Galactic Neutrino Sources

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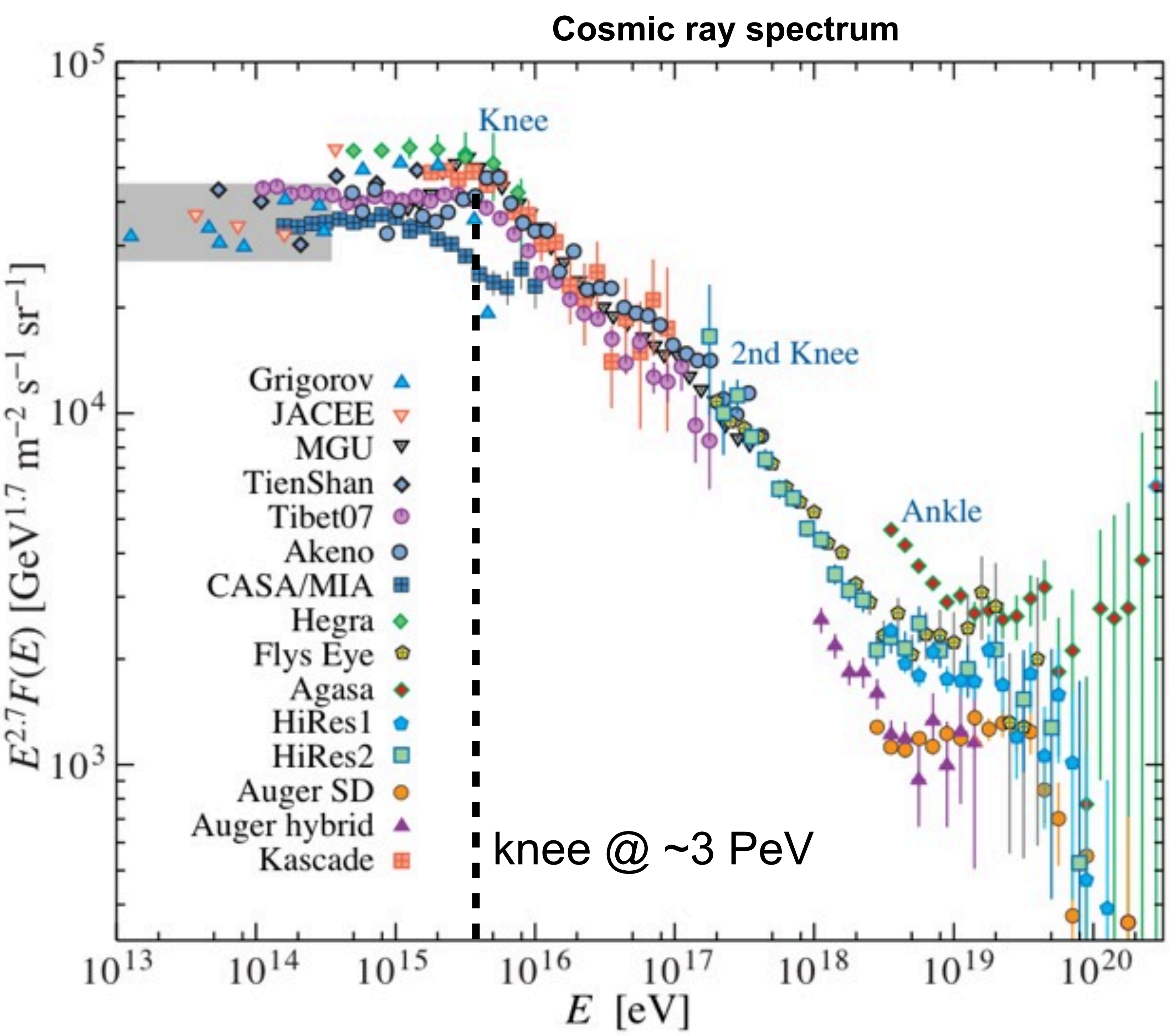
MANTS Meeting 2011
Uppsala, September 24, 2011

HUMBOLDT-UNIVERSITÄT ZU BERLIN

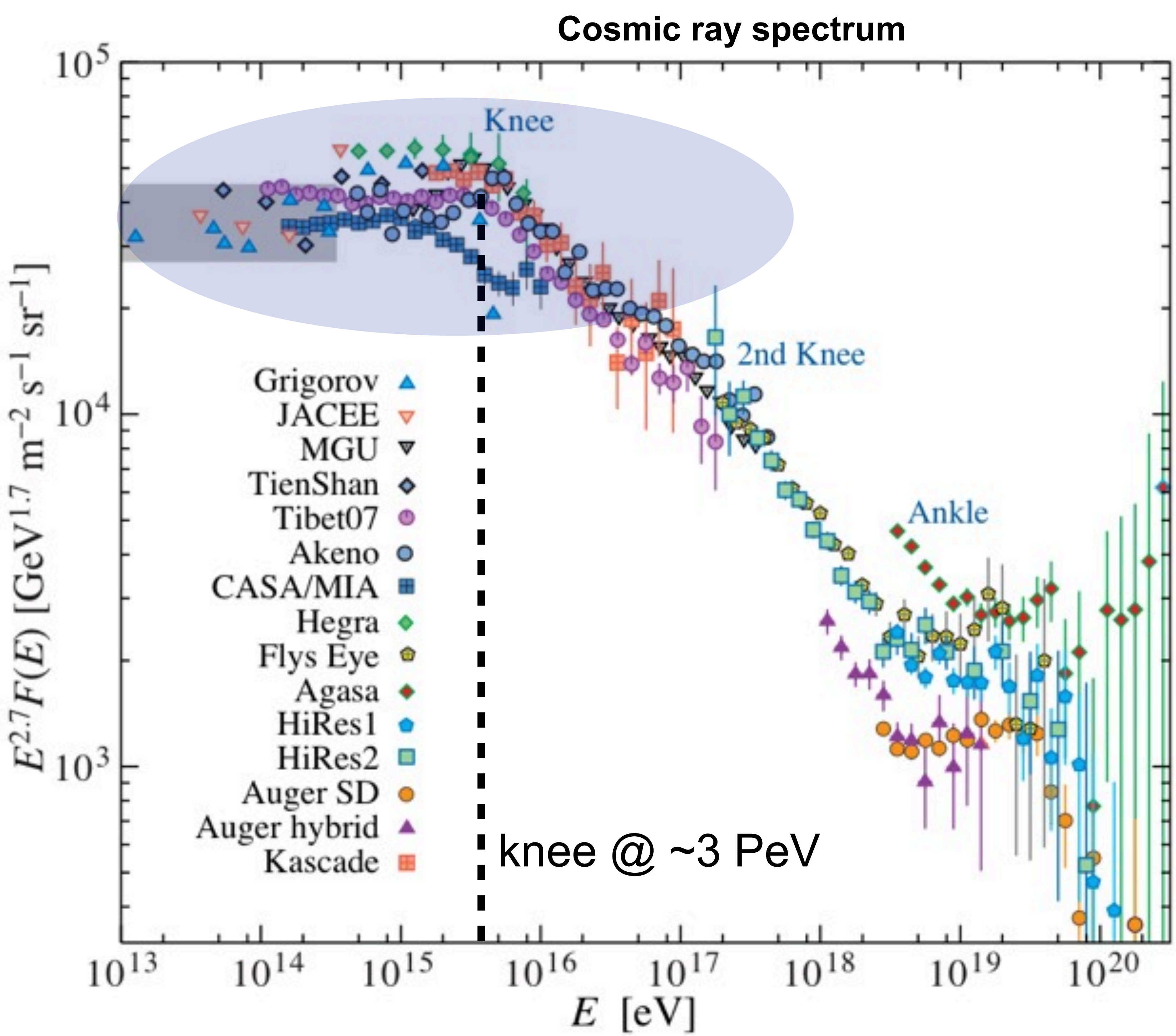
Outline

- Introduction
- Galactic neutrino-source candidates
  - supernova remnants
  - binary systems
  - pulsars
  - molecular clouds
- Observational results so far

