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# Observation of the microquasar LS 5039 with H.E.S.S.

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for the H.E.S.S. Collaboration

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Radio and X-ray observations have led to the presumption that some X-ray binaries (XRB) called microquasars behave as scaled down active galactic nuclei. Several models predict detectable emission of such objects by atmospheric Cherenkov telescopes above 100 GeV. LS 5039 is one of the two microquasars possibly associated with an EGRET source, and it exhibits strong radio and X-rays emission presumably associated with a relativistic jet, making it the most promising candidate for GeV-TeV emission. LS 5039 is located in the Southern Hemisphere in a region that was scanned in the summer of 2004 by the High Energy Stereoscopic System. Dedicated follow-up observations are planned for the summer of 2005. Results of these two observation campaigns are presented.

## 1. Introduction

High resolution radio maps of some X-ray binaries (XRB) have revealed powerful outflows which are similar, albeit on much smaller scale, to those observed in active galactic nuclei (AGN). As in AGN, these outflows probably result from the accretion of material onto the central compact object and produce radio emission via synchrotron radiation from accelerated particles. In AGN, and especially in Blazars, the particles can reach energies such that their nonthermal emission extends to the GeV-TeV domain via Compton upscattering of ambient photons or as a result of high energy hadron interaction.

Due to this close kinship, very high energy $\gamma$-rays (VHE) could be expected from some XRB if the physical processes in the vicinity of the compact object are indeed analogous. However, previous observations of VHE emission from XRB remained inconclusive [1].

Amongst the known microquasars, only two (LS 5039 and LSI $+61°303$) have a possible EGRET counterpart in the MeV-GeV domain. These counterparts are about 10 times more luminous than the X-ray source in the 1-10 keV band. The $\gamma$-ray spectra measured by EGRET are hard, with photon indices close to 2, suggesting that the emission could extend to the $\geq$ 100 GeV domain, in the sensitivity region of current atmospheric Cherenkov telescopes.

## 2. H.E.S.S. Observation

H.E.S.S. [2] is an array of four 13 m diameter telescopes [3], each equipped with a $5°$ field of view camera composed of 960 pixels [4], and located in the Khomas Highlands of Namibia ($23°16'18''$ S,$16°30'1''$ E) at 1800 m above sea level. It is designed to study VHE $\gamma$-rays above 100 GeV. The H.E.S.S. sensitivity reaches 1% of the Crab Nebula flux after 25 hours of observation close to zenith, with arcmin source localisation.

This unprecedented sensitivity was verified by the Galactic Survey [5] carried out in the summer of 2004, which led to the discovery of eight extended sources within $\pm30°$ of the Galactic Centre and $\pm3°$ of the Plane. After standard quality selection, a total of 25 pointings (10.5 h live time) taken during the scan were found to cover the position of LS 5039. The results presented here are based on the comparison of the actual shower images with a semi-analytical model (*Model Analysis*). This method, first developed for the CAT experiment [6], has been extended to stereoscopic observations and further improved for H.E.S.S. [7, 8, 9]. Standard H.E.S.S. analysis techniques [10, 11] based on Hillas Parameters were used independently as a cross-check and yielded compatible results. Details on the calibration procedure can be found in [12].

Figure 1-left shows the distribution of the squared angular distance ($\theta^2$) of $\gamma$-ray candidates from the position of LS 5039 for on-source events (filled histogram) and for normalized off-source events (black points), taken in a ring around the centre of the camera at the same angular distance as LS 5039. The *Model Analysis* provides a discrimination variable $g$, called *goodness-of-fit*, whose distribution of simulated gammas is compatible with a gaussian of mean 0 and width 1. The $\gamma$-ray candidates are selected with a cut on this variable $g \leq 0.7$ which retains more than 80% of $\gamma$ with an hadron rejection factor of about 10. The number of events in a $\theta^2 \leq 0.01^{\circ 2}$ cut are respectively $N_{ON} = 1091$ and $N_{OFF} = 15323$ with a normalisation factor of $\alpha = 18.4$, leading to a significance of 8.2 $\sigma$ with an excess of 256 $\gamma$ for this new source, denoted as HESS J1826-148.

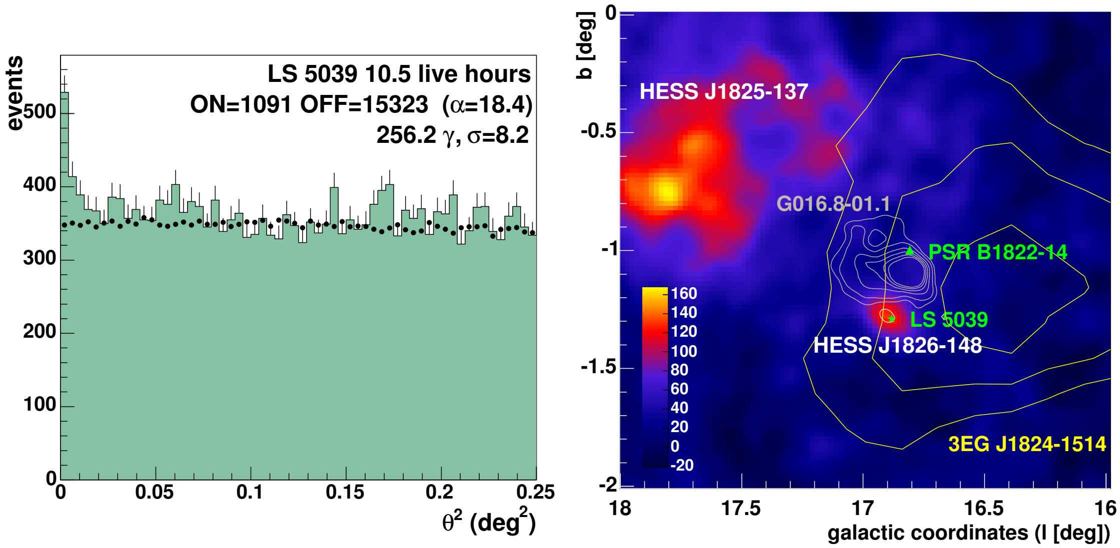


**Figure 1.** *Left:* Distribution of $\theta^2$ (squared angular distance to source) for on-source events (filled histogram) and normalized off-source events (black points). *Right:* Map of excess $\gamma$-ray emission in units of counts for the region around LS 5039. The map has been smoothed by the point spread function. The white ellipse shows the $3\sigma$ confidence region for HESS J1826-148. The radio emission from SNR G016.8-01.1 is represented by grey contours (0.05, 0.1, 0.2, 0.3, 0.4 and 0.5 Jy/beam) obtained from the Parkes-MIT-NRAO 6 cm radio survey map [13, 14]. The yellow contours show the 68%, 95% and 99% confidence level region of the EGRET source 3EG J1824-1514. The green star marks the position of the radio source associated with LS 5039. HESS J1825-137 is discussed in [5].

The map of excess $\gamma$-ray emission for the region around LS 5039 is shown on Figure 1-right, together with the possible counterparts. The source is point-like, with a size upper limit of $50''$ $(1\sigma)$ given by a likelihood fit to a Gaussian source profile folded through the detector response. The best position is $\alpha(J2000) = 18^h26^m15^s$ and $\delta = -14°49'30''$ with 32" statistical and 30" systematic uncertainties. The radio source, shown as a green star, is $84''$ away but well within the $3\sigma$ confidence region (white ellipse).

The $\gamma$-ray spectrum was derived from the comparison of reconstructed event energies (in a circle of 6 arcmin around the source) to the prediction for a given spectral shape. The prediction uses energy resolutions and

