关于LHAASO的多信使研究

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首次LHAASO合作组会议 · 南开

Messengers in astronomy
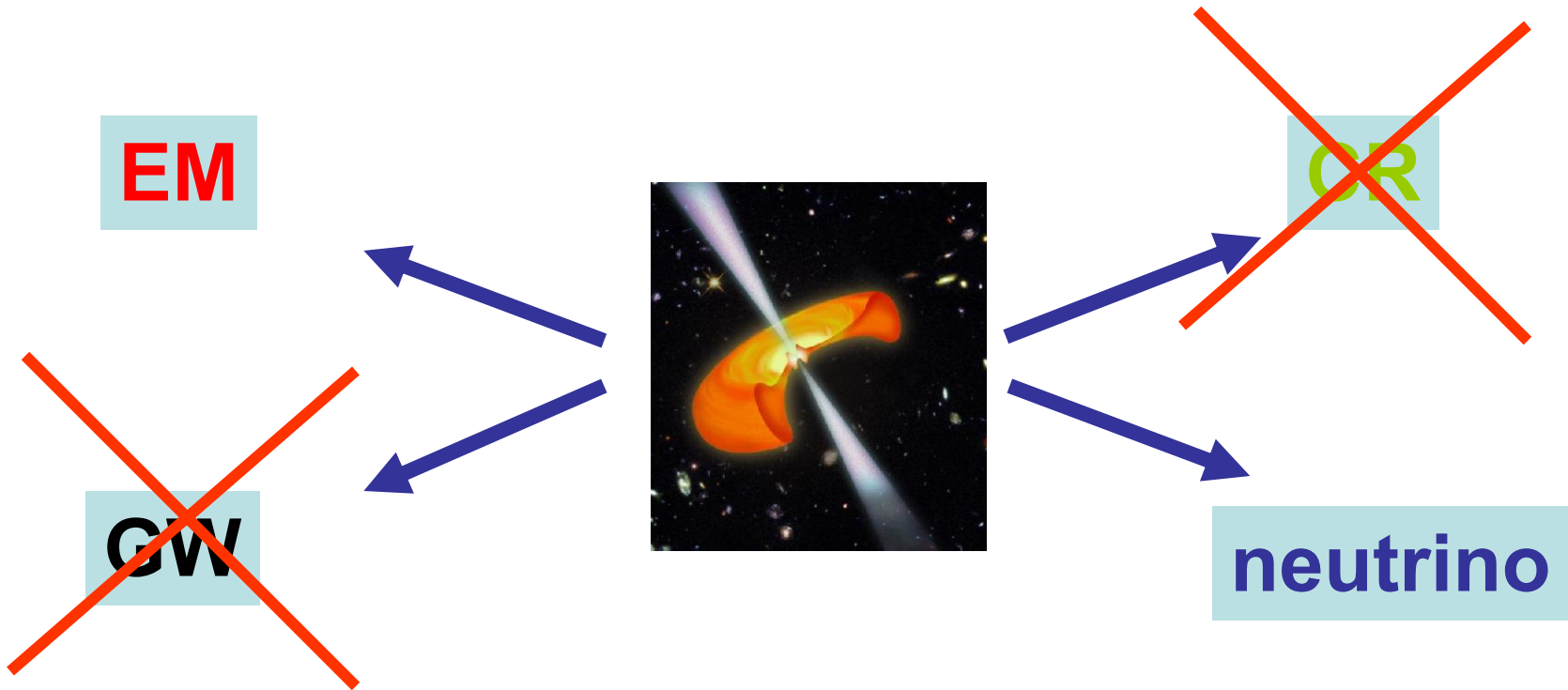
EM

CR

GW
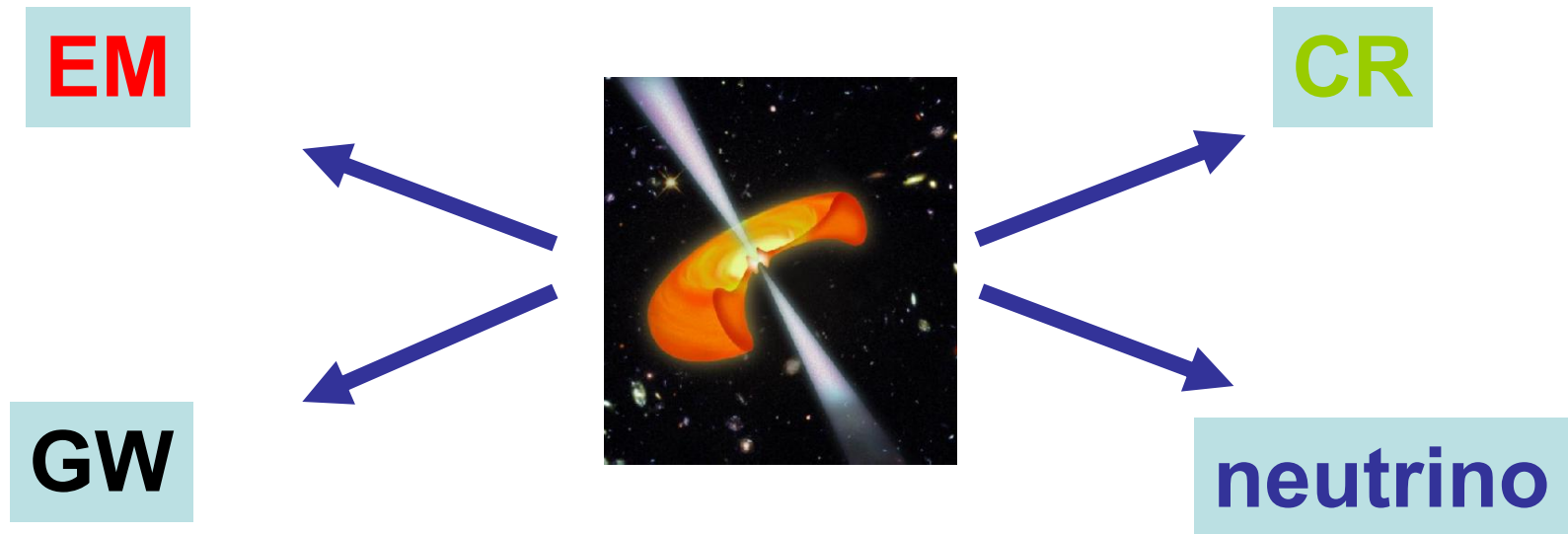
neutrino

TeV CR sky: tiny anisotropy
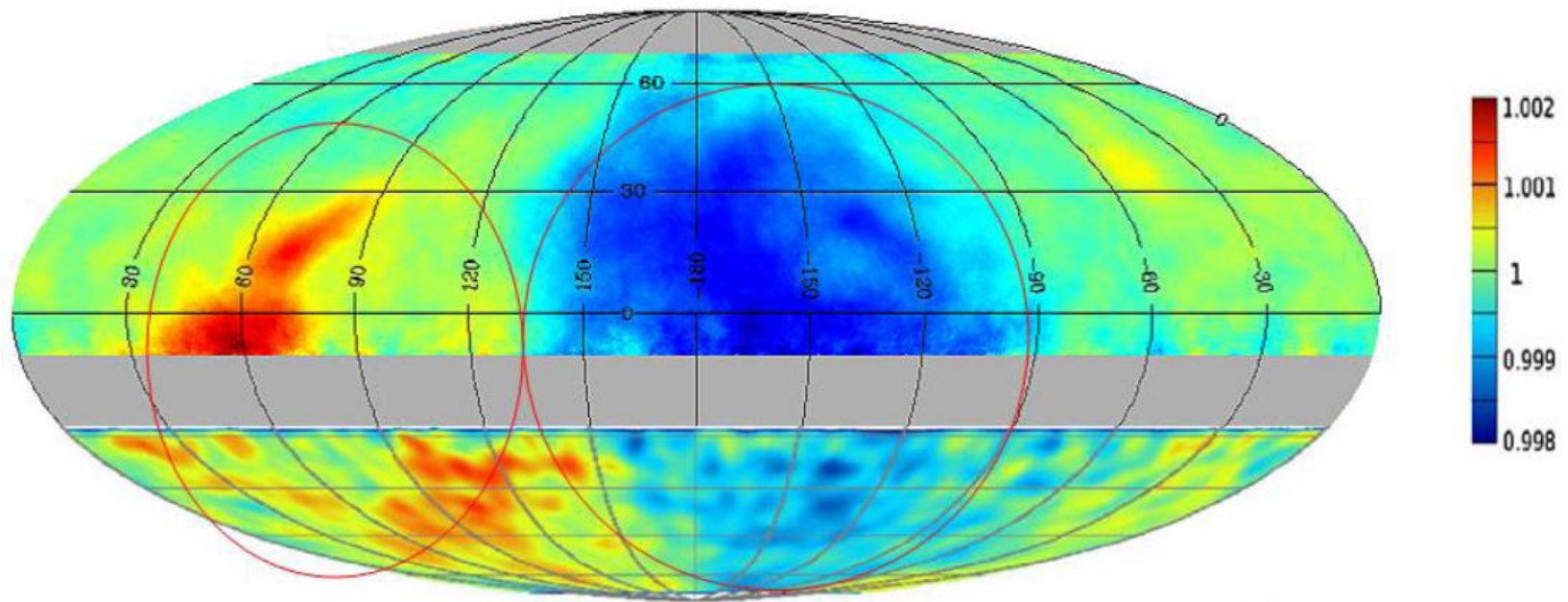
CRs easily deflected by magnetic field

