Detection of very-high-energy $\gamma$-ray emission from the vicinity of PSR B1706−44 with H.E.S.S.

S. Hoppe*, E. de Oña Wilhelmi*, B. Khélifi†, R. C. G. Chaves‡, O.C. de Jager†, C. Stegmann§ and R. Terrier¶ for the H.E.S.S. Collaboration

* Max-Planck-Institut für Kernphysik, Heidelberg, Germany
† Laboratoire Leprince-Ringuet, Ecole Polytechnique, CNRS/IN2P3, Palaiseau, France
‡ Unit for Space Physics, North-West University, Potchefstroom, South Africa
§ Universität Erlangen-Nürnberg, Physikalisches Institut, Germany
¶ Astroparticule et Cosmologie (APC), CNRS, Université Paris VII, Paris, France

Abstract. The energetic pulsar PSR B1706−44 and the adjacent supernova remnant (SNR) candidate G 343.1−2.3 were observed by H.E.S.S. during a dedicated observational campaign in 2007. A new source of very-high-energy (VHE; $E > 100\text{ GeV}$) $\gamma$-ray emission, HESS J1708−443, was discovered with its centroid at $\alpha_{2000} = 17^h 8^m 10^s$ and $\delta_{2000} = -44^\circ 21'$ ($\pm 3\text{ stat}$ on each axis) The VHE $\gamma$-ray source is significantly more extended than the H.E.S.S. point-spread function, with an intrinsic Gaussian width of $0.29^\circ \pm 0.04^\circ$. Its energy spectrum can be described by a power law with a photon index $\Gamma = 2.0 \pm 0.1_{\text{stat}} \pm 0.2_{\text{sys}}$. The integral flux measured between 1−10 TeV is $\sim 17\%$ of the Crab Nebula flux in the same energy range. The possible associations with PSR B1706−44 and SNR G 343.1−2.3 are discussed.

Keywords: HESS J1708−443, PSR B1706−44, G 343.1−2.3

I. INTRODUCTION

The pulsar PSR B1706−44 was first detected in a high-frequency radio survey [31]. With a spin period of 102 ms, a characteristic age of 17.500 yr and a spin-down luminosity of $3.4 \times 10^{36}\text{ erg s}^{-1}$, it belongs to the class of relatively young and very energetic pulsars. Estimates for its distance range from 1.8 kpc [31] [46] to 3.2 kpc [35]. The positionally-coincident $\gamma$-ray source 2CG342−02 [44] was firmly identified with PSR B1706−44 when EGRET observed pulsed emission with the same period seen in the radio waveband [47]. PSR B1706−44 is therefore one of the very first pulsars from which pulsed emission was detected not only in radio [31] and X-rays [28], but also in high-energy $\gamma$-rays.

The pulsar PSB B1706−442 is surrounded by a synchrotron nebula with an extension of 3' at radio wavelengths [25] [27]. The observed polarization and the flat spectrum of the radio emission (photon index of 0.3) suggest a pulsar wind nebula (PWN) origin. The synchrotron nebula is also visible in X-rays, first reported by Finley et al. [24] using ROSAT observations. Employing the superior resolution of Chandra, Romani et al. [40] were able to map the morphology of the PWN at the arcminute scale. Their findings suggest a diffuse PWN with a spectral index of 1.77, surrounding a more complex structure comprising a torus and inner and outer jets. The diffuse PWN has a radius of $\sim 110''$ and exhibits a fainter, longer extension to the West. The non-deformed X-ray jets support the low scintillation velocity of the pulsar of less than 100 km s$^{-1}$ [32].

