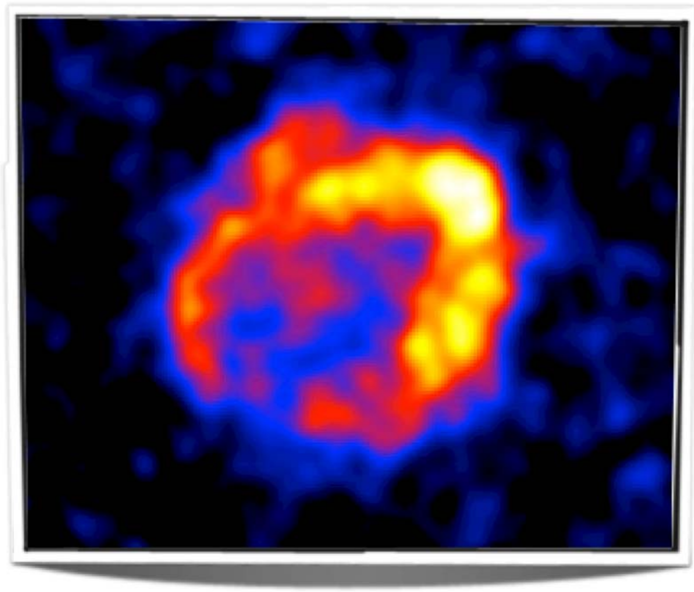
Gamma-ray Supernova remnants

Stefan Funk, August 5th 2011, TeVPA

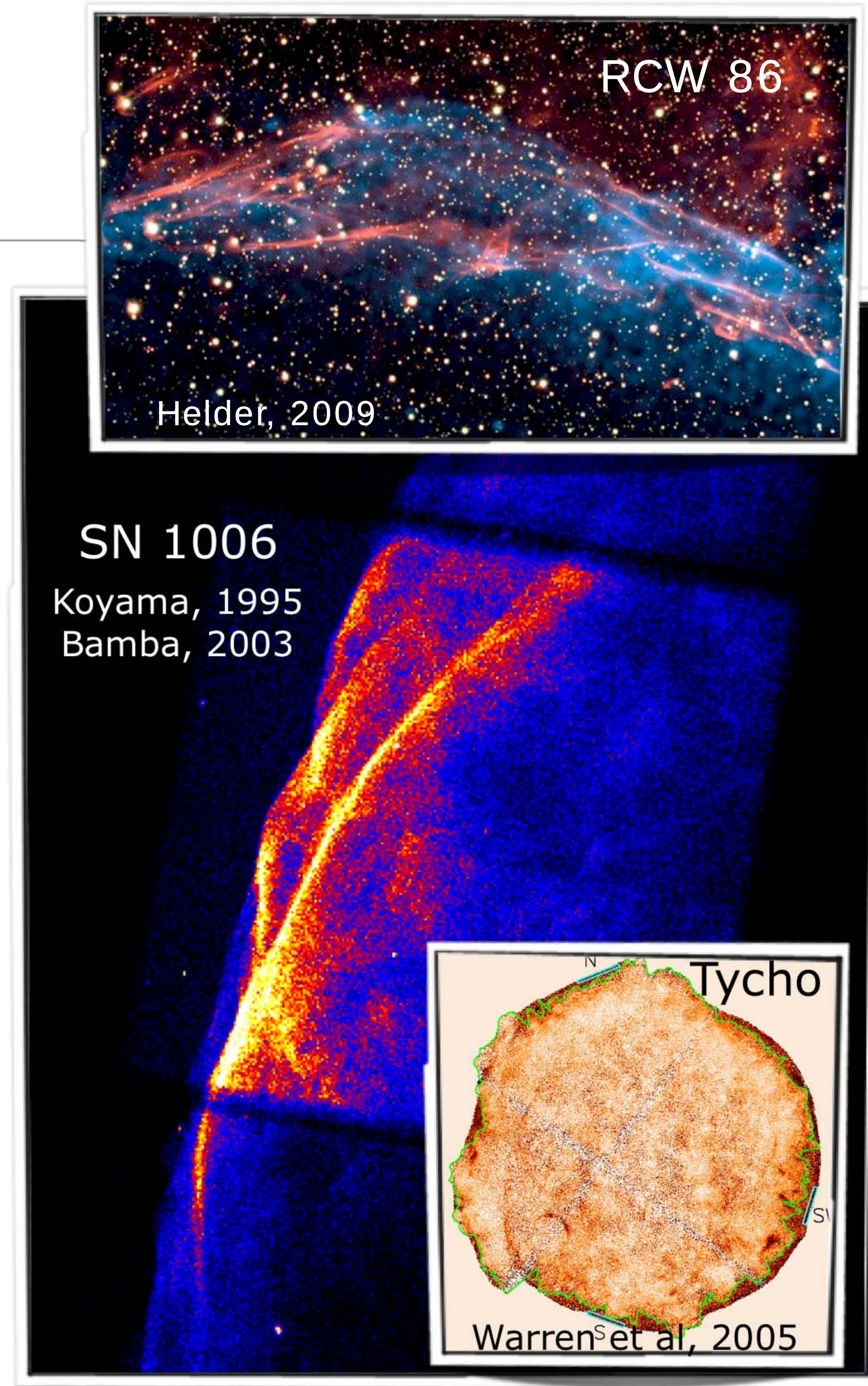
High-energy Supernova remnants



- Cosmic particle accelerators (X-ray synchrotron suggesting 100 TeV e^-)
- Prime candidate for Proton acceleration to the knee
  - Energetics: 10% of kinetic energy of SN would suffice
  - Diffusive shock acceleration (prediction: power-law in energy)
- Magnetic field amplification by factor O(100), SNRs accelerate protons to 10^{15} eV

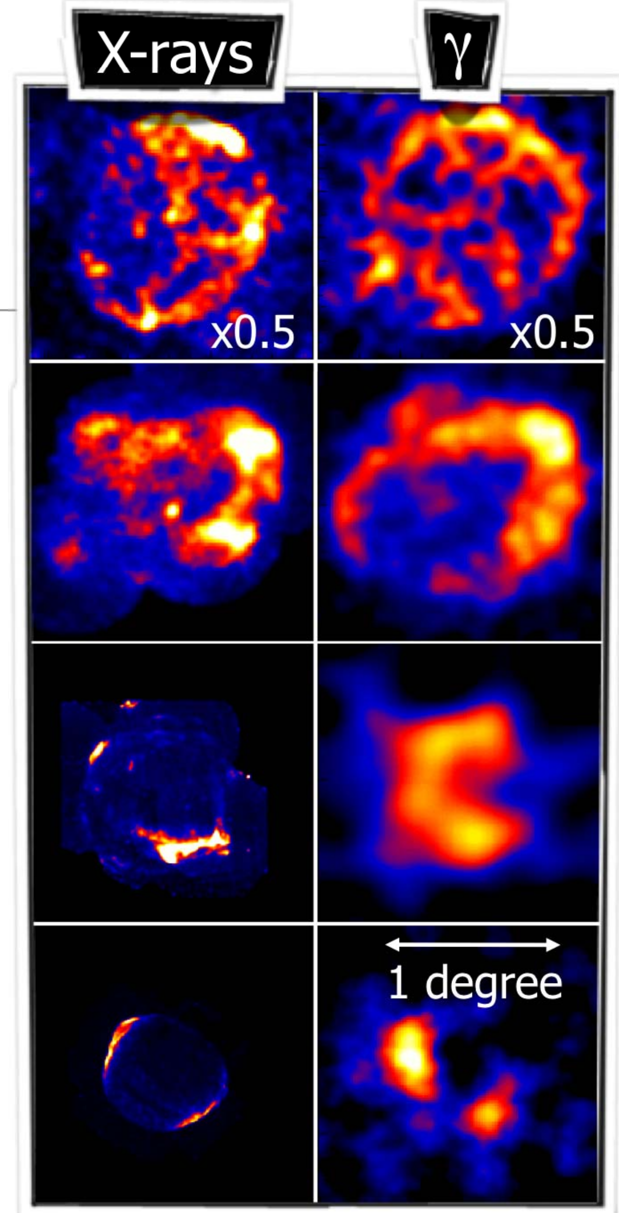
Observational evidence for protons

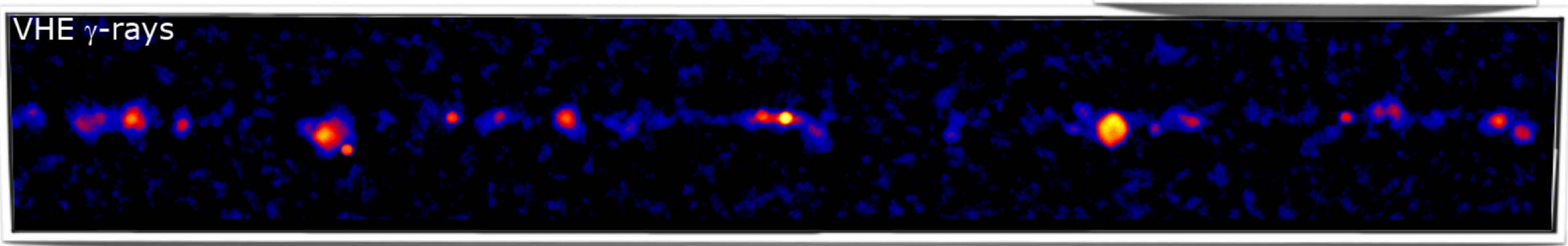
- Strong indirect indications for p^+ in young SNRs, mainly from Chandra X-rays:
  - **Large (mG) B-Fields**:
    - Small filaments (cooling times), (Bamba 2003, ...)
    - X-ray variability on yearly timescale, (Uchiyama 2008, ...)
  - **Large proton pressure:**
    - Large B-fields (CR pressure)
    - Proximity of contact discontinuity to forward shock (Warren 2005)
    - Post-shock temperature very low. CRs are an additional sink of energy (Helder 2009)



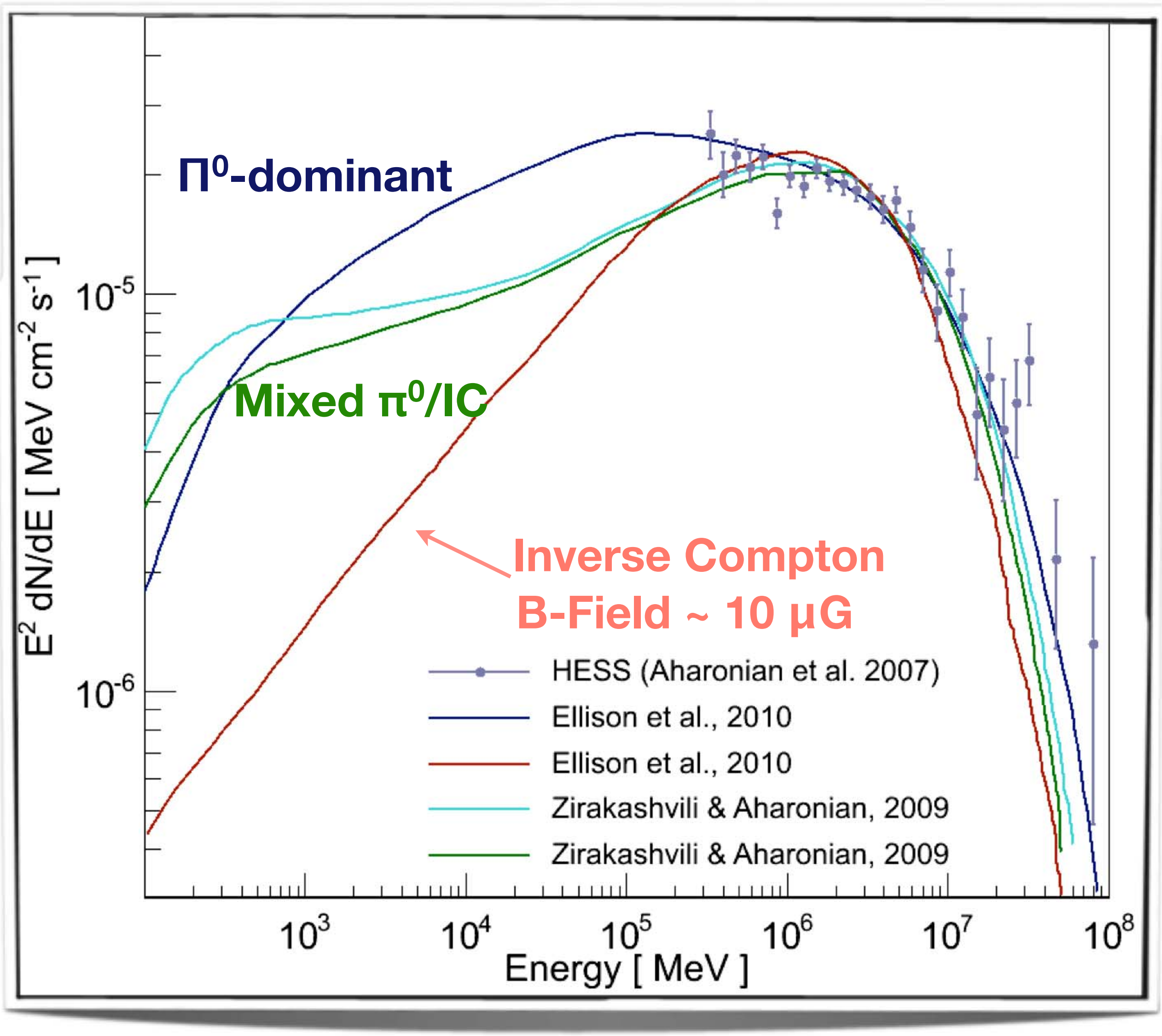
Shell-type SNRs in TeV γ-rays

- 4 Young (historical) SNRs resolved at TeV energies
  - Vela Junior
  - RX J1713.7-3936
  - RCW 86
  - SN 1006
- Clear correlation with non-thermal X-rays
- Detection of Cas A, Tycho, W28 (~15 safe associations)
- upper limits for Kepler SNR





