Istituto Nazionale di Fisica Nucleare

Fermi-LAT observations of Supernova Remnants

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(INFN Torino)

on behalf of the

***Fermi*-LAT Collaboration**

Very High Energy Phenomena in the Universe

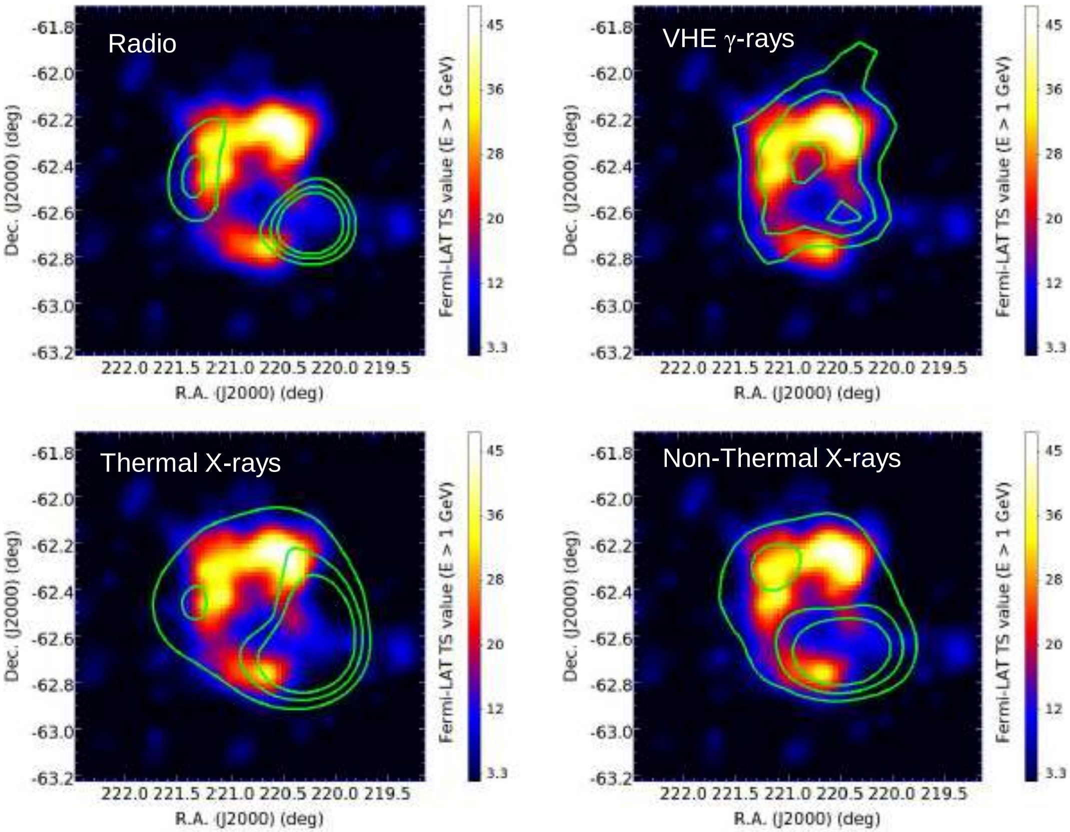
14^{th} Rencontres du Vietnam

Outline

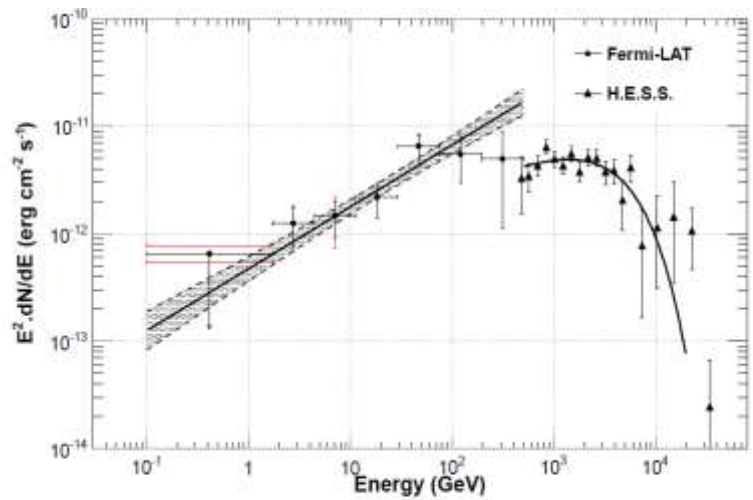
- Single source analysis:
  - Morphologies
  - Spectra
- Catalog studies
- Future experiments: CTA

MORPHOLOGIES

RCW 86 Morphology & Spectrum



- Detected as extended with Pass8: **radius ~ 0.37° ±0.02°**
- Best morphological photon distribution: **H.E.S.S. template**
- Not statistically relevant improvements splitting the templates



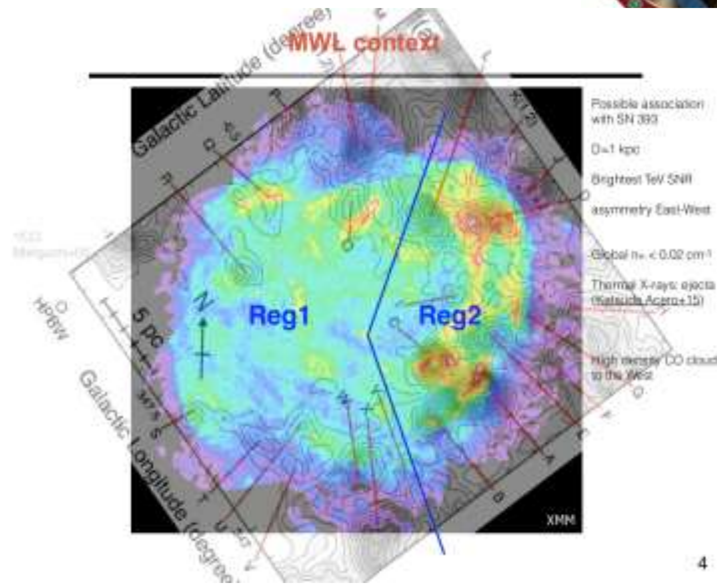
- Pure power-law function
- The broadband emission from radio to TeV cannot be described by a pure hadronic scenario

