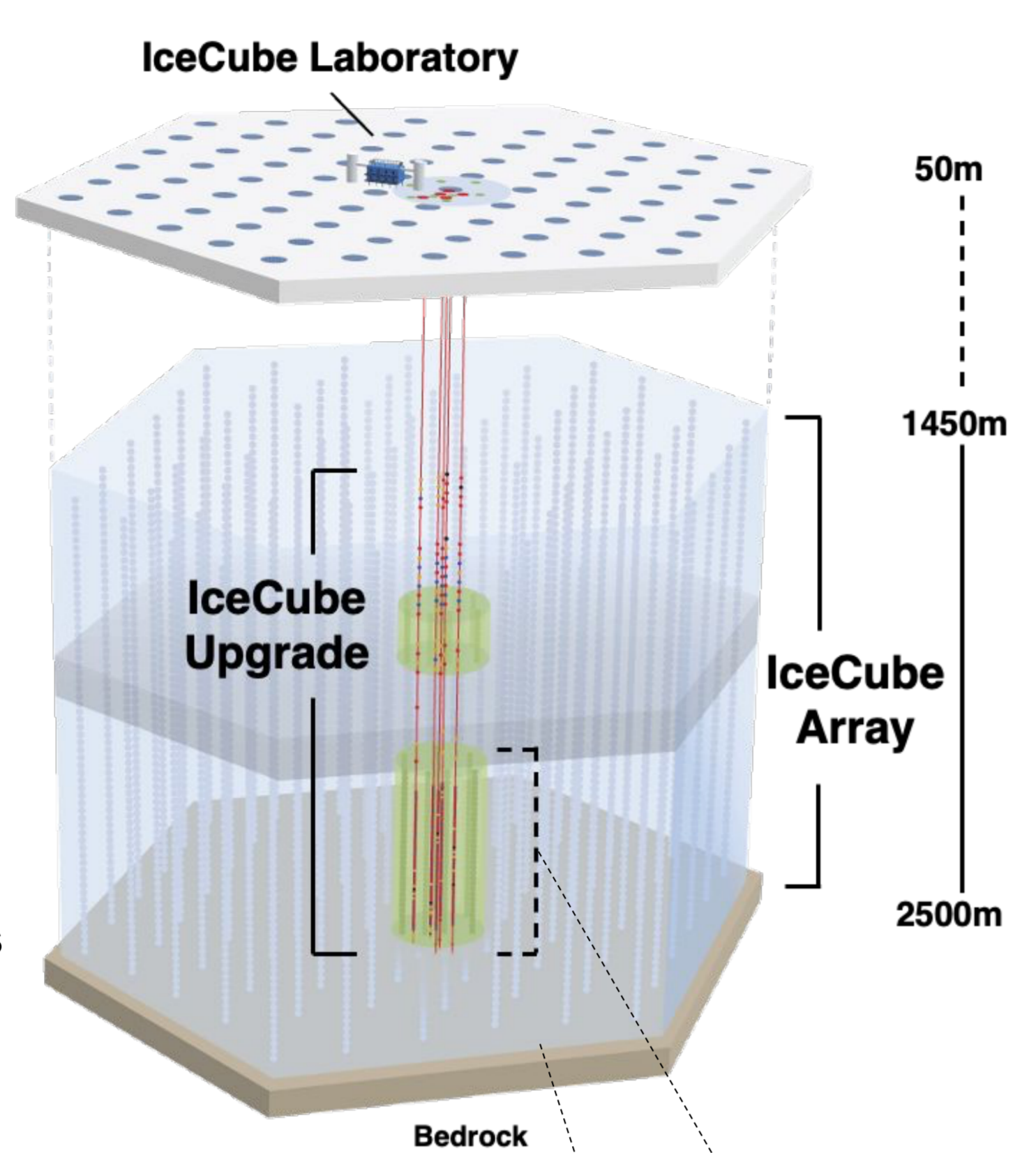


## IceCube Neutrino Observatory

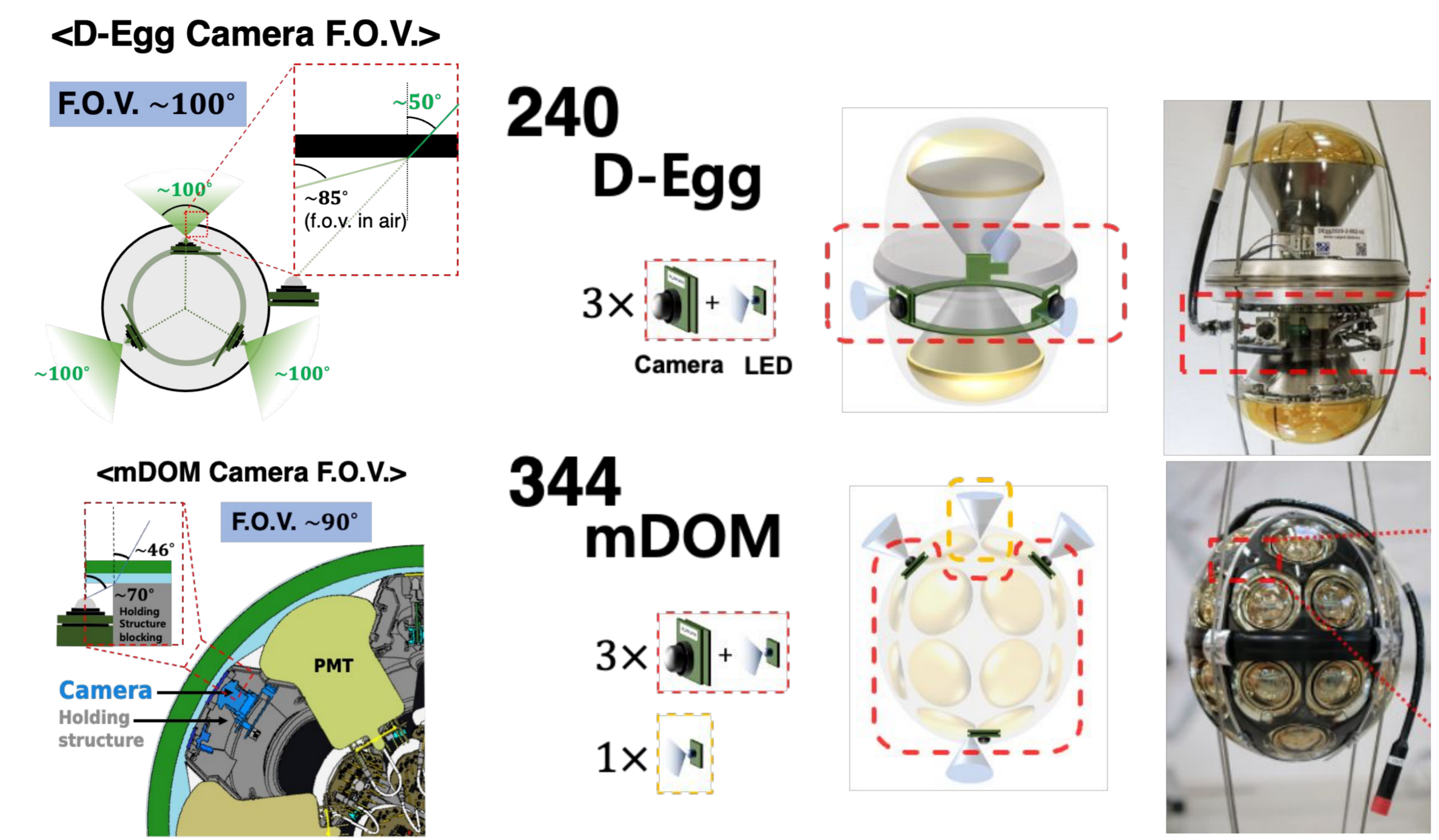
- **World's largest neutrino telescope**, located at the South Pole, using 1km<sup>3</sup> of ice as a natural detection medium.
- **86 cables (strings)** with 5,160 Digital Optical Modules (DOMs) equipped with photomultiplier tubes (PMTs).
- Detects neutrinos by observing **Cherenkov light** from charged particles produced by **neutrino interactions in ice**.
- A decade of breakthrough science, including observation of high-energy astrophysical neutrinos.



