Southern Sky Sources with Deep Core

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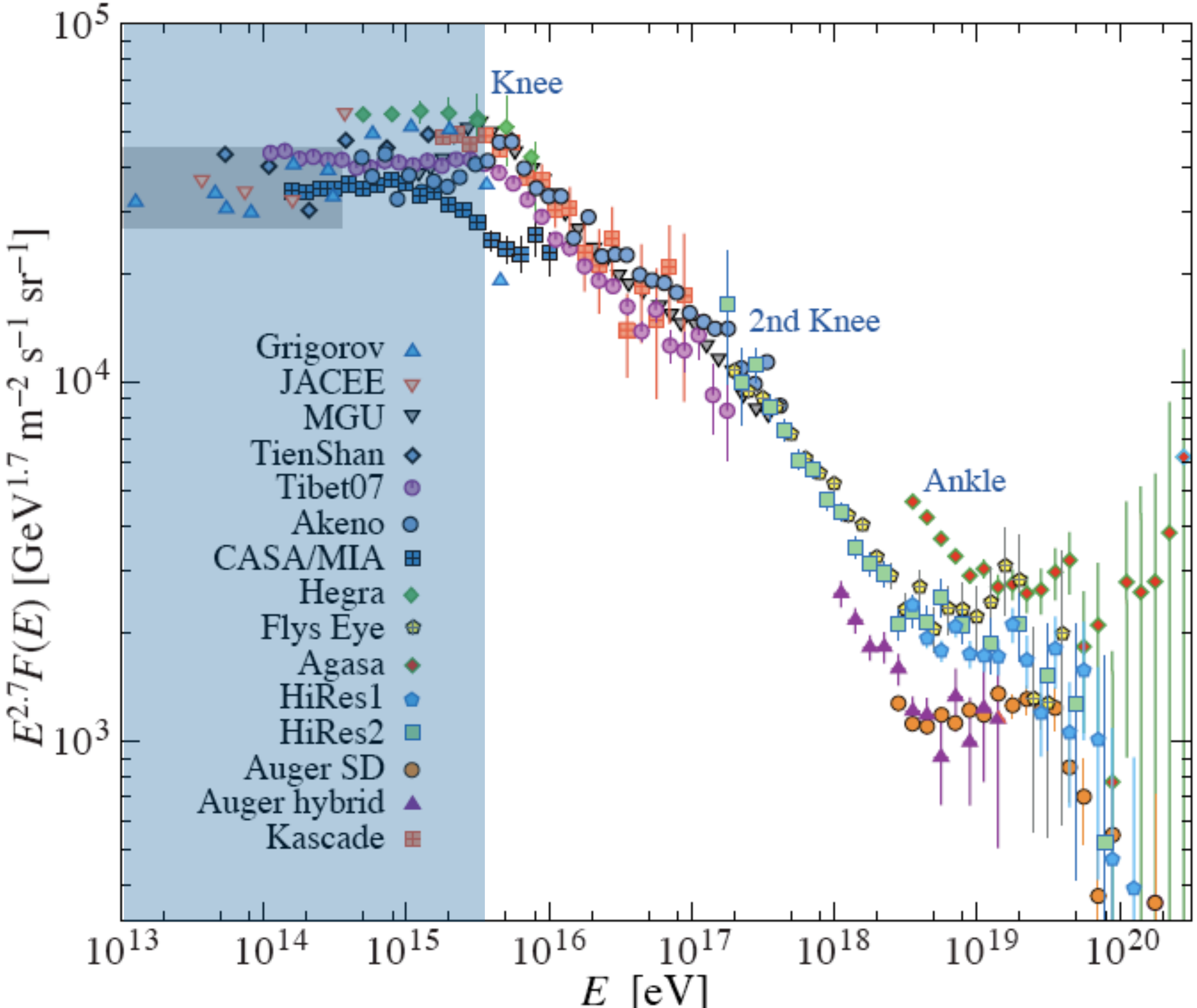
In collaboration with John Beacom

HESS

TeV Cosmic Rays

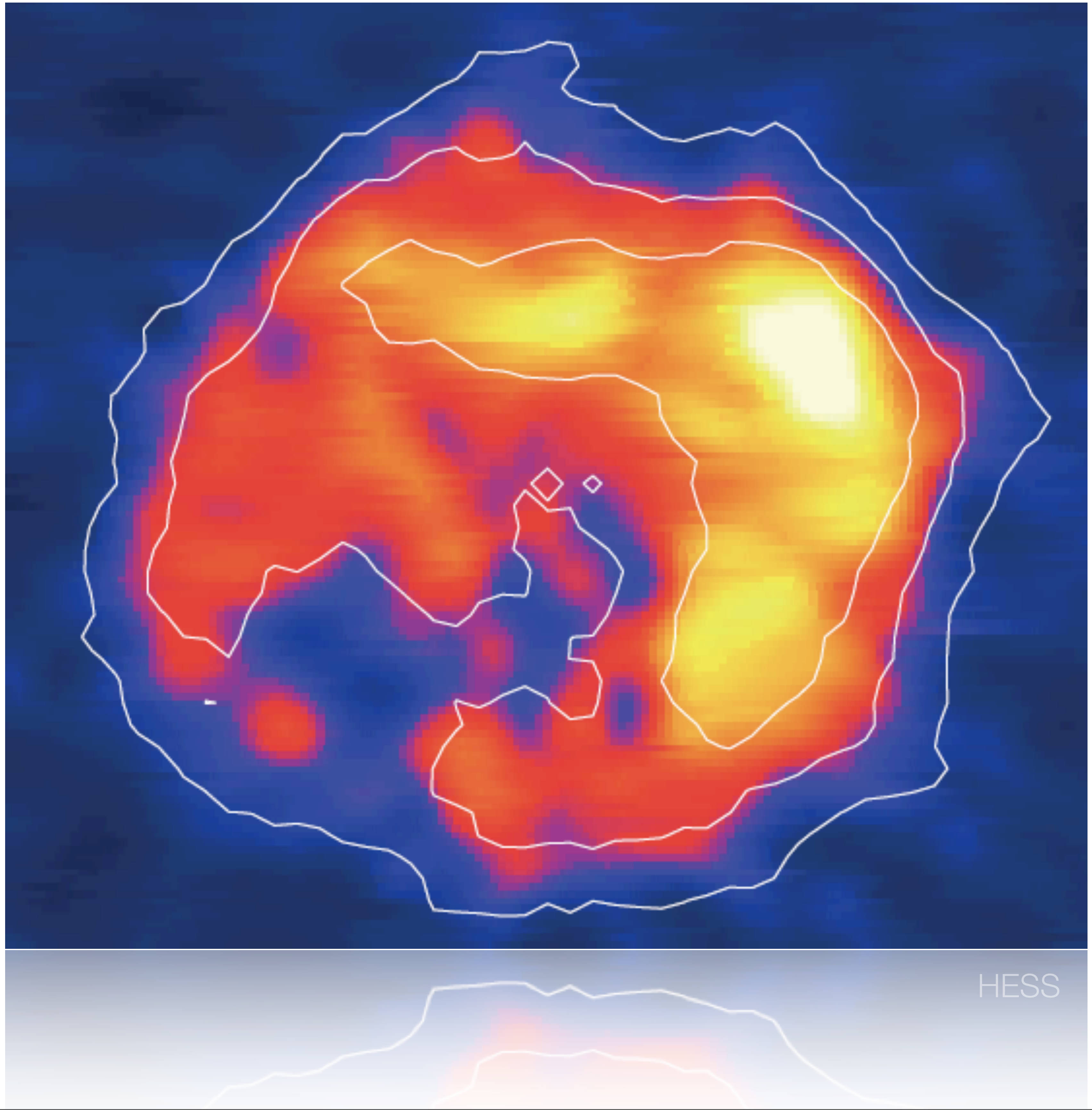


RPP: Gaisser, Stanev (2008)

Cosmic rays, gamma rays, and neutrinos

First uncover gamma rays and neutrinos from the pile of cosmic rays

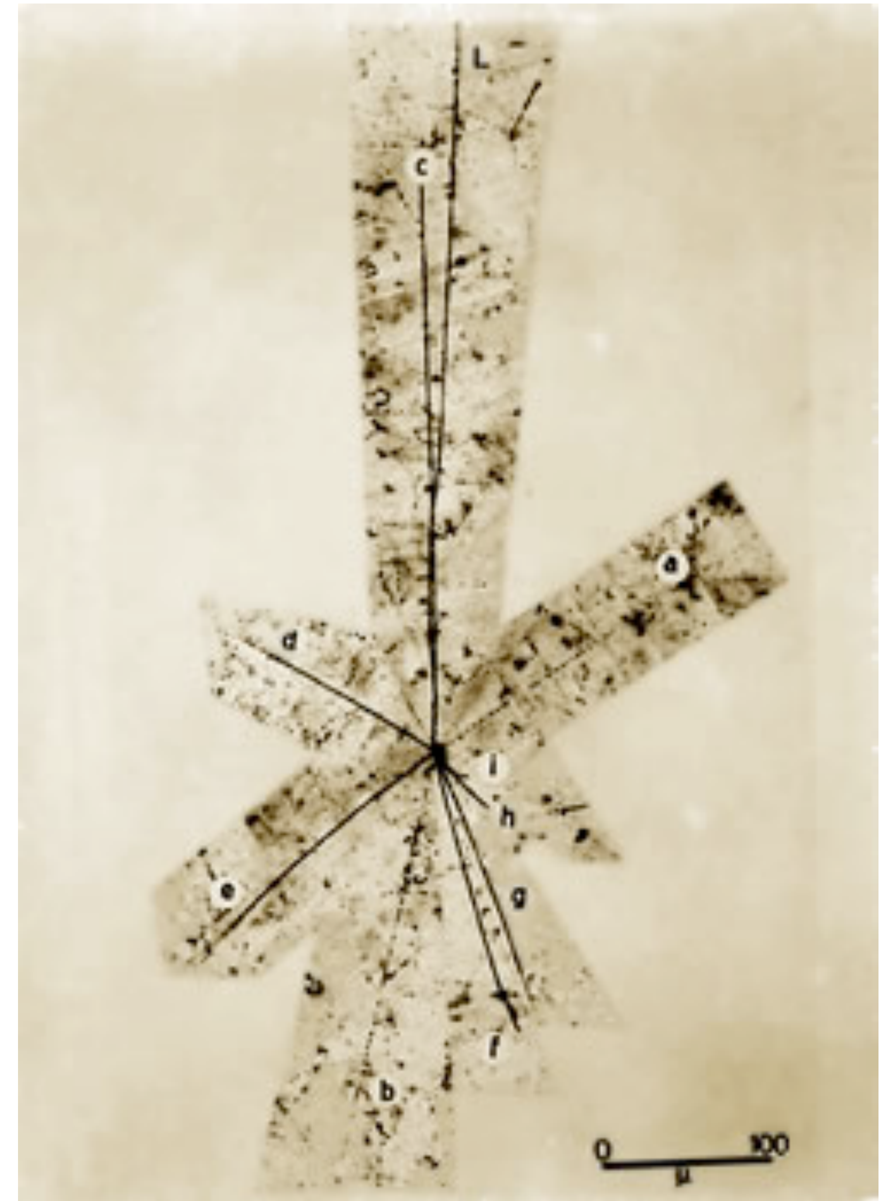
Then use them to find the sources of the cosmic rays



Discerning between hadronic/leptonic

Inverse Compton

$$e^- \gamma \rightarrow \gamma e^-$$



Proton-Proton Scattering

$$\pi^0 \rightarrow \gamma\gamma$$

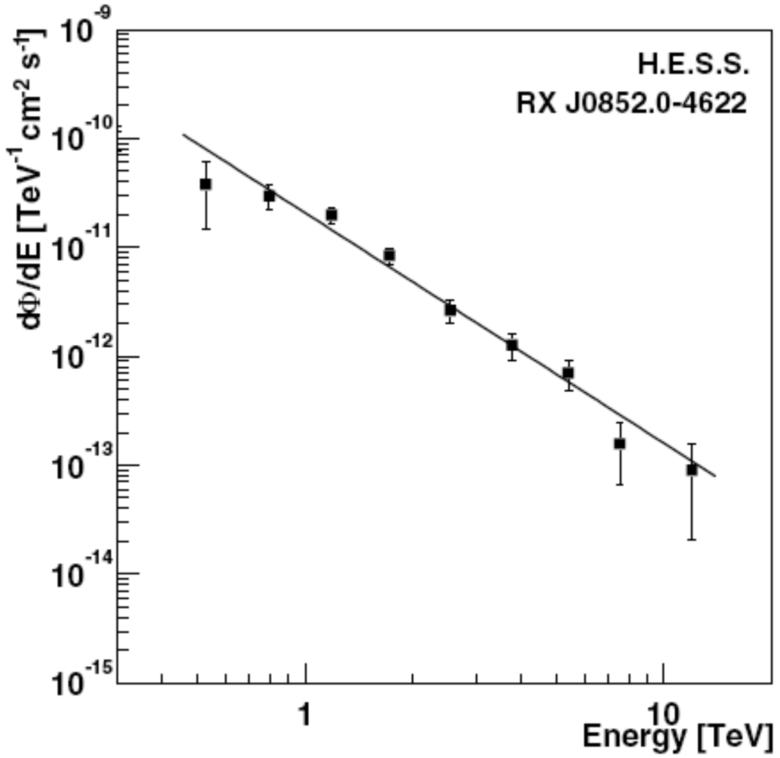
$$\pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \bar{\nu}_\mu \nu_e \nu_\mu$$

