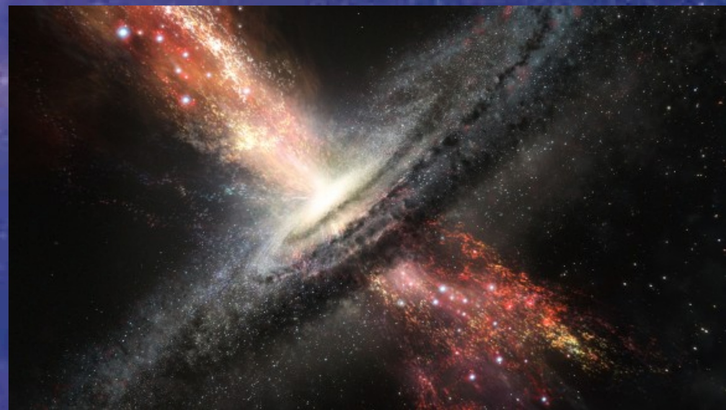
(SELECTED) RESULTS FROM ICECUBE

Teresa Montaruli

UNIVERSITÉ DE GENÈVE

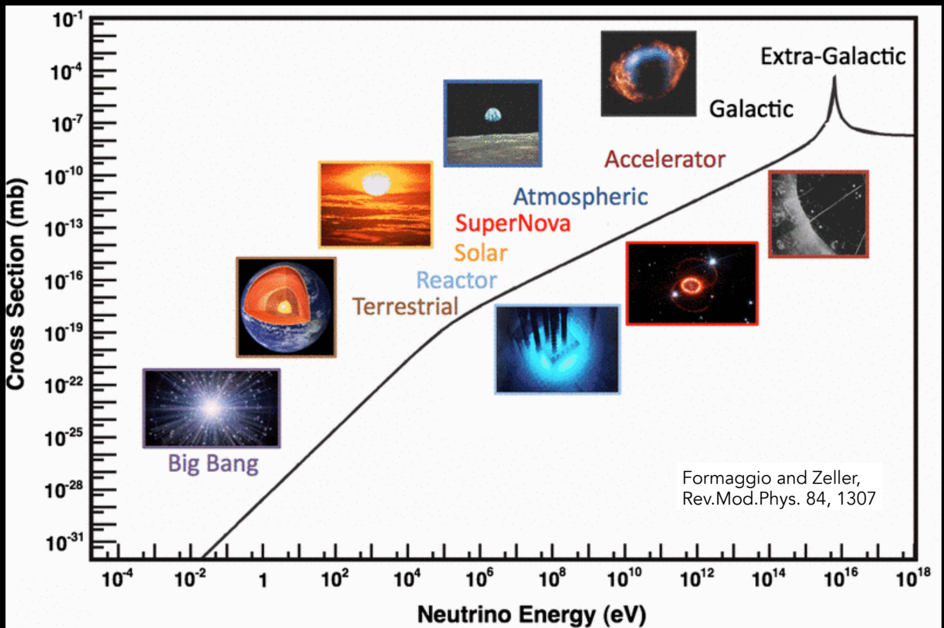
for the IceCube Collaboration

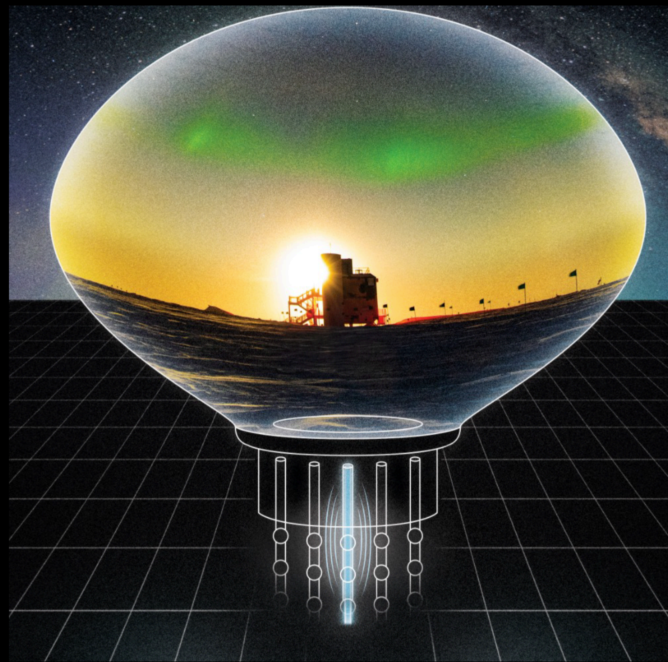


CRIS 2022, Napoli, 13.08.2022

Contents

- IceCube, the detectors and its environment
- The detector: the environment, photosensing, and the future network of NTs
- The signal and the background: neutrino topologies and their reconstruction
- Diffuse granted fluxes: Cosmogenic, Galactic Plane
- Extragalactic searches: Blazars, starbursts & GRBs



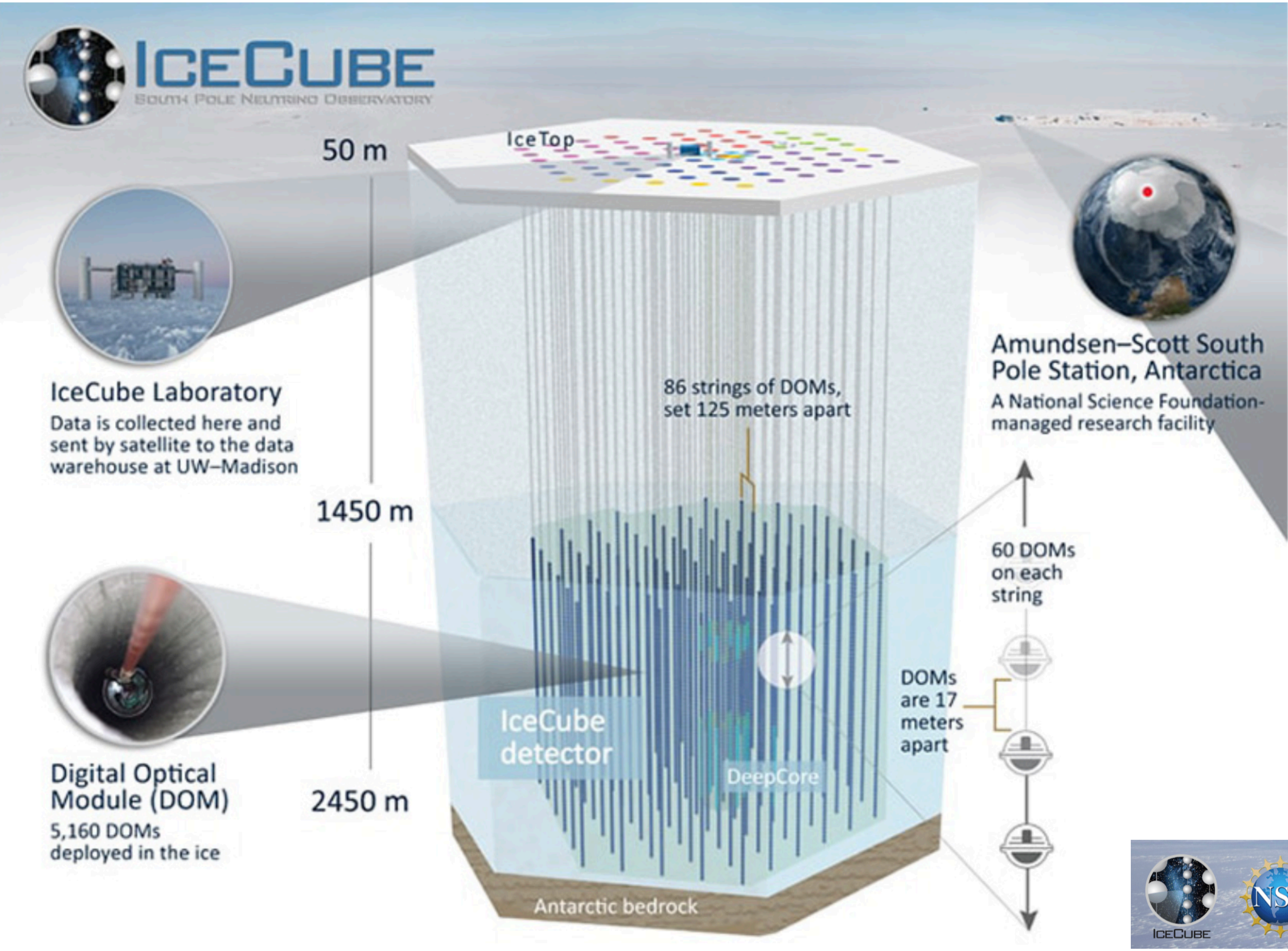


IceCube and its detector environment

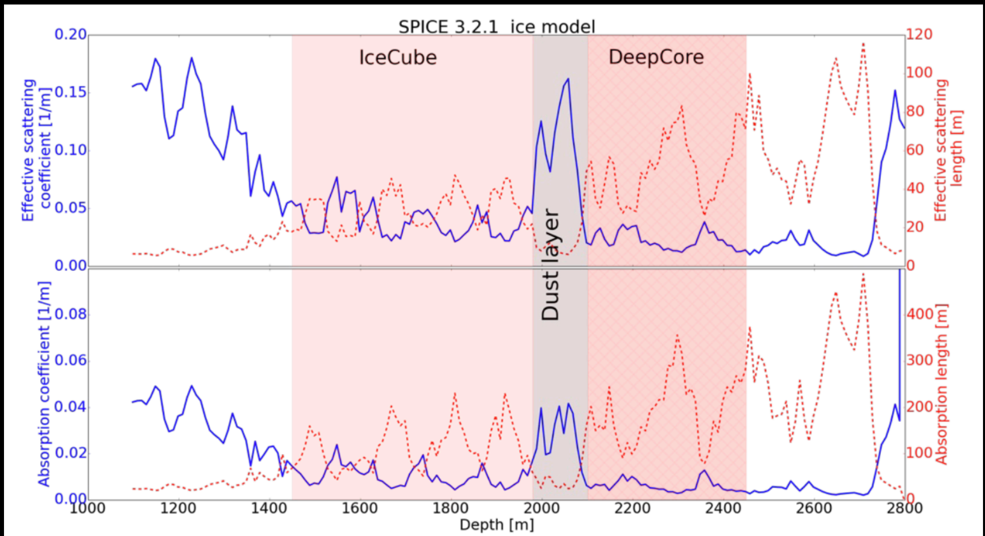
Neutrino telescopes in the future

Photodetection

Signal and background

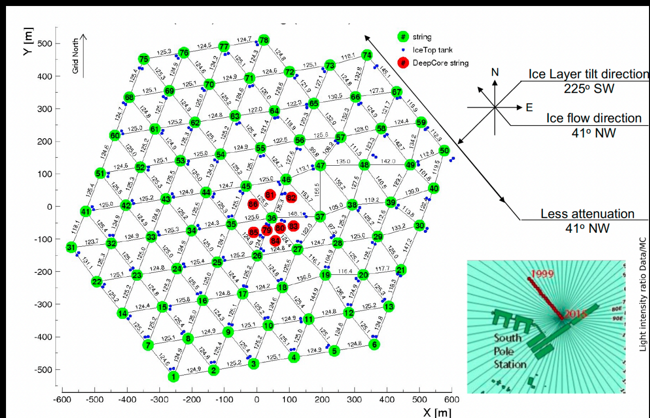

ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY
IceTop
50 m
IceCube Laboratory
Data is collected here and
sent by satellite to the data
warehouse at UW–Madison
86 strings of DOMs,
set 125 meters apart
Amundsen–Scott South
Pole Station, Antarctica
A National Science Foundation-
managed research facility
1450 m
60 DOMs
on each
string
DOMs
are 17
meters
apart
IceCube
detector
DeepCore
Digital Optical
Module (DOM)
5,160 DOMs
deployed in the ice
2450 m
Antarctic bedrock

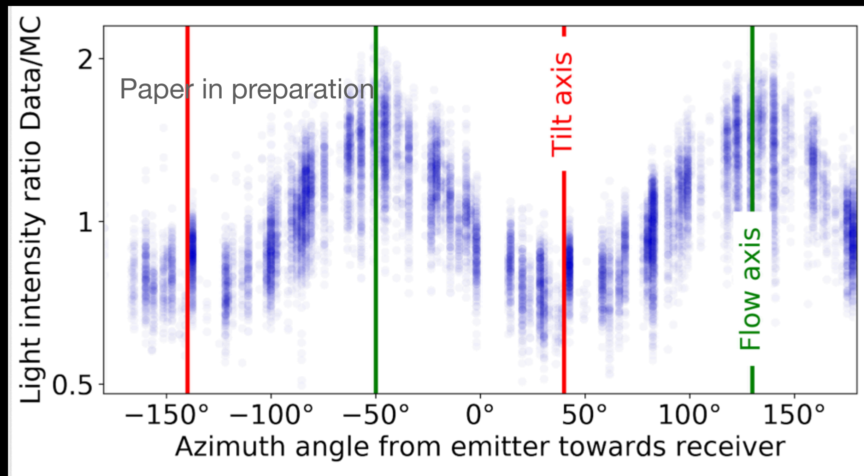
Knowing the detector and simulation: Environment and photon propagation



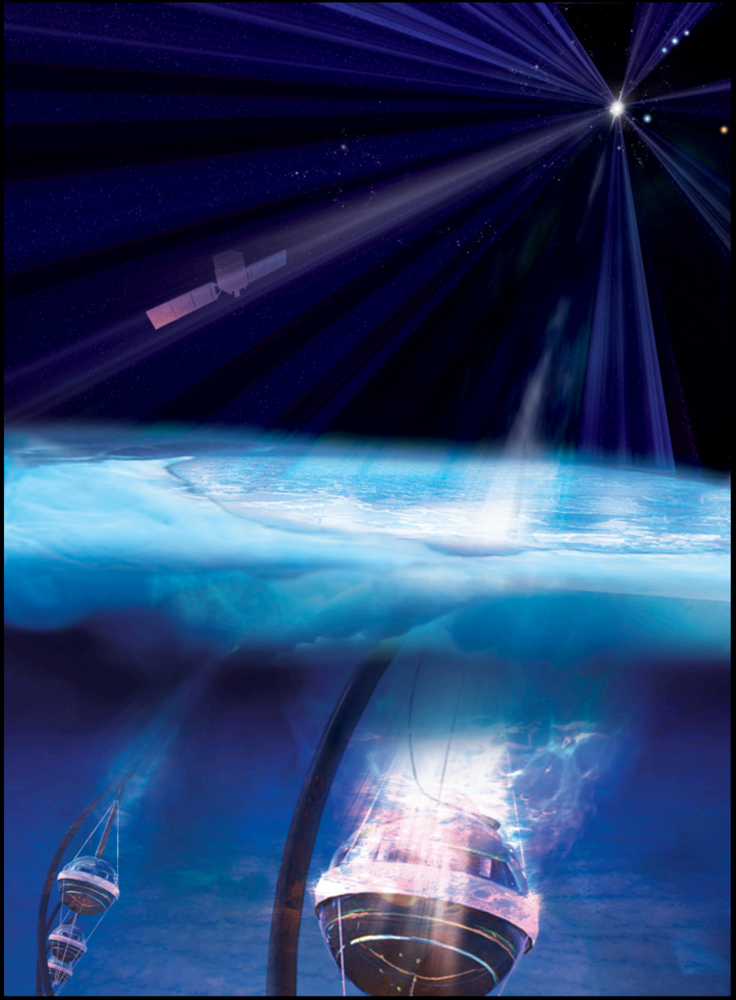
Anisotropy in photon attenuation is linked to birefringence of ice polycristal deformation in a direction perpendicular to the crystal axis. This results in photons slowly being deflected towards the axis of the ice flow of 10 m/yr.
Larger diffusion for light propagation along the axis of the ice flow and smallest for light propagation along the perpendicular tilt direction.
The tilt is primarily an effect of the underlying, undulating bedrock having gradually been filled up to a flat ice surface as we see today. Tilt and flow are orthogonal because the river flows down the local topological gradient.
See D. Chirkin et al at SCAR 2022 and (Rongen and Chirkin et al ICRC2019)

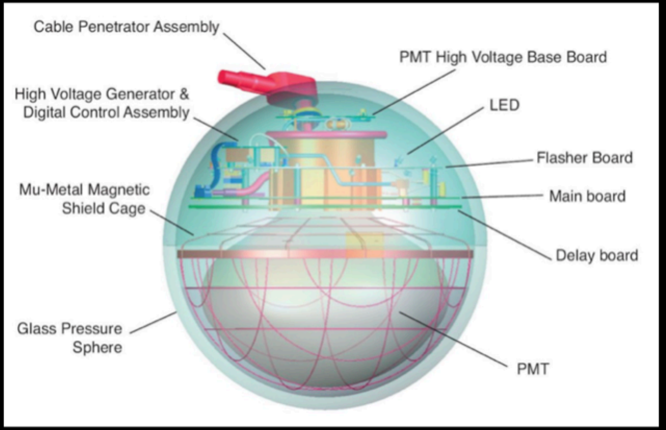
Photon propagation is ideally suited for GPUs
(see H. Schwanekamp et al, 2022) [NIM A711:73,2013]

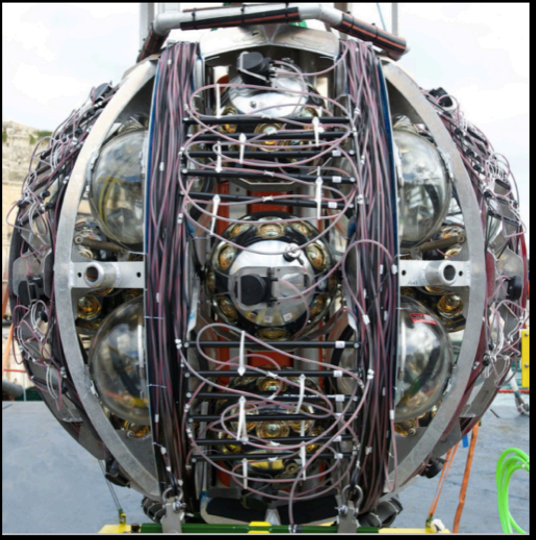




It's all about photosensing!



