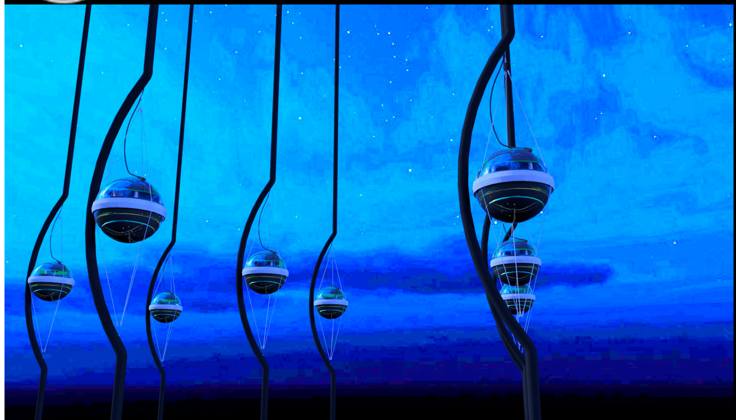
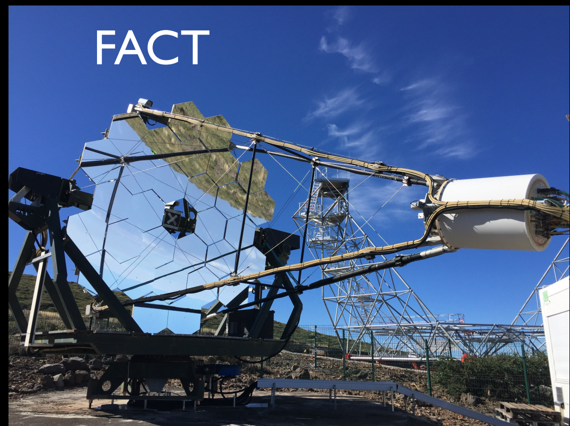
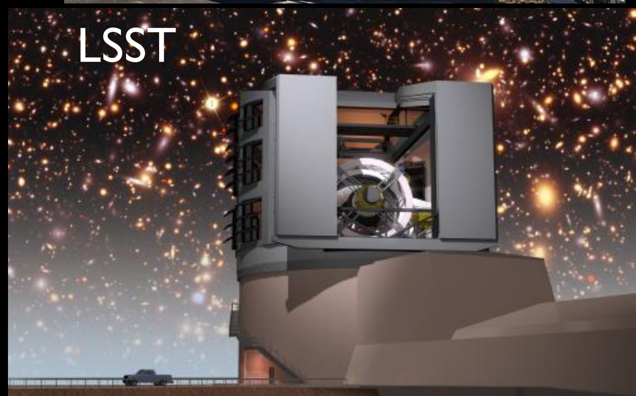
Multi-Messenger Astrophysics

Teresa Montaruli
University of Geneva



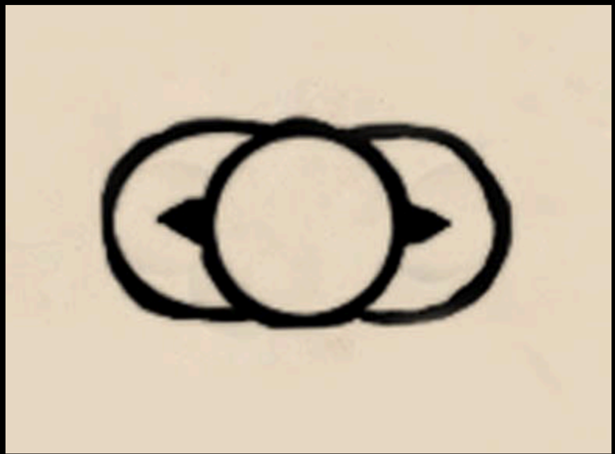




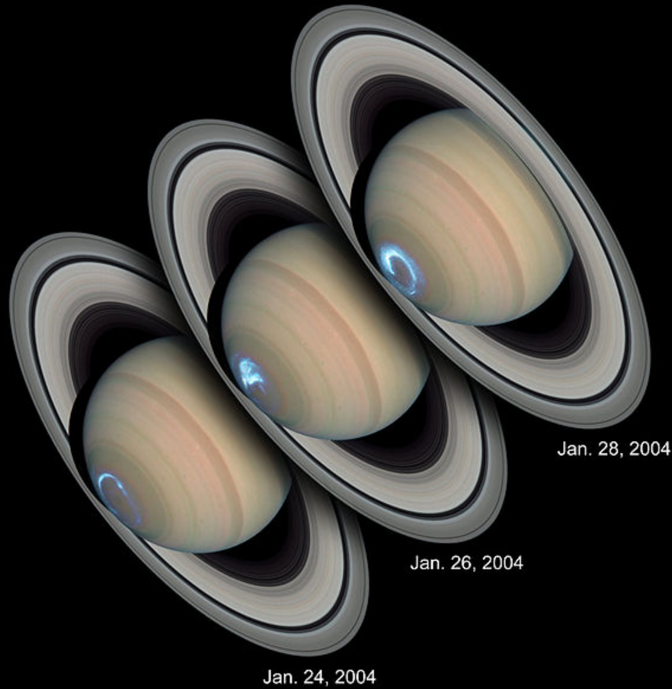
LAYOUT

- Recent breakthroughs
- Gravitational waves
- Multimessenger strategies :
  - Neutrinos and GW
  - Cosmic rays-neutrinos-gamma-rays
- Target of Opportunity programs
- Future Outlook

New astronomical windows



Galileo's

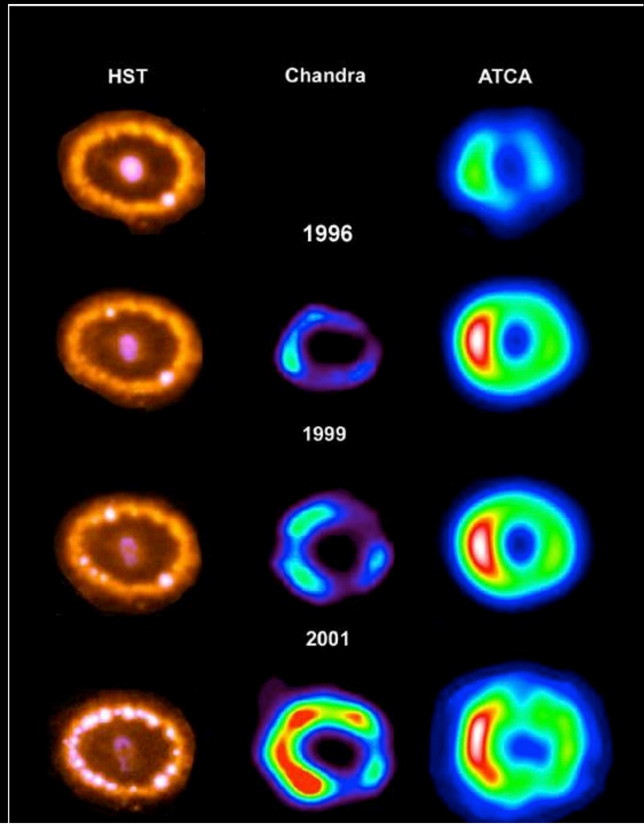


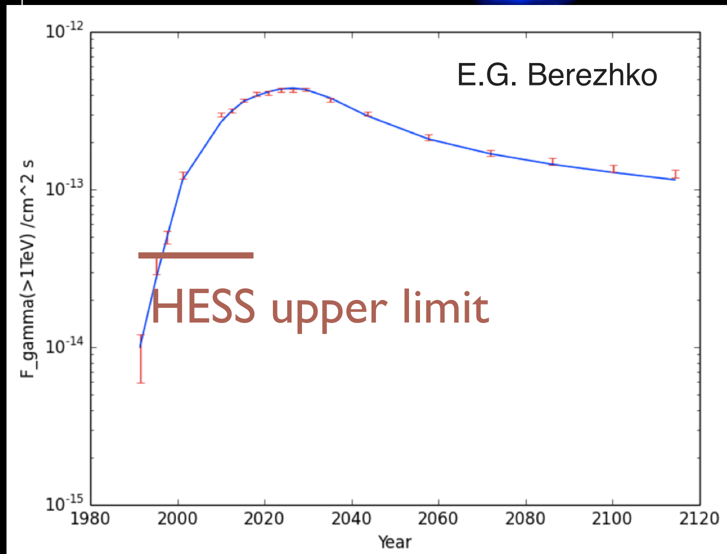
HST

Stolen from G. Losurdo

First outstanding multi-messenger event: SN1987A

- The remnant of the nearest SN since Kepler (1604):
  - photons (over a wide spectrum)
  - neutrinos (Kamiokande, IMB, Baksan)
- Many lessons learned:
  - physics of collapse and signatures of non-spherical collapse
  - formation of heavy elements up to Fe, Ni, C
  - detection of circumstellar and interstellar material
  - Physics of neutrino oscillations in matter and mass hierarchy
  - Limits on coupling of ALP-gamma-rays (Primakoff process in the hot dense medium of core-collapse SN)
- Future long-term monitoring:
- The non-thermal radio and hard X-ray emission is evidence of particle acceleration in the SN blast wave
- Future VHE observations will complete the picture of interaction between the SN shock wave and the circumstellar medium and the efficiency versus age. A non-linear shock acceleration scenario foresees 2 x flux in the next 20 years, leading to a possible detection of CTA. HESS limits contradicts this picture.



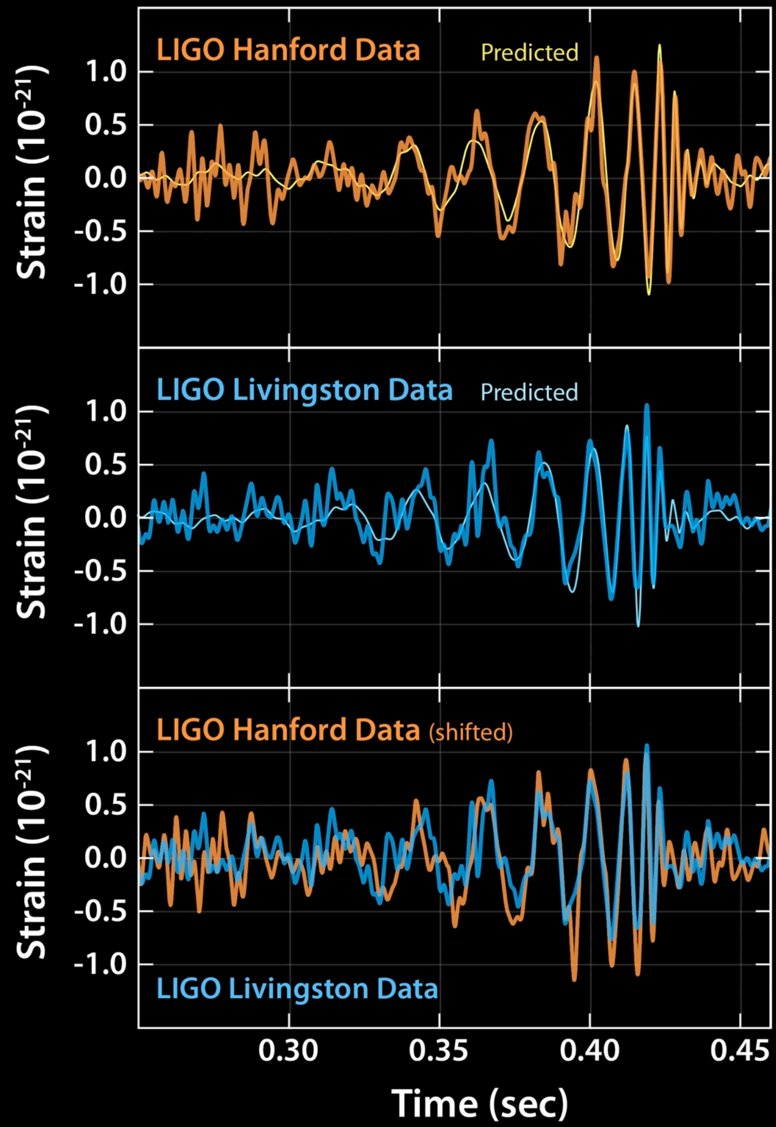


Nobel prize in 2002

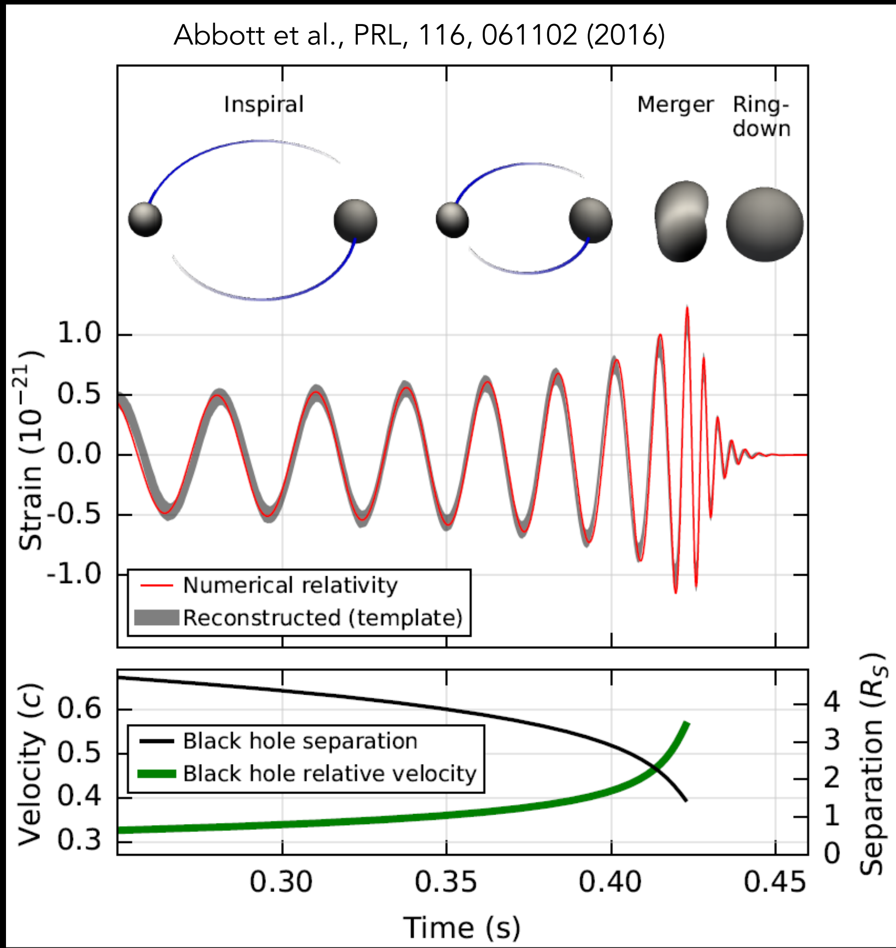
New breakthrough: the GW discovery

GW150914

Abbott et al., PRL, 116, 061102 (2016)



A BINARY BLACK HOLE MERGER: First tests of general relativity in strong field (extreme) conditions. The most luminous event ever observed.