PSR B1706−44 is located at the southeast end of an incomplete arc of radio emission [37] suggested to be the shell of a faint supernova remnant (SNR G 343.1−2.3). The arc itself is embedded in weak, broad-scale radio emission [25] for which polarization measurements suggest an association with synchrotron radiation from the SNR [22]. No X-ray emission was detected from the radio structure (see e.g. [13]). The question of a possible association between PSR B1706−44 and G 343.1−2.3 could not be answered unambiguously so far. The dispersion distance for the pulsar of $2.3 \pm 0.3\text{ kpc}$ (and references therein) using the free electron distribution model by Cordes and Lazio [20] is compatible with the $\Sigma − D$ distance of $\sim 3\text{ kpc}$ for the SNR [37]. However, the off-center position of the pulsar relative to the radio-arc implies a rather high proper motion velocity ($\sim 700\text{ km s}^{-1}$) which is incompatible with the measured scintillation velocity. Bock et al. [16] suggested a scenario whereby an off-centered cavity explosion would release the restrictions on the implied velocity and invalidate the age estimate for the SNR of $\sim 5000\text{ yr}$ [37], which is based on a Sedov-Taylor model. In this scenario, the radio arc is identified with the former boundary of the wind-blown cavity that was overtaken and compressed by the expanding SNR. The diffuse, broad-scale radio emission would then result from the interaction of the SNR with the parent molecular cloud.

At very-high energies (VHE; $E > 100\text{ GeV}$), the region of interest was observed using ground-based atmospheric Cherenkov telescopes. The CANGAROO Collaboration reported the detection of steady emission coincident with the pulsar using the 3.8-m CANGAROO-I telescope in 1992−1993 [38] [34]. They measured an integral flux above 1 TeV of $\sim 35\%$ of the Crab Nebula flux. It was later revealed that the actual mirror reflectiv-
ity at the time of the observations would have resulted in a higher minimum energy threshold of \(\sim 2\) TeV \[39\]. The 4-m BIGRAT telescope \[41\] also observed the pulsar in 1993–1994 and reported a compatible upper limit (UL). Observations in 1996 with the Durham Mark 6 telescope \[18\] appeared to confirm the detection, with a reported integral flux that was compatible within the large systematic uncertainties (\(\pm 30\%\) for CANGAROO-I and \(\pm 50\%\) for the Mark 6). Further observations with the 10-m CANGAROO-II telescopes in 2000–2001 again seemed to confirm the detection. However, when the H.E.S.S. Collaboration observed the pulsar in 2003 during its commissioning phase—operating only two out of four telescopes, without a stereo hardware trigger—they did not detect any significant VHE \(\gamma\)-ray emission from the vicinity of PSR B1706–44. The derived UL on the integral flux was found to be \(\sim 5\%\) of the Crab, in stark disagreement with the previous findings \[1\]. Shortly thereafter, preliminary analysis of stereo observations with the 4 \(\times\) 10-m CANGAROO-III telescope array did not confirm the earlier CANGAROO-I detection but instead resulted in an UL of \(\sim 10\%\) Crab \[43\], in agreement with the H.E.S.S. results. Very recently, the CANGAROO Coll. undertook a comprehensive re-analysis of their archival CANGAROO data and now find an UL to the integral flux at \(\sim 13\%\) Crab \[50\], also compatible with the H.E.S.S. UL. In 2007, additional H.E.S.S. data was taken on the pulsar, now utilizing the superior sensitivity of the fully-operational H.E.S.S. telescope array. In this proceeding, the findings of this observation campaign are presented. No point-like emission is detected at the pulsar position. However, an extended source of VHE \(\gamma\)-rays was discovered in the region of interest. Its centroid appears significantly displaced from the pulsar position. Although the measured flux from the extended region exceeds the previously-published UL by a small margin, a re-analysis of the older H.E.S.S. data set (originally published in \[1\]), using the up-to-date H.E.S.S. standard analysis framework, yields revised flux ULs which are consistent with the currently-detected flux.

