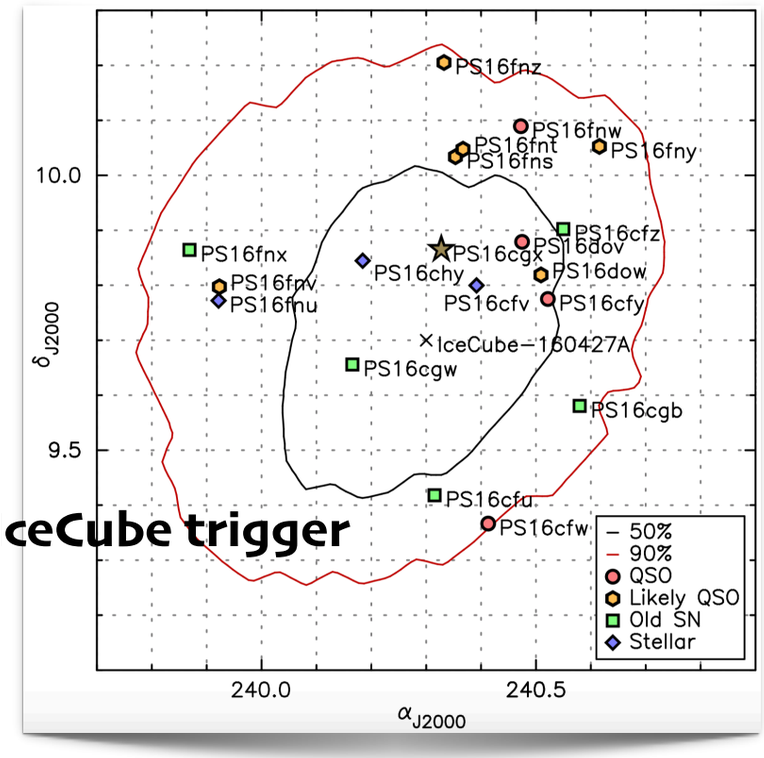
The global Network of Neutrino Telescopes

Elisa Bernardini, University of Padova (Italy)

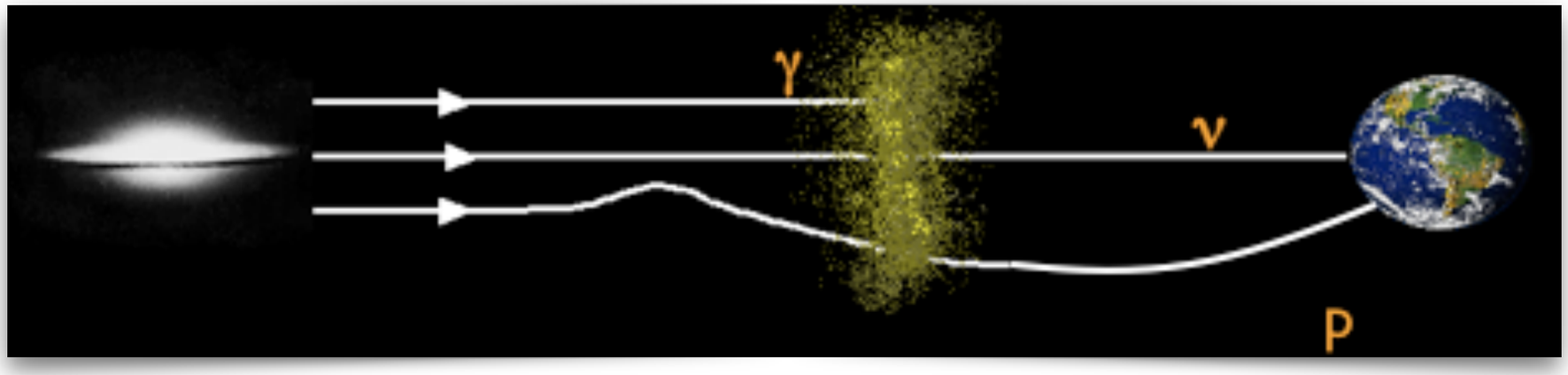
Neutrino follow-up: challenges

… on the multi-wavelength side

- Too many objects in the error circle of a neutrino
- Most instruments have a limited field of view and can observe in dark time

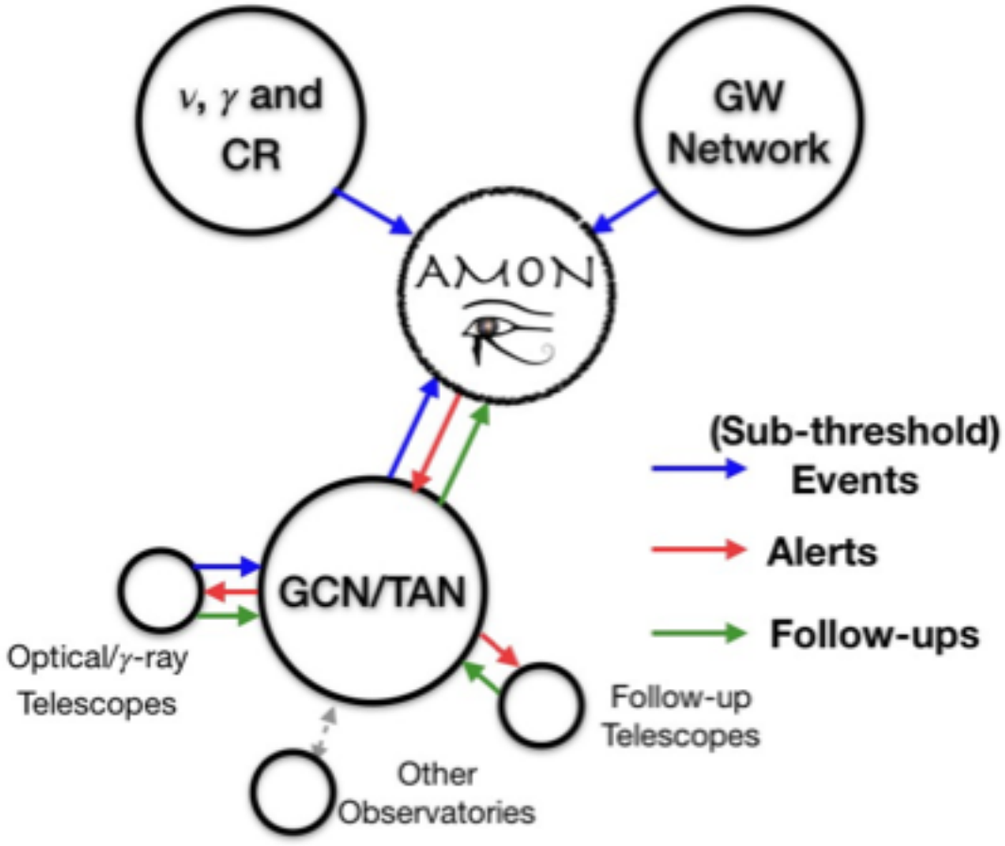


- Being fast can make the difference for short transients
- Need for complex algorithm to decide on best bet (brokers)
- High-energy photons are absorbed on their way to the Earth



Astrophysical Multimessenger Observatory Network (AMON)

- Established to explore sub-threshold coincidences between messengers
- Trigger followup observations



Ayala Solares et al. 2019, Astropart. Phys. 114, 68

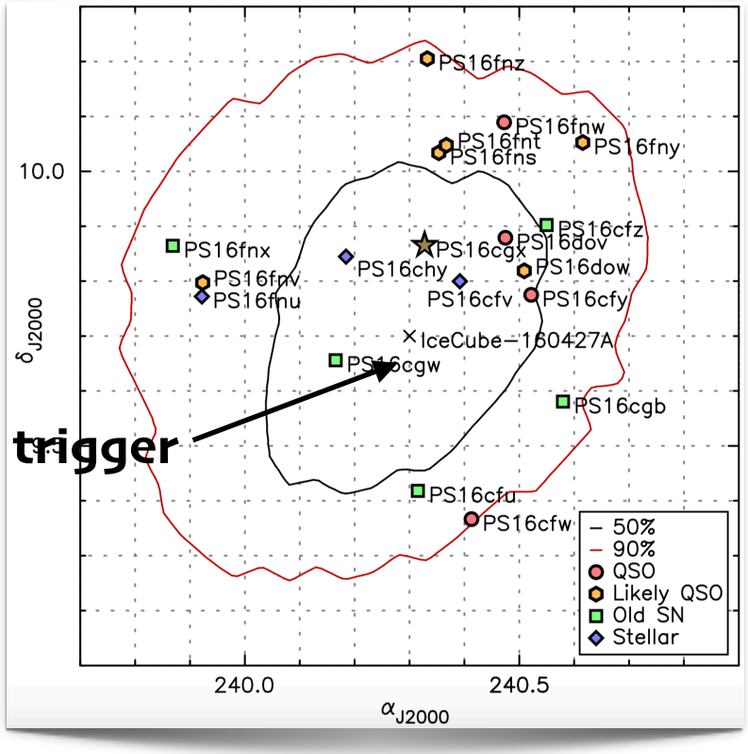
- First searches coming to maturity:
  - Search for IceCube neutrinos in coincidence with HAWC hot-spots
  - ANTARES - Fermi-LAT coincidences
- Public alerts expected soon

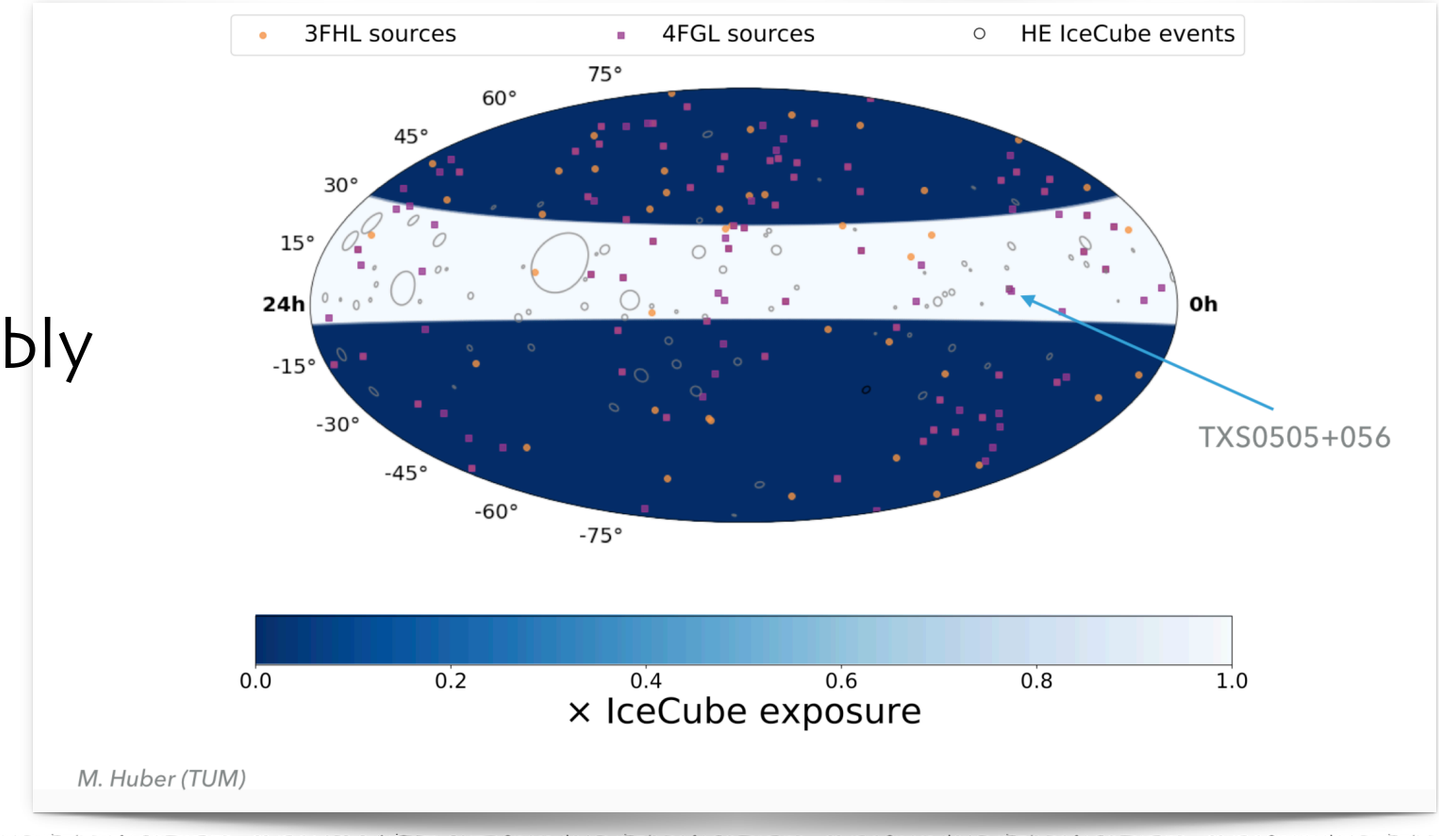
Neutrino follow-up: challenges

… on the neutrino side

- Too few neutrinos
- Angular uncertainty is large compared to astronomical instruments
- In the highest energy range, the highest efficiency is limited at around "horizon"
- Better theoretical understanding to reliably bet on counterparts
- …

