

IceCube Upgrade

Instrumentation and Operations Overview

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Upgrade Logistics Review

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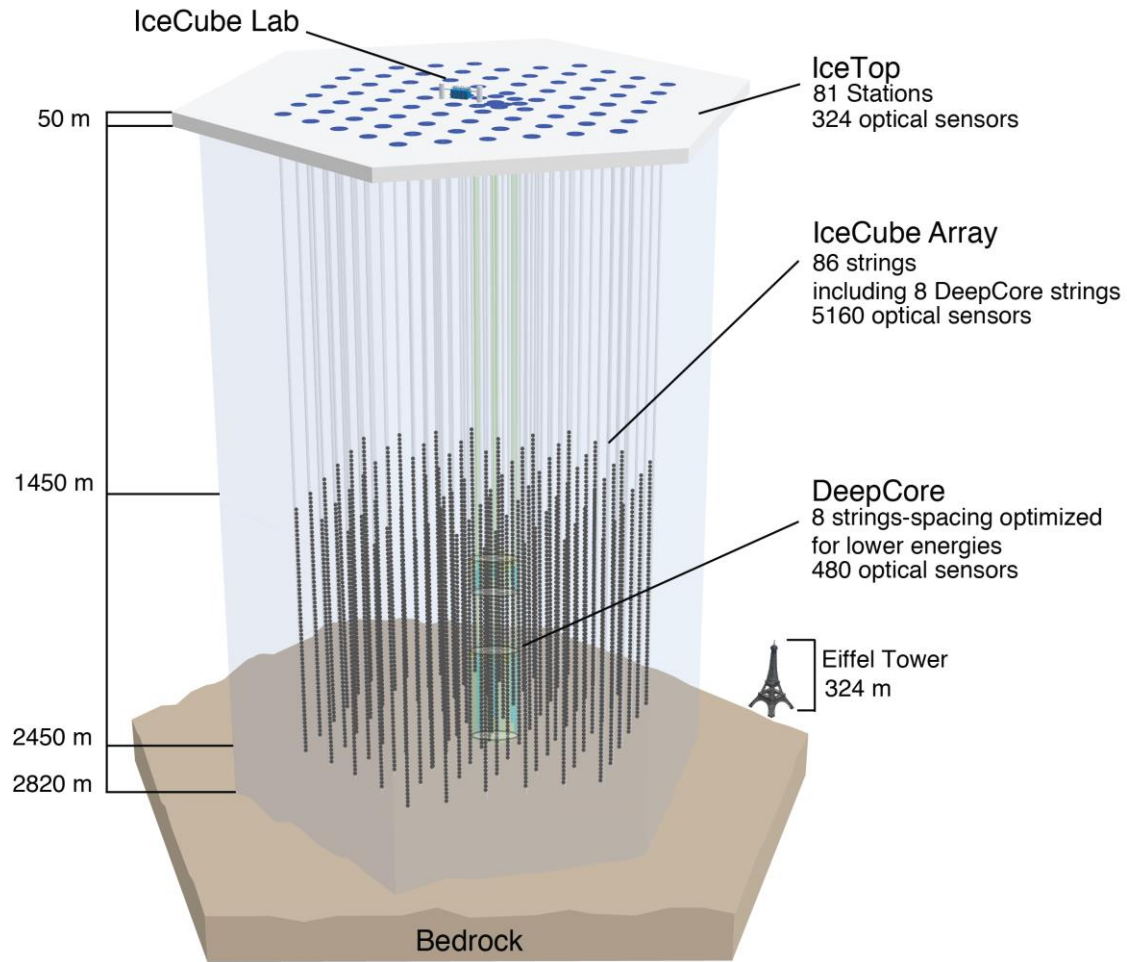
Scope and Purpose

This slide deck addresses the Review Charge Questions Cargo, 2a and 3a, by justifying the instrumentation deployed (see Array Configuration slide for detail):

- Provide historical context of IceCube instrumentation reliability and sparing.
- Motivate Upgrade instrumentation
- Describe how the Upgrade fits into IceCube – electrically *and* managerially – once construction is completed.

