Brand-new optical modules for the KM3NeT neutrino detector

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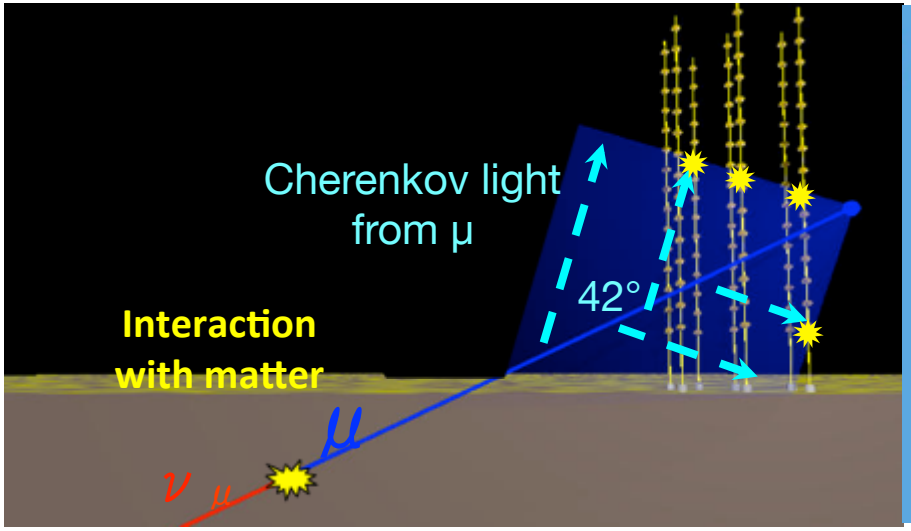
The KM3NeT project

The KM3NeT Collaboration started building in two marine sites of the Mediterranean Sea a new generation cubic kilometer sized neutrino telescope



KM3NeT-Fr Toulon

KM3NeT-It Capo Passero

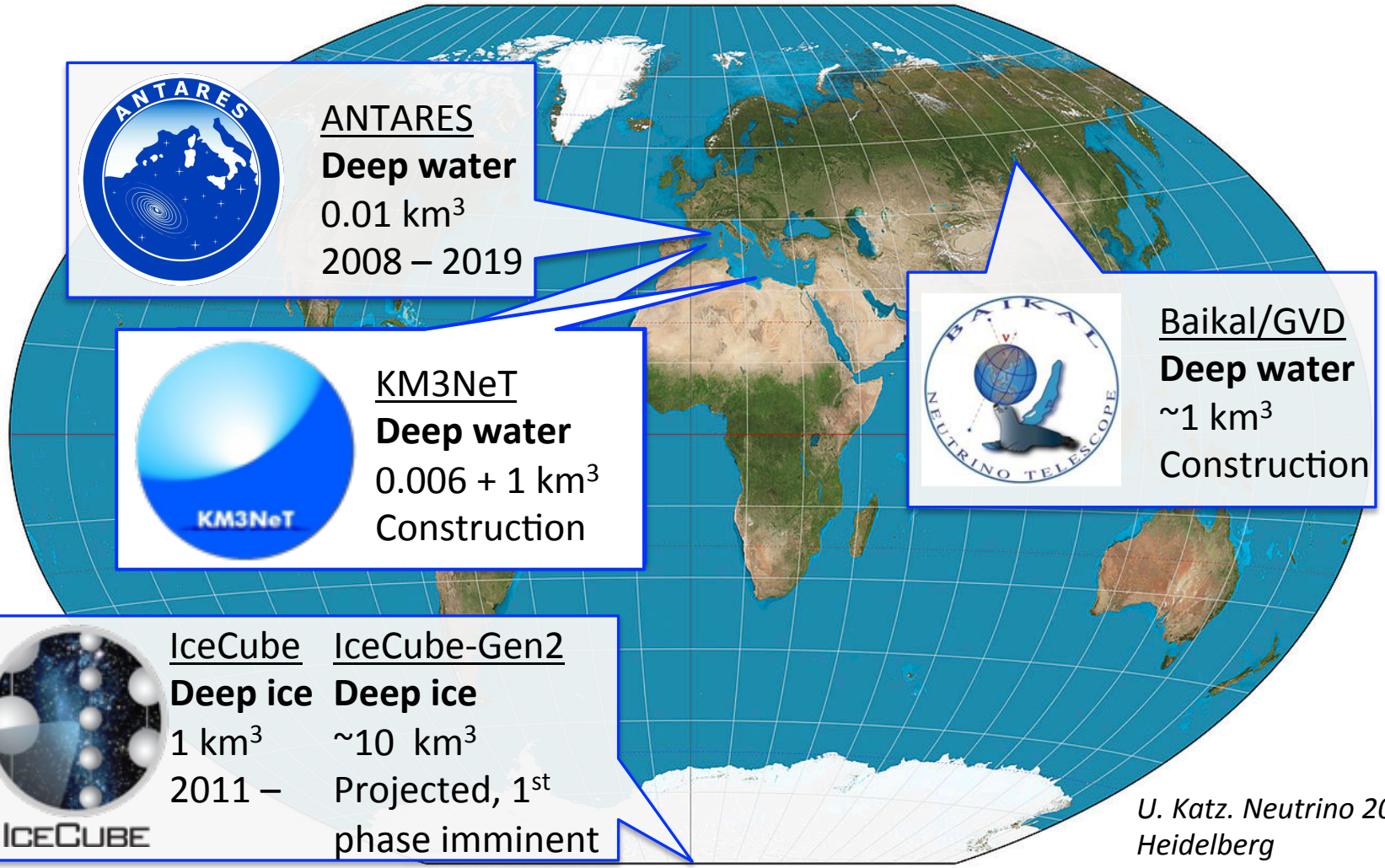
It's composed by a 3D array of photosensors sensitive to the Cherenkov radiation emitted by products of neutrino.

Each photodetector system is called Optical Module

The arrival time of the Cherenkov light on optical modules, together with the knowledge of their spatial positions, are used to reconstruct the trajectory of the particles.

The amount of detected light provides information about the energy of the particle

The neutrino telescope world map 2018



ANTARES
Deep water
0.01 km^3
2008 – 2019

KM3NeT
Deep water
0.006 + 1 km^3
Construction

Baikal/GVD
Deep water
~1 km^3
Construction

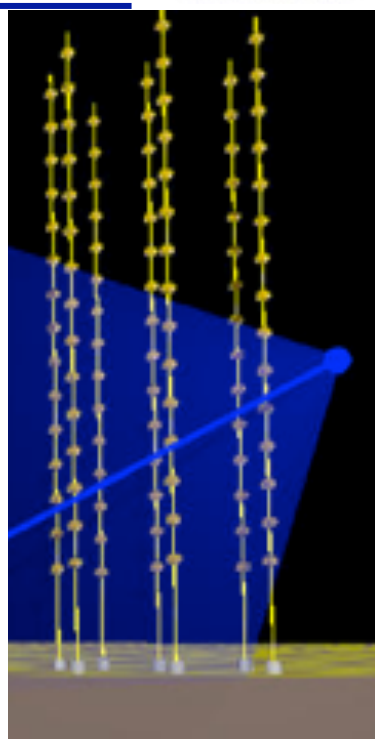
IceCube
Deep ice
1 km^3
2011 –

IceCube-Gen2
Deep ice
~10 km^3
Projected, 1st phase imminent

U. Katz. Neutrino 2018, Heidelberg

The Global Neutrino Network (GNN) aims for a closer collaboration and a coherent strategy among the neutrino telescope projects.

