Hadronic CosmicRays Origin from AGILE's SNRs

A. Giuliani
IASF Milano

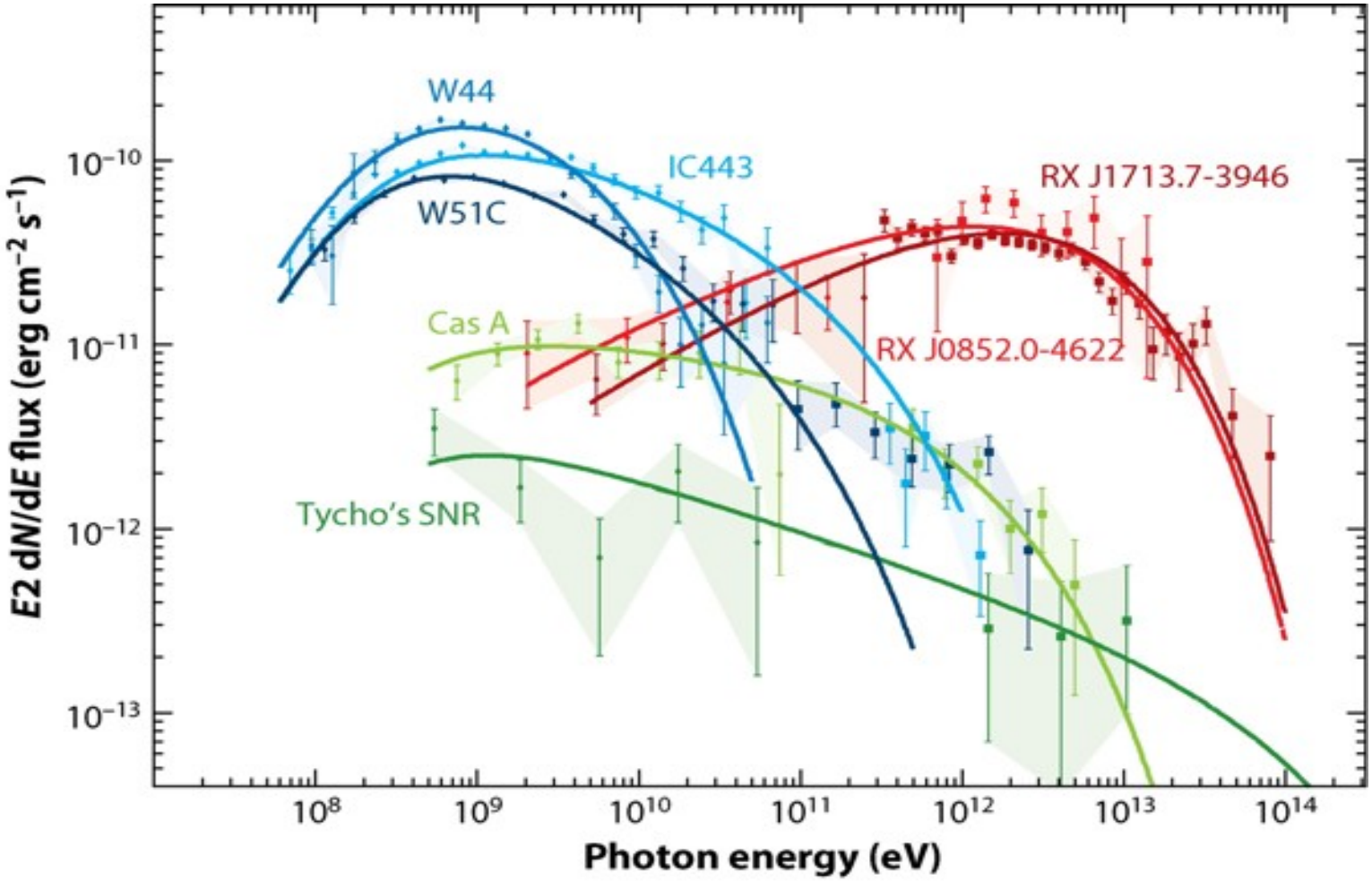
Outline of the talk

→ ***The AGILE's SNRs***

→ ***What did we learn from them ?***

→ ***Do they still have something to teach us ?***

2(3?) SNR classes



Funk S. 2015.
Annu. Rev. Nucl. Part. Sci. 65:245–77

classes of gamma-rays SNRs

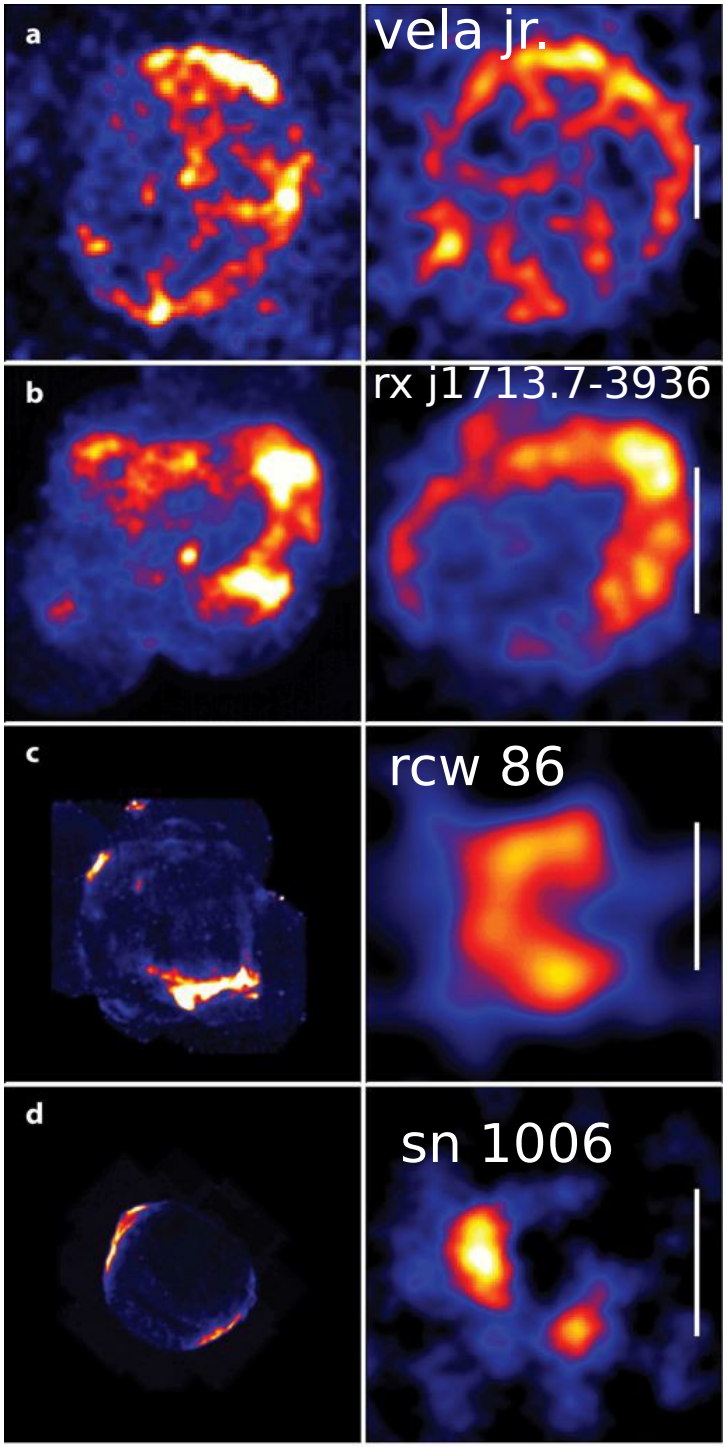
1) young (10^2 - 10^3 yrs) shell-like

SNRs, expanding in a relatively low density medium.

The morphology shown in gamma rays is usually

very nicely correlated with the radio or X-rays emission

from the shell



Hinton JA, Hofmann W. 2009.
Annu. Rev. Astron. Astrophys. 47:523–65

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1) young (10^2 - 10^3 yrs) shell-like

SNRs, expanding in a relatively low density medium.

The morphology shown in gamma rays is usually

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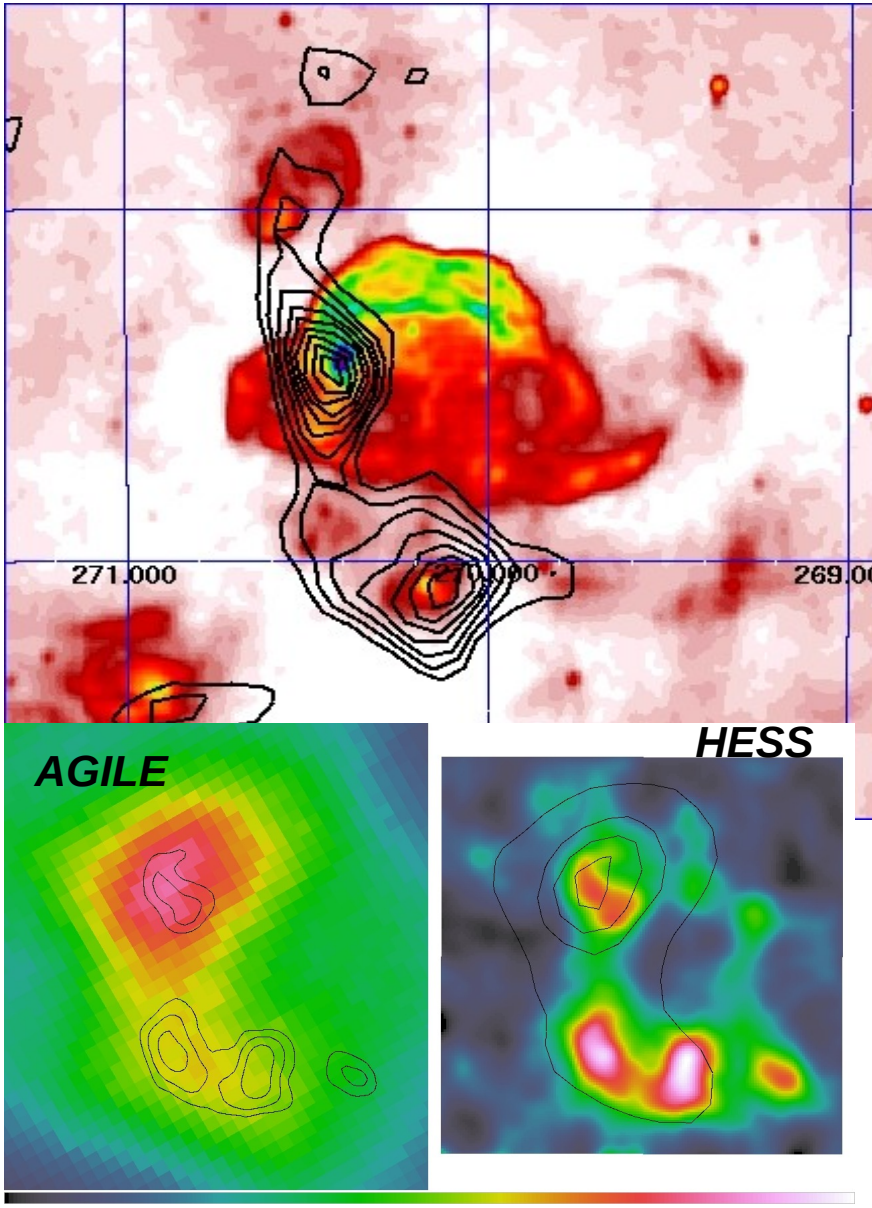
2) older (103 - 104 yrs) mixedmorphology

