News on TeV supernova remnant shells

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+ Y. Cui, P. Yeung, P.-H. Tam,
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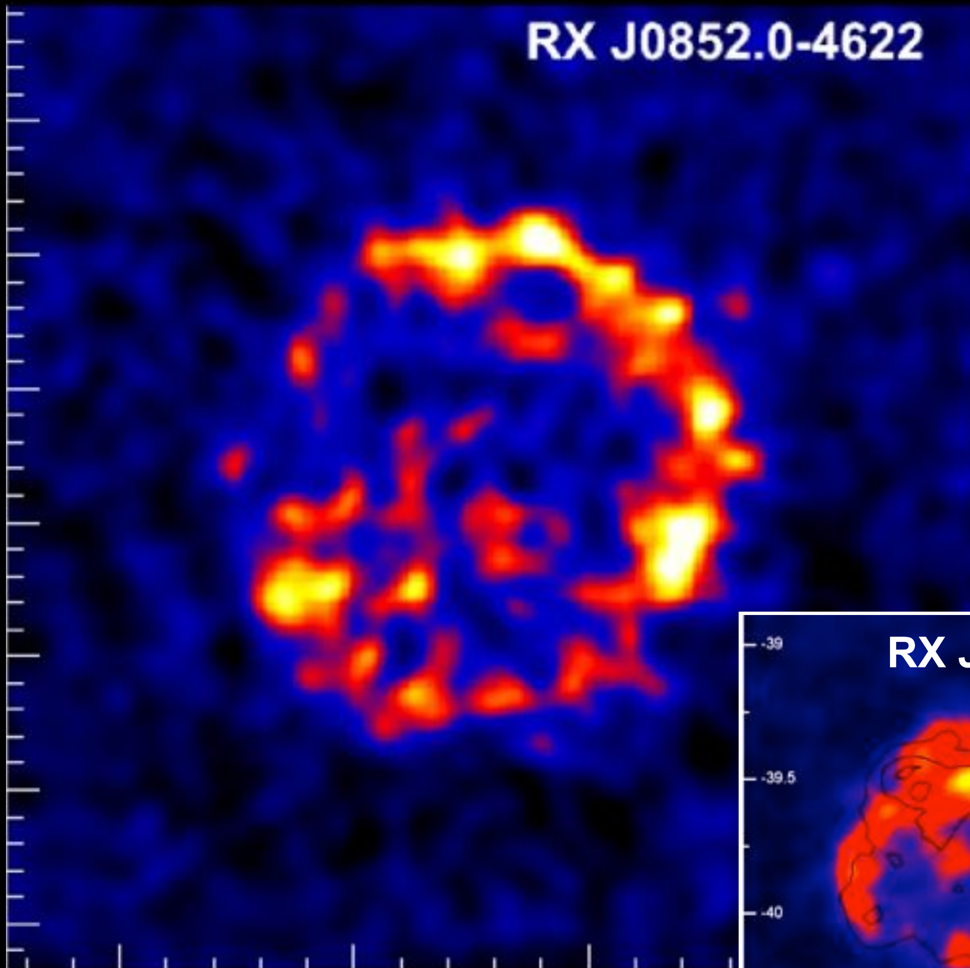
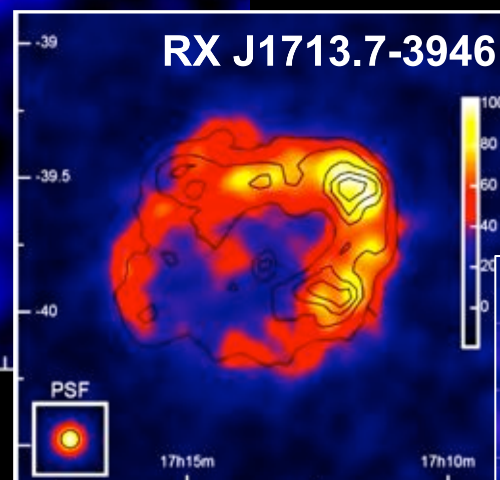
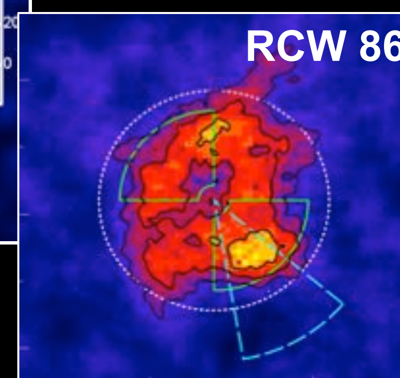
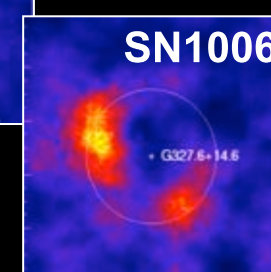
+ D. Gottschall, M. Capasso, N. Maxted, M. Sasaki, ... (H.E.S.S. collaboration), A. Bamba, Y. Fukui, H. Sano, S. Yoshiike, ...

Resolved shell-type supernova remnants in the TeV band









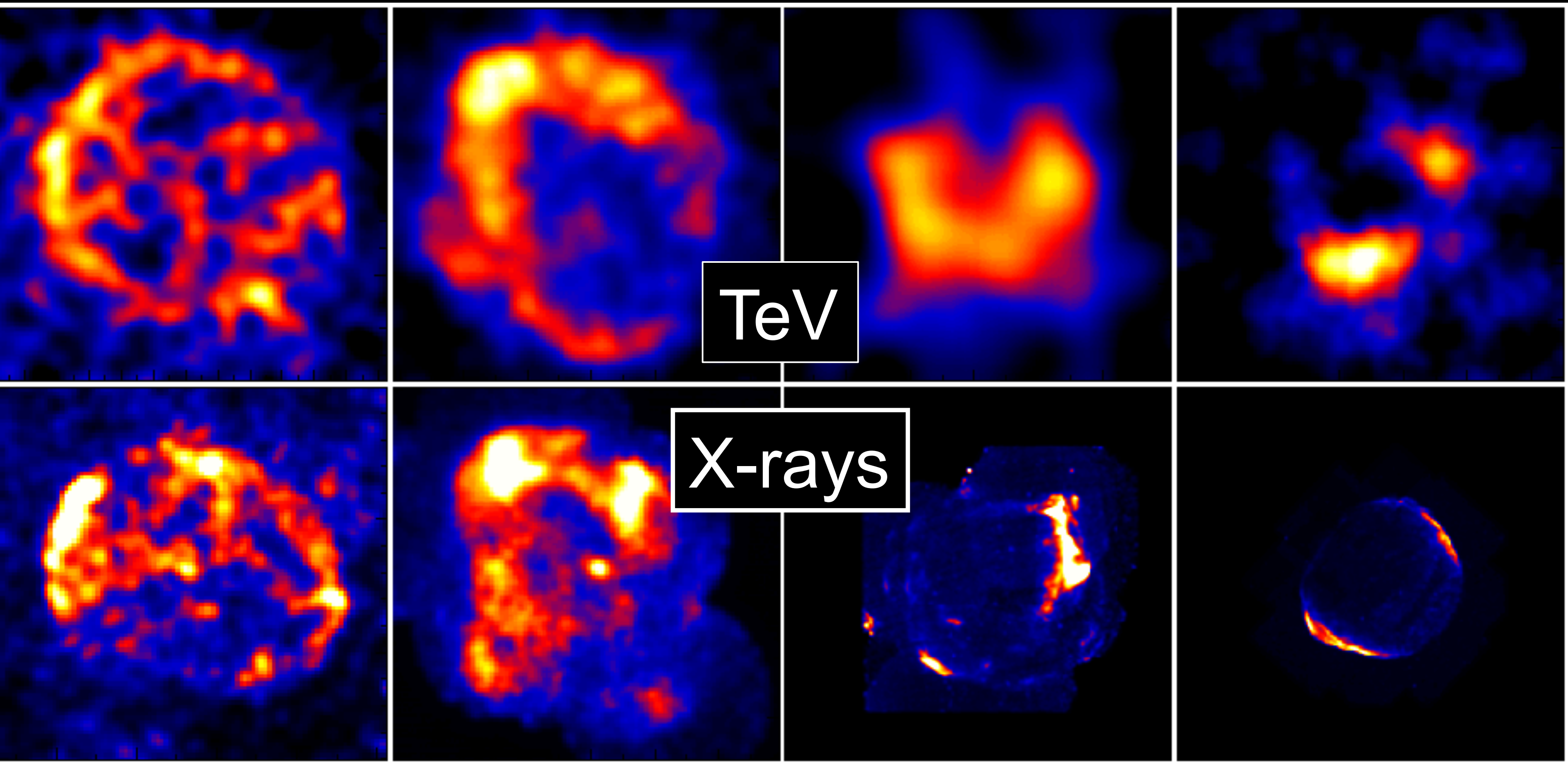
roughly to scale

Young, resolved (in TeV), TeV-dominated (in γ-rays)

Strong X-ray synchrotron emission, correlated with TeV

→ just leptonically dominated (i.e. Inverse Compton)?

Resolved shell-type supernova remnants in the TeV band



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→ just leptonically dominated (i.e. Inverse Compton)?

