Multi-messenger astronomy with CTAO LST and IceCube/-Gen2

Koji Noda (Chiba Univ.)

7th KMI symposium
9 Nov 2026

CHIBA UNIVERSITY

ICEHAP

Multi-celebrations in Oct!

CTAO LST-subarray inauguration (15 Oct)

宇宙の謎解く望遠鏡完成　北大西洋に、日本開発主導



国際共同観測「CTAO計画」の大口径望遠鏡の完成記念式典で、テープカットをする関係者＝15日、スペイン領・ラパルマ島（共同）

2026年10月16日 05時54分 共同通信

【プレスリリース】「極限宇宙の探究、新時代へ ラ・パルマ島で大口径ガンマ線望遠鏡アレイが完成」

プレスリリース 2026.10.15

発表のポイント

◆スペイン・カナリア諸島ラ・パルマ島のチェレンコフ望遠鏡アレイ天文台（CTAO）北半球サイトで、口径23メートルの大口径望遠鏡（LST）4基が完成しました。

◆約20ギガ電子ボルト以上の宇宙ガンマ線を観測でき、CTAOの望遠鏡の中で最も低いエネルギー領域の観測を担います。

◆暗黒物質の正体、宇宙線（宇宙を飛び交う高エネルギー粒子）の発生源と、極めて高いエネルギーまで加速される仕組みなど、天体物理学、素粒子物理学、宇宙論の根本的な問いに取り組みます。



完成した4基の大口径望遠鏡（LST）Credit:LST Collaboration

日本経済新聞

朝刊・夕刊 LIVE中 Myニュース 日経会社情報 人事ウオッチ

トップ 速報 ビジネス マーケット 経済 国際 オピニオン もっと見る

宇宙の謎解く望遠鏡が完成　国際観測の中核、北大西洋に

社会・調査

2026年10月16日 2:00（2026年10月16日 10:29更新） 夕刊掲載

保存



スペイン領・ラパルマ島の天文台に完成した国際共同観測「CTAO計画」の大口径望遠鏡群の一部（15日）=共同

Nobel prize in Physics to Francis Halzen (6 Oct)





IceCube Collaboration meeting & celebration @ Madison (19-23 Oct)



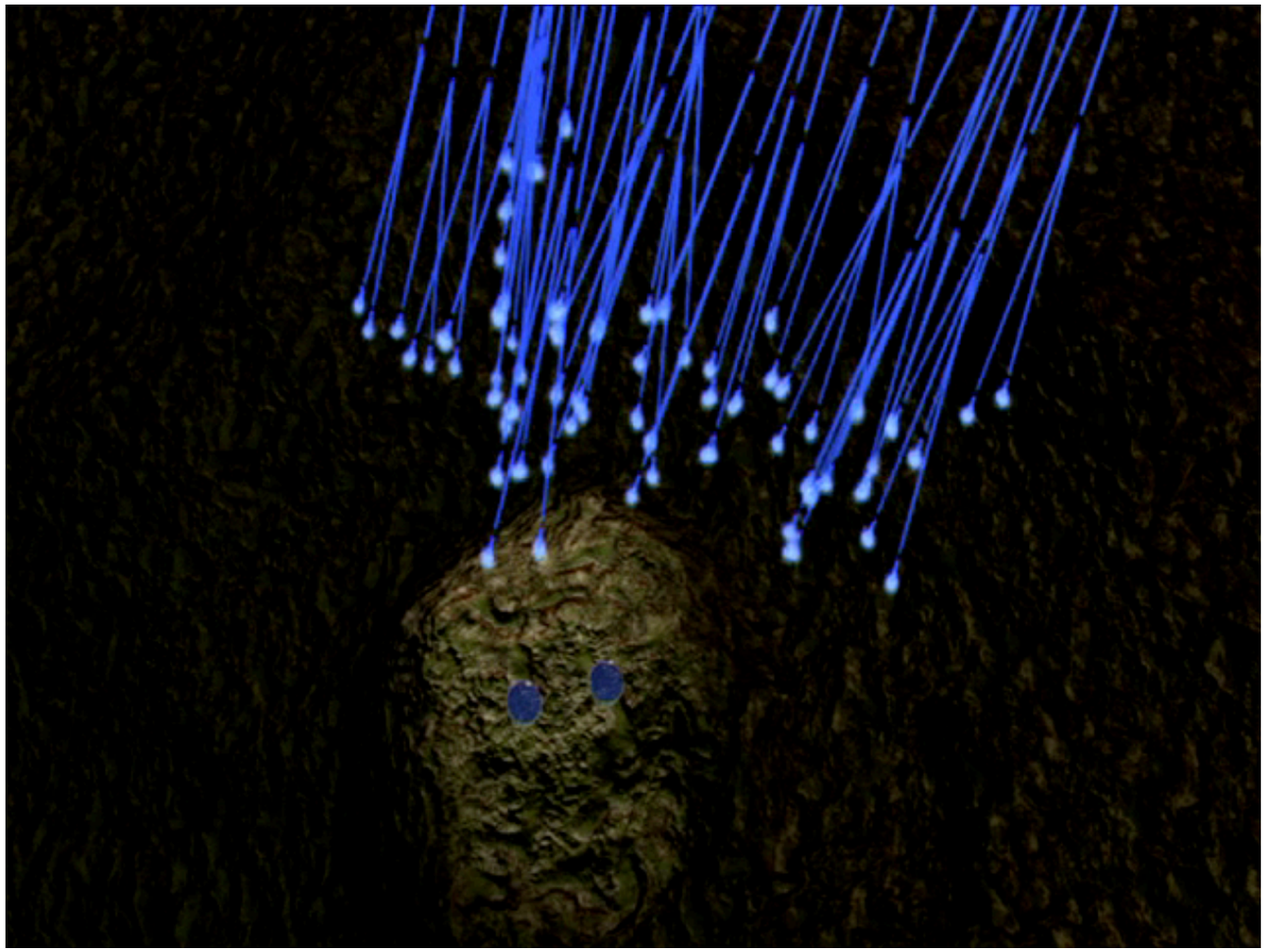


Outline

- **Gamma-ray astronomy:** Imaging Atmospheric Cherenkov Telescopes (IACTs) on the ground
  - Expectation for LSTs of CTA Observatory
- **Neutrino astrophysics:** IceCube at the South Pole
  - Status of neutrino source studies and ν-EM multi-messenger astronomy
- Strategies in the coming MM era
  - Updates in **gamma-ray follow-up**
  - Developments of **new instruments**
- Summary

IACTs

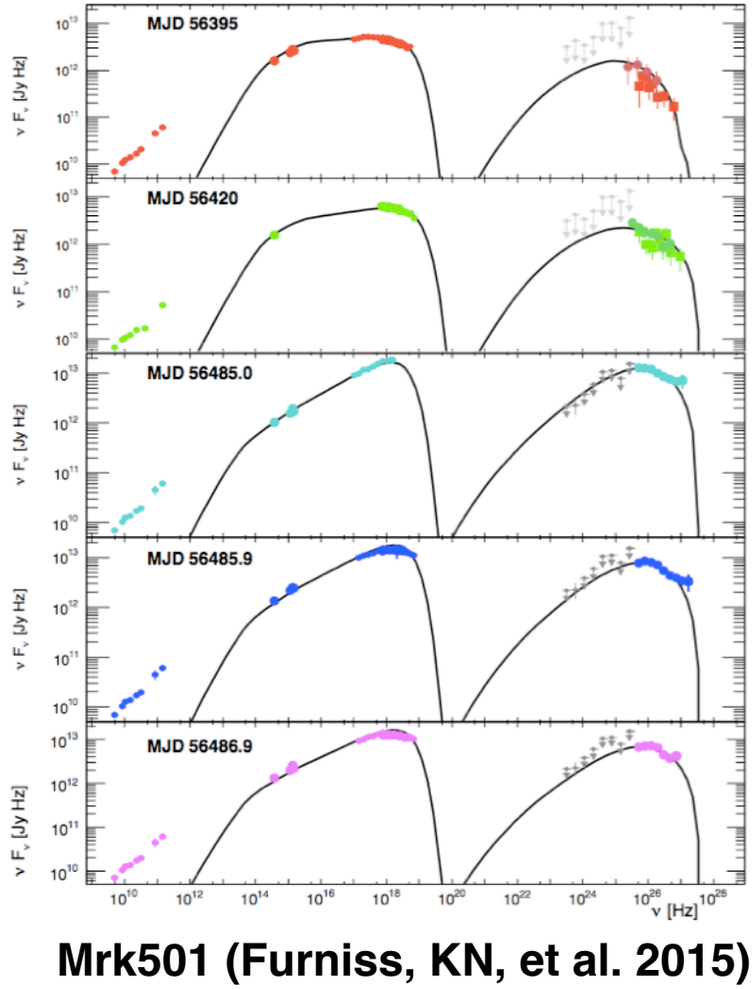
- High-E (>GeV) γ-rays detected via the pair creation in the detector. Tiny flux in VHE (>10 GeV) needs a **huge detector = atmosphere**
- “Telescope” taking images of interactions in the air (air showers)
- Started in 80’s. Experiments in 00’s (e.g., MAGIC) established as astronomy at the highest* end of MWL (* until the LHAASO era)