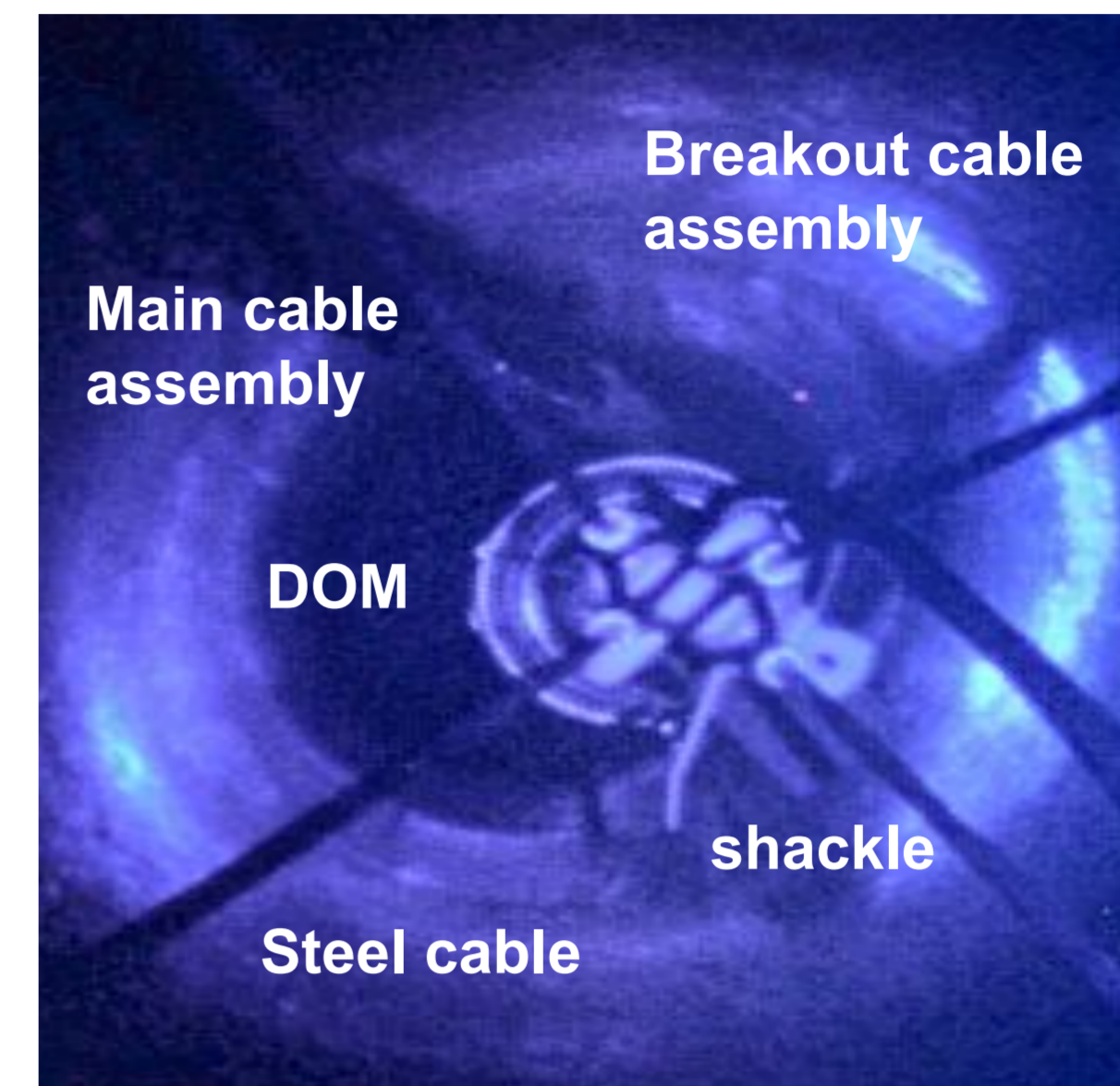
## IceCube Upgrade

- **5 additional strings** with denser spaced DOMs with improved sensitivity
- Successfully deployed during **2025-26 South Pole field season**
- Better resolution for **lower-energy neutrino events**
- To improve our understanding of **Antarctic ice properties**
- Provides an unparalleled opportunity to measure the optical properties of South Pole ice at a fine granularity!