Protons or Electrons? E.g. RX J1713.7-3946



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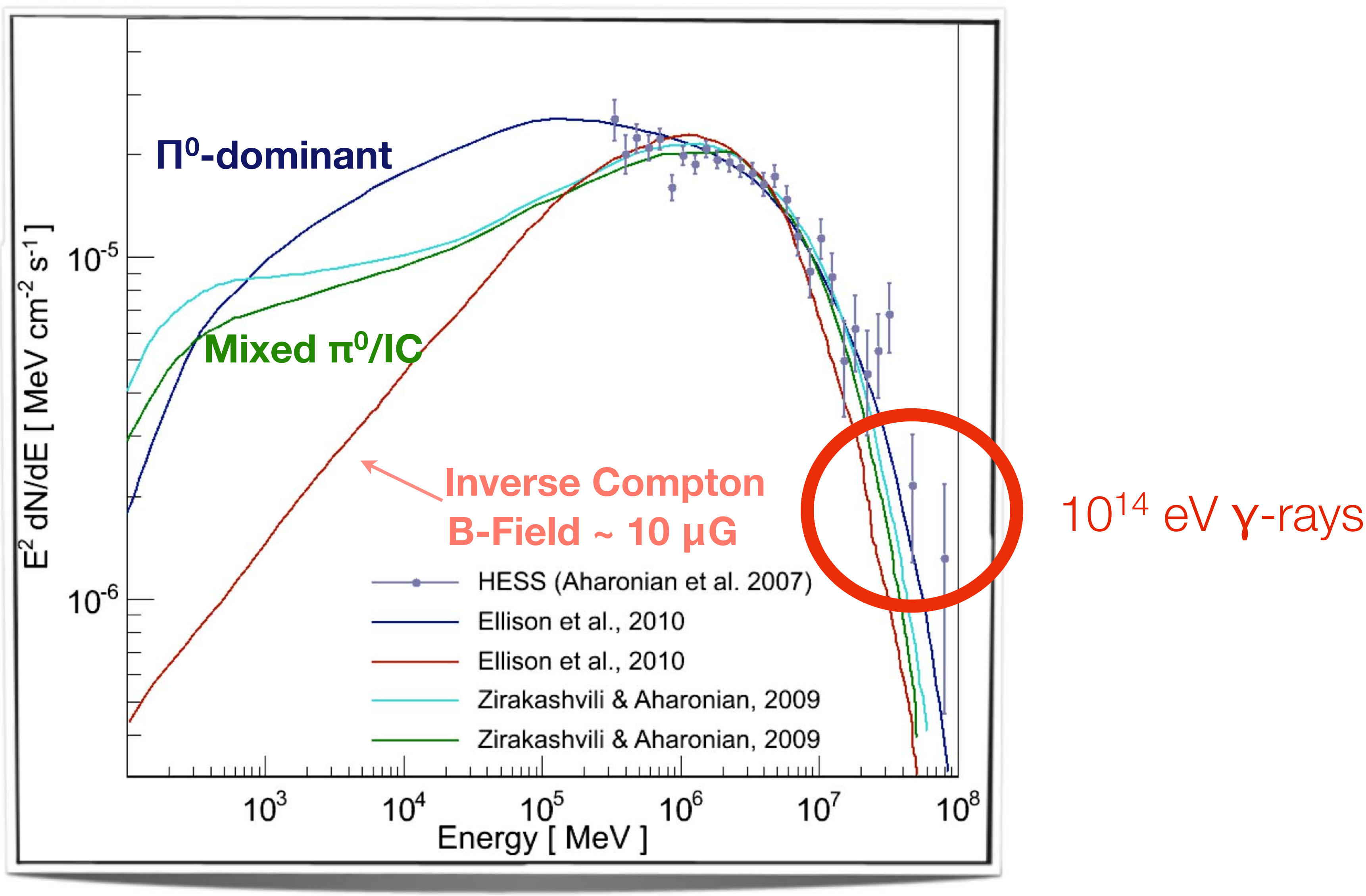
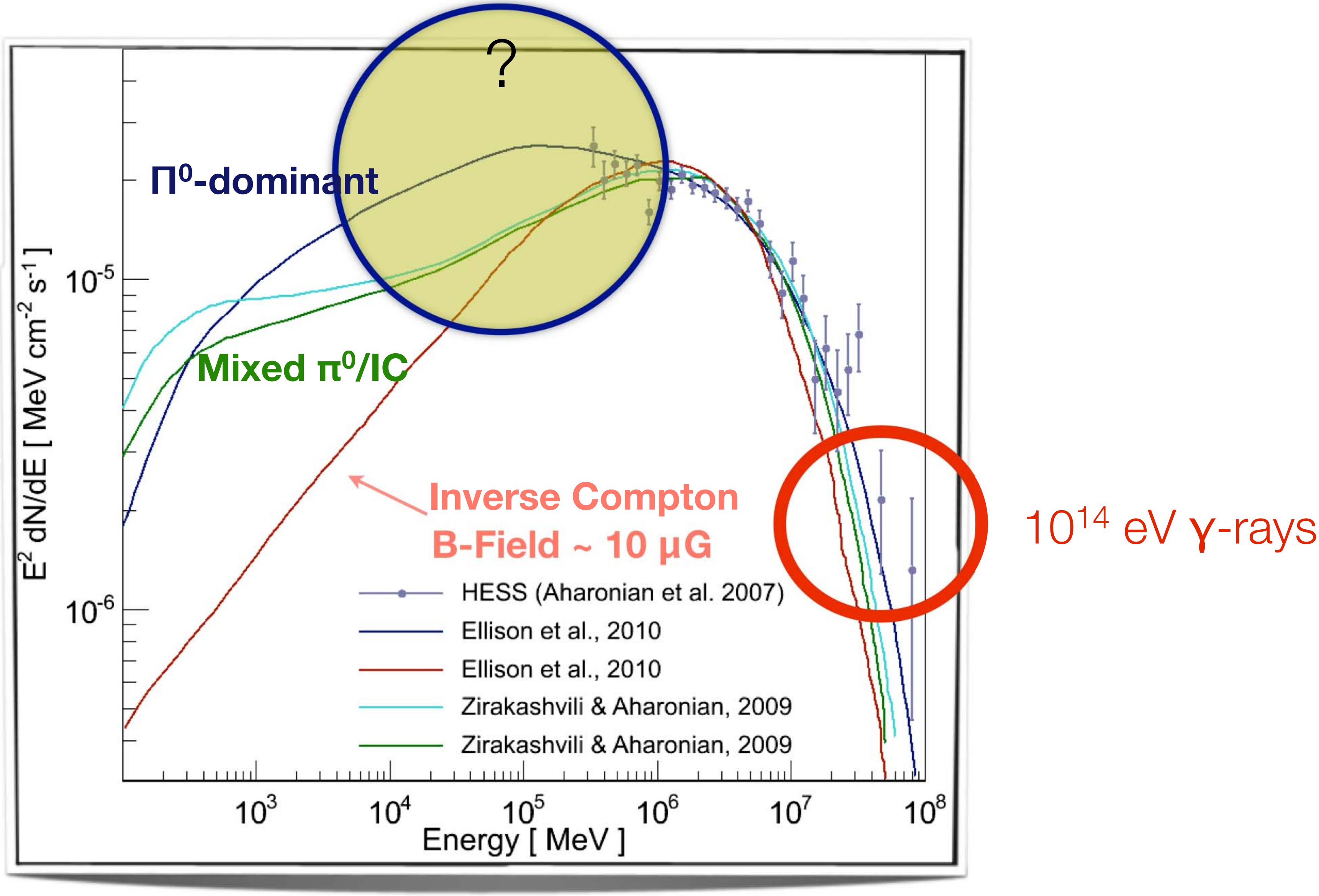
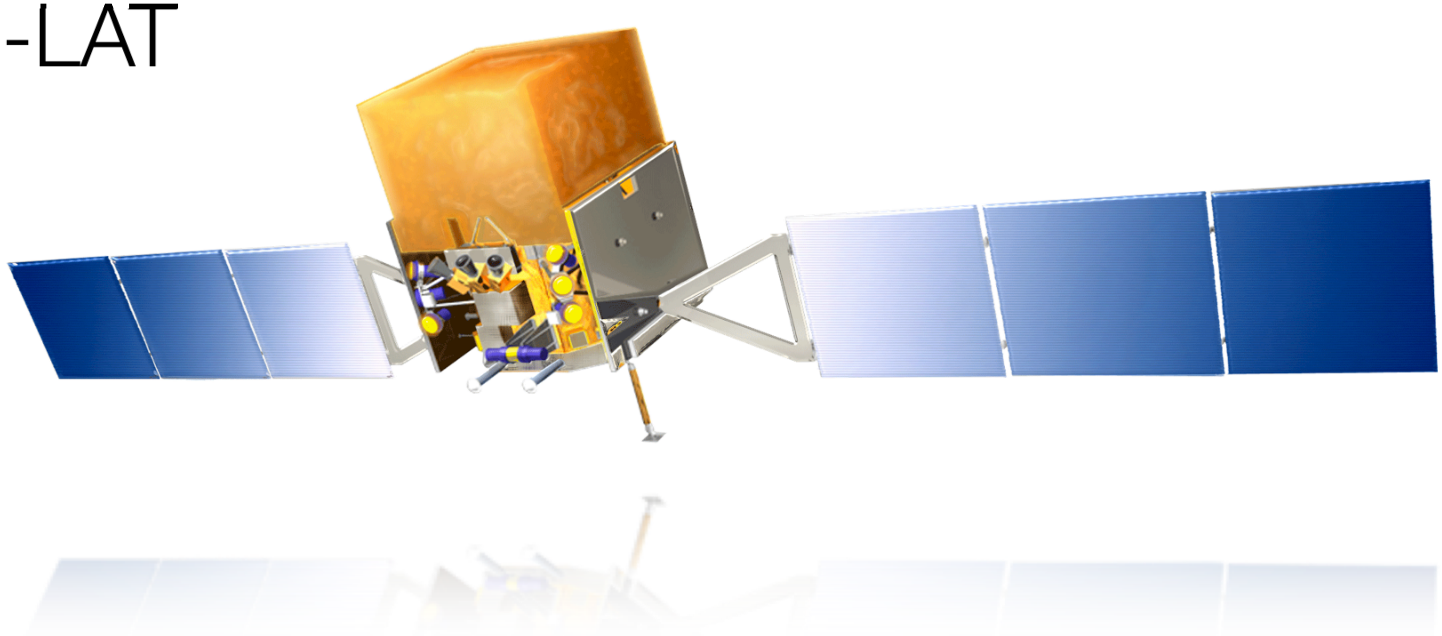
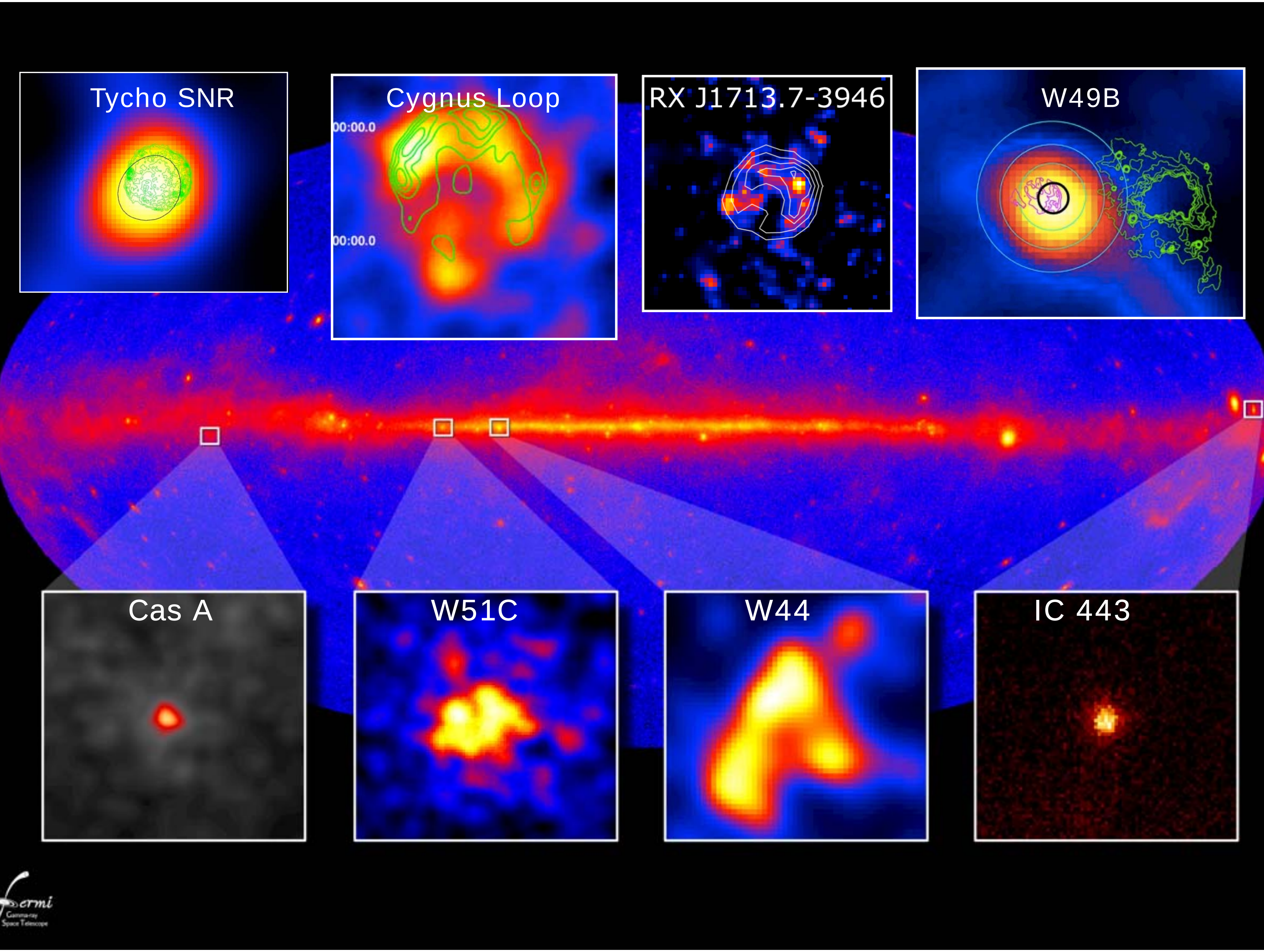