SNRs, interacting with giant molecular

clouds. Their gamma-rays morphology correlates

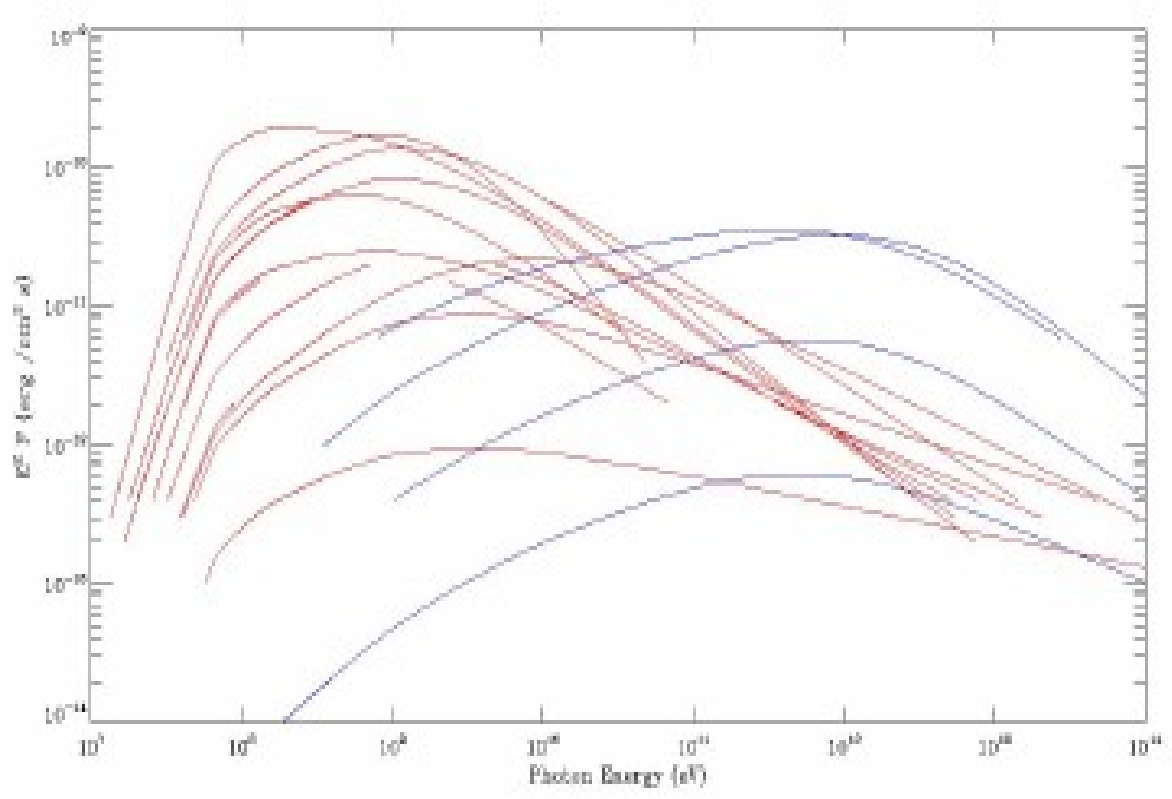
with the molecular clouds associated to the SNR



Hardness Ratios of SNRs spectra

Giuliani and Crestan et al , ICRC17

$$\frac{dN_{p,2}}{dE} = K_p \left(\frac{E}{E_c}\right)^{-p_1} \left(\frac{1}{2}\left(1 + \frac{E}{E_{br}}\right)\right)^{p_1 - p_2}$$



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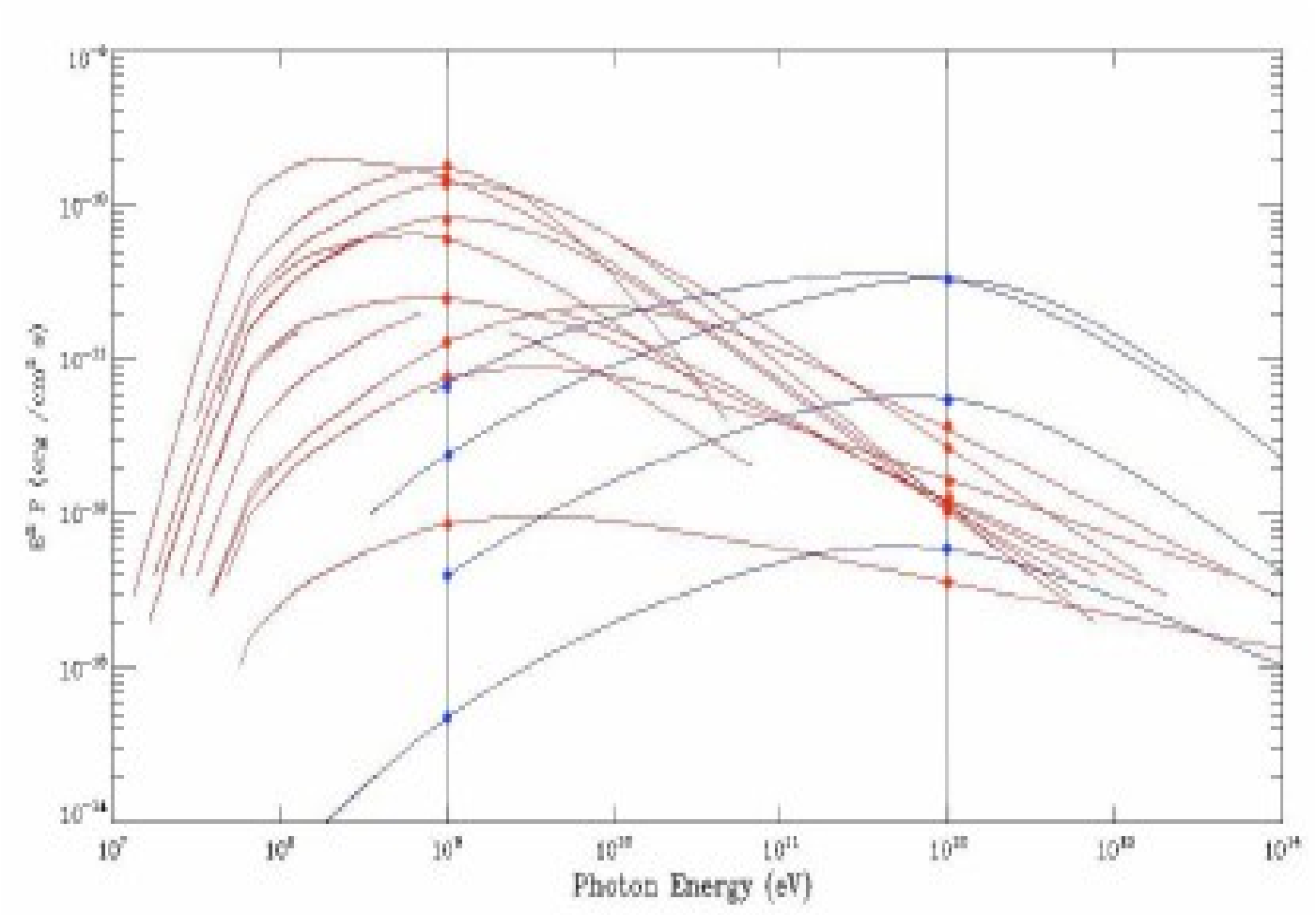

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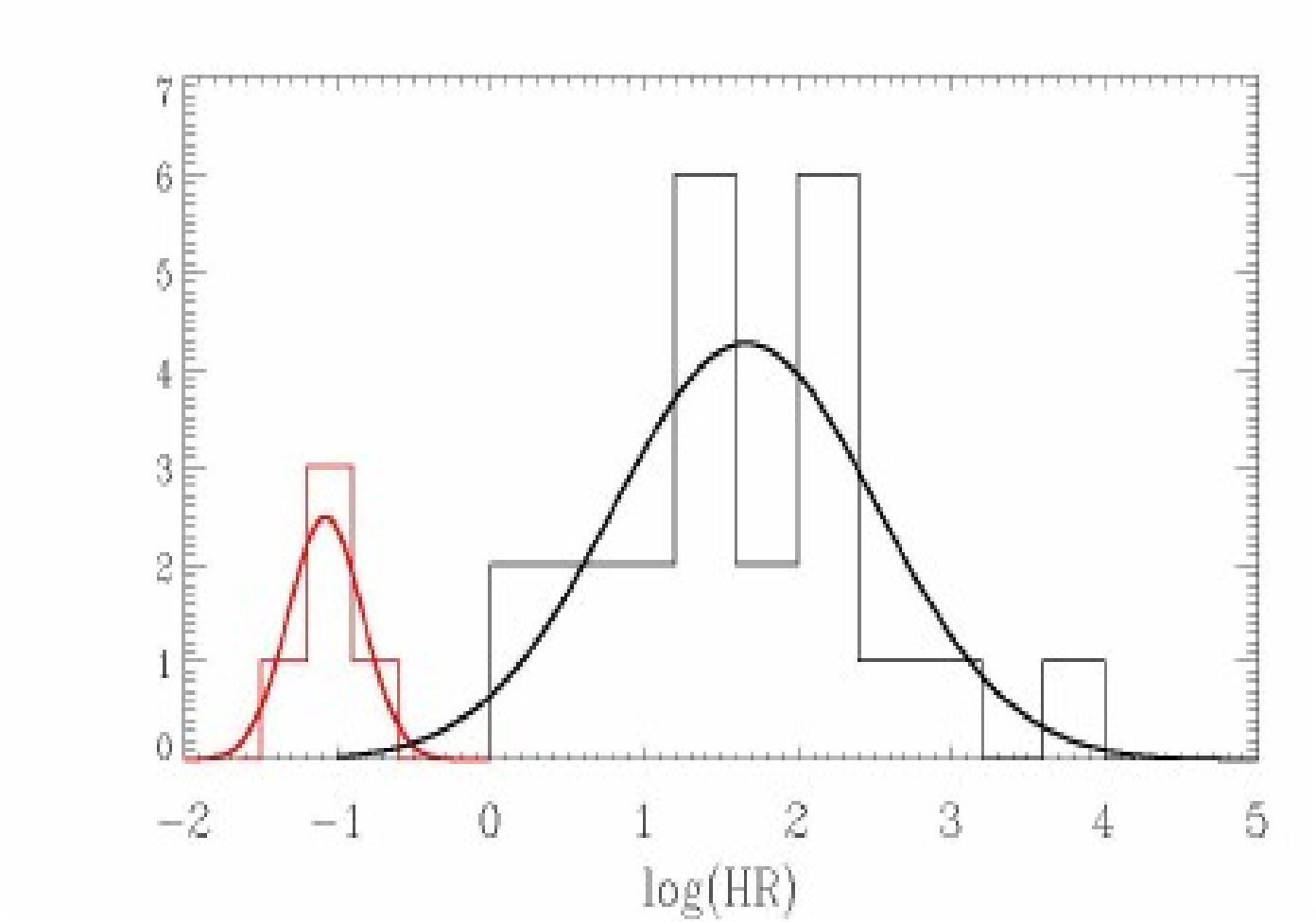

