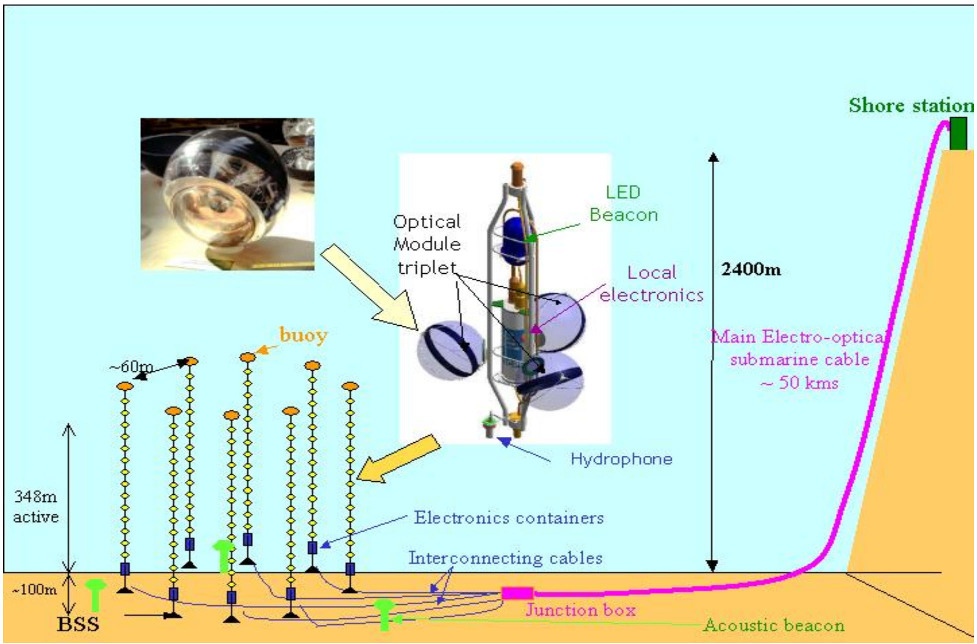
Technical Design Report

of the

ANTARES 0.1 km^2 project



Version 1.0

July 2, 2001

Next Previous

Foreword

The Technical Design Report (TDR) for the ANTARES 0.1 km^2 project is intended to fulfill several purposes:

- As a Technical Design Report, it defines the technical details of the project in order to allow the practical realisation of the components necessary for the experiment. The physics requirements can be found in the ANTARES proposal and CDR, and are not repeated here. The specifications are based on various design choices made in the early stages of the project and the results of the detector performance studies given in the ANTARES proposal and in several theses.
  Only the main aspects of the TDR will be presented in the **paper** version, which is printed from pdf images of the html files. Additional technical details are available from the **WEB** pages, via http://antares.in2p3.fr/internal/tdr. A copy of the html pages, including the 0.1 km^2 technical notes which are the basic references of the detector, can be found in the accompanying **CD**-ROM.
- The TDR is also an internal documentation tool for communication within the collaboration, and it describes the components of the detector. It has proven useful for many purposes:
  - defining the objects of the detector
  - describing the details of interfaces between components,
  - identifying missing objects and functions.
  - following the progress in the implementation of the detector: tests of components, tests of functionalities, assembly protocols, test protocols, databases, logbooks. Some of these items are not yet available, but the WEB TDR is an active tool in the process of assembling them.

The detector components are defined in the Product Breakdown Structure (PBS) page. Individual pages describing components are accessible by clicking through the PBS list or from the main chapters. Every hardware object has a PBS name and number for identification, and its description can be found on the WEB following the PBS list. In the paper version, the individual object pages are included at the end of the chapter which is the most relevant.

This TDR is divided in several chapters, grouped according to the organisational structure of the ANTARES collaboration, with its division of tasks and responsibilities. It is accessed most conveniently on the WEB or CD via the table of contents.

The introduction gives a brief account of the ANTARES project and the general concept of the deployment in the Mediterranean sea of strings equipped with photomultipliers. The detector and its main components are briefly described there.

The Mechanics, Optical Modules, and Readout, Trigger, Data Acquisition chapters, address different aspects of the construction. In each part, we have aimed at providing a general overview of the conceptual design of the functionalities and specifications of each object. After that introduction, the individual component objects are listed and described, interfaces are identified, and links are (or will be) integrated to the test protocols, database, and logbook files. Since the functionalities of the ANTARES Electronics are described in Chapter 4, on Readout, Trigger and

DAQ, they are only summarised in Chapter 5 when necessary to explain the functions of each individual object. The electric power design and the associated objects are presented in Chapter 7 on Infrastructure, but they are closely related to the mechanics and the electronics of the detector.

