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Communication

Searching for Gamma-Ray Binaries in Multiwavelength Catalogs

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Abstract: The number of gamma-ray binaries currently known is still so small that even a new finding represents a significant expansion of its population. We present a possible hunting strategy based on screening different catalogs to filter potential peculiar stars consistent with gamma-ray sources whose association at lower energies is not yet certain. So far, two candidate systems have emerged from this process; we report about them here.

Keywords: gamma-ray stars; X-ray stars; variable stars

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1. Introduction

Gamma-ray binary stars are one of the hottest topics that have been added to the domain of high- and very-high-energy astrophysics in the last twenty years. It is mainly in these stellar systems where energetic acceleration and nonthermal emission processes can be easily studied on human time scales and under repetitive conditions along their orbital cycles. Despite their low number ($\sim$10), their importance has been widely recognized and reviewed by several authors [1–5]. Moreover, they are expected to play a major role as priority targets of future gamma-ray observatories [6]. This remains true even if the perspectives for future discoveries are not extremely optimistic considering that the estimated Milky Way population does not exceed $\sim 10^2$ systems [7]. The most recent successful additions to the scarce census of gamma-ray binaries resulted thanks to systematic searches for periodic gamma ray signals in data from the *Fermi* space observatory [8,9].

In the context provided above, different search approaches are worthwhile to be explored. We notice here that a significant fraction of currently known (or suspected) gamma-ray binaries are associated with bright optical objects already present in historical catalogs of luminous or emission line stars [10–12]. The Be star MWC656, proposed to be the counterpart of an AGILE transient source and hosting a black hole companion [13,14], stands out as a recent example. Other systems with bright optical counterparts, such as LS I +61°303, LS 5039, or MWC 148, were also flagged as peculiar stars and included in these old catalogs decades before their gamma-ray detection. This circumstance prompted us to develop an alternative strategy to find signatures of any nonthermal phenomena in early-type stars by cross-correlating their spectroscopic catalogs with modern multiwavelength surveys [15]. In fact, LS 5039 itself was first spotted in this way as an extraordinary nonthermal radio emitter [16] prior to its later recognition as a true gamma-ray binary [17].

In this paper, we present an updated account of our efforts to pursue this search from which a couple of interesting candidates recently emerged. The work being conducted is scientifically worthwhile to be carried out, even if no positive reliable identifications finally occur. Some of the past benefits in this process have been to narrow dubious identifications of blazar sources [18] or the discovery of new eclipsing binary systems [19].

2. Materials and Methods

Nonthermal emission mechanisms in stars are often a clear tracer of relativistic electron populations that, in turn, could be related to the production of much higher energy photons in the gamma-ray domain. Our previous radio searches for nonthermal stars were severely limited by the sensitivity and angular resolution of present-day surveys at centimetric wavelengths. In this way, the candidates reported in [15] were simple line-of-sight coincidences within a few arc-seconds of luminous stars with synchrotron emitting radio sources of extragalactic origin. Here, we explore a more straightforward approach by directly cross-identifying the spectroscopic stellar catalogs quoted above with the latest 4th Fermi catalog of gamma-ray sources [20]. In particular, its incremental 10-year version (4FGL-DR2) was used as starting point. The different steps followed in this process are illustrated in Figure 1.

The raw outcome of this cross-identification exercise amounted to more than a hundred of potentially interesting objects. Among them, some of the well-known gamma-ray binaries were blindly recovered. This is indeed reassuring, but for the rest of stars, they need to be considered with care. Certainly, the position agreement of an object with the typical, few arc-minute, 95% confidence Fermi ellipse does not guarantee at all a physical association with the gamma-ray source. Additional constraints need to be applied in order to narrow the search.

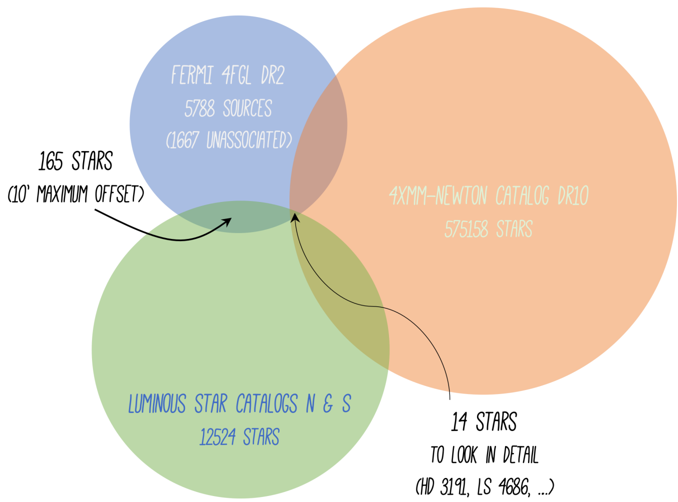

Figure 1. Sketch showing the multiple cross-identification procedure followed in this work.

