High-energy neutrinos from Galactic sources

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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Erlangen Centre for Astroparticle Physics
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Friedrich-Alexander-Universität Erlangen-Nürnberg

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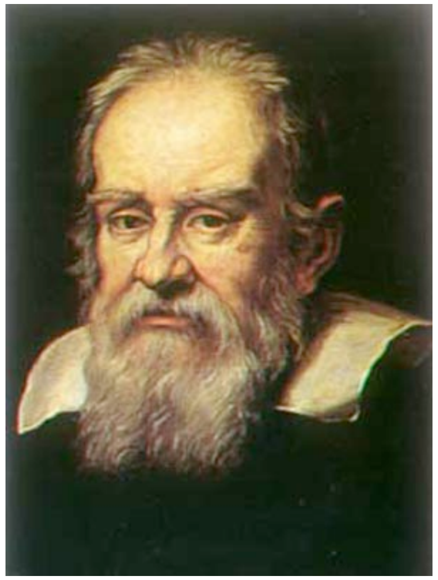
Outline

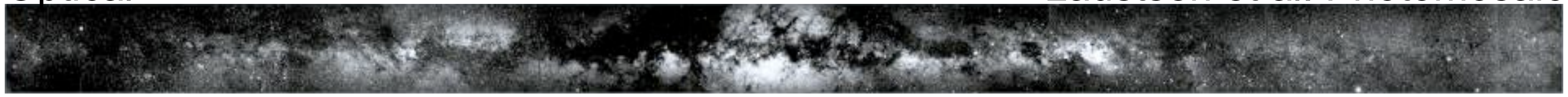
- Introduction to neutrino astronomy
- Potential Galactic neutrino sources
- Expected fluxes and event rates
- The mystery of the missing PeVatrons
- Prospects for detection of Galactic neutrino sources

The Milkyway in different light



Optical

Laustsen et al. Photomosaic



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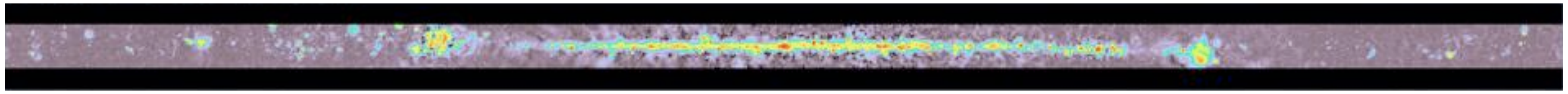
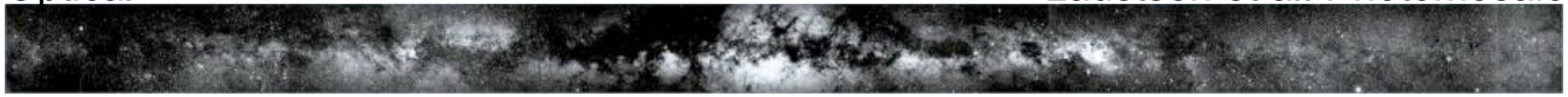
The Milkyway in different light

Radio Continuum 2.4–2.7 GHz Bonn & Parkes



1930’s

Optical Laustsen et al. Photomosaic



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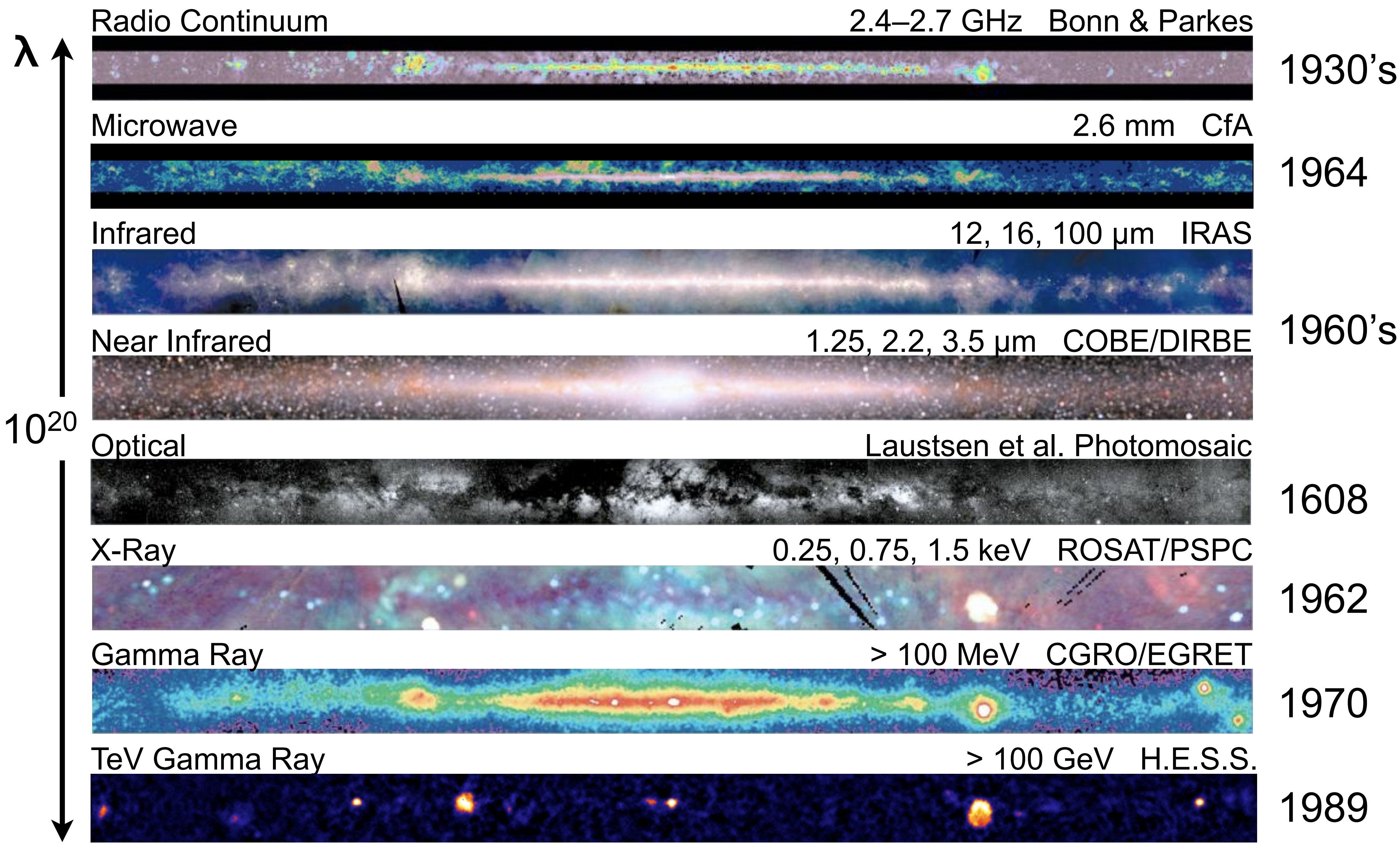