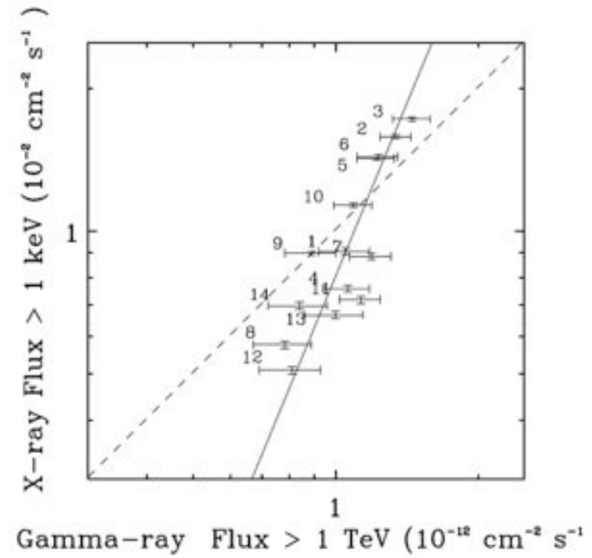
The case of RX J1713.7-3946

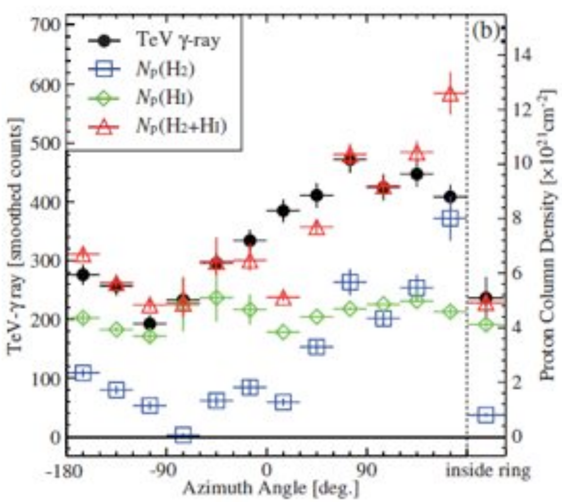
- Good (local) correlation between (nonthermal) X-rays and gas absorption
- TeV emission and (nonthermal) X-ray emission well correlated (e.g. *Acero et al. 2009*)

→ SNR shell co-located with (asymmetric) gas

→ TeV and X-rays brighten in regions of high density

- Good correlation between TeV emission and gas (CO+HI)

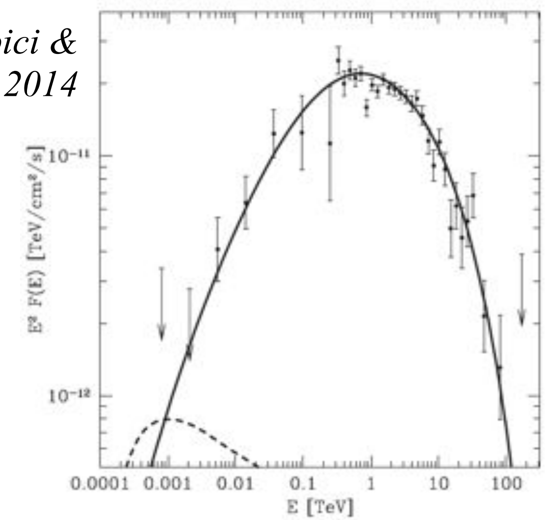




Fukui et al, ApJ 2012

Need to invoke clumpy gas geometry in order to make hadronic interpretation of γ-ray spectrum work

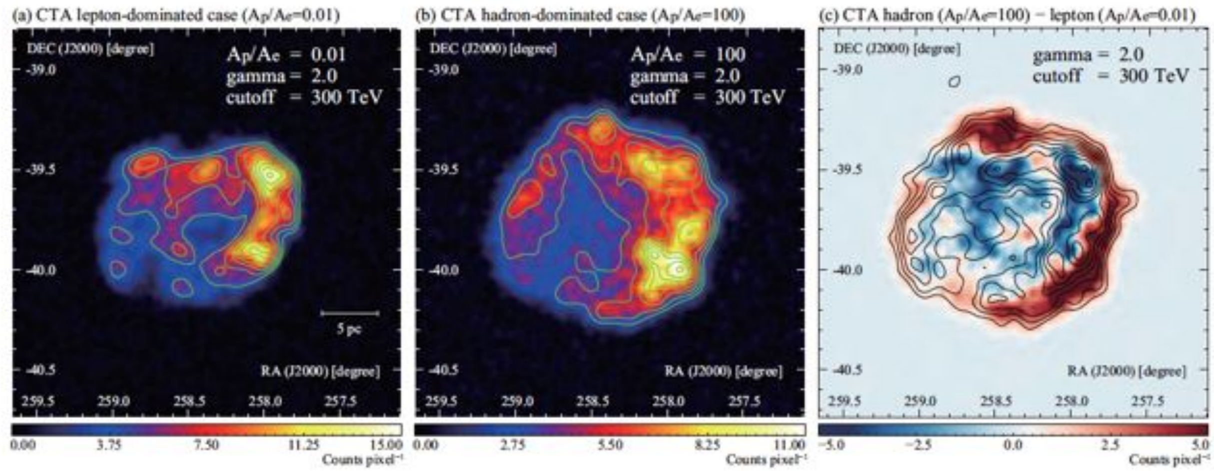
Gabici & Aharonian 2014

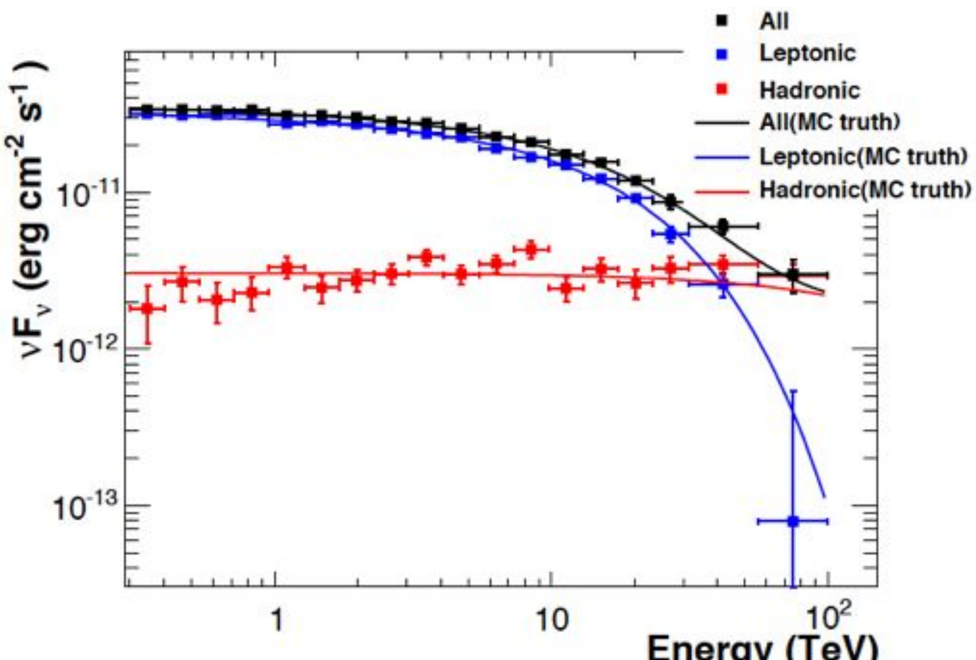


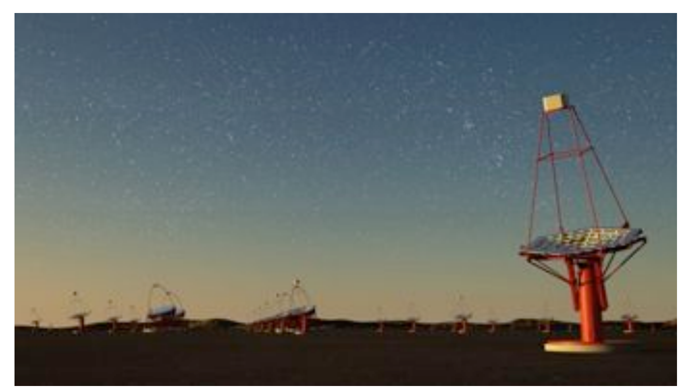
RX J1713.7-3946 with CTA

- Simulation of an extra (hadronic pevatron) component
- CTA (Cherenkov telescope array) key target

