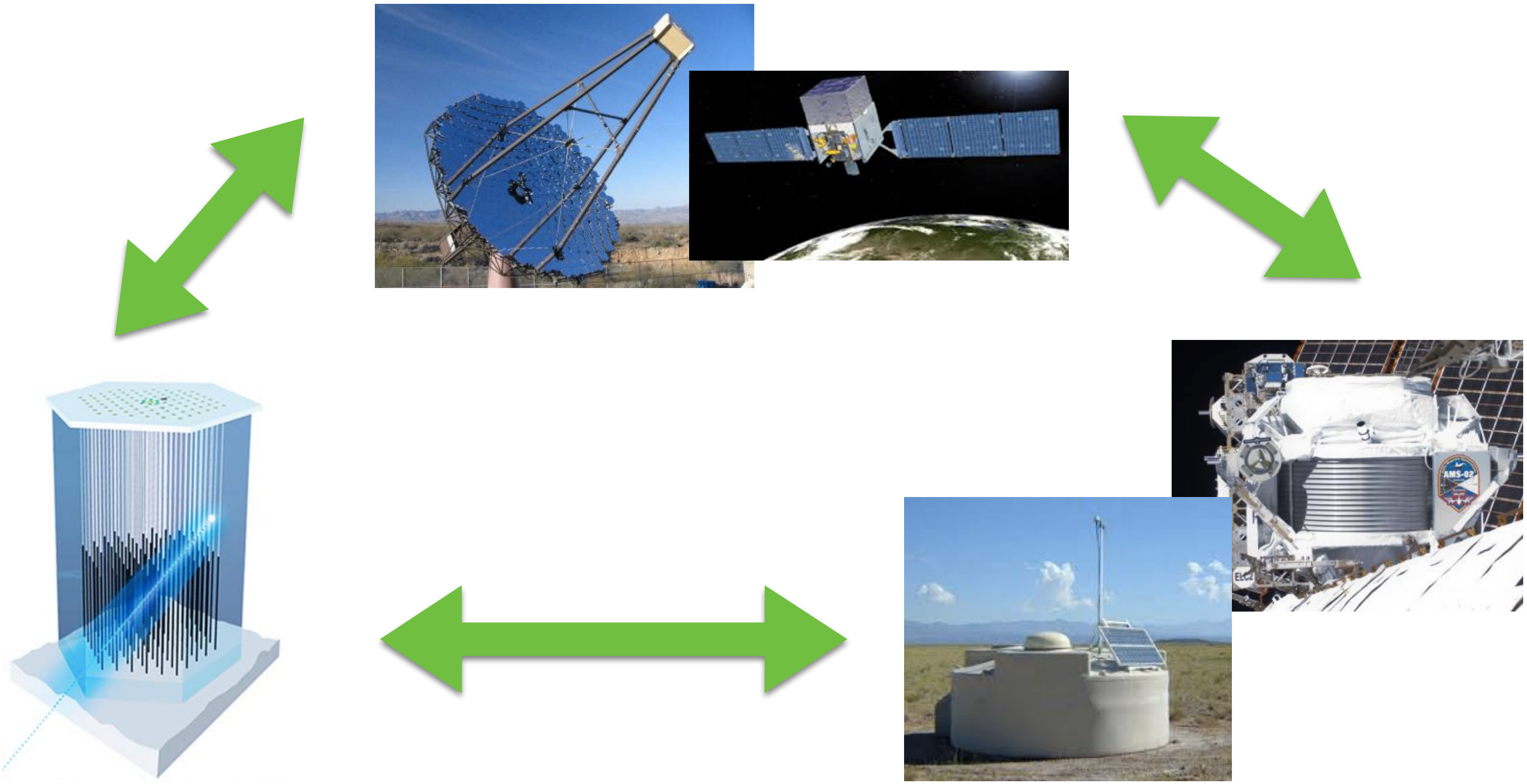
Multi-messenger analysis.

… connecting the dots in the non-thermal universe

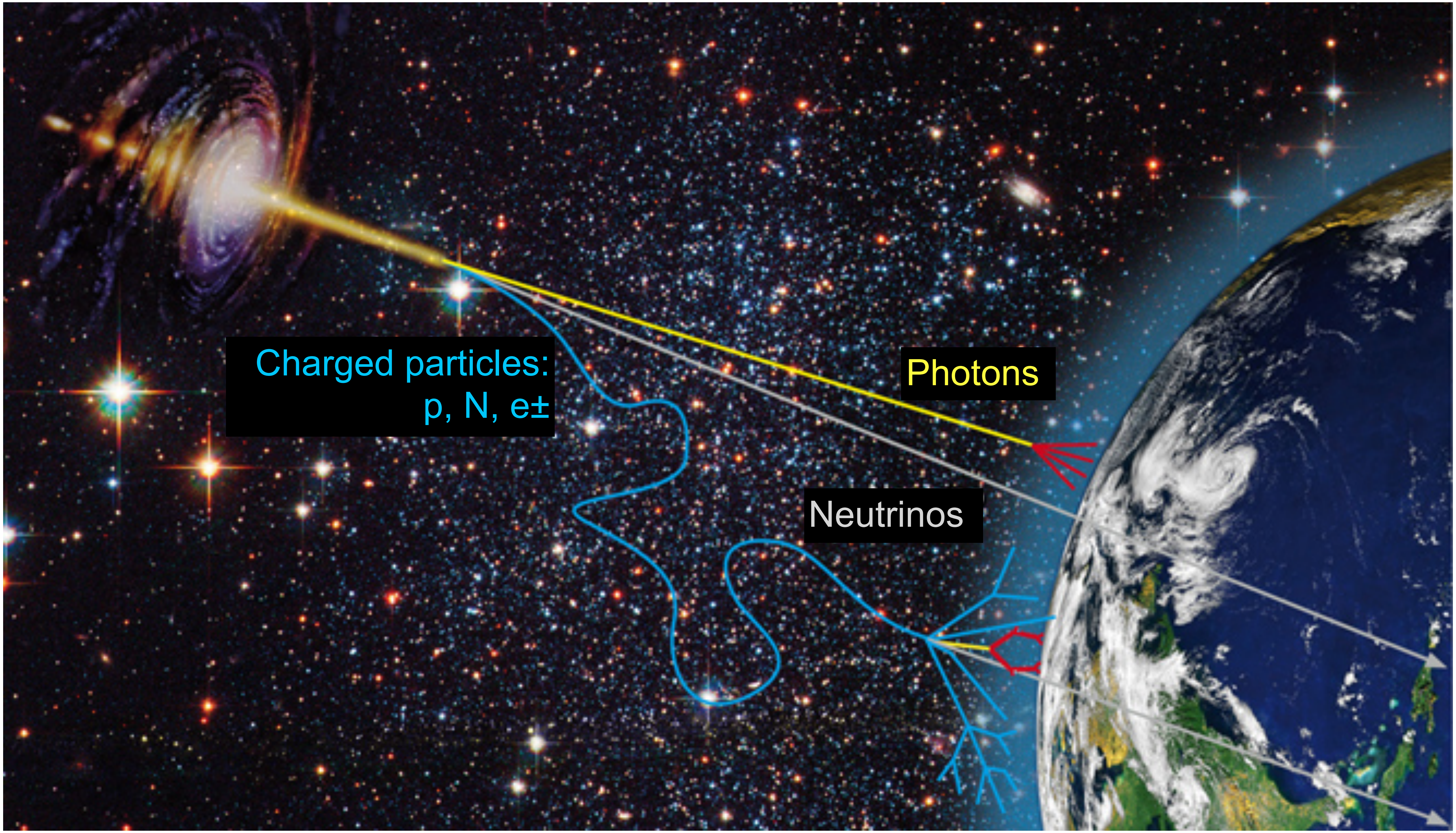


Markus Ackermann

Astroteilchenphysik in Deutschland
Status und Perspektiven 2014
Karlsruhe, 30.09.2014

Multi-messenger astronomy in 2012.

> Three messengers are available to study the non-thermal universe…



Multi-messenger astronomy in 2012.

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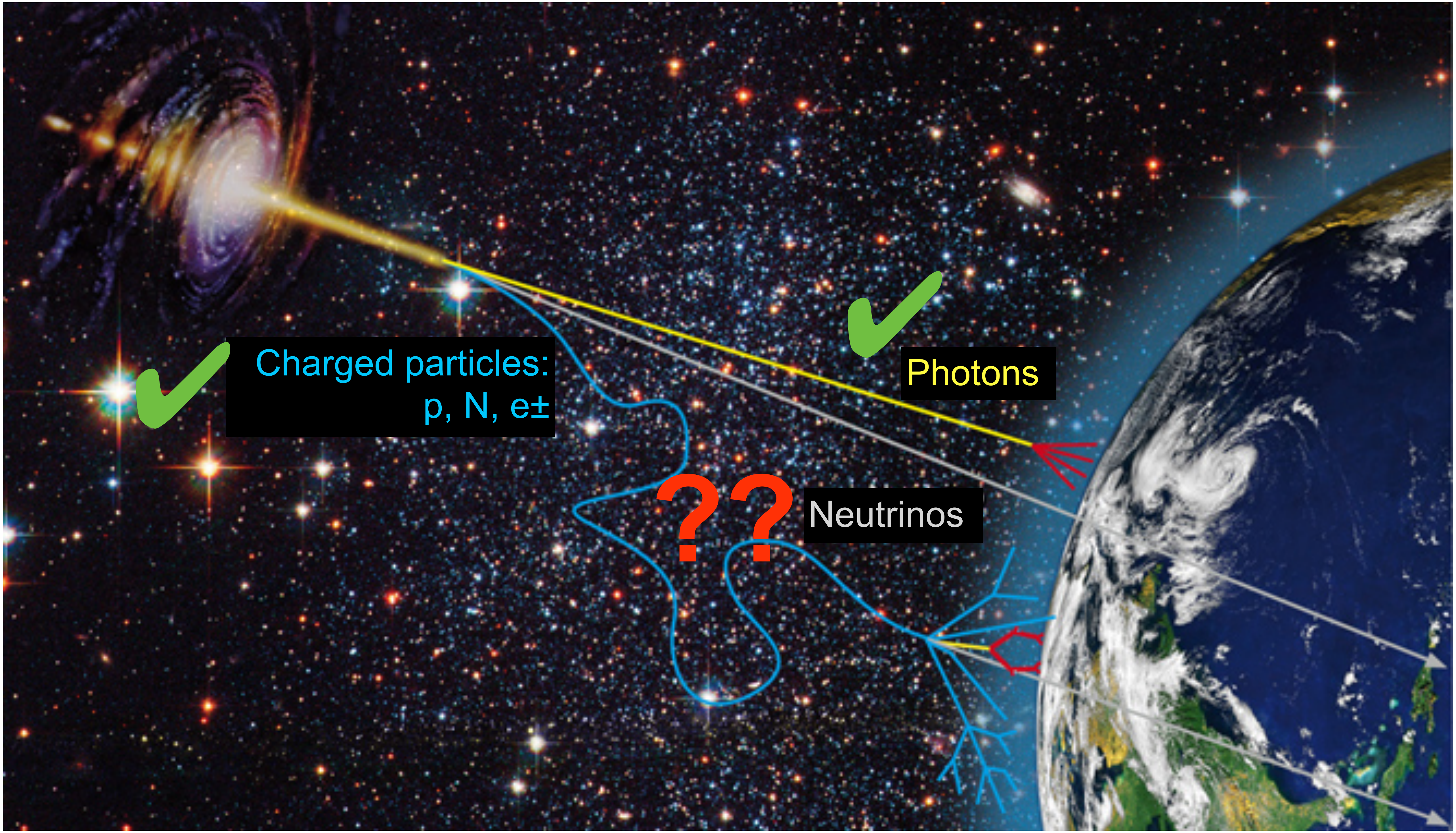
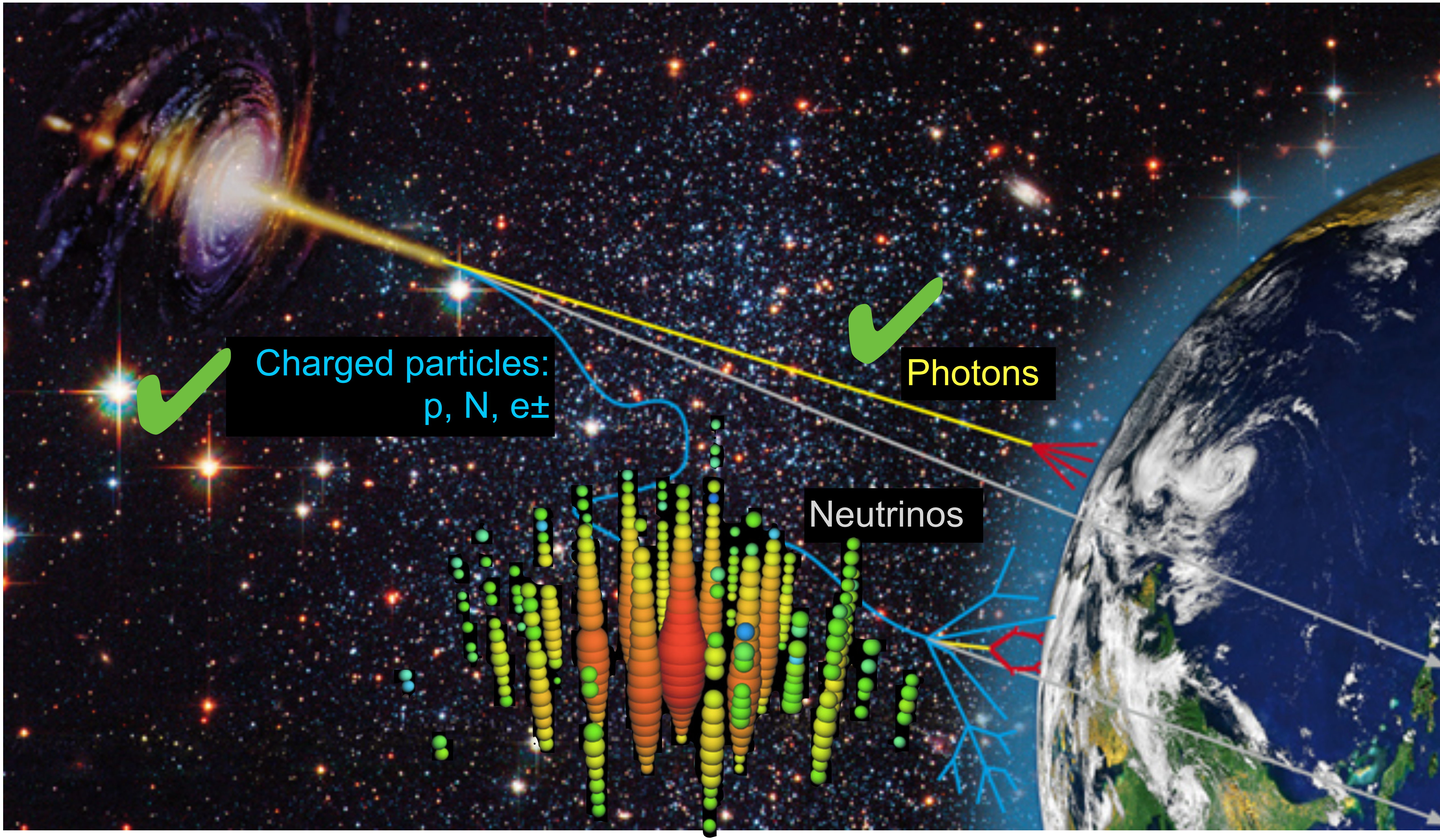


> … two of them have been observed.

Multi-messenger astronomy in 2014.

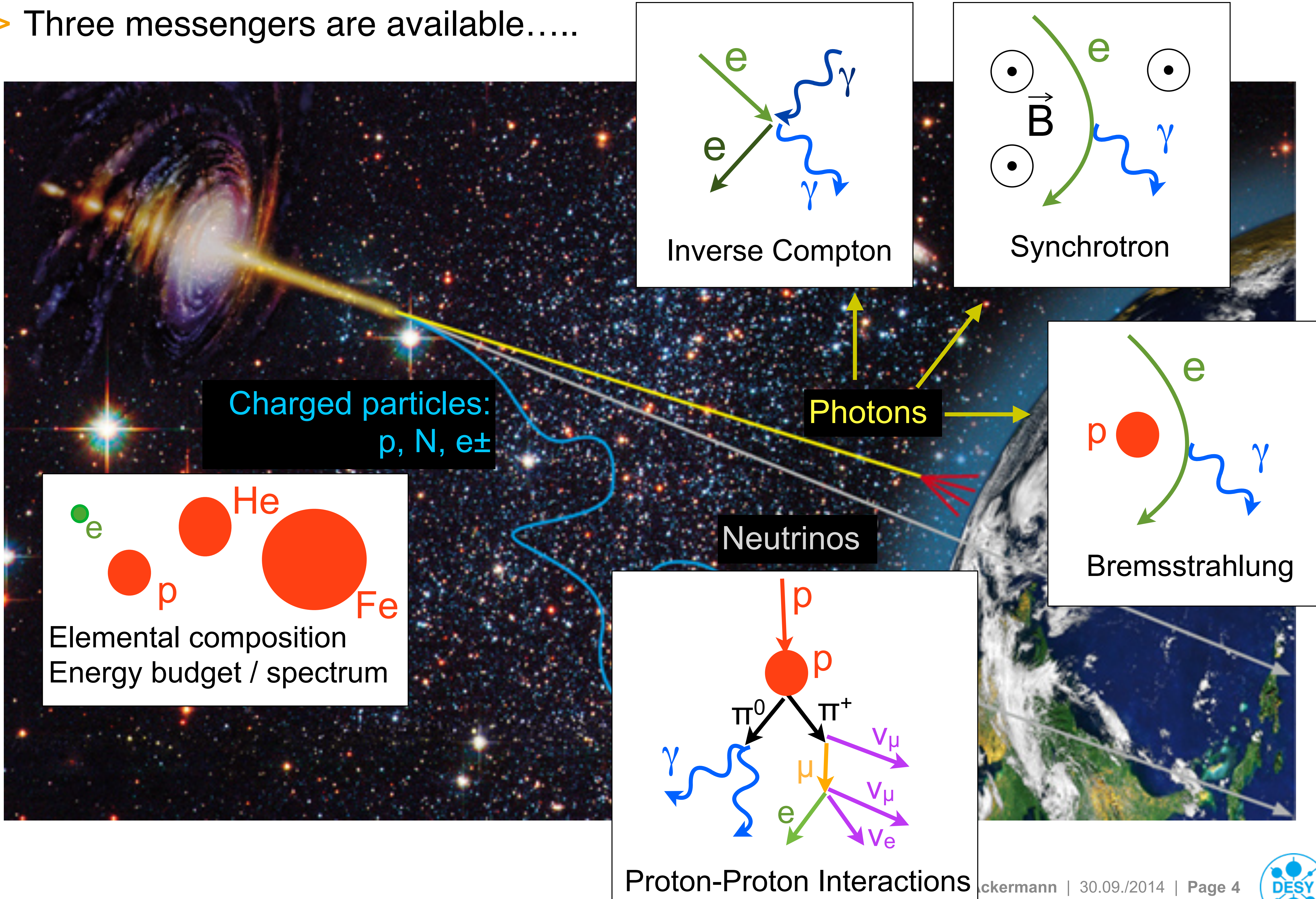
> Three messengers are available…..



