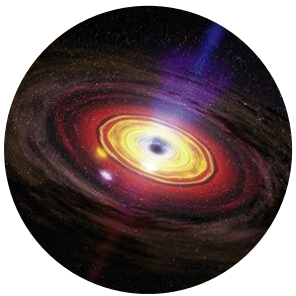
The IceCube Neutrino Observatory and future extensions

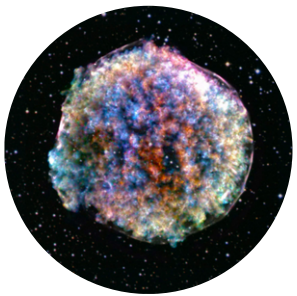
Partikeldagarna 2024 – 21st of October 2024

Jakob Beise presenting for IceCube Sweden

Neutrinos are cosmic messengers

- Neutrinos are produced along with gamma-rays and cosmic rays in cosmic accelerators

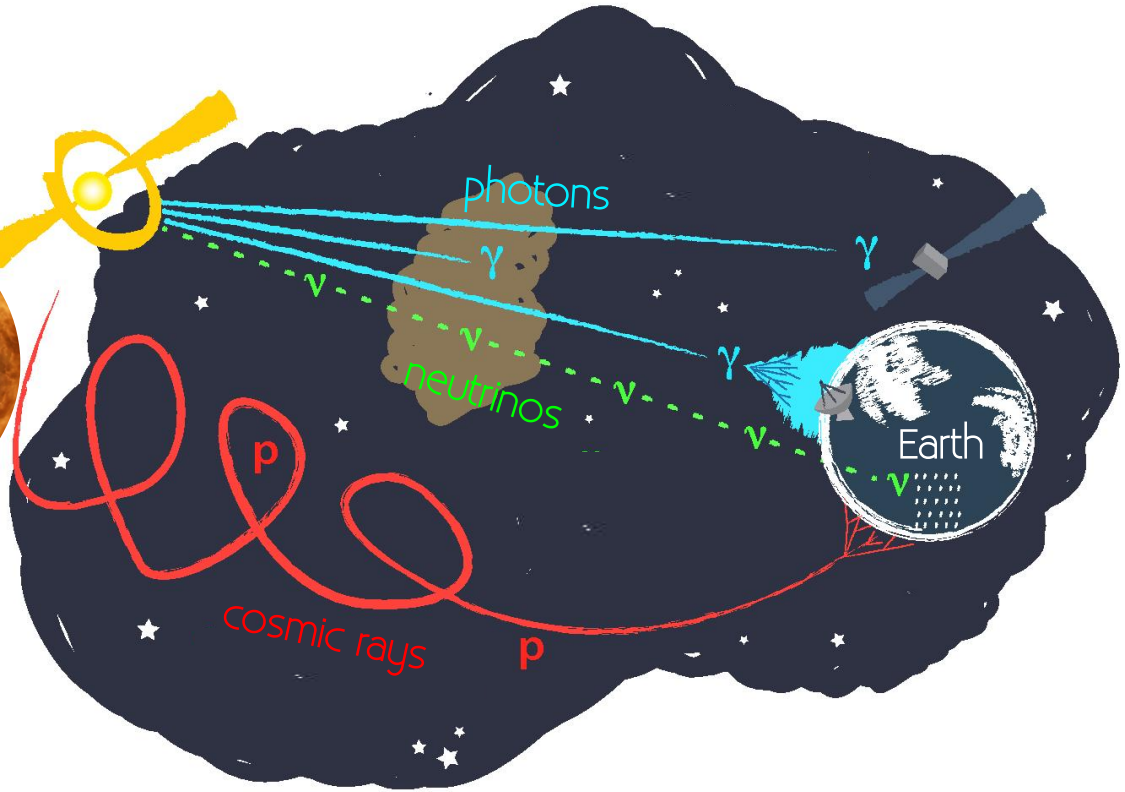

Credit: D. Berry


Credit: T. Sato et al


Credit: M. Kornmesser

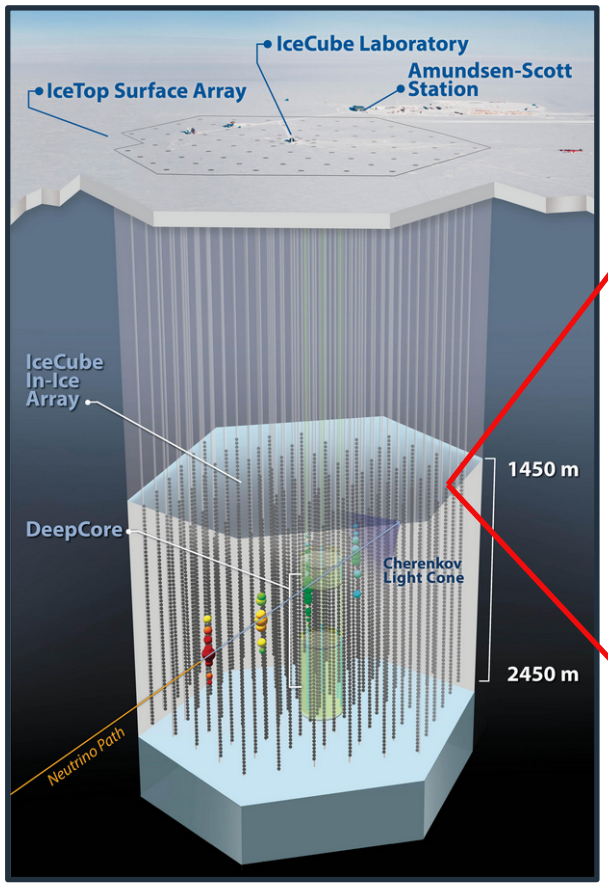
- Neutrinos point back to their sources and can reveal the sources of cosmic rays


Credit: particlezoo.net

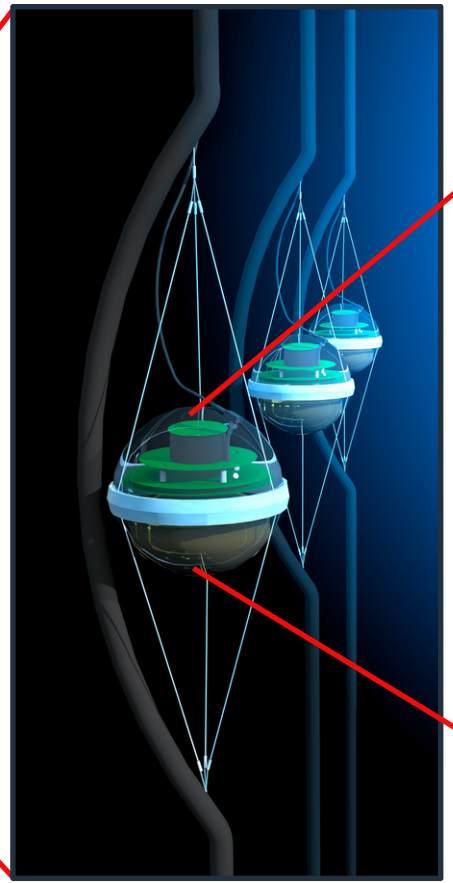


IceCube is a 1 km^3 detector frozen into the South Pole glacier

5160 sensors over 1 km^3 (1 Gton)

