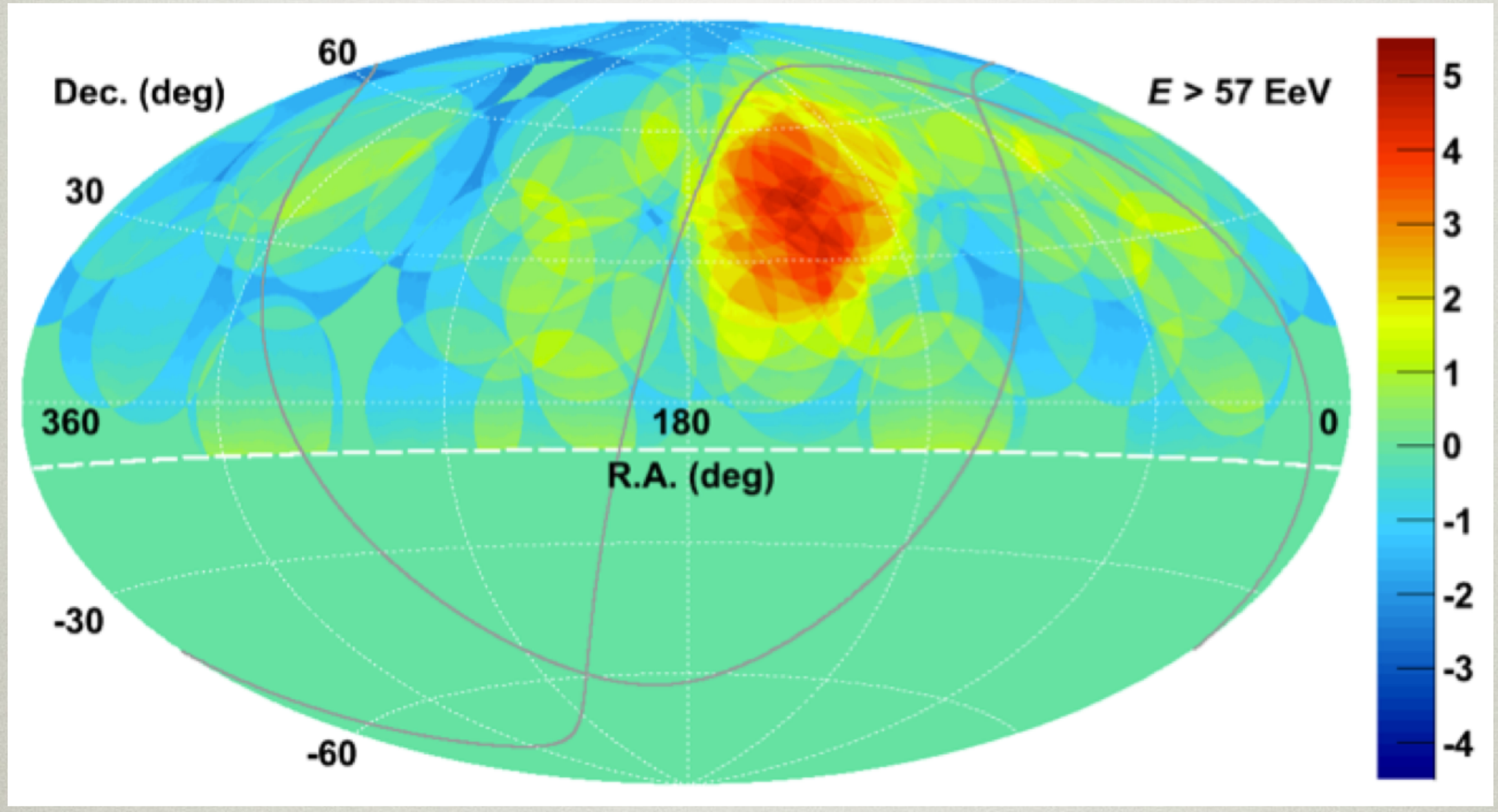
The TA Cosmic Ray Excess and High Energy Neutrinos

Ke Fang

High-Energy Messenger Workshop

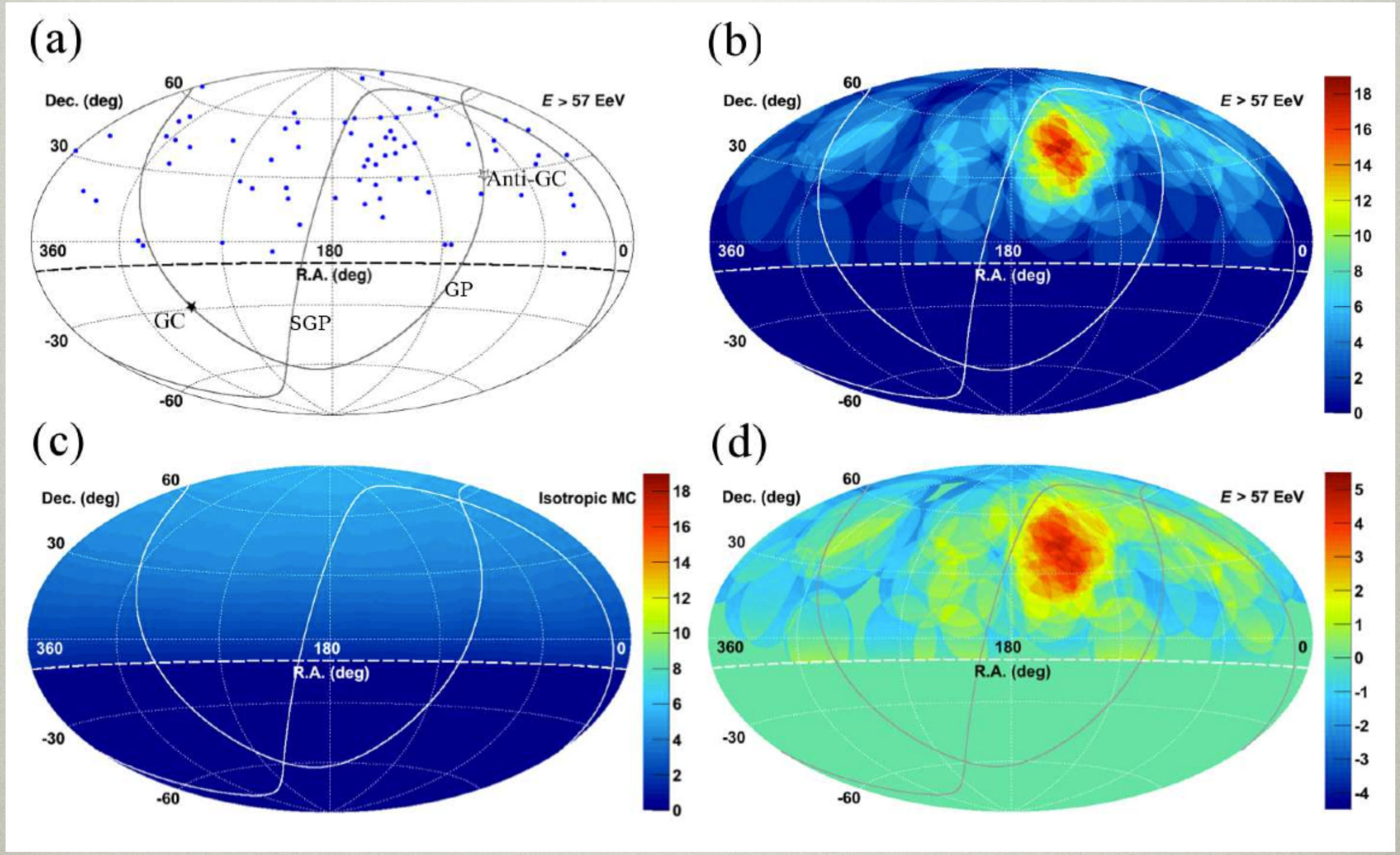
June 11, 2014

5-sigma TA UHECR excess

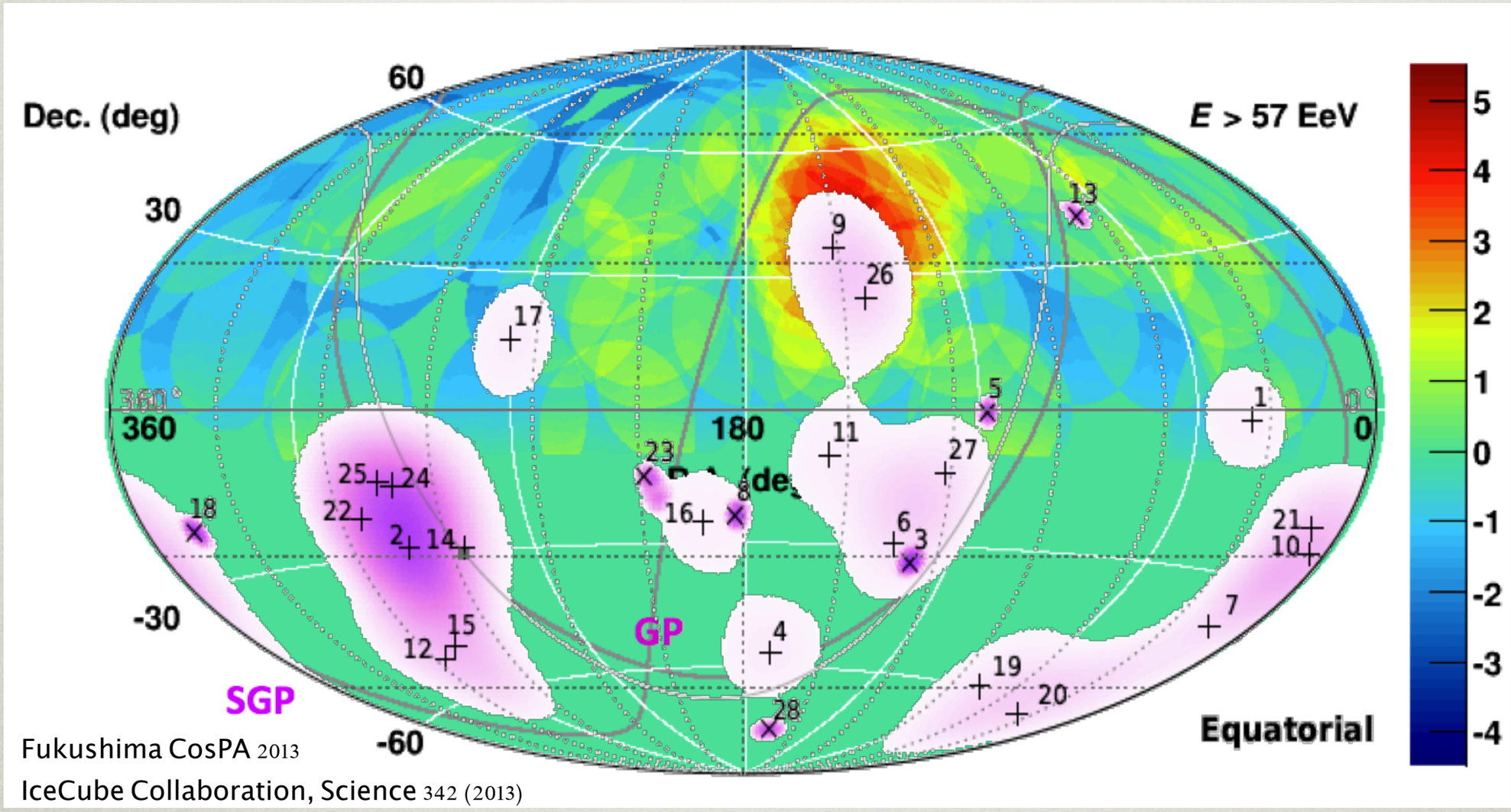


a cluster of events of 5.1σ significance, found using 20 degree radius oversampling centered at R.A. = 146.7, Dec. = 43.2.