> ….and used to study the non-thermal universe.

Multi-messenger astronomy in 2014.

> Three messengers are available…..

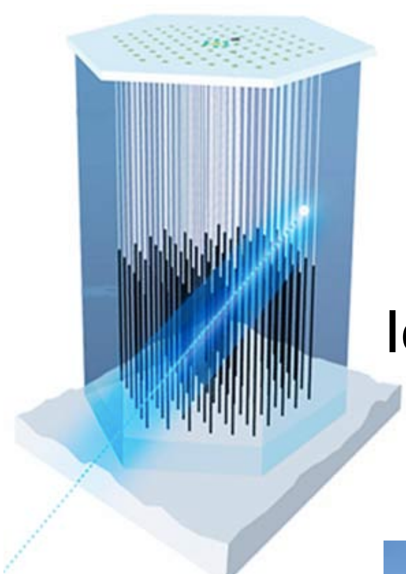


Multi-messenger astronomy concepts: Transient phenomena.

> Triggered follow-up observations.

Large field-of-view / All-sky

Fermi LAT



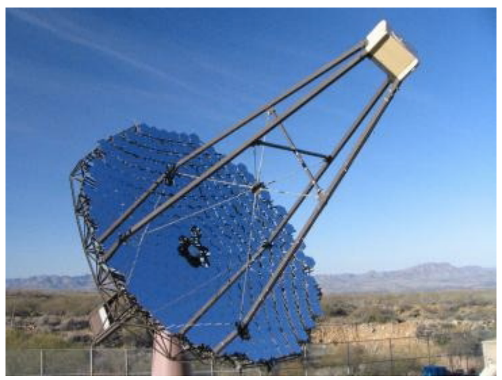
IceCube / Antares

Pierre Auger Obs.

ALERT

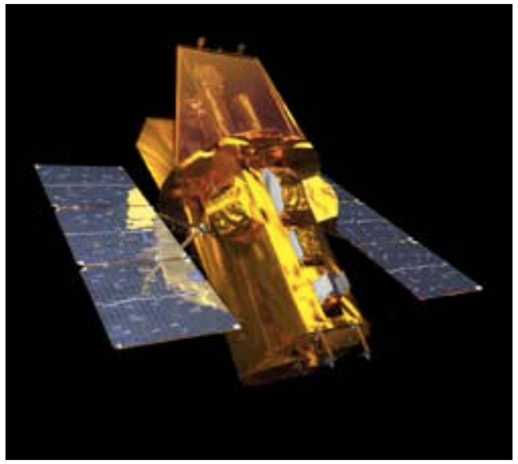
Pointed observations

HESS/MAGIC/Veritas



Optical telescopes

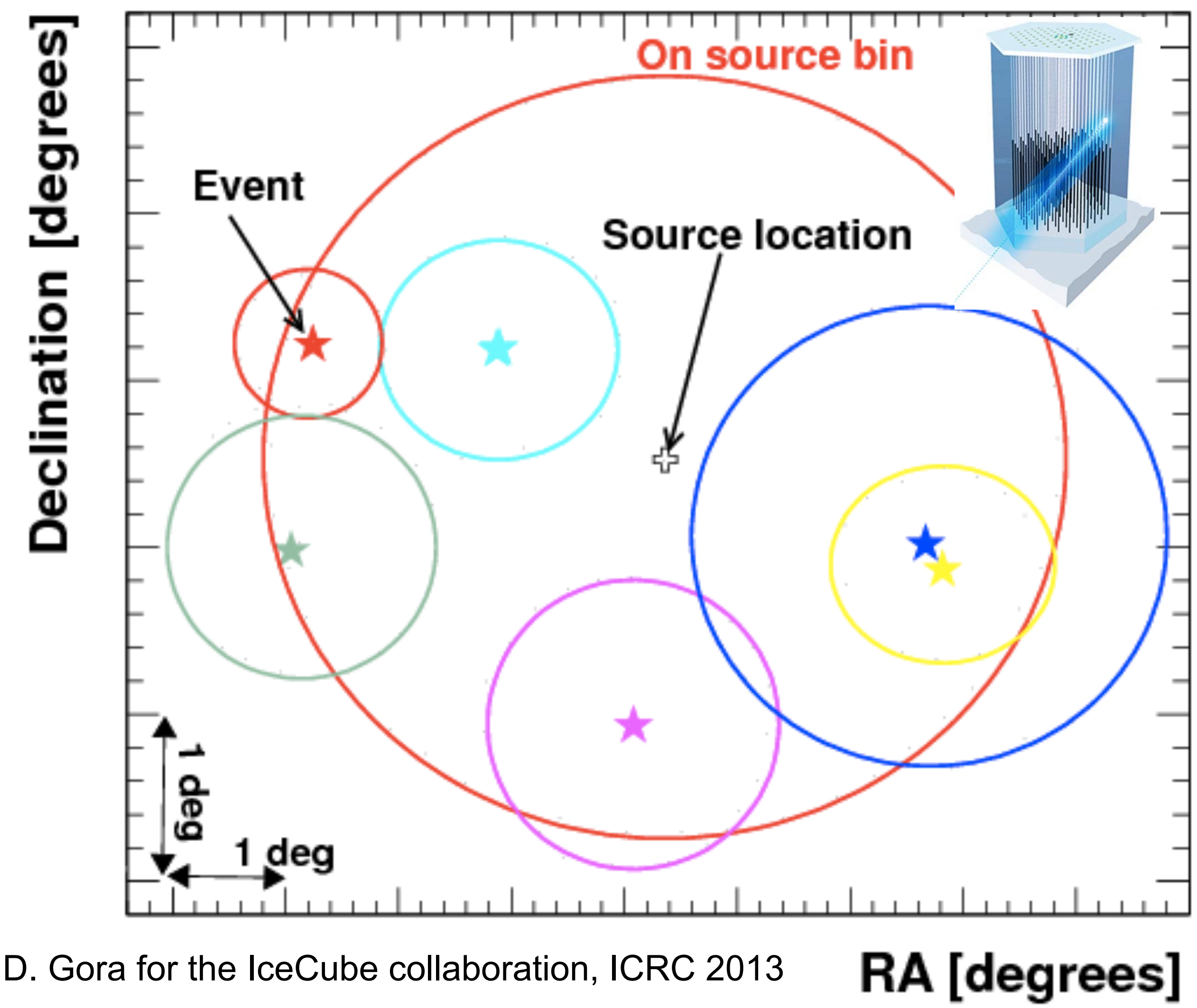
X-ray telescopes



Search for coincident neutrino/gamma-ray flares.

- Trigger TeV gamma-ray observations from IceCube neutrino data.
- More than 100 candidate sources in programs with VERITAS, MAGIC, HESS.
- Near real-time analysis: Search for unusual clustering of neutrino events.
- Minutes to days timescale.
- No detections of gamma-ray flares after IceCube triggers so far.

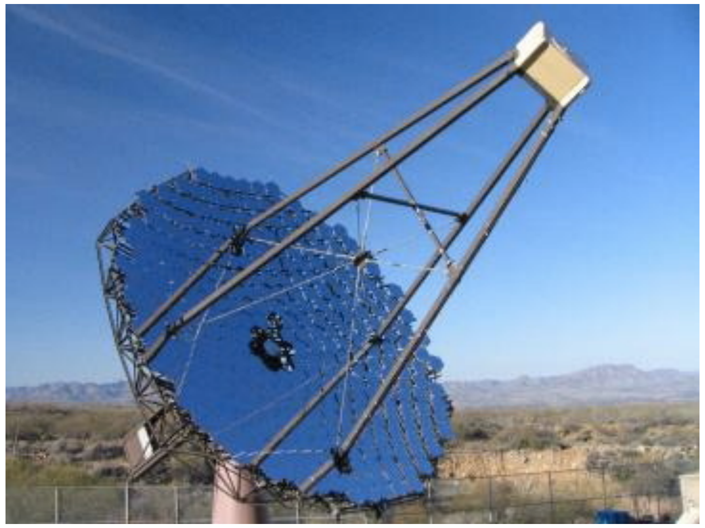
No coordinates here! - Blindness policy



D. Gora for the IceCube collaboration, ICRC 2013

MAGIC threshold: 0.2 alerts/src/yr
Veritas threshold: 0.05 alerts/src/yr

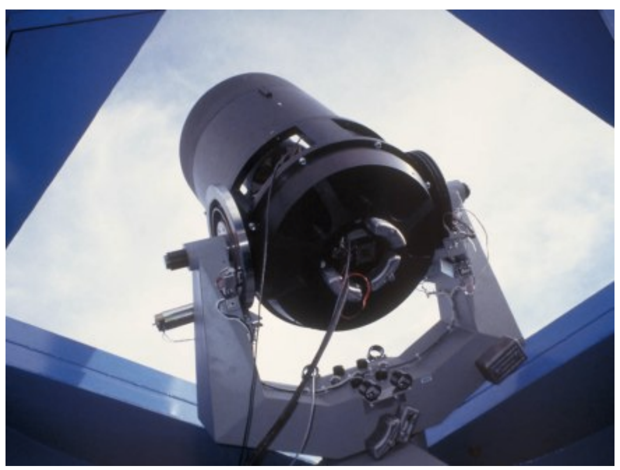
ALERT

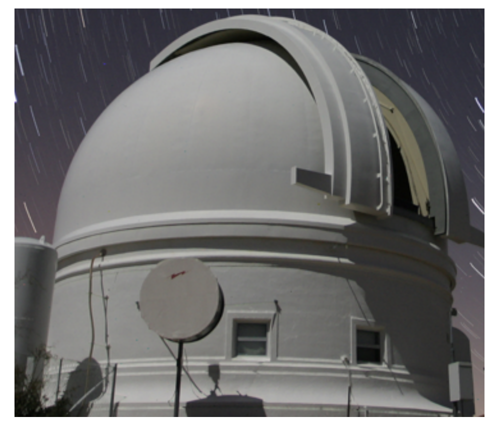


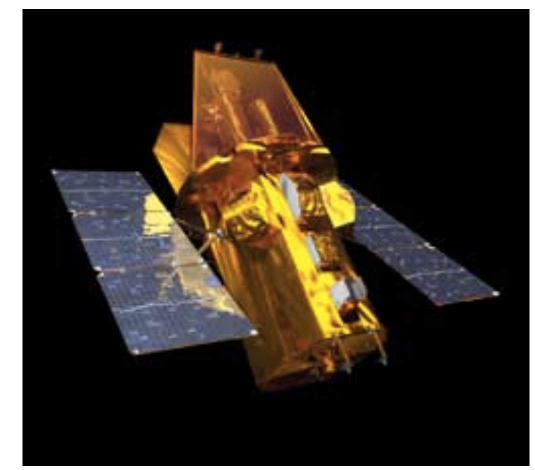
Search for high-energy neutrinos from core-collapse SNe.

> Online search for spatio-temporal clustering of neutrinos to trigger optical / x-ray follow-up observations:
  - $\Delta t < 100$ s and $\Delta\Psi < 4$ deg

> Search for SNe in the directions of the detected neutrino directions.

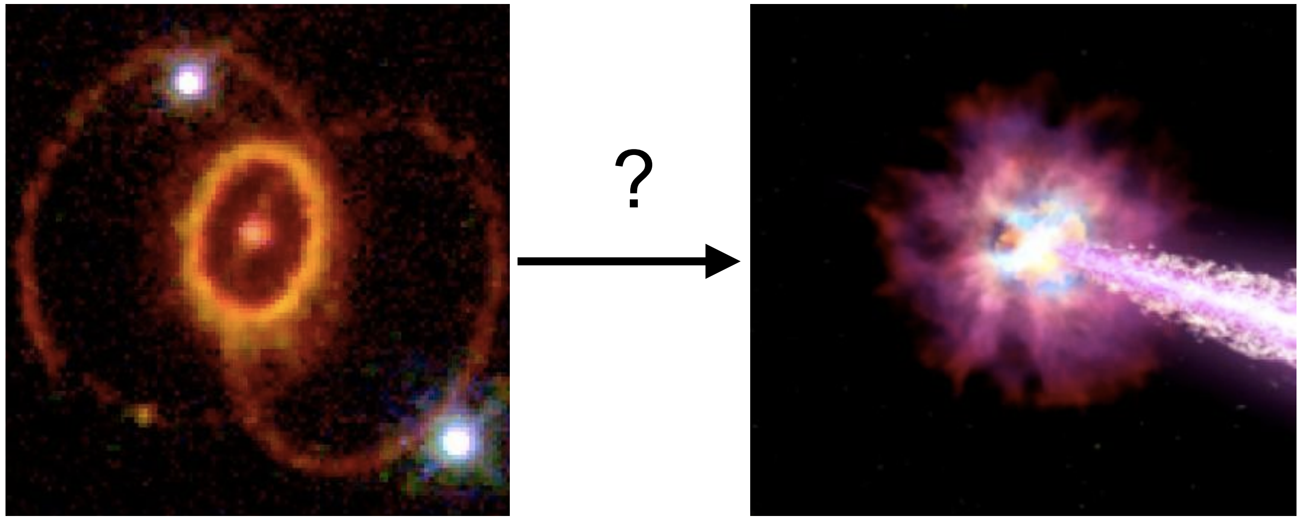




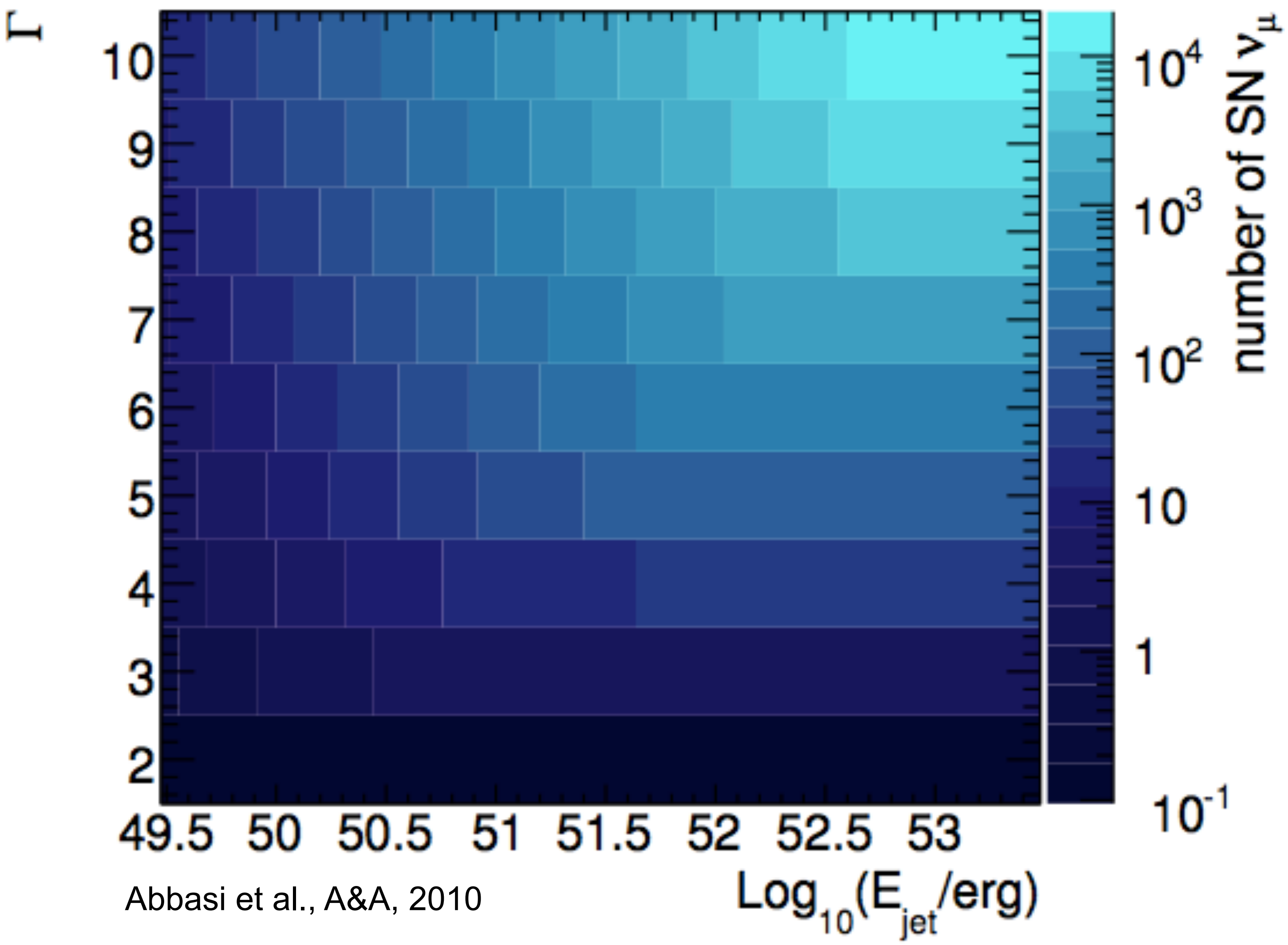


Instrument name	ROTSE	PTF	Swift
Follow-up since	Dec 2008	Aug 2010	Feb 2011
Alerts per year	≈ 25	≈ 10	≈ 7
FoV in $(^\circ)^2$	3.42	7.26	0.79

