AGILE and the Supenova Remnants

A. Giuliani
IASF Milano

Outline of the talk

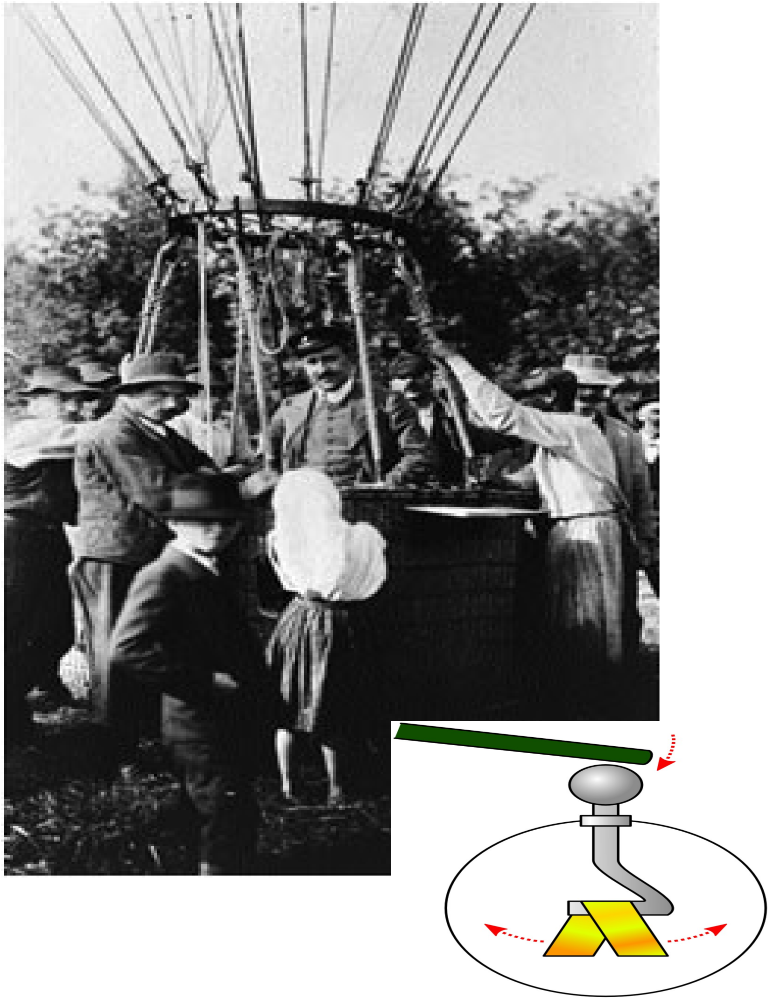
→ What we know after AGILE and Fermi

→ Open questions

→ AGILE SNRs

One century in one slide

1912 : Discovery of CRs



One century in one slide

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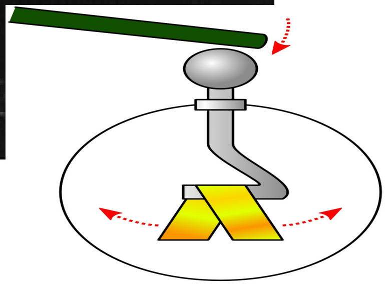
60s : SNR proposed as sources of the Galactic CRs

- Energy budget (Ginzburg e Syrovatskii 1964)
- Radio obs. of relativistic electrons



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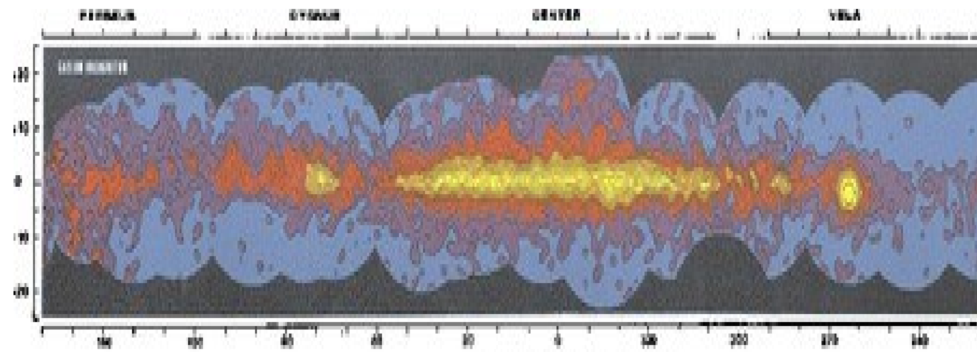
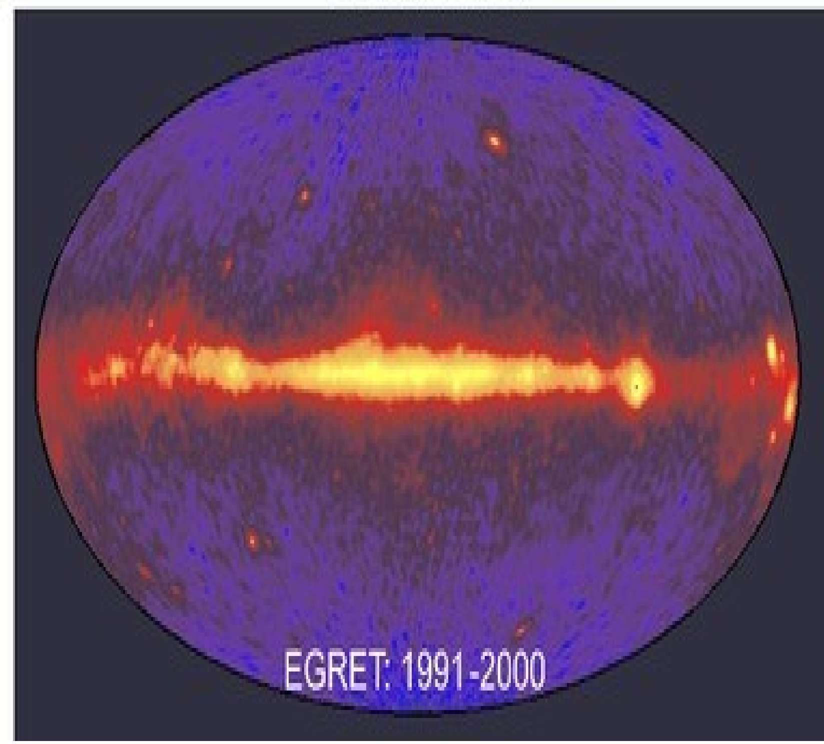


COS-B: 1975-82



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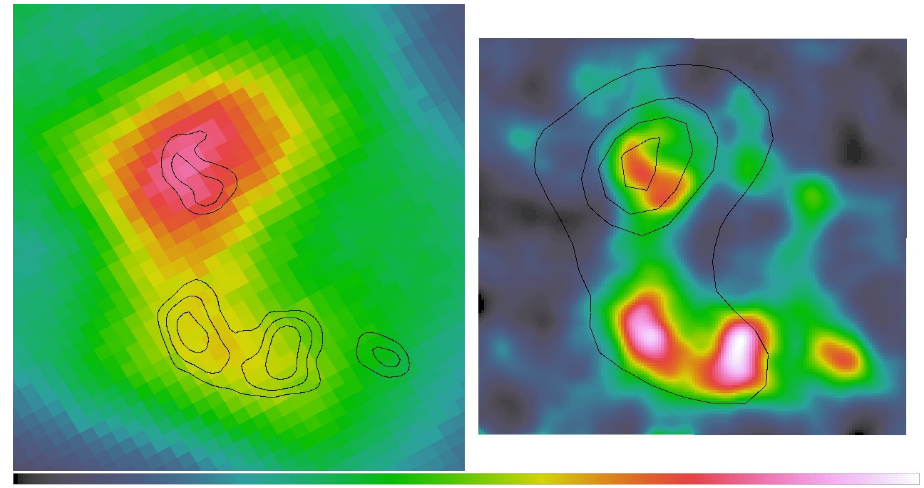

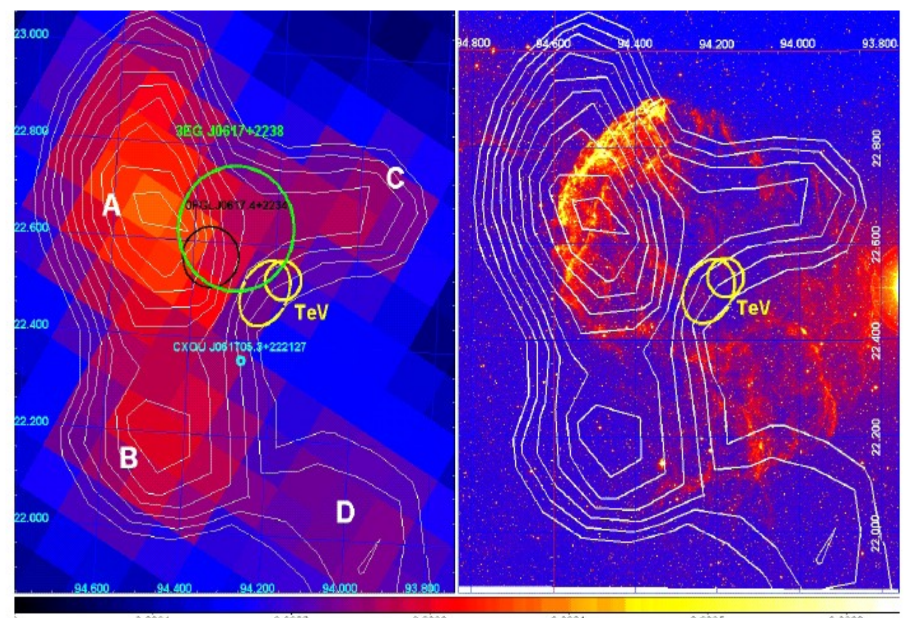

Tavani et al. 2010 ApJ L.

One century in one slide

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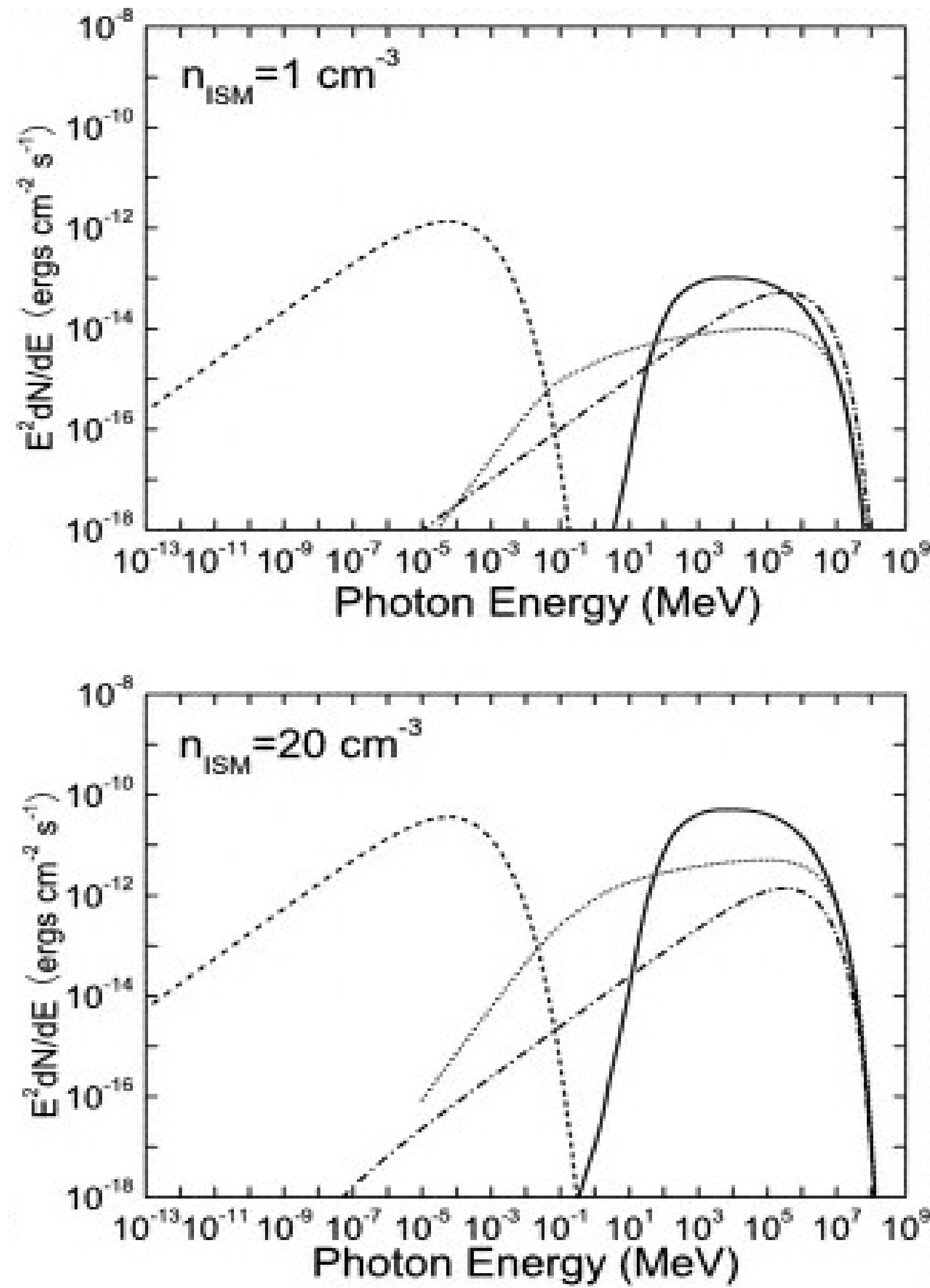
10s : Clear identification of emission from π^0 decay