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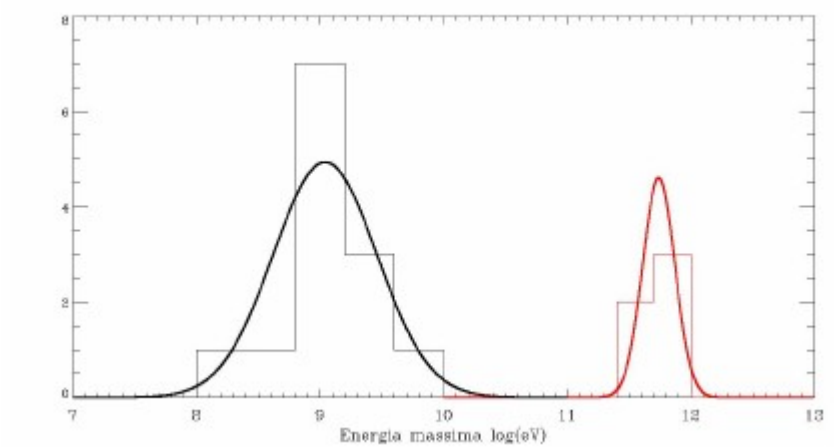
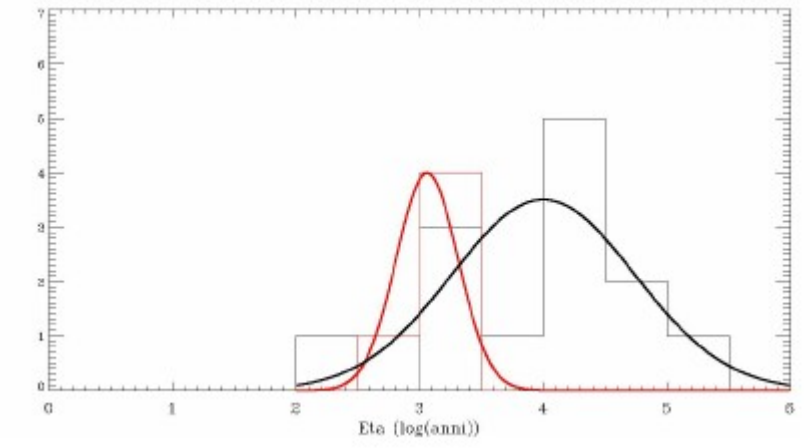
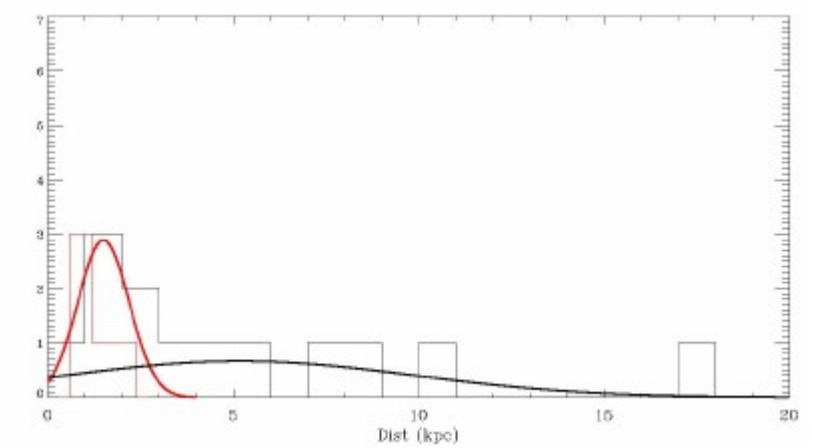
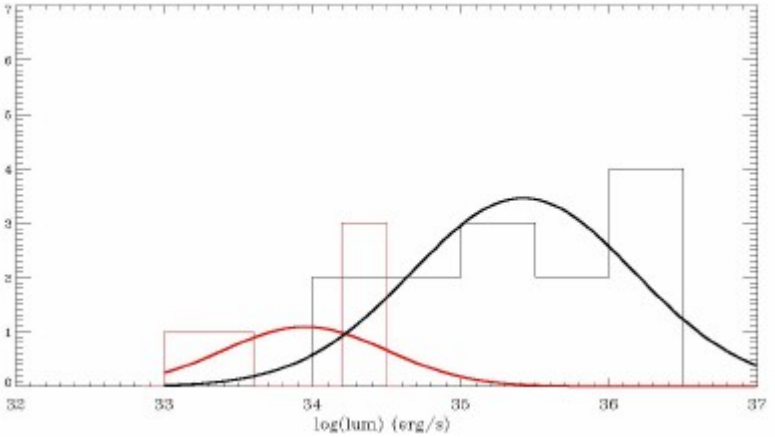








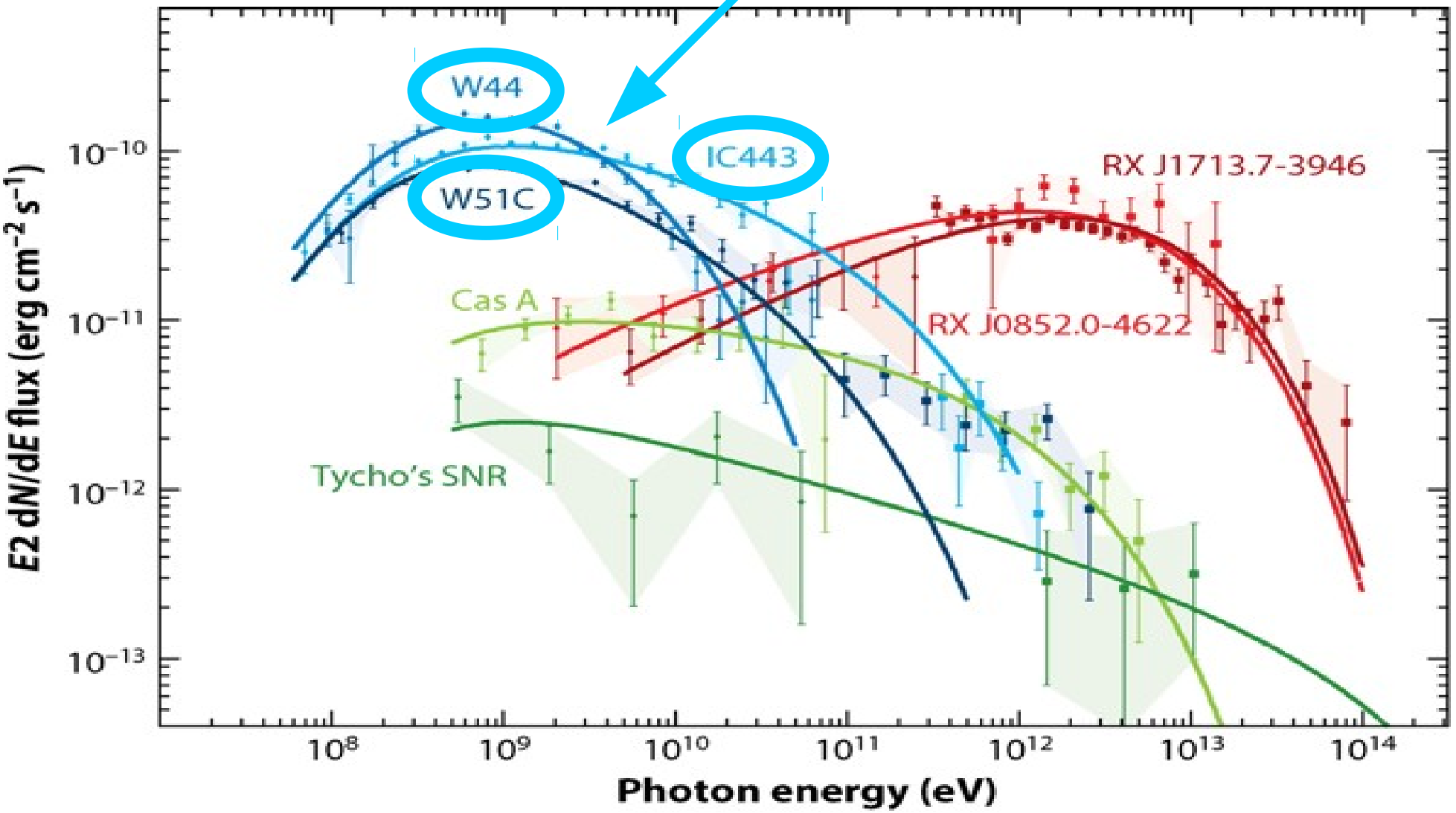
The AGILE SNRs

(Giuliani, Cardillo et al in prep.)

	Age	dist	GeV	TeV (C.u.)	1 GHz (Jy)
W44	***20000***	***3.0***	***115***	***-----***	***230***
IC443	**30000**	**1.5**	**50**	**0.03**	**160**
W28	**40000**	**2.0**	**40**	**0.38**	**310**
W51C	**20000**	**6.0**	**66**	**0.003**	**160**
W49B	**2000**	**8.0**	**10**	**0.005**	**38**
W30	**16000**	**4.0**	**30**	**0.2**	**23**

All of them are middle-aged, interacting-with-GMCs SNRs

AGILE's SNRs



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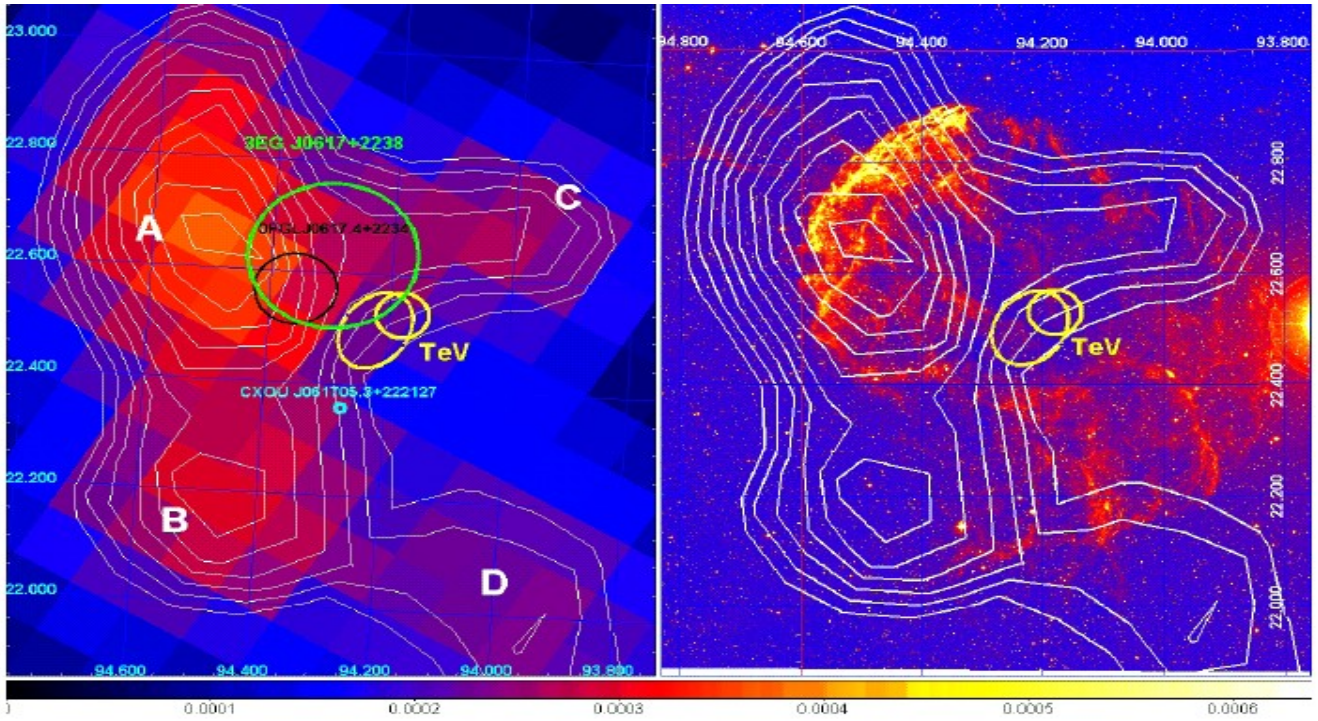
What did we learn from them ?