General requirements for the optical modules



Optical modules are the key sensitive part of a neutrino detector

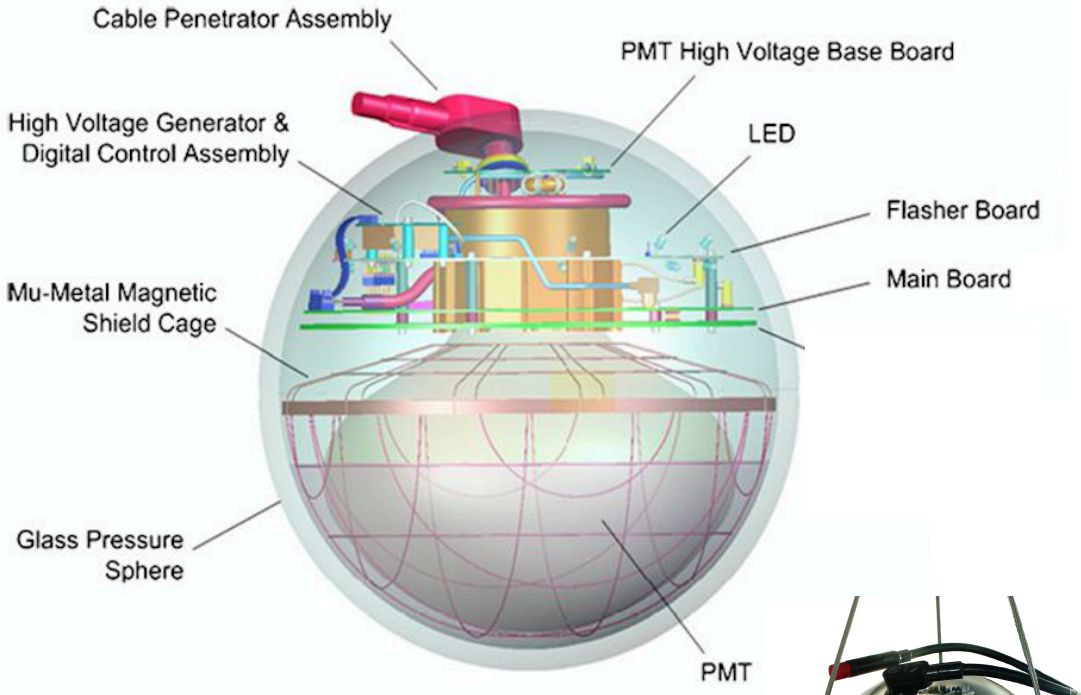
- **Light collection and detection must be optimized.**
- **An overall large photo-detection area must be used.**
- **The optical coupling between the water and photosensors must be the best possible**
- **The influence of the Earth's magnetic field must be minimized.**
- **Due to the pressure at high depths, photosensors and associated electronics must be housed in pressure-resistant transparent vessels**
- **The vessel must withstand to environmental and handling conditions such as hydrostatical pressure, corrosion, shocks and vibration, while ensuring light transmission**
- **The optical module life-time should be greater than 10 years, without maintenance, then reliability of all components must be high.**

Different components in different design compose the optical modules of different projects !

The ICECUBE optical module

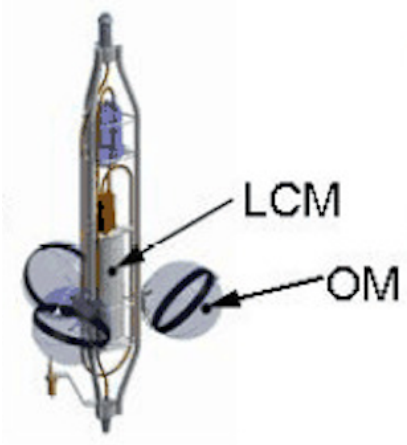
The principle combines a large area phototube with support electronics for PMT power and digitization of the PMT anode pulses inside a sphere glass vessel

- **Hamamatsu R7081-02 10-inch 10-stages PMT (QE≈25% at peak)**
- **13-inch transparent glass sphere**
- **RTV optical gel**
- **a mu-metal (high permittivity alloy) cage surrounds the PMT as magnetic shielding**
- **LED flasher for calibration**
- **high voltage controllable generator board**
- **Passive HV PMT divider circuit**
- **digital data acquisition system**
- **external connection by a penetrator**

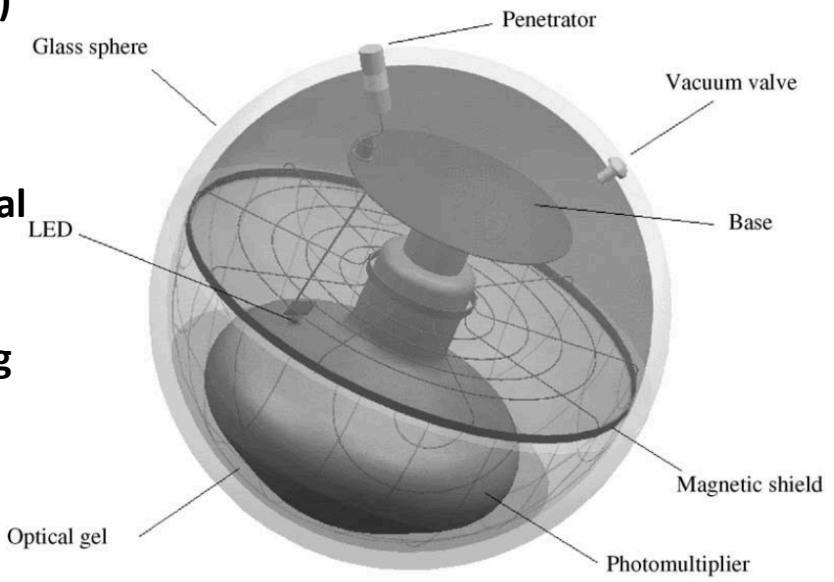


The ANTARES optical module

Its main component is a large area hemispherical photomultiplier glued in a pressure resistant glass sphere with optical gel.



