Radio observations of the pulsar wind nebula HESS J1303 – 631 with *ATCA*

I. Sushch*[1,2], I. Oya[3], U. Schwanke[4], S. Johnston[5], M. Dalton[6]

*iurii.sushch@nwu.ac.za

1 North-West University, Potchefstroom, South Africa
2 Ivan Franko National University of L'viv, L'viv, Ukraine
3 DESY, Zeuthen, Germany
4 Humboldt-Universität zu Berlin, Berlin, Germany
5 Australia Telescope National Facility, Epping, Australia
6 Active Space Technologies GmbH, Berlin, Germany

HESS J1303 – 631

- HESS J1303 – 631 was initially unidentified very high energy (VHE; $E \gtrsim 100$ GeV) gamma-ray source which was recently associated with the pulsar PSR J1301 – 6305 and identified as evolved pulsar wind nebula (PWN).
- Association with the pulsar was based on its energy-dependent morphology. With the increase of the energy threshold a very extended emission region ($\sim 0.4^\circ \times 0.3^\circ$ at the $(0.84 - 2)$ TeV band) of VHE γ-rays "shrinks" towards the position of the pulsar at $E > 10$ TeV.
- Such an energy-dependent morphology is expected for ancient pulsar wind nebulae (PWNe), which feature several populations of relativistic electrons generated by the pulsar.
- The association of HESS J1303 – 631 with the pulsar is further supported by the detection of its X-ray counterpart with *XMM-Newton* [1] with a much smaller emission region around the pulsar.
- Recently, the counterpart of HESS J1303 – 631 was finally detected at GeV energies with *Fermi*-LAT [2] revealing a similar morphology and larger size comparing to the TeV source.

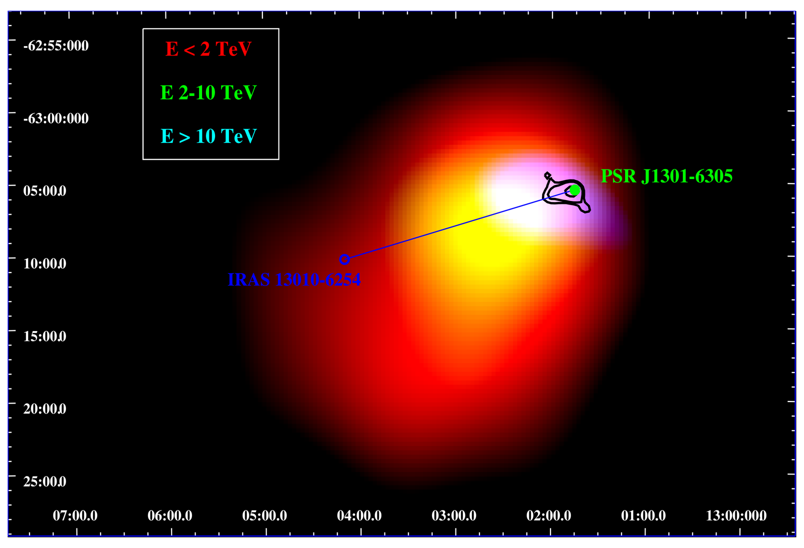

Figure: Energy mosaic of HESS J1303 – 631. Red: $E = (0.84 - 2)$ TeV, green: $E = (2 - 10)$ TeV and blue: $E > 10$ TeV. The highest energy photons originate nearest the pulsar, PSR J1301 – 6305 (marked by the green dot). The visible red corresponds roughly to the 10 σ significance contour of the entire source. *XMM-Newton* X-ray contours are shown in black. A potential birthplace for the pulsar, IRAS 13010 – 6254, as indicated by the X-ray extension, is shown by a blue circle. The figure is taken from [1]

Non-detection of the radio PWN

Data description

- The *ATCA* observations of the field of view (FOV) around PSR J1301 – 6305 were conducted on September 5th, 2013.
- Observations were performed with the 1.5A configuration of the array at 5.5 and 7.5 GHz frequencies and centered at $\alpha = 13^h02^m10.00^s$, $\delta = -63^\circ05'34.8''$ (J2000.0).
- The total time of observations was 2626.7 minutes.

Analysis results

- The data analysis was performed using the `miriad` package [3].
- No significant extended emission coincident with the pulsar position was detected at $5.5/7.5$ GHz.
- Archival $1.384/2.368$ GHz data also do not reveal any significant emission coincident with the pulsar.

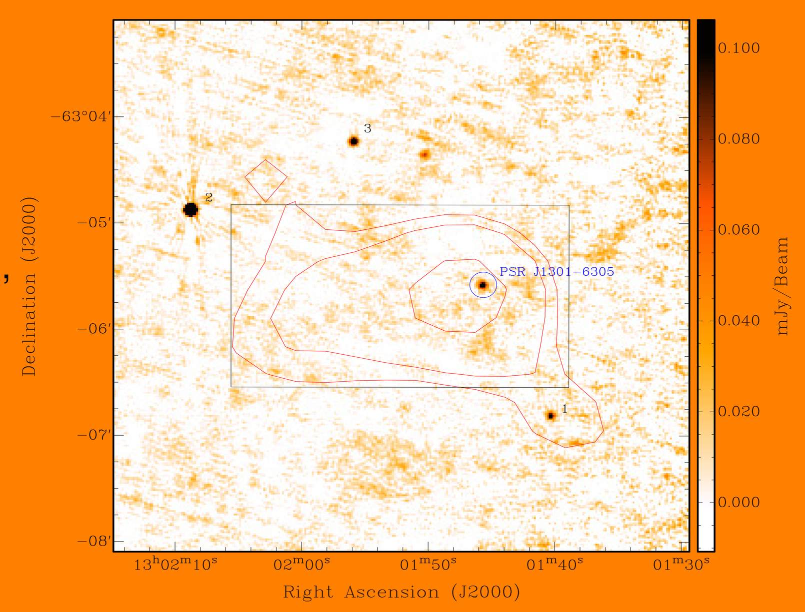

Figure: Radio map of the HESS J1303 – 631 FoV at 5.5 GHz overlaid with contours of the X-ray PWN (red) as detected with *XMM-Newton* [1]. The blue circle indicates the position of the pulsar PSR J1301-6305. The black box determines the region used for the flux upper limit calculation. New point-like sources are indicated with numbers. The synthesized beam is determined by an ellipse with the major and minor axes of 3.79″ and 3.65″ respectively and the positional angle of -7.6°.

Detection of a new Supernova remnant?

- The archival 1.384 GHz data reveal a shell-like structure to the east of the pulsar position which might potentially be a Supernova remnant (SNR).
- The center of the structure is at $\alpha = 13^h04^m29.059^s \pm 0.035^s$ $\delta = -63^\circ01'22.140'' \pm 0.926''$.
- The fitted image RMS noise is estimated to be 6.965×10^{-1} mJy/beam.
- The brightest parts of the shell-like structure reach the significance of 13 σ.
- Infrared and optical observations (e.g. the Two Micron All-Sky Survey (2MASS) in the H-band (1.65 μm) [4]) do not show any extended emission from the region of the shell-like structure. This suggests that the radio emission from the shell-like structure is most probably non-thermal, as expected for SNRs.

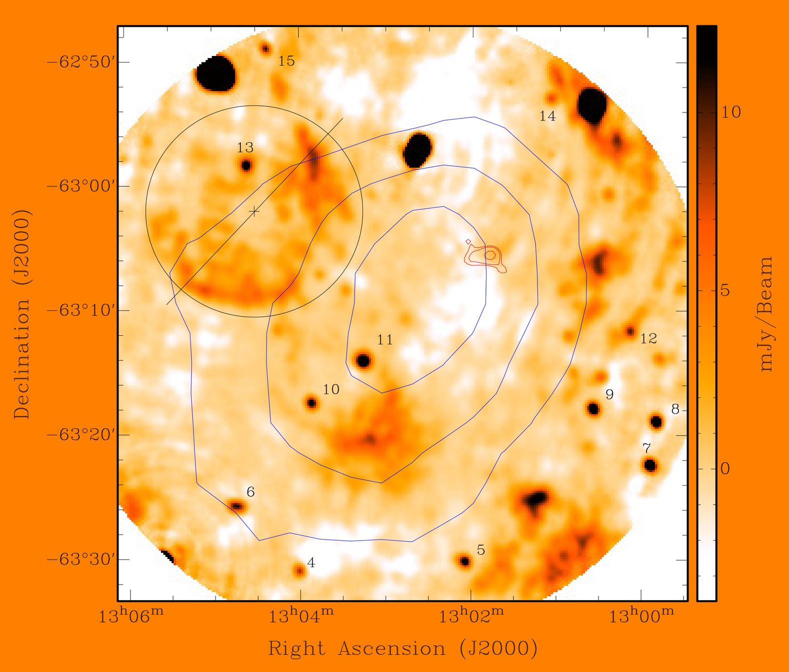

Figure: Radio map of the HESS J1303 – 631 FoV at 1.384 GHz. Red contours represent the X-ray PWN as detected with *XMM-Newton* and blue contours represent HESS J1303 – 631 as detected by H.E.S.S. [1]. The black circle indicates the shell-like structure and the black cross indicates its centre. New point-like sources are indicated with numbers. The synthesized beam is determined by an ellipse with the major and minor axes of 51.3″ and 43.8″ respectively and the positional angle of 20.9°.

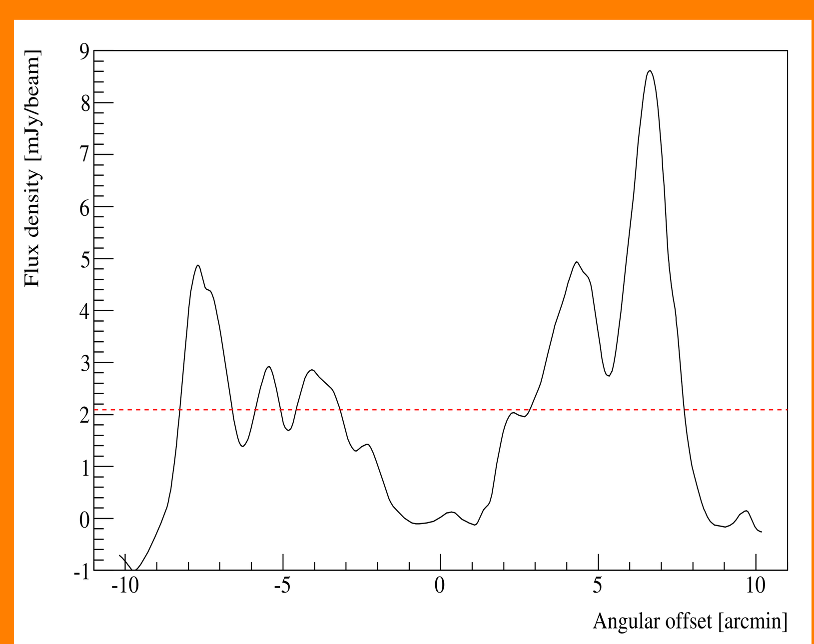

Figure: 1D radial profile of the shell-like structure, i.e. flux density along the black line shown on the radio map. Red dashed line indicates a significance level of 3σ.

The birth place of PSR J1301 – 6305?

- In case the extended source with a shell-like morphology detected at 1.384 GHz is an SNR it could be the birth place of the pulsar PSR J1301 – 6305.
- Assuming a distance to the pulsar of 6.6 kpc [1], the angular size of the SNR candidate corresponds to 30 pc in diameter.
- The angular distance between the pulsar and the center of the SNR candidate of about 19′ corresponds to a projected distance of 36 pc.
- This distance corresponds to a lower limit on the pulsar velocity of $V_p \geq 3000$ km/s assuming the characteristic age of the pulsar of 11 ky [5]
- This value would make PSR J1301 – 6305 the fastest known pulsar