Intermediate-Scale Anisotropy of Cosmic Rays with Energy > 57 EeV measured by TA



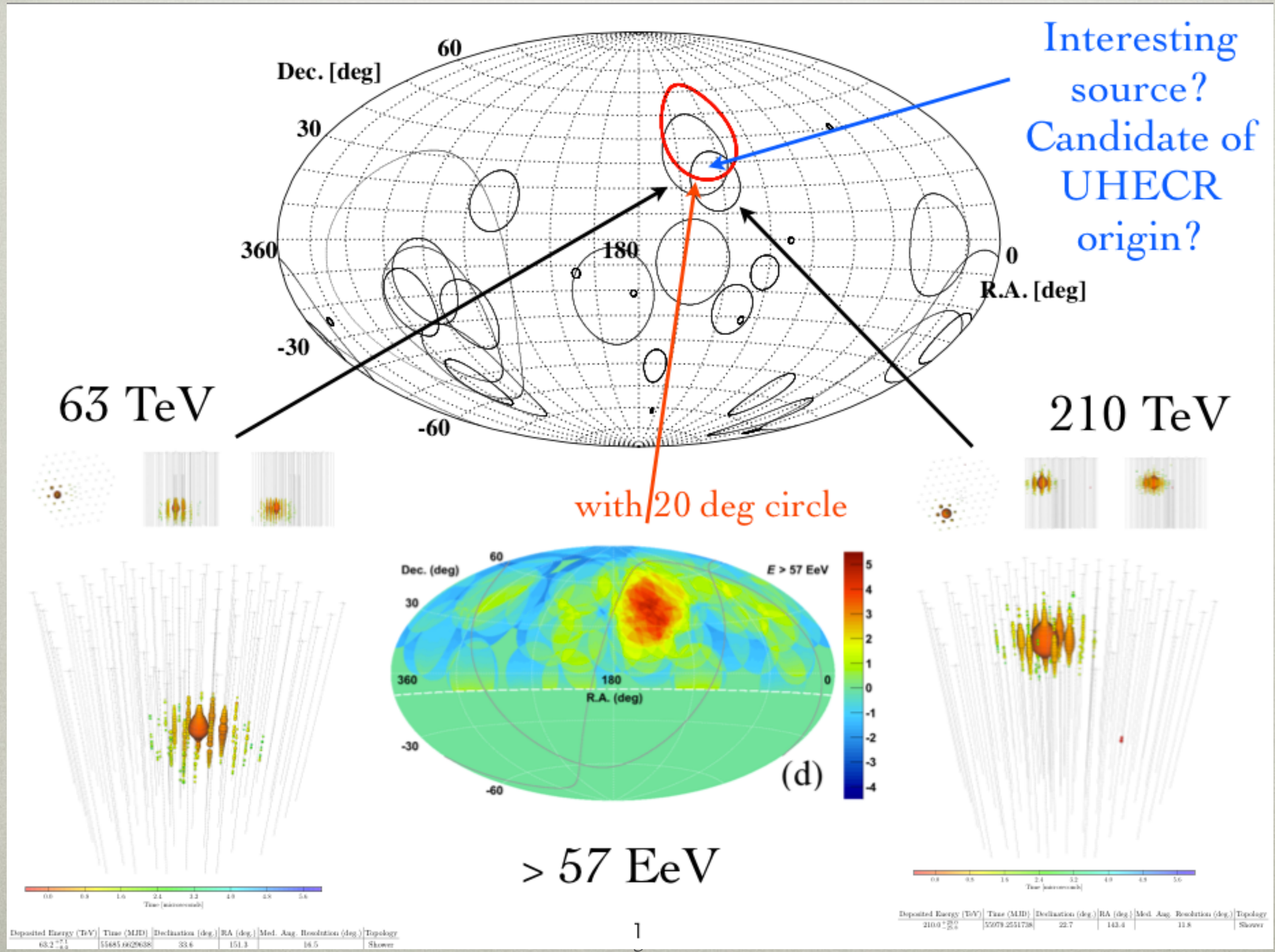
An interesting “coincidence” - TA & IceCube



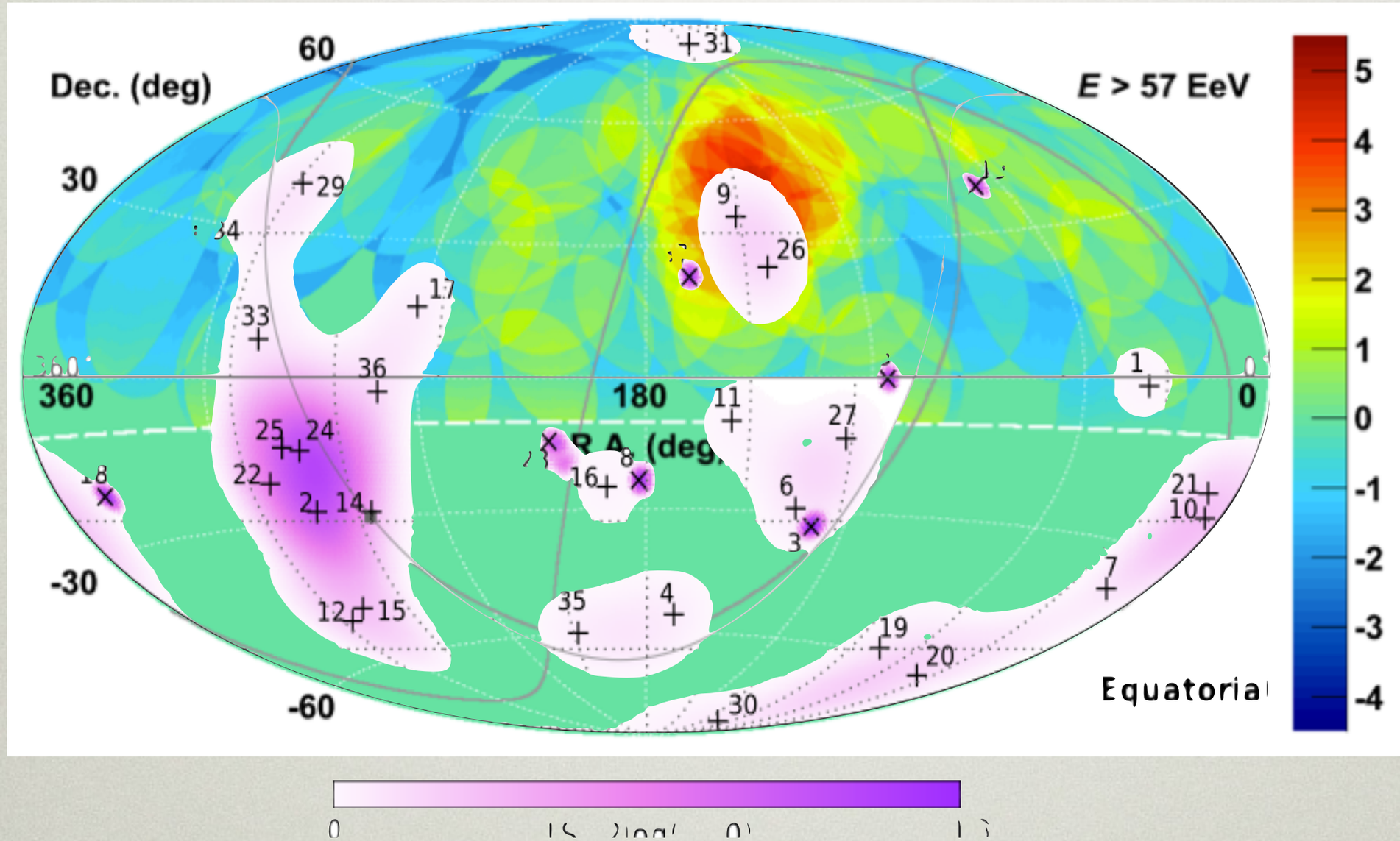
Fukushima CosPA 2013

IceCube Collaboration, Science 342 (2013)