II. THE H.E.S.S. TELESCOPES / ANALYSIS TECHNIQUE

The High Energy Stereoscopic System (H.E.S.S.) is an array of four, imaging atmospheric Cherenkov telescopes, dedicated to the observation of VHE \(\gamma\)-rays. The array is located in the Khomas Highlands of Namibia (23°16’17” S, 16°29’58” E). Each telescope is equipped with a tessellated, spherical mirror of 107 m\(^2\) area and a camera comprised of 960 photomultiplier tubes, covering a field-of-view (FoV) 5° in diameter. The telescopes are operated in coincidence mode, which requires a trigger of at least two telescopes for an air shower to be recorded. The stereoscopic approach allows a high angular resolution of \(< 0.1°\) per event, a good energy resolution of \(\sim 16\%\) (on average) and an effective background rejection \[5\]. The H.E.S.S. array can detect point sources at flux levels of about 1% of the Crab Nebula flux near zenith with a statistical significance of \(5\sigma\) in 25 h of observations. Its large FoV and good off-axis sensitivity not only make it ideally suited for surveying the Galactic plane \[2\] \[10\] \[19\], but also for studying extended sources like HESS J1708–443.

The region of interest, which includes PSR B1706–44 and the SNR G 343.1–2.3, was observed with the full H.E.S.S. telescope array in 2007. The observations were dedicated to search for VHE \(\gamma\)-ray emission from the pulsar and were therefore taken in wobble mode, alternating around its radio position (\(\alpha_{2000}=17^h49^m42.73^s, \delta_{2000}=44^\circ29'8.2''\) \[48\]). In this observation mode, the array is pointed towards a position offset from the source of interest to allow for simultaneous background estimation.

The data set was analyzed using the Hillas second-moment method \[5\]. For \(\gamma\)-hadron separation, hard cuts were used, which require a minimum of 200 photo electrons (p.e.) to be recorded per shower image. Compared to std cuts (80 p.e.), this relatively strict requirement results in better background rejection and an improved angular resolution, but also in an increased energy threshold (560 GeV for this data set). The time-dependent optical response of the system was estimated from the Cherenkov light of single muons passing close to the telescopes \[17\].

Three different background estimation procedures \[14\] were used in this analysis. For 2D image generation, the Ring Background Method was used with a mean ring radius of 0.85°. Since this method includes an energy-averaged model for the camera acceptance to account for the different offsets of the signal and background regions.
from the camera center, it was not used for spectral extraction. The Reflected Region Method was instead used to measure the flux from the pulsar position. For spectral extraction from very extended regions which also enclose the pointing positions of the telescopes, the background was estimated from off-source (OFF) data taken in regions of the sky where no $\gamma$-ray sources are known. To match the observing conditions between on-source (ON) and OFF data, the two observations had to be taken within six months of each other and at similar zenith angles, in a procedure similar to that used for Vela Jr [3]. The normalization between ON and OFF observations was performed using the total event number in the two observations, excluding regions with significant VHE $\gamma$-ray signal.

### III. RESULTS

Figure 1 shows the excess count map of the $2^\circ \times 2^\circ$ region around the source smoothed with a Gaussian profile of width $0.15^\circ$ to reduce statistical fluctuations.

A clear excess of VHE $\gamma$-rays is observed with a peak statistical significance of $7.5 \sigma$ using an integration radius of $\theta = 0.4^\circ$. Fitting the fine-binned and unsmoothed excess map with a radially-symmetric Gaussian profile ($\phi = \phi_0 e^{-r^2/(2\sigma^2)}$) convolved with the point-spread function (PSF) of the instrument leads to a best fit position of $\alpha_{2000} = 17^h 4^m 10^s$ and $\delta_{2000} = -44^\circ 21'$, with a statistical error of $3^\circ$ on each axis, as indicated by the white cross in Fig. 1. Consequently, the new VHE $\gamma$-ray source is called HESS J1708$-$443. The fit results also provide the intrinsic Gaussian width, $0.29^\circ \pm 0.04^\circ$ stat.

