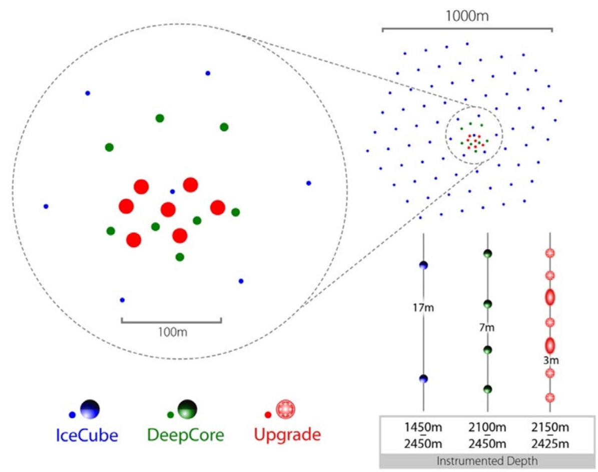
# Project Scope

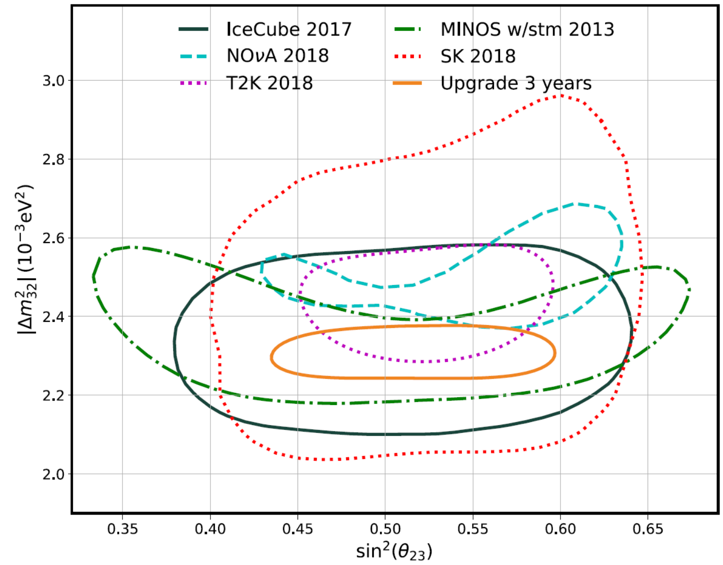
The IceCube Upgrade is an in-fill array comprising 7 strings of 100 advanced optical detector modules, a suite of precision calibration devices, and R&D devices for future neutrino observatories. It will be deployed at the center of the existing IceCube Neutrino Observatory during the 2022/2023 Austral Summer Season. Detector instrumentation is primarily provided by in-kind contributions from collaborating institutions around the world. UW-Madison, the project headquarters, also will deliver enhancements to the IceCube Enhanced Hot Water Drill that provides the 2.5 km deep holes in the ice in which the instrumentation is deployed.



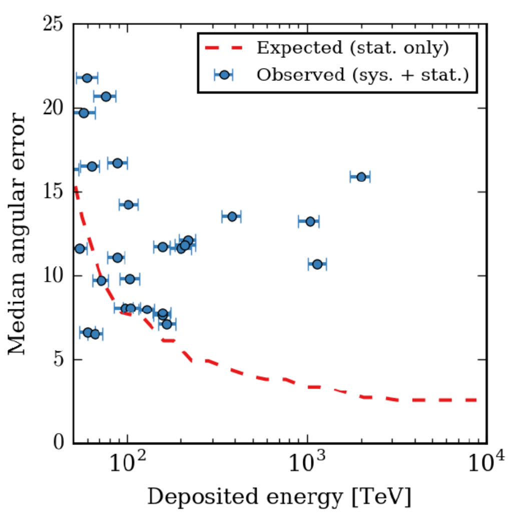

| WBS L2 Element | Description |
|---|---|
| 1.1 Project Management | Provide oversight and direction in managing and facilitating the IceCube Upgrade Project. Provide ongoing support for daily activities required and review processes to ensure accuracy of reporting data while providing leadership in developing tools, preparing for purchases and manufacturing equipment required for IceCube Upgrade completion. Staffing, Acquisitions, Organization, Project Definition, and technical coordination are also the responsibility of the Project Management team. |
| 1.2 IceCube Upgrade Drill | Full development and operation of the hot water drill system in support of the IceCube Upgrade array installation. Includes resurrection of available Enhanced Hot Water Drill (EHWD) equipment; Design, procurement, and construction of new drill subsystems that, together with EHWD equipment, satisfies the project's drilling requirements; Integration, verification, and testing of the drill system and its subsystems; and field operation of the drill system to deliver required installation borehole specifications. Provide support and infrastructure for cable and DOM installations |
| 1.3 Deep Ice Sensor Modules | This element is responsible for the design and production of the deep-ice optical sensor modules. The modules connect mechanically and electrically to the downhole cable assembly (WBS 1.4.1) and shall communicate with the Field Hub (WBS 1.4.3). The modules must provide interfaces for calibration assemblies (WBS 1.5.2) and shall support in-situ calibration (WBS 1.5.1). Deliverables are up to 1000 deployment-ready optical sensors that meet the high-level design requirements of the IceCube Upgrade. |
| 1.4 Communication, Power, and Timing System | This category is responsible for the physical and electronic systems providing the interface between new sensor and calibration instrumentation and ICL/station infrastructure (power, communications for control and readout, global timing). Deliverables include the physical cables and structures to which new instruments are connected, the surface readout electronics, software, and firmware, and the systems for connecting these readout electronics to the station network and power system and the IceCube master clock. This category also includes construction of a test system in the Northern Hemisphere for testing DAQ and control software and firmware prior to deployment at Pole. |
| 1.5 Calibration and Characterization | This category is responsible for calibrating and characterizing the detector, which consists of both modules and ice. The deliverables are well characterized modules which meet the high level design requirements of the IceCube upgrade for stability and performance, and improved measurements of the modules and the ice relative to our current knowledge of the detector. |
| 1.6 M&O Data Systems Integration | This element is responsible for the seamless integration of all new systems from the IceCube upgrade project into the existing IceCube detector maintenance and operations structures. This includes integration with online software systems, databases, offline software components, simulation software packages, and computing infrastructure needed to support this effort. |

# Scientific Objectives

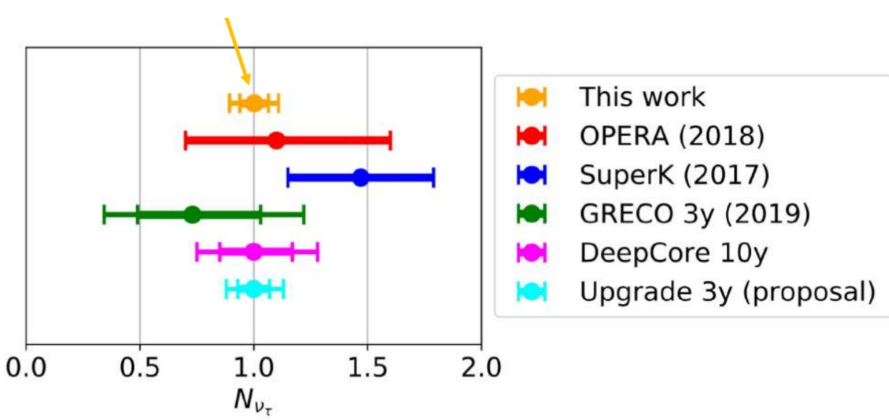
The IceCube Neutrino Observatory is NSF's flagship instrument for multimessenger astrophysics with neutrinos. With the addition of the DeepCore, IceCube also became a worldwide leading facility for study of the elementary particle properties of neutrinos, namely the *neutrino mixing parameters*. Current measurements point towards a special condition called *maximal mixing* which, if true, likely results from fundamental symmetries beyond the Standard Model of Particle Physics. The Upgrade will give IceCube a much enhanced capability to continue these measurements, making it the most sensitive detector in the world.




The natural ice in which IceCube is deployed is crucial to its operation in detecting neutrinos. Imperfect knowledge of the optical properties of the ice remain among the largest systematics in reconstructing particle directions and energies. Multiple devices dedicated to the precision characterization of scattering, absorption, anisotropy, and birefringence will be deployed in the Upgrade. Improvements in the ice model are key to better angular resolution in reconstructed high energy astrophysical neutrino events.




As the figure at left demonstrates, ice effects case angular errors to hit a sys-tematics floor at around 10° in particular at high energies where optimal performance is expected. Improved ice models from The Upgrade's calibration devices will unlock IceCube's full potential as a multimessenger neutrino observatory: real-time alerts to the community will be better localized and point sources will come into focus on existing sky maps as the ice models are applied retroactively to archival data.




Precision ice characterization is also essential to the performance of The Upgrade's hallmark measurement: the unitarity of the neutrino mixing matrix (figure at left). If the Upgrade measures a normalization inconsistent with that expected to make the matrix unitary, new physics such as the existence of additional unknown neutrino flavors or non-standard particle interactions must be at play.