Neutrino Telescopes: *Networking Initiatives*

Christian Spiering

XX International Workshop on Neutrino Telescopes

Venice, October 2023

Design Kirsty Pargeter

Basic Messages

- Diversity of tools and locations necessitates networking of neutrino telescopes
- Multimessenger character of sources necessitates multimessenger methods

Design Kirsty Pargeter

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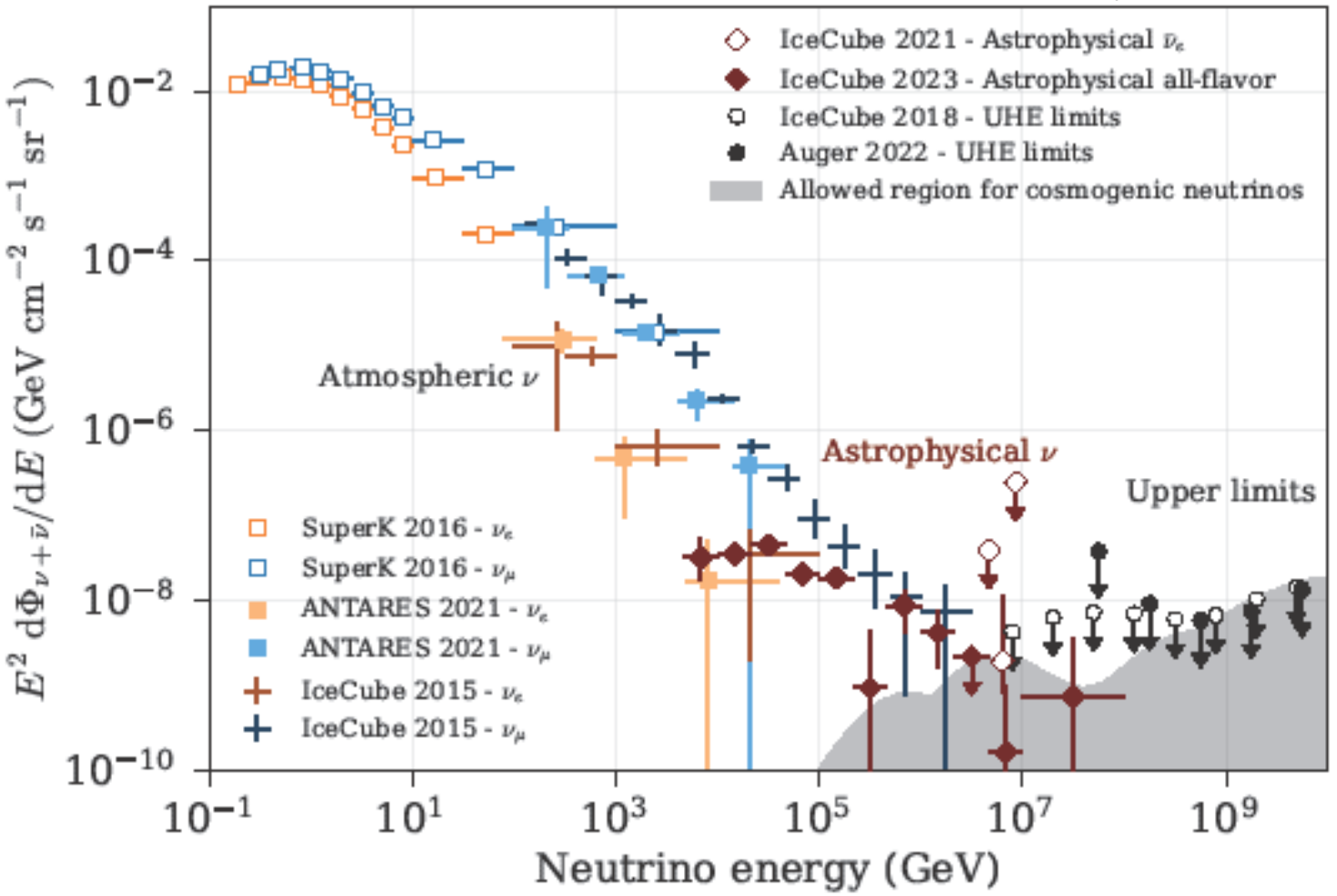
Design Kirsty Pargeter

Neutrino Telescopes: definition for this talk

- Energy ≥ GeV
  (with the exception of neutrinos from SN collapses)
- optical underwater/ice detectors
  (like the present members of the Global Neutrino Network: ANTARES, Baikal-GVD, IceCube, KM3NeT)
- radio ice detectors
- air shower detectors
- (very large underground detectors)

Ch. Haack/L. Schumacher



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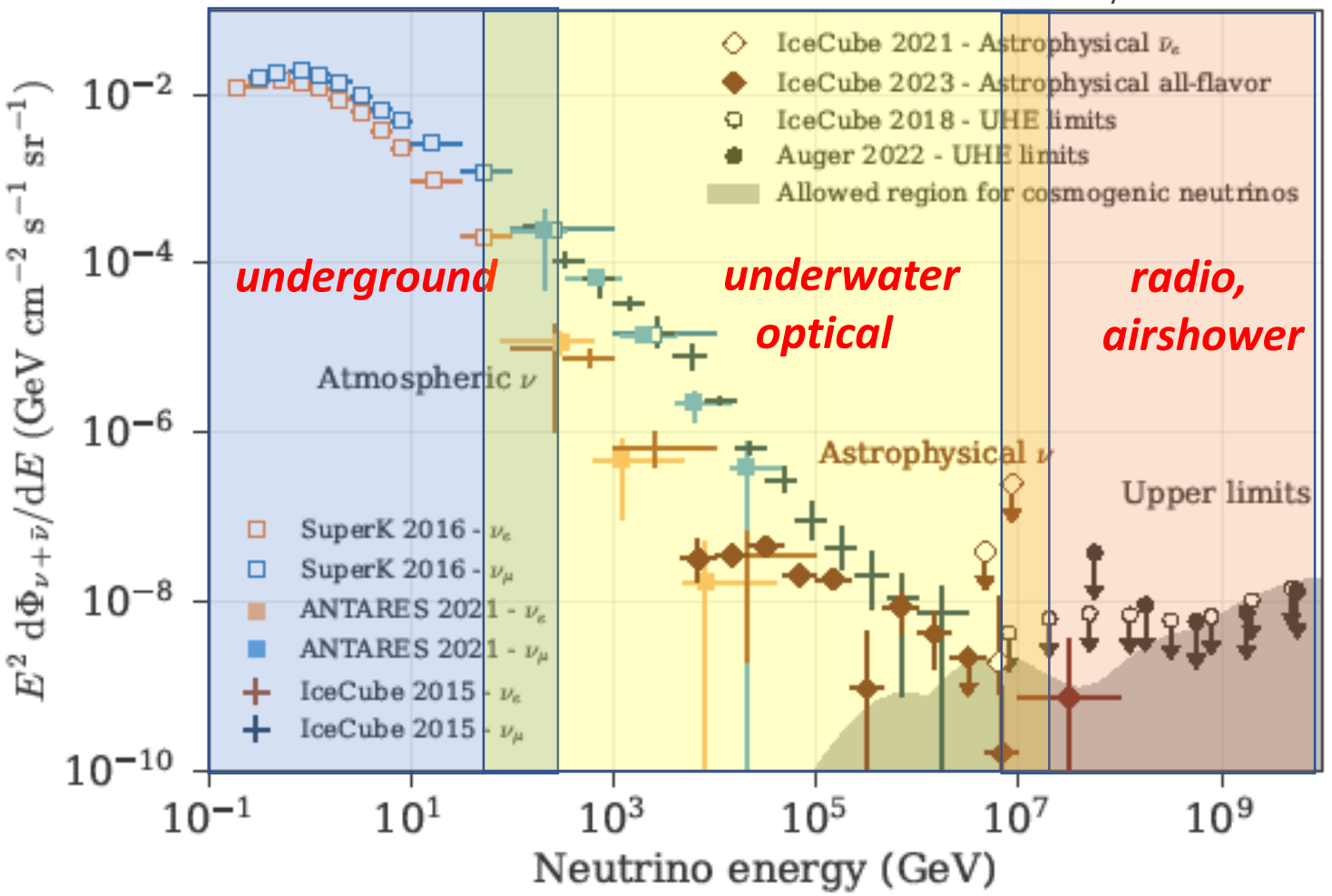

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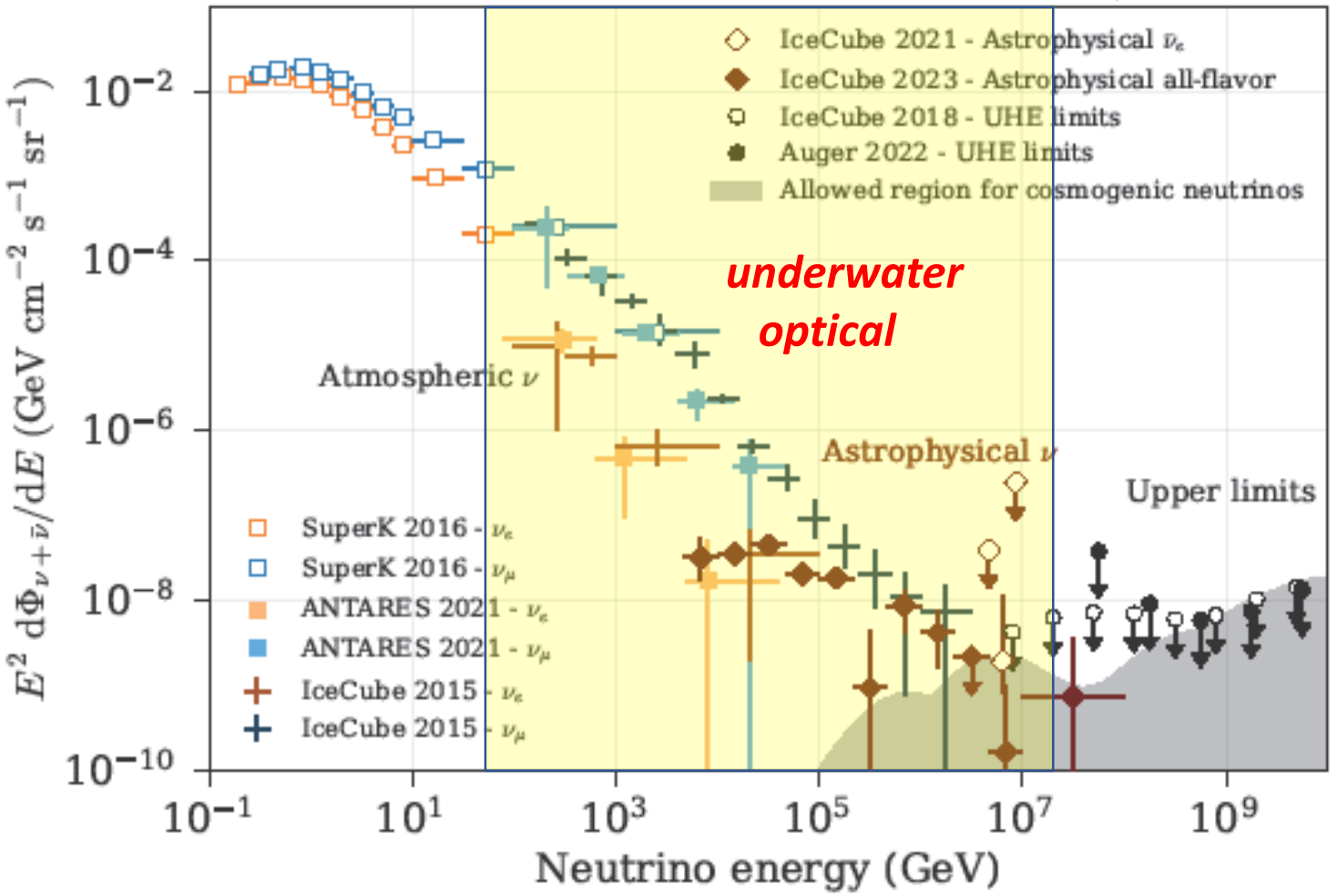


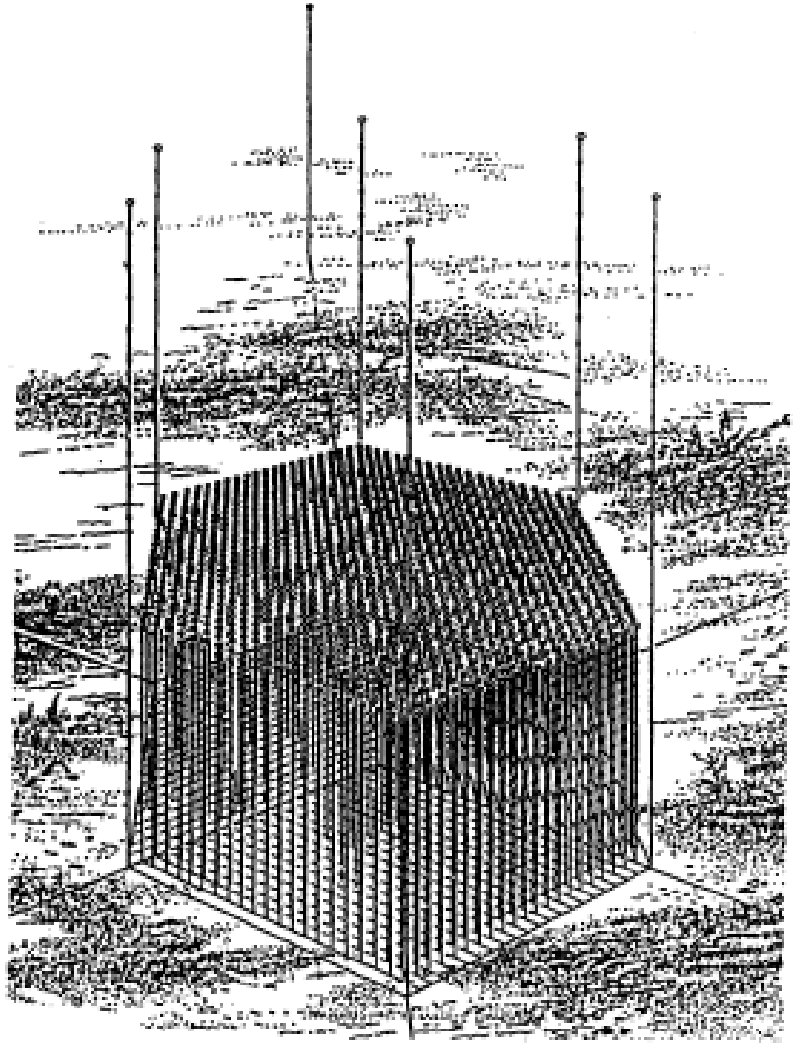
The case for a network

- You have partners to form a network

and you want:

- to define a common strategy
- or/and to exchange know-how (technology, software, …)
- or/and – if you have an *operating* detector – to combine data, exchange alerts etc.

Some history



1978

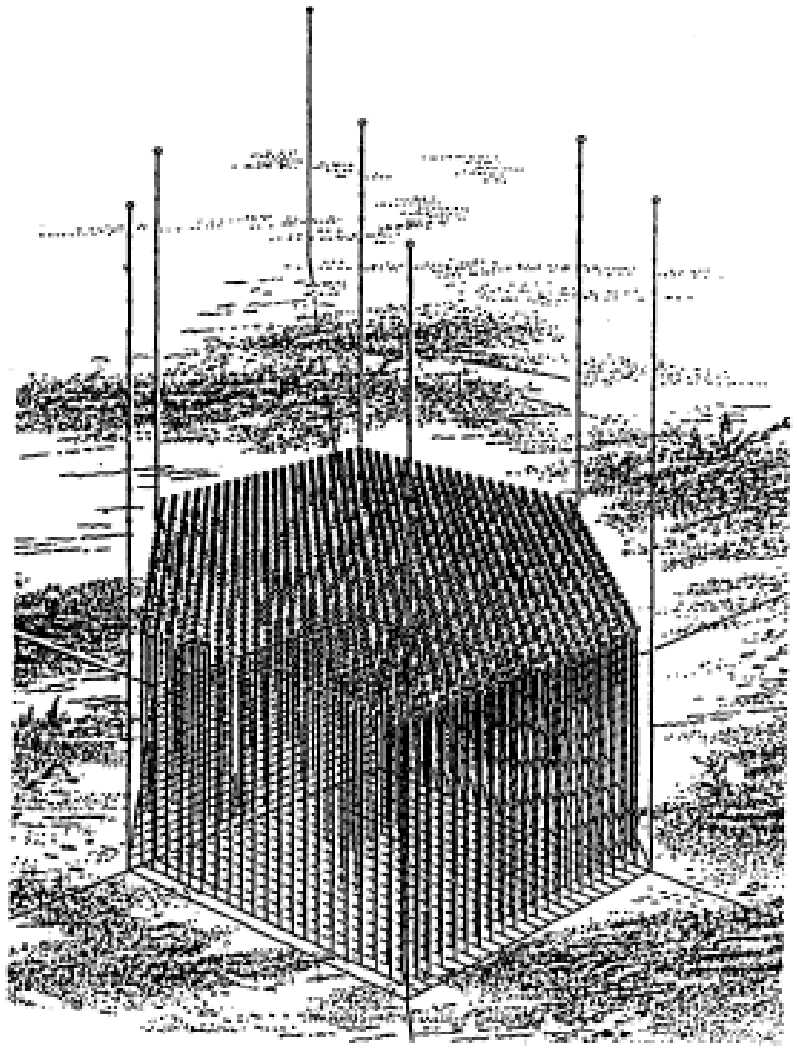
Plan to build a 1.26 km³ detector

DUMAND (Hawaii)

stepwise reduced design

terminated 1996

Some history



Start Construction

Completion

Termination

1993-1998-2010
NT200
Lake Baikal

1995-2000-2009
AMANDA
South Pole

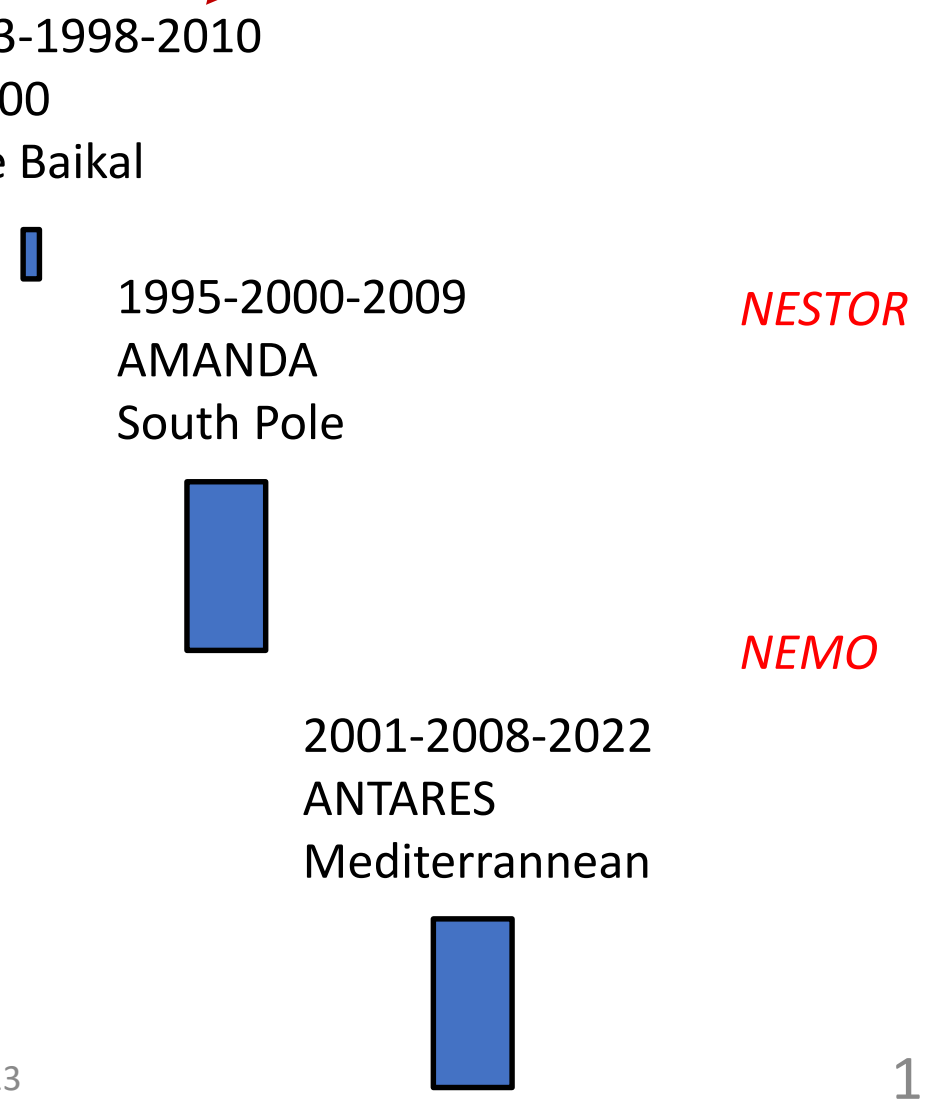
NESTOR

NEMO

2001-2008-2022
ANTARES
Mediterrannean

Some history

Amsterdam 2003
Catania 2005
Toulon 2008
Athens 2009
Erlangen 2011
Stockholm 2013
Rome 2015
Dubna 2018
Valencia 2022