IceCube, arXiv: 1901.11080





Neutrino follow-up: challenges

… on the neutrino side

- Too few neutrinos
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- Better theoretical understanding to reliably bet on counterparts
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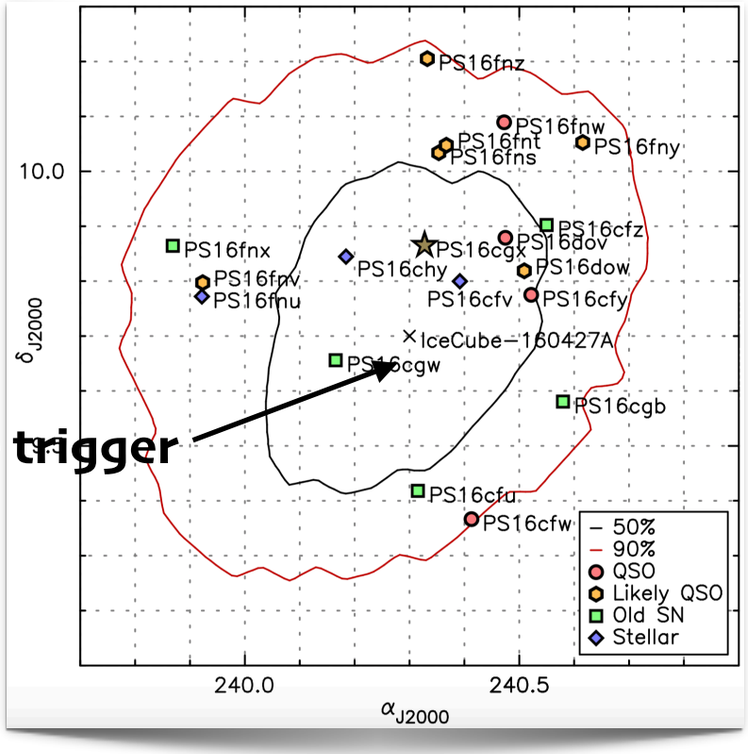
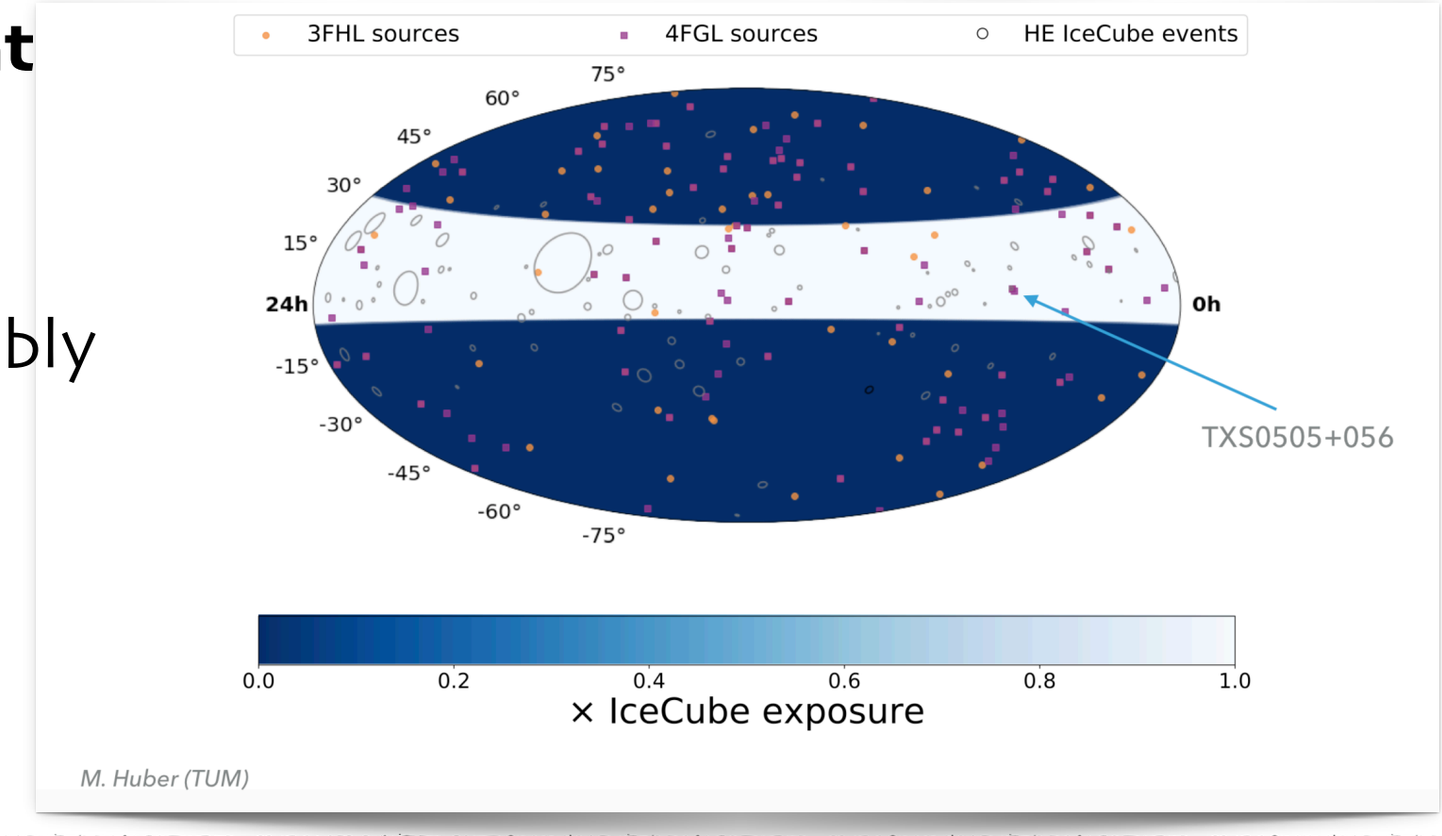
IceCube, arXiv: 1901.11080





Worldwide installations

>1 km3
Construction
Completion ~2030

1 + 0.006 km
Construction
started 2015
Completion ~2021

P-one
path
finder:
STRAW

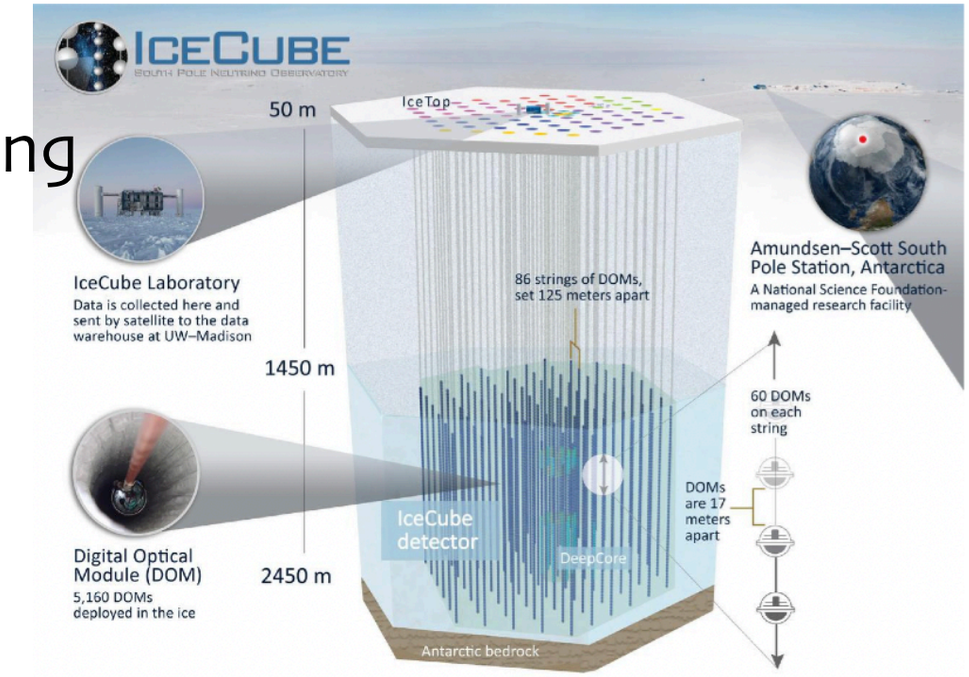
Nu telescope in the
Pacific...?

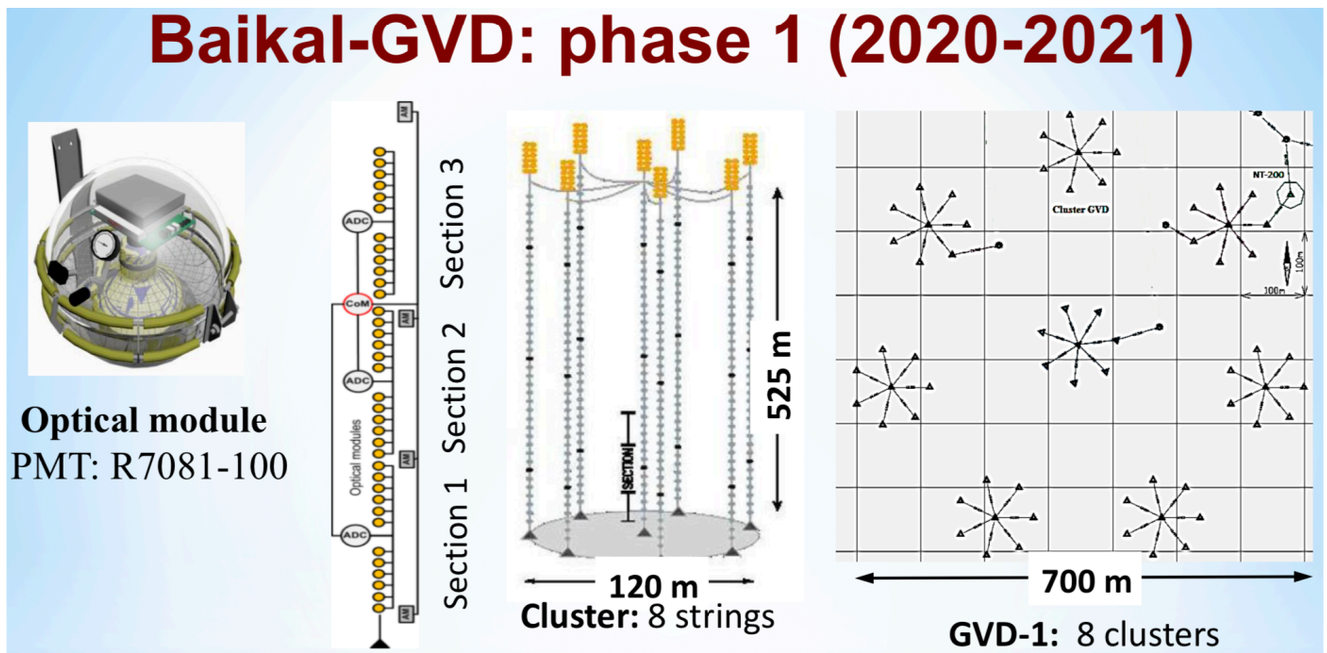
IceCube

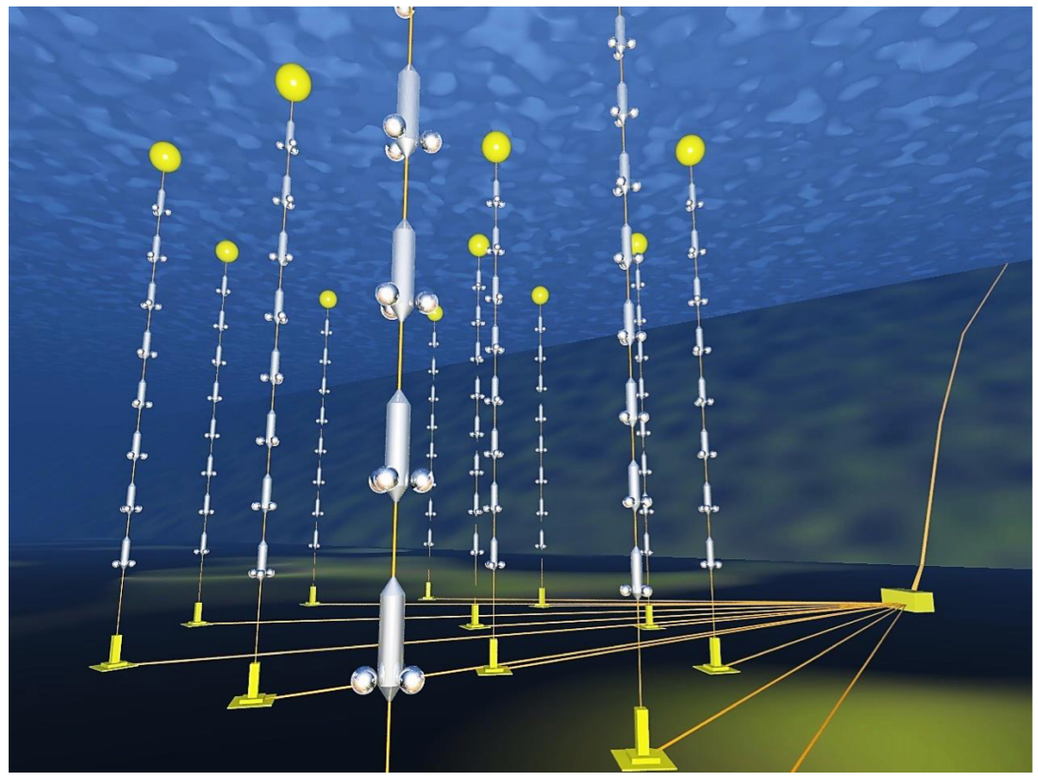
IceCube-Gen2:
10 km3
Ice Č + radio + surf.
array
Upgrade - approved!
Construction start
~2022

