

RUHR-UNIVERSITÄT BOCHUM

Neutrino Sources

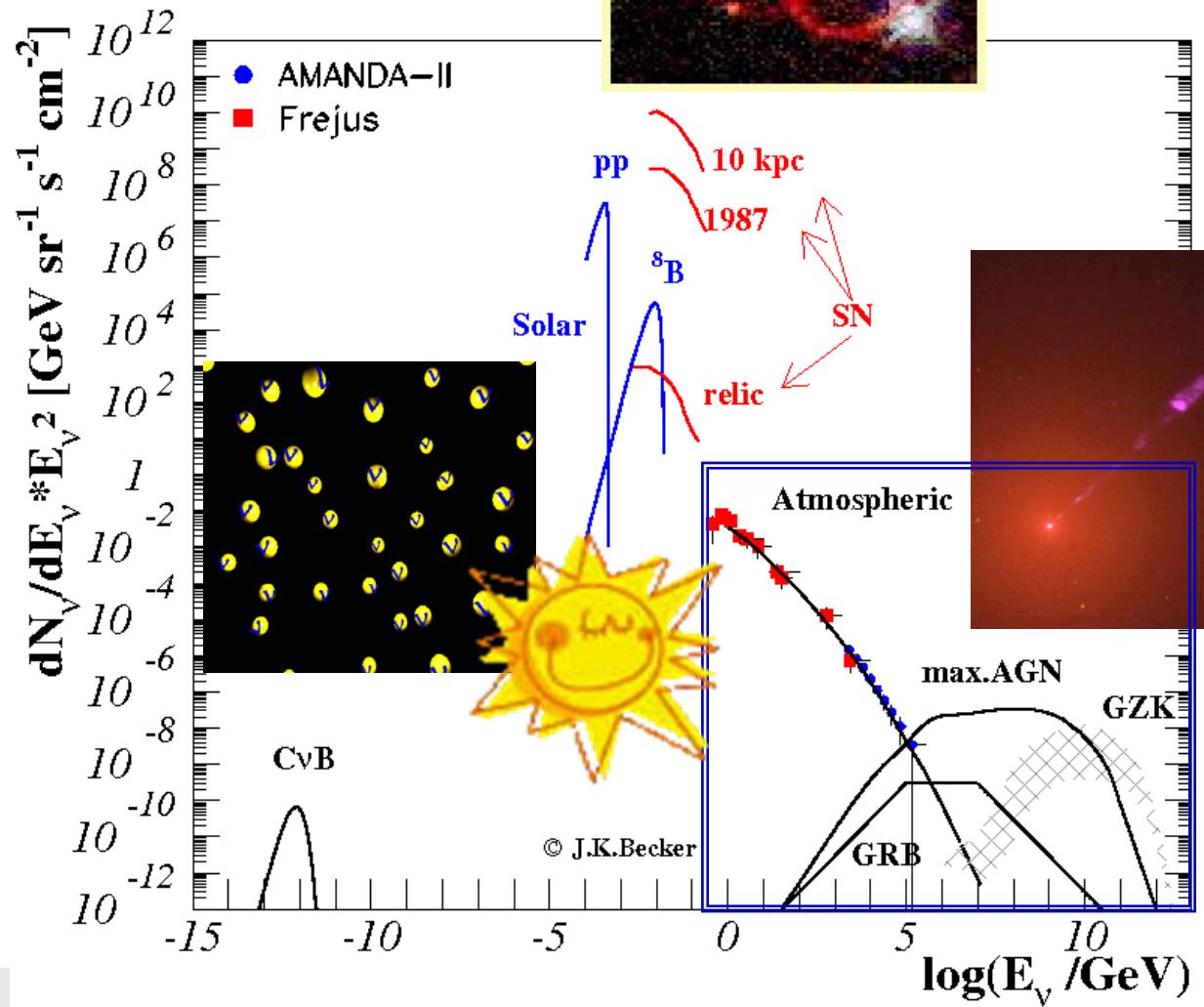
Julia Tjus

For a review, see

J.K. Becker, Phys. Rep. 458:173(2008)
[arXiv:0710.1557]

FAKULTÄT FÜR PHYSIK & ASTRONOMIE
Theoretische Physik IV

Neutrino sources



High-energy neutrino production

- $p p \rightarrow \#(\pi^{+/-} 0)$
- $p \gamma \rightarrow \Delta^+ \rightarrow \pi^{+/-} N$
- $\pi^+ \rightarrow \mu^+ \bar{\nu}_\mu \rightarrow e^+ \bar{\nu}_e \bar{\nu}_\mu \nu_\mu$
- $\pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \nu_\mu \bar{\nu}_\mu$
- $\pi^0 \rightarrow \gamma\gamma$ ($E \sim \text{TeV}$)

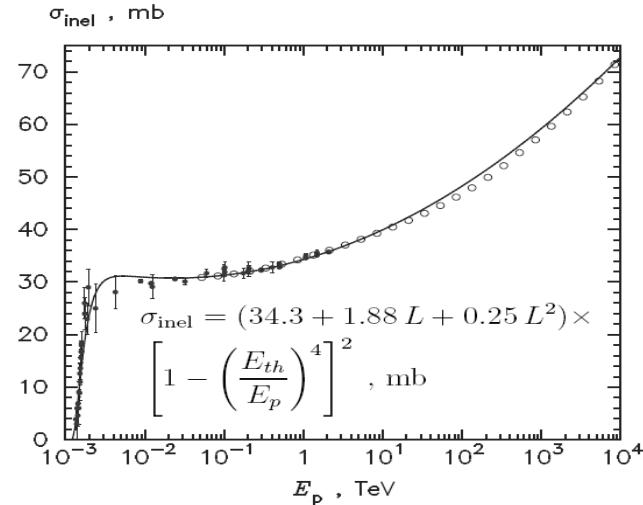


Fig:
Kelner et al, PRD (2008)

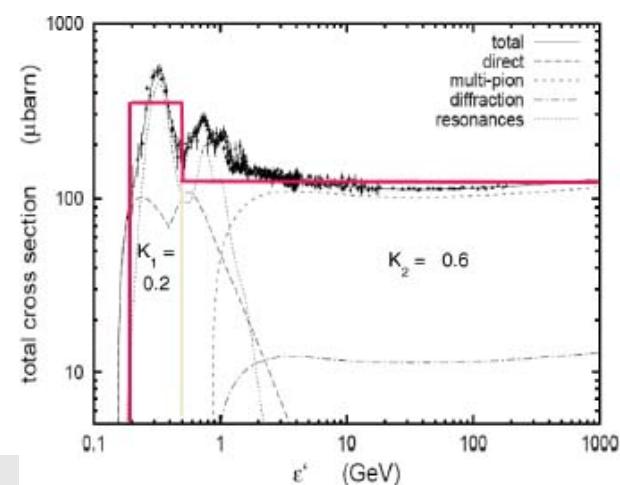


Fig:
Dermer&Atoyan, New J Phys (2006)