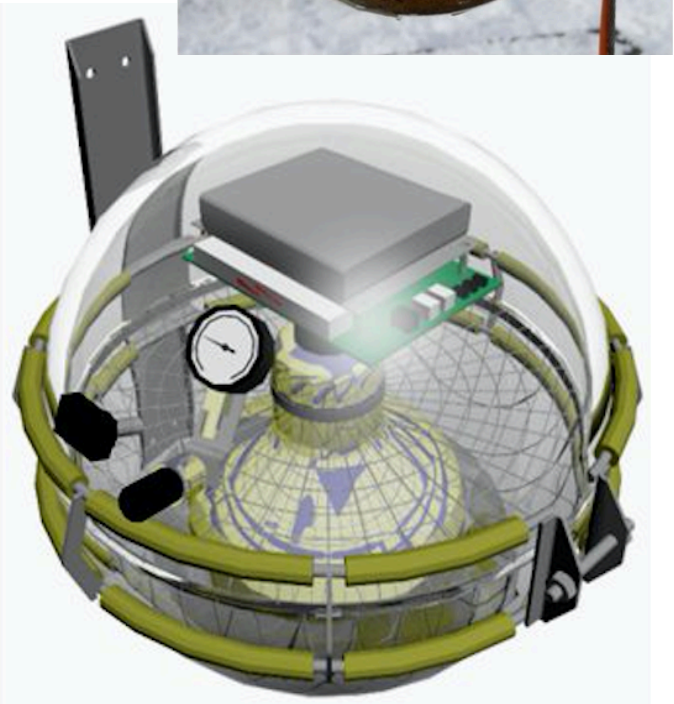
- **14-stages 10-inch Hamamatsu PMT R7081-20 (QE≈25% at peak)**
- **The optical glue is a silicone rubber gel (SilGel 612 A/B) from Wacker**
- **A mu-metal cage is used to shield the PMT against the Earth's magnetic field**
- **A 17-inch Nautilus glass sphere contains PMT and electronics**
- **PMT high voltage power supply (active base by ISEG)**
- **LED system used for internal calibration.**
- **Each optical module is controlled by an external Local Control Module (LCM)**
- **LCM contains a variety of electronic boards including DAQ and slow control.**
- **External electrical connection by a penetrator**



The BAIKAL-GVD optical module

The OM contains a large area photomultiplier enclosed in a transparent spherical housing together with its electronics

- **PMT Hamamatsu R7081-100 with 10-stages and a 10-inch super bialkali photocathode (QE at peak up to 35%)**
- **Nautilus spherical glass sphere of 17 inch**
- **The optical contact between the phototube and the pressure sphere is provided by optically silicone gel.**
- **A high permittivity alloy cage surrounds the PMT, shielding it against the Earth's magnetic field.**
- **The OM electronics unit is mounted directly on the PMT base, and includes a controller, a high voltage power supply unit, a fast two-channel amplifier, and a LED flasher.**
- **The PMT base is a passive HV divider circuit.**
- **External connections are provided by a deep-underwater connector**



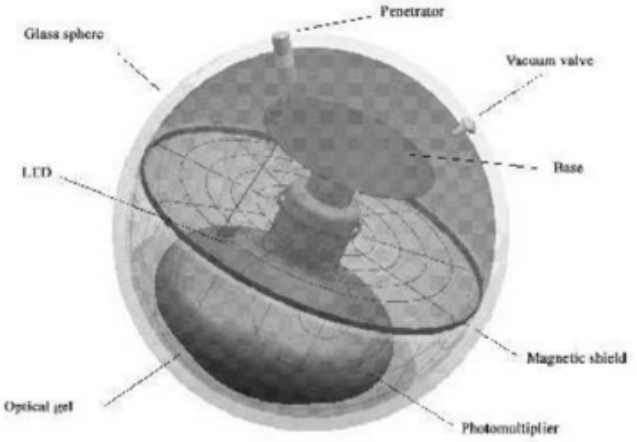
KM3NeT Digital Optical Module (DOM)

Each DOM is composed of a transparent 17-inch diameter pressure resistant glass sphere that hosts inside 31 3-inch photomultipliers and all the front-end and readout electronics.

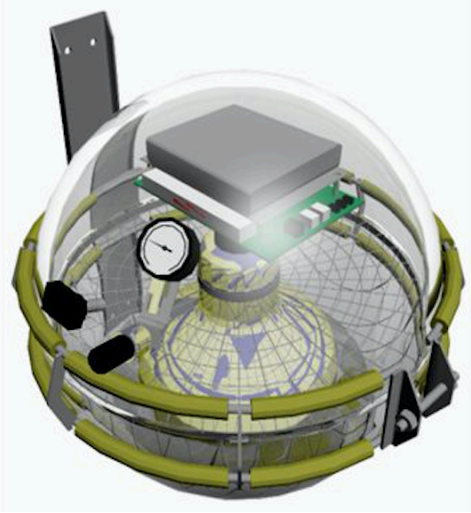
Advantages of a multi-PMT design vs. single large area PMT

- **a photocathode area almost three times of a single 10” PMT**
- **an almost isotropic field of view**
- **the influence of the Earth’s magnetic field on small size PMTs is negligible and magnetic shield is not required.**
- **accurate photon counting of the detected radiation**
- **directional information about the detected radiation**
- **atmospheric muon detection on single DOM**
- **more efficient rejection of the optical background caused by K^{40} and bioluminescence in water**

