The XMM-Newton (and multiwavelength) view of the nonthermal supernova remnant HESS J1731-347

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The search for „hadronic“ SNRs

• Several historic SNRs have been advocated in the last years to be hadronic SNRs (hadronic = γ-ray emission dominated by π⁰ decay)
• Examples: IC 443, W44, W49B, W51C, Tycho, Cas A
• Mostly based on π⁰-bump detected with Fermi-LAT
• Interaction with molecular clouds
• Young and middle-aged SNRs
• TeV emission of these sources (if detected and identified as SNR emission) mostly unresolved or marginally resolved
• GeV-dominated (in the γ-ray band), hard to track the highest energy particles (if present)
Resolved shell-type supernova remnants in the TeV band roughly to scale

Young, resolved (in TeV), TeV-dominated (in γ-rays)
Strong X-ray synchrotron emission, correlated with TeV
→ just leptonically dominated?
• Similar TeV luminosity as RX J1713.7-3946
• First discovered in TeV γ-rays; SNR nature through radio synchrotron shell
• Object not discovered in ROSAT survey (fainter + stronger absorption compared to RX J1713.7-3946)
• Before this work, partial coverage with XMM-Newton + Suzaku
  → pure nonthermal X-rays
• SED similar to RX J1713.7-3946
  → leptonic ?
• New: complete XMM-Newton coverage of the source

### Observation Table

<table>
<thead>
<tr>
<th>Observation ID</th>
<th>Observation Date</th>
<th>Duration, ks</th>
<th>Exposure (M1/M2/PN), ks</th>
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<tr>
<td>total:</td>
<td></td>
<td>314</td>
<td>239.2/251.1/96.2</td>
</tr>
</tbody>
</table>

**HESS J1731-347**
XMM-Newton complete coverage

Questions (to this data set):
- Distance estimate to the source
- Co-location with gas/molecular clouds?
- Photon index variations? ↔ SNR/density geometry?
- Absorption column ↔ X-ray surface brightness?

After HESS coll., A&A 2011
XMM-Newton complete coverage

- Strong contamination by stray light from nearby LMXB
- Exclude most heavily contaminated regions and treat residual stray-light as additional background component
- Residual soft proton/QPB and astrophysical background (GRXE) further complicate the analysis (different in different observations)
- For spatially resolved analysis fit all spectra simultaneously:
  - No evidence for thermal emission
  - No significant variation of the power-law index
    → mainly probe $N_H$ variations with fixed power law index $\Gamma$

Image: observed flux, corrected for all identified backgrounds, including (a large fraction of) straylight
The broadband spectral energy distribution (SED) of the SNR has been discussed by several authors (H.E.S.S. Collaboration).

3.1. Spectral energy distribution

3. Discussion
to contain at least 300 counts per pixel in each band. and Fig. 1 was adaptively smoothed using the task in each sky pixel. The resulting count images for the quiescent and Fig. 3. shows the combined exposure map in 0.4-10 keV band where regions most heavily contaminated by stray light and excluded from the analysis can be identified. The right panel shows the derived absorption column density (linear scale in range surface brightness roughly correlates with the reduction of exposure due to exclusion of regions presented above, and then multiplied by the observed expo-

Fit 157 spectra simultaneously to single-out the background (stray light, QPB, soft protons, GRXE for 5 obs, 21 regions, 3 instruments, but not all regions covered by all combinations), all linked in a complex way with each other to reduce the number of free parameters.

Fit: residual stray light component

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3.1. Spectral energy distribution

3. Discussion

to contain at least 300 counts per pixel in each band. The same results were interpreted to favor leptonic scenario. Here we present an analysis at this stage, so we stick to the model used in previous work (Nayana et al. 2017) over the remnant. The quality of radio, X-ray, and TeV emission clearly show variation of intensity between leptonic and hadronic TeV emission. However, Acero et al. (2015) and Yang et al. (2014; Acero et al. 2015) based on integrated TeV and radio fluxes and X-ray flux detected from the eastern part is, in fact, much dimmer. The source is not de-absorbed TeV and radio fluxes and X-ray flux detected from the eastern part is, in fact, much dimmer. The source is not de-absorbed XMM-Newton view of the SNR HESS J1731-347.

→ Intrinsic X-ray flux variation: drop towards West

Intrinsic (deabsorbed) surface brightness

Absorption column

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X-ray and TeV data does not permit, however, a more detailed integration over the entire remnant, and assuming a simple single-zone synchrotron-inverse Compton model. It is important to estimate as absorbed, deabsorbed TeV and radio fluxes and X-ray flux detected from the eastern part is, in fact, much dimmer. The source is not de-absorbed.
The broadband spectral energy distribution (SED) of the SNR has been discussed by several authors (H.E.S.S. Collaboration).

