IceCube neutrino results and its implications on astrophysical models

Juan A. Aguilar
for the IceCube collaboration

UNIVERSITÉ DE GENÈVE

Introduction

- Why neutrinos?
- Current results on point-sources of neutrinos.
- What can these limits tell us on astrophysical models?
  - Galactic sources: SNRs, mqrs.
  - Extra-Galactic sources: AGNs, GRBs
- Conclusions

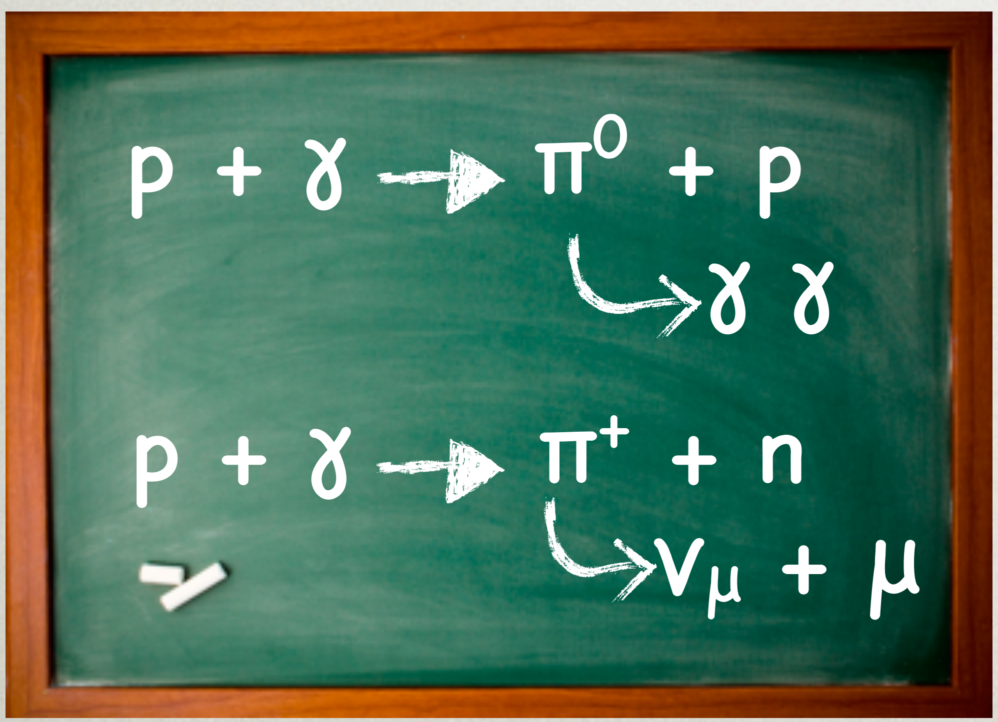
Disclaimer: I will focus on point-source results. I will not cover DM and cosmogenic neutrinos.

Why neutrinos?

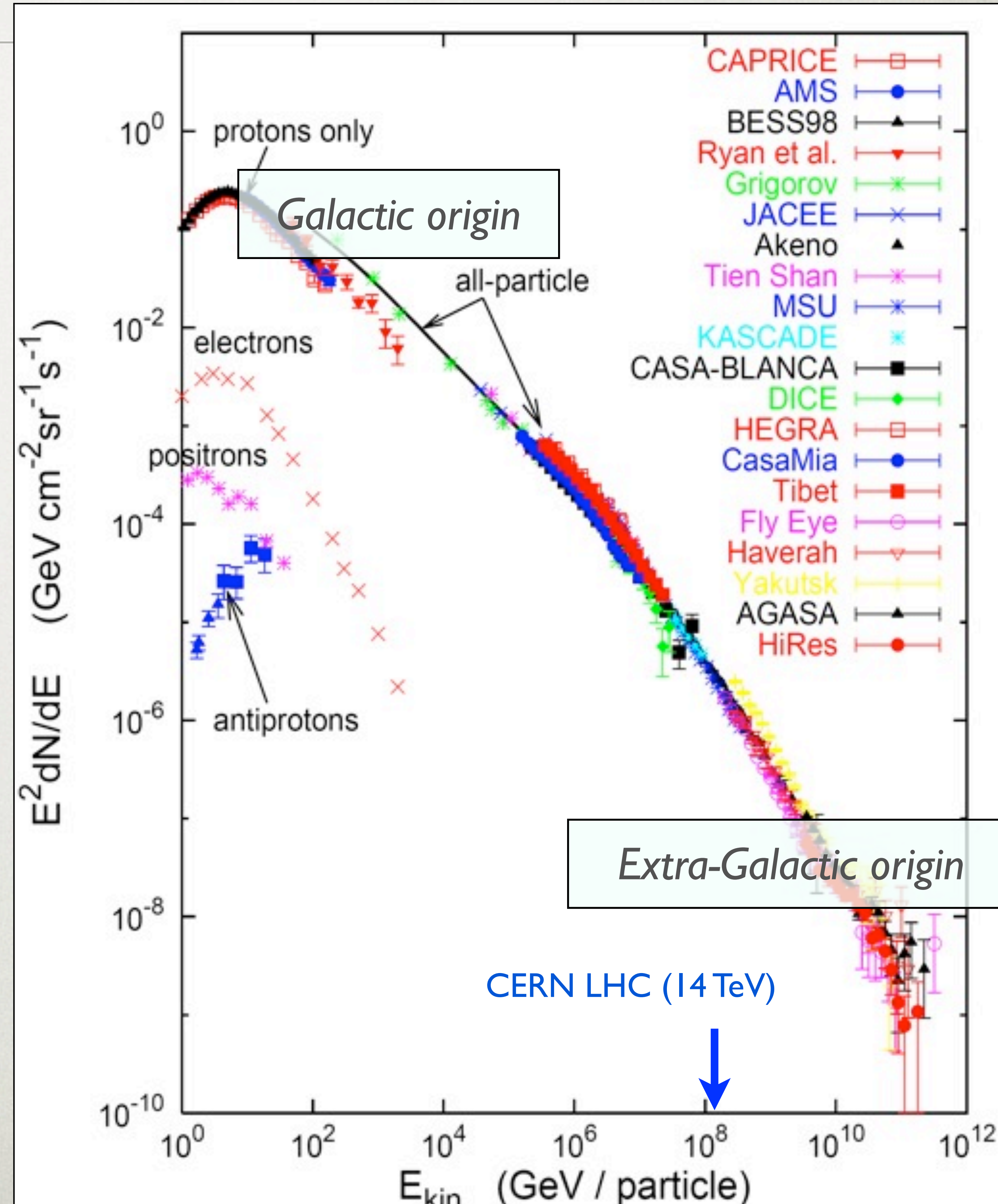
- Protons are deviated by magnetic fields ($E_p < 10^{19}$ eV) and very energetic protons travel distances of a few Mpc.
- Neutrons reach distances of ~kpc at very high energy.
- Photons interact with the EBL (~100 Mpc) and CMB (~10 kpc).
- Neutrinos are neutral, stable and weakly interacting particles.

Why neutrinos?

- Cosmic Rays spectrum spans 10 decades of energy. Origin still unknown.
- Galactic CRs: Supernova remnants*?
- Extra-Galactic CRs: AGNs, GRBs, magnetars?

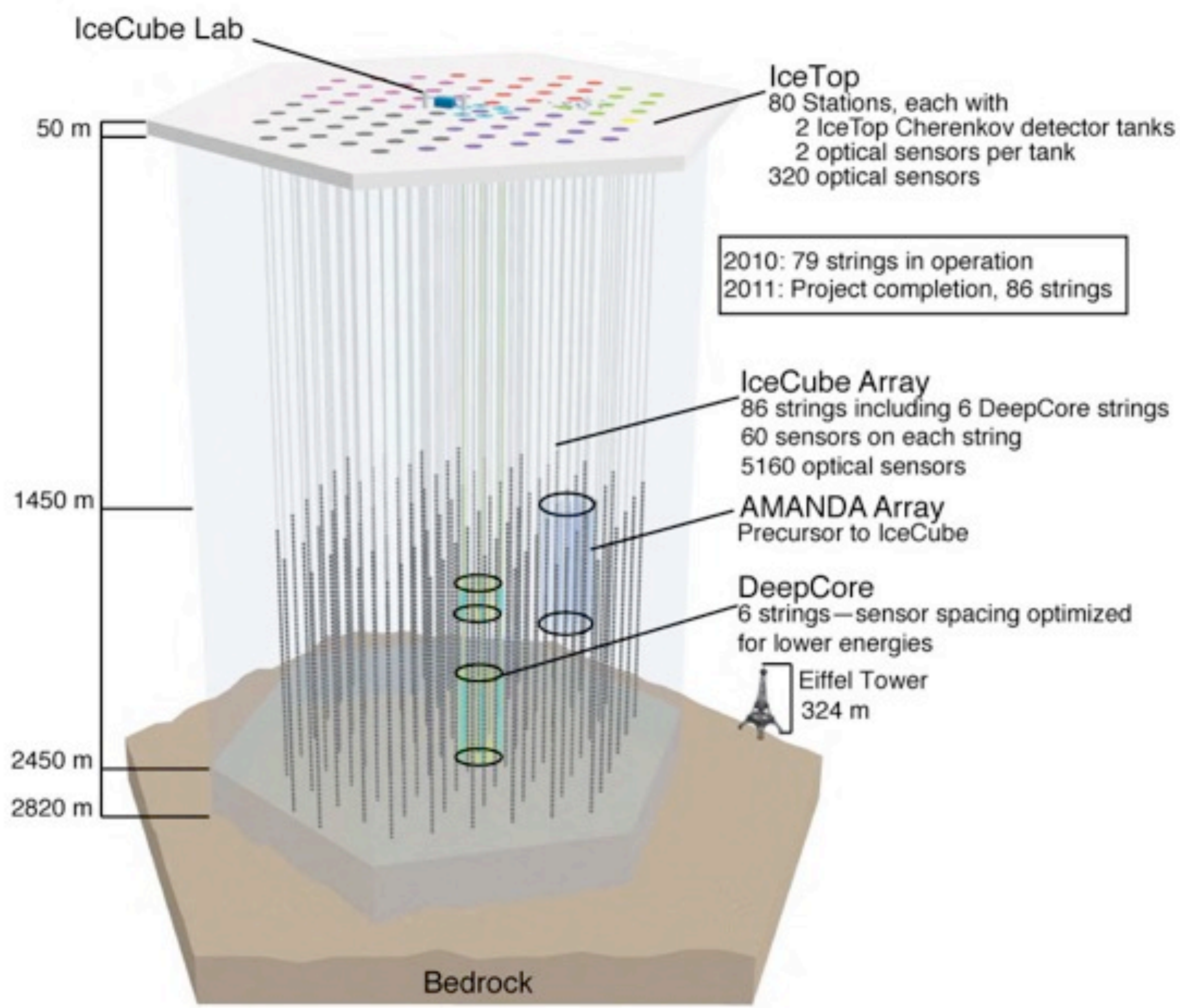


***Science 15 Feb 2013, Fermi finds the pions: evidence of proton acceleration**



IceCube

See talk from Albrecht Karle



CONSTRUCTION PHASES:

IceCube 40 (2008-9)

IceCube 59 (2009-10)