High-energy neutrino sources

CR flux:

$$\Phi_{CR} = A_{CR} \cdot \left(\frac{E_{CR}}{GeV} \right)^{-p}$$

{ at source: $p \sim 2$
at Earth: $p \sim 2.7$

Normalization:

$$L_{radio} = f_e \cdot L_p$$

→ Neutrinospectrum:

$$\Phi_{CR} = A_\nu \cdot \left(\frac{E_\nu}{GeV} \right)^{-\alpha}$$

Proton-interactions @ source:

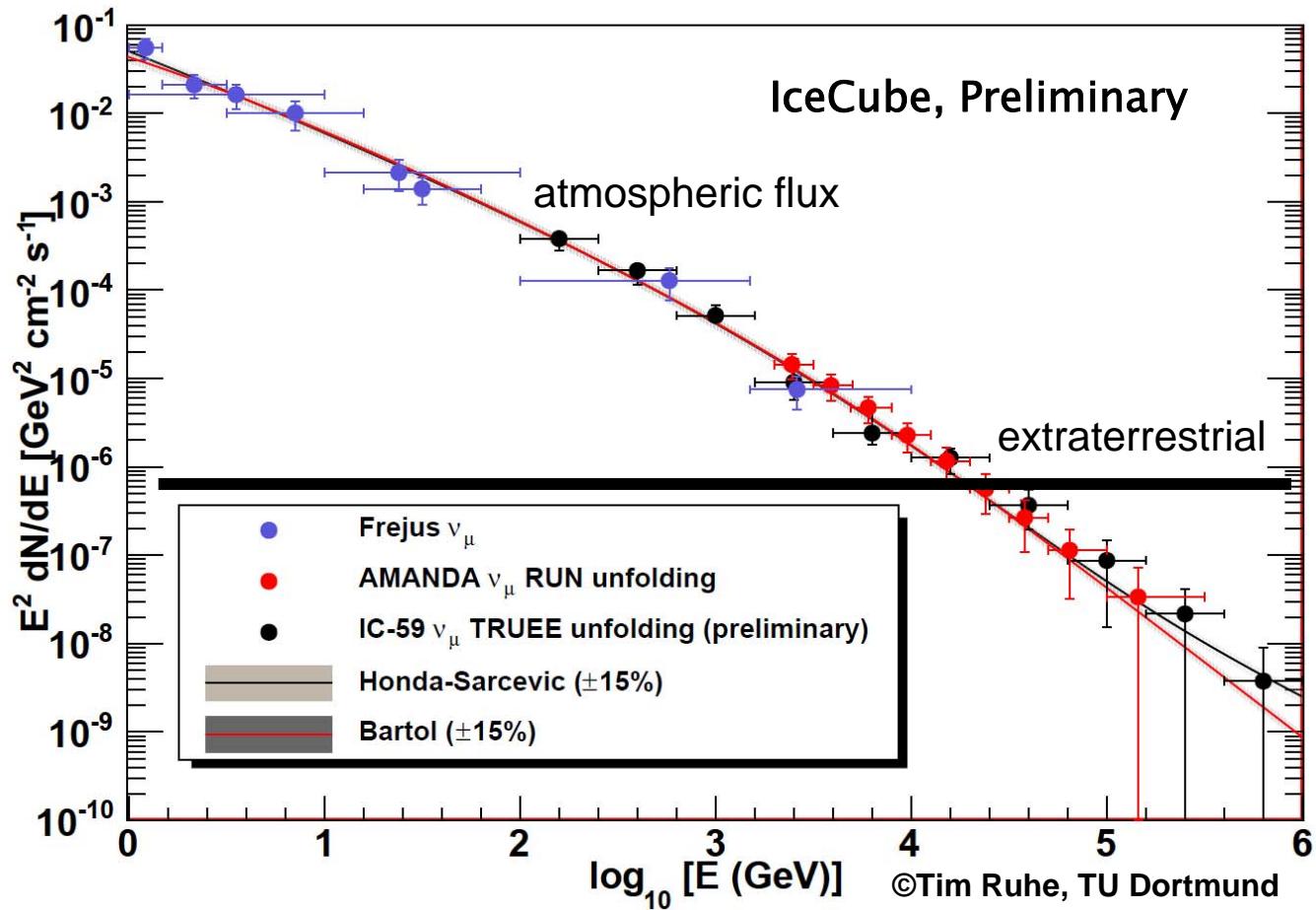
$$\alpha \approx \frac{4}{3} \left(p - \frac{1}{2} \right)^{p \sim 2} \approx 2$$

Proton-interactions in atmosphere: $\alpha \approx p - 1 \stackrel{p \sim 2.7}{\approx} 3.7$

→ Atmospheric spectrum much steeper than astrophysical one:

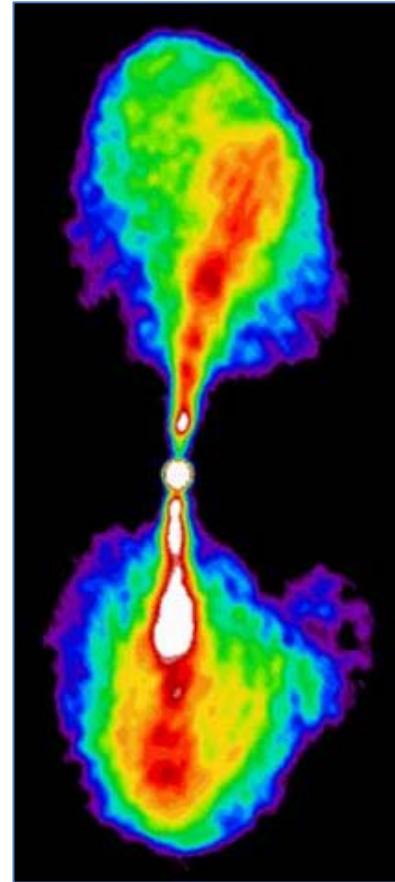
Relevant information on high-energy neutrino sources

- Diffuse flux
→ high energies
- Point sources
→ space & time
- Adding signal hypothesis
→ e.g. stacking



