



## A launching vehicle for optical modules of a deep-sea neutrino telescope



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### For the KM3NeT Consortium

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#### ABSTRACT

KM3NeT is a future deep-sea research facility that will be built at depths between 3 and 5 km in the Mediterranean Sea. The facility will host a neutrino telescope consisting of several hundreds of detection units—vertical mechanical structures that suspend the optical sensor modules of the telescope. During the design phase of the KM3NeT telescope, two concepts for the mechanical design for the detection unit have been worked out, one of which is a mooring consisting of two parallel ropes with 20 optical sensor modules attached at regular intervals; a data cable runs along the full length of the structure. For this design, which usually is referred to as a string, a novel deployment method using a recyclable launching vehicle has been successfully tested during two cruises in the Ionian Sea. We will present the design and the results of the deployment tests.

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### 1. Introduction

KM3NeT is a future research facility which will house a neutrino telescope [1,2]. It will be built at the bottom of the Mediterranean Sea at depths between 3 and 5 km. The KM3NeT detector will contain in the order of 10,000 optical sensor modules to detect the faint Cherenkov light from neutrino induced muons traveling through the detection volume of several cubic kilometers sea water. An optical module consists of a high pressure resistant glass sphere containing 31 photomultiplier tubes, instruments for position and timing calibration and all readout and control electronics boards [3,4]. During the KM3NeT design study,<sup>1</sup> a mooring has been designed as a detection unit which allows for the distribution of the optical modules as evenly as possible over the detector volume while minimizing the amount of material in the deep-sea. Several hundreds of these detection units would have to be anchored to the seabed within the few years of construction of the KM3NeT detector. For this, during the KM3NeT preparatory phase study,<sup>2</sup> a recyclable

launching vehicle has been designed and successfully tested during two cruises in the Ionian Sea. We will describe the design of this launcher for optical modules (LOM) and its validation with three deployments of a mechanical model of a string type detection unit.

### 2. The launcher for optical modules

The requirements for the design of the LOM were to deploy a string type detection unit—a 700 m long mooring with two parallel ropes suspending 20 optical modules with a diameter of 17 in. at intervals of 30 m (Fig. 1). A data cable with a diameter of 6 mm runs the full length of the mooring [5]. The cable switches suspension rope support after every optical module. The distance between the seabed and the lowest module is about 100 m. Since the foreseen horizontal distance between these moorings in the KM3NeT detector is 100 m, the deviation of the top of the mooring is required to be less than 100 m at a horizontal sea current of 0.30 m/s. To comply with these requirements, 12 strands braided Dyneema<sup>®</sup> ropes with a diameter of 4 mm were chosen. The ropes are neutrally buoyant, sea water resistant and have according to the provider a maximum breaking load (MBL) of 1200 kg. This figure has been confirmed by stress tests in the laboratory. The ropes were pre-stretched and provided with 1 m marks. With a top buoy system of five empty glass spheres, the

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**Fig. 1.** Drawing of the string type detection unit optical module designed for use in the KM3NeT detector volume during the KM3NeT design study [2].



**Fig. 3.** Left: Springs keeping the optical module in position (bottom) and the rope tight (top). Right: Spreader structure on top of the LOM.



**Fig. 4.** Empty launching vehicle floating at the sea surface.



**Fig. 2.** The loaded launcher for optical modules (LOM) in the rotator. See text.

total net buoyancy of the mooring is about 3900 N. The deviation of the top of the mooring in case of a horizontal sea current of 0.30 m/s is calculated at 87 m [2].

Before deployment, the mooring is wound in the laboratory onto a custom designed spherical aluminium launching vehicle—the LOM (Fig. 2). For storage of the ropes and the data cable, the LOM has three sets of parallel cable trays running round its circumference from pole to pole. The sets are offset by  $60^\circ$ . Three tubes, which run through the LOM frame at the equator perpendicular to the cable tray sets, allow for the use of a rotary spooling traction when loading the launcher. About 12 empty glass spheres with a total buoyancy of 3120 N are part of the LOM to allow for its surfacing after unrolling the mooring. During loading the LOM with the mooring, first the five glass spheres of the top buoy system (buoyancy 1300 N) are placed at guiding rails through the hole at the North Pole. The optical modules are stored one by one on rings in the cavities between the cable tray sets while rotating the launcher and the ropes and the data cable are laid in the trays.

The optical modules are kept in place by a spring, while a small spring keeps the rope tight (Fig. 3, left). Once the first upper most eight optical modules are placed, the launcher is rotated around the North–South axis by  $60^\circ$  for placement of the next six

modules. The winding axis is changed accordingly. This cable tray is then filled followed by the third one. Finally, the remaining 100 m of ropes are wound onto the launcher. The total weight in air of the loaded launcher is about 1170 kg. Its diameter is 2.18 m. The launcher also serves as a compact transport vehicle for the detection unit. Multiple loaded LOMs can be transported in a single standard transport container. The LOM requires modest deck space and a modest crane for deployment. After deployment of the mooring, the launching vehicle floats to the sea surface for recovery (Fig. 4).

