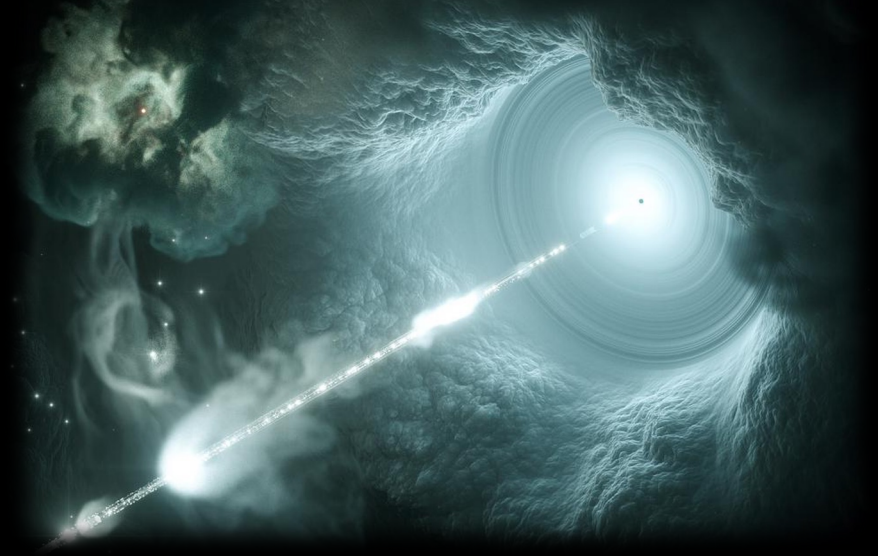


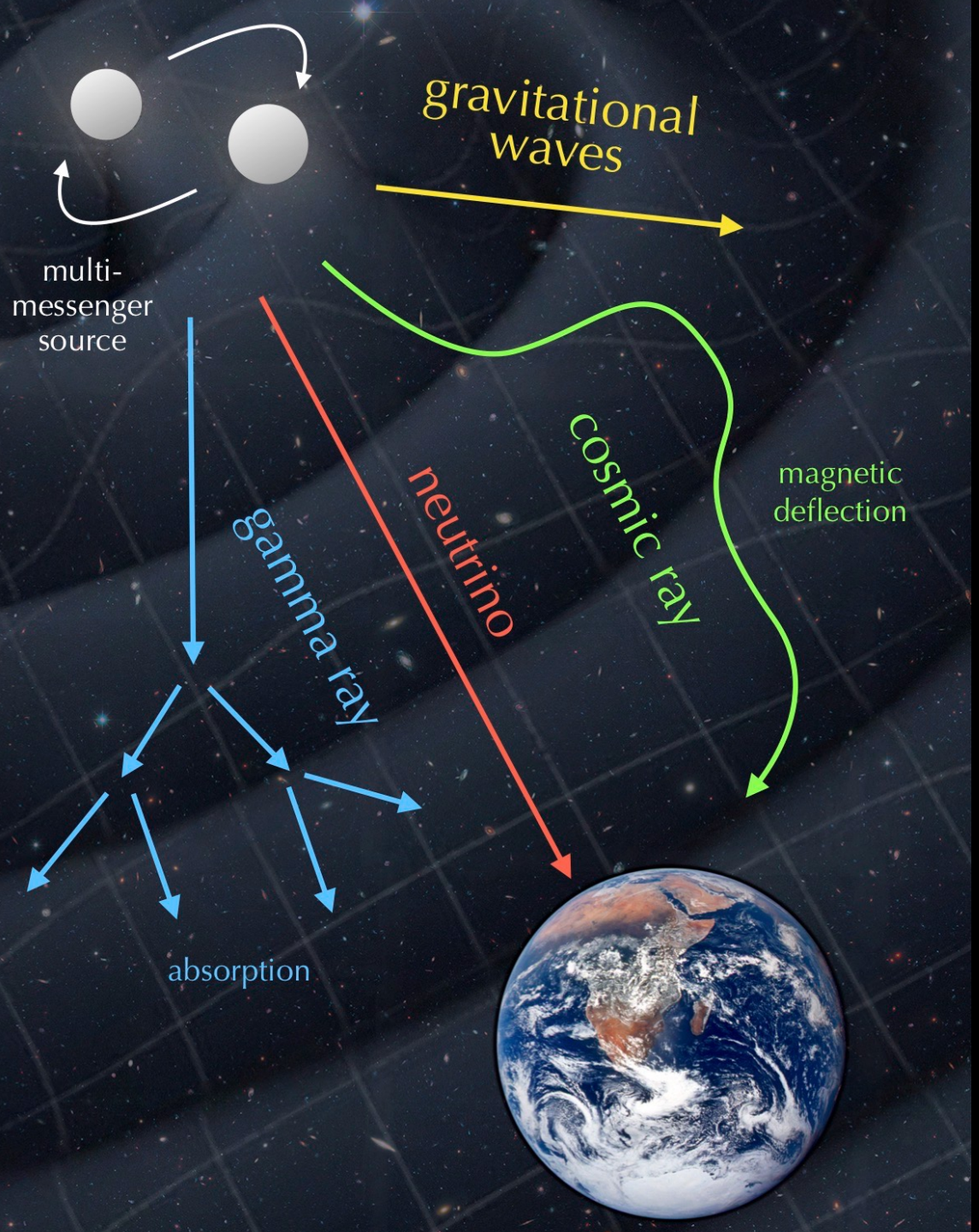
KM3NeT
physics perspective

Dorothea Samtleben on behalf of the KM3NeT collaboration

Nikhef

Universiteit Leiden
Instituut voor Onderzoek in de Natuurkunde

KM3NeT

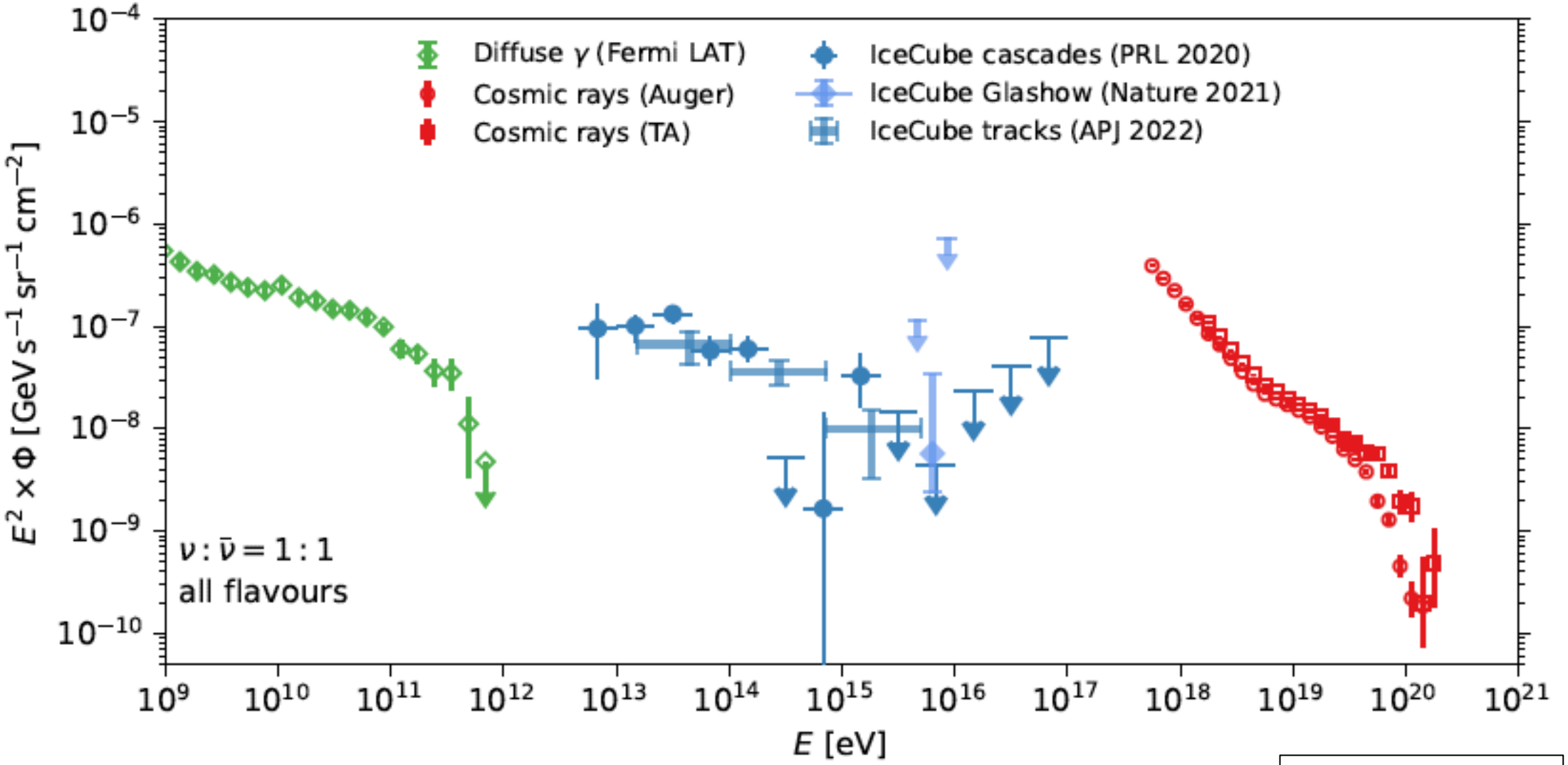


The neutrino as messenger

What is the origin of cosmic rays?

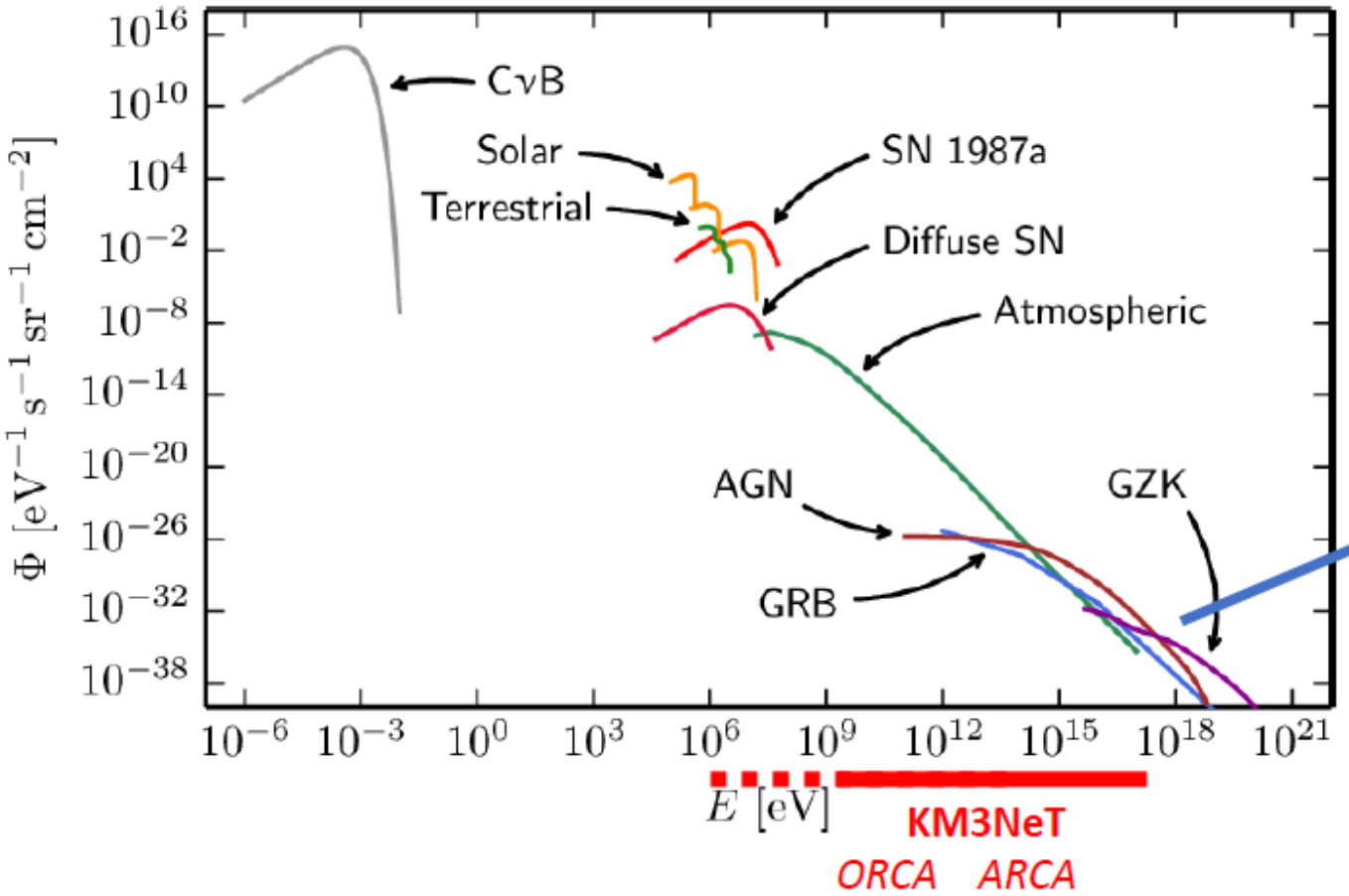
What are the sources of high energy neutrinos?

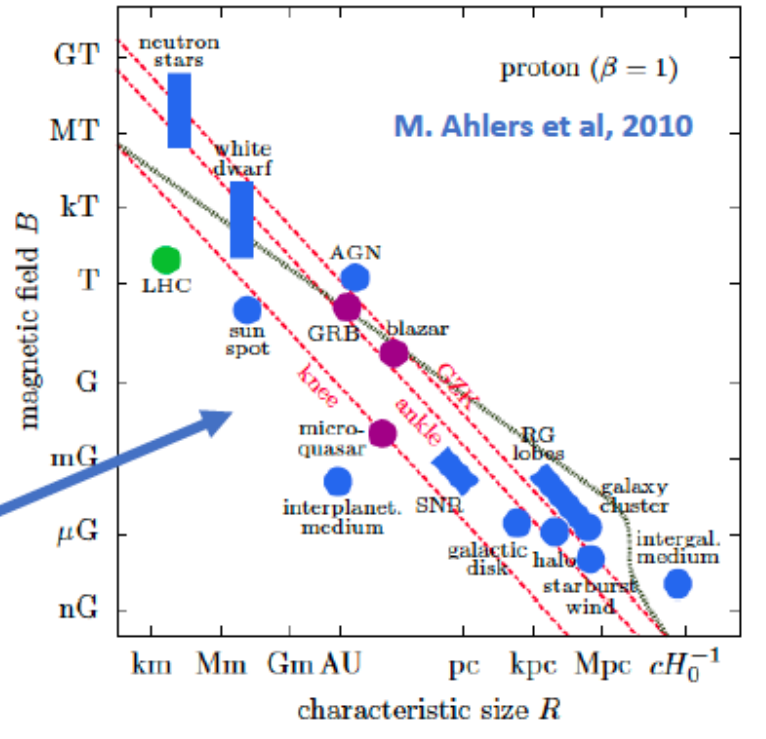
Hints of new physics?