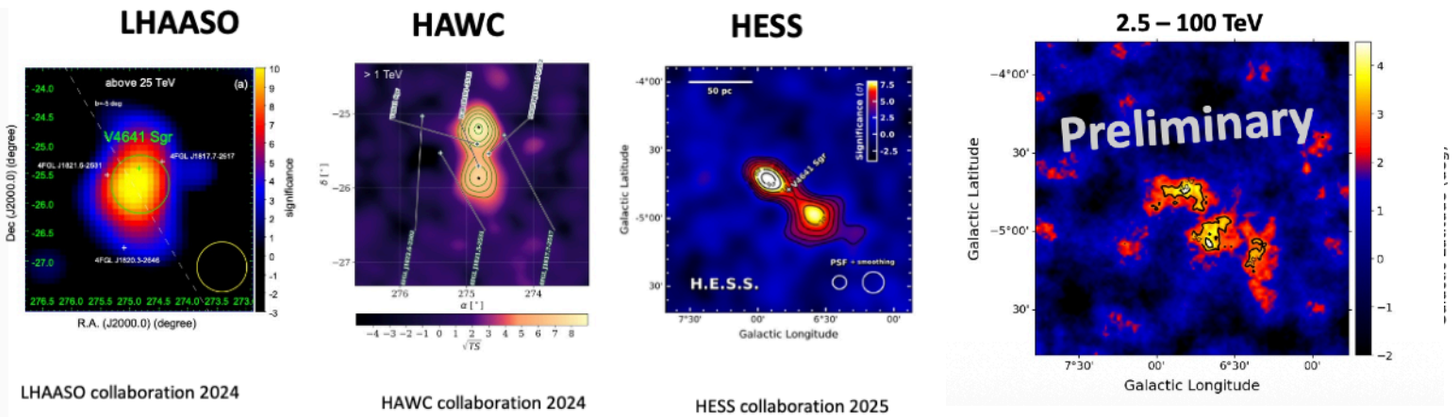


VHE γ-ray astronomy

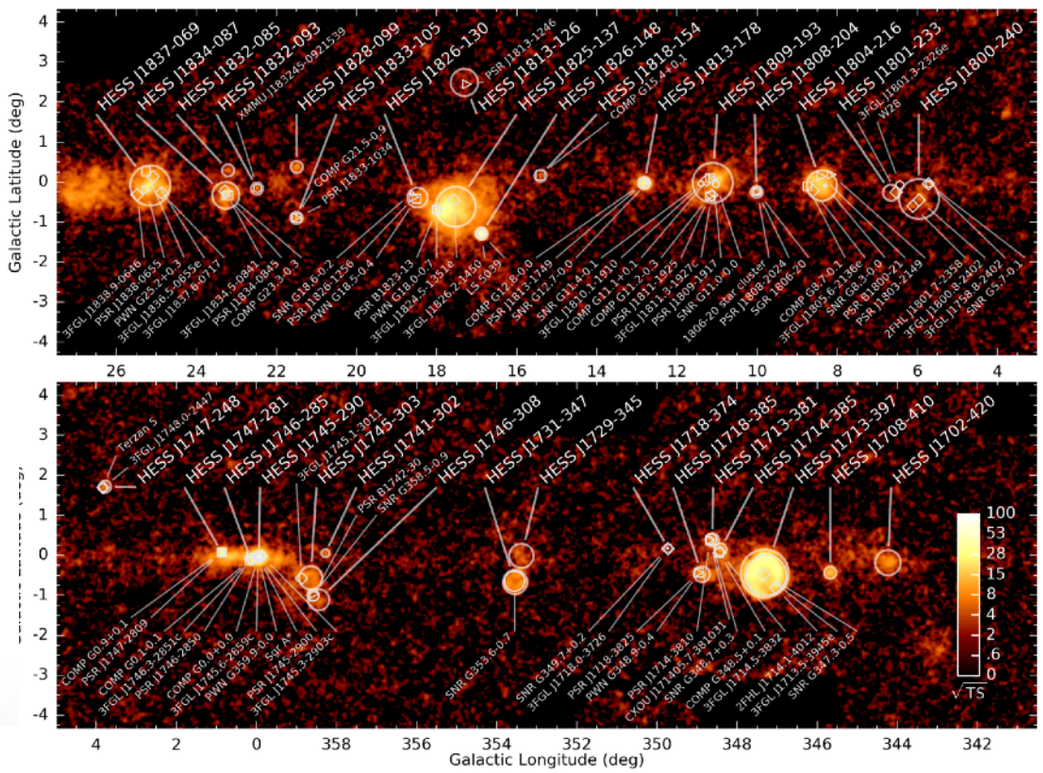
- AGN studies: clear Inverse Compton bump with significant energy fraction. **VHE γ is needed to understand the energy budget**
  - Hunt for more of such objects
- Distant AGN: EBL (γ-γ attenuation by IR BG) smaller than expected, more distant sources. Current record: **FSRQ OP313 @ z=0.997**
- Galactic accelerators (SNR, Pulsars, binaries, microquasars,,,), hyped now with PeVatrons (LHAASO & IceCube)



Mrk501 (Furniss, KN, et al. 2015)



V4641 Sgr by VHE-γ experiments (Morita, JPS talk)

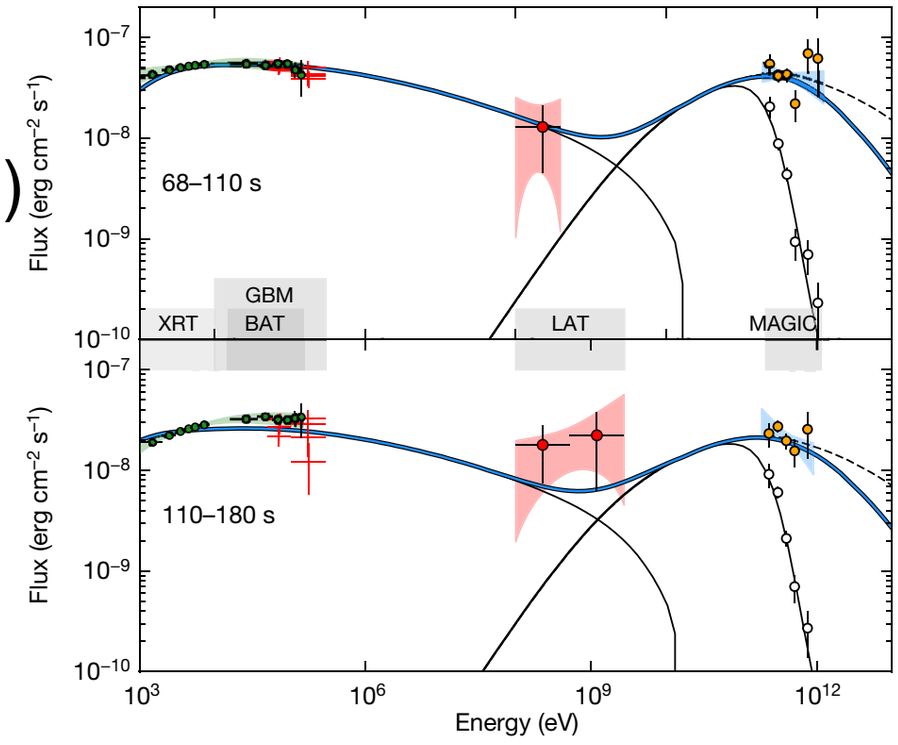


Galactic Plane Survey by H.E.S.S.

VHE Gamma-Ray Bursts



- Long-awaited detection by IACTs, based on GeV results
- First VHE GRB 190114C (2019), with a clear Inverse Compton bump (analogy with AGN)
- + ~5 VHE GRBs in 7 yrs (incl. 201216C @z =1.1)
  - 2-3 classes? (LL GRBs, SGRBs) More stat! => more sensitive telescopes with the fast follow-up capability and lower E threshold