Messengers in astronomy

Photon – neutrino connection
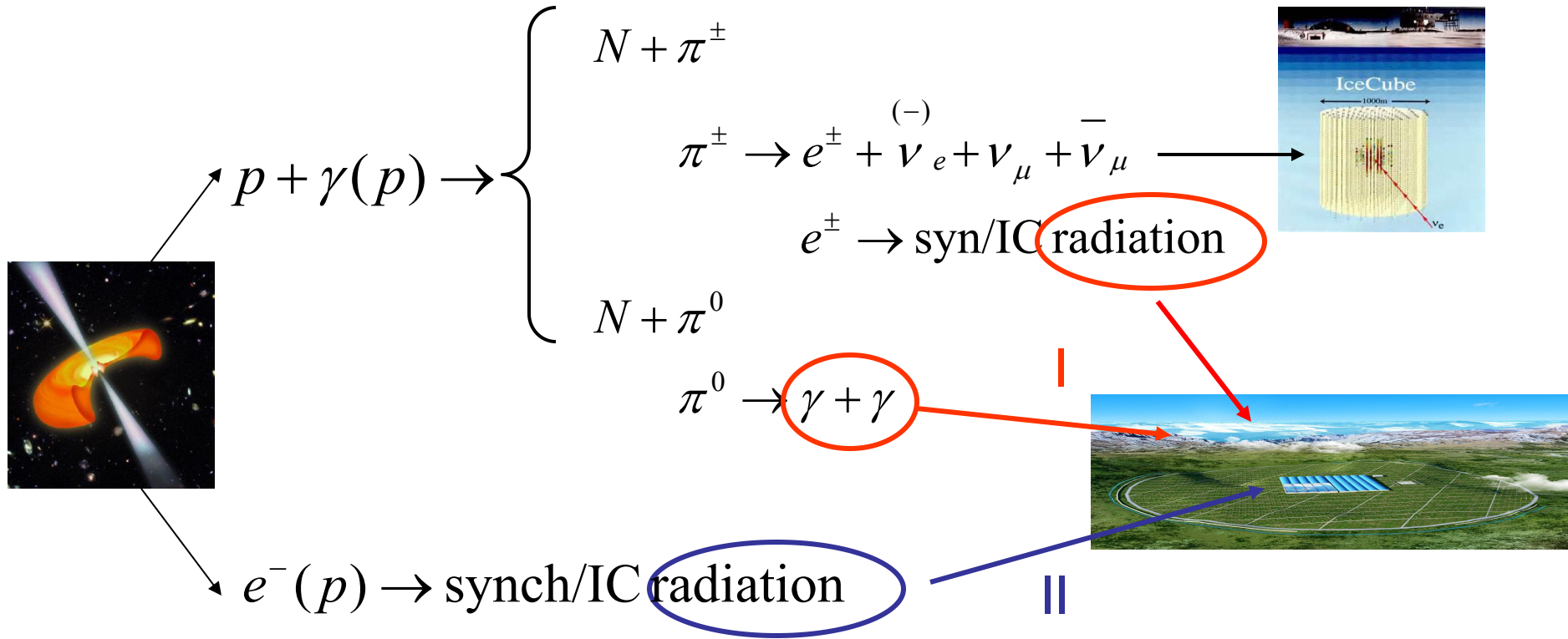
$$p + \gamma(p) \rightarrow \begin{cases} N + \pi^{\pm} \\ \\ \\ N + \pi^0 \end{cases}$$

$$\pi^{\pm} \rightarrow e^{\pm} + \overset{(-)}{\nu}_e + \nu_{\mu} + \bar{\nu}_{\mu}$$

$$e^{\pm} \rightarrow \text{syn/IC radiation}$$

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

I

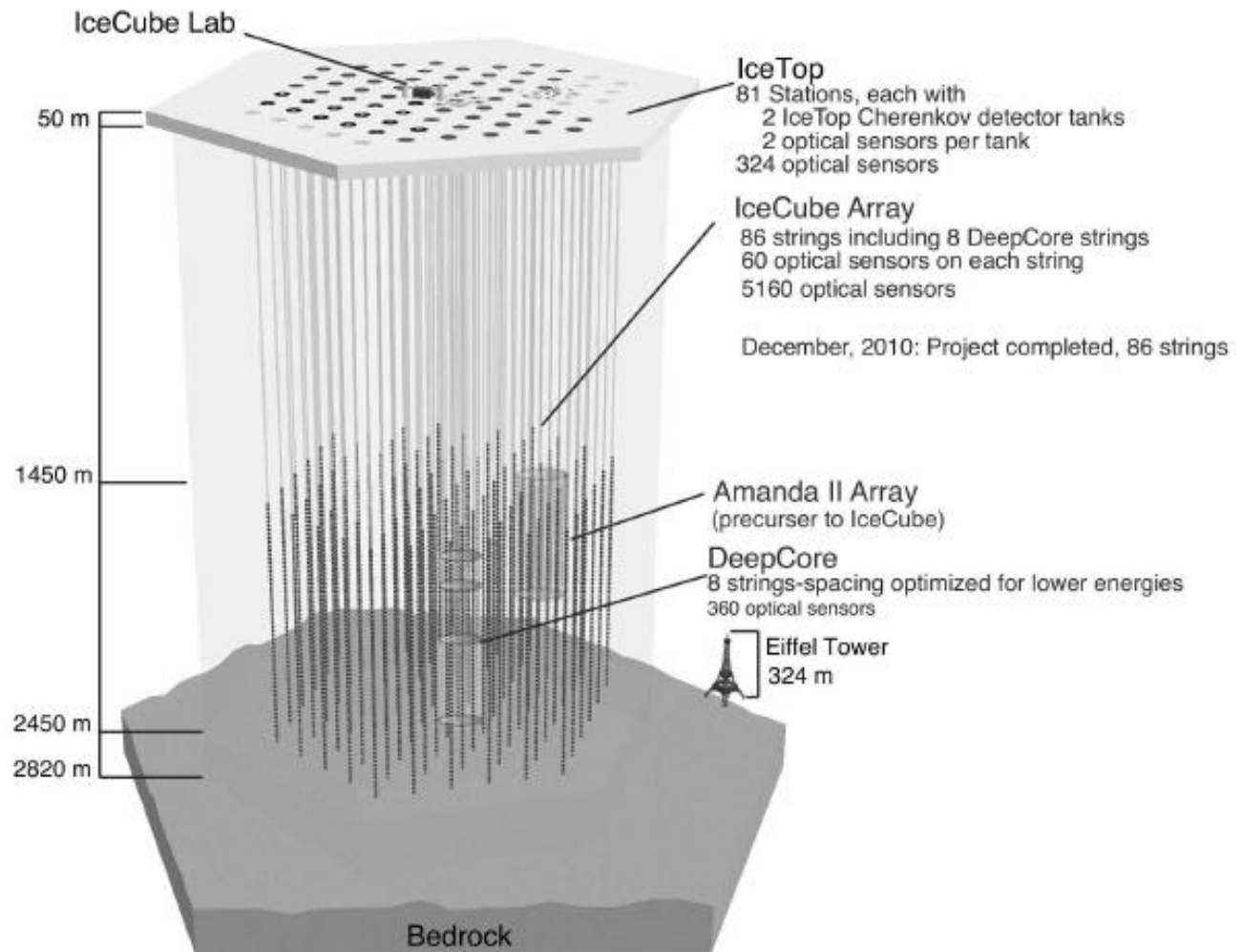$$e^-(p) \rightarrow \text{synch/IC radiation}$$

