Fermi-LAT observations of Supernova Remnants

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on behalf of the

Fermi LAT Collaboration

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Symposium 331

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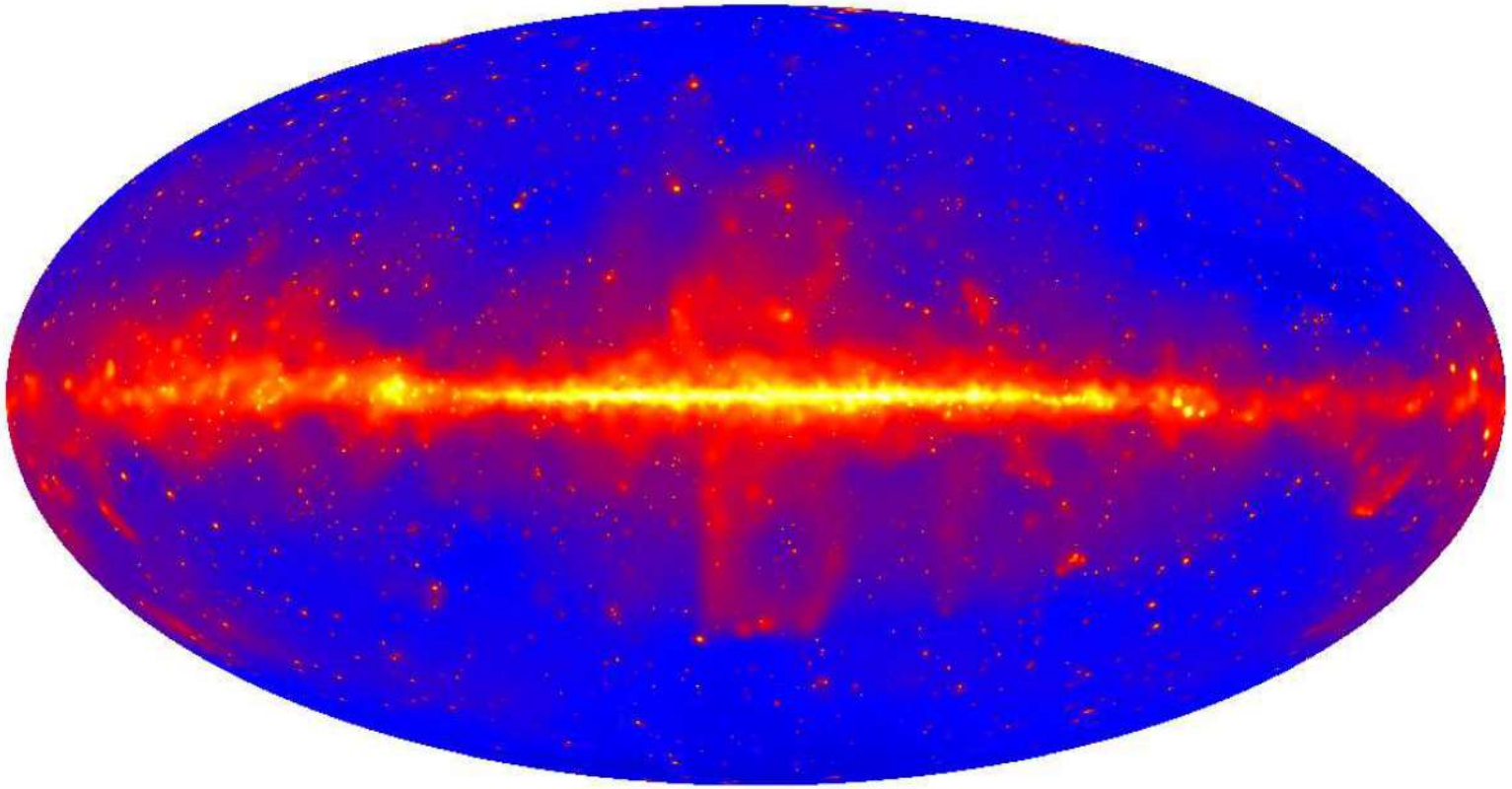
Outline

- Galactic sources in *Fermi*-LAT catalogs:
  - 3FHL
  - FGES
- Morphological studies with Pass 8
- SNR Catalog:
  - Results
  - Multiwavelength correlations
  - Constraining Cosmic Ray (CR) acceleration
- Conclusions

Fermi LAT Skymap [10-10^3 GeV]



0 0.0099 0.03 0.07 0.15 0.31 0.62 1.2 2.5 5 10

3FHL identification & association

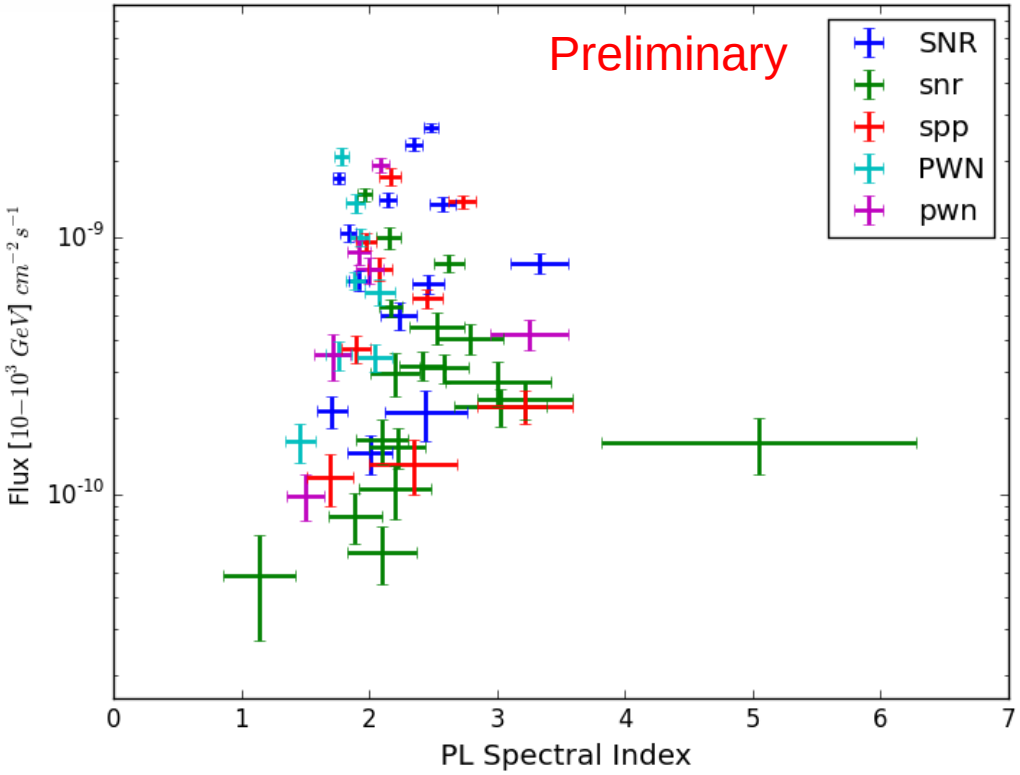
Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar	PSR	58	psr	7
Pulsar Wind Nebula	PWN	8	pwn	6
Supernova remnant	SNR	13	snr	19
Supernova remnant / Pulsar wind nebula	...	...	spp	9
High-mass binary	HMB	3	hmb	1
Binary	BIN	1	...	...

