SYNERGIES BETWEEN NEUTRINO TELESCOPES AND e-ASTROGAM

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e-ASTROGAM workshop: the extreme Universe | Padova | Feb. 28 - Mar. 02 2017

- NEUTRINO: ASTROPHYSICAL MESSENGER
- SYNERGIES BETWEEN MeV GAMMA-RAYS AND NEUTRINO TELESCOPES

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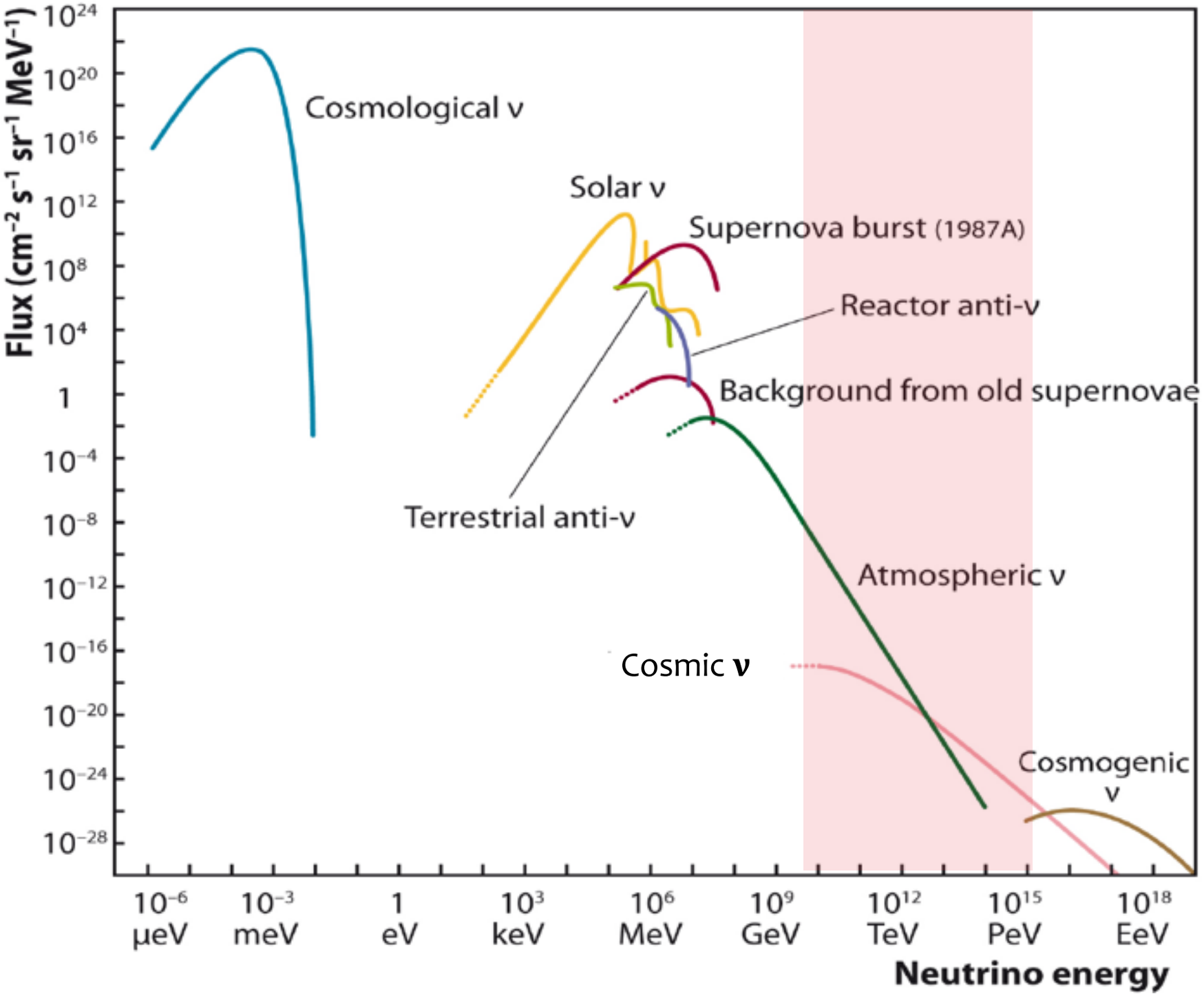
NEUTRINO SPECTRUM



Katz, U.F. *et al.* Prog.Part.Nucl.Phys. 67 (2012)

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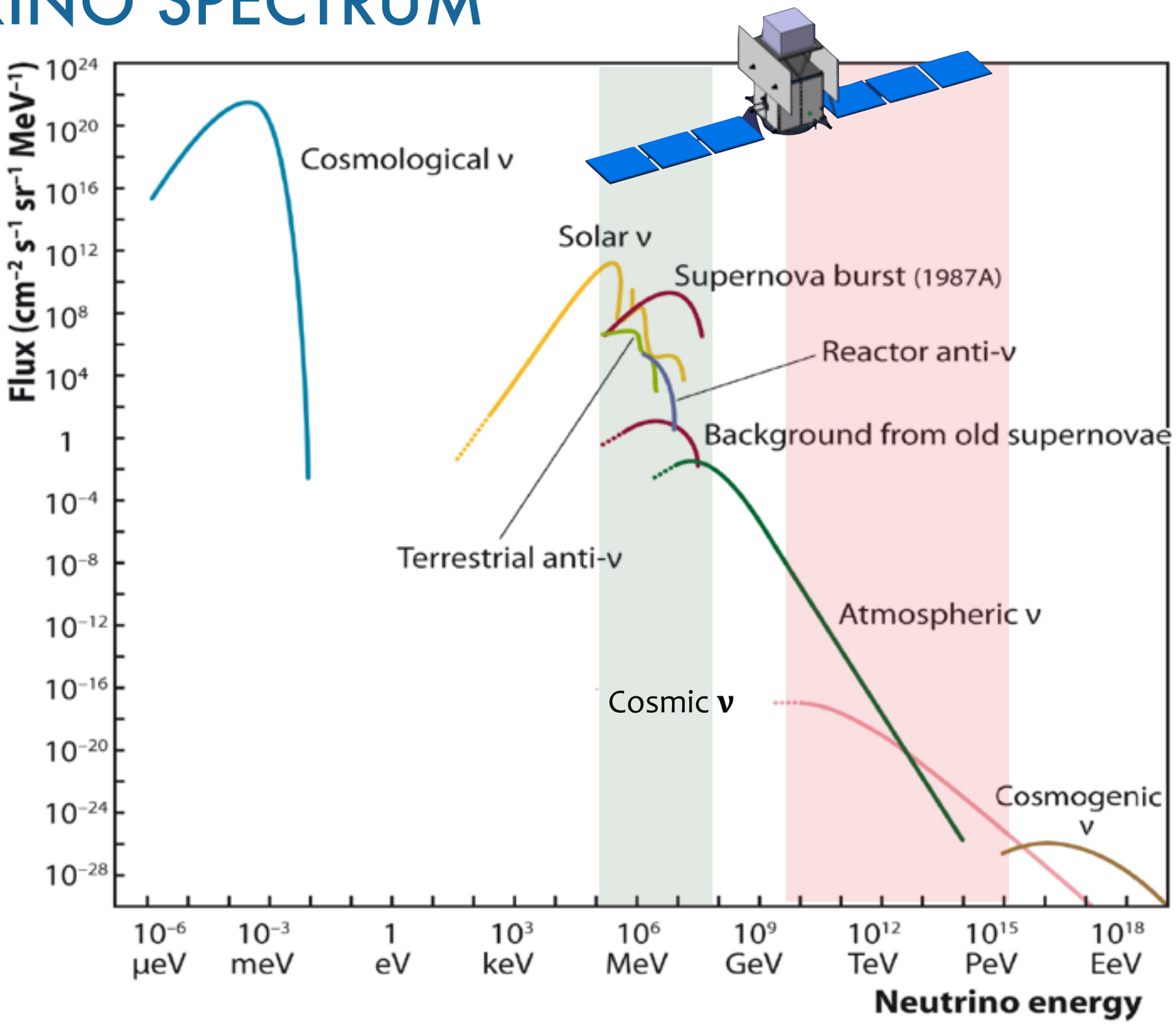

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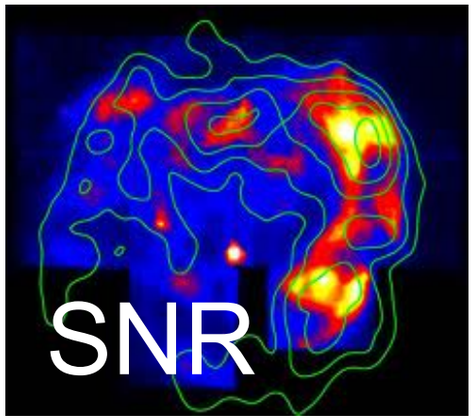
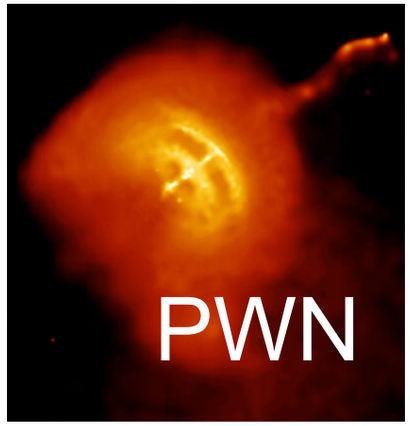
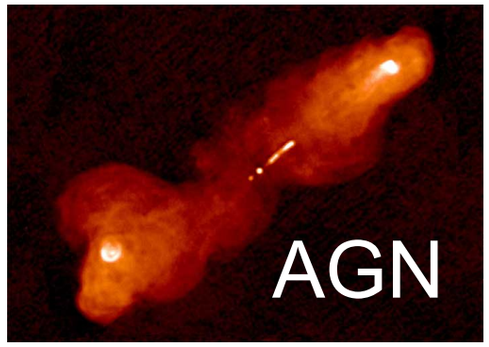
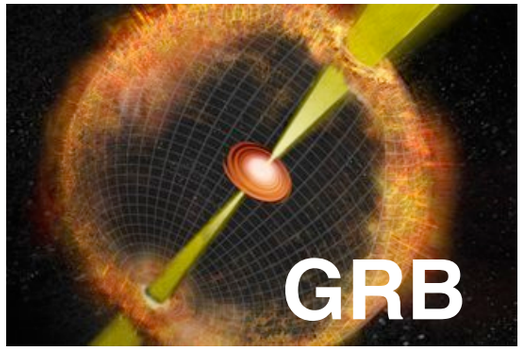
HE NEUTRINO SOURCES

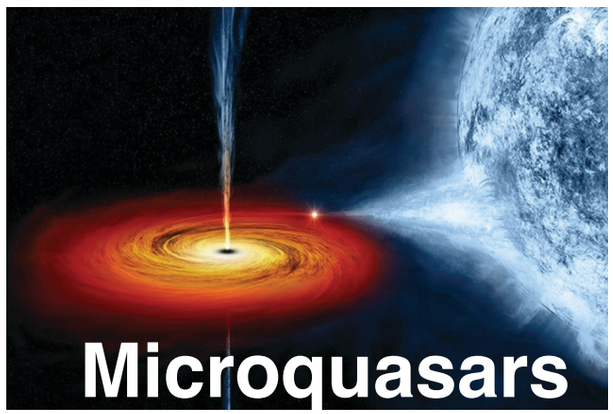
- High-Energy neutrinos = tracers of hadronic processes and sites of production/acceleration of cosmic rays



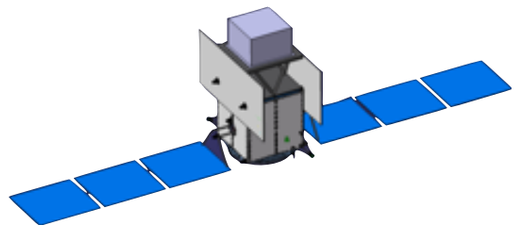






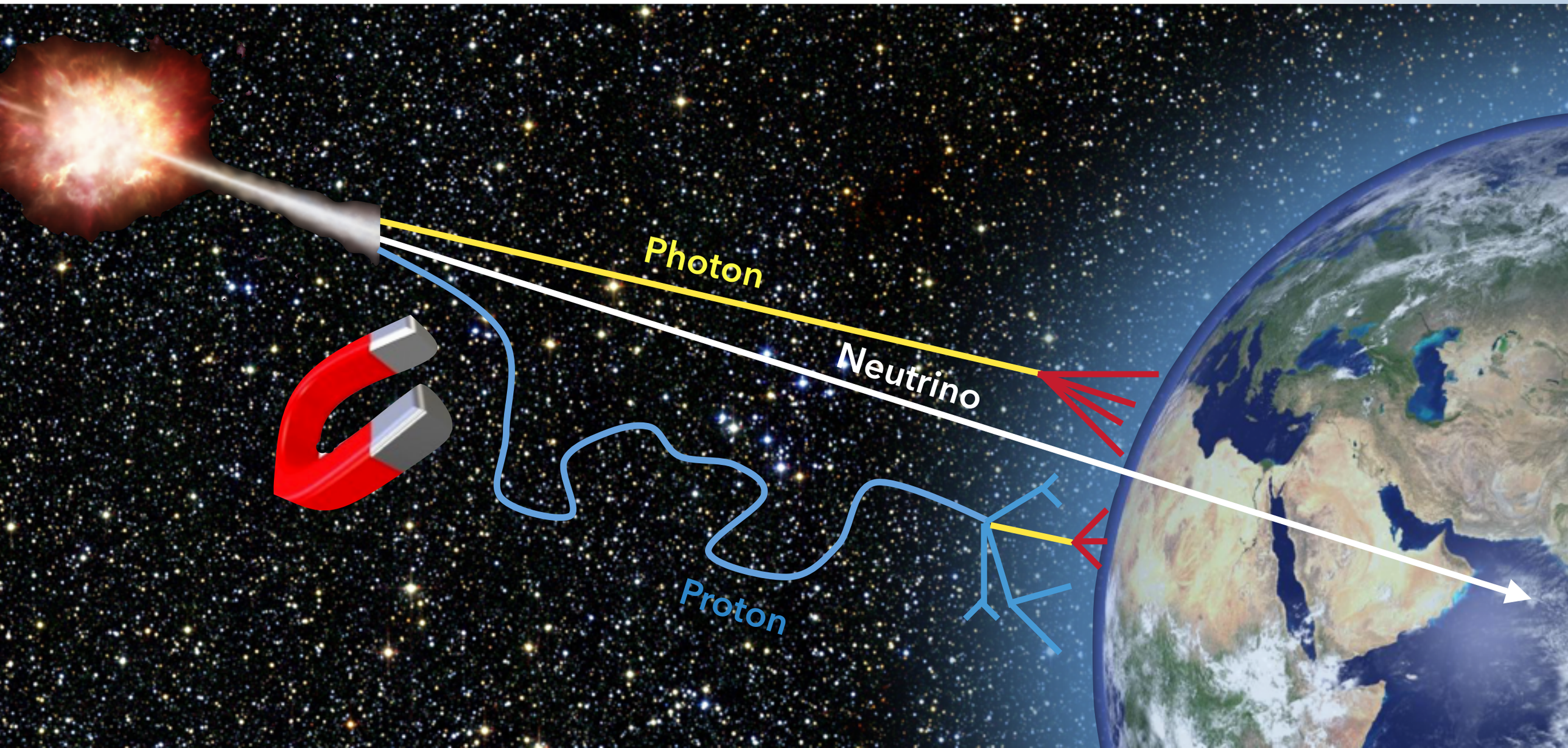


- HE sources studied by e-ASTROGAM as well
- Further constrain the HE/acceleration processes



MULTI-MESSENGER CONNEXION

- Photons (γ-rays): absorbed and interact with CMB/IRB (pair production for d≳Mpc)
- Cosmic Rays: deflected by magnetic fields ($E<10^{19}$ eV)
- Neutrinos: Neutral, weakly interacting particles, point to the source



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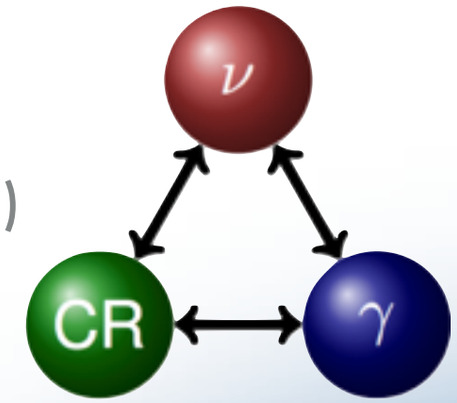

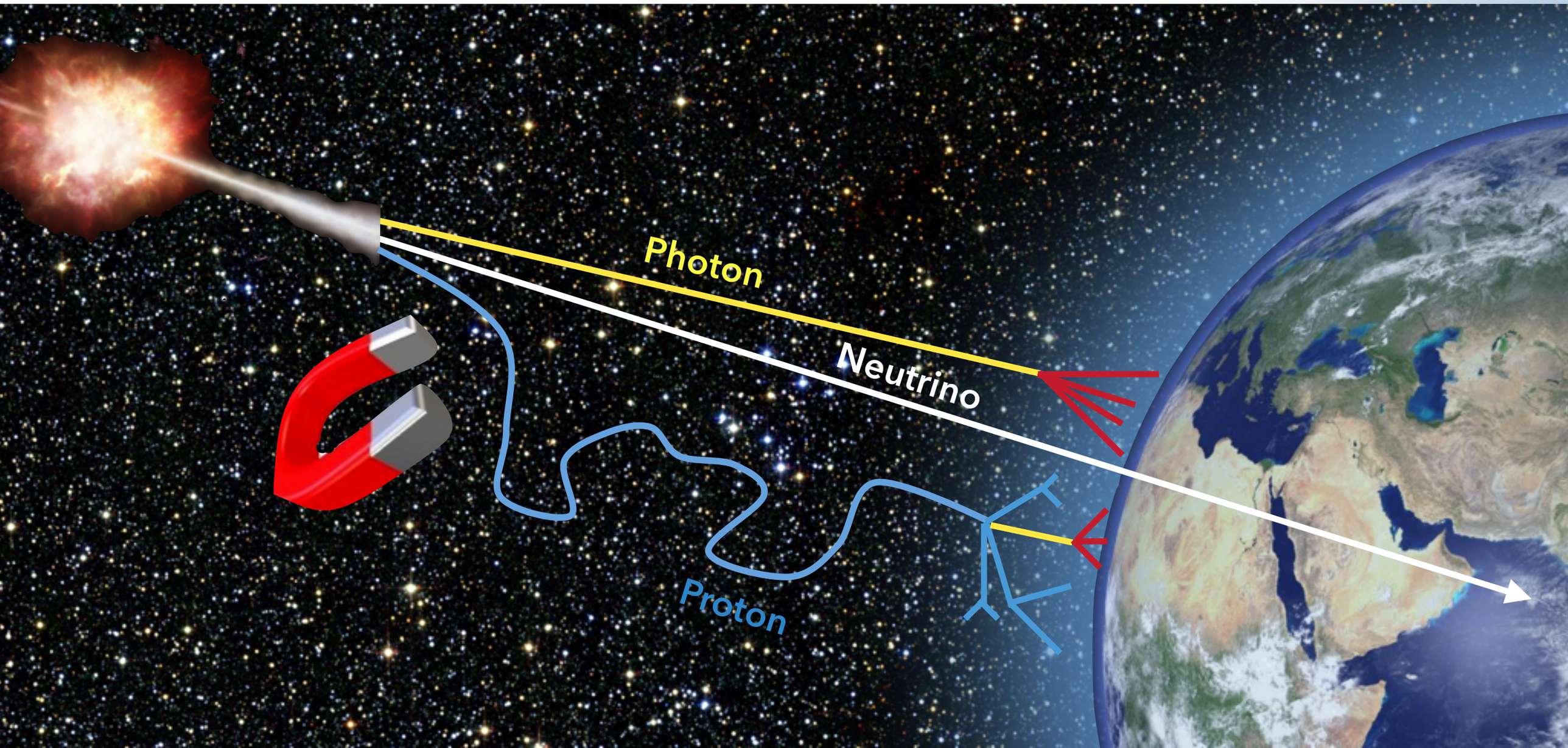

HE NEUTRINO PRODUCTION PROCESSES

- Hadronuclear (e.g. starburst galaxies, galaxy clusters, galactic cosmic rays)

$$pp \rightarrow \begin{cases} \pi^0 \rightarrow \gamma\,\gamma \\ \pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \nu_\mu \bar{\nu}_\mu \\ \pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

- Photohadronic (e.g. gamma ray-bursts, AGN, microquasars,…)

$$p\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p\,\pi^0 \rightarrow p\,\gamma\,\gamma \\ n\,\pi^+ \rightarrow n\,\mu^+ \nu_\mu \rightarrow n\,e^+ \nu_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