The precision on the ANTARES track reconstruction relies on the calibration of the timing and amplitudes of the signals, and on the positioning of the detector strings; Chapter 6 is dedicated to the description of the instruments that have been developed for ANTARES (e.g. acoustic system, laser and LED optical beacons).

Due to the size of the strings, special logistics and tools need to be set up for their assembly; the present concepts for the integration of strings and their testing are reported in Chapter 8. A prototype string called the 'prototype sector line' will be built; it is also described in chapter 8.

The ANTARES collaboration has many years of experience of sea operations with small test lines and by the deployment and recovery of two prototype strings. The logistics and protocols involved are described in Chapter 9 on sea operations.

Last in sequential order for the TDR paper version, but not least in importance, Chapter 10 considers the management aspects of the experiment. ANTARES gives high priority to the quality control and assurance of the experiment, since the detector is aimed at working for ten years with the minimum possible maintenance. A list of milestones is also provided, together with the PBS list of components in the detector.

The annexes include a list of acronyms and a list of units used in the TDR. Most references are indicated either by links or explicitly in the individual pages where they belong.

ANTARES 0.1 km^2 TDR

Table of Contents

Ch 5: Electronics

Ch 6: Calibration and Instrumentation

Ch 10: Management and Quality Assurance

Annexes

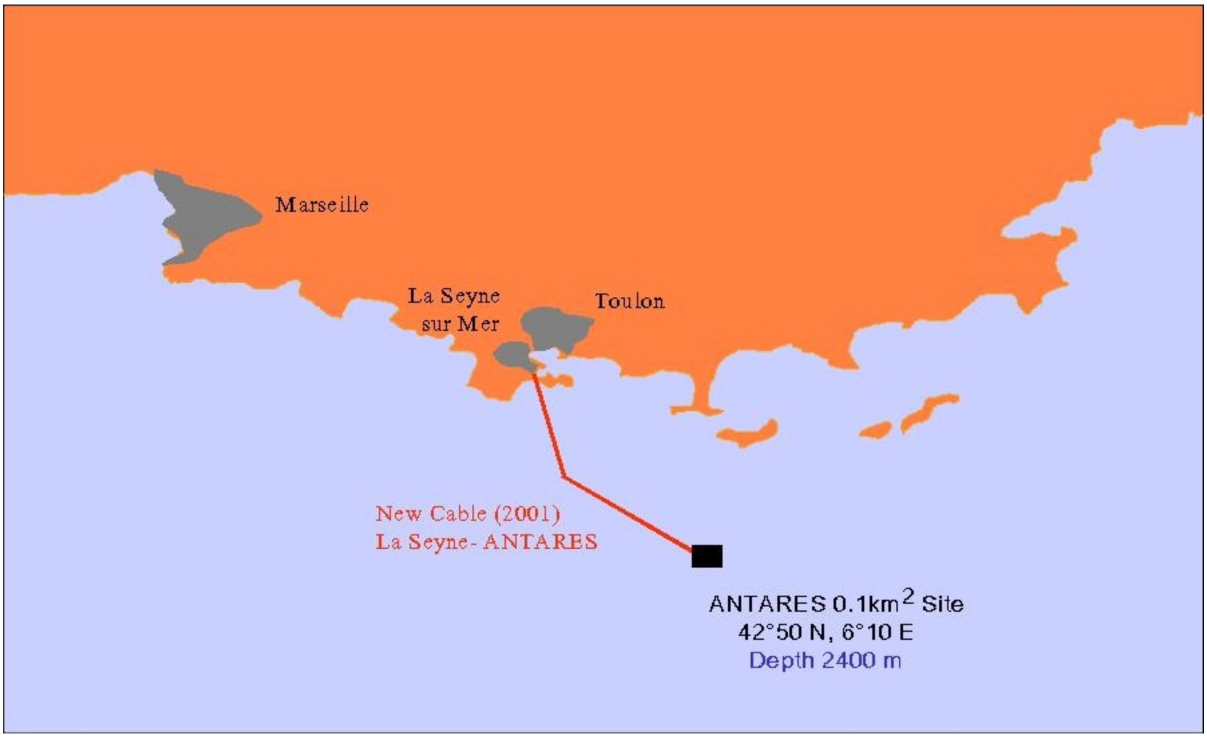
Chapter 1 : Introduction

The ANTARES Project

The ANTARES Collaboration was formed in 1996 with the objective of building a neutrino telescope in the Mediterranean Sea. The first phase of the project has been to acquire the technology and experience necessary to construct such an instrument. More than 30 successful deployments and recoveries have been performed with autonomous strings. 350 m long demonstrator strings have been deployed and recovered twice successfully. Data acquisition with a 37 km long electro-optical cable (available from France Telecom before the purchase of the final cable) has demonstrated the possibility of precise positioning measurements and atmospheric muon trigger and reconstruction. The experience gained is described in the 'line 5 papers' [1], and has been integrated to improve the final design of the detector.