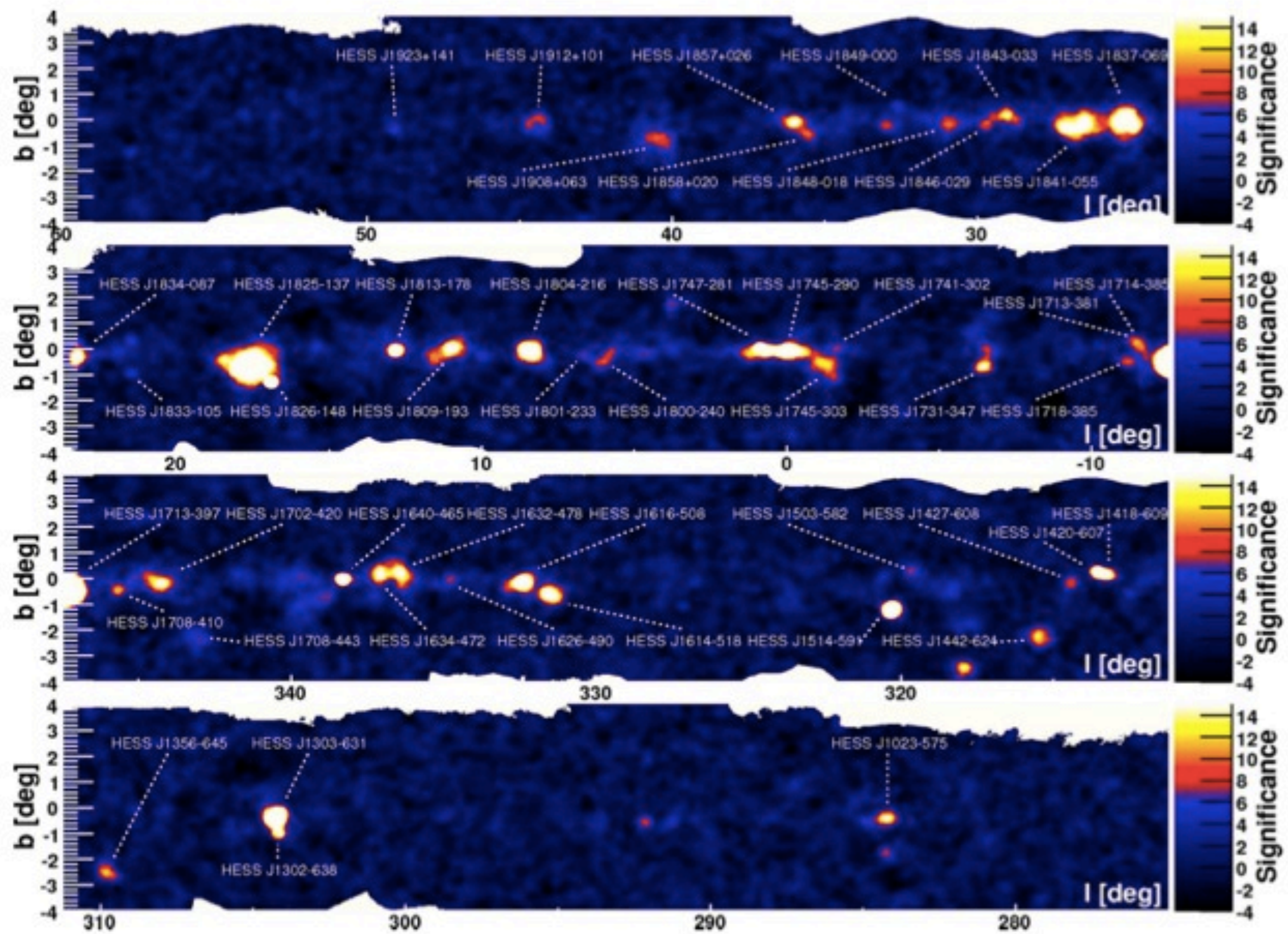
Cosmic-ray spectrum



Cosmic-ray spectrum



Galactic plane in TeV gamma rays (HESS)



All Cherenkov telescopes:

- 21 pulsar wind nebulae
- 11 shell type SNRs
- 5 molecular clouds
- 3 X-ray binaries (microquasars)
- 2 star clusters
- 21 unidentified (ambiguous)

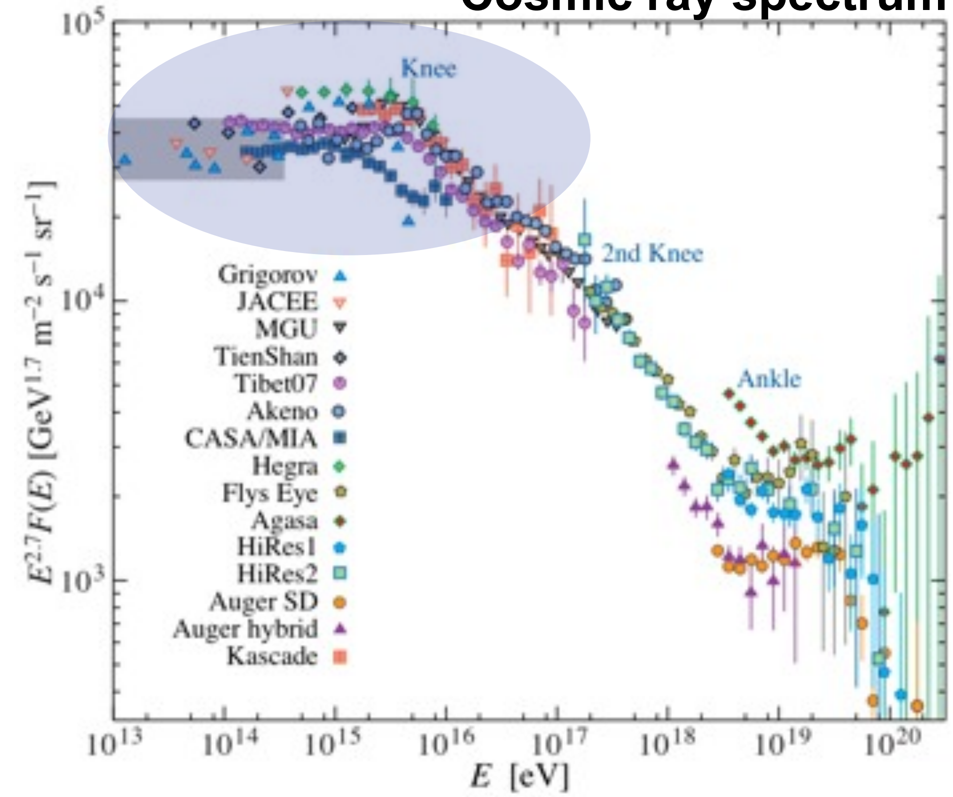
PhD thesis R.C. Gonçalves Chaves (2011)

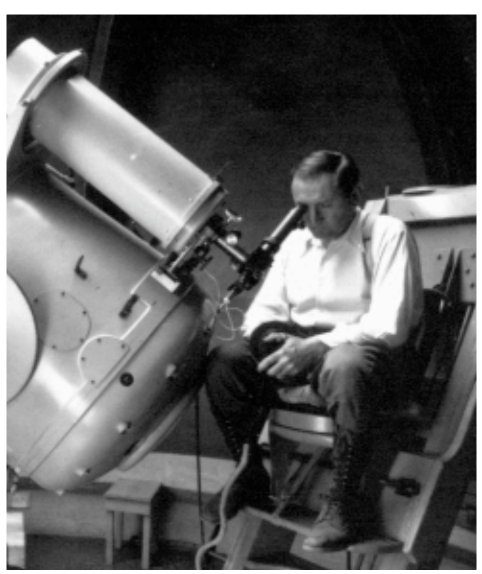
Galactic sources

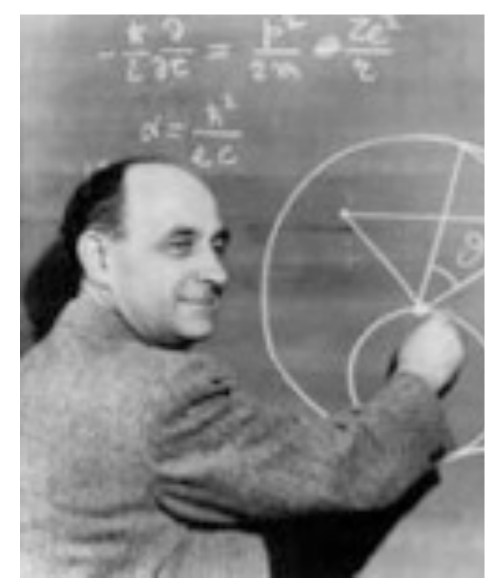
- **Energy Galactic CRs:** ~10^{-12} erg/cm^3
  → injection power: ~10^{-26} erg/(cm^3 s)
  (escape time CRs ~3×10^6 yr)

- **SNe provide energy and environment**
  - 10% of 10^{51} erg/SN every 30 yr
    (Baade and Zwicky 1934)
  - shock acceleration
    (Fermi 1949)