3.1. Spectral energy distribution

3. Discussion
to contain at least 300 counts per pixel in each band.

and Fig. 1 was adaptively smoothed using the task image without the correction for absorption presented in Fig 2 using a gaussian kernel with constant width of 0.3 absorption-corrected image presented in Fig. 8 was smoothed image was corrected for uneven exposure and smoothed. The added and subtracted from the combined net image. The final particle, soft proton, and stray-light backgrounds were then co-
in each sky pixel. The resulting count images for the quiescent sure maps to estimate the expected number of stray light photons ters presented above, and then multiplied by the observed expo-
the most heavily polluted regions shown in Fig. 2. The contours show equal brightness levels for the extended emission for reference.

factor of two higher energy flux for a given photon flux. Surface brightness roughly correlates with the reduction of exposure due to exclusion of be identified. The right panel shows the derived absorption column density (linear scale in range shows the combined exposure map in 0.4-10 keV band where regions most heavily contaminated by stray light and excluded from the analysis can

Left panel shows the mosaic pseudo colour image in 0.4-1.8 keV (red), 1.8-2.8 keV (green), and 2.8-10 keV (blue) energy bands corrected The two panels show average surface brightness of the SNR emission (left) and residual "stray-light" contamination (right) in units of

\[ \text{erg cm}^{-2} \text{s}^{-1} \text{arcmin}^{-2} \]

12 12 17 17 19 14 14 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4

\[ n_h [10^{22} \text{ cm}^{-2}] \]

H.E.S.S. coll., A&A 531 (2011)

\[ N_H \]

\[ \in \times 10^{22} \text{ cm}^{-2} \]

→ can correlate \( N_H \) map with CO map

XMM-Newton view of the SNR HESS J1731-347

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X-ray Universe 2017, Rome, June 6-9
Correlation between $N_H$ and gas map for different distances

Quantitative correlation analysis independently confirms the distance lower limit of $\sim 3.2$ kpc

**Lower limit on distance (renewed)**

Correlation between $N_H$ and gas map for different distances

Quantitative correlation analysis independently confirms the distance lower limit of $\sim 3.2$ kpc
Optical extinction is well correlated with X-ray absorption:

→ independent check of validity of X-ray analysis
→ alignment with other gas tracers and SNR boundary in the N-W
Morphological correspondence shell-gas?

Apparent correspondence of gas tracers with SNR boundary in the N-W
→ suggests co-location and interaction of SNR and molecular cloud at 3.2 kpc
• Updated SED: no scaling due to partial coverage necessary any more
• SED parameters not much affected wrt. earlier analyses
• Favours leptonic interpretation (?)
Asymmetry

- TeV emission azimuthally flat
- X-rays show strong E-W asymmetry
- Leptonic picture for γ-rays? Possibilities:
  - Inverse Compton in the West enhanced by higher target photon field
  - Lower B-field and higher electron density in the West
- Or: additional hadronic component?
  - Consistent with gas in the West if SNR is indeed co-located with gas

XMM-Newton view of the SNR HESS J1731-347

\[
\begin{align*}
\text{TeV} & \quad 11.2 \text{ TeV}, \text{ background field of } (Zabalza 2015).
\text{assuming a distance of 3.2 kpc). The derived magnetic field is}\nonumber \\
\text{Fig. 5 yields values similar to that reported by Yang et al. (2014)}.
\end{align*}
\]
Asymmetry: HESS J1731-347 vs. RX J1713.7-3946

- RX J1713.7-3946: High (non-thermal) X-ray emissivity explained with high gas density
- HESS J1731-347: similar X-ray geometry as RX J1713.7-3946, still possibly a different explanation:
  - TeV emissivity pattern is different!
  - X-ray - dim part in region of high gas density (if co-location interpretation is correct)
A blend of leptonic and hadronic TeV emission?

Not a complete model, just for illustration

Full SNR

North-West (region 19): TeV excess modeled by additional hadronic component
Conclusion

- SNR age: Age of 27 kyrs (Tian et al. 2008) was most likely overestimated (simple Sedov SNR solution)
  → Cui, GP et al. 2016: 2.4 – 6.1 kyrs
  → Doroshenko, GP et al. 2016: ~4.5 kyrs
- Distance: most likely 3.2 kpc (this work); see also
  → Maxted et al. 2015, 2017 submitted
  → distance to companion star (Doroshenko, GP et al. 2016): 3.8±0.7 kpc (Vickers et al. 2015)
- SNR likely in a wind bubble (Cui, GP et al. 2016)
- SNR likely co-located with dense gas material at 3.2 kpc (this work)
- SNR possibly interacting with dense cloud in the West; dimming of non-thermal X-rays due to slowing shocks? No thermal X-rays detected yet ...
- TeV emissivity and X-ray (intrinsic) non-thermal emissivity different (on large scale across the SNR):
  → TeV emission possibly a blend of leptonic and hadronic emission?