The ANTARES site

A major aspect of this stage of the project was the choice and evaluation of the site, which will be 40 km south of Toulon in France at a depth of 2400 m. The location of the chosen site (42° 50' N, 6° 10' E) allows a sky coverage of 3.6π sr and a 0.6π sr overlap with the AMANDA neutrino telescope [3]. A 50 km long electro-optical cable connects the detector to the shore, landing on the beach of La Seyne-sur-Mer (cf section on Infrastructure).



A map showing the position of the ANTARES site

Sea water properties

Extensive measurements of the sea-water properties of this site have been made and these results have been reported in a number of publications and presentations [2].

- The background light with a base rate of about 60 kHz for a 10 inch photomultiplier tube, consists of two roughly equal components: β-decay of ^{40}K, naturally present in the sea salt and light emission from living organisms in the sea (bioluminescence). Short bursts of a few ms risetime are observed, which decay typically within 1 or 2 seconds, with counting rates reaching tens of MHz. (cf ANTARES/Site-2000-3)
- The surfaces of optical modules exposed to sea water are affected by the combination of two processes: living organisms, mostly bacteria, which grow on the outer surface, and sediments, which fall on upward-looking surfaces. The bacterial growth is almost transparent, but sediments adhere to the surface and make it gradually opaque. Measurements have shown that fouling is significantly reduced for polar angles larger than 50 degrees. At the equator, fouling induces a transmission loss of 1.5% after eight months of immersion, an upper limit on the fouling expected on the actual detector, where optical module axis will be oriented at a polar angle of 135 degrees with respect to the zenith. (cf ANTARES/Site-2001-003)
- The water transparency affects the muon detection efficiency, while the amount of scattered light determines the limit on the angular resolution of the detector. Measurements and analysis performed in the ANTARES site give an absorption length in the 55 m range (resp. 25 m) in blue (resp.UV), and an effective scattering length in the 300 m range (resp. 120 m) in blue (resp.UV). (cf ANTARES/Site-2001-002)

Some basic numbers

Besides ^{40}K and bioluminescence, the main light sources in deep sea originates from atmospheric muon Cerenkov light emission (around 760 γ/cm between 300-600 nm). The average muon energy is about 350 GeV at the depth of 2400 m and a majority of the muons that will be reconstructed in ANTARES are multiple muon events. The vertical downgoing muon flux at a depth of 2400 m (10 Hz -30 Hz depending on threshold energy and solid angle definition) is still about 10^6 times larger than the vertical upgoing muon flux from atmospheric neutrinos (about 10^{-13}/cm^2/s, ie, roughly 3000/year or 1 every 2 hours per a 0.1 km^2 detector). This is a formidable challenge for the detector.

Detector concepts

With the successful completion of the first phase of the project, the collaboration has moved on to the construction of a detector of a size sufficient to start to observe neutrino events from outer-space: a detector with an effective area of 0.1 km^2. This detector will be a further step towards the ultimate goal of the construction of a Neutrino Telescope with volume 1 km^3.

ANTARES has decided on a detector configuration based on the detection of Cerenkov light with photomultipliers (PMT) arranged as a three-dimensional array in the sea at a depth of 2400 m. The 0.1 km^2 detector will consist of 10 to 14 flexible strings (depending on the finances available for the construction) containing each 30 storeys with a separation of 12 m between them. Each storey contains 3 PMTs oriented at an angle of 45 degrees below the equator to give high efficiency for tracks between the upward vertical direction and the horizontal, and minimise effects due to biofouling.

The PMTs are sensitive to single photons and the amplitude of single photoelectrons (SPE) signals will be between 60 to 100 mV. A timing precision around 1 ns is expected from the electronics chain. Signals are digitised and read out via optical fibres in cables laid on the sea bed.

A submarine will connect the cables from the individual strings to a junction box which links to a single electro-optical cable sending the signals to a shore base where the data are recorded.

