High Energy Gamma Ray and Neutrino Astronomy

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How Is This Talk Topic Even Possible?

High Energy Gamma Ray and Neutrino Astronomy

Energy E large (!)

Luminosity L large (!)

Pointing θ small (!)

And what about detecting those neutrinos…?

Plan of the Talk

Is there a high energy universe to discover?
Is it important for astro- and particle physics?

Motive: Charged Cosmic Rays Exist

Means: Gamma Ray and Neutrino Production

Opportunity: Gamma Ray Astronomy

Opportunity: Neutrino Astronomy

Judgment: Concluding Perspectives

Motive: Charged Cosmic Rays Exist

How are they given such large energies?

What are their sources?

Theory: Solve Energy Problem

Made energetic:

Natural Accelerators (or *unnatural* ones)
Magic of shocks giving up kinetic energy
Requirement of escape
E arbitrarily large; nonthermal power-law spectrum

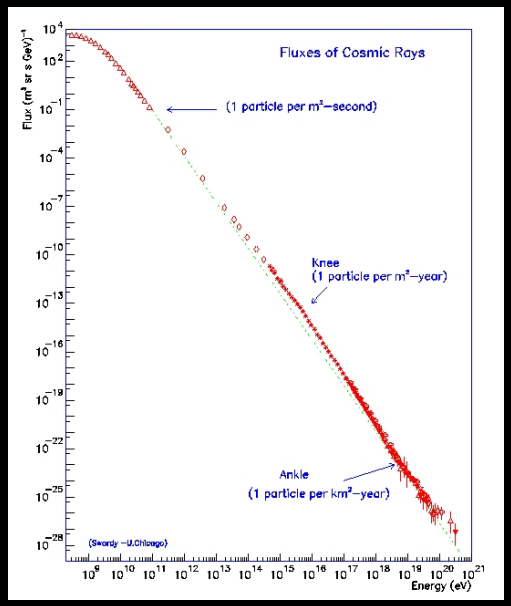
Born energetic:

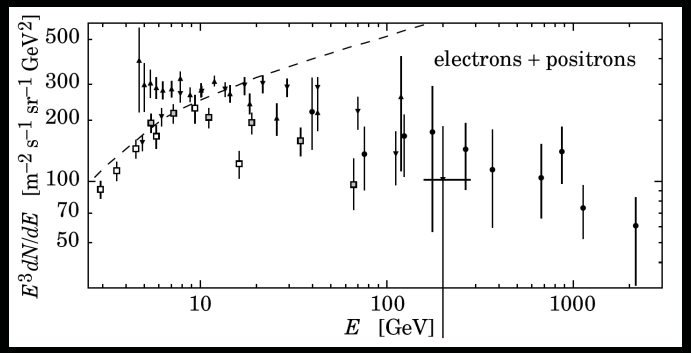
Dark Matter (or a *new* heavy thing)
Magic of annihilation or decay giving up mass energy
Requirement of Standard Model final states
E large but less than M_{DM}; calculable spectra

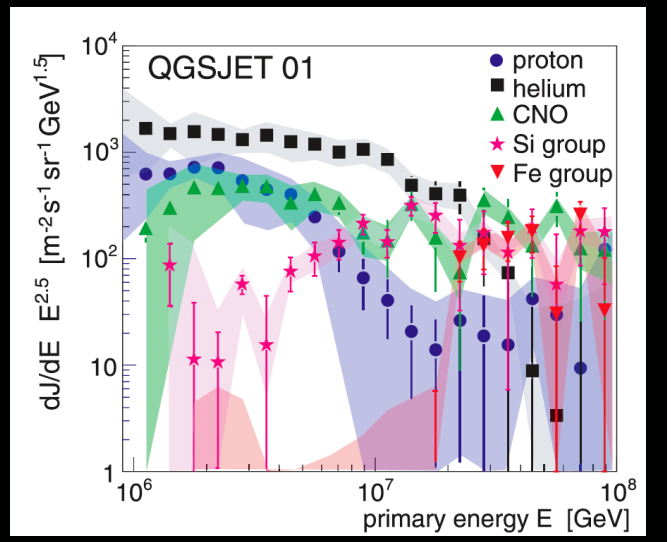
But what about luminosity, pointing?

Experiment: Solve Energy, Luminosity Problems

Charged cosmic rays of many species are detected







Energy: up to 10^{20} eV
Luminosity: large (seen 100 years ago, $U_{CR} \sim U_{starlight}$)
Pointing: isotropic

Origin and sources unknown … so what about pointing?

Politicians: Solve Pointing Problem

"Beam on" … somewhere

Need to find some experts on pointing

Results of required Environmental Impact Study:
Charged cosmic rays always come with appreciable fluxes of gamma rays and neutrinos

Gamma rays and neutrinos (and only these) can provide pointing … but what about detection?

Means: Gamma Ray and Neutrino Production

Why must there be gamma rays and neutrinos?

How well are their spectra known?

Accelerators

Cosmic rays were seemingly cleanly accelerated, but the accelerating fields require matter and radiation

No ideal accelerator exists

Cosmic rays must interact in the sources and en route

If there are any accelerated charged particles, then gamma rays and neutrinos are inevitable

E arbitrarily large; nonthermal power-law spectrum

Sample Charged Cosmic Ray Interactions

- Hadronic mechanism

$$p + p \rightarrow p + p + \pi^0,\ p + n + \pi^+$$

$$\pi^0 \rightarrow \boxed{2\gamma},\ \pi^\pm \rightarrow e^\pm + \boxed{3\nu}$$

- Leptonic mechanism

$$e^- + \gamma \rightarrow \boxed{\gamma} + e^-$$

- Nuclear (A*) mechanism

$$A' + \gamma \rightarrow A^* + X$$

$$A^* \rightarrow A + \boxed{\gamma}$$

Dark Matter

Dark matter seemingly does not interact, but the dark matter self-annihilation cross section is nonzero

$$\langle \sigma_A v \rangle \sim 1/\Omega_{DM} \sim \text{weak scale}$$

Annihilation in the early universe due to high density; annihilation in the late universe due to clumping

If there are any Standard Model final states, then gamma rays and neutrinos are inevitable

E large but less than M_{DM}; calculable spectra

Opportunity: Gamma Ray Astronomy

How can we detect and identify these?

What have we learned so far?