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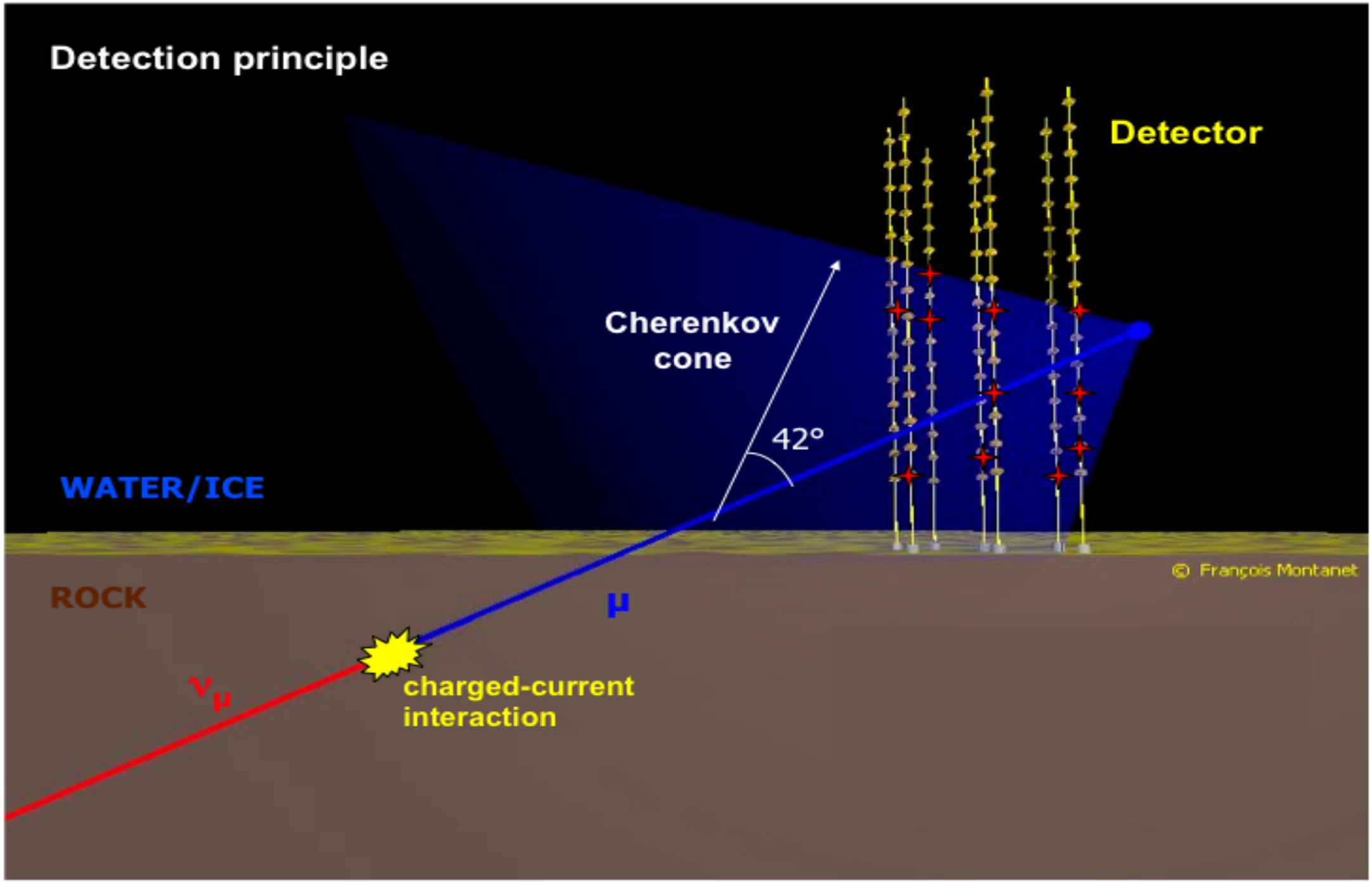
ν carries ~3–5% of p energy
⇒ TeV–PeV neutrinos produced by p with PeV–100 PeV energies

DETECTION PRINCIPLE

Different ways to detect HE ν.

One way particularly useful in astronomy:
observation of muons produced in CC interaction of ν_μ



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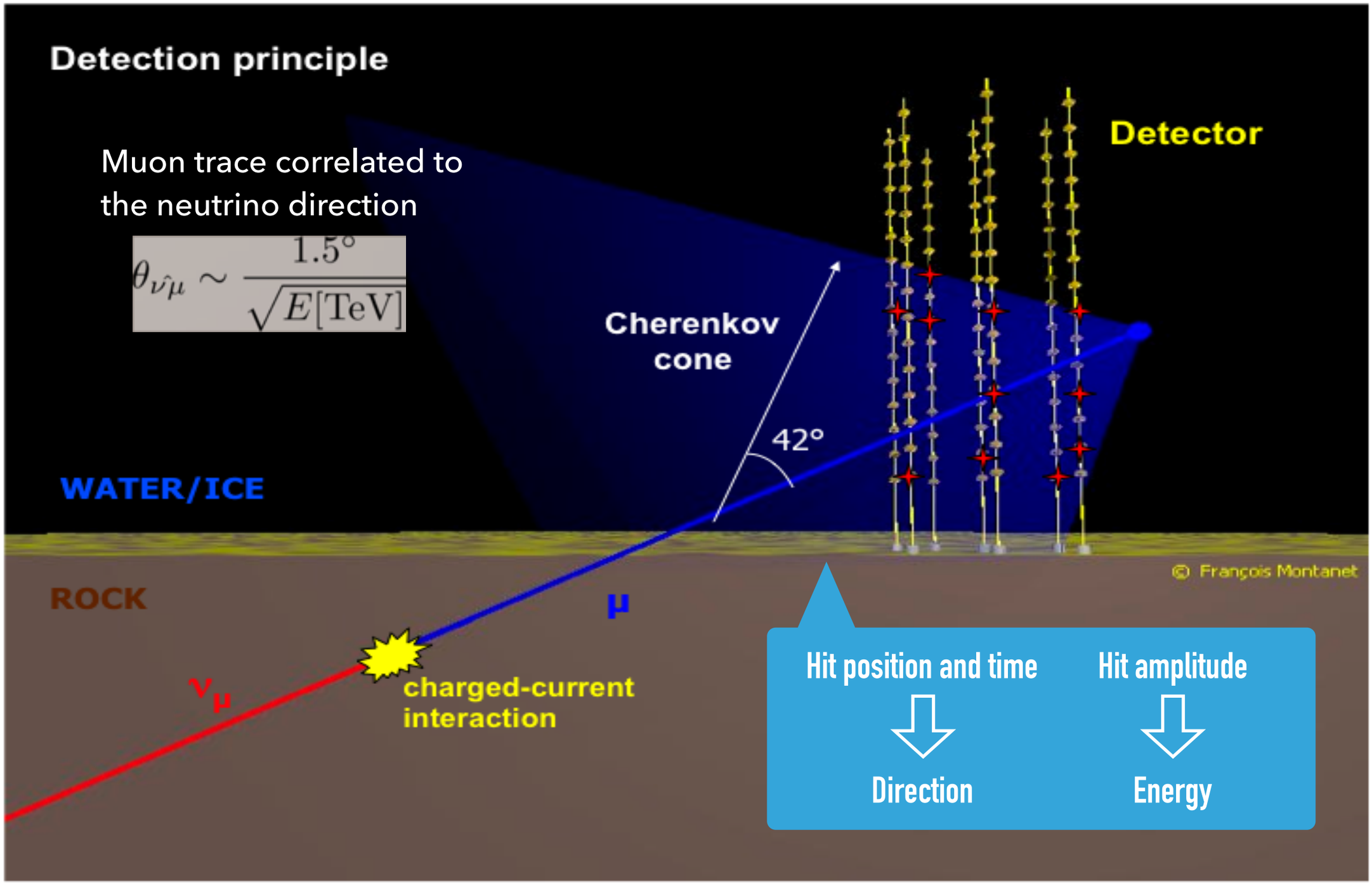

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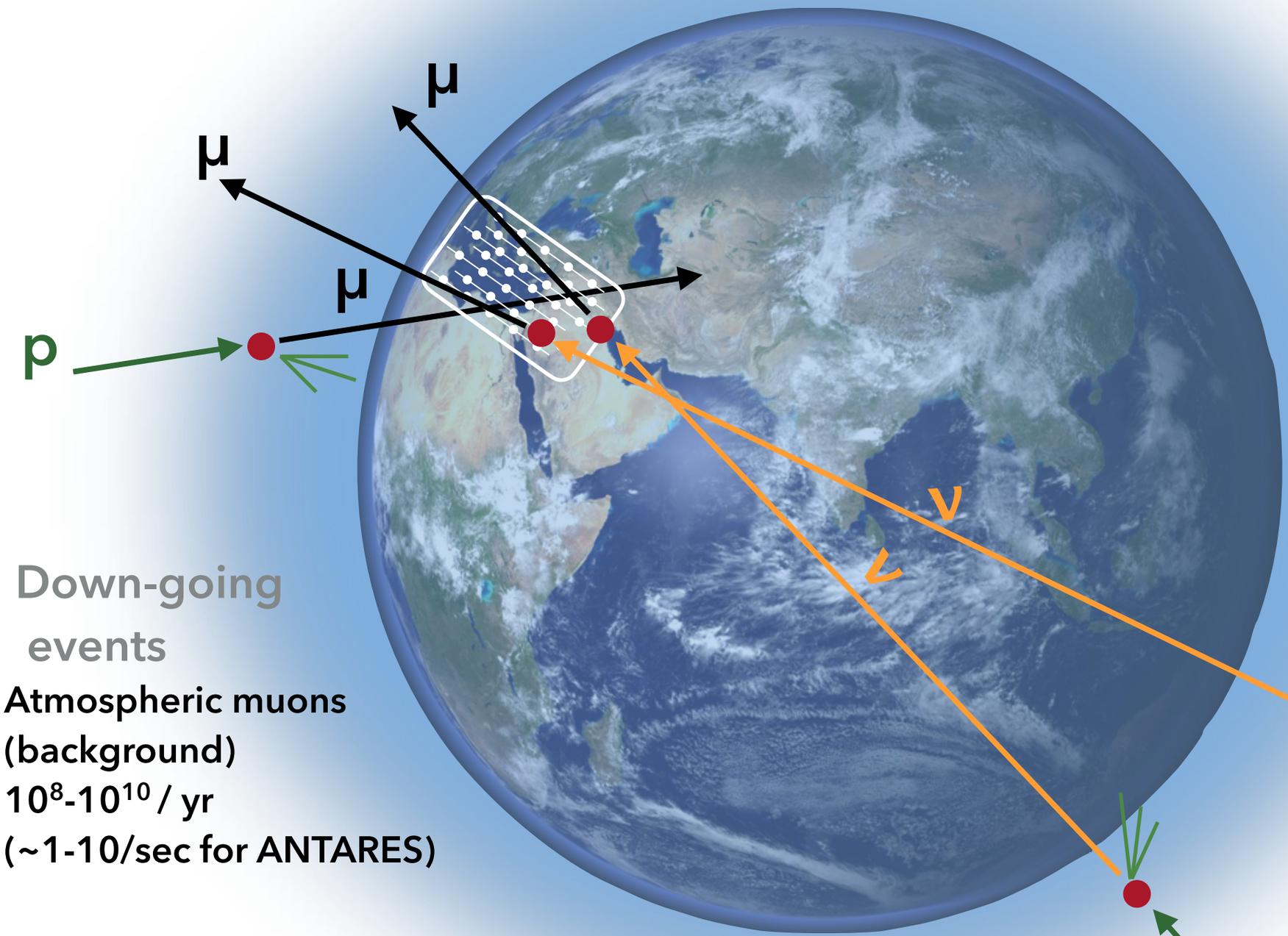


Up-going events

Atmospheric neutrinos (background)
10^3-10^5 / yr
(a few/day for ANTARES)

Cosmic neutrinos (signal)

Down-going events

Atmospheric muons (background)
10^8-10^{10} / yr
(~1-10/sec for ANTARES)

- The huge atmospheric muon background (down-going events) can be removed by looking for up-going events.

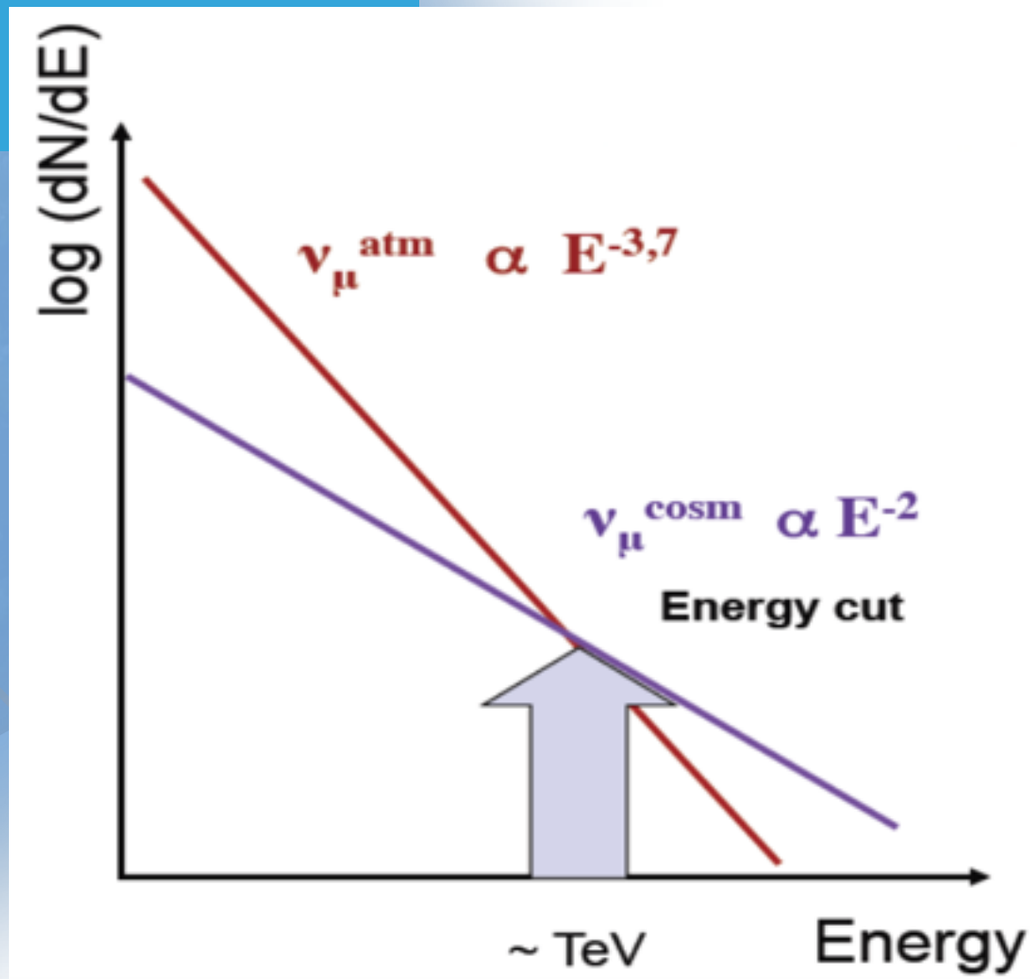
- The atmospheric neutrinos that cross the Earth have unfortunately the same instrumental signature as cosmic neutrinos (both seen as up-going events).

- High-energy cut

Up-going events

Down-going events

Atmospheric muons (background)
10^8-10^{10} / yr
(~1-10/sec for ANTARES)



ANALYSIS PRINCIPLE

How to identify cosmic neutrinos ?

Looking for excess at high energies:

➜ diffuse flux analyses

- Concerns mainly extragalactic sources
- Requires good energy resolution

Looking for anisotropies (clusters of events) in the sky:

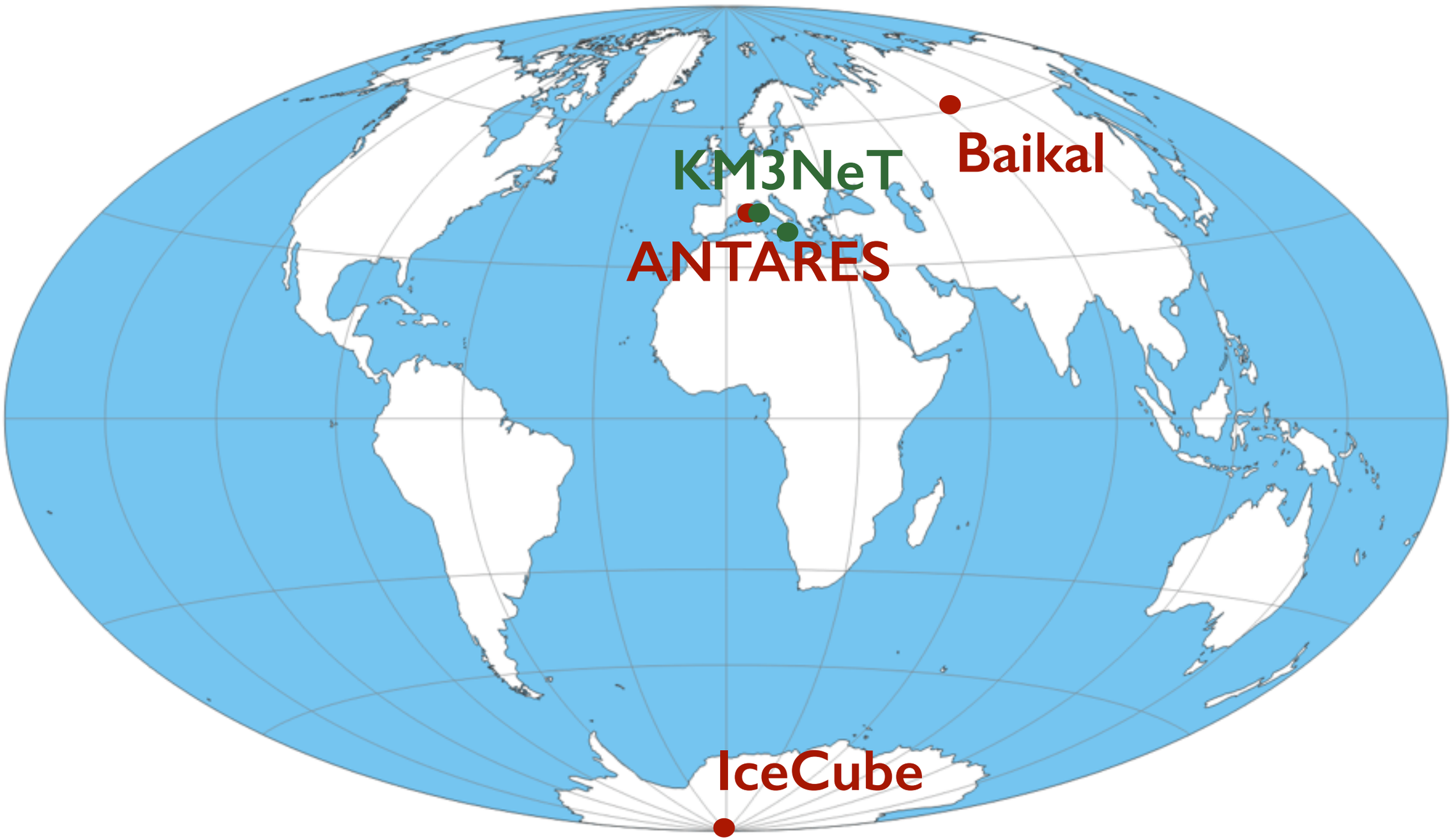
➜ point source searches

- Requires good angular resolution

Looking for coincidences with other astrophysical signals:

➜ multi-messenger searches

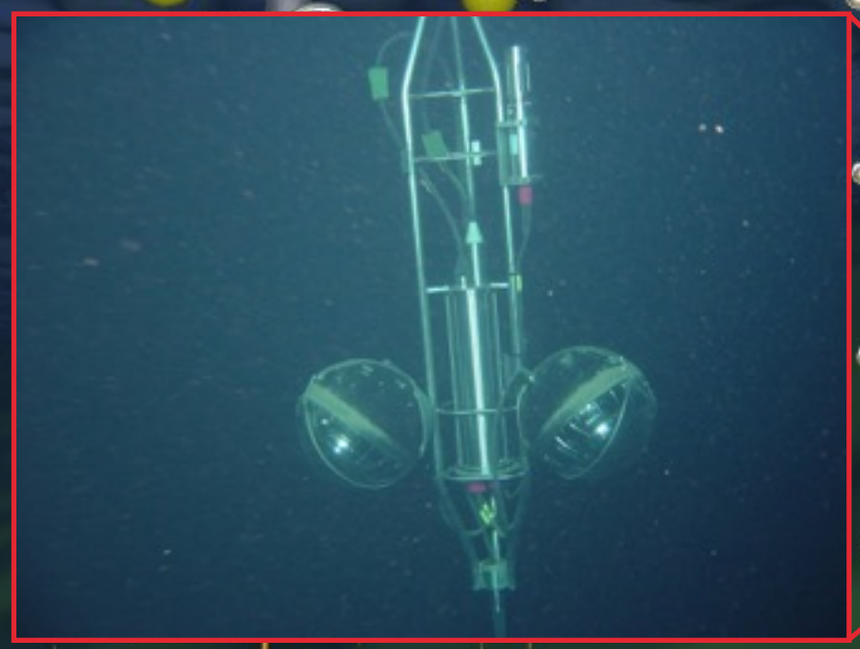
- Requires temporal coincidences with other probes (GW, photons)