The design lifetime of the detector is 10 years with the option of repairing detector elements by recovery from the sea and re-deployment.

Scientific aims

ANTARES aims, with other similar projects world-wide [3,4], to open a new field of scientific exploration of the universe. Neutrino detection provides a novel tool to explore high-energy phenomena in astrophysical objects. The neutrinos escape without interacting in the material surrounding sources and travel to the Earth with no deviation from the galactic magnetic fields. Hence it is possible to obtain unique information on the nature of known sources and perhaps to observe hitherto unknown objects.

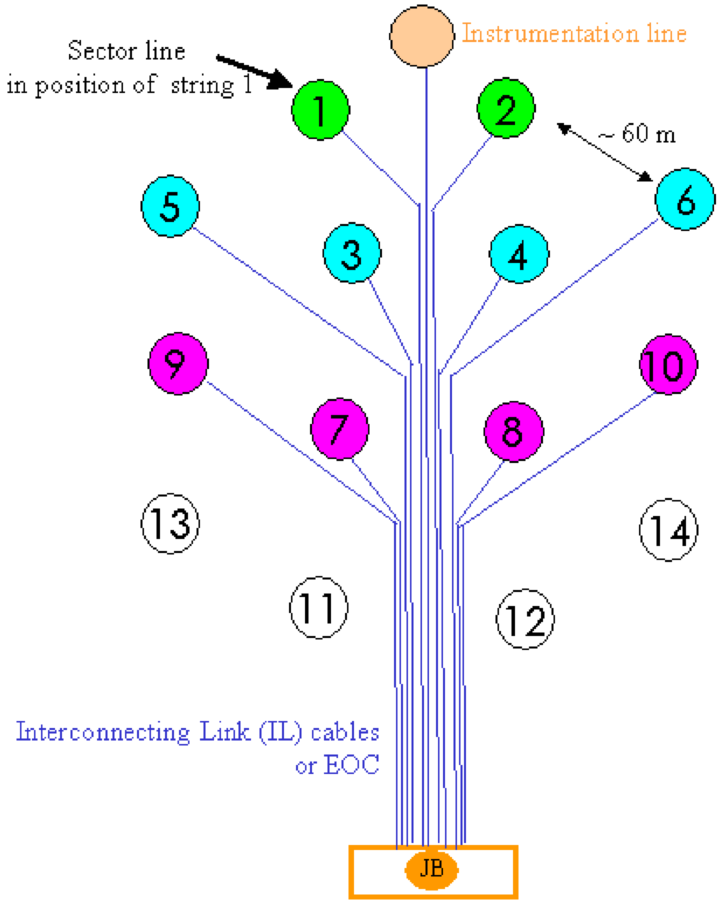
In addition to exploratory astrophysics, the scientific programme of ANTARES includes particle physics and cosmology. Neutrinos with energies larger than 10^{11}GeV might relate to speculative but highly spectacular sources such as ``topological defects", remnants from the phase transition at the Grand Unification scale. If the dark matter in the universe consists of neutralinos, the stable particles predicted in many R-parity conserving supersymmetric models, these will accumulate in the centres of massive astronomical objects. ANTARES will search for the neutrinos produced in the annihilation processes of neutralinos captured in the centres of the earth, the sun and the Galaxy. Cosmic neutrinos with energies much higher than those achievable with man-made accelerators are of great interest because of their possible relation with Big Bang relics or Active Galactic Nuclei.

The threshold energy is set by the separation between storeys and the muon energy loss by ionization in water (5m/GeV) : for 12 m, this corresponds to a threshold of roughly 5 GeV. ANTARES will be able to measure the neutrino mass difference and the mixing angle with improved precision if the true value lies in the region of parameter space of atmospheric neutrino oscillations allowed by the recent results of the Super-Kamiokande experiment [5]. For a $\Delta m^2 = 3\ 10^{-3}\ eV^2$, the first oscillation minimum occurs for $E / \cos\theta \sim 30$ GeV, in the sensitivity region of the ANTARES detector.

The ANTARES proposal [6] gives more complete details of the scientific programme together with the results of simulations of the detector performance. The Conceptual Design Report [7] has defined the main concepts for the design of the 0.1 km^2 project. Detailed studies have been described in the first two ANTARES thesis [8].