Protons or Electrons? E.g. RX J1713.7-3946



The Fermi-LAT




Tycho SNR
Cygnus Loop
00:00.0
00:00.0
RX J1713.7-3946
W49B
Cas A
W51C
W44
IC 443

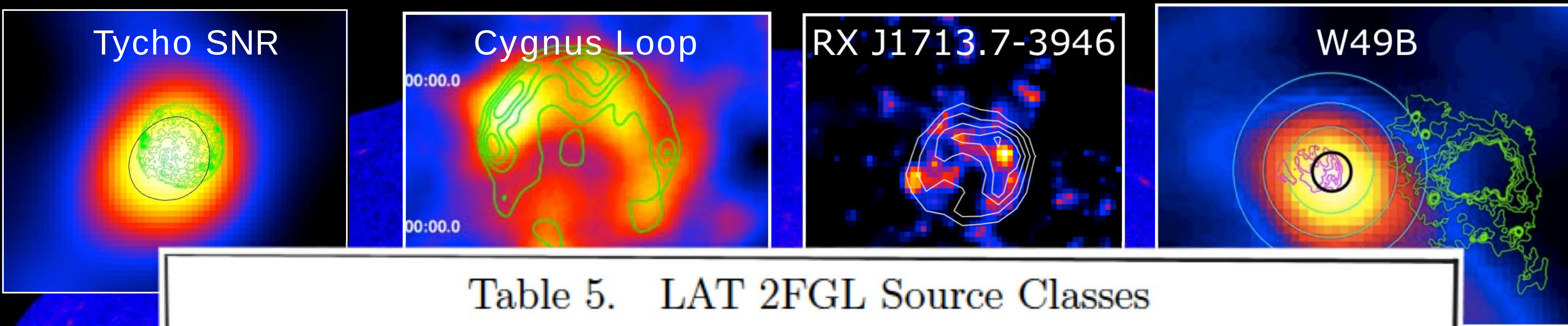
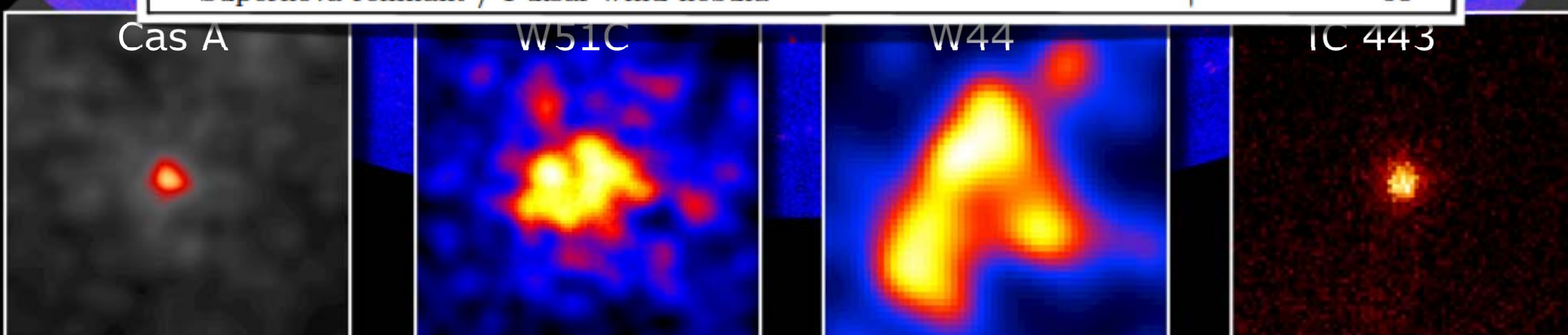
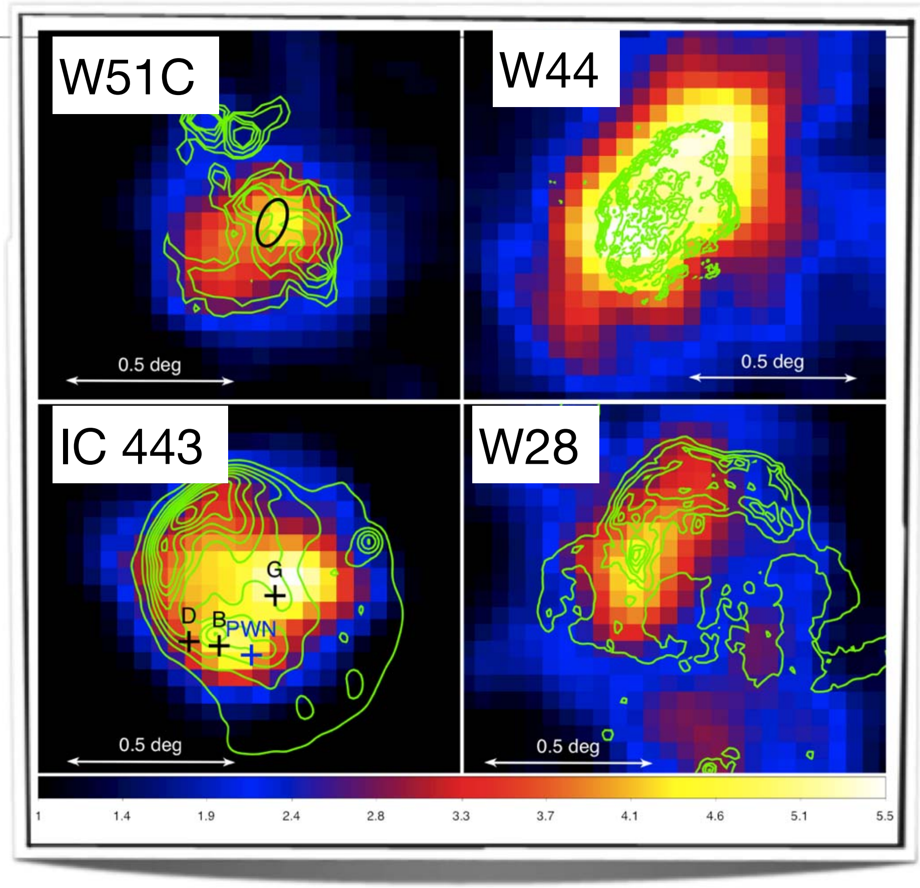


Table 5. LAT 2FGL Source Classes

Description	Identified Designator	Identified Number	Associated Designator	Associated Number
Pulsar, identified by pulsations	PSR	83	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	25
Pulsar wind nebula	PWN	3	pwn	0
Supernova remnant	SNR	6	snr	4
Supernova remnant / Pulsar wind nebula	...	...	†	58

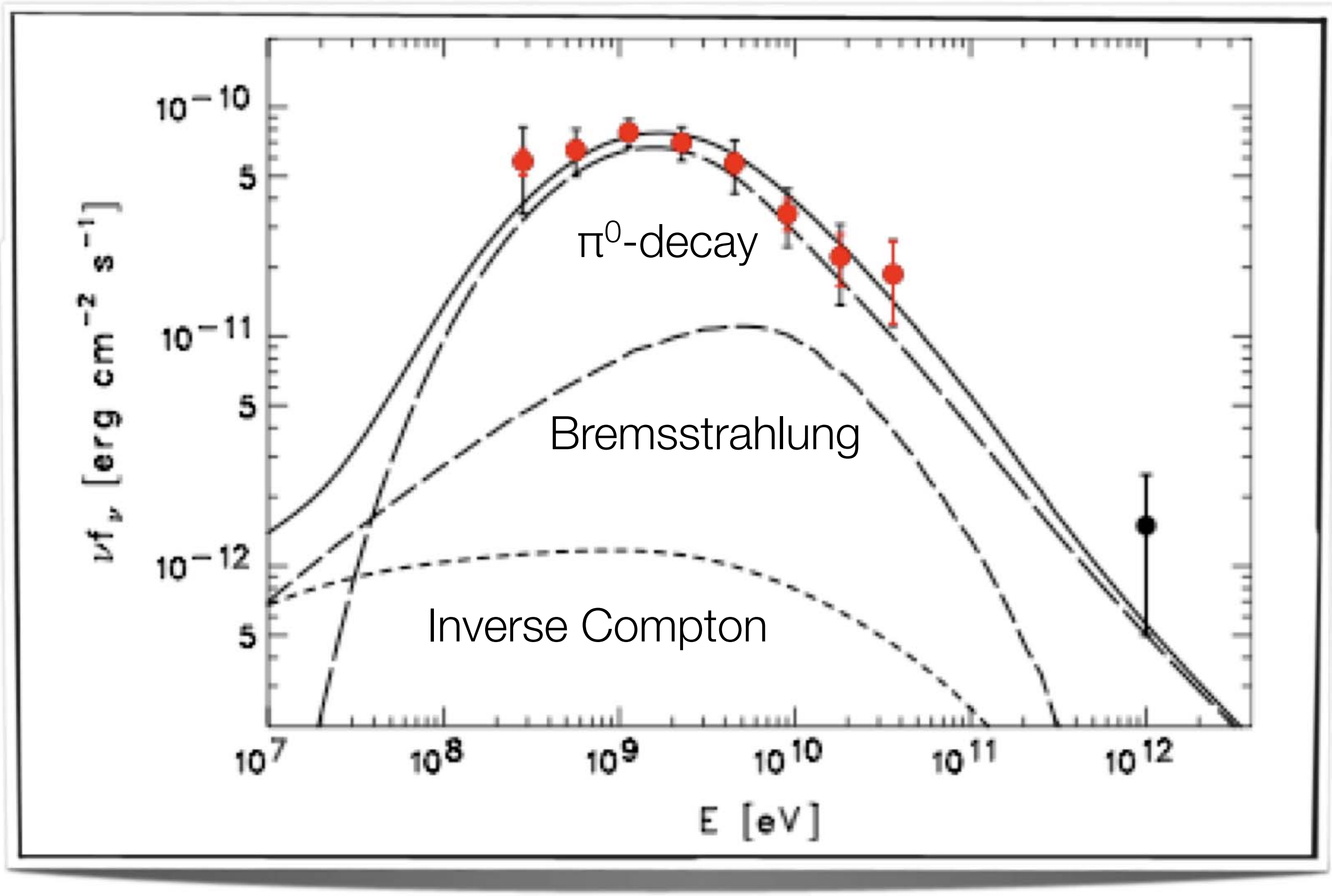


Mid-aged SNRs interacting with clouds



- W51C, W44, IC 443, W28, ... extremely GeV bright
- Ages: ~5000 - 40000 years
- Archetypal remnants interacting with molecular clouds (shock overtaking the cloud)

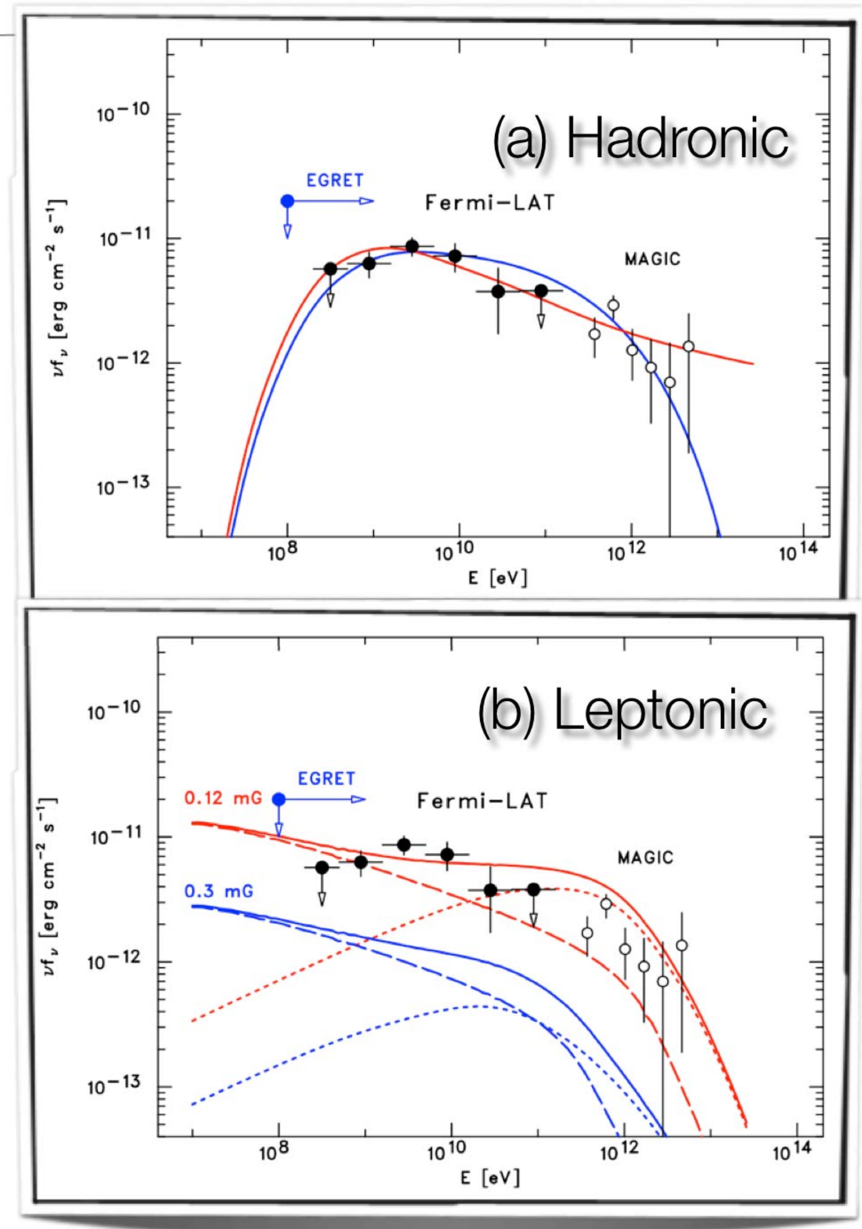
Mid-aged SNRs interacting with clouds



- Spectra show cutoffs in the 1-10 GeV range.
- Large density favors Bremsstrahlung and π^0-decay, e/p ratio favors the latter

Young SNRs with Fermi

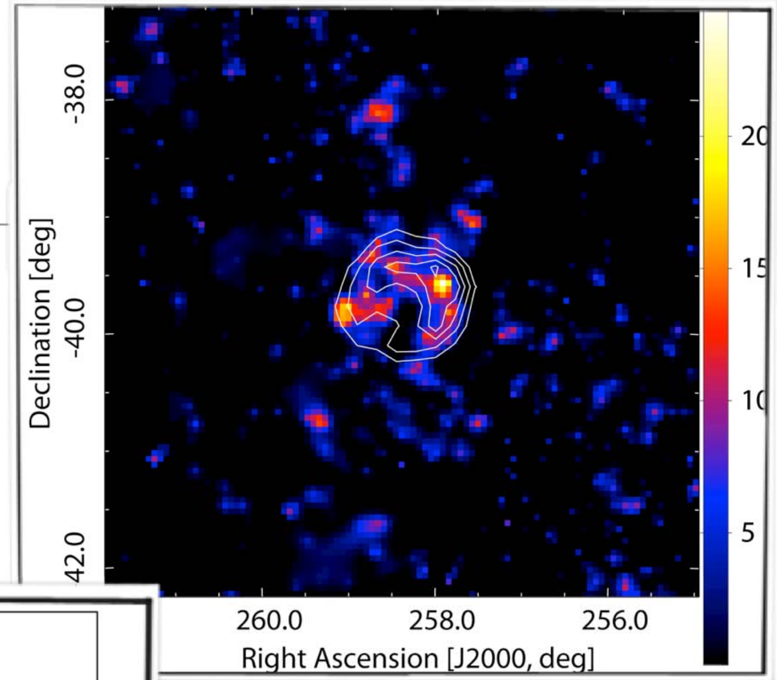
- Detection of young SNRs (Tycho, Cas A, RX J1713.7-3946, Vela Jr. ...) provides spectral measurements over more than 5 orders of magnitude in energy
- E.g. Cas A:
  - At publication (11 month of data) could not distinguish between hadronic and leptonic scenarios
  - In either scenario CR content ~2% of SN explosion energy
  - Measurements below 500 MeV crucial for determining emission mechanism

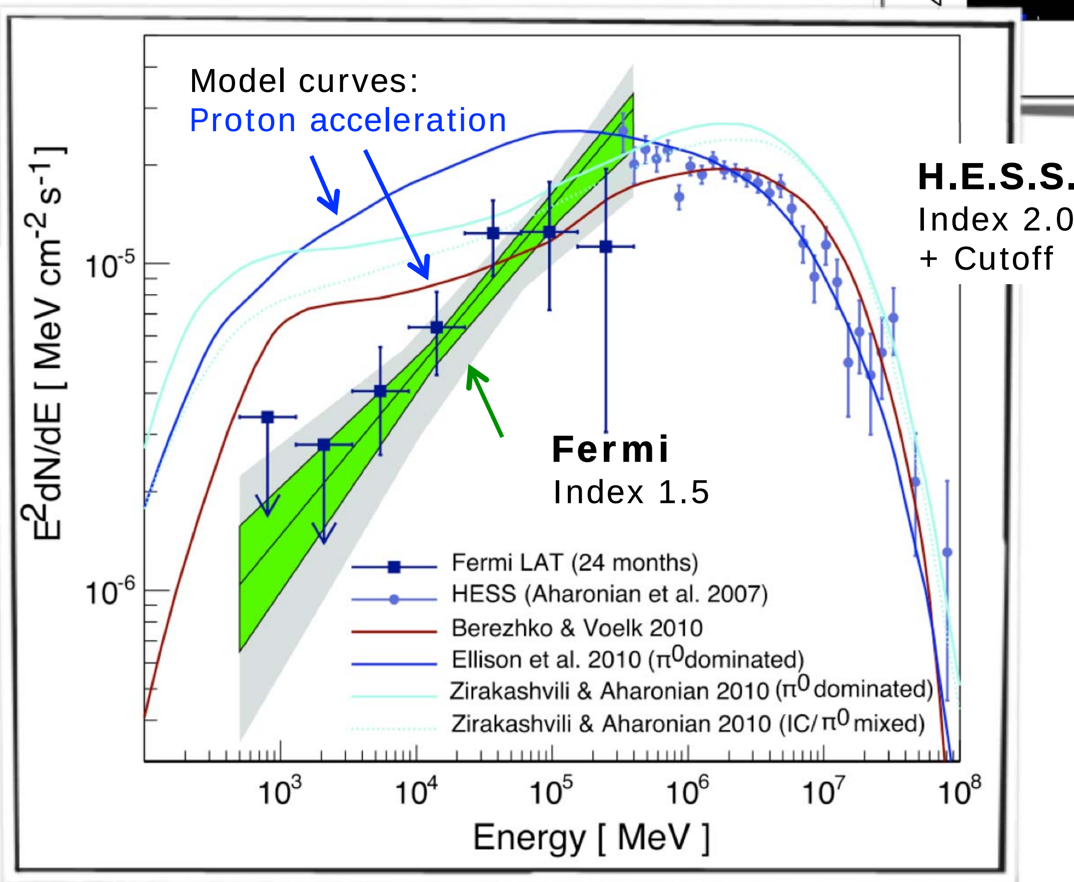


Abdo et al. 2009

RX J1713.7-3946 with Fermi

- Very complicated region, but emission clearly detected coinciding with TeV emission
- Absence of X-ray lines in Suzaku (Tanaka 2008)