An interesting "coincidence" - TA & IceCube



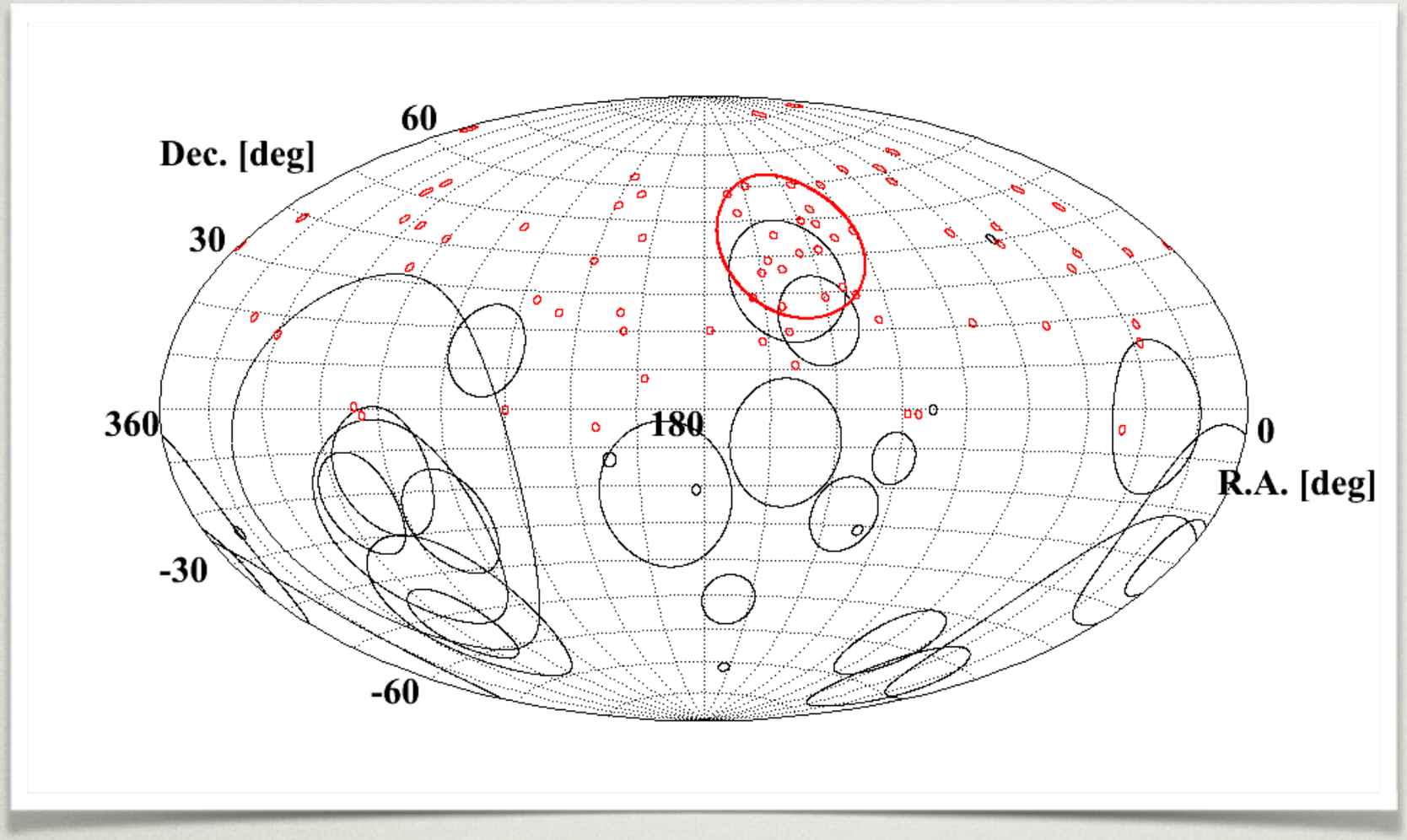
An interesting "coincidence" - TA & IceCube with 3 year IceCube data



TA: Abbasi et al 2014, 1404.5890
IceCube: Aartsen et al 2014, 1405.5303

The same origin? - Significance

KF, Toshihiro, Linden, Olinto 2014
arXiv: 1404.6237

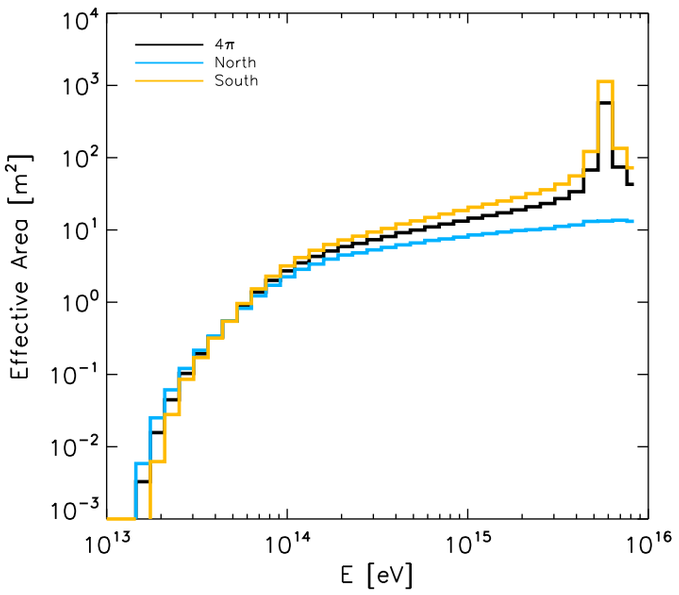


Assuming a flat effective detection area, The hotspot has 2 out of the 4 IceCube events in north hemisphere

=> coincidence rejected at 2.1 sigma

“Preferred” spectrum index by the two neutrinos

IceCube Collaboration, Science 342 (2013)



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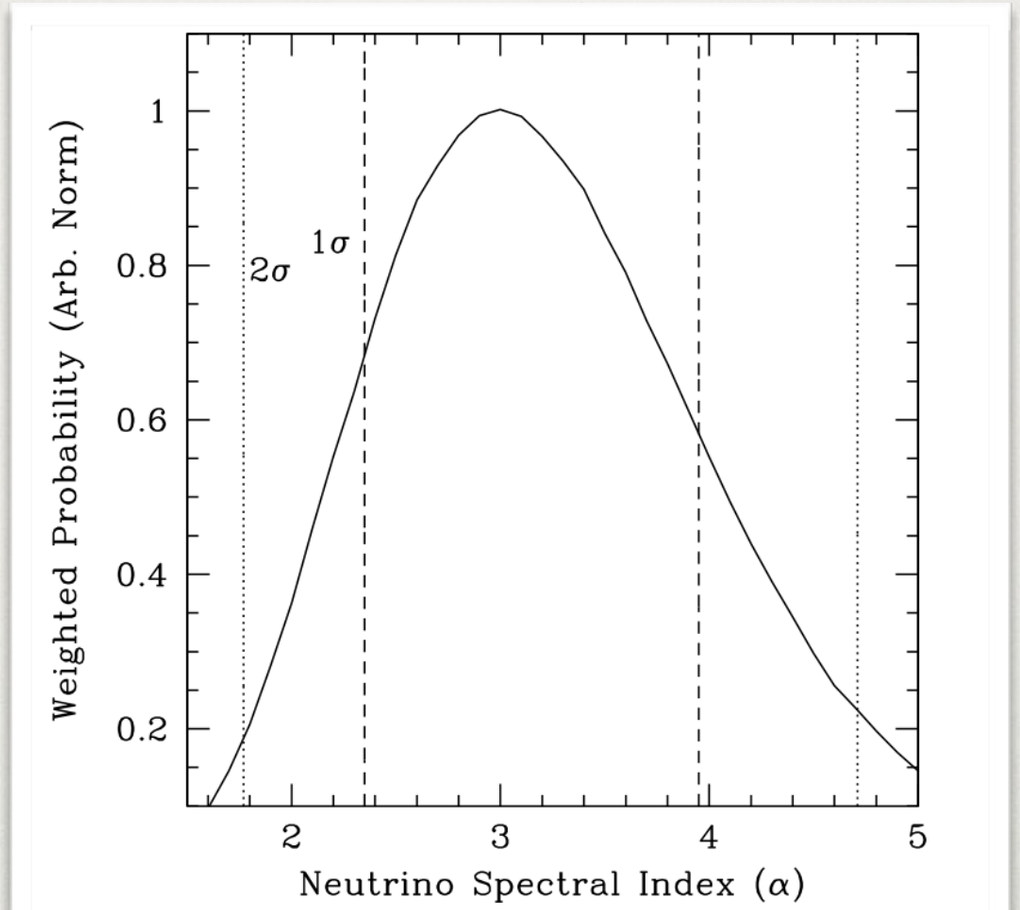


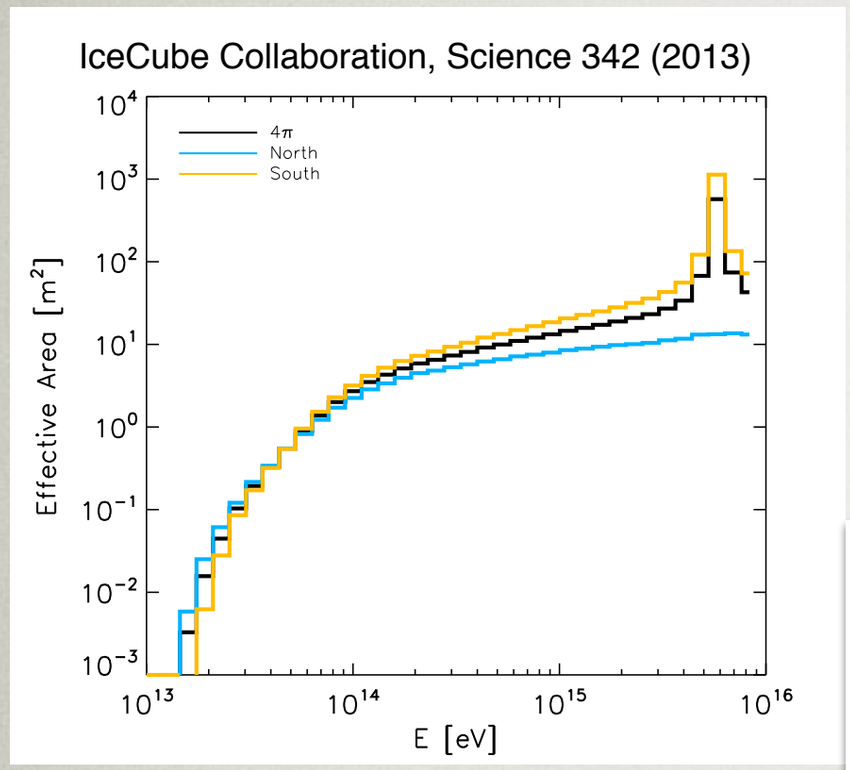
a flat prior on the spectral index

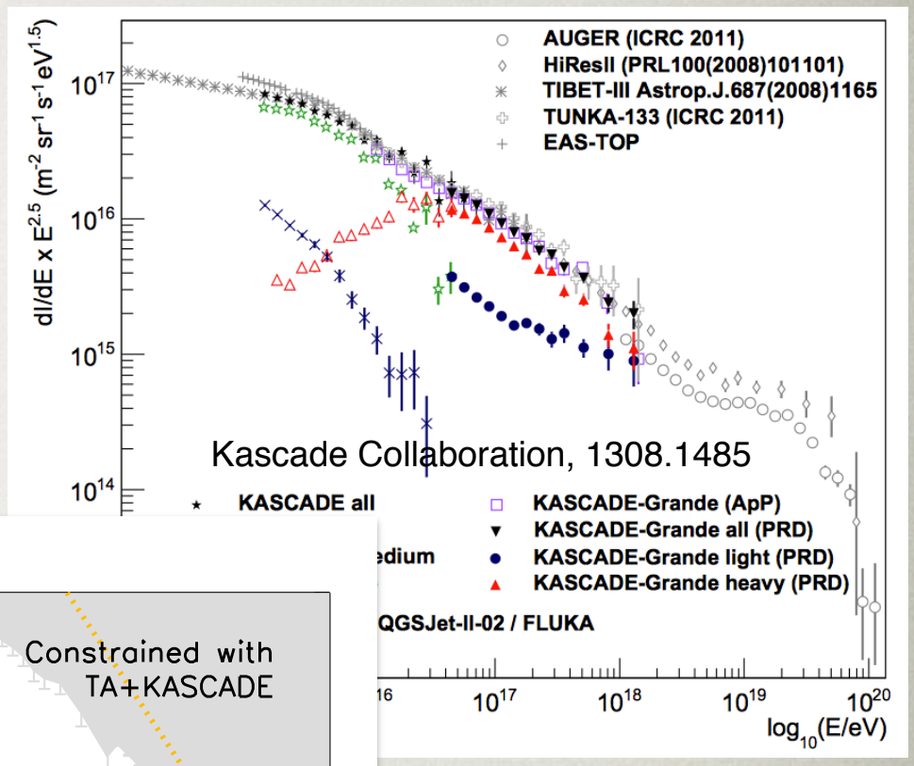
a Monte Carlo population of neutrinos for each spectral index.

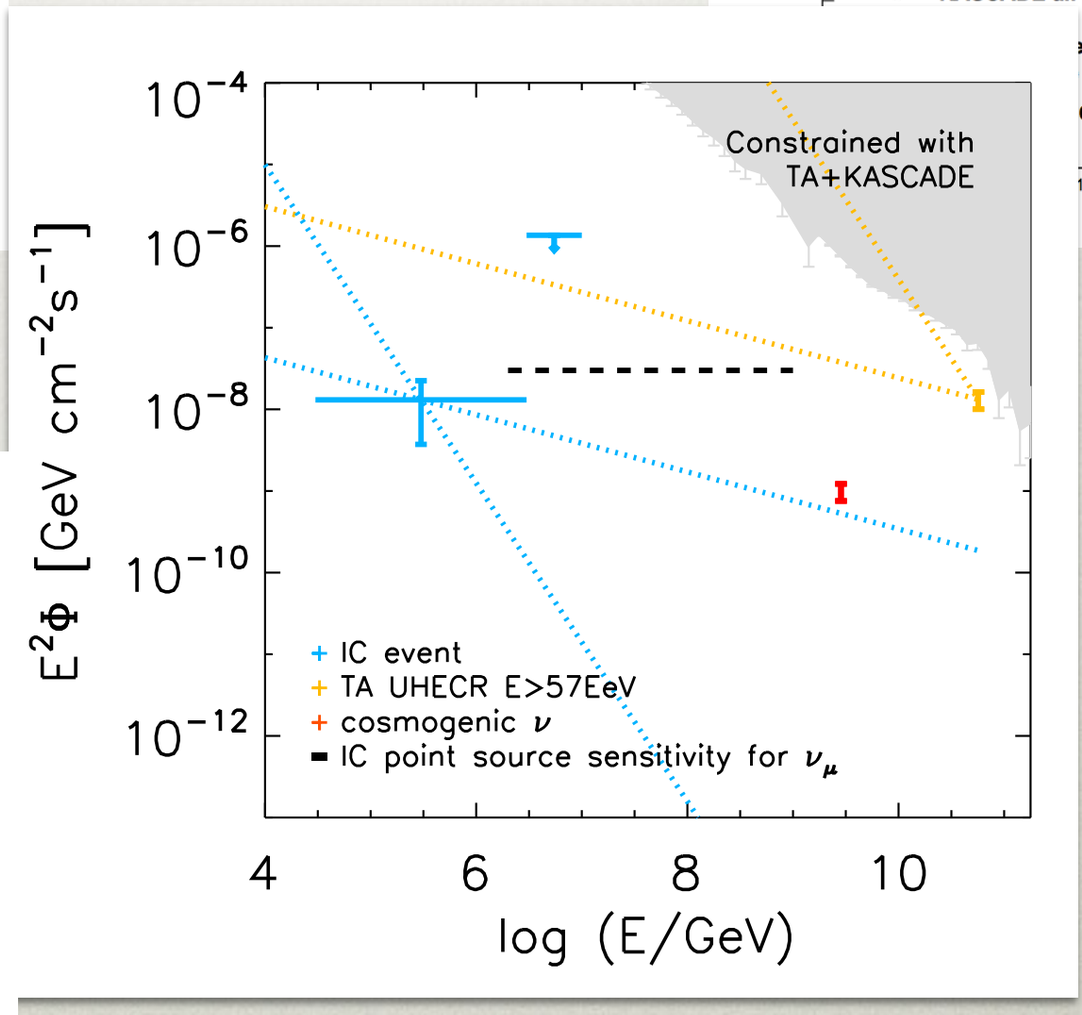
Weighting the spectrum by the energy dependent effective area

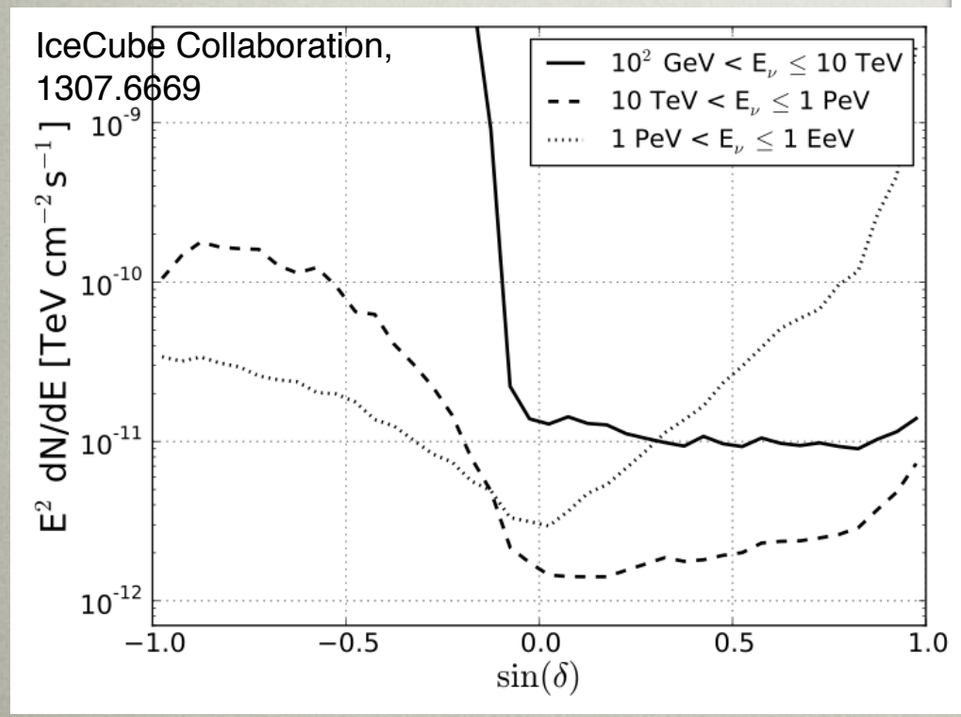
=> relative likelihood that emission spectra with varying spectral indices would produce the observed data.

The same origin? - Flux









KF, Toshihiro, Linden, Olinto 2014
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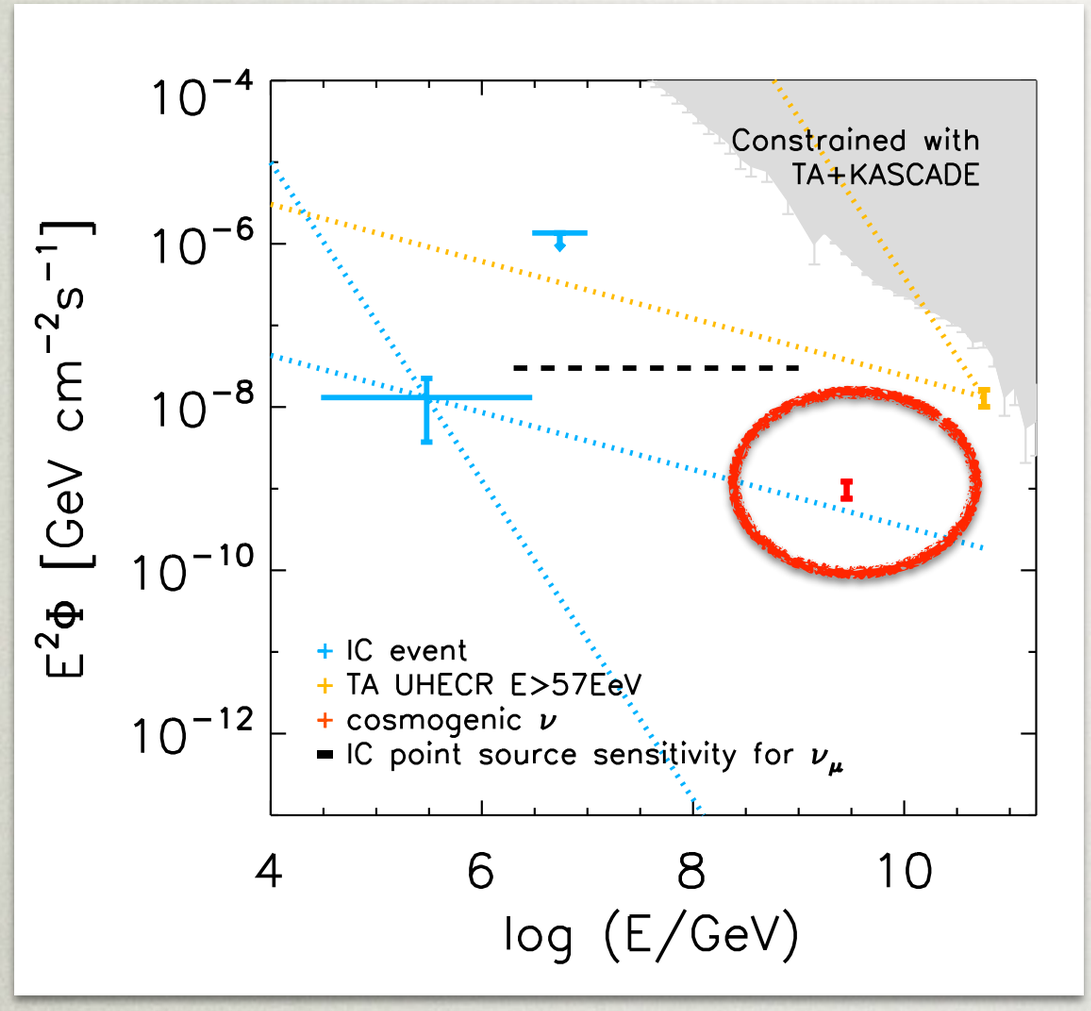