Search for high-energy neutrinos from core-collapse SNe



Expected neutrinos from SN at 10 Mpc in IceCube



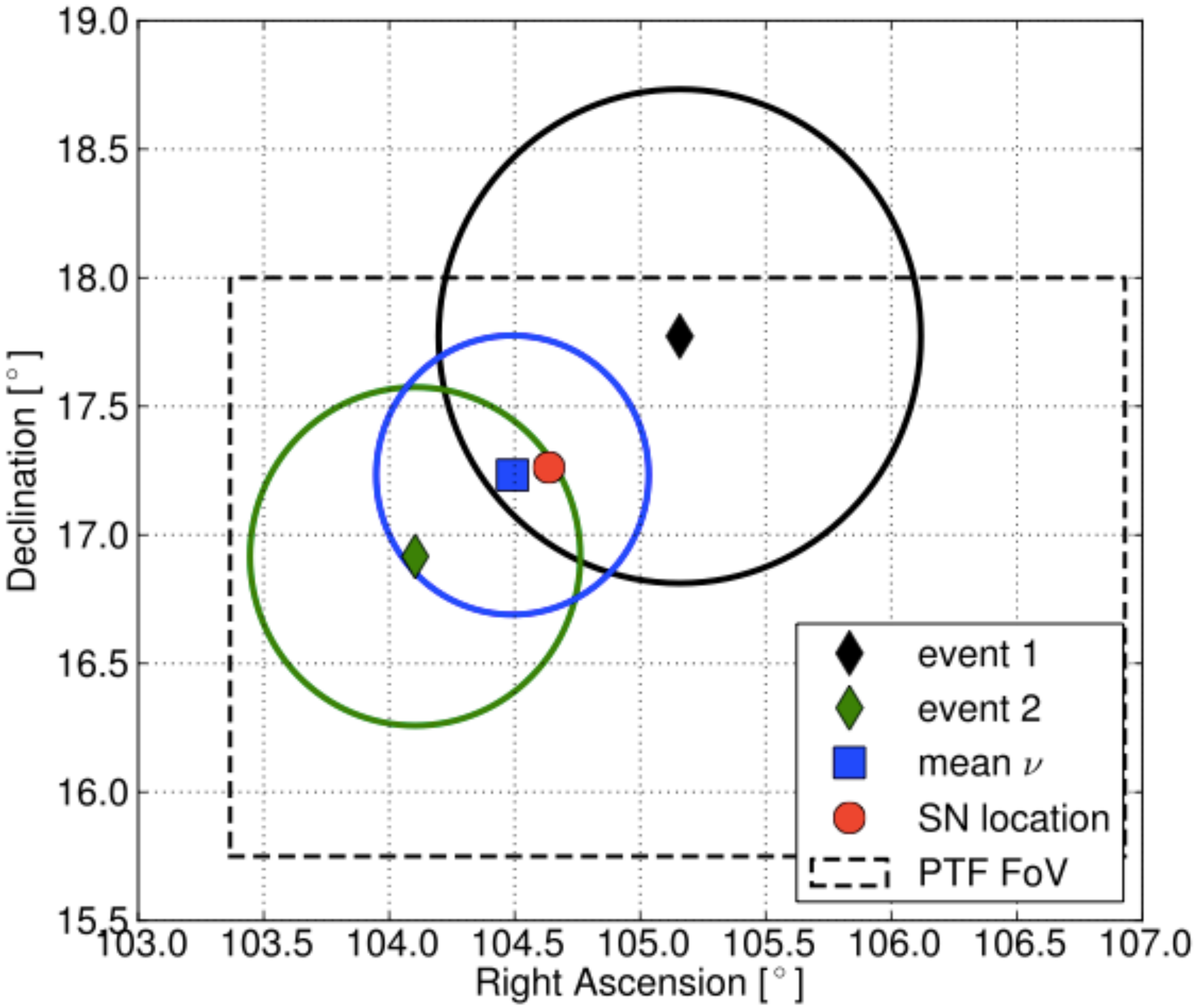
Abbasi et al., A&A, 2010

- Connection between supernovae and gamma-ray bursts.
- Few % of core-collapse SNe might develop mildly relativistic jets.
- Favorable for neutrino production, no visible prompt gamma signal.
- Neutrino signal could be observed out to tens of Mpc distance.

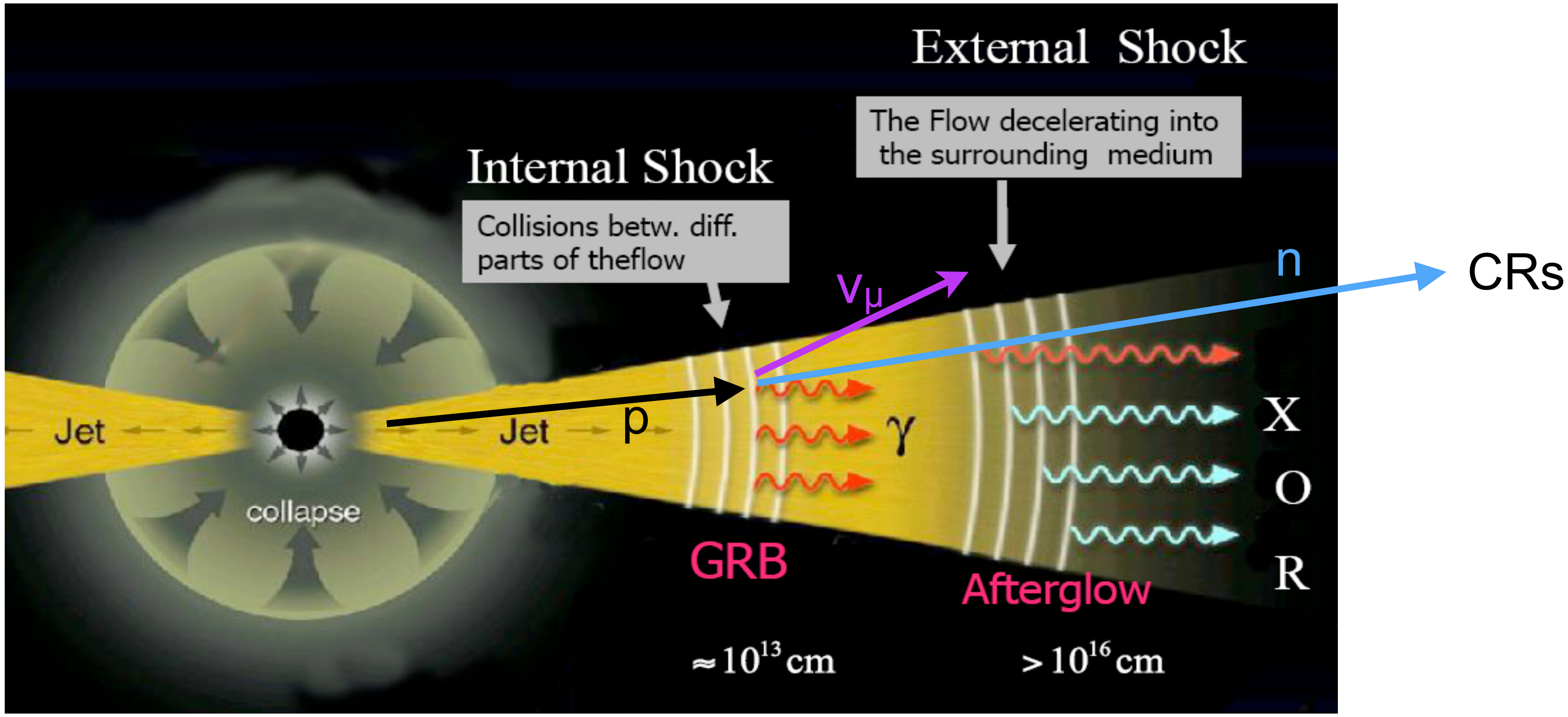
Search for high-energy neutrinos from core-collapse SNe

- March 30, 2012.
- 2 neutrinos observed within 1.79 s and within 1.3 deg.
- Alert sent to ROTSE, PTF and Swift
- PTF observes type IIn supernova coincident with neutrino position at 300 Mpc distance.
- Chance coincidence probability: ~4%.
- SN already several months old.

M.Voge for the IceCube collaboration, ICRC 2013



GRBs and their connection to CR production.

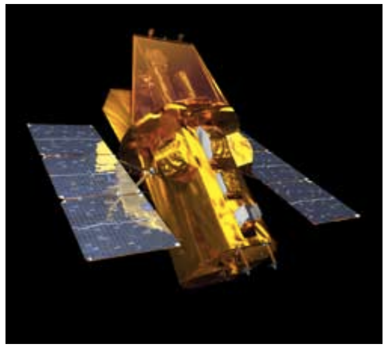


> Gamma-ray bursts (GRB) are prime candidates for the production of ultra-high-energy CRs.
  - Similar energy needed in CRs as observed in gamma-rays to produce observed 10^{20} eV CRs.
  - CRs are produced via Fermi acceleration in internal shocks with high Lorentz factors.

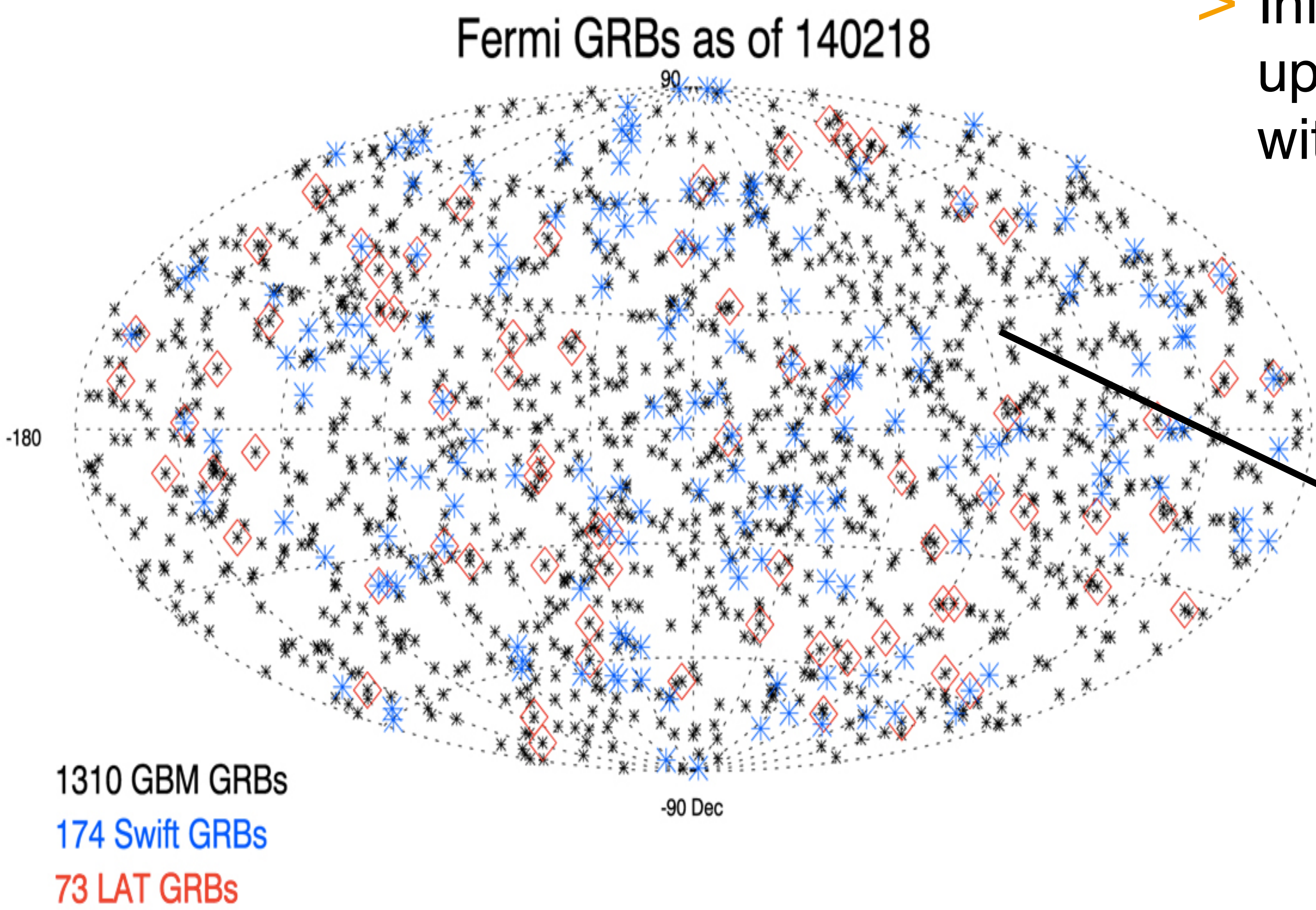
> Neutrinos can be used to probe CR acceleration in GRBs.

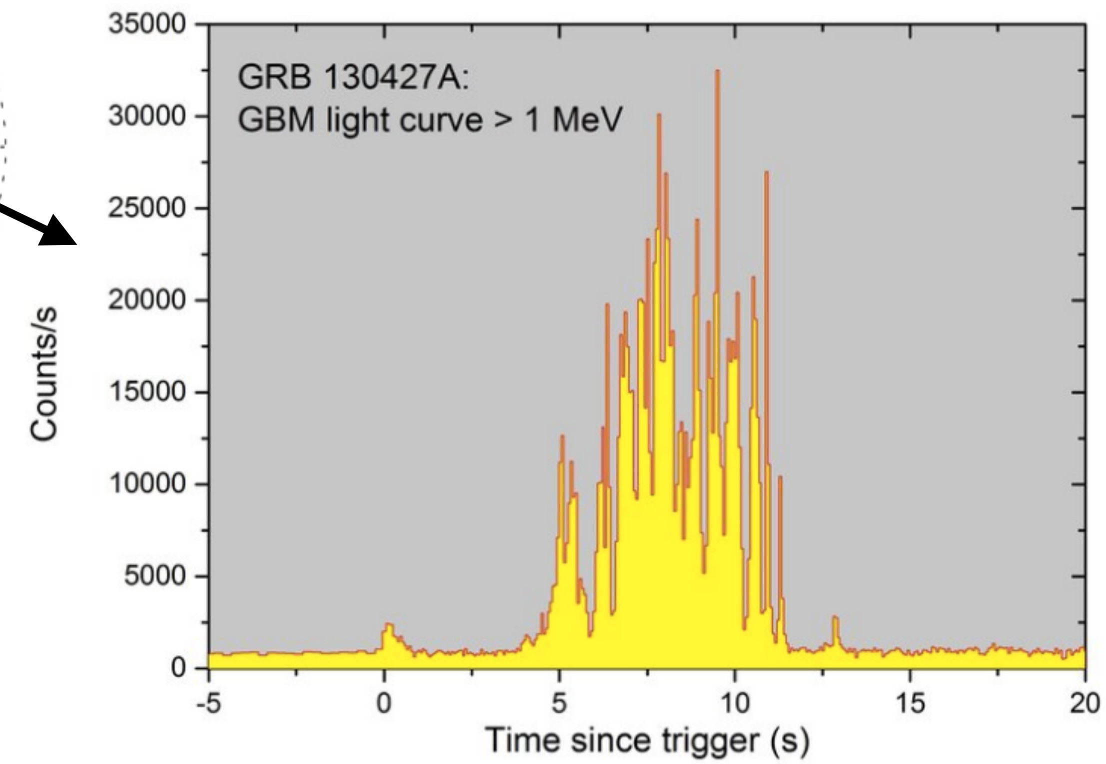
GRB observations.