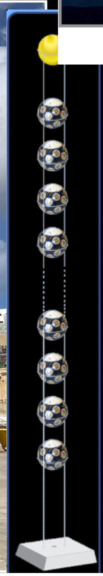




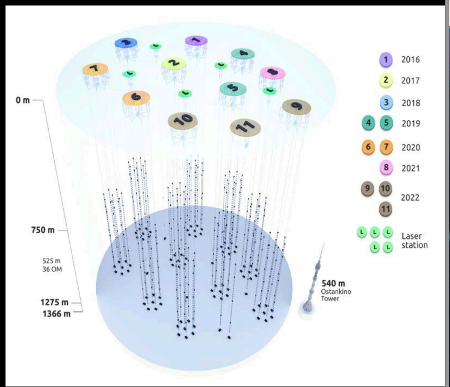
KM3NeT, GVD and IceCube-Gen2

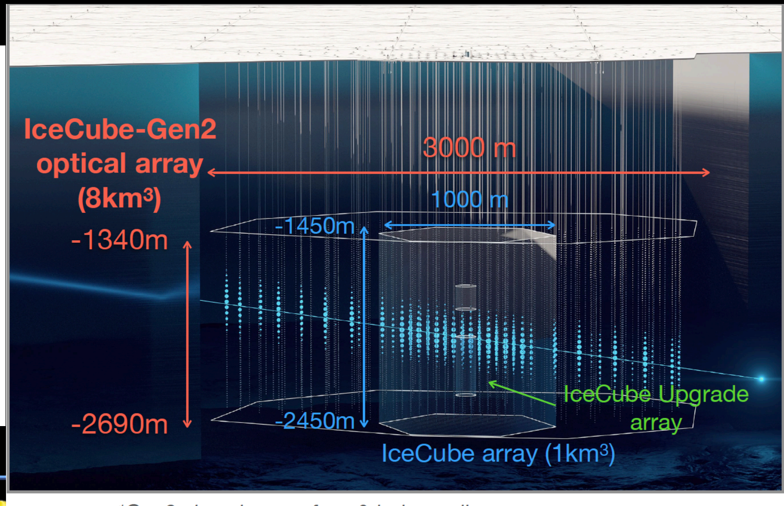
At this conference

31 PMTS of 3”

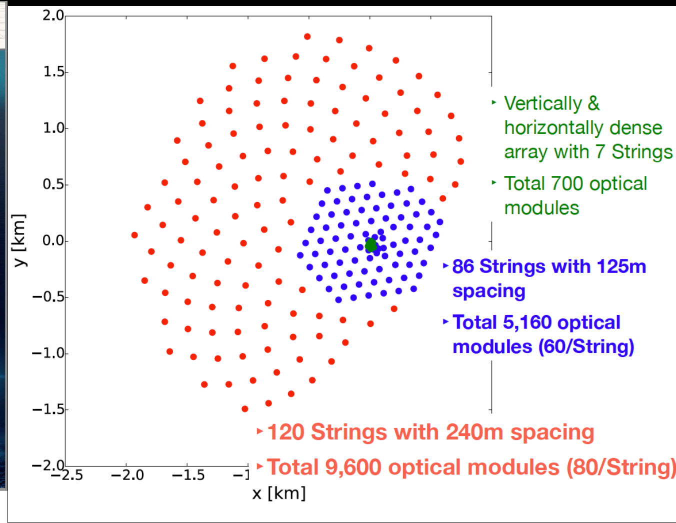


GVD 2022

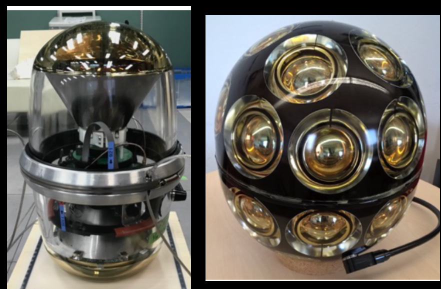




*Gen2 also plans surface & in-ice radio arrays (J. Phys. G 48 2021)

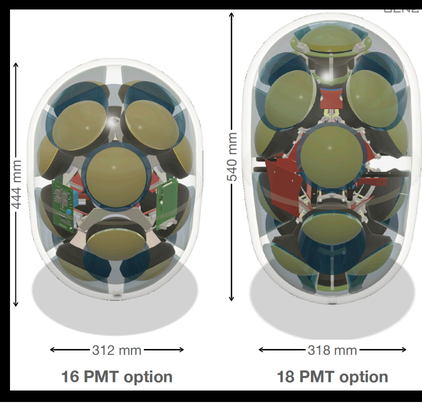


D-Egg and mDOM for upgrade



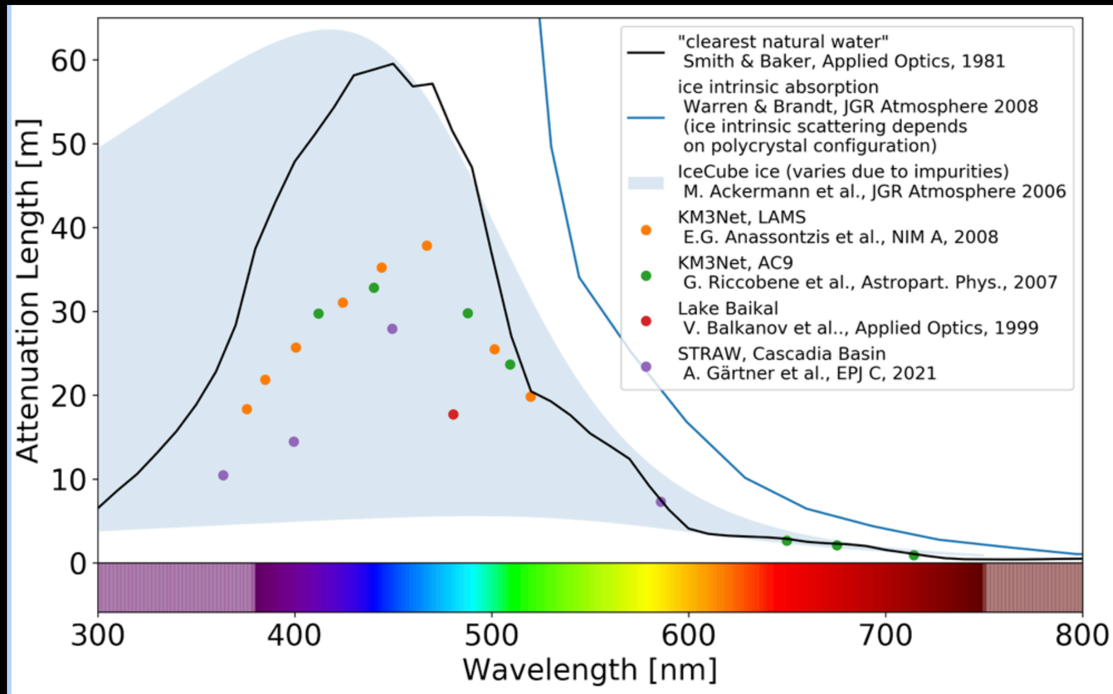
S Yoshida at this conference
and Y. Makino ICHEP2022

Gen2 design



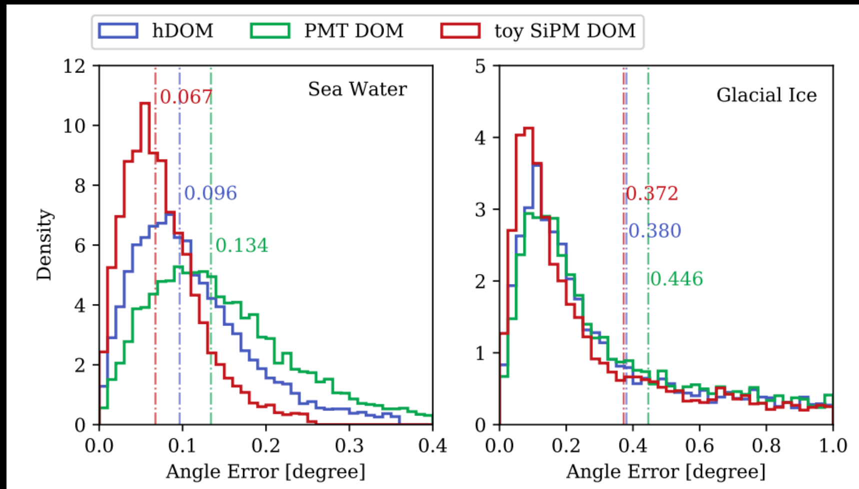
A future network of neutrino telescopes with PMTs…

Plot by M. Rongen



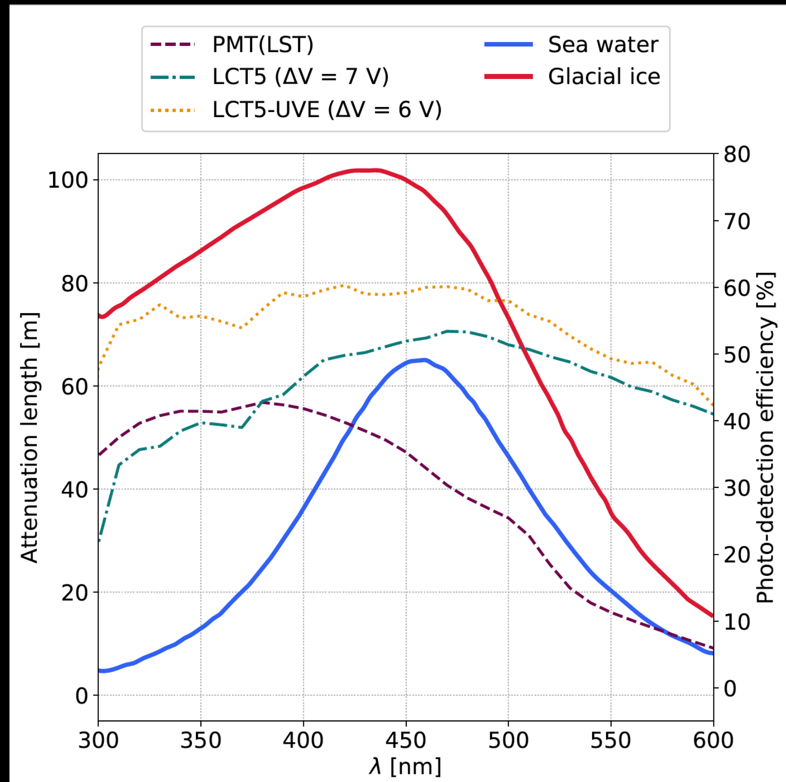
...with SiPM!

TRIDENT proposal: 5σ discovery of NGC 1068 in 2 yr and of Galactic Centre in 6 yr



20 hDOMs separated by 30 m along each string of 0.7 km (F. Hu et al ICRC2021): total physical area 1260 cm^2 PMT/ 146 cm^2 SiPM and 40% improvement in angular resolution due to 100 ps TTS of SiPM. Toy SiPM is for `SiPM arrays' of PMT size.

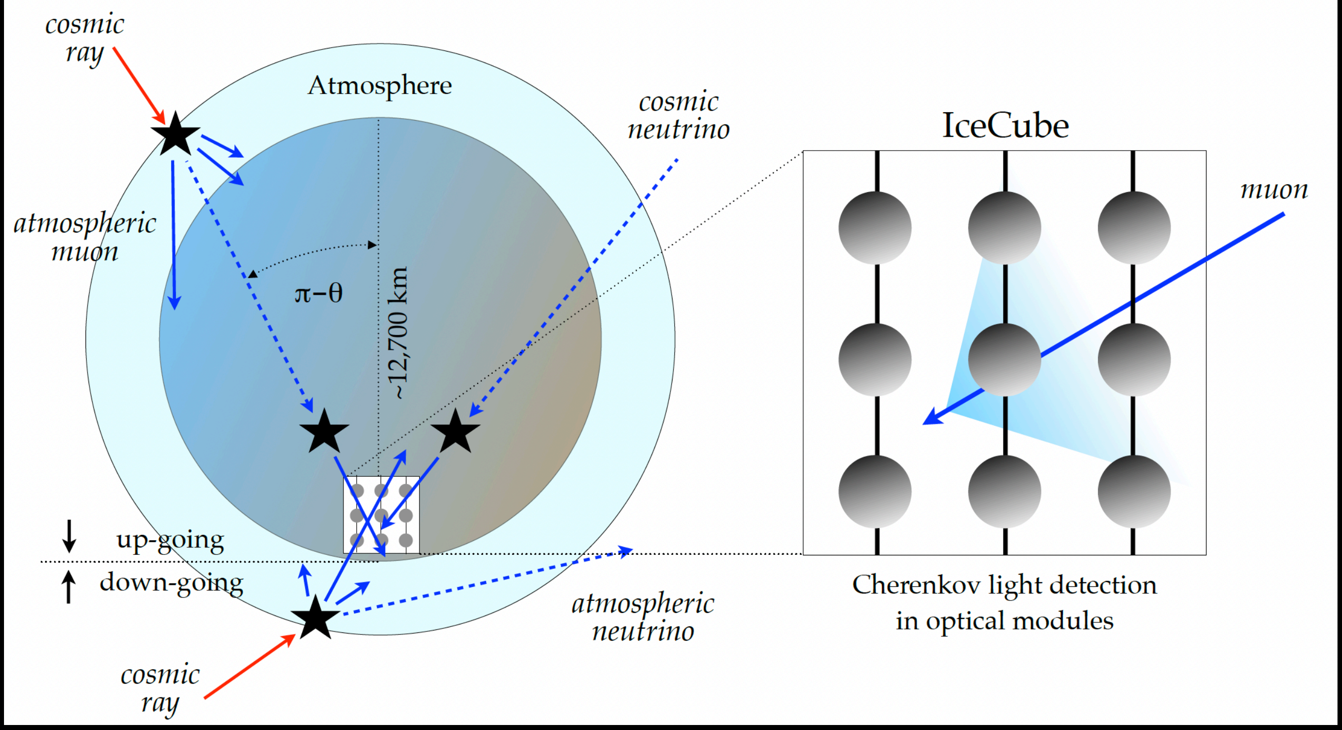
A real toy SiPM DOM can become a reality!
Low power consuming GHz bandwidth electronics for large SiPM is being developed for large size cameras of IACTs (M. Heller et al, ICRC2021)

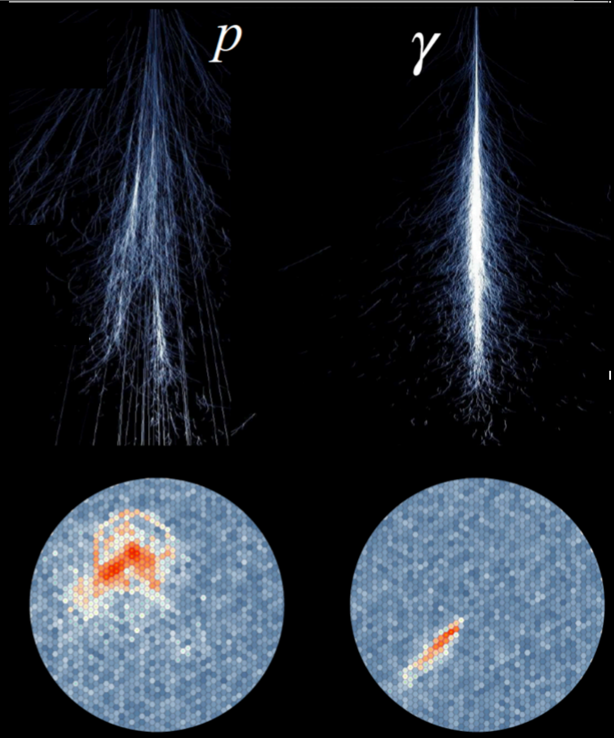


Perfect match of Cherenkov spectrum and PDE with two low cross talk technologies of Hamamatsu

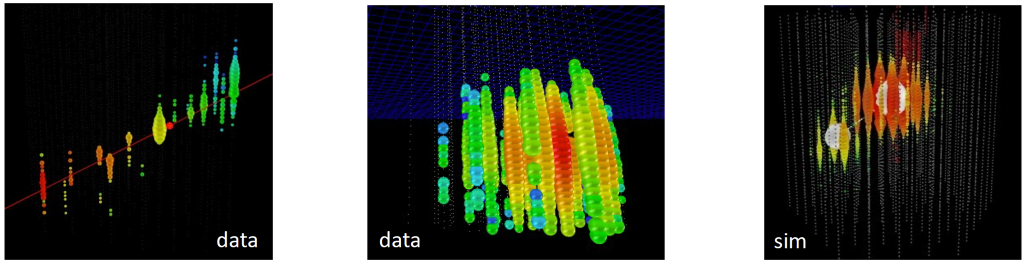
INDIRECT DETECTION OF NEUTRAL MESSENGERS AND BACKGROUNDS

In deep sea, ice or lake neutrino telescopes the signal is extracted among O(10^5) larger atmospheric induced muon and neutrino bakgrounds.
Imaging Atmospheric Cherenkov Telescopes or Extensive air shower detect the gamma-ray signal as well among O(10^5) larger cosmic ray induced showers.
In both cases the results of the interaction process is detected but in the case of IACTs the calorimeter is the atmosphere, while for neutrinos it is the instrumented region.





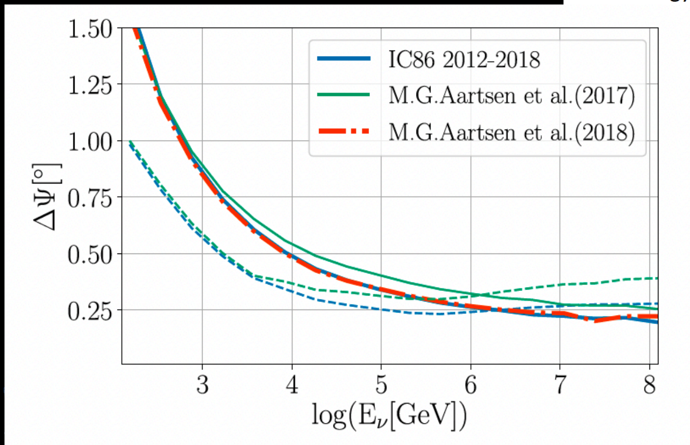
The neutrino telescope signal signature

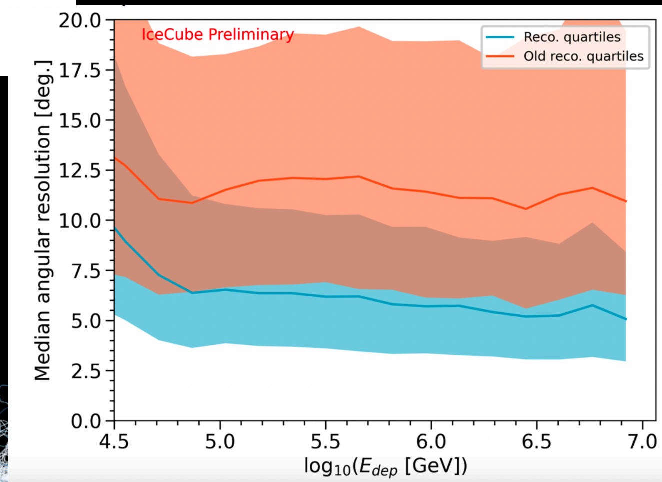


CC muon neutrino	NC or CC electron neutrino	CC tau neutrino
$\nu_\mu + N \rightarrow \mu + X$	$\nu_e + N \rightarrow e + X$ $\nu_x + N \rightarrow \nu_x + X$	$\nu_\tau + N \rightarrow \tau + X$
track	cascade	double cascade
angular resolution ~ 0.5° energy resolution ~ x2	angular resolution ~ 8° energy resolution ~ 10%	~2 expected in 6 years

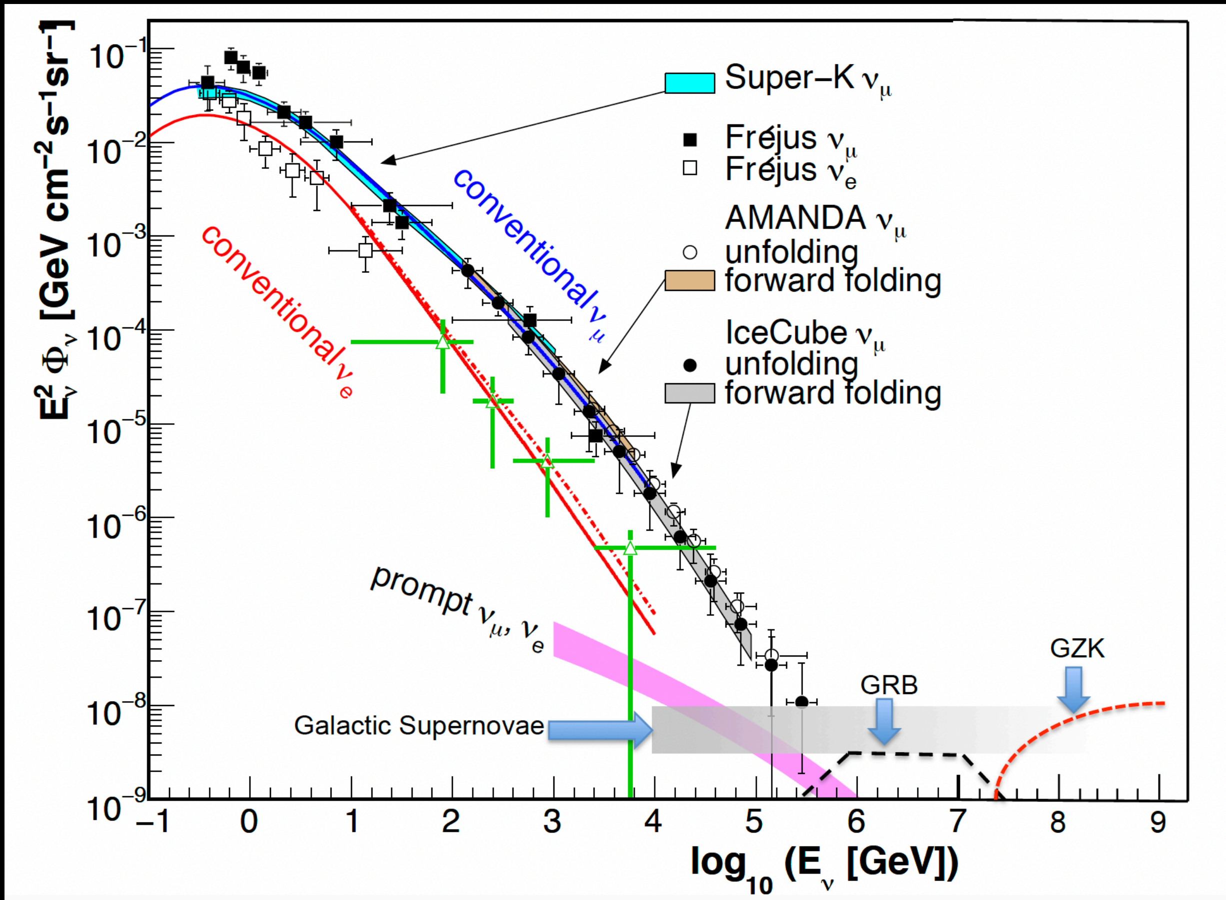
The improvement on the reconstruction of cascades has boosted IceCube results as atmospheric neutrinos are less than muon neutrinos and

Tianlu Yuan RICH 2022: accounting for birifrangence of ice crystals (Rongen and Chirkin et al ICRC2019)





Atmospheric measured/calculated ν fluxes and expected astrophysical fluxes



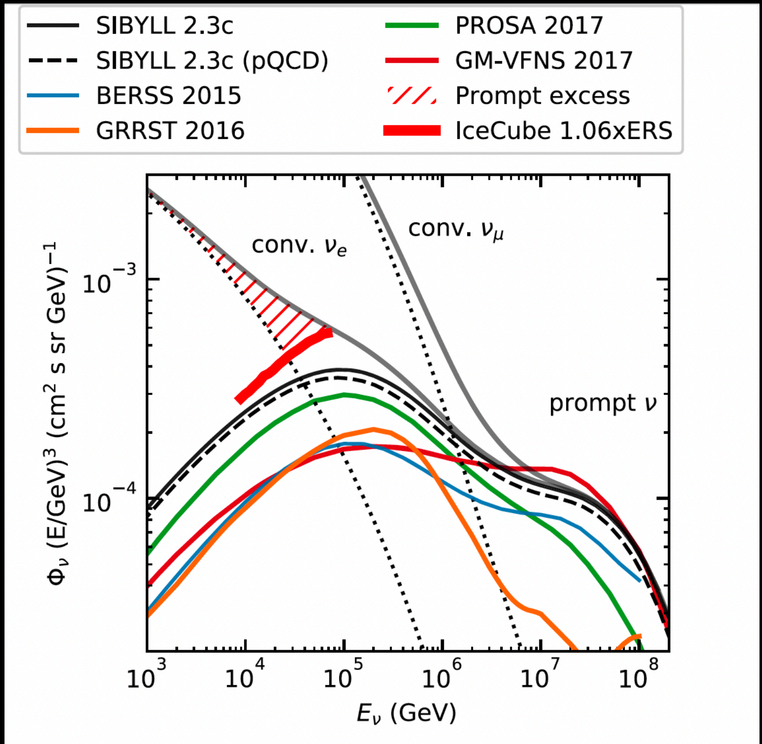
Tau neutrinos are almost absent in atmospheric showers except for some contribution from charmed mesons in the prompt component or neutrino oscillations.