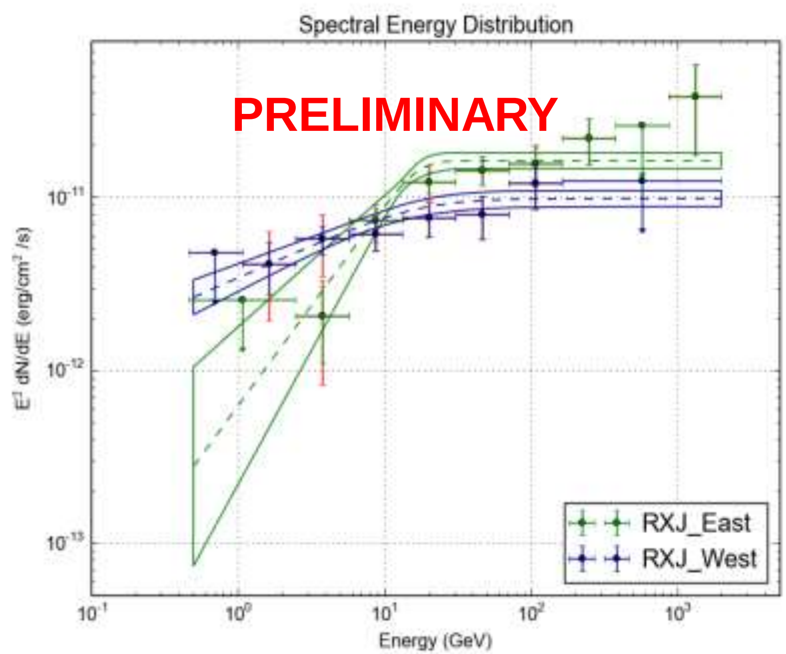
M. Ajello+ ApJ 2016

RX J1713 morphological analysis

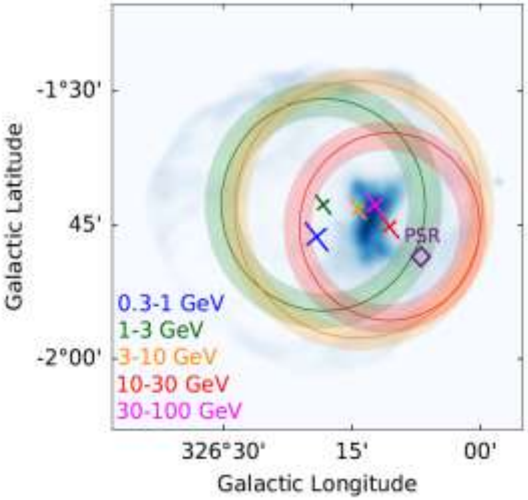
- *Fermi*-LAT analysis with 7.5 years of Pass 8 data
- A nice shell matching the TeV morphology
- Break in the spectrum of the whole remnant at 17 GeV
- Difference between low energy index in the two regions at 3.5 σ

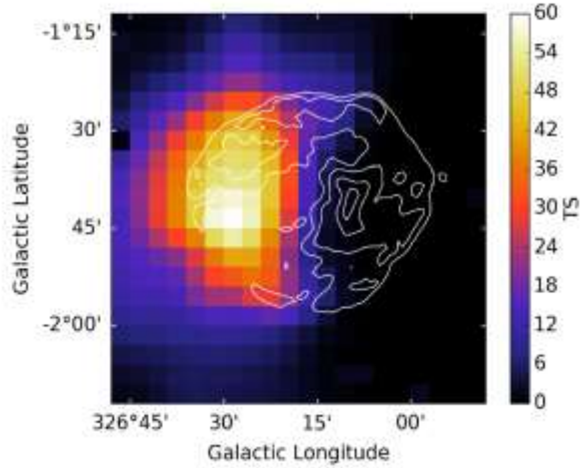
Condon B.+ @ Gamma 2016

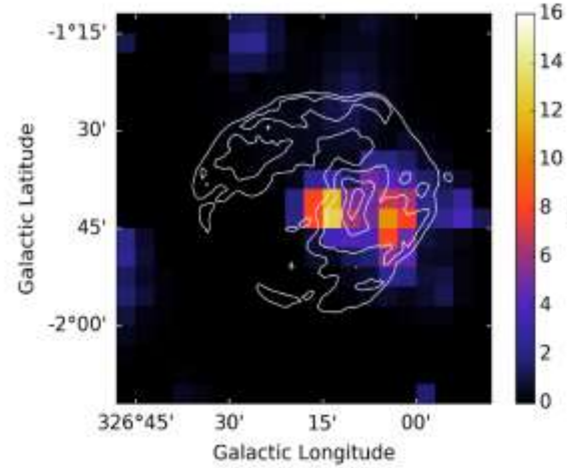




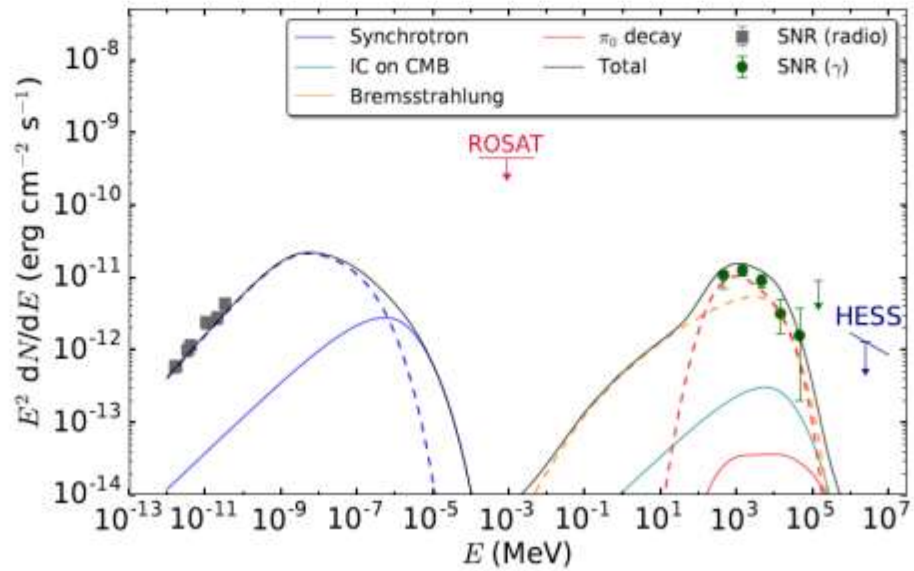
SNR G326.3-1.8







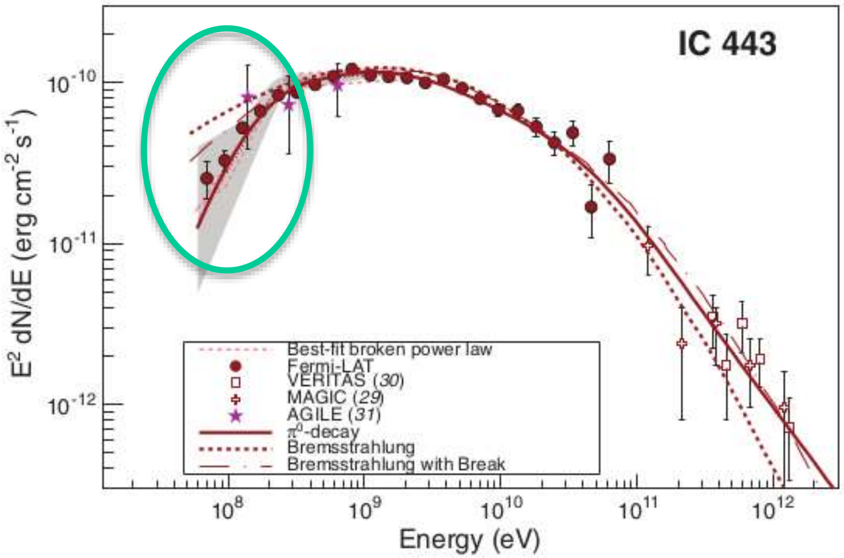
- Composite SNR + PWN region
- Disentangled with a sub-selection of new Pass8 data
- MW modelling in the hadronic scenario