Swift



Fermi GBM

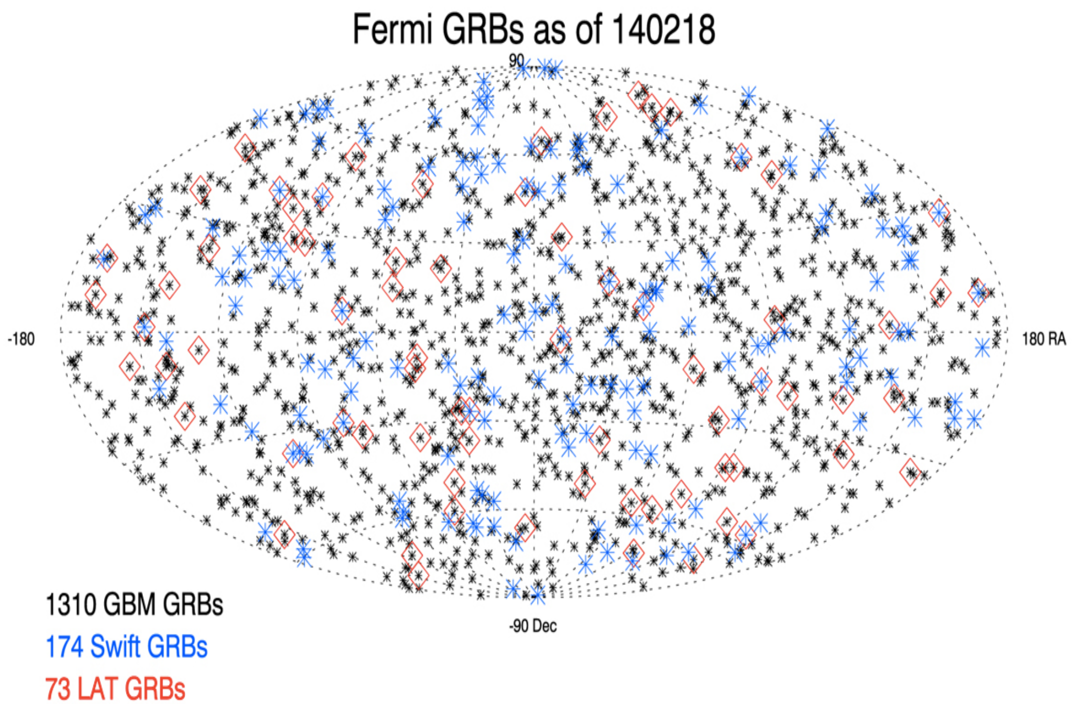


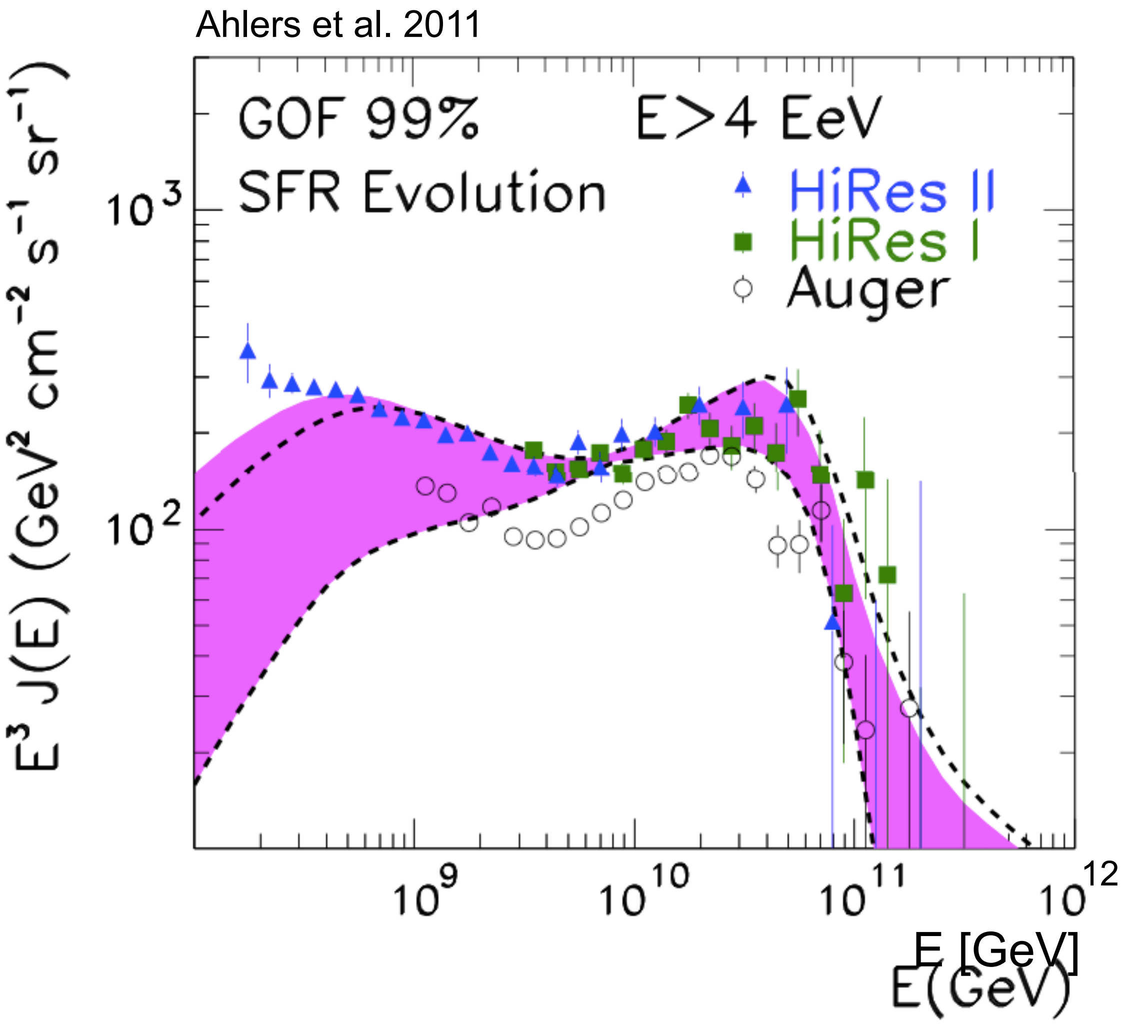


- Dedicated instruments like the Fermi Gamma-ray Burst Monitor (GBM) scan for GRBs
- Community is alerted via GCN notices
- Information can be used for follow-up observations / cross-correlation with other messengers.

GRBs and their connection to CR production.

predicted CR spectrum

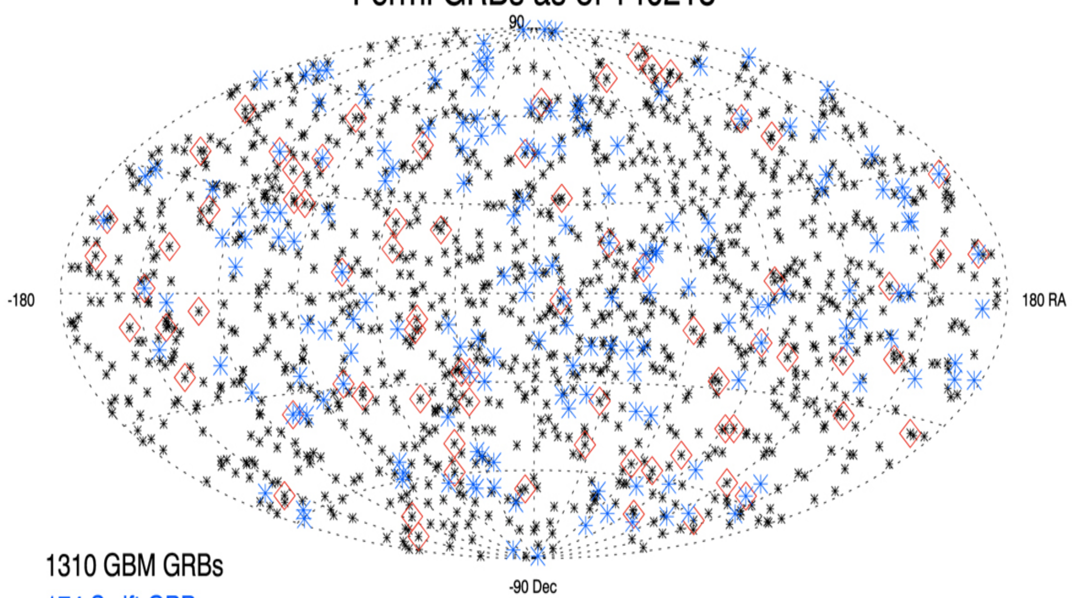




GRBs and their connection to CR production.

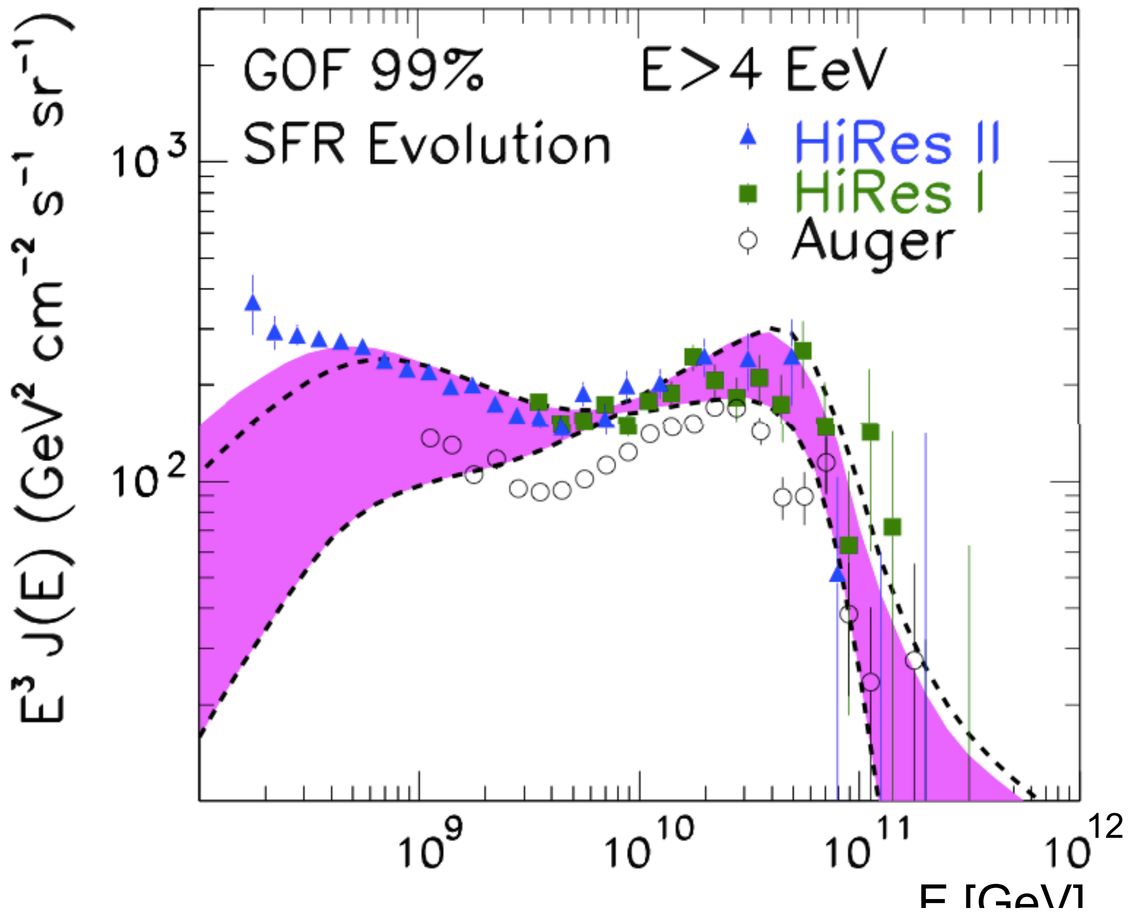
predicted CR spectrum

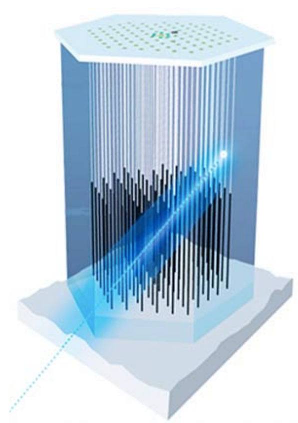
Fermi GRBs as of 140218



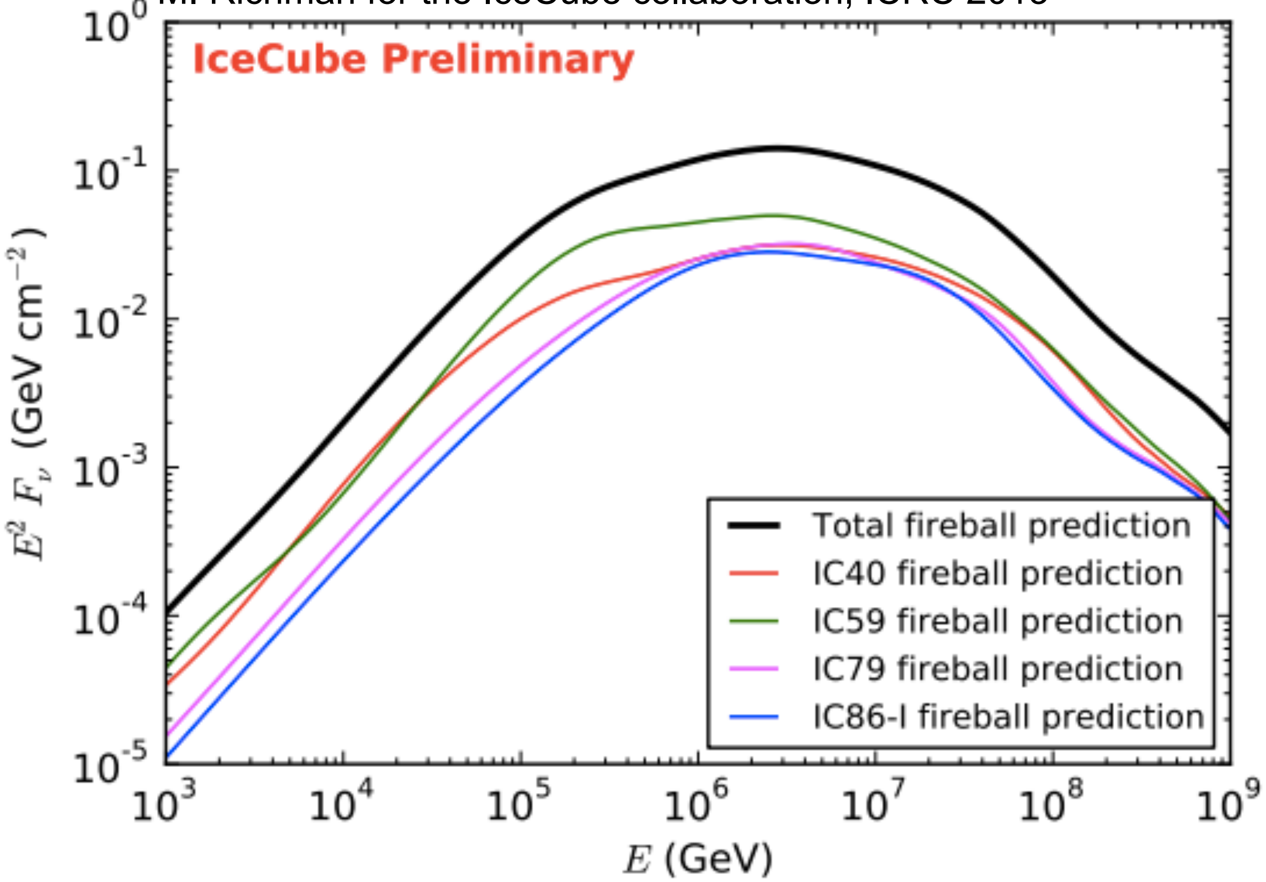
1310 GBM GRBs
174 Swift GRBs
73 LAT GRBs

Ahlers et al. 2011





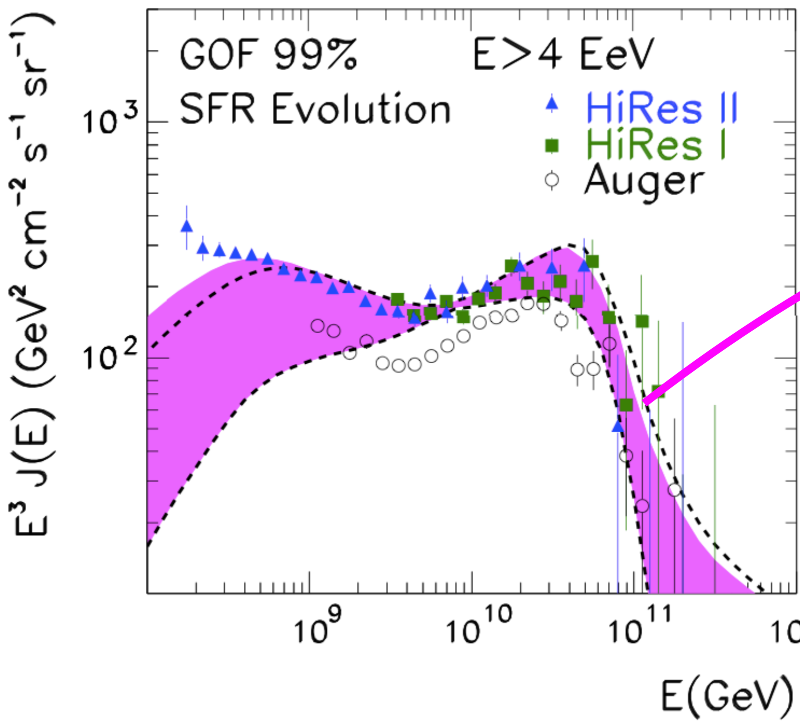
M. Richman for the IceCube collaboration, ICRC 2013



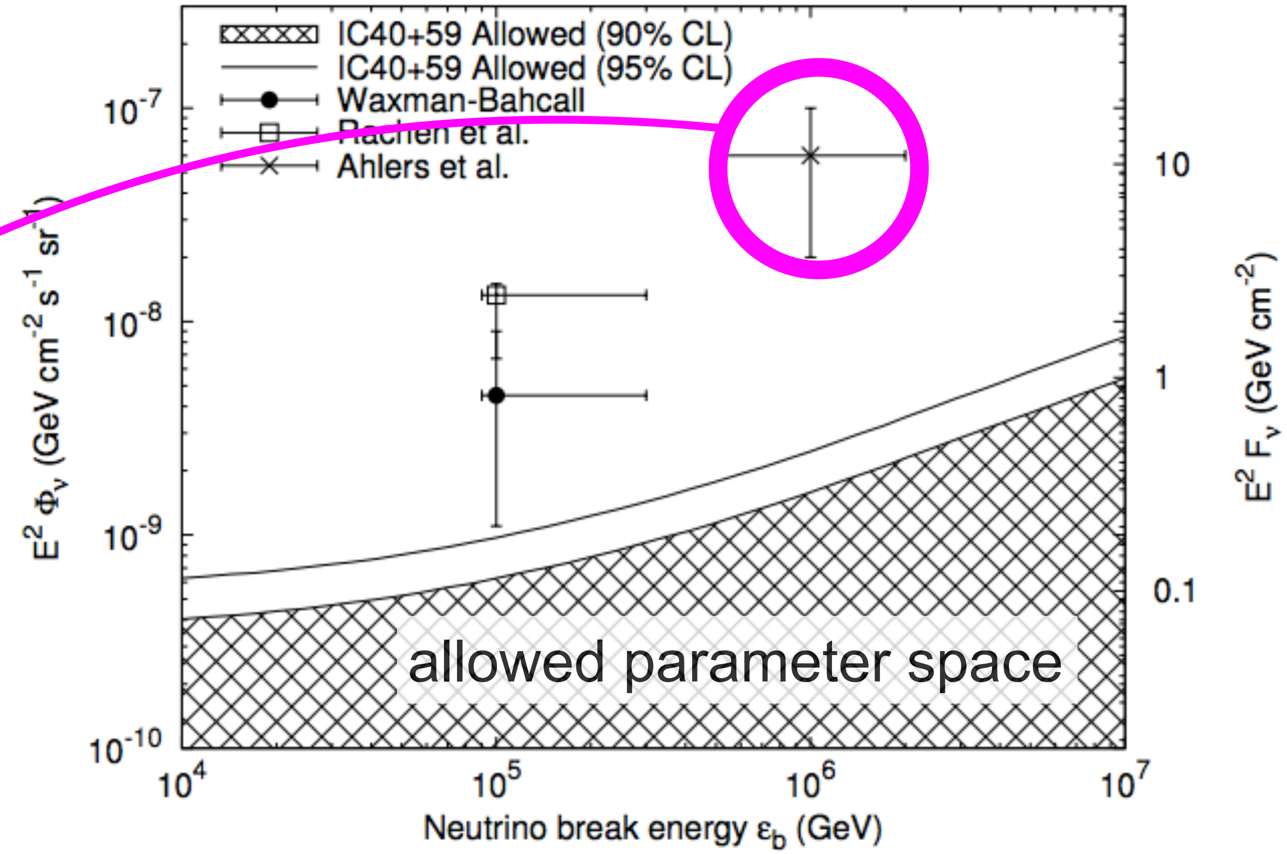
predicted ν spectrum

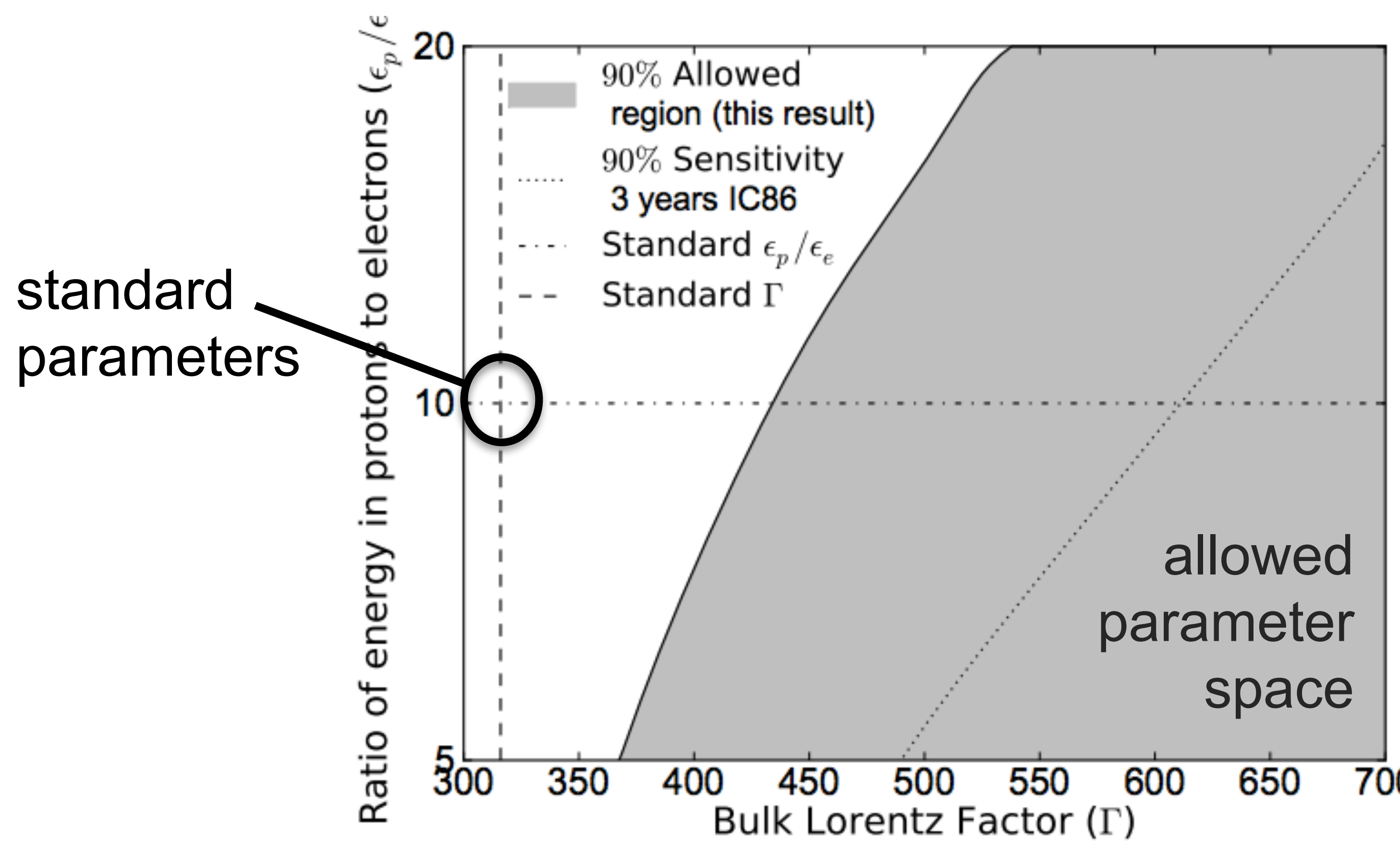
GRBs and their connection to CR production.

Ahlers et al. 2011



Abbasi et al., Nature 2012



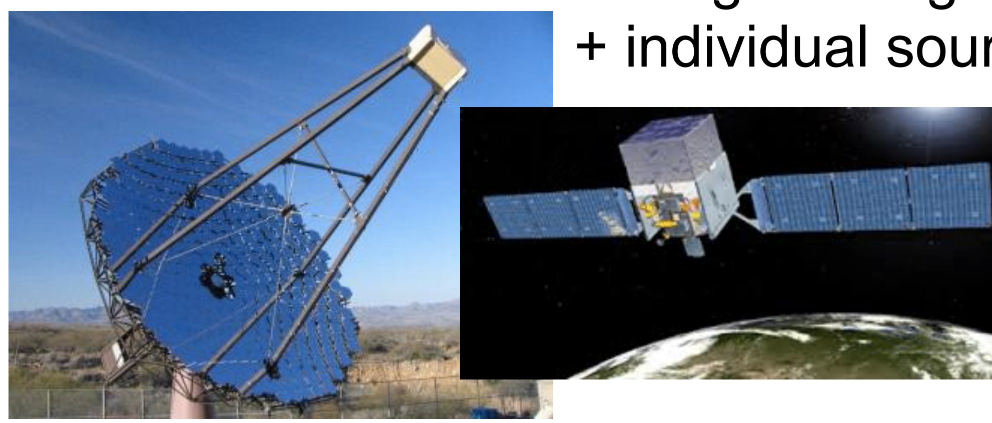


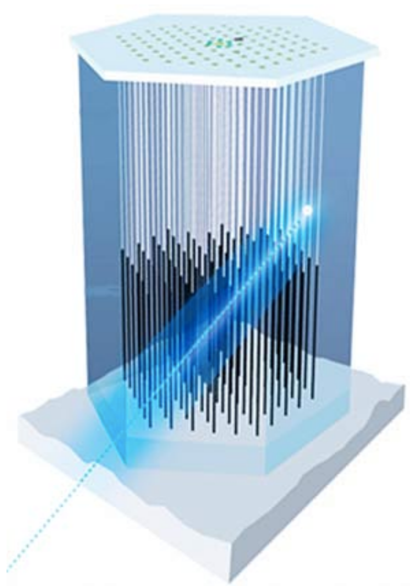
- No excess of neutrinos found in coincidence with GRBs in IceCube/Antares data
- GRBs as dominant cosmic-ray production sites disfavored for wide variety of (internal shock) models.

Multi-messenger astronomy concepts: Dataset correlation.

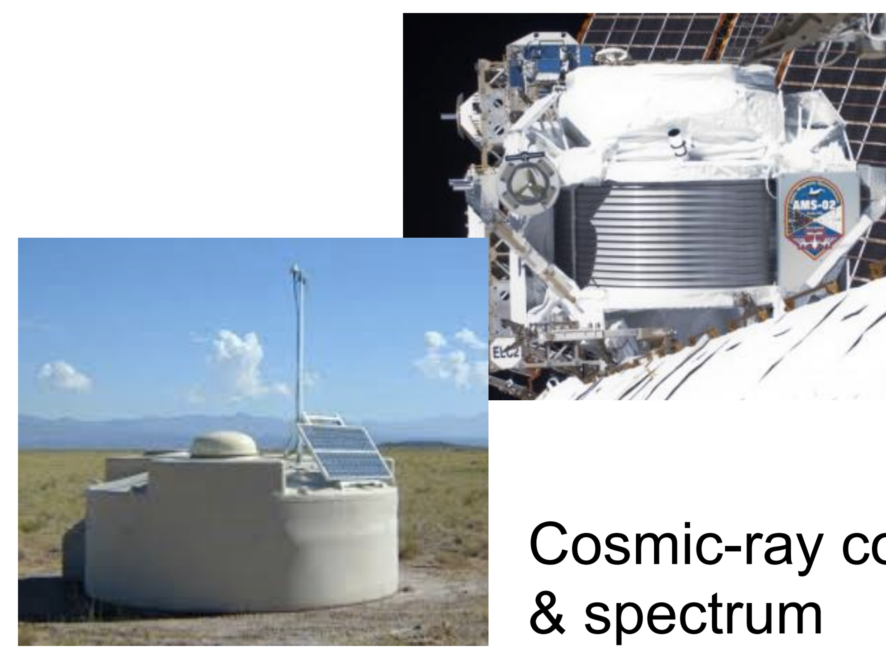
- Cross-correlation of available data.
- Combined interpretation of photon / neutrino / cosmic-ray observations

Extragalactic gamma-ray background
+ individual sources.





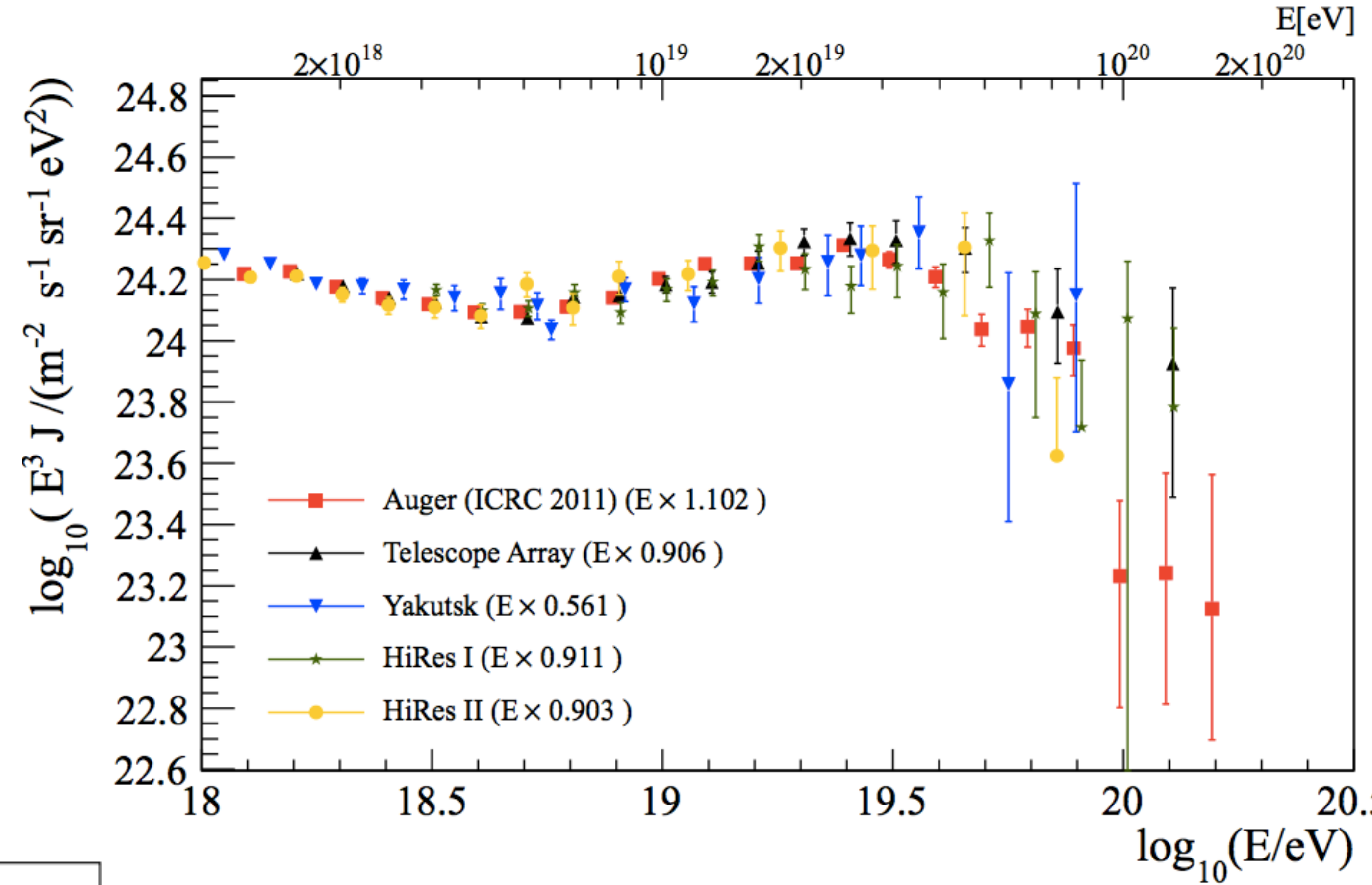
Astrophysical neutrino flux

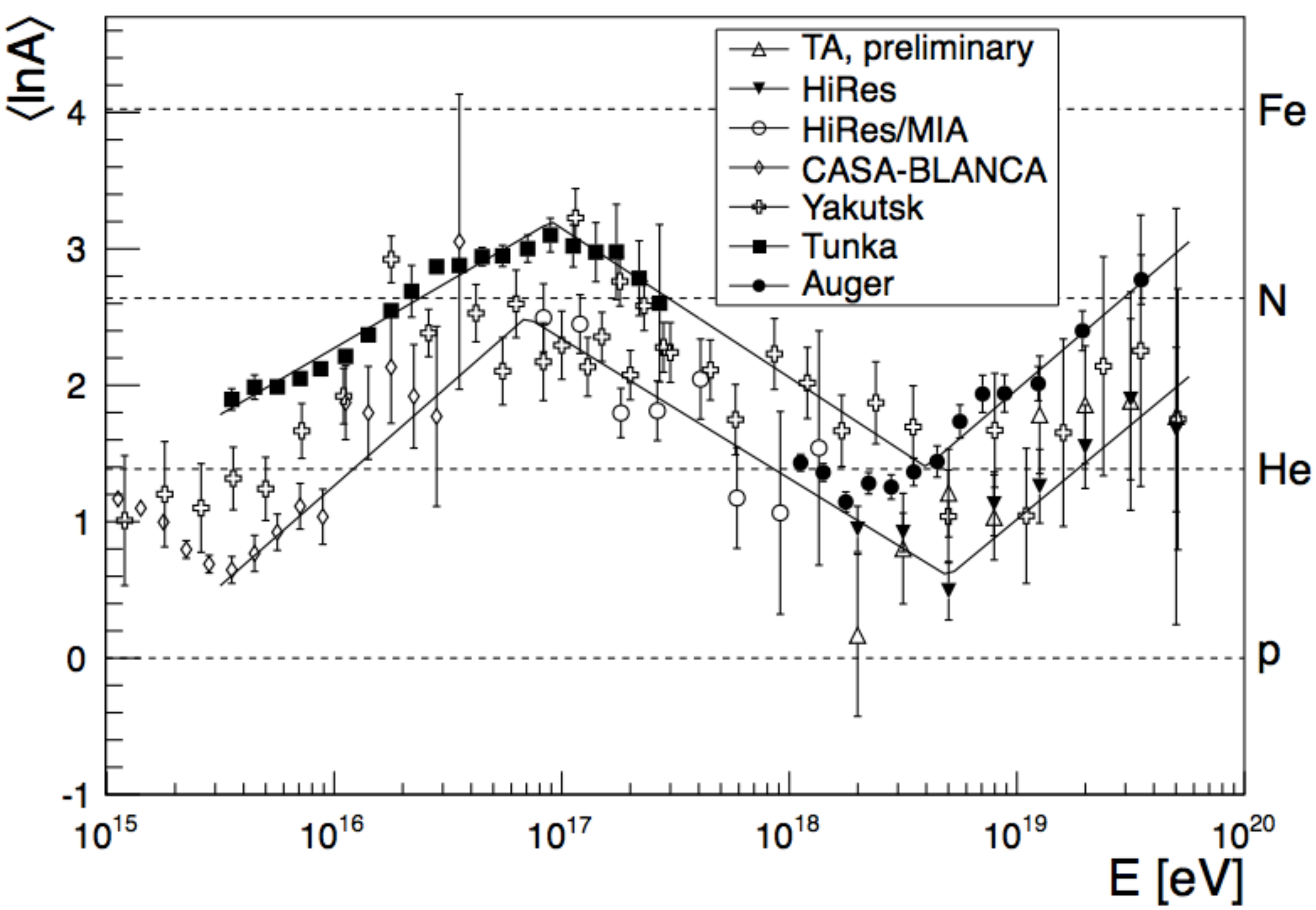


Cosmic-ray composition
& spectrum

High-energy cosmic-ray spectrum and composition.

