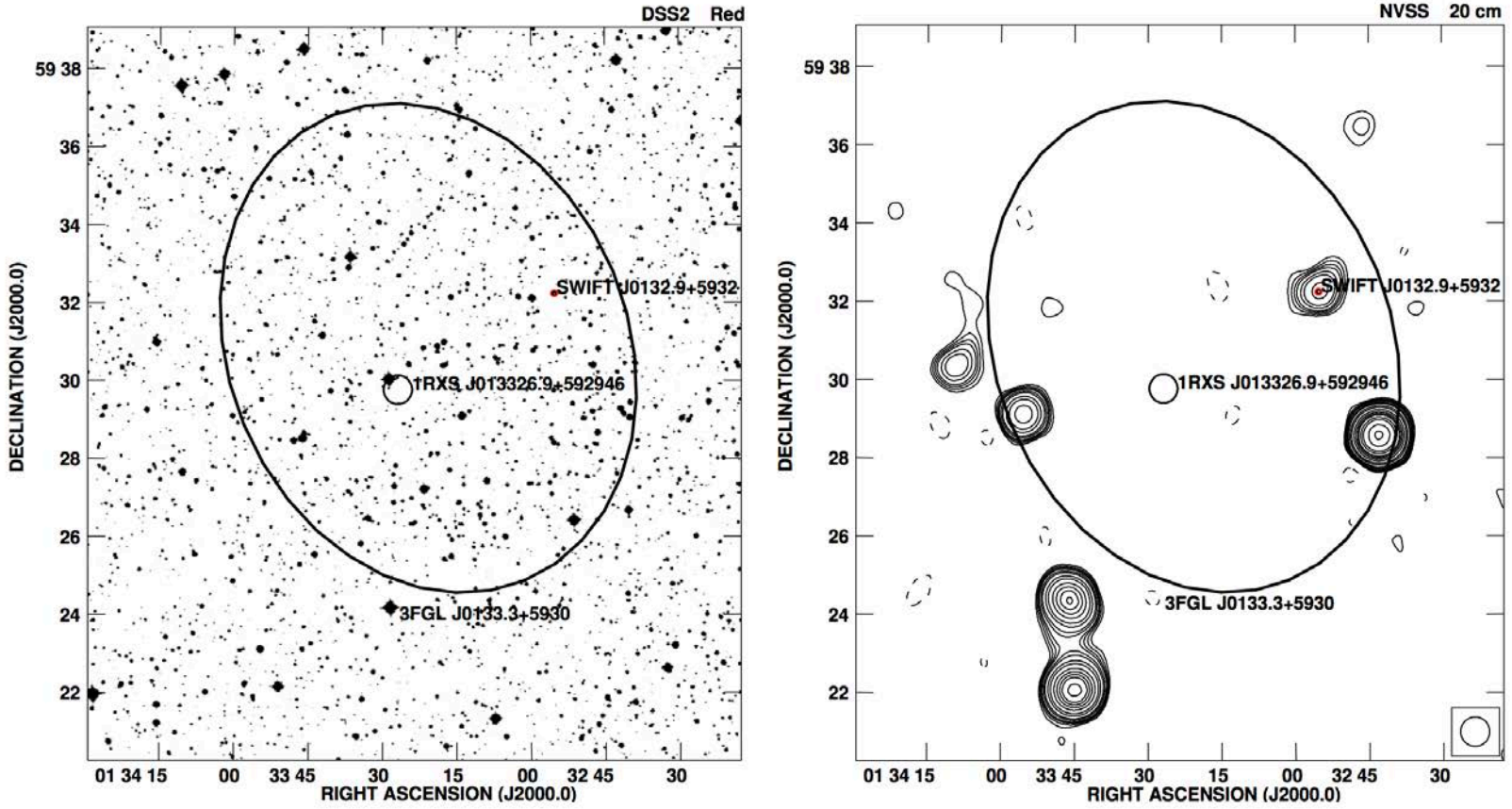


Fig. 1. *Left*: the 95% confidence ellipse of the gamma-ray source 3FGL J0133.3+5930 overplotted against the Second Digitized Sky Survey (red) distributed by the Space Telescope Science Institute. The small black and the tiny red circles indicate the positions of the ROSAT and *Swift* X-ray sources inside the *Fermi* LAT ellipse, respectively. TYC 3683-985-1 is the brightest star at the edge of the ROSAT circle. *Right*: same field as it appears in radio at the 20 cm wavelength according to the NVSS. The contour levels shown correspond to −3, 3, 4, 5, 6, 8, 10, 15, 20, 30, 40, 50, 60, 80, 100, 150, and 200 times the rms noise level of 0.4 mJy beam^{-1}. The lower right circle illustrates the NVSS restoring beam with 45″ FWHM.

The *Fermi* gamma-ray source vanished in the 4FGL catalogue, but the discovery of **LSI+5979** as a peculiar eclipsing Be-binary system remains to be interpreted (Martí et al. 2014).

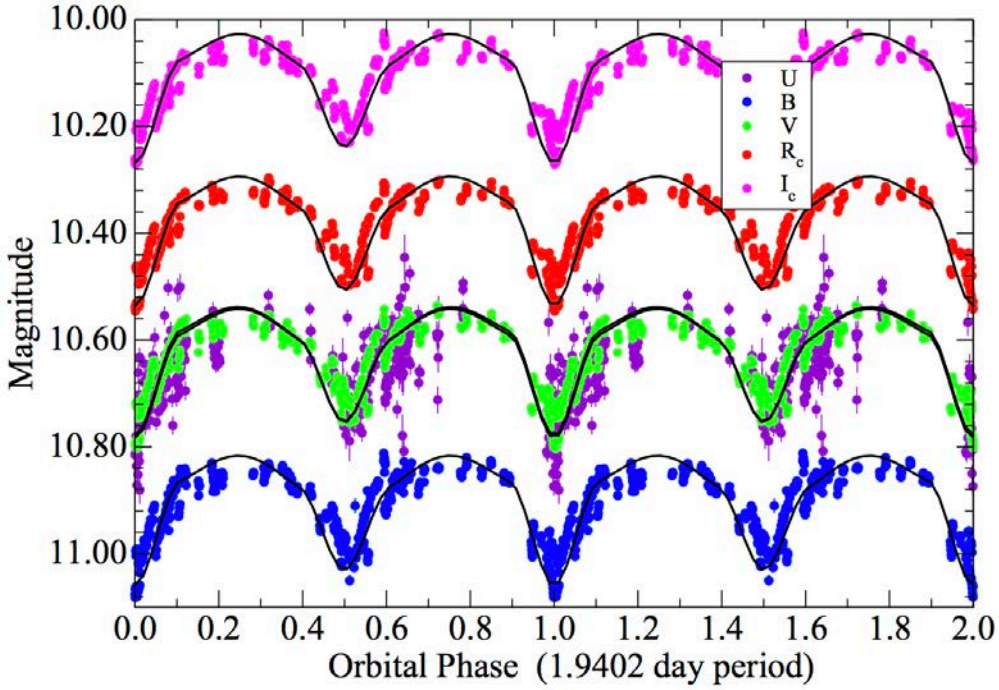


Fig. 3. $UBVR_cI_c$ light curves of TYC 3683-985-1 as observed with the UJT and folded using the orbital period value of 1.9402 d reported in this work. The continuous lines correspond to the synthetic light curves generated using the PHOEBE software packages with the physical parameters listed in Table 1. HJD 2 457 378.306 has been adopted as phase origin. All points are plotted twice for easier display.

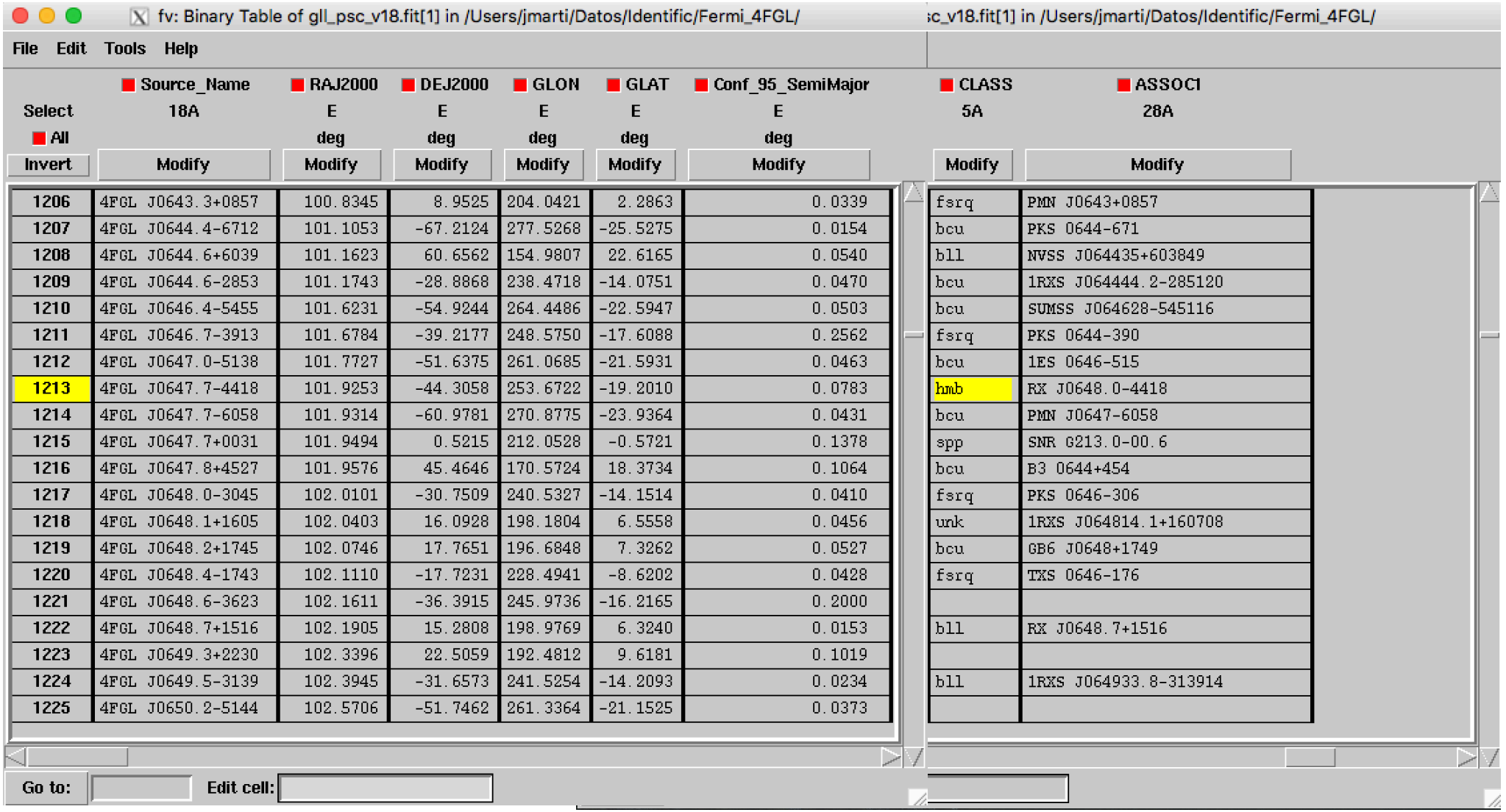
4. Unmasking hidden blazars

… sometimes failure in one sense
means success in the opposite direction!!!!!

The candidate GB system **HD 49798**
according to the *Fermi* 4FGL catalogue

(Martí et al. 2019, in prep.)

Possible association with HD 49798 as a HMXB already noted in the Fermi 4FGL catalogue!!!



fv: Binary Table of gll_psc_v18.fit[1] in /Users/jmarti/Datos/Identific/Fermi_4FGL/

File Edit Tools Help

Select / All / Invert	Source_Name 18A Modify	RAJ2000 E deg Modify	DEJ2000 E deg Modify	GLON E deg Modify	GLAT E deg Modify	Conf_95_SemiMajor E deg Modify	CLASS 5A Modify	ASSOC1 28A Modify
1206	4FGL J0643.3+0857	100.8345	8.9525	204.0421	2.2863	0.0339	fsrq	PMN J0643+0857
1207	4FGL J0644.4-6712	101.1053	-67.2124	277.5268	-25.5275	0.0154	bcu	PKS 0644-671
1208	4FGL J0644.6+6039	101.1623	60.6562	154.9807	22.6165	0.0540	bll	NVSS J064435+603849
1209	4FGL J0644.6-2853	101.1743	-28.8868	238.4718	-14.0751	0.0470	bcu	1RXS J064444.2-285120
1210	4FGL J0646.4-5455	101.6231	-54.9244	264.4486	-22.5947	0.0503	bcu	SUMSS J064628-545116
1211	4FGL J0646.7-3913	101.6784	-39.2177	248.5750	-17.6088	0.2562	fsrq	PKS 0644-390
1212	4FGL J0647.0-5138	101.7727	-51.6375	261.0685	-21.5931	0.0463	bcu	1ES 0646-515
1213	4FGL J0647.7-4418	101.9253	-44.3058	253.6722	-19.2010	0.0783	hmb	RX J0648.0-4418
1214	4FGL J0647.7-6058	101.9314	-60.9781	270.8775	-23.9364	0.0431	bcu	PMN J0647-6058
1215	4FGL J0647.7+0031	101.9494	0.5215	212.0528	-0.5721	0.1378	spp	SNR G213.0-00.6
1216	4FGL J0647.8+4527	101.9576	45.4646	170.5724	18.3734	0.1064	bcu	B3 0644+454
1217	4FGL J0648.0-3045	102.0101	-30.7509	240.5327	-14.1514	0.0410	fsrq	PKS 0646-306
1218	4FGL J0648.1+1605	102.0403	16.0928	198.1804	6.5558	0.0456	unk	1RXS J064814.1+160708
1219	4FGL J0648.2+1745	102.0746	17.7651	196.6848	7.3262	0.0527	bcu	GB6 J0648+1749
1220	4FGL J0648.4-1743	102.1110	-17.7231	228.4941	-8.6202	0.0428	fsrq	TXS 0646-176
1221	4FGL J0648.6-3623	102.1611	-36.3915	245.9736	-16.2165	0.2000		
1222	4FGL J0648.7+1516	102.1905	15.2808	198.9769	6.3240	0.0153	bll	RX J0648.7+1516
1223	4FGL J0649.3+2230	102.3396	22.5059	192.4812	9.6181	0.1019		
1224	4FGL J0649.5-3139	102.3945	-31.6573	241.5254	-14.2093	0.0234	bll	1RXS J064933.8-313914
1225	4FGL J0650.2-5144	102.5706	-51.7462	261.3364	-21.1525	0.0373		

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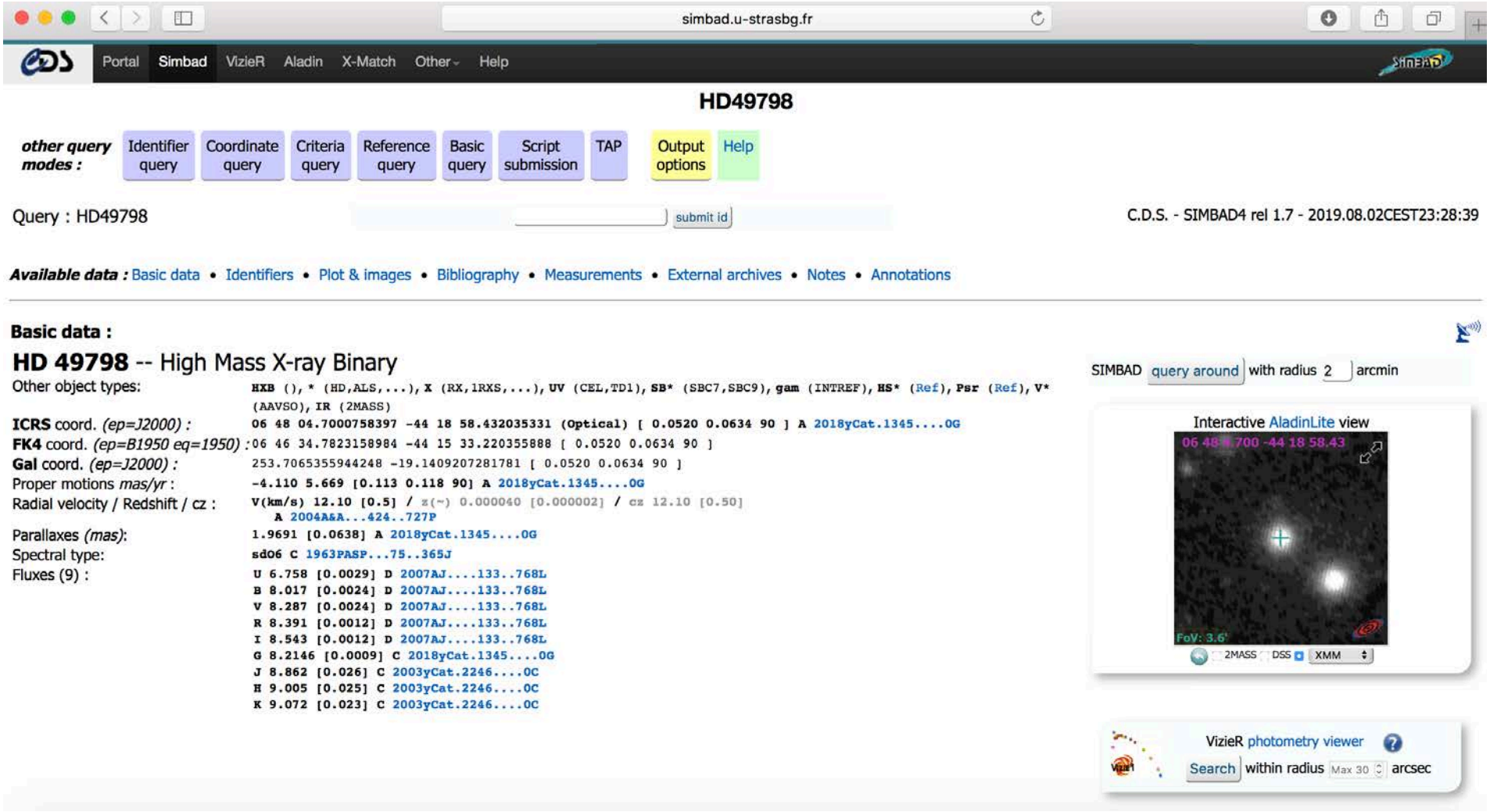
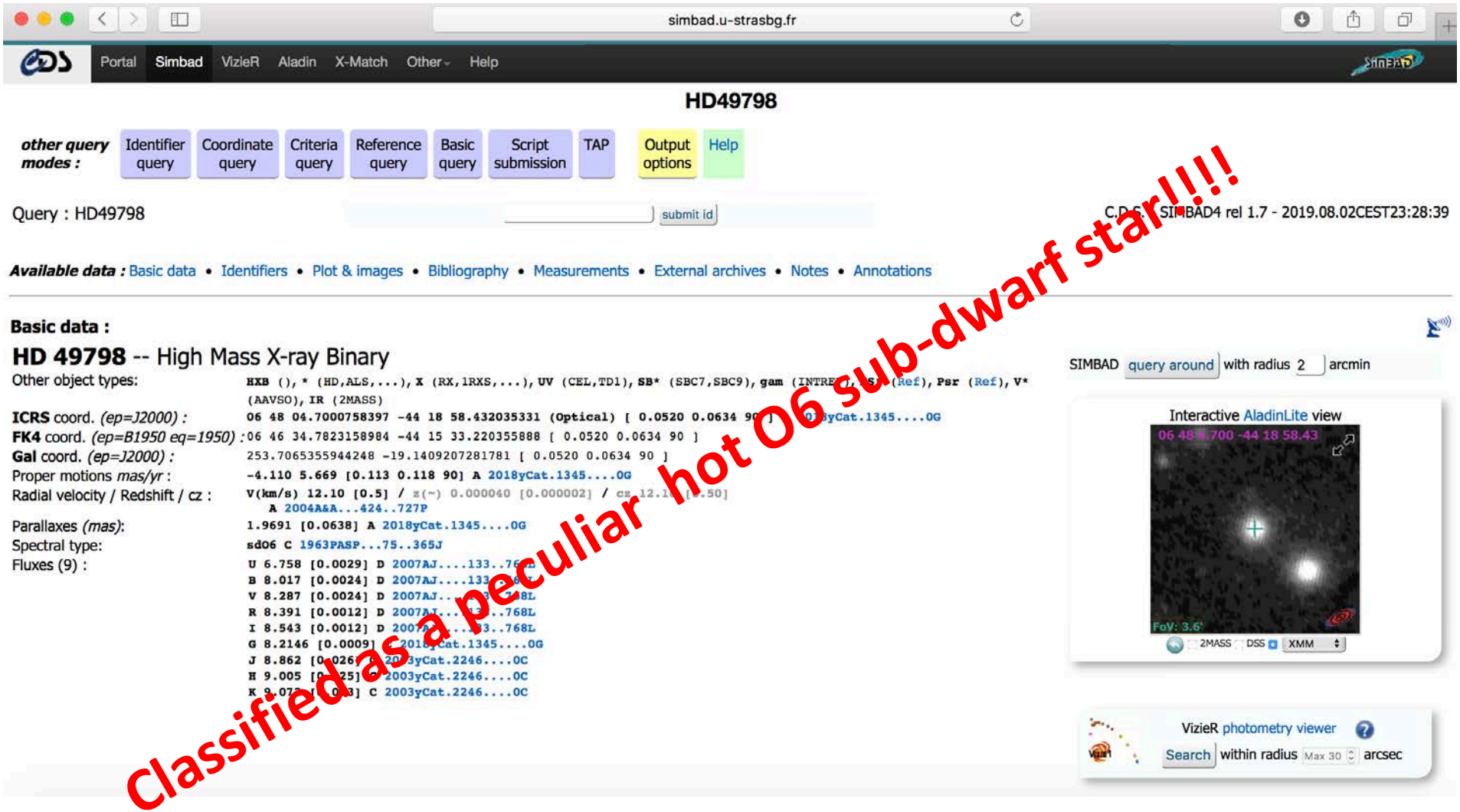
HD 49798

An O6 early-type star consistent in position with **4FGL J0647.7-4418**

Catalogued as a HMXB in the SIMBAD database!!!


simbad.u-strasbg.fr
Portal Simbad VizieR Aladin X-Match Other Help
HD49798
other query modes :
Identifier query
Coordinate query
Criteria query
Reference query
Basic query
Script submission
TAP
Output options
Help
Query : HD49798
submit id
C.D.S. - SIMBAD4 rel 1.7 - 2019.08.02CEST23:28:39
Available data : Basic data • Identifiers • Plot & images • Bibliography • Measurements • External archives • Notes • Annotations
Basic data :
HD 49798 -- High Mass X-ray Binary
Other object types: HXB (), * (HD,ALS,...), X (RX,1RXS,...), UV (CEL,TD1), SB* (SBC7,SBC9), gam (INTREF), HS* (Ref), Psr (Ref), V* (AAVSO), IR (2MASS)
ICRS coord. (ep=J2000) : 06 48 04.7000758397 -44 18 58.432035331 (Optical) [0.0520 0.0634 90] A 2018yCat.1345....0G
FK4 coord. (ep=B1950 eq=1950) : 06 46 34.7823158984 -44 15 33.220355888 [0.0520 0.0634 90]
Gal coord. (ep=J2000) : 253.7065355944248 -19.1409207281781 [0.0520 0.0634 90]
Proper motions mas/yr : -4.110 5.669 [0.113 0.118 90] A 2018yCat.1345....0G
Radial velocity / Redshift / cz : V(km/s) 12.10 [0.5] / z(~) 0.000040 [0.000002] / cz 12.10 [0.50] A 2004A&A...424..727P
Parallaxes (mas): 1.9691 [0.0638] A 2018yCat.1345....0G
Spectral type: sdO6 C 1963PASP...75..365J
Fluxes (9) :
U 6.758 [0.0029] D 2007AJ....133..768L
B 8.017 [0.0024] D 2007AJ....133..768L
V 8.287 [0.0024] D 2007AJ....133..768L
R 8.391 [0.0012] D 2007AJ....133..768L
I 8.543 [0.0012] D 2007AJ....133..768L
G 8.2146 [0.0009] C 2018yCat.1345....0G
J 8.862 [0.026] C 2003yCat.2246....0C
H 9.005 [0.025] C 2003yCat.2246....0C
K 9.072 [0.023] C 2003yCat.2246....0C
SIMBAD query around with radius 2 arcmin
Interactive AladinLite view
06 48 4.700 -44 18 58.43
FoV: 3.6'
2MASS DSS XMM
VizieR photometry viewer
Search within radius Max 30 arcsec



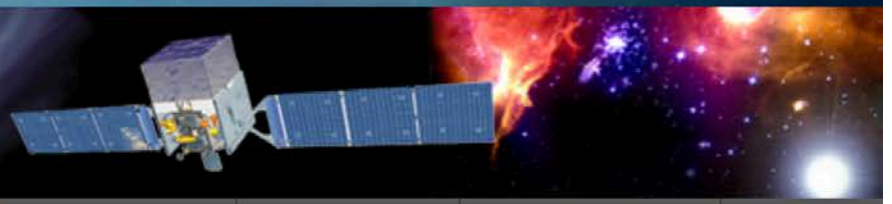
Classified as a peculiar hot O6 sub-dwarf star!!!!

The peculiar nature of **HD 49798** was originally discovered

in Argentina

by the renowed **Jaschek** spectroscopists using plates taken at the Bosque Alegre station of Córdoba Observatory in Argentina (Jaschek & Jaschek, 1963, PASP, 75, 365).

Fermi
Gamma-ray Space Telescope



Data

- Data Policy
- **Data Access**
  - + LAT Data
  - + LAT Catalog
  - + LAT Data Queries
  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
- Data Analysis
- Caveats
- Newsletters
- FAQ

Query L190802173041 49E50DAF79 submitted.

Please see LAT Data Caveats for important information about Fermi LAT data.

Your search criteria were:

Equatorial coordinates (degrees)	(102.02,-44.3162)
Time range (MET)	(570803507,586355507)
Time range (Gregorian)	(2019-02-02 12:31:42,2019-08-01 12:31:42)
Energy range (MeV)	(100,300000)
Search radius (degrees)	5

The estimated time for your query to complete is 12 seconds. The results of your query may be found at https://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/QueryResults.cgi?id=L190802173041 49E50DAF79.

4FGL J0647.7-4418

Results of our own Fermi LAT analysis (Martí et al. 2019, in prep.)

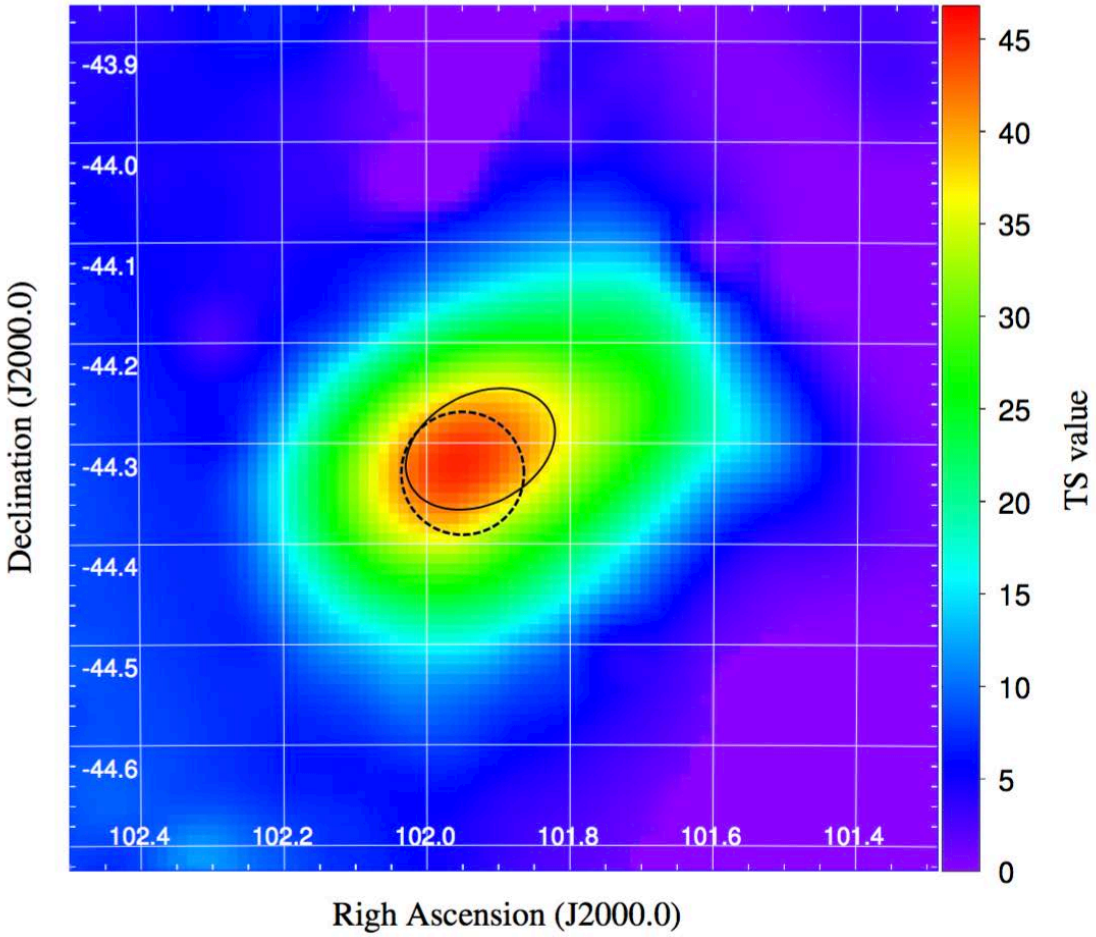


Fig. 1. TS residual map (1° × 1°) of the 4FGL J0647.7−4418 region resulting from our own analysis of *Fermi*-LAT data. The black dashed circle represents the improved 95% confidence level gamma-ray source location. For comparison, the black ellipse corresponds to the same confidence level location according to the original 4FGL catalogue.

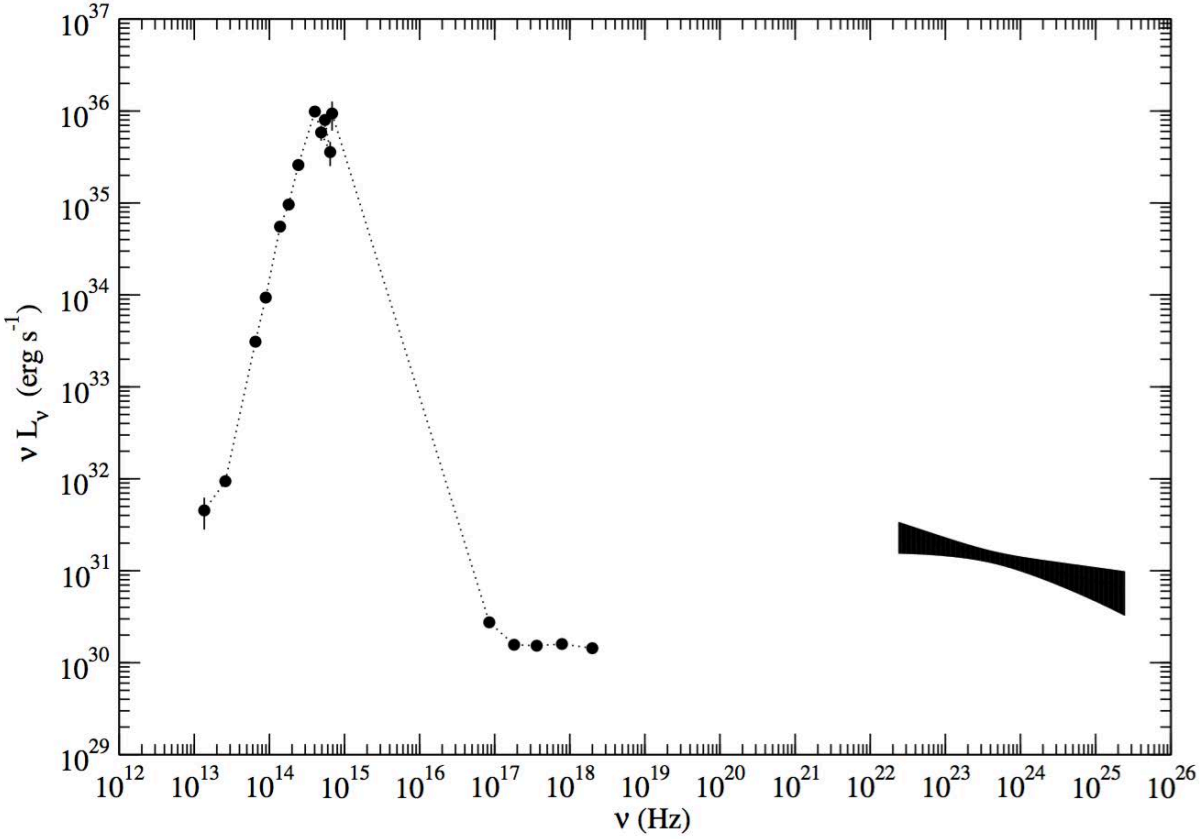
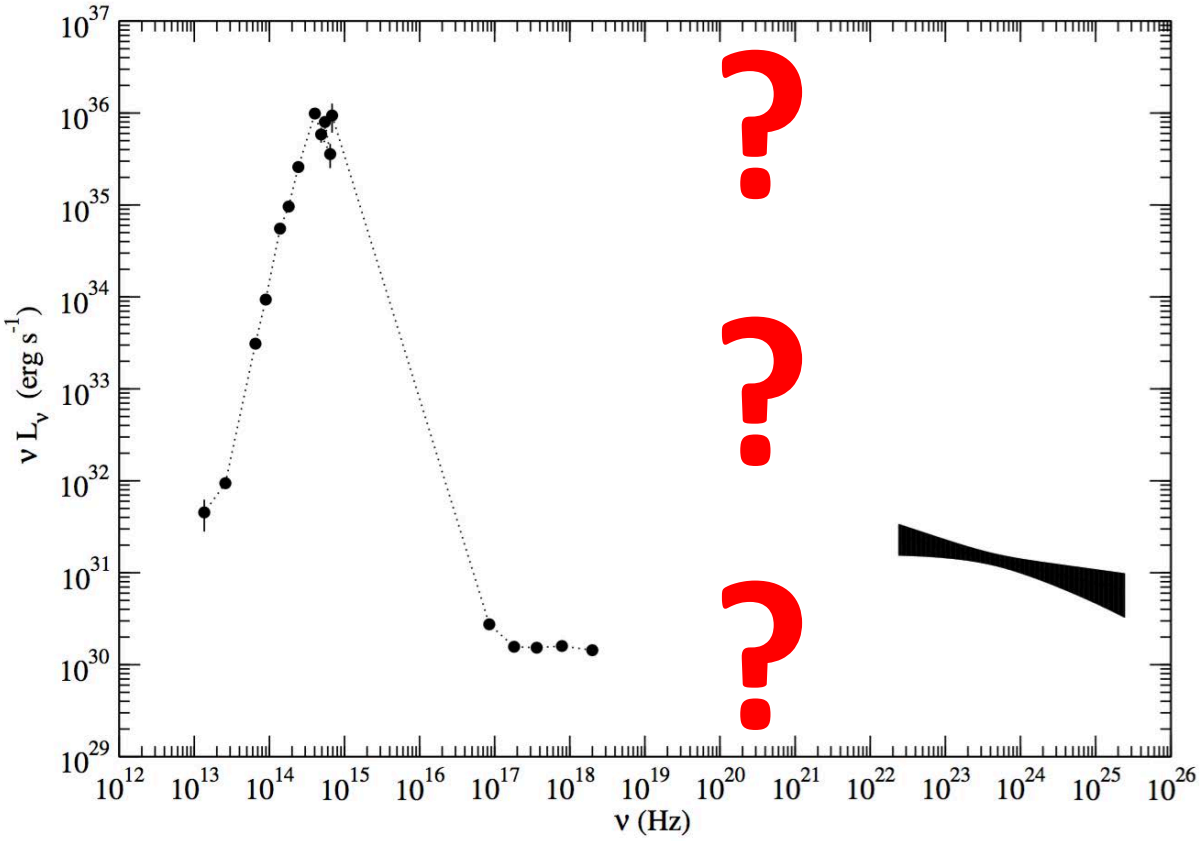


Fig. 3. SED of HD 49798 combined with the *Fermi*-LAT spectrum of 4FGL J0647.7−4418 that we tentatively associate with it and scale to the distance of the star.

$$L_\gamma \simeq 4.9 \times 10^{31} \text{ erg s}^{-1}$$

(1-100 GeV)



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(1-100 GeV)

HD 49798, some data:

Orbital period: 1.55 d (Thackeray 1970)

Distance 508 +/- 16 pc (Gaia DR2)

Pulsations of 13.2 s in X-ray (Israel et al. 1997). Coud be NS or WD.

X-ray eclipses (Mereghetti et al. 2011) constrained inclination and rendered masses of 1.50 $M_\odot$ and 1.28 $M_\odot$ for the sub-dwarf and compact object, respectively.

Discovery of **spin-up** ($dP/dt = -2.15 \times 10^{-15}$) by Mereghetti et al. (2016). Accretion spin-up by sub-dwarf stellar wind cannot account for it! The proposed alternative scenario is a **young contracting white dwarf**!

Could this scenario also account for gamma-rays?

Due to spin-up:

$$\dot{E}_{\rm rot} = -\frac{2\pi^2 I}{P^3}\dot{P}$$

… and for a plausible WD moment of inertia and the observed spin-up:

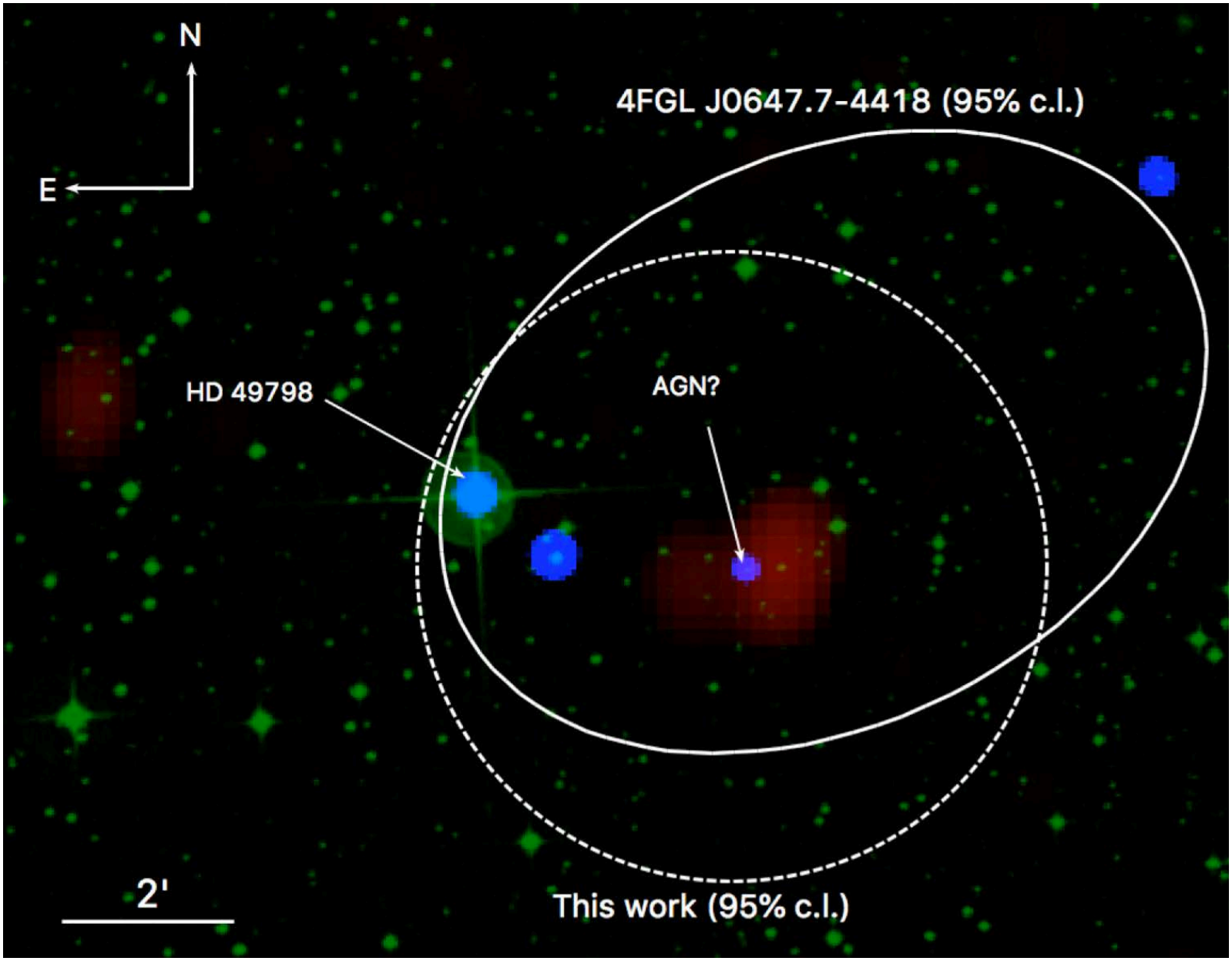
$$\dot{E}_{\rm rot} \simeq 2.1 \times 10^{33}\ {\rm erg\ s^{-1}}$$

Intriguingly, this rotational energy excess exceeds the gamma-ray luminosity by two orders of magnitude!!!

- An energetically plausible powering source (WD contraction) has been proposed that could render HD49798 a new kind of gamma-ray binary.

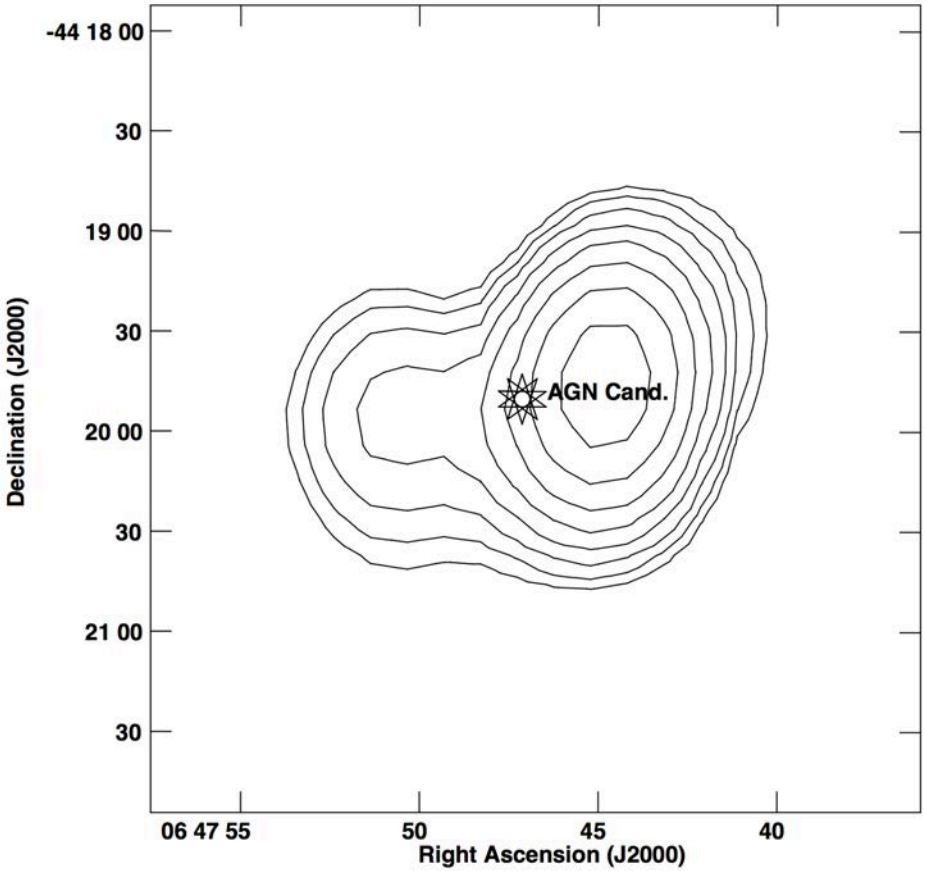
- But, this requires confirmation as the details of the emission mechanism have not yet been worked out.

- However, …



Martí et al. (2019)

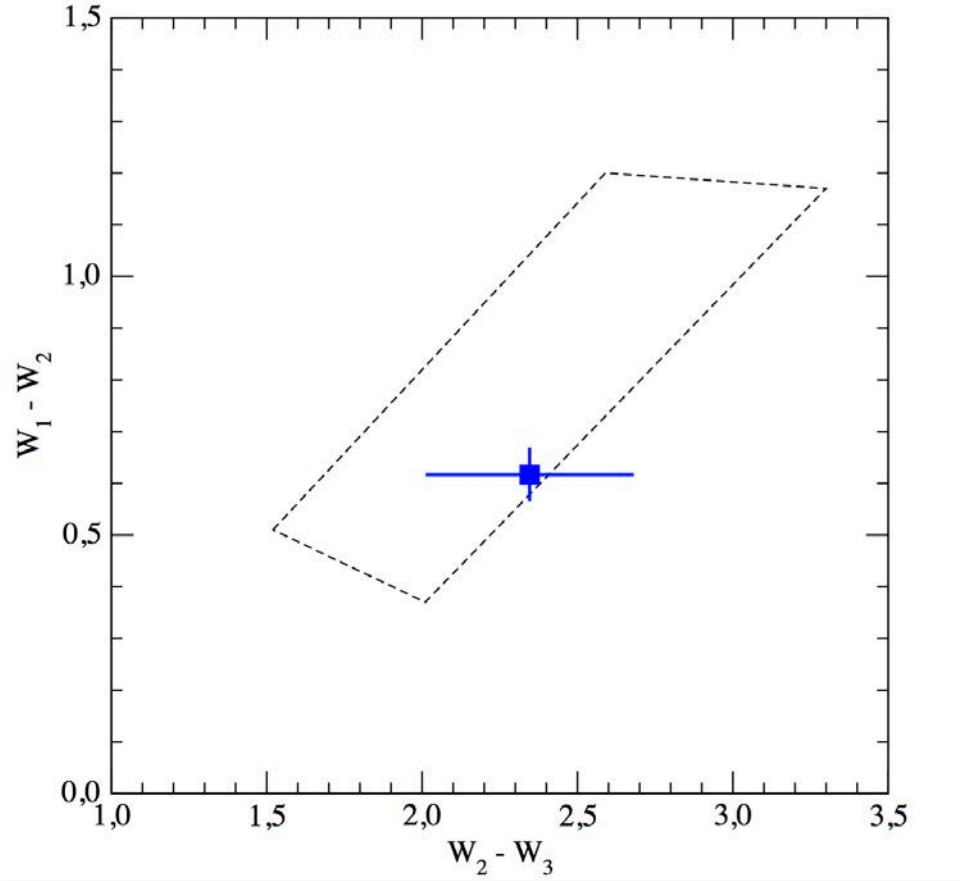
SUMSS radio map at 843 MHz of the candidate AGN in the field of HD49798



- An energetically plausible powering source (WD contraction) has been proposed that could render HD49798 a new kind of gamma-ray binary.

- But, this requires confirmation as the details of the emission mechanism have not yet been worked out.

- However, we must not forget that at least one alternative counterpart to the *Fermi* source is present (AGN?). This could kill the gamma-ray binary idea …upsssss!!!!



Location of the AGN candidate in the **WISE Gamma-ray strip** (Massaro et al. 2012).

This fact renders it a very serious counterpart candidate to the *Fermi* LAT source!!!!

5. Conclusions and future perspectives

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Despite failures in the identfication of new GBs among LS stars, we are conviced that this series of catalogues remain as a promising niche for future discoveries.

The *WISE Blazar Strip* approach has found a useful utility beyond its original purpose in extragalactic astrophysics.

Upcoming gamma-ray observatories with improved sensitivity and angular resolution, suchs as the *Cherenkov Telescope Array* (CTA), years will play a major role in future discovries.

Thank you!!!