Atmospheric electron neutrino fluxes are one order of magnitude lower than muon neutrino fluxes.

NC interactions produce all flavors but have a cross section lower by about 3 than CC interations.

As a consequence: cascades can constitute a purer sample of cosmic neutrinos over atmospheric for diffuse fluxes while point-like source searches profit of good track reconstruction of tracks induced by muon neutrinos.

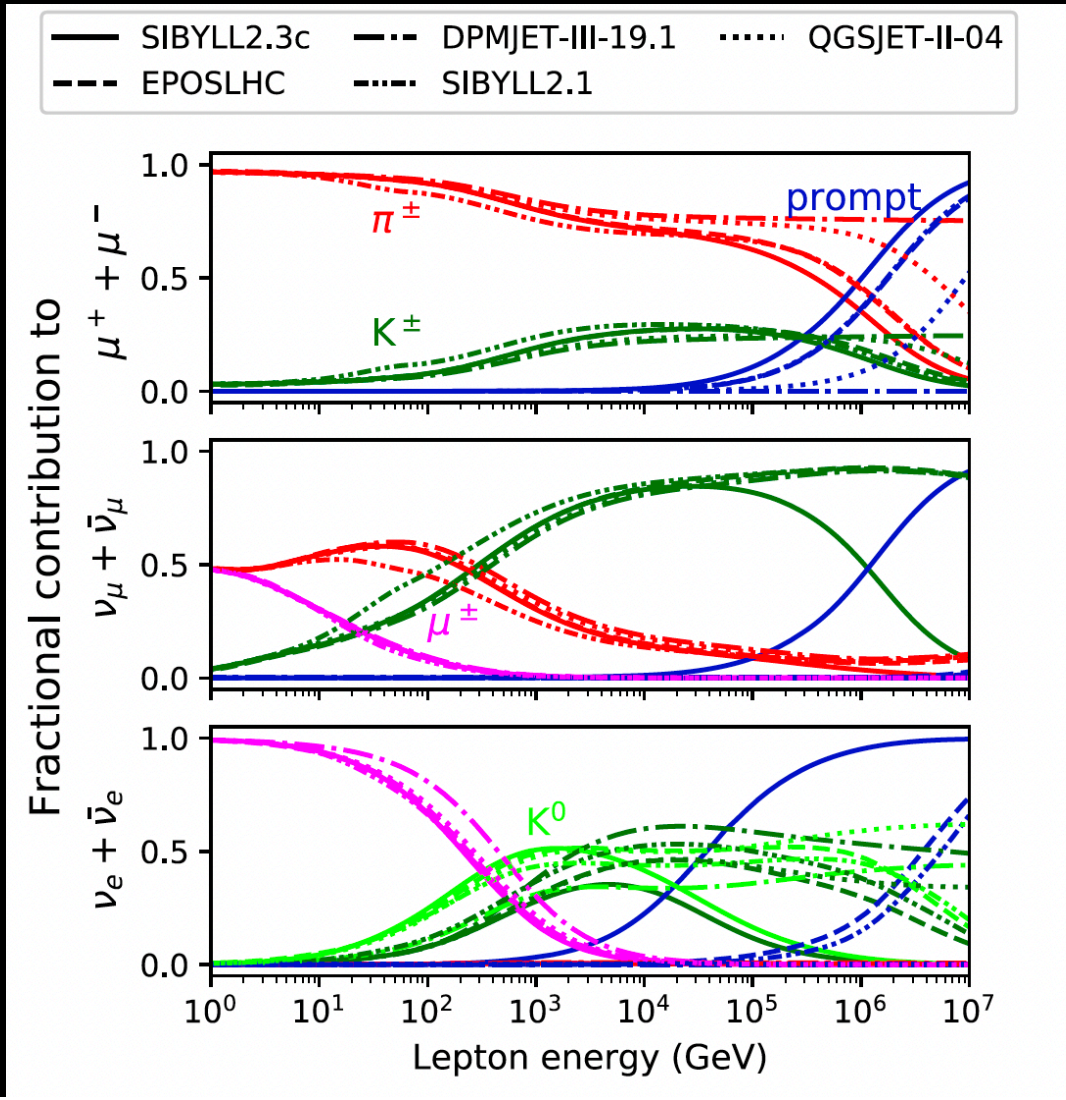
Prompt component



A. Fedynitch Neutrino 2022

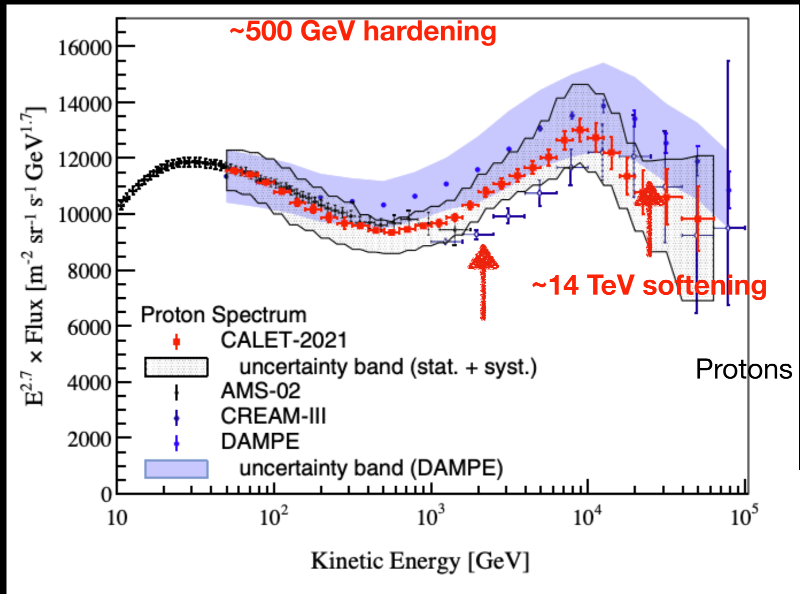
and AF et al, PRD 2019

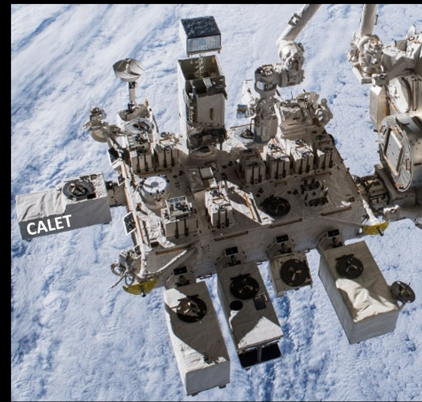
Icecube limit is from 6 yr muon diffuse paper (ApJ 2016)



H AND HE SPECTRA BELOW THE KNEE

The atmospheric muon and neutrino background essential knowledge depends on the primary cosmic ray spectrum (**surely not a simple power law!**) and hadronic interactions.

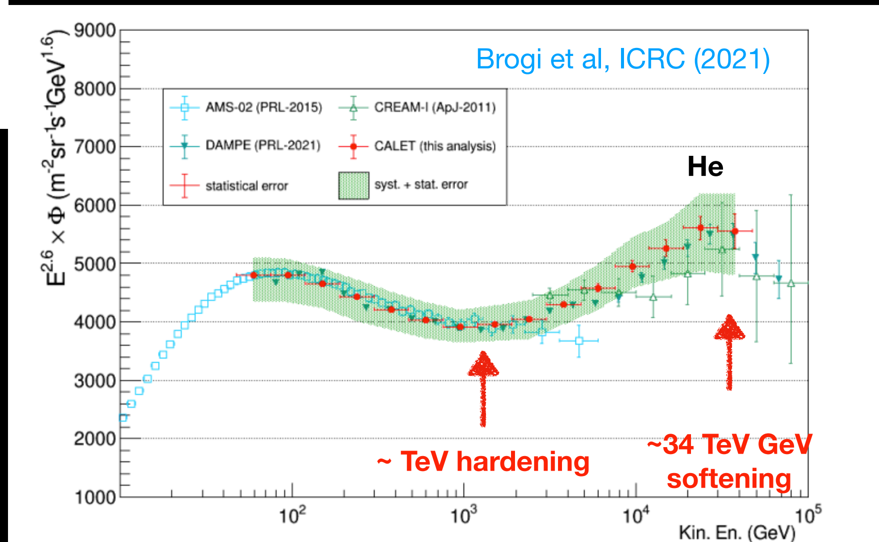




DAMPE latest results in An et al, Sc Adv 5, 9 (2019)

See also discussion in P. Mertsch ICRC2021

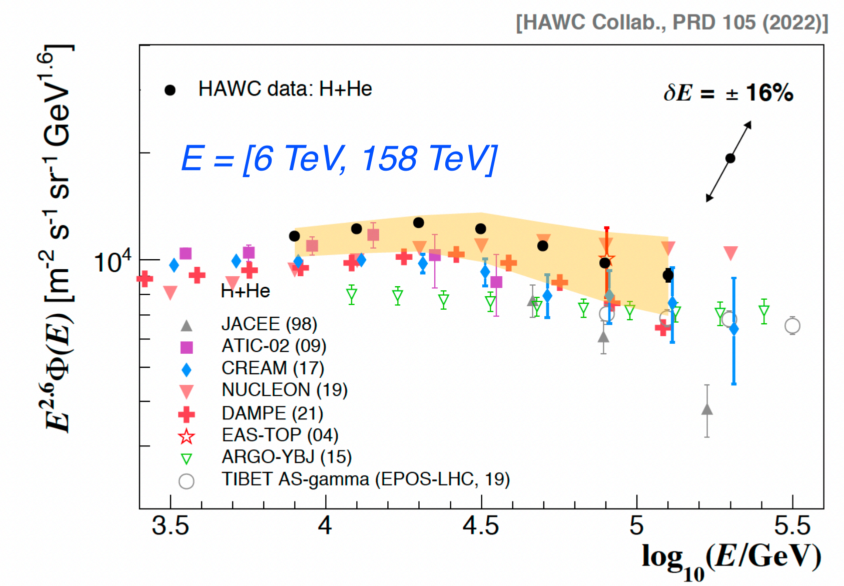
CALET latest results in PRL 122 (2019) 181102

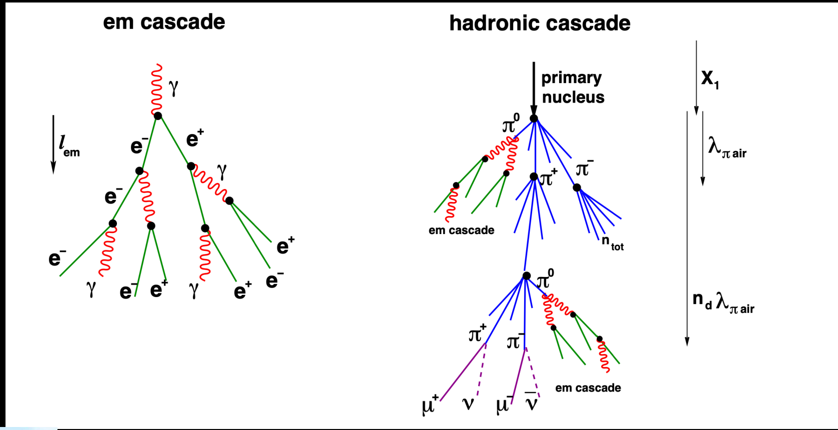


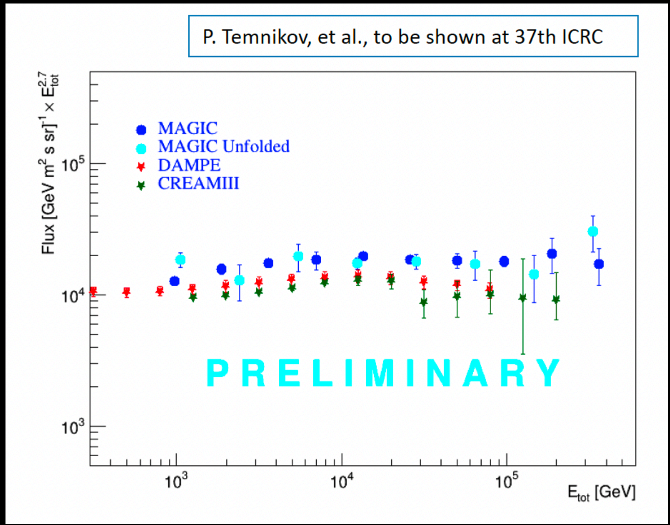
See also Alemanno et al, ICRC2021

...ACROSS THE KNEE

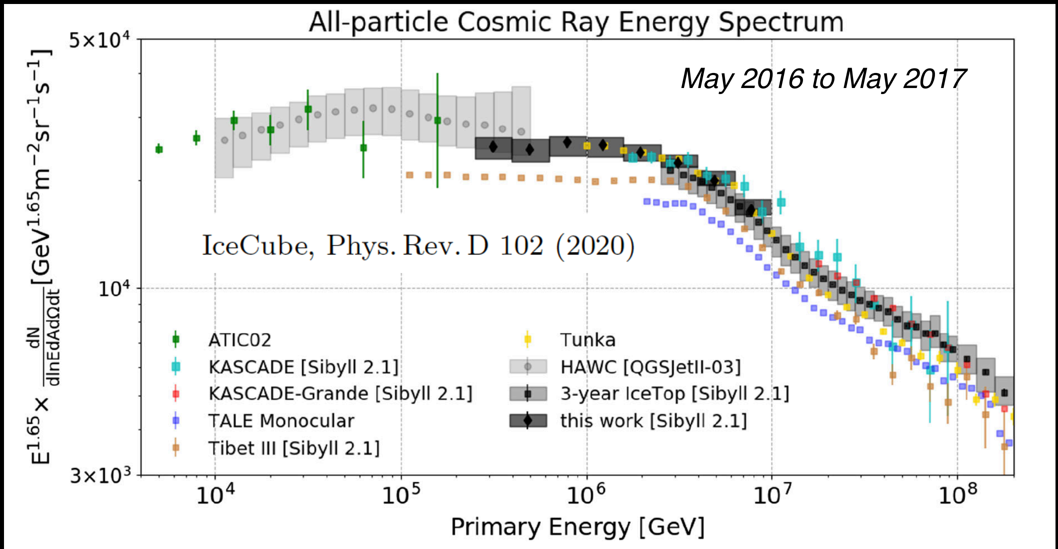
H + He fluxes from gamma-ray IACTs and EAS agree with the softening at some tens of TeV and ten to support NUCLEON rather than CREAM (disagreement at 10-100 TeV)





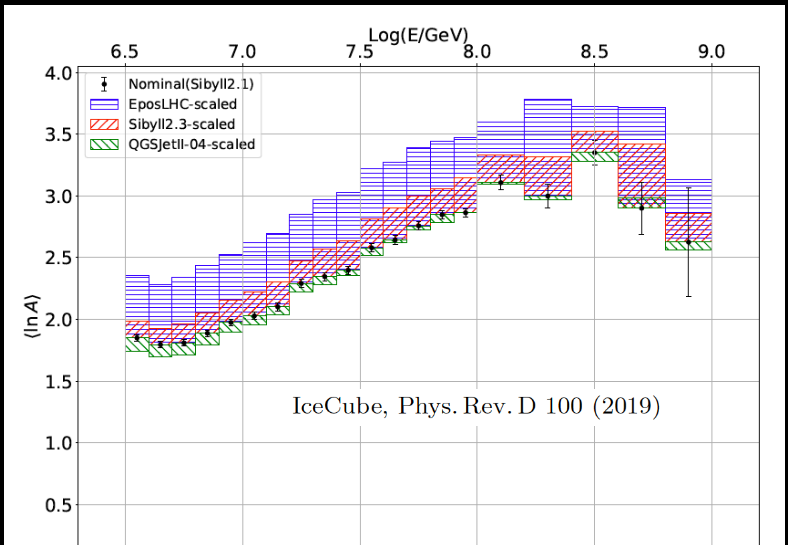


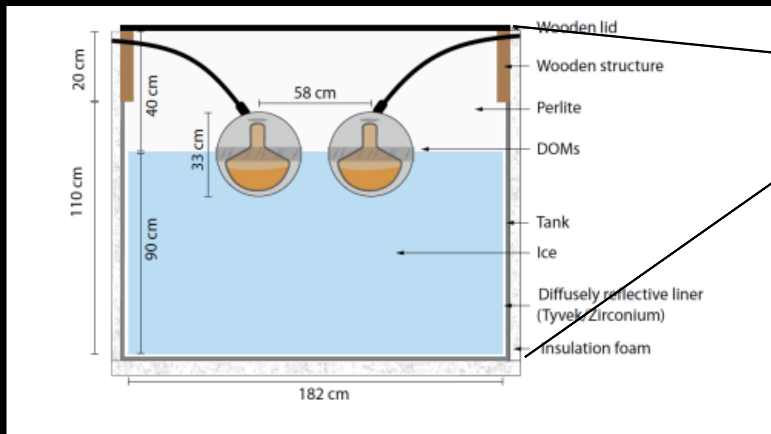
All particle spectrum above the knee: IceTop

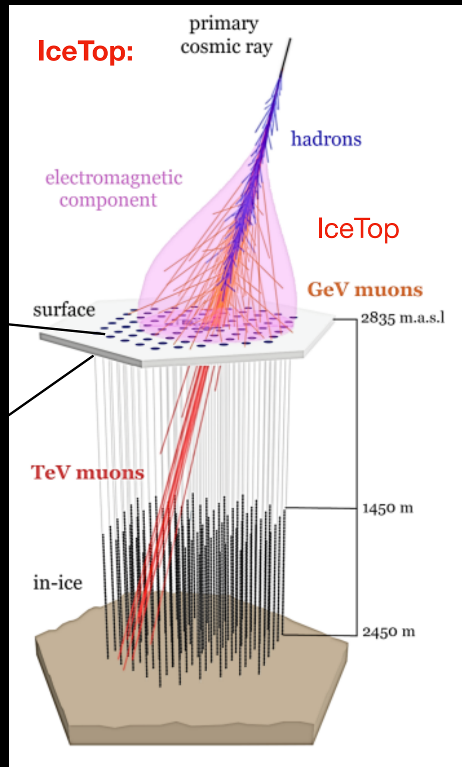


- $\sim 1\,\mathrm{km}^2$ surface array
- Atmospheric depth $\sim 690\,\mathrm{g/cm}^2$
- 162 ice Cherenkov tanks in 81 stations
- 2 DOMs per tank

Effect of hadronic interaction uncertainties on all particle spectrum and composition

