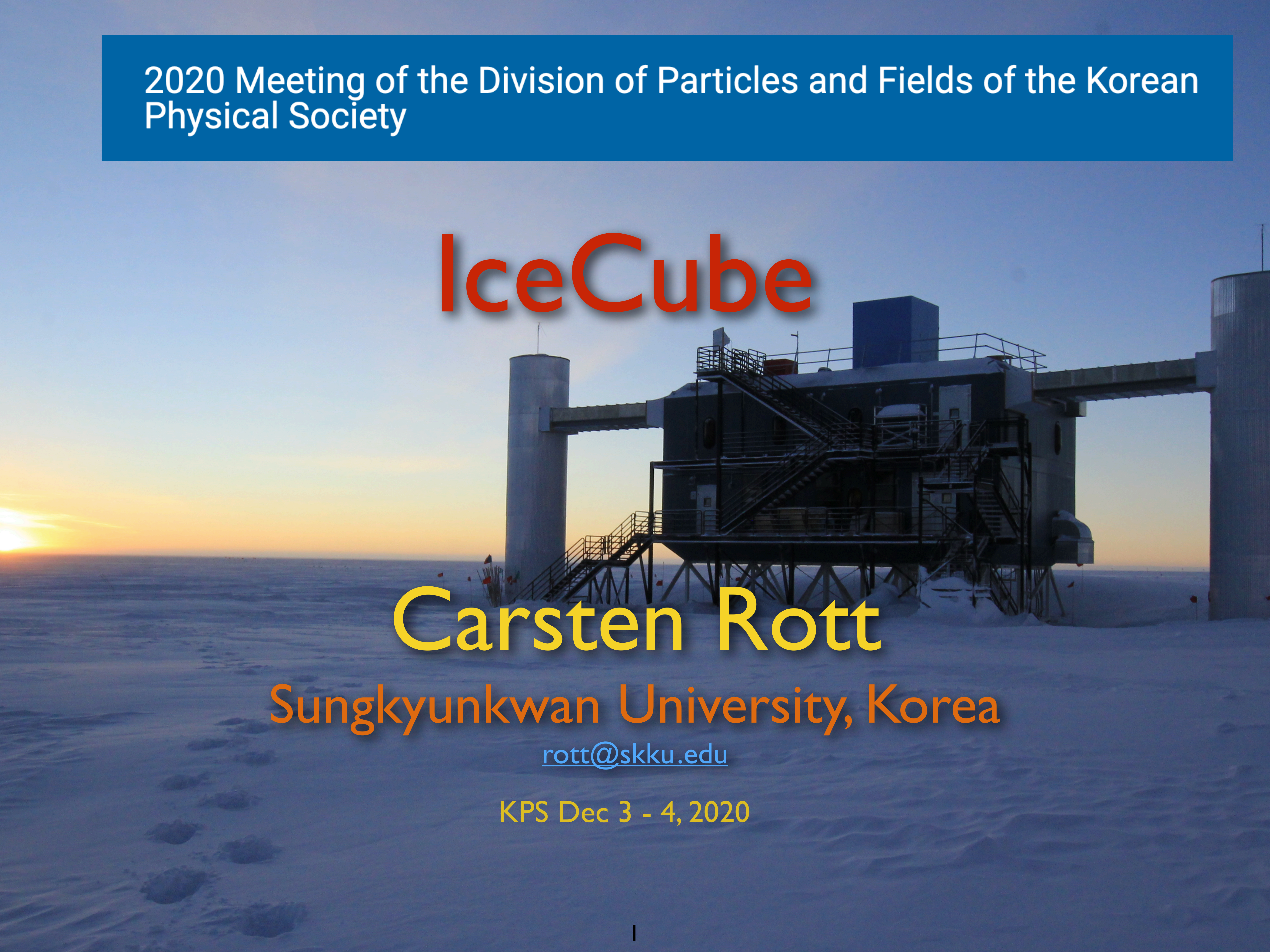


2020 Meeting of the Division of Particles and Fields of the Korean Physical Society

IceCube

Carsten Rott

Sungkyunkwan University, Korea

rott@skku.edu

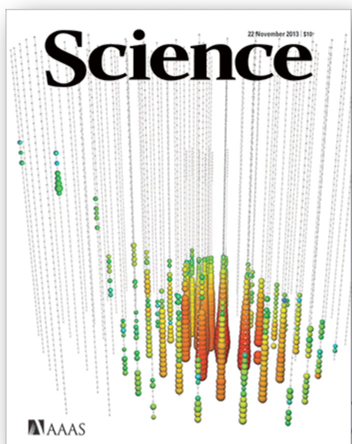
KPS Dec 3 - 4, 2020

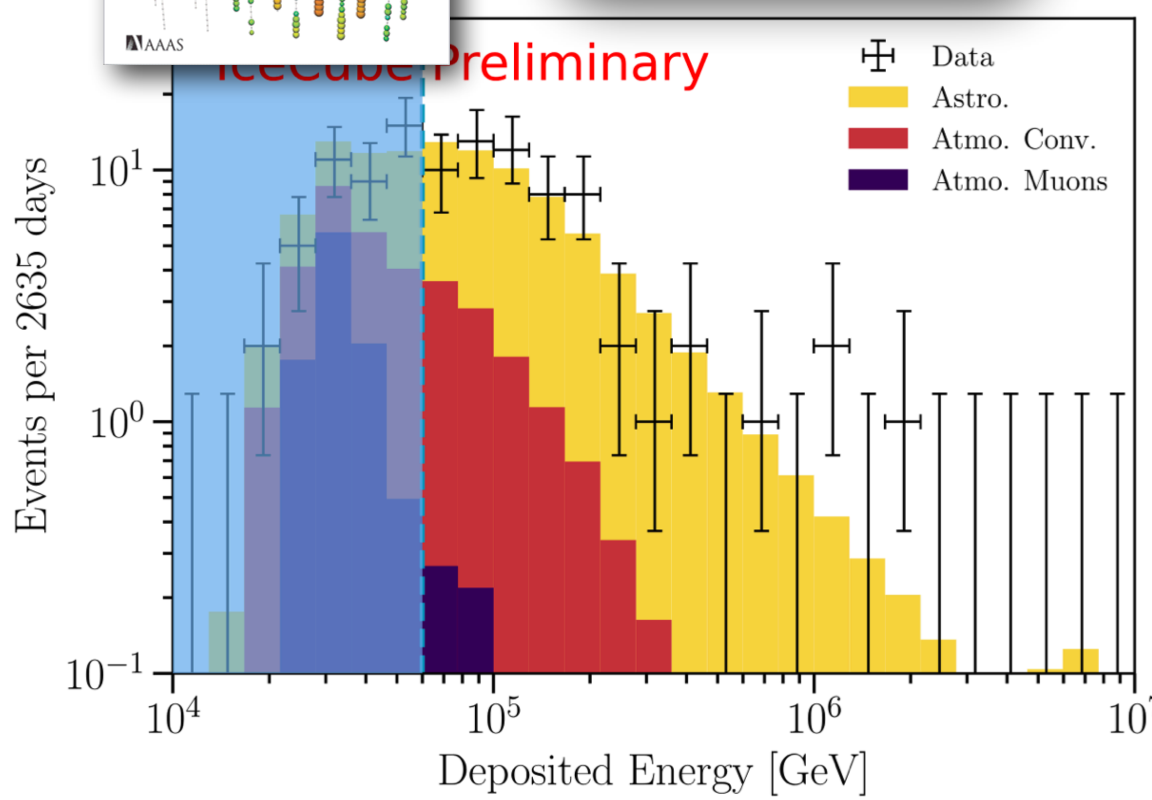
New Window to the Universe !

2002

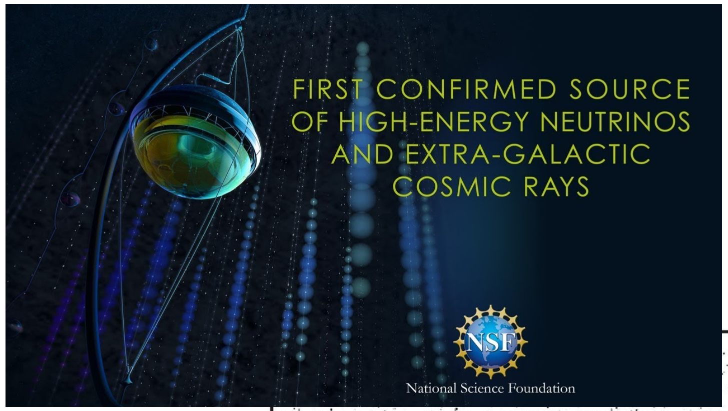
Following the observation of supernova burst neutrinos in 1987, neutrino astronomy is becoming a reality quickly now …

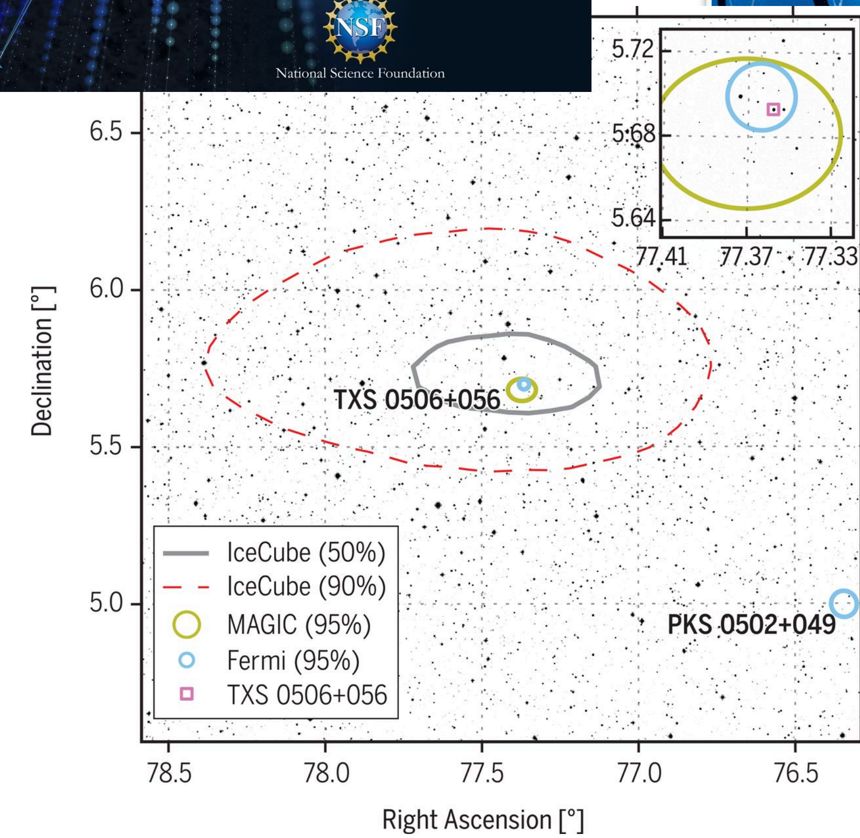
2013 Discovery of diffuse astrophysical neutrino flux





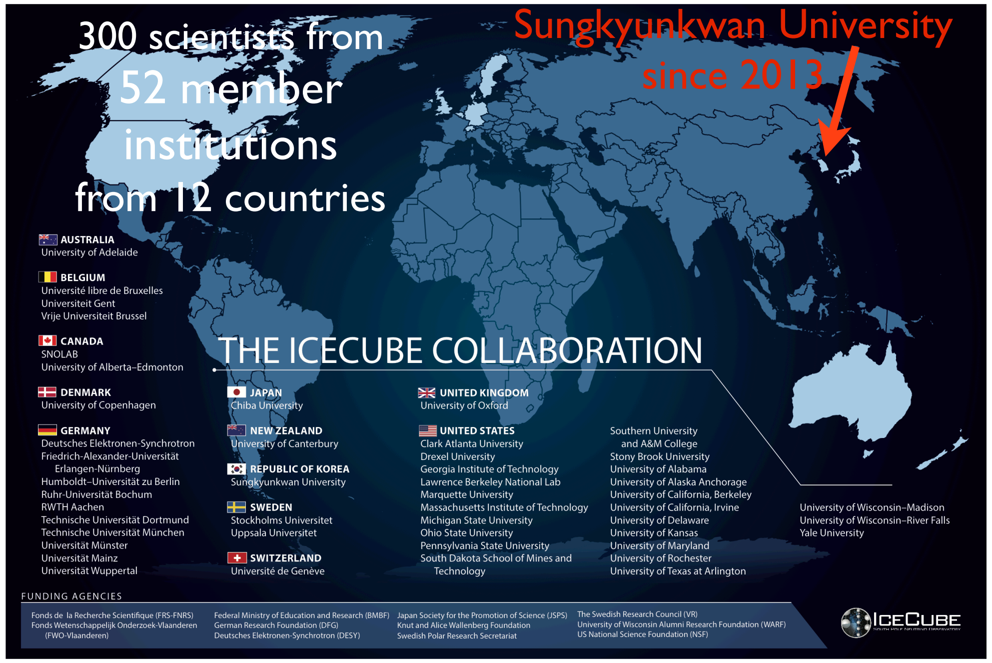
2018 Neutrino multi-messenger astroparticle physics

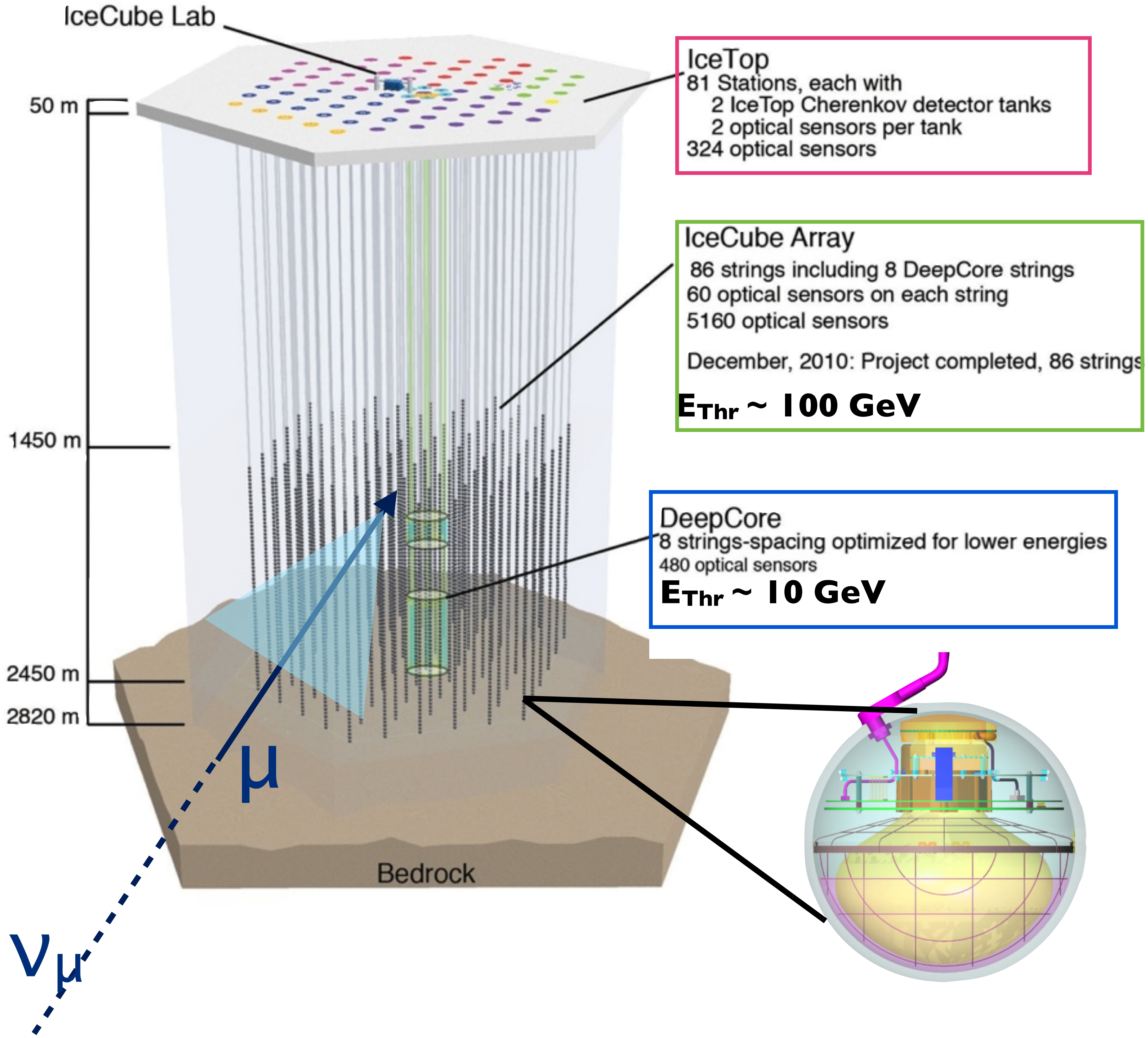




The IceCube Neutrino Telescope

- Gigaton Neutrino Detector at the Geographic South Pole
- 5160 Digital optical modules distributed over 86 strings
- Completed in December 2010
- Extremely stable: >99% uptime and 98% of sensor modules in perfect condition !
- Neutrinos are identified through Cherenkov light emission from secondary particles produced in the neutrino interaction with the ice





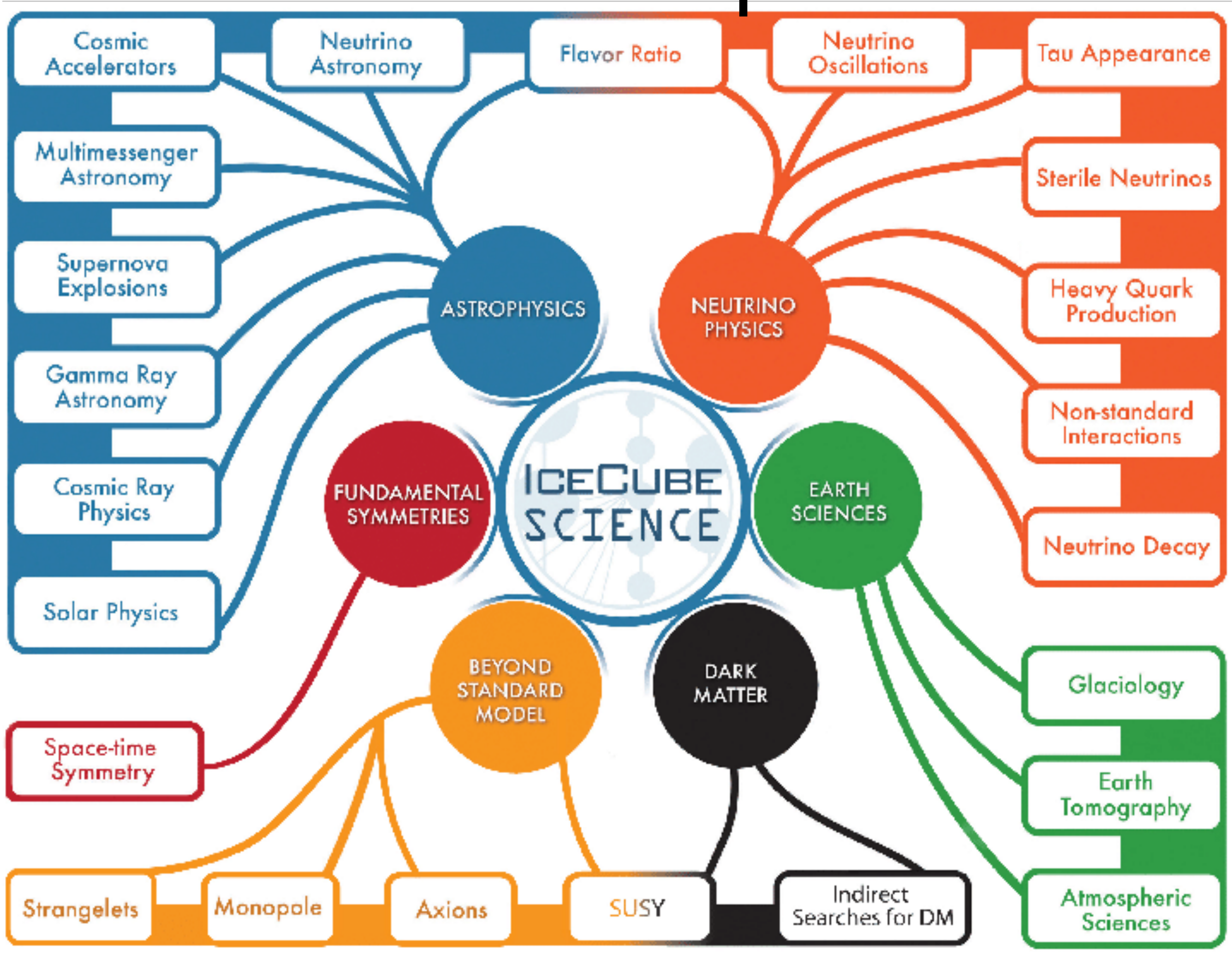
Neutrino Observatory Science

Scientific Scope

- ASTROPHYSICS & NEUTRINO SOURCES
  - Point sources of ν's (SNR, AGN …), extended sources
  - Transients (GRBs, AGN flares …)
  - Solar Atmospheric Neutrinos
  - Diffuse fluxes of ν's (all sky, cosmogenic, galactic plane …)
- BSM PHYSICS & DARK MATTER
  - Indirect DM searches (Earth, Sun, Galactic center/halo)
  - Magnetic monopoles
  - Violation of Lorentz invariance
- PARTICLE PHYSICS
  - ν oscillations, sterile ν's
  - Charm in CR interactions
  - Neutrino Cross Sections
- COSMIC RAY PHYSICS
  - Energy spectrum around "knee", composition, anisotropy
- SUPERNOVAE (galactic/LMC)
- EARTH SCIENCE

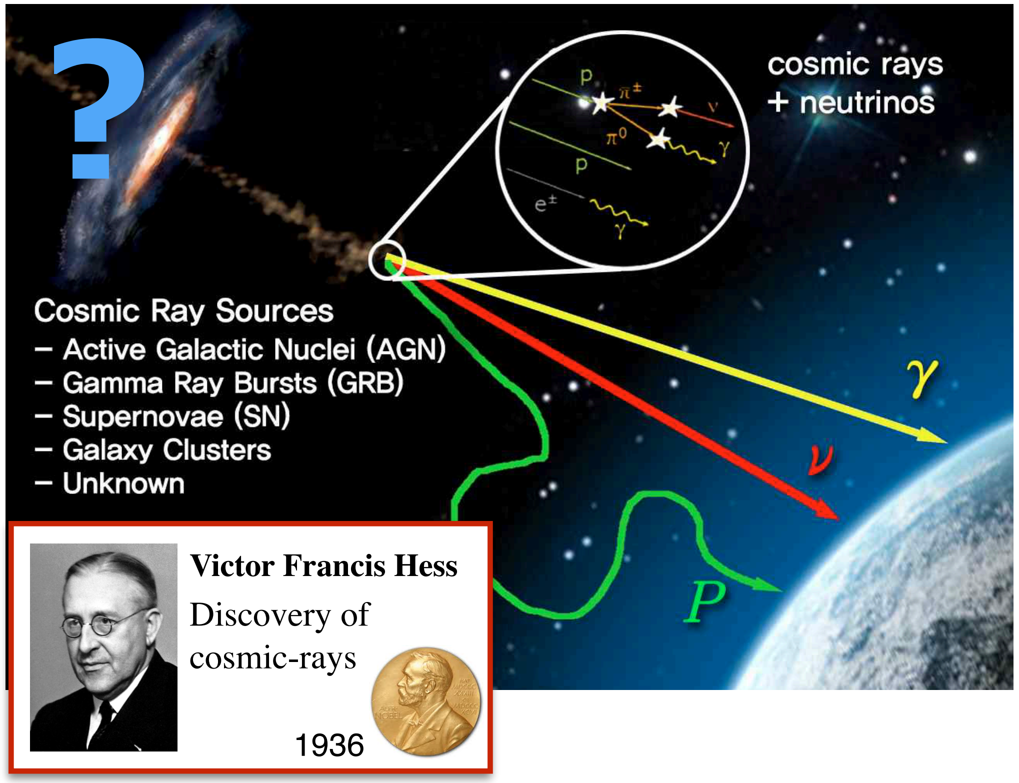
Very diverse science program, with neutrinos from 10GeV to EeV, and MeV burst neutrinos

IceCube Science Map



Main Objectives of the Korea IceCube Program

- What is the origin of the (high-energy) astrophysical neutrinos ?
  - What is are the sources of the high-energy cosmic rays ?
  - Are there any hints of physics beyond the standard model associated with the observed astrophysical neutrino flux ?
    - Explore energy scales beyond the reach of colliders
  - Are there energetic neutrinos coming from the solar atmosphere ?

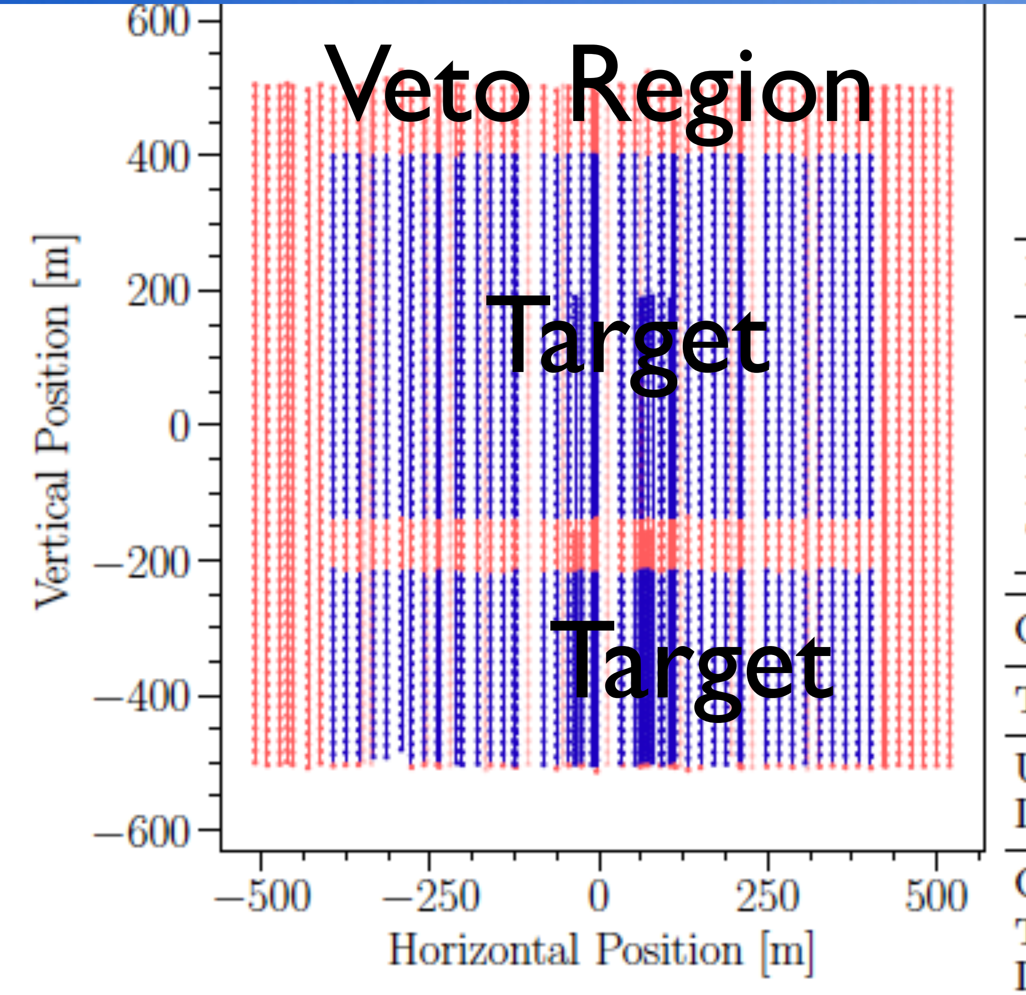


- **Challenge**: Neutrino directional pointing uncertainty
  - Overcome challenge with new detector calibration system (Korea camera)
    - Improved pointing of neutrino telescopes → multi-messenger science
    - Better understanding of IceCube detector medium → Reduced systematic uncertainties