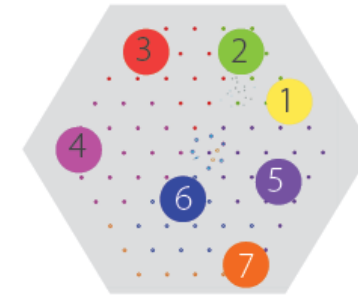


The IceCube Detector



Detector Construction

7 seasons of construction, 2004-2011



28,000 person-days to complete construction, or 77 years of continuous work



4.7 million pounds of cargo shipped, 1.2 million of which was the drill

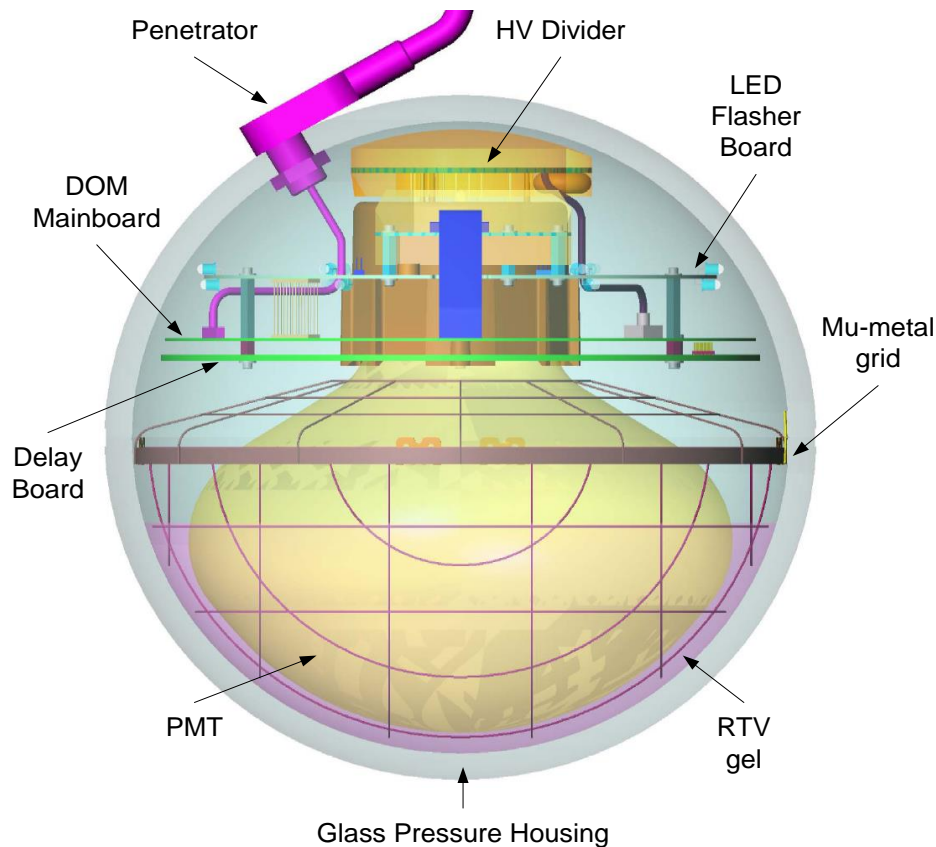


48 hours to drill and 11 hours to deploy sensors per hole



4.7 megawatts of drill thermal power with 200 gallons of water per minute delivered at 88 °C and 1,000 psi

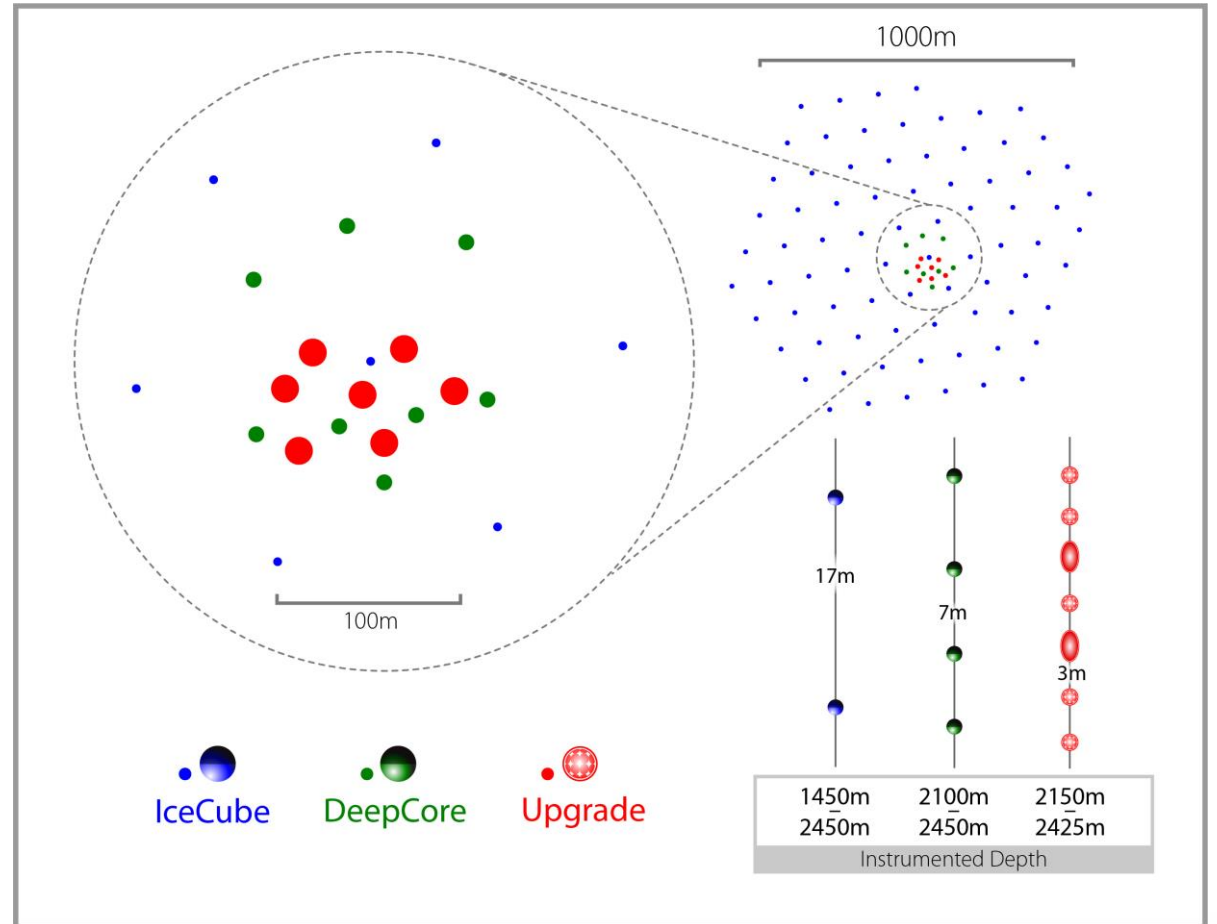
The IceCube Digital Optical Module (DOM)