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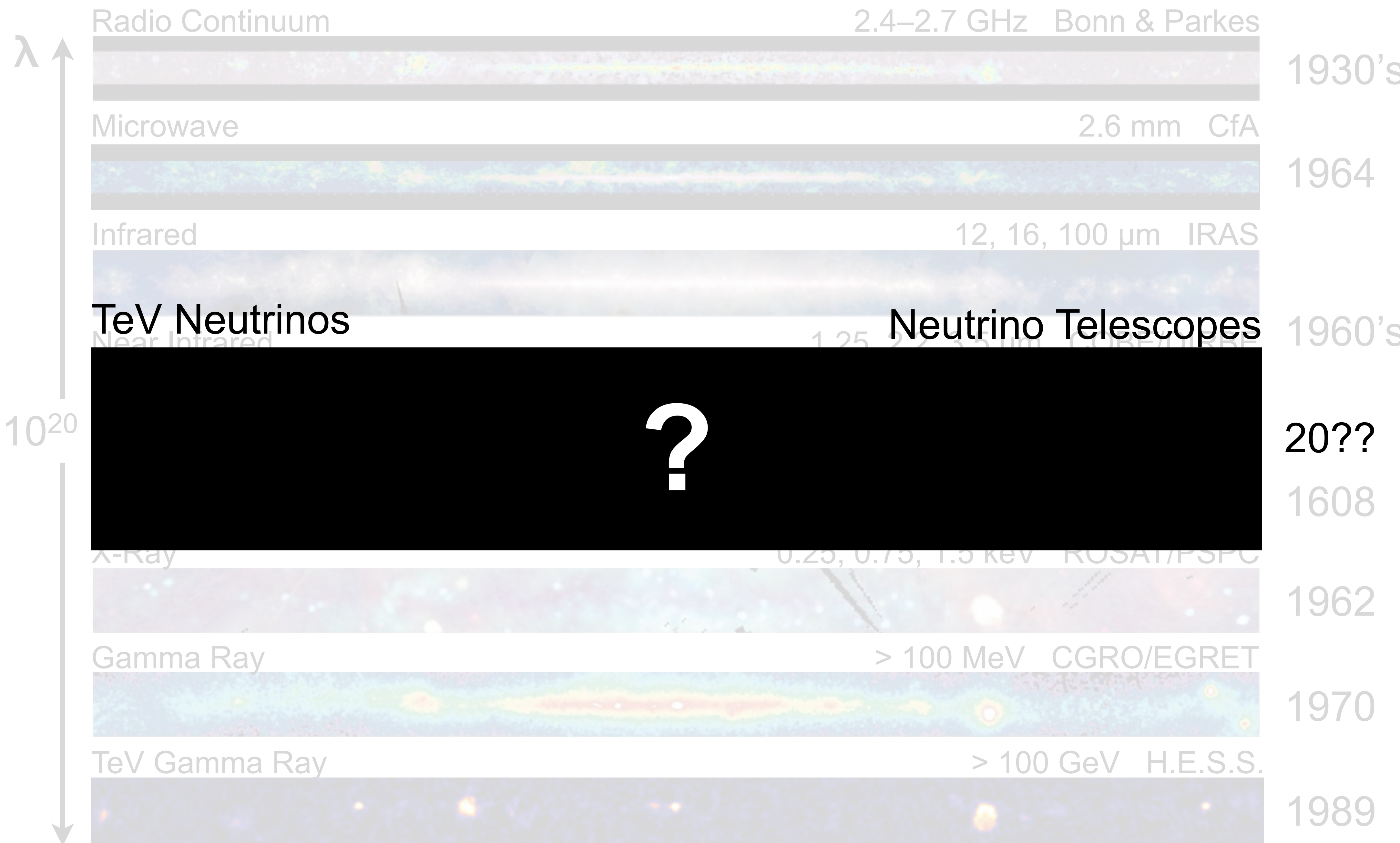
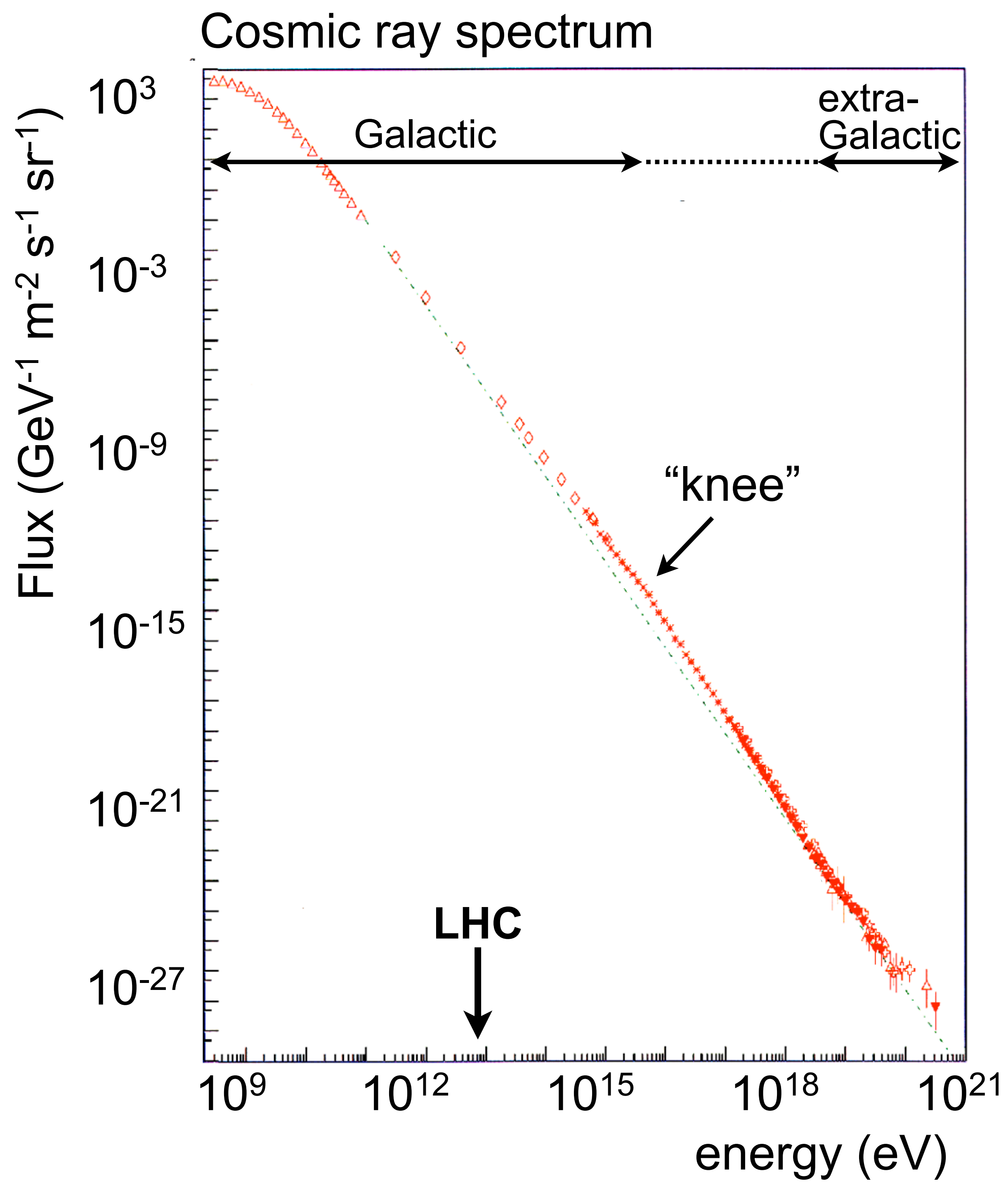
The Milkyway in different light



Cosmic-rays

- Spectrum measured over 12 orders of magnitude in energy
- Power law spectrum (non thermal)
- Consists of particles
- Sources still active

Sources still unknown !



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High-energy particle production

Accelerator (source)

- Shock fronts (Fermi acceleration)
- Objects with strong magnetic fields (pulsars, magnetars)

Beam dump (secondary particle production)

- Interaction with photon and matter near the source
- Protons: pion decay

$$p + p(\gamma) \rightarrow \pi^{\pm} + X$$
$$\quad \hookrightarrow \mu + \nu_\mu$$
$$\qquad \hookrightarrow e + \nu_\mu + \nu_e$$

$$p + p(\gamma) \rightarrow \pi^{0} + X$$
$$\quad \hookrightarrow \gamma + \gamma \text{ (TeV)}$$

- Electrons: inverse Compton-scattering of photons

$$e + \gamma \rightarrow e + \gamma \text{ (TeV)}$$

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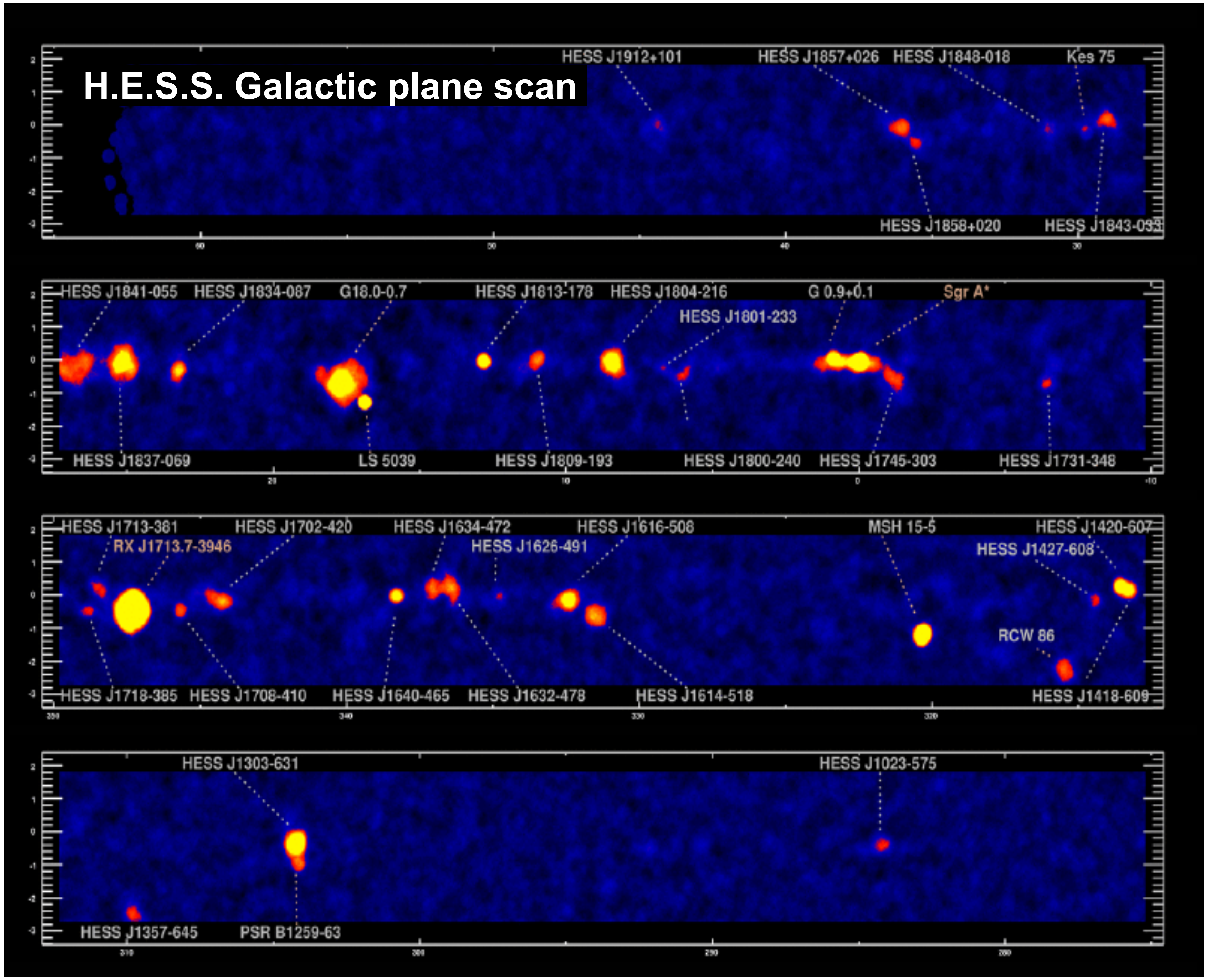
Potential Galactic neutrino sources



Classes of TeV γ-ray sources:

- 8 SNRs
- 12 PWNe
- 4 Binaries
- 4 Others
- 20 Unidentified

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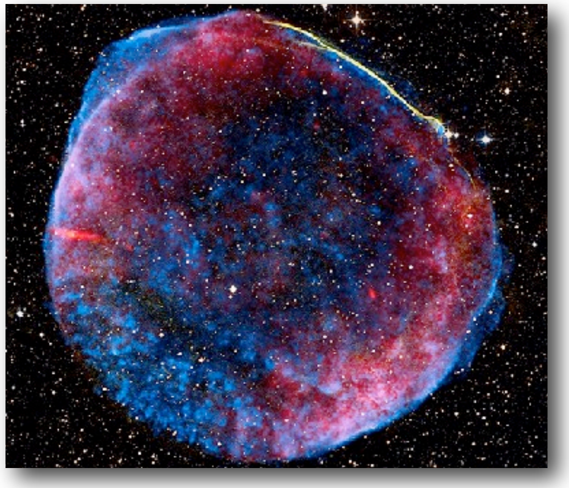
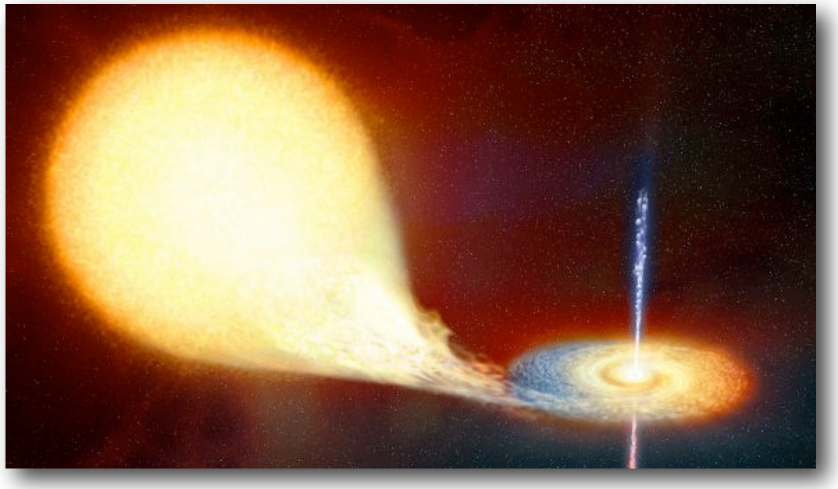
Source candidates

supernova remnants
(SN1006, optical, radio, X-ray)



micro-quasars
(artist's view)



pulsars
(Crab pulsar, optical, X-ray)

star-forming regions
(Cygnus region, optical)

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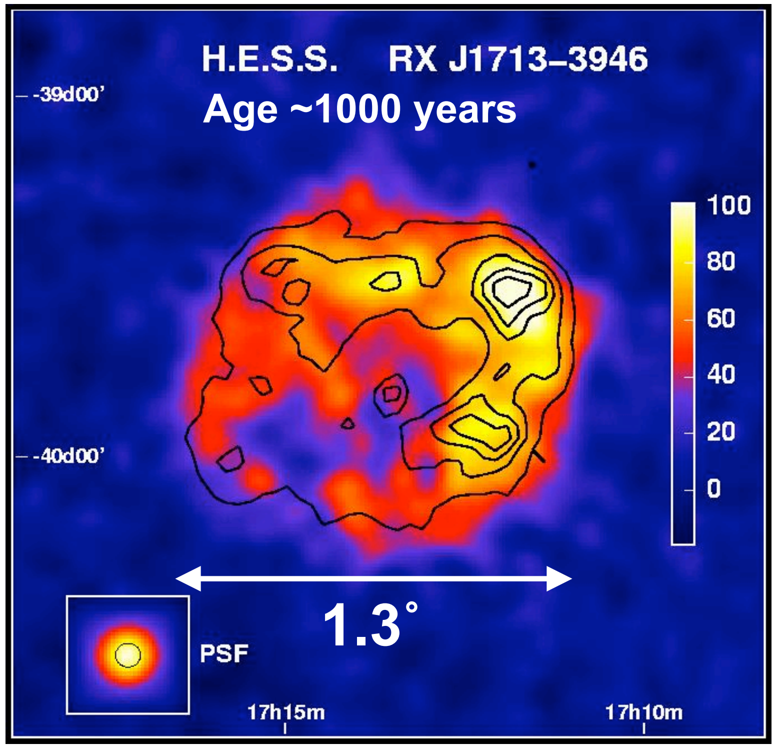
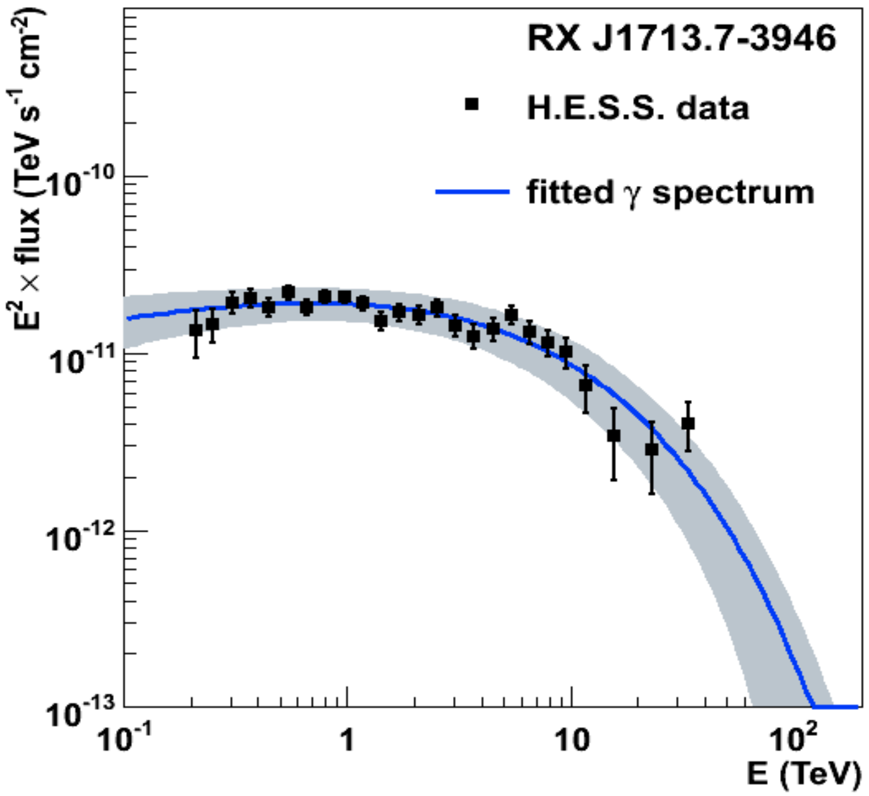
SNR: RX J1713.7–3946

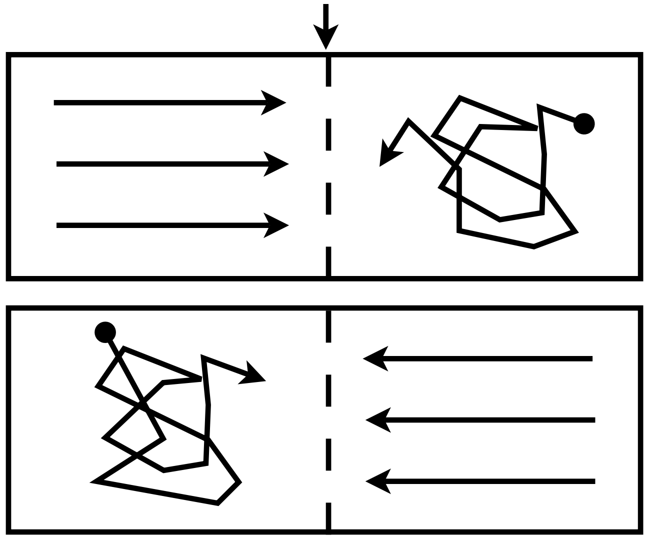


Moon



Fermi acceleration:

- energy gain after each crossing of shock front
- repetitive process
- yields power law



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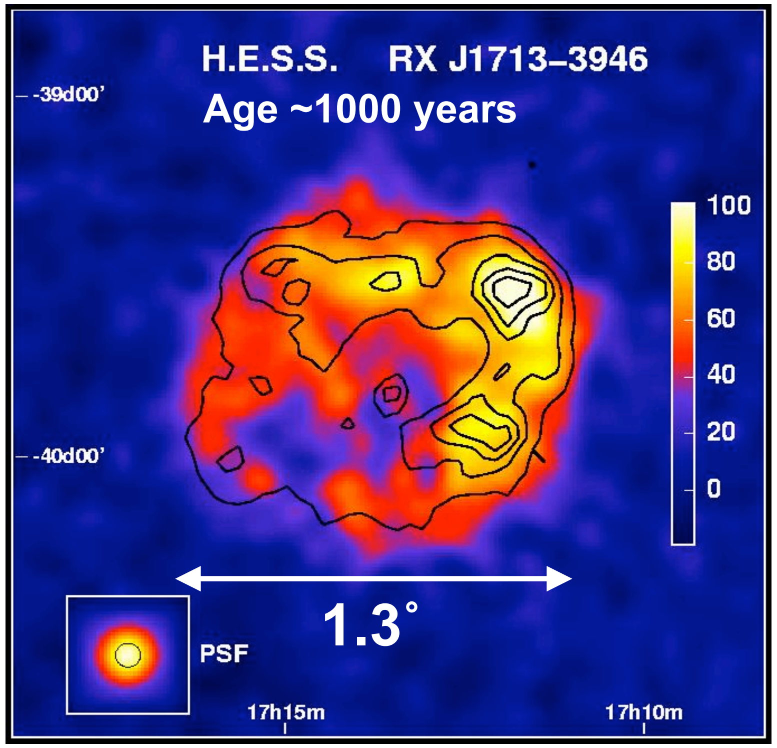

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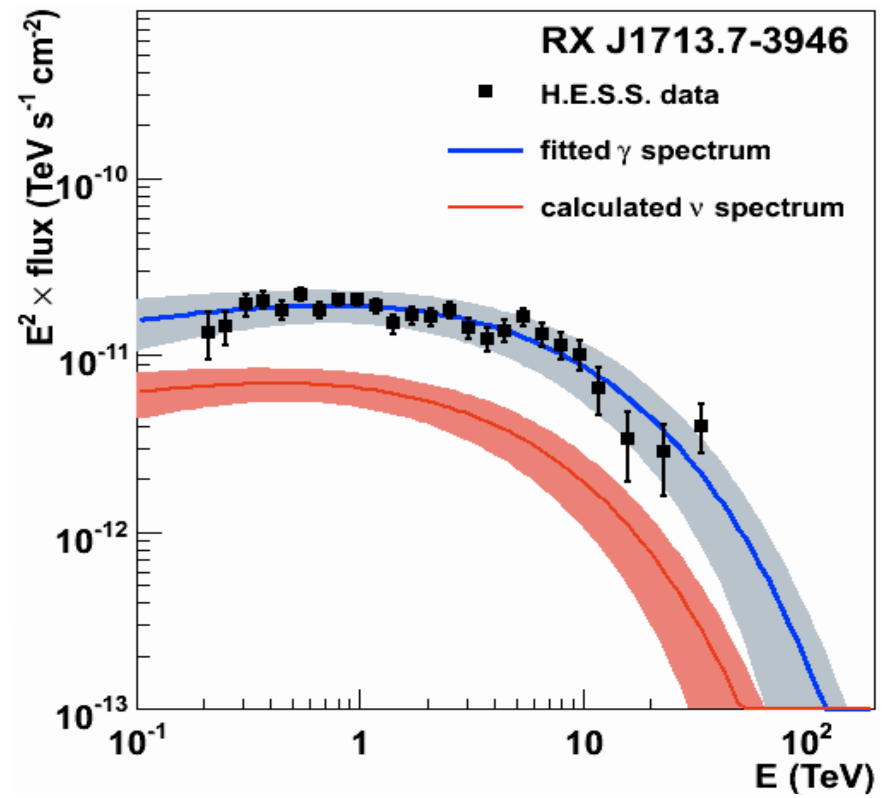

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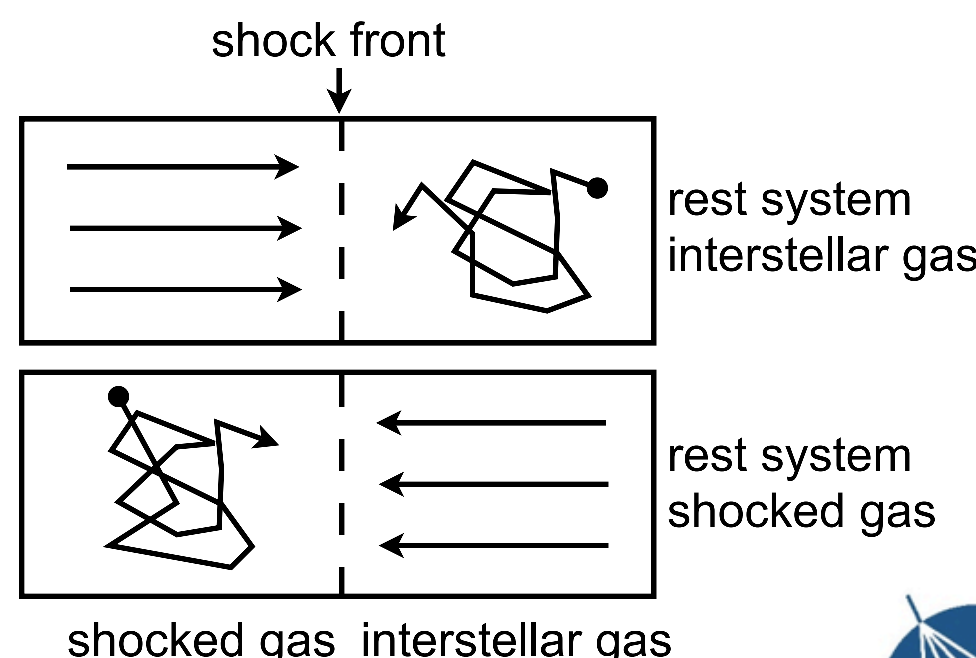
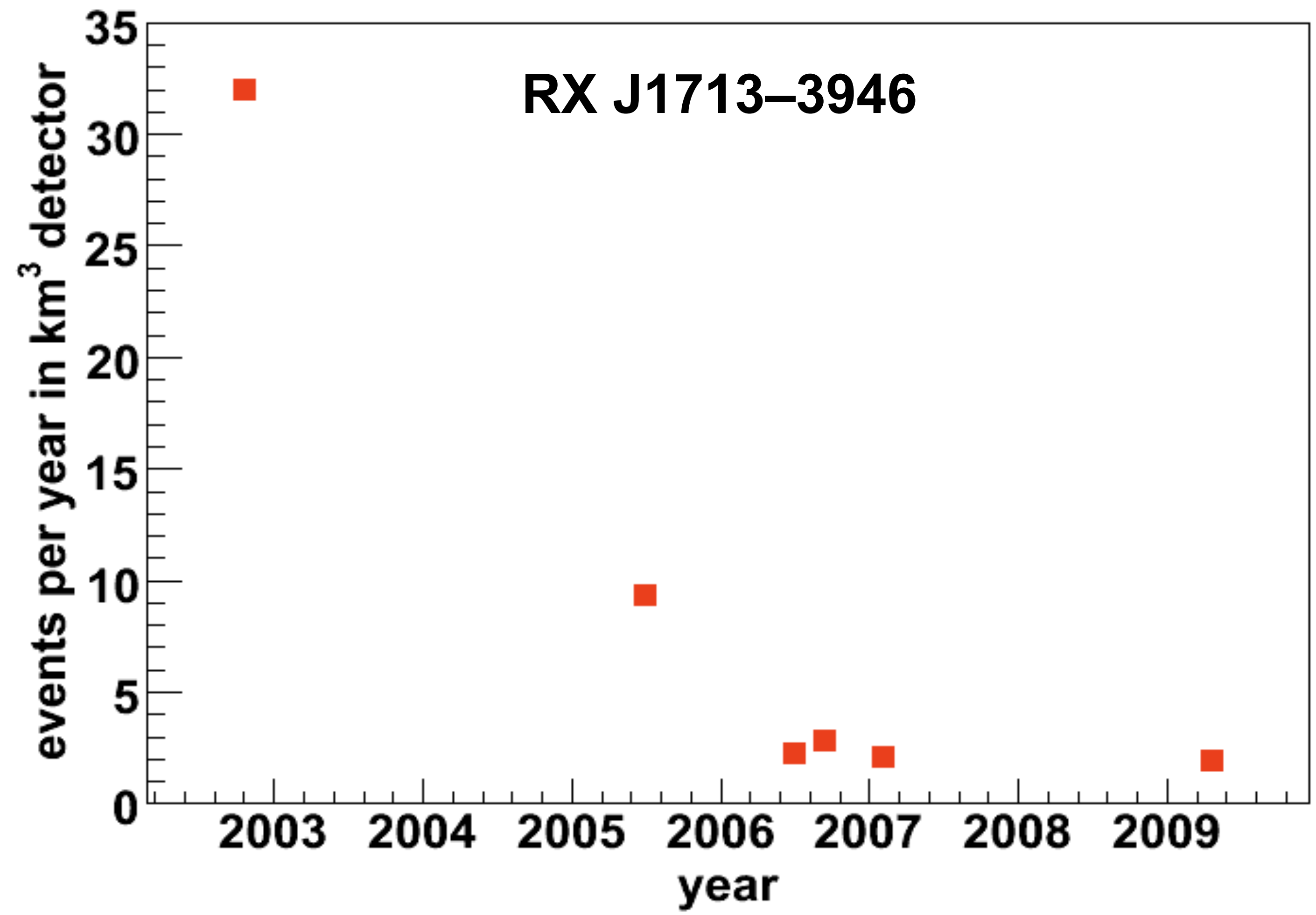
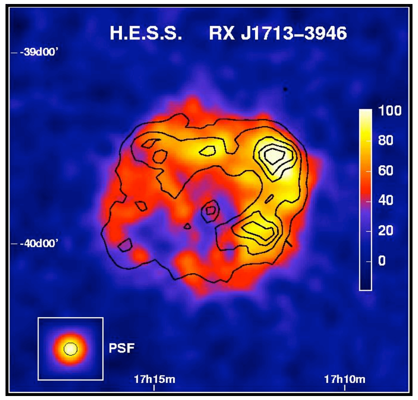
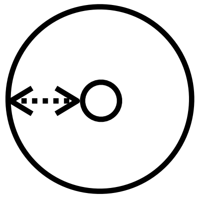


RX J1713: History of neutrino rate predictions





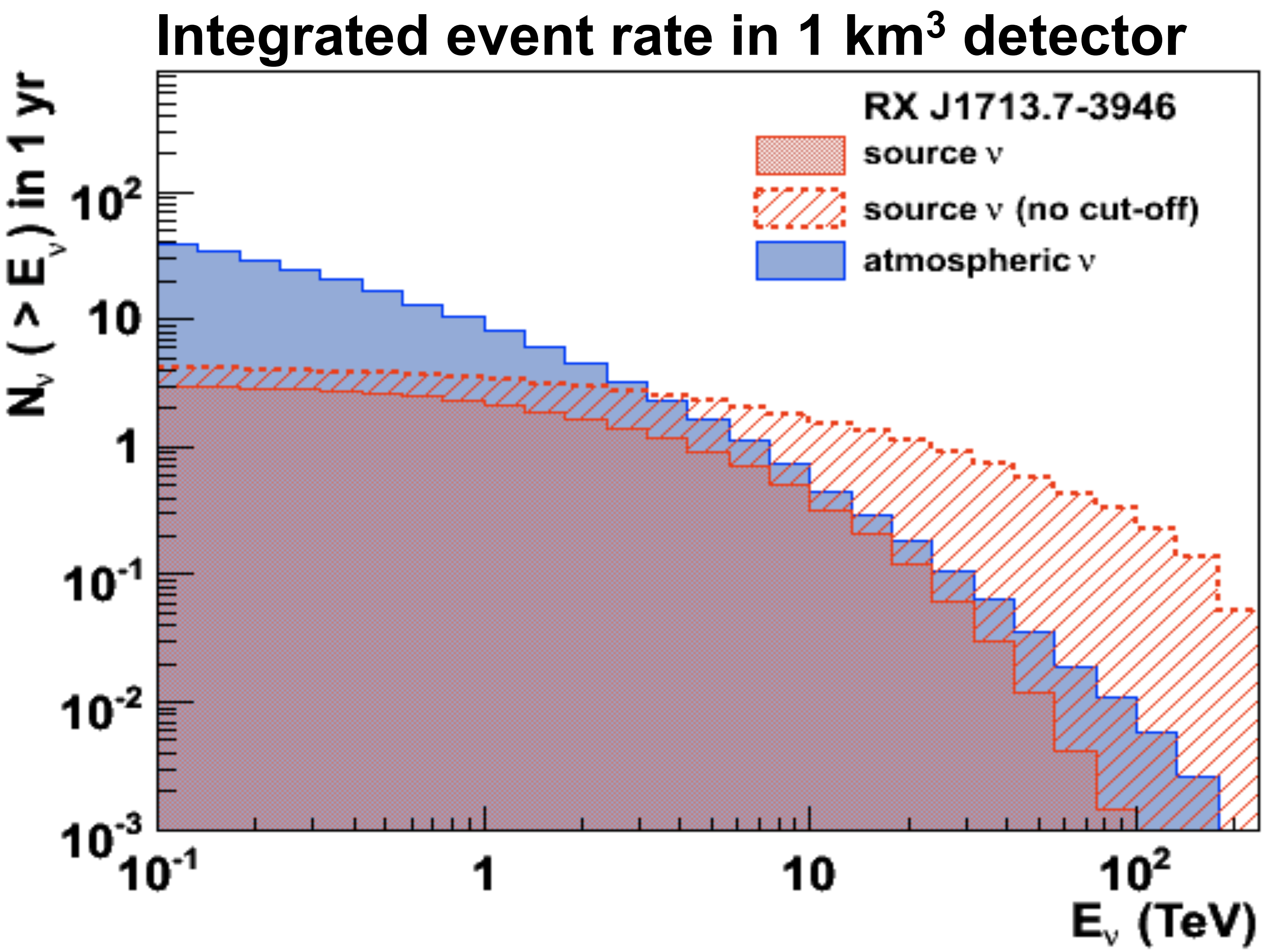


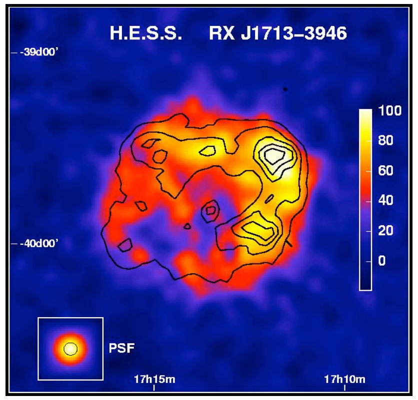
PSF
ν telescopes
(> 10 TeV)

Alvarez-Muniz & Halzen (2002)
Costantini & Vissani (2005)
Distefano (2006)
Kistler & Beacom (2006)
Kappes et al. (2007)
Morlino et al. (2009)

- Early predictions too optimistic
  (wrong γ-ray measurements, no ν oscillation, no cut-offs)
- Now expecting (1 km^3, E_ν > 1 TeV): 1 – 3 evt yr^{-1}
- Source size important: ∅ = 1.3° → $N_{bkg} \approx 8$

RX J1713: Impact of High Energy Cut-Offs





- Effective area increases rapidly with energy
  → high energy cut-offs have large impact on event rates

  E_ν > 1 TeV: 2.1 evt yr^{-1} (cut-off) → 3.6 evt yr^{-1} (no cut-off)

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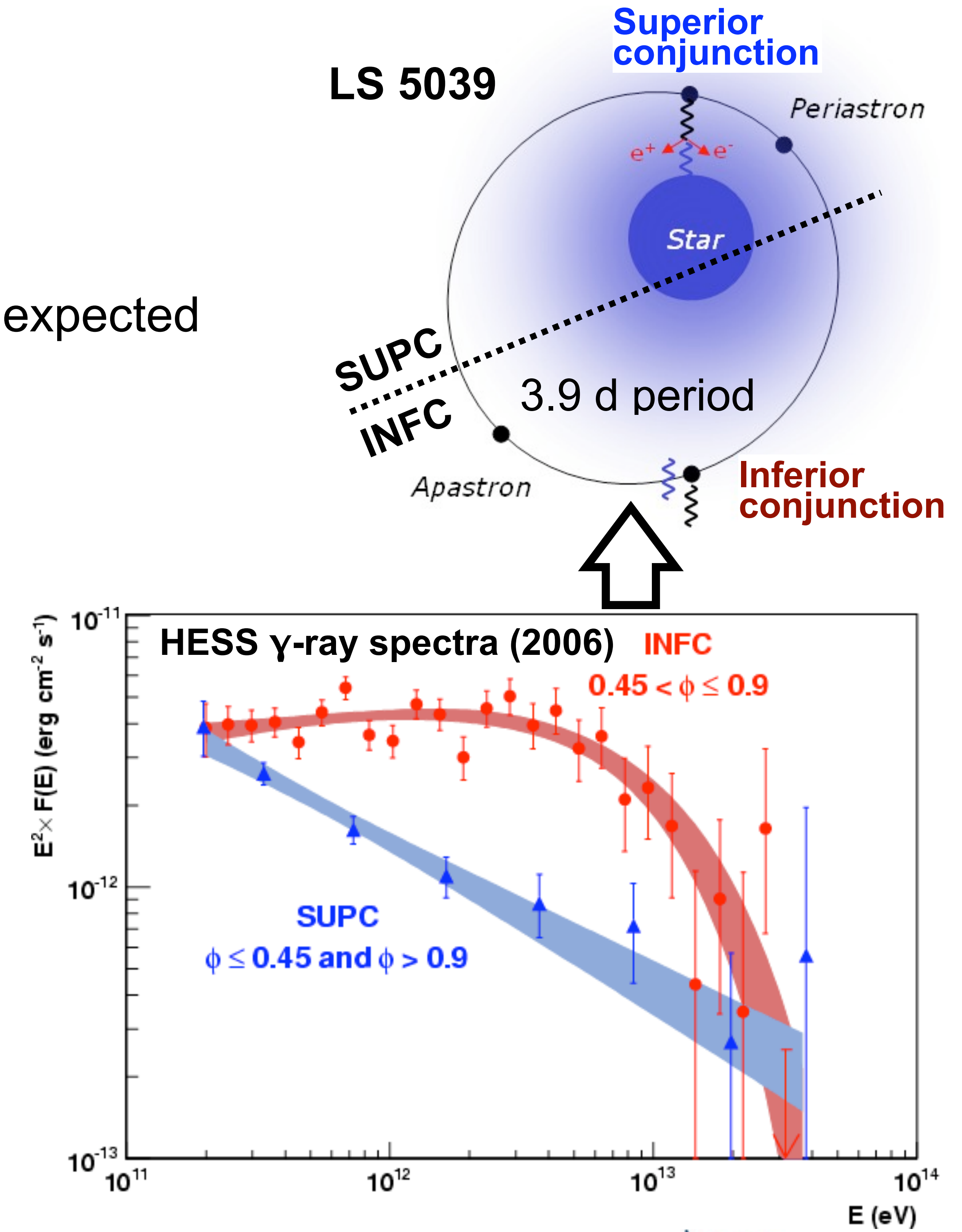
Binary Systems

- Potentially large γ-ray absorption

  → Neutrino flux much higher than expected

- LS 5039:
  - Evts in km³ detector (> 1 TeV)
    (Kappes et al. (2007))

    INFC: 0.3 – 0.7 yr^{-1}
    SUPC: 0.1 – 0.3 yr^{-1}
  - Up to 100 times higher !
    (Aharonian et al. (2006))
  - Point-like source (∅ ≈ 0.1˚)