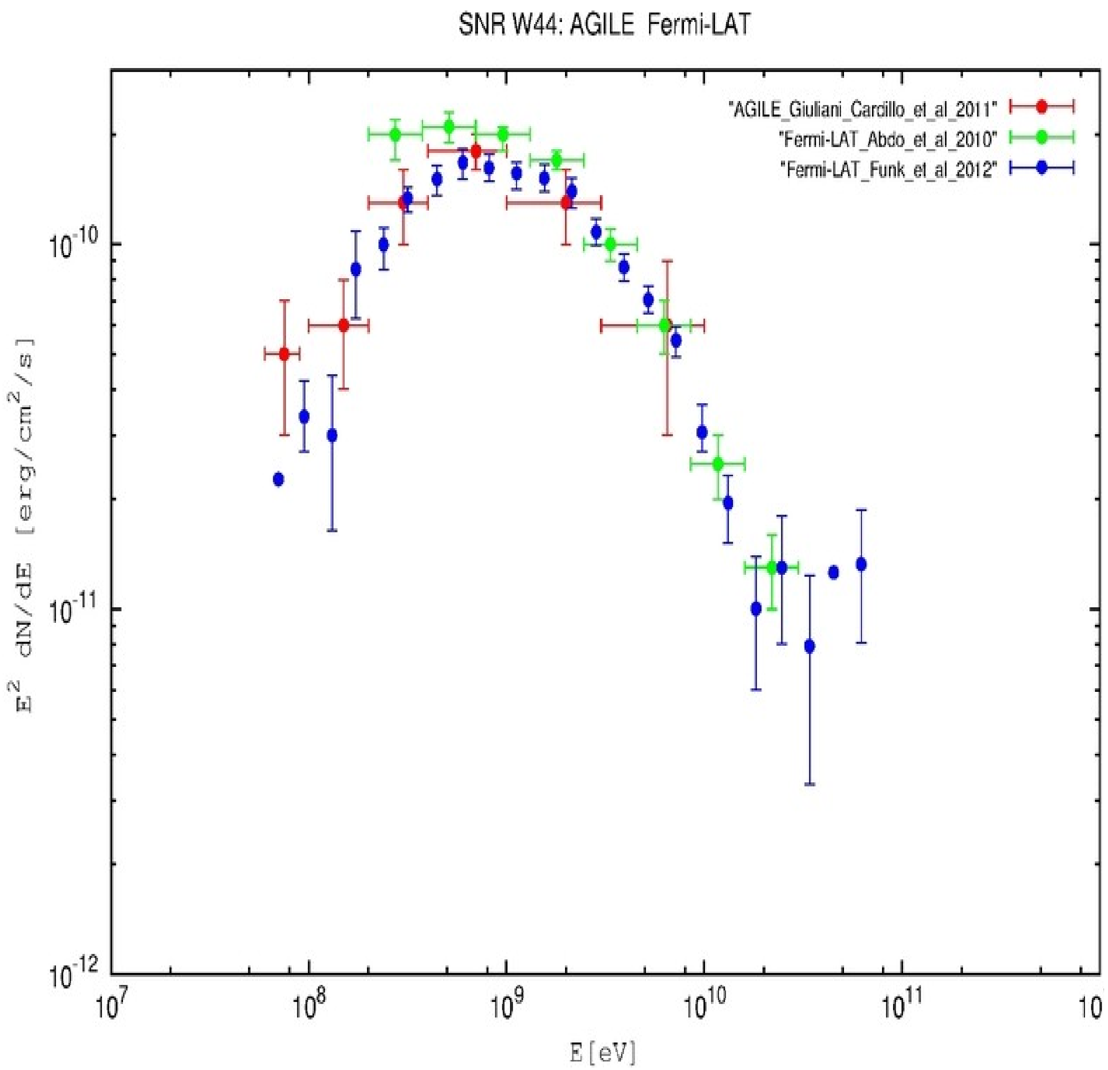


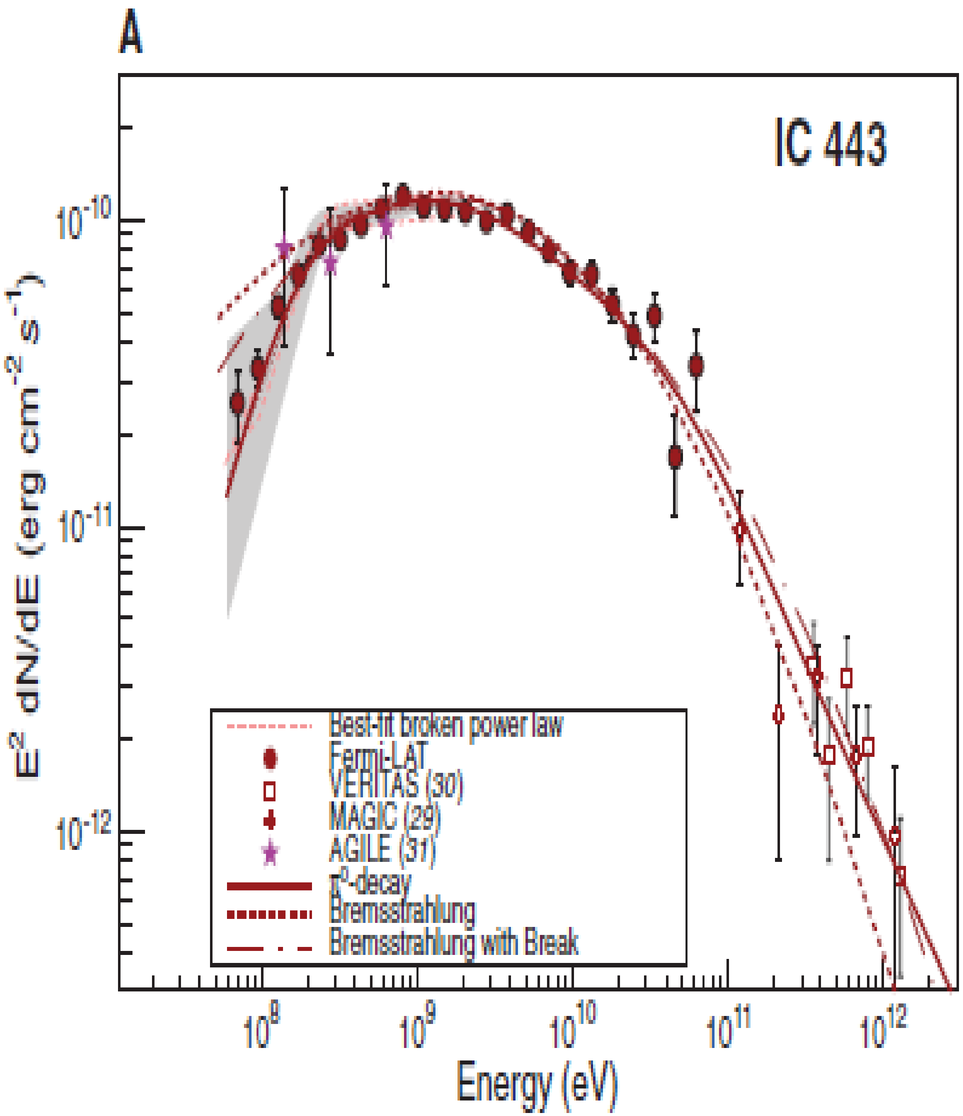
What we know after Agile and Fermi

→ Protons emission dominates in (at least) few SNRs

→ Few classes of SNRs

Protons !

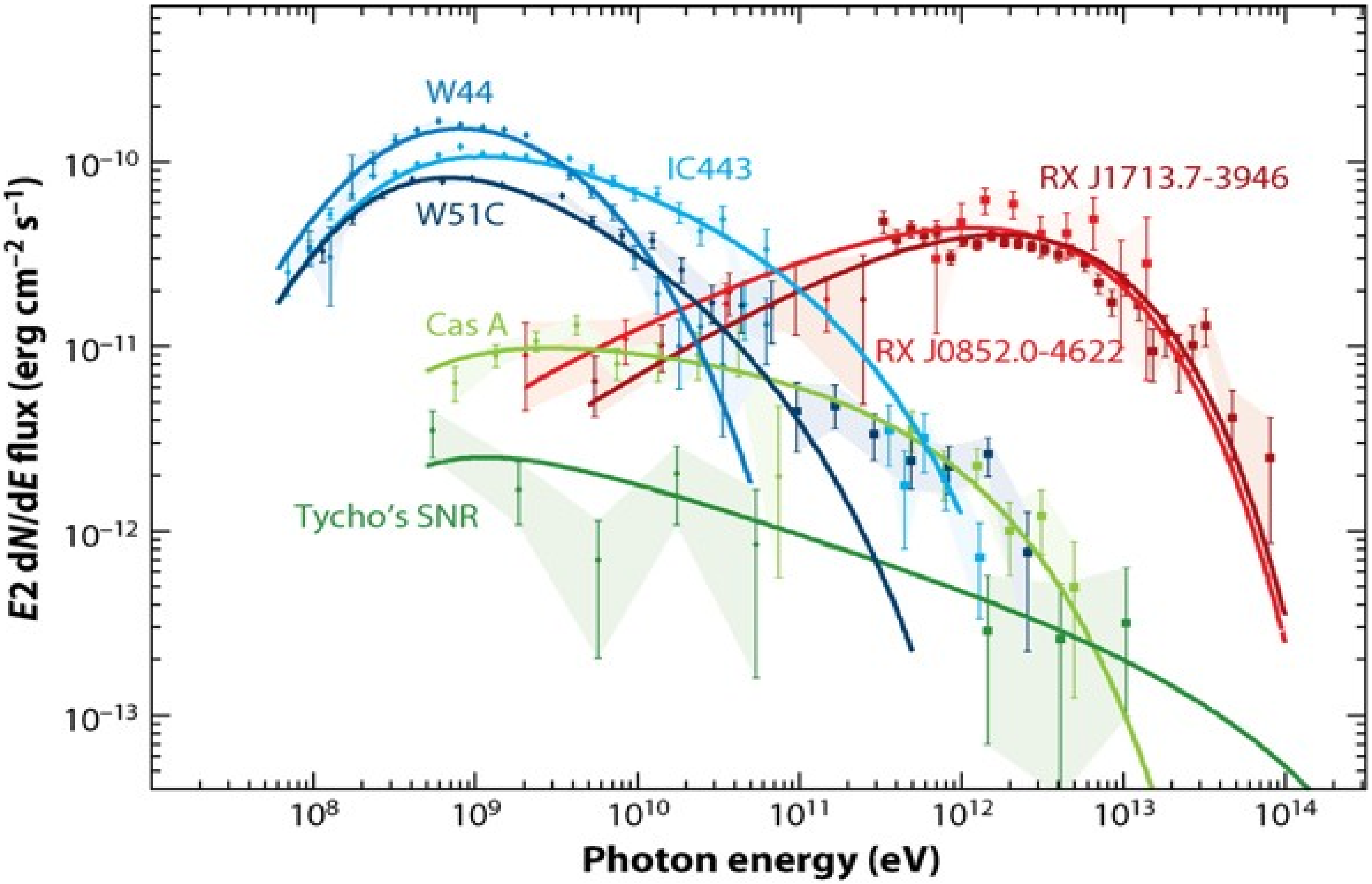




Giuliani,Cardillo et al. 2011
Cardillo et al. 2014

Ackermann et al. (2013)

2(3?) SNR classes



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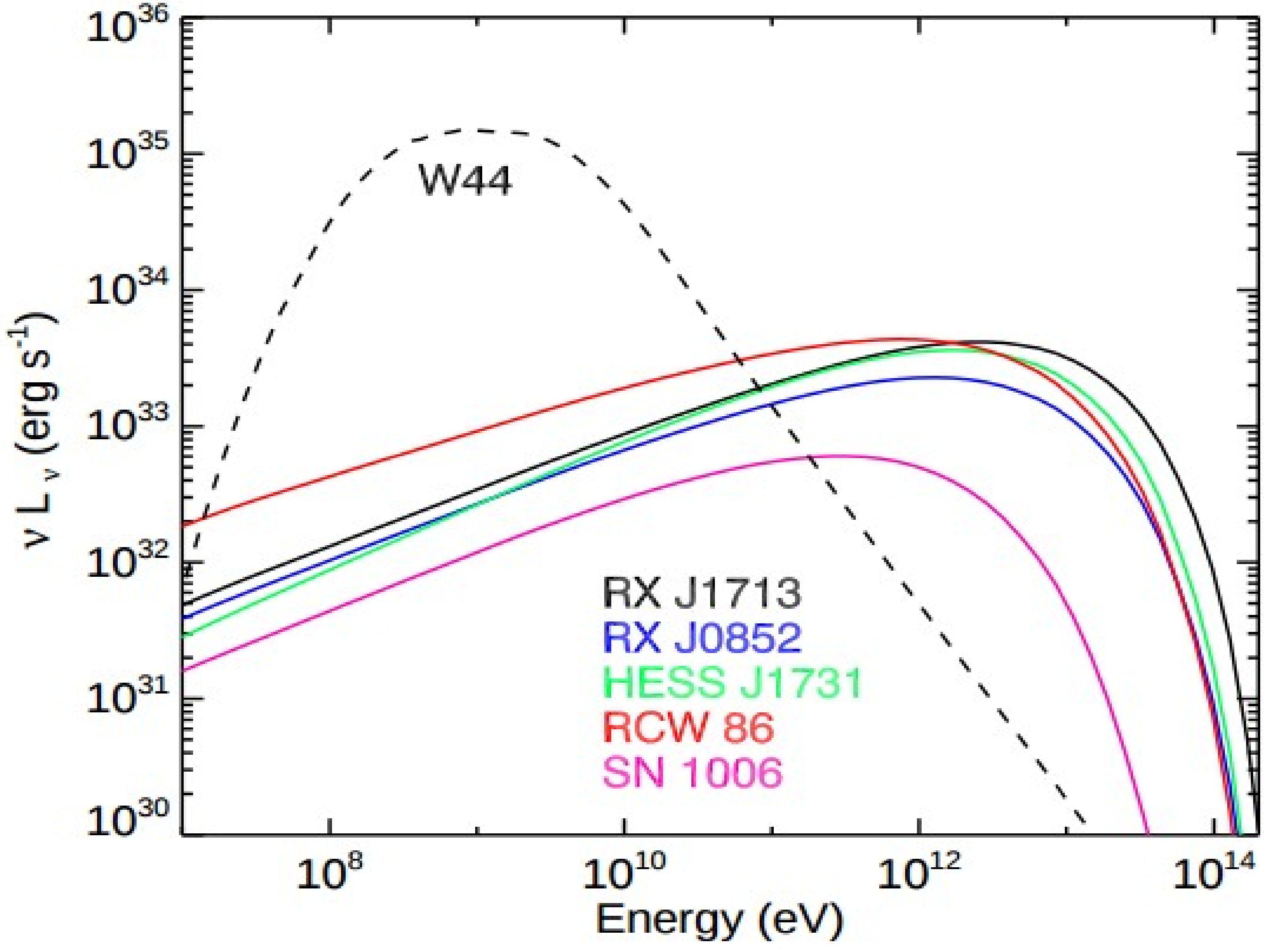
2(3?) SNR classes



From : ***Acero et al. A&A 2015***

Open Questions

→ Hadronic / Leptonic contributions (for both classes)

→ Spectral shapes

→ Pevatrons ?

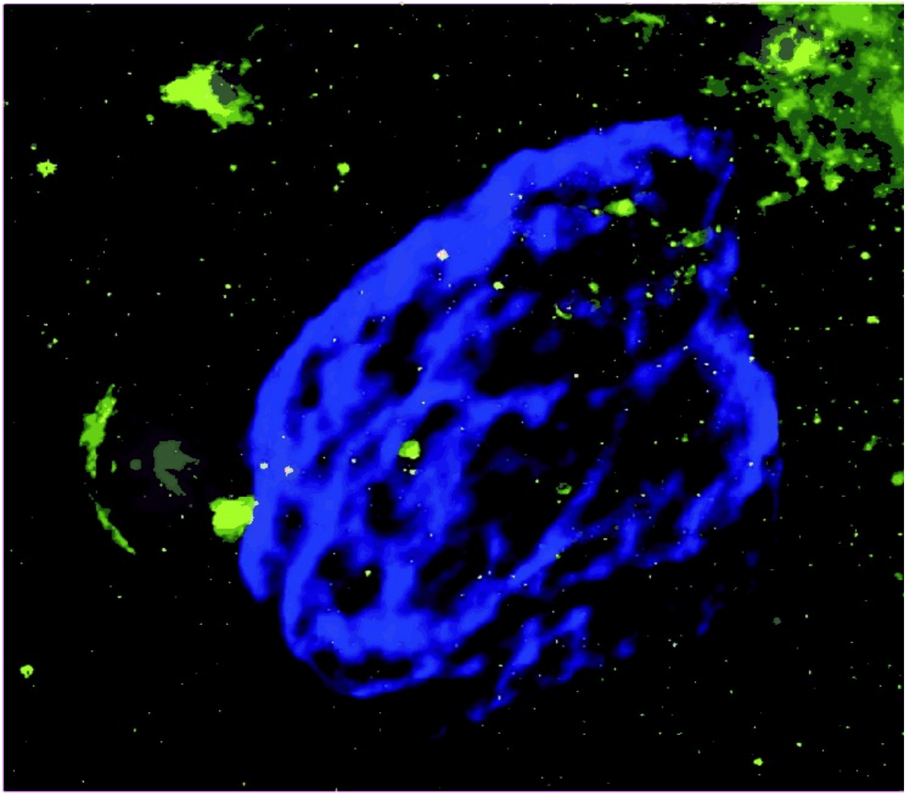
AGILE SNRs

Middle-aged and interacting with GMCs

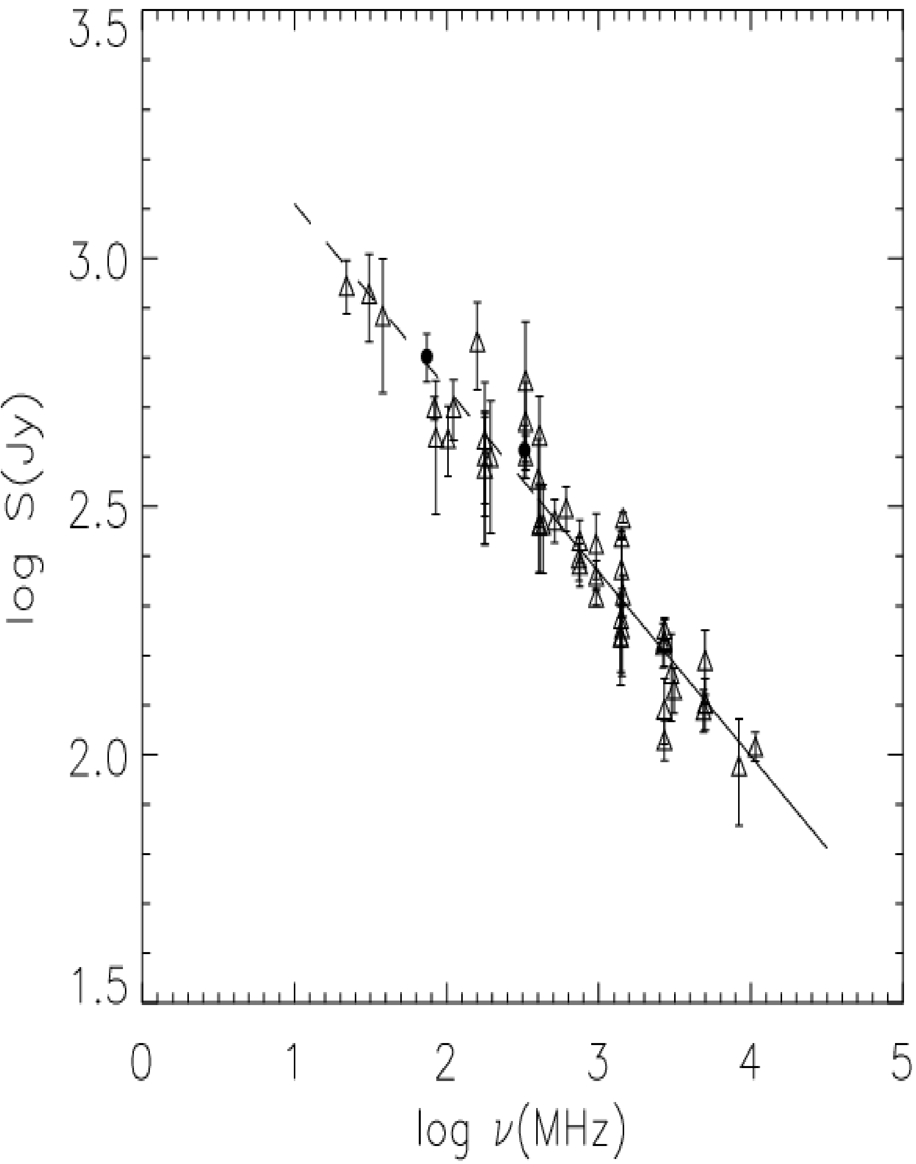
	Age	dist	GeV	TeV (C.u.)	1 GHz (Jy)	
W44	*20000*	*3.0*	*115*	*-----*	*230*	(Giuliani et al, 11, Cardillo et al 14)
IC443	30000	1.5	50	0.03	160	(Tavani et al, 10)
W28	40000	2.0	40	0.38	310	(Giuliani et al, 10)
W51C	20000	6.0	66	0.003	160	(*in prep.*)
W49B	2000	8.0	10	0.005	38	(*in prep.*)
W30	16000	4.0	30	0.2	23	(*in prep.*)