A preliminary differential energy spectrum was determined within a circular region of $0.71^\circ$ radius (indicated by a dashed circle in Fig. 1), chosen as a compromise between optimal signal-to-noise ratio and independence of source morphology. Within this region, 605 excess events were found, corresponding to a statistical significance of $6.7 \sigma$ (pre-trials). The spectrum is well-described by a power law $\phi = \phi_{1\text{TeV}} \cdot E^{-\Gamma}$ with a spectral index of $\Gamma = 2.0 \pm 0.1_{\text{stat}} \pm 0.2_{\text{sys}}$ and a flux normalization at $1 \text{ TeV}$ of $\phi_{1\text{TeV}} = (4.2 \pm 0.8_{\text{stat}} \pm 1.0_{\text{sys}}) \cdot 10^{-12} \text{ cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}$. The integral flux between 1 and 10 $\text{TeV}$ is $1.2 \cdot 10^{34} \text{ erg s}^{-1}$. The implied effective conversion efficiency from rotational energy to $\gamma$-rays in this energy range is then $\sim 0.4\%$, comparable to the efficiency of 0.8\% inferred for PSR J1420$-$6048 [6]. This suggests the pulsar’s wind nebula as a possible origin of the observed VHE $\gamma$-ray emission, similar to other PWN associations such as Vela X [7] and HESS J1825$-$137 [8]. In this scenario, the VHE $\gamma$-emission originates from accelerated electrons which up-scatter ambient photons to VHE energies (leptonic scenario).

The larger size of the TeV PWN compared to the “bubble” nebula seen in X-rays (radius $\sim 110''$) [40] can usually be explained by the different energies, and hence cooling times, of the electrons which emit X-rays and VHE $\gamma$-rays; such differences in size have already been observed in other PWN associations such as HESS J1825$-$137 [8]. However, in contrast to the PWN of PSR J1826$-$1334, where a magnetic field strength of $10 \mu G$ was inferred from X-ray observations [26], Romani et al. [40] estimated a magnetic field as strong as $140 \mu G$ within the $\sim 110''$ X-ray PWN of PSR B1706$-$44. In such high magnetic fields, electrons that emit keV X-rays and those that emit TeV $\gamma$-rays have comparable energies and hence comparable cooling times. Thus, the TeV PWN should appear almost point-like on the $5'$ scale of the H.E.S.S. PSF. Furthermore, given that the ratio of X-ray to VHE $\gamma$-ray energy flux $(dN/dE \cdot E^2)$ is determined by the energy density in magnetic fields and inverse Compton (IC) target photon fields (considering here only the CMB), the detected X-ray flux of $2.7 \cdot 10^{-13} \text{ erg cm}^{-2} \text{s}^{-1}$ at 1.7 keV predicts a $\gamma$-ray flux of $1.4 \cdot 10^{-16} \text{ erg cm}^{-2} \text{s}^{-1}$ at 1.7 TeV, well below the level observable by H.E.S.S.

Fig. 2. Differential energy spectrum of HESS J1708$-$443, extracted from the circular region indicated in Fig. 1. The solid line shows the result of a power law fit. The error bars denote 1-σ statistical errors; the bottom panel shows the residuals of the fit. Events with energies between 600 GeV and 28 TeV were used in the determination of the spectrum.

### IV. THE ORIGIN OF THE TeV EMISSION

While a superposition of multiple sources cannot be excluded, each of the following objects could individually account for the observed VHE $\gamma$-ray emission.

#### A. A relic nebula from PSR B1706$-$44

With its high spin-down luminosity of $3.4 \cdot 10^{36} \text{ erg s}^{-1}$, the pulsar PSR B1706$-$44 is energetic enough to power the observed VHE $\gamma$-ray emission. Assuming the pulsar is at a distance of 2.5 kpc, the energy flux from the H.E.S.S. source between 1 and 10 $\text{TeV}$ is $1.2 \cdot 10^{34} \text{ erg s}^{-1}$. The implied effective conversion efficiency from rotational energy to $\gamma$-rays in this energy range is then $\sim 0.4\%$, comparable to the efficiency of 0.8\% inferred for PSR J1420$-$6048 [6]. This suggests the pulsar’s wind nebula as a possible origin of the observed VHE $\gamma$-ray emission, similar to other PWN associations such as Vela X [7] and HESS J1825$-$137 [8]. In this scenario, the VHE $\gamma$-emission originates from accelerated electrons which up-scatter ambient photons to VHE energies (leptonic scenario).