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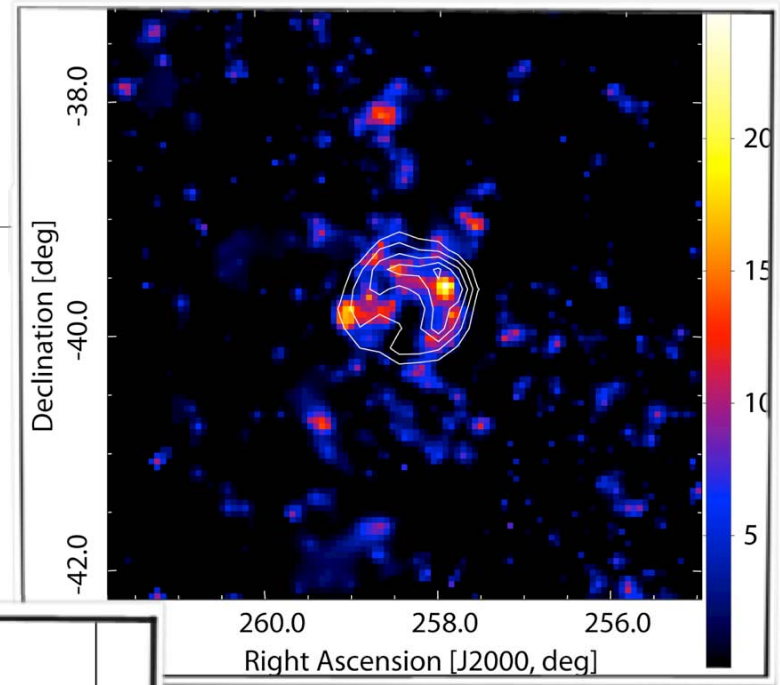
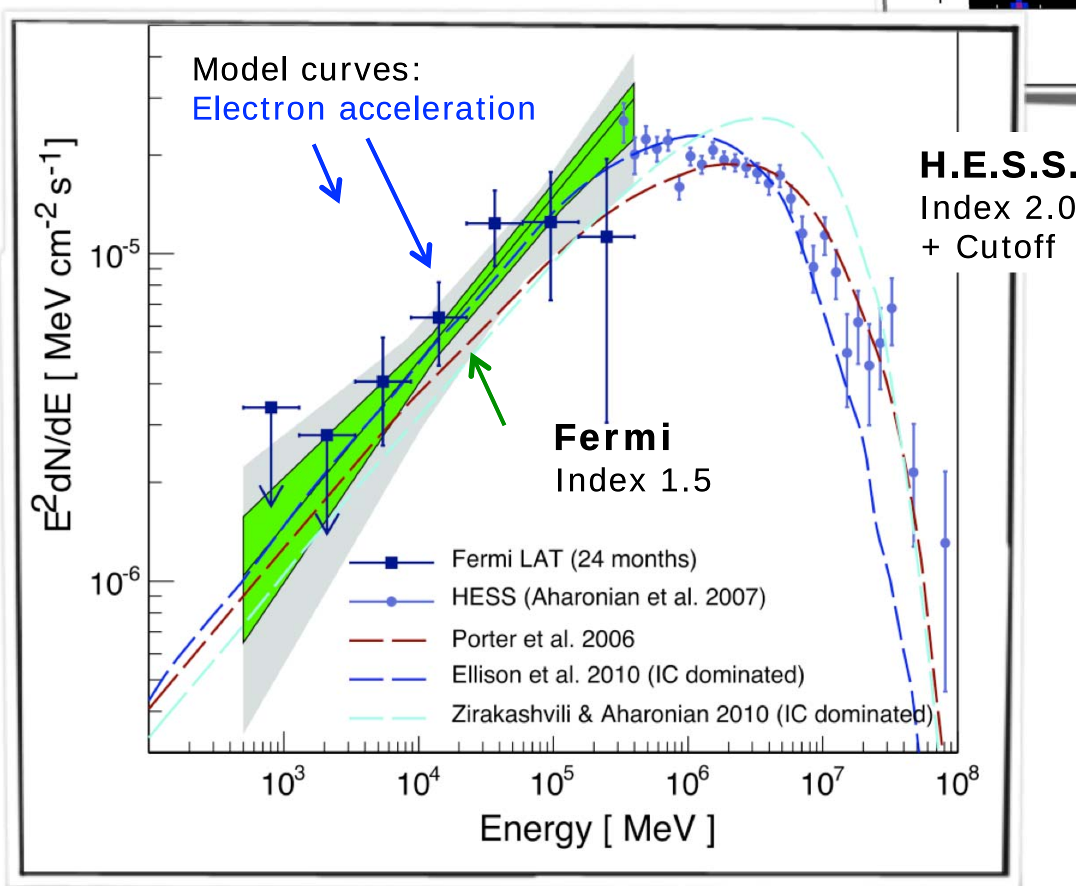
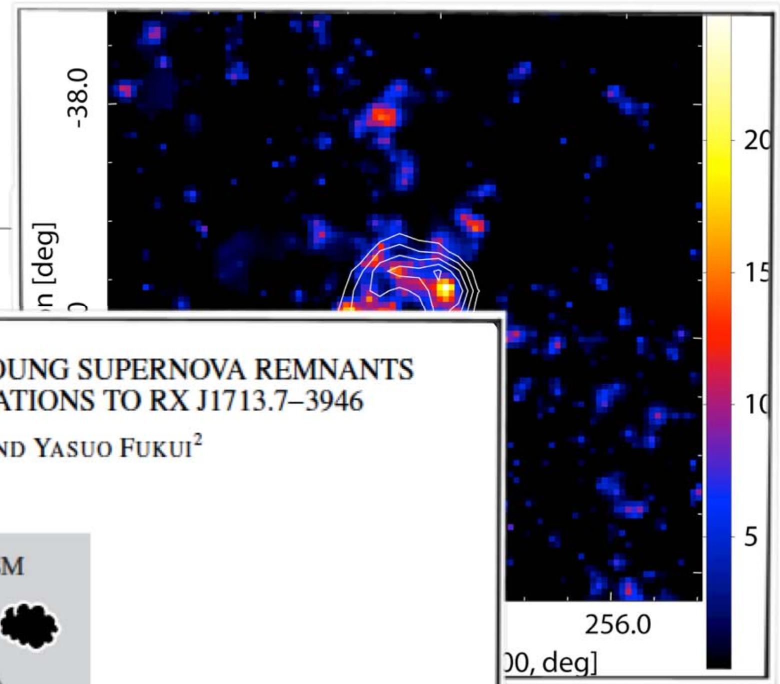




RX J1713.7-3946 with Fermi

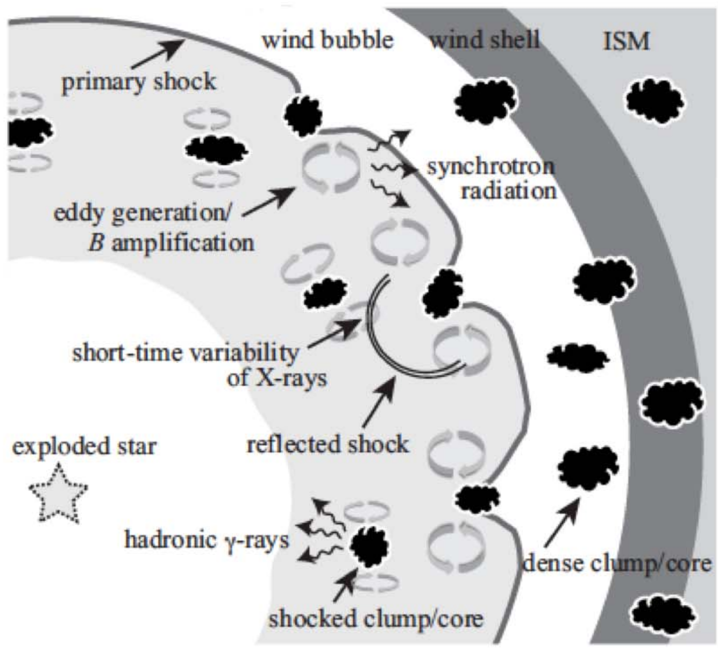
- Very complicated region, but emission clearly detected c
- Absence c



TOWARD UNDERSTANDING THE COSMIC-RAY ACCELERATION AT YOUNG SUPERNOVA REMNANTS INTERACTING WITH INTERSTELLAR CLOUDS: POSSIBLE APPLICATIONS TO RX J1713.7–3946

TSUYOSHI INOUE[1], RYO YAMAZAKI[1], SHU-ICHIRO INUTSUKA[2], AND YASUO FUKUI[2]

Draft version June 17, 2011



Penetration depth into dense clouds ~ $E^{0.5}$

→ Target mass ~ $E^{0.5}$

→ Spectra ~ $E^{-2.0 + 0.5}$

RX J

- Very c
  detect

- Absence
  2008) su

The Astrophysical Journal, 735:120 (9pp), 2011 July 10
doi:10.1088/0004-637X/735/2/120