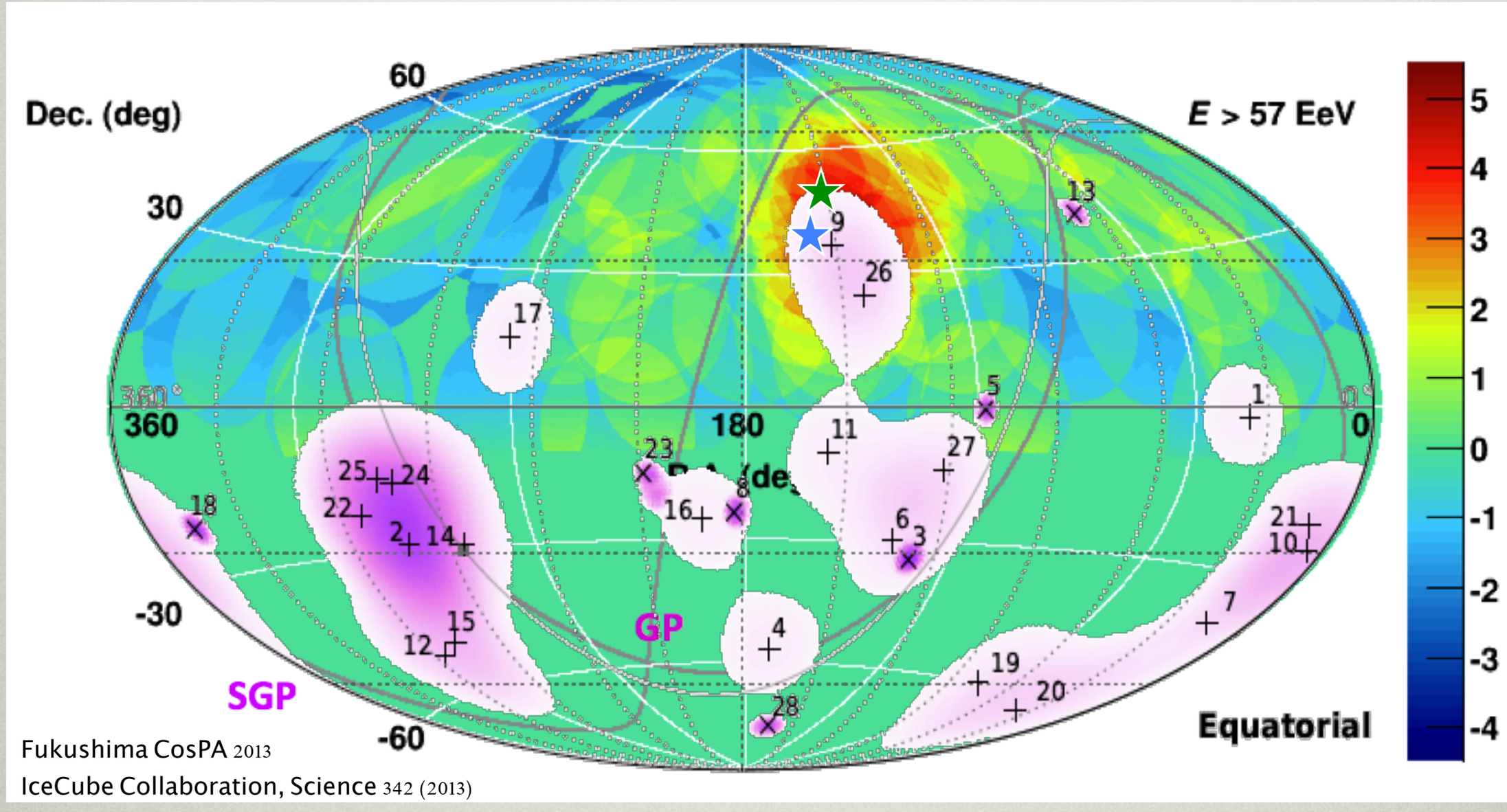
Upper limit of Cosmogenic Neutrinos

$$E^2 J_H = E^2 J(E)_{4\pi} \left(\frac{N_H}{N_{4\pi}}\right)\left(\frac{4\pi}{\Omega_{20^\circ}}\right)\left(\frac{A_{4\pi}}{A_H}\right)$$
$$= (4.4 \pm 1.0) \times 10^{-8} \left(\frac{E}{10^{19.5}\,\mathrm{eV}}\right)^{-2.6} \frac{\mathrm{GeV}}{\mathrm{cm^2\,s\,sr}}$$
$$E_\nu^2 \Phi_\nu = 3/8\, E^2 J(E)_{\mathrm{H}}\, f_\pi$$

Flux levels of UHECRs and neutrinos are consistent with a single source scenario

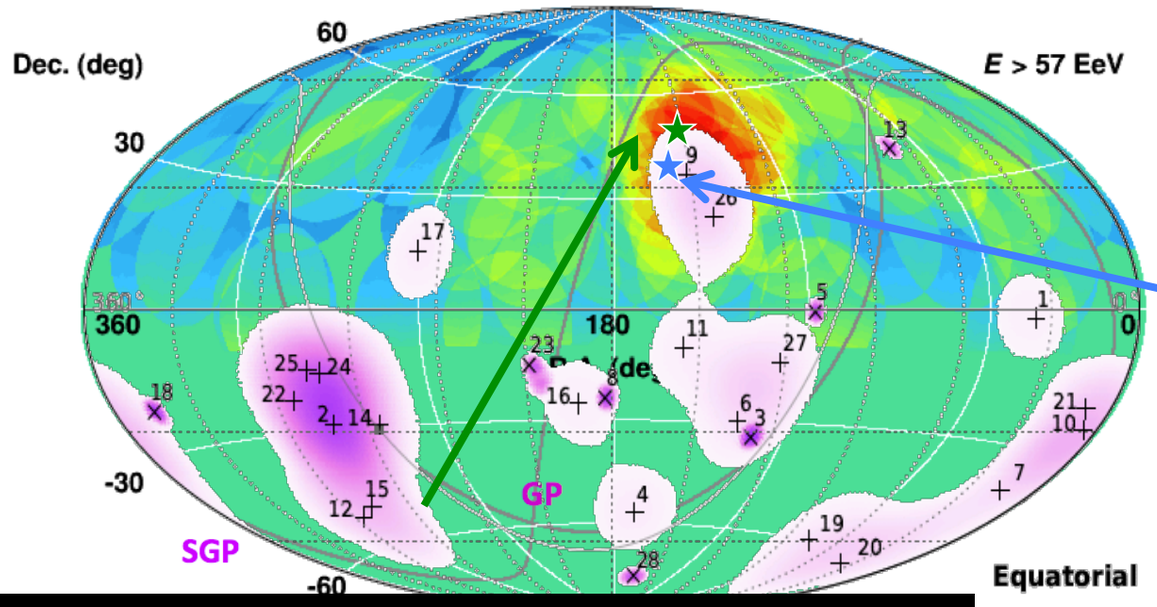
KF, Toshihiro, Linden, Olinto 2014
arXiv: 1404.6237

Possible Sources?



Fukushima CosPA 2013

IceCube Collaboration, Science 342 (2013)



1ES 1011+496

Canonical Name:	1ES 1011+496
TeVCat Name:	TeV J1015+494
Other Names:	
Source Type:	HBL
R.A.:	10 15 04.1 (hh mm ss)
Dec.:	+49 26 01 (dd mm ss)
Gal Long:	165.53 (deg)
Gal Lat:	52.71 (deg)
Distance:	z=0.212
Flux:	0.07 (Crab Units)
Energy Threshold:	200 GeV
Spectral Index:	4
Extended:	No
Discovery Date:	2007-09
Discovered By:	MAGIC
TeVCat SubCat:	Default Catalog

Source Notes:

Source position and its uncertainty:
- no information available
- the position provided by NED is used

Spectral Properties:
From Albert et al. (2007):
- Index: 4.0 +/- 0.5(stat) +/- 0.2(syst)

Seen by: MAGIC

More candidates in Fermi catalogues!