Ackermann et al.,
Snowmass 2021

Neutrino energy spectrum

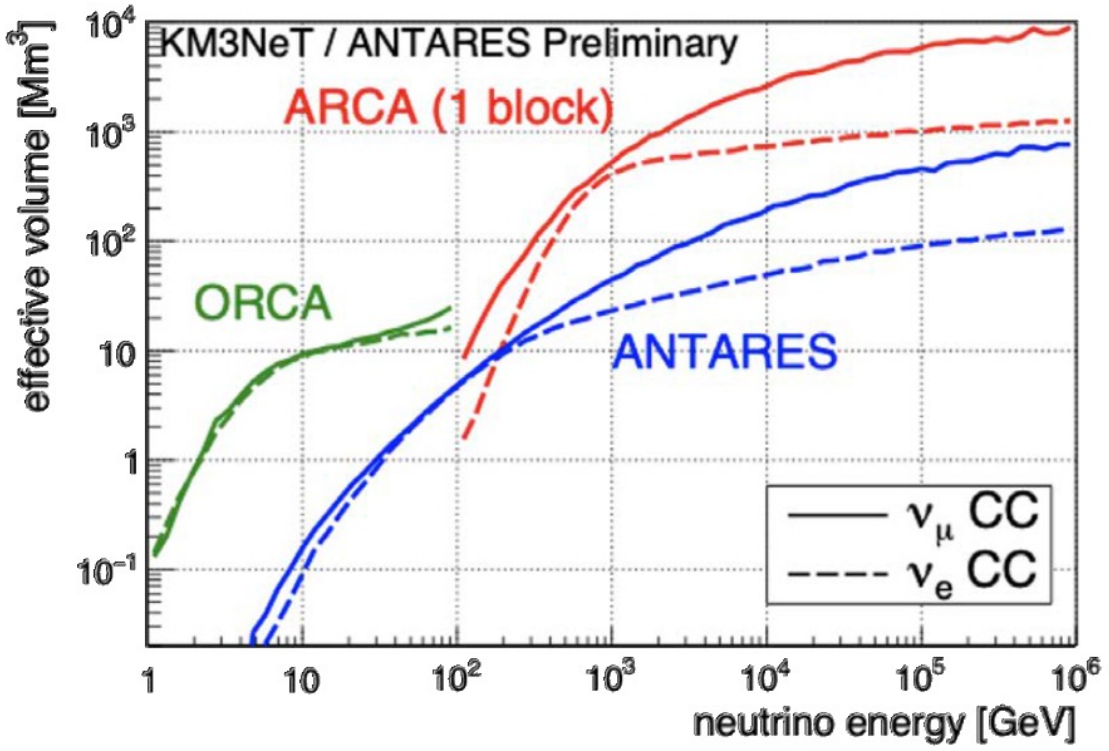




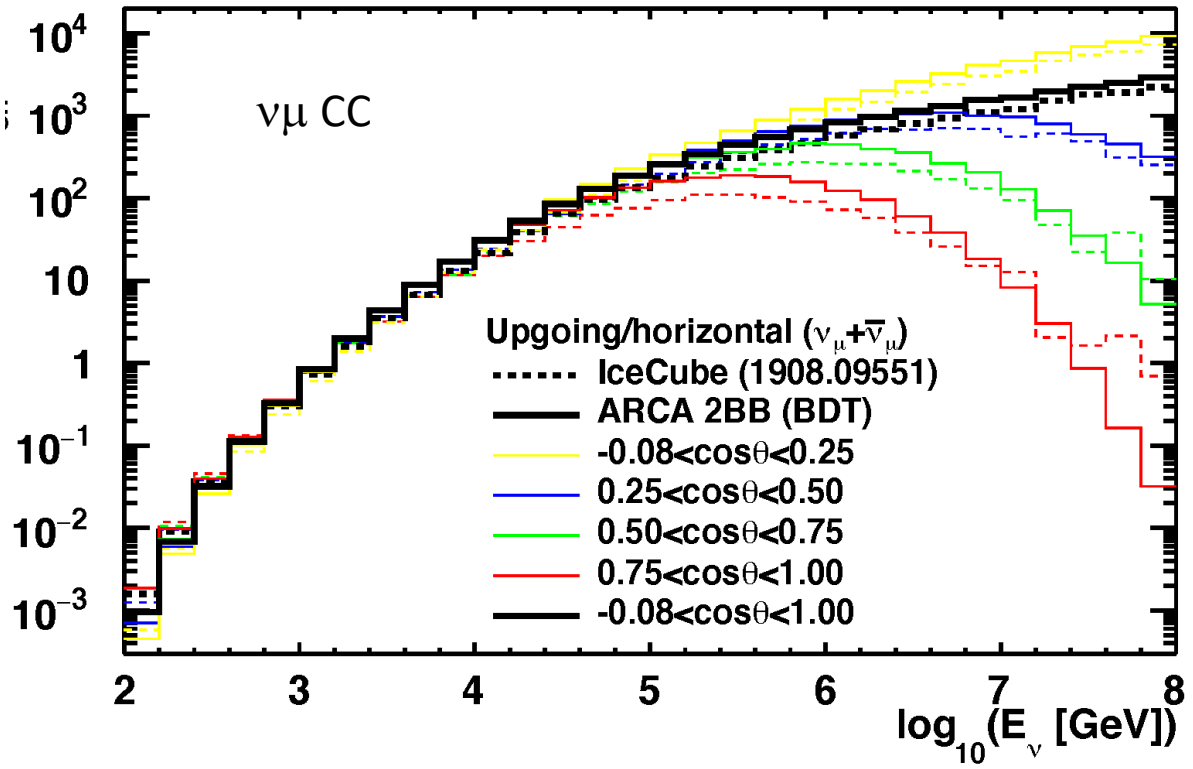
"Hillas plot"

KM3NeT characteristics

KM3NeT effective area



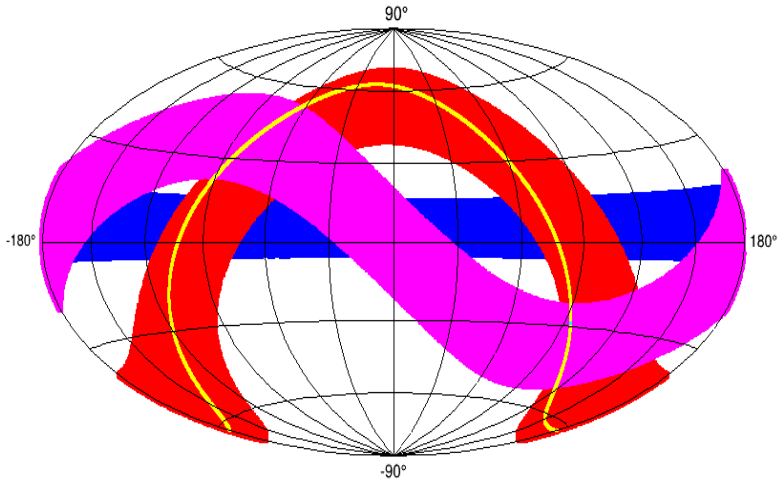
KM3NeT/ARCA (analysis cuts) comparison to **IceCube**



Caiffi et al., *JINST* **16** C09030, 2021

KM3NeT strengths

Instantaneous Field of view with horizontal tracks
-> ‘sweet spot’ for PeV events
-> complementary between neutrino detectors

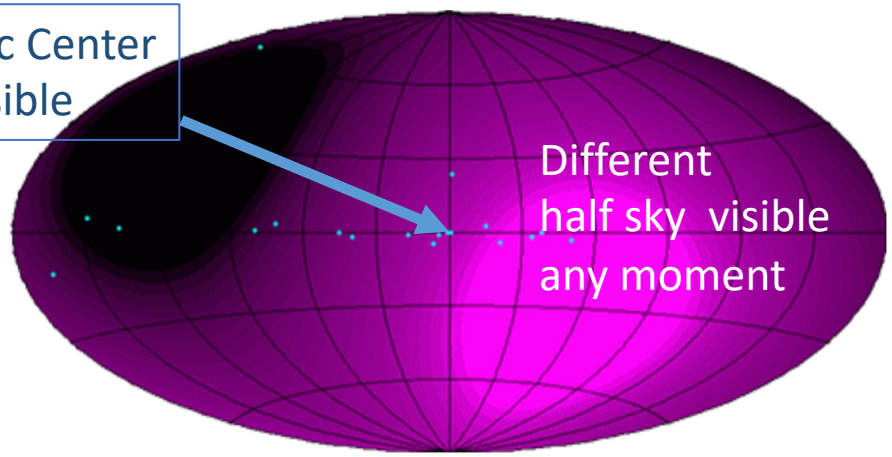


Equatorial coordinates

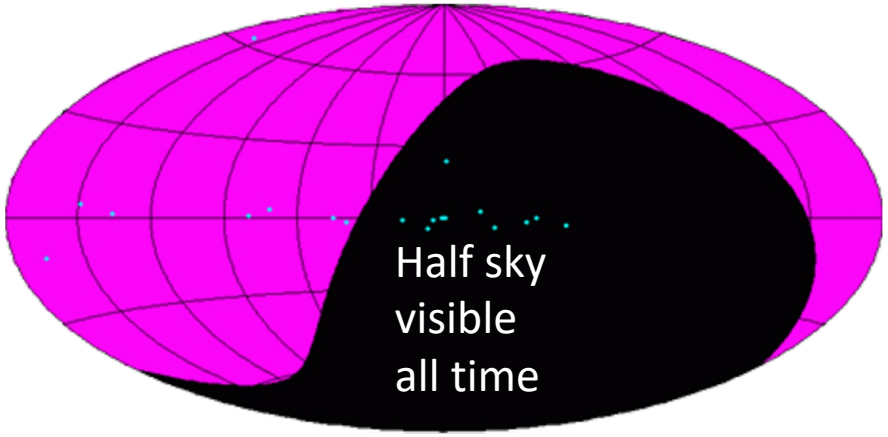
South pole
Mediterranean
Lake Baikal

Average visibility for ‚*background-free*‘ view (upwards) in galactic coordinates:

Galactic Center well visible



Mediterranean Sea (~43deg North)

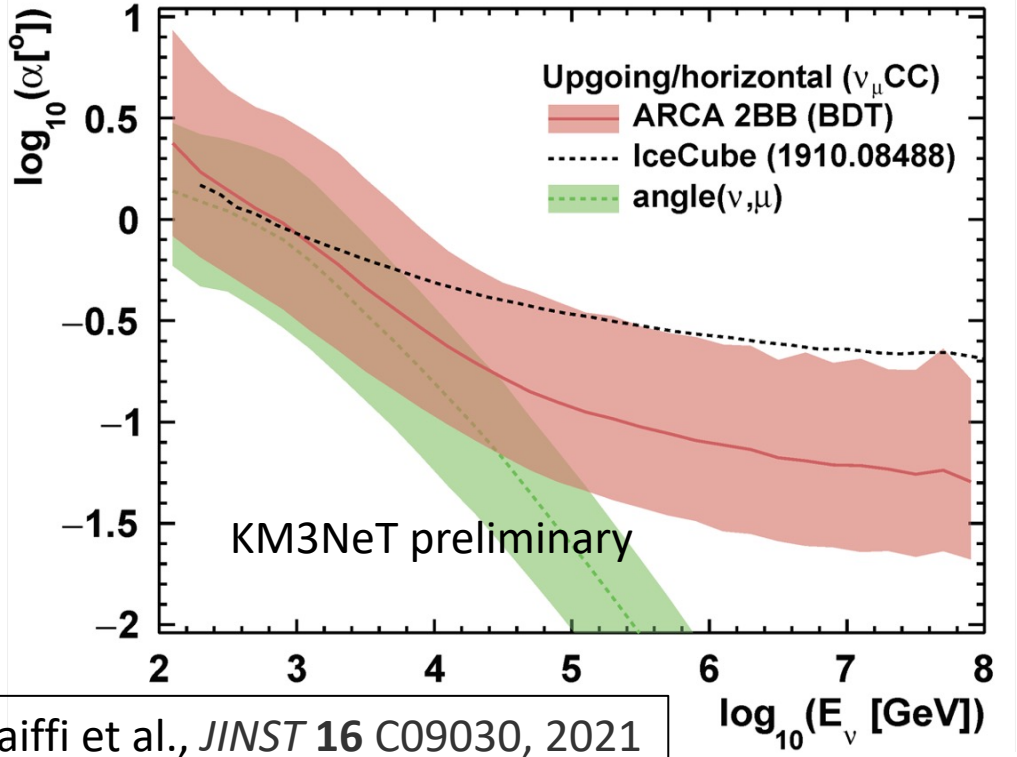


South Pole

KM3NeT strengths

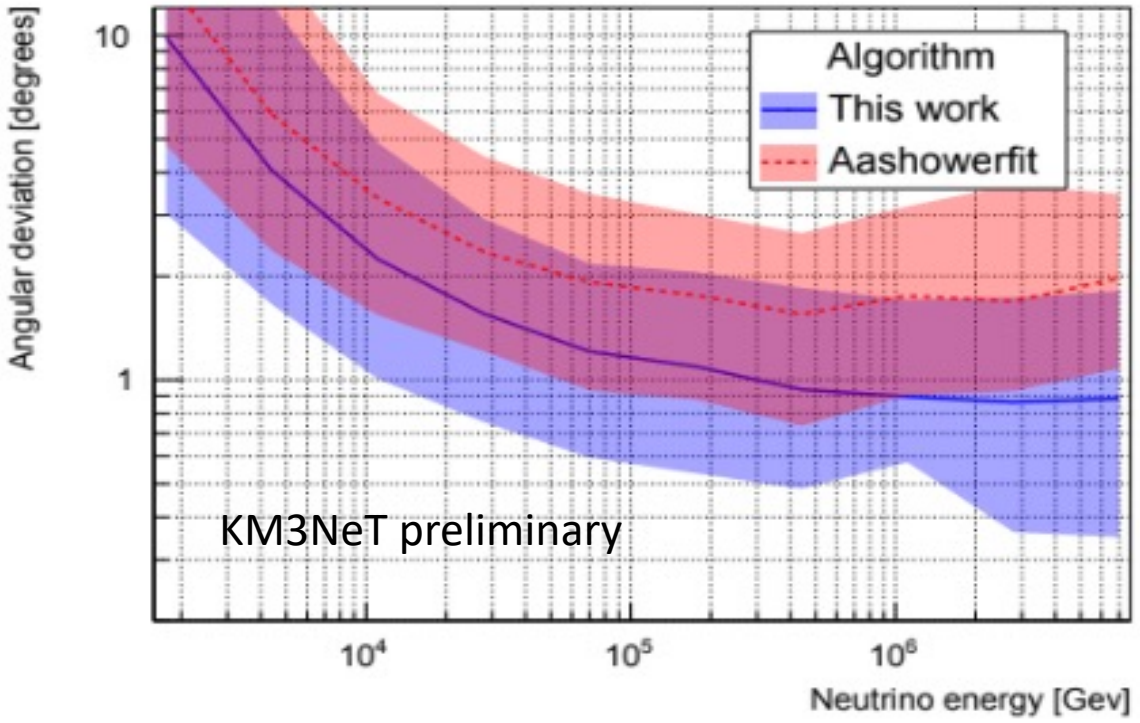
Mediterranean Sea:
Transparent water, good scattering properties
=> Excellent angular resolutions for track- and cascade signatures (all flavors)

Tracks



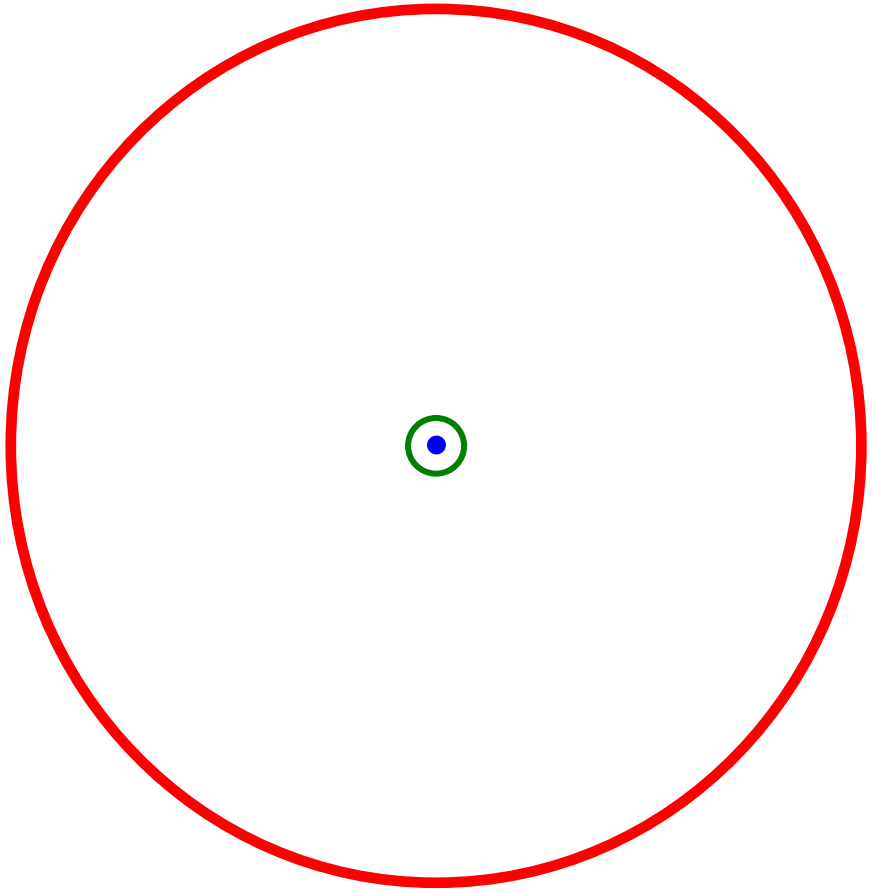
Caiffi et al., *JINST* **16** C09030, 2021

