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Simultaneous H.E.S.S. and Chandra observations of Sgr A⋆ during an X-ray flare

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Abstract: The rapidly varying non-thermal X-ray emission observed from Sgr A⋆ points to particle acceleration taking place close to the supermassive black hole. The TeV γ-ray source HESS J1745$-$290 is coincident with Sgr A⋆ and may be closely related to the X-ray emission. Simultaneous X-ray and TeV observations are required to elucidate the relationship between these two objects. Here we report on joint H.E.S.S./Chandra observations in July 2005, during which an X-ray flare was detected. Despite a factor > 10 increase in the X-ray flux of Sgr A⋆, no evidence is found for an increase in the TeV γ-ray flux. We find that an increase of the γ-ray flux of a factor 2 or greater can be excluded at a confidence level of 99%. This finding disfavours scenarios in which the bulk of the γ-ray emission observed is produced close to Sgr A⋆.

Introduction

The existence of a supermassive $(3.6 \pm 0.3 \times 10^6$ solar mass) black hole at the centre of our galaxy has been inferred using measurements of stellar orbits in the central parsec (see e.g. [1]). The supermassive black hole (SMBH) is coincident with the faint radio source: Sgr A⋆. The compact nature of Sgr A⋆ has been demonstrated both by direct VLBI measurements [2] and by the observation of X-ray and near IR flares with timescales as short as a few minutes (see for example [3, 4]). Variability on such short timescales limits the emission region (via causality arguments) to within < 10 Schwarzschild radii of the black hole. X-ray flares from Sgr A⋆ have reached fluxes of 4×10^{35} erg s^{-1}, two orders of magnitude brighter than the quiescent flux [4, 5], and exhibit a range of spectral shapes [4]. Several models exist for the origin of this variable emission, all of which invoke non-thermal processes close to the event horizon of the central black hole to produce a population of relativistic particles.

Model independent evidence for the existence of ultra-relativistic particles close to Sgr A⋆ can be provided by the observation of TeV γ-rays from this source. Indeed, TeV γ-ray emission has been detected from the Sgr A region by several ground-based instruments [6, 7, 8, 9]. The most precise measurement of this source, HESS J1745$-$290, are those made using the H.E.S.S. telescope array. The centroid of the source is located $7'' \pm 14''_{\mathrm{stat}} \pm 28''_{\mathrm{sys}}$ from Sgr A⋆, and has an rms extension of $< 1.2'$ [10].

TeV emission from Sgr A⋆ is expected in several models of particle acceleration in the environment of the black hole. In some of these scenarios [11, 12] TeV emission is produced in the immediate vicinity of the SMBH and variability is expected. In alternative scenarios particles are accelerated at Sgr A⋆ but radiate in within the central $\sim$10 parsec region [13], or are accelerated at the termination shock of a wind driven by the SMBH [14]. However, several additional candidate objects exist for the origin of the observed γ-ray emission. The radio centroid of the supernova remnant (SNR) Sgr A East lies $\sim 1'$ from Sgr A⋆,

only marginally inconsistent with the position of the TeV source given in [10]. Shell-type SNR are now well established TeV γ-ray sources [15, 16] and several authors have suggested Sgr A East as the origin of the TeV emission (see for example [17]). However, recent improvements in the statistical and systematic uncertainties of the centroid of HESS J1745−290 effectively exclude Sgr A East as the dominant γ-ray source in the region [18]. The recently discovered pulsar wind nebula candidate G 359.95-0.04 [19] lies only 9 arcseconds from Sgr A⋆ and can plausibly explain the TeV emission [20]. Particle acceleration at stellar wind collision shocks within the central young stellar cluster has also been hypothesised to explain the γ-ray source [21]. Finally, an origin of this source in the annihilation of WIMPs in a central dark matter cusp has been extensively discussed [22, 23, 10].

Given the limited angular resolution of current VHE γ-ray telescopes, the most promising tool for identification of the TeV source is the detection of *correlated variability* between the γ-ray and X-ray and/or NIR regimes. A significant increase of the flux of HESS J1745−290 simultaneous with a flare in wavebands with sufficient angular resolution to isolate Sgr A⋆, would provide an unambiguous identification of the γ-ray source. Therefore, whilst not all models for TeV emission from Sgr A⋆ predict variability of the VHE source, coordinated IR/keV/TeV observations can be seen as a key aspect of the ongoing program to understand the nature of this enigmatic source.