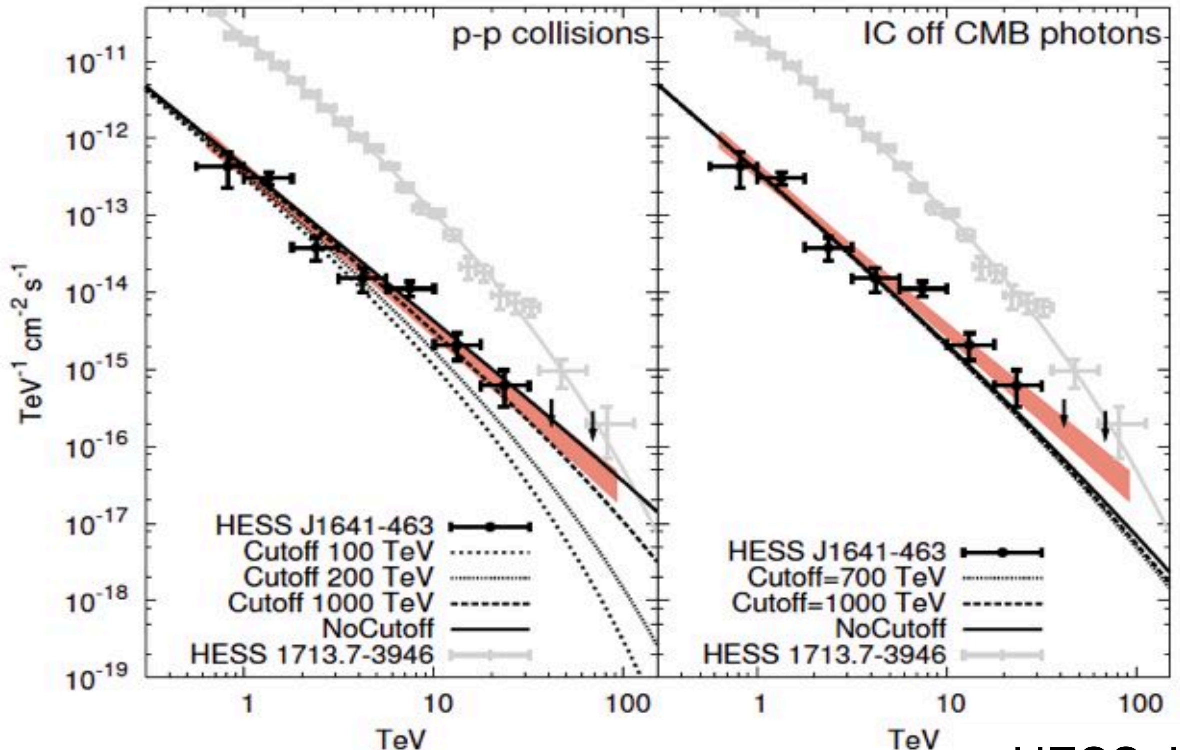
Acero et al. (CTA context) 2017

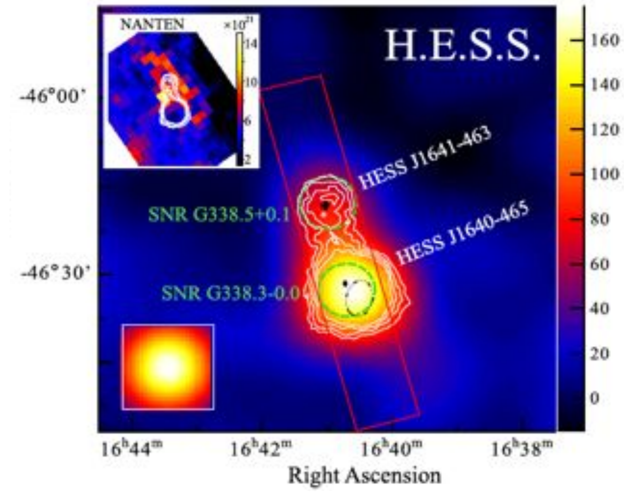






Potential PeVatrons amongst unidentified H.E.S.S. sources?





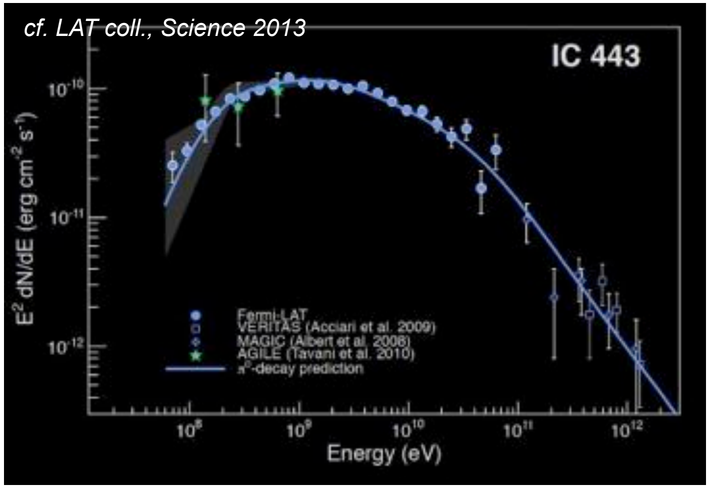
H.E.S.S. collaboration, A&A 2014

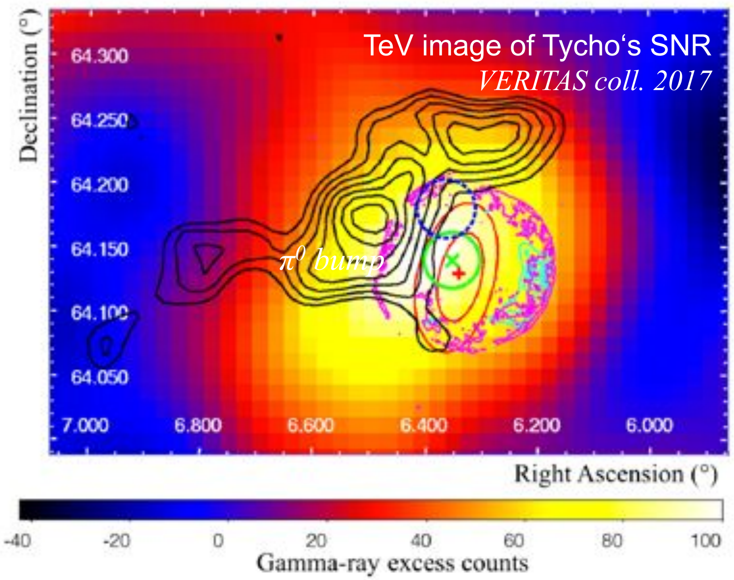
- HESS J1641-463
- Very hard spectrum, index 2.07
- Data points up to 20 TeV
- Lower limit on cutoff energy: 100 TeV

→ a potential PeVatron?

The search for „hadronic“ SNRs with Fermi-LAT

- Several historic SNRs have been advocated in the last years to be hadronic SNRs (hadronic = γ-ray emission dominated by π^0 decay)
- Examples: IC 443, W44, W49B, W51C, Tycho, Cas A
- Mostly based on π^0-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)

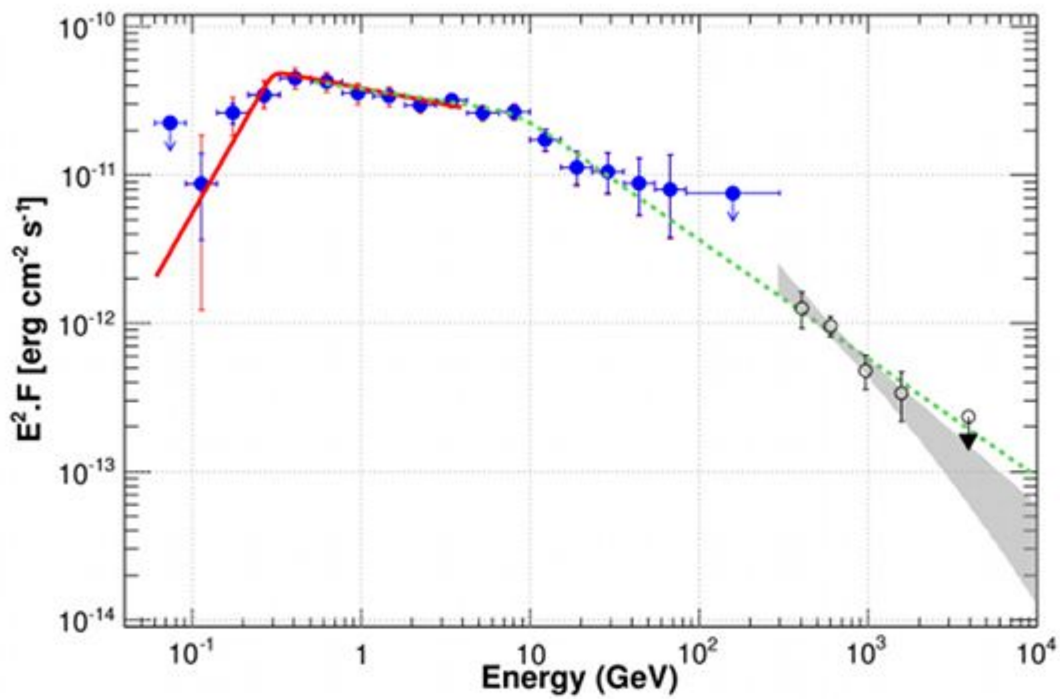


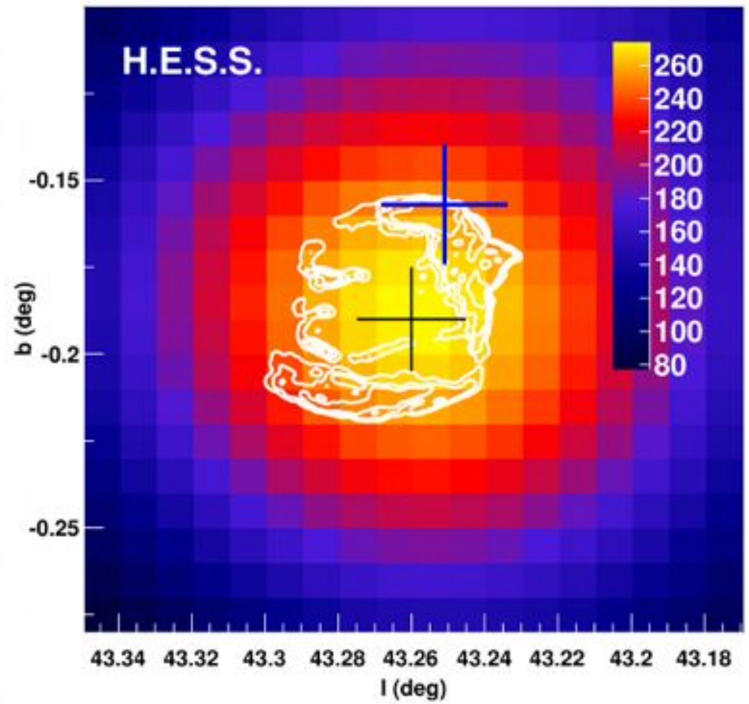


W49B – An interacting SNR

- Rather young (1-4 kyr) SNR, interacting with dense clouds (~10^3 cm^{-3})
- Low energy break → π^0 signature (as for IC 443, W44 and W51C)