KM3NeT
ANTARES
Baikal
IceCube

12 line detector completed in May 2008

8 countries
31 institutes
~150 scientists + engineers

- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs



350 m

100 m

~70 m

14.5 m

Deployed in 2001

40 km

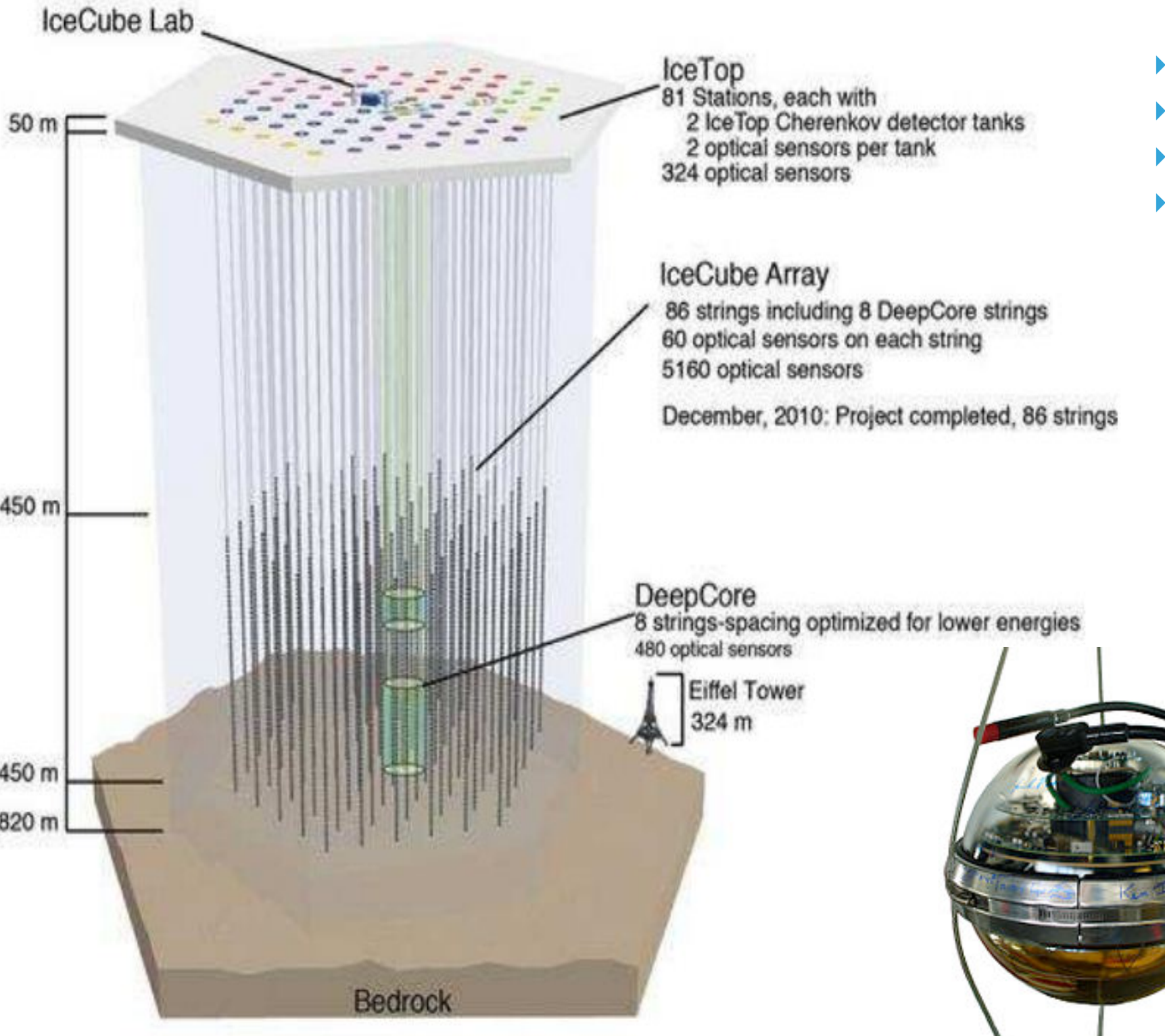
Junction box (since 2002)

Anchor/line socket

Interlink cables

©Montanet

ICECUBE

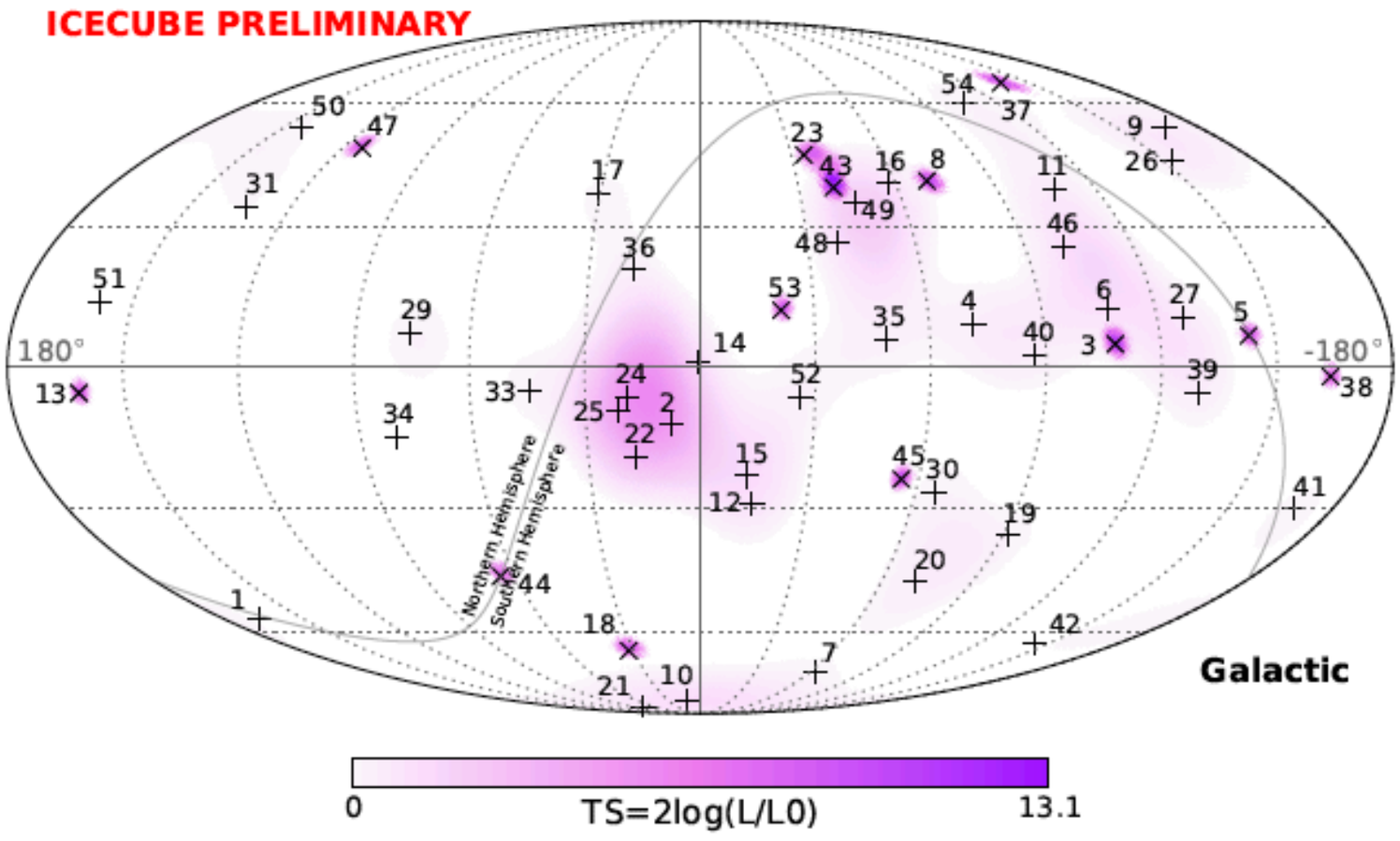


- 86 lines, completed end 2010
- 1 km^3 instrumented volume
- DeepCore: denser (8 strings)
- IceTop: air shower detectors

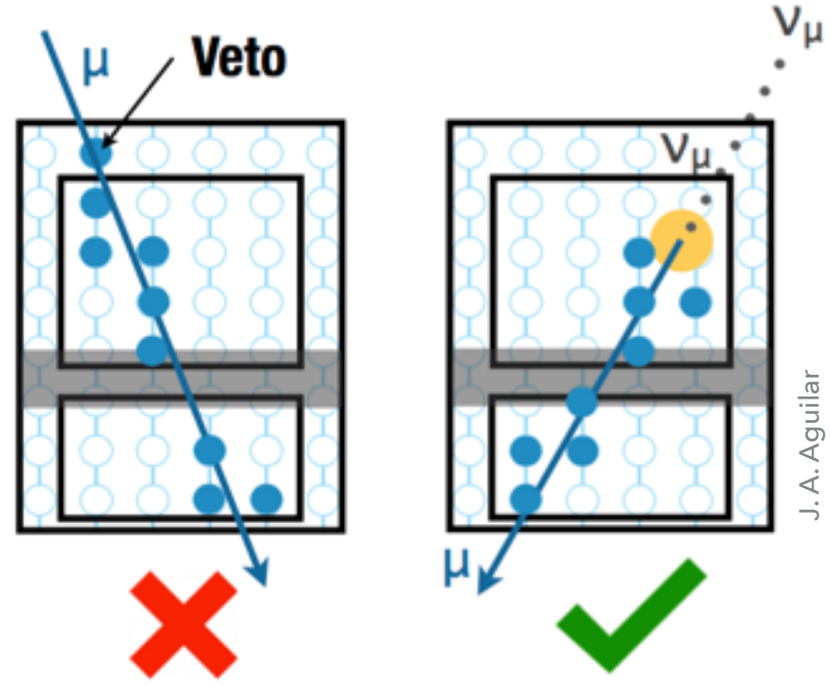
Different media: different technical challenges

A COSMIC HE NEUTRINO FLUX

In the months following the detection of 2 first PeV events, IceCube pointed a clear excess of events above ~100 TeV w.r.t. the atmospheric ν background (e.g. IceCube coll., PRL 113, 2014).



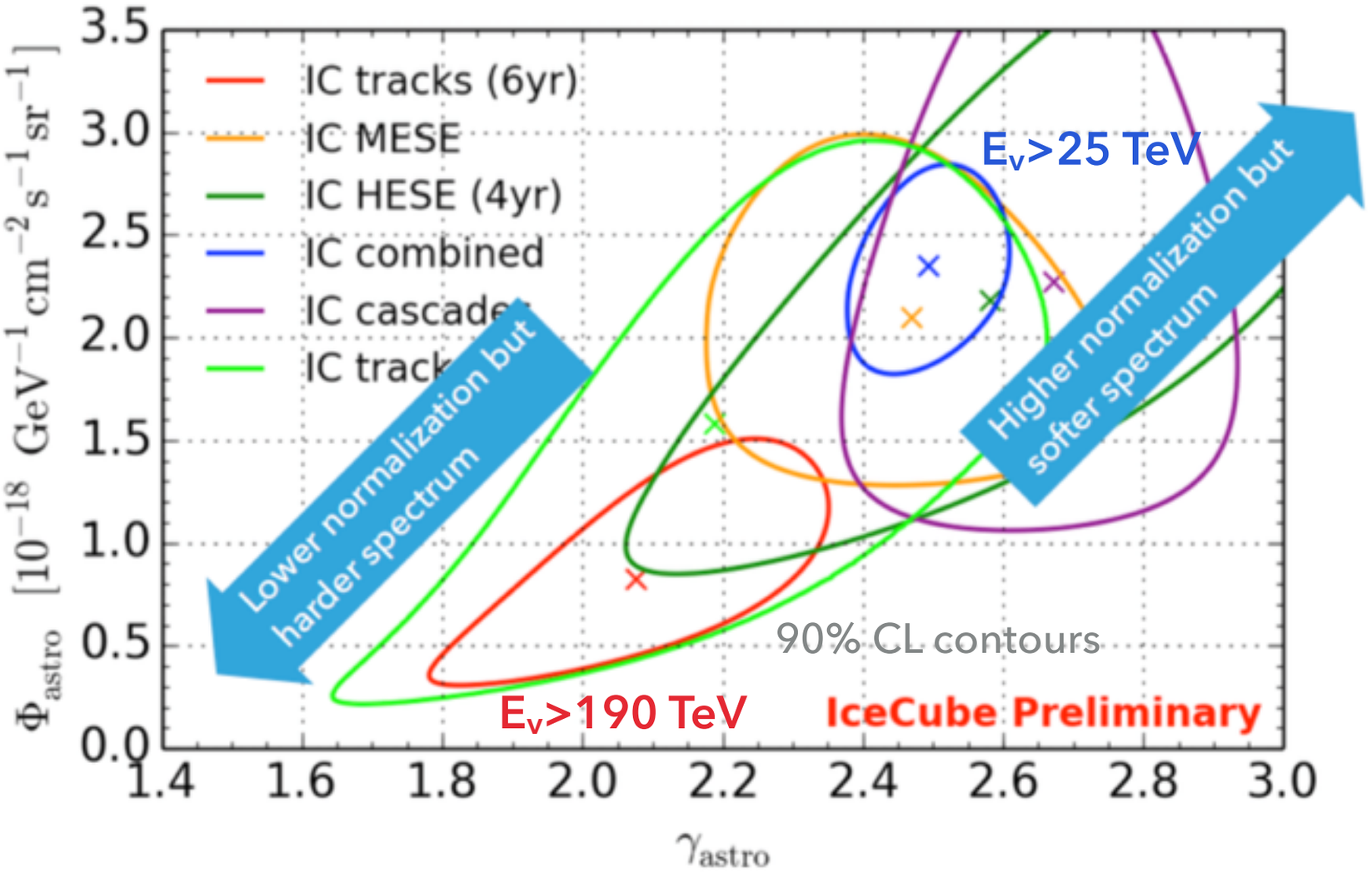
HE starting events - 5 years - all flavors



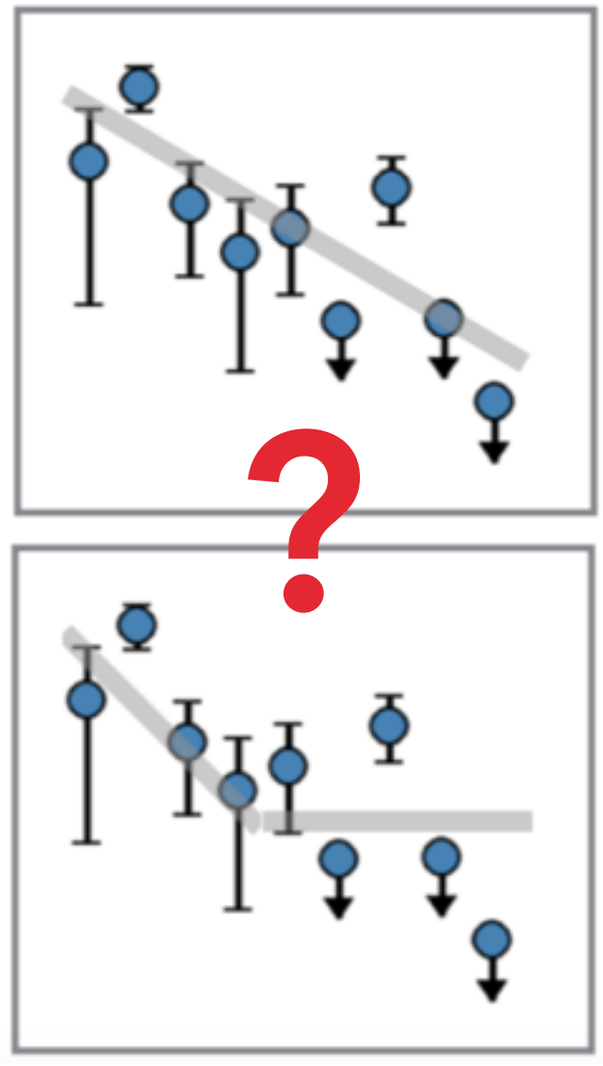
- Compatible with isotropy
- Sources non identified yet
- Excess also visible in track channel (5.6σ)

now ~7σ significance

A COSMIC HE NEUTRINO FLUX



Adapted from Juan A. Aguilar (RICAP 2016) + M. Kowalski (Neutrino2016)



- Results of IC tracks (6yr) and IC combined not compatible at > 3.3σ level (IceCube coll., ApJ, 833, 2016).
- Indication of spectral break (different energy thresholds) ?
- Indication of Galactic and extra-galactic contributions (different hemispheres) ?

- NEUTRINO: ASTROPHYSICAL MESSENGER
- SYNERGIES BETWEEN MeV GAMMA-RAYS AND NEUTRINO TELESCOPES

– Where these HE neutrinos come from ?
– Constrain hadronic acceleration processes

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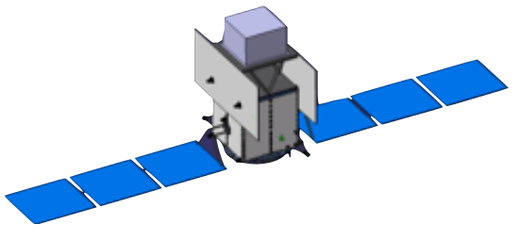