Cosmic ray spectrum



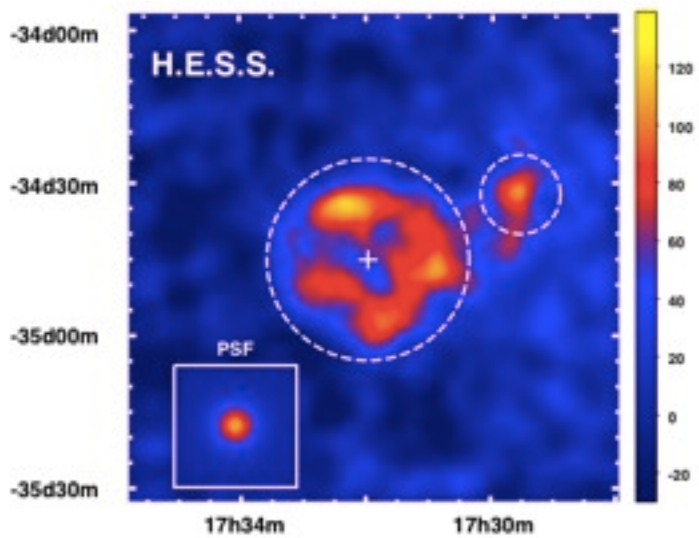




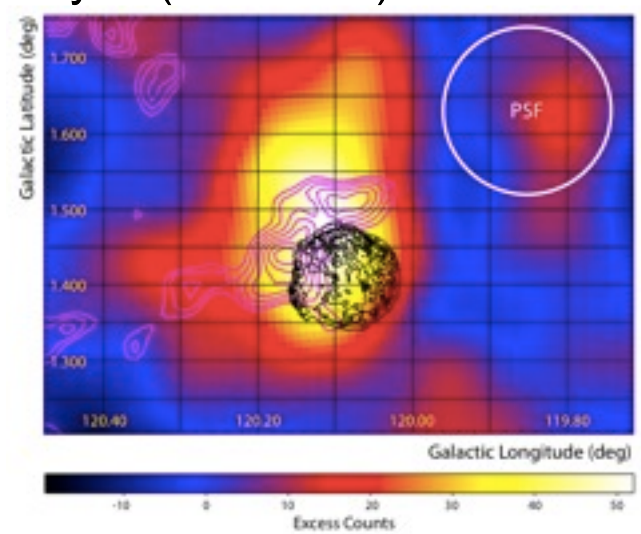
SNRs in TeV gamma rays

- 11 shell type SNRs discovered up to now

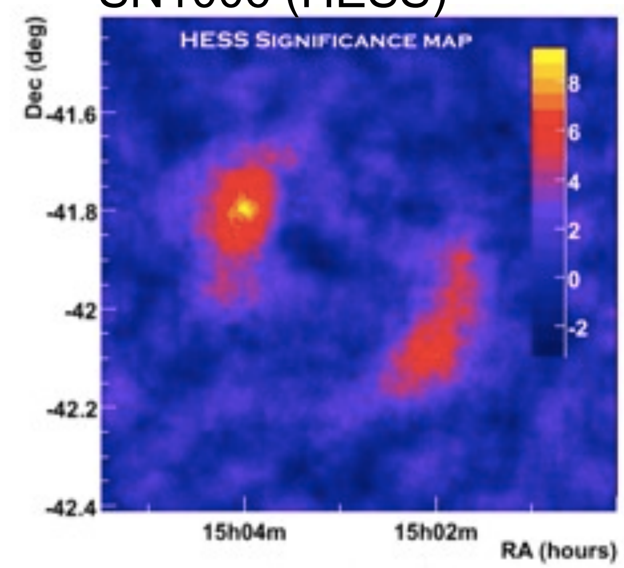
HESS J1731 (HESS)



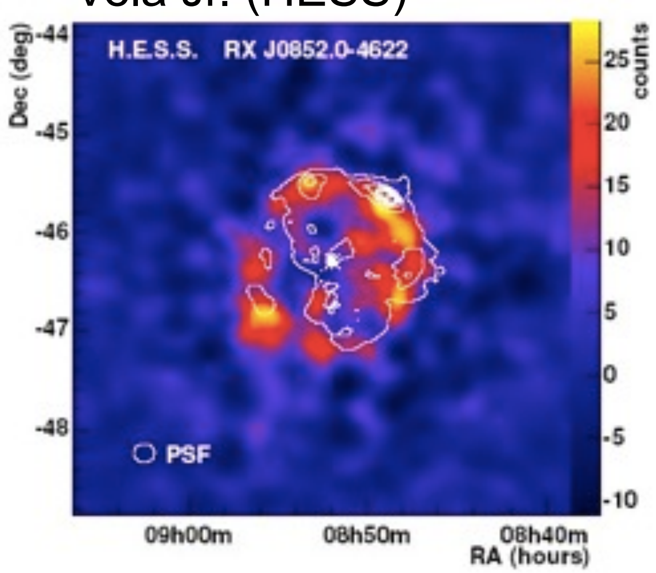
Tyco (VERITAS)



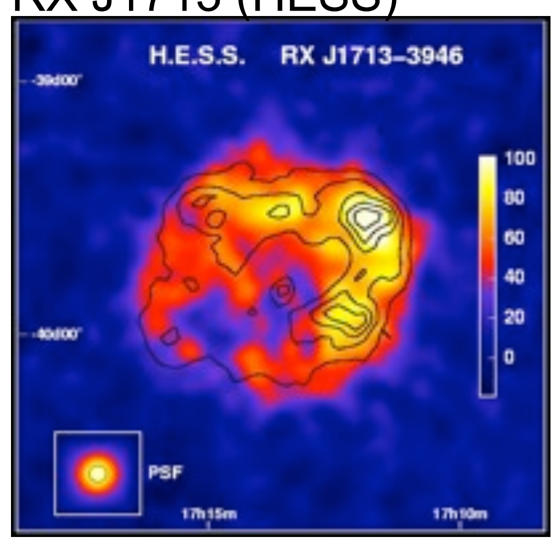
SN1006 (HESS)



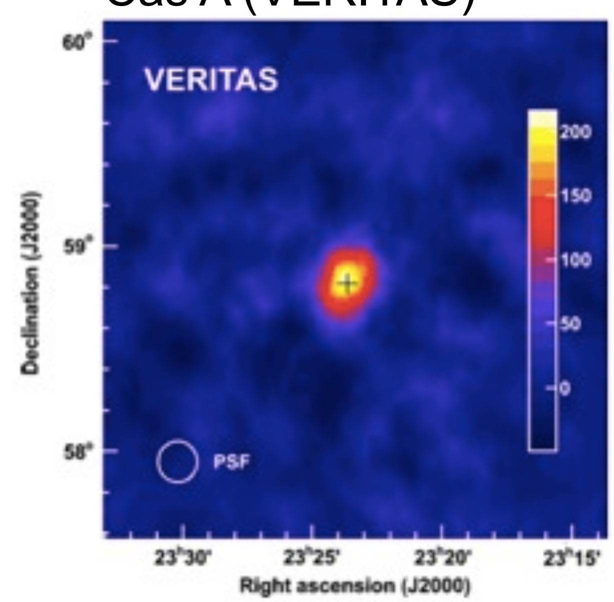
Vela Jr. (HESS)



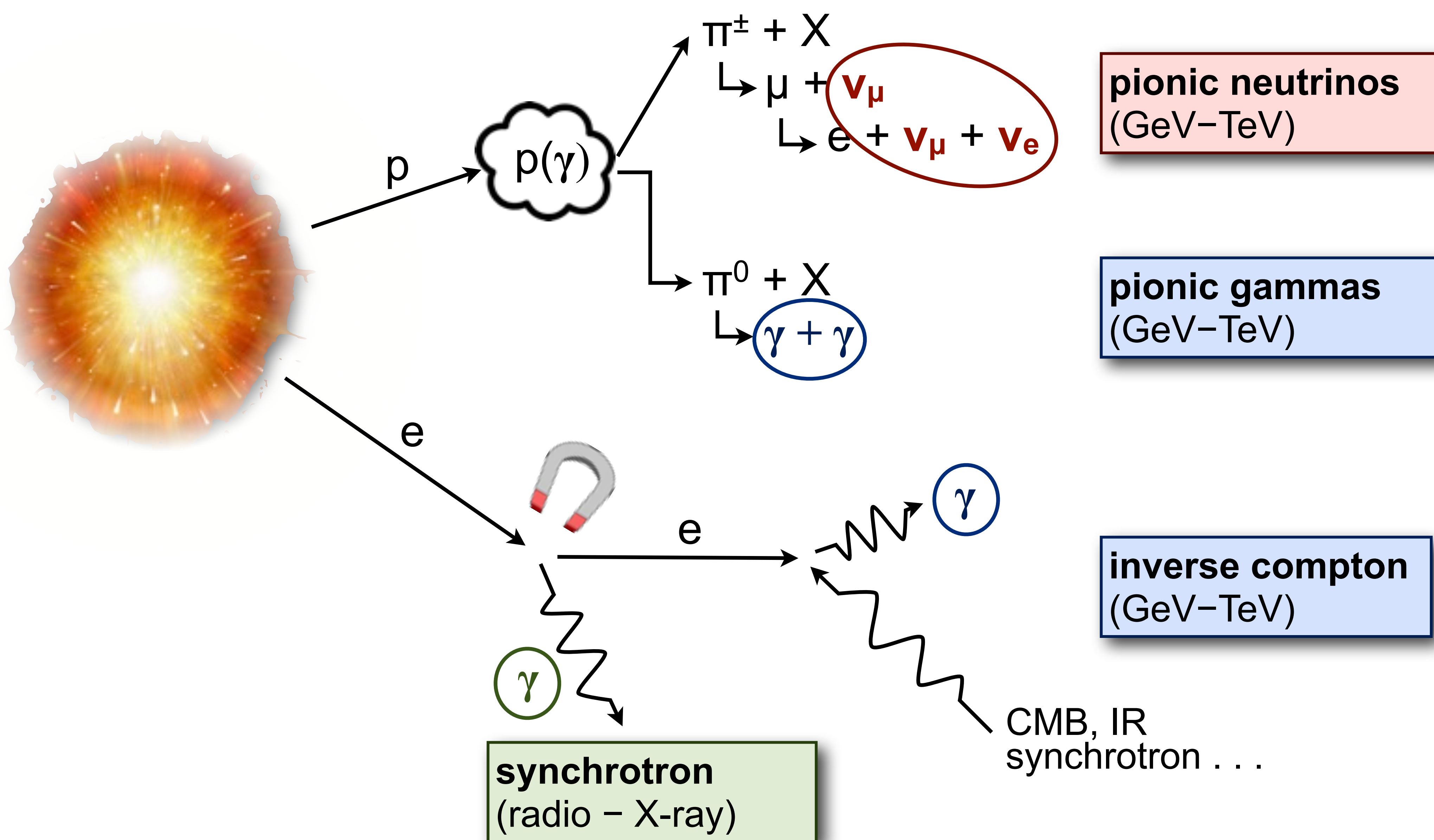
RX J1713 (HESS)