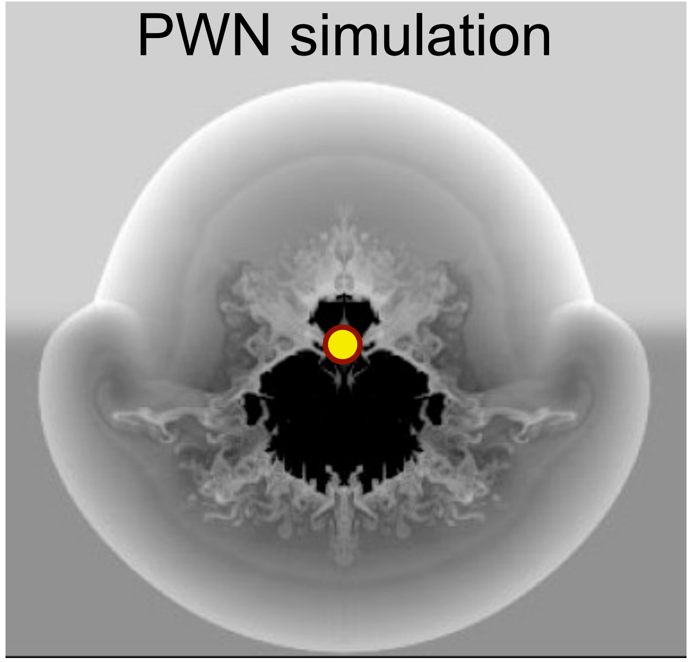


Pulsar wind nebulae

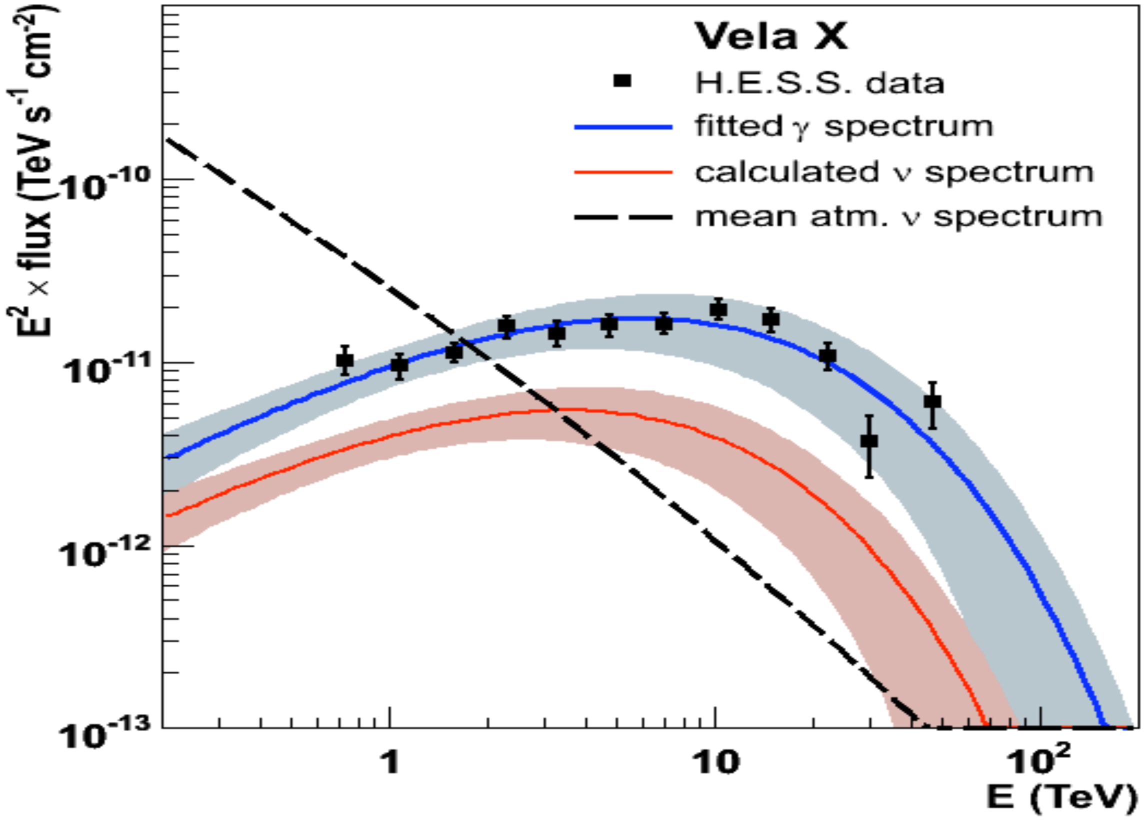
- PWNe generally expected to accelerate electrons

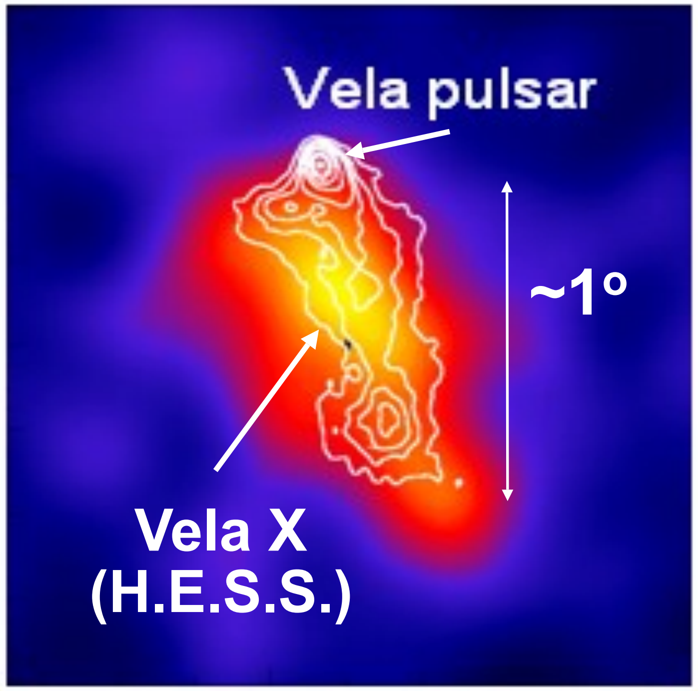
  ... but maybe significant fraction of nuclei in pulsar wind !?
  (e.g. Horn et al. (2006))

- Example Vela X:
  1 – 5 evts yr^{-1} (km^3; > 1 TeV)
  (Kistler & Beacom (2006), Kappes et al. (2007))



Blondin et al. (2001)





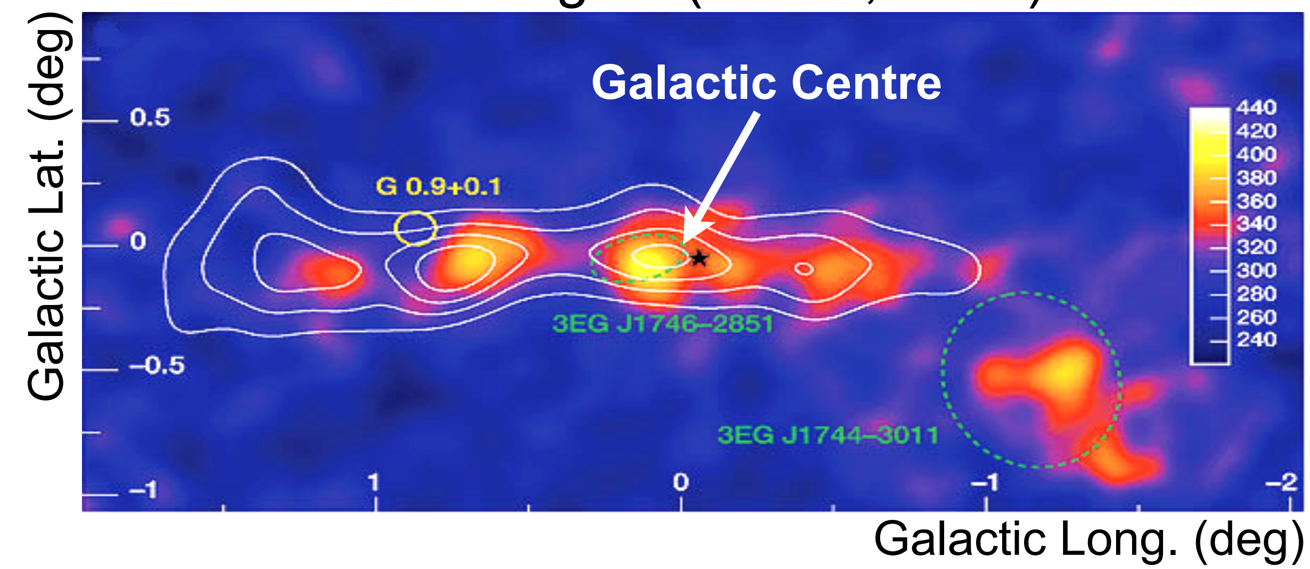
Molecular clouds

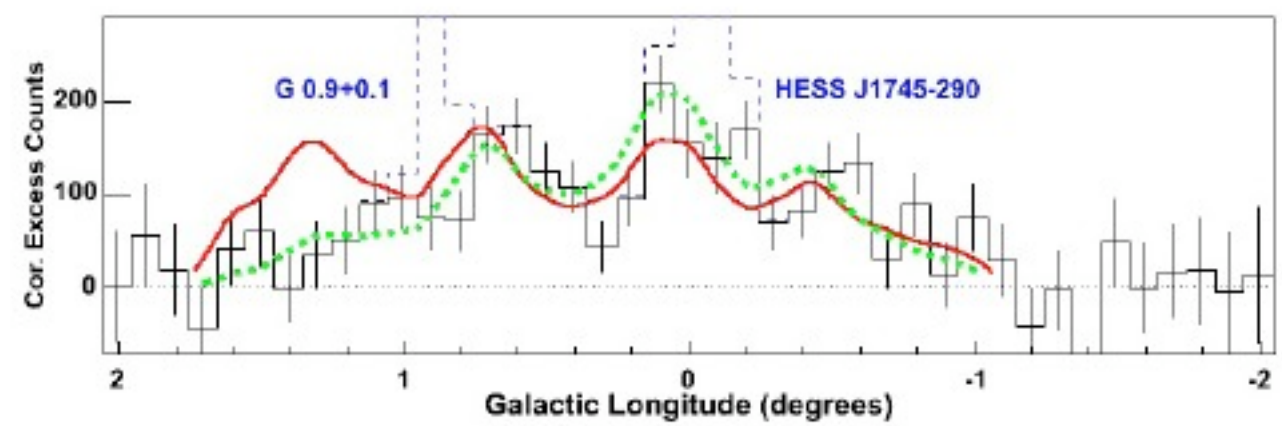
- Interaction of cosmic rays with molecular clouds
- TeV γ-ray emission follows matter density

- Galactic Centre region: garantied neutrino source . . .

  . . . but rather weak (< 1 evt yr^{-1})

Galactic Centre region (HESS, 2006)





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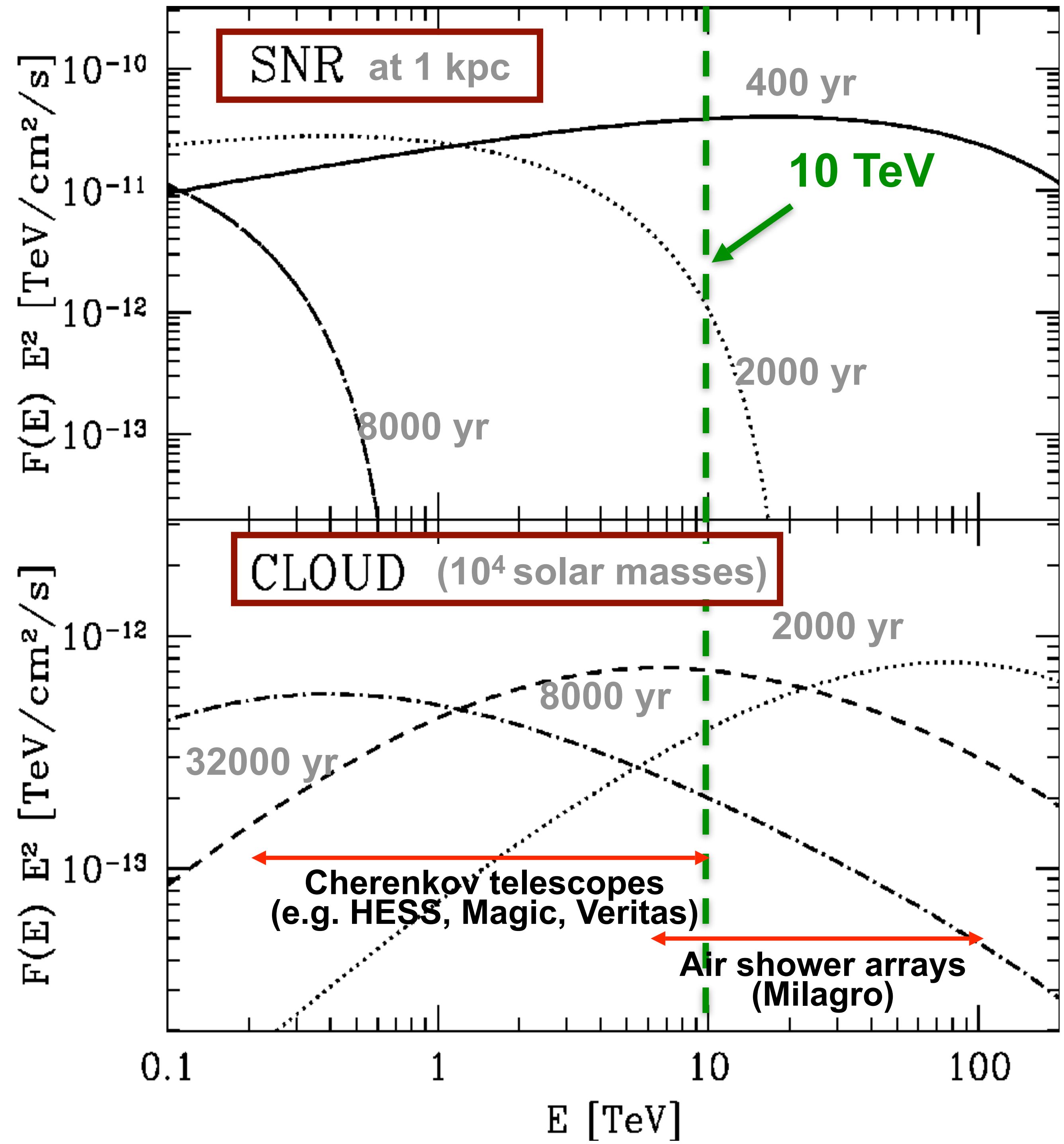
The missing PeVatrons

- No γ rays above few 10 TeV ("knee" corresponds to ~300 TeV)
- "Direct" γ-rays maybe only in first few hundred years
- Detection by observing secondary ν's or γ-rays from clouds near sources

Gabici & Aharonian, arXiv:0705.3011



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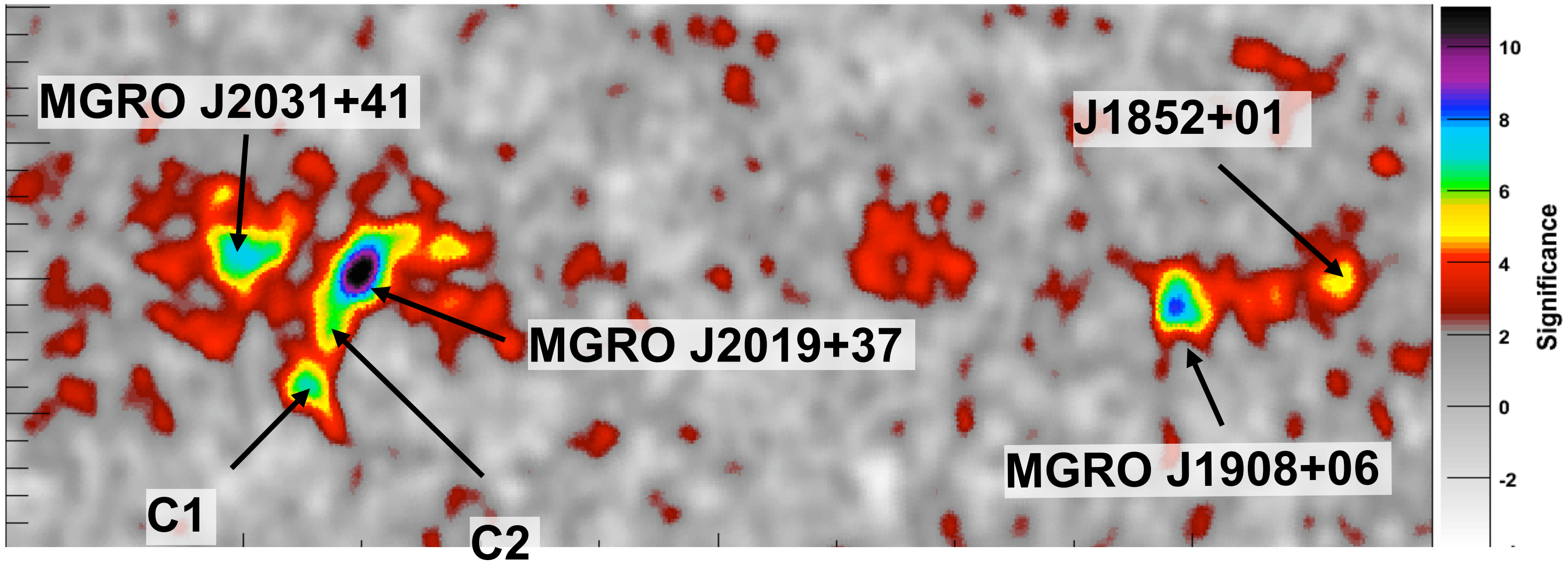
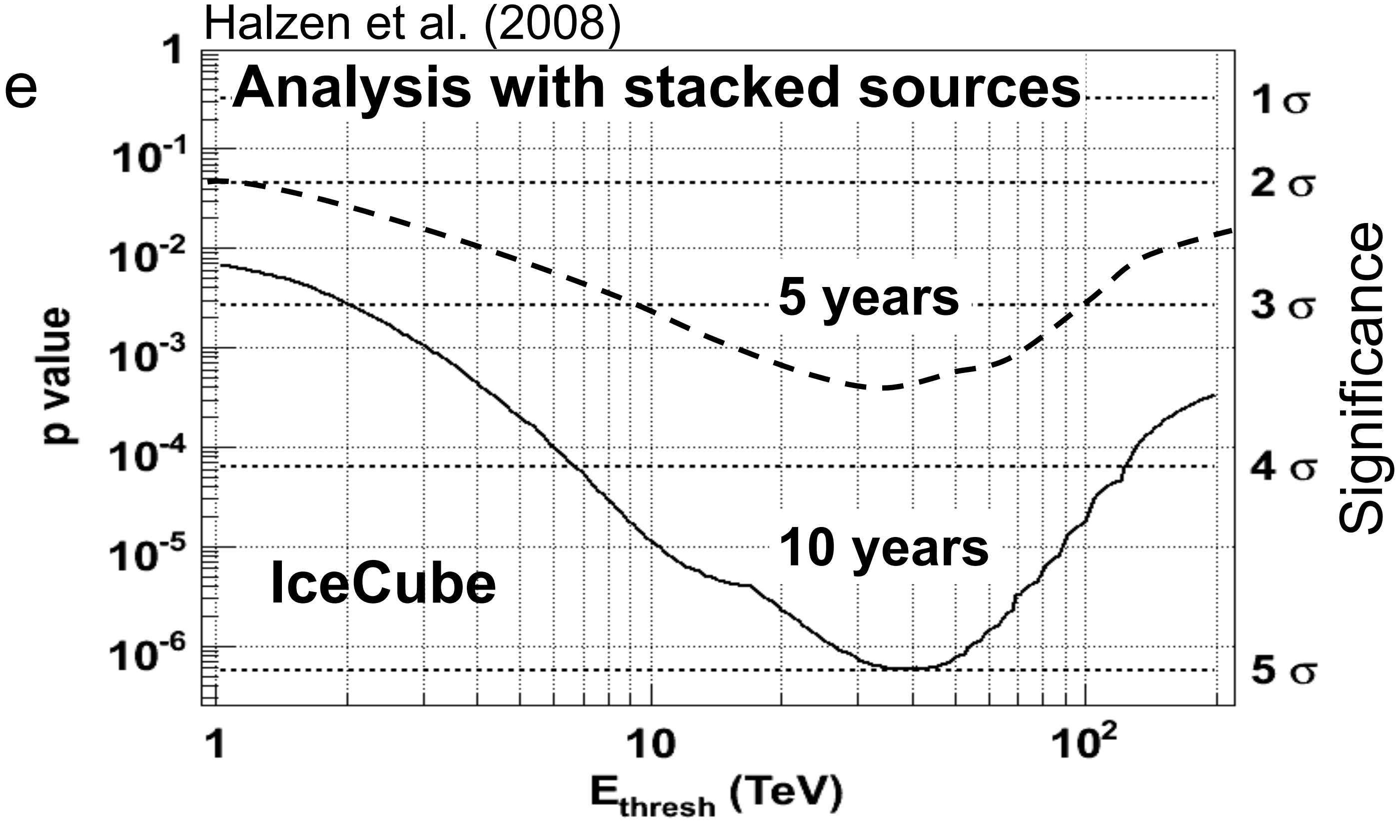
PeVatron candidates

Part of Galactic plane in γ-rays @ 12 TeV (Milagro)



- If PeVatrons, sources detectable with IceCube
- Energy resolution important

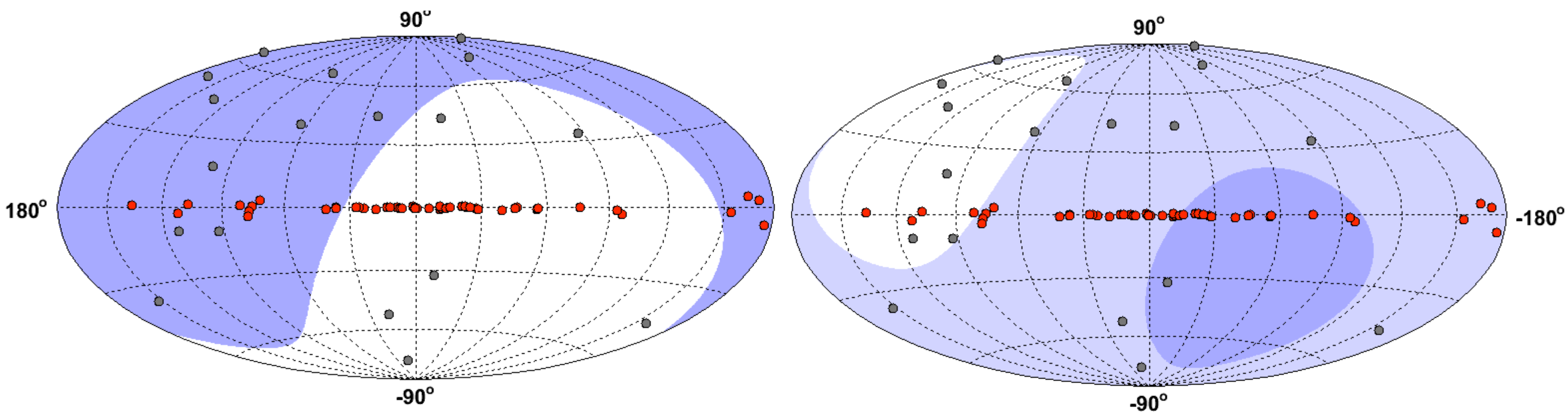
Halzen et al. (2008)



