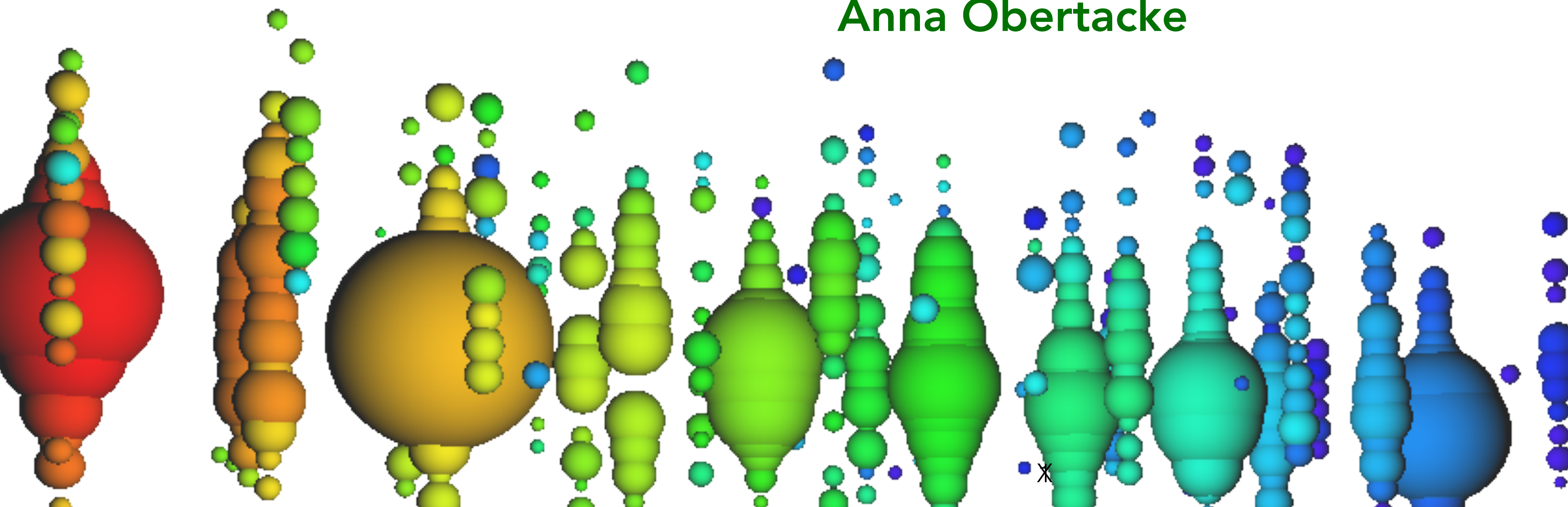


High energy neutrino telescopes in water and ice

and how they search for magnetic monopoles

Anna Obertacke



Multi-Messenger Astronomy

Linked at
source

Linked at
propagation

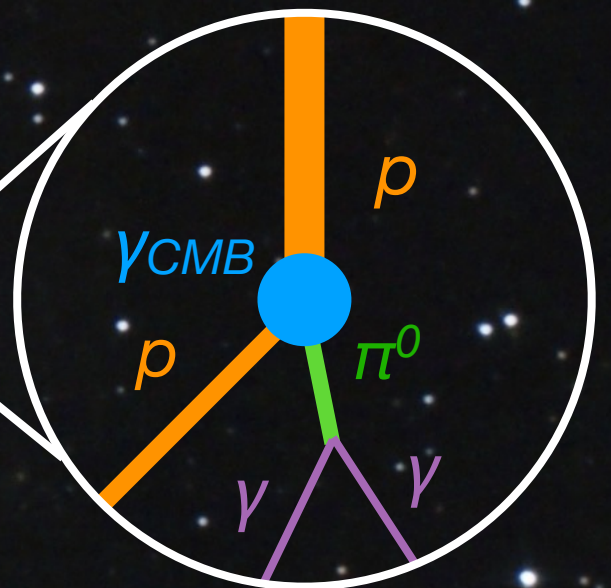
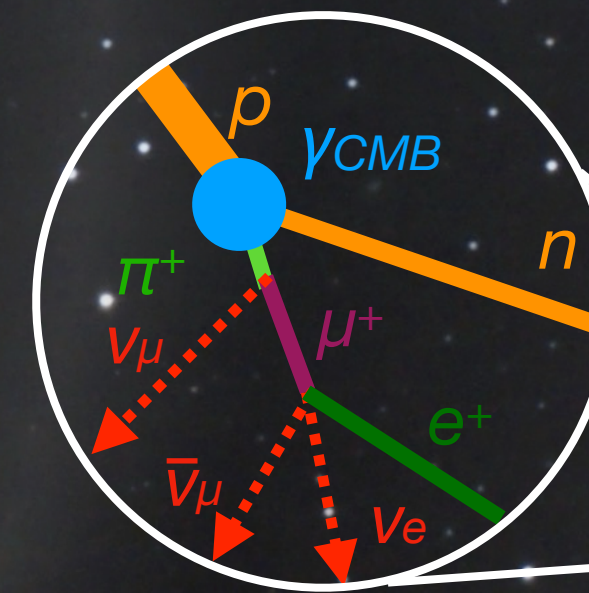
Gravitational
Waves

Photons /
X-rays / γ -rays

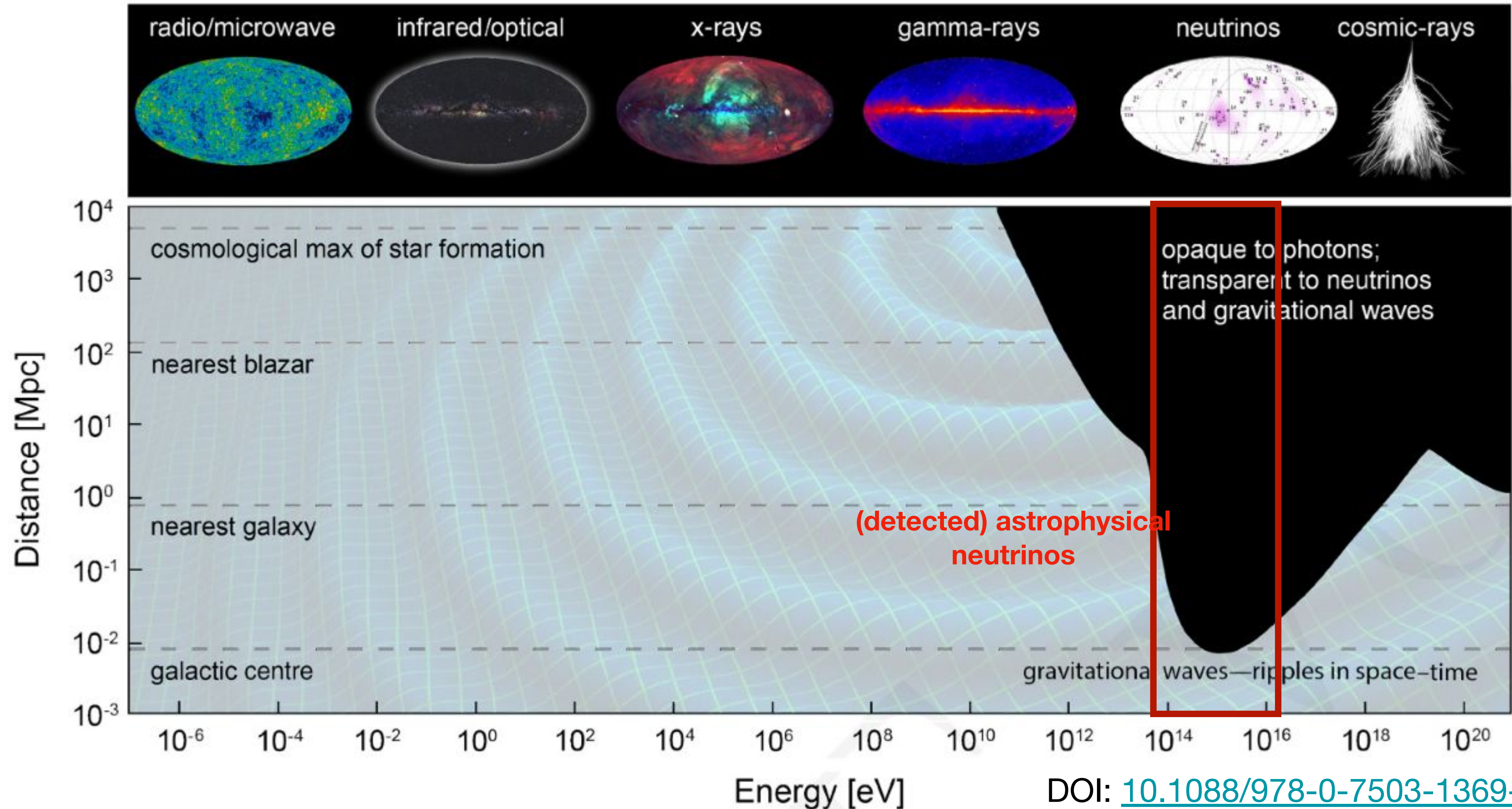
Intergalactic
magnetic field

Charged
cosmic rays

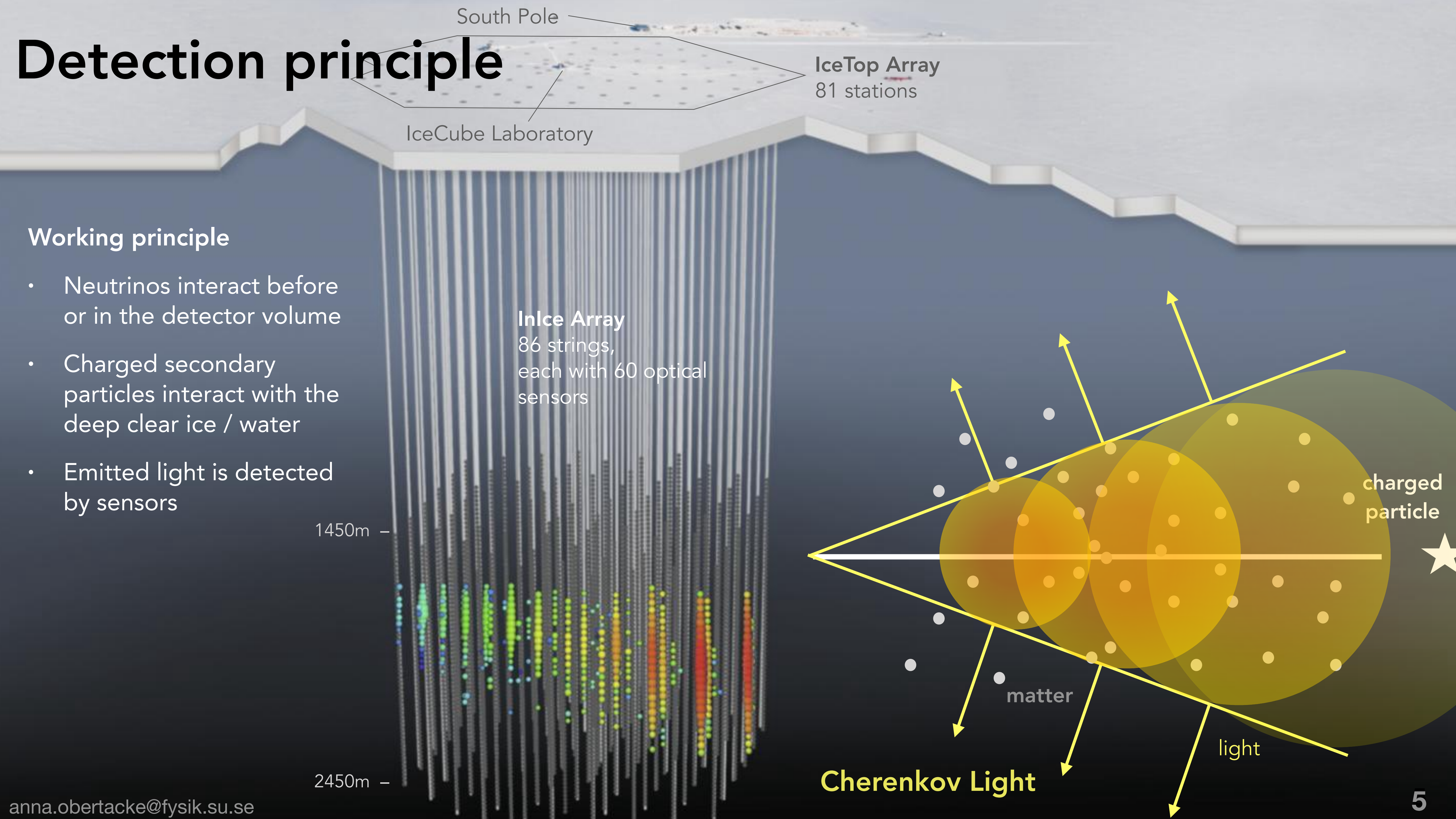
Neutrinos



> TeV Astroparticles

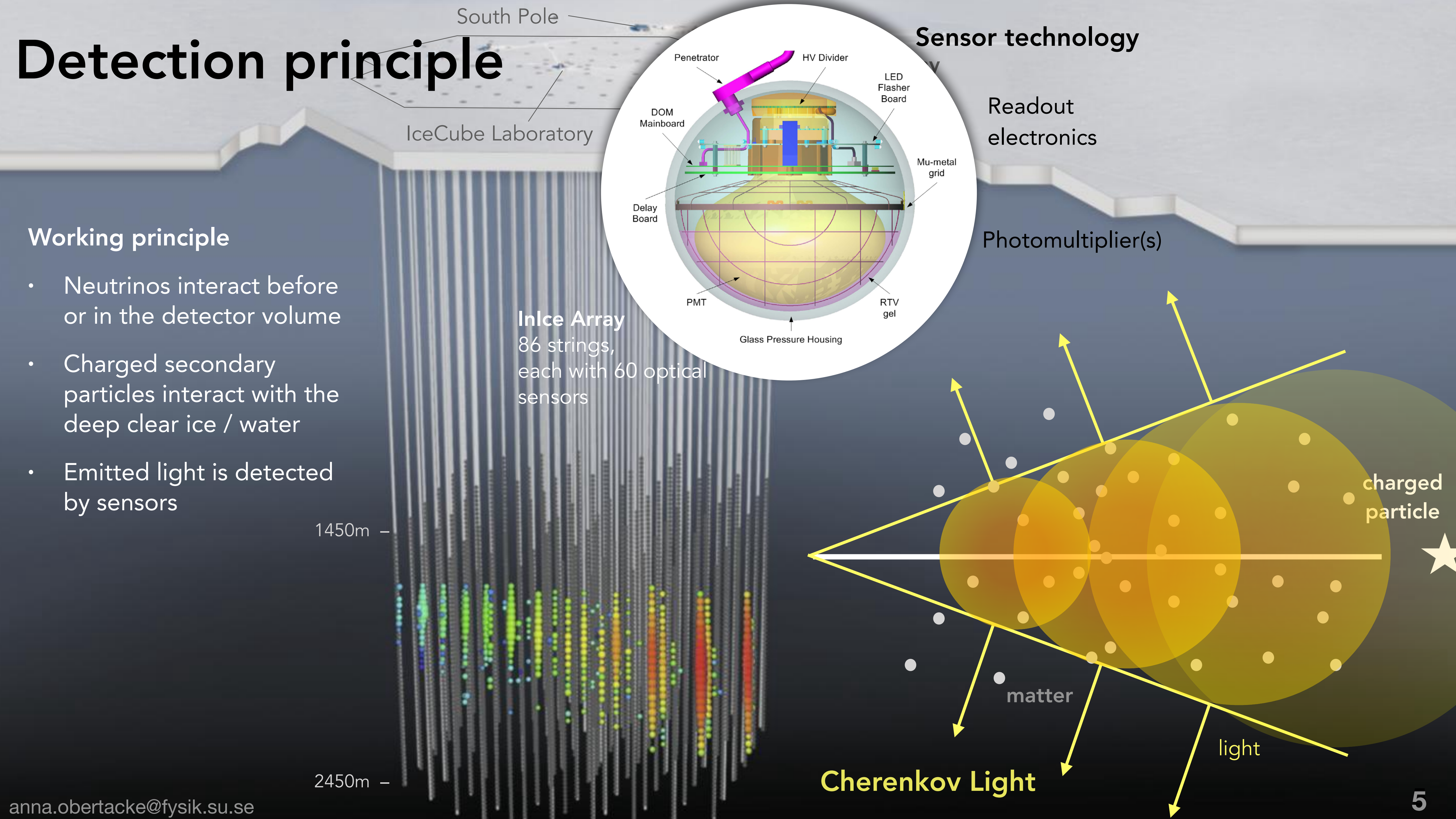


Detection principle

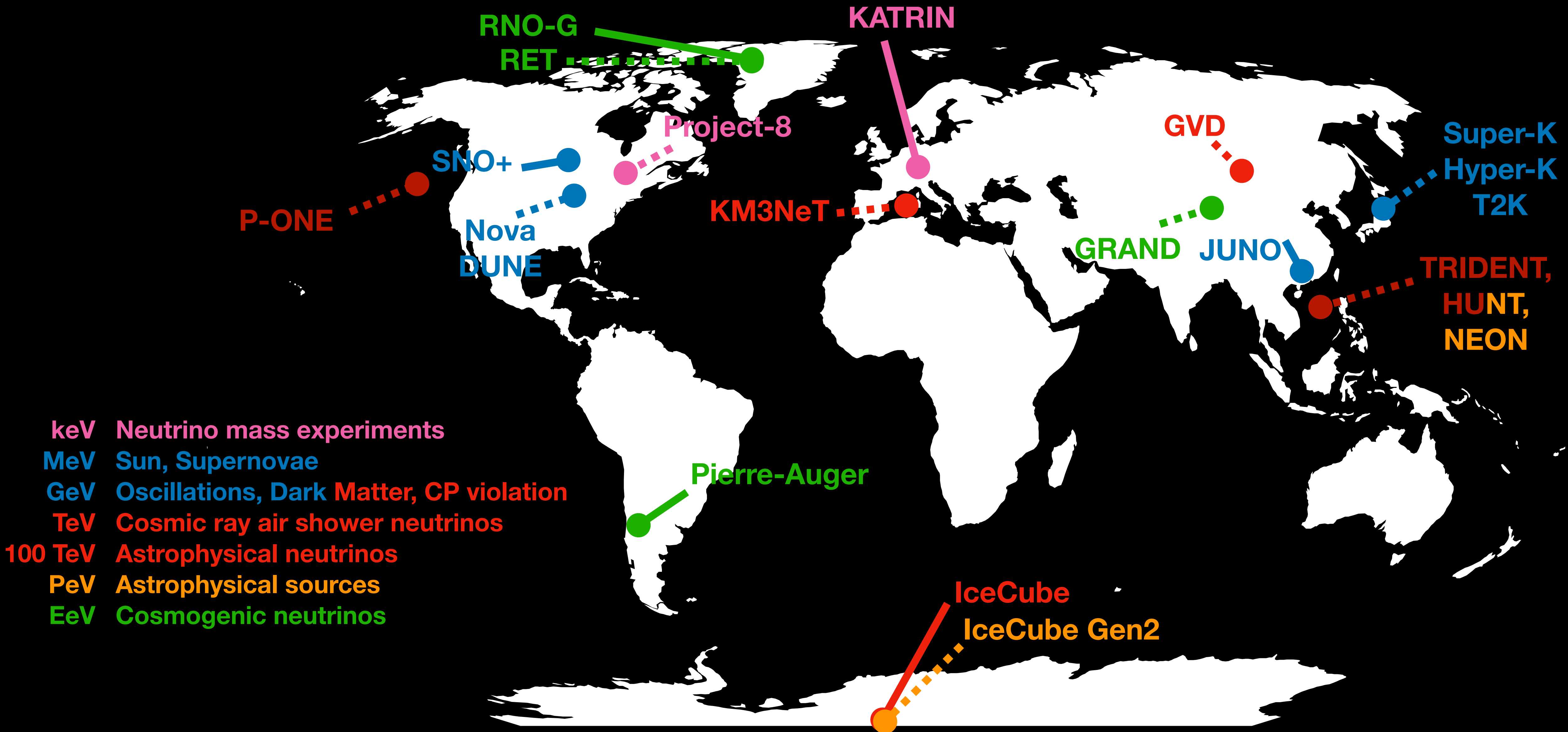


Working principle

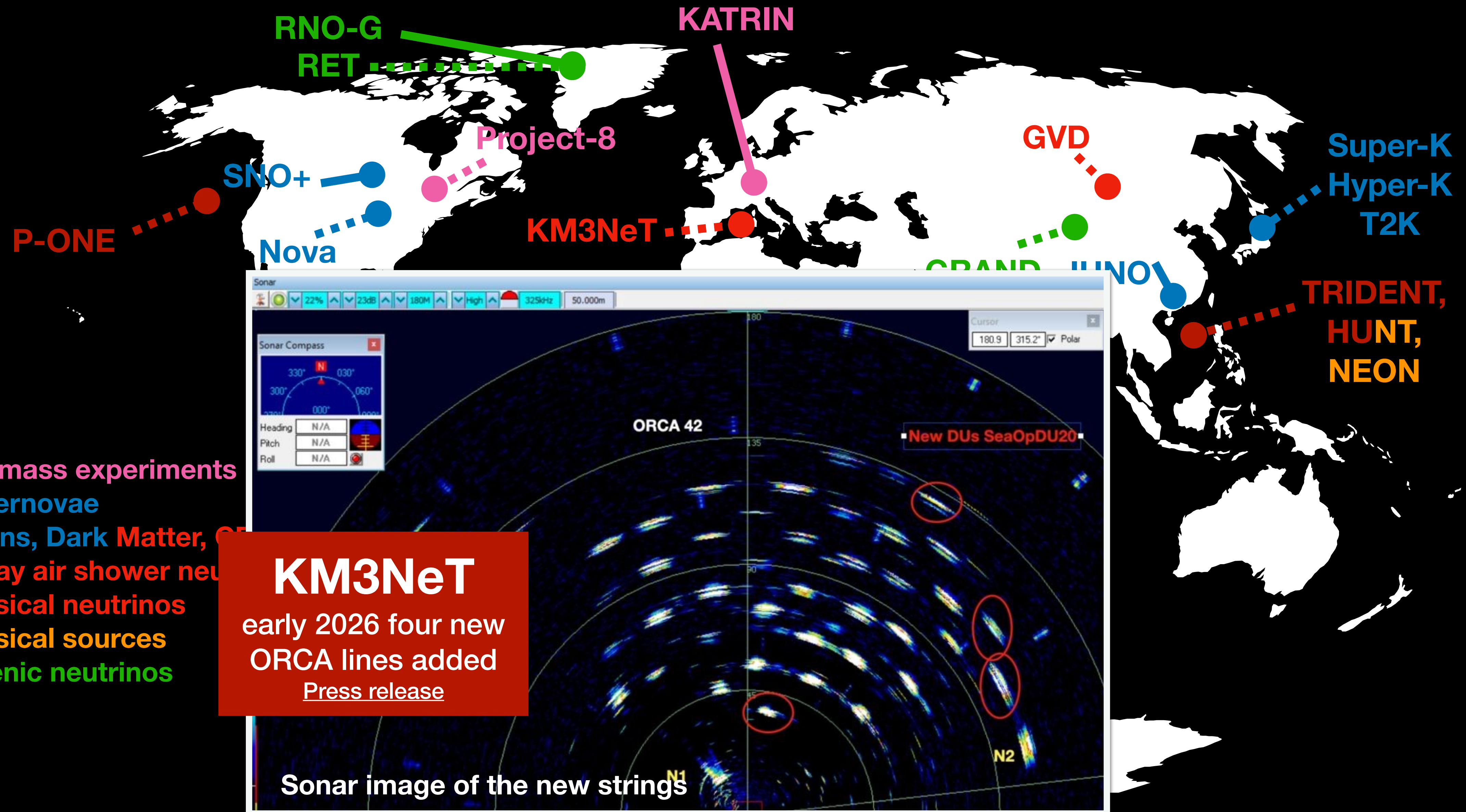
- Neutrinos interact before or in the detector volume
- Charged secondary particles interact with the deep clear ice / water
- Emitted light is detected by sensors