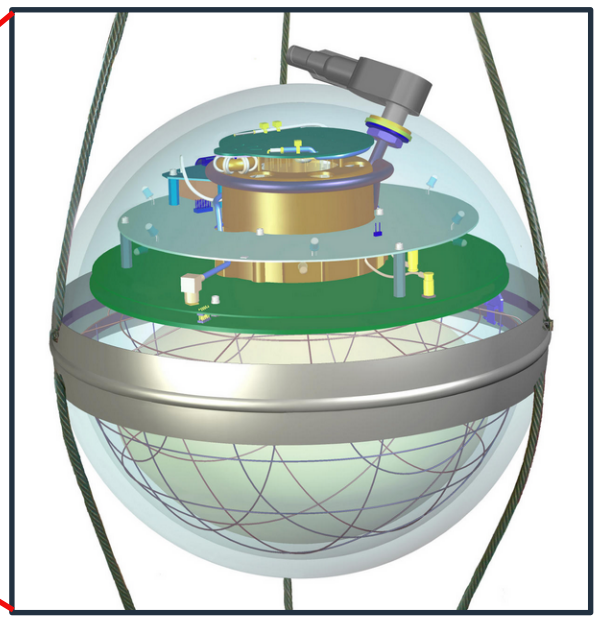


86 cables ("strings")

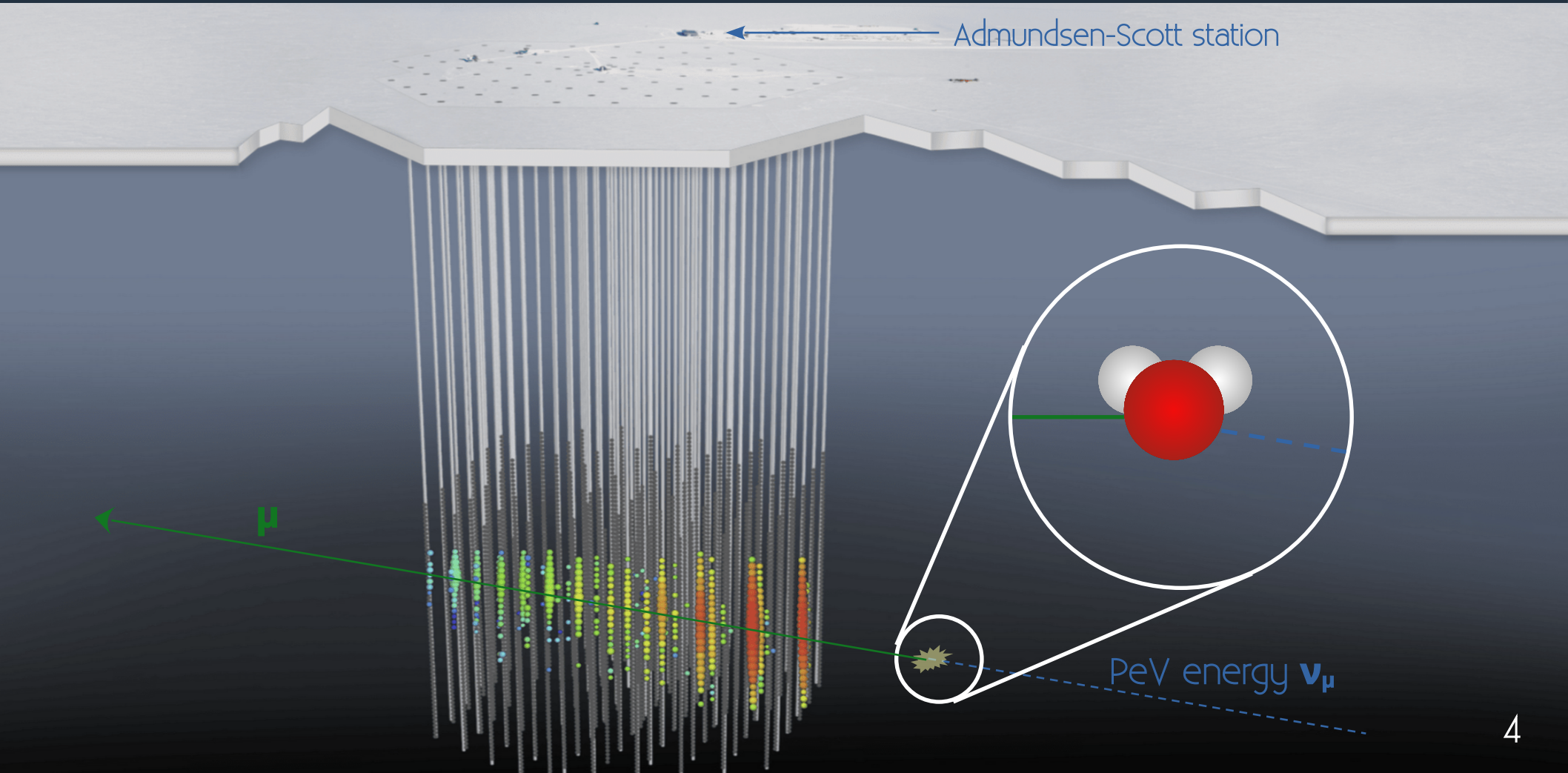


Digital Optical Module (DOM)