Full bandwidth waveforms wo filtering compared to numerical relativity models of BH horizons during coalescence

Also with the contribution of Philippe Jetzer's group, UniZH

Black Holes of Known Mass

Abbott et al., PRL, 116, 061102 (2016)

Primary black hole mass	$36^{+5}_{-4}\,M_\odot$
Secondary black hole mass	$29^{+4}_{-4}\,M_\odot$
Final black hole mass	$62^{+4}_{-4}\,M_\odot$
Final black hole spin	$0.67^{+0.05}_{-0.07}$
Luminosity distance	410^{+160}_{-180} Mpc
Source redshift, z	$0.09^{+0.03}_{-0.04}$

TOTAL ENERGY RADIATED IN GW:

$3.0^{+0.5}_{-0.5} M_\odot c^2$

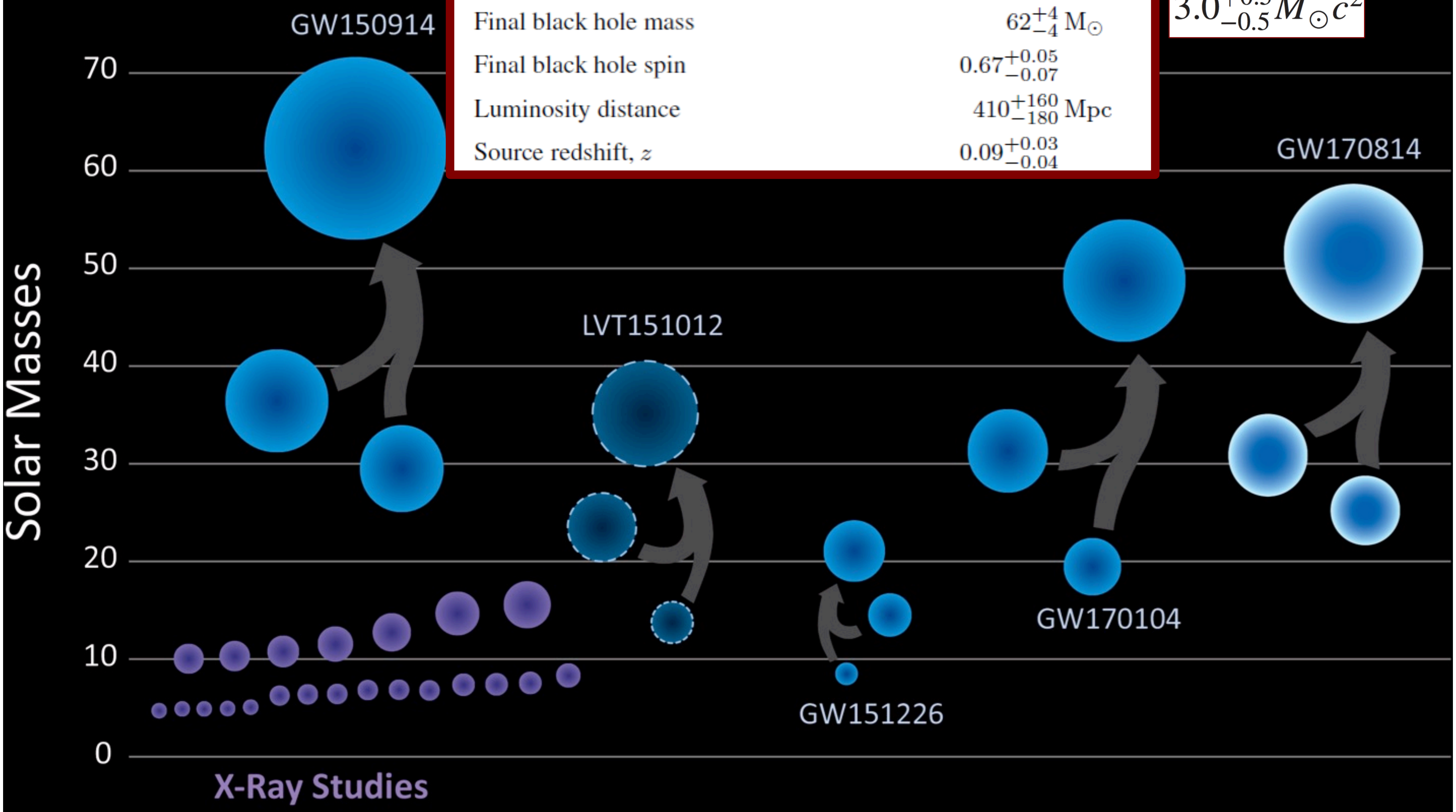
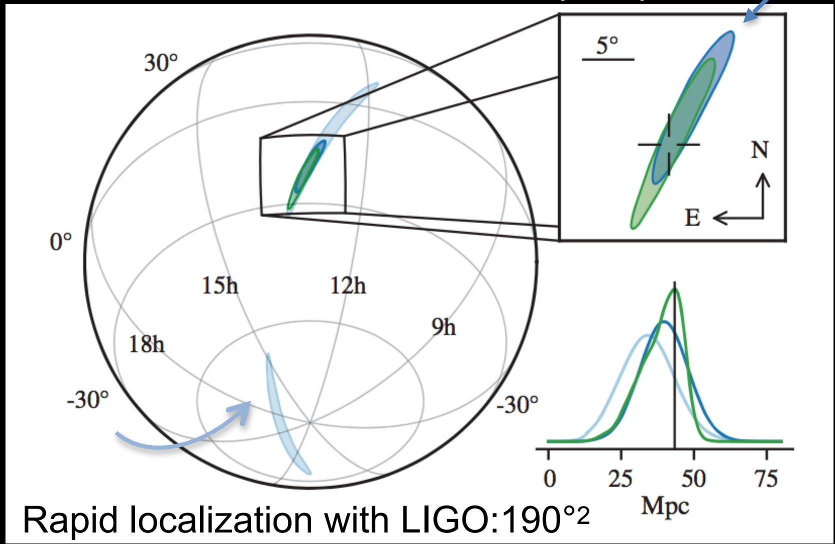


Image credit: LIGO/Caltech/Sonoma State (Aurore Simonnet)

GW170817

Abbott et al., PRL., 119, 161101 (2017)



rapid localization with LIGO-Virgo: 31°2

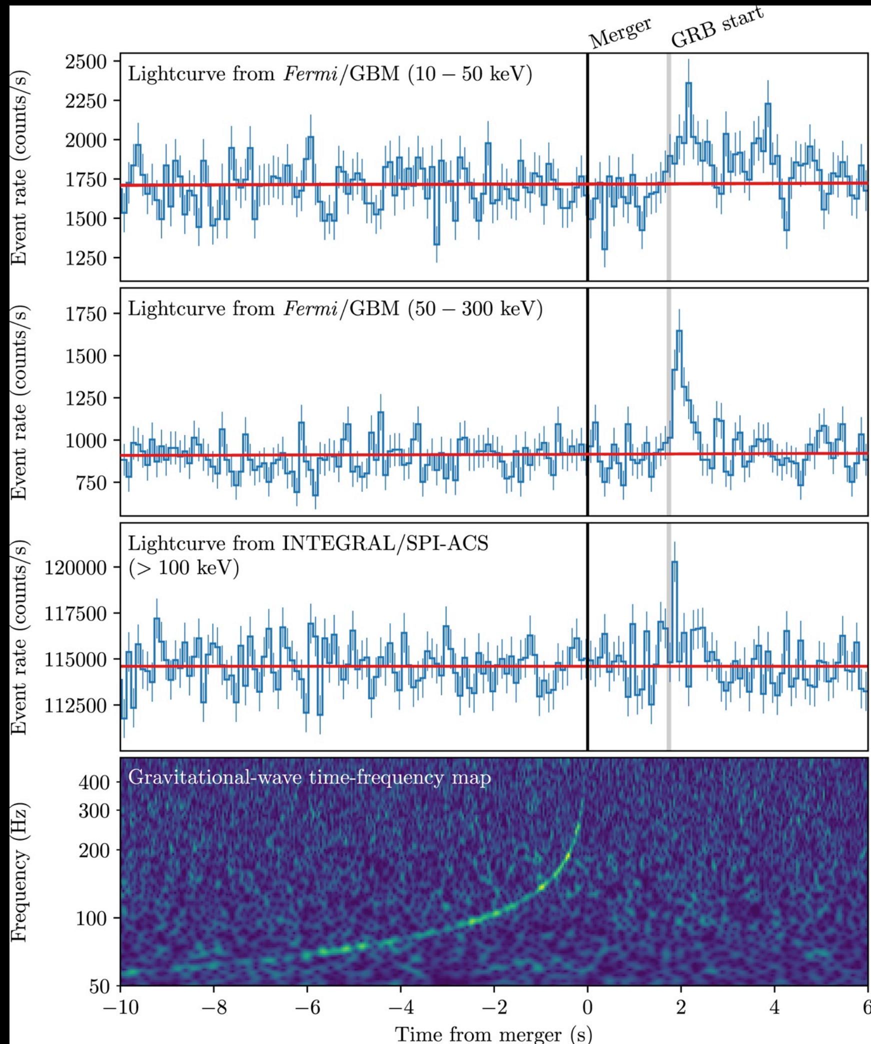
high-latency follow-up: 28°2

- Constraint on the two masses (broad range due to mass-spin degeneracy)

$$0.86 < m_i < 2.26\ M_\odot$$

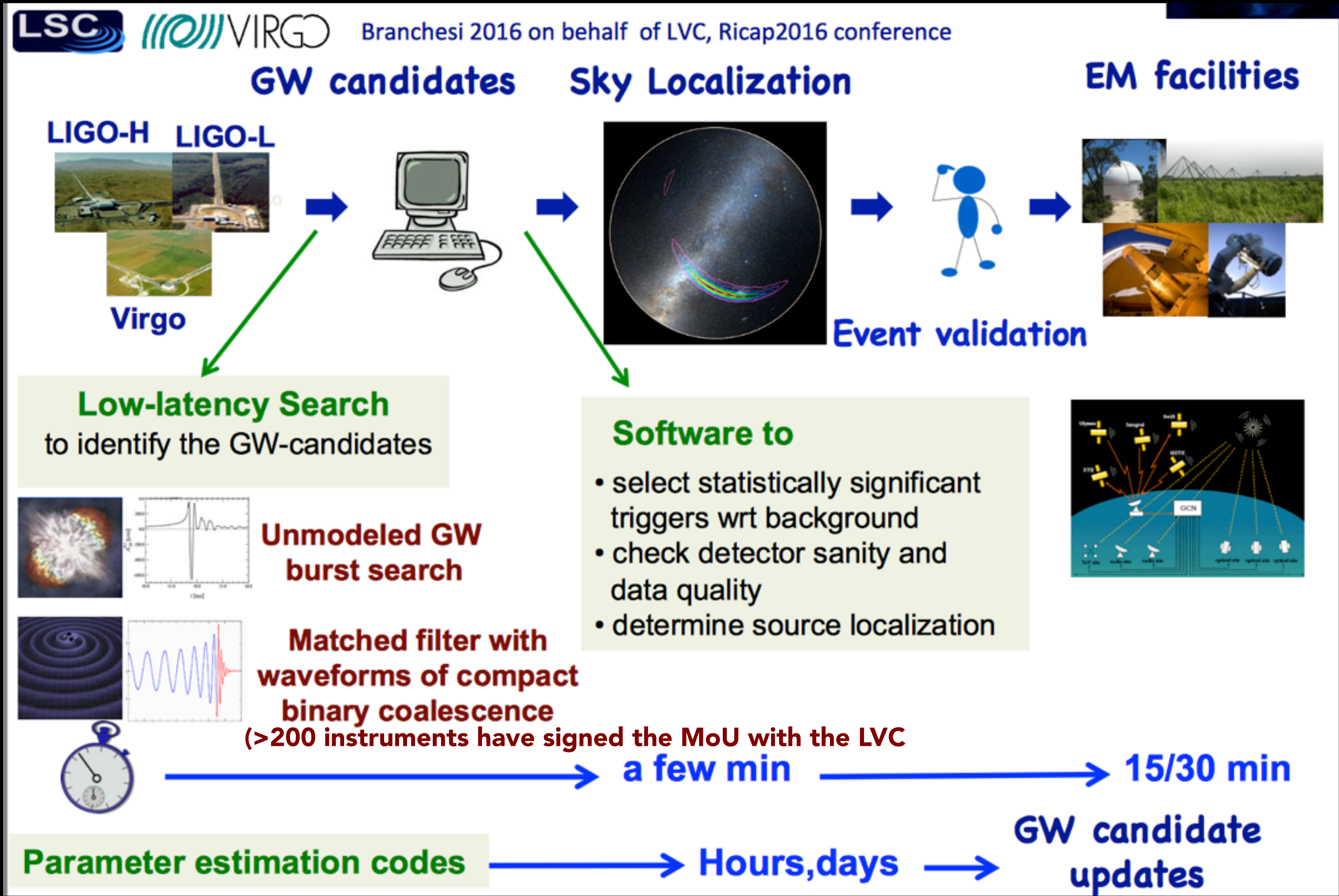
- Luminosity distance:

$$D_L = 40^{+8}_{-14}\ \mathrm{Mpc}$$



- On August 17, 2017 Adv LIGO and Adv Virgo observed GW170817 from a binary NS inspiral (Abbot et al 2017)
- Fermi-GBM and INTEGRAL detected a short GRB consistent with the location 1,7 s after GW event
- Optical counterpart in the galaxy NGC4993
- X-ray and radio afterglow consistent with short GRB
- Strong evidence for Kilonova model (isotropic thermal emission by radioactive decay of rapid nucleon capture elements synthesised in the merger ejecta

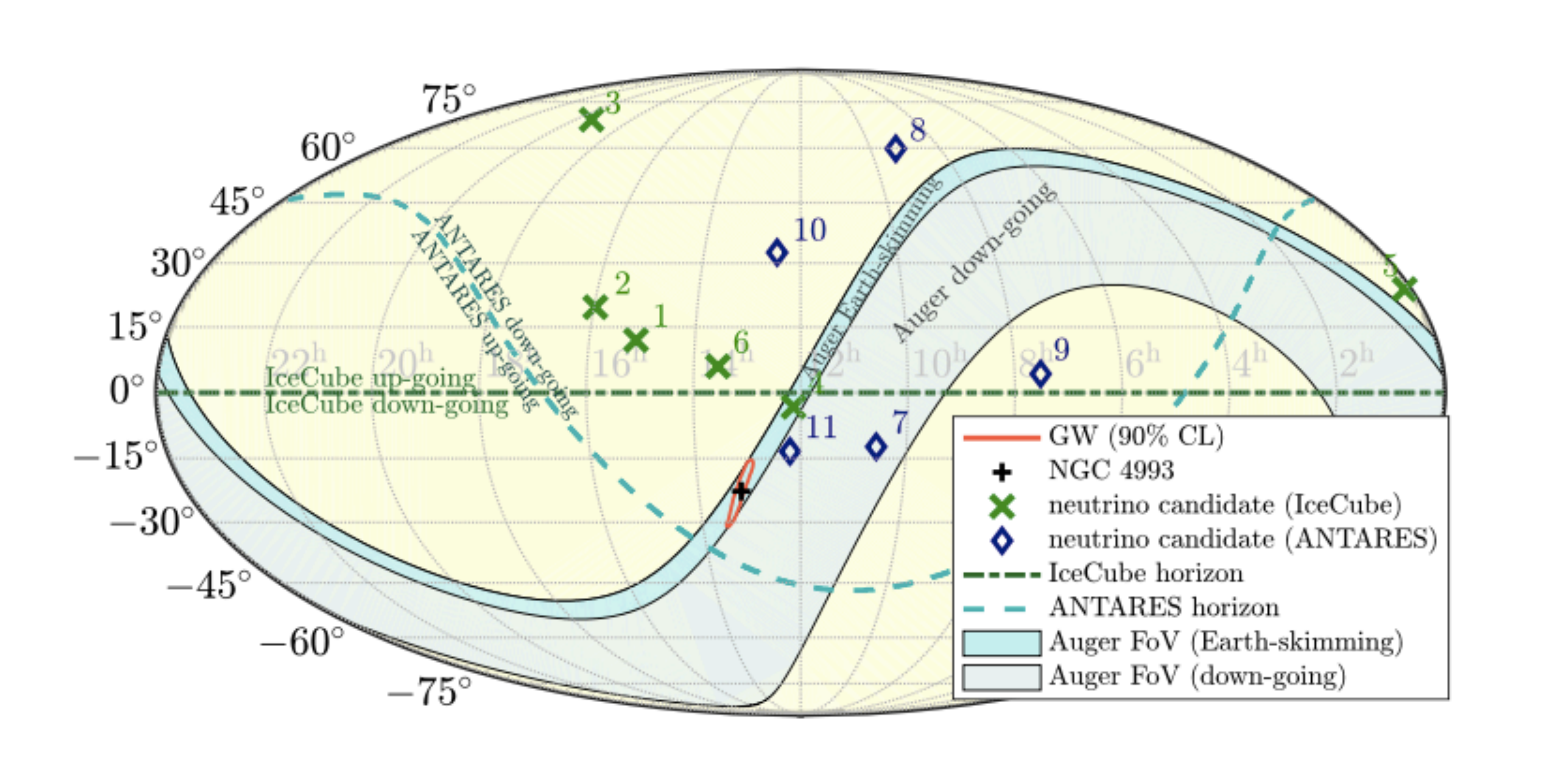
MULTI-MESSENGER NETWORKS



- GCN content: time, localisation 3D sky map, false alarm rate, luminosity distance
- Typical latency: tens of minutes (sometimes longer due to technical issues)

Neutrinos from GW170817?