Cas A (VERITAS)



High-Energy particle production



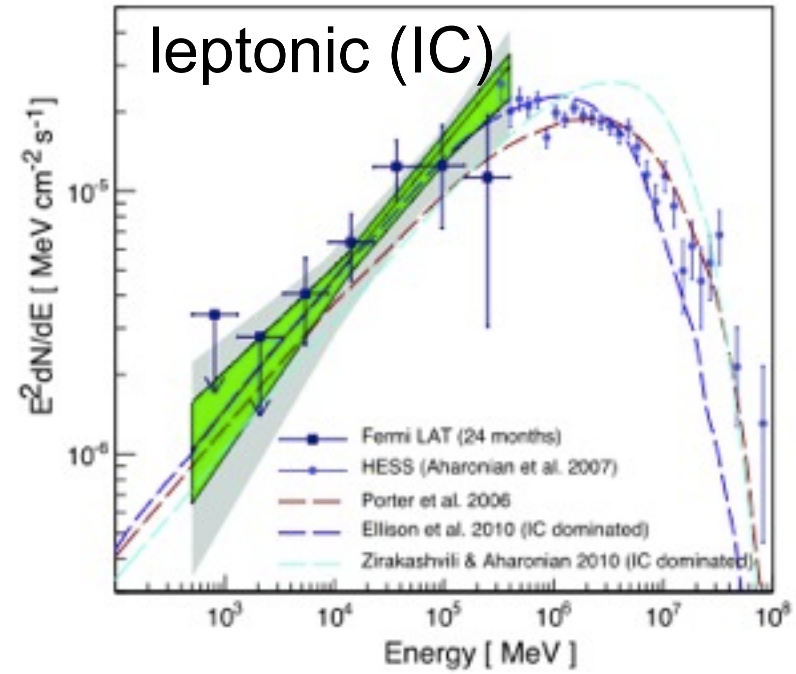
RX J1713.7-3946

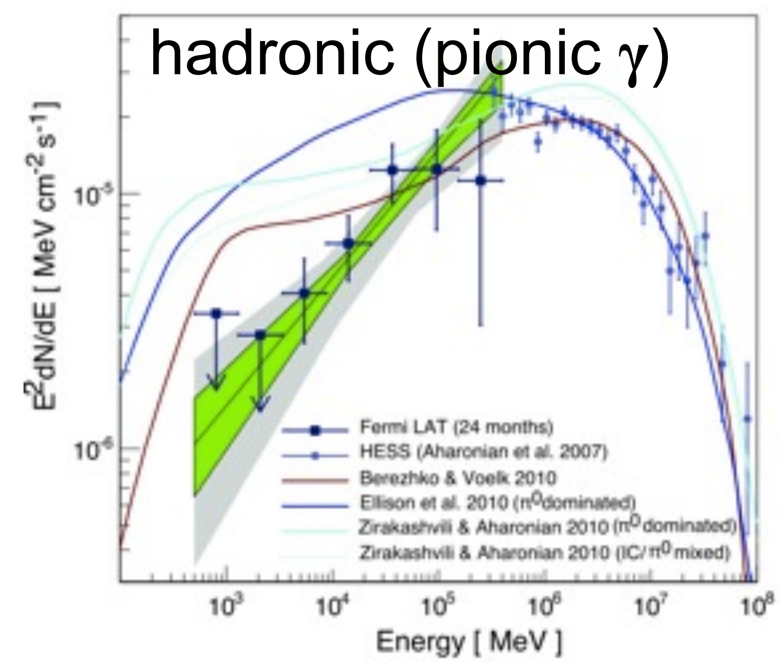
- One of the brightest TeV gamma-ray sources
  - Distance: 1 kpc
  - Age: ~1000 yr
  - Extension: 1.3 degree
  - γ-rays up to 100 TeV observed
    → particle acceleration above 100 TeV
- If purely hadronic → KM3NeT @ 5σ in ~7 yr

Fermi-LAT measurements seem to point to leptonic scenario

but . . .