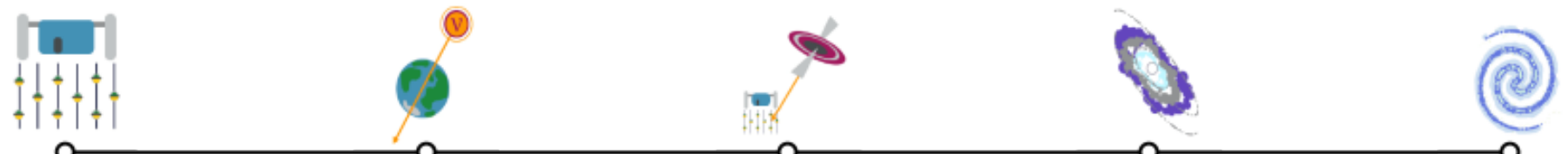
25 cm down-wards facing PMT



IceCube detects the Cherenkov light from charged secondaries



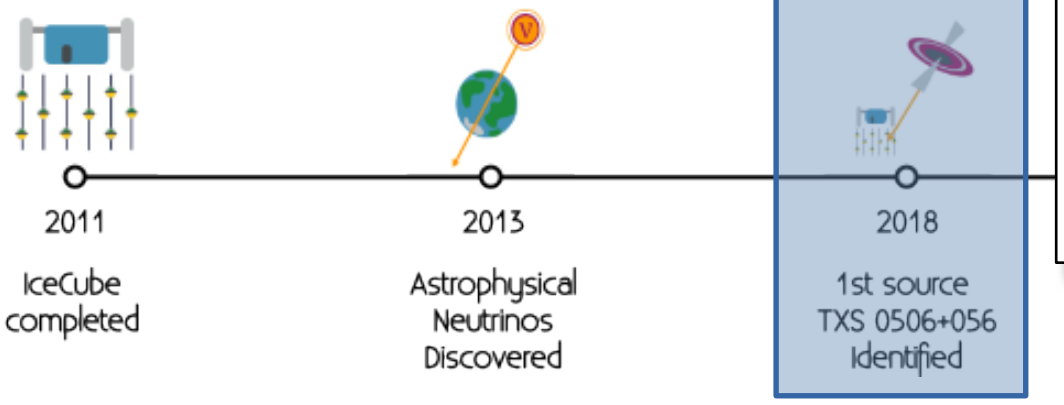
IceCube found three likely sources!

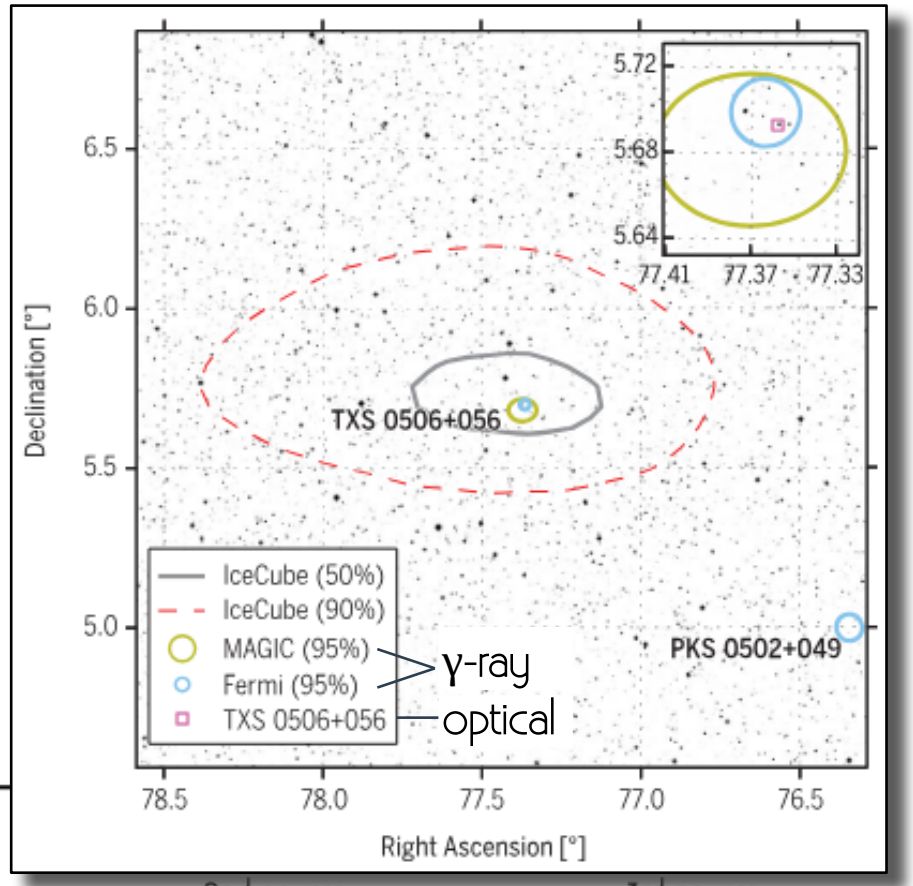


TXS 0506+056 is an extragalactic transient of HE neutrinos

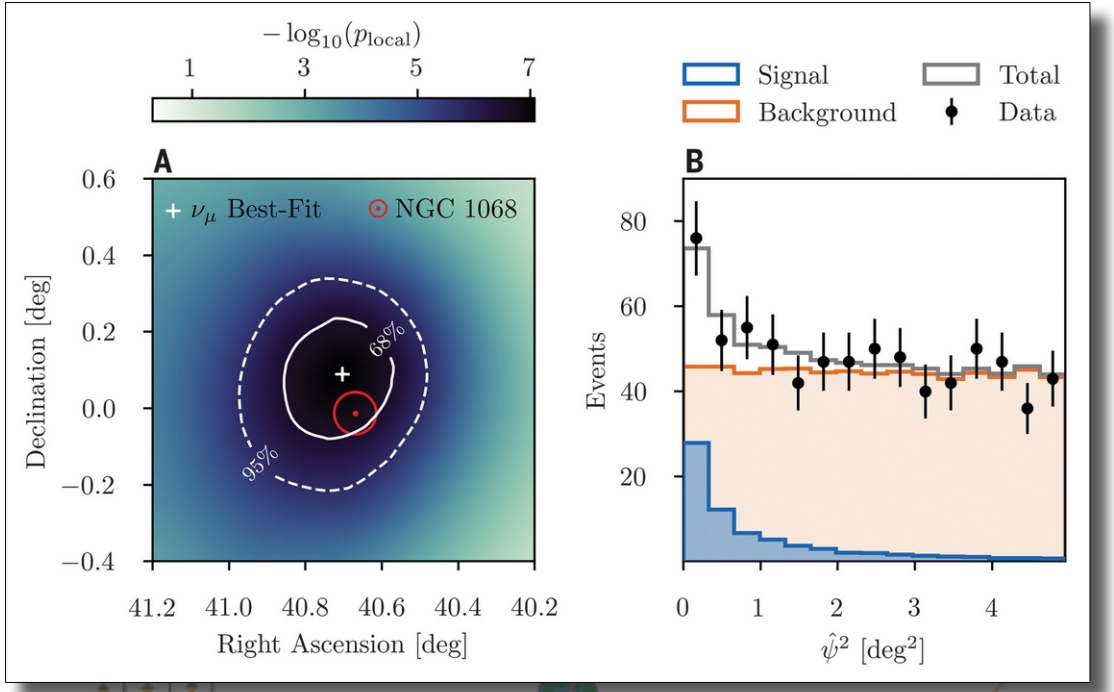
- A 290 TeV neutrino from the direction of a flaring γ-ray blazar triggered multi-wavelength follow-up
- Multimessenger milestone