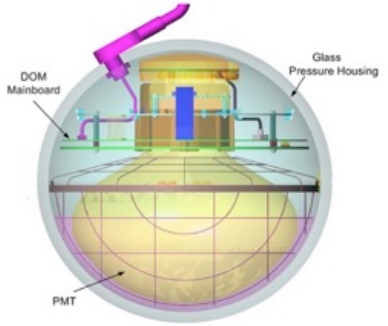
KM3NeT 17”DOM with 31 3” PMTs



ANTARES 17” OM with 10” PMT



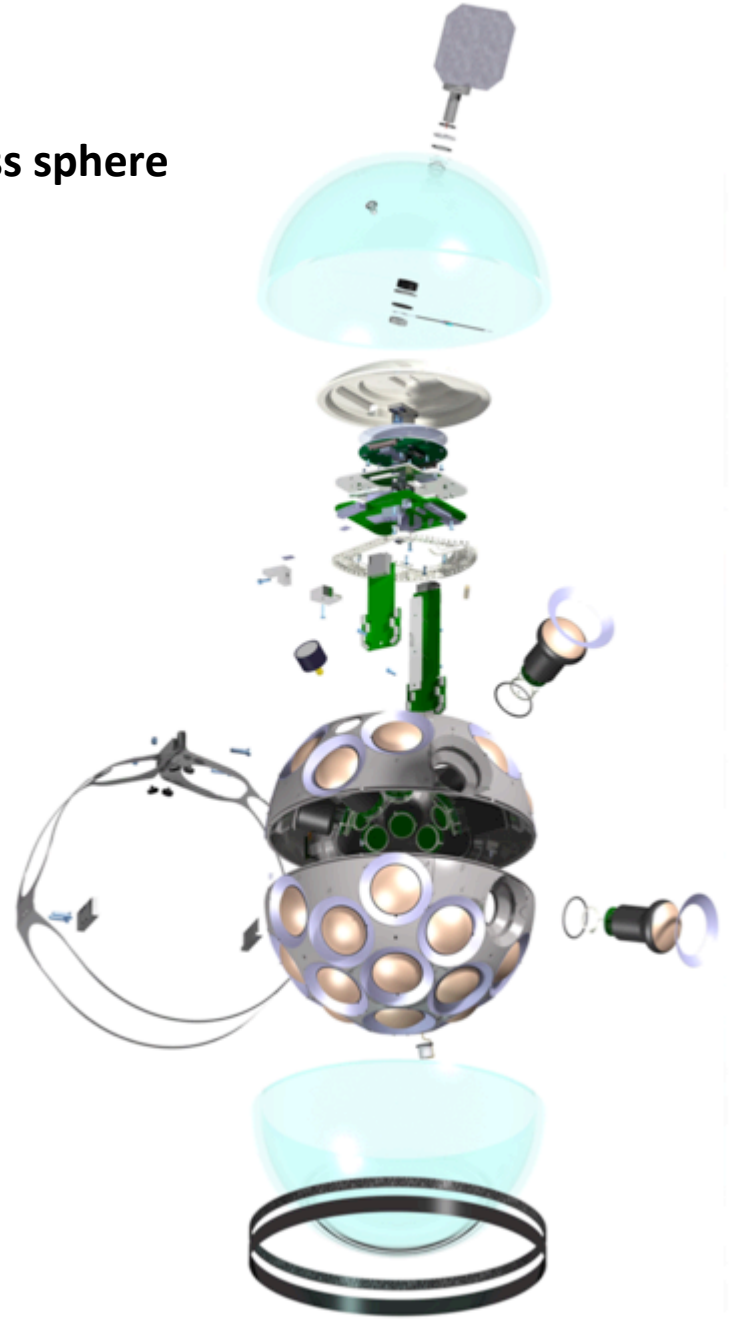
BAIKAL 17” OM with 10” PMT



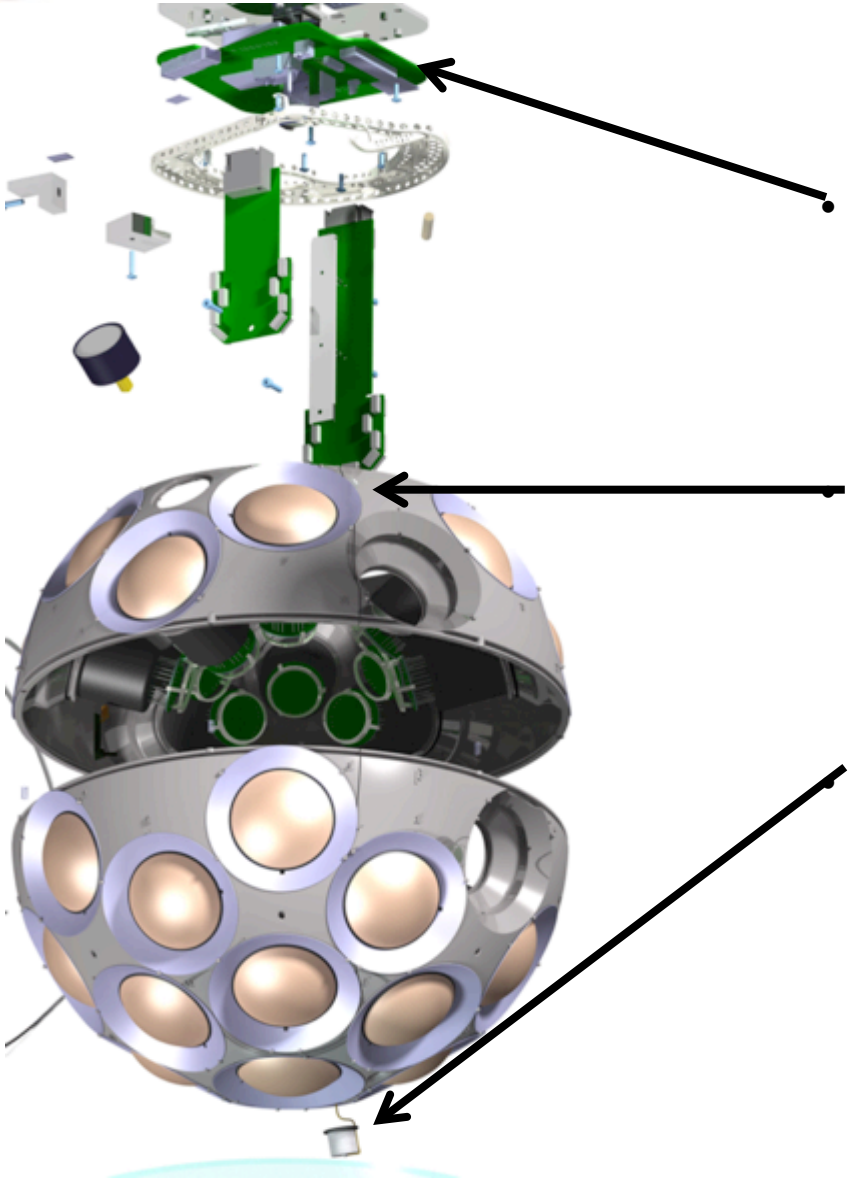
ICECUBE 13” OM with 10” PMT

KM3NeT DOM main components

- A transparent 17-inch Nautilus pressure resistant glass sphere of two separate hemispheres.
- 31 PMTs. 19 in the lower hemisphere. 12 in the upper hemisphere.
- In the first phase of KM3NeT, the PMT are Hamamatsu R12199-02 with 3-inch convex bialkali photocathode and 10-stage
- The PMTs are kept in place by a 3D-printed support structure
- The photon collection is increased by 20–40% by a reflector ring surrounding the face of the PMTs.
- The space between support structure, PMTs and glass sphere is filled with an optical glue (SilGel 612 A&B from Wacker)



KM3NeT DOM ancillary custom sensors



a custom system provides compass, tilt- and accelerometer data, to reconstruct the orientation of a DOM in the water

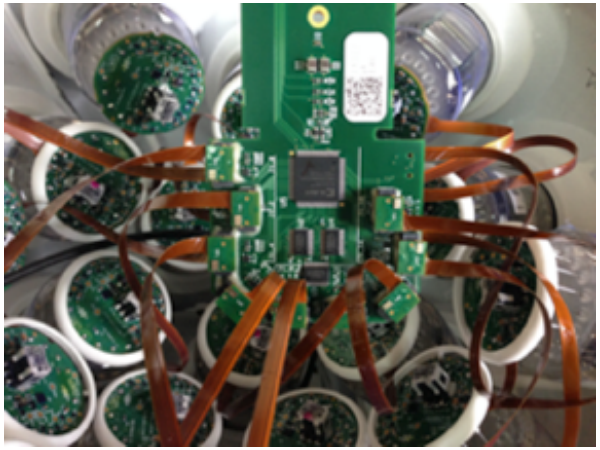
a custom LED nano-beacon injects calibrated light in water to illuminate the neighbouring optical modules for time calibration

a custom acoustic piezo sensor allows for DOM acoustic positioning in water

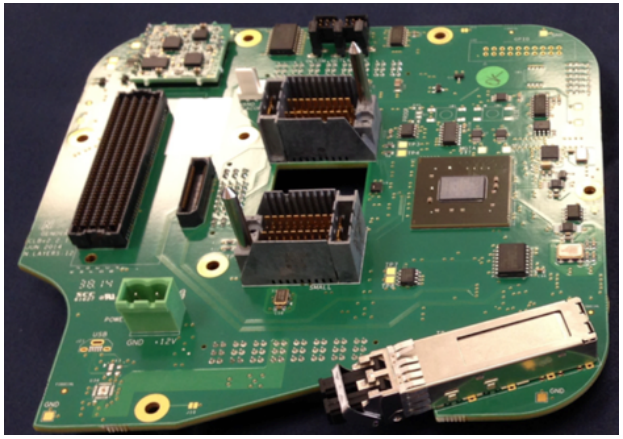
Inside the DOM: electronics and power

In Digital Optical Module each PMT works as an individual optical sensor

- Individual low-power custom made active base with integrated amplification and discrimination
- All the data provided by each PMT base are collected and sent to processor by means of two so-called Octopus Boards.
- A power board provides the DC voltage supply for all the systems inside the DOM
- The CLB is the main board for signal processing, communication and control.
- FPGA (Xilinx Kintex 7) processor implements TDC channels for PMT signals and acoustic sensor
- The CLB transfers the data to shore via a Gb-Ethernet network of optical fibers
- A White Rabbit protocol implements the broadcast of the clock signal and the synchronization of all the PMTs and all the DOMs with 1 ns resolution



PMT bases to "octopus" board



Control Logic Board

Digital Optical Modules mass production

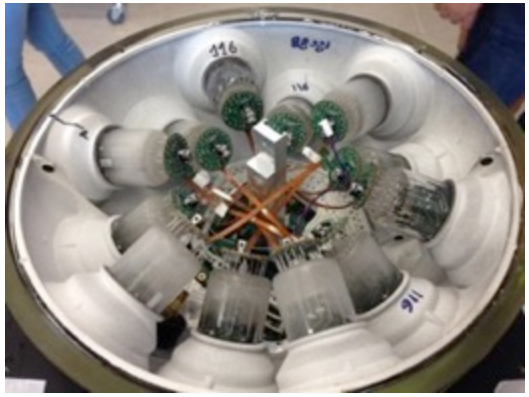
Over 80 elements compose a single DOM: mechanics, electronics, optics and sensors

Long R&D phase to define the DOM assembly procedures and tools

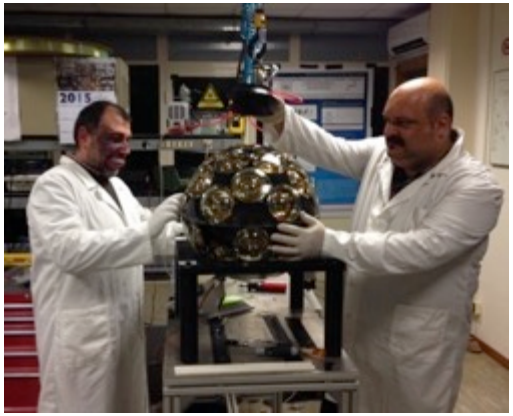
Picture of Catania integration site

Gluing of the cooling system

Cabling of electronic and optical parts



PMT mounted on the 3D structure



Closure and sealing of DOM halves

Picture of a produced DOM

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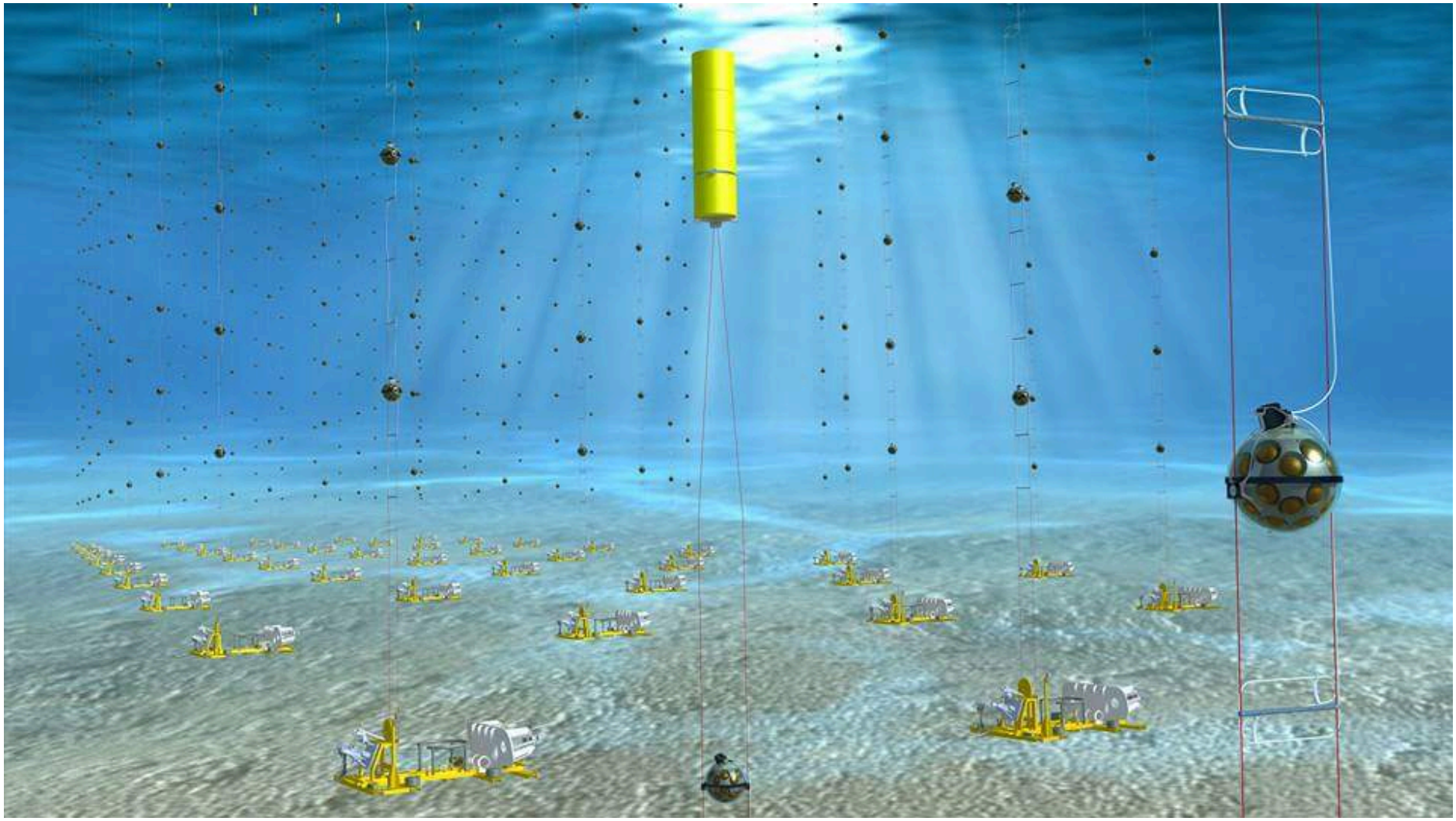
Conclusions