Gamma Ray Detection Processes

Gamma rays are not detected directly, but only through the consequences of their EM interactions

$$\gamma + A \rightarrow e^{+} + e^{-} + A$$

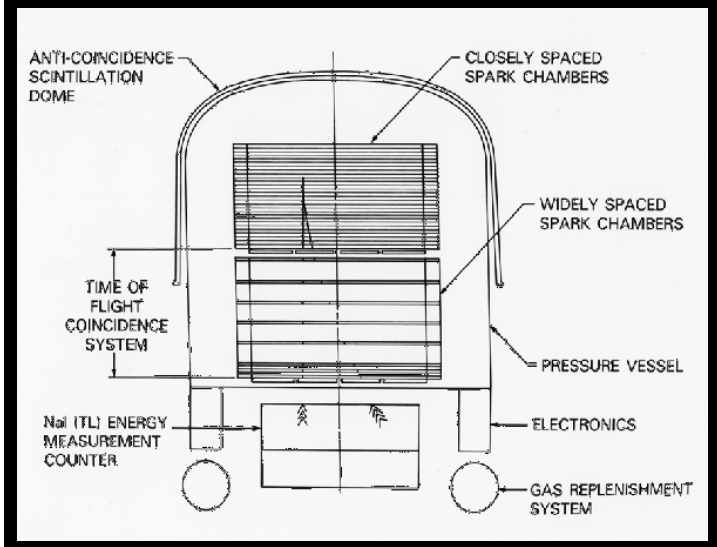
$$e + A \rightarrow e + \gamma + A$$

ionization, etc.

Gamma rays point, but they can be attenuated and do not uniquely reveal their birth processes or energies

