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Camera Calibration for the IceCube Upgrade and Gen2

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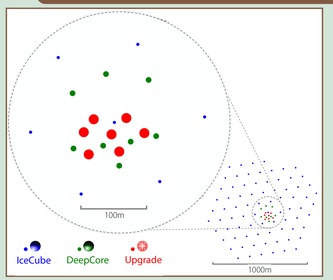
on behalf of the IceCube Collaboration[+]

Abstract

An upgrade to the IceCube Neutrino Telescope is currently under construction. For this IceCube Upgrade, seven new strings will be deployed in the central region of the 86 string IceCube detector to enhance the capability to detect neutrinos in the GeV range. One of the main science objectives of the IceCube Upgrade is an improved calibration of the IceCube detector to reduce systematic uncertainties related to the optical properties of the ice. We have developed a novel optical camera and illumination system that will be part of 700 newly developed optical modules to be deployed with the IceCube Upgrade. A combination of transmission and reflection photographic measurements will be used to measure the optical properties of bulk ice between strings and refrozen ice in the drill hole, to determine module positions, and to survey the local environments surrounding the sensor module. In this contribution we present the production design, acceptance testing, and plan for post-deployment calibration measurements with the camera system.

IceCube Upgrade

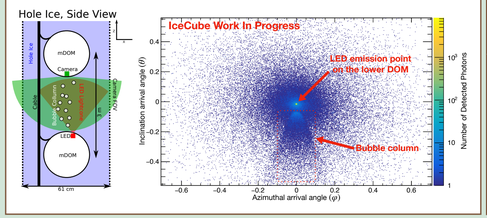


- Designed to carry out an improved neutrino oscillation study and an enhanced precise detector calibration [1].
- Deploying 7 new strings in the centre of the existing IceCube detector.
- Consisting of 700 new optical sensor modules and a series of novel calibration devices.
- Horizontal string spacing: 20m
- Vertical module spacing along string: 3m

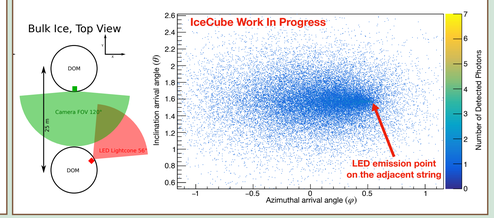
Objective and setups of the camera system

► Optical properties of ice in the vicinity of optical modules measured by capturing the light signature and analysing its distribution in the image data.
►The relative orientation & position of each optical module surveyed from the examination of multiple images.
► For the two primary proposed measurements, the system setups with their schematic diagrams and the representative results from the camera simulation studies shown in the left boxes.

Refrozen hole ice: a downwards facing camera and an illumination module in the DOM just below along the string



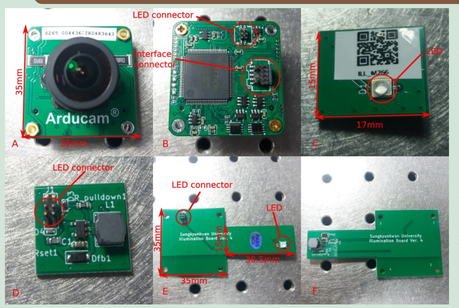
Inter-string bulk ice: a sidewise facing camera and an illumination module in the DOM on the neighboring string



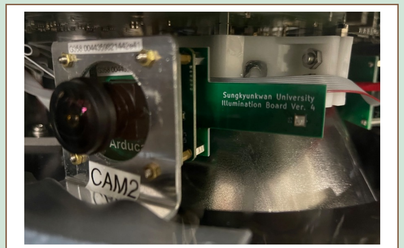
►In-ice camera run plan
- Simultaneous operations of the multiple cameras with LED lights.
- Fraction of detector, not affected by camera activities, in normal data-taking mode.
- Switch-off the PMT HV in the region where camera system on.

⇒ To mitigate the impact on the detector up-time and the readiness for scientific events like supernova.

