the First Fermi-LAT Catalog of Supernova Remnants

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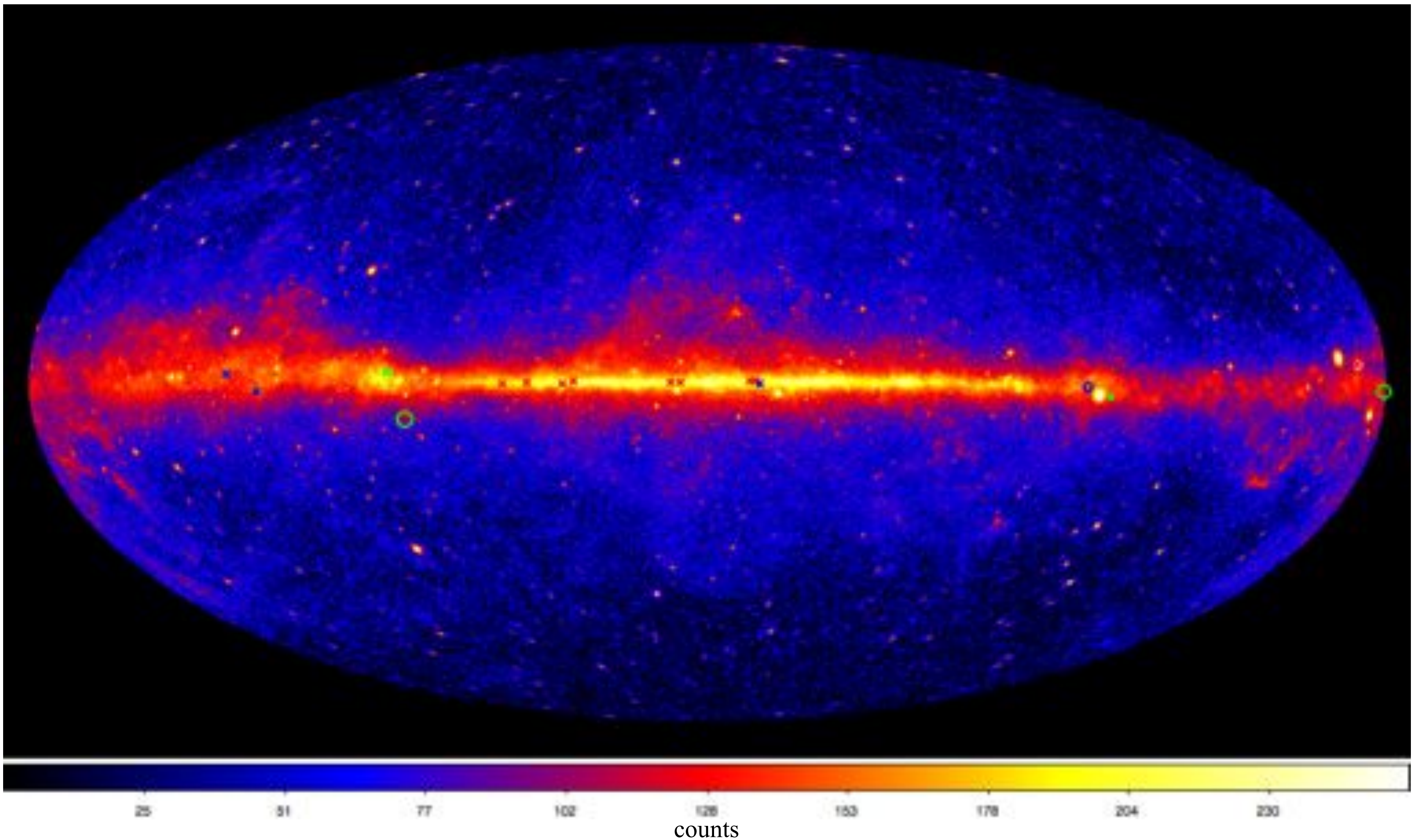
Greenbelt, MD

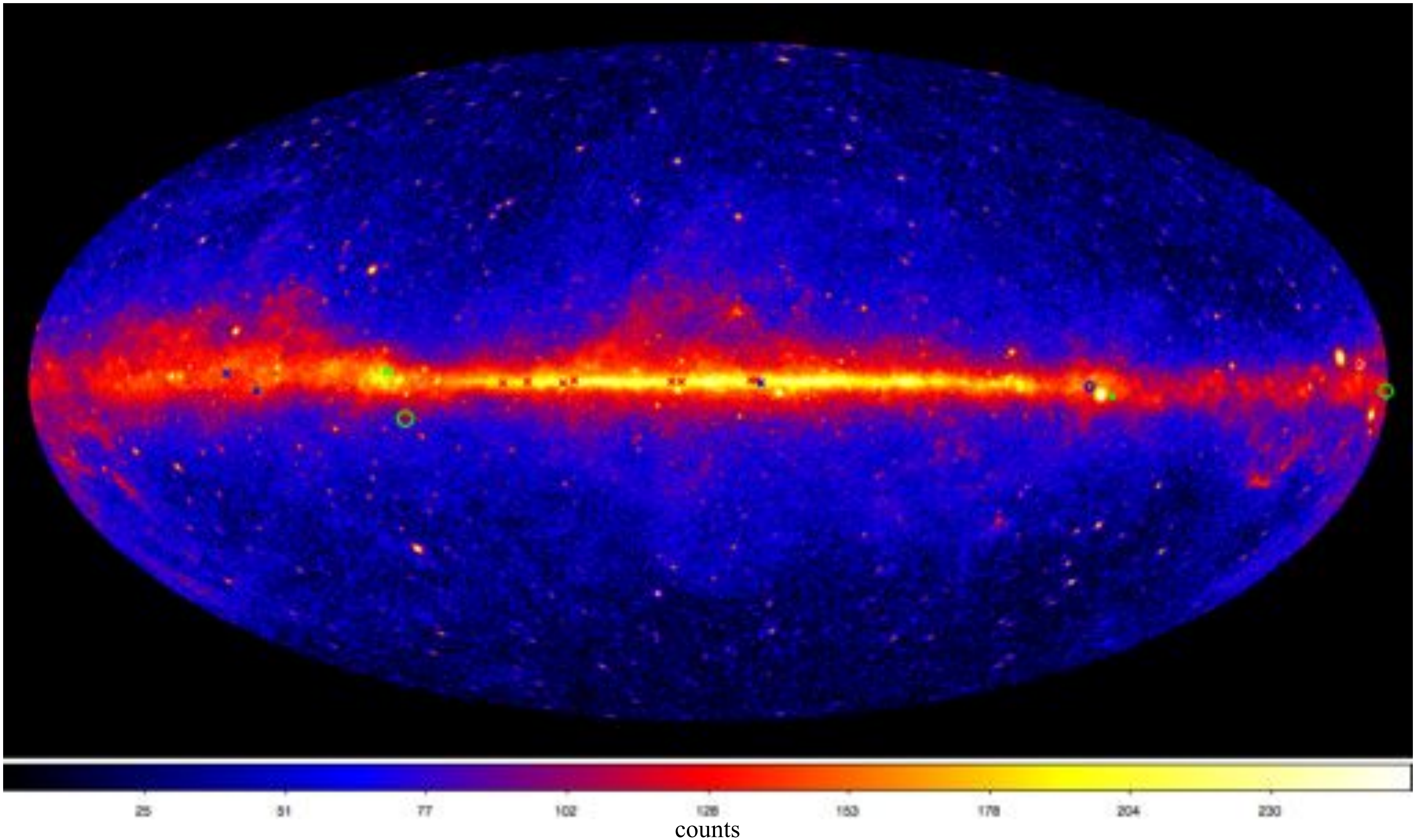
Fermi Symposium
30 Oct 2012
Monterey, CA

Fermi-Detected γ-ray Emission



Fermi-Detected SNRs

13 identified SNRs, including
- 9 interacting
- 4 young SNRs



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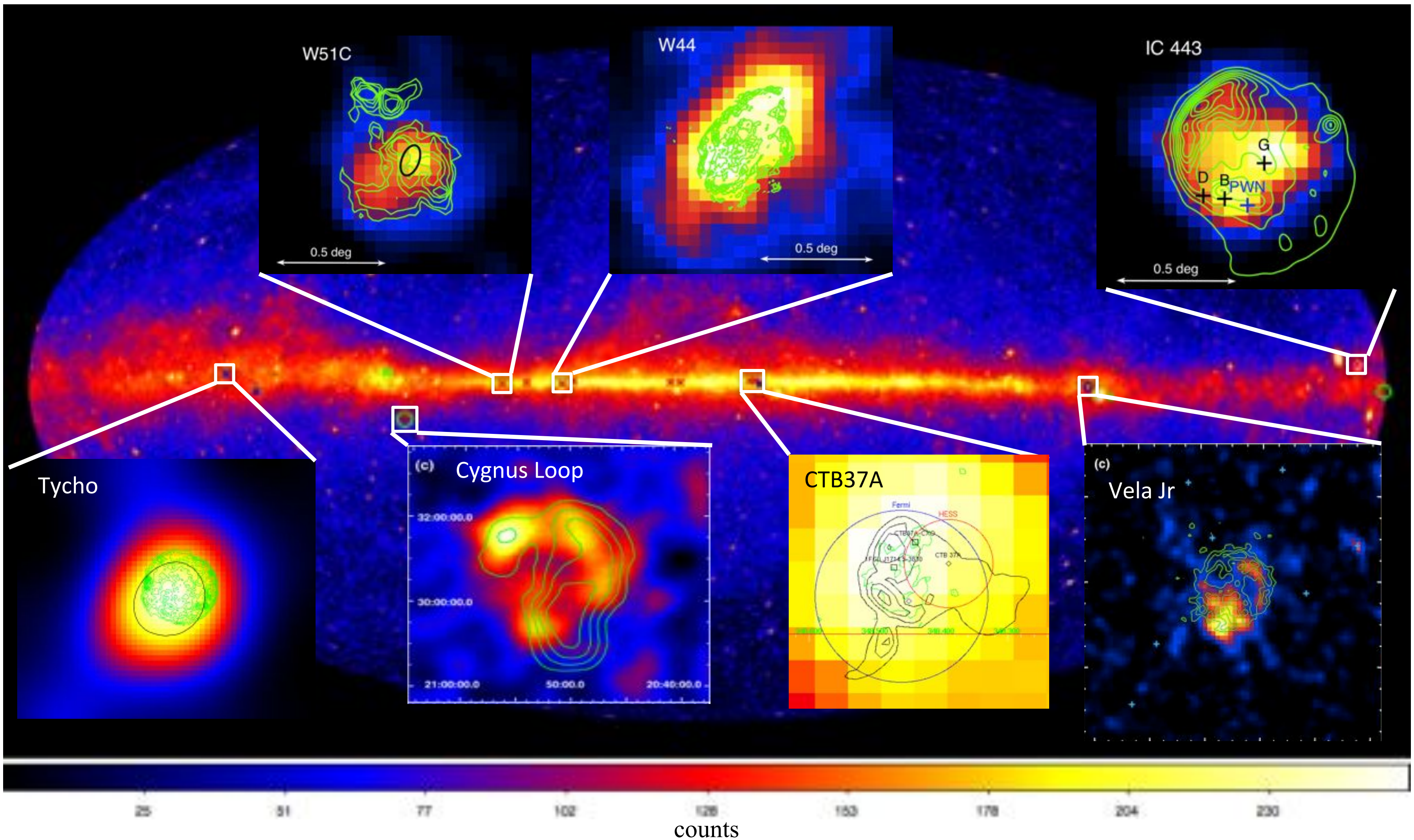

Fermi-Detected SNRs

13 identified SNRs, including
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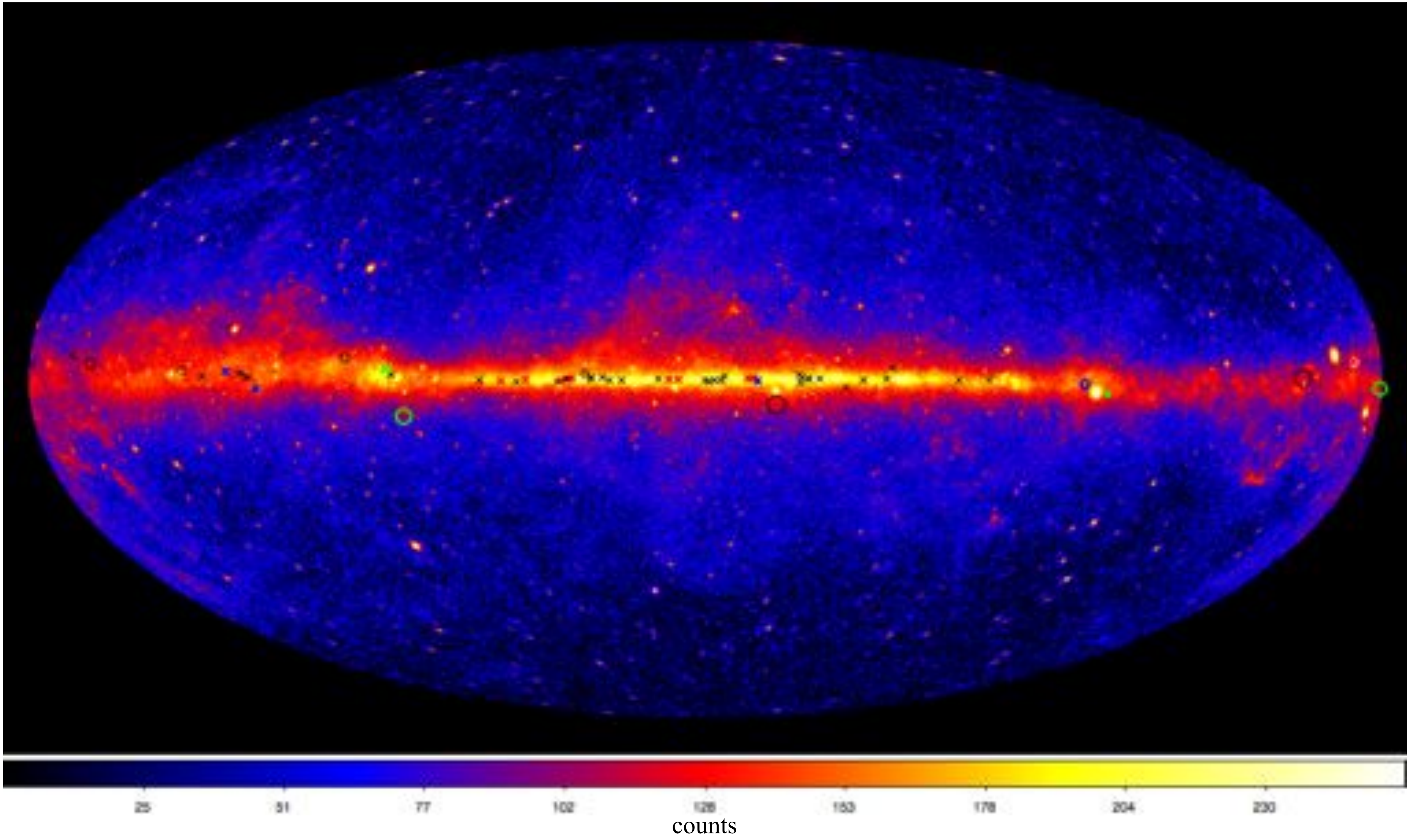
+ 43 2FGL candidates,
excluding identified PSRs, PWN, AGN



SNR Catalog:

To better understand SNRs in a statistically significant manner within a MW context.

- Characterize GeV emission in regions containing SNRs
- Examine multi-wavelength (MW) correlation, including spectrum + morphology for radio, X-ray, and TeV and CO, maser, IR, …
- Determine statistically significant SNR classification(s) and perform spectral modeling

With particular efforts from:

F. Acero, J. W. Hewitt (NASA/Goddard)

F. de Palma, F. Giordano (INFN/Bari)

CTB 37a: an Example

Detection: Fermi-LAT data shows non-variable emission from a region coincident with the MW SNR.

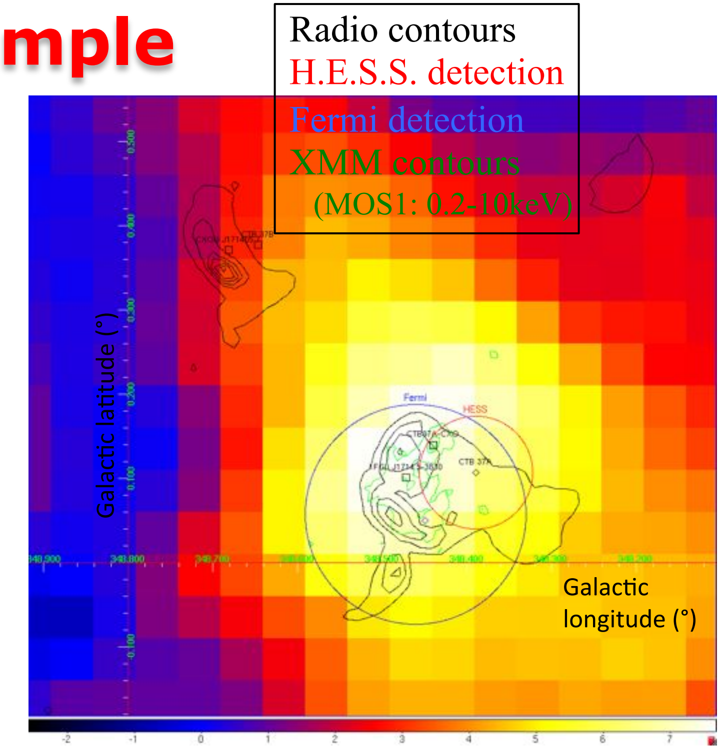
Spectral study: MW model fitting shows emission is best-fit with π^0-decay + bremsstrahlung.