Gamma Ray Detectors

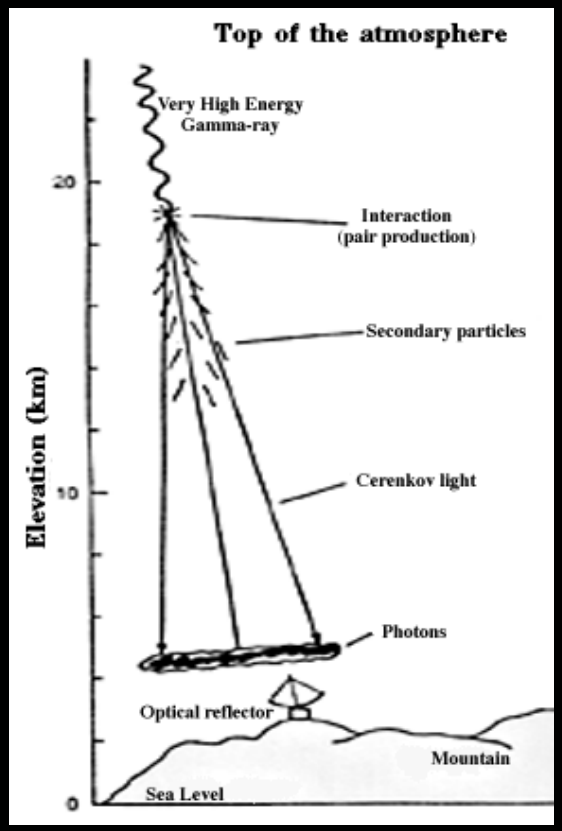
below ~ 0.3 TeV



shower in detector

EGRET, Fermi

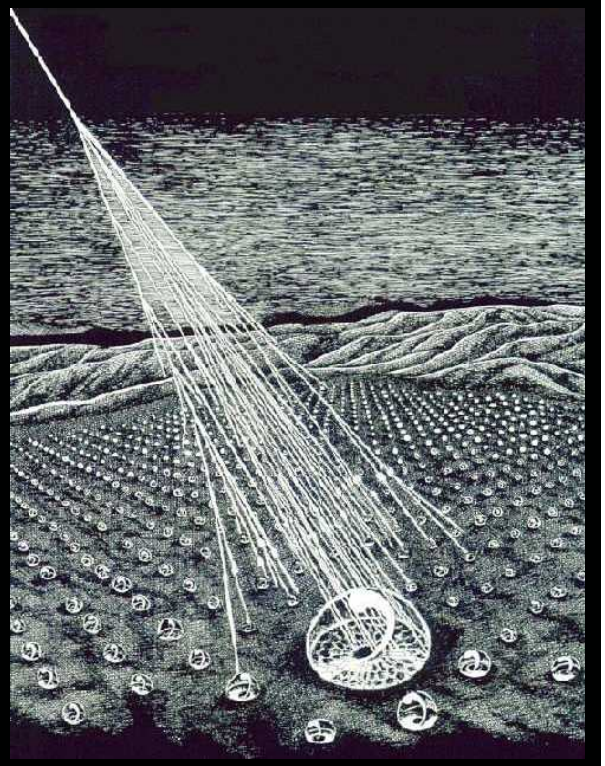
~ 0.3-30 TeV



Cerenkov from shower in air

HESS, VERITAS, MAGIC

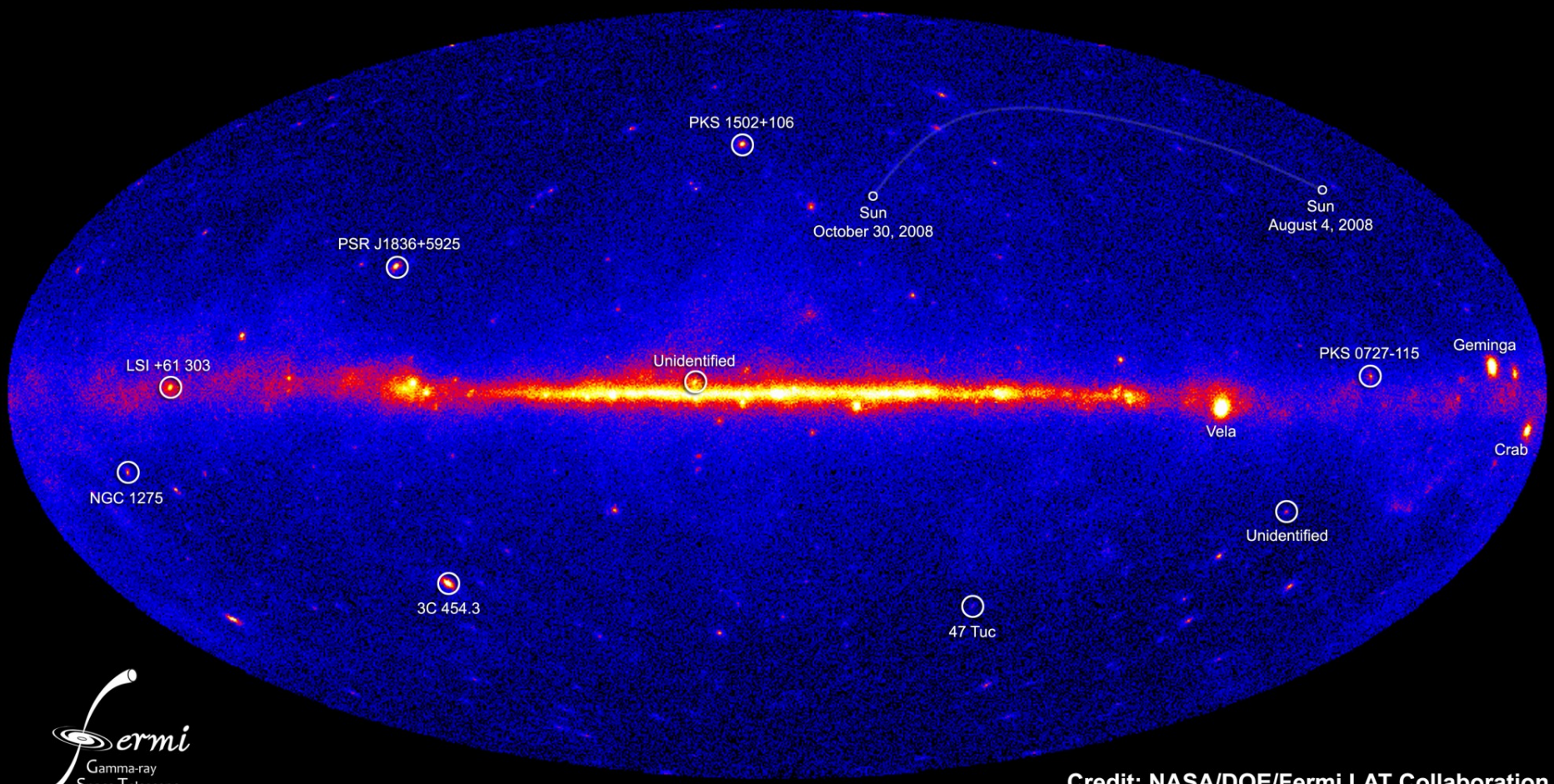
above ~ 3 TeV



shower at ground

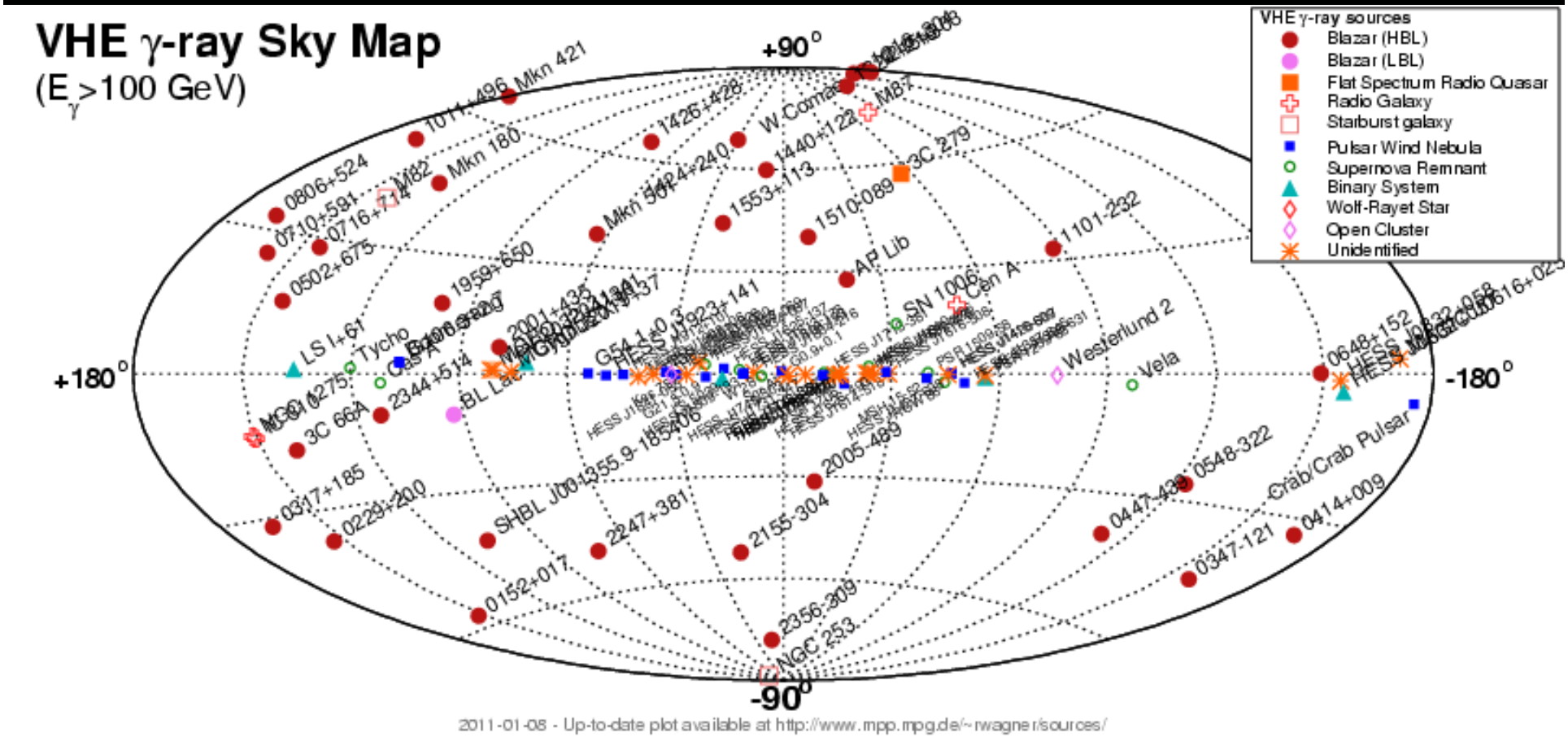
Milagro, HAWC

Sub-GeV Gamma Ray Skymap



Fermi Collaboration (2009)