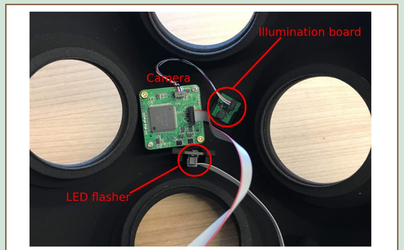
IceCube Upgrade Camera System



- The camera system developed for the IceCube Upgrade [2] currently in the mass production stage.
- More than 2000 camera modules and the illumination modules to be produced for all new optical sensors.
- Camera module using *IMX225* CMOS image sensor from SONY
- Illumination module using *SSL 80 GB CS8PM1.13* LED from Oslon



– Camera system installed in a D-Egg

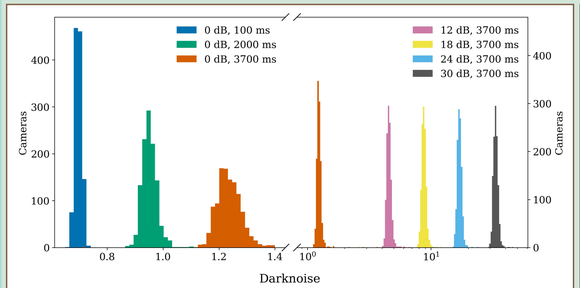


– Camera system installed inside of a PMT holding structure for the mDOM

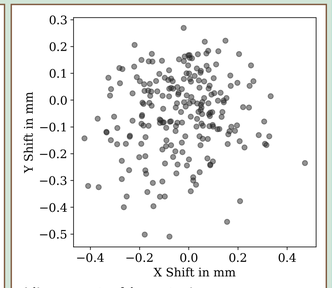
- For D-Egg [3], three cameras are installed connected to the illumination module.
- For mDOM [4], three cameras paired with the smaller illumination module to be equipped, an additional illumination module pointing upward from the optical sensor.

System calibration and verification

- To verify the normal operation of the system and to calibrate the cameras and LEDs before their deployment, all components to be subjected to an extensive suite of tests.
- 48 hours of testing per camera acquiring over 3,000 images.
- Data captured under low temperature conditions (at −40˚C) in a freezer as well as room temperature conditions (at 20˚C) in a dark box.



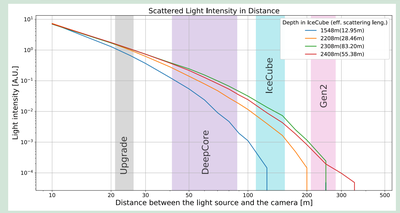
- The characterisation of the pixel darknoise is paramount as the camera system will operate in sparse light conditions.
- Variation of pixel counts over multiple images from dark condition.
- The distributions of Mean Pixel Darknoise over 1,178 cameras for multiple settings at −40˚C shown in the above histogram.



Alignment of lens to image sensor of each camera. The shifts can be determined with sub-pixel accuracy, which translates into an angular error estimated below 0.2˚.

- To understand the camera response to a light source, each camera captures multiple images of a diffused LED at 1m distance with different camera settings. Generally, the response of unsaturated pixels scales linearly with the exposure time and the magnification (in terms of the camera gain as $\sqrt{10^{Gain/10}}$) for each camera. (see Proceeding for details)

Camera system for IceCube-Gen2



- Hole ice related measurements using a similar camera system.
- String to string measurements to be challenging and not to have priority for camera system.
- Recent test on survey for the bulk ice using the back scattered light at the South Pole [5].

Conclusions

- IceCube Upgrade Camera System, a key component for a comprehensive understanding of the IceCube detector medium; the Antarctic ice.
- Calibration measurements with the camera system will enhance the science capabilities of IceCube by a substantially improved ice model.
- A significant fraction of cameras have been tested and integrated into the new optical sensor modules for the IceCube Upgrade, and their evaluated test data demonstrate the quality of the system and its capabilities.
- For IceCube-Gen2, a similar camera system will be employed to perform the hole ice surveys, which also has a potential for the bulk ice studies.

References

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[3] IceCube Collaboration, C. Hill *PoS* ICRC2021 **(these proceedings) 1042.**
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[5] IceCube Collaboration, D. Kim *PoS* ICRC2021 **(these proceedings) 1047.**

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Proceeding