ANTARES/IceCube/LigoSC/Virgo. Phys.Rev. D93 (2016), 122010, Phys.Rev. D96 (2017), 022005, arXiv:1710.05839

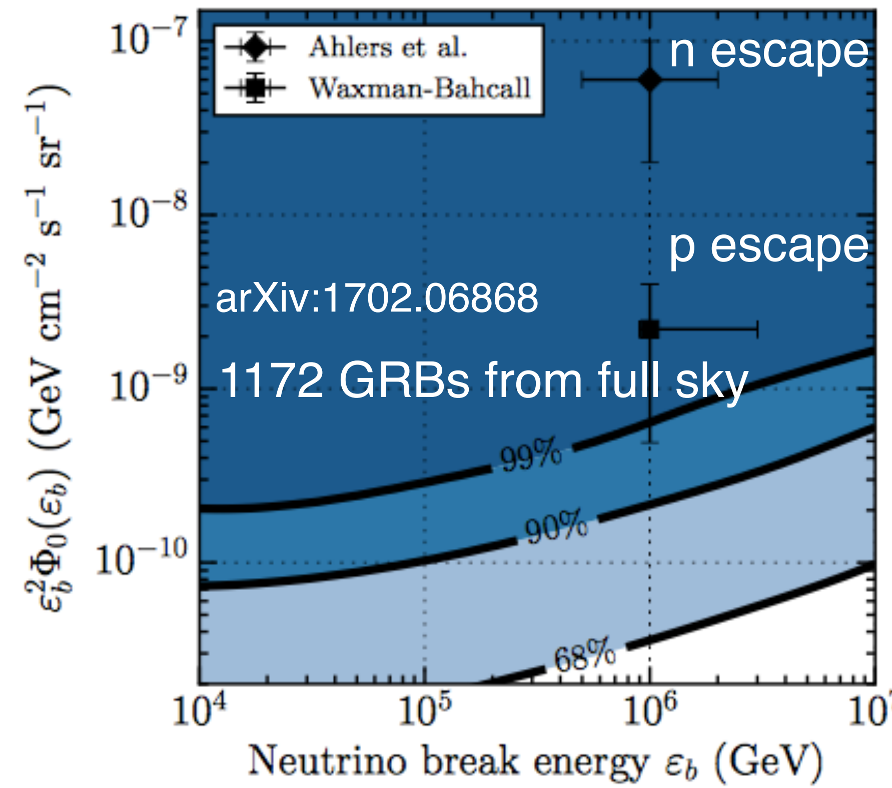


Within ±500 s and 14 d no significant neutrino from IceCube, ANTARES and Auger

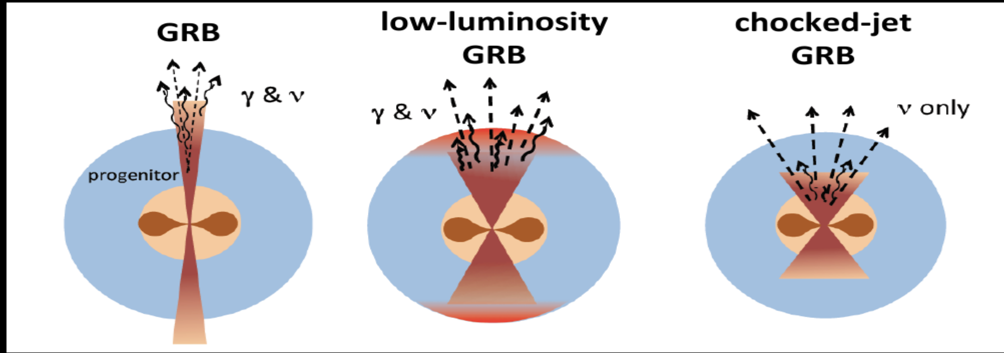
This non-detection is consistent with our expectations from a typical GRB observed off-axis, or with a low-luminosity GRB.

Are GRBs sources of cosmic rays?

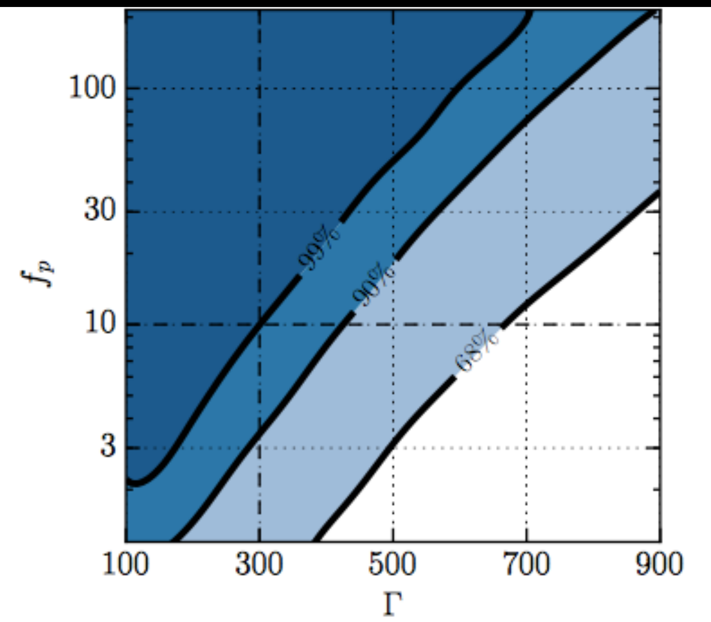
Models assume GRBs are sources of UHECRs



$$\Phi_\nu(E_\nu) = \Phi_0 \times \begin{cases} \varepsilon_b^{-1} E_\nu^{-1}, & E_\nu \le \varepsilon_b \\ E_\nu^{-2}, & \varepsilon_b < E_\nu \le 10\varepsilon_b \\ E_\nu^{-4} (10\varepsilon_b)^2, & 10\varepsilon_b < E_\nu, \end{cases}$$



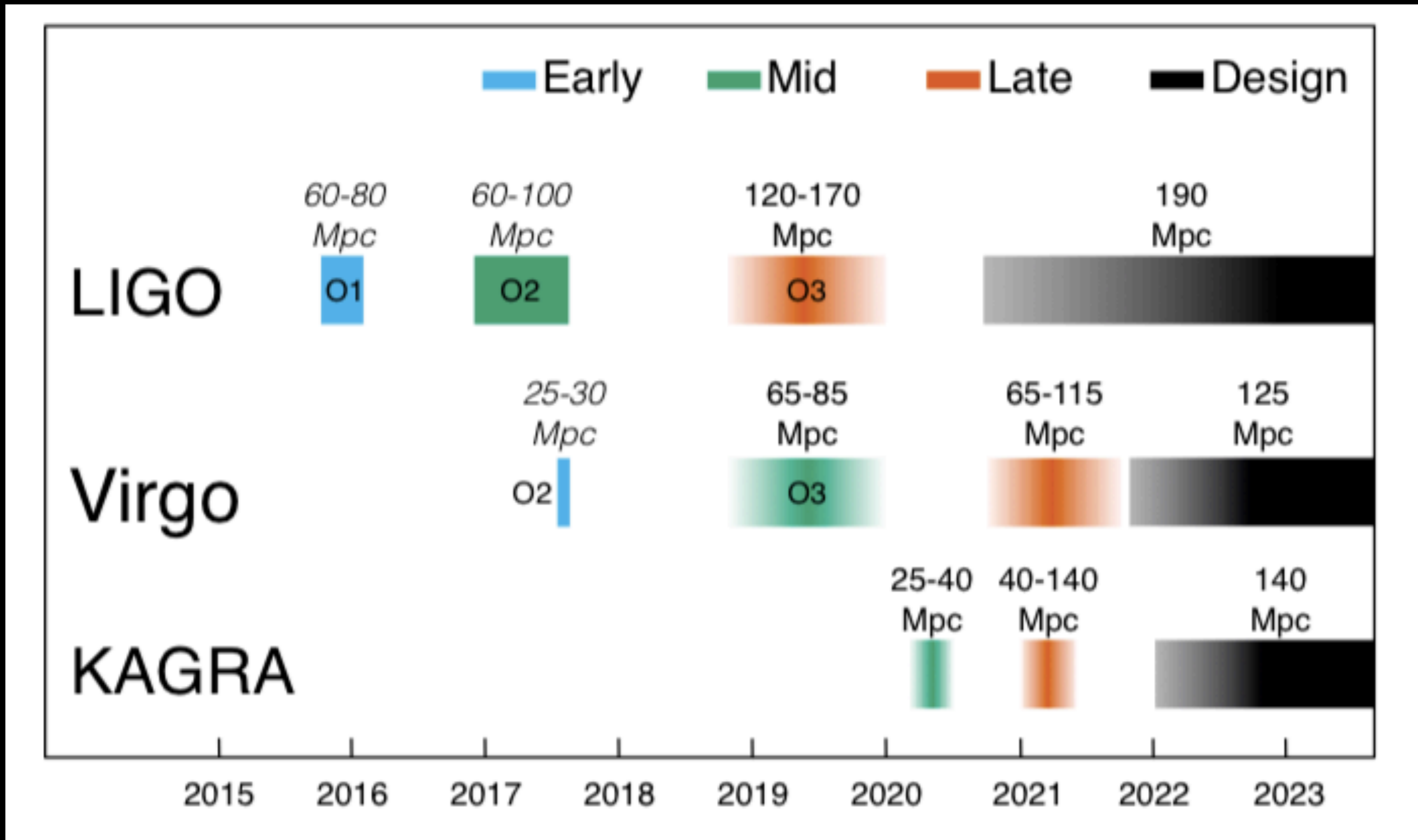
The internal shock and photospheric fireball models are shown to be excluded at the 99% CL for benchmark model parameters. Models that yet cannot be severely constrained require small baryon loading and large Lorentz factors



Prompt emission from GRBs can produce < 1% of observed neutrino flux

Gravitational wave observational limits

The new astronomical messengers are mainly limited by precision and sensitivity of instruments.
And for neutrino/gamma-rays from ground also by noise from the atmosphere.

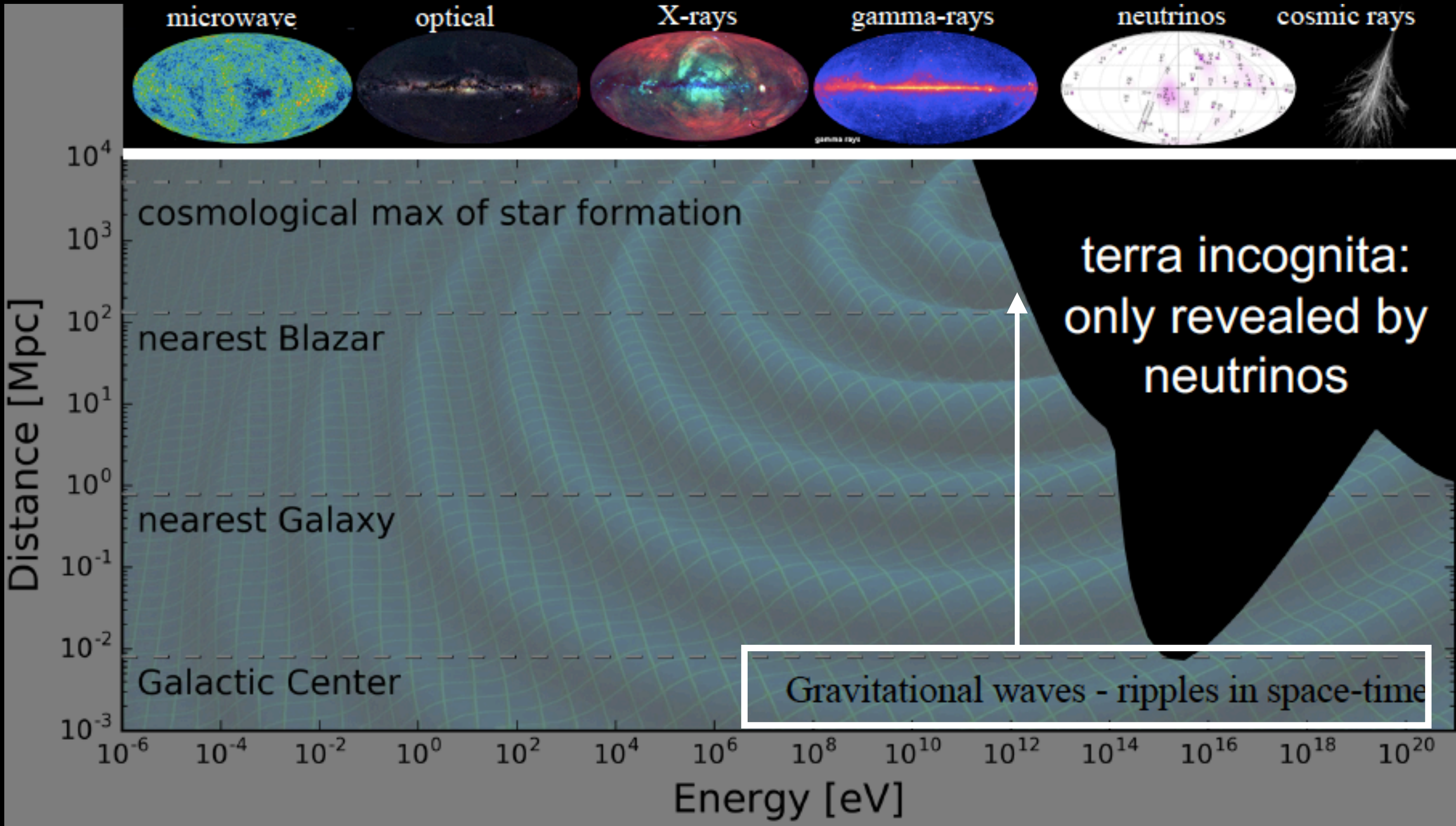


EVENTS ∝ d^3 T

1 day of data at a range of 80 Mpc is equivalent to 64 days at 20 Mpc
1 day of data at a range of 100 Mpc is equivalent to 2 days at 80 Mpc