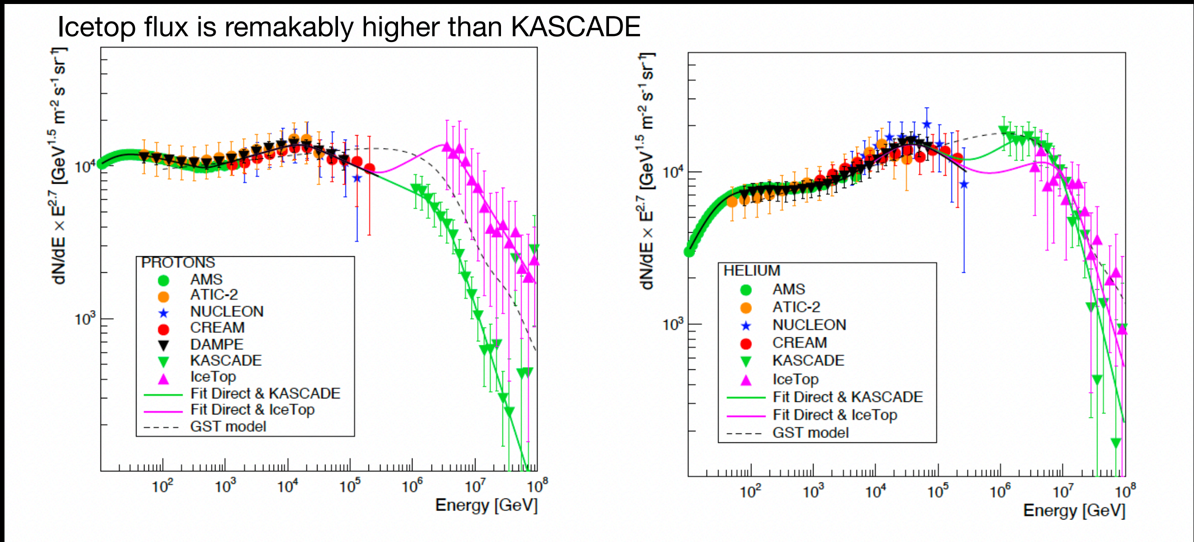


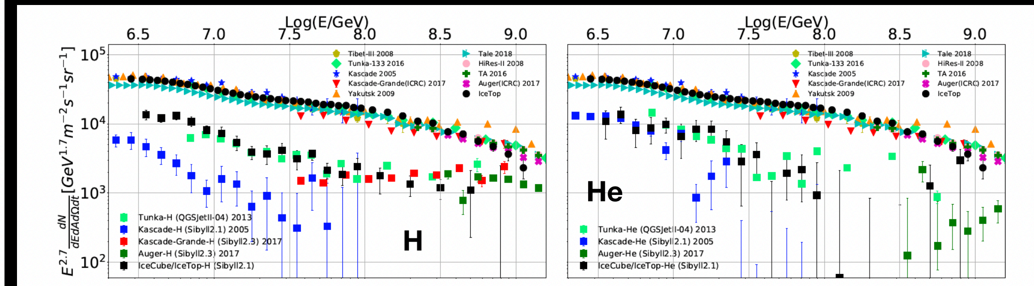




The proton and He knees

The uncertainties and systematic errors of EAS introduce a tension in the proton flux > PeV region of the knee. These uncertainties directly enter the calculation of diffuse fluxes of gamma-rays and neutrinos from the Galactic Plane

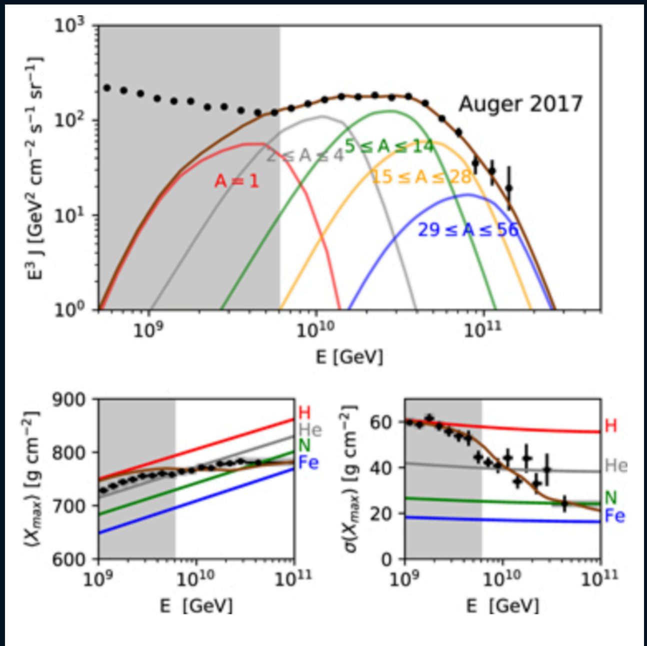




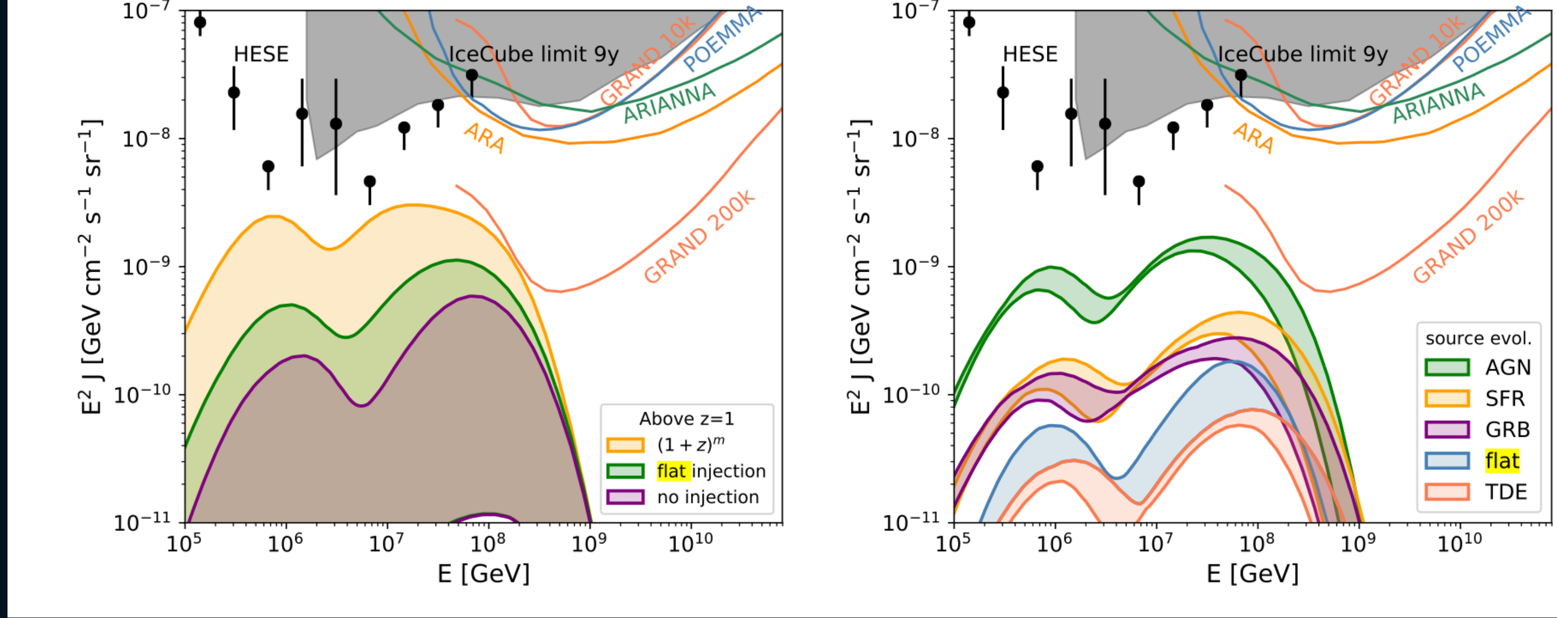
IceCube, Phys. Rev. D 100 (2019)

Lipari & Vernetto 2018, ICRC2021

UHECR at the ankle and Cosmogenic neutrino fluxes



IceCube latest limit PRL 2018



Snowmass 2022 paper, Heinze et al 2019

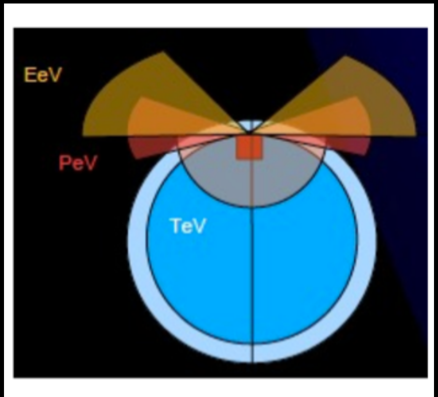
The composition of UHECRs and evolution of sources strongly influence cosmogenic prediction.
Prediction of cosmogenic flux from TXS 0606+056

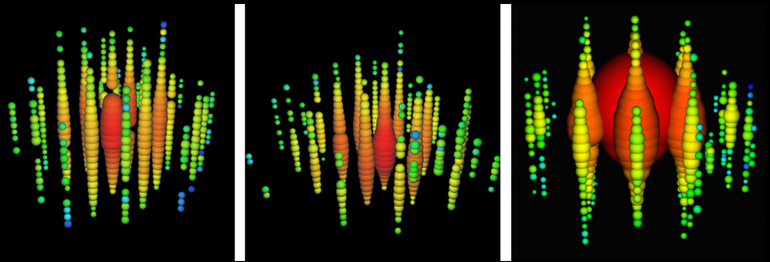
The HESE sample:

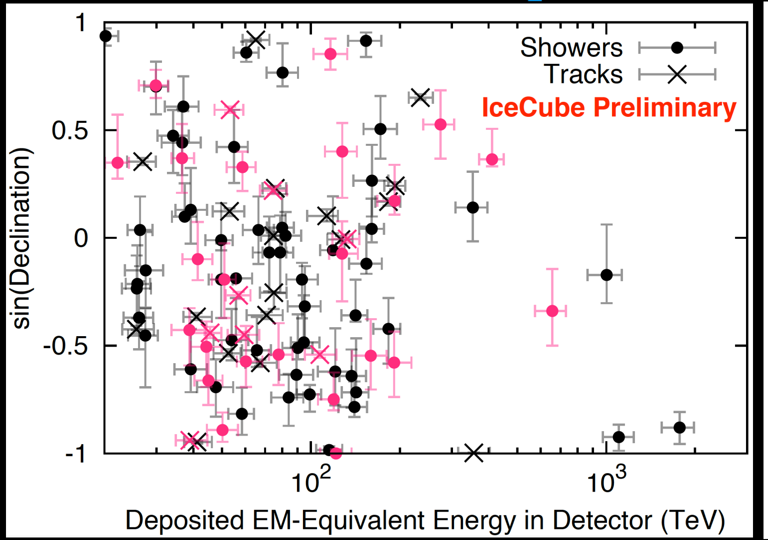
Dominantly cascades and Dominantly astrophysical

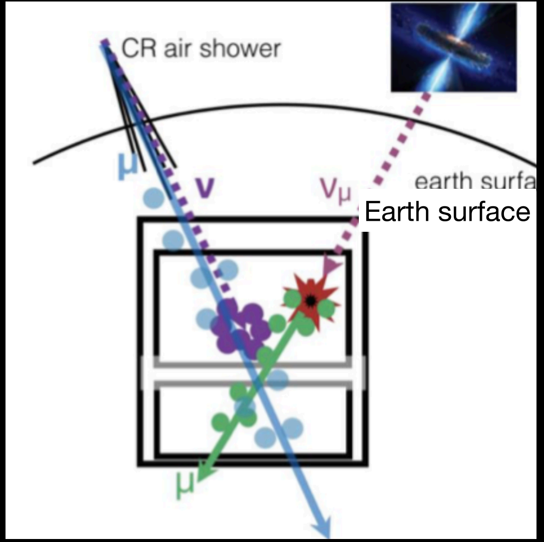
> 100 TeV HESE sample

Discovery in 2013, PRD 104 (2021) : 102 High Energy Starting Events neutrino events in 7.5 yr, atmospheric $\nu's$ disfavored at 5σ.
Dominated by **cascades** and beyond 100 TeV mostly of astrophysical origin.

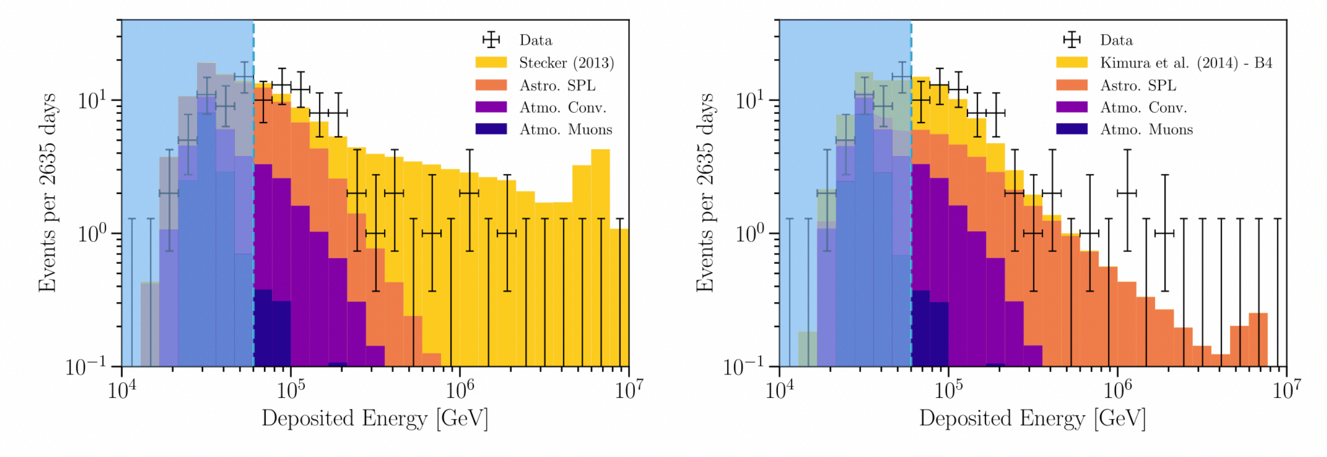




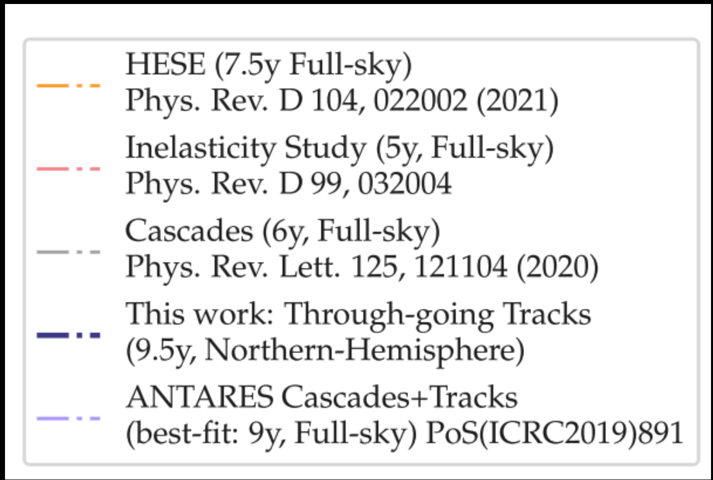




Astronomy beyond PeV is mostly horizontal!



Spectrum of diffuse samples

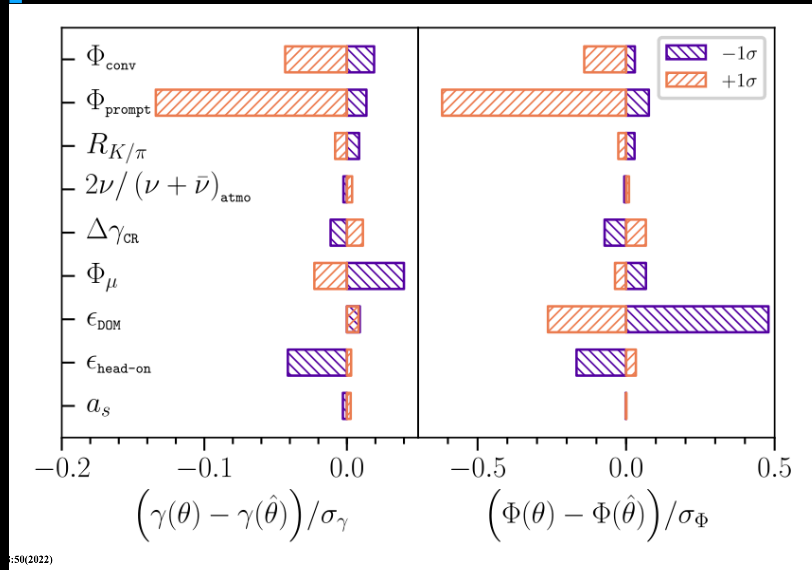


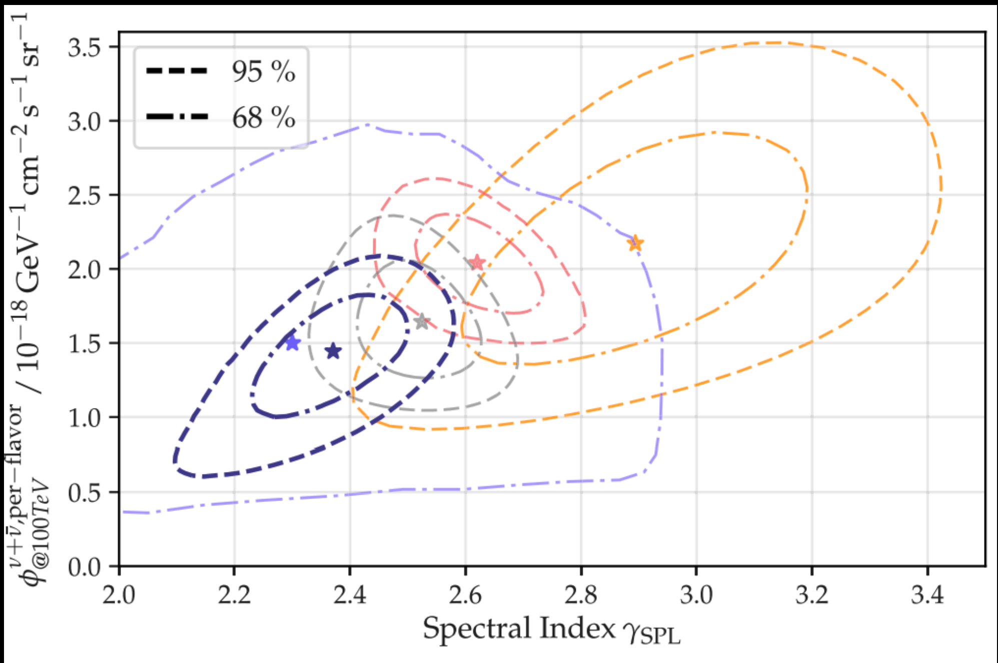
$$\Phi_\nu = \phi \times (E_\nu / 100\,\mathrm{TeV})^{-\gamma}$$

