Work Breakdown Structure (WBS) (7 strings within Deep Core footprint)

WBS	Name	Lead	Institution	WBS Dictionary Definition to Level 4 only
1.1	**Project Office**	**Feyzi**	**UW**	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. Technical Coordination includes the resources required to provide overall technical leadership of the project. Tech Coordination supports the definition of requirements including scientific, logistical, environmental, contractual, reliability, quality and safety, interface control; provides solutions to meet these requirements; and documents and provides configuration management of these solutions. Technical oversight includes preliminary, final, production readiness, and deployment readiness reviewing of systems and subsystems. Production Coordination provides design for manufacturability guidance for engineering work. In production, manages the relationships between the project, the vendors, and the quality assurance process. Oversees the quotation process on serially produced parts.
1.1.1	**Project Management**			Creation and maintenance of Project Execution Plan and Project Management Plans; annual reporting to NSF and stakeholders. Liaison to advisory groups and stakeholders.
1.1.2	**Project Controls**	**Vakhnina**	**UW**	Project Controls develops, maintains and uses a consistent set of cost and schedule baselines for the development, implementation and commissioning of the IceCube Upgrade. These baselines use the IceCube Work Breakdown Structure as the basis for planning. Coordinates and facilitates activities related to project involving report preparation, subaward management, financial reporting, document control, and stakeholder related issues.
1.1.2.1	EVMS	Vakhnina	UW	Provides oversight of planning operations and Earned Value report preparation to satisfy sponsor-imposed requirements. Conducts detail plan preparation for both cost and schedule representing scope in sufficient detail to manage delivery of key components. Maintains data to support baseline and funding profiles for reporting purposes. Gathers information from appropriate levels to consolidate and prepare periodical reports for sponsor and other project stakeholder reviews. Provides expertise and guidance for reporting Earned Value and Schedule updates as necessary.
1.1.2.2	Sub Award Management	Vakhnina	UW	Provides expertise in preparing, awarding, managing and monitoring all aspects of subawards. Prepares documentation and requirements for subaward participation and reporting to IceCube Upgrade. Acts as liaison for reporting and other related issues and communicates with all levels of management.
1.1.2.3	Financial Reporting	Vakhnina	UW	Communicates and coordinates with accounting for gathering and reporting of financial data related to the project. Acts as liaison to accounting and management for all issues involving expenditures, funding and collection of financial data. Reviews data and verifies accuracy to prepare for interface with reporting tool and generation of reports for project stakeholder review. Reviews the project financial status and trends with project key stakeholders, advising them on optimal utilization of financial resources within the project.
1.1.2.4	Project Reviews	DuVernois	UW	Supports project manager and other project key stakeholders with preparation and management of project internal and external reviews. Includes travel costs for project reviews and internal collaboration meetings, and the expenses incurred for meeting rooms and coordination.
1.1.3	**Quality and Safety Management**	**Zernick**	**UW**	Quality and Safety Management encompasses non-conforming materials, incoming inspections, document control, audits, and corrective and preventive actions. It is an integral part of the design, procurement, fabrication, and deployment phases. The program objective is to ensure the completion of high quality, reliable advanced detectors.Provide expertise in all areas related to Quality Assurance and Safety. Prepare plans outlining requirements and operation parameters to ensure environs are within acceptable standards. Coordinate and conduct periodic reviews and report findings recommending best course of action to resolve issues. Maintain open communication with all levels of management.Ensures that proper environmental, health, and safety guidelines are followed. Issues PPE (personnel protective equipment) as needed. Provides accident investigation procedures, verifies health insurance coverage, and provides overtime and irregular shift guidance. Manages IEE/CEE (environmental impact documents) required for activities at the South Pole. Tracks failures, parts not accepted from vendors, and reworked components.
1.1.3.1	Risk Management	DuVernois	UW	Maintains the risk registry with input from the WBS managers. Coordinates with university council on equipment risk (for example in shipping) and human risk (in concert with the safety manager). Acts as an ombudsperson for risk concerns raised at any level, including in the field at South Pole.
1.1.3.2	Document Control	Zernick	UW	Maintains the document databases with the input from the WBS managers and other key stakeholders.
1.1.4	**Polar Operations**	**Haugen**	**UW**	This element includes the planning and execution of all of the activities needed at South Pole to successfully install sensor instrumentation into 7 deep drilled holes. It includes working with the Antarctic Support Contract (ASC) to plan movement of cargo and people to the South Pole. It includes working closely with ASC and IceCube Upgrade Drill management to coordinate fuel delivery at Pole.
1.1.4.1	Logistics	Haugen	UW	Coordination of annual cargo shipments and personnel deployments to and from the South Pole. Also includes management of international and domestic shipping schedules to mesh with USAP flights from Christchurch to Antarctica.