Implicatios of the lack of radio emission

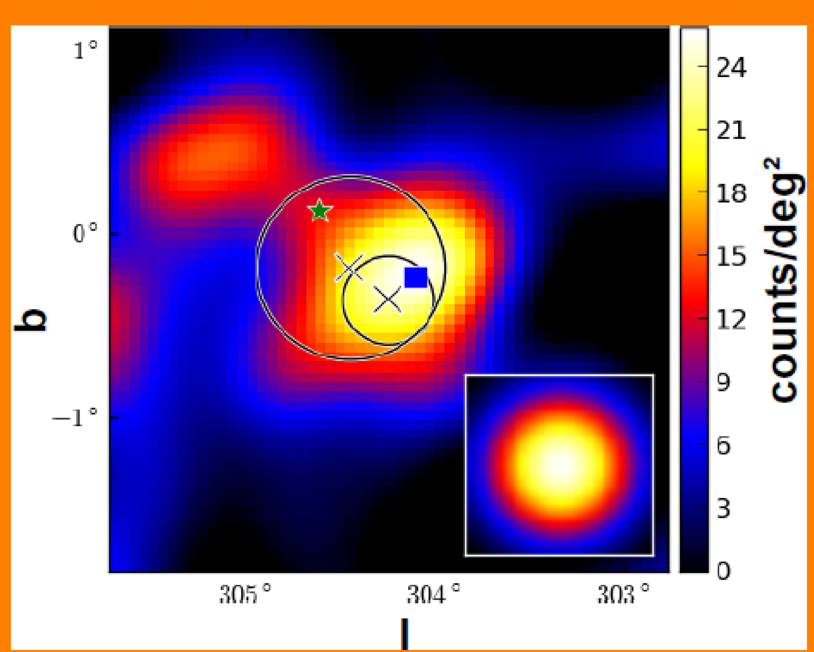

Figure: Counts map of the region of HESS J1303 – 631 above 31 GeV. The green star indicates the position of the SNR Kes 17 and the blue square represents the position of PSR J1301 – 6305. The small and big circles show the extension of the H.E.S.S. [1] and *Fermi*-LAT [2] sources, respectively. The figure is taken from [2].

- The size of the GeV emission region of 0.9° [2] indicates that a high amount of relatively low energy relativistic electrons is spread out to large distances from the pulsar.
- The same electrons are also responsible for the generation of the radio emission via the synchrotron mechanism, therefore, the radio emission region might be at least as large as the GeV PWN.
- In this case the putative radio PWN is larger than the FoV of radio observations and cannot be detected.
- The size of the putative radio PWN can be also constrained by the region of higher magnetic field, i.e. by the size of the X-ray PWN with extension of $\sim 176''$
- Upper limits on the radio flux at 5.5 GHz and at 1.384 GHz were estimated at the level of 3 RMS noise in the region of the X-ray PWN defined by a box (black box shown in the 5.5 GHz map). Upper limits are 0.17 mJy at 5.5 GHz and 2.6 mJy at 1.384 GHz.
- The upper limit at 5.5 GHz is by two orders of magnitude more constraining than the one reported in [1] for the insignificant radio feature of a similar size detected at 4.85 GHz.
- Assuming the electron spectral index of 1.0 based on the two low-energy data points of the GeV spectrum [2] and scaling the total GeV flux to the X-ray PWN region, constraints on the radio emission correspond to the upper limit on the magnetic field of ~ 1 mG.
- Similarly the comparison of the X-ray and TeV emission for results in the upper limit on the magnetic field of 17 μG.

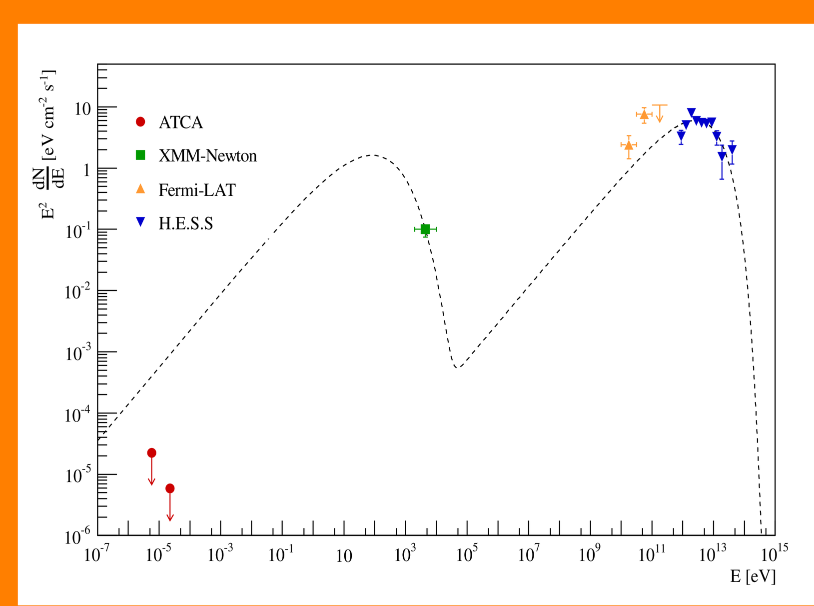

Figure: Spectral energy distribution of HESS J1303 – 631. For the radio upper limit the size of the putative radio PWN is assumed to be comparable to the X-ray PWN. The dashed line represents a simple one-zone leptonic model proposed in [1]. A simple one-zone model cannot explain the observed emission.

References

[1] H.E.S.S. Collaboration, A. Abramowski, et al., *Identification of HESS J1303-631 as a pulsar wind nebula through γ-ray, X-ray, and radio observations*, ***A&A***, **548 (Dec., 2012) A46.**

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