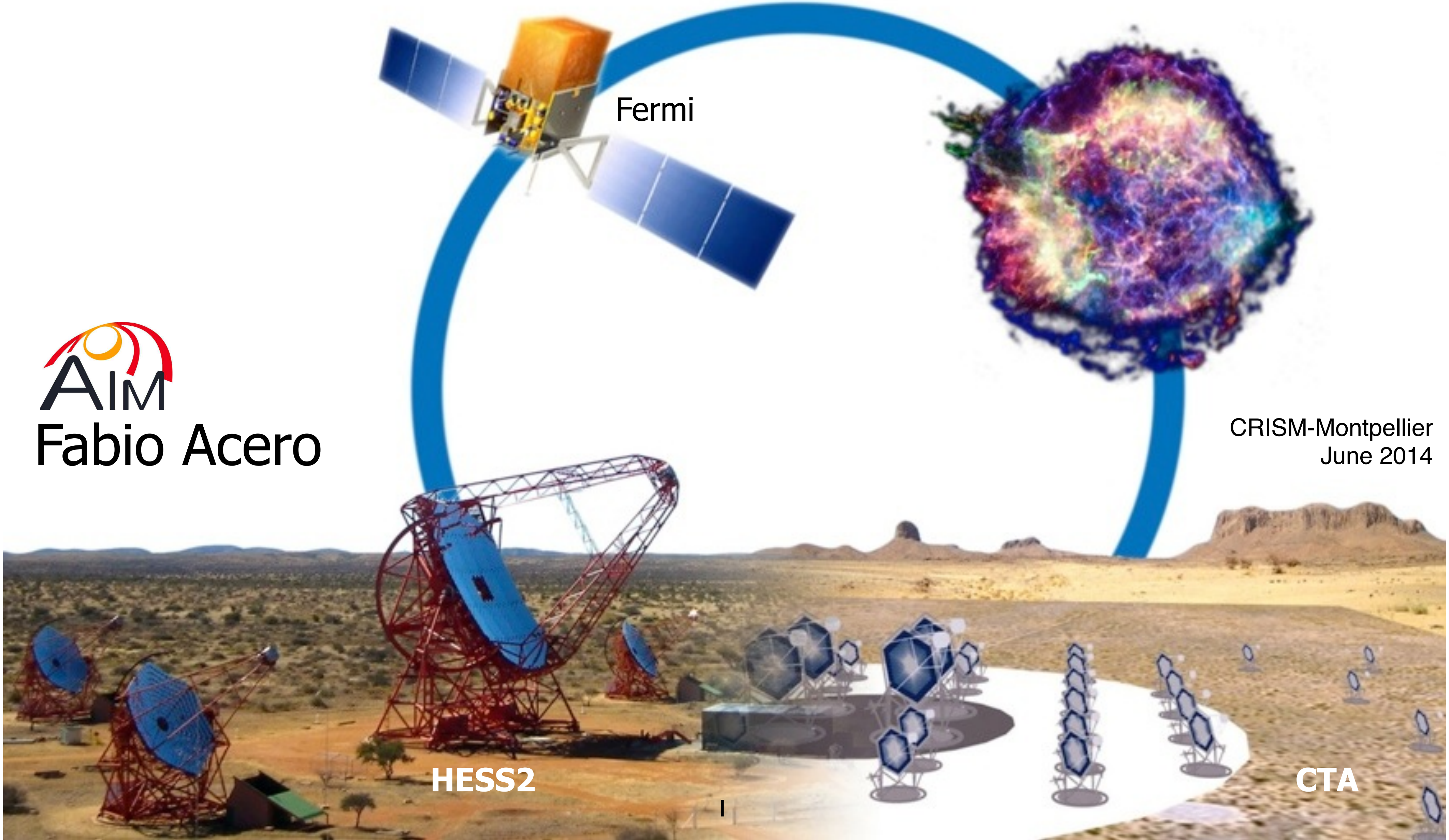
GeV constraints of young SNRs:

the case of SN 1006 and HESS J7131-347

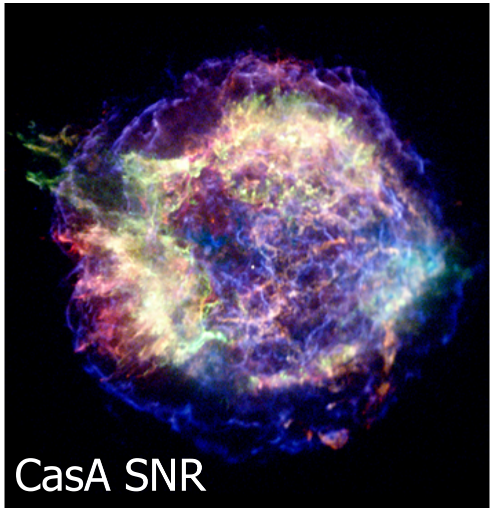


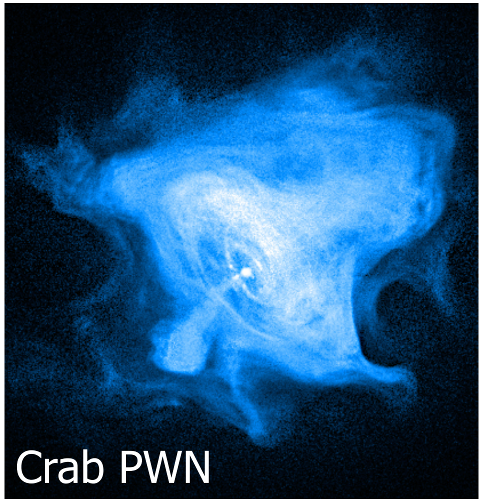
Fabio Acero

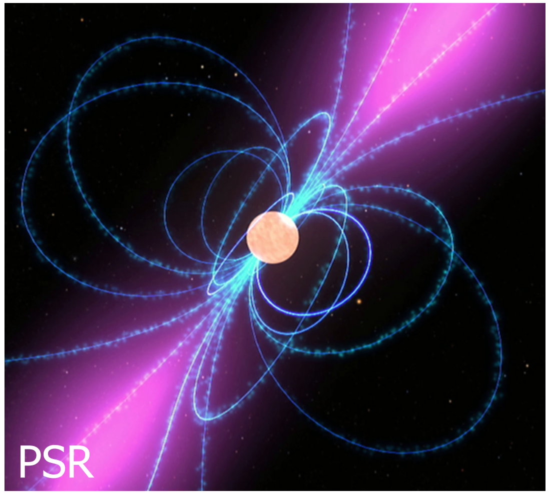
CRISM-Montpellier
June 2014

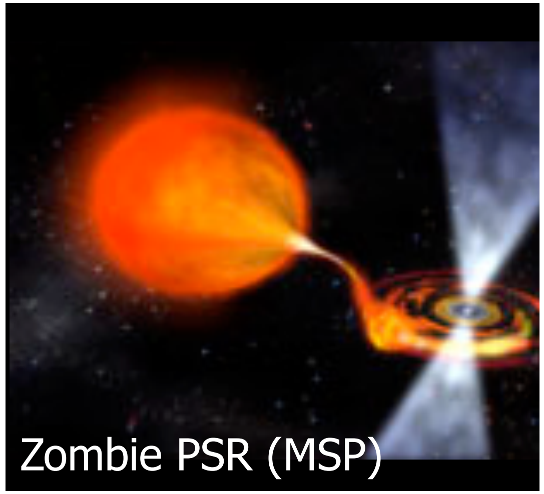
Particle acceleration in the stellar graveyard

SNR, PWN, Pulsar, Recycled Pulsar







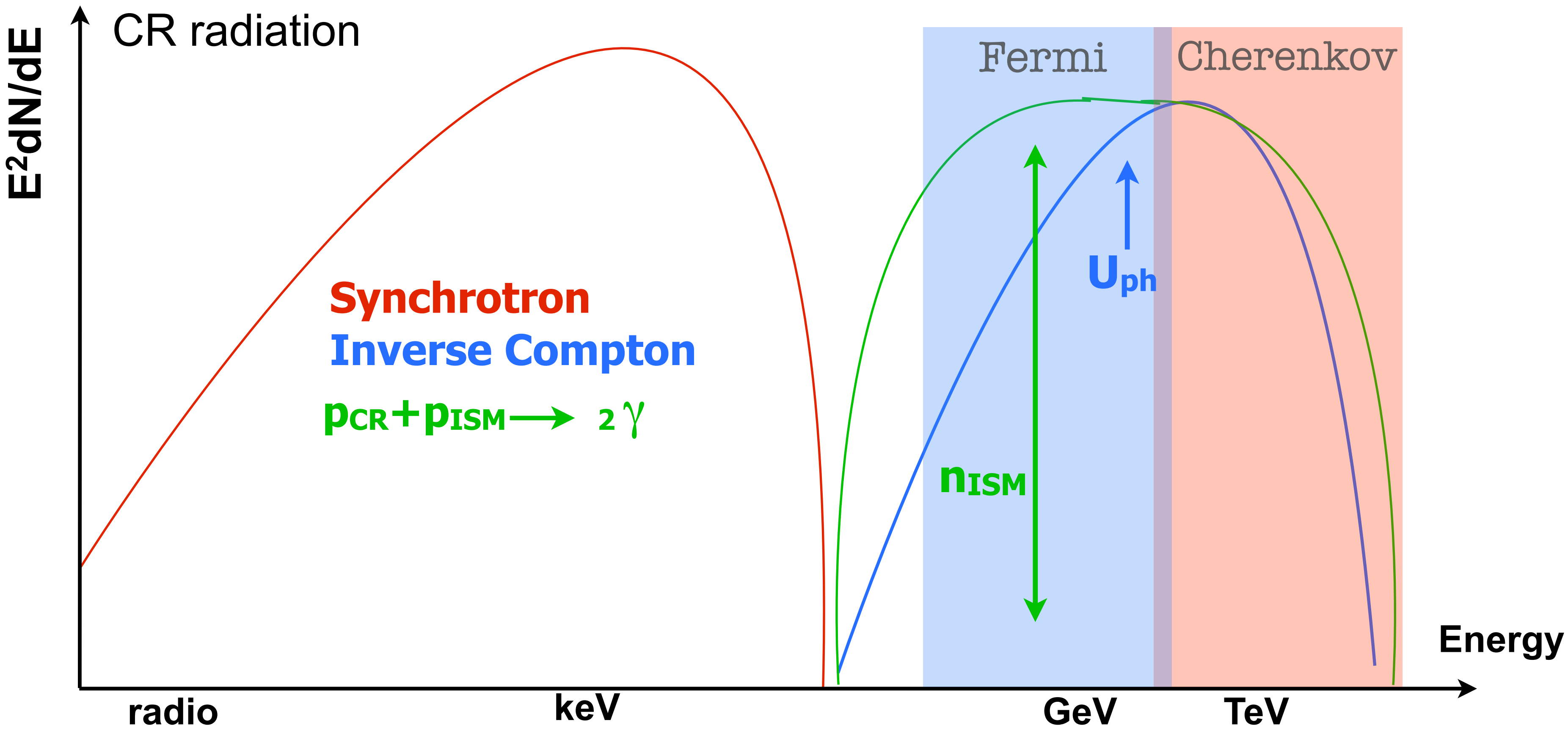


Acceleration at:			
Front shock	Relativistic shock	Polar cap, slot gap ?	Polar cap, slot gap ?
Powered by:			
Explosion Energy	PSR rotation	Electric field generated by PSR rotation	Momentum transfer (accretion)
Acceleration lasts[1]:			
few kyrs	few 10 kyrs	few 100 kyrs	~ Myrs