MODELING THE MULTI-WAVELENGTH EMISSION OF THE SHELL-TYPE SUPERNOVA REMNANT RX J1713.7−3946

Qiang Yuan[1], Siming Liu[2,3], Zhonghui Fan[4], Xiaojun Bi[1,5], and Christopher L. Fryer[6,7]
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[2] Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK
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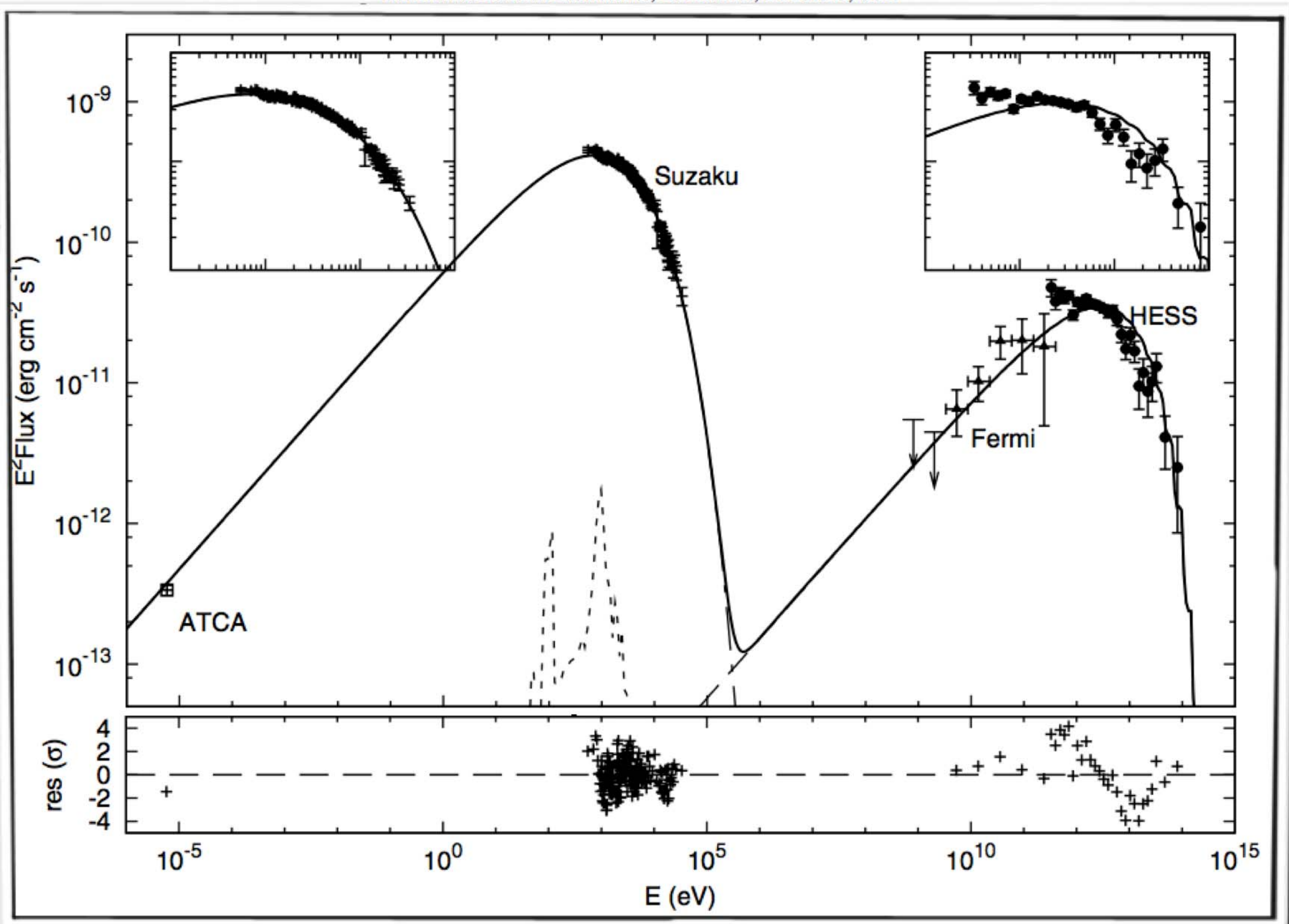
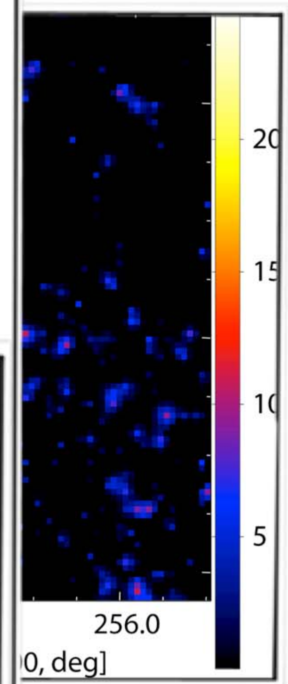
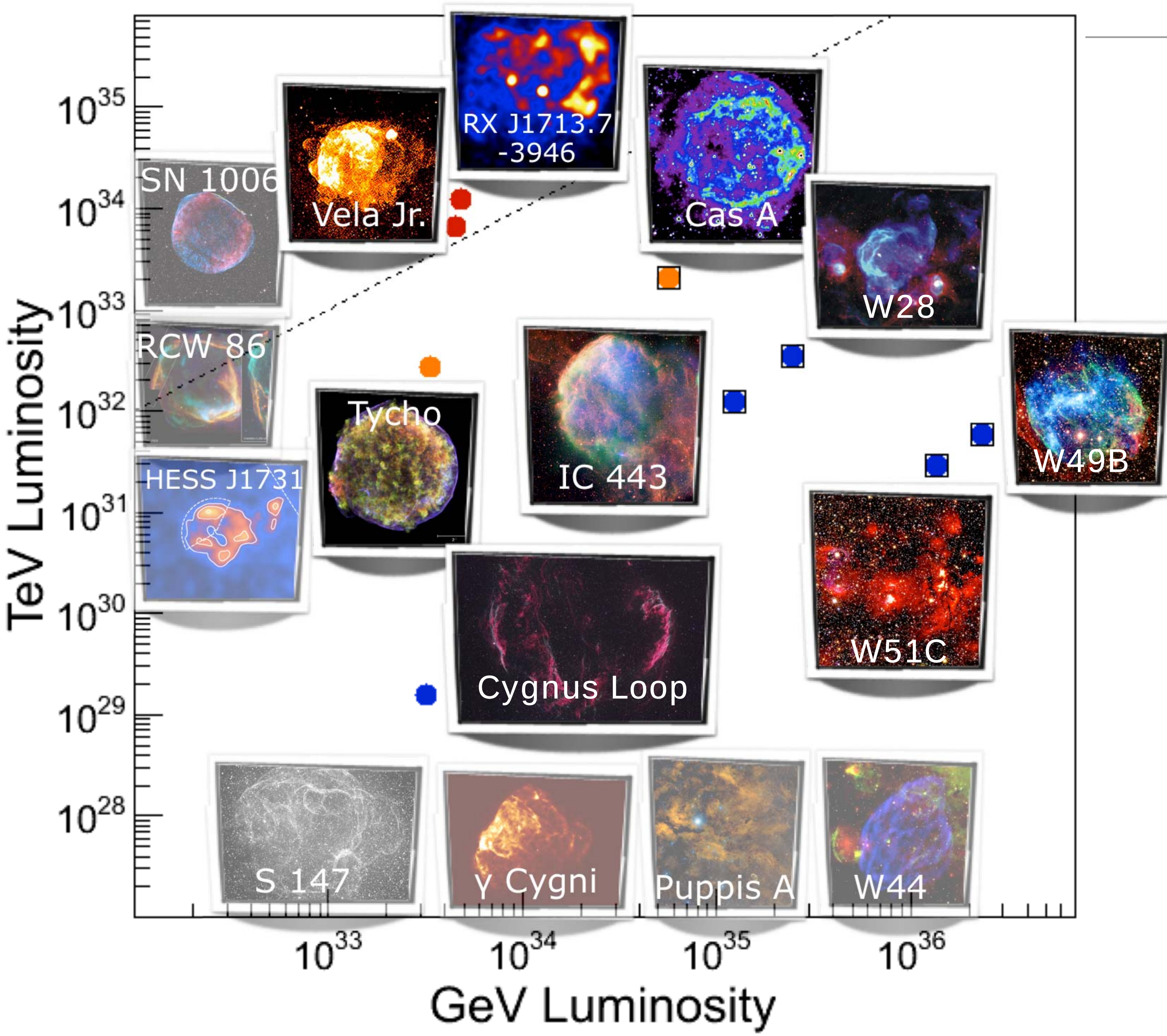
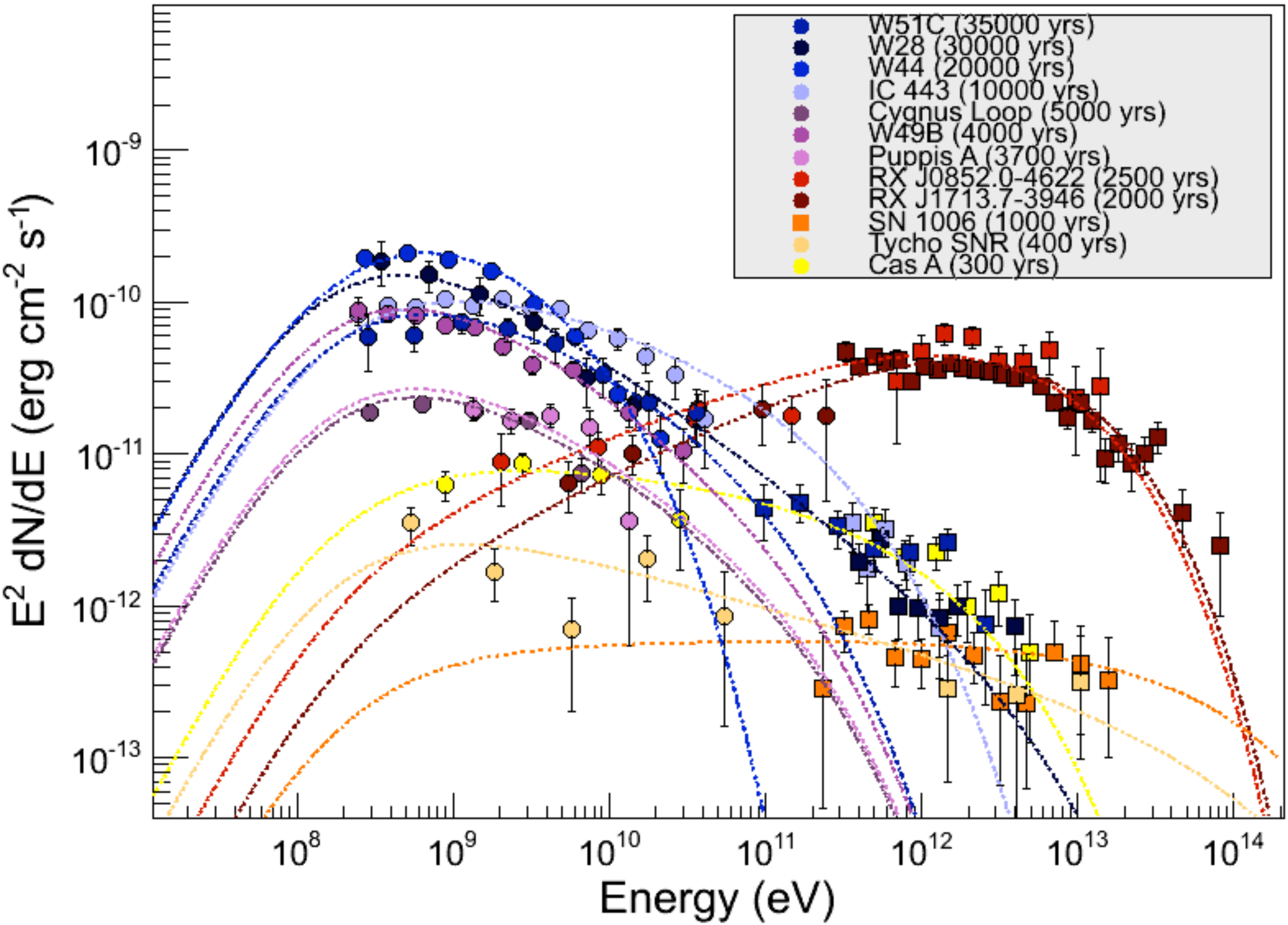
[5] Center for High Energy Physics, Peking University, Beijing 100871, China
[6] Los Alamos National Laboratories, Los Alamos, NM 87545, USA





The gamma-ray SNR zoo




W51C (35000 yrs)
W28 (30000 yrs)
W44 (20000 yrs)
IC 443 (10000 yrs)
Cygnus Loop (5000 yrs)
W49B (4000 yrs)
Puppis A (3700 yrs)
RX J0852.0-4622 (2500 yrs)
RX J1713.7-3946 (2000 yrs)
SN 1006 (1000 yrs)
Tycho SNR (400 yrs)
Cas A (300 yrs)
E^2 dN/dE (erg cm^{-2} s^{-1})
Energy (eV)
10^{-9}
10^{-10}
10^{-11}
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10^{-13}
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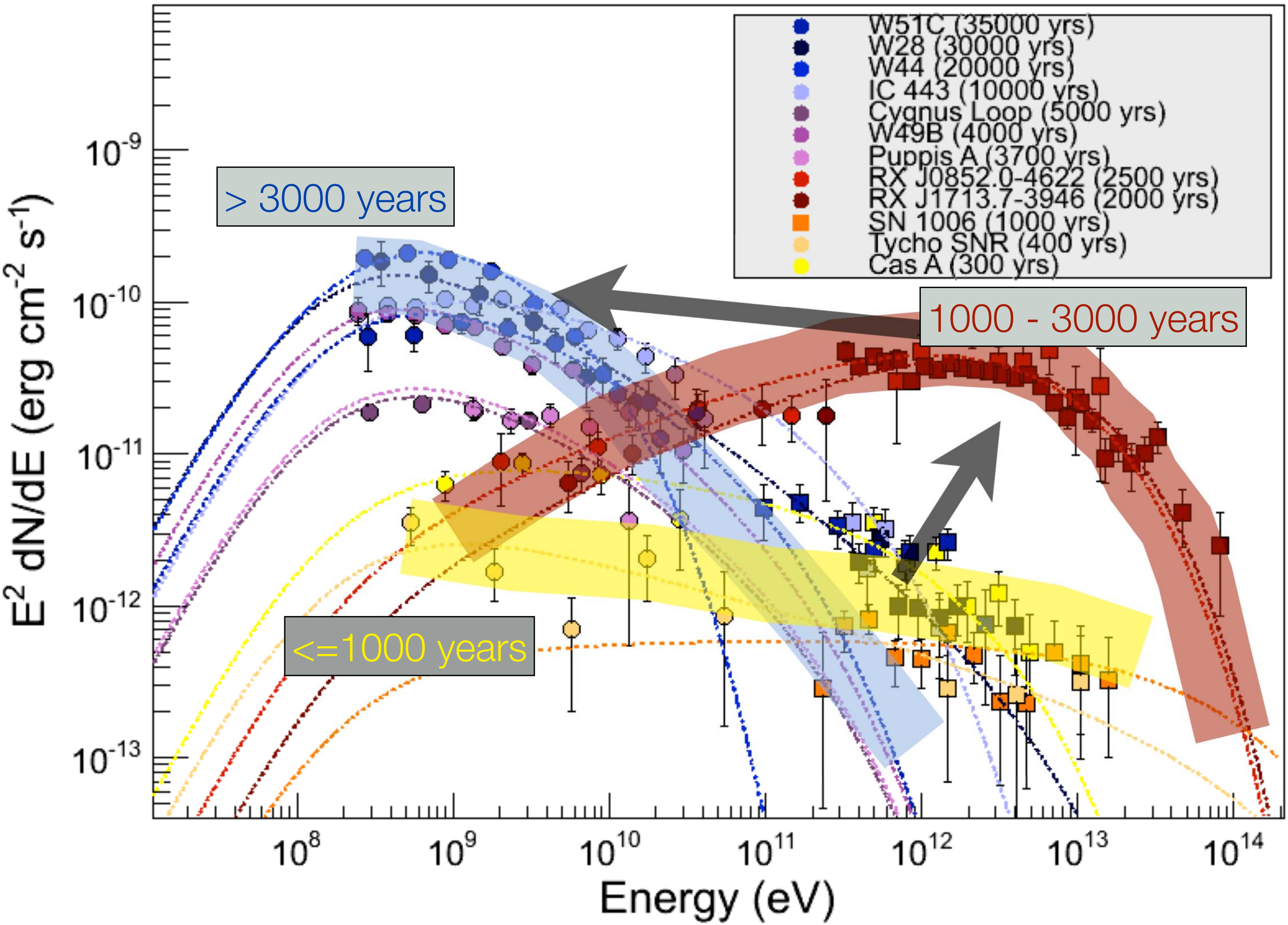
10^{12}
10^{13}
10^{14}



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SN 1006 (1000 yrs)
Tycho SNR (400 yrs)
Cas A (300 yrs)
> 3000 years
1000 - 3000 years
<=1000 years
E^2 dN/dE (erg cm^{-2} s^{-1})
Energy (eV)
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^8
10^9
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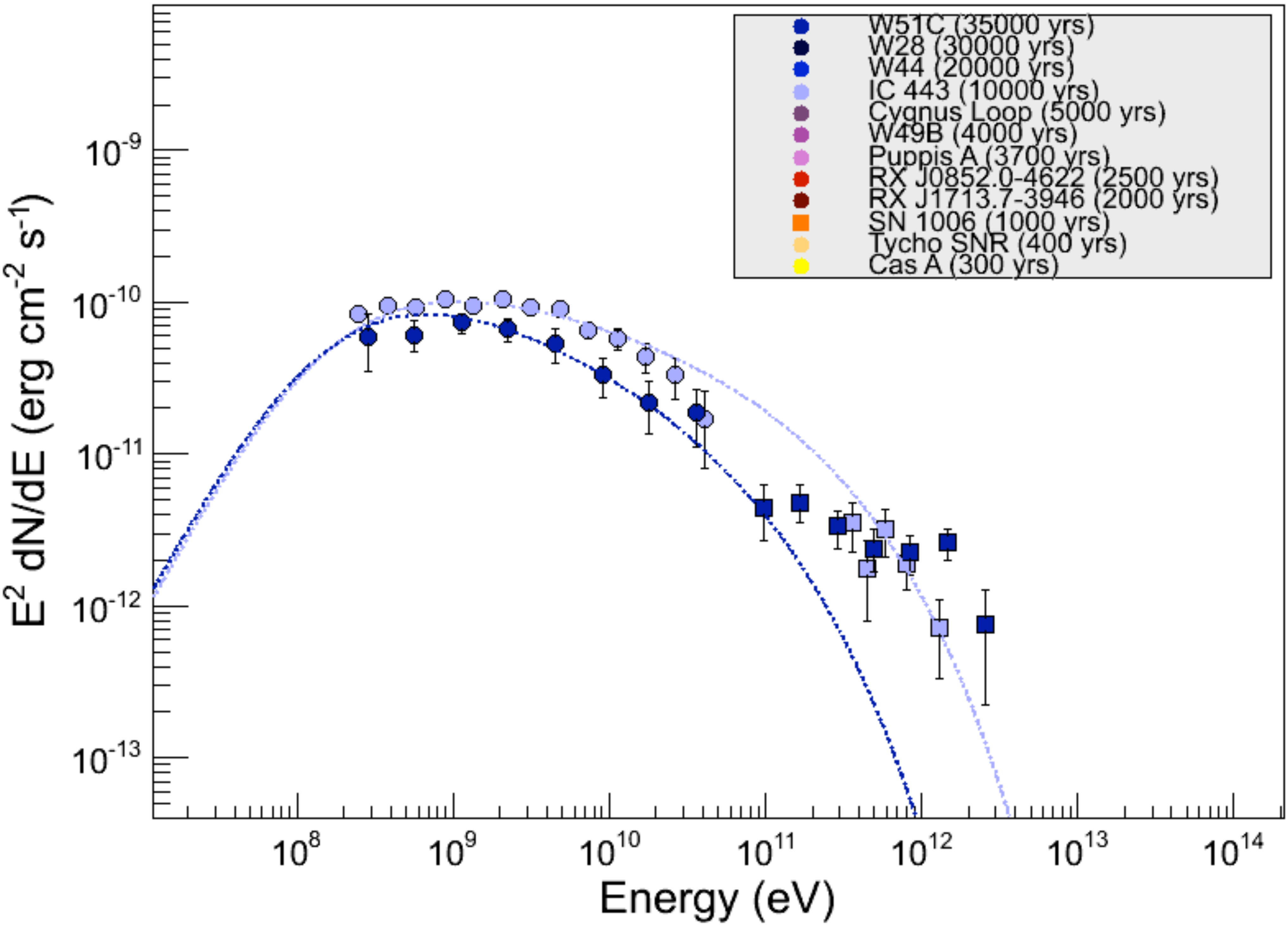
10^{11}
10^{12}
10^{13}
10^{14}



