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A search for VHE γ-ray binaries in the H.E.S.S. Galactic Plane Scan

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Abstract: Utilising the unprecedented TeV sky coverage of the H.E.S.S. galactic plane scan, we present the results of a search for Very High Energy gamma-ray sources coincident with the positions of known X-ray binaries. Although no significant detections were obtained, upper limits to the TeV flux from 18 X-ray binaries were derived.

Introduction

The H.E.S.S. galactic plane scan [1] is an extensive survey of the inner part of the galaxy in TeV γ-rays. It consists of 230 hours of observation comprising 500 pointings between $\pm 30^\circ$ in galactic longitude and $\pm 3^\circ$ in galactic latitude. The average flux sensitivity of the scan is $\sim 2\%$ of the Crab nebula flux at photon energies above 200 GeV.

X-ray binaries are galactic systems containing a normal donor star which is in the process of transferring mass onto a compact object, such as a neutron star or black hole, to which it is gravitationally bound. A significant fraction of the gravitational potential liberated by this mass transfer is emitted as X-radiation, hence the nomenclature.

Some X-ray binaries are observed to eject a proportion of the accreted matter in collimated and often highly relativistic jets (See e.g. [2, 3]). These 'microquasars' are named for their structural similarities with Active Galactic Nuclei (AGN), several of which are known VHE γ-ray sources (See e.g. [4, 5]). Indeed, the extremes of temperature, pressure and radiation density likely to be generated close to the compact object in X-ray binary systems provide excellent conditions for the acceleration of charged particles to multi-TeV energies. Such acceleration, although not synonymous with VHE γ-ray emission, has nonetheless been identified as an apparent prerequisite for the production of photons with energies $E_\gamma > 200$ GeV.

Several plausible mechanisms exist which permit the generation of VHE γ-rays in X-ray binary systems. Indeed, both the necessary particle acceleration and the actual photon production can proceed via a number of potential avenues. In general, particle acceleration is thought to be accomplished at shock fronts either at the interface between the infalling matter and an outflow or jet , or within the outflow itself.

In systems where the companion is a low-mass star, the mass transfer proceeds mainly via Roche lobe overflow. In such systems particle acceleration can occur across internal shocks within the jet structures. In systems containing high-mass donor, accretion is often wind-fed, with high energy particles from the stellar wind being accreted onto the compact primary. If the primary is a pulsar, shocks can occur at the pulsar standoff distance, where the ram pressures due to the stellar and pulsar winds equilibrate [6].

Given a population of energetic charged particles, the mechanisms of γ-ray production may be broadly segregated into two categories: Those in which the emitting particles are hadronic, and those where they are leptons. Leptonic models closely resemble those used to explain the continuum spectra of AGN, relying as they do on the Synchrotron Self-Compton (SSC) and External Compton (EC) processes [7, 6, 8]. The SSC process involves the up-scattering of low energy synchrotron photons by the high energy electrons which generated them, while in the EC process, the target photons are generated elsewhere. In relativistic jets aligned close to the observer line-of-sight, the Comptonised radiation is both beamed and Doppler boosted, producing a measurable flux of photons in the TeV band.

While protonic SSC and EC processes are possible [9, 10], most hadronic emission models rely on the production and subsequent decay of neutral pions.

$$pp \rightarrow pp\pi^0 \rightarrow e^+e^-\gamma$$

For example, [11] and [12] show that pions and consequently TeV photons can be produced via the interaction of stellar wind protons with those in a microquasar jet.

Only three X-ray binary systems are known to emit VHE γ-rays. LS 5039 [13] and PSR B1259-63 [14] were detected by the H.E.S.S. Telescope array while in the northern hemisphere LS I +61°303 [15] has been observed by the MAGIC collaboration. While their detections by the MAGIC and H.E.S.S. collaborations confirm the existence of γ-ray binaries , the catalogue of such objects remains rather small. In terms of morphology, PSR B1259-63 is a Be star-pulsar binary with a 3.4 yr orbital period and while both LS 5039 and LS I +61°303 are high-mass X-ray binaries with donor masses of 23 and 12 $M_\odot$ and orbital periods of 3.9 and 26.5 days respectively. The nature of the compact primaries in both systems is uncertain, although the LS I +61°303 system seems likely to contain a pulsar [16]. [6] argues that despite observed milliarsecond radio structure [17, 18], the observed TeV emission of both LS I +61°303 and LS 5039 is rotationally derived from pulsars.

The aim of this work was to expand the catalogue of known γ-ray binaries and identify candidates for further observation. As galactic objects, X-ray binaries are concentrated in the plane of the galaxy. Consequently, the H.E.S.S. galactic plane scan is an excellent dataset for our purposes. We make no selections on the basis of target morphology and test the positions of all known X-ray binaries with sufficient exposure.

The Sample

As a source of targets for the search we utilise the catalogues of [19] for high-mass X-ray binaries and [20] for low-mass systems. The selection criteria required only that the target object was within 1.5° of the H.E.S.S. camera centre in at least one good observation run in the galactic plane scan. Run quality selection was carried out as discussed in [21] in an effort to minimise the systematic uncertainties introduced inherently by the telescope system itself and also by the atmosphere which, in effect, forms the scintilliating medium of the detector.

The resulting sample consists of 29 X-ray binaries comprising 8 high-mass systems with the remaining 21 having low-mass donors.