The larger size of the TeV PWN compared to the “bubble” nebula seen in X-rays (radius $\sim 110''$) [40] can usually be explained by the different energies, and hence cooling times, of the electrons which emit X-rays and VHE $\gamma$-rays; such differences in size have already been observed in other PWN associations such as HESS J1825$-$137 [8]. However, in contrast to the PWN of PSR J1826$-$1334, where a magnetic field strength of $10 \mu G$ was inferred from X-ray observations [26], Romani et al. [40] estimated a magnetic field as strong as $140 \mu G$ within the $\sim 110''$ X-ray PWN of PSR B1706$-$44. In such high magnetic fields, electrons that emit keV X-rays and those that emit TeV $\gamma$-rays have comparable energies and hence comparable cooling times. Thus, the TeV PWN should appear almost point-like on the $5'$ scale of the H.E.S.S. PSF. Furthermore, given that the ratio of X-ray to VHE $\gamma$-ray energy flux $(dN/dE \cdot E^2)$ is determined by the energy density in magnetic fields and inverse Compton (IC) target photon fields (considering here only the CMB), the detected X-ray flux of $2.7 \cdot 10^{-13} \text{ erg cm}^{-2} \text{s}^{-1}$ at 1.7 keV predicts a $\gamma$-ray flux of $1.4 \cdot 10^{-16} \text{ erg cm}^{-2} \text{s}^{-1}$ at 1.7 TeV, well below the level observable by H.E.S.S.

One way to reconcile the difference in emission region
size and the high VHE flux level is to assume that the size of the X-ray PWN is essentially governed by the extent of the high-field region, and that the magnetic field falls off by a large factor outside the X-ray PWN. The electrons can then escape from the high-field region and—by accumulating over a significant fraction of the pulsar’s lifetime—form a larger nebula visible only in VHE γ-rays.

This scenario still does not explain the asymmetry of the VHE γ-ray nebula with respect to the pulsar location. Such asymmetries have been observed before in other TeV PWNs, e.g. HESS J1718−385, HESS J1809−193 [12] and HESS J1825−137 [4] [8]. They were explained either by the proper motion of the pulsar or by a density gradient within the ambient medium that either causes an asymmetry in the reverse shock of the original supernova or different expansion velocities of the TeV-emitting electrons [15] [43]. In some of the simulations of Swaluw et al. [43], the displaced PWN is indeed well-separated from its pulsar. Both explanations are in principle applicable in this situation. However, the measured scintillation velocity of less than 100 km s−1 for the pulsar renders the former explanation unlikely. The latter explanation would favor a displacement of the TeV PWN towards a low-density region, contrary to the observed offset, where the TeV emission is closer to the higher density region along the Galactic plane. It should be noted that a local density gradient, e.g. directly at the position of the pulsar, could affect the spatial distribution of the TeV PWN.

In this discussion it was assumed that the pulsar dominantly accelerates electrons. If a considerable fraction of the accelerated particles are hadrons, as discussed by Horns et al. [40], the constraints imposed by the large magnetic field within the X-ray PWN are removed. The TeV emission would then originate from π0 meson decay produced in inelastic interactions of accelerated protons with ambient gas (hadronic scenario), and the VHE γ-ray emission would trace the distribution of the target material. The bright radio arc, which was interpreted by Bock et al. [16] as the compressed outer boundary of the former wind-blown bubble, could act as such a region of enhanced target material density, which would explain its coincidence with the H.E.S.S. source.

B. SNR G 343.1−2.3

The following discussion will investigate the scenario where the VHE γ-ray emission originates in the SNR shell. The H.E.S.S. source is partially coincident with the bright radio arc and the surrounding diffuse emission of the SNR, visible in the 1.4 GHz observations taken with the ATCA instrument [22]. The best-fit position of the H.E.S.S. source is consistent with the apparent center of the bright radio arc (α2000 = 17h48m and δ2000 = −44°16′48″). However, due to relatively low statistics in the VHE data, no further conclusions can be made about morphological similarities.

