Photo: Martin Wolf

Results from the IceCube Neutrino Observatory

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2022 June 17

IceCube in Scandinavia

Stockholm
since 1992

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Chad Finley
Christian Walck
Attila Hidvegi
Kunal Deoskar
Matti Jansson

Uppsala
since 1992

Olga Botner
Allan Hallgren
Carlos de los Heros
Erin O'Sullivan
Christian Glaser
Ankur Sharma
Nora Valtonen-Mattila
Jakob Beise
Nils Heyer

Copenhagen
since 2013

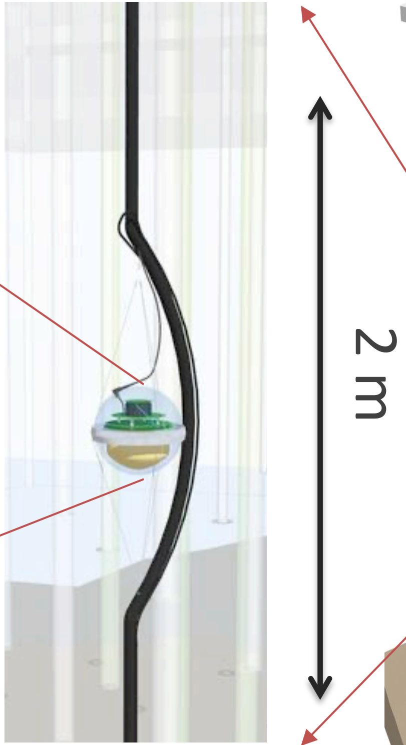
Jason Koskinen
Markus Ahlers
Tom Stuttard
James Vincent Mead
David Ribers
Tetiana Kozynets
Kathrine Mørch Groth

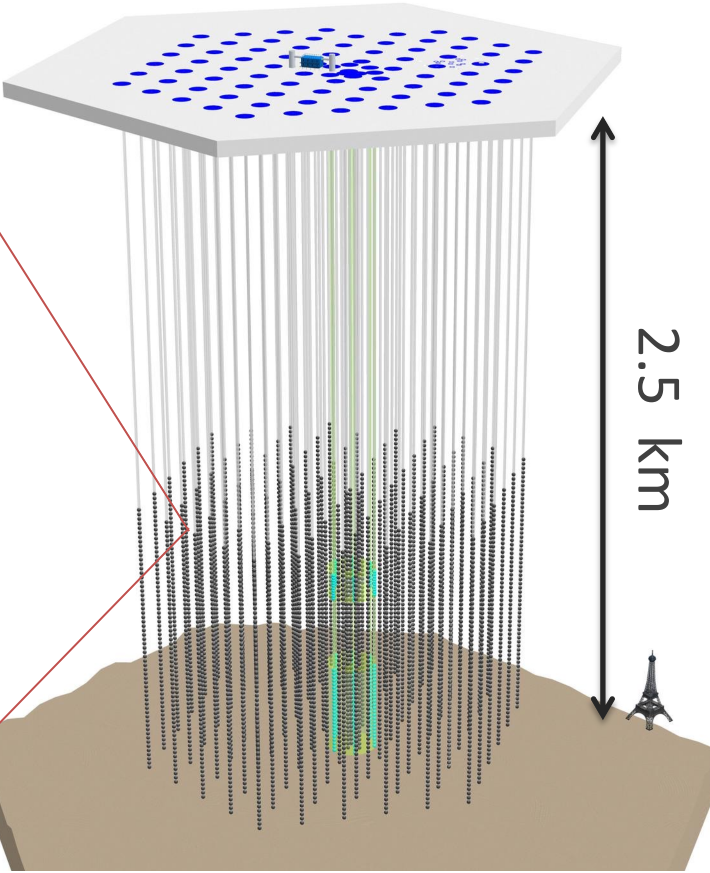
IceCube Collaboration: 350 scientists, 14 countries, 56 institutes

IceCube Neutrino Observatory

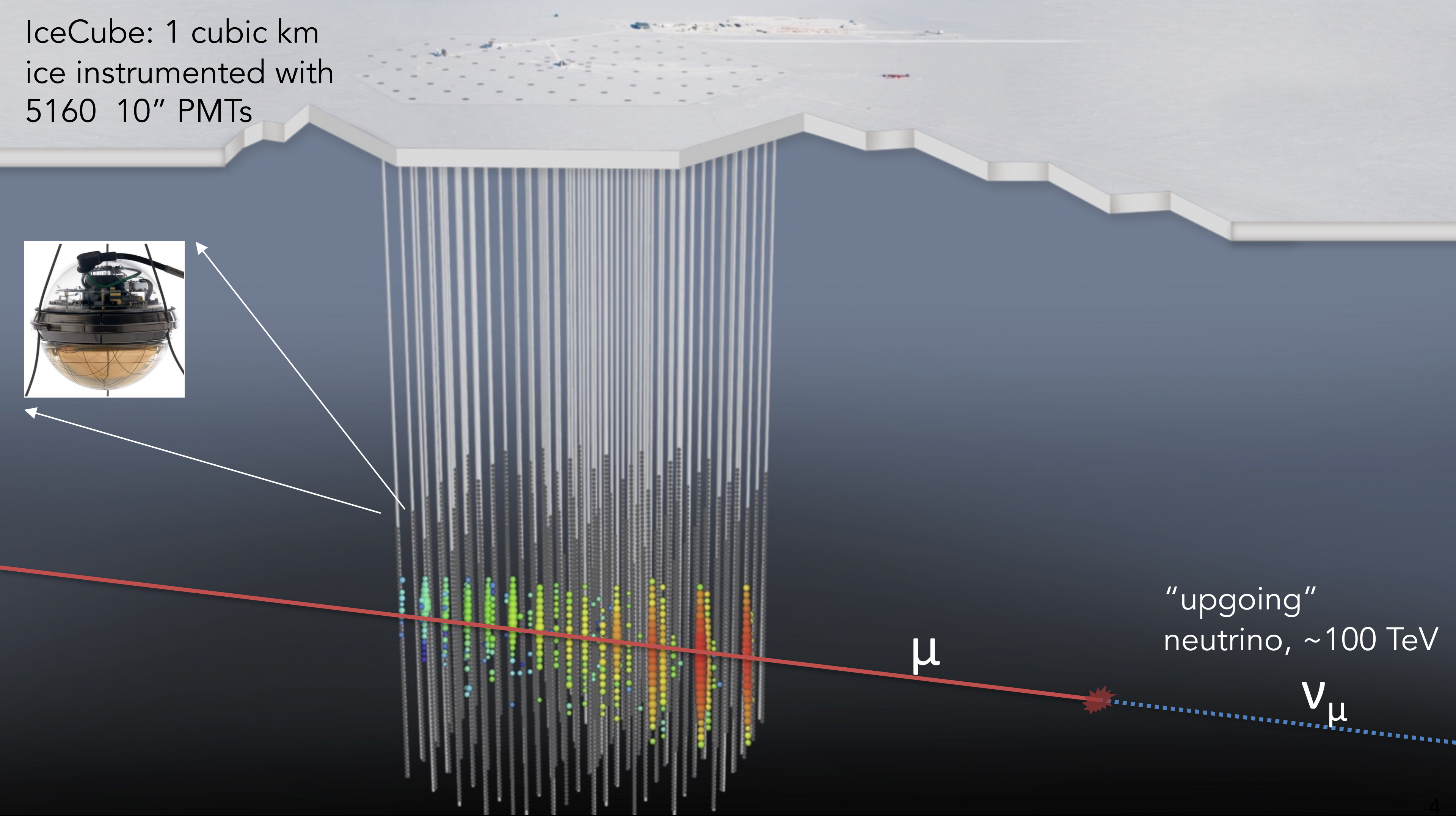
DOM: Digital Optical Module

10″ PMT Hamamatsu

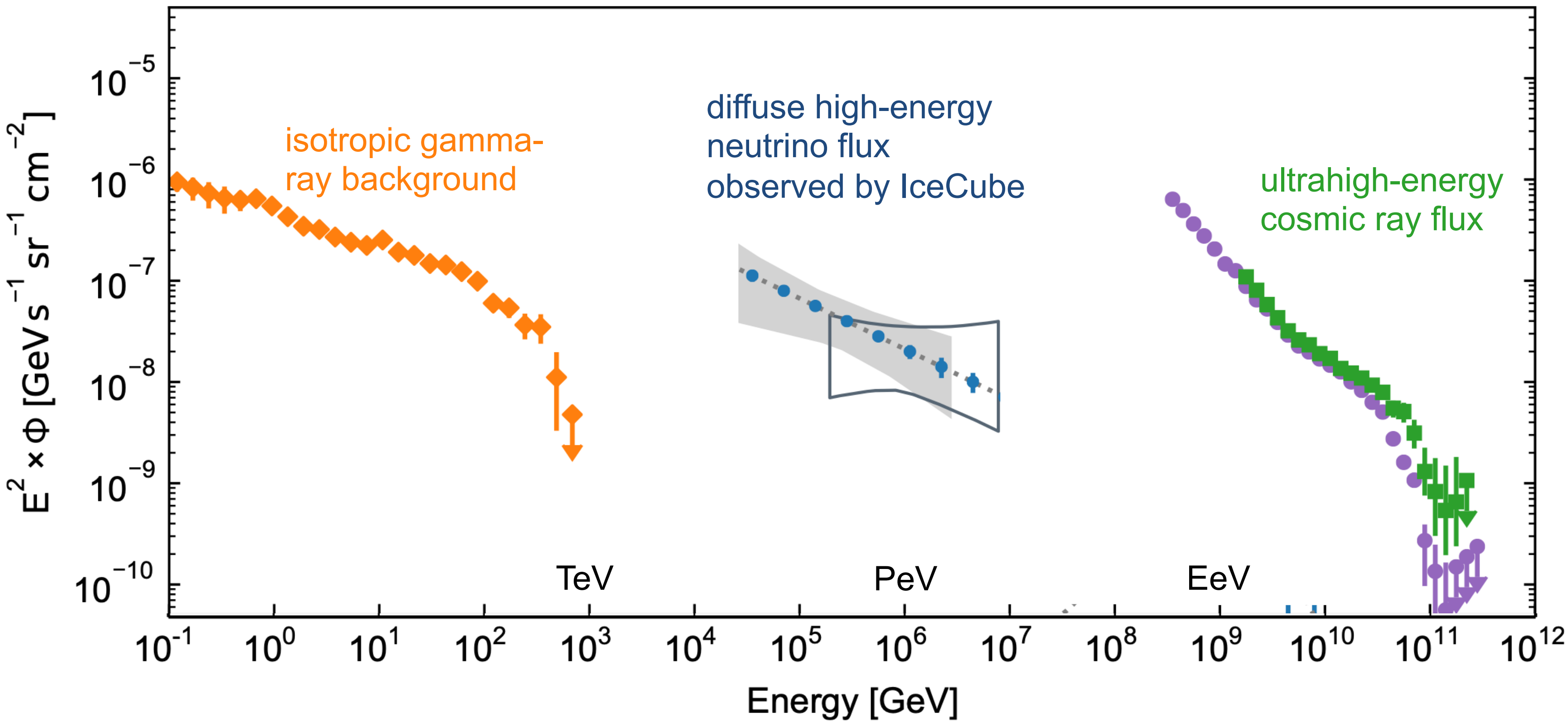




5160 DOMs spread over 1 km^3 = 1 Gigaton instrumented volume


IceCube: 1 cubic km
ice instrumented with
5160 10” PMTs
“upgoing”
neutrino, ~100 TeV
μ
ν_μ

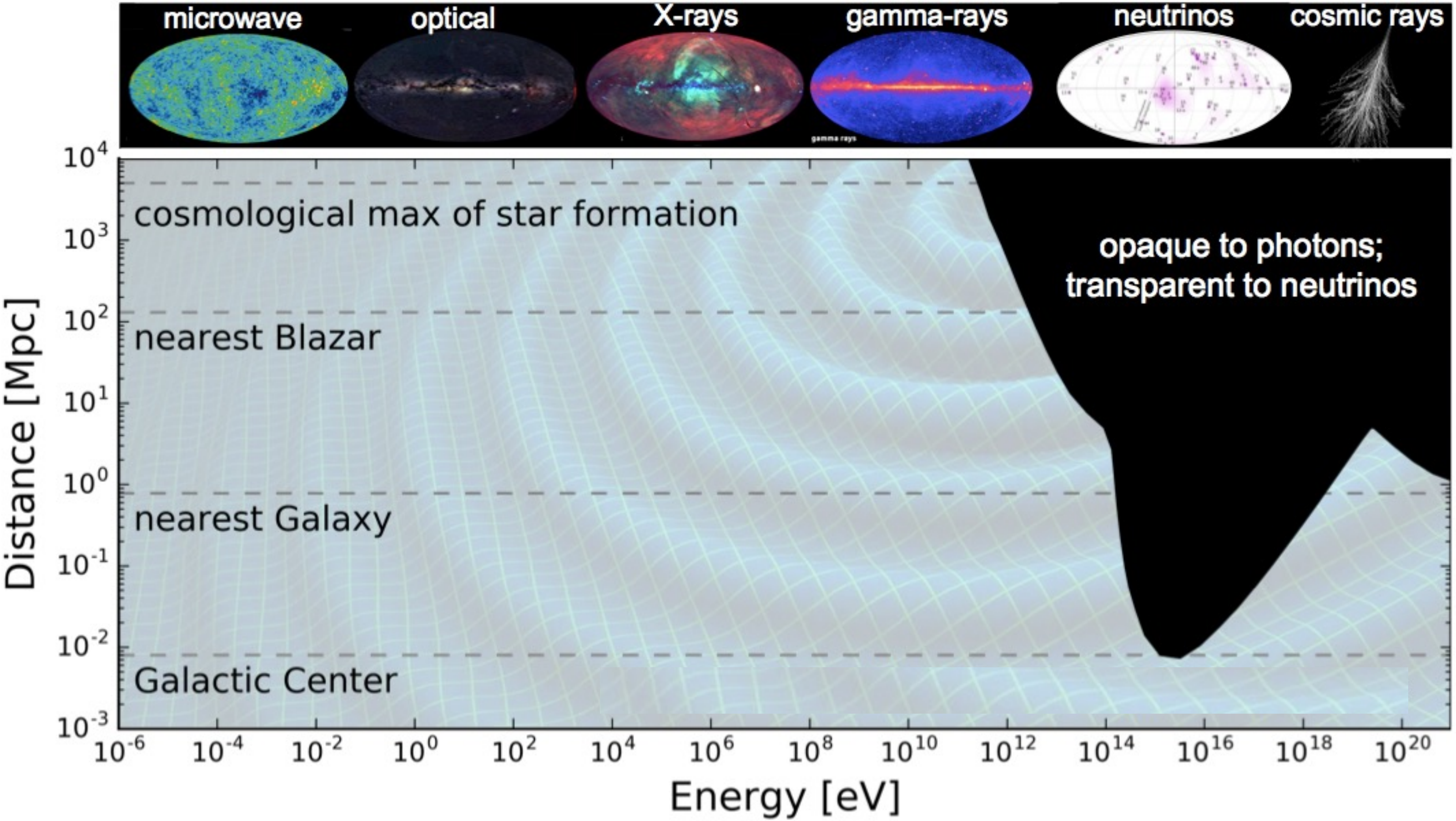
Cosmic Particle Accelerators – What, where, how?



Neutrinos are unique tracers of hadronic interactions – sites of CR interactions

Above TeV, universe starts to become opaque for photons, due to pair-production off background radiation fields

$\gamma + \gamma_{IR,CMB,radio} \rightarrow e^+ + e^-$



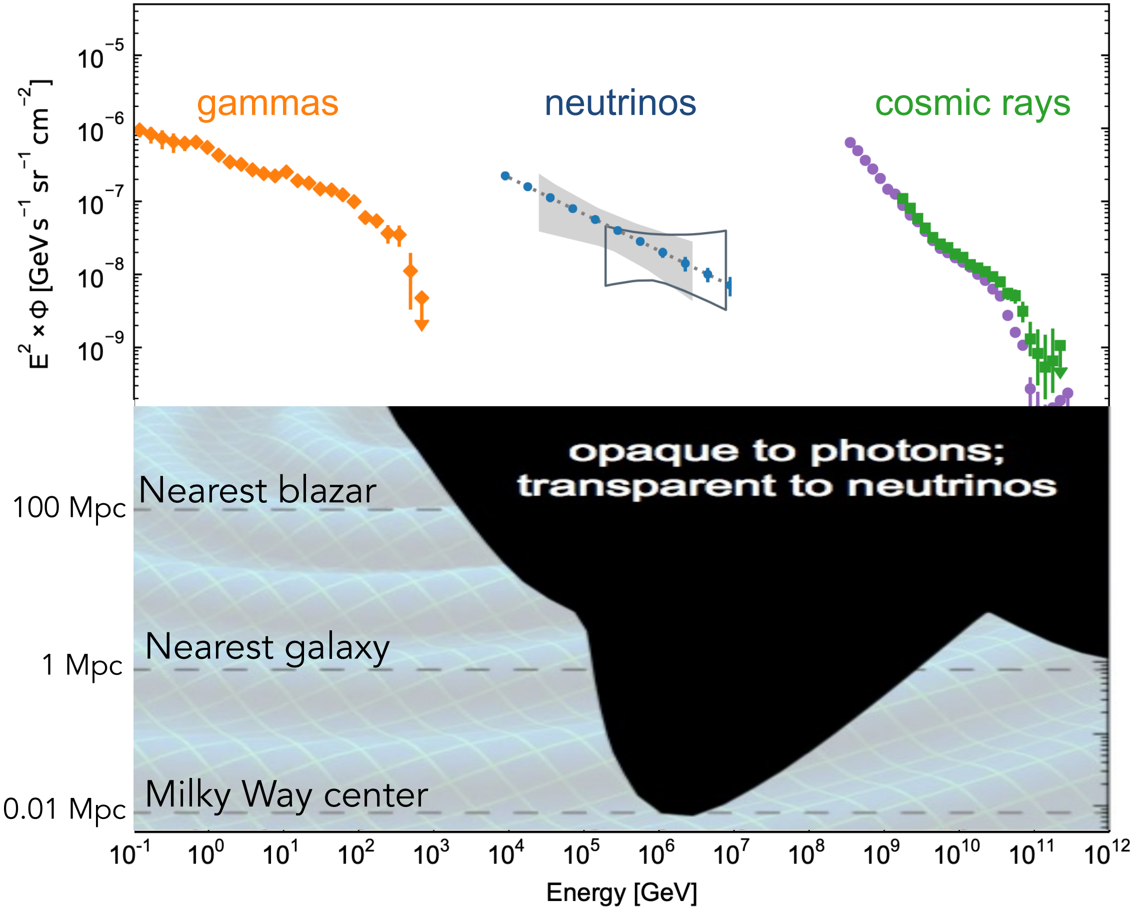
Neutrinos: Window onto the High Energy Universe

Multimessenger astronomy: complementary messenger to photons, probing higher energy range

What are the sources of the nu flux?

- Gamma Ray bursts – increasingly ruled out
- Blazars / Active galactic nuclei – evidence, not 5 sigma yet

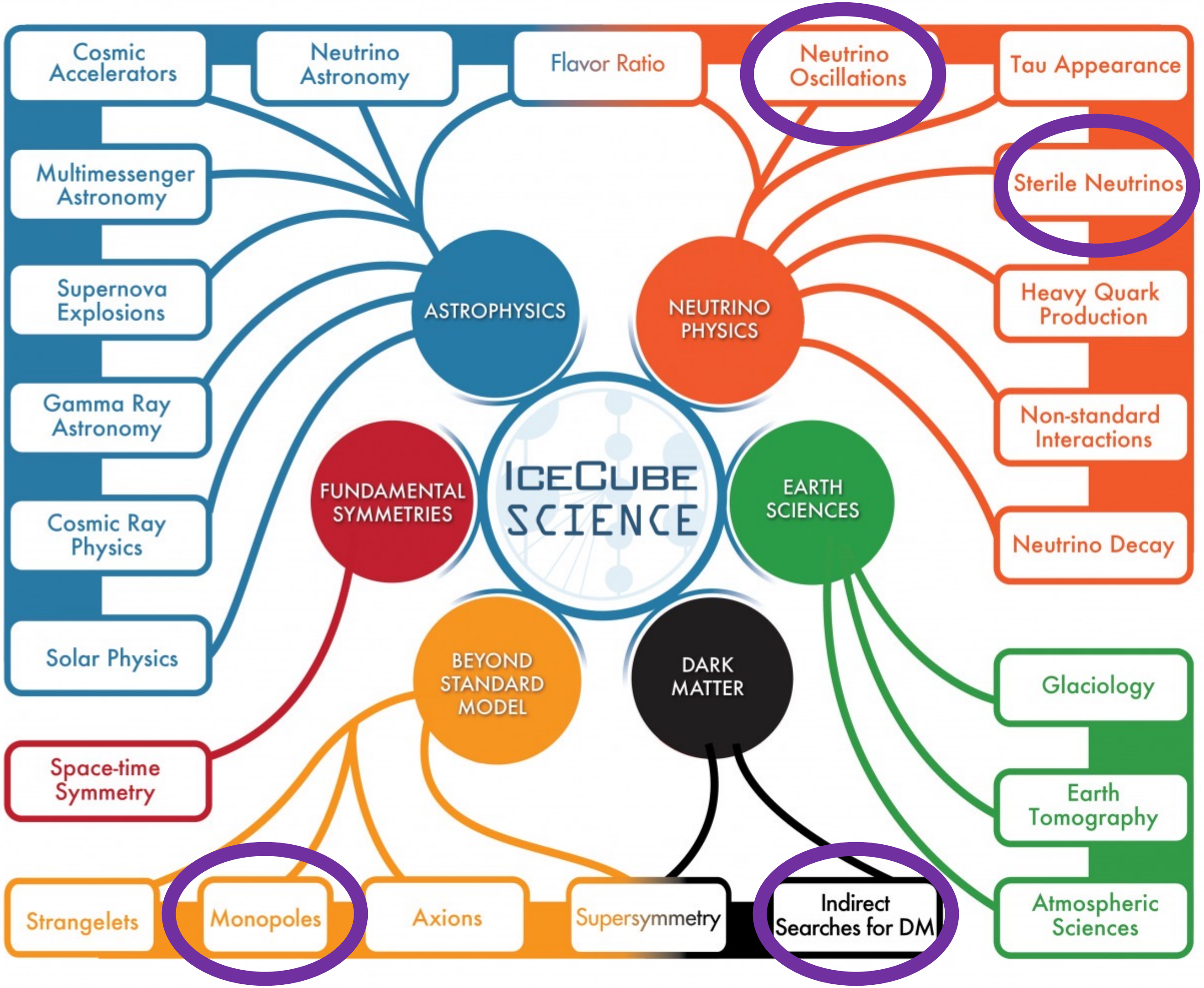
Less than 1% currently associated with sources.



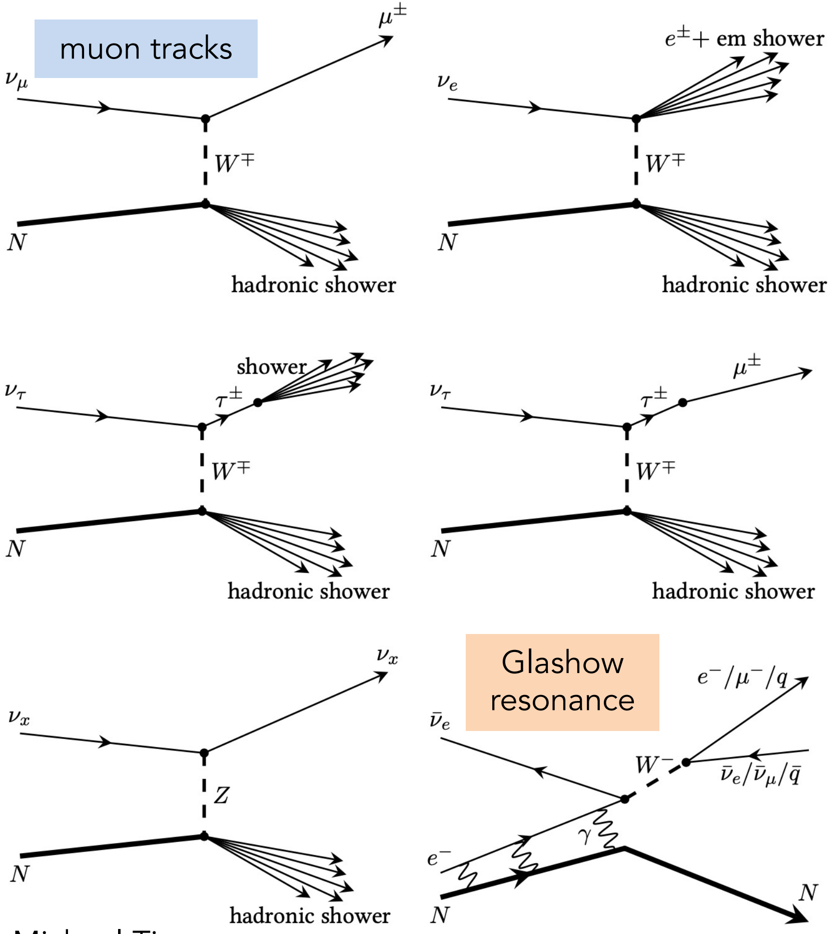
Neutrino Astronomy, and the quest to understand Nature's most powerful particle accelerators,
is the chief science driver.

Unique detector makes many further science topics accessible.

"Search for Relativistic Magnetic Monopoles with Eight Years of IceCube Data", PRL 128, 051101 (2022), IceCube, A. Burgman, C. de los Heros et al.



High-energy Neutrino Interaction Signatures

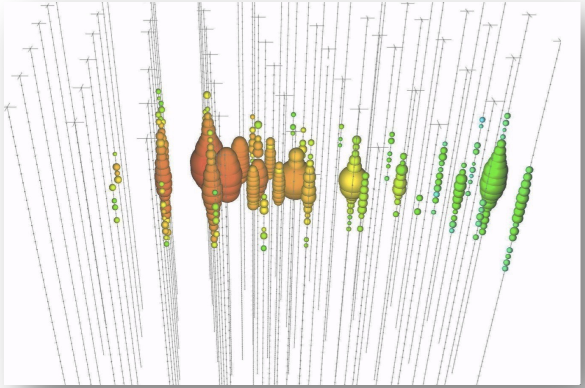


Michael Tino

Event Topologies

Tracks:

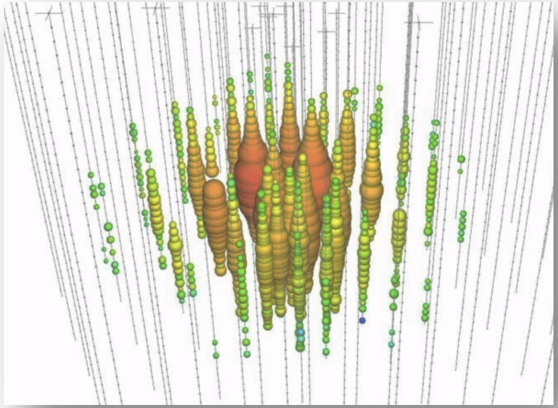
Charged-current muon neutrino interaction

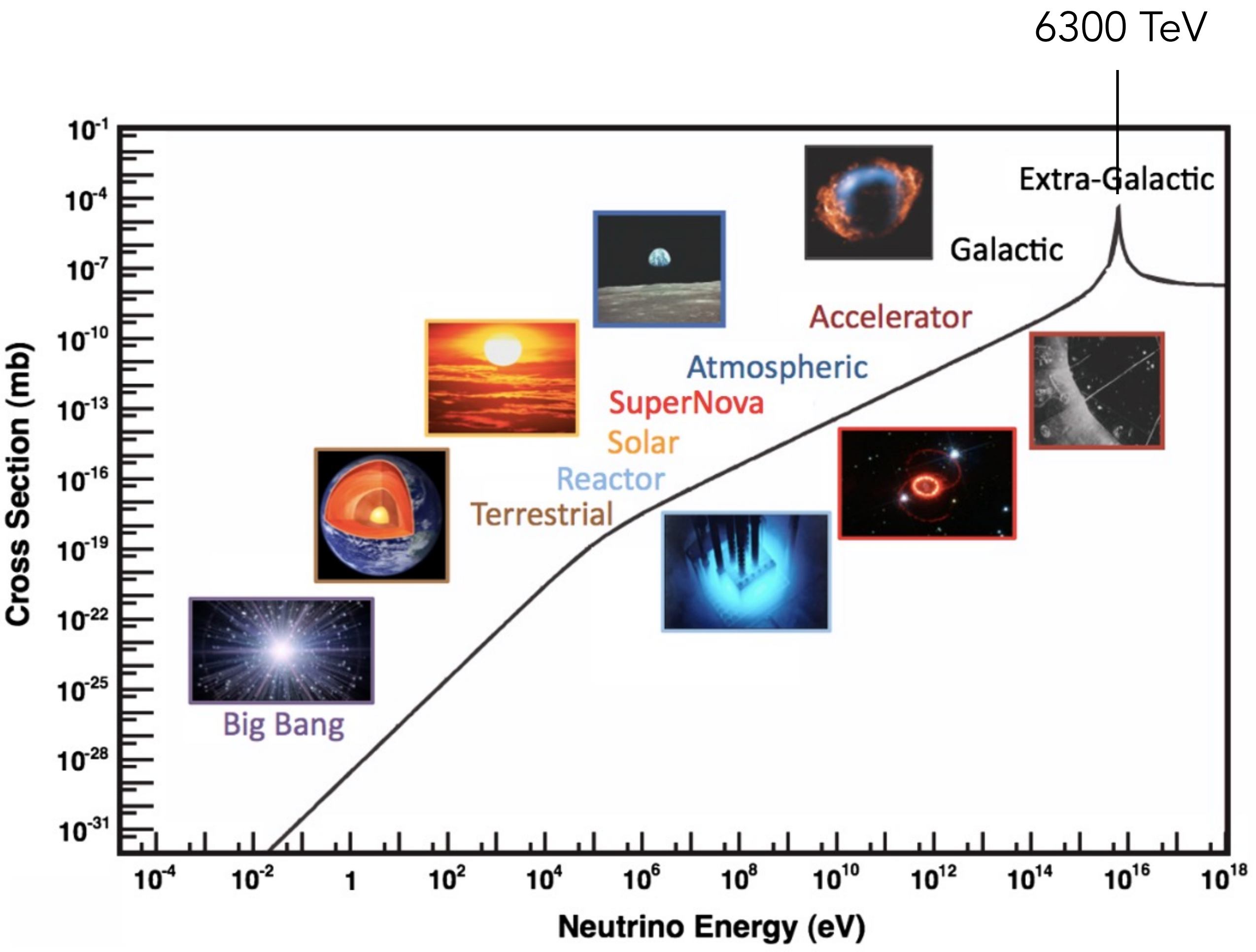


Cascades:

Nearly all other CC and NC neutrino interactions

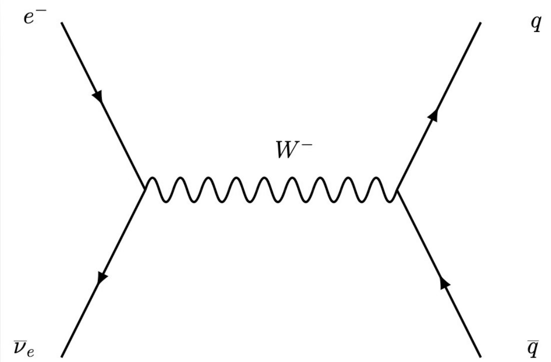
Glashow resonance interactions (except if W decays to muon)





Cross section for electron anti-neutrino scattering on free electrons, as a function of neutrino energy

Formaggio and Zeller, Rev.Mod.Phys. 84, 1307



Electron anti-neutrino at 6.3 PeV interacts with electron at rest, produces W^- boson

Nature **591**, 220–224 (2021)

Detection of a particle shower at the Glashow resonance with IceCube

https://doi.org/10.1038/s41586-021-03256-1

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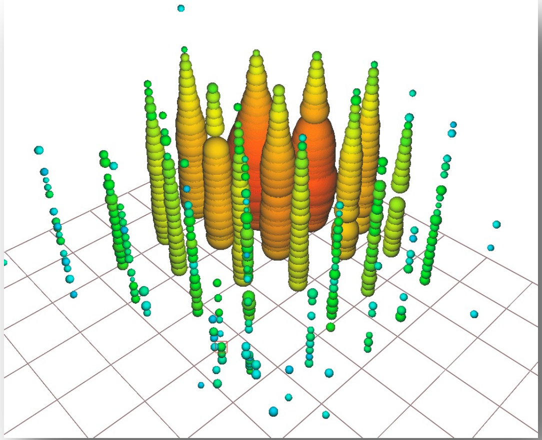
Accepted: 18 January 2021

Published online: 10 March 2021

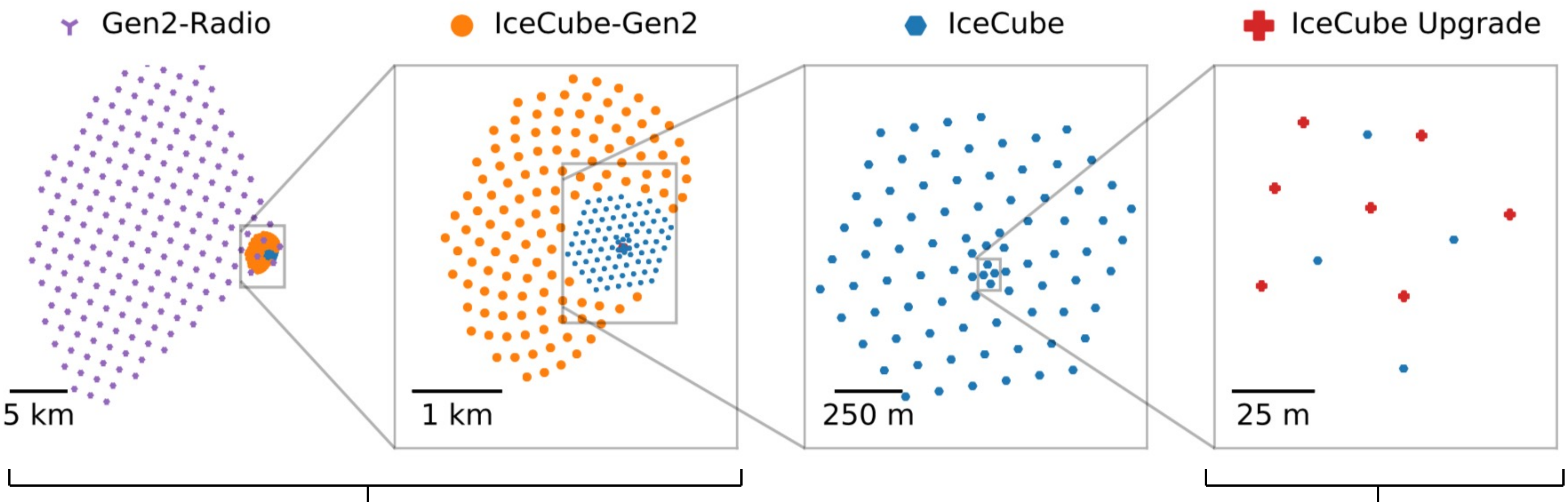
Check for updates

The IceCube Collaboration*

The Glashow resonance describes the resonant formation of a W^- boson during the interaction of a high-energy electron antineutrino with an electron[1], peaking at an antineutrino energy of 6.3 petaelectronvolts (PeV) in the rest frame of the electron. Whereas this energy scale is out of reach for currently operating and future planned particle accelerators, natural astrophysical phenomena are expected to produce antineutrinos with energies beyond the PeV scale. Here we report the detection by the IceCube neutrino observatory of a cascade of high-energy particles (a particle shower) consistent with being created at the Glashow resonance. A shower with an energy of 6.05 ± 0.72 PeV (determined from Cherenkov radiation in the Antarctic Ice Sheet) was measured. Features consistent with the production of secondary muons in the particle shower indicate the hadronic decay of a resonant W^- boson, confirm that the source is astrophysical and provide improved directional localization. The evidence of the Glashow resonance suggests the presence of electron antineutrinos in the astrophysical flux, while also providing further validation of the standard model of particle physics. Its unique signature indicates a method of distinguishing neutrinos from antineutrinos, thus providing a way to identify astronomical accelerators that produce neutrinos via hadronuclear or photohadronic interactions, with or without strong magnetic fields. As such, knowledge of both the flavour (that is, electron, muon or tau neutrinos) and charge (neutrino or antineutrino) will facilitate the advancement of neutrino astronomy.



IceCube Present & Future



Build: after Upgrade

Completed: 2011

Build: 2025-26

IceCube-Gen2:
Neutrino Astronomy from TeV to EeV
see Erin's talk

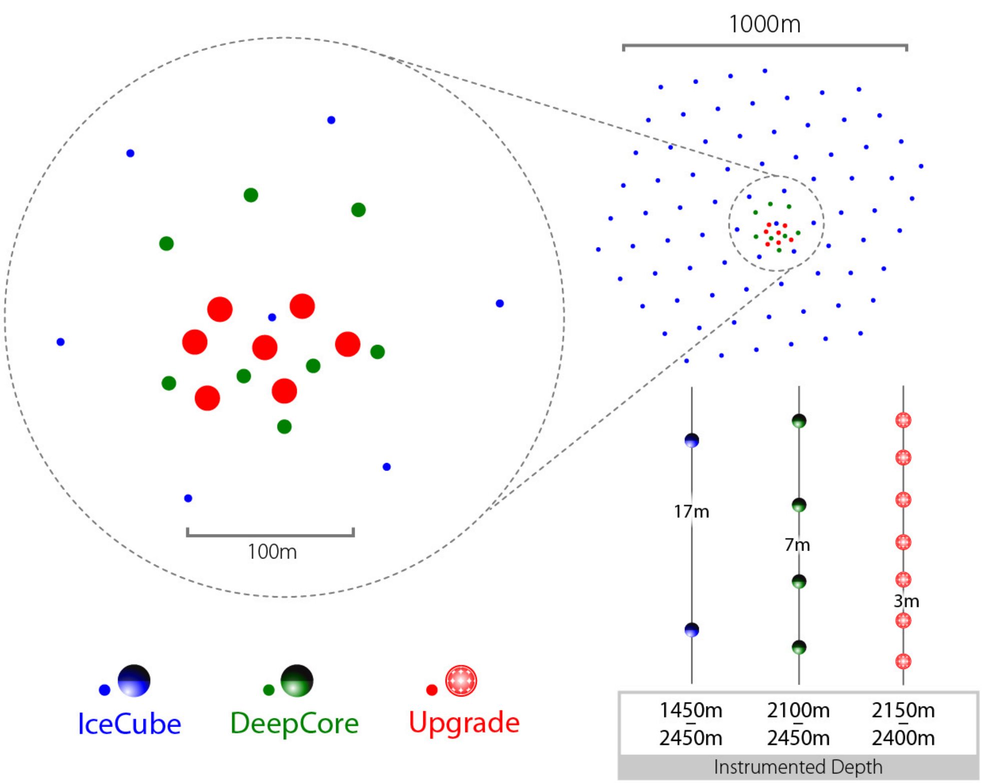
IceCube Upgrade

IceCube Upgrade 2025/26

7 new strings, close together (~25 m)

Goals:

- Neutrino oscillation physics
- Many new calibration devices
  - Better detector/ice modelling will allow re-analysis of all existing IceCube data
- R&D for IceCube-Gen2



Fully funded; delayed by Covid

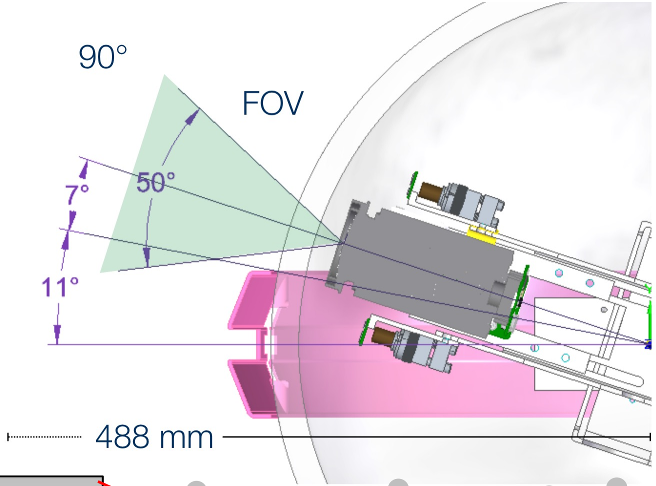
Swedish contribution (RFI grant):

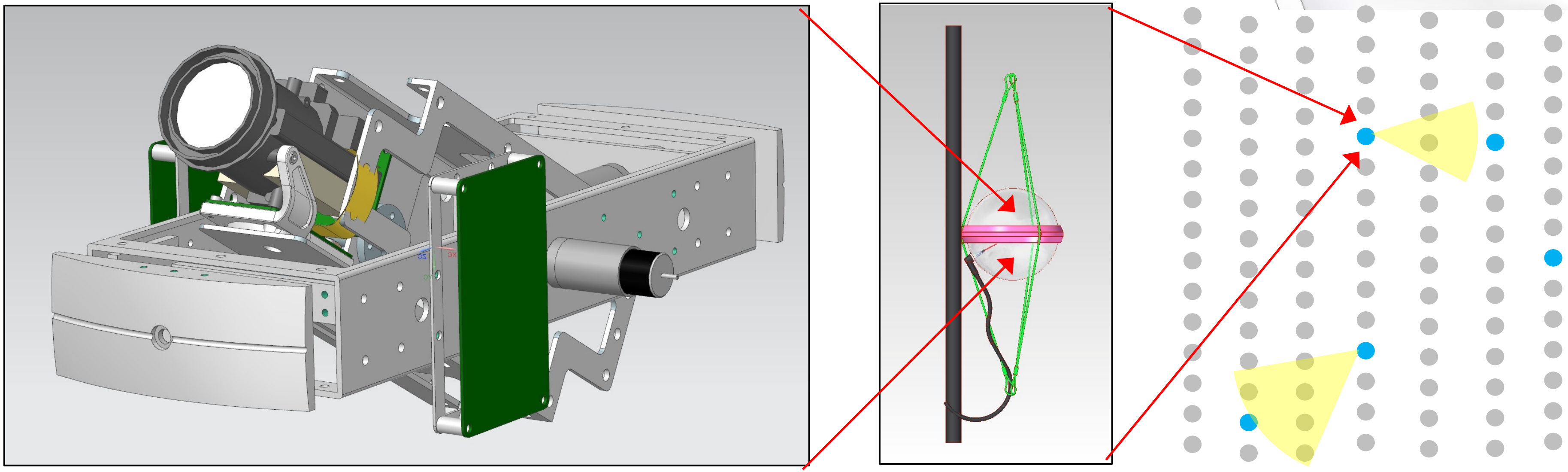
- the cables, made by Hexatronic in Hudiksvall
- video camera calibration system, “Sweden Camera 2.0” (SU/UU)

Sweden Camera System 2.0

- 5 modules with steerable video camera + LEDs and lasers
- Operate in manual and autonomous modes

Objective: Through direct visual inspection, improve our understanding of the optical properties of the ice, and the detector's embedding within it.





Summary

Most promising way to identify and study cosmic accelerators: neutrino messengers

Association with blazars intriguing, even if not the dominant source (see Ankur's talk)

Previously favorite source class, Gamma Ray Bursts, seems ruled out, including on long time scales (IceCube, Kunal Deoskar et al.: https://arxiv.org/abs/2205.11410)

IceCube is unique experimental facility for neutrino physics and particle physics

IceCube Upgrade: both R&D for future, and re-calibration of past data

Extra

Beyond Confirmation – a tool to explore the Cosmos

Glashow resonance is the only probe of the antineutrino - neutrino fraction

$\bar{\nu}:\nu$ fraction directly related to production mechanism of astro. neutrinos

At or near sources, cosmic rays (mostly protons) interact either with ambient matter (mostly protons) and / or radiation (gammas)

Generic model expectation for $\bar{\nu}:\nu$ ratio at Earth (after flavor oscillations in route):

pp: $\bar{\nu}_e : \nu_e = 1 : 1$ — 1.55

$p\gamma$: $\bar{\nu}_e : \nu_e = 1 : 3.5$ — 0.69

(1.55, 0.69: expected GR events in"PEPE" analysis)

$p\gamma$: $\bar{\nu}_e : \nu_e = 0 : 1$ (strong B fields, muon synchrotron losses before decay)