Contents

- Supernova Remnants
- Active Galactic Nuclei
- Gamma-ray bursts



SNRs: available information from observations

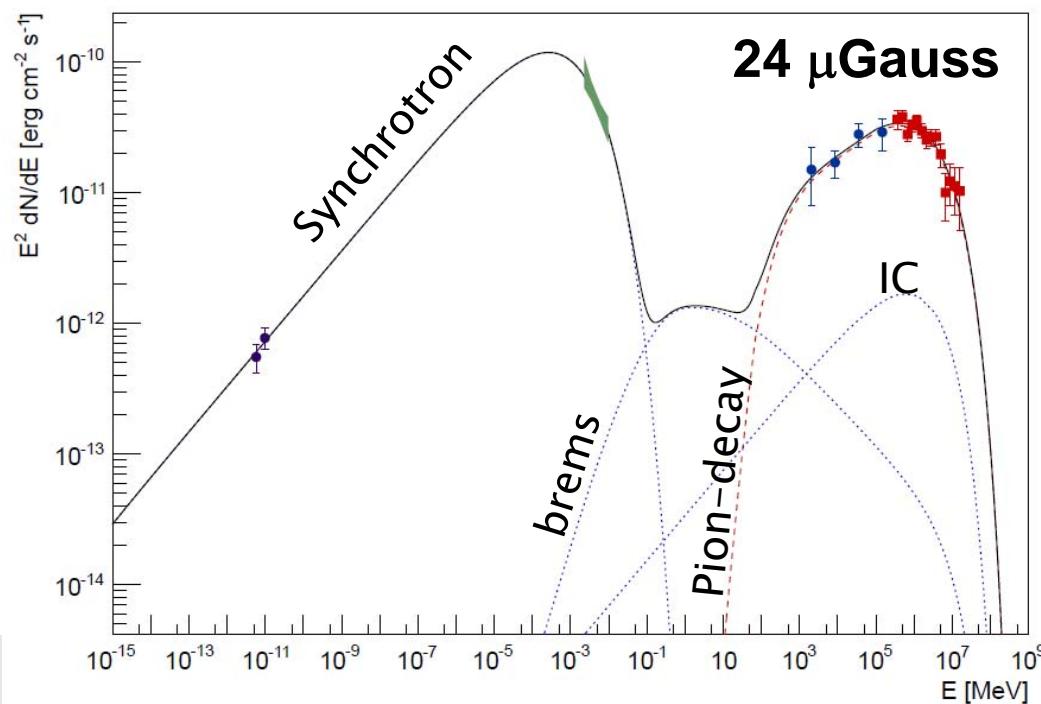
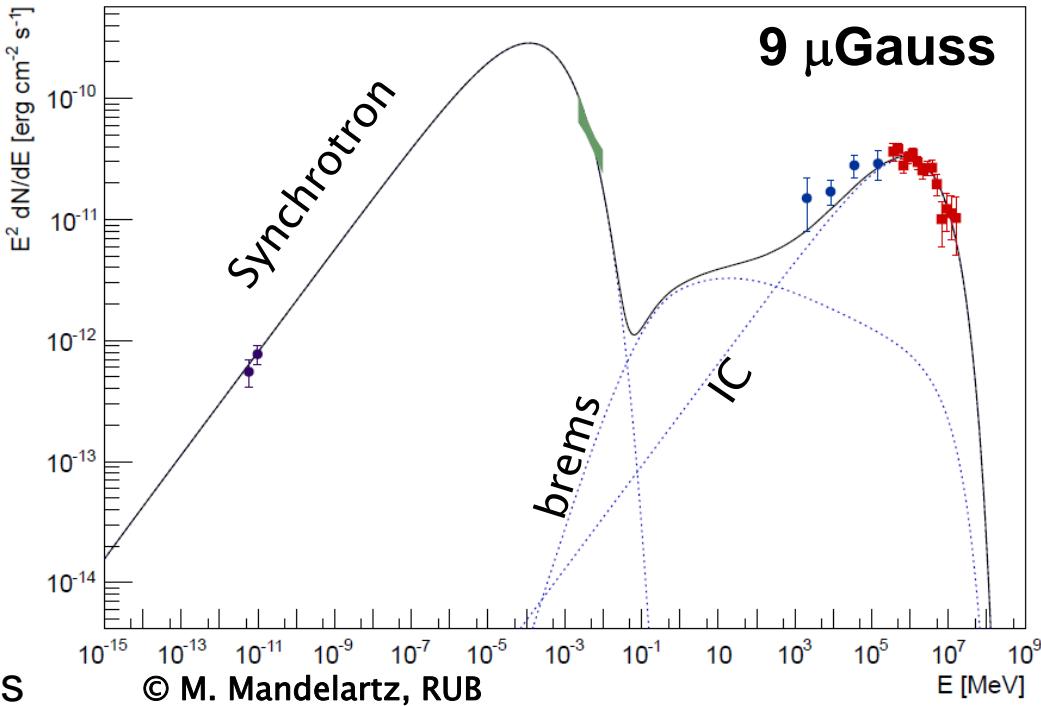
- **Radio observations** → non-thermal electrons
- **Gamma-ray radiation** → hadrons/leptons
 - π^0 -decays, IC, brems
- **Molecular ions: lines**
 - Cosmic ray ionization
 - *Difficulty:* CR spectrum at low energies not known



