New constraints on the TeV SNR shells RX J1713.7-3946 and HESS J1731-347

G. Pühlhofer[1], P. Eger[2], V. Doroshenko[1], Y. Cui[1], D. Klochkov[1], H.E.S.S. collaboration
[1] Institut für Astronomie und Astrophysik Tübingen, [2] Max Planck Institut für Kernphysik Heidelberg

All RX J1713.7-3946 images: Eger et al., for the HESS collaboration, ICRC 2015. All RX J1713.7-3946 numbers and plots are preliminary.

RX J1713.7-3946

An updated TeV sky map and spectrum of RX J1713.7-3946

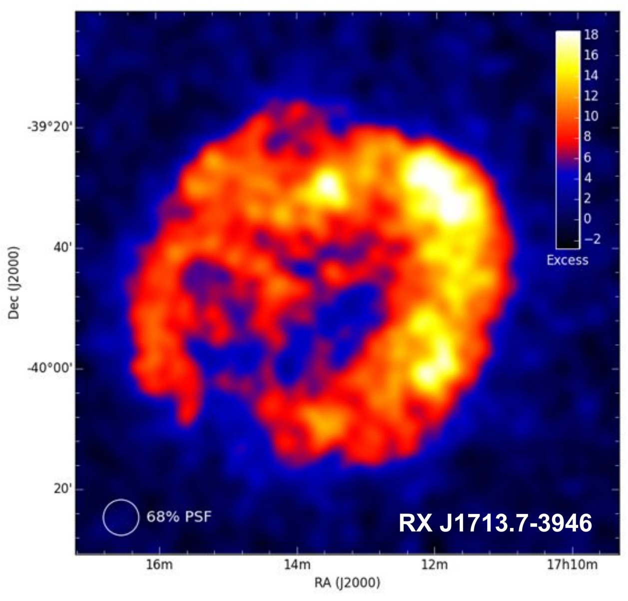
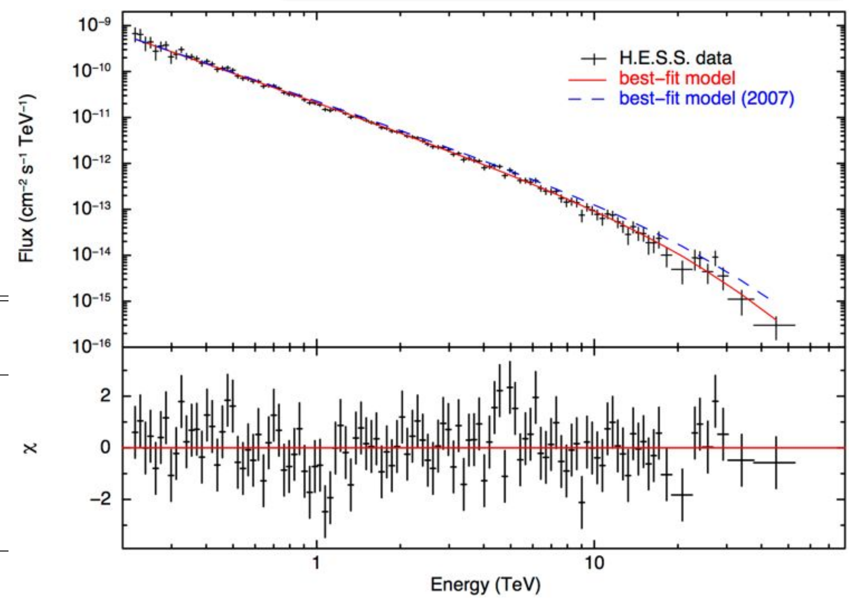