→ After Death Timescale

(1): Acceleration of high energy particles (~GeV-TeV)

Key Science questions



Composition : e^-/e^+, ions **(98% of CRs)**

Flux of CRs

Energy (max): ~3 x 10^{15} eV

- **Other goals:**

  - Time evolution of acceleration, escape, and propagation of CRs

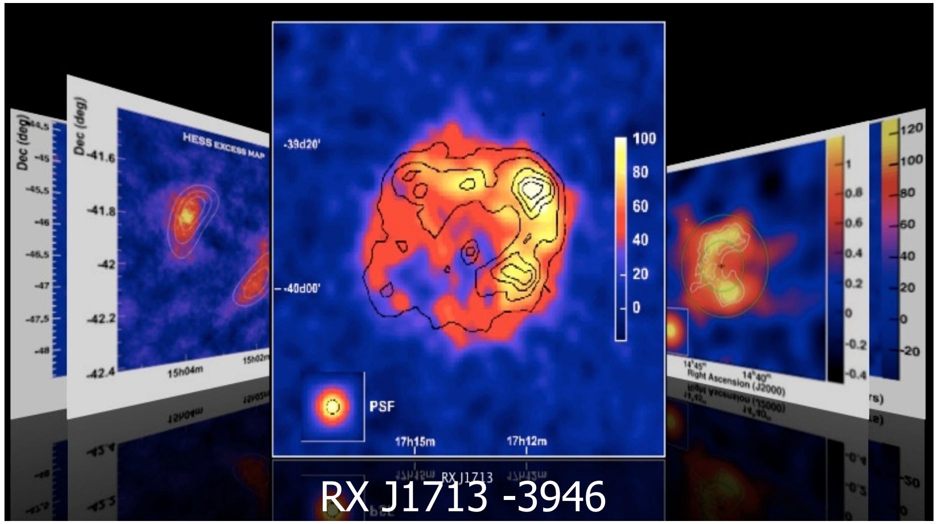
  - Effects of the surrounding environment

SNRs at TeV energies

Shell-morphology

young SNRs: few kyrs

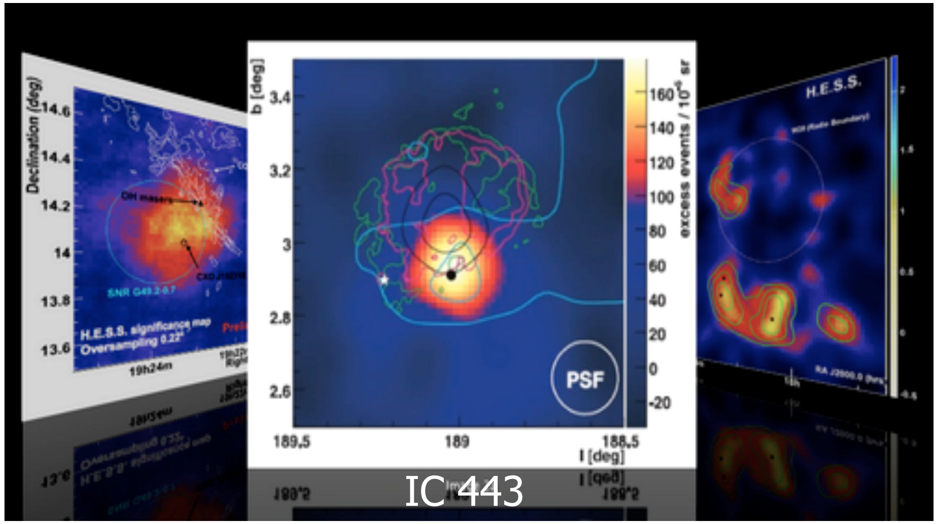
Vela Jr, RX J1713-3946,
RCW 86, SN 1006, HESS J1731



Interacting with molecular clouds

older SNRs: t~10 kyrs

IC 443, W28, W51, etc



SNRs at TeV energies

<u>Shell-morphology</u>

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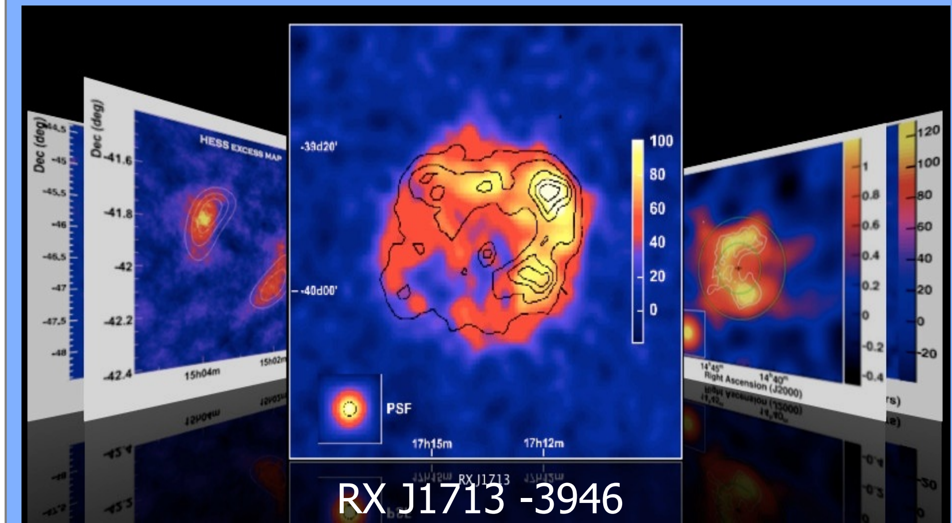

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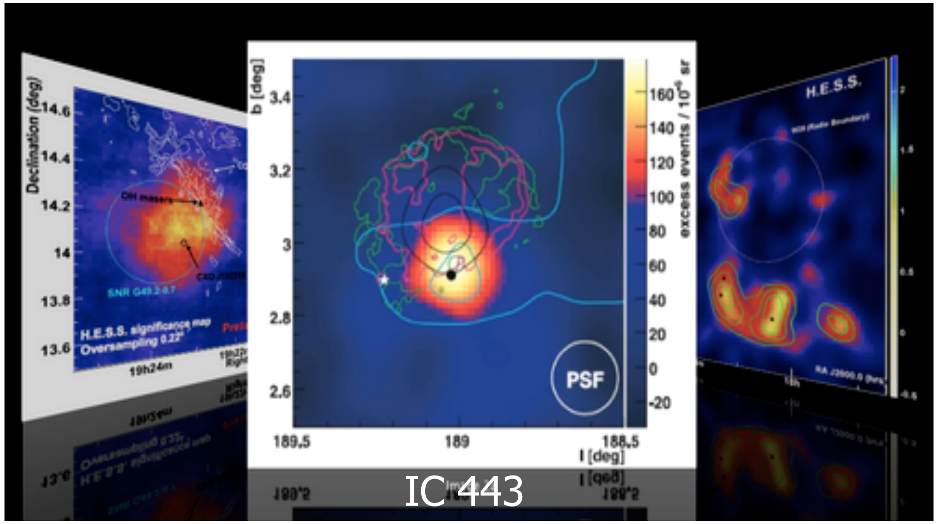
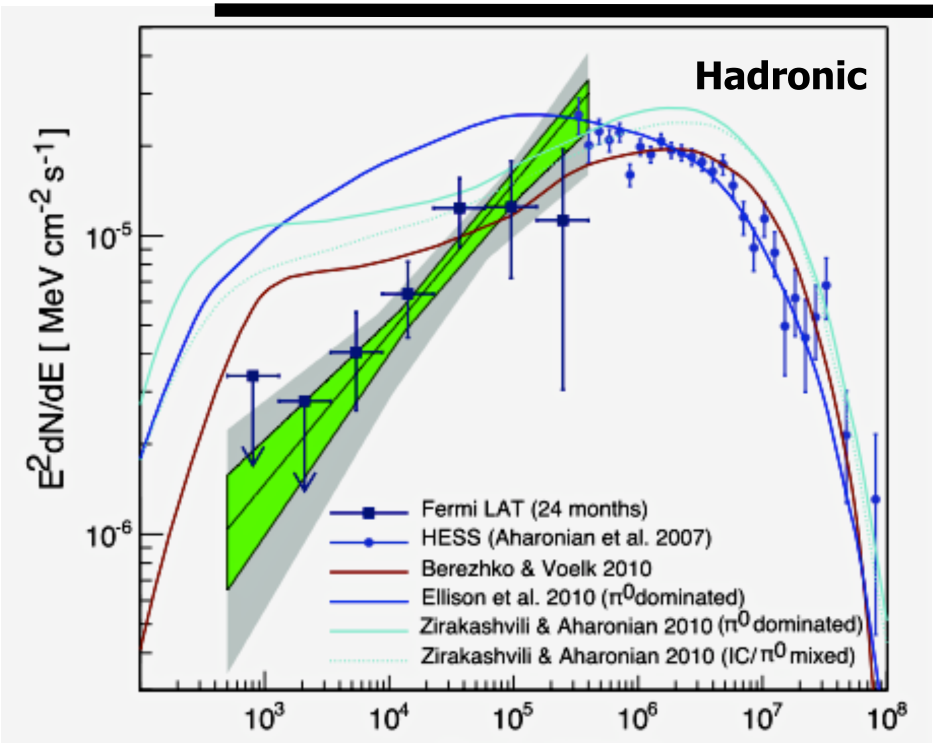
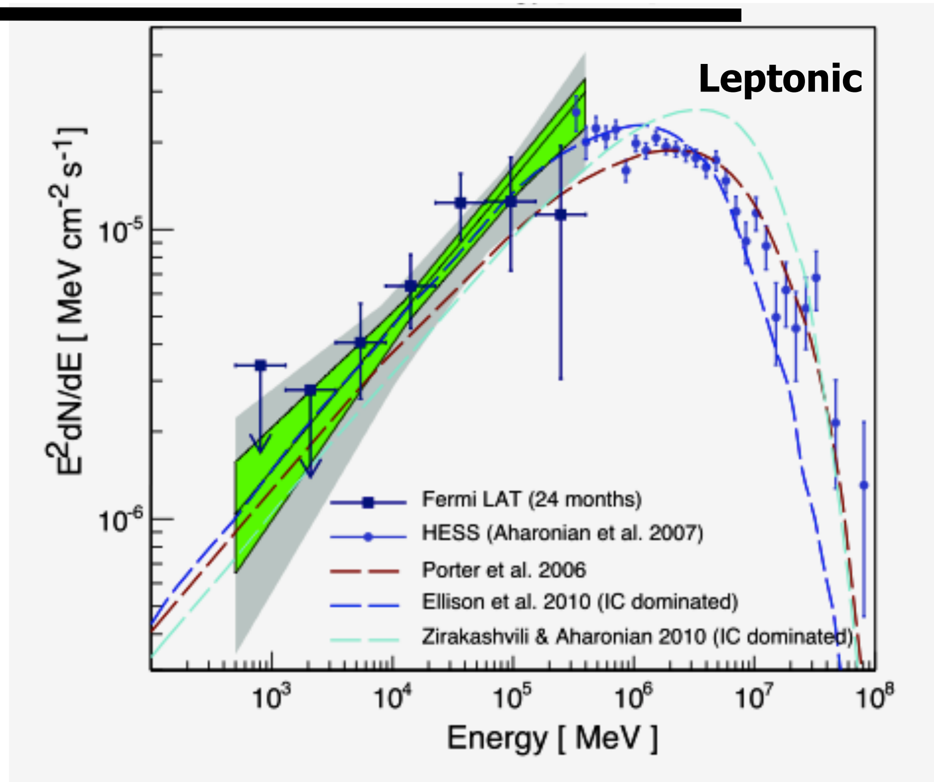


RX J1713-3946 : hadronic or leptonic ?