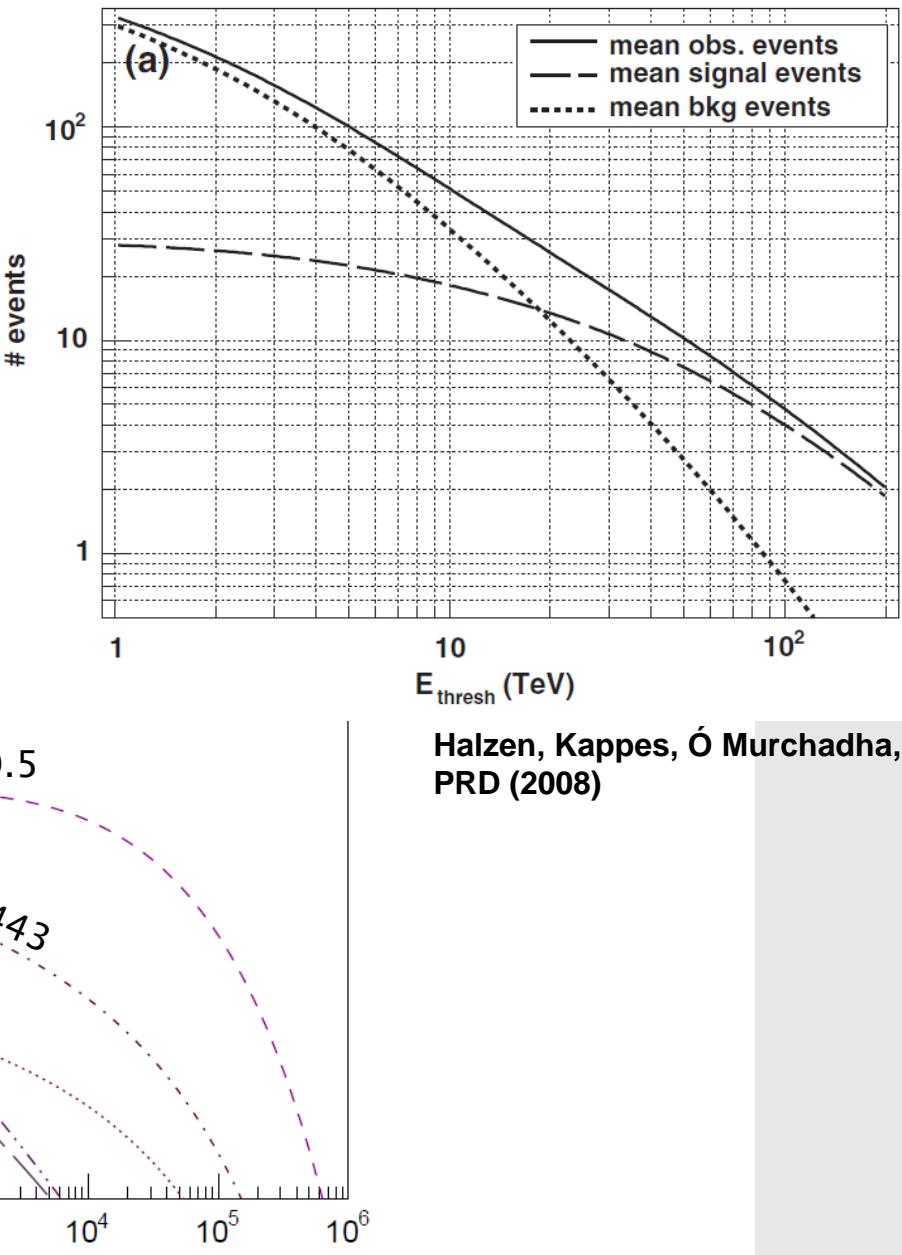
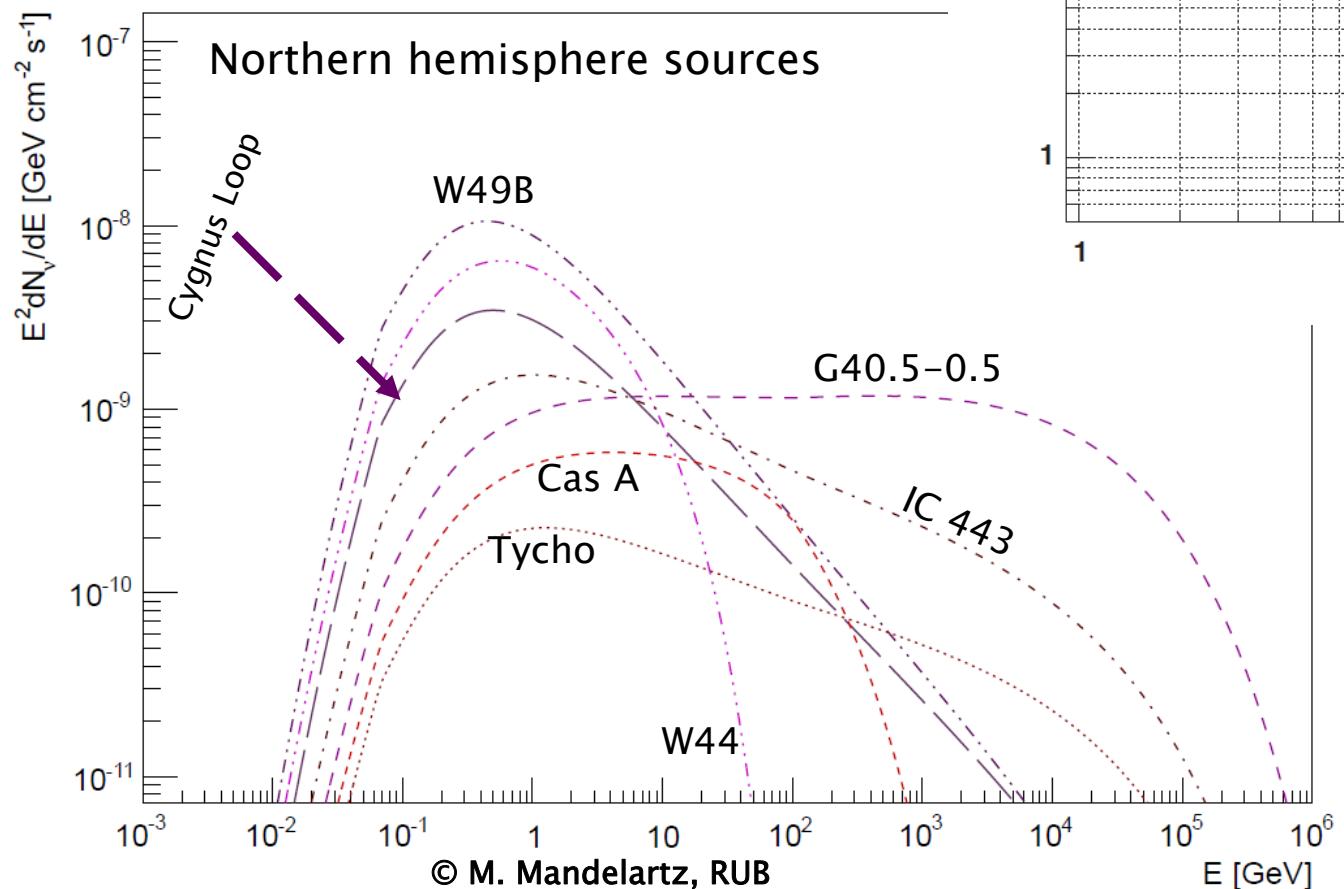
© NASA