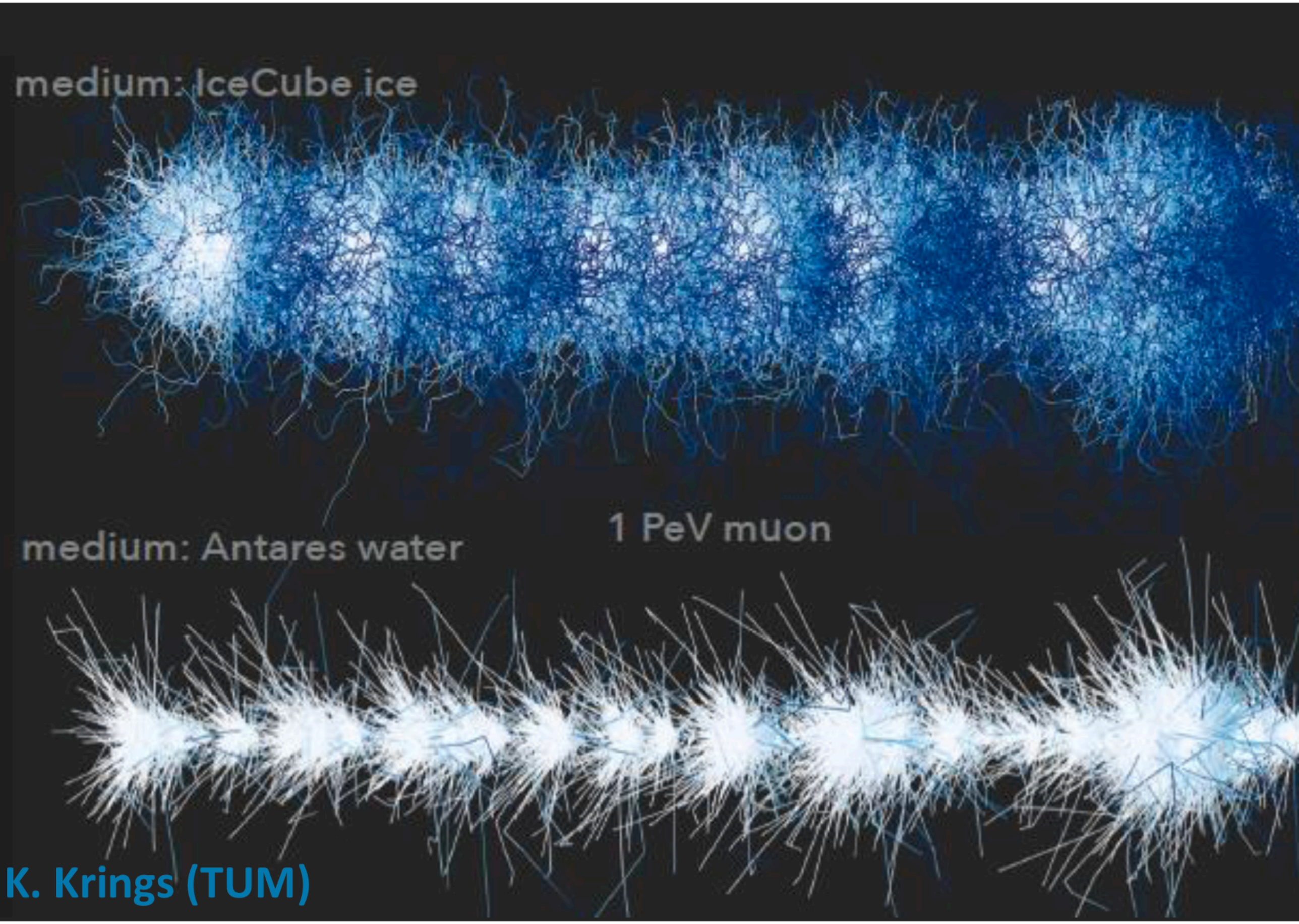
Alerts from neutrino detectors

- A rapid growing network of large high-energy neutrino detectors are now providing alerts to the astronomy community with
  - High-duty factor (>95% observing)
  - Half/Full sky coverage
- Rapid communication (< 30 s)
- Good angular resolution: ~0.5° (tracks)

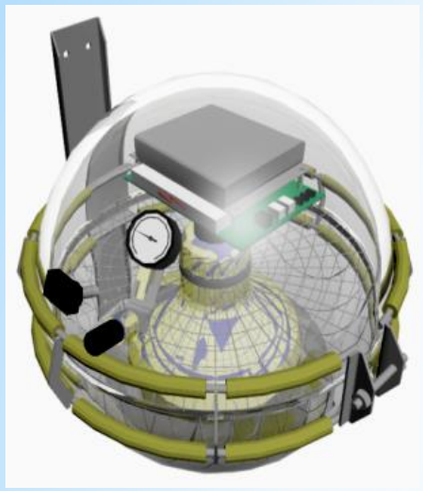




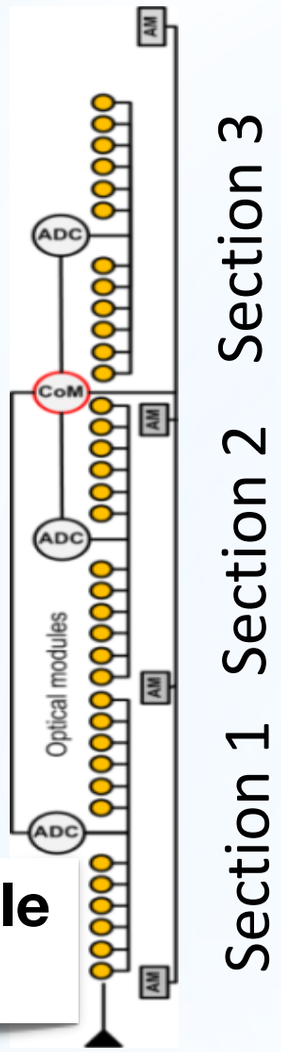


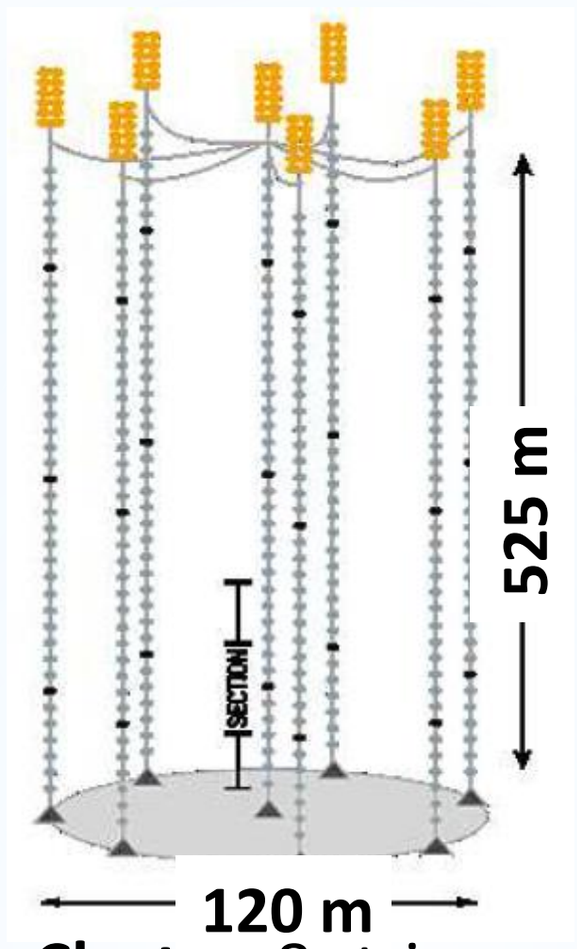

medium: IceCube ice
1 PeV muon
medium: Antares water
K. Krings (TUM)

Baikal-GVD: phase 1 (2020-2021)

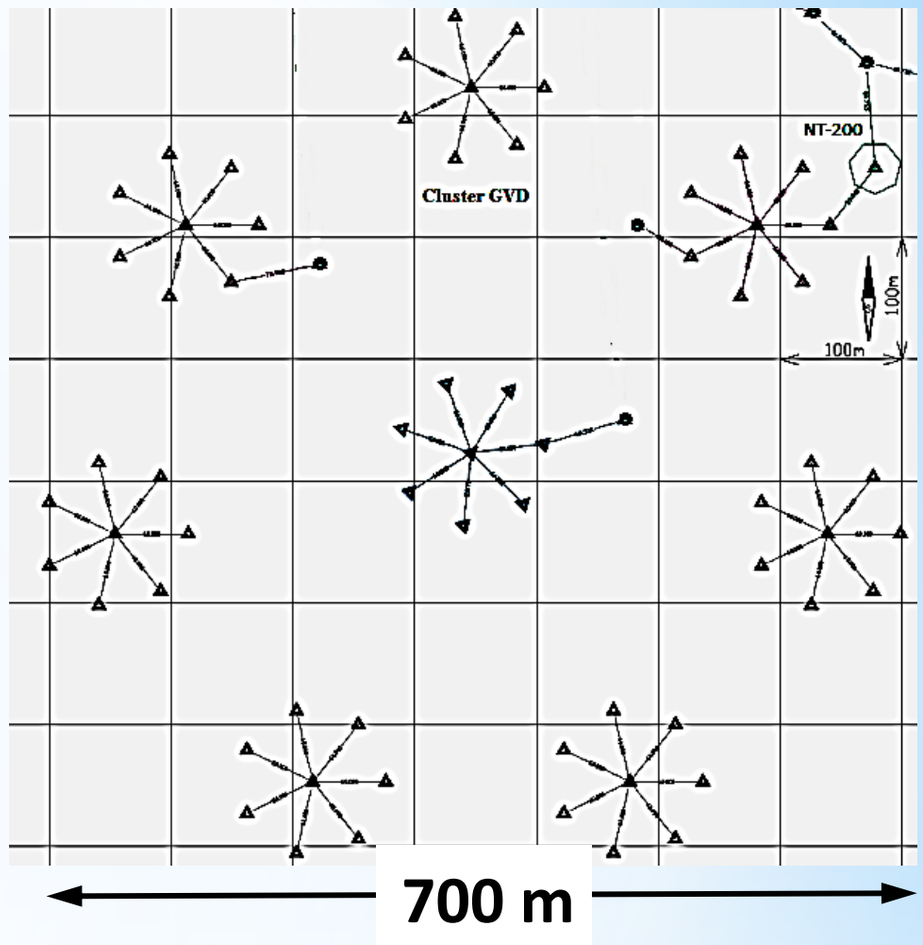


Optical module
PMT: R7081-100





Cluster: 8 strings



GVD-1: 8 clusters

O. Suvorova@Marseille
Dec2019

GVD-1	
OMs	2304
Clusters (8 Strings)	8
Depths, m	750 – 1275
Eff. Volume	0.4 km^3

Directional resolution	Energy resolution
Cascades: 4.5°	$\delta(E/E_{sh}) \sim 0.30$
Muons: 0.25° - 0.5°	$\delta(\lg E) \sim 0.4$