Planned Operations

The assembly of the first sector will start in June 2001 at CPPM, where detailed tests will be performed. This first sector will constitute a prototype line (sector line) that will be deployed in the sea in June 2002. Its operation will allow potential problems to be detected prior to the mass production of the strings. Subsequently, two complete lines will be built for deployment in 2003. The remaining strings will follow at regular intervals of a few months. The bases of the string anchors are arranged on the seabed with a nominal distance between anchors of 60 m.



Foreseen string layout on the seabed of the ANTARES site.

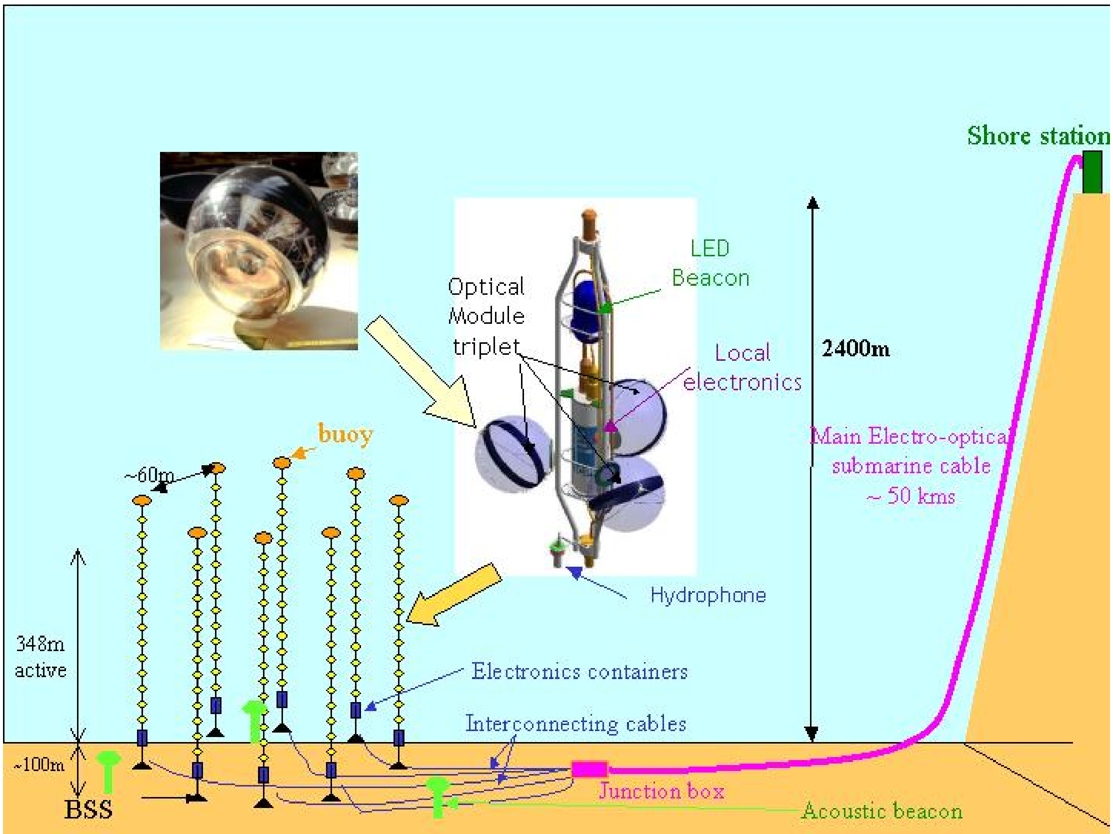
The present funding estimates allow for 10 strings, but components will be designed and ordered to allow for up to14, if extra funds become available or if cost savings can be made.

List of references

1. Bertin et al., 'Results on Line 5 immersion', ANTARES-MECA/2000-001
   Benhammou et al., 'Results of Line-5', ANTARES-Prot/2000-001
2. ANTARES Collaboration, ``Background light in potential sites for the ANTARES undersea neutrino telescope'', in Astroparticle Physics 13 (2000) p. 127-136. Also astro-ph/9910170.
   ANTARES/Site-2000-3, Optical Background measurements -Test 1.10
   ANTARES/Site-2001-003, The fouling of optical surfaces in the ANTARES site
   ANTARES/Site-2001-002 Bue and UV transmission in the ANTARES site (test 3')
3. A. Biron et al., ``Proposal: AMANDA-B Upgrade to AMANDA-II'', DESY-PRC-97/05.
4. I.A. Sokalski and Ch. Spiering (eds.), BAIKAL 92-03 (1992),
   I.A. Belaptikov et al., Astropart. Phys. **7** (1997) 263.
5. Y. Fukuda et al., (Super-Kamiokande Collaboration), Phys. