Localising the H.E.S.S. Galactic Center point source

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Abstract: Observations by the H.E.S.S. system of imaging atmospheric Cherenkov telescopes provide the most sensitive measurements of the Galactic Centre region in the energy range 150 GeV - 30 TeV. The vicinity of the kinetic centre of our galaxy harbours numerous objects which could potentially accelerate particles to very high energies (VHE, > 100 GeV) and thus produce the γ-ray flux observed. Within statistical and systematic errors, the centroid of the point-like emission measured by H.E.S.S. was found [1] to be in good agreement with the position of the supermassive black hole Sgr A* and the recently discovered PWN candidate G359.95-0.04 [2]. Given a systematic pointing error of about 30", a possible association with the SNR Sgr A East could not be ruled out with the 2004 H.E.S.S. data. In this contribution an update is given on the position of the H.E.S.S. Galactic Centre source using 2005/2006 data. The systematic pointing error is reduced to 6" per axis using guiding telescopes for pointing corrections, making it possible to exclude with high significance Sgr A East as the source of the VHE γ-rays.

Introduction

The centre of the Milky-Way is the most violent and active region in our galaxy. Dust along the line of sight prevents observations of the Galactic Centre (GC) by optical telescopes, but precise data from this region have been obtained at radio, infrared, X-ray, and hard X-ray/soft γ-ray (< 200 keV) energies. These data have established the existence of a 2.6×10^6 $M_\odot$ black hole at the kinematic centre of our galaxy, commonly identified with the bright compact radio source Sgr A*, surrounded by a massive star cluster, a bright supernova remnant shell, and giant molecular clouds (see, e.g., [3, 4] for recent reviews).

VHE γ-ray emission from the direction of the Galactic Centre was reported by several ground-based γ-ray observatories [5, 6, 7, 8]. A recent deep exposure by H.E.S.S. [9] revealed the existence of two discrete VHE γ-ray sources, on top of diffuse emission along the inner 300 pc of the Galactic Centre ridge. One of the sources, HESS J1747-281 [10], is identified with the pulsar wind nebula (PWN) associated with the supernova remnant (SNR) G0.9+0.1. However, no unique identification is possible for HESS J1745-290, the position of which is within errors coincident with the kinematic centre of our galaxy.

A firm identification of HESS J1745-290 is difficult because the GC region is densely packed with sources of non-thermal radiation – possibly emitting at VHE energies. In direct vicinity of the H.E.S.S. source, at least three different objects are discussed as possible counterparts of HESS J1745-290. First, various models predict VHE γ-ray production near the super-massive black hole itself (see, e.g., [11]). Sgr A* is partially surrounded by the bright, shell-like radio emission of the SNR Sgr A East [12], which is the second favoured candidate counterpart of the VHE γ-ray emission. Finally, in a deep Chandra survey, G359.95-0.04, a candidate pulsar wind nebula, was recently discovered [2] only $8.7''$ away from Sgr A*. Despite its faint X-ray flux, models [13] predict a TeV γ-ray flux that is compatible with H.E.S.S. observations.

A precise localisation of HESS J1745-290 is essential for shedding light onto this source confusion. In this paper preliminary results concerning a refined position measurement of HESS J1745-290 are reported using an improved telescope pointing strategy, for which the systematic error on the ob-

servation position is reduced by a factor of three compared to previous results.

H.E.S.S. observations of the Galactic Centre region

The most precise published results on the position of HESS J1745-290 are based on a 50 h exposure carried out with the H.E.S.S. array in 2004. Within a statistical error of 14" the best-fit position of HESS J1745-290 was found [1] to coincide with the position of Sgr A*. The systematic pointing error of the H.E.S.S. telescope system for this data set is about 28", already the most precise pointing in the field of ground-based γ-ray astronomy.

The results reported here are based on data recorded between May 14th and July 27th, 2005, and between April 4th and September 24th, 2006. The total good-quality exposure of the dataset is 73.2 h (live time). Most of the data (66.1 h) were taken in "wobble mode" around Sgr A*, i.e. the observation direction was offset from the source direction by typically $0.5° - 0.7°$ in either right ascension or declination. The remaining data were taken at various offsets, within $1.4°$ from Sgr A*. The zenith angle distribution ranges from $6° - 60°$, and the mean zenith angle of observation is $21.6°$.

Data were analysed with the standard H.E.S.S. calibration and reconstruction chain [14]. *Hard cuts* [15] were used for γ-ray selection, resulting in a sample of well-reconstructed showers with an average angular resolution of $0.07°$ (68% containment radius). The data show a strong excess of γ-rays from the direction of the GC source HESS J1745-290, accompanied by diffuse γ-ray emission along the Galactic Plane. An excess of 1300 γ events is found within $0.1°$ from the GC, corresponding to a statistical significance of 44.3 standard deviations above background. The integral γ-ray flux above 1 TeV is in agreement with published results based on 2004 data [1].

Precision pointing

For an exact localisation of the centroid of the VHE γ-ray emission, precise knowledge of the telescope pointing direction is mandatory. The pointing de-

viation of individual telescopes is typically of the order of 2-3'. Various causes have been identified, with the most important ones being small misalignments of azimuth and altitude axes during construction, sagging of telescope foundations over time, (mostly) elastic deformations of the masts connecting the camera body to the mirror dish, gravitational bending of the mirror dish, and inelastic deformations of the whole structure leading to hysteresis effects. The amount these effects contribute to the mispointing strongly depends on the observation direction. It should however be noted that - due to the rigidity of the steel construction - the overall pointing deviation is very small given the size and weight of the H.E.S.S. telescopes.
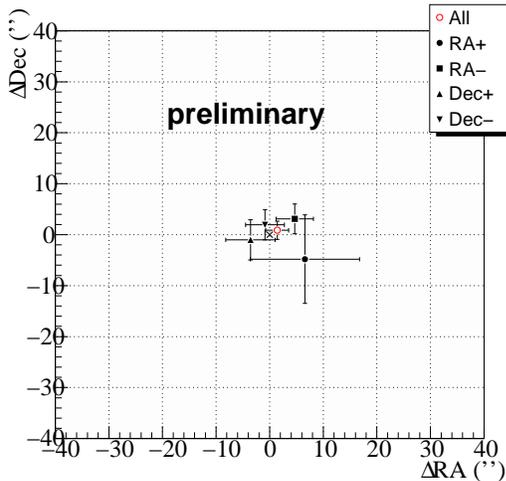

Figure 1: Position of the centroid of VHE γ-ray emission from PKS 2155-304 relative to its nominal position. Data were taken in 2006 during an exceptional VHE γ-ray flare of this source [16]. The γ-ray excess was fit by a two-dimensional multi-gaussian profile representing the point spread function of the H.E.S.S. instrument. The red data point shows the position derived from the full data set. When subdividing the data into the four wobble offsets, the positions shown by the black symbols are obtained. Note that for most of the RA+ wobble data, no bright stars were found in the field of view of the guiding telescopes, reducing the available live time for this analysis.

Most pointing deviations can be corrected for by taking calibration data at regular intervals. Each telescope is pointed at typically 50 bright stars uni-

formly distributed in the sky. The star is imaged by the telescope mirror onto a screen in front of the Cherenkov camera, and an image of the spot is recorded by a central CCD camera mounted at the centre of the mirror dish. The position of each spot is then compared to the nominal centre of the Cherenkov camera as determined from eight positioning LEDs mounted on the camera body. The data are fit with a 17 parameter model which accounts for elastic deformations of the telescope structure. In the analysis of γ-ray data, this model is then used to correct the position of the shower images in the focal plane of the Cherenkov cameras. The precision achieved on the observation direction of the H.E.S.S. array is about 20" per axis [17].

For the 2005-2006 data set presented here, the systematic error is reduced further using guiding cameras mounted at each telescope. During γ-ray observations, stars in the field of view ($0.3° \times 0.5°$) of these cameras are recorded at a typical rate of $1 \, \text{min}^{-1}$, and their reconstructed positions matched to the Hipparcos and Tycho star catalogues. From this information position-dependent corrections in right ascension and declination are calculated for the individual H.E.S.S. telescopes. Additionally, the position of the Cherenkov camera is monitored by the central CCD camera. With this method, the systematic error on the telescope orientation is reduced to 6" per axis for observations with the full H.E.S.S. array ([18], details will be published elsewhere).