First of all, we restricted our exploration to coincidences with Fermi unassociated sources or to sources with a tentative association at lower energies. To us, this means sources with a blank or dubious association in the Fermi catalog. Second, one needs to filter the raw candidate list by pinpointing any evidence suggestive of a posible connection with the high-energy emitter. This could include the display of X-ray or radio emission, periodic variability, or spectral accretion disk signatures, among other peculiarities. At this point, only stars with a reliable X-ray counterpart were allowed to proceed in the search. We admit this constraint even if the X-ray luminosity is below that of typical X-ray binary systems to avoid excluding quiescent X-ray binary systems such as MWC 656 in the search. We used the latest 4XMM-DR10 X-ray catalog [21], whose arc-second astrometric accuracy allows reliable stellar counterpart identifications, for this purpose. However, even with all of these cautions in mind, every object is different and requires a case-by-case study that is not always conclusive.

After surveying the literature for the 14 remaining X-ray detected stars, two of them attracted our attention as plausible alternatives to the proposed 4FGL counterpart identifications of two Fermi sources, namely 4FGL J0035.8+6131 and 4FGL J1808.8-1949c. We refer here to the early-type stars HD 3191 and LS 4686. Their corresponding X-ray counterparts are the sources 4XMM J003550.8+612735 and 4XMM J180827.0-195207. Both stars have relatively low values of their X-ray to bolometric luminosity ratio. Based on the XMM average count rates, known spectral types, and distances, L_X/L_{bol} values of 4×10^{-7} and

1×10^{-8} were found, respectively. While these estimates could agree with a single stellar object, they cannot strictly exclude the existence of a binary companion because of the large scatter in the L_X/L_{bol} relation for B-type stars [22]. For instance, the ratio found in the MWC 656 case is just a few times 10^{-8}.

As HD 3191 and LS 4686 are bright optical objects, follow-up observations using the recently available spectrograph at the OUJA facilities in Jaén (Spain) were undertaken. This is a university observatory with a 0.4 m telescope equipped for accurate $UBVR_cI_c$ photometry and low-resolution ($\lambda/\Delta\lambda \simeq 1000$) spectroscopy up to magnitudes $V \simeq$ 10–12 even under the light pollution of its urban location [23]. Additional archival resources from the TESS space observatory for photometry were also used when available. In the following sections, we present and discuss the main findings that support the tentative gamma-ray candidacy of these two stars.

3. Results and Discussion on HD 3191

While our methodology identified this bright ($V = 8.6$) star with spectral type B1IVnn as a potential gamma-ray source, we soon realized that previous authors already pointed a possible Fermi source connection for it. Together with a possible blazar of unknown type (LQAC 008+061 [24]), HD 3191 has been proposed as candidate counterpart to the Fermi transient J0035+6131 [25,26]. The transient detection is now consistent with the gamma-ray source 4FGL J0035.8+6131 in the latest Fermi catalog (see Figure 2).

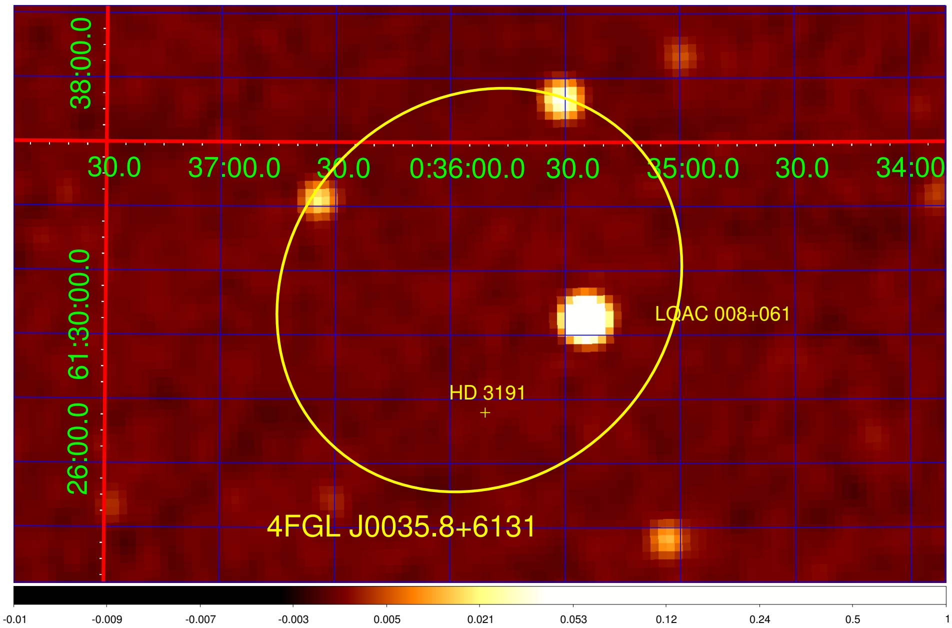

Figure 2. View of the 95% confidence ellipse of Fermi source 4FGL J0035.8+6131 plotted against the NRAO VLA Sky Survey image at the 20 cm wavelengths [27]. The brightest radio source is LQAC 008+061, which has been proposed as a blazar counterpart candidate. The small cross marks the HD 3191 location, which is also consistent with the Fermi ellipse. Red axes display J2000.0 equatorial coordinates and the horizontal scale indicates the radio brightness scale in Jy beam^{-1}.