Water properties:
Abs. length: 22 ± 2 m
Scatt. length: Ls ~ 30-50 m Ls /(1- <cosθ>) ~ 300-500 m

Baikal-GVD status 2019: 5 clusters with 1440 OMs

Configuration	2015	2016	2017	2018	2019
The number of OMs	192	288	576	864	1440
Geometric **sizes, m**	**□80×345**	**∅120×525**	**2×∅120×525**	**3×∅120×525**	**5×∅120×525**
Eff. Volume	**0.03 km^3**	**0.05 km^3**	**0.1 km^3**	**0.15 km^3**	**0.25 km^3**

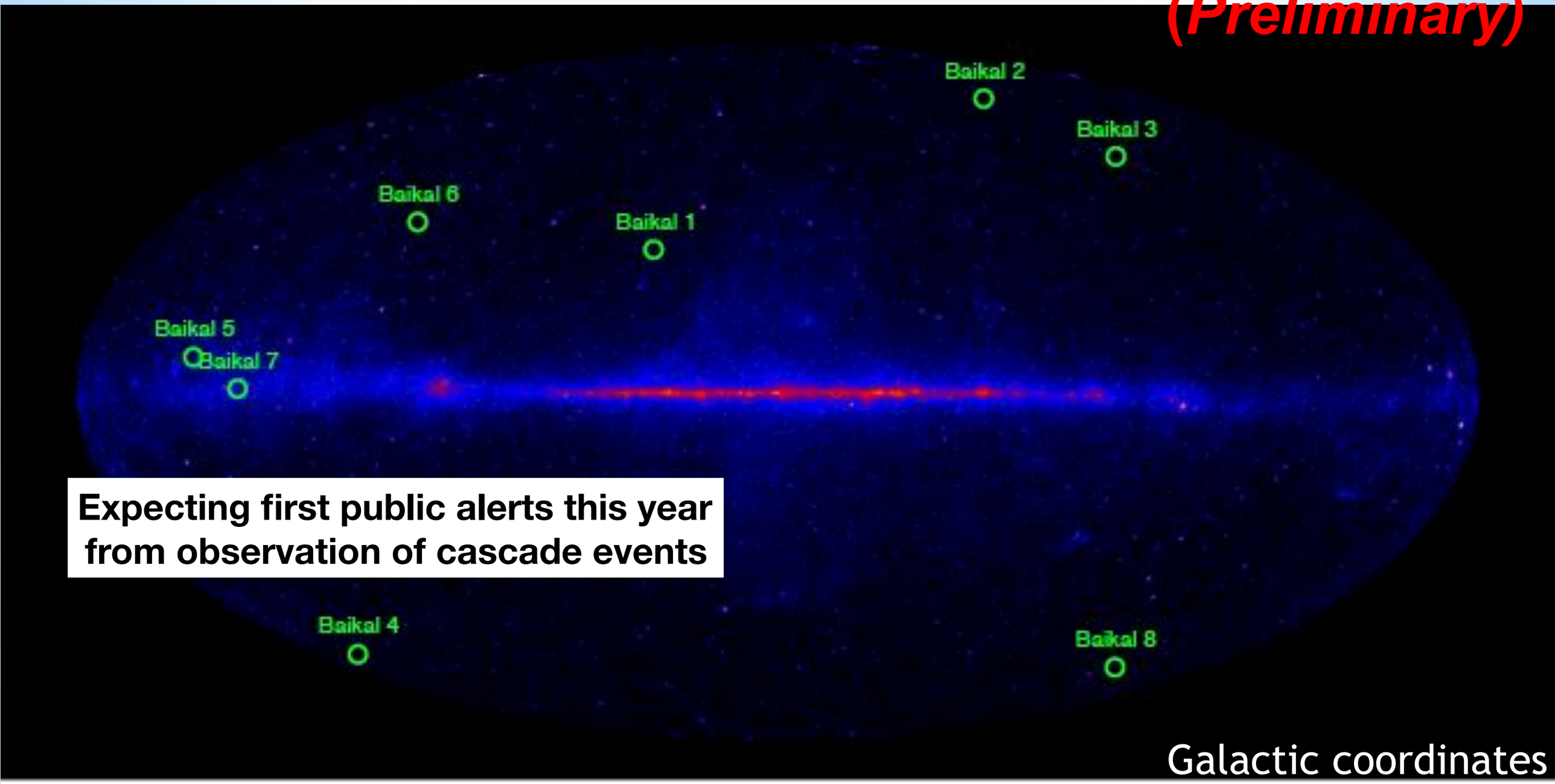
Total: 5 Clusters → 40 Strings → 120 Sections → 1440 OMs

- Cluster 1 since 2016
- Cluster 2 since 2017
- Cluster 3 since 2018
- Clusters 4 and 5 since 2019
- Powerful isotropic laser sources

O. Suvorova@Marseille Dec2019

GVD alert base of 8 cascades : 2015-2016, 2018-2019

(*Preliminary*)

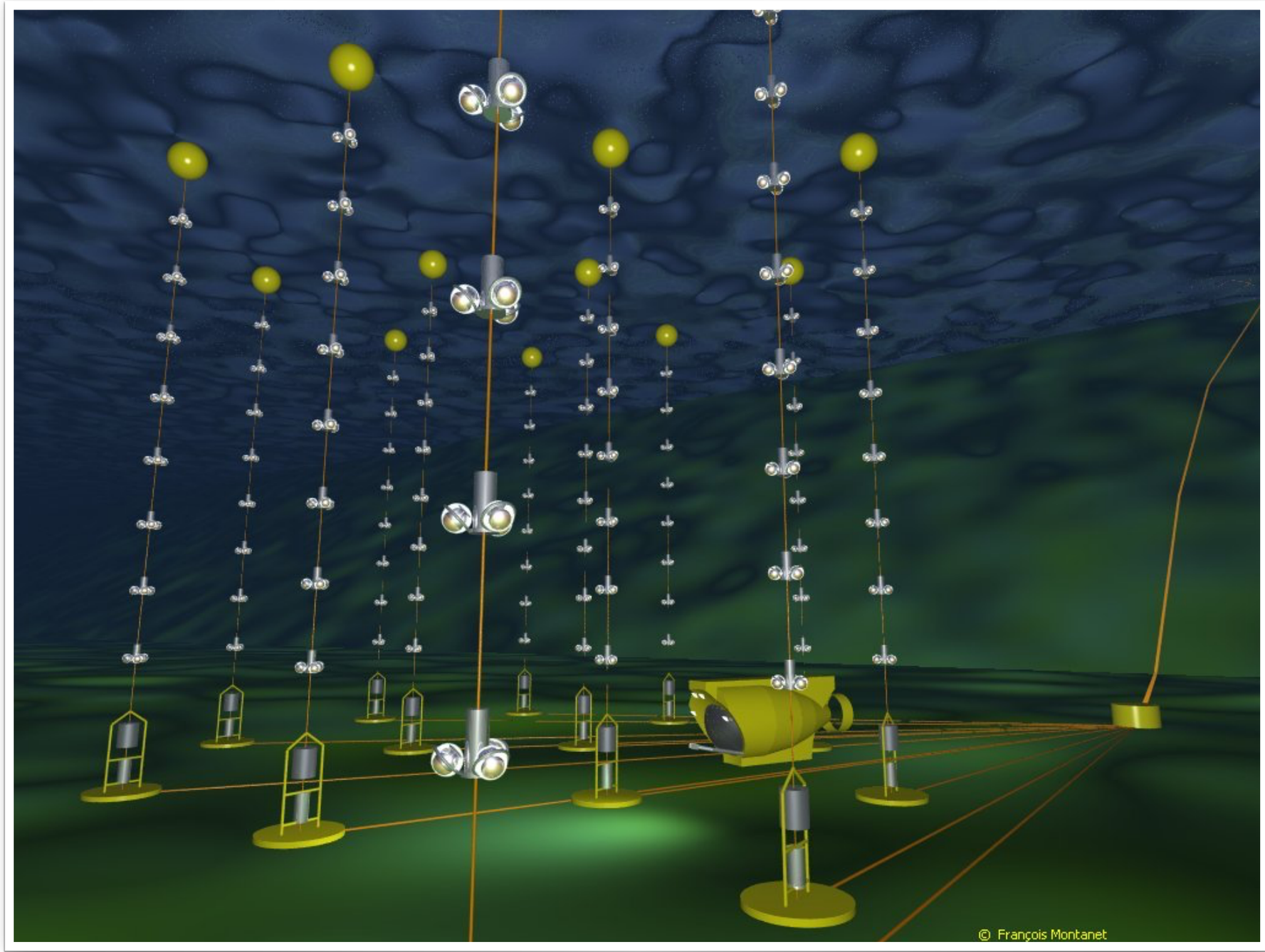


Expecting first public alerts this year from observation of cascade events

4FGL, map for E_γ>10 GeV (credits to D.Semikoz, A.Neronov)

ANTARES

Consisting of 885 PMTs deployed in the Mediterranean sea at depths between 2.01 km and 2.47 km below sea level, it instruments a volume of ~1% of IceCube



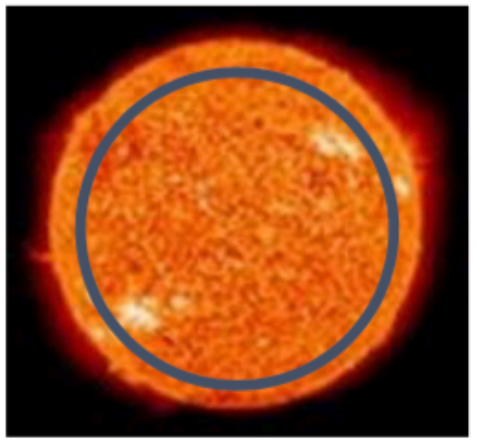
ANTARES neutrino alert selection

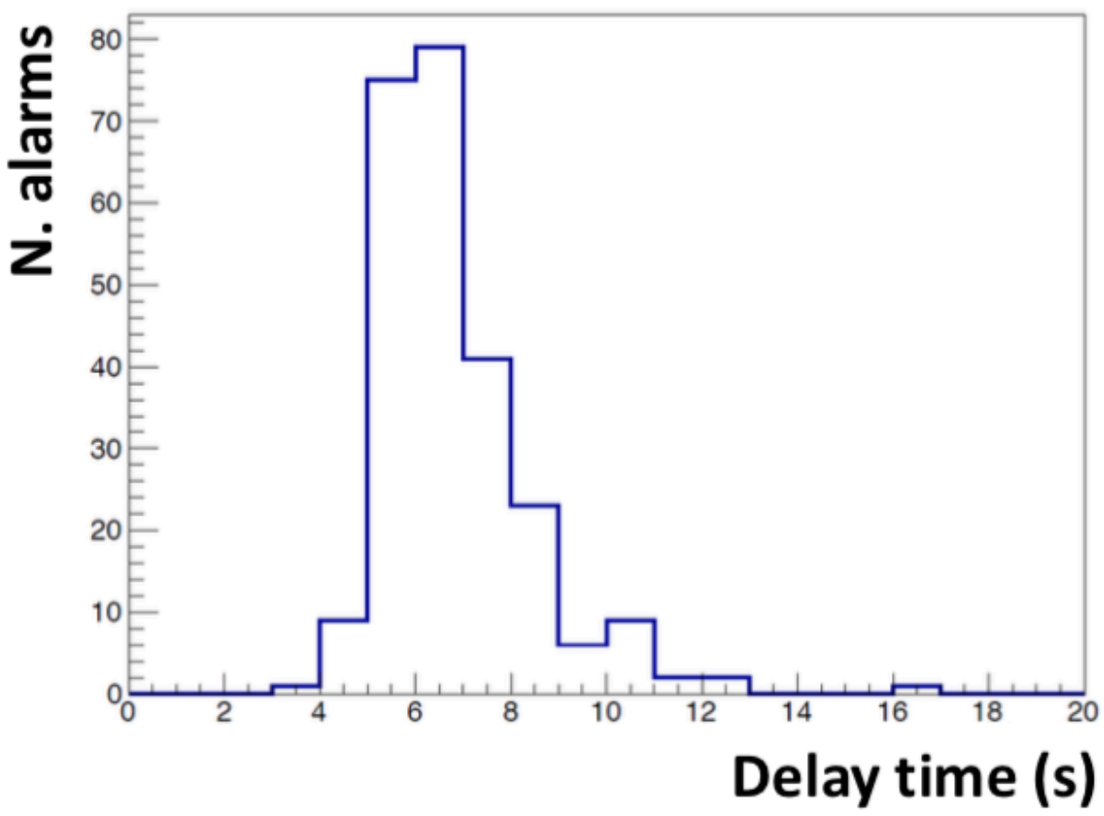
Triggers (upgoing tracks):

- Doublet of neutrinos: ~0.04 evt / yr.
- Single neutrino with direction close to local galaxies (1 TeV): ~10 evt / yr.
- Single HE neutrinos (7 TeV): ~ 15 evt/yr
  - VHE neutrinos (30 TeV): ~ 3-4 evt/yr.