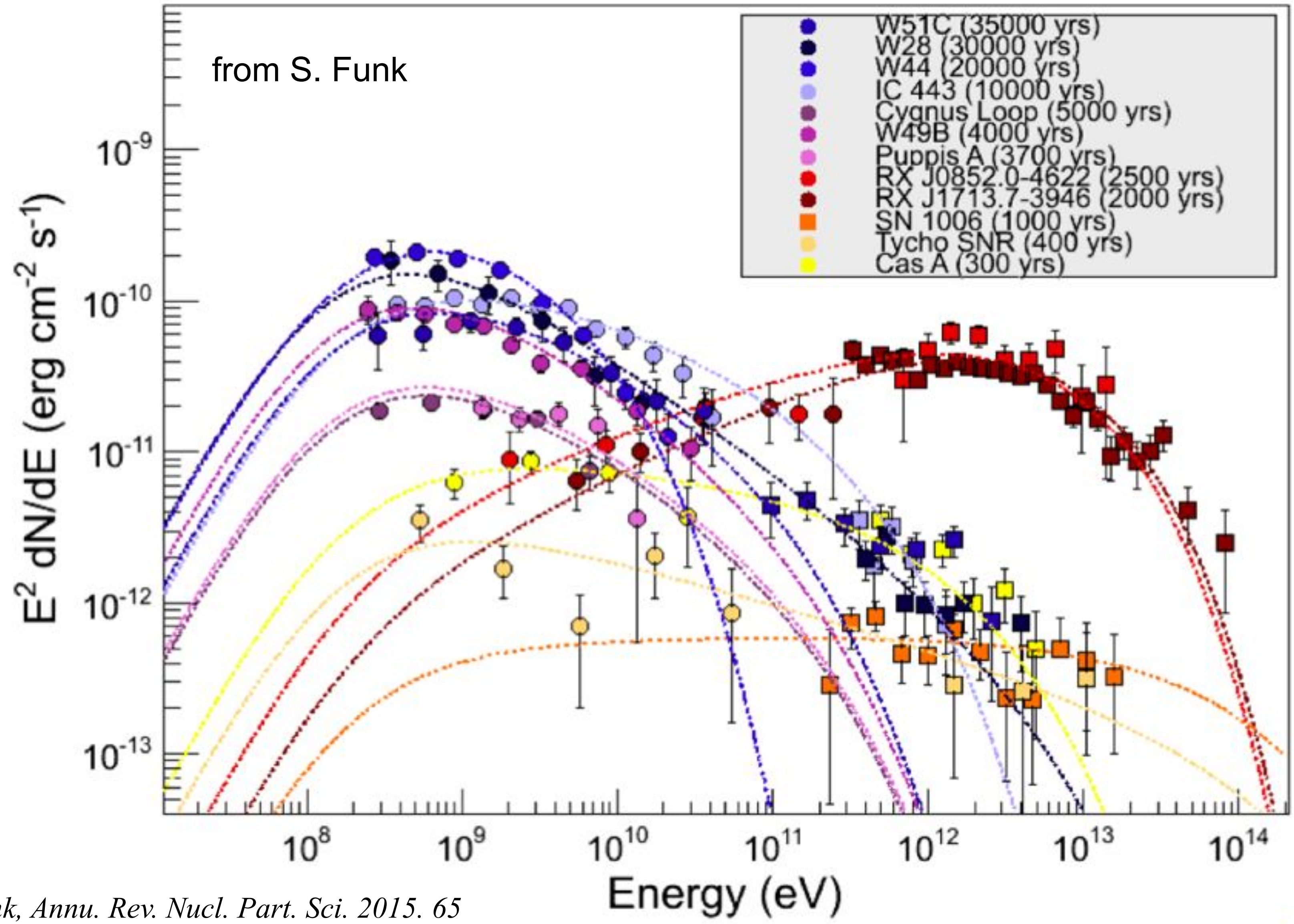
→ Likely also a hadronic source (accelerator)





H.E.S.S. & Fermi-LAT collaborations, A&A 2018 in press

GeV-TeV spectra of supernova remnants



cf. Funk, Annu. Rev. Nucl. Part. Sci. 2015. 65

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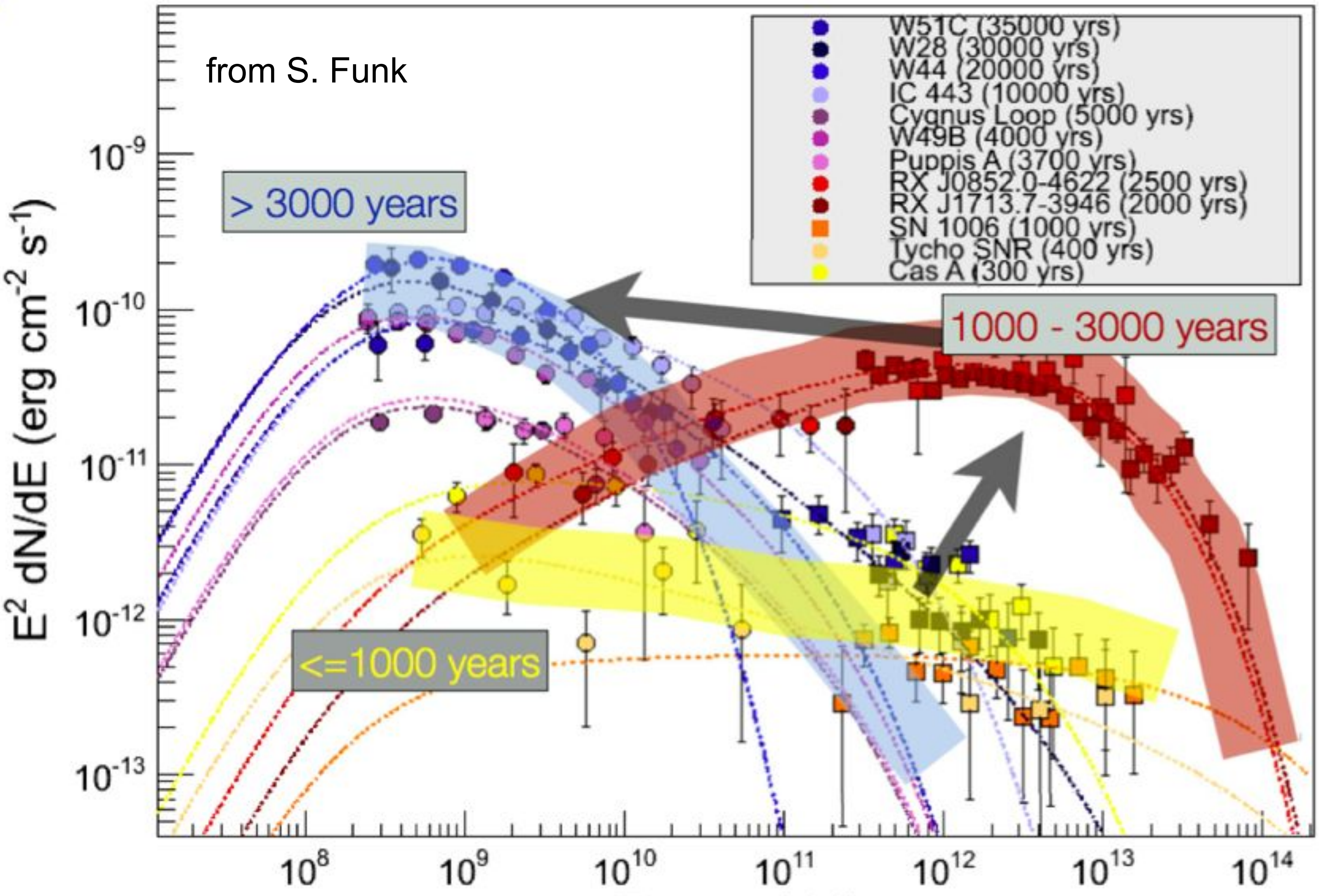

cf. Funk, Annu. Rev. Nucl. Part. Sci. 2015. 65

New SNR (candidates) identified in the H.E.S.S. Galactic plane survey

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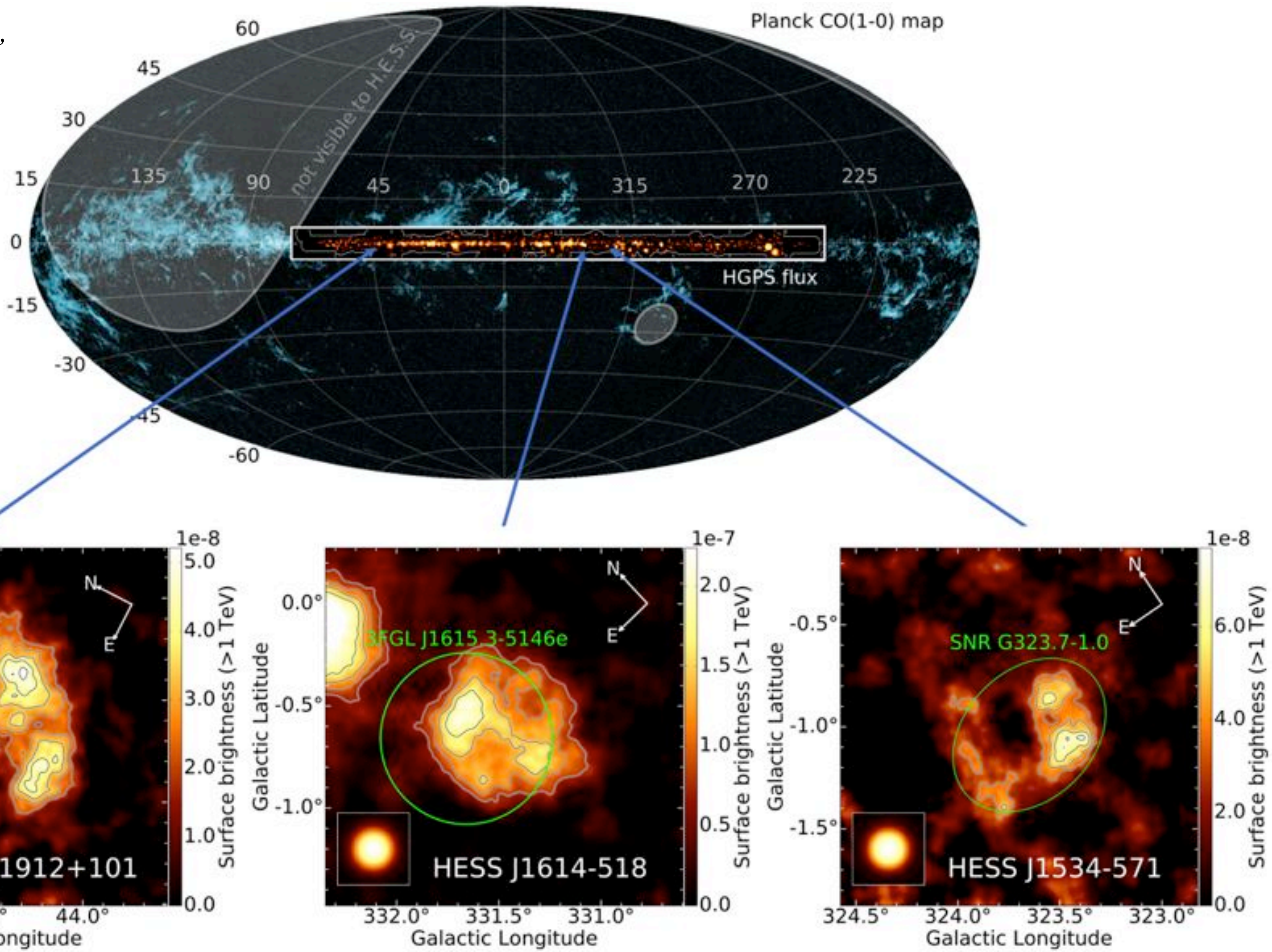
H.E.S.S. collaboration, A&A 2018 in press; H.E.S.S. SOM 03/18