Neutrino detectors around the World



Neutrino detectors around the World



keV Neutrino mass experiments
MeV Sun, Supernovae
GeV Oscillations, Dark Matter, CP
TeV Cosmic ray air shower neutrinos
100 TeV Astrophysical neutrinos
PeV Astrophysical sources
EeV Cosmogenic neutrinos

Neutrino detectors around the World

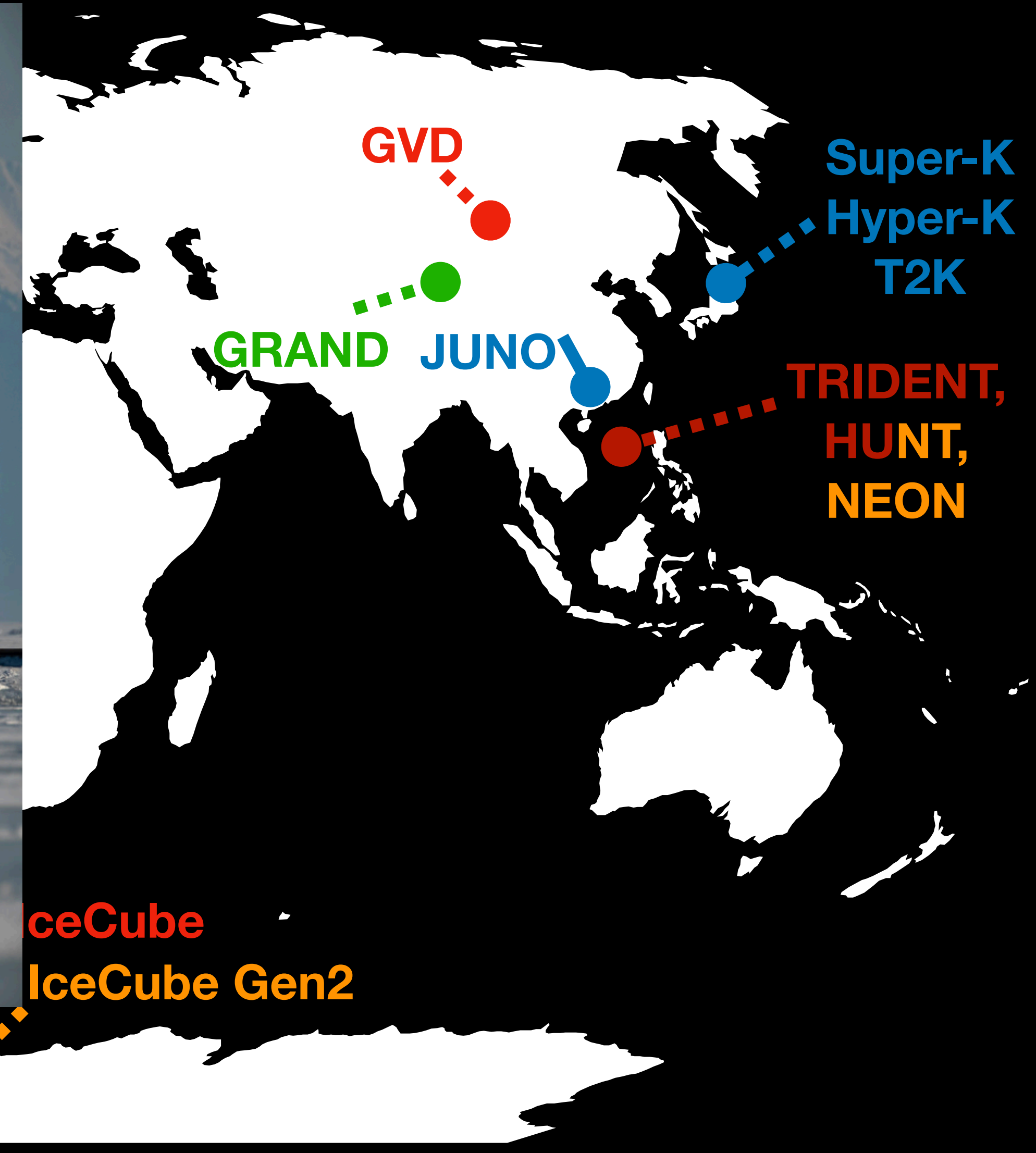
RNO-G

KATRIN

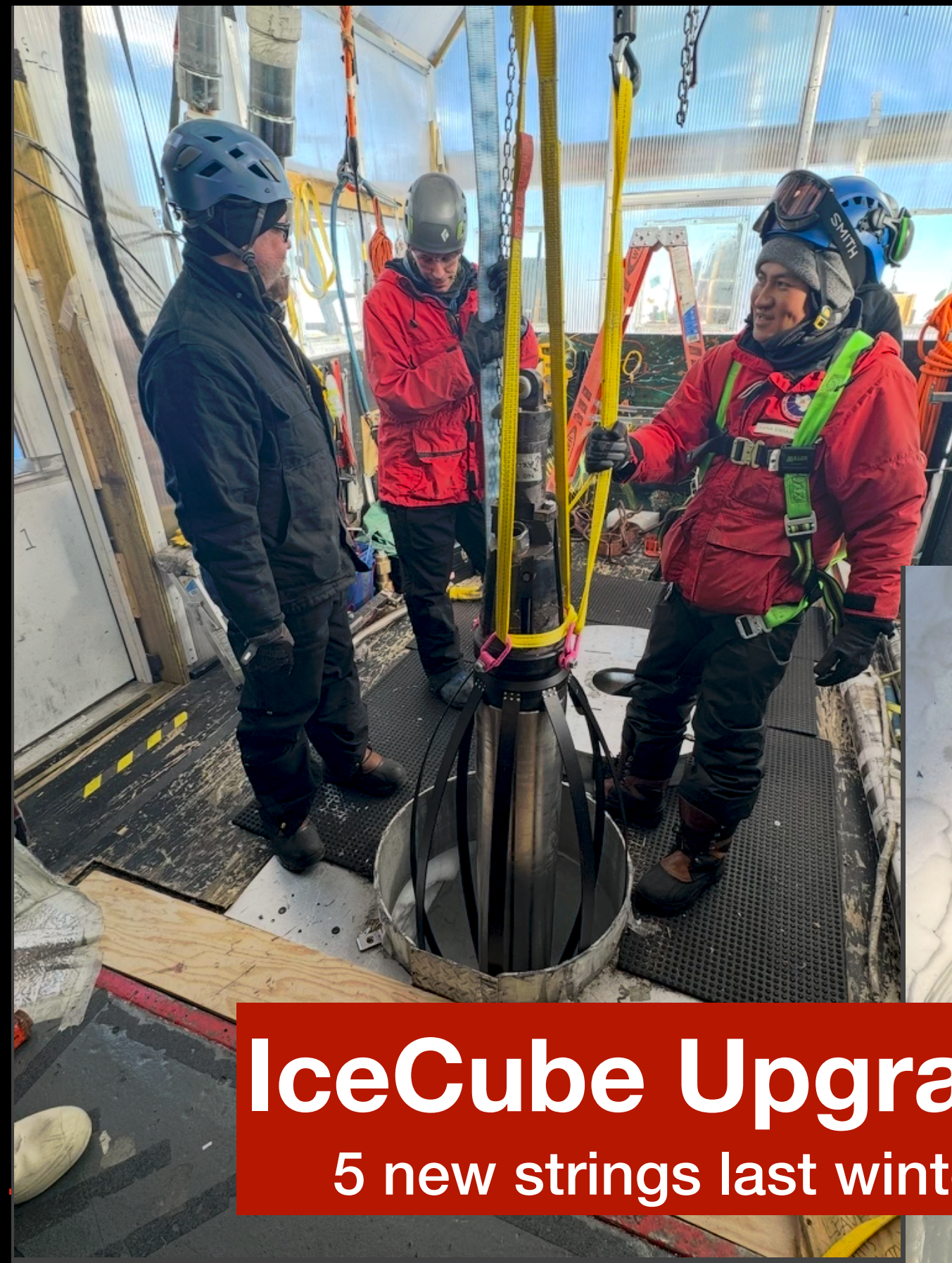


BAIKAL-GVD

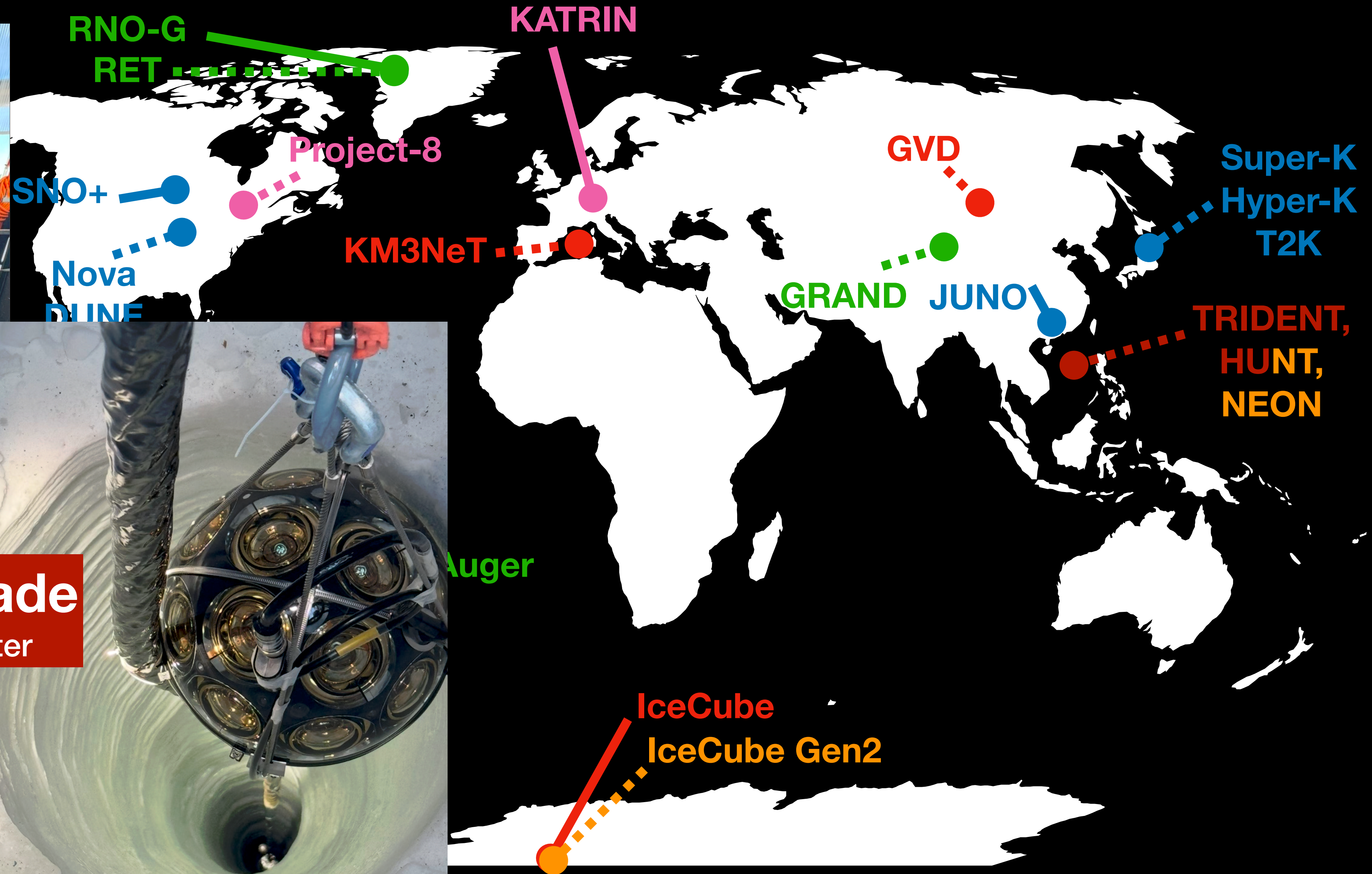
2 new clusters in winter 2026
reaching 16 cluster $\sim 0.7 \text{ km}^3$
Press release



Neutrino detectors around the World



PeV Astrophysical sources
EeV Cosmogenic neutrinos

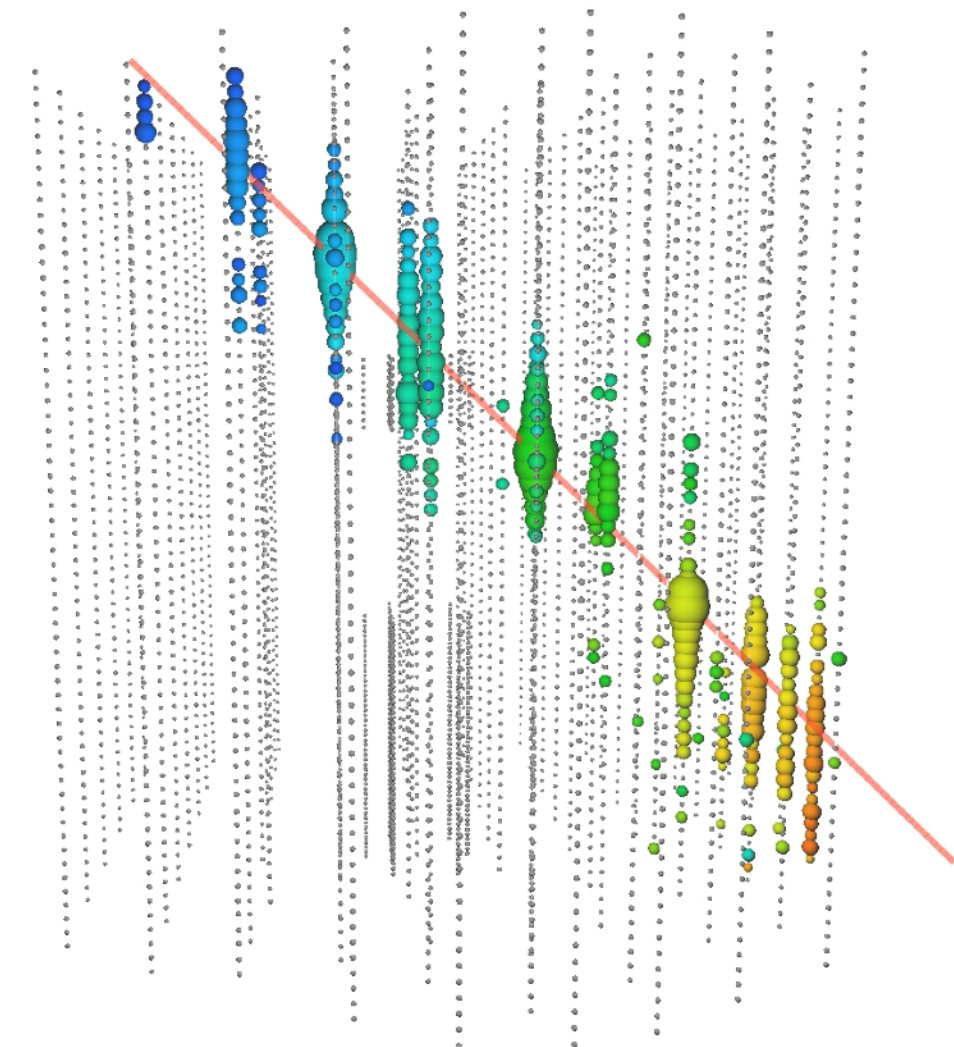
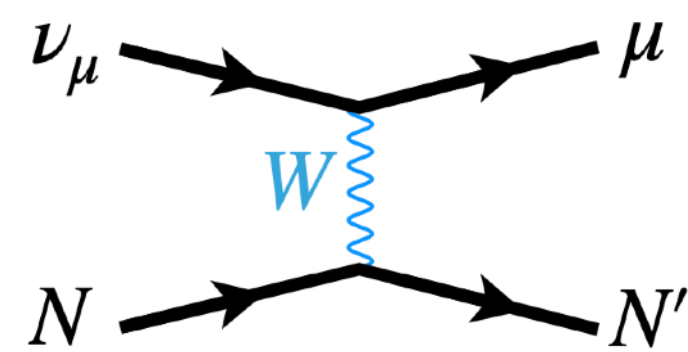


Neutrino signatures

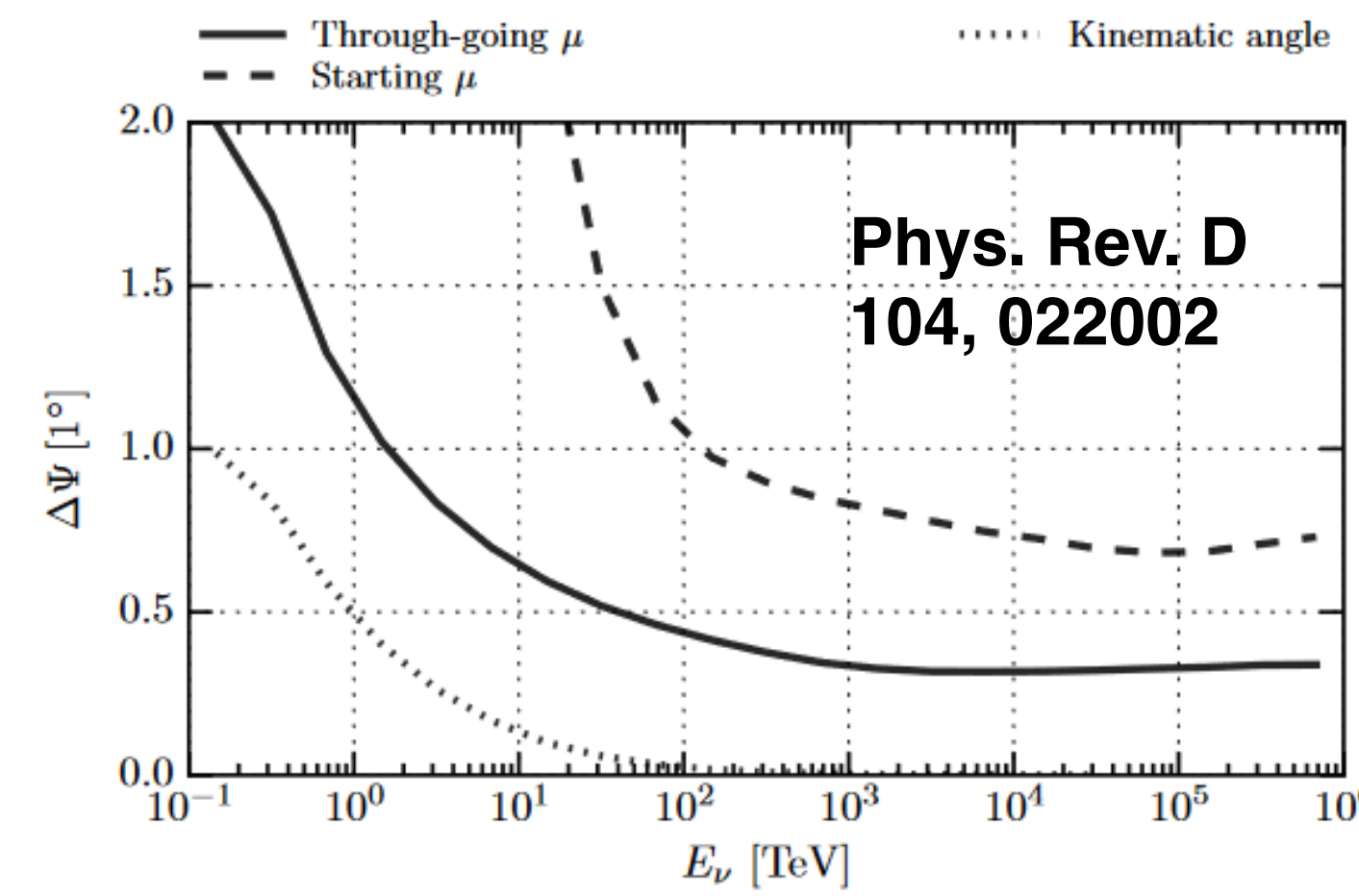
Characterized by reconstructed quantities: direction, energy, angular uncertainty