Example: Vela Junior – SED fit

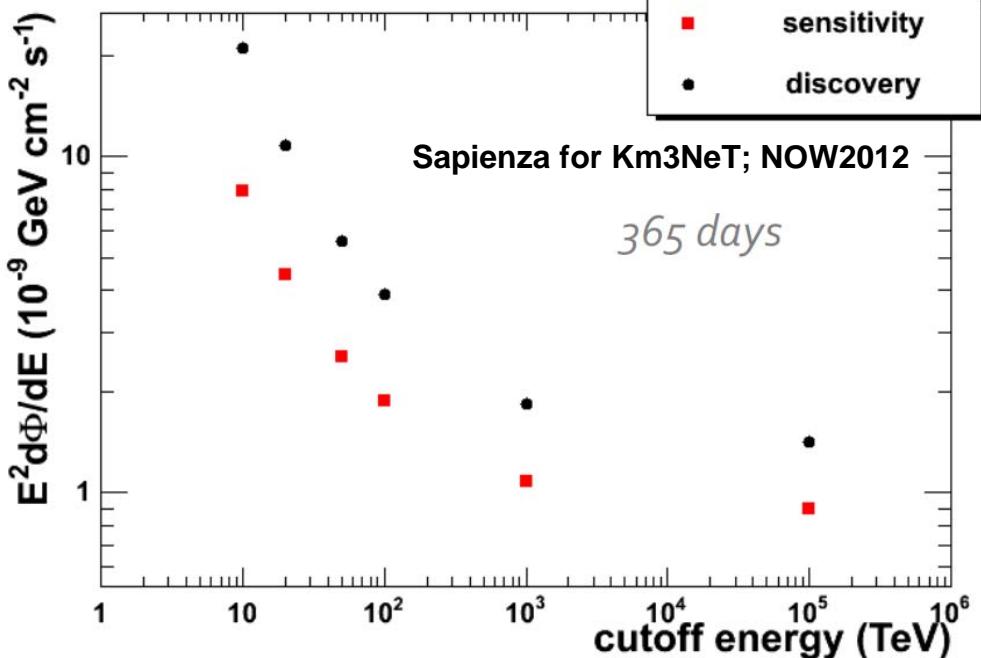
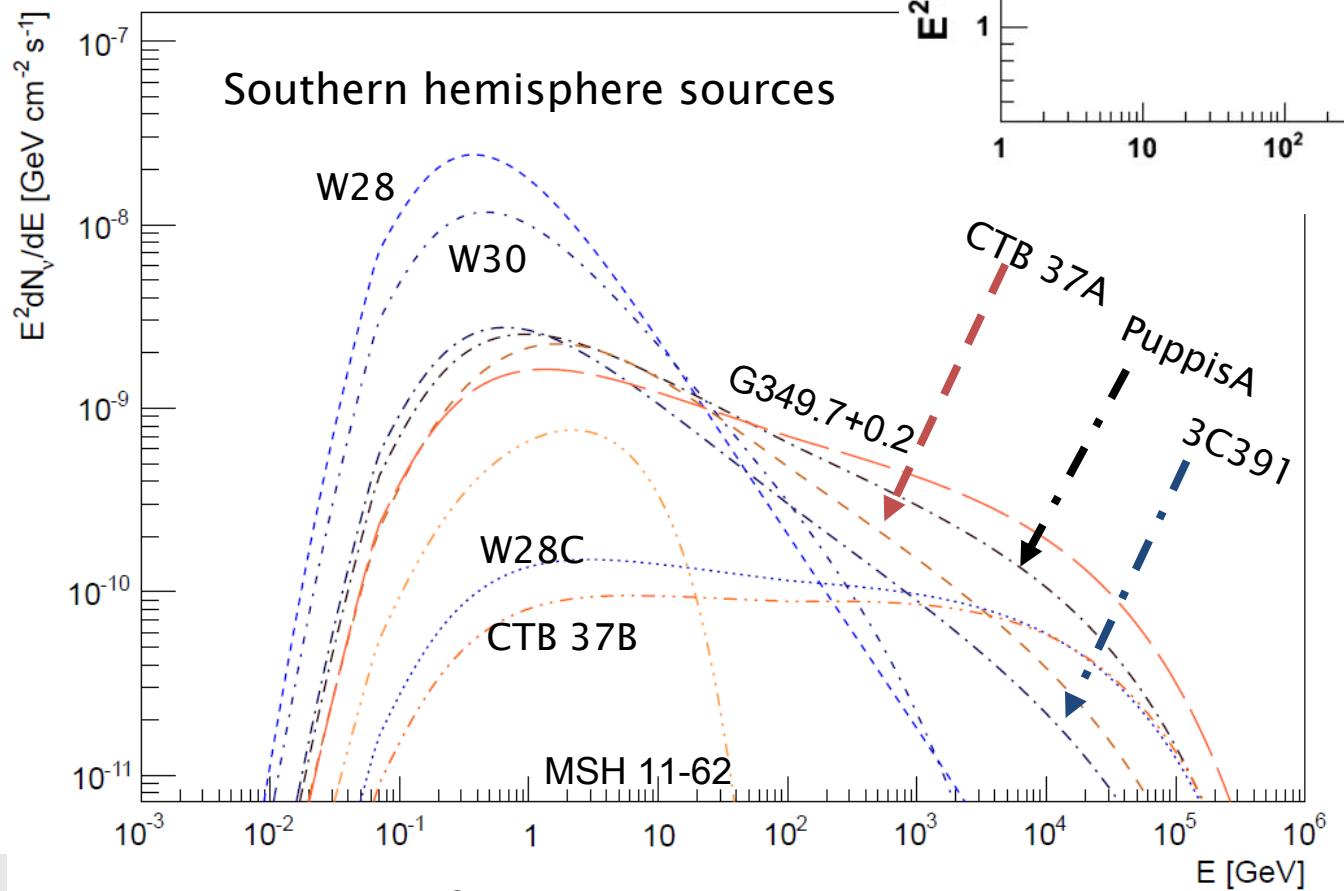
- Gamma-ray signal: not always unambiguous
- → Neutrinos to distinguish scenarios
- Assumption of hadronic dominance
- → Exact information on expected neutrino flux in measured gamma-ray region



Neutrino emission from SNRs

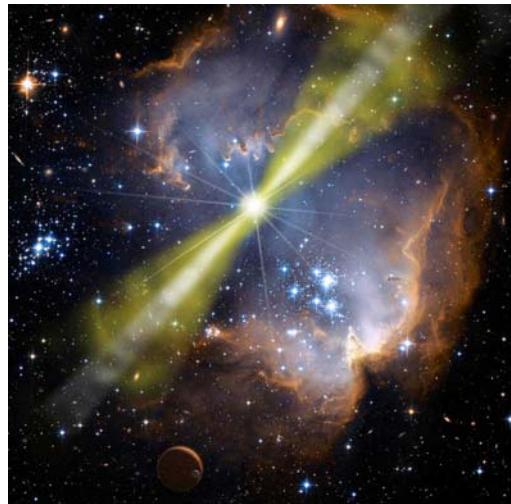
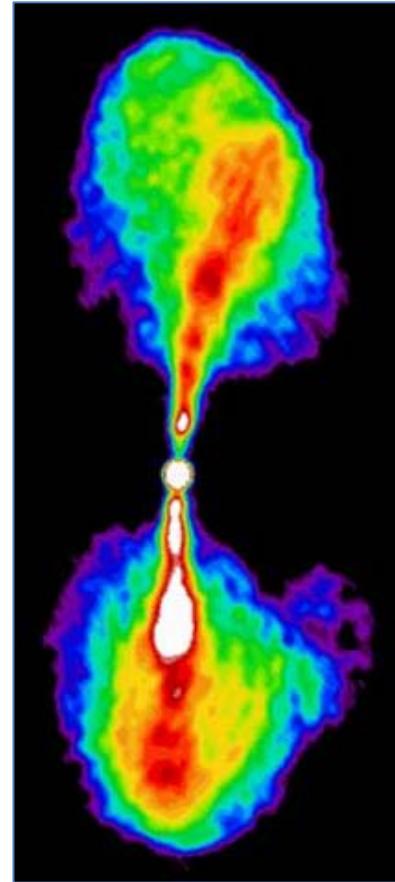


Neutrino emission from SNRs

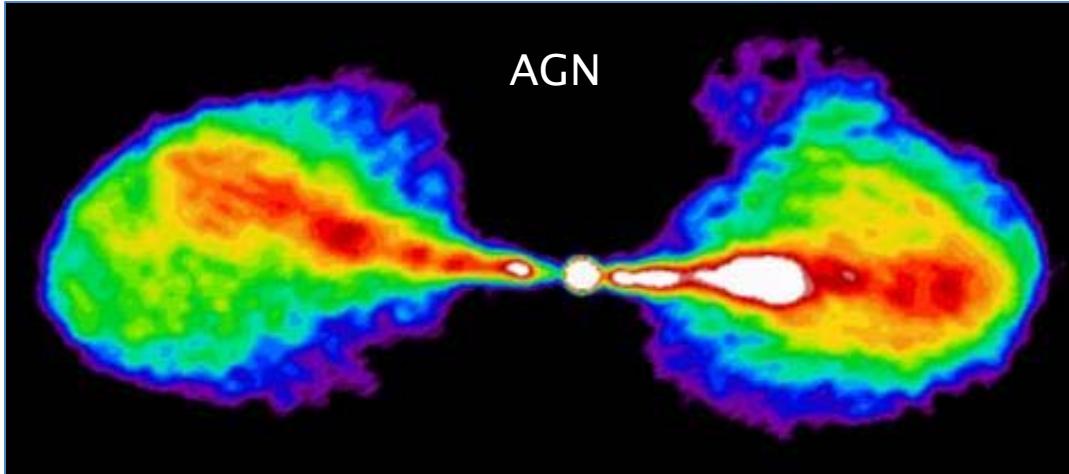


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Unification scheme



Radio-loud (10%)



Strong radio



Orientation

Radio quiet (90%)