These are the central objectives of the Korean program

Astrophysical Neutrino Search

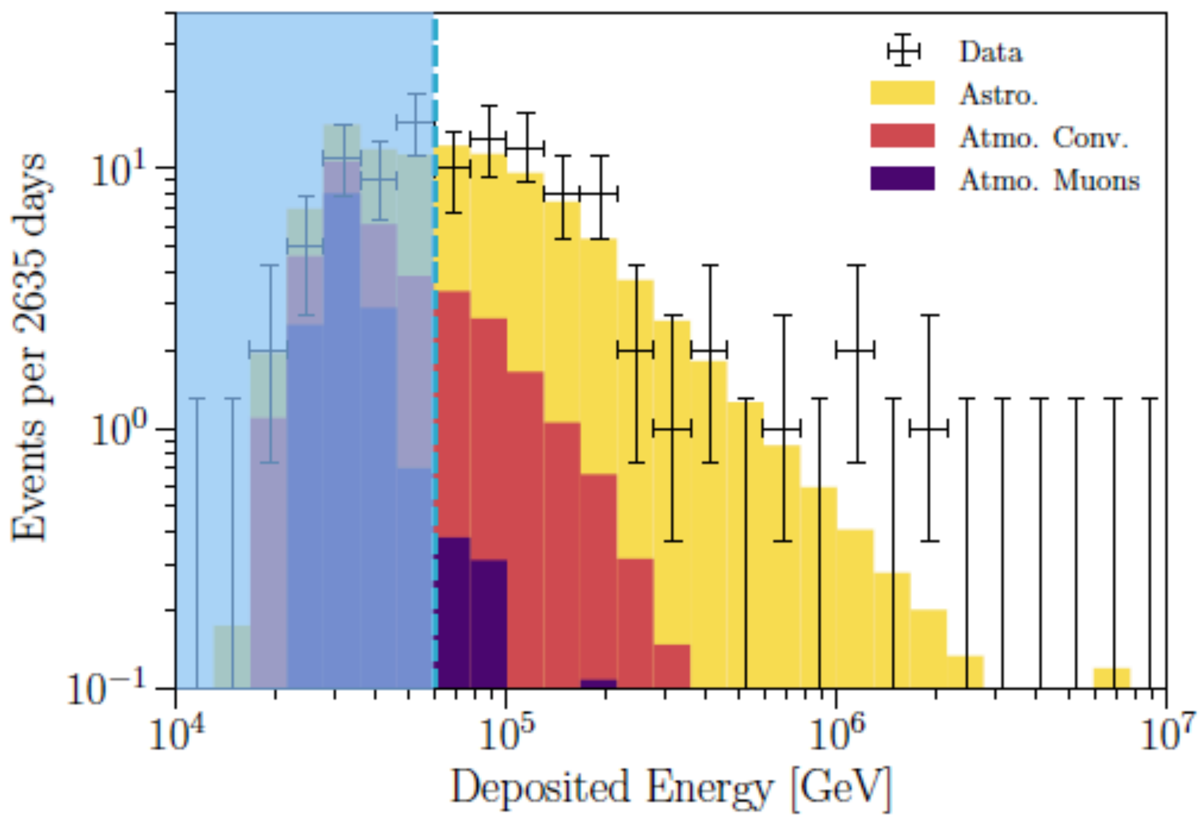
HESE 7.5 years

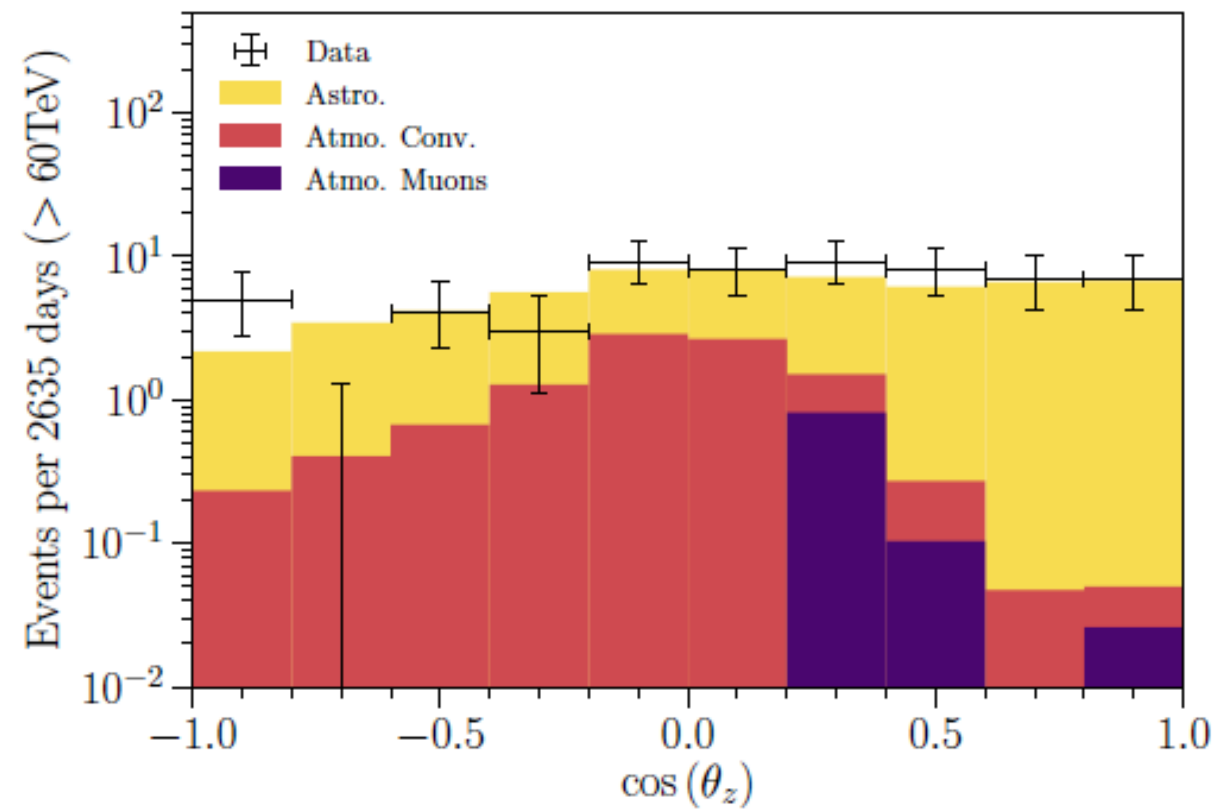


Parameter	Value
Event start time charge threshold	250 PE
Maximum veto charge	3.0 PE
Maximum DOMs with veto hits	2
Minimum total charge	6000 PE
Trigger time window	3 μs

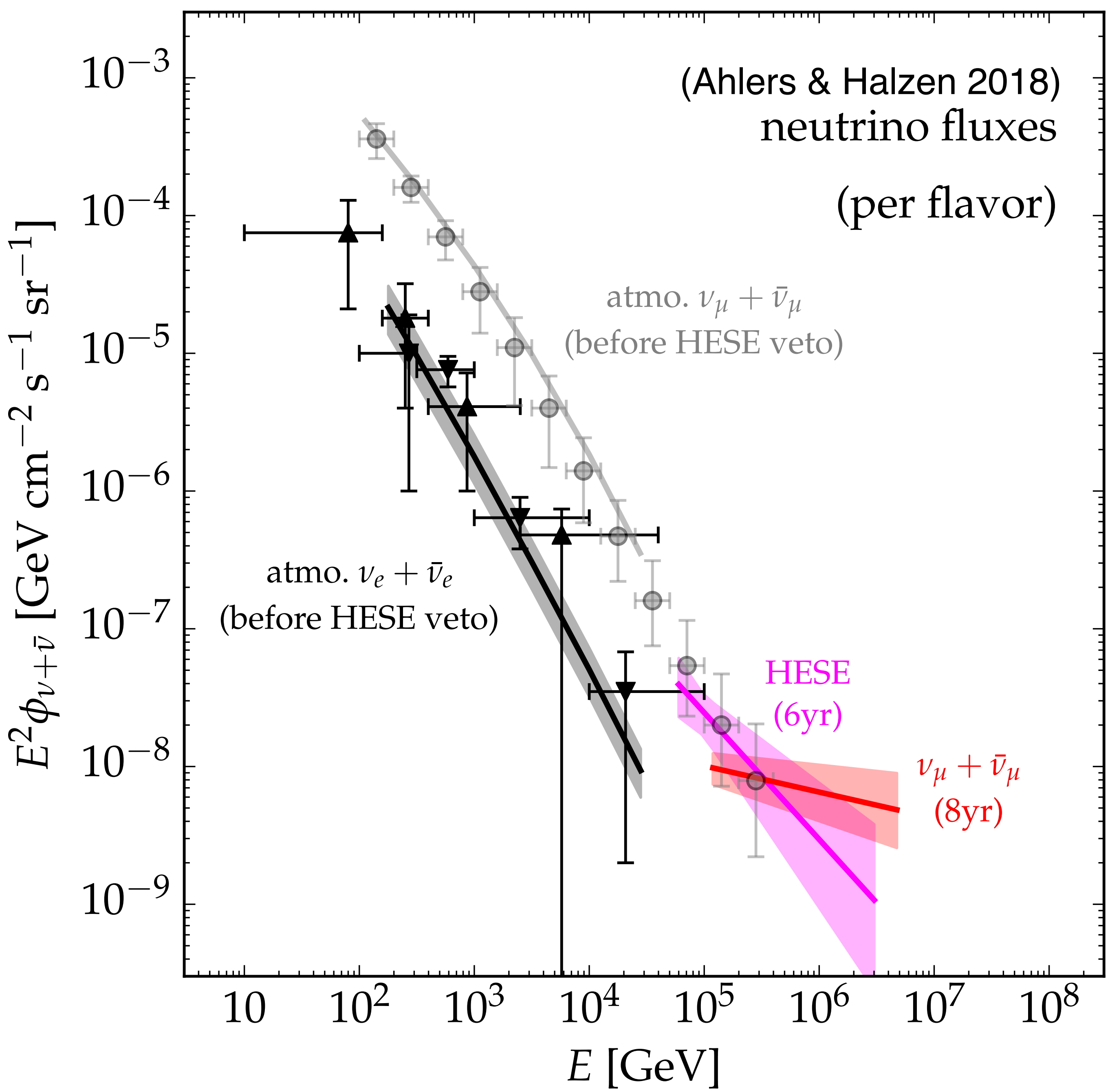
Category	$E < 60$ TeV	$E > 60$ TeV	Total
Total Events	42	60	102
Up	19	21	40
Down	23	39	62
Cascade	30	41	71
Track	10	17	27
Double Cascade	2	2	4

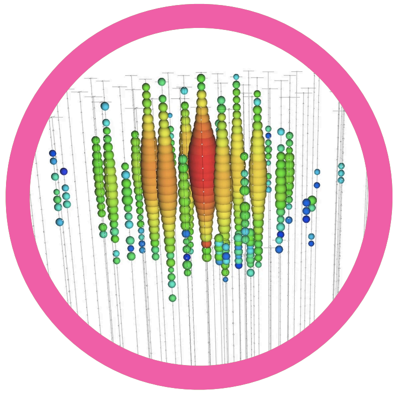
IceCube Collaboration
arXiv:2011.03545



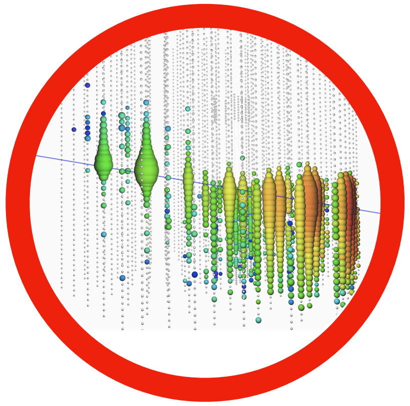


Astrophysical Neutrino Flux





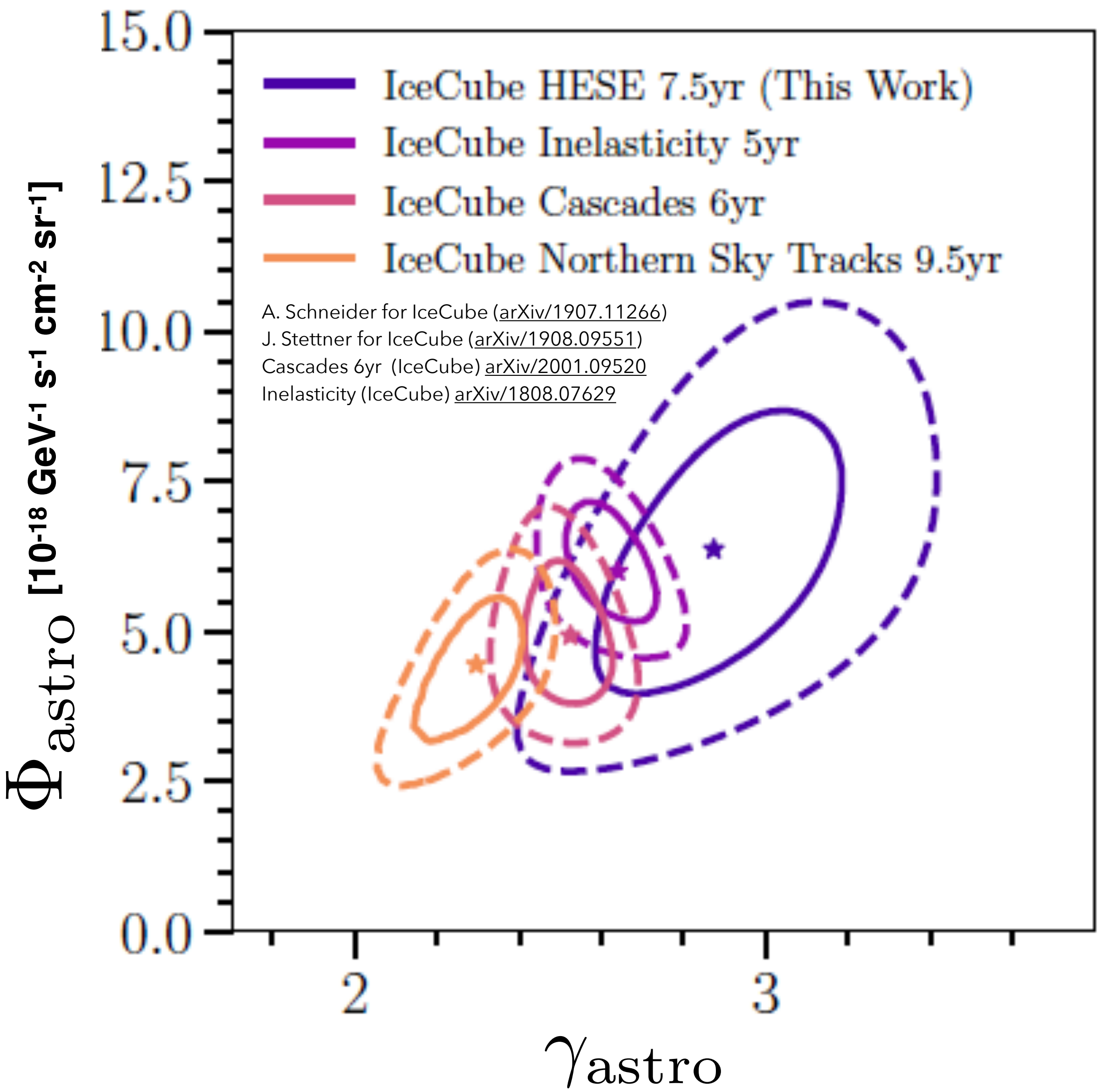
High-energy starting events (HESE)
Interaction vertex in the detector, All flavor, all sky



Up-going tracks
Muon-dominated Northern sky

- **Astrophysical flux in the 20 TeV - 9PeV range**
- **Various channels and analysis methods**

Neutrino energy spectrum



- Flux modeled with a simple power-law spectrum.

$$\Phi(E_\nu) = \Phi_{\text{astro}} \left(\frac{E_\nu}{100\ \text{TeV}} \right)^{-\gamma_{\text{astro}}}$$

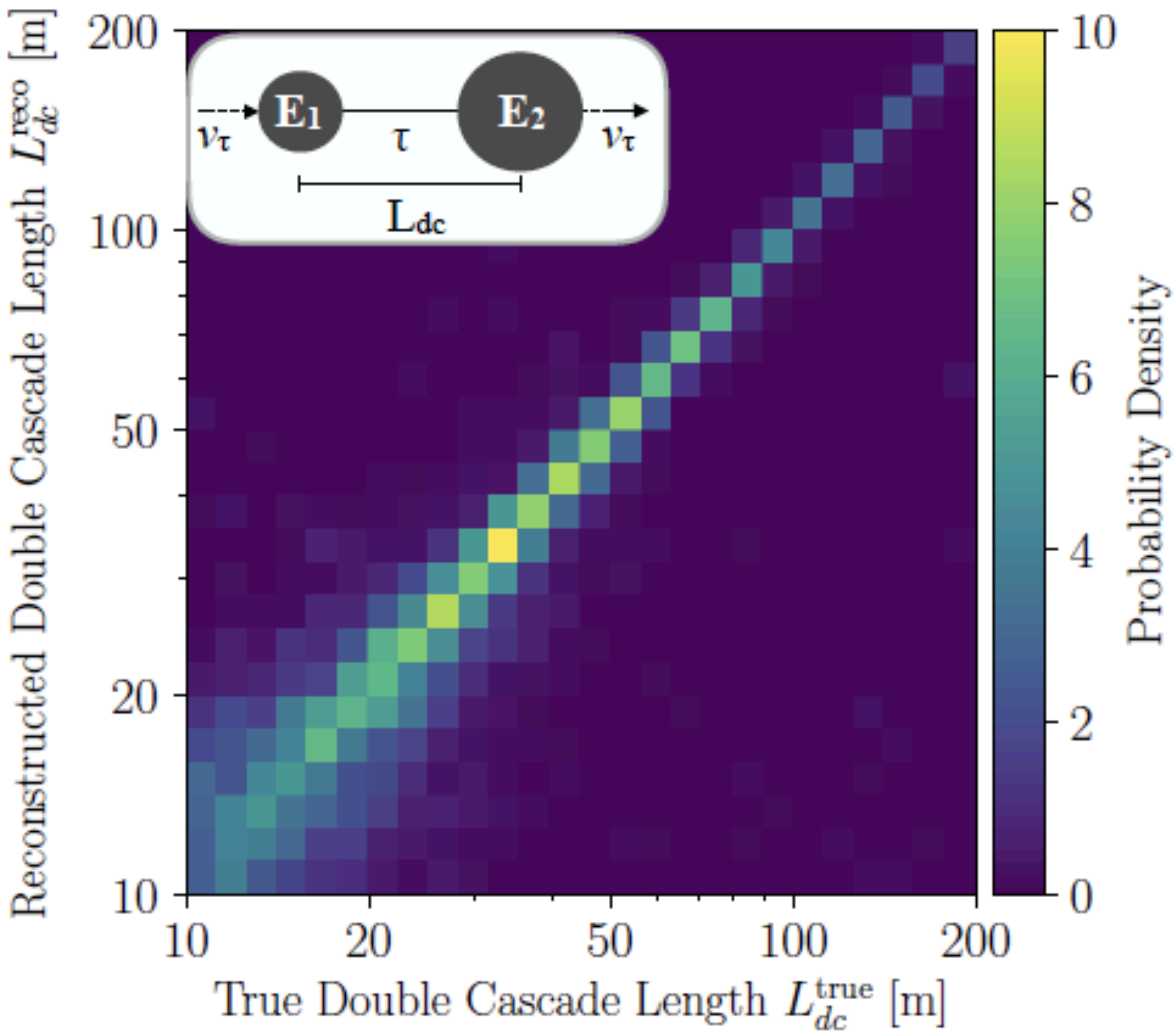
- Different event samples (covering different energy ranges, topologies, or sky hemispheres) favor slightly different indices, normalizations.

- Several independent analyses (on completely different samples and signatures) confirm diffuse astrophysical neutrino flux
- Single power law ("simplest" astrophysical source assumption) is not a good fit ! ⇒ Much more to learn !

HESE conclusions

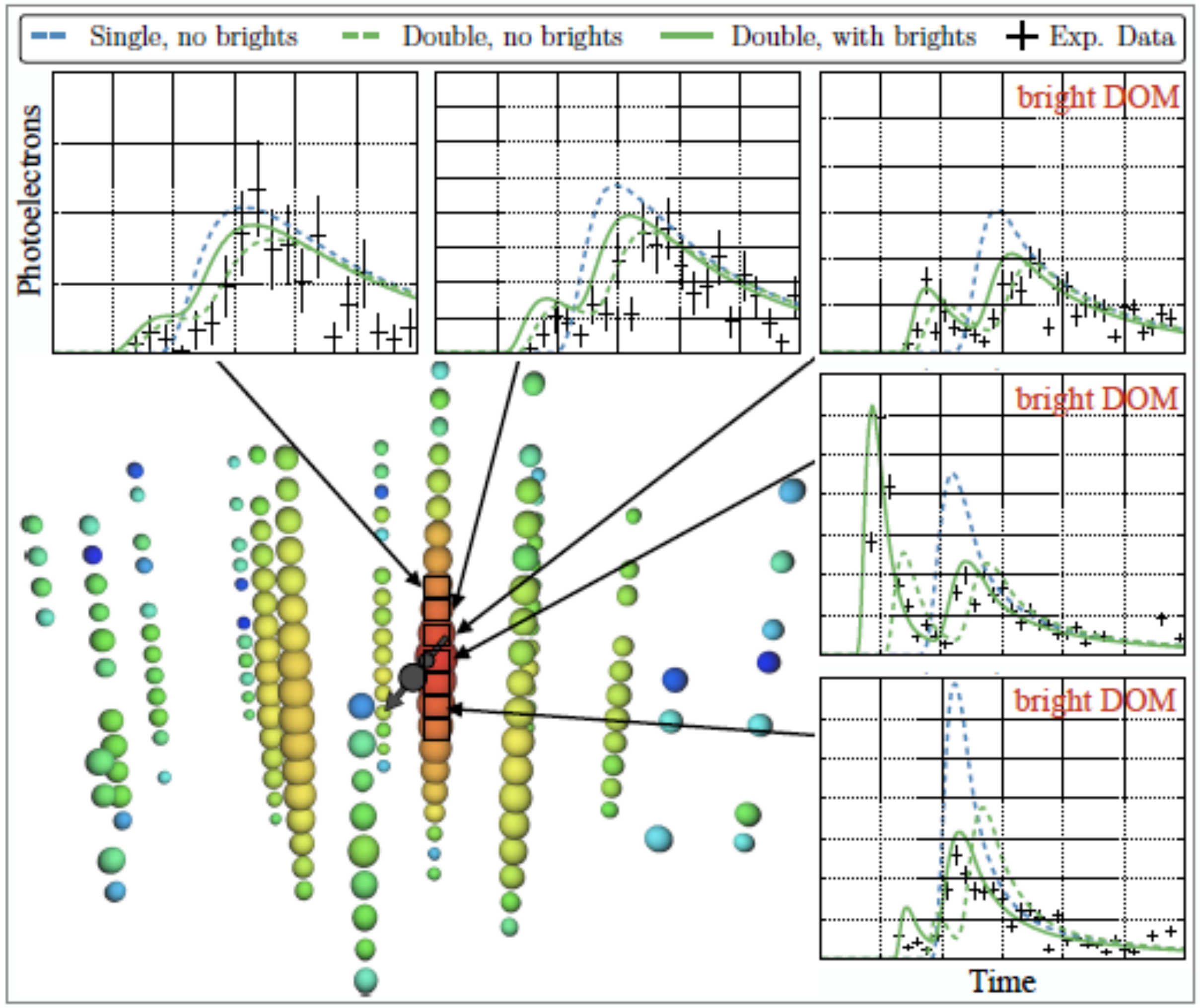
- Based on the 7.5yrs HESE data sample and it’s sensitive energy range, the astrophysical neutrino flux is well described by a single power law
  - No evidence for additional spectral structure
  - Many models remain compatible with the data, and larger samples will be required to differentiate between the different proposed spectra

Tau Neutrinos



	Event #1	Event #2
Year	2012	2014
Energy of 1st cascade	1.2 PeV	9 TeV
Energy of 2nd cascade	0.6 PeV	80 TeV
Energy Asymmetry	0.29	-0.80
Length	16 m	17 m

"Big Bird" 76% "Double double" 98%

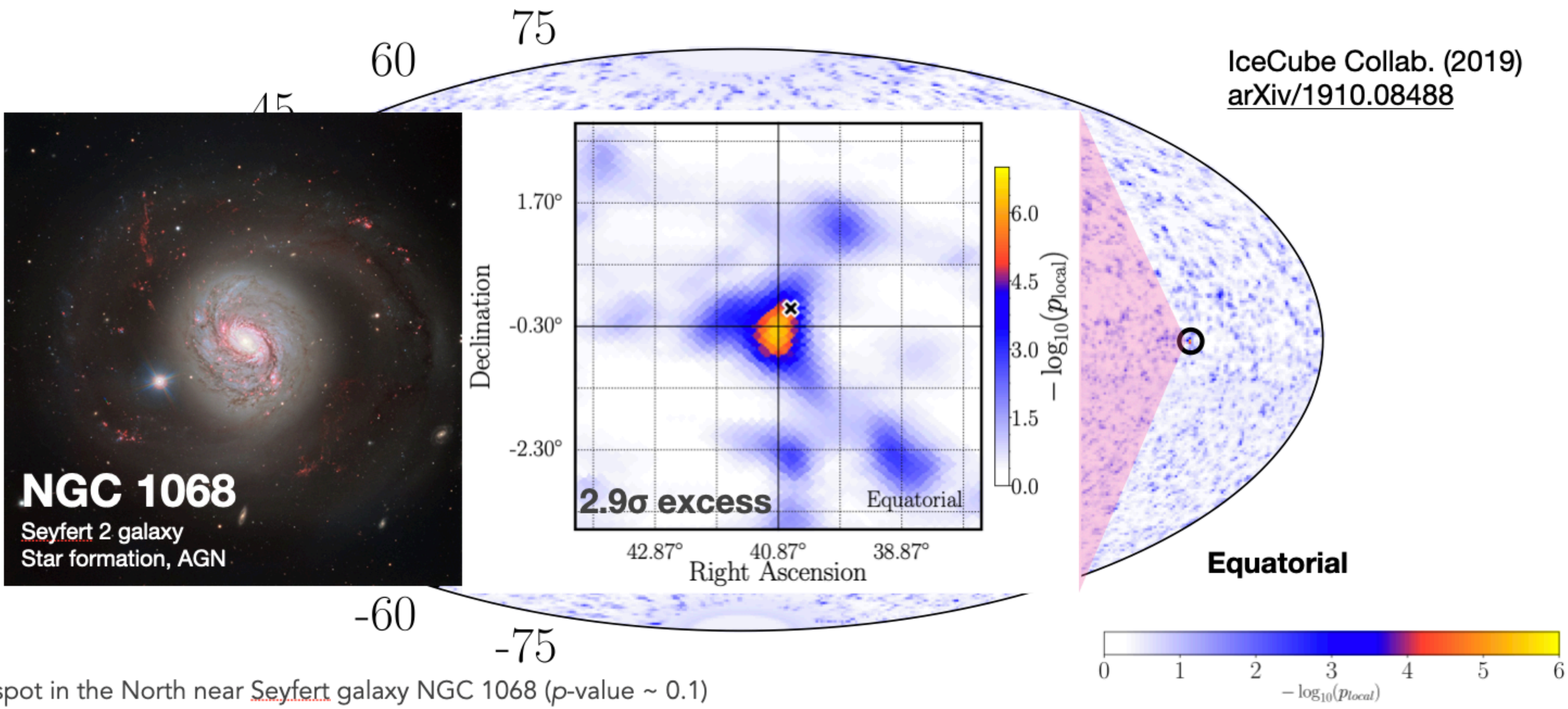


2 candidate events detected in HESE 7.5yr sample with E>60TeV
1PeV tau travel about ~50m

Astrophysical Neutrino Sources

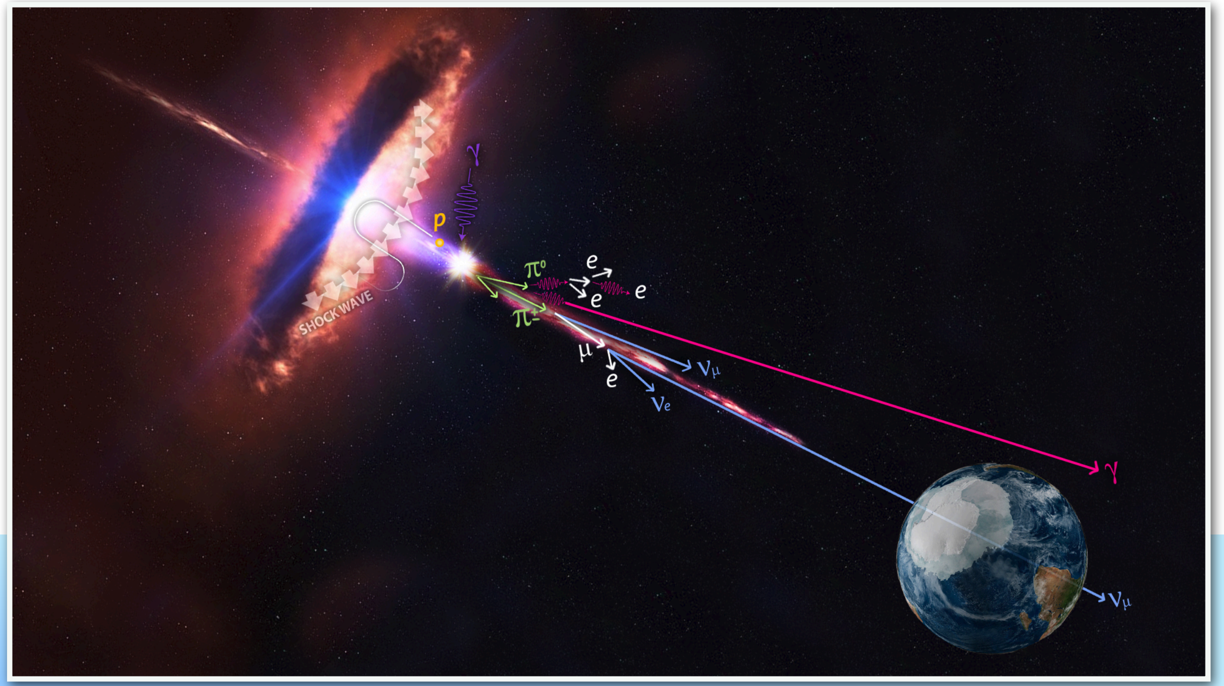
Point source search

Search for point sources in 10 years of IceCube data



IceCube Collab. (2019)
arXiv/1910.08488

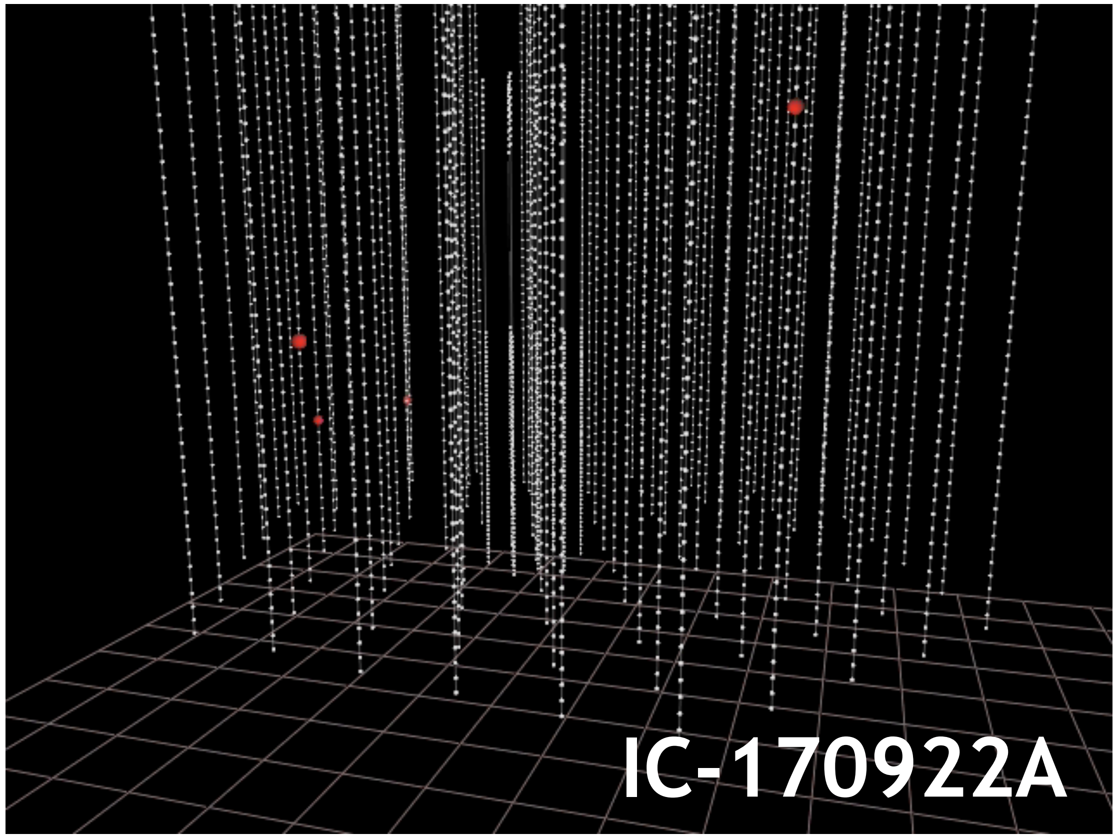
- Hottest spot in the North near Seyfert galaxy NGC 1068 (p-value ~ 0.1)
- Excess at NGC 1068 location: **2.9σ**
- **3.3σ** from a source catalog search

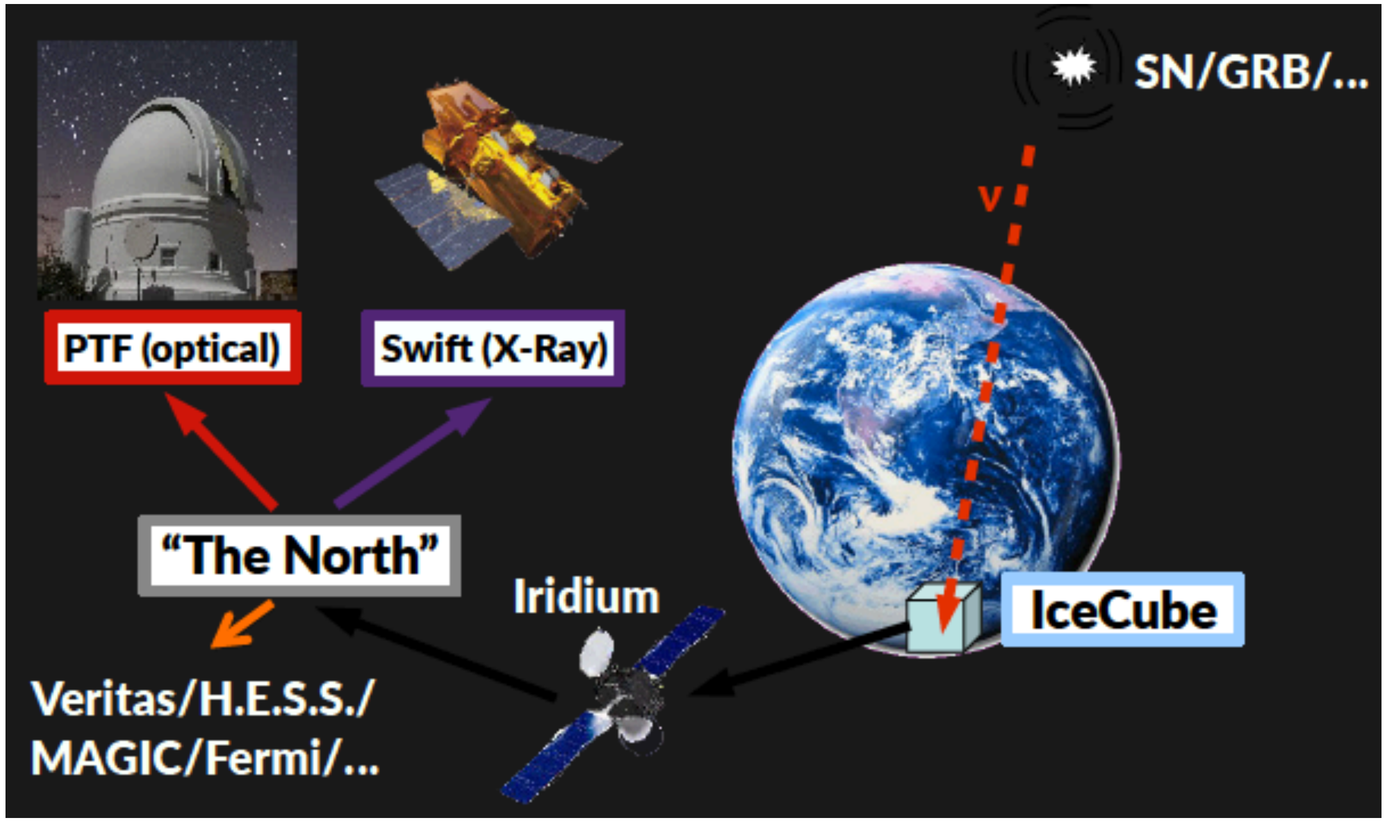


Multi-messenger Neutrino Astronomy and IceCube-170922A

Astropart. Phys. 92 (2017) 30
A&A 607 (2017) A115

IceCube-170922A

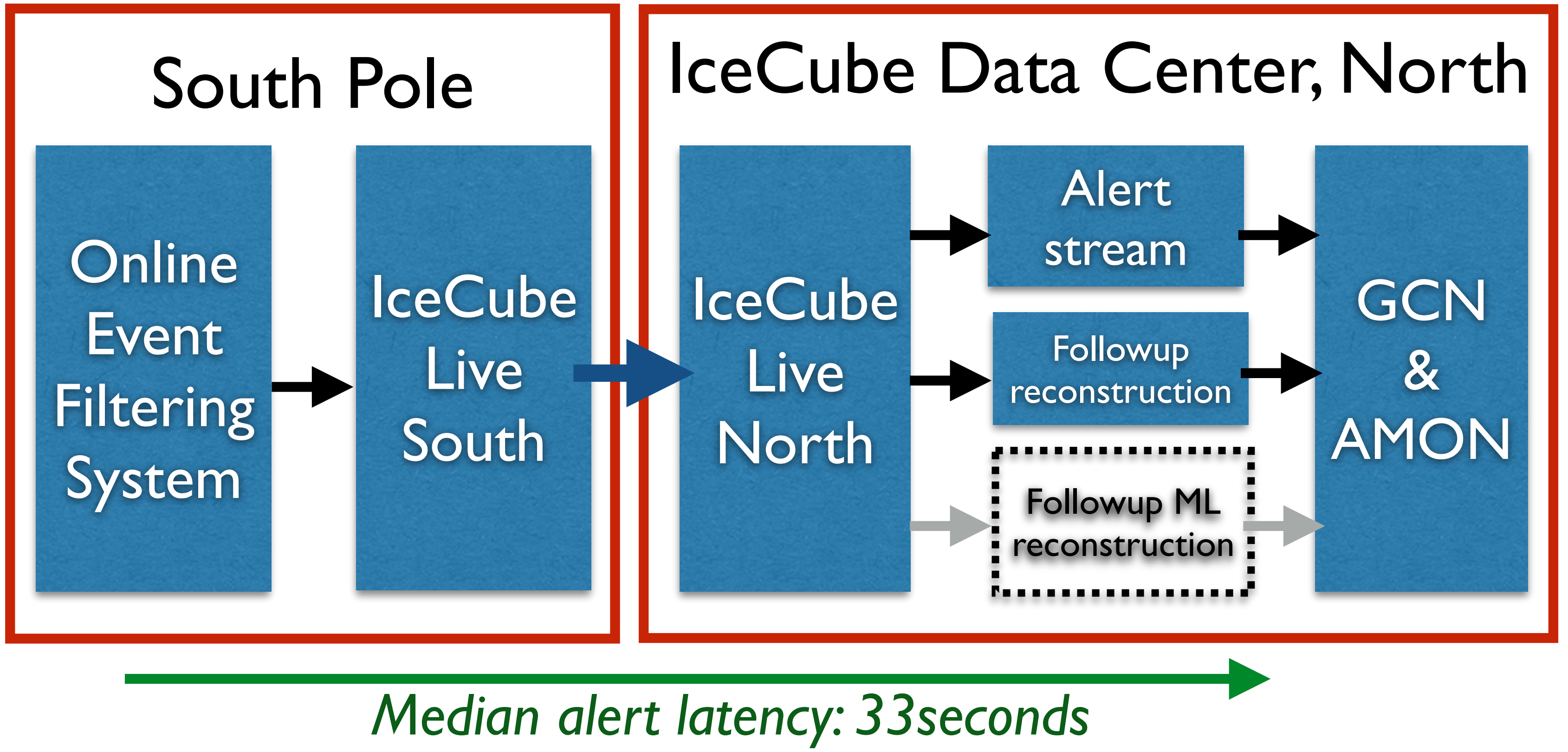




Real-time alerts

- Good angular resolution (0.5° - 2° 90% of events)

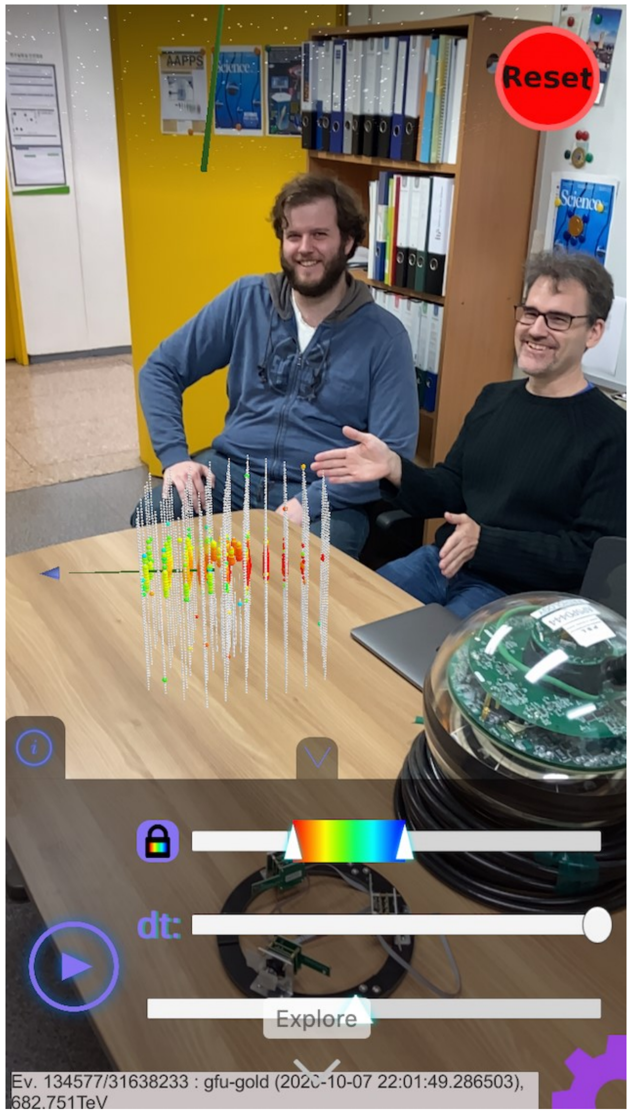
Updated alerts	Gold	Bronze
Signalness	> 50%	>30%
Expected signal/yr	6.6	2.8
Expected bkgd/yr	6.1	14.7

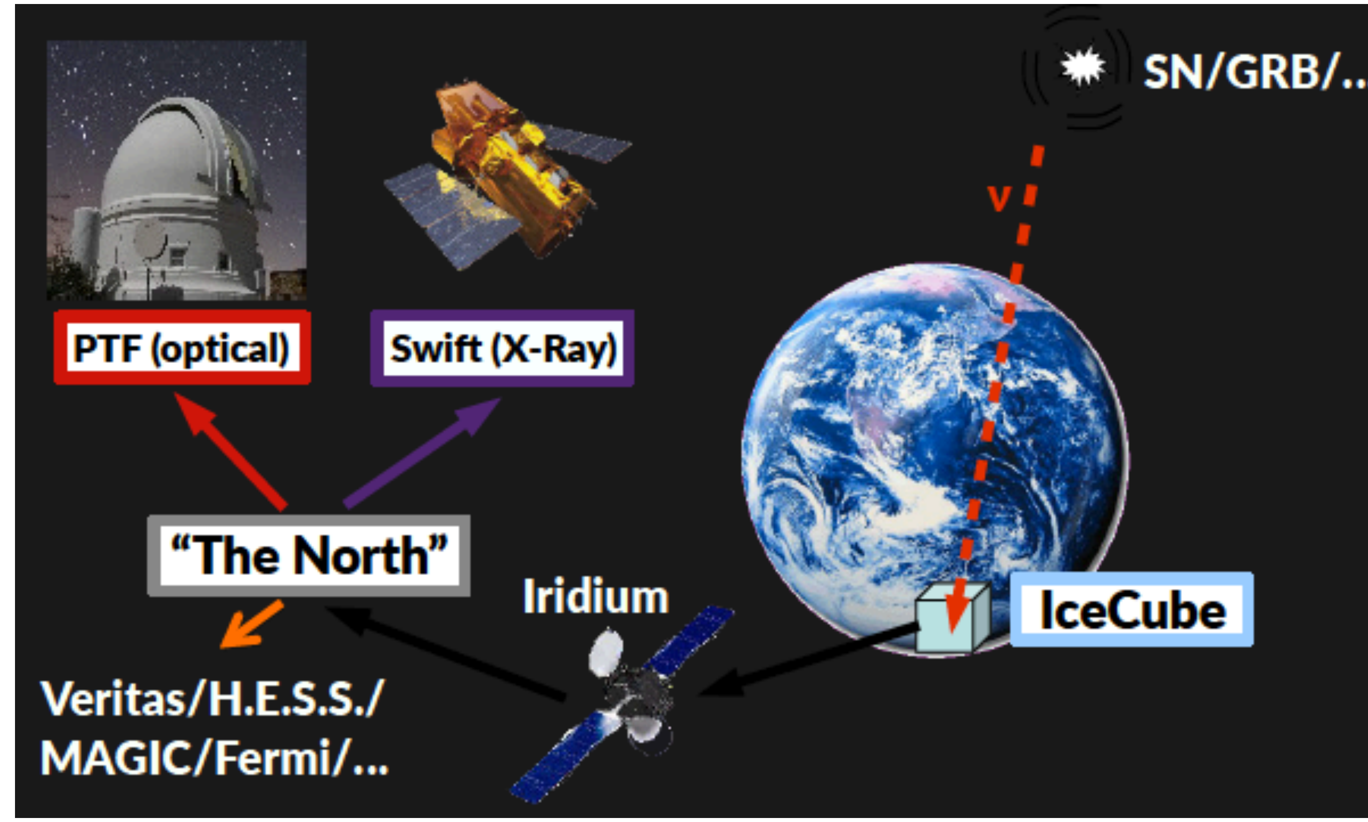


Astropart. Phys. 92 (2017) 30
A&A 607 (2017) A115

IceCube-170922A

IceCuBeAR - https://icecube.wisc.edu/news/view/776





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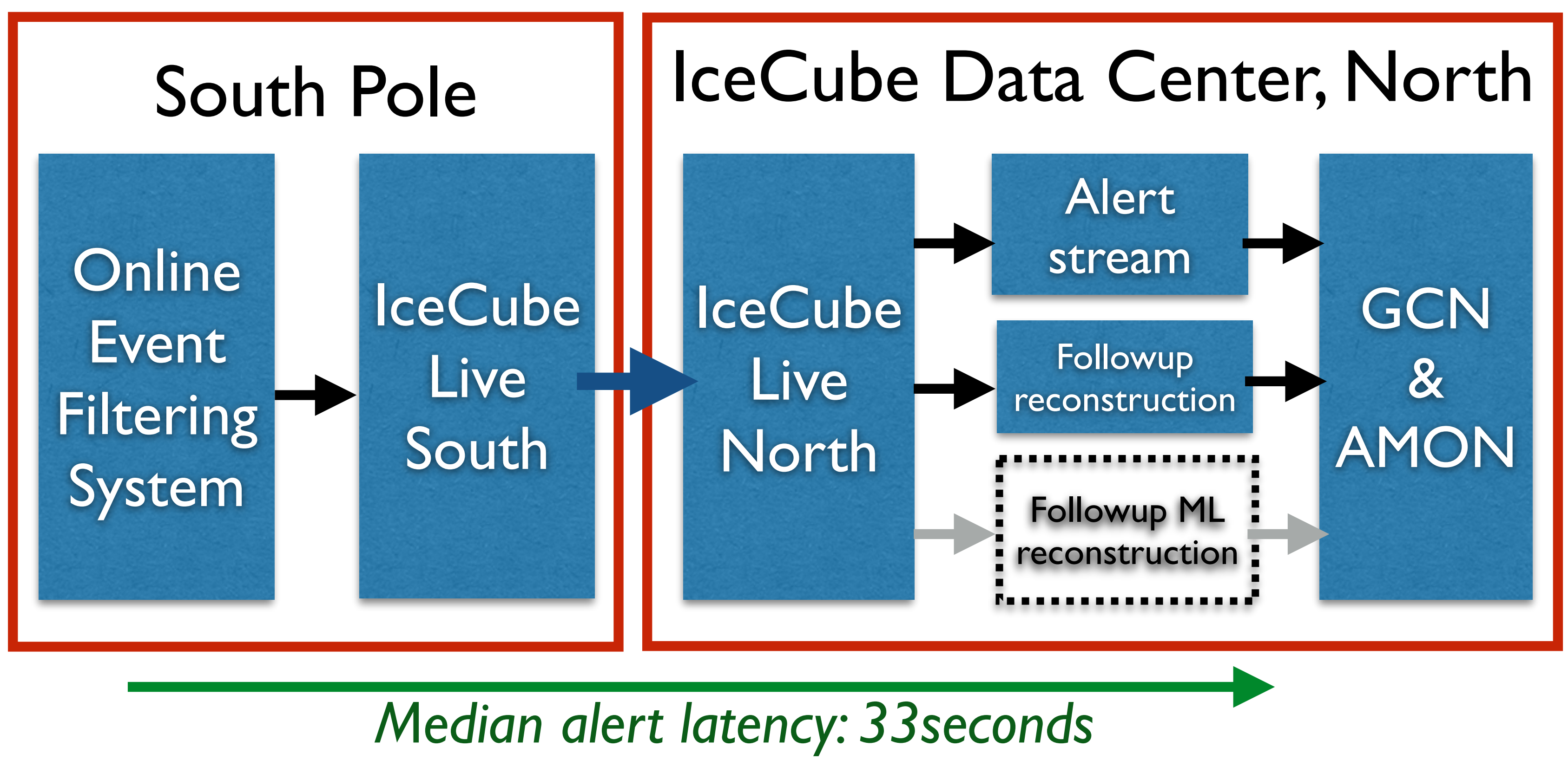
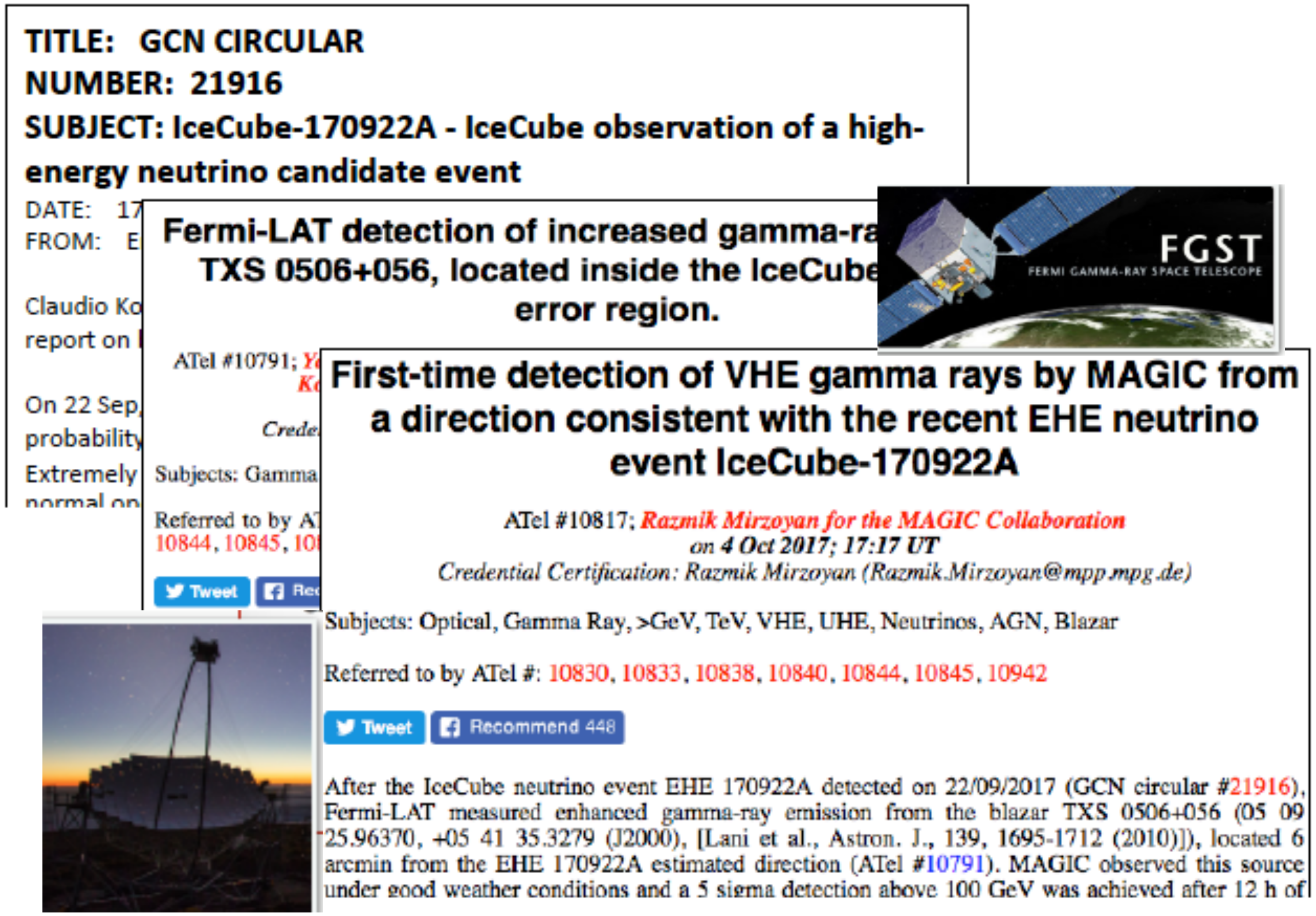
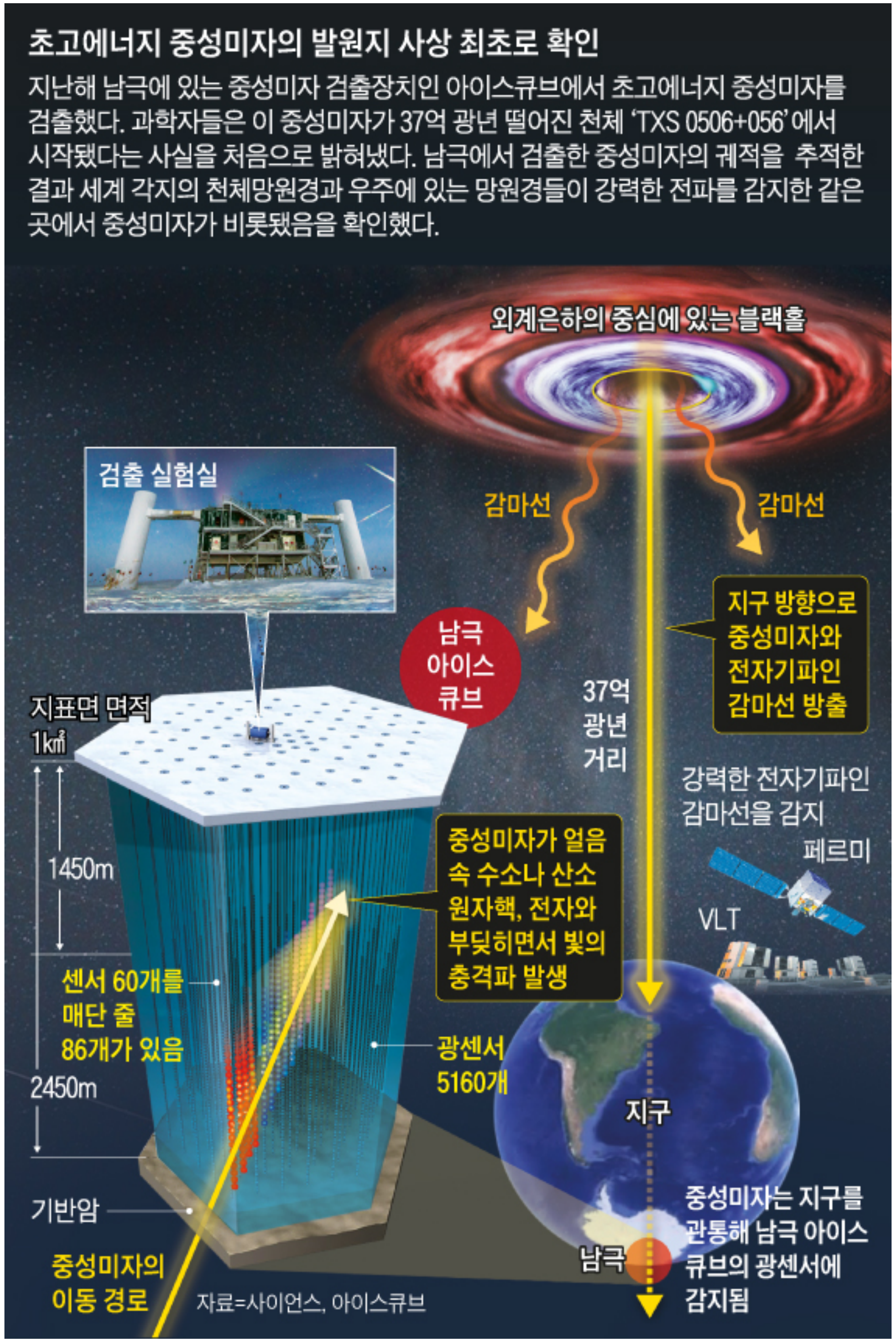


Astropart. Phys. 92 (2017) 30
A&A 607 (2017) A115

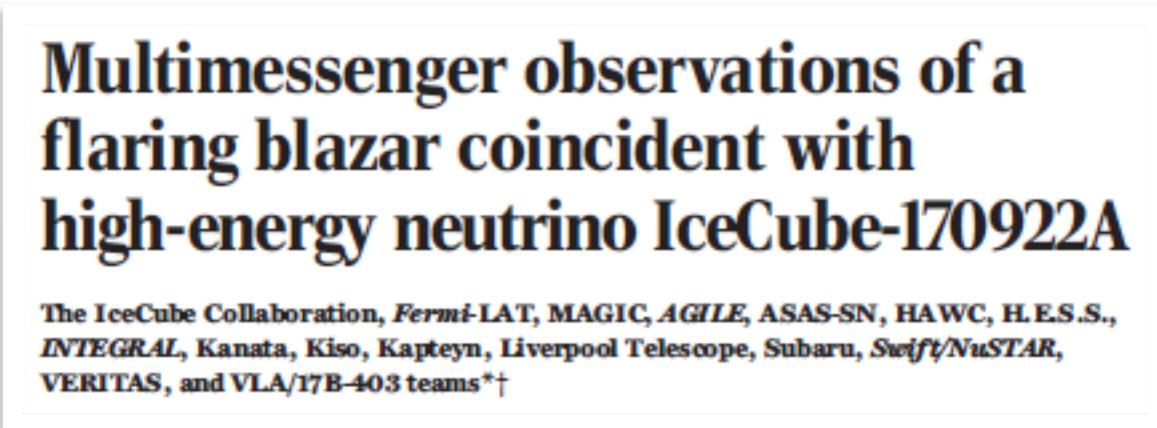
IceCube-170922A & TXS 0506+056



- September 22, 2017: a neutrino alert issued by IceCube
- Fermi-LAT and MAGIC identify a spatially coincident flaring blazar (TXS 0506+056)
- Very active multi-messenger follow-up from radio to γ-rays