1.1.4.2	Antarctic Support Contract	Haugen	UW	Liaison and formal single channel of communications between the project and the Antarctic Support Contractor. Makes personnel schedules for field deployments, arranges PQ (physical qualifying) exams, communicates rules and expectations to field workers, and manages requests to the contractor. support includes fuel, lodging at the South Pole, flight reservations on commercial and military aircrafts, cargo handling, equipment operations at Pole, and waste handling.
1.1.5	**Project Engineering**	Sandstrom	UW	Determine appropriate standards for purchased or fabricated elements of instrumentation systems. Responsible for standardizing appropriate system definitions, requirements, and interfaces. Provide design engineering support to instrument developers and project management. Provide engineering expertise for milestone design status reviews. Review contract manufacturing proposals for project requirements and manufacturability. Help identify tradeoffs and risks of particular design choices. Communicate system conflicts and potential resolutions to instrument developers and project management. Determine consistent naming conventions for configuration Items and interface elements. Devise a tailored system for tracking design requirements, design status and system interfaces. Provide guidance to WBS leads regarding design for reliability and design for manufacture.
1.2	**IceCube Upgrade Drill**	**Hutchings**	**UW (PSL)**	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
1.2.1	**Drill Management & Systems Engineering**	**Hutchings**	**UW (PSL)**	Includes drill system and drilling project management, systems engineering, borehole and system thermal modeling, procurement support, season planning, CAD support, technical reviews, drill safety/EHS, quality assurance, recruitment, training, and documentation.
1.2.1.1	Drill Management			EHWD Upgrade management; Plan, schedule, and budget development; Develops EHWD logistics and support requirements, works closely with Polar Ops. Facilitates design, production, and field season readiness reviews; Recruitment; Training; post-drill season close-out.
1.2.1.2	Systems Engineering			Systems engineering, thermal modeling, fuel analyses, CAD support, procedures, post-drill season wrap up.
1.2.1.3	Drill Quality and Safety			Drill safety, drill quality assurance, documentation, post-drill season wrap up.
1.2.1.4	Travel			Travel for meetings and reviews, recruitment, and vendor visits.
1.2.2	**Thermal Plant**	**Duling**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of subsystems associated with the drill system's hot water thermal plant: PreHeat System, Main Heating Plants, a new Seasonal Equipment Site fuel day tank and fuel distribution system. Mainly legacy EHWD thermal plant subsystems. Excludes generator exhaust heat recovery system.
1.2.2.1	Main Heating Plants			Recon, identify/procure upgrades/replacements/spares, retrofitting and testing. Including burner rebuilds, sensor replacements, and integrated networking.
1.2.2.2	Pre-Heat System			Recon, identify/procure upgrades/replacements/spares, retrofitting and testing.

WBS	Name	Lead	Institution	WBS Dictionary Definition to Level 4 only
1.2.2.3	Fuel Storage and Delivery			Recon, design/specify/procure/fabricate/test new fuel storage day tank; Review and identify/procure replacements/spares, retrofit and testing. Review, specify/procure fuel delivery systems throughout EHWD
1.2.3	**Tower Operations Site**	**Benson**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of subsystems located at the borehole: Tower Operations Structure, Drill Tower, Drillheads and controls, Main Drill Cable Reel, Main Drill Hose Reel, Main Drill Hose, Return Water Hose Reel, Return Water Cable Reel, and downhole drill cables.
1.2.3.1	Tower Operations Structures (TOS and Tower)			Includes the design, procurement, resurrection, construction, integration, and testing of subsystems located at the borehole. Tower Operations Structure, Drill Tower, Drillheads and controls, Main Drill Cable Reel.
1.2.3.2	Drillheads			Recon, identify/procure upgrades/replacements/spares, retrofitting and testing. Drill head testing and rebuild.
1.2.3.3	Reels & Winches			Main Drill Hose Reel, Main Drill Hose, Return Water Hose Reel, Return Water Cable Reel, and downhole
1.2.3.4	Down-hole Main Drill Hose			Specify and procure new Main Drill Hose. Review, specify, and fabricate hose strain reliefs.
1.2.3.5	Down-hole Main Drill Cables			Review specifications and procure new downhole drill cables, including main drill cable and return water pump combo cable, connectorization, testing.
1.2.4	**Computing and Control System**	**Laundrie**	**UW (PSL)**	Includes development and verification of new drill control system software and hardware, network, sensors, e-stop, network and e-stop cabling and connectors, motor drives, and the Drill Control Center.
1.2.4.1	Architecture			Evaluate EHWD system and define IceCube Upgrade Drill requirements, system design.
1.2.4.2	Control System Hardware			Motor controllers and readouts, sensors, network controllers, indoor cables (sensor and network).