- **An innovative optical module with a multi-PMT layout was designed for the KM3NeT neutrino telescope.**
- **The novel design offers several advantages with respect the single-PMT design of the other neutrino detector projects**
- **The design has been demonstrated *in-situ* by several prototypes**
- **Mass production of the KM3NeT DOMs is currently on-going in 8 different integration sites**
- **Installation of operative Detection Units at the two KM3NeT sites in the Mediterranean Sea has already started**

A KM3NeT postcard



Thanks for your attention

Backup slides

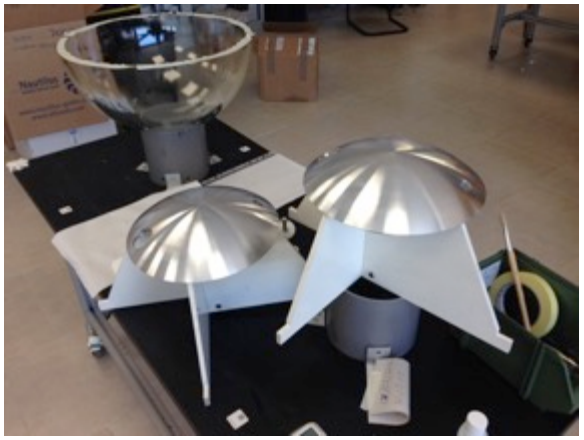
Status of the KM3NeT project

- Mass production of the KM3NeT DOMs is on-going in different integration sites.
- Installation of operative Detection Units at the two KM3NeT sites in the Mediterranean Sea has already started.

- ARCA DU1 at sea and taked data in Italian Sea-site from December 2015.
- ARCA DU2 at sea and taked data in Italian Sea-site from May 2016.
- ARCA DU3 at sea in Italian Sea-site from May 2016. Recovered on July 2016.
- ARCA detector in Italian Sea-site is temporary power off from April 2017
- Improvements in seabed network ongoing. DU deployment will resume by mid 2019

- ORCA DU1 at sea and taked data in France Sea-site from September 2017.
- ORCA detector in France Sea-site is temporary power off from December 2017.
- Cable problem, replacement in summer 2018

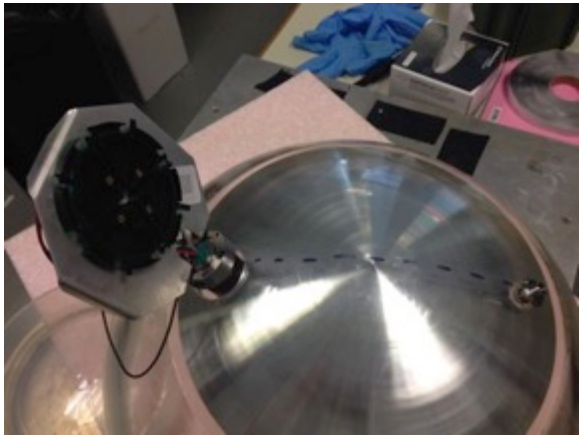
Pictures from DOM Integration site in Catania



Preparation of components

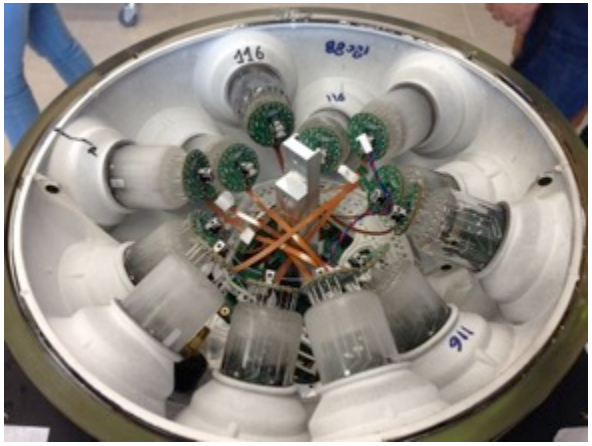
Gluing of the aluminium heat dissipator

Mounting of the electronics and optical fibre



Mounting of the external penetrator

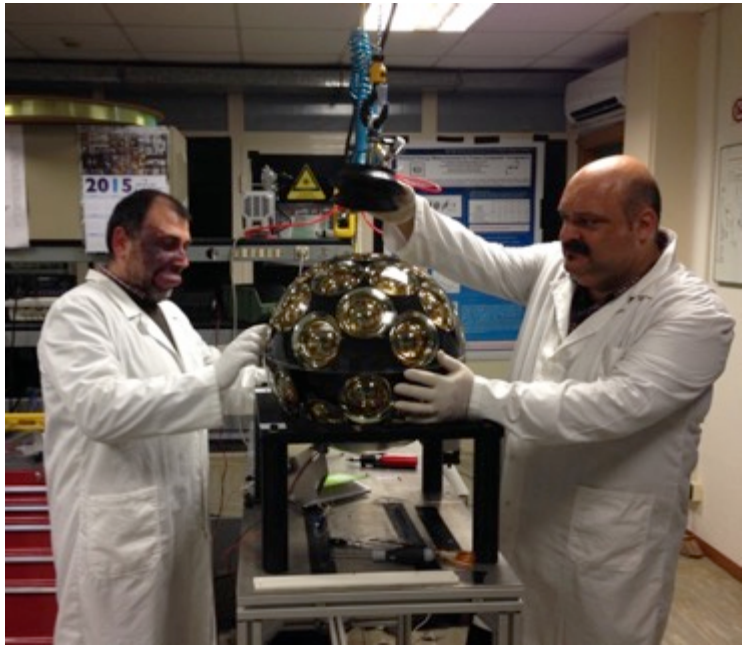
PMTs insertion in structure



Lower part of the DOM

Pictures from DOM Integration site in Catania

Optical gel pouring



DOM closure with an internal 0.2 Bar underpressure

Photodetectors of the optical modules

Large or small area photomultipliers are the photodectors chosen

ICECUBE: Hamamatsu R7081-02 10-inch convex bialkali photocathode (QE≈25% at peak) - 10-stages

ANTARES: Hamamatsu R7081-20 10-inch convex bialkali photocathode (QE≈25% at peak) - 14-stages

BAIKAL: Hamamatsu R7081-100 10-inch convex super bialkali photocathode (QE≈35% at peak) – 10 stages

KM3NeT: Hamamatsu R12199-02 3-inch convex bialkali photocathode (QE≈25% at peak) - 10-stage

PMT performances:

- A large total detection area (over 500 cm^2)
- low cost at large size (> tens of cm^2)
- High gain (over $1x10^7$)
- Single photon detection
- High time resolution (TTS lower than 5ns FWHM)
  - accurate particle-track reconstruction
  - efficient background rejection
- Low Dark Count Rate at spe (100 count/mm^2sec)
- High spectral response in the 350-650 nm range