→ ***First detection of GeV from a SNR*** (IC443, Tavani et al. 2010)



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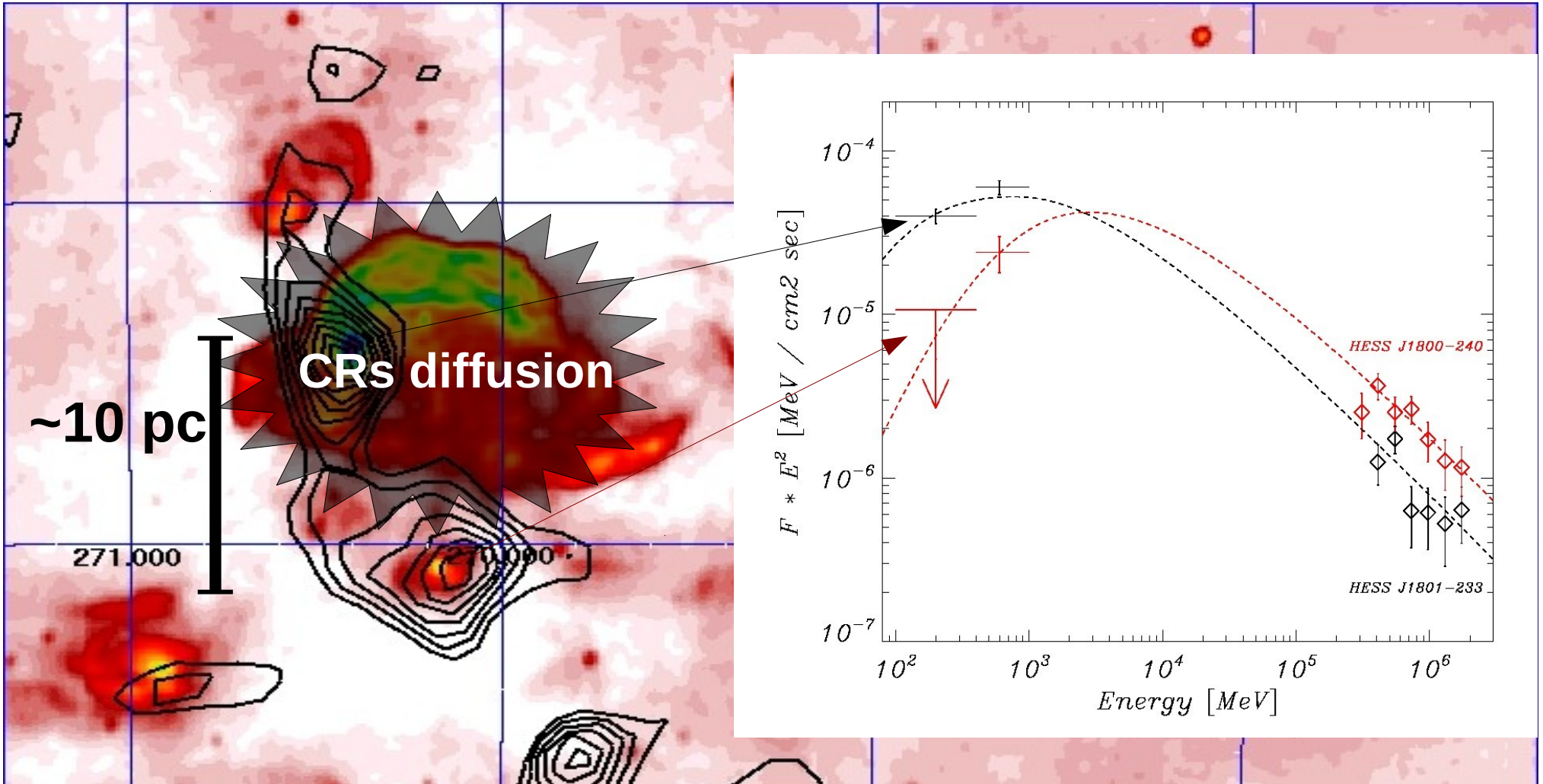

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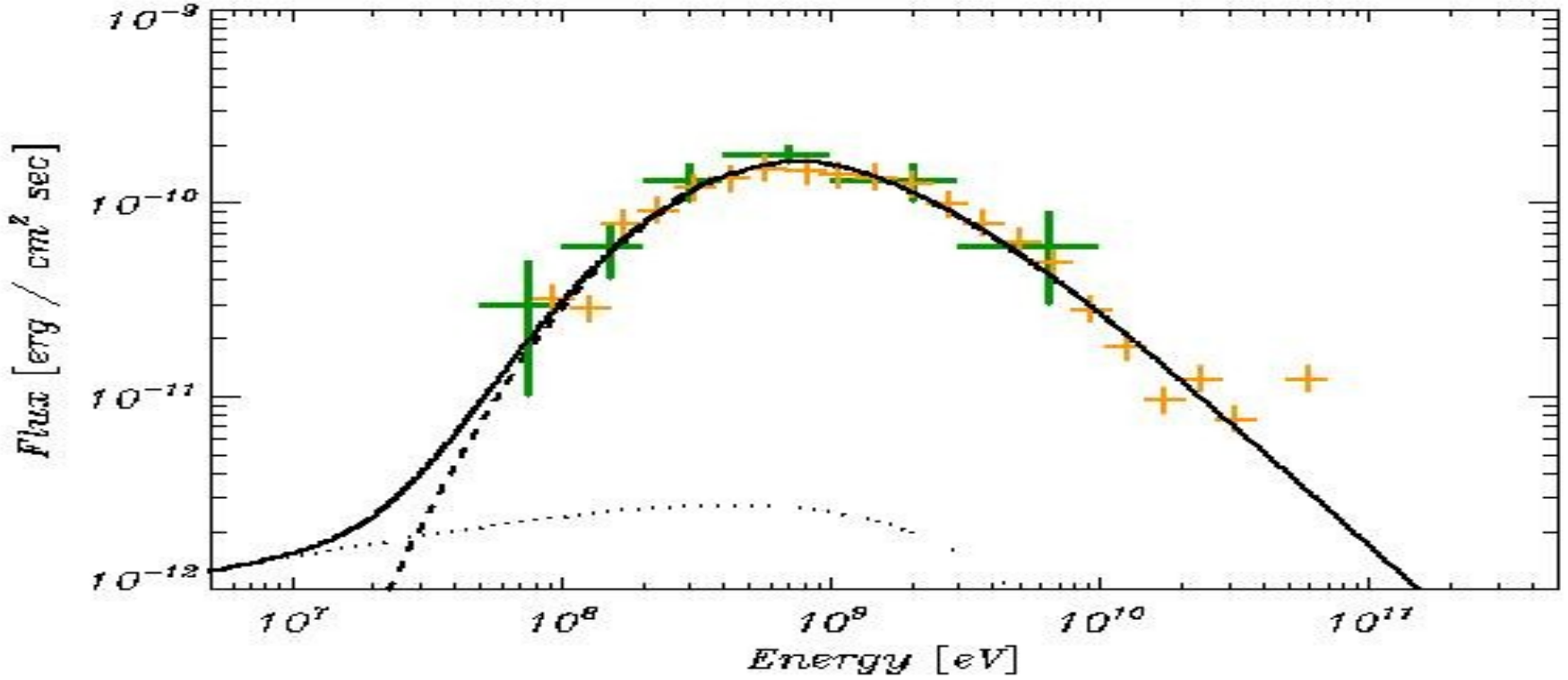

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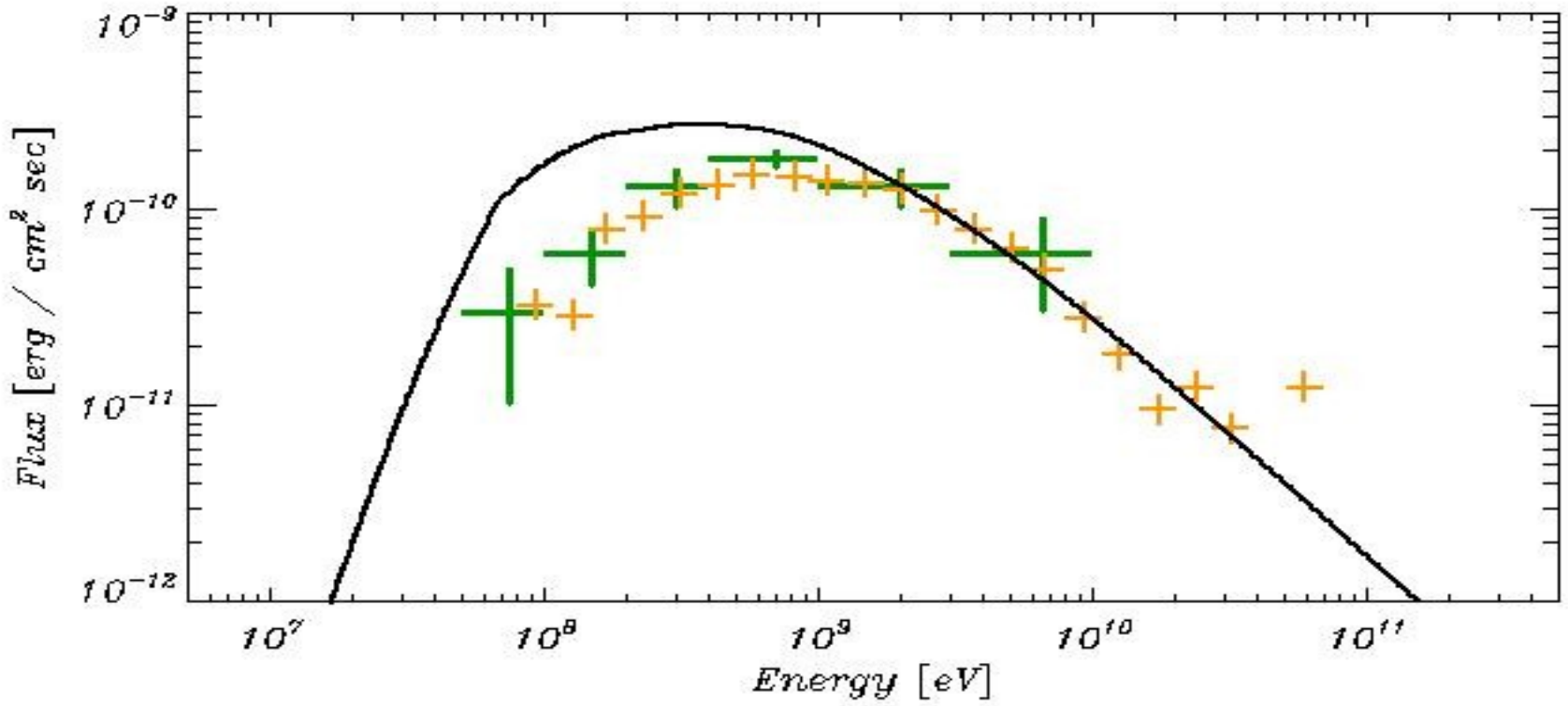

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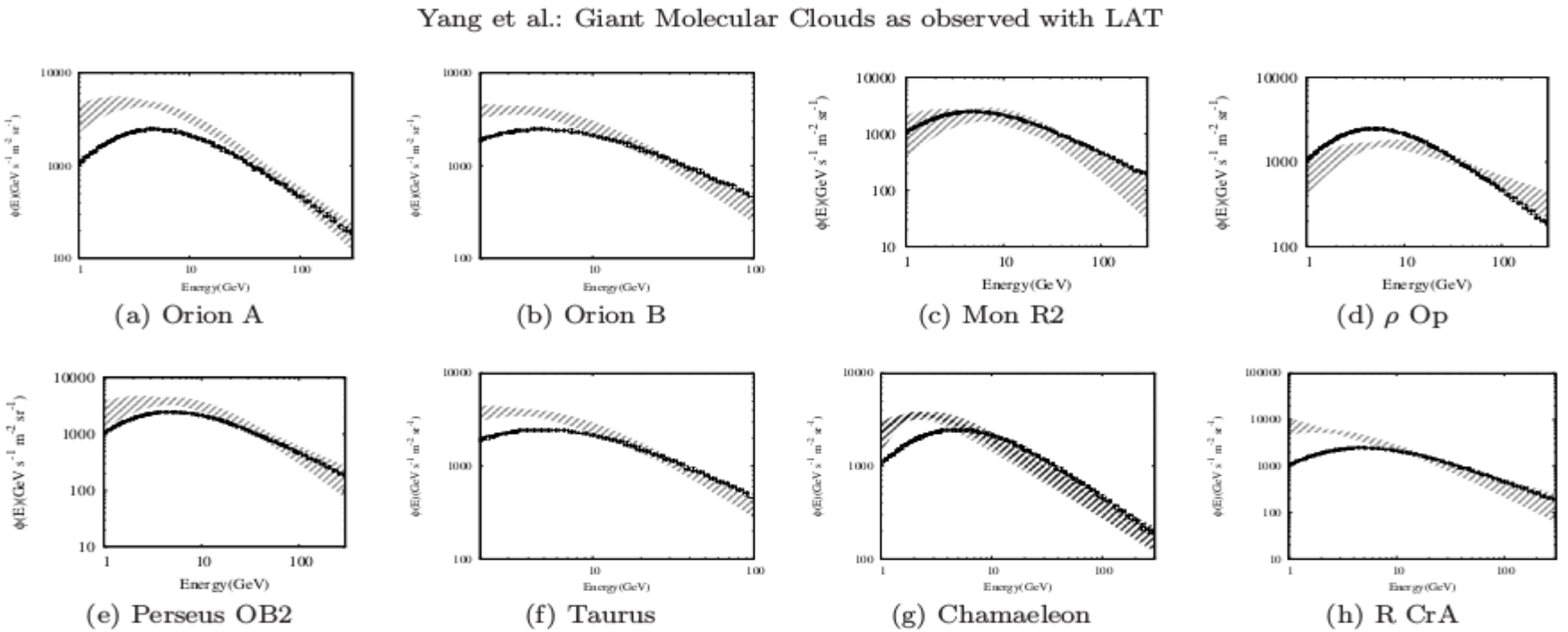

Fig. 5. Energy spectra of CR protons in different clouds derived from the γ-ray data. It is assumed that the interactions of CR with the ambient gas are fully responsible for the observed γ-ray fluxes. The shaded regions represent 1σ fits for the proton spectra. For comparison, the measurements of CR protons by PAMELA are also shown (black crosses).