SNR W44

Age : ~ 20000 yr
Distance : ~ 3 Kpc
Type : mixed-morphology



SNR W44

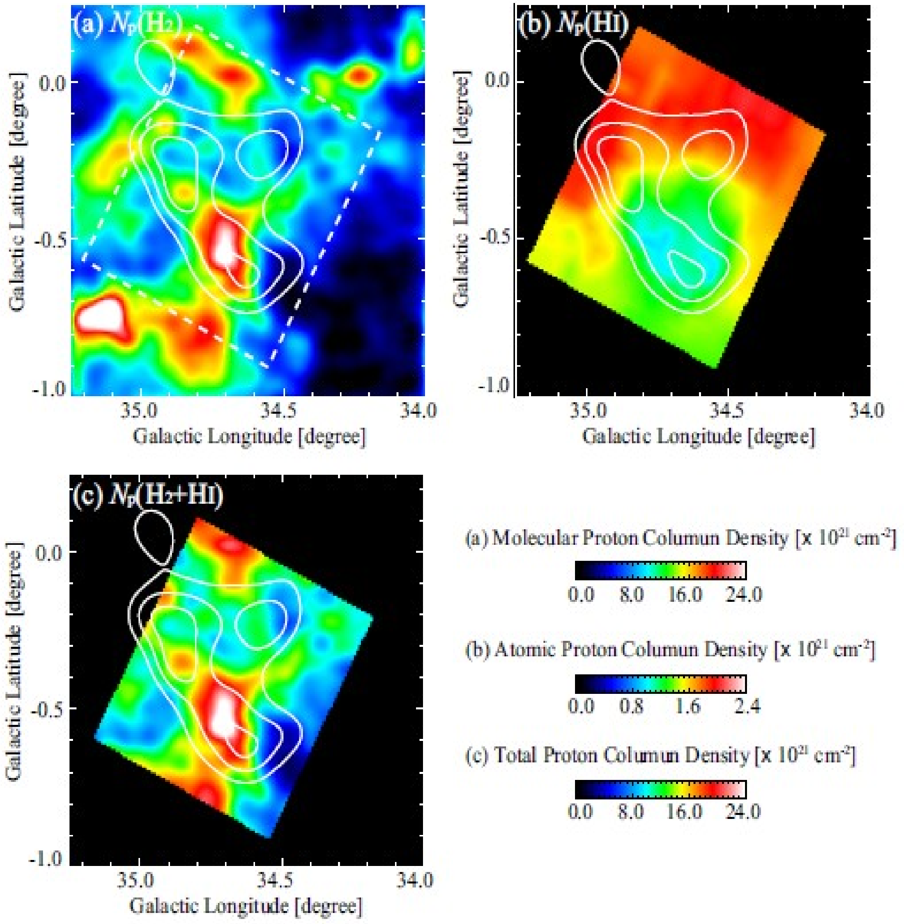


Age : ~ 20000 yr
Distance : ~ 3 Kpc
Type : mixed-morphology

- Strong non-thermal radio emission, power-law featurless in the frequency range ~ 10 MHz - 10 GHz

[Castelletti et al 2007]

SNR W44



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Distance : ~ 3 Kpc
Type : mixed-morphology

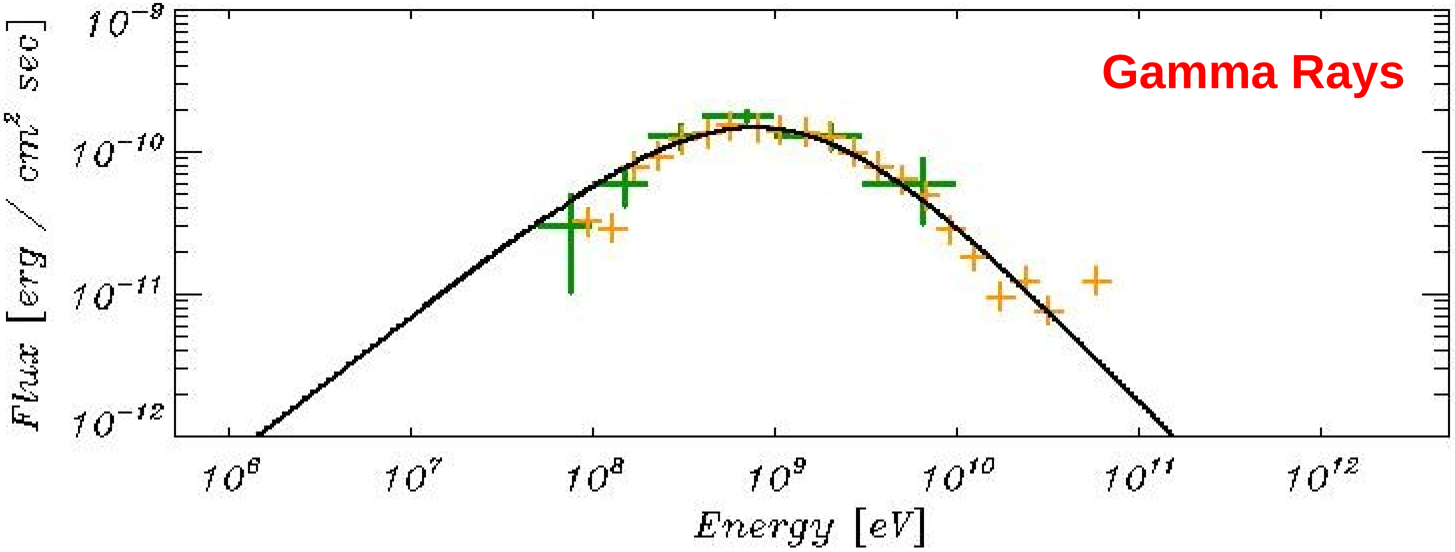
- Strong non-thermal radio emission, power-law featurless in the frequency range ~ 10 MHz - 10 GHz

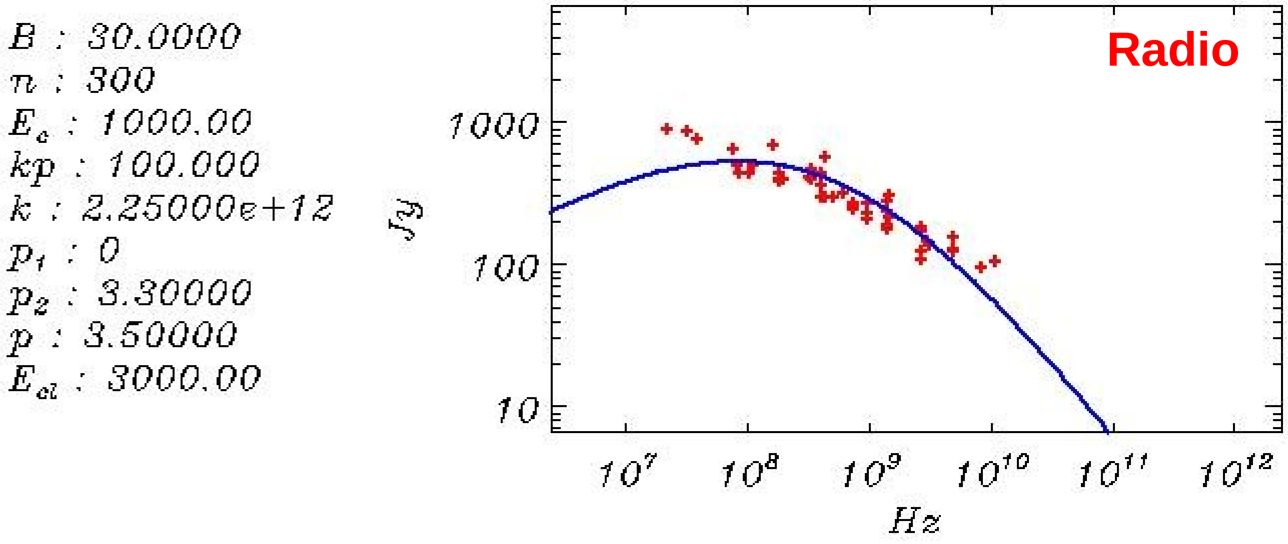
[Castelletti et al 2007]

- Expanding in a dense medium

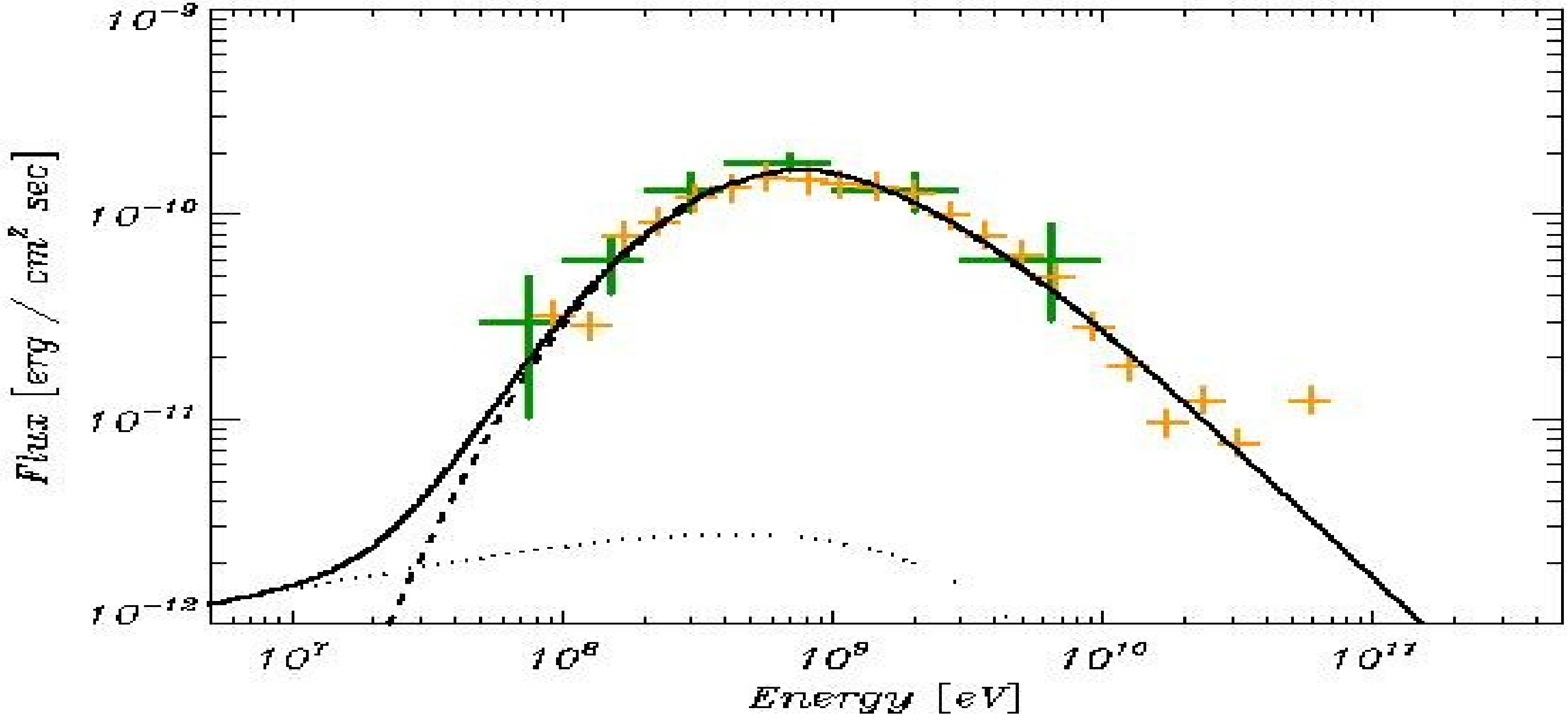
[Yoshiike et al. 2013]

Bremsstrahlung ? Doesn't work !





Pion decay !