II

Connections:

I.   neutrino – secondary electron/gamma-ray

II.   neutrino – primary electron/proton

Two ways

- Gamma-ray detection trigger neutrino observation

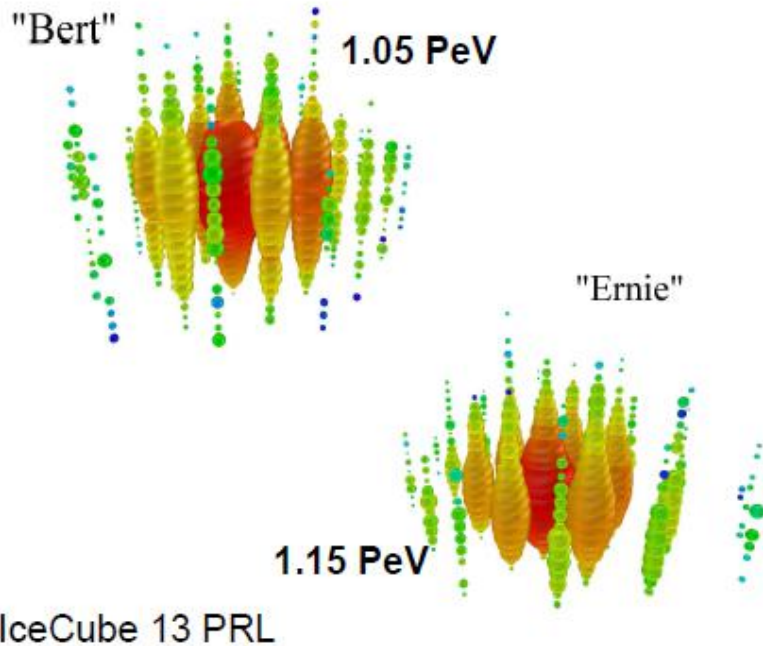- Neutrino detection trigger gamma-ray observation

IceCube neutrino experiment

- Expected to reach sensitivity for XG sources
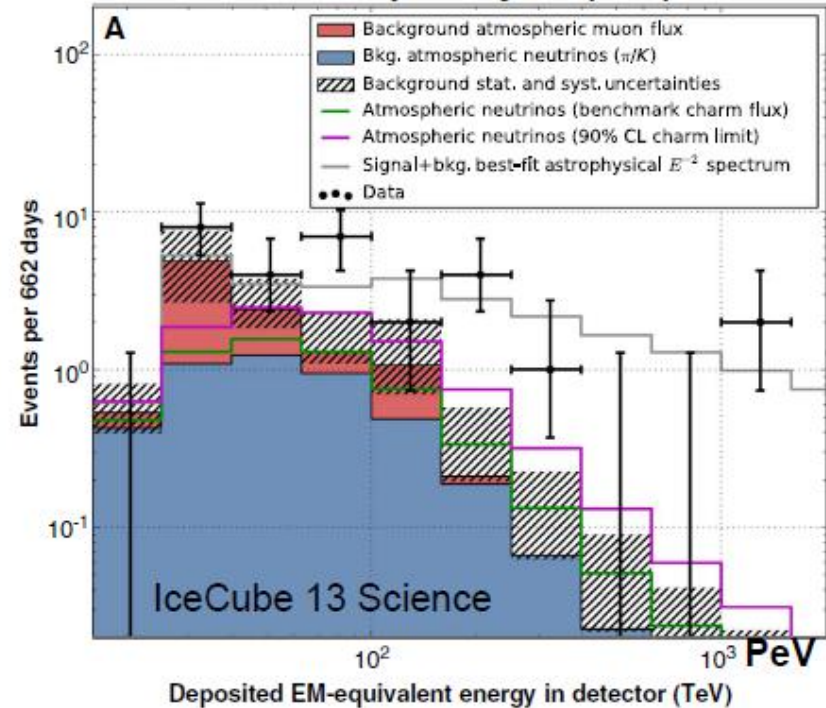- Completion in 04/2011

Diffuse neutrinos discovery

First detection of PeV events (~3σ)

"Bert"   1.05 PeV

"Ernie"

1.15 PeV

IceCube 13 PRL

Follow-up analysis (~4σ)

A

- Background atmospheric muon flux
- Bkg. atmospheric neutrinos (π/K)
- Background stat. and syst. uncertainties
- Atmospheric neutrinos (benchmark charm flux)
- Atmospheric neutrinos (90% CL charm limit)
- Signal+bkg. best-fit astrophysical E^{-2} spectrum
- Data

Events per 662 days

IceCube 13 Science

Deposited EM-equivalent energy in detector (TeV)
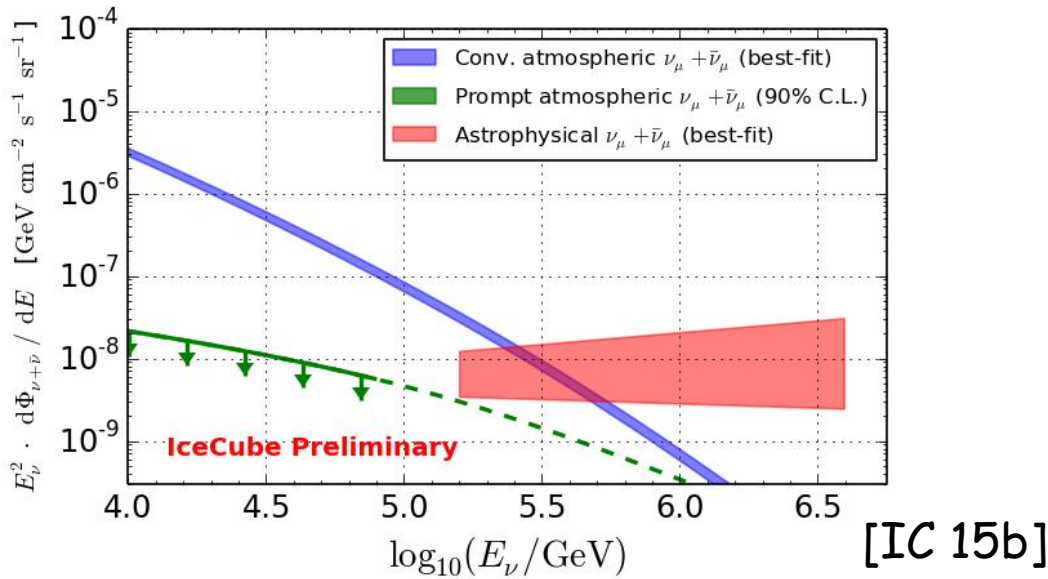
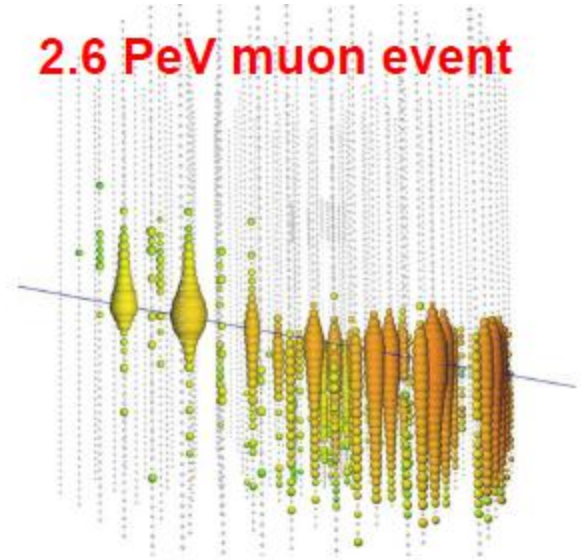$$E_\nu^2 \Phi_\nu^{total}(E_\nu) = 3.6 \times 10^{-8} \ \mathrm{GeV \ cm^{-2} \ s^{-1} \ sr^{-1}}$$