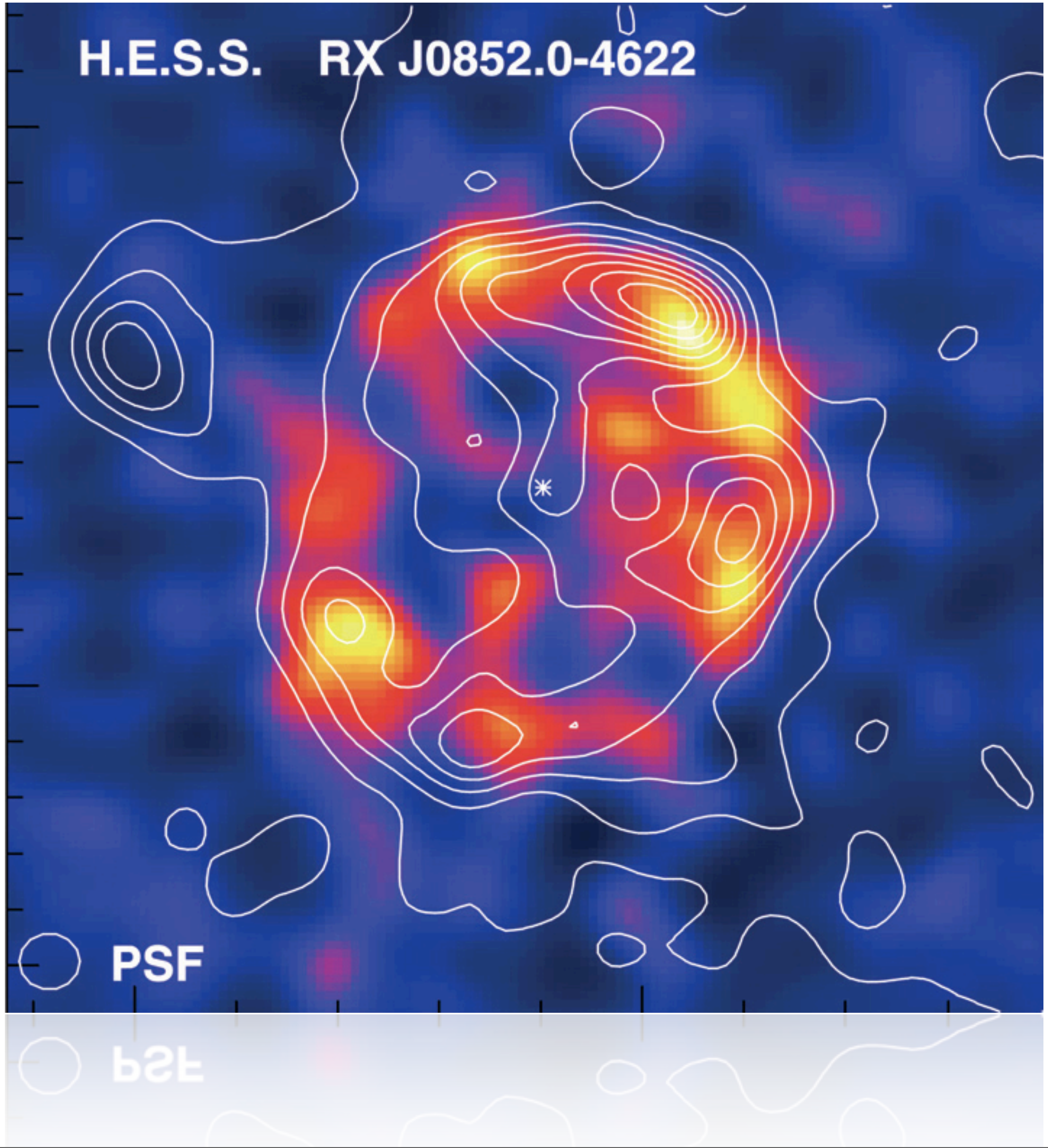
$$\pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \nu_\mu \bar{\nu}_e \bar{\nu}_\mu$$

Air Cherenkov Telescopes

A plethora of TeV sources

Vela Junior

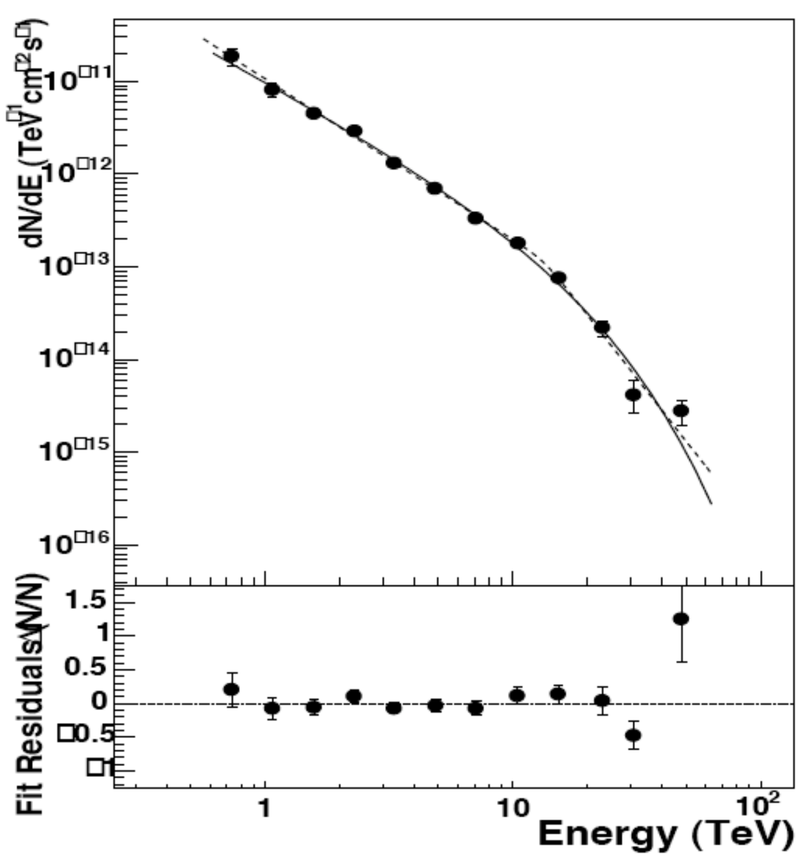


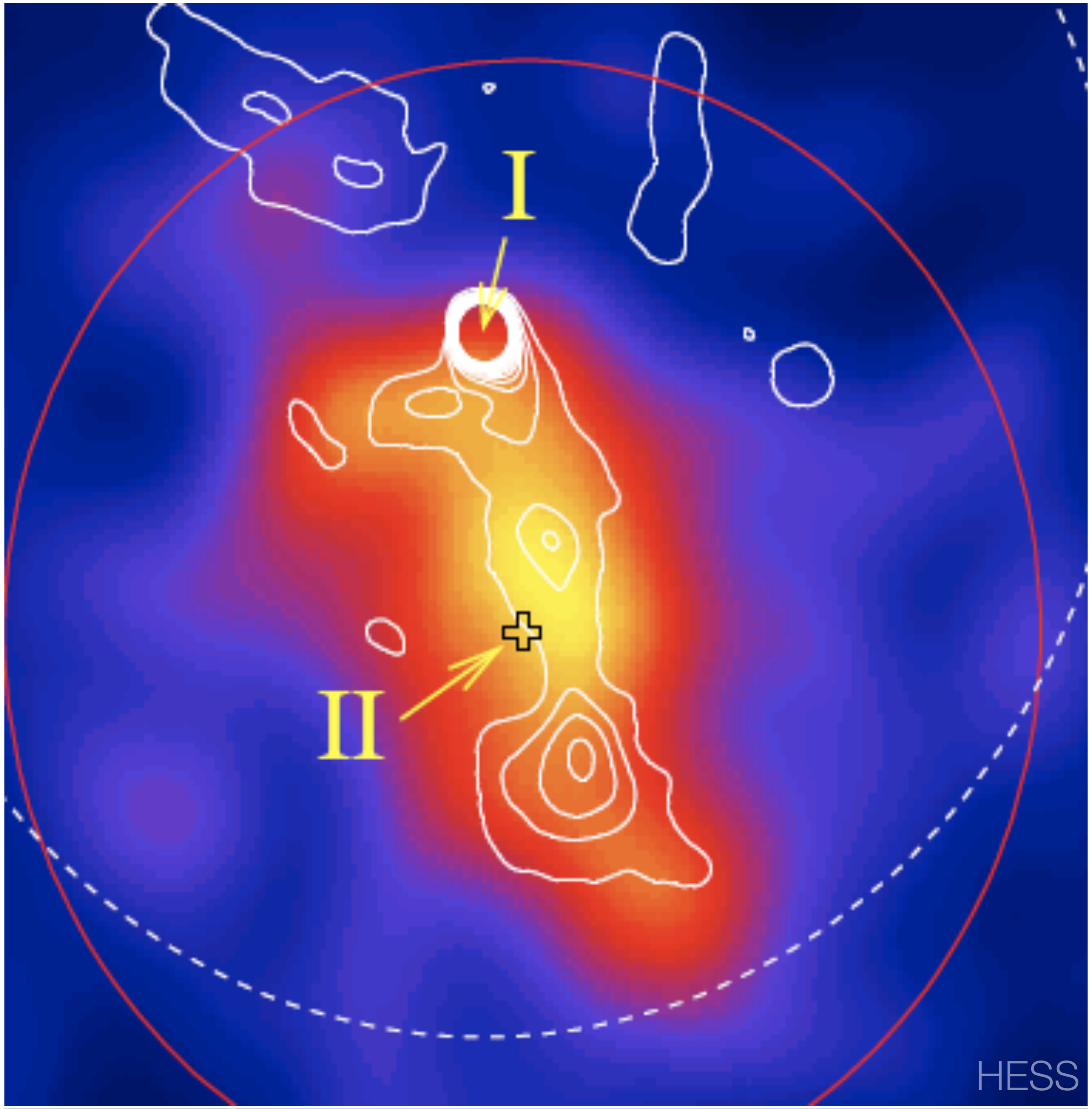


A plethora of TeV sources

Pulsar Wind Nebula

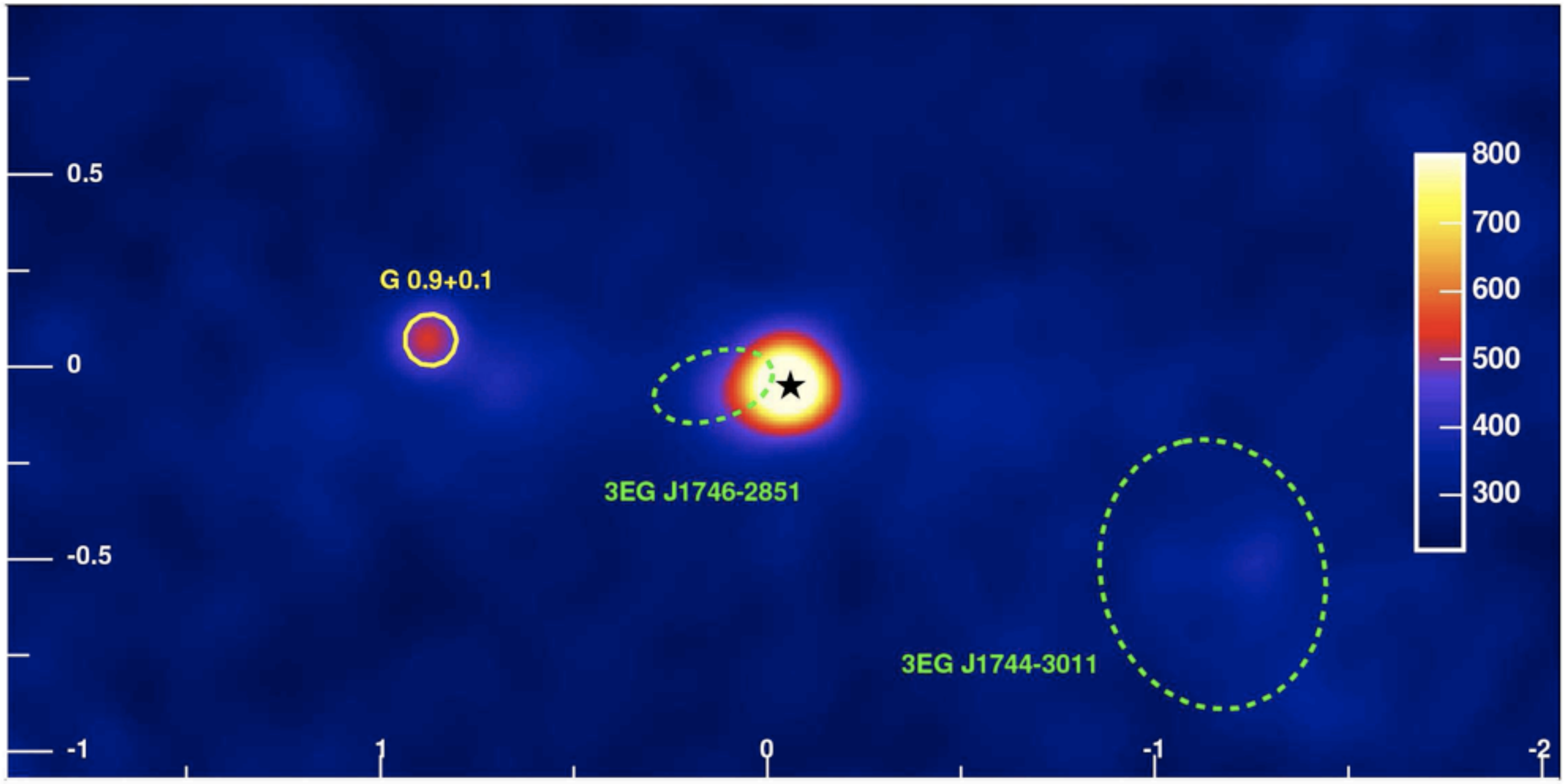
Vela X



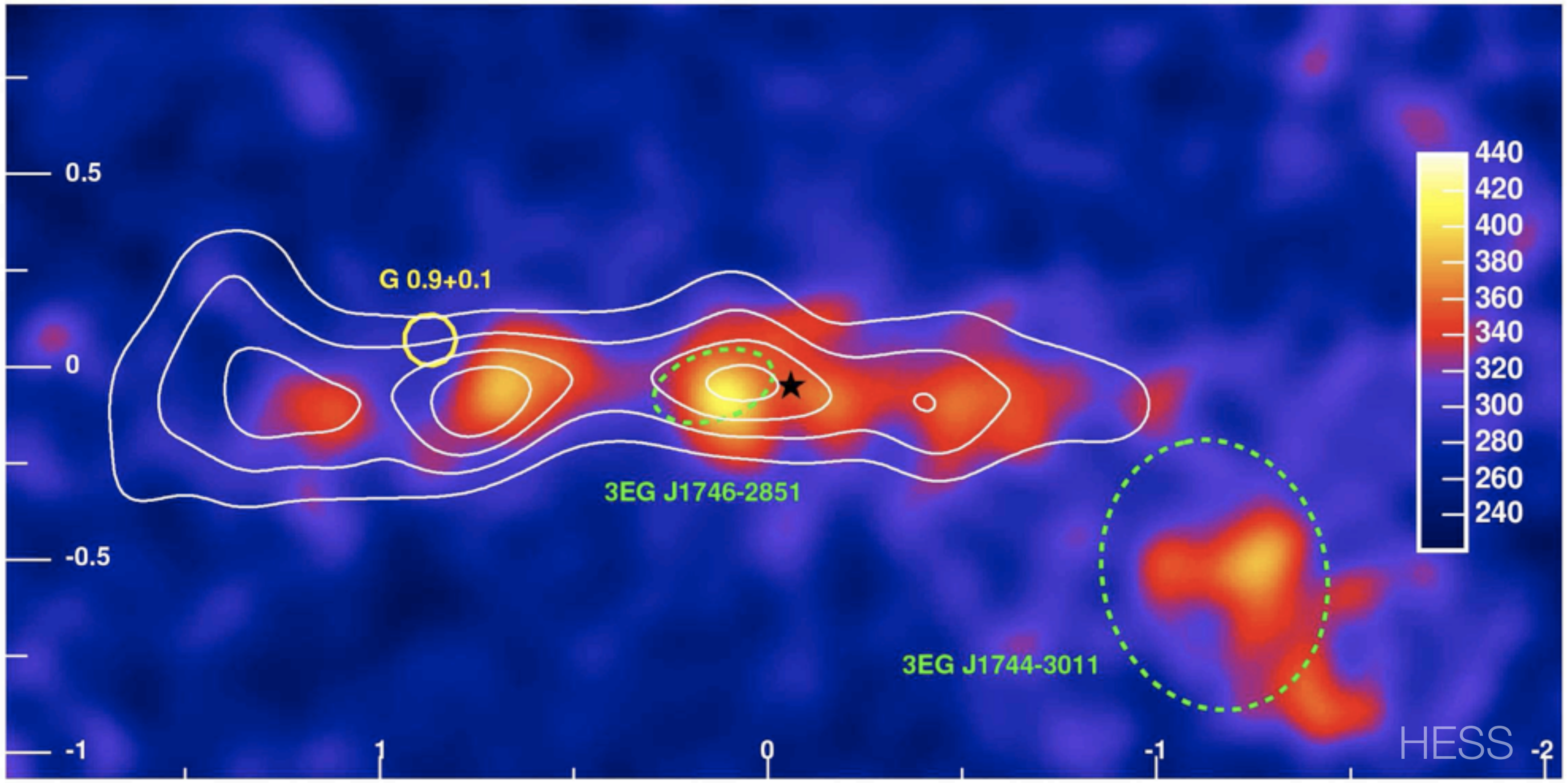


A plethora of TeV sources

Galactic Center point source



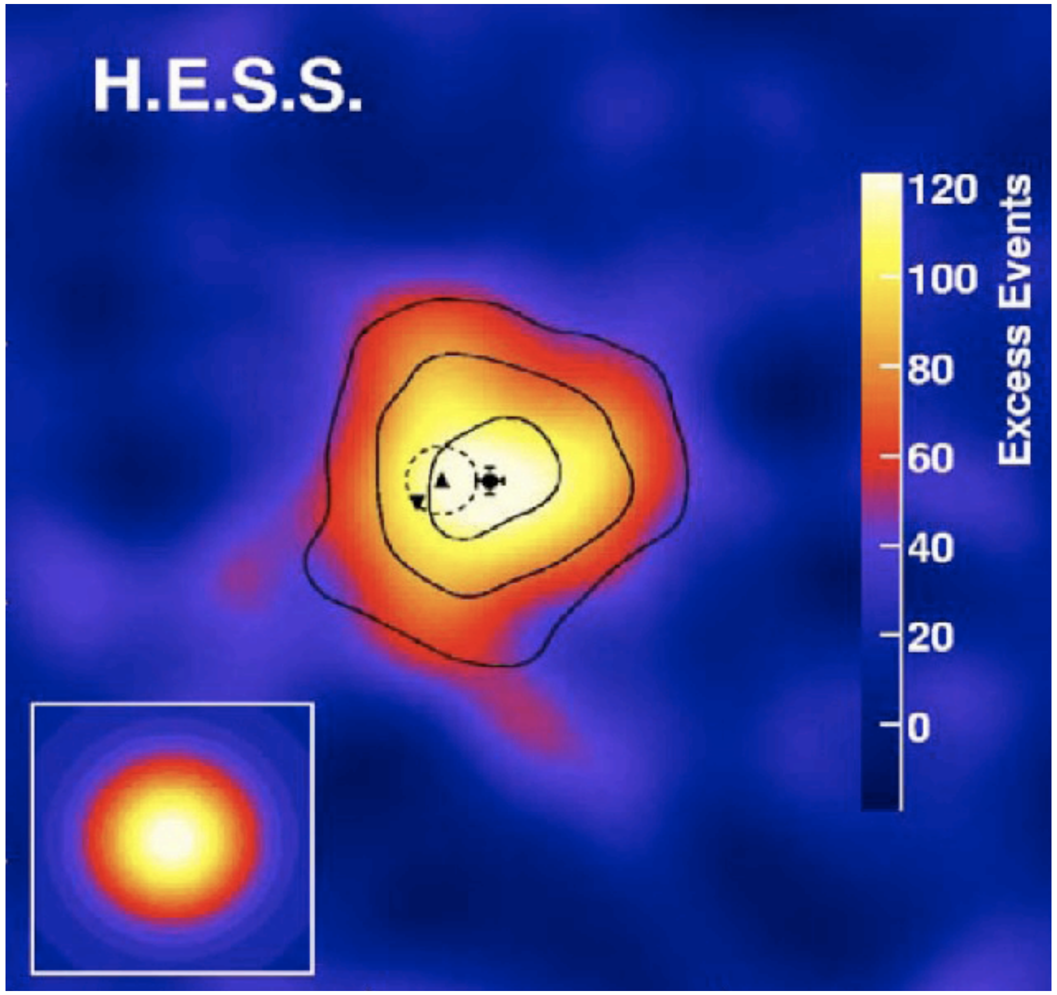
Galactic Center Diffuse



A plethora of TeV sources

HESS J1023-575

WR 20a?



Air Shower Telescopy

Use of muon content to discriminate between gamma-ray and hadronic showers

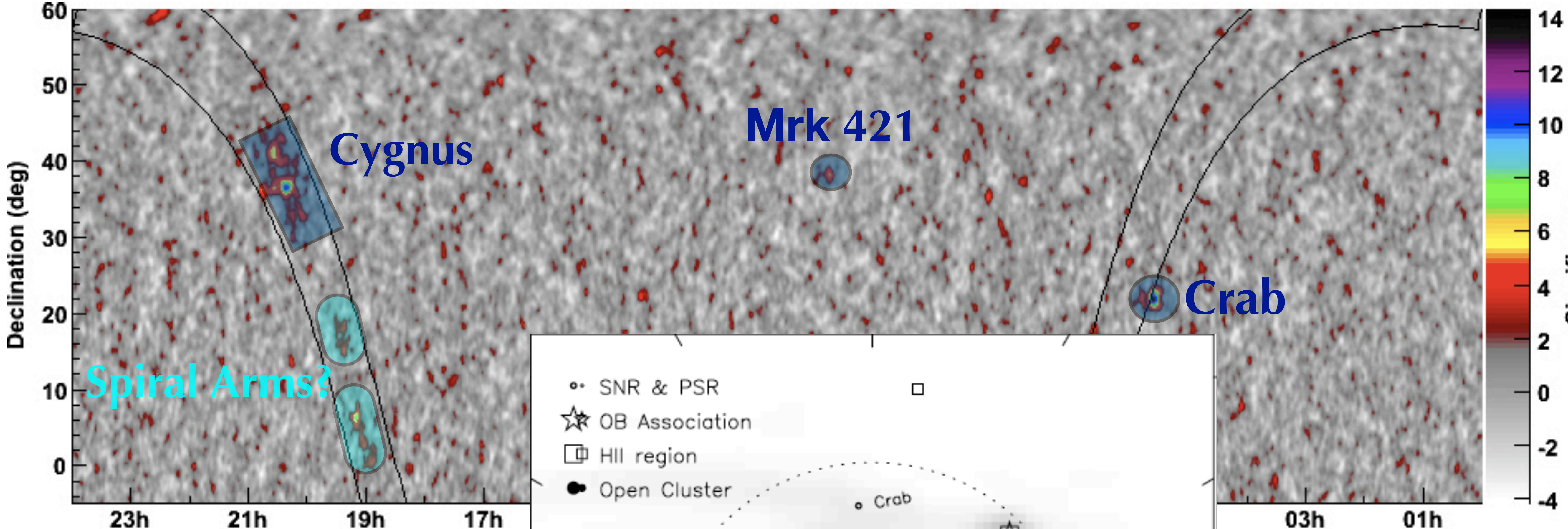
Large field of view

High duty cycle

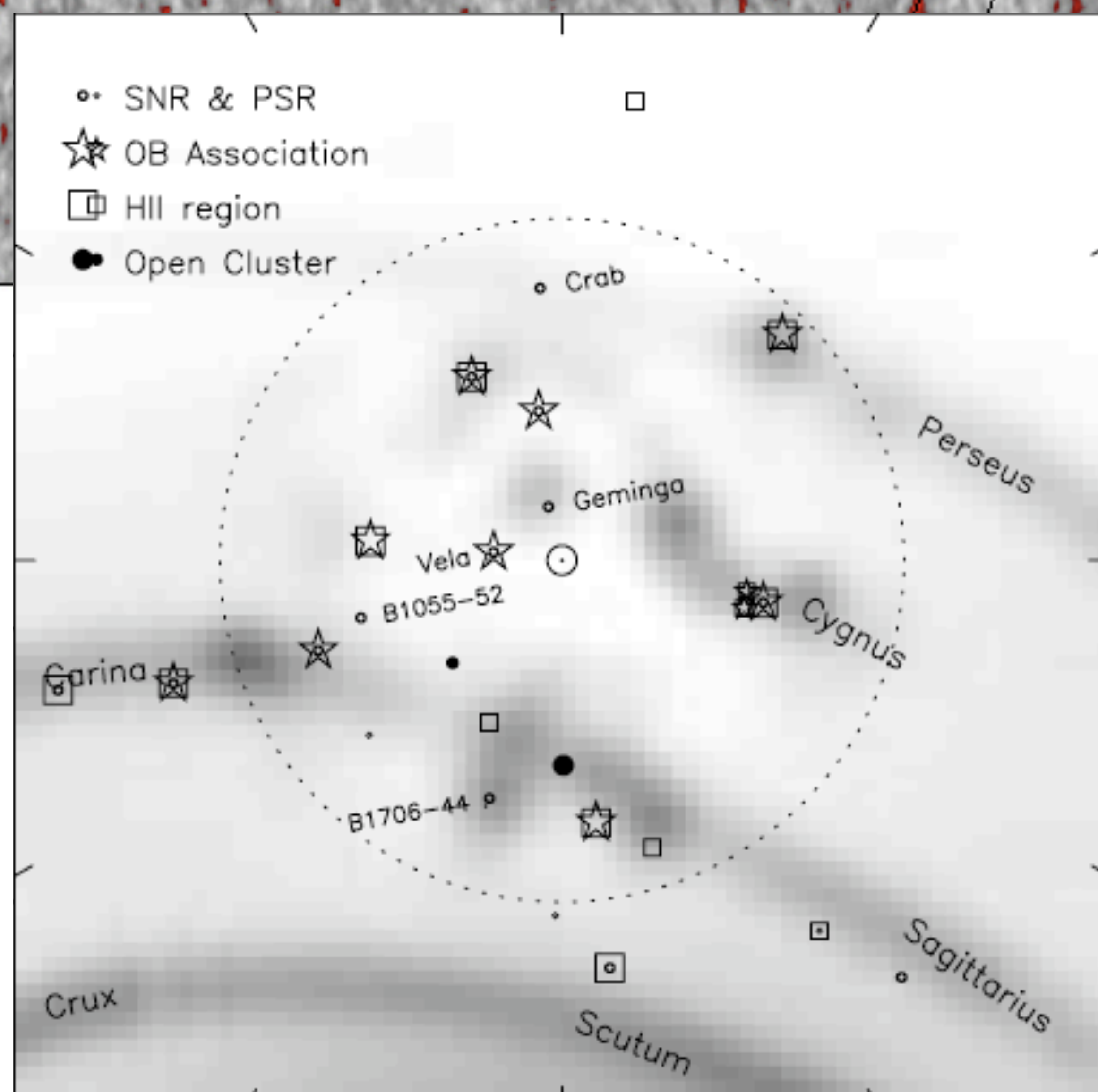
Milagro

Also Tibet and CASA-MIA

Milagro View of the TeV Sky



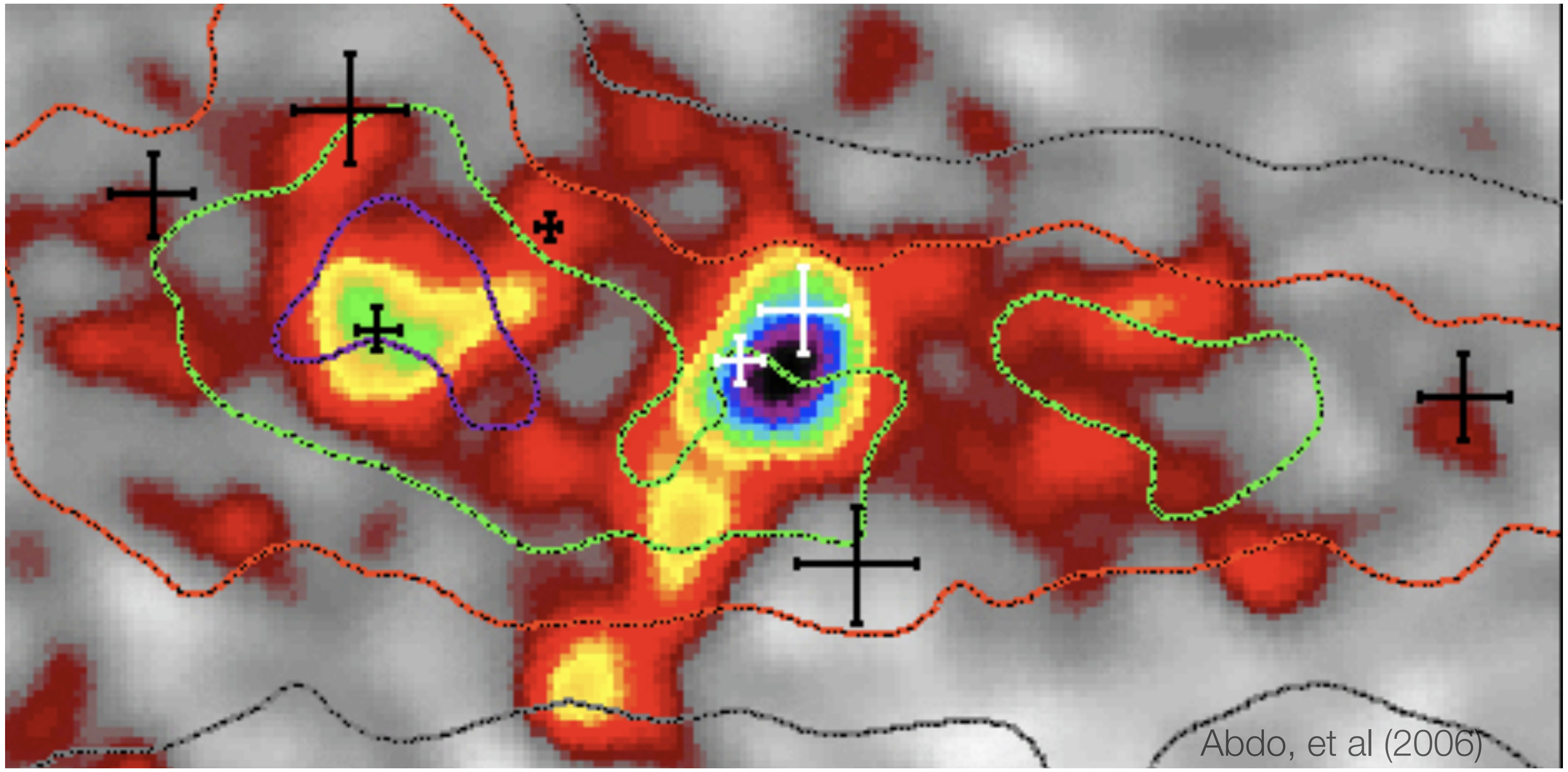
Abdo, et al (2006)



Yadigaroglu, Romani (1997)

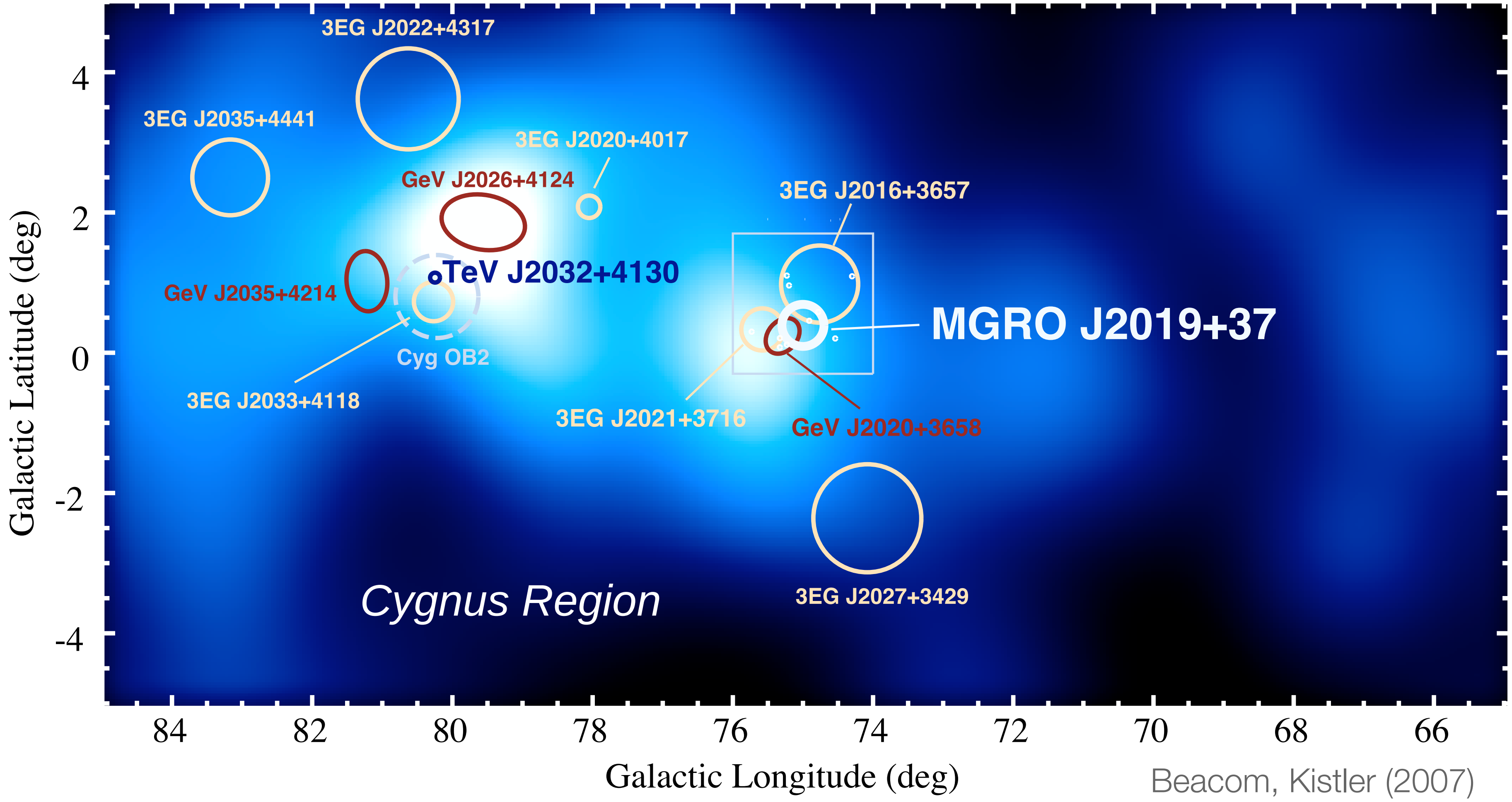
Cygnus in the TeV

Reasonable correlation between GeV/TeV diffuse



bright at ~12 TeV

unidentified

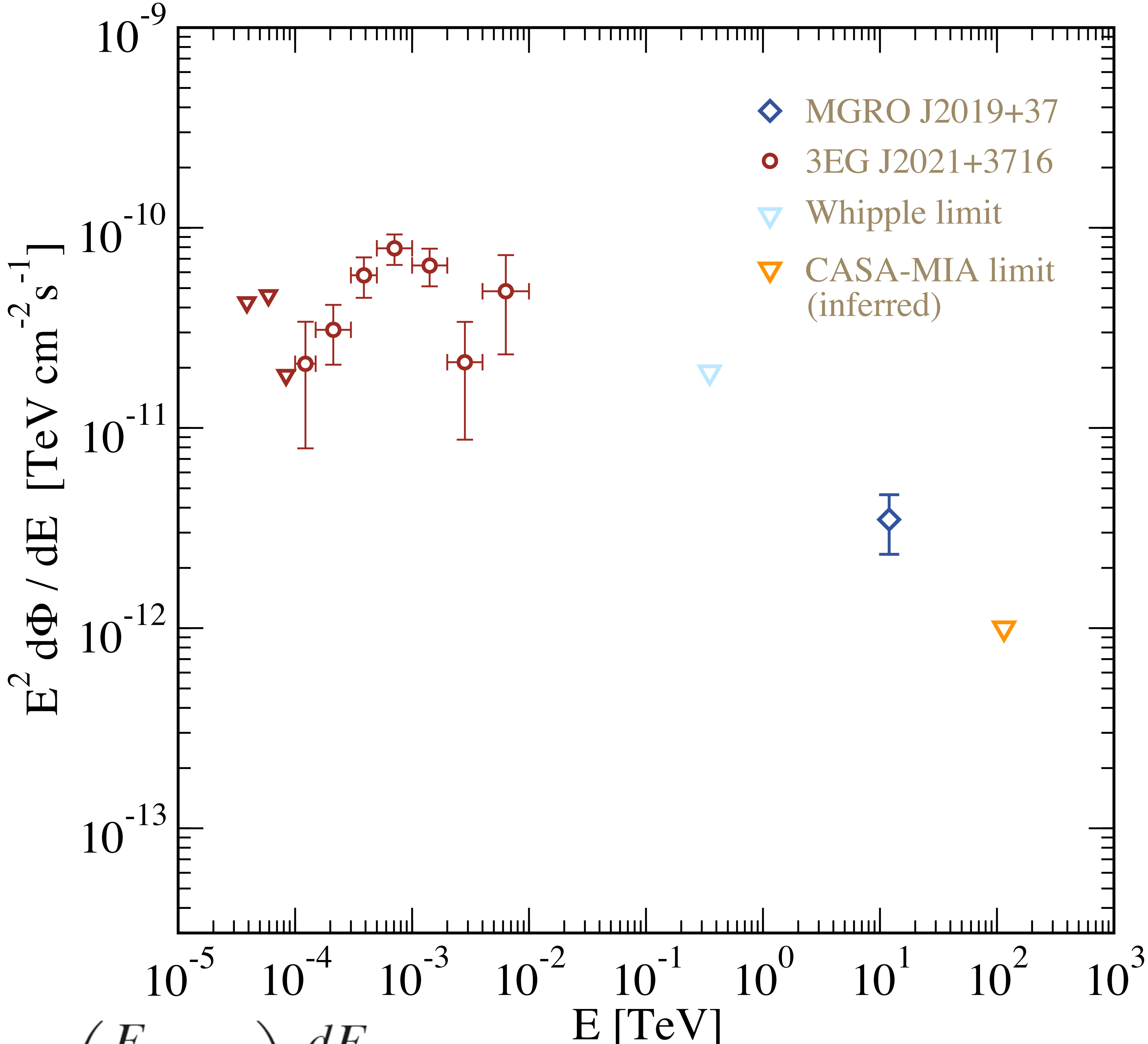


Beacom, Kistler (2007)

Constructing a spectrum

We assume a source proton spectrum of the form

$$d\Phi_p/dE_p = A_p E_p^{-\alpha} \exp\left[-\left(E_p/E_p^{\rm cut}\right)\right]$$



The decay of neutral pions produced in p-p scattering gives the spectrum:

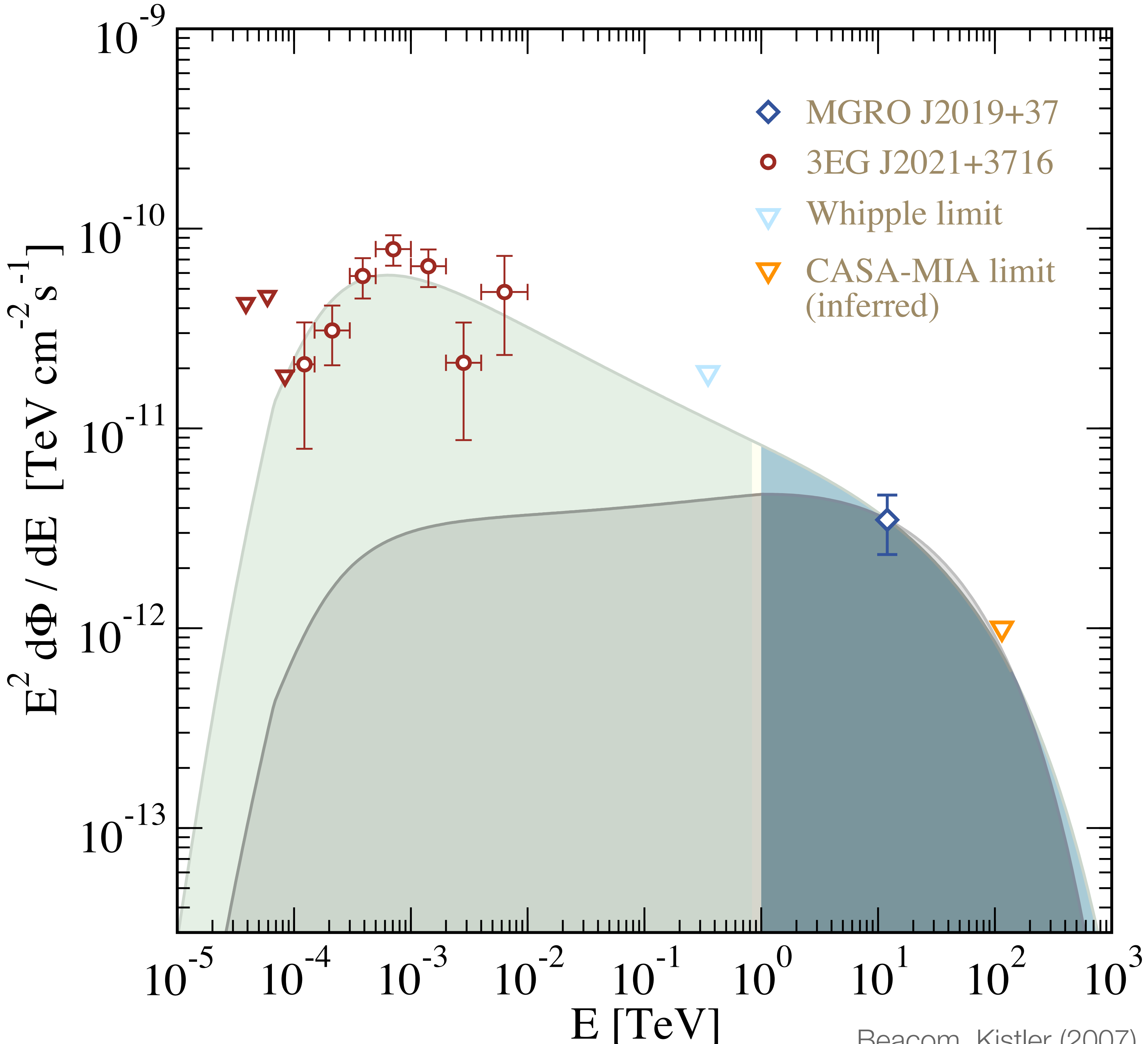
$$\frac{d\Phi_\gamma}{dE_\gamma} = c\, n_H \int_{E_\gamma}^{\infty} \sigma_{\rm inel}(E_p)\, \frac{d\Phi_p}{dE_p}\, F_\gamma\!\left(\frac{E_\gamma}{E_p}, E_p\right) \frac{dE_p}{E_p}$$

Constructing a spectrum (cont.)

First, to account for both the EGRET and Milagro measurements, we consider an $E_p^{-2.35}$ proton spectrum with $E_p^{\rm cut} = 1000$ TeV. This requires an input proton energy of

$$\mathscr{E}_p \approx 5\times 10^{50} \left(\frac{1\,{\rm cm}^{-3}}{n_H}\right)\left(\frac{\mathscr{D}}{1\,{\rm kpc}}\right)^2 {\rm erg}$$

If we do not require to fit EGRET, we can us an E_p^{-2} proton spectrum with $E_p^{\rm cut} = 500$ TeV. This reduces the energy budget.

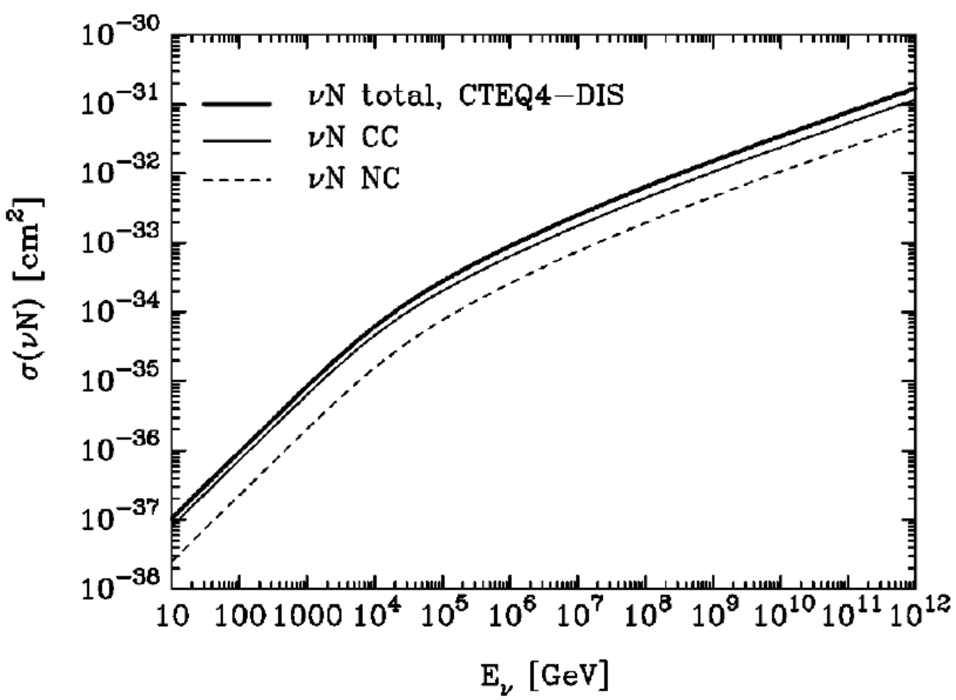


Beacom, Kistler (2007)

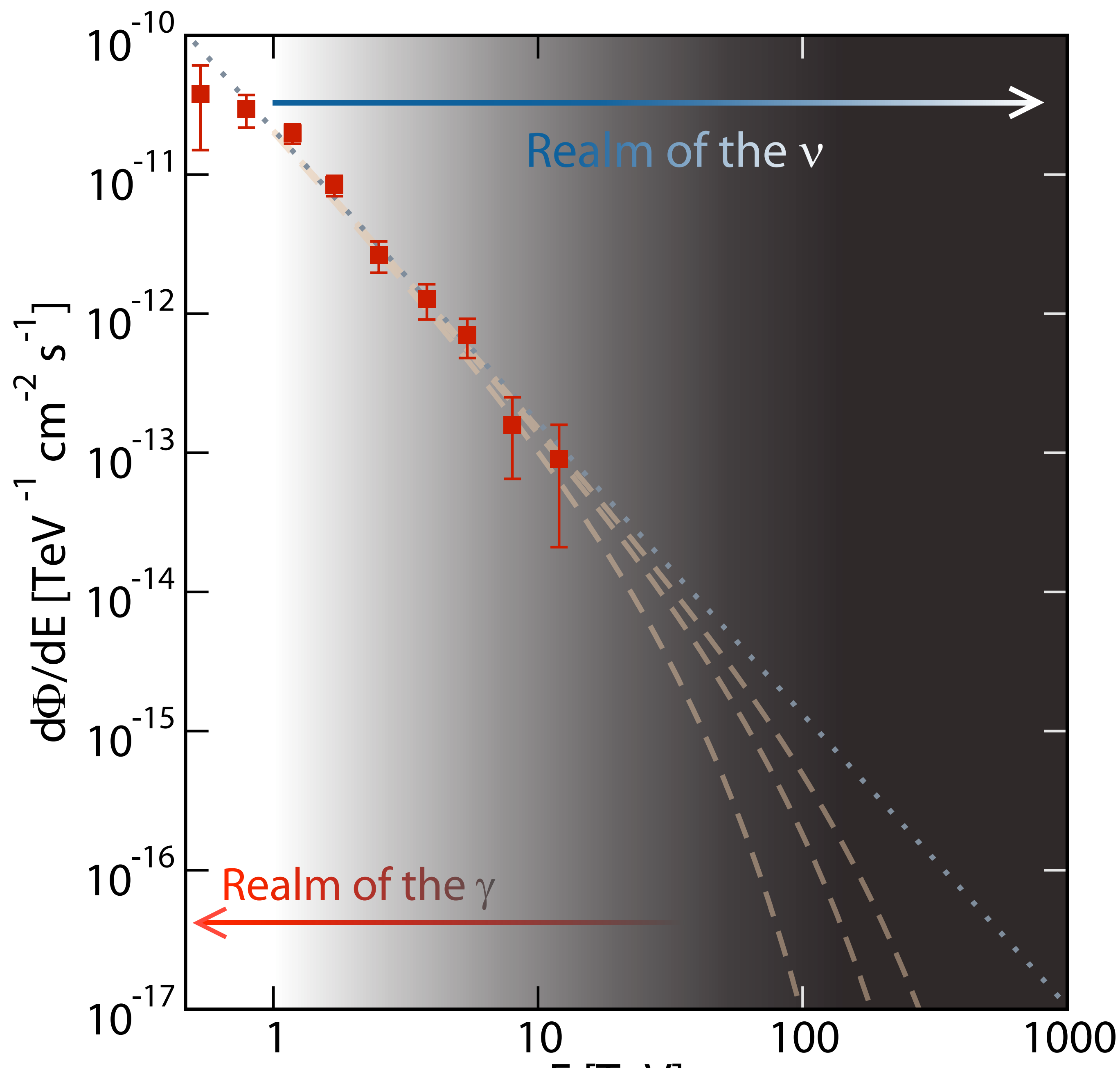
Neutrinos as weapons

IACT excellent for ~1-10 TeV, declining signal above

Neutrinos have benefits of rising cross section, increasing muon range, continuous operation, and rapidly falling background



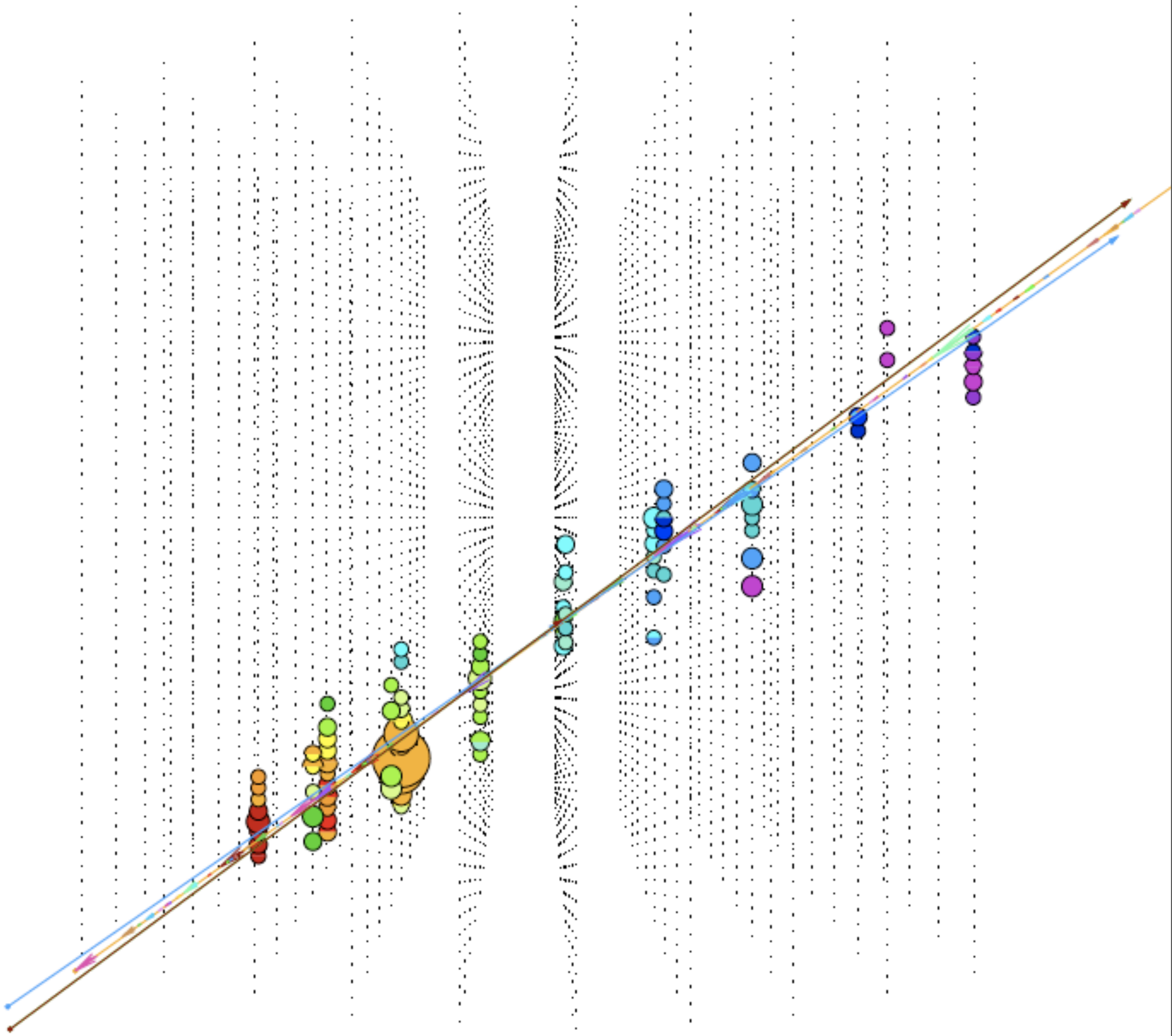
Gandhi, Quigg, Reno, Sarcevic (1998)