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IGRB measurement

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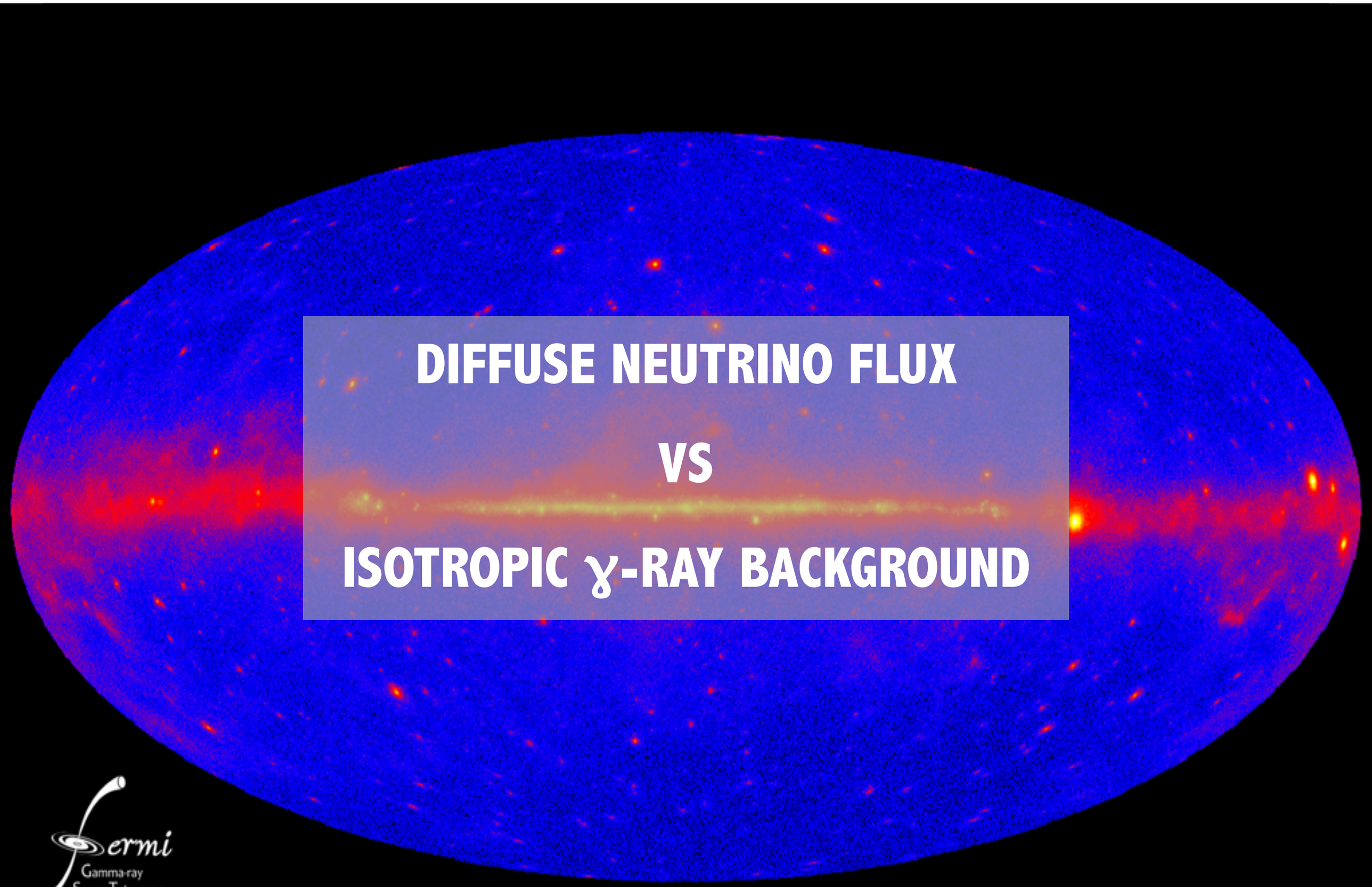
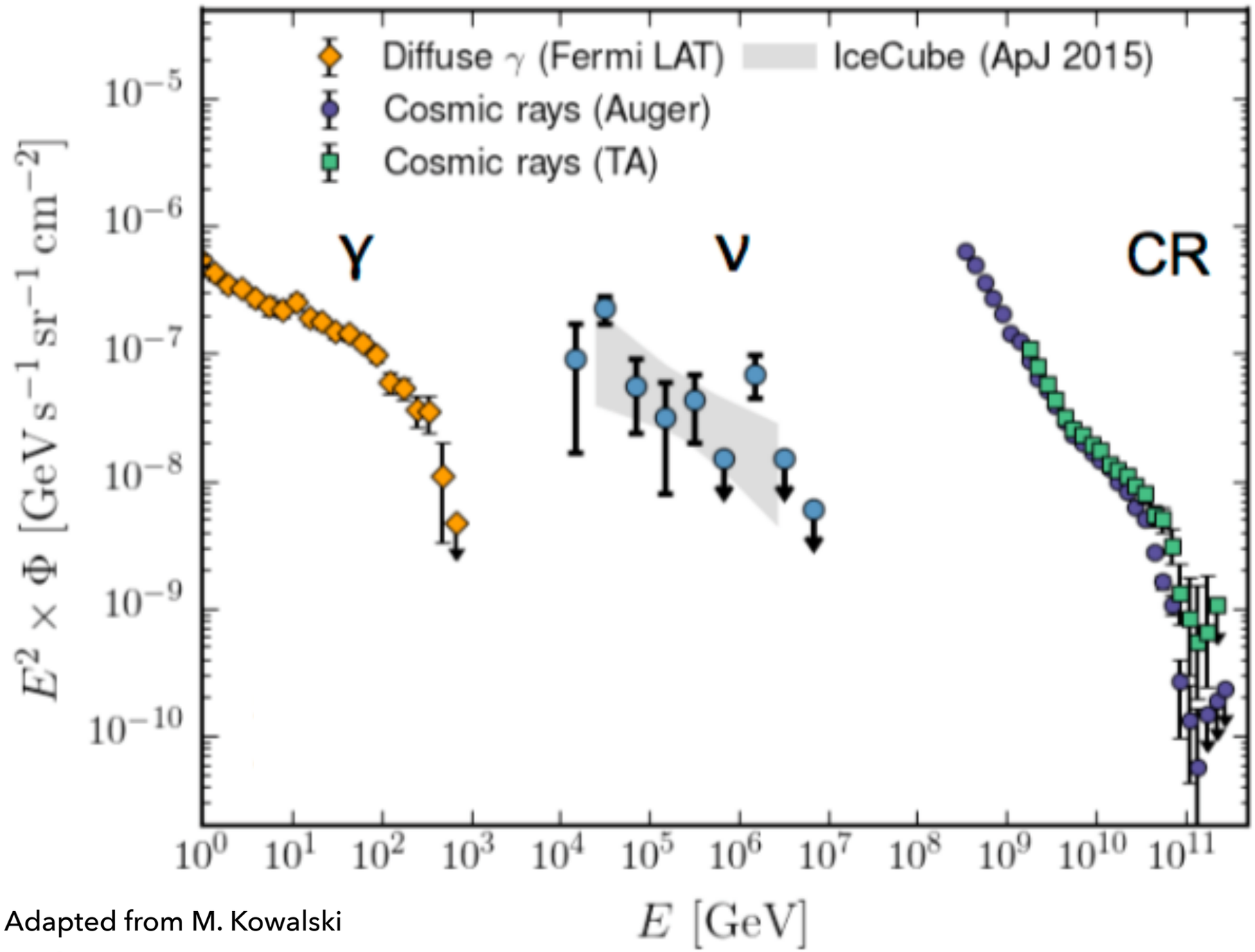
(Transient) point sources


DIFFUSE NEUTRINO FLUX
VS
ISOTROPIC γ-RAY BACKGROUND
Fermi
Gamma-ray
Space Telescope



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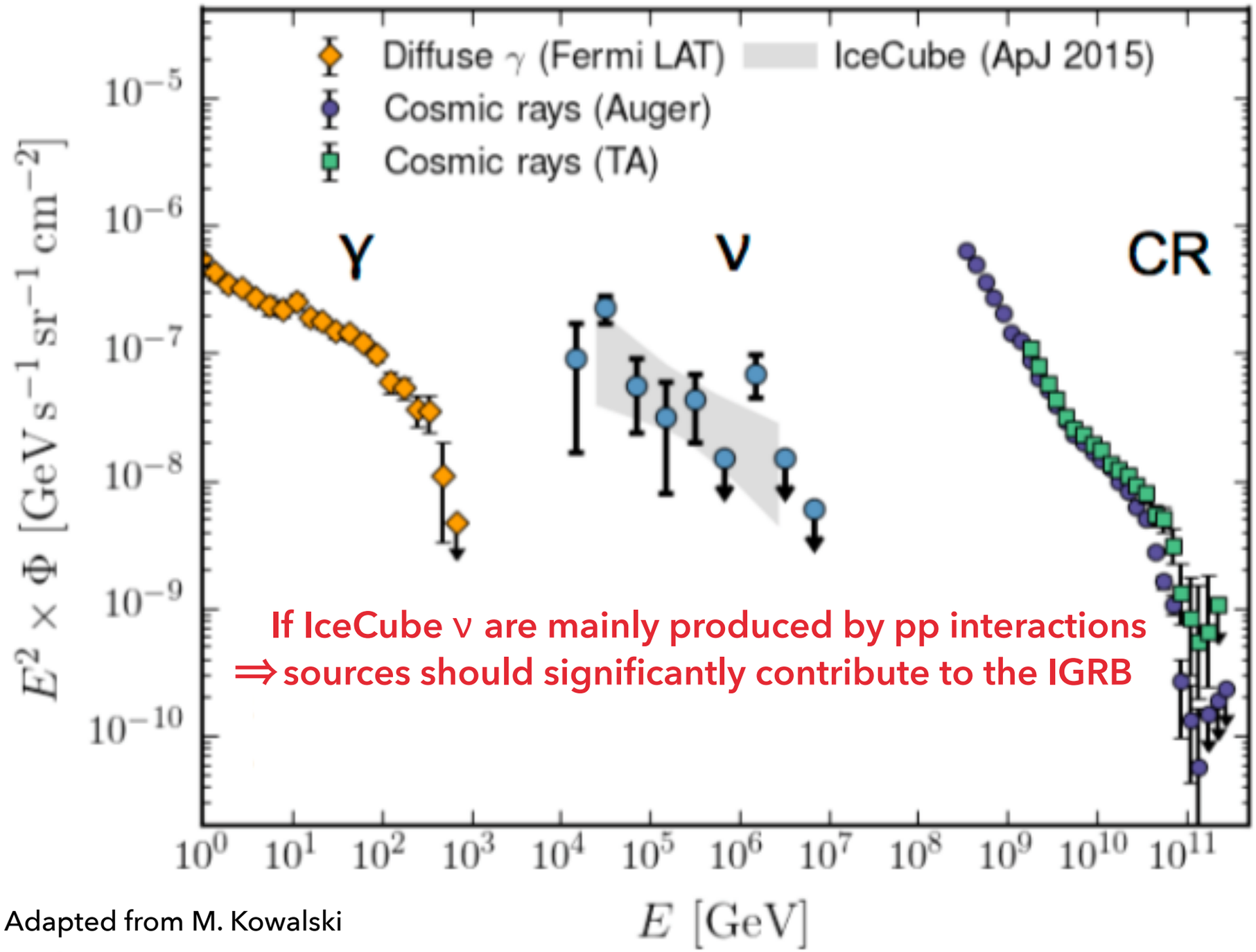

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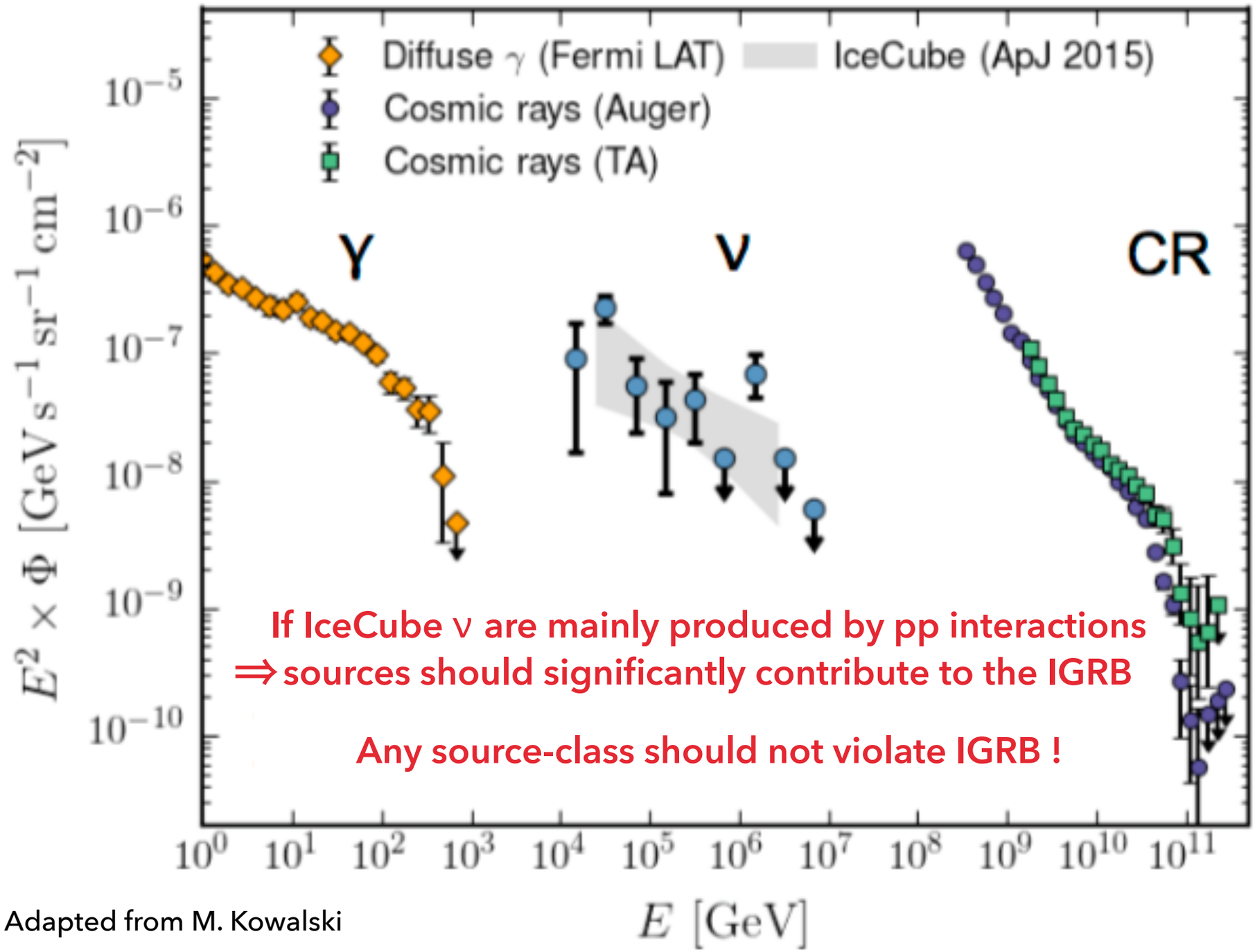

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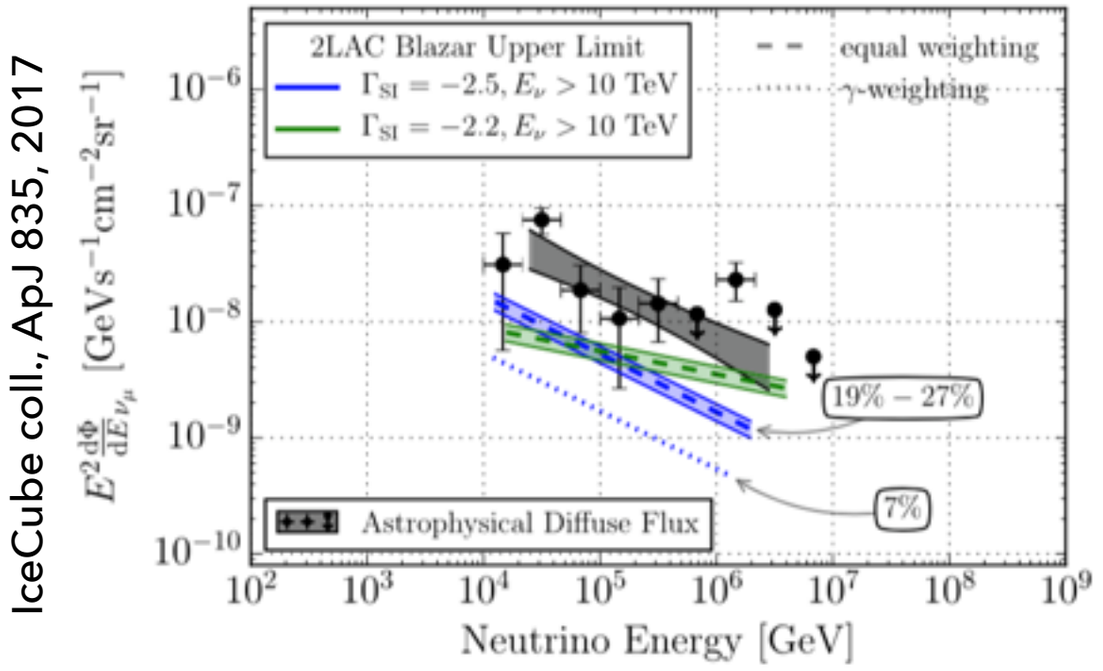

IceCube coll., ApJ 835, 2017

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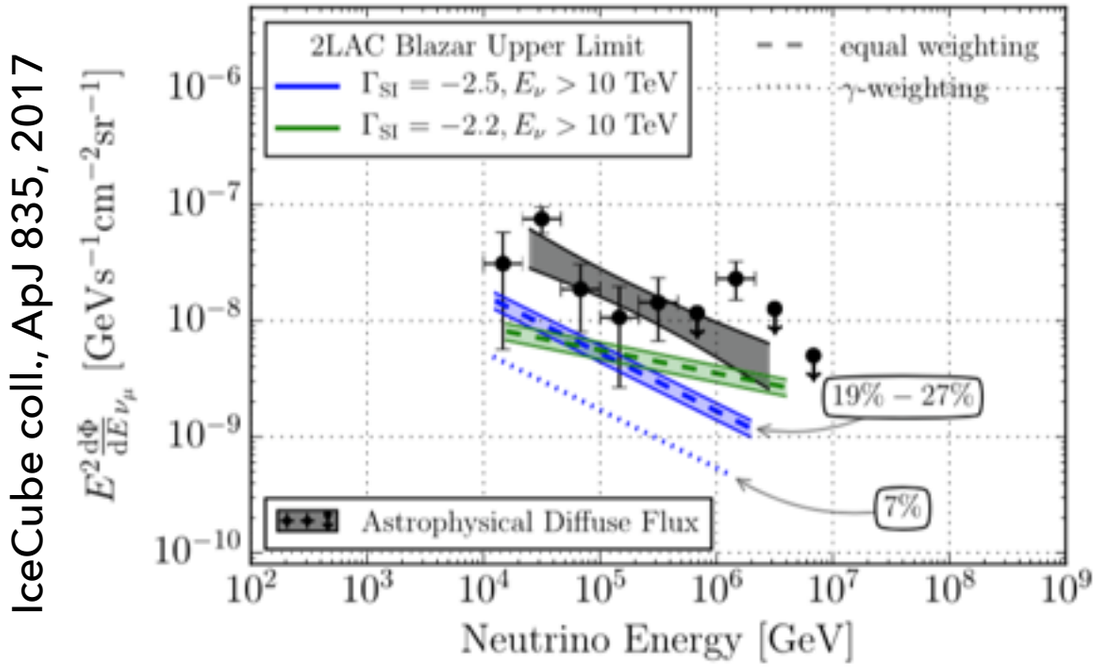

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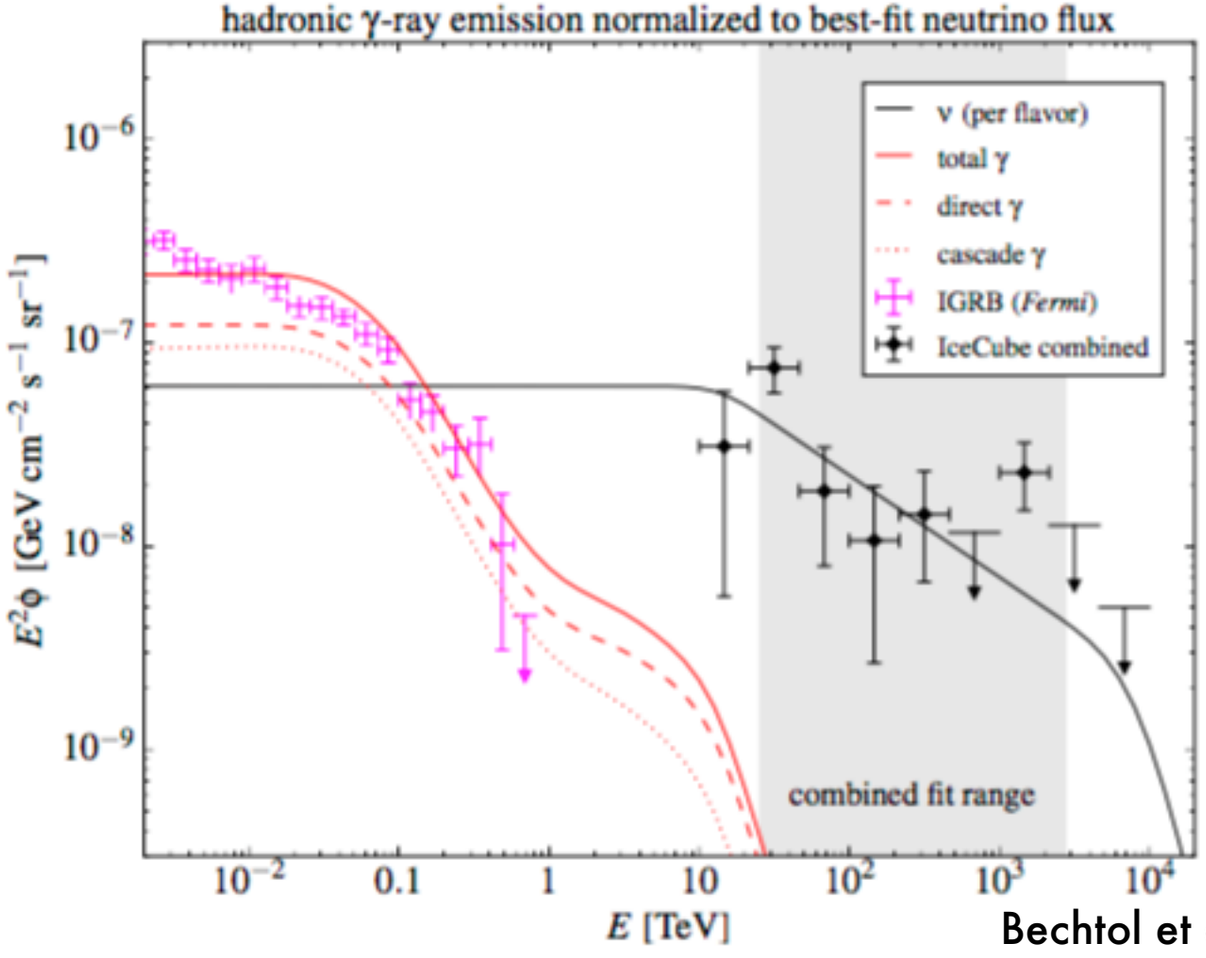