Are SNRs the sources of CRs ?

- **SNRs must emit gamma rays**
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- **Total energy ~ 10^49 erg**
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- **Protons spectrum up to ~ PeV** ***?***

Pevatrons : What ?

Accelerators of protons (or nuclei) up to 1 PeV
(spectrum without cut-offs up to 1 PeV)

Interaction with ISM gives gammas with energy up to ~ 10 % E_p

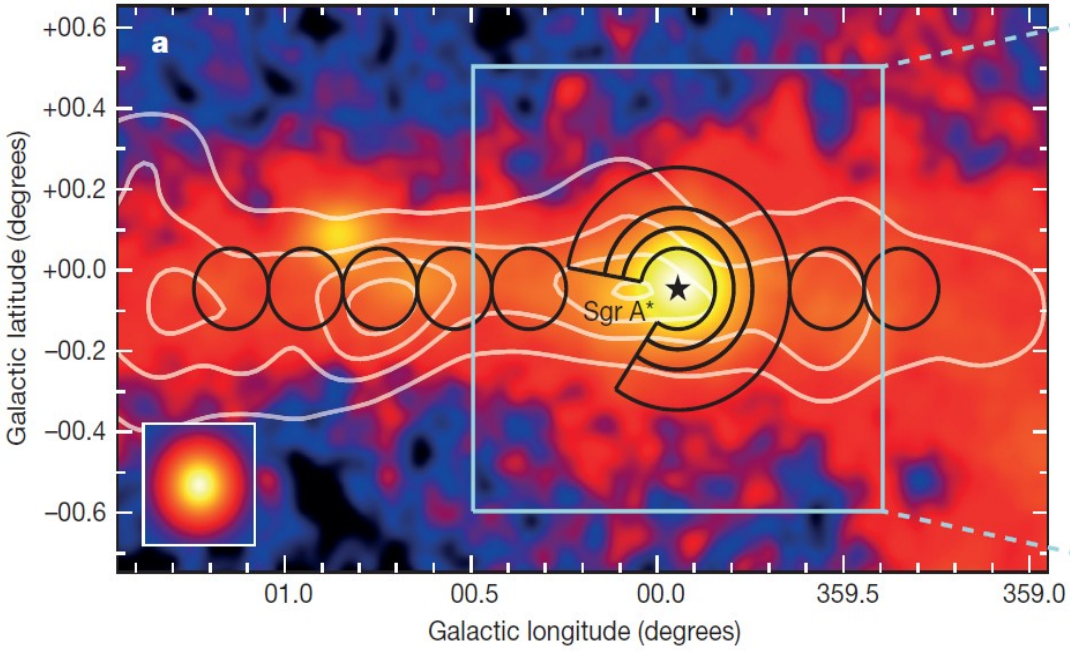
→ ***Hadronic gamma-ray emission,***
<u>with without cut-offs</u> up to ~ 100 TeV

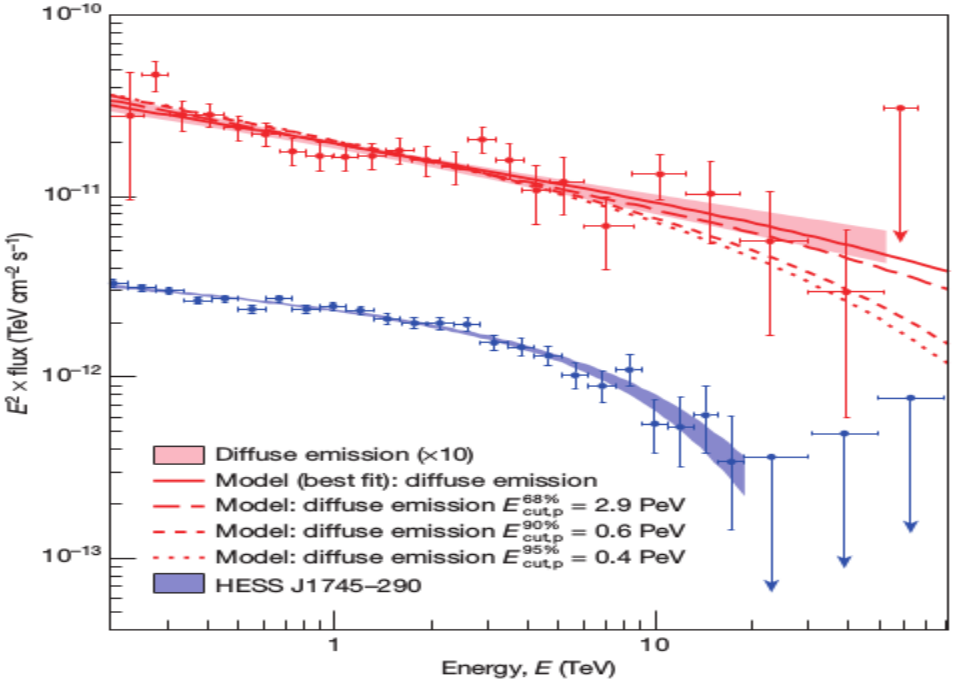
Pevatrons : Where ?

SN Remnants ? can accelerate of CRs !

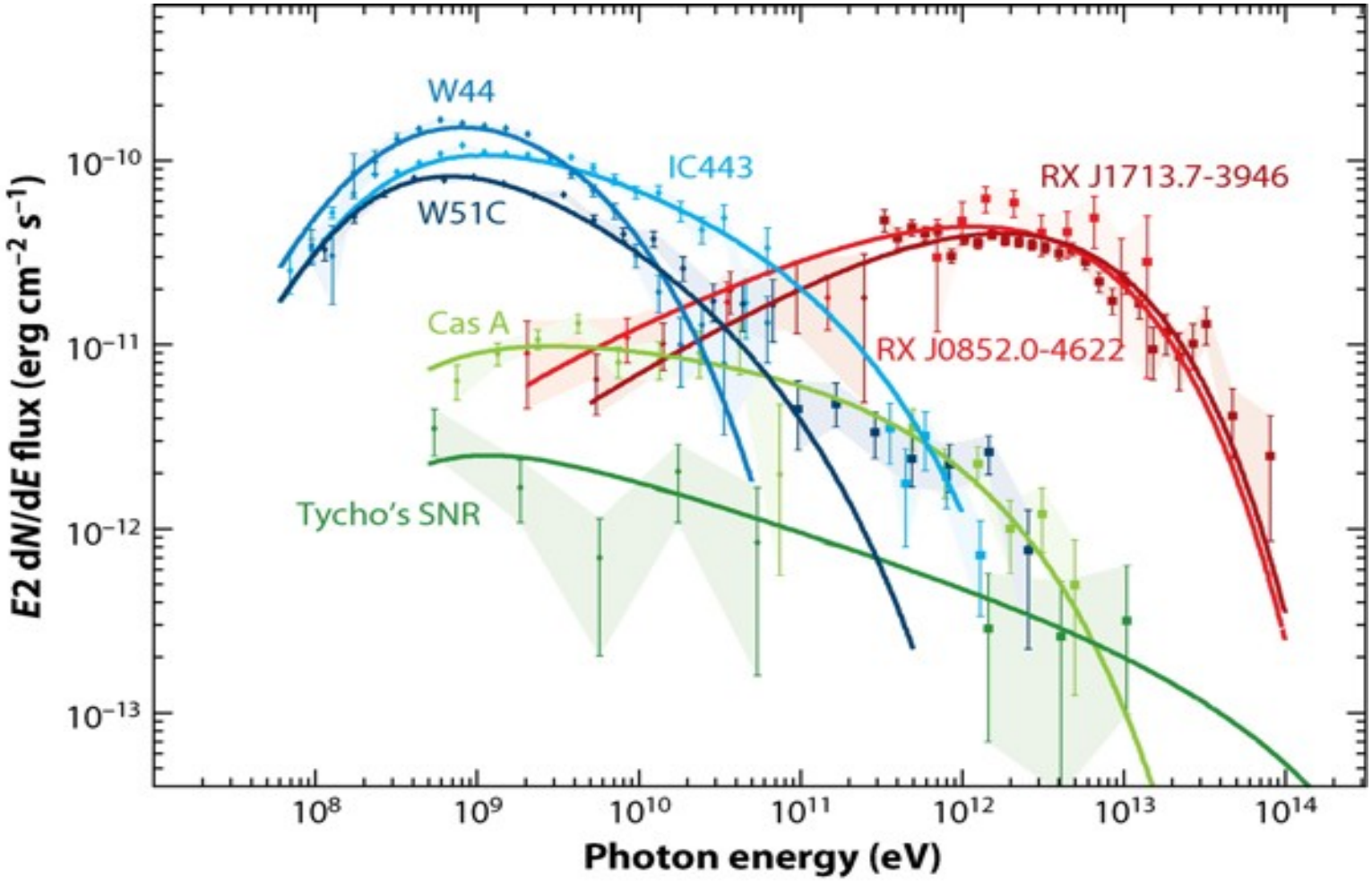
but still no evidence SNR = Pevatron

Galactic Center ? First Pevatron ? (HESS Coll., Nature 2016)