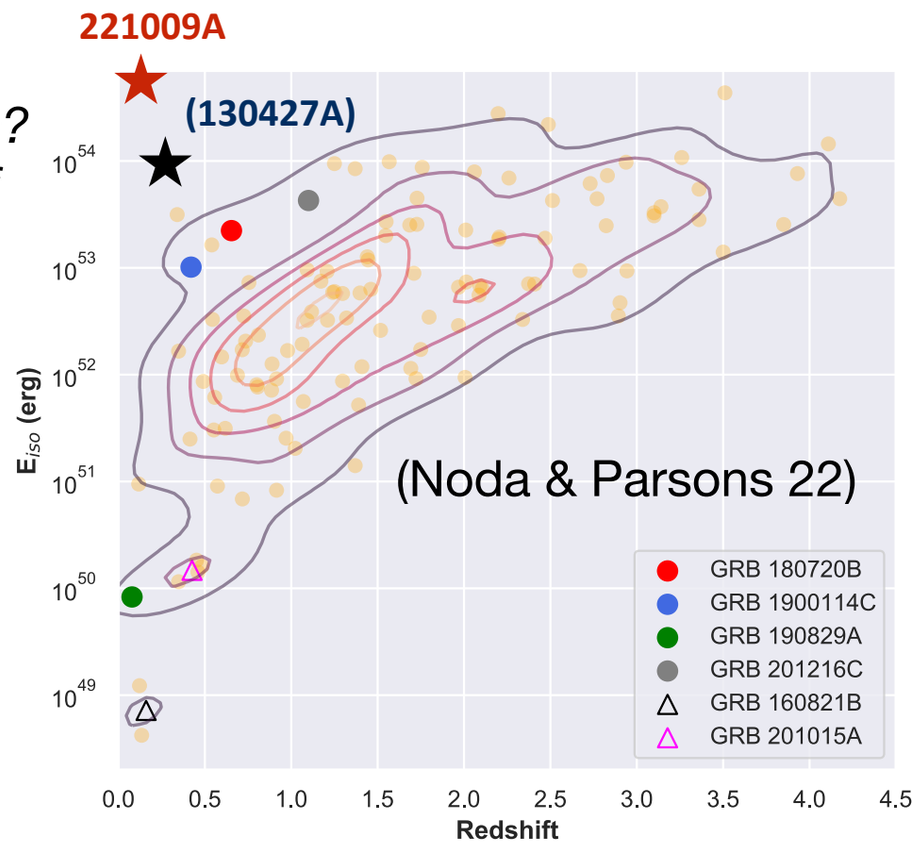


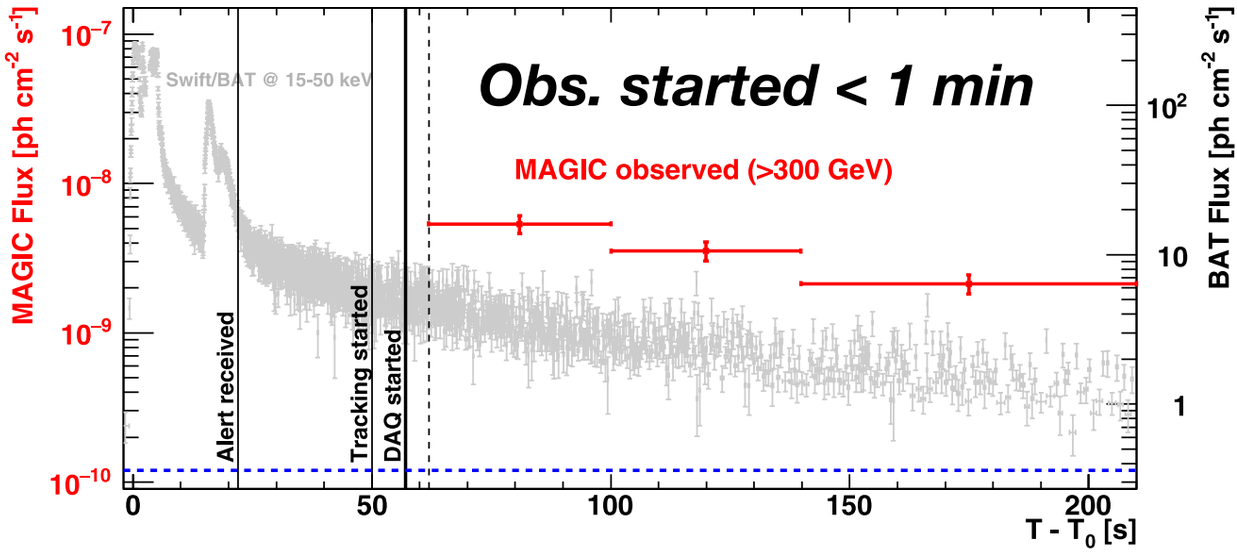
MAGIC Coll.+, Nature (2019)

Brightest GRBs? or just a tail of normal ones?

LL GRBs?

SGRBs?





CTAO Large-Sized Telescopes (LSTs)

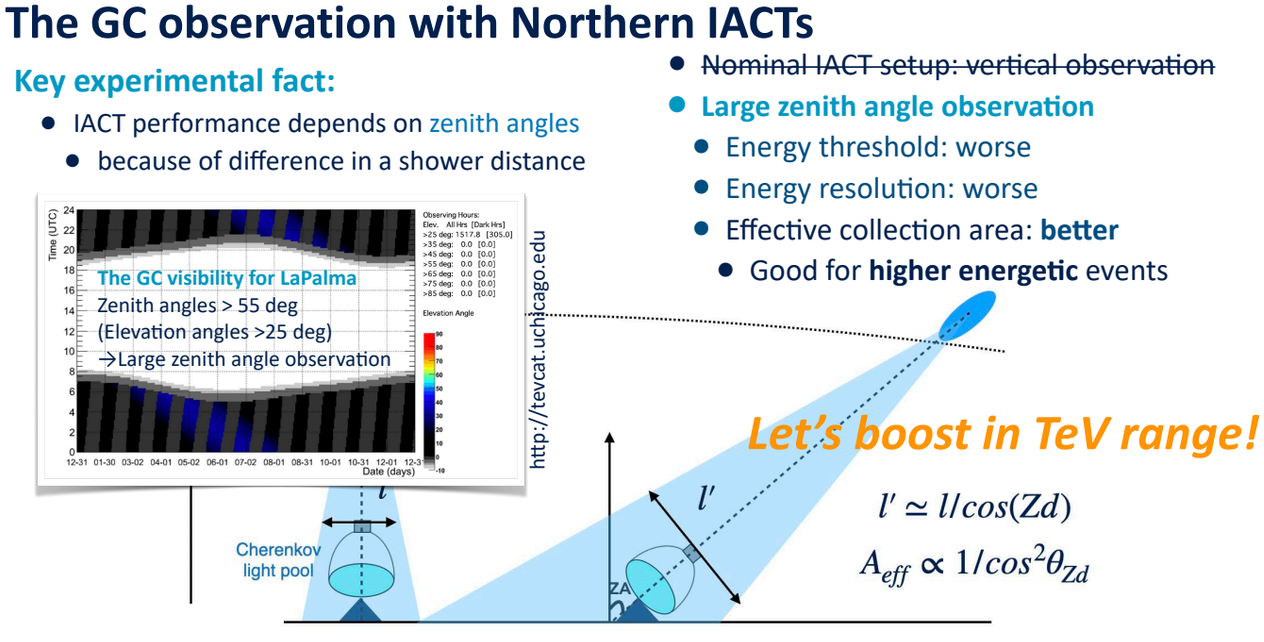
- **Cherenkov Telescope Array (CTA) Observatory** under construction
  - Collaboration of 25 countries, >1500 people
  - **North site: La Palma, Spain** (same as MAGIC), South: Paranal, Chile
- **Large-Sized Telescopes (LSTs)**: Φ 23 m, 4 / site, covering 20-200 GeV (and higher w/o MSTs), *successor of MAGIC with ~x10 sensitivity*
- **LST1** **Operational** since 2018, scientific observation since 2020
  - joint with MAGIC since 2024 (3 telescopes in total)
- **LST2-4** **Completed in 2026!** Will improve VHE-γ science, but not only.

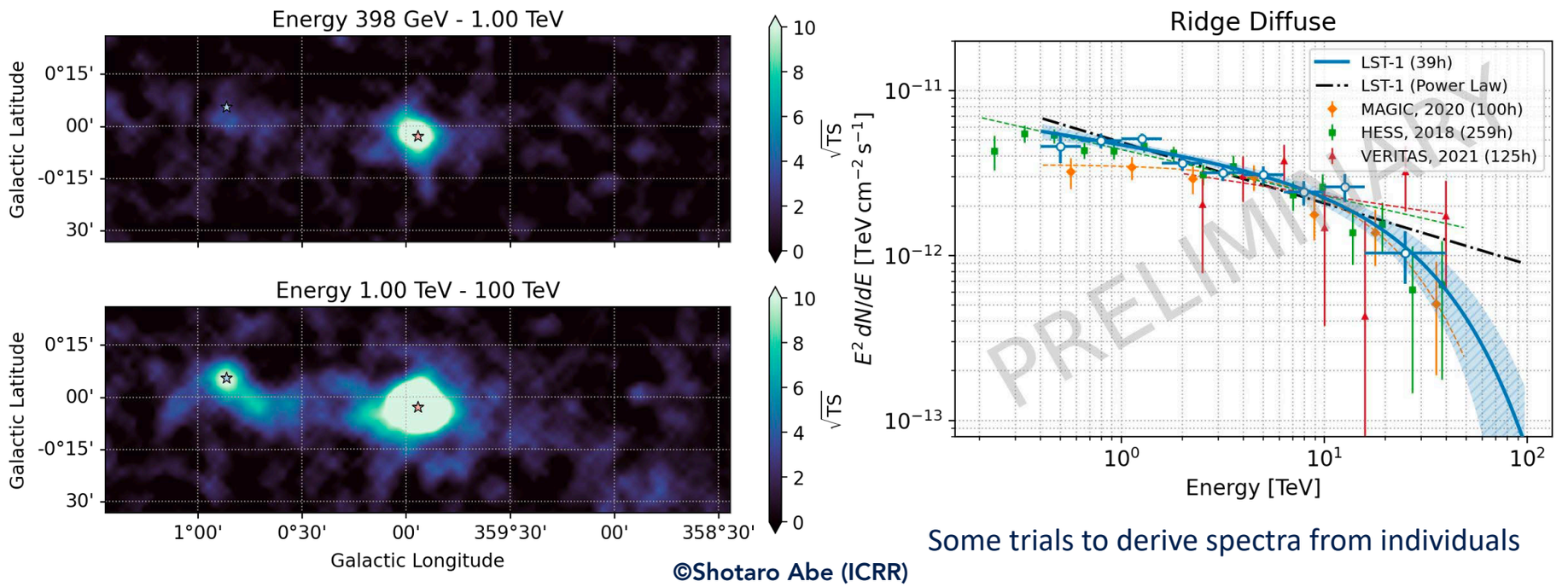
Gamma-ray telescopes for new topics of coming decades