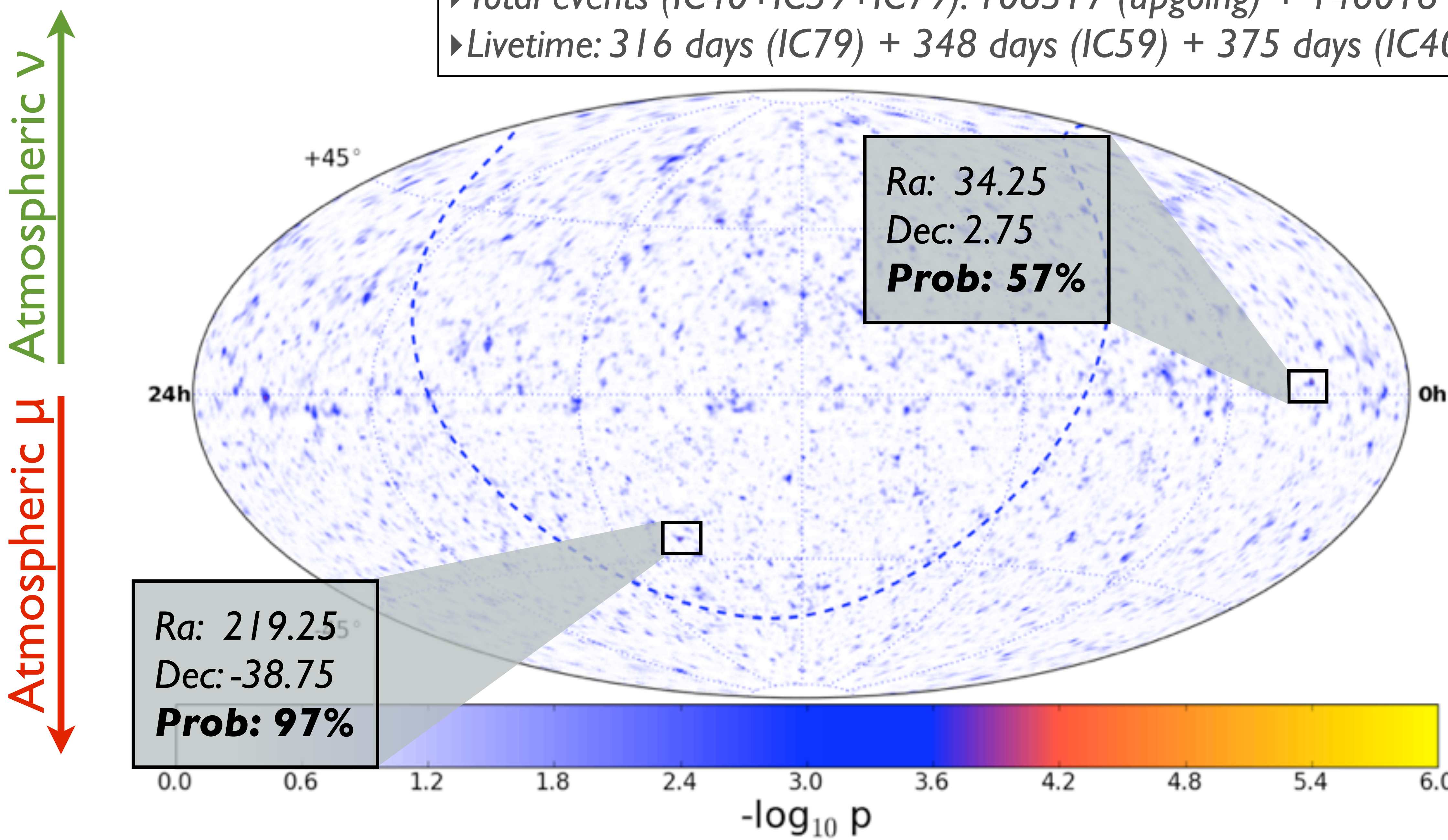
IceCube 79 (2010-11)

Most recent point-source results (data added to IC40+IC59).

Completion with 86 strings in December 2010.

Point Sources of Neutrinos

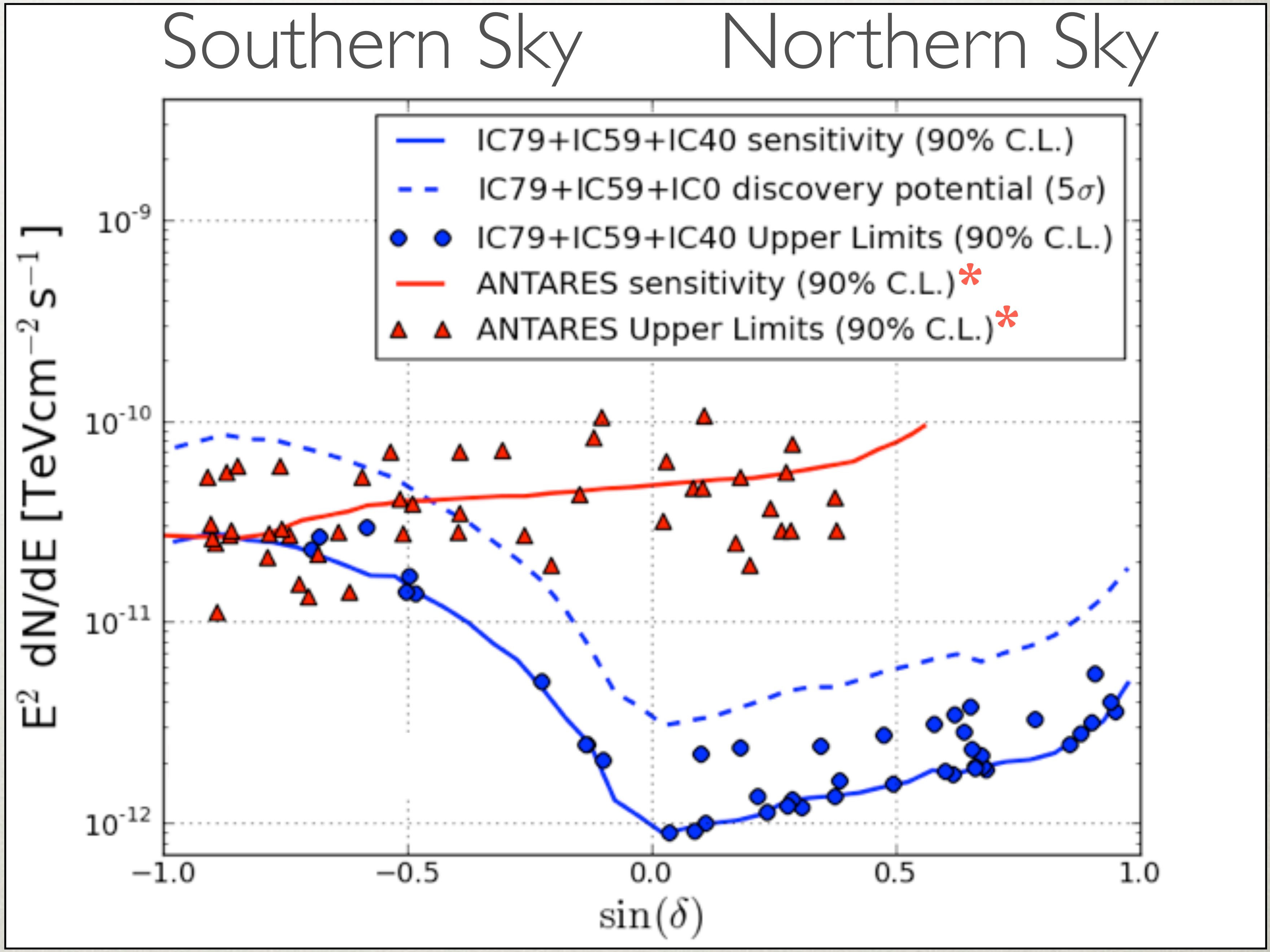
- *Total events (IC40+IC59+IC79): 108317 (upgoing) + 146018 (downgoing)*
- *Livetime: 316 days (IC79) + 348 days (IC59) + 375 days (IC40)*



- Post-trial p-values compatible with background fluctuations: No evidence of neutrino point-source found

E^{-2} Upper Limits

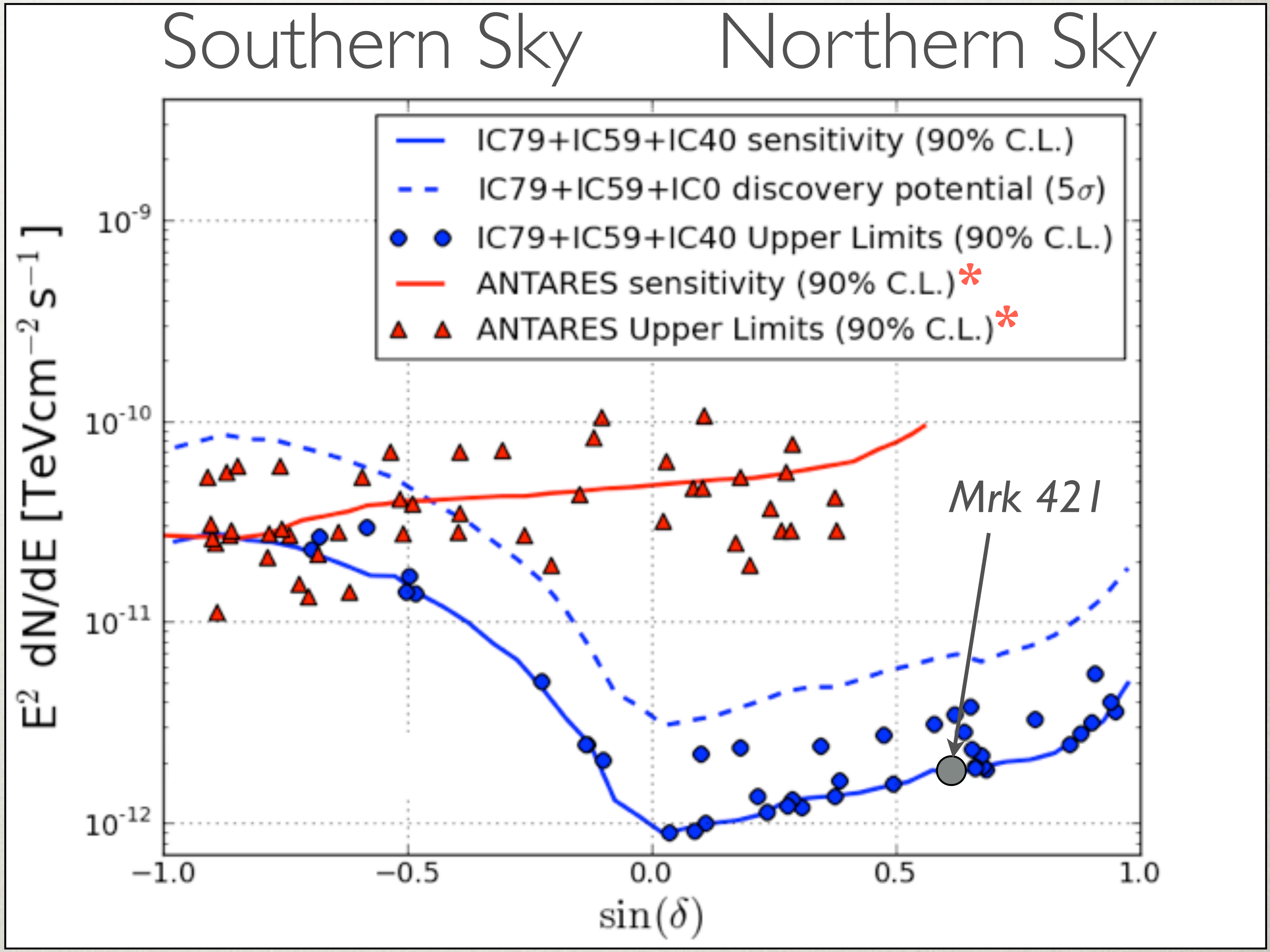
- Source list E^{-2} muon neutrino upper limits based on the classical (frequentist) construction of upper limits (Neyman 1937).
- IceCube sensitivity better than ANTARES almost every where in the sky. But in reality two very different energy regimes.