Kistler, Beacom (2006)

Muon neutrino detection

Background from downgoing muons and atmospheric neutrinos

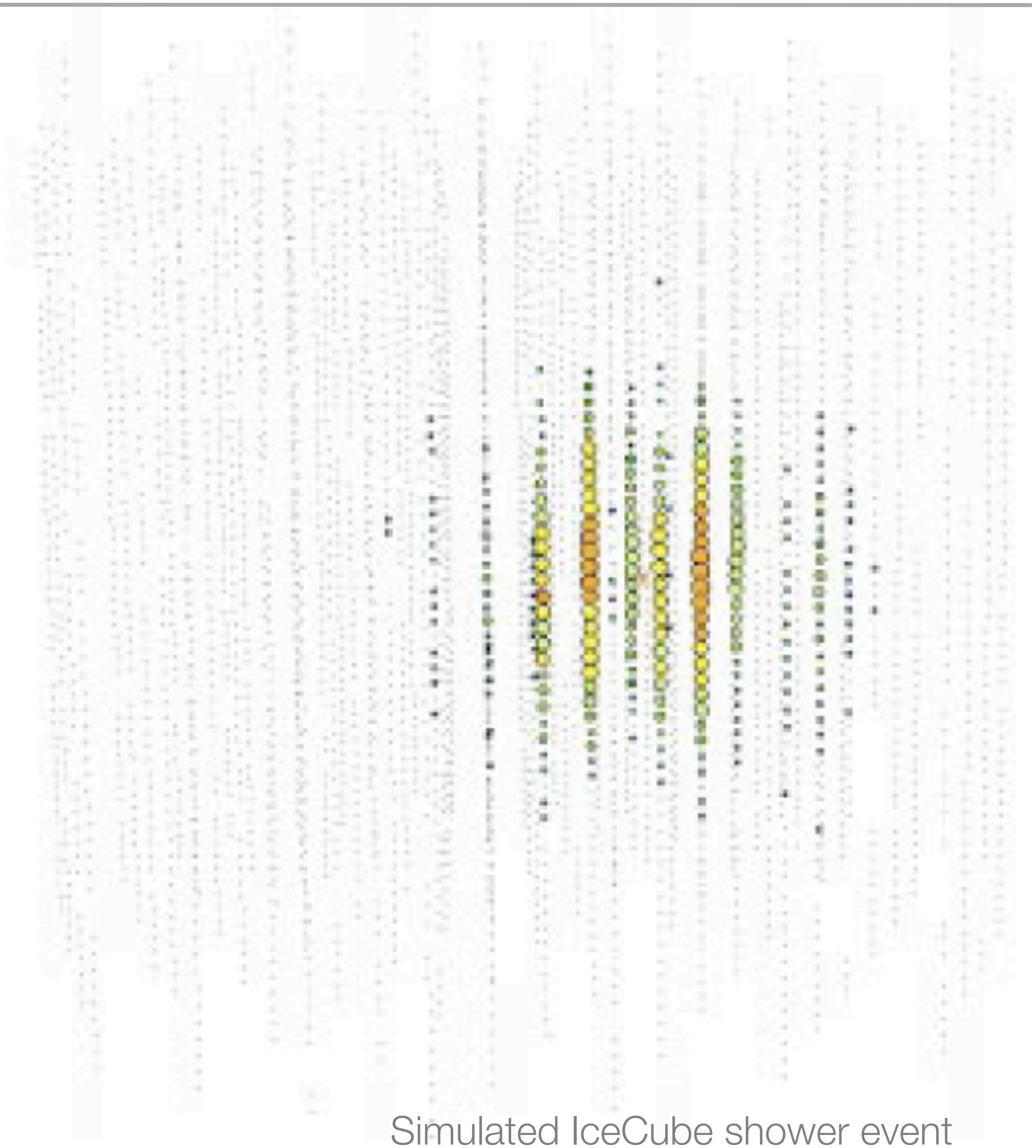


Simulated IceCube muon event

Shower events

Better energy resolution than muons, but lesser angular resolution

Makes it possible (in principle) to measure neutrino flavor ratio



Simulated IceCube shower event

Neutrinos from Cygnus

$$\nu_e : \nu_\mu : \nu_\tau = 1:2:0 \underset{\text{oscill}}{\longrightarrow} 1:1:1$$

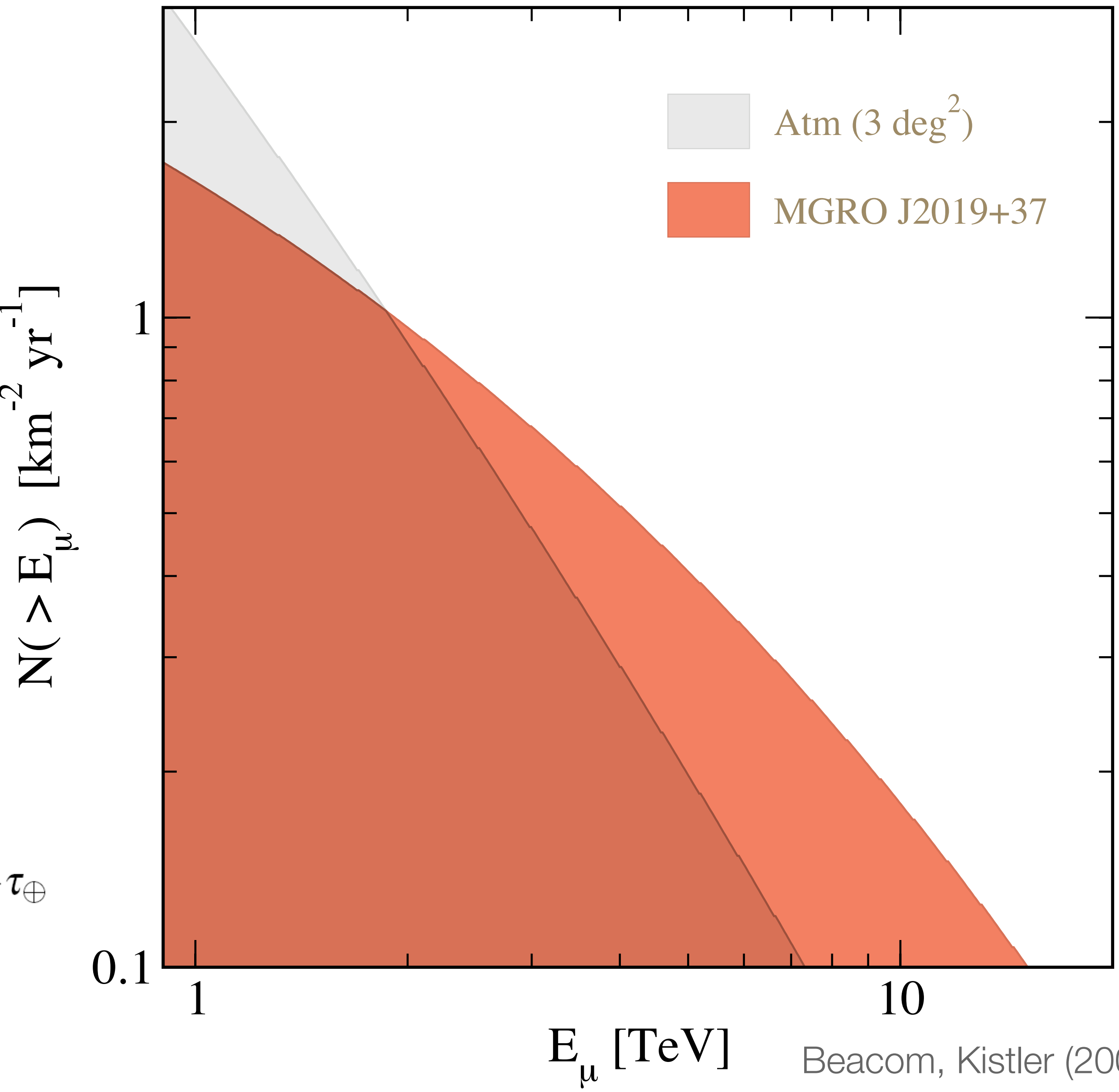
For a power law photon spectrum, the neutrino spectrum can be approximated as

$$\frac{d\Phi_\nu}{dE_\nu} = (1/2)^{\Gamma-1}\,\phi_\gamma E_\nu^{-\Gamma} = \phi_\nu\, E_\nu^{-\Gamma}$$

Neutrino spectrum in hand, we can find the spectrum of muons produced in the detector

$$\left(\frac{dN_\mu}{dE_\mu}\right)_{\text{cont}} =$$

$$N_A\,\rho\,T\,\langle 1-y(E_\nu)\rangle^{-1} V_{\text{det}}\,\frac{d\Phi_\nu}{dE_\nu}\,e^{-E_\nu/E_\nu^{\text{cut}}}\,\sigma_{CC}(E_\nu)\,e^{-\tau_\oplus}$$



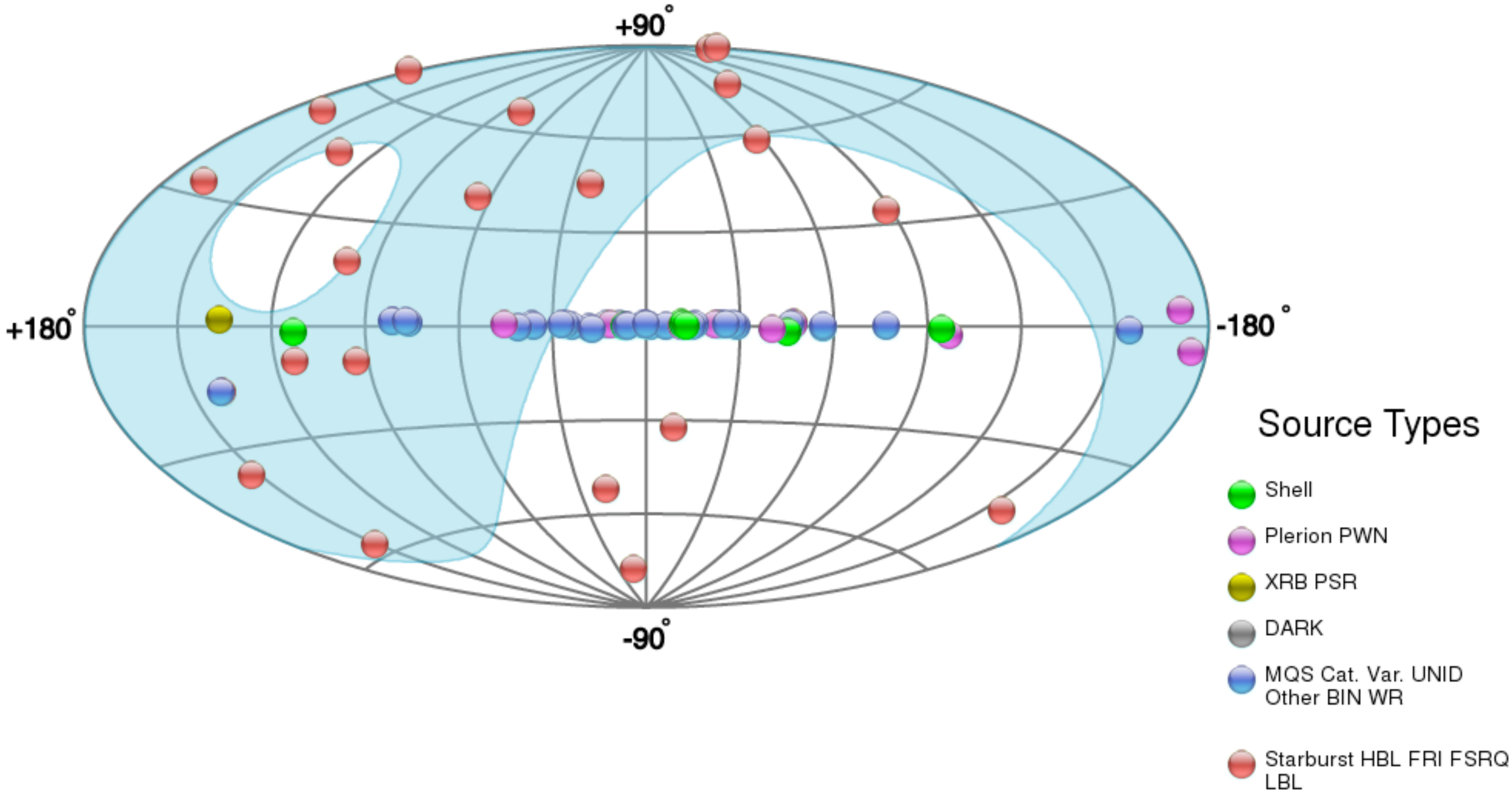
Beacom, Kistler (2007)