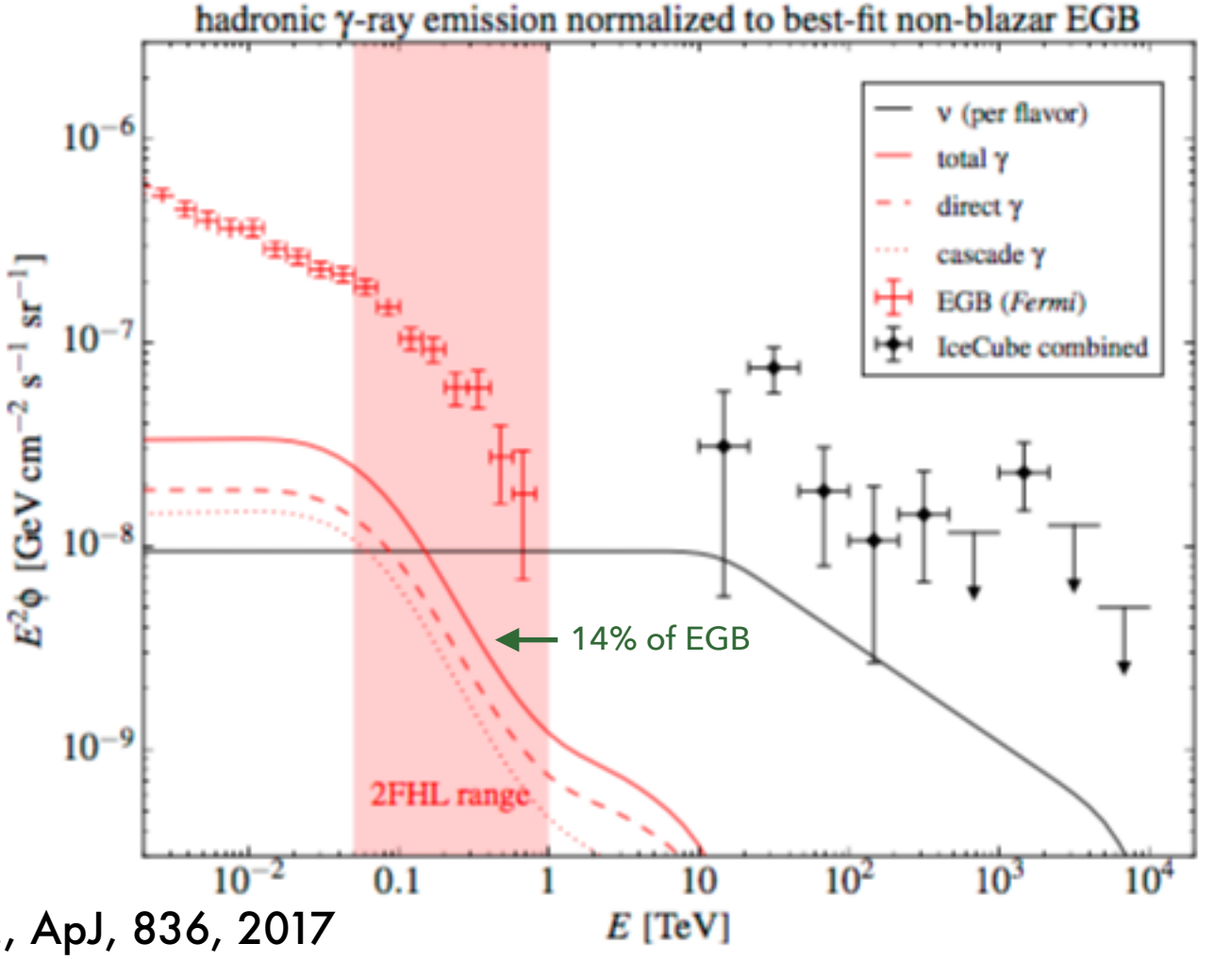

Bechtol et al., ApJ, 836, 2017

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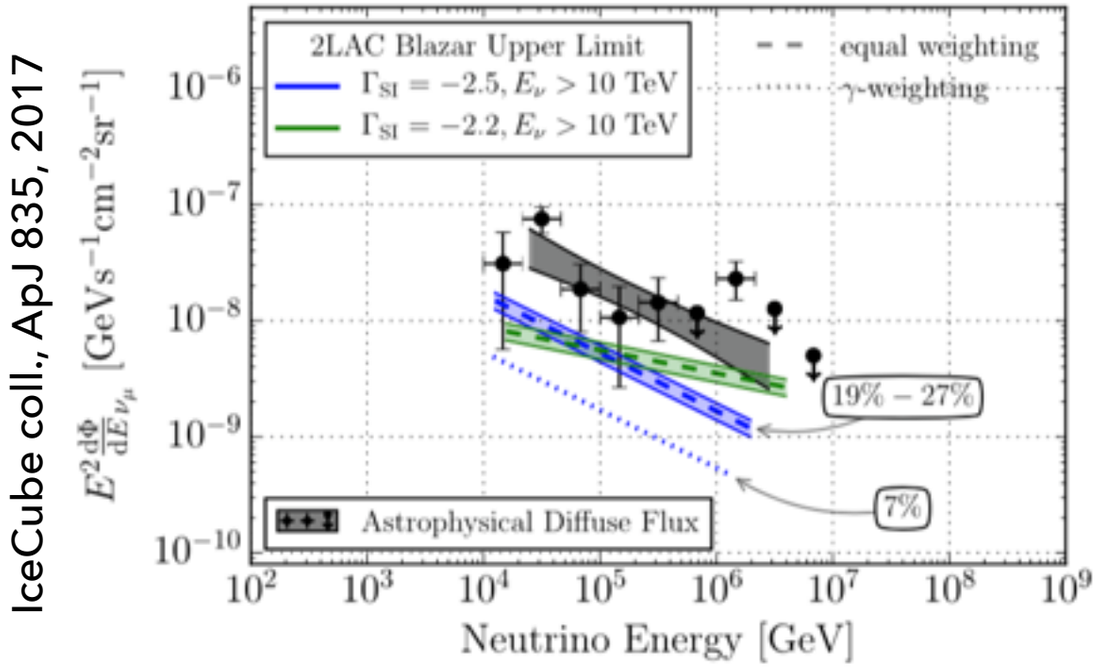

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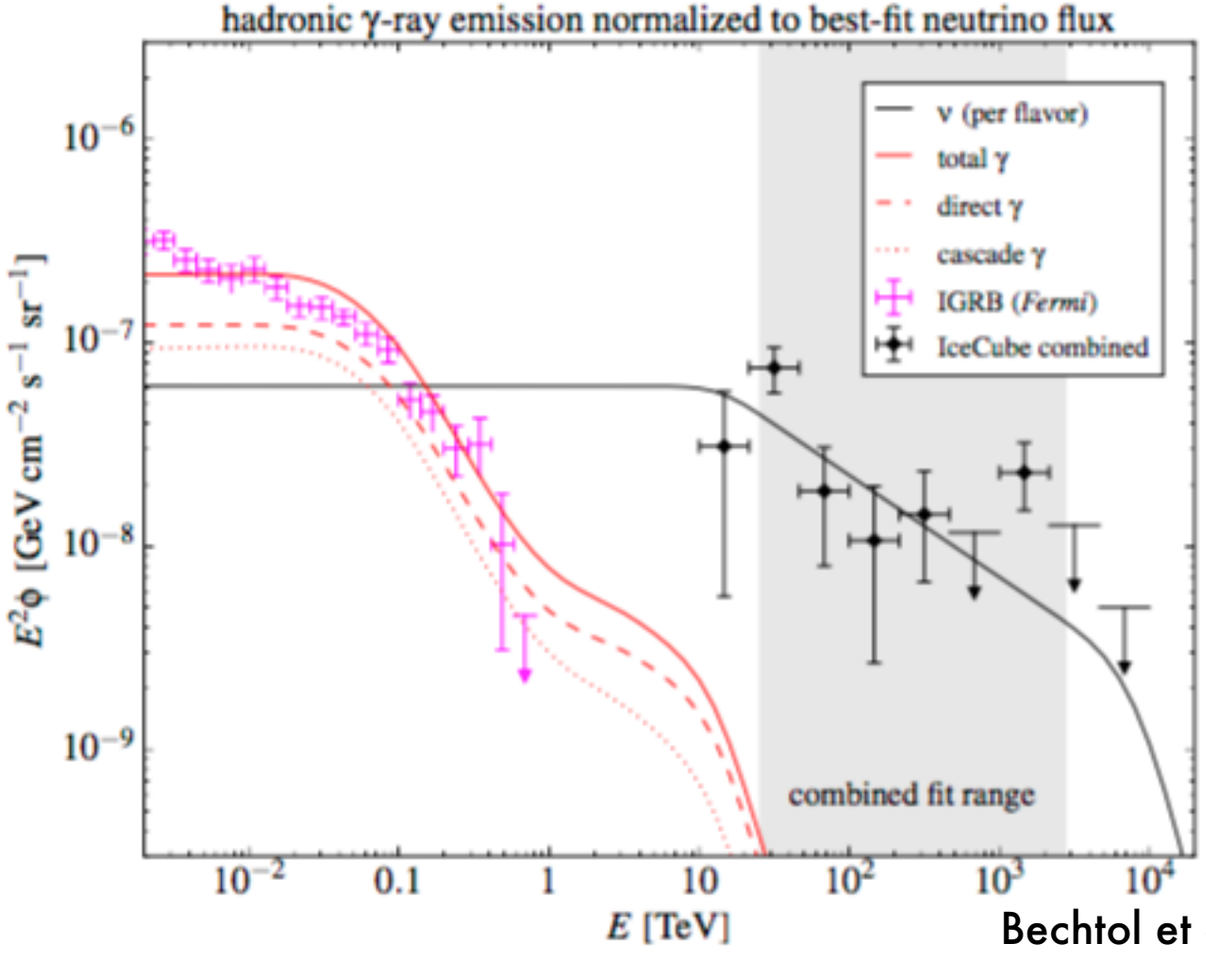

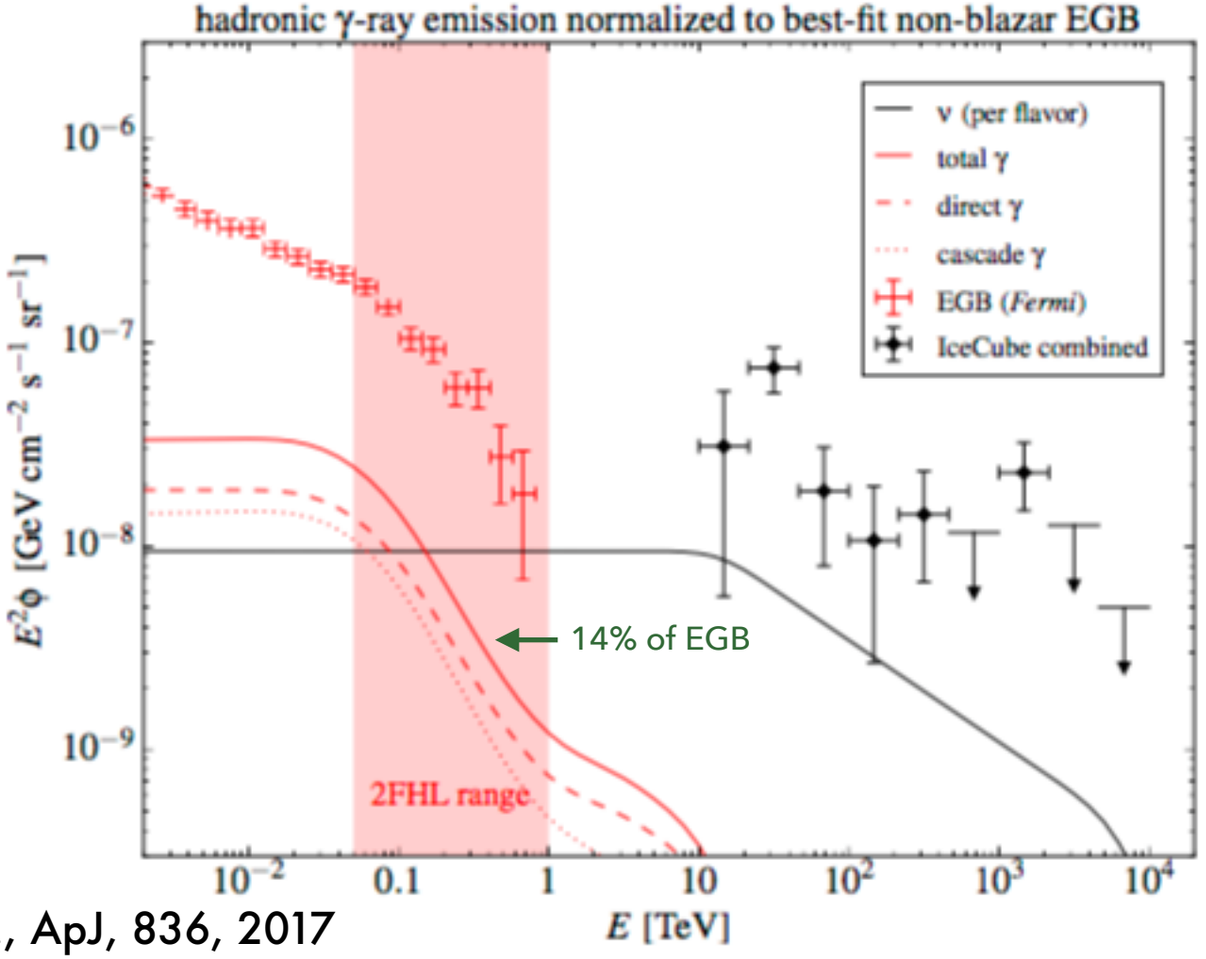

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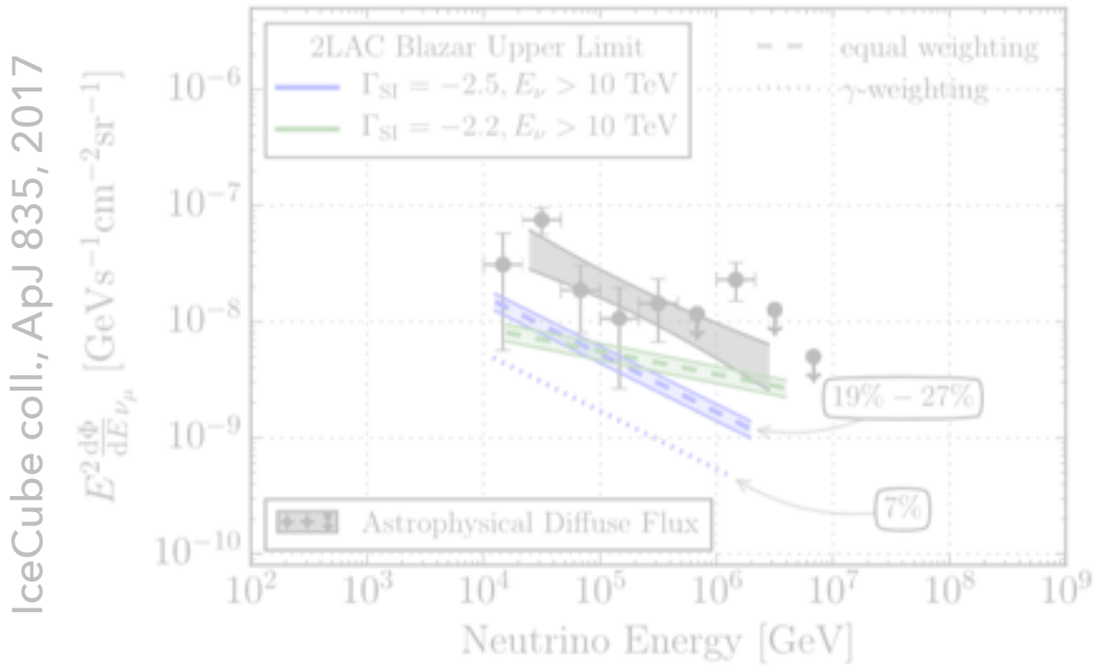