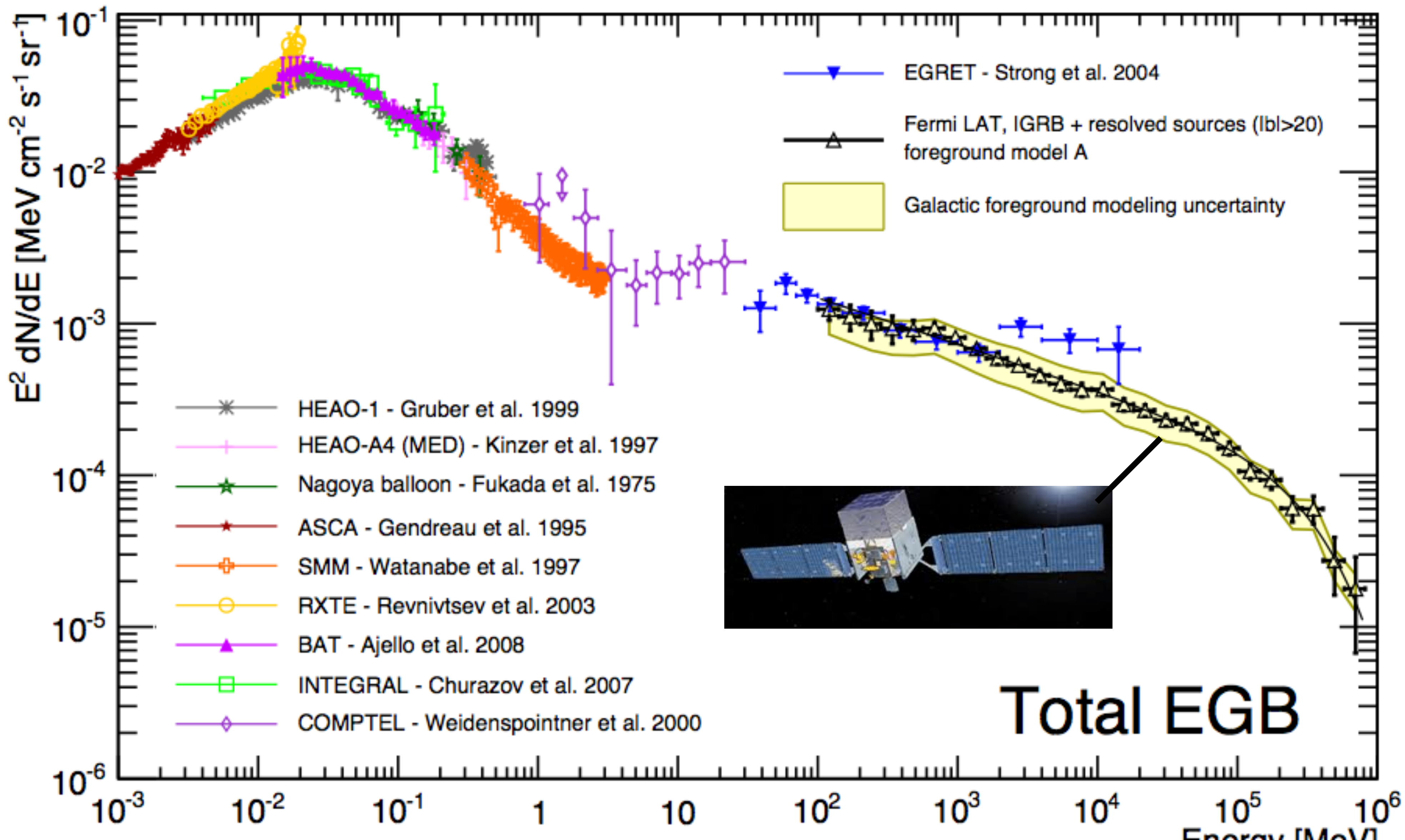
- Spectrum and composition from air-shower sampling with ground based detectors.





- Only mean elemental composition measurement possible.
- Large uncertainties due to hadron shower physics.

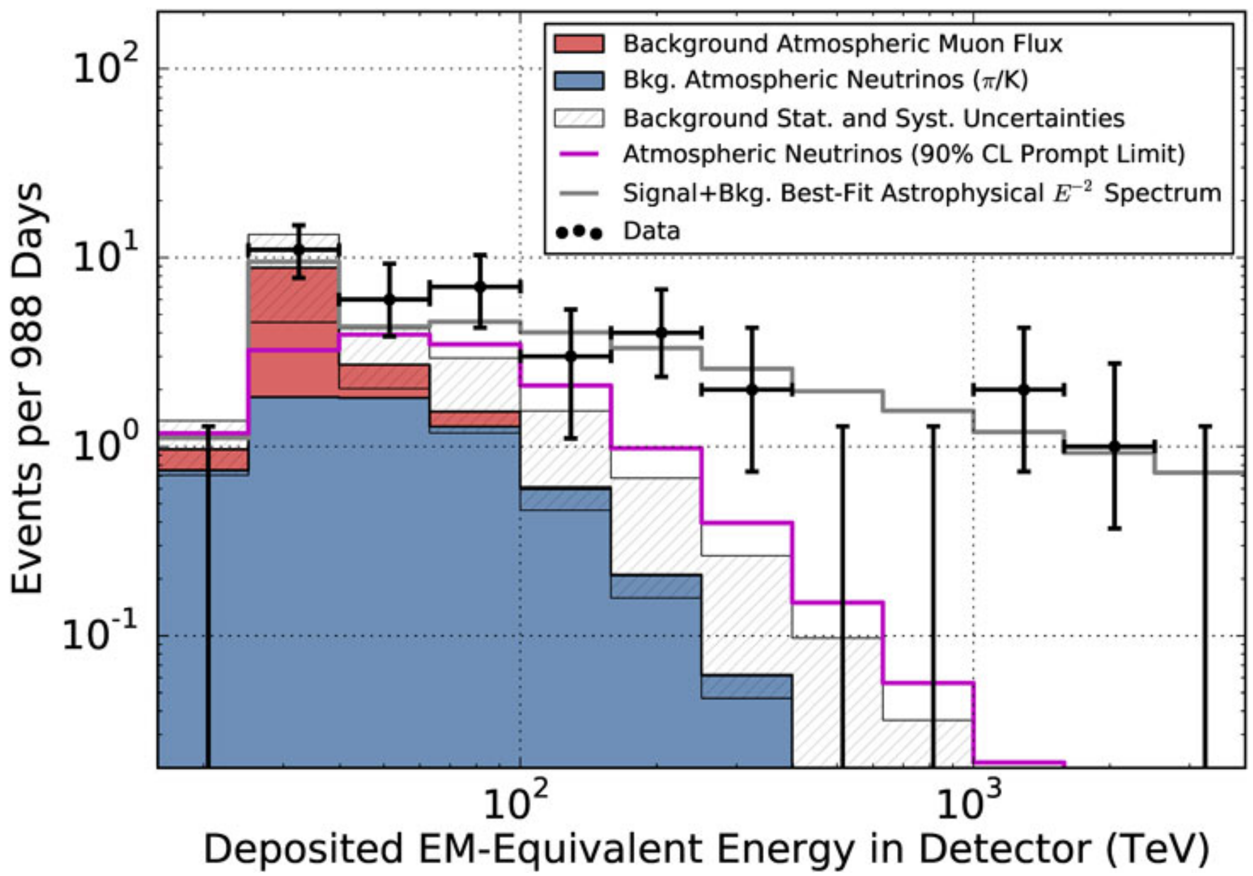
The extragalactic gamma-ray background.

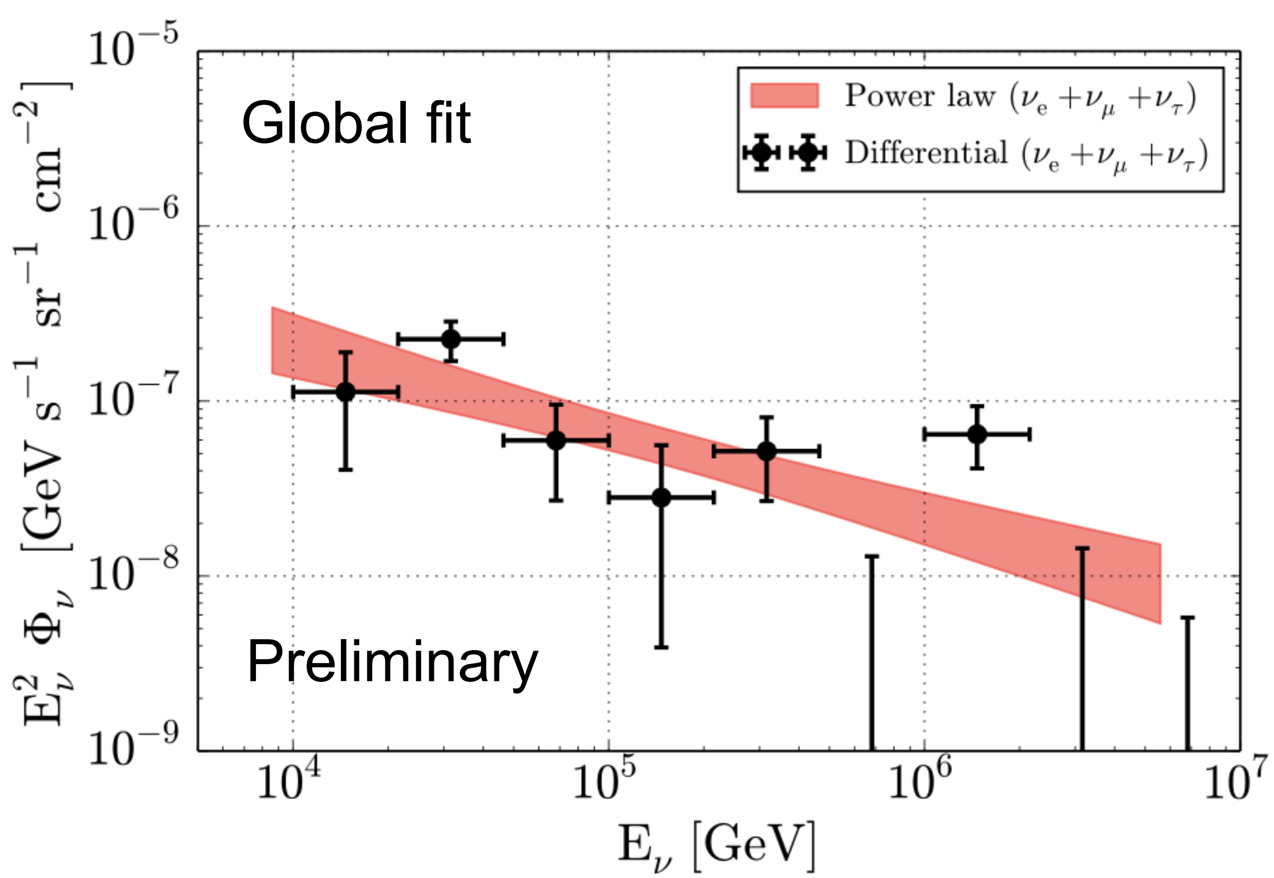


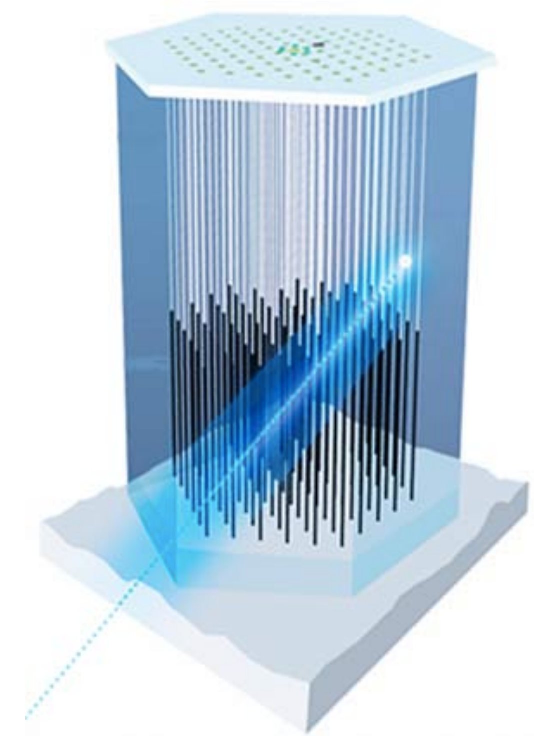
M. Ackermann for the Fermi LAT collaboration - TeVPA 2014

> Total intensity of gamma-ray emission attributed to extragalactic sources.
> Measured over nine orders of magnitude in energy.
> Above 100 GeV cutoff from absorption in the extragalactic background light.

The astrophysical neutrino flux.







> Origin unknown.

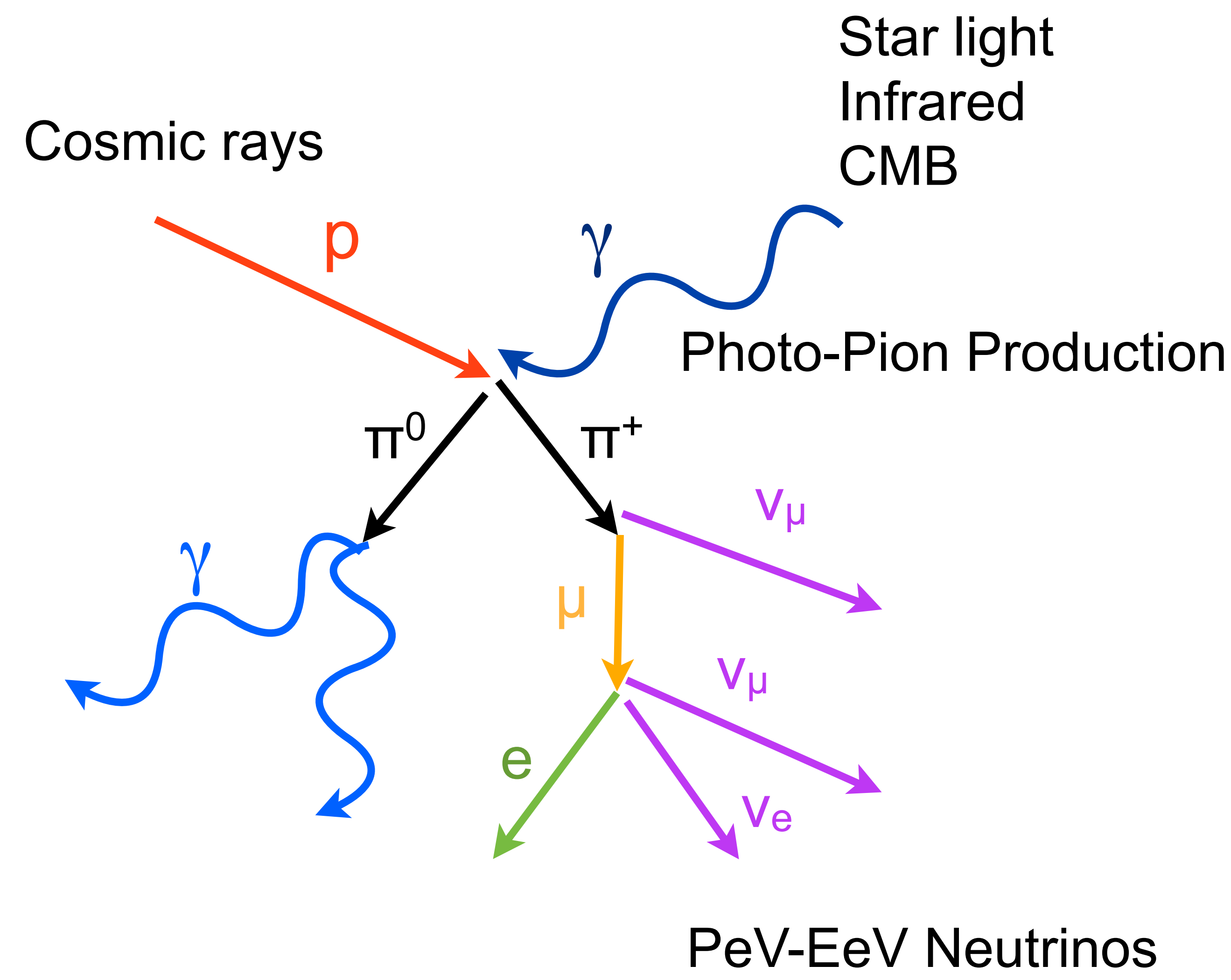
> Distribution compatible with isotropic.

- But a fractional contribution from Galactic sources is possible.