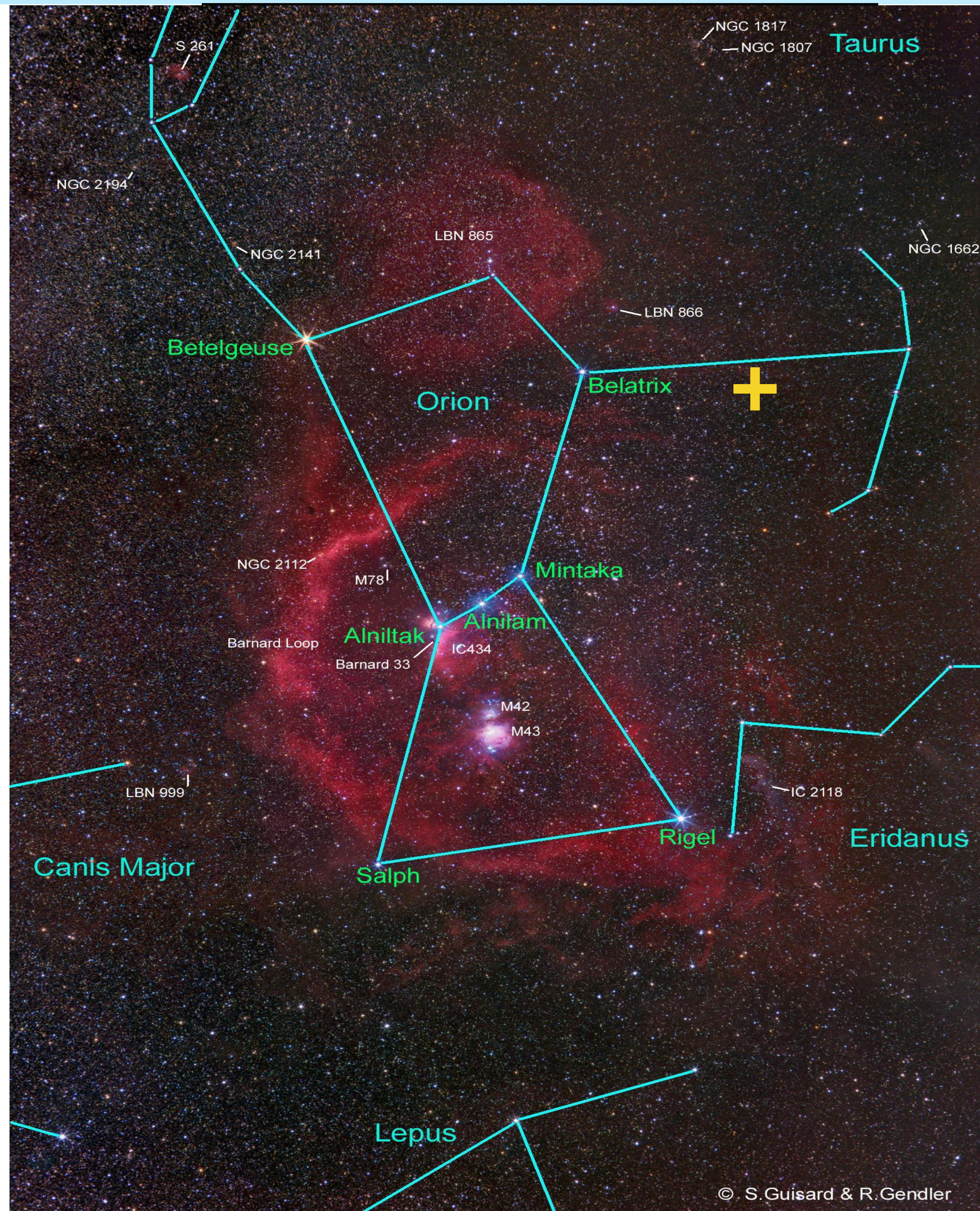
IceCube-170922A



Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

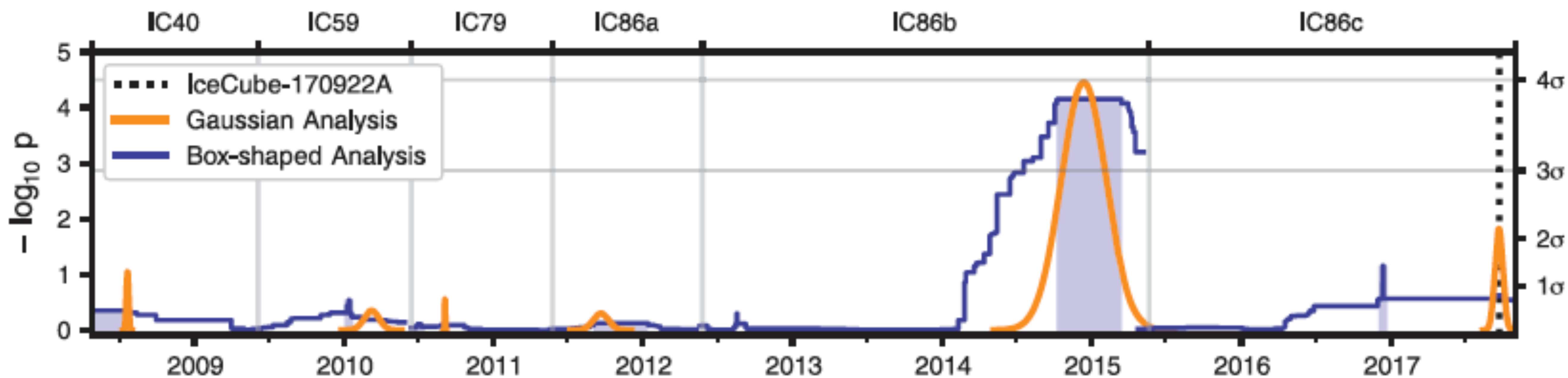
The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

- Chance probability of a Fermi-IceCube coincident observation: **~3σ** (determined based on the historical IceCube sample and known Fermi-LAT blazars)
- Time-integrated neutrino spectrum is approximately $E^{-2.1}$
- **TXS 0506+056 redshift determined to be z=0.3365** (S. Paiano et al. ApJL 854.L32(2018))
- Time-average luminosity about an order of magnitude higher than Mkn 421, Mkn 501, or 1ES 1959+605

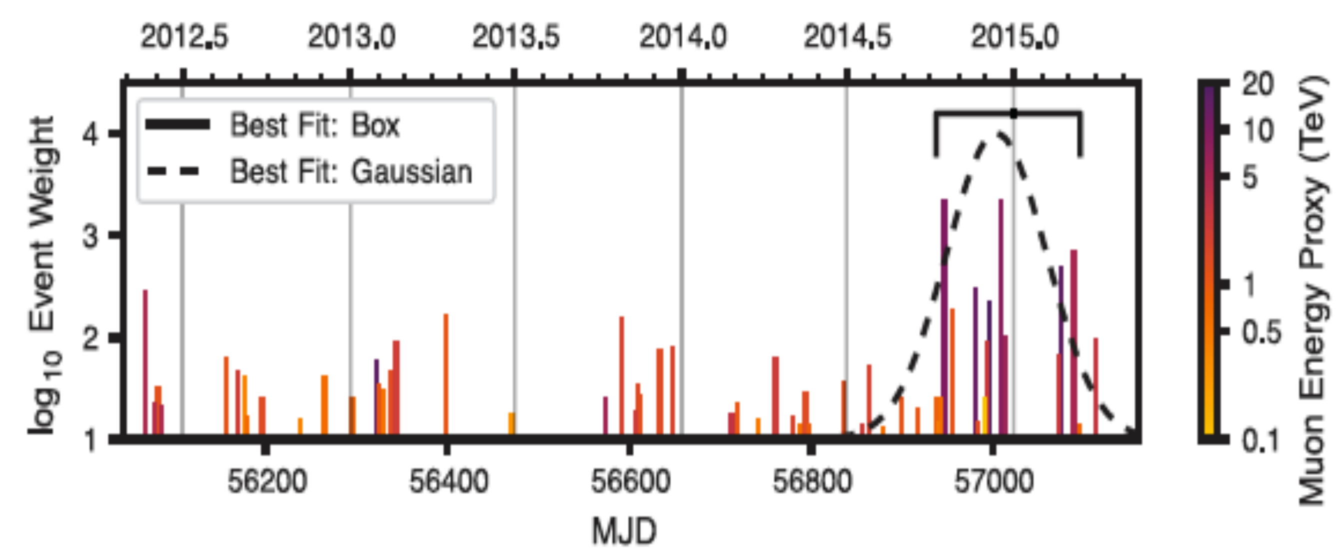


Science 361 (6398), 147-151.

IceCube-170922A



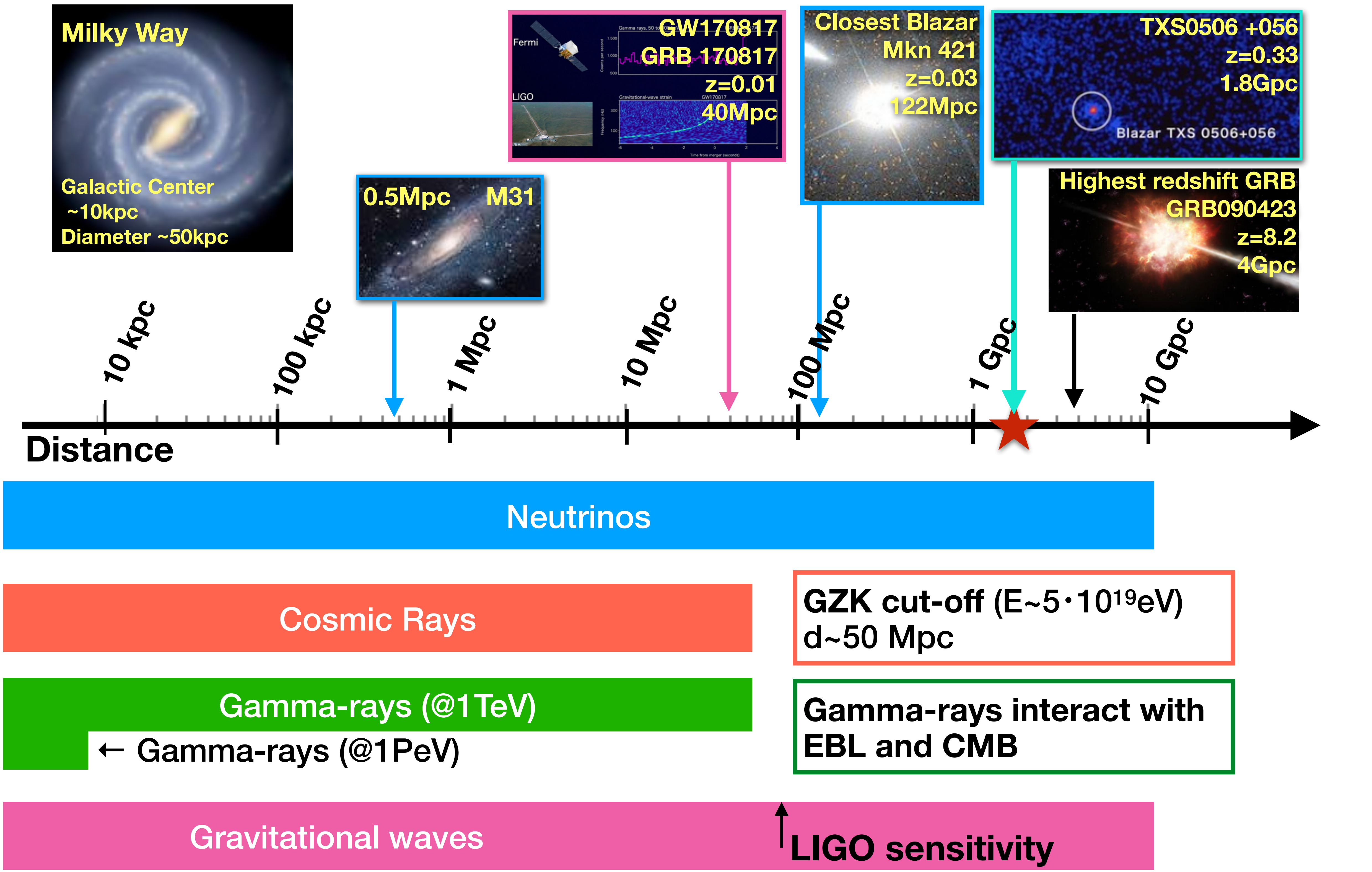
- 9.5 years of archival data was evaluated in direction of TXS 0506+056
- An excess of 13±5 events above background was observed during Sep 2014 - March 2016
- Inconsistent with background only hypothesis at **3.5σ** level (independently of the **3σ** associated with IceCube-170922A alert)



Time-independent weight of individual events during the IC86b period.

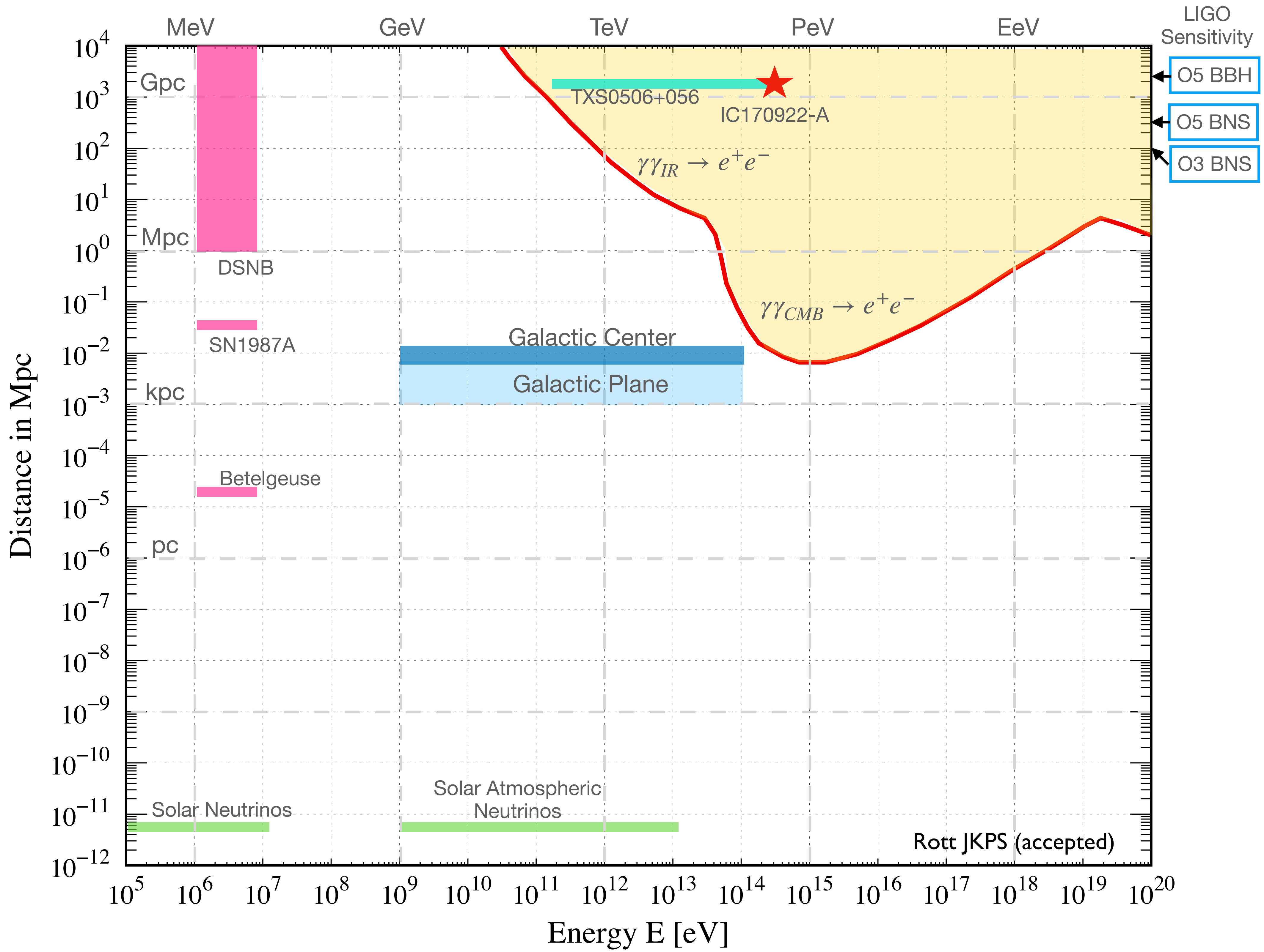
However: Maximum contribution of the 2LAC blazars to the observed astrophysical neutrino flux to be 27% or less between around 10 TeV and 2 PeV [IceCube Astrophys.J. 835 (2017) no.1, 45]

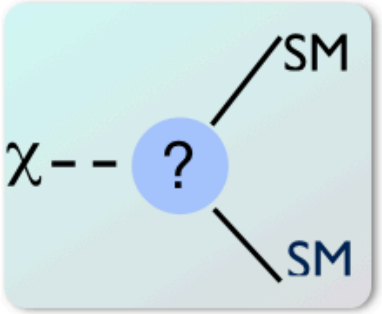
Distance scales …



1 pc = 3.26 ly

Note: Distant sources also allow to test rare interactions K.Choi, J.Kim, **C.Rott** PRD 2019

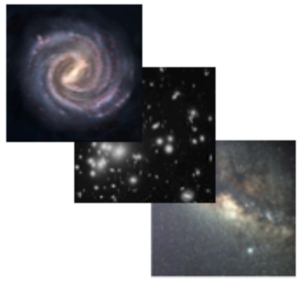

MeV
GeV
TeV
PeV
EeV
LIGO Sensitivity
O5 BBH
O5 BNS
O3 BNS
Gpc
Mpc
kpc
pc
DSNB
SN1987A
Betelgeuse
TXS0506+056
IC170922-A
$\gamma\gamma_{IR} \rightarrow e^+e^-$
$\gamma\gamma_{CMB} \rightarrow e^+e^-$
Galactic Center
Galactic Plane
Solar Neutrinos
Solar Atmospheric Neutrinos
Rott JKPS (accepted)
Distance in Mpc
Energy E [eV]



DM Decay searches

ν from SM particle decay or directly produced

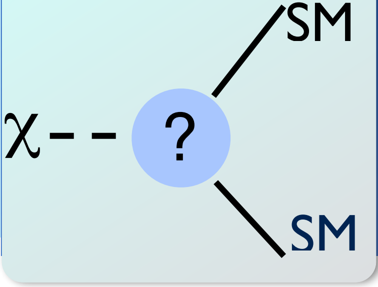
- Extragalactic
- Galactic Halo
- Galaxy clusters
- …



DM Lifetime $\boldsymbol{\tau}_\chi$

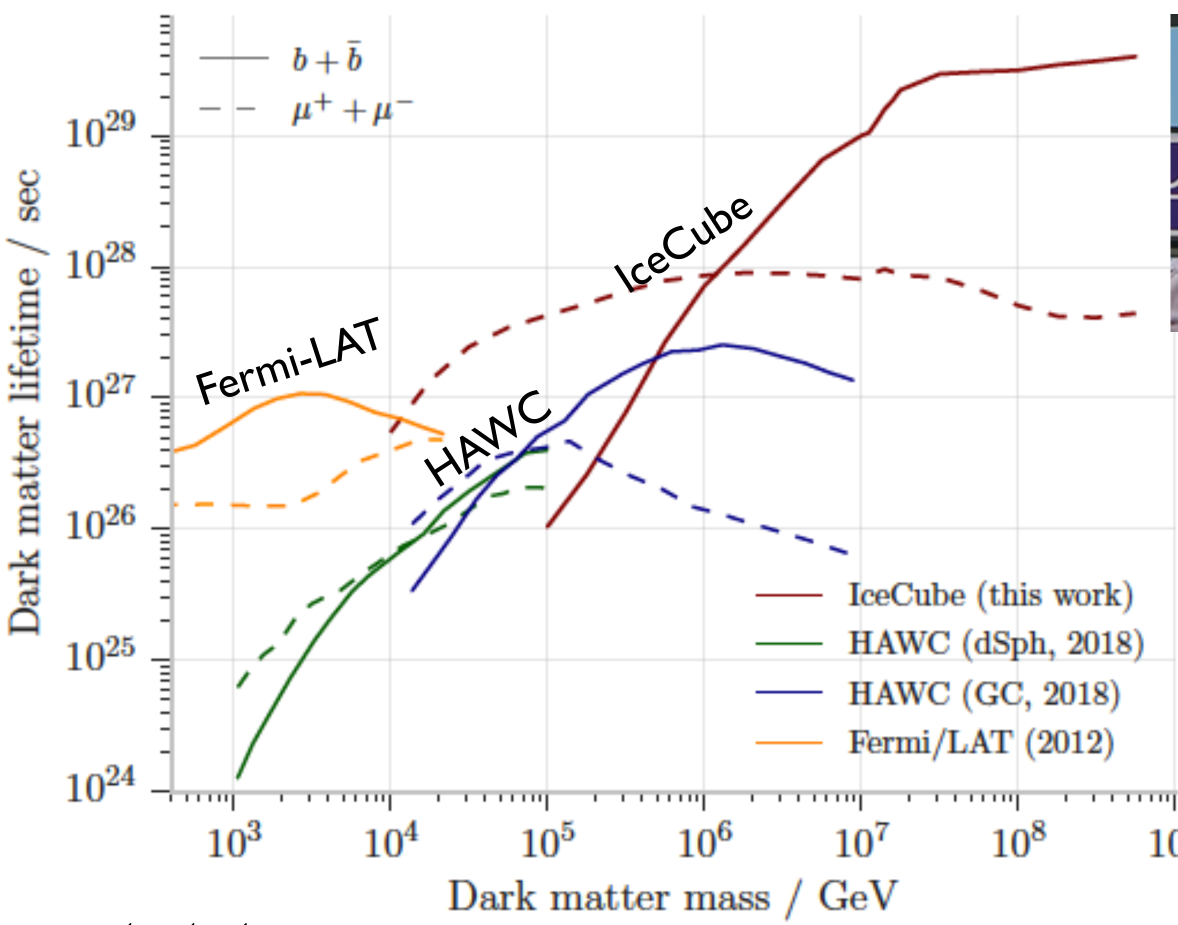
DM Mass $\mathbf{m}_\chi$
(Branching fractions)

Dark Matter Decay

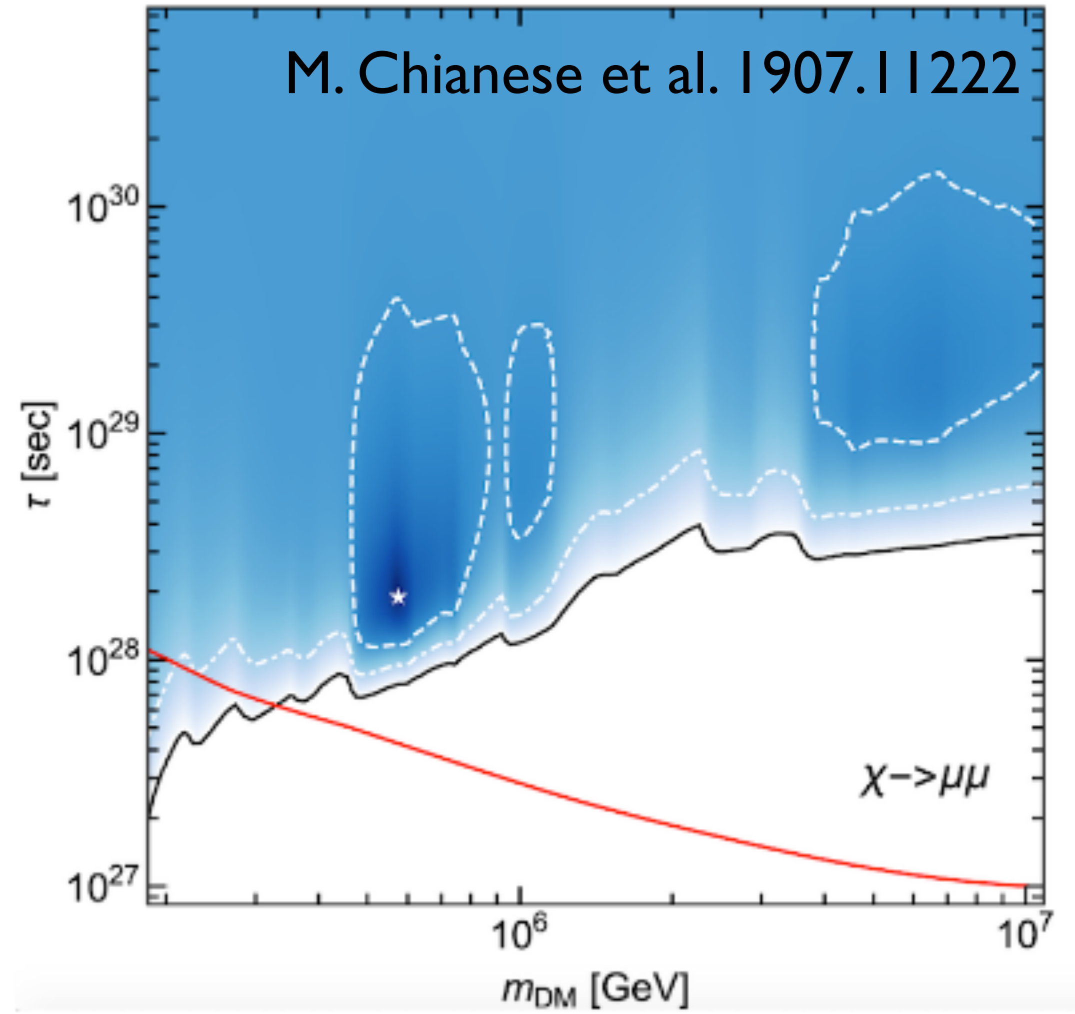


Heavy Dark Matter Decay

IceCube Collaboration arXiv:1804.03848v1 (published EPJC)



Hrvoje Dujmovic

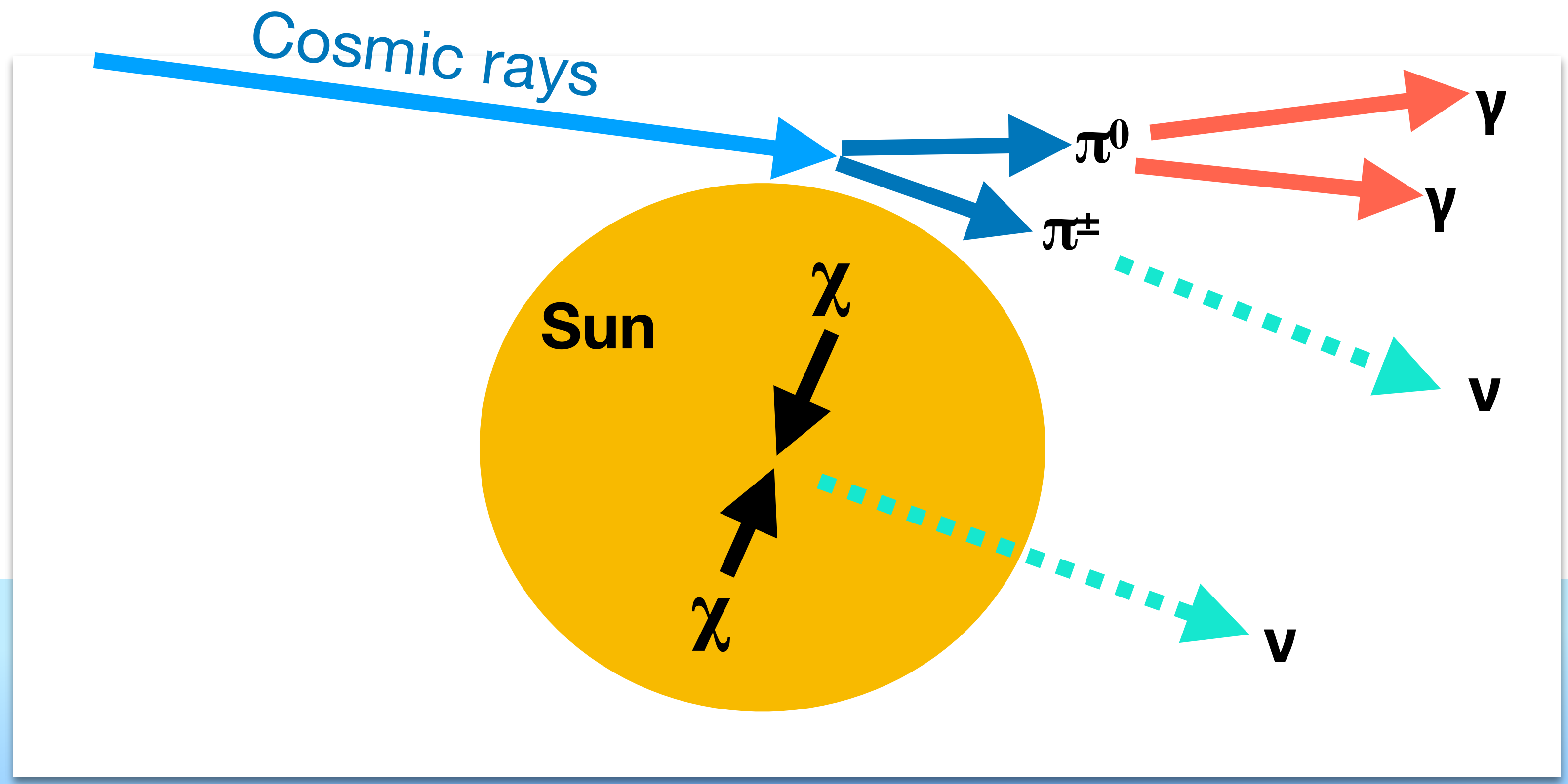


- **Current status:**
  - IceCube provides leading bounds (~10^{28}s) on heavy decaying dark matter / Neutrinos extremely competitive above ~10TeV
  - Dark matter alone cannot explain the observed astrophysical neutrino flux
- **Future prospects and priorities**
  - Opportunities for combined searches in TeV range (broader coverage of models), extremely competitive at high energies
  - Highest priority - understand astrophysical neutrino spectrum
    - Is IceCube's data already showing any hints of dark matter (TeV excess ?)

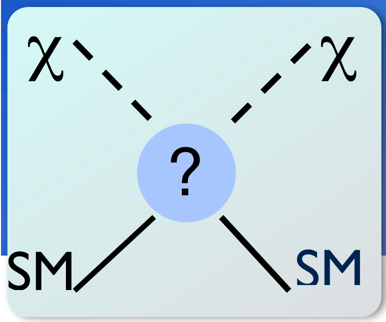
Evidence for dark matter in in the diffuse high-energy astrophysical neutrino flux ?