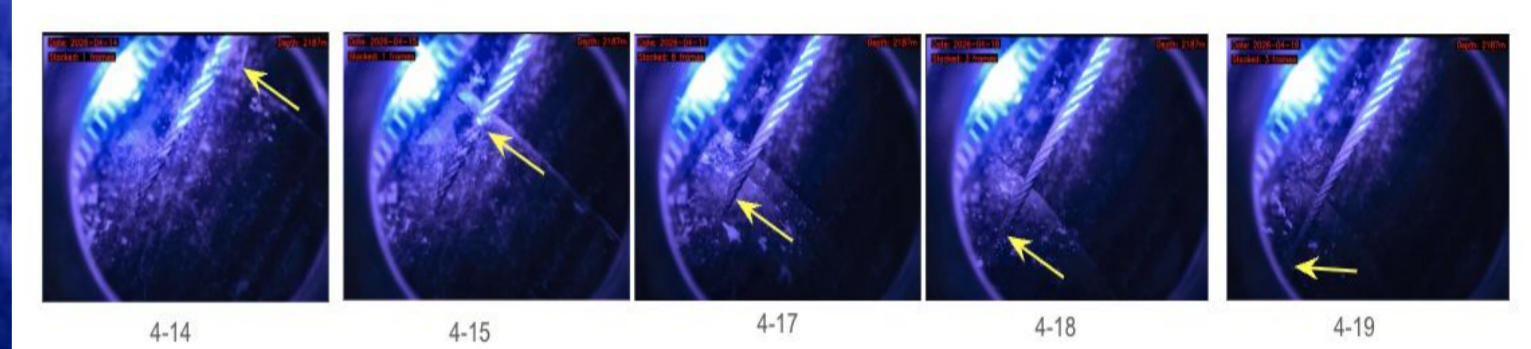
## IceCube Upgrade Camera Modules



## Drill hole geometry