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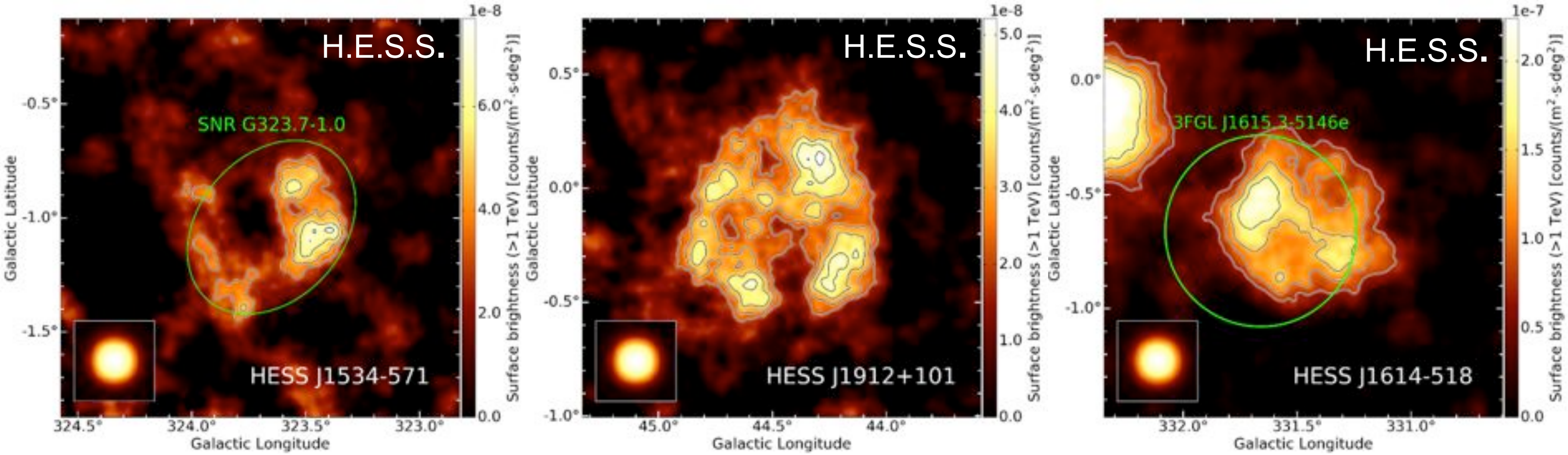


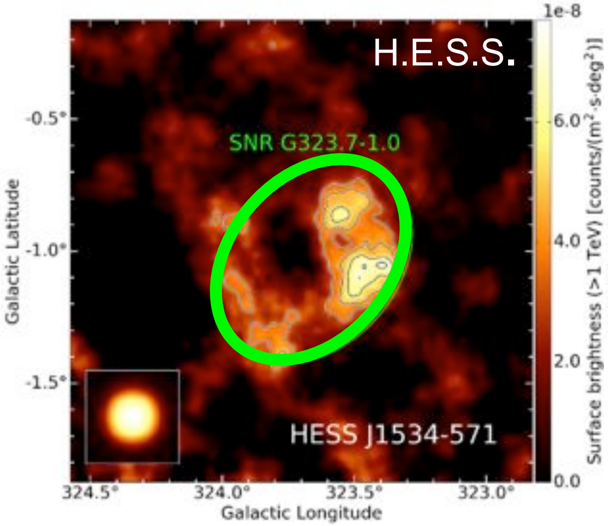
HESS J1534-571: SNR nature confirmed w/ radio counterpart

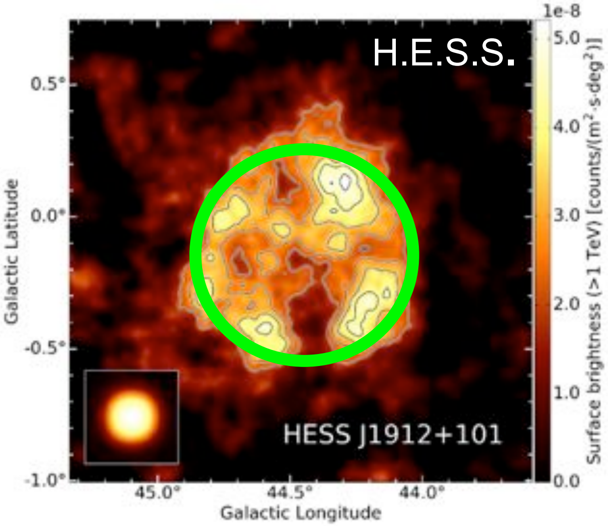
HESS J1912+101, HESS J1614-518: no counterparts that permit identification

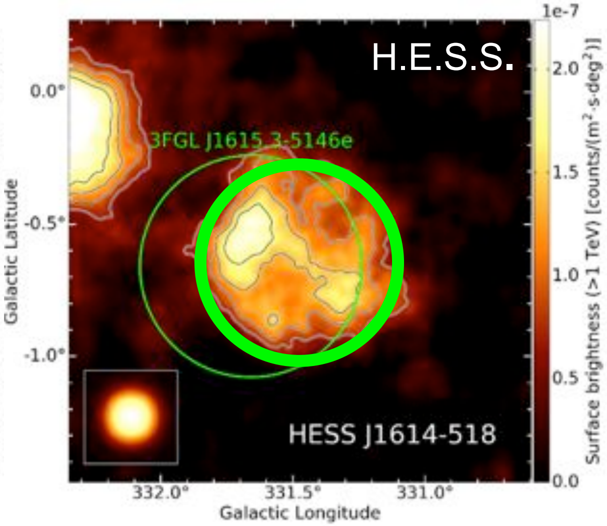
H.E.S.S. collaboration, A&A 2018 in press

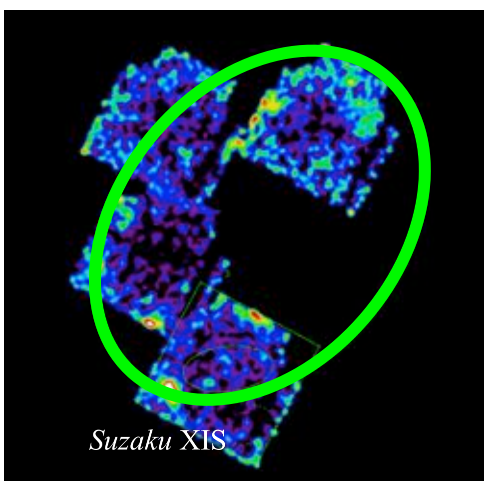
- Large angular diameters (0.4° .. 0.5°)
- Distances unknown, but in any likely association scenario (spiral arms / molecular gas, other possible counterparts): 15 .. >50 pc
- A possible scenario: young to middle-aged (~1000 .. >10000 years) SNRs, evolving in wind-blown cavities (cf. RX J1713.7-3946, Vela Jr., HESS J1731-347, ...)

New TeV shells: What about X-rays?