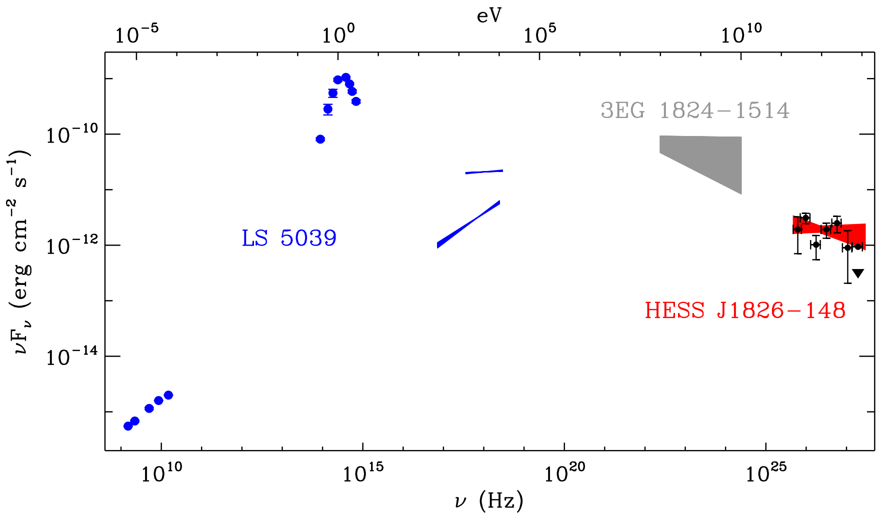


**Figure 2.** Spectral Energy Distribution of LS 5039 including the spectrum of HESS J1826-148 (points in black, power law fit in red). The average radio, IR, optical and X-ray fluxes are shown in blue [14, 15, 16, 17]. Optical fluxes are not dereddened. The two X-ray spectra correspond to the historical 1998 high (Rossi X-ray Timing Explorer, RXTE) and 2003 low (X-ray Multi-mirror Mission, XMM) flux observations of LS 5039. The multi-year average flux above 100 MeV from the EGRET source 3EG J1824-1514 is shown in grey [18].

system acceptances derived from simulations, taking into account the zenith angle pointing of the array and the off-axis angle of the shower in the field-of-view for each observation. We find an acceptable fit (chance probability of 7% of getting a worse fit) to a power-law with a photon index $\Gamma = 2.12 \pm 0.15$ (Figure 2). The relatively low statistics currently limit further investigation of more complex spectral shapes. The average integral flux above 250 GeV is $(5.1 \pm 0.8_{\mathrm{stat}} \pm 1.3_{\mathrm{syst}}) \times 10^{-12}$ ph cm$^{-2}$ s$^{-1}$, corresponding to a luminosity $\approx 10^{33}$ erg s$^{-1}$ at 3 kpc [19]. Errors on the spectral parameters correspond to $1\sigma$ confidence interval. The highest energy measurement is at $\approx 4$ TeV.

Reobservations of LS 5039 started in April 2005, and have already yielded a $> 10\sigma$ signal. Further results on the 2004 and 2005 data will be presented at the conference.

## 3. Discussion

The positions of the supernova remnant G016.8-01.1 and pulsar PSR B1822-14, which are both in the error box of the EGRET source and plausible $\gamma$-ray sources, are inconsistent with the position of HESS J1826-148 (Figure 1-right). Production of $\gamma$-rays from the interaction of cosmic-rays with the interstellar medium is precluded by the low H column density at the location of HESS J1826-148 compared to its surroundings [20].

Several processes can lead to $\gamma$-ray emission in LS 5039. Stellar photons from the O6.5V stellar companion could be boosted to $\gamma$-ray energies by inverse Compton scattering on VHE electrons [21], but the high radiative density close to the star ($L_\star \approx 10^{39}$erg s$^{-1}$) imposes a strict upper limit of the radiative timescale ($\sim$ 300s). Moreover, the opacity through $e^+e^-$ pair creation for 100 GeV photons emitted close to the star reaches $\tau_{\gamma\gamma} = \sigma_{\gamma\gamma} n_\star r \approx 20$, thus leading to a strong absorption of the VHE $\gamma$-rays. Although particular geometries could partially solve this problem, the observation of X-ray emission from XRB parsec scale jets [22] suggests that the electrons could be accelerated at a shock >1 AU away from the stellar companion (and outside the $\gamma$-photosphere). Very high energies may be easier to reach for protons, which suffer fewer radiation losses. VHE $\gamma$-rays may then be emitted via *pp* interactions with the stellar wind.

## 4. Summary

The detection by H.E.S.S. of VHE emission associated with the microquasar LS 5039 confirms that like some AGN, XRB are able to accelerate particles to at least TeV energies. Shocks from colliding ejecta or from jet - interstellar medium interactions are natural candidates, although relativistic motion has not been directly detected in radio for this object. Further insights into this system may be gained from combined radio and $\gamma$-ray observations.

## 5. Acknowledgements

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