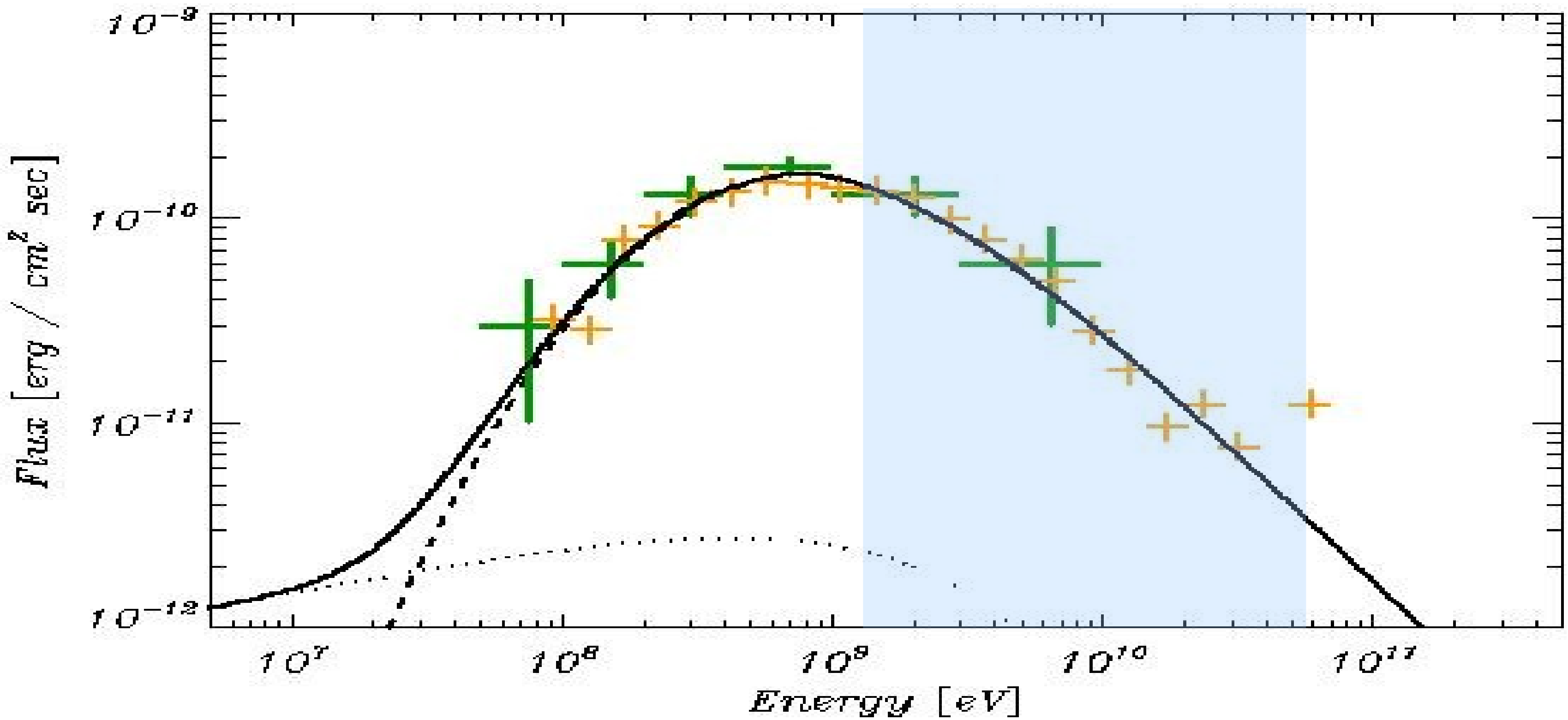


10^{-9}
10^{-10}
10^{-11}
10^{-12}
Flux [erg / cm^2 sec]
10^7
10^8
10^9
10^{10}
10^{11}
Energy [eV]

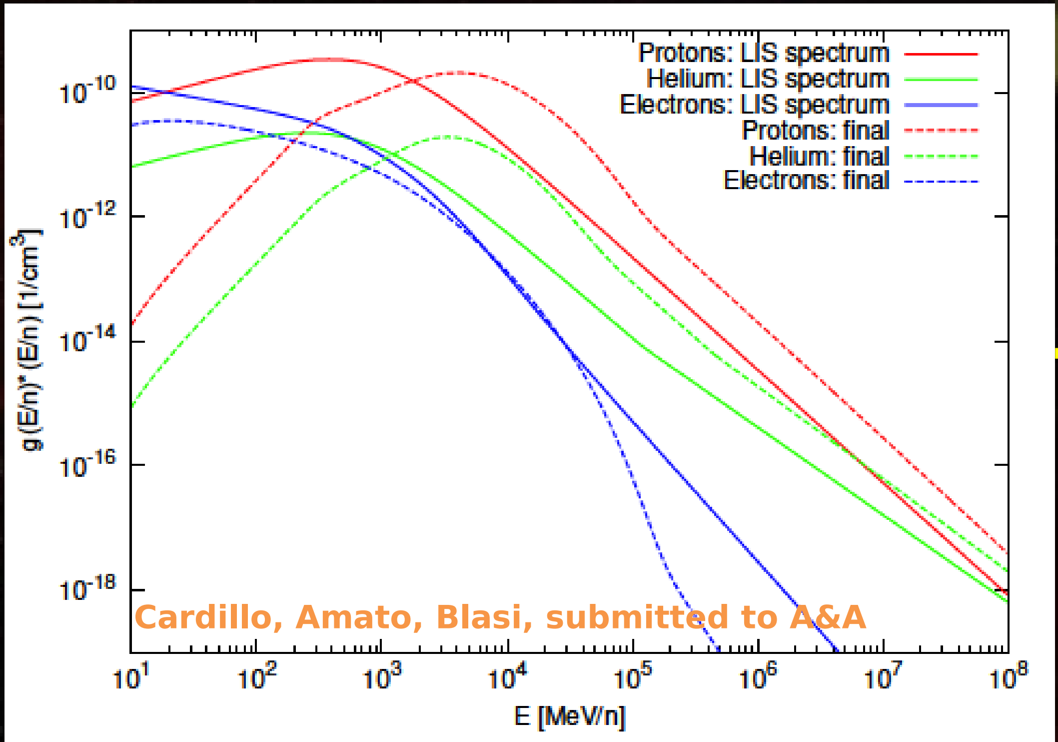
The protons spectrum is very soft for energies greater than ~ 4-5 GeV

Power law (in p) with index 3.5 (!!)

At least up to ~ 50 GeV (challenge for CTA)

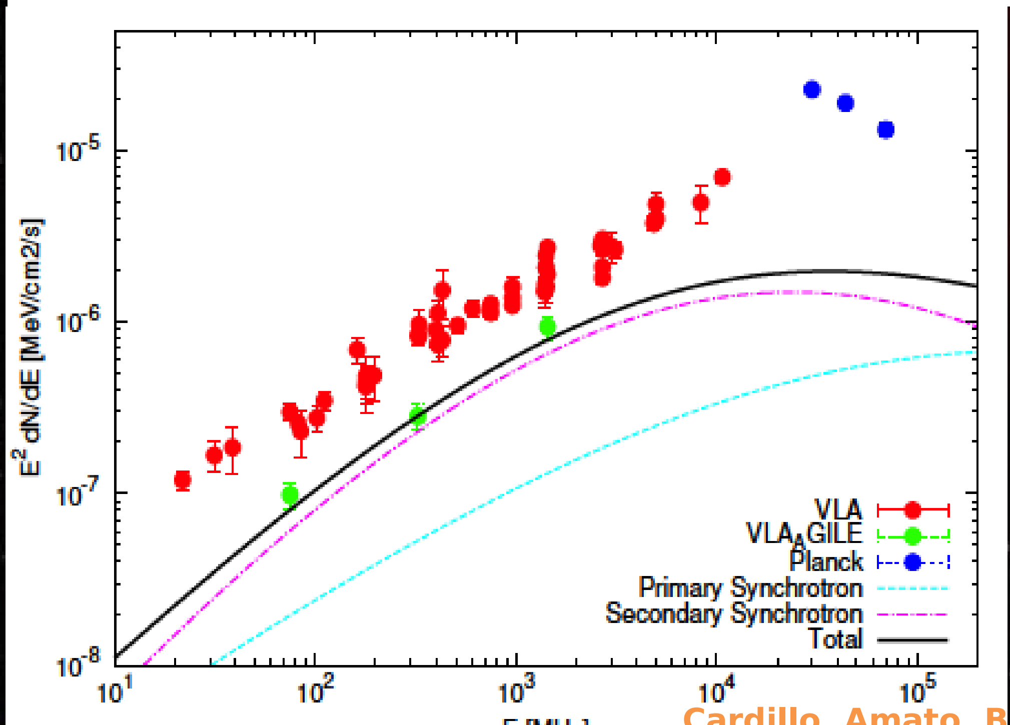


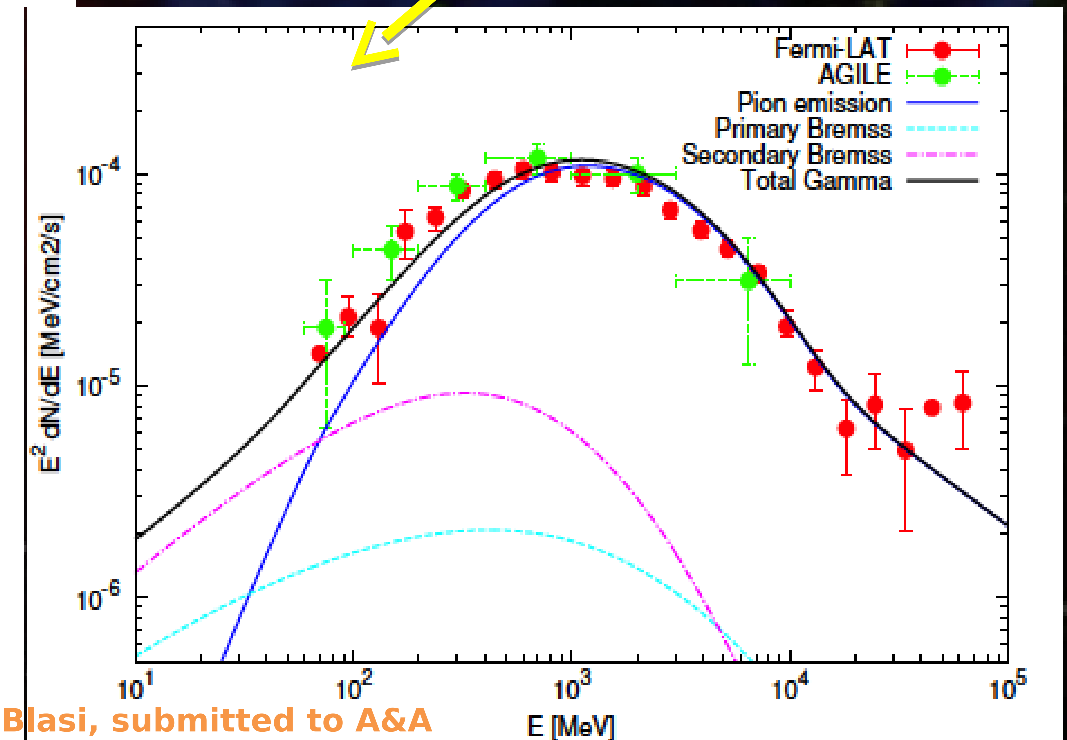
REACCELERATION: our model



r_{sh} = 3.5÷4 □ α=4.2-4

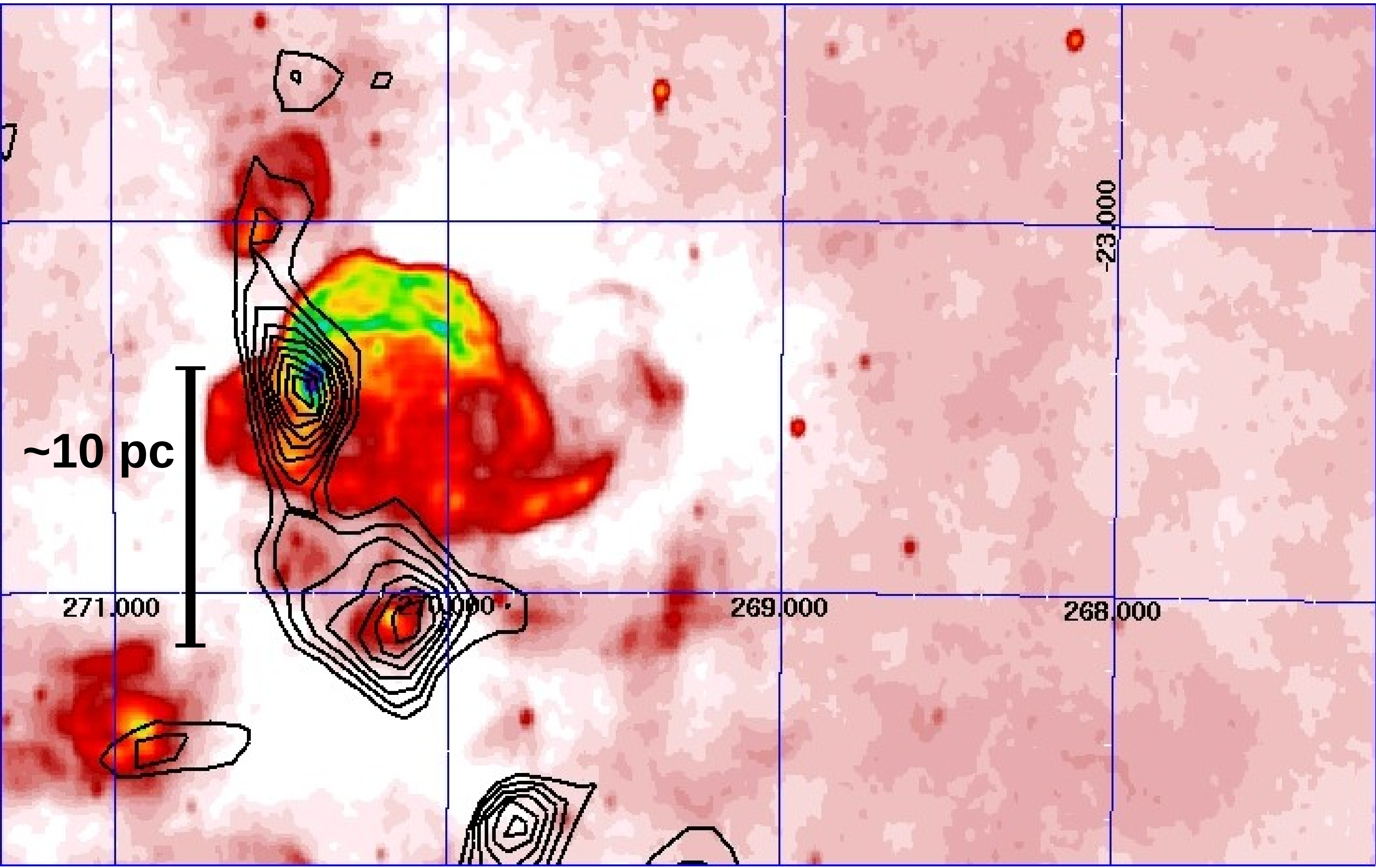
surf. filling factor ξ~ 50%





Cardillo, Amato, Blasi, submitted to A&A

SNRs at “low” energy : diffusion of CRs (W28)



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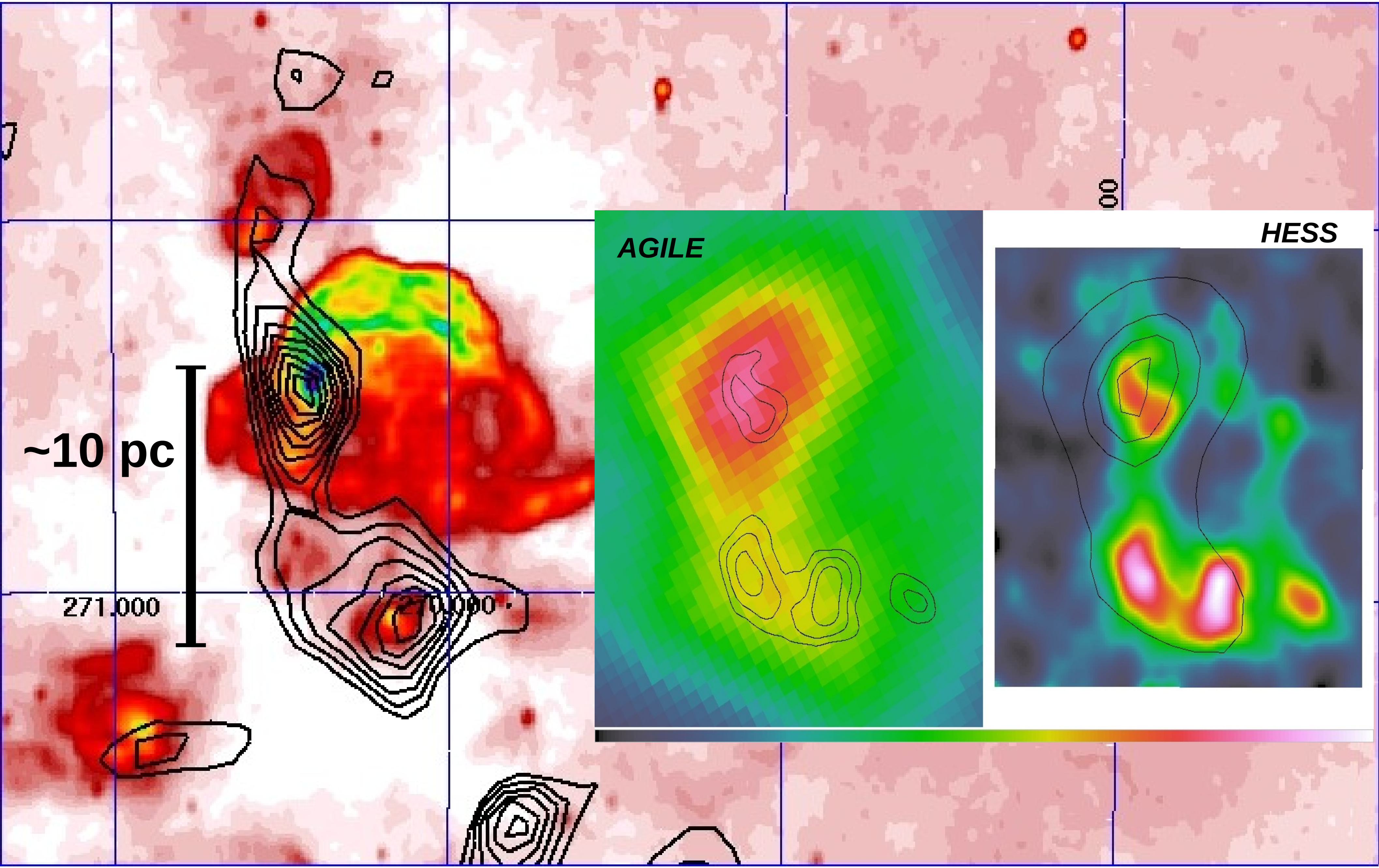