*S. Adrián-Martínez et al. Submitted to Astrop. J., arXiv:1207.3105

E^{-2} Upper Limits

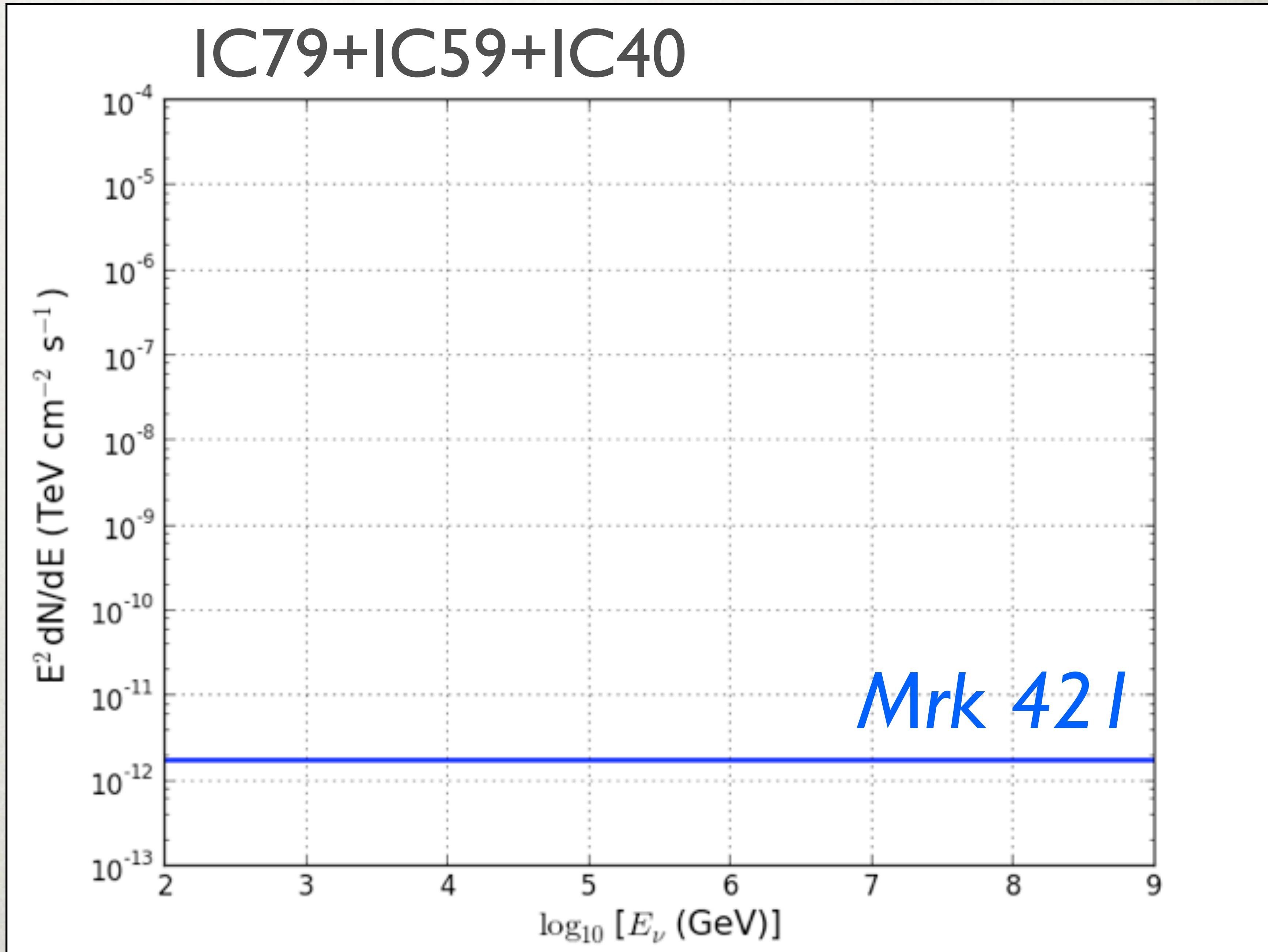
- Source list E^{-2} muon neutrino upper limits based on the classical (frequentist) construction of upper limits (Neyman 1937).
- IceCube sensitivity better than ANTARES almost every where in the sky. But in reality two very different energy regimes.



*S. Adrián-Martínez et al. Submitted to Astrop. J., arXiv:1207.3105

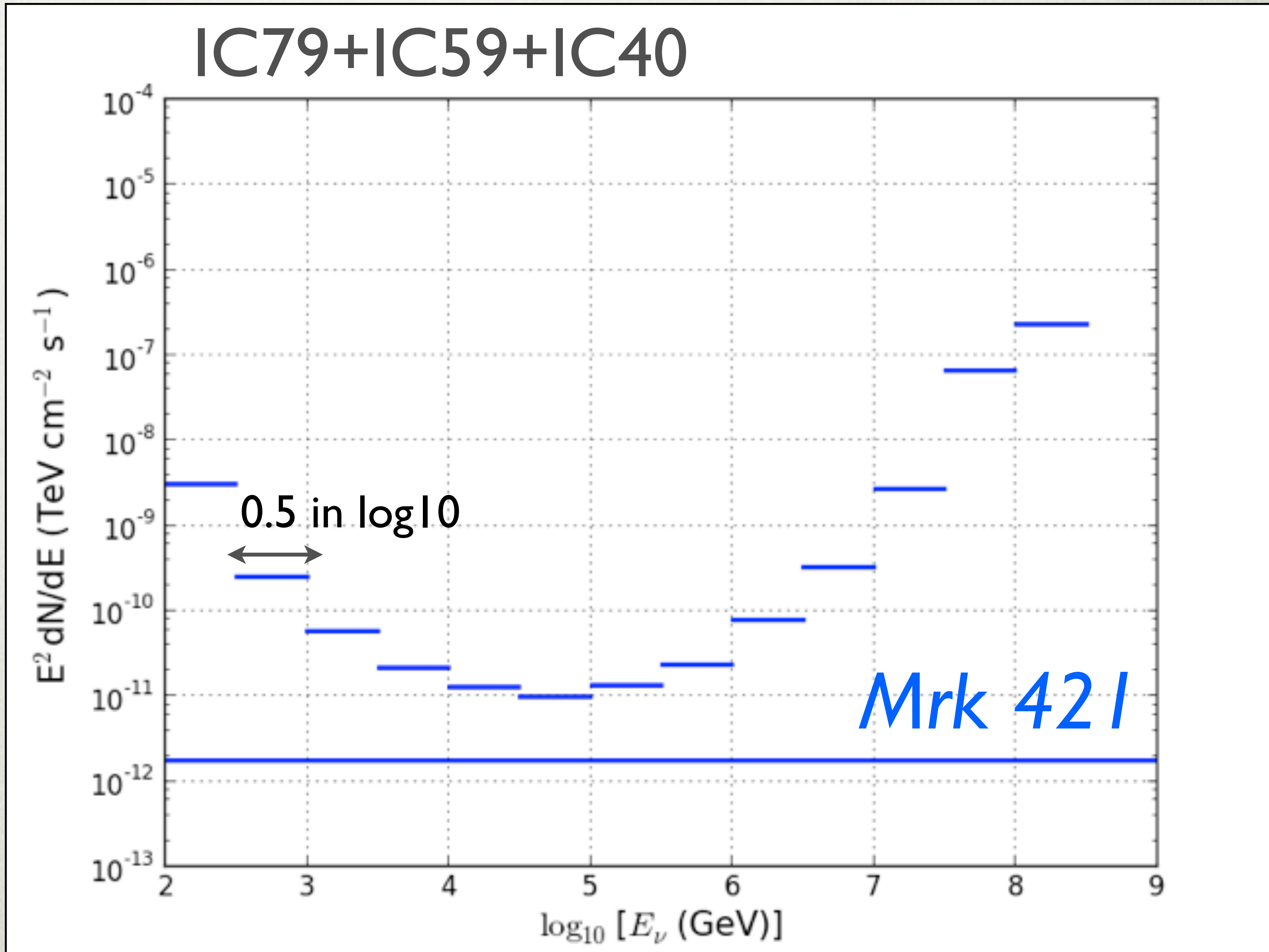
Differential Upper Limits

- Unbroken E^{-2} power law limits as function of energy.



Differential Upper Limits

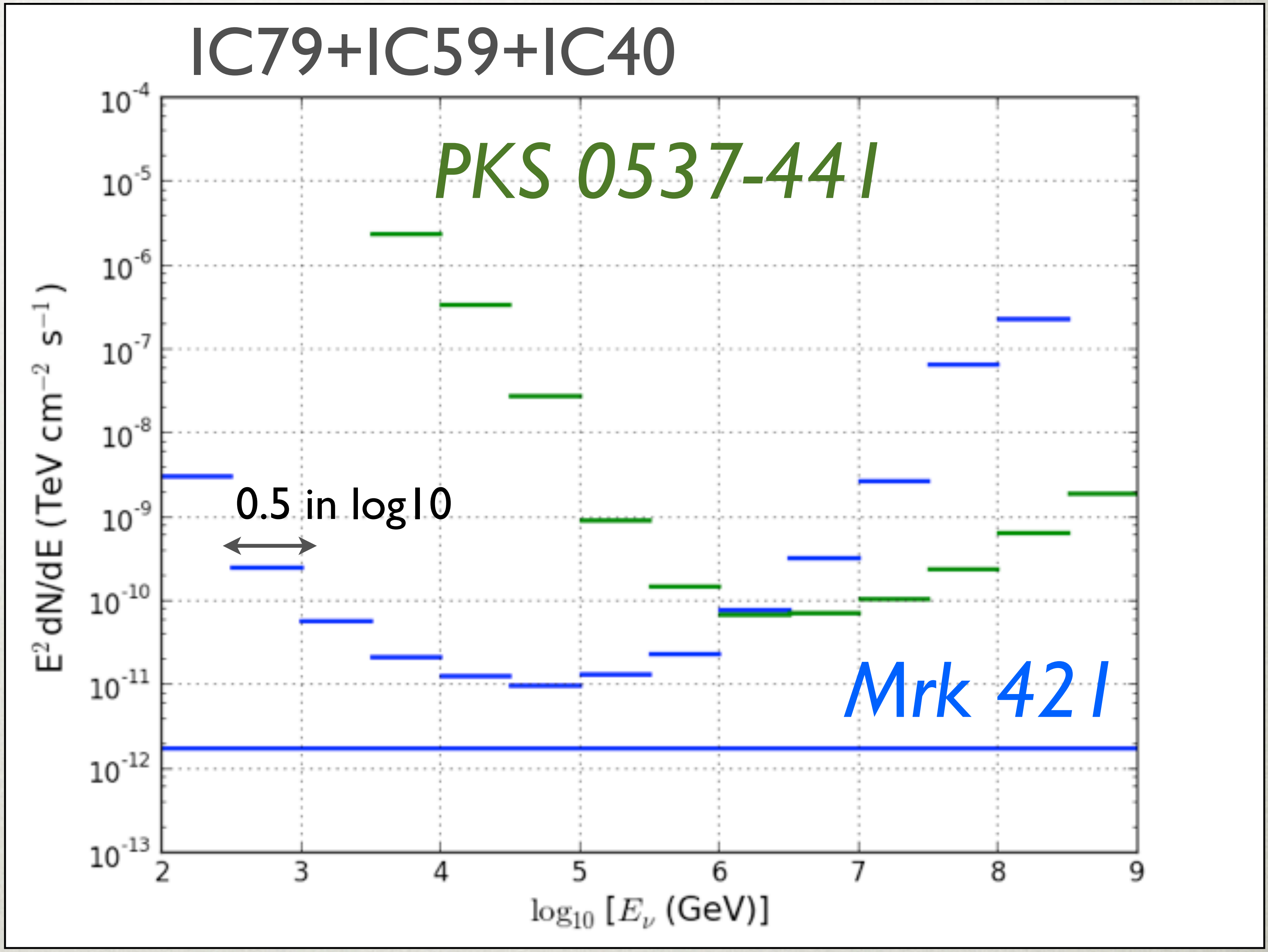
- Unbroken E^{-2} power law limits as function of energy.
- Minimum of the sensitivity depends on **declination**.
- For this particular location (Mrk 421) IceCube is more sensitive between *10 - 100 TeV*.



miércoles, 20 de marzo de 13

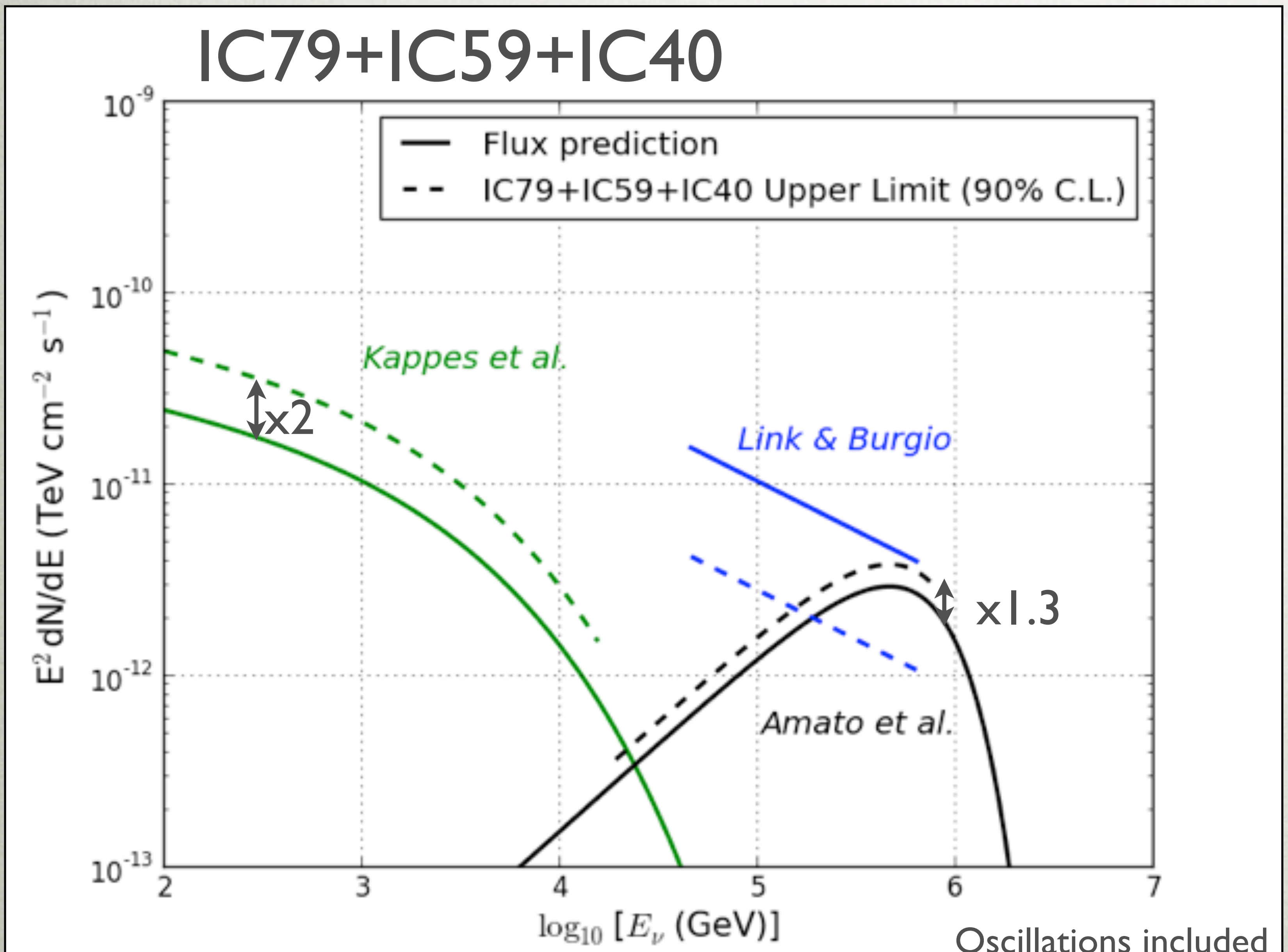
Differential Upper Limits

- Unbroken E^{-2} power law limits as function of energy.
- Minimum of the sensitivity depends on **declination**.
- For this particular location (Mrk 421) IceCube is more sensitive between *10 - 100 TeV*.



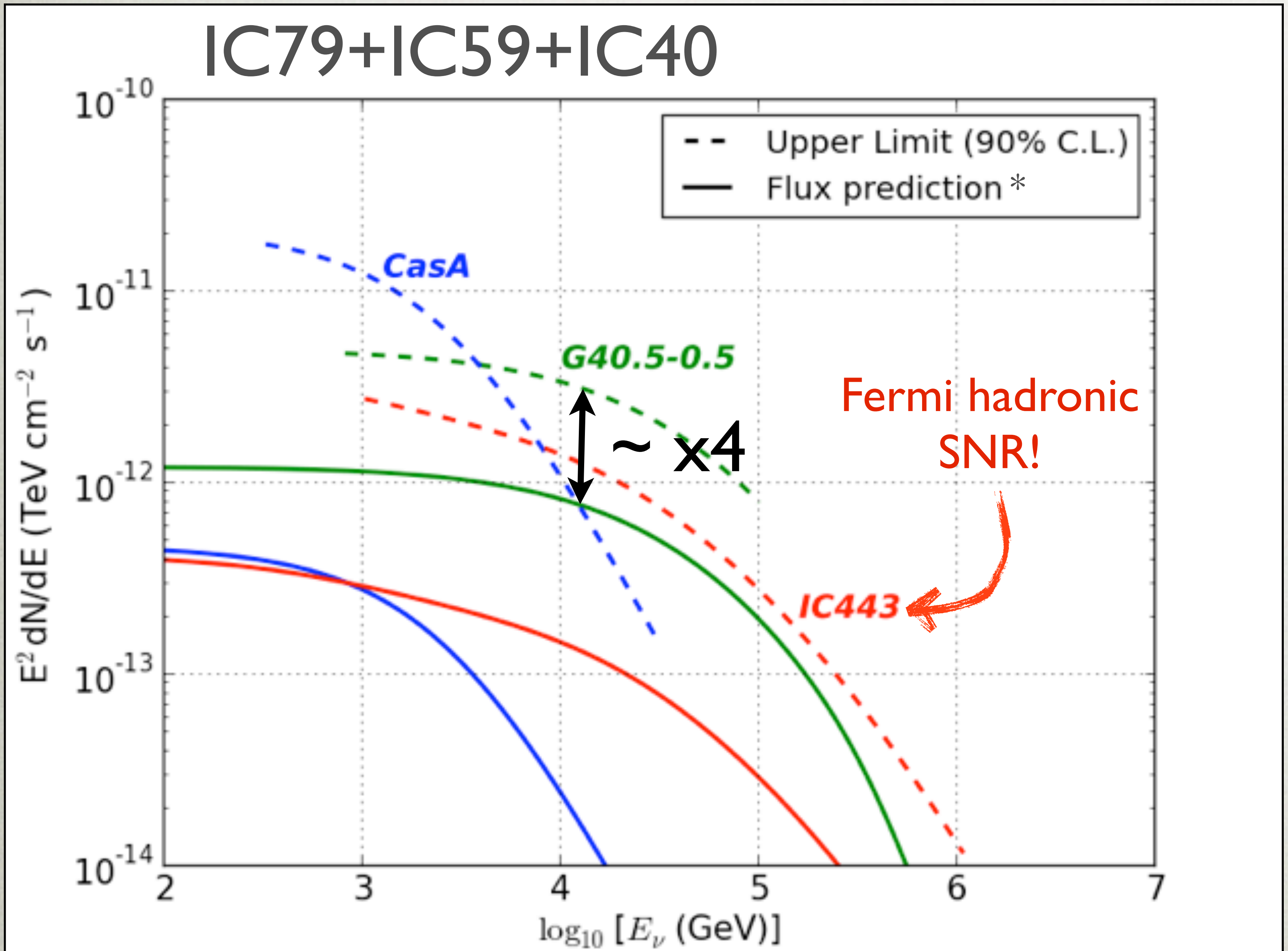
Galactic sources: The Crab

- The Crab is regarded as mainly leptonic, but past gamma-ray flares up to TeV energies challenged these theories.



- Link & Burgio (2006): ions accelerated to Δ threshold with linearly increasing E-field with height above n star surface. (Rejected > 90% C.L.)
- Amato et al. (2003): close to exclude most optimistic models with wind Lorentz Factor (10^7)
- Kappes et al. (2007): neutrino from fitted H.E.S.S. spectrum.