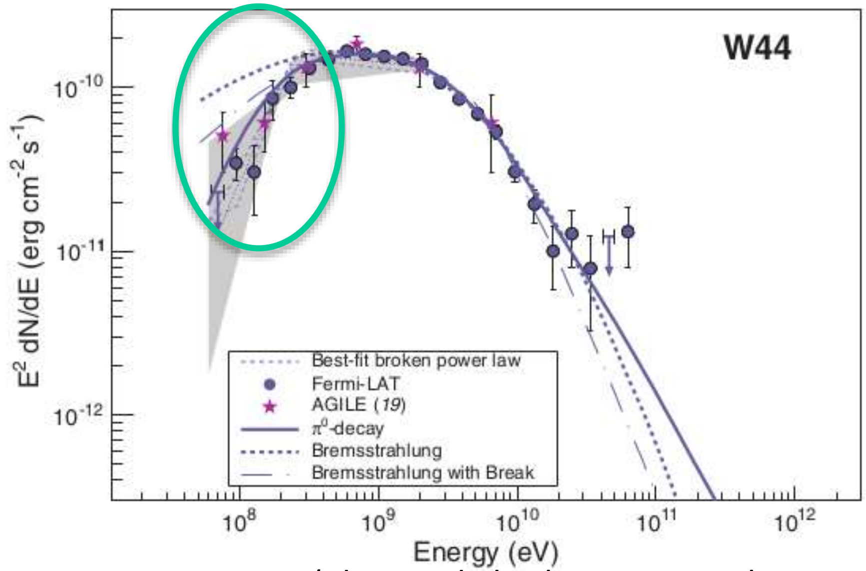


Devin, J. + arXiv:1805.11168

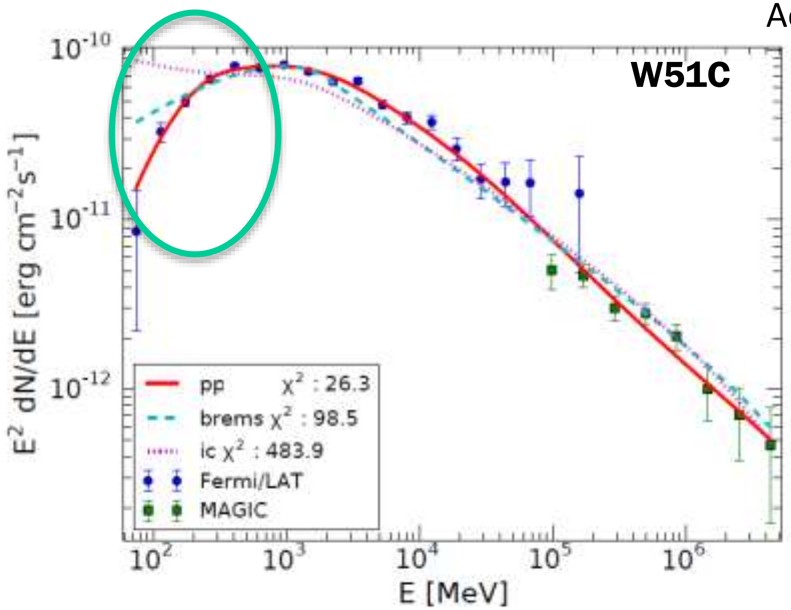
SPECTRA

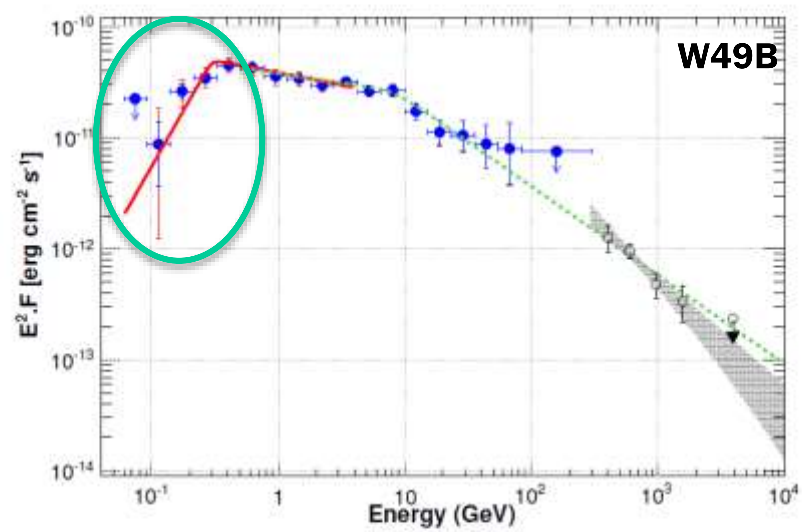
SNRs with hadronic emission





Ackermann, M.+ 2013 Science (detected also by AGILE: Giuliani+ 2011)





T. Jogler and S. Funk, ApJ 2016

HESS + Fermi-LAT Abdalla+ 2018, A&A

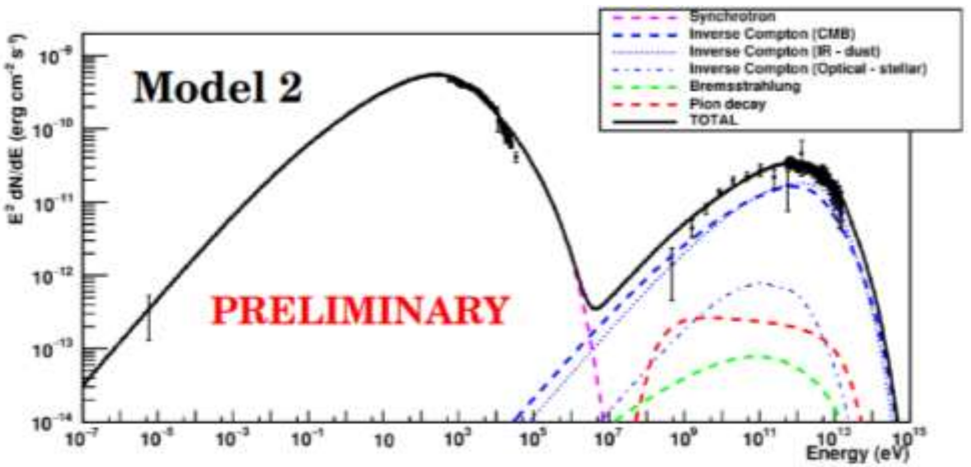
Young SNRs

- Approx. few thousands years old
- Simple environments
- Small energy losses

→ Ideal targets to test the acceleration theory and look for ‘Pevatrons’

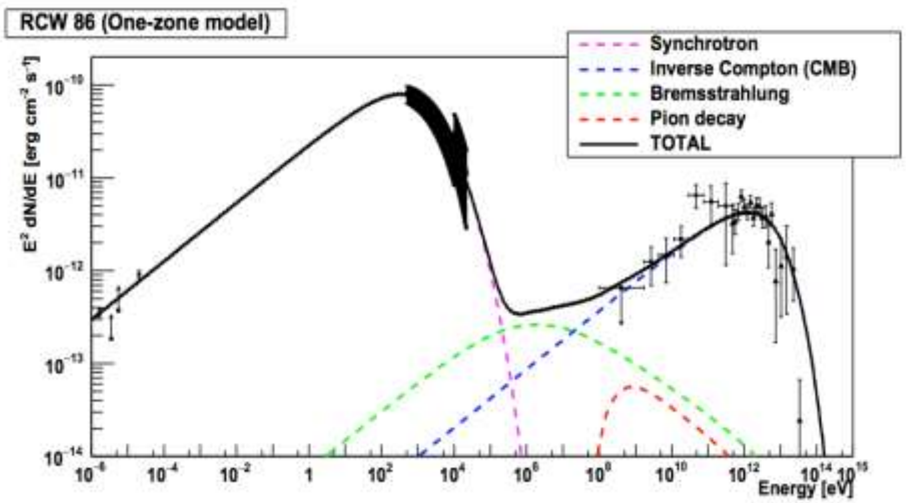
Leptonic scenario

RX J1713.7-3946



B. Condon+ @ Gamma 2016

RCW 86



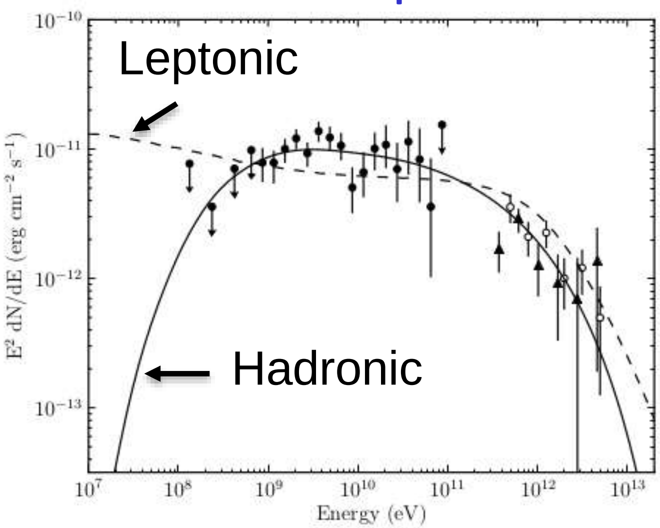
M. Ajello+ ApJ 2016

γ-ray emission dominated by Inverse Compton

Young SNRs

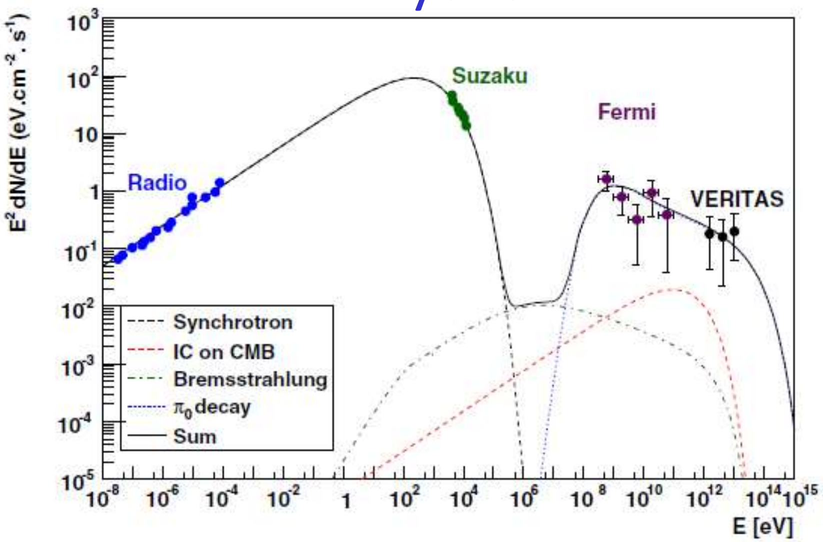
Hadronic scenario

Cassiopeia A



Yuan, Y. + ApJ 2013

Tycho

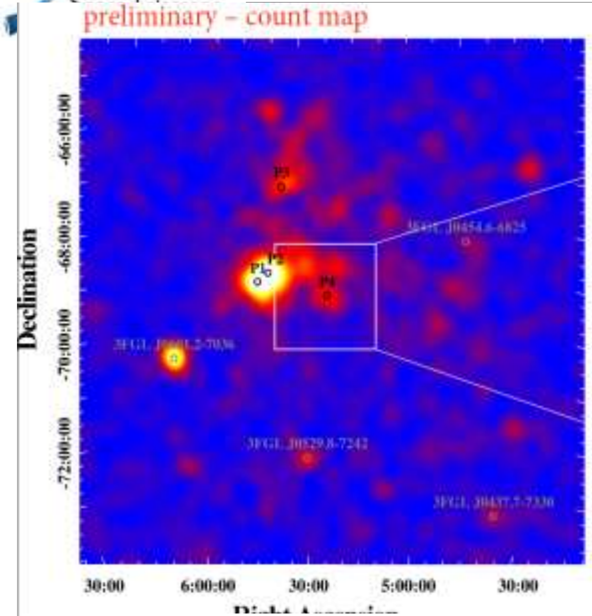


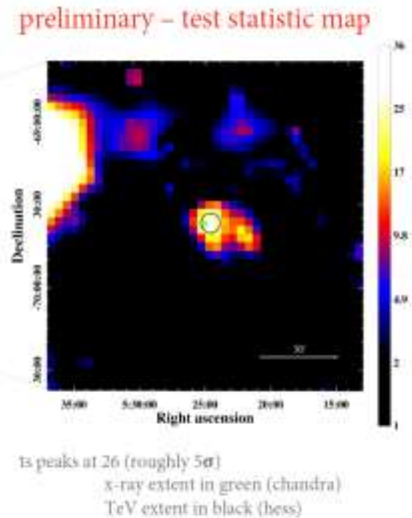
Giordano, F.+ ApJL 2012

γ-ray emission dominated by pion decay

Presence of accelerated protons

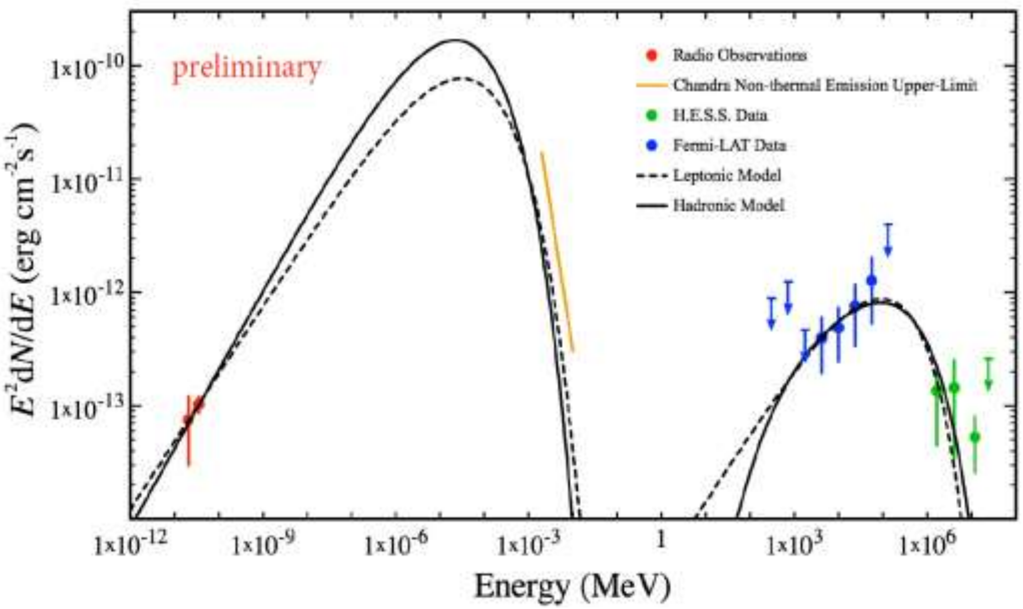
An SNR in another galaxy: N132D in the LMC





- Brightest x-ray SNR in the LMC
- High energy reacceleration?
- Both leptonic and hadronic models require $E_{cr} > 10^{51}$ erg

Castro, D.+ @Fermi Symposium 2017



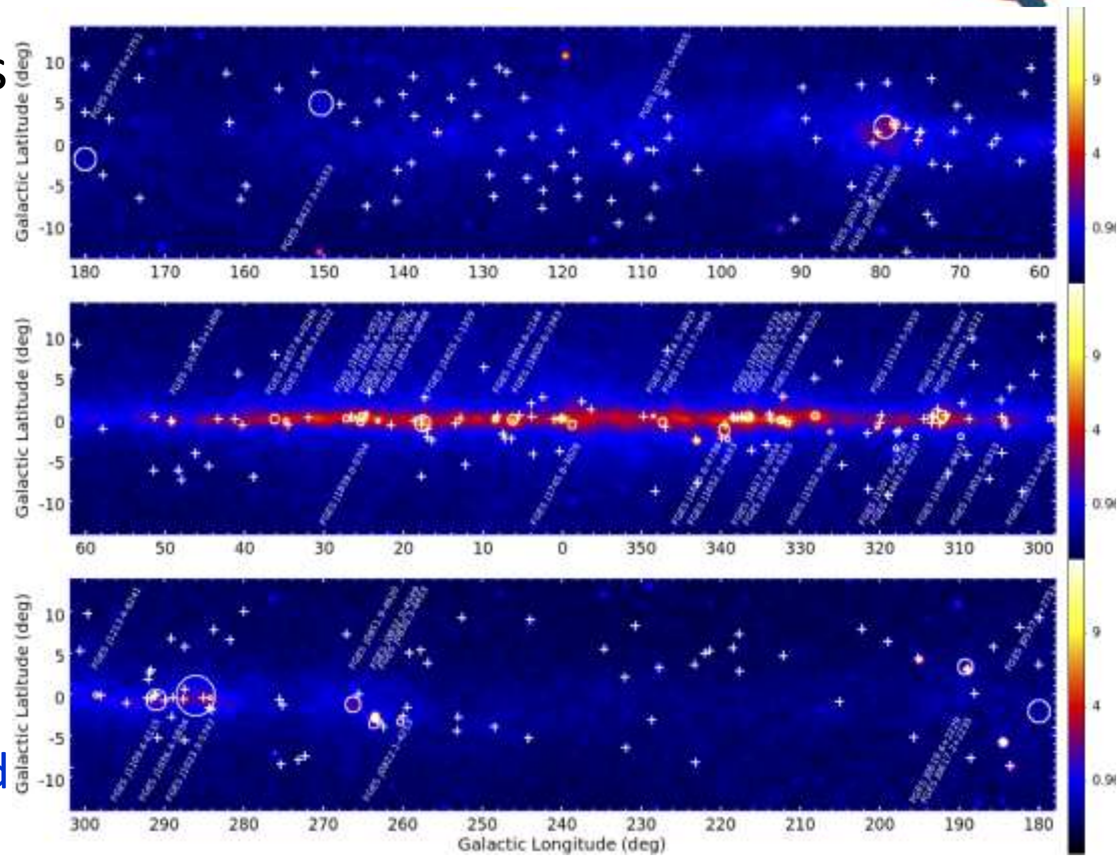
preliminary

	luminosities (erg/s)		
	radio 1 GHz	x-ray 0.1-10 keV	γ-ray 0.1-100 GeV
n132d	1.3×10^{33}	9.9×10^{37}	1×10^{36}
w49b	4.4×10^{32}	4.5×10^{37}	2×10^{36}
w51c	5.5×10^{32}	$\sim 9 \times 10^{36}$	8×10^{35}
w44	1.9×10^{32}	$\sim 2 \times 10^{36}$	5×10^{35}
ic443	6.1×10^{31}	$\sim 1 \times 10^{36}$	1×10^{35}
cas a	3.6×10^{33}	2.6×10^{37}	8×10^{34}
tycho	1.3×10^{32}	1.2×10^{36}	4×10^{33}

CATALOGS

Fermi Galactic Extended Source (FGES) Catalog

- Study of extended sources in the Galactic plane
- Detected 46 extended sources:
  - 16 are new
  - 13 agree with previous publications
  - 17 have a different morphology.
  - Only 4 known LAT extended sources were not detected since they don't have emission above 10 GeV



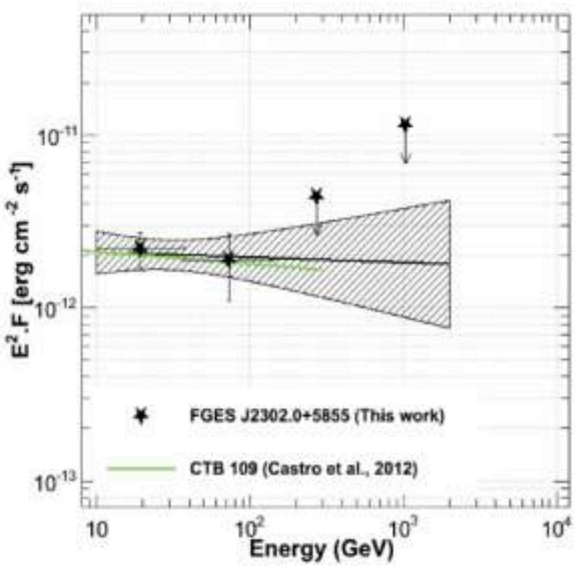
Data:
- Pass 8,
- 6 Years,
- 10 GeV - 2 TeV

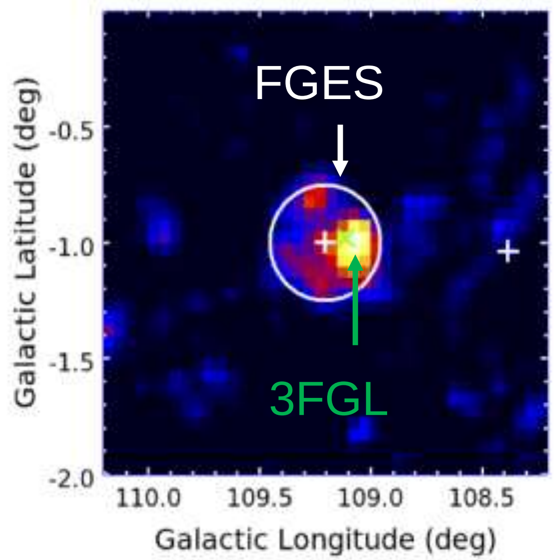
Sources modeled as flat disk

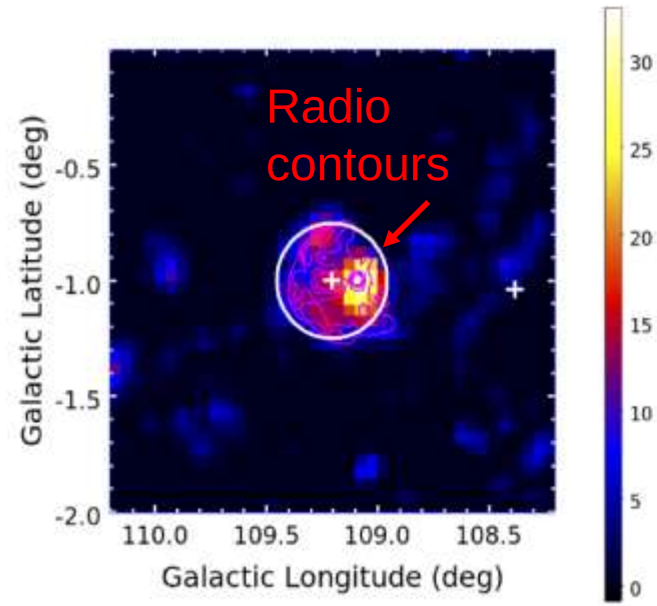
Ackermann, M. + 2017, ApJ, 843, 139

New extended sources in FGES: CTB109

- First detection of gamma-ray extension (point source in Castro+ 2012)
- Good agreement with x-ray/radio size
- Rules out giant molecular cloud west of remnant
- Good candidate for TeV observation







SNR catalog results

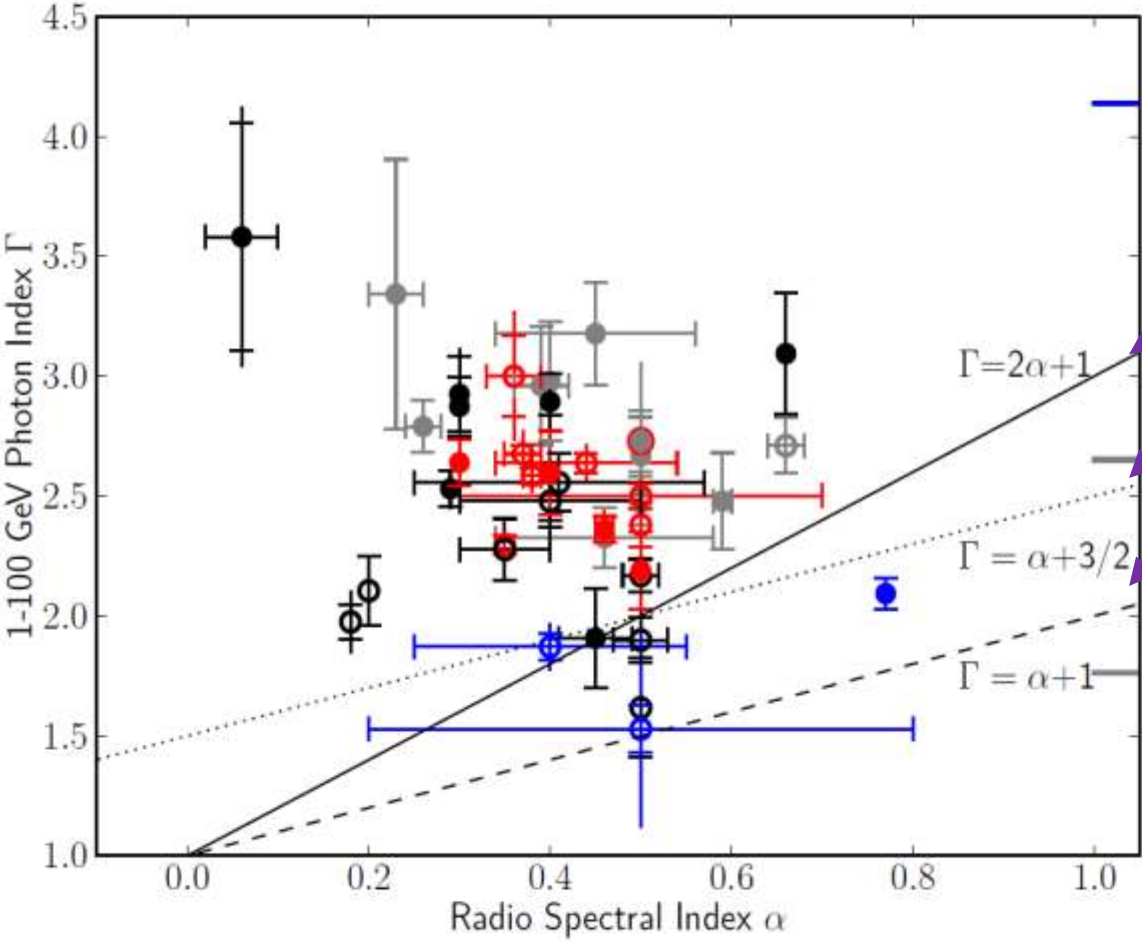
Characterized 279 regions containing known radio SNRs:

- 102 candidates have significant GeV emission:
  - 36 candidates classified through spatial association with radio data:
    - 17 extended: 4 new!
      - 2 show spectral curvature
    - 13 point-like hypothesis preferred: 10 new!
    - 2 are flagged for IEMs systematics
    - 4 identified as other sources (Crab, binary, and PWN/PSR)
  - 14 marginally classified candidates
- For the 245 candidates that don't have a significant GeV emission or that fail classification, we report their ULs.
- All the detected sources were tested for effects related to the choice of IEMs.

