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Middle-aged SNRs W44 & IC443 and Cosmic-Rays: most likely reacceleration

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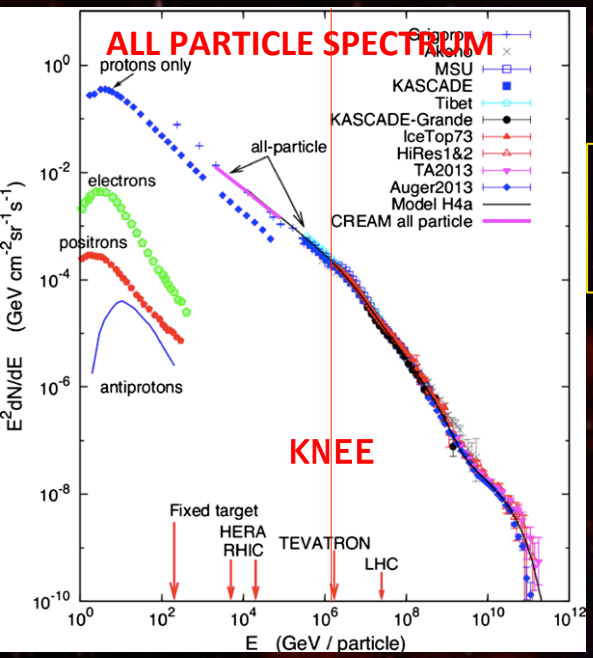
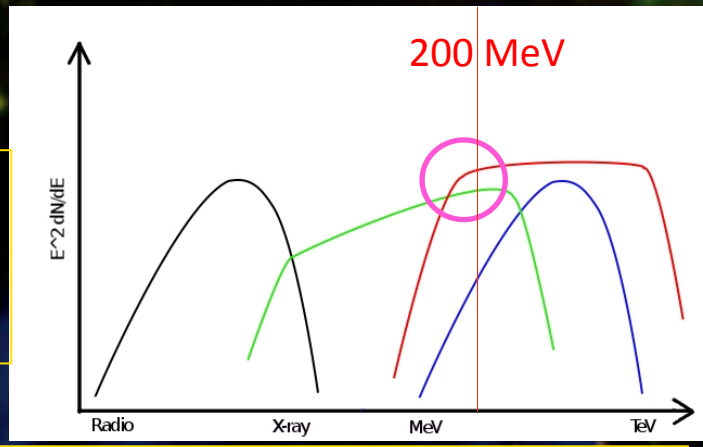
OVERVIEW



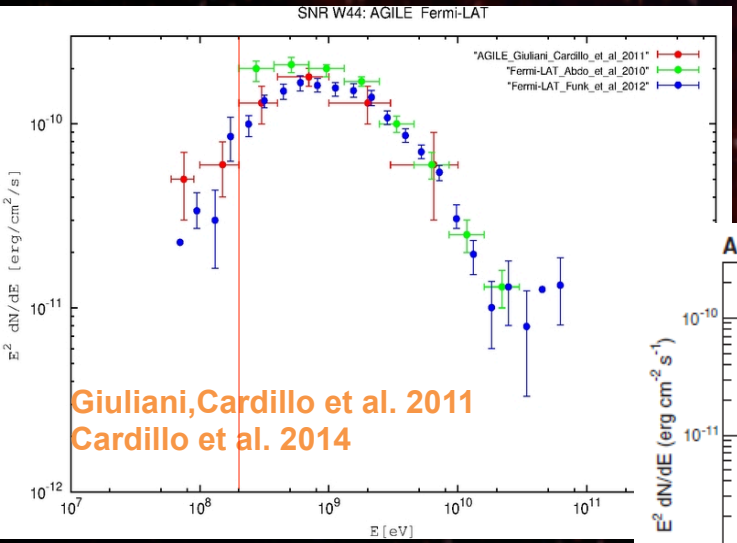
SNR accelerate Galactic Cosmic-Rays

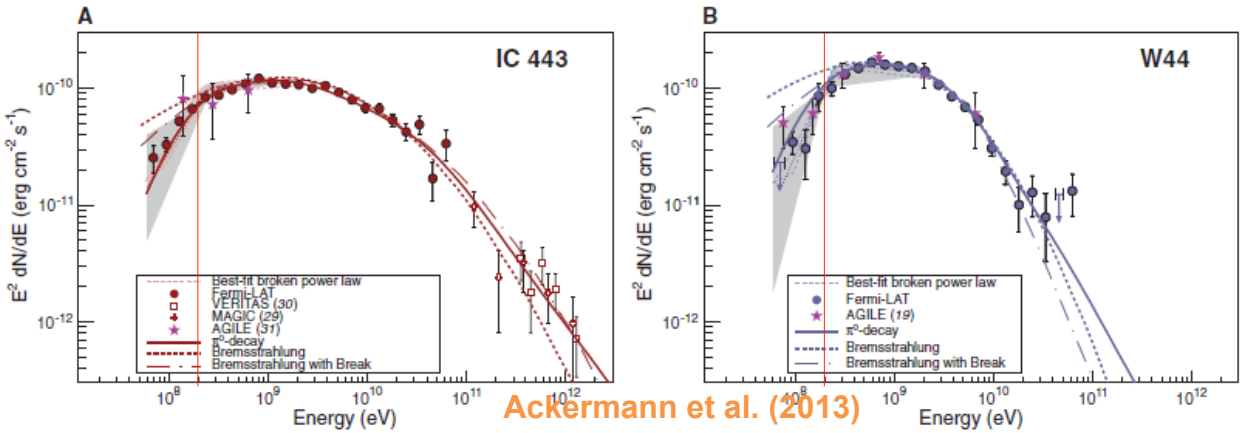
Need to distinguish hadronic and leptonic components



Gamma-ray emission below 200 MeV detected by AGILE from the SNR W44, then confirmed by Fermi-LAT, also in IC443

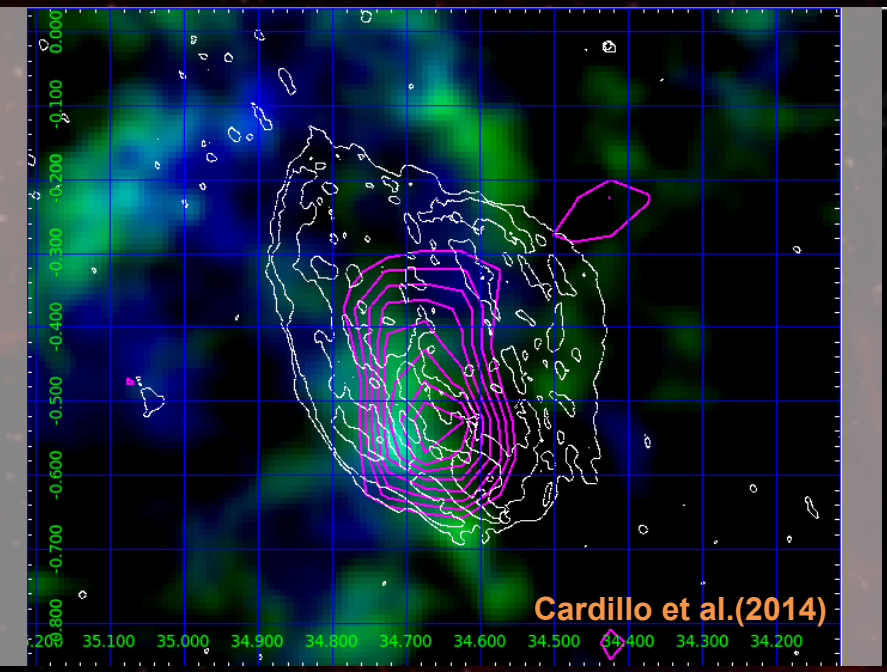
Cosmic-Rays in SNRs…
but acceleration or reacceleration?

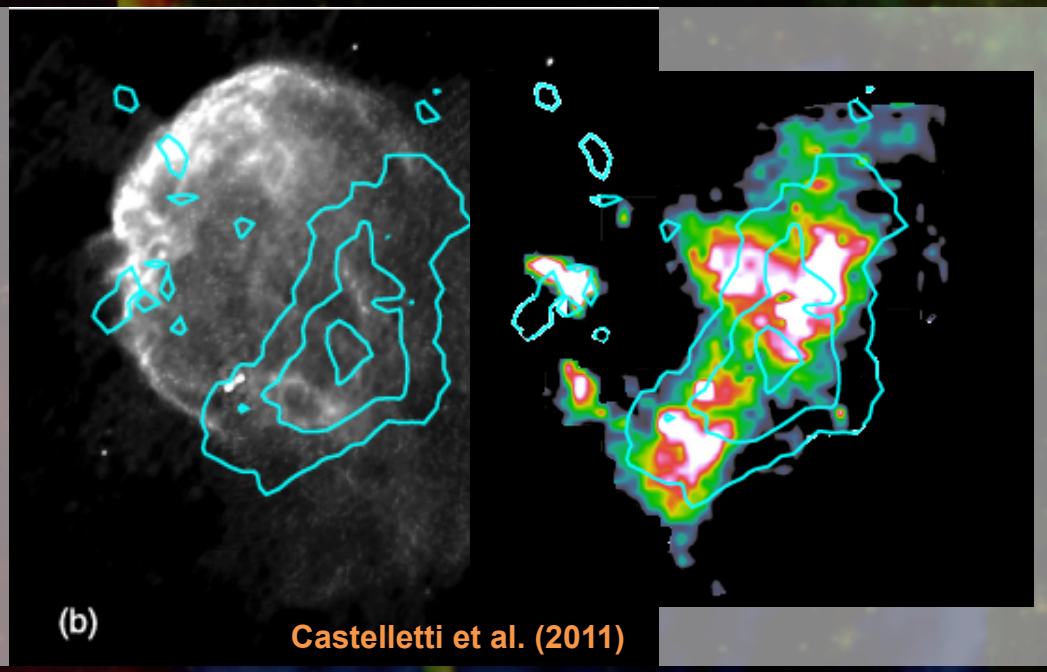




Ackermann et al. (2013)

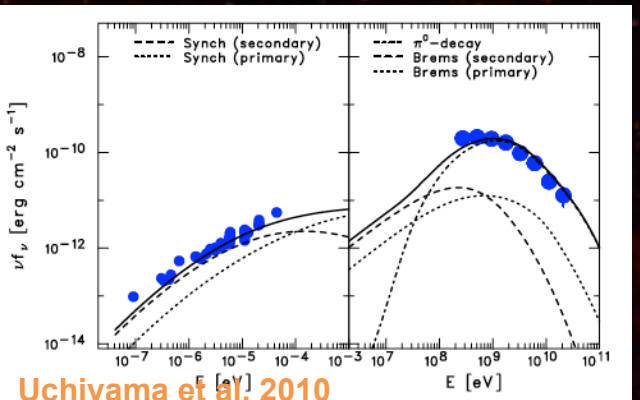
WHO ARE W44 AND IC443?



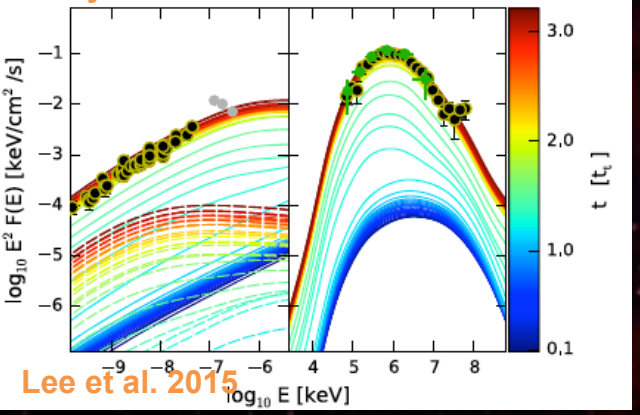


- Middle aged SNRs ($t \geq 10^4$ yrs) with a slow shock velocity ($v_s \sim$ 100 km/s)
- Interaction with a molecular cloud (high average density, $n \sim 200$ cm^{-3}) → correlated with GeV (and TeV for IC443) gamma-ray emission
- Correletion with only a fraction of the radio emission
- Hadronic emission described by a broken power-law with a very steep high-energy spectral index

REACCELERATION OR ACCELERATION?



Uchiyama et al. 2010



Lee et al. 2015

REACCELERATION

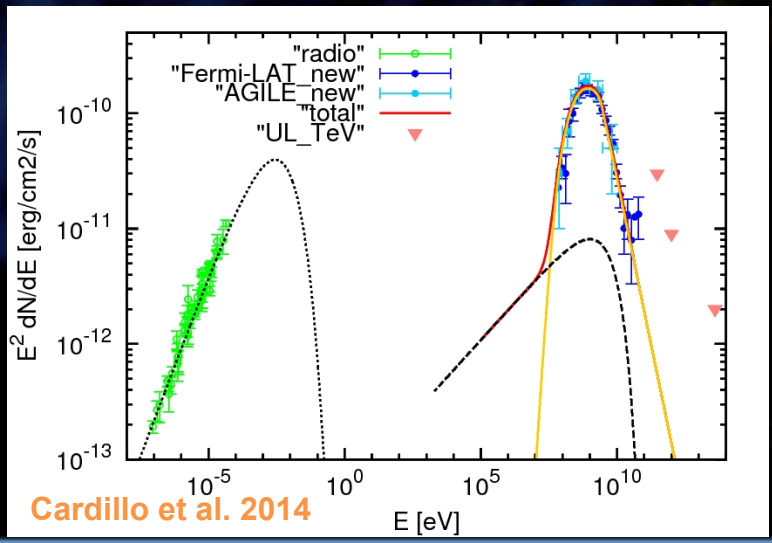
- Pre-existing Galactic CR protons & electrons
- Reacceleration → hardening of spectral indices steeper than $\alpha=(3r_{sh})/(r_{sh}-1)$
- Compression → higher energies, higher spectrum $(s=(n_2/n_0)/r_{sh})$
- Energy losses pp/ionization & ioniz/synch/Brems/IC
- Low-energy cut off and Malkov steepening

Crushed Cloud model (Blandford & Cowie 1982)

n_0, B_0	n_1, B_1, r_{sh}	n_2, B_2, s
Galactic CRs (or injected CRs)	Reacceleration (or acceleration)	Compression

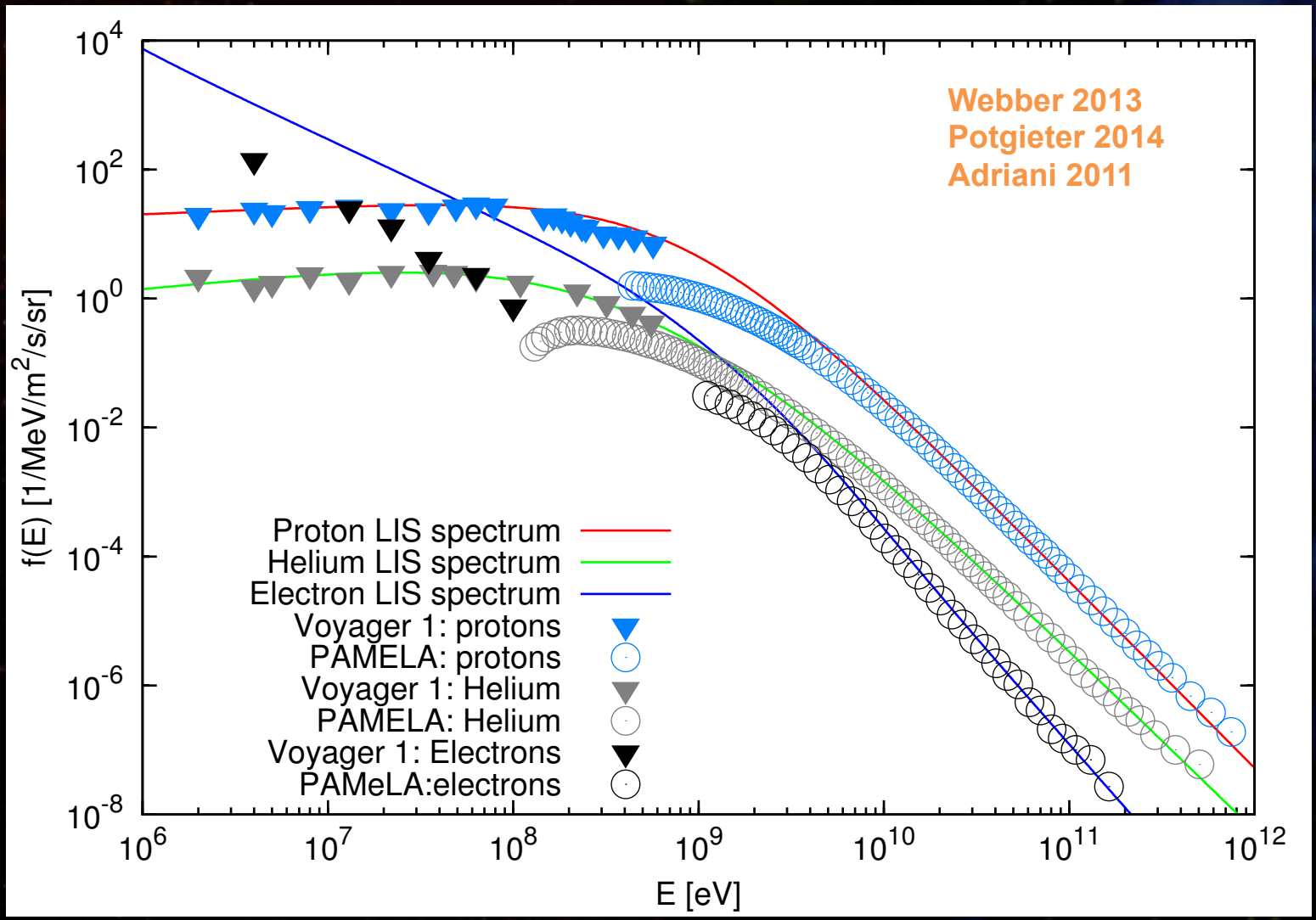
ACCELERATION

- Freshly accelerated CRs with a spectral index $\alpha=(3r_{sh})/(r_{sh}-1)$
- Compression → higher energies, higher spectrum $(s=(n_2/n_0)/r_{sh})$
- Energy losses
- Broken power-law with Malkov steepening



Cardillo et al. 2014

GALACTIC SPECTRUM: VOYAGER 1 + PAMELA



REACCELERATION: our model

Crushed Cloud model (Blandford & Cowie 1982)

n_0, B_0	n_1, B_1, r_{sh}	n_2, B_2, s
Galactic CRs (or injected CRs)	Reacceleration (or acceleration)	Compression

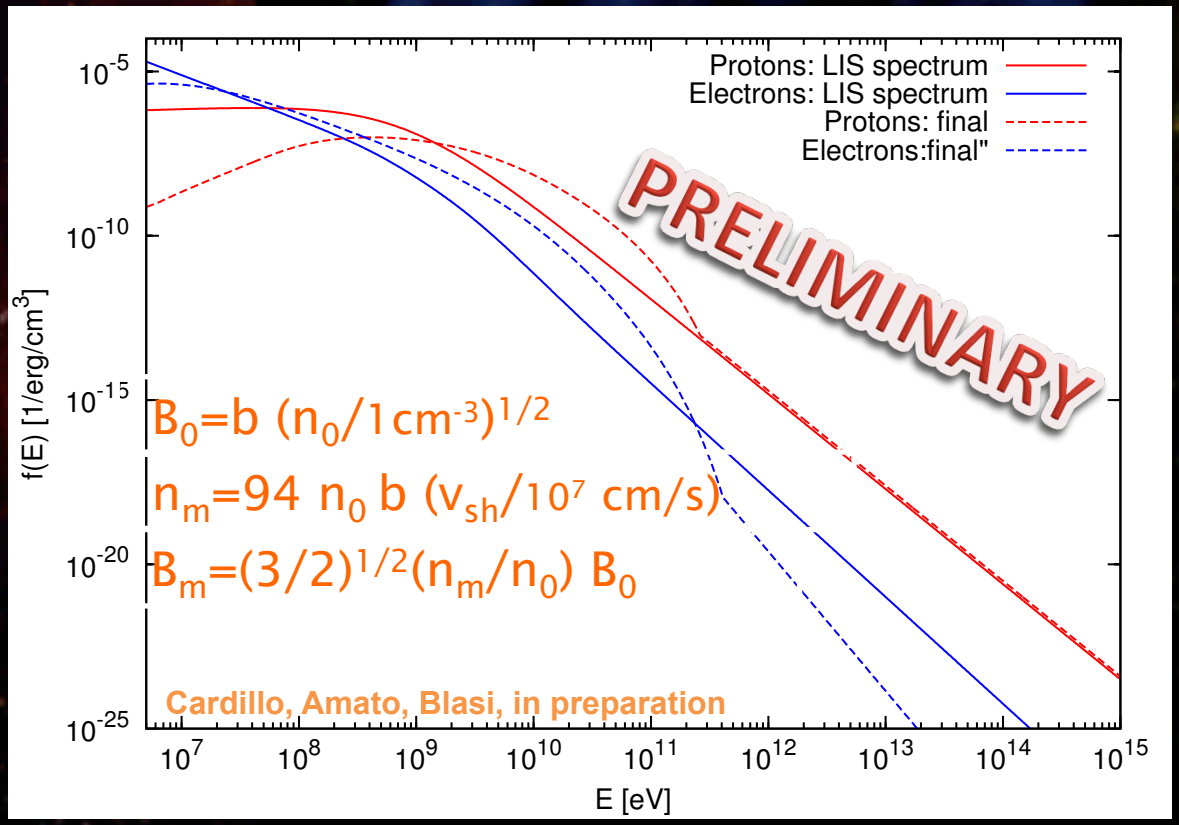
- Local Interstellar Spectrum from Voyager 1 (Potgieter 2013)
  → harder at low-energy: no need low-energy cut-off

- Hydrogen and Helium contribution with HE hardening.

- Adding also the only compressed Galactic component.

- Simple PL spectrum

- No steepening but HE cut-off



REACCELERATION: our model

Maximum momentum

$$p_M = 8.7\times10^{-1}(B_0/1\mu G)\,(t_{int}/10^4 yrs)^2\,(L_c/1pc)^{-1}\,(v_{sh}/10^7 cm/s)^4$$

Kraichnan diffusion

$$D(E)=1/3\; r_L c\; (k/k_0)^{1/2}$$

p_M~21.5 GeV/c

t_{int} ~1700 yrs< t_{age}

r_{sh} = 3.72 → α=2.1

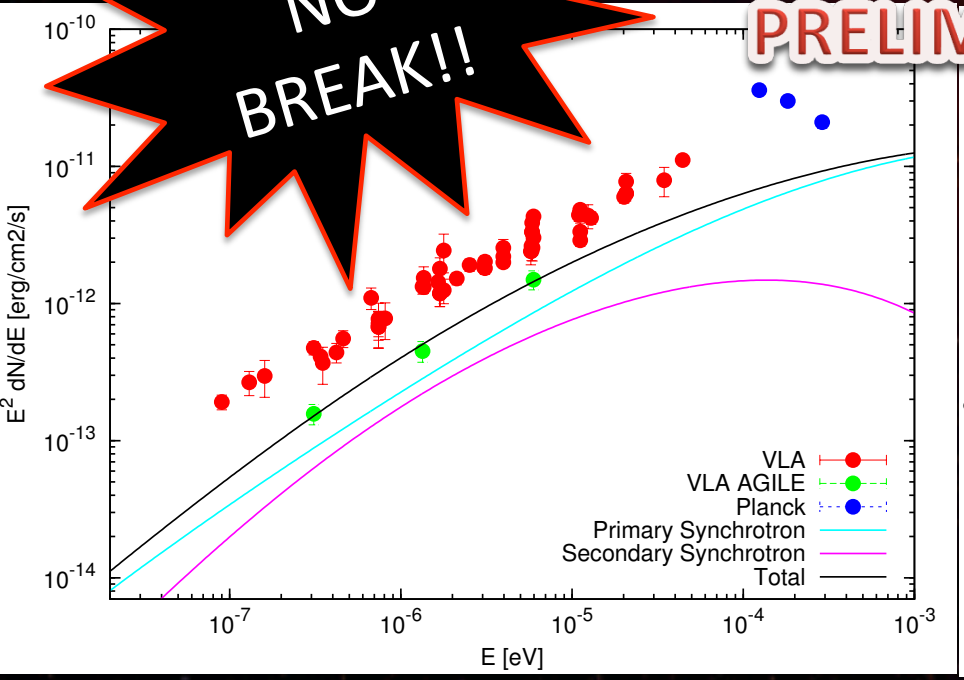
n_2~10^4 cm^{-3}, B_2~1 mG

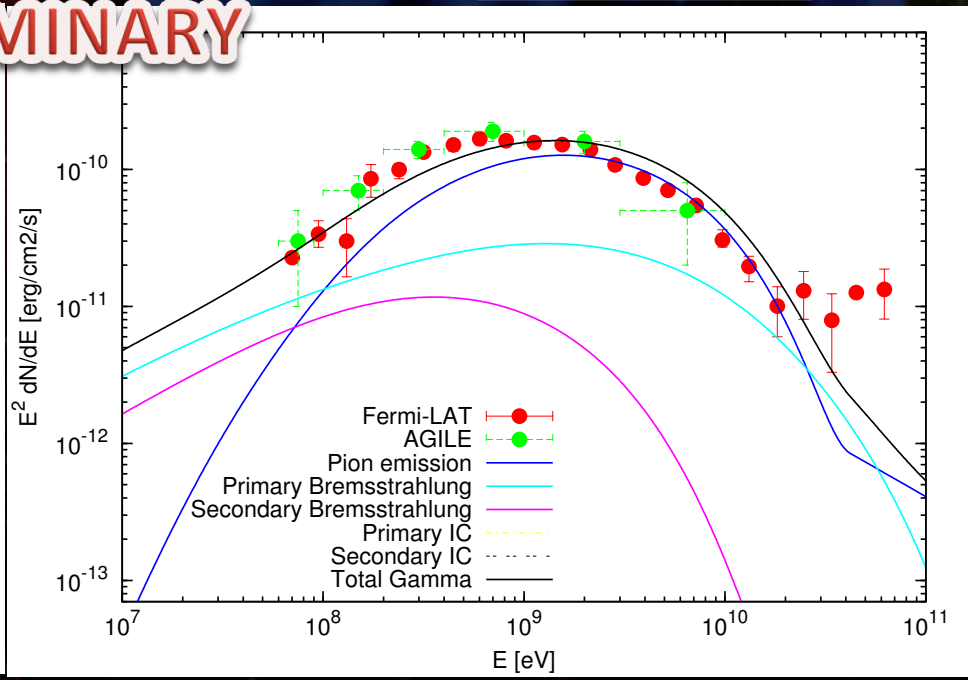
filling factor f~ 20%

L_c~ 0.1 pc

NO BREAK!!

PRELIMINARY





Cardillo, Amato, Blasi, in preparation

ACCELERATION: our model

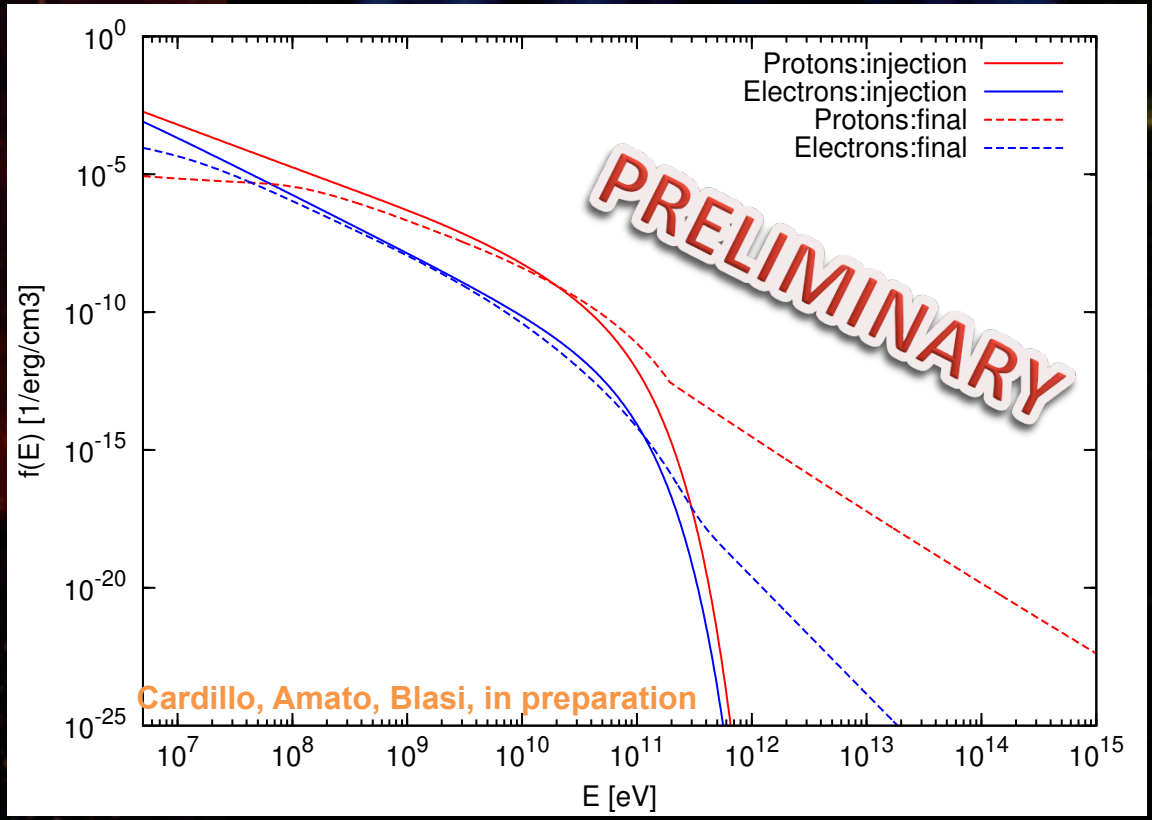
Gamma-ray emission can be explained by the only reacceleration

→ upper limit for efficiency of possible CR acceleration

- Hydrogen and Helium galactic contribution with HE hardening
- Simple PL spectrum equal for electrons and protons
- Electron/proton ratio

$\kappa_{ep} \sim 10^{-2}$

- No steepening but HE cut-off



ACCELERATION: our model

Maximum momentum

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$$D(E)=1/3\; r_L c\; (k/k_0)^{1/2}$$

p_M~21.5 GeV/c

ξ_{CR}~10^{-4}

t_{int} ~1700 yrs< t_{age}

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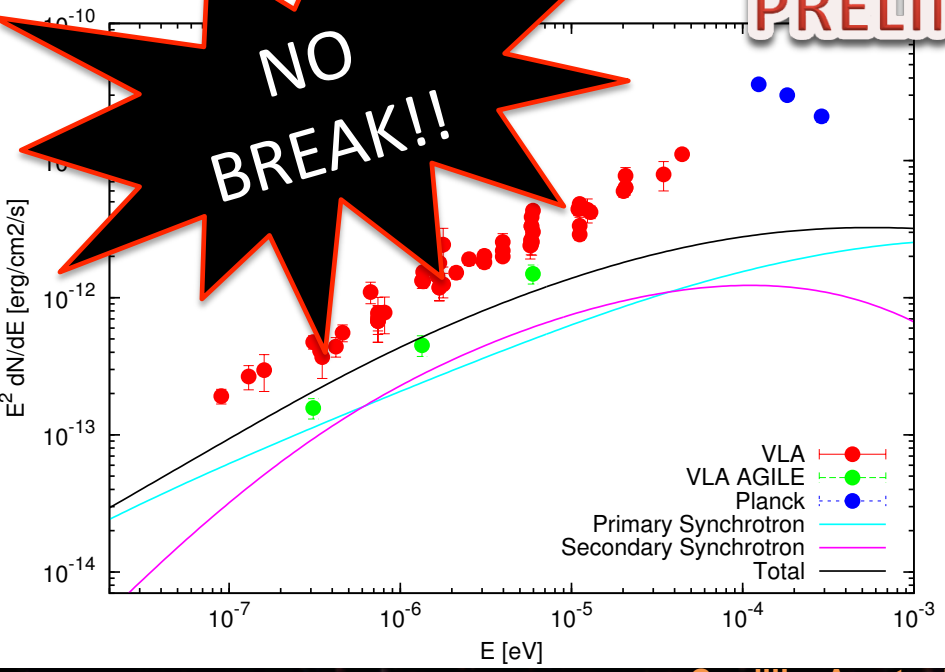
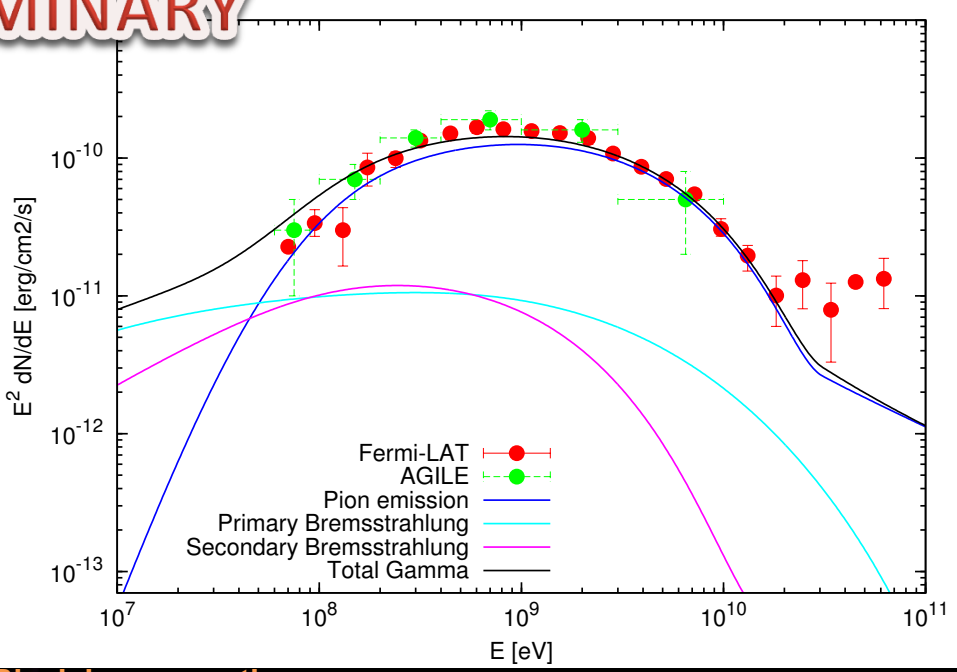
PRELIMINARY

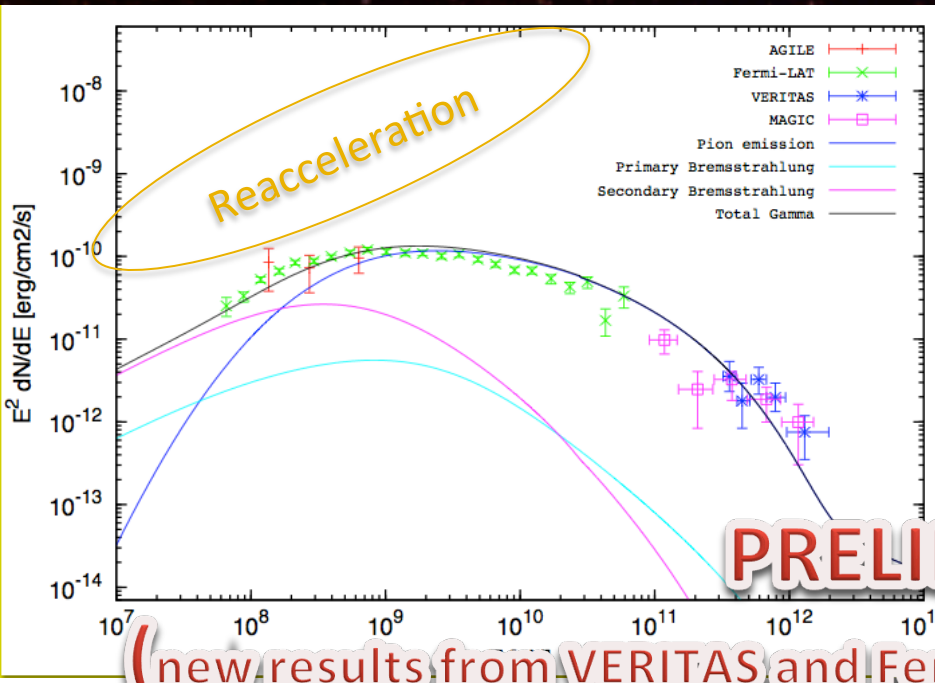


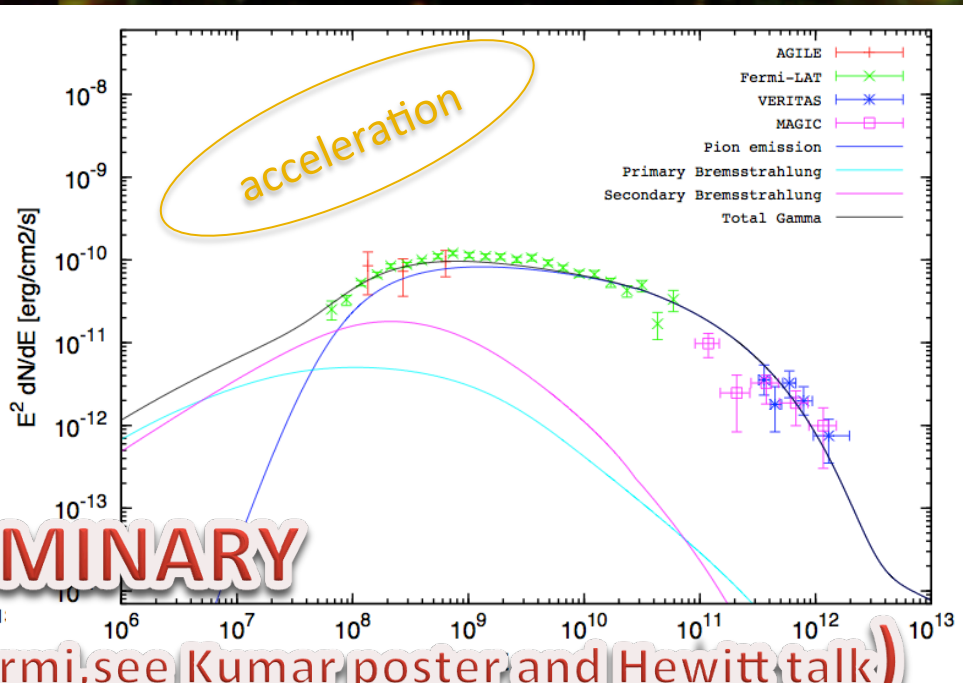


Cardillo, Amato, Blasi, in preparation

IC443

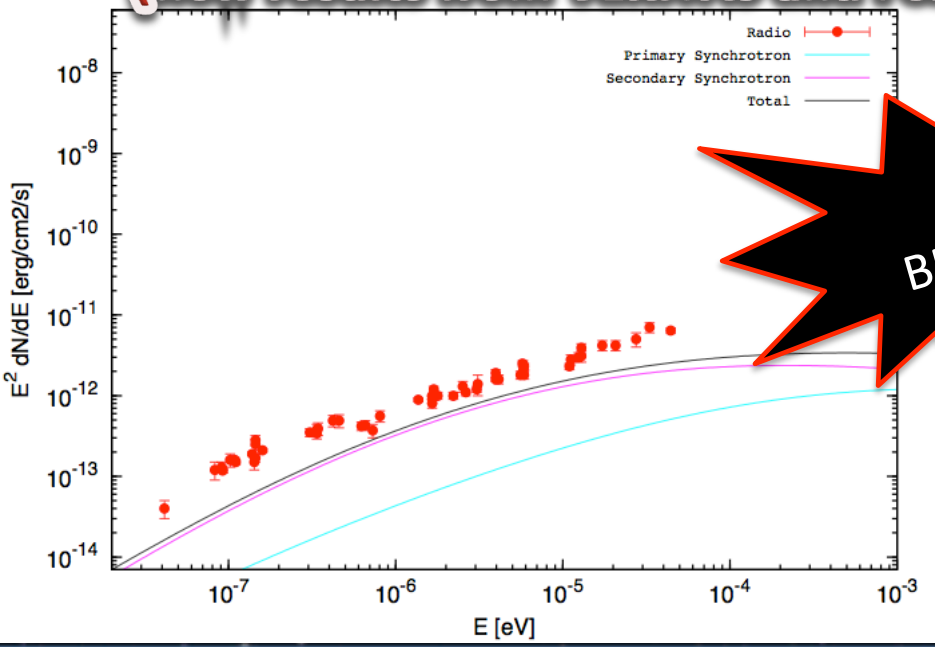
Cardillo, Amato, Blasi II
in preparation



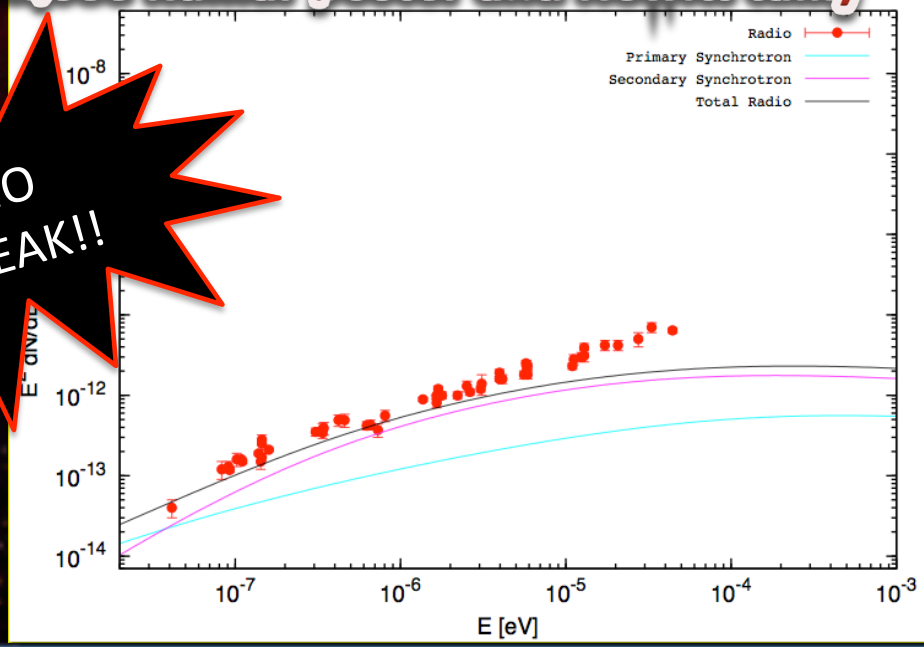


PRELIMINARY

(new results from VERITAS and Fermi, see Kumar poster and Hewitt talk)



NO BREAK!!



IMPLICATIONS

✧ The evidence of CR presence in the middle-aged SNRs can not imply acceleration with certainty

✧ Reacceleration and compression of pre-existing CRs can explain gamma-ray emission from W44 and IC443

→ only upper limit for freshly accelerated CR efficiency

✧ In both reacceleration and acceleration case, we can explain gamma-ray emission with a simple power-law with a high-energy cut-off

→ no broken-power law distributions

→ no very steep high-energy index

✧ However, the spectral index is likely steeper than the value provided by linear and no-linear DSA theory


Thank you
very much!