Impact of sys errors on
Cosmic power law flux

$$\gamma_{\mathtt{astro}}^{7.5\text{ years}} = 2.87^{+0.20}_{-0.19}$$

$$\Phi_{prompt} = 0.00 \pm^{5.34}_{-0.00}$$

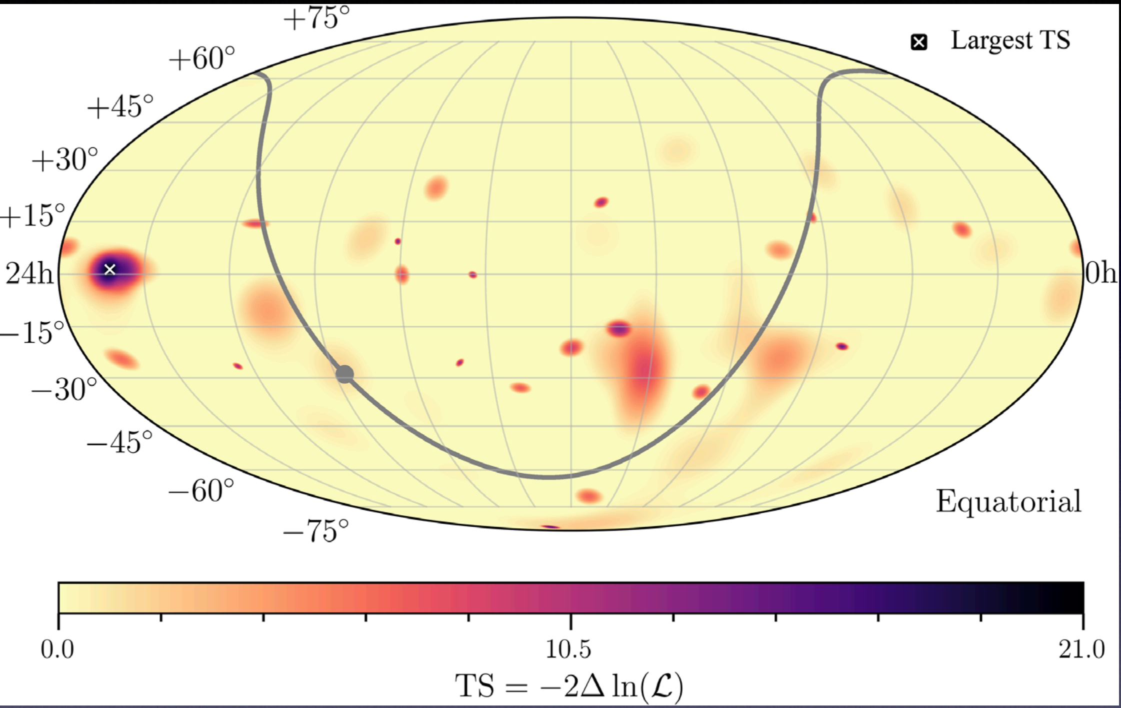


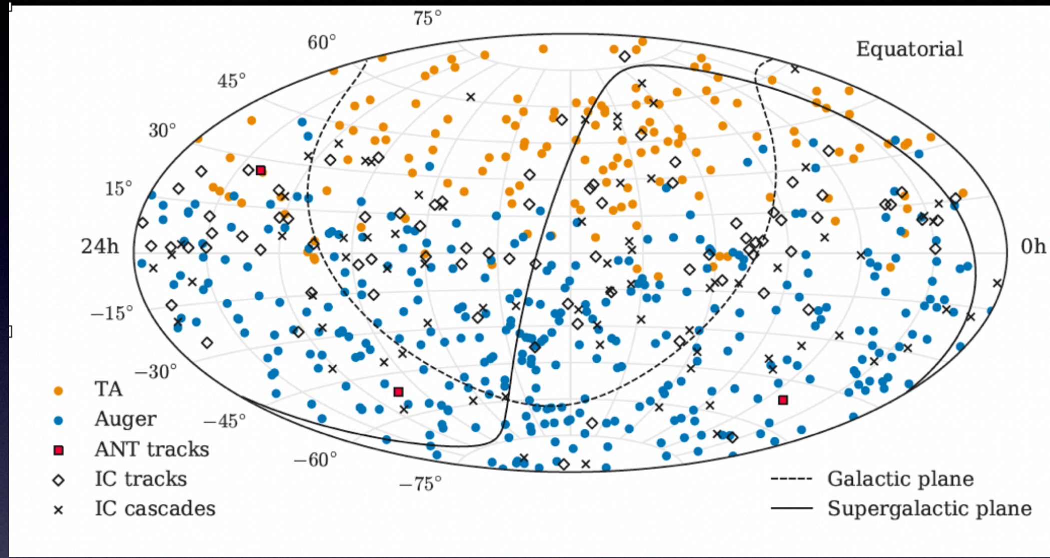


Orange curve is HESE sample in IceCube, PRD 104 (2021)

The plot is in IceCube Coll, ApJ928:50(2022)

The HESE directions



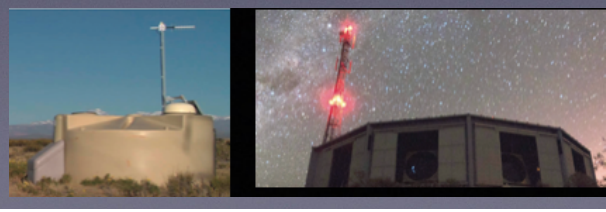


IceCube, ANTARES, PAO and TA, 2022

Post.trial p-value ~1%

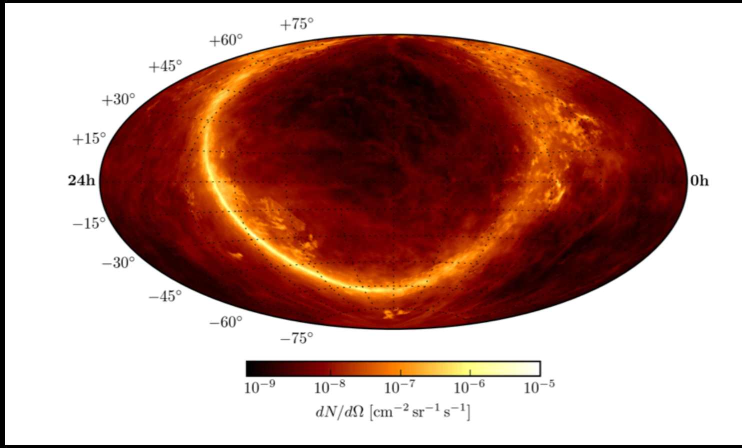
IceCube (ApJ 2016) set an upper limit of about 30% (50%) to the blazar contribution to the diffuse ν flux between 10 TeV- PeV but it assumes all blazars produce similar power law spectra with spectral index -2.5 (-2.2).
Assuming that all sources in a class are identical ignores the role of host environments and different characteristics of accelerators.

The absence of correlation of UHECRs (TA and PAO) with IceCube(including HESE)/ANTARES neutrinos maybe related to the composition/magnetic field uncertainties.



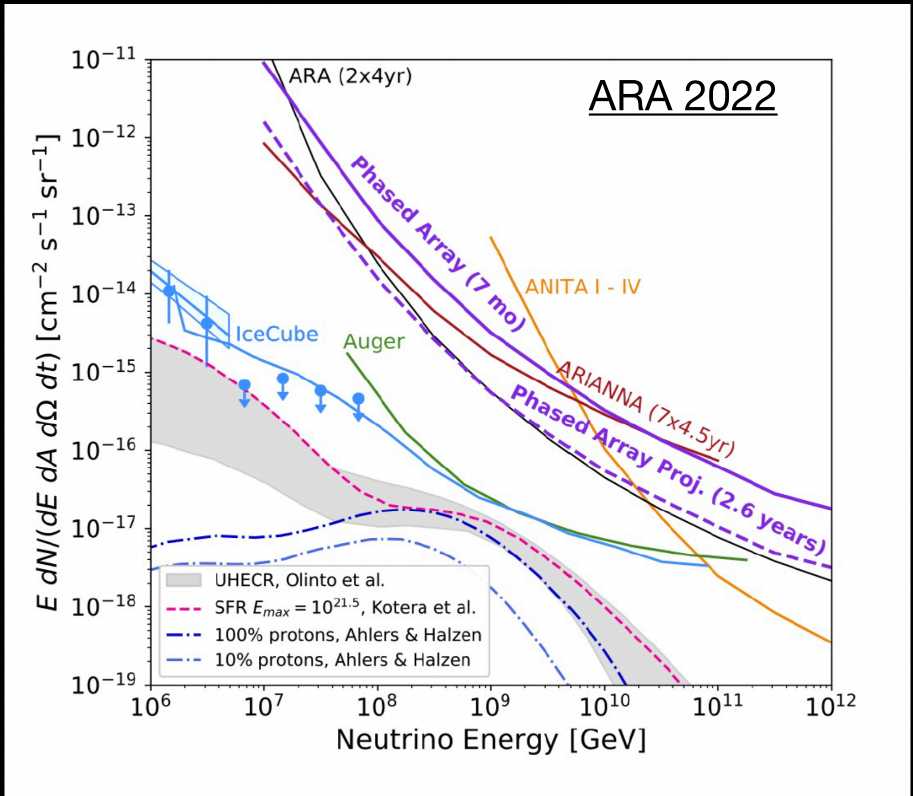
Do the granted diffuse fluxes contribute to the diffuse astrophysical fluxes?

Galactic



IceCube limit on cosmogenic neutrinos in PRD2016 and PRL 2018
More in S. Yoshida's talk

Extra-Galactic

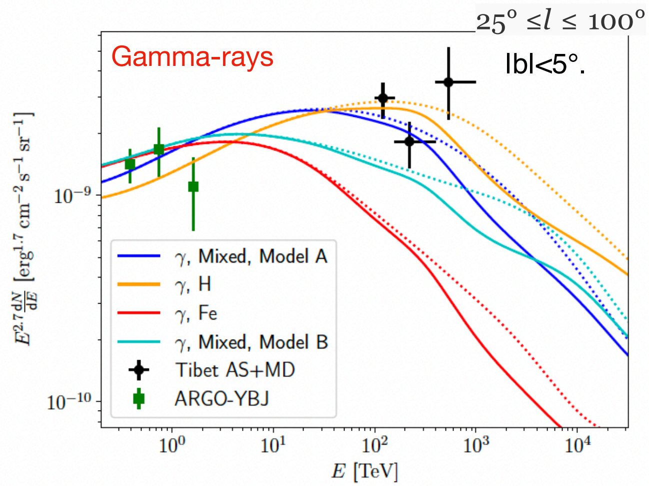


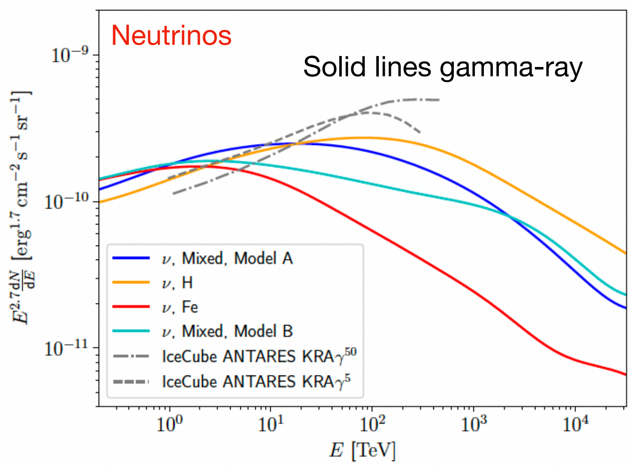
Snowmass 2022 paper, Heinze et al 2019, Shigeru's talk

The contribution to diffuse fluxes from the galactic plane cosmic ray interactions

The composition is relevant to calculate neutrino and gamma-ray spectra and EAS and IACTs with reach to PeV energies will be cricial to understand the diffuse components of gamma-ray fluxes and of neutrinos.

Breuhaus et al , 2022; De La Torre Luque et al 2022, Ahlers et al, 2016

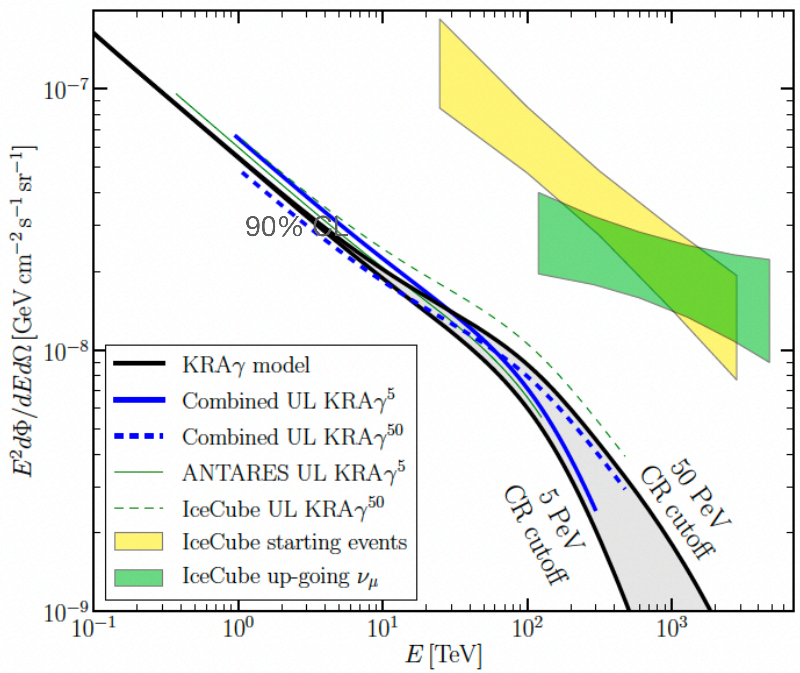




Model A and Model B account for the disagreement of CREAM and NUCLEON on p and He fluxes and Mixed indicates 50% H, 50% O - ISM
Tibet AS+MD data at 100 TeV do not favour pure Fe models. Solid and dashed lines are with and wo absorption of gammas

Neutrino limits touch KRA models (Gaggero et al 2015, 2017) of diffuse galactic emission from CRs interacting on ISM. **The contribution of the diffuse neutrino flux to the > 20 TeV diffuse neutrino fluxes is of the order of 10%.**
Discovering the Galactic Plane neutrino flux requires lowering the threshold in ν energy and using the **cascade samples** of neutrino telescopes.

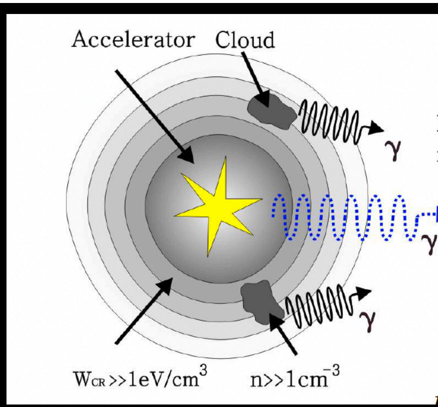
ANTARES-IceCube arXiv:1808.03531 IceCube arXiv:1707.03416



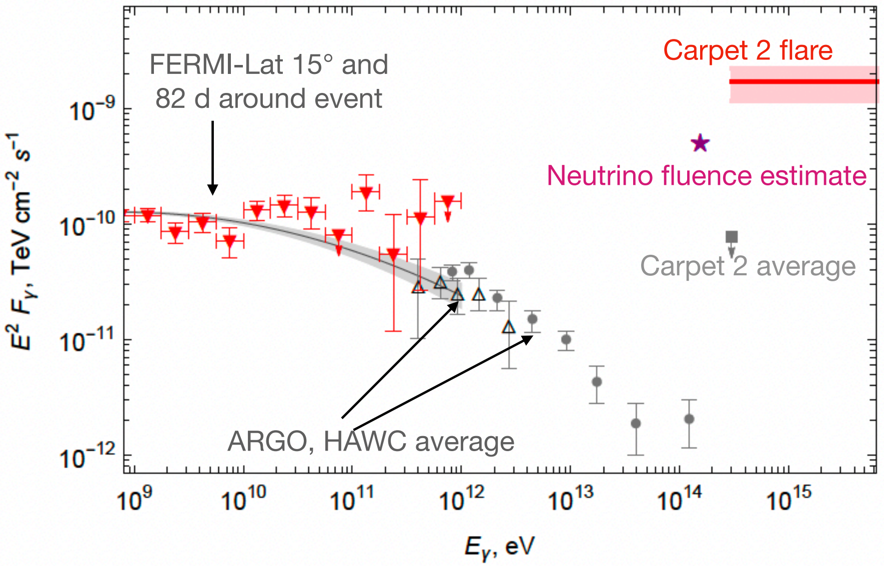
From the Galaxy: PeVatrons

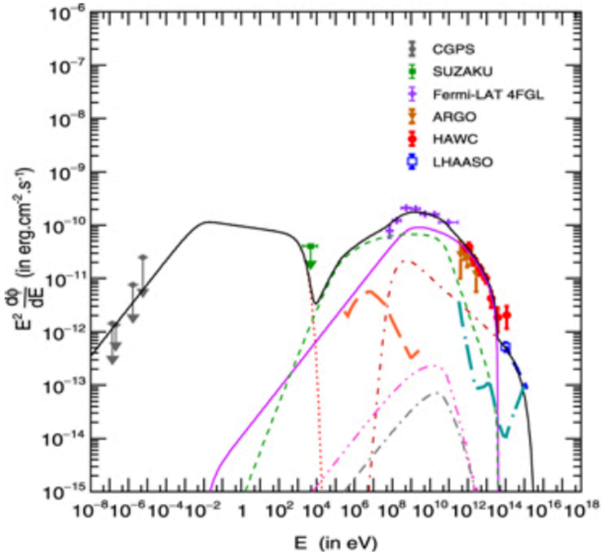
Neutrinos are unique tools for discovery of PeVatrons in the Galaxy in synergy with UHE gamma-rays

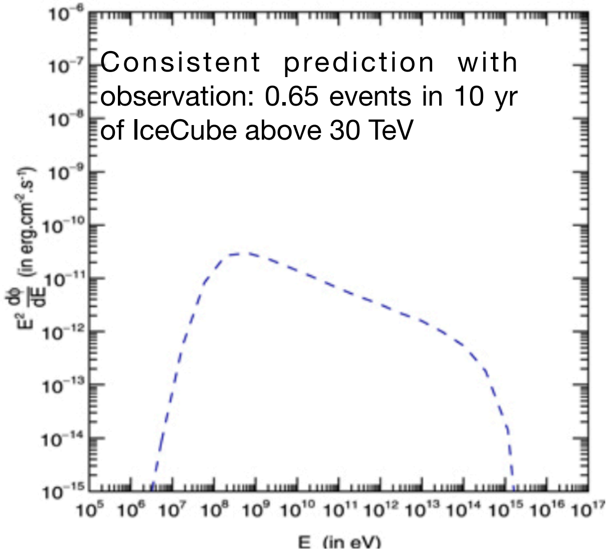
HAWC spectrum to > 100 TeV & LHAASO detected a 1.4 PeV gamma.
Carpet2: > 300 TeV photon flare with estimated fluence of $13 \pm 4 \mathrm{GeV/cm^2}$ in Nov 2020 in a 3.1σ coincidence with a 150 TeV IceCube neutrino track (bronze alert) in Dzhapphuev et al ApJL 2021



Banik et al 2022







Cygnus cocoon with HAWC (grey circles) and Fermi (red triangles) (Nature 2021)

See also Ambrogi, Celli, Aharonian 2018

Cosmic ray/gamma-ray/neutrino connection

Halzen & Kheirandish 2022
Waxman & Bahcall 1998

$$\left[E_p^2 Q_p(E_p)\right]_{10^{19.5}\mathrm{eV}} \sim (0.5-2.0)\times 10^{44}\mathrm{erg/Mpc^3/yr}$$

Local Emission rate density to feed UHECRs

Relation between the neutrino flux per flavor and the CR rate density:

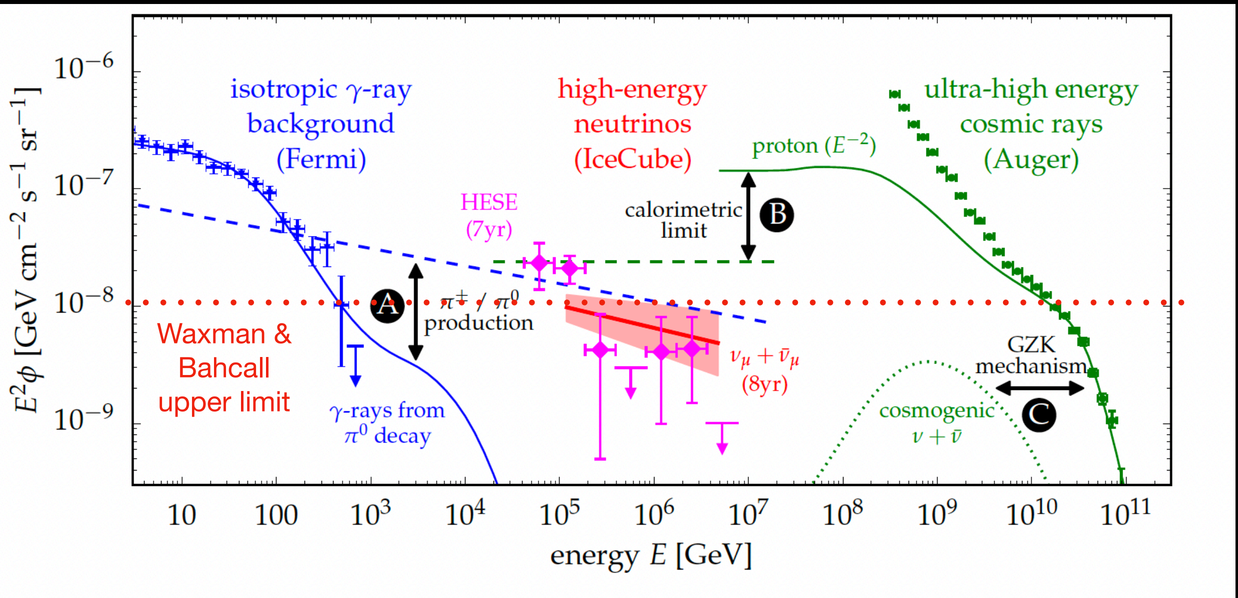
$$\frac{1}{3}\sum_\alpha E_\nu^2 \phi_{\nu_\alpha}(E_\nu) \simeq 3\times 10^{-8} f_\pi \left(\frac{\xi_z}{2.6}\right)\left(\frac{[E_p^2 Q_p(E_p)]_{E_p=10^{19.5}\mathrm{eV}}}{10^{44}\,\mathrm{erg/Mpc^3/yr}}\right)\frac{\mathrm{GeV}}{\mathrm{cm^2\,s\,sr}}.$$

f_π = efficiency of pion production from CRs = $1-e^{-\tau_{p\gamma}}$

With $\tau_{pp,p\gamma} = \kappa \ell \sigma_{pp,p\gamma} n$

Target nucleon density

Target dimension



(A) common origin of γ's and ν's from π production in pp

(B) CRs and ν's have a common origin

$f_\pi \to 1$ calorimetric limit (Waxman & Bahcall upper limit)

$f_\pi = 1$ $\tau = \kappa\ell\sigma n >> 1$ fully efficient conversion of CRs total energy into gamma and neutrinos (e.g. starbursts, galaxy clusters)

$f_\pi << 1$ Optically thin sources : neutrino production is a small by product of the acceleration process and UHECR acceleration not limited by it

(C) CRs and cosmogenic ν's

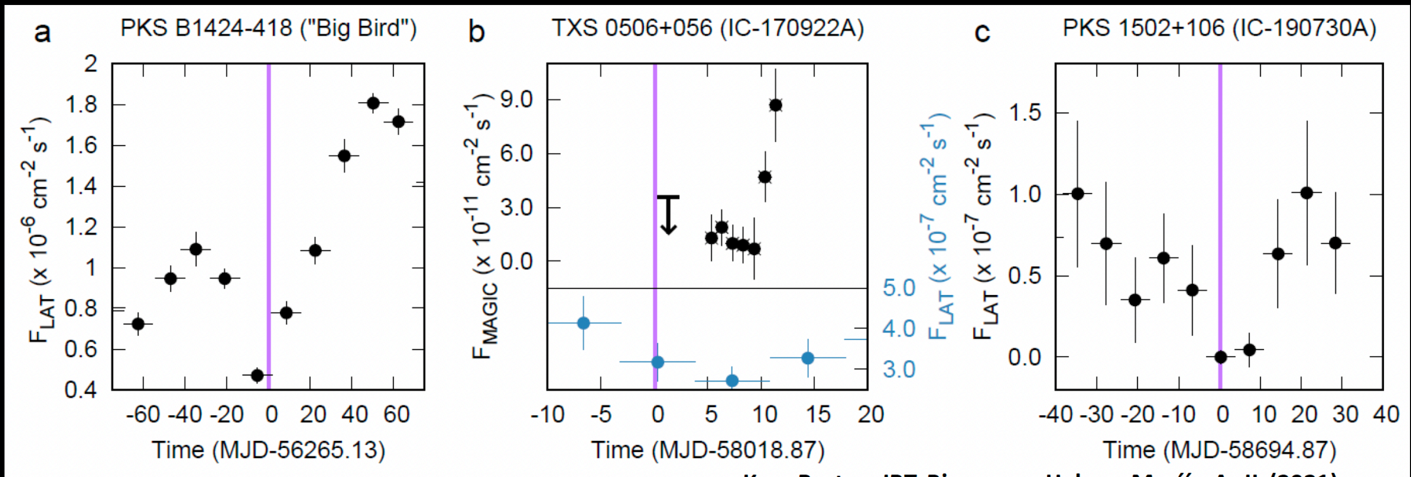
Blazars: A special class of neutrino emitters?

Where does acceleration occurs and how is an open problem: at the termination shocks of the jets in intergalactic space or at distances of 100 Mpc where the material is reduced and consequently neutrino production?

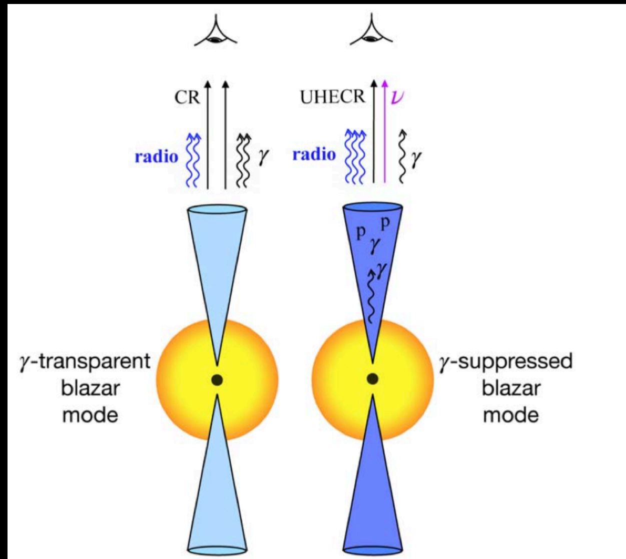
Where/When does production of neutrinos occur? in the corona near the BH or in collisions of accelerated particles diffusing in the magnetic field of the host galaxy of the BH.

Is there a special class of blazars?

A sub-class of blazars with TXS 0506+056 luminosity and flaring for ~100 d, representing 5% of blazars, are very efficient accelerators when VHE photons are more absorbed can explain IceCube diffuse flux. For TXS 0506+056, $\tau_{p\gamma} \sim 0.4 \Rightarrow \tau_{\gamma\gamma} \sim O(100)$



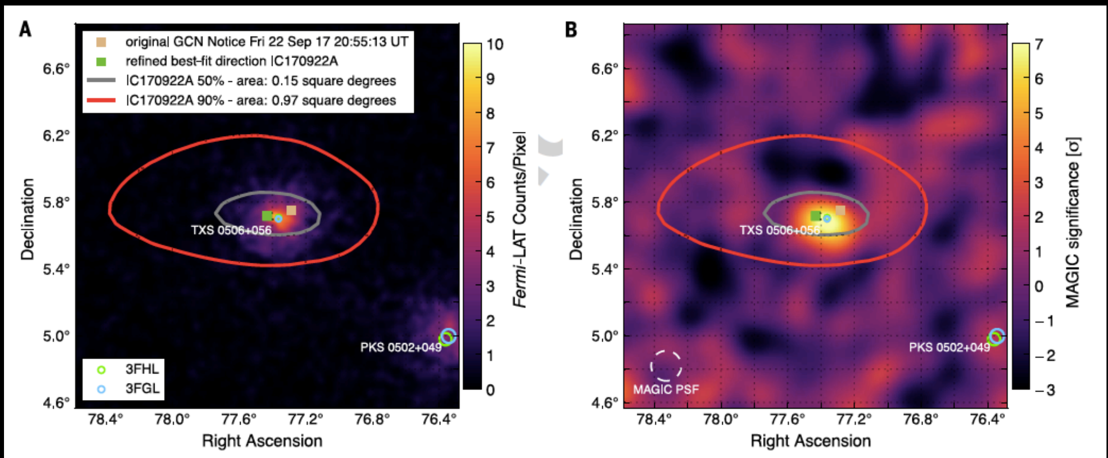
Kun, Bartos, JBT, Biermann, Halzen, Mez´´o ApJL (2021)

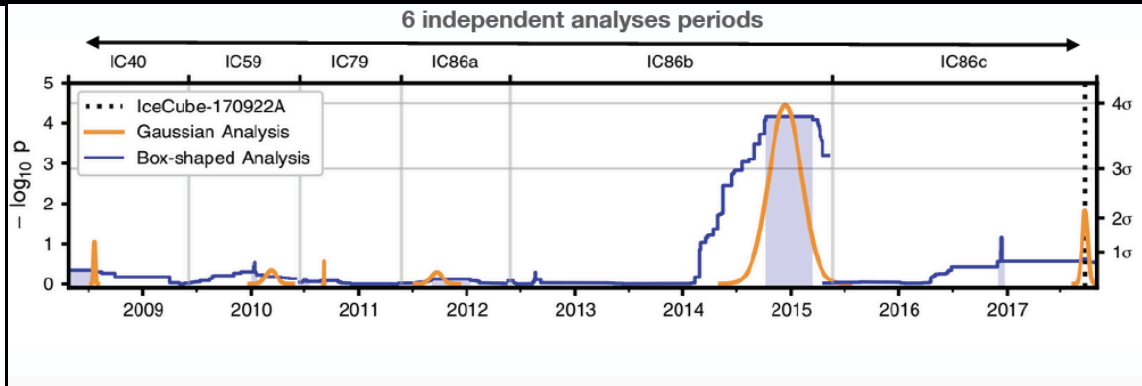


IC170922A and TXS 0506+056

IceCube sent an alert including the direction of a muon neutrino event of ~ 3 x 10^{14} eV in only 43 s. Shortly after, Fermi (20 MeV-300 GeV) discovered a blazar, TXS 0506+056 at 0.06° distance from the IceCube event in a flaring state (ATel#10791). In a follow up from 1.3-40 d, MAGIC detected gamma rays of > 300 GeV energy from the source with >6.2σ (ATel#10817, MAGIC 2018). The probability that this is not a casual coincidence is 3σ post-trial. IceCube found a 2nd flare from the source in 2014-15 with higher significance of 3.5σ post-trial.

Variability up to x6 in 1 d. Among the top 3% most intense blaars in Fermi catalogue. z= 0.336.

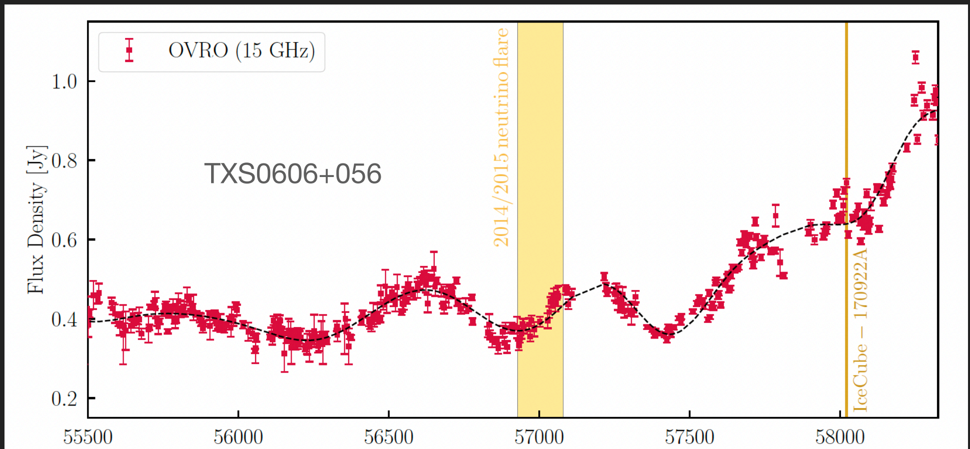


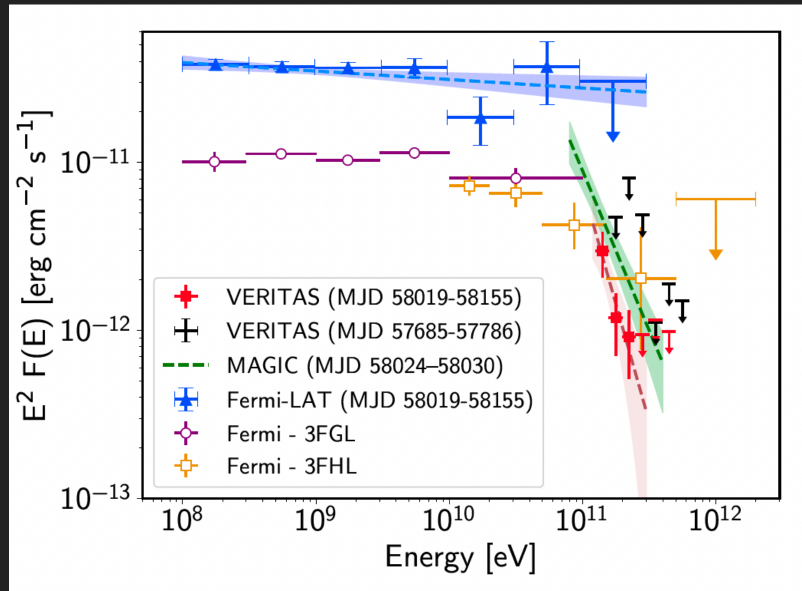


Science 361, 147-151 (2018)
A. Christov thesis UNIGE archive

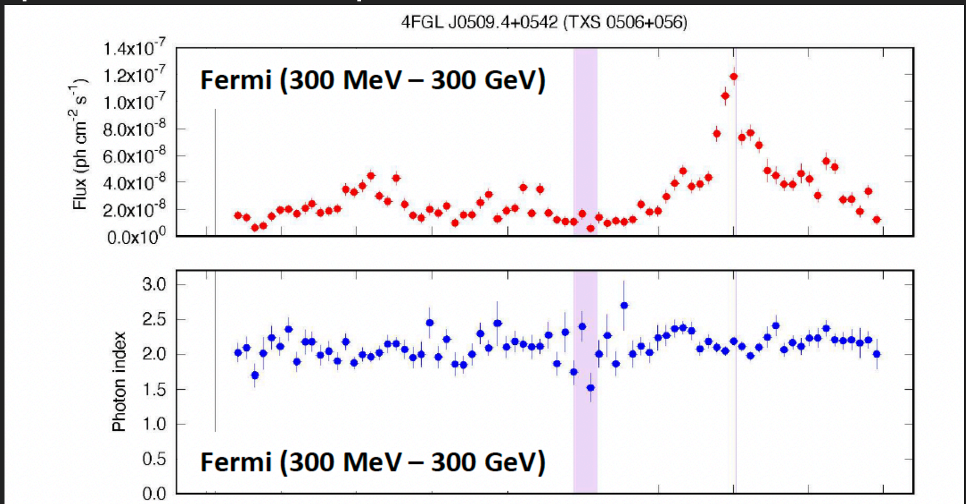
MAGIC @ Los Roche de los Muchachos, La Palma

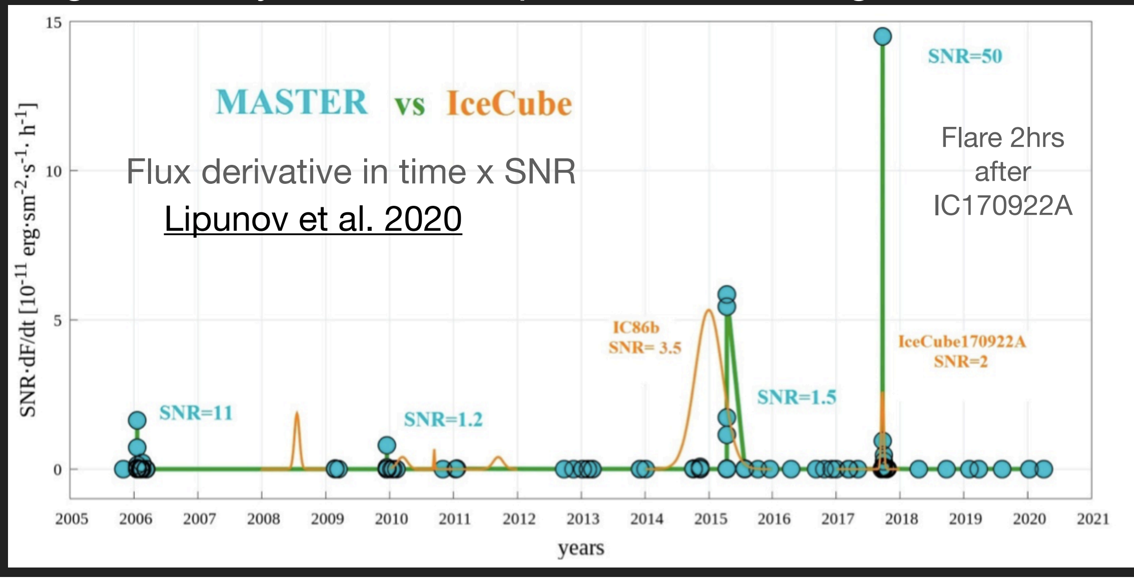
TXS0506+056 IN OTHER BANDS





A huge flare in Fermi-LAT for 2017 event, no MWL activity in gamma-rays aside from possible hardening. In the optical MASTER reports flares in 2014-2015 and 2017





ANOTHER EVENT?

IceCube Another 300 TeV neutrino is observed in space-coincidence with PKS 1502+106 (z ~1.8) low-spectral peaked and highly polarized quasar (Stein et al GCN 25225).

[Previous | Next | ADS]

Neutrino candidate source FSRQ PKS 1502+106 at highest flux density at 15 GHz

ATel #12996; ***S. Kiehlmann (IoA FORTH, OVRO), T. Hovatta (FINCA), M. Kadler (Univ. WÃ¼rzburg), W. Max-Moerbeck (Univ. de Chile), A. C.S. Readhead (OVRO)***
*on **7 Aug 2019; 12:31 UT***
Credential Certification: Sebastian Kiehlmann (skiehlmann@mail.de)

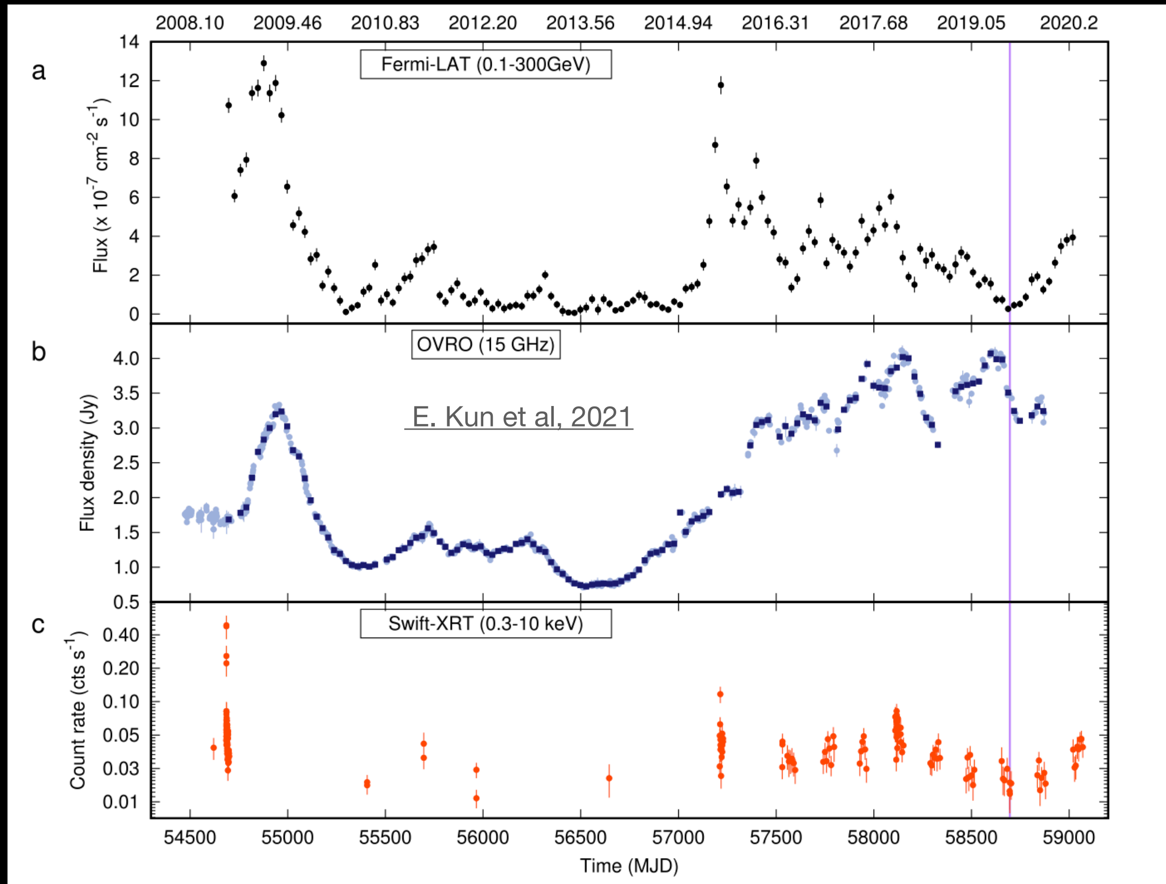
Subjects: Radio, Neutrinos, AGN, Blazar, Quasar

Tweet

On 2019/07/30.86853 UT IceCube detected a high-energy astrophysical neutrino candidate (Atel #12967). The FSRQ PKS 1502+106 is located within the 50% uncertainty region of the event. We report that the flux density at 15 GHz measured with the OVRO 40m Telescope shows a long-term outburst that started in 2014, which is currently reaching an all-time high of about 4 Jy, since the beginning of the OVRO measurements in 2008. A similar 15 GHz long-term outburst was seen in TXS 0506+056 during the neutrino event IceCube-170922A.

Related

12996	Neutrino candidate source FSRQ PKS 1502+106 at highest flux density at 15 GHz
12985	IceCube-190730A: Swift XRT and UVOT Follow-up and prompt BAT Observations
12983	Optical fluxes of candidate neutrino blazar PKS 1502+106
12981	ASKAP observations of blazars possibly associated with neutrino events IC190730A and IC190704A
12974	Optical follow-up of IceCube-190730A with ZTF
12971	IceCube-190730A: MASTER alert observations and analysis
12967	IceCube-190730A an astrophysical neutrino candidate in spatial coincidence with FSRQ PKS 1502+106
12926	VLA observations reveal increasing brightness of 1WHSP J104516.2+275133, a potential source of IC190704A



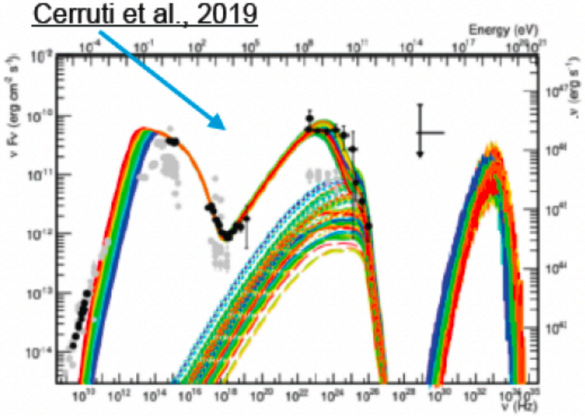
Phenomenological interpretation

Rate of neutrinos can work but energetics high
~10^{-2} - 10^{-1} ν/yr but
$L_{jet} > L_{edd} \sim 10^{46} \div 10^{47}$erg/s

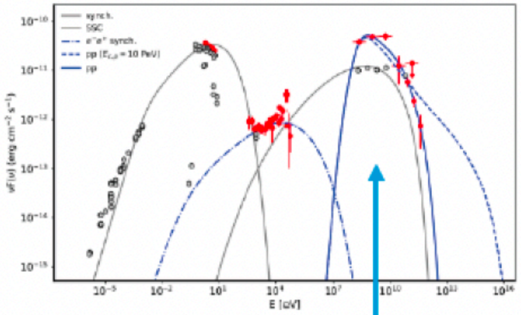
TXS 0506+056

Theoretical interpretations

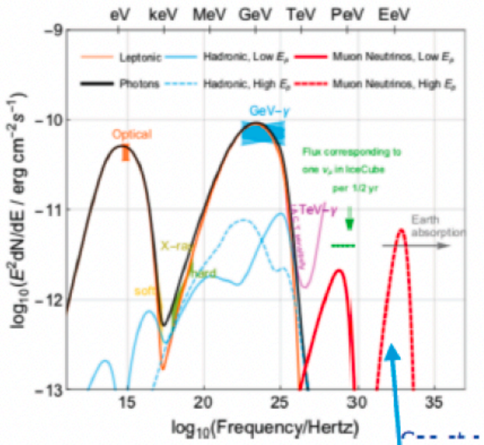
Rate of neutrinos low
10^{-5} - 10^{-3} ν/yr



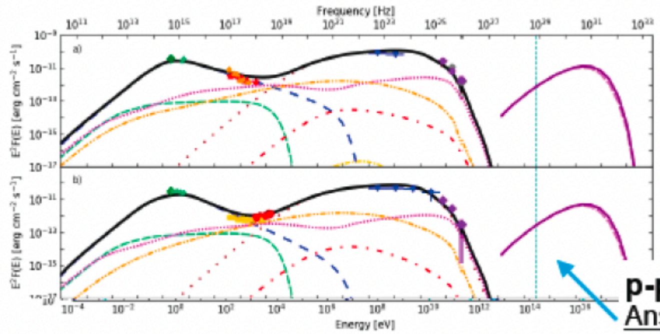
Proton-synchrotron
Keivani et al., 2018
Gao et al., 2018
Cerruti et al., 2019



Jet+cloud (pp)
Sahakyan et al., 2018
Liu et al., 2019



Hadro-leptonic
Gao et al., 2018
Cerruti et al., 2019



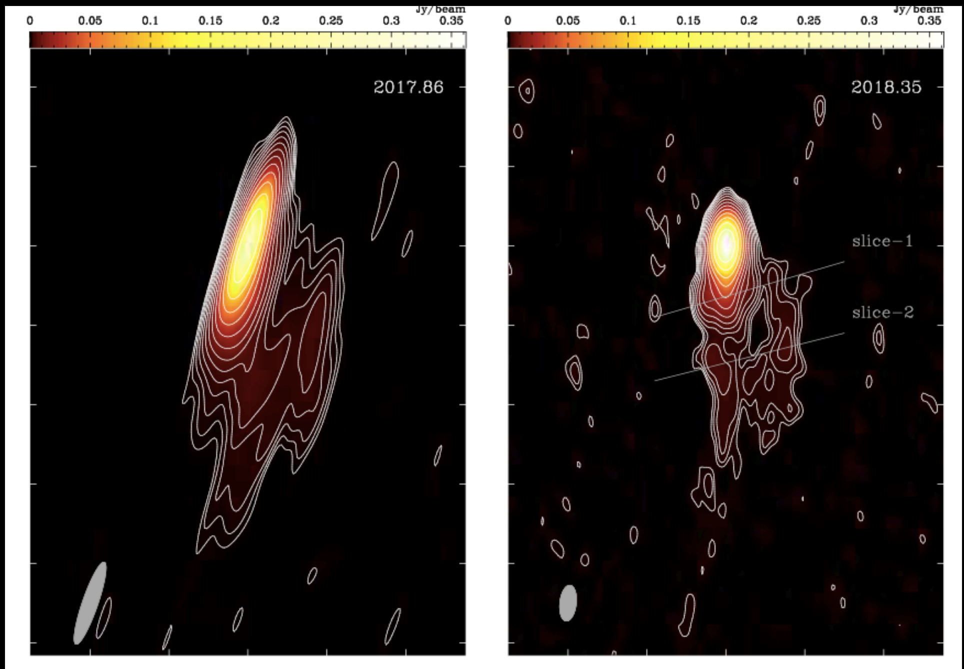
p-ph on external ph field
Ansoldi et al., 2018 (jet layer)
Keivani et al, 2018 (BB)
Righi et al., 2019 (RIAF)

Rate of neutrinos low
~ ~10^{-2} - 10^{-1} ν/yr but
$L_{jet} \sim 10^{45} \div 10^{46}$erg/s

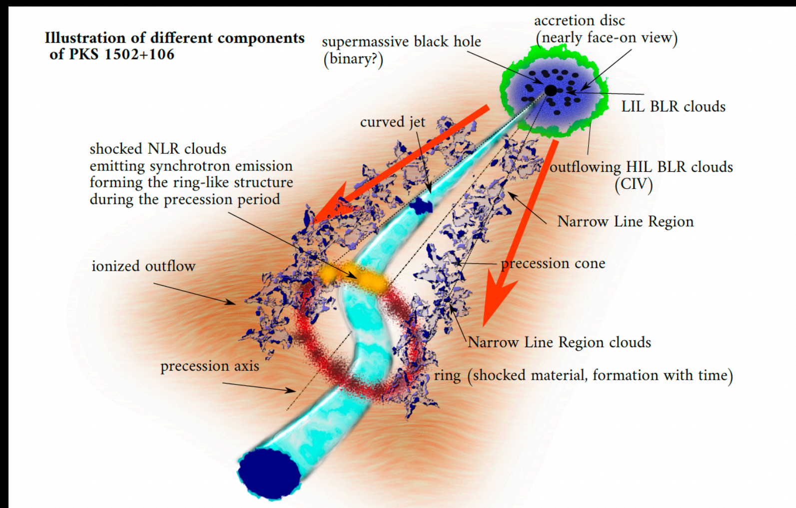
Collection of models borrowed from R: Mirzoyan ISVECHRI 2022
And Cerruti at TeVPA2022

Radio observations and events concerning the jet

Ros et al A&A 633, 2020:
Nov. 2017 and May 2018 mm-VLBI radio 43 GHz observations indicate a compact core with highly collimated jet and a downstream jet showing a wider opening angle (slower) external sheat (loss of collimation of the jet beyond 0.5 mas). The slower flow serves as seed photons for $p-\gamma$ interactions producing neutrinos. Initially proposed by MAGIC (Ansoldi et al 2018)



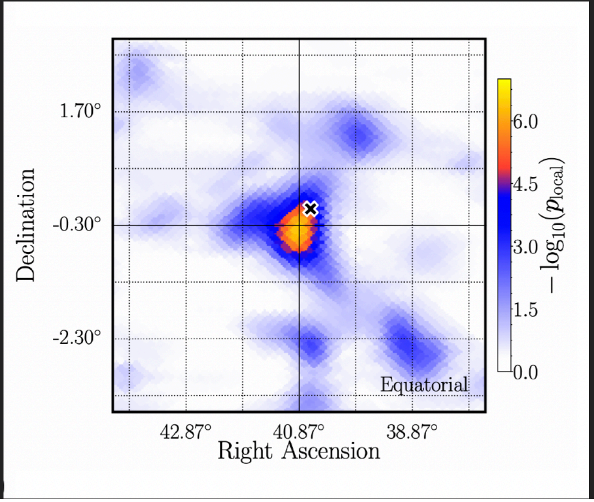
Brizen et al 2021
PKS1506+106: Precessing curved jet interacting with the Narrow Line Region clouds at distance of 330 pc and a ring-like and arc like configuration developing right before the neutrino emission and not present at all times. The ring is offset from the jet axis



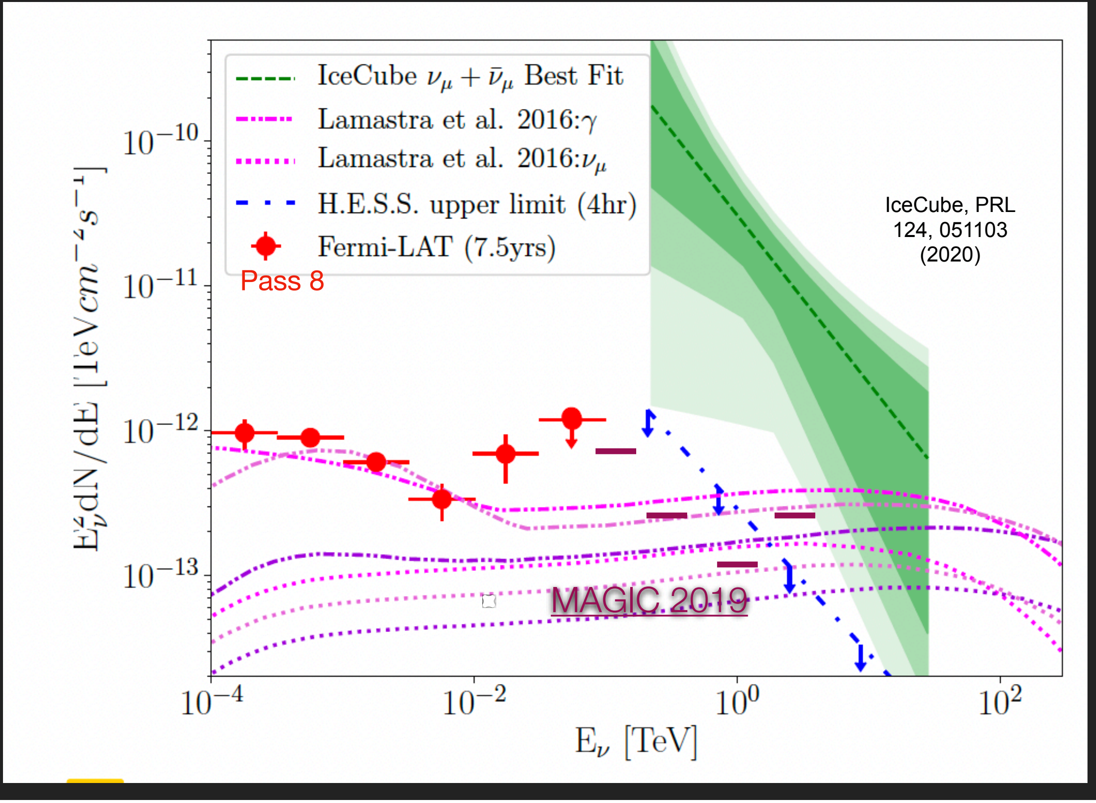
NGC 1068: THE HOTTEST SPOT IN 10 YR ICECUBE DATA

Hottest spot in all sky scan + and 2.9σ from the catalogue search of 110 motivated sources with high emission in Fermi + starburst. The excess is centered ~0.35°from NGC 1068 => Offset consistent with simulated tests for a soft flux from it for $E^{-3.3}$ spectrum resulting from the fit.

Excess of 3.3σ from the population study of the catalogue dominated by NGC 1068, TXS 0506+056, PKS 1424+240,GB6 J1542+6129.

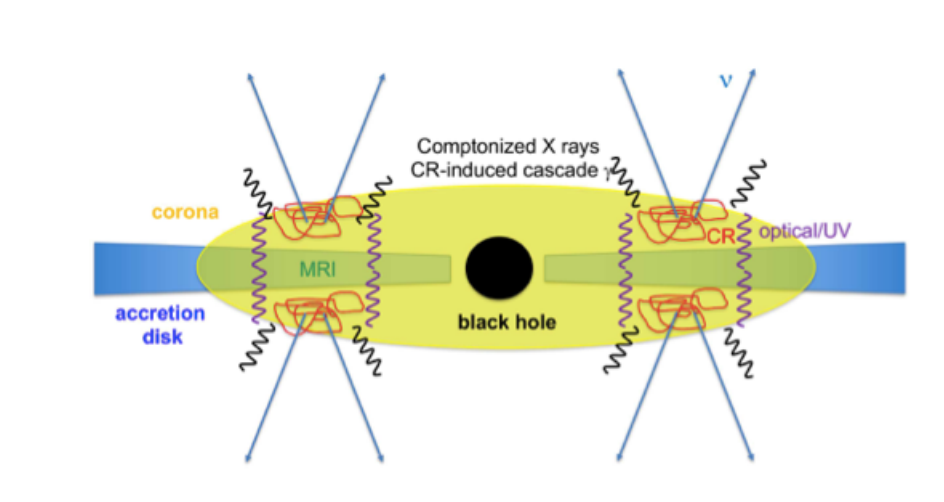


NGC 1068 region in neutrinos (IceCube PRL 124 (2020))



Neutrinos from the core of AGNs

Murase, Kimura, Meszaros 2020, Inoue et al. ApJL 891 (2020), IceCube Collaboration PRD 2022



$$\tau \approx \frac{\sigma_{\gamma\gamma}}{4\pi c}\epsilon_X^{-1} L_X R^{-1} \simeq 10^5 \left(\frac{\epsilon_X}{1\ \mathrm{keV}}\right)^{-1} \frac{L_X}{L_{\mathrm{Edd}}}\frac{R_s}{R}$$

selection:

- X-ray catalogues 2RXS + XMMSL2
- IR WISE catalogue: X-rays associated with the core produce infrared light on dust at the center of the galaxy

correlation between cores of active galaxies and cosmic neutrinos

(γ = -2.03; 2.6σ post trial)

The neutrino emission is assumed to be proportional to the accretion disk luminosity estimated from the soft X-ray flux. Next to the observed soft X-ray flux, the objects for the 3 samples have been selected based on their radio emission and infrared color properties.

Another Search: IceCube search for ULIRG

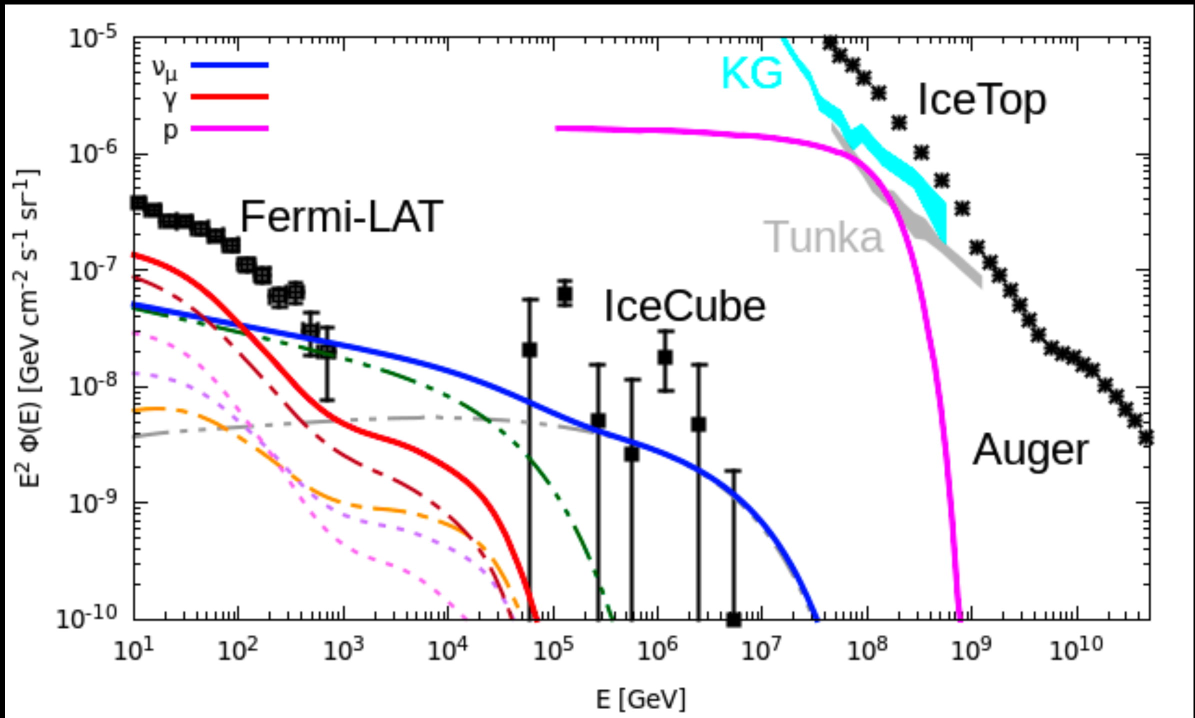
Ultra-Luminous Infrared Galaxies

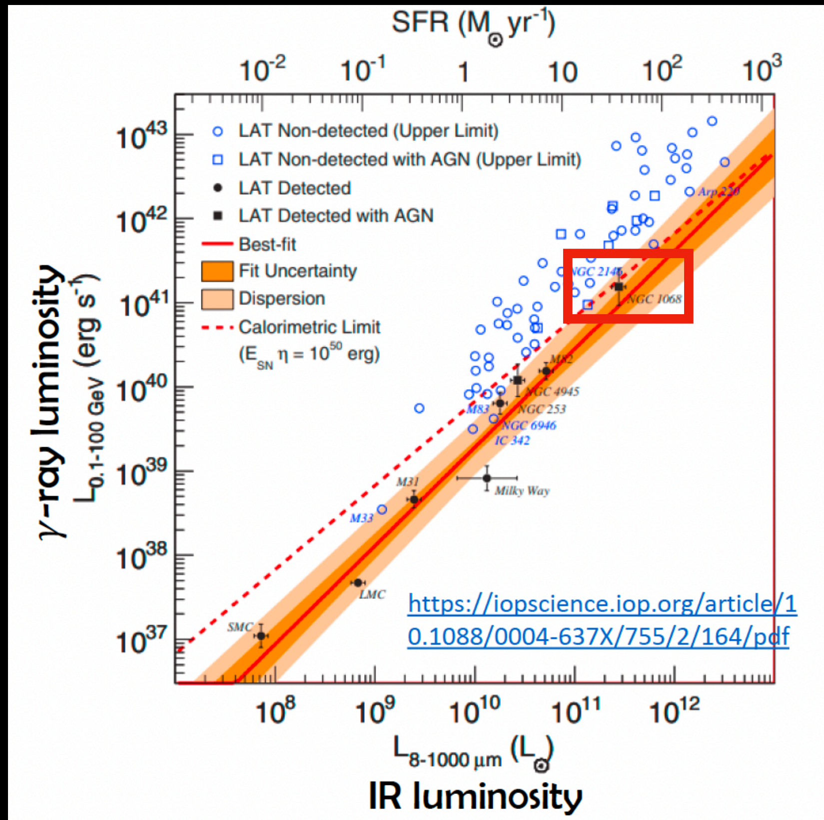
NGC 1068: tthe neutrino emission can be produced in the vicinity of the supermassive BH in the center of the galaxy, namely in the **corona, an optically thick environment.** A large optical depth requires the presence of a **compact and dense** X-ray target of keV photons.

Gallimore et al (1996, 2004) detects in the radio the mildly relativistic jet extending several kpc in the radio with change of direction of 0.2” presumably due to an interaction with a molecular cloud. Additionally, near and mid-IR emission associated with inner radio jet as result of shock heating on the dust by passage of jet

Mildly relativistic jets in star formation regions and stellar winds

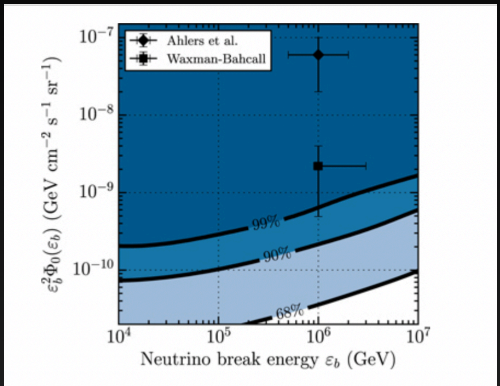
Starburst proposed long ago as neutrino sources (Waxman & Loeb, 2006). Small scale anisotropy detected by PAO UHECRs but the role of starburst as UHECRs sources is yet controversial (Lunardini et al. 2019). Starburst winds can accelerate to 100 PeV (Peretti et al, 2022, talk at Gamma 2022).