DM Physics w/LSTs in North

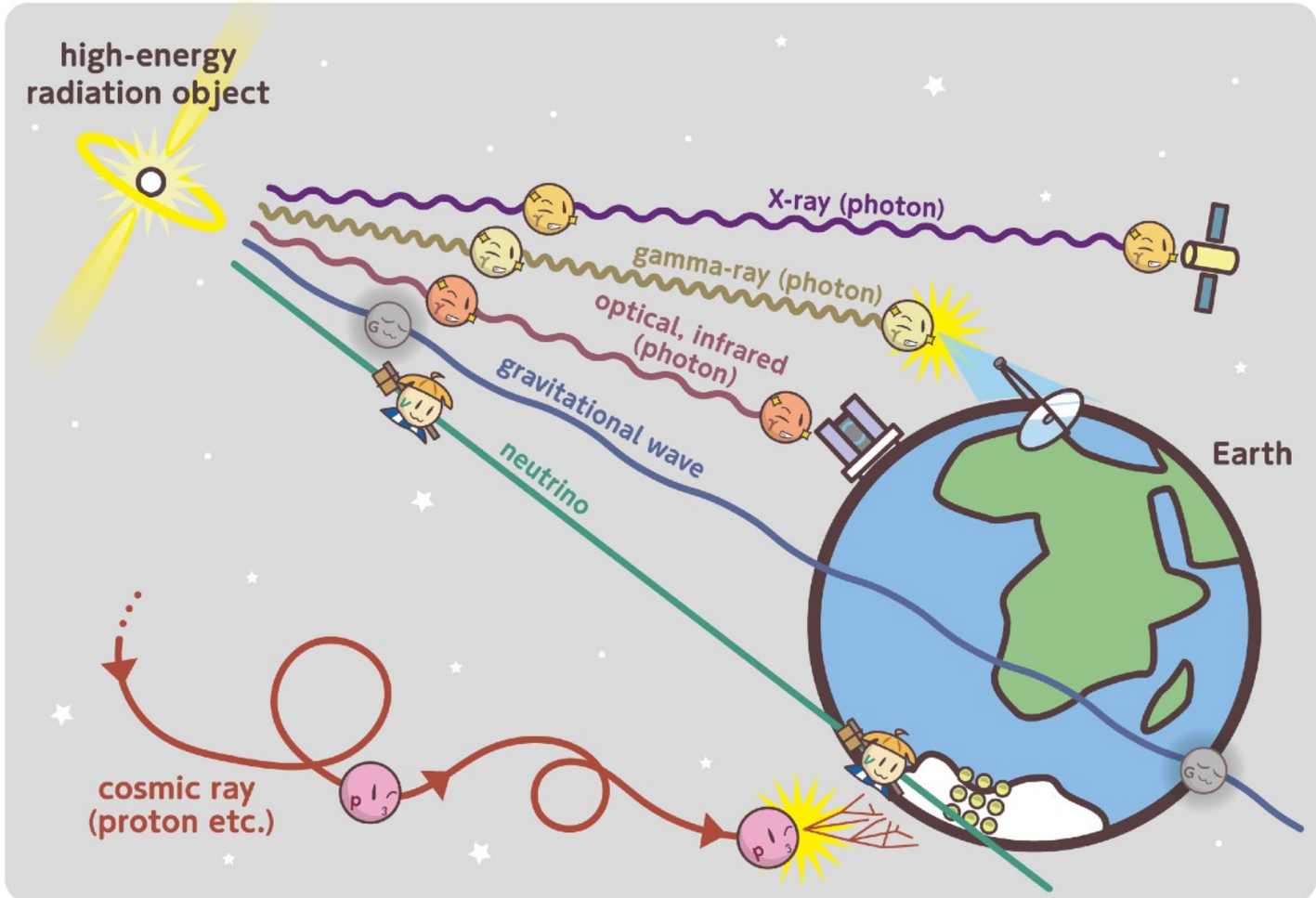
- (From Inada talk in KMI 2025)
- Galactic Center with a large zenith angle = higher E (>TeV)
  - Line searches in La Palma: complementary with the continuum search by HESS
  - proof-of-concept completed, ready for the observation
- Dwarf
  - Clean signal (if exists)
  - Uncertain J-factor, but better than the GC profile diff.



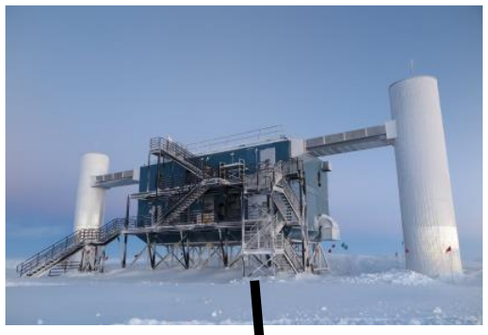


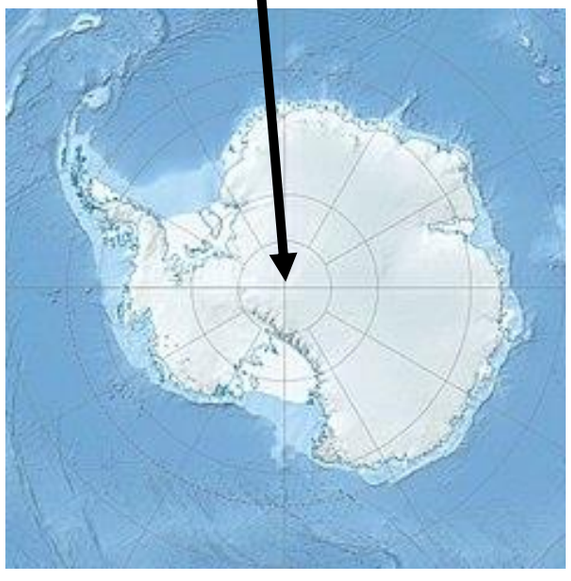
Transients/MM by IACTs?

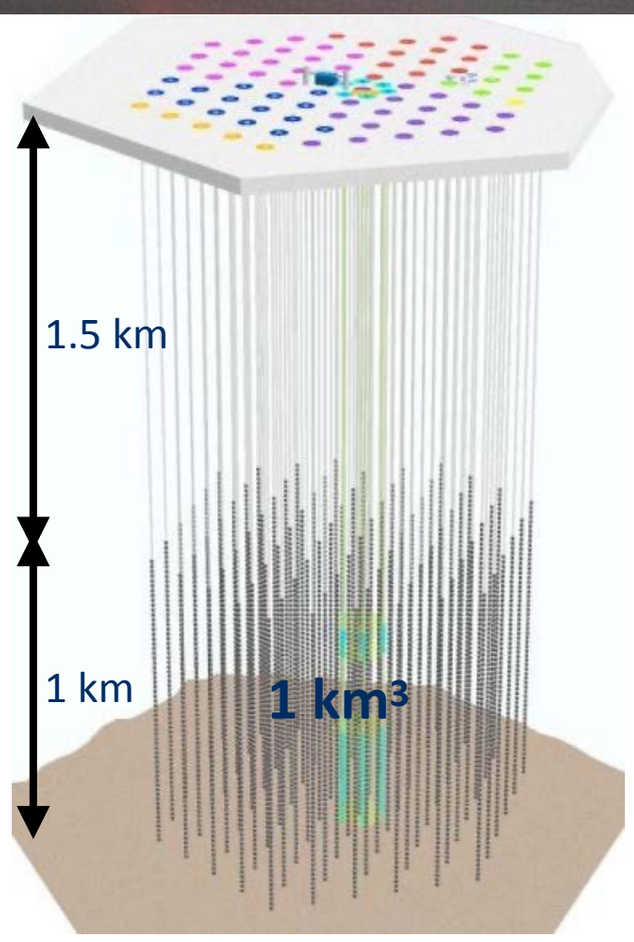
- GRBs. More EM transients?
  - AGN flares / SNe / TDE by opt/IR, Binaries by X, FRBs by radio,,, Updates for new telescopes (e.g., Vera Rubin)
- New era of non-EM **Multi-Messenger (MM) triggers / transients!**
  - **GW:** currently to be updated for LVK O5. Future: Einstein Telescope under the ground, LISA and DECIGO from space
    - More BNS/SGRB? VHE γ from SGRB? (Cf. GRB 160821B)
  - **Neutrino: currently IceCube** Near future; KM3NeT, IceCube-Gen2, more and more experiments
    - *Plenty of ν-γ science!*



IceCube

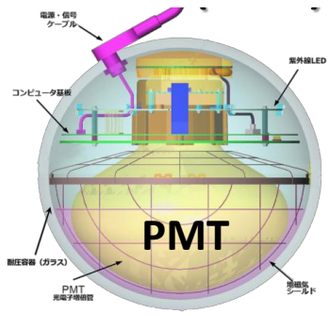






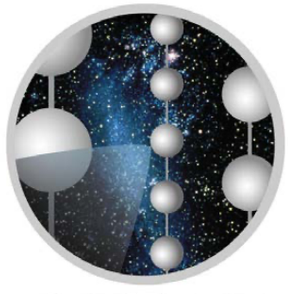
78 strings x 60 DOM/string (HE array) +
8 DeepCore separation: h 125m, v 17 m