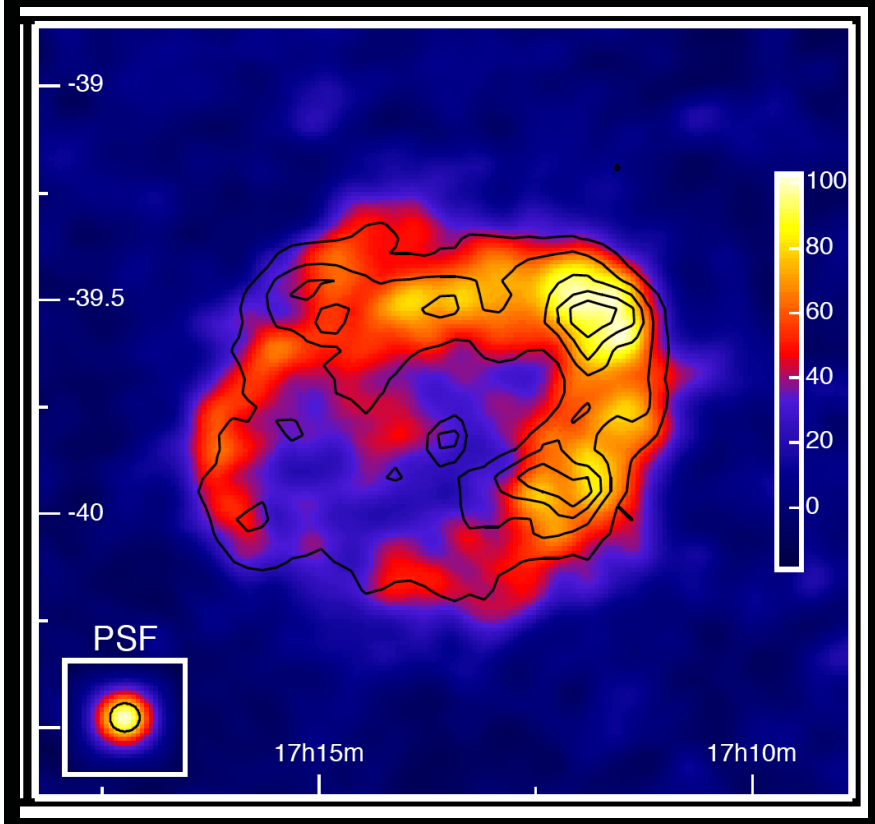
Partial Catalog of sub-TeV Gamma Ray Sources

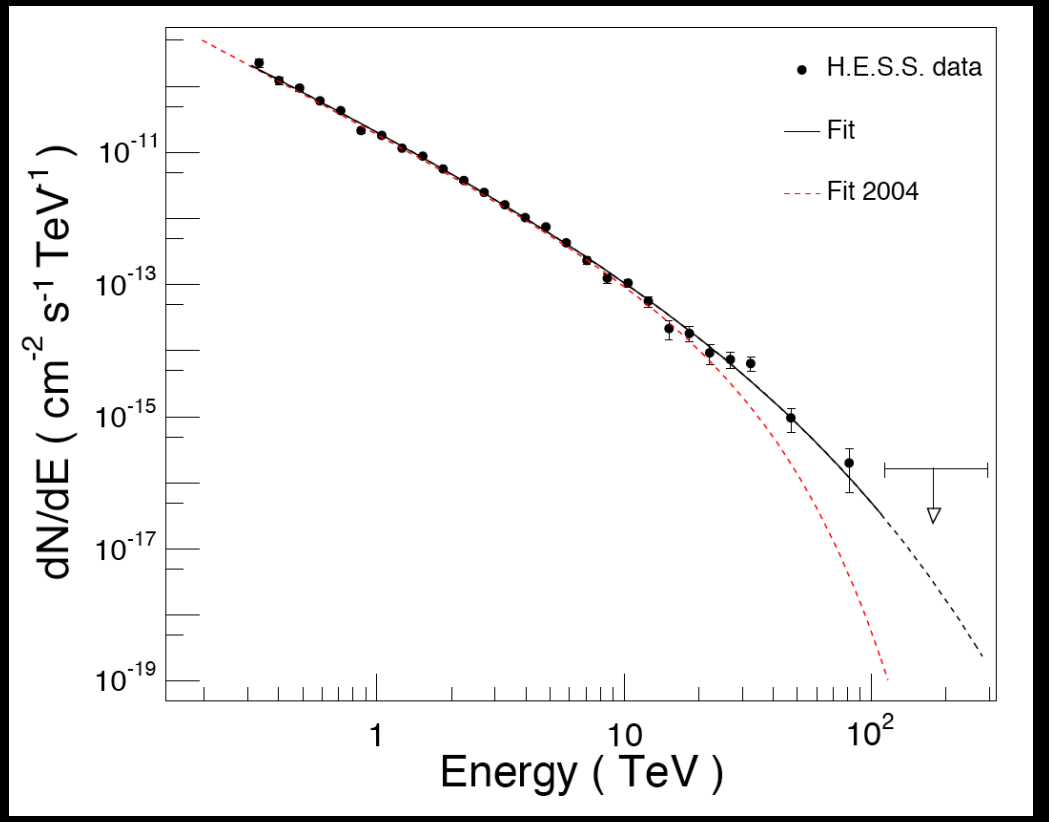


Wagner (2011)

Sources are High-Energy and Luminous

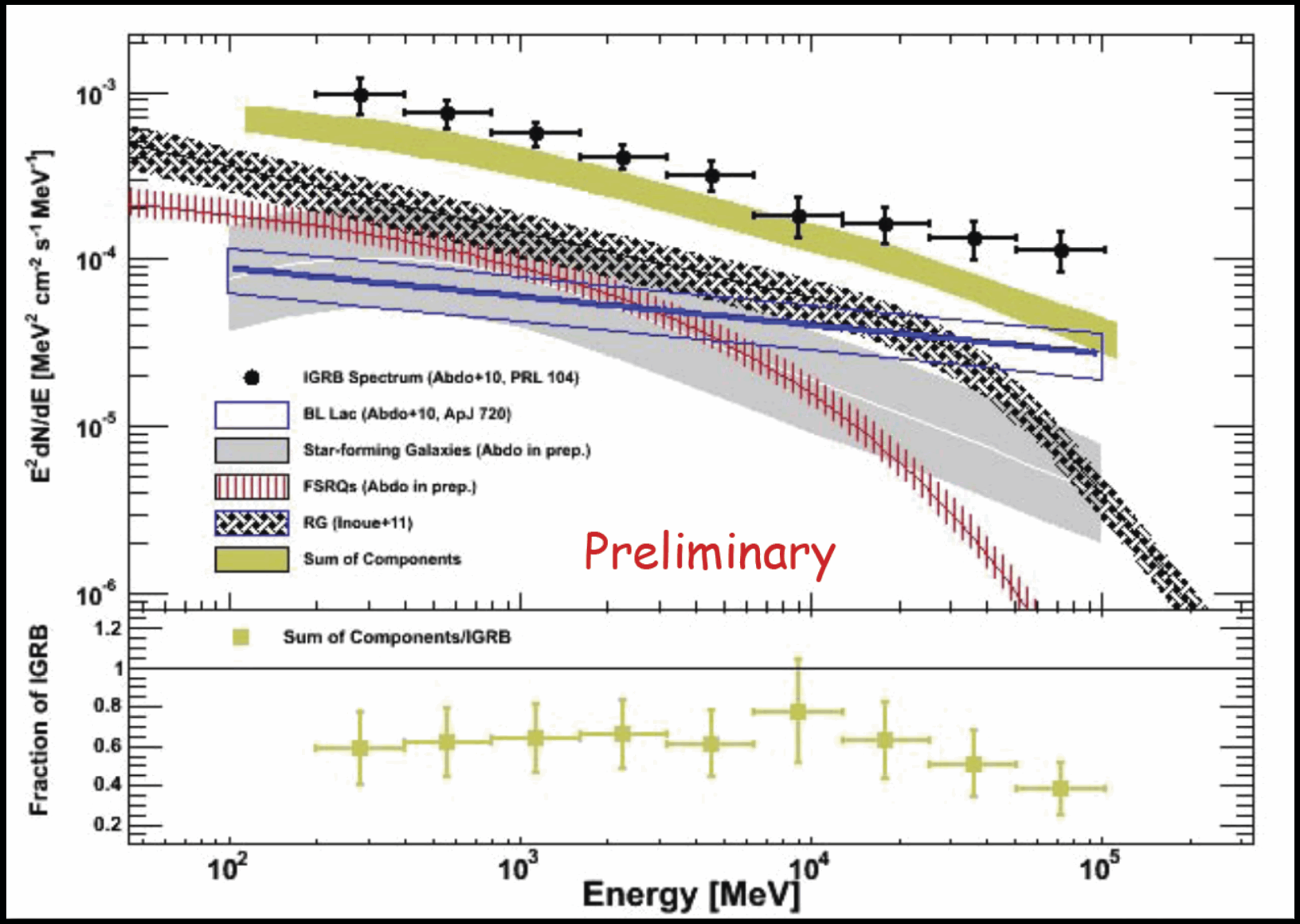
supernova remnant RX J1713.7-3946





HESS Collaboration (2006)

Diffuse Gamma Ray Spectra



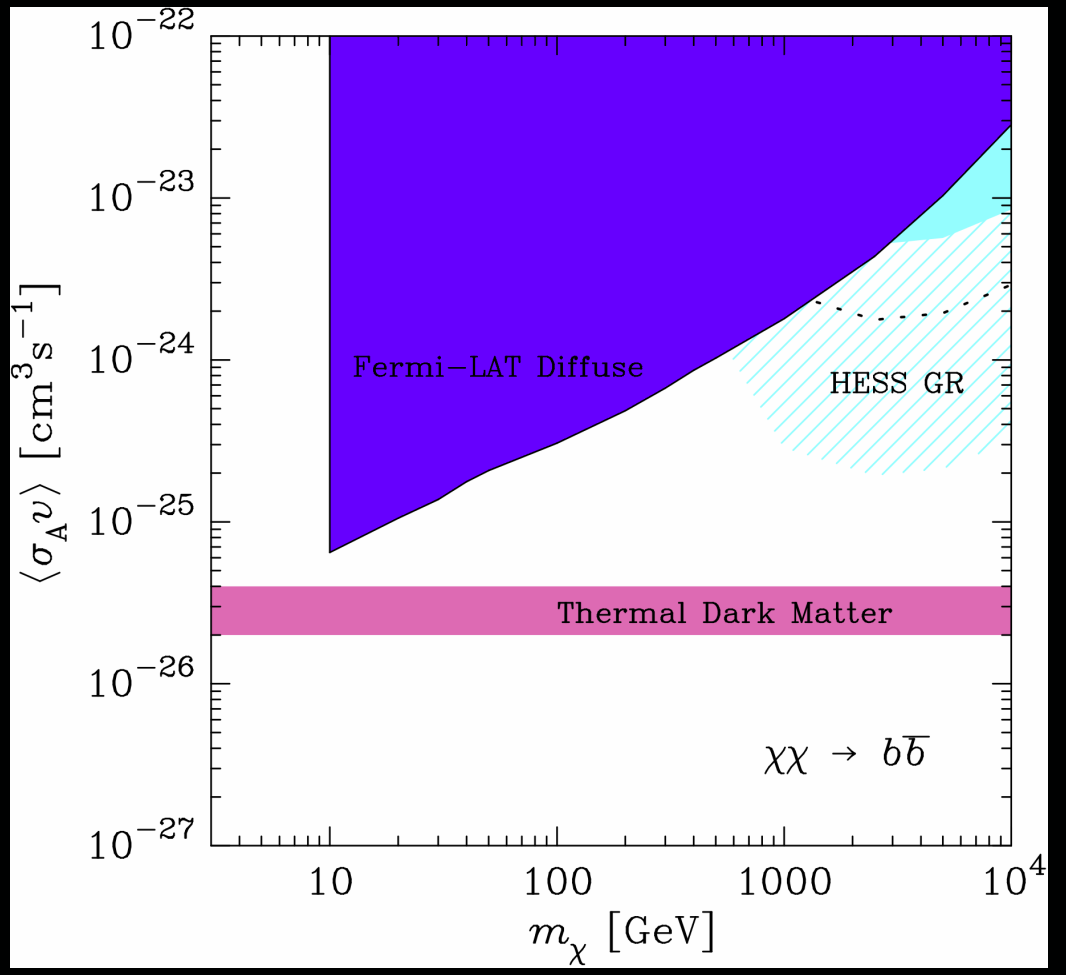
Ajello, Fermi Collaboration (2011)

Dark Matter Annihilation and Gamma Rays

Total cross section and average mass density known, but…

Many possible final states, with different gamma ray spectra

Real uncertainties in dark matter clumping



Abazajian et al. (2010)

See Geringer-Sameth and Koushiappas (to appear)

Opportunity: Neutrino Astronomy

How can we detect and identify these?

What have we learned so far?

Neutrino Detection Processes

Neutrinos are not detected directly, but only through the consequences of their weak interactions:
EM showers, hadronic showers, and muon tracks