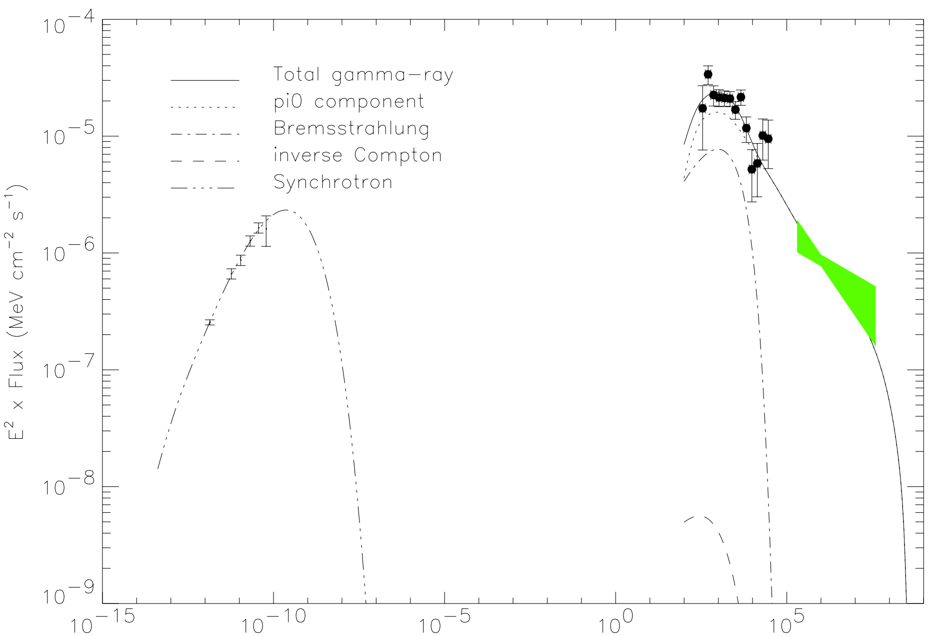
Energetics: ~5% of the energy goes into (hadronic) CRs.

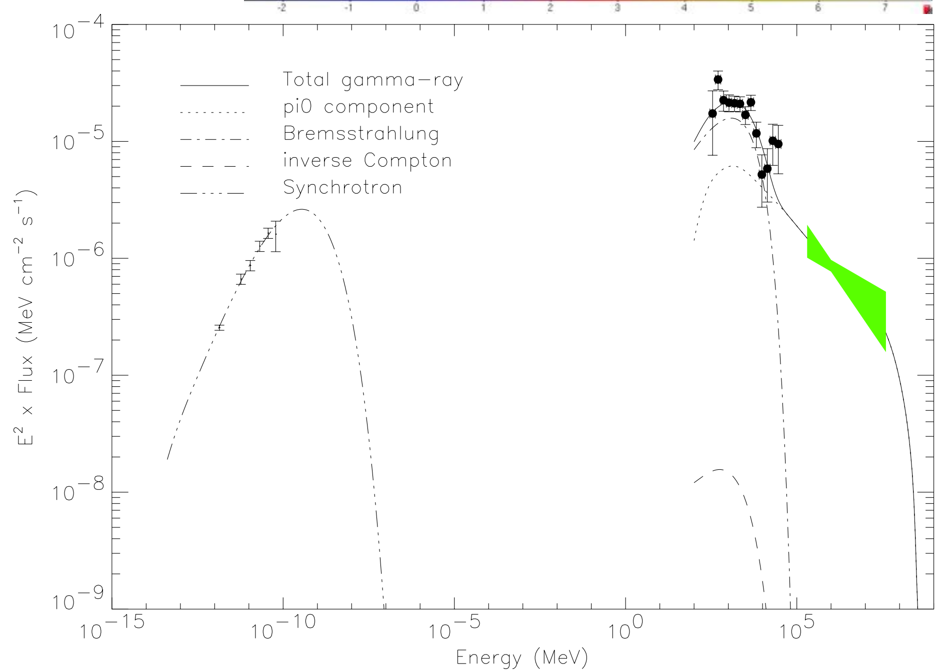
Particle populations' and environment constraints:

Particle power laws: flux, index, (lepton) cutoff E

B-field: first lower limit, constraining UL







T. J. Brandt et al. 2011

Charaterize GeV Emission: Analysis Procedure

Data Set:
- 3 years of P7SOURCE_V6 LAT data
- E: 1-100 GeV
- Region Of Interest: 10° around each SNR

Green's Catalog: (2009)
- 278 SNRs

Starting Model:
- 2FGL

Overlapping sources?
- = None: Add a new extended source
- = 1 source (not PSR): Replace w extended source
- > 1 source: Replace (non-PSR) source closest to radio centroid w extended source. Delete all other (non-PSR) sources.

Localize source, fit extension
- Disk extension seed = radio size
- Spectral model: power law
- Normalization of Galactic diffuse and all sources w/in 5° of candidate are free during minimization procedure.

Output:
- Position, extension, significance
- Spectral energy distribution
- Region and residual maps
- Diagnostics

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Effect of starting model:
- See J. Cohen's poster!

Localize source, fit extension
- Disk extension seed = radio size
- Spectral model: power law
- Normalization of Galactic diffuse and all sources w/in 5° of candidate are free during minimization procedure.

Characterizing systematic error from the interstellar emission model:
- See F. de Palma's poster!

Output:
- Position, extension, significance
- Spectral energy distribution
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Details of analysis pipeline:
- See F. Giordano's poster!

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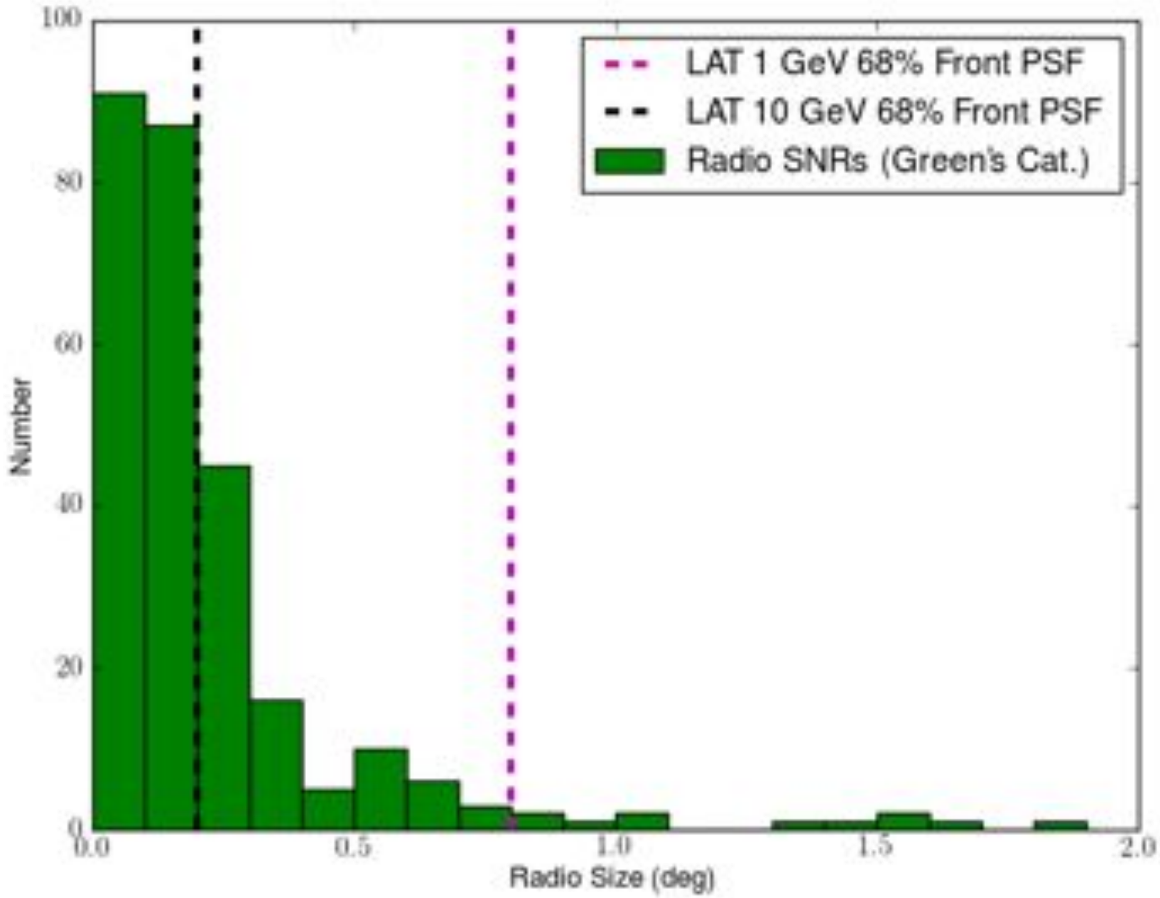
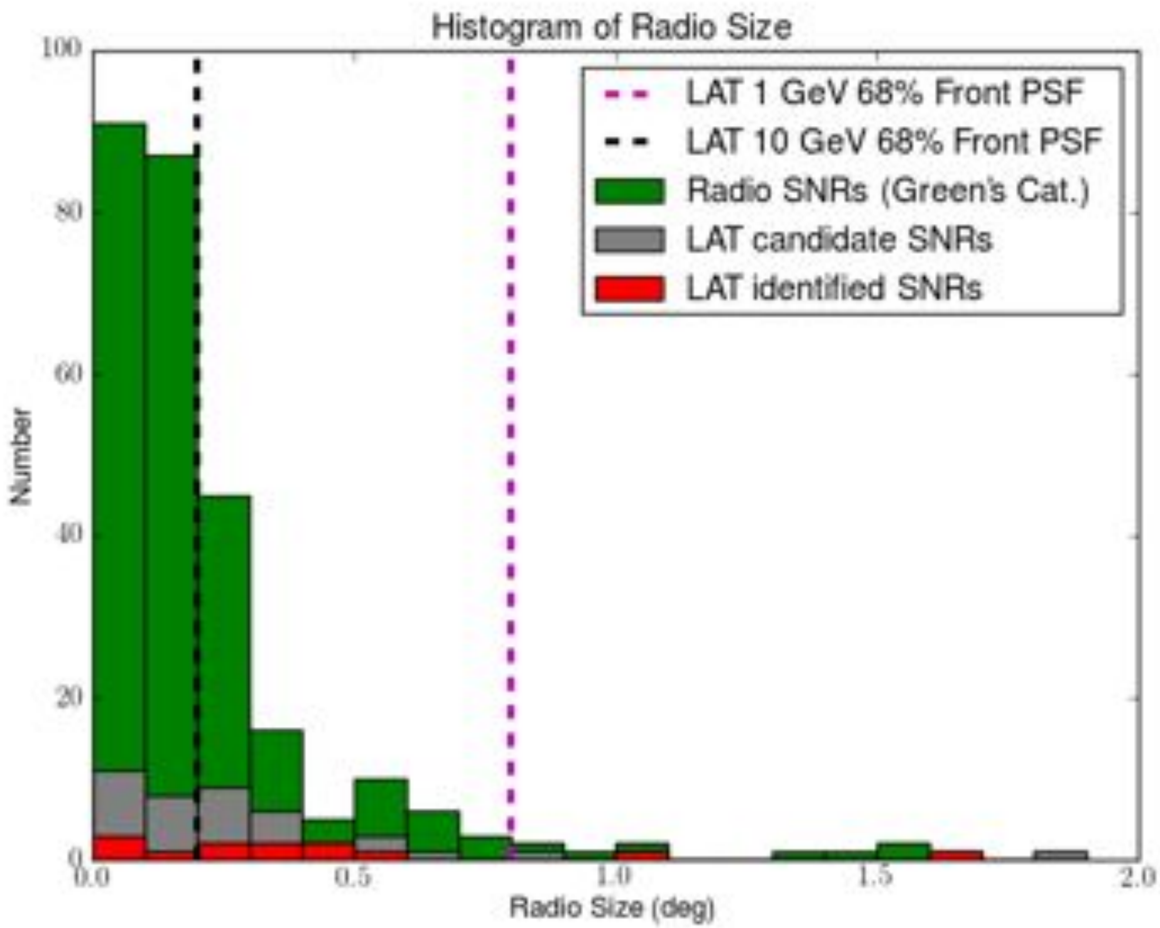
SNR Catalog:

- Fermi-LAT has the ability to spatially resolve a large number of the 278 known SNRs.



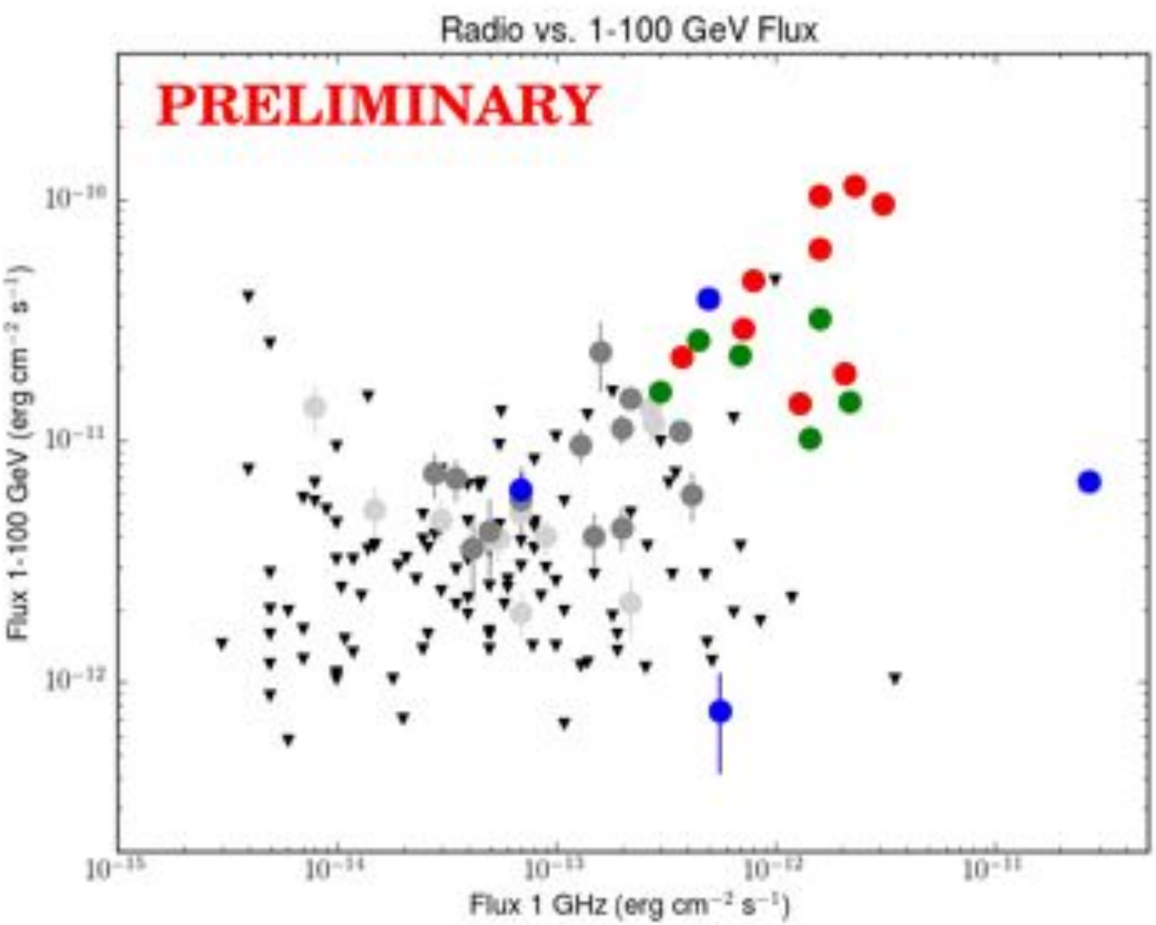
SNR Catalog:

- Fermi-LAT has the ability to spatially resolve a large number of the 278 known SNRs.
- Spatial extension measured for 15 SNRs, including 6 new candidates, permitting clear identification.



Radio-GeV Correlation?

Radio synchrotron emission indicates the presence of relativistic leptons.
LAT-detected SNRs tend to be radio-bright:



- Interacting SNRs: general correlation suggests a physical link
- Young SNRs show more scatter

Pt. Candidate SNRs
Pt. Candidate PSRs
Ext. Candidate SNRs
ID'd Interacting SNRs
ID'd Young SNRs

upper limits
(i=2.5, 99%)

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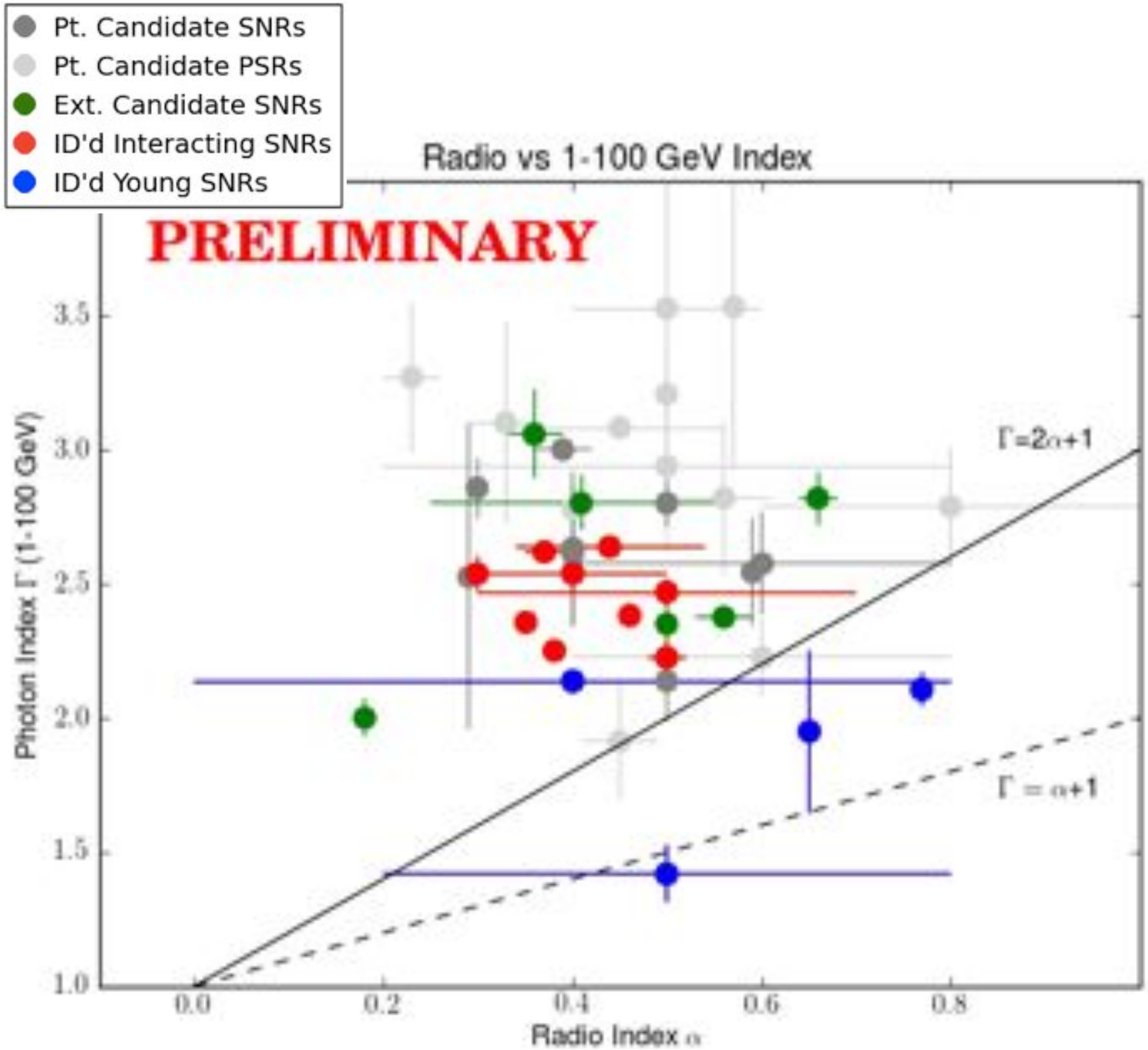
Radio-GeV Index

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

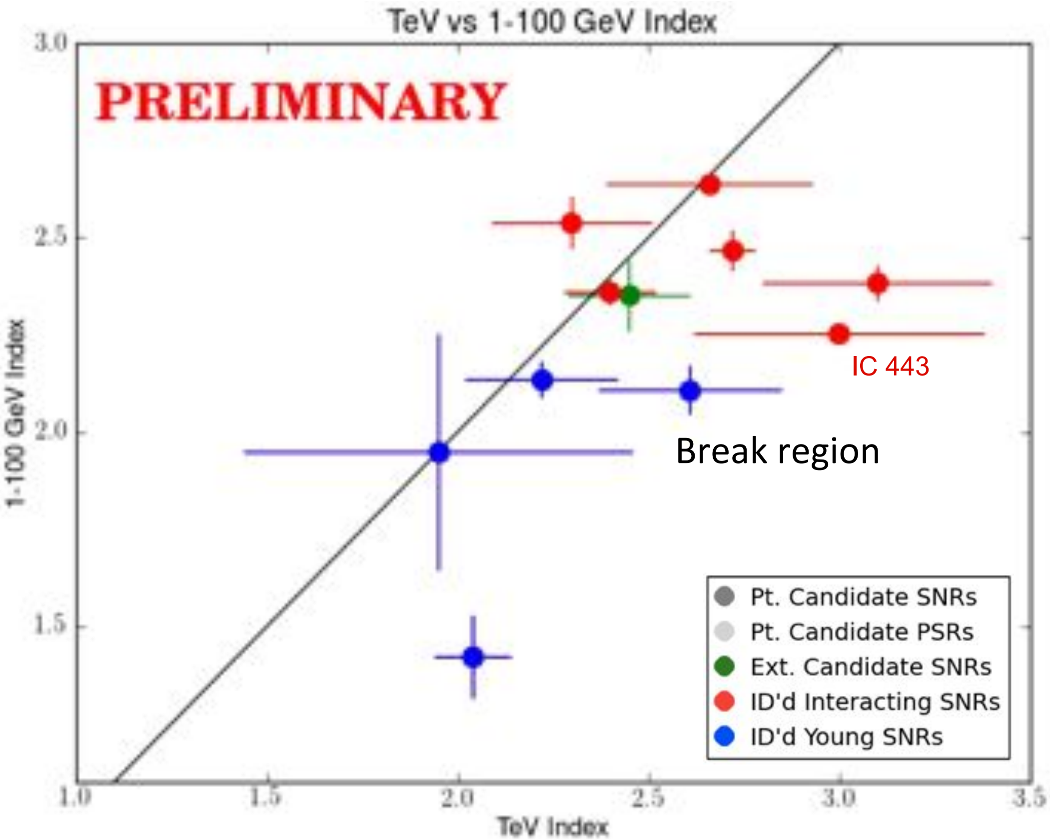
GeV-Radio slope correlation for:

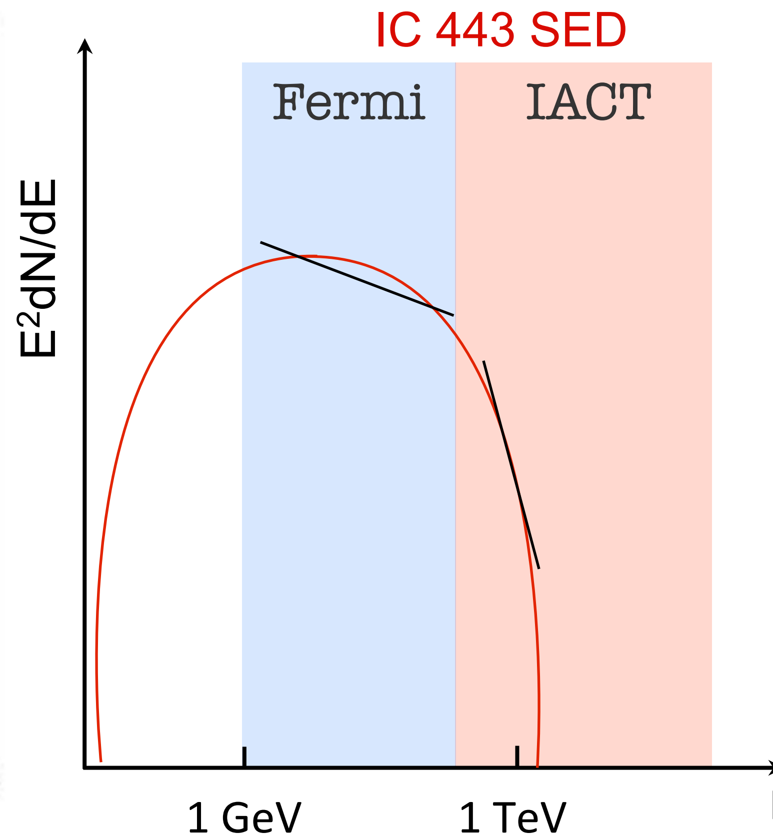
- π^0 decay or $e^{+/-}$ bremmstrahlung
- inverse Compton

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?

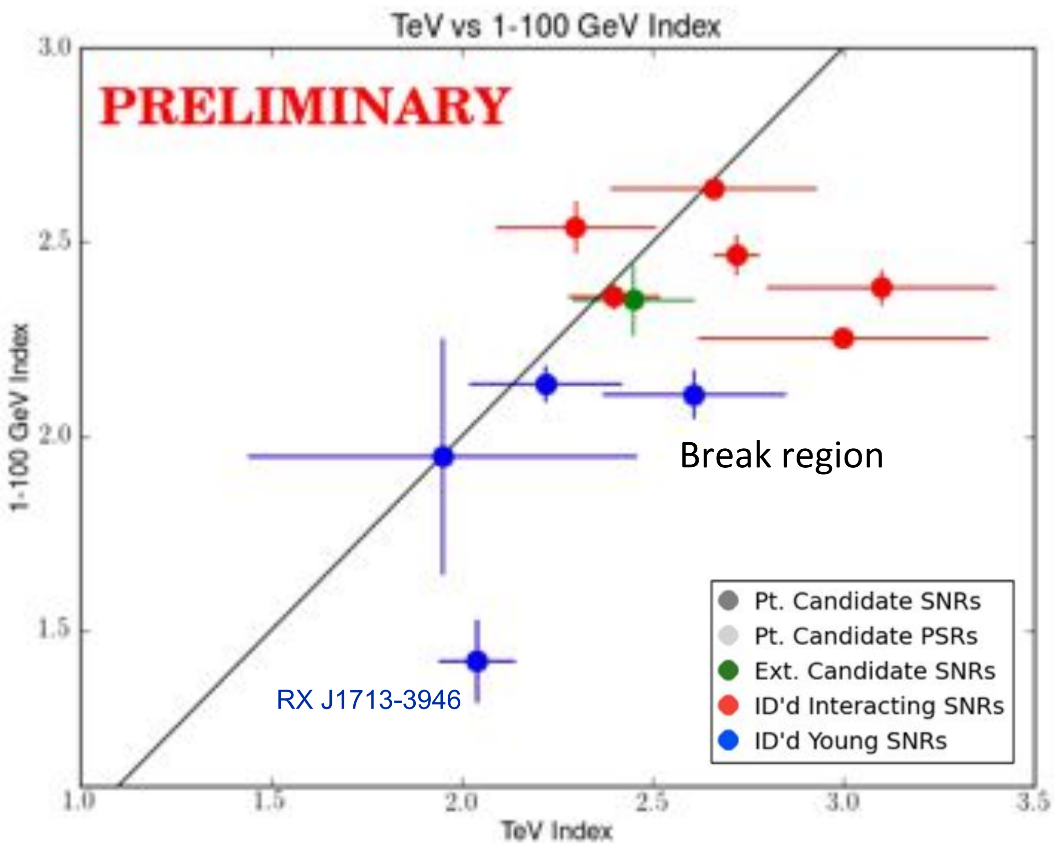
GeV-TeV Index

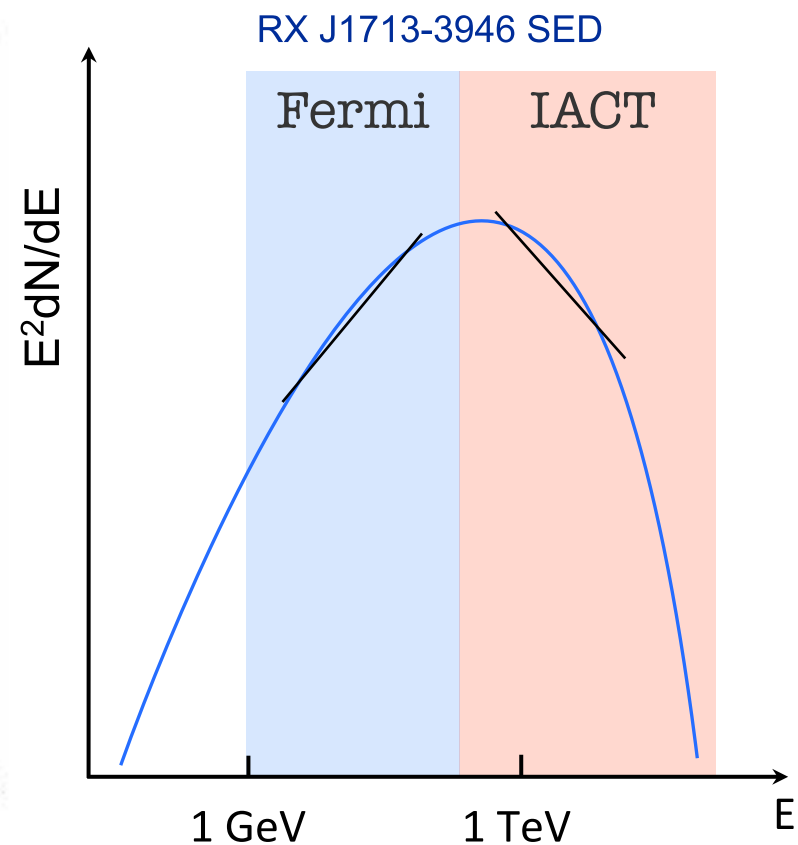




- Indication of break at TeV energies
- Caveat: TeV sources are not uniformly surveyed.

GeV-TeV Index





- Indication of break between GeV and TeV
- Caveat: TeV sources are not uniformly surveyed.

Environment?

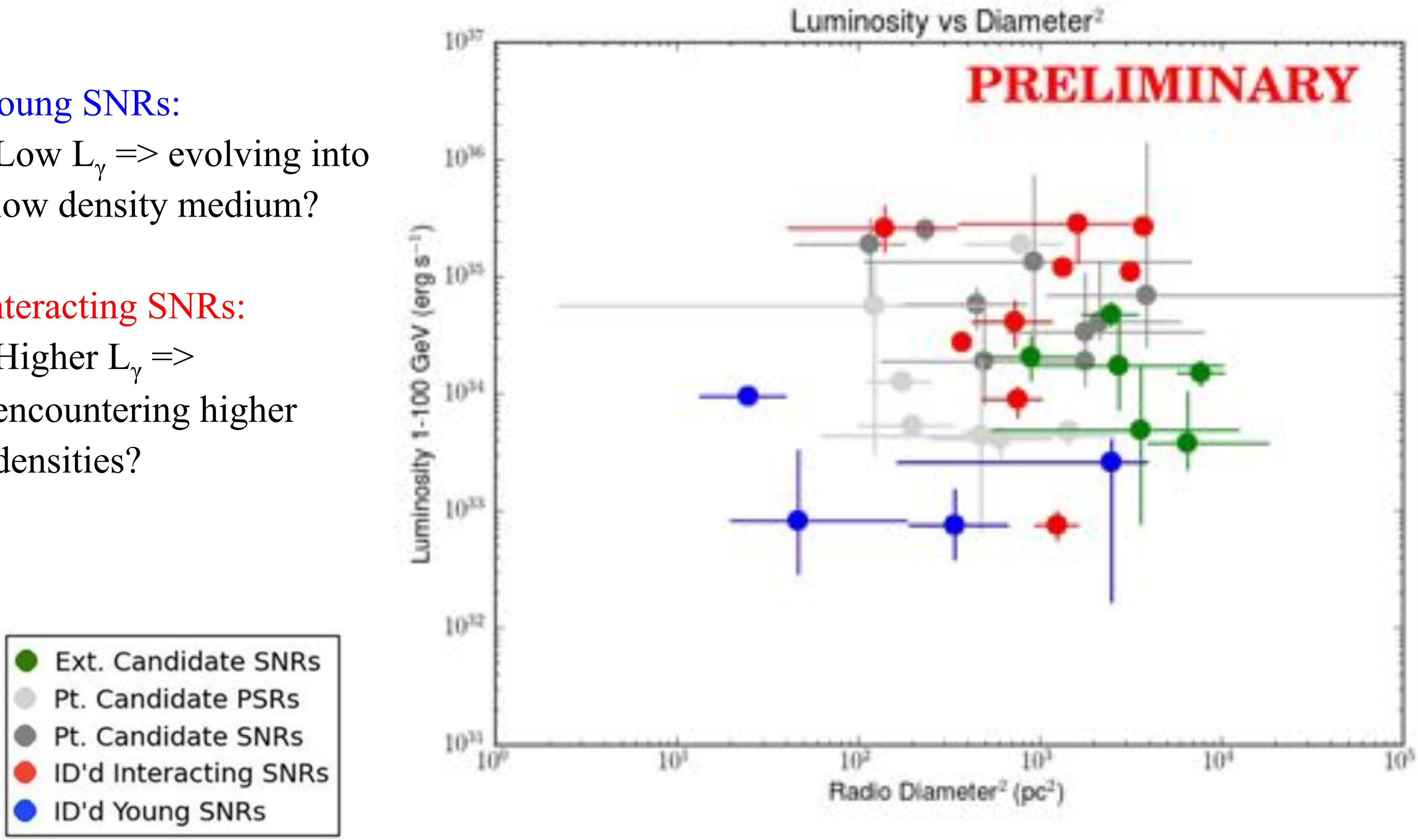
Interacting SNRs tend to be more luminous than young SNRs.

Young SNRs:

- Low L_γ => evolving into low density medium?

Interacting SNRs:

- Higher L_γ => encountering higher densities?

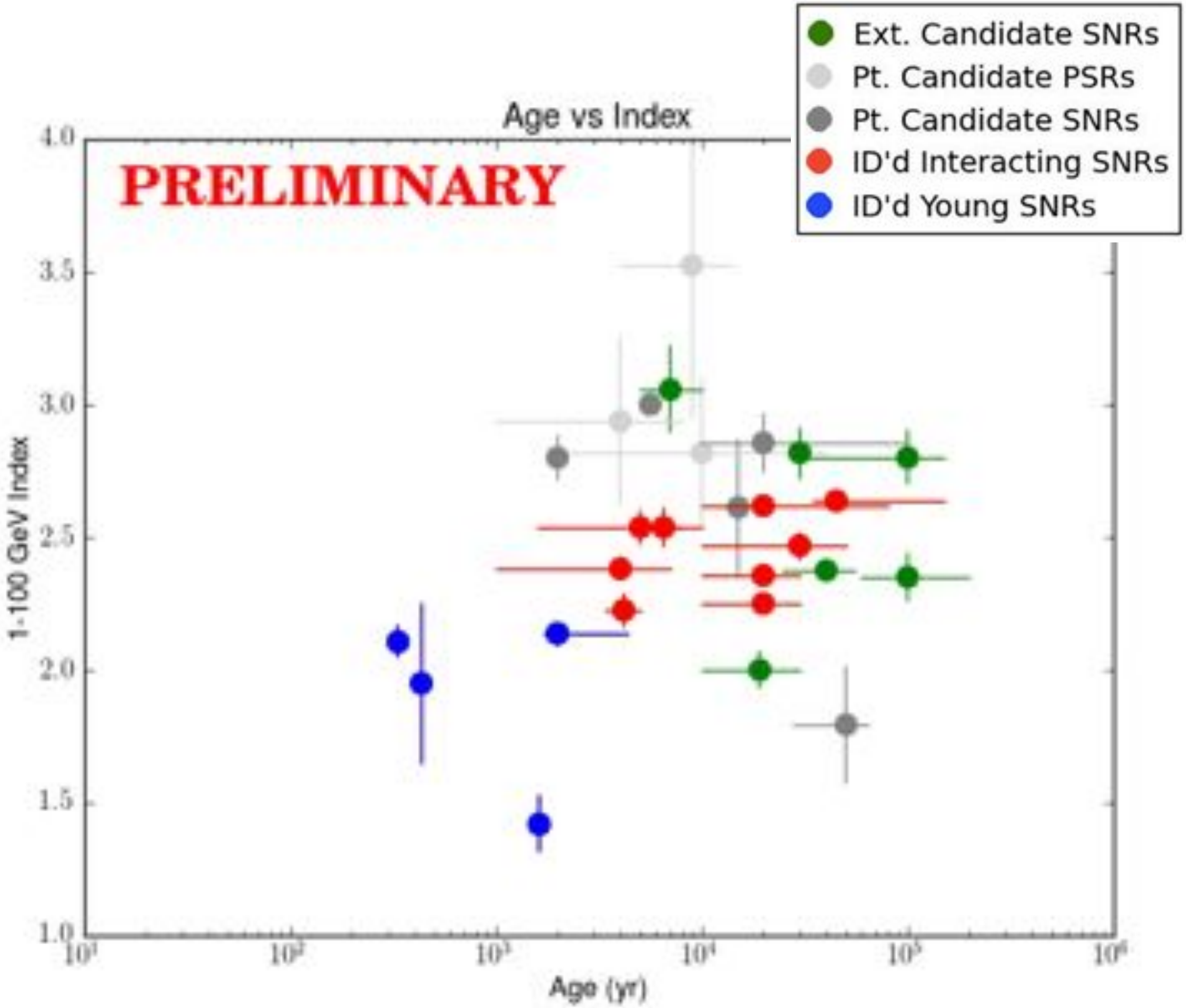


… or Evolution?

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

Due to

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

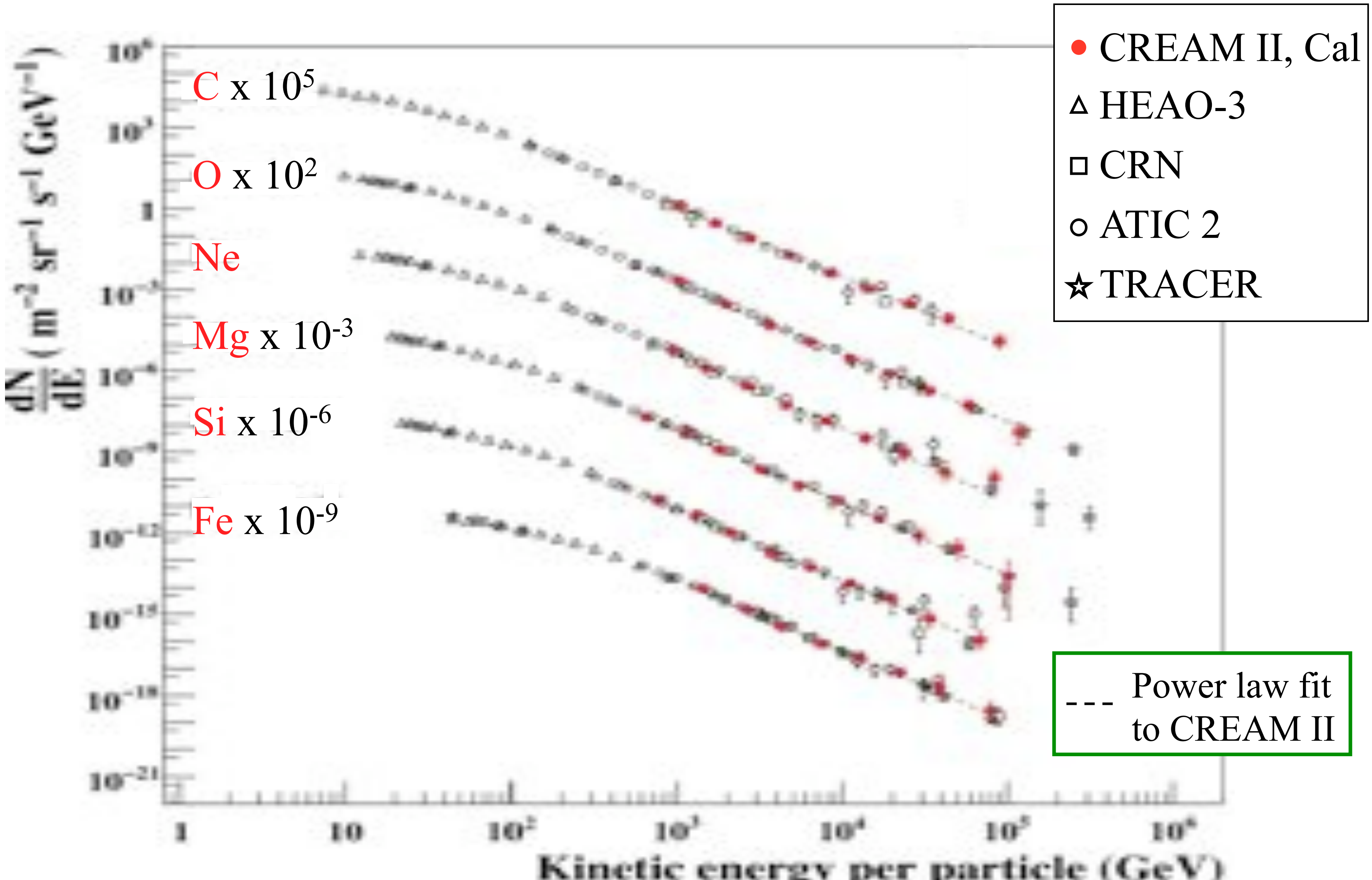


Conclusions

- Our systematic study of a statistically significant population of galactic SNRs
  - has identified 6 new extended and >25 new point-like SNR candidates
  - in at least 2 GeV-luminous classes: young and interacting SNRs.
- Combining our GeV with MW observations
  - suggest that some SNRs' emitting particle populations are linked
  - demonstrates that our simple assumptions are no longer sufficient and
  - allows us to test more complex acceleration and emission models for a variety of environments, ages, and progenitors.
- Improved observations and modeling will
  - give us greater insight into SNRs, their acceleration mechanisms and their accelerated particles
  - yield further evidence for CR origin and acceleration
- Accurately estimating SNRs' aggregate particle acceleration ability will also allow us to better quantify SNRs' ability to produce the observed CRs.