Cascades

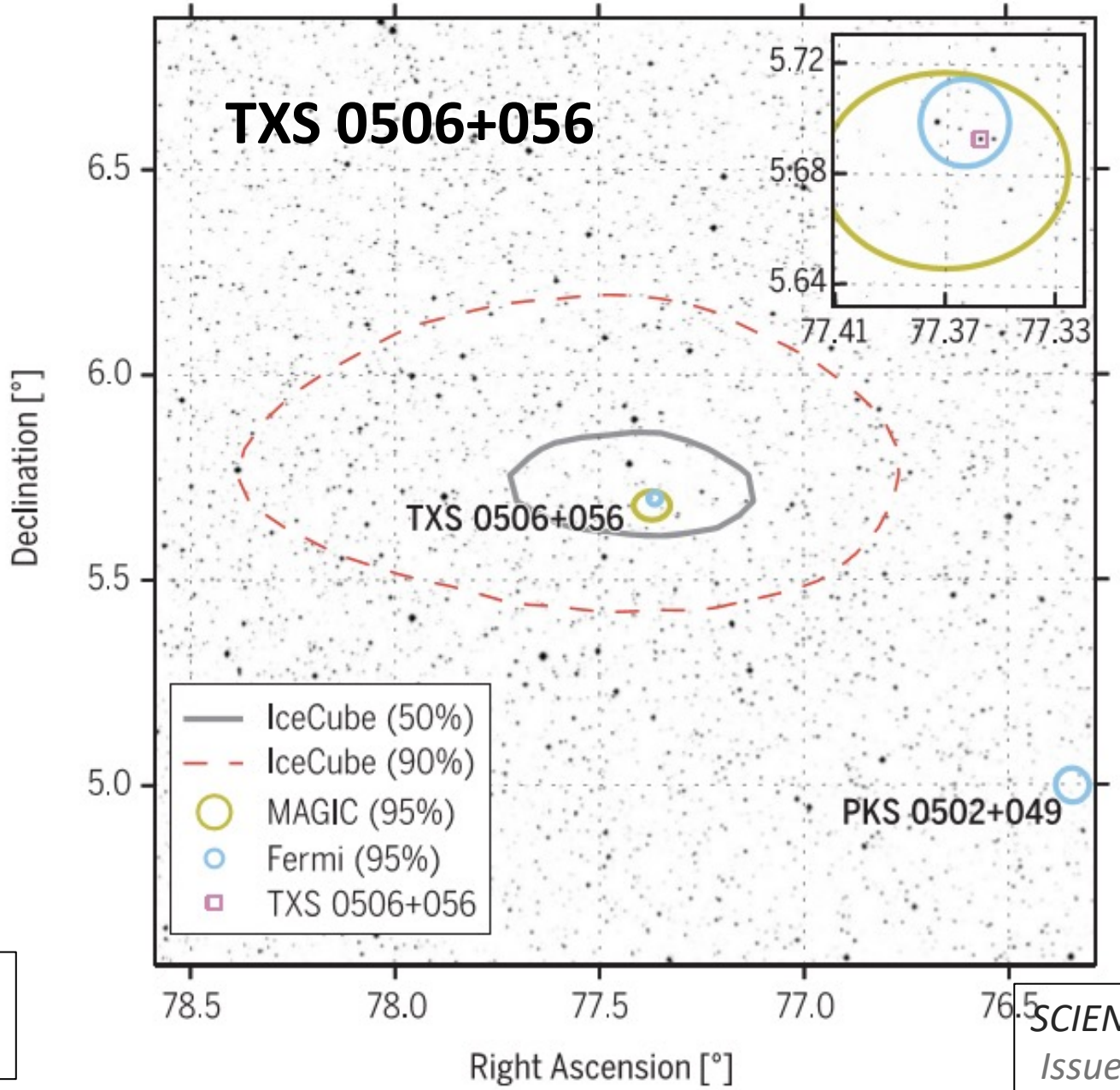


KM3NeT resolution

KM3NeT/ARCA expected intrinsic resolution for high energy (>=PeV) tracks/cascades



Morphology of extended sources can be explored (track events)



SCIENCE Vol 361, Issue 6398, 2018

KM3NeT Physics potential

- Cosmic Rays
- Astrophysical diffuse neutrino flux
- Galactic neutrino flux
- Cosmic sources
  - => MeV -> PeV
  - => Steady/Transients
- Dark matter / exotics
- *Oscillations -> talk Paschal Coyle*

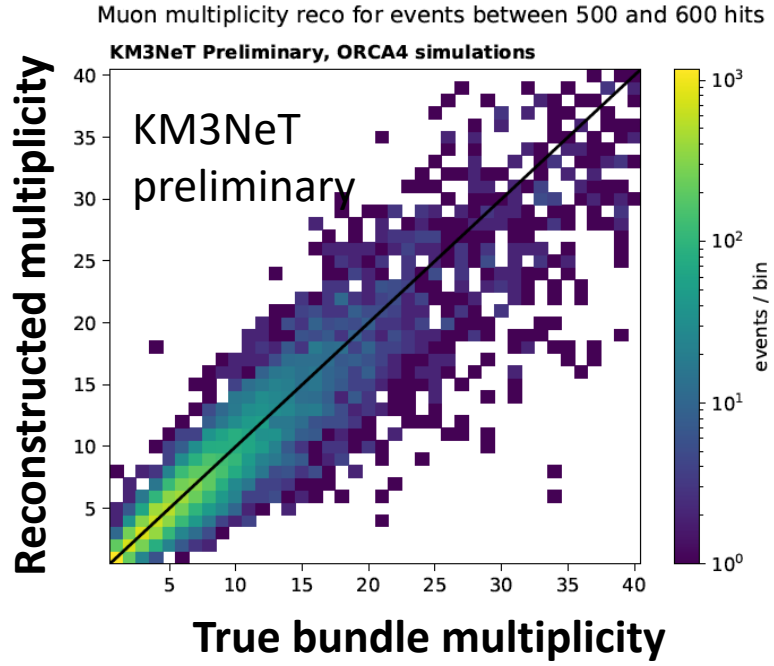
Cosmic Rays

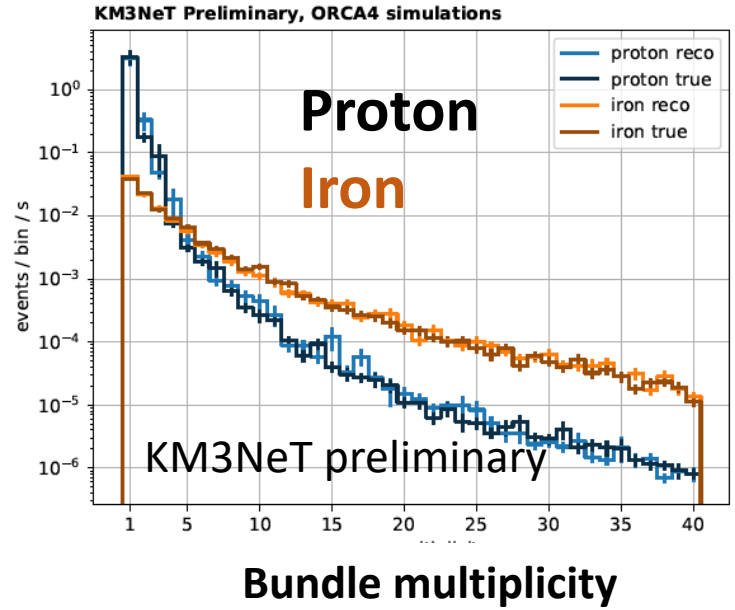
Most signals (muons & neutrinos) in detector from atmospheric cosmic ray interactions

=> information on hadronic interaction models
=> measurement of muon prompt flux
=> information on cosmic ray composition

Observables:
- muon bundle multiplicity/diameter/zenith/energy
  => First promising reconstructions using GNNs
  on few-string detector simulations

Excellent resolutions of event topologies already with few strings





Cosmic Neutrinos

Discovery of astrophysical neutrino flux by IceCube

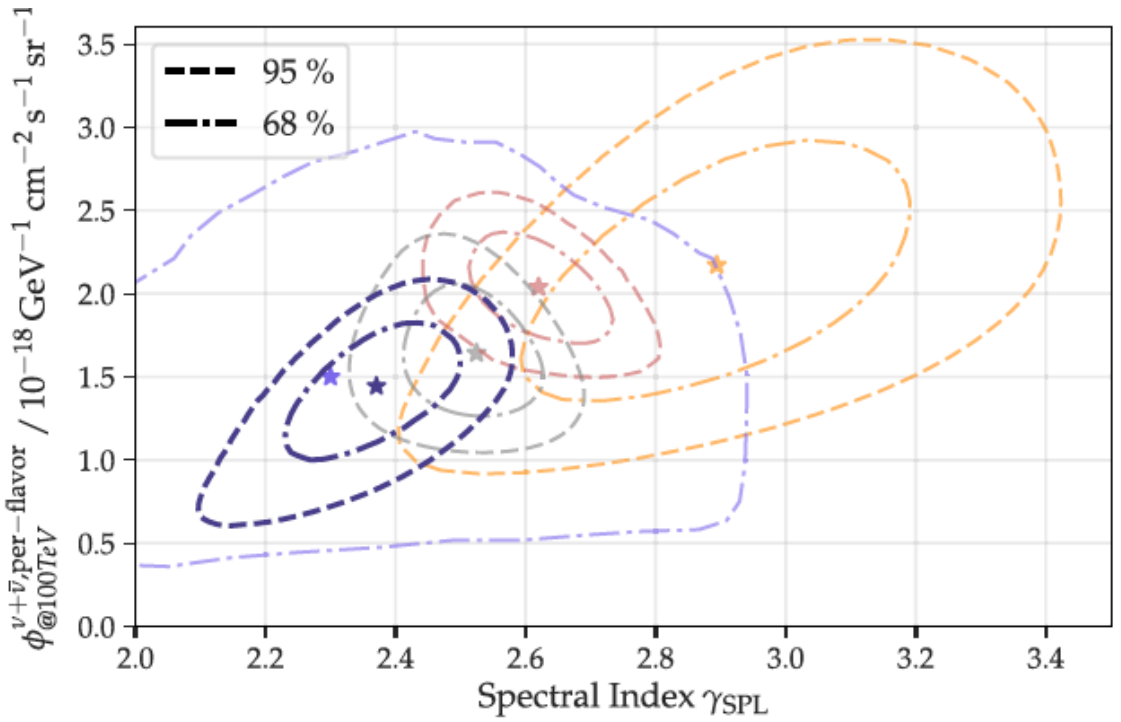
$3\sigma/2\sigma$ confirmation from GVD/ANTARES

Where does it come from?

Differences in flux size and spectral index for different subsets of neutrinos?

To be taken into account:

- different energy ranges
- different parts of the sky probed
- different interaction and observation channels
- different. systematic uncertainties



Abbasi et al , ApJ 928 50, 2022

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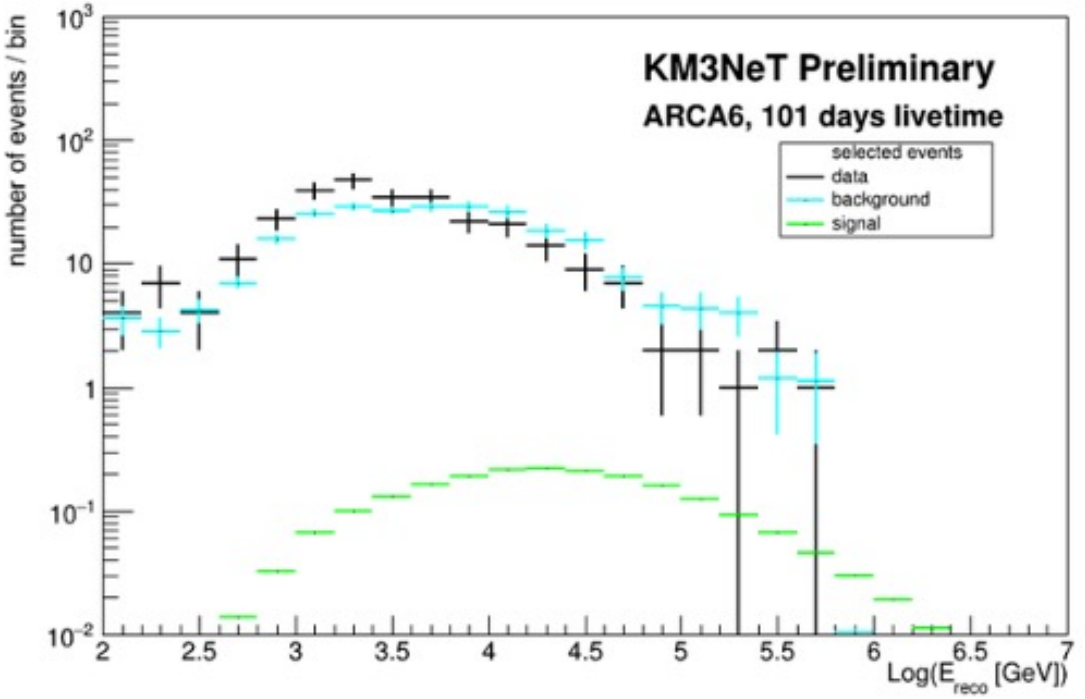
KM3NeT will probe neutrino flux with complementary view



For the diffuse cosmic neutrino flux of [2]: $1.44 \times 10^{-18}\ (E/100\text{TeV})^{-2.28}$ [GeV^{-1} cm^{-2} s^{-1} sr^{-1}]		Number of events
$\Phi_{90\%CL}$ [GeV^{-1} cm^{-2} s^{-1} sr^{-1}]	$\Phi_{5\sigma}$ [GeV^{-1} cm^{-2} s^{-1} sr^{-1}]	$N_{atm.mu\&nu} = 68.4$
17.3×10^{-18}	51.4×10^{-18}	$N_{cosmic\ nu} = 1.3$

Cosmic Neutrinos

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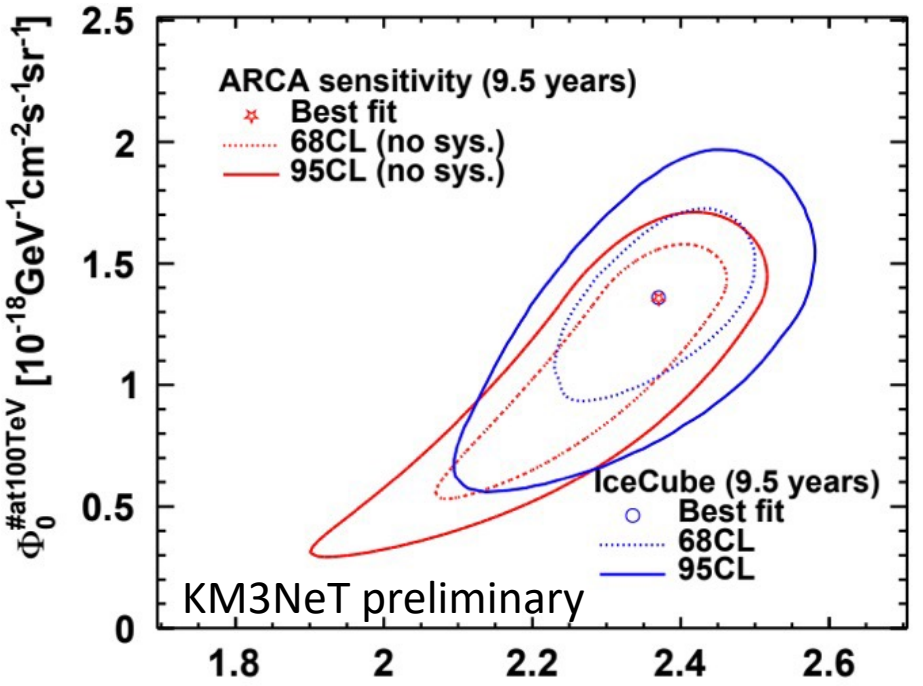
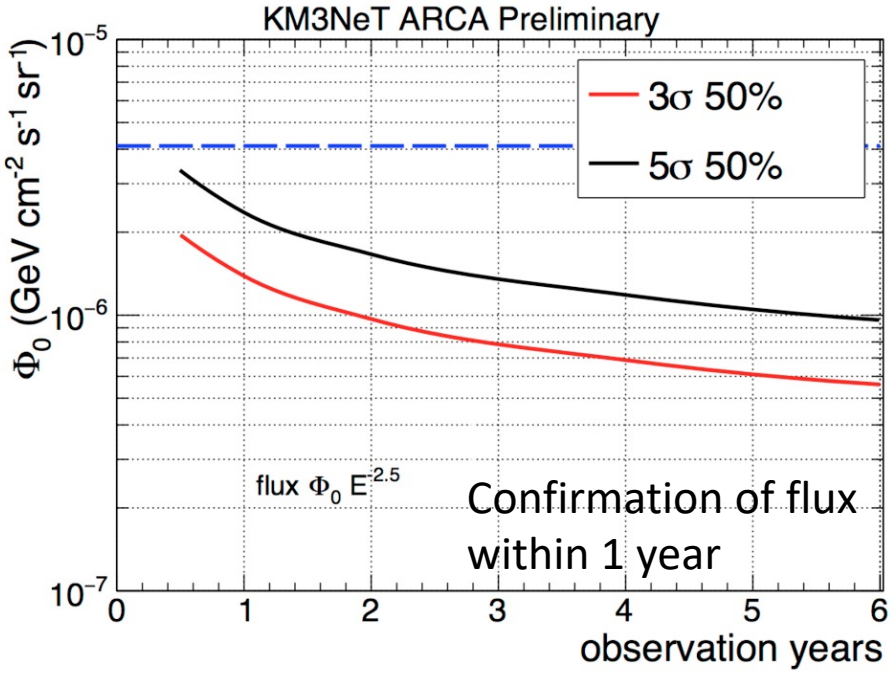