5160 PMT modules
(DOMs) installed in
the ice of ~1 km³
under the South Pole

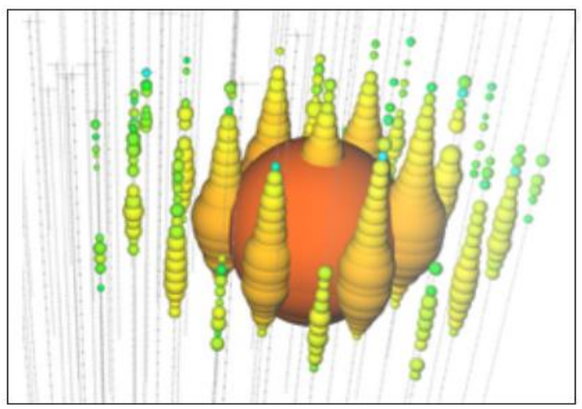


Construction started in 2002
All 86 strings since 2011

12 countries, >300 people



Flavor identification



cascade

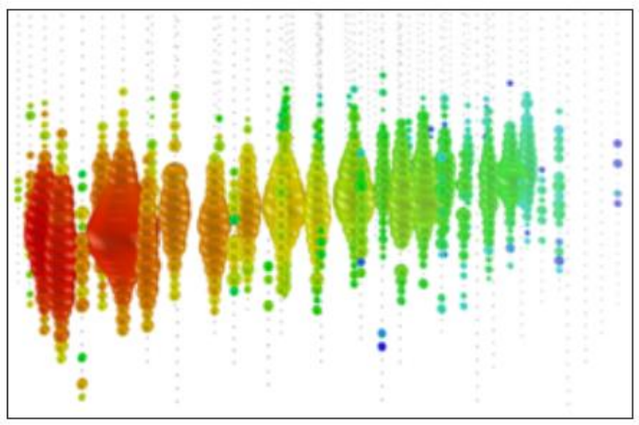
$\boldsymbol{\nu_e} + N \rightarrow e + X$

$\nu + N \rightarrow \nu + X$

σ_ψ~4-8°

$\sigma_E/E \sim 15\%$

Calorimetric, can be from South, with sub-optimal angular resolution



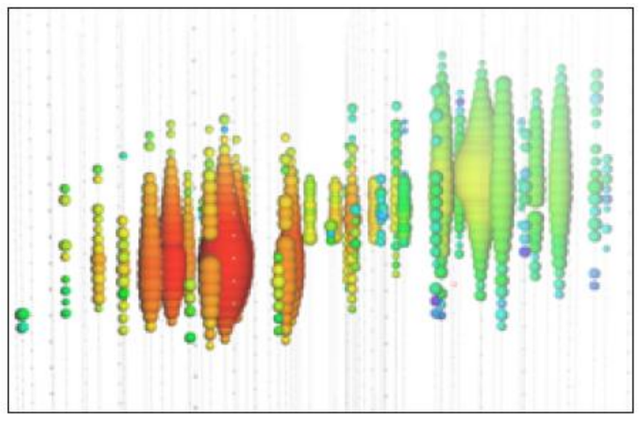
"Track-like"

$\boldsymbol{\nu_\mu} + N \rightarrow \mu + X$

σ_ψ~0.5°

$\sigma_E/E \sim 25\%$

Good to identify sources (in North), difficulty in the neutrino E reco



"Double-bang"
"Double-cascade"

$\boldsymbol{\nu_\tau} + N \rightarrow \tau + X$

↳ decay
65% hadronic, 18% to e
creates the 2nd cascade

Flight length ~ 50 m × E/PeV

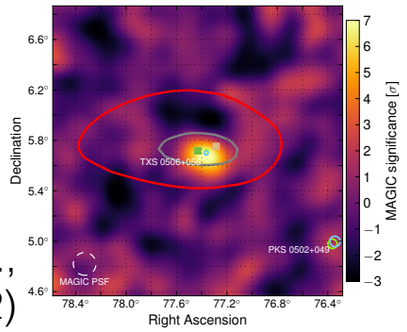
Low E tau candidate looks two cascades close to each other (See IceCube 2022)

ν-γ science: AGN?

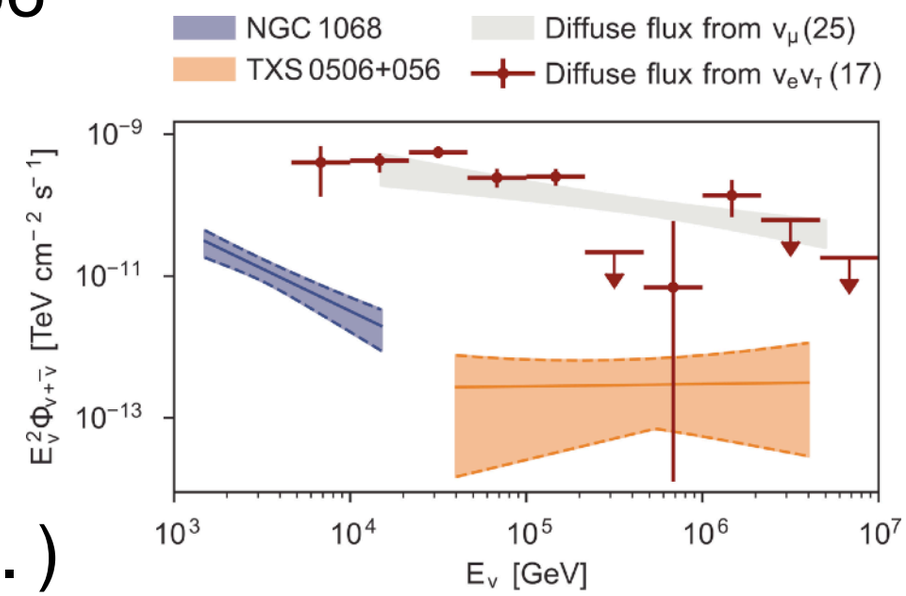
- The only ν-γ blazar IC170922/TXS 0506+056 but, no more ν blazar after ~10 years
  - Sub-threshold hints? Anyway, rare
- NGC 1068, Seyfert (radio-quiet AGN)
  - Not bright in gamma (UL by MAGIC)
  - Hints from other Seyferts (NGC 4151 etc.)
- **Masquerading** BL Lac? (e.g., Padovani+ 2022)

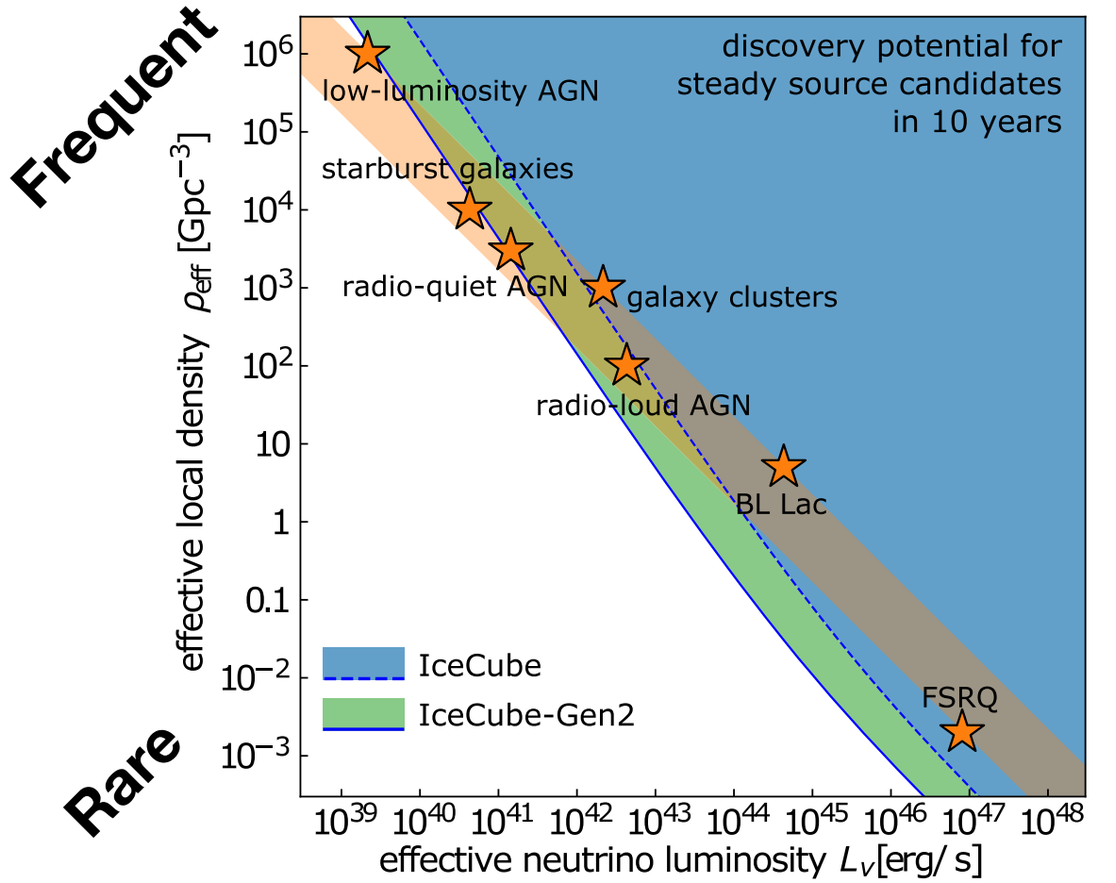


  - Featureless optical spectrum (w/o lines) mimicking BL Lac, but FSRQ intrinsically (lines are just hidden)
- “Steady” or stably variable in yrs? ‘Changing-look AGN’ (e.g., Ricci+ 2022) like NGC 4151? ***Monitoring of the γ-bright blazars is still important***



IceCube Coll., Science (2018, 2022)

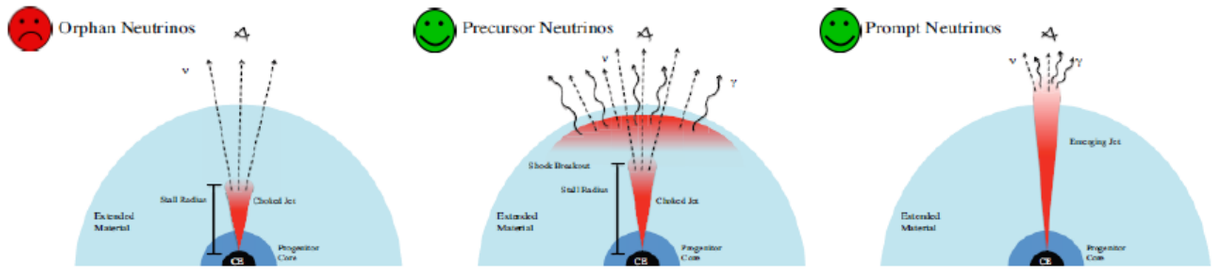




Dark (Aartsen+ 2021) **Bright**

ν-γ science: Transients? Galactic?