At first glance, the relatively short duration of the gamma-ray flare (few days) points to a similarity with an active galactic nucleus as pointed out in [26]. However, having an outstanding B-type star inside the uncertainty ellipse of a Fermi transient was, in our view, strongly reminiscent of the MWC 656 case. Although flares from binaries usually develop on longer time scales (several days), in some systems, comparable shorter events have been occasionally detected, at least in soft gamma-rays [28]. This encouraged us to start an observational investigation on HD 3191 in order to see if the MWC 656 parallelism could be strengthened. For this purpose, we conducted a series of spectroscopic observations of HD 3191 complemented with the analysis of TESS data. The main results are outlined below, while the reader is referred to [29] for a more detailed account.

The first finding of this campaign was the discovery of an He II emission line in HD 3191 as shown in Figure 3. This is not frequent in B-type stars, as it requires a source of hot photons in order to ionize helium atoms. The line persisted over other nights of observation with variable intensity. At this point, we remind the reader that a similar emission feature from an accretion disk in MWC 656 was what prompted its identification as a black hole system[14]. Unfortunately, the currently available OUJA data lacks enough spectral resolution for radial velocity studies. In any case, the presence of He II emission in both HD 3191 and MWC 656, the two of them toward flaring gamma-ray sources, is a puzzling coincidence that deserves further investigation.

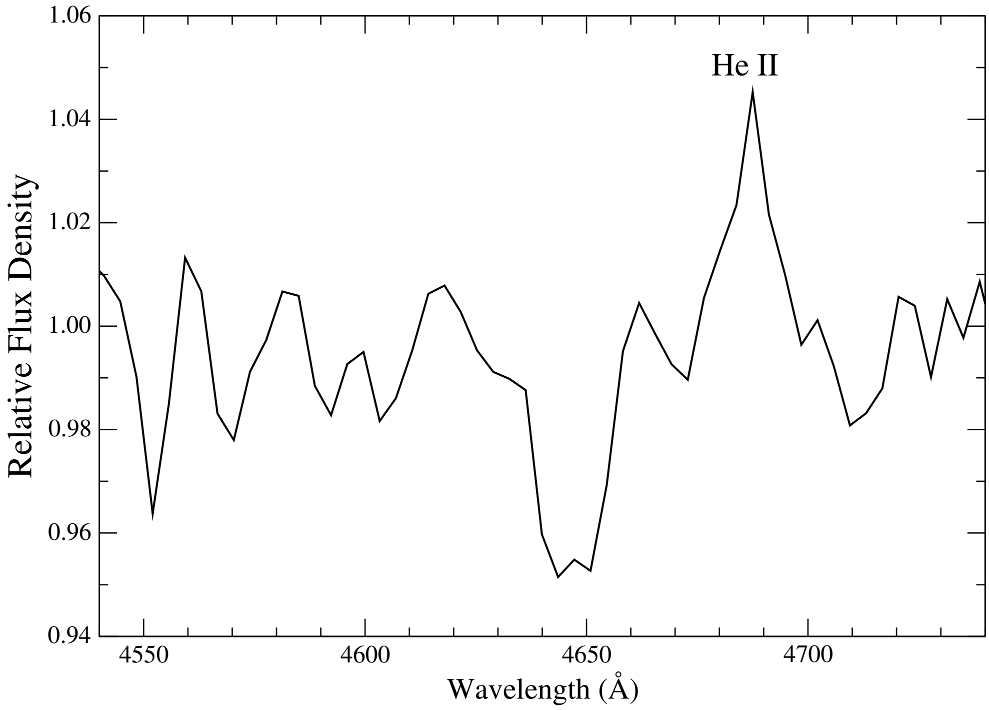

Figure 3. Low-resolution optical spectrum of HD 3191 as observed from the OUJA on 16 December 2019. The He II emission line at 4686 Å is prominently detected above the stellar continuum.

Another important finding of this work came from the analysis of OUJA and TESS photometry. Based on the periodicity separately detected in the respective HD 3191 optical light curves, an independent confirmation that this star is indeed a binary system was obtained [29]. The best estimate of the HD 3191 orbital period amounts to 16.09 ± 0.01 d. To illustrate this cycle, in Figure 4, we show a partial HD 3191 light curve created from TESS FFI data of sky sector #24. The large (± 0.02 mag) amplitude modulation can be interpreted in terms of ellipsoidal variability as the distorted optical star is seen from different perspectives along its orbit. The estimated sixteen day period remained stable over the whole duration of TESS data that covered about half of a year. The shorter suborbital oscillations were also found to display a period close to 0.6 d. However, its interpretation in terms of stellar rotation or pulsation still remains controversial.

A preliminary attempt to test the existence of the orbital period in the *Fermi*-LAT light curve of 4FGL J0035.8+6131 turned out to produce negative results. In particular, we performed our search with the phase dispersion minimization (PDM) technique [30] in the 10–60 d interval, with a time binning of 3 d and in the 0.3–10 GeV energy range. Only the instrumental periodic components due to the satellite precession (53.4 d) were present in the periodograms. In any case, knowing the orbital cycle leaves the door open to apply the period search approach with future Fermi data. This could lead to a final identification, but we have to keep in mind the difficulties to find a consistent gamma-ray period if the high energy emission is actually not persistent.