Sky coverage of neutrino telescopes

Visibility South Pole (IceCube)
- 100%
- 0%

Visibility Mediterranean (Antares, KM3NeT)
- > 75%
- 25% – 75%
- < 25%



TeV γ-ray sources
- Galactic
- extra-Galactic

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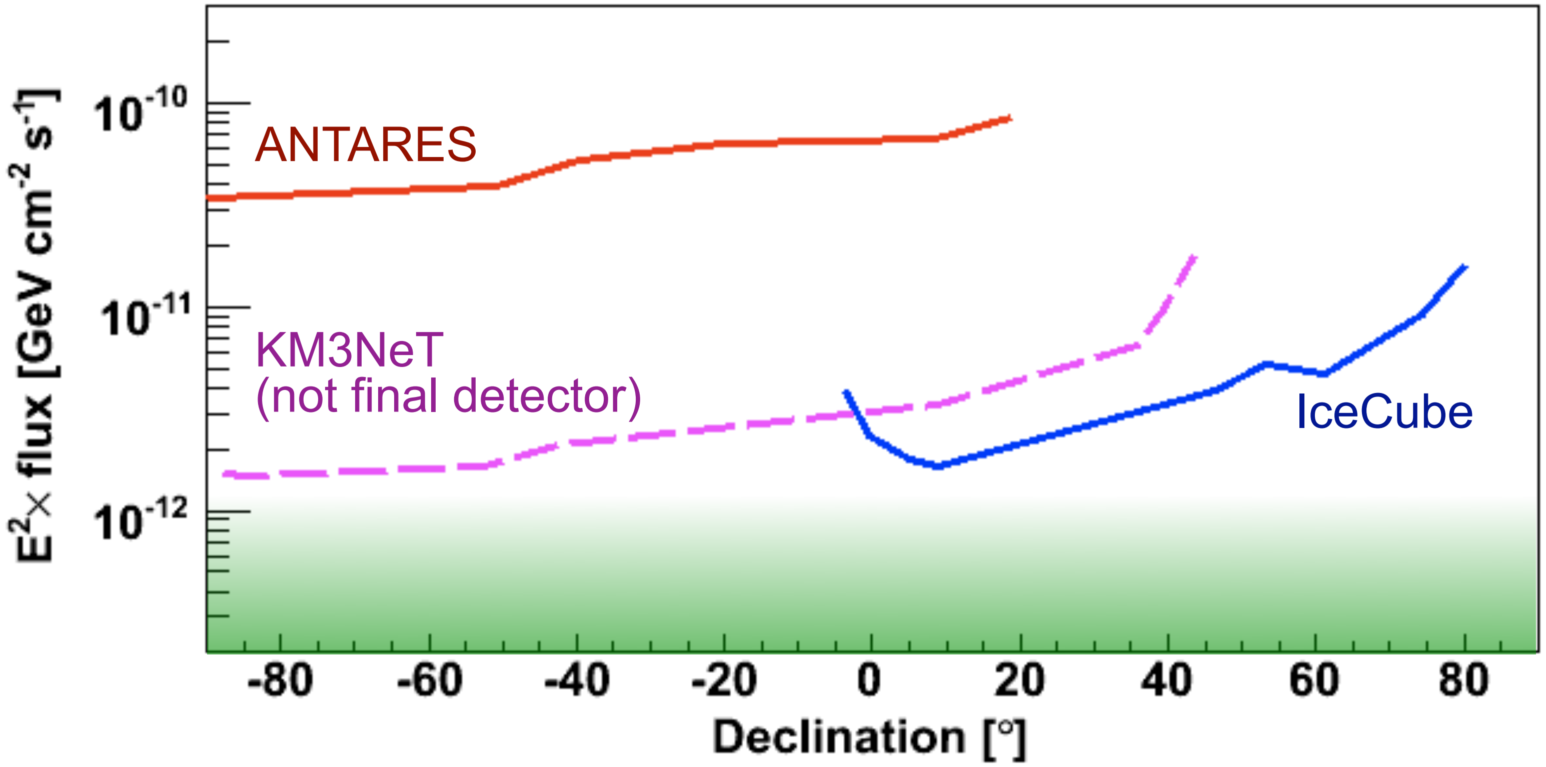
Point-source sensitivities

90% CL sensitivity for E^{-2} spectra (preliminary)



ANTARES: 1 yr (pred. sensitivity)

IceCube: 1 yr (pred. sensitivity)

KM3NeT: 1 yr (pred. sensitivity)

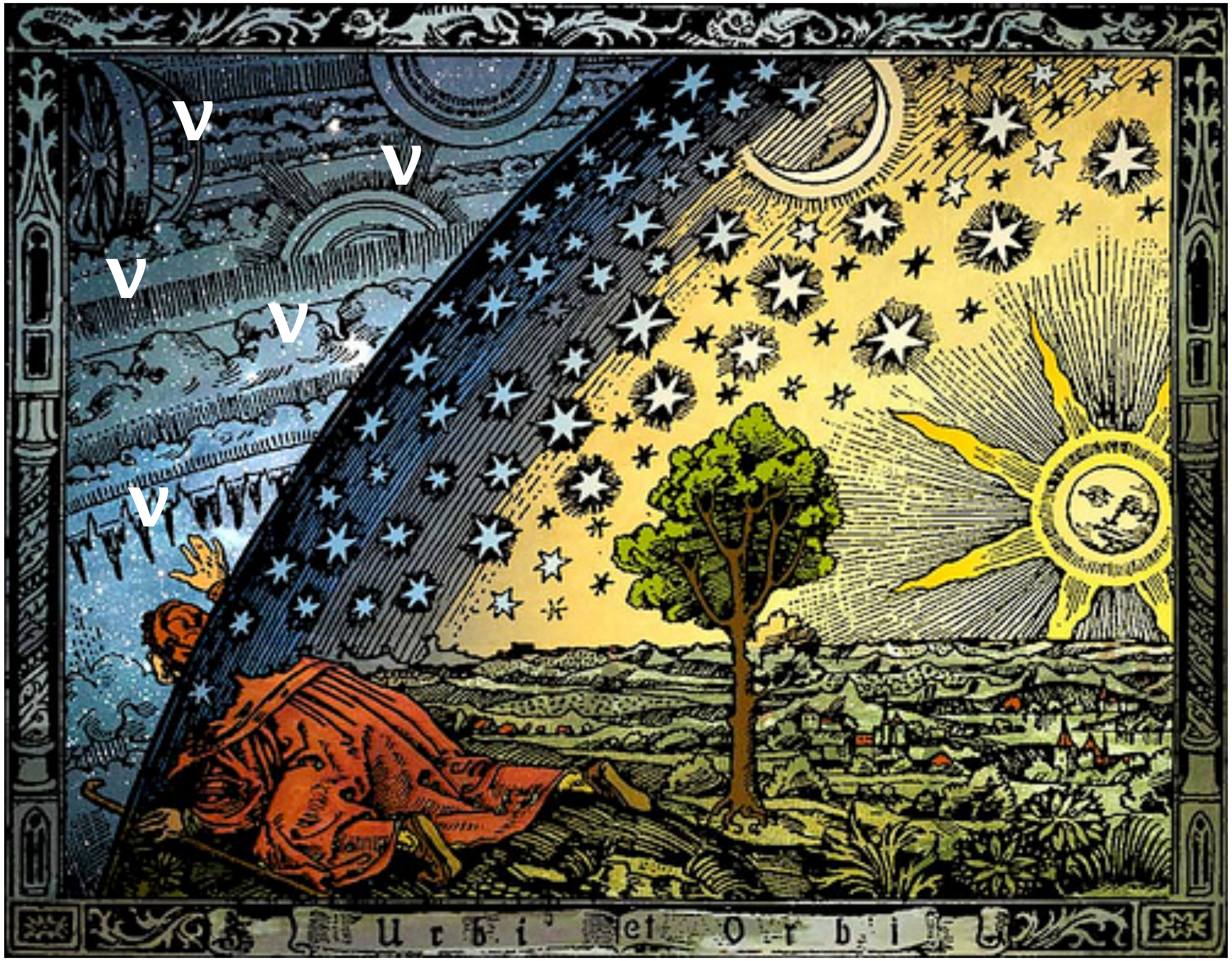
Predicted fluxes
Halzen, AK, O'Murchadha, PRD (2008)
AK, Hinton, Stegmann, Aharonian, ApJ (2006)
Kistler, Beacom, PRD (2006)
Costantini & Vissani, App (2005) . . .

Detectability of individual sources depends on many details:

- Cut-off energy
- Source size
- Energy resolution (Lower energy cuts improves Signal/Bckg ratio)

Gamma-ray dark sources

Neutrinos open a new window to the universe . . .



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Conclusions

- Neutrino telescopes open new window to our galaxy and beyond (complete picture requires multi-messenger approach)

- Galactic high-energy neutrino sources must exist
  but up to now no source of high-energy neutrino emission identified

- km^3-class detectors (IceCube, KM3NeT) will enter discovery region
  - several good source candidates
  - will likely detect cosmic neutrinos within next years
  - detection significance depends on source-specific details

- Expect surprises !

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Marie Curie Actions
Human Resources and Mobility Activity

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