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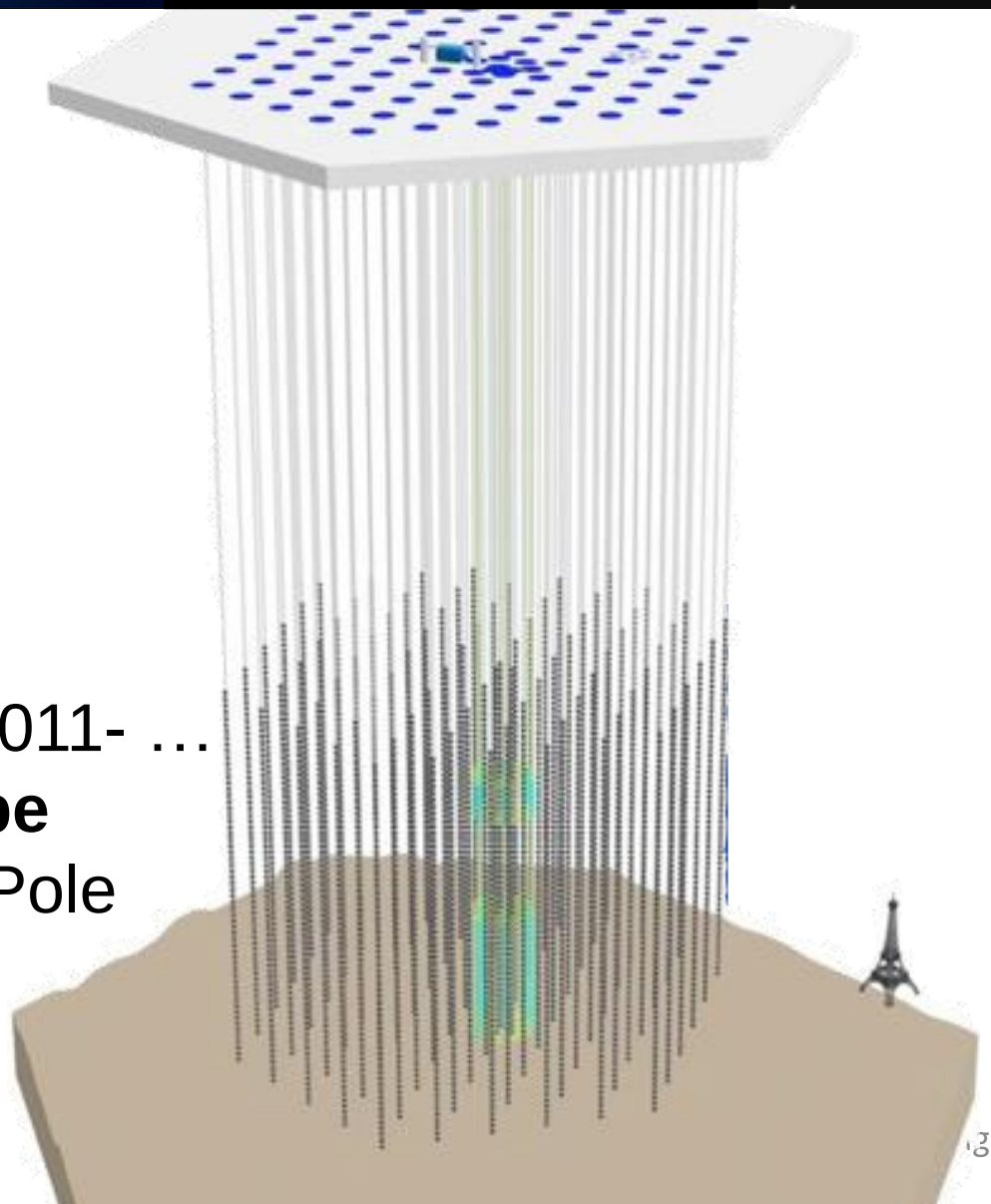

Some history

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2013: Global Neutrino Network GNN

MANTS Meeting

“Mediterranean-Antarctic Neutrinos TelescopeS”

GNN internal workshop alternating with VLVνT

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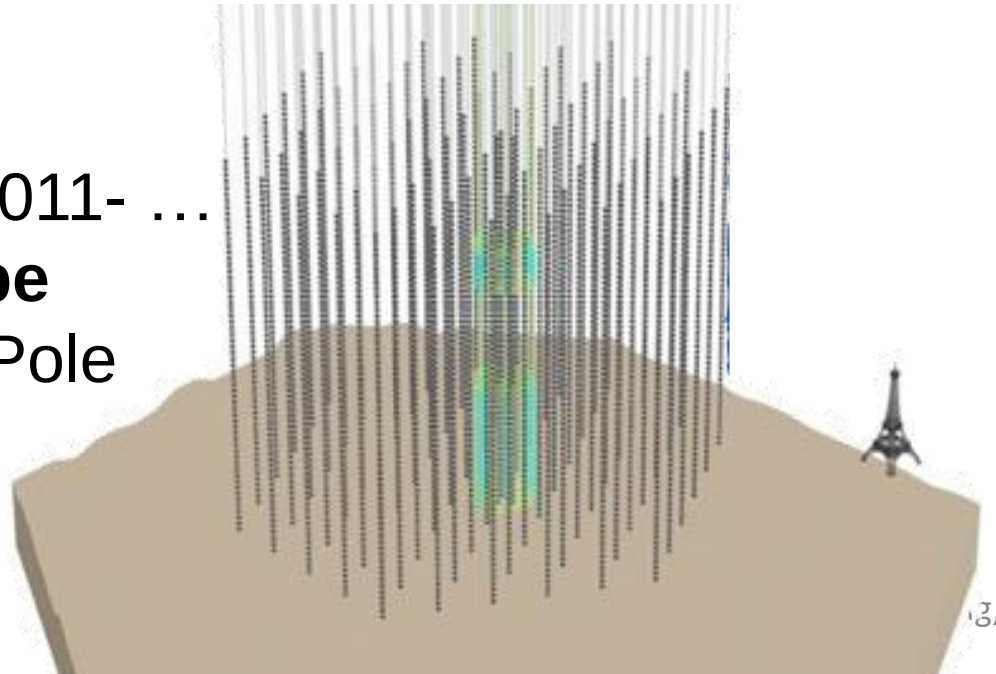
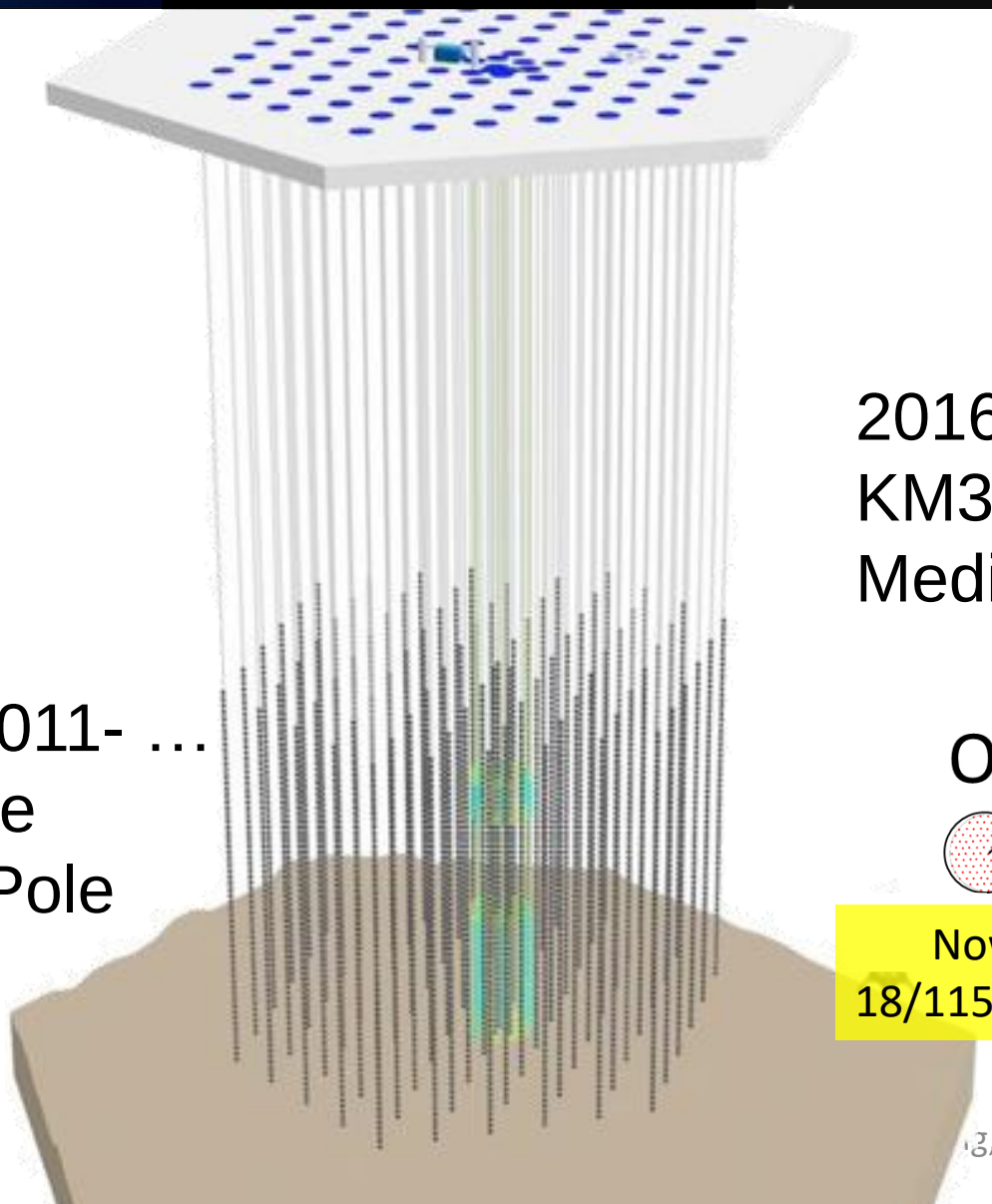
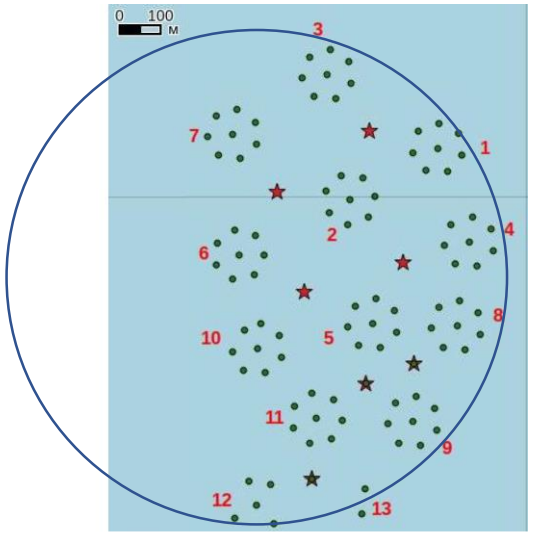


Operating neutrino telescopes 2023



2004-2011- …
IceCube
South Pole

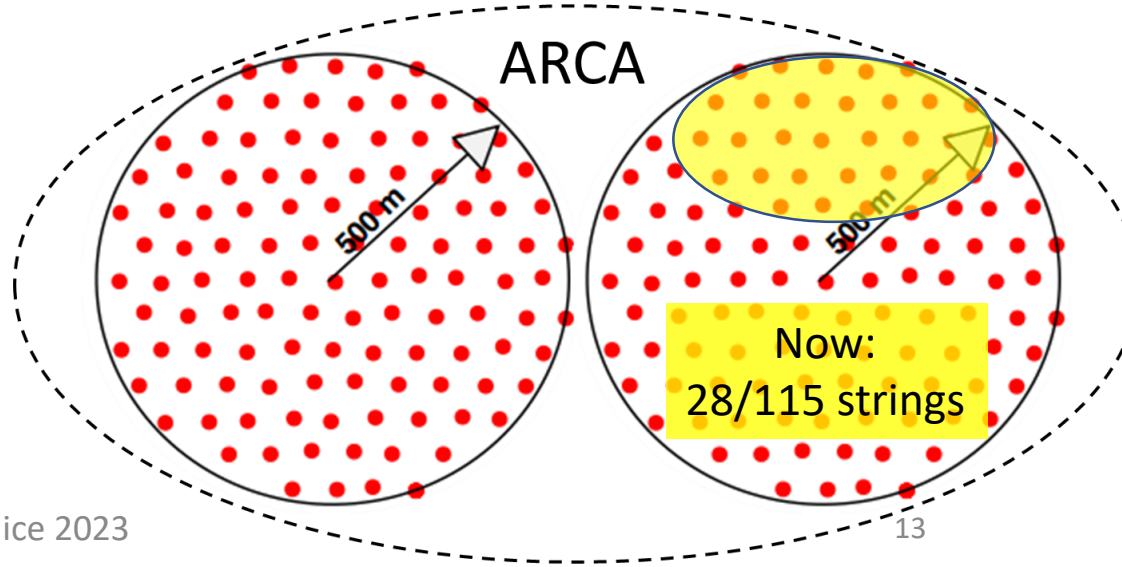
2015-2026- …
Baikal GVD
Now: 12 of 18 clusters



2016-(2026/27)- …
KM3NeT
Mediterranean Sea

ORCA

Now:
18/115 strings



Right time to take networking to a next level

- Baikal GVD and KM3NeT/ARCA are approaching the cubic kilometer scale
- With its superior pointing, KM3NeT/ARCA might soon achieve a similar sensitivity to point sources like IceCube.
- Field of views are overlapping → combine data!

GNN: basics

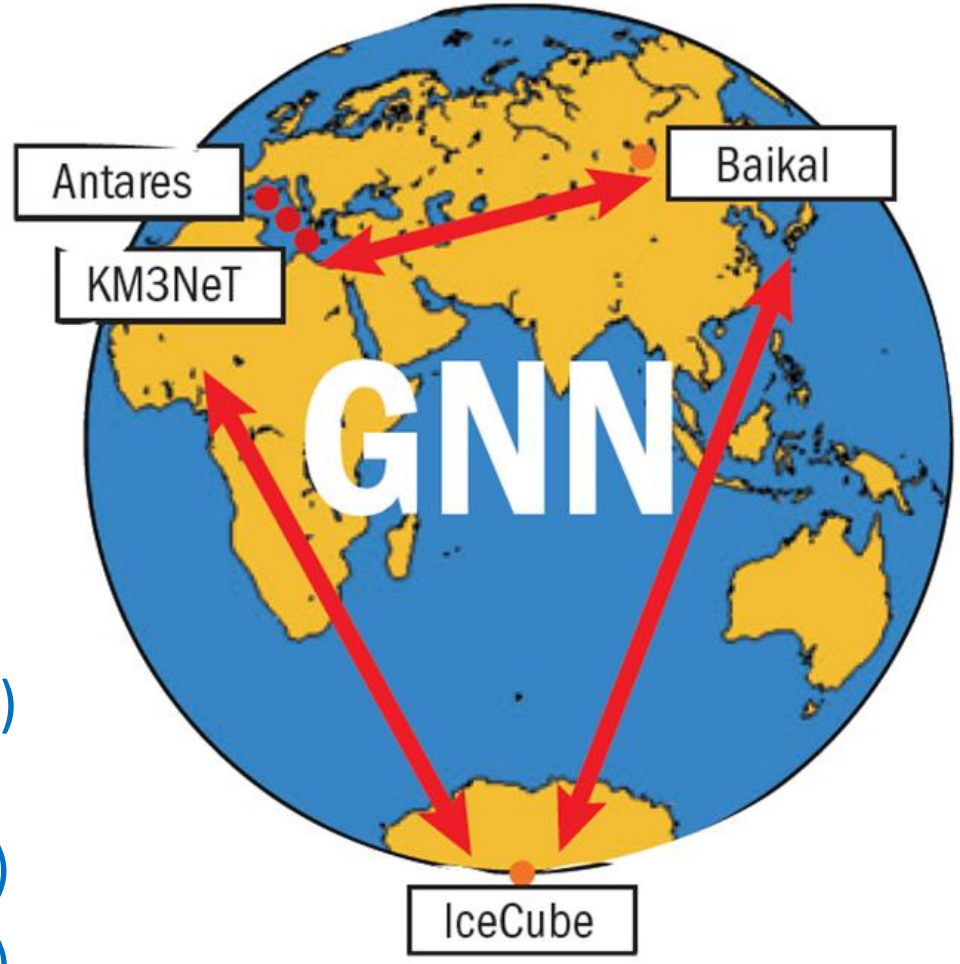
GNN
The Global Neutrino Network

Formed 2013:

- ANTARES
- Baikal
- IceCube
- KM3NeT

Chairs of the GNN Board:

- 2013-17: Christian Spiering (IceCube)
- 2017-22: Uli Katz (KM3NeT/ANTARES/IceCube)
- Since 2022: Greg Sullivan (IceCube)



https://www.globalneutrinonetwork.org/

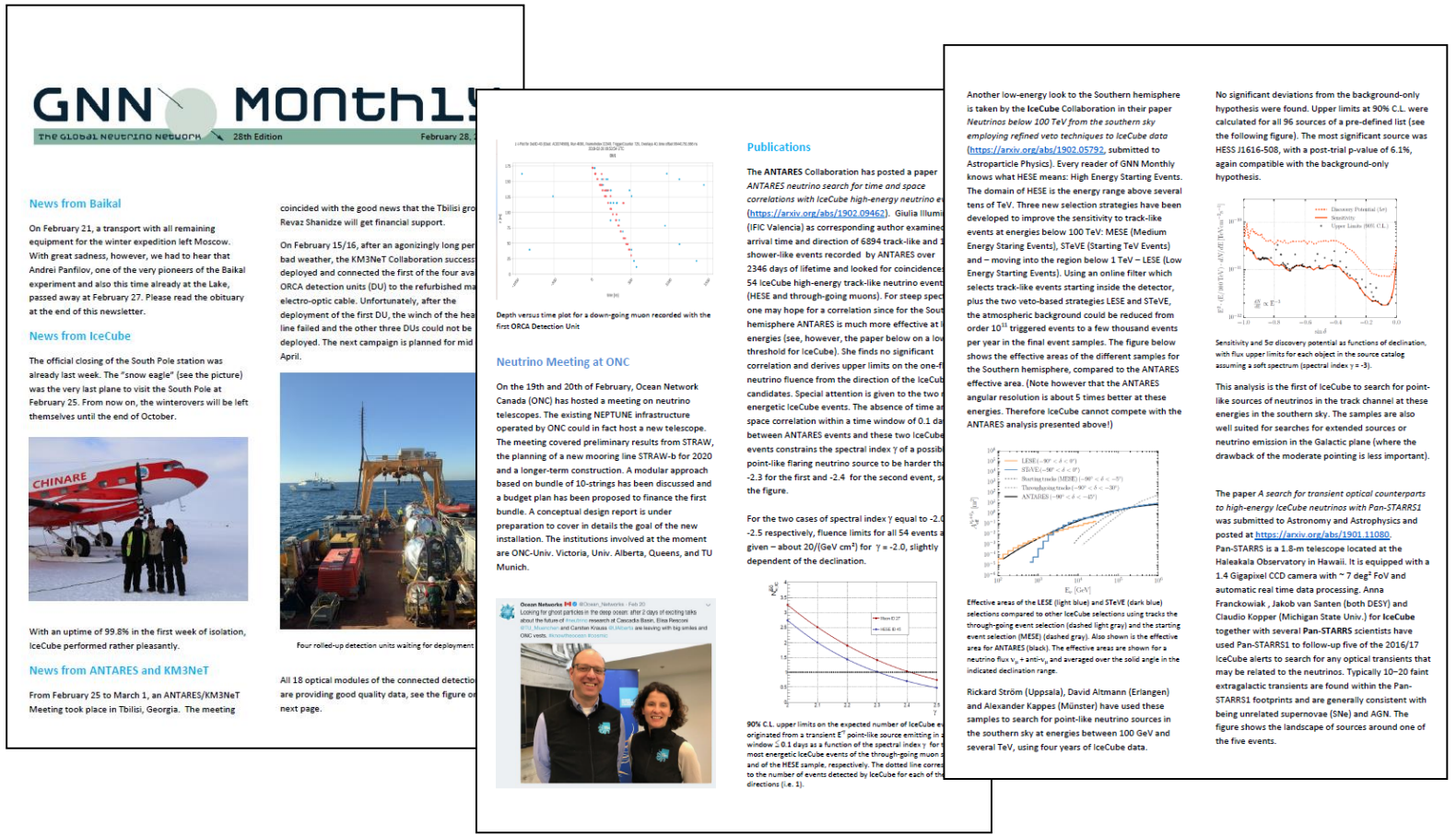
GNN: goals

- 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

GNN: goals

- 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 outstanding PhD thesis/theses
- Monthly Newsletter (“GNN Monthly”)

GNN: goals



GNN Monthly

The Global Neutrino Network — 28th Edition — February 28,

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Four rolled-up detection units waiting for deployment

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Effective areas of the LESE (light blue) and STeVE (dark blue) selections compared to other IceCube selections using tracks the through-going event selection (dashed light gray) and the starting event selection (MESE) (dashed gray). Also shown is the effective area for ANTARES (black). The effective areas are shown for a neutrino flux ν_μ + anti-ν_μ and averaged over the solid angle in the indicated declination range.