Outgoing muon

- charged current interaction

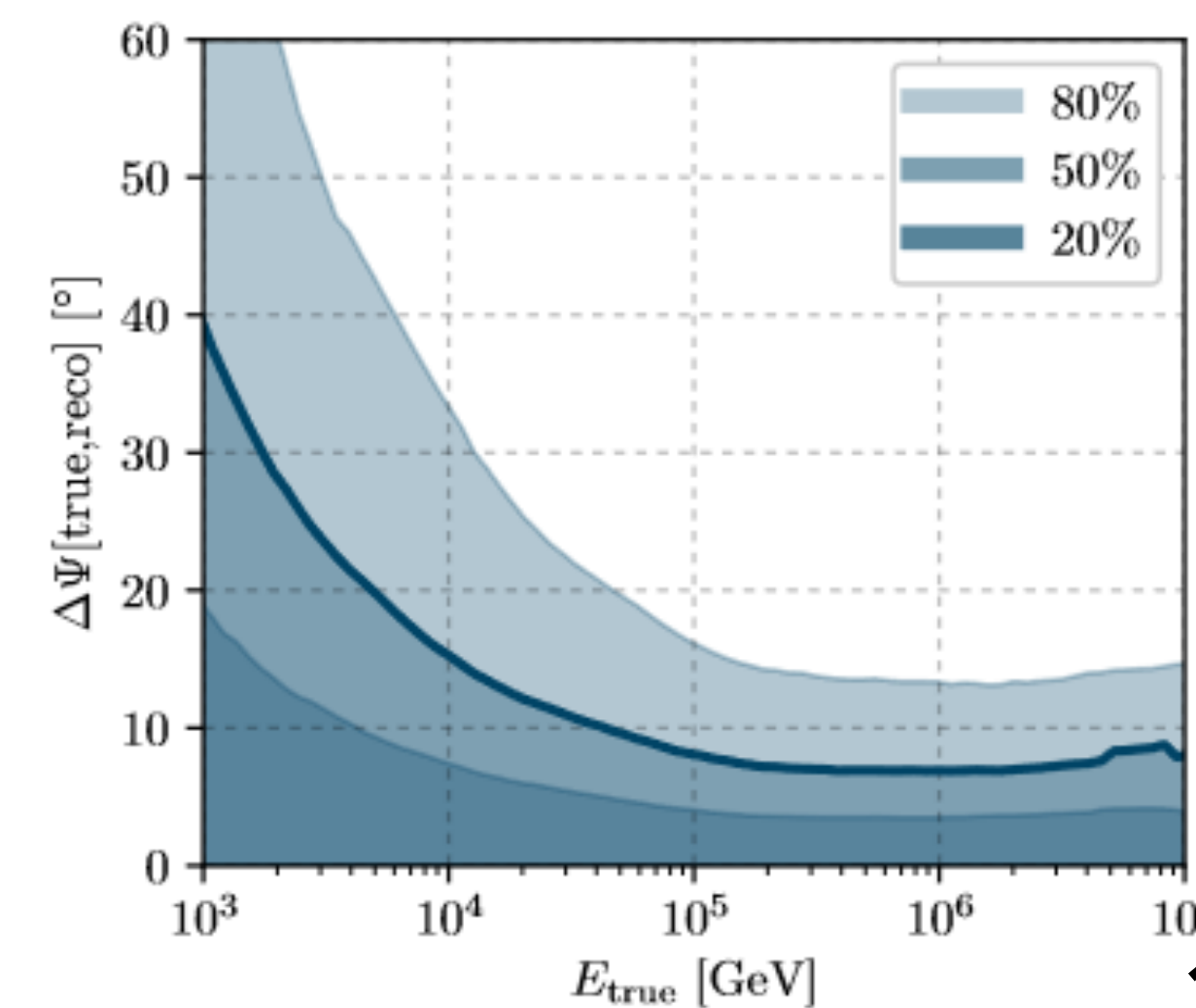
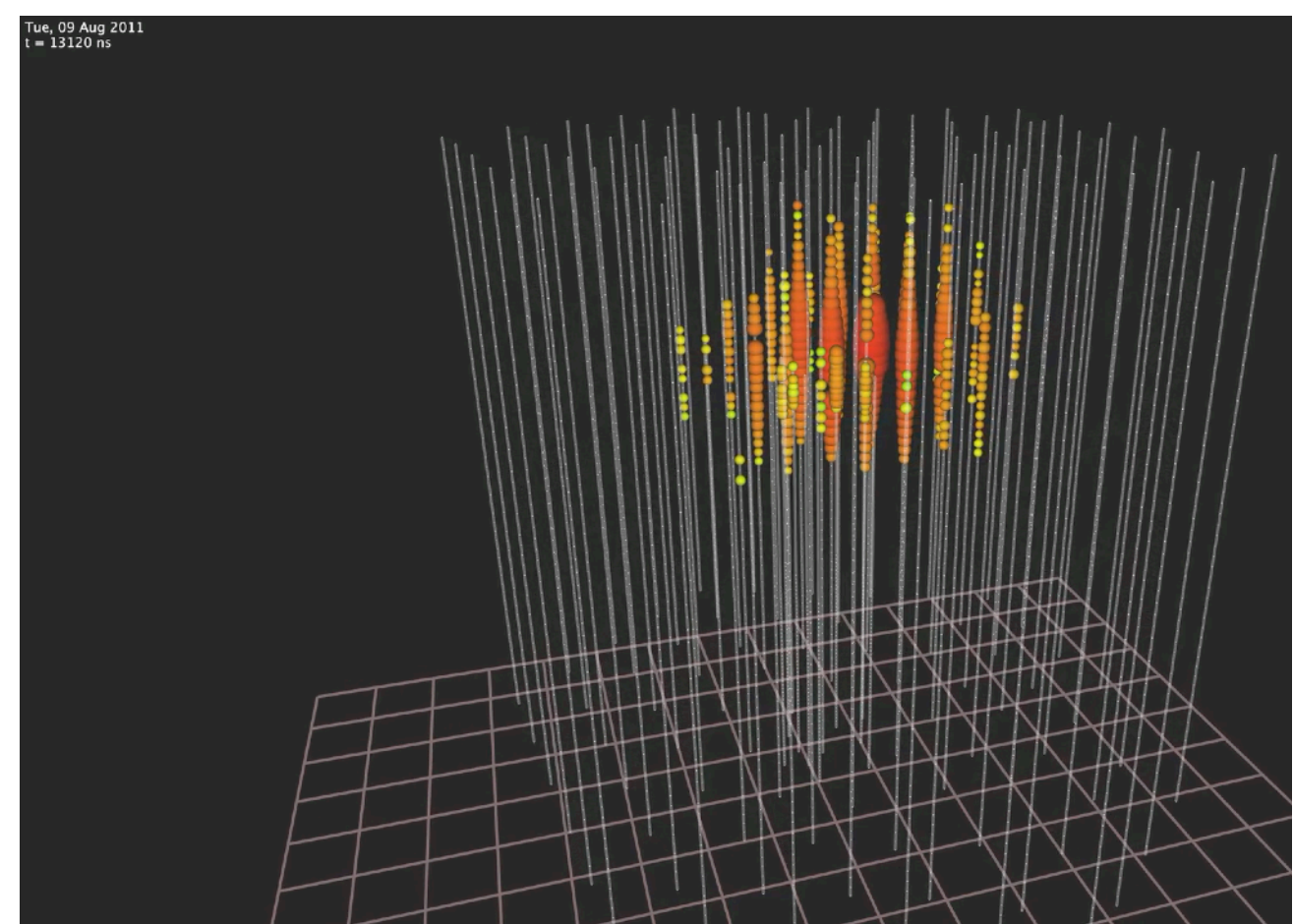
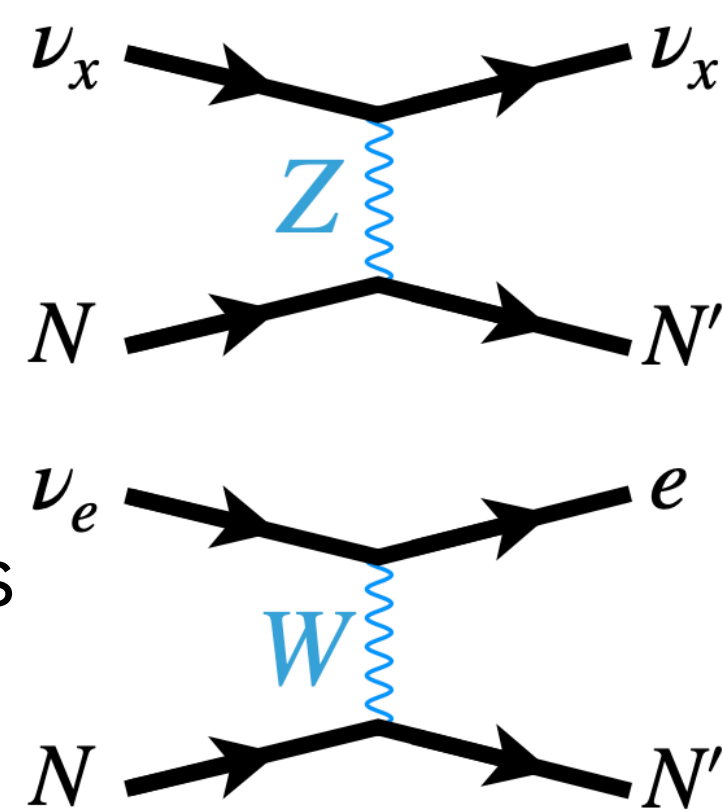


Precision @ IceCube

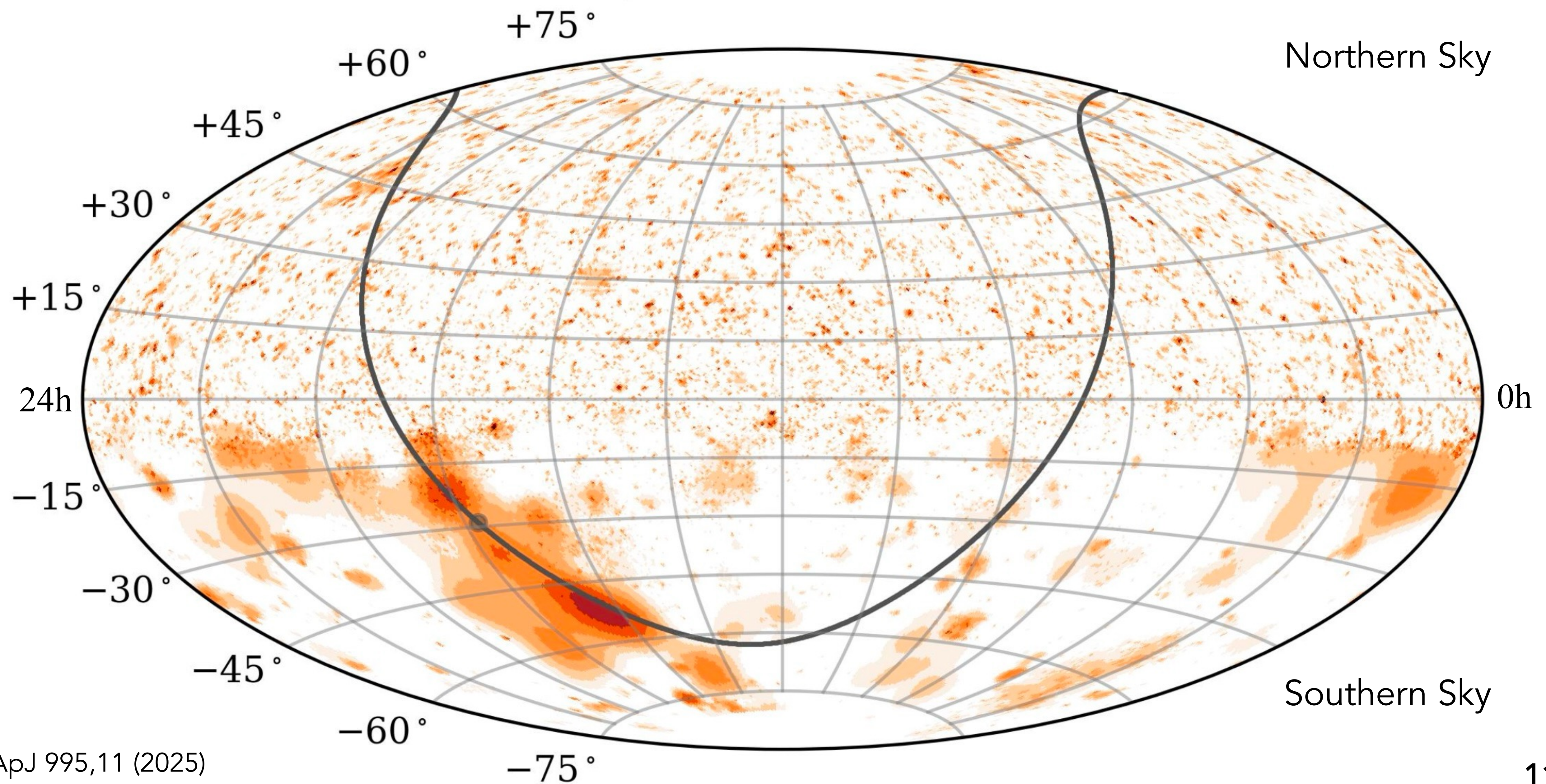


Particle showers

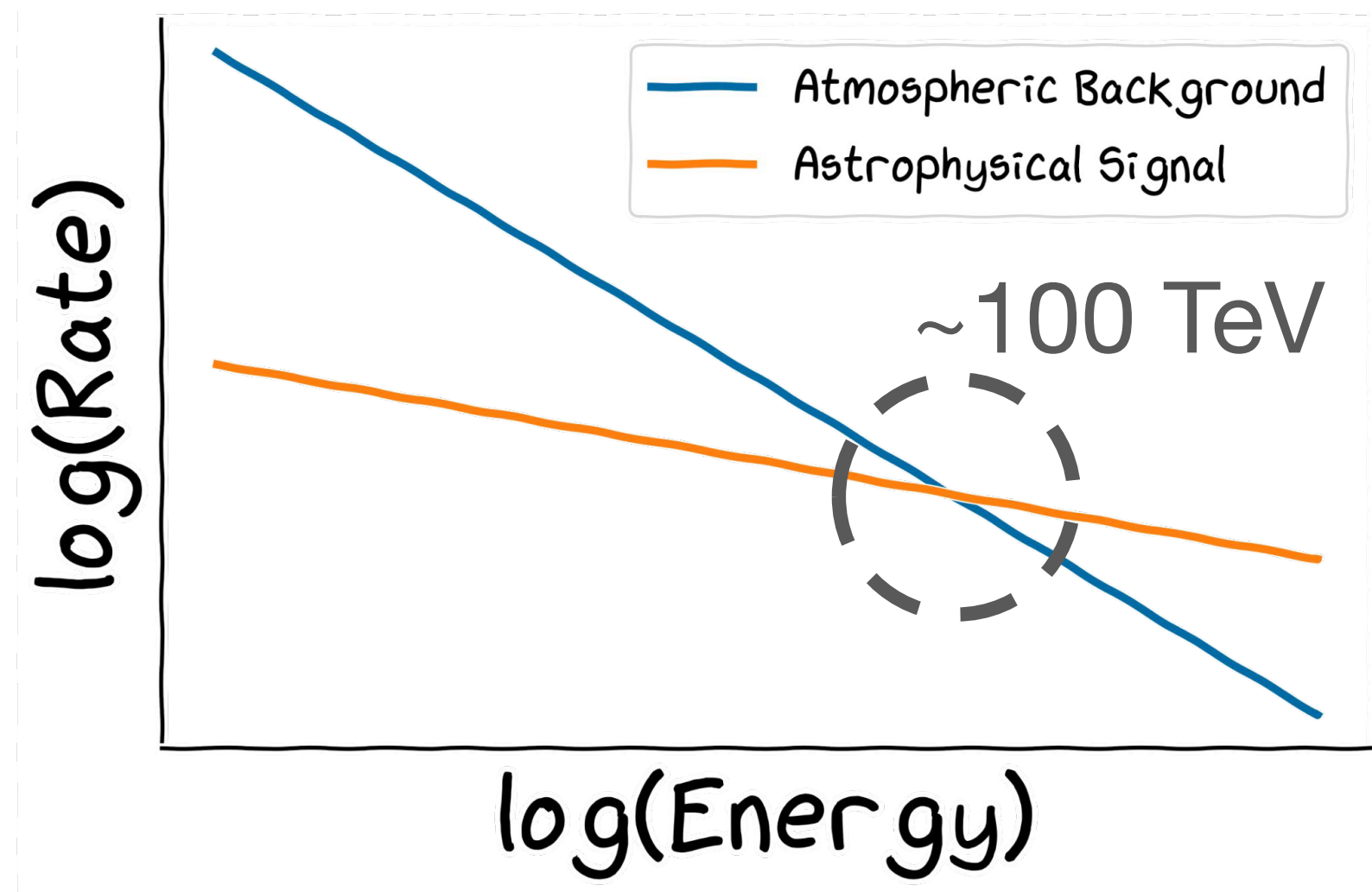
- neutral interaction
- electron- and tau-neutrino charged current interactions



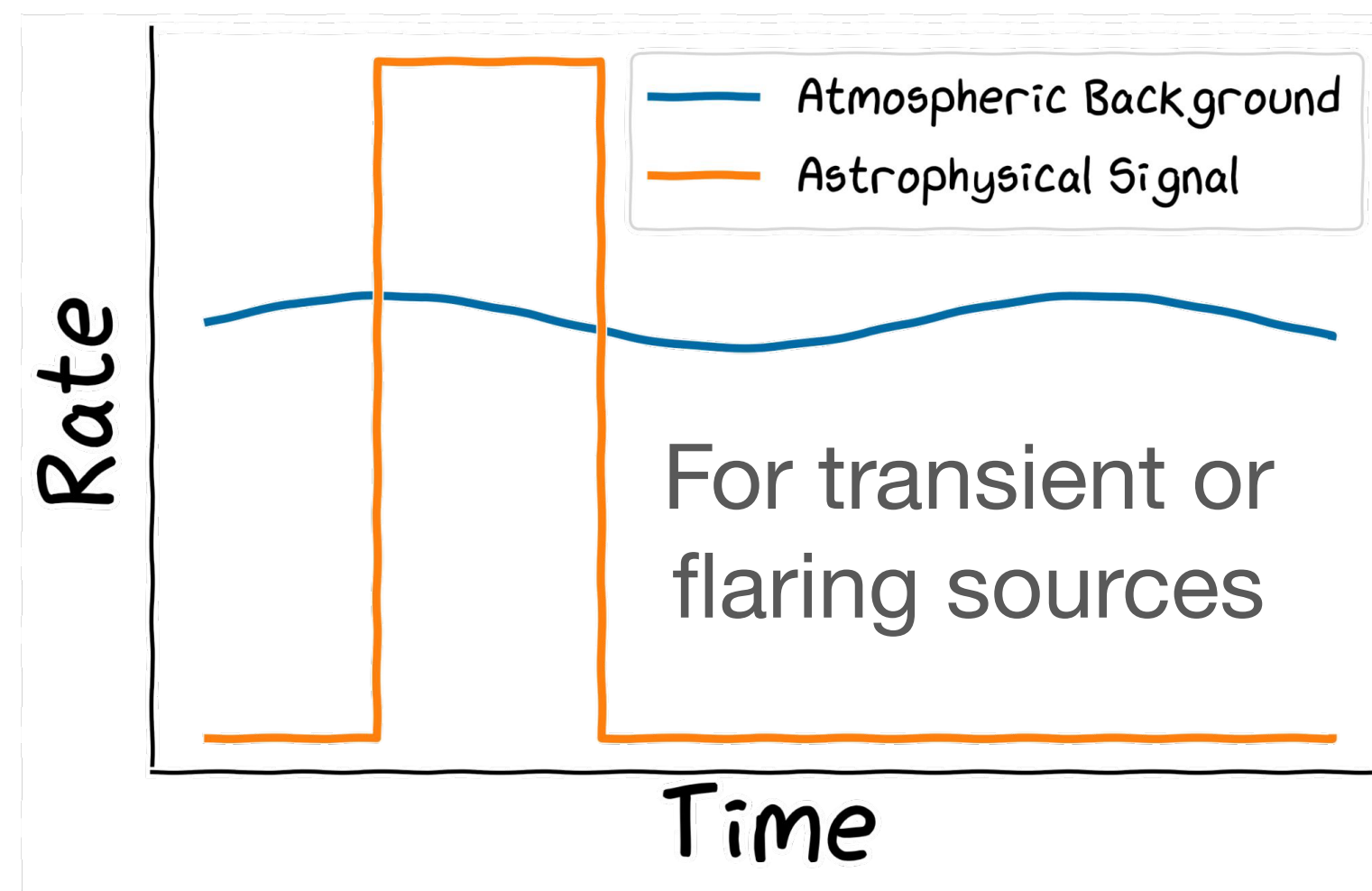
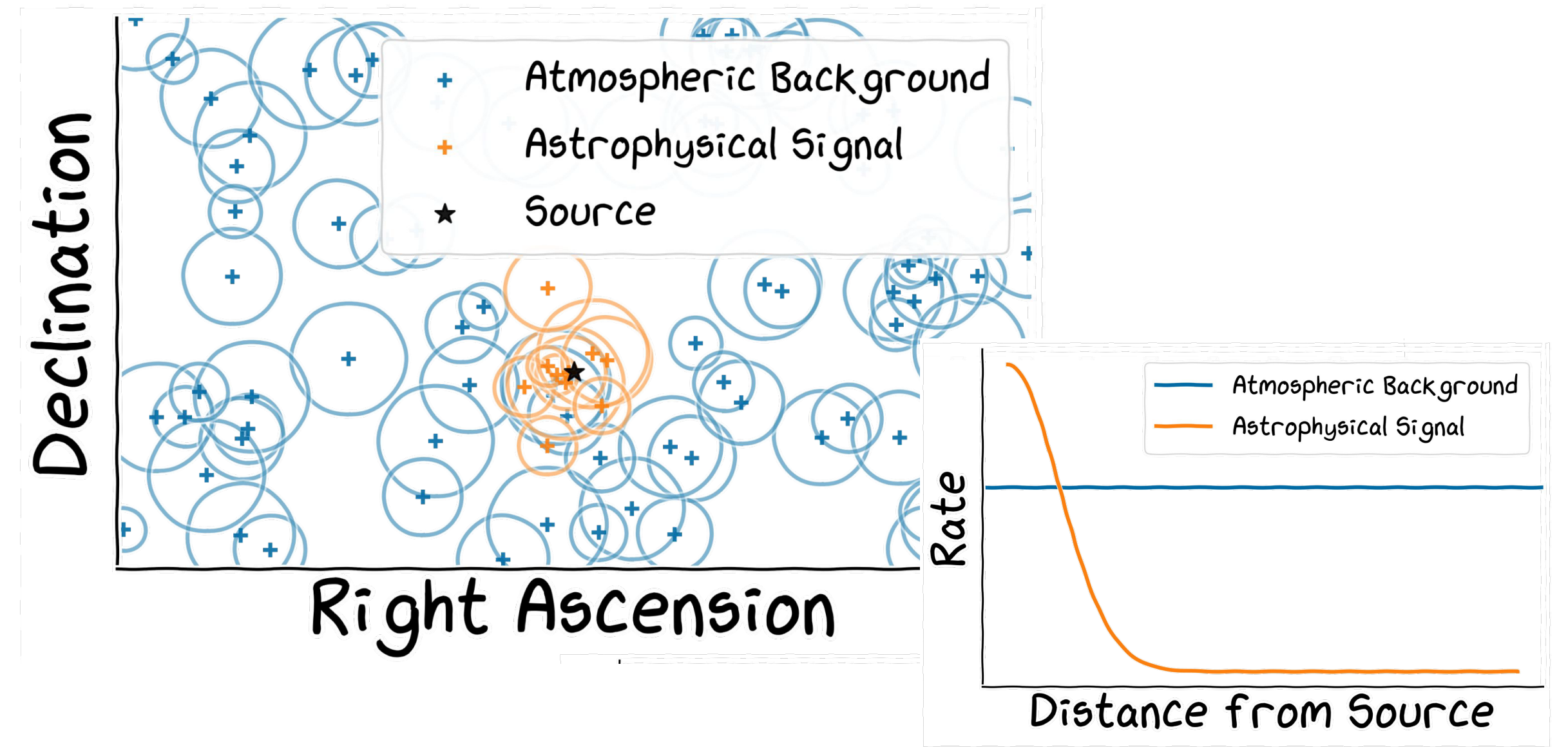
The Neutrino Sky as seen by IceCube



Analyses strategies



Power-law flux falls off faster than cross-section increases



Highlights in Neutrino Astronomy



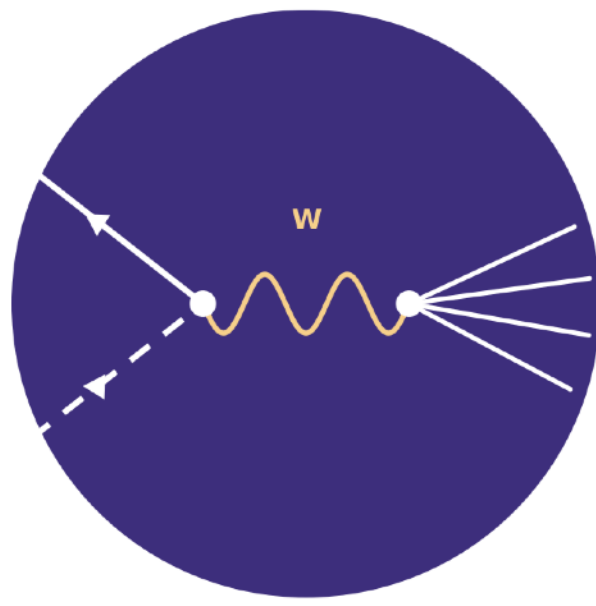
**ASTROPHYSICAL NEUTRINOS
DISCOVERED**
.....●.....
2013

Science 342, 1242856 (2013)



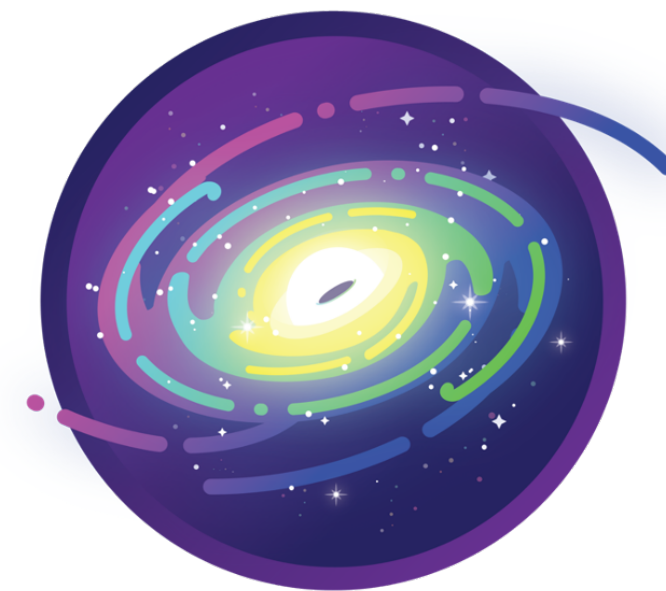
**BLAZAR TXS 0506+056
NEUTRINO EMISSION IDENTIFIED**
.....●.....
2018

Science 361, eaat1378 (2018);
Science 361, 147 (2018)



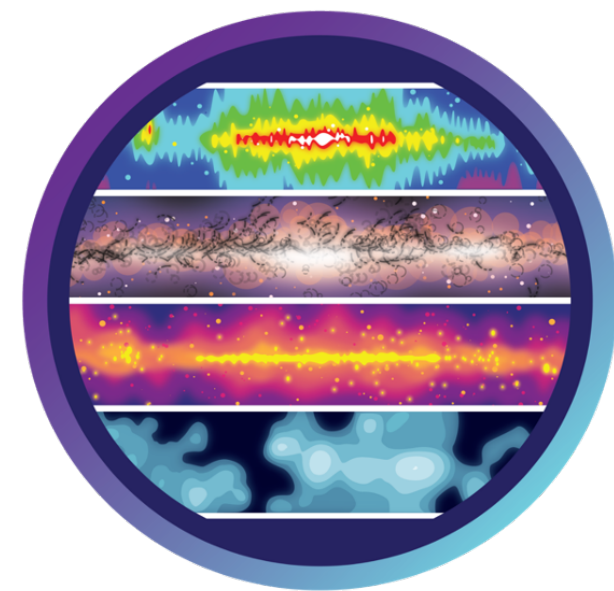
**GLASHOW RESONANCE
STANDARD MODEL CONFIRMED**
.....●.....
2021

Nature 591, 220–224
(2021)



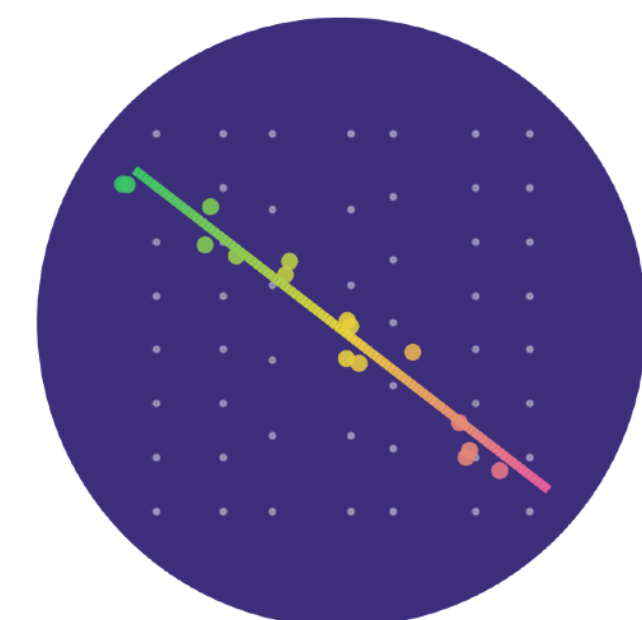
**ACTIVE GALAXY NGC 1068
NEUTRINO EMISSION IDENTIFIED**
.....●.....
2022

Science 378, 538 (2022)



**MILKY WAY
NEUTRINO EMISSION IDENTIFIED**
.....●.....
2023

Science 380, 1338 (2023)

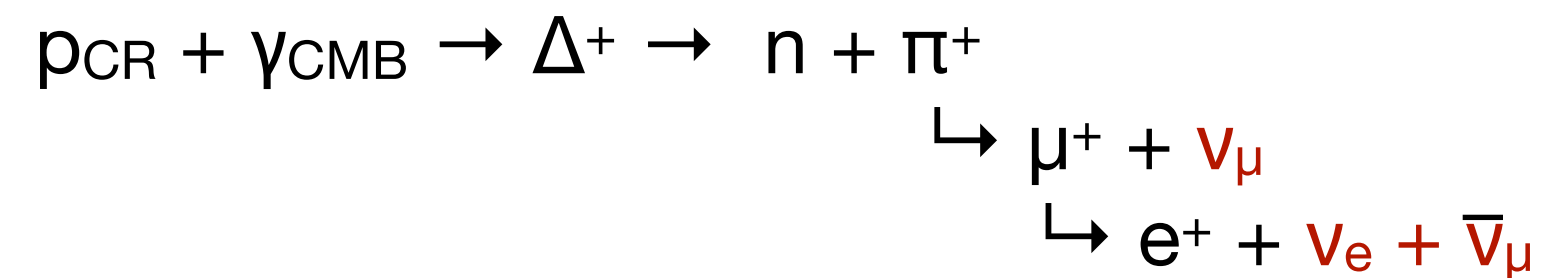


**KM3-230213A
HIGHEST-ENERGY NEUTRINO**
.....●.....
2025

Nature 638, 376–382 (2025)

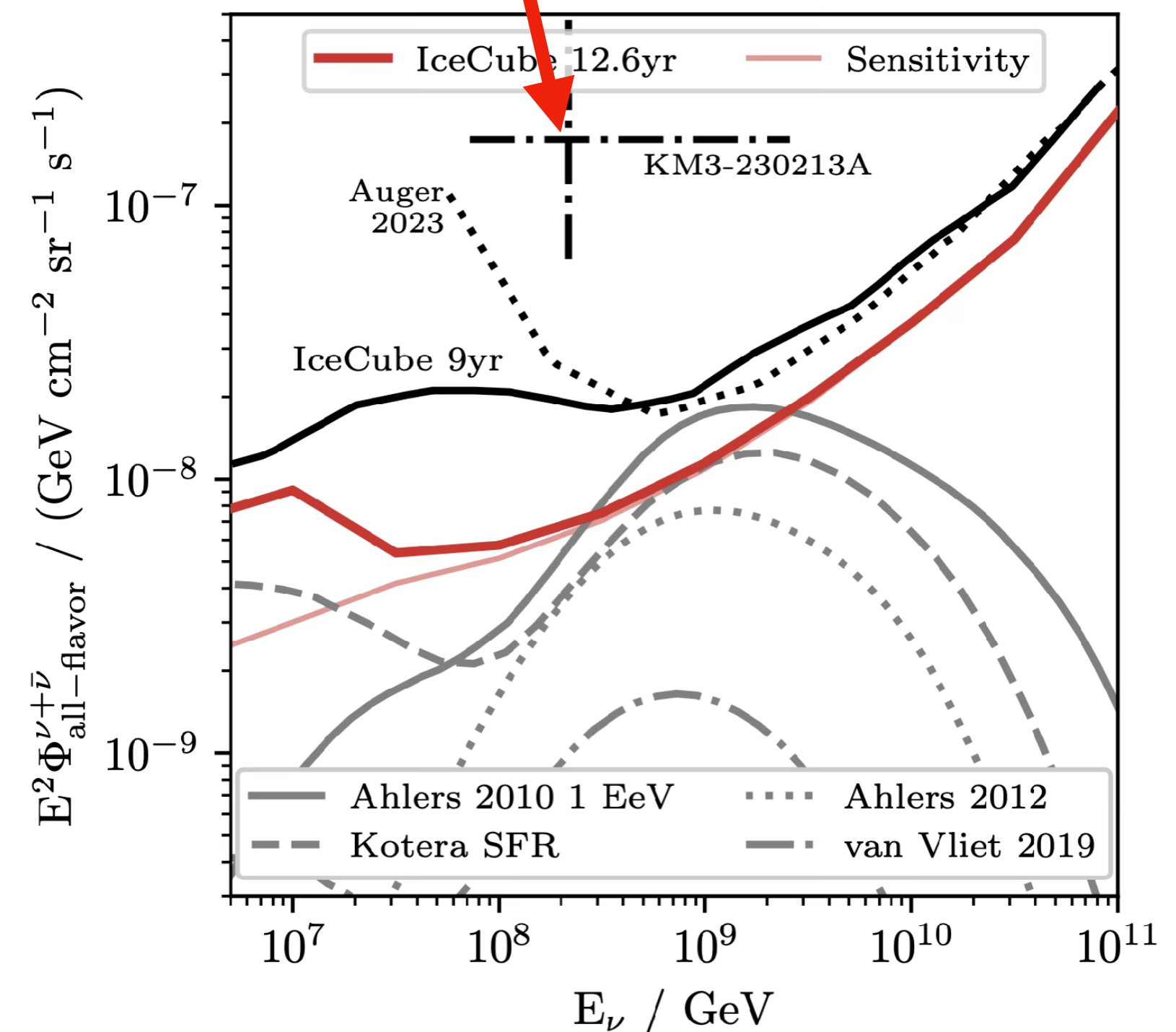
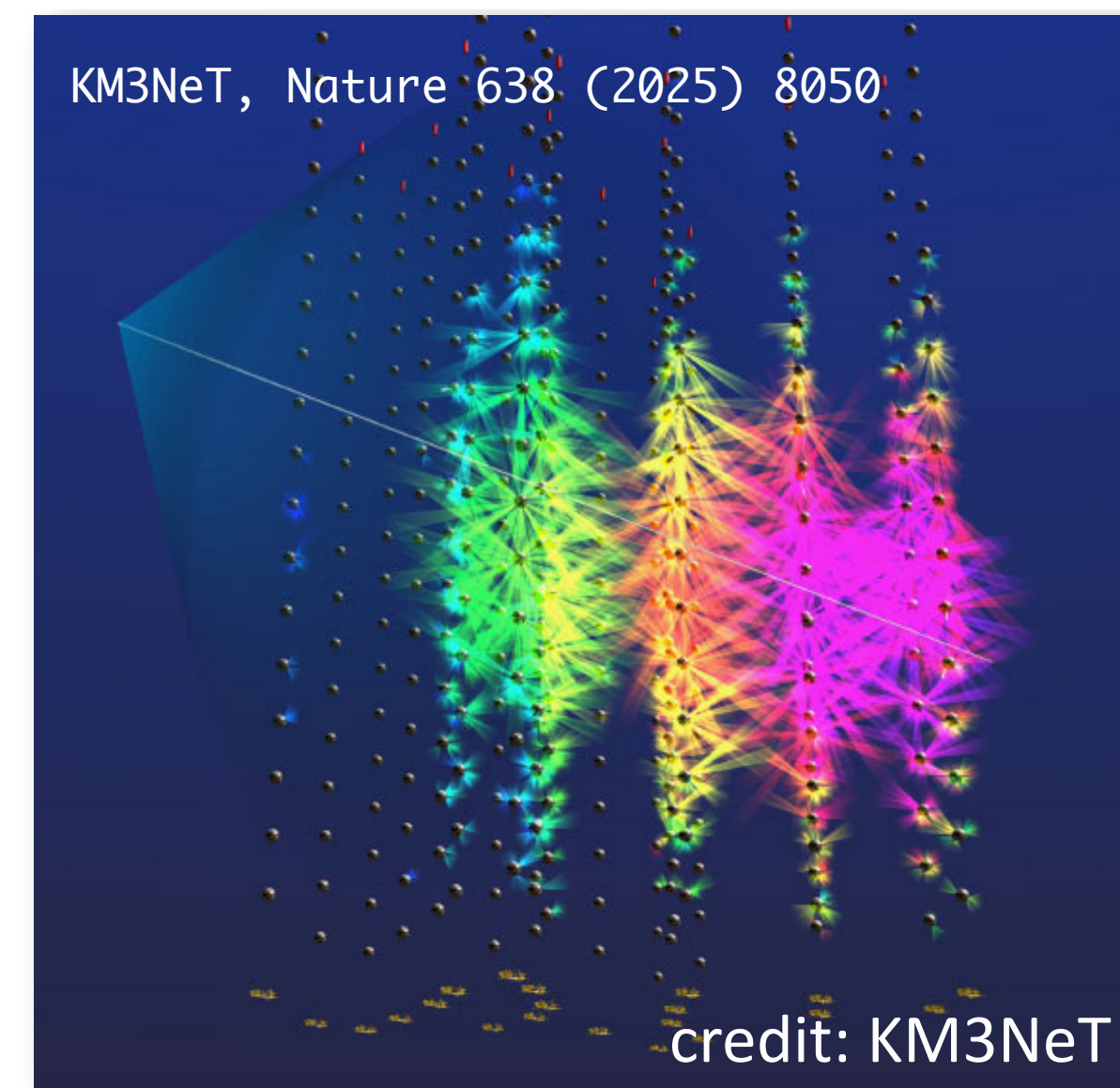
Cosmogenic neutrinos

- cosmic ray cutoff at $> 10^{20}$ eV might be due to GZK effect, giving extreme high energy neutrinos



- new data of IceCube + Auger constrains proton fraction to at most 80%
- some tension with KM3NeT's ~ 220 PeV event on the level of 2.9σ