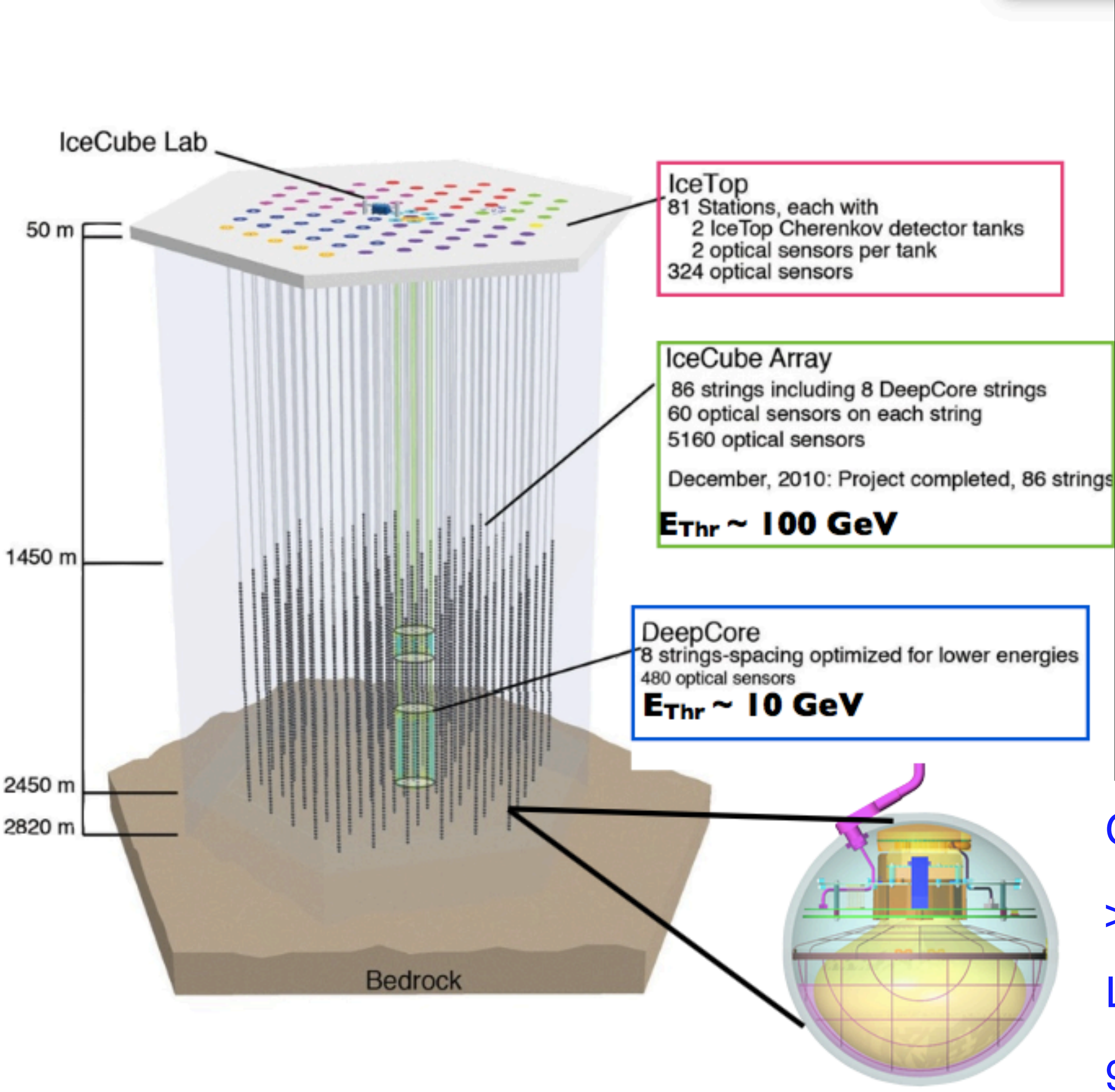
B.P. Abbott et al. ArXiv 1304.0670 (2018)

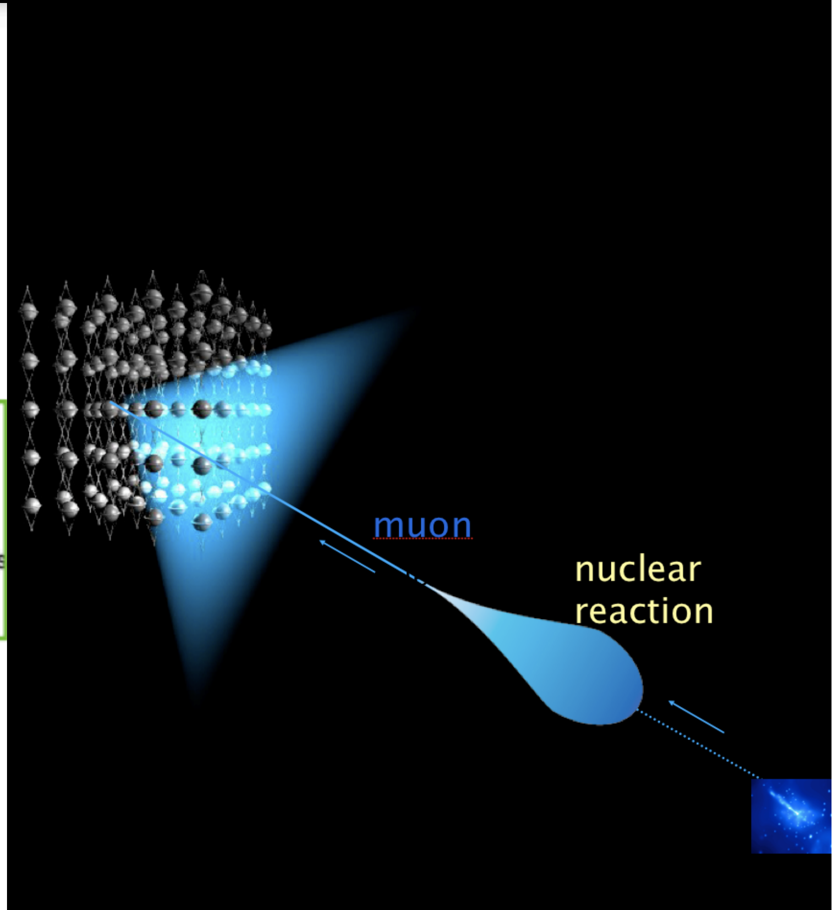
Gamma-Neutrino-Cosmic Ray Horizons



- 20% of the Universe is opaque to the EM spectrum
- non-thermal Universe powered by cosmic accelerators
- probed by gravity waves, neutrinos and cosmic rays

IceCube





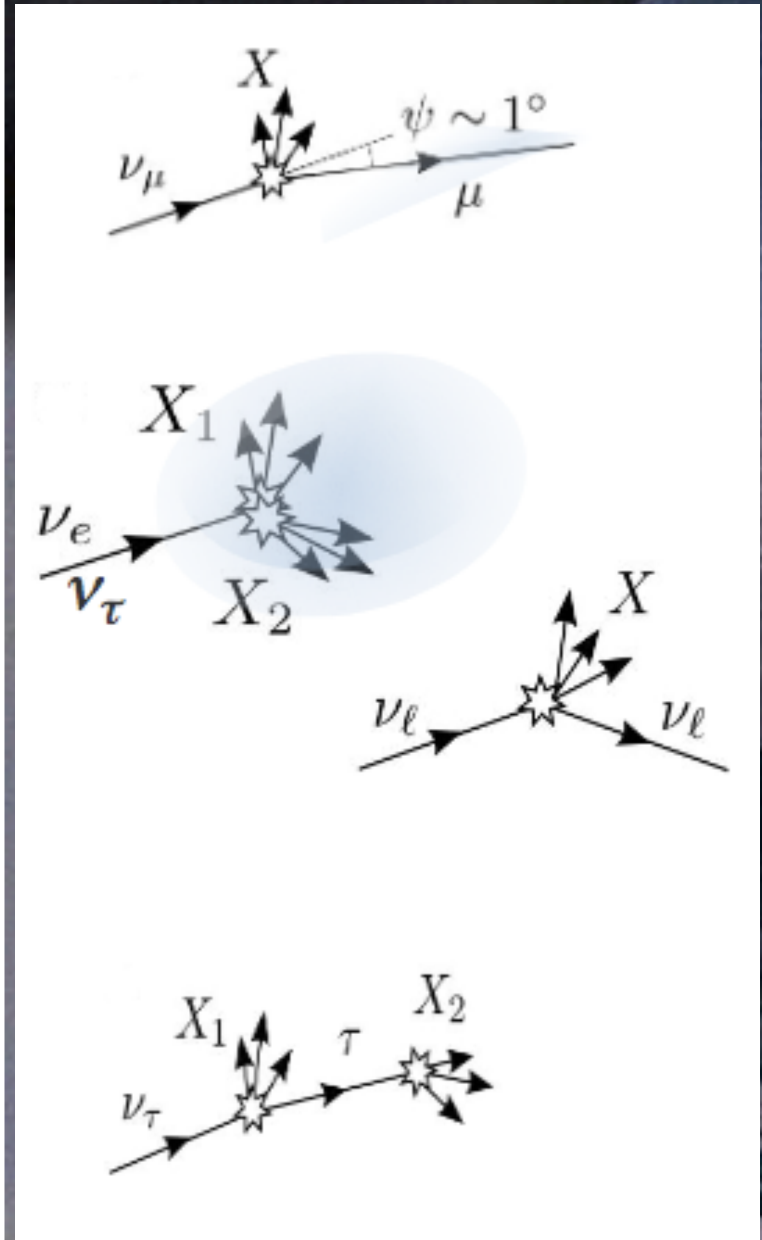
Operation of IC86 in May 2011;

>98% sensor modules ON

Livetime > 99% (since 2014)

97-98% (analysis-ready data)

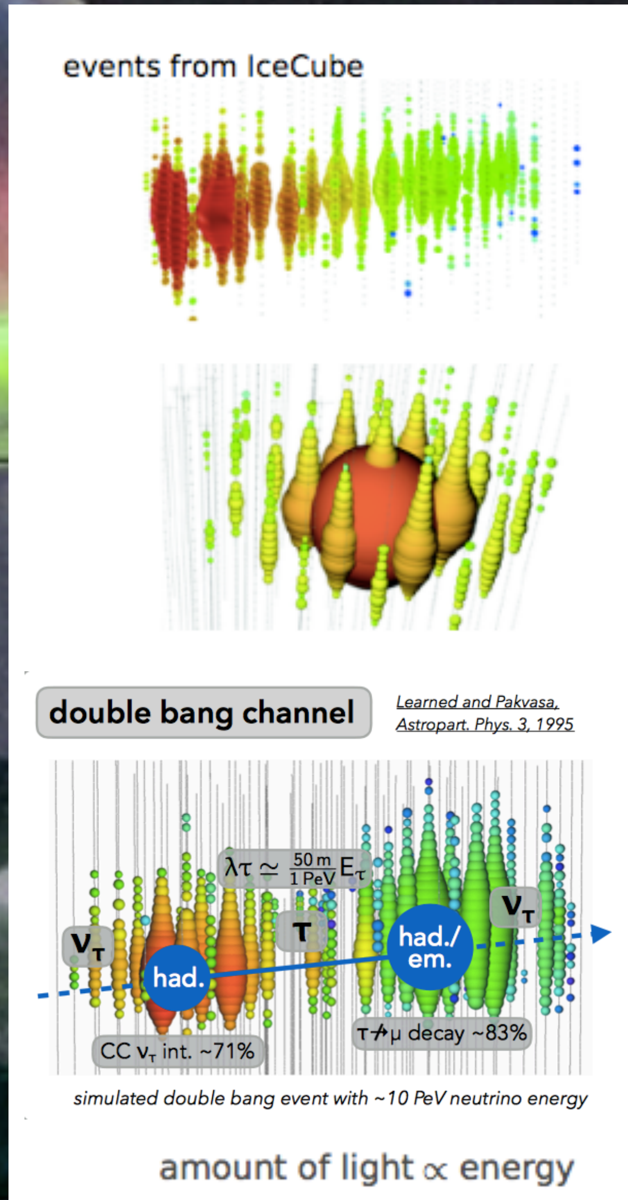
The precision of IceCube



Track
Standard reconstruction;
about x2 energy resolution
Angular resolution ~0.5°
(0.3° for E > 100 TeV)

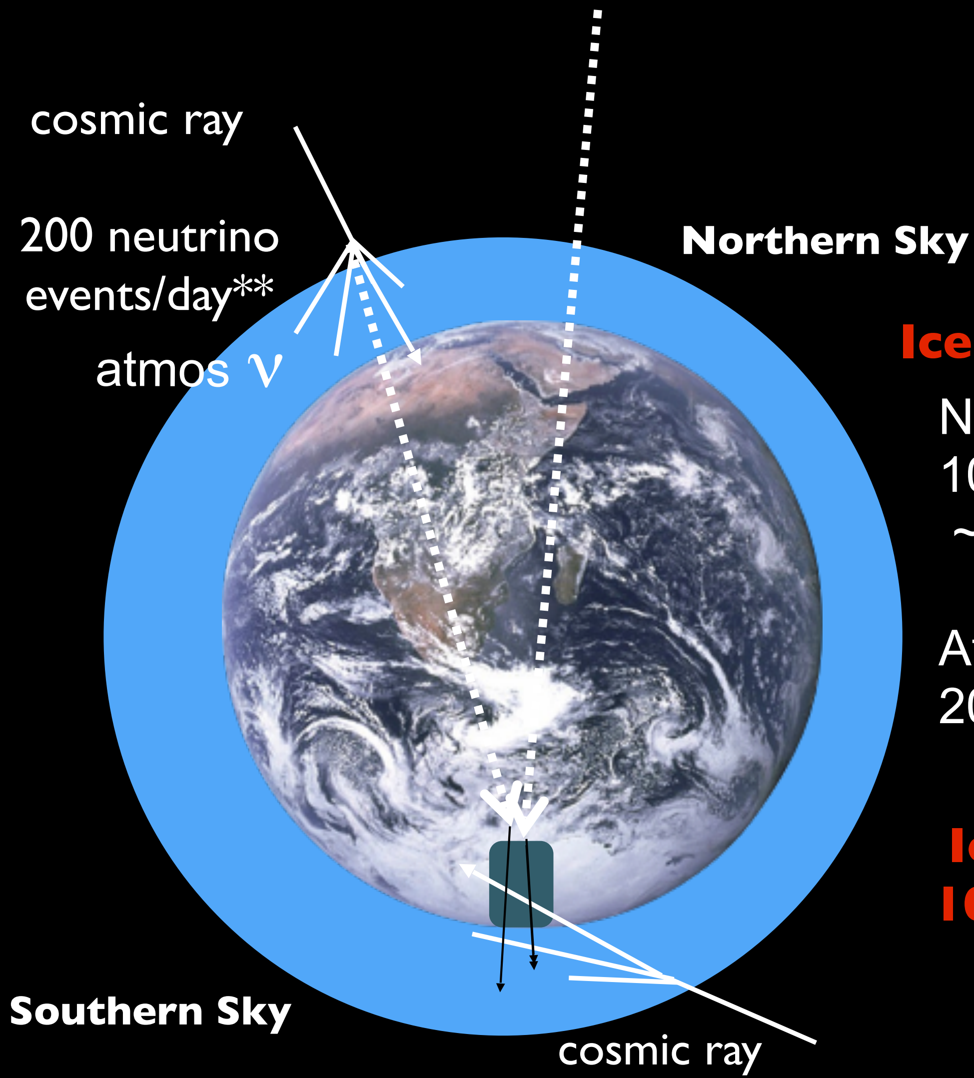
Cascade
10-15% energy resolution
for E > 100 TeV
Angular resolution O(10°)

Tau neutrino double bang
Decay length ~ 50 m/PeV
None observed till now



Signal and background in IceCube

Atmospheric showers induced by cosmic rays in the atmosphere produce the muon and neutrino background to cosmic neutrino signals. We saw first cosmic signals applying vetos.