Observations & Results

A coordinated multi-wavelength campaign on Sgr A⋆ took place during July/August 2005. As part of this campaign observations with H.E.S.S. occurred for 4-5 hours each night from the 27th of July to the 1st of August (MJD 53578-53584). Four Chandra observations with IDs 5950-5954 took place between the 24th of July and the 2nd of August. A search for flaring events in the X-ray data yielded two significant events during the Chandra campaign, both during observation ID 5953 on the 30th of July. The second of these flares occurred during a period of H.E.S.S. coverage, at MJD 53581.94.
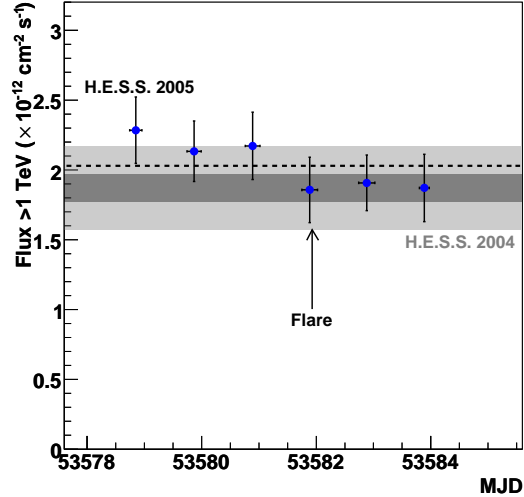

Figure 1: Nightly γ-ray flux light-curve of HESS J1745−290 from the 27th of July to the 1st of August 2005. The H.E.S.S. data have typical thresholds of 150-300 GeV. The grey band shows the mean flux from 2004 observations as published in [10]. Statistical (dark grey) and systematic (light grey) errors are shown. The dashed line is a fit to the MJD 53578-53584 data.

The γ-ray data consist of 72 twenty-eight minute runs, 66 of which pass all the quality selection cuts described by [24]. All runs on the night of the X-ray flare pass these cuts and in addition we find no evidence for cloud cover in the simultaneous sky temperature (radiometer) measurements (see [24, 25]). These data were analysed using the H.E.S.S. standard *Hillas parameter* based method described in [24]. An independent analysis based on the *Model Analysis* method described in [26] produced consistent results. Figure 1 shows a night-by-night TeV flux light-curve for this period. There is no evidence for variations of the flux on day timescales and the mean > 1 TeV γ-ray flux for this week of observations was $2.03 \pm 0.09_{stat} \times 10^{-12}$ cm^{-2} s^{-1}, consistent with the average value for H.E.S.S. observations in 2004, $1.87 \pm 0.1_{stat} \pm 0.3_{sys} \times 10^{-12}$ cm^{-2} s^{-1} [10].

Figure 2 shows the X-ray and γ-ray light curves for the night MJD 53581-2. There is a clear in-

crease in the X-ray flux of Sgr A* with an excess of 103 ± 10 events with respect to the quiescent level. The time-profile of this excess is consistent with a Gaussian of rms 13.1 ± 2.5 minutes. The time window for the γ-ray analysis is defined as the region within $\pm 1.3\sigma$ of the X-ray flare (containing 80% of the signal). The lower panel of Figure 2 shows the mean TeV flux within this time window (grey shaded region) of $2.05 \pm 0.76 \times 10^{-12}$ cm^{-2} s^{-1} as a short dashed line. This flux level is almost identical to the mean flux level for this week of observations. There is therefore no evidence for an increase in γ-ray flux of HESS J1745-290 during the flare and a limit on the relative flux increase of $<$ a factor 2 is derived at the 99% confidence level. In principle a (positive or negative) time lag might be expected between the X-ray and any associated γ-ray flare. The existence of a counterpart γ-flare with a flux increase $\gg 2$ requires a lag of at least 100 minutes.

Summary

For the first time simultaneous TeV γ-ray observations have been presented for a period of X-ray activity of Sgr A*. The non-detection of an increase in the TeV flux provides an important constraint on scenarios in which the source HESS J1745-290 is associated with the supermassive black hole.

References

[1] Eisenhauer, F. et al. 2005, Astrophys. J. 628, 246.

[2] Shen, Z.-Q. et al. 2005, Nature 438, 62.

[3] Eckart, A. et al. 2006, Astron. & Astrophys. 450, 535.

[4] Porquet, D. et al. 2003, Astron. & Astrophys. 407, L17.

[5] Baganoff, F.K. et al. 2003, Astrophys. J. 591, 891.

[6] Kosack, K. et al. 2004, Astrophys. J. Letters 608, L97.

[7] Tsuchiya, K. et al. 2004, Astrophys. J. Letters 606, L115.

[8] Aharonian, F. et al. 2004, Astron. & Astrophys. 425, L13.

[9] Albert, J. et al. 2006, Astrophys. J. Letters 638, L101.

[10] Aharonian, F. et al. 2006, Physical Review Letters 97, 221102.

[11] Levinson, A., Boldt, E. 2002, Astroparticle Physics 16, 265.

[12] Aharonian F.A., Neronov A. 2005, Astrophys. J. 619, 306.

[13] Aharonian F.A., Neronov A. 2005, Space Sci. Rev. 300, 255.

[14] Atoyan A.M., Dermer C.D. 2004, Astrophys. J. Letters 617, L123.

[15] Aharonian, F. et al. 2006, Astron. & Astrophys. 449, 223.

[16] Aharonian, F. et al. 2007, Astrophys. J. 661, 236.

