AGILE 15° Science Workshop

May, 23-24 - ASI

The SNR W44: A reference source for understanding the CR origin

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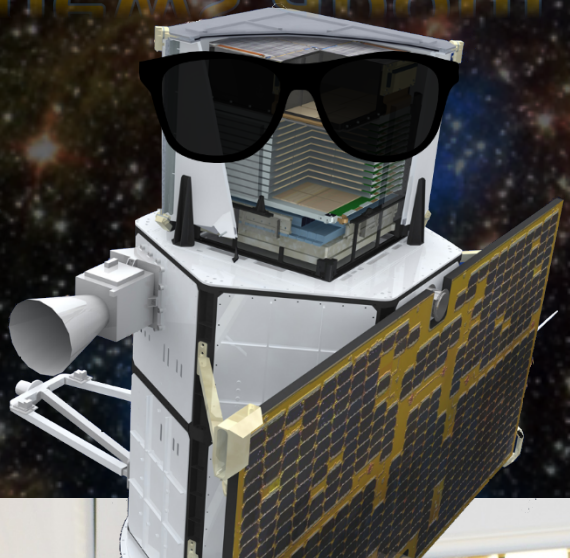
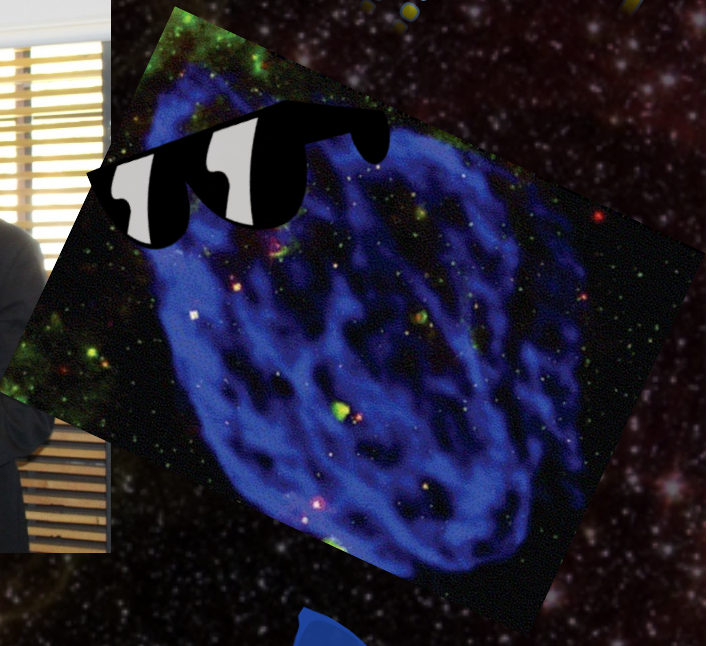
Great news about our PI…

After the Bruno Rossi Prize…:

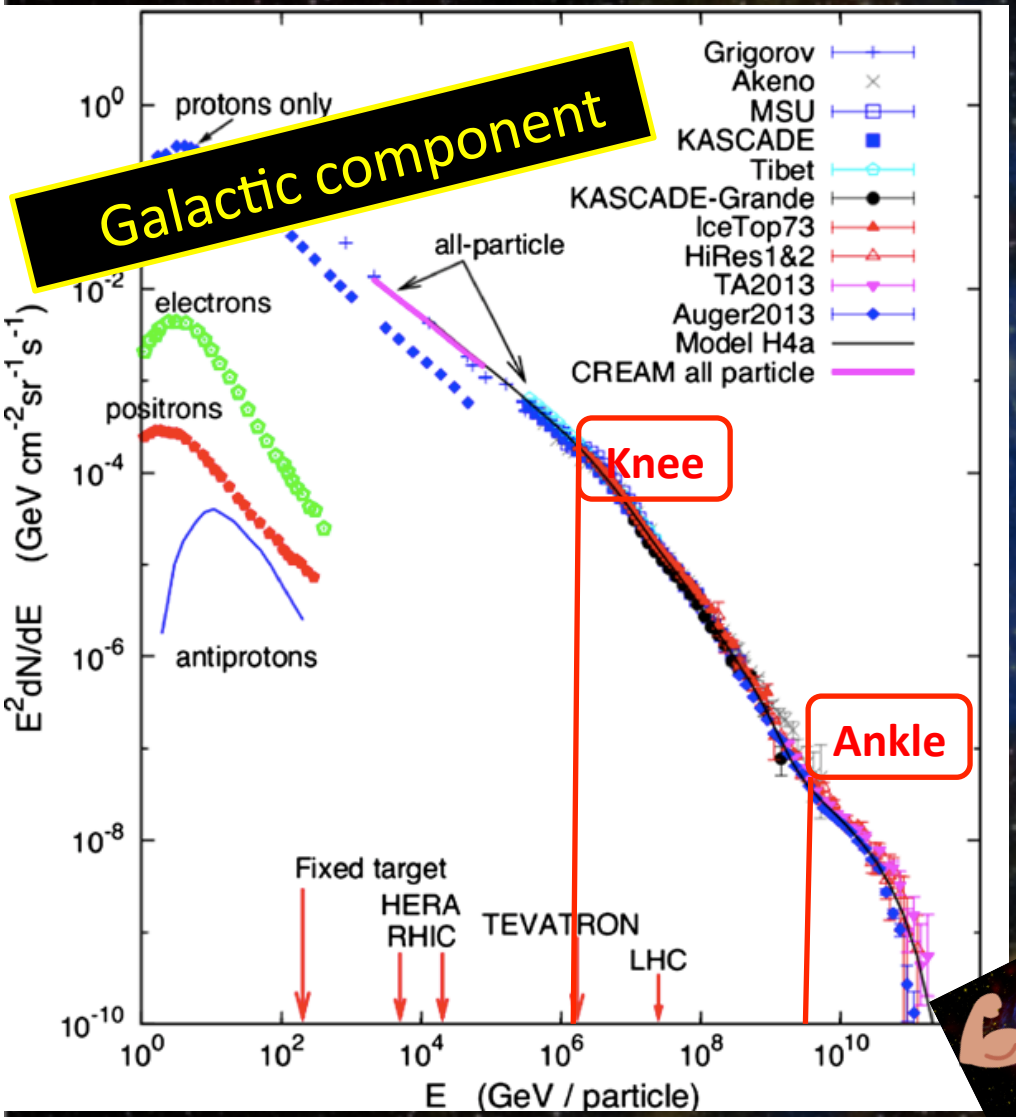


…The Matteucci Medal!!



The astounding AGILE team!

Cosmic-Ray overview



- High-energy particles (mostly protons and nuclei) up to 10^{20} eV
- Bending below 30 GeV due to solar modulation
- Power-law distribution with an index $\alpha \simeq 2.7$ up to PeV energies
- Two main features:
  - Steepening at PeV energies, $\alpha \simeq 3.1$ (*Knee*, 1 part/m^2/yr)
  - Hardening at about E=10^{18} eV (*Ankle*, 1 part/km^2/yr)
- Galactic component likely originates in the SNR shocks

Energetics → with only 10% of SN energy we can explain CR energy density

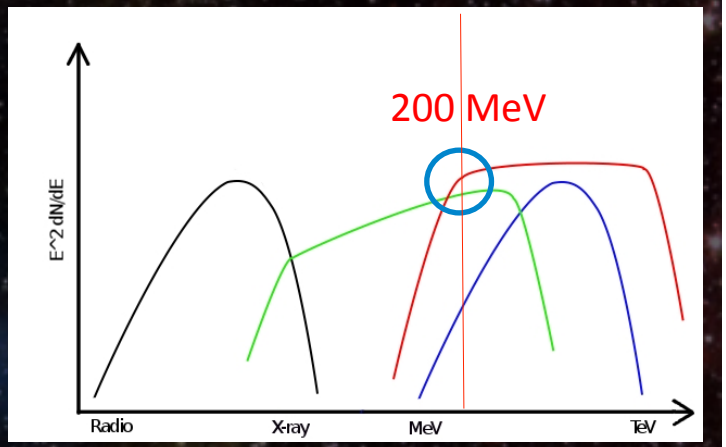
SNRs and CRs: direct proofs

GAMMA-RAY PHOTONS

- No deviations → source direction
- Same spectrum of primary protons
- $E_{\gamma,M} \simeq 10\% E_{p,M}$

$p+p/target \rightarrow \ldots + \pi^0 \rightarrow 2\gamma$

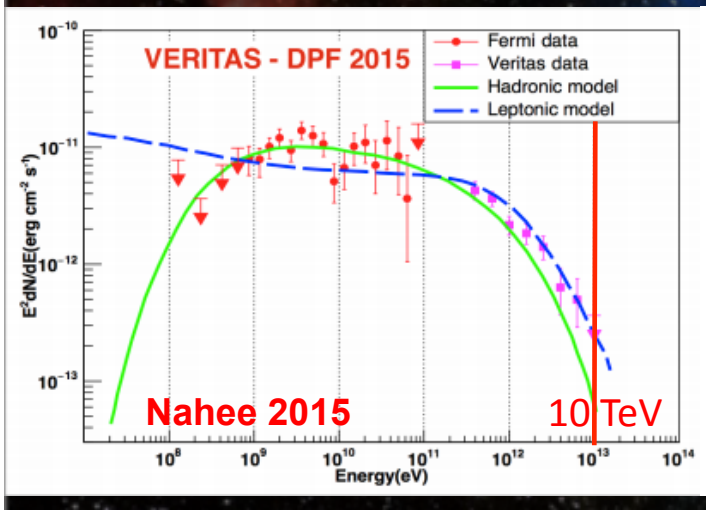
Low-Energies

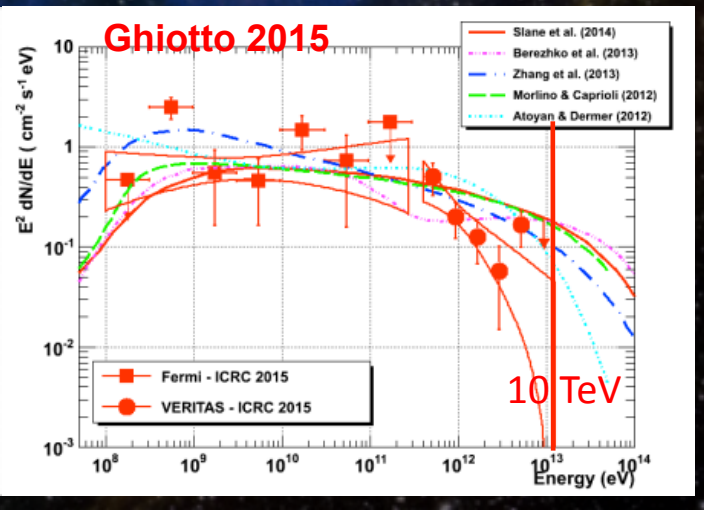


Confirming hadronic origin

→ We can distinguish leptonic from hadronic component only at E<200 MeV

High-Energies → **CTA**



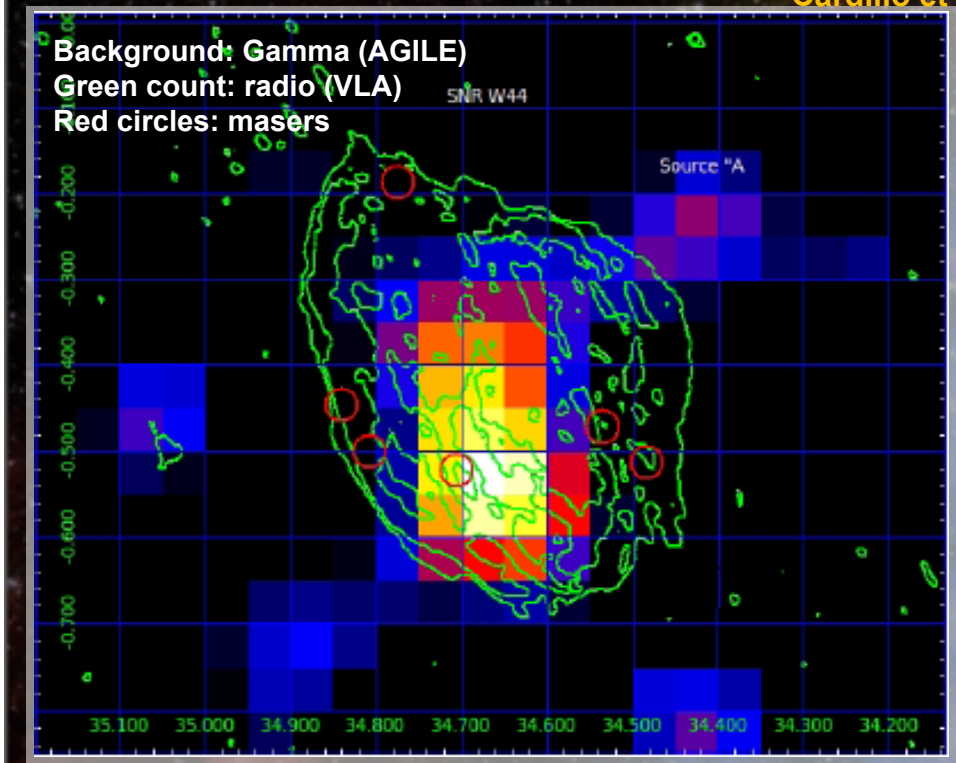


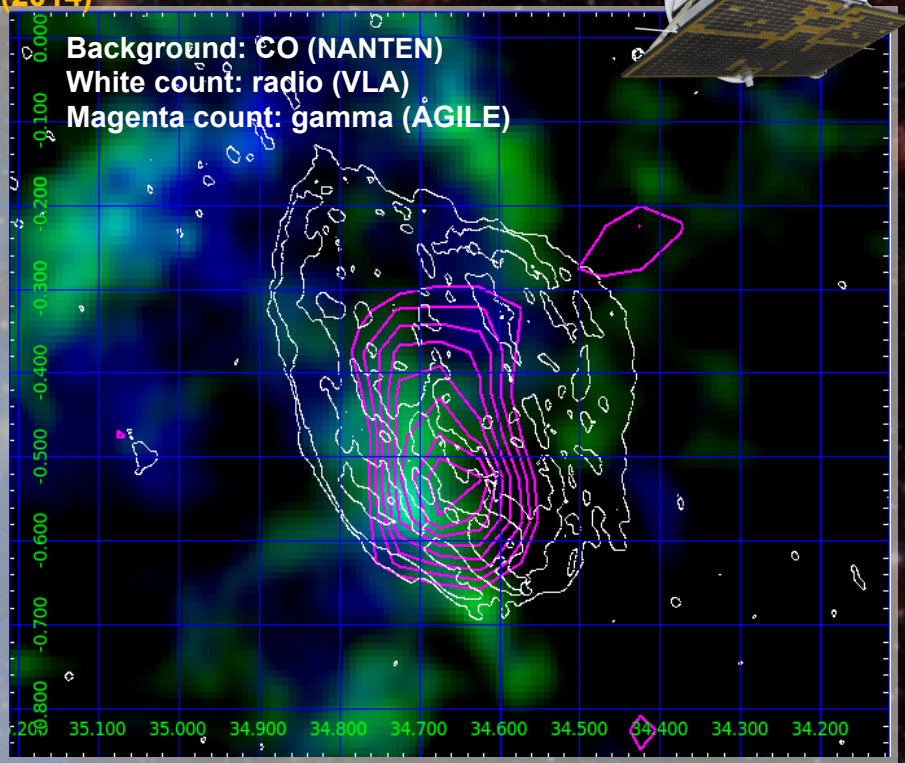
Revealing PeV emission from young SNRs

→ In spite of the large number of young SNRs detected in the gamma-ray band, none of these seems to reach E= 100 TeV