and freeze-in

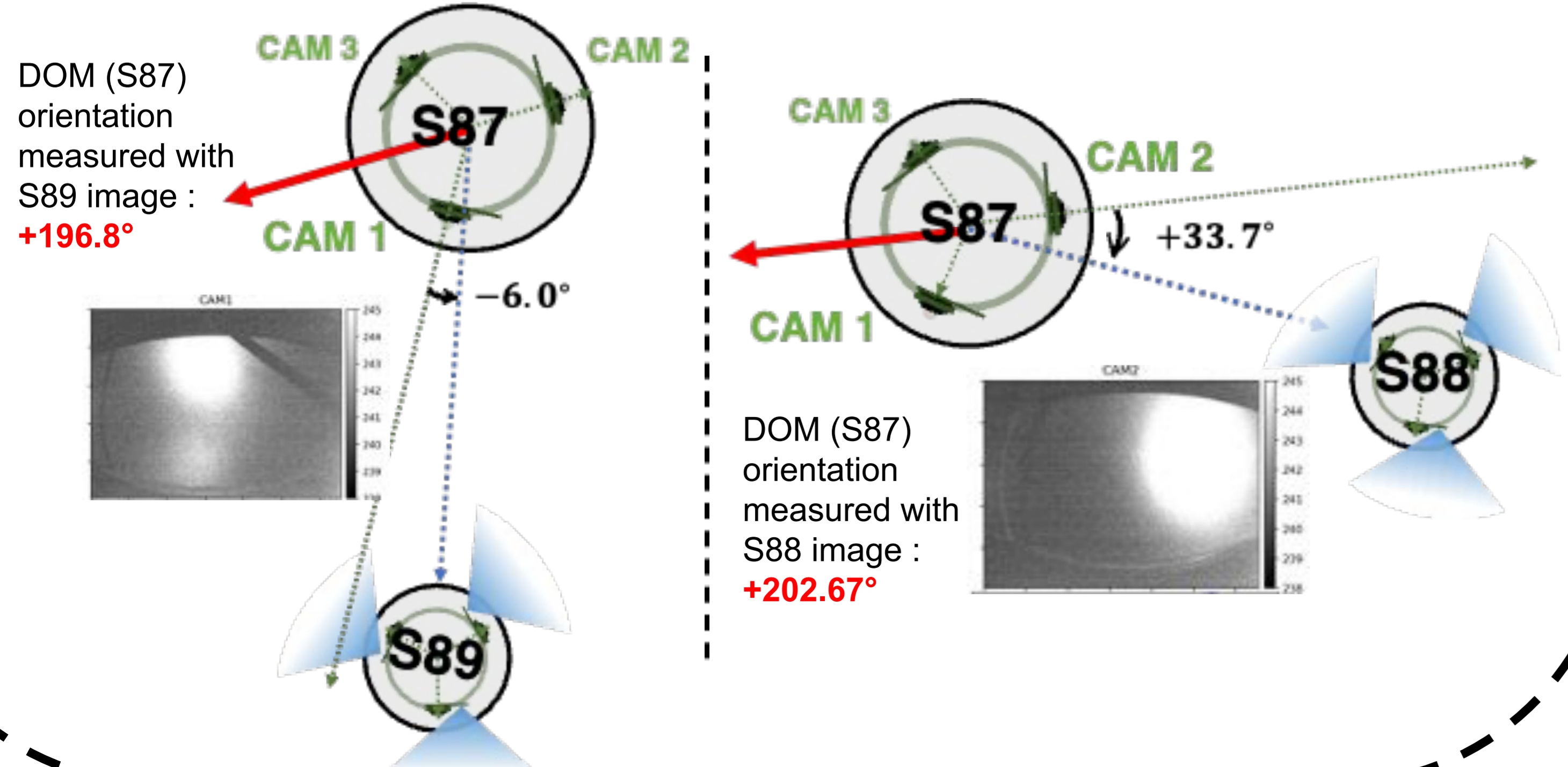
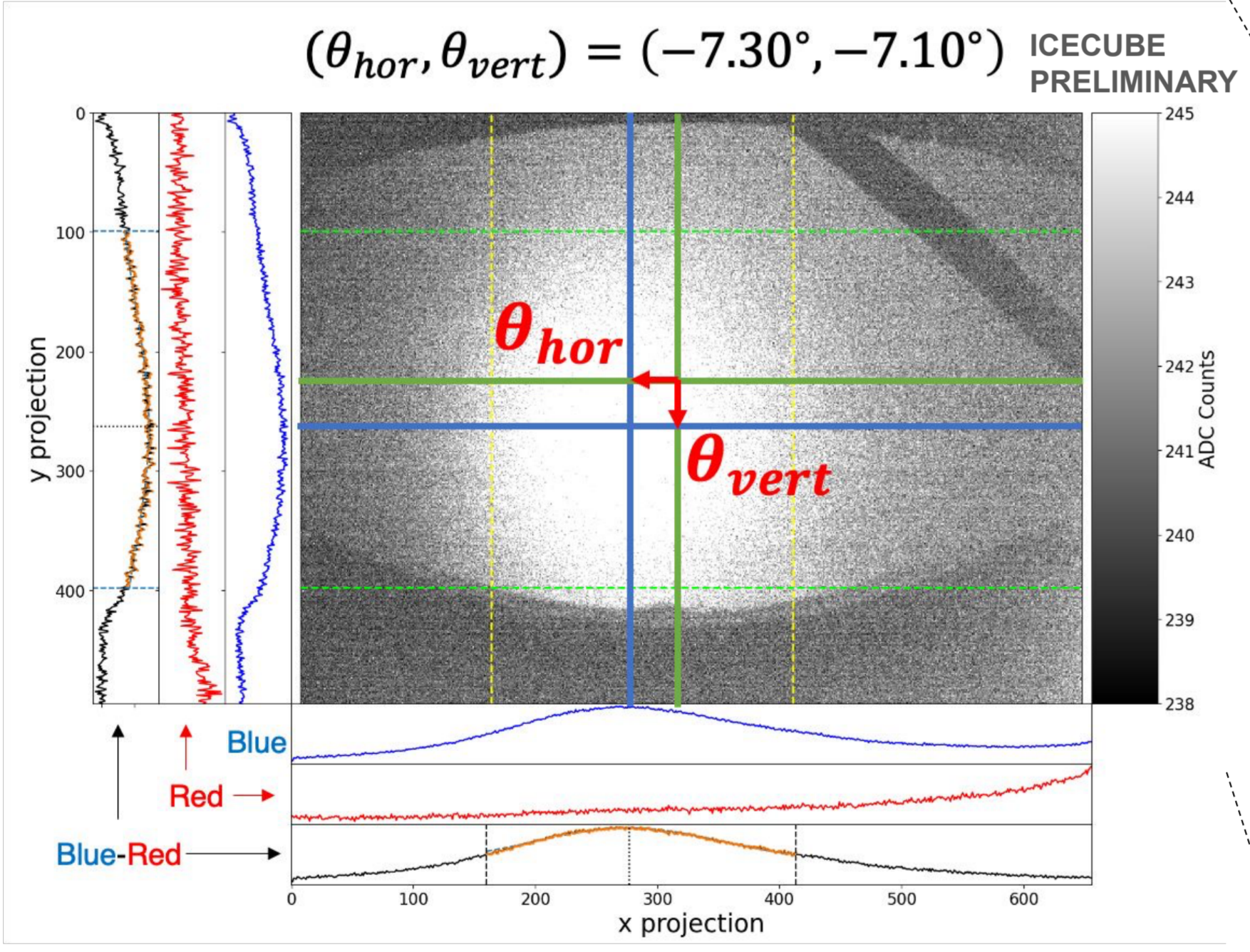