Abdo et al., 2011



Red --- (Berezhko 2010) :
$n_H = 0.25$ cm^{-3}

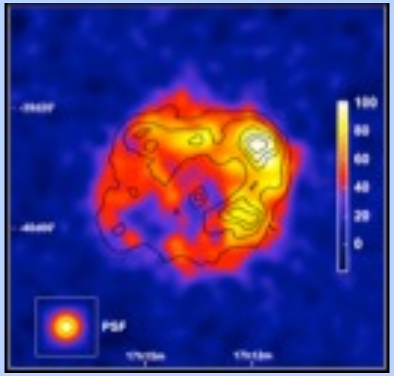
Blue --- (Ellison, 2010) :
$n_H = 0.05$ cm^{-3}

γ-ray emission is dominantly from leptonic processes*
Does NOT exclude existence of protons

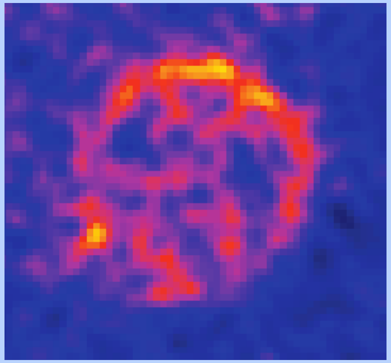
*: a hard spectrum could also be obtained from hadrons-clumps interaction (e.g. Inoue+12, Gabici+14)

The TeV-shell SNRs club

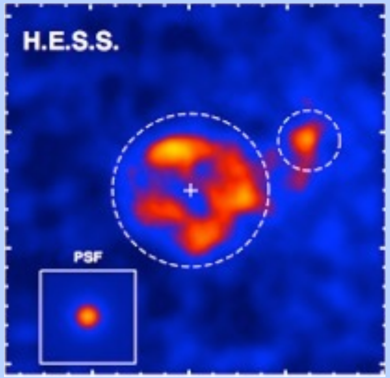
RX J1713



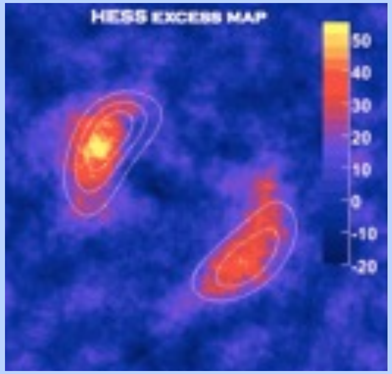
VelaJr



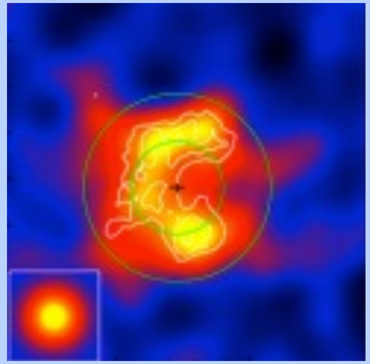
HESS J1731



SN 1006



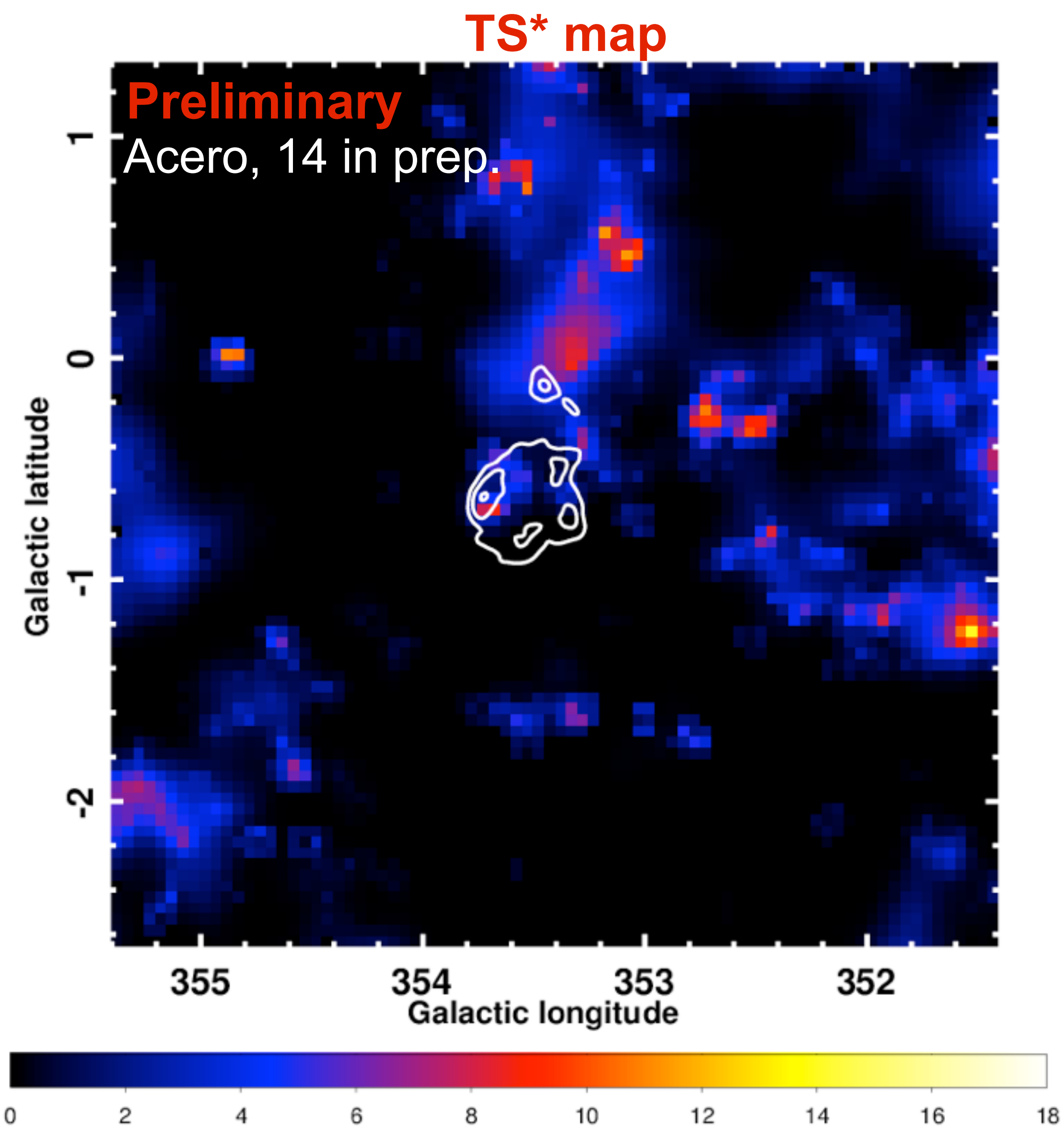
RCW 86



Core collapse SN (RX J1713, VelaJr, HESS J1731) — Type Ia (SN 1006, RCW 86)

	RX J1713	VelaJr	HESS J1731	SN 1006	RCW 86
Density	$<0.02\ cm^{-3}$	$<0.03\ cm^{-3}$	$<0.02\ cm^{-3}$	$<0.05\ cm^{-3}$	$0.01 - 1\ cm^{-3}$
Age	1.6 kyrs	2-4 kyrs	2-4 kyrs (?)	1.006 kyrs	1.8 kyrs
Radius	10 pc	12 pc	14 pc	10 pc	15 pc
GeV spectral index	1.5 ± 0.1	1.85 ± 0.06	?	?	< 1.8

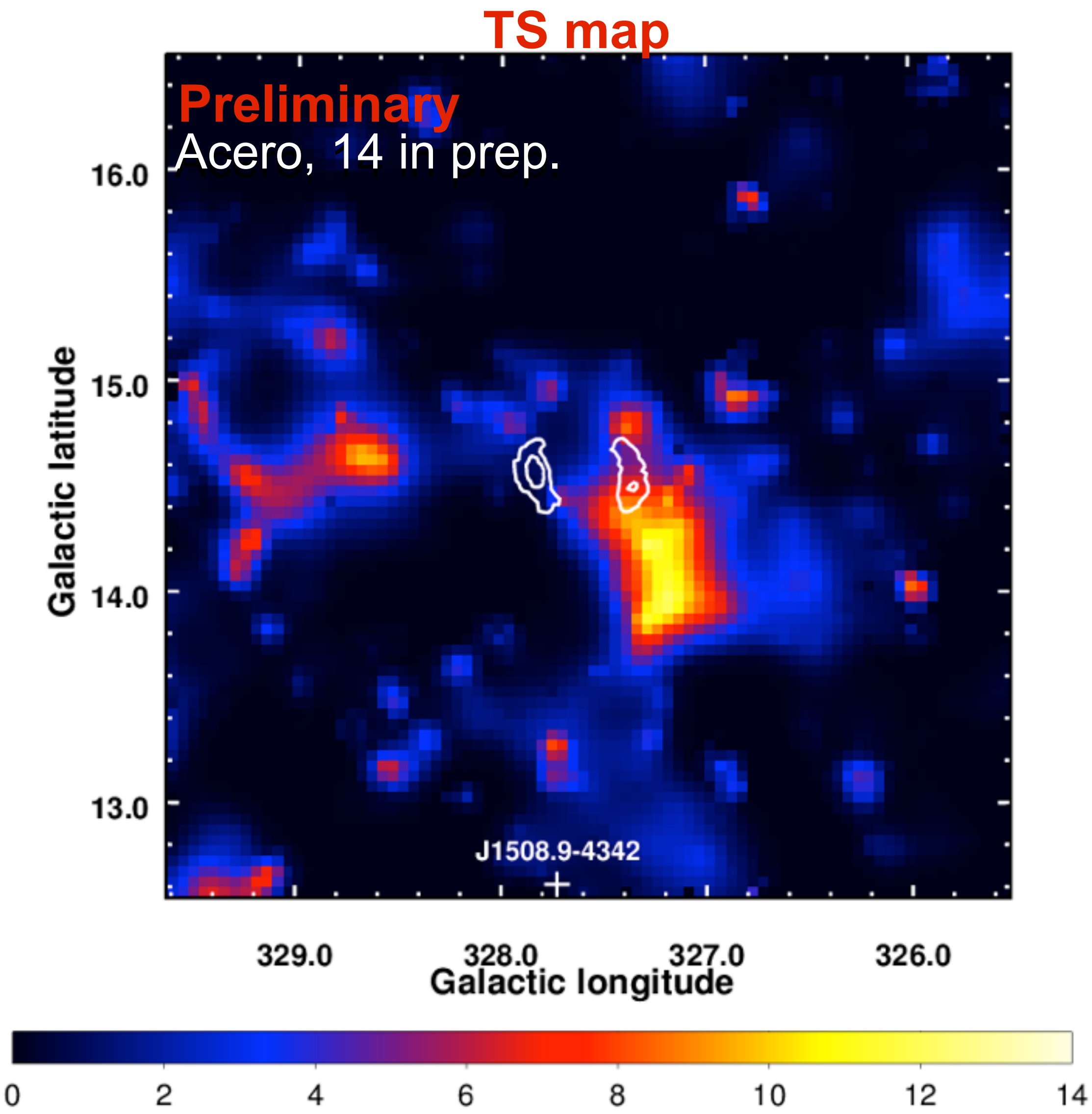
Fermi analysis of HESS J1731



- Analysis on 7°x7° ROI for E > 1 GeV with 5 yrs of P7REP data
- No significant source on SNR
- Using the HESS spatial template upper limits are derived (99.7% CL)