Science 361, 146 (2018)



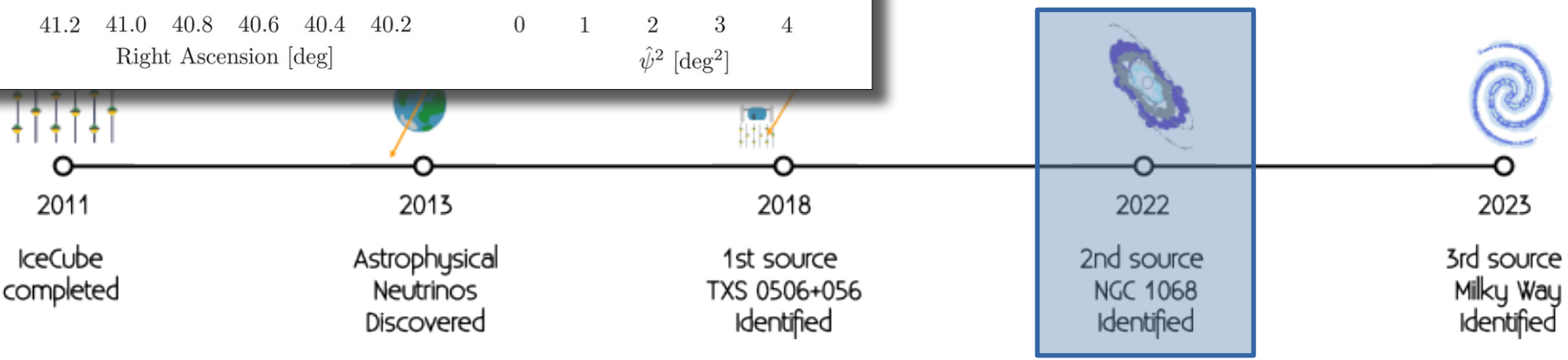


NGC 1068 is an extragalactic, steady-state source of HE-neutrinos

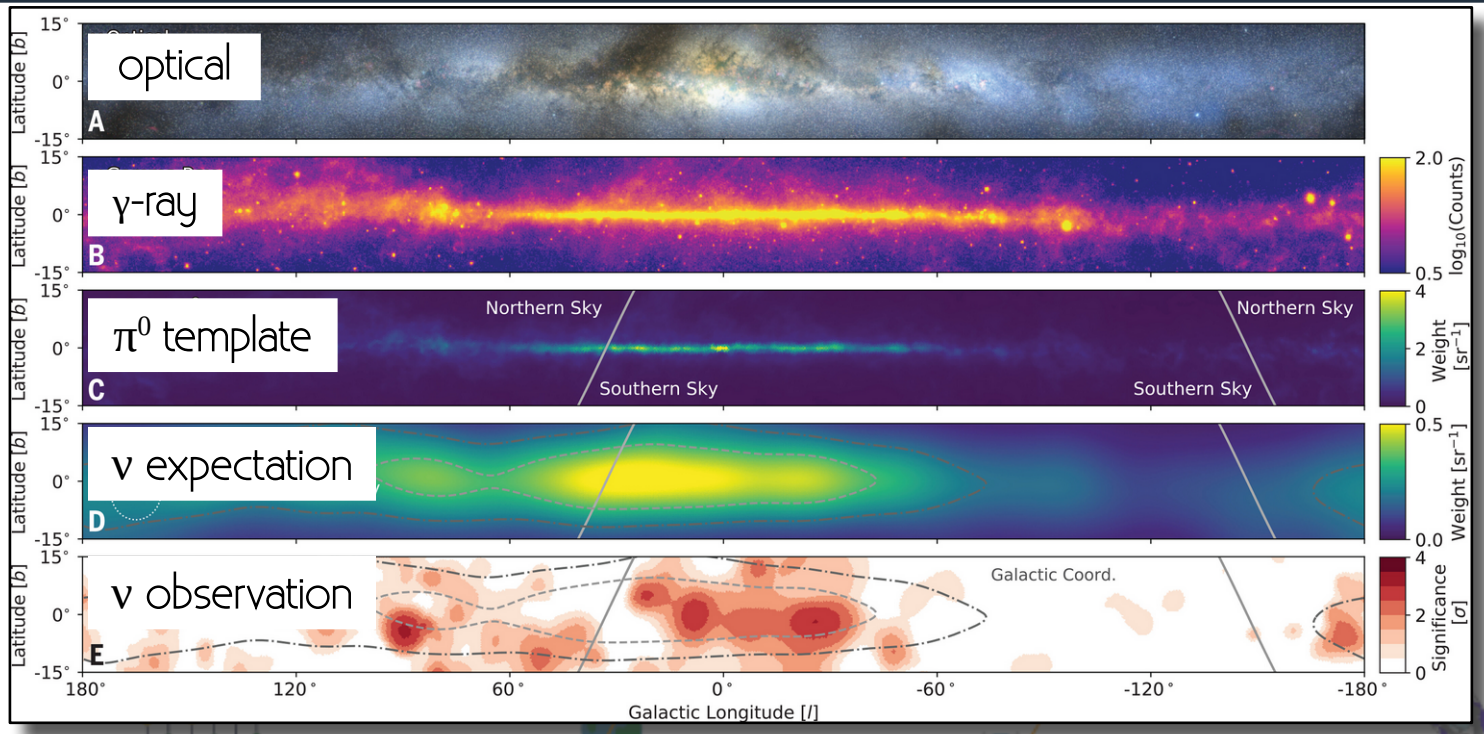


- NGC 1068 identified among 110 gamma-ray sources at 4.2σ global significance
- Neutrino flux >O(10) higher than γ-ray flux

Science 378, 538-543 (2022)