The procedure was extensively tested on VHE γ-ray point sources of known position. Fig. 1 shows a representative study on the position of the high-frequency peaked BL Lac PKS 2155-304. Excellent agreement with the nominal position of the source is found even when splitting the data into different wobble offsets.

Position of HESS J1745-290

The position of HESS J1745-290 is determined by fitting, in a window of $\pm 0.2°$ around the maximum excess, the acceptance corrected and background subtracted γ-ray count map. Diffuse γ-ray emission is subtracted prior to the fit using the model presented in [9]. The width of the 2-dimensional

gaussian fit to these data is composed of a fixed term describing the mean angular resolution of the data set, and a parameter left free to fit the intrinsic size of the source. The count map is divided into sky bins of $0.04° \times 0.04°$, and the fit function is integrated over the bin area for best accuracy. χ^2-minimisation is used to obtain the best-fit position.
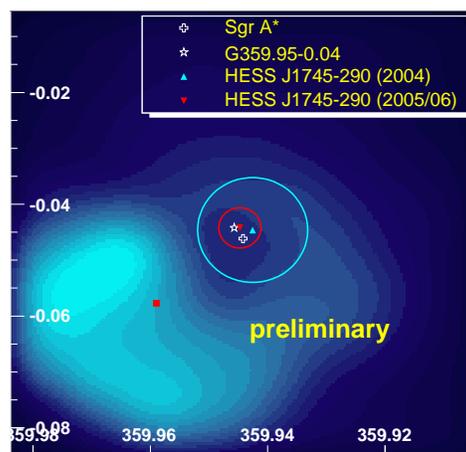

Figure 2: Smoothed 90 cm VLA radio image (reproduced from [19]) of the SNR Sgr A East in Galactic coordinates. The position of Sgr A* and G359.95-0.04 are marked with a cross and a star, respectively. The blue triangle and circle mark the best fit position and total error (68% CL) from the 2004 data set [1]. The best fit result of this analysis is shown by the red triangle and red circle. The red square marks the expected position of the centroid of the VHE γ-ray emission if it followed the observed radio flux of Sgr A East.

The best-fit position of HESS J1745-290 in Galactic coordinates is $l = 359°56'41.1'' \pm 6.4''$ (stat.), $b = -0°2'39.2'' \pm 5.9''$ (stat.). These results are preliminary and subject to final checks. Fig. 2 shows the new H.E.S.S. position measurement on top of a 90 cm VLA radio image of the inner 10 pc region of the GC. The shell-like structure of the SNR Sgr A East is clearly visible. The position of HESS J1745-290 is coincident within $7.3'' \pm 8.7''$ (stat.) $\pm 8.5''$ (syst.) with the radio position of Sgr A* [20], and is also consistent with

the position reported from the 2004 data set [1]. While the latter was marginally consistent with the radio emission from Sgr A East, the result obtained in this analysis does rule out Sgr A East as the counterpart of HESS J1745-290 with high significance. Due to the improved pointing accuracy of the H.E.S.S. array, the probability that the observed γ-ray flux is produced near the radio maximum of Sgr A East is about 10^{-11}. Assuming that the VHE γ-ray flux follows the radio morphology of Sgr A East (corresponding to the red square in Fig. 2), the chance probability of finding the centroid of the emission at the reported position is 10^{-7}.

The position of HESS J1745-290 agrees well with the location of the other two counterpart candidates, Sgr A* and G359.95-0.04, which are separated by only $8.7''$. Since the pointing precision obtained in this work is at the limit of what can be achieved with an instrument such as H.E.S.S., other measures have to be taken to disentangle the remaining source confusion. The most promising method is to search for variability in the VHE γ-ray flux, which would hint at a connection between the VHE flux and Sgr A*. The most convincing signature would be the detection of correlated flaring in X-rays and VHE γ-rays. Such searches have been presented at this conference [21, 22].

Acknowledgements

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