R7081 10-inch by Hamamatsu

R12199-02
PMT 3-inch
by Hamamatsu

The KM3NeT scientific objectives and sites

The KM3NeT Collaboration started building a research infrastructure in the depths of the Mediterranean Sea hosting a new generation cubic kilometer sized neutrino telescope

Two main scientific goals:

- **Fundamental physics with atmospheric neutrinos: mass hierarchy, oscillations**
- **Astronomy by observing high energy neutrino sources from the Universe**

Two main research lines:

- **ORCA: Oscillation Research with Cosmics in the Abyss** targets atmospheric neutrinos oscillations in few-GeV range

- **ARCA: Astroparticle Research with Cosmics in the Abyss** targets astrophysical neutrinos above TeV energies

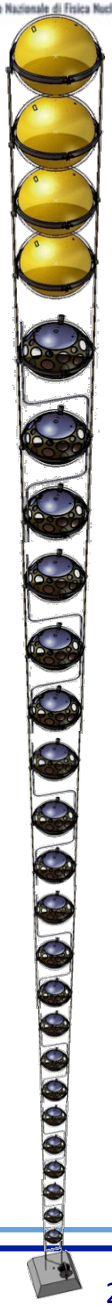
KM3NeT Letter of Intent, J. Phys. G 43 (2016)

Two main marine sites:

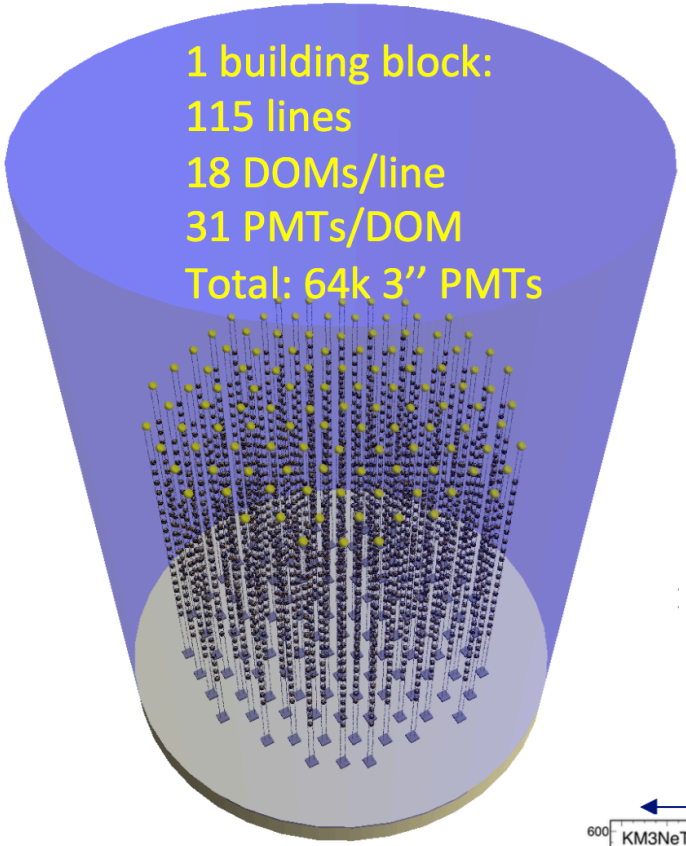
- **KM3NeT-Fr site; 2475 m depth ; Toulon, France**
- **KM3NeT-It site; 3400 m depth; Capo Passero, Italy**

The KM3NeT detection unit

- In the sea, the Digital Optical module are suspended in vertical structures, called Detection Units (DUs).
- The Detection Unit (DU) each hosts 18 DOMs.
- Each DU comprises two thin parallel Dyneema® ropes to which the DOMs are attached by the external titanium collar.
- Each DU is anchored to the seabed and kept taut by a system of submerged buoy at the top that reduces the horizontal displacement
- Attached to the ropes is the electro-optical cable (VEOC), that contains 2 wires for power transmission and 18 optical fibres for data transmission.
- in ARCA (E > TeV) each DU is about 700 m in height, with DOMs 36-m vertically spaced. The DU horizontal spacing is about 95 m.
- In ORCA (E ≈ few GeV) each string is 200 m in height with DOMs vertically spaced 9 m. The DU horizontal spacing is about 20 m.



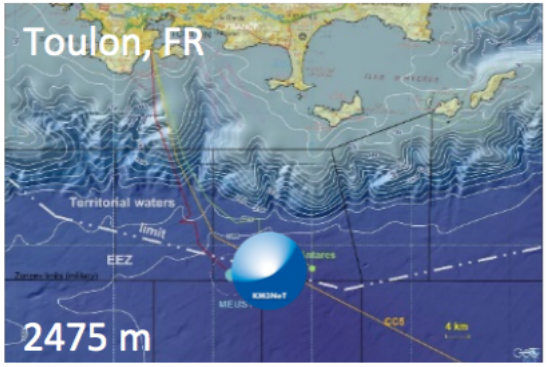
The KM3NeT layout



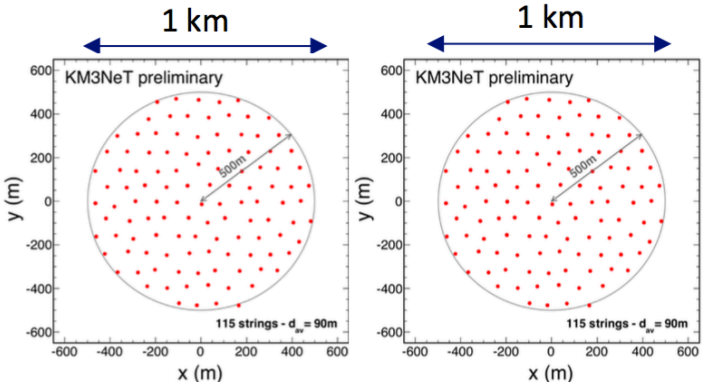
ARCA:Astroparticle Research with Cosmics in the Abyss

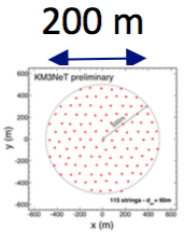
2 building blocks (1 Gton)
Inter DOM spacing: 36m
Inter DU spacing: 90m