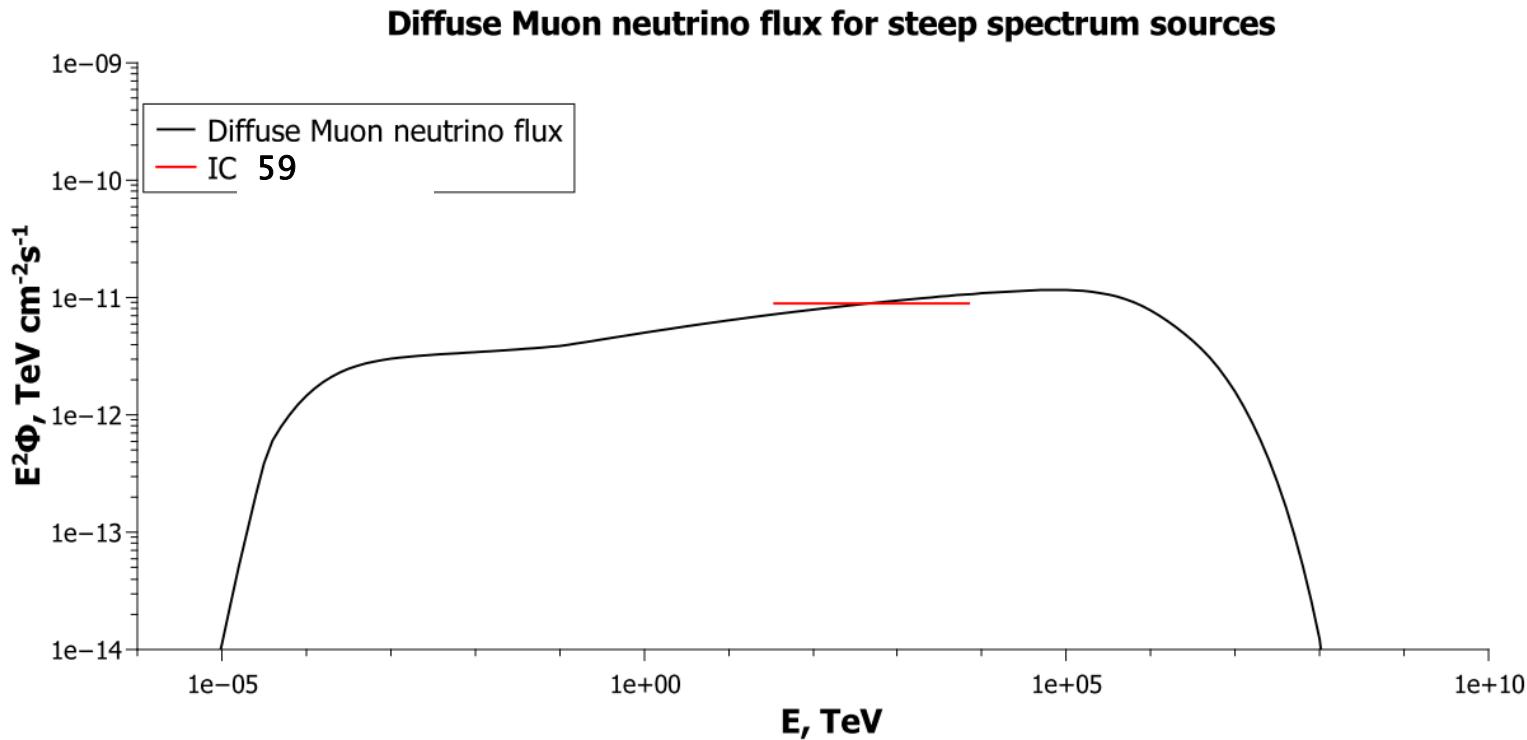
Strong optical



Weak optical

Orientation

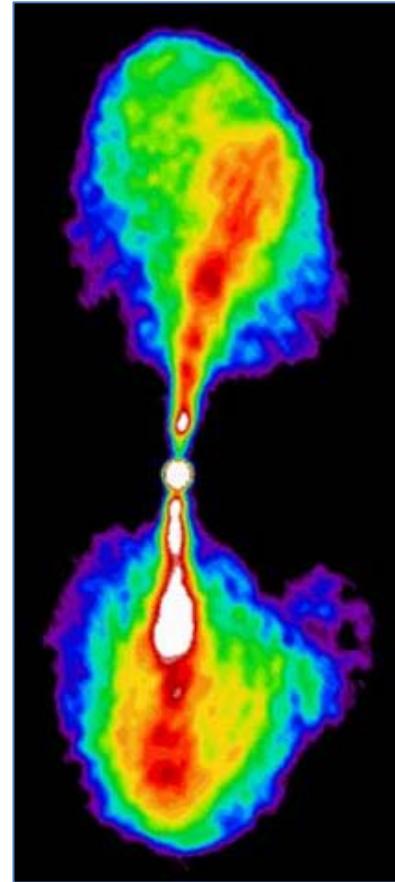
Constraints on astrophysical parameters from diffuse limits



IC59 Sensitivity → $n_H < 0.2 \text{ cm}^{-3} * (f_e/0.1)$

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GRBs as cosmic accelerators & neutrino source

- GRBs suited to accelerate up to 10^{21} eV
- Leptonic non-thermal energy budget matches what is needed for hadronic sources above ankle
- Neutrino production via interaction with synchrotron photon field

See e.g. Piran (2005) for review

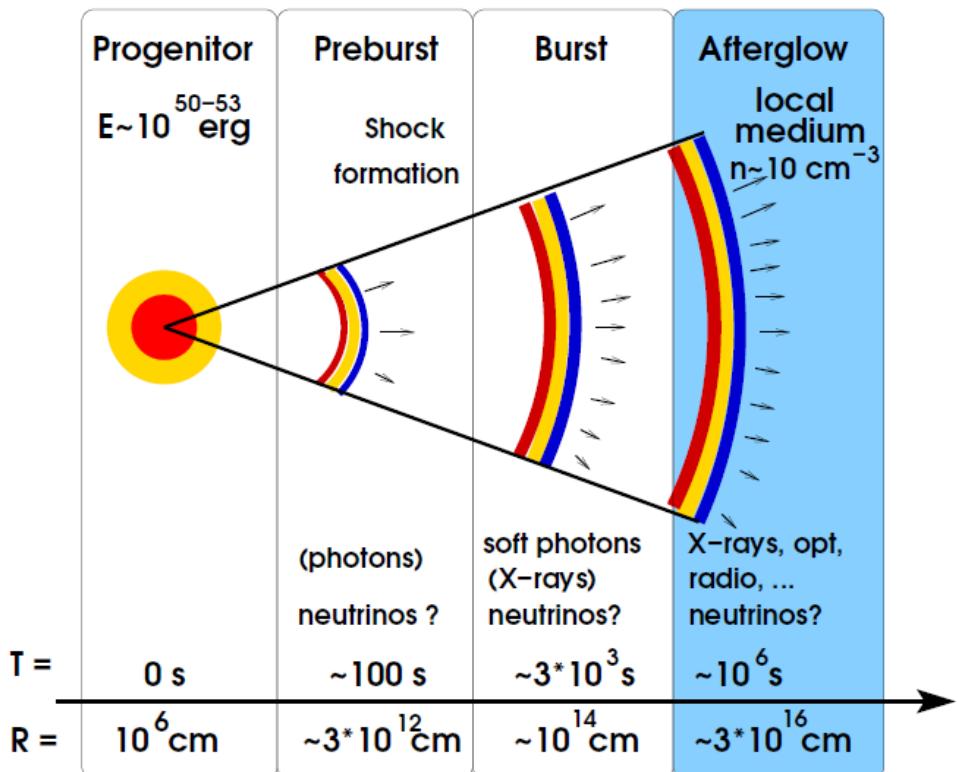
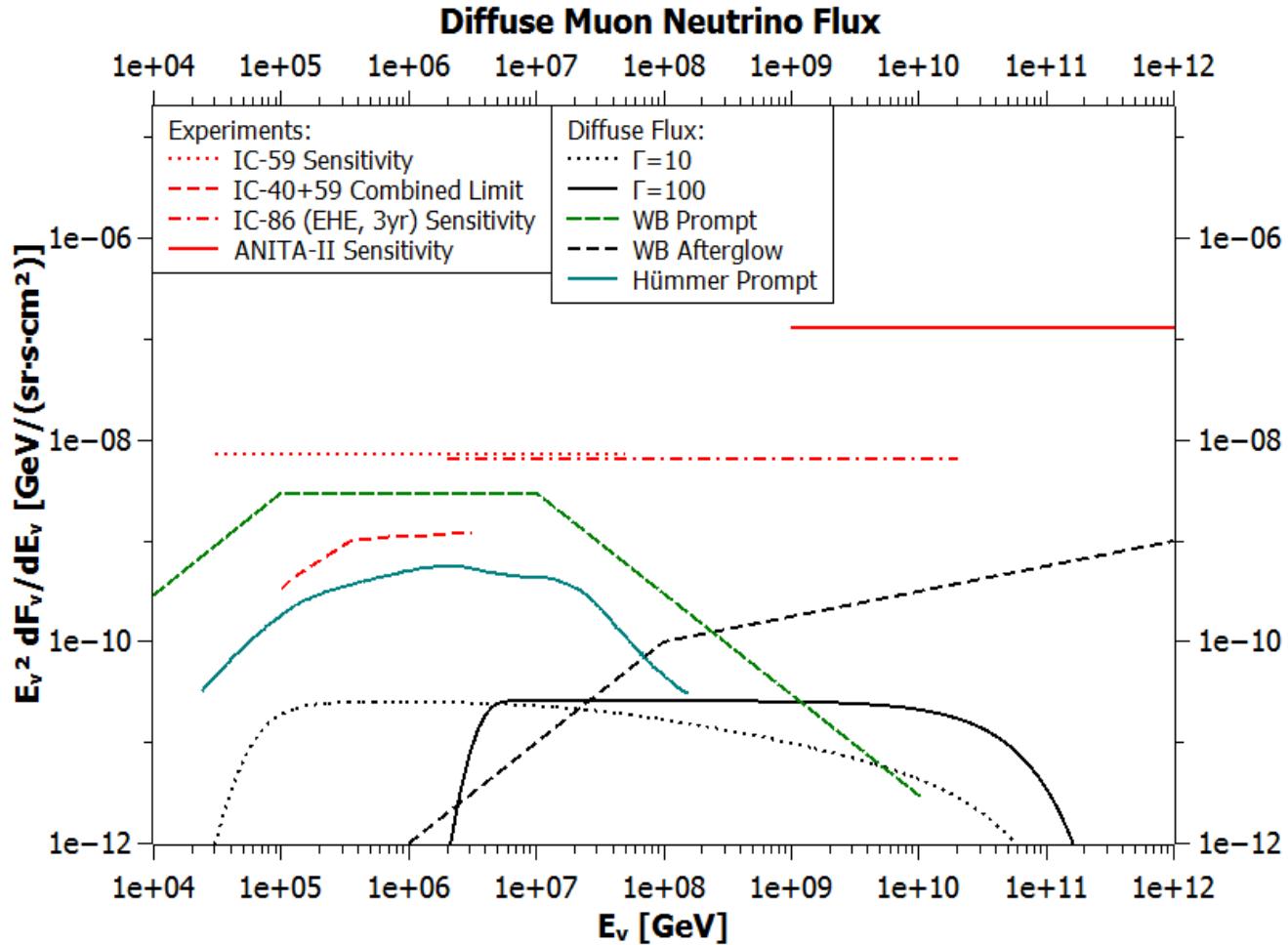