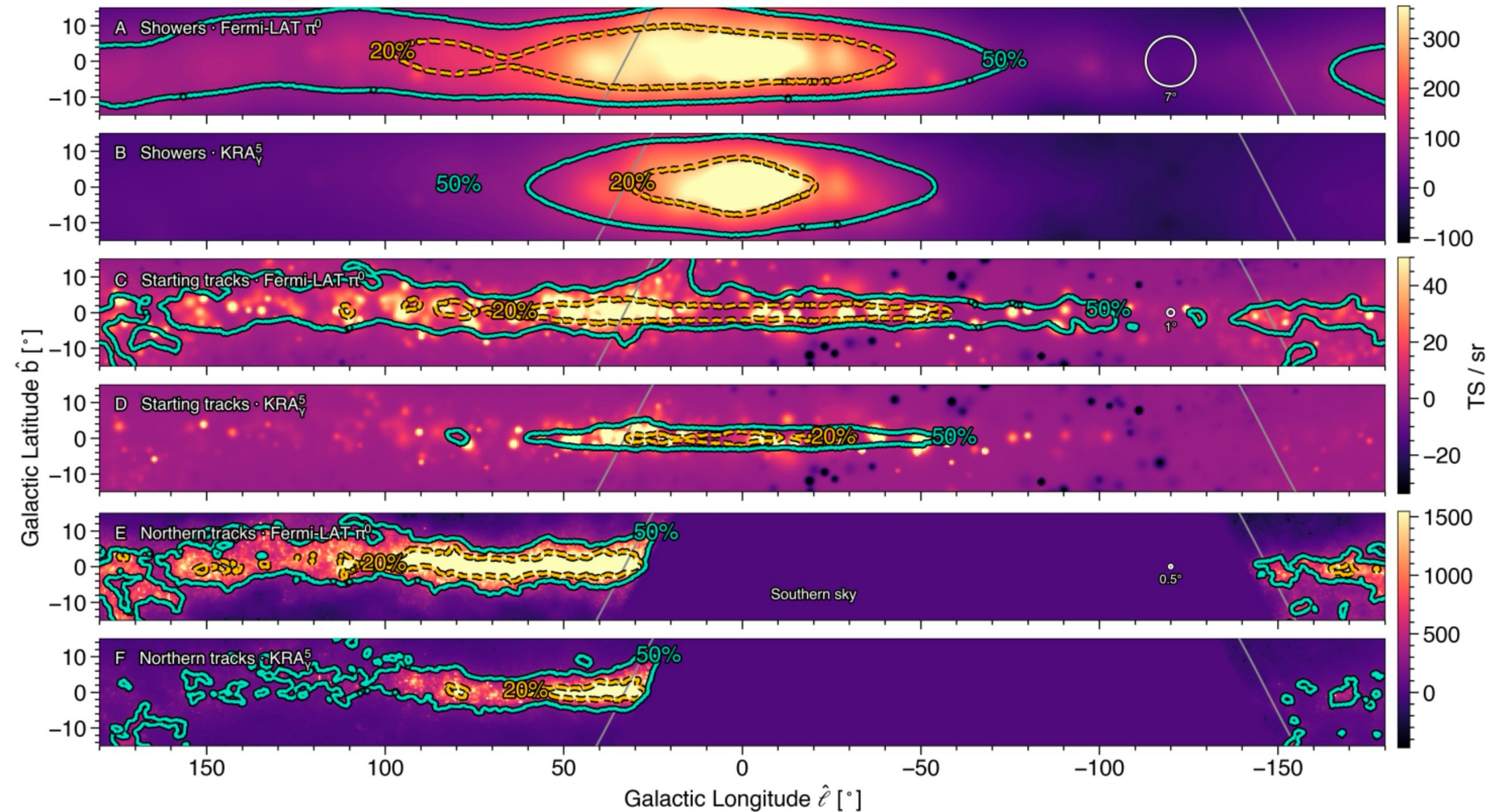
Phys.Rev.X 15 (2025) 3, 031016



IceCube, Phys. Rev. Lett. 135, 031001 (2025)

Galactic plane

- 2023: First significant detection of neutrino emission from the Galactic Plane (*Science* 380, 6652, 1338)
- 2026: $> 5 \sigma$ observation of the Galactic Plane for different templates of neutrino emission ([arXiv:2607.25966](https://arxiv.org/abs/2607.25966))
- 2026: first measurement along the galactic plane

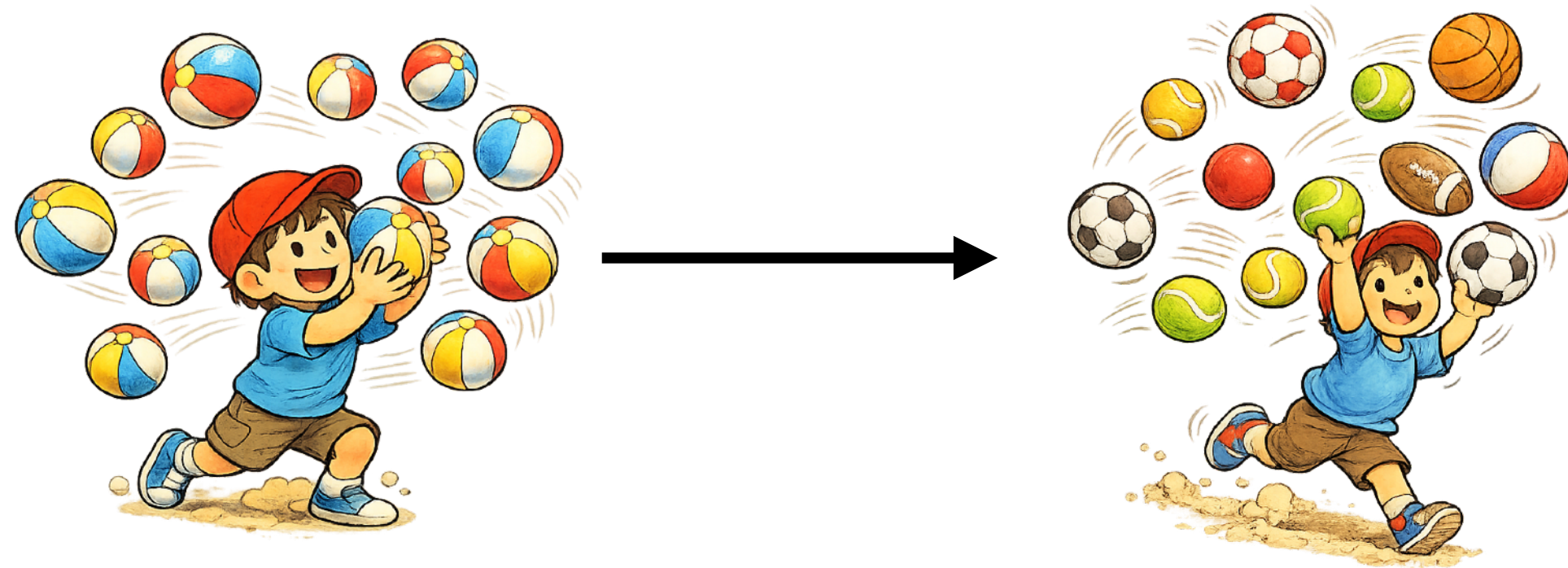
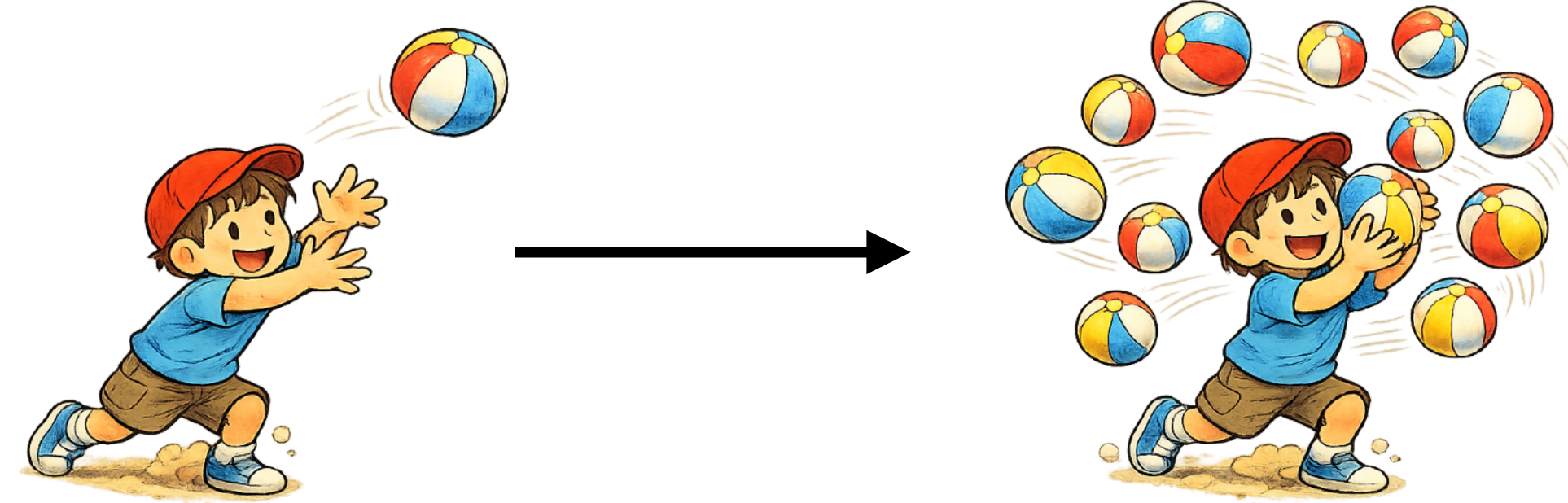


General foreseeable developments



From detection → characterization

- flavor, directionality, energy systematics
- composition of astrophysical flux
- atmospheric neutrinos as precision tools



From single-messenger → multi-messenger

- neutrinos + GW + gamma + EM follow-up
- real-time alerts, rapid analysis pipelines

From cuts/fits/drawing board → AI

- anomaly detection
- detector-aware generative models
- AI detector design



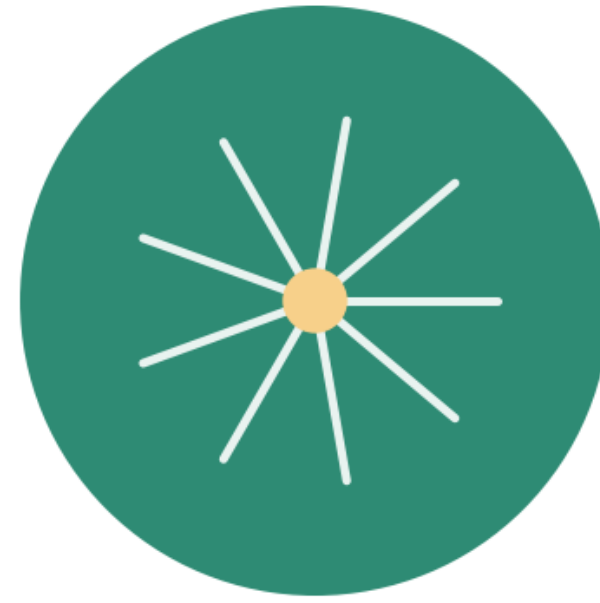
Versatility of Neutrino Telescopes

Combined published results across IceCube, KM3NeT, Baikal-GVD and ANTARES



Oscillations & particle physics

Tau appearance, Glashow resonance, oscillation & cross-section measurements



Diffuse flux & point sources

Discovery (2013) through TXS 0506+056, NGC 1068, KM3-230213A
galactic ridge excess



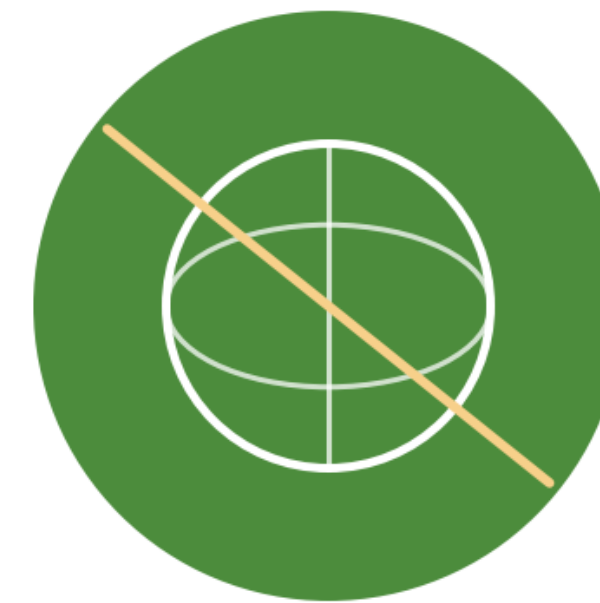
Dark matter (indirect)

Sun, Earth, Galactic Center, dwarf galaxies



Exotics / BSM

Magnetic monopole and nuclearite flux limits

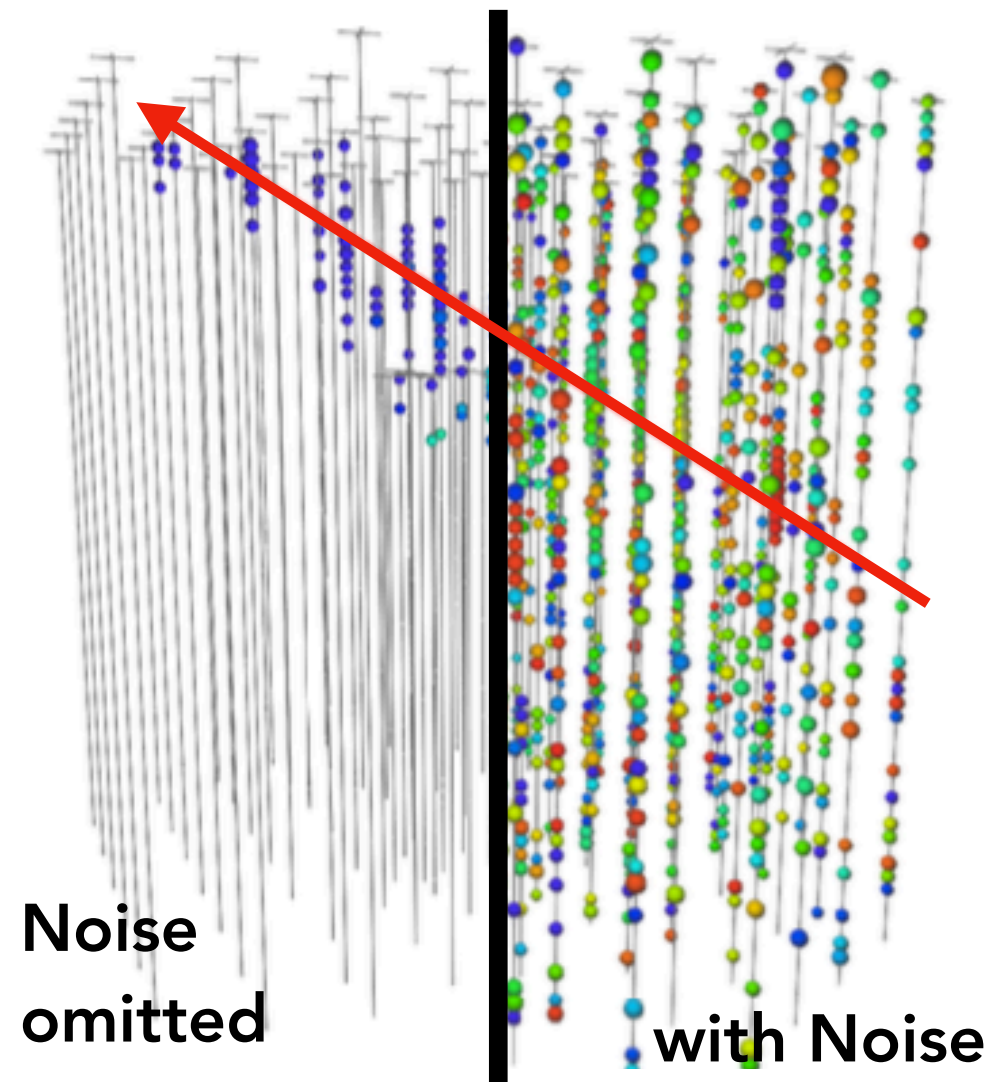


Earth sciences

Ice tomography & glaciology; bioluminescence & water monitoring

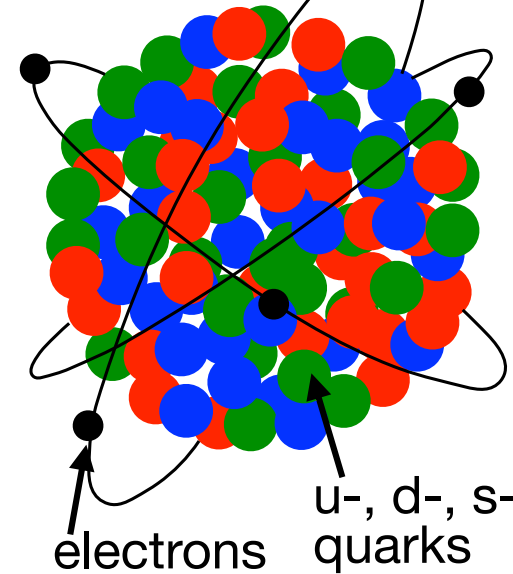
From neutrinos to exotic particles

- large volume -> large sensitivity
- direct detection "only" needs light emission
- extremely heavy would be slow ($< 0.1 c$)
- light emission process might be exotic, too



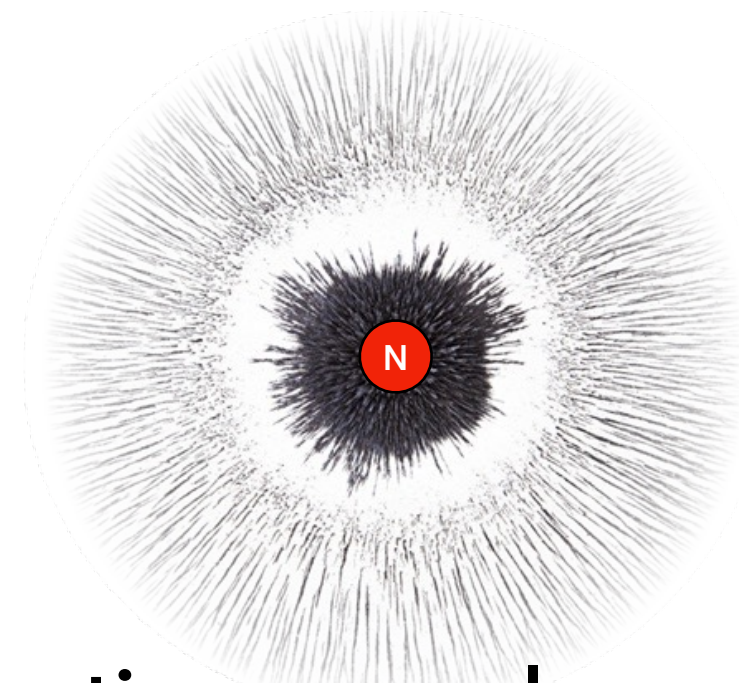
Nuclearites

- stable states in SM!
- equal amounts of u-, d-, s-quarks
- produced after BB or as lumps of neutron stars



Magnetic monopole

- single magnetic charge
- well motivated as its existence is tied to quantized electric charge



model dependent!

(indirect) Cherenkov

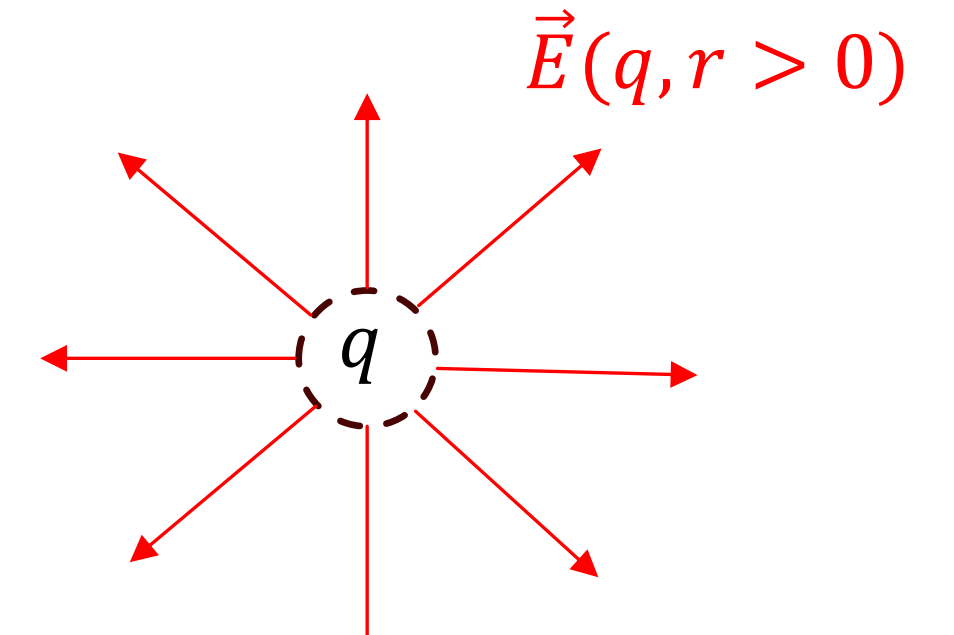
Proton decay

Luminescence

Thermal shock

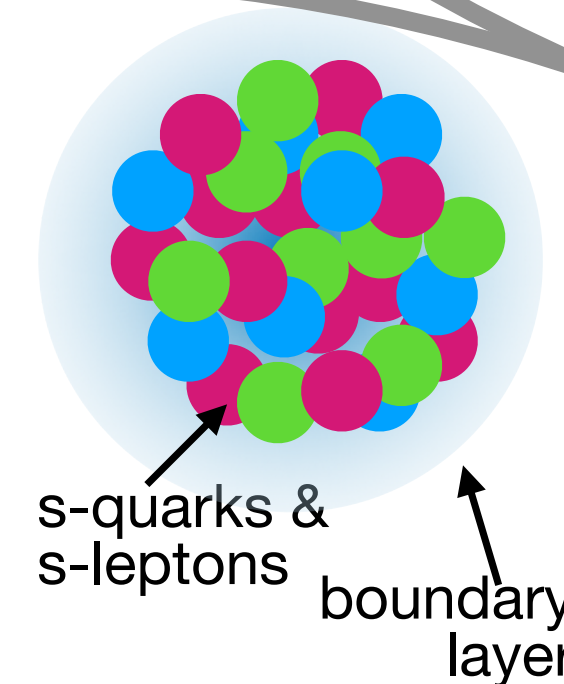
Shadow charge

- DM candidate
- doesn't respond to EM fields but is electrically charged
- follows geodesics