Markarian 421

Canonical Name:	Markarian 421
TeVCat Name:	TeV J1104+382
Other Names:	1ES 1101+384 1H 1104+382 H 1105+38
Source Type:	HBL
R.A.:	11 04 19 (hh mm ss)
Dec.:	+38 11 41 (dd mm ss)
Gal Long:	179.88 (deg)
Gal Lat:	65.01 (deg)
Distance:	z=0.031
Flux:	0.3 (Crab Units)
Energy Threshold:	500 GeV
Spectral Index:	2.2
Extended:	No
Discovery Date:	1992-08
Discovered By:	Whipple
TeVCat SubCat:	Default Catalog

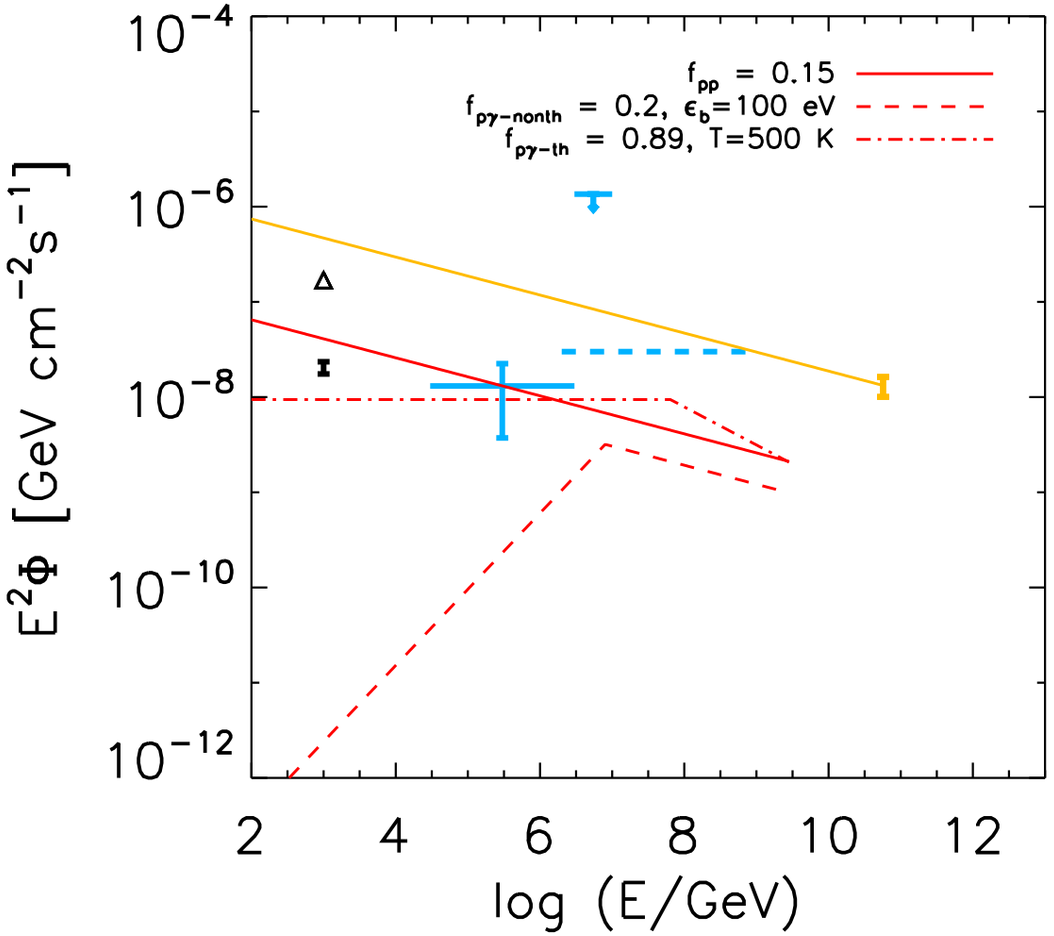
Source Notes:

Source position and its uncertainty:
From Albert et al. (2007):
- R.A. (J2000): 11 04 19
- Dec. (J2000): +38 11 41
- syst. uncertainty: 2'
- this is consistent with the source position provided by N

The flux from Markarian 421 is highly variable.

Spectral Index:
The spectral index has been found to vary.
From Albert et al. (2007):
- 2.20 +/- 0.08
- the spectrum shows evidence for an exponential cutoff

Possible Scenarios



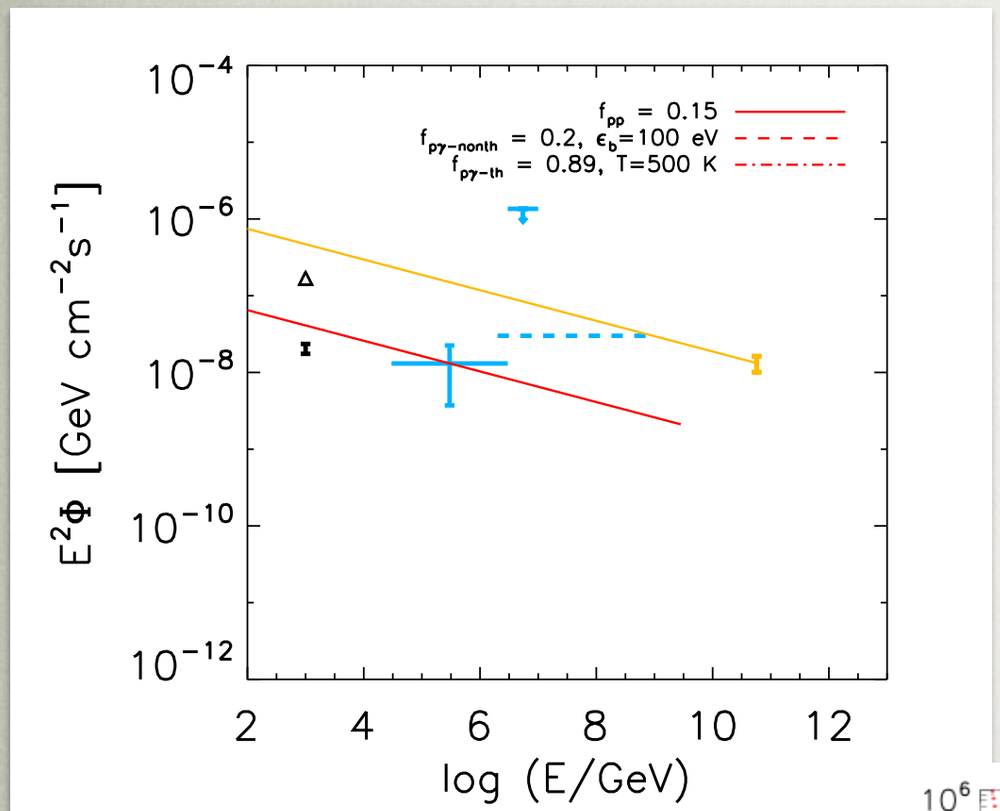
Depending on Interaction ambience

Case 1. baryons

Case 2. non-thermal photons emitted by jets

Case 3. thermal photons emitted by disk/torus

Possible Scenarios - Baryon Background



$$E_\nu^2 \Phi_\nu = 3/8\, f_{\rm pp}\, E_p^2\, J_p$$

$$f_{\rm pp} = \min(1, n_p\, \sigma_{\rm pp}\, \kappa_{\rm pp}\, R)$$

Galaxy Clusters

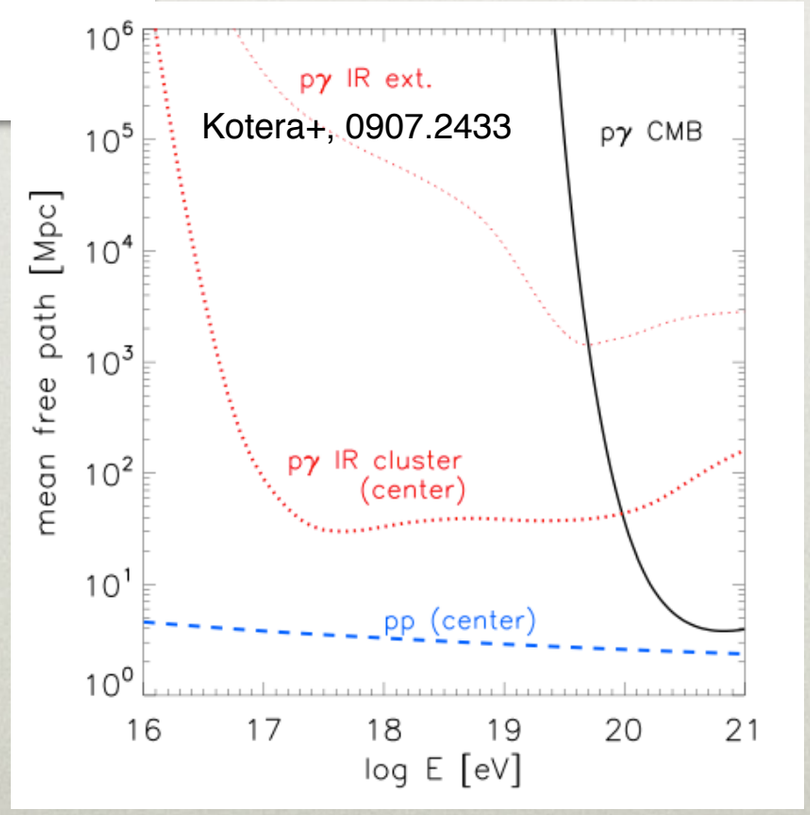
fpp ~ 0.001 - 0.01

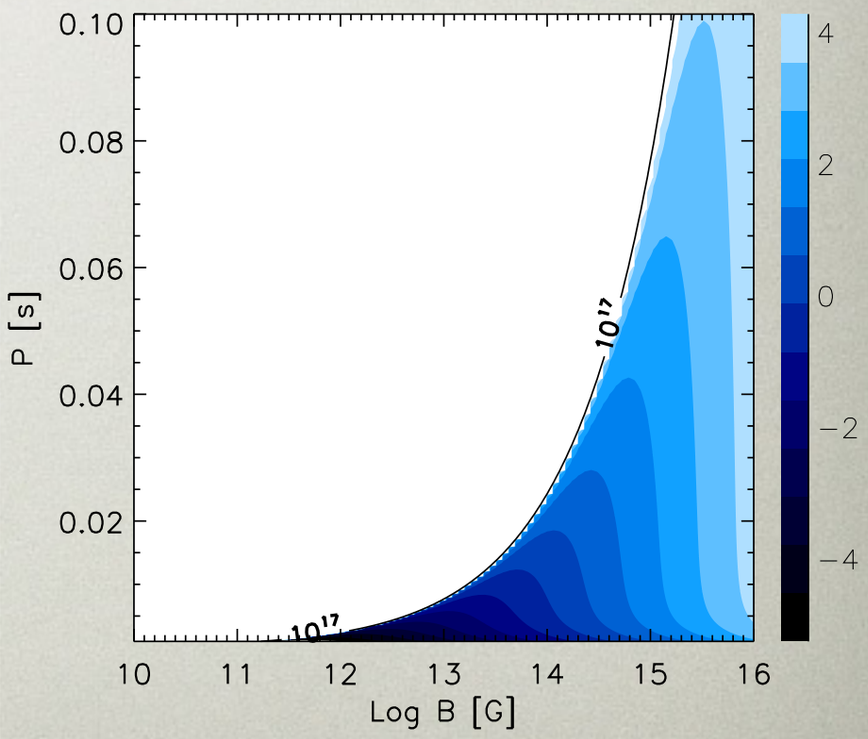
Pulsars and magnetars

fpp ~ 1

fpp ~ 0.15

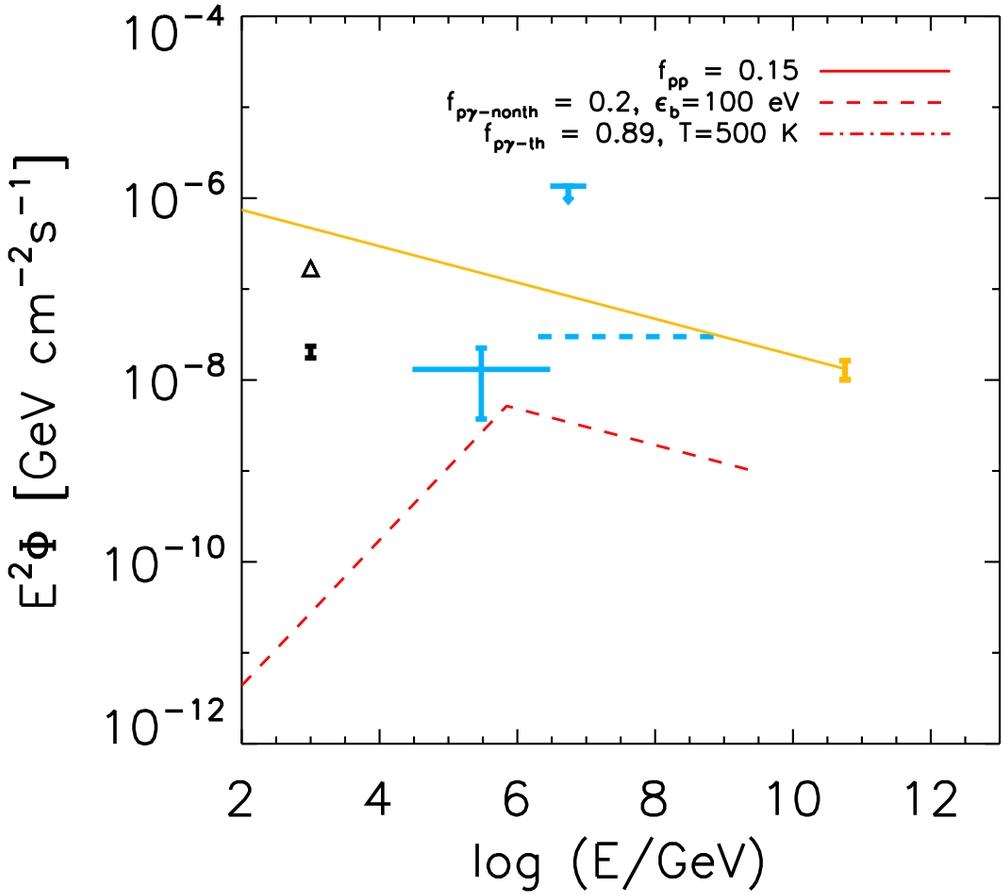
to connect hotspot UHECRs and high energy neutrinos





Possible Scenarios - non-thermal Photons from GRB Fireballs

Waxman & Bahcall 1997 , Guetta+ 2003, Murase+ 2006

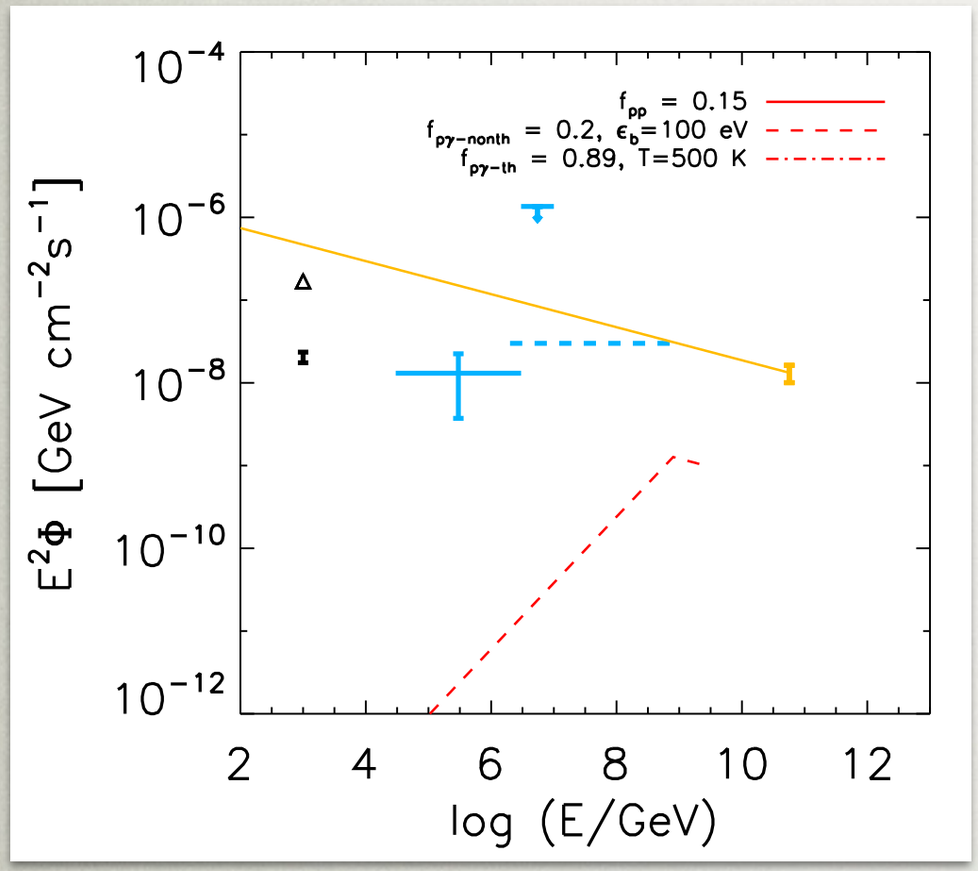


$$\varepsilon_\nu^b = 7\times 10^{14}\frac{1}{(1+z)^2}\frac{\Gamma_{2.5}^2}{\varepsilon_{\gamma,\mathrm{MeV}}^b}\mathrm{eV}.$$

$$f_\pi(\varepsilon_p)\sim 0.2\frac{L_{\gamma,52}}{\Gamma_{2.5}^4 t_{v,-2}\varepsilon_{\gamma,\mathrm{MeV}}^b}\times\begin{cases}(\varepsilon_p/\varepsilon_p^b)^\alpha & \varepsilon_p>\varepsilon_p^b\\ (\varepsilon_p/\varepsilon_p^b)^\beta & \varepsilon_p<\varepsilon_p^b\end{cases}$$

f_pgamma = 0.2

Possible Scenarios - non-thermal Photons from blazar jet



$$E_\nu \Phi_\nu = \frac{3}{8} f_{p\gamma} E_p J_p$$
$$\propto \begin{cases} (E_\nu/E_\nu^b)^{1+\beta-s} & E_\nu \leq E_\nu^b \\ (E_\nu/E_\nu^b)^{1+\alpha-s} & E_\nu > E_\nu^b \end{cases}$$

Blazar jets, fpgamma ~ 10^-4 - 0.01

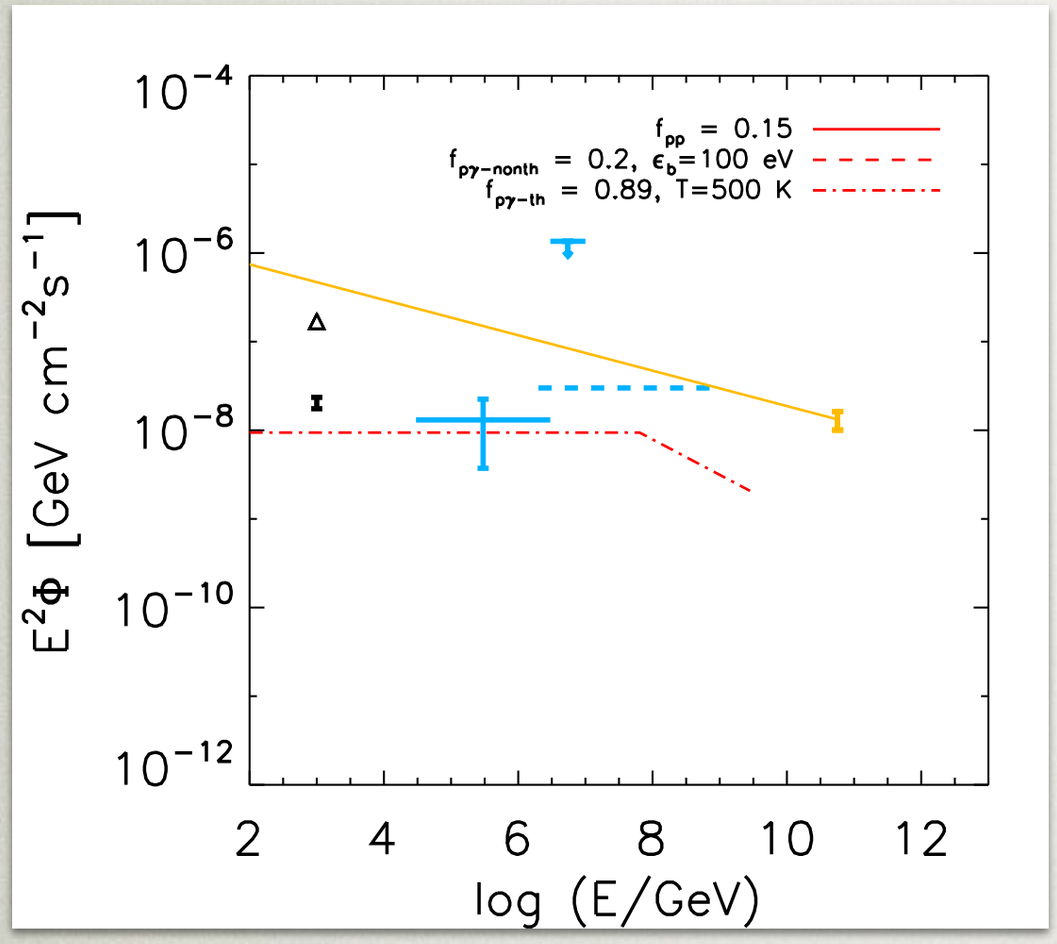
Murase, Inoue, Dermer 1403.4089

$$f_{p\gamma}(E'_p) \sim 7.8 \times 10^{-5} L^s_{r,45} \Gamma_1^{-4} \delta t'^{-1}_5 (E'_s/100\ \mathrm{eV})^{-1}$$
$$\times \begin{cases} (E'_\nu/E'^b_\nu)^{\beta_h-1} & (E'_p \leqq E'^b_p) \\ (E'_\nu/E'^b_\nu)^{\beta_l-1} & (E'^b_p < E'_p) \end{cases}$$

f_pgamma = 0.2

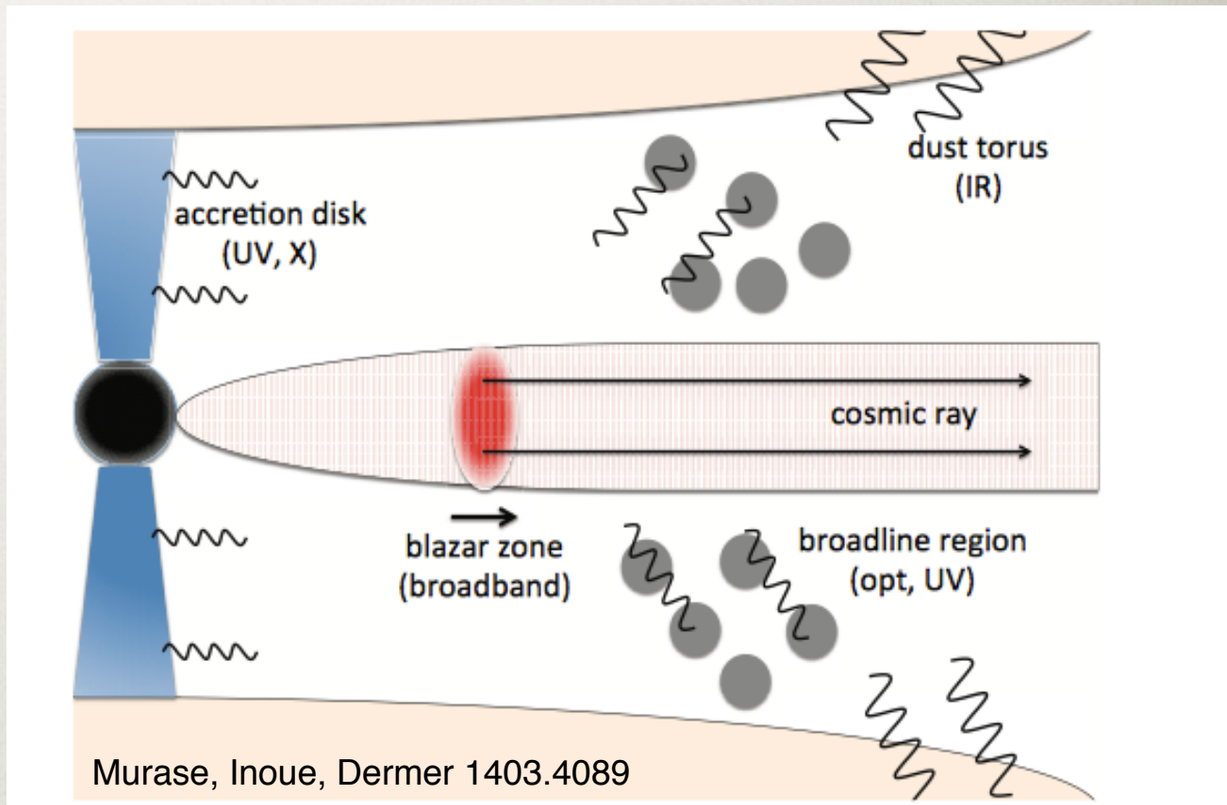
non-thermal photons in Mkr 421 can hardly produce the desired neutrino flux

Possible Scenarios - thermal photons



Needs FSRQs with high luminosity

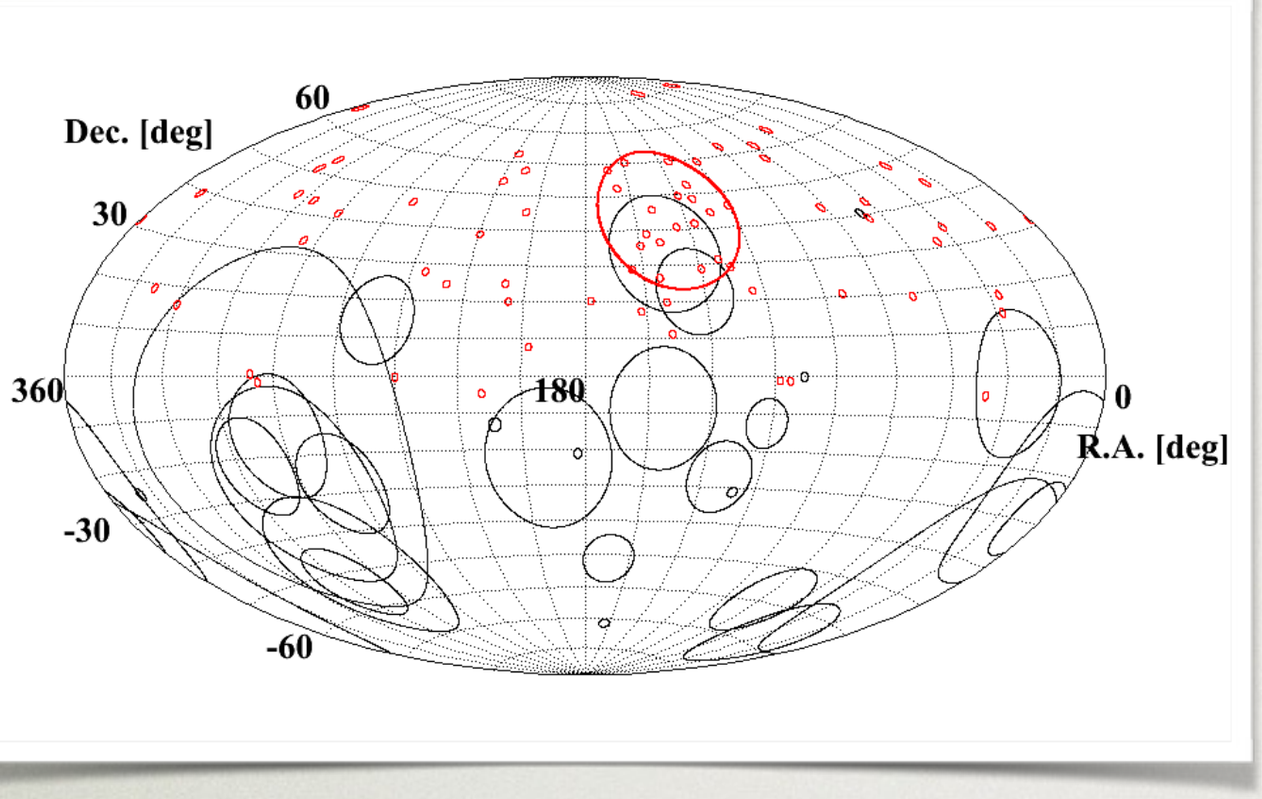
$$E_\nu \Phi_\nu \propto \begin{cases} (E_\nu/E_\nu^b)^2 & E_\nu \le E_\nu^b \\ (E_\nu/E_\nu^b)^{2-s} & E_\nu > E_\nu^b \end{cases}$$

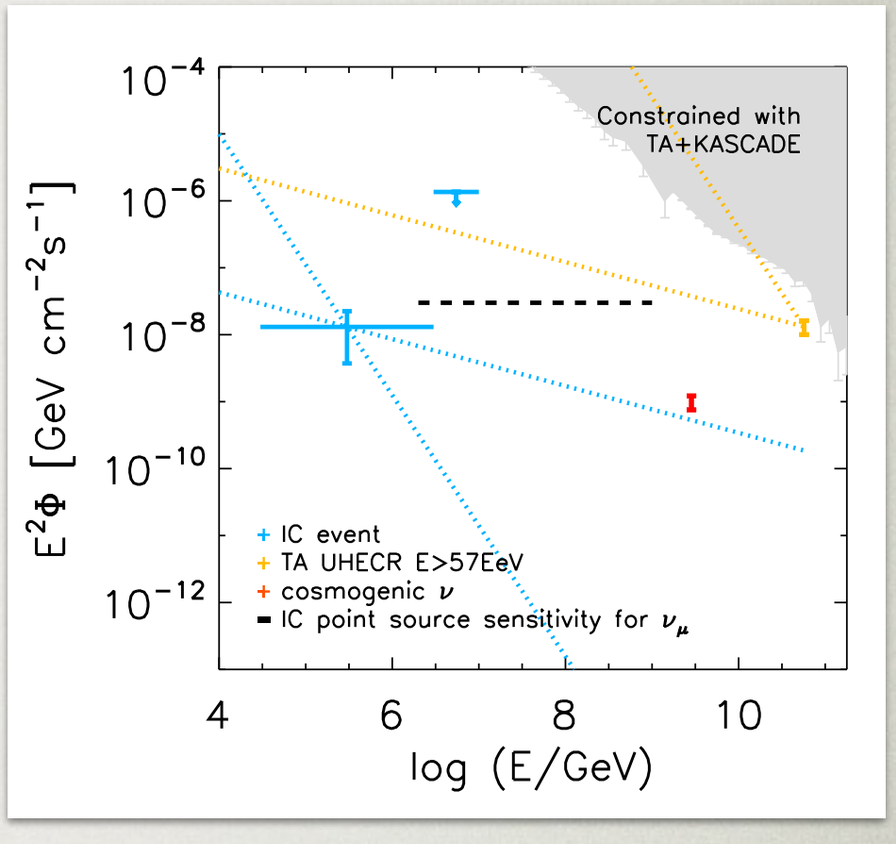


Murase, Inoue, Dermer 1403.4089

$$f_{p\gamma} \simeq 0.89\ L_{\rm AD,46.5}^{1/2} (T_{\rm IR}/500\ {\rm K})^{-1}$$

Conclusions





- TA excess and IceCube high energy neutrinos share spacial correlation 2.1 sigma (1.6 with 3-year IceCube data)

- Flux levels of UHECRs and neutrinos in the hotspot are consistent with a single source

- Possible single source scenario include pulsars and magnetar, FSRQ type blazers and other sources with strong interaction targets.