$$\nu_e + n \rightarrow e^- + p$$

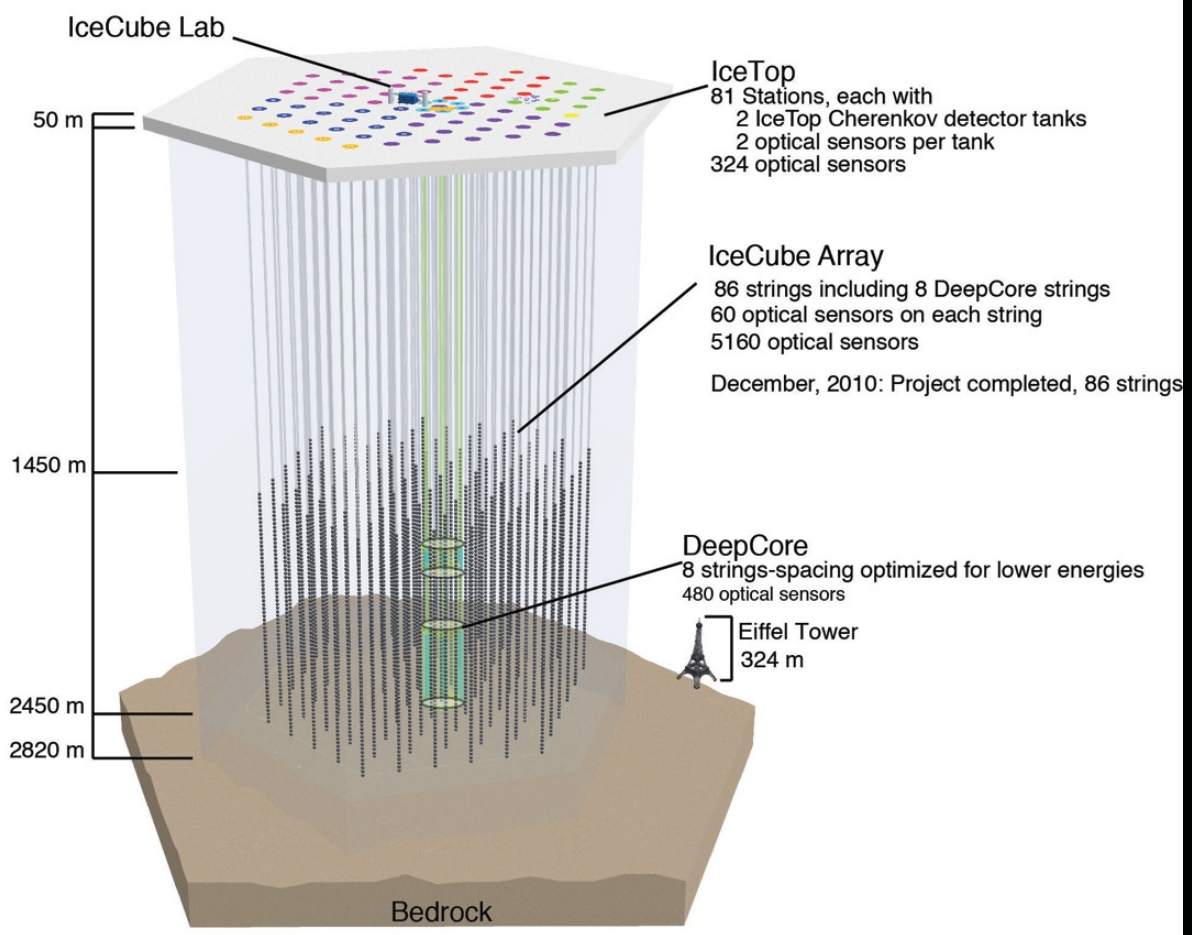
$$\nu_\mu + n \rightarrow \mu^- + p$$

$$\nu_\tau + n \rightarrow \tau^- + p$$

Plus charge conjugates
Plus neutral-current channels

Neutrinos point, and flavors can help reveal the parent processes, but neutrinos are hard to detect

Neutrino Detectors



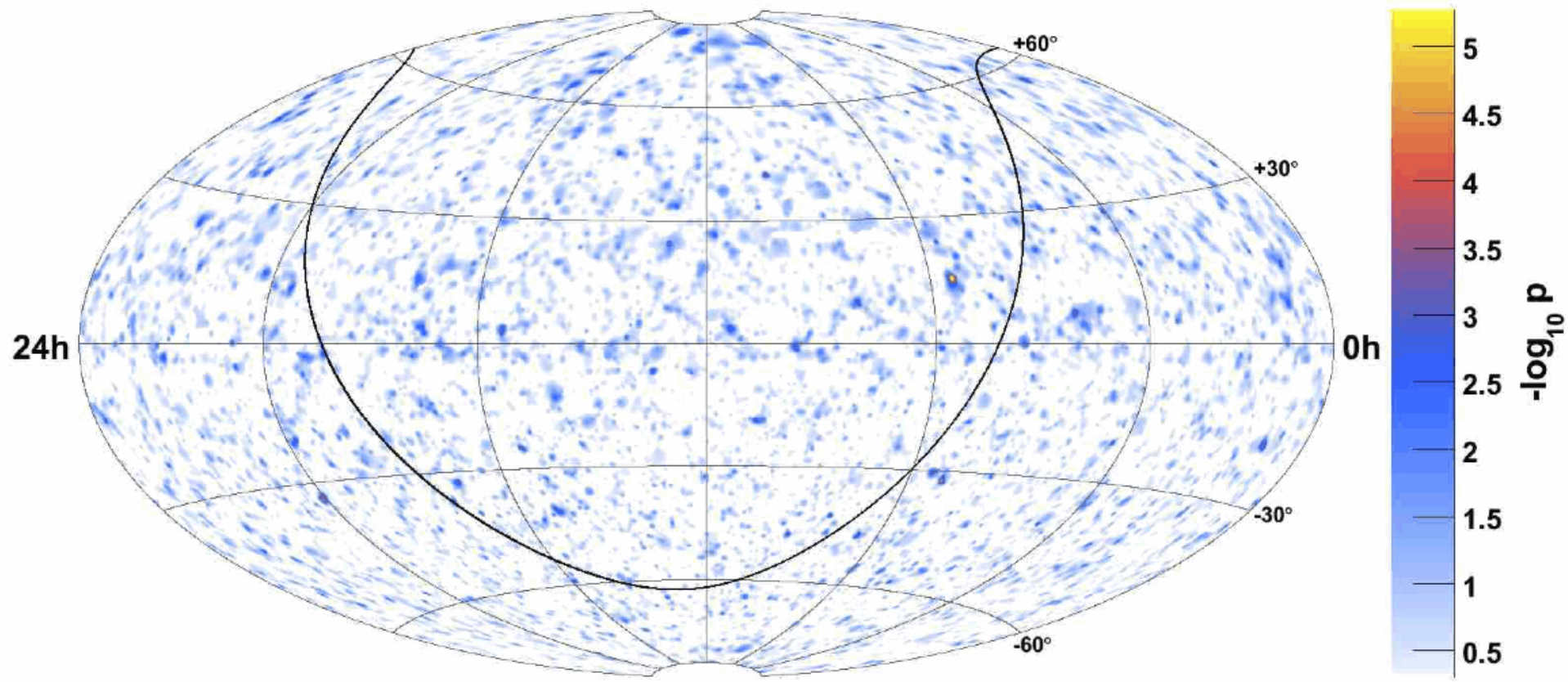
IceCube at the South Pole is complete

Size ~ 1 km^3

Sees the Northern sky

Similar plans for the Mediterranean Sea (km3net)