2(3?) SNR classes



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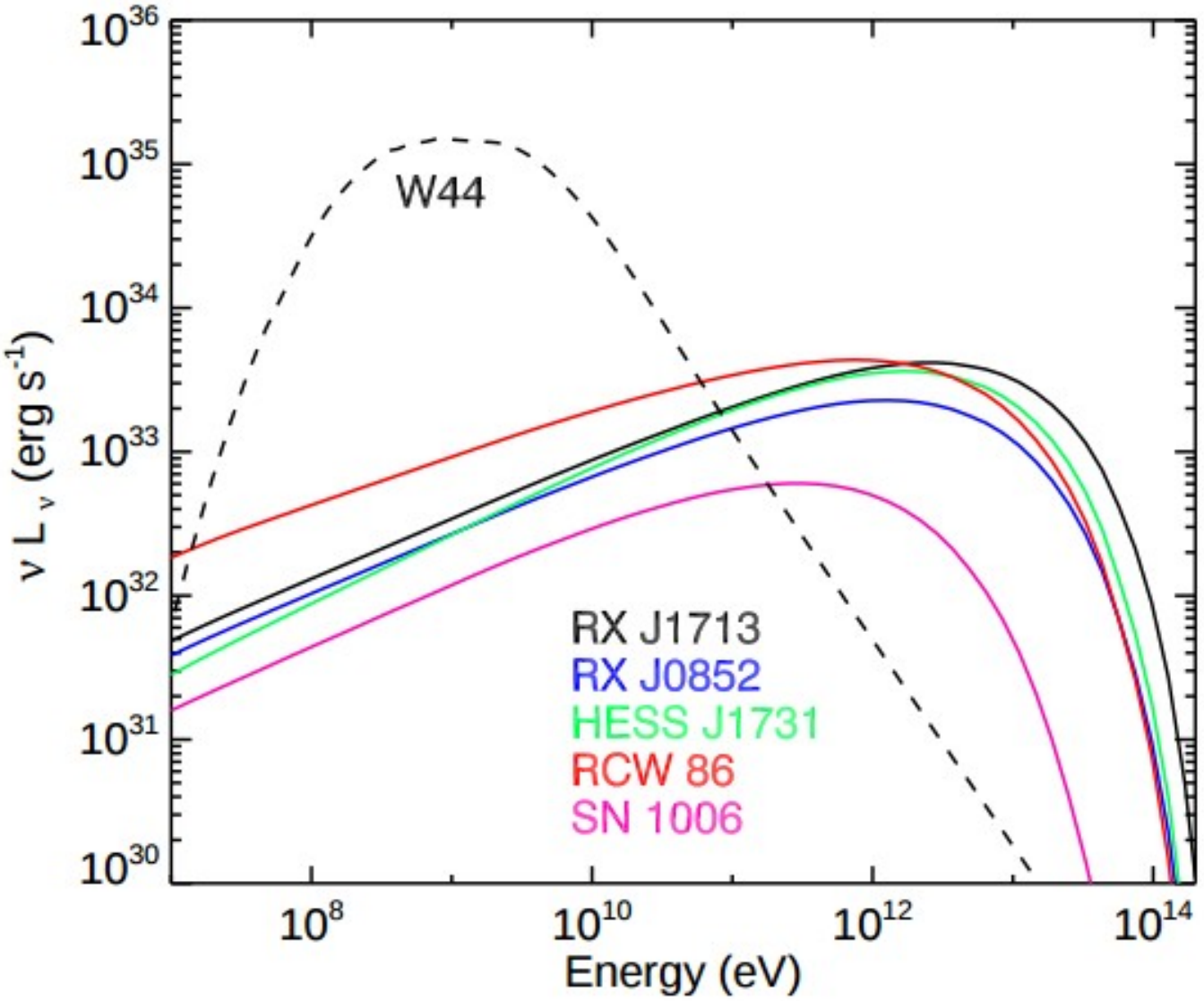
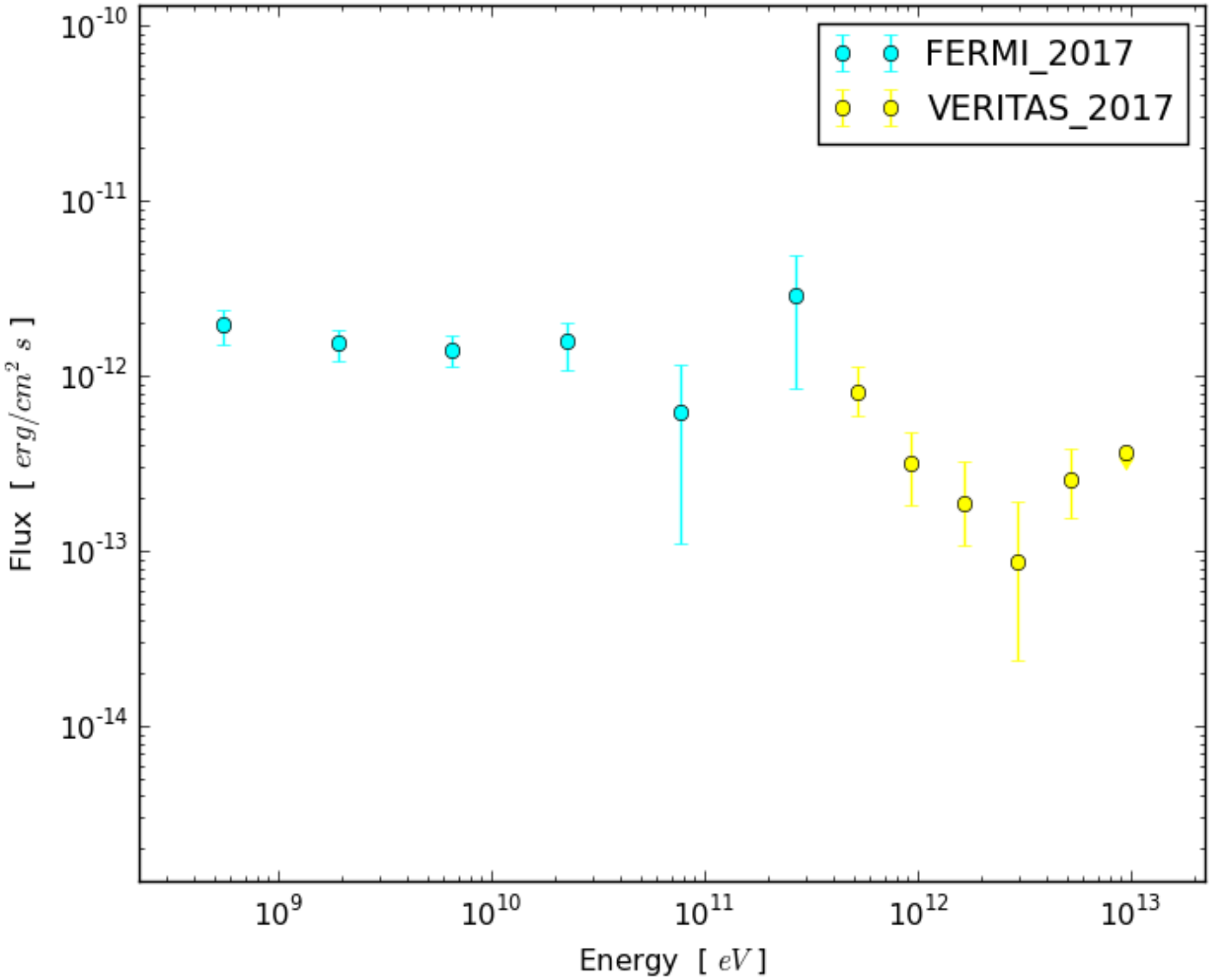
Shell-like (TeV-peaked) SNRs

Acero et al. A&A 2015



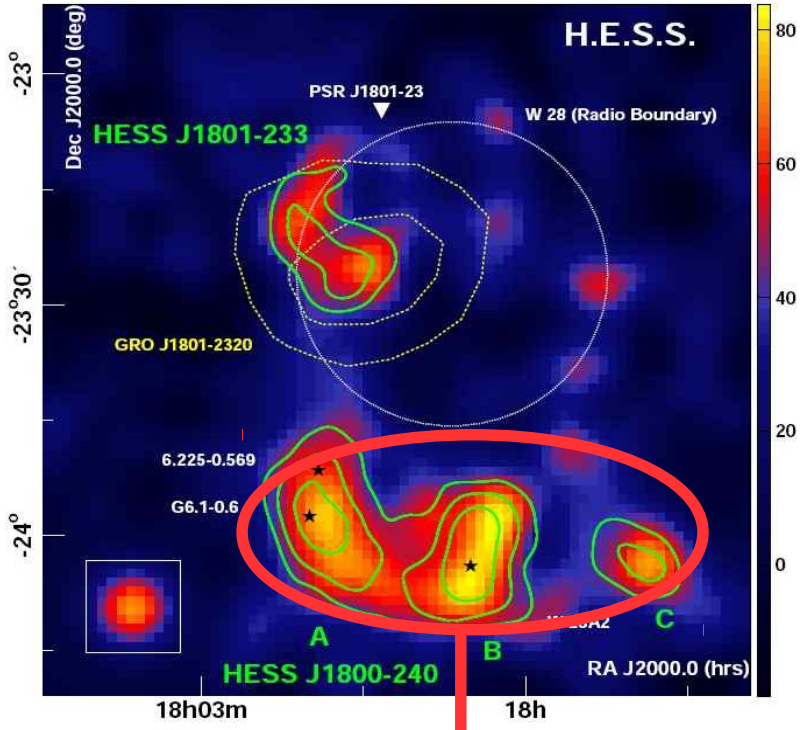
Tycho SNR

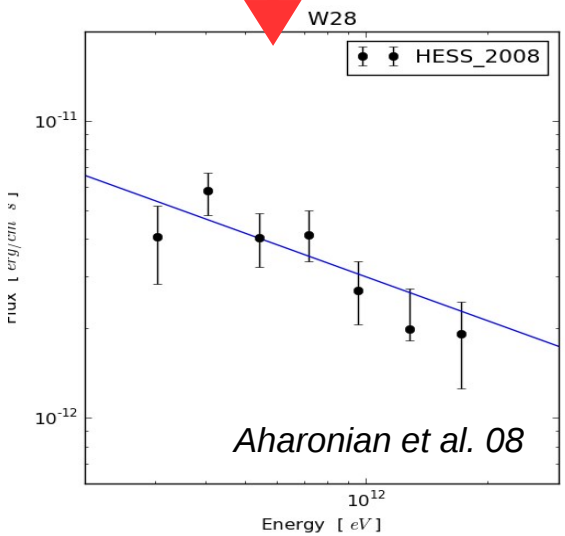


Veritas coll. 2017. arXiv:1701.06740

Was W28 a Pevatron ?

M.Paruscio, A.Giuliani
INAF/IASF Milano





HESS J1800-240 is a soft (index -2.49) but bright source associated to the giant MCs interacting with the CRs accelerated by W28 during its life (~30000 yrs).

HESS J1800-240 gives then insights on the acceleration history of W28 .

CTA can extend the HESS spectrum to higher energies .

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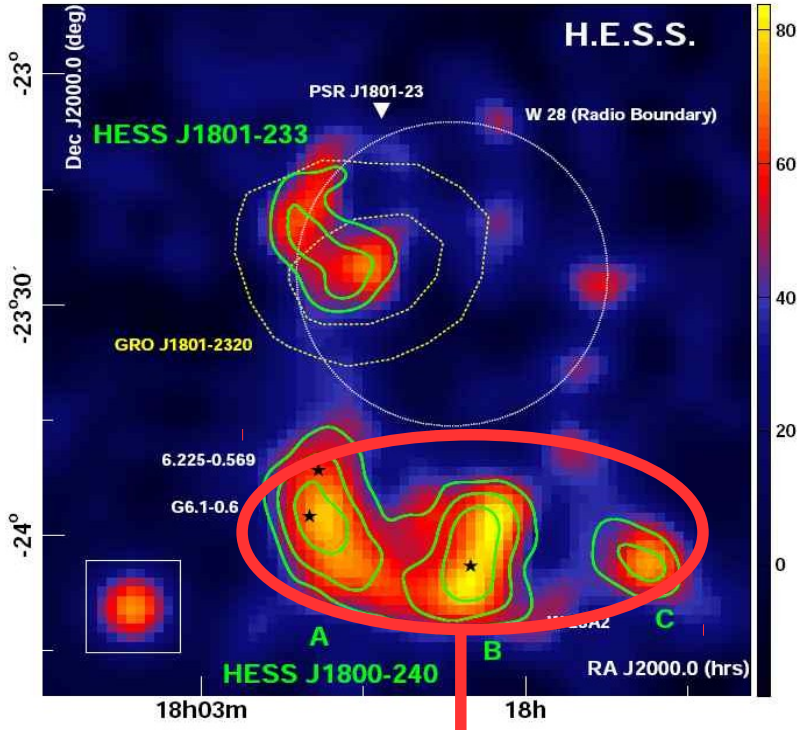