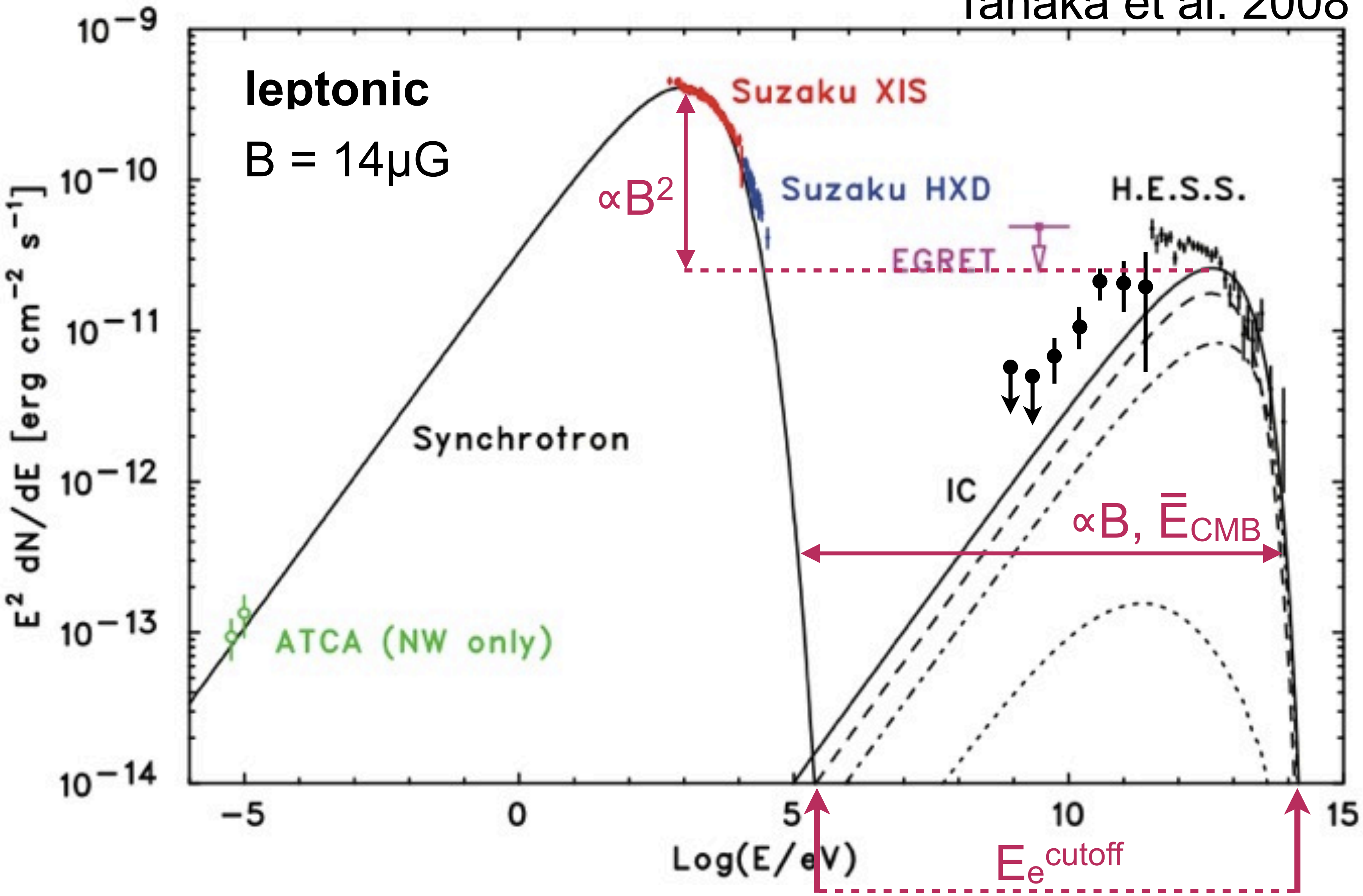
Fermi LAT





RX J1713.7-3946: broadband spectrum

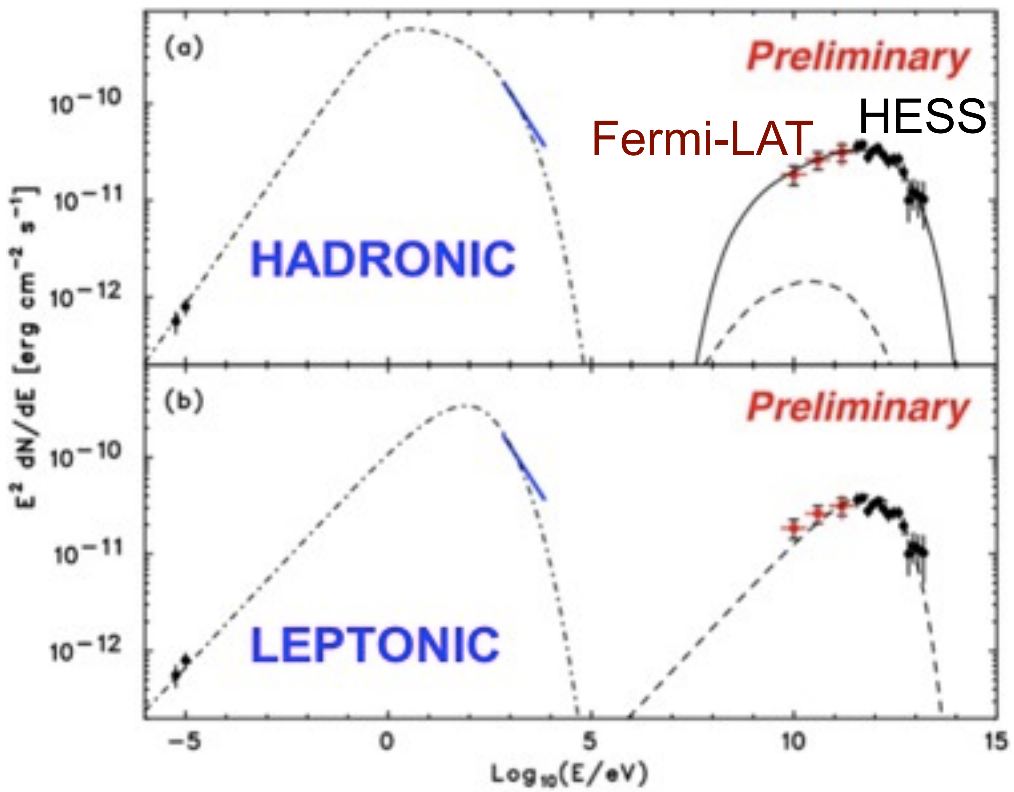
Tanaka et al. 2008



- More than 1 electron population?
- Mixed hadronic/leptonic model?

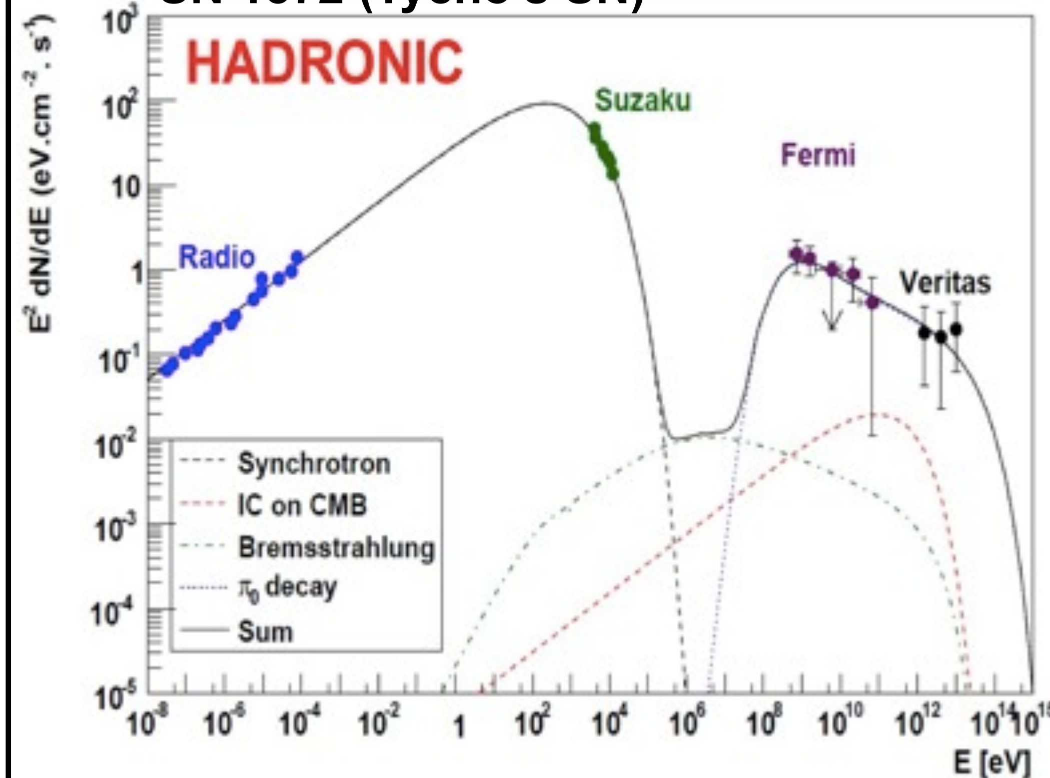
Other supernova remnants

RX J0852 (Vela Jr.)



- very bright source (but large: ∅=2°)
- problems with models:
  - Leptonic: very weak B-field (~10μG)
  - Hadronic: $5{\times}10^{50}$ erg in CRs

SN 1572 (Tycho's SN)



- hadronic model fits very well
- rather dim TeV source
  Flux(VERITAS) ~ 1% Crab, $\Gamma_{LAT} = 2.3$

Razzaque, Nusky 2011

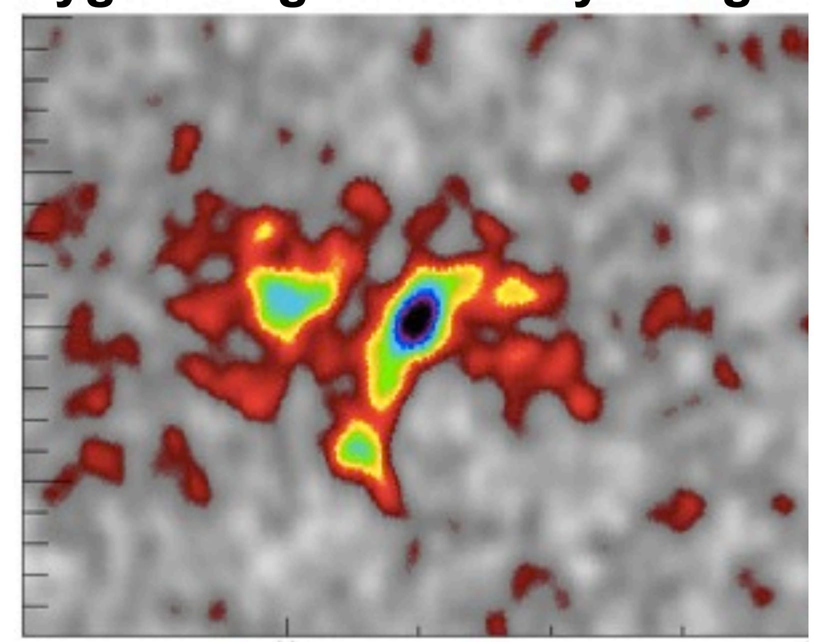
- Old SNRs (≳ 10kyr): hadronic model work/favored but low fluxes

Star forming regions

- **Good targets: SNRs + molecular clouds**
  → star forming regions

- **Cygnus region:**
  - nearby (~1 kpc), northern sky
  - contains several TeV γ-ray sources (Milagro)

Cygnus region seen by Milagro



- **Stacking of 6 Milagro SNRs**
  (5σ in 3−8 yr IC86, Gonzalez-Garcia et al. (2008))

	model	sensitivity	p-value	upper limit
IC40	3 events	2.9 × model	2% (posteriori)	7.2 × model
IC59	7 events	0.7 × model	> 50%	

model: Halzen et al. (2008)