Consistent with isotropic; flavor ratio 1:1:1; spectral best fit $E^{-2.3}$, or E^{-2} spectrum + PeV cutoff

Upgoing muon track events

[IC 15b]

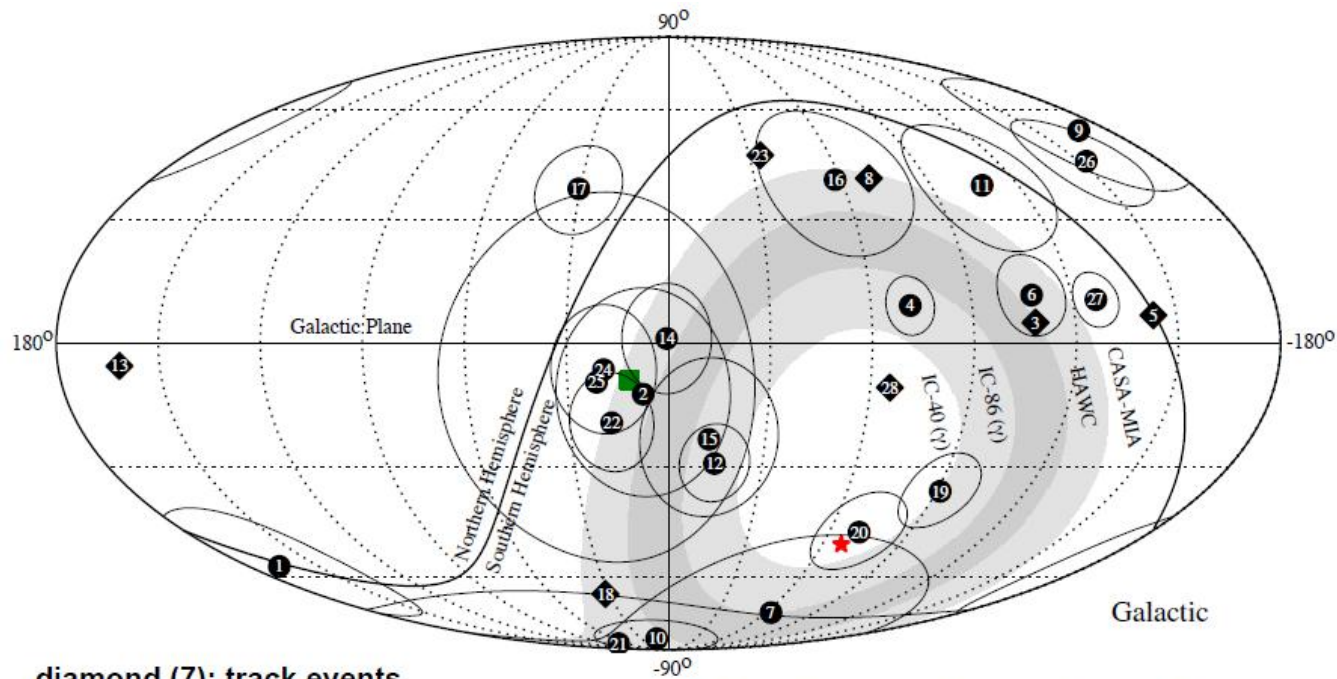Hard spectrum at >200 TeV: s~-2

$E^2\Phi$~0.8e-8 GeV/cm^{2}s sr @100TeV

Consistent with southern hemisphere events

# Begin of high energy neutrino astronomy

diamond (7): track events
circle (21): shower event

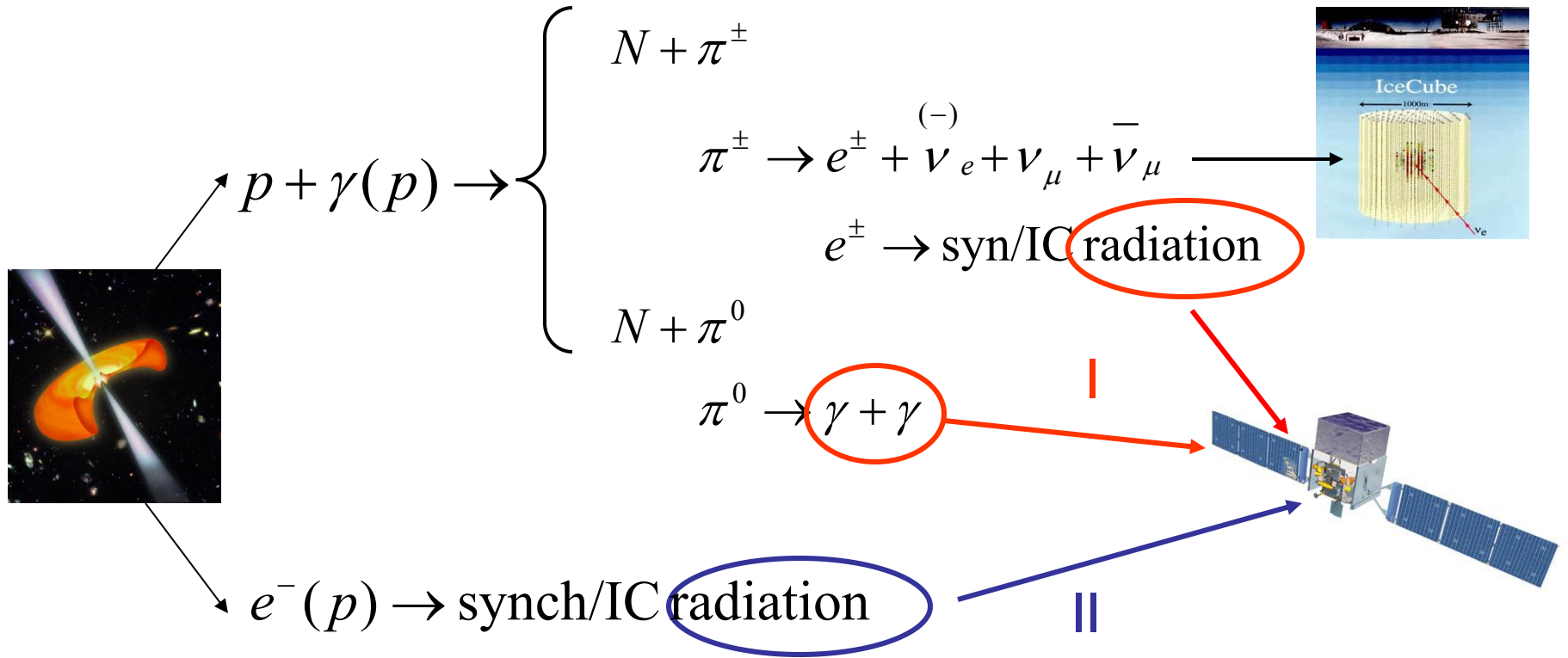Ahlers & KM 13; complied from IceCube 13 Science

Skymap: no significant spot
Also no clustering in time,
no correlation with GRB

Where are HE neutrinos from?