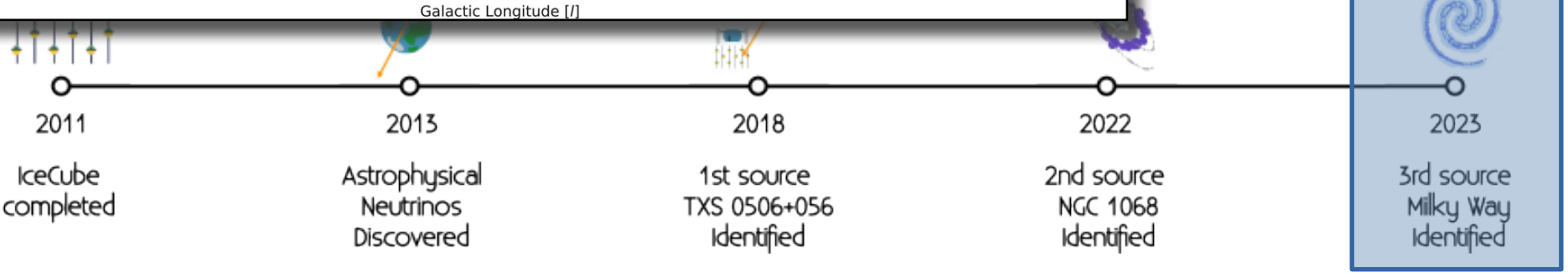


Our Galactic plane is a steady-state source of HE neutrinos



- π-decay produces γ-rays and neutrinos
- 4.5σ significance excess for π^0-template over background hypothesis

Science 380, 1338-1343 (2023)

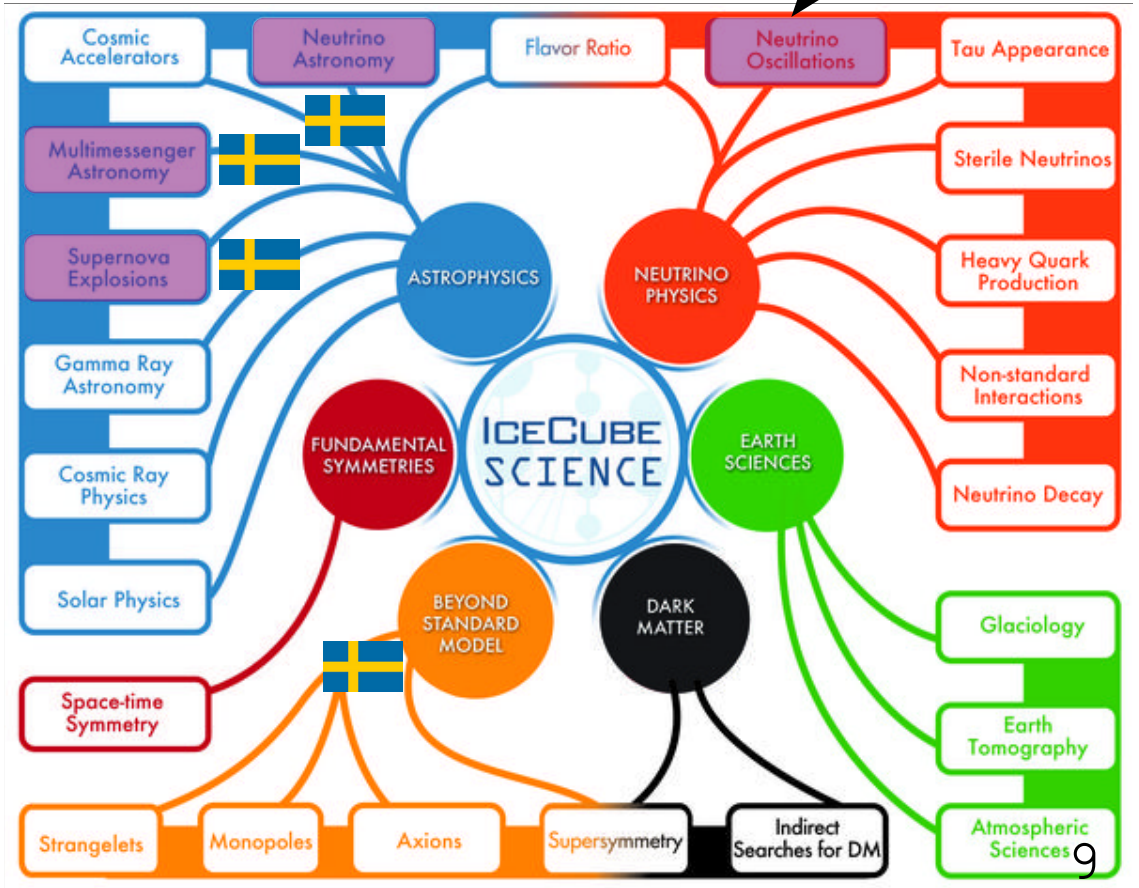


IceCube is a multi-purpose detector

- Detected flux of high-energy extraterrestrial neutrinos in 2013
- Identified galactic and extra-galactic sources
- IceCube is a multi-purpose detector

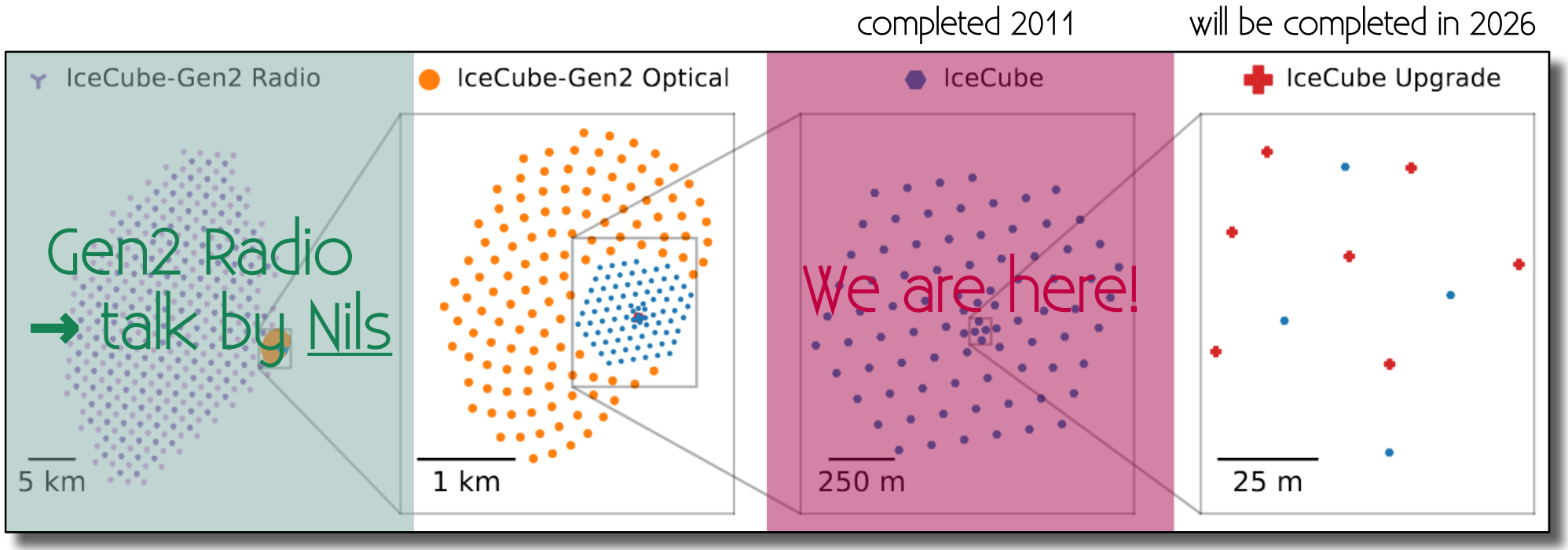
Most precise measurement of atm. **ν** oscillation (5-100 GeV)
arXiv:2405.02163 (PRL accepted)

Current IceCube Sweden Activities

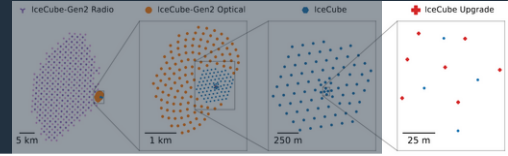


The future of IceCube

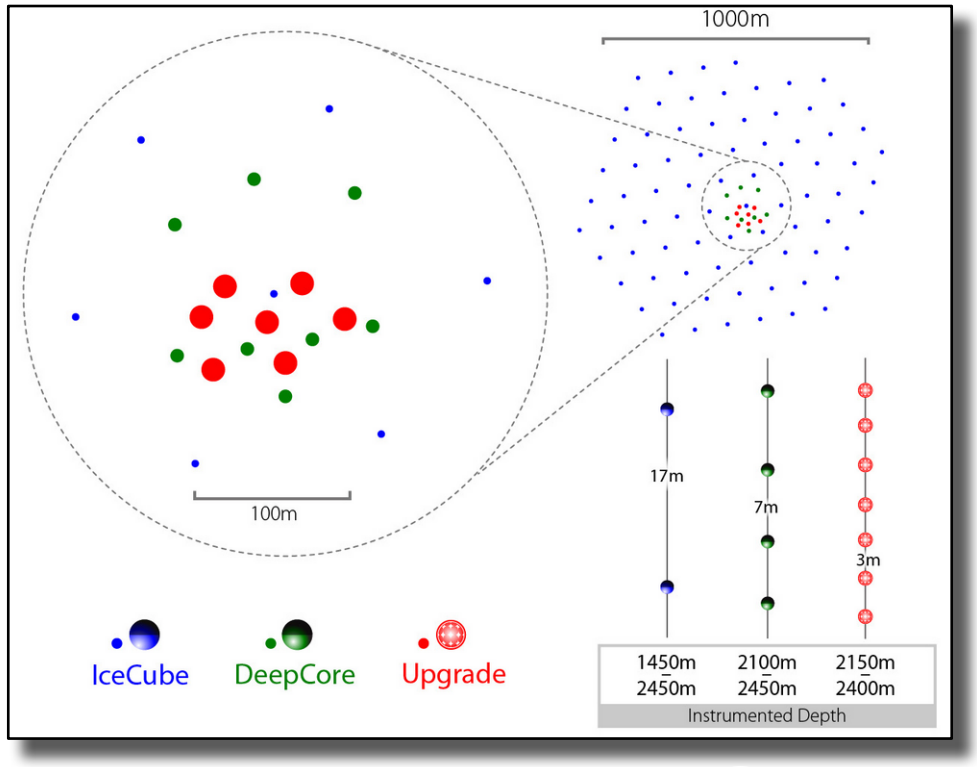
IceCube-Gen2 TDR (2023)

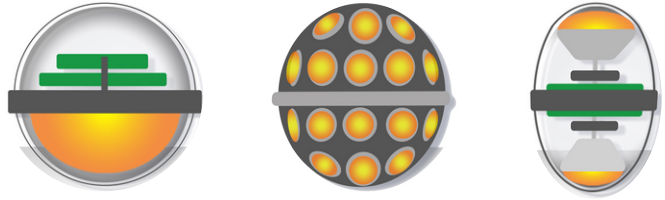


IceCube Upgrade

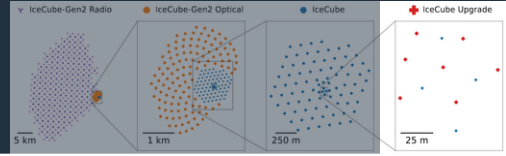


- 7 new "strings" with ~700 new sensors, preparations on-going, drilling 2025/26
- Science Goals:
  - Neutrino oscillation studies ~1GeV
  - Improved ice calibration (re-analysis of existing data)
  - Testbed of new sensors for Gen2
- Swedish contributions:
  - Sweden Camera 2.0, Hexatronic cables, Swedish Drillers



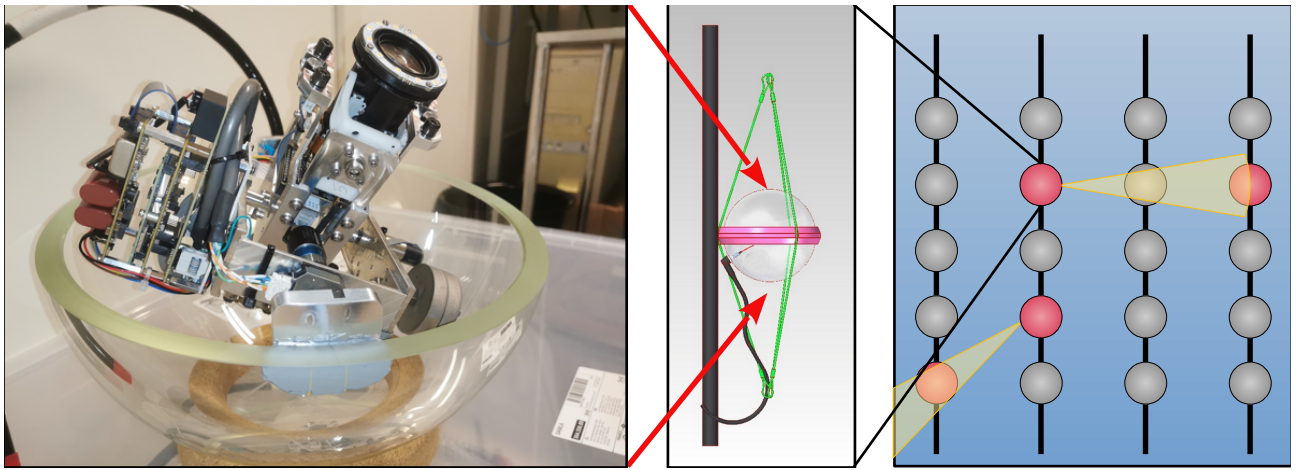


Swedish Hardware contributions – SweCam 2.0

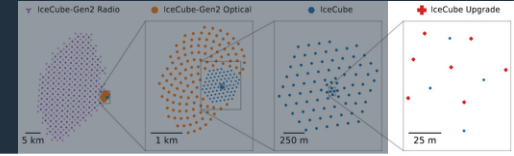


- Low-light sensitive, steerable, focusable camera
- Improve understanding of light propagation in ice through visual inspection (critical for calibration)
- 7 cameras will be installed