ANTARES PSF :

~0.4º (median)





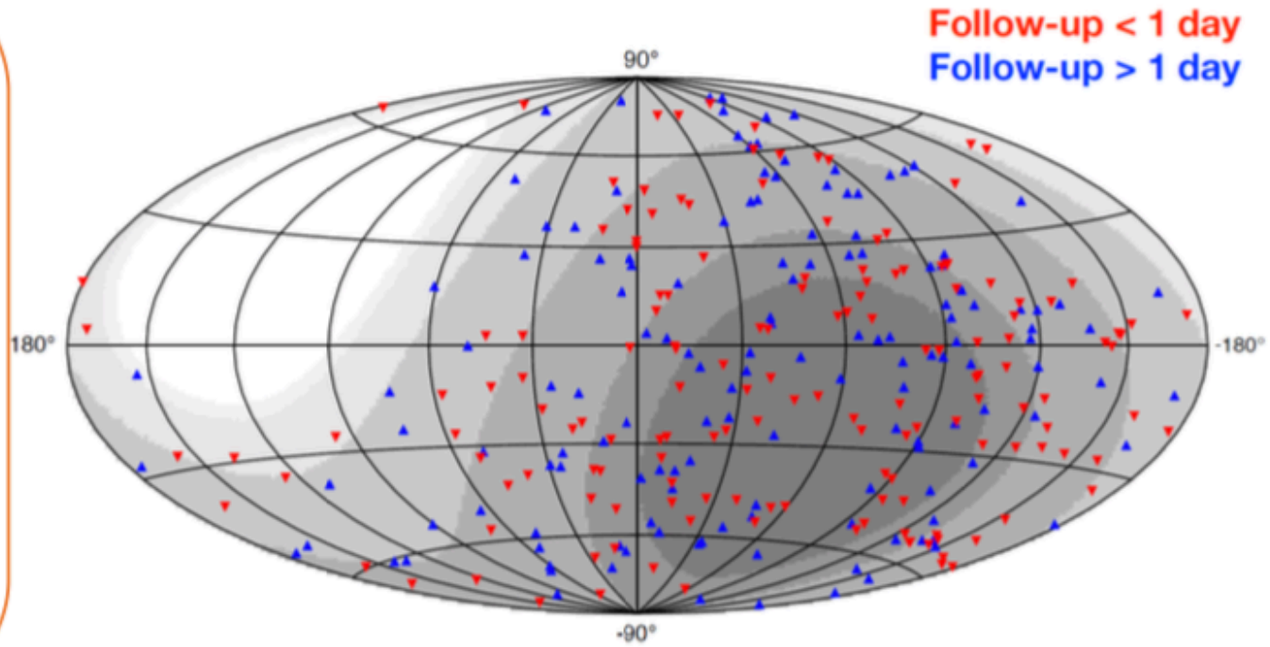
Alert delay:

- Alert message sent via GCN using GCN socket/VO Event (XML file)
- Average delay: **~6-7 s** (filtering, online reco, neutrino selection, alert message)

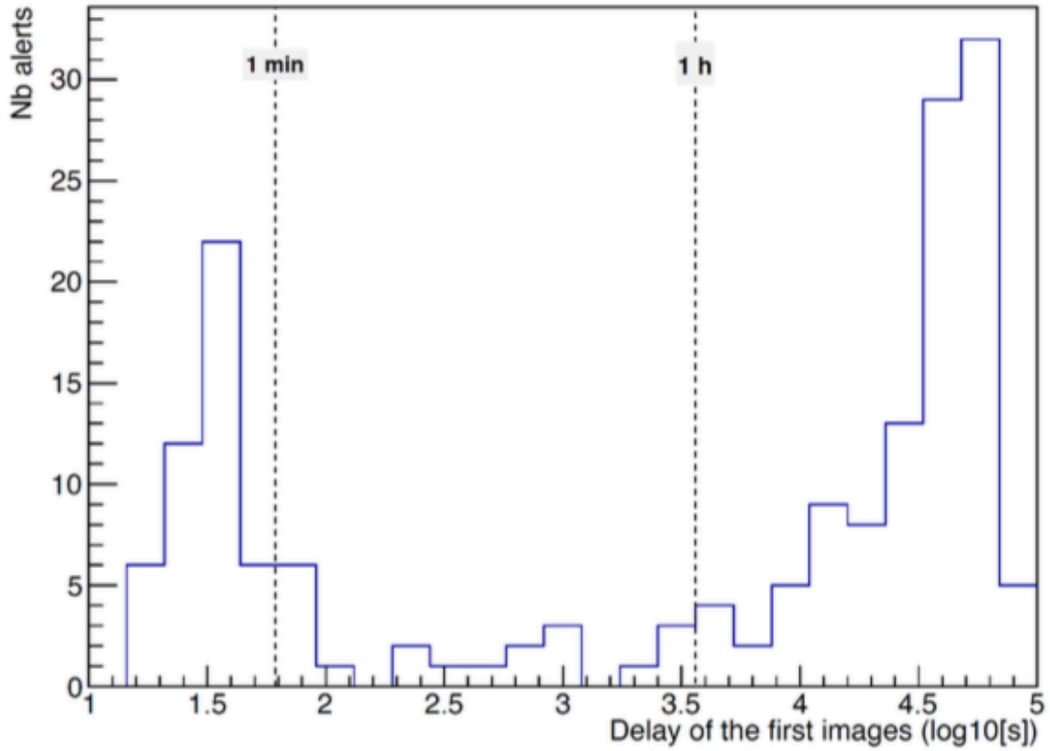
ANTARES neutrino alert selection: follow-ups

Status ANTARES alerts (Oct 2009 - July 2019):

- 311 robotic **optical** telescopes
- 18/25 followed by **Swift-XRT**
- 4 followed by Integral
- 4 followed by MWA
- 2 followed by H.E.S.S.



JCAP02(2016)062



To date: no significant association found

Follow-up delay (optical):

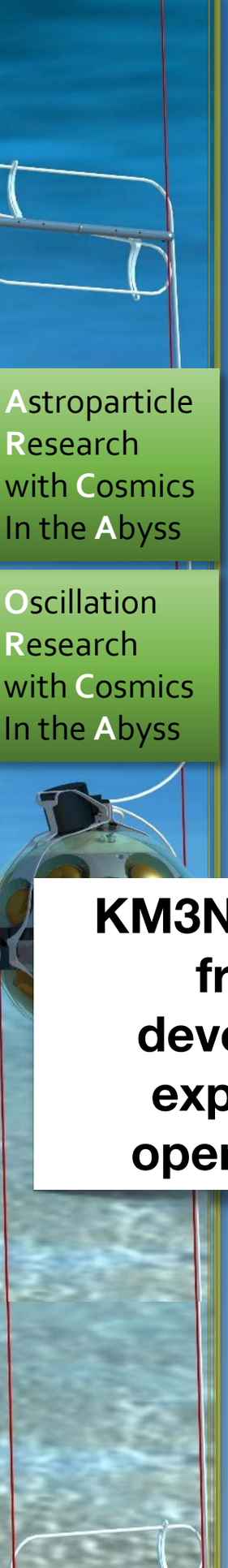
- Δt between 1st image/trigger:
  - **55 alerts < 1 min**
  - **208 alerts < 1 day**

(wait for the alert visibility, stop previous acquisition, point the telescope, start the acquisition)

KM3NeT

PHASE	BLOCKS	PRIMARY DELIVERABLES	FUNDS
1	0.2	Proof of feasibility and first science results 24 ARCA + 6 ORCA strings	Fully funded
2	2+1	All flavor neutrino physics and astronomy 2 x 115 ARCA strings 1 x 115 ORCA strings	Funding in progress
3	6	Neutrino astronomy including Galactic sources	Not yet

Slide from M. Taiuti



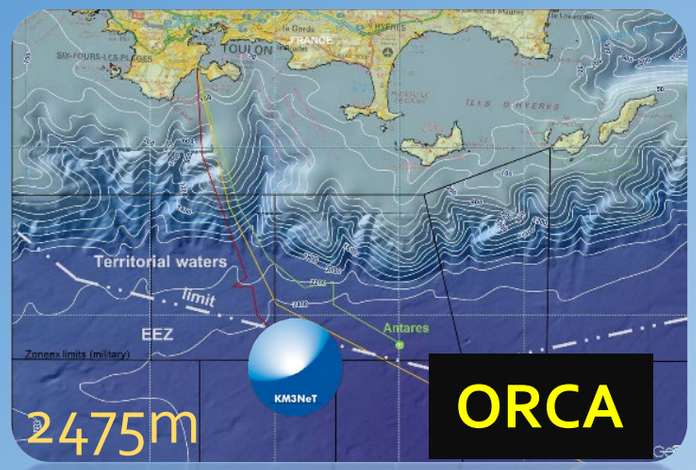
Astroparticle Research with Cosmics In the Abyss

Oscillation Research with Cosmics In the Abyss

Motivations & Objectives

- **KM3NeT** is the neutrino research infrastructure in the deep Mediterranean Sea
  - **ARCA** (off shore Capo Passero, It @ 3500 m depth)
  - **ORCA** (off shore Toulon, Fr @2500 m depth)

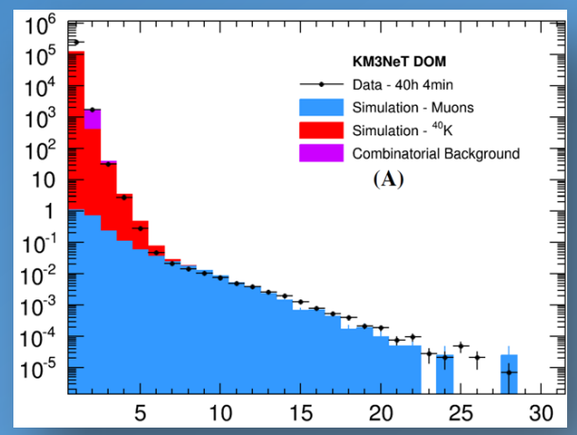
KM3Net realtime alert framework in development now, expected to start operation this year



- Same collaboration, same technology, two deep sea sites

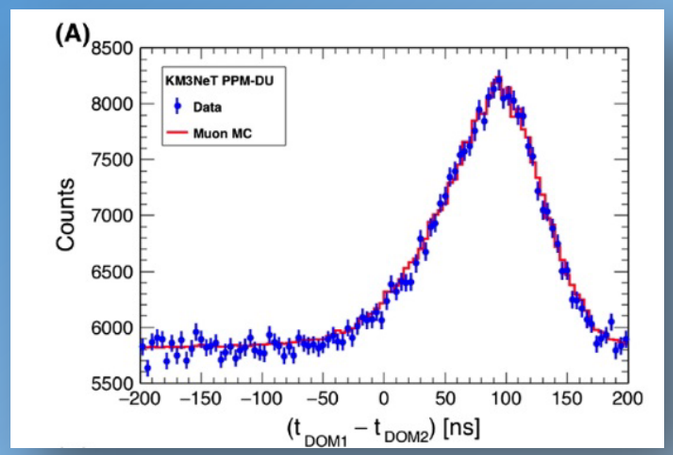
From Validation to Construction

Prototype DOM deployed at Antares site April 2013



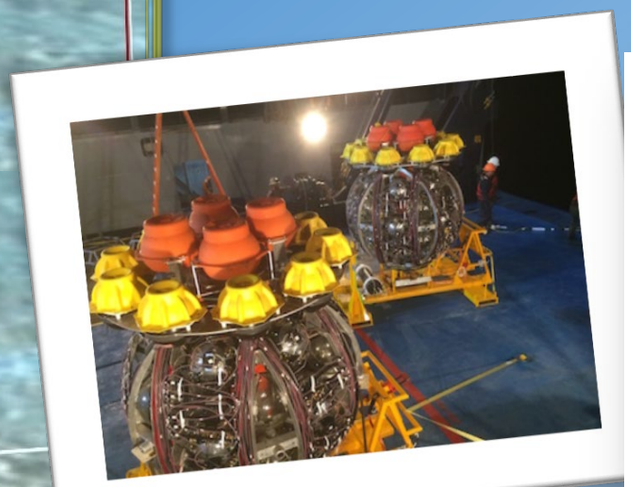
Test of photon counting capabilities and directional sensitivity of DOM
Eur. Phys. J. C (2014) 74:3056

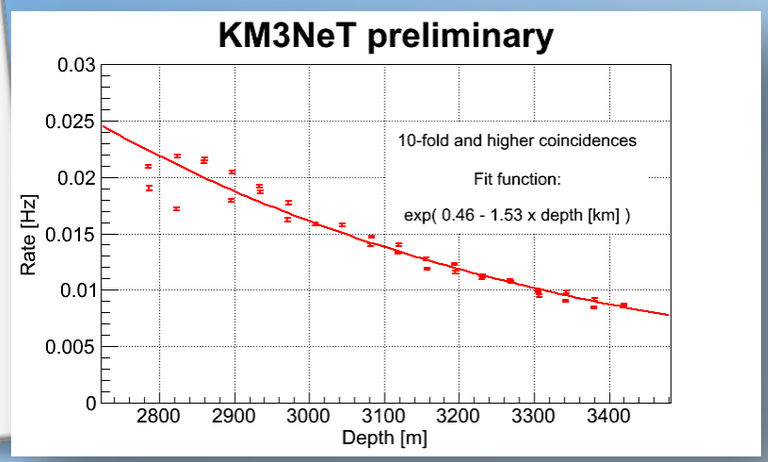
Prototype DU (three DOMs) deployed in Capo Passero May 2014



Test of DU structure functionality
Test of intra-DOM and inter-DOM calibration - *Eur. Phys. J. C (2016) 76:54*

First ARCA DU deployed in Capo Passero December 2015





Muon flux dependence on depth
DU calibration
Trigger implementation
Track reconstruction and MC comparison (papers in preparation)

A Phased Approach

PHASE	BLOCKS	PRIMARY DELIVERABLES	FUNDS
1	0.2	Proof of feasibility and first science results 24 **ARCA** + 6 **ORCA** strings	Fully funded
2	2+1	All flavor neutrino physics and astronomy 2 x 115 **ARCA** strings 1 x 115 **ORCA** strings	Funding in progress (presently 1/3 available)
3	6	Neutrino astronomy including Galactic sources **P2O** – Long Base Line **Protvino-ORCA**	Next step

Phase 1 - **ARCA**

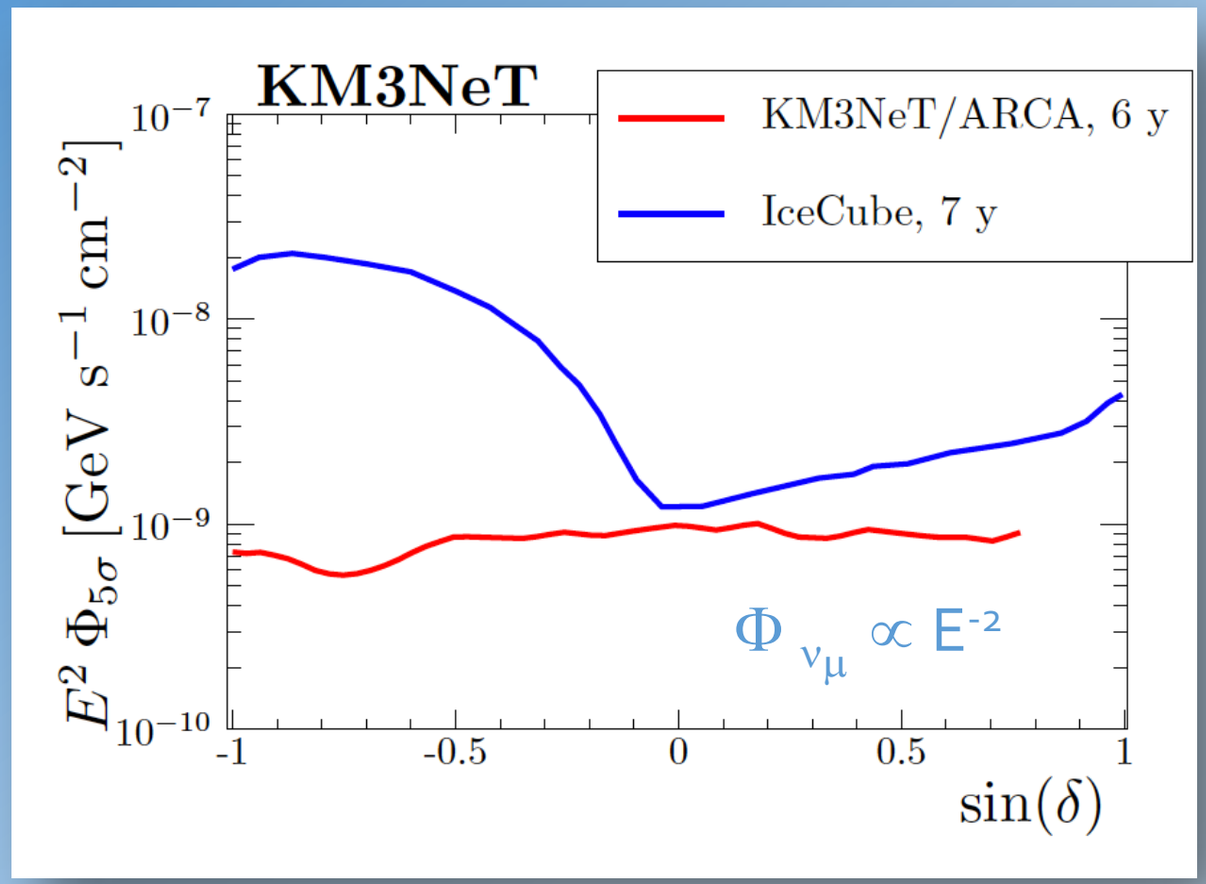
- ARCA-DU1 and ARCA-DU2 deployed December 2015 and May 2016 at Capo Passero, Sicily and worked till April 2017
- ARCA-DU1 operativity resumed in January 2019
- Plenty of data
- Presently the on-shore station is under renovation to host the second cable power supply
- The seafloor network is scheduled to return operative before summer 2020 with 6 DUs connected

ARCA Sensitivity to Point-like Sources

- **ARCA** can survey almost the whole sky with a discovery potential @ 5σ about one order of magnitude better than **IceCube** for equivalent exposure

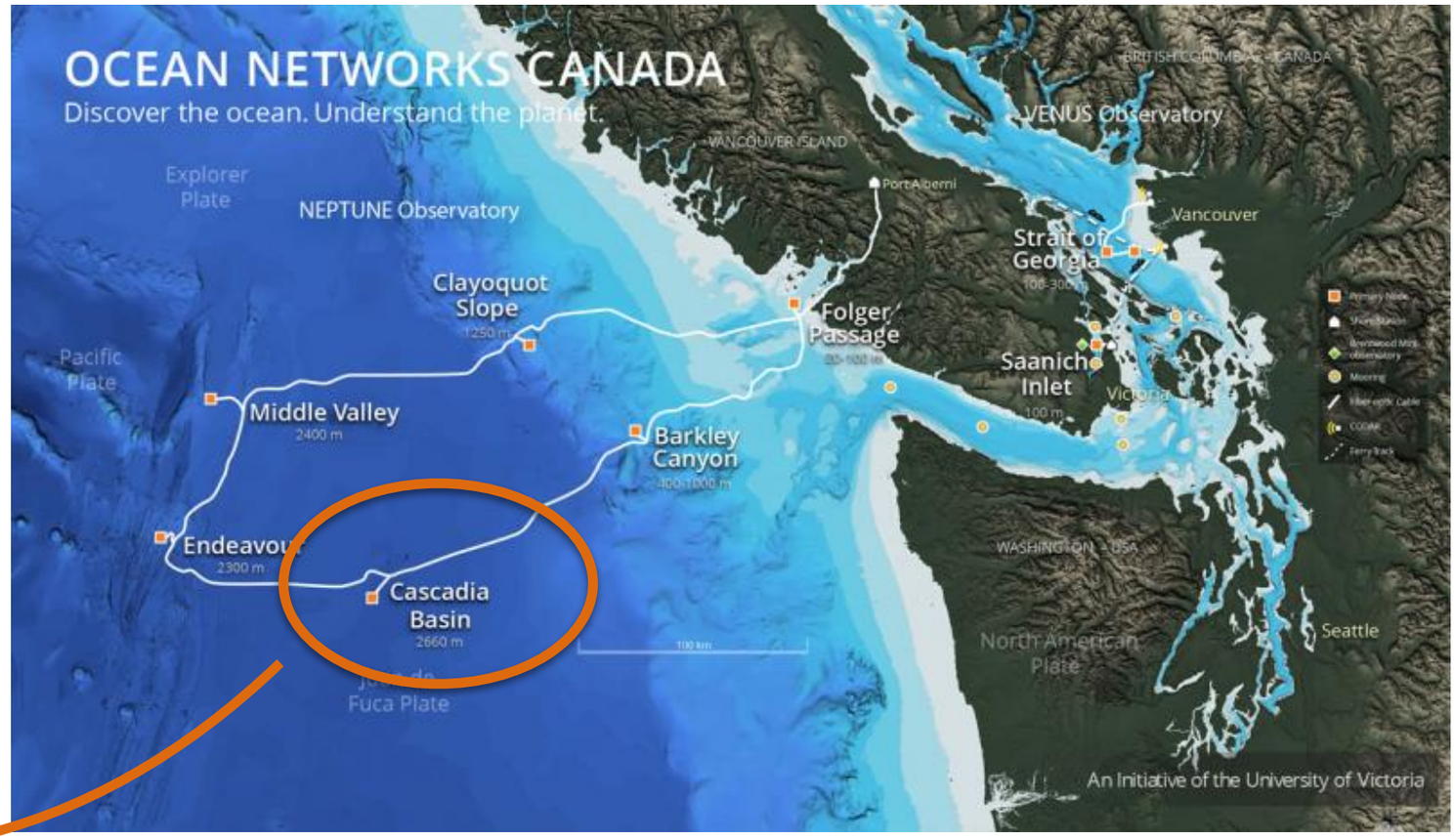
DATA and SIMULATION combined

SIMULATION only



Pacific Ocean Neutrino Explorer @ ONC

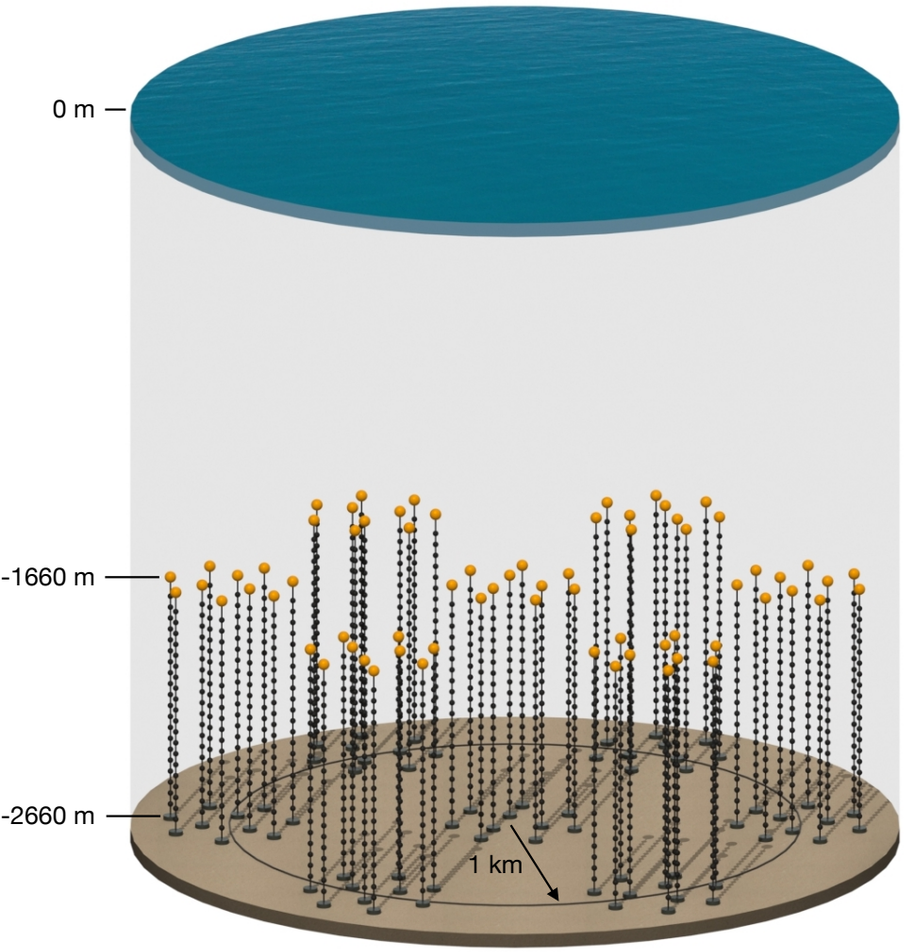
- already existing infrastructure:
  - 800km cabled sub-sea infrastructure
  - ~10years experience with deep sea deployments
- P-ONE @ Cascadia Basin
- depth of 2660m

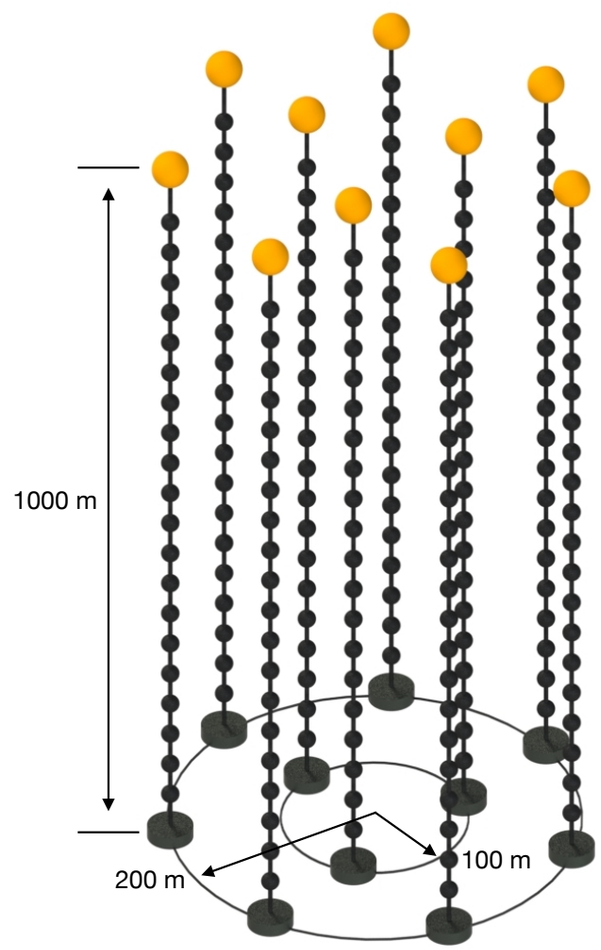


credits to https://www.oceannetworks.ca

Matthias Huber
Dec. 2019

Pacific Ocean Neutrino Explorer





- attenuation length in water ~20-50m @460nm
  → segmented detector
- 10 strings per cluster
- ~3km^3 covered in cluster segments
- 20 Optical Modules and 1 calibration module per string

Image: K. Holzapfel

Matthias Huber
Dec. 2019

Path towards P-ONE: STRAW

- STRings for Absobrtion length in Water (STRAW)
- Study of optical properties at Cascadia Basin
- First preliminary absorption length @465nm: $31.4m \pm 3.0m(\mathrm{stat}) \pm 5.0m(\mathrm{sys})$
- background rate likely influenced from bioluminescence from microorganisms

https://arxiv.org/pdf/1810.13265.pdf

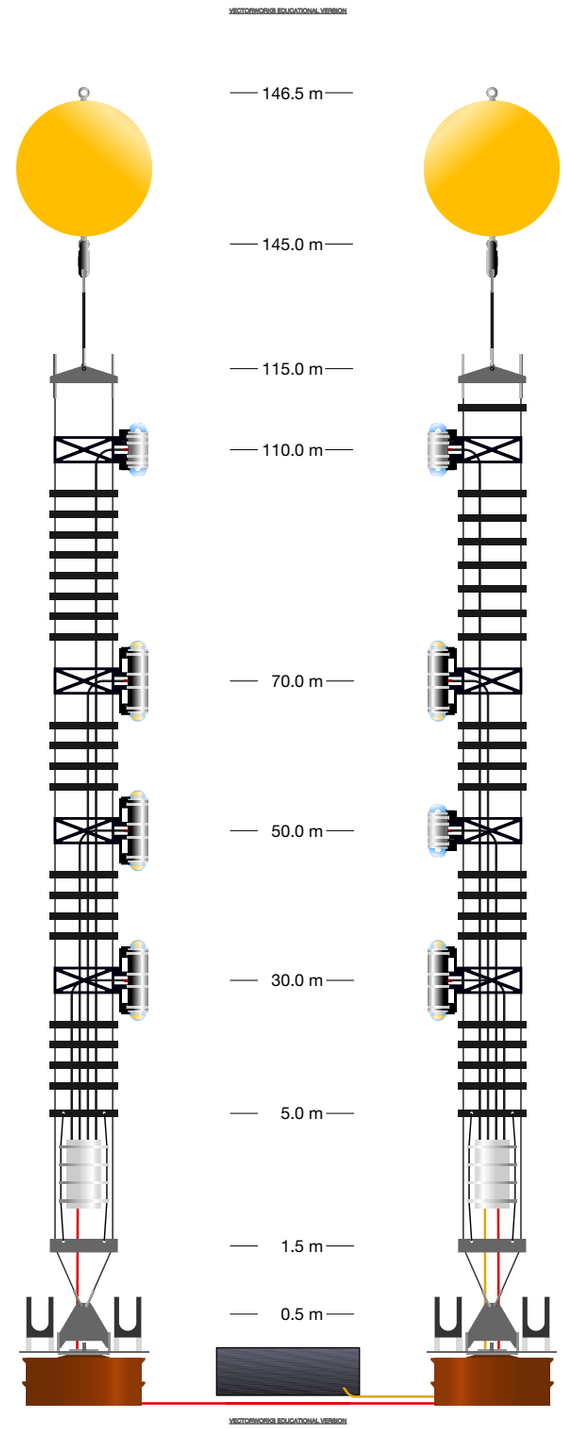
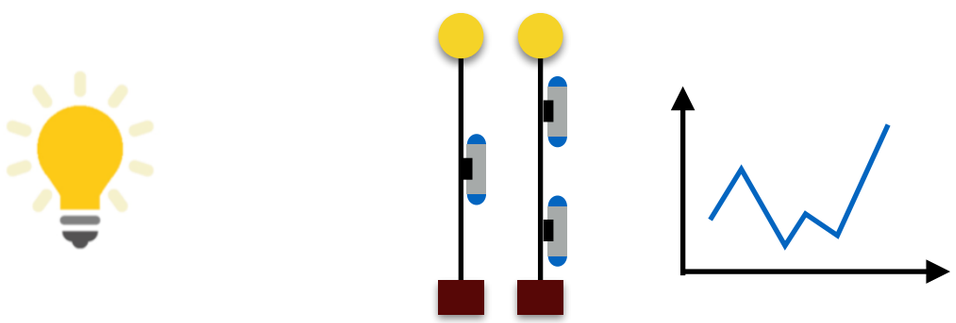
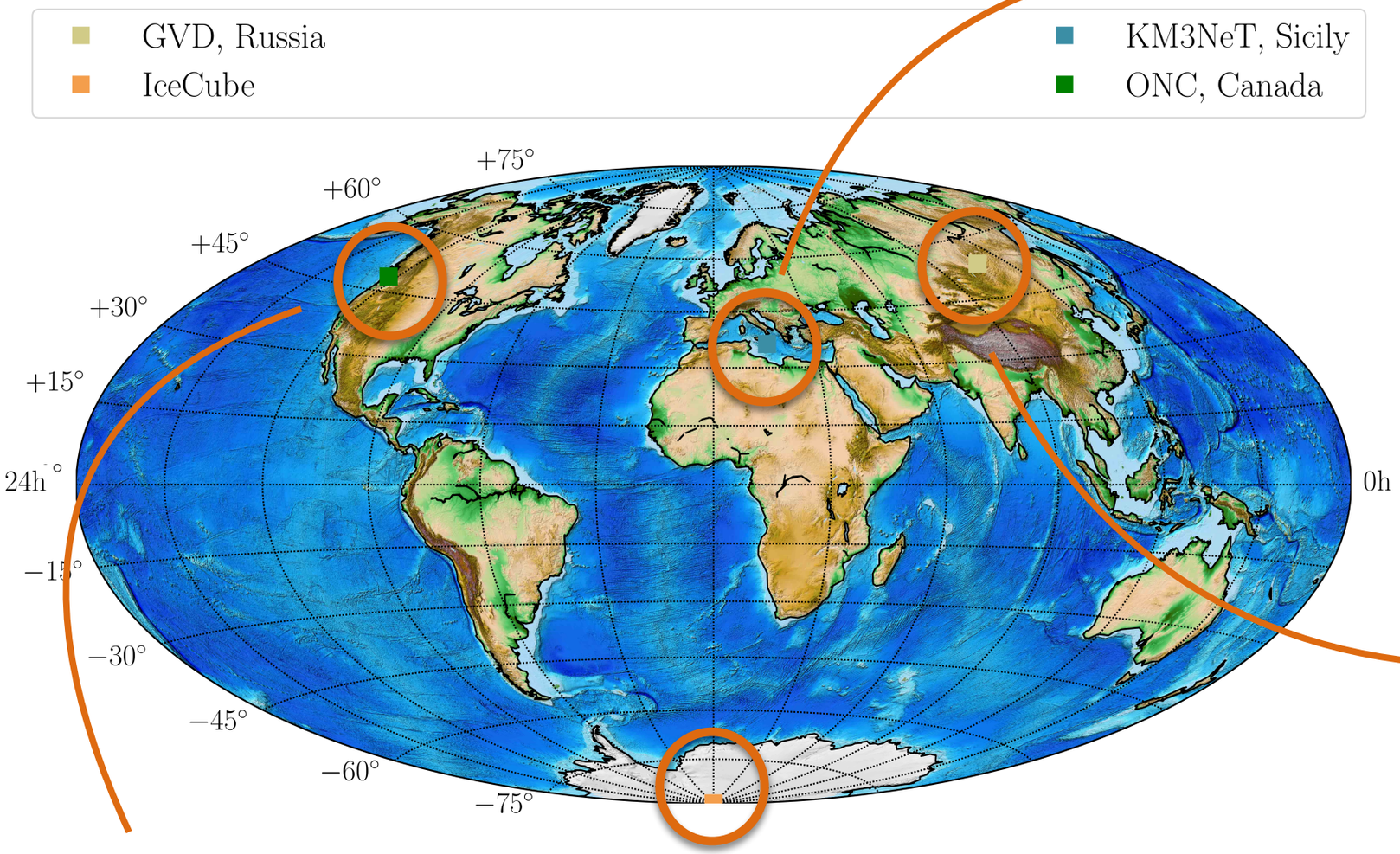


Image: K. Holzapfel



Aug 2017 June 2018 July 2018

PLEνM : A planetary neutrino telescope



KM3NeT

E>10GeV

under construction

BAIKAL-GVD

E>50TeV

under construction

OCEAN NETWORKS CANADA

E>50TeV

under construction

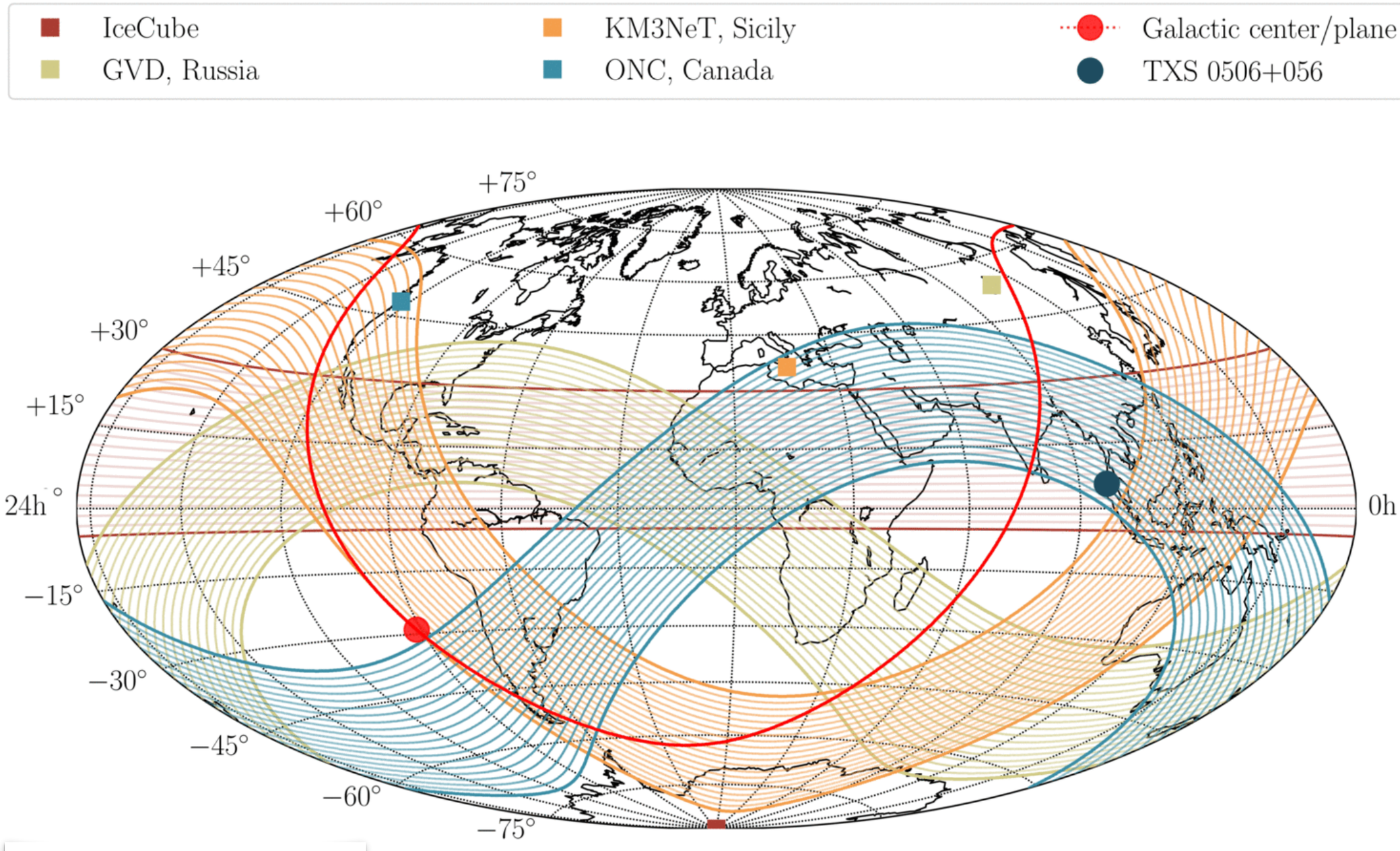
ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