*: Sigma ~ sqrt(TS)   5 sigma ~ 25 TS

Fermi analysis of SN 1006



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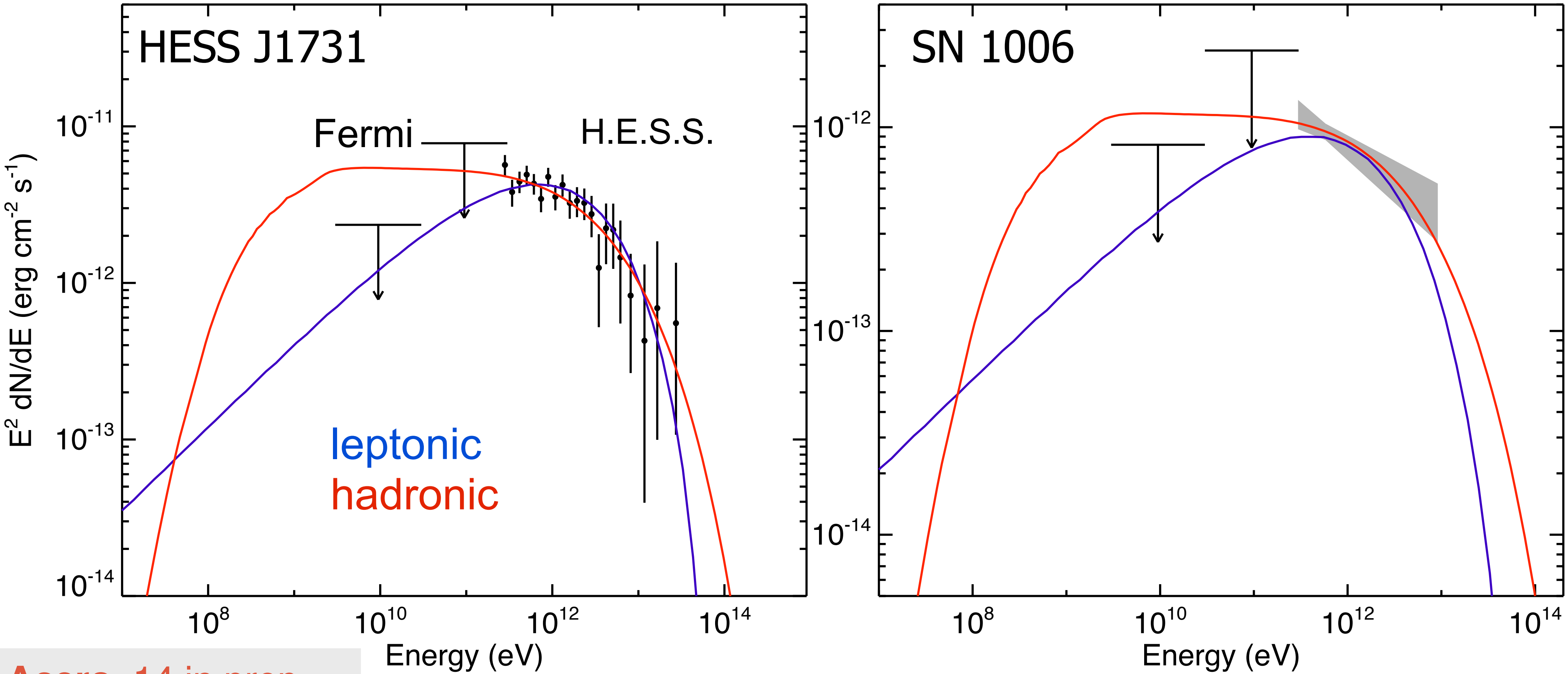
GeV-TeV spectral analysis

5 years of Fermi data



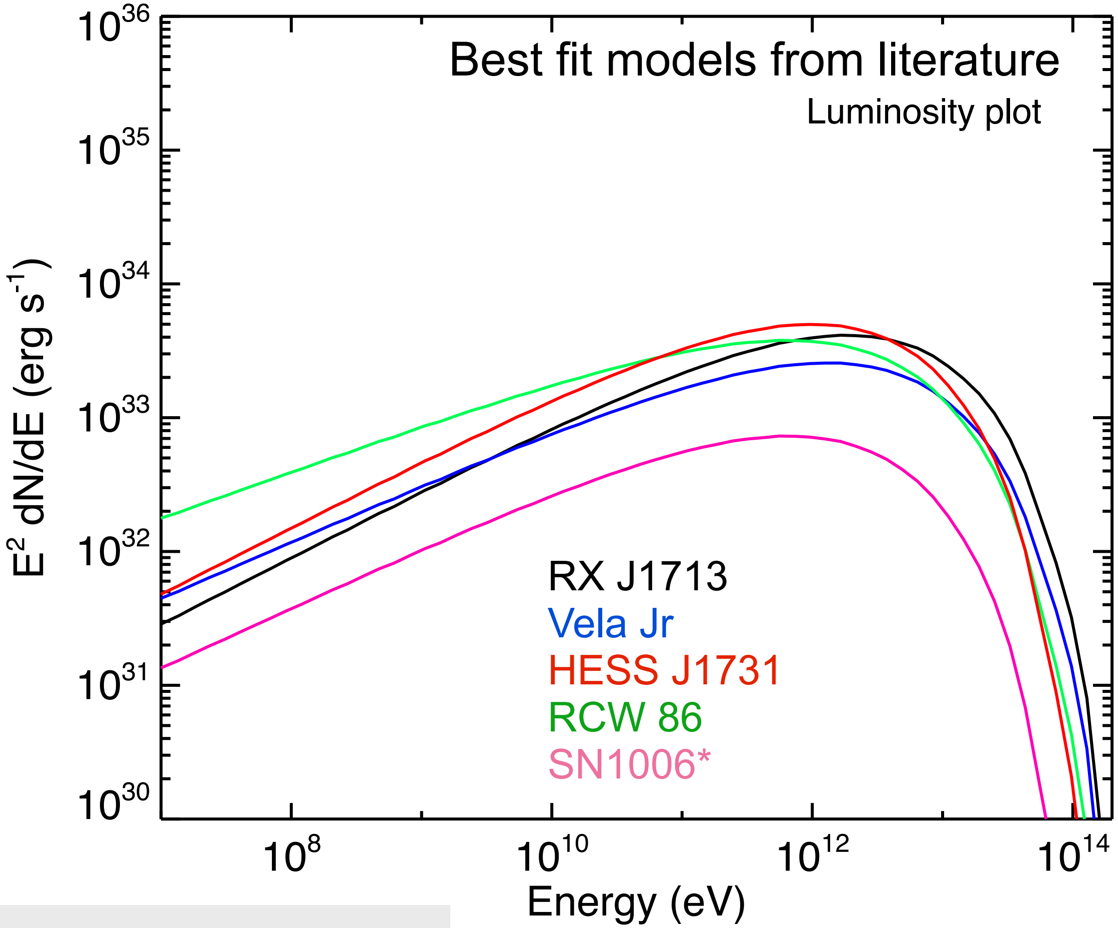
Acero, 14 in prep.

Simple hadronic model rejected

Similar to RX J1713

Electron radiation dominates GeV-TeV regime

Leptonic dominated model comparison

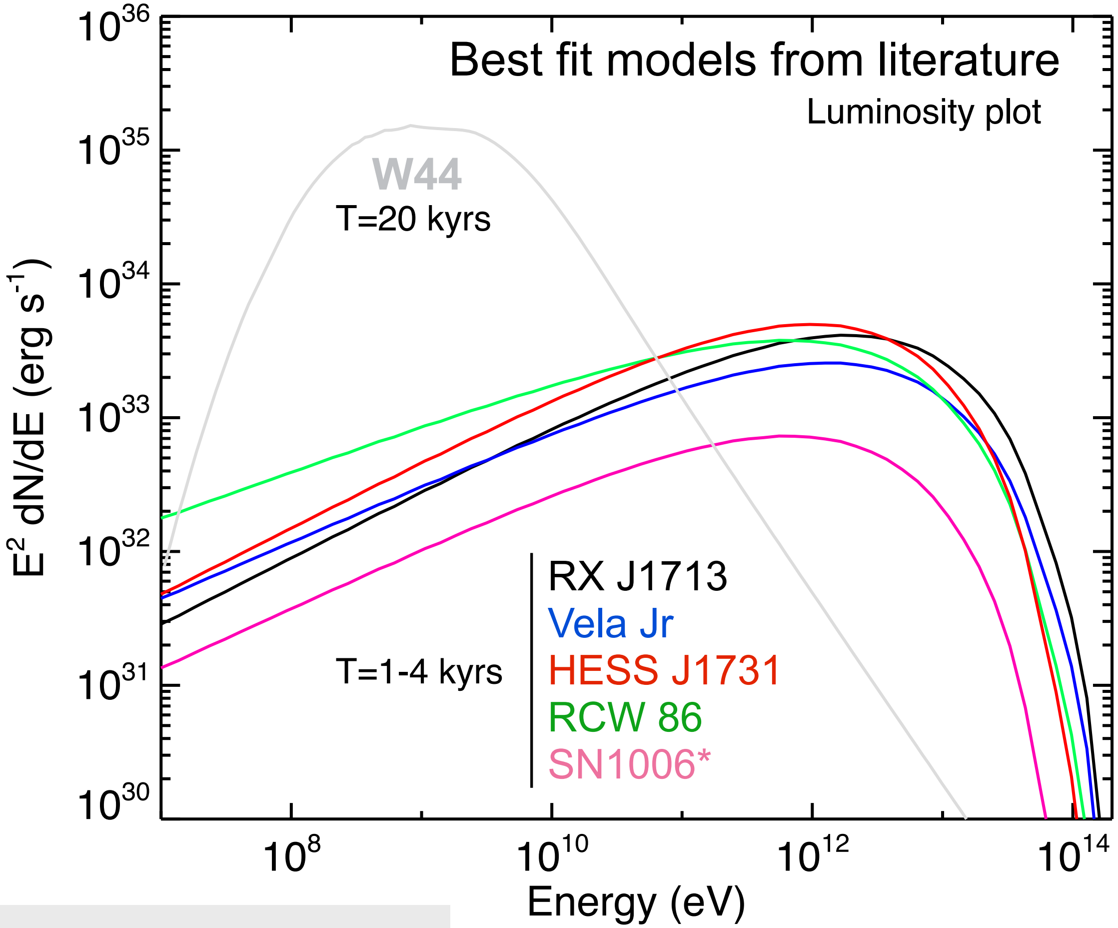


Acero, 14 in prep.