Similar to the potential association with the PWN of PSR B1706−44, both leptonic and hadronic scenarios for VHE γ-ray production have to be considered. The leptonic scenario suffers from the non-detection of the SNR at X-ray energies. The VHE γ-ray spectrum reaches as far 20 TeV. Assuming IC scattering in the Thompson regime, the energy of the electrons upscattering CMB photons up to 20 TeV have an energy of roughly 80 TeV. For a reasonable magnetic field strength of 5 μG, such electrons would emit synchrotron photons with an energy of ~1 keV, i.e. within the detectable energy range of current X-ray instruments. However, no stringent UL on the X-ray flux from within the H.E.S.S. source can be derived due to the vicinity of the luminous low-mass X-ray binary 4U 1705−440, whose stray light might be obscuring diffuse X-ray emission from the SNR.

In the hadronic scenario, where synchrotron radiation is expected only from secondary electrons, the lack of X-ray detection can easily be accounted for. In this scenario, the total energy within the whole proton population can be estimated by \( W_{\text{P}}(\text{tot}) \approx 3.9 \times 10^{46} \text{ erg cm}^{-2} \text{ keV}^{-1} \left( \frac{D}{\text{kpc}} \right)^2 \), following the approach described in [29] (the proton spectrum was assumed to follow a power law with a spectral index of α = 2 down to 1 GeV). For a total energy of \( 10^{51} \text{ erg} \) released in the supernova explosion, an acceleration efficiency of ε = 0.15 and a distance \( D = 2.5 \text{kpc} \), the necessary average proton density is \( n \approx 1.6 \text{ cm}^{-3} \), only slightly larger than the average Galactic ambient density.

However, an association of SNR G 343.1−2.3 with the pulsar PSR B1706−44, a scenario debated in the literature, (see e.g. [16] and/or [40]), would make the SNR rather old (on the order of 10,000 yr) and place it in the late Sedov-Taylor phase, or more likely, in the radiative phase. In this scenario, the SNR would be older than SNRs from which shell-morphology γ-ray emission has been unambiguously detected, e.g. RX J1713.7−3946 [9] and RX J0852.0−4622 [11] (∼2,000 yr).

V. Summary

H.E.S.S. observations have led to the discovery of a new VHE γ-ray source, HESS J1708−443. The γ-ray emission is extended, but the exact morphology of the emission region is still under study. The flux from the source is ∼17% of the Crab Nebula flux, with a hard spectral index of 2.0. The possible associations of HESS J1708−443 with a relic PWN of PSR B1706−44 and the SNR G 343.1−2.3 have been discussed. Although a possible association between the SNR and pulsar PSR B1706−44 suggests that the SNR is in a later evolutionary stage than other previously-detected VHE γ-ray emitting SNRs, there is at present no ground to favor either of these two possible counterparts as being associated with the H.E.S.S. source.
VI. ACKNOWLEDGMENTS

The support of the Namibian authorities and of the University of Namibia in facilitating the construction and operation of H.E.S.S. is gratefully acknowledged, as is the support by the German Ministry for Education and Research (BMBF), the Max Planck Society, the French Ministry for Research, the CNRS-IN2P3 and the Astroparticle Interdisciplinary Programme of the CNRS, the U.K. Science and Technology Facilities Council (STFC), the IPNP of the Charles University, the Polish Ministry of Science and Higher Education, the South African Department of Science and Technology and National Research Foundation, and by the University of Namibia. We appreciate the excellent work of the technical support staff in Berlin, Durham, Hamburg, Heidelberg, Palaiseau, Paris, Saclay, and in Namibia in the construction and operation of the equipment.