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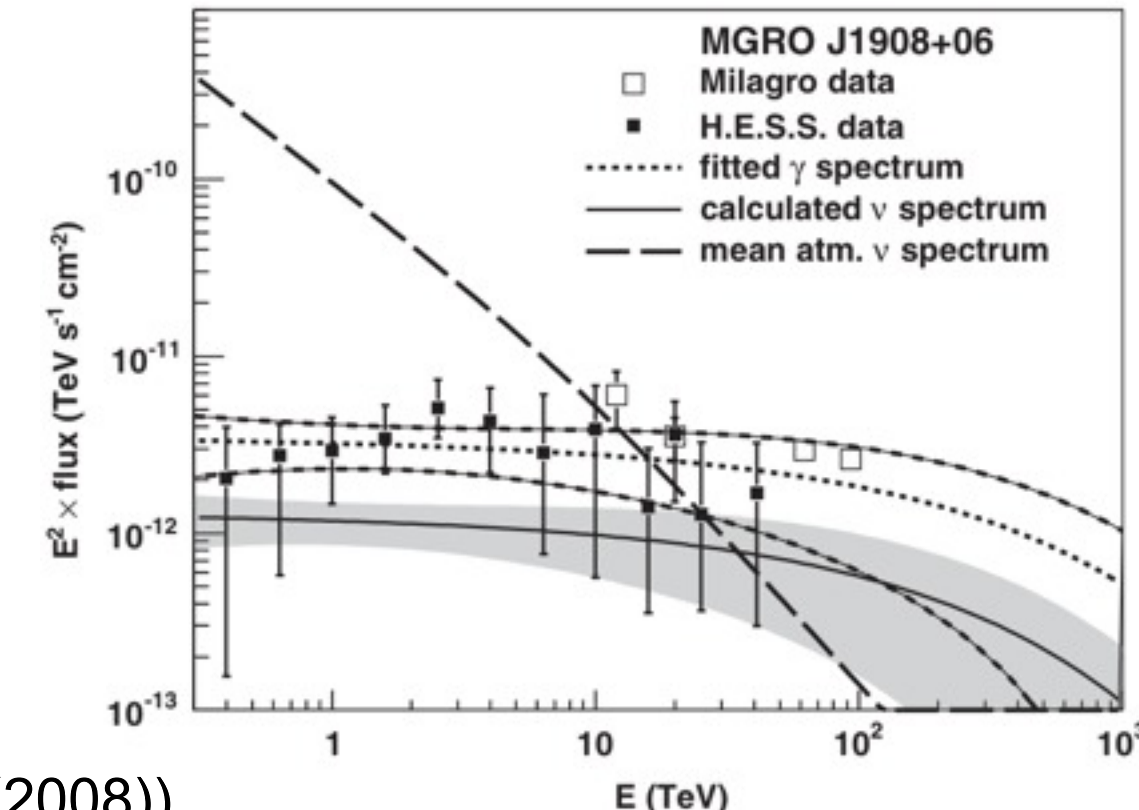
MGRO J1908+06



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Molecular clouds

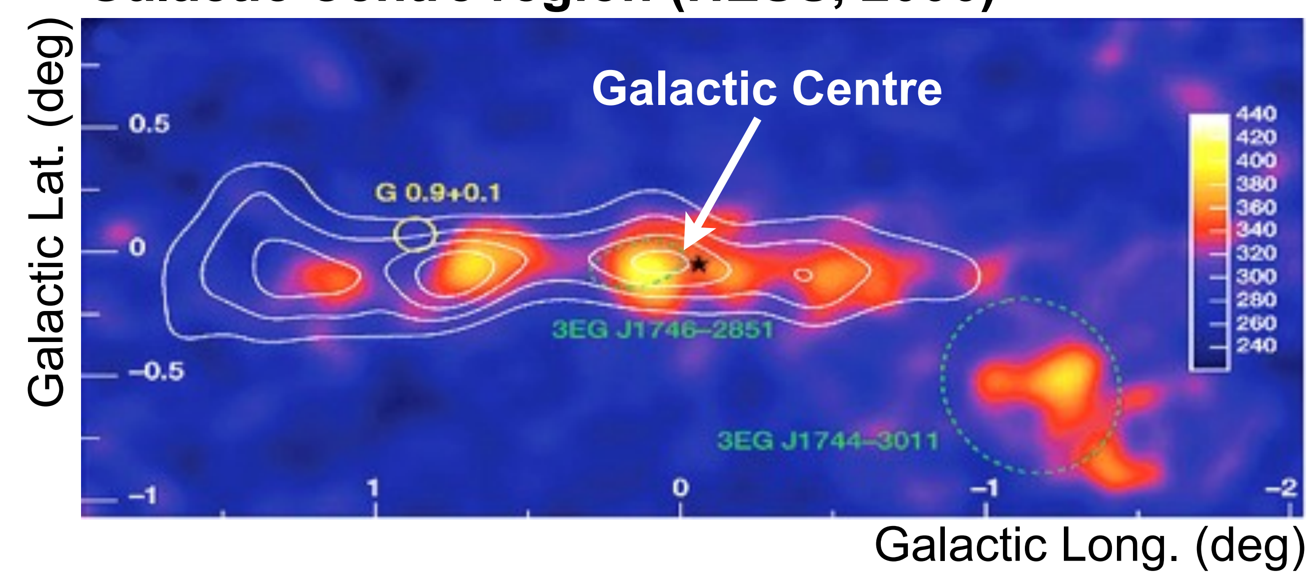
- Interaction of cosmic rays with molecular clouds
- TeV γ-ray emission follows matter density

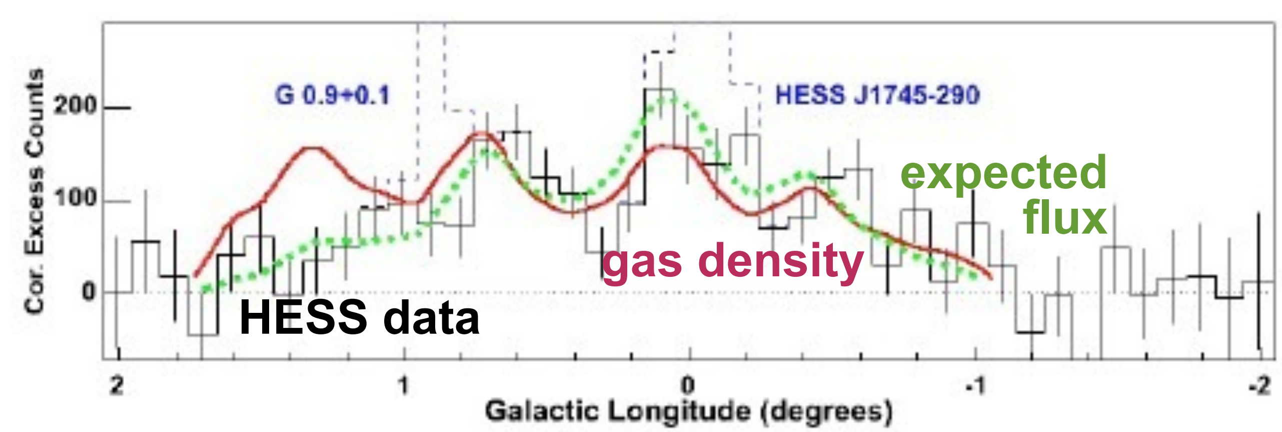
- **Galactic Centre region**

  guaranteed neutrino source . . .

  . . . but rather weak and large background

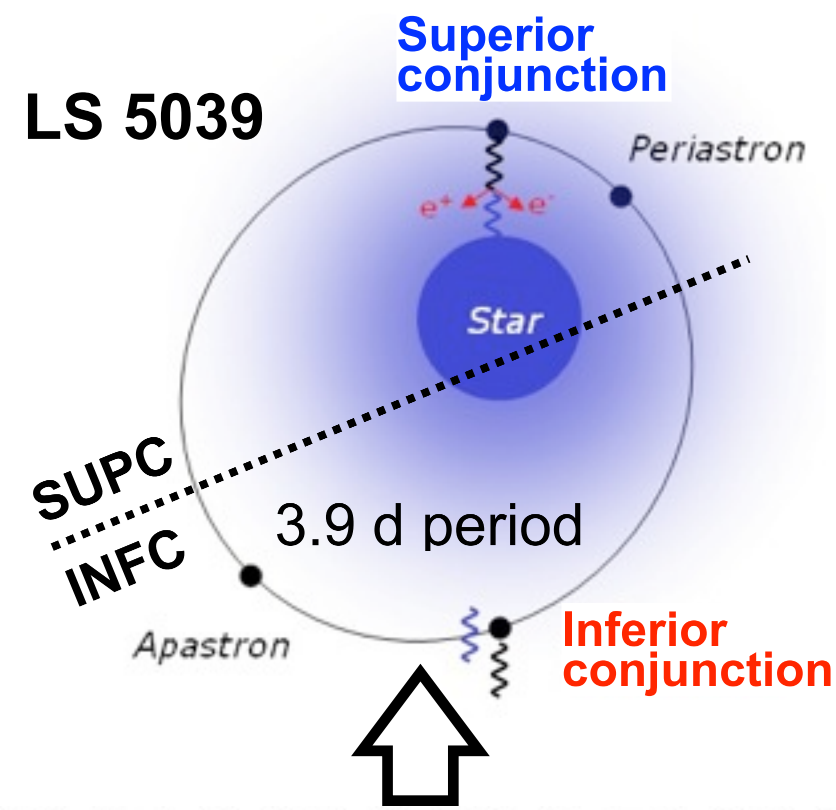
Galactic Centre region (HESS, 2006)