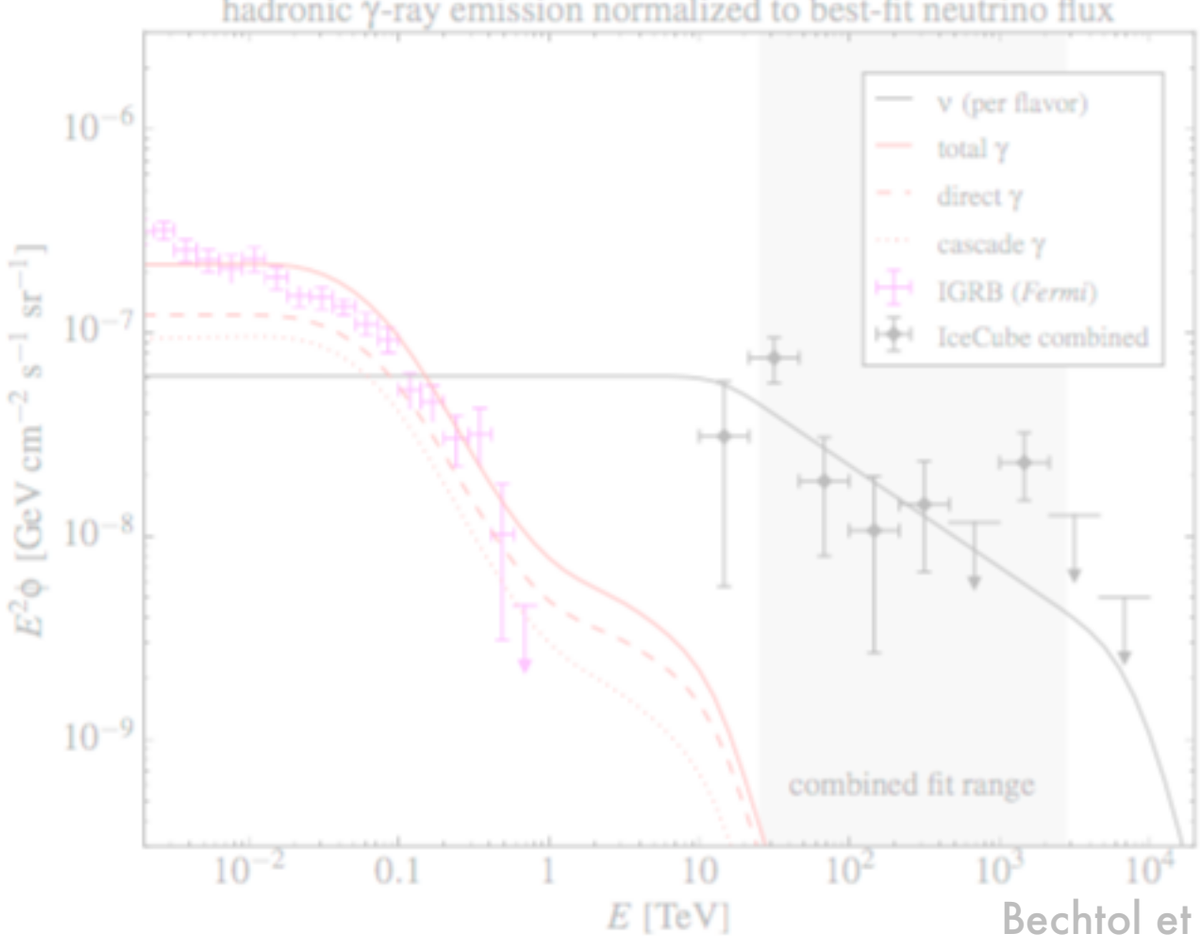

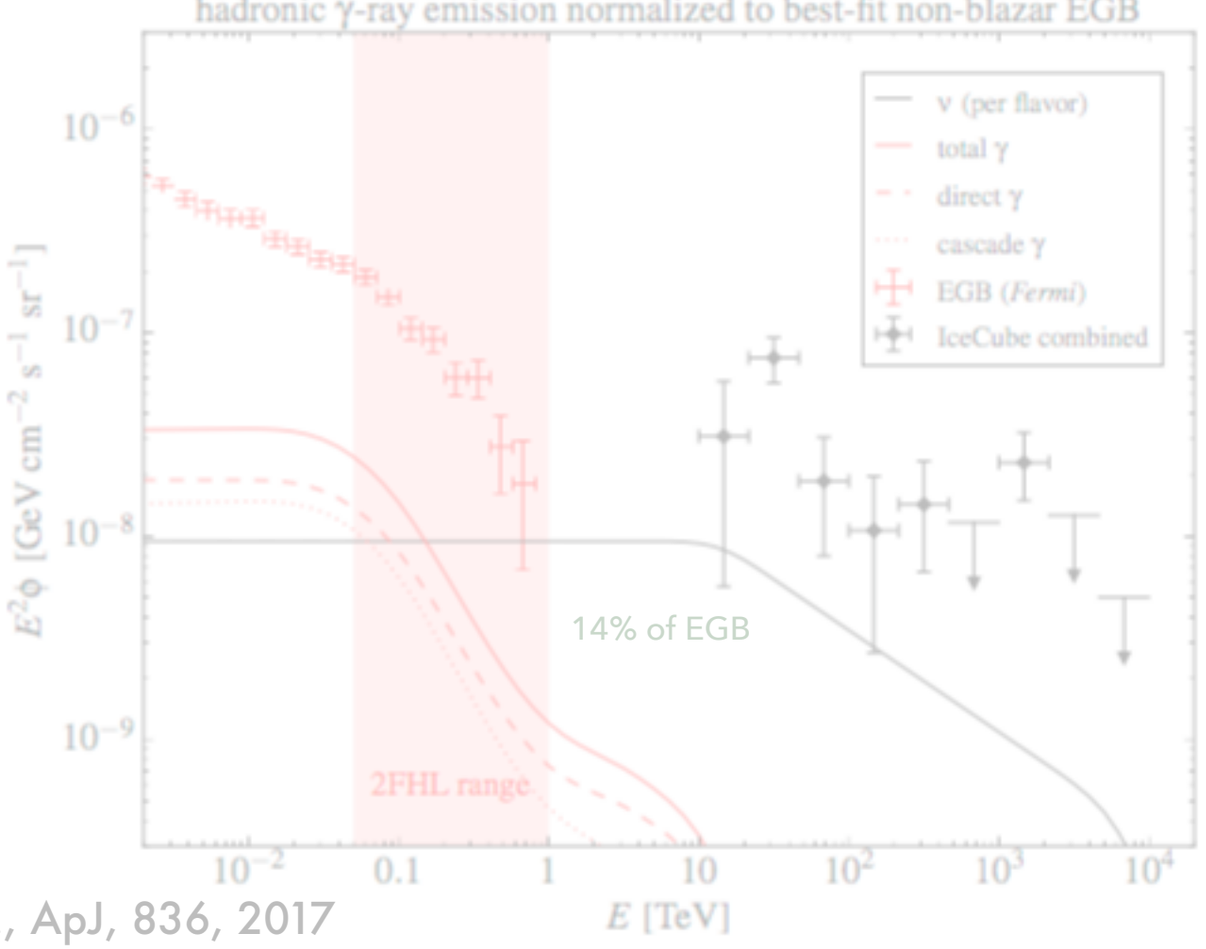

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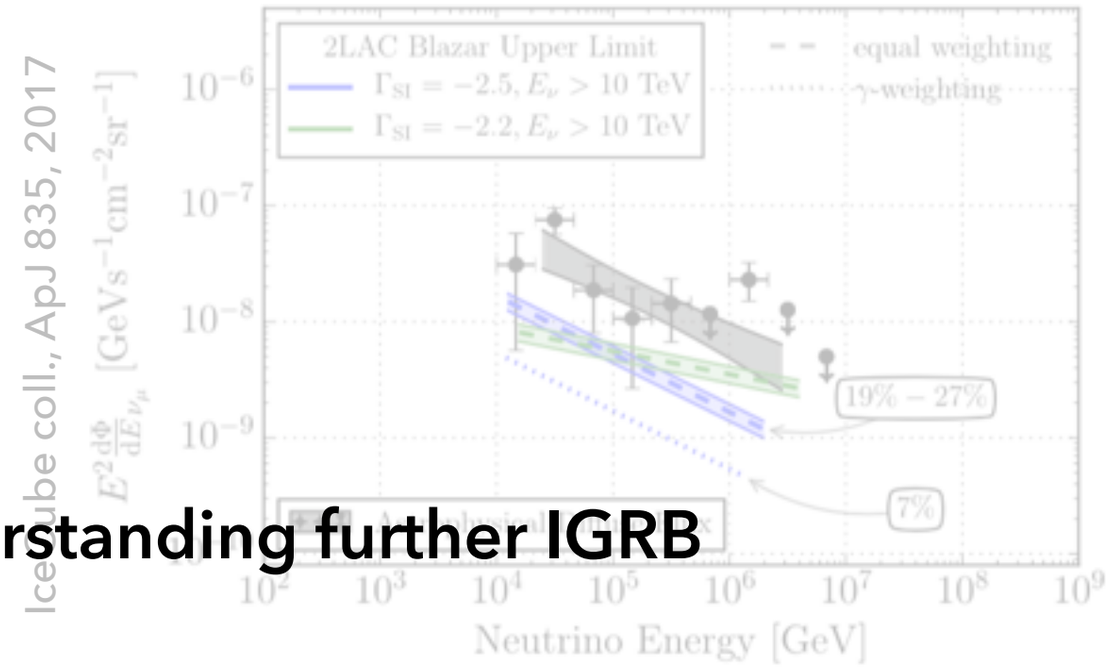
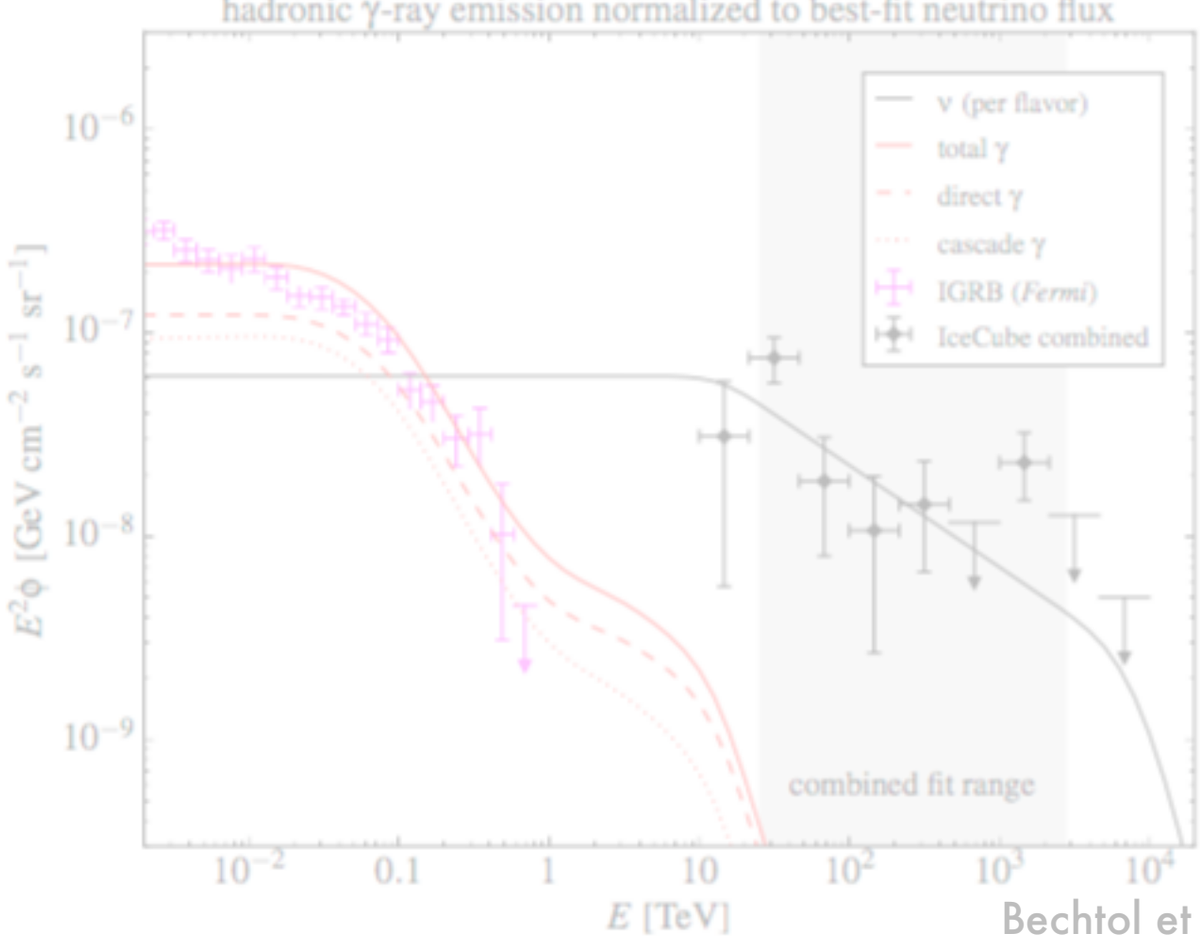
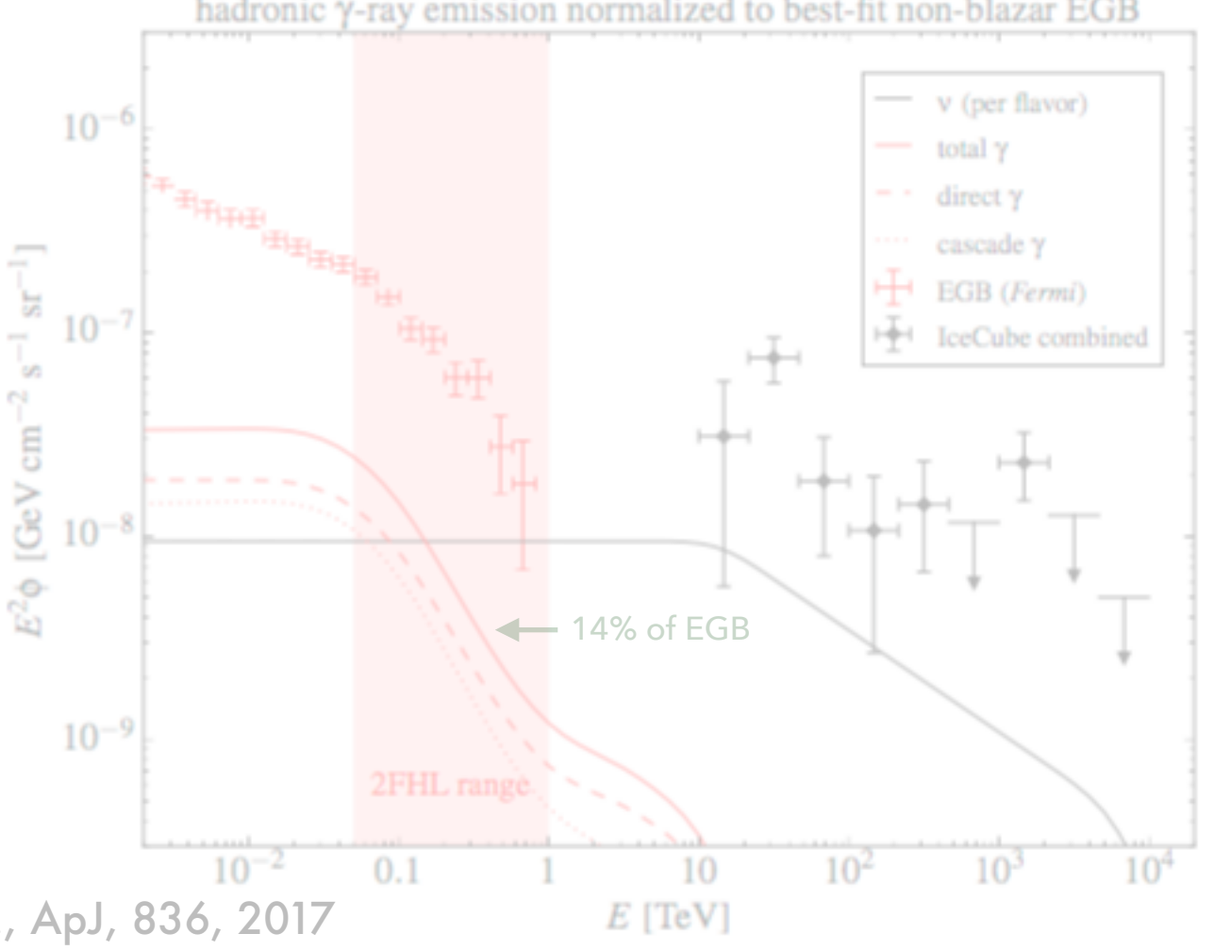
- **Can we improve these constraints by understanding further IGRB composition ?**







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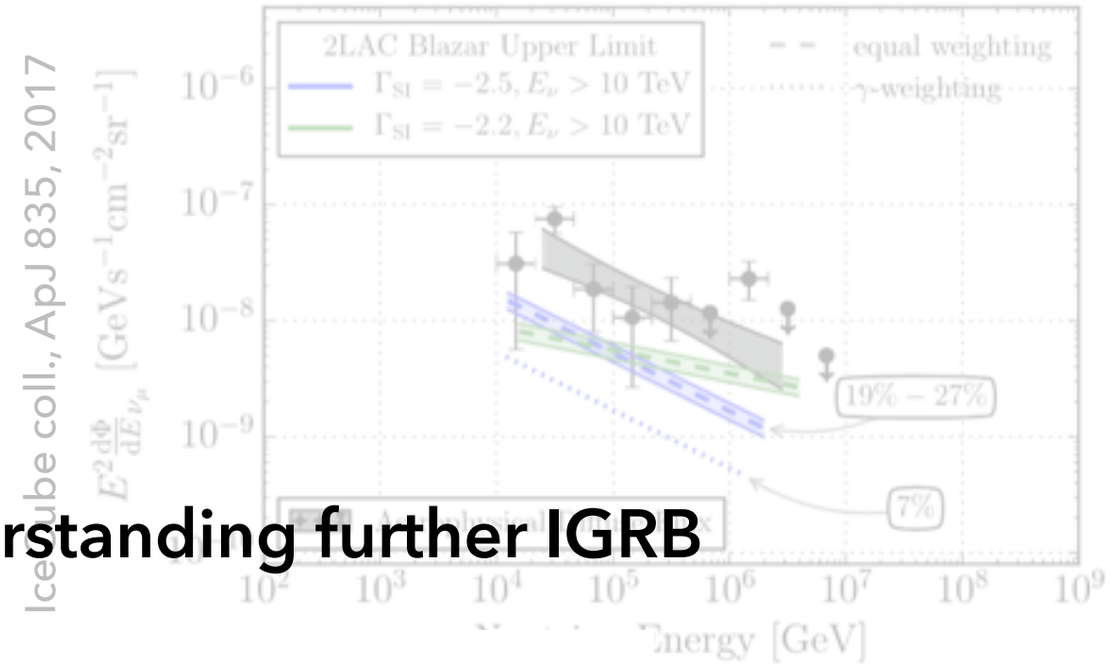

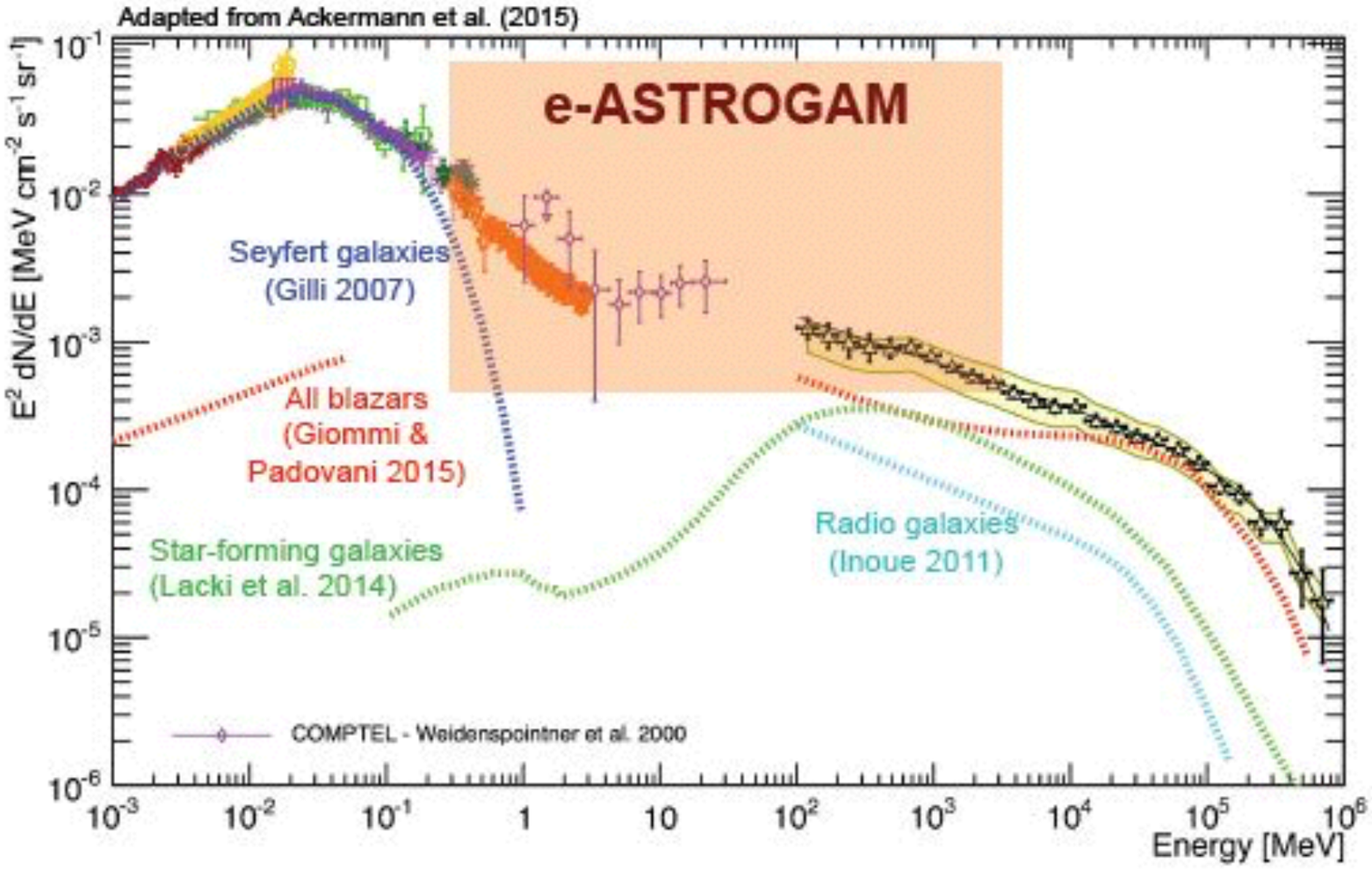

- p-γ processes could be dominant $p\gamma \rightarrow \Delta^{+} \rightarrow \begin{cases} p\,\pi^{0} \rightarrow p\,\gamma\,\gamma \\ n\,\pi^{+} \rightarrow n\,\mu^{+}\,\nu_{\mu} \rightarrow n\,e^{+}\,\nu_{e}\,\bar{\nu}_{\mu}\,\nu_{\mu} \end{cases}$

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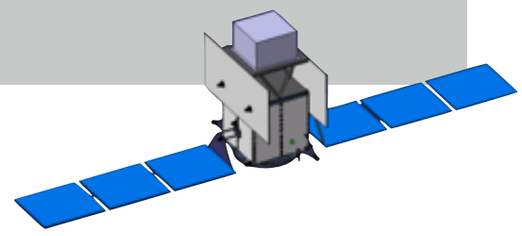
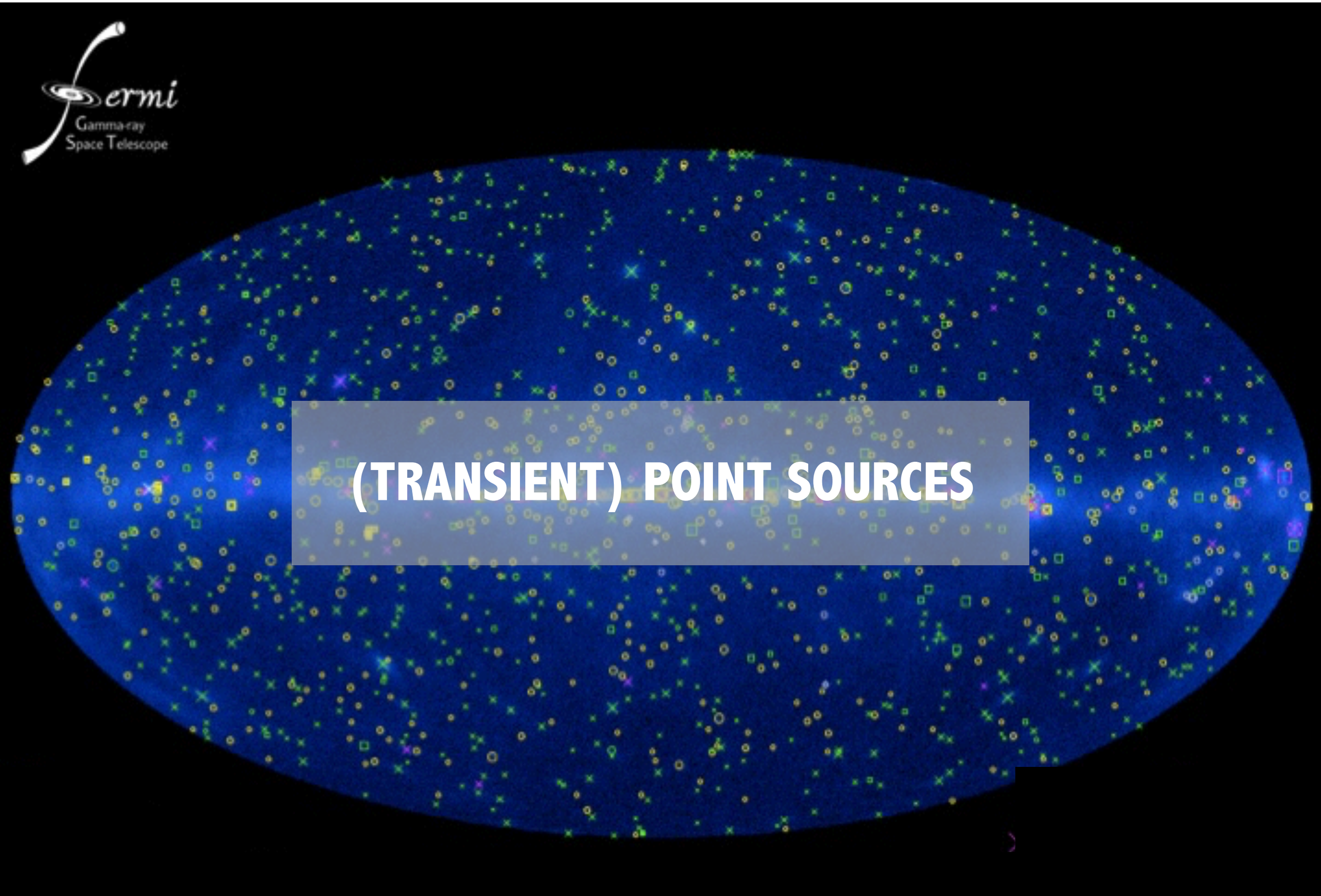
- Tension with IGRB relaxed compared to pp scenarios if **γ**-ray dark sources (Murase et al., PRL **116**, 2015)

1-100 GeV **γ**-rays should suffer from **γγ** → $e^{+}e^{-}$

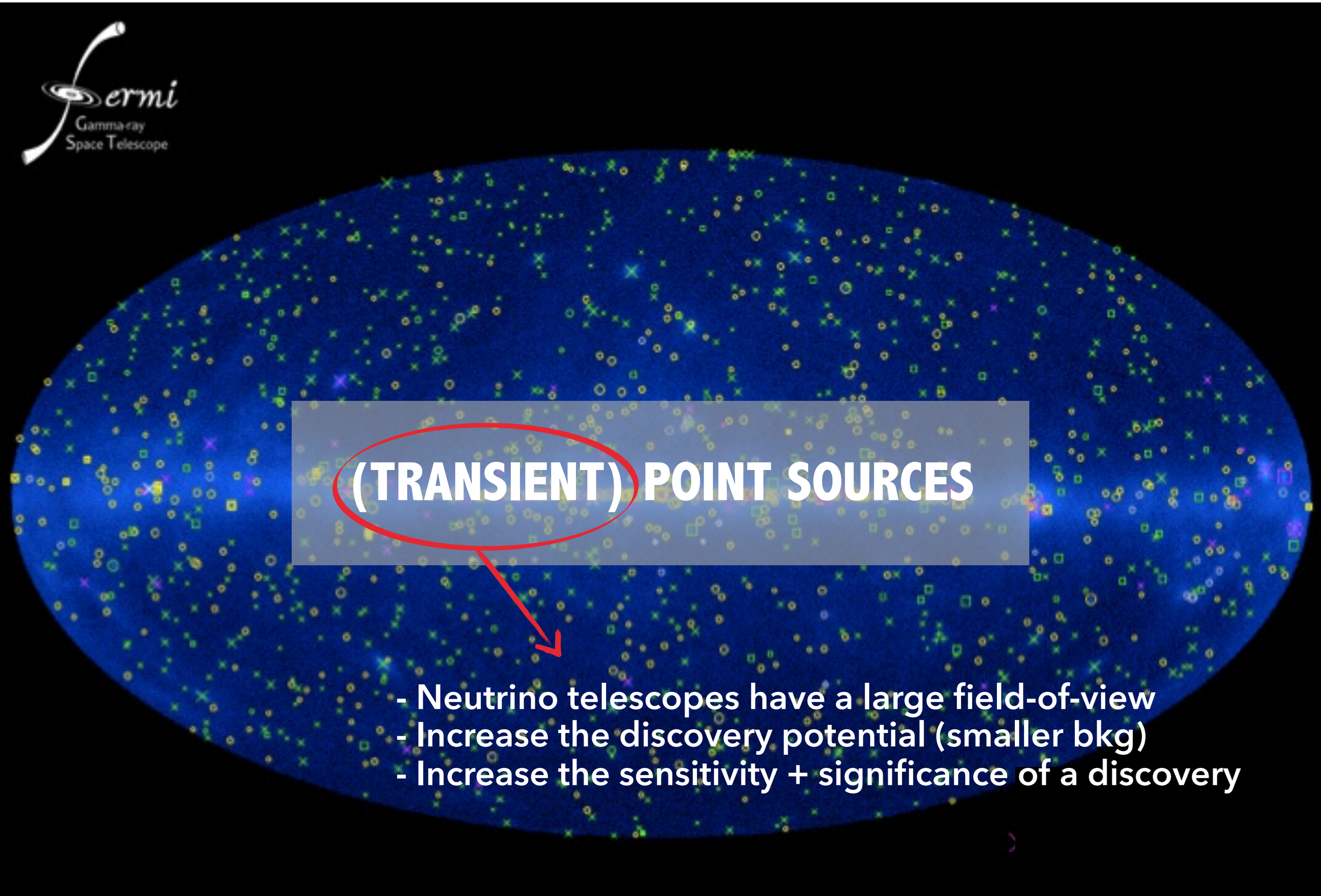
⇒ « searches for X-ray / MeV counterparts are encouraged »

(Murase et al., PRL 116, 071101, 2015)





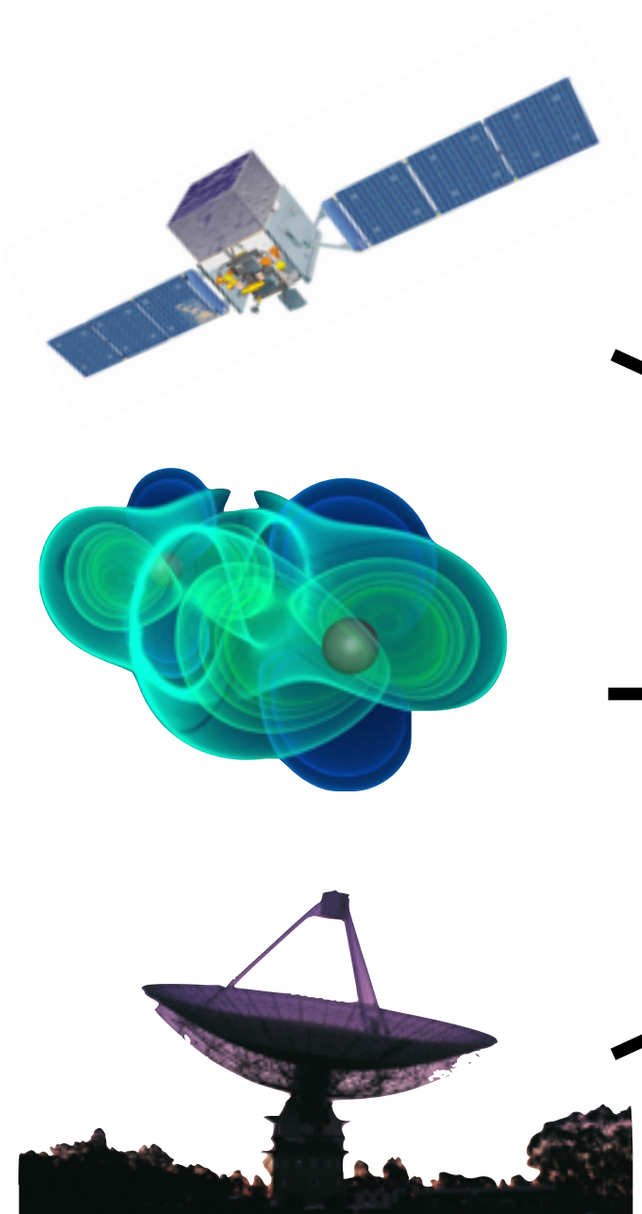
(TRANSIENT) POINT SOURCES

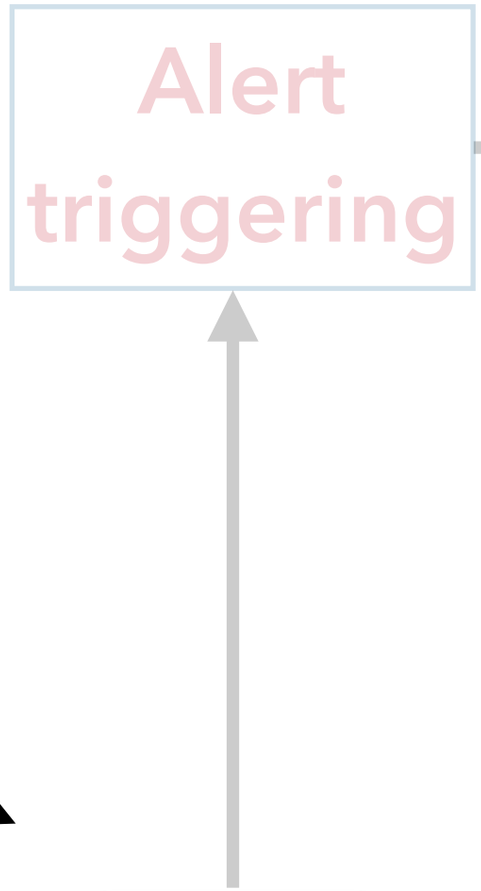


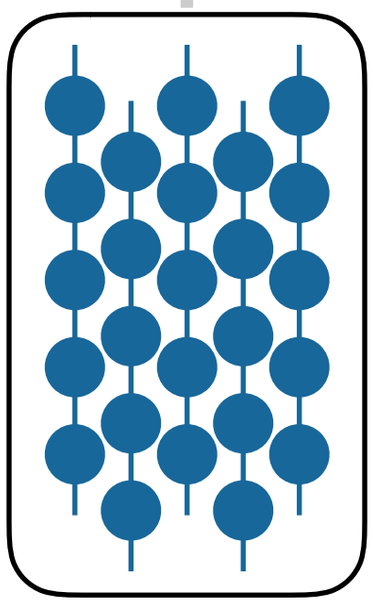
(TRANSIENT) POINT SOURCES

- Neutrino telescopes have a large field-of-view
- Increase the discovery potential (smaller bkg)
- Increase the sensitivity + significance of a discovery

TWO APPROACHES:







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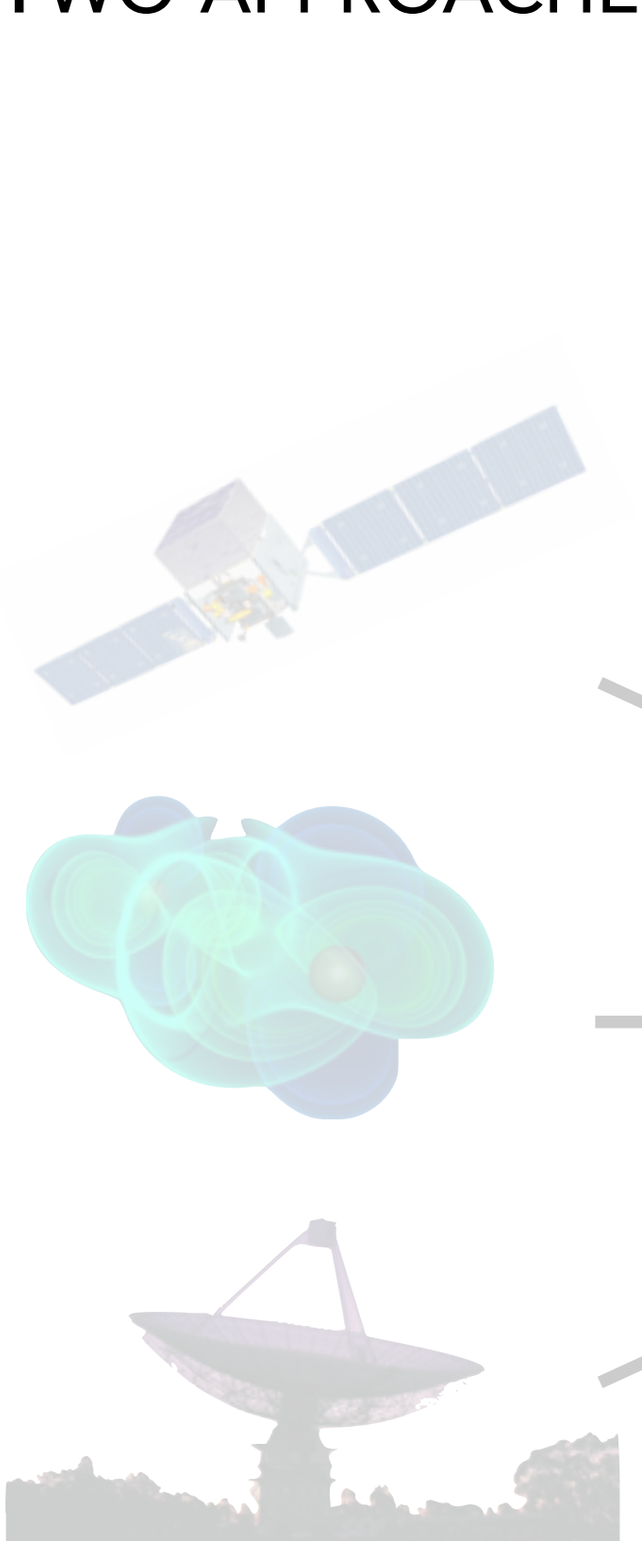
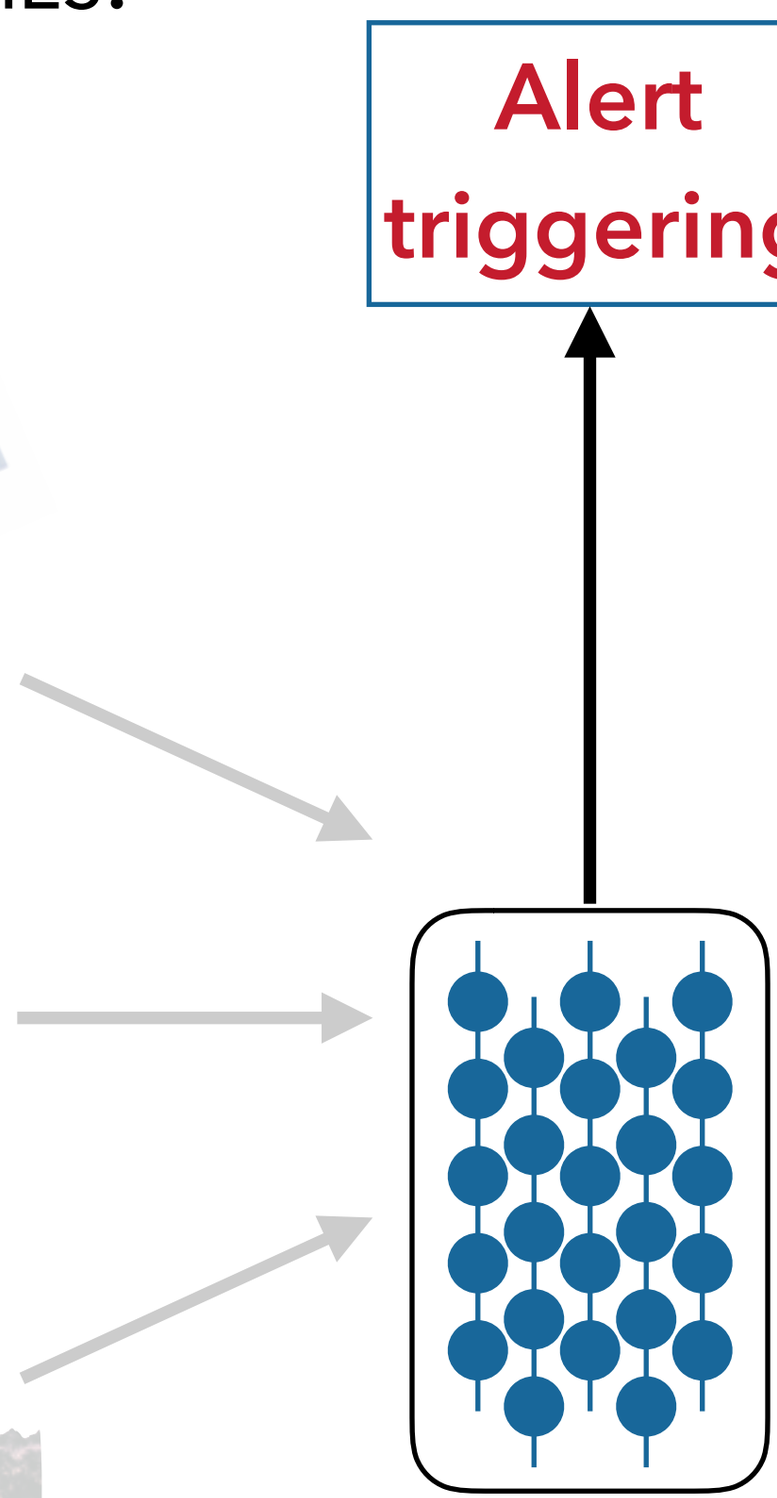


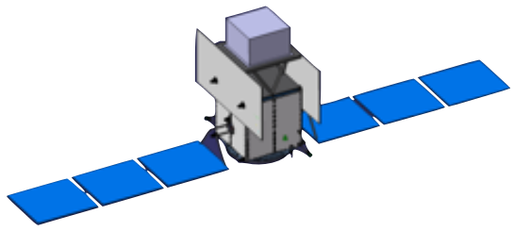


MULTI-WAVELENGTH FOLLOW-UP OF NEUTRINO ALERTS

Radio	Optical	X-ray	GeV	TeV
MWA (12/yr)	TAROT ZADKO MASTER GWAC (30/yr)	Swift (6/yr)	Fermi (offline)	HESS (2/yr) HAWC (10/yr)

ANTARES coll., Astropart. Phys. 35, 2012

Requires:

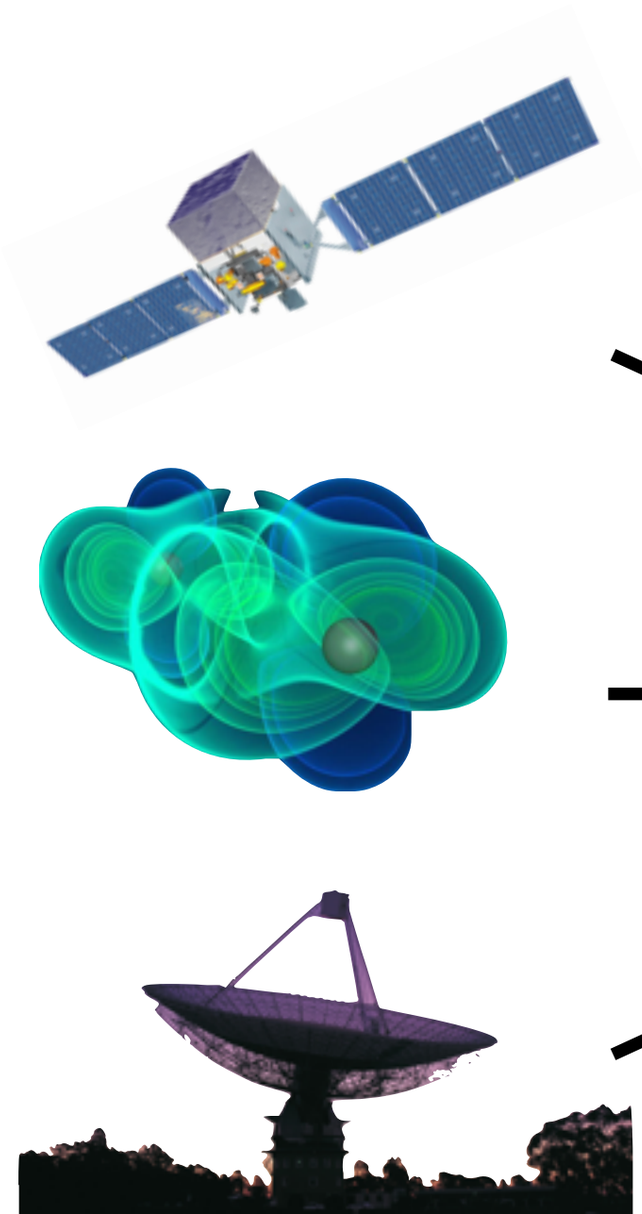


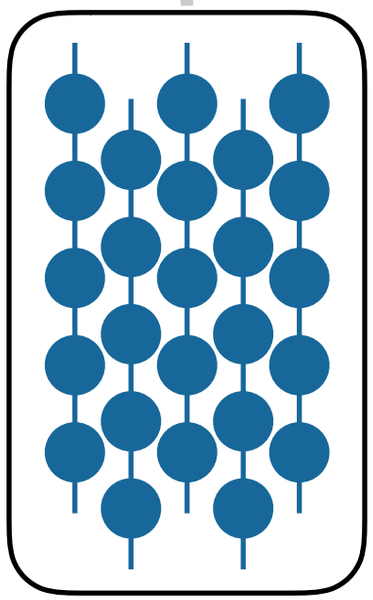
- **low-latency follow-up**
  e-ASTROGAM: within 6-12 h (3-6 h) ⇔ Swift ToO triggers for ANTARES

  important to test association with transients e.g. neutrino/GRB

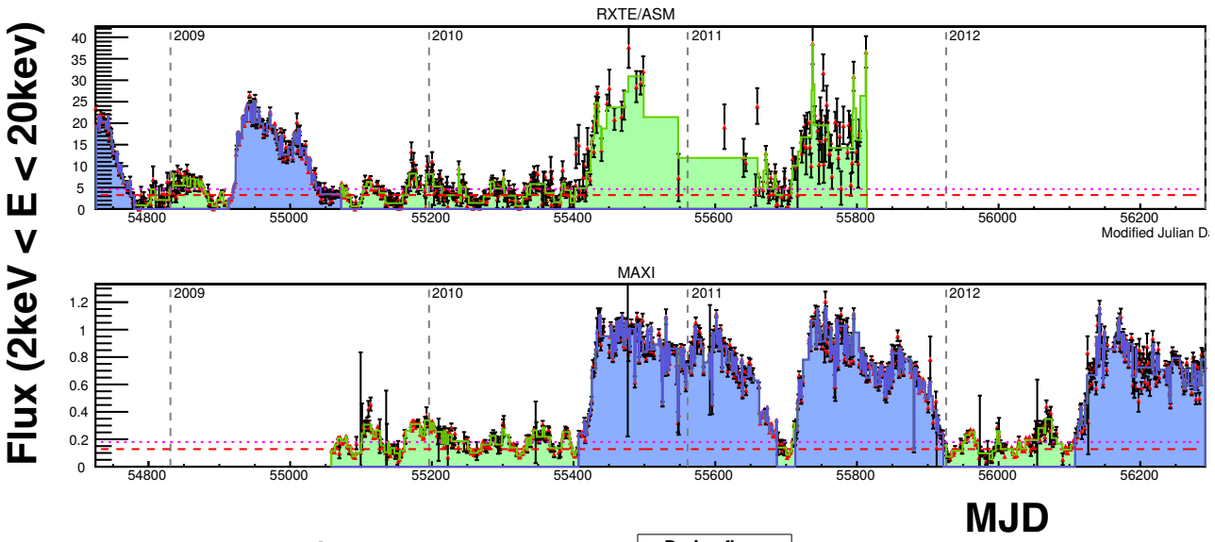
- **X-ray / MeV counterparts (see Murase et al., PRL 116, 2015):**
  e-ASTROGAM: 30 keV - 3 GeV