- B. Feldstein, A. Kusenko, S. Matsumoto, and T. T. Yanagida, PRD 88 no. 1, (2013) 015004, arXiv:1303.7320
- A. Esmaili and P. D. Serpico, JCAP11(2013) 054, arXiv:1308.1105
- Y. Ema, R. Jinno, and T. Moroi, PLB 733 (2014) 120–125, arXiv:1312.3501
- A. Bhattacharya, M. H. Reno, and I. Sarcevic, JHEP06 (2014) 110, arXiv:1403.1862
- C. Rott, K. Kohri, and S. C. Park, PRD 92 no. 2, (2015) 023529, arXiv:1408.4575
- K. Murase, R. Laha, S. Ando, and M. Ahlers, PRL 115 no. 7, (2015) 071301, arXiv:1503.04663
- L. A. Anchordoqui, V. Barger, H. Goldberg, X. Huang, D. Marfatia, L. H. M. da Silva, and T. J. Weiler, PRD 92 no. 6, (2015) 061301, arXiv:1506.08788. [Erratum: PRD 94, 069901 (2016)].
- M. Chianese, G. Miele, and S. Morisi, PLB 773 (2017) 591-595, arXiv:1707.05241
- M. Ahlers, Y. Bai, V. Barger, and R. Lu, PRD 93no. 1, (2016) 013009, arXiv:1505.03156
- ….

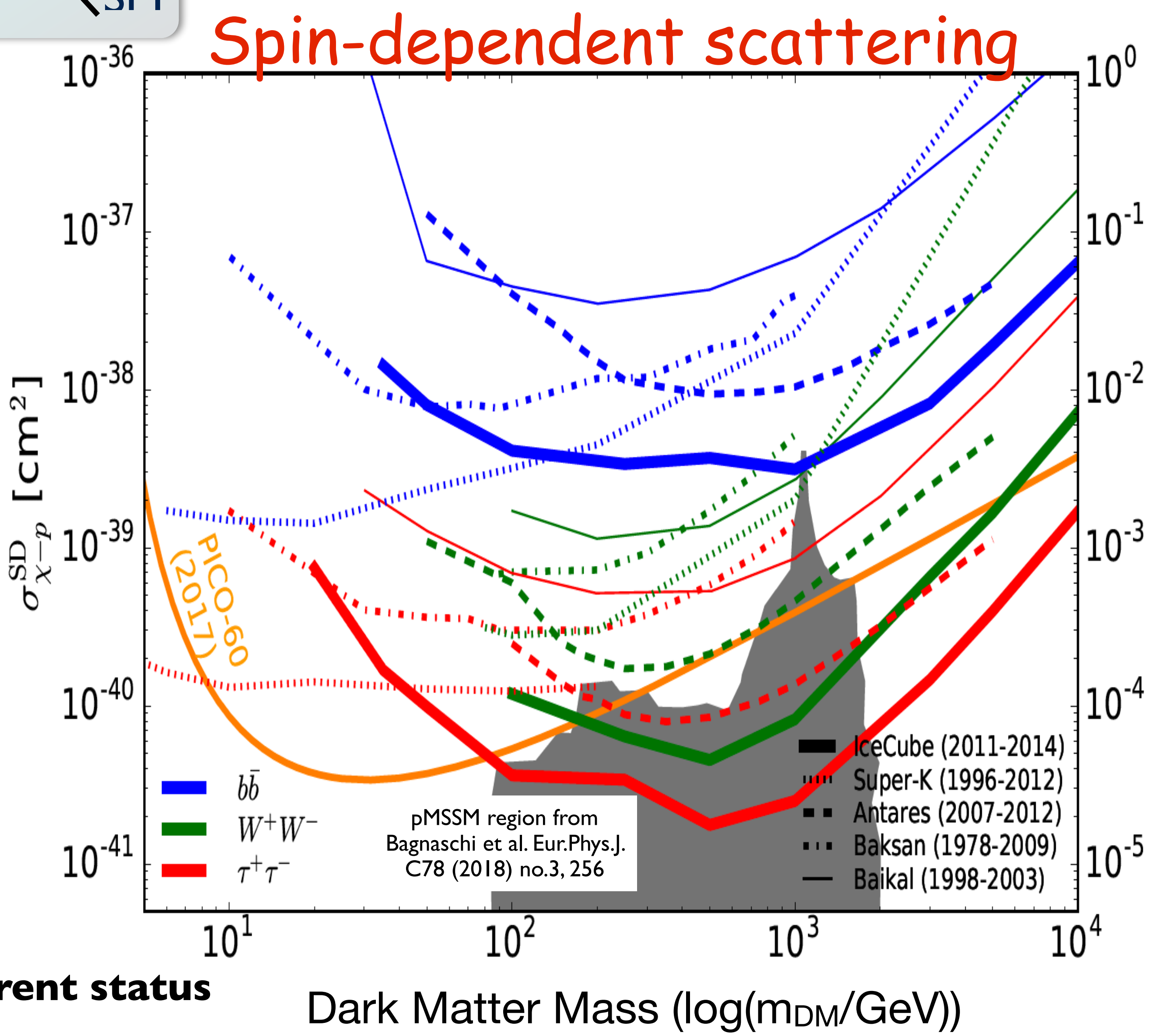
SKKU student Minjin Jeong search for neutrinos from Galaxy clusters



Energetic Neutrinos from the Sun

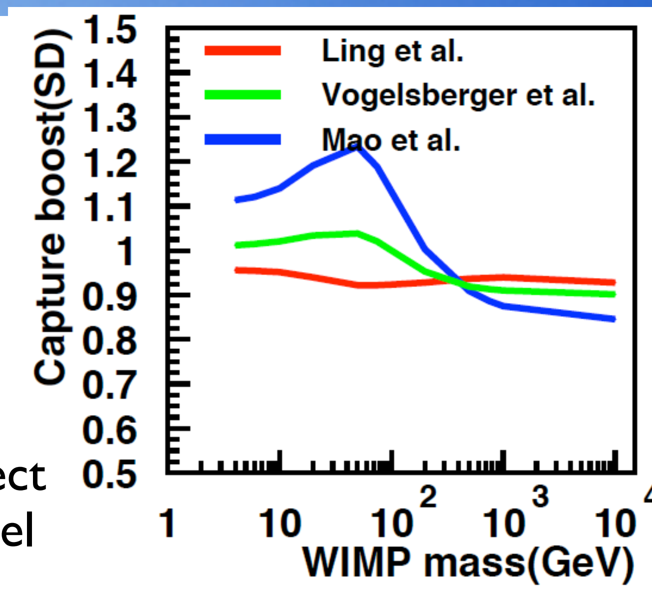


Solar Dark Matter



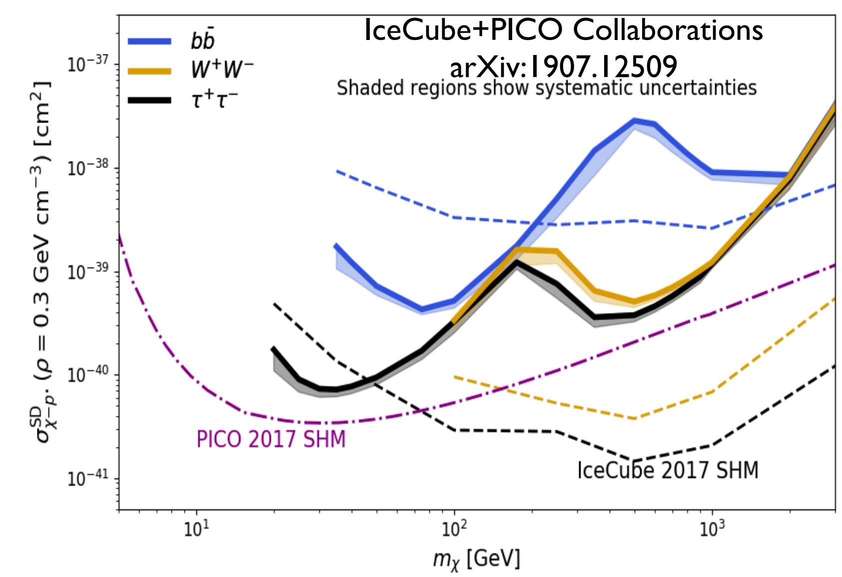
Largely halo model independent

see for example: Choi, Rott, Itow (2014), Danninger & Rott (2014), Nuñez-Castiñeyra, Nezri, Bertin (2019)



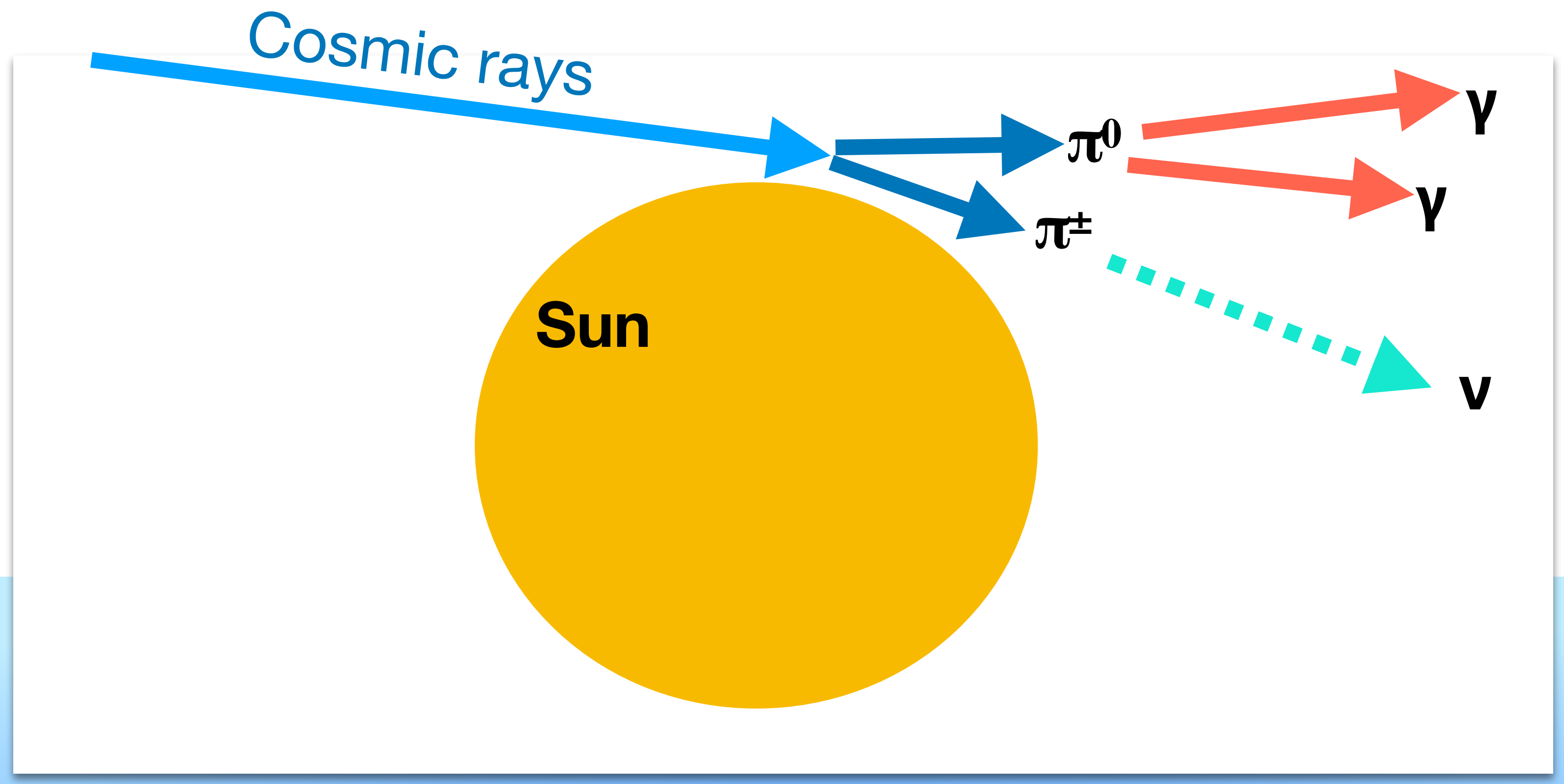
Combination with direct detection formal model independent results

following: Ferrer Ibarra & Wild (2015)



- **Current status**
  - Very strong bounds on spin-dependent DM nucleon scattering. Leading bounds from IceCube and Super-K
  - Velocity independent framework in combination with direct detection
- **Future prospects**
  - Extremely competitive to explore DM model space from GeV - TeV range
  - Complementarity to direct detection & minimal halo model dependence
  - Marching towards the solar atmospheric neutrino floor (~x10 below current bounds) … new physics !

Solar dark matter searches on-going by SKKU group members Koun Choi, Lilly Peters, and Christoph Toennis

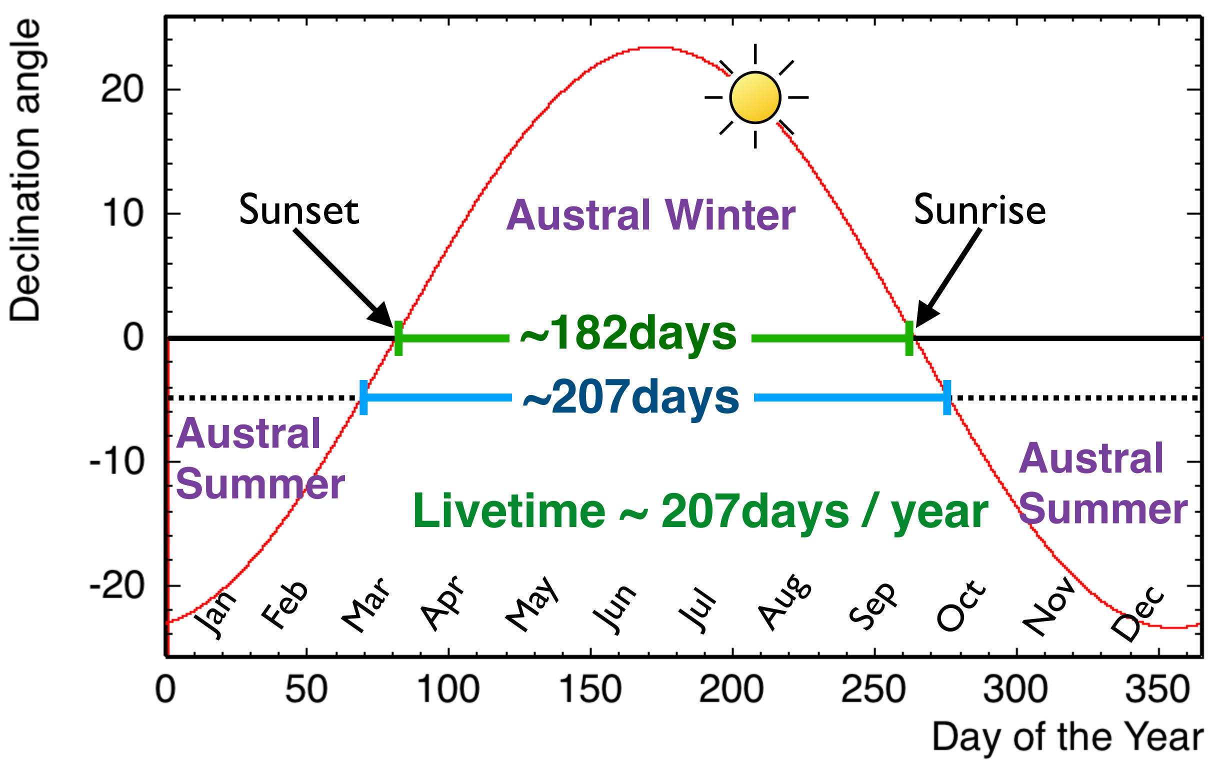


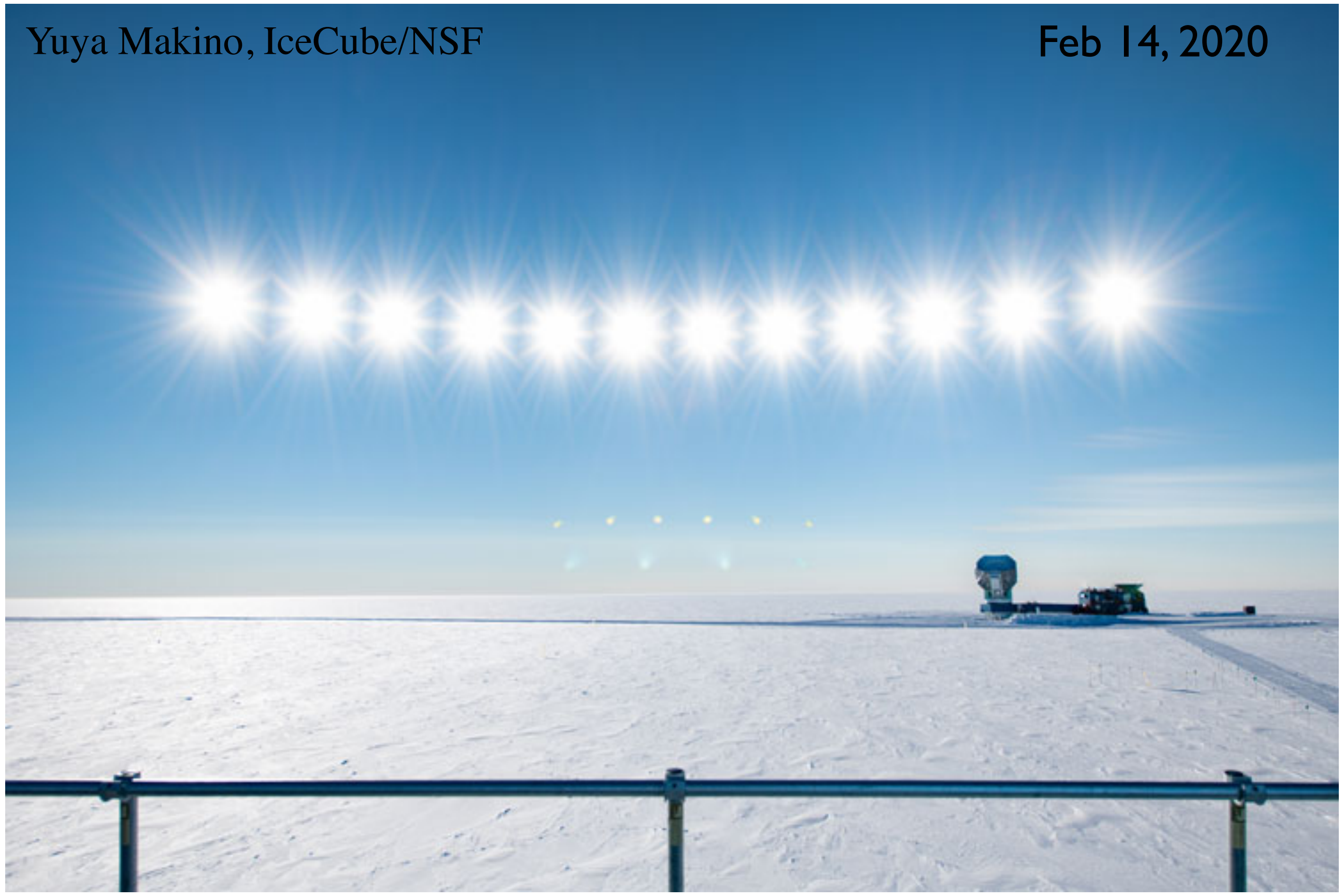
Solar Atmospheric Neutrinos

Solar Atmospheric Neutrino Analysis

Seongjin In (SKKU)

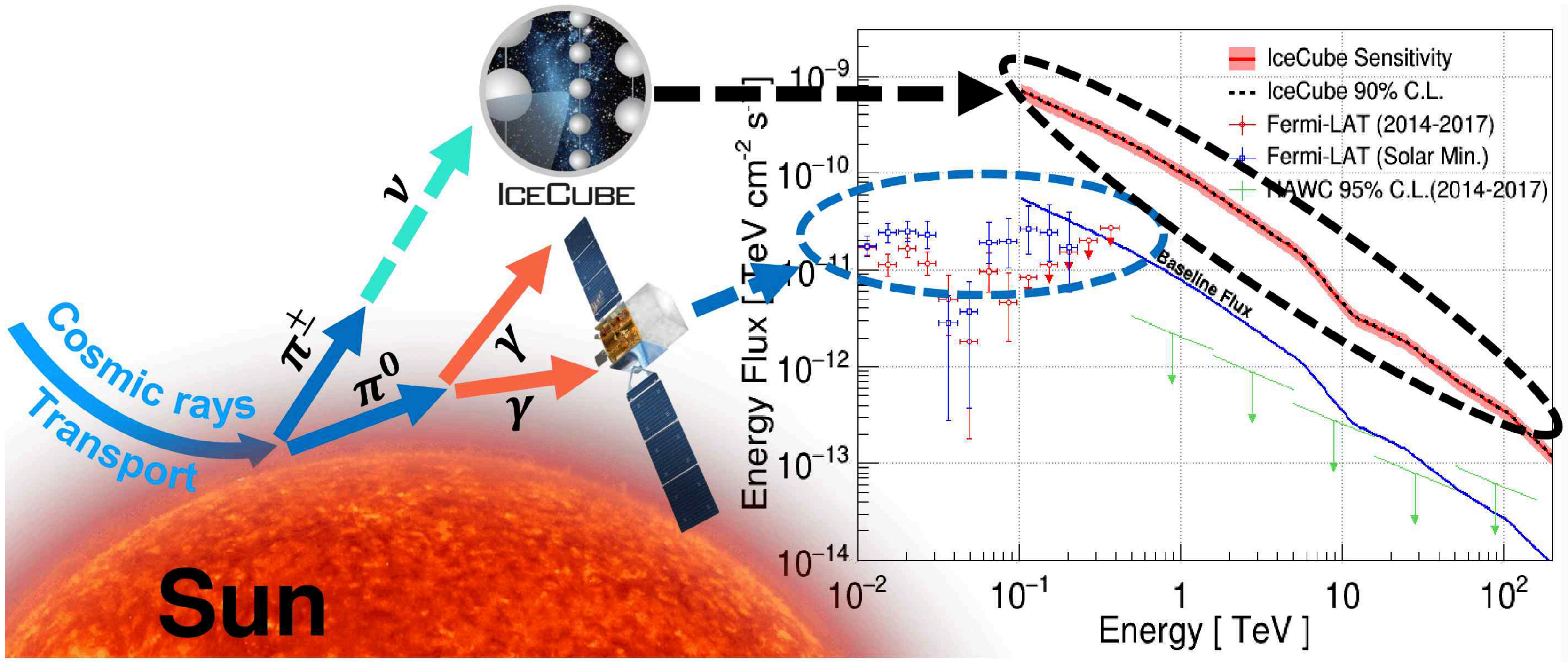
- Conducted first search for solar atmospheric neutrinos
- The analysis utilizes data collected over a 7 year period (May 31, 2010 - May 18, 2017)
  - Up-going muon neutrino candidate events are selected using the well established IceCube point source analysis selection procedure
  - We only consider events from the winter season when the Sun is below the horizon (δ=[-5°,23°]). This results in a total analysis livetime of 1420.73 days.

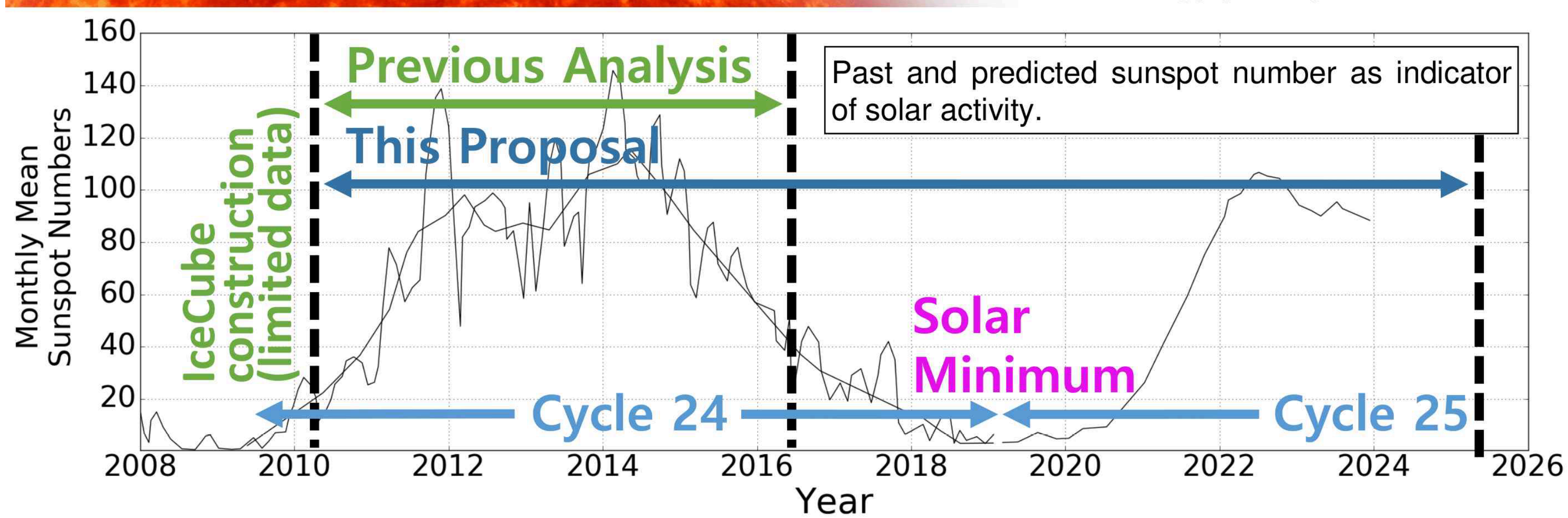




- Experimental result:
  - Flux consistent with background only
  - First experimental bound on solar atm. neutrino flux - Accepted for publication at JCAP arxiv:1912.13135

Solar Atmospheric Neutrino Prospects





Event selection improvements (this program)

- Neutrino flavors
  - up-going muon neutrinos ⇒ all flavors
- Livetime:
  - 3.5years (winter 7yrs) ⇒ 15years
- Neutrino energies:
  - 100GeV - 100TeV ⇒ 10GeV - 100TeV
- Latest event reconstruction algorithms

Analysis improvements / techniques

- Differential flux limit (universal useful)
- Time dependent (+ time integrated) analysis

Importance of result

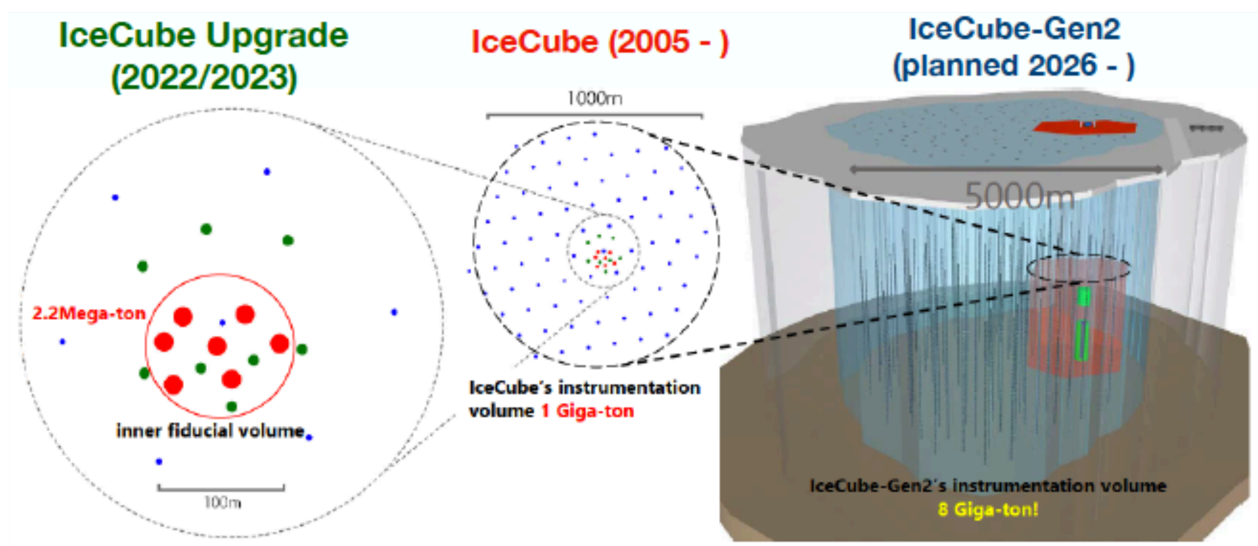
- **Neutrino Source Discovery** - first *steady* high-energy neutrino "point source"
- Cosmic ray transport in the inner solar system
- Understanding solar magnetic fields
- Solar atmosphere and cosmic ray interaction models

Solar Minimum (2019-2020)

- Enhanced neutrino flux expected
- Strong time dependence expected and evidence from gamma-ray observations
- First observable minimum - previous minimum (2009) during IceCube construction