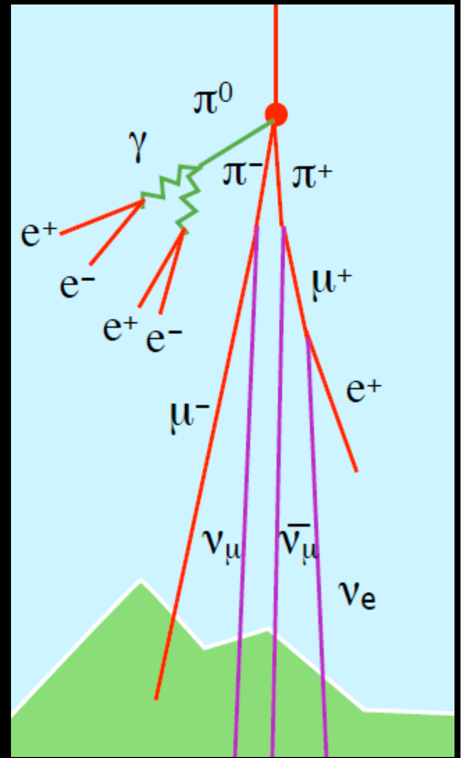


IceCube analysis level/day

Neutrino cosmic signal
100 events/yr above 1 TeV
~few/yr above 50 TeV

Atmospheric neutrinos
200’000 events/yr

IceCube trigger rate:
10^8 atmospheric muons/day

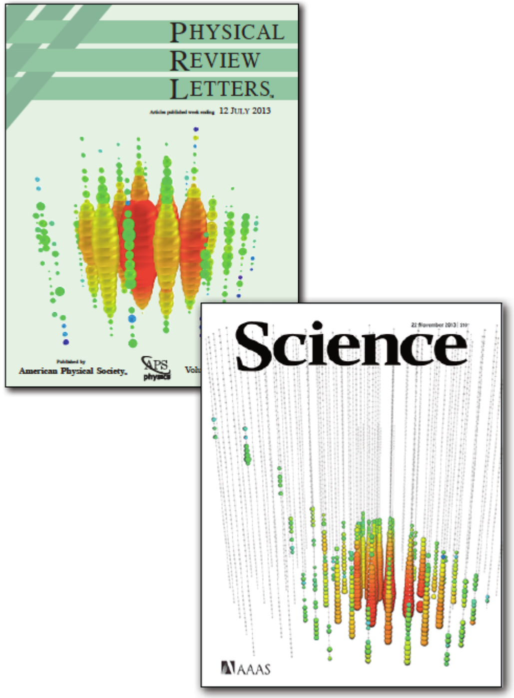


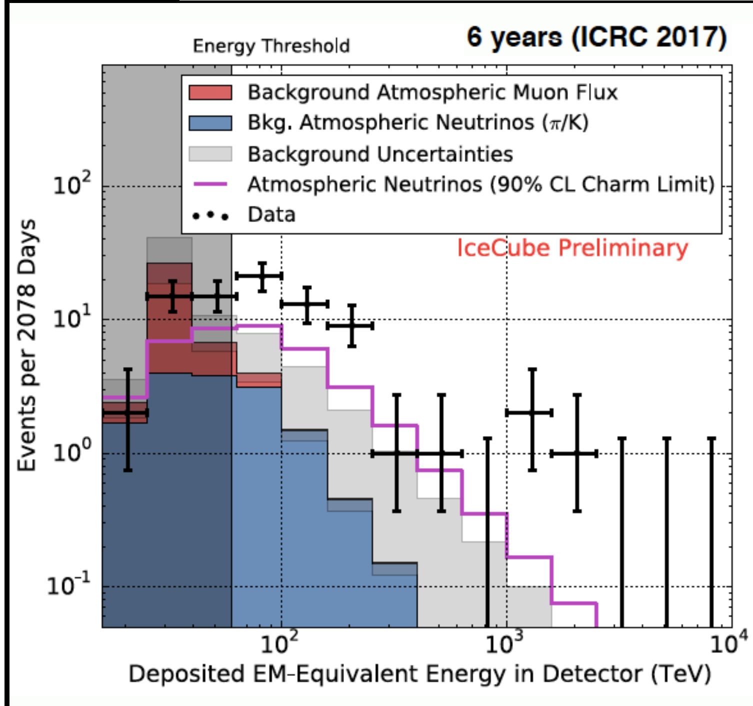
Signal from the heavens

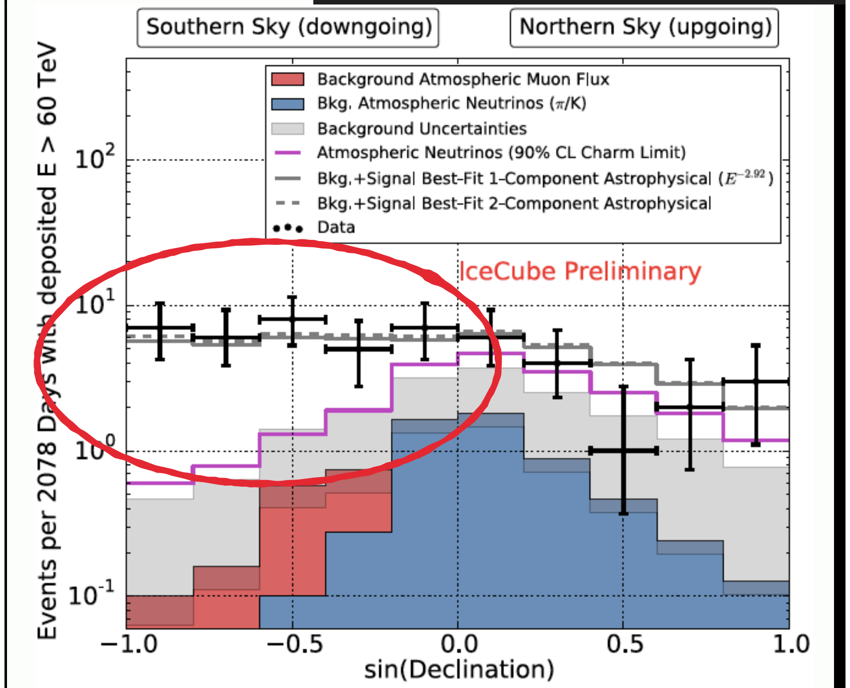
80(+2) events/6 yrs (2010-2015)

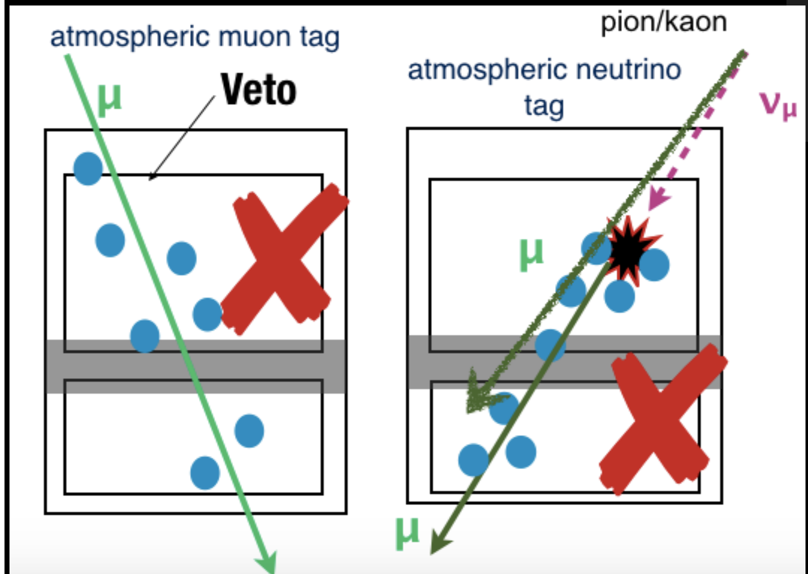
$15.6^{+11.4}_{-3.9}$ atm. neutrinos

25.2±7.3 atm. muons







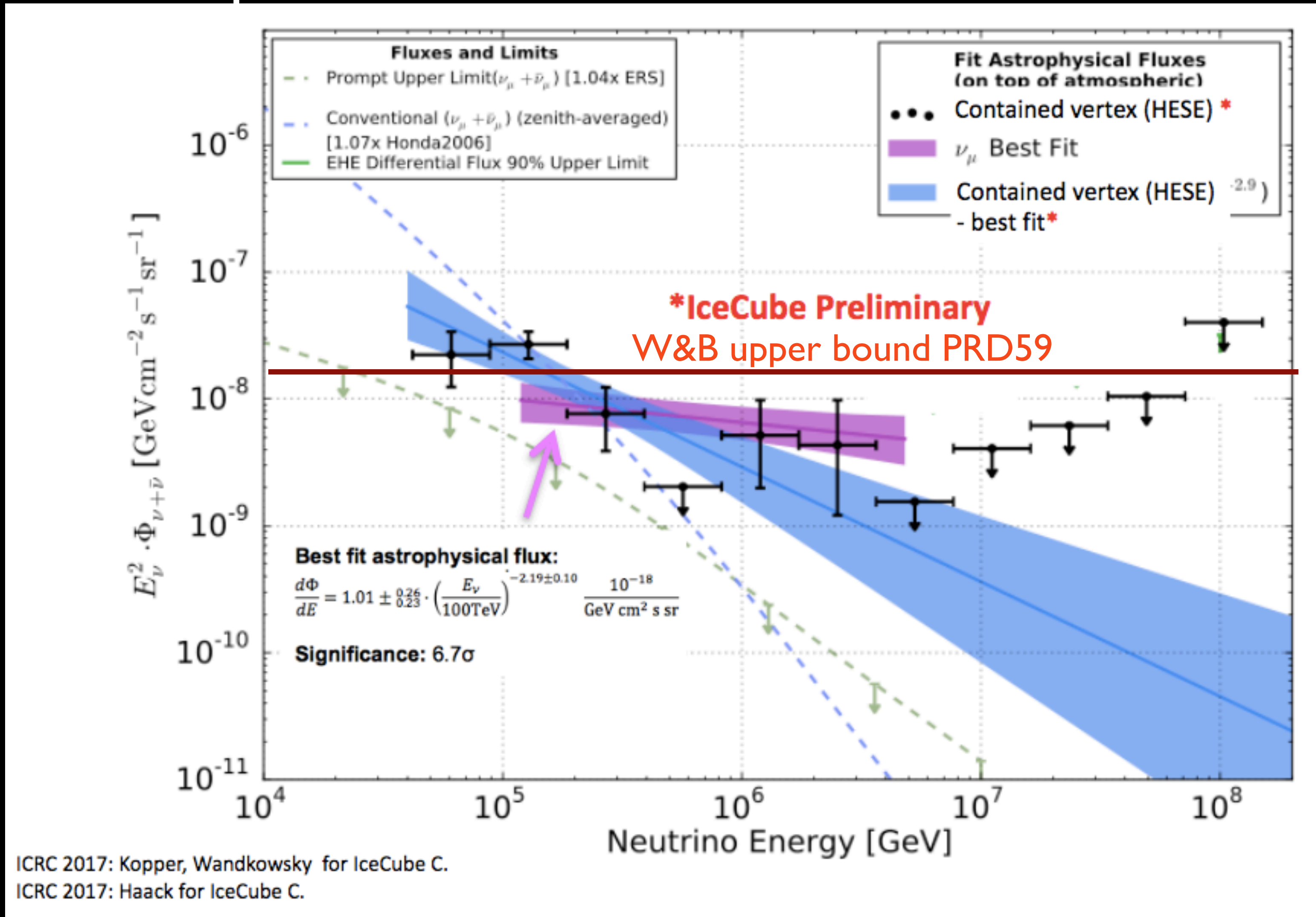


Best fit spectral index ($E^{-\gamma}$): $\gamma=-2.92^{+0.33}_{-0.29}$

Background only hypothesis rejected at ~8 σ

Yet it is not possible to distinguish single power law or more components

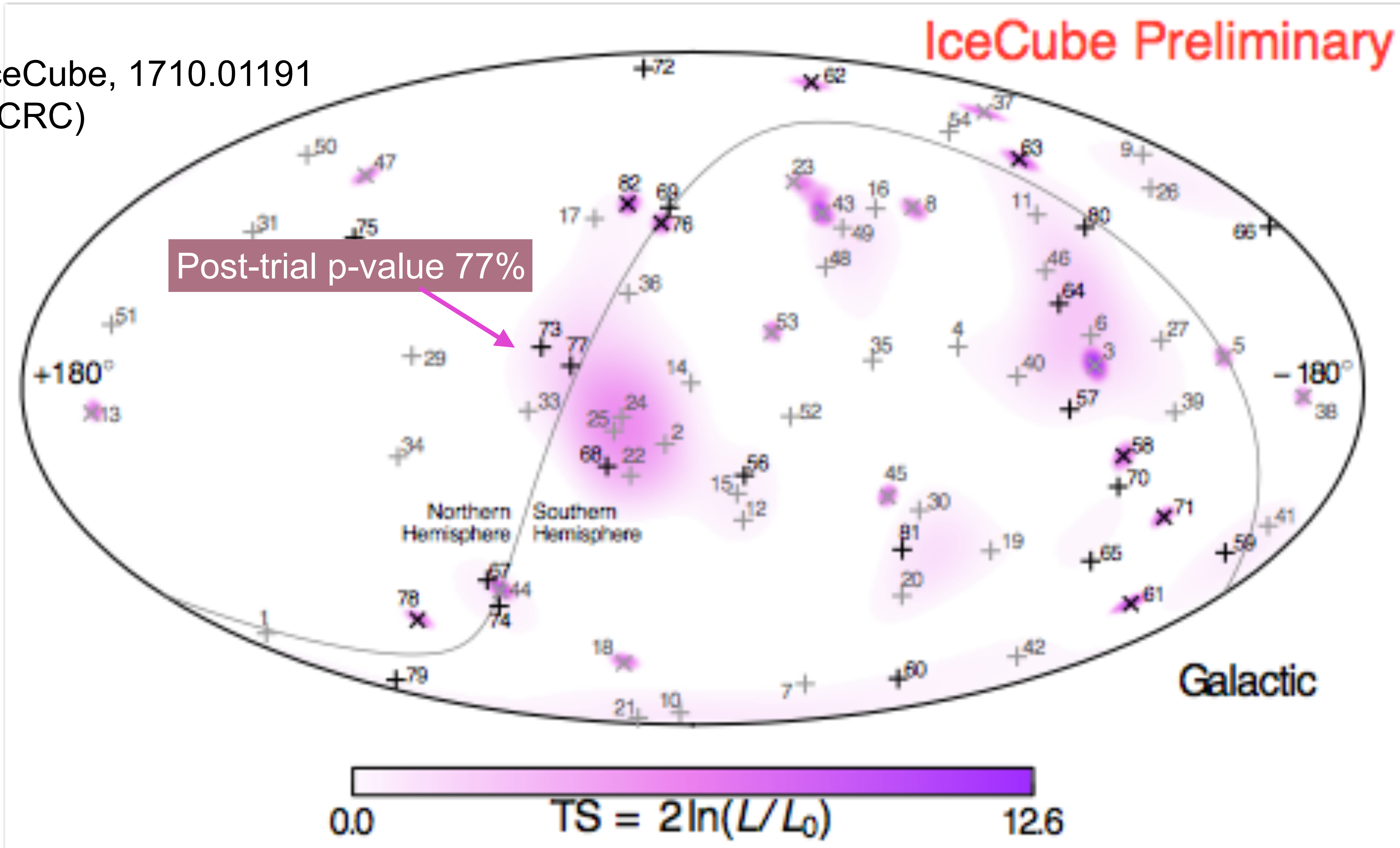
A coincidence: neutrino fluxes at the upper bound of neutrino production from UHECR sources



The coincidence of IC signal and WB upper bound implies that the power injected in UHECRs (>10^{19} eV) is similar to the power in 0.1-1 PeV neutrinos. Model: the UHECR sources produce an E^{-2} proton diff. spectrum. Protons stay confined in the ‘calorimetric’ source environments longer than their energy-loss time so that protons of energy 50-100 PeV loose all energy in meson production. [Murase & Waxman, PRD 2016]

IceCube high-energy starting events (6 years)

IceCube, 1710.01191
(ICRC)

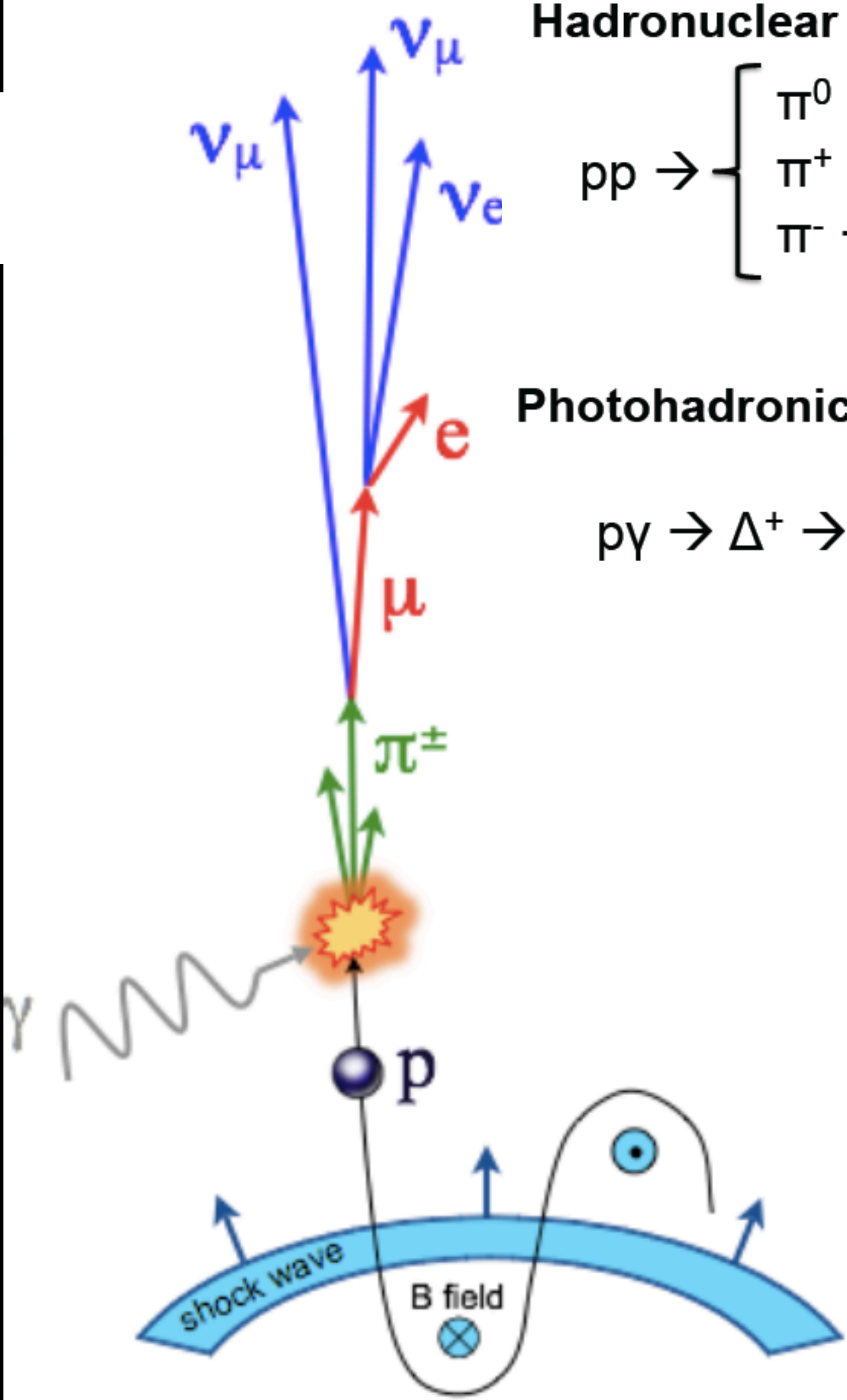


No significant clustering observed (82 events)

Arrival directions compatible with isotropy.

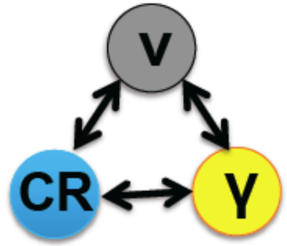
Interaction of cosmic rays on galactic plane ISM can contribute

Cosmic-ray-neutrino-gamma-ray sources



Hadronuclear (e.g. star burst galaxies and galaxy clusters)

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



Photohadronic (e.g. gamma-ray bursts, active galactic nuclei)

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

cosmic ray + gamma

cosmic ray + neutrinos

Neutrino flavour ratio at source:

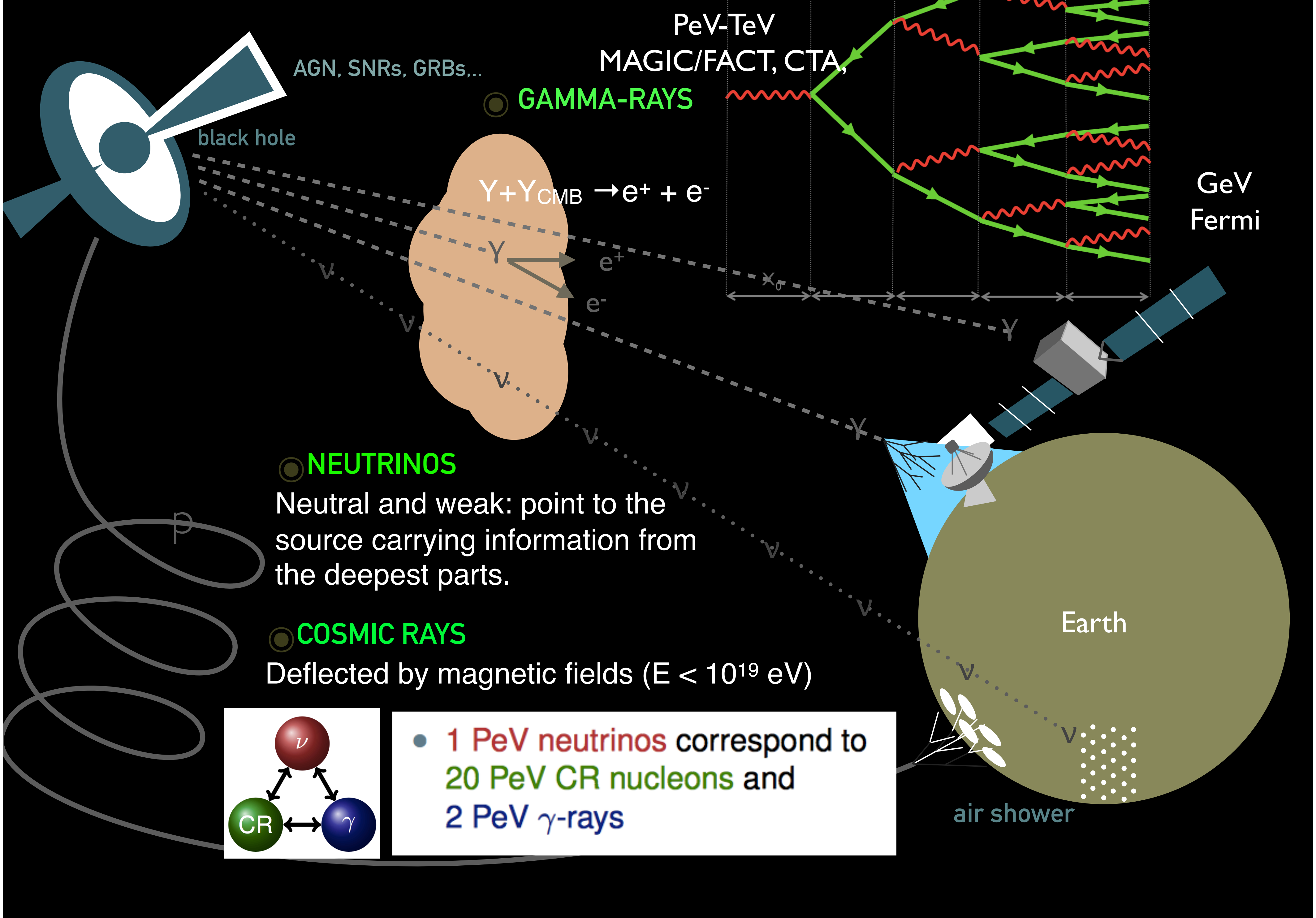
pion-muon decay

$$\nu_e : \nu_\mu : \nu_\tau \sim 1 : 2 : 0$$

Oscillations average out over cosmic baselines

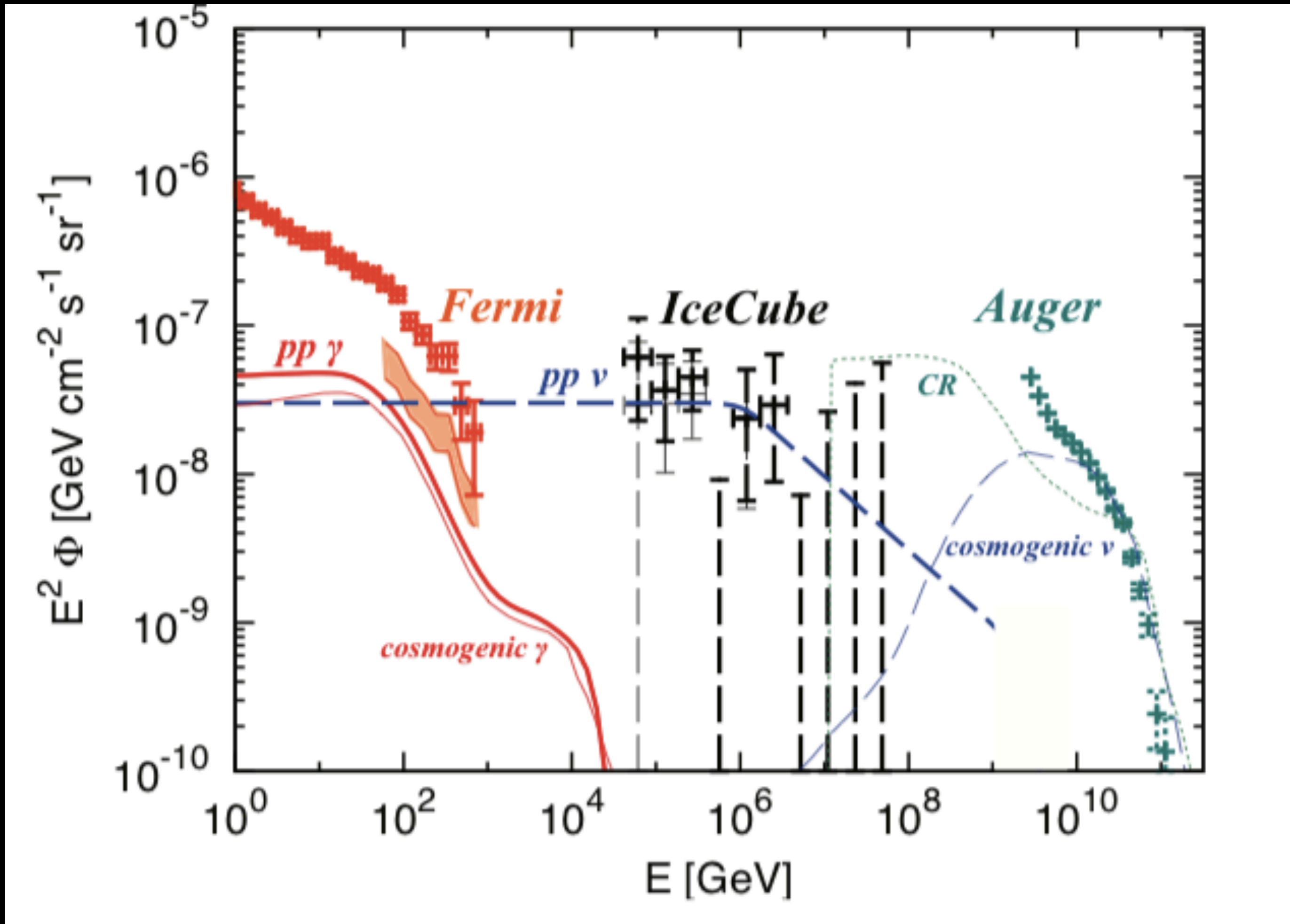
$$\nu_e : \nu_\mu : \nu_\tau \sim 1 : 1 : 1$$

CR-gamma-ray-neutrino messengers



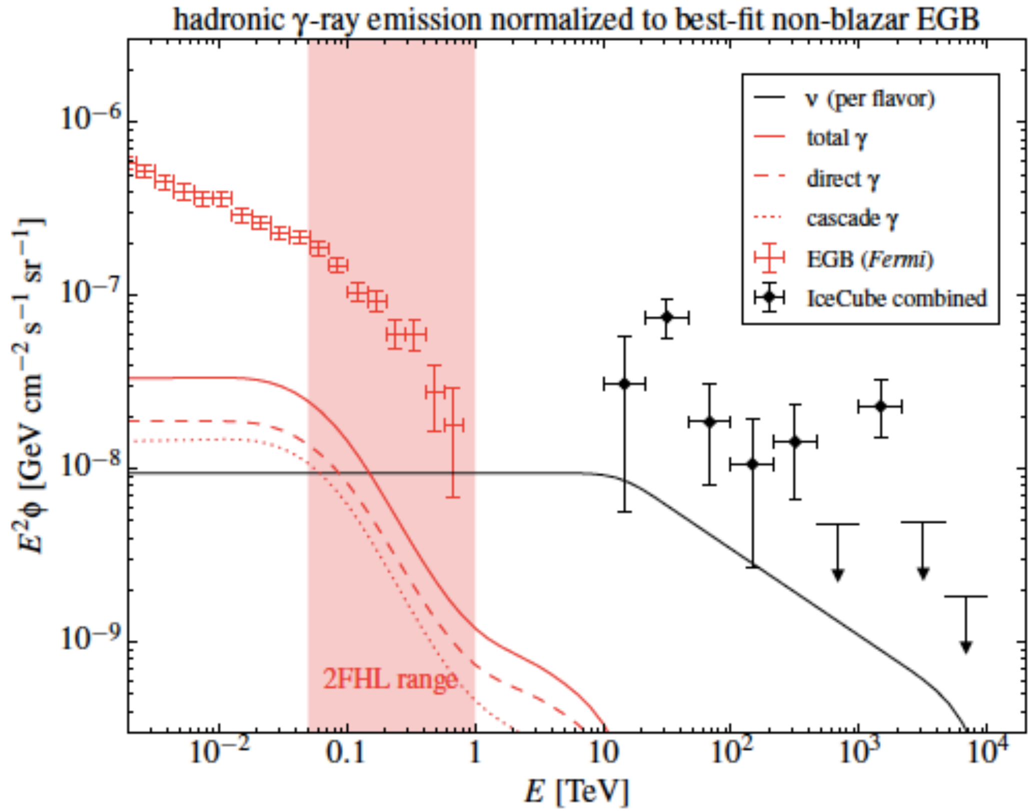
Energy balance in diffuse fluxes

Fermi diffuse isotropic gamma background (IGRB) constrains cosmic neutrino diffuse emission (Murase, Ahlers & Lacki'13; Chang & Wang'14)



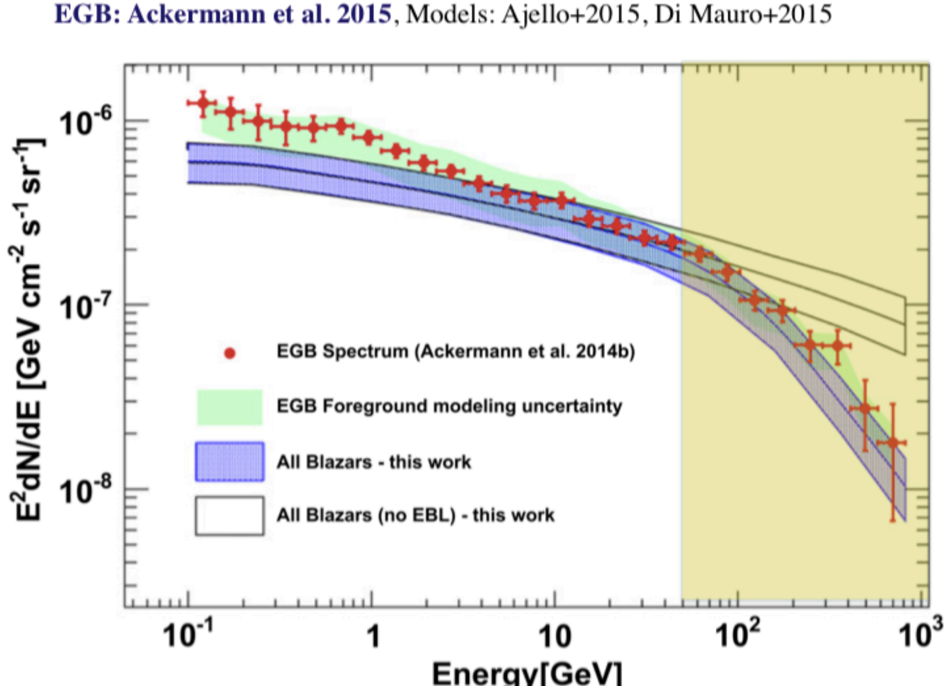
Energy density of neutrinos in the non-thermal Universe is the same as that in Fermi gamma-rays.

Constraints on Blazars



[Bechtol, MA, Ajello, Di Mauro & Vandenbroucke'15]

Fermi-LAT



Models predict that the >50 GeV EGB is produced by blazars, only

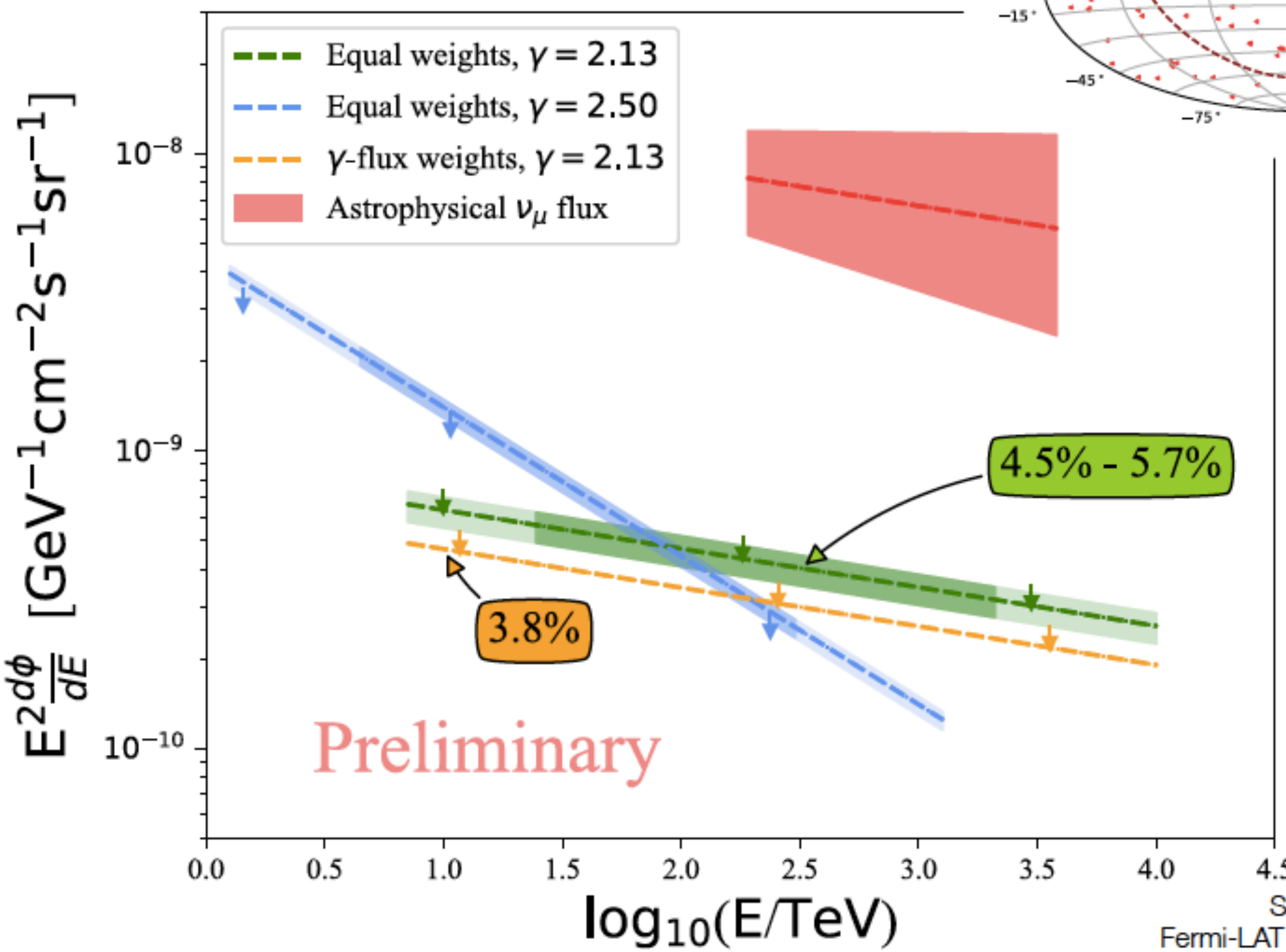
$14^{+14}_{-14}\%$ of EGB

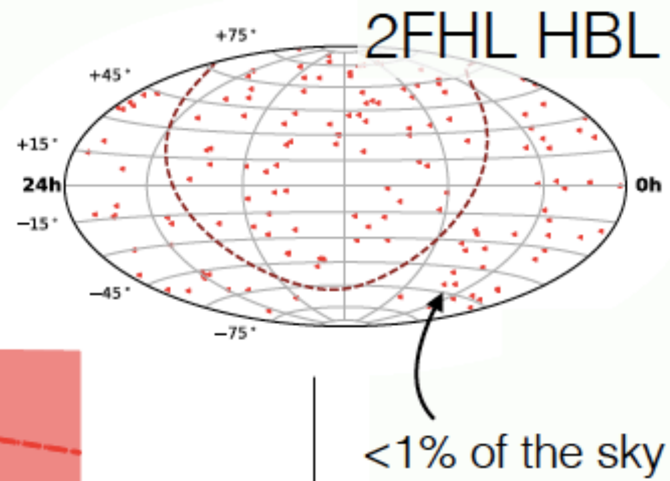
is left to other sources.

For pp scenarios, normalization of the neutrino spectrum at PeV energies has immediate consequences on γ-ray spectra at GeV energies following initial CR spectra due to Feynman scaling. Combing the IceCube and Fermi data leads to strong upper limits on Y_{astro} and lower limits on the diffuse IGB contribution.

Neutrinos from Fermi blazars

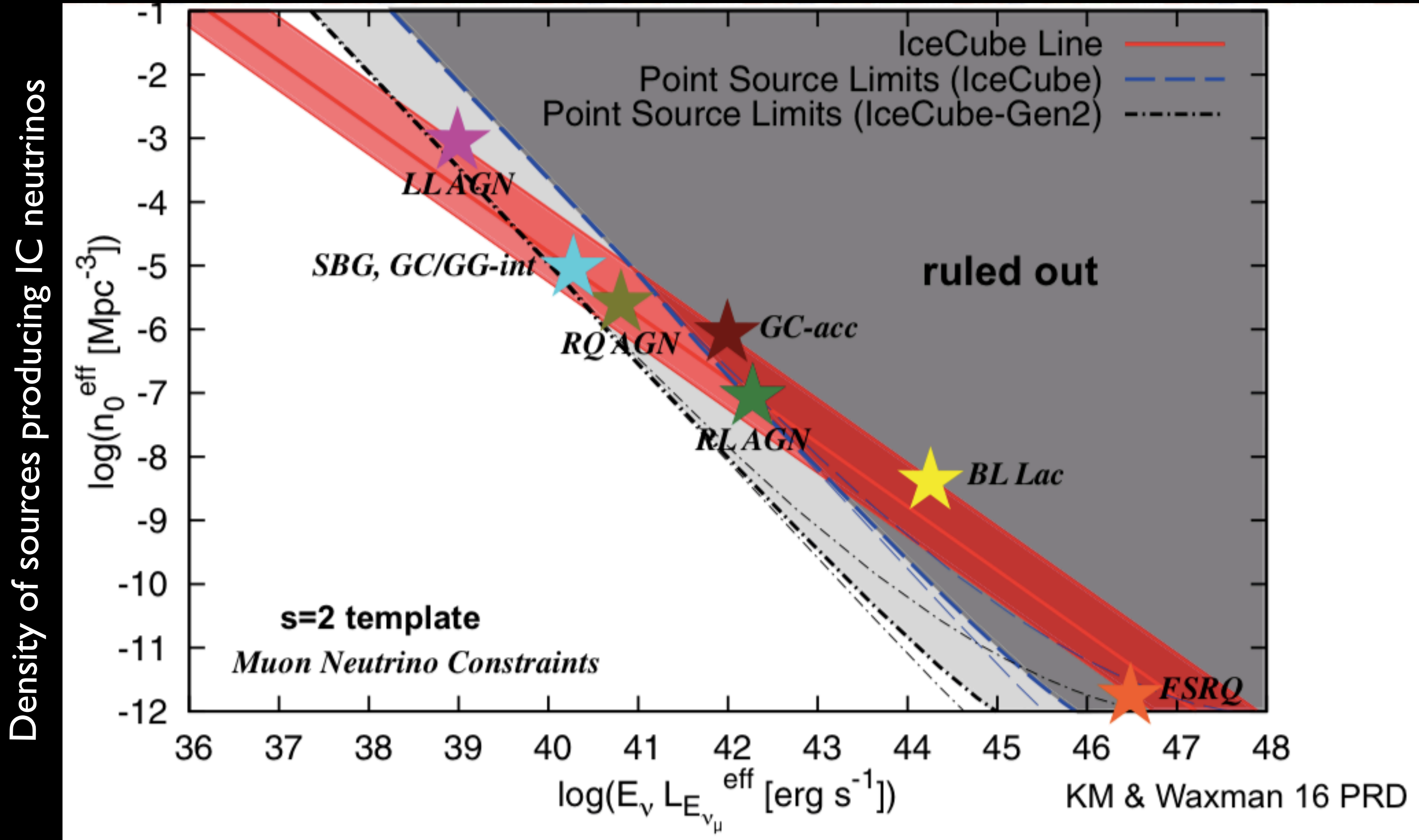
Blazars account for:
85% of extragalactic γ background
< 6% of the IceCube neutrino flux





See: M. Huber, NU043
Fermi-LAT PRL 116(15) 151105
Astrophys.J. 835 (2017) no.1, 45

Implication of non-detection of multiplets

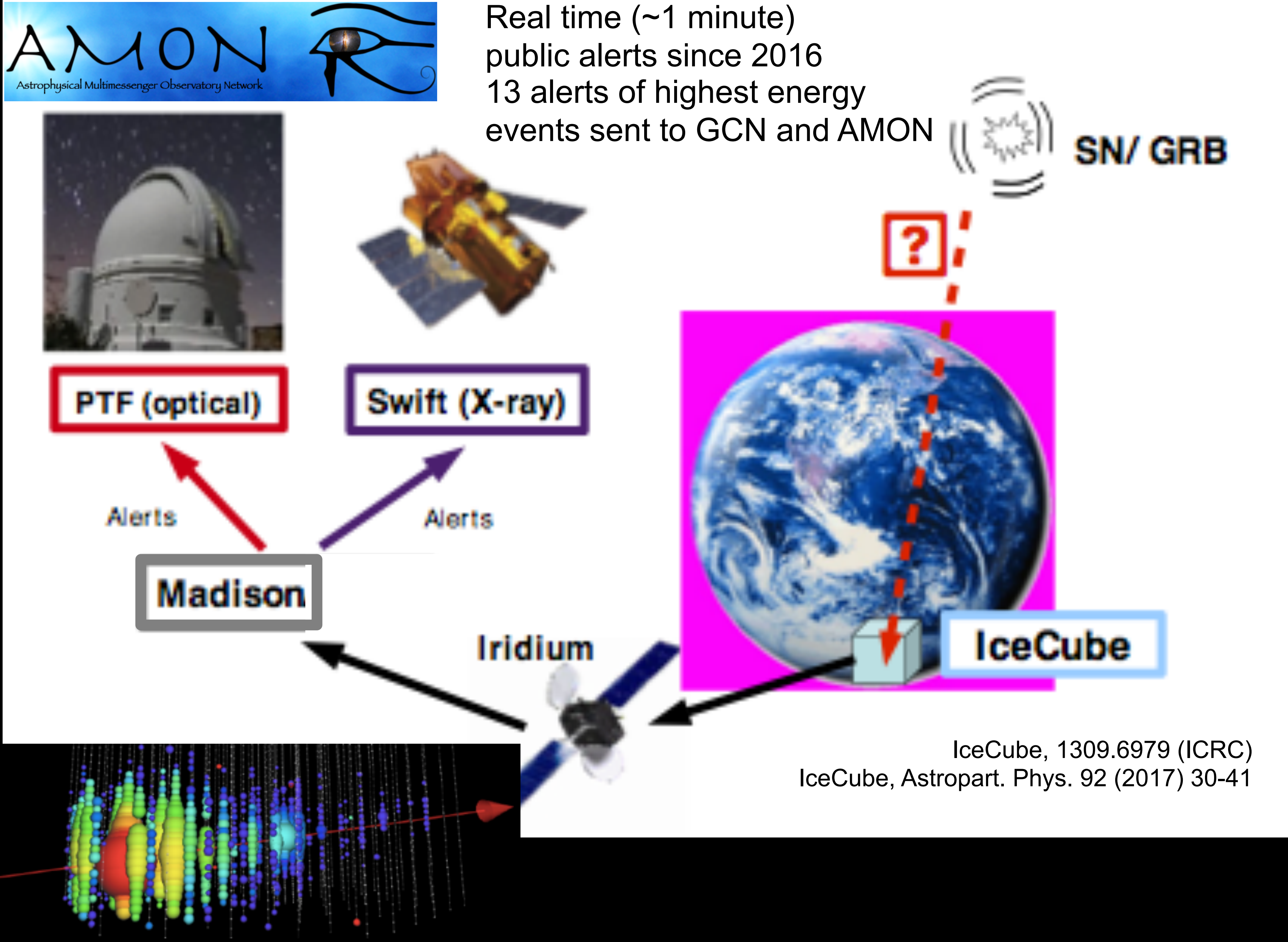


Red: IceCube local neutrino emissivity for no evolution $(1+z)^0$ or for star formation rate (SFR) $ns \propto (1 + z)^3$ and AGN evolution.