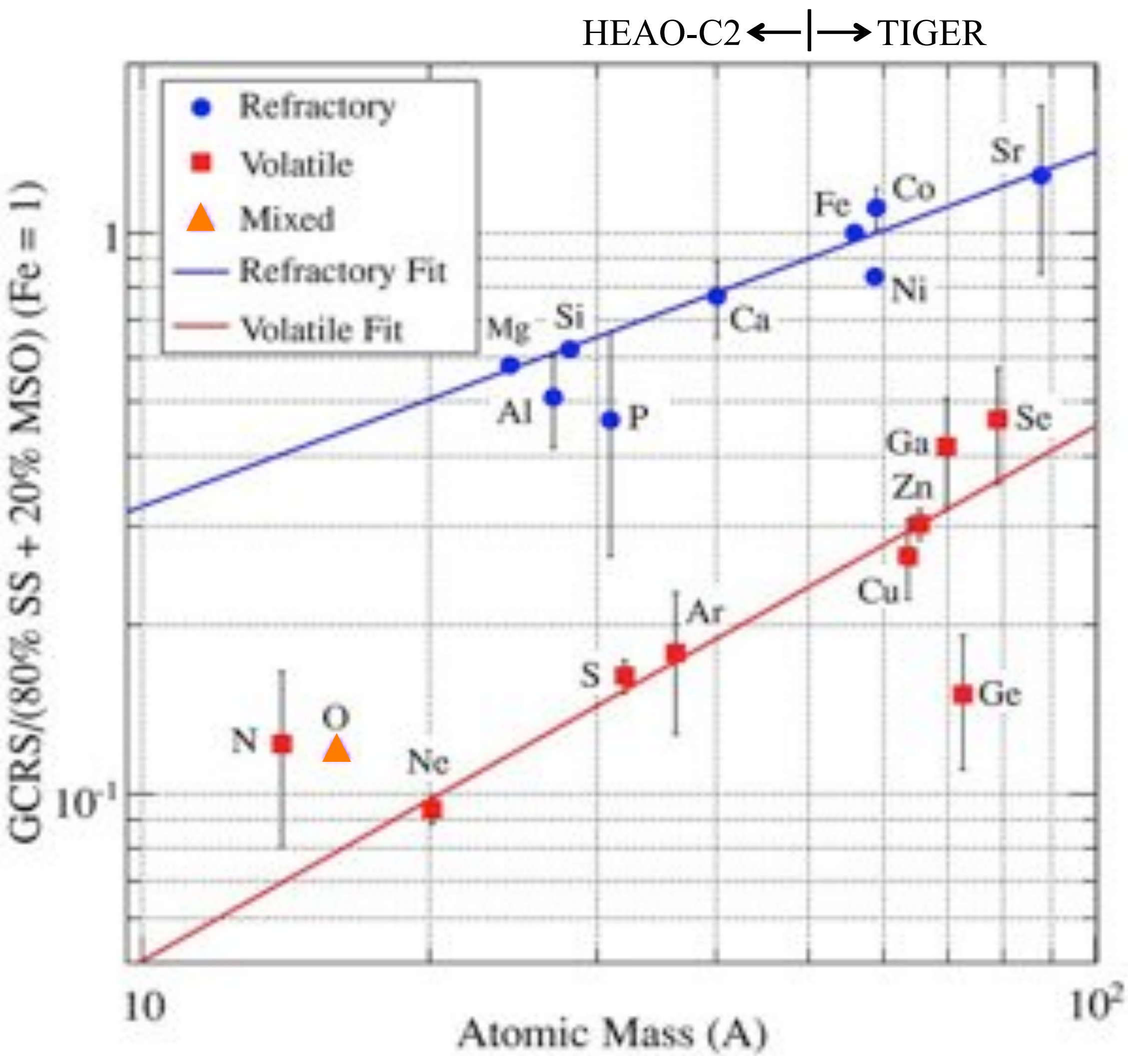
End of slide show

Primary Nuclei Spectra



Ahn, et al. ApJ 2010

TIGER Results: 50 days' Data



- Volatile: low boiling point
- Refractory: found in interstellar dust

Super-TIGER adds

- Refractory:
  Zr (A=91) and Mo (A=96)
- Volatile:
  Kr (A=84) and Rb (A=86)

TIGER + Super-TIGER:

- Statistical error reduced by ~factor of 3

B. F. Rauch et al. 2009 ApJ 697

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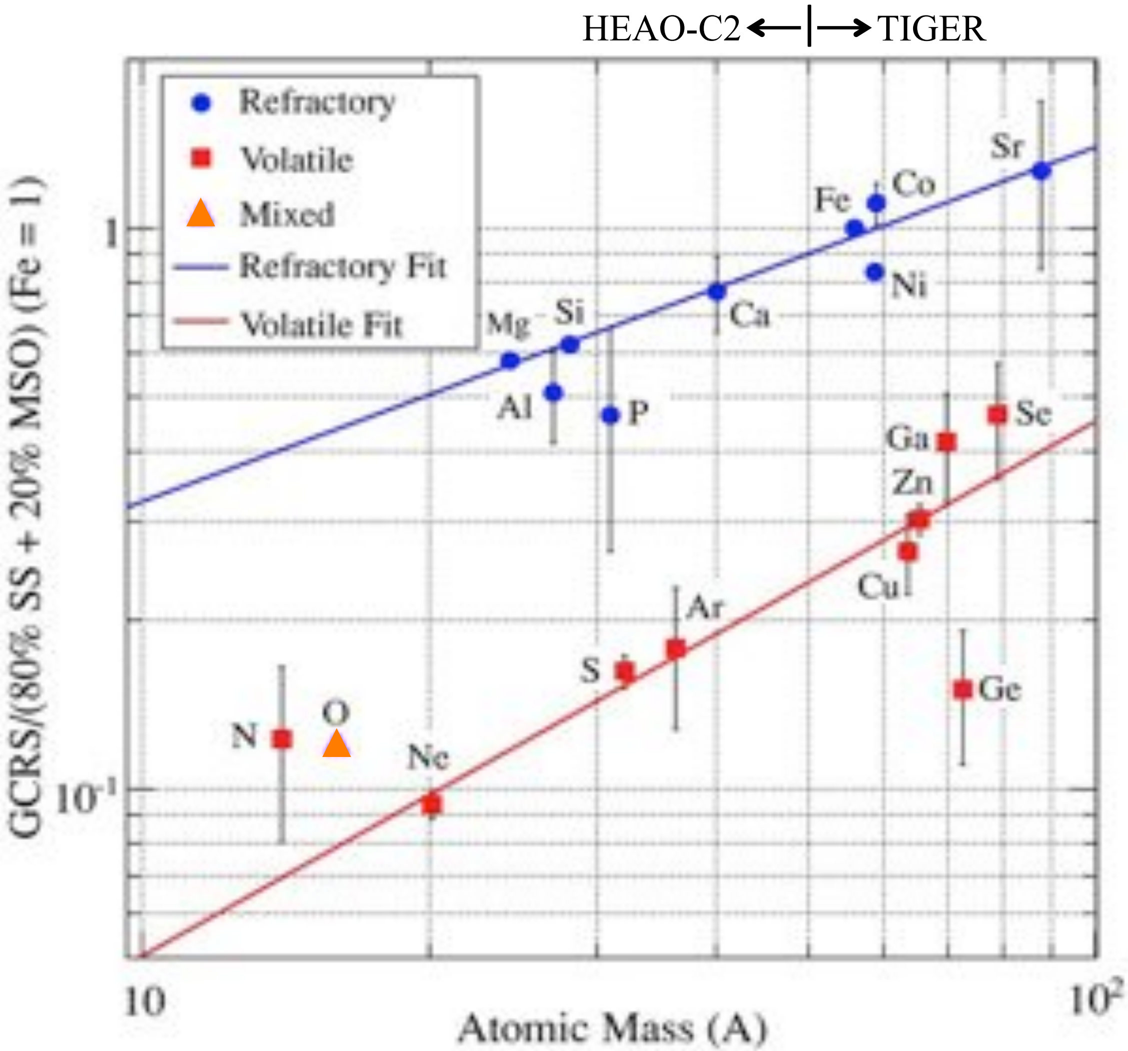

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CR Source:
- ~20% massive star ejecta
- ~80% solar system

Acceleration:
- Mass-dependent:
  - refractory ~ $A^{2/3}$
  - volatile ~ A^1
- More efficient for refractories than volatiles

Check:
- ~12% O sequestered in dust grains
- O excess is ~12% of the expected abundance for a refractory at A=16

B. F. Rauch et al. 2009 ApJ 697