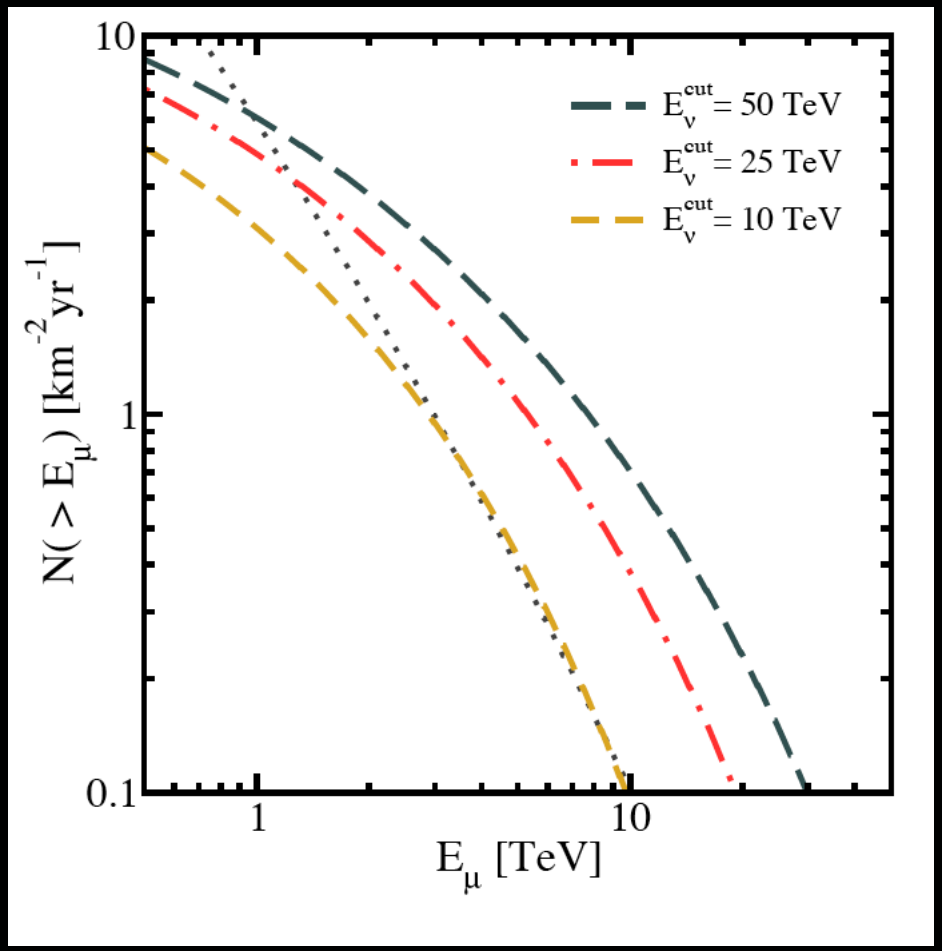
Neutrino Skymap … Background Dominated



IceCube Collaboration (2011)

Neutrino Sources

Vela Jr. supernova remnant

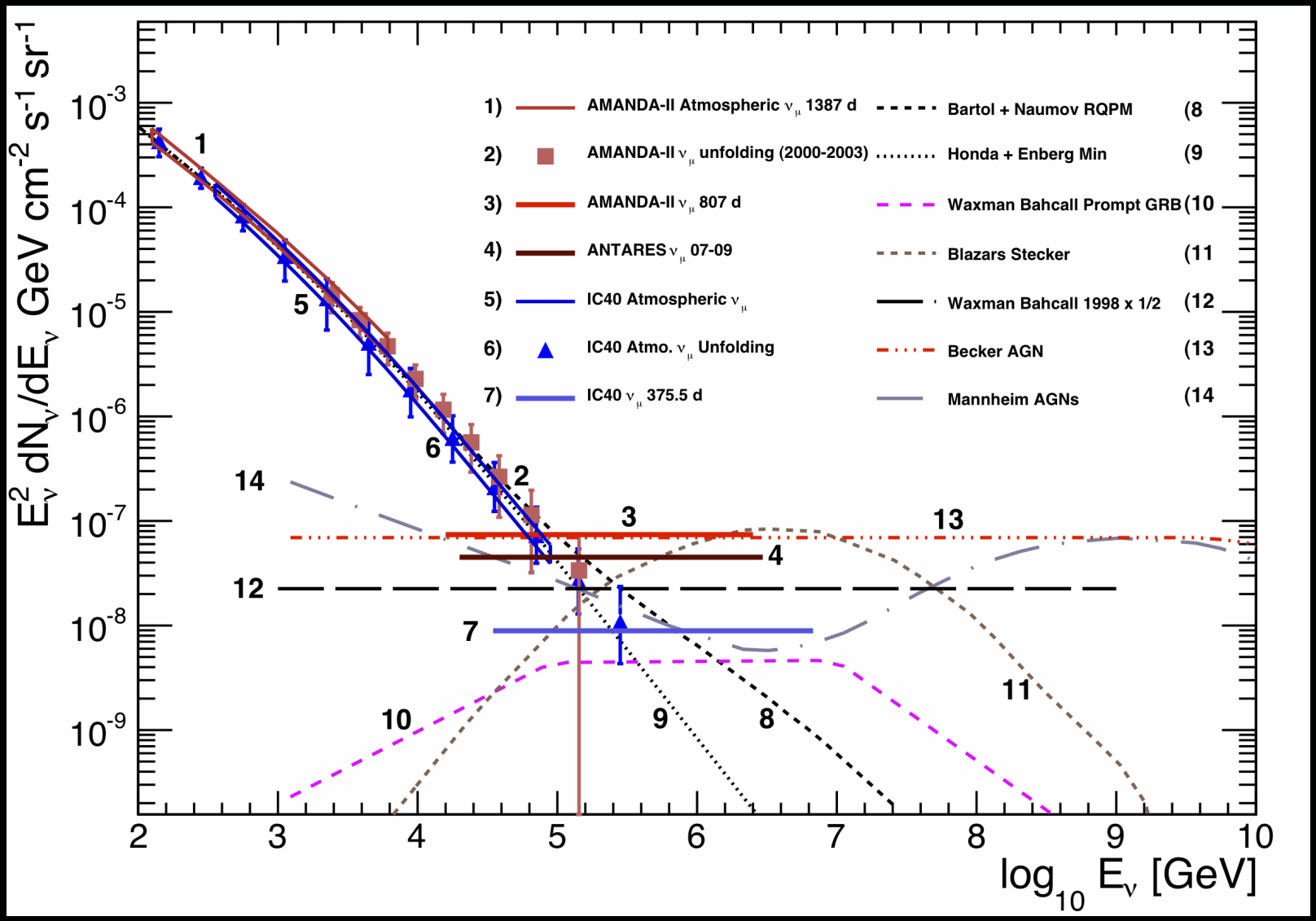


Kistler, Beacom (2006)

IceCube (2011):
no sources seen yet in blind or directed searches

Limits approaching models and will soon improve with more data, better analysis techniques, and more gamma ray data

Diffuse Neutrino Spectra



IceCube Collaboration (2011)