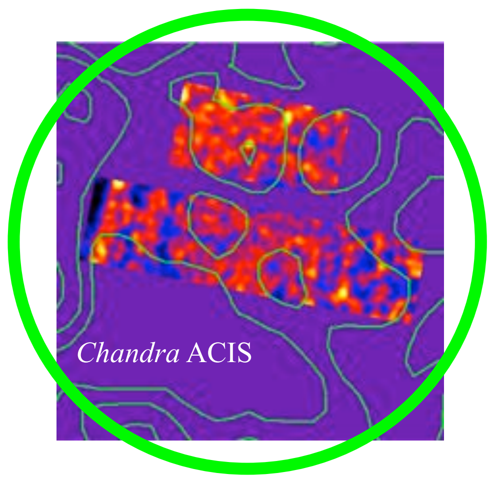




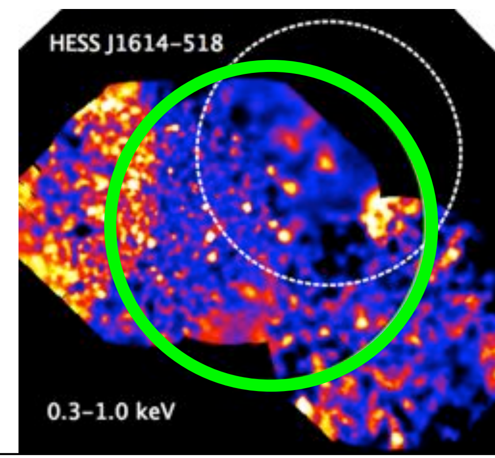




Sensitive limit with Suzaku-XIS

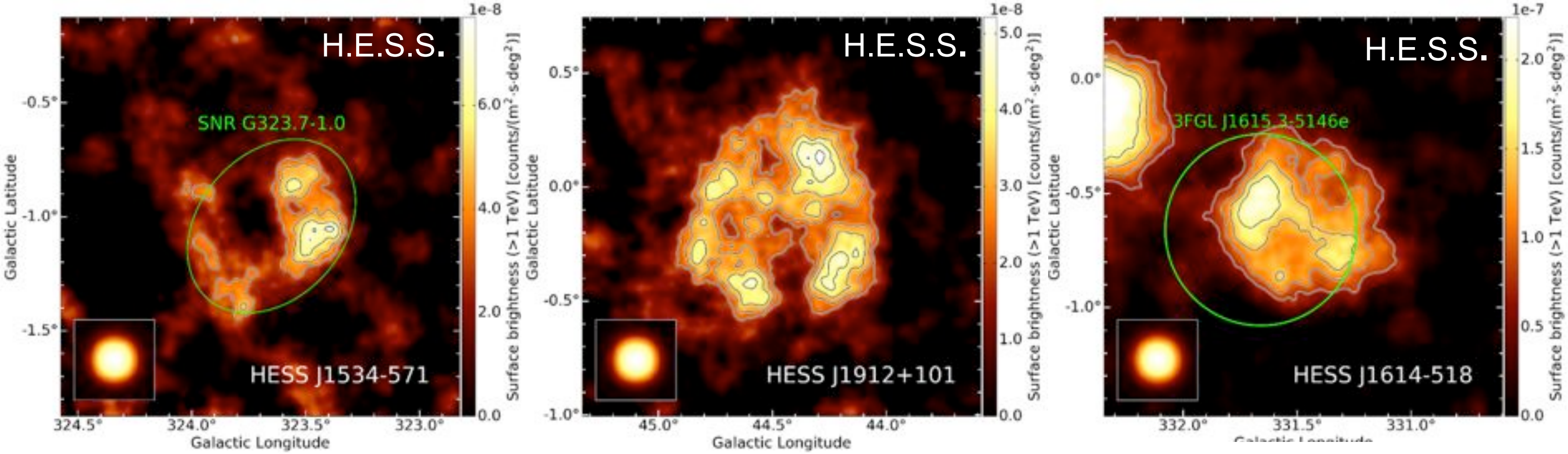


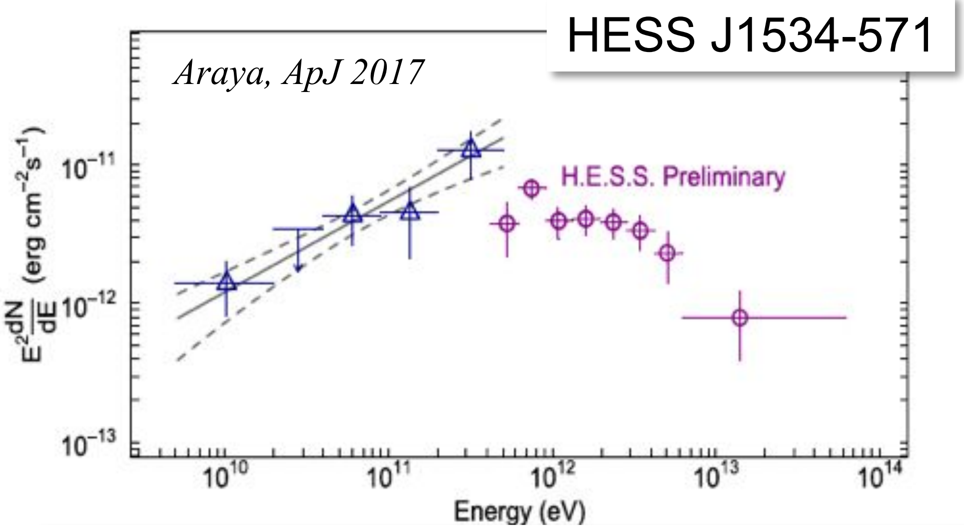
No sensitive coverage yet

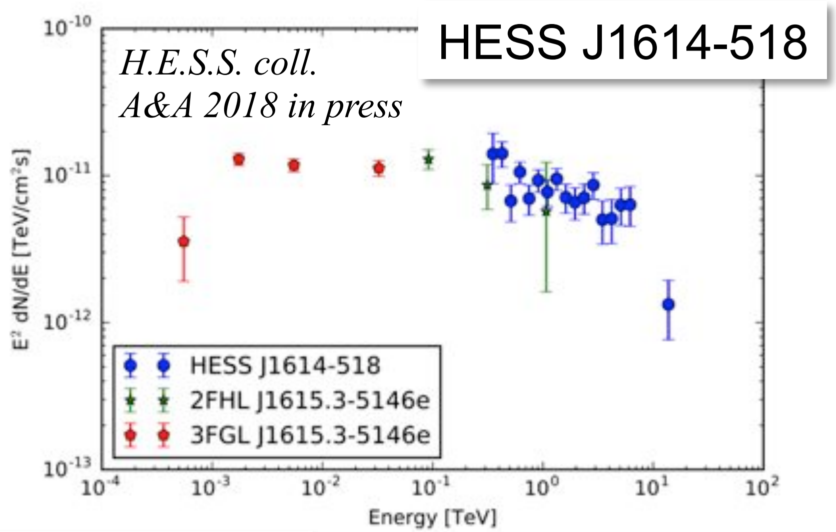


XMM-Newton coverage inconclusive due to straylight

New TeV shells: What about GeV?

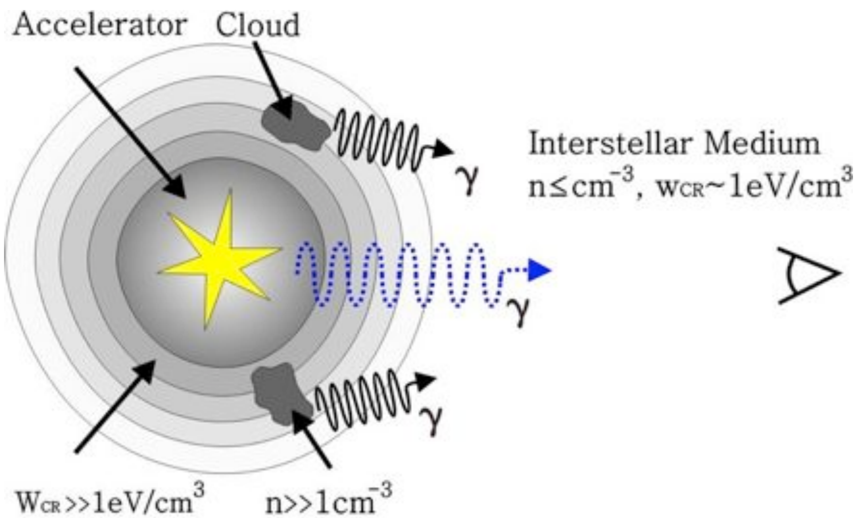






- Conclusion about hadronic vs. leptonic: make your choice

Molecular clouds as CR calorimeters



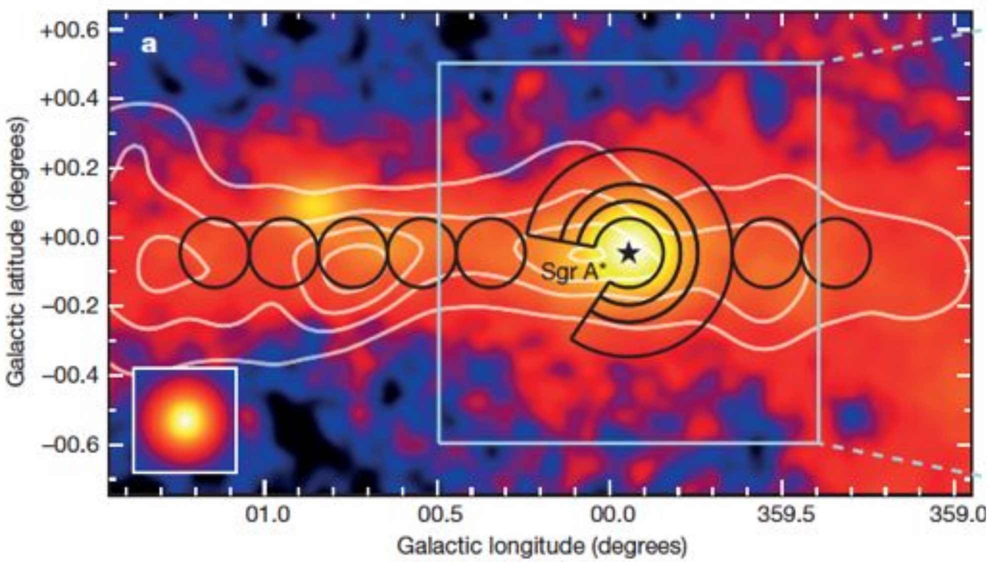
- Molecular clouds near CR accelerators should give clues about the CR source spectrum, injection and propagation
- Works with the Galactic center (pevatron)