- Daily images show progression in freeze in and location of the MCA - main cable assembly, break out cables, structural cables and water-bulk ice interface.
- A **time series** was created to observe the **process of the hole refreezing** and observe Freeze-in dynamics

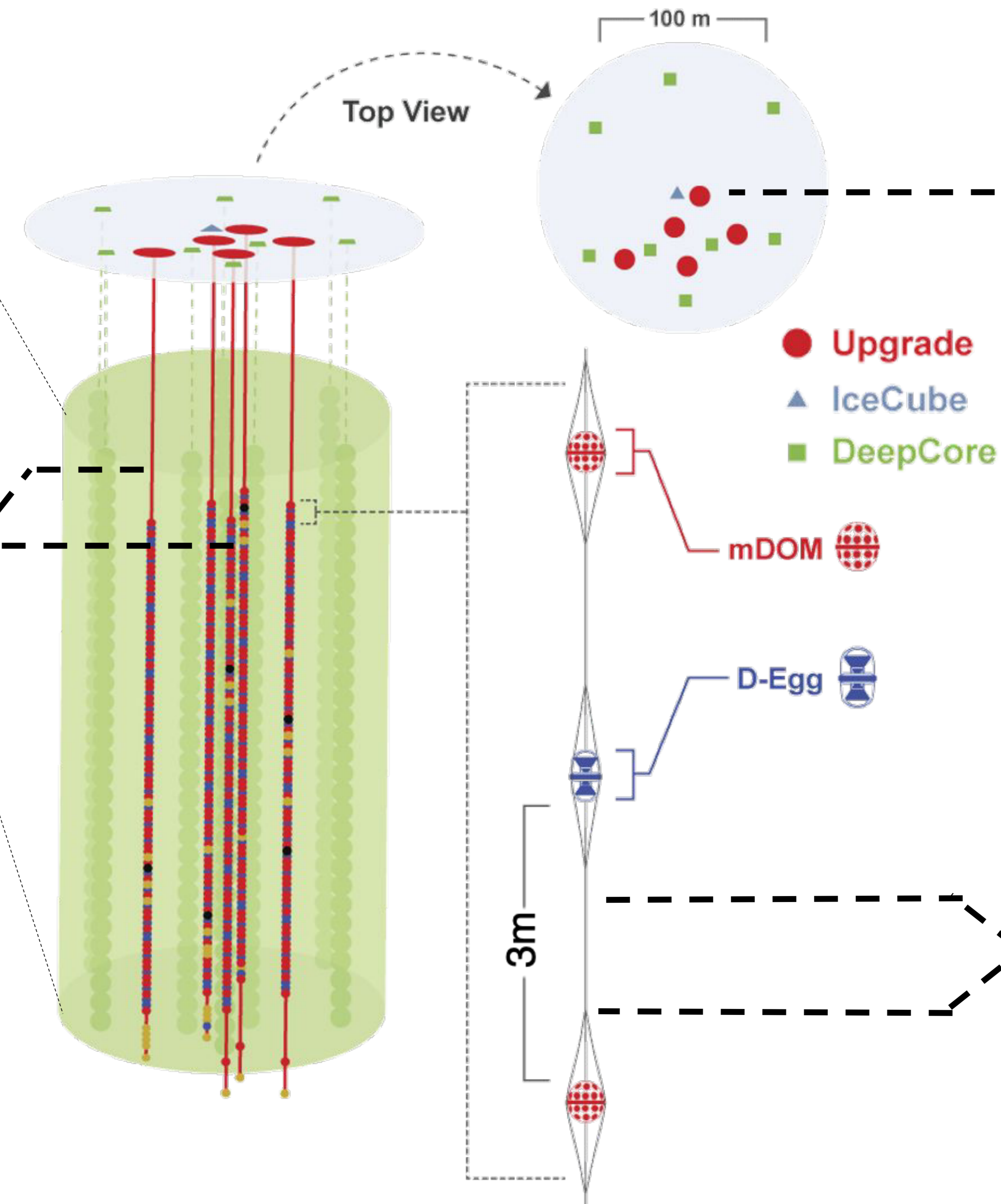


## Inter-string Imaging

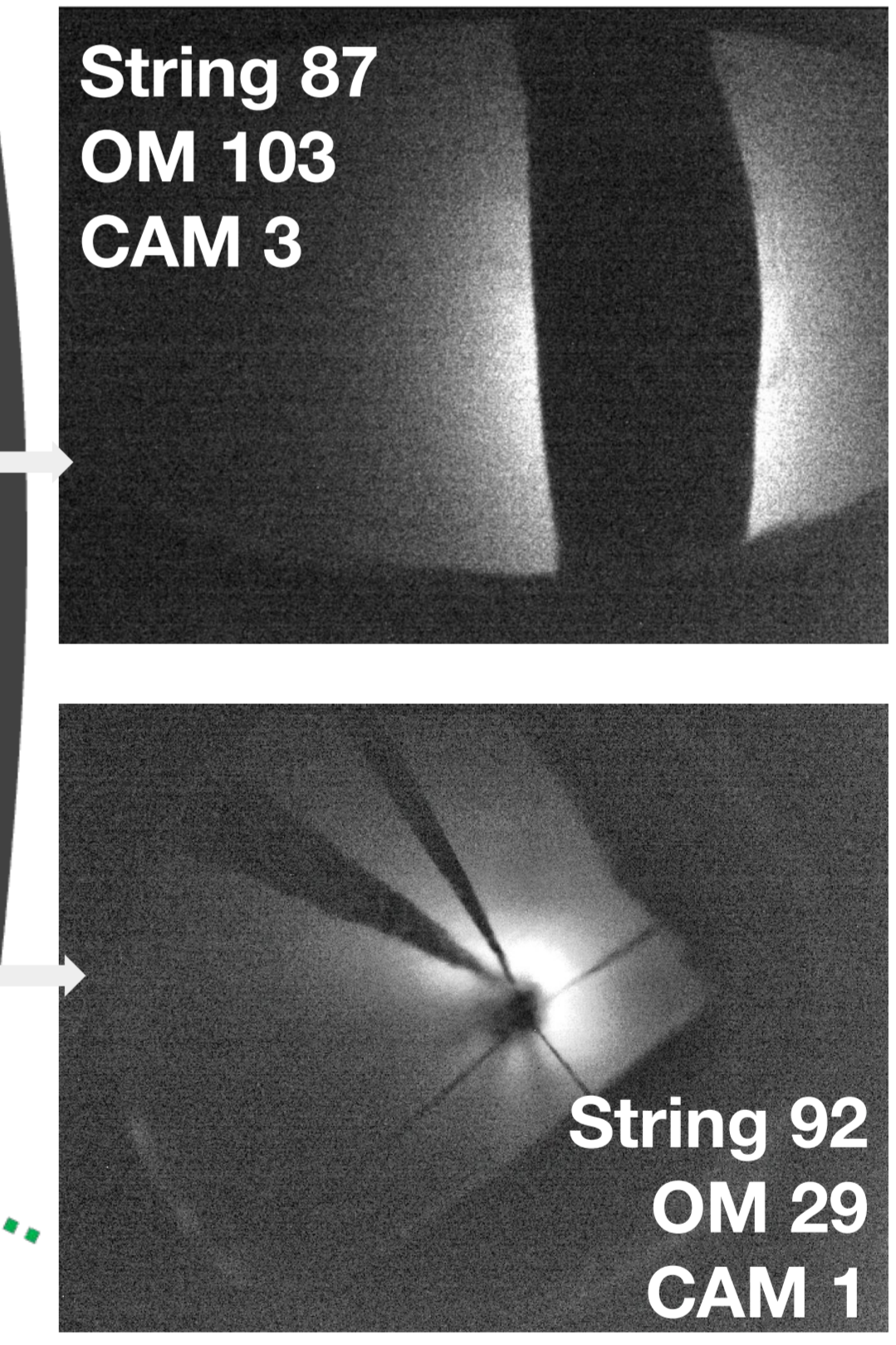
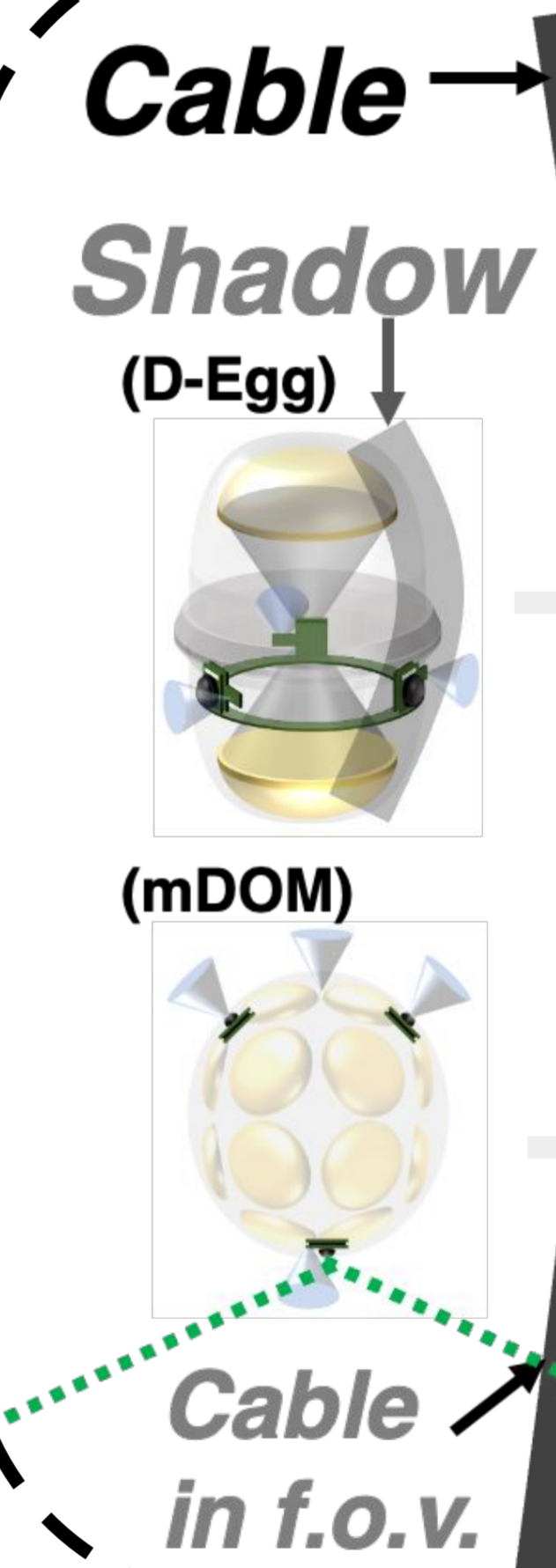
- We use an **LED emitter module on one string**, and a **camera on a different string**
- Measures **optical properties** of the interstitial 'bulk' ice.
- Knowing which strings were emitters, we can also **measure module orientations** in azimuth (camera parameter-induced angular **uncertainty ~6 degrees**)
- **Triangulation** using the measured bearings allows for an **independent evaluation of module positions** after freeze-in