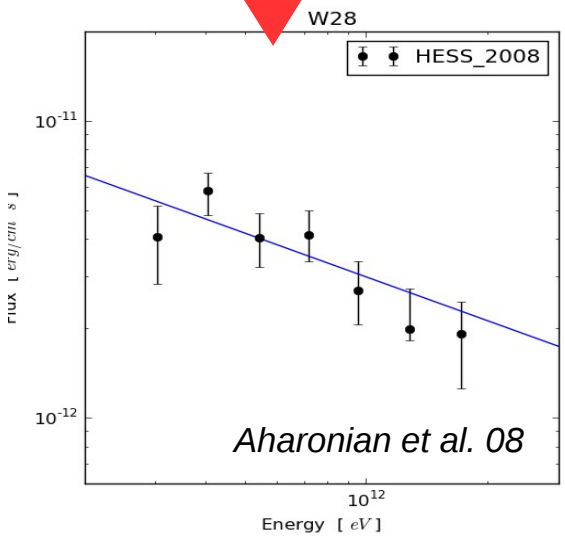

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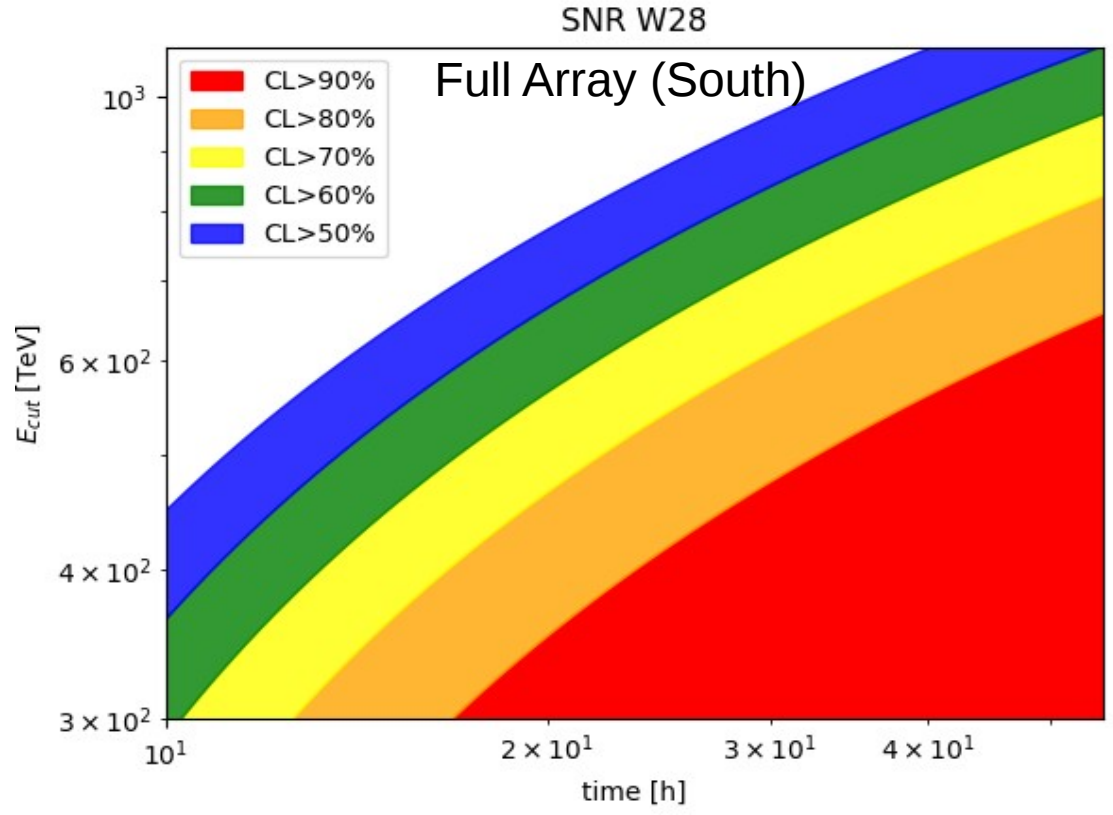
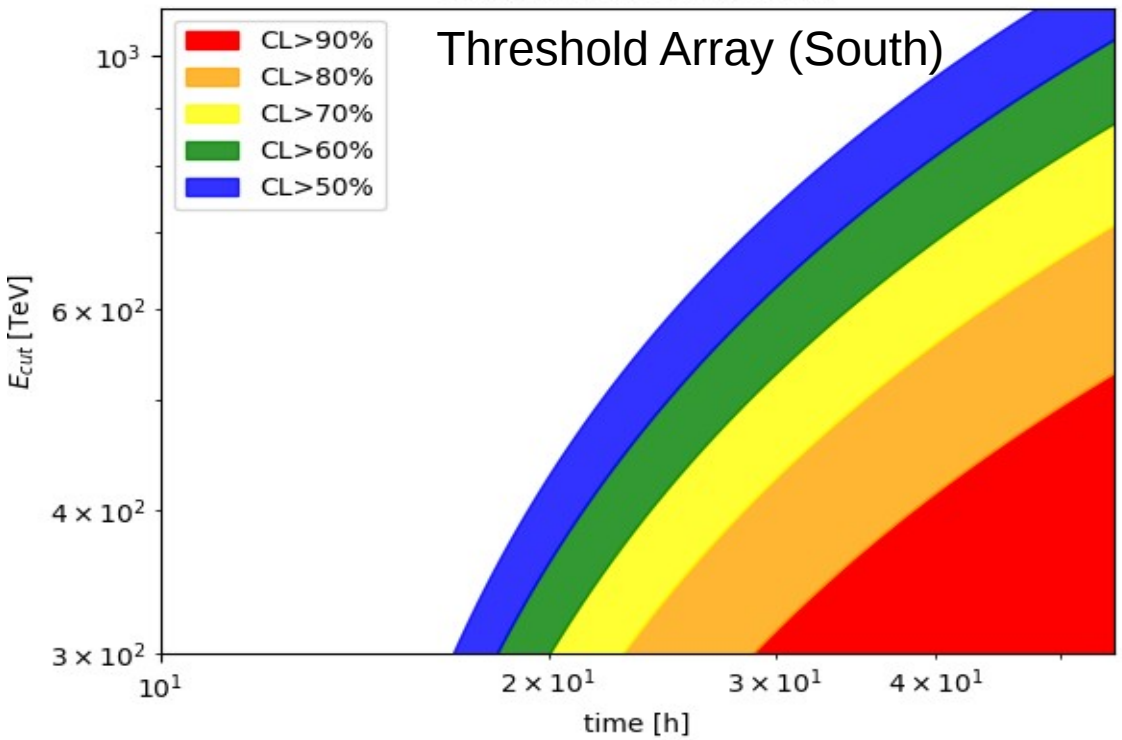
CTA can extend the HESS spectrum to higher energies .

Can CTA test if W28 was a PeVatron ?

or equivalently,

can CTA exclude a cut-off in the protons spectrum below ~0.5 PeV ?





Spectral studies of SNR W28

We modeled the g-rays emission from HESS J1800-240 assuming a protons distribution with an energy spectrum ***without*** cut-offs and index 2.49.

We performed 100 simulations and analysis (CTOOLS + NAIMA) for several exposure times.

The plots show the percentile of realizations for which we can exclude a cut-off above a given energy and exposure time.

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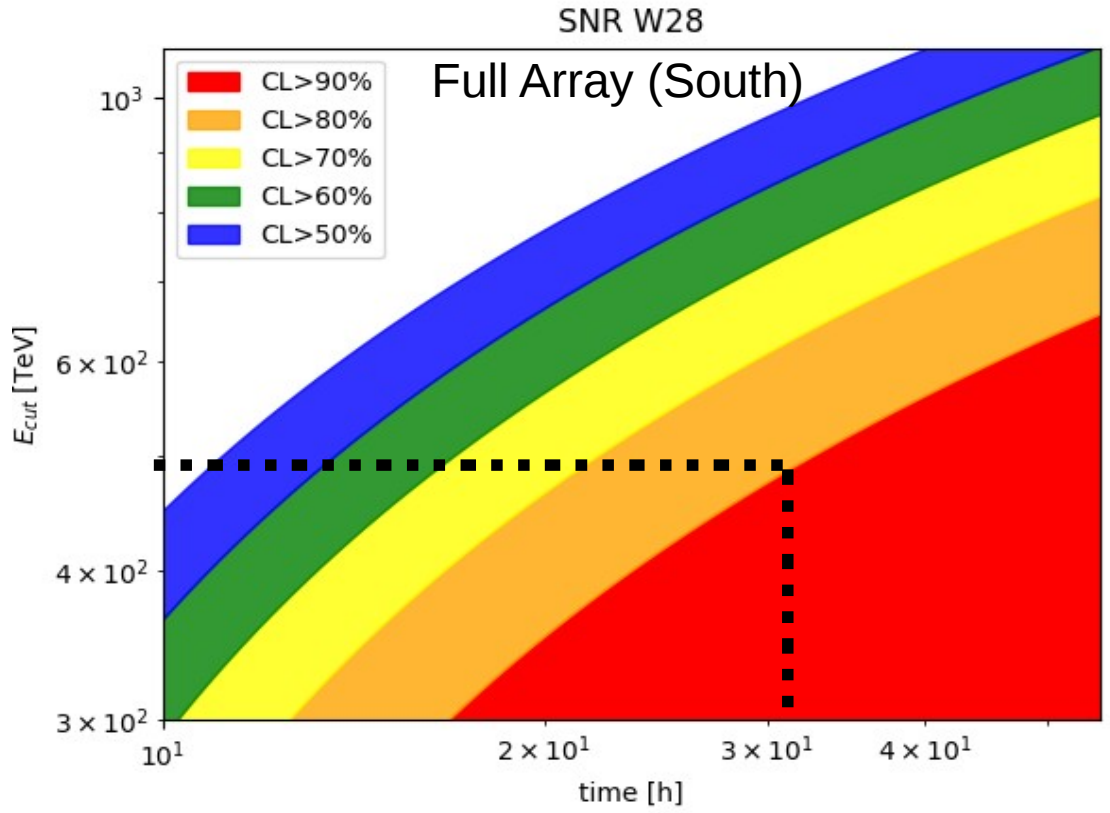

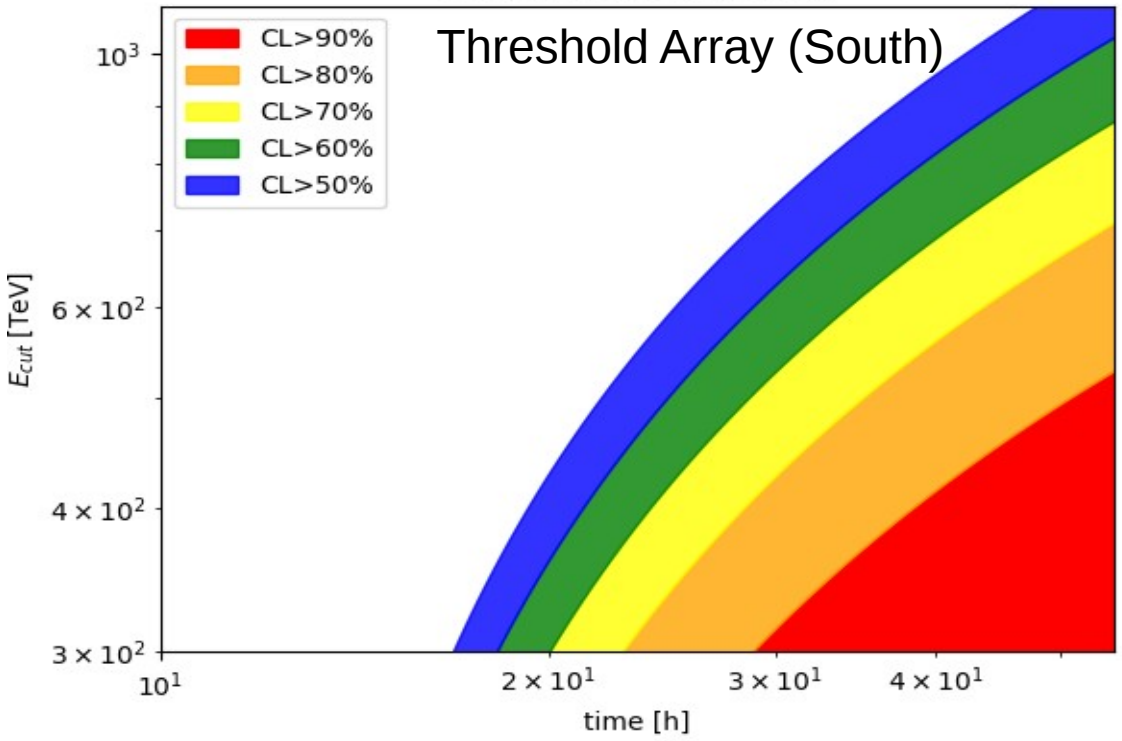

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with ~30 hrs of data CTA can exclude cut-offs in the spectrum up to 0.5 PeV in the 90% of cases.