On board of the deployment vessel, the ropes are connected to a steel anchor with a weight in air of 960 kg. Steel cables running through the three North–South tubes in the launcher connect the anchor with a spreader structure at the top (Fig. 3, right) which contains an acoustic release to start unrolling of the mooring after its anchoring at the seabed. These cables take all the weight forces during deployment. The spreader structure contains five empty glass spheres to allow for its separate surfacing. The total weight of the package (Fig. 5) in air is 2265 kg.

### 3. Validation tests

The concept of a compact deployment followed by unrolling to the full length of the mooring using a launching vehicle has been validated using a mechanical model of the mooring. During two KM3NeT sea campaigns [6,7] the mooring has been deployed at depths between 800 and 950 m in the Ionian Sea near the coast of Pylos, Greece ( $37^\circ 05.719'N$   $021^\circ 25.506'E$ ). The LOM was lowered at a winch speed of about 0.5 m/s. During the first test deployment (with LOM1) the sea current at a height of about 580 m above the seabed was measured up to about 0.15 m/s relatively to

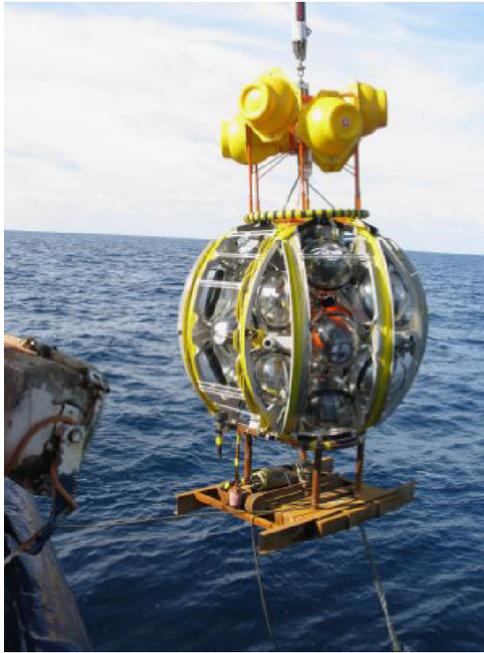


Fig. 5. The full package of the loaded LOM, the anchor and the spreader structure.

the current near the sea bottom. The LOM was loaded in the laboratory and transported to the harbor with the deployment vessel. The anchor and spreader structure were attached on deck of the deployment vessel. During the second sea campaign, after the initial deployment and recovery test, the LOM was loaded again at sea on deck of the deployment vessel for a third test deployment. During the first deployment test, it became apparent that the first design of the spreader structure could obstruct the start of unrolling of the mooring line. For the subsequent deployment tests this structure was successfully replaced by the current design (Fig. 3, right). Also during the first test it appeared that the 'naked' glass spheres of the buoy system could easily be damaged while floating at the sea surface before recovery. In an attempt to minimize such damage, in the subsequent tests the buoy spheres were coated with rubber paint. However, this rubber paint can obstruct the release of the buoy sphere. Since from the KM3NeT detector, moorings will not be recovered, the rubber paint coating will not be applied in the future.

#### 4. Unrolling of the mooring

After the package was deployed at the seabed and the deployment cable was released, the spreader structure was disconnected from the LOM using the acoustic release and the launcher could freely float to the surface while unrolling the mooring, the lowest sensor module first. To monitor the behavior of the mooring, a video camera was installed at the anchor of the mooring and compasses and accelerometers were mounted in each optical module and on the LOM frame. From a study of the data collected with these monitoring devices it has been measured that unrolling the full mooring takes about 9 min. The initial velocity of the launcher is measured about 1.6 m/s decreasing to about 1.1 m/s toward the end of the unrolling. The initial tension on the ropes is 5700 N which decreases to 3900 N after unfurling. In each glass sphere a weight was installed simulating the weight distribution inside a KM3NeT optical module (Fig. 6).

On the weight a 3-axis digital compass (Honeywell HMC5843) was mounted to allow for monitoring the orientation of the glass spheres prior, during and after unfurling. Fig. 6 (right) shows the

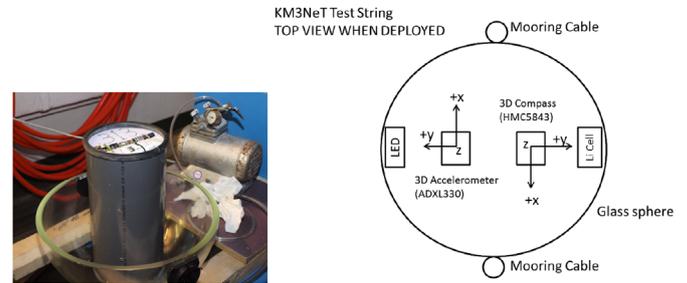


Fig. 6. Left: Weight in a glass sphere inside a KM3NeT optical module with a 3D compass meter and an accelerometer on top. Right: Axis orientations of the compass and accelerometer.