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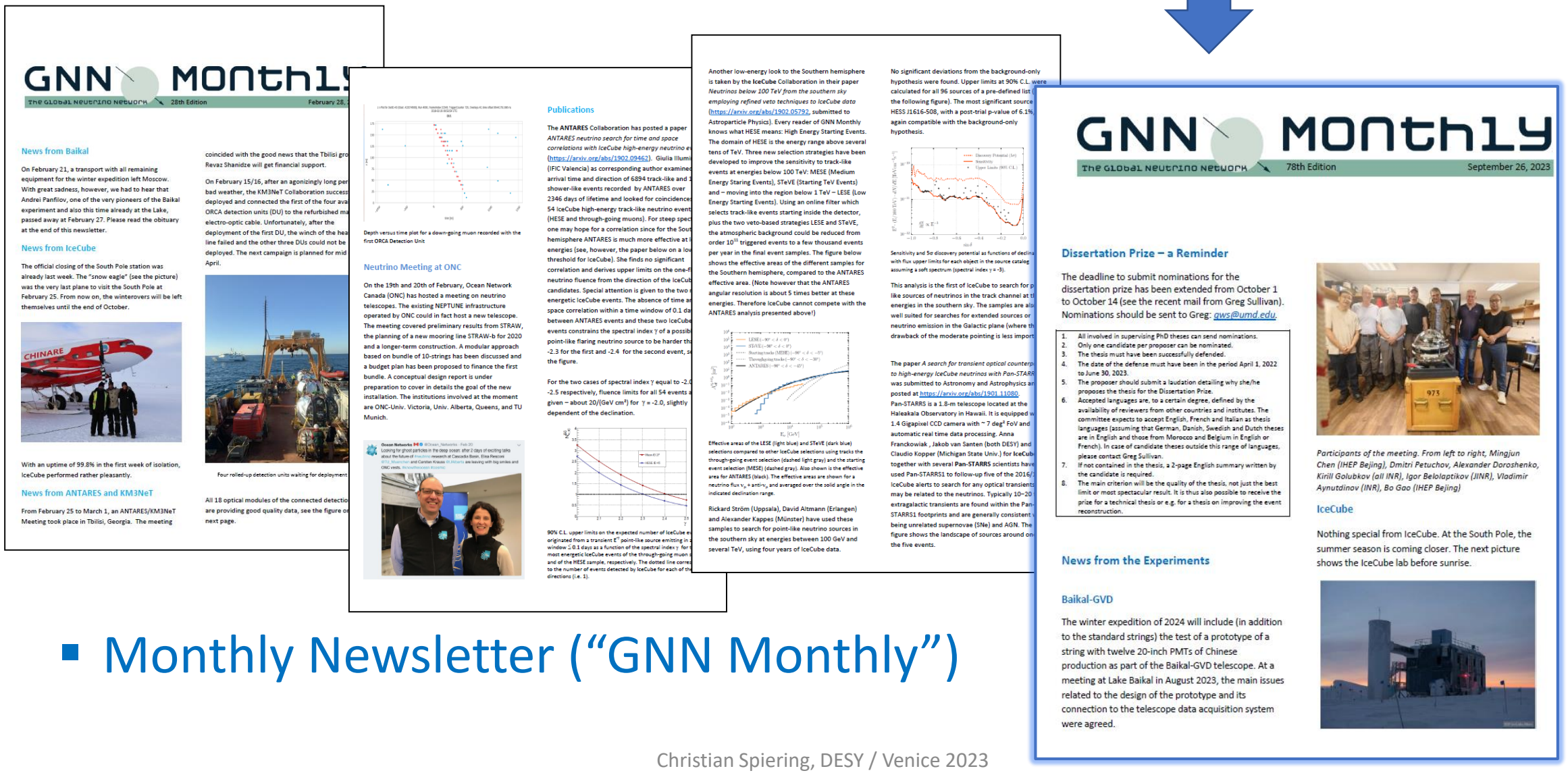
- Typically 5-6 pages
- News from the GNN partner experiments
- GNN Matters
- Calls, Prizes, Obituaries, …
- Summaries of recent publications of the four Collaborations

- Monthly Newsletter (“GNN Monthly”)

GNN: goals

September 2023
78th edition



GNN MONTHLY
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The Global Neutrino Network — 78th Edition — September 26, 2023

Dissertation Prize – a Reminder

The deadline to submit nominations for the dissertation prize has been extended from October 1 to October 14 (see the recent mail from Greg Sullivan). Nominations should be sent to Greg: gws@umd.edu.

1. All involved in supervising PhD theses can send nominations.
2. Only one candidate per proposer can be nominated.
3. The thesis must have been successfully defended.
4. The date of the defense must have been in the period April 1, 2022 to June 30, 2023.
5. The proposer should submit a laudation detailing why she/he proposes the thesis for the Dissertation Prize.
6. Accepted languages are, to a certain degree, defined by the availability of reviewers from other countries and institutes. The committee expects to accept English, French and Italian as thesis languages (assuming that German, Danish, Swedish and Dutch theses are in English and those from Morocco and Belgium in English or French). In case of candidate theses outside this range of languages, please contact Greg Sullivan.
7. If not contained in the thesis, a 2-page English summary written by the candidate is required.
8. The main criterion will be the quality of the thesis, not just the best limit or most spectacular result. It is thus also possible to receive the prize for a technical thesis or e.g. for a thesis on improving the event reconstruction.

News from the Experiments

Baikal-GVD

The winter expedition of 2024 will include (in addition to the standard strings) the test of a prototype of a string with twelve 20-inch PMTs of Chinese production as part of the Baikal-GVD telescope. At a meeting at Lake Baikal in August 2023, the main issues related to the design of the prototype and its connection to the telescope data acquisition system were agreed.

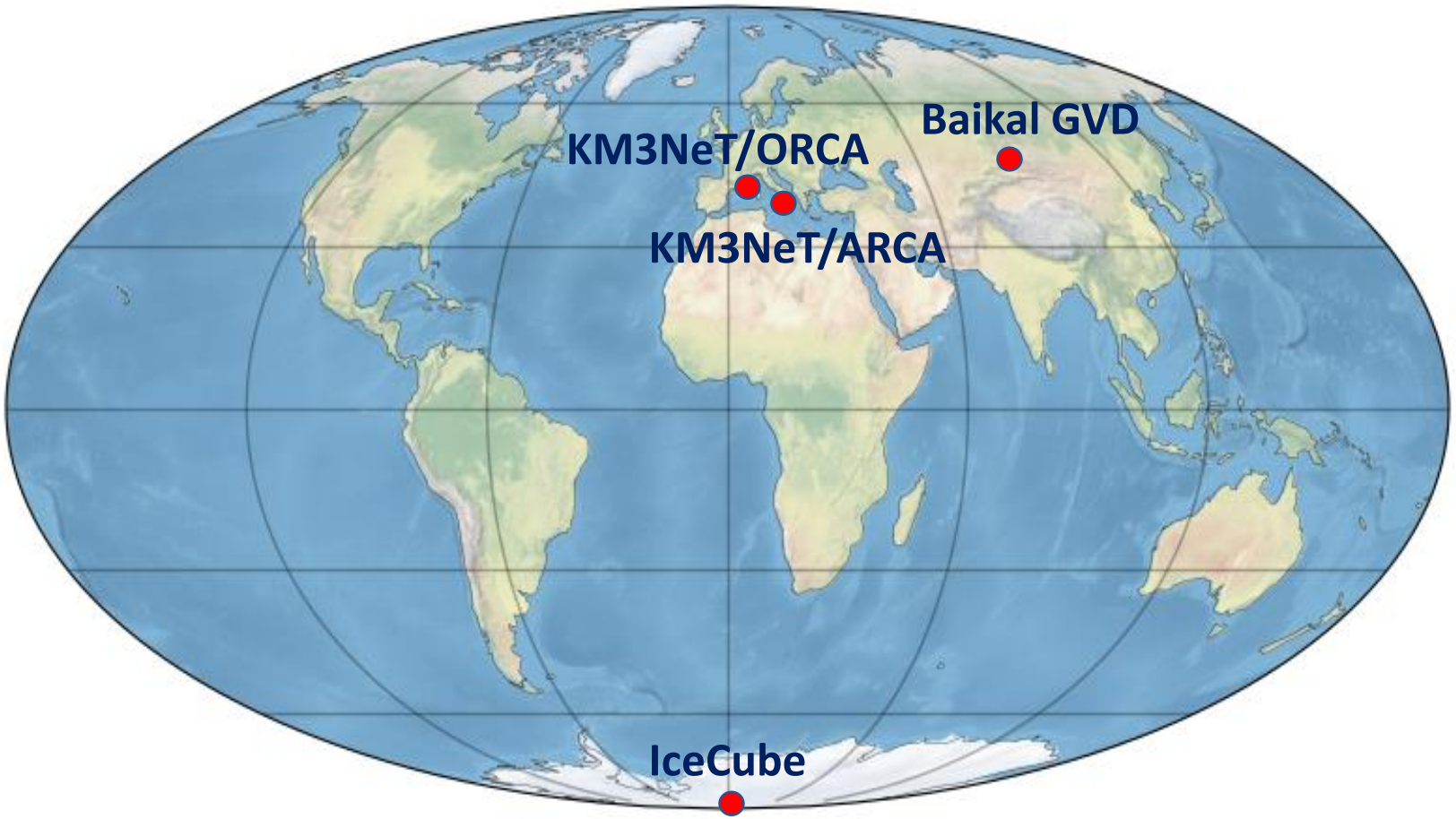
Participants of the meeting. From left to right, Mingjun Chen (IHEP Bejing), Dmitri Petuchov, Alexander Doroshenko, Kirill Golubkov (all INR), Igor Belolaptikov (JINR), Vladimir Aynutdinov (INR), Bo Gao (IHEP Bejing)

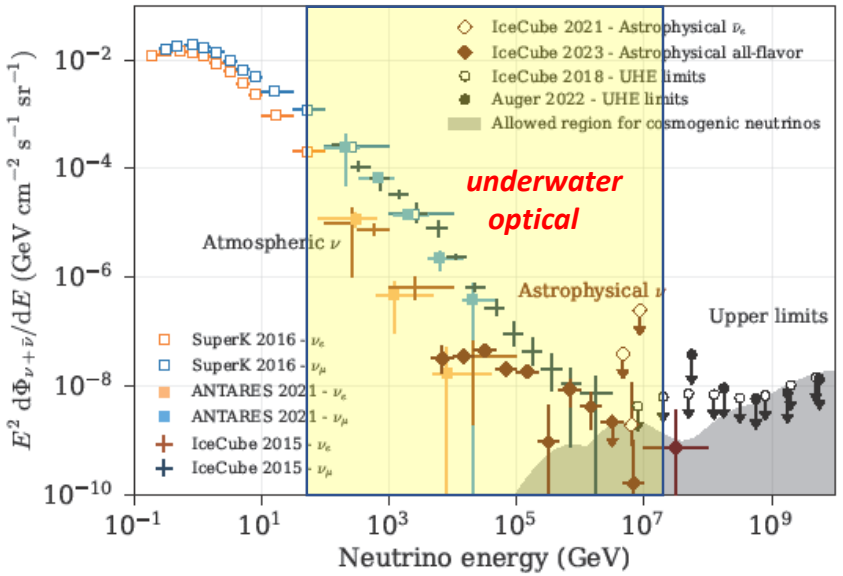
IceCube

Nothing special from IceCube. At the South Pole, the summer season is coming closer. The next picture shows the IceCube lab before sunrise.

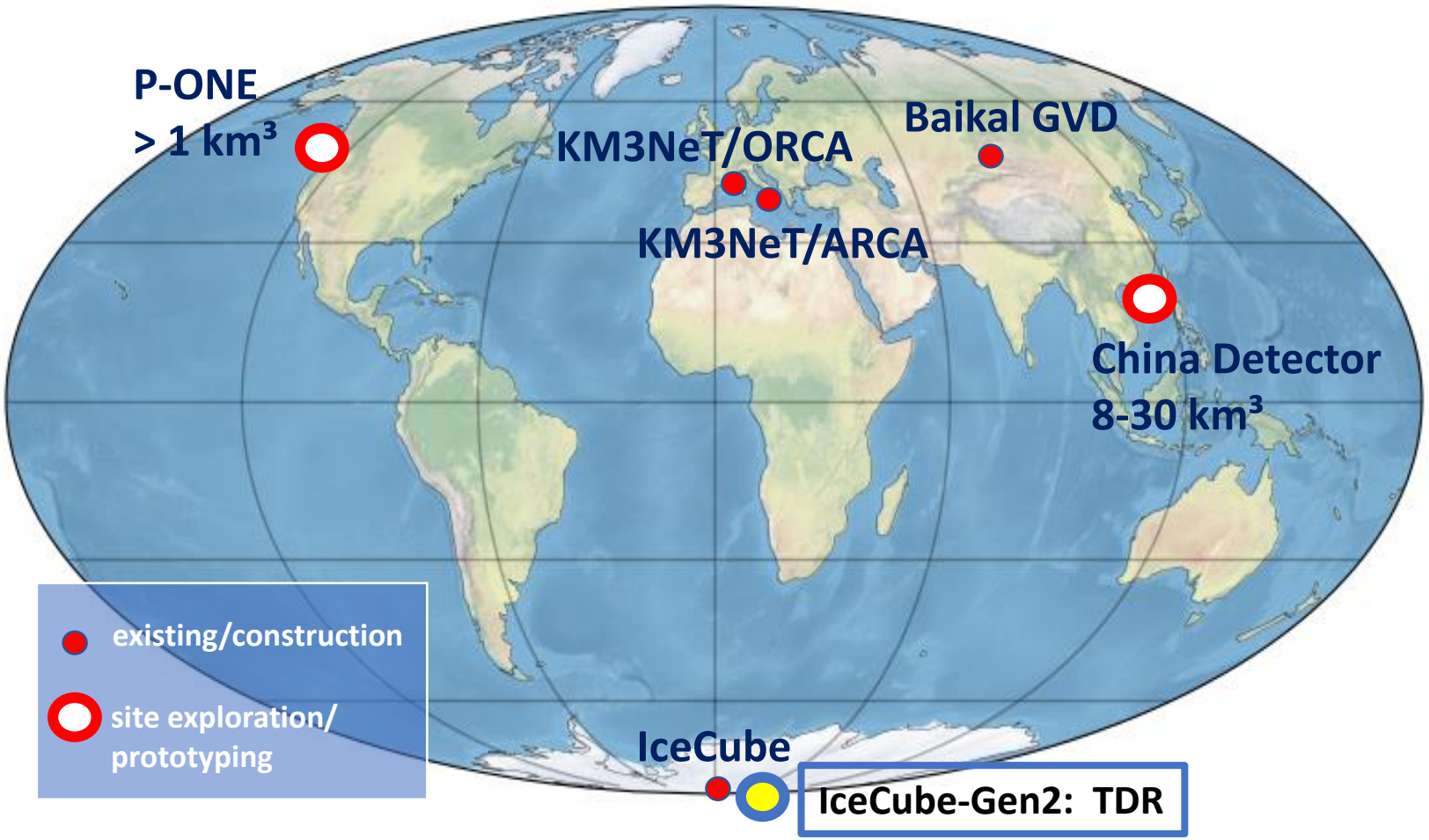
- Monthly Newsletter ("GNN Monthly")

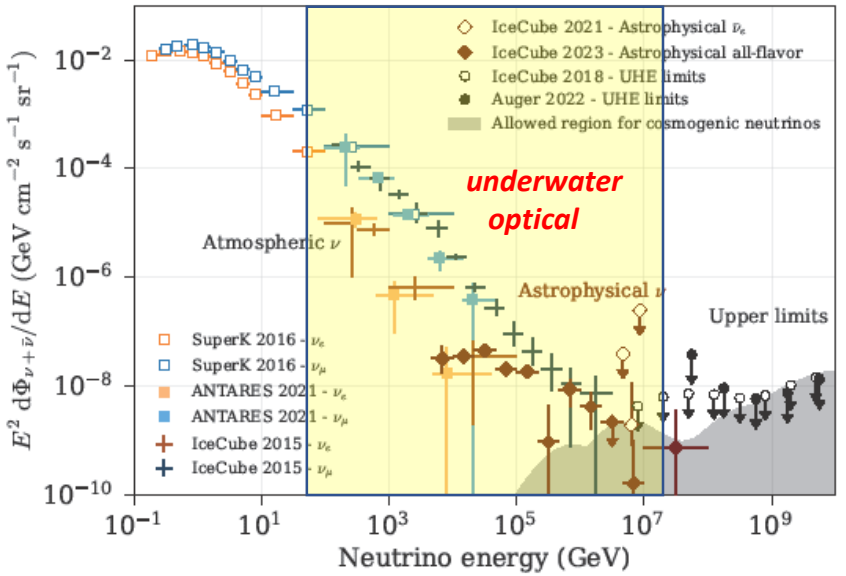
Neutrino Telescopes: present players





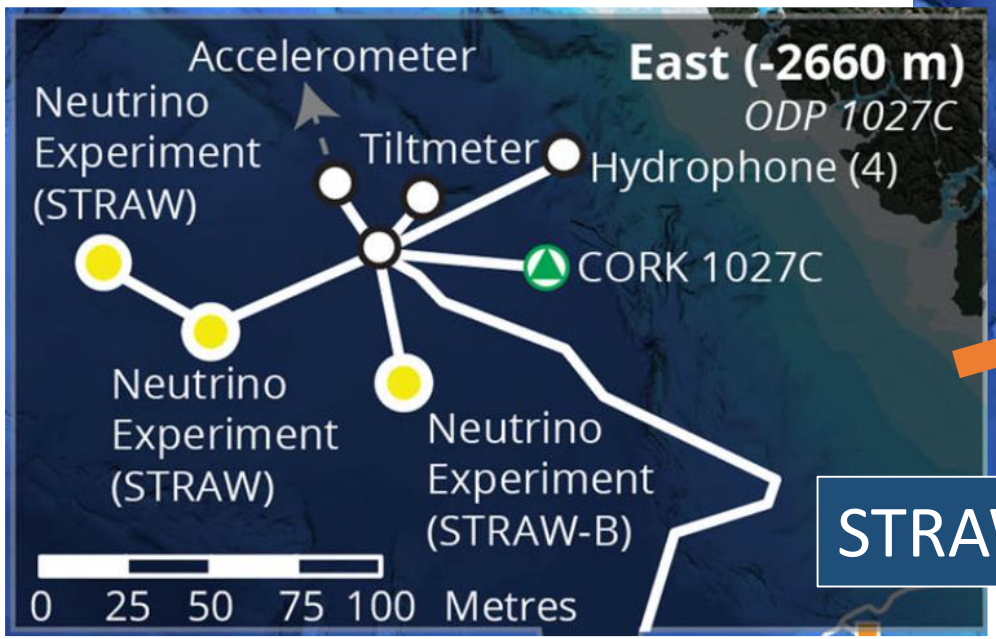
Neutrino Telescopes: present plus new players

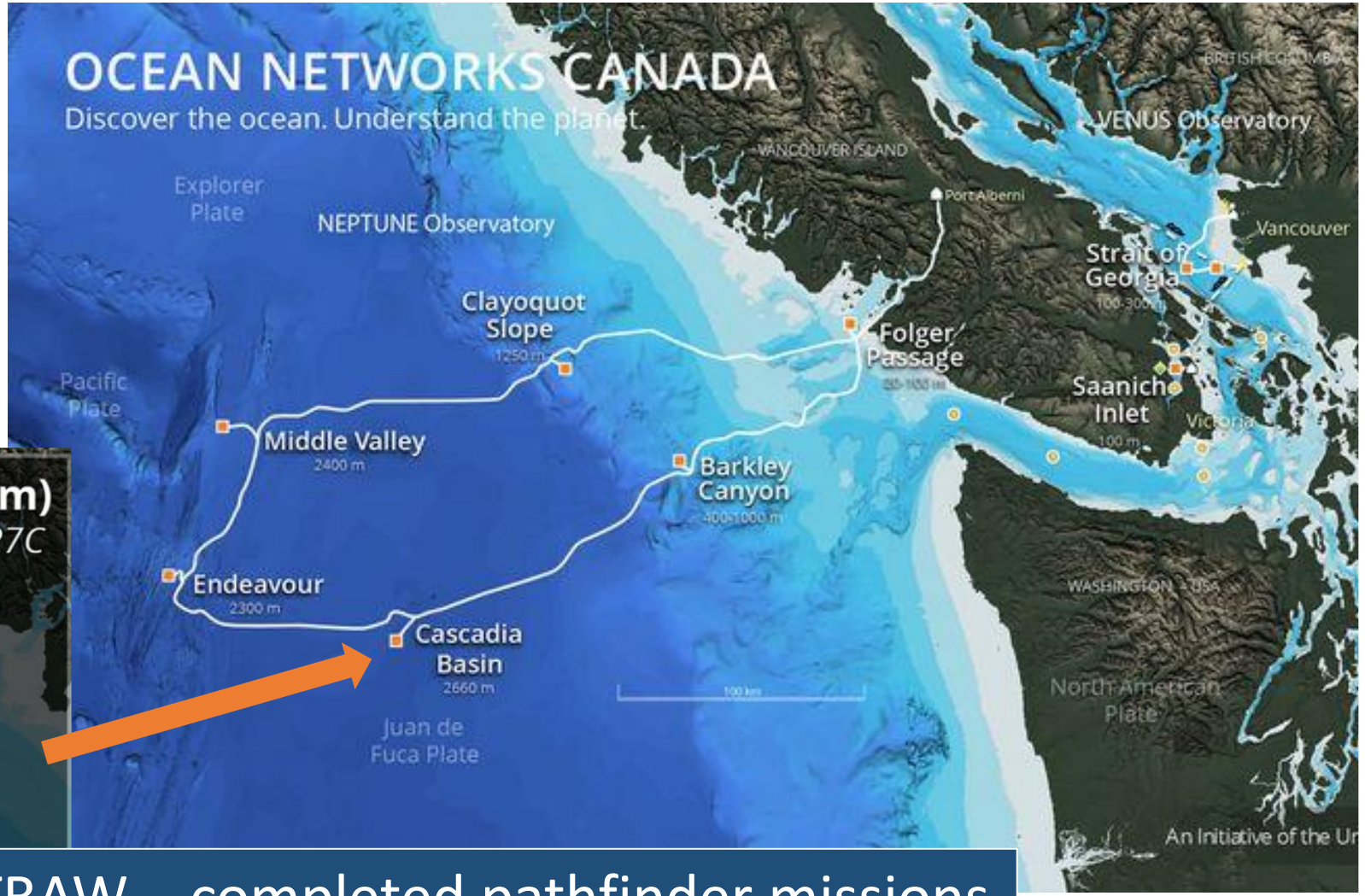




P-ONE (Pacific Ocean Neutrino Experiment)

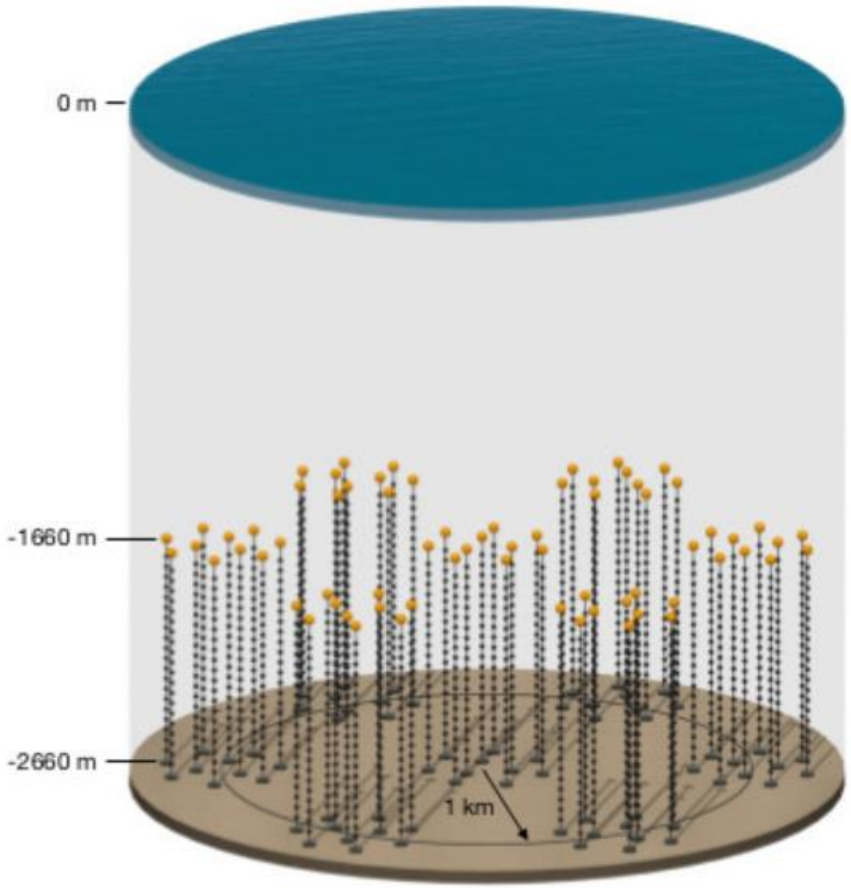
- Prototyping and R&D phase
- Pacific Ocean near Vancouver
- Depth 2600 m
- Interface, anchoring and deployment operation by ONC (Ocean Network Canada)

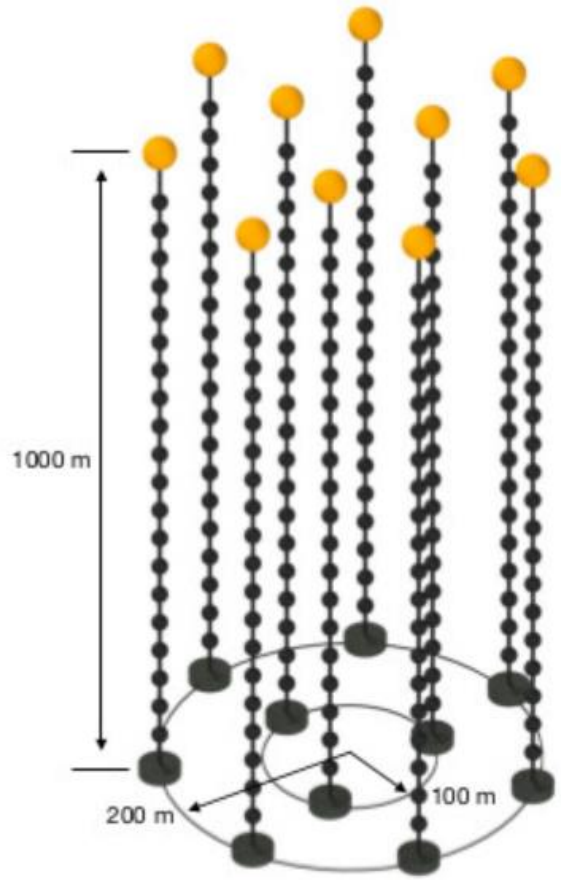




STRAW – completed pathfinder missions

P-ONE (Pacific Ocean Neutrino Experiment)





- **Conceptual Design:**

  7 clusters x 10 strings x 20 DOMs (total: 70 strings, 1400 sensors)

- Attenuation length at 450 nm ~28m

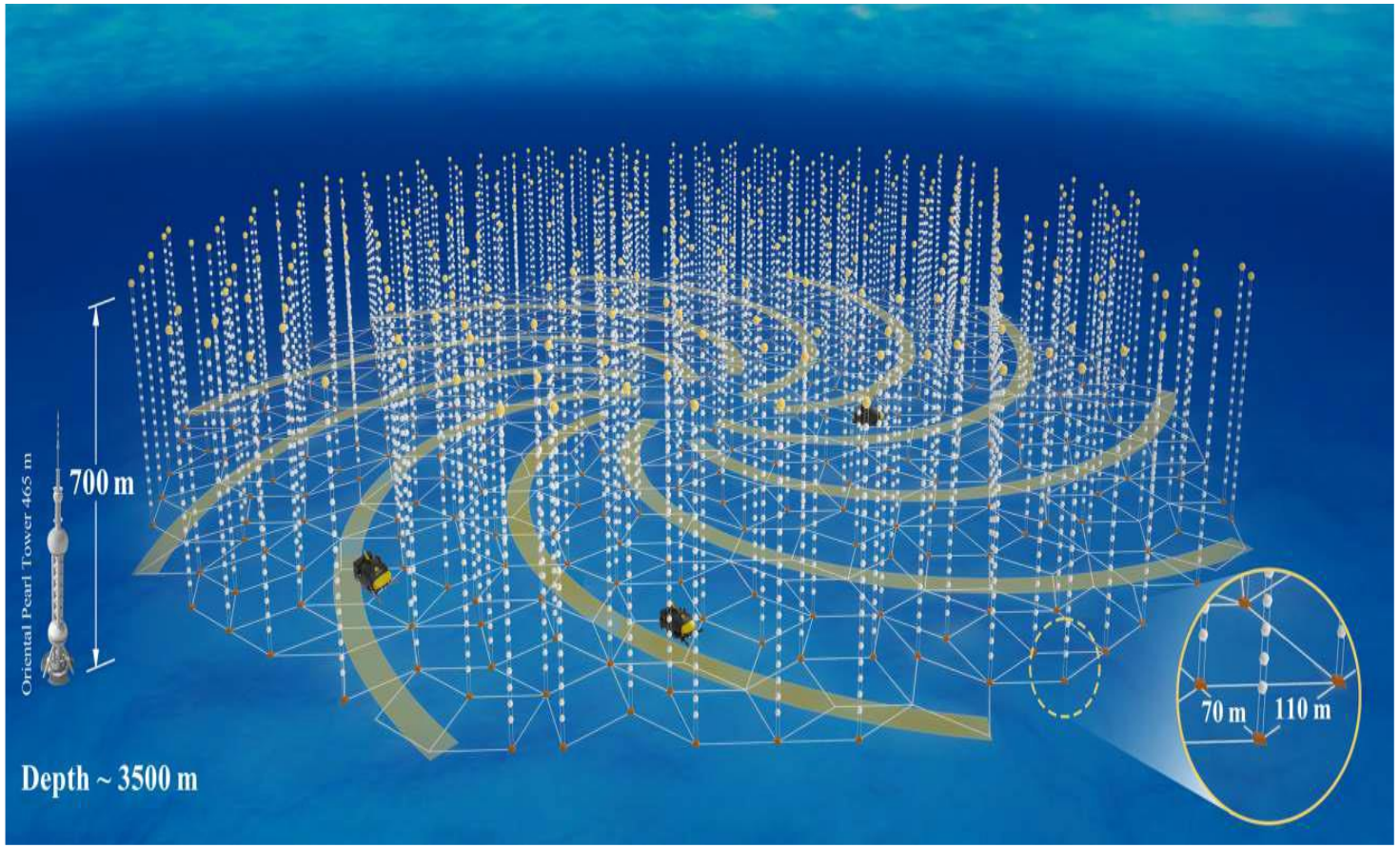
- 2024/25:

  P-ONE-1 - one single string

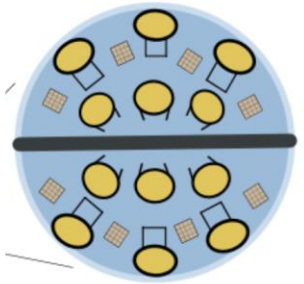
- 2025-27:

  P-ONE demonstration cluster (5 strings)

Chinese Detector Plans: TRIDENT



- **Conceptual Design:**
  1211 strings each with
  30 multi-PMT DOMs

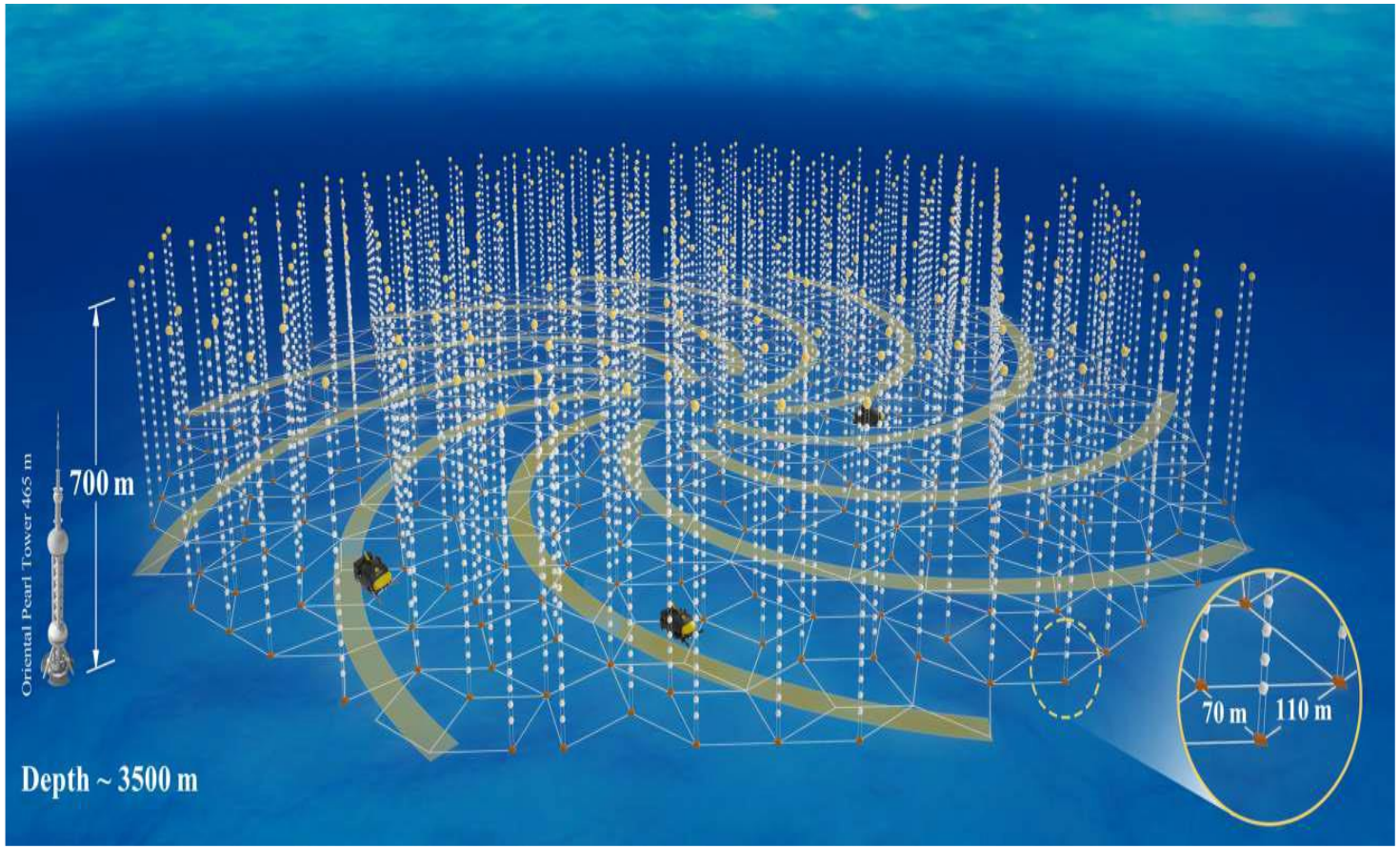


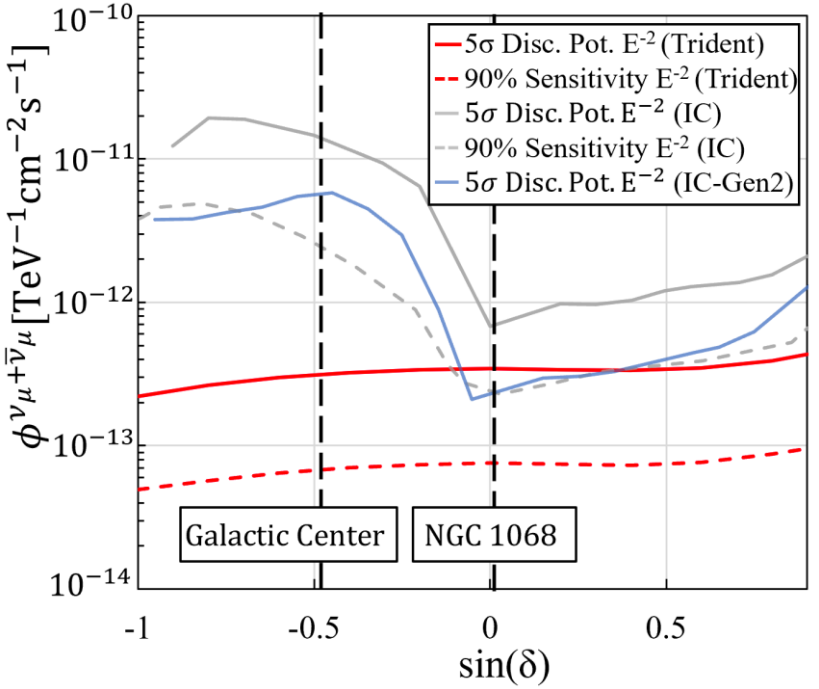
- **Volume: 7.5 km³** (~10 km² diameter and 750 m height)
- Location: South China Sea
- Depth: 3475m
- Attenuation length: 20-30 m

Started building 10 strings and seafloor cabling system (2022-2026)

See talk of Donglian Xu

Chinese Detector Plans: TRIDENT





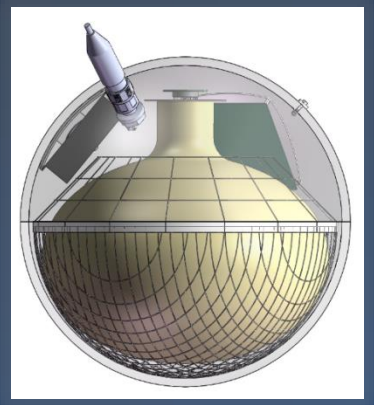
- Location: South China Sea

Almost balanced coverage on both hemispheres

Started building 10 strings and seafloor cabling system (2022-2026)

Chinese Detector Plans: HUNT

Optical Modules (OMs)
- 20-inch PMT
- 2,304 strings of OMs
- 55,296 OMs in total



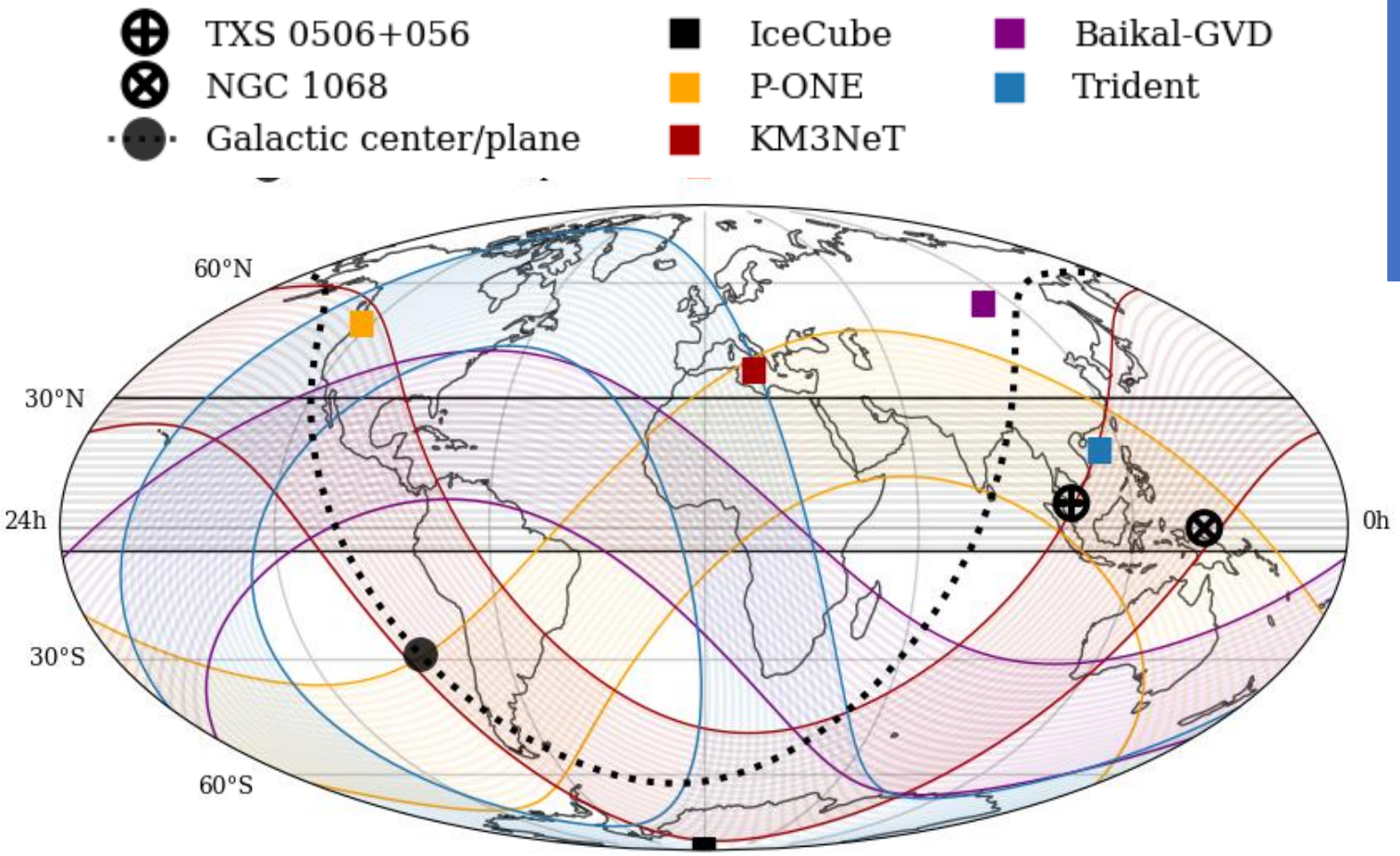
First pathfinder mission in China accomplished

Prototype string to be deployed in Lake Baikal (next spring)

30 km³

Two locations considered:
South China Sea or Lake Baikal

Neutrino Telescopes: fields of view*



Lisa Schumacher, PLEνM

At any time, ~80% of the sky is in the field of view of at least one neutrino telescope.
(for ν energies ≤ 100 TeV even more)

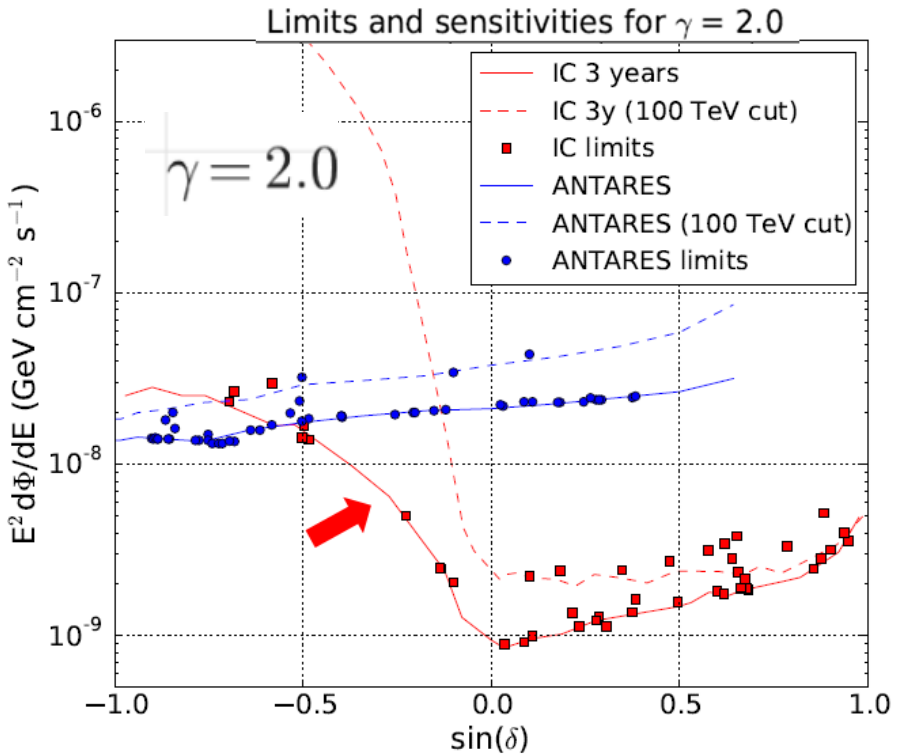
See
TOWARDS A PLANETARY NEUTRINO MONITORING SYSTEM
E. Resconi, Venice 2019
and
PLEνM: A global and distributed monitoring system of high-energy astrophysical neutrinos
L. Schumacher et al., PoS (ICRC2021) 1185

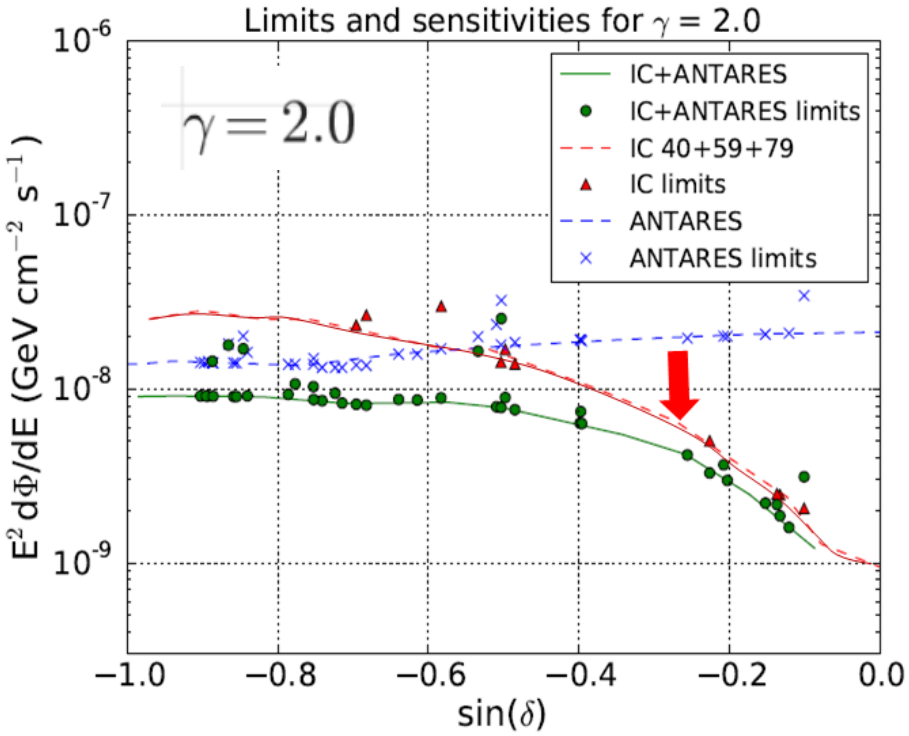
* bands cover a zenith region between 5° above and 30° below horizon
[transmission of Earth at 30° b.h.: ~ 80% for 100 TeV, 40% for 1 PeV]

Combining skymaps: 2016

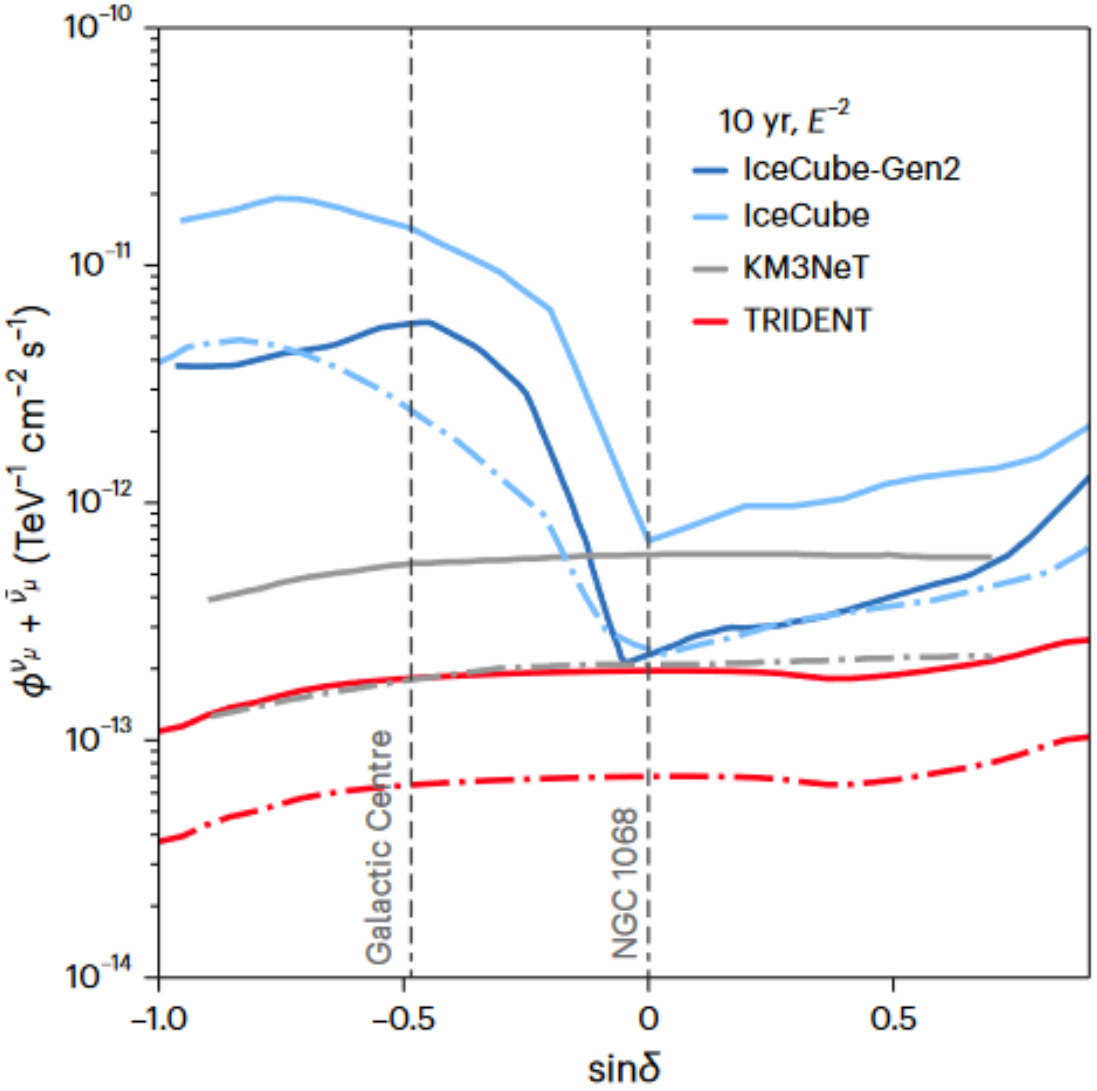
First combined search for neutrino point-sources in the Southern Hemisphere with the ANTARES and IceCube neutrino telescopes

Astrophys. J. 823:65,2016





Sky Coverage with 1-km³ and 8-km³ detectors



All-sky point source
90% CL median sensitivity (dashed dot lines)
and 5σ discovery potential (solid lines)

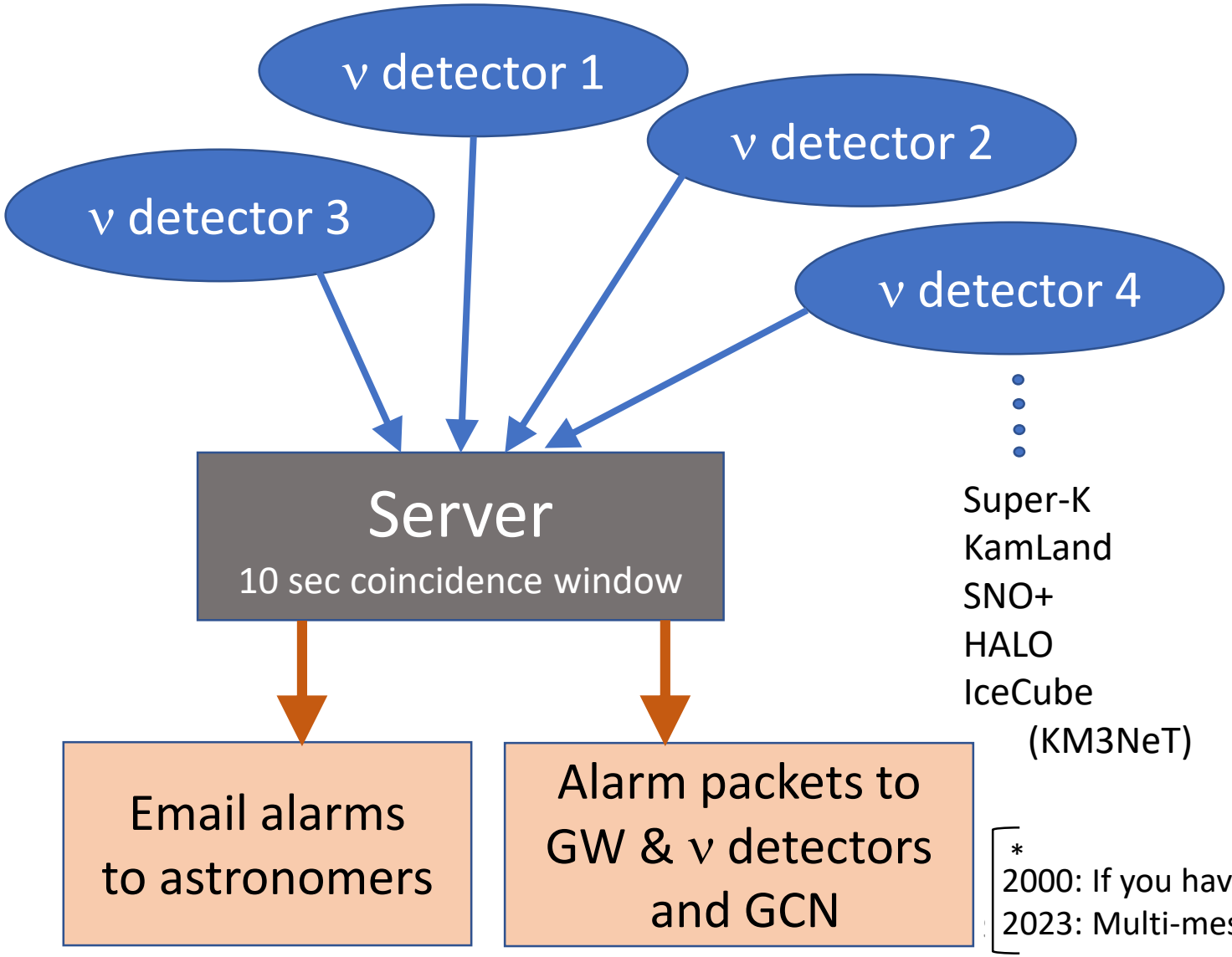
taken from Z.P. Ye et al. (TRIDENT Coll.)
Nature Astronomy, Oct. 9, 2023

Basic Message 2

- Multimessenger character of sources necessitates multimessenger methods
  - SNEWS: catching supernovae
  - AMON: discovering transient multimessenger sources
  - ν alerts: IceCube and ANTARES
  - Follow-ups with neutrinos

Design Kirsty Pargeter

SNEWS: SuperNova Early Warning Network



Test mode since 2001

Fully operational since 2005

Goals

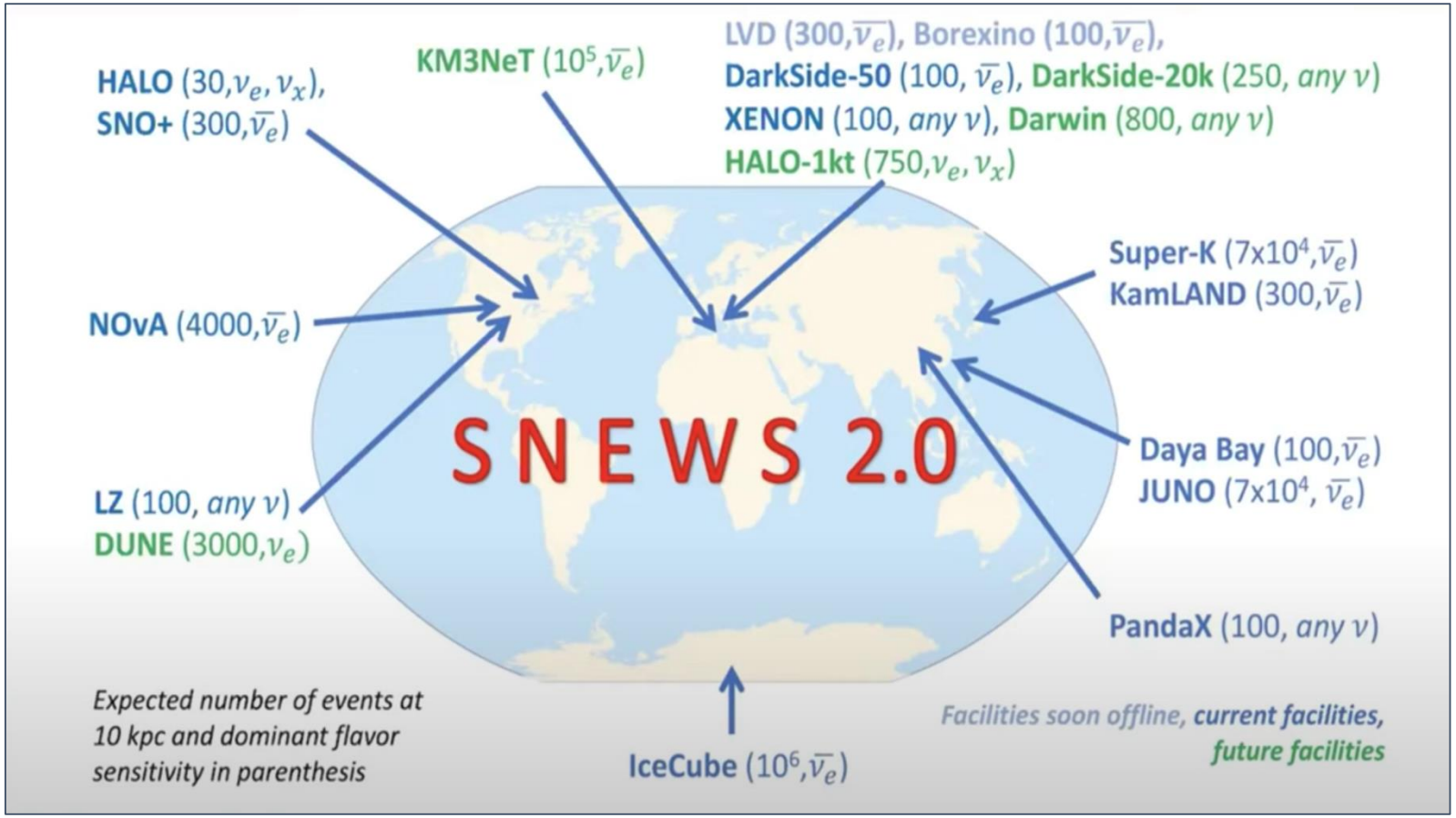
- Enable optical observation of the early phase just after shockwave breakout
- Pointing via triangulation

Requirements 2001:

- Prompt (≤ hours)
- False alarms < 1/century *

* 2000: If you have even one false alarm, no one will ever believe you again.
2023: Multi-messenger astronomy generates oodles of alerts, no problem

SNEWS: SuperNova Early Warning Network



Habig & Scholberg, Nature Review Physics 2 (2020),

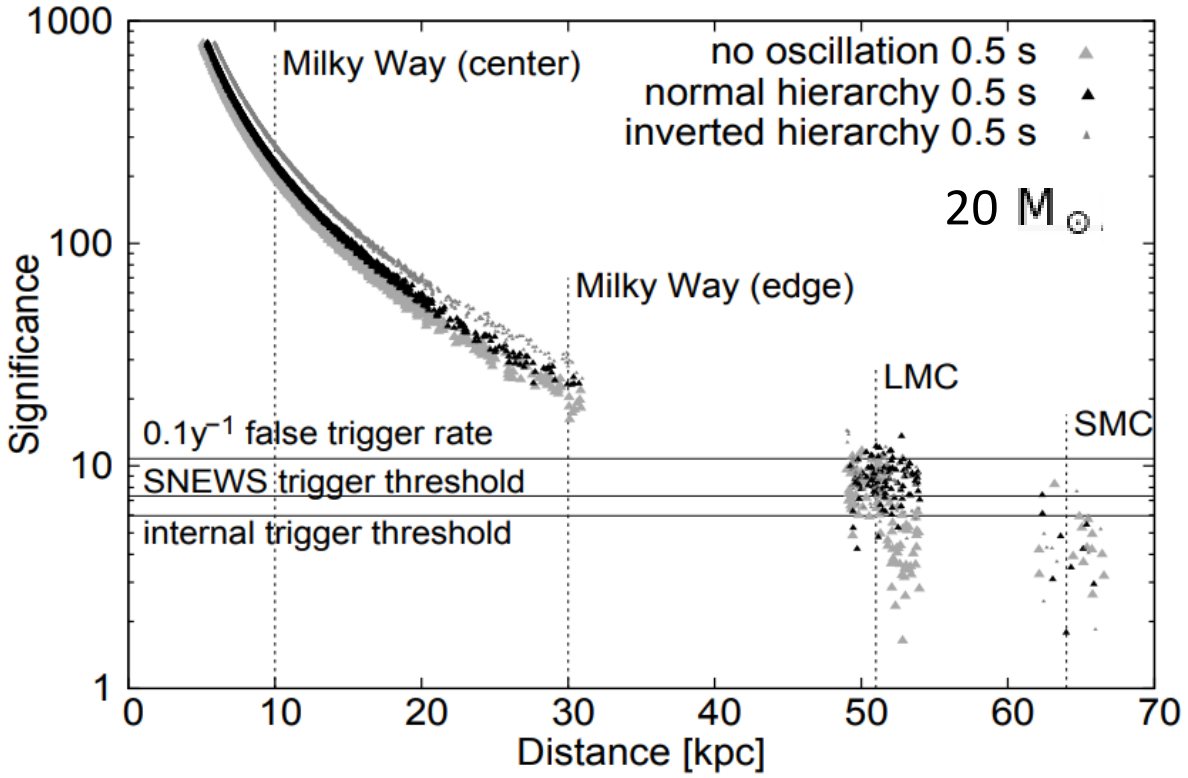
SNEWS 2.0

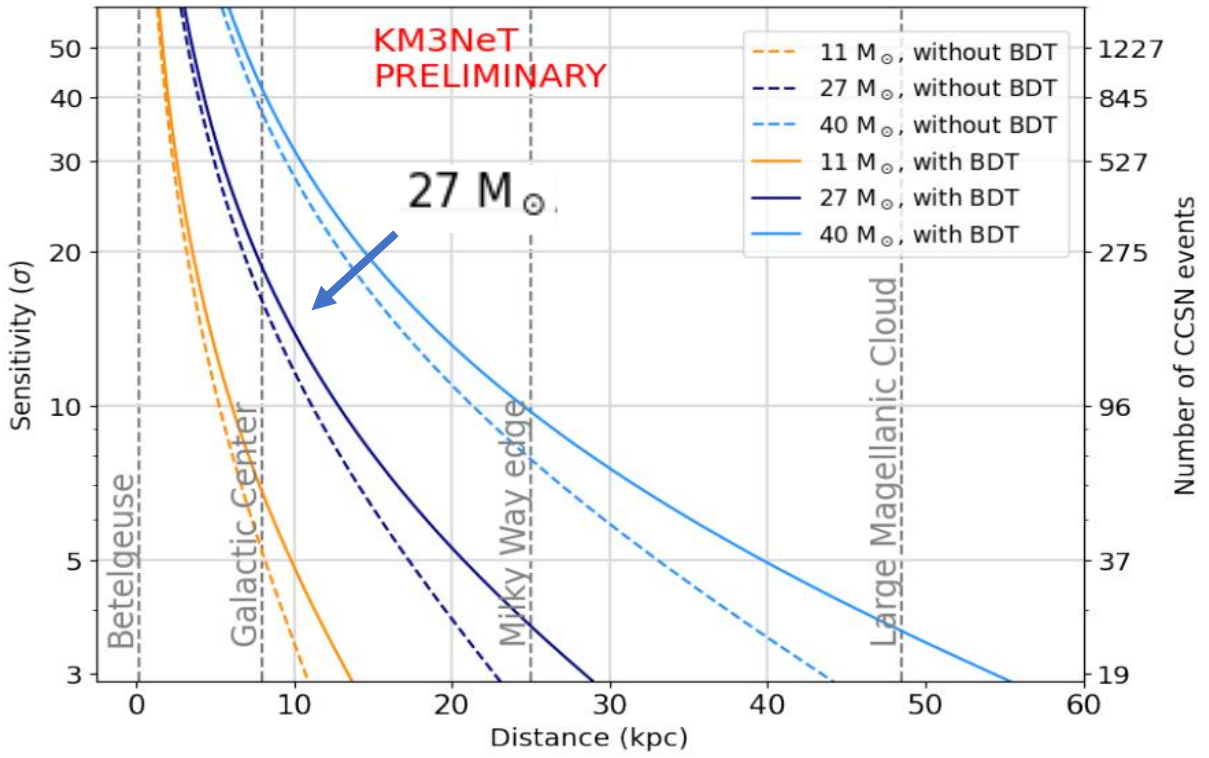
- Enable optical observation of the early phase just after shockwave breakout
- Sensitivity to „pre-supernovae ν“ from nearby SN
- Pointing via triangulation: information implemented
- Various other analysis options (time series, ….)
- false alarms acceptable
- low probability events will be reported
- Include large DM detectors (< 1 keV threshold)

SNEWS: SuperNova Early Warning Network

IceCube and KM3NeT are sensitive to MeV neutrinos from CCSN bursts – via an increase in PMT counting rates (sensitivity of IceCube much higher due to lower dark noise rates)

Precise timing. No information on energy of single events, or on direction.

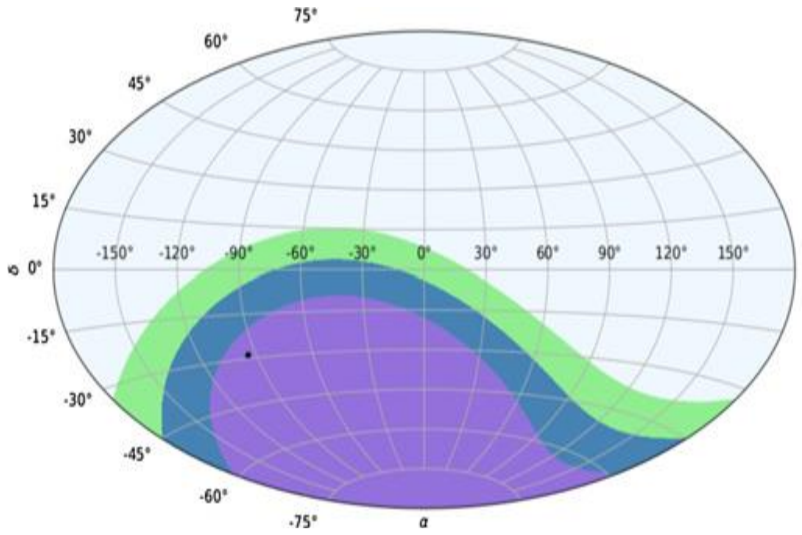




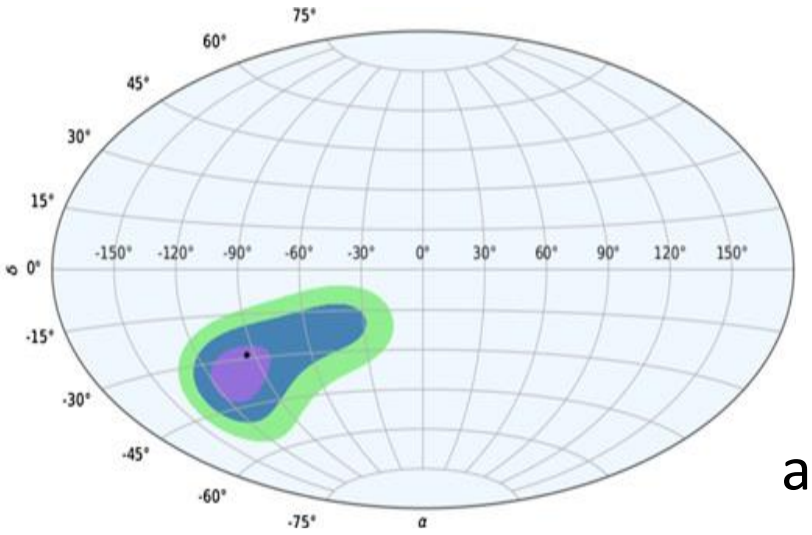
Pointing via triangulation

Sky area determined at 1σ for a SN at the Galactic center combining timing information from

IceCube + Super-K



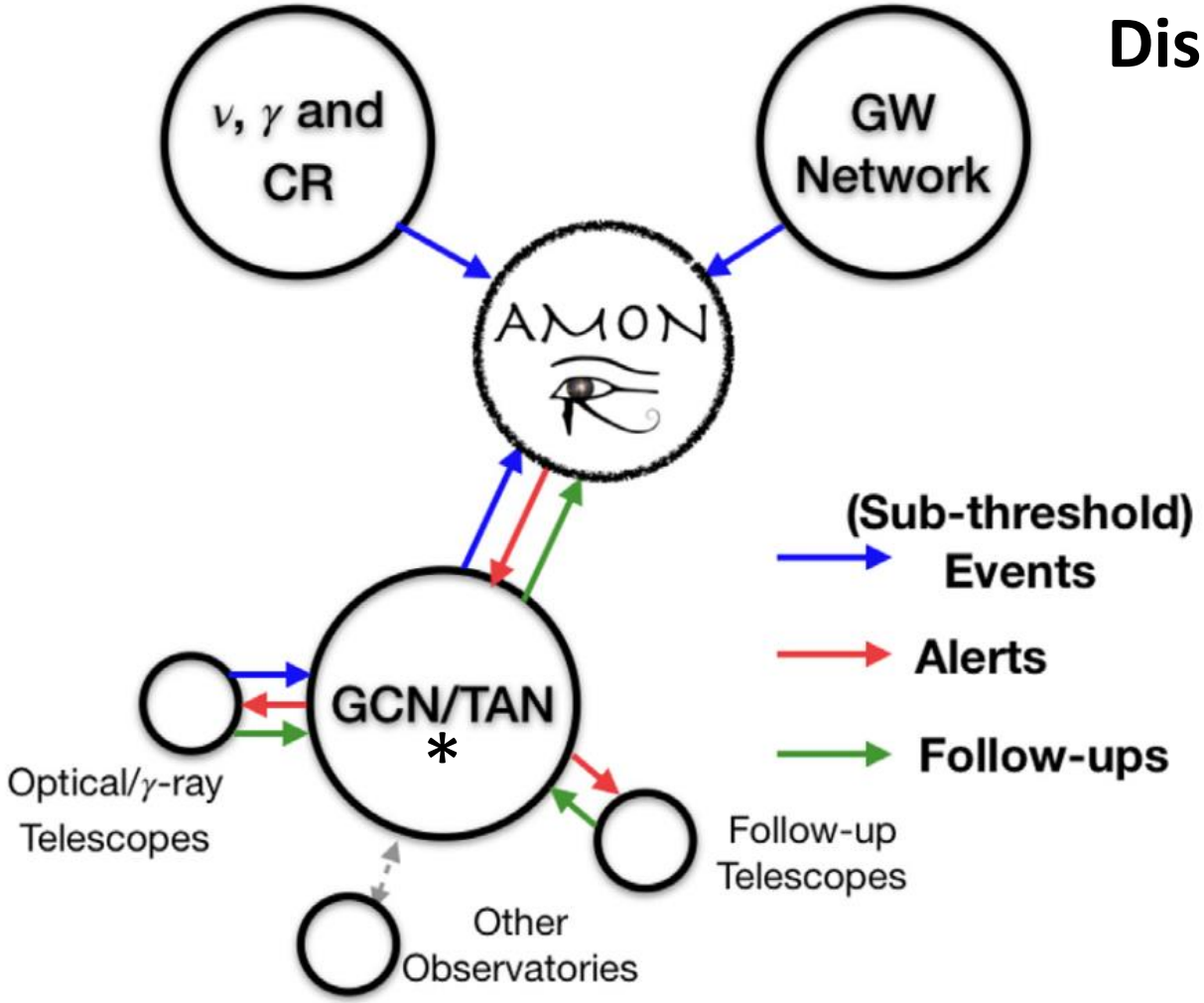
IceCube, DUNE, JUNO, Hyper-K



assuming normal hierarchy

(Hudepohl 2014 and Linzer & Scholberg 2019)

Astrophysical Multimessenger Observatory Network

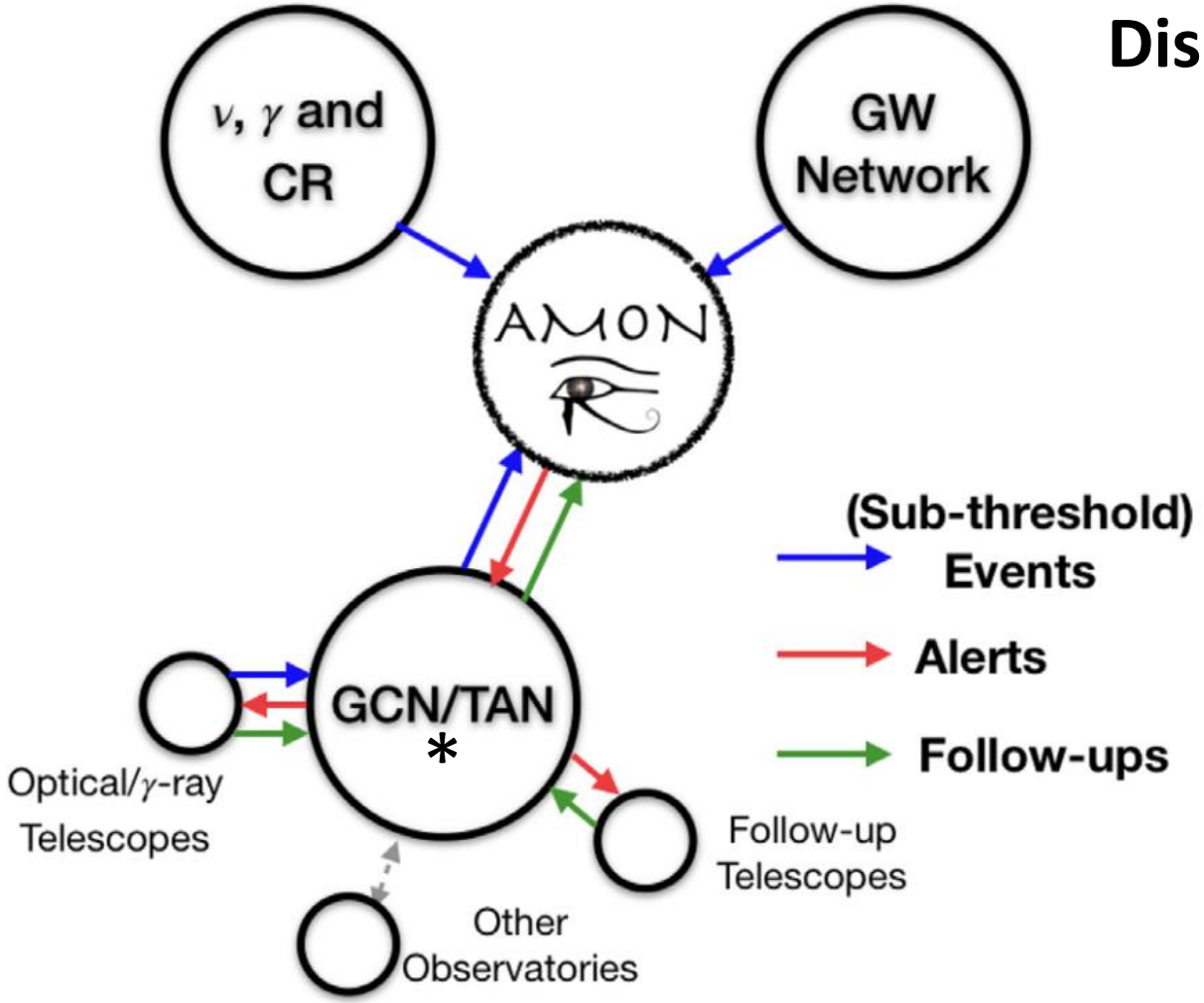


Discover transient multi-messenger sources

- Prompt distribution of electronic alerts for follow-up observations to identify and study counterparts
- Real-time and near real-time sharing of sub-threshold data between multimessenger observatories
- Real-time and archival searches for coincident signals

* General Coordinates Network/Transient Astronomy Network

Astrophysical Multimessenger Observatory Network



Discover transient multi-messenger sources

Alert partners

- IceCube, (ANTARES), Auger, HAWC, VERITAS, FACT, Swift BAT, Fermi, LIGO/VIRGO

Follow-up partners

- Swift XRT & UVOT, VERITAS, FACT, MASTER, LCOGT

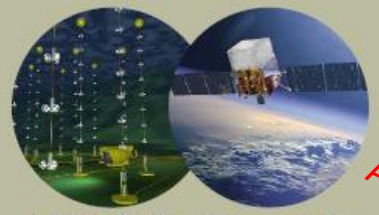
* General Coordinates Network/Transient Astronomy Network

Astrophysical Multimessenger Observatory Network

The NuEM channel: analyses

Archival Analysis

Real-time analysis

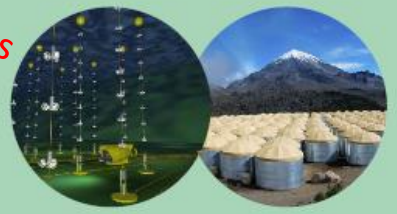


ANTARES +Fermi LAT
H. A. Ayala Solares et al
2019 ApJ 886 98

IceCube + HAWC
H. A. Ayala Solares et al
2021 ApJ 906 63

Antares has terminated operations

IceCube +Fermi LAT
C. F. Turley et al 2018
ApJ 863 64



ANTARES + HAWC
H. A. Ayala Solares et al
2023 ApJ 944 166

Hugo Ayala, talk at TAUP 2023

ν alerts

Single-event alerts

IceCube

- Gold channel: ~10/year, >50% signal
- Bronze channel: ~20/year, 30% -50% signal

} Publicly broadcasted through GCN / plus AMON

ANTARES

- High energy: ~ 12/year
- Very-high energy: 3-4/year
- ν close to local galaxies: 12/year

} Sent to private partners (MoU) → for coincidence → GCN / plus AMON
TAToO (Telescope ANTARES Target of Opportunity)

Baikal GVD

- Very-high energy cascades (1/cluster and year) → Some fraction released after human inspection as ATel (Astronomer's Telegram)

ν alerts

Single-event alerts

IceCube

- Gold channel: ~10/year, >50% signal
- Bronze channel: ~20/year, 30% -50% signal

Publicly broadcasted through GCN / plus AMON

ANTARES

- High energy: ~ 20/year
- Very-high energy: 3-4/year
- ν close to local galaxies: 12/year

Sent to private partners (MoU) → for coincidence → GCN / plus AMON

TAToO (Telescope ANTARES Target of Opportunity)

Sent neutrino alerts: (ANTARES 2009-2021)

322 to robotic telescopes, 26 to Swift, 15 to INTEGRAL, 20 to radio tel., 2 to HESS

Follow-up efficiencies: ~70% (X-ray /optical) ; ~20% (radio)

ν alerts: IceCube

Single-event alerts

Gamma-ray Coordinate Network (GCN) Notices and Circulars

GCN Notice (Rev0)

- Processed at South Pole.
- With:
  - Discovery time and date;
  - IceCube run and event number;
  - Best-fit coordinates;
  - Angular radii 50% and 90%;
  - Signalness;
  - False Alarm Rate;
  - Likely Neutrino energy (assuming a spectral index = 2).

GCN Circular

- Processed at north.
- More sophisticated algorithm.
- Refined direction and angular coordinates (rectangular error region).

GCN Notice (Rev1)

- Best-fit position and angular radii updated with circularized errors from GCN Circular.

ν alerts: IceCube

Single-event alerts

Subject IceCube-231014A - IceCube observation of a high-energy neutrino candidate track-like event
Date 2023-10-14T23:19:35Z (8 days ago)
From Marcos Santander at U of Alabama <jmsantander@ua.edu>
Via legacy email

The IceCube Collaboration (http://icecube.wisc.edu/) reports:

On 2023-10-14 at 22:00:06.27 UT IceCube detected a track-like event with a high probability of being of astrophysical origin. The event was selected by the ICECUBE_Astrotrack_BRONZE alert stream. The average astrophysical neutrino purity for Bronze alerts is 30%. This alert has an estimated false alarm rate of 4.853 events per year due to atmospheric backgrounds. The IceCube detector was in a normal operating state at the time of detection.

After the initial automated alert (https://gcn.gsfc.nasa.gov/notices_amon_g_b/138449_20481611.amon), more sophisticated reconstruction algorithms have been applied offline, with the direction refined to:

Date: 2023-10-14
Time: 22:00:06.27 UT
RA: 297.16 (+2.73 / -4.32 deg 90% PSF containment) J2000
Dec: +1.34 (+1.24 / -1.11 deg 90% PSF containment) J2000

We encourage follow-up by ground and space-based instruments to help identify a possible astrophysical source for the candidate neutrino.

Two Fermi 4FGL-DR4 sources are located in the 90% uncertainty region of the event. The sources are 4FGL J1947.0+0031 at RA = 296.76 deg, Dec = +0.52 and 4FGL J1955.7+0214 at RA = 298.94 deg, Dec = +2.24, located 0.91 and 1.99 deg away from the best fit position, respectively.

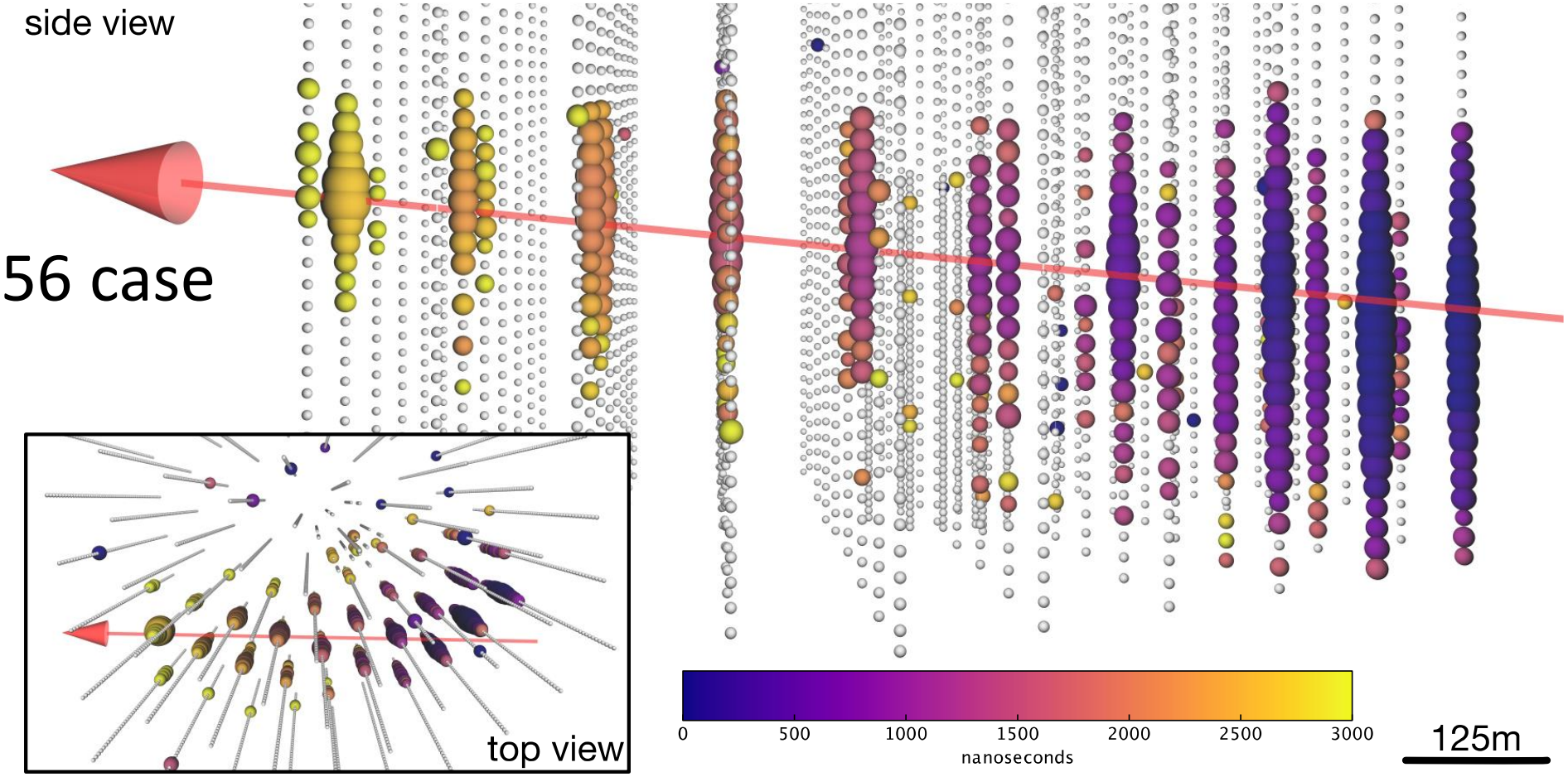
The IceCube Neutrino Observatory is a cubic-kilometer neutrino detector operating at the geographic South Pole, Antarctica. The IceCube realtime alert point of contact can be reached at roc@icecube.wisc.edu

ν alerts

Single-event alerts

The TXS 0506+056 case

22. Sept. 2017
290 TeV Neutrino
(IceCube-170922A)

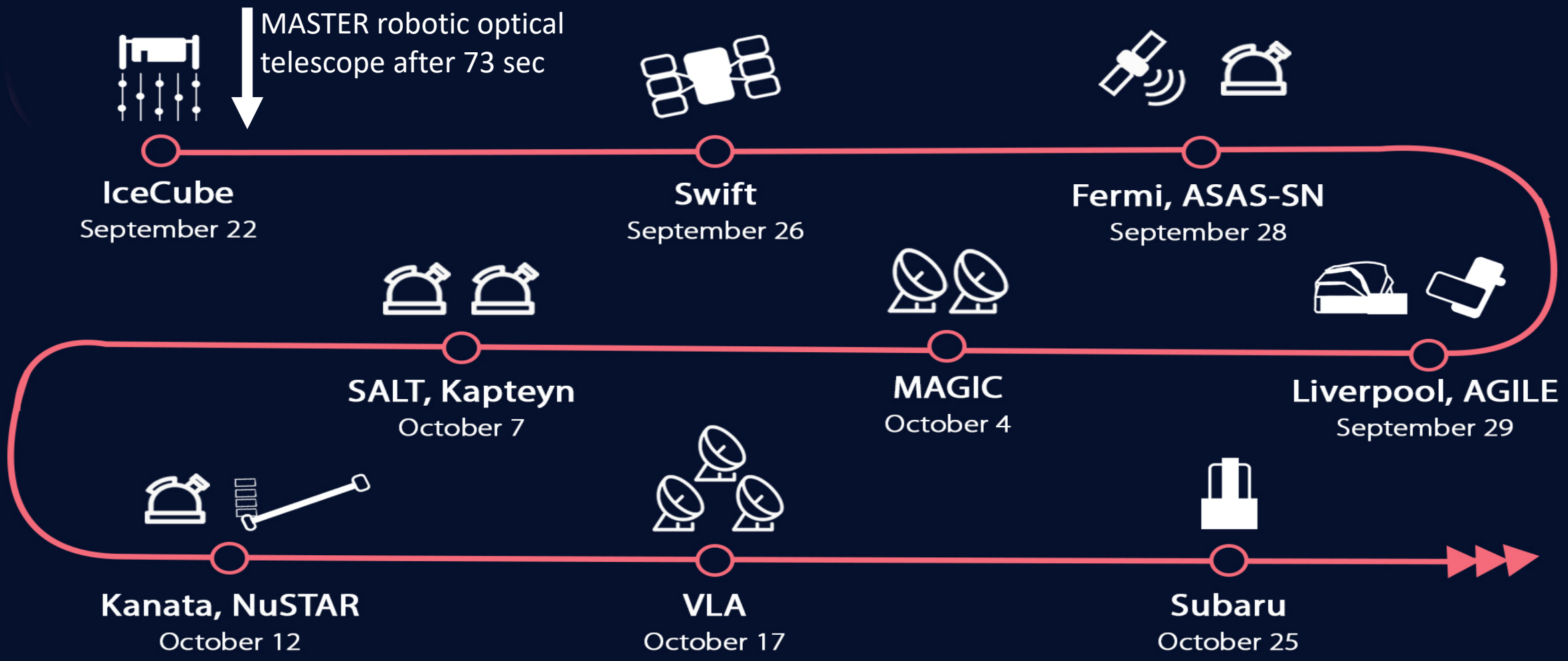


Signalness: 56.5%

ν alerts

IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kapteyn, Kanata, Kiso, Liverpool, Subaru, Swift, VERITAS, VLA, Science 2018

Follow-up detections of IC170922 based on public telegrams

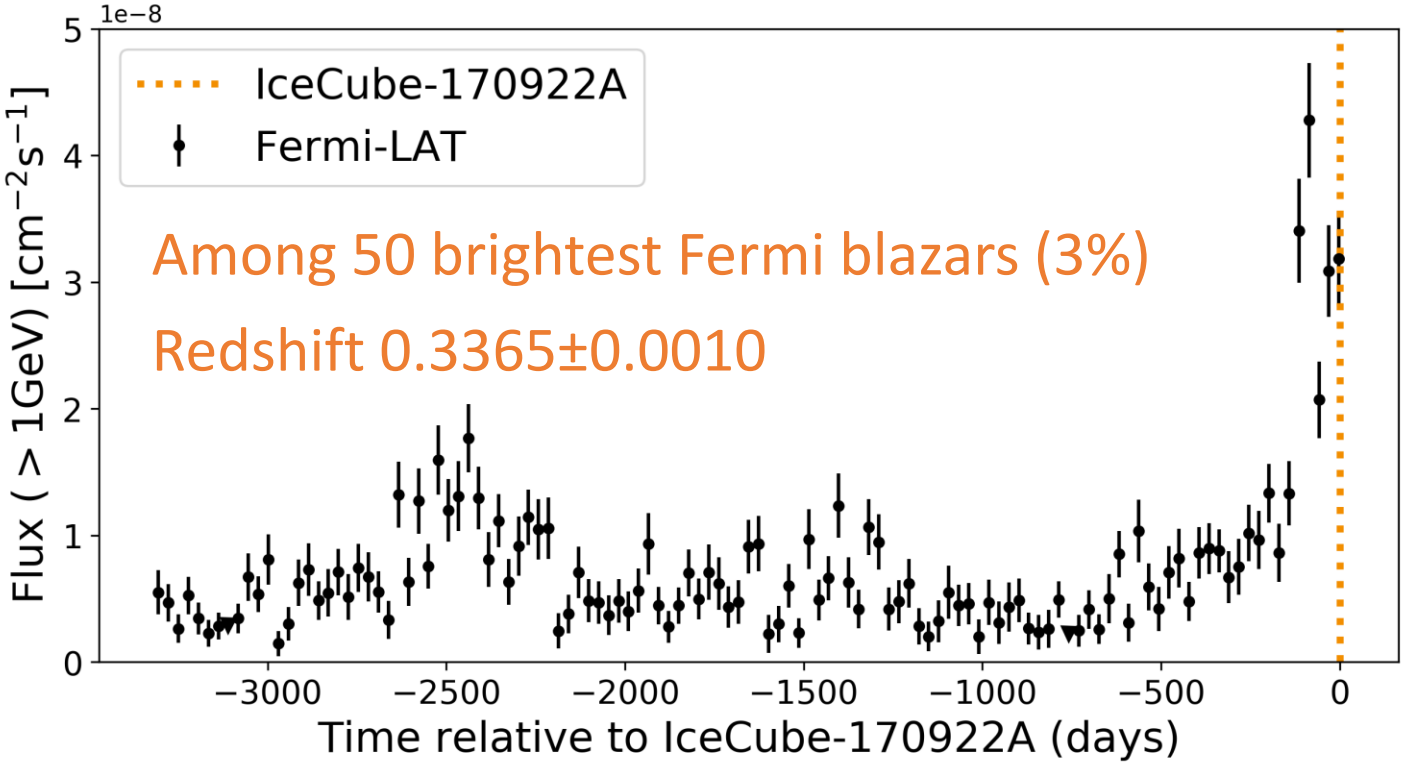


ν alerts

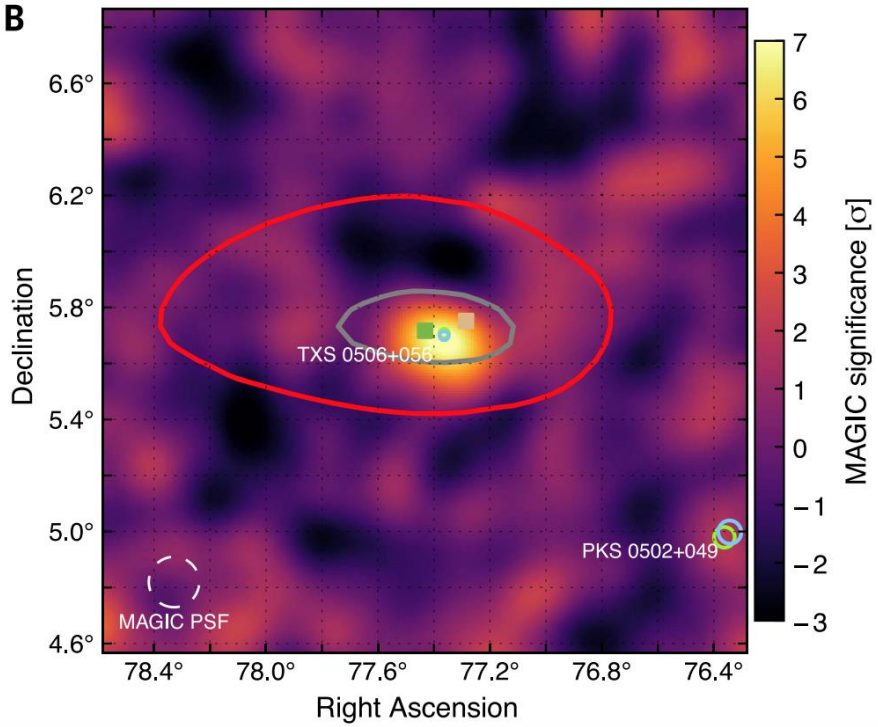
Single-event alerts

Coincidence with Flaring Blazar, TXS 0506+056

Fermi-LAT light curve

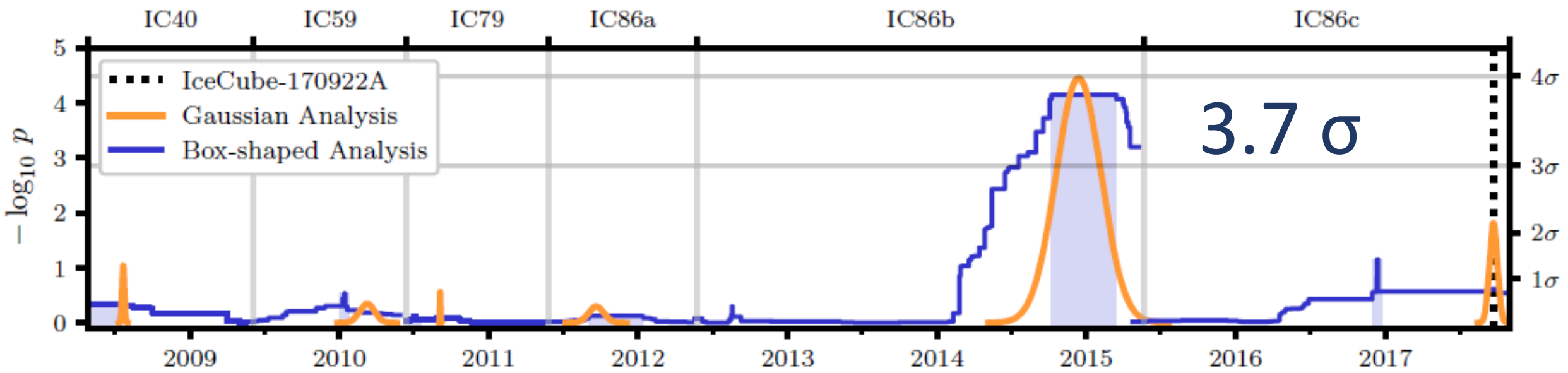


MAGIC Significance map



TXS 0505+056: Looking back to archival data

Science 361 (2018) 147



ν alerts

multiplet alerts

IceCube

- Multiplets within 100 sec
- Neutrino clusters on all time scales up to 180 days (GFU program)

ANTARES

- Multiplets (< 3°, < 15 min)

Sent to private partners (MoU)

ν alerts

multiplet alerts

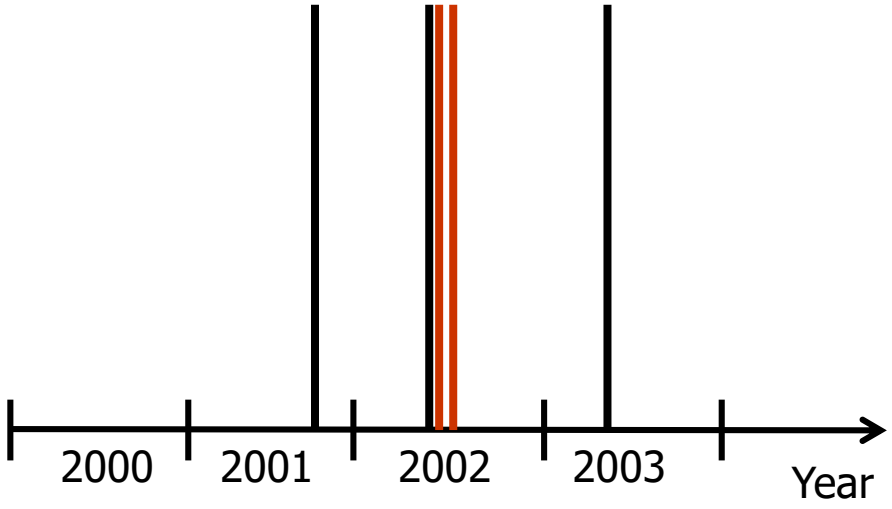
2002: a tantalizing coincidence …

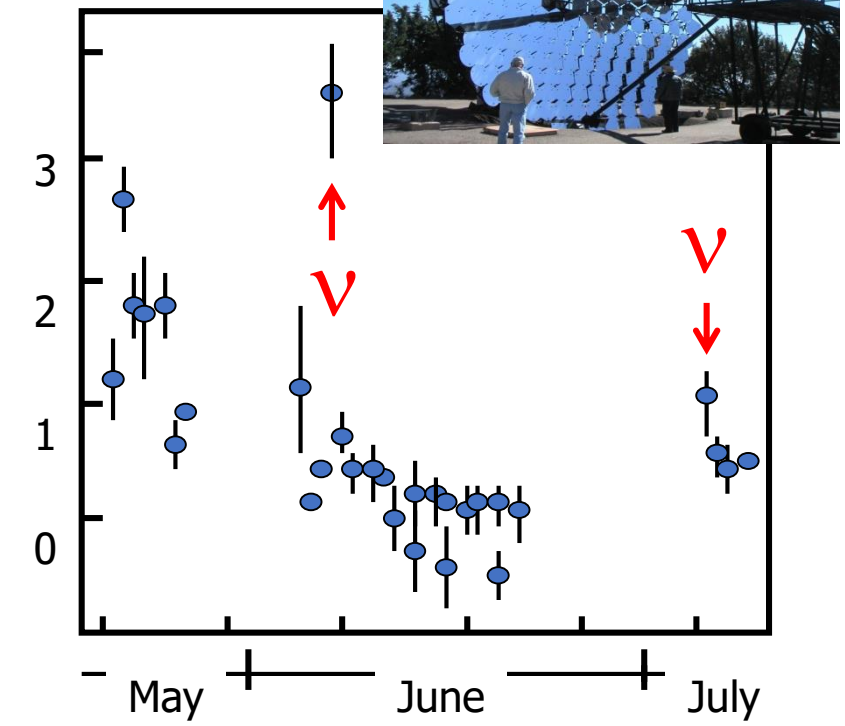
initiating the Target of Opportunity program: look for „neutrino flares“ and alert IACTs !

IceCube:
Gamma-ray Follow-Up Trigger (GFU)

(identify neutrino flares as they begin to evolve)

Arrival time of AMANDA neutrinos from the direction of AGN 1ES 1959+650





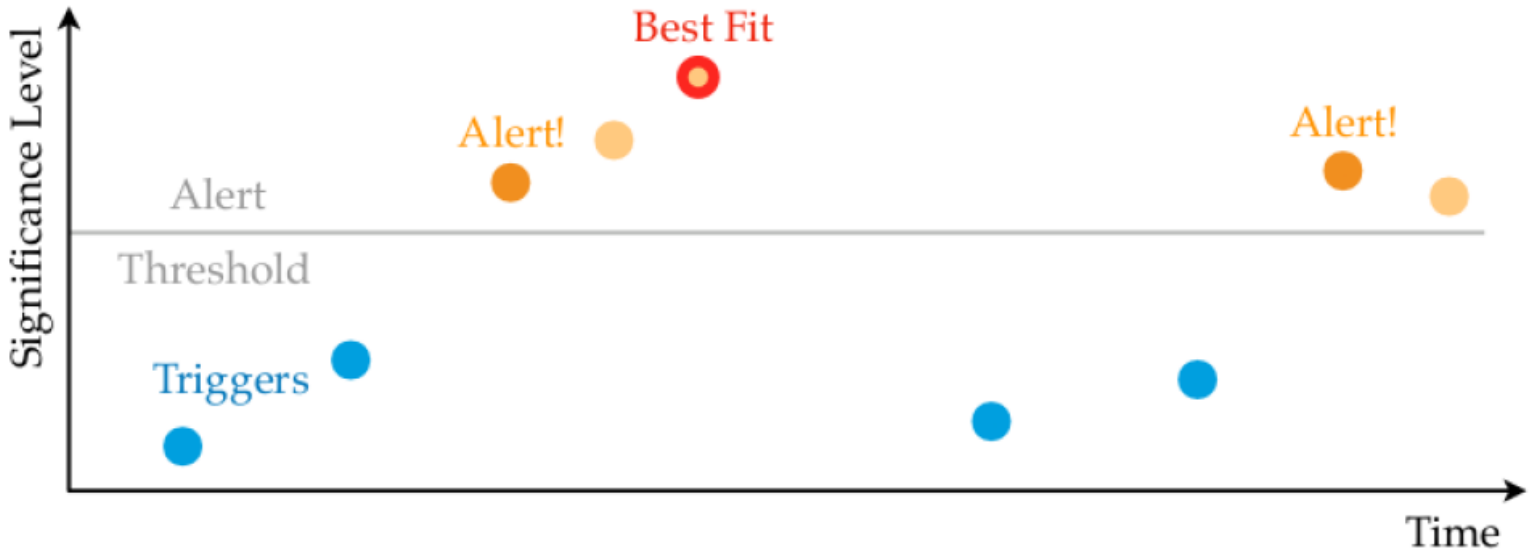
M. Ackermann, E. Bernardini 2005

ν alerts

multiplet alerts

IceCube GFU alerts to IACTs:

neutrino *flare* passes a pre-defined significance threshold (3.0 - 3.5σ for known γ-ray sources, depending on the choice of each IACT, and 4.2σ for all-sky alerts) .



Temporal evolution of the trigger significance

Light orange: muted triggers

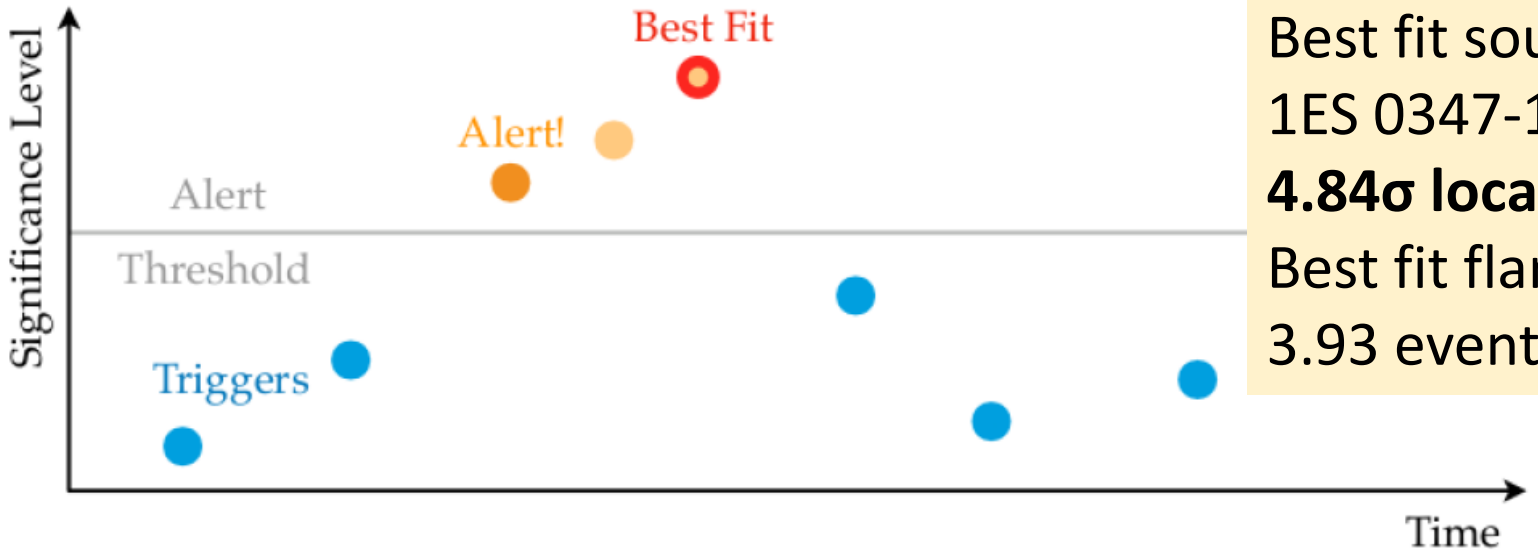
(PhD thesis T. Kintscher 2020)

ν alerts

multiplet alerts

IceCube GFU alerts to IACTs:

neutrino *flare* passes a pre-defined significance threshold (3.0 - 3.5σ for known γ-ray sources, depending on the choice of each IACT, and 4.2σ for all-sky alerts) .

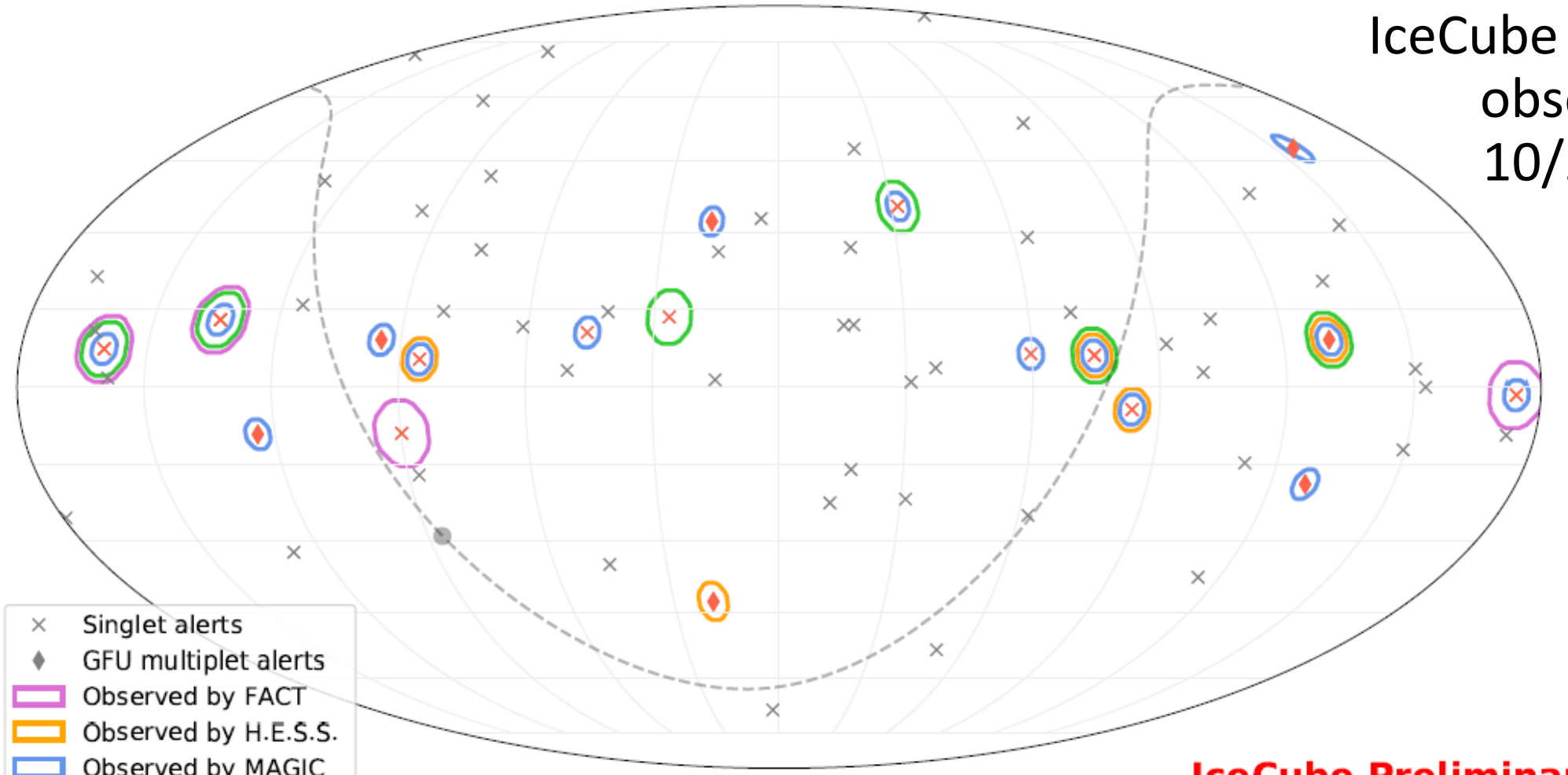


Best fit source (archival data):
1ES 0347-121 (δ=-11.98°)
4.84σ local → 1.81σ post-trial significance,
Best fit flare parameters: 6.9 hours and 3.93 events (see talk Sarah Mancina)

ν alerts

multiplet alerts

IceCube alert positions
observed by IACTs
10/2017 – 3/2021

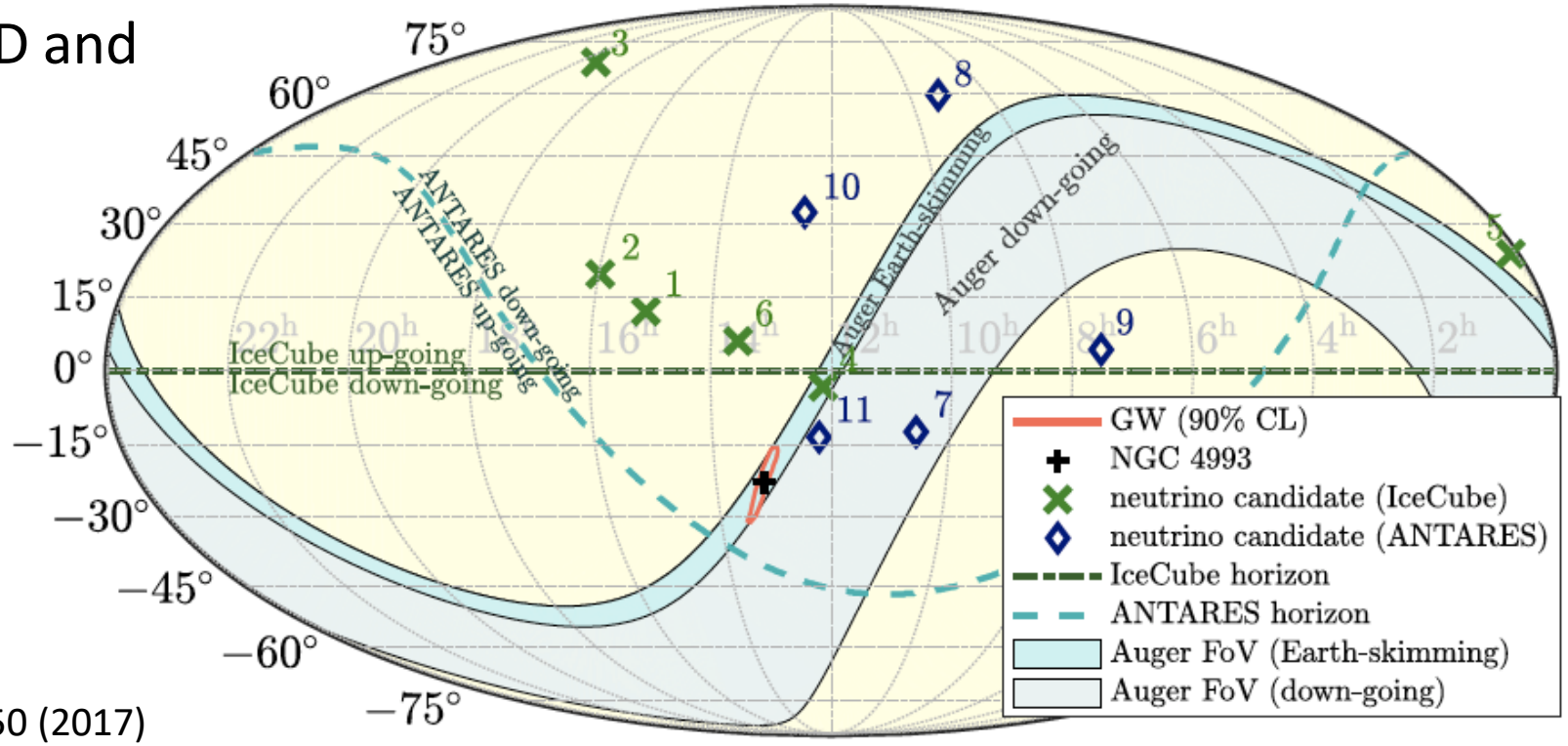


… and finally: Neutrino Follow-ups

All four experiments (ANTARES, Baikal-GVD, IceCube, KM3NeT) follow-up **gravitational** or **electromagnetic alerts**/events/flares

Example: Search for neutrinos from GW170817 in ANTARES, Auger, Baikal-GVD and IceCube data in +/-500 sec

no counterpart found



LIGO, Virgo, Auger, ANTARES, IceCube,ApJ 850 (2017)

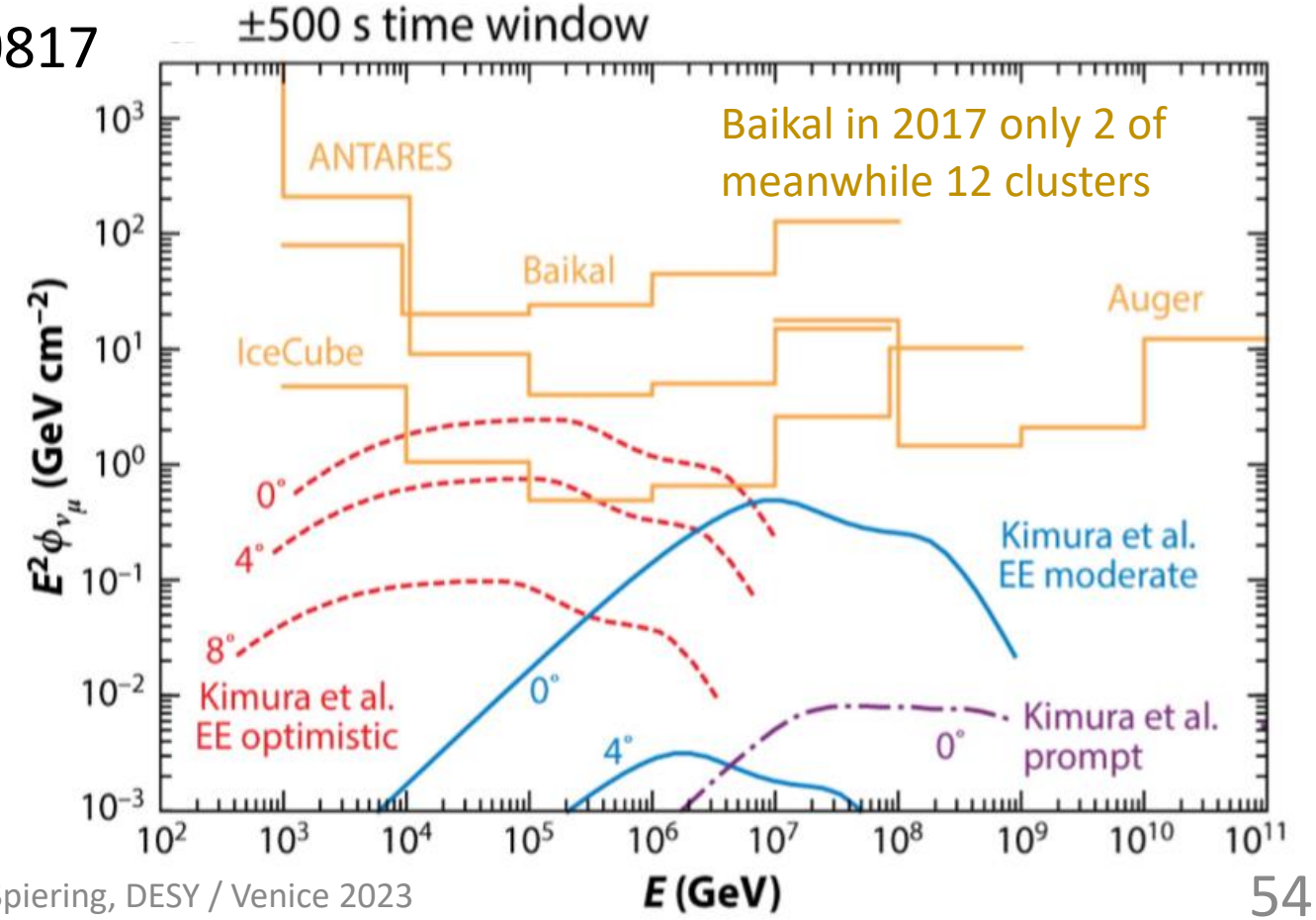
… and finally: Neutrino Follow-ups

All four experiments (ANTARES, Baikal-GVD, IceCube, KM3NeT) follow-up **gravitational** or electromagnetic alerts/events/flares

Example: Search for neutrinos from GW170817 in ANTARES, Auger, Baikal-GVD and IceCube data in +/-500 sec

no counterpart found

Constraining of optimistic models is in sight !



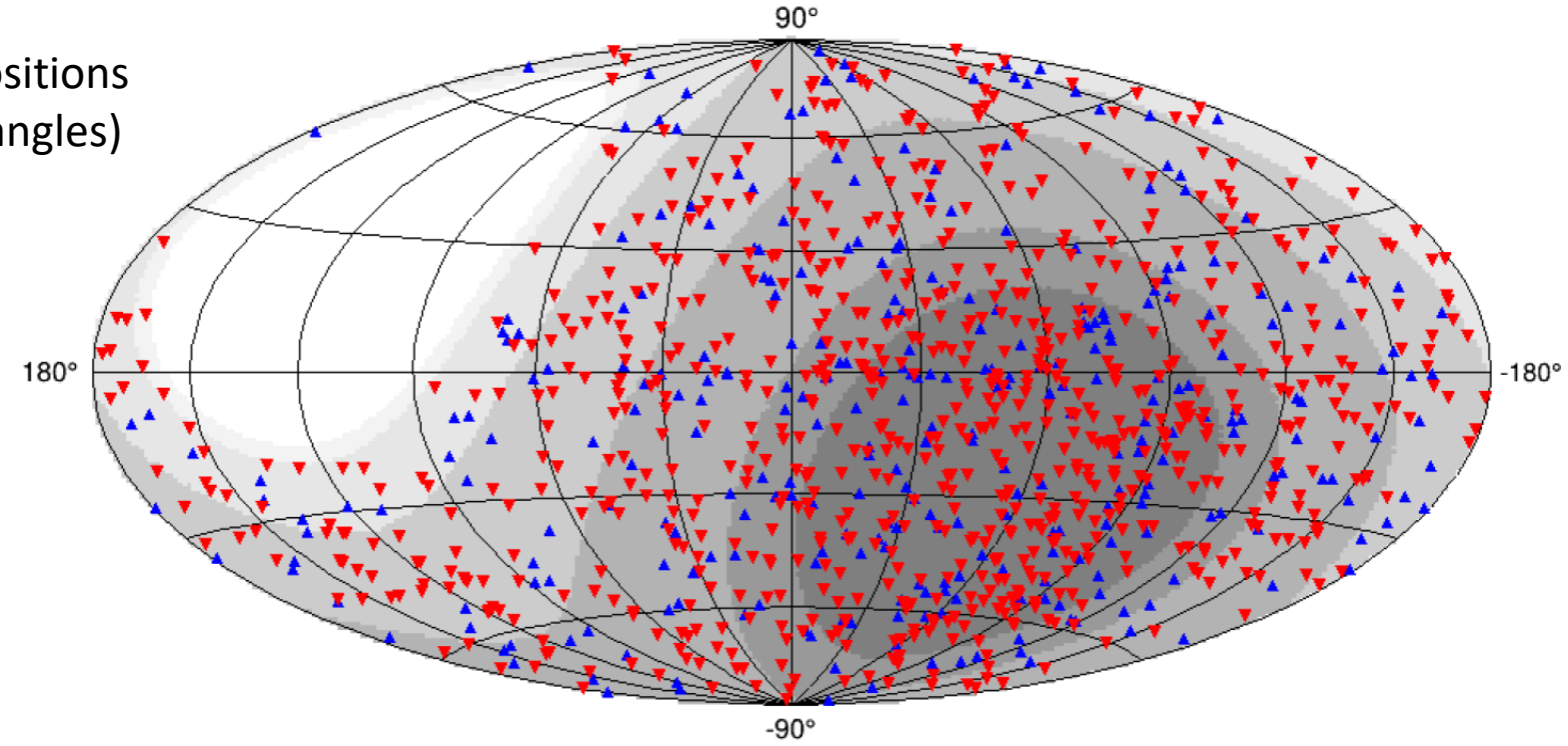
… and finally: Neutrino Follow-ups

All four experiments (ANTARES, Baikal-GVD, IceCube, KM3NeT) follow-up **gravitational** or electromagnetic alerts/events/flares

Example: ANTARES GRB follow-up

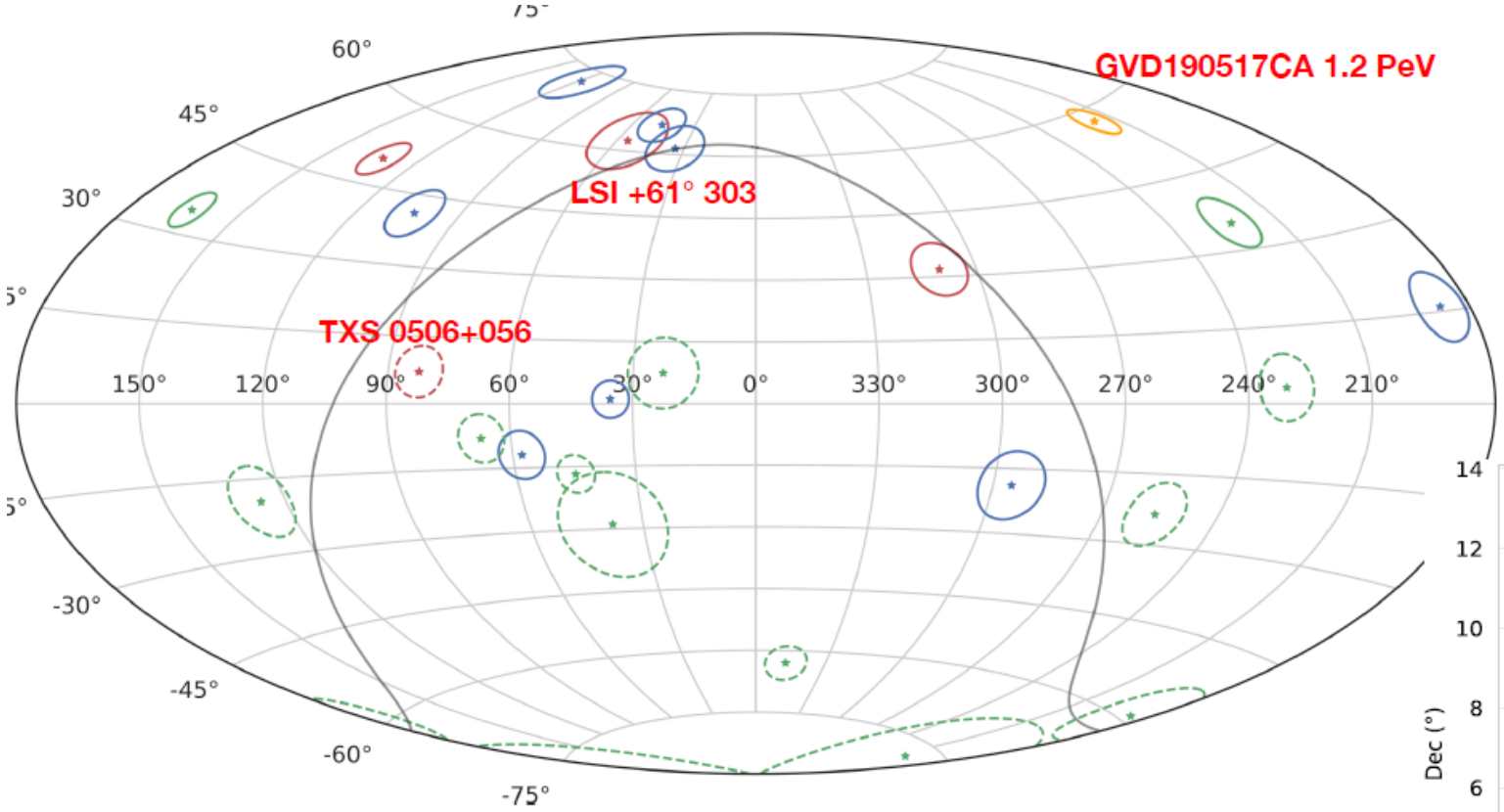
Sky map in Galactic coordinates with the positions the Fermi (red triangles) and Swift (blue triangles) GRBs followed by ANTARES between 01/2014 and 02/2022.

Shade of grey indicates ANTARES visibility.



Albert et al., arXiv:2211.0755

Baikal GVD ATel/follow ups: 2018 – Feb 2022: 25 cascade-like events



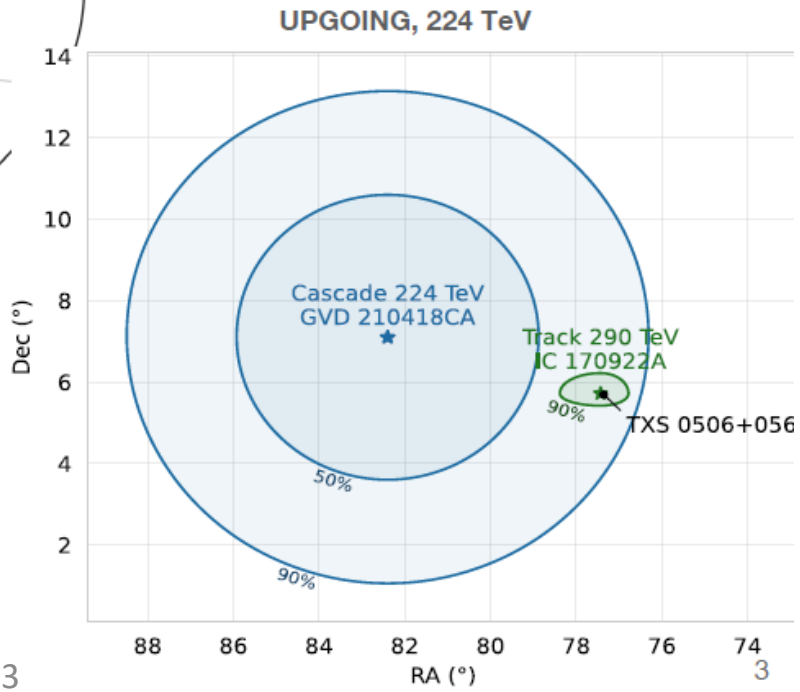
15 < E< 100 TeV

100≤ E< 200 TeV

200≤ E< 1000 TeV

E≥ 1 PeV

90% uncertainty circles:
Downgoing- solid ; Upgoing – dashed



2211.09447 Baikal-GVD: e-print 2210.01650

Slide taken from Olga Suvorova

Conclusions

- With KM3NeT and Baikal-GVD, IceCube has partners of similar power → networking will be taken to a new level!
- The Global Neutrino Network with its present partners has a 10 year-history, with a true community formed. It will likely be broadened by new partners and
- realized in all ist aspects.
- Combining data from different neutrino telescopes will signifcantly enhance the discovery potential.

- We are just at the beginning of the era of Multi-Messenger (MM) astronomy!
- Many potential MM sources are transient → fast coordinated observations are necessary.
- Networks to trigger and coordinate observations exist/are under development.
- Correlations sub-threshold excesses promise new disoveries.

Design Kirsty Pargeter