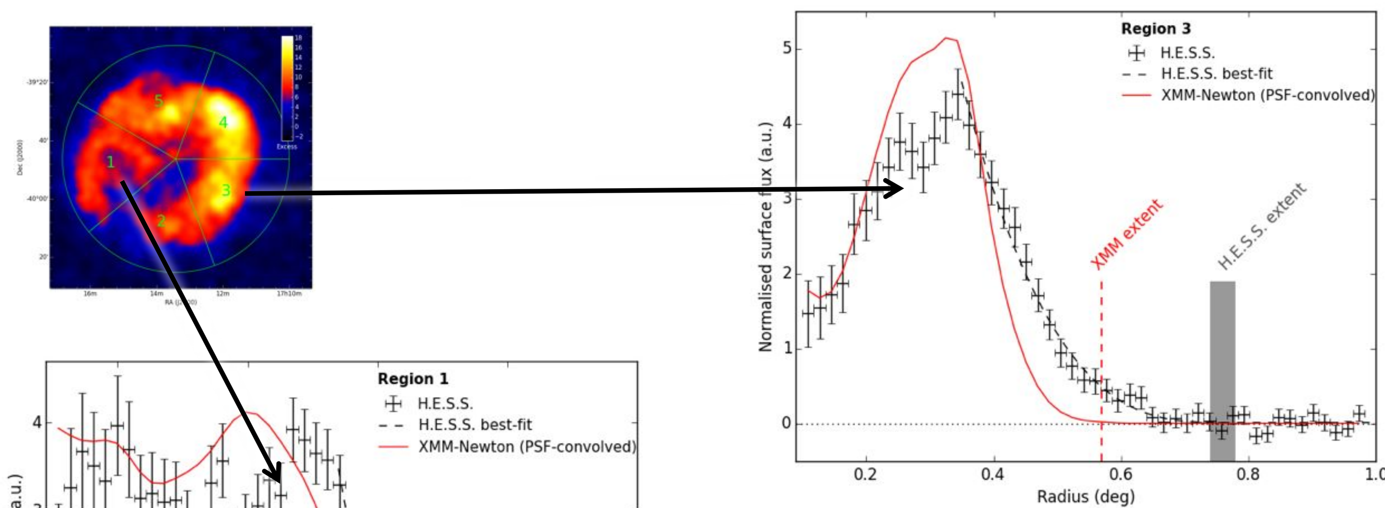
Image exposure:	170 h (2× previous 2004, '06, '07 H.E.S.S. papers)
Angular resolution:	0.05°
Energy threshold:	250 GeV
Analysis:	Model with HiRes cut (de Naurois & Rolland, 2007)

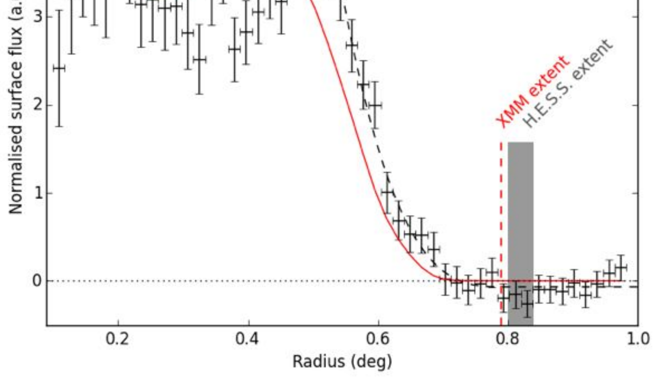
Spectrum exposure:	150 h
Energy threshold:	200 GeV
Excess:	> 27000 counts



Spectral Model	Γ	$E_{\rm cut}$ (TeV)	$F(>1$ TeV) (10^{-11} cm^{-2} s^{-1})	χ^2 / ndf
$F_0E^{-\Gamma}$	2.32±0.02	-	1.52±0.02	304.2/118
$F_0E^{-\Gamma}\exp\left(-\frac{E}{E_{cut}}\right)$	2.06±0.02	12.9±1.1	1.64±0.02	120/117
$F_0E^{-\Gamma}\exp\left(-\frac{E}{E_{cut}}\right)^2$	2.17±0.02	16.5±1.1	1.63±0.02	113.8/117
$F_0E^{-\Gamma}\exp\left(-\frac{E}{E_{cut}}\right)^{0.5}$	1.82±0.04	2.7±0.4	1.63±0.02	142.1/117

Radial profiles: protons vs. electrons?