Sweden Camera 2.0



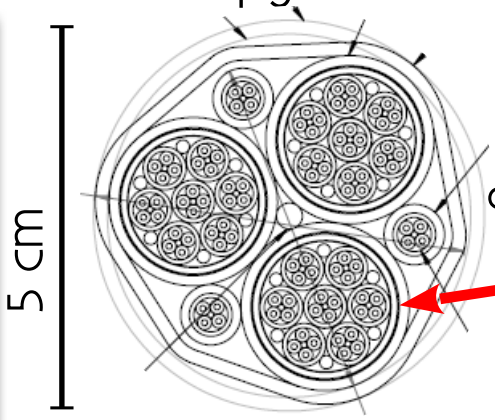
Swedish Hardware contributions – Cables

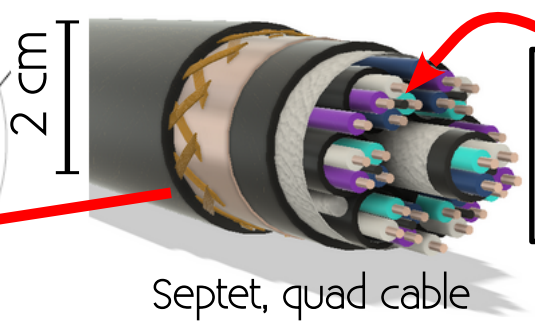


IceCube Lab

surface cables

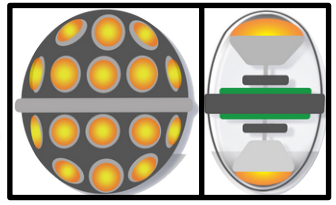
Upgrade – Length: 18.4 km, Price: 17.5 MSEK





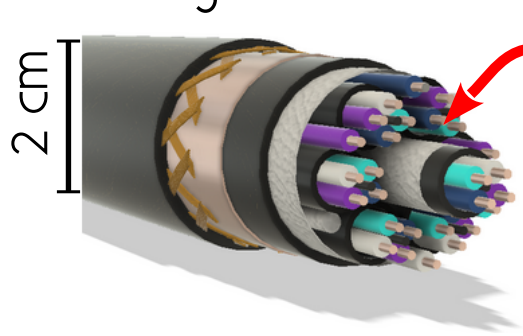
Septet, quad cable

x6

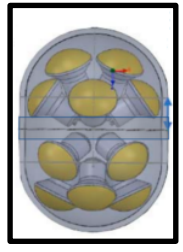


downhole cables

IceCube-Gen2 – Length: >300 km



x12

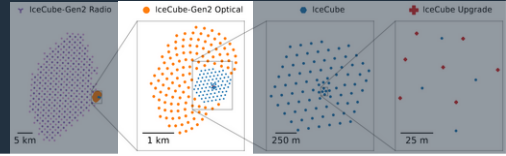


Requirements

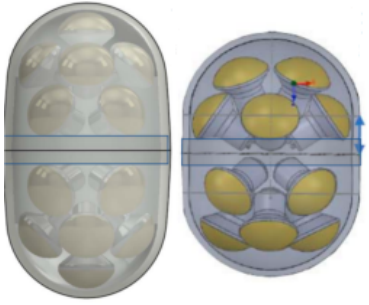
- Low attenuation
- Little cross-talk
- Good pulse timing
- Extreme conditions

Manufacturer: Hexatronic

IceCube-Gen2 Optical

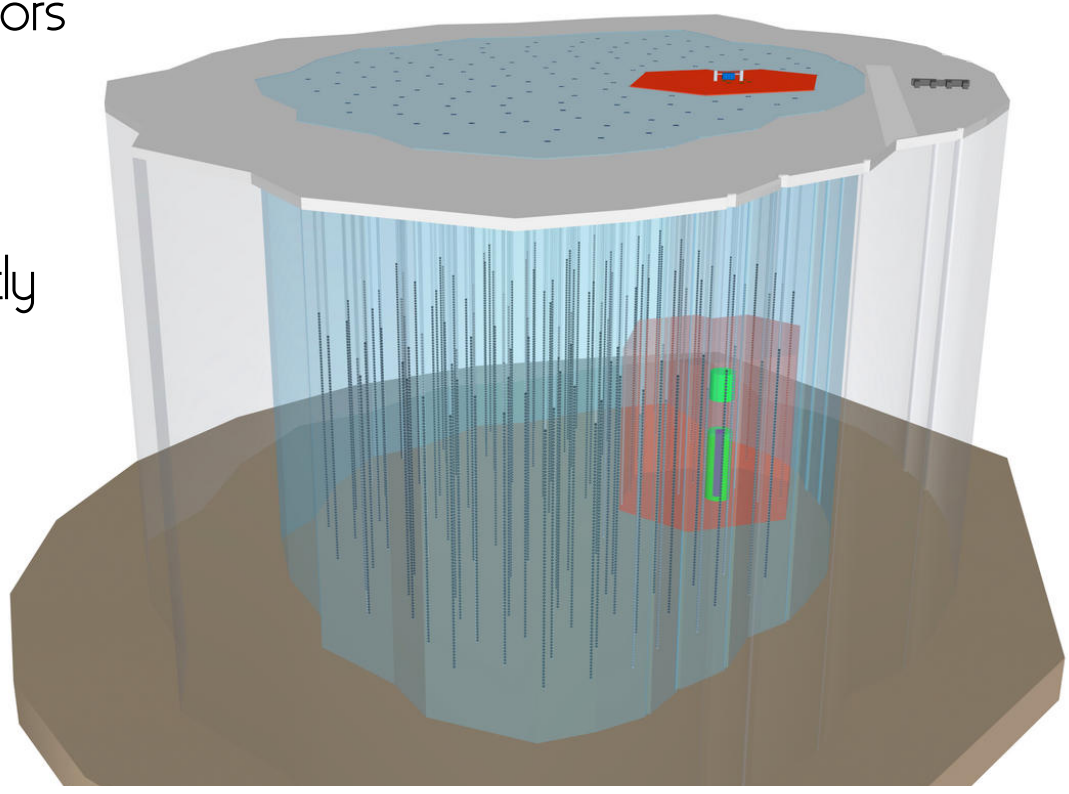


- 120 new "strings" with ~10,000 new sensors
- Science Goals:
  - Detect 1) fainter sources
    2) bright sources more robustly
  - Improved directional reconstruction
  - Optimal for TeV – PeV neutrinos, also sensitive to MeV