Data:

- Pass 8,
- 7 Years,
- 10-10^3 GeV

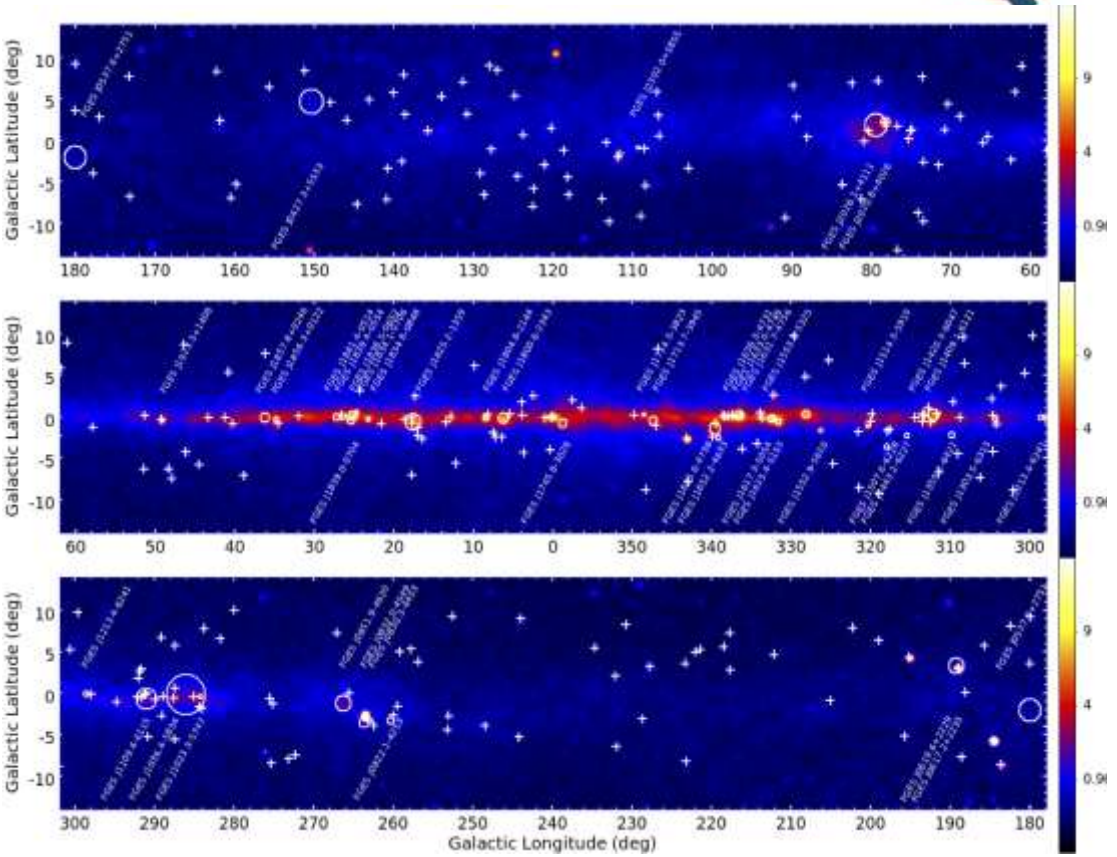
Preliminary version:
Arxiv:1702.00664

Fits on the FSSC webpage:
gll_psch_v11.fit



FGES

- 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

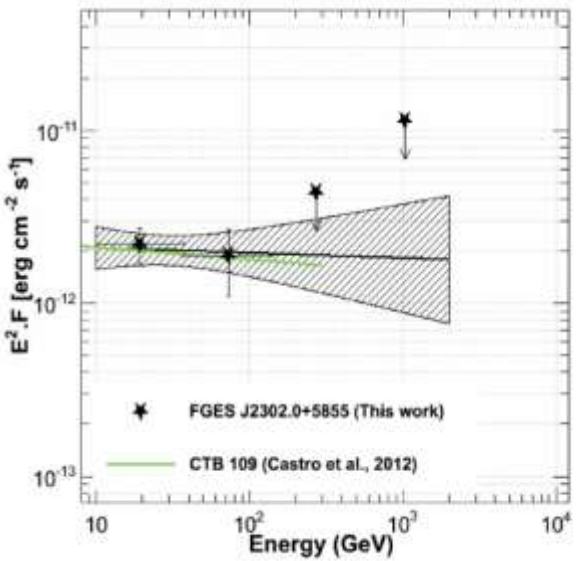


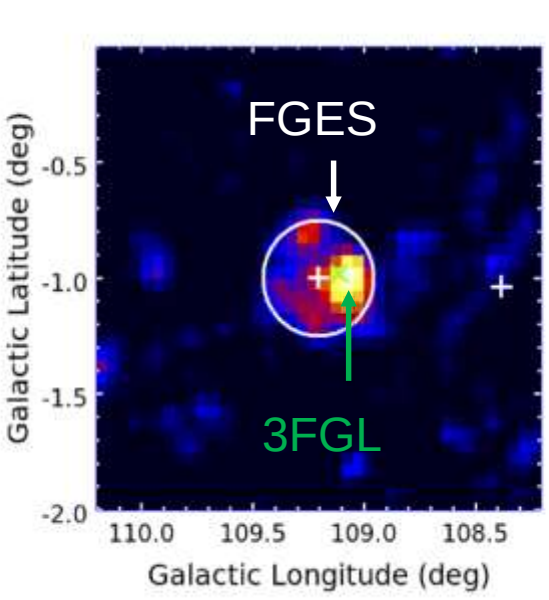
Data:
- Pass 8,
- 6 Years,
- 10 GeV - 2 TeV

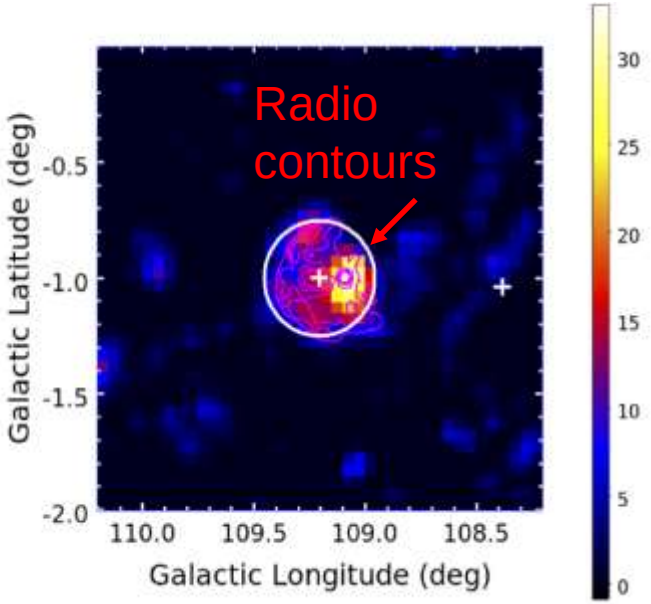
Sources modeled as flat disk

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

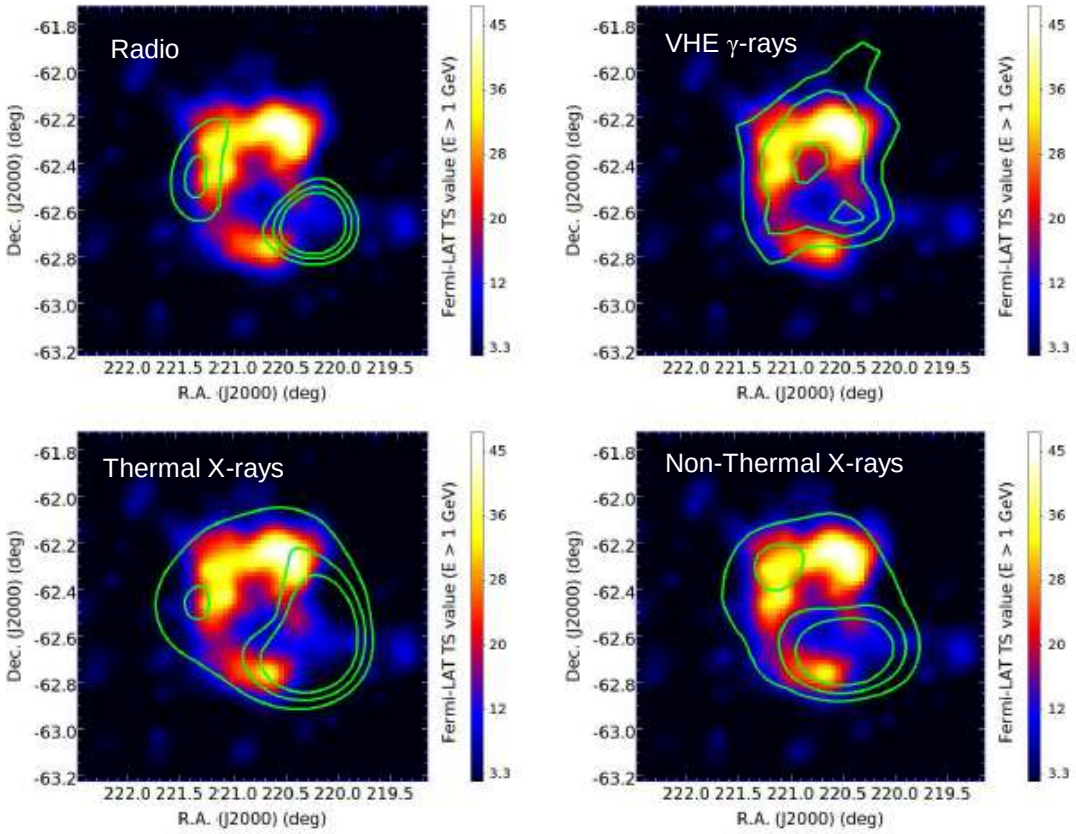






Morphological studies with Pass 8

RCW 86



M. Ajello+ ApJ 2016

Detected as extended with Pass8:
radius ~ 0.37° ±0.02°

Best morphological photon distribution: **H.E.S.S. template**
(A. Abramowski+,
accepted for publication by A&A)

Multi-zone analysis ongoing

RX J1713.7-3946
Preliminary results in
Condon+ @ Gamma 2016

G 326.3-1.8
J. Devin poster & presentation
(PSF3 photons)

IC 443
Preliminary results in
Hewitt+ @ Fermi Symposium 2015
See J. McEnery talk

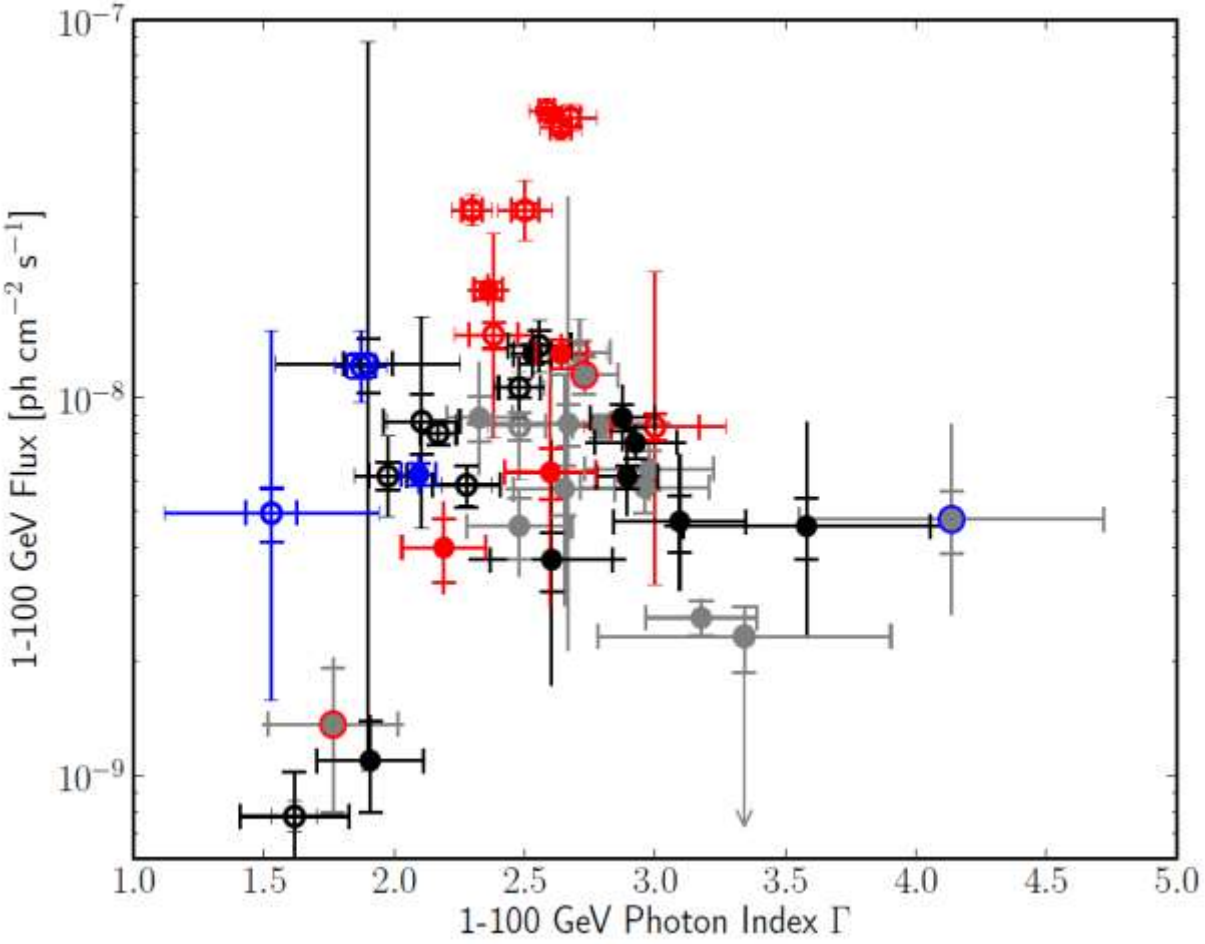
SNR catalog results

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.

GeV Flux Vs. Index

Indexes of the candidate sources are distributed in the large range between 1.5 and 5, while fluxes are in a two orders of magnitude interval.

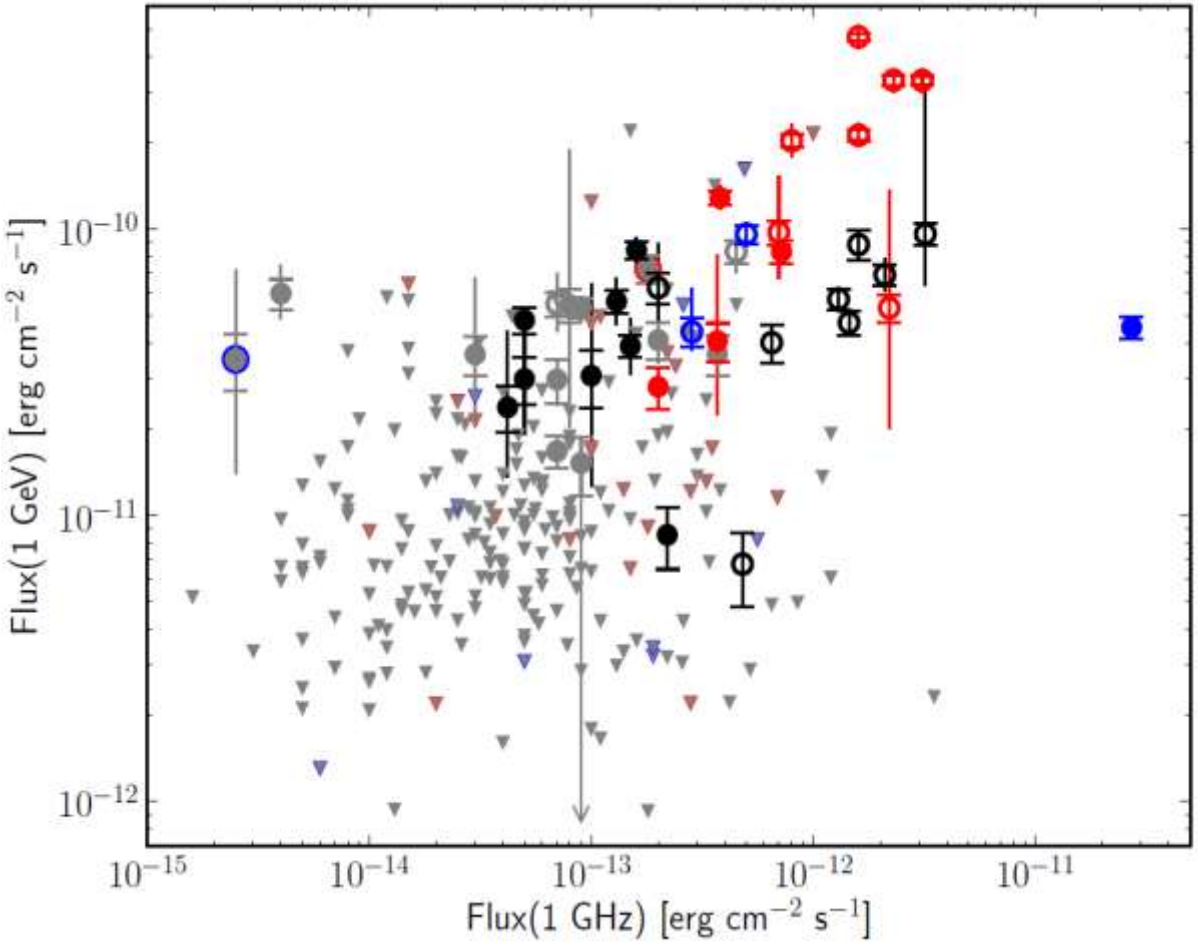


- Interacting SNRs density $\geq$ 100 cm^{-3}
- Young SNRs show evidence of non-thermal X-ray emission
- Classified candidates
- Marginal candidates
- Pointlike sources
- Extended sources

- Capped error bars: statistical errors
- Uncapped: systematic uncertainties.

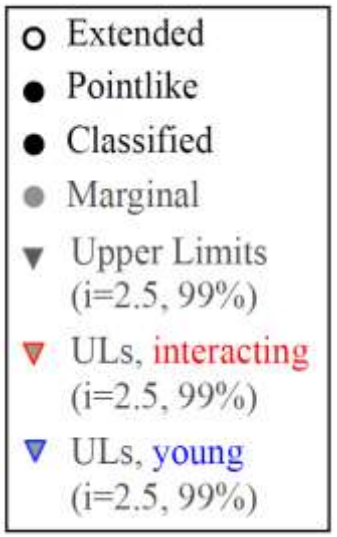
Radio-GeV Flux

LAT-detected SNRs tend to be radio-bright:



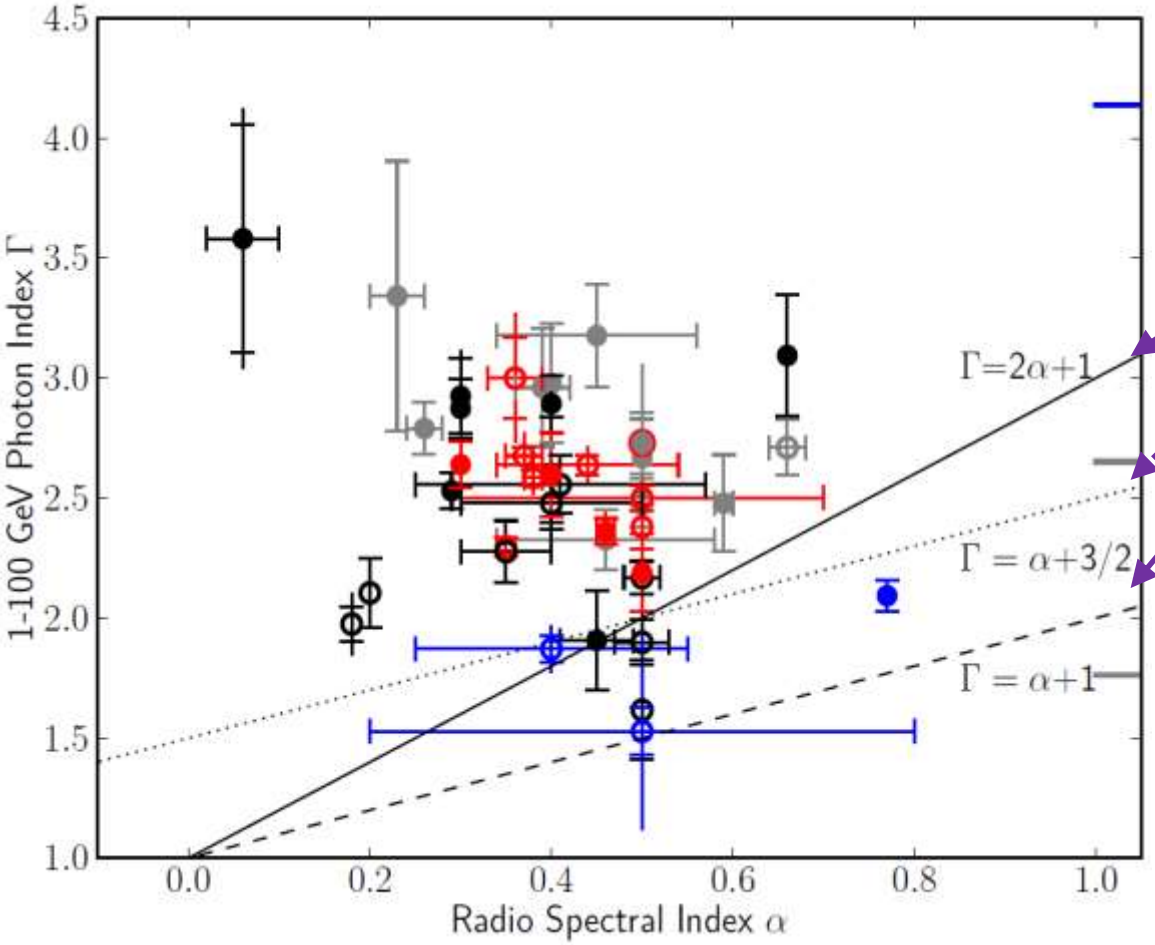
- Interacting SNRs: general correlation?
- Young SNRs show more scatter

Applied Kendall τ test: no deviation from non-correlation for any (sub)set of candidates.



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:

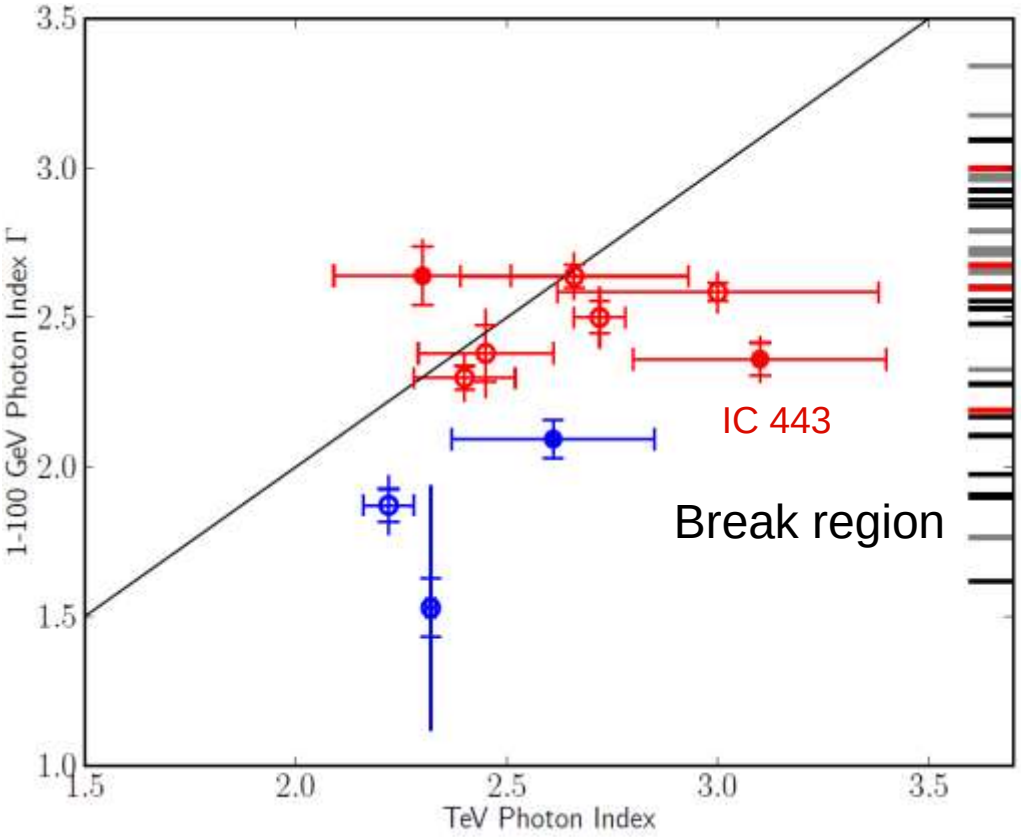


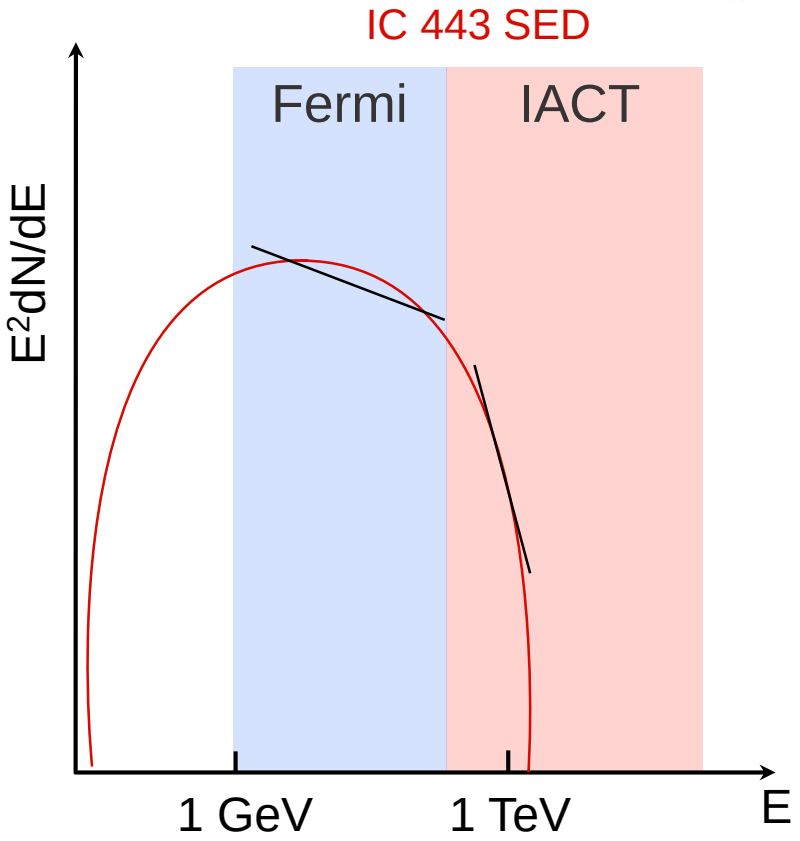
- Young SNRs: seem consistent
- Others, including interacting SNRs: softer than expected
  - π^0 decay or $e^{+/-}$ brem.
  - Inverse Compton w cooling
  - inverse Compton w/o cooling

<u>Data now challenge model assumptions!</u>

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

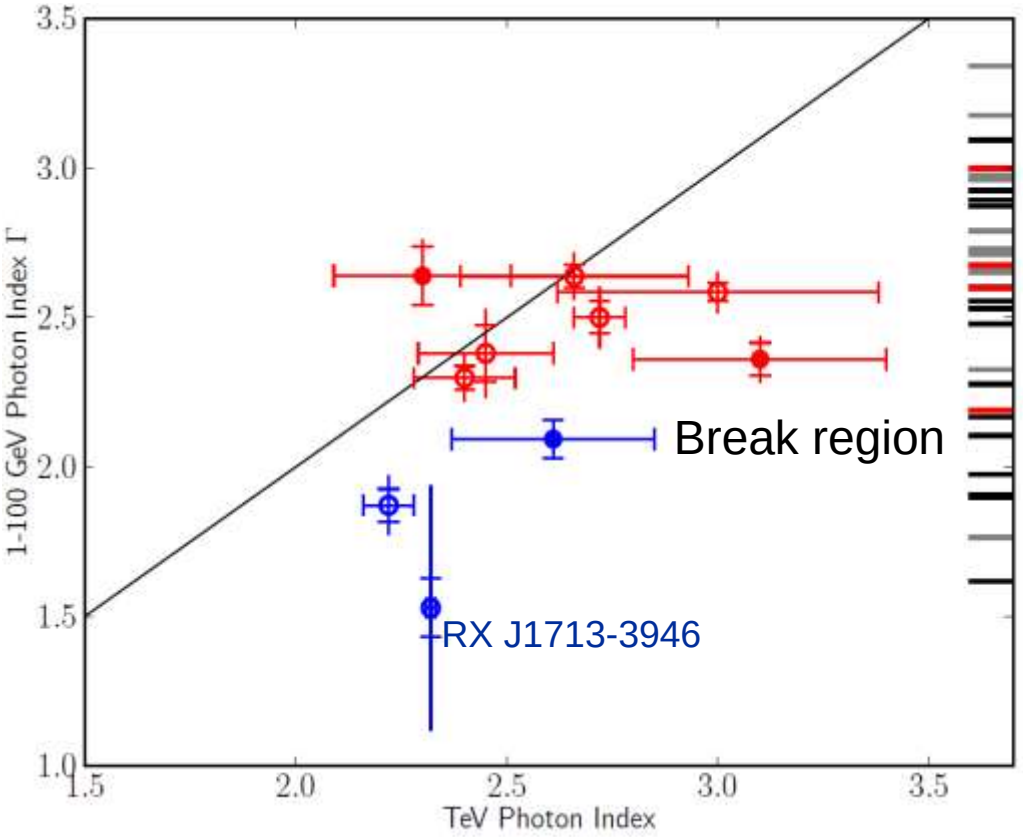
GeV-TeV Index

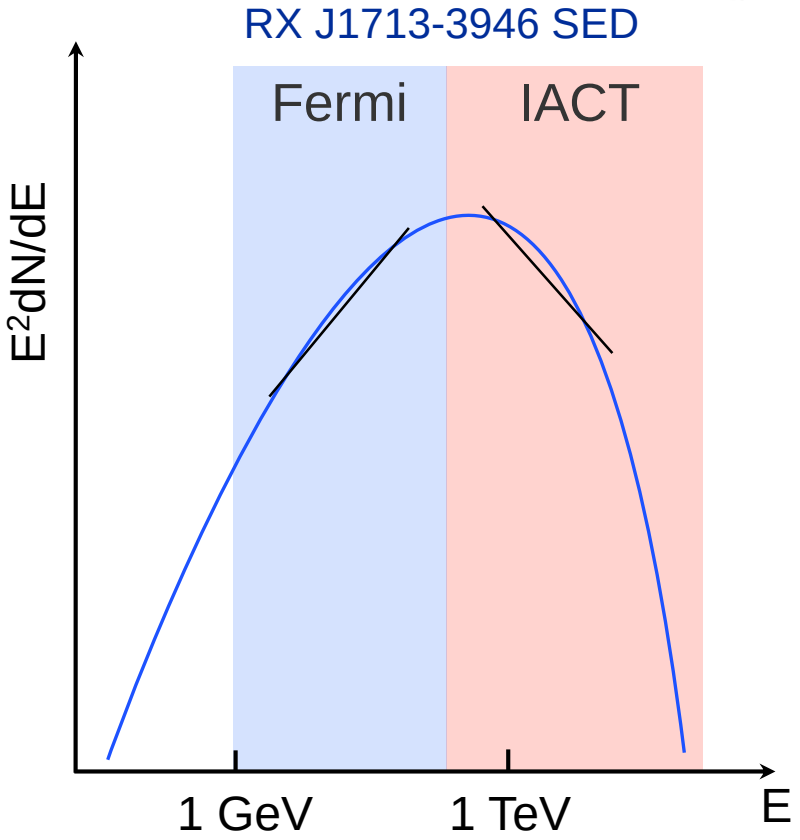




- Indication of break at TeV energies
- Caveat: TeV sources are not uniformly surveyed.

GeV-TeV Index





- Indication of break at TeV energies
- Caveat: TeV sources are not uniformly surveyed.

Environment?

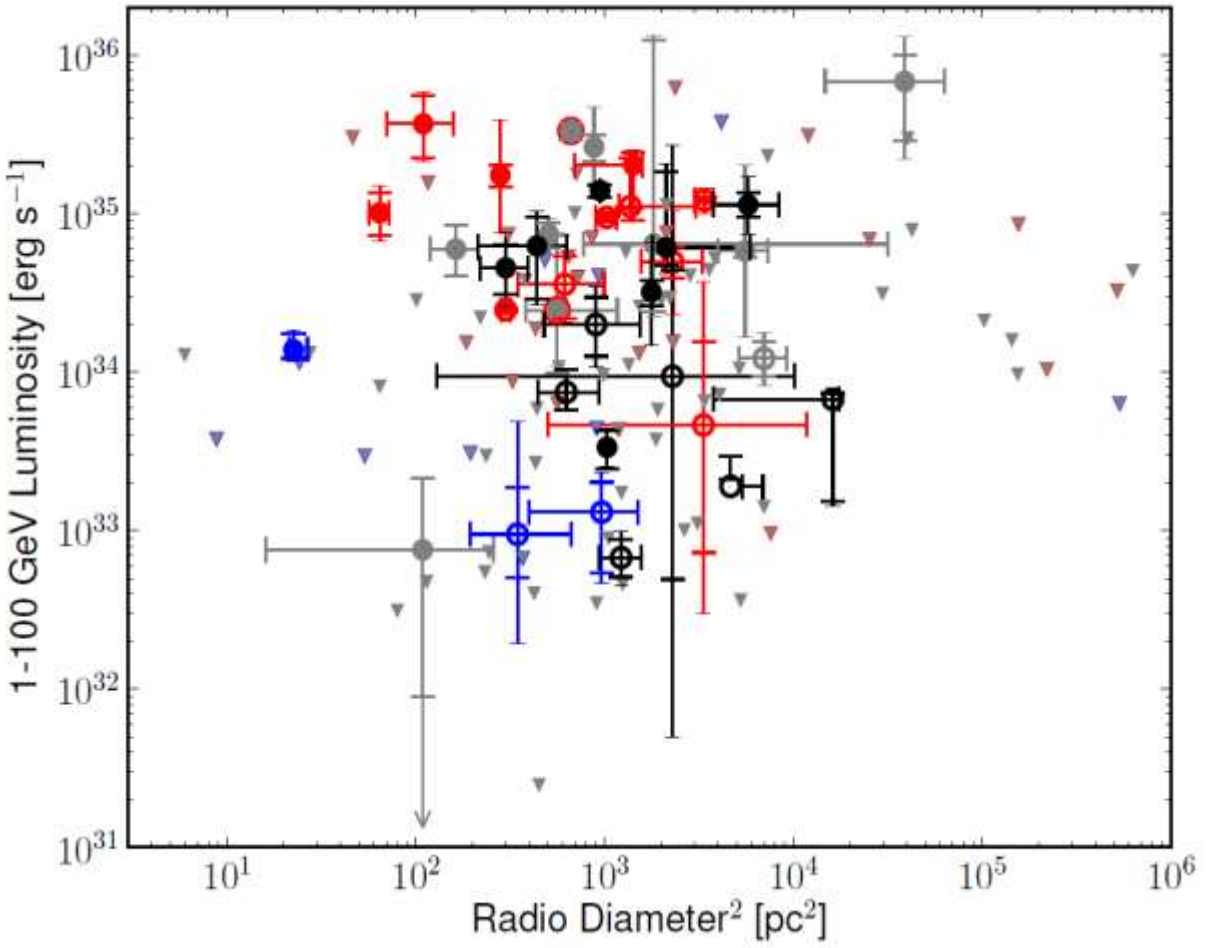
No clear trend though both axes are proportional to distance^2. Some separation between classes, diminishing as we find more, fainter candidates.

Young SNRs:

- Low $L_\gamma \rightarrow$ evolving into low density medium?

Interacting SNRs:

- Higher $L_\gamma \rightarrow$ encountering higher densities?



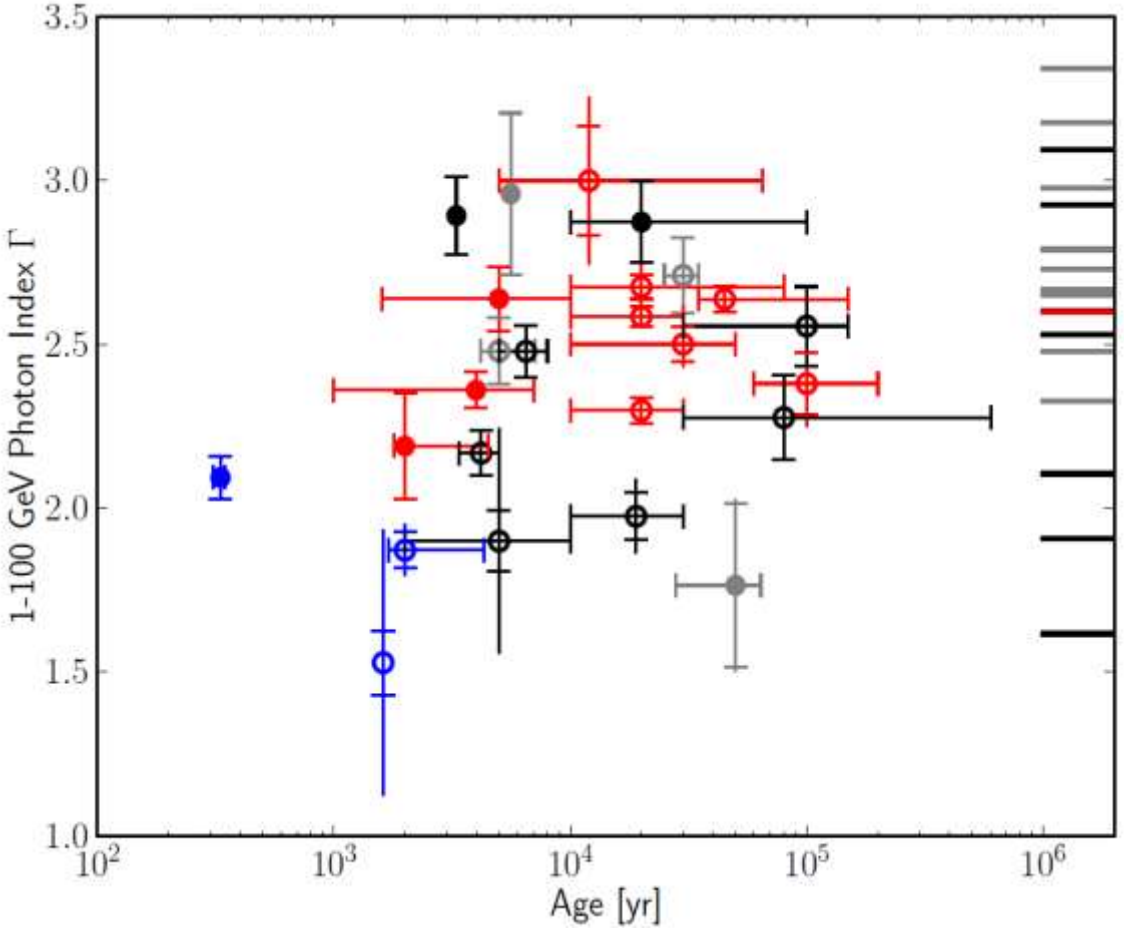
Or Evolution?

Young SNRs tend to be harder than older, interacting SNRs.

GeV index evolves with time: apparent increase for older remnants

May be due to a combination of:

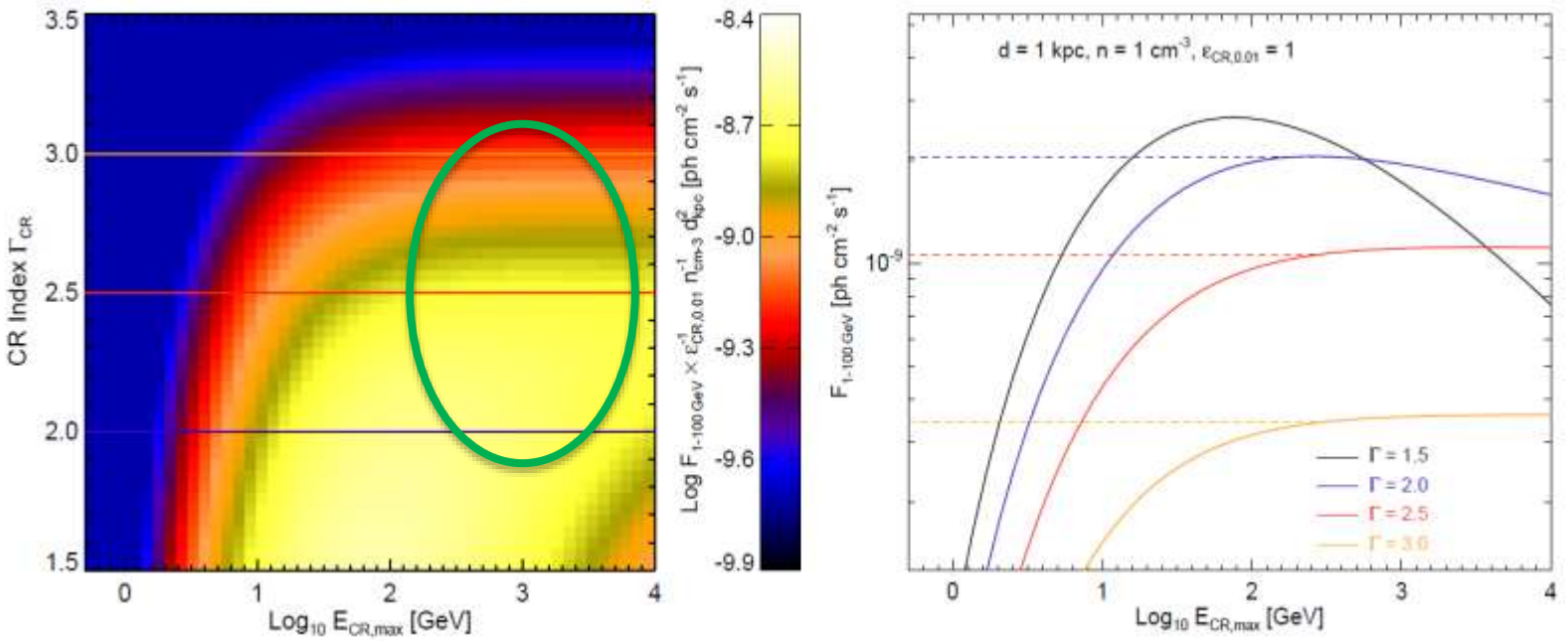
- decreasing shock speed allowing greater particle escape?
- decreasing maximum acceleration energy as SNRs age?



Constraining CR emission

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

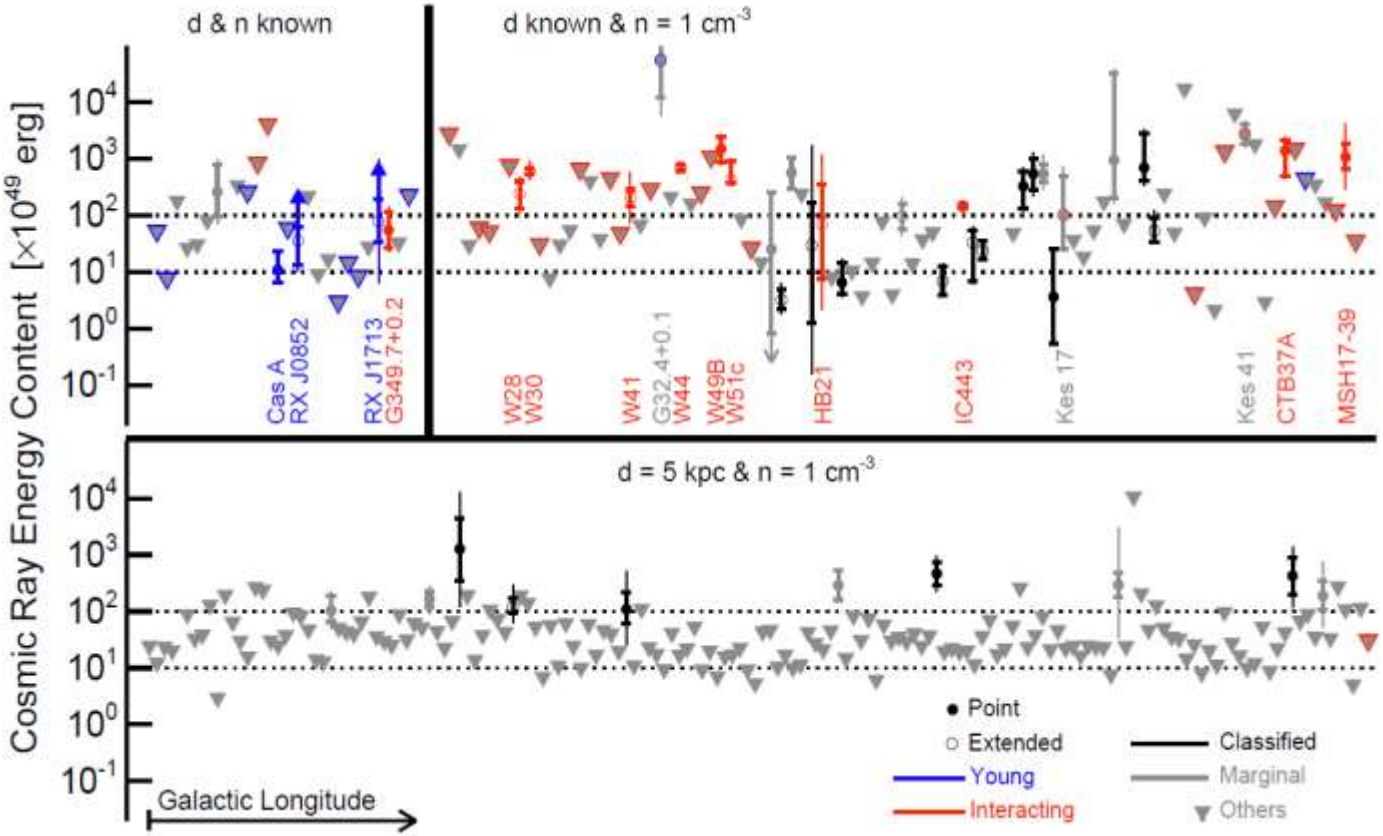
$$F(1-100\,\mathrm{GeV}) \approx f(\Gamma_{\mathrm{CR}}) \times \frac{\epsilon_{\mathrm{CR}}}{0.01} \times \frac{E_{\mathrm{SN}}}{10^{51}\,\mathrm{erg}} \times \frac{n}{1\,\mathrm{cm}^{-3}} \times \left(\frac{d}{1\,\mathrm{kpc}}\right)^{-2} \times 10^{-9}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$$



Constraining CRs from detections and ULs

The estimates and upper limits on the CR energy content span more than three orders of magnitude, from a few $10^{49}\ erg$ to several $10^{52}\ erg$.

- 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.



Conclusions

- Fermi has proved to be extremely successful in finding and studying galactic sources
- Pass 8 is allowing the detection of new extended sources and detailed studies of the morphology of extended sources, better identifying emitting regions.
- Multiwavelength analysis allows to study the emission mechanism.
- In the SNR catalog we have identified a statistically significant population of Galactic SNRs, including:
  - 17 **(4 new)** extended and 13 **(10 new)** pointlike SNR candidates
  - Candidate distribution to flux completeness of $10^{-8}\ ph\ cm^{-2}s^{-1}$ with a characteristic index of 2.5 and range [1.5, 4]
  - Candidates SNRs and ULs are generally within expectations if SNRs provide the majority of Galactic CRs.