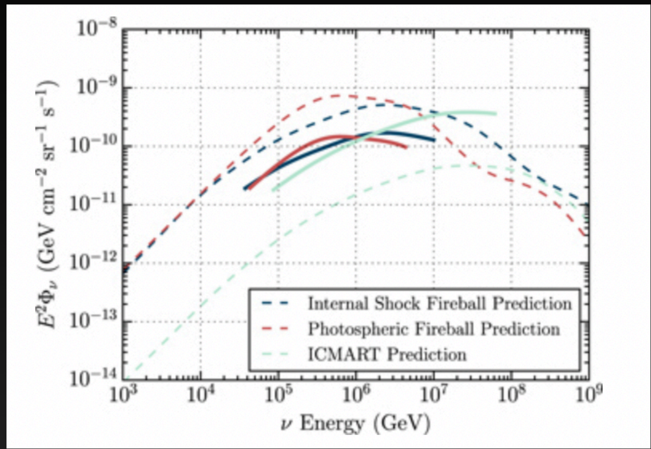




1172 GRBs and IceCube (2010-2015)

IceCube 2017





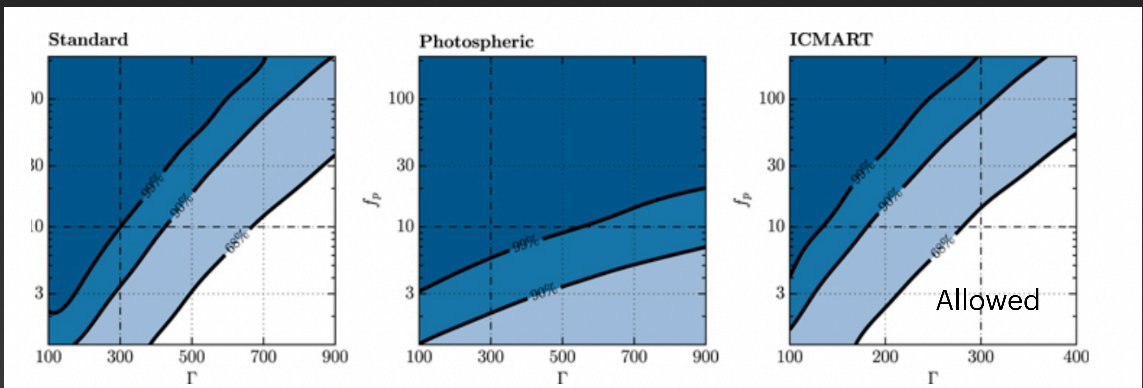
More recently a new paper has been submitted extending the window to 14 d after the prompt and for a catalogue of precursors (IceCube 2022)

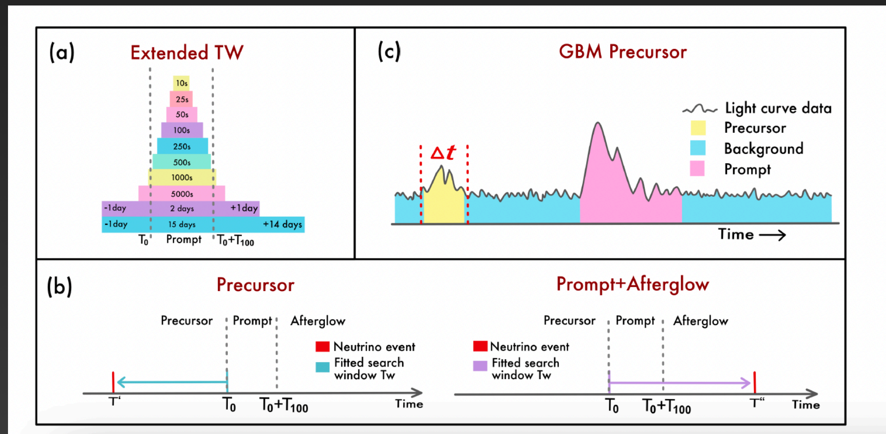
From per flavor burst g flux to diffuse

$$\Phi_{\Gamma,f_p}(E_\nu) = \left[\sum_g F_{g;\Gamma,f_p}(E_\nu)\right] \times \left(\dot{N}_{\rm GRB}/N_{\rm obs}\right) \times (4\pi\ {\rm sr})^{-1}$$

Assumes equal fluence at Earth

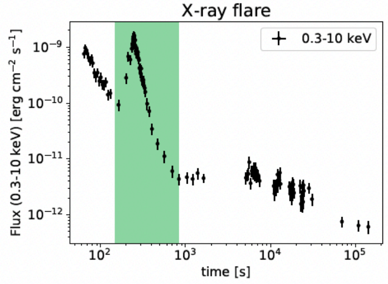
Allowed



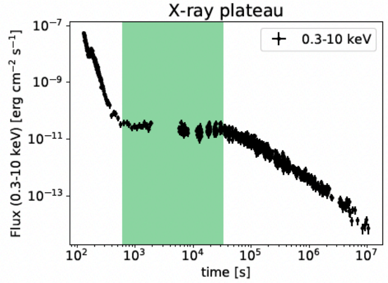


Motivated catalogs for prompt and afterglow phases

After glow phase (Swift



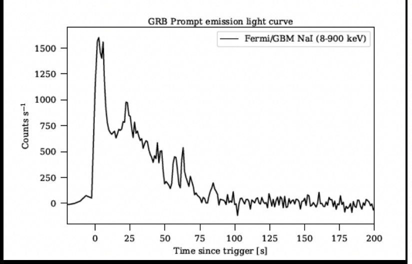
(b) GRB 100727



(c) GRB 060729

X-ray flares might originate from internal shocks similar to prompt phase.

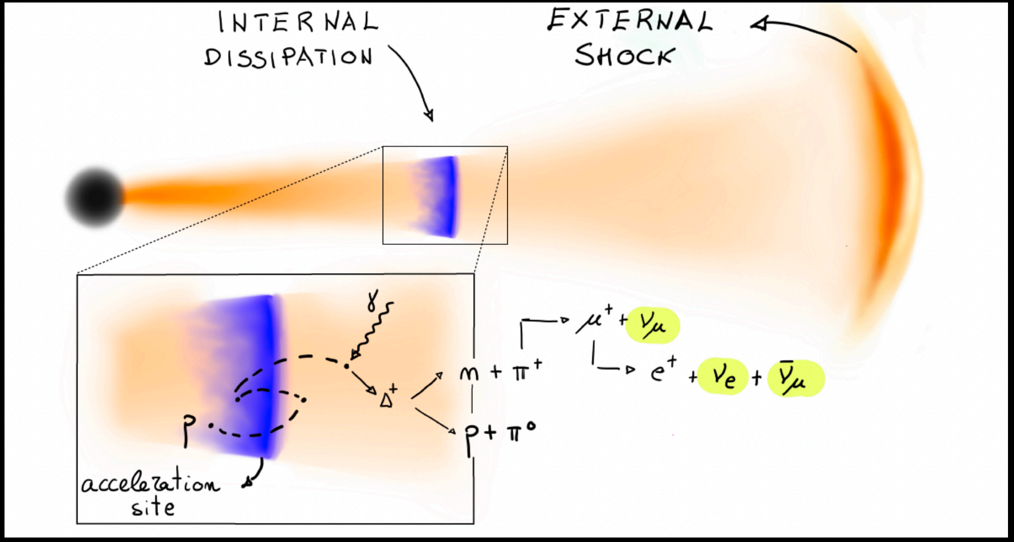
Prompt



(sub)catalog	North	South	weights $\gamma = 1$	weights $\gamma = 2$	Constrained parameters
Catalogs of GRBs with and without measured redshift					
Prompt	959	792	$S_{\rm iso} E_{\gamma,\rm peak}^{-1.6}$	$S_{\rm iso} E_{\gamma,\rm peak}^{-1.6}$	ξ_p–Γ, ξ_p–$\delta t_{\rm obs}$, ξ_p–B
X-ray plateau	141	119	$S_{\rm iso}^X$	$S_{\rm iso}^X$	ξ_p–Γ
X-ray flare	117	83	$S_{\rm iso}^X$	$S_{\rm iso}^X$	ξ_p–Γ
Subcatalogs of GRBs with measured redshift					
Prompt	73	51	$L_{\rm iso} S_{\rm iso} (1+z)^2$	$L_{\rm iso} S_{\rm iso} E_{\gamma,\rm peak}^{-1}$	ξ_p–Γ, ξ_p–$\delta t_{\rm obs}$
X-ray plateau	63	54	$L_X S_{\rm iso}^X (1+z)$	$L_X S_{\rm iso}^X/(1+z)$	ξ_p–Γ
X-ray flare	43	45	$L_X S_{\rm iso}^X (1+z)$	$L_X S_{\rm iso}^X/(1+z)$	ξ_p–Γ

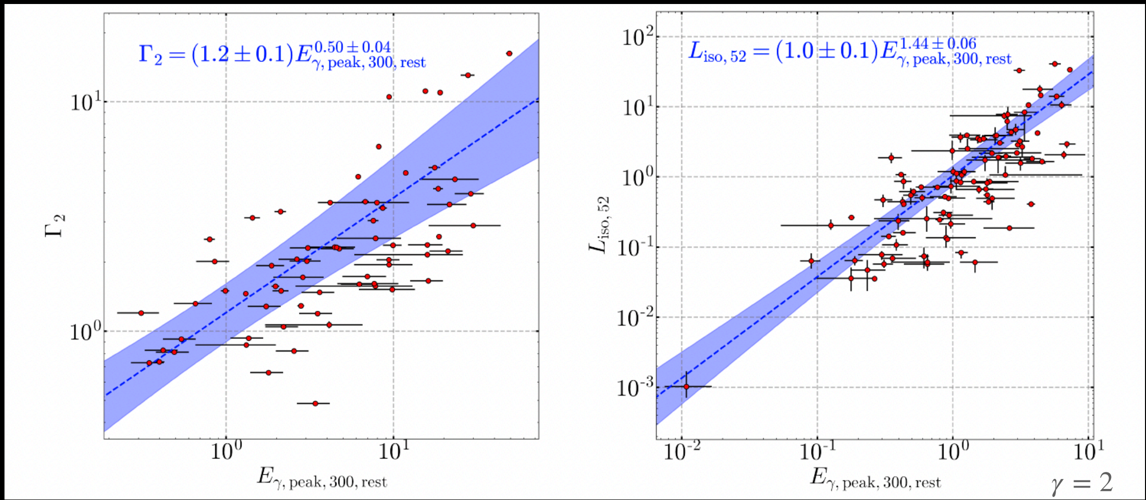
Plateau between 10^2-10^4 s after the prompt emission indicating a shallow decay phase in the lightcurve (with slope $t^{-\alpha}$ and $\alpha < 0.7$). The soft lightcurve may indicate an energy injection supplied in the late emission activity by the central engine.

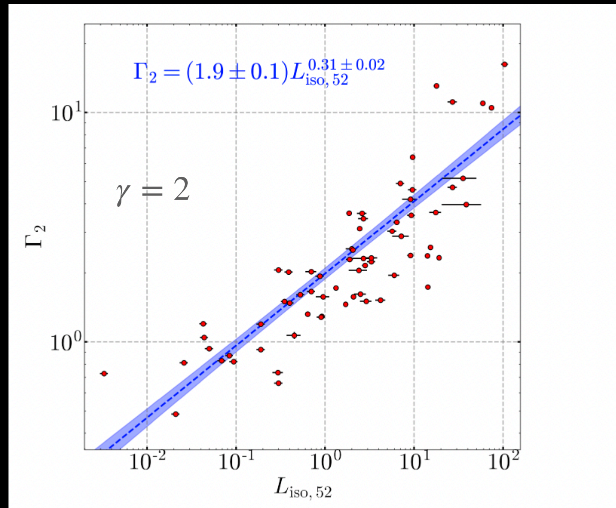
$$F_\nu = \frac{1}{8} f_{p\gamma} f_\pi^{\rm syn} f_\mu^{\rm syn} E_p^2 N_p(E_p) \frac{1+z}{4\pi d_L^2} = \frac{1}{8} \xi_p f_p f_\pi^{\rm syn} f_\mu^{\rm syn} f_{p\gamma} S_{\rm iso}$$



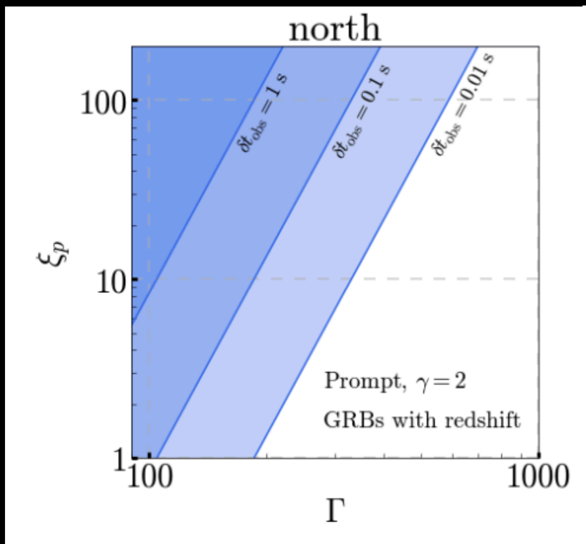
Lucarelli et al, arXiv:2208.13792

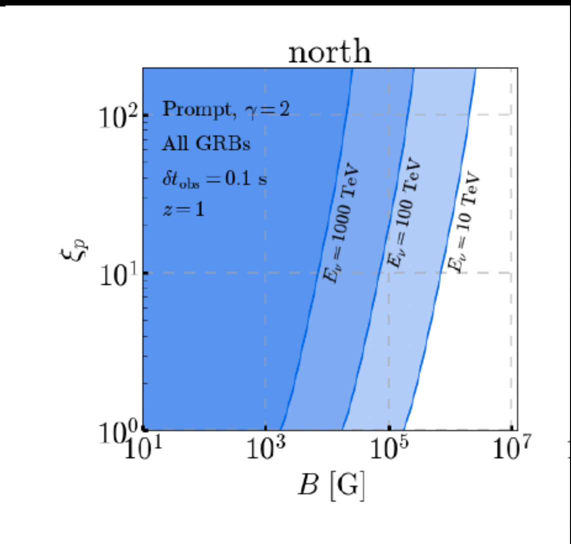
Use properties of GRBs and constrain single zone fireball model





Lucarelli et al, arXiv:2208.13792





Typically the barion loading is $\xi_p < 10$. Jets may not be baryon dominated and magnetic dominated ejecta which would produce lower energy neutrinos (KM3NeT, IceCube Upgrade)

10 yr Data sample in HEASARC and open software for point-source searches

See: https://github.com/orgs/icecube/repositories

For point source analysis and transient sources
https://github.com/icecube/PSLab_PS_analysis
https://github.com/icecube/flarestack
https://github.com/icecube/skyllh
https://github.com/icecube/FastResponseAnalysis

FIRESONG to simulatie populations of neutrinmo sources

Browse this table... | **ICECUBEPSC - IceCube All-Sky Point-Source Events Catalog (2008-2018)** | HEASARC Archive

Overview

IceCube has performed several searches for point-like sources of neutrinos. The events contained in this release make up the sample used in IceCube's 10-year time-integrated neutrino point source search [1]. Events in the sample are track-like neutrino candidates detected by IceCube between April 2008 and July 2008.

The data contained in this release of IceCube's point source sample shows 3.3 sigma evidence of a cumulative excess of events from a catalog of 110 potential sources, primarily driven by four sources (NGC 1068, TXS 0506+056, PKS 1424+240, and GB6 J1542+6129). NGC 1068 gives the largest excess and appears in spatial coincidence with the hottest spot in the full Northern sky search [1].

IceCube's 10-year neutrino point source event sample includes updated processing for events between April 2012 and May 2015, leading to differences in significances of some sources, including TXS 0506+056. For more information, please refer to [2].

This release contains data beginning in 2008 (IC40) until the spring of 2018 (IC86-VII). In order to standardize the release format of IceCube's point source candidate events, this release duplicates and supplants previously released data from 2012 and earlier. Events from this release cannot be combined with other IceCube public data releases.

Please note that this dataset is dominated by background events from atmospheric muons and neutrinos detected by IceCube, with a subdominant astrophysical event contribution. Any spatial or temporal correlations should therefore be carefully evaluated on a statistical basis. See [1] and references therein for details regarding the statistical techniques used by IceCube.

[1] Time-integrated Neutrino Source Searches with 10 years of IceCube Data, Phys. Rev. Lett. 124, 051103 (2020)

[2] IceCube Data for Neutrino Point-Source Searches: Years 2008-2018, https://arxiv.org/abs/2101.09836

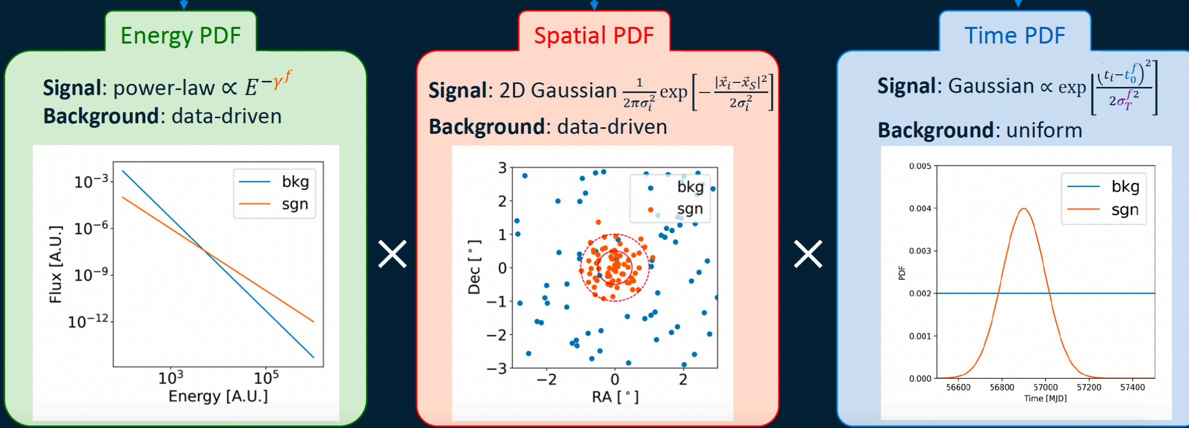
For additional questions about this table, please contact the authors: data [AT] icecube.wisc.edu.

Catalog Bibcode

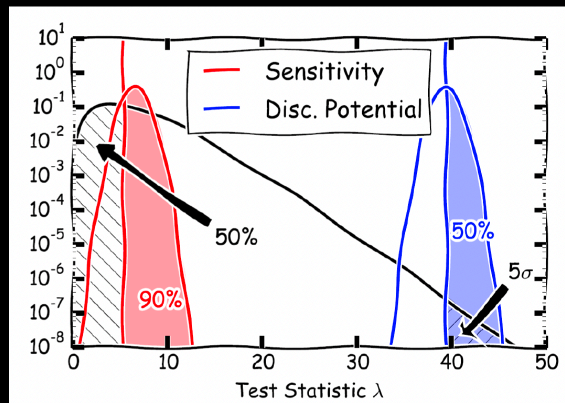
2021arXiv210109836I

https://heasarc.gsfc.nasa.gov/W3Browse/icecube/icecubepsc.html

$$\mathcal{L}(\vec{n}_s, \vec{\gamma}, \vec{t}_0, \vec{\sigma}_T) = \prod_{i=\text{events}} \left\{ \sum_{f=\text{flares}} \left[\frac{n_s^{(f)}}{N} S_i^{(f)}(\gamma^f, t_0^f, \sigma_T^f) \right] + \left(1 - \sum_f \frac{n_s^{(f)}}{N} \right) B_i \right\}$$



Phys. Rev. Lett. 124, 051103 (2020), arXiv:2101.09836v2



Conclusions

- IceCube measured diffuse fluxes with an established astrophysical component
- Despite systematic errors mostly due to the knowledge of cosmic ray composition and hadronic models, gamma-rays offer solid benchmark for preictions of neutrino fluxes (in a short time 3 more LSTs will be close to LST-1+ 2 MAGIC telescopes)
- The Galactic plane component is minor in the diffuse fluxes but is at reach.
- Established gamma Galactic PeVatrons will take time for an evidence
- Blazar flares are promising due to the multi-messenger connection
- Some close-by starbursts offer environments with mild-jets, molecular cloud targets and stellar winds
- GRBs are sources of UHECRs? If we are ready to accept multiple zone models for AGNs models can be twicked and we need more observations… (Gen2, KM3NeT, GVD, TRIDENT, …), radio and detection from space