Fig: Becker, Phys.Rep. (2008)

Expected diffuse flux from GRBs

- **Waxman&Bahcall:**
normalize to CR flux
- **Hümmer, Winter,
Baerwald:**
full particle physics
description, normalize
via
 $L_{\text{synch}} \sim L_e = f_e * L_p$
- **Afterglow:**
high-energy (no pion
synchrotron losses)



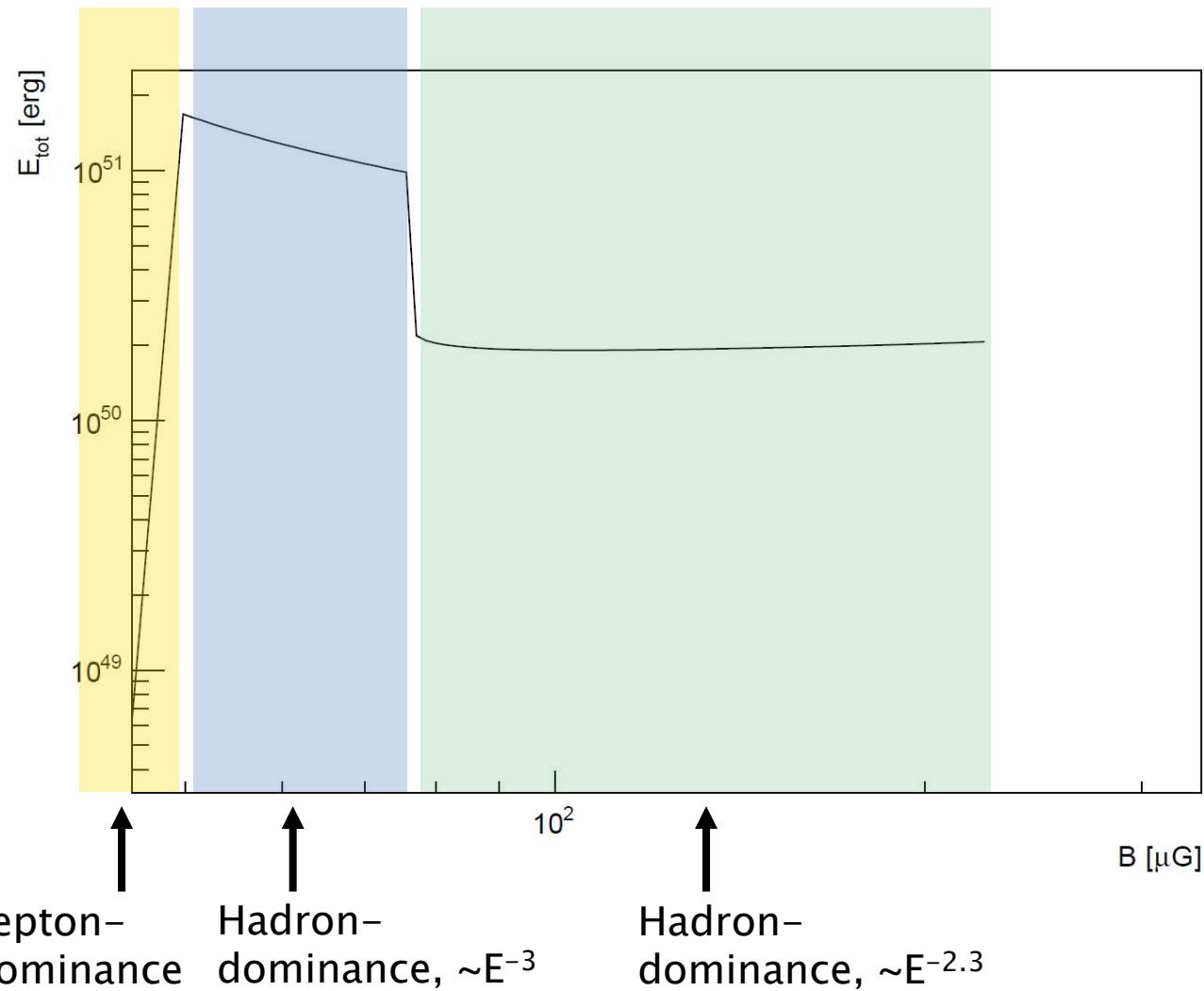
Summary

- Neutrino limits start to **constrain electron-proton ratio** in different source types
- **Galactic sources:** TeV supernova remnants should become visible within **a few years of IceCube/KM3NeT observation time**
- **Active Galactic Nuclei:** combination of hydrogen density and electron-proton ratio can be constrained → important for astrophysical processes
- **Gamma Ray Bursts:** IceCube starts to reach sensitivity to **seriously investigate GRBs as the sources of UHECRs**

Thank You!

Questions?

Tycho: total required energy



Propagation: Available information from observations

- Electron spectrum (ATIC, Fermi, H.E.S.S.) → **primary electrons from local sources**
- Radio haze (WMAP, PLANCK) → **Synchrotron radiation**
- Hadron spectrum and composition → **primary ions, deduction of diffusion coefficient**
- Hadron anisotropy (MILAGRO, TA, IceCube) → **combination of sources and magnetic field?**
- Positrons (PAMELA) → **hadronic interactions (local sources)**