Galactic sources: Other SNRs

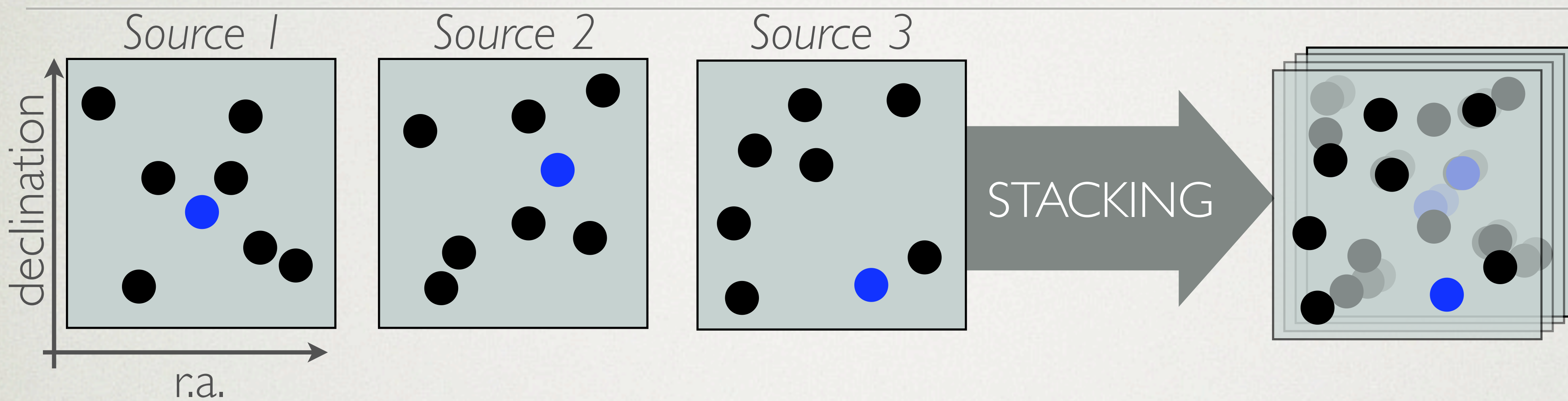


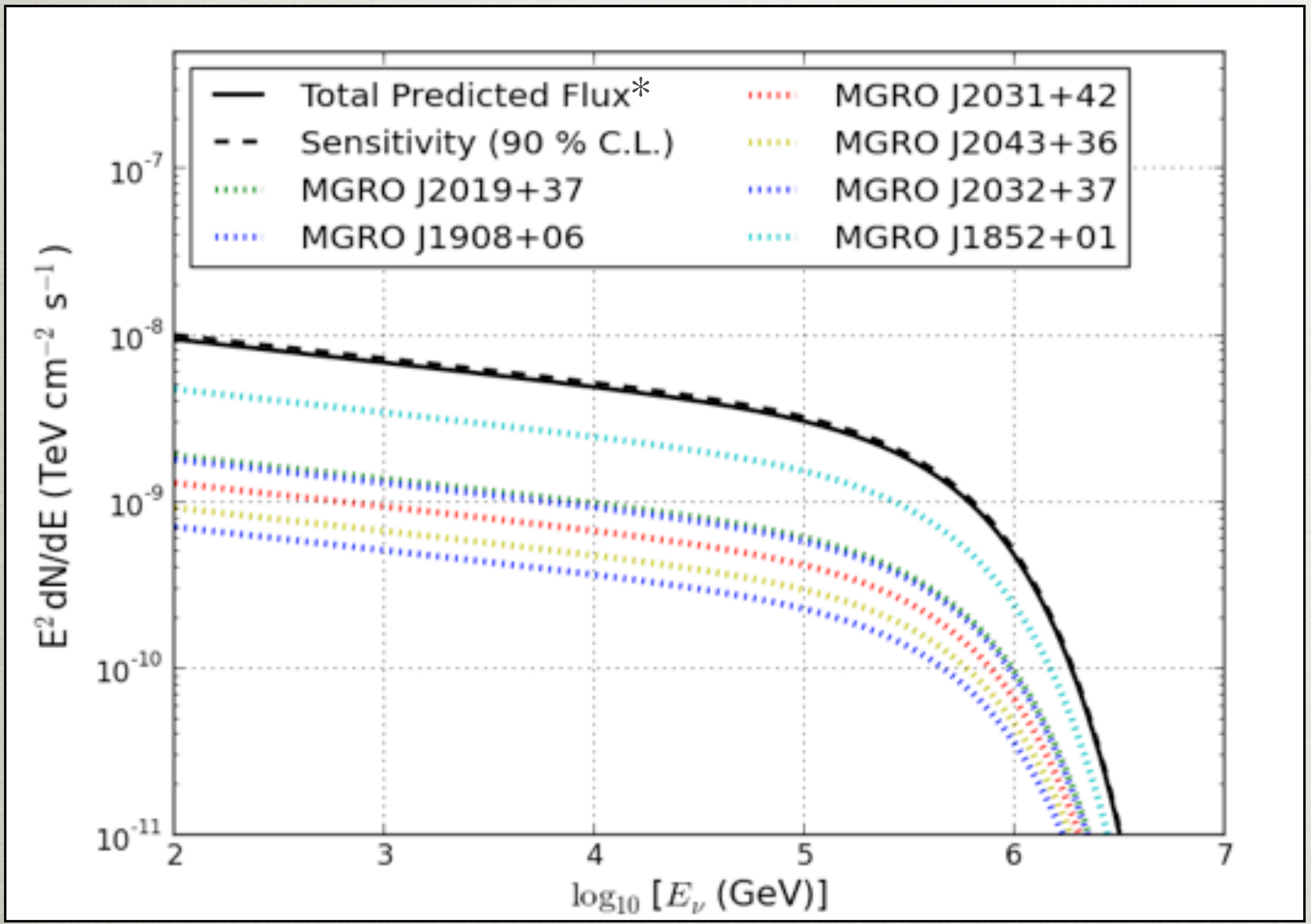
*M. Mandelartz, J. Becker Tjus. http://arxiv.org/abs/1301.2437

- Still a bit far to exclude/detect SNRs (factor ~ 4).
- But, cut-off energies imposed by assuming SNR as sources of CR up the *knee*. Limits without cut-off closer to models.

miércoles, 20 de marzo de 13

Galactic sources: Stacking signal

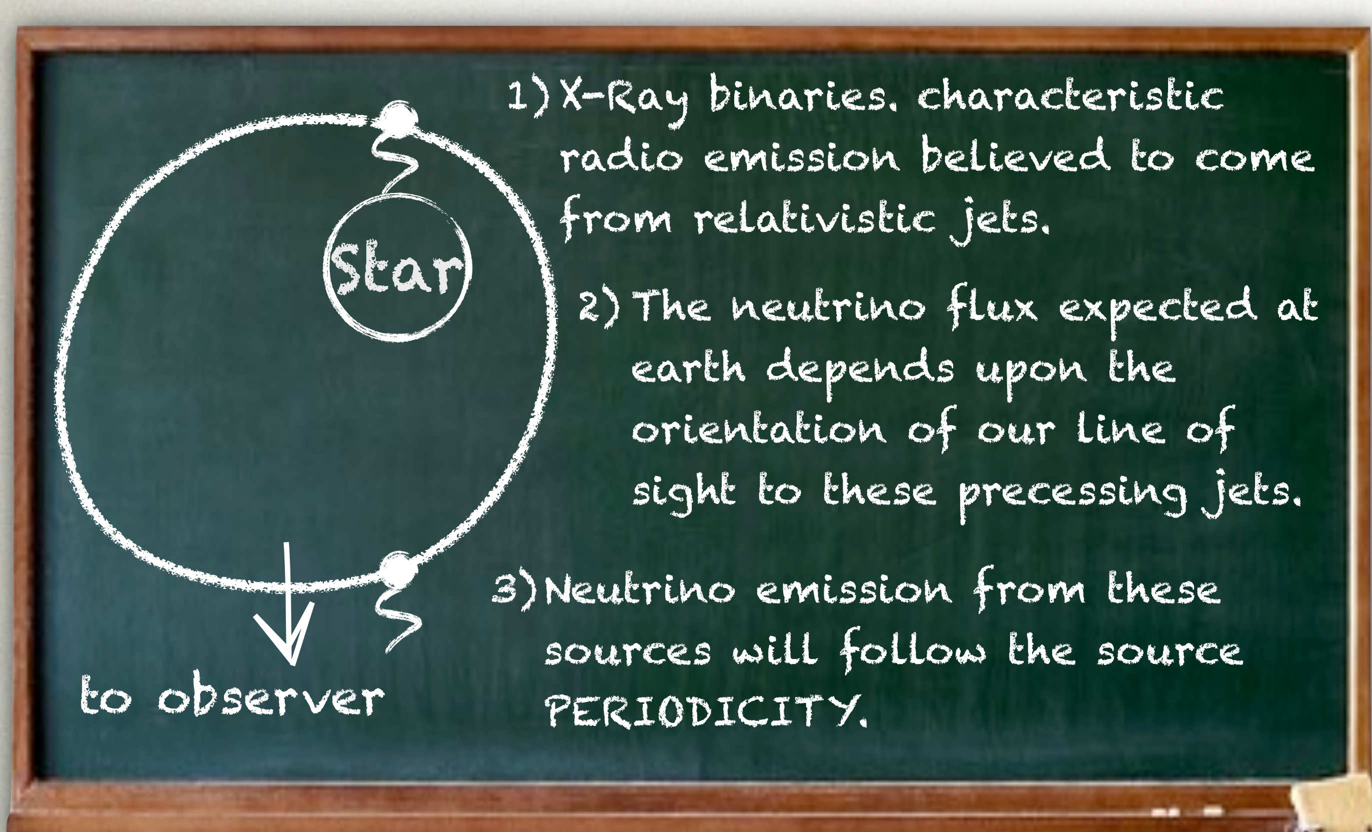




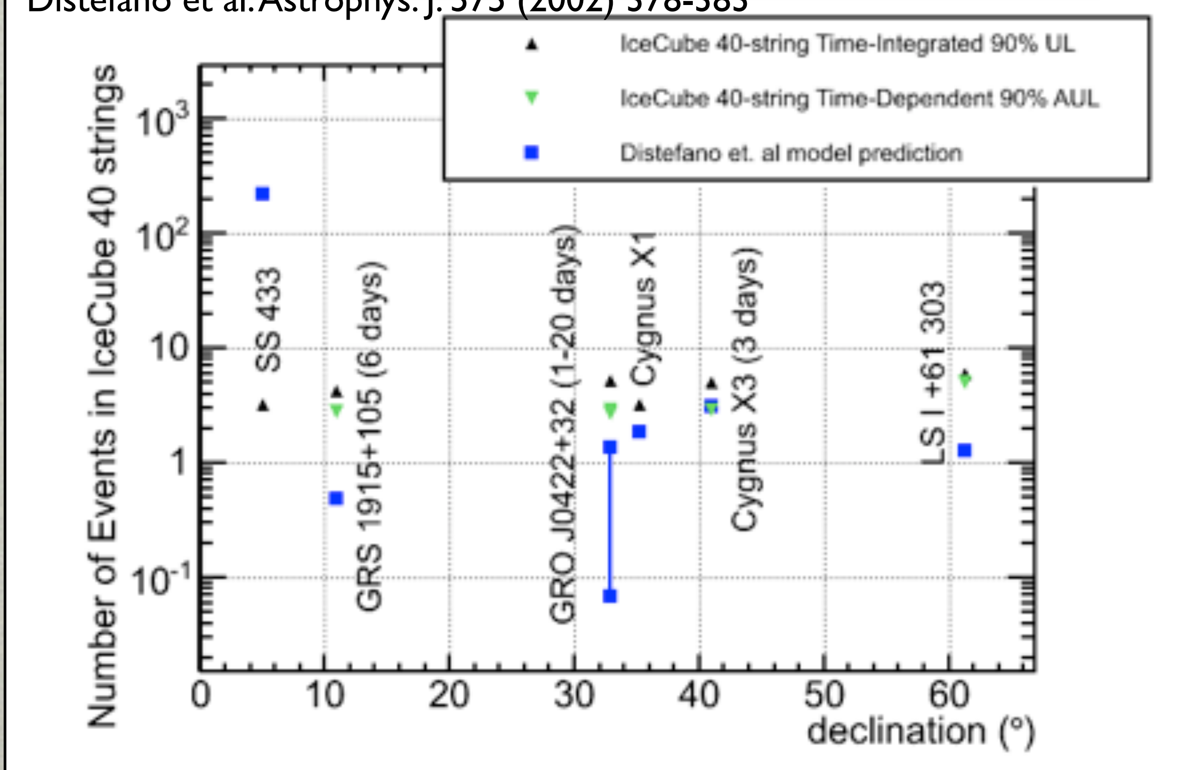
- 6 TeV associations with supernova remnants based on Milagro observations. Models from Halzen et al.
- Model at the level to be excluded at 90% C.L.
- CAVEAT: Model assumed higher energy gamma-ray cut-offs.

*F. Halzen, A. Kappes and A. O'Murchadha (Phys. Rev. D78:063004, 2008)