[17] Crocker R.M. et al. 2005, Astrophys. J., 622, 892.

[18] Van Eldik, C. (for the H.E.S.S. Collaboration) 2007, These Proceedings.

[19] Wang, Q.D., Lu, F.J., Gotthelf, E. V. 2006, MNRAS 367, 937.

[20] Hinton, J.A., Aharonian, F.A. 2007, Astrophys. J. 657, 302.

[21] Quataert, E. and Loeb, A. 2005, Astrophys. J. Letters 635, L45.

[22] Hooper , D. et al. 2004, Journal of Cosmology and Astro-Particle Physics 9, 2.

[23] Profumo, S. 2005, Phys. Rev. D 72, 103521.

[24] Aharonian, F. et al. 2006, Astron. & Astrophys. 457, 899.

[25] Le Gallou, R. et al. 2003, Proc. International Cosmic Ray Conference, 2879.

[26] de Naurois, M. 2005, Proc. Conf. Towards a Network of Atmospheric Cherenkov Detectors VII, Palaiseau, France, 2005, p. 149
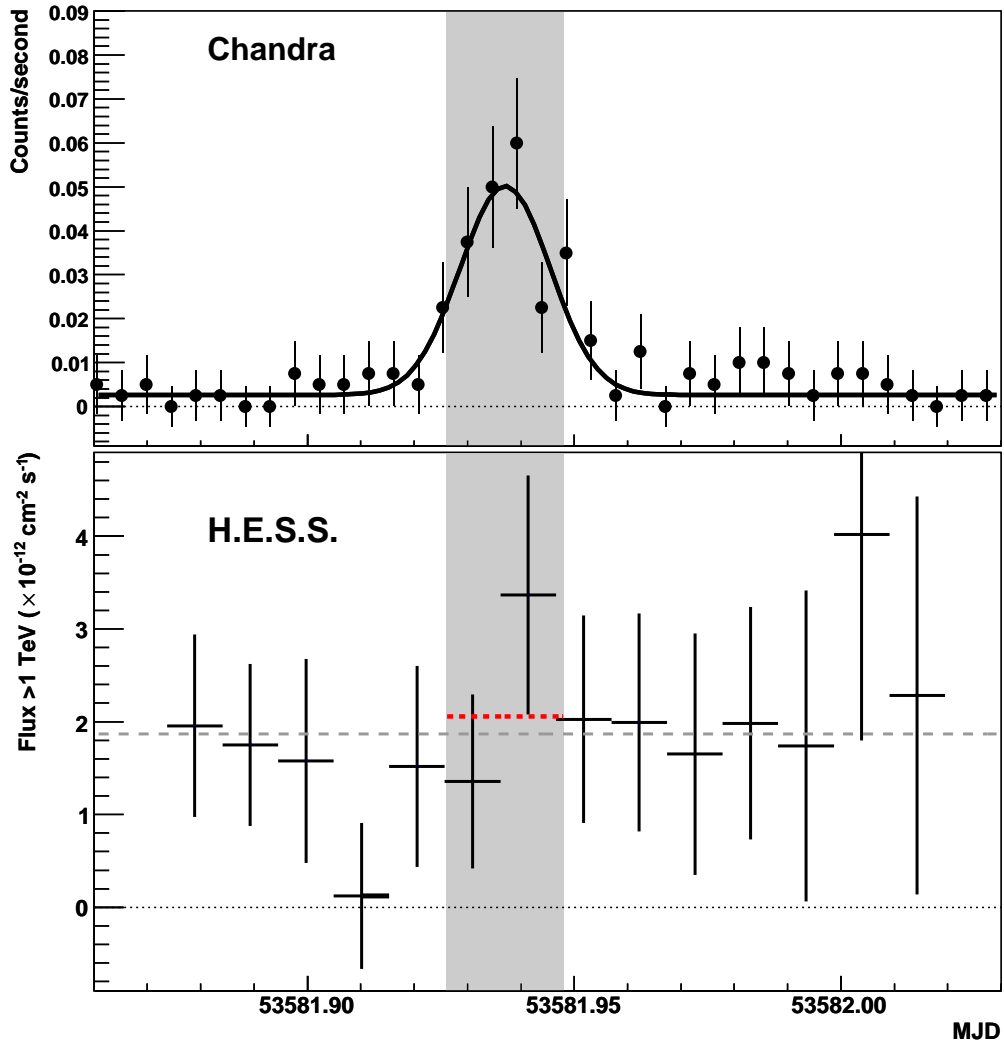
Figure 2: X-ray and γ-ray light curves for the Galactic Centre on MJD 53581. Top: Chandra 1-10 keV count rate in 400 second bins. The X-ray flare is well described by Gaussian (solid curve), the shaded region shows $\pm 1.3\sigma$ of the flare position. Bottom: Very High Energy γ-ray light curve from H.E.S.S. in 15 minute bins. The long dashed line shows the historical flux level [10]. The short dashed line indicates the mean TeV flux during the X-ray flare.