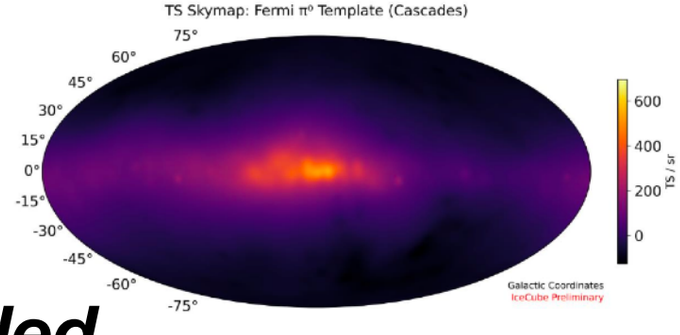
- Same study for transients: normal GRBs not dominant, **LL GRBs & SNe** still alive
  - LL GRB connected to failed GRBs?



(Fig from Senno+ 2016)

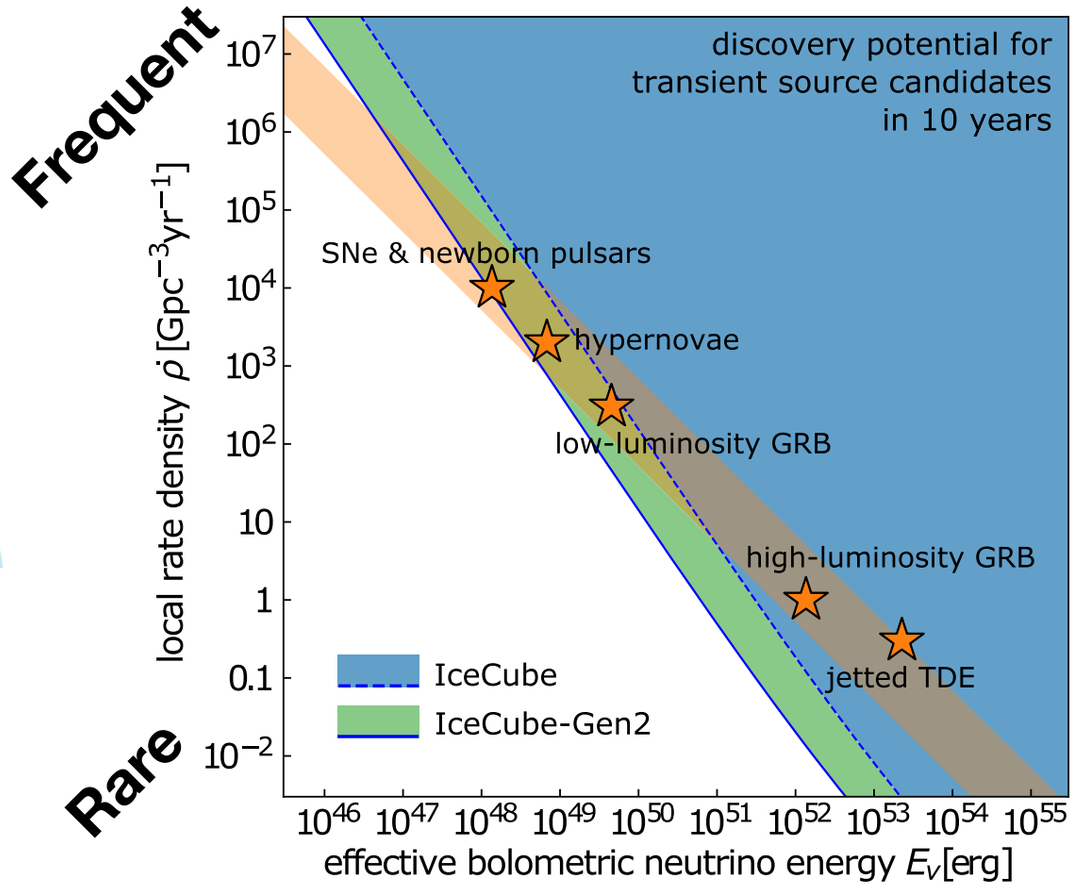
  - Interacting SNe: Dense ISM around. a possible new VHE γ source class

- Galactic neutrinos
  - IceCube reported (2023) 4.5 sigma from Galactic Plane (only **cascades**)
    - TS map with a template assumed
  - >5 σ with **tracks**, w/ a different template (2025)

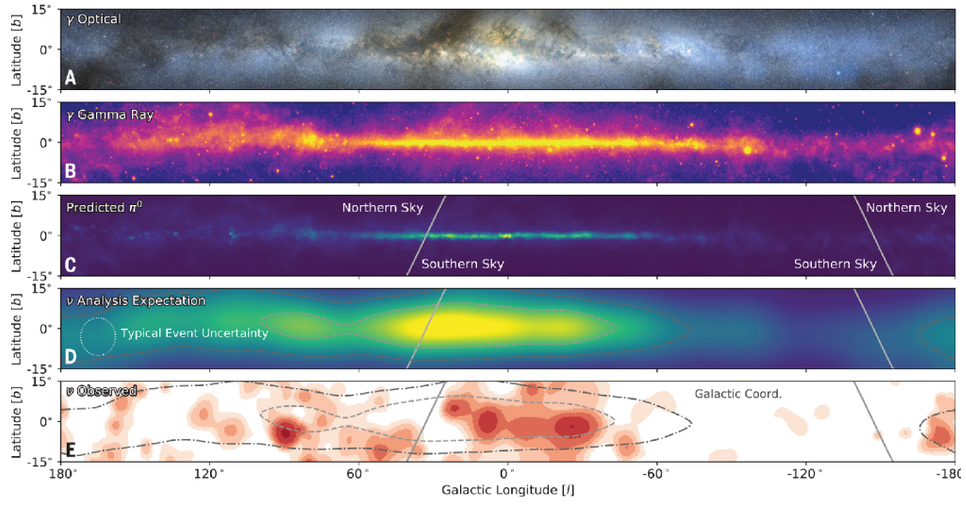


Thiesmeyer+, ICRC 2025

More follow-ups needed



Dark (Aartsen+ 2021) **Bright**

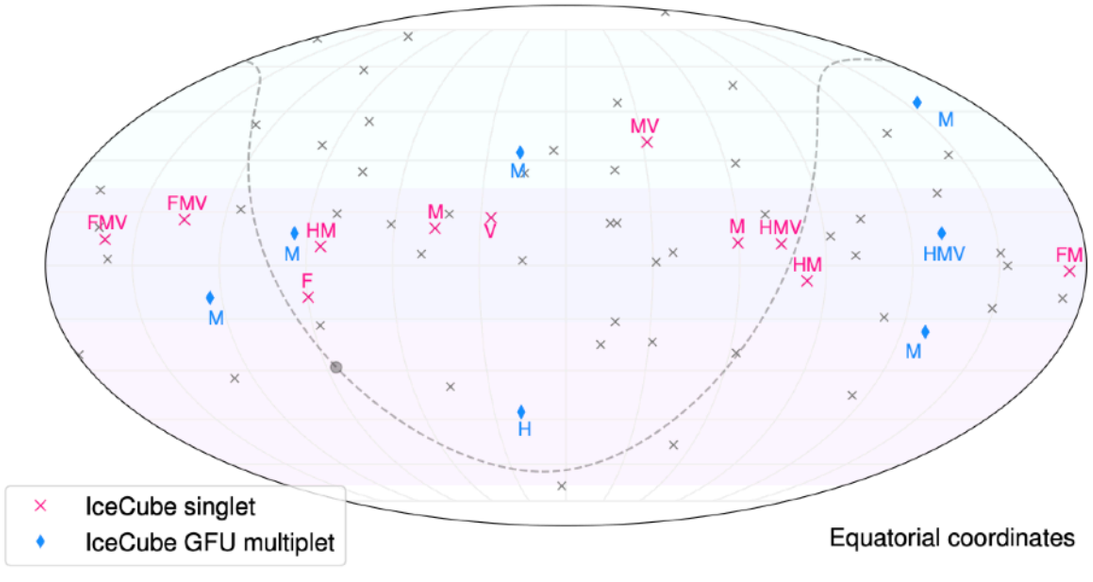


IceCube Coll. Science (2023)

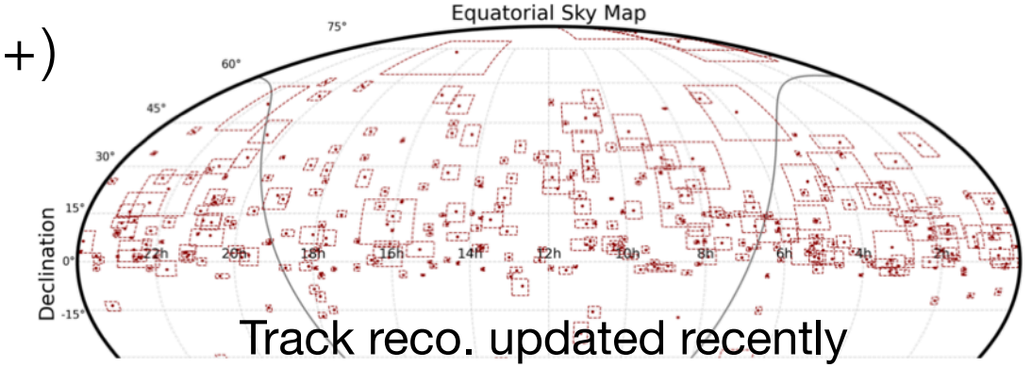
Gamma-ray follow-up *updates*

IceCube alerts currently 2x2 = 4 kinds

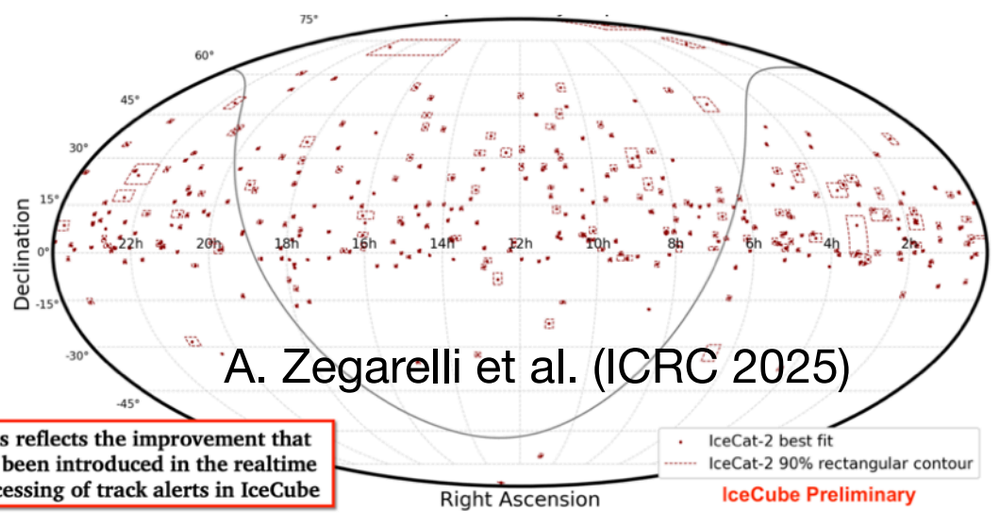
- **Singlet**: public via GCN
  - Track (Gold/Bronze, ν_μ): horizontal ~ upward at South = **Good for CTAO-N** ,,, but can come from far, not optimal for VHE γ under EBL → **Following up only good** (170922A-like) events
    - Reco. improved, clearer src ID (Zegarelli+)
  - Cascade (ν_e): ang. reso. 5-10 deg is not realistic to follow → Possible with **tiling** (for GW) and **large FoV** of LST (4.5 deg)
    - New inclusive reco. w/ NN (Rosted+)



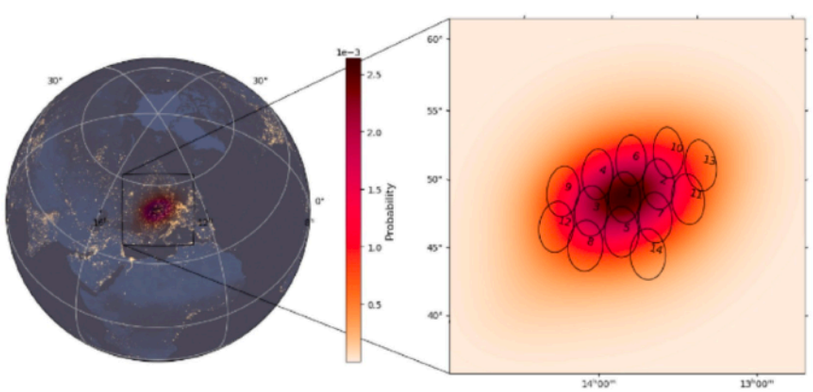
(F. Schuessler+, ICRC(2023) 1501)



Track reco. updated recently



A. Zegarelli et al. (ICRC 2025)

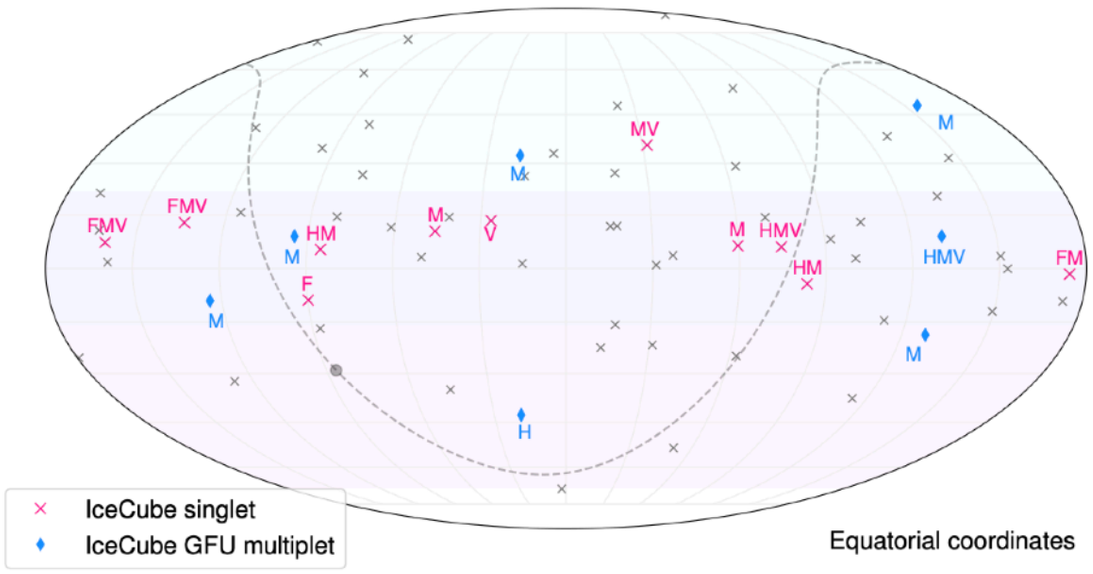


A. Carosi+, ICRC(2021)

Gamma-ray follow-up *updates*

IceCube alerts currently 2x2 = 4 kinds

- **Singlet**: public via GCN
  - Track (Gold/Bronze, ν_μ)
  - Cascade (ν_e)
- **Multiplet**: currently private under MoU
  → will be public soon (Mancina+, 2025)

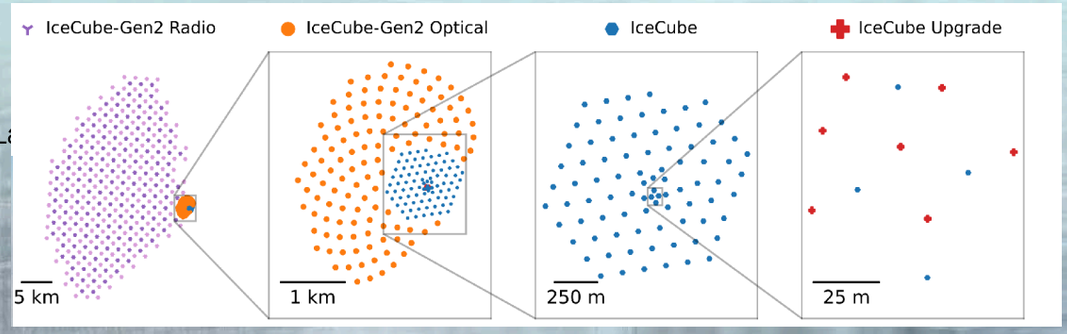


(F. Schuessler+, ICRC(2023) 1501)

- **Gamma Follow Up** (GFU, ν_μ)
  Multiple ν evts + correlation with known γ-ray objects
  Preselected gamma source list (mostly blazars) → **Updating the list with more X-ray AGN, TeV sources, Galactic,,,** with recent knowledge (KN+)
- **Generic alert** without any correlation (ν_μ, ν_e)
  Currently very rare, due to the optimization (algo & thres.) for the above
  → **New alert** being developed in Chiba (Shimizu+), e.g., for nearby SNe

Multiplet has a larger flux than singlet, favoring nearby sources
Good for 'unknown' searches with VHE γ-rays (w/EBL)

Updates of instruments: IceCube-Gen2 (2030's)



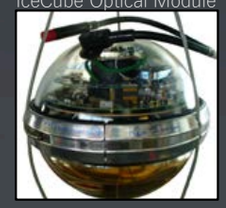
3km

1km

IceCube-Gen2 array
(1.34km~2.69km depth)

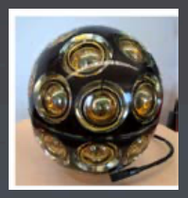
IceCube array (1.45km~2.45km depth)

IceCube Optical Module



IceCube-Upgrade Optical Modules

dia 36cm

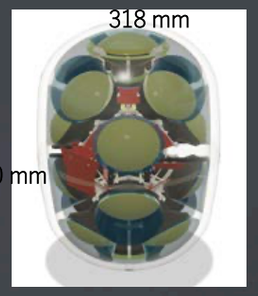


3" x 24 ch

dia 30cm



8" x 2 ch



DeepCore
IceCube-Upgrade array

120 strings x 80 DOM
separation: h 240 m, v 17 m

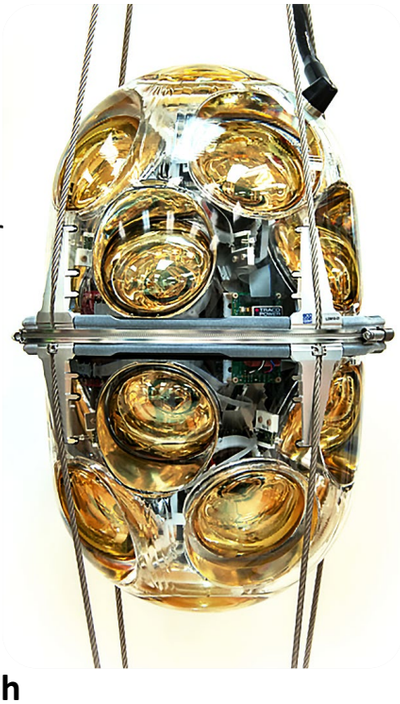
IceCube Gen2

- 9600 DOMs ~= x2 of Gen1, but ~x8 effective volume due to **~4 x higher sensitivity of each DOM**
  - Key development: **multi-PMT** DOM (Chiba, UWM, etc.)
  - Need **better calibration** among the DOMs
- ~x2 better ang. resolution, ~x5 point source sensitivity

LOM-18:
ICEHAP Chiba

- **18× 4" PMTs** in 3 layers per hemisphere:

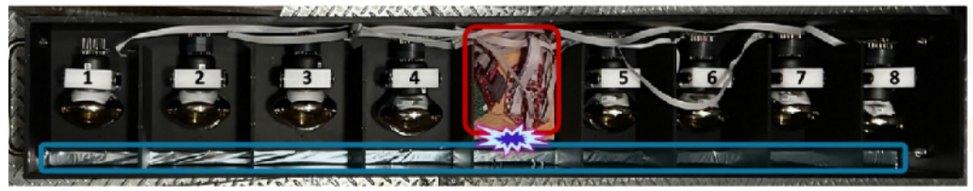
  2 additional 4" PMTs @ top / bottom of module



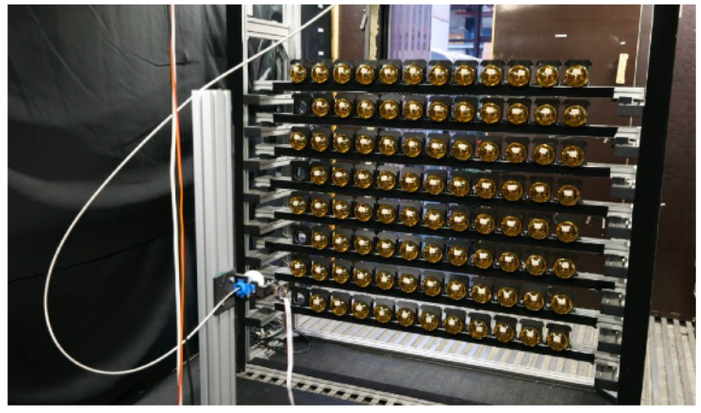
► **Ø 31.8 cm, 54.0 cm length**

DOM developments status

- Design: Merging Chiba and UWM solutions
  (E.g., Butterfield & Wendt, arXiv:2604.08785)
  - Pressure vessel: low BG one by Okamoto
  - 4” PMTs by Hamamatsu & NNVT
    - >100k mass inspection, various methods
    - # PMTs / DOM still under discussion
  - Gel Pads: >100k mass prod. with QC
  - Mechanics and electronics baseline agreed
  - **Calibration devices** (at Apex region) not settled
    - Brighter light source (for a larger separation)
- Assembly: **not yet fully settled**
  - Teams joining (e.g., Thai)
    Still a good timing to join
- Production, logistics, etc.:
  Not yet fully planned

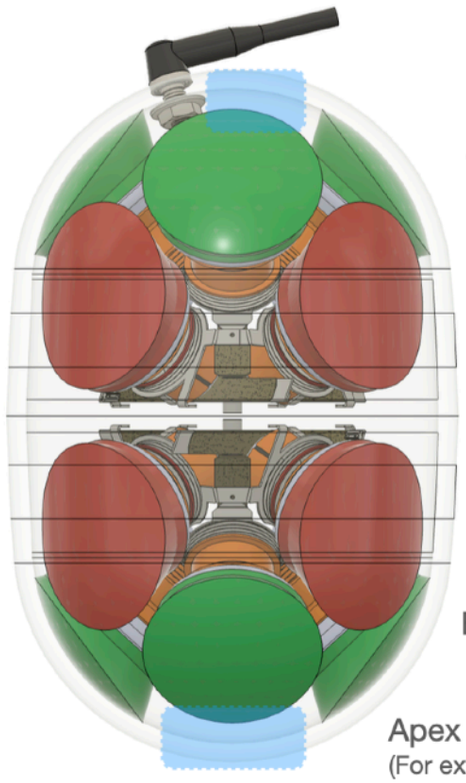


x8 by Chiba



x90 by DESY

R. Abbasi et al 2024 JINST 19 P07038



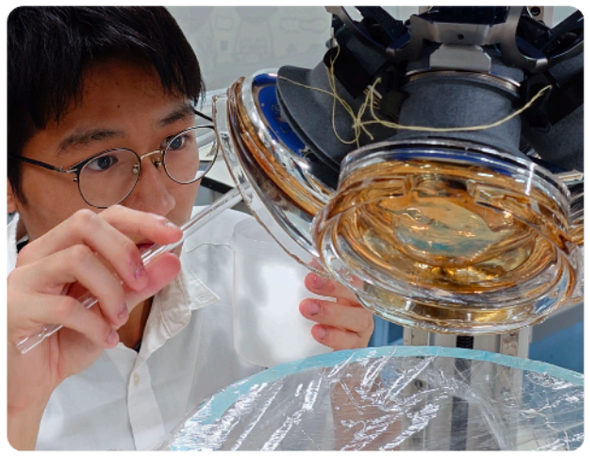
From Yuya Makino (NU alumni) at Madison

Polar layer

Equatorial layer

Apex region
(For extra sensor/device ideas)

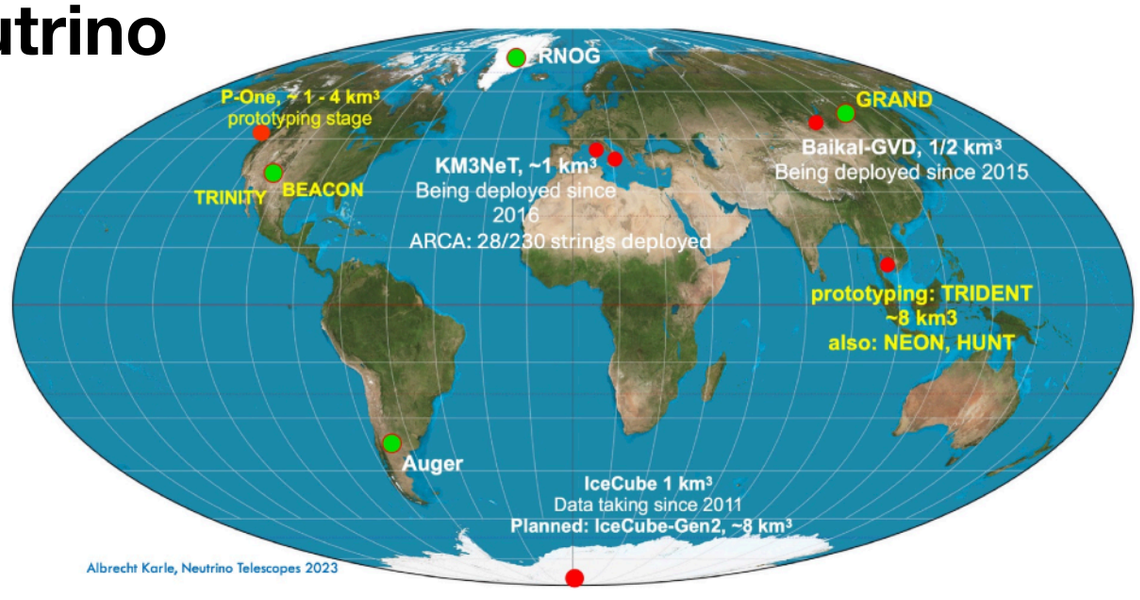
Tentative Gen2 DOM design



...**application of un-cured gel** to **rim** of gel pads...

Near future of ν-γ MM astronomy

- **VHE gamma** is already in shape
  - Experiences in previous/current experiments (Cangaroo, MAGIC,,,)
  - Hardware contributions to CTAO since years, as community efforts. Now starting to harvest physics (Do not forget it!)
  - γ-ray researchers are now in various places, which is sustainable
- Let's try similarly in **high energy neutrino**
  - Contributions (both hardware & physics) since years, in Chiba
  - Next-gen experiments: Contributions as a community, in order to harvest physics later



- More experiments coming (after the Nobel prize ☺🏅)
  Experiences now are crucial to work in various places later, which will be eventually good for the sustainability of community

Summary



- VHE gamma-ray astronomy with Imaging Atmospheric Cherenkov Telescopes: AGN, PeVatrons, GRB, & even Dark Matter physics
- 4 **LSTs of CTAO** North at La Palma have been just completed
- Transient phenomena, often triggered by non-EM messengers: multi-messenger astronomy with neutrino is not a dream any more
- **IceCube** at South Pole started the high-energy neutrino astronomy from AGN, but there is still a big puzzle for the neutrino emitters



- Transients and Galactic sources should be also investigated, by updating the follow-up strategy
- Developments for the next, such as IceCube-Gen2, **needed now** for the future ν-γ MM astronomy