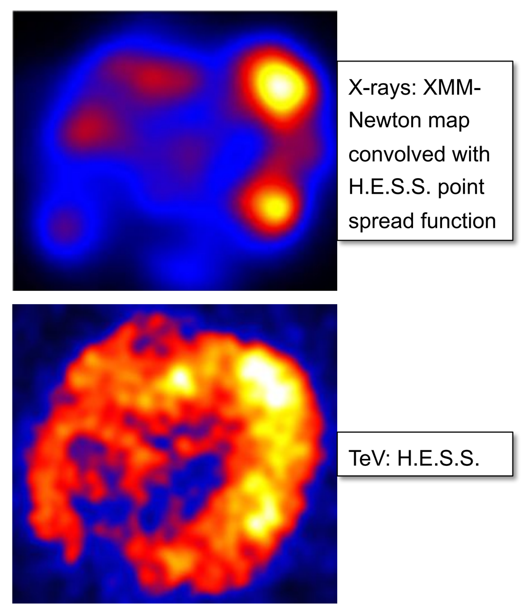


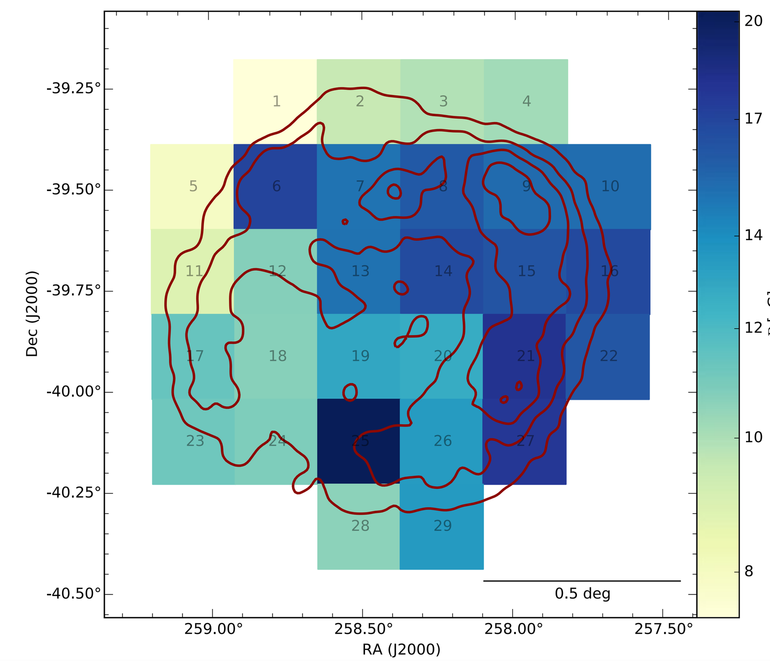


A significant difference of the shell extent between X-rays (XMM-Newton) and TeV γ-rays (H.E.S.S.) has been observed (top panel). Possible interpretations include:

- If the TeV emission is due to protons: Escape of CR protons beyond the forward shock position could explain the difference
- If the TeV emission is due to electrons: B-field evolution could lead to a spatial difference between X-ray synchrotron and TeV Inverse Compton emission

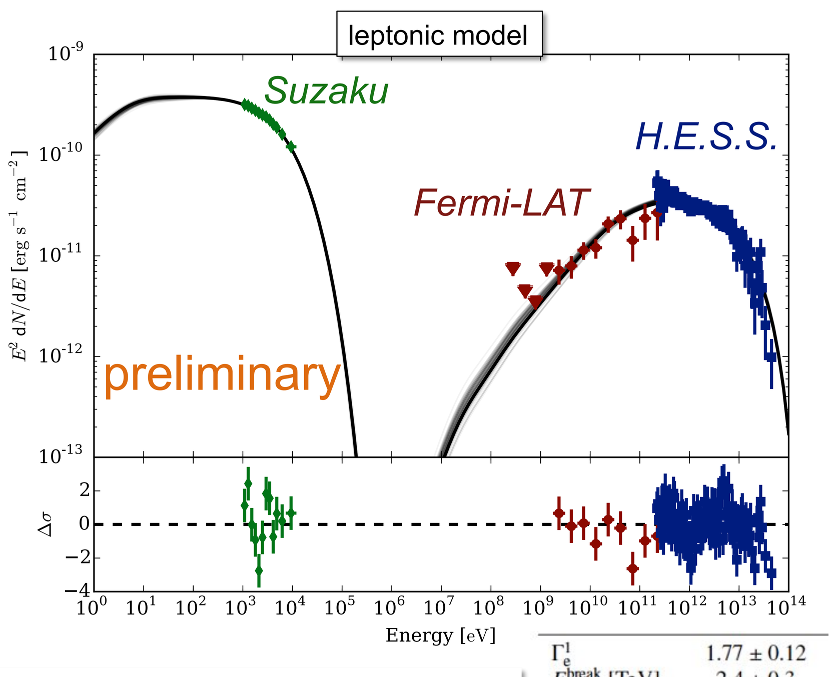
Mapping the B-field (leptonic assumption of TeV emission)



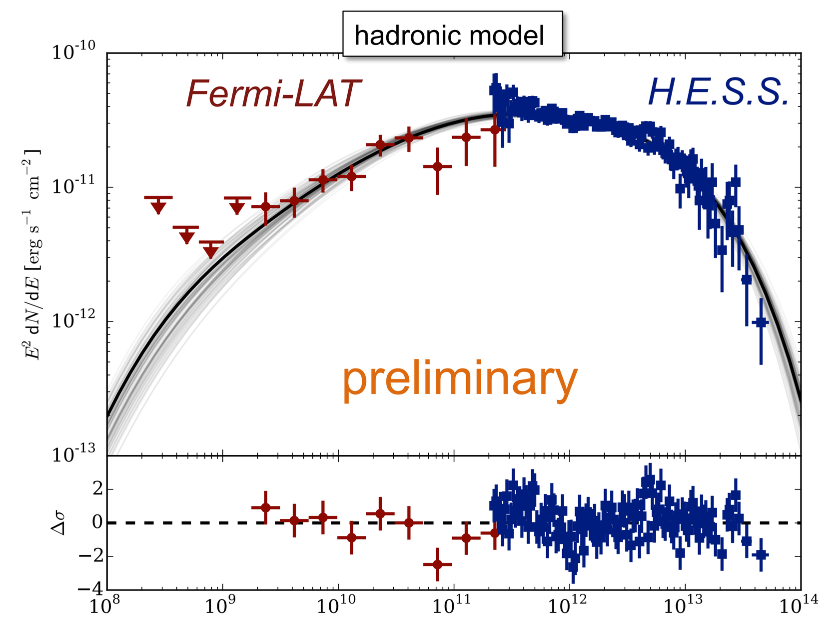


Under the assumption that the TeV emission is due to electron Inverse Compton emission, a significant variation of the B-field across the remnant is observed.

Modeling the spectral energy distribution (entire source)



Γ_e^1	1.77 ± 0.12
$E_e^{\rm break}$ [TeV]	2.4 ± 0.3
Γ_e^2	2.93 ± 0.02
$E_e^{\rm cutoff}$ [TeV]	88.4 ± 1.2
W_e [10^{46} erg]	11.8 ± 0.5
B [μG]	14.17 ± 0.18



Γ_p^1	1.50 ± 0.08
$E_p^{\rm break}$ [TeV]	1.4 ± 0.5
Γ_p^2	1.94 ± 0.05
$E_p^{\rm cutoff}$ [TeV]	92 ± 15
W_p [10^{49} erg]	5.80 ± 0.12

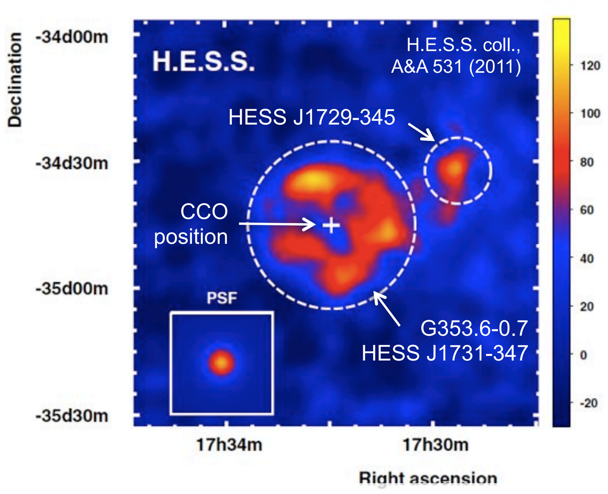
- Interpreting the electron spectrum break (at ~2.5 TeV) as due to synchrotron cooling results in a B-field of ~70 μG, at odds with the B-field derived from the SED model
- The B-field in the SED model could be lowered by increasing the IC target photon field density, however far beyond usually assumed densities

SED fits have been performed with ‚naima' (Zabalza, ICRC 2015)

- The break in the proton spectrum (at ~1 TeV) might be explained by energy-dependent diffusion into dense molecular clumps
- Cf. Porter et al. (2006), Inoue et al. (2012), Fukui et al. (2012), Sano et al. (2013, 2015), Maxted et al. (2013), Gabici & Aharonian (2014)

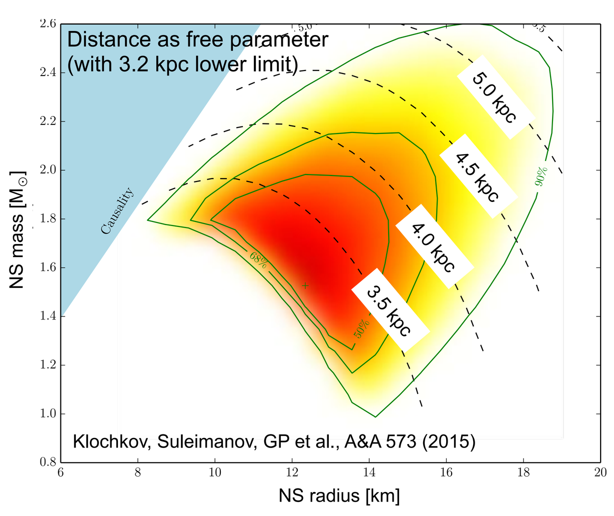
HESS J1731-347

The SNR HESS J1731-347 and its surroundings

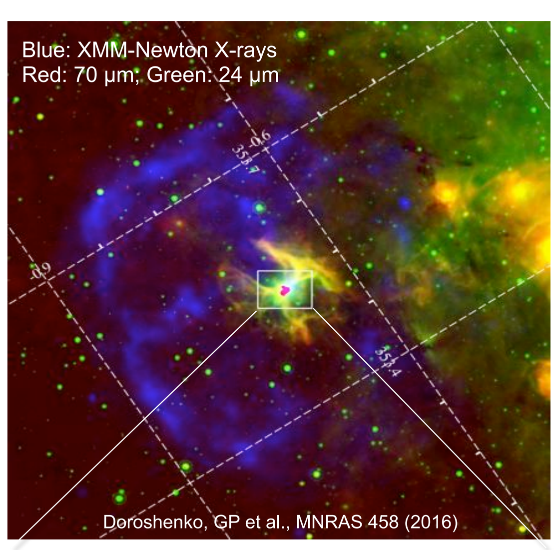


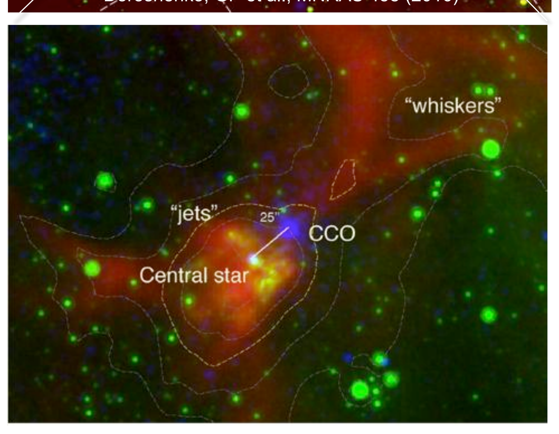
HESS J1731-347 is a TeV γ-ray source that was discovered in 2008 in the course of the then ongoing H.E.S.S. galactic plane survey. The discovery of a radio SNR candidate counterpart, the detection of shell-type non-thermal X-ray emission, and the TeV shell appearance matching the radio shell confirmed the SNR nature of the source. Located at the geometrical center of HESS J1731-347, the thermal X-ray point source XMMUJ173203.3−344518 is interpreted as a „central compact object" (CCO), the neutron star that remained after the supernova core-collapse explosion. Another TeV source, HESS J1729-345, is located in direct neighborhood of HESS J1731-347. The astrophysical nature of HESS J1729-345 is so far unknown.

The central compact object and its likely progenitor binary system



A lower distance limit of 3.2 kpc to the SNR HESS J1731-347 has been derived from matching the foreground absorption pattern seen in the X-ray emission from the SNR to the molecular gas density seen in sub-mm emission towards the direction of the SNR. The X-ray spectrum of the central compact object XMMUJ173203.3−344518 in the center of the SNR permits to further constrain the distance to the SNR. In close analogy to the CCO detected in the center of the SNR Cassiopeia A, also the spectrum of XMMUJ173203.3−344518 indicates the presence of a carbon atmosphere around the neutron star (spectral fitting prefers a carbon atmosphere over a blackbody fit, and a blackbody fit would place the CCO at a unreasonably large distance). As shown on the left plot, the fit of a model carbon atmosphere to the CCO spectrum prefers a canonical NS mass and radius, as well as a low distance to the source, close to the lower limit of 3.2 kpc.

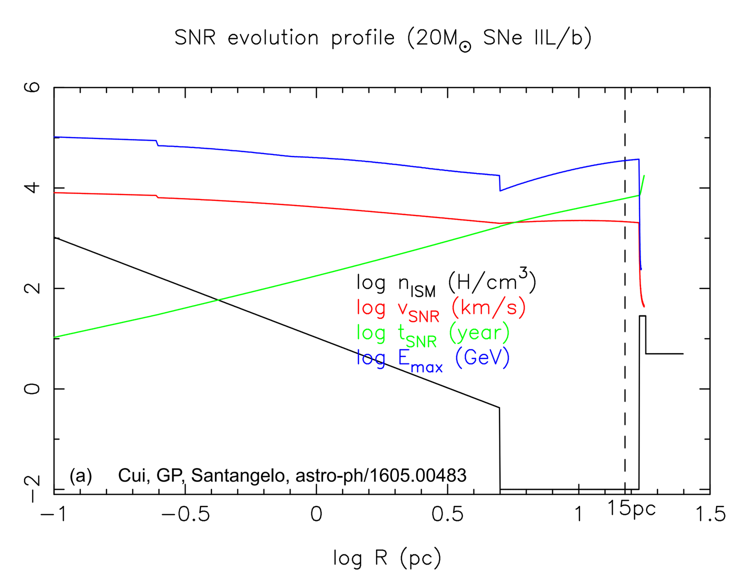




CCOs are usually thought to be isolated, thermally emitting neutron stars. A detailed analysis of Spitzer infrared data recorded around the CCO position revealed however that the nearby (25" distance to the CCO) post-AGB star IRAS 17287-3443 has likely been in a binary system with the progenitor star of the CCO, before the supernova explosion happened. As shown on the images to the left, the central star IRAS 17287-3443 is surrounded by a dust shell that is heated by the star to temperatures of ~90 K. The dust temperature increases in the vicinity of the CCO, spatially linking the two stars. The SNR's age and the active mass loss phase of the optical star are much shorter than the lifetime of either object, suggesting that the supernova explosion and the onset of the mass loss phase started simultaneously, and that the two events are therefore causally connected. This is only possible if the two objects have been members of the same binary system that was finally disrupted by the supernova explosion.

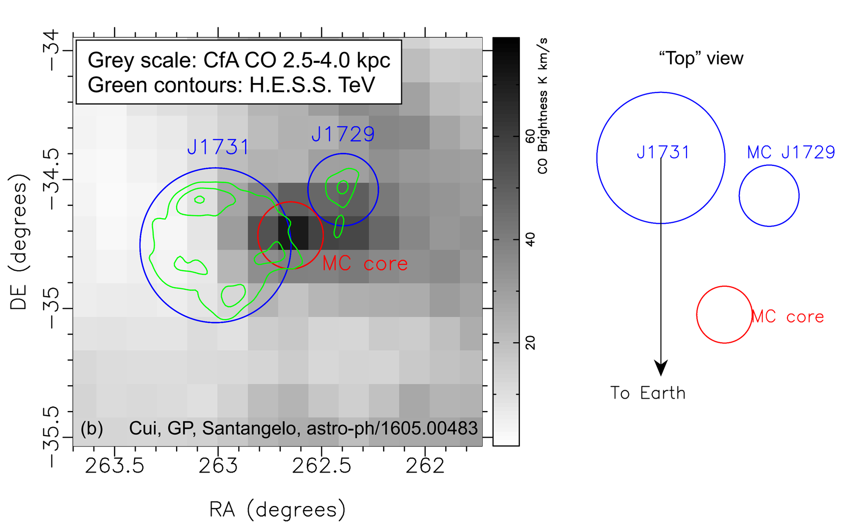
An identifying property of CCOs is their low surface dipole magnetic fields, in comparison to typical neutron stars. One possible explanation for this characteristics is that the neutron star's magnetic field is „buried" by a hyper-accretion episode shortly after the supernova explosion. The proposed binary system scenario would naturally fit into this picture, by providing a substantial mass reservoir for accretion beyond the supernova ejecta, which normally constitute the only reservior for accretion.

A model to explain the adjacent TeV source HESS J1729-345 with CRs escaping from the SNR



Many parameters of the SNR HESS J1731-347 (such as the SNR's age or the density of the environment) are still unknown. Therefore, different progenitor star assumptions for shaping the pre-supernova environment have been modeled in the presented study. A distance to the source of 3.2 kpc was adopted, corresponding to a shock radius of 15 pc. To obtain a high shock speed at present time (neccessary to explain the non-thermal X-ray spectrum), the shock must either still reside inside the main-sequence (MS) bubble carved by the massive progenitor star wind, or has just entered the wind shell. For the first case, the SNR shock parameter evolution after explosion is shown to the left (panel (a)), using the following set of parameters:

SN type: SNe IIL/b	Total SN energy: 1×10^{51} erg
Initial progenitor star mass: 20 $M_\odot$	Ejecta mass of the SN: 2 $M_\odot$
Size of MS wind bubble: 18 pc	Age of the SNR: 6.1 kyr
RSG wind bubble size: 5 pc	Shock speed today: 2140 km/s

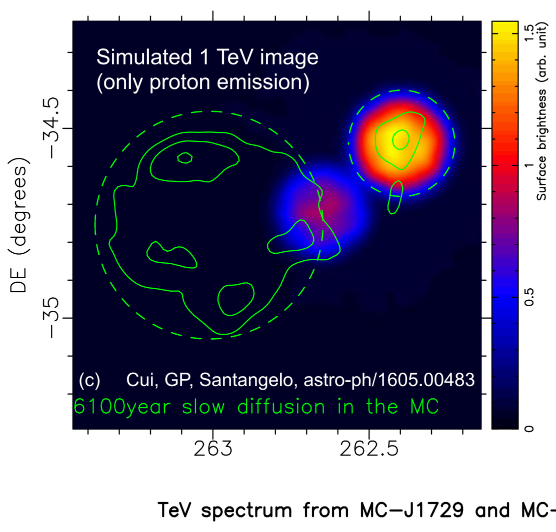


Cosmic rays above a threshold energy may escape the acceleration region at the SNR forward shock, and can diffuse outwards into the surrounding medium. To estimate the density and the energies of these escaping cosmic rays over the course of the SNR evolution, the prescriptions of Zirakashvili & Ptuskin (2008) were adopted. The following parameters characterize the process:

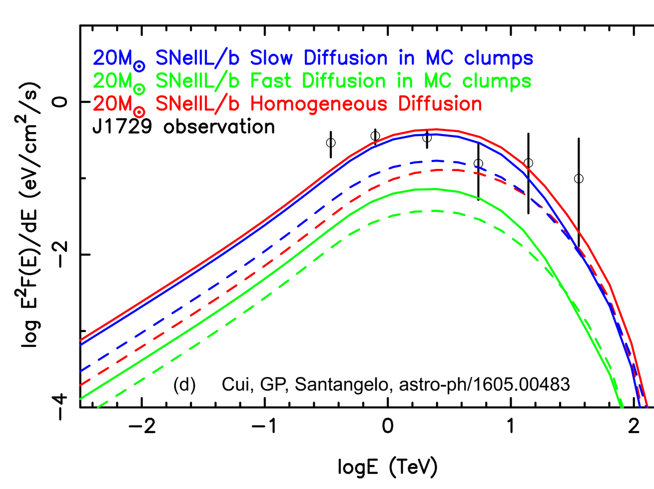
Ratio of escaping CR energy flux to upstream medium kinetic energy flux: η_{esc} = 0.02

Present-day maximum CR escape energy: E_{max} = 35 TeV

Total energy flux of escaped CRs until today: E_{CR} = 5% × 10^{51} erg



To simulate the diffusion of cosmic rays after escape into an inhomogeneous surrounding medium, Monte Carlo simulations were used. A simplified Molecular Cloud setup (panel (b)) was chosen that satisfies the measured molecular gas density in the region around 3.2 kpc and can fit the TeV image (after simulating the TeV emission). For simplicity, the assumption of isotropic diffusion was preserved, although CR propagation on the relevant spatial scales of the model (several 10s of pc) may be strongly influenced by the magnetic field structure.



The simulated TeV image (panel (c)) and spectrum (panel (d)) of the region surrounding the SNR is shown on the left. Only hadronic processes were considered. The simulation is in satisfactory agreement with the data measured with H.E.S.S. In the framework of the presented model, the emission from the SNR itself is dominated by electron Inverse Compton emission, which was not simulated.

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