> Preliminary best fit spectrum: simple power-law with index 2.5 +/- 0.08

The cosmic-ray / gamma / neutrino connection

- High-energy cosmic rays interact with the EBL during propagation.
- Neutrino/Gamma production via pγ-interactions
- Reprocessing of gamma rays to GeV energies



EBL=extragalactic background light

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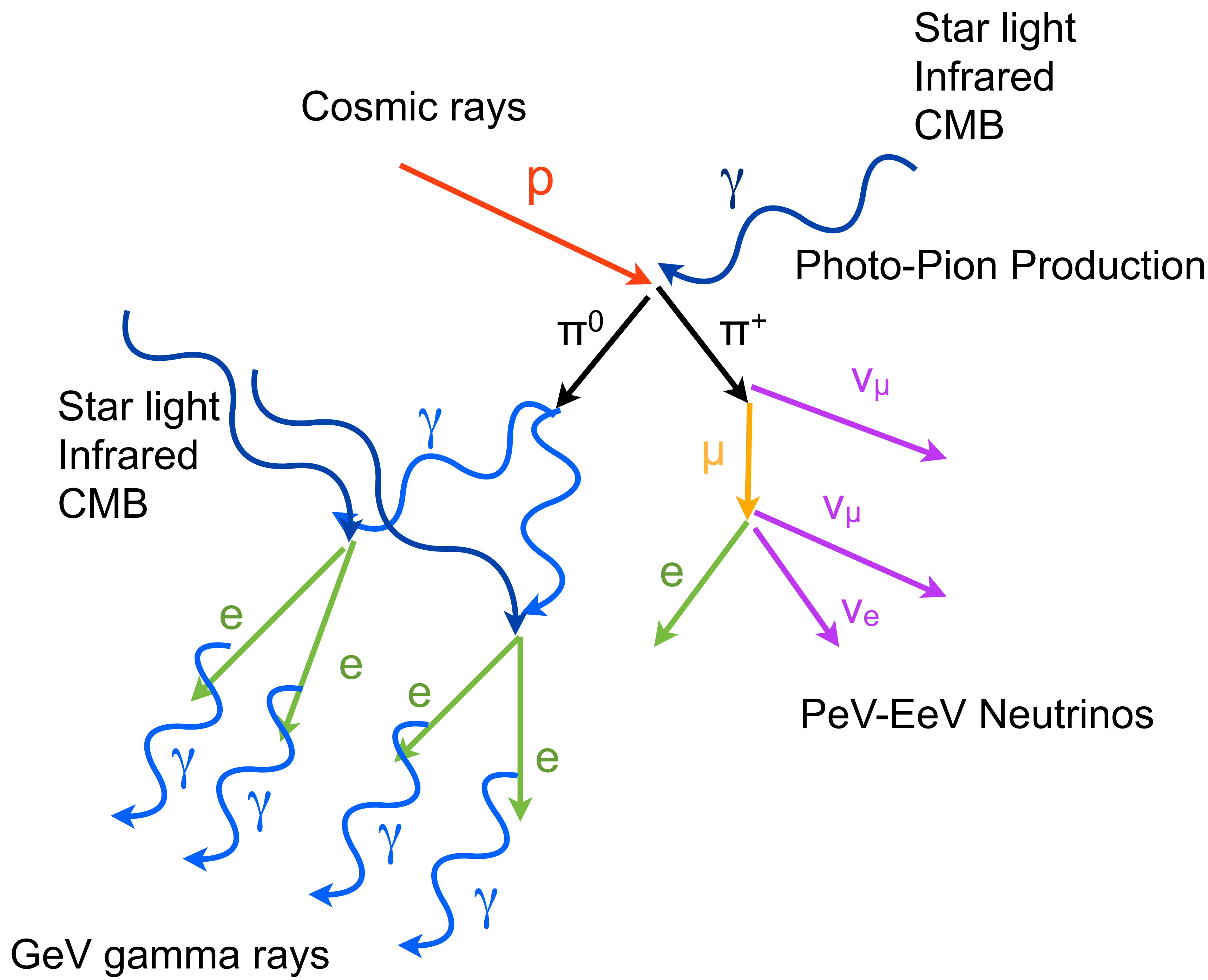
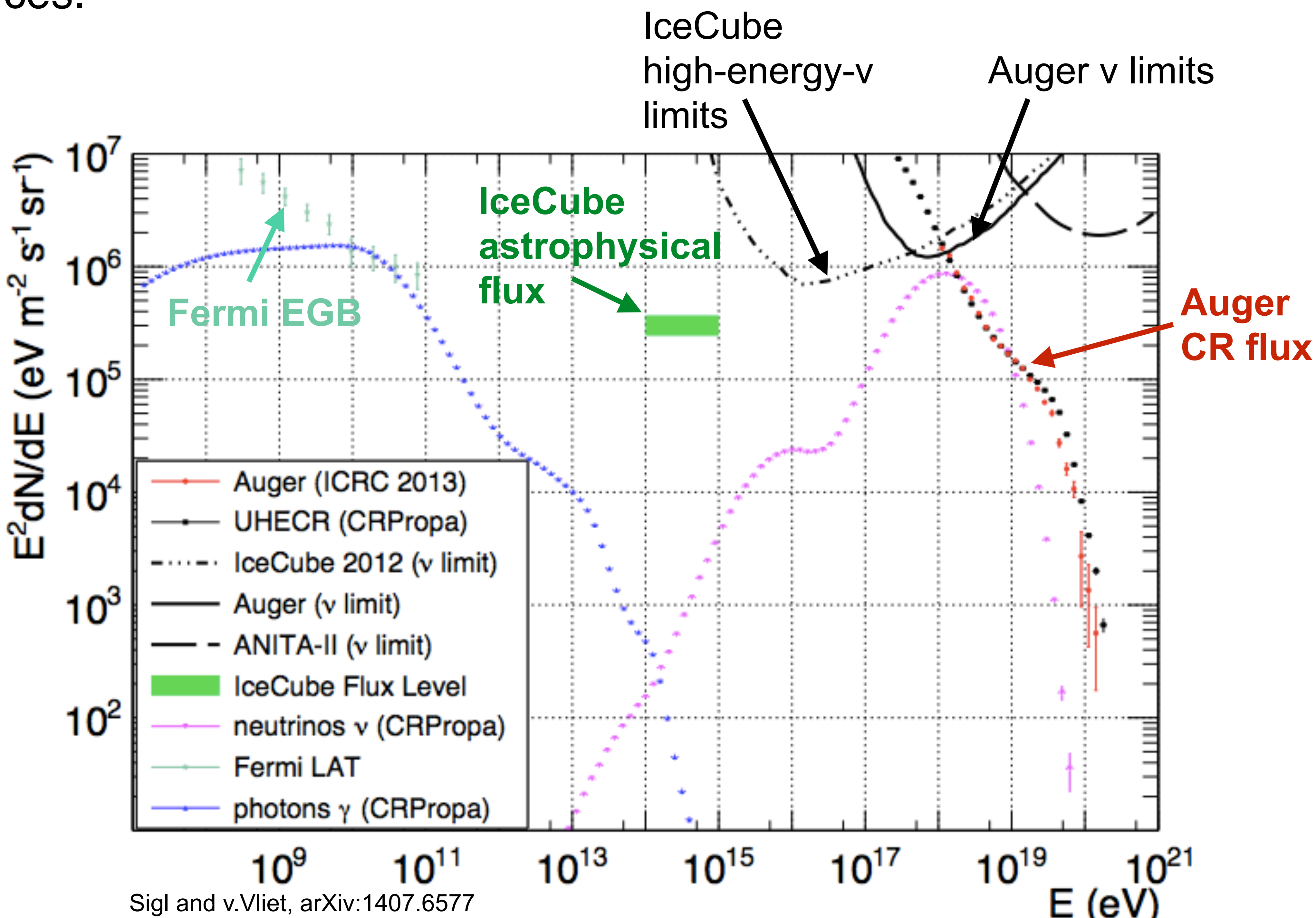


EBL=extragalactic background light

Multi-messenger constraints on UHECR properties.

- CR, neutrino and gamma-ray spectrum from propagation code.
- Cosmological evolution of sources corresponds to **FR-II galaxy evolution.**
- Proton sources.



Sigl and v.Vliet, arXiv:1407.6577

Multi-messenger constraints on UHECR properties.

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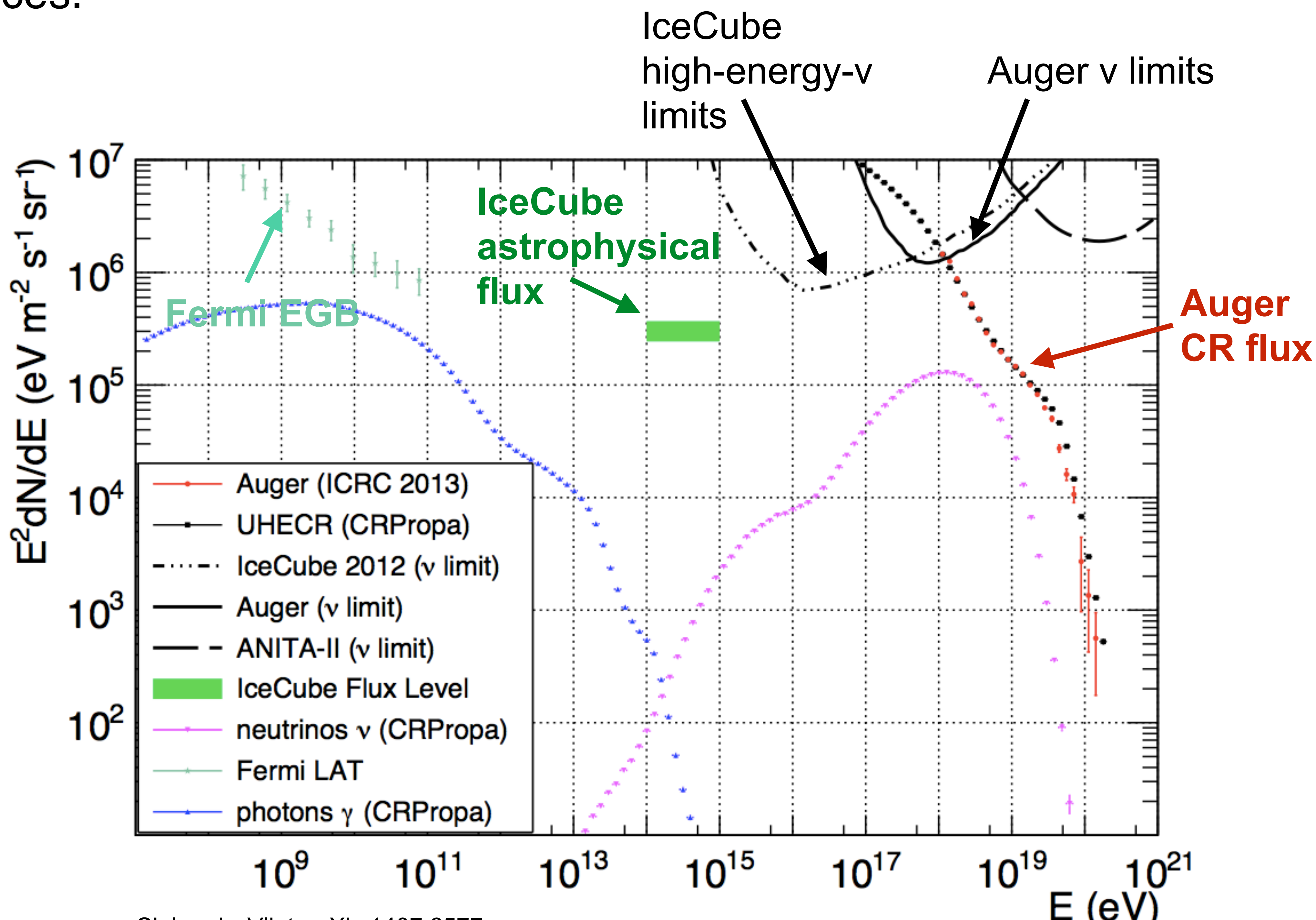
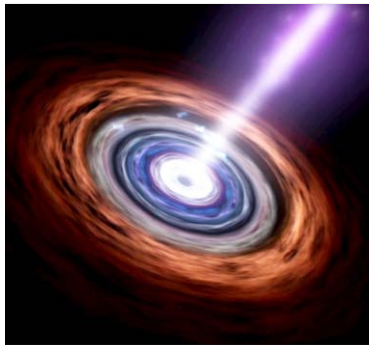


Sigl and v.Vliet, arXiv:1407.6577

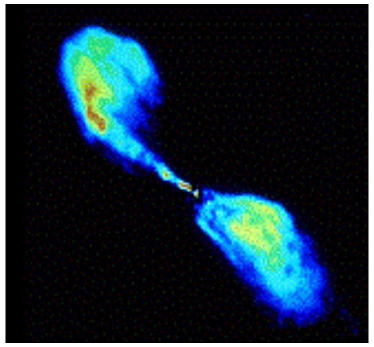
The origin of the astrophysical neutrino flux.

> Candidate populations to produce high-energy neutrinos:



Blazars

Gamma-ray Bursts



AGN / Radio Galaxies

Galaxy Cluster

Star-forming Galaxies

Galactic Sources

The origin of the astrophysical neutrino flux.

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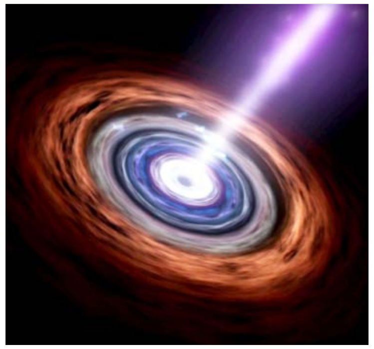
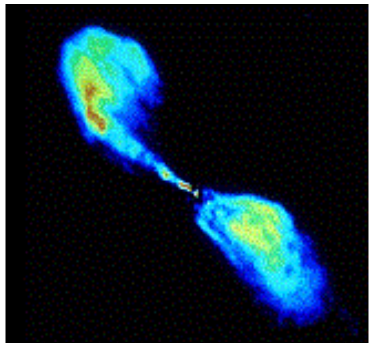


Blazars

... not more than small fraction of diffuse flux (see Wolfgang's talk)

Gamma-ray Bursts

... disfavored for standard scenarios.



AGN / Radio Galaxies

Galaxy Cluster

Star-forming Galaxies

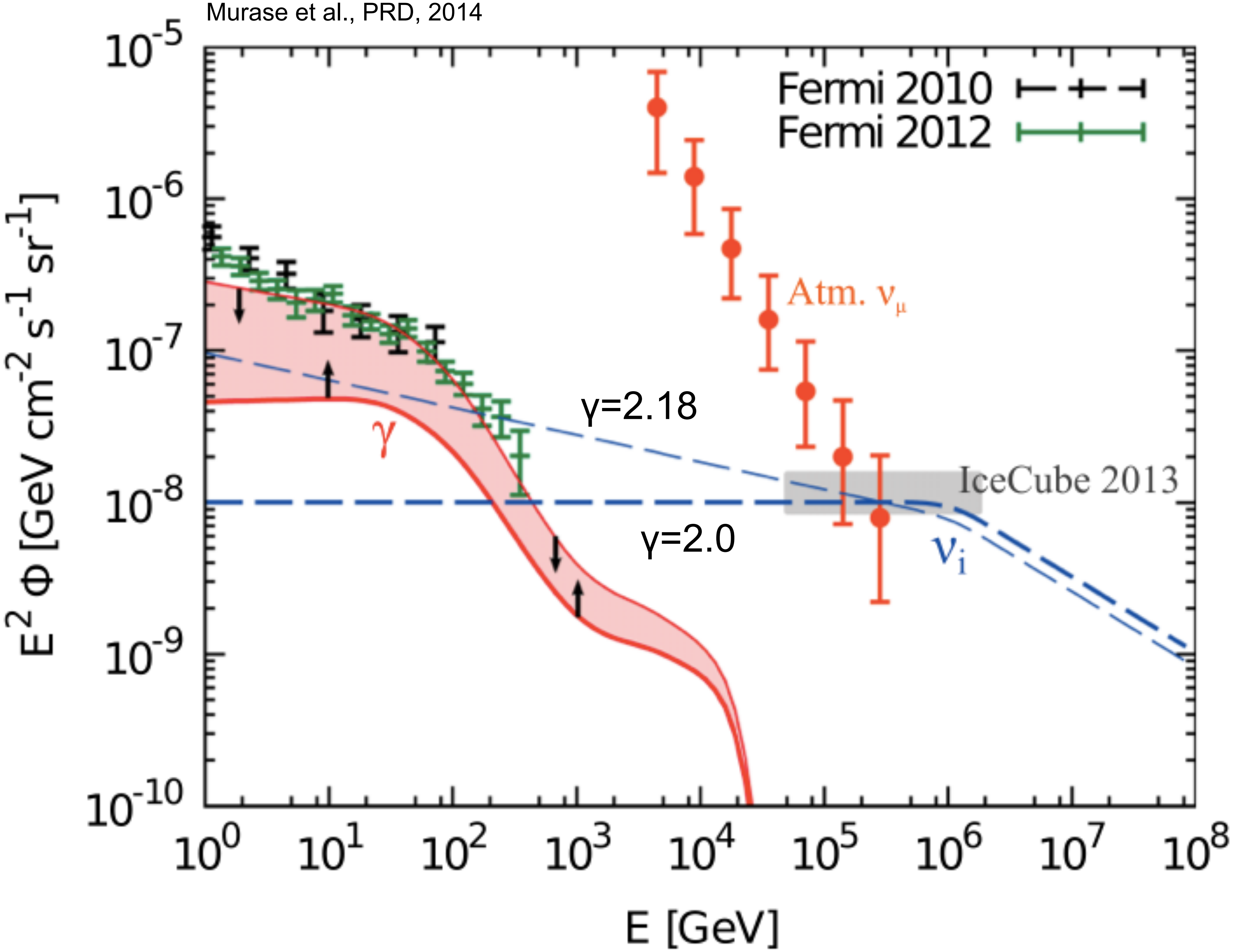
Galactic Sources

... only a fraction of diffuse neutrinos can be Galactic.

The origin of the astrophysical neutrino flux.

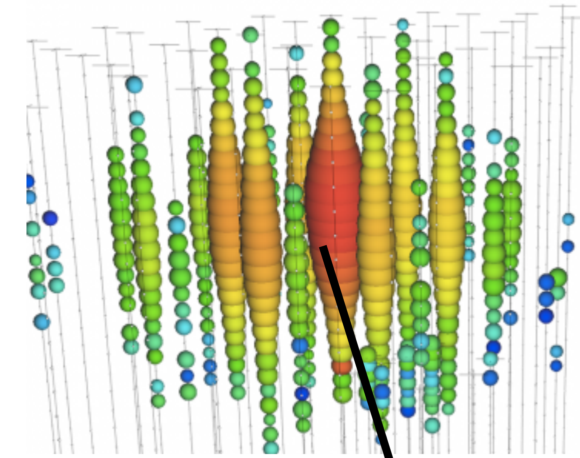
- If neutrinos originate from pp-interactions → strong constraints on the low-energy spectrum.
- Applies to e.g. star-forming galaxies, galaxy cluster emission.
- Both lower and upper limit on contribution to the EGB.
- Weak dependence on source evolution.