Ladies and Gentleman..W44

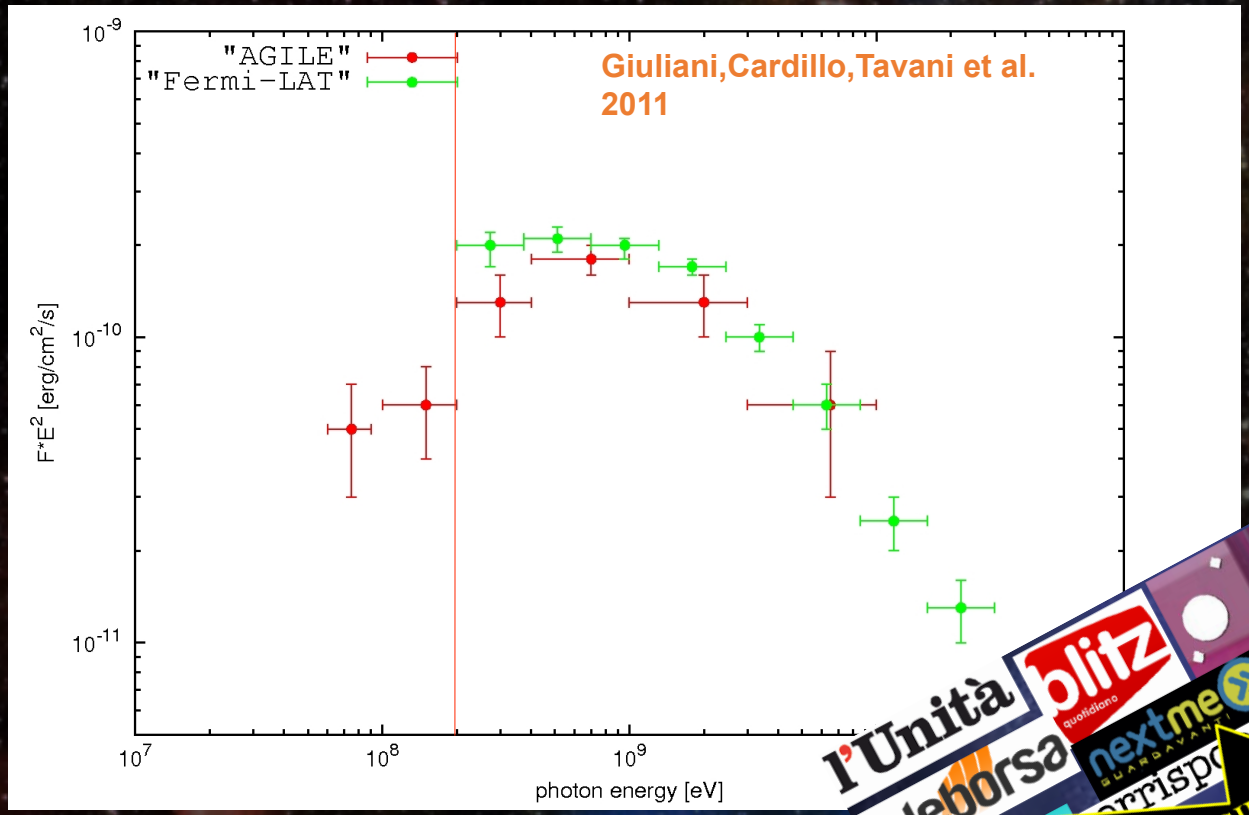
Cardillo et al.(2014)





- Middle aged SNR ($t \geq 10^4$ 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 gamma-ray emission
- Correletion with part of the radio emission in W44

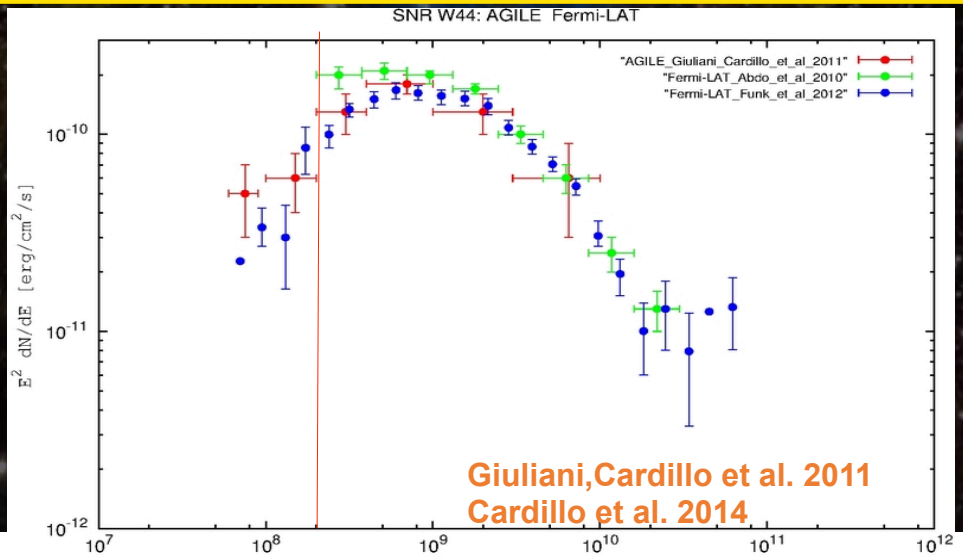
AGILE,W44 and the breakthrough



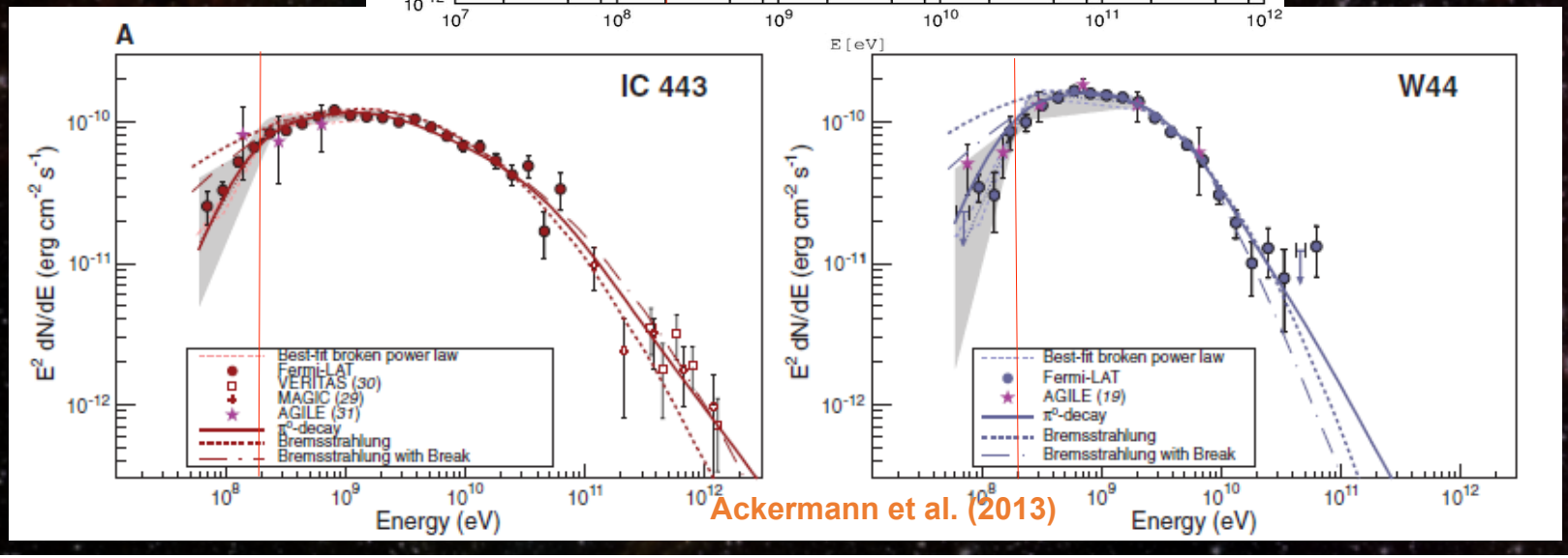
Gamma-ray emission below 200 MeV detected, for the first time, by AGILE from the SNR W44

AGILE,W44 and the breakthrough

Gamma-ray emission below 200 MeV then confirmed by Fermi-LAT, also in IC443

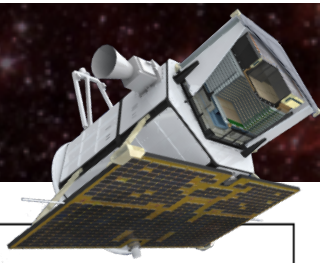


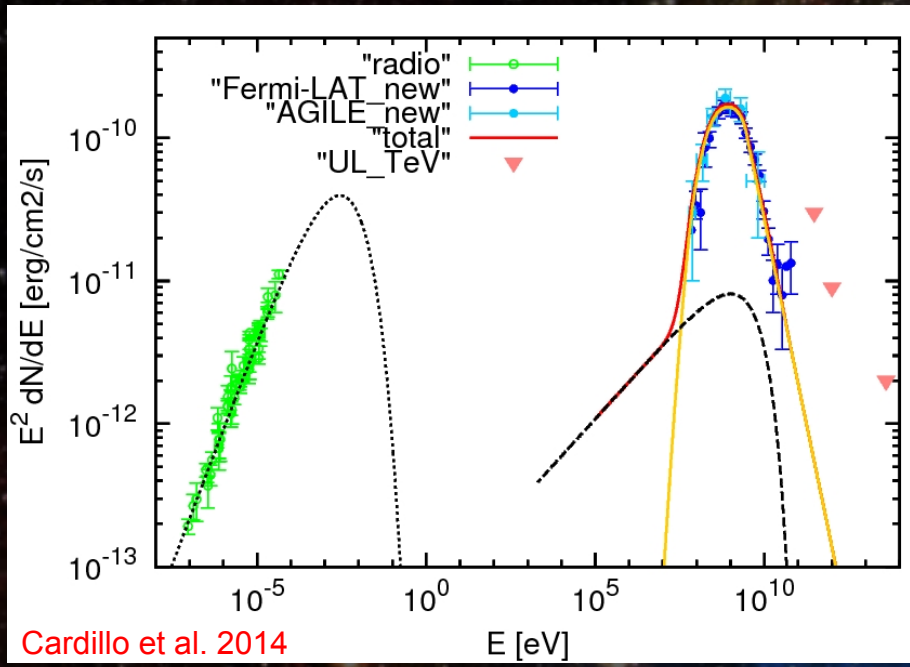
Giuliani,Cardillo et al. 2011
Cardillo et al. 2014



Ackermann et al. (2013)

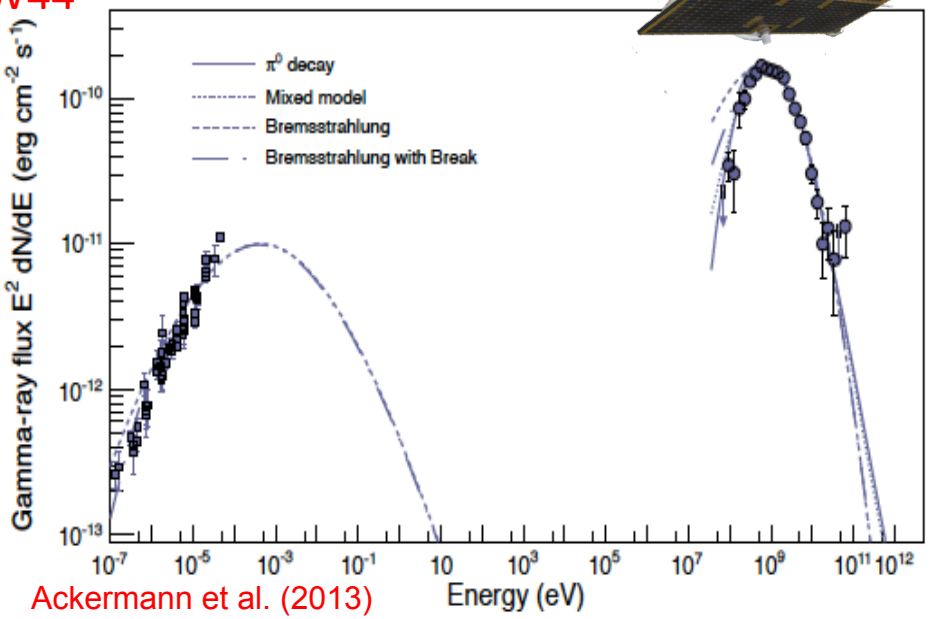
Acceleration…





Cardillo et al. 2014

W44



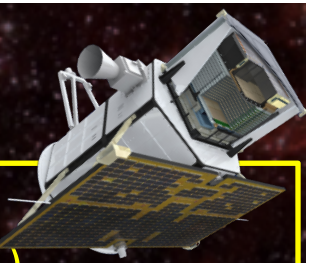
Ackermann et al. (2013)

- ✧ Freshly accelerated CRs with a spectral index $\alpha=(3r_{sh})/(r_{sh}-1)$ at low-energies
- ✧ Broken power-law $\alpha=2.2$ below E~10 GeV and $\alpha=3.2$ above E~10 GeV
- ✧ Malkow steepening due to Alfvèn damping

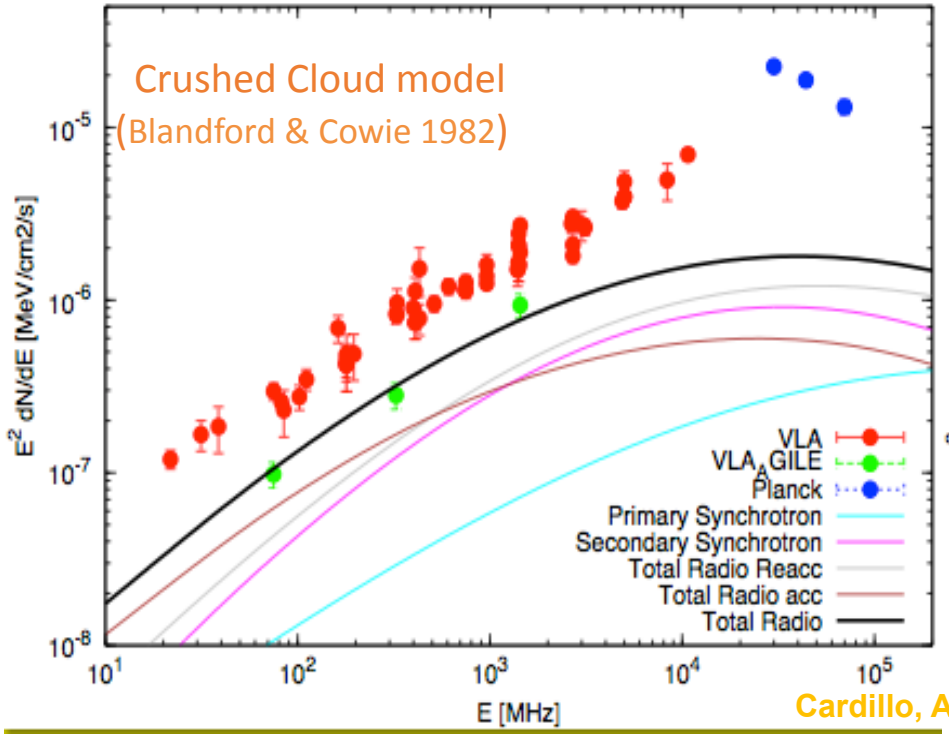
PROBLEMS WITH ACCELERATION

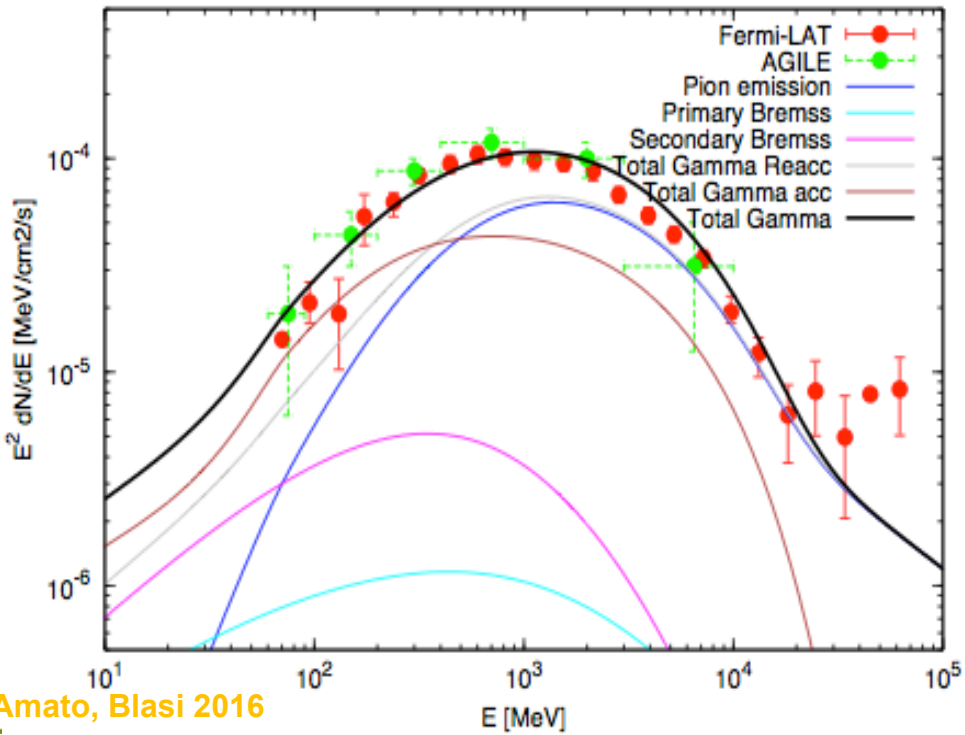
- Presence of a broken PL and of a so steep HE spectral index → not expected from diffusive shock acceleration theory;
- The shock of middle-aged remnants are slow → acceleration efficiency cannot be sufficiently high (→ $P_{CR} = \xi_{CR} p_{th} v^2$)

…or reacceleration?



- ✧ Pre-existing Galactic CR protons, He nuclei and electrons (Voyager spectra)
- ✧ Reacceleration → hardening of spectral indices steeper than $\alpha=(3r_{sh})/(r_{sh}-1)$
- ✧ Compression → higher energies, higher spectrum ($s=(n_2/n_0)/r_{sh}$)
- ✧ Contributions from secondary particles and low-efficiency accelerated CRs
- ✧ Simple PL spectrum ($r_{sh} = 3.5 \div 4 \rightarrow \gamma_p = 4.2-4$) with no steepening but HE cut-off due to the limited time (fully ionized pre-shock medium)
- ✧ A lot of parameters: magnetic field, density, interaction time, correlation length, shock velocity…

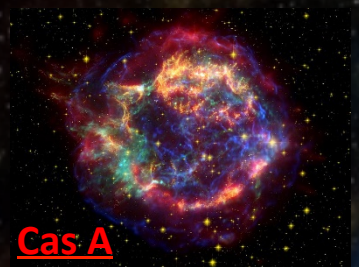




Cardillo, Amato, Blasi 2016

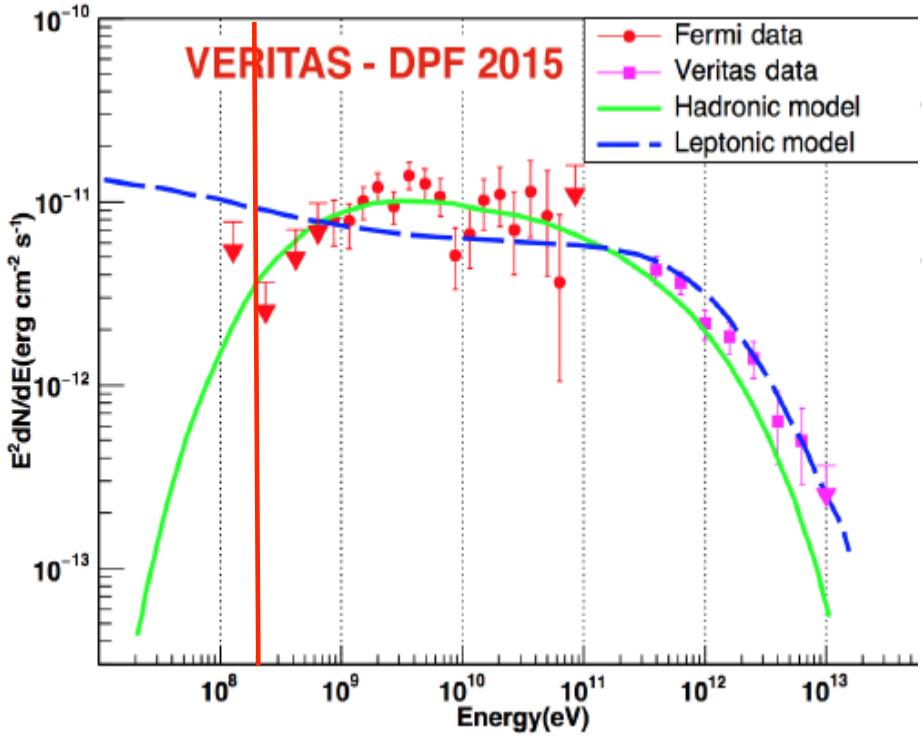
The importance of young SNRs at MeV energies

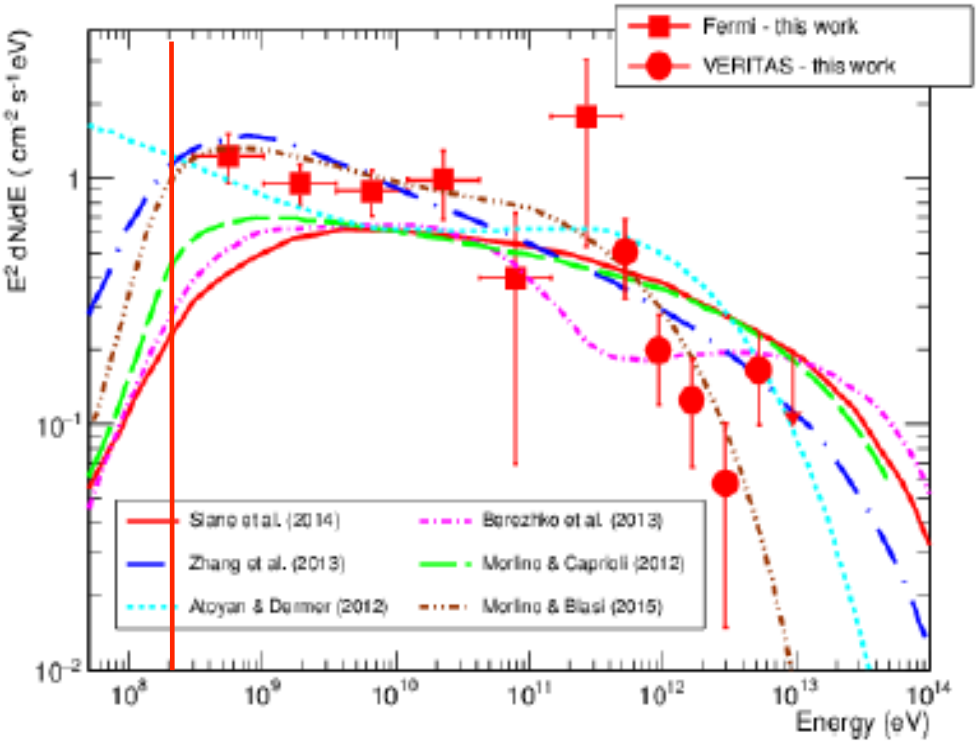
In order to have more chances to confirm the presence of freshly accelerated CRs in correspondence of the SNRs shocks, we need to detect young-fast ($\geq 10^{13}$ *km/s*) shocks SNRs at E<200 MeV.



Cas A

Tycho





Summary

✧ The SNR W44 is a very bright gamma-ray source interacting with a molecular cloud: a perfect target to be analyzed by gamma-ray instruments.

✧ Thanks to its brightness, AGILE detected for the first time gamma-ray emission from a SNR at E<200 MeV

→ first proof of the presence of CRs in a SNR shock

✧ Fermi-LAT confirmed AGILE results on this SNR (and detected also IC443)

→ W44 is the most important SNR in the CR context

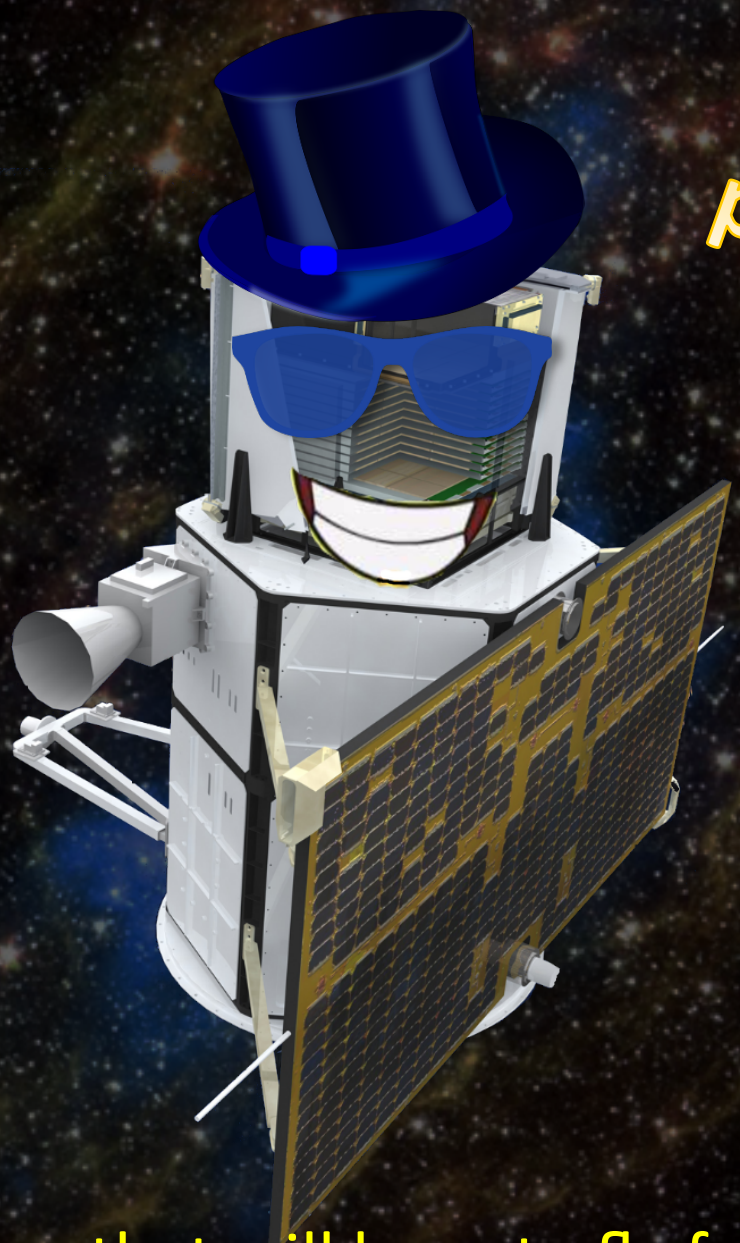
✧ W44 allowed us to study CR acceleration and reacceleration models

→ however, we do not have the proof of efficient acceleration

✧ We need to detect young SNRs with fast shocks at E<200 MeV in order to confirm the presence of freshly accelerated CRs

We really need an instrument with improved capabilities at MeV energies in order to give the final answer to the question:
how is the CR origin?

Even if it can never be cool like our AGILE…



Tanti auguri piccolo grande AGILE!!!

…that will keep to fly for another 100 years.


Thank you
very much!