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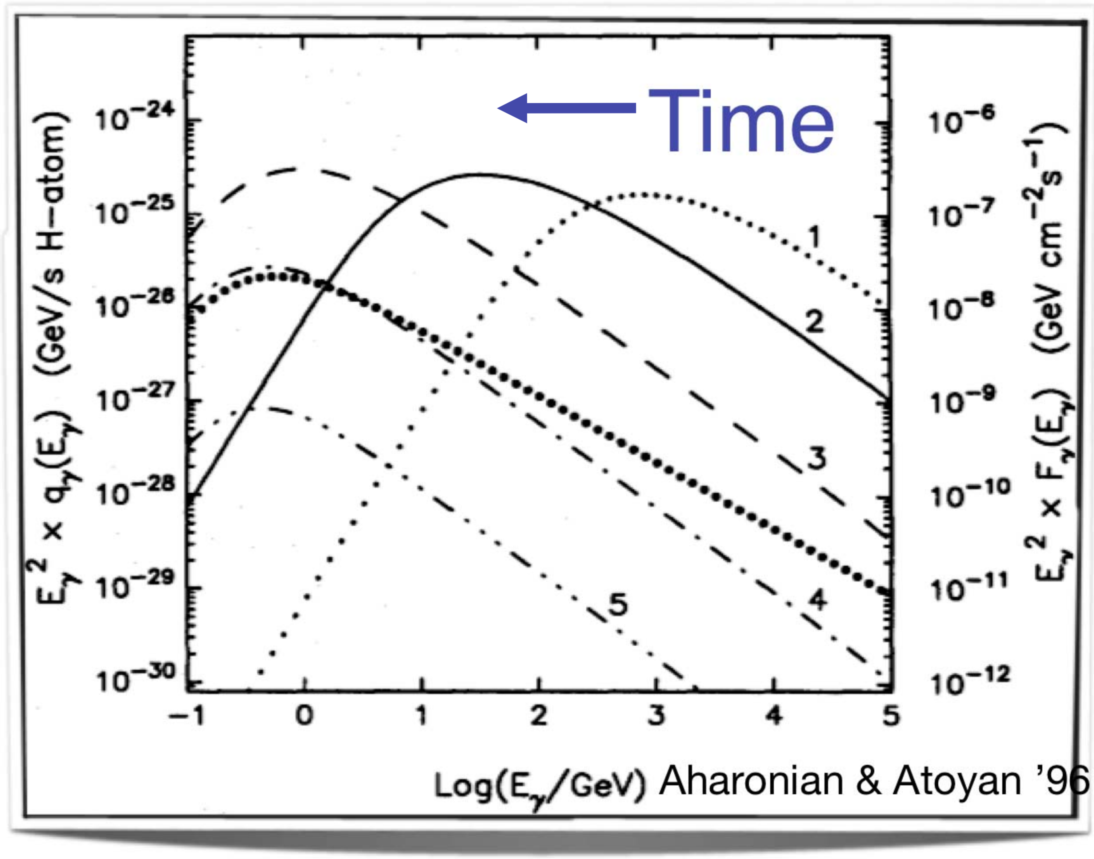
10^{11}
10^{12}
10^{13}
10^{14}
Energy (eV)

What do we expect?

- Complicated:
  - Shock weakens with time, B-field drops. Maximum energy drops with time
  - More detailed model of shock-evolution describes evolution of shock-velocity, density of surrounding medium, ...
  - Additional complication: density of surrounding medium



Aharonian & Atoyan ’96

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Understanding hadronic gamma-ray emission from supernova remnants

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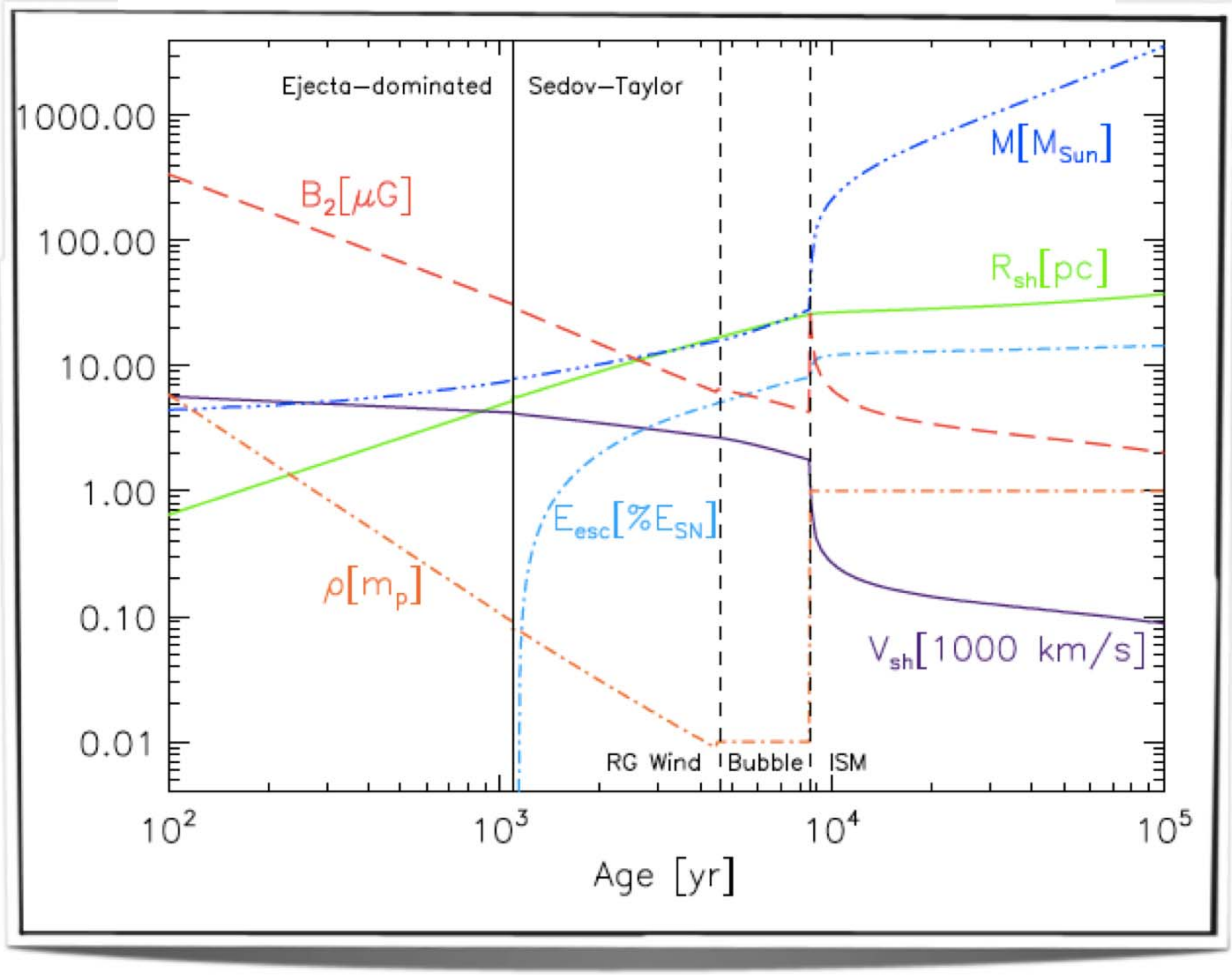
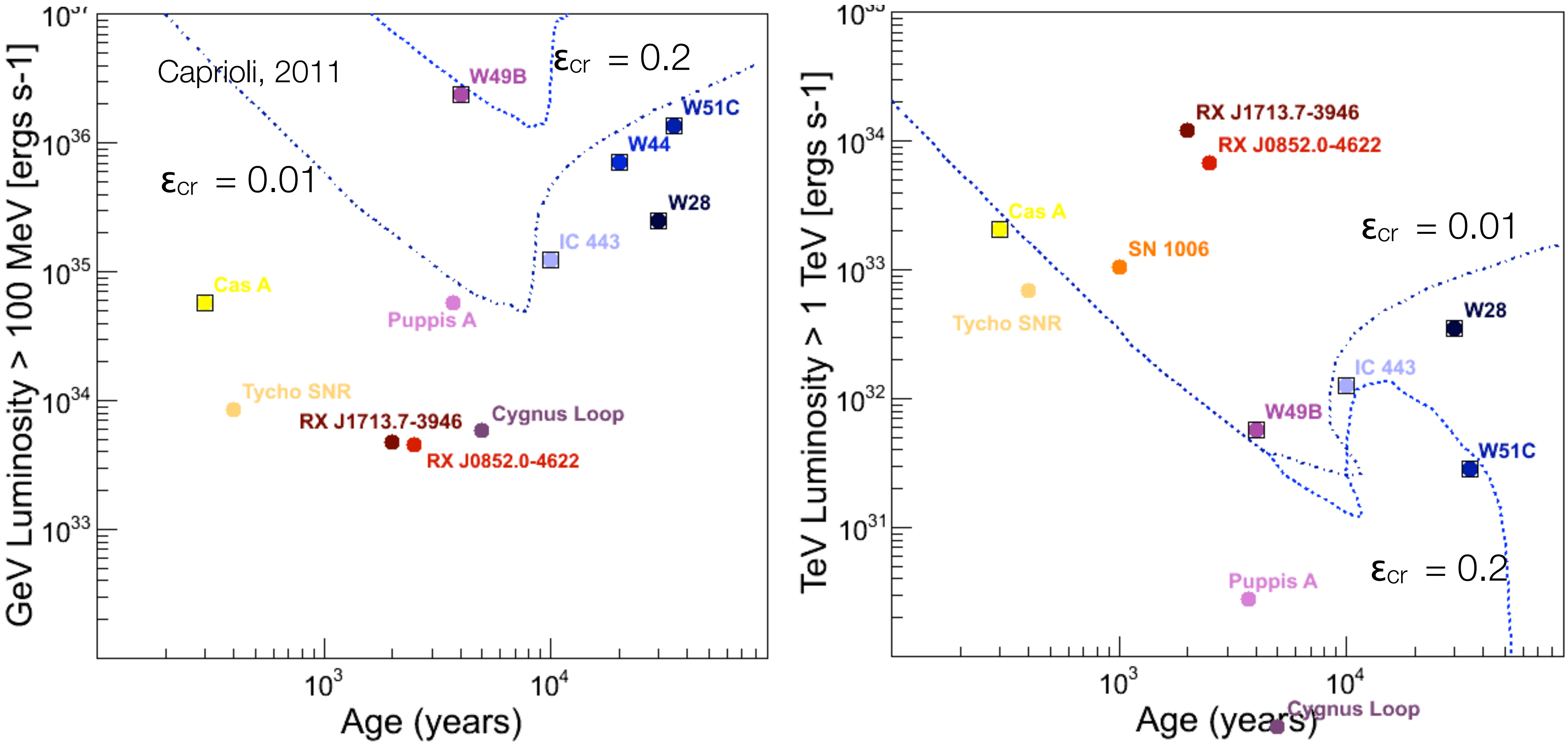
For core-collapse SNRs

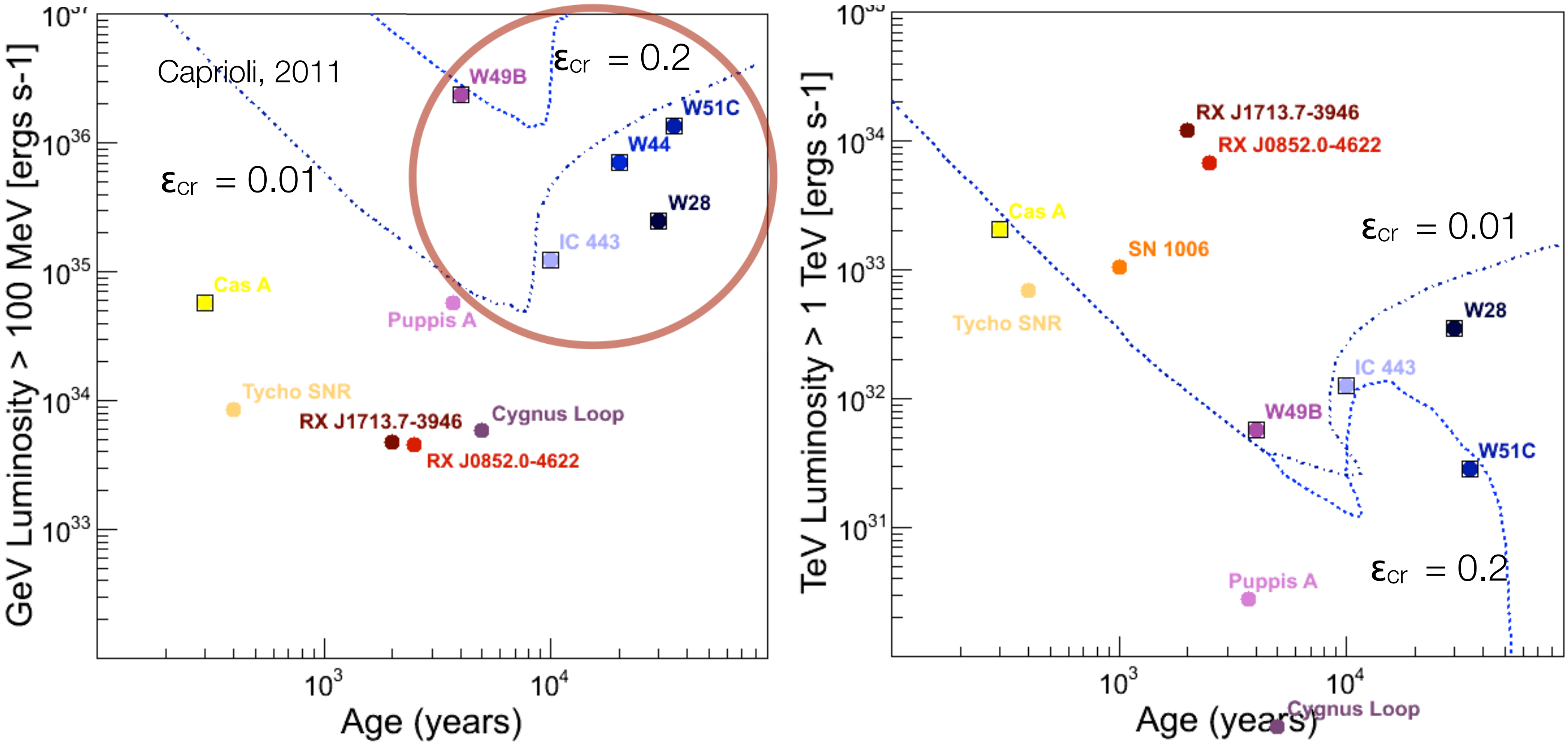


What do we expect?



- "The total luminosity may be orders of magnitudes larger at earlier and later stages, inside the dense wind and inside the ISM, respectively"

What do we expect?