Using the expression for continuous muon energy loss: $\frac{dE}{dX} = -\alpha - \beta E$

we find the thrugoing muon spectrum

$$\left(\frac{dN_\mu}{dE_\mu}\right)_{\text{thru}} = \frac{N_A\,\rho\,T\,A_{\text{det}}}{\alpha+\beta E_\mu} \times \int_{E_\mu}^{\infty} dE_\nu \frac{d\Phi_\nu}{dE_\nu}\,e^{-E_\nu/E_\nu^{\text{cut}}}\,\sigma_{CC}(E_\nu)\,e^{-\tau_\oplus}$$

TeV scorecard

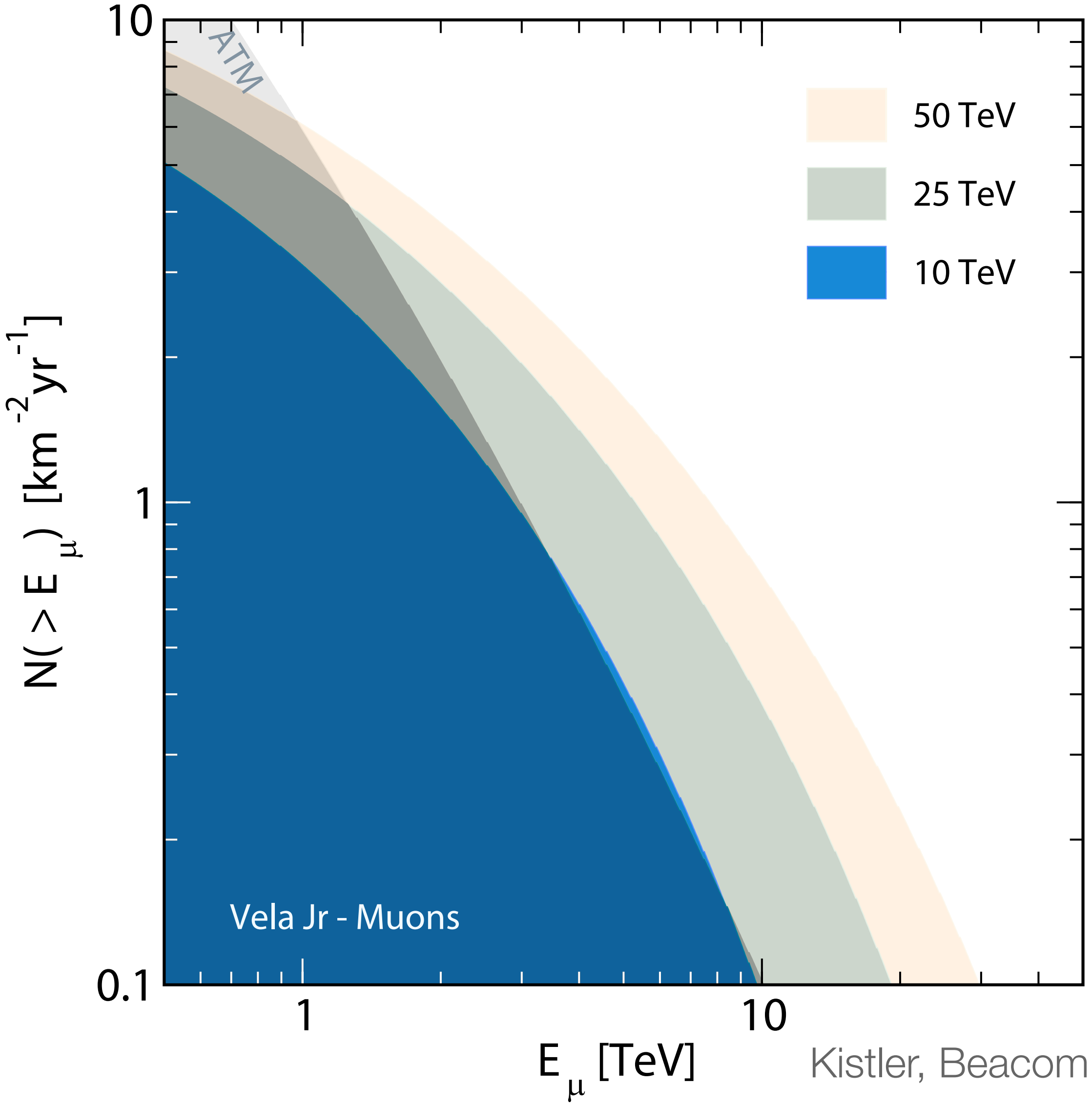


tevcat - 3/2009

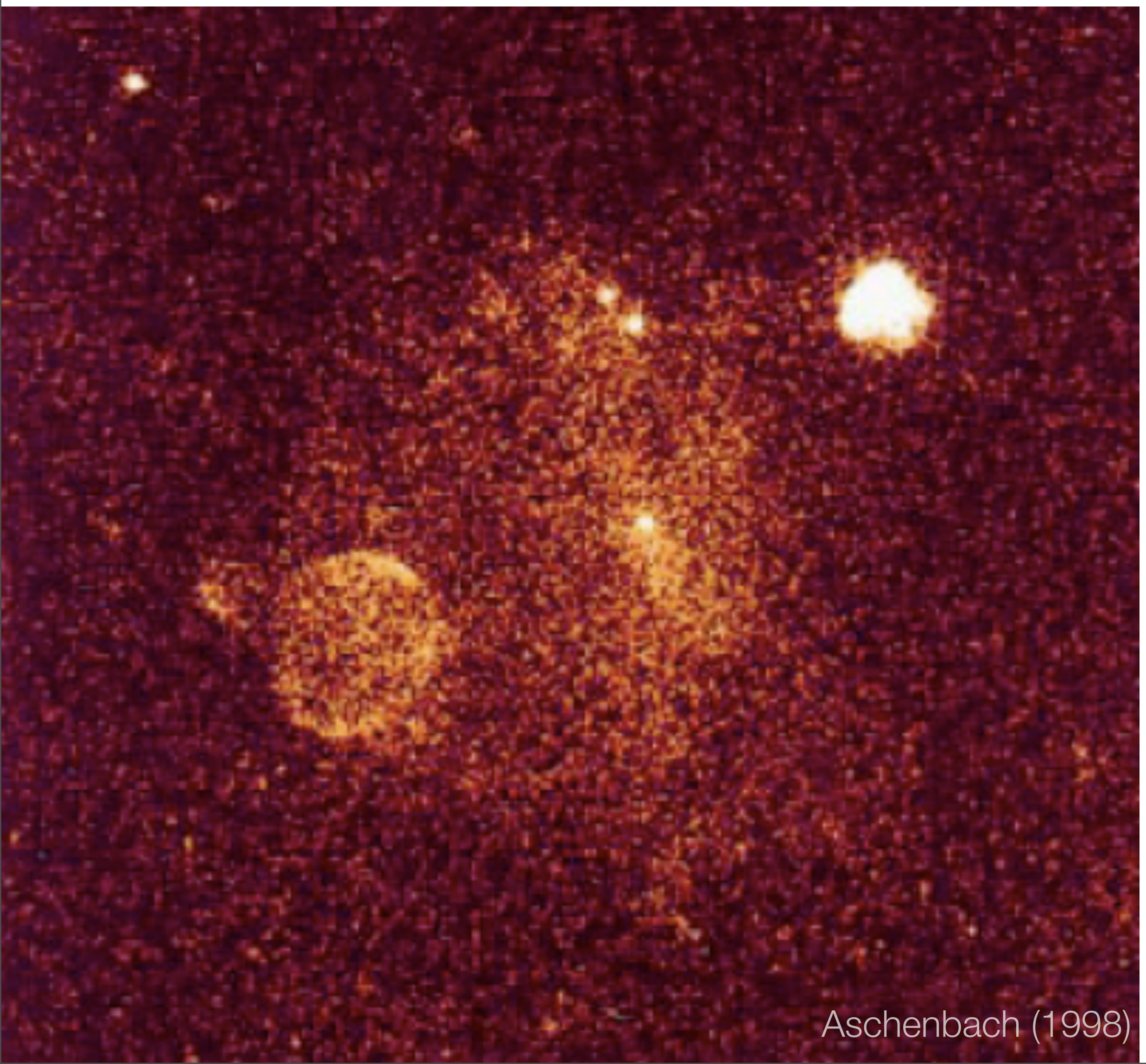
Vela Junior

Bright, shell-type SNR

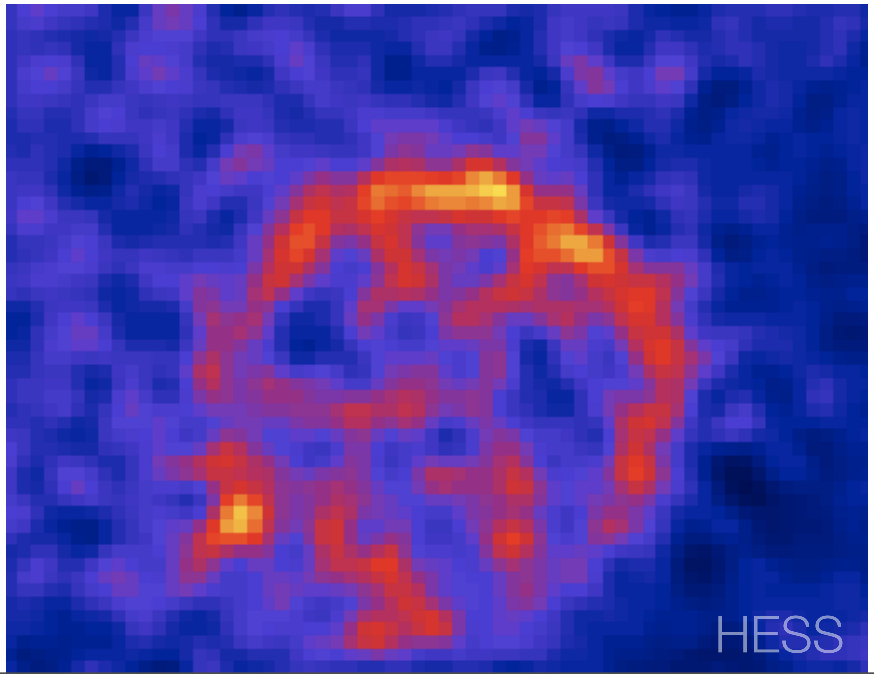
Southern sky source



Kistler, Beacom (2006)



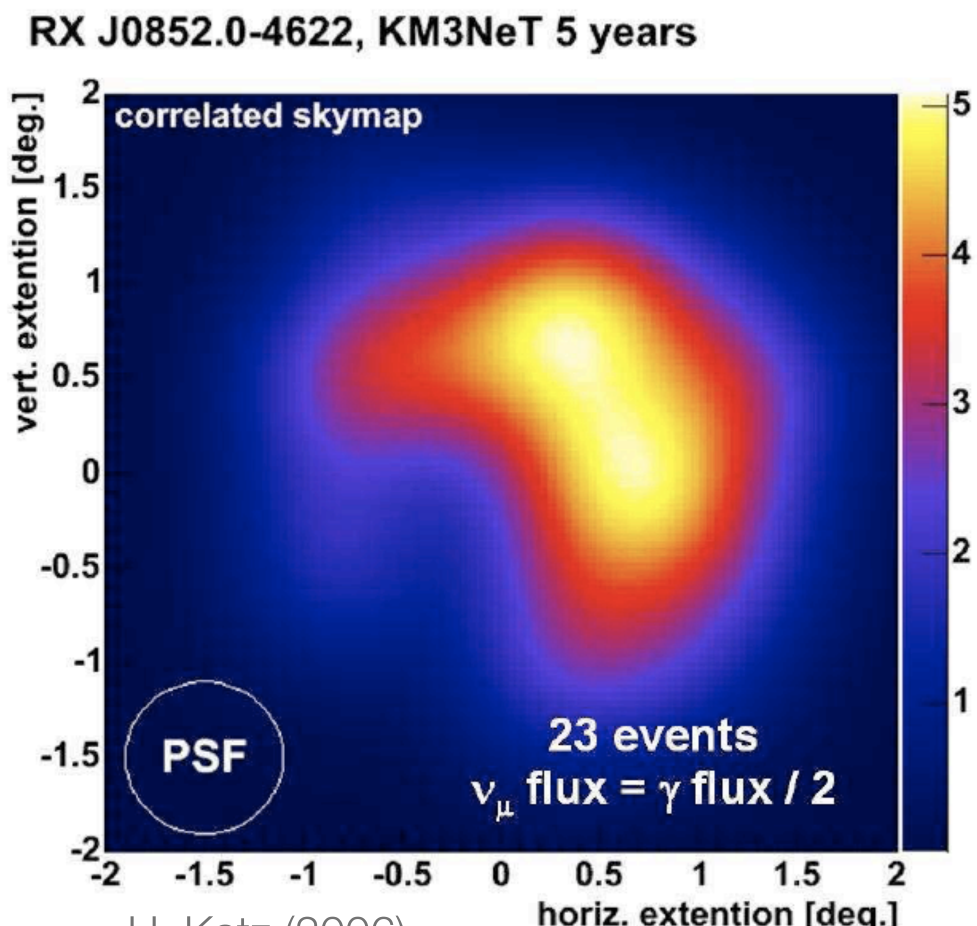
Aschenbach (1998)



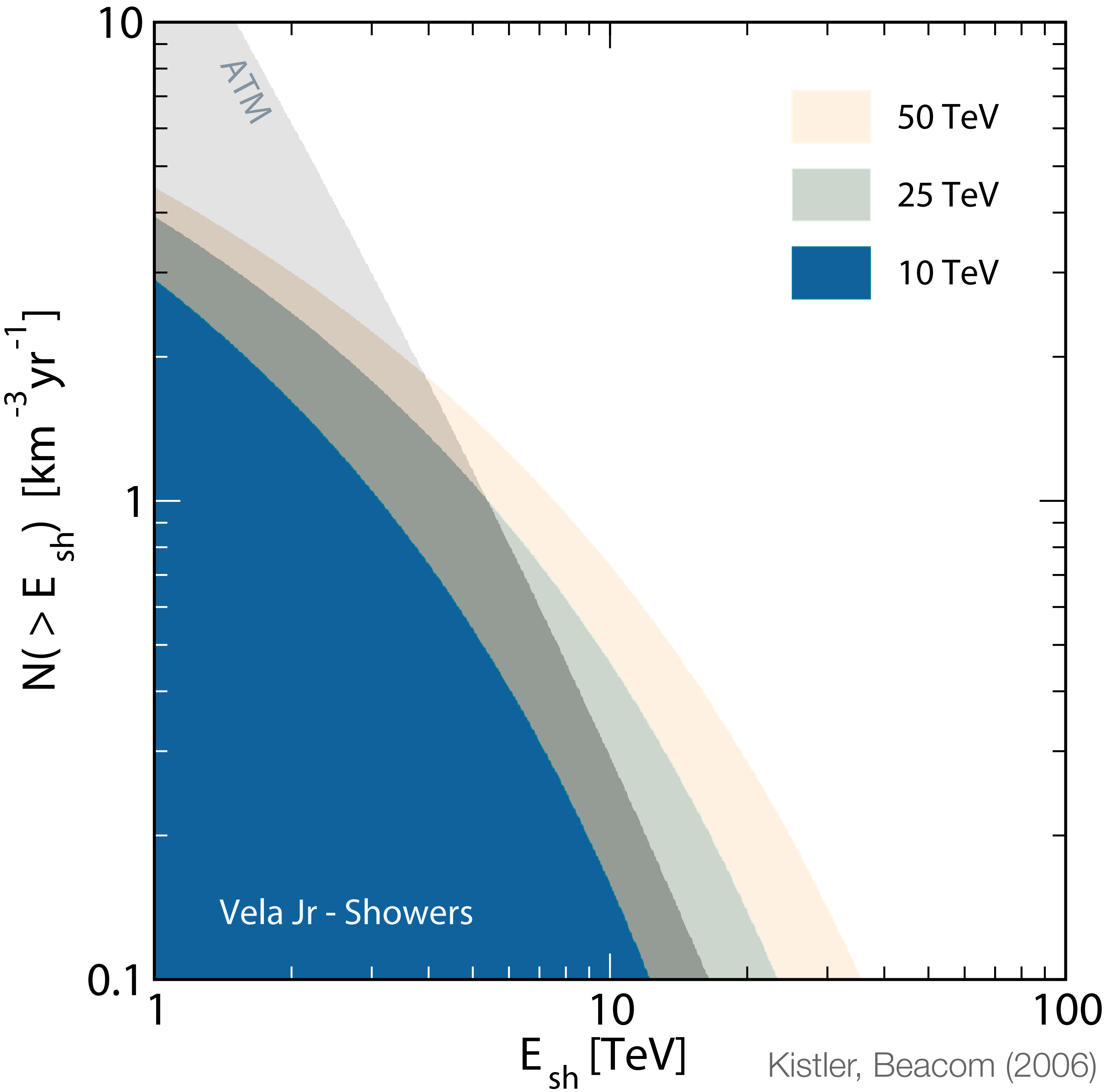
HESS

Vela Junior Showers

Potential for shower measurements and possibly a neutrino map



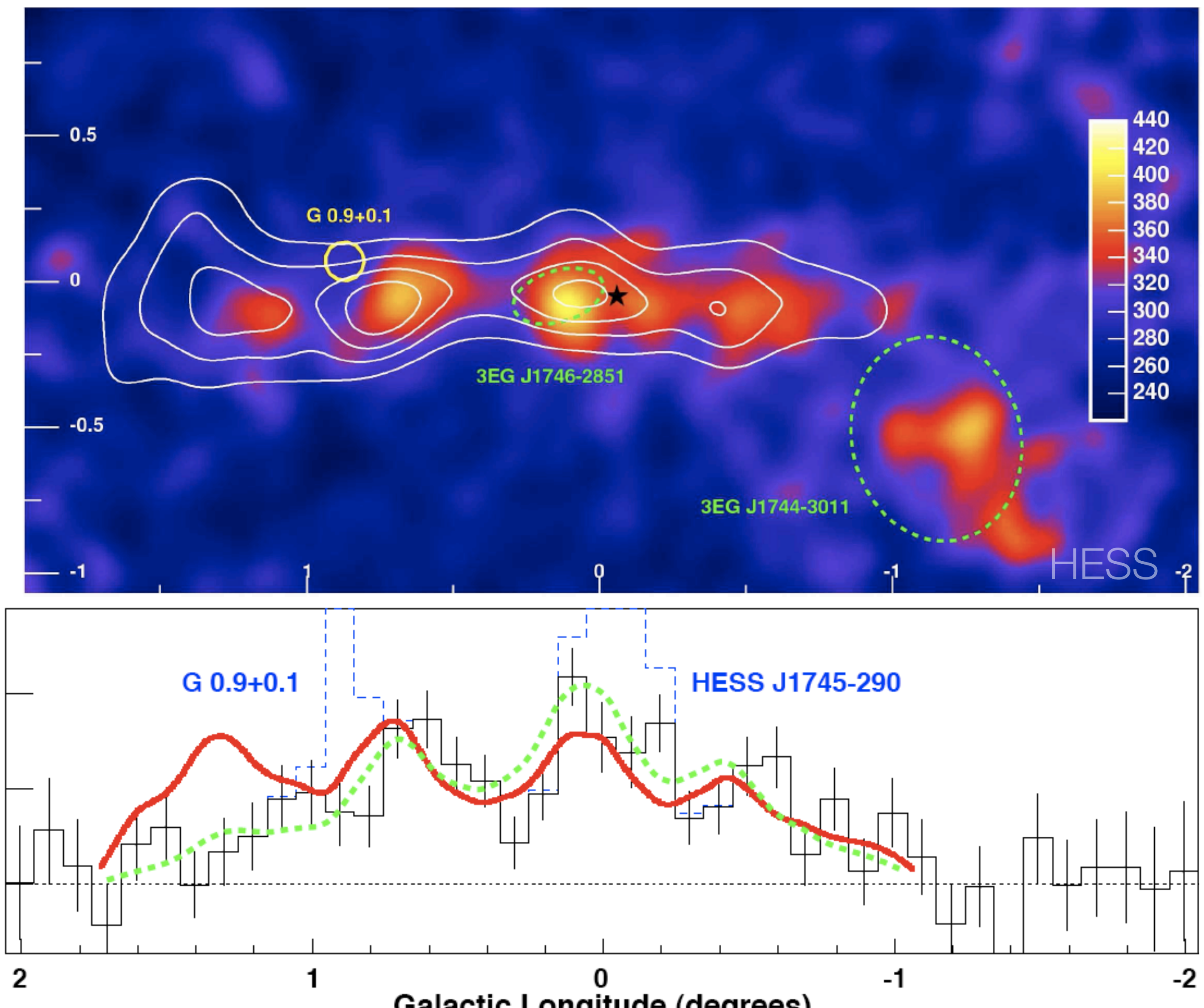
U. Katz (2006)

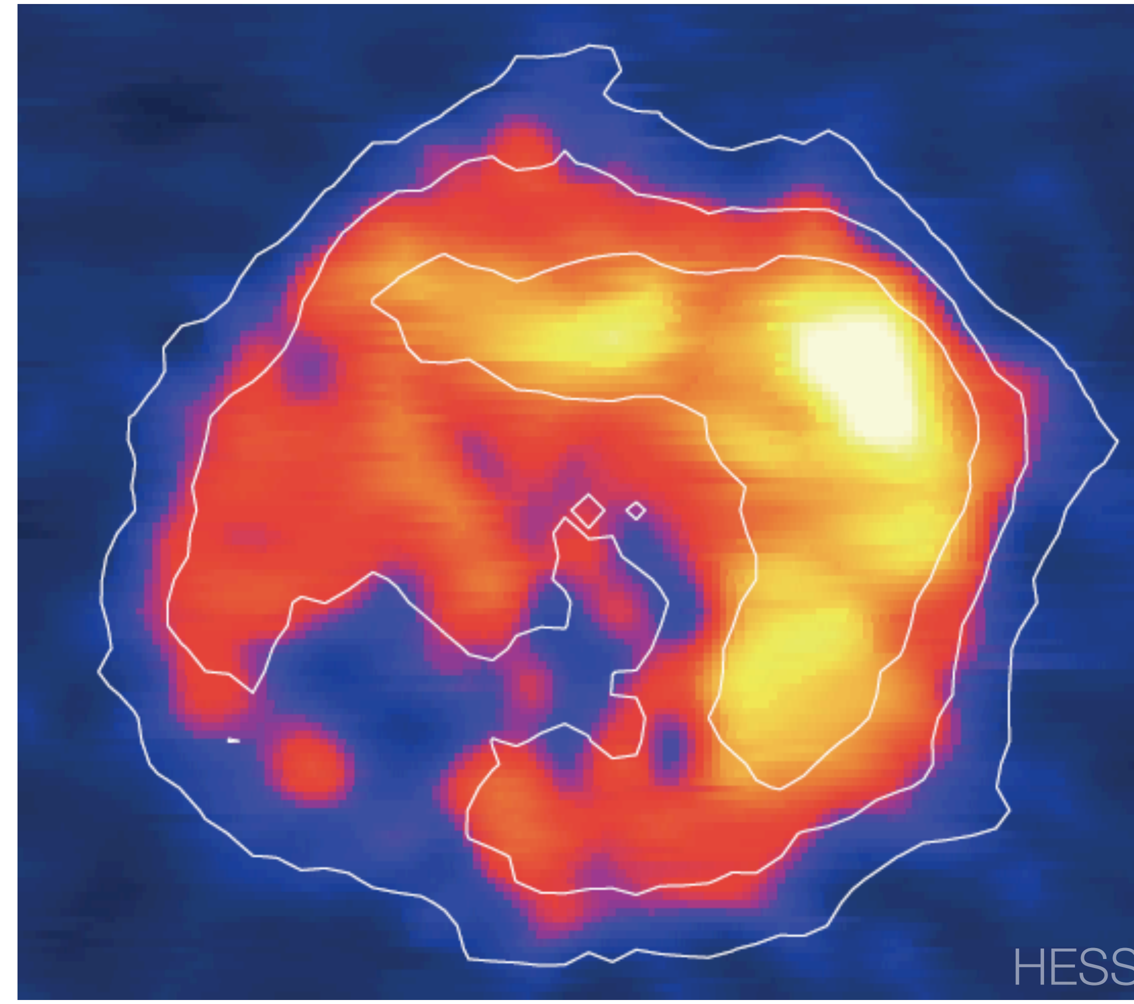


Kistler, Beacom (2006)

GCD and RX J1713.7-3946

Diffuse TeV emission from Galactic Center well-correlated with molecular clouds (most likely pionic)





RX J1713.7-3946

(Alvarez-Muniz and Halzen (2002); Costantini and Vissani (2005))

Potential for a few events/year

Expected yearly rates

Several	Few	Any?
Vela Junior	MGRO J2019	Crab
	RX J1713	Vela X
	GC Region	

Many other TeV sources may also be prospective neutrino sources, but the above are the most promising

The confirmed observation of high energy neutrinos from any such source would confirm a cosmic-ray accelerator

The Good, the Bad, ...

Strongside	Weakside
DC bigger, better than AMANDA	DC smaller than IC-Mantle
IceCube being built	Earth upside down
No Earth attenuation when looking up	1/1000th the overburden
Showers care about volume	What are the shower capabilities?

Summary - Observable Fluxes?

COSMIC RAYS FROM SUPER-NOVAE

By W. Baade and F. Zwicky

Mount Wilson Observatory, Carnegie Institution of Washington and California Institute of Technology, Pasadena

Communicated March 19, 1934

TeV gamma-ray observations offer enticing clues towards the origin of Galactic cosmic rays

Measurement of neutrino fluxes will clinch both cosmic-ray birthplaces and gamma-ray production

What about the south?