Non detection of point source limits constrain source classes (eg blazar jets)

IceCube alerts optical, x-ray, and gamma-ray observatories

Real time (~1 minute)
public alerts since 2016
13 alerts of highest energy
events sent to GCN and AMON



IceCube, 1309.6979 (ICRC)
IceCube, Astropart. Phys. 92 (2017) 30-41

IceCube-170922A

With the help of gamma-rays the discovery of the first cosmic ray source is possible (a MWL paper and a IceCube paper subm. to Science, NSF press release being prepared).

```
Date: 22 Sep, 2017
Time: 20:54:30.43 UTC
RA: 77.43 deg (-0.80 deg/+1.30 deg  90% PSF containment) J2000
Dec: 5.72 deg (-0.40 deg/+0.70 deg 90% PSF containment) J2000
```

E proxy of about 120 TeV

https://gcn.gsfc.nasa.gov/notices_amon/50579430_130033.amon

Fermi reports an increase from TXS 0506+056, a BL Lac at z~0.3 (RA=77.43° and Dec=5.72°, J2000), AGILE confirms, also ASAS-SN

Outside

GCN
IAUCs

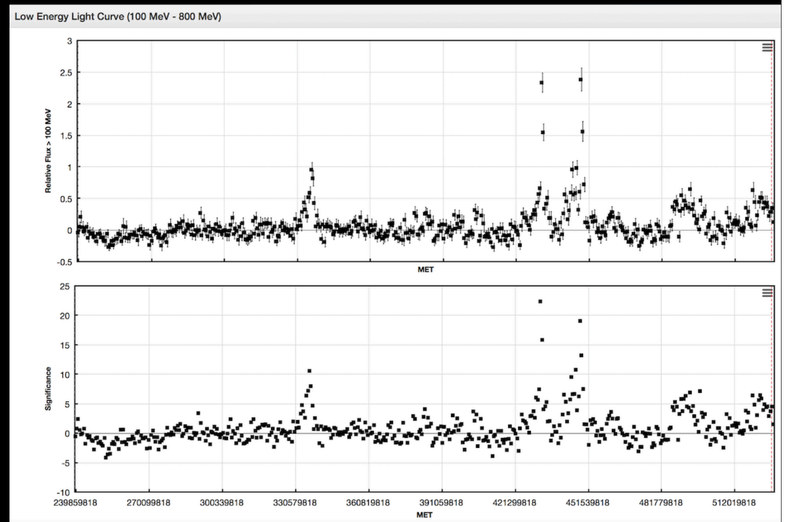
Other

ATel on Twitter and Facebook
ATELstream
ATel Community Site
MacOS: Dashboard Widget

The Astronomer's Telegram

Post | Search | Policies
Credential | Feeds | Email

29 Nov 2017; 15:46 UT



[Previous | Next | ADS]

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; ***Razmik Mirzoyan for the MAGIC Collaboration***
on 4 Oct 2017; 17:17 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10833, 10838, 10840, 10844, 10845, 10942

Tweet | Recommend 448

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi-LAT measured enhanced gamma-ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays

Related

- 10942 IceCube-171106A: Swift observations
- 10890 Subaru/FOCAS Optical Spectroscopy for a possible IceCube-170922A counterpart TXS 0506+056
- 10861 VLA Radio Observations of the blazar TXS 0506+056 associated with the IceCube-170922A neutrino event
- 10845 Joint Swift XRT and NuSTAR Observations of TXS 0506+056
- 10844 Kanata optical imaging and polarimetric follow-ups for possible IceCube counterpart TXS 0506+056
- 10840 VLT/X-Shooter spectrum of the blazar TXS 0506+056 (located inside the IceCube-170922A error box)
- 10838 MAXI/GSC observations of IceCube-170922A and TXS 0506+056
- 10833 VERITAS follow-up observations of IceCube neutrino event 170922A

VERITAS, HAWC, ANTARES set upper limtis More details to come in a paper.SWIFT notes 5 X-ray sources in the IceCube error box!! 2 of which are luminous blazars.

The next future


SpringerLink

Living Reviews in Relativity
December 2016, 19:1 | Cite as

Prospects for Observing and Localizing Gravitation
Wave Transients with Advanced LIGO and Advance
Virgo

Authors | Authors and affiliations

B. P. Abbott, The LIGO Scientific Collaboration, Virgo Collaboration, R. Abbott, T. D. Abbott, M. R. Abernathy, F.
K. Ackley, C. Adams, T. Adams, P. Addesso, R. X. Adhikari, V. B. Adya, C. Affeldt, M. Agathos, show 930 more

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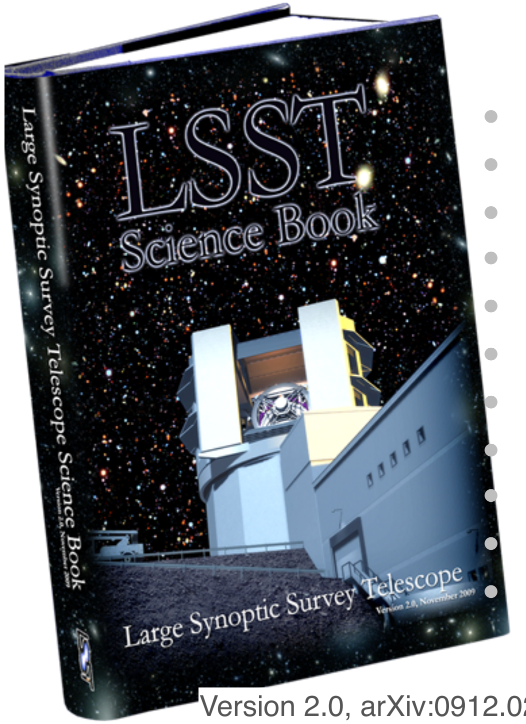
CTA will run in the era of the synoptic observations of LSST and GW network



- The Solar System
- Stellar Populations
- The Milky Way and Local Volume
- The Transient and Variable Univer
- Galaxies
- Active Galactic Nuclei
- Supernova
- Strong Lenses
- Large-Scale structure
- Weak Lensing
- Cosmological Physics

Version 2.0, arXiv:0912.0201,

ArXiv:1709.07997

1. Dark Matter Programme
2. Galactic Centre
3. Galactic Plane Survey
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. Transients
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Beyond Gamma Rays


South
cta
See U. Straumann talk


North

APPEC Strategy Book (2017-2025)

APPEC fully supports the CTA collaboration in order to secure the funding for its timely, cost-effective realisation and the subsequent long-term operation of this observatory covering both northern and southern hemispheres.

With its global partners and in consultation with the Gravitational Wave International Committee (GWIC), APPEC will define timelines for upgrades of existing as well as next-generation ground-based interferometers. APPEC strongly supports further actions strengthening the collaboration between gravitational-wave laboratories. It also strongly supports Europe's next-generation ground-based interferometer, the Einstein Telescope (ET) project, in developing the required technology and acquiring ESFRI status. In the field of space-based interferometry, APPEC strongly supports the European LISA proposal.

APPEC strongly supports the Auger collaboration's installation of AugerPrime by 2019. At the same time, APPEC urges the community to continue R&D on alternative technologies that are cost-effective and provide a 100% (day and night) duty cycle so that, ultimately, the full sky can be observed using very large observatories.

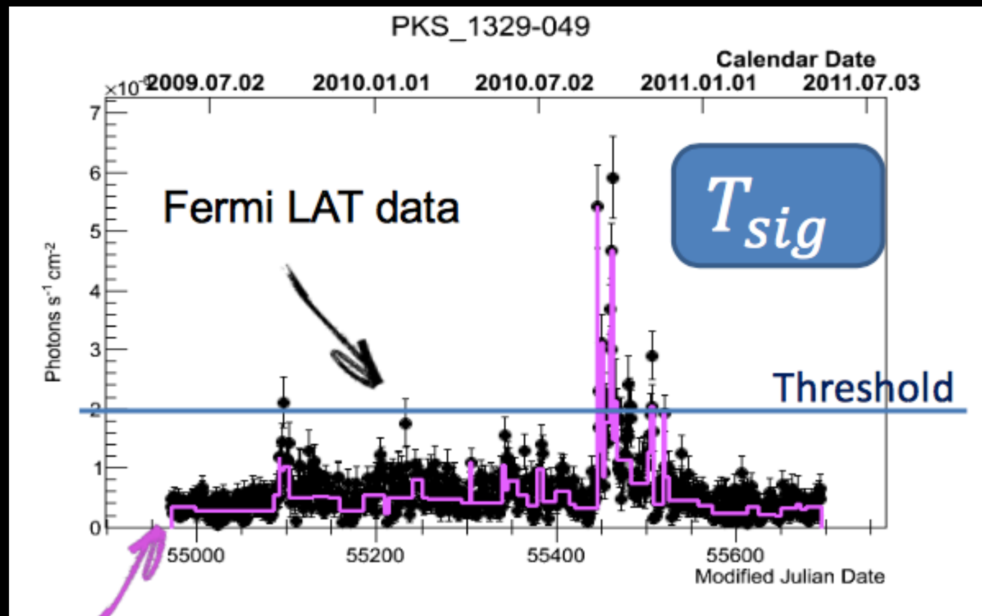
For the northern hemisphere (including Baikal GVD), APPEC strongly endorses the KM3NeT collaboration's ambitions to realise, by 2020: (i) a large-volume telescope with optimal angular resolution for high-energy neutrino astronomy; and (ii) a dedicated detector optimised for low-energy neutrinos, primarily aiming to resolve the neutrino mass hierarchy. For the southern hemisphere, APPEC looks forward to a positive decision in the US regarding IceCube-Gen2.

Conclusions : the detection of cosmic accelerators requires a synergic program

IceCube is probing the contribution of possible sources to particle acceleration in the cosmos.

- Star-forming galaxies
- Average blazar emission
- Blazar flares
- Fast radio bursts
- Tidal disruption events
- Binary black hole or neutron star mergers
- Supernovae
- Galactic diffuse emission
- Discrete Galactic sources
- dark matter

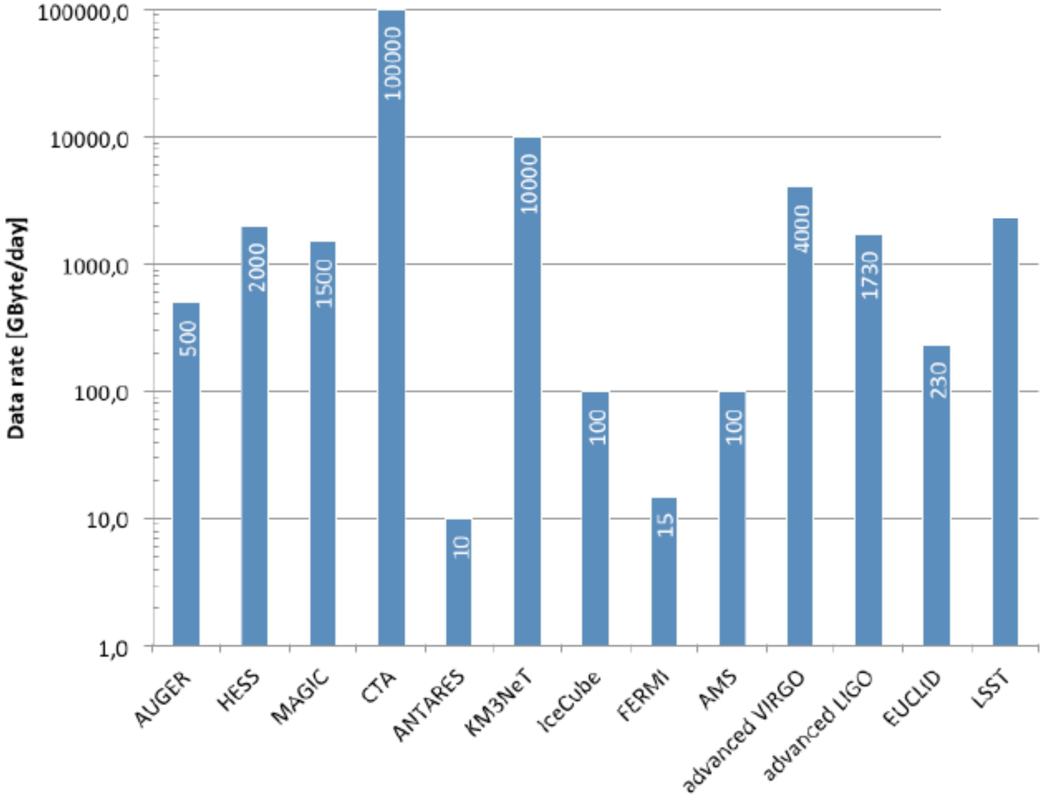
} transients

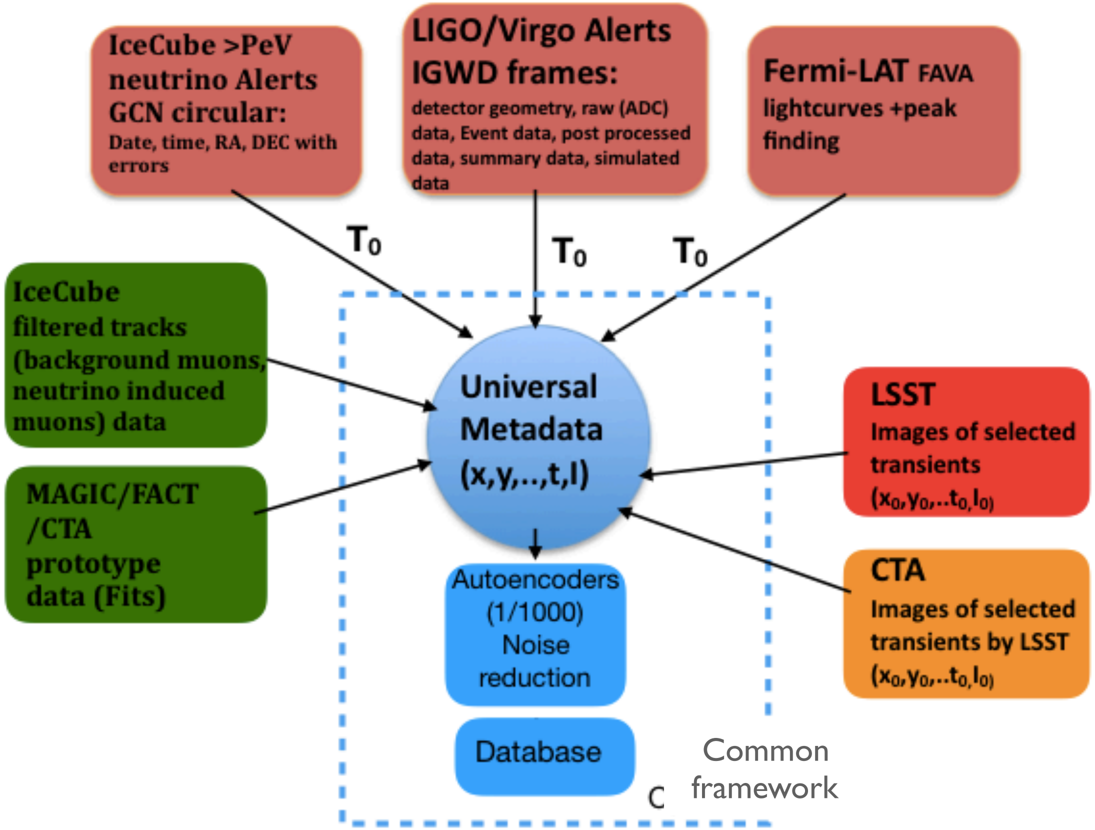


Conclusions

Switzerland is strongly involved in CTA construction

Switzerland should host an important data center also capable of handling Pbyte data (CTA, LSSTs,…)





See R. Walter's talk

http://www.appec.org/wp-content/uploads/Documents/Docs-from-old-site/AModelForComputing-2.pdf

Implication of non-detection of multiplets

Red: IceCube local neutrino emissivity for no evolution $(1+z)^0$ or for star formation rate (SFR) $n_s \propto (1+z)^3$ and AGN evolution.

Non detection of point source limits constrain source classes (eg blazar jets)