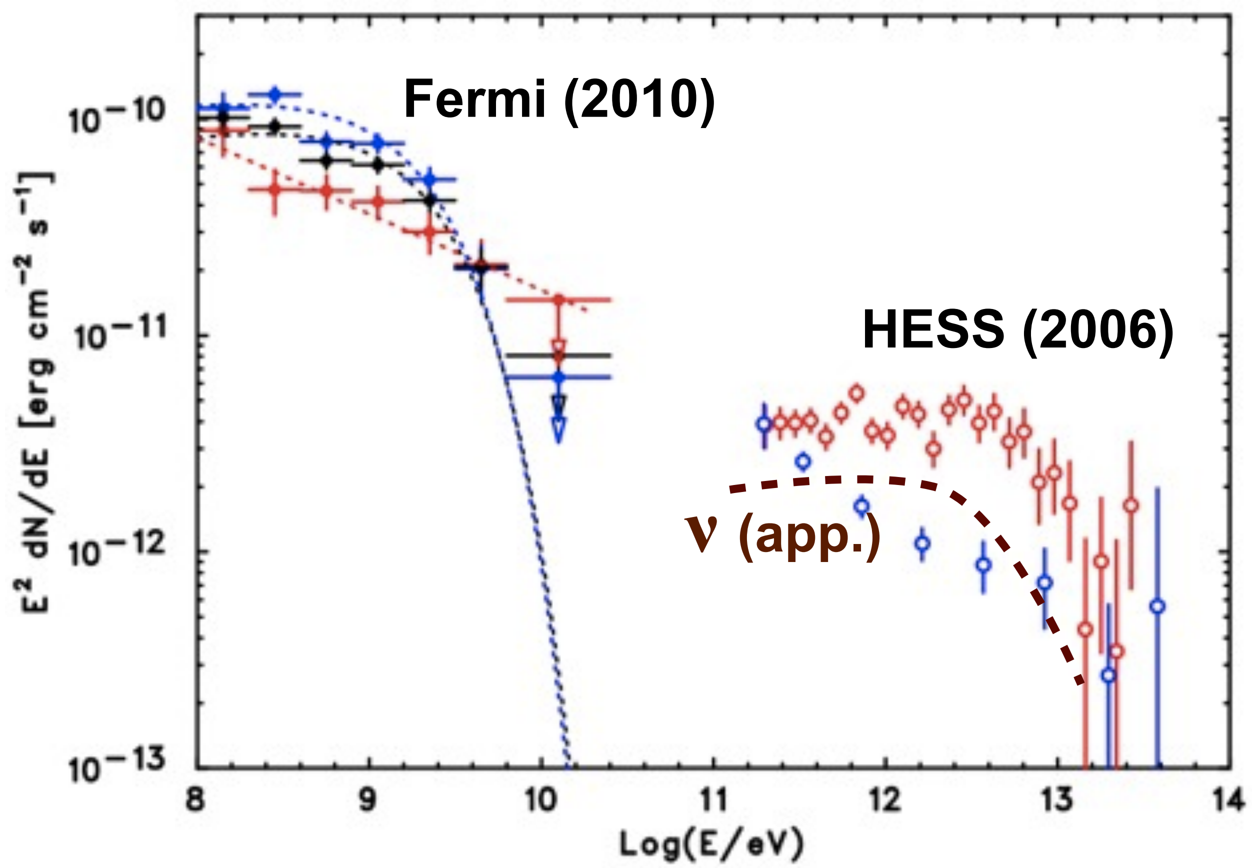




Binary systems

- **General model:**
  - GeV & TeV gamma-rays through IC scattering
  - cascading of TeV γ-rays in superior conjunction
- **If π^0 production of γ-rays**
  $\rightarrow$ ν flux much higher than expected
  (Aharonian et al. JPCS (2006))
- **LS 5039 (hadronic scenario):**
  - **Events in 1 km^3 detector:**
    $\sim$ 0.5 in 5 yr
  - **ANTARES (304 d):**
    0 observed
    (UL: 2.2×10^{-10} erg cm^{-2} s^{-1})