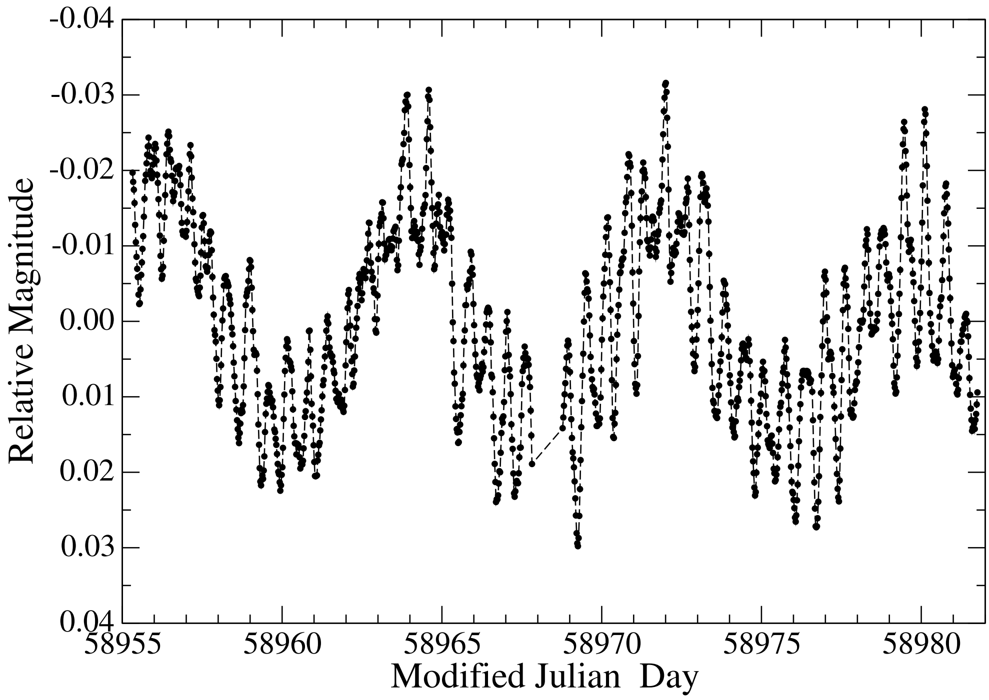

Figure 4. Section of the TESS light curve of HD 3191 during 2020 April/May covering about one and a half orbital periods. The fast intraday oscillations are suspected to be caused by stellar rotation or pulsation.

4. Results and Discussion on LS 4686

LS 4686 is a bright ($V = 8.4$ mag) supergiant star of early Be spectral type. It sky position is just at the edge of the Fermi source 4FGL J1808.8-1949c[1] as displayed in Figure 5. In fact, it is located as close to the center of the Fermi ellipse as the globular cluster 2MASS-GC01 [31] associated with it according to the 4FGL catalog. Both objects appear just outside the Fermi ellipse. Incidentally, there is also another X-ray and bright early-type star consistent in position with the Fermi emission, HD 165918 with B5 IV/V classification, but without emission lines reported so far. Concerning the strong radio sources inside the Fermi ellipse, they are apparently of ordinary thermal nature being related to an HII region [32] and a young stellar object [33]. High-energy emission from this kind of sources seems less likely, although one has to keep in mind that it is not impossible. For instance, diffuse gamma-ray emission has been recently claimed from the star-forming region W40, also in the vicinity of a cluster, but in this case, a young one [34]. In this context, the presence of a Be star such as LS 4686 is certainly appealing and worthwhile to be considered in addition to the globular cluster identification. Moreover, pulsarlike candidates from the 2MASS-GC01 region have been searched for in recent times, but none have been reported so far [35].

Spectra of LS 4686 were repeatedly acquired from OUJA showing strong Hα emission that confirms the star Be classification. We paid special attention to the He II region. Only on 2020 September 2, hints of a possible double-peaked emission line were observed (see Figure 6). If this marginal detection was real, the Keplerian rotation velocities involved would be as high as 500 km s^{-1}. Additional observations are still required to confirm the reality of this feature.