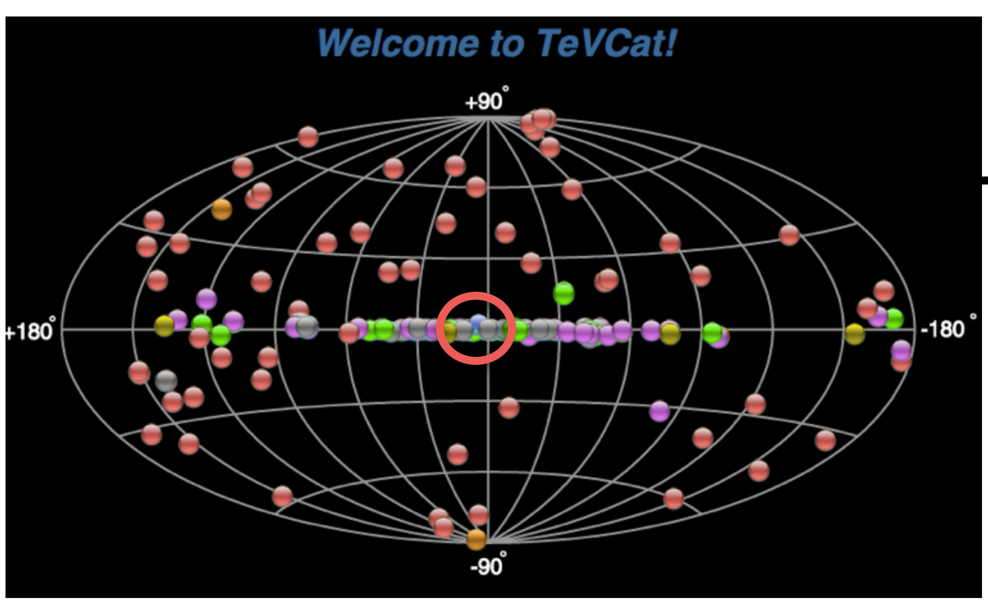
Murase et al., PRD, 2014

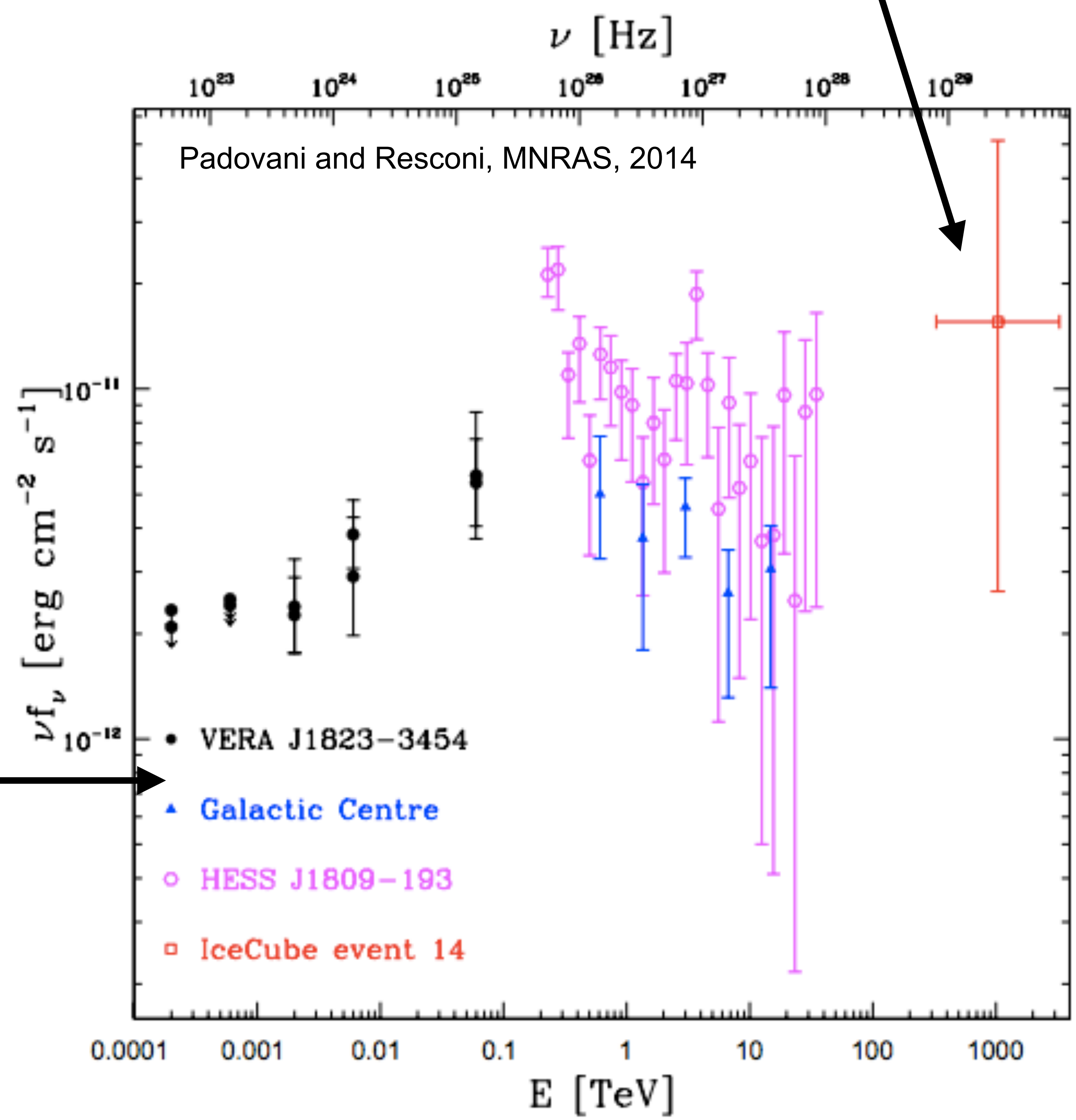


The origin of the astrophysical neutrino flux.

- Search for possible counter parts in TeV gamma-ray source catalog.
- IceCube shower events have 10° — 15° angular resolution.
- Compare power emitted in gamma-rays to power in neutrinos.
- Several Blazars and PWN found as potential TeV counterparts to neutrino sources.







Or is it something different all together ?

PHYSICAL REVIEW D **89,** 123516 (2014)

Galactic PeV neutrinos from dark matter annihilation

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(Received 11 April 2014; published 18 June 2014)

The IceCube Neutrino Observatory has observed highly energetic neutrinos in excess of the expected atmospheric neutrino background. It is intriguing to consider the possibility that such events are probing fundamental physics beyond the standard model of particle physics. In this context, $\mathcal{O}$(PeV) dark matter particles decaying to neutrinos have been considered, while dark matter annihilation has been dismissed invoking the unitarity bound as a limiting factor for the annihilation rate. However, the latter claim was done ignoring the contribution from dark matter substructure, which in a PeV cold dark matter scenario would extend down to a free-streaming mass of $\mathcal{O}(10^{-18}\ \mathrm{M}_{\odot})$. Since the unitarity bound is less stringent at

> no reason to speculate, yet…

But:

> Indirect dark matter search is another very interesting multi-messenger topic

> I will leave this to the talk about DM searches tomorrow

Summary

> Each messenger of the non-thermal universe has its limitations:

γ

- Many different emission processes.
- Large fractions of universe opaque above the GeV regime.

ν

- Low statistics.
- Even lower statistics with good pointing resolution.

CR

- No pointing resolution in most energy ranges.
- Information washed out by propagation.

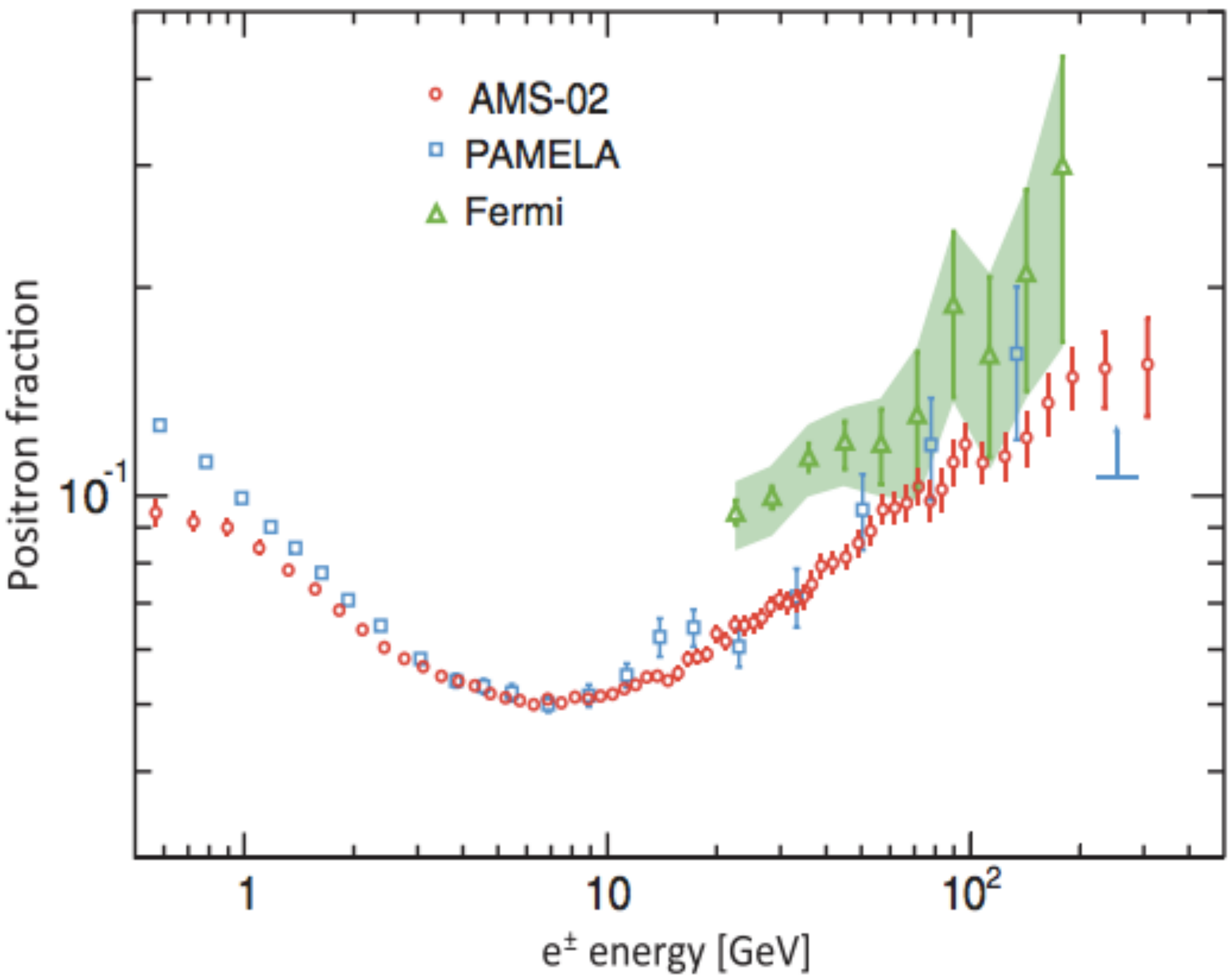
> Combining them allows us to understand the non-thermal universe much better than we could with each single one of them.

> We are just at the beginning of multi-messenger astronomy, not at its end.

> The near future might bring us a 4th messenger: Gravitational waves.

Backup

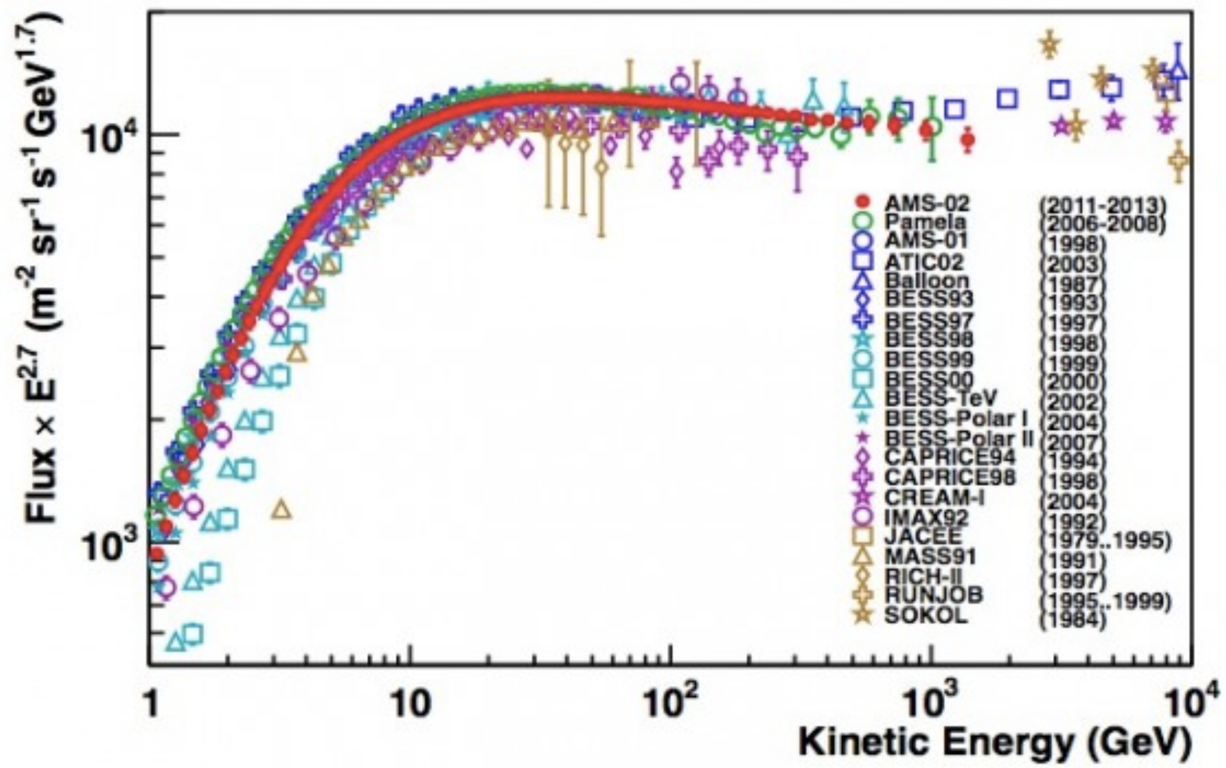
Direct measurements of CR composition.



- Detailed elemental spectra and composition of cosmic rays, including anti-particles.

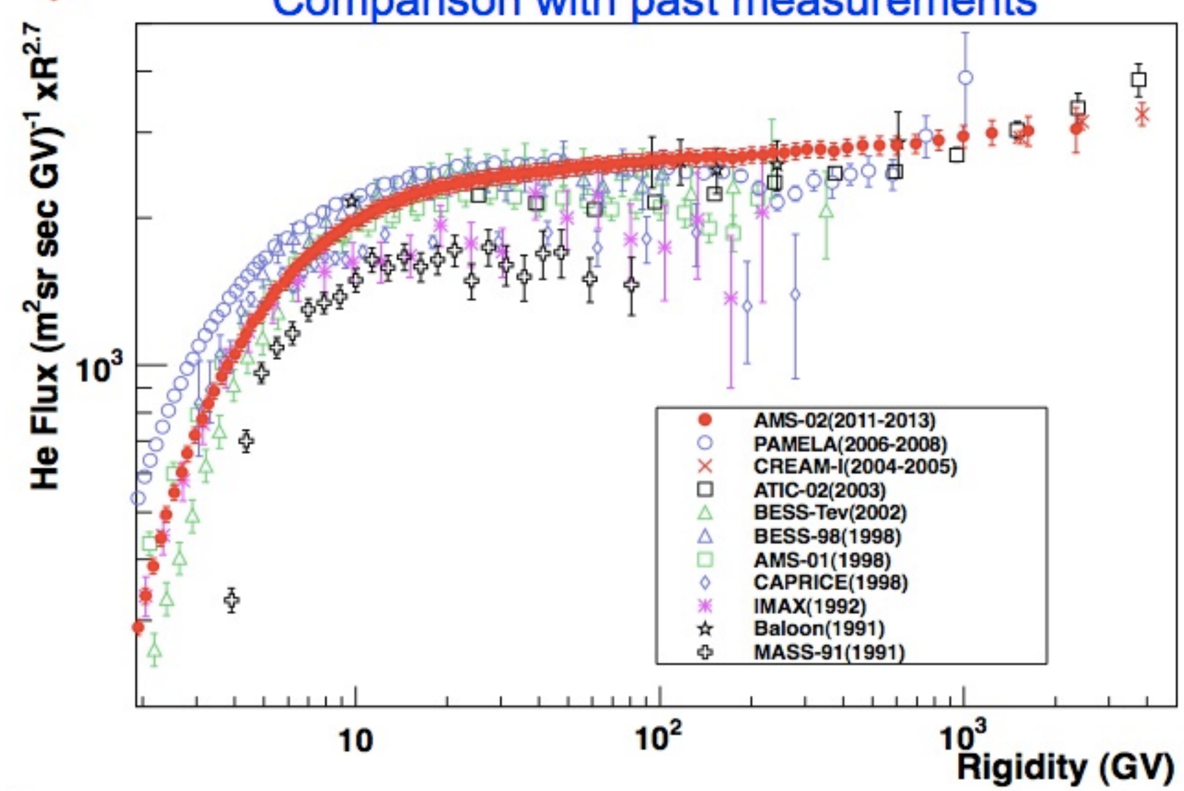
Proton flux

Comparison with past measurements

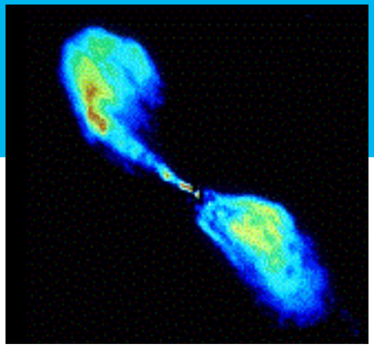


Helium flux

Comparison with past measurements



The origin of the astrophysical neutrino flux.



- > Model: Diffuse neutrino flux originates from CR accelerated in AGN
- > CR produce neutrinos & gammas in interactions with the EBL.
- > Strong bounds from observed CR flux.
- > Peak in the neutrino spectrum at ~ 1 PeV predicted.

Kalashev et al., PRL, 2013