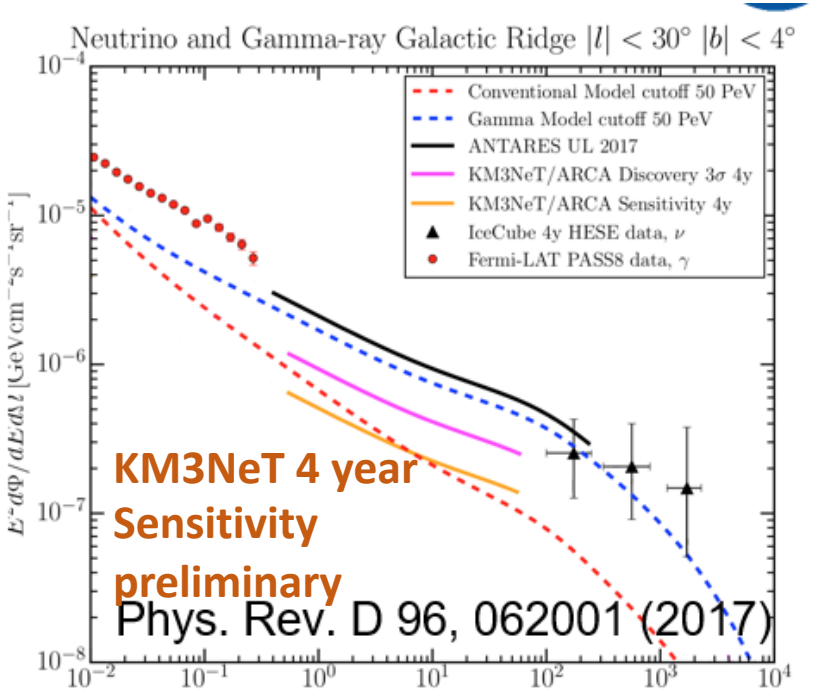


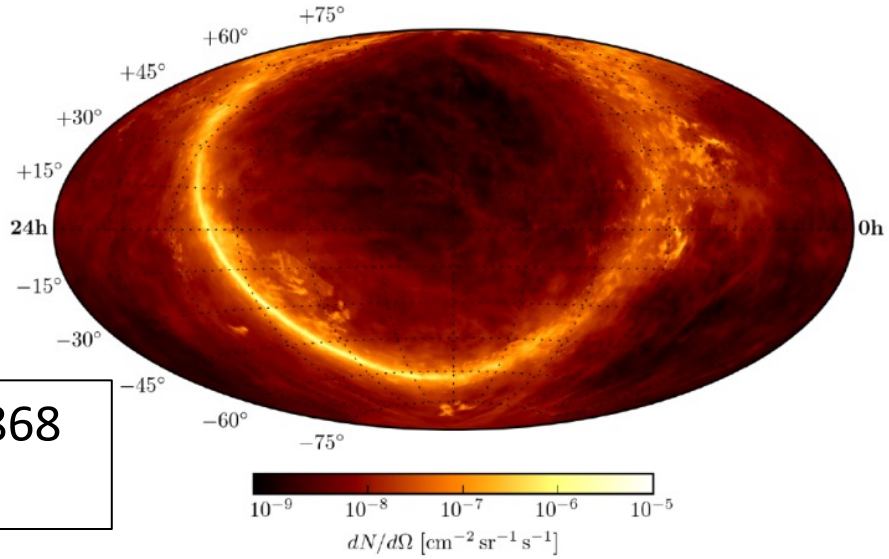
Galactic contribution

Neutrinos expected from Cosmic Ray interactions with interstellar gas in Galactic Plane

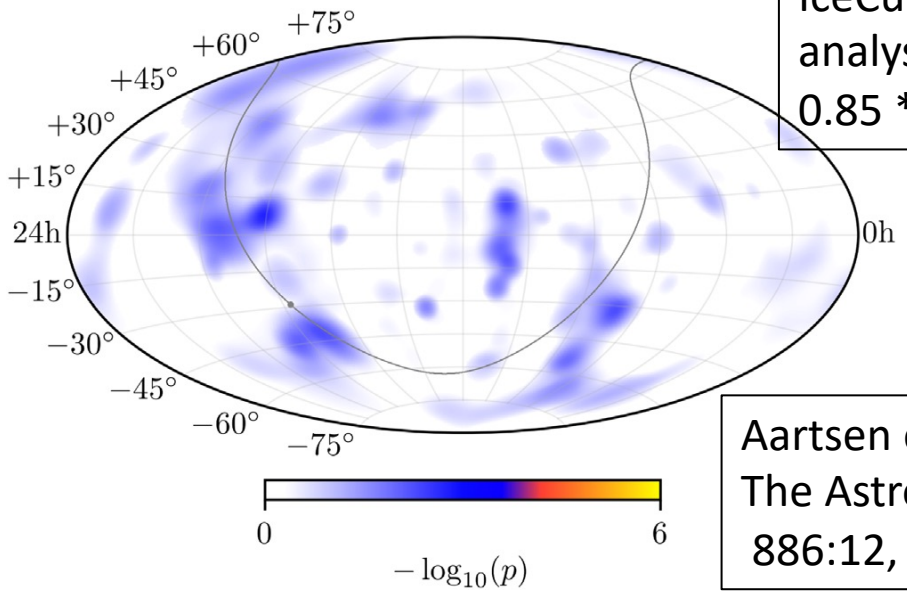
IceCube&ANTARES analyses show
excess in Galactic Plane

-> KM3NeT has direct view of Galactic Centrum
=> Measurement / constraint of flux





Astrophys.J. 868 (2018) 2, L20



IceCube cascade analysis best fit
0.85 * KRAγ model

Aartsen et al.,
The Astrophysical Journal,
886:12, 2019

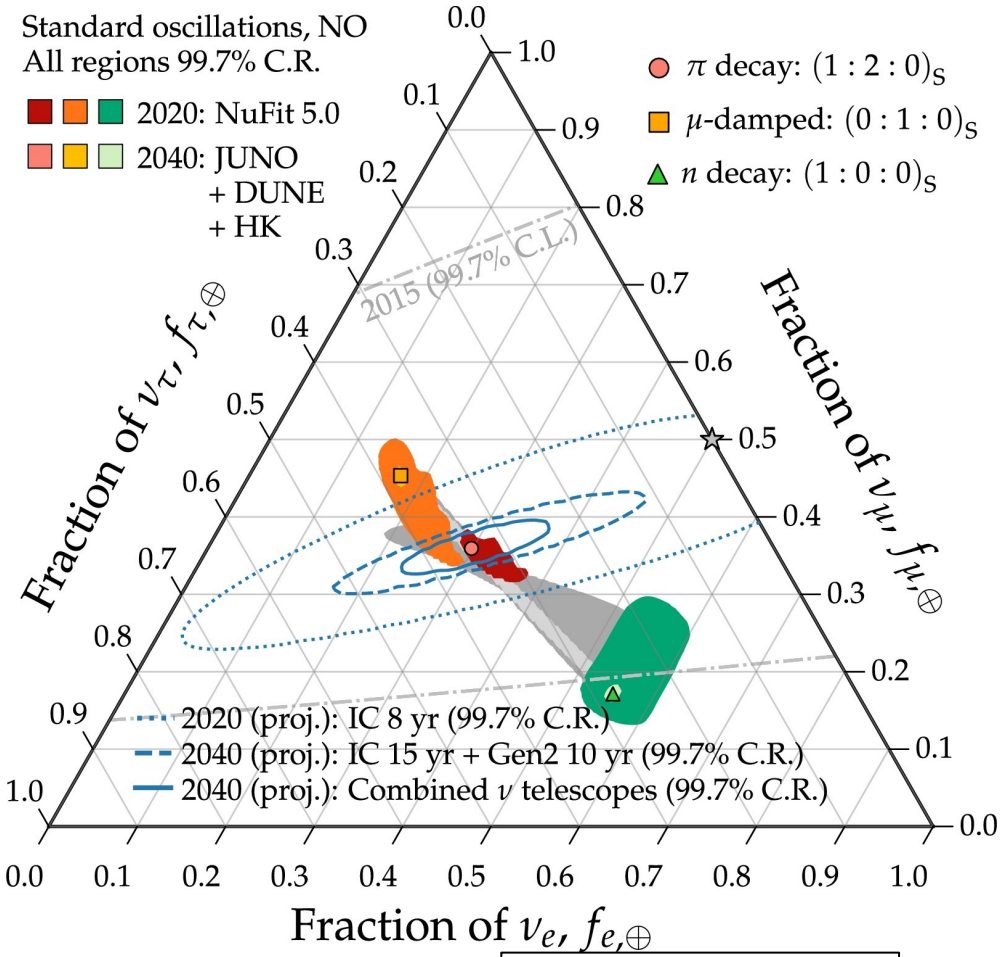
Flavor triangle

Neutrino flavor composition expected
in ‘standard’ scenario 1:1:1

-> Different astrophysics or new physics
=> different flavor ratio

KM3NeT

Good event topology resolution
-> efficient recovery of tau neutrino
‘double bang’ signature
=> additional information for flavor distribution



Ackermann et al.,
Snowmass 2021

Flavor triangle

New physics assumptions

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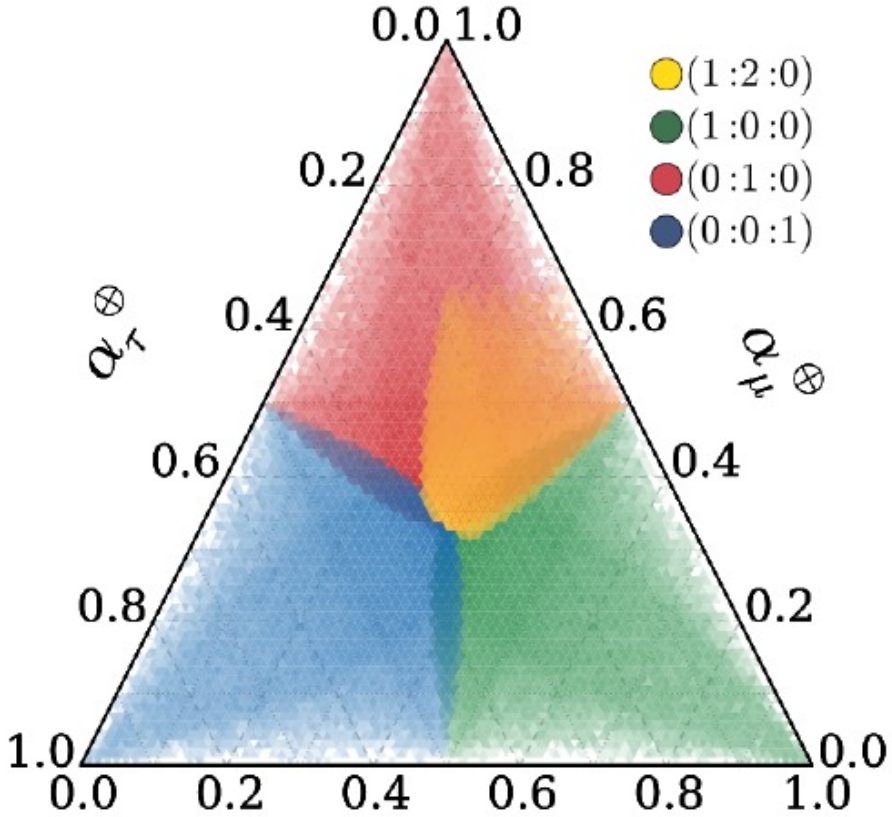

Ackermann et al.,
Snowmass 2021

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KM3NeT

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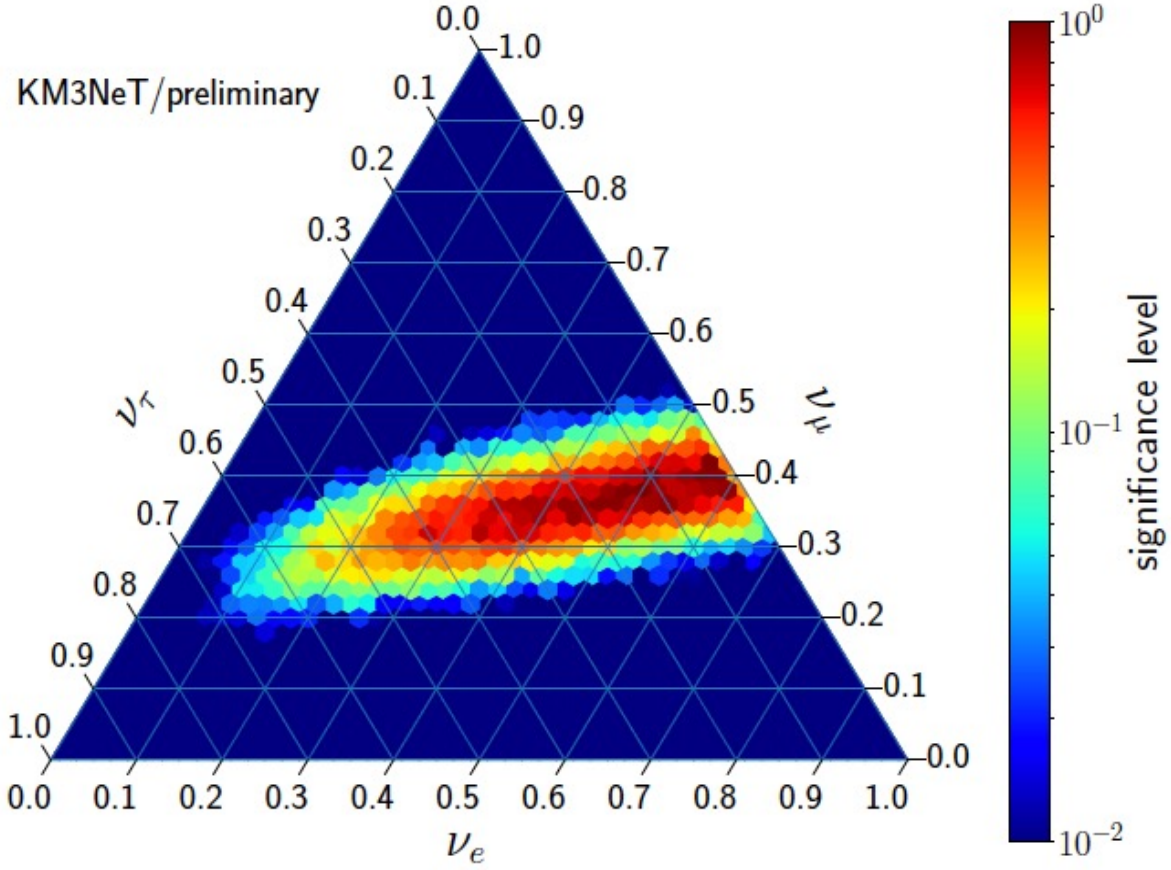
=> additional information for flavor distribution
(not yet used in this evaluation)

10 years ARCA
2x115 strings



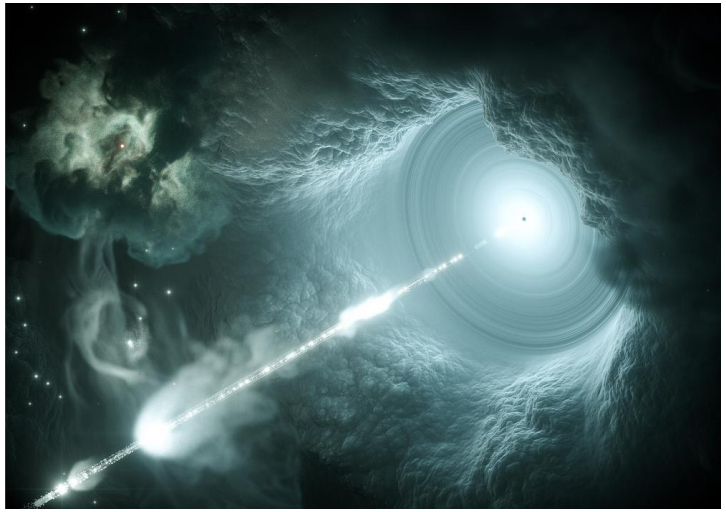
T. Eberl, T. Heid,
PoS(ICRC2017)1006

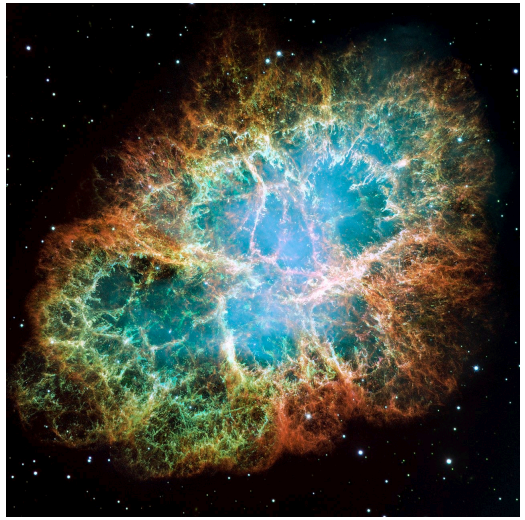
Lowest significance level here limited by number of pseudo-experiments

Cosmic neutrino source candidates: The usual suspects

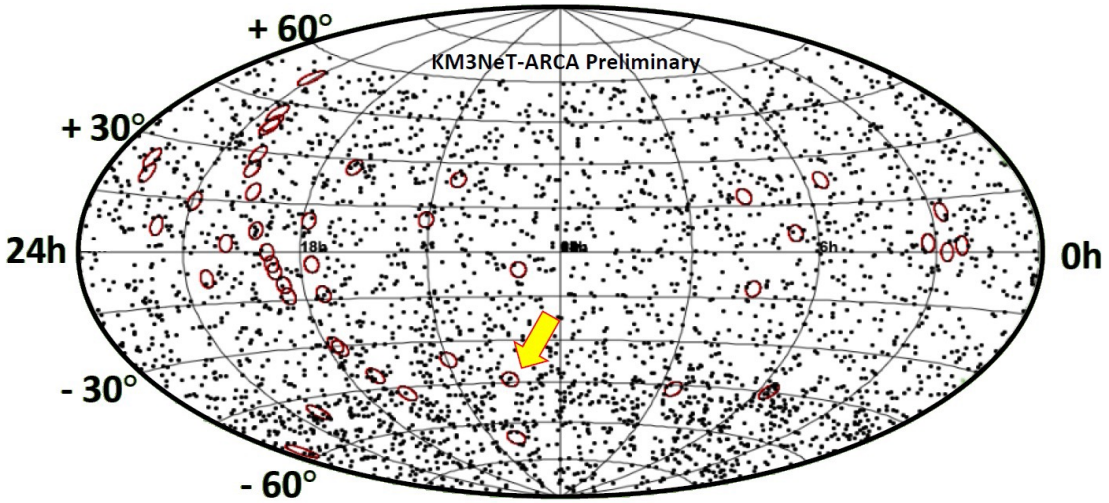
Blazars, Starburst galaxies, GRBs, TDEs, Supernoavae remnants, ….

- Best evidence so far for blazar TXS0506, several hints also for other neutrino correlations
  -> no clear picture yet
- Multi-messenger observation needed for understanding of production and acceleration
  -> separate unambigously leptonic/hadronic processes
- Real-time follow-up crucial





Cosmic point sources

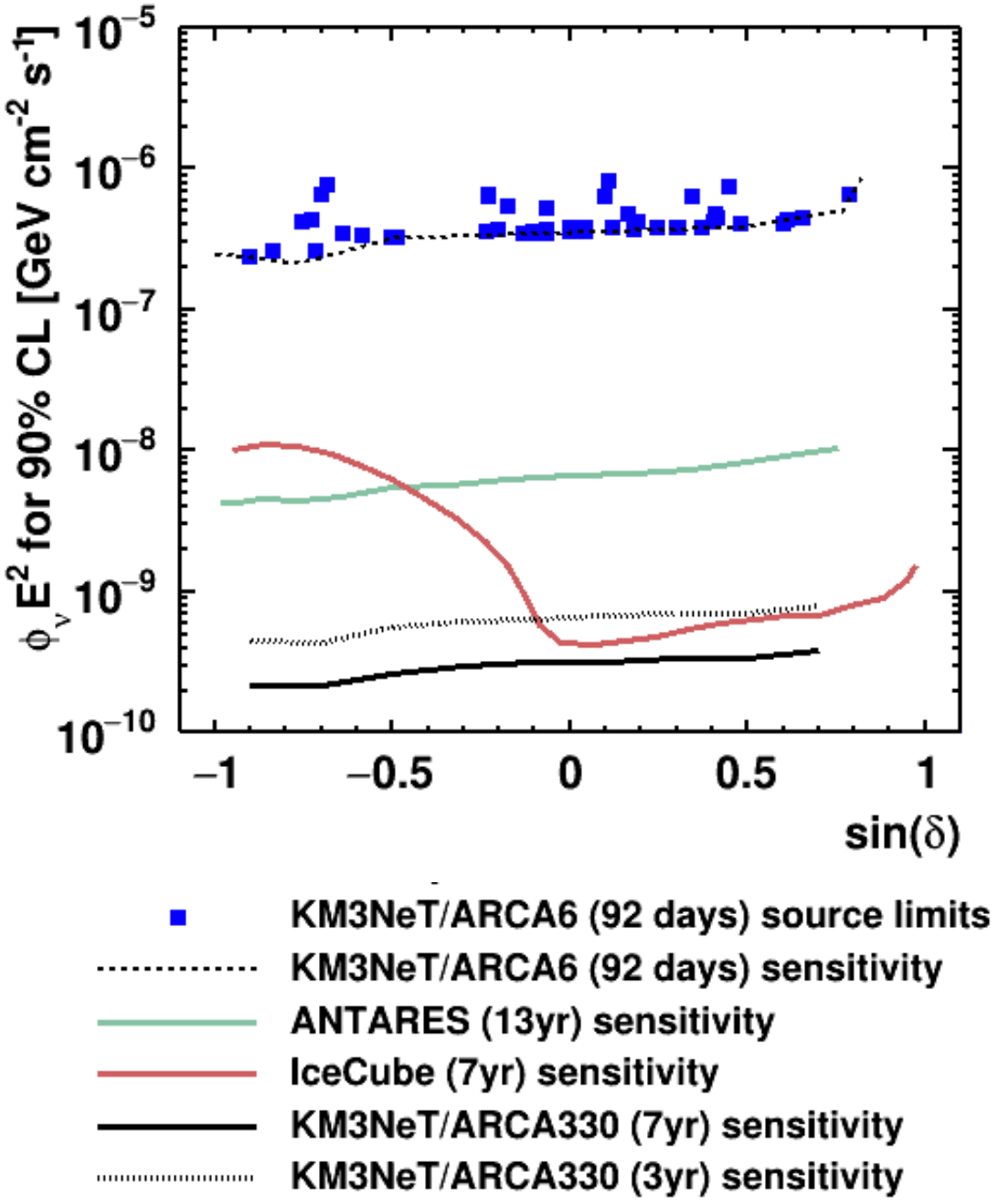


KM3NeT/ARCA-6 results May-Sep 2021

- 46 candidate sources (red circles)
- $\Delta\psi$~1.3deg

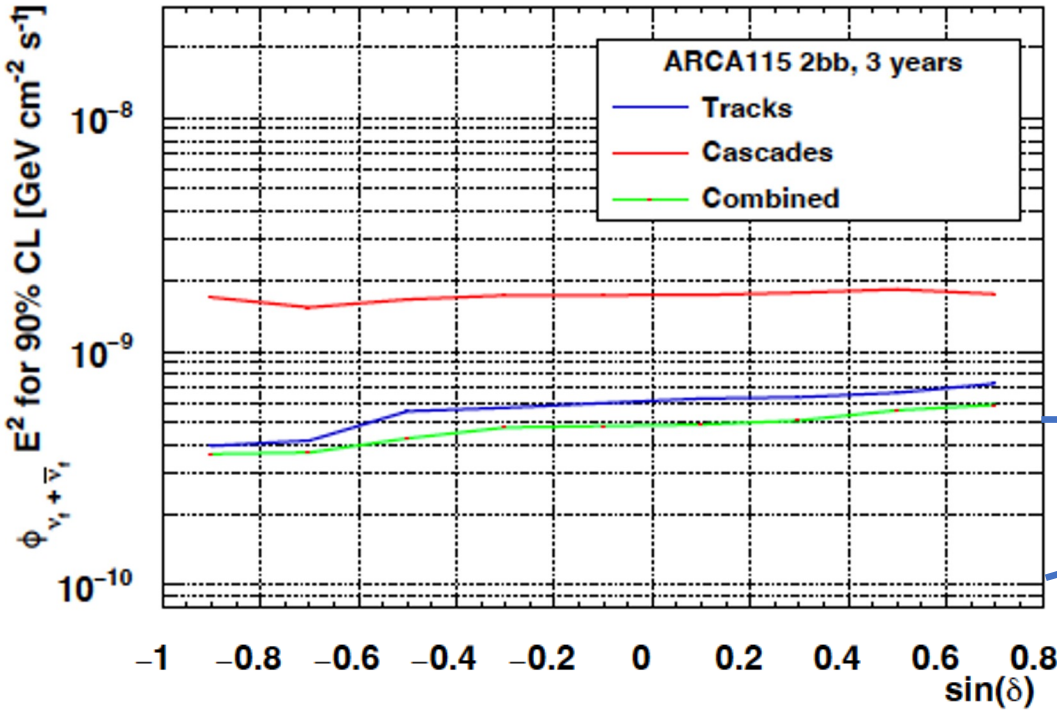
- No significant excess [expected]
- Limits not (yet) competitive [expected]
- Best source: Centaurus A (p = 0.02)
  -> radio galaxy, yellow arrow

Muller et al., NEUTRINO 2022

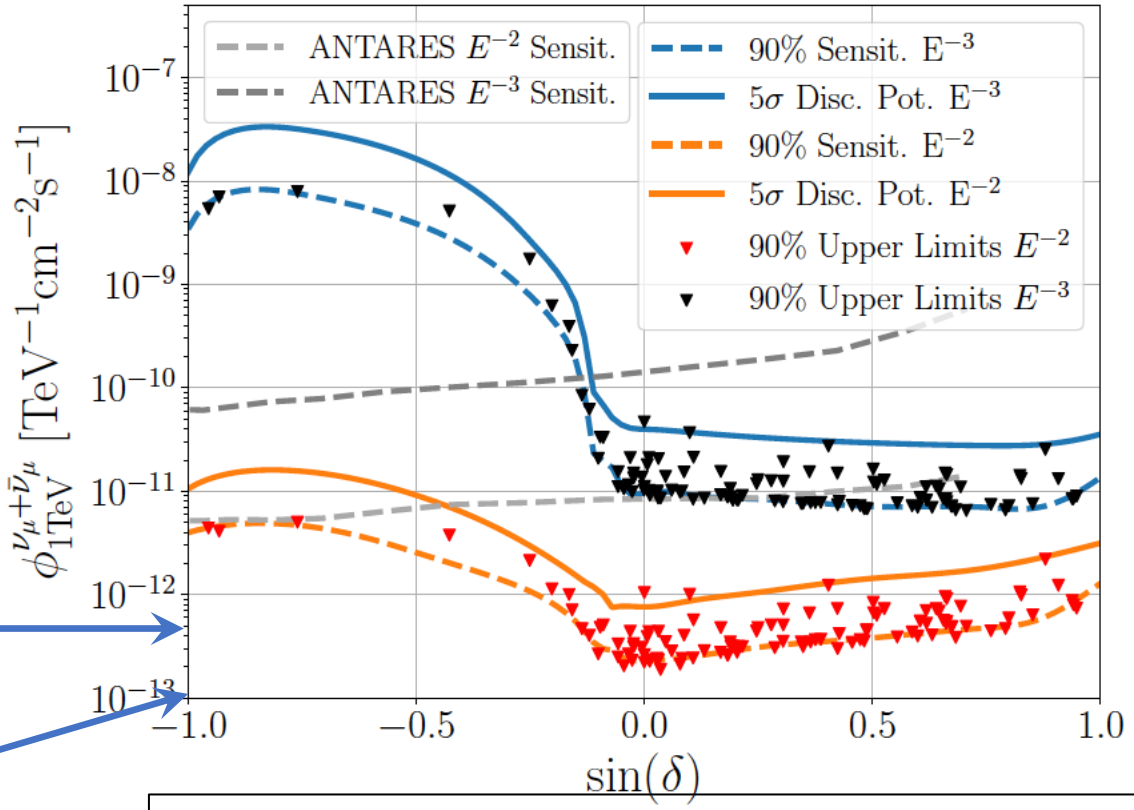


KM3NeT/ARCA 2x115 string prospects (3 years)

Probing potential neutrino sources
-> sensitivity sufficient confirm/reject current hints (e.g. NGC 1068)
Unique prospects for Southern Hemisphere



10-year IceCube results



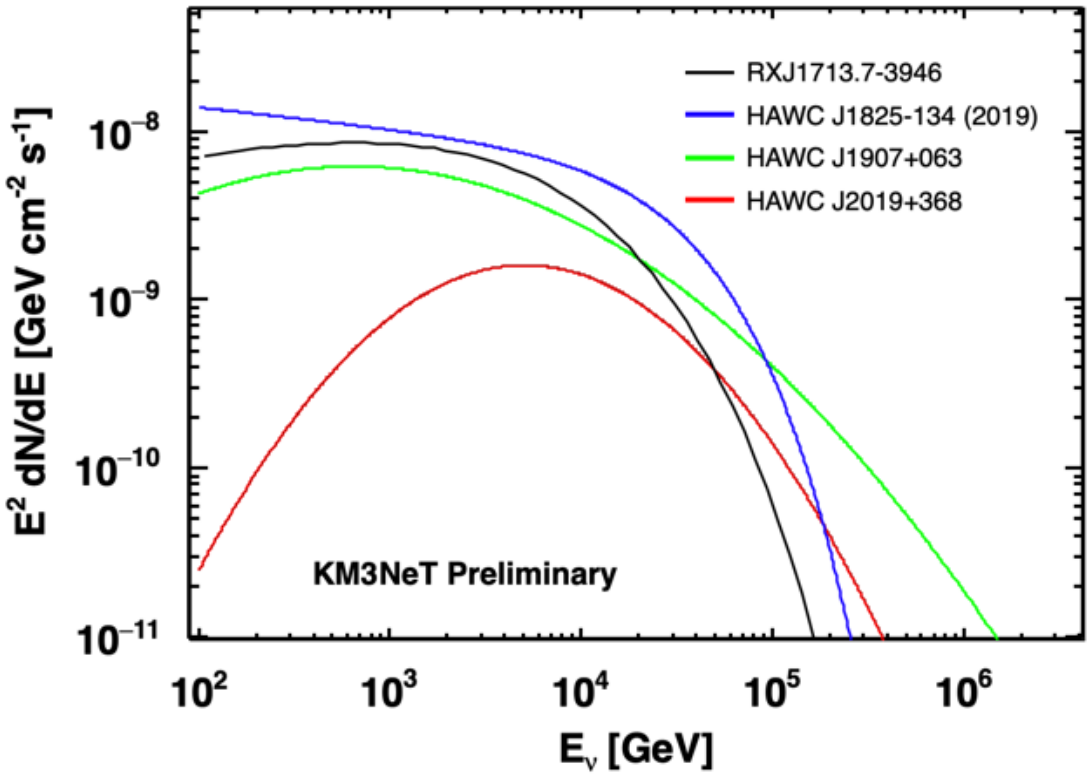
Aartsen et al., Phys. Rev. Lett. **124**, 051103, 2020

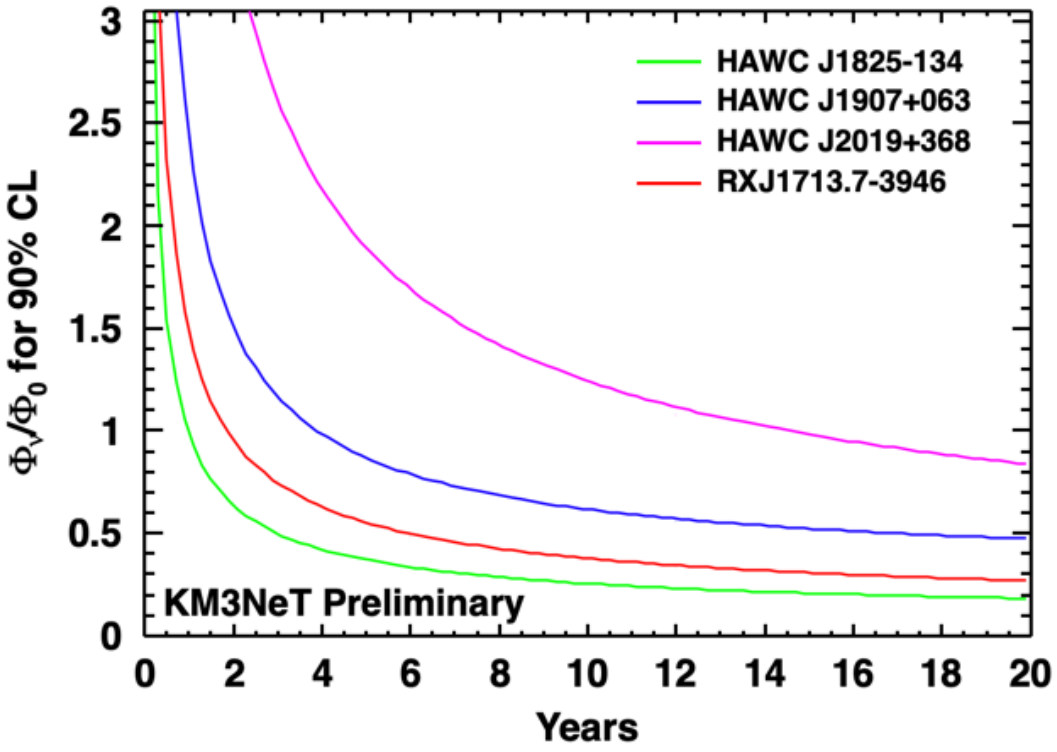
In addition stacking analyses provide best sensitivity towards source populations
-> check on e.g. IR-AGNS (IceCube observed 2.6σ signal)

Galactic sources

Prospects for prominent TeV γ-sources, flux assumption based on γ flux
Flux sensitivity versus time (assuming 2 x 115 strings for KM3NeT/ARCA)

Modeled fluxes of the sources





Caiffi et al., *JINST* **16** C09030, 2021

In 4 years detection/constraint on hadronic fraction for the sources

Galactic sources

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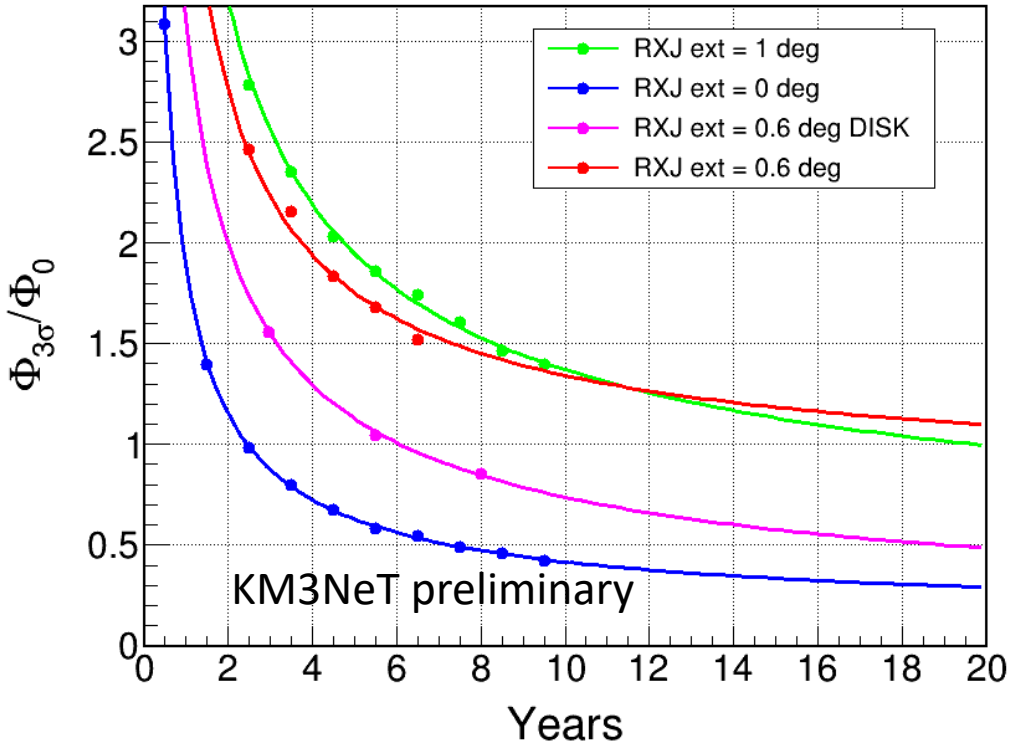
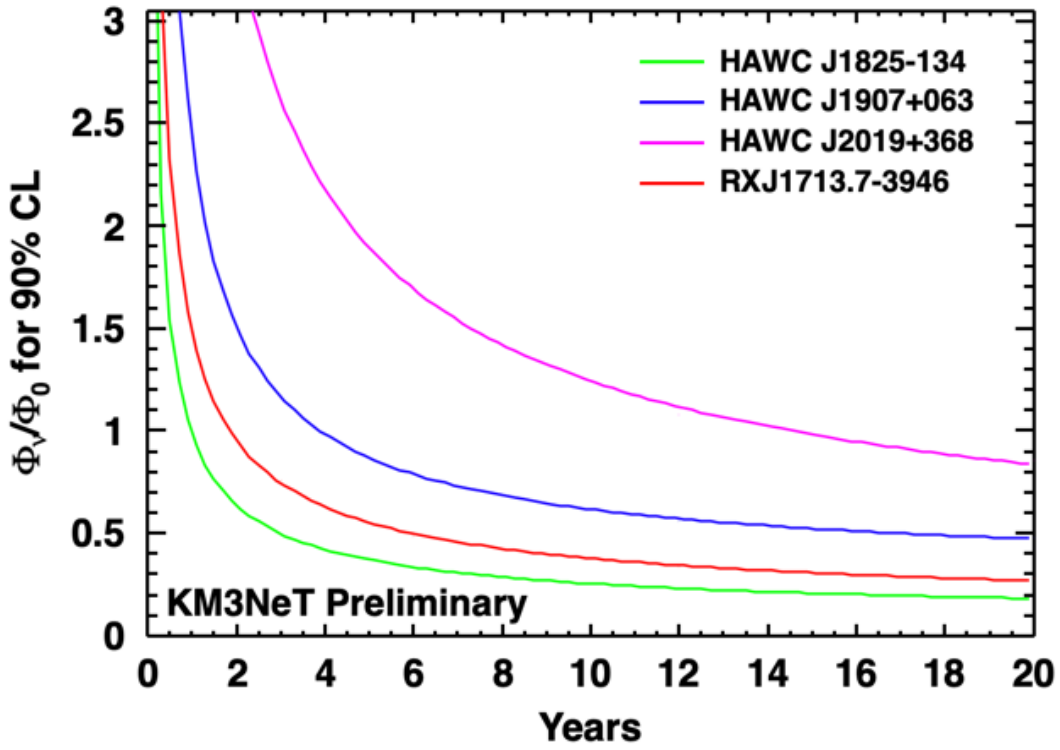


Taking into account different extensions for RXJ1713

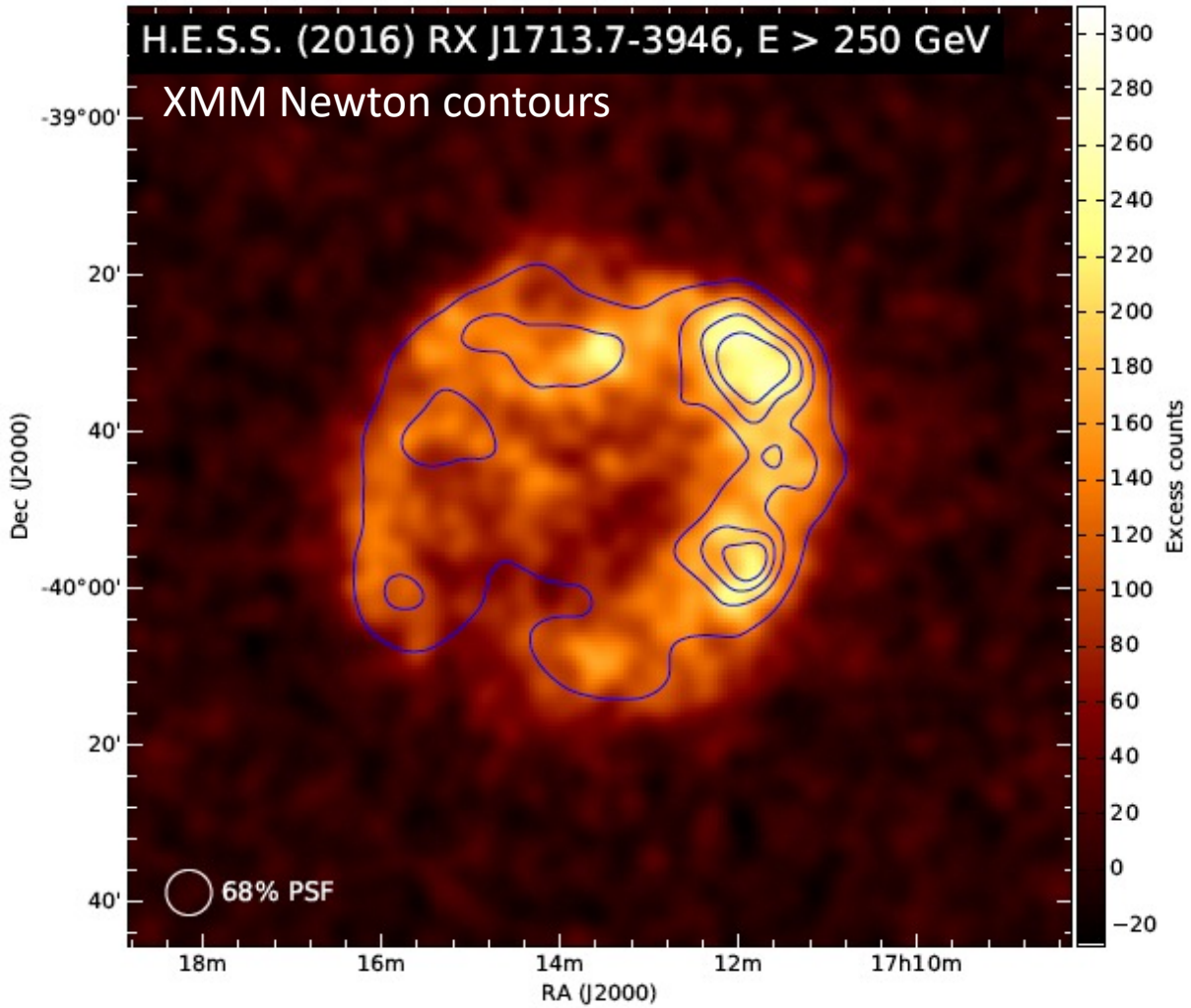


In 4 years detection/constraint on hadronic fraction for the sources

KM3NeT track
resolution **@100TeV**

KM3NeT track
resolution **@10TeV**

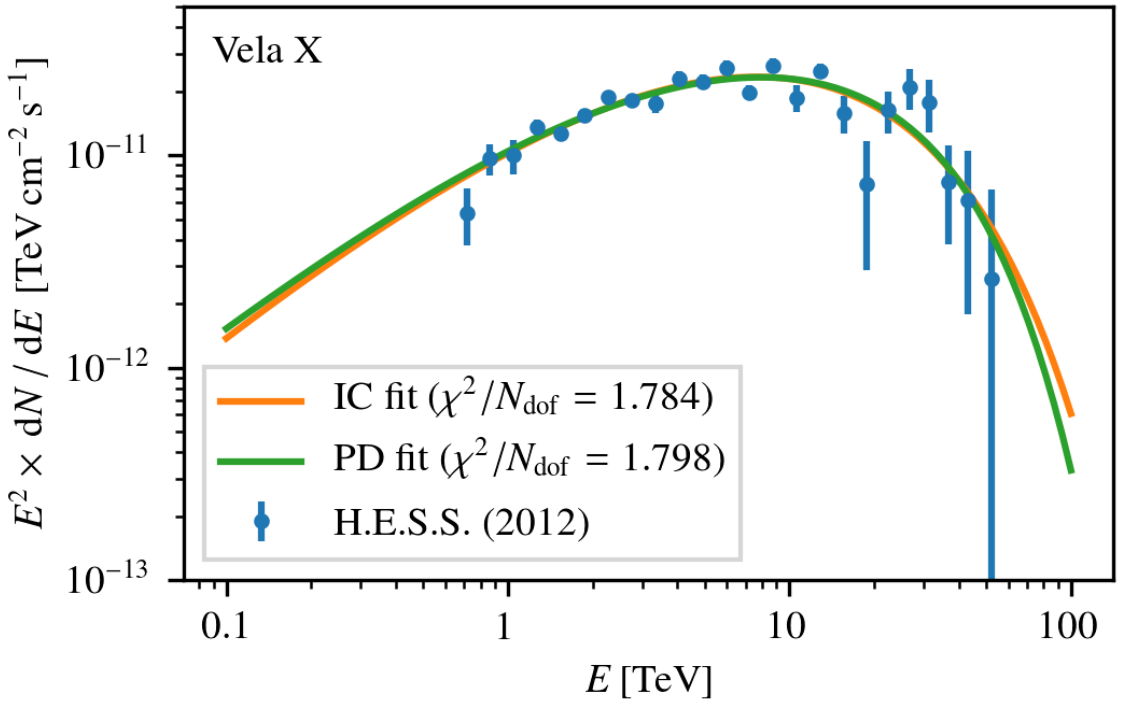
At lower energies
also intrinsic neutrino-muon
distance relevant



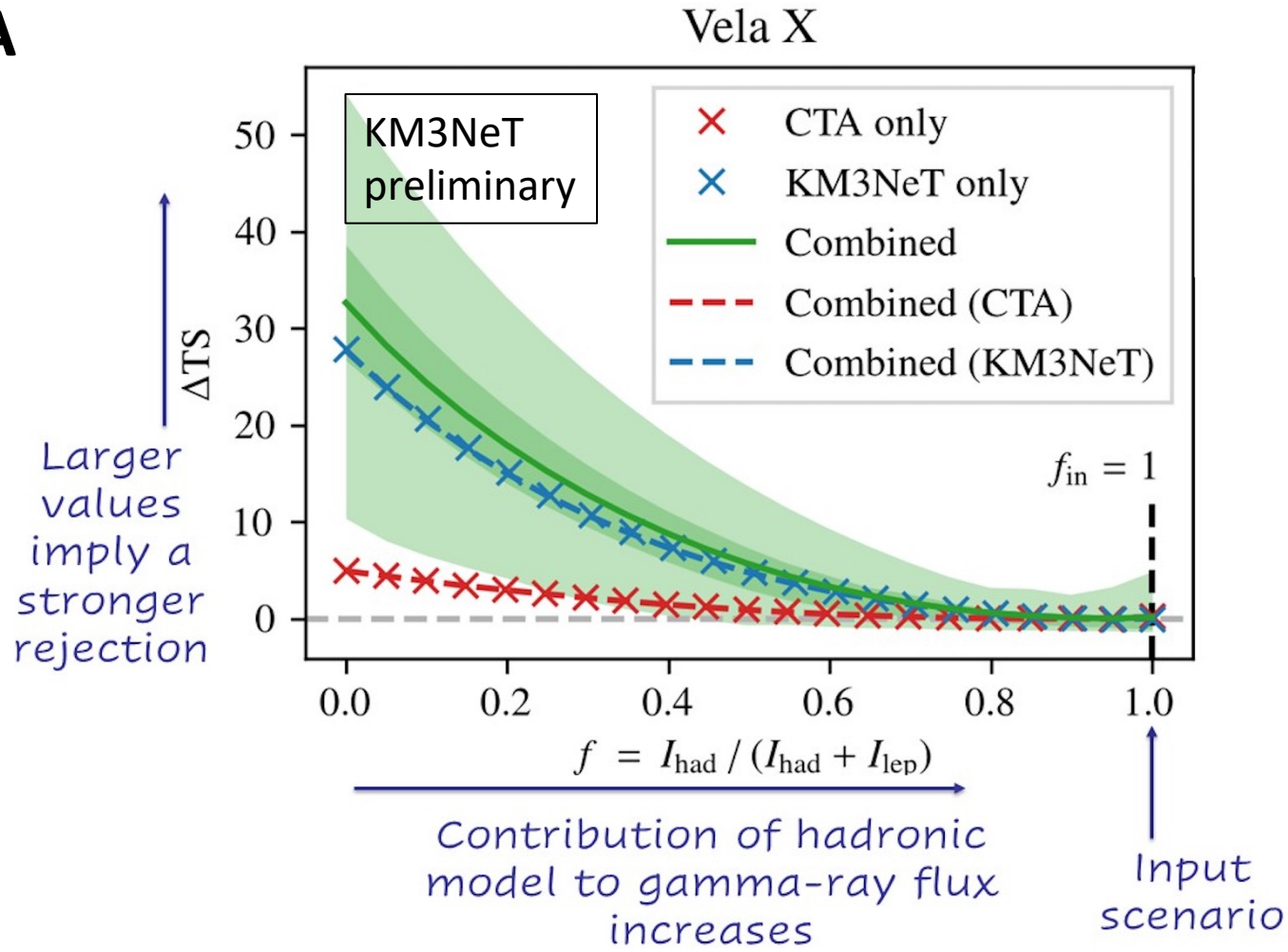
H.E.S.S. collaboration,
Astronomy & Astrophysics, Volume 612, 2018

Probing leptonic/hadronic scenarios in combination with CTA

Inverse Compton (IC) / Pion decay (PD) model fits to HESS data



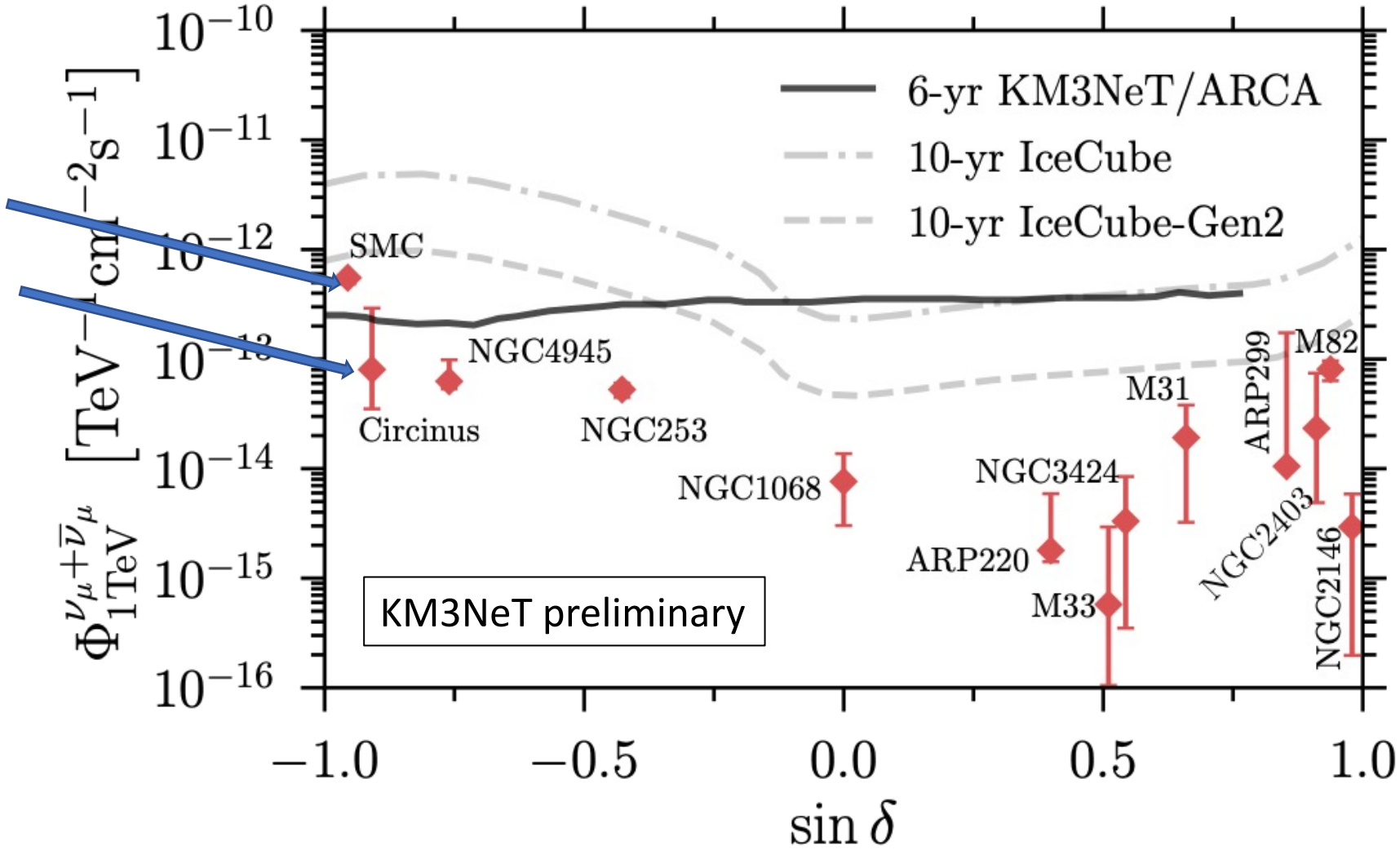
Combination with γ–ray information (CTA) strengthens power to discriminate leptonic and hadronic scenarios



Unbehaun et al., NEUTRINO 2022

Starburst Galaxies as cosmic neutrino sources

Sensitivity to detect or constrain Starburst galaxies in the Southern Hemisphere

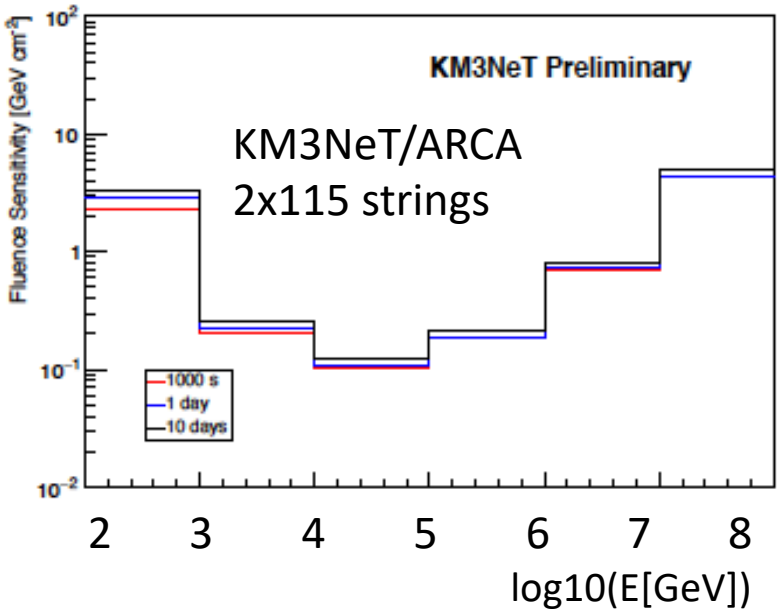


Walid Idrissi Ibnsalih et al., RICAP 2022

Transient sources

KM3NeT already generates and acts on alerts (GCN, SNEWS)

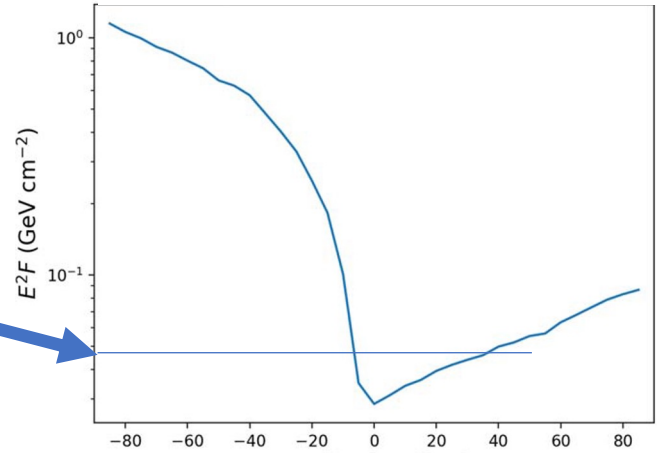
Promising prospects for full detector



KM3NeT/ARCA 2x115 strings
Estimation for source at declination -70deg

Time window	Optimum RoI radius MRF	Expected background events	Fluence sensitivity (GeV · cm^{-2})	Discovery $N_{sg}^{5\sigma}$ (50%)
1000 s	6.5°	$1.2 \cdot 10^{-2}$	0.047	2.7
1 day	3.0°	$3.3 \cdot 10^{-2}$	0.050	3.6
10 days	2.0°	$1.2 \cdot 10^{-1}$	0.061	4.6

IceCube transient sensitivity
For 1000s time window

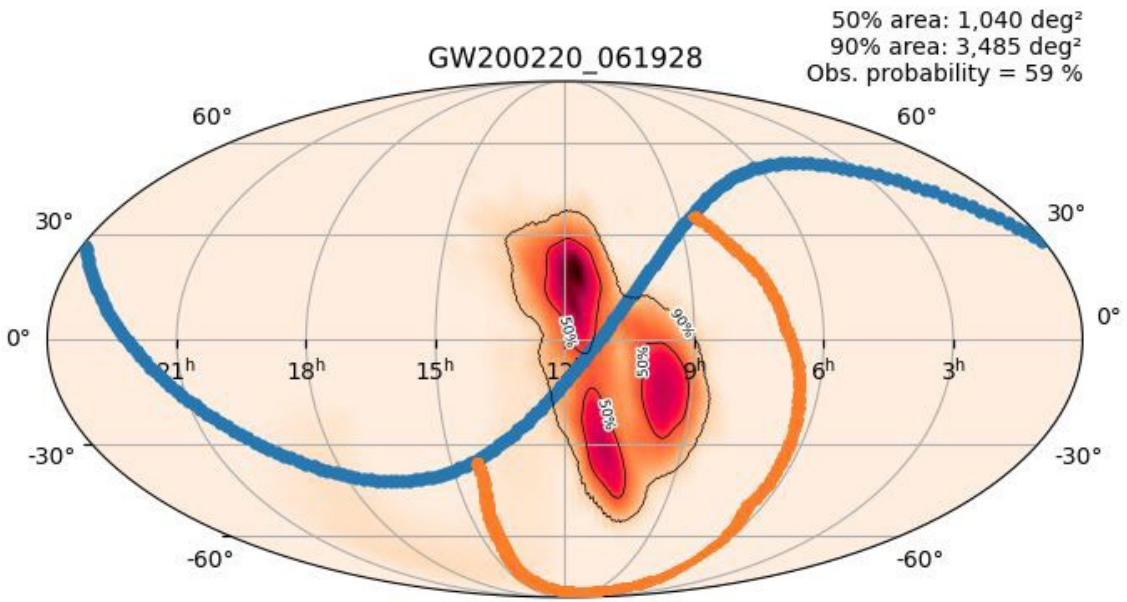


Palacios et al.,, PoS (ICRC2021) 1162

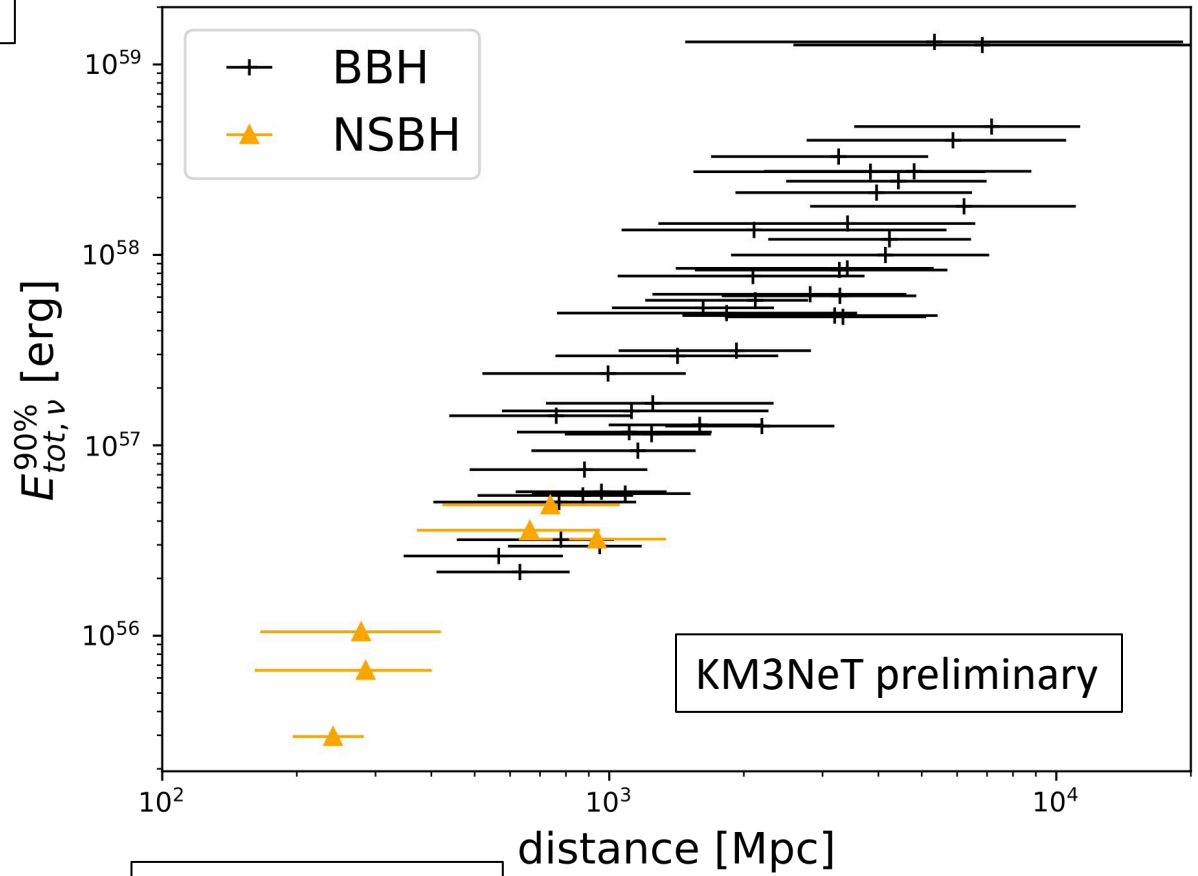
Aartsen et. Al, Astrophys. J. Lett. 898, 2020

Transient sources

Results for KM3NeT/ORCA follow-up of 55 GW events
In MeV and GeV-TeV
=> no significant correlation



Limits in GeV-TeV range



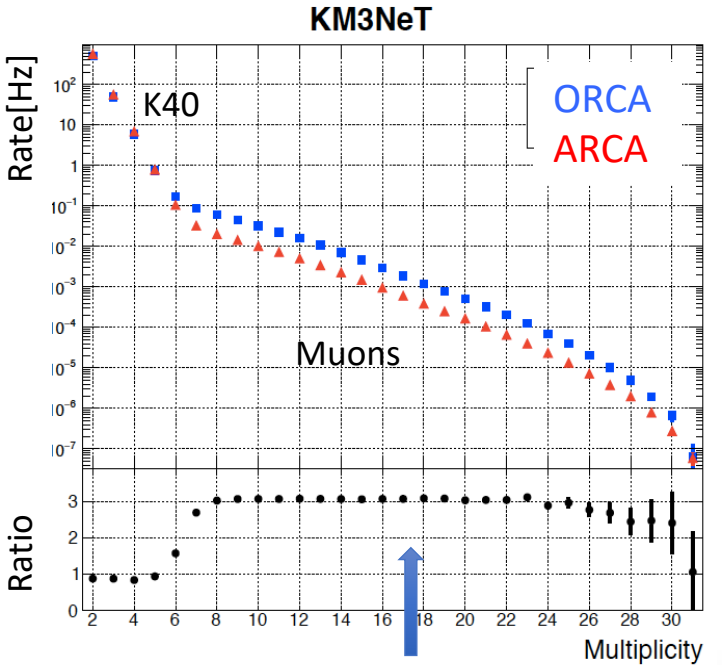
D. Dornic et al.
NEUTRINO 2022,

Supernova (SN) monitoring in KM3NeT

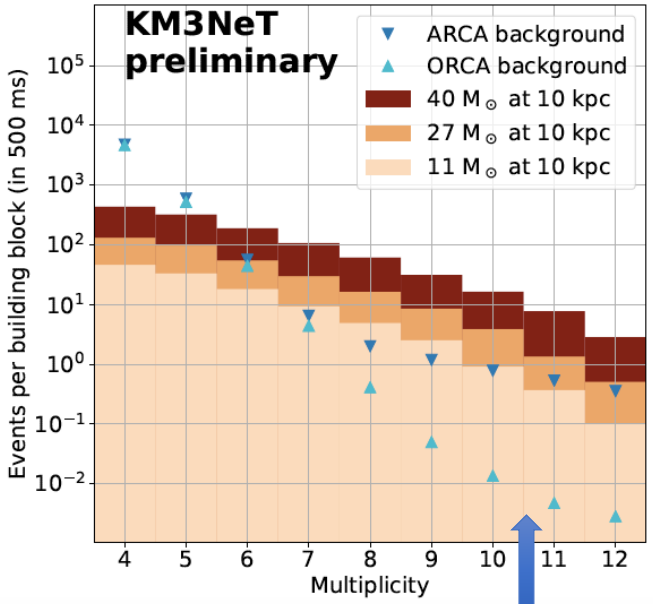
Supernova MeV neutrinos => collective excess of multi-fold coincidences on all DOMs

- Real-time monitoring of activity

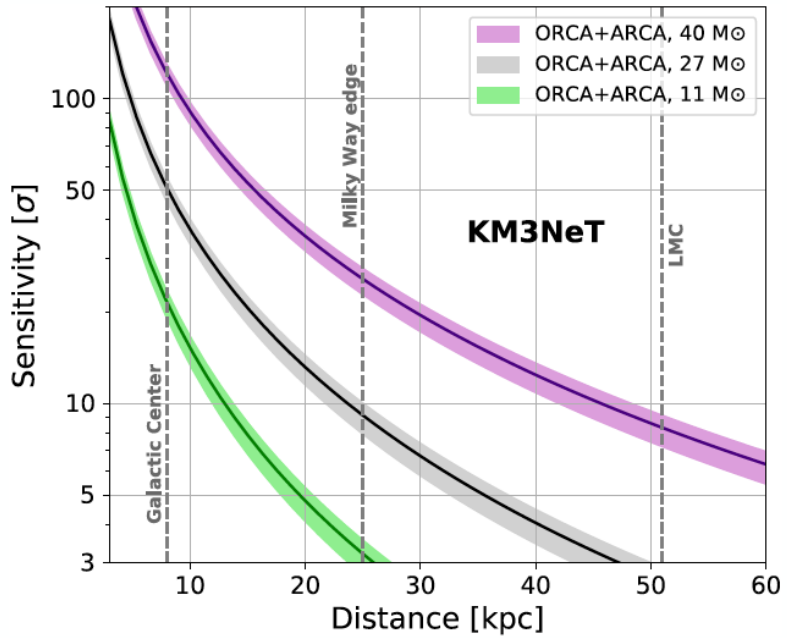
- KM3NeT already in **SNEWS**:
  SN alerts sent and followed up
- Grav. Wave follow-up for SN evaluation