## Top View

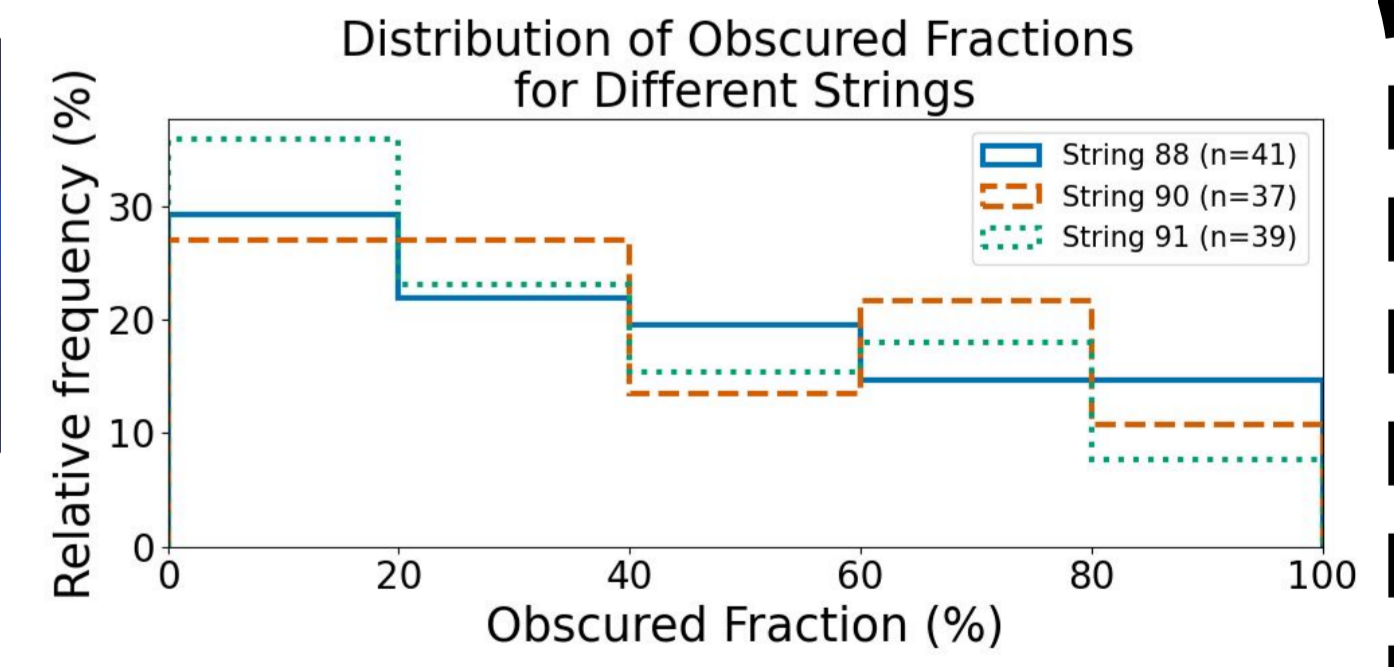
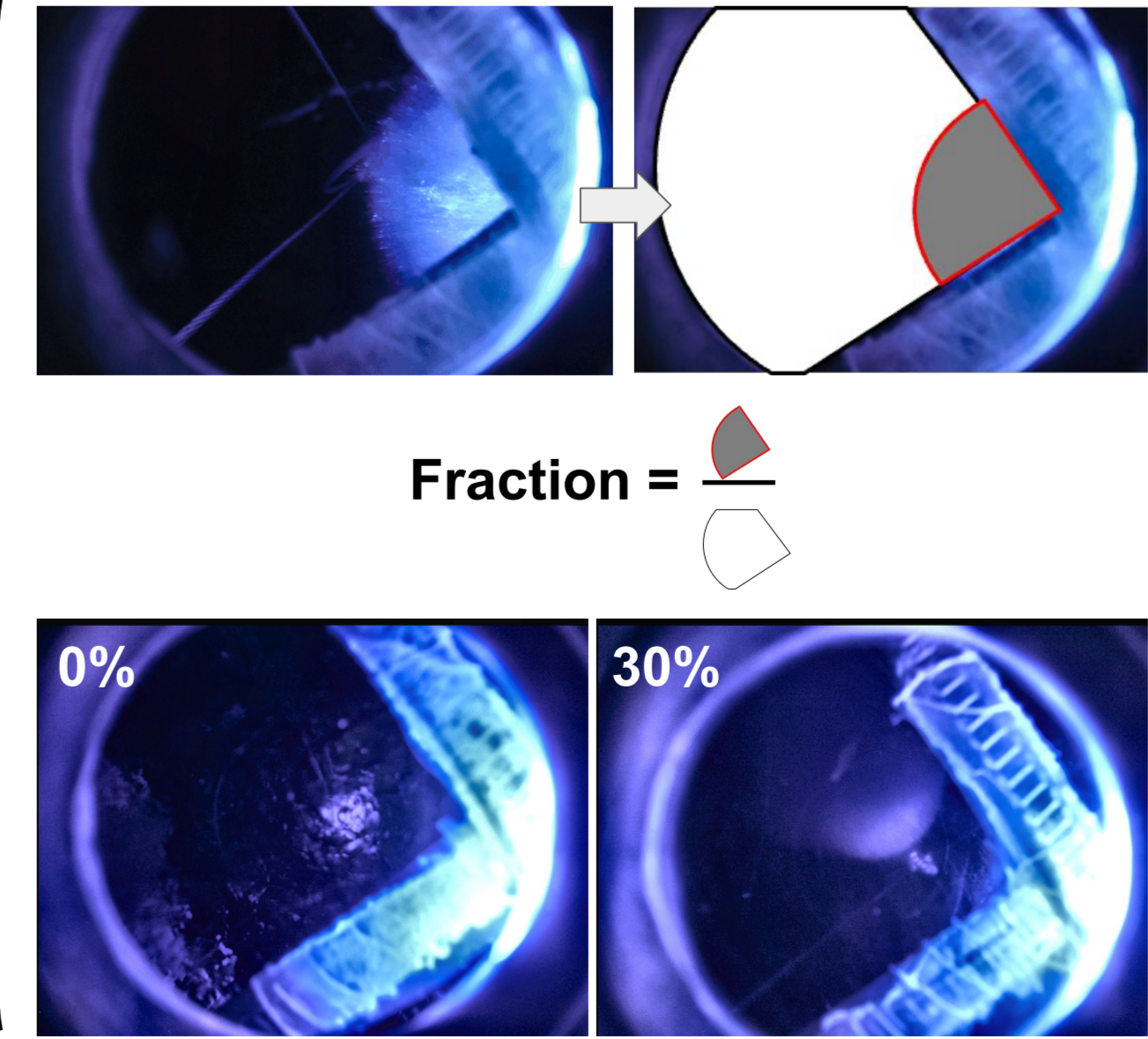


## Main Cable Imaging



- Cable can **partially obstruct** incoming light from **certain direction**
- Image can identify **cable's position relative to module**, to aid in simulating expected photon yields

## Obscured Fraction



- After freeze-in downward facing **mDOM cameras** were used to determine obscuration in the image
- Preliminary results are based subjective by observer judgement
- **Conclusions: Fraction varies widely along the string**