1.2.4.3	Control System Software			Motor controllers and readouts, data acquisition, system operator functions.
1.2.4.4	Motor Drives			Define functional and electrical requirements, specify and procure drives, programming and testing.
1.2.4.5	E-Stop System			Evaluate EHWD system and define IceCube Upgrade Drill requirements, system design and testing.
1.2.4.6	Drill Control Center			Computing system and electrical improvements.
1.2.4.7	Outdoor Cables			Assess existing cabling, design and procure, testing.
1.2.5	**Electrical Generation and Distribution System**	**Benson/Laundrie**	**UW (PSL)**	Includes evaluation and repairs, logistics and sub-contract arrangements for the overhaul and repairs of the IceCube Gen1 Generators, Power Distribution Module, and Electrical Grid. Design, specification, procurement, integration, and testing of power generation systems, generator exhaust heat recovery systems ; Procurement of ISO-3 sled; Procurement and fabrication of replacement skis; Design review/procurement of breakers, connectors, etc replaced/removed by previous custodians.
1.2.5.1	Generator 1			Develop IceCube Generator -1 overhaul, integration, and tune-up statement of work. Arrange and facilitate sub-contract with Caterpillar engineers to perform overhaul work. Develop specifications, procurement plans, integration and testing, commissioning.
1.2.5.2	Generators 2, 3, and PDM			Develop IceCube Generator 2, 3, and PDM evaluation and testing plans. Procure Caterpillar sub-contractor to deploy and implement generator tests, tune-up, and identify/perform repairs, as well as troubleshoot PDM synchronization. Develop specifications, procurement plans, integration and testing, commissioning. Fabricate replacement skis for 3 generator modules, 1-PDM, 1-Reel Container
1.2.5.3	ISO-3 Sled (Removed - Part of Microturbines)			
1.2.5.4	System Electrical Distribution			Evaluate EHWD electrical distribution system, define requirements, design/build, testing.
1.2.6	**Water Handling Systems**	**Duling**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of subsystems associated with water storage, transfer, and makeup: Water tanks, High Pressure Pump system, an new water filtration and degassing system, all pumps including downhole return pump but excluding Preheat System pumps, all interconnect hoses and plumbing including the surface transfer hose to/from the TOS, and the ARA Hot Water Drill (to replace the Rodriquez Well System).
1.2.6.1	Water Tanks			Recon, identify/procure upgrades/replacements/spares, retrofit and testing.
1.2.6.2	Pumps			Recon, identify/procure upgrades/replacements/spares, retrofit/recondition/testing.
1.2.6.3	Filtration and Degassing			Define requirements, design and specify, procurement, fabrication and assembly, integration/verification/testing.
1.2.6.4	Interconnects - External			Recon, identify/procure replacements/spares, includes MDS interconnects and surface hose.
1.2.6.5	MDS Internal Hoses			Evaluate, procure, and replace, as needed, MDS internal water and fuel hoses
1.2.6.6	ARA Hot Water Drill Subsystem			Recon, identify/procure replacements/spares, subsystem testing, integration and commissioning.
1.2.7	**Support Equipment**	**Duling**	**UW (PSL)**	Includes the design, procurement, resurrection, construction, integration, and testing of other drill support systems and equipment: Mobile Expandable Container Configuration (MECC), Mechanical Shop, Electrical Shop, Spares and equipment milvans, Independent Firn Drill (IFD), and special handling equipment. Deployment hardware that directly interfaces with the drill infrastructure is included here.
1.2.7.1	Independent Firn Drill			Identify/procure replacements/spares, system testing and commissioning.
1.2.7.2	Inventory Storage			Recon, identify/procure replacements/spares.
1.2.7.3	Shops			Identify/procure replacements, spares for tooling shops. Repair structure, workbenches, internal systems.
1.2.7.4	Test Bed			Identify/procure replacements/spares, annual commissioning, maintenance, and decommissioning.
1.2.7.5	Tools and Equipment			General and specialty tools and equipment, resupply.
1.2.8	**Drill Field Seasons**	**Hutchings**	**UW (PSL)**	Includes detailed pre-planning and on-site management of polar field season work, seasonal staffing to support this work in the field and receive training prior to field deployment, travel expenses, M&S, and drill logistics.
1.2.8.1	Seasonal Staffing & Training, Off-Ice Coordination			Driller recruitment and summer training at PSL. Travel for training. Provide support and assistance to on-ice team.
1.2.8.2	18/19 On-Ice Activities			Recon and retro mission. Perform preliminary inspection and bulk inventory of major EHWD components
1.2.8.3	19/20 On-Ice Activities			Deep recon and retro season; Begin sub-system testing, component replacements. Perform testing of generators 2, 3, and PDM in McMurdo.