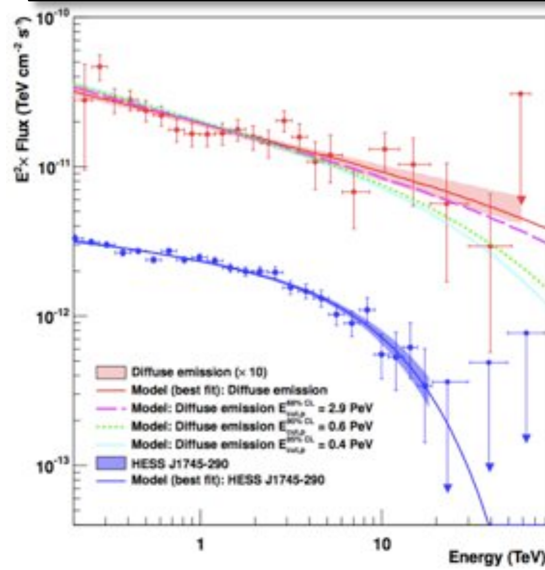
LETTER

doi:10.1038/nature17147

Acceleration of petaelectronvolt protons in the Galactic Centre

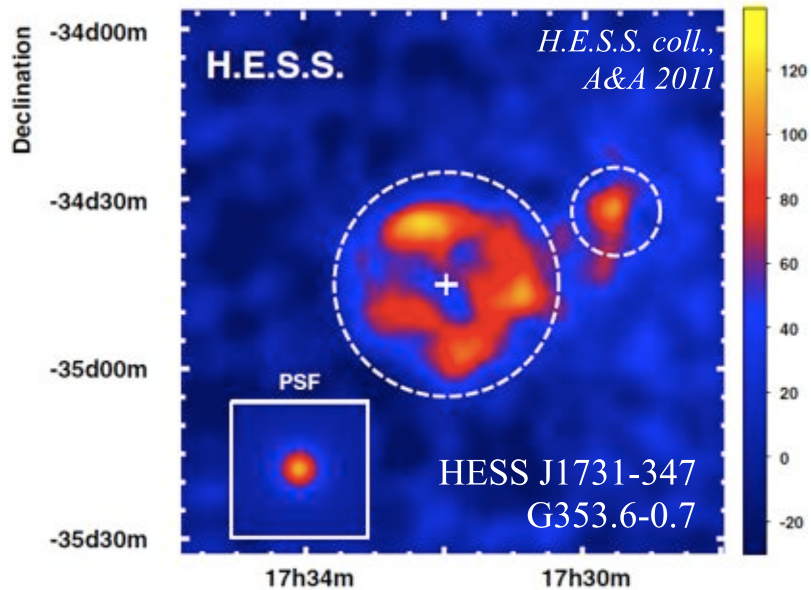
HESS Collaboration*



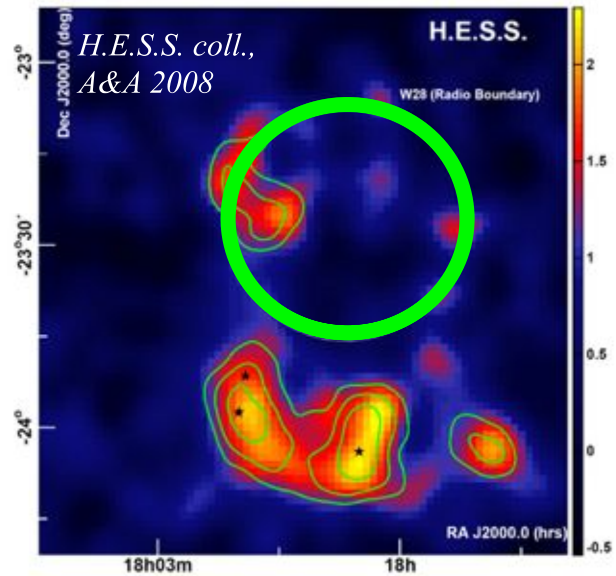


Two SNRs with possible CR escape: Proton signature and ISM/ICM probes

HESS J1731-347



W 28



- Simulation of temporal evolution of SNR, including CR acceleration and energy-dependent escape into the surrounding medium
- 3d setup of surrounding molecular clouds (MC); assumption that γ-ray emission is from CR proton – MC gas collisions
- Spatially-dependent CR diffusion coefficient (from B-field turbulence); related to gas turbulence

Cui, GP +, A&A 2016, Cui, .. GP 2018 in prep.

HESS J1731-347: a young SNR with possible CR escape

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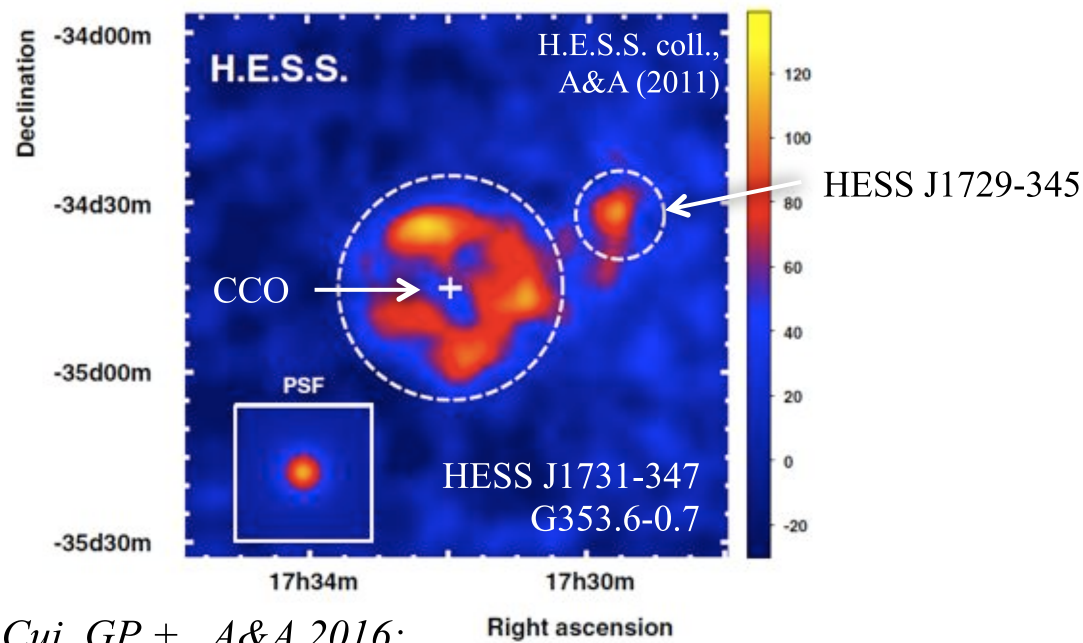
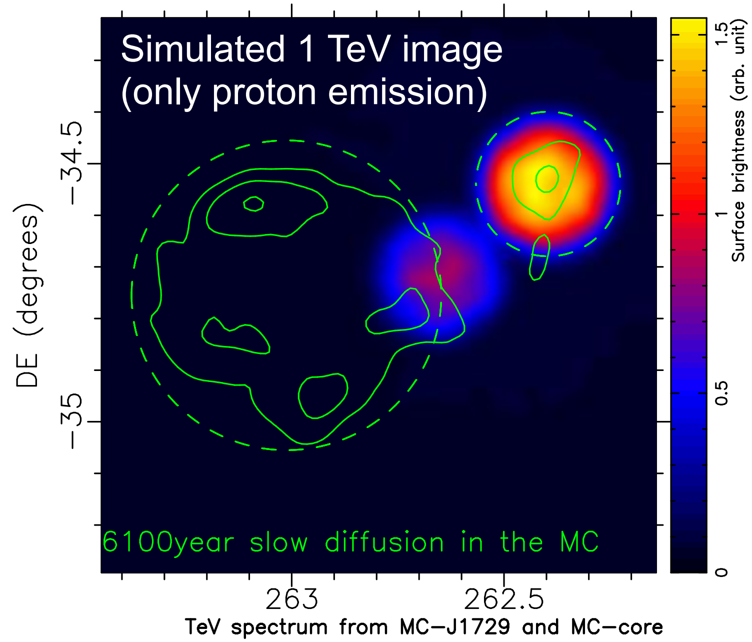
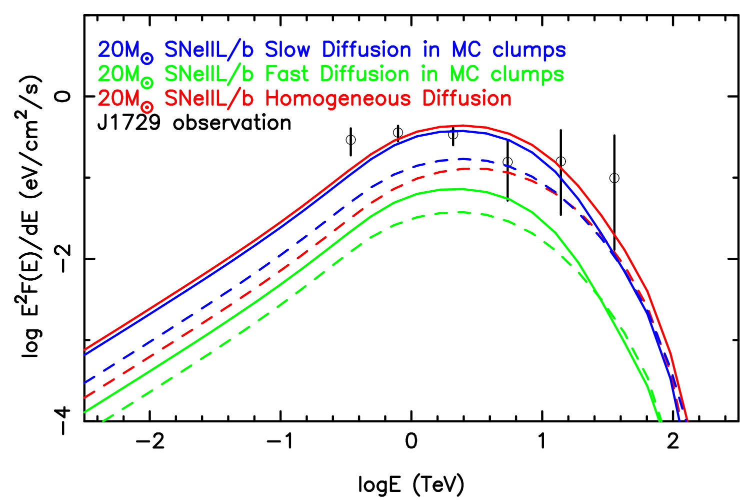




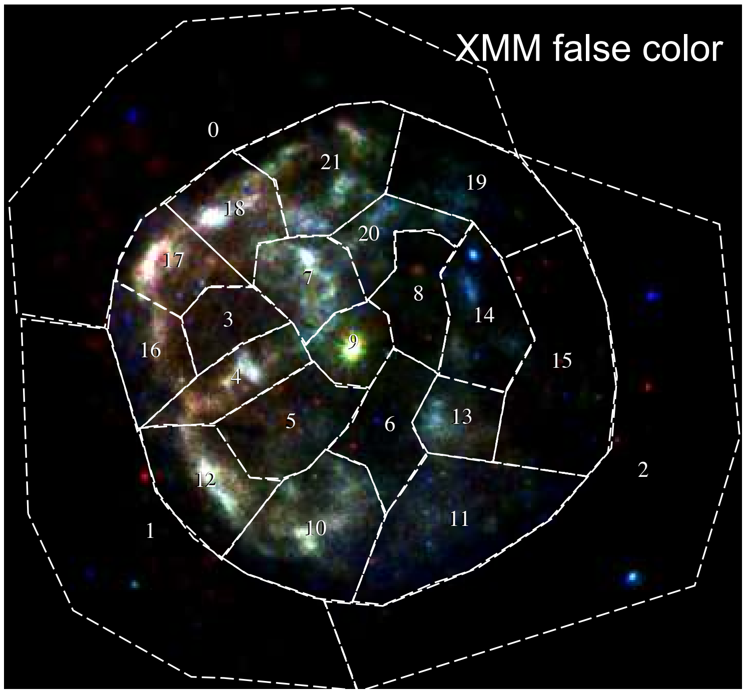
Cui, GP +, A&A 2016:

- 20 $M_\odot$ progenitor, 6 kyr old SNR still inside wind bubble (shock ~2000 km s^{-1})
- SNR shell emission mostly leptonic (IC)
- Only escape of ~TeV++ (not yet ~GeV) particles
- Short timescales imply that TeV and MC morphology don‘t need to match perfectly
- Diffusion coefficient in ICM ~ Galactic standard