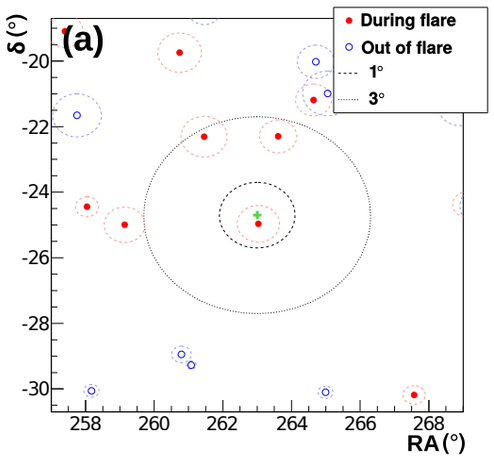
TWO APPROACHES:

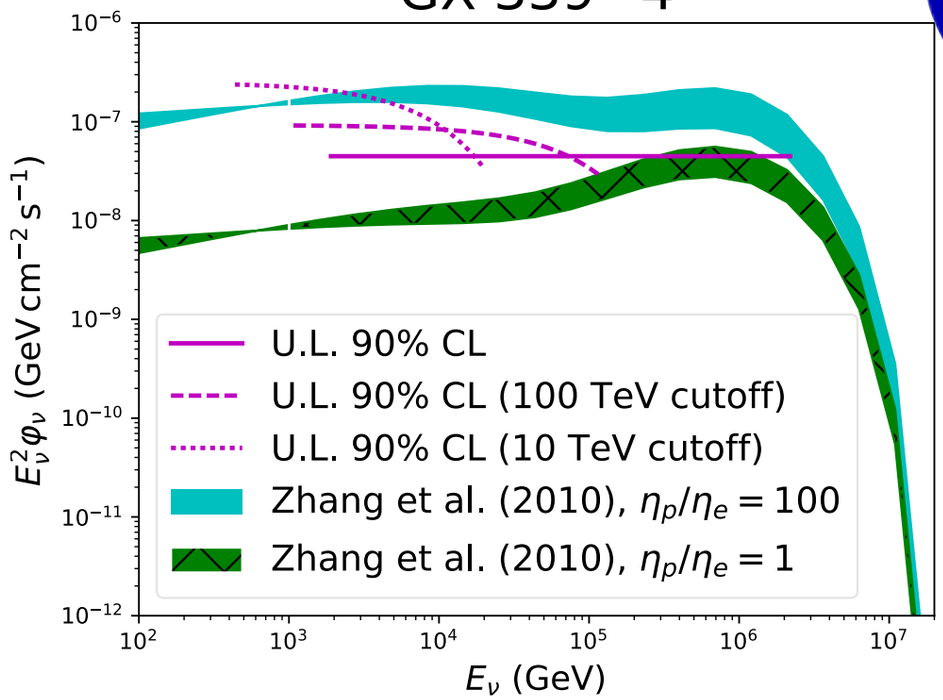




FLARING SOURCES (1)



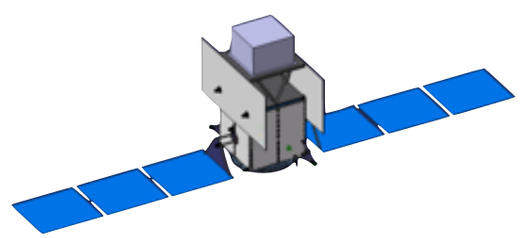




ANTARES coll., JCAP 12, 2015
+ ANTARES coll., JHEA, 3-4, 2014

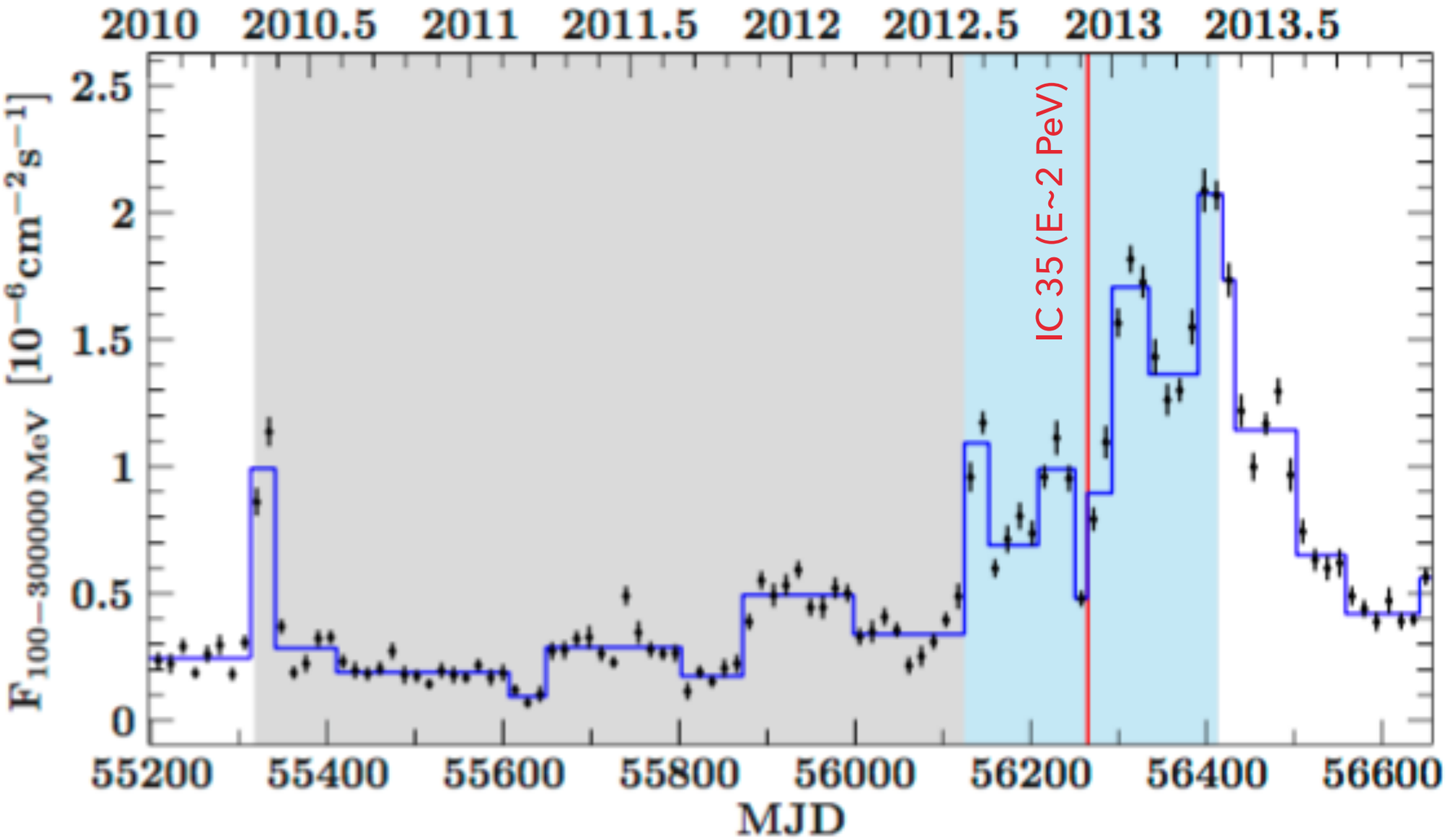
Requires:

- **wide field-of-view instruments:** e-ASTROGAM: > 2.5 sr
- **outburst/transient event times (HE -galactic- surveys)**
  e-ASTROGAM: survey mode + ToO



FLARING SOURCES (2)

gamma-ray flare of PKS B1424-418



Probability for a chance coincidence: ~5%

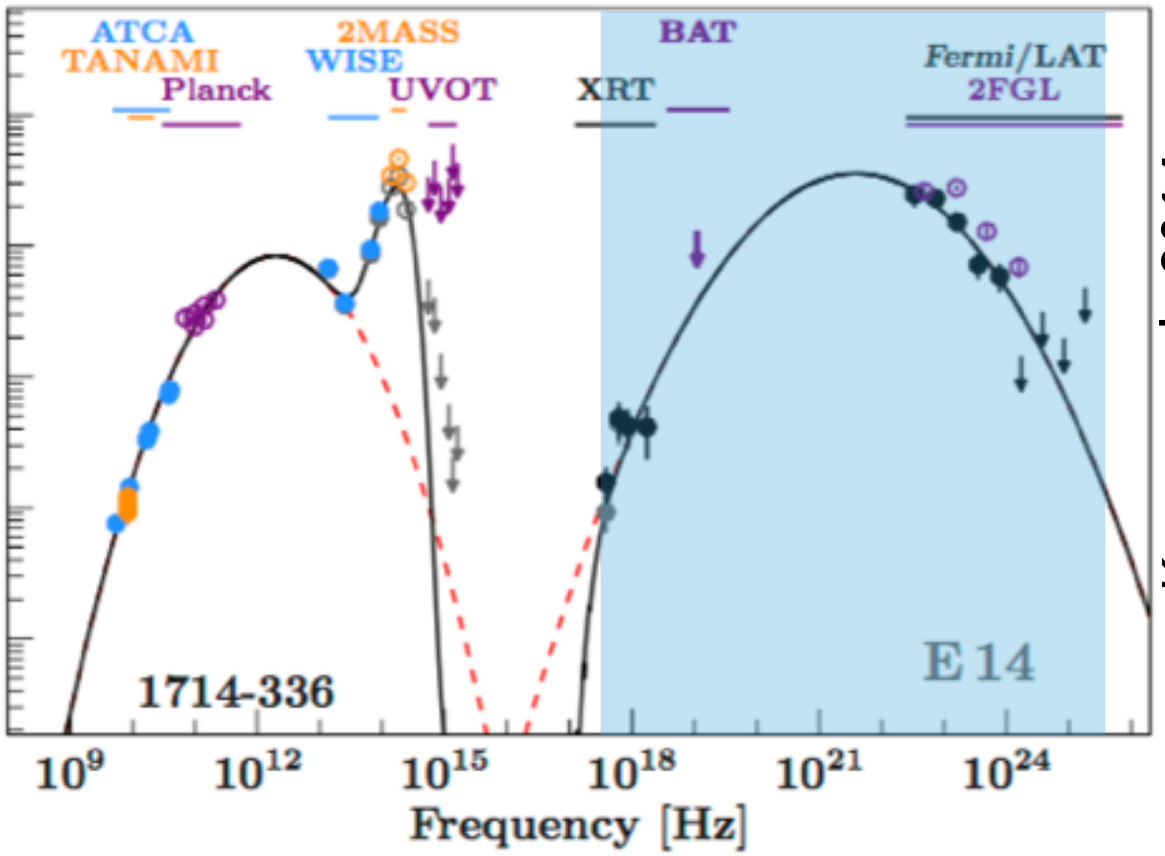
(Kadler et al., Nature Physics, 12, 2016)

FLARING SOURCES (2)

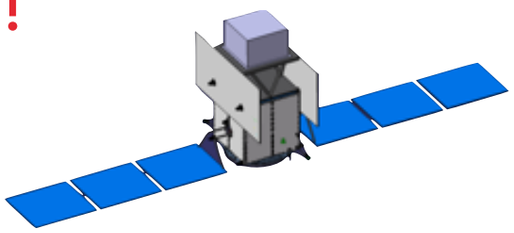
- Blazars have their emission max. in the MeV range
- If photo-hadronic processes:

$F_\nu \approx F_\gamma$ in the keV-GeV range
(Mücke et al., 2000 + Krauss et al., 2014)

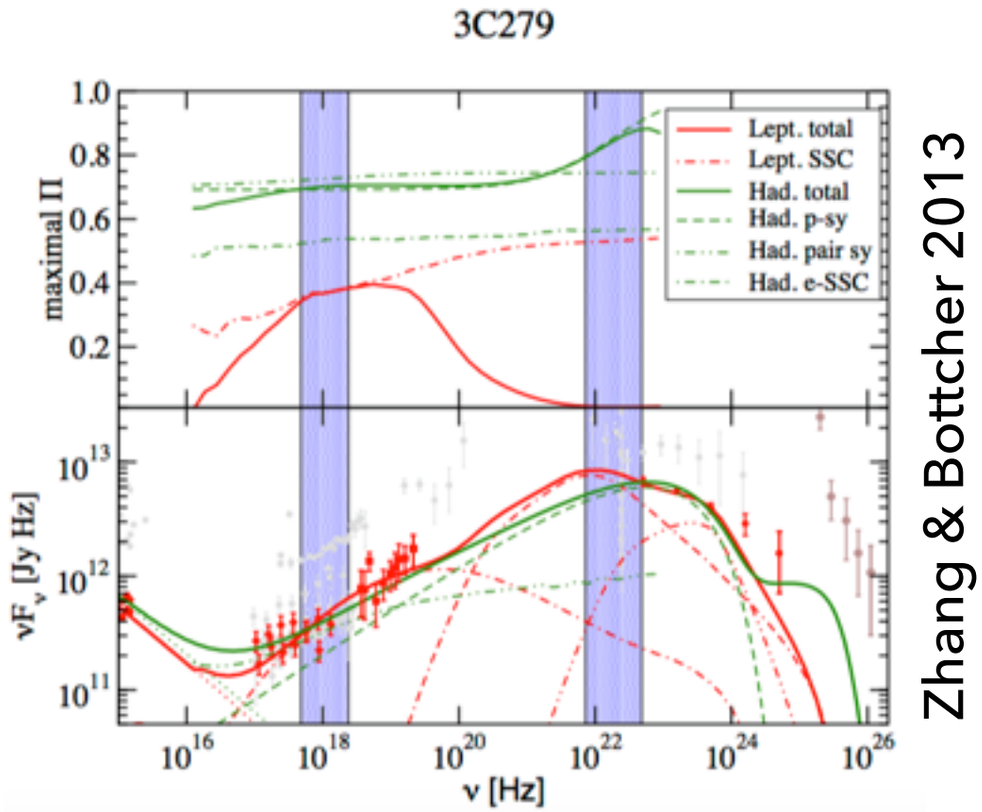
⟹ MeV photons = good proxy for neutrino emission !



Krauss et al., 2014

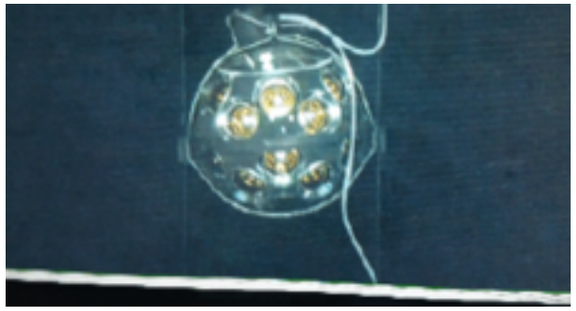


- Hadronic models predict:
  - high level of polarization in the MeV band **(detectable by e-ASTROGAM)**
  - + neutrinos !

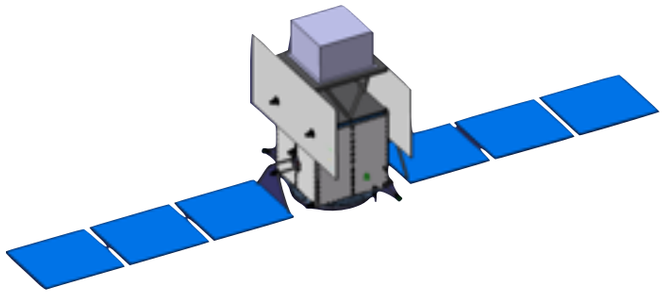


Zhang & Bottcher 2013

24 lines @ARCA + 7 lines @ORCA
already funded (currently under deployment)

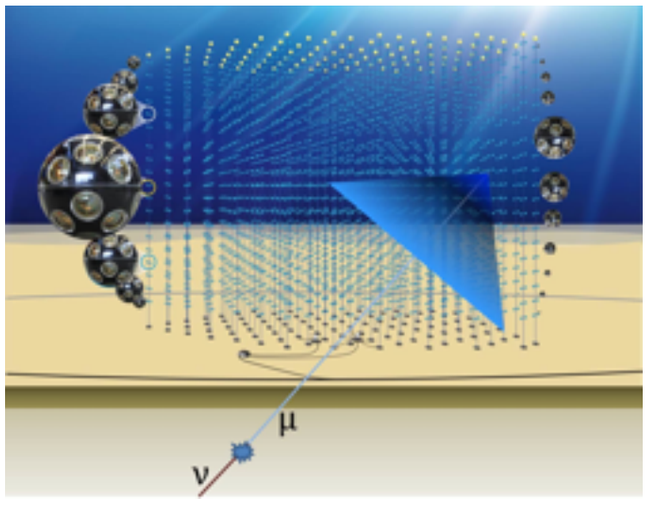


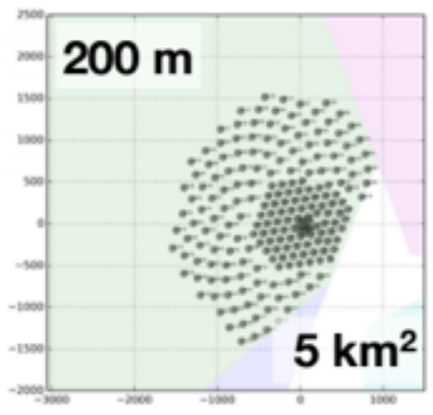
IceCube Gen-2 phase 1
NSF proposal

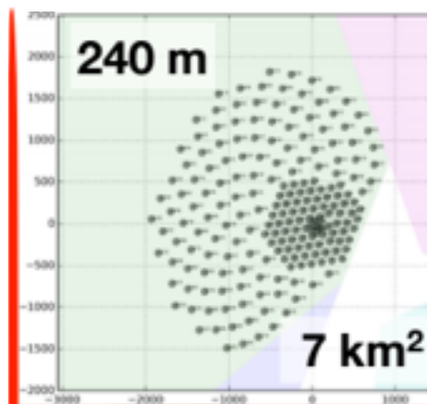


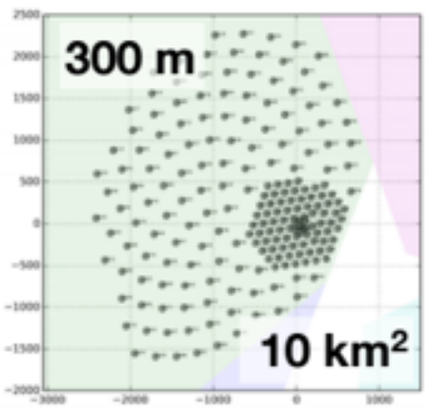
2017 2020 2021 2023 2030

KM3NeT deployment — IceCube Gen2 phase 1 — ••• — e-ASTROGAM









2x115 lines in Sicily (ARCA)
115 lines in France (ORCA)

~120 new lines
Perf. increased by 1 order of mag.

- **We are at the very beginning of the neutrino astronomy + multi-messenger era !**
- **e-ASTROGAM jointly with next-generation neutrino telescopes (KM3NeT + IceCube Gen-2)**
- **e-ASTROGAM may help to constrain neutrino source populations (IGRB)**
- **e-ASTROGAM may help to discover (transient) neutrino point sources because:**
  - wide field-of-view high-energy facility (!)
  - low-latency follow-up capabilities (ToO)
  - MeV (polarization) observations = good proxy of neutrino emission from flaring sources (blazars)
  - + … (Galactic plane, catalogue of steady sources, …)