Conclusions

The AGILE SNR's

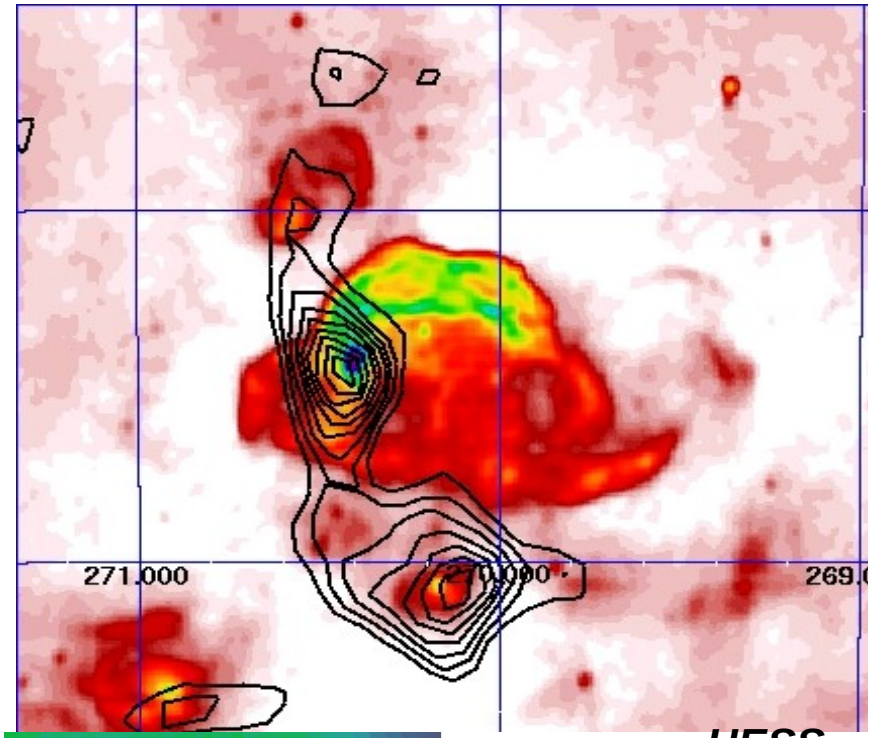
(= evolved and interactiong with MCs)

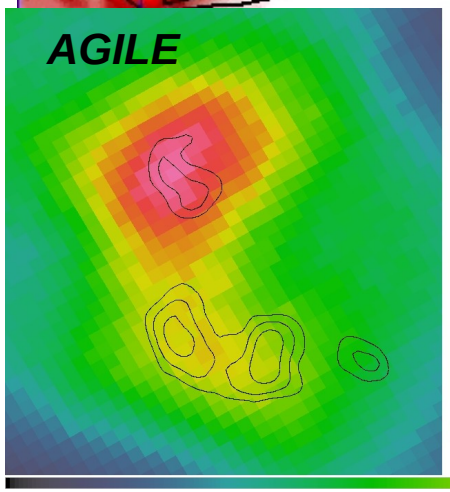
were (and will be) the best sources to study the

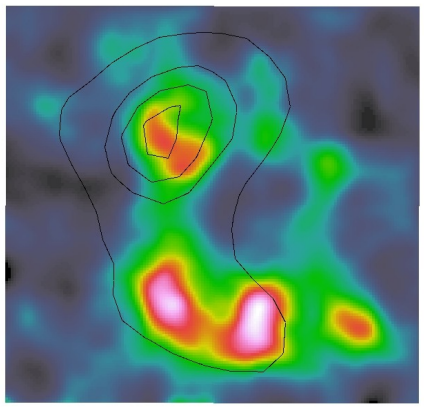
hadronic origin of CRs

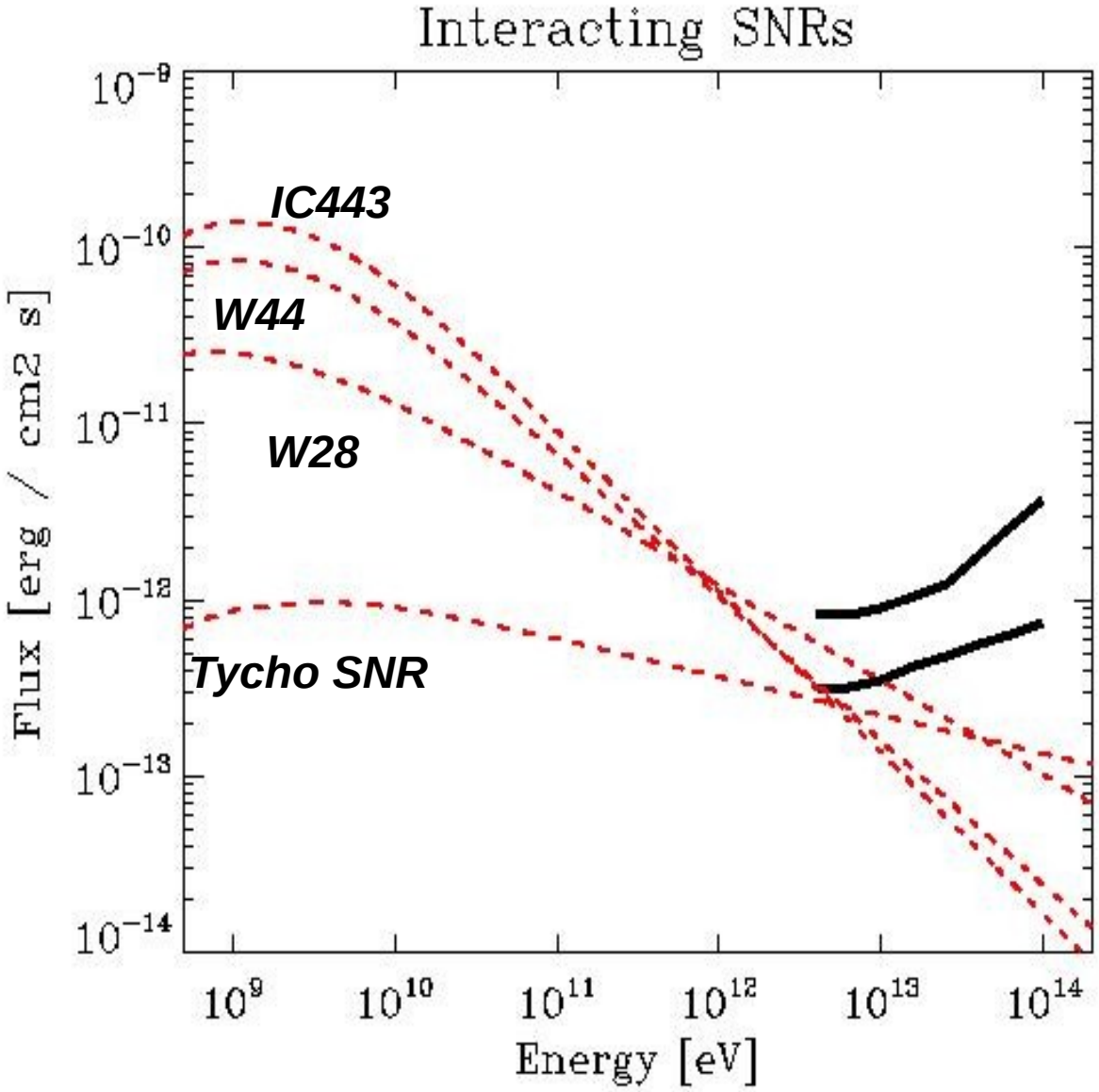
Thanks!

SNR W 28


271.000
269.

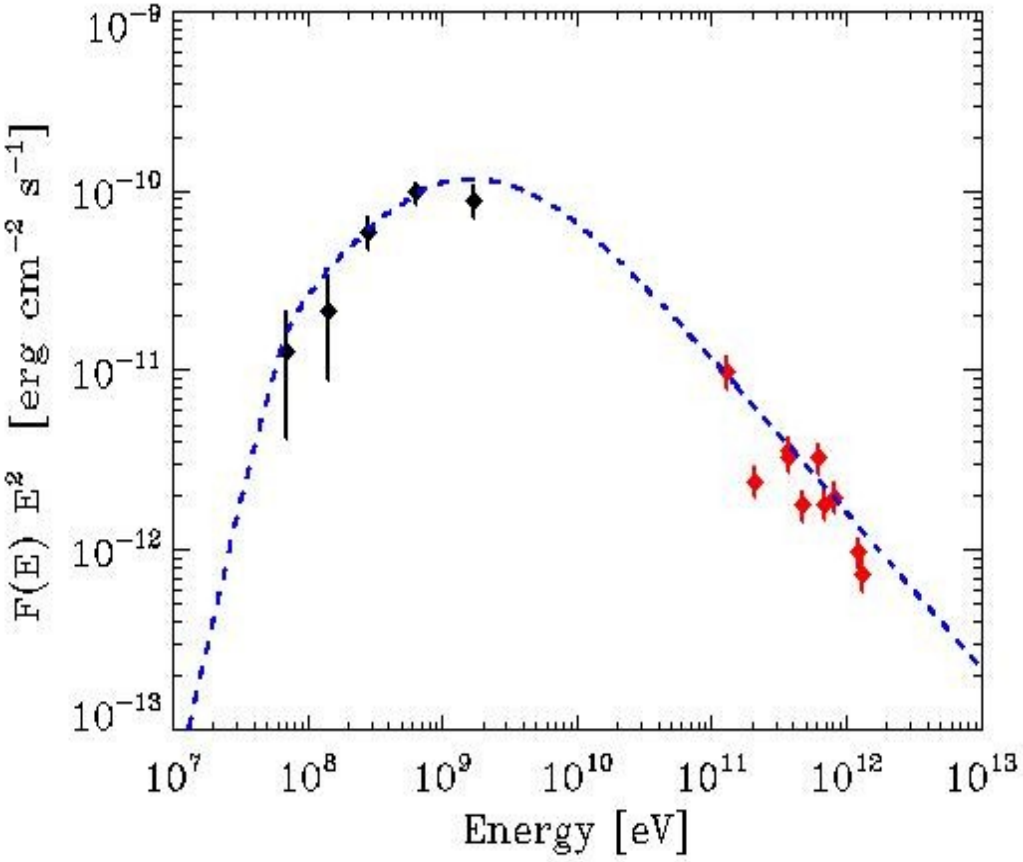

AGILE

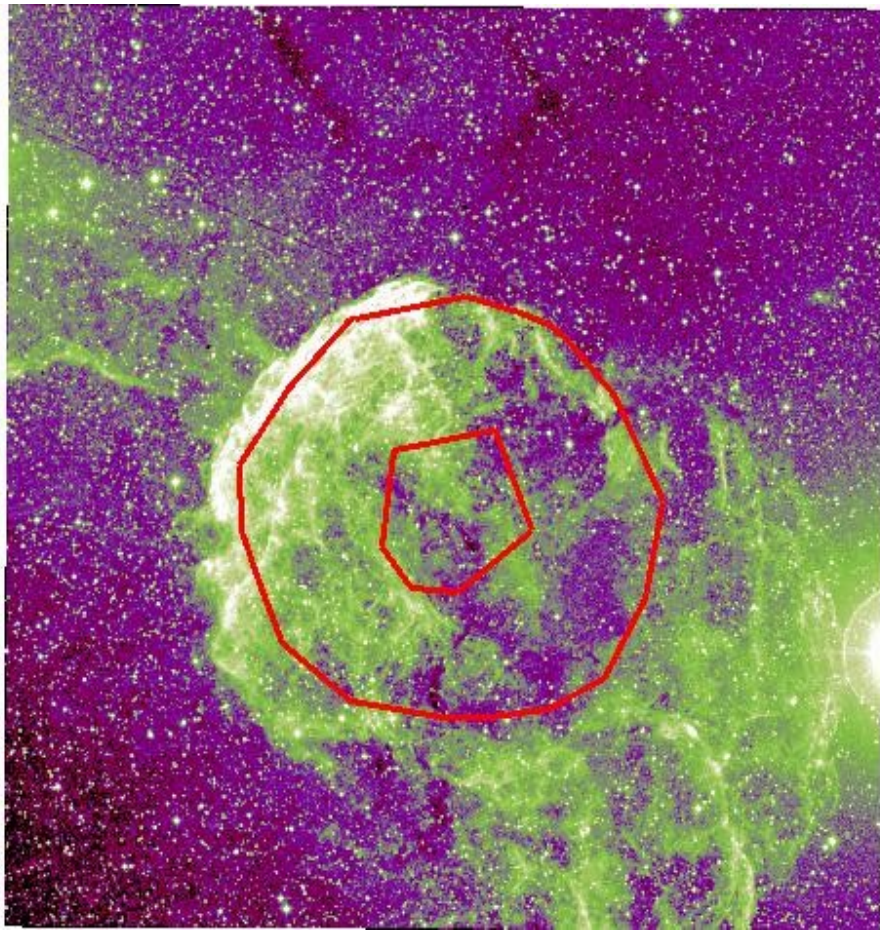

HESS


Interacting SNRs
IC443
W44
W28
Tycho SNR
Flux [erg / cm2 s]
Energy [eV]
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^9
10^10
10^11
10^12
10^13
10^14

SNR IC 443

Break : 3.1 → 2.0+0.1





SNR W30

Break : 3.5 → 2.0+0.2