Solar minimum is now ! Starting improved analysis

SKKU student Gerrit Roellinghoff investigating Solar minimum

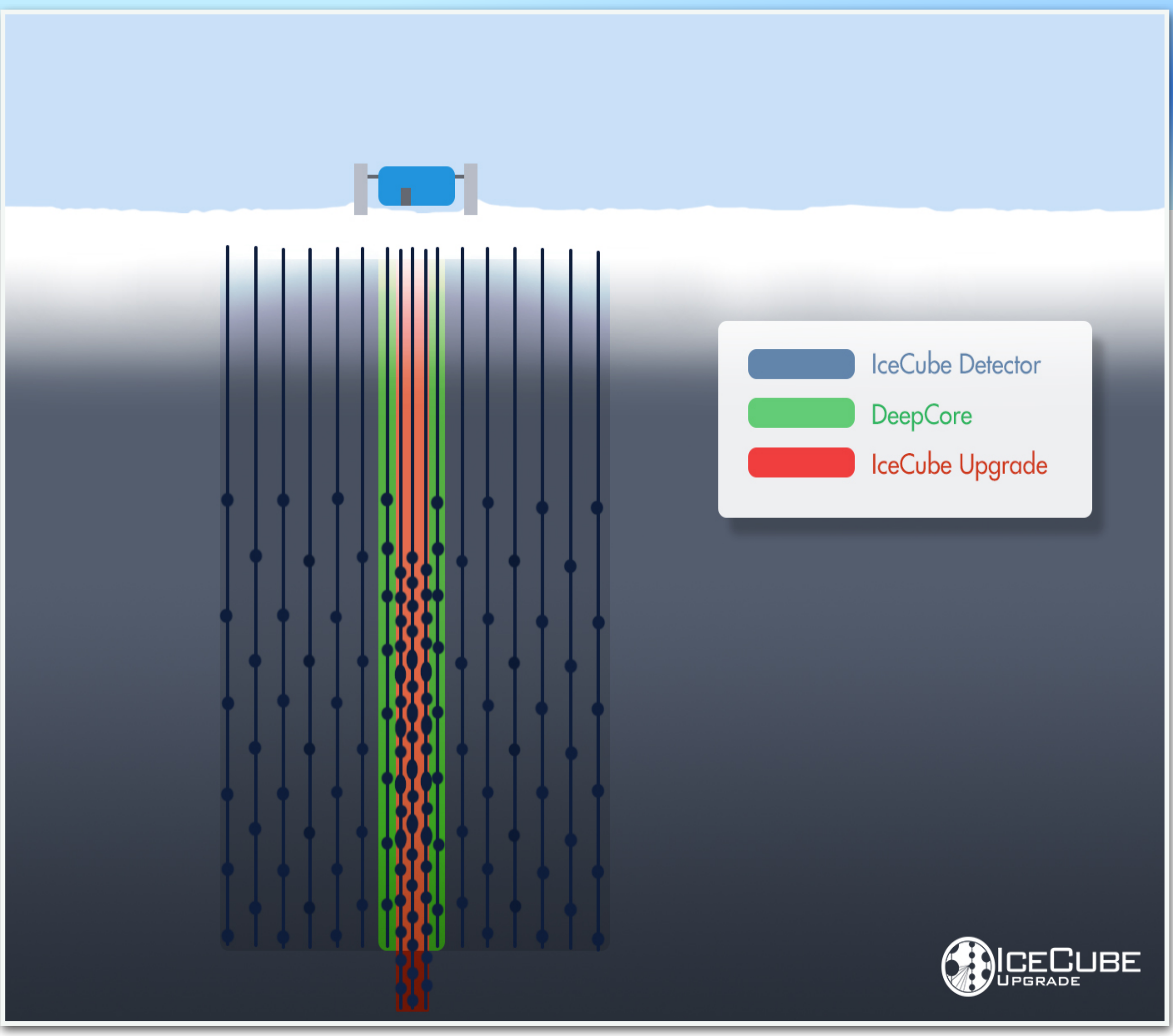


IceCube (2005 - ...)	1 Giga-ton	• Diffuse astrophysical neutrinos • Optimized for TeV Neutrinos
IceCube Upgrade (2022/2023)	2.2 Mega-ton	• GeV neutrinos, PMNS unitarity • Calibration of the IceCube detector
IceCube-Gen2 (planned 2026 -)	~ 8 Giga-ton	• Astrophysical neutrino sources • GZK neutrinos, PeV Neutrinos

IceCube Upgrade

The IceCube Upgrade was approved in 2019 !
Expected deployments in 2022/2023

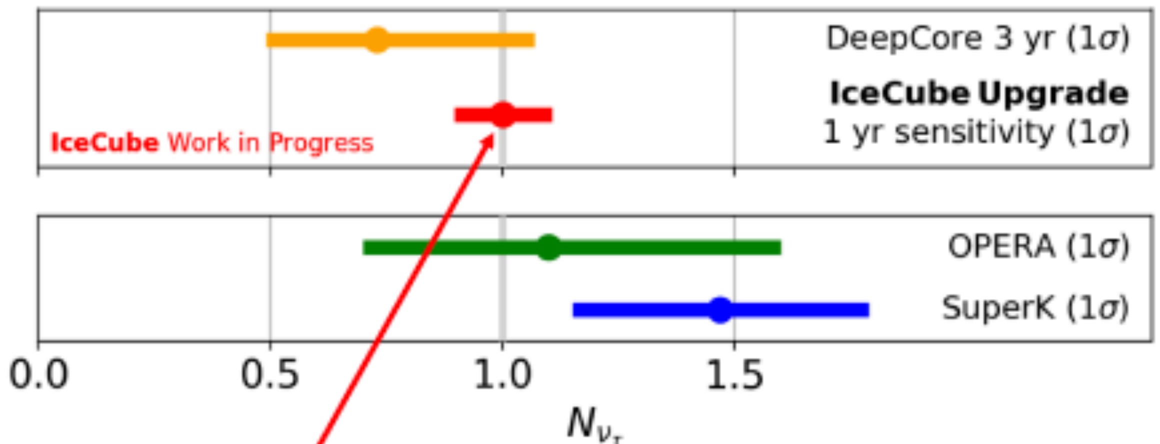
IceCube Upgrade



Science goals and objectives

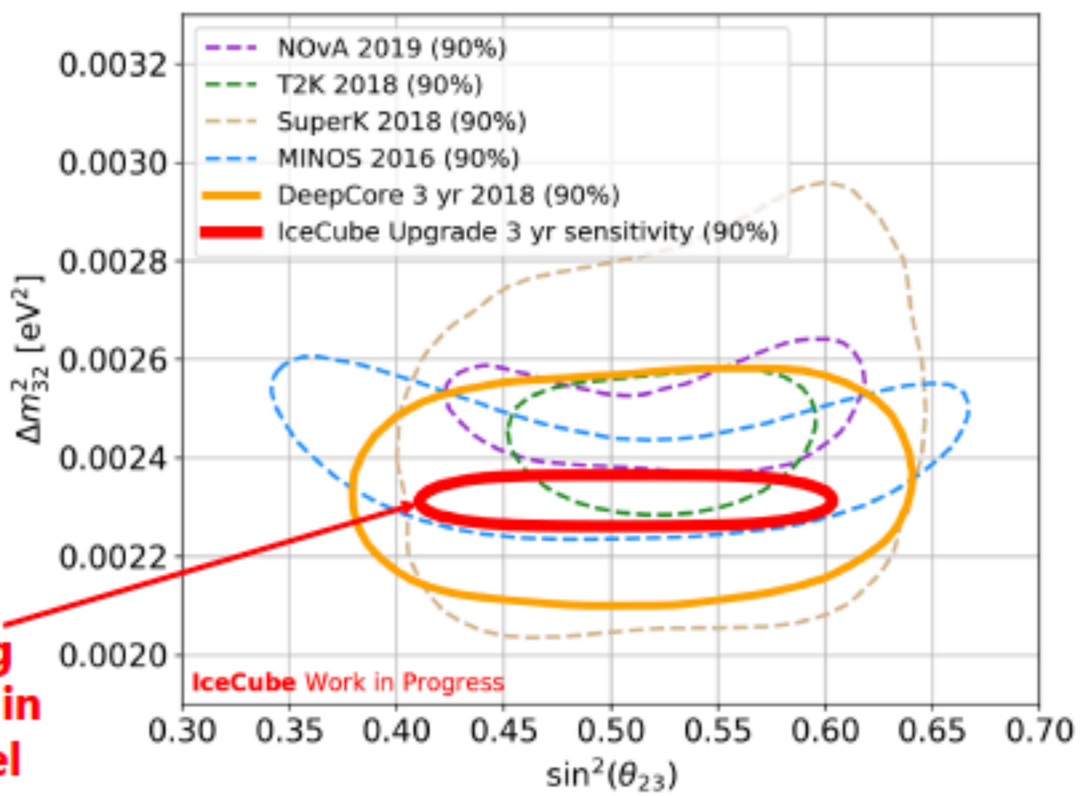
- Tau neutrino appearance - Test unitarity of the PMNS matrix
- Recalibration campaign - Retroactively apply improved ice-model to archival data (since 2010)

υ_τ appearance sensitivity (1 yr)



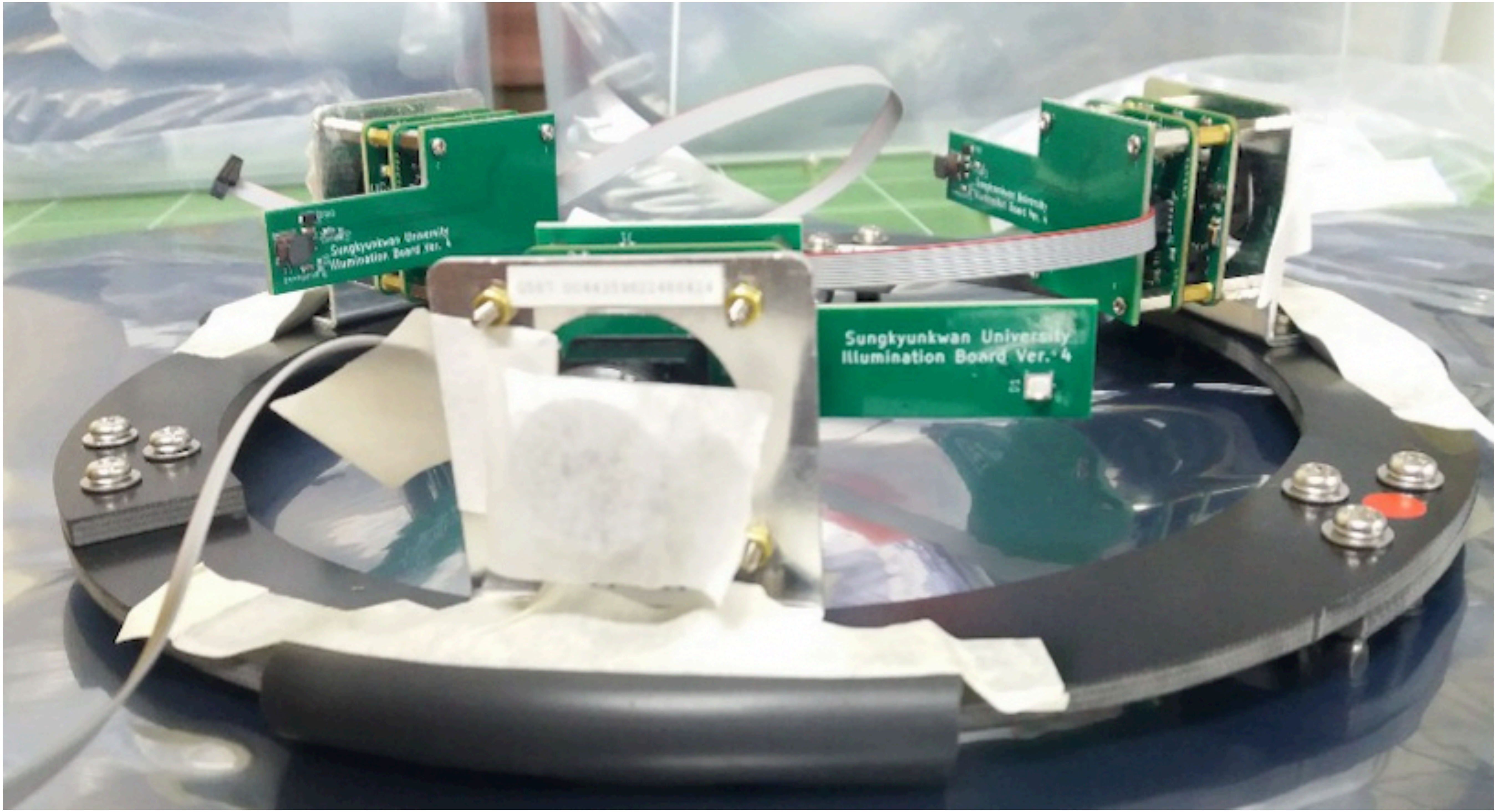
10% precision after 1 year
(6% after 3 years)

υ_μ disappearance sensitivity (3 yr)



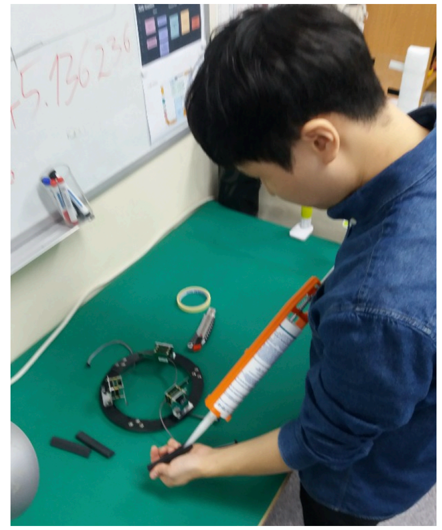
Competitive with long baseline experiments in disappearance channel

Korea Camera System Production for the IceCube Upgrade

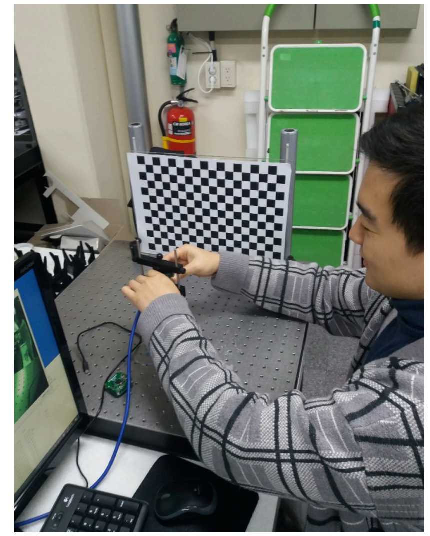


Mayor novelty for the IceCube Upgrade - new camera based calibration system to precisely measure detector medium

Camera Production Status



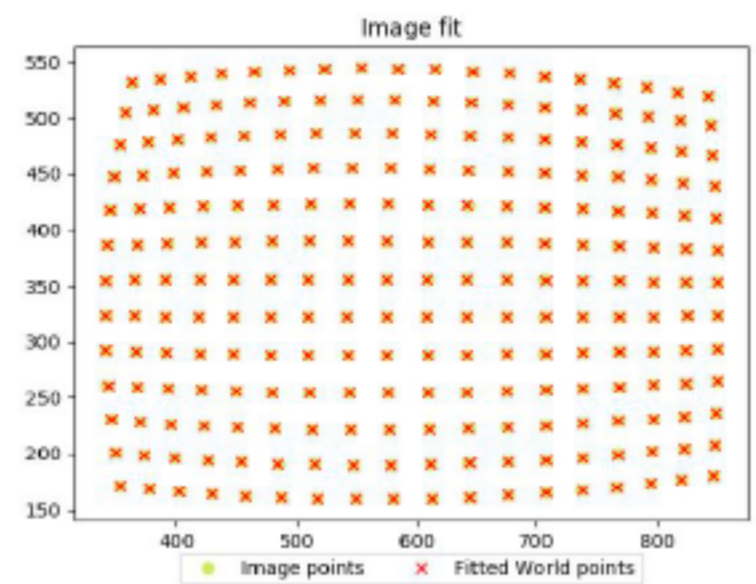
SKKU undergrad
Taehee Kim
(ring assembly)



SKKU undergrad
Danim Kim
(focus test)

SKKU undergrad
Nayoung Jeon
(visual inspection)

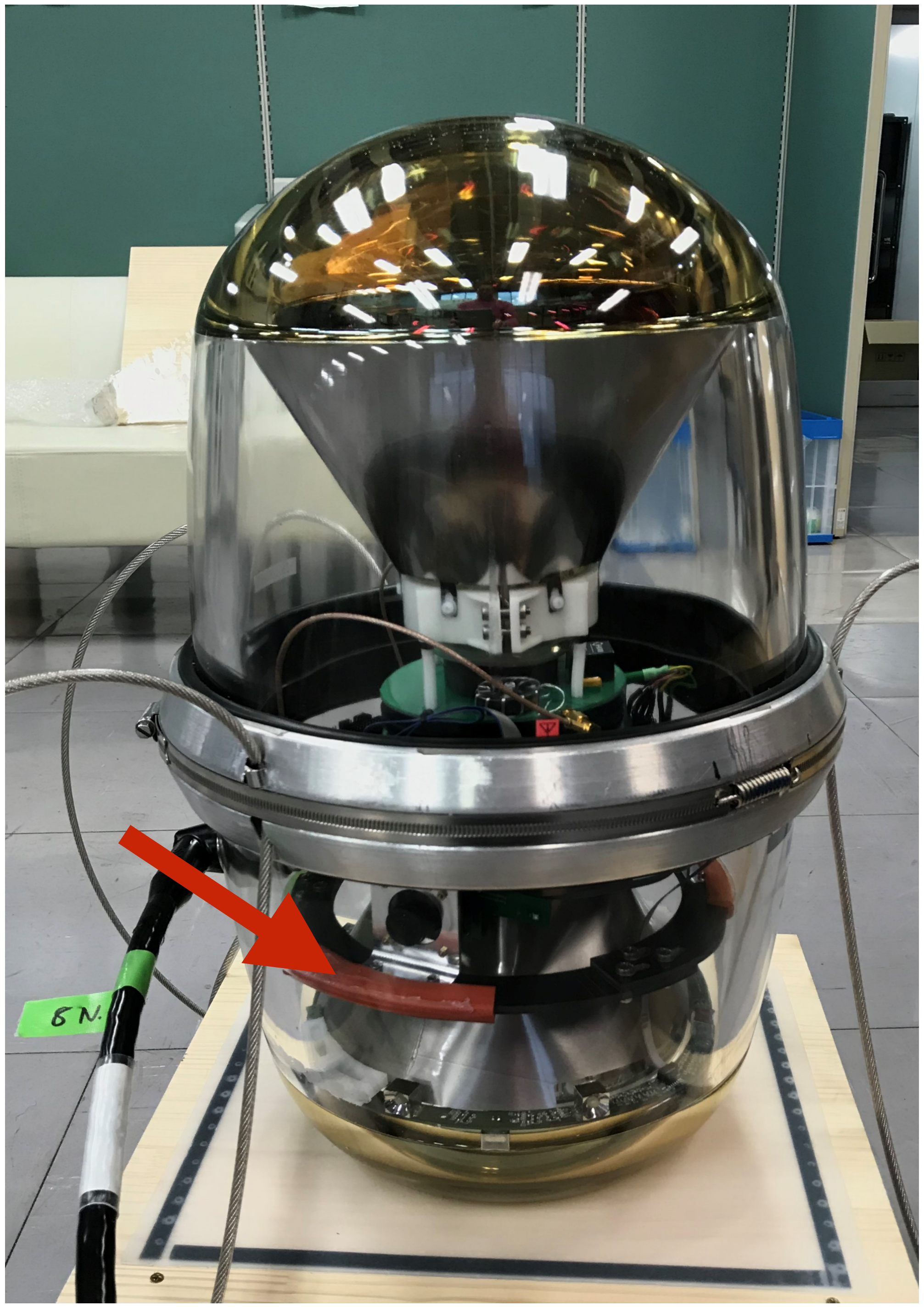
SKKU grad student
Jiwoong Lee
(sending cameras to integration centers)



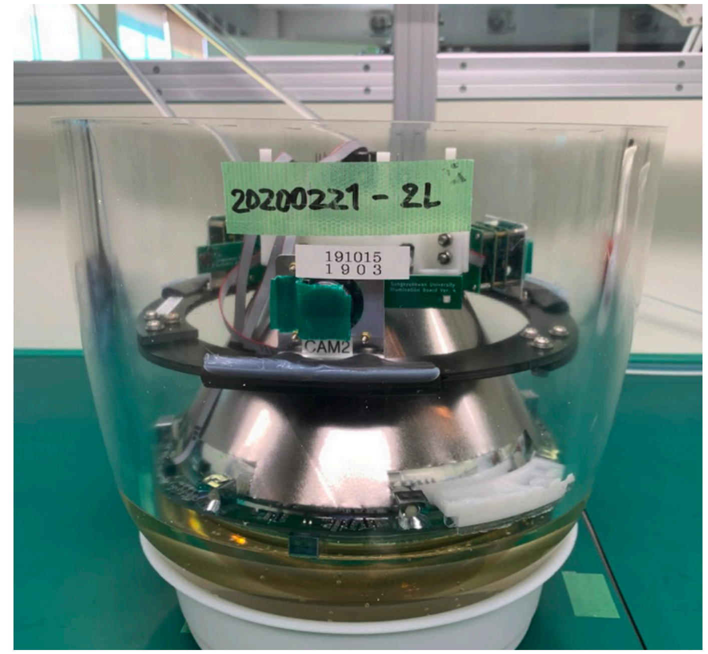
Automated image analysis and verification - SKKU students Gerrit Roellinghoff & Woosik Kang

Camera system integration

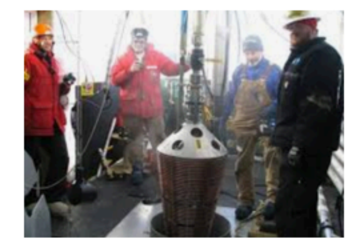
Camera system integrated in D-EGG



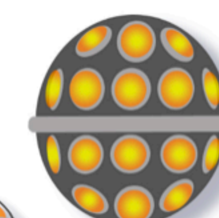
Camera systems for 180 modules delivered to integration sites



South Pole Operations



mDOM



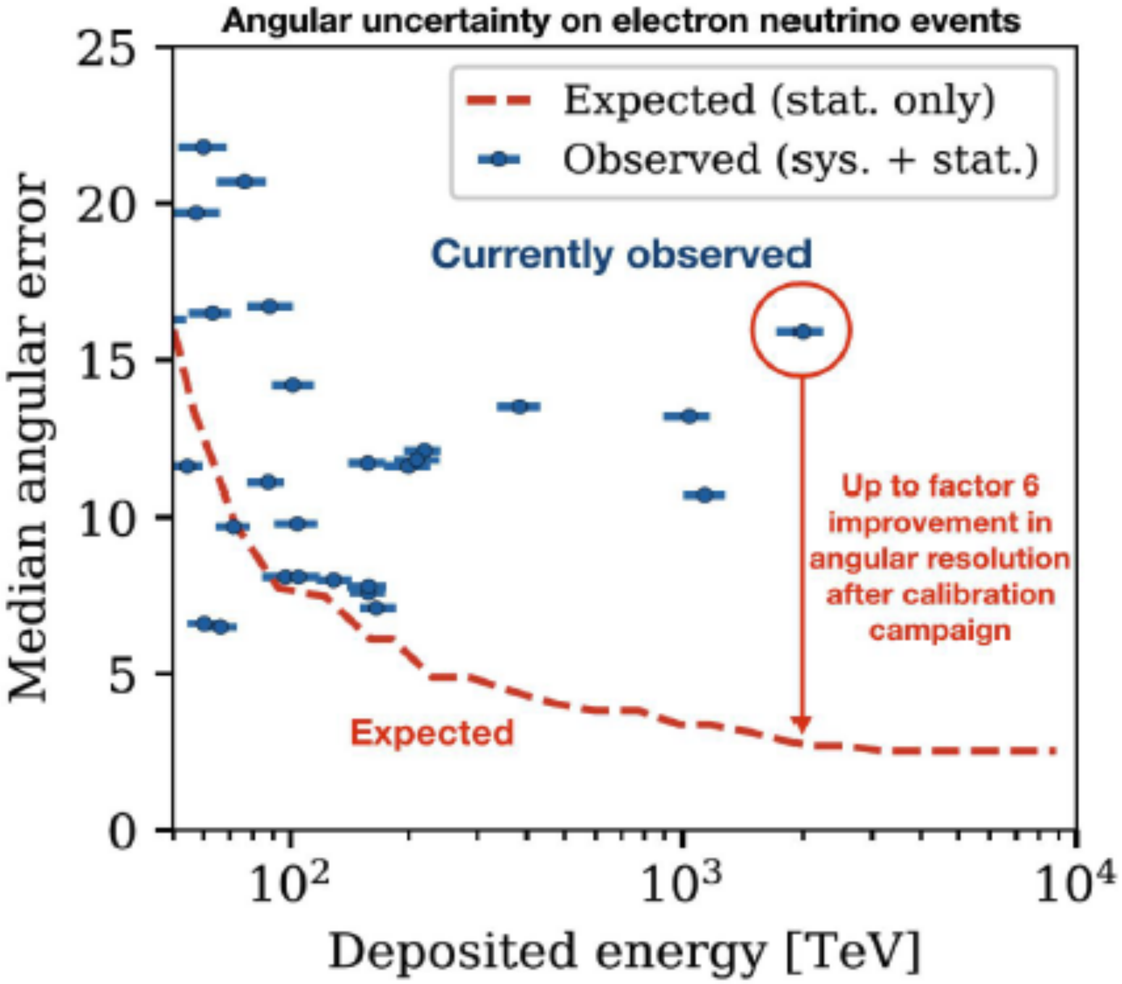
~650 sensor modules

D-EGG

Novel calibration

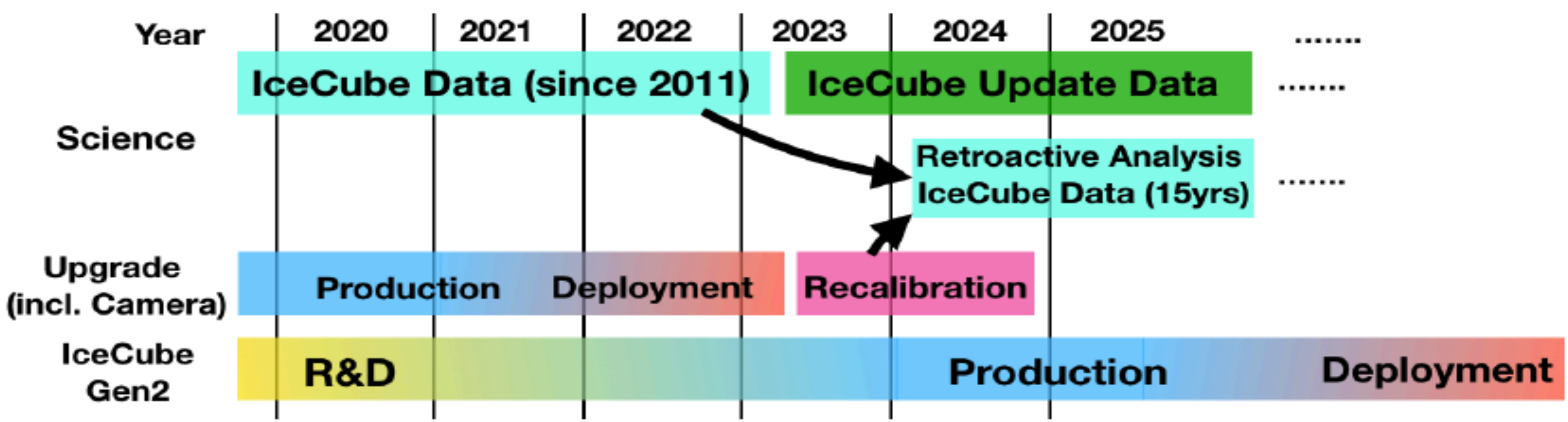
~3 camera systems / module

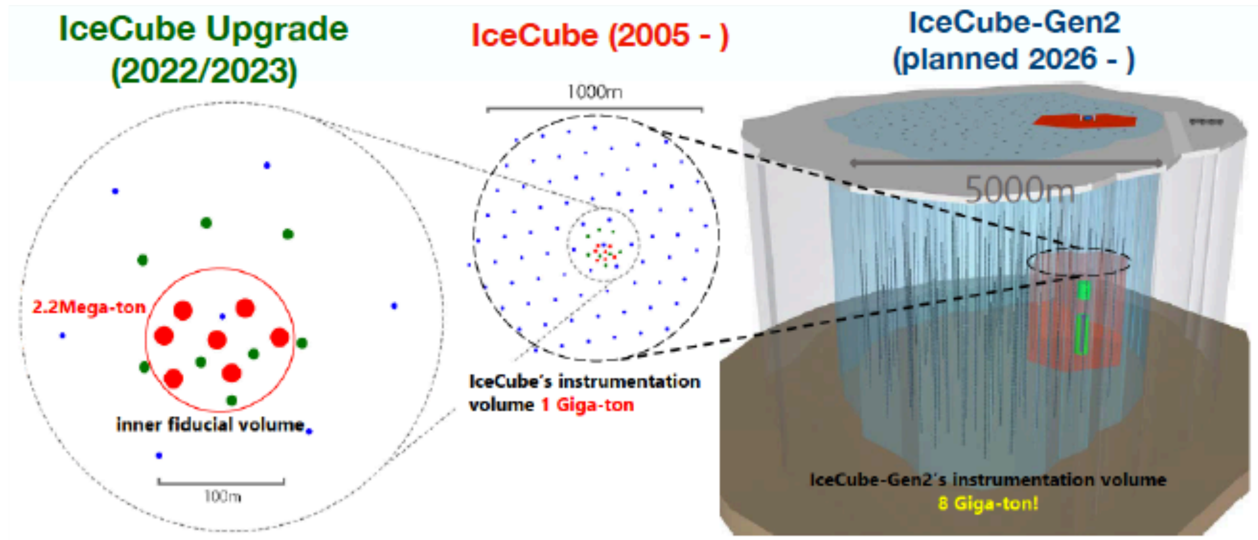
Camera system impact



Camera system key to comprehensive understanding of the detector medium

- ***Science multiplier*** Retroactively analyze more than 15 years of IceCube data with substantially improved angular and energy resolution
- ***Improved neutrino event pointing*** critical for multi messenger science





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IceCube-Gen2 (planned 2026 -)	~ 8 Giga-ton	• Astrophysical neutrino sources • GZK neutrinos, PeV Neutrinos