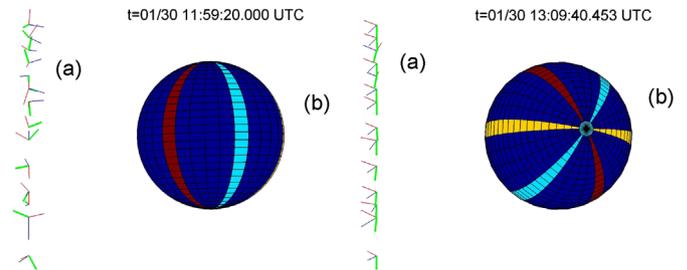
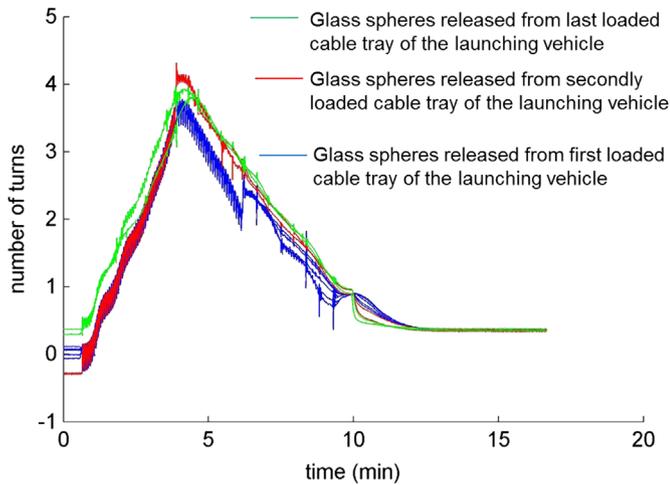


Fig. 7. The orientations of the three axes of the compasses inside the optical modules. Left: before unfurling. Right: after unfurling. See text. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

orientation of the axes of the compasses. Also on the frame of the launching vehicle a compass was mounted close to its equator. The compasses are battery operated stand-alone devices which prior to deployment were programmed to start measurements at the foreseen start of unfurling of the mooring.<sup>3</sup>

In Fig. 7 the results of the compass measurements are shown prior (left) and after (right) unfurling of the mooring during the third deployment test. The measured axis systems of each well functioning compass are shown vertically ((a) in Fig. 7) ordered according to their position on the mooring (green: z-axis). In Fig. 7 (left) the launching vehicle ((b) in Fig. 7) is still at rest on the seabed and the measured compass directions are not aligned, as expected. In Fig. 7 (right) the situation is shown about 70 min later after unfurling of the mooring and the launching vehicle being recovered. All measured compass axis systems are aligned parallel and the z-axes (green) do not deviate from the vertical more than 10°, indicating that the glass spheres are oriented as expected. One vector is off due to a bad (noisy) sensor. The compass measurements were also used to monitor rotations of the mooring around the vertical. The results measured during the third deployment test are shown in Fig. 8 which shows the rotation of individual glass spheres (grouped in the three main axes of the LOM structure) with respect to the direction of the cable tray set that was loaded first. As can be seen in Fig. 8 the directions of the spheres loaded in the first cable tray set (blue lines) are close to an offset of 0°, while the directions of the spheres in the other two cable trays sets are offset by about 60° as expected. While unrolling the lowest 100 m of the mooring and subsequently releasing the six glass spheres from the last loaded cable tray set (green lines), the mooring makes in total four rotations around the vertical. When about 3 min later the unloading of the next cable tray set starts (red lines), the mooring starts

<sup>3</sup> The battery of six out of 20 compasses appeared to be empty or malfunctioning prior to deployment.



**Fig. 8.** Number of rotations around the vertical of the mooring during unfurling. See text. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)

to rotate back. This continues when the third and last loaded cable tray set is unloaded starting about 2.5 min later (blue lines). After about 8.5 min since the start of unrolling the mooring, the LOM detaches from the mooring. About 3 min later the mooring has returned to a stable position with a rotation of about  $60^\circ$  around the vertical with respect to the orientation of the first loaded cable tray set (as expected). It was verified in the laboratory that even in the case of a full twist of the ropes, the data cable escapes the pressure points of the ropes and will not be damaged.

## 5. Summary and outlook

With three deployments of a mechanical model of a string type detection unit, the concept of the launching vehicle for optical modules was validated in compliance with the requirements. The LOM is a recyclable frame for deployment which can also serve as

a compact transport frame for the detection unit. Multiple loaded LOMs can be transported in a single standard transport container. The LOM requires modest deck space and a modest crane for deployment. During unrolling of the detection unit four rotations around the vertical were measured which disappeared a few minutes after the LOM had disconnected from the detection unit. For use of the method for the deployment of a neutrino telescope, two design issues of the mooring need further development: the mechanical interface between the glass spheres and the suspending ropes and the storage of a breakout unit in the data cable above the penetrator through the glass sphere.

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