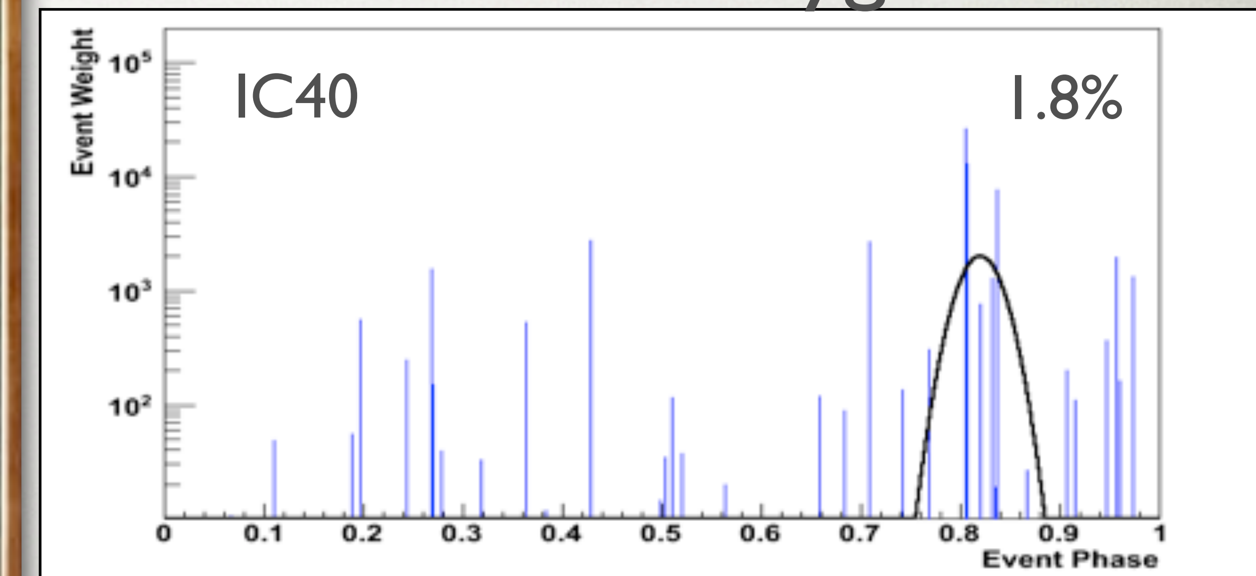
Galactic sources: mqso

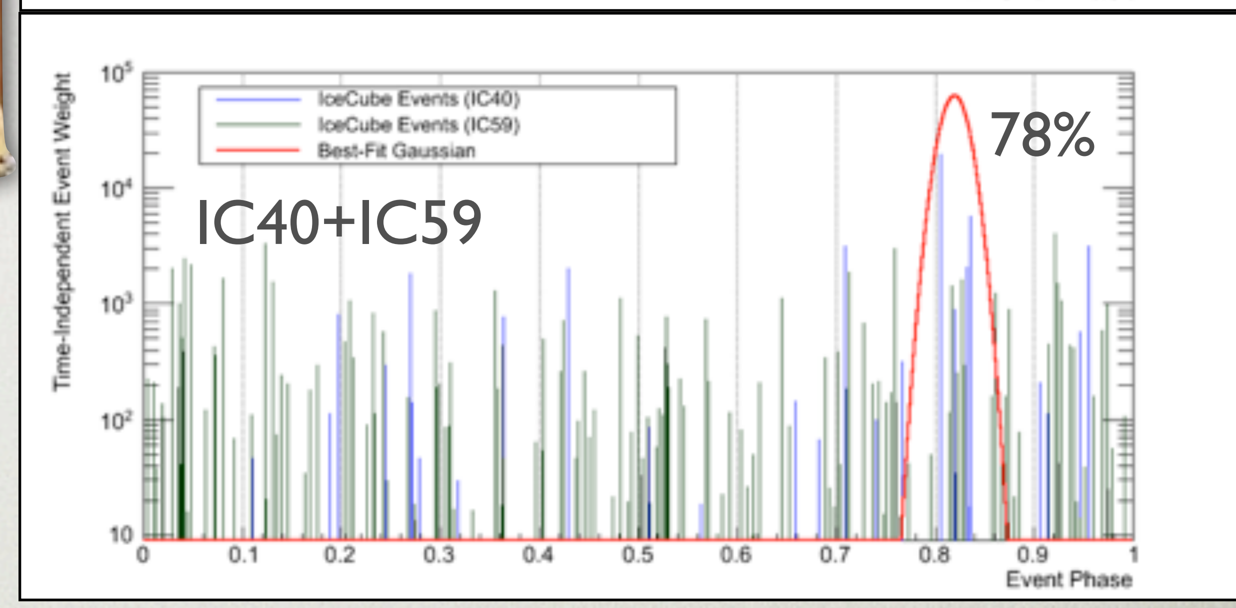


Distefano et al. Astrophys. J. 575 (2002) 378-383



Hottest source: Cygnus X-3



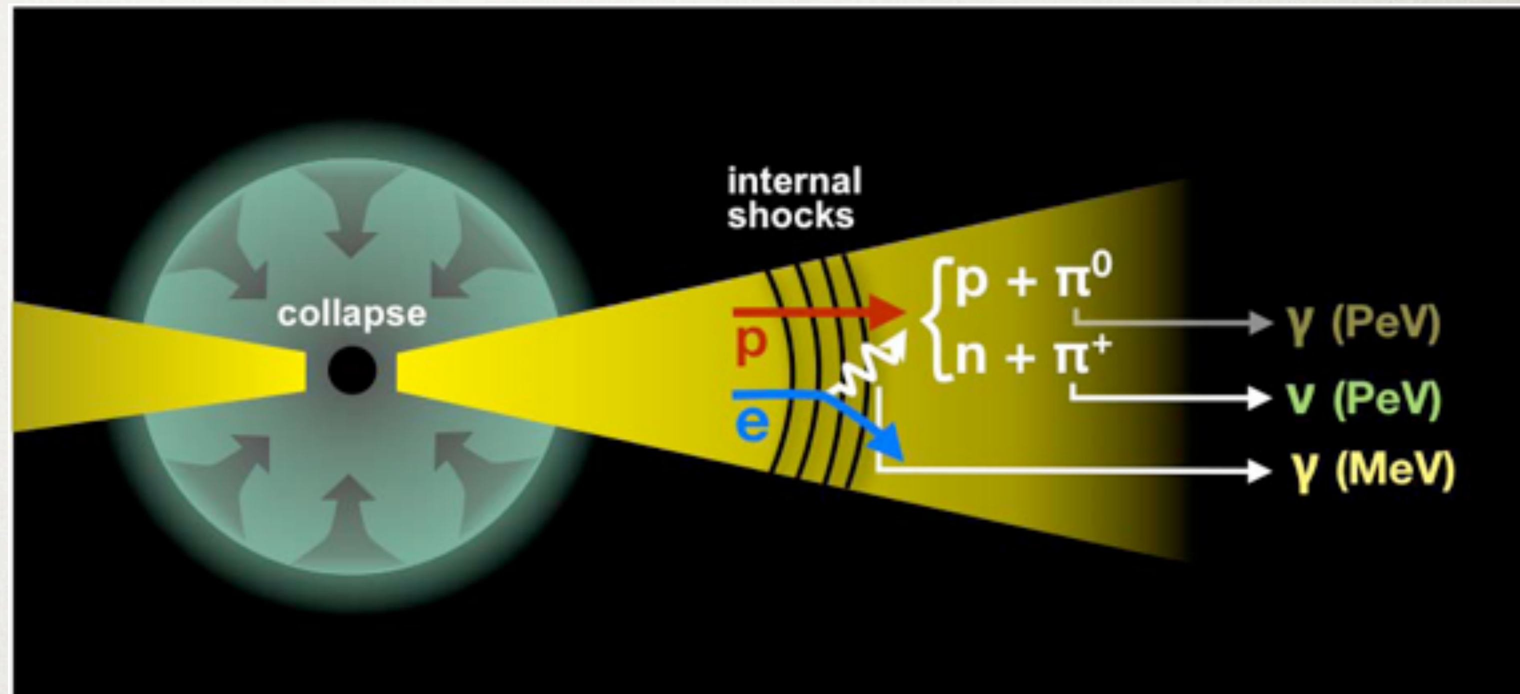


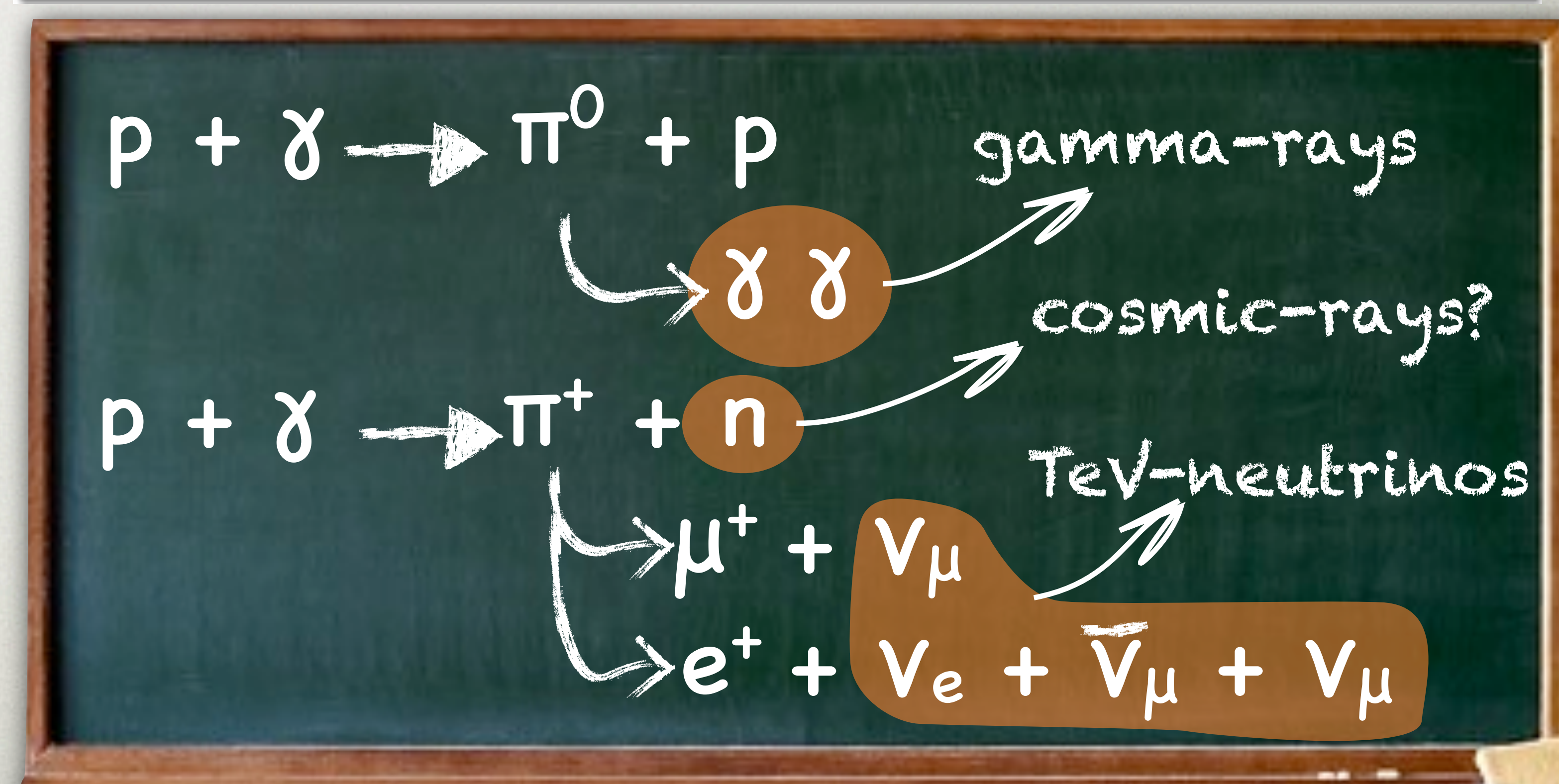
IC40+IC59+IC79 pending to be unblinding!

Extra-Galactic sources: GRBs

<u>Fireball model:</u>

- Internal shocks as fireball expands, accelerate particles via Fermi mechanism.
- High energy protons and photons in the expanding fireball interact.
- Photo–pion production leads to neutrinos via pion decay, muon decay.



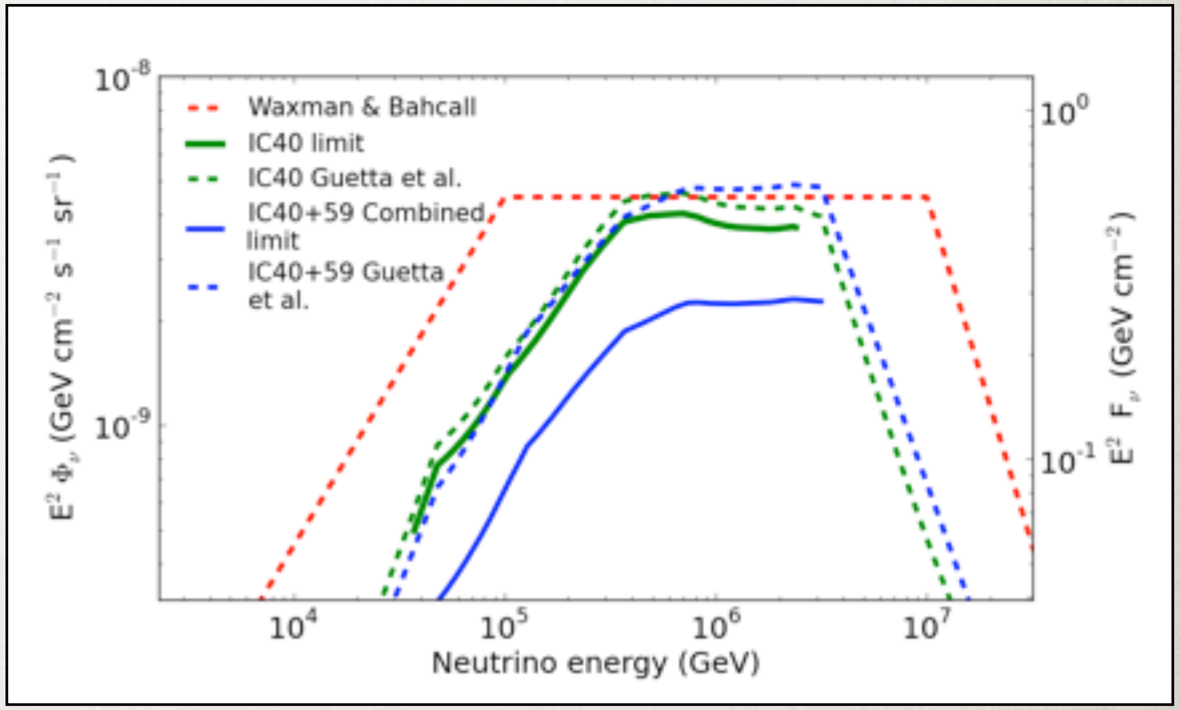


TWO ANALYSIS:
-Model-Dependent (most sensitive is model is right)
-Model-Independent (*catch-all* analysis)