Analysis and Results

Data reduction and analysis were carried out using the standard H.E.S.S. analysis procedure outlined in [21]. The event selection cuts placed on image size, θ^2 and the mean reduced scaled parameters are identical to those described as standard in [21], and are consistent with the expected point-like nature of the target objects. The γ-ray background was estimated using a 'reflected' background model with several run dependent *off* regions defined the same distance from the camera camera as the on region. Areas of the sky containing known TeV γ-ray sources are precluded from being chosen as *off* regions to ensure that the background estimate remains as uncontaminated as possible. Nonetheless, contamination can occur when the *on* region coincides with a known γ-ray source. Despite having excellent angular resolution for an instrument of its type, the H.E.S.S. point spread function is somewhat extended, with a 68% containment radius of $\sim 0.1°$. For this reason it can be impossible to disentangle the signals from nearby objects. This is particularly difficult when the expected target spectrum and flux are unknown.

As reported in [1] the region exposed by the galactic plane scan is somewhat crowded with VHE γ-ray sources, and it is therefore unsurprising that some contamination of our targets did indeed occur. Table 1 outlines the results of the search. Up-

Target Name	Significance [σ]	Excess [counts]	Livetime [hours]	Mass	Flux Upper Limit ($E_\gamma > 1$ TeV) [ph cm^{-2}s^{-1}]
RX J1744.7-2713	1.367	114.874	7.71613	H	5.472×10^{-12}
AX J1749.2-2725	3.021	320.949	13.46	H	6.3659×10^{-12} (HESS J1747-281)
GRO J1750-27	1.521	94.006	4.715	H	1.050×10^{-11}
AX J1820.5-1434	-1.582	-22.290	4.339	H	1.507×10^{-12}
H 1833-076	1.074	23.038	8.075	H	1.882×10^{-12} (HESS J1837-069)
GS 1839-04	0.178	2.059	1.701	H	2.530×10^{-12}
AX 1845.0-0433	0.639	6.574	1.711	H	5.142×10^{-12}
2S 1845-024	0.805	7.111	1.711	H	5.142×10^{-12}
J1744-28	4.652	461.619	10.874	L	1.569×10^{-11} (HESS J1745-290)
1742.8-2853	11.202	1060.91	10.0287	L	2.564×10^{-11} (HESS J1745-290)
1742.9-2852	7.397	214.67	11.309	L	4.700×10^{-12} (HESS J1745-290)
1743.1-2852	6.064	177.667	11.741	L	4.013×10^{-12} (HESS J1745-290)
1742.9-2849	5.553	162.729	11.741	L	3.637×10^{-12} (HESS J1745-290)
1742.5-2845	2.364	67.242	11.966	L	2.253×10^{-12} (HESS J1745-290)
1743-288	3.521	101.948	11.7405	L	2.910×10^{-12} (HESS J1745-290)
1743.1-2843	3.102	93.775	12.594	L	2.918×10^{-12} (HESS J1745-290)
J1750.8-2900	0.346	10.159	12.392	L	1.479×10^{-12}
1739-278	2.563	65.670	5.068	L	2.556×10^{-11}
J1748-288	3.100	260.002	13.656	L	1.254×10^{-11} (HESS J1747-281)
1735-269	-0.661	-5.023	1.288	L	2.755×10^{-12}
1749-285	-1.570	-117.739	9.444	L	6.684×10^{-12}
1744-265	-0.238	-4.268	5.148	L	1.964×10^{-12}
1745-248	-1.736	-36	0.435	L	1.372×10^{-11}
1758-258	-1.124	-36.520	1.727	L	4.395×10^{-12}
1758-250	-0.270	-14.736	3.013	L	6.083×10^{-12}
J1806-246	-0.079	-1.921	5.491	L	9.490×10^{-12}
1758-205	-0.501	-8.545	3.890	L	1.534×10^{-12}
1811-171	1.777	50.112	10.626	L	1.609×10^{-12}
1813-140	-1.088	-7.373	0.855	L	2.451×10^{-12}

Table 1: The results of the X-ray binary search. Where obtainable, upper limits to the γ-ray flux at energies > 1 TeV are given. Where the target region is contaminated by the flux from a known TeV source, the derivation of an upper limit is not possible, but there is no way to safely associate the observed flux with the X-ray binary system. In this case the contaminating object is indicated in the *Flux Upper Limit* column. Negative excesses and significances result purely from fluctuations in the γ-ray background and should not be interpreted as a genuine deficit in the photon flux. In the *Mass* column, 'H' indicates a high-mass system and 'L' a low mass system.

per limits to the photon flux above 1 TeV have been derived for 18 of the 29 targets. These upper limits represent 99% confidence intervals derived using the unified Feldman-Cousins method [22]. The remaining 11 targets were too close to known TeV emitters for a reliable upper limit or flux estimate to be obtained. In particular, those lying along a line of sight to the galactic centre are subject to heavy contamination from HESS J1745-290.

Conclusions

99% confidence upper limits have been derived for 18 X-ray binaries. The absence of a conclusive detection by H.E.S.S. could be explained in a number of ways. The flux from all three known γ-ray binaries is highly variable, and their detection would be somewhat dependent upon the timing of observations. Additional variability can occur due to $\gamma\gamma \rightarrow e^+e^-$ interactions with near infra-red photons absorbing the intrinsic γ-ray flux. [23] shows that the angular dependence of this process leads to an orbital modulation of the γ-ray flux similar to that observed in LS 5039 [24]. In some cases the intrinsic flux may be low enough, or the near IR radiation density high enough that no γ-rays are detected. Finally it may be the case that highly specific conditions are required for the emission of VHE γ-rays to occur.

Nonetheless, with the increasing sensitivity of ground based Cherenkov telescopes and the advent of experiments such as *GLAST* and H.E.S.S. Phase II to bridge the gap between soft and VHE γ-rays, it seems unlikely that the γ-ray binary catalogue of three will remain so small for long.

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