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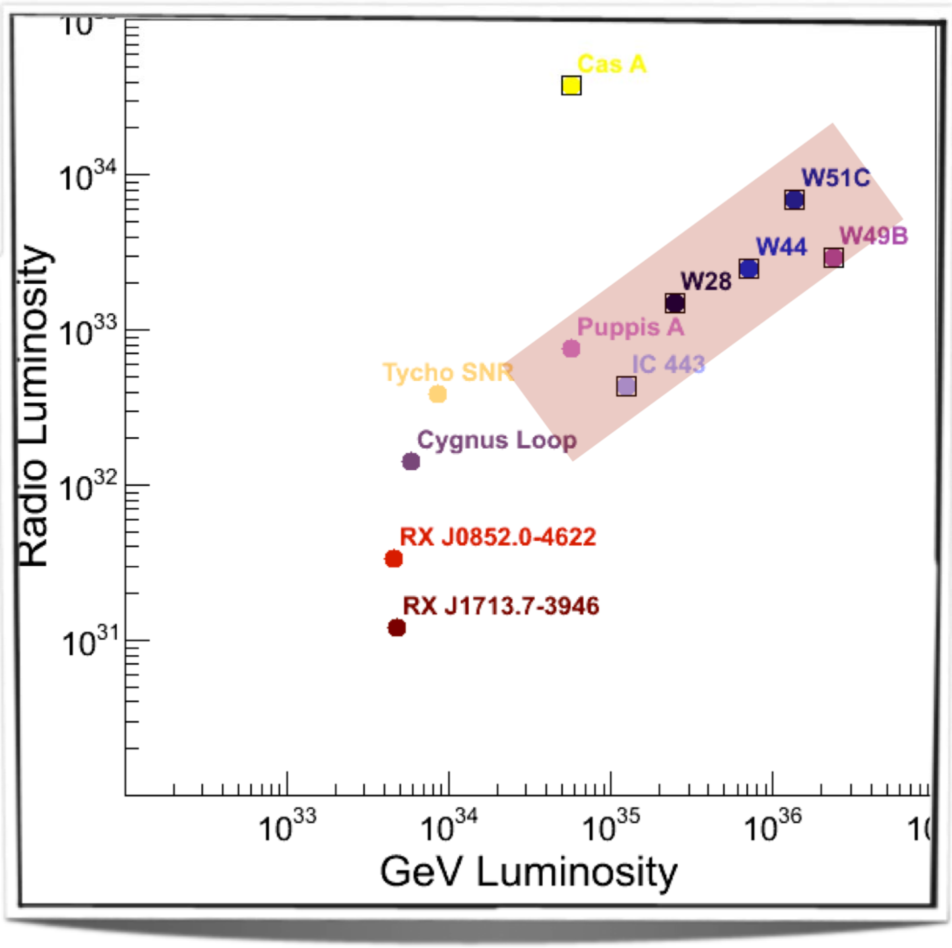
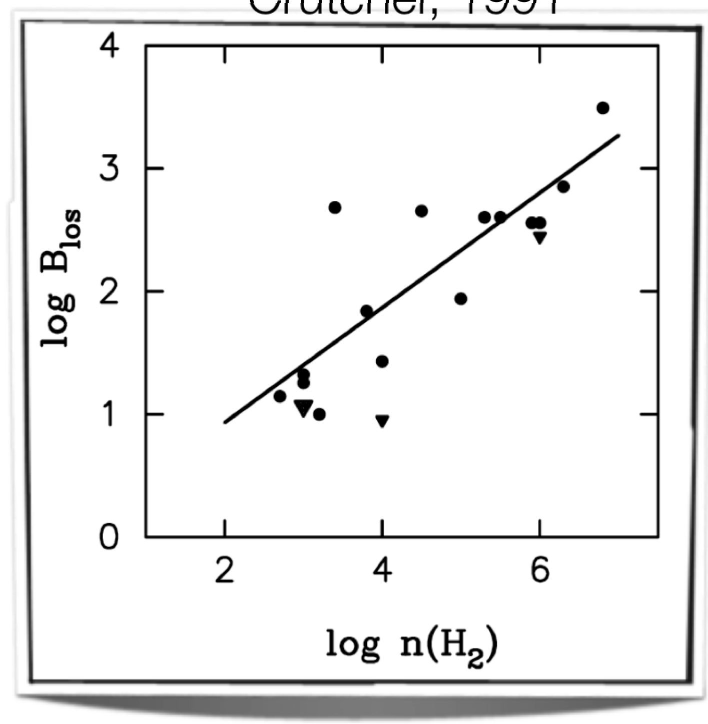
Radio and GeV gamma rays



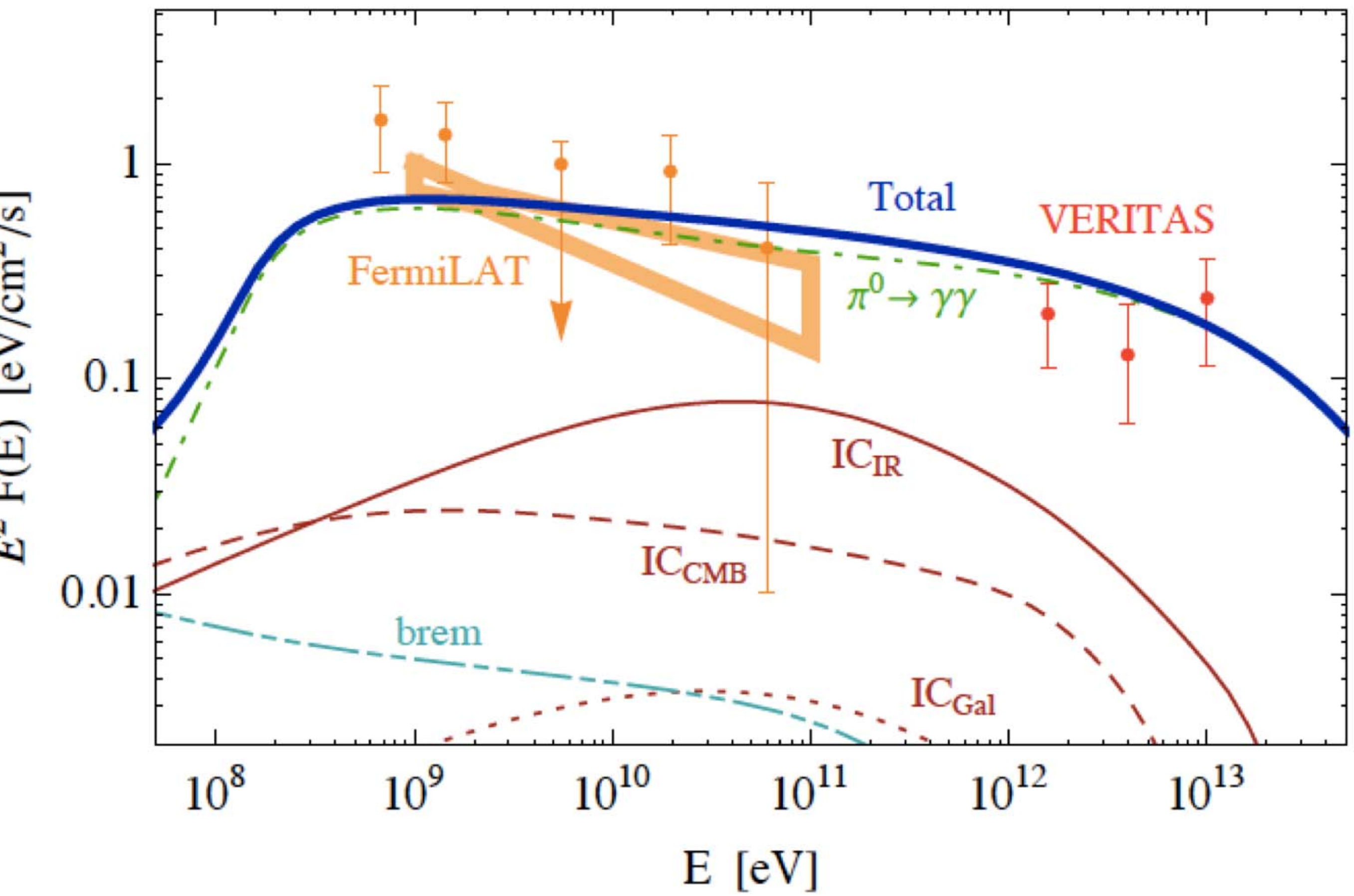
Crutcher, 1991



- For cloud-interacting remnants expect relation due to $n \sim B^2$ relation in dense molecular clouds

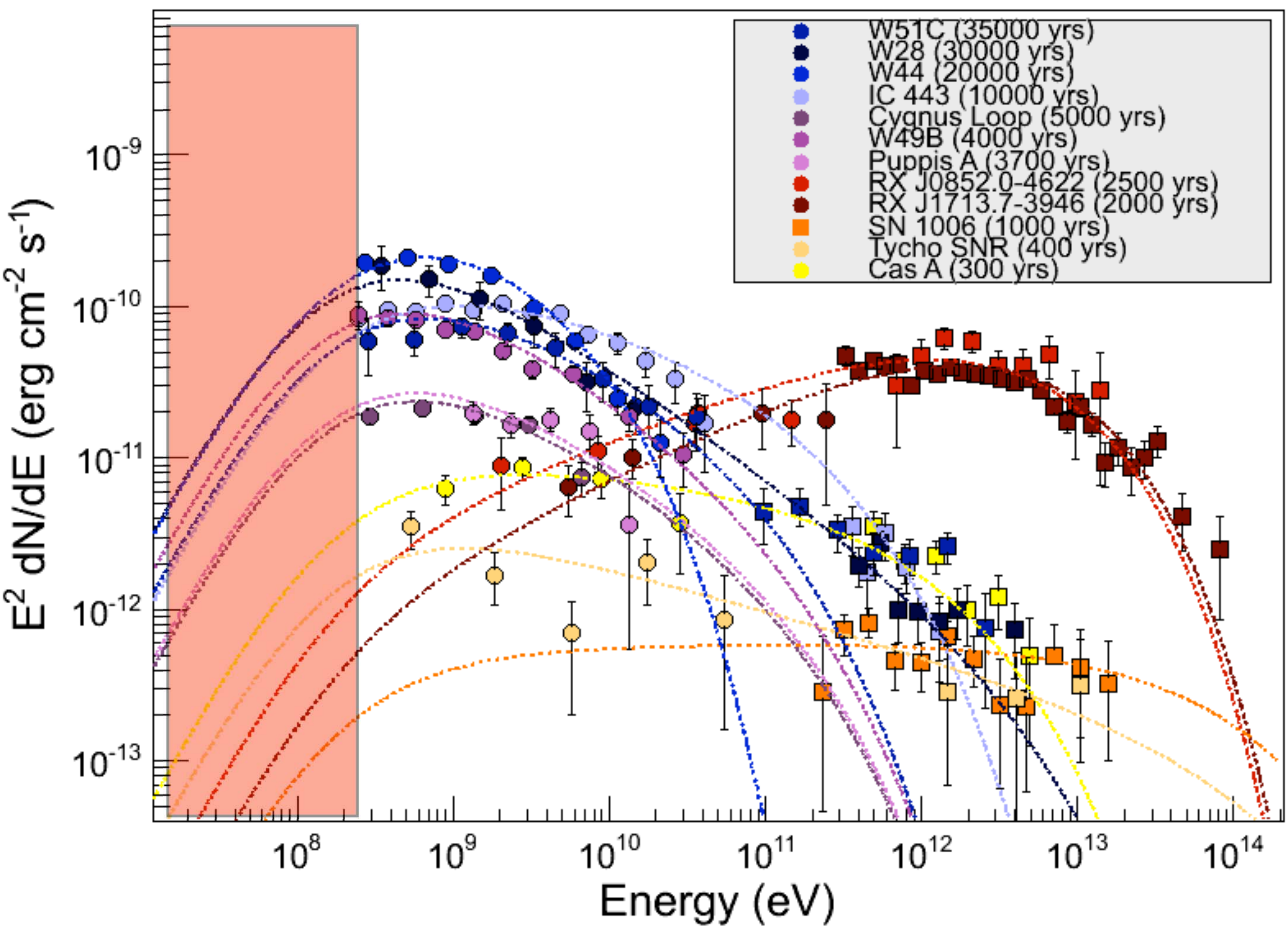
The unequivocal evidence of hadron acceleration in Tycho's Supernova Remnant

G. Morlino[1*], D. Caprioli[1]†,
[1]INAF-Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 5, 50125, Firenze, Italy



E_{max} = 500 TeV

The Future



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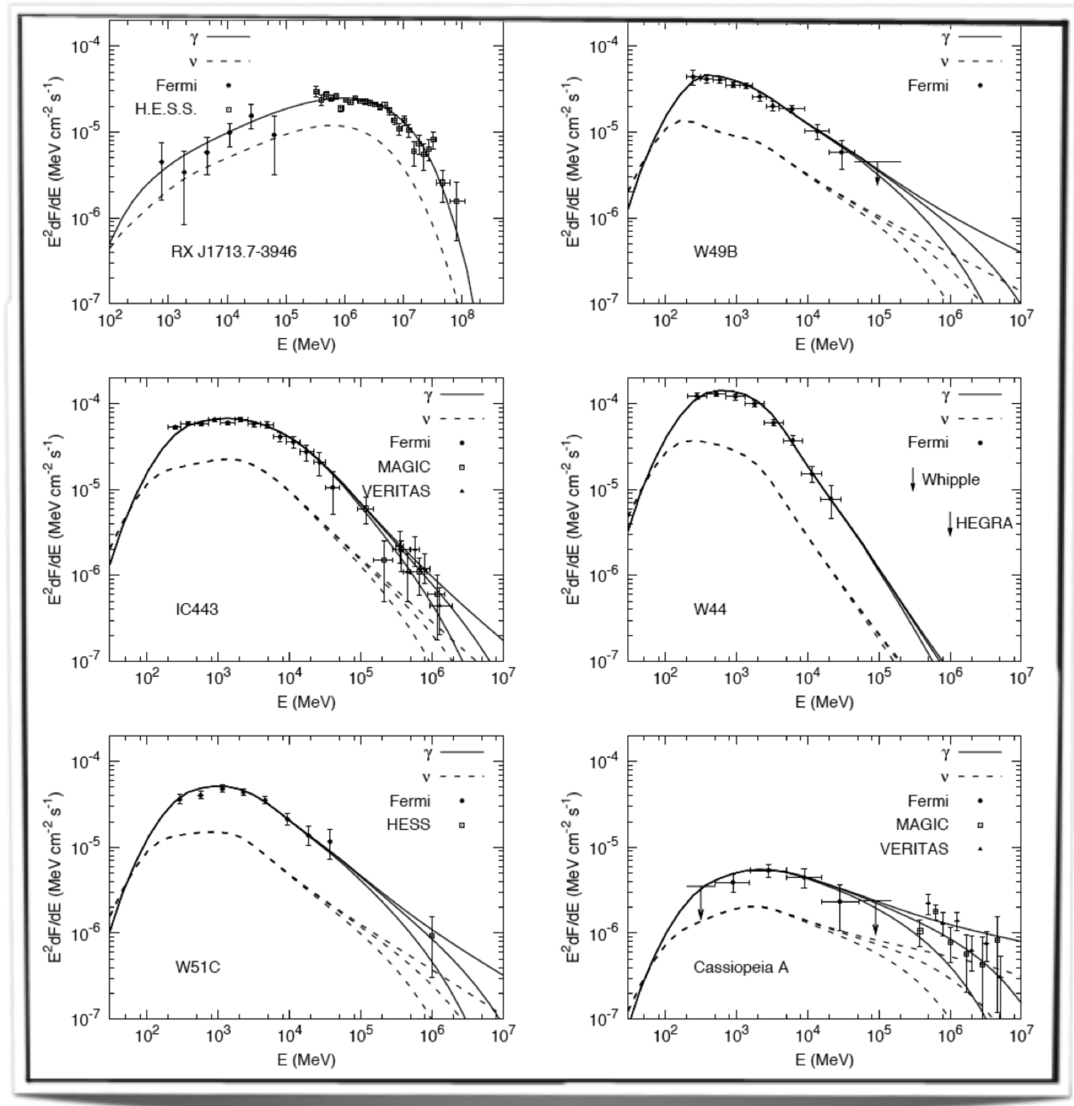
10^-10
10^-11
10^-12
10^-13
10^8
10^9
10^10
10^11
10^12
10^13
10^14

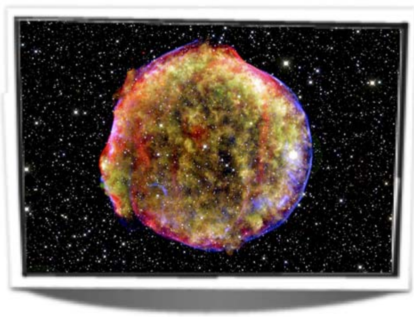
Neutrinos?