- Galactic origin
  - Diffuse emission (from CR propagation)?
  - Galactic point sources?
- Extragalactic origin
  - (Diffuse emission from CR propagation?)
  - Gamma ray bursts?
  - Active galactic nuclei jets/cores?
  - Star forming/starburst galaxies?
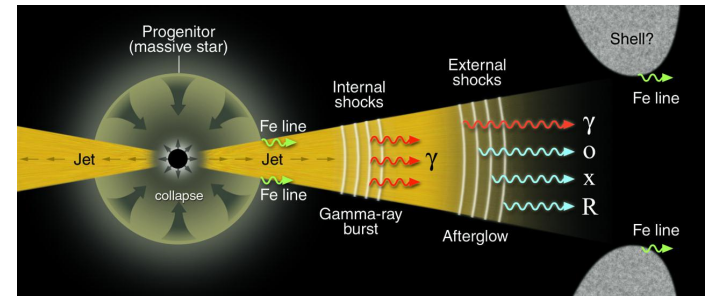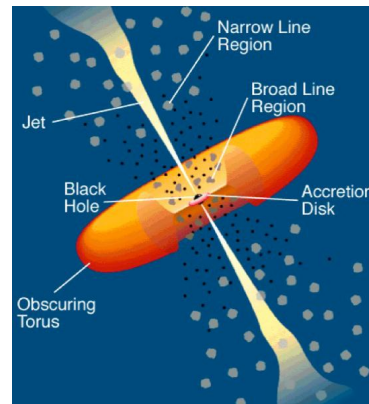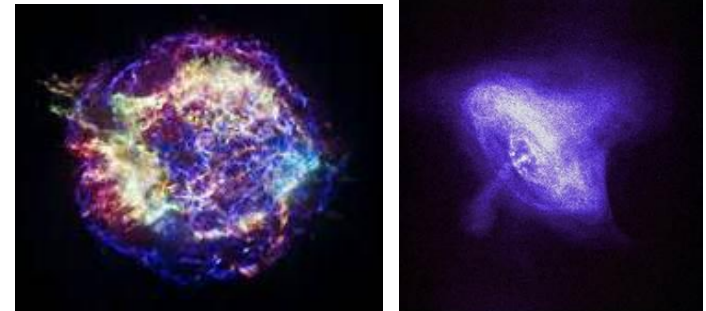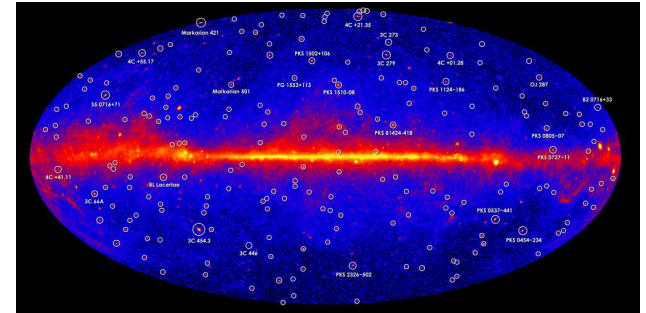
Photon – neutrino connection

$$p + \gamma(p) \rightarrow \begin{cases} N + \pi^{\pm} \\ \\ \pi^{\pm} \rightarrow e^{\pm} + \overset{(-)}{\nu}_e + \nu_{\mu} + \bar{\nu}_{\mu} \\ \\ e^{\pm} \rightarrow \text{syn/IC radiation} \\ \\ N + \pi^0 \end{cases}$$

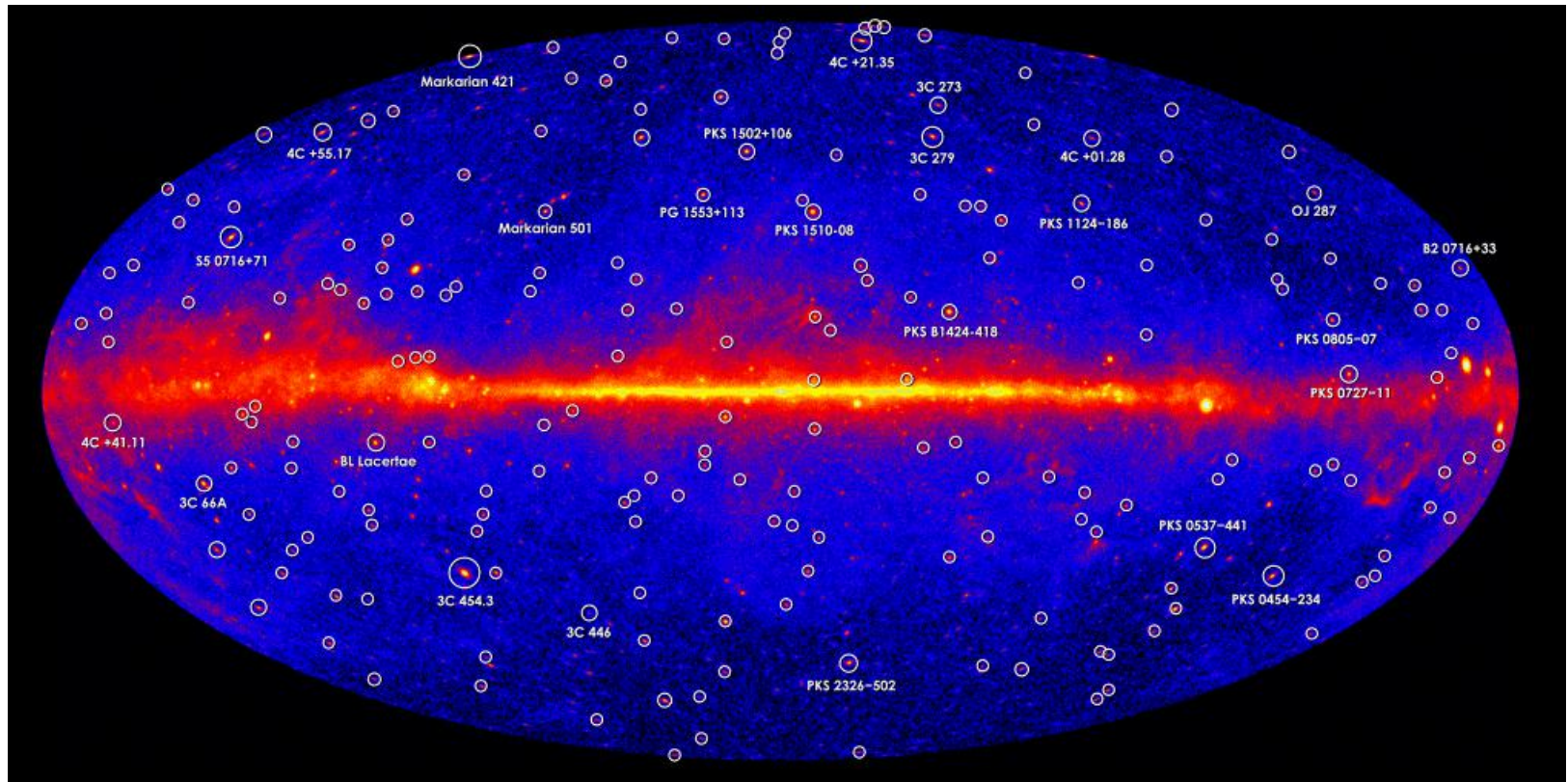$$\pi^0 \rightarrow \gamma + \gamma$$

$$e^-(p) \rightarrow \text{synch/IC radiation}$$

I

II

Connections:

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Fermi-LAT probes neutrino origin

Whether various candidate sources can produce
the all-sky neutrino flux?

$$E_\nu^2 J_{\nu,\mathrm{IC}} \approx 1.2 \times 10^{-7}\,\mathrm{GeV\,cm^{-2}\,s^{-1}}$$ (single flavor)

Fermi-LAT tells IceCube

- ☹diffuse Galactic emission, ~<10%
- ☹Galactic point sources
- ☹GRBs, ~<10%
- ☹AGN jets, ~<10%
- ☺Starburst galaxies
- ?AGN cores
- …