1.2.8.4	20/21 On-Ice Activities			Reconditioning and rebuild existing on-site subystems. Continue sub-system upgrades and replacements.
1.2.8.5	21/22 On-Ice Activities			Generator & PDM system integration, verification, and testing. Traverse/air shipment of drill components to NPX. Initial system integration and "wet-testing" of EHWD; Perform "firn" drilling of all holes.
1.2.8.6	22/23 On-Ice Activities			Drill system commissioning; Deep drilling all holes; Assist with string installation; Drill system decommissioning and storage/retro.
1.2.9	**String Installation**	**Tosi**	**UW**	Plan & Coordinate String Installation Area. Work closely with 1.3 (DOM's) and 1.4 (Cables) to determine requirements, schedules, logistics, and constraints. Develop detailed plans and procedures for deep string installation. Assemble and lead a team of "deployers" during 2022/23 season to deploy 7 instrumented strings safely and successfully.
1.2.9.1	2018/19 Installation Coordination			Plan & coordinate String Installations. Develop site plans. Review and coordinate cable & DOM designs. Develop procedures, hazard analysis & safety plans.
1.2.9.2	2019/20 Installation Coordination			Plan & coordinate String Installations. Develop site plans. Review and coordinate cable & DOM designs. Develop procedures, hazard analysis & safety plans. Develop procurement lists of Installation related hardware and equipment.
1.2.9.3	2020/21 Installation Coordination			Plan & coordinate String Installations. Develop site plans. Review and coordinate cable & DOM designs. Develop procedures, hazard analysis & safety plans. Design DOM Handling Facility (DHF). Oversee fabrication and material procurements pf the DHF. Procure related Installation hardware and equipment.
1.2.9.4	2021/22 Installation Coordination			Plan & coordinate String Installations. Develop site plans. Review and coordinate cable & DOM designs. Develop procedures, hazard analysis & safety plans. Develop safety & installation training program, train installers. Ship hardware & equipment. Determine Installation Team - Drillers, Winterovers, Contributed Deployers, etc.
1.2.9.5	2022/23 Installation Coordination			Plan & coordinate String Installations. Develop site plans. Review and coordinate cable & DOM designs. Develop procedures, hazard analysis & safety plans. Directly manage on-ice string installation. Decommission and retro equipment.

WBS	Name	Lead	Institution	WBS Dictionary Definition to Level 4 only
1.3	**Deep Ice Sensor Modules**	**Karg**	**DESY**	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 800 deployment-ready optical sensors that meet the high-level design requirements of the IceCube Upgrade.
1.3.1	**mDOM**	**Kappes**	**Münster**	This element is responsible for the design and production of the mDOM, including software and firmware to integrate it into the IceCube Upgrade data acquisition system, acceptance tests, and procedures and tools for safe transport and deployment. Deliverables are up to 500 deployment-ready mDOMs delivered to Port Hueneme that meet the high-level design requirements of the IceCube Upgrade.
1.3.1.1	mDOM DAQ Electronics			Design, development, production, and testing of the electronic circuit PCB or PCBs responsible for PMT analog signal processing, digitization, time-stamping, and transmission to the surface. Also included is firmware and software.
1.3.1.2	mDOM PMT			Selection and procurement of the photomultiplier tube detectors (24) in each mDOM. The photomultiplier, or PMT, is the fundamental detecting element of the sensor.
1.3.1.3	mDOM High Voltage Subsystem			Design, development, procurement, and production of the subassemblies to produce the high voltage bias to the photomultiplier tubes. Includes generator, base, and digital control / interface to the DAQ electronics.
1.3.1.4	mDOM Pressure Vessel			The delicate mDOM photomultipliers and electronics are housed in borosilicate glass pressure housings to protect them from the high pressure environment of deployment. Material UV transparency and background light production through a combination of intrinsic radioactivity and scintillation are key performance parameters. This element covers design, development, and procurement of these housings.
1.3.1.5	mDOM PMT Support Structure			The PMT support structure provides the mechanical interface for the 12 PMTs, reflector rings to shape the PMT angular acceptance profile, the calibration devices, and the containment of the optical gel in one hemisphere of the integrated mDOM. This element covers design, development, and production of the support structures and the reflector rings.
1.3.1.6	mDOM Gel			The gel provides optical coupling between the PMT entry window and the pressure vessel. It further protects the PMT during transport. This element covers the selection and procurement of the optical gel.
1.3.1.7	mDOM Harness			The harness provides the mechanical interface to mount the mDOM to the main cable. This element covers the design, development, and procurement of the mDOM harness.
1.3.1.8	Integrated mDOM			This elements covers the design of the integrated mDOM sensor module and includes: the physical subcomponents such as mechanical support structures and fasteners; integrated module design verification testing; packaging and shipping; deployment tools and procedures.