E>10GeV

measuring data for more than 10years

Matthias Huber
Dec. 2019

PLEνM : Simplified Combined field of view



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Dec. 2019

The Global Neutrino Network

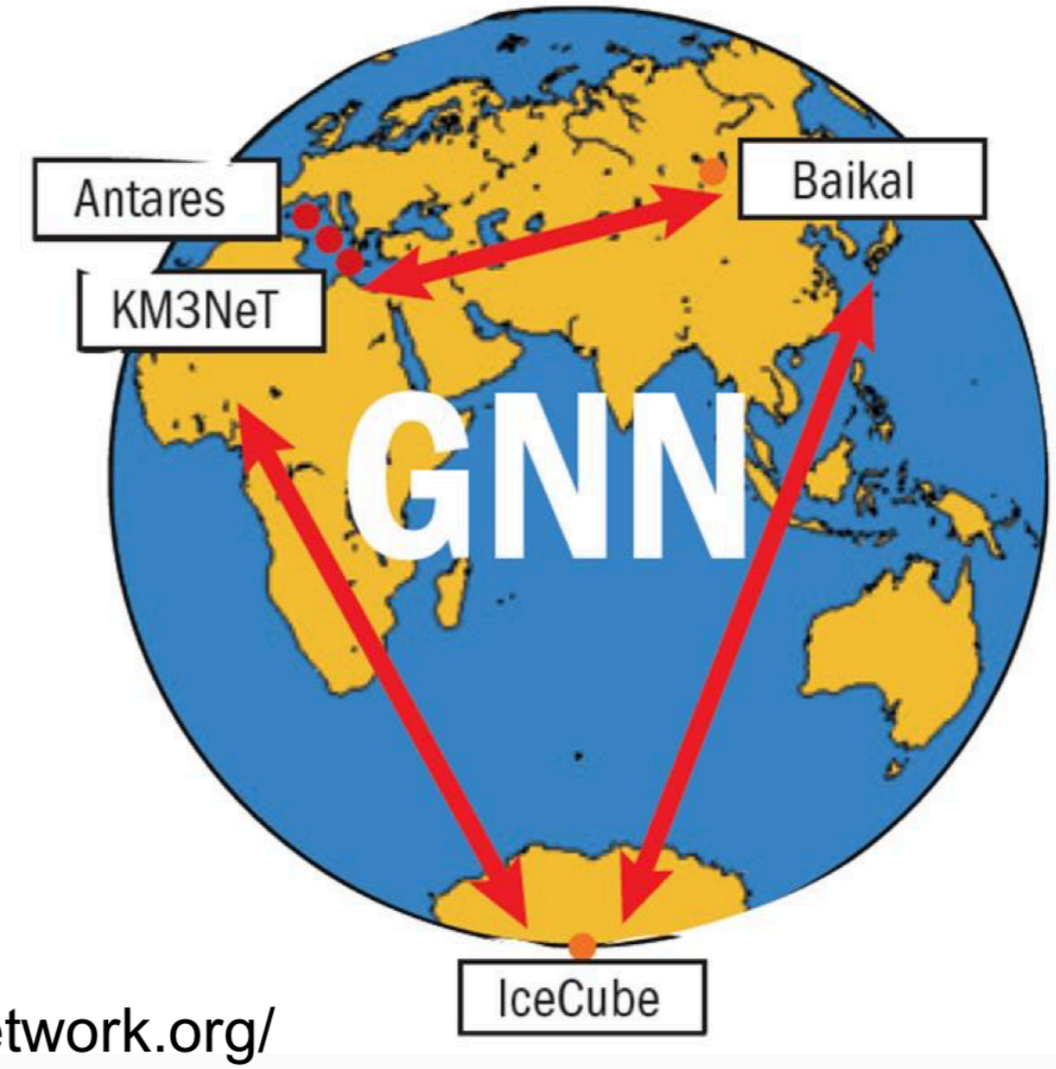
GNN

The Global Neutrino Network

Slide from C. Spiering

Formed 2013:

- **ANTARES**
- **Baikal**
- **IceCube**
- **KM3NeT**



https://www.globalneutrinonetwork.org/

GNN: goals

- Develop coherent strategy to maximize the synergistic effects: **exchanging** information, analysis methods, cross- checking results, defining common ways of presenting data
- Work toward framework for **coordination** of cooperative actions and self-organization of the neutrino astronomy community
- Fostering **future technological developments**
- Facilitate preparation of a "**Global Neutrino Observatory**": future detectors of similar scale in both North and South.

From:
https://www.globalneutrinonetwork.org

GNN: community

Need for coordination:

GNN
The Global Neutrino Network

Chair 2013-2017: C.S, since 2017: U. Katz

Present members of GNN Board:

Paschal Coyle (CPPM, Marseille, France)
Zhan Djilkibaev (INR Moscow, Russia)
Grigorij Domogatsky (INR Moscow, Russia)
Darren Grant (University Alberta, Alberta, Canada)
Albrecht Karle (Univ. Wisconsin, Madison)
Uli Katz - chair (ECAP, Univ. Erlangen, Germany)
Antoine Kouchner (APC/University Paris, France)
Christian Spiering (DESY, Zeuthen, Germany)
Maurizio Spurio (Univ. Bologna/INFN, Bologna, Italy)
Mauro Taiuti (Univ. Genova/INFN, Genova, Italy)
Shigeru Yoshida (Chiba University, Chiba, Japan)

GNN activities

- Cooperative projects, e.g.
  - Common analyses
  - cross-checks of results with different systematics
  - coordination of alert and multi-messenger policies
  - exchange and mutual checks of software
  - standards for data representation
  - exchange of expertise through mutual working visits of scientists and engineers
- Topical workshops, e.g. MANTS meetings /VLVNT Workshops
- Annual award for an outstanding PhD thesis
- Monthly Newsletter ("GNN Monthly")

GNN activities

VLVνT (open) and MANTS (internal)

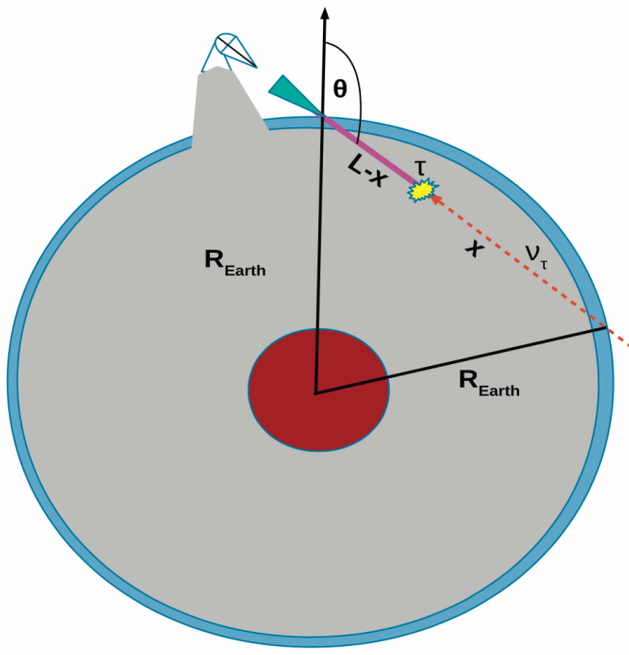
- Amsterdam 2003
- Catania 2005
- Toulon 2008
- Athens 2009
- Erlangen 2011
- Stockholm 2013
- Rome 2015
- Dubna 2018

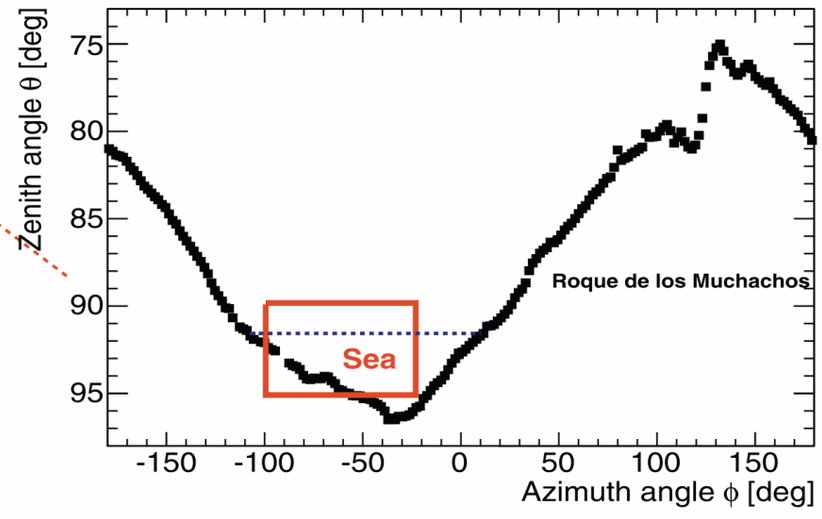
MANTS Meeting

"Mediterranean-Antarctic Neutrinos TelescopeS"

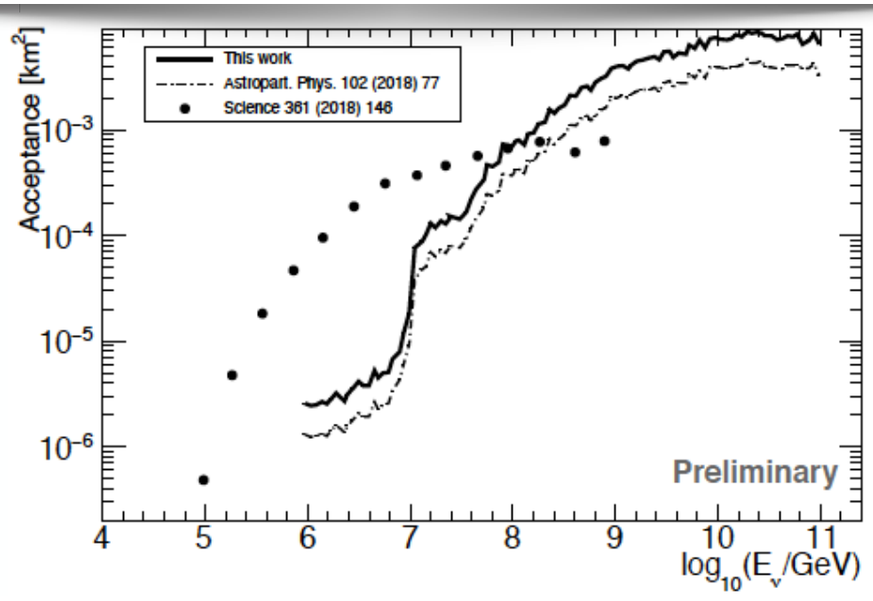
GNN internal workshop alternating with VLVνT

New techniques?





M.Mallamaci et al., PoS(ICRC2019)953



- Imaging Air Cherenkov Telescopes can look for tau induced showers from the sea/rock
- Sensitive to tau neutrinos of PeV-EeV energies
- Follow-ups implemented by MAGIC (M.Mallamaci et al., PoS(ICRC2019)953)
- Since 2019: automatic check for each IC alert, if visible in the Sea window in the next 7 days