Extra-Galactic sources: GRB results

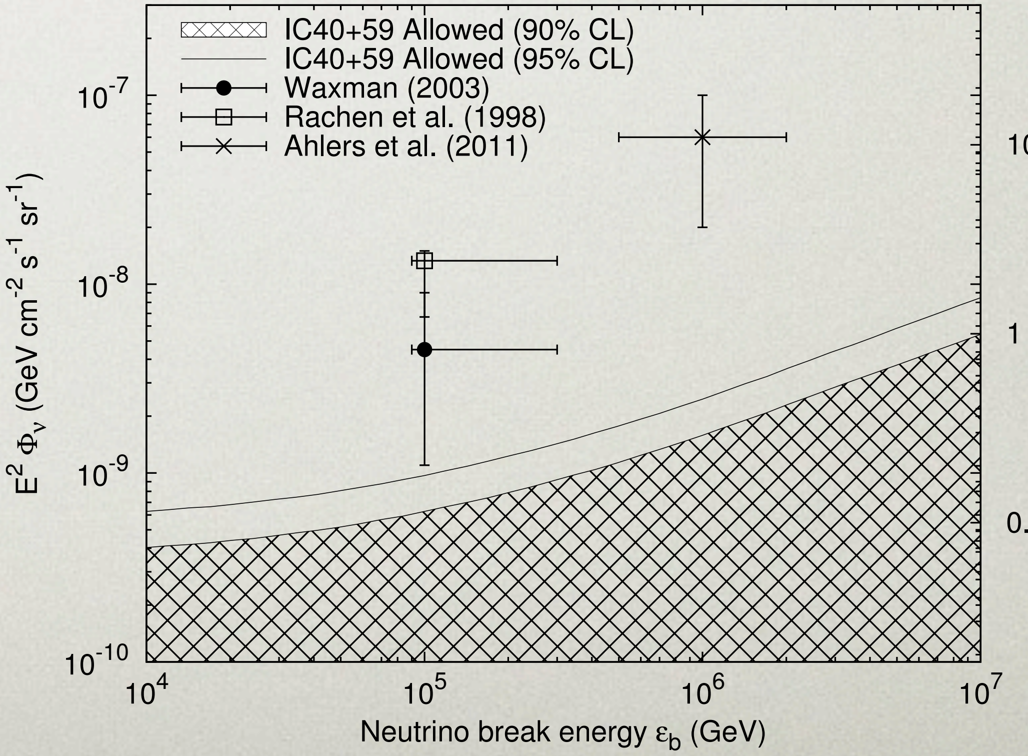
Model-Dependent

- Prediction: 5.2 events (Guetta et al.)
- Results: 0 events (No events within time-window and 10° of GRB position) Upper limit ~ 2.44 events excluded at 90% C.L.



Model-Independent

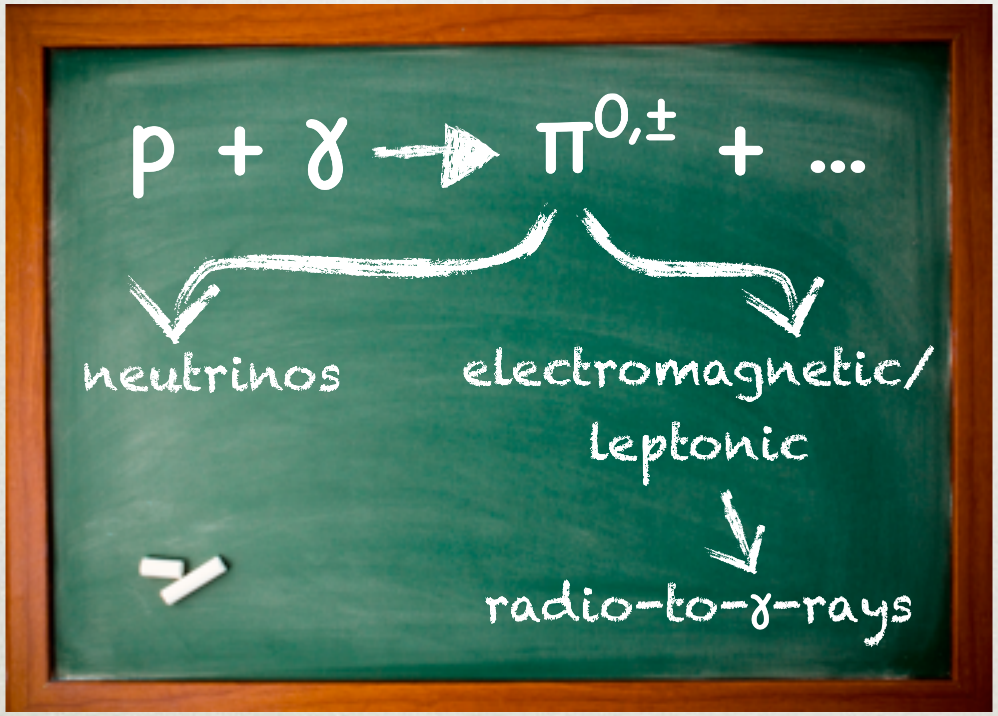
- Two low significant events found
- Leading models for neutrinos associated with ultra-high-energy cosmic rays in gamma-ray bursts excluded
- GRB not (only) sources of CR?

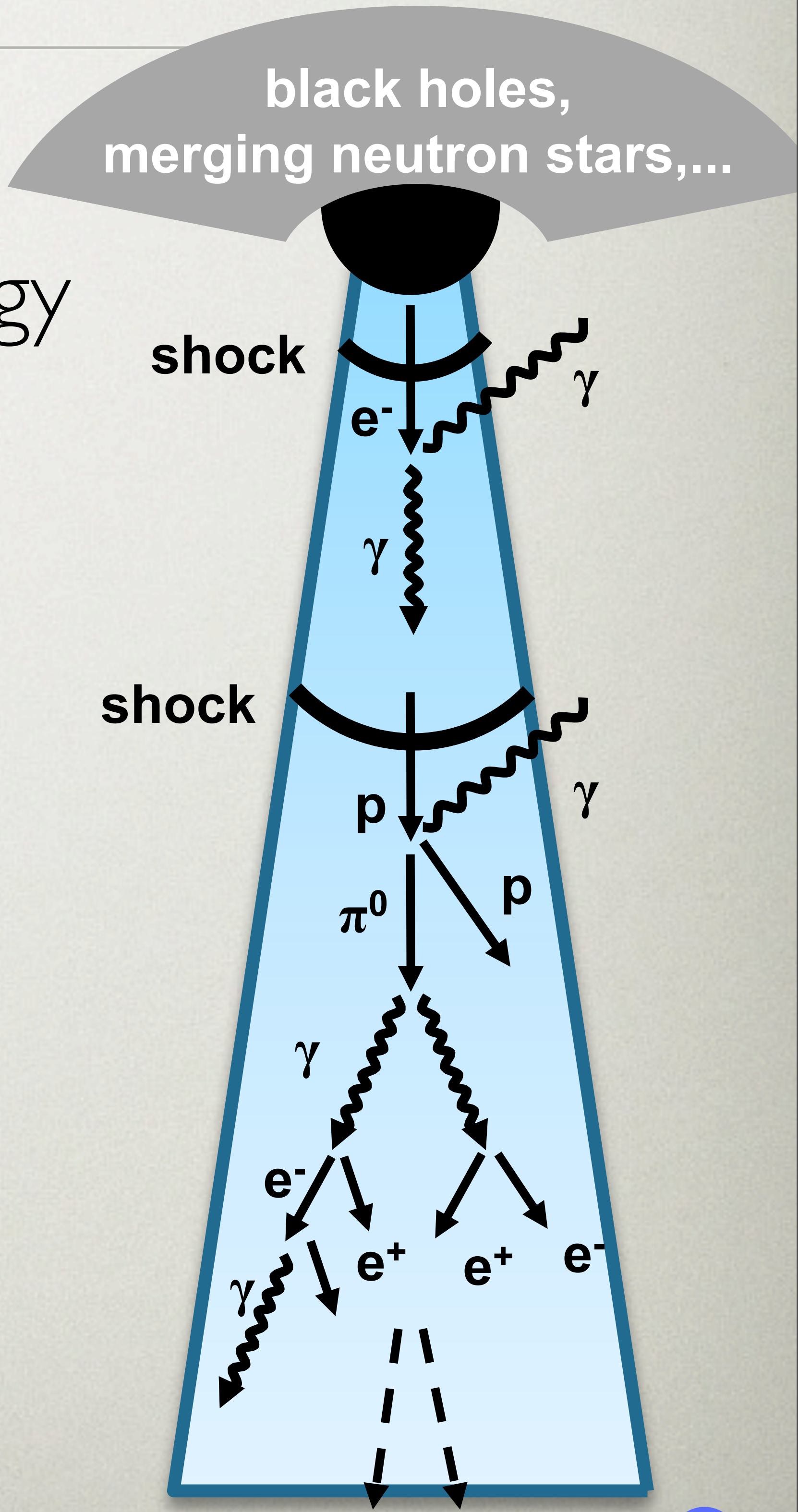


Nature, Vol. 484, 351 (2012)

Extra-Galactic sources: AGNs

- In AGNs protons are probably accelerated together with electrons. They will loose energy in pp and pγ interactions or synchrotron emission.





- The power is distributed between neutrinos and radio-to-γ-rays emission.

