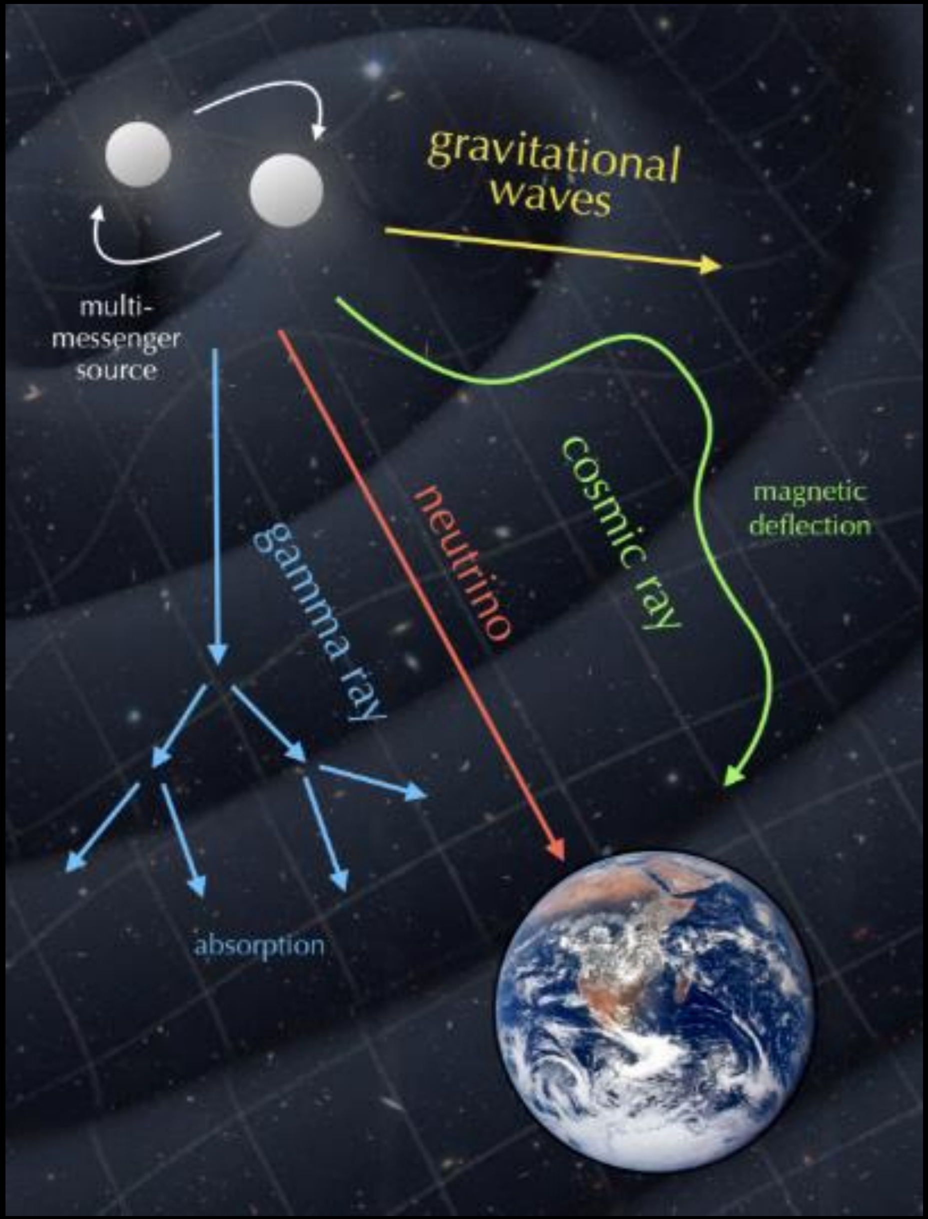
CHARACTERIZING THE LONG-TERM BEHAVIOUR OF ICECUBE SUPERNOVA SCALER RATES

Tayler East[1], Dr. Nahee Park[1]

[1]*Department of Physics, Engineering Physics and Astronomy, Queen's University, Canada*

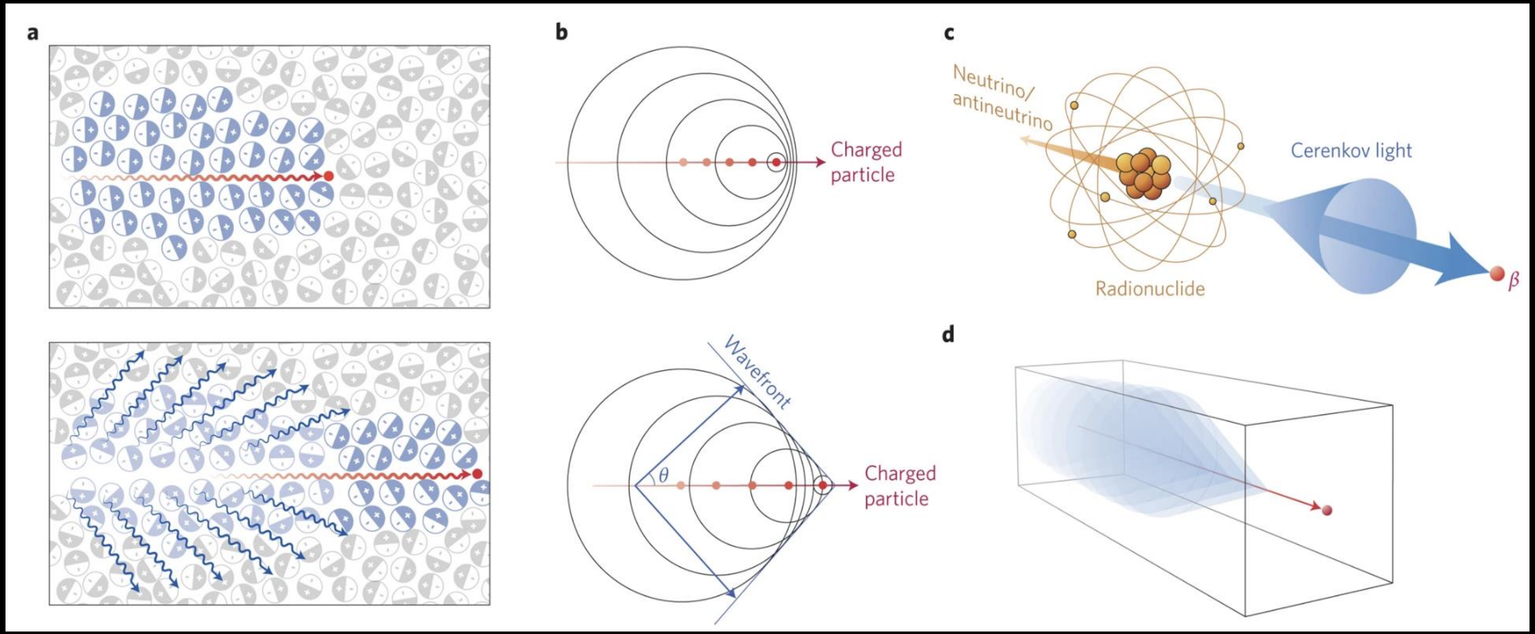
MULTIMESSENGER ASTRONOMY

- **Electromagnetic radiation** (light) : reveals the visible and energetic processes occurring around cosmic sources.
- **Cosmic rays** : high-energy charged particles that provide information about extreme acceleration processes.
- **Gravitational waves** : ripples in spacetime produced by massive accelerating objects.
- **Neutrinos** : rarely interacting particles that can escape dense environments and provide information about the cores of energetic events.
- They are a group of signals collected from deep-space events that act as messengers from the universe.



https://nbi.ku.dk/english/research/experimental-particle-physics/icecube/astroparticle-physics/

SEEING NEUTRINOS

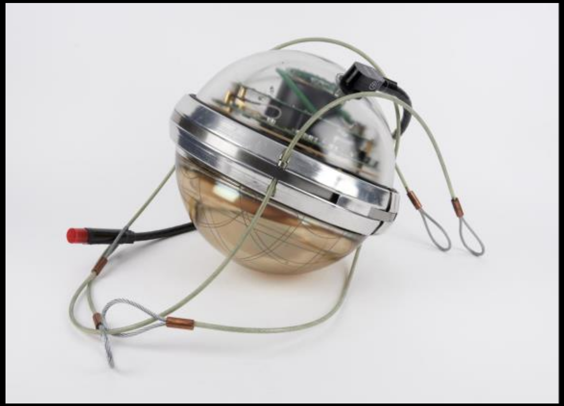


https://www.nature.com/articles/nnano.2016.301

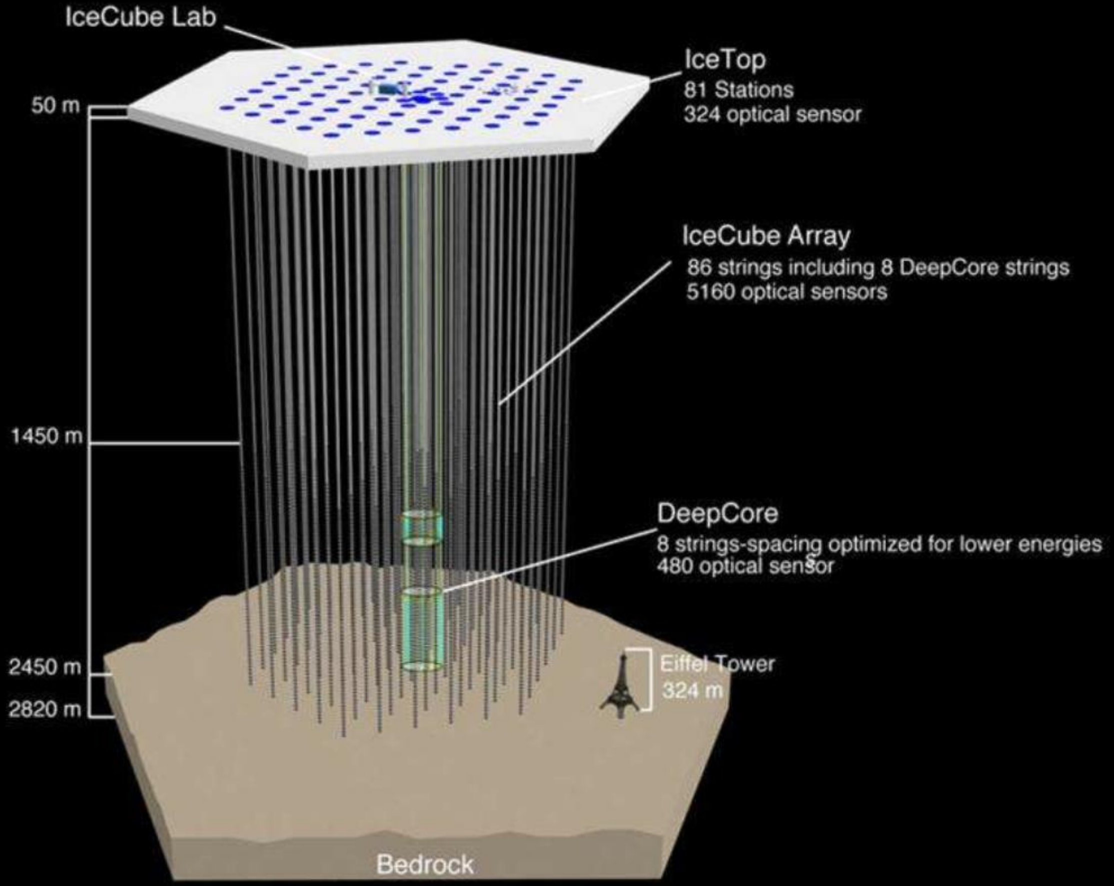
- Neutrinos rarely interact, but occasionally collide with an atom in the detector medium (water or ice for neutrino astronomy).
- This interaction produces a fast-moving charged particle (typically an electron or muon).
- If the particle travels **faster than light travels in that medium** *(not faster than light in a vacuum)*, it emits **Cherenkov radiation**—a cone of blue light, similar to the optical equivalent of a sonic boom.
- **Photomultiplier Tubes (PMTs)** inside the detector measure the arrival time and intensity of this light.
- Using the timing, charge, and positions of the detected photons, the neutrino's direction, energy, and interaction point can be reconstructed.

ICECUBE NEUTRINO OBSERVATORY

- Cubic-kilometer neutrino detector located in ice at the South Pole
- Was finished being built in 2011
- Consists of 5160 DOMs (digital optical modules), 86 strings.
- South Pole: clear and stable medium (good for faint Cherenkov detection)
- Detects high energy neutrinos (optimized for TeV-PeV)



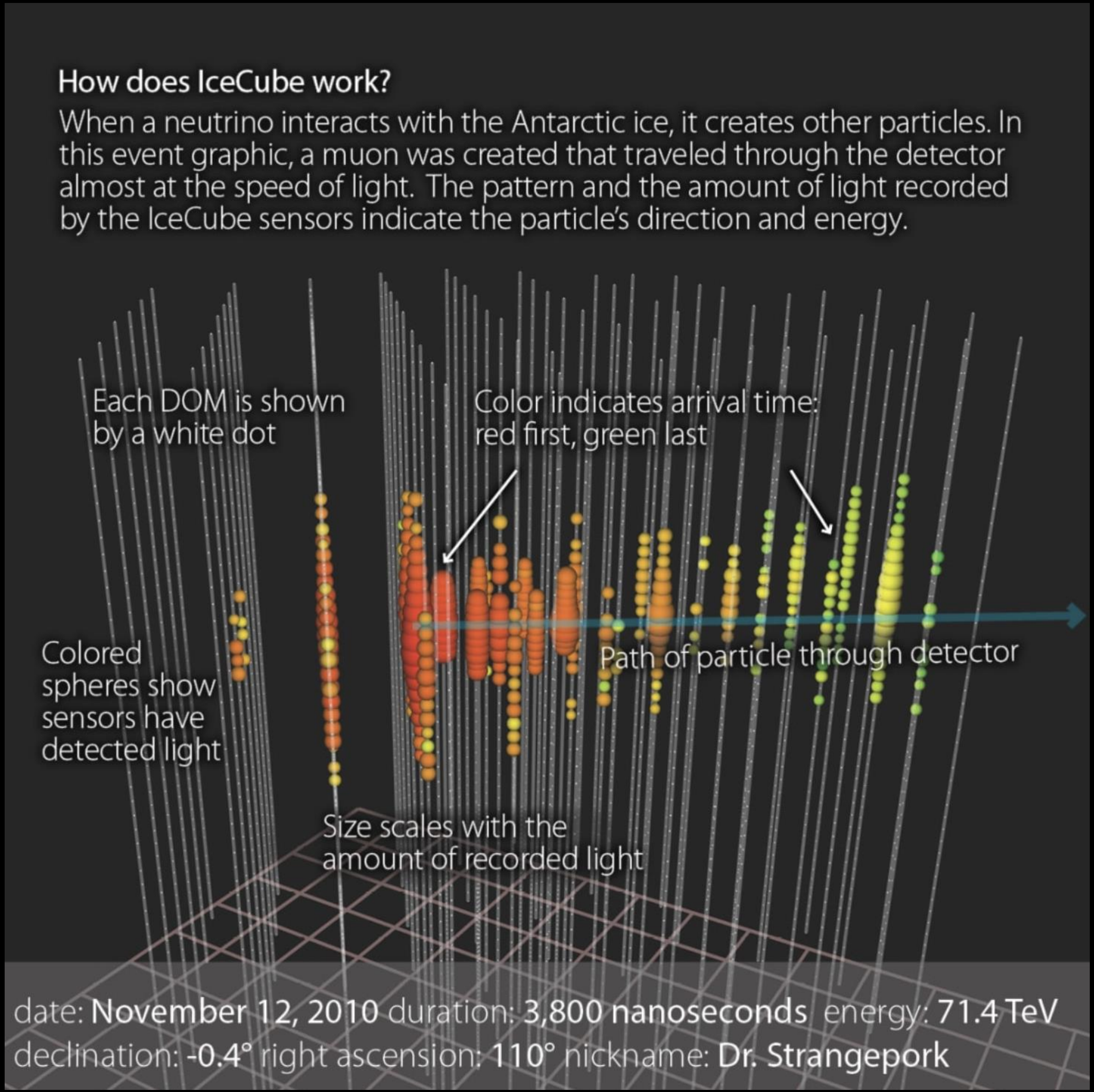
https://collection.sciencemuseumgroup.org.uk/objects/co8234420/digital-optical-module-dom-from-the-icecube-neutrino-detector



https://phys.org/news/2015-04-detector-south-pole-explores-mysterious.html

ICECUBE DETECTING NEUTRINOS

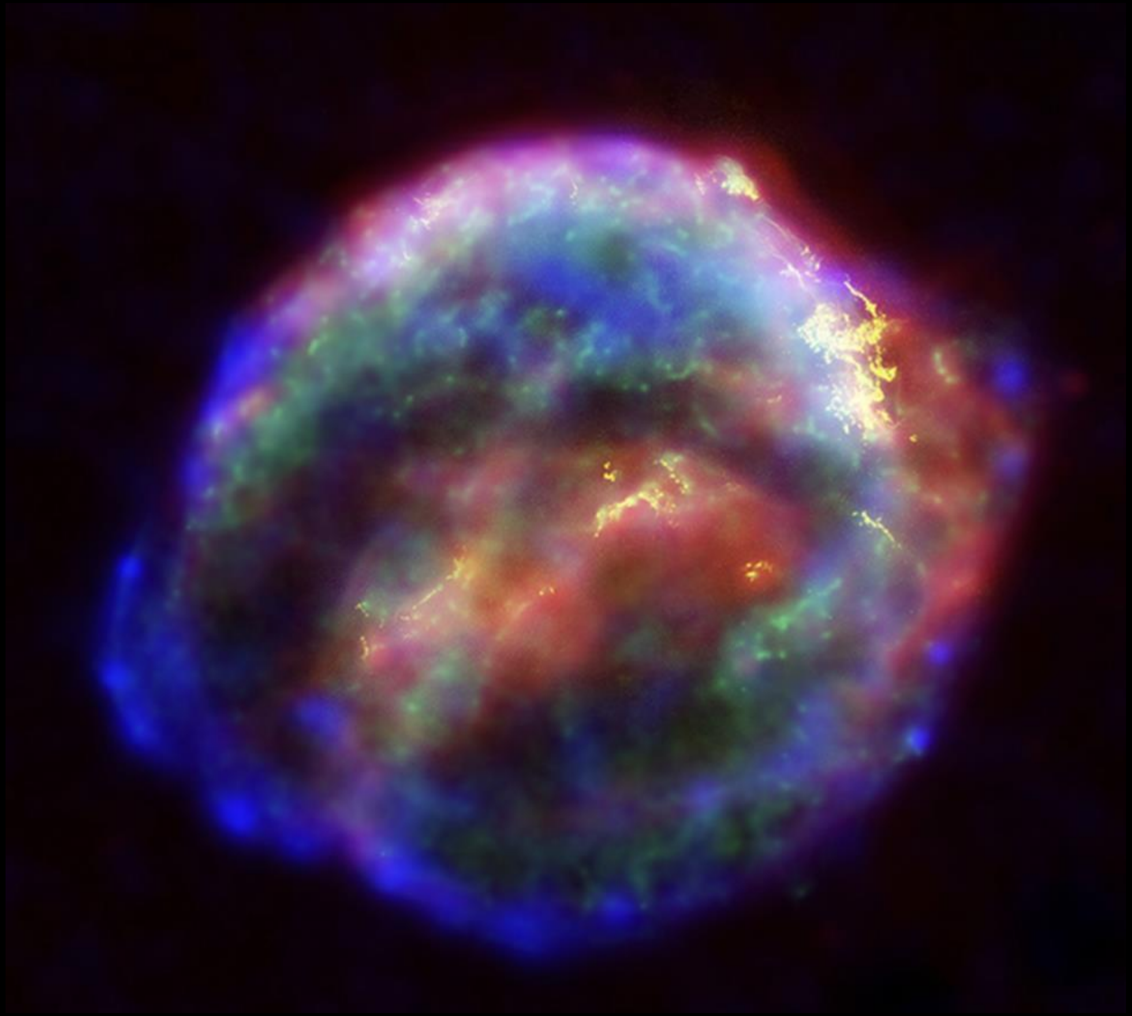
- Each basketball-sized DOM has a large 10-inch PMT facing downward to capture the Cherenkov photons
- Neutrino interacts in the ice.
- Produces a charged particle.
- Charged particle emits Cherenkov light.
- PMTs detect the light.
- Event reconstruction (for high-energy neutrinos).



https://icecube.wisc.edu/science/icecube/

MOTIVATION FOR SUPERNOVA (SN) SCALERS

- Core-collapse supernovae release **~99% of their energy as low-energy (~10 MeV) neutrinos.**
- Individual supernova neutrino interactions in IceCube are **too weak to reconstruct as events.**
- Instead, IceCube monitors the **SN scaler rate**—the number of PMT hits recorded by each DOM in **500 ms** intervals.
- A nearby supernova produces a **small, simultaneous increase in the scaler rate across thousands of DOMs.**
- Reliable supernova detection therefore requires understanding the **background scaler rate** and how it changes over time. (No false alarms).

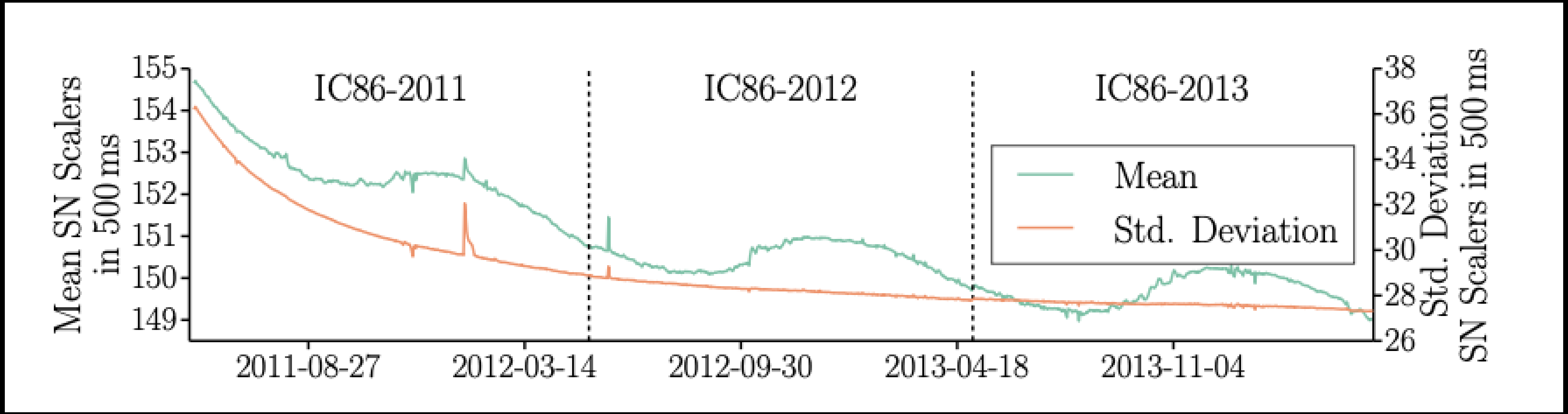


https://en.wikipedia.org/wiki/Kepler%27s_Supernova

PRIOR WORK DONE

Previous IceCube analysis:

- Observed a **long-term decrease in average DOM dark noise rates** (~3.5% over three years).
- The reduced background noise increased sensitivity to **atmospheric muons**, leading to a ~50% increase in false positive supernova alerts.
- The decrease was correlated with **DOM deployment date and depth**, suggesting detector-dependent effects.
- Proposed explanation: possible **faint light produced from ice deformation during freeze-in**.
- **→ Motivated the need to understand long-term evolution of SN scaler rates.**



(V. Baum et al. , 2015)

MOTIVATION FOR MY WORK

- Prior studies observed a long-term decrease in IceCube DOM dark noise rates.
- These changes affected the detector's sensitivity and increased false supernova trigger rates.
- This work extends the analysis using a longer dataset and models the observed long-term trend.
- Understanding how SN scaler rates evolve over longer timescales is essential for detector calibration and reliable supernova searches.

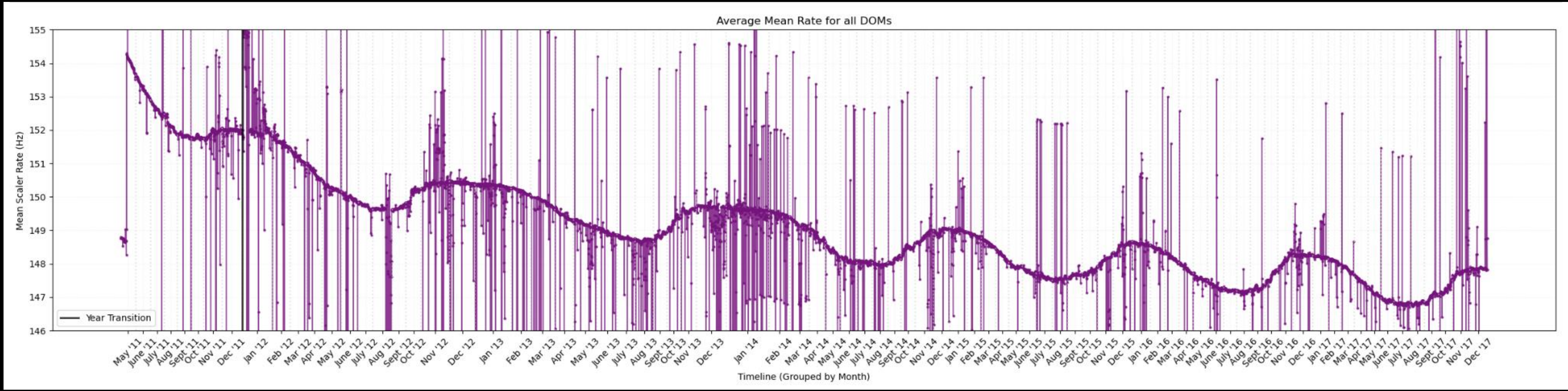
DATA AND METHOD

- IceCube SN scaler data (2011–2017… for now)
- Good Run List (GRL) selection (quality cut for clean validated runs)
- Average scaler rates calculated
- Timeline constructed from run start times then converted to proper time units

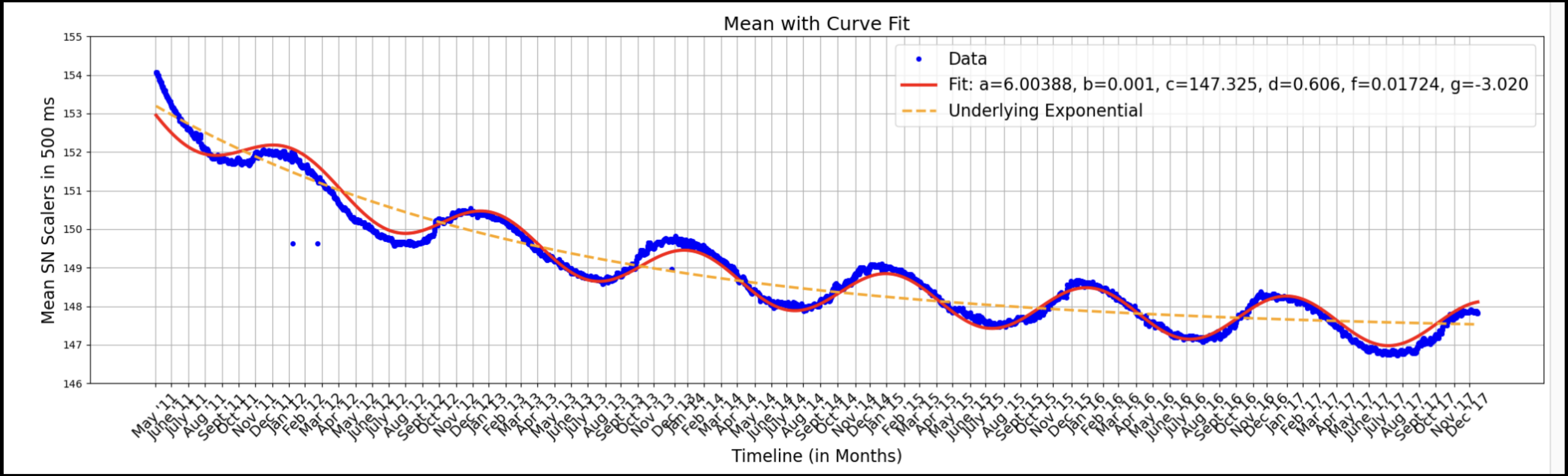
DATA PROCESSING

- Removed bad runs using the GRL
- Converted run times to a continuous timeline
- Combined runs into a single dataset
- Removed missing/corrupted entries

Prior to processing the data



RESULTS



Fit Equation: $a{*}e^{(-b\,*\,x)} + c + d * \sin(f * x + g)$

INTERPRETATION OF RESULTS

Long-term decrease is observed.

Exponential decay model captures the trend.

Findings are consistent with previous IceCube observations (extended dataset confirms trend over long timescales).

Stronger evidence of a genuine detector effect.

Identified and modeled seasonal periodic component.

CONCLUSIONS & FUTURE

Conclusions

- Extended previous IceCube analysis.
- Characterized long-term SN scaler evolution.
- Combination of exponential decay and periodic oscillation provides a good description of the behaviour.

Future work

- Seasonal effects (separate plots per season of deployment)
- Depth dependence (suggested by earlier work)
- Continuous timeline mapping (see if it flattens)
- Comparisons with IceCube's Upgrade (effects of the newer sensor technology long term)

https://en.wikipedia.org/wiki/IceCube_Neutrino_Observatory

THANKS FOR LISTENING!

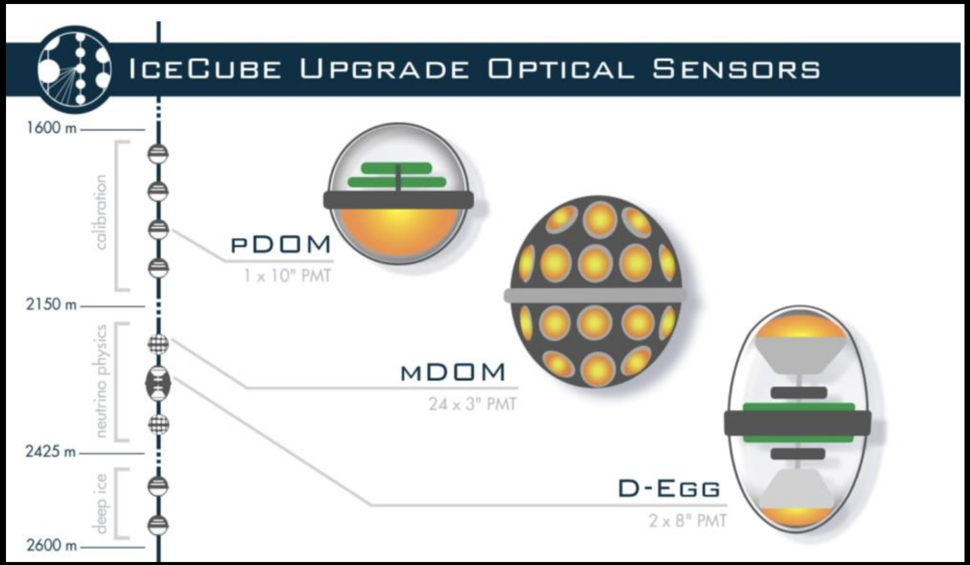
References:

- V. Baum et al. *Recent Improvements in the Detection of Supernovae with the IceCube Observatory.* Proceeding of Science. 2015.
- Naoko Kurahashi. *Highlights from the IceCube Neutrino Observatory.* Proceeding of Science. 2023.

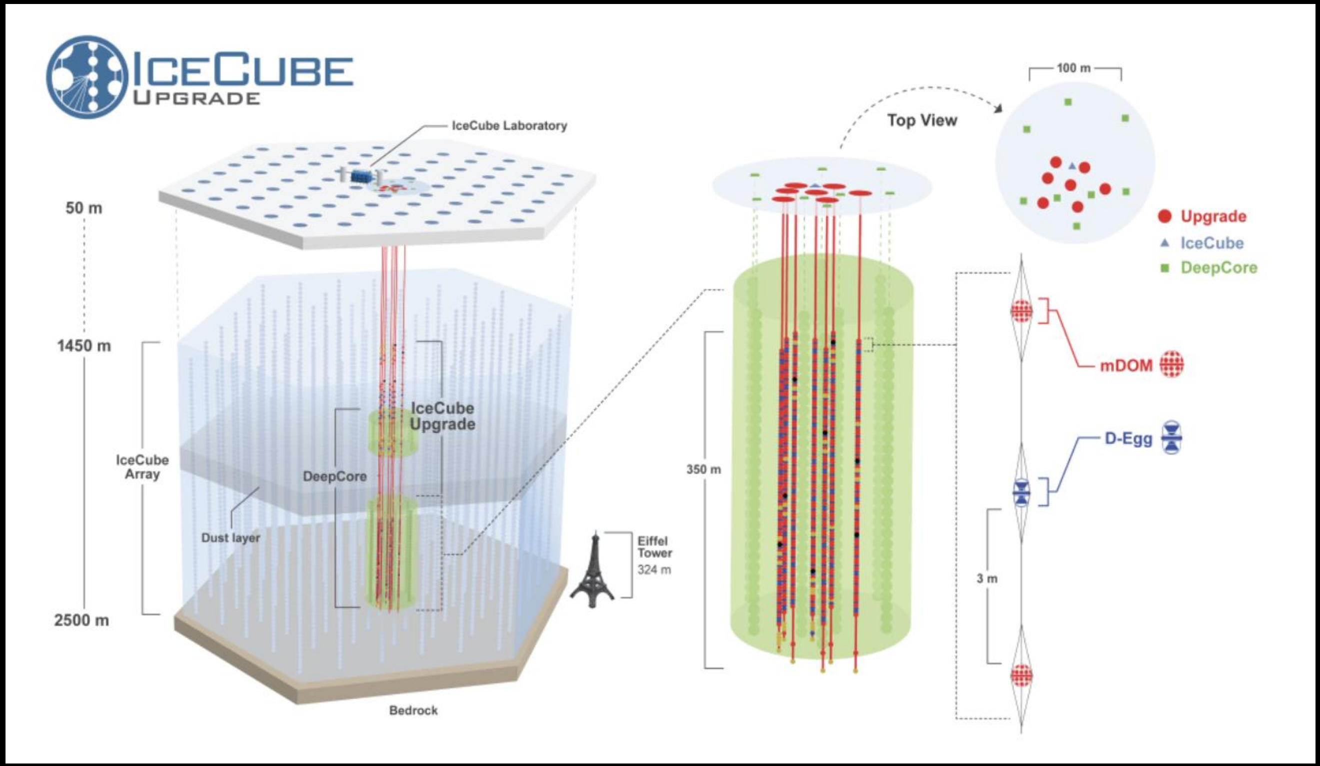
ICECUBE UPGRADE

Goal:

- Long-term study of module behaviour in a stable environment
  - Better calibration, oscillations measurements, low energy transients
- Compare to in-ice modules as the strings freeze



https://icecube.wisc.edu/news/press-releases/2019/07/nsf-mid-scale-award-sets-off-first-extension-of-icecube/



https://icecube.wisc.edu/news/research/2025/09/quantifying-the-estimated-sensitivity-of-the-icecube-upgrade-to-atmospheric-neutrino-oscillations/

- 5665 DOMs (Digital Optical Modules) on 91strings (extra 505 DOMs on 5 new strings)
- Improved sensitivity for 1-10 GeV

DARK NOISE RATE

- The mean scaler rate they track only has one processing step applied which is a 250-microsecond artificial dead time that suppresses correlated afterpulse noise within a single DOM.
- Instead of removing muon-triggered hits, they see two distinct effects layered together in the raw mean rate: an overall decay, which they attribute to the dark rate, and a seasonally varying influence from atmospheric muons on top of it.