1.3.1.9	mDOM Production Facilities			The labor, material, and capital equipment to design, purchase, and operate facilities for mDOM series production and final acceptance testing. Deliverables are production facilities, including procedures and tools, with the capacity for series production of up to 600 mDOMs in one year. This element also includes the development, purchase, and production of unified facilities, procedures and tools for final acceptance testing of mDOMs during series production.
1.3.1.10	mDOM Production and Testing			This element captures labor and consumables expended during production and testing of up to 600 mDOMs. This element also includes the expenses of delivery to Port Hueneme.
1.3.2	**D-Egg**	**Ishihara**	**Chiba**	This element is responsible for the design and production of the D-Egg, including software and firmware to integrate it into the IceCube Upgrade data acquisition system, acceptance tests, and procedures and tools for safe transport and deployment. Deliverables are about 300 deployment-ready D-Eggs delivered to Port Hueneme that meet the high-level design requirements of the IceCube Upgrade.
1.3.2.1	D-Egg DAQ Electronics			Design, development, production, and testing of the electronic circuit PCBs for PMT analog signal processing, digitization, time-stamping, and transmission to the surface. Also included is firmware and software.
1.3.2.2	D-Egg PMT			Selection and procurement of the photomultiplier tube detectors (2) in each D-Egg. The photomultiplier, or PMT, is the fundamental detecting element of the sensor.
1.3.2.3	D-Egg High Voltage Subsystem			Design, development, procurement, and production of the subassemblies to produce the high voltage bias to the photomultiplier tubes. Includes high voltage generator, PMT base, and the interface to the DAQ electronics.
1.3.2.4	D-Egg Pressure Vessel			The delicate D-Egg photomultipliers and electronics are housed in borosilicate glass pressure housings to protect them from the high pressure environment of deployment. The UV transparency of the material and background light production through a combination of intrinsic radioactivity and scintillation are key performance parameters. This element covers the design, development, and procurement of these housings.
1.3.2.5	D-Egg Gel			The gel provides optical coupling between the PMT entry window and the pressure vessel. It further protects the PMT during transport. This element covers the selection and procurement of the optical gel.
1.3.2.6	D-Egg Harness			The harness provides the mechanical interface to mount the D-Egg to the main cable. This element covers the design, development, and procurement of the D-Egg harness.
1.3.2.7	Integrated D-Egg			This elements covers the design of the integrated D-Egg sensor module and includes: the physical subcomponents such as mechanical support structures and fasteners; integrated module design verification testing; packaging and shipping; deployment tools and procedures.
1.3.2.8	D-Egg Production Facility			The labor, material, and capital equipment to design, purchase, and operate facilities for D-Egg series production and final acceptance testing. Deliverables are production facilities, including procedures and tools, with the capacity for series production of 300 D-Eggs in one year. This element also includes the development, purchase, and production of unified facilities, procedures and tools for final acceptance testing of D-Eggs during series production.
1.3.2.9	D-Egg Production and Testing			This element captures labor and consumables expended during production and testing of 300 D-Eggs. This element also includes the expenses of delivery to Port Hueneme.
1.3.3	**PDOM**	**Sandstrom**	**UW**	This element is responsible for upgrading 20 spare IceCube Gen1 DOMs with PDOM readout electronics, HV systems, calibration devices, and penetrators. This includes software and firmware to integrate it into the IceCube Upgrade data acquisition system, acceptance tests, and procedures and tools for safe transport and deployment. Deliverables are 20 deployment-ready refurbished IceCube DOMs delivered to Port Hueneme that meet the high-level design requirements of the IceCube Upgrade.
1.3.3.1	PDOM DAQ Electronics			Design, development, production, and testing of the electronic circuit PCBs for PMT analog signal processing, digitization, time-stamping, and transmission to the surface. Also included is firmware and software.
1.3.3.2	PDOM High Voltage Subsystem			Design, development, procurement, and production of the subassemblies to produce the high voltage bias to the photomultiplier tubes. Includes high voltage generator, PMT base, and the interface to the DAQ electronics.
1.3.3.3	IceCube DOM Refurbishment			The labor, material, and capital equipment to refurbish IceCube DOMs with PDOM readout electronics, HV systems, calibration devices, and penetrators. The expected yield is 20 PDOMs. This element also includes final acceptance testing and the expenses of delivery to Port Hueneme.
1.3.4	**Ice Comms Module**	**Sulanke**	**DESY**	Common to all 3 sensor types, may be implemented completely on the main board or as a standalone module that can be fitted onto all 3 sensor main boards. Will also be used in Standalone Calibration devices. Directly 'talks' to the Surface Comms Module that is located in the FieldHub. This element includes the firmware running on the ICM, including the golden image with boot loader and firmware update functionality, communications and error detection, and device addressing, and RapCal functionality.
1.3.5	**Special Devices**	**Böser**	**Mainz**	This element is responsible for the coordination of R&D optical modules that can be co-deployed in small numbers. It ensures that all R&D modules meet the interface requirements of the IceCube Upgrade and that they do not add any unnecessary risk to the project goals. It may also include R&D devices that are not optically based.

WBS	Name	Lead	Institution	WBS Dictionary Definition to Level 4 only
1.4	**Comms, Power, and Timing (CPT) Distribution System**	**DeYoung**	**MSU**	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 to which new instruments are connected, surface readout electronics and associated software and firmware other than the Comms Module, 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.
1.4.1	**Downhole Cable Assemblies**	**Ferguson**	**MSU**	This element includes design, procurement, and quality assurance of the physical cable assemblies running to the in-ice sensors and calibration devices, as well as their delivery to Port Hueneme.
1.4.1.1	Main Cable Assembly (MCA)	Ferguson	MSU	The labor, material, and capital equipment required to design, spec, purchase and assure quality of the main downhole cables with breakout connectors. This element is responsible for cable vendor selection, including purchase and testing of samples as required for final selection, and for delivery of the completed cables to Port Hueneme.
1.4.1.2	Breakout Cable Assemblies (BCA)	Ferguson	MSU	The labor, material, and capital equipment required to design, spec, purchase and assure quality of the breakout cable assemblies connecting the main cable to the deployed instruments.
1.4.1.3	Penetrator Cable Assembly (PCA)	Ng	MSU	The labor and materials required to design, procure and assure quality of the common penetrator assembly carrying conductors from the breakout cable assemblies through the pressure vessels surrounding DOMs and calibration instruments.
1.4.1.4	String Hardware	Ng	MSU	The labor, material, and capital equipment required to design, spec, purchase and assure quality of deployment chains and attachment points, cable weights, cable stops, penetrator assemblies used by in-ice sensors, and miscellaneous cable hardware. This element also includes specification of common requirements (size, load capacity, attachment points, etc.) for harnesses used to connect DOMs and stand-alone calibration devices to the cables. Delivery of related equipment to Port Hueneme is also included.
1.4.2	**Surface Cables**	**Kelley**	**UW**	This element includes design, procurement, and quality assurance of the physical cables running along the surface from the IceCube Laboratory (ICL) building to the Upgrade strings. It also includes labor and materials associated with modifications to the ICL required by the Upgrade project which are not provided by ASC, and transportation of equipment to Port Hueneme.
1.4.2.1	Surface Cable Assemblies	Ferguson	MSU	The labor, materials, and capital equipment required to design, spec, purchase and assure quality of the cable assemblies carrying power, communications, and timing information from the ICL to the terminations of the MCAs in the surface junction boxes.
1.4.2.2	Surface Junction Boxes	Ng	MSU	Labor, material, and equipment required to design and construct or purchase the junction boxes housing the connections between the MCAs and SCAs.
1.4.2.3	ICL Upgrade	Kelley	UW	The labor to support definition of requirements for SCA entry into the ICL and infrastructure support of CPT surface electronics within the ICL. Includes surface cable entry, power usage, and heat load; any modifications of the ICL are implemented by ASC.
1.4.3	**FieldHub**	**Sulanke**	**DESY**	This element includes design, production and testing of the FieldHubs, which will control, read out, and supply power and timing signals to the instrumentation and calibration devices connected to the downhole cables. The FieldHub hosts a Comms Module that communicate with the in-device Ice Comms Module over the downhole cable assembly.
1.4.3.1	FieldHub Electronics	**Sulanke**	**DESY**	The labor and materials required to design and produce the FieldHub electronics.
1.4.3.2	FieldHub Control, Readout, and Timing Firmware & Software		DESY	The labor and materials required to develop and test FieldHub-resident control, readout and synchronization firmware and software other than that running on the FieldHub Comms Module.
1.4.4	**CPT Central Infrastructure**	**Kelley**	**UW**	This element includes design, production and testing of the electronics infrastructure required to distribute timing signals from the IceCube master clock to the FieldHubs in the ICL. This element also includes the power supplies which will supply power to in-ice devices through the FieldHubs.
1.4.4.1	Network and Timing	Kelley	UW	The labor and materials required to design, test, and install custom or semi-custom electronics necessary for distributing timing signals from and network communications from the IceCube DAQ to the FieldHubs in the ICL
1.4.4.2	Power Supply Modules	Kelley	UW	The labor and materials required to design, test, and install power supplies in ICL, for distribution to in-ice instrumentation through the FieldHubs
1.4.5	**Northern Test System**	**Ng**	**MSU**	This element includes design, construction and maintenance of a string-scale test facility in the Northern Hemisphere suitable for testing of DAQ software and firmware. The test facility will be remotely accessible to IceCube developers.
1.4.5.1	IceCube Emulator	Ng	MSU	The labor, materials, and capital equipment required to set up compute servers, GPS receivers, etc. capable of emulating the IceCube DAQ, master clock, control systems, and CPT central infrastructure. The actual software emulating the IceCube DAQ and control systems, and the compute servers hosting this software, are the responsibility of WBS 1.6.
1.4.5.2	Cable/Quad	Ng	MSU	The labor, materials, and capital equipment required to procure and install a downhole cable or substitute in the Northern test facility.
1.4.5.3	Dark Facility	Ng	MSU	The labor, materials, and capital equipment required to design and install a dark facility to house the sensors and calibration instruments included the Northern Test System.
1.4.5.4	NTS Operations	Ng	MSU	The labor and materials required to maintain and operate the Northern Test System after construction.
1.5	**Characterization and Calibration System**	**Williams**	**Alabama**	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.
1.5.1	**Module Calibration**	**Kauer**	**UW**	This element is calibration of the individual module response. Includes calibration in the lab and after deployment.
1.5.1.1	Production Calibration			Calibrates module response in the laboratory as a function of angle, wavelength and intensity. Each element under 1.3 (Deep Ice Sensor Modules) must have a calibration plan. Deliverable is a usable database of calibration constants which can be incorporated into simulation and analysis.
1.5.1.2	In situ sensor response Calibration			Responsible for design of in-situ individual module response calibration (equivalent to IceCube DOMCal), using onboard light sources such as LED, pulses and dark noise. Integrated array calibration, including ice, is handled under 1.5.3.
1.5.2	**Calibration Assemblies**	**Resconi**	**Munich**	This element is responsible for design, testing, production and integration of devices whose purpose is calibration of modules, the ice or both.
1.5.2.1	Onboard LED flashers	Nuckles	UW	This element is responsible for light sources which are integrated into modules, expected to be LEDs. Responsible for design, integration, production and testing of LEDs and supporting electronics, including LED mechanical holder, optical interface to the glass and LED driver circuit. All light sources must be integrated into the module data flow in such a way that light sources are always flagged as such in the data stream. Includes responsibility for demonstrating with simulation that the light source as designed will meet high level requirements of improving detector an ice characterization. Onboard light sources must not negatively impact normal operation of the module. Deliverables are stable, well characterized, light sources with complete coverage of the deployed modules.

WBS	Name	Lead	Institution	WBS Dictionary Definition to Level 4 only
1.5.2.2	Standalone light sources	Resconi	Munich	This element is responsible for design, integration, production and testing of light sources which are not included in photosensor modules, including glass, interface to cable and electronics. Design must include integration into the data stream so that operation of standalone light sources is always flagged as such in the data stream. Testing must include stress testing, freeze-testing and any other survivability testing which would normally be done for a photosensor module under section 1.3. Includes responsibility for demonstrating with simulation that the light source as designed will meet high level requirements of improving detector and ice characterization. Standalone light sources must not negatively impact the normal operations of the detector.
1.5.2.3	Camera and Light Detection	Rott	Sungkyunkwan University	Responsible for light detection devices (other than the modules themselves), such as cameras, specifically designed for detector calibration. Includes design, testing and integration of cameras into modules where applicable. Includes responsibility for demonstrating with simulation that the camera as designed will meet high level requirements of improving detector and ice characterization. Cameras integrated into modules must not negatively impact normal module operation and must meet power and communication requirements for integration in the module. Where cameras use light sources, such light sources must be integrated into the data stream so that operation of standalone light sources is always flagged as such in the data stream.
1.5.2.4	Acoustic Sensors	Wiebusch	Aachen	Responsible for design, testing, production and integration of acoustic sensors and transmitters in modules. Responsible for demonstrating that these sensors will deliver precise geometry measurement in excess of what we can achieve with LEDs, either in the upgrade or in the larger Gen2 detector.
1.5.2.5	Inclinometers, Compasses	DuVernois	UW	Responsible for design, testing, production and integration of inclinometers, compasses and other devices meant to measure absolute direction and orientation.
1.5.2.6	Mini Mainboard	Feldhauser	Aachen	Responsible for design and testing of a small ICM compatible mainboard which will be a common interface for standalone calibration devices.
1.5.3	**Array Calibration**	**Blot**	**DESY**	This element is responsible for characterization and calibration of the deployed array.
1.5.3.1	Calibration benchmarks			Responsible for final establishment of benchmarks for 1) calibration and characterization of the newly deployed detector elements and 2) improved calibration of the existing detector.
1.5.3.2	Timing calibration			Responsible for verification of the timing precision and overall timing accuracy of the deployed instruments.
1.5.3.3	Geometry calibration			Responsible for measurement and correction of the geometrical position of the deployed modules with respect to the surface and with respect to other IceCube modules. Includes development of deployment instrumentation such as pressure sensors and laser rangers, and measurement of geometry post-deployment with LED flashers, acoustic sensors and muons.
1.5.3.4	Ice properties calibration	Chirkin	UW	Responsible for using newly deployed and existing instrumentation to measure the ice properties, for verifying the hole ice properties of newly drilled holes.
1.5.3.5	Pre-deployment Hole measurement			Responsible for devices such as the dust logger which measure the drillhole properties before freeze-in.
1.5.4	**Calibration Management**	**Williams**	**Alabama**	Responsible for management of the calibration effort.
1.5.4.1	Calibration Management			Coordinate all calibration elements, organize reviews, monthly reports, oversee schedule and budget.
1.5.4.2	Calibration Travel			Travel to reviews and working meetings
1.6	**M&O Data Systems Integration**	**Blaufuss**	**UMD**	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.
1.6.1	**Online Software**	**Braun**	**UW**	This element will ensure that all hardware seamlessly integrates into the current IceCube online software systems. This include: The IceCube DAQ, where new systems will integrate at the trigger, event readout, control and monitoring levels with the current DAQ system, yielding a completely unified data readout system. The IceCube experiment control: new systems will be fully controlled and configured by existing IceCube control systems, including storage of configuration and calibration items into databases, and realtime and long-term monitoring of new systems. The IceCube online filtering system: data from new systems will be included in the online event filtering system and used as part of the event filtering decision process.
1.6.1.1	DAQ			Integrate new optical sensors and calibration devices into a unified data acquisition system, providing seamless triggering and data readout across all optical sensors
1.6.1.2	Experiment control and configurations			Provide support for configuration management of all optical sensors and calibrations in operations in IceCube. This includes control of all calibration devices during operation, and database storage of configuration information.
1.6.1.3	Online filtering			Provide support to extend the online event filtering system to provide online filters for the unified data readout from existing and new optical sensors.
1.6.1.4	DOM Software			Provide OM resident software for testing, calibration, and data collection for all types of OMs.
1.6.1.5	FieldHub-DAQ Interface Software			Provide Field-Hub resident software that provides the interface between CPT infrastructure, including the ICM and associated firmware, and the IceCube DAQ infrastructure.
1.6.2	**Offline Software**	**Oivas**	**UMD**	This element will ensure that offline software packages are updated to include classes and methods to accommodate data produced by new systems. This can include raw data readout classes; calibration, configuration and monitoring information; as well as adapting core software packages to properly utilize this additional information in reconstruction algorithms, and verification of software functionality against simulation and calibration information.
1.6.2.1	Core Software			provide extensions to IceCube core software (IceTray framework and data structures) to support new optical sensors and calibration devices (including data structures and supporting software for raw data readout, calibration and configuration information)
1.6.2.2	Reconstruction support			Provide software support to IceCube reconstruction software to include information from new optical sensors and calibration devices for use in event reconstruction. Including photon feature extraction from calibration sensor data and integration into advanced likelihood reconstruction algorithms.
1.6.2.3	Tools and infrastructure			Provide support for Upgrade software development and testing within the IceCube systems, including: source code revision control management, and build and testing infrastructure.
1.6.3	**Simulation Software**	**Stuttard**	**NBI**	This element will ensure that all new systems are accurately simulated within the IceCube simulation packages, including new optical sensors, calibration systems, and software systems used in readout (triggering) and calibration, as well as production of data samples for verification comparisons with data.
1.6.3.1	Electronic readout and digitization simulation			Provide accurate simulation of optical sensor signal digitization, readout electronics and data acquisition software in the IceCube simulation package.
1.6.3.2	Calibraton device simulation			Provide accurate simulation of calibration devices within the IceCube simulation package
1.6.3.3	Simulation Production			Ensure complete simulation packages are available for design verification, calibration tasks and data simulation verification tasks.
1.6.4	**Computing Infrastructure**	**Auer**	**UW**	This element will provide computing infrastructure needed by data systems to support new systems. This includes: Computing systems at South Pole (SPS), northern hemisphere testing hardware (SPTS), as well as local and distributed computing (processing and storage) needs for data and calibration verification tasks.
1.6.4.1	SPTS/NTS computing needs			Provide computing and networking hardware and OS/admin support for software and hardware development in the north is available at the northern hemisphere test setups (SPTS and NTS)
1.6.4.2	SPS/IDF computing needs			Provide computing and networking hardware and OS/admin support for the integration of new optical sensors and calibration devices in the ICL at South Pole.
1.6.4.3	Distributed computing needs			Provide support for mass processing and storage needs within the IceCube computing system to support IceCube Upgrade design and verification activities.