Acero+ 2016 APJS

Radio-GeV Index

If radio and GeV emission arise from the same particle population(s), under simple assumptions, the GeV and radio indices should be correlated:



- Young SNRs: seem consistent
- Others, including interacting SNRs: softer than expected

- π^0 decay or $e^{+/-}$ brem.
- Inverse Compton w cooling
- inverse Compton w/o cooling

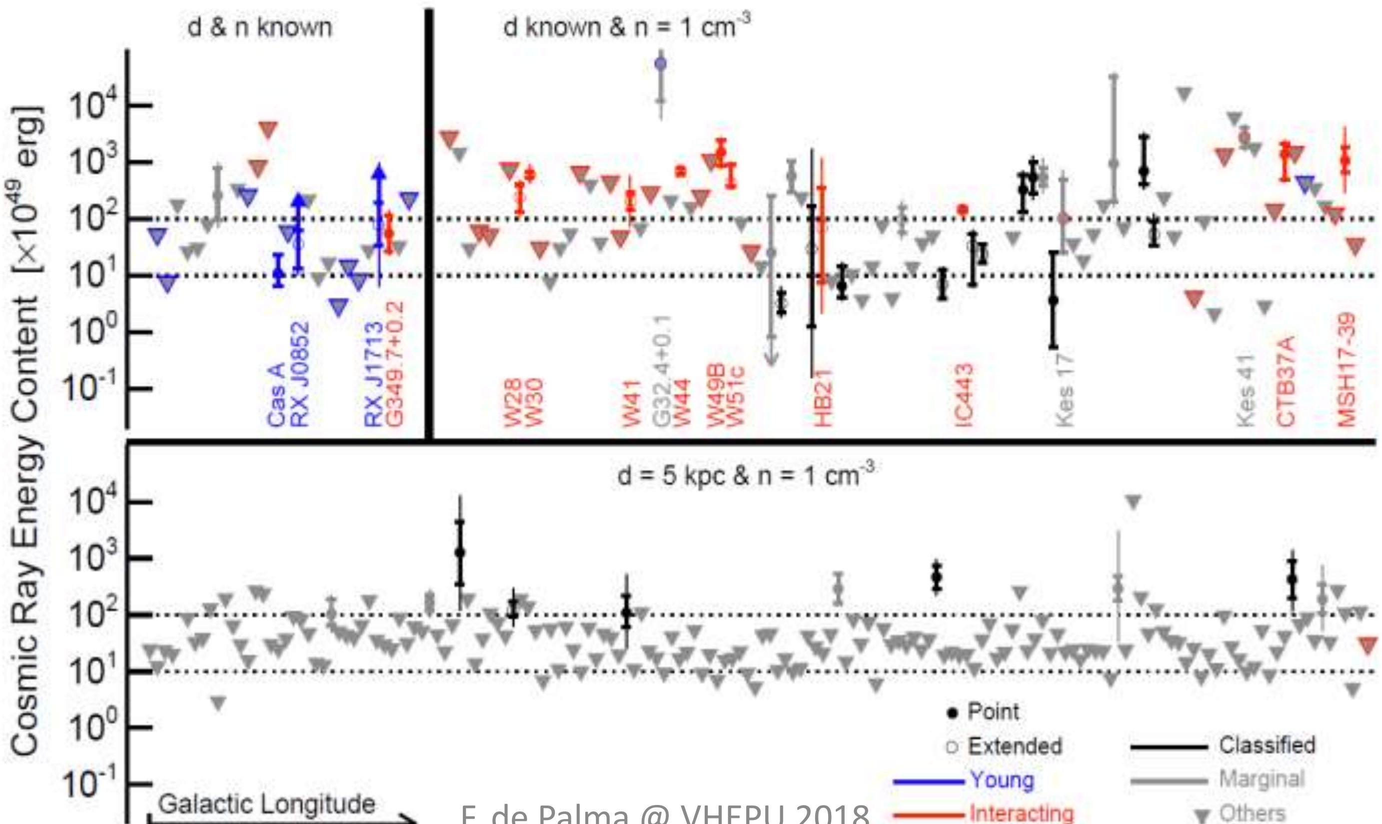
Data now challenge model assumptions!

- Underlying particle populations may have different indices.
- Emitting particle populations may not follow a power law: breaks?
- Multiple emission zones?

Constraining CRs from detections and ULs

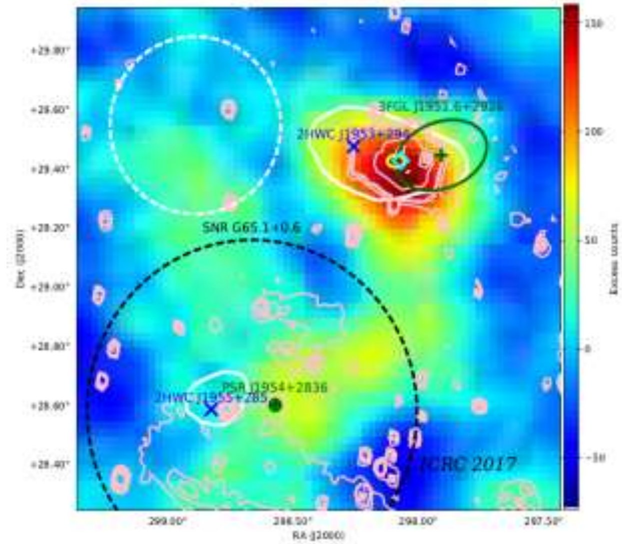
Assuming that the whole gamma ray emission arises from the interaction of CR with the ISM.

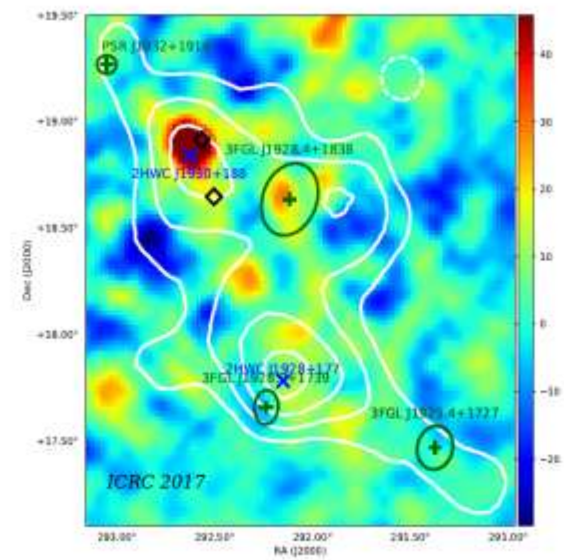
- SNRs above the $\epsilon_{CR} = 1 \,(E_{CR} = E_{SN} = 10^{51}\, erg)$ → higher density than derived from X-ray or assumed → interacting SNRs are in dense environment.
- Young SNRs $\epsilon_{CR} \sim 0.1$ → IC processes may contribute to their measured luminosity.



2HWC catalog follow ups

- Analysis in Fermi-LAT and Veritas data of 13 sources that are more than 3° away from known TeV sources.
- VERITAS found weak gamma-ray emission in the region of PWN DA 495 coinciding with 2HWC J1953+294
- LAT detected a GeV counterpart of SNR G54.1+0.3, a known TeV source detected by both VERITAS and HAWC associated to a PWN.





Park, N.+ ICRC 2017 Arxiv:1708.05744v1

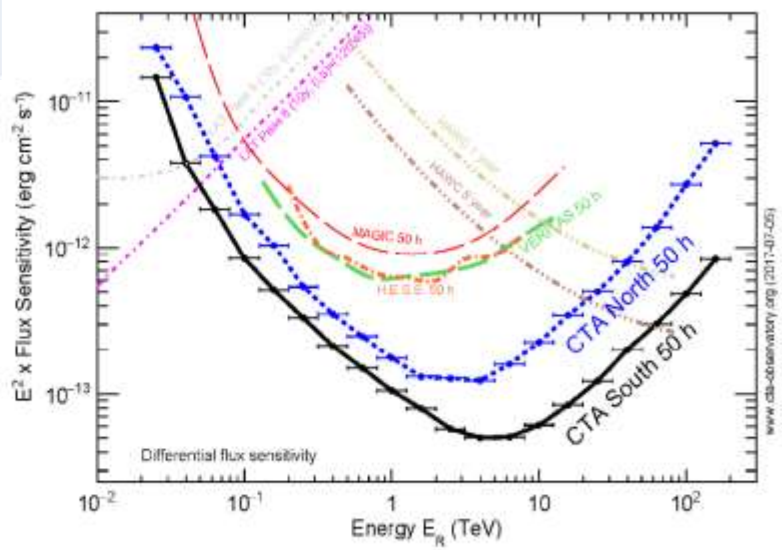
For more on Fermi-LAT catalogs, see J. Ballet talk Thursday

CHERENKOV TELESCOPE ARRAY

CTA: Key Science Projects (KSP)

		GPS	PeVatrons
CRs acc.	What are the sites of high-energy particle acceleration in the universe?	✔✔	✔
	What are the mechanisms for cosmic particle acceleration?	✔	✔✔
	What role do accelerated particles play in feedback on star formation and galaxy evolution?		
Extreme environments	What physical processes are at work close to neutron stars and black holes?	✔	✔✔
	What are the characteristics of relativistic jets, winds and explosions?	✔	✔✔
	How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?		

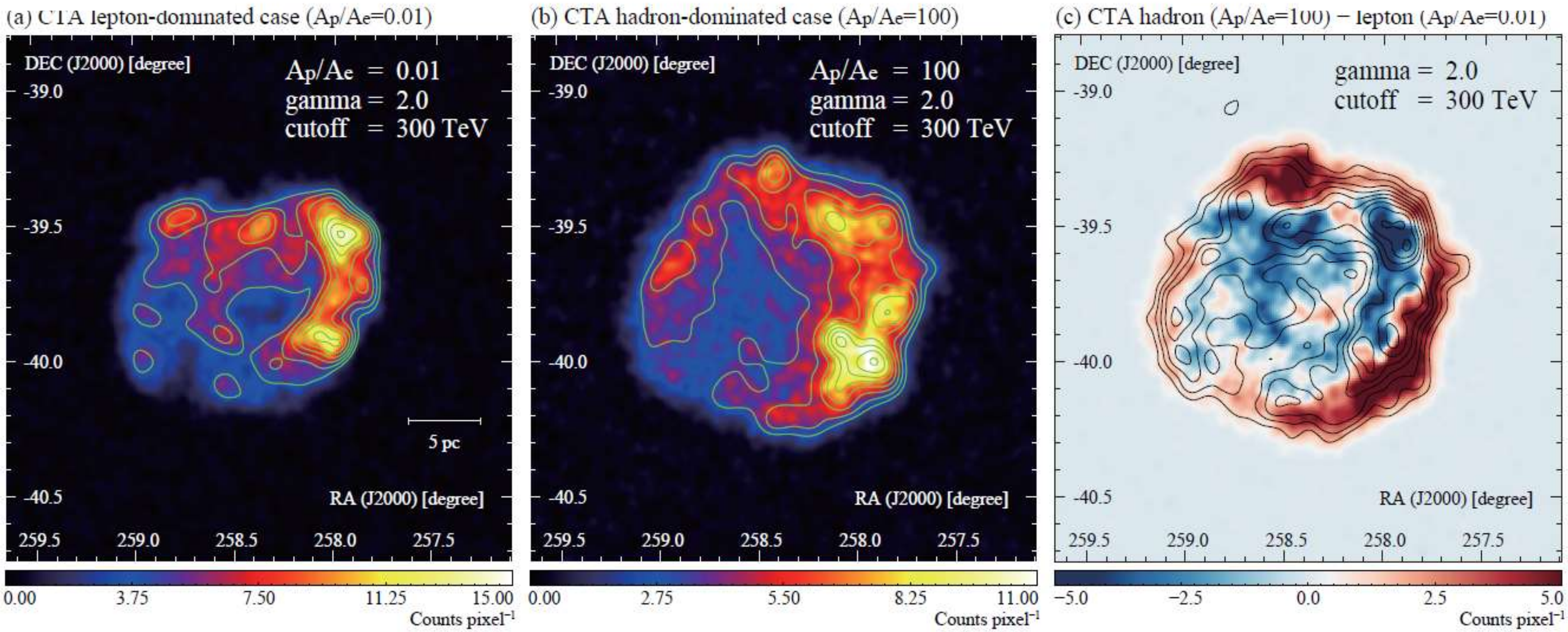
See S. Funk talk Thursday



Major sensitivity improvement & wider energy range

The CTA Consortium, Science with the Cherenkov Telescope Array, arxiv:1709.07997

Morphology studies for RX J 1713



Simulated morphologies for different emission mechanisms with 50h of observation.

Acero +, ApJ 2017, 840, 74

Conclusions

- *Fermi* has proved to be extremely successful in studying Supernova Remnants
- Pass 8 is allowing detailed studies of the morphology of extended sources, better identifying emitting regions at different energies.
- Detailed spectral studies, with MW information, are increasingly improving our knowledge of emission mechanisms.
- Relevant new results from catalogs.
- CTA observations of the Galactic plane will strongly improve our understanding of the Galactic high energy emission.
- Spatial resolved spectroscopy will be possible given CTA high spatial and spectra resolution.