Optical studies of potential counterparts for unidentified EGRET sources

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Abstract. We present optical observations of candidate X-ray counterparts for the EGRET sources 3EG J2020+4017, 3EG J0010+7309 and 3EG J1835+5918. Preliminary spectroscopic observations of the late-type star coincident with the X-ray counterpart of 3EG J2020+4017, the γ-Cygni source, show no evidence of binariety. In the case of 3EG J0010+7309, the CTA-1 source, we performed deep optical imaging, finding a red $V \sim 22$ magnitude object inside the ROSAT contour. Finally, a detailed analysis of optical observations of several X-ray sources within the EGRET error box of 3EG J1835+5918 is presented.

THE IDENTIFICATION PROGRAMME

The Third EGRET catalog contains 170 unidentified of high-energy γ-ray sources. The distribution of these objects in the sky indicates a strong Galactic component. Unidentified EGRET sources are concentrated towards the Galactic Plane and Galactic Centre, in a similar way than pulsars, the only identified Galactic population of high-energy γ-ray emitters. The identification of Geminga, the second brightest source in the sky in the range $E_\gamma > 100\,\mathrm{MeV}$, as a radio-quiet pulsar ([5]) opened the possibility that some of these sources could be of the same nature. In fact, it is expected that at least a fraction of the unidentified EGRET sources *are* Geminga-type pulsars.

Our identification programme follows the steps which led to the identification of Geminga and is aimed at identifying the best radio-silent candidates through observations at different spectral bands, mainly X-rays and optical. Apart from our data, we rely on the public radio data, like those from the Green-Bank survey at 4.85 GHz ([4]), through the study presented in [6] regarding the identifications

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of γ-ray sources with radio-loud flat-spectrum sources. None of the sources studied has a strong association with radio-loud flat-spectrum sources.

We start selecting bright, non-variable γ-ray sources, and compute an improved positional error-box using photons with energies above 1 GeV, taking advantage of the narrower EGRET point-spread function at GeV energies. We then proceed to identify X-ray point sources from X-ray images of the $\geq$ 1 GeV error-box, which then are targets of optical follow-up observations. Up to now ROSAT archival data and pointed observations have been used for the X-ray analysis.

Optical observations of the ROSAT X-ray candidate counterparts of the given unidentified EGRET source are useful to identify the best of these candidates. Radio-quiet AGNs, Seyfert, starburst, normal galaxies, binary and flaring stars can be X-ray sources without expected detectable γ-ray emission. Finding no likely optical counterpart for a given X-ray source strengthens the case for the association between the X-ray and γ-ray sources. And at some level, faint blue optical objects can also be considered neutron star candidates on their own right. The ultimate goal of our programme is finding pulsations in X-ray data and test the γ-ray data for their presence.

Optical observations presented here have been carried out with the 2.12m telescope of the Observatorio Astrofísico Guillermo Haro (Cananea, Sonora) and with the 6m telescope of the Special Astrophysical Observatory (Zelenchuk, Russia). We present results for: (i) 3EG J2020+4017 (γ-Cygni); (ii) 3EG J0010+7309 (CTA-1) and, (iii) 3EG J1835+5918.

3EG J2020+4017: THE γ-CYGNI SOURCE

The multiwavelength analysis of this EGRET and COS-B source was presented in [1]. A single X-ray point source was found within the γ-ray ($\geq$ 1 GeV photons) error-box of 3EG J2020+4026, the region also showing extended X-ray emission, reminiscent of SN remnants. Inside the X-ray $\lesssim$ 10" ROSAT-HRI error box is located a 14.5 magnitude star, spectroscopically identified as K0V, late-type star, with no signs of chromospheric activity and therefore ruled out as γ-ray source and the X-ray source.

We performed spectroscopic observations using the Boller & Chivens spectrograph at the 2.12m Cananea telescope on September 27 and 29, 1997. The purpose of these was to test the K0V star for orbital motion looking at the λ5890 NaI absorption line, with a sampling of 0.43Å/pixel. Preliminary analysis shows no sign of doppler orbital displacements. Although more systematic observations -considering the expected ranges of periods and velocity amplitudes- might be of interest, we conclude unlikely that the K0V star might have a neutron star companion. Imaging observations of the star are underway to detect fainter objects inside the ROSAT error box.

3EG J0010+7309 = CTA-1

The multiwavelength analysis of this EGRET source, previously associated with a radio-l;oud AGN, was presented in [2]. The improved X-ray contours ruled out the association with the AGN and a single ROSAT source, RX J0007.0+7302 is included inside the 95% confidence γ-ray contour. Independent analysis by [8] concludes this X-ray source to be a plerion. BVRI observations with the 2.12m inside the X-ray $\lesssim$ 10" ROSAT-HRI error box of RX J0007.0+7302 showed no optical counterpart down to $R \gtrsim 23$.

We performed observations with the 6m telescope at SAO in November 19, 1997, under poor seeing conditions. BVR images (figure shows the R image) clearly show a point source, of R magnitude between 22 and 23, which in fact can be seen in the original Cananea R and I images shown in Fig 4 of [2], just below the detection level for the 2m images. The 6m R image has a detection limit of about 24.5 magnitudes and only the cited object is seen above that threshold.

Further observations under good -photometric- conditions were performed this year (to be reported in detail elsewhere, [3]). The visual magnitude is estimated as V=22.59 $\pm$ 0.09, with the object showing clear red colours (V-R=0.92$\pm$0.10). The magnitude limit of these new images is around 25th magnitude. The colours are more consistent with a faint dwarf star or a late-type galaxy than with a neutron star, weakening its possible association with the X-ray and γ-ray source(s). Spectroscopic identification might require 8-10m class telescope.