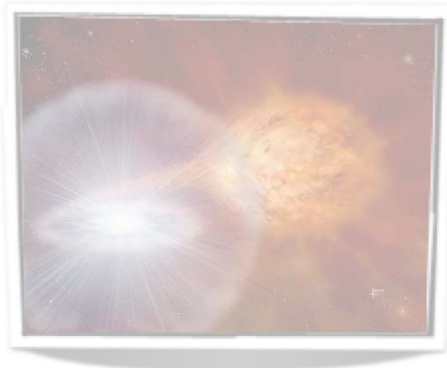
- Gamma-rays in part trace neutrino sources
- Can make detailed prediction of neutrino fluxes in IceCube or KM3Net
    - Will be very difficult for northern Galactic SNRs (typical neutrino rates are of order 0.1/year).
    - Might be very different for flaring Fermi sources ... (ratio of neutrinos to gamma-rays can get very large due to γγ-absorption)

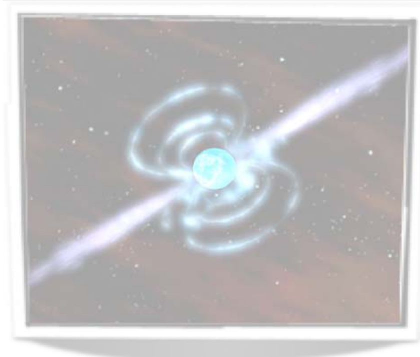
Yuan et al. 2011



The origin of Cosmic rays - population of SNRs



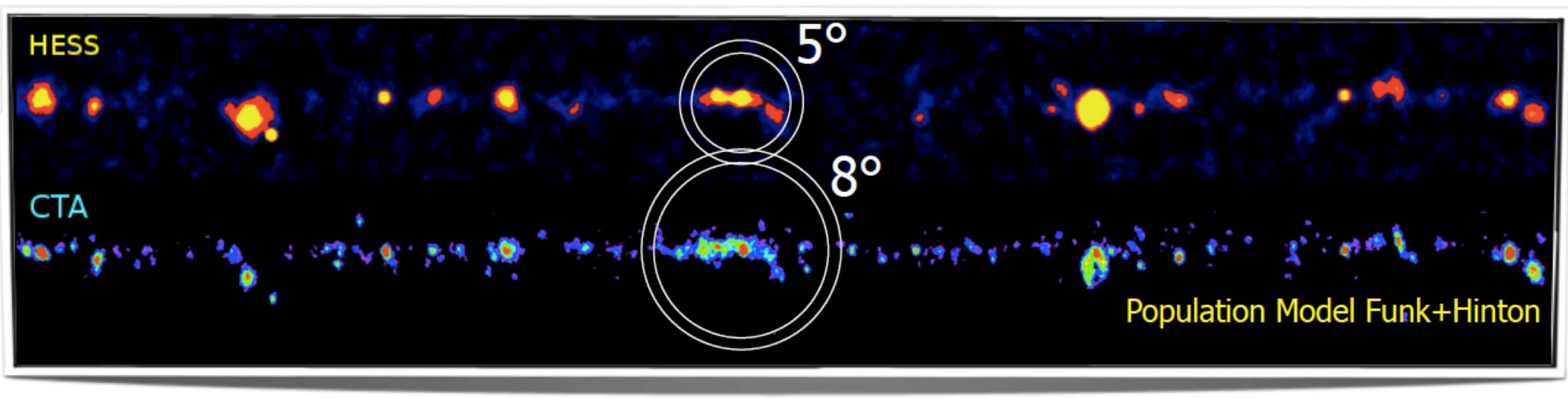




- No clear sign of other ‘potential’ source of CRs (Novae, stellar winds, ...)
- Cosmic ray power in our Galaxy: **~ 5 x 10^{40} ergs/s**
    - Fermi-LAT data will give upper limit to CR content in SNRs
        - Next step: CR content as function of age, shock speed, ...
    - Connect this as a population to the total CR power in our Galaxy

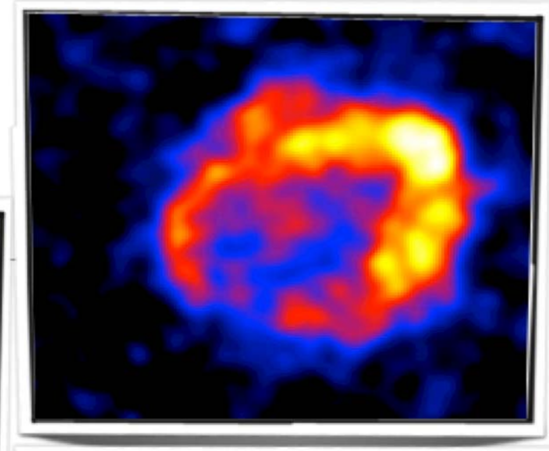
The Future

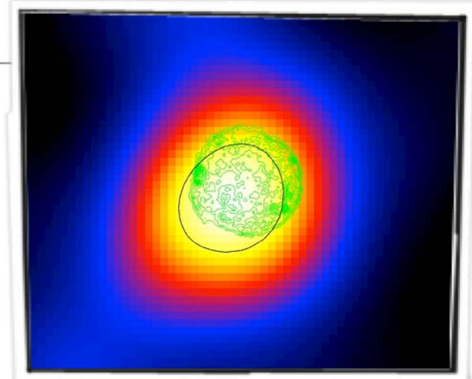
- Can explain all H.E.S.S. Galactic plane survey sources with reasonable population of SNRs (CR efficiency, SN frequency, ambient density, ...) (see e.g. Funk & Hinton 2008)
    - From that derive O(200) SNRs should be visible by CTA
    - Detecting SNRs with gamma rays! (see e.g. HESS J1731-341)

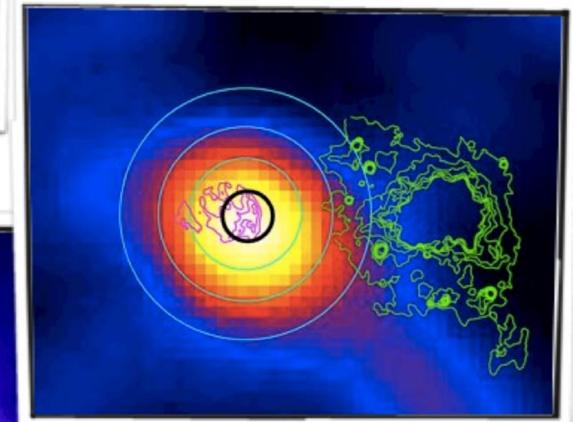


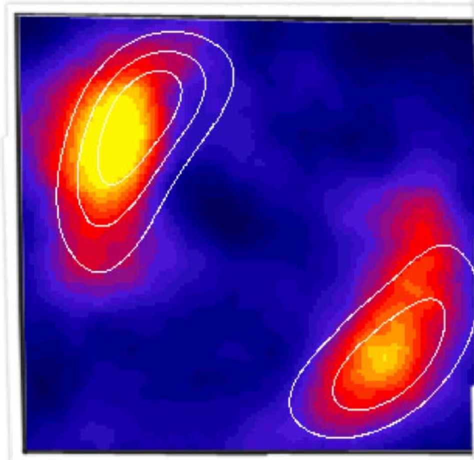
Summary

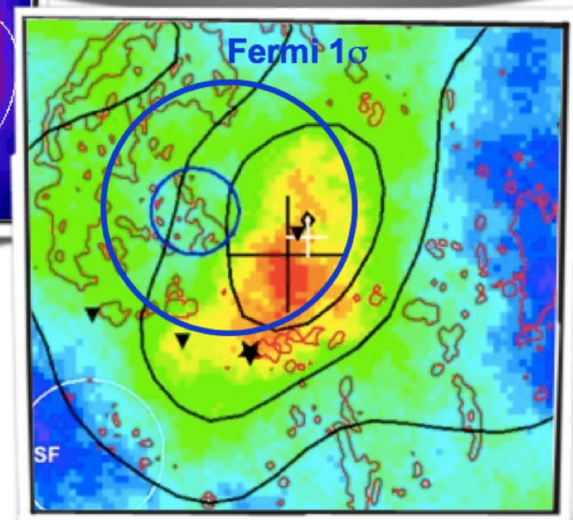
- Supernova remnants are an abundant source of gamma rays
  - Both at GeV and TeV energies
- Start to address the evolution of particle acceleration in remnants
- Disentangle source intrinsic from external effects (in particular ambient density)



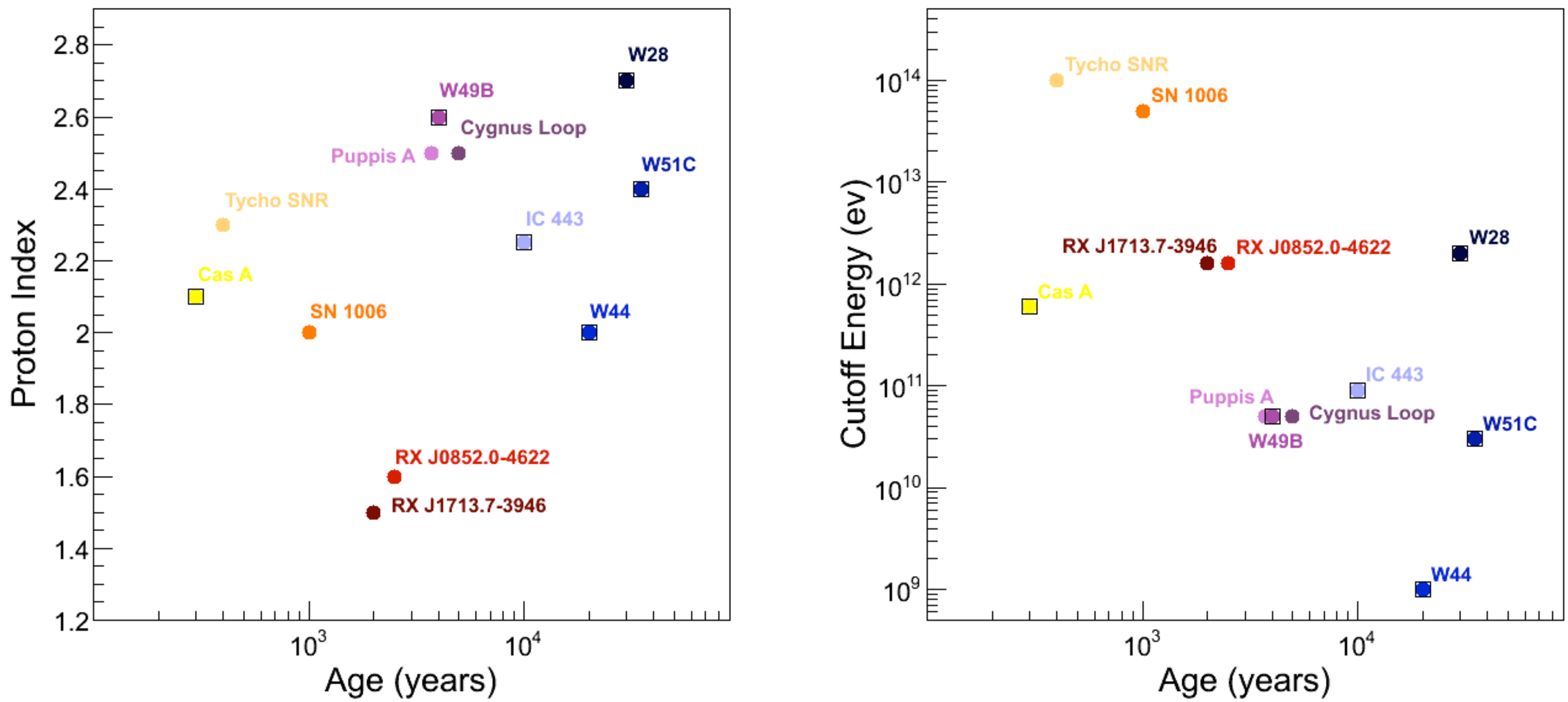








Spectra versus age

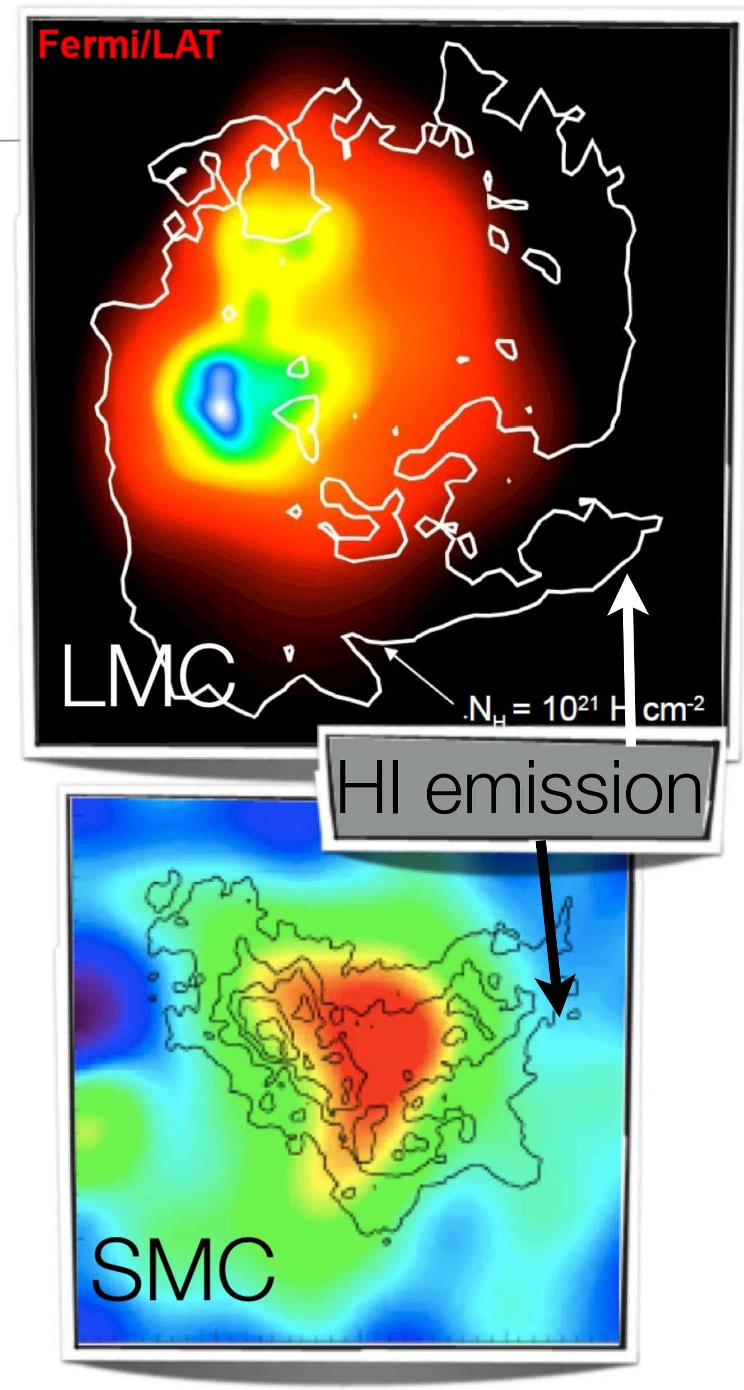


- For cloud-interacting remnants expect lower E_{max} since shock-speed will be lower

Abdo et al. 2010

Cosmic rays in other Galaxies

- Diffuse emission similar to our own Galaxy observable for close-by galaxies, or those with enhanced star-formation
- Detection of M82, NGC 253, SMC, LMC, M31
- LMC: clear correlation with star-formation, no obvious correlation with HI (target material). Implies CR gradient in the LMC



Other Galaxies

- Start to see trend of correlation between GeV γ-ray luminosity and Star formation
- Suggest that CR density is related to star-formation
- Important to estimate contribution of star-forming galaxies to Isotropic diffuse emission
- And possibly the star-formation history of the Universe ...