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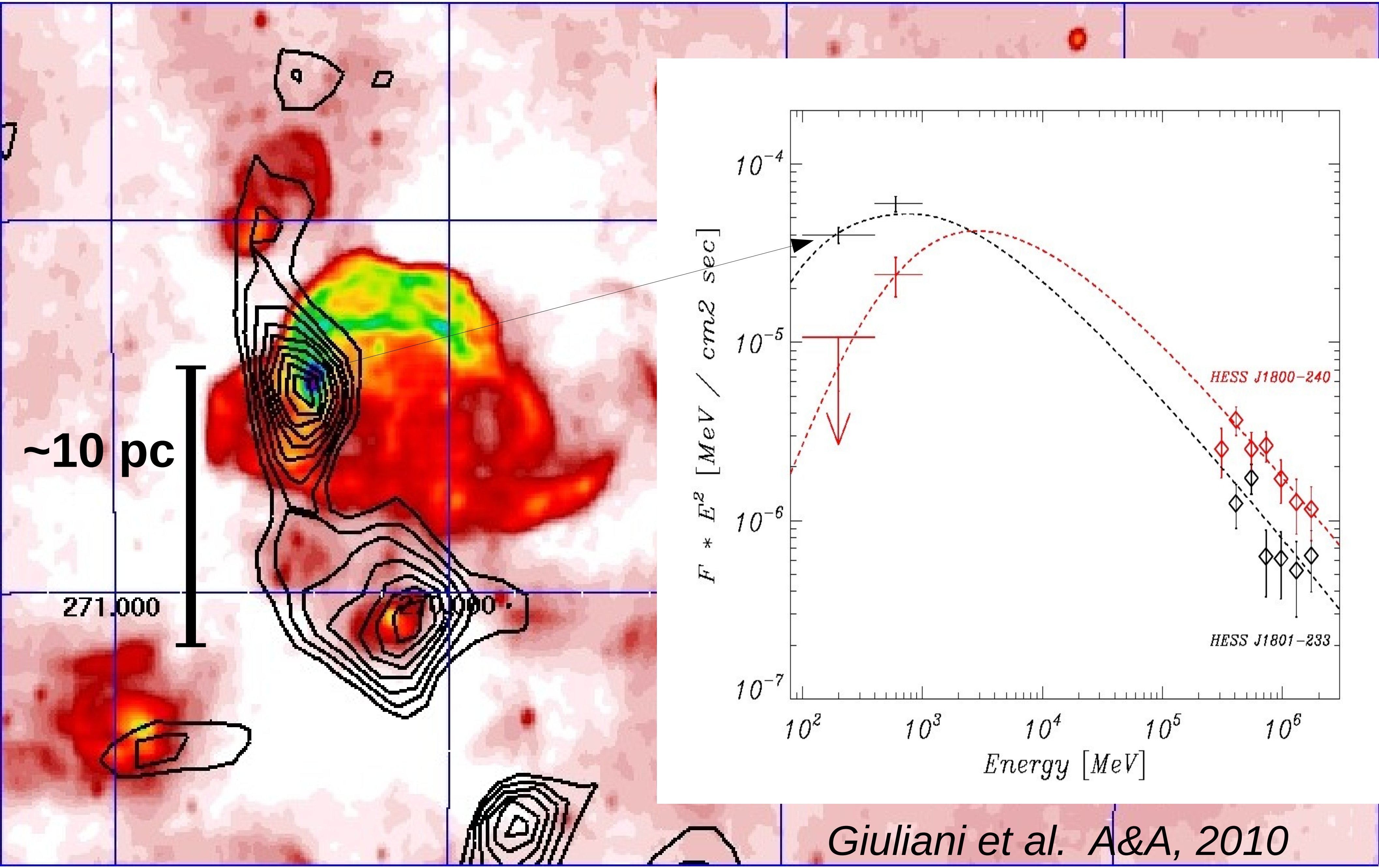

Giuliani et al. A&A, 2010

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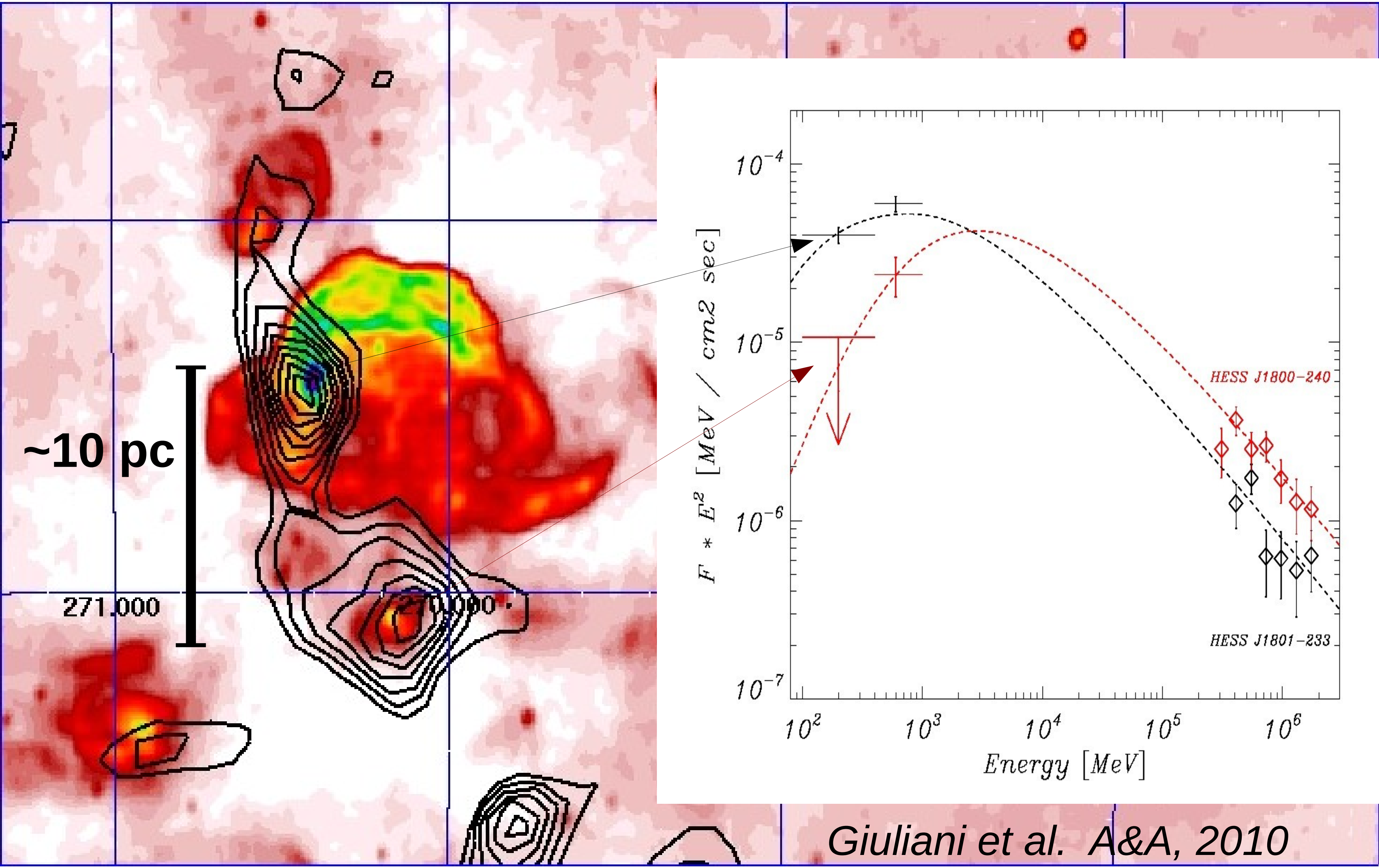

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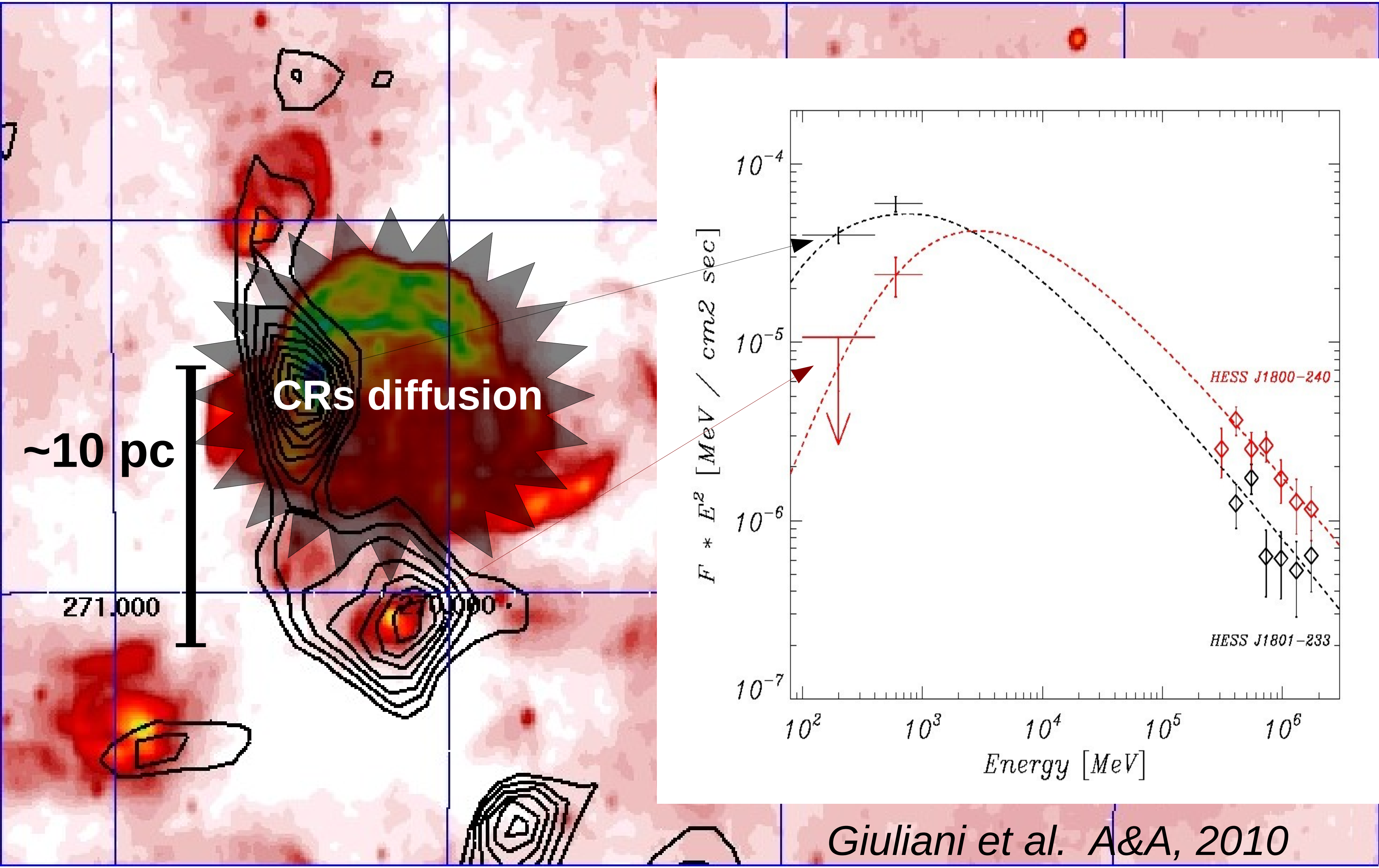
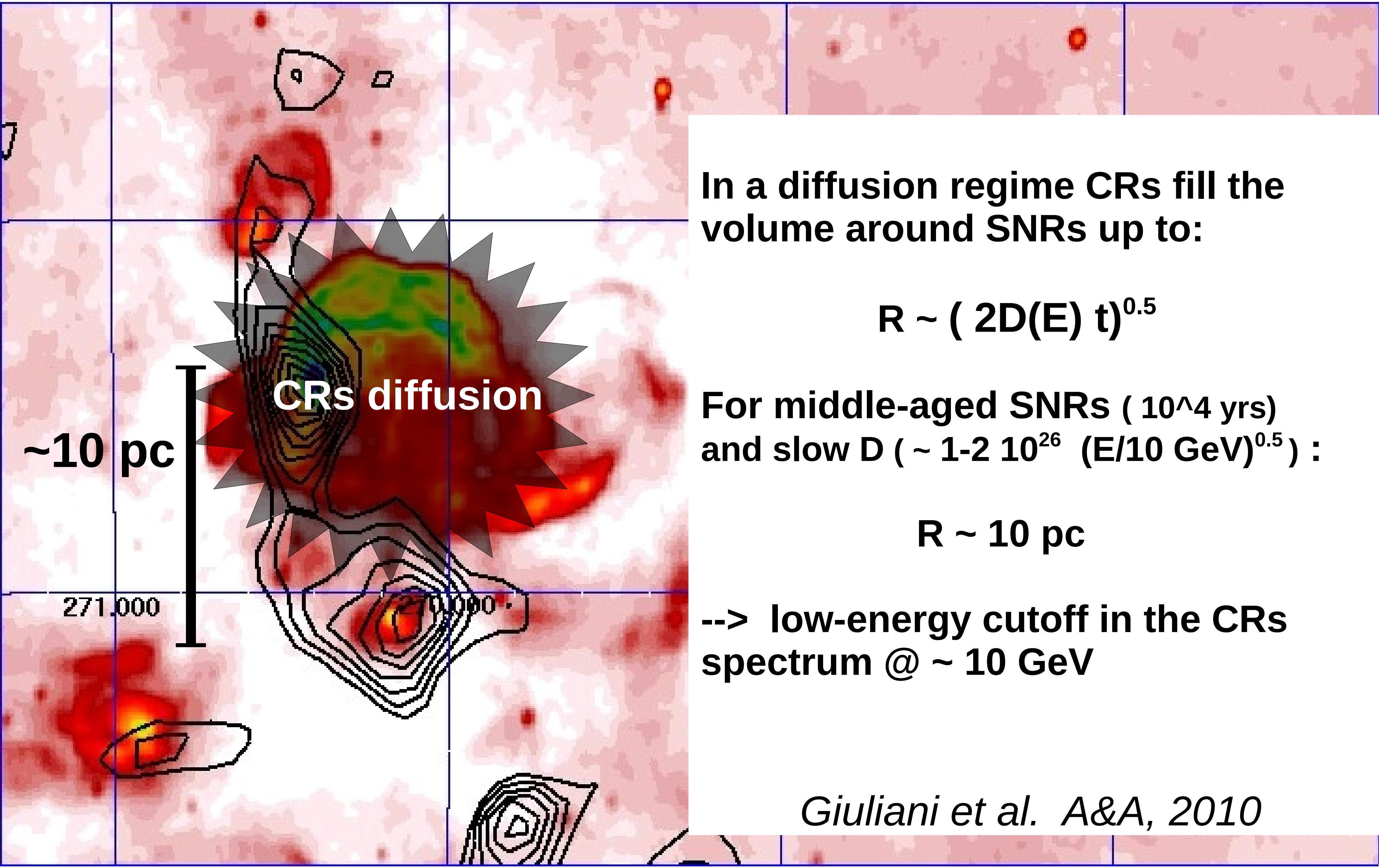


Giuliani et al. A&A, 2010

SNRs at "low" energy : diffusion of CRs



In a diffusion regime CRs fill the volume around SNRs up to:

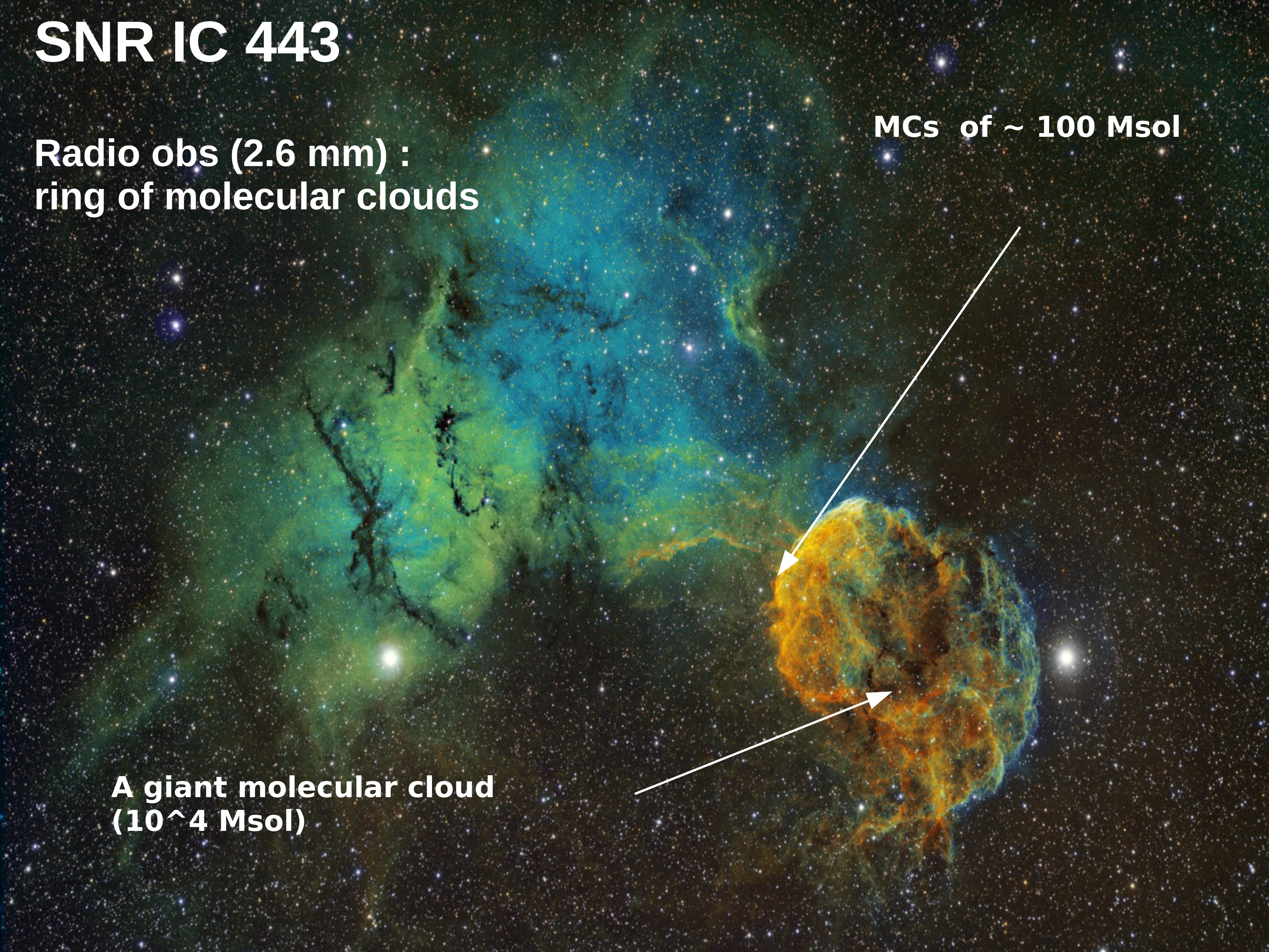
$$R \sim (2D(E)\,t)^{0.5}$$

For middle-aged SNRs (10^4 yrs) and slow D (~ 1-2 10^{26} $(E/10\ \mathrm{GeV})^{0.5}$) :

$$R \sim 10\ \mathrm{pc}$$

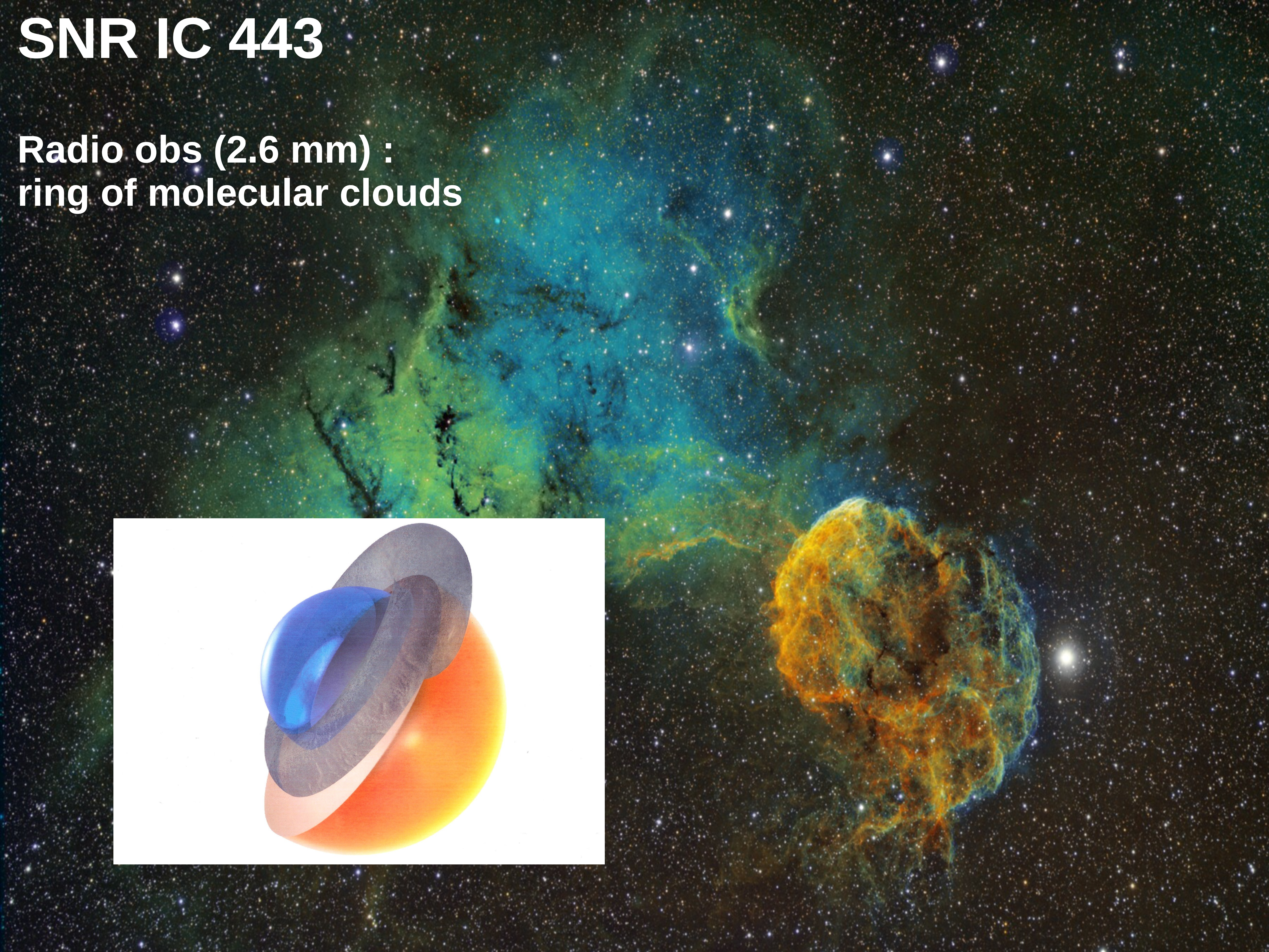
--> low-energy cutoff in the CRs spectrum @ ~ 10 GeV

Giuliani et al. A&A, 2010


SNR IC 443
Radio obs (2.6 mm) :
ring of molecular clouds
MCs of ~ 100 Msol
A giant molecular cloud
(10^4 Msol)

SNR IC 443

Radio obs (2.6 mm) :
ring of molecular clouds



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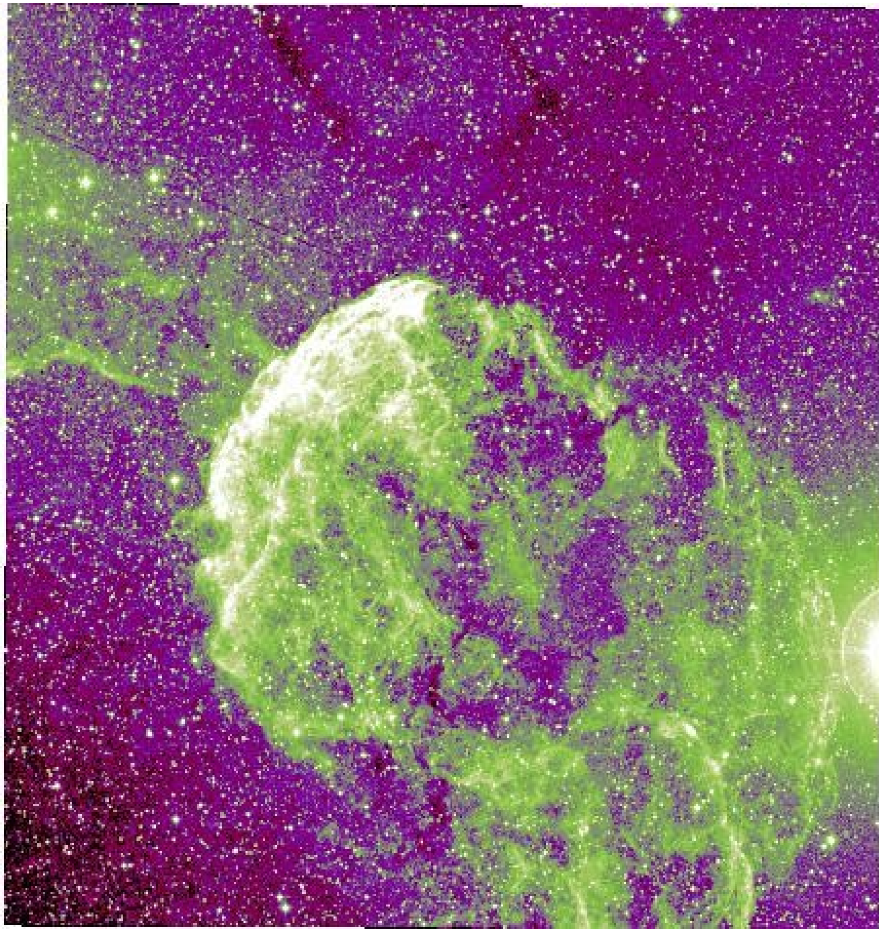

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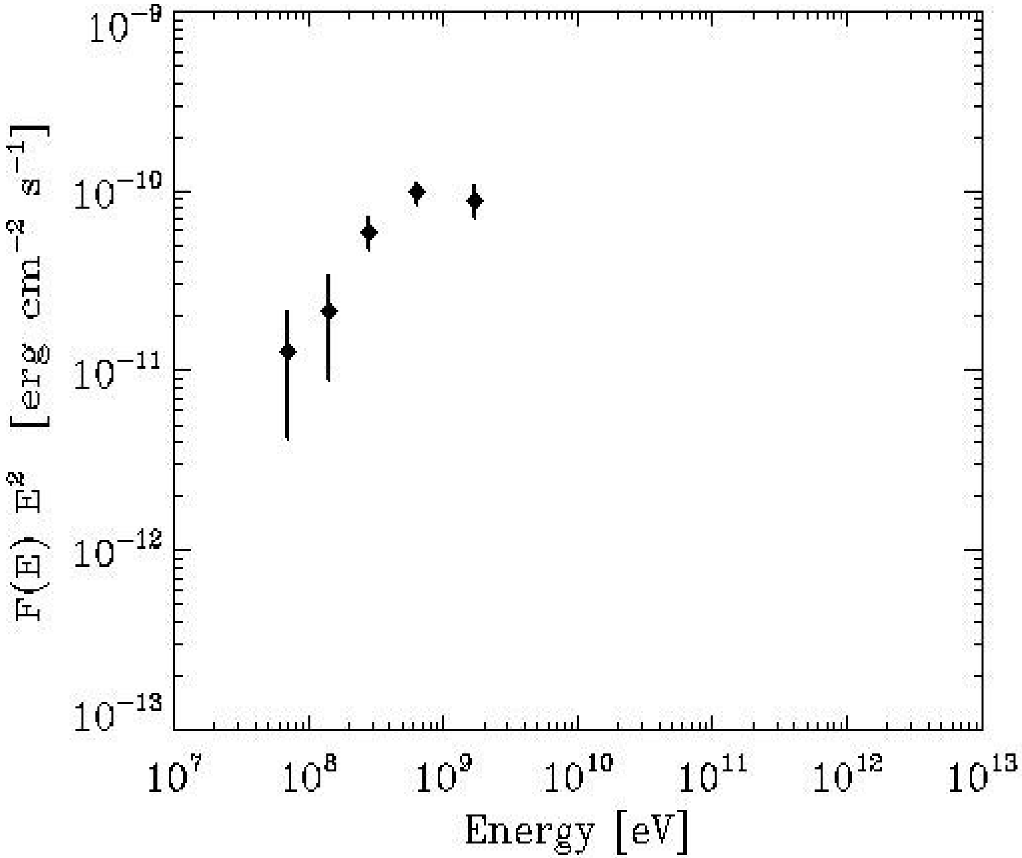
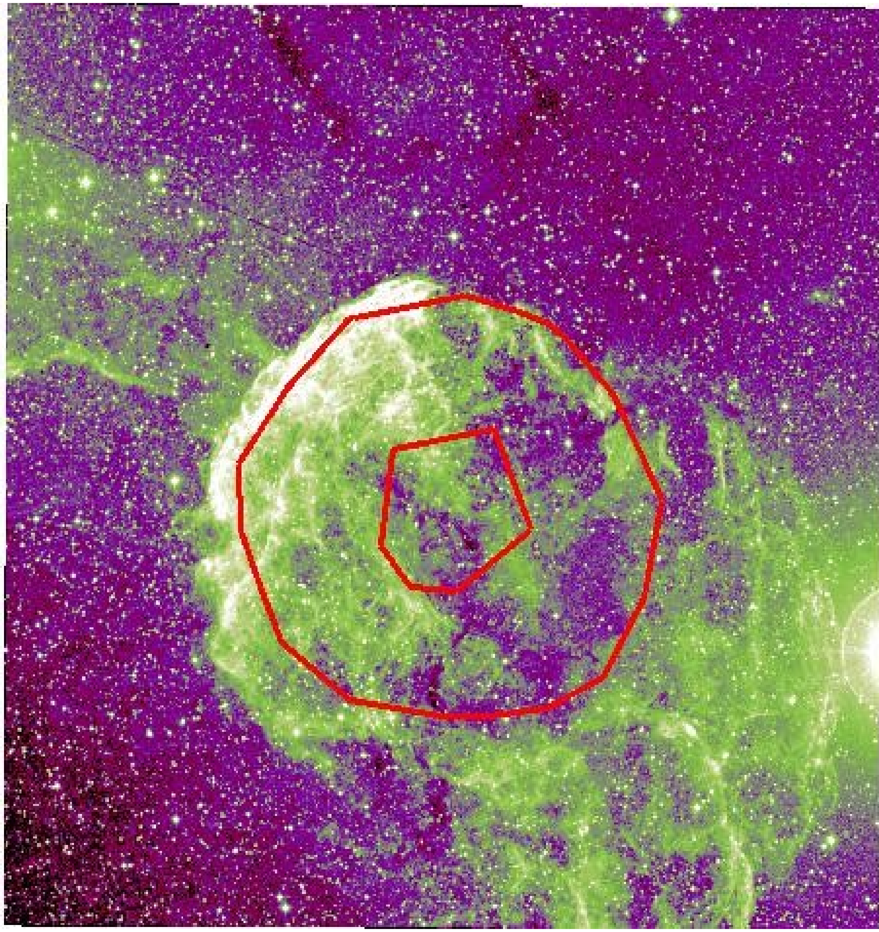


F(E) E^2 [erg cm^{-2} s^{-1}]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
Energy [eV]