IceCube Gen2

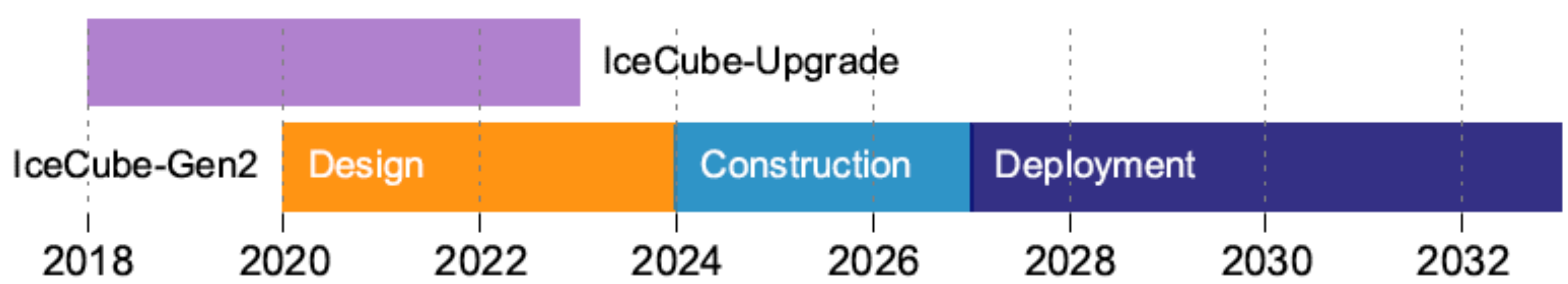
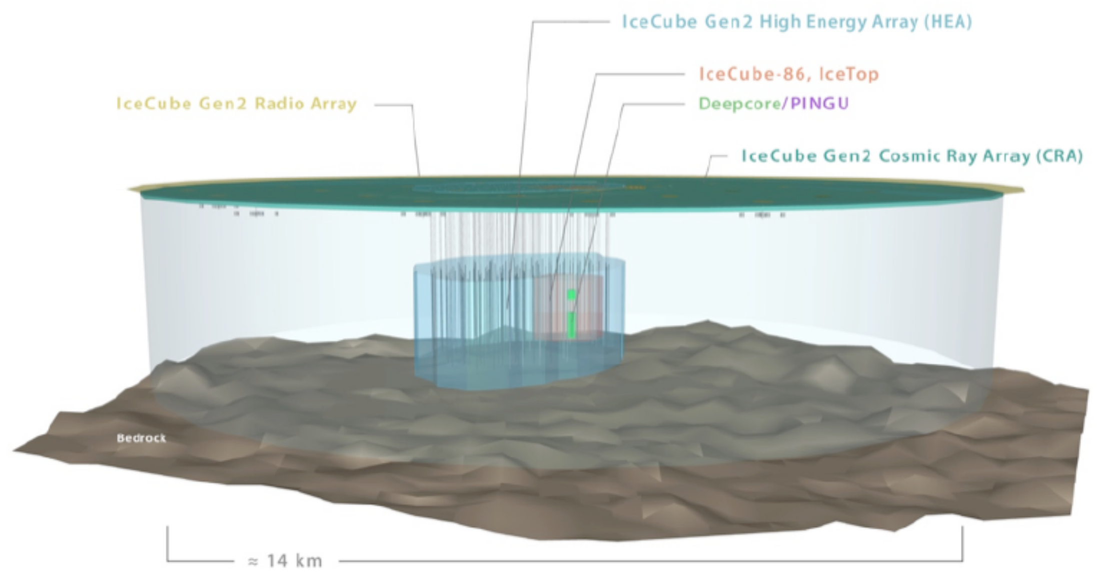


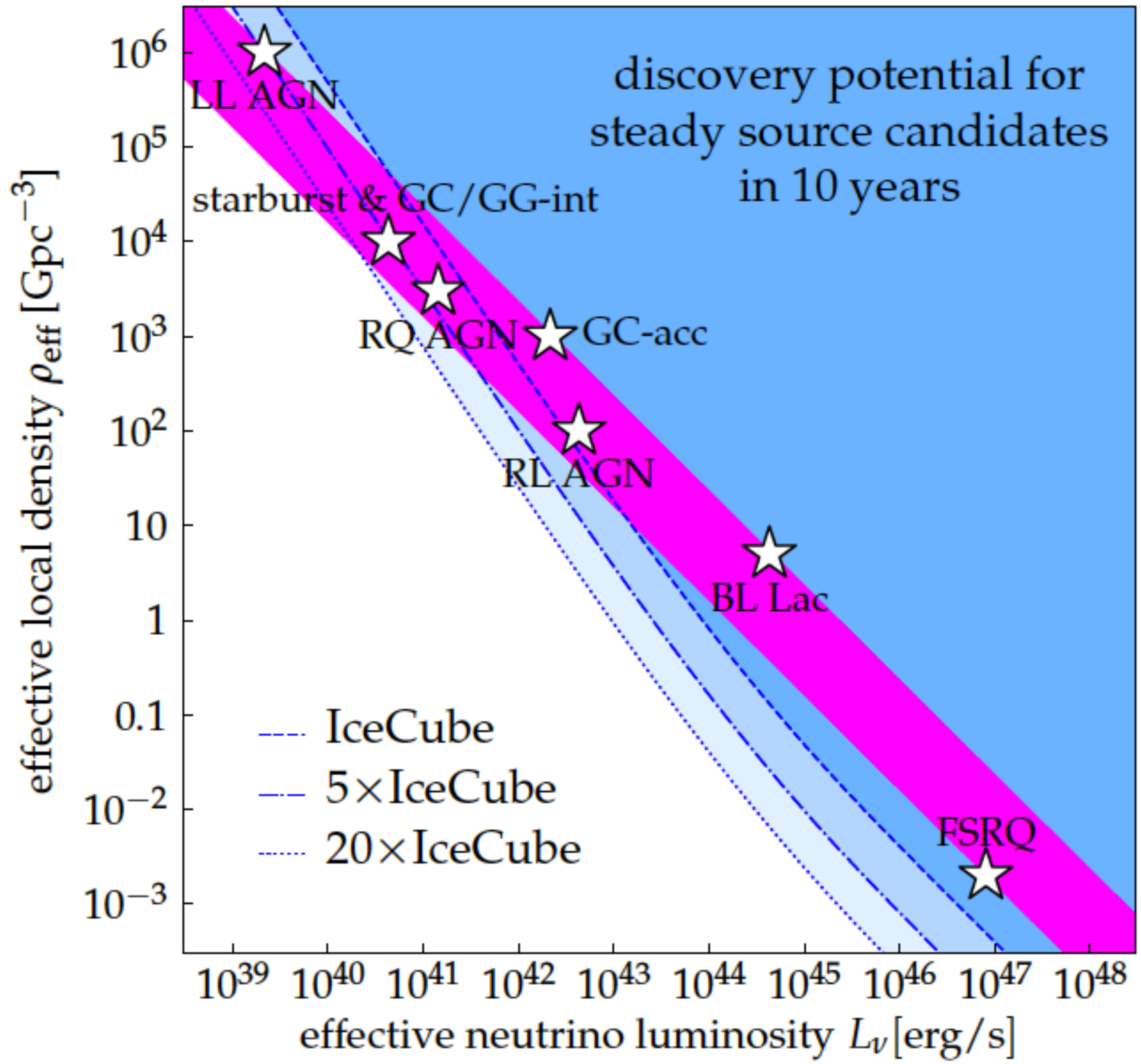
Figure 29: Time line for the IceCube Upgrade and projected time line for IceCube-Gen2.

IceCube-Gen2



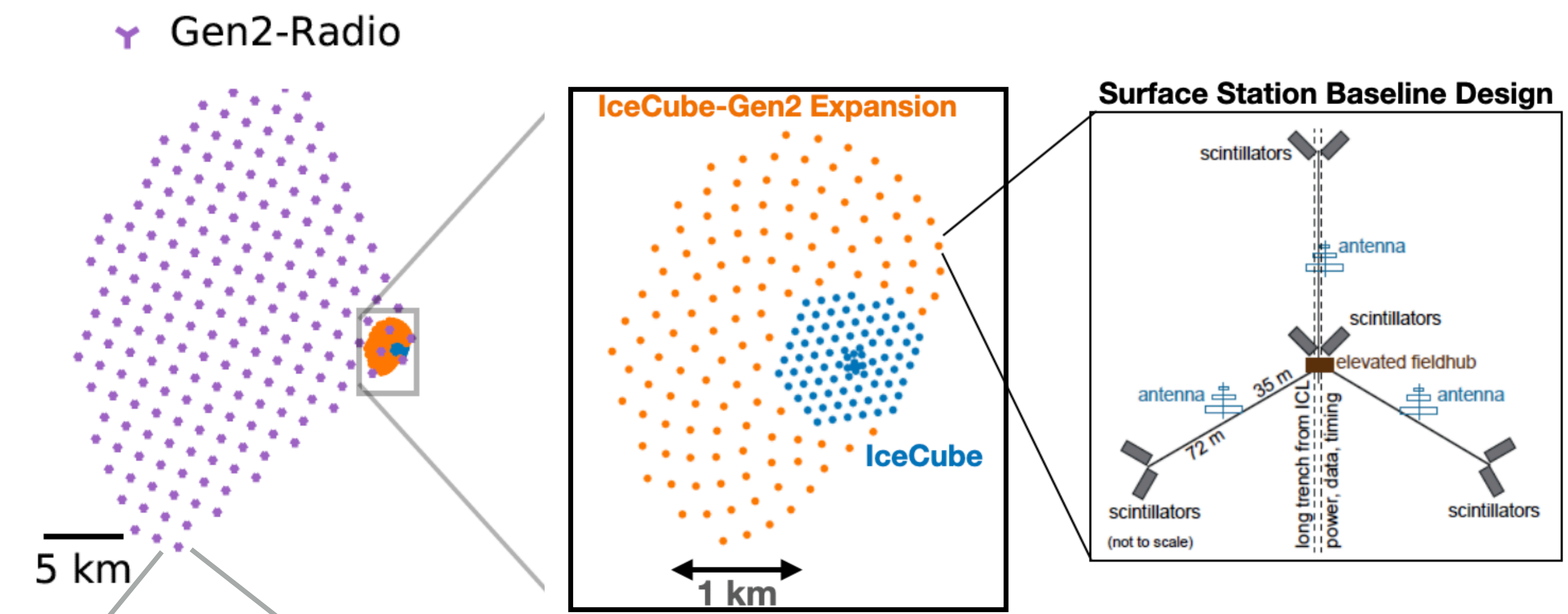
- IceCube has provided an amazing sample of events, but is still statistics limited
- Observed astrophysical flux is consistent with a isotropic flux of equal amounts of all neutrino flavors
- Gen2 objectives
  - High precision flavor composition studies
  - Detailed measurement of features / cut-off in neutrino spectrum
  - Multi-messenger astrophysics astronomy
  - Detection of steady astrophysical neutrino sources
  - GZK neutrinos
  - New physics or something unexpected

Astrophysics Uniquely Enabled by Observations of High-Energy Cosmic Neutrinos arXiv:1903.04334v1

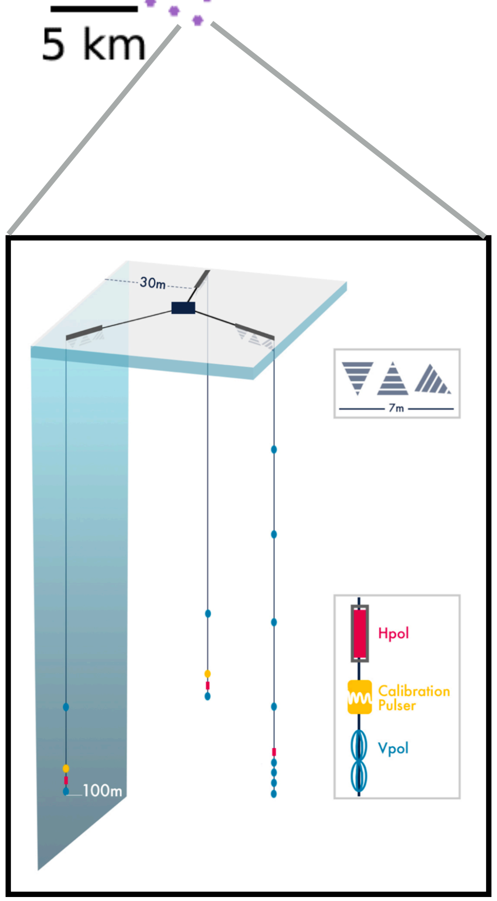


Future vision with 10x larger detector

IceCube-Gen2



References:
Submission to Decadal Survey on Astronomy and Astrophysics 2020 White paper: IceCube-Gen2: The Window to the Extreme Universe. (accepted in J. Physics G, arxiv.org/abs/2008.04323)



- Preliminary baseline design (as outlined in arXiv2008.04323):
  - Radio Array:
    - 500 km² for neutrino detection above 10PeV. 200 stations similar design to RNO-G
  - Surface Array
    - 32 scintillator stations (upgrade) + ~140stations Gen2
    - CR anisotropy, CR mass composition at Galactic/Extra-galactic transition, PeV Photon, hadronic interactions, Veto for in-ice array
  - Optical Modules:
    - 120 new strings are added to the existing IceCube strings with an average horizontal spacing of 240 m. Each string hosts 80 modules (vertically separated by 16m), totaling 9600 new modules, between 1325 m and 2575 m below the surface.
    - Instrumented geometric volume of 7.9km³

Korean IceCube Group @ SKKU (Aug 2020)

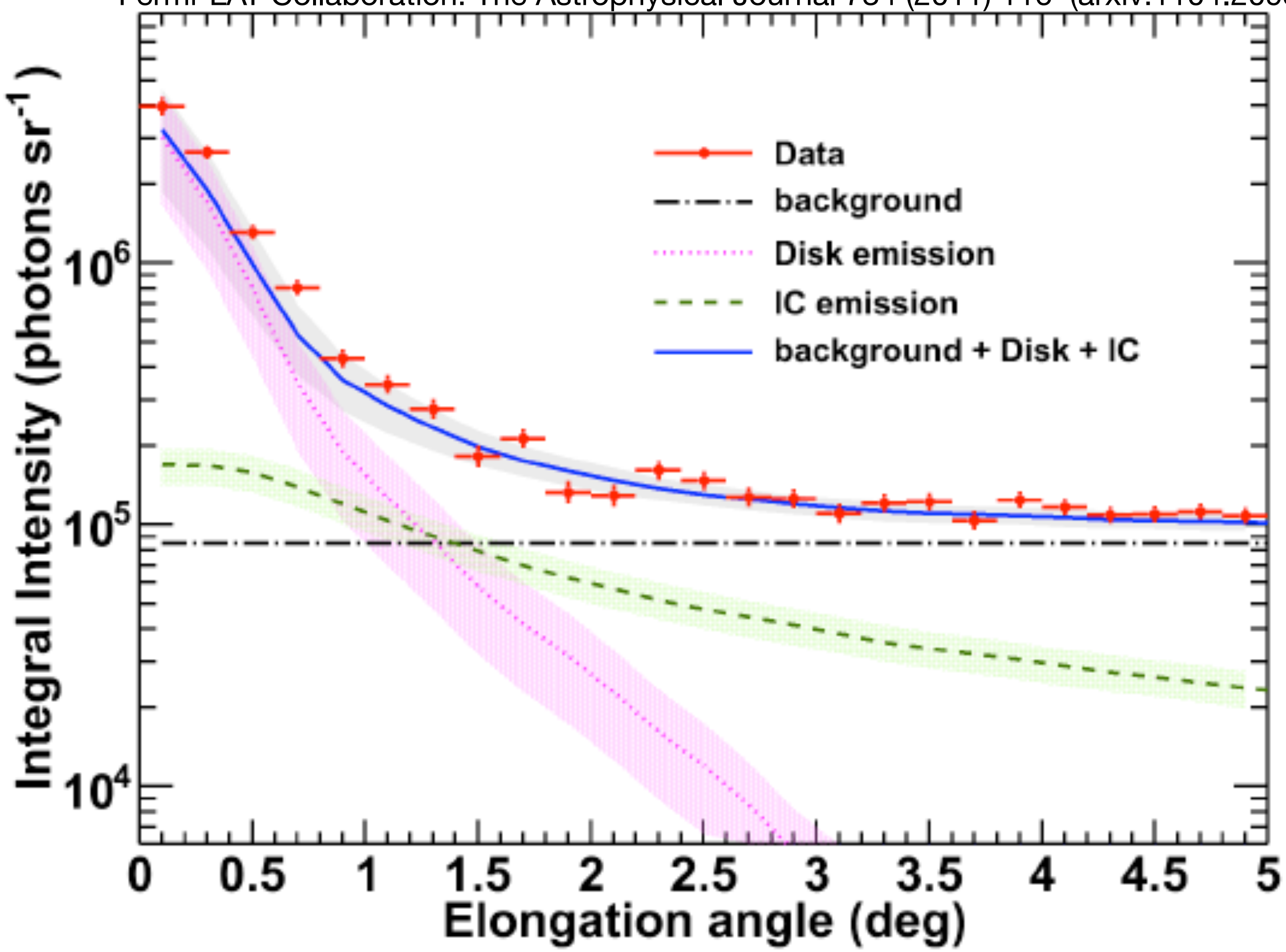
Summary and Conclusions

- High-energy astrophysical neutrinos are a new window to the Universe (first breakthrough discoveries, but we are just at the very beginning of a new era)
- Neutrino Telescopes are multipurpose experiments with an extremely diverse and very high impact science program
- Neutrino astronomy is a central part of the multi messenger astroparticle physics field - identify sources of hadronic acceleration
- The IceCube Upgrade has been fully funded, deployment 2022/2023 and we can look forward to many exciting discoveries in the near future

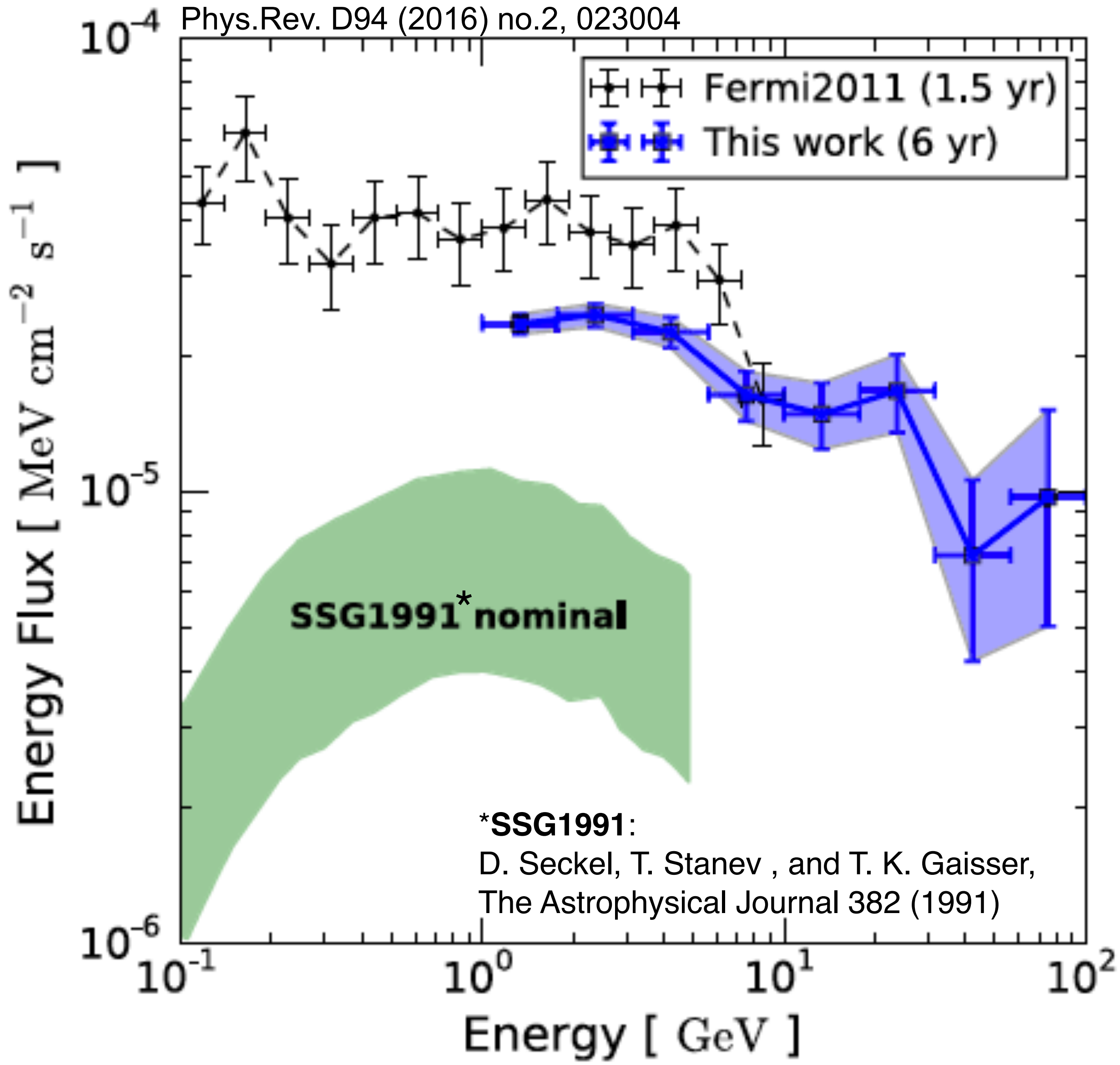
Image:Stephan Richter, IceCube/NSF

Gamma-ray emissions from the Sun

Fermi-LAT Collaboration: The Astrophysical Journal 734 (2011) 116 (arxiv:1104.2093)



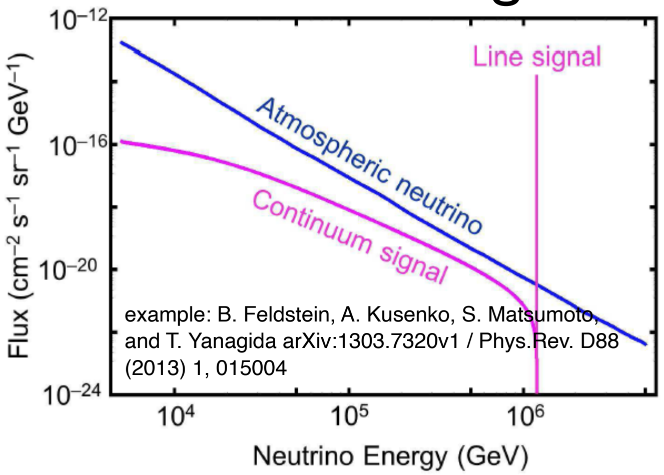
Kenny C.Y. Ng, John F. Beacom, Annika H.G. Peter, **Carsten Rott**
Phys.Rev. D94 (2016) no.2, 023004



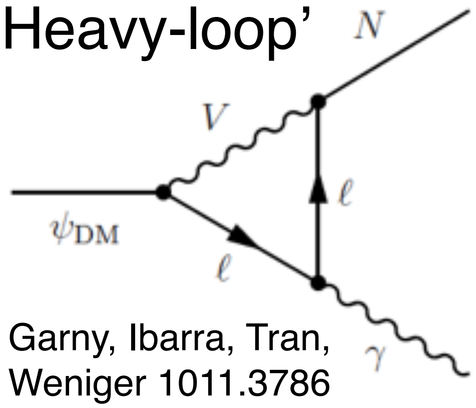
- **Cosmic ray interactions in the Solar atmosphere produce gamma-rays and neutrinos**
- **First detection** of gamma-rays up to 10GeV reported by Fermi-LAT Collaboration (2011) later shown spectrum extends beyond 100GeV in public Fermi-LAT data (K.C.Y. Ng, J. F. Beacom, A.H.G. Peter, C. Rott (2016))
- Surprisingly **little known about solar gamma-ray and neutrino production**
- Evidence that the gamma-ray flux shows a **strong dependence on the solar cycle** - significantly enhanced high-energy flux during solar minimum

Heavy Dark Matter Decay

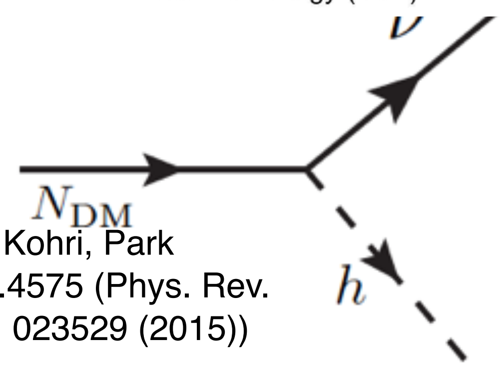
Decay process might produce mono-energetic neutrinos



'Heavy-loop'

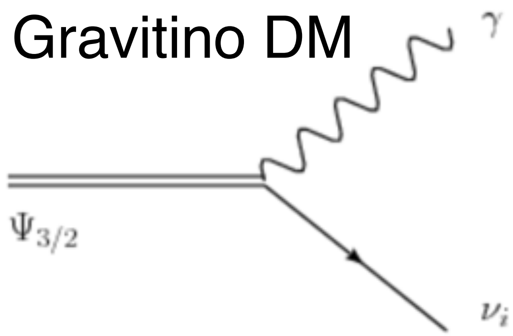


Garny, Ibarra, Tran, Weniger 1011.3786

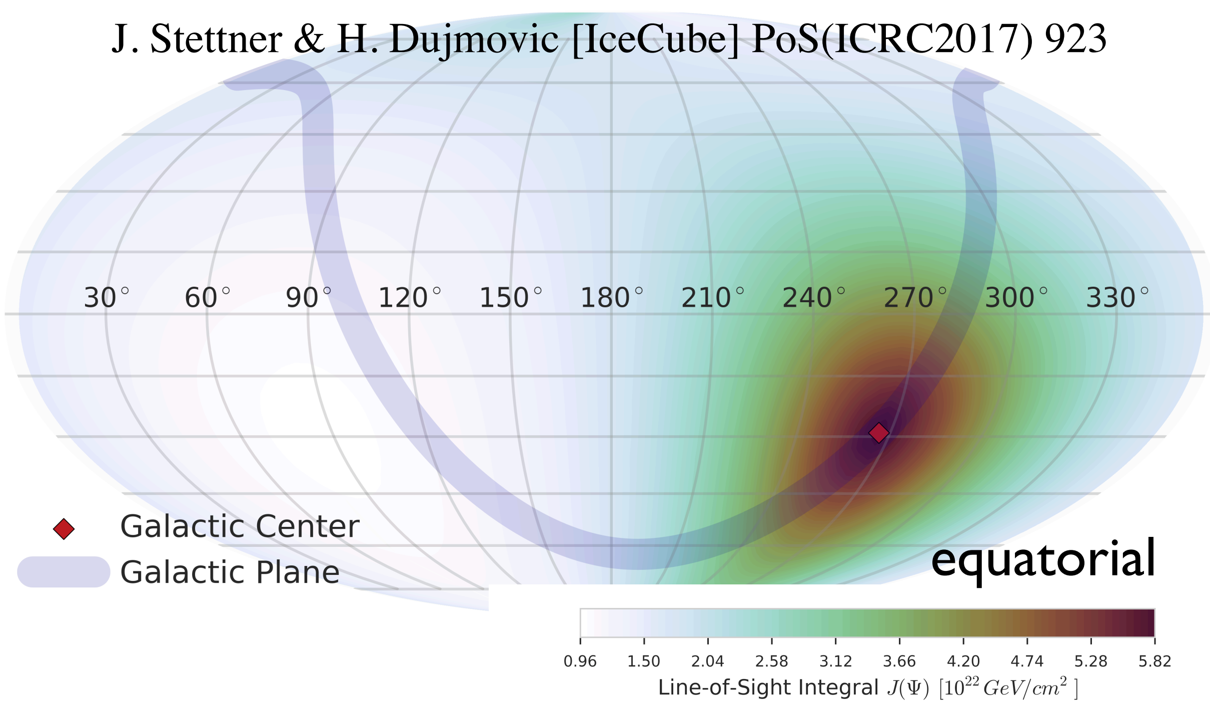


Rott, Kohri, Park 1408.4575 (Phys. Rev. D 92, 023529 (2015))

Gravitino DM



J. Stettner & H. Dujmovic [IceCube] PoS(ICRC2017) 923



Two flux contributions: Galactic and Extra galactic

$$\frac{d\Phi_{\mathrm{DM},\nu_\alpha}}{dE_\nu} = \frac{d\Phi_{\mathrm{G},\nu_\alpha}}{dE_\nu} + \frac{d\Phi_{\mathrm{EG},\nu_\alpha}}{dE_\nu}$$

- Characteristics of the signal components:
  - (1) Dark Matter decay in the Galactic Halo (Anisotropic flux + decay spectrum)