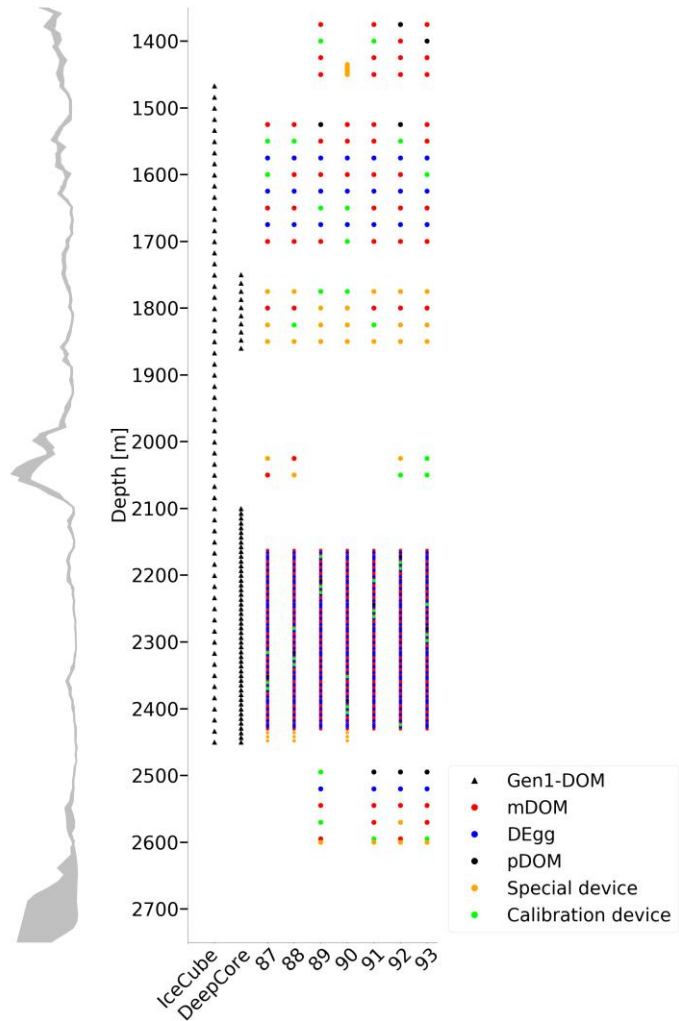
- Conceptually, Upgrade optical modules are very similar to IceCube *Gen1* DOMs – rugged, autonomous optical sensors with large photocathode areas.
- Very reliable – 5616 manufactured, 5581 shipped, 5484 deployed.
- Today 5408 modules taking data: 1.4% lost mostly at deployment / refreeze.
- Cables are bundles of 22 twisted quads: no single point of failure, no spare cables in IceCube

IceCube Upgrade – Plan View Geometry

- More effective photon catching area – Upgrade modules are ~ 2x IceCube modules;
- Denser spacing between strings
 - 125 m (IceCube) downto
 - 75 m (DeepCore) downto
 - 25 m (Upgrade)
- Also denser along strings : 17 m \rightarrow 3 m
- More active area per volume for low-energy (< 25 GeV) performance
- Closer spacings to get below 1 scattering length of photons in the ice