*Except SN 1006. Why ?
- high latitude
- Bipolar morphology, lower V_{accel}

- Similar γ-ray luminosity
  For different SN type
- Similar physical scenario ?
  Leptonic scenario dominating ?
  Same electrons energetics ?
- SNRs are led by their environment

Leptonic dominated model comparison



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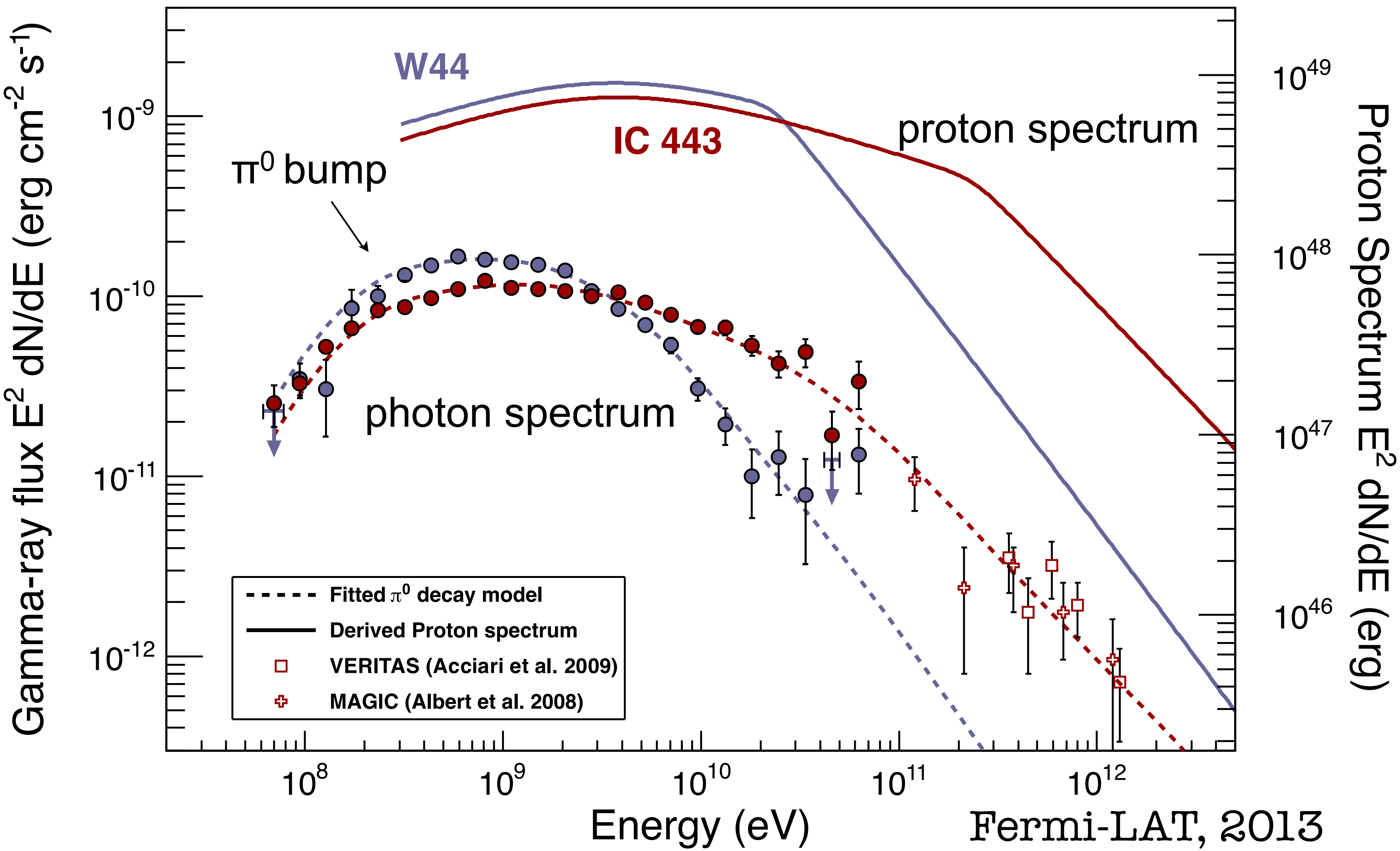
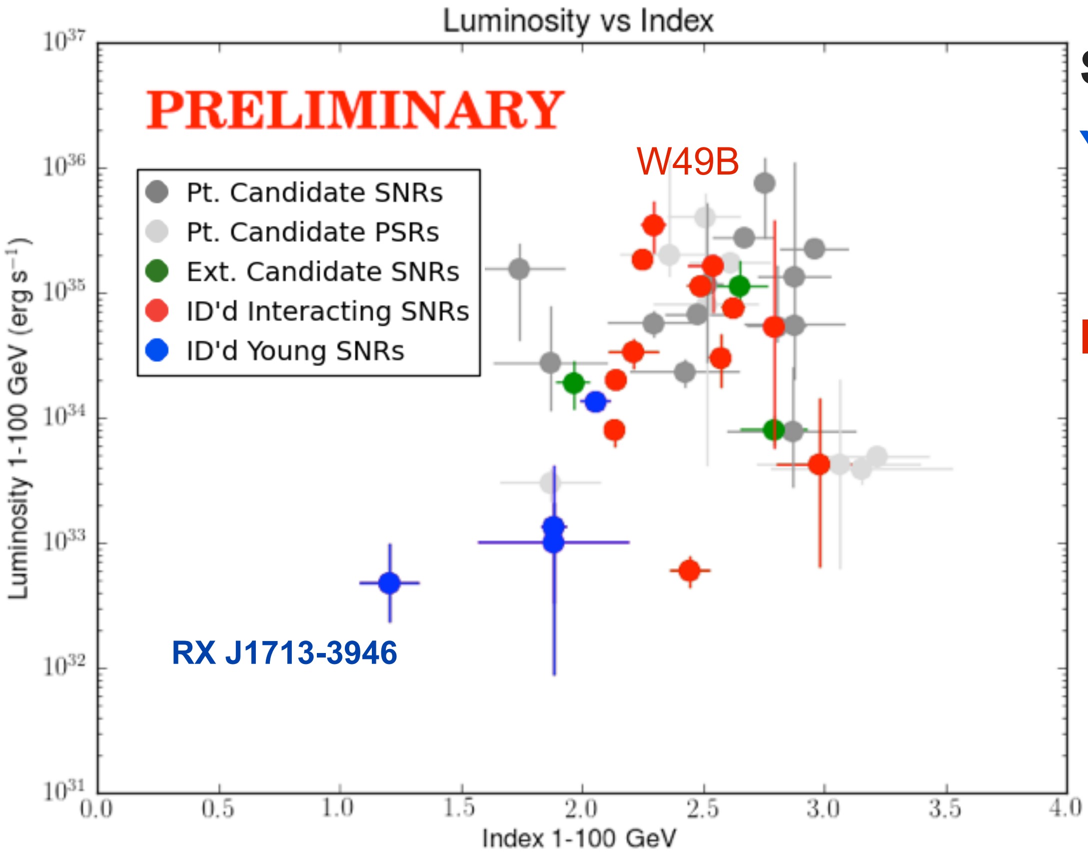
W44 at GeV

Evidence of accelerated protons in SNRs !



Fermi-LAT, 2013
AGILE, 2011

GeV index-Luminosity



1st Fermi SNR catalog
Brandt, Hewitt, DePalma, Giordano, Acero and more

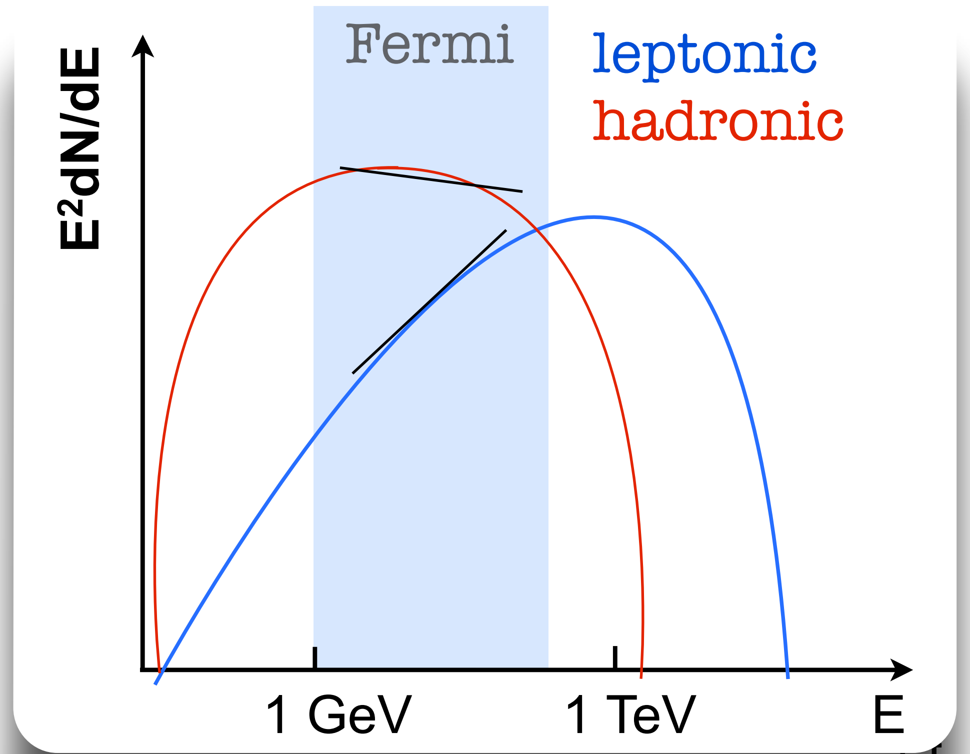
Scatter on two orders of magnitude in Lγ

Young SNRs have low Lγ, hard index

Evolving in low ambient densities ?

Interacting SNRs have higher Lγ, soft index

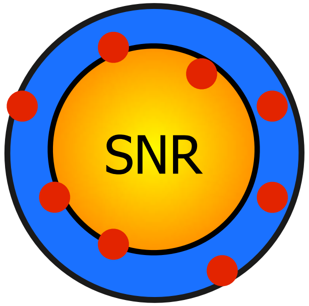
Encountering higher densities



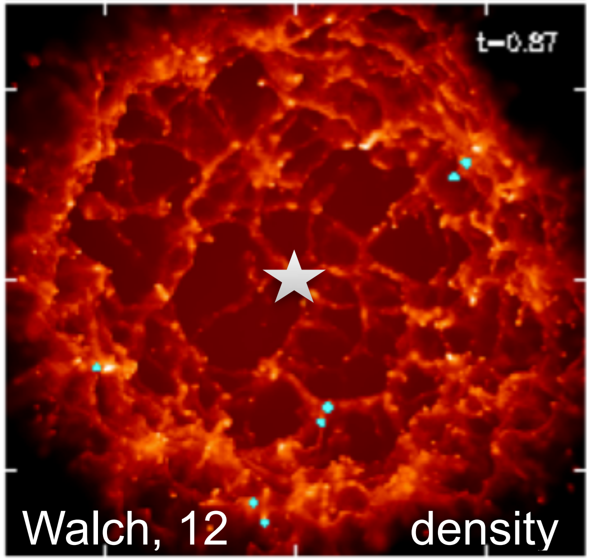
Emerging picture (simple)

- **Time evolution of gamma-ray emission from SNRs**

T ~ few kyrs

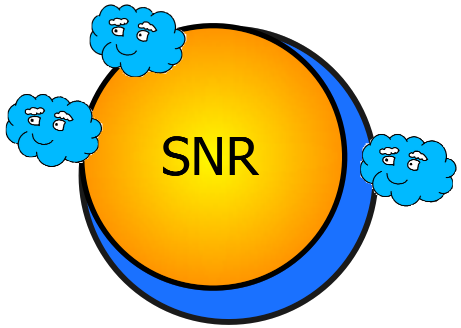


Low density cavity+clumps

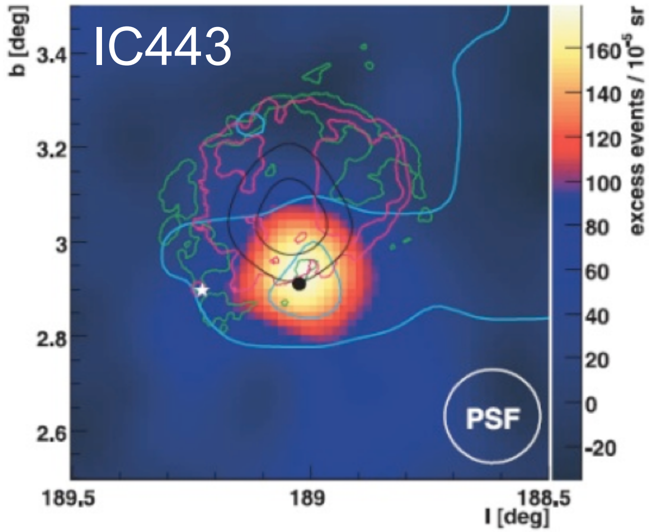


Leptonic γ-ray
+hadronic from clumps

T ~ few 10 kyrs

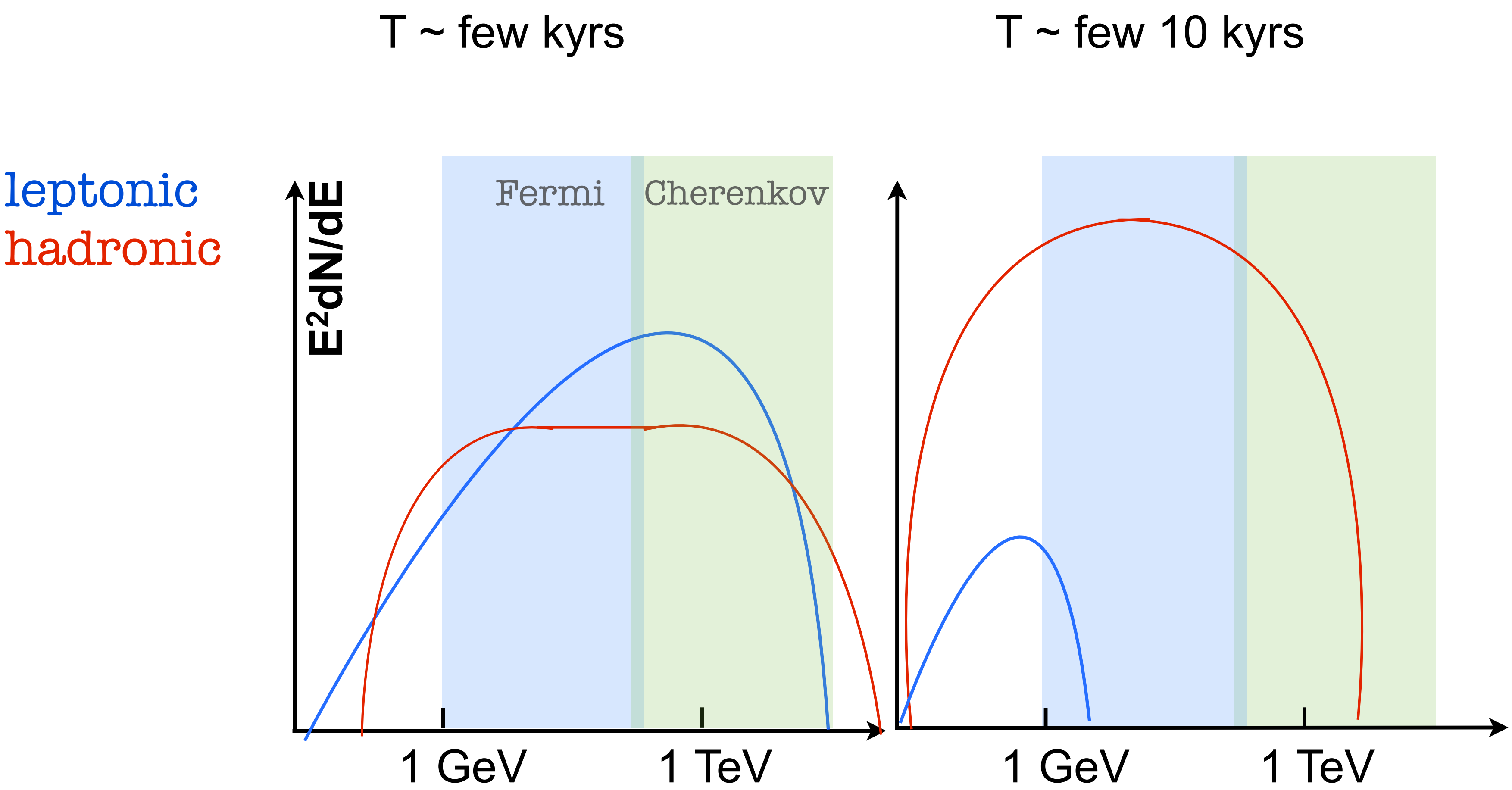


Cavity border + clouds



Hadronic from shock-cloud
interaction
(no X/γ leptonic emission)

Simple SED time evolution



Leptonic
+ hadronic from clumps
Hadronic slope could be harder

Hadronic from shock-cloud
Spectral break at TeV (low Vshock)
No high energy electrons

Conclusion

- **Emerging global picture for SNRs for the HE emission:**
  - **Time evolving dominant mechanism**
  - **SNRs are led by their environment**

- **Composition:** e^- shining (young SNRs), protons (evolved SNRs)
- **Flux:** population study will tell
- **Emax:** E_{max}(p) measured only with old SNRs

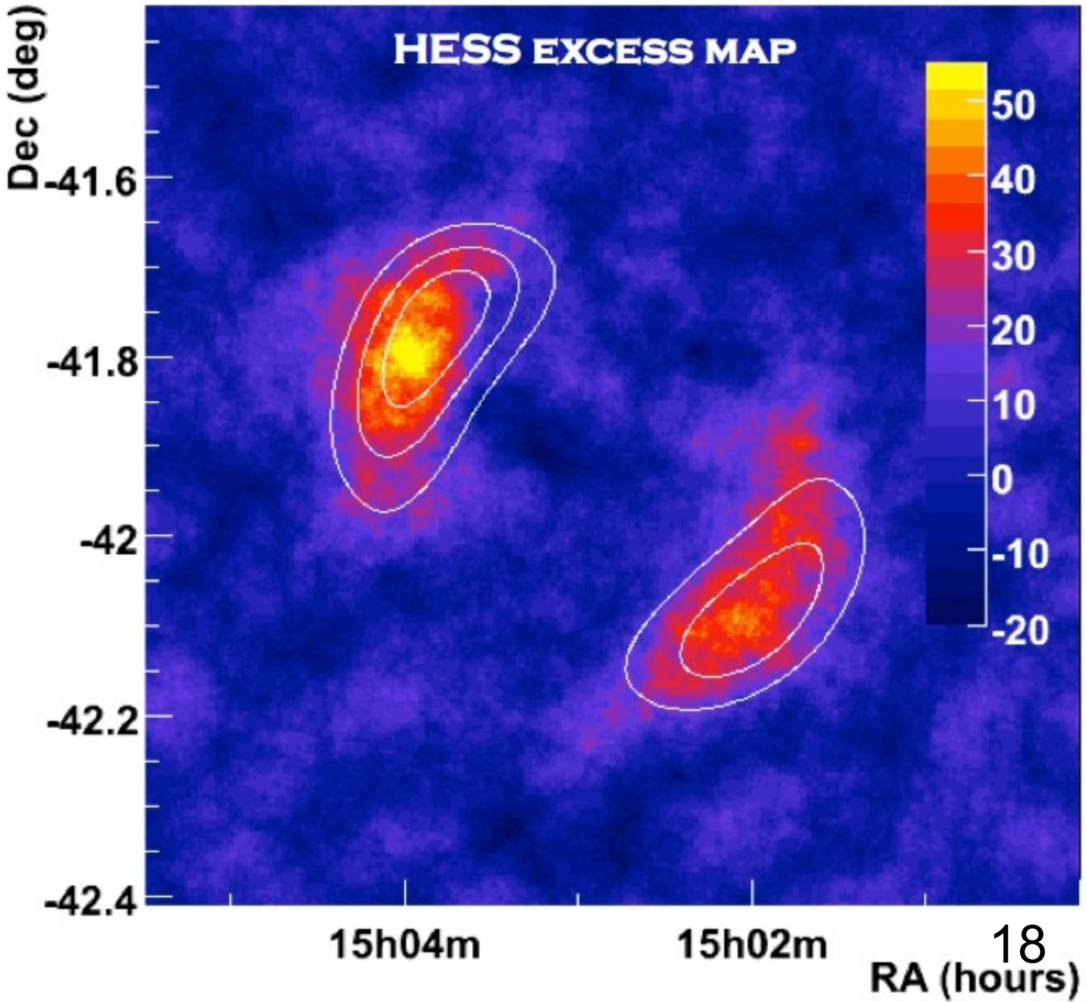
Main issues:

High density -> V_{shock} decreases -> E_{max} decreases

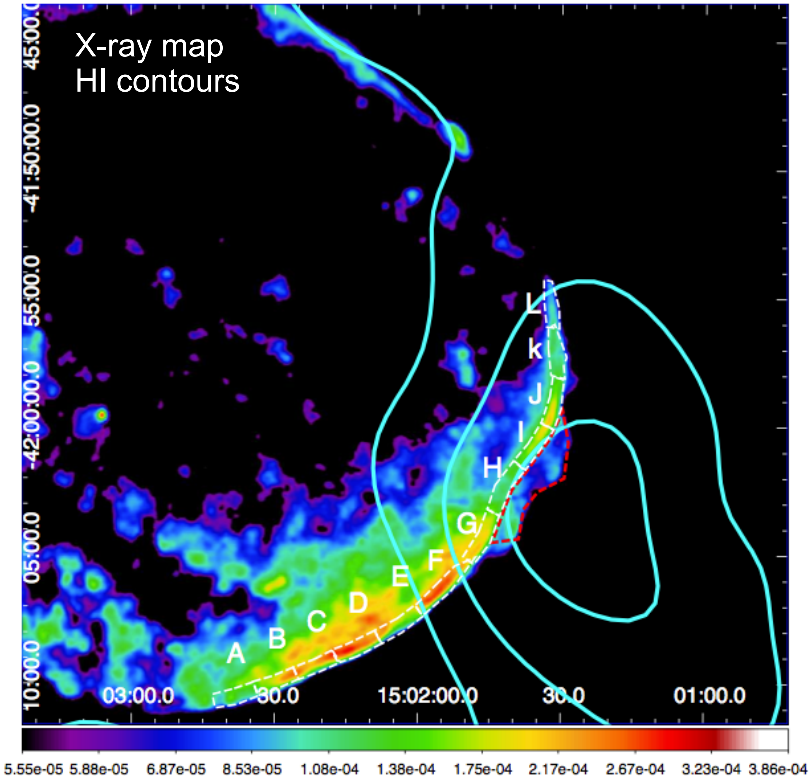
CR(Emax) escape the SNR quickly

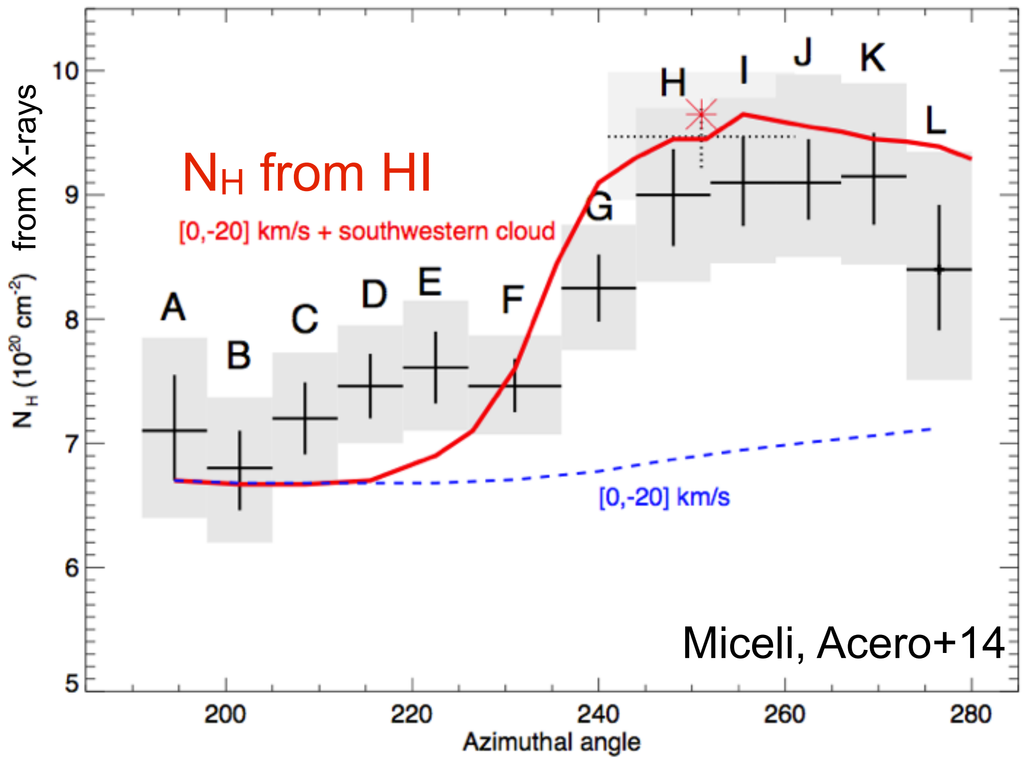
Side note - densities in SN 1006

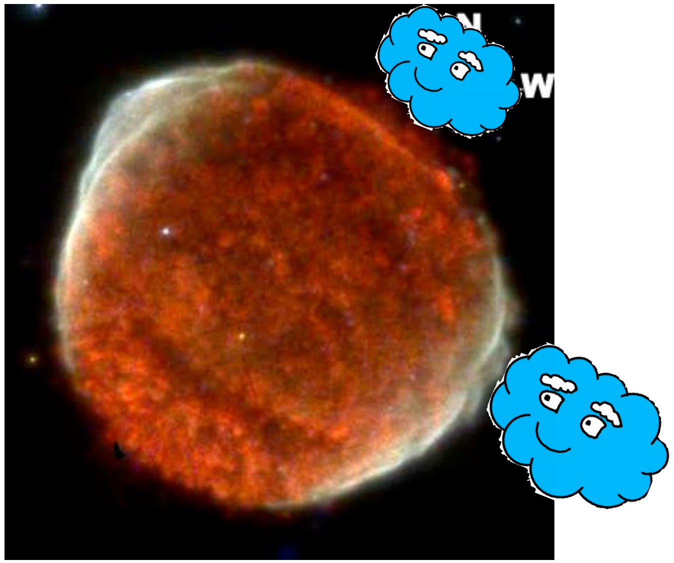
- Low average density of ~ 0.05 cm^{-3}
  - Known shock-cloud interaction in the NW (density ~1 cm^{-3})
  - But acceleration is only efficient in bright limbs (B field effect)



Discovery of interaction in the SW

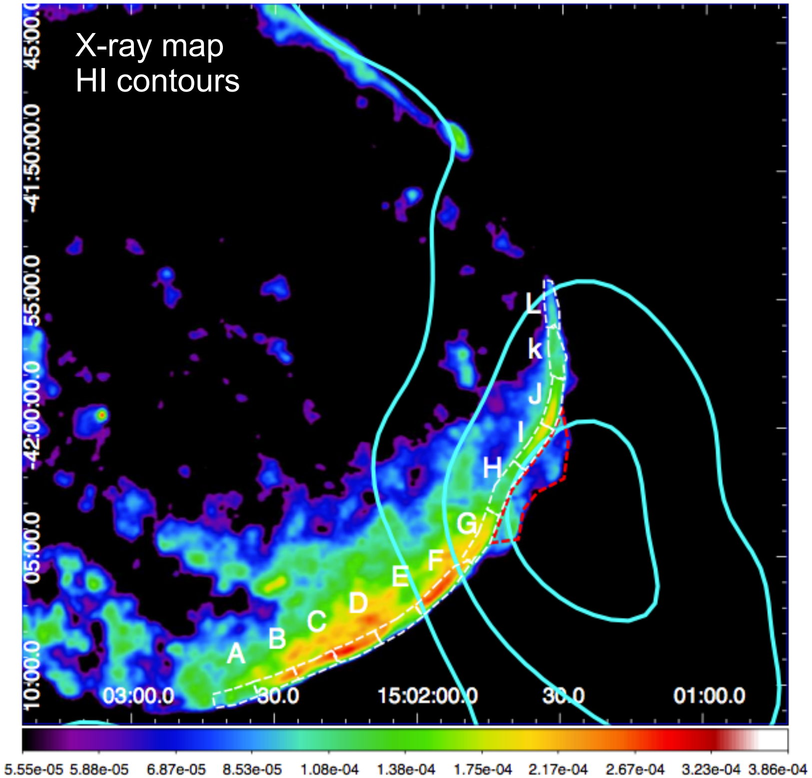


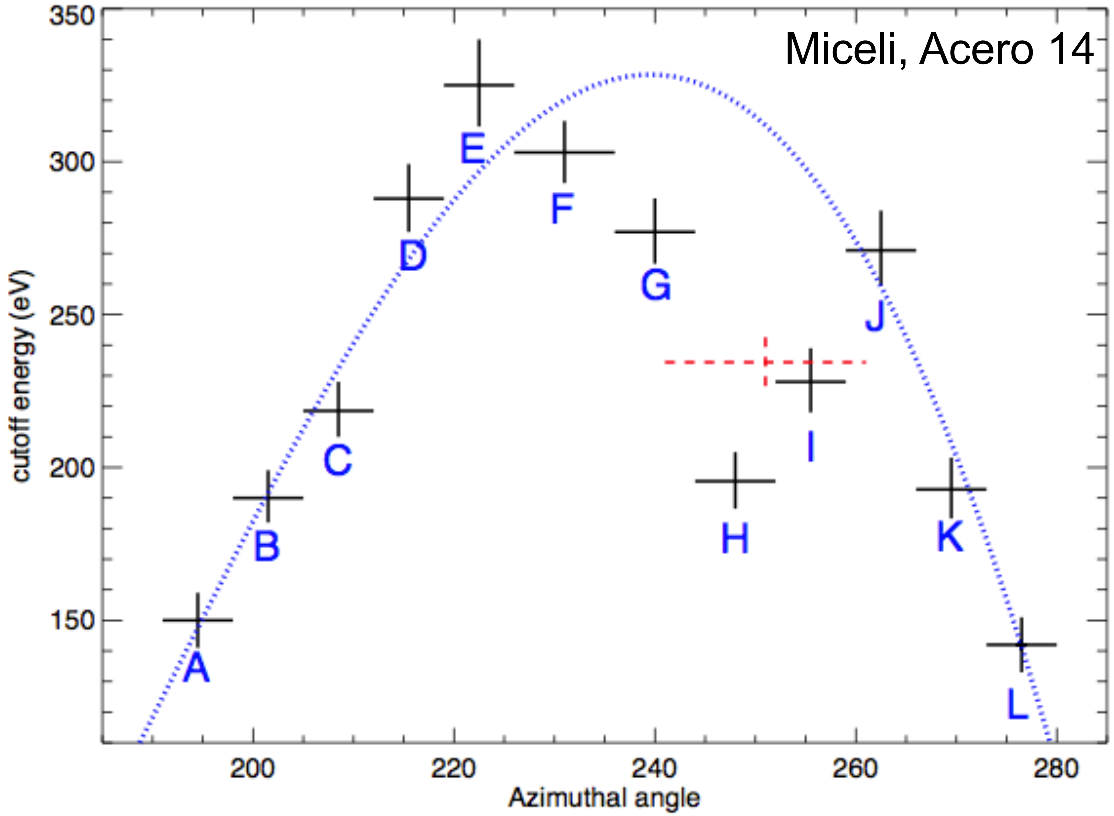


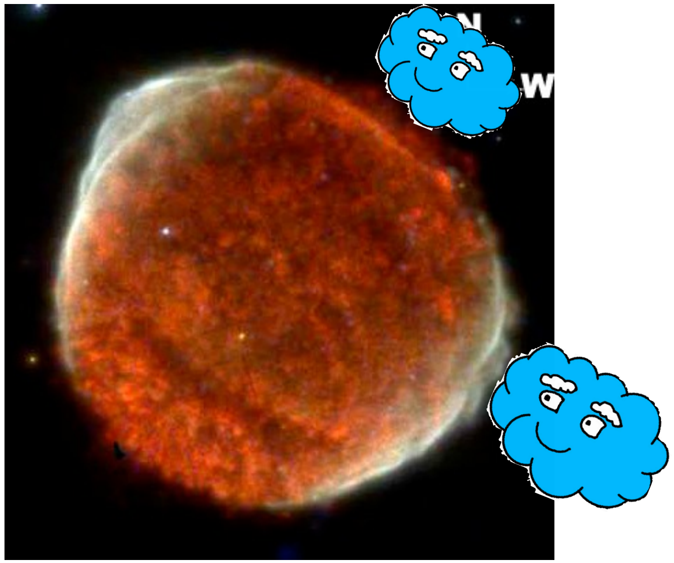


- Cloud at same V_{LSR} as NW cloud
- HI reproduce perfectly X-ray N_H
- Gas is in front of line sight