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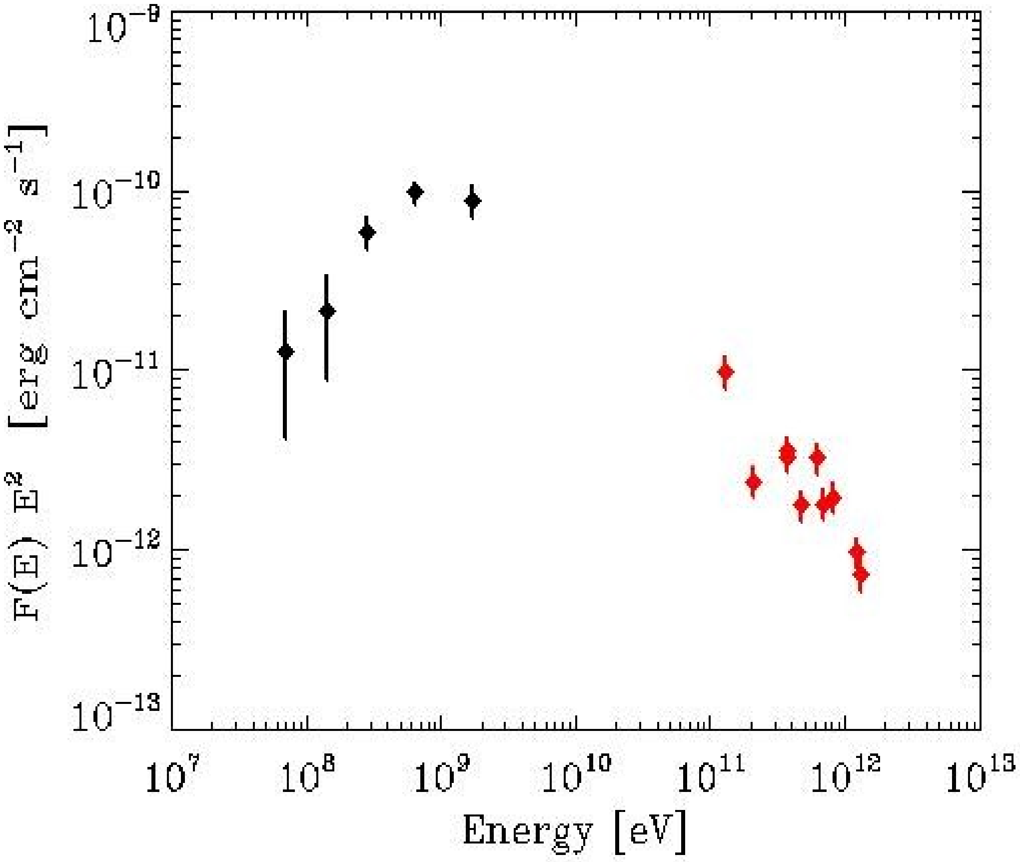

10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
F(E) E^2 [erg cm^{-2} s^{-1}]
10^7
10^8
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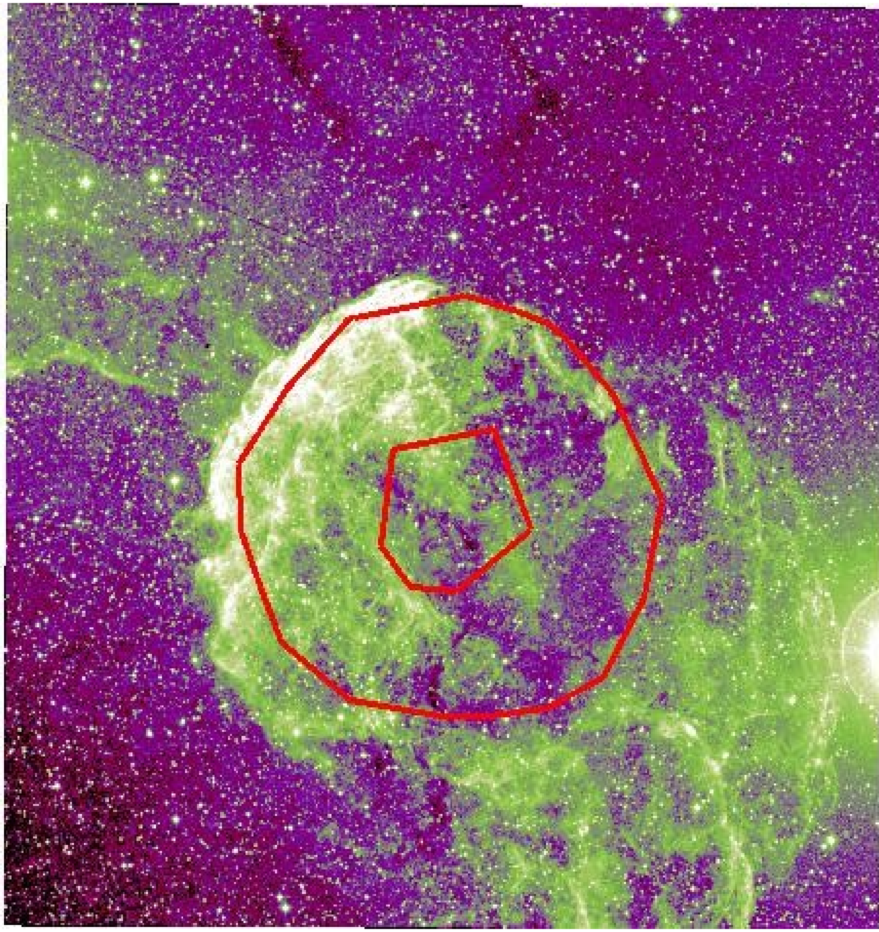
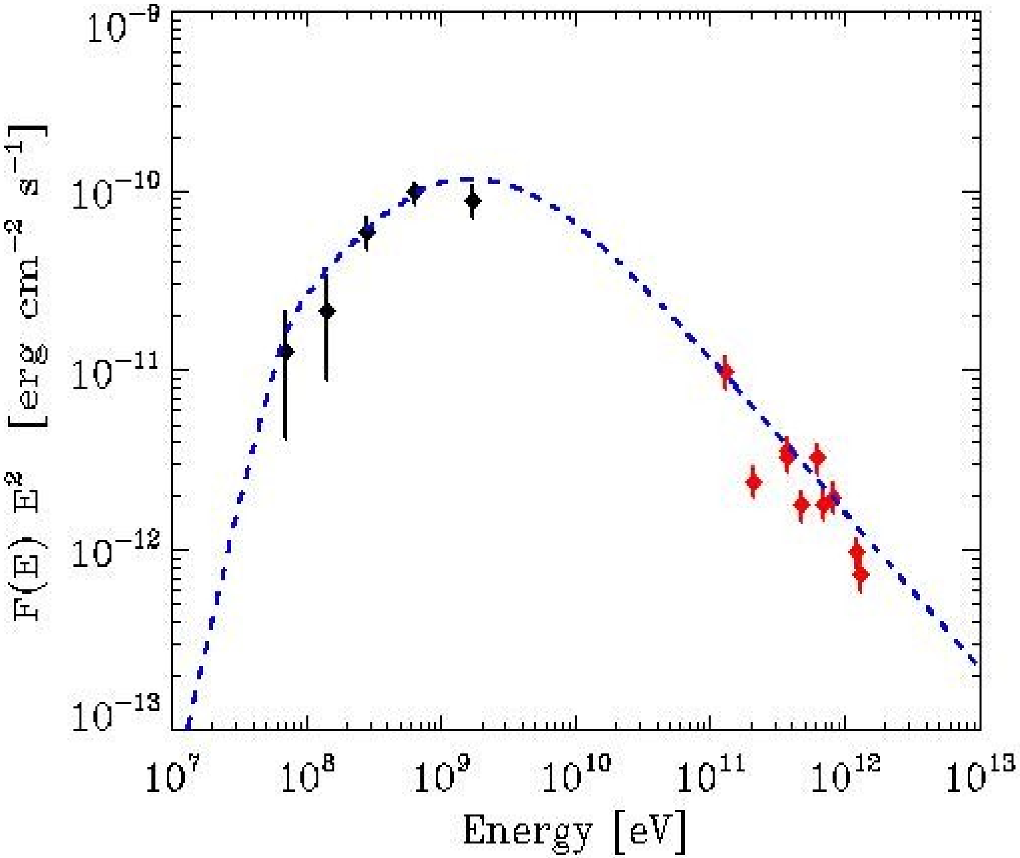
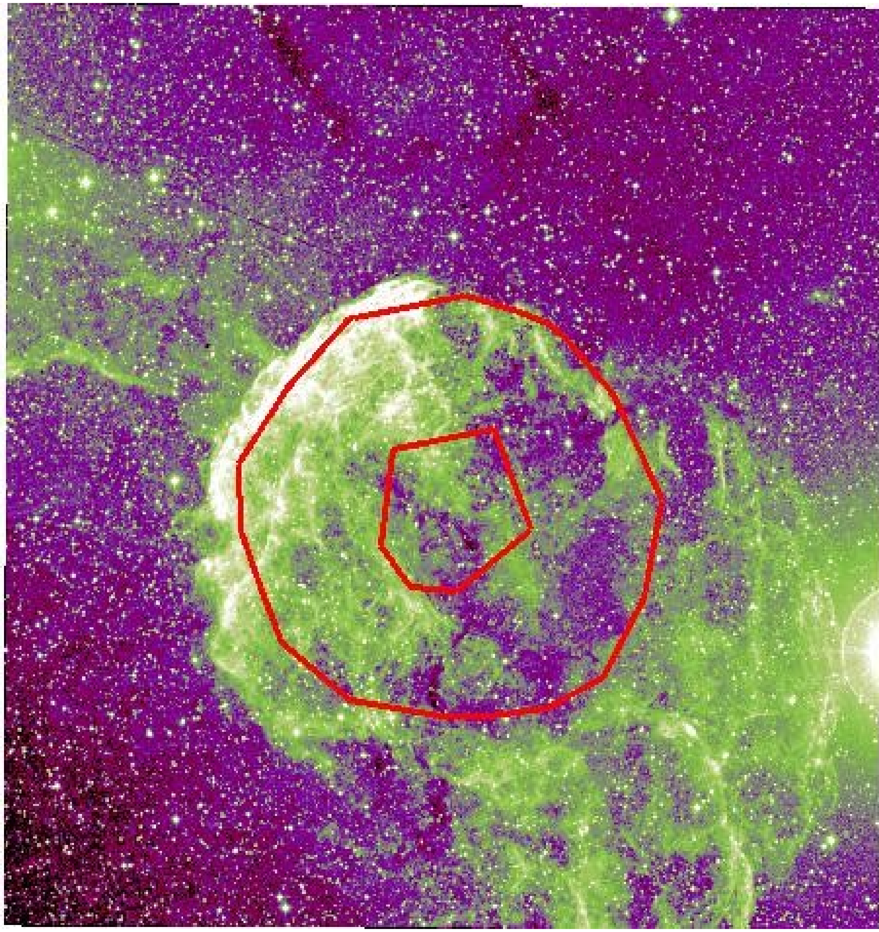


SNR IC 443

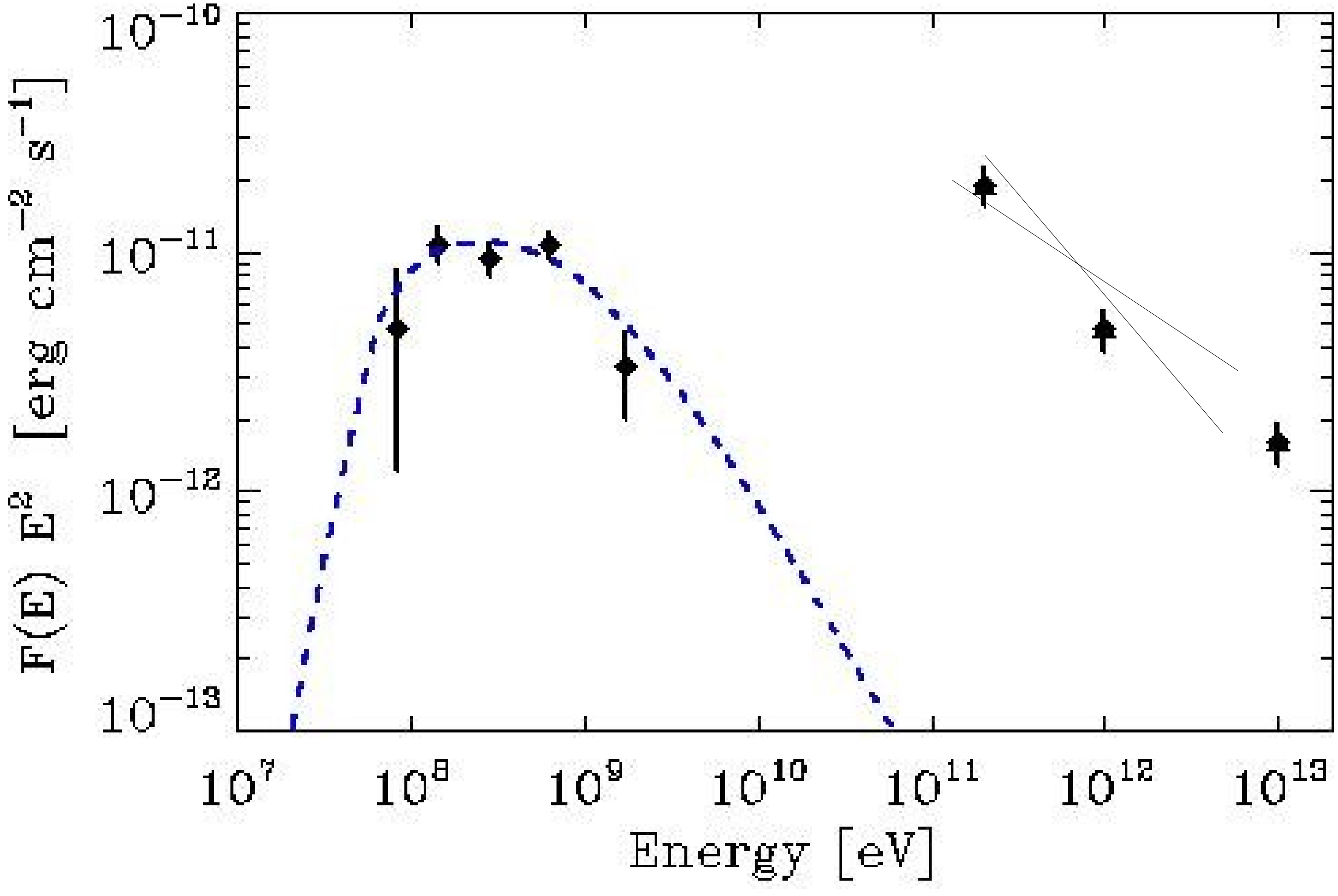
Break : 3.1 → 2.0+0.1





SNR W30

Break : 3.5 → 2.0+0.2



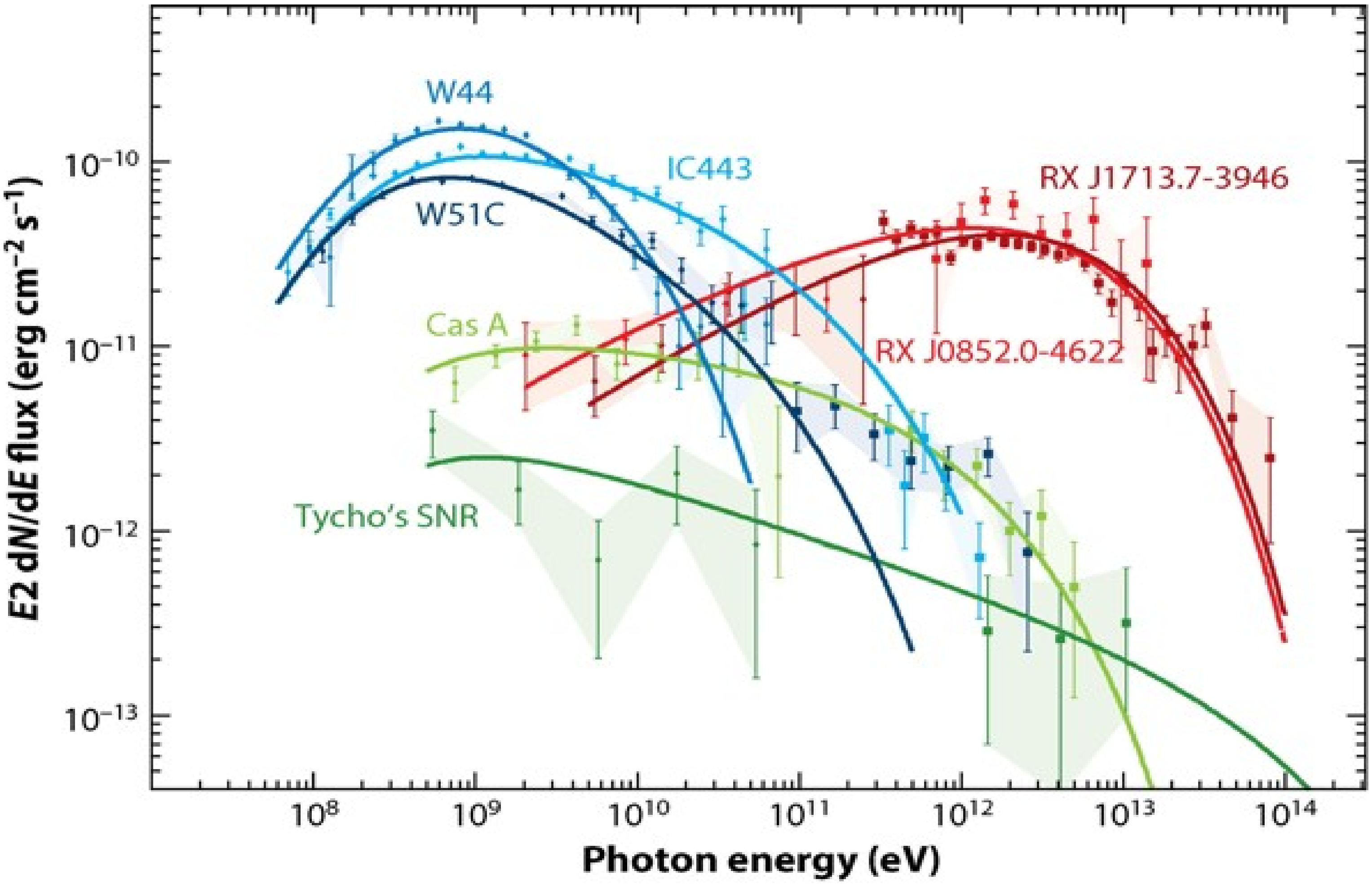
Pevatrons : What ?

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,*
with without cut-offs up to ~ 100 TeV

Pevatrons (SNRs) : who ?



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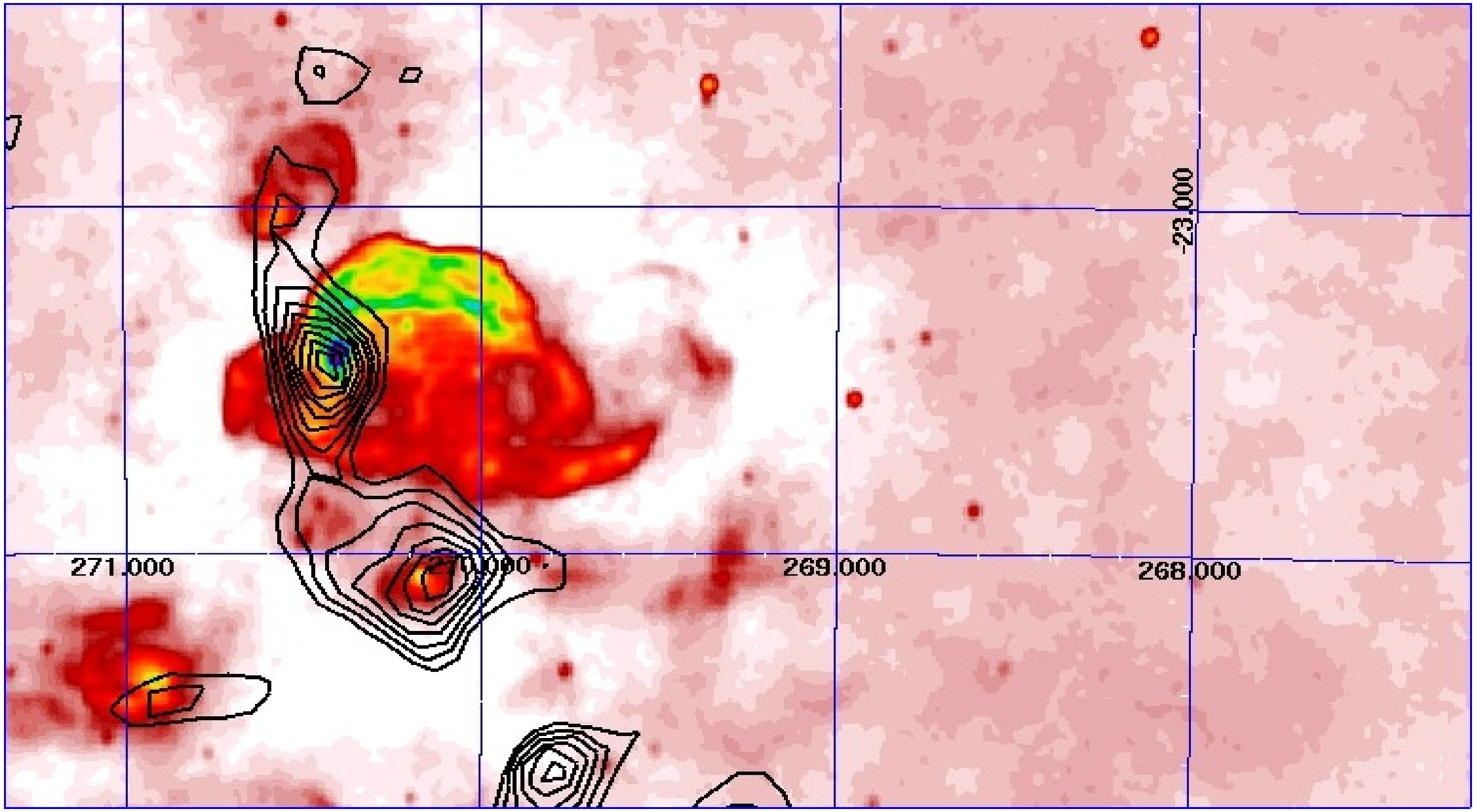
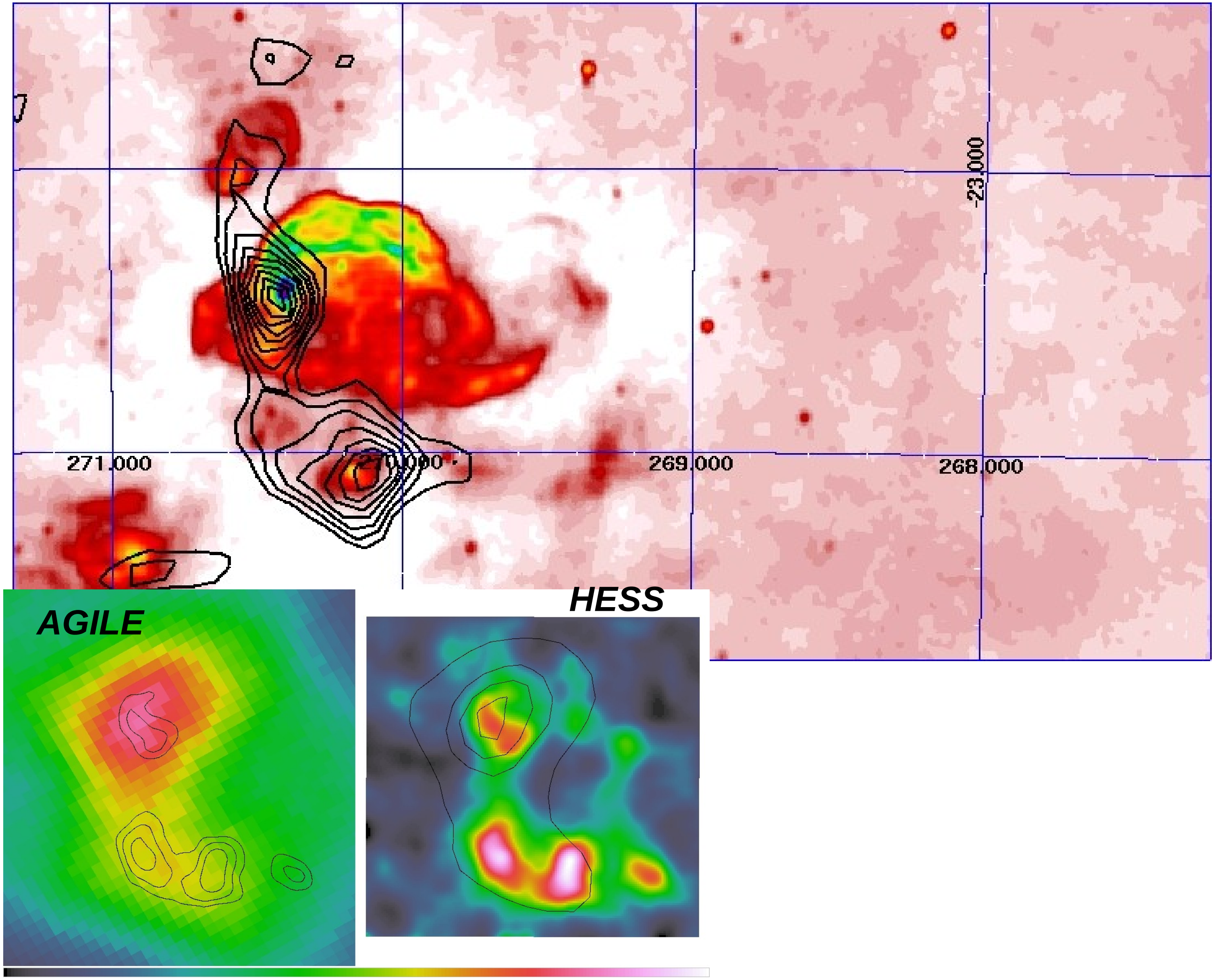
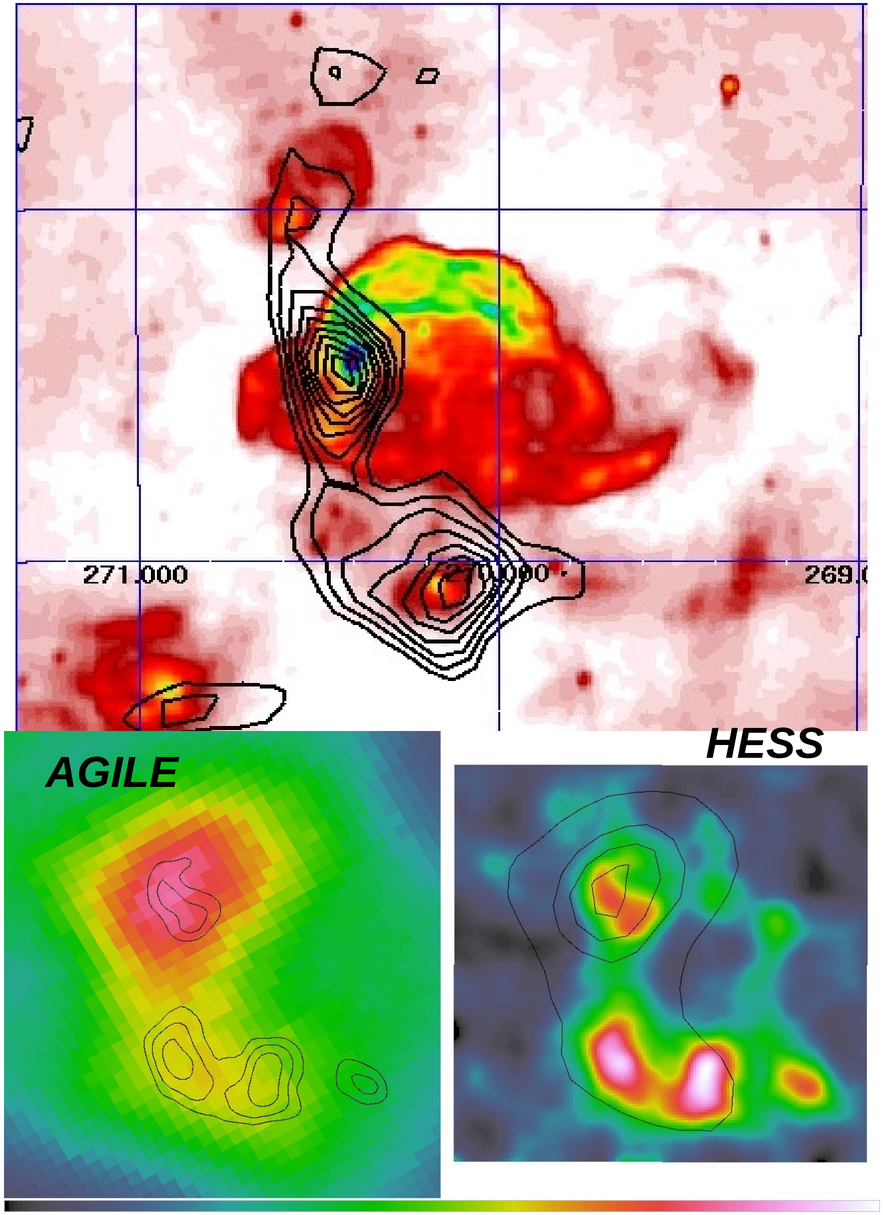
SNR W 28

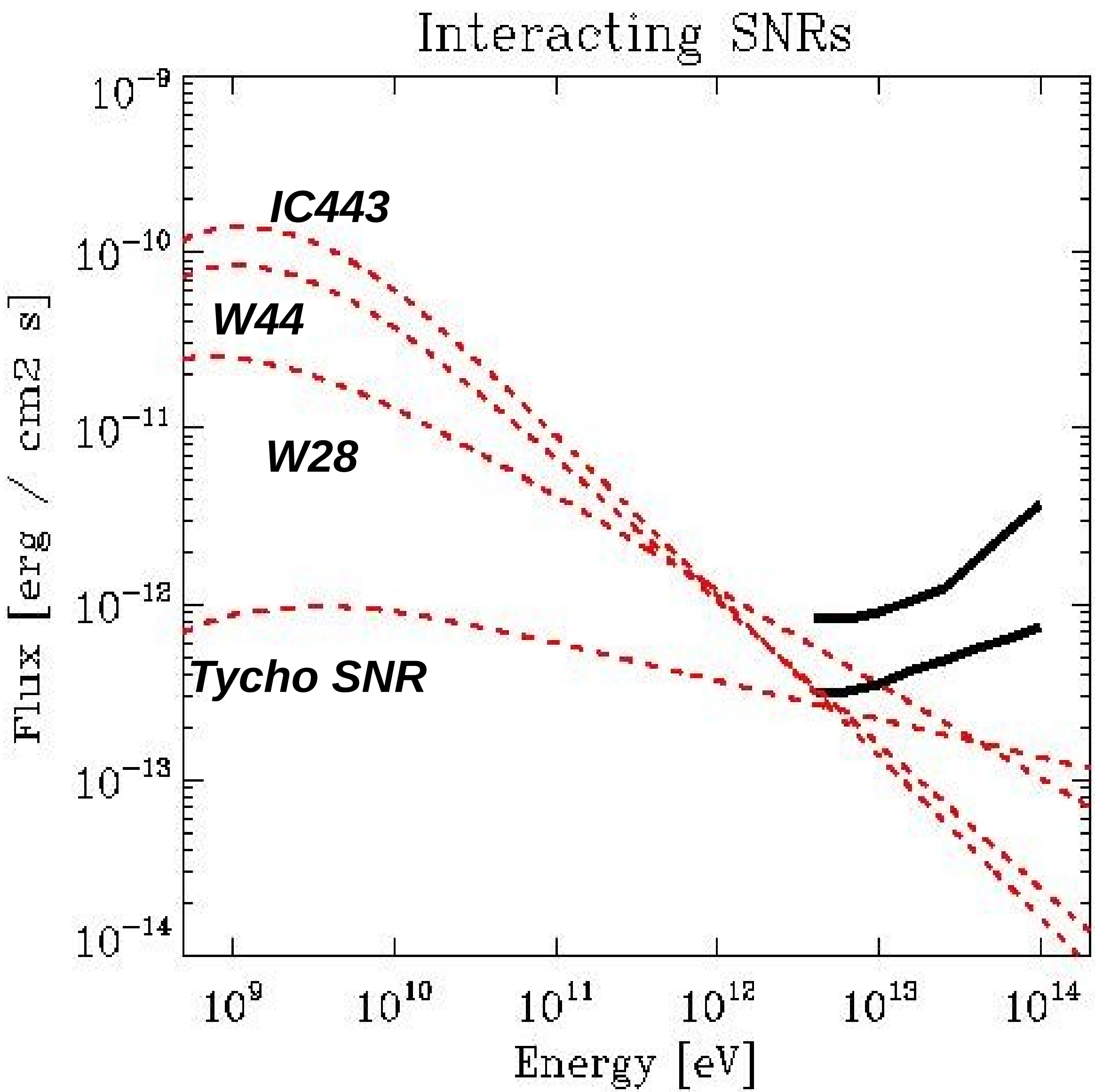


SNR W 28



SNR W 28


271.000
270.000
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}

Thanks!