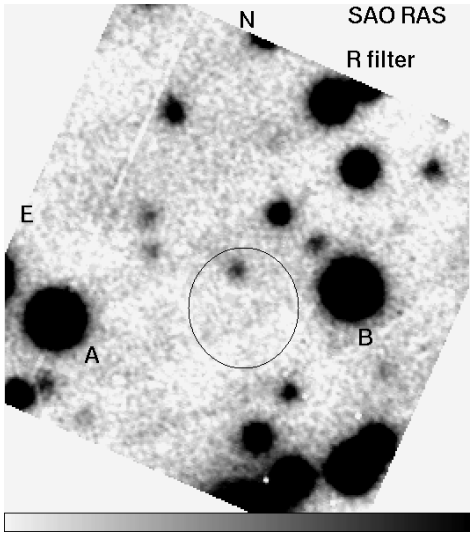

FIGURE 1. SAO 6m R image of the ROSAT error box of RX J0007.0+7302.

3EG J1835+5919

HRI observations of this bright EGRET source were performed during ROSAT AO8. Our analysis found ten X-ray point sources, which we labelled as X1 to X10 and targetted for optical observations. Although the improved 95% confidence GeV error-box excludes X1 and X10 we did include them in the optical study. A more complete multiwavelength analysis of 3EG J1835+5918 is presented elsewhere in these proceedings ([7]).

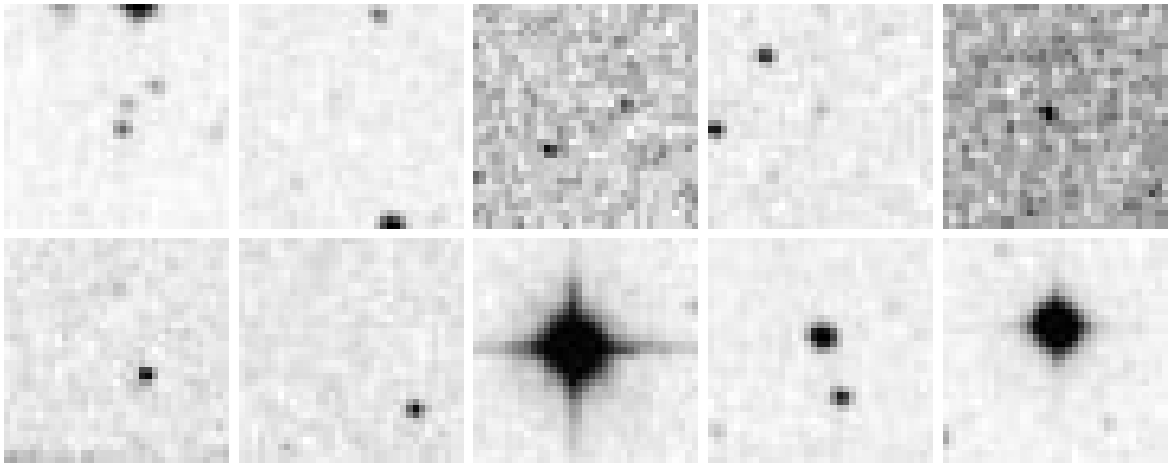

FIGURE 2. POSS 1×1 images centered in the positions of the ten X-ray sources found in the 3EG J1835+5919 region. Top images correspond, from left to right, to X1 to X5 and bottom images to X6 to X10

POSS 1×1 arcmin images of these sources are shown in Figure 2. From optical examination of these images the optical 2m follow-up strategy was decided. We summarize our results for each object:

- X1: this X-ray source is practically ruled out by positional arguments. Two objects are consistent with the X-ray position, and the spectrum obtained for the closest to the ROSAT position indicates a line emitting quasar, with $z \simeq 0.466$. We propose identifying this (radio-quiet) AGN with the X-ray source and ruling it out as counterpart for the γ-ray source.
- X2: a very faint object is seen. VRI imaging was performed, with preliminary analysis giving a non-detection in V ($m_V > 20.2$) and marginal detection in R ($m_R \simeq 20.5 \pm 0.7$). No conclusion is made on this object.
- X3: two objects lie just outside the ROSAT error box. VRI imaging performed, giving non detections inside the ROSAT contour. No conclusion is made.
- X4: very faint object inside error-box. VRI imaging performed, with weak detections ($m_V \simeq 19.0 \pm 0.2$ and $m_R \simeq 19.5 \pm 0.2$), suggesting a red object. Spectroscopy attempted with null results. No conclusion is made.

- X5: single object inside error-box, bright enough for spectroscopy. The spectrum shows an emitting line quasar at $z \simeq 1.865$. We propose identifying this (radio-quiet) AGN with the X-ray source and ruling it out as counterpart for the γ-ray source.
- X6: single object at the edge of the error-box, bright enough for spectroscopy. The spectrum indicates a late type star, probably a M5V star.
- X7: nothing inside error box; VRI imaging and spectroscopy of nearby object was performed. The S/N of the spectrum doesn't allow us to identify the object. No conclusion is made.
- X8: single very bright object at X-ray positions ($m_V \sim 11$). The spectrum obtained indicates a G dwarf star. We propose its identification as the X-ray source and ruling it out as the γ-ray source.
- X9: two fairly bright objects inside error box. Both spectra correspond to late type stars, M-type for the brightest and G for the faintest. The positional coincidence with the M star makes the identification likely, ruling it out as the γ-ray source.
- X10: practically ruled out by positional arguments. A single very bright object is at X-ray positions and its spectrum indicates a K5V star. We rule out the X-ray source as the γ-ray source.

In short we consider the association of X1, X5, X6, X8, X9 and X10 with the γ-ray source unlikely. We are left with four candidates (X2, X3, X4 and X7) which deserve further optical study. With the exception of X7, conclusive observations almost certainly require observations with a $>$ 4m telescope.

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