Discovery of interaction in the SW



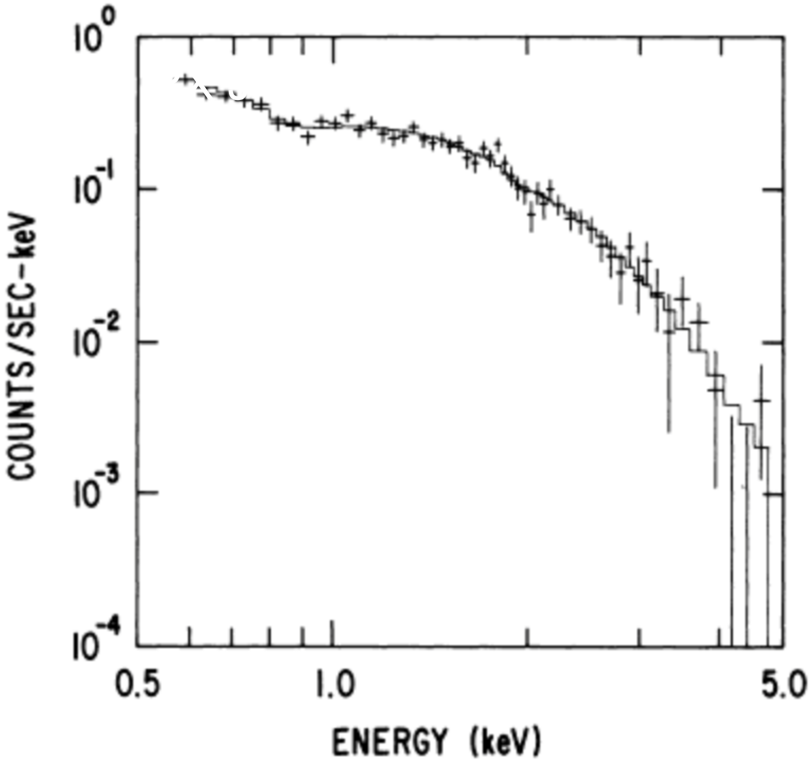




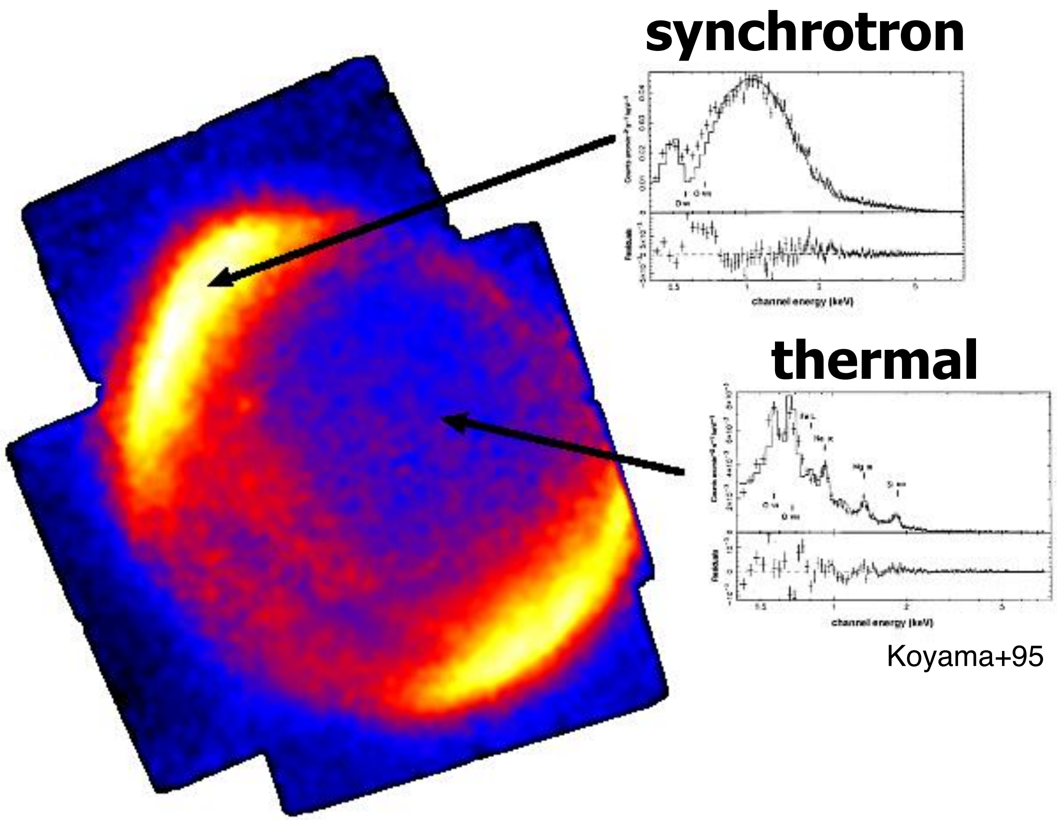
Shock has decellerated due to interaction

1980 - 2010 : disentangling components

- **In 1980's : SN 1006 is thermal or synchrotron ?**



OSO8-1980



Koyama+95

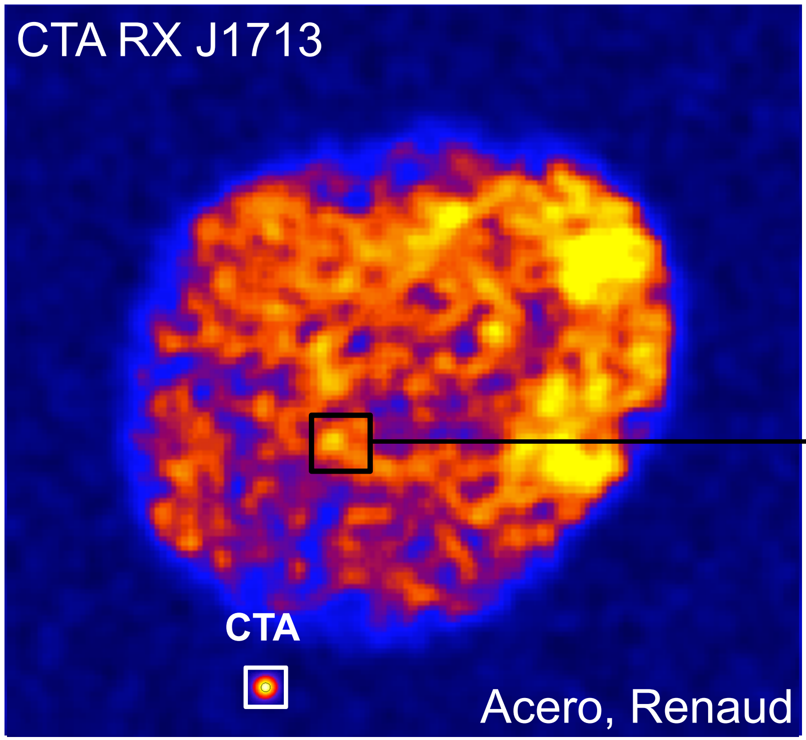
ASCA - 1995

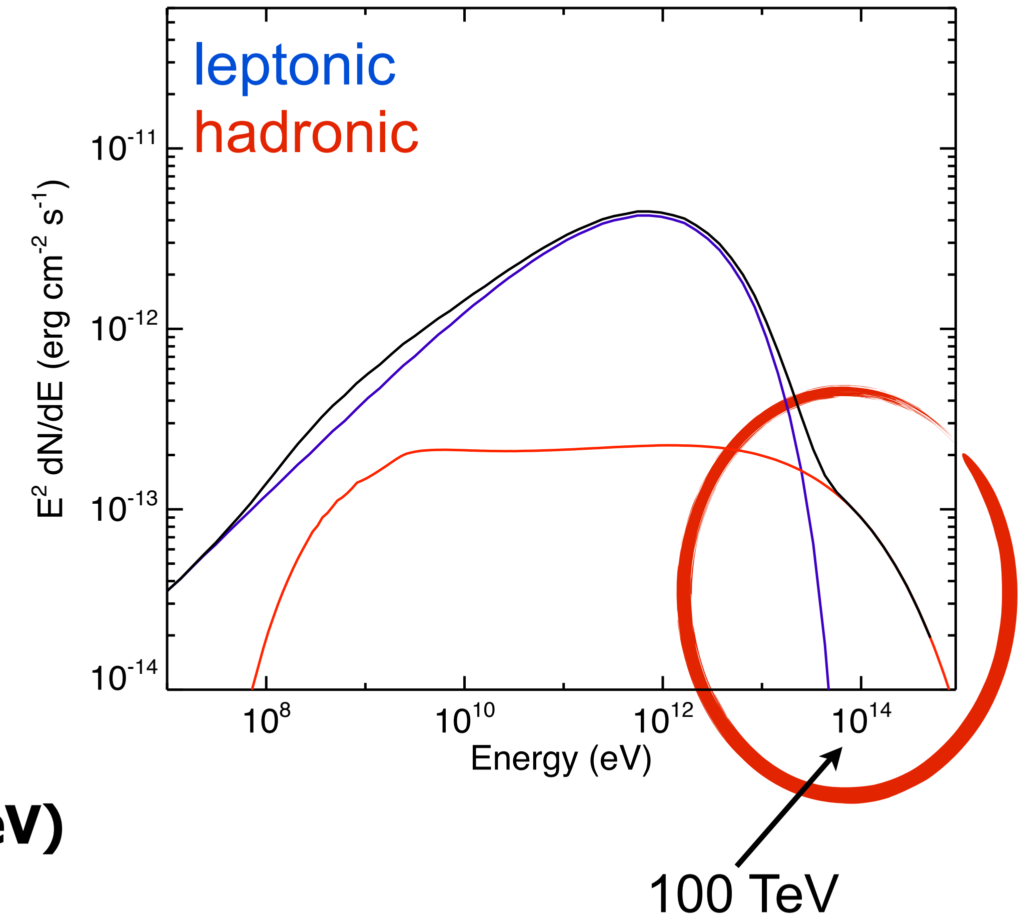
HESS

CTA ?

Spatially resolved spectroscopy with CTA

- **SNRs are a mix of hadronic and leptonic emission**





- **PeVatron search (CR of 10^{15} eV)**