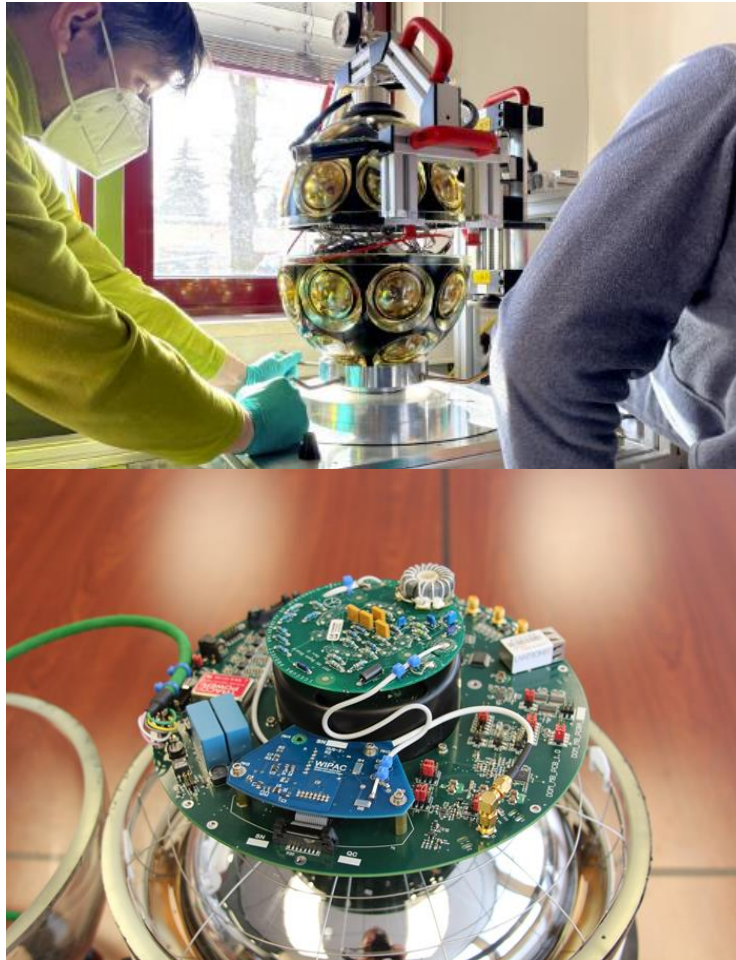


Array Configuration



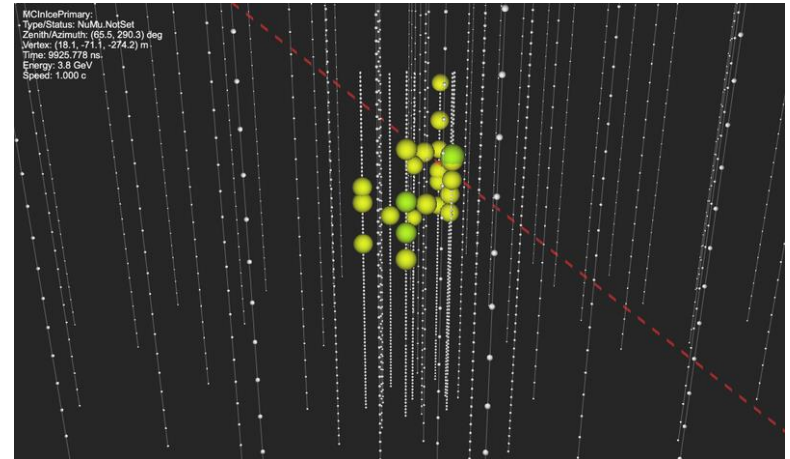
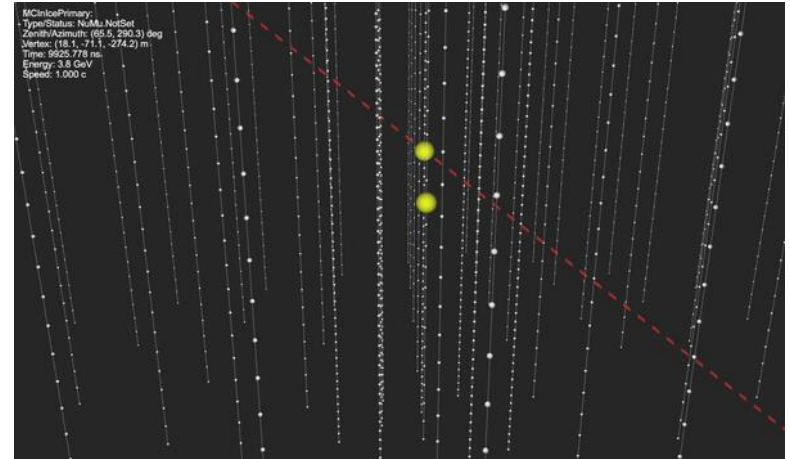
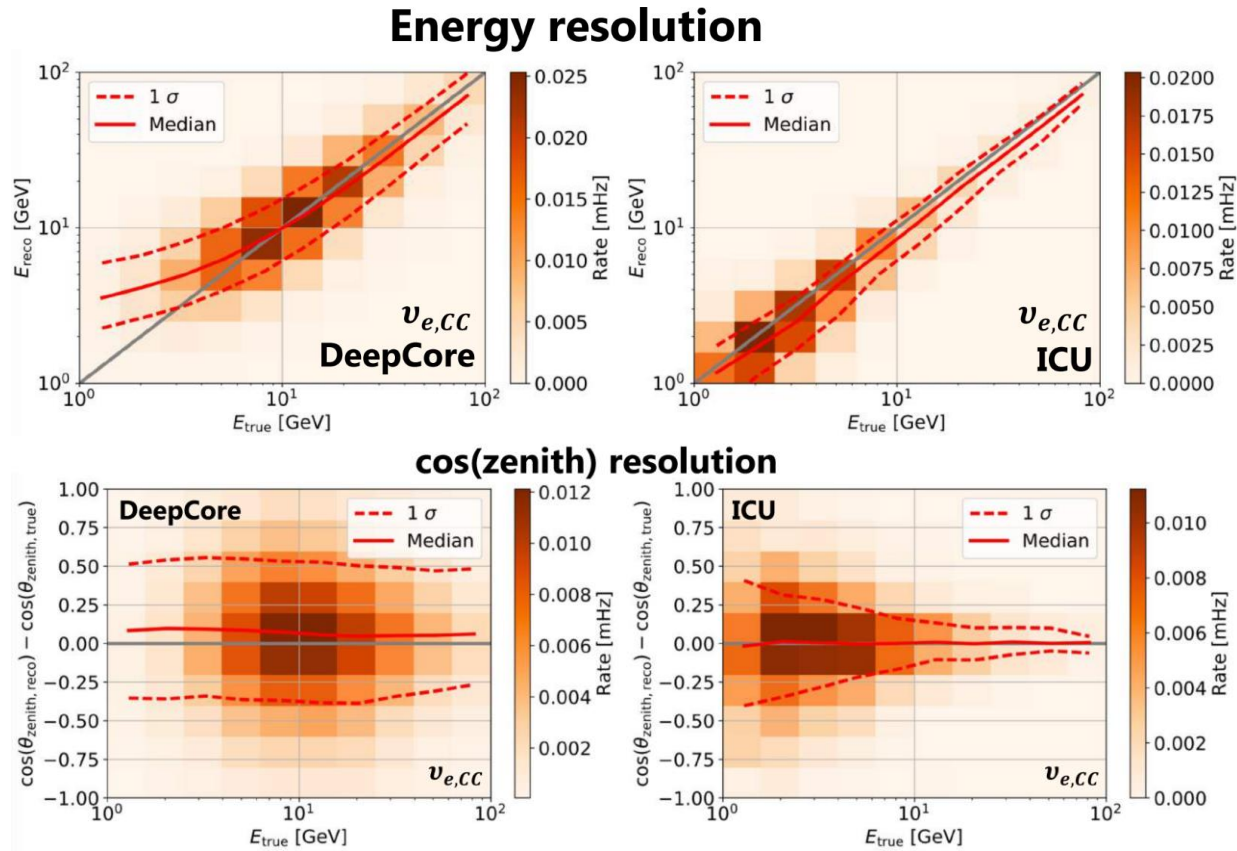
- Optical sensors
 - 402 mDOMs (DESY and MSU)
 - 277 D-Eggs (Chiba U)
 - 14 PDOMs (UW Madison)
- Calibration Devices
 - 2000 imaging CMOS cameras for hole ice bubble column characterization
 - 21 POCAMs (Precision Optical Calibration Modules)
 - 11 Pencil Beam modules for ice scattering function
 - 10 acoustic geometry calibration modules (xyz independent of ice optics)