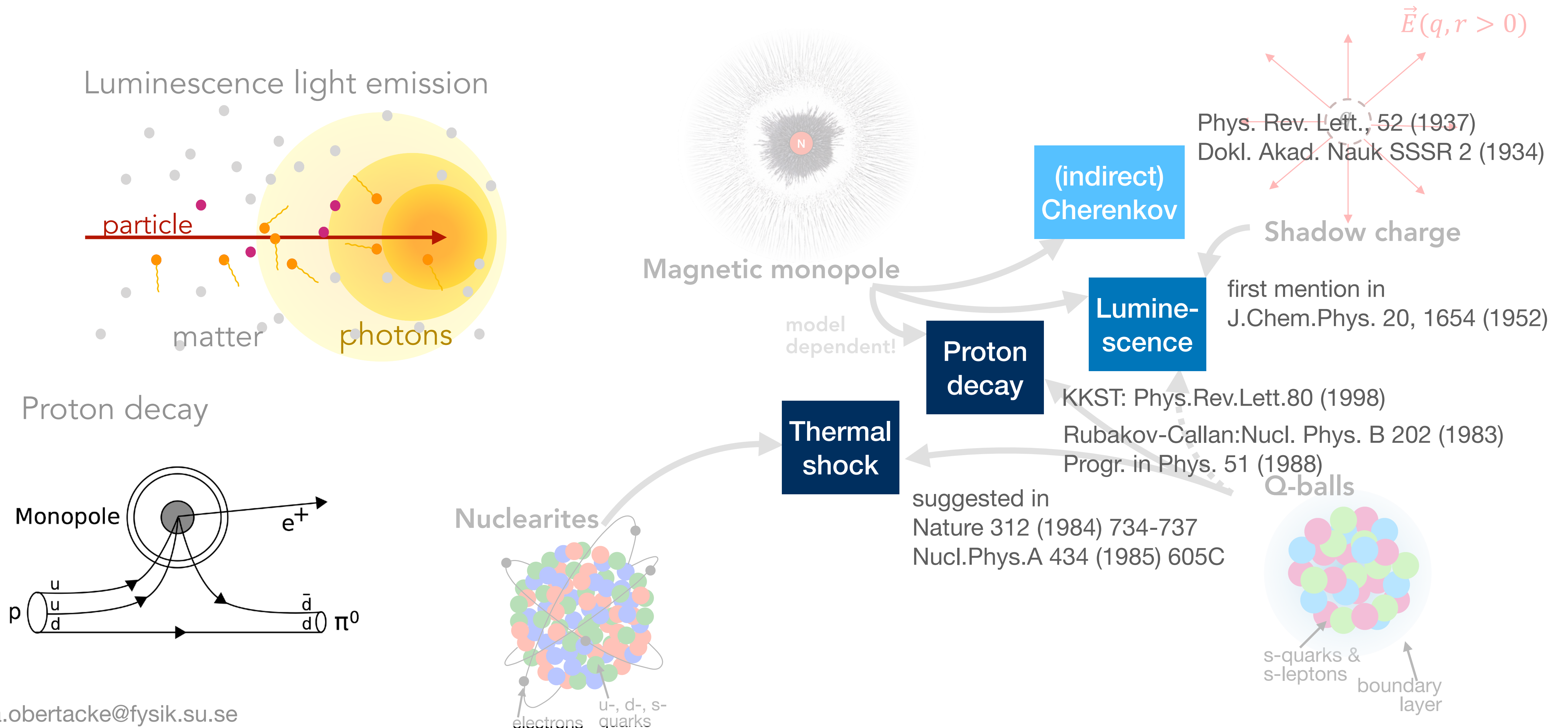


Q-balls

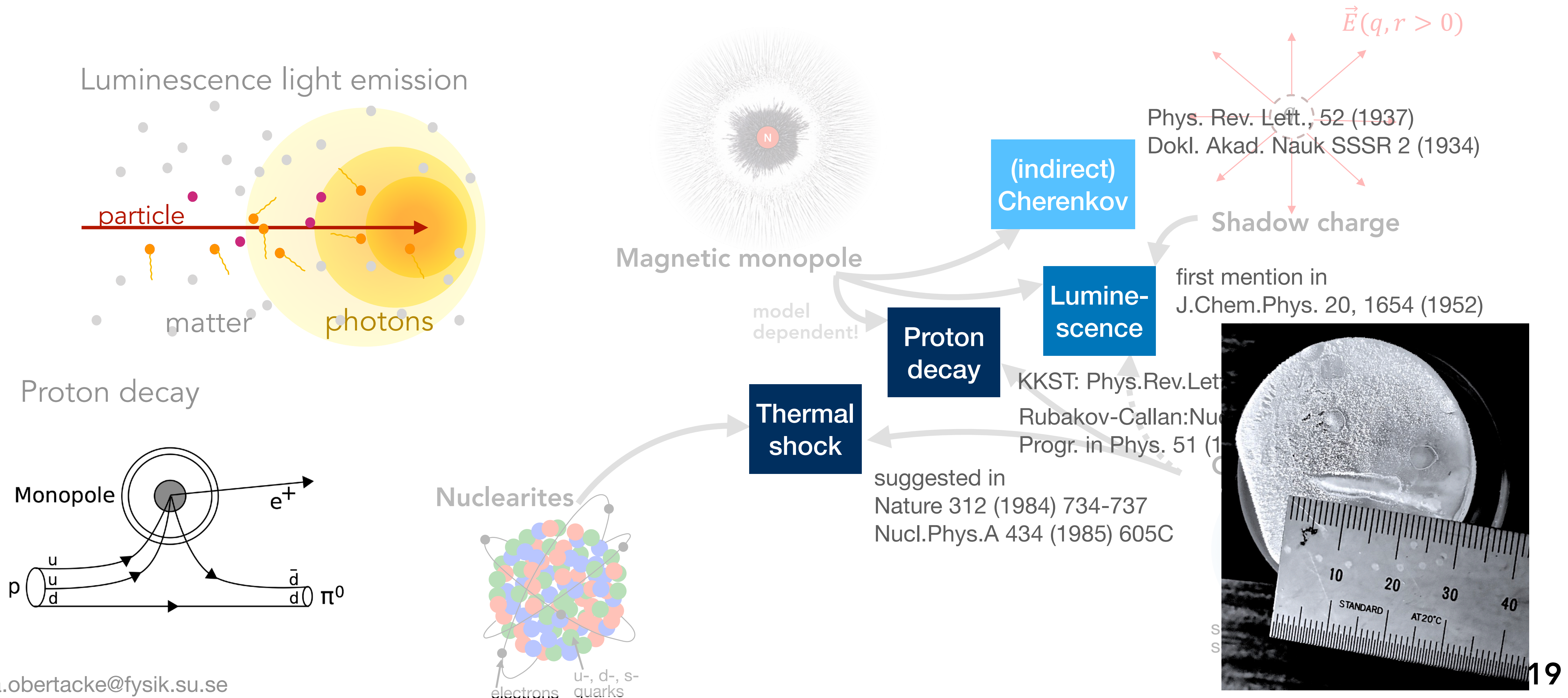
- predicted by supersymmetry
- coherent states of squarks, sleptons and the Higgs field
- charged or neutral