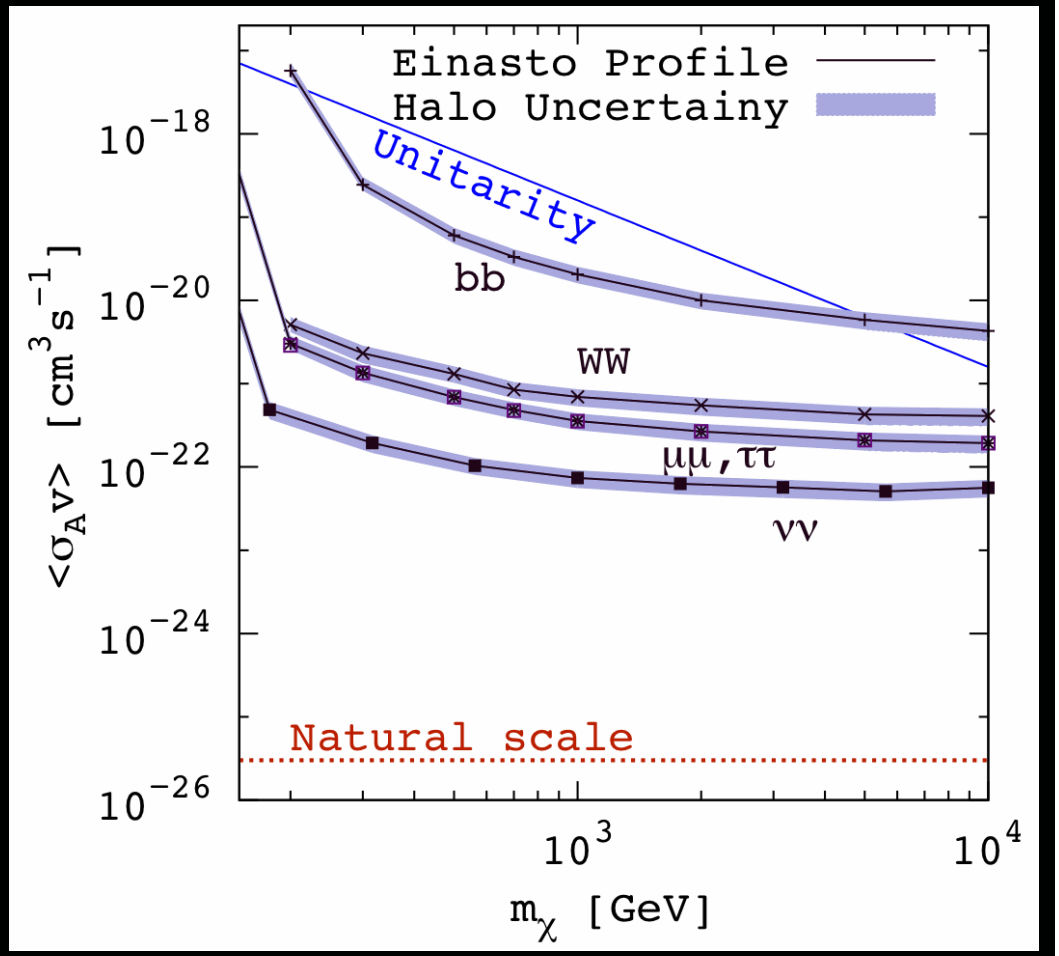
Dark Matter Annihilation and Neutrinos

What if dark matter annihilation tries to hide from us?

The hardest SM case is pure neutrinos

Even then, there will be good sensitivity

Beacom, Bell, Mack (2006)



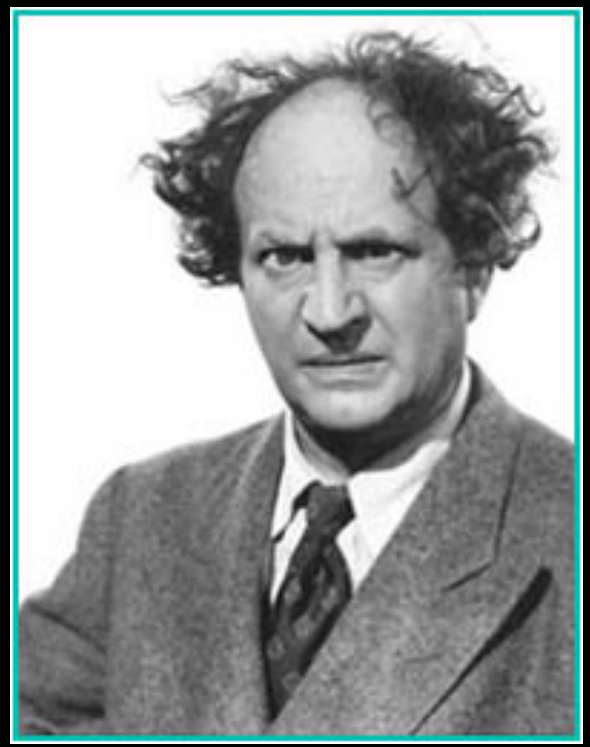
Rott, IceCube Collaboration (2011)

IceCube and Super-K can make big improvements

Judgment: Concluding Perspectives

Astronomy with New Messengers

cosmic rays	gamma rays	neutrinos
energetic	direct	revealing
divertable	stoppable	untrustworthy?



Commentary Following Matchev

Essential link between astrophysics and physics:
Astrophysics is unrivaled in its prospecting power, and laboratory work is essential for decisive tests

Essential link between theory and experiment:
Theory must play an empirical and synthetic role, and experiment must present generic constraints

Lots of great work being done by young theorists:
These people are well positioned to help make big discoveries; don't let them fall through the cracks!

Conclusions

Great unsolved questions in high energy astronomy:
Origin of cosmic rays, nature of gamma ray sources, particle properties of dark matter and neutrinos, etc.

Big steps in sensitivity give new opportunities:
Probing extremes of energy, distance, density, and fields that cannot be matched in the laboratory

Neutrino observations can be decisive:
Even a few neutrinos can identify a hadronic source, the emission energy scale, hidden sources, etc.

Astrophysical Neutrino Sources

MeV: Thermal Sources

Milky Way supernova, ~ few per century
nearby supernovae, ~ 1 per year
Diffuse Supernova Neutrino Background, constant flux

TeV: Nonthermal Sources

steady sources, e.g., Milky Way supernova remnants
varying sources, e.g., Active Galactic Nuclei
transient sources, e.g., gamma-ray bursts
possible sources from dark matter annihilation

EeV: Extreme Sources

almost certain flux from UHE cosmic ray propagation
likely fluxes from those accelerators directly
possible sources from supermassive particle decays

CCAPP at Ohio State

The Ohio State University's Center for Cosmology and AstroParticle Physics

Center for Cosmology and AstroParticle Physics

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Postdoctoral Fellowship applications welcomed in Fall