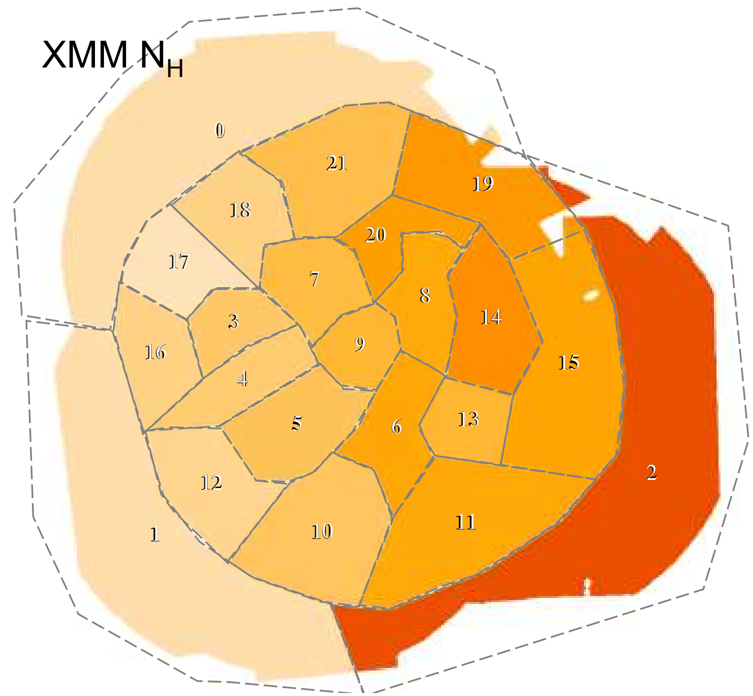


HESS J1731-347: X-ray synchrotron surface brightness and N_H

Intrinsic (deabsorbed) surface brightness



Absorption column



Doroshenko, GP +, A&A 2017

→ pure non-thermal X-ray emission

→ NH increases towards West because of foreground/surrounding MC

→ intrinsic X-ray flux variation: drops towards West

→ fraction of TeV emission from Western part of SNR may stem from protons

Are CRs really diffusively transported?

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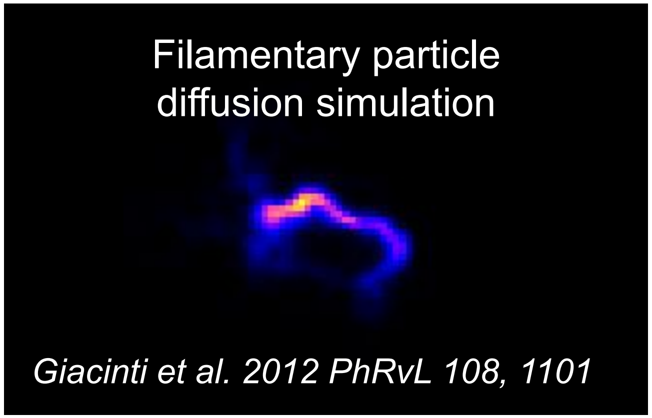
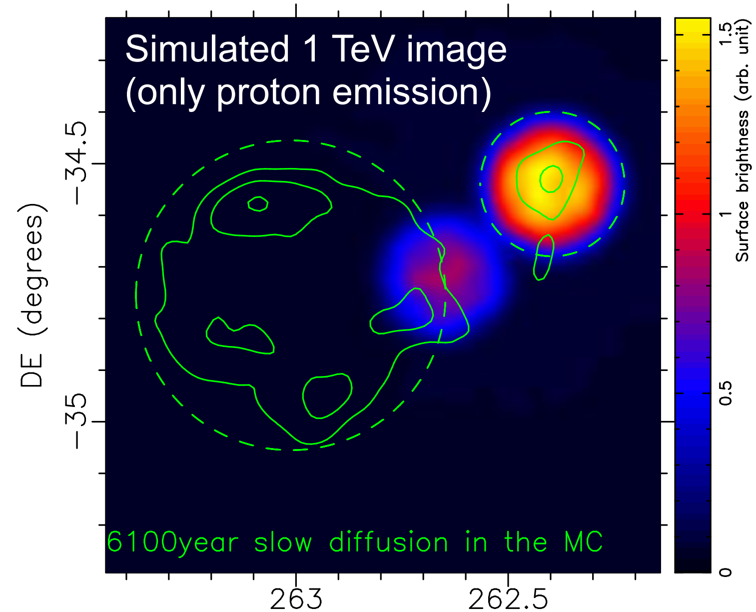
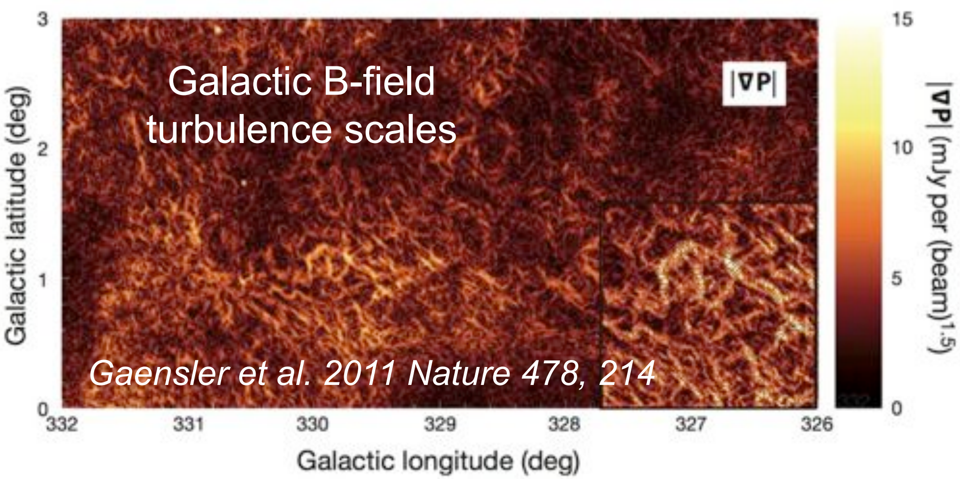




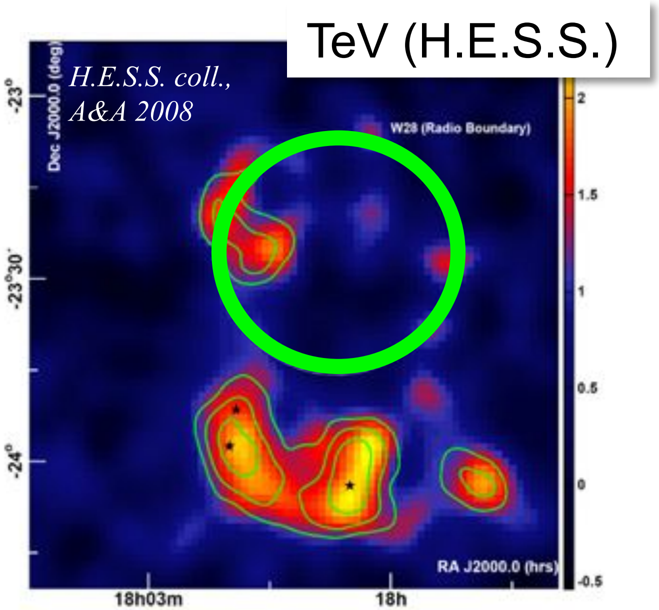
Cui, GP +, A&A 2016

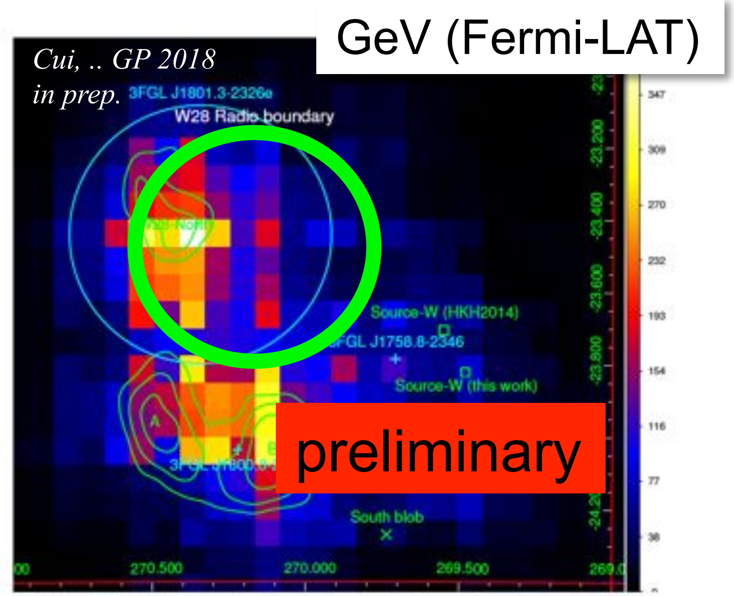


- Distance of SNR to MC ~ turbulence scales

→ anisotropic diffusion / particle transport possible in this case

W 28: a middle-aged SNR with CR escape





- 8 $M_\odot$ progenitor, no wind bubble (could also be Ia), 37 kyr SNR (shock ~100 km s^{-1})
- Escape of ~TeV particles throughout evolution from entire shell, escape of GeV particles through broken shell; in the „damping“ case, additional escape of GeV particles from entire shell at late times
- Diffusion coefficient in ICM ~10% Galactic standard (from TeV data, as in all other similar W28 studies)
- TeV and GeV spectra at four different MC locations to fit, constraints e.g. on the diffusion coefficient

Cui, .. GP 2018 in prep.

Conclusions

- Identification of particle species (leptonic vs. hadronic) in γ-ray emitting SNRs continues to be an issue
- Search for PeVatrons / PeVatrons SNRs to identify accelerators up to knee energies (and identify them as proton accelerators)
- π^0-bump in LAT spectra of several SNRs identifies them as proton sources, but not as PeVatrons; many are evolved/interacting with molecular clouds
- New TeV SNR shells can be interpreted as proton sources, where SNR shells interact with wind-blown cavities (connecting young TeV shells with evolved LAT-selected SNRs)
- CR escape from SNRs can be used as a tool to
  - identify them as proton accelerators
  - identify them as PeVatrons (SNR PeVatron lifetime is short)
  - study the ISM through CR propagation