Starburst galaxies

- Dense gas as CR targets

- Strong magnetic field confines CRs

- → high efficiency of nu/gamma production

Starburst galaxies
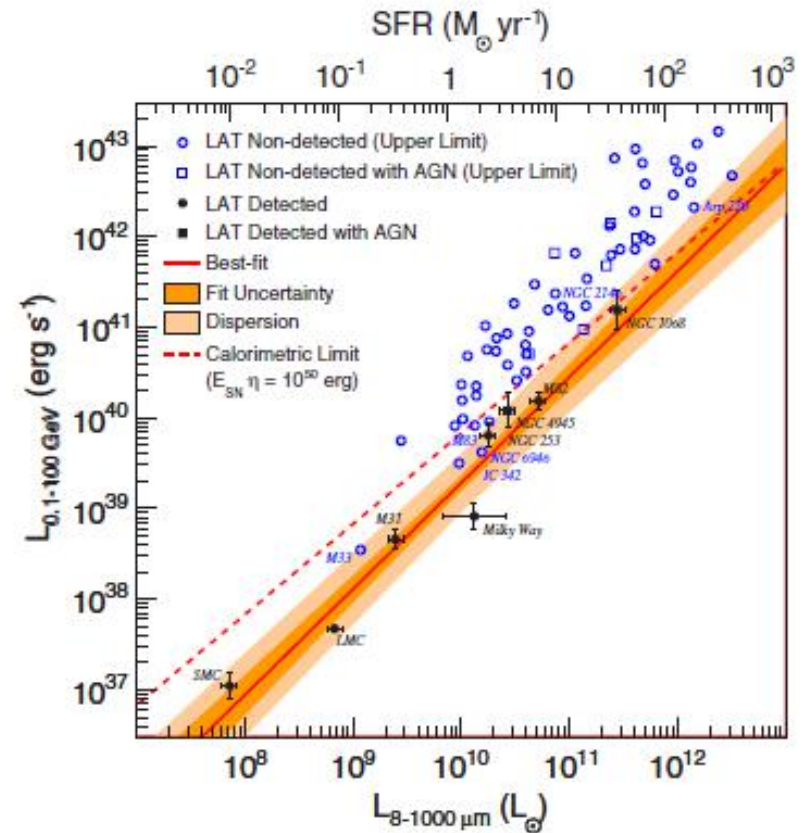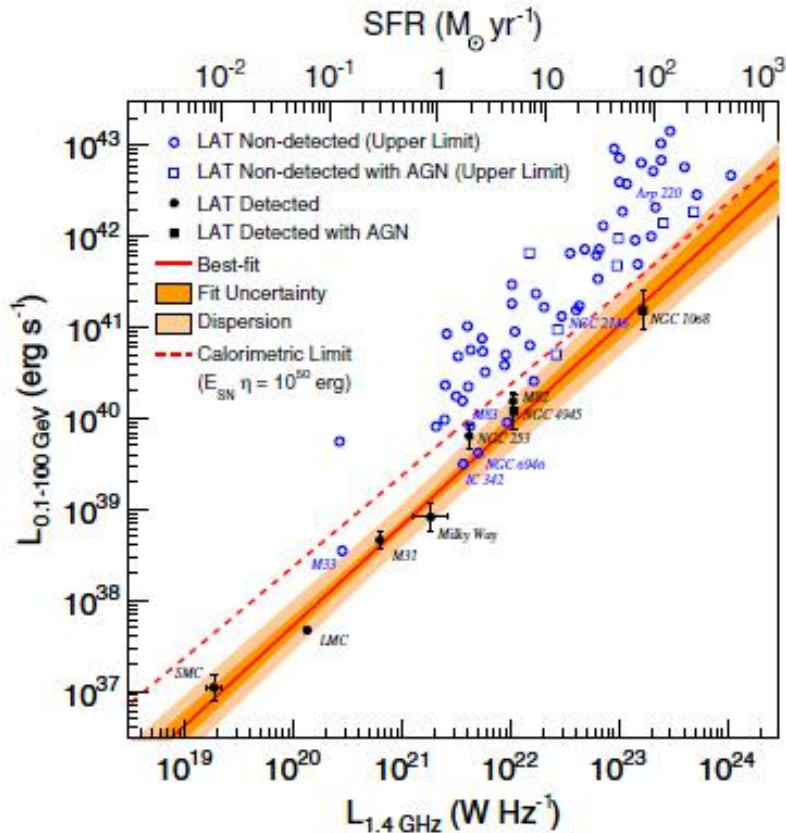
$$\nu L_\nu(\text{GeV})/\text{SFR} \approx 10^{46}\,\text{erg}/M_\odot$$

[Fermi-LAT, Ackermann+12]

Starburst galaxies

- Local-universe (z=0) gamma-ray production rate density

$$E_\gamma^2 Q_\gamma (\mathrm{GeV}) = \rho_{\mathrm{SFR}}(\nu L_\nu (\mathrm{GeV})/\mathrm{SFR})$$

- Gamma-ray flux from SBGs from whole universe

$$E_\gamma^2 \Phi_\gamma (\mathrm{GeV}) = \xi_z t_{\mathrm{H}} (c/4\pi) E_\gamma^2 Q_\gamma (\mathrm{GeV})$$
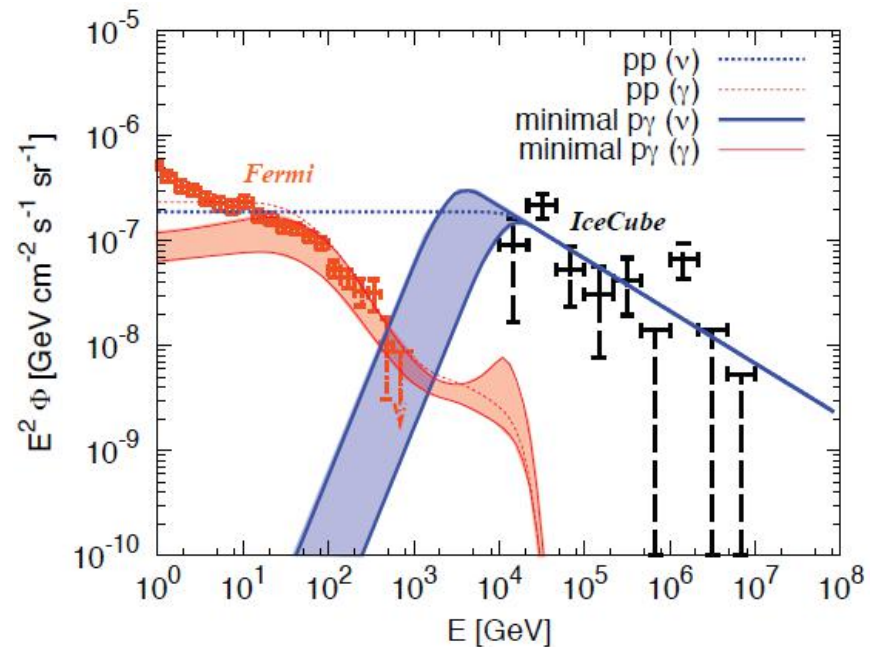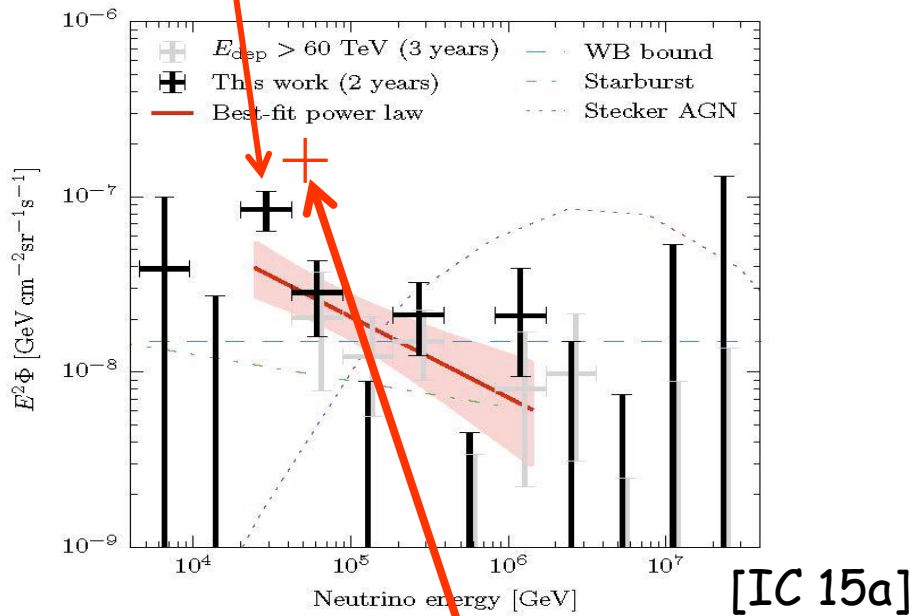
- Assume connection I for SBGs
  - if CRs injected with $\sim E_p^{-2.2}$
  - if <100PeV CRs lose energy significantly as expected in SBGs
  - Neutrino flux extrapolated from GeV to PeV:

$$E_\nu^2 \Phi_\nu \approx 10^{-8} \frac{\xi_z}{3} \left(\frac{E_\nu}{1\mathrm{PeV}} \right)^{-0.2} \mathrm{GeV\, cm^{-2} s^{-1} sr^{-1}}$$