REFERENCES

[1] Aharonian, F., et al. (H.E.S.S. Collab.) 2005, A&A, 432, L9
[2] Aharonian, F., et al. (H.E.S.S. Collab.) 2005, Science, 307, 1938
[3] Aharonian, F., et al. (H.E.S.S. Collab.) 2005, A&A, 437, L7
[4] Aharonian, F., et al. (H.E.S.S. Collab.) 2005, A&A, 442, L25
[5] Aharonian, F., et al. (H.E.S.S. Collab.) 2006, A&A, 457, 899
[6] Aharonian, F., et al. (H.E.S.S. Collab.) 2006, A&A, 456, 245
[7] Aharonian, F., et al. (H.E.S.S. Collab.) 2006, A&A, 448, L43
[8] Aharonian, F., et al. (H.E.S.S. Collab.) 2006, A&A, 460, 365
[9] Aharonian, F., et al. (H.E.S.S. Collab.) 2007, A&A, 464, 235
[10] Aharonian, F., et al. (H.E.S.S. Collab.) 2006, ApJ, 636, 777
[11] Aharonian, F., et al. (H.E.S.S. Collab.) 2007, ApJ, 661, 236
[12] Aharonian, F., et al. (H.E.S.S. Collab.) 2007, A&A, 472, 489
[13] Becker, W., et al. 1995, A&A, 298, 528
[14] Berge, D., et al. 2007, A&A, 466, 1219
[15] Blondin, J. M., et al. 2001, ApJ, 563, 806
[16] Bock, D. C.-J., et al. 2002, A&A, 394, 533
[17] Bolz, O. 2004, Universität Heidelberg, Ph.D. Thesis
[18] Chadwick, P. M., et al. 1998, ApJ, 9, 131
[19] Chaves, R. C. G. (H.E.S.S. Collab.) 2009, these proceedings
[20] Cordes, J. M. & Lazio, T. J. W. 2002, arXiv:astro-ph/0207156
[21] Di Salvo, T., et al. 2005, ApJL, 623, L121
[22] Dodson, R., et al. 2002, MNRAS, 334, L1
[23] Finley, J. P., et al. 1998, ApJ, 493, 884
[24] Forman, W., et al. 1978, ApJS, 38, 357
[25] Frail, D. A., et al. 1994, ApJ, 437, 781
[26] Gaensler, B. M., et al. 2003, ApJ, 588, 441
[27] Giacani, E. B., et al. 2001, AJ, 121, 3133
[28] Gotthelf, E. V., et al. 2002, ApJL, 567, L125
[29] Hoppe, S. D., et al. 2007, AIPC, 1085, 332
[30] Horns, D., et al. 2007, APSS, 309, 189
[31] Johnston, S., et al. 1992, MNRAS, 255, 401
[32] Johnston, S., et al. 1998, MNRAS, 297, 108
[33] Kehner, S. R., et al. 2006, Phys Rev D 74, 34018
[34] Kifune, T., et al. 1995, ApJL, 438, L91
[35] Koribalski, B., et al. 1995, ApJ, 441, 756
[36] Kushida, J., et al. (CANGAROO Collab.) 2003, ICRC, 4, 2493
[37] McAdam, W. B., et al. 1993, ICRC, 1, 392
[38] Ogio, S., et al. 1993, ICRC, 3, 281
[39] Roberts, M., et al. 1997, ICRC, 3, 281
[40] Romani, R. W., et al. 2005, ApJ, 631, 480
[41] Rowell, G. P., et al. 1998, A&A, 332, 194
[42] Szajno, M., et al. 1985, ApJ, 299, 487
[43] van der Swaluw, E., et al. 2001, AAP, 380, 309
[44] Swanenburg, B. N., et al. 1981, ApJL, 243, L69
[45] Tanimori, T., et al. 2005, ICRC, 4, 215
[46] Taylor, J. H., et al. 1993, ApJ, 411, 674
[47] Thompson, D. J., et al. 1992, Nature, 359, 615
[48] Wang, N., et al. 2000, MNRAS, 317, 843
[49] Wright, A. E., et al. 1994, ApJS, 91, 111
[50] Yoshikoshi, T., et al. 2009, arXiv:0906.4924