ORCA: Oscillation Research with Cosmics in the Abyss



1 building block (8Mton)
Inter DOM spacing: 9m
Inter DU spacing:23m





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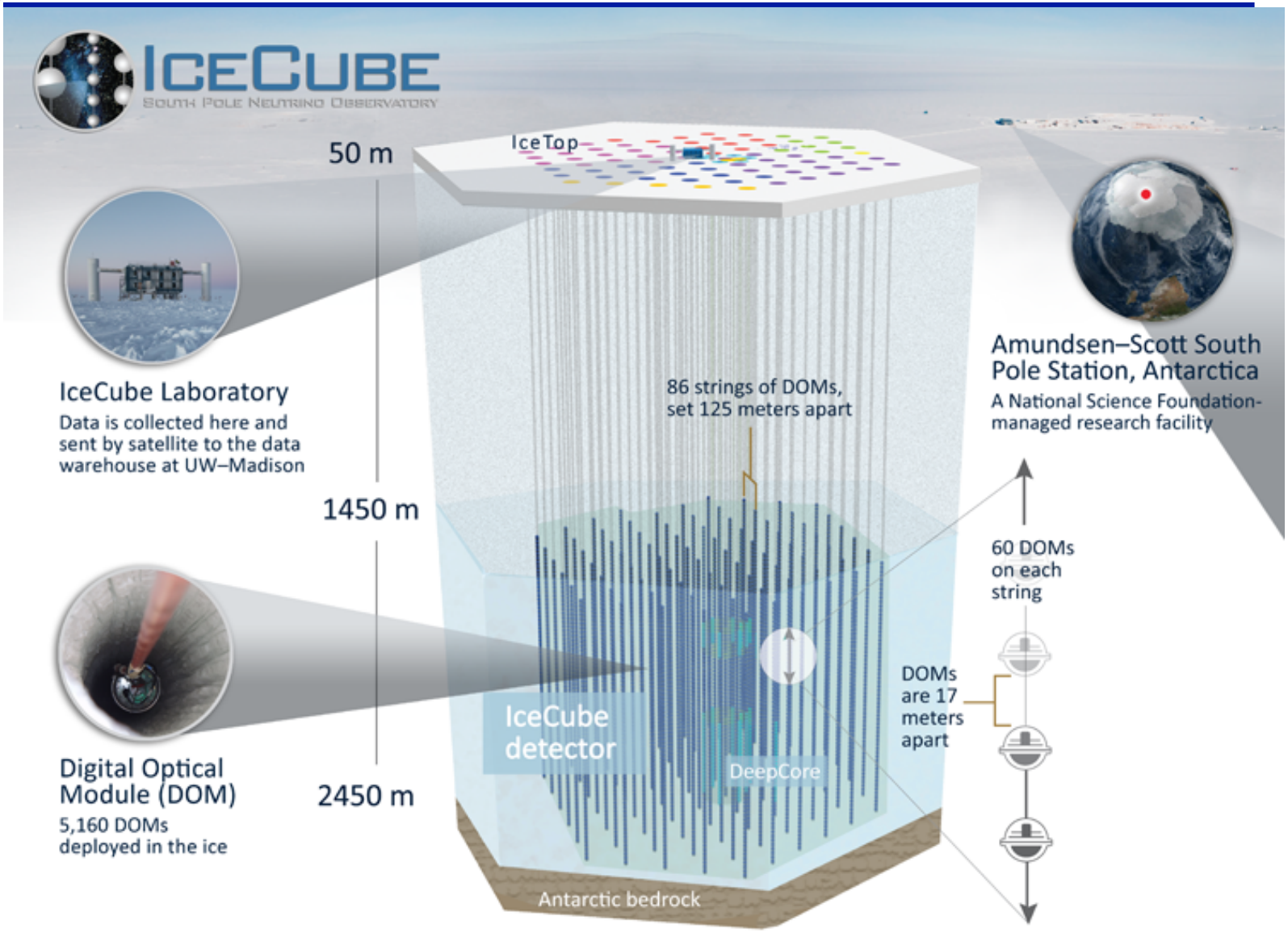
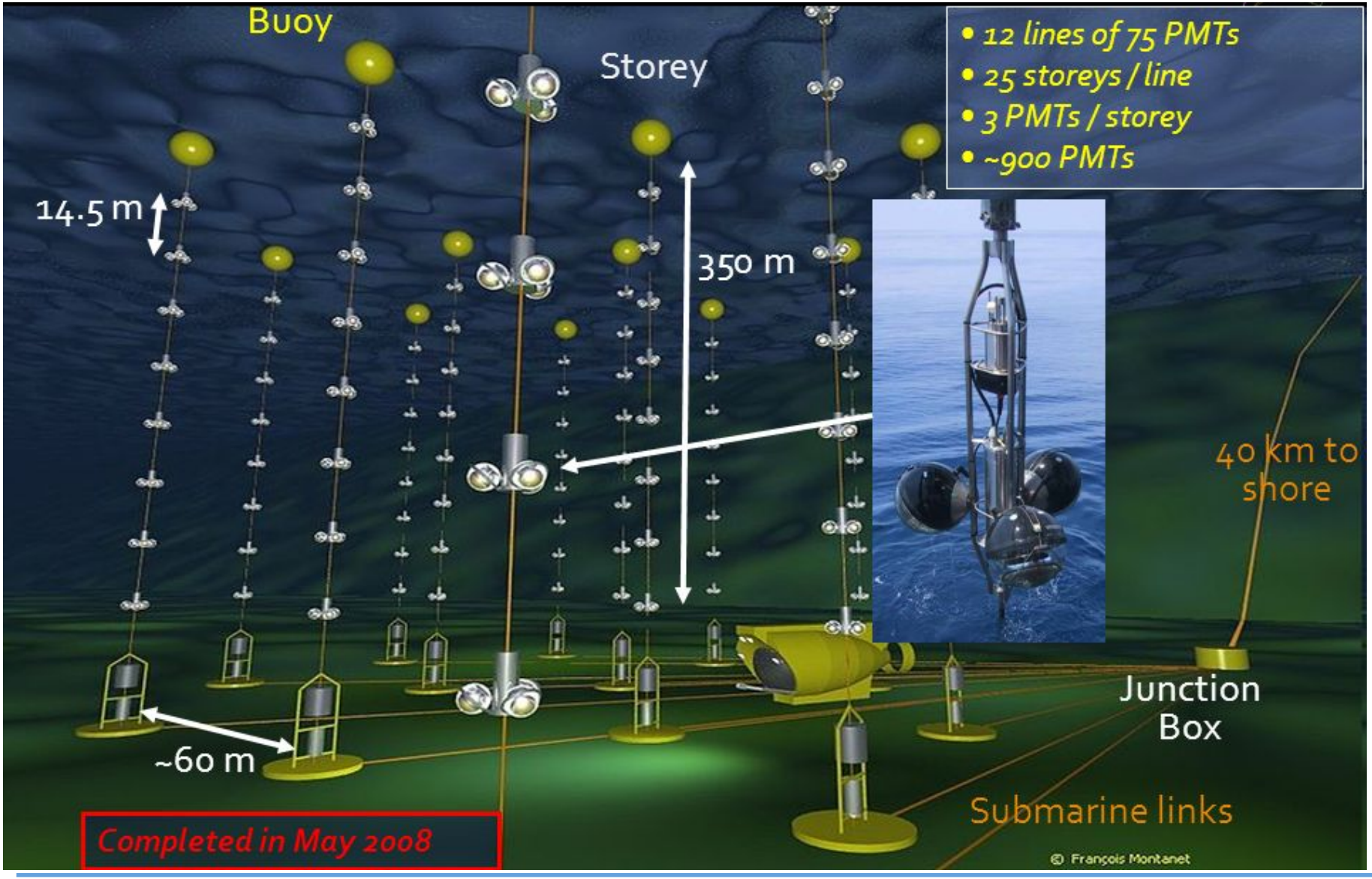
The ICECUBE layout



The ANTARES layout



The Baikal layout