Consistent with IC measurement in both flux and spectrum at >60TeV

Tension -- low energy neutrinos vs. gamma background

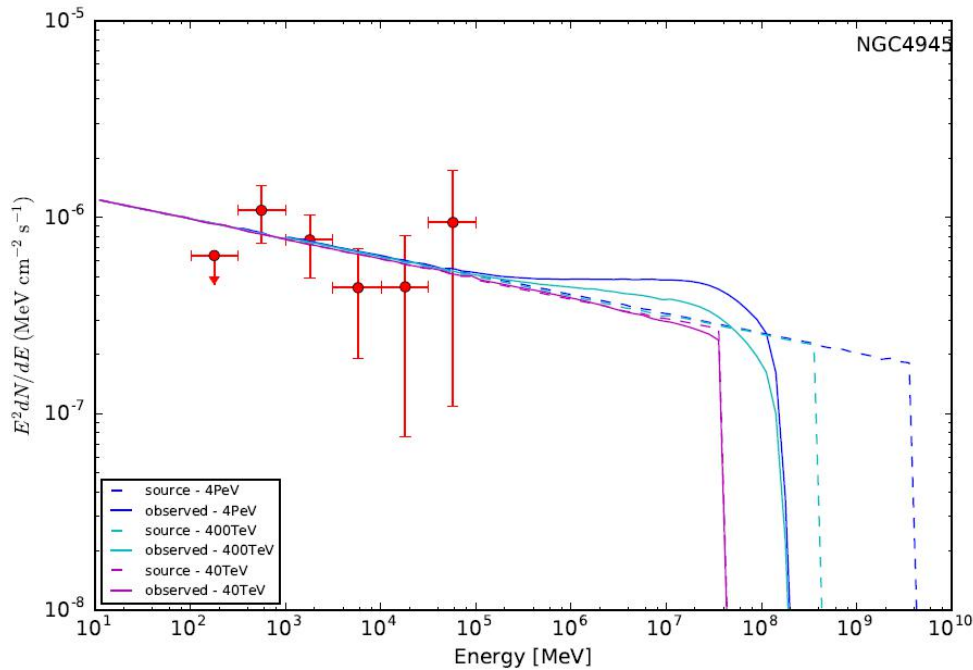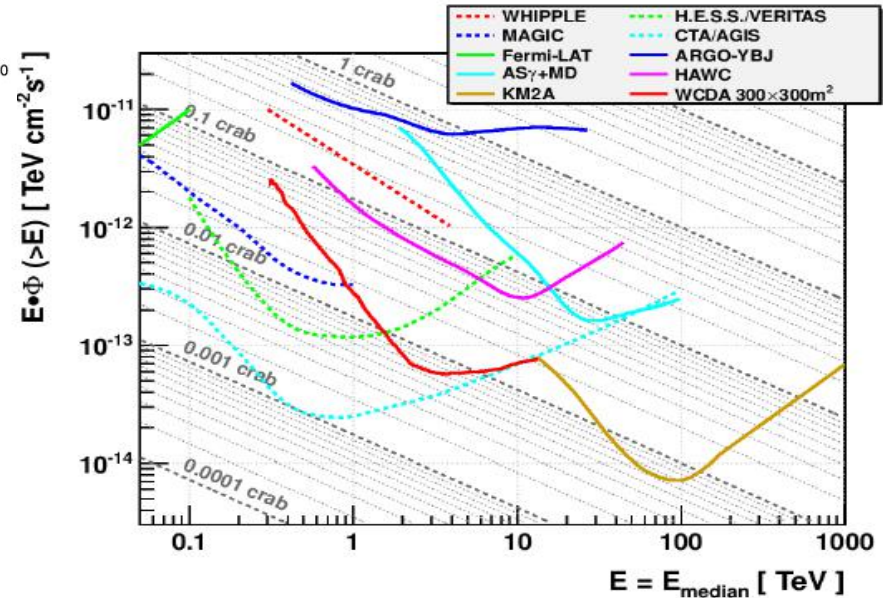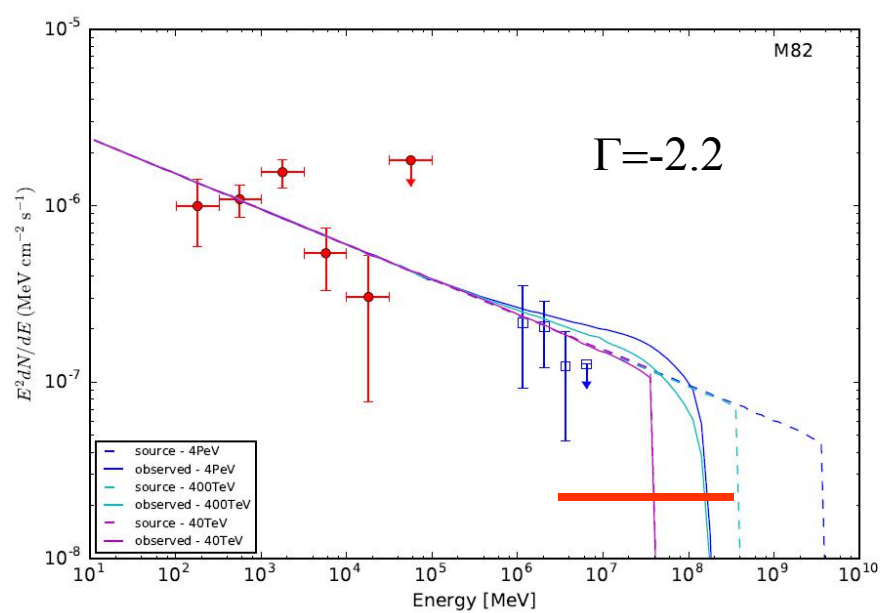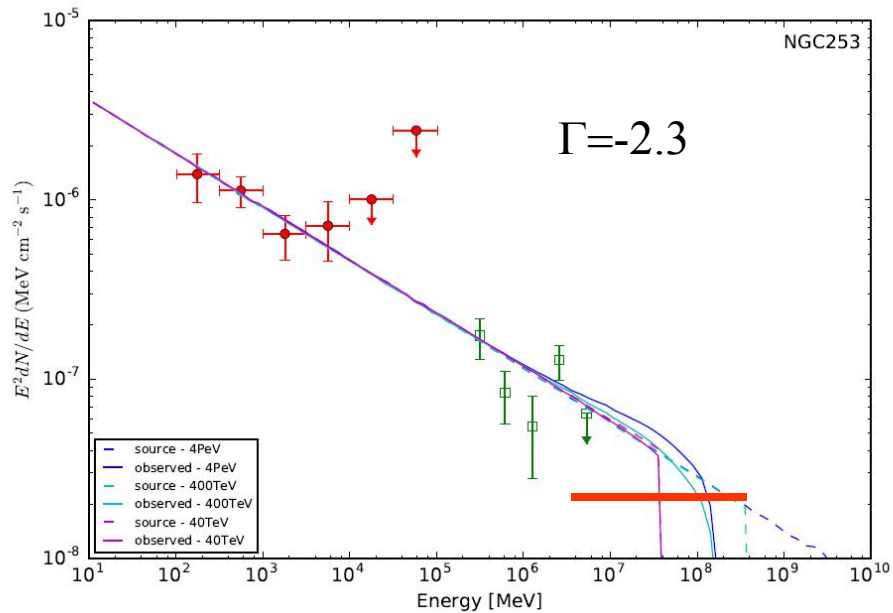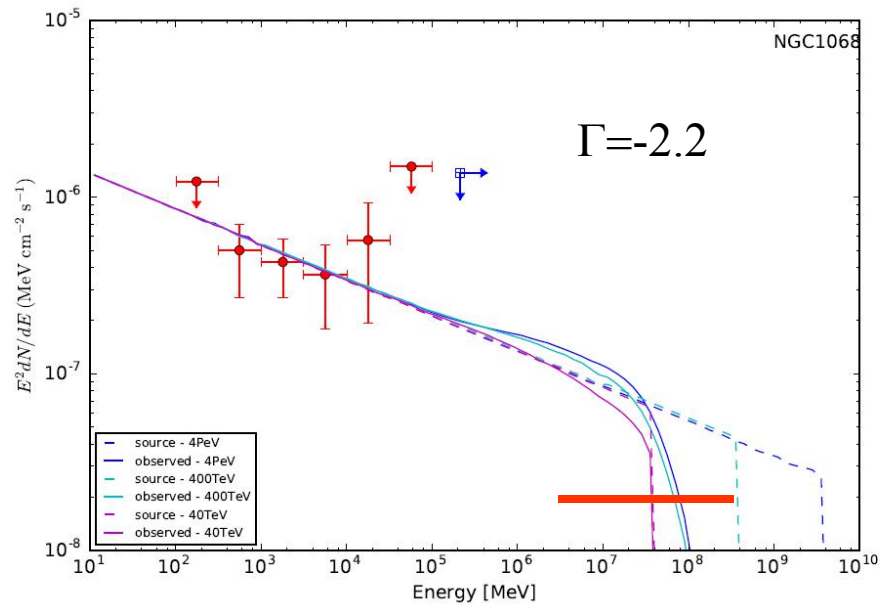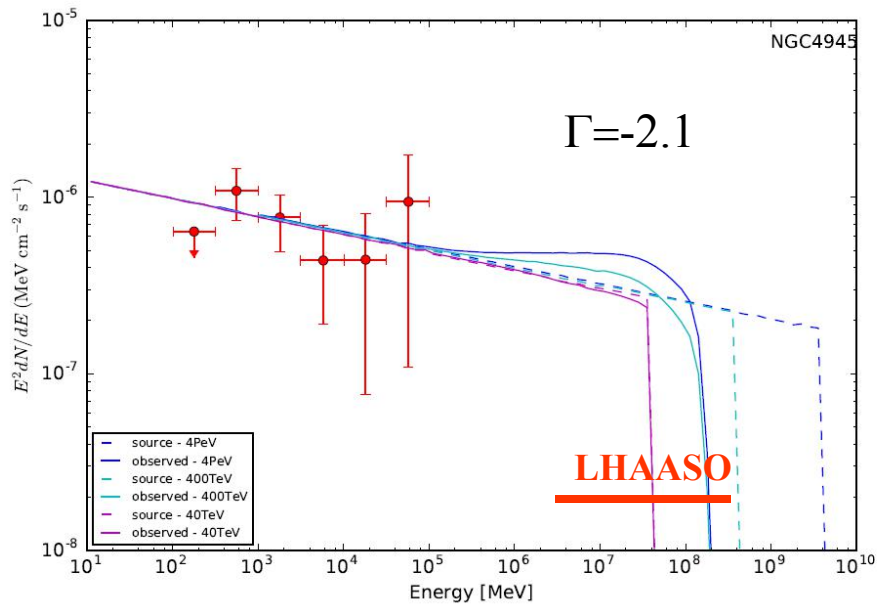Neutrino excess at 30TeV?