Upgrade Optical Modules ...



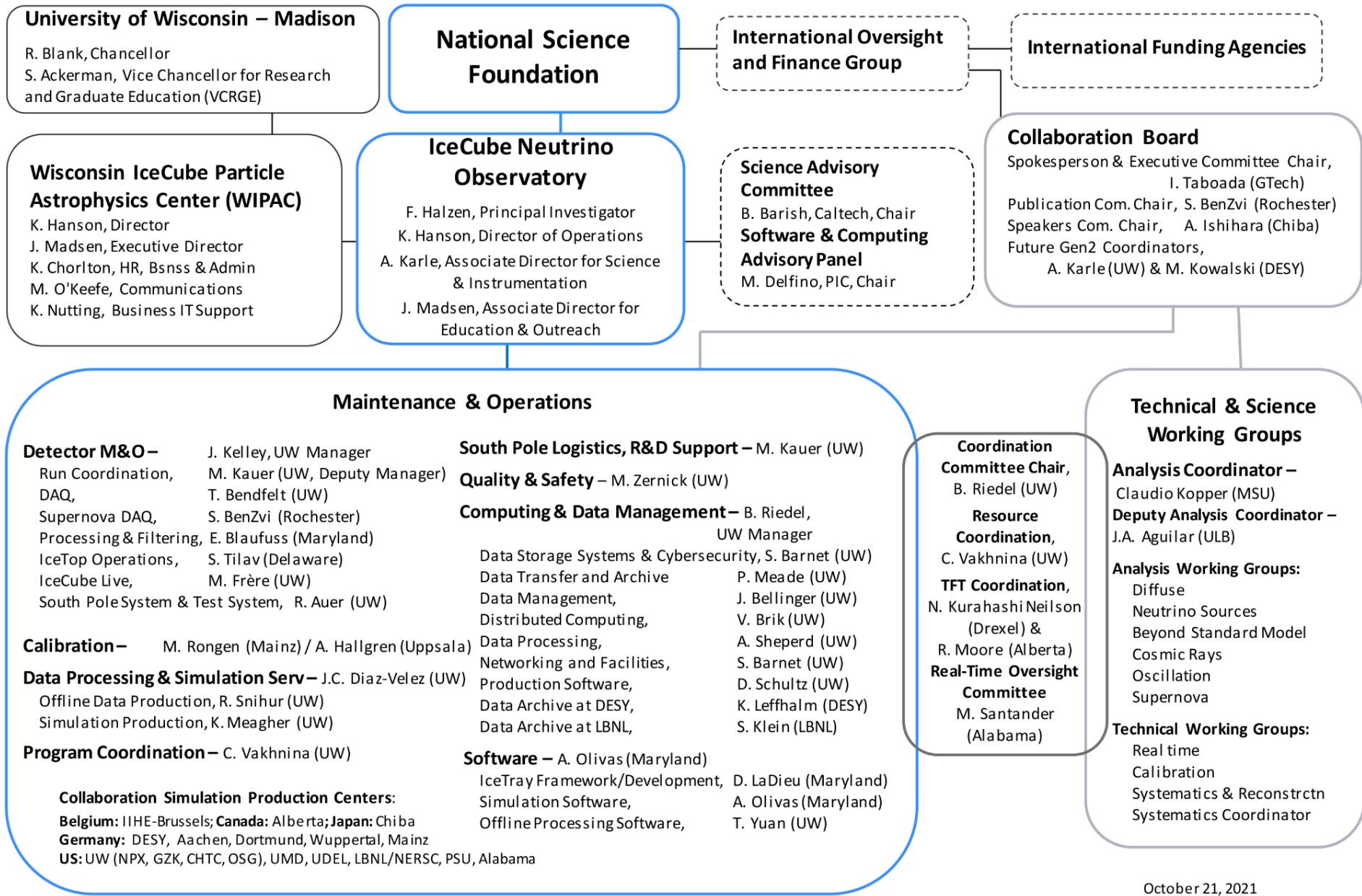
- mDOM and D-Egg provide $> 2x$ effective photon area at similar cost to IceCube DOM.
- Multi-PMT boosts reconstruction performance by 10-25% (more with ML techniques) *after factoring out larger photon area!*
- Upgrade PDOMs optically equivalent to IceCube DOMs – deployed for cross-calibration.

... Dense Photocathode Coverage with Directional Info



Bringing it all Together – ICNO Infrastructure

- Enormous benefit from existing IceCube Data Acquisition / Processing / Transportation / Storage architecture
 - IceCube Upgrade sensors “plug in” to IceCube DAQ through well-defined S/W and network interfaces
 - Analysis and simulation S/W are being modified to support multi-PMT sensors
- After Upgrade is commissioned, operations will be subsumed into ICNO facility
 - Additional power : + 12 kW
 - Additional B/W : + 10% (+ 100 GB/day raw to disk)
 - Additional WO : zero



October 21, 2021



Summary

- Upgrade evolves design of proven reliable IceCube optical instrumentation to enable neutrino particle properties measurements that cannot be made at any other site until the next decade.
- Furthermore, through precision calibration of the ice, it will immediately double the sensitivity of IceCube for high-energy neutrino astrophysics to be applied retroactively to > 10 years of data on disk.
- Existing ICNO infrastructure and in-kind contributions by worldwide IceCube Collaboration means:
 - Relatively small NSF investment in facility upgrade equiv to 2 years of operations budget.
 - Handshake with operations is solidly within known territory from 13+ years of ICNO operations: there's an entire organization ready to operate the Upgrade.