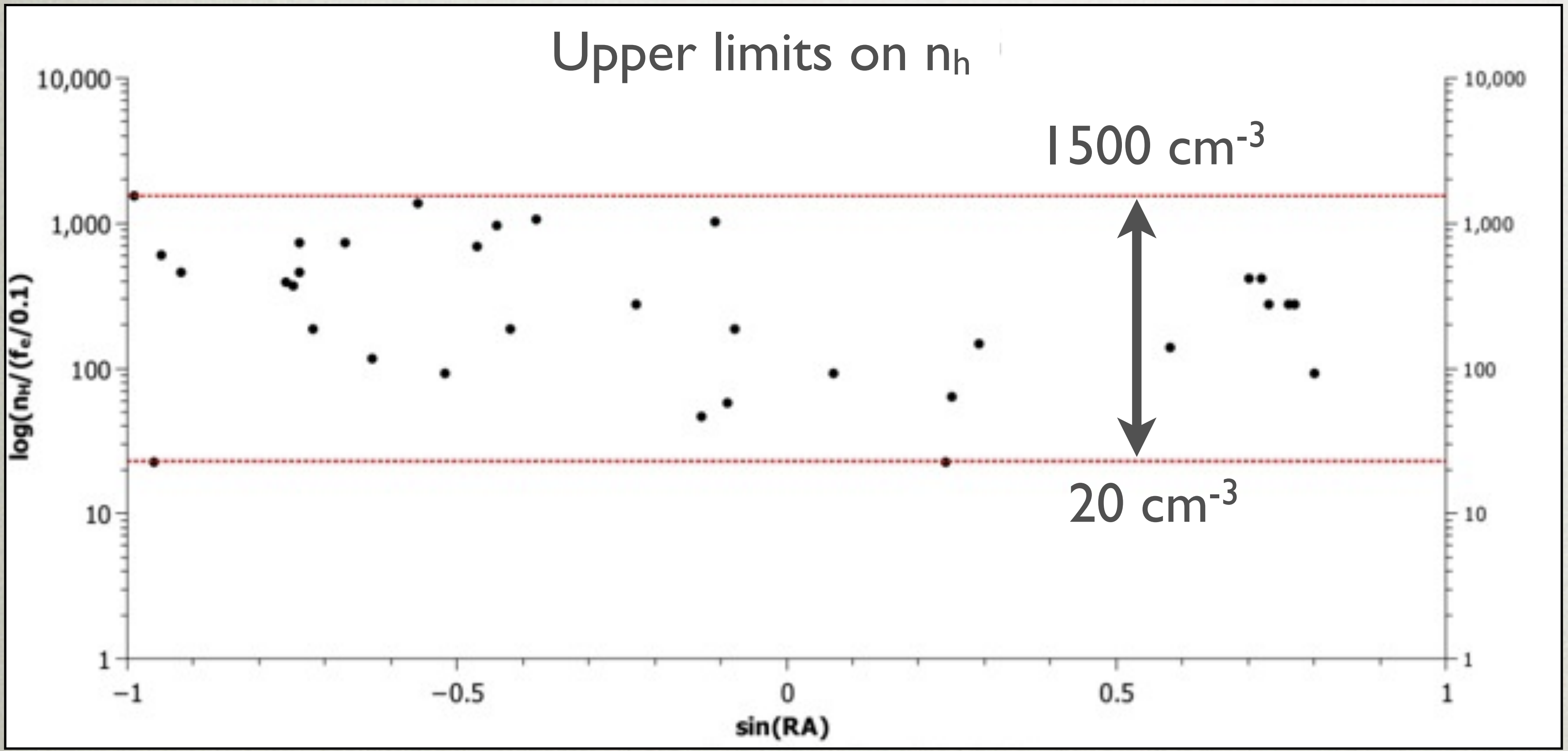
pp interactions (FR-I galaxies)

$$p + p \rightarrow \pi^{[\pm,0]} + X \qquad E_{th} = m_p + m_\pi(m_\pi + 4m_p)/2m_p \approx 1.2\ \text{GeV}$$

ν follow parent proton spectrum

- Main parameters are the target density n_H and ratio electrons-to-protons f_e
- Primary e^+e^- responsible of radio emission by synchrotron emission.

$$\mathcal{L}_e = \mathcal{L}_{radio} = f_e \cdot \mathcal{L}_p$$

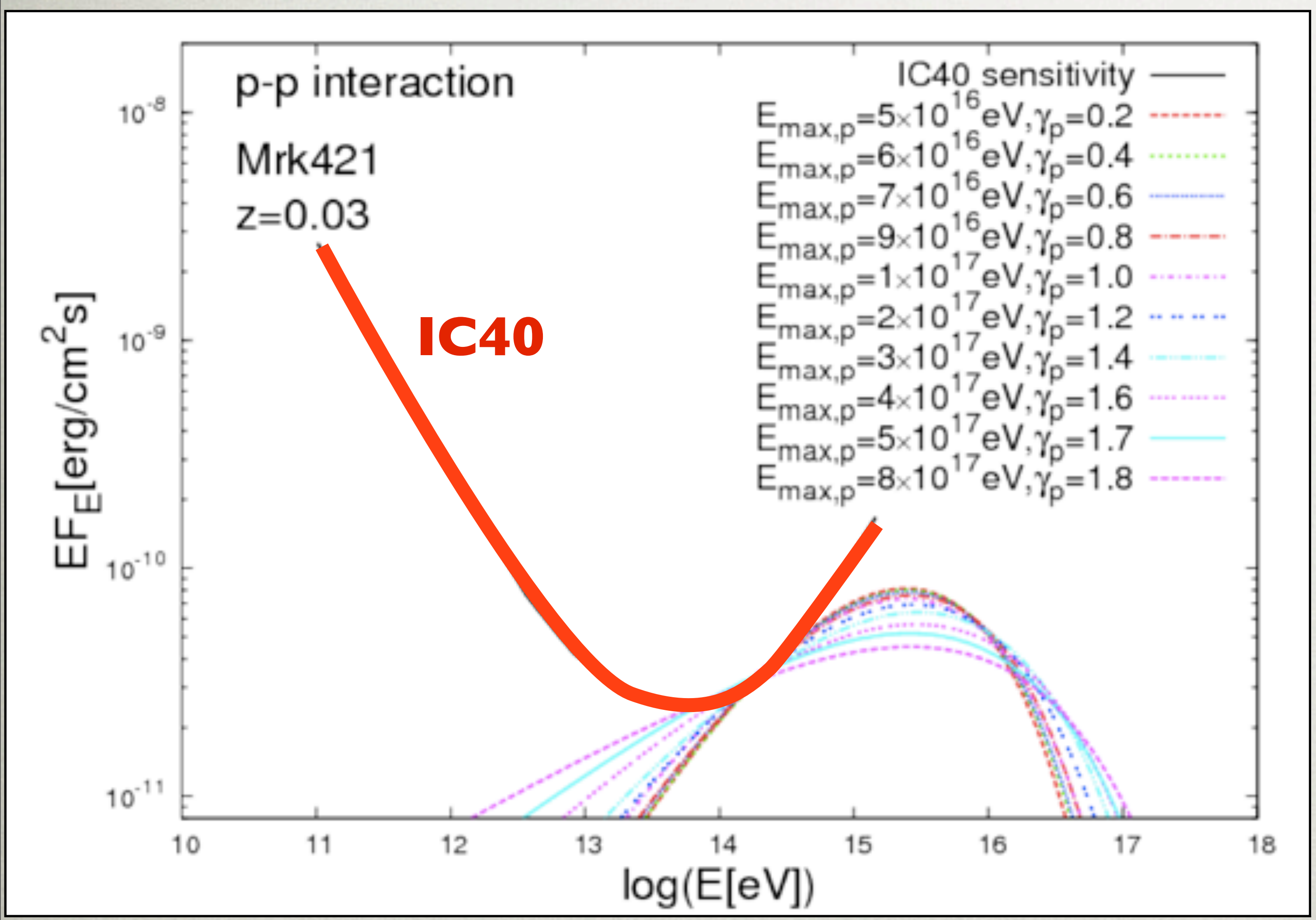


I. Saba, J. Becker Tjus & F. Halzen http://arxiv.org/abs/1302.1015

- Target density for a constant ratio $f_e = 0.1$
- Neutrino flux normalized to IceCube IC40 upper limits (E^{-2}).

pp interactions (Blazars)

- Simplest proton spectrum with free normalization, E_{cut} and spectral index: $$\frac{dN_p}{dE_p} = A \cdot E^{-\gamma} \exp(E/E_{cut})$$ Kelner et al, PHYSICAL REVIEW D 74, 034018 (2006)

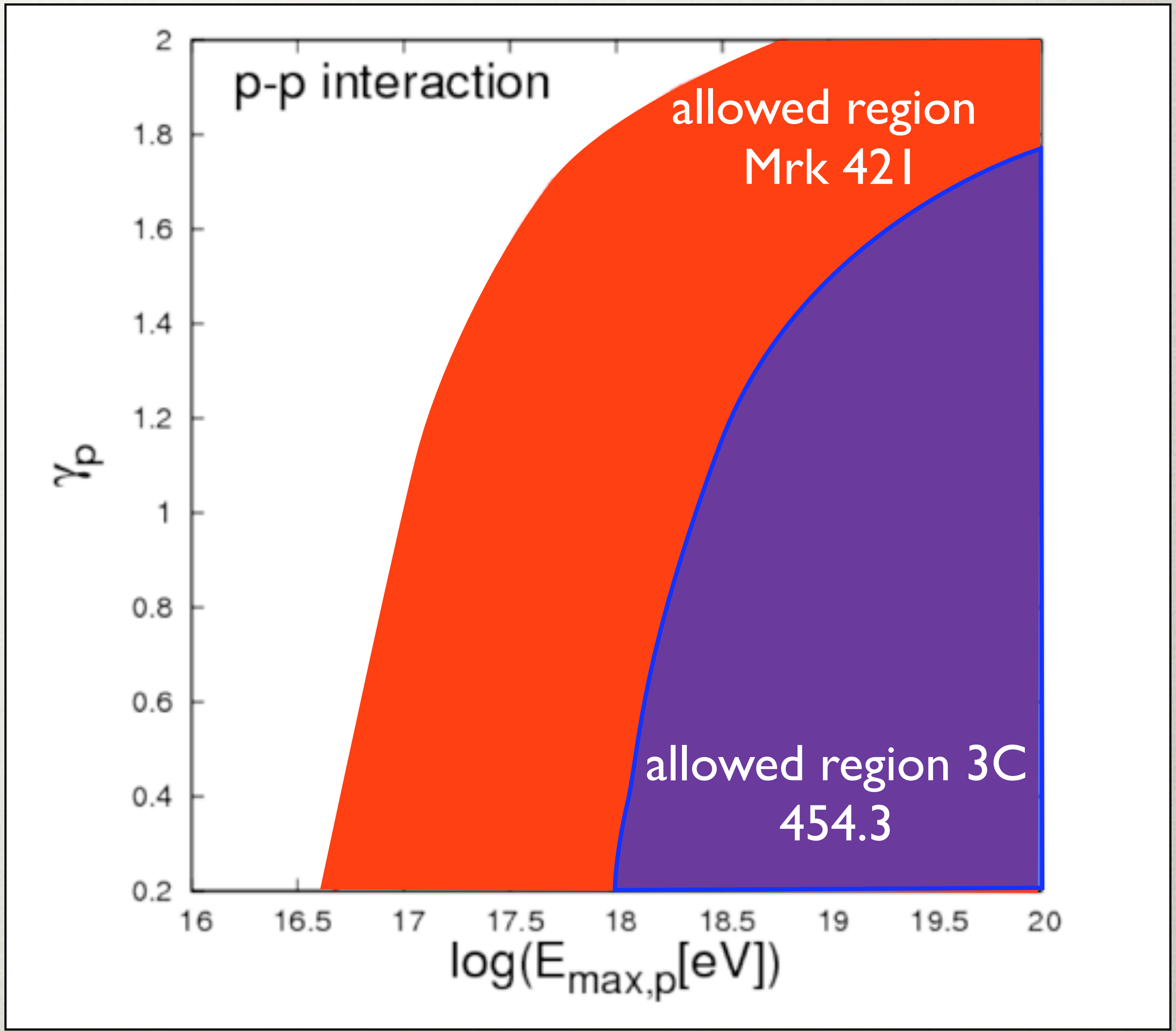


- Calculate the nu-flux and normalize it to the *Fermi* total energy flux.
- Scan the parameter space (γ_p, E_{cut}) that yields neutrino fluxes below IC40 sensitivity for that source.

C. Tchermin, J. A. Aguilar, A. Neronov & T. Montaruli
Submitted to A&A

pp interactions: exclusion

- The tightest constrains obtained for brightest Northern Hemisphere blazars (3C 454.3).
- But some assumptions have been made:
  - purely hadronic model (all em. power comes from pp interaction).
  - Gamma-ray emission from induced Compton emission.



C. Tchermin, J. A. Aguilar, A. Neronov & T. Montaruli
Submitted to A&A

Conclusions

- ***No evidence of a neutrino point source*** has been found in the combination of 3 datasets: IC79+IC59+IC40

- Individual SNR are still difficult to detect with IceCube but different analysis techniques such as stacking should be able to bring down the sensitivity to the flux prediction level.

- The absence of signal from GRBs challenges the idea of GRBs as the only responsible of UHECR.

- Some parameter space of models from AGN CR acceleration can be constrained based on current limits (under some assumptions)