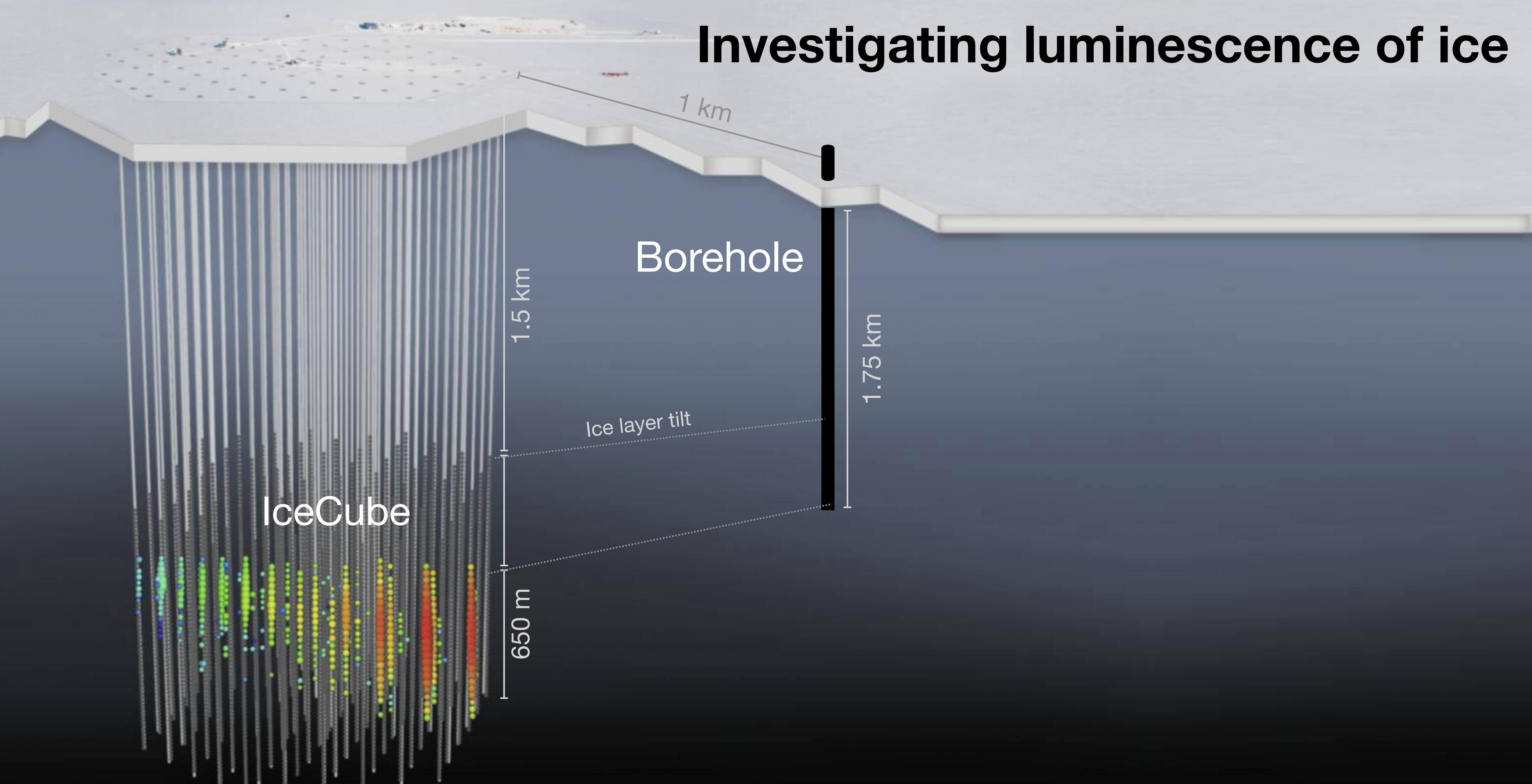
Versatility of light emission channels



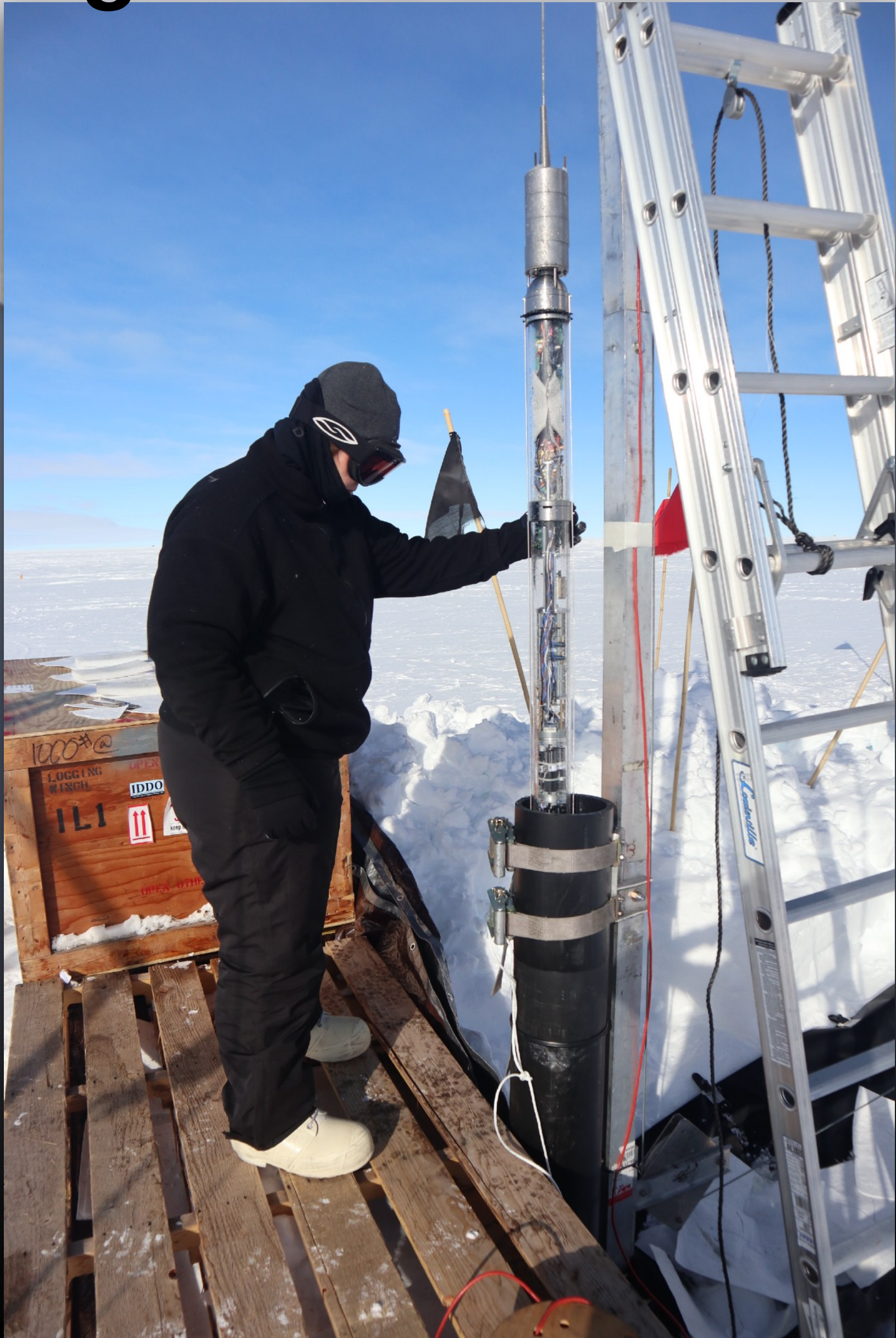
Versatility of light emission channels



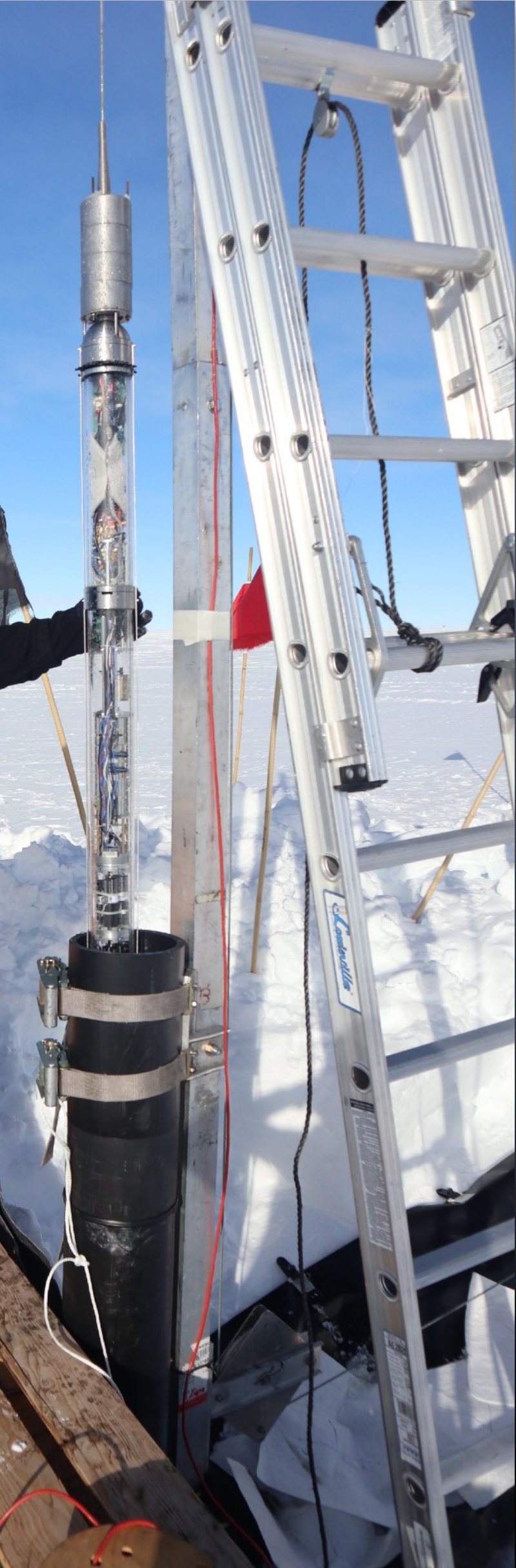
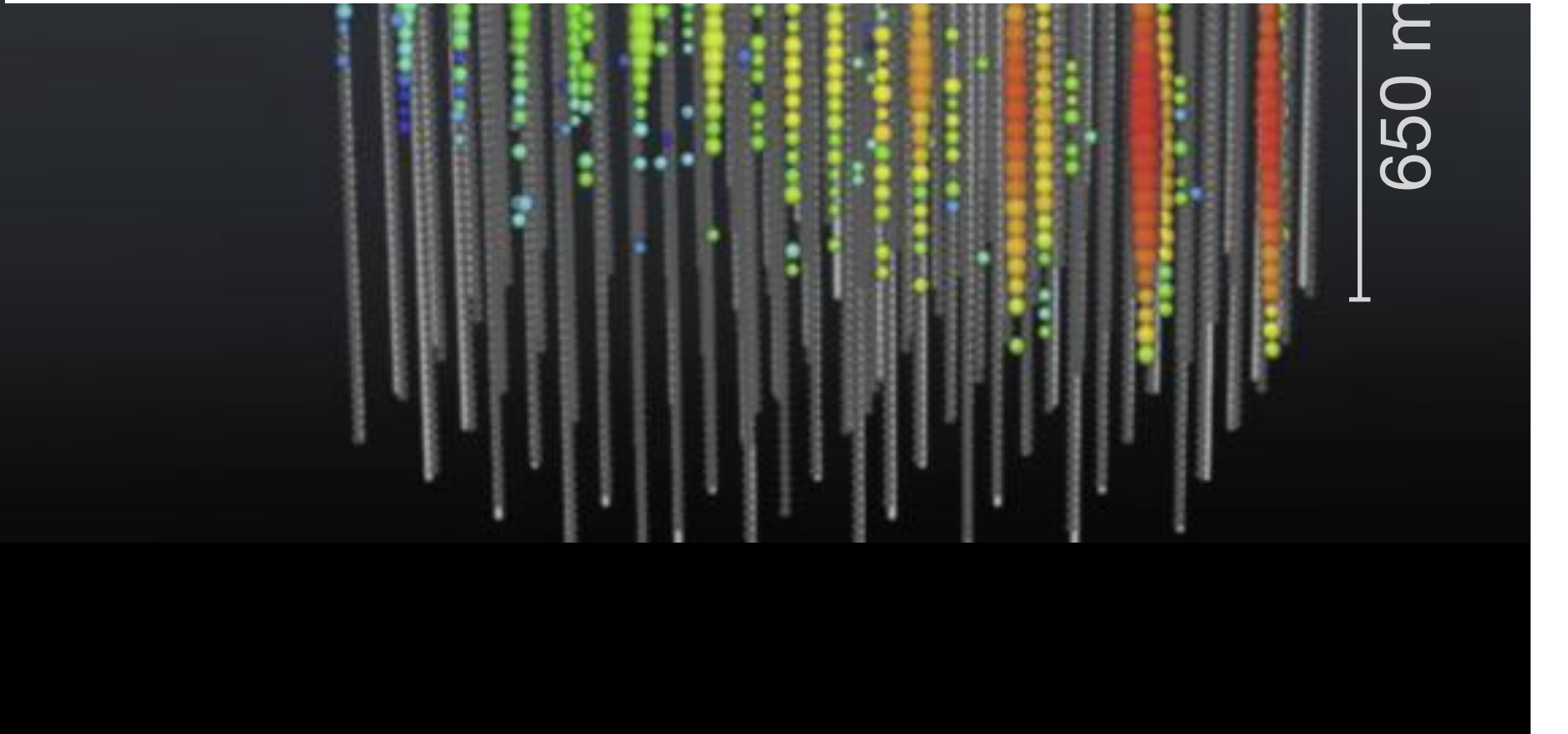
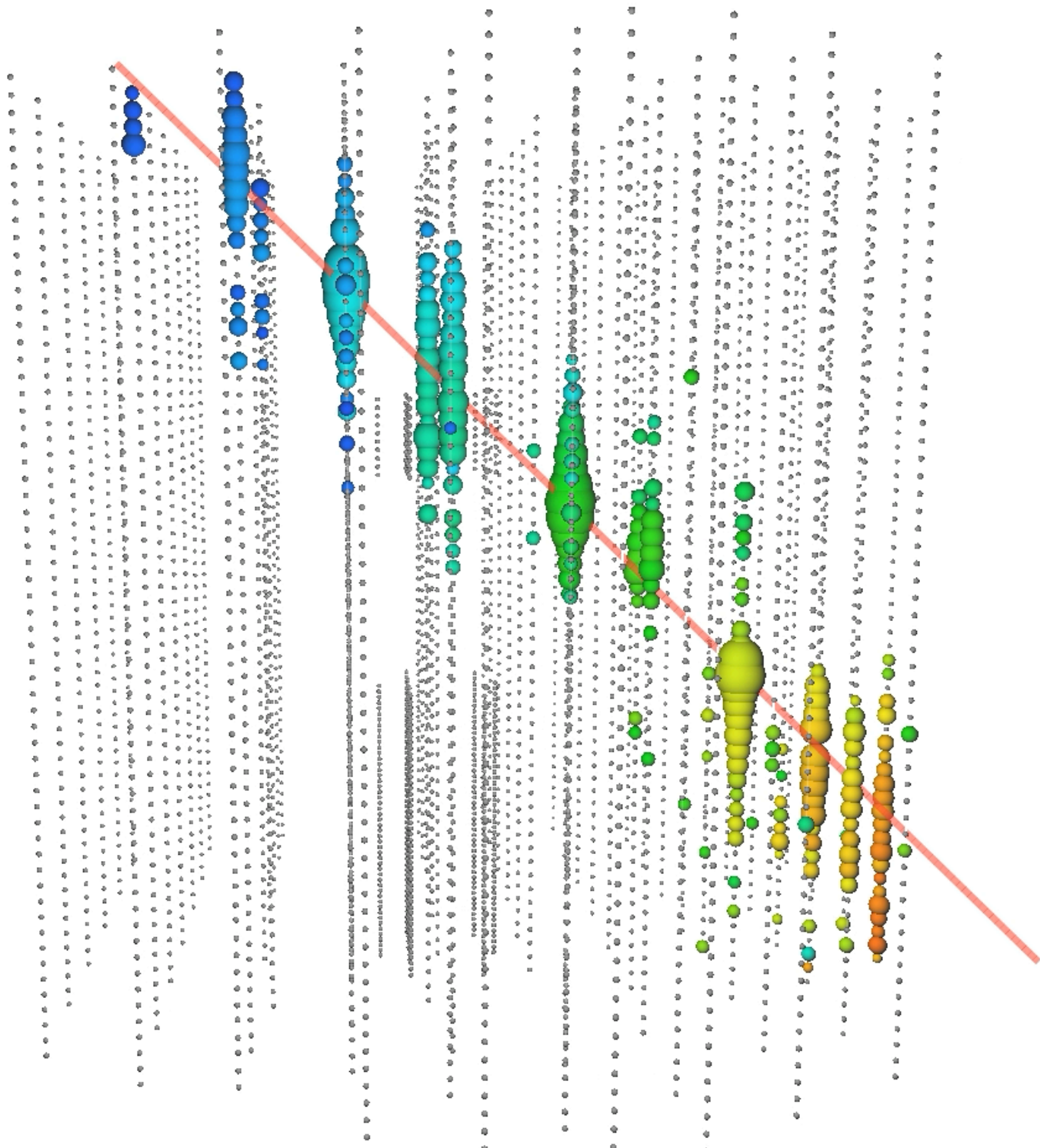
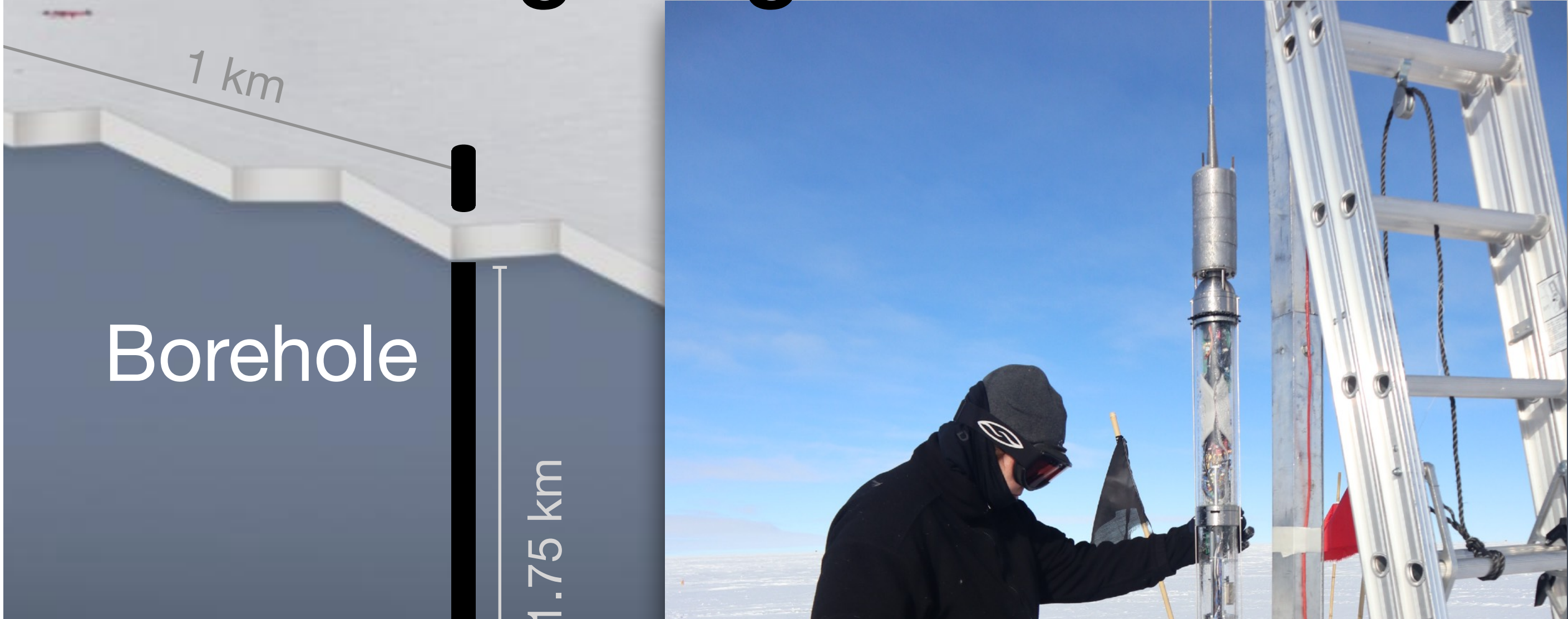
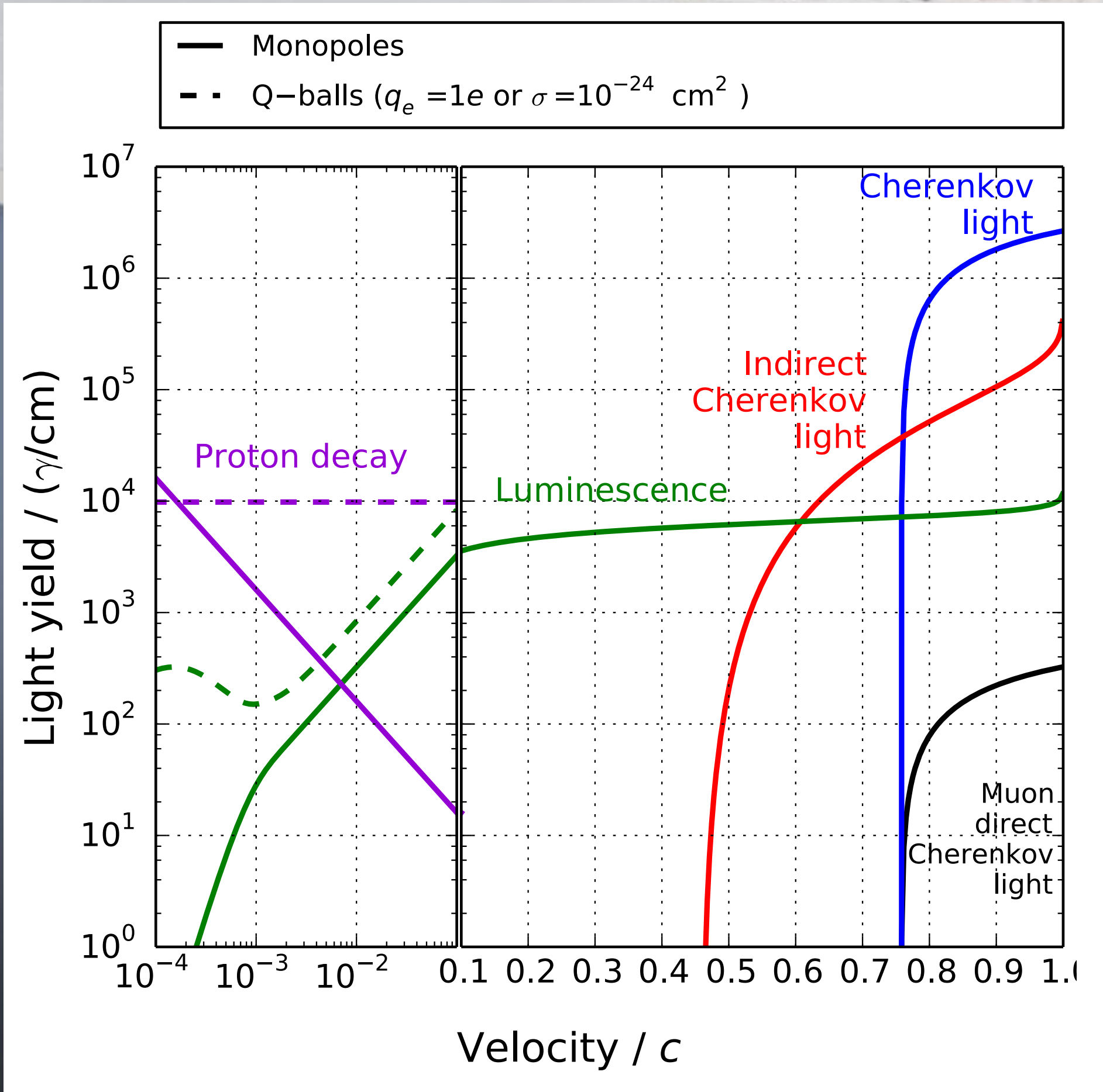
Investigating luminescence of ice



Investigating luminescence of ice

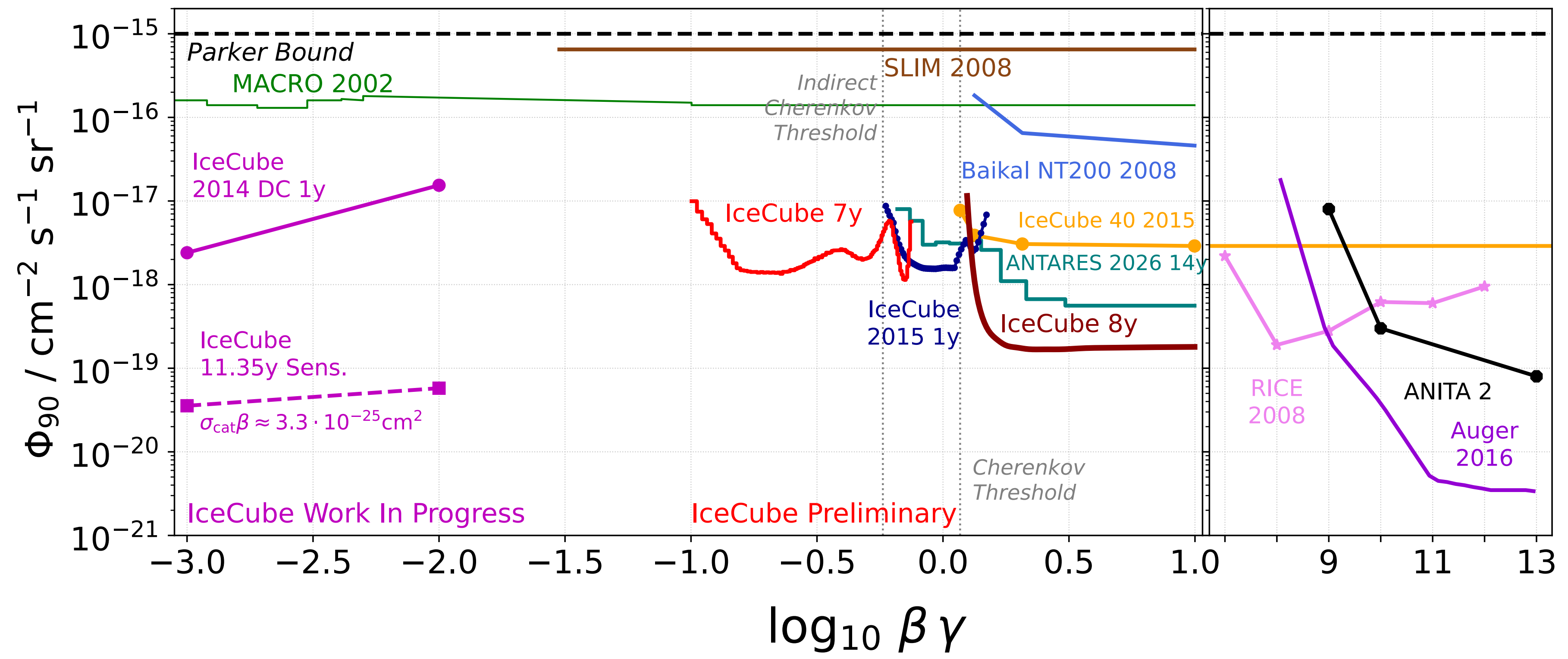


Investigating luminescence of ice

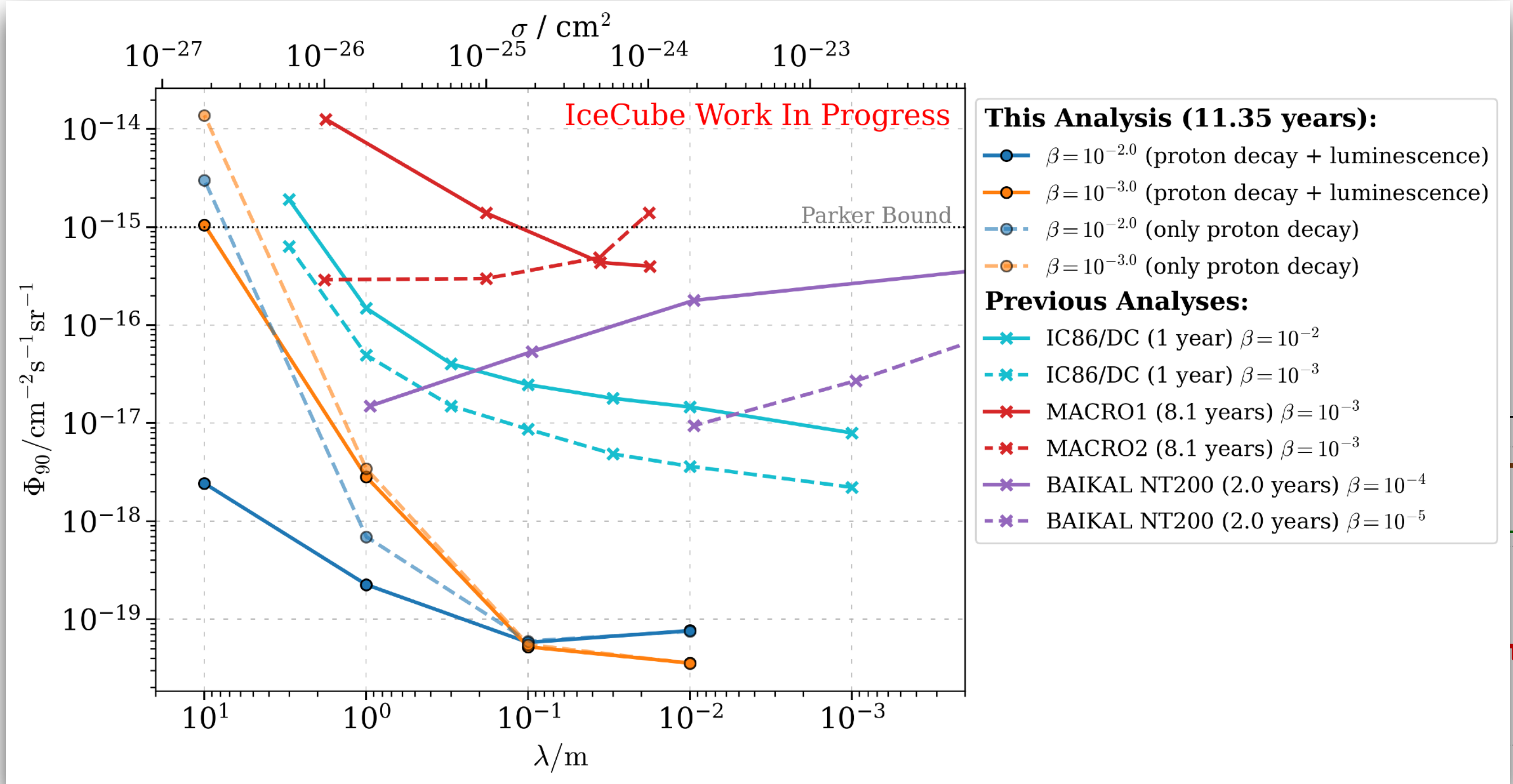


Magnetic Monopole Flux Limits

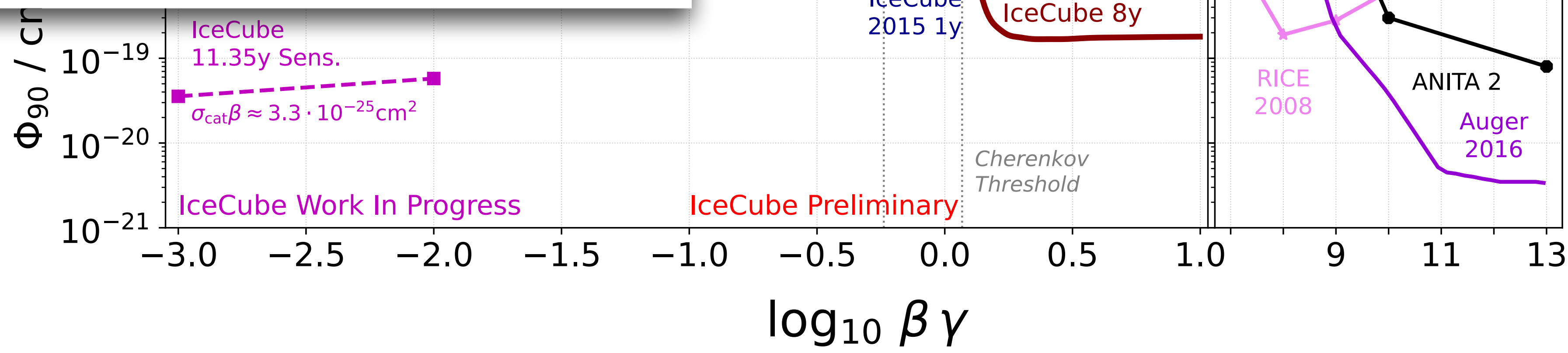
Ambrosio et al., Eur. Phys. J. C25 (2002) 511
Albert et al., JHEAp 50, 100500 (2026)
Antipin et al., Astropart. Phys. 29 (2008) 366
Balestra et al., Eur. Phys. J. C 55 (2008) 57
Hogan et al., Phys. Rev. D 78, 075031 (2008)
Phys. Rev. D 83, 023513 (2011)
Pierre Auger Coll., Phys. Rev. D 94, 082002 (2016)
Turner, Parker, Bogdan, Phys. Rev. D26 (1982) 1296