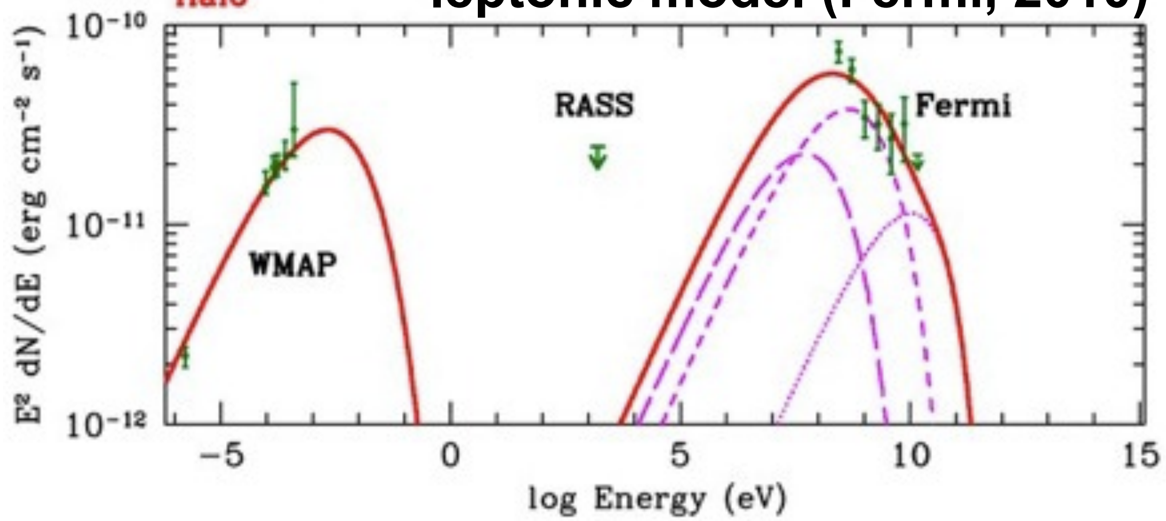


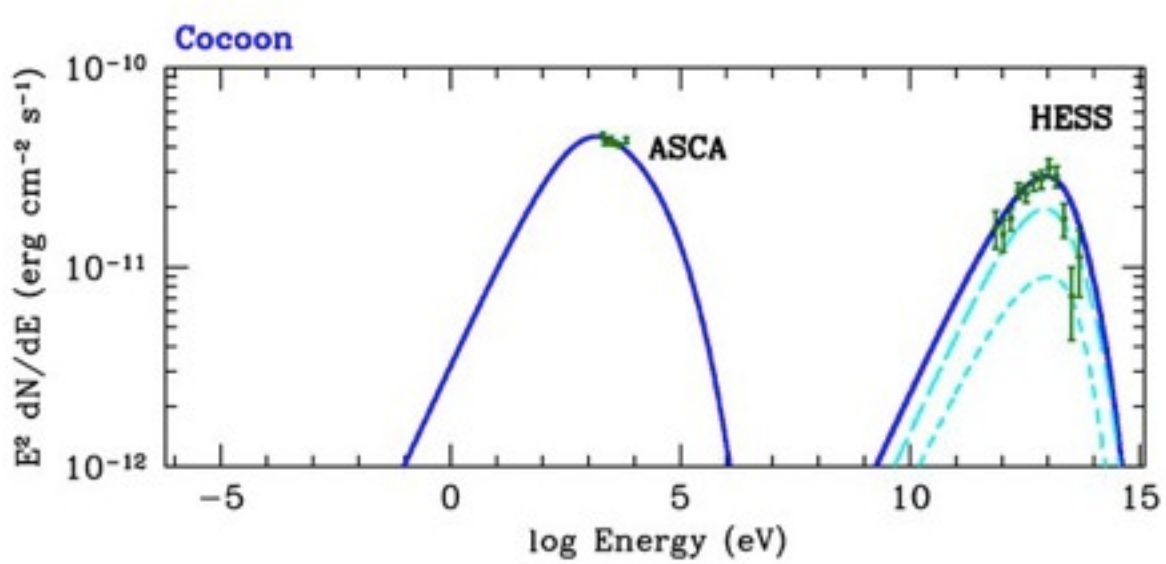
Pulsar wind nebulae

- **Generally expected to accelerate electrons**

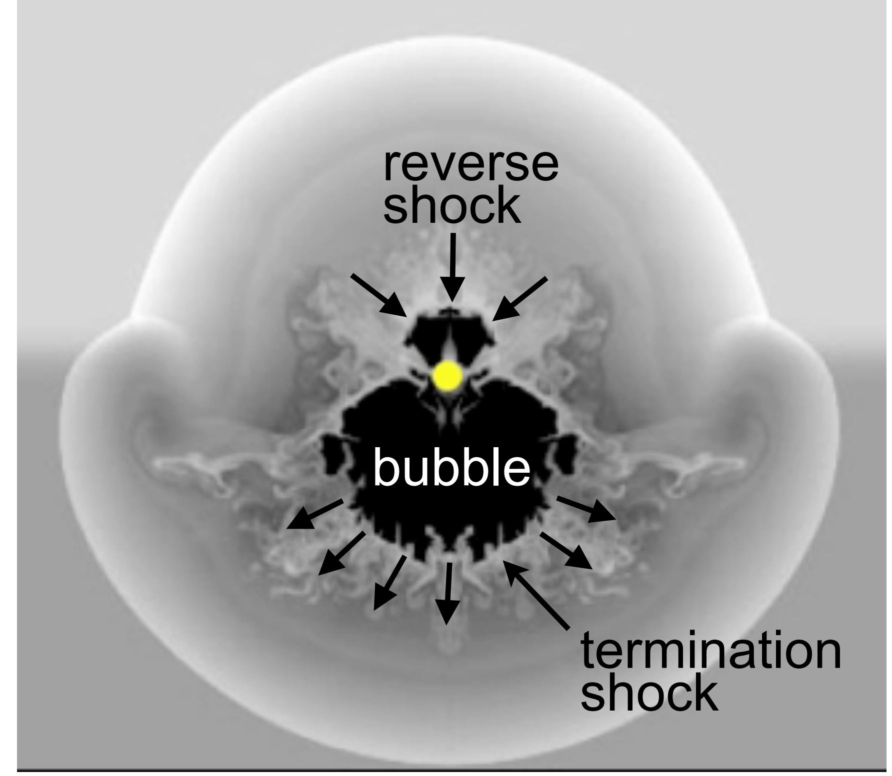
  ... but also models with significant fraction of nuclei in pulsar wind
  (e.g. Horns et al. A&A (2006))

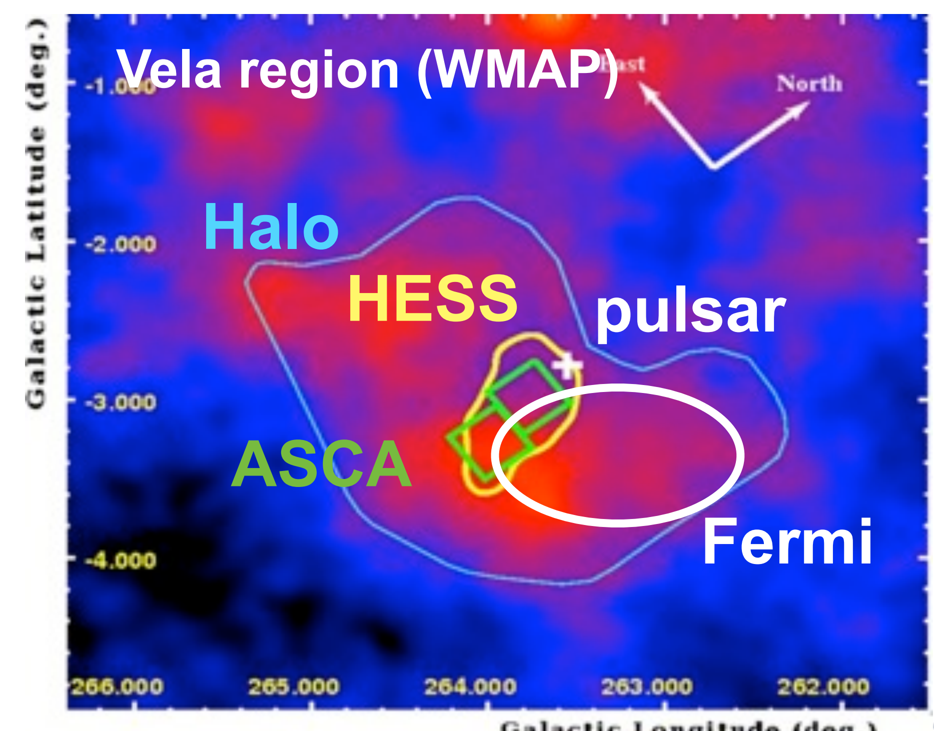
leptonic model (Fermi, 2010)





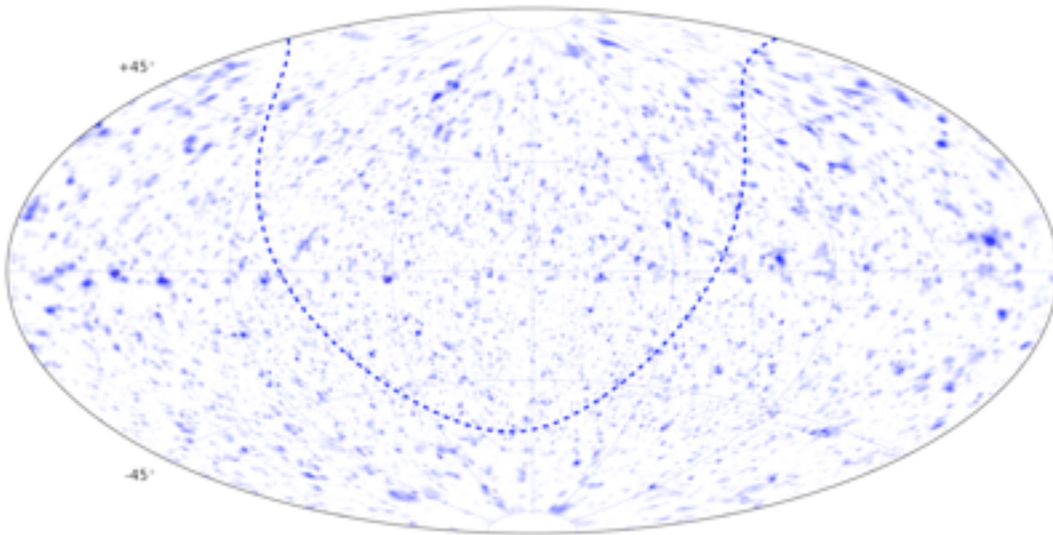
Pulsar simulation (Blondin et al. (2001)



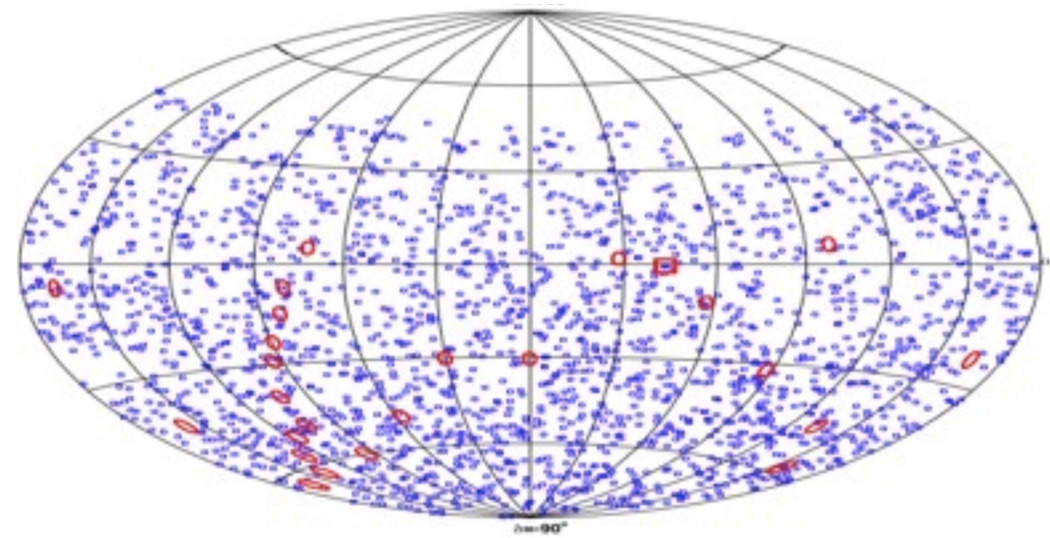


Present results from ν telescopes

IceCube



ANTARES



- **Data analyzed so far:**
  - IceCube: equivalent to 1 yr IC86
  - ANTARES: 304 days
- Neither all-sky nor source-lists show hint of a neutrino source (best fluctuations have p-value > 10%)
- Trial factor for all-sky analyses significant (several 10k for IC86) → keep investigating new scenarios

Conclusions

- SNR still prime CR-source candidates but data remains inconclusive
- IceCube enters region of (optimistic) flux predictions
- Predictions for other source types rather uncertain
  . . . but chances for surprises
- No hint for a neutrino signal in IceCube or ANTARES

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"Patience is the key to paradise."
Turkish Proverb

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"We have looked at so many distributions [from LHC] and have found nothing. It is too early for dispair, but it is enough for depressions."
Altarelli @ EPS (Grenoble, July 2011)

RX J1713: Chandra

Large variability in X-rays

→ fast cooling of electrons

→ large B fields $\mathcal{O}$(mG)