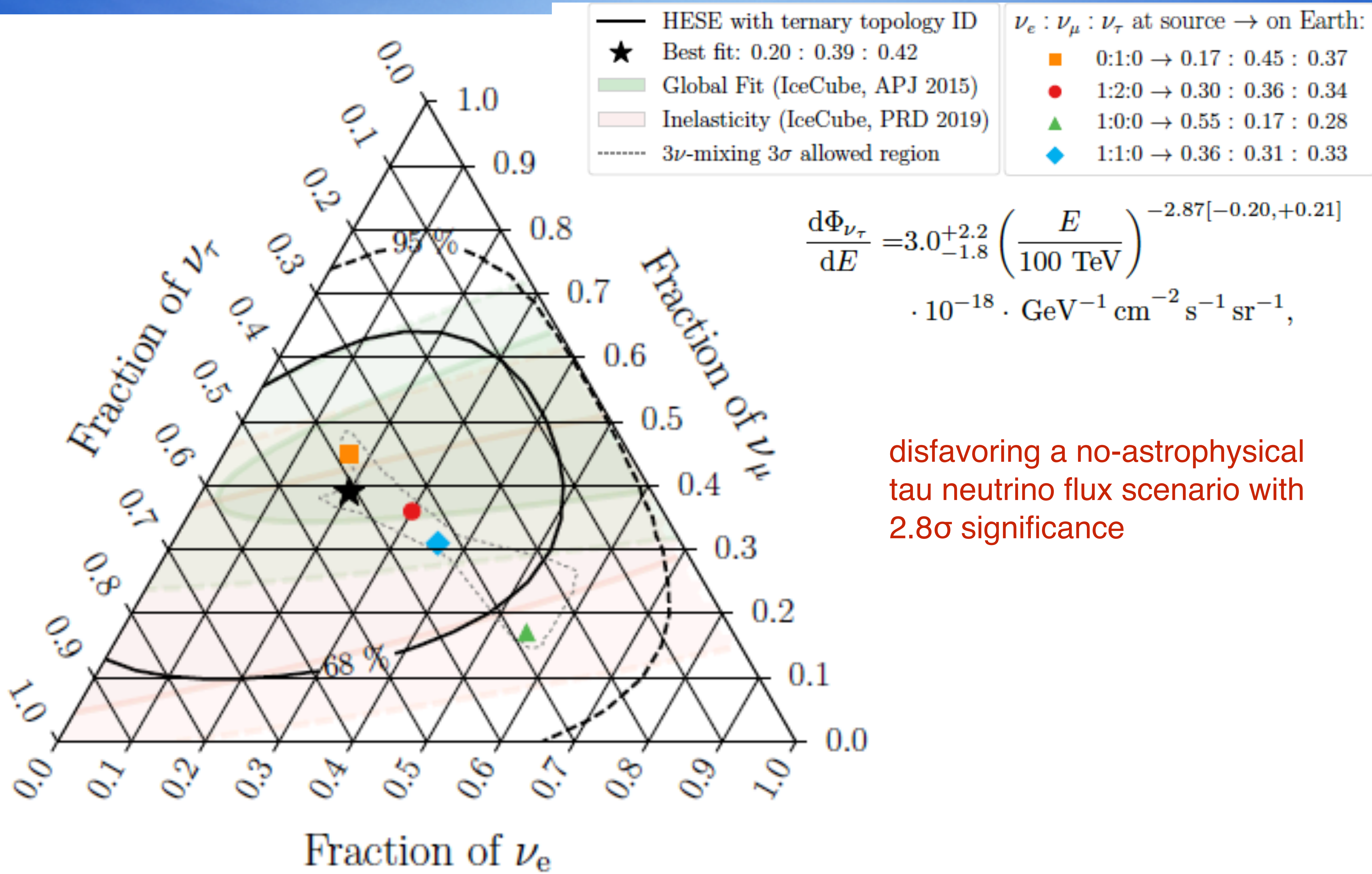
$$\frac{\mathrm{d}\Phi^{\mathrm{G}}}{\mathrm{d}E_\nu} = \frac{1}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \int_0^\infty \rho(r(s,l,b))\,\mathrm{d}s$$

  - Dark Matter decay at cosmological distances (Isotropic flux + red-shifted spectrum)

$$\frac{\mathrm{d}\Phi^{\mathrm{EG}}}{\mathrm{d}E} = \frac{\Omega_{\mathrm{DM}}\, \rho_c}{4\pi\, m_{\mathrm{DM}}\, \tau_{\mathrm{DM}}} \int_0^\infty \frac{1}{H(z)} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu}[(1+z)E_\nu]\,\mathrm{d}z$$

"Measurement of Astrophysical Tau Neutrinos in IceCube's High-Energy StartingEvents" (IceCube Collaboration) arXiv:2011.03561

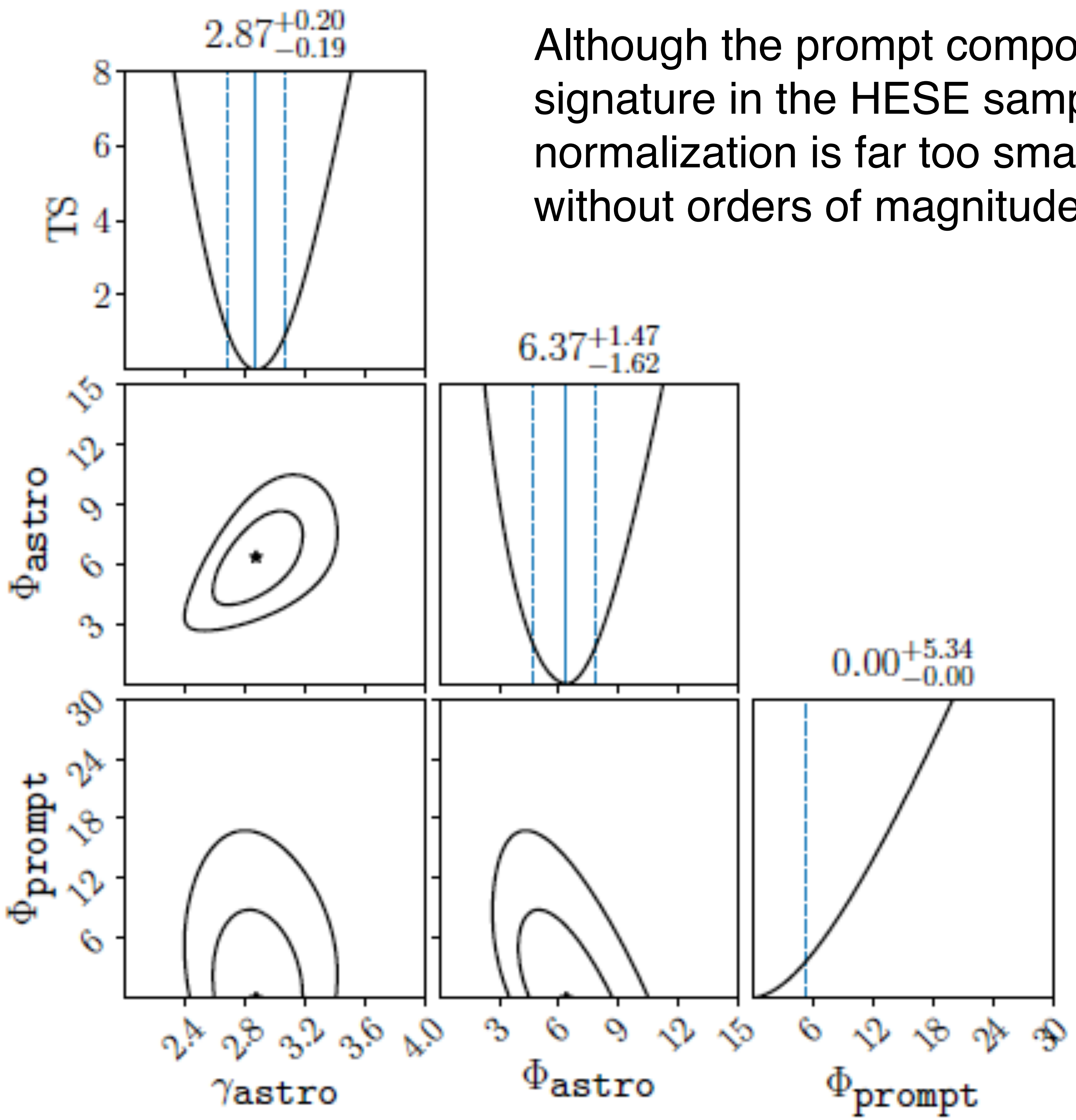
Tau Neutrinos



$$\frac{d\Phi_{\nu_\tau}}{dE} = 3.0^{+2.2}_{-1.8} \left(\frac{E}{100\ \text{TeV}}\right)^{-2.87[-0.20,+0.21]} \cdot 10^{-18} \cdot \text{GeV}^{-1}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1},$$

disfavoring a no-astrophysical tau neutrino flux scenario with 2.8σ significance

Prompt neutrinos

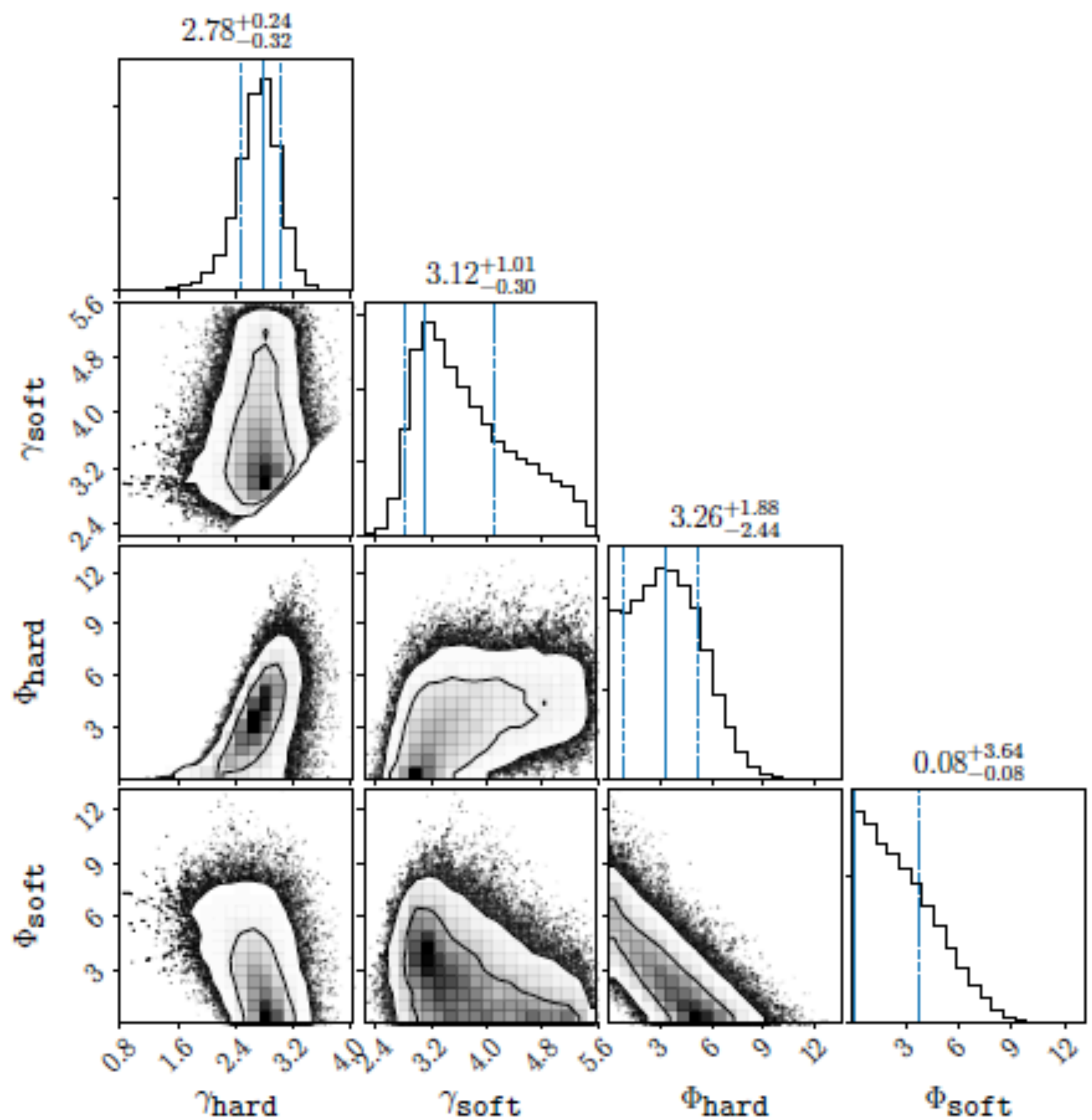


Although the prompt component has a distinct angular signature in the HESE sample, the component's normalization is far too small for this analysis to be sensitive without orders of magnitude more data.

Baseline Model: Atri Bhattacharya, Rikard Enberg, Mary Hall Reno, Ina Sarcevic, and Anna Stasto, "Perturbative charm production and the prompt atmospheric neutrino flux in light of RHIC and LHC," JHEP 06, 110 (2015), arXiv:1502.01076 [hep-ph].

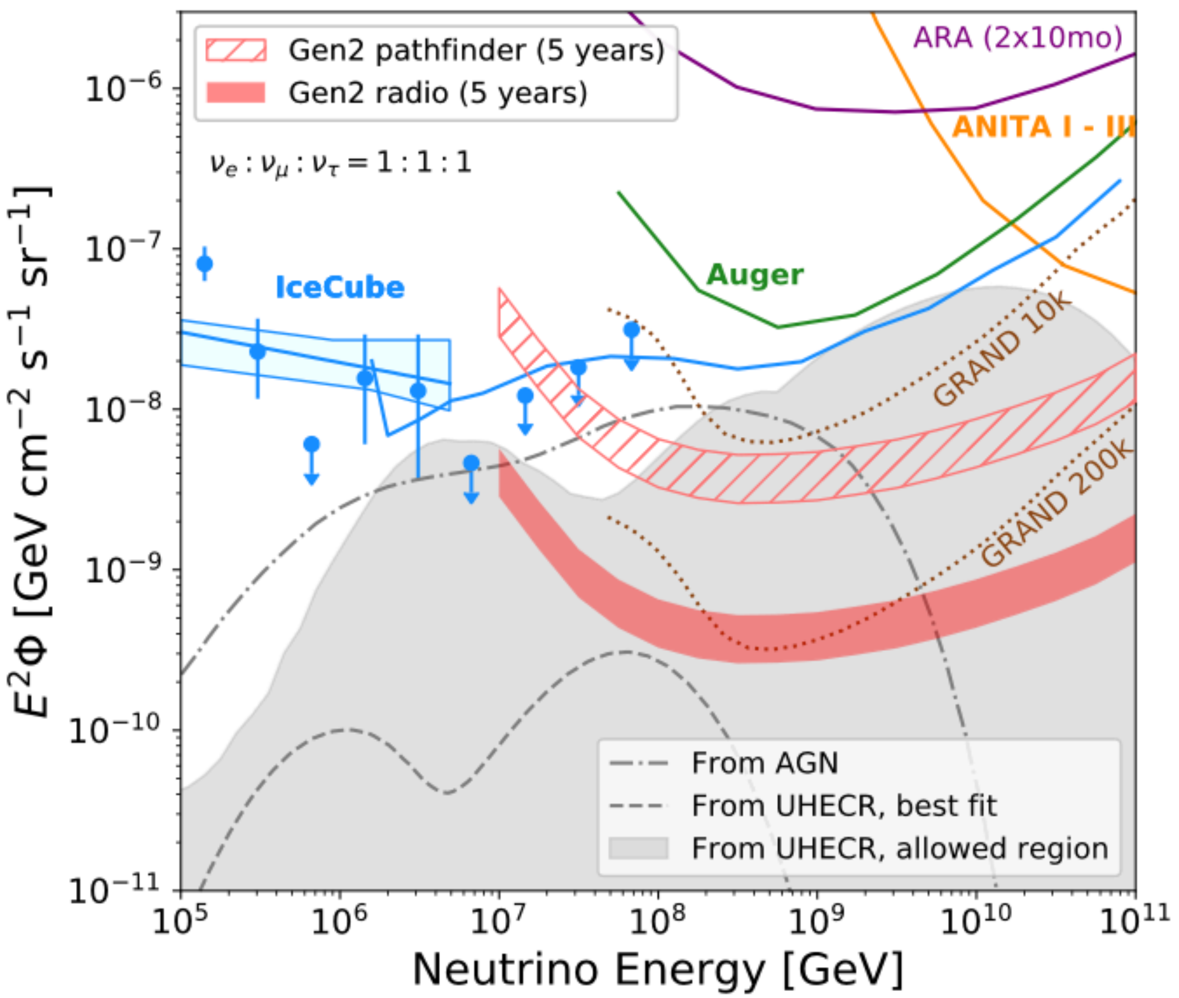
Double power law

$$\frac{d\Phi_{6\nu}}{dE} = \left(\Phi_{\mathrm{hard}}\left(\frac{E_\nu}{100\,\mathrm{TeV}}\right)^{-\gamma_{\mathrm{hard}}} + \Phi_{\mathrm{soft}}\left(\frac{E_\nu}{100\,\mathrm{TeV}}\right)^{-\gamma_{\mathrm{soft}}}\right)$$



- Double power law fit finds:
  - hard index (γ_{hard}~2.8) close to single fit (γ_{astro}~2.9)
  - soft spectral index poorly constrained (γ_{soft}~2.1)
  - two components' normalizations are highly correlated, with either equal to zero allowed within the two-dimensional 68.3% highest probability density region

IceCube-Gen2 Surface&Radio



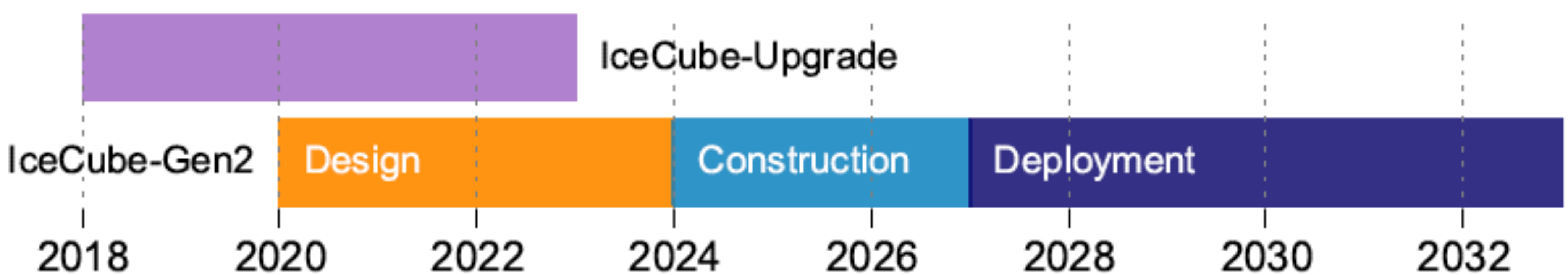
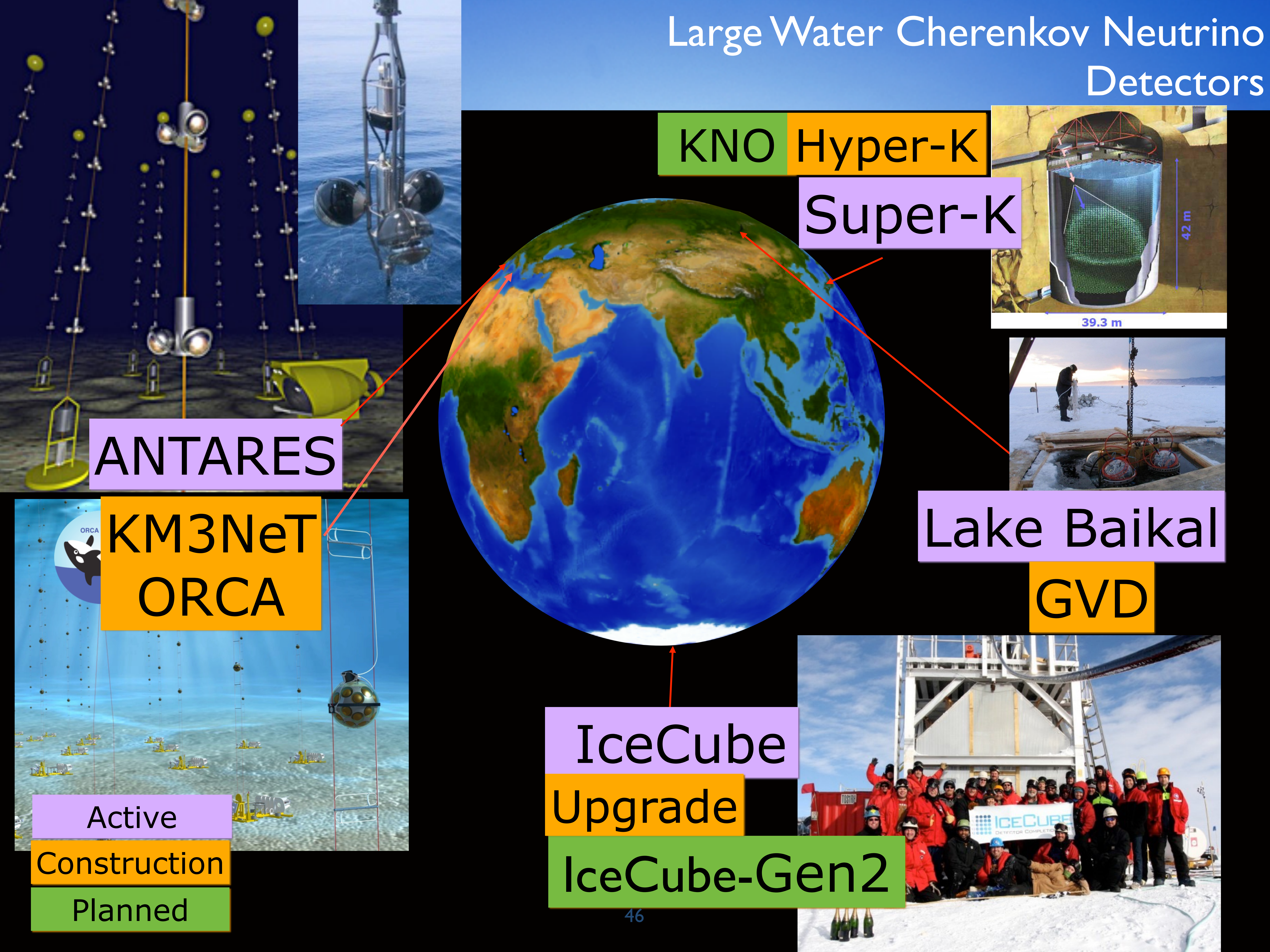
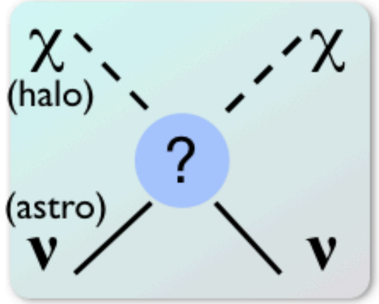


Figure 29: Time line for the IceCube Upgrade and projected time line for IceCube-Gen2.



Large Water Cherenkov Neutrino Detectors
KNO
Hyper-K
Super-K
42 m
39.3 m
ANTARES
KM3NeT ORCA
ORCA
Lake Baikal
GVD
IceCube
Upgrade
IceCube-Gen2
Active
Construction
Planned



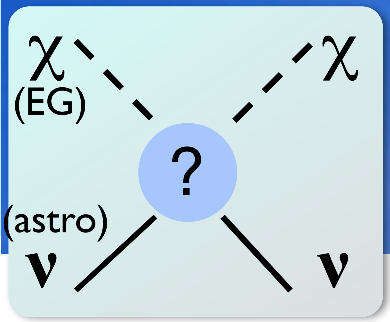
Neutrino DM scattering

Astrophysical ν scatter off χ from Galactic halo - resulting in anisotropy

- Milky Way Halo

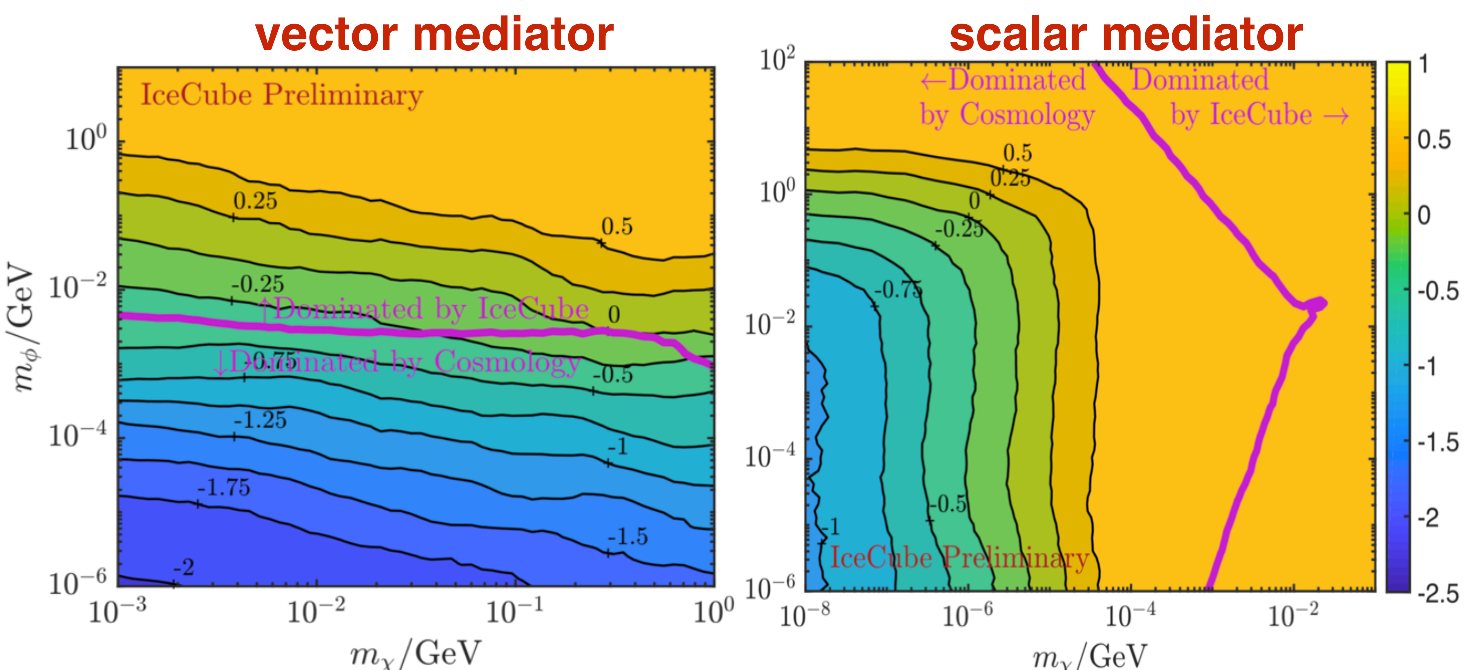
Combination of coupling strength **g** and masses $\mathbf{m_\phi}$ $\mathbf{m_\chi}$

Neutrino-Dark Matter Scattering

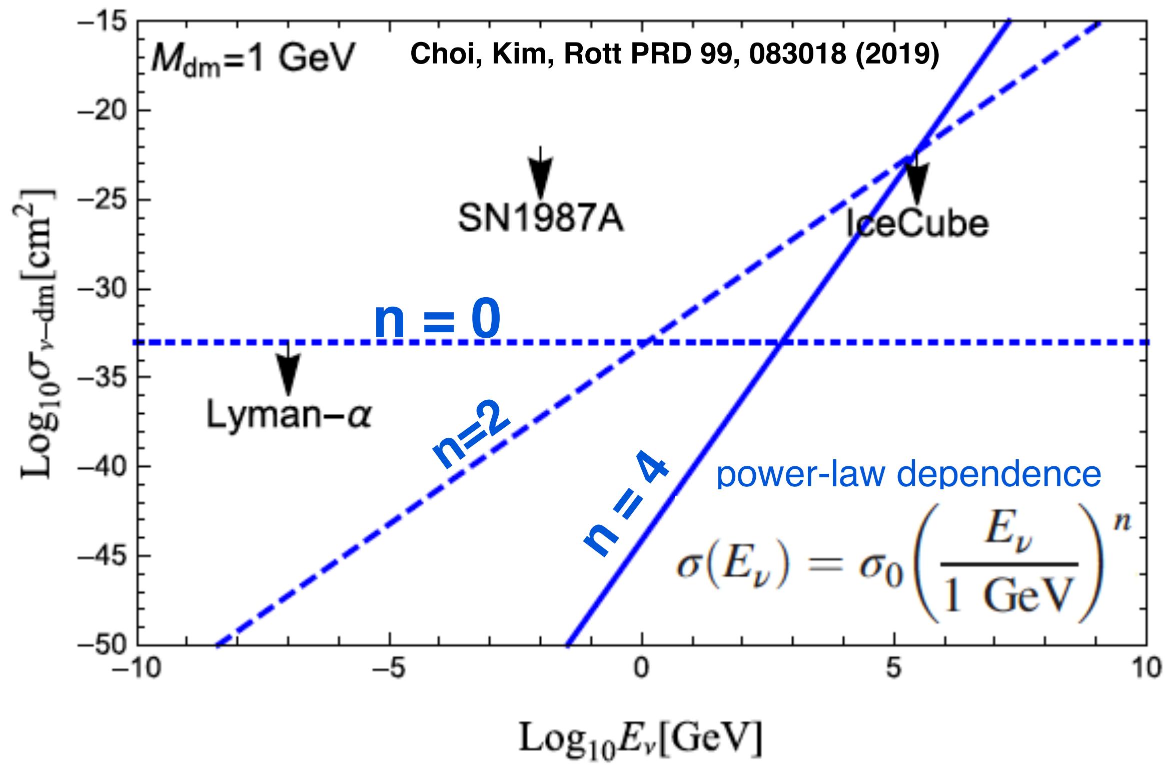


Neutrino Dark Matter Interactions

- Scattering of high energy astrophysical neutrinos on DM
  - "Isotropic" astrophysical neutrino flux on Galactic dark matter halo
  - Opportunities to probe very rare processes by observing neutrinos from distant sources
    - Example IceCube-170922A : Scattering of high energy astrophysical neutrinos from Blazar TXS0506+056 (z=0.33 / 5.7 billion light-years)



[C. A. Argüelles, A. Kheirandish A. C. Vincent Phys.Rev.Lett. 119 (2017) no.20, 201801 (arXiv:1703.00451)]



- **Current status**
  - First experimental searches have started - competitive with cosmological bounds
- **Future prospects and priorities**
  - Identification of new astrophysical neutrino sources in the future could increase sensitivities
  - High statistics sample of astrophysical neutrinos essential

see also DM-neutrino coupling by looking for neutrino survival from a point source (https://arxiv.org/abs/1808.02889), deviations on the shape of the spectrum (https://arxiv.org/abs/1401.7019, but at higher energies, like https://arxiv.org/abs/2001.04994), or delays in arrival times (https://arxiv.org/abs/1903.08607).