ARCA: ~3 times lower muon rate



Muon veto
-> ORCA less background



Aiello et al.,
Eur. Phys. J. C81,
445, 2021

Looking for the ‘known unknowns’

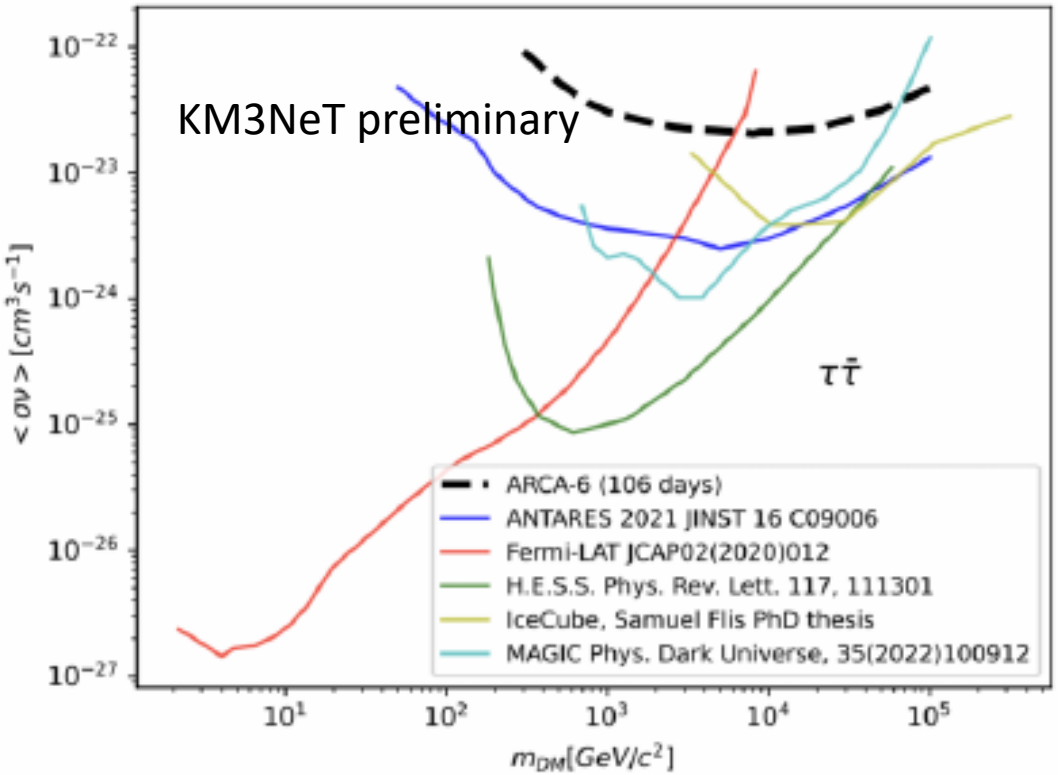
Dark matter (DM) (e.g. in Sun, Galactic Center)

WIMP annihilation or decay to Standard Model Particles
=> expect also neutrino flux
=> astrophysical effects (e.g. matter profile) relevant in evaluation

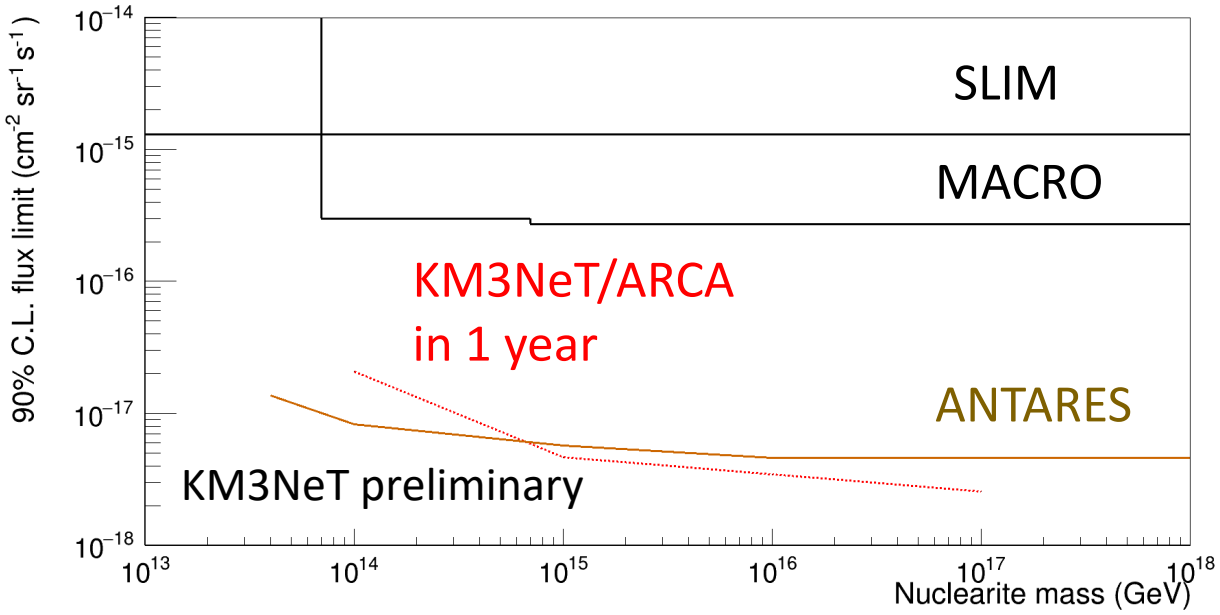
Looking for the ‘known unknowns’

First dark matter evaluation by KM3NeT/ARCA

Limits from Galactic Center



KM3NeT/ARCA 2x115 string sensitivity



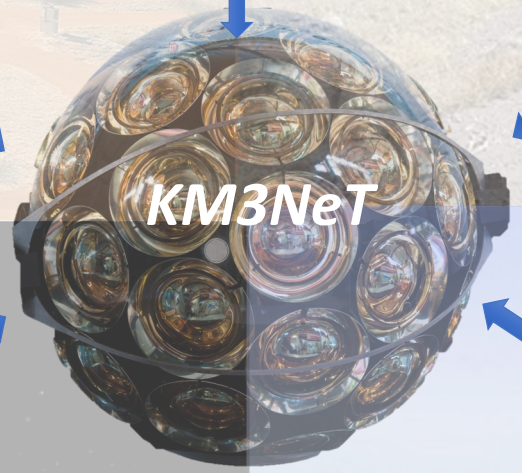
Excellent resolution of event topologies also allows sensitive search for further dark matter signatures, e.g. ‘double bang’ or muon-doublets

Multi-messenger network

Neutrinos
IceCube,
GVD-Baikal

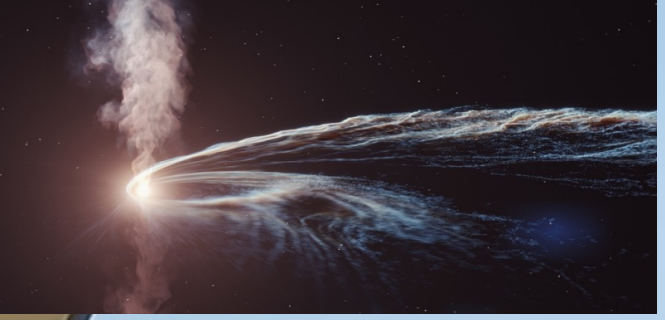
GeV/TeV γ rays
Fermi, H.E.S.S.
HAWC/LHAASO/…

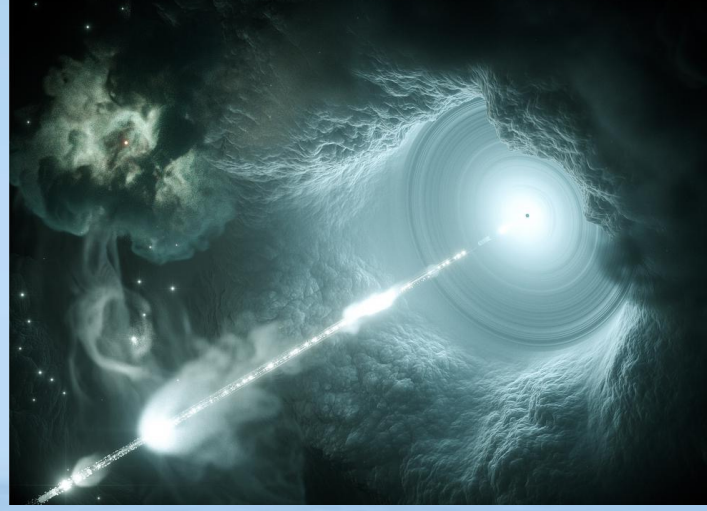
Cosmic Rays
Pierre Auger,
Telescope Array



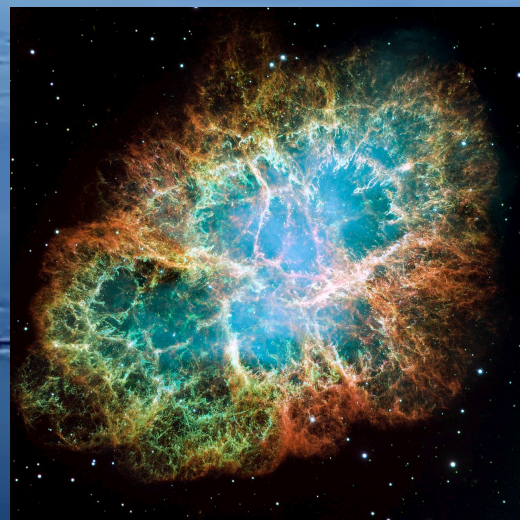
Radio/Optical/X-ray
MWA, TAROT, MASTER,
Swift, INTEGRAL

Grav Waves
LIGO, VIRGO





A decade of discoveries lies ahead!



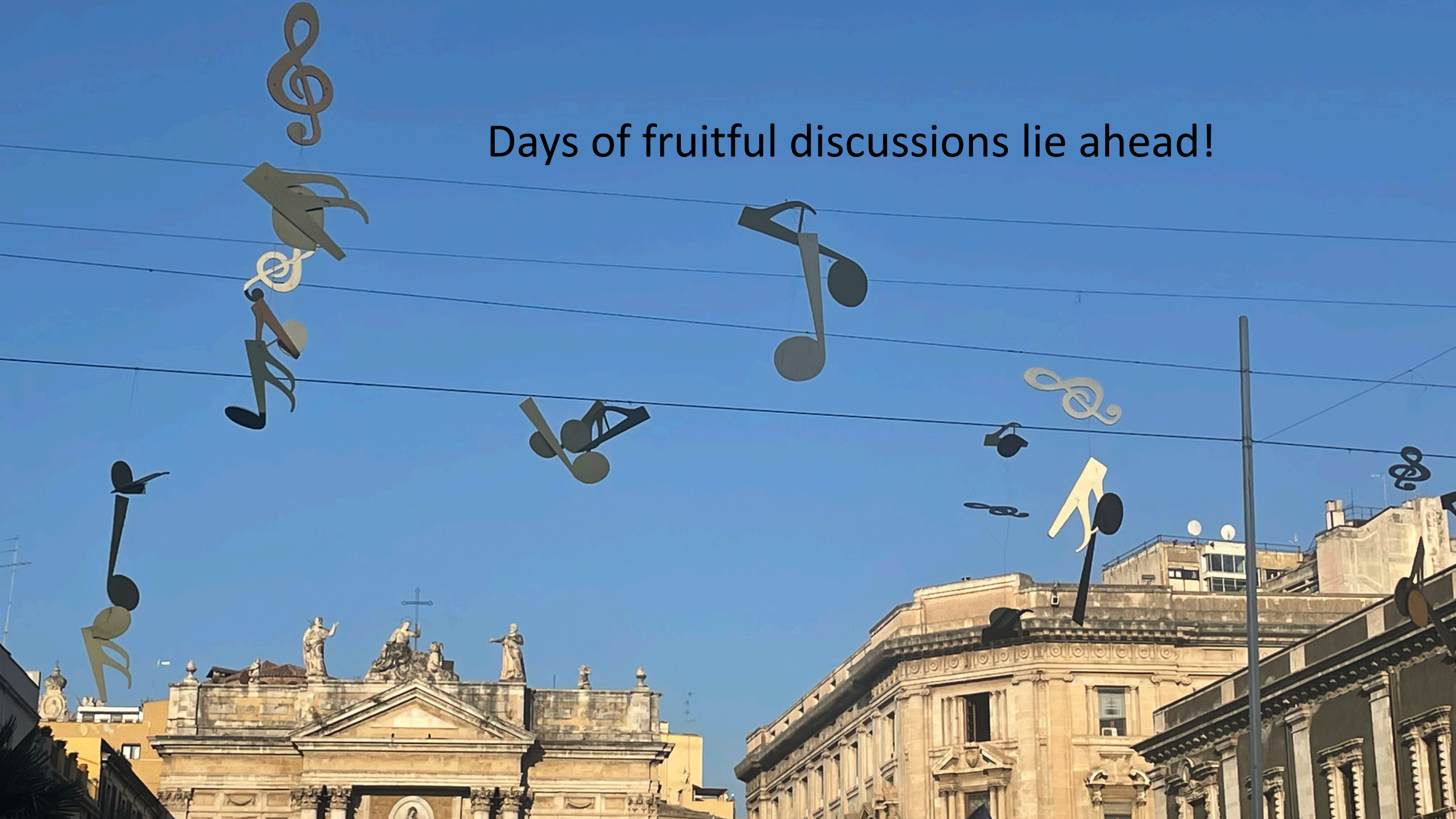
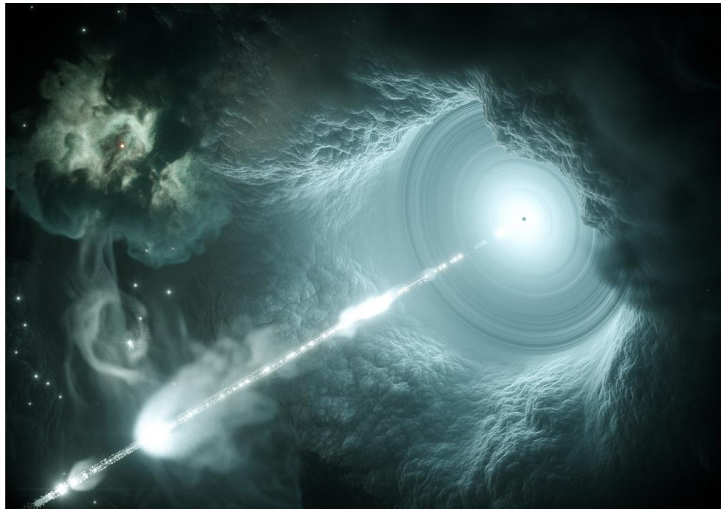

Days of fruitful discussions lie ahead!

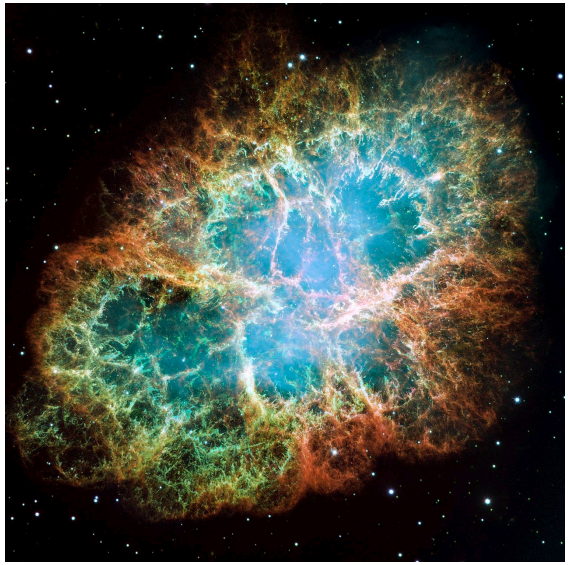
Image credits

TDE, artists view
DESY, Science Communications Lab



Blazar, artists view
DESY, Science Communications Lab

Starburst Galaxy: M82
NASA, ESA, and The Hubble Heritage Team (STScI/AURA)



SN remnant: Crab Nebula
NASA and STScI