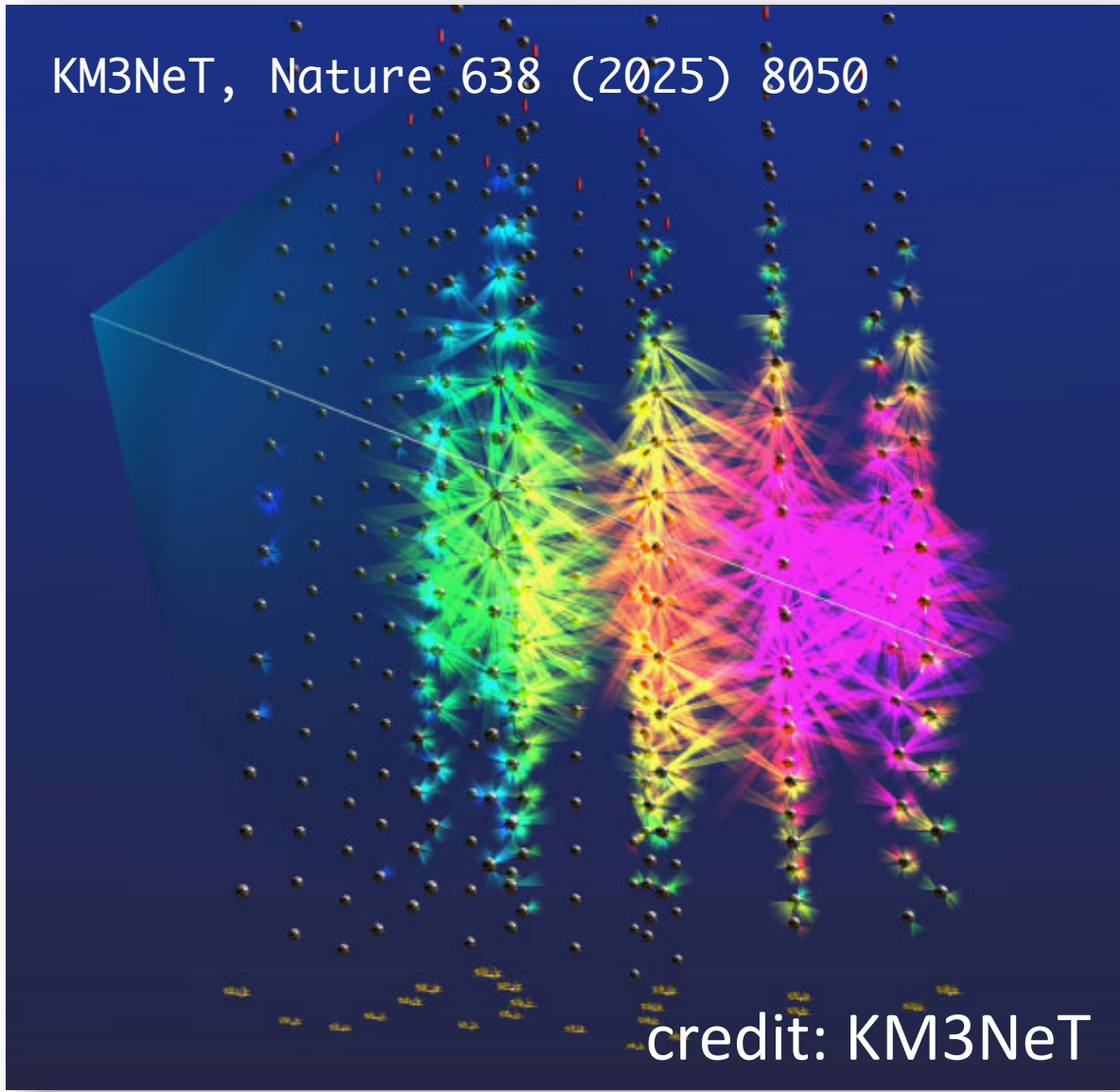
Magnetic Monopole Flux Limits



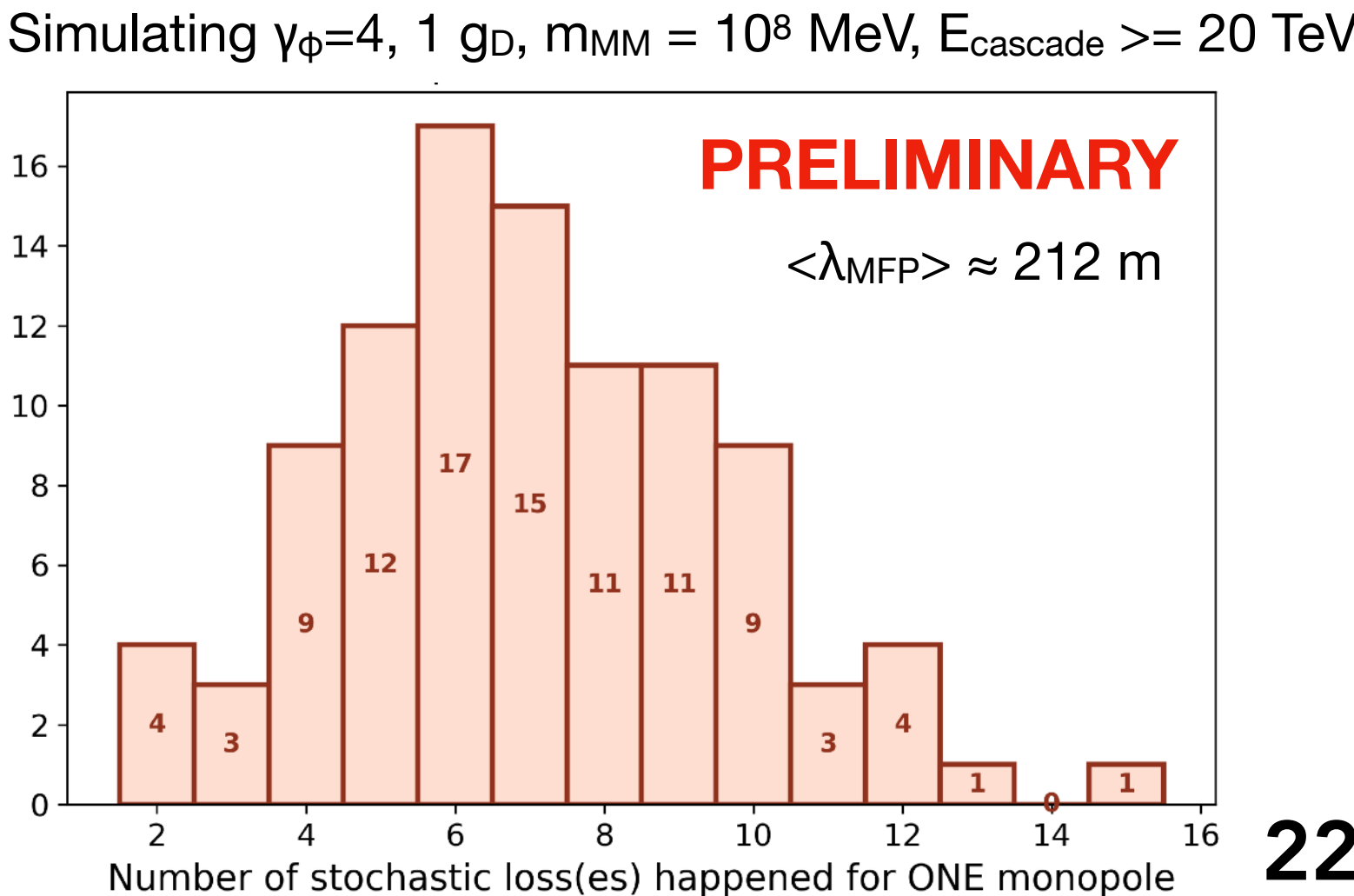
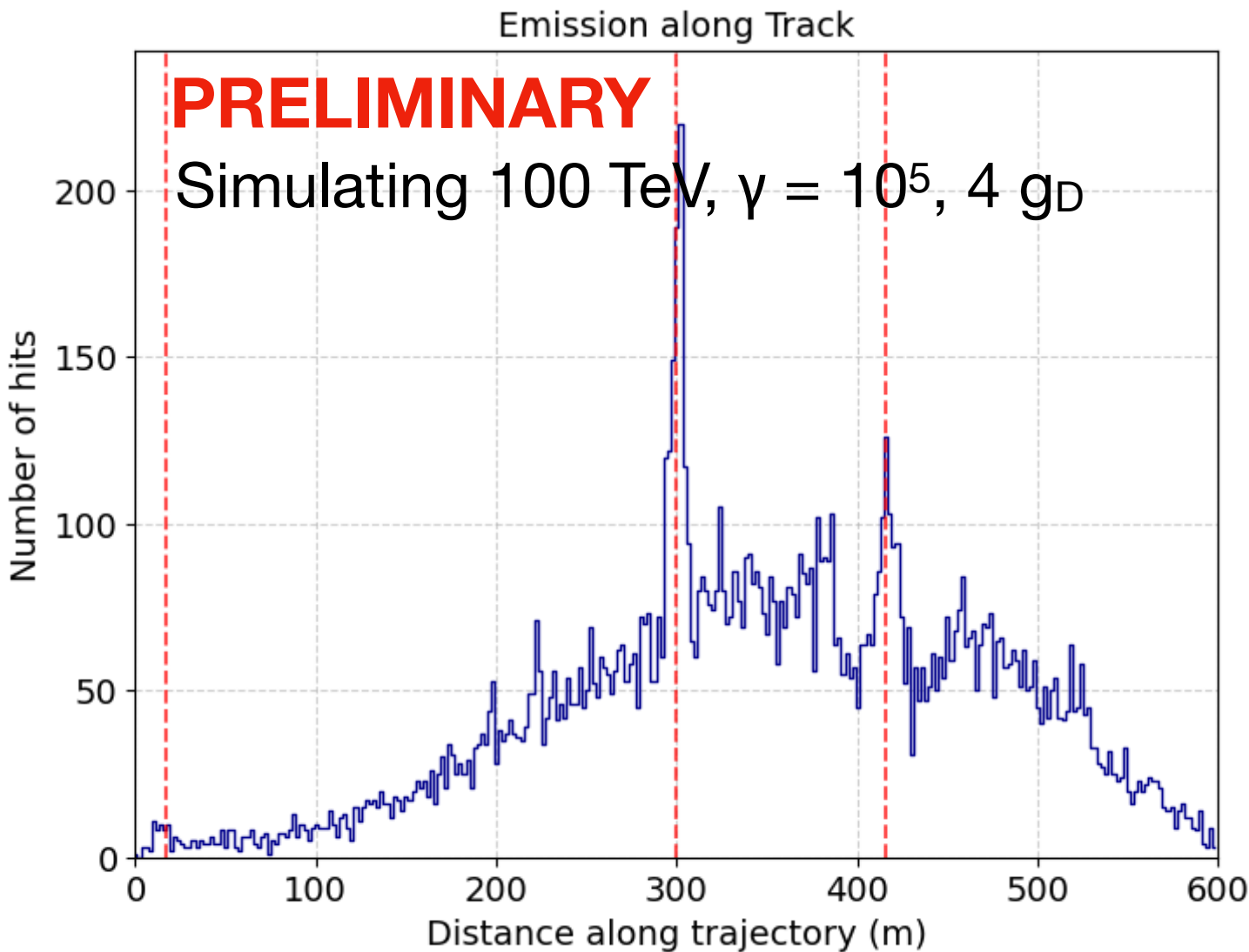
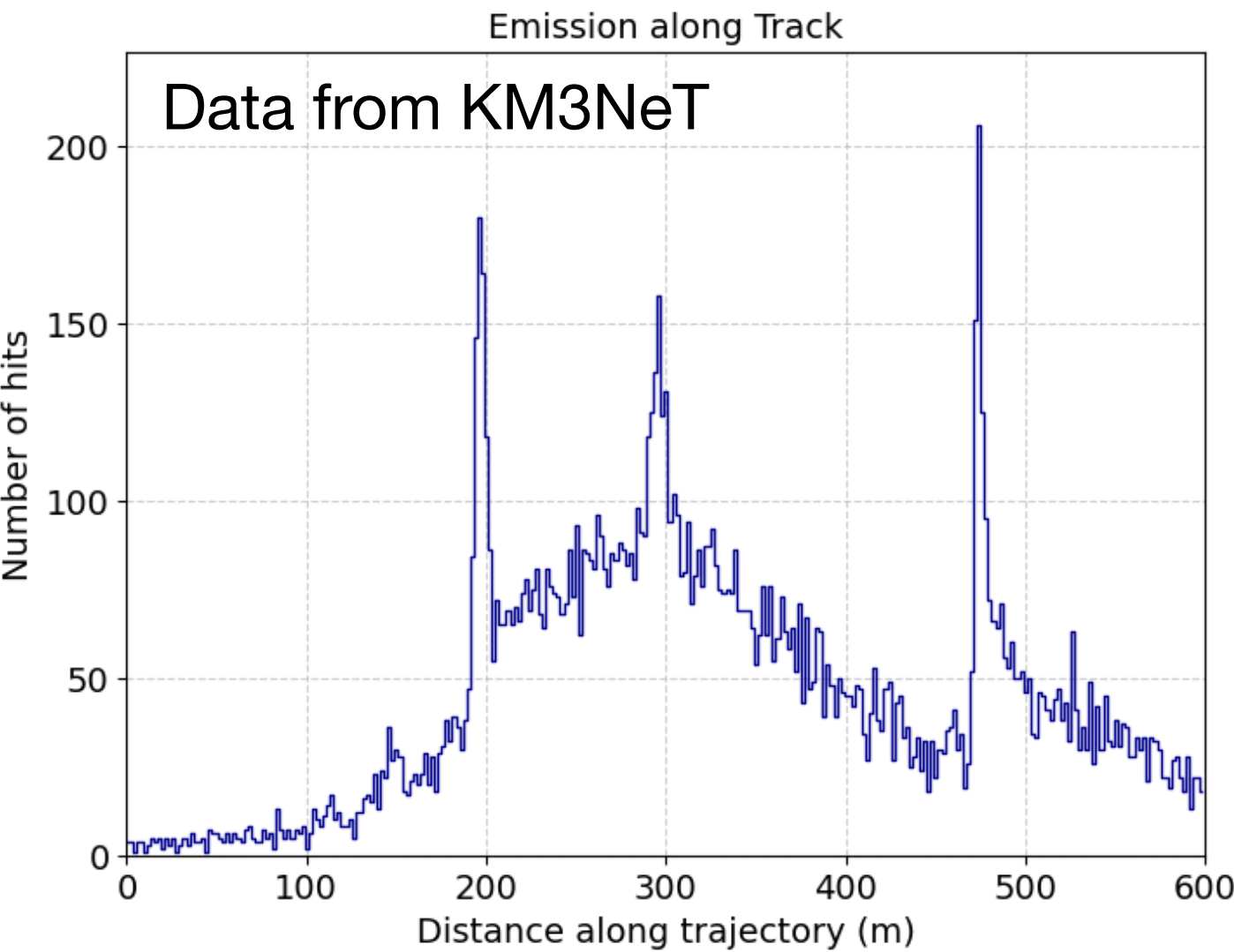
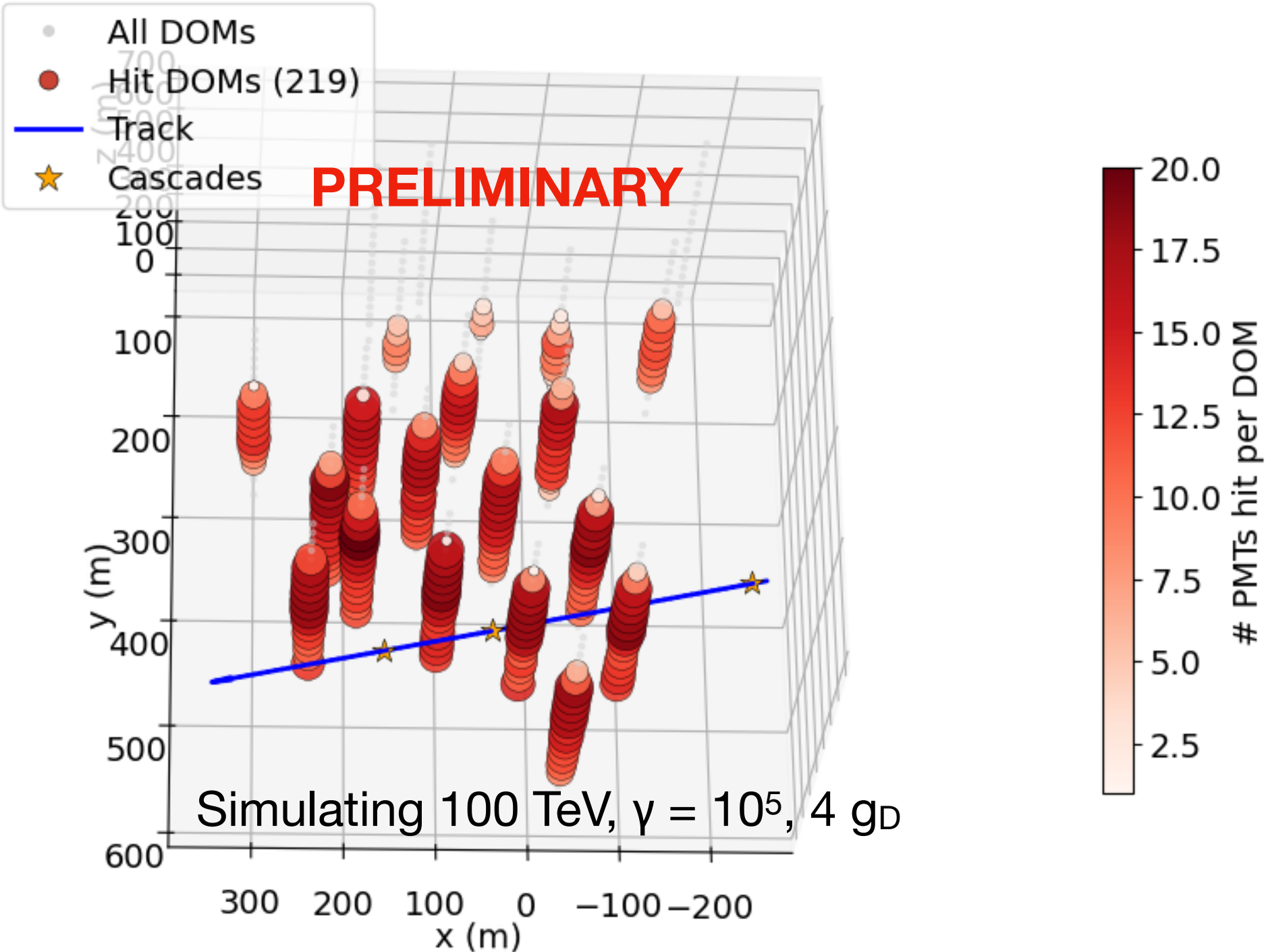
Ambrosio et al., Eur. Phys. J. C25 (2002) 511
Albert et al., JHEAp 50, 100500 (2026)
Antipin et al., Astropart. Phys. 29 (2008) 366
Balestra et al., Eur. Phys. J. C 55 (2008) 57
Hogan et al., Phys. Rev. D 78, 075031 (2008)
Phys. Rev. D 83, 023513 (2011)
Pierre Auger Coll., Phys. Rev. D 94, 082002 (2016)
Turner, Parker, Bogdan, Phys. Rev. D26 (1982) 1296



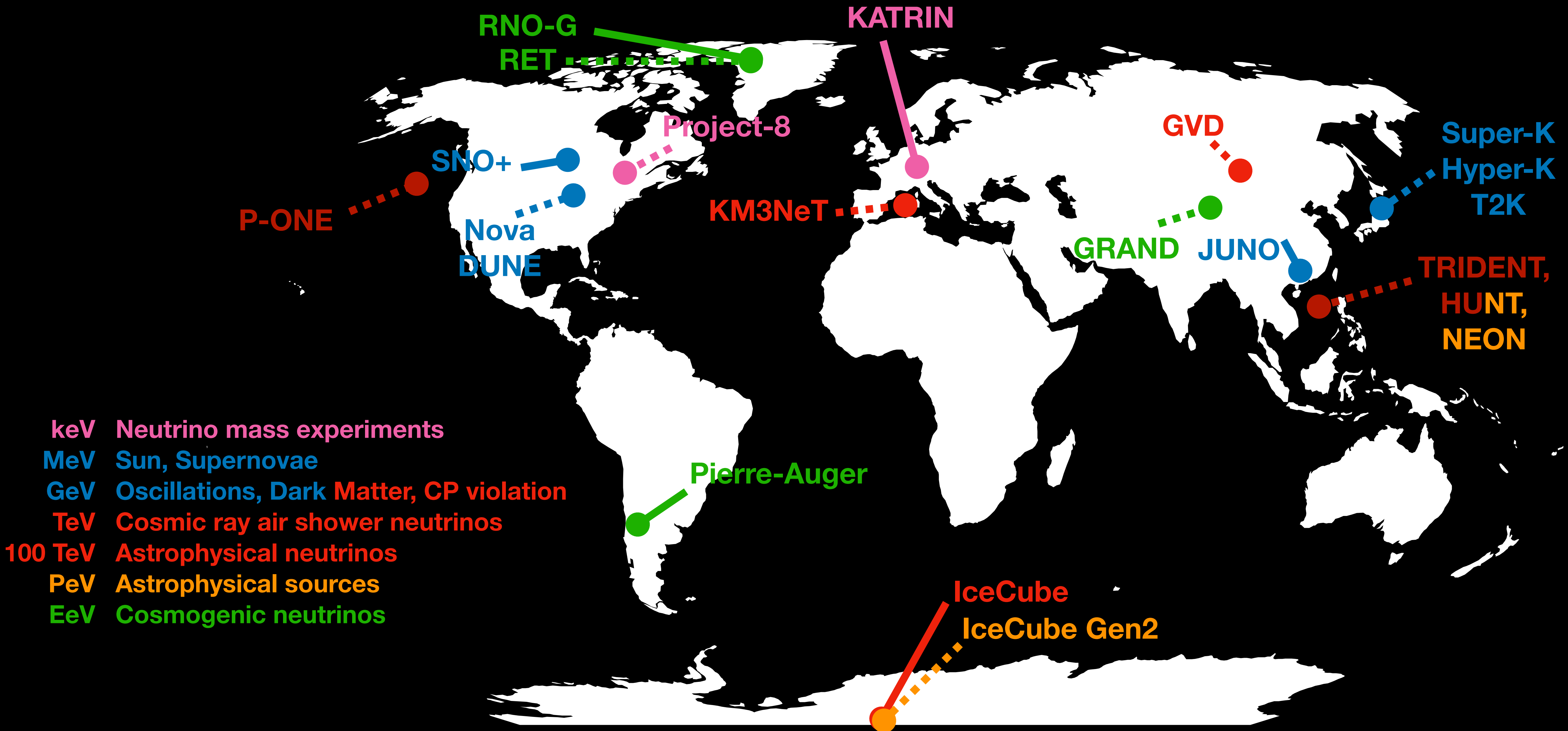
Investigation of the KM3NeT event



Rather a muon-neutrino
or a magnetic
monopole?



Neutrino detectors around the World



Summary

- new analyses transition from detecting sources of high-energy neutrinos to measuring detailed properties of their fluxes
- a lot of momentum in increasing detector volumes and refining technology
- leading sensitivities for exotic physics offer significant discovery potential
IceCube's "slow particle" analysis will unblind soon
- gaps in astrophysical searches for magnetic monopoles and unusual events motivate new detector ideas