[IC 15a]

[Murase+15]

Galactic diffuse gamma-rays (avoid overproduce gamma background)
LHAASO can reach this flux level and answer this question

Starburst galaxy as PeV neutrino origin

NGC4945

source - 4PeV
observed - 4PeV
source - 400TeV
observed - 400TeV
source - 40TeV
observed - 40TeV

4Mpc
Gamma-ray initiated EM cascade
considered

NGC4945 — $\Gamma=-2.1$

$E^2 dN/dE$ (MeV cm^{-2} s^{-1})

Energy [MeV]

LHAASO

- source - 4PeV
- observed - 4PeV
- source - 400TeV
- observed - 400TeV
- source - 40TeV
- observed - 40TeV

NGC1068 — $\Gamma=-2.2$

- source - 4PeV
- observed - 4PeV
- source - 400TeV
- observed - 400TeV
- source - 40TeV
- observed - 40TeV

NGC253 — $\Gamma=-2.3$

- source - 4PeV
- observed - 4PeV
- source - 400TeV
- observed - 400TeV
- source - 40TeV
- observed - 40TeV

M82 — $\Gamma=-2.2$

- source - 4PeV
- observed - 4PeV
- source - 400TeV
- observed - 400TeV
- source - 40TeV
- observed - 40TeV

LHAASO help to clarify neutrino origin

- Diffuse 60TeV photon excess
- Individual starburst galaxy observation

How to identify sources?

- Neutrino point source search
    - larger size, higher energy
    (but only for bright sources)
- Neutrino-EM association
    - Cross correlations
    - Neutrino search for known EM candidate sources
        - Individuals; stacking
    - EM search for neutrino events (for transients)
        - IceCube160427 alert (0.5deg sky area)
        - Archive EM data for detected neutrino events
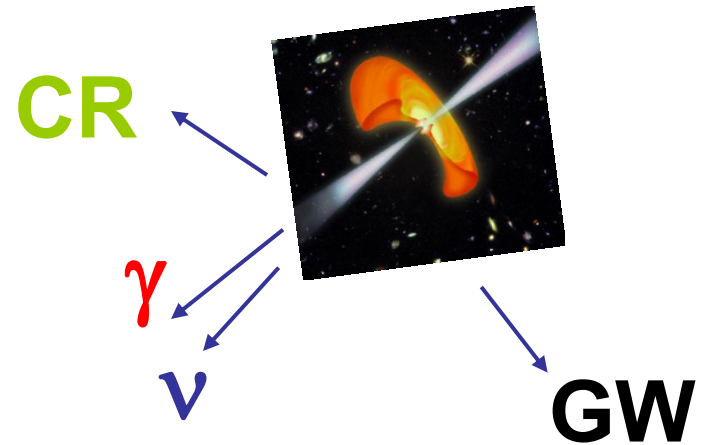
How about numerous weak starburst galaxies?

CR

γ

ν

GW

Diffuse Galactic emission

- Connection I

- $\pi^+ : \pi^- : \pi^0 = 1 : 1 : 1$

  $E_\nu = \frac{1}{2} E_\gamma$

  $E_\nu^2 J_\nu(E_\nu) = \frac{1}{2} E_\gamma^2 J_\gamma(E_\gamma)$

- Extrapolation 100GeV to PeV
  - Neutrinos follow CR spectrum
- DGE accounts for <1% IC flux
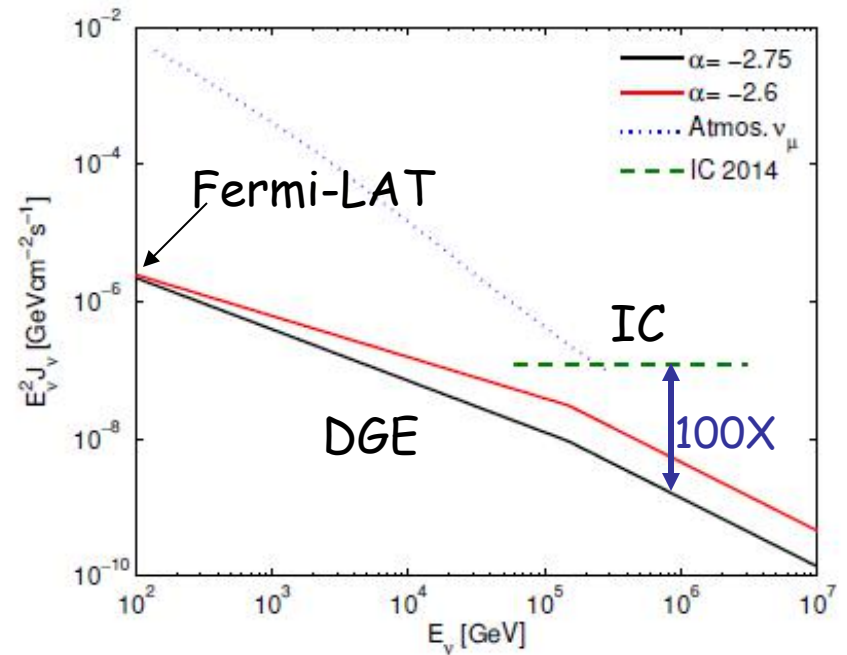
Diffuse Galactic emission unlikely