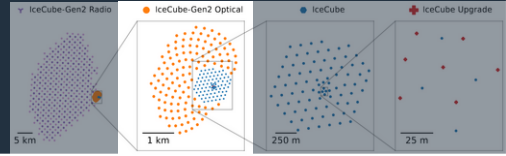


Gen2 sensors

IceCube-Gen2 radio → Nils' talk



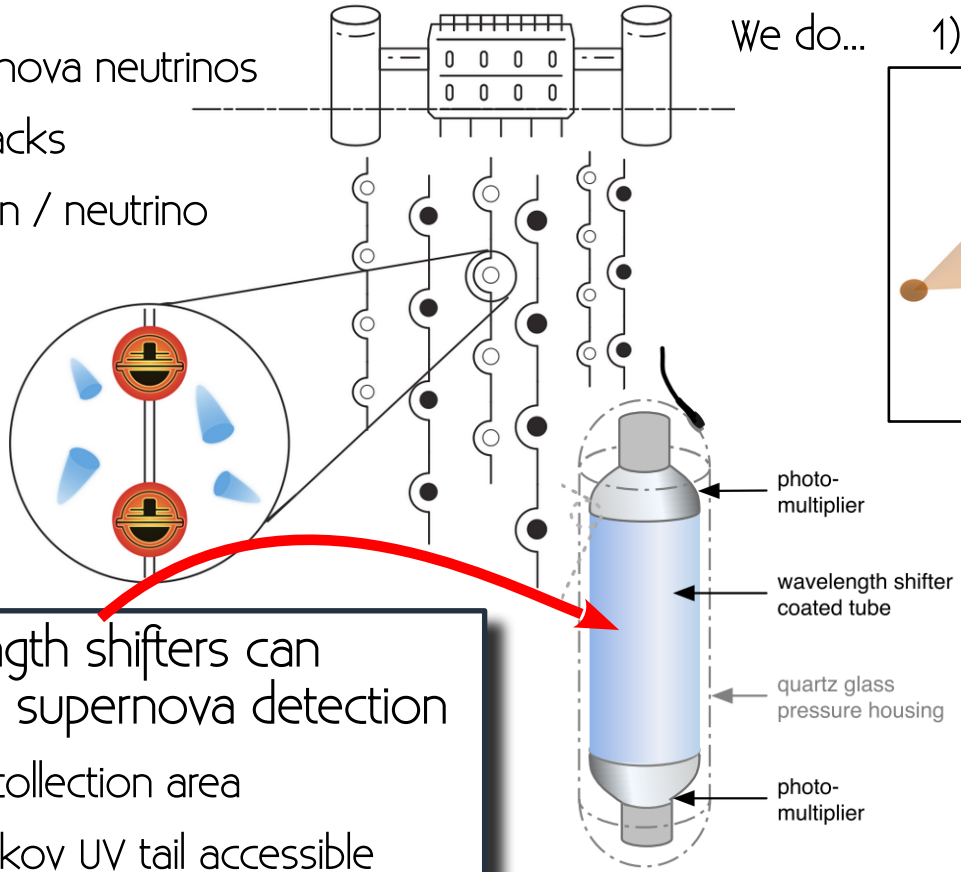
Swedish Contribution – Wavelength shifters



MeV supernova neutrinos

➞ short tracks

➞ ~ photon / neutrino



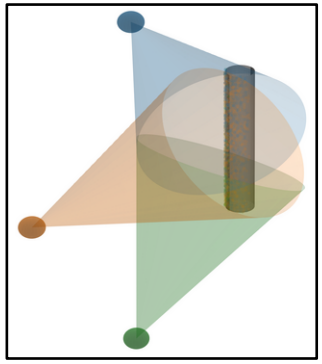
Wavelength shifting Optical Module (WOM) for IceCube Upgrade

Wavelength shifters can improve supernova detection

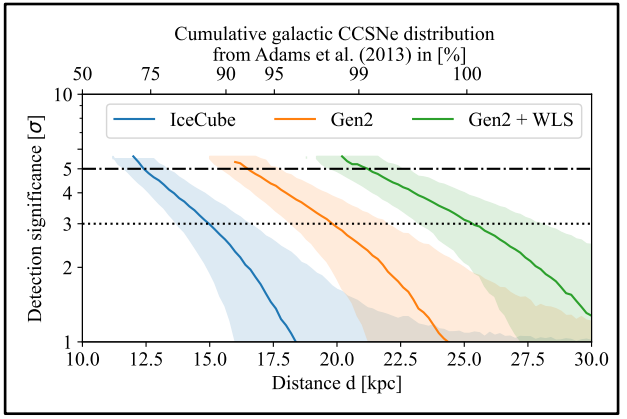
- Large collection area
- Cherenkov UV tail accessible
- Small, low-noise PMTs

We do...

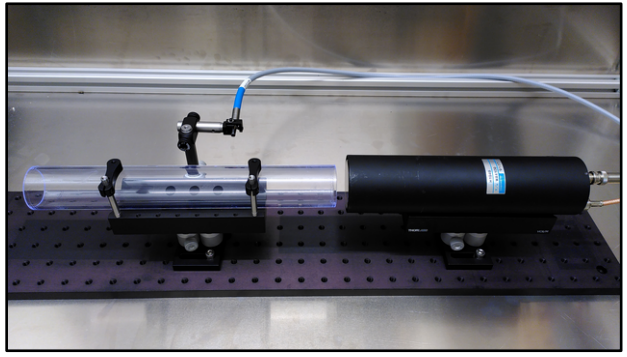
1) Simulation



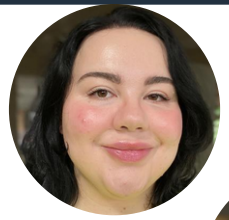
2) Prospect Studies



3) Lab work



What else is happening in IceCube Sweden?



Nora – Search for MeV neutrinos from astrophysical transients

Thorsten – Neutrino reconstruction with deep learning (DL)

Axel – Search for exotic long lived particles in the atmospheric muon background

Martin – Galactic plane improved DL event selection with transformers

Ludwig – Galactic plane neutrinos spatial distribution and spectrum

Jakob – MeV Supernova prospect studies for IceCube-Gen2

Conclusions

- IceCube has been successfully operating with 99% up-time for 13 years
- IceCube Upgrade is under way and will improve calibration and neutrino oscillation
- IceCube-Gen2 has great potential for MeV-EeV neutrinos

Thank you for your attention!