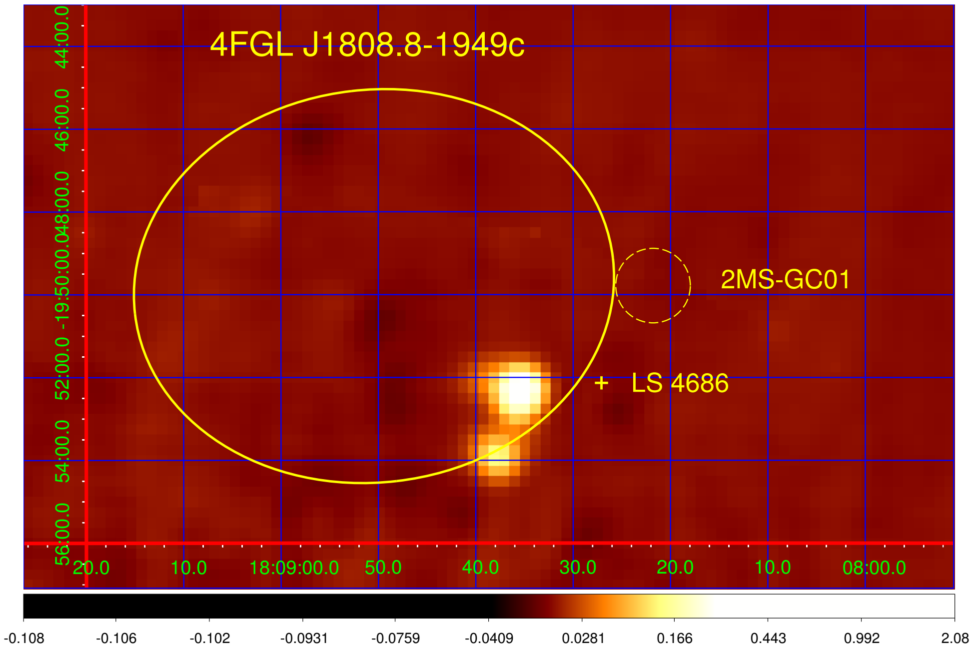

Figure 5. View of the 95% confidence ellipse of Fermi source 4FGL J1808.8-1949c plotted against the NRAO VLA Sky Survey image at the 20 cm wavelengths [27]. The brightest radio sources inside are of thermal nature. The small cross marks the LS 4686 location; the dashed circle represents the globular cluster 2MASS-GC01 in the field. Red axes display J2000.0 equatorial coordinates and the horizontal scale indicates the radio brightness scale in Jy beam^{-1}.

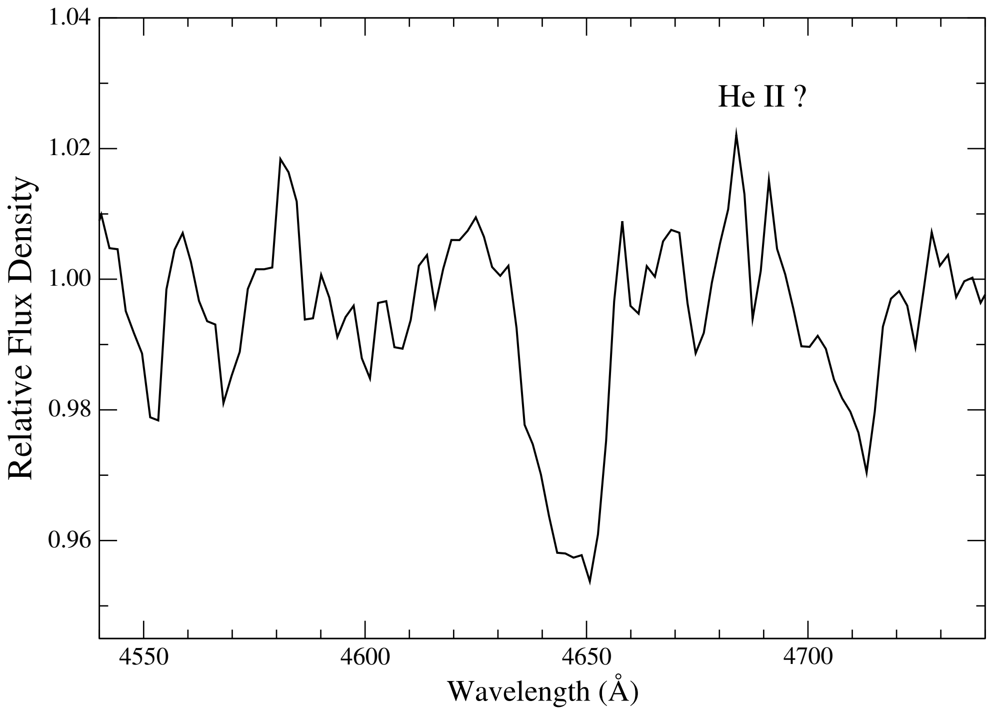

Figure 6. Low-resolution optical spectrum of LS 4686 as observed from the OUJA on 2020 September 2. The double-peaked He II emission line at 4686 Å could be present barely above the stellar continuum.

We have also searched for optical photometric variability of LS 4686 that could reveal a binary companion. Unfortunately, this star is not yet covered in public TESS sectors, although other less accurate but useful photometric surveys are available. In particular, a light curve with several years of time span could be retrieved from the the ASAS-SN Variable Stars Database [36,37], and we show it in Figure 7. A long-term variability trend, with ∼0.1 amplitude, is clearly visible that could be related to slow changes in the Be circumstellar envelope. A periodicity analysis was carried out using the PDM algorithm [30] trying to find evidence for an orbital period, but none was found. For trial periods below 200 days, the only deep minima in the PDM periodogram (not shown here) were too close to the sidereal and synodic periods of the Moon and some harmonics. Similarly, additional deep minima for longer periods were placed too close to the beating periods between these two cycles. Therefore, all these features look like mere artifacts of the time sampling window and should be ignored. Photometric variability in LS 4686 seems reliably detected, but testing its periodicity clearly requires higher-quality photometric observations.

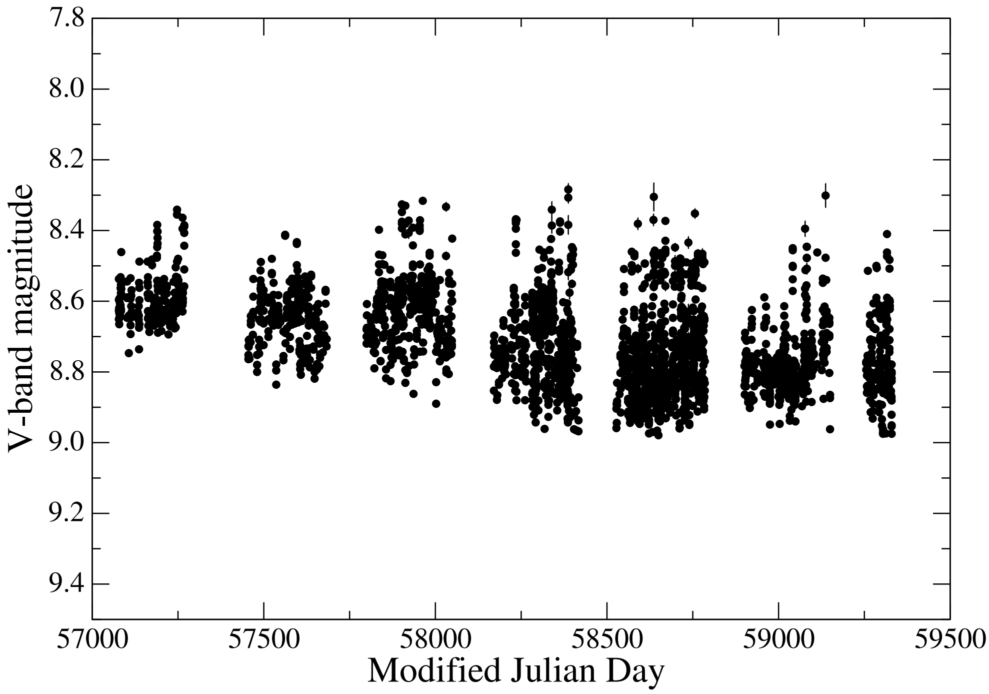

Figure 7. *V*-band light curve of LS 4686 over several years from the ASAS-SN Variable Stars Database.

5. Conclusions

We have developed a multiwavelength cross-identification approach to select distinctive luminous stars toward gamma-ray sources whose low-energy counterparts remain yet uncertain. In our view, these stellar objects deserve to be taken into account and followed up observationally, especially in the galactic plane. This effort is potentially rewarding even if alternative counterpart candidates are apparently more likely.

Up to now, our catalog-based practice has signaled the early-type and X-ray stars HD 3191 and LS 4686 as remarkable objects toward the gamma-ray sources 4FGL J0035.8+6131 and 4FGL J1808.8-1949c, respectively. Evidence, or at least some hint, of ionized helium emission is present in their optical spectra, a fact that renders them reminiscent of the gamma-ray binary candidate MWC 656. HD 3191 is confirmed as a binary system with an orbital period of about 16 d based on TESS photometric data analysis. Although the fingerprint of this cycle remains presently undetected in gamma-rays, an eventual future detection would exclude an alternative blazarlike counterpart also inside the Fermi ellipse. LS 4686 stands as a Be star next to another Fermi source location and slightly closer in the sky than a nearby globular cluster also proposed as the counterpart. For this star, optical variability is detected, although a reliable photometric period to be searched for in gamma-rays is still awaiting for more data to be gathered.

All these results reinforce the need for caution in the painful task of identifying high-energy sources, particularly in the galactic plane where gamma-ray binaries may play a role more important than anticipated.

Author Contributions: J.M. and P.L.L.-E. contributed similarly. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: OUJA data is available from the authors on request. TESS data is available from the Mikulski Archive for Space Telescopes (MAST) at https://archive.stsci.edu (accessed on 1 June 2021).

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviation

The following abbreviations are used in this manuscript:

LS	Luminous stars
MWC	Mount Wilson Catalog
HD	Henry Draper Catalog
LQAC	Large Quasar Astrometric Catalog
OUJA	Observatorio astronómico de la Universidad de Jaén
4FGL	4th Fermi LAT Catalog
TESS	Transiting Exoplanet Survey Satellite
FFI	Full Frame Image
4XMM-DR10	XMM-Newton serendipitous source catalog
ASAS-SN	All-Sky Automated Survey for Supernovae
PDM	Phase Dispersion Minimization

Notes

[1] The letter c stands for coincidence with a interstellar clump. It was also detected in the previous Fermi LAT catalog as 3FGL J1808.5-1952.

References

1. Chernyakova, M.; Malyshev, D. Gamma-ray binaries. In Proceedings of the Multifrequency Behaviour of High Energy Cosmic Sources—XIII, Palermo, Italy, 3–8 June 2019; p. 45.
2. Paredes, J.M.; Bordas, P. Broad-band Emission from Gamma-ray Binaries. In Proceedings of the Frontier Research in Astrophysics—III, Palermo, Italy, 28 May–2 June 2018; p. 44.
3. Lamberts, A. γ-ray Binaries: A Bridge Between Be Stars and High Energy Astrophysics Invited Review. In *Bright Emissaries: Be Stars as Messengers of Star-Disk Physics*; Sigut, T.A.A., Jones, C.E., Eds.; Astronomical Society of the Pacific Conference Series; ASP: San Francisco, CA, USA, 2016; Volume 506, p. 231.
4. Dubus, G. Gamma-ray emission from binaries in context. *Comptes Rendus Phys.* **2015**, *16*, 661–673. [CrossRef]
5. Dubus, G. Gamma-ray binaries and related systems. *Astron. Astrophys. Rev.* **2013**, *21*, 64. [CrossRef]
6. Paredes, J.M.; Bednarek, W.; Bordas, P.; Bosch-Ramon, V.; De Cea del Pozo, E.; Dubus, G.; Funk, S.; Hadasch, D.; Khangulyan, D.; Markoff, S.; et al. Binaries with the eyes of CTA. *Astropart. Phys.* **2013**, *43*, 301–316. [CrossRef]
7. Dubus, G.; Guillard, N.; Petrucci, P.O.; Martin, P. Sizing up the population of gamma-ray binaries. *Astron. Astrophys.* **2017**, *608*, A59. [CrossRef]
8. Corbet, R.H.D.; Chomiuk, L.; Coe, M.J.; Coley, J.B.; Dubus, G.; Edwards, P.G.; Martin, P.; McBride, V.A.; Stevens, J.; Strader, J.; et al. A Luminous Gamma-ray Binary in the Large Magellanic Cloud. *Astrophys. J.* **2016**, *829*, 105. [CrossRef]

9. Corbet, R.H.D.; Chomiuk, L.; Coe, M.J.; Coley, J.B.; Dubus, G.; Edwards, P.G.; Martin, P.; McBride, V.A.; Stevens, J.; Strader, J.; et al. Discovery of the Galactic High-mass Gamma-Ray Binary 4FGL J1405.1-6119. *Astrophys. J.* **2019**, *884*, 93. [CrossRef]
10. Hardorp, J.; Rohlfs, K.; Slettebak, A.; Stock, J. Luminous stars in the Northern Milky Way. Part I. *Hambg. Sternw. Warn. Swasey Obs.* **1959**, *C01*.
11. Wackerling, L.R. A catalogue of early-type stars whose spectra have shown emission lines. *Mem. R. Astron. Soc.* **1970**, *73*, 153. [CrossRef]
12. Stephenson, C.B.; Sanduleak, N. *VizieR Online Data Catalog: Luminous Stars in the Southern Milky Way (Stephenson+ 1971)*; VizieR Online Data Catalog: Strasbourg, France, 1995; p. III/43.
13. Casares, J.; Ribó, M.; Ribas, I.; Paredes, J.M.; Vilardell, F.; Negueruela, I. On the binary nature of the γ-ray sources AGL J2241+4454 (= MWC 656) and HESS J0632+057 (= MWC 148). *Mon. Not. R. Astron. Soc.* **2012**, *421*, 1103–1112. [CrossRef]
14. Casares, J.; Negueruela, I.; Ribó, M.; Ribas, I.; Paredes, J.M.; Herrero, A.; Simón-Díaz, S. A Be-type star with a black-hole companion. *Nature* **2014**, *505*, 378–381. [CrossRef]
15. Martí, J.; Luque-Escamilla, P.L.; Casares, J.; Marcote, B.; Paredes-Fortuny, X.; Ribó, M.; Paredes, J.M.; Núñez, J. In quest of non-thermal signatures in early-type stars. *Astrophys. Space Sci.* **2015**, *356*, 277–284. [CrossRef]
16. Marti, J.; Paredes, J.M.; Ribo, M. The system LS 5039: A new massive radio emitting X-ray binary. *Astron. Astrophys.* **1998**, *338*, L71–L74.
17. Aharonian, F.; Akhperjanian, A.G.; Aye, K.M.; Bazer-Bachi, A.R.; Beilicke, M.; Benbow, W.; Berge, D.; Berghaus, P.; Bernlöhr, K.; Boisson, C.; et al. Discovery of Very High Energy Gamma Rays Associated with an X-ray Binary. *Science* **2005**, *309*, 746–749. [CrossRef]
18. Martí, J.; Sánchez-Ayaso, E.; Luque-Escamilla, P.L.; Paredes, J.M.; Bosch-Ramon, V.; Corbet, R.H.D. A blazar as the likely counterpart to 4FGL J0647.7-4418 instead of a gamma-ray binary. *Mon. Not. R. Astron. Soc.* **2020**, *492*, 4291–4297. [CrossRef]
19. Martí, J.; Luque-Escamilla, P.L.; Paredes, J.M.; Iwasawa, K.; Galindo, D.; Ribó, M.; Marín-Felip, V. Peculiar objects towards 3FGL J0133.3+5930: An eclipsing Be star and an active galactic nucleus. *Astron. Astrophys.* **2017**, *598*, A81. [CrossRef]
20. Abdollahi, S.; Acero, F.; Ackermann, M.; Ajello, M.; Atwood, W.B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Bastieri, D.; et al. Fermi Large Area Telescope Fourth Source Catalog. *Astrophys. J. Suppl. Ser.* **2020**, *247*, 33. [CrossRef]
21. Webb, N.A.; Coriat, M.; Traulsen, I.; Ballet, J.; Motch, C.; Carrera, F.J.; Koliopanos, F.; Authier, J.; de la Calle, I.; Ceballos, M.T.; et al. The XMM-Newton serendipitous survey. IX. The fourth XMM-Newton serendipitous source catalogue. *Astron. Astrophys.* **2020**, *641*, A136. [CrossRef]
22. Nazé, Y. Hot stars observed by XMM-Newton. I. The catalog and the properties of OB stars. *Astron. Astrophys.* **2009**, *506*, 1055–1064. [CrossRef]
23. Martí, J.; Luque-Escamilla, P.L.; García-Hernández, M.T. The University of Jaén Astronomical Observatory. *Bulg. Astron. J.* **2017**, *26*, 91.
24. Souchay, J.; Andrei, A.H.; Barache, C.; Kalewicz, T.; Gattano, C.; Coelho, B.; Taris, F.; Bouquillon, S.; Becker, O. The third release of the Large Quasar Astrometric Catalog (LQAC-3): A compilation of 321 957 objects. *Astron. Astrophys.* **2015**, *583*, A75. [CrossRef]
25. Pandel, D.; Kaaret, P. Possible X-ray Detection of Fermi J0035+6131. *Astron. Telegr.* **2016**, *8783*, 1.
26. Pandel, D.; Kaaret, P. Rapid Flaring in the Galactic-plane Gamma-Ray Transient Fermi J0035+6131. *Astrophys. J.* **2018**, *862*, 83. [CrossRef]
27. Condon, J.J.; Cotton, W.D.; Greisen, E.W.; Yin, Q.F.; Perley, R.A.; Taylor, G.B.; Broderick, J.J. The NRAO VLA Sky Survey. *Astron. J.* **1998**, *115*, 1693–1716. [CrossRef]
28. Hjellming, R.M.; Rupen, M.P.; Hunstead, R.W.; Campbell-Wilson, D.; Mioduszewski, A.J.; Gaensler, B.M.; Smith, D.A.; Sault, R.J.; Fender, R.P.; Spencer, R.E.; et al. Light Curves and Radio Structure of the 1999 September Transient Event in V4641 Sagittarii (=XTE J1819-254=SAX J1819.3-2525). *Astrophys. J.* **2000**, *544*, 977–992. [CrossRef]
29. Martí, J.; Luque-Escamilla, P.L.; Sánchez-Ayaso, E.; Paredes, J.M. Orbital and sub-orbital period determination of the candidate high-mass X-ray binary HD 3191. *arXiv* **2021**, arXiv:2105.03189.
30. Stellingwerf, R.F. Period determination using phase dispersion minimization. *Astrophys. J.* **1978**, *224*, 953–960. [CrossRef]
31. Hurt, R.L.; Jarrett, T.H.; Kirkpatrick, J.D.; Cutri, R.M.; Schneider, S.E.; Skrutskie, M.; van Driel, W. Serendipitous 2MASS Discoveries near the Galactic Plane: A Spiral Galaxy and Two Globular Clusters. *Astron. J.* **2000**, *120*, 1876–1883. [CrossRef]
32. Bronfman, L.; Nyman, L.A.; May, J. A CS(2-1) survey of IRAS point sources with color characteristics of ultra-compact HII regions. *Astron. Astrophys. Suppl. Ser.* **1996**, *115*, 81.
33. Urquhart, J.S.; Hoare, M.G.; Purcell, C.R.; Lumsden, S.L.; Oudmaijer, R.D.; Moore, T.J.T.; Busfield, A.L.; Mottram, J.C.; Davies, B. The RMS survey. 6 cm continuum VLA observations towards candidate massive YSOs in the northern hemisphere. *Astron. Astrophys.* **2009**, *501*, 539–551. [CrossRef]
34. Sun, X.N.; Yang, R.Z.; Liang, Y.F.; Peng, F.K.; Zhang, H.M.; Wang, X.Y.; Aharonian, F. Diffuse γ-ray emission toward the massive star-forming region, W40. *Astron. Astrophys.* **2020**, *639*, A80. [CrossRef]
35. Hui, C.Y.; Lee, J.; Li, K.L.; Kim, S.; Oh, K.; Luo, S.; Leung, A.P.; Kong, A.K.H.; Takata, J.; Cheng, K.S. Searches for pulsar-like candidates from unidentified objects in the Third Catalog of Hard Fermi-LAT Sources with machine learning techniques. *Mon. Not. R. Astron. Soc.* **2020**, *495*, 1093–1109. [CrossRef]

36. Shappee, B.J.; Prieto, J.L.; Grupe, D.; Kochanek, C.S.; Stanek, K.Z.; De Rosa, G.; Mathur, S.; Zu, Y.; Peterson, B.M.; Pogge, R.W.; et al. The Man behind the Curtain: X-Rays Drive the UV through NIR Variability in the 2013 Active Galactic Nucleus Outburst in NGC 2617. *Astrophys. J.* **2014**, *788*, 48. [CrossRef]
37. Kochanek, C.S.; Shappee, B.J.; Stanek, K.Z.; Holoien, T.W.S.; Thompson, T.A.; Prieto, J.L.; Dong, S.; Shields, J.V.; Will, D.; Britt, C.; et al. The All-Sky Automated Survey for Supernovae (ASAS-SN) Light Curve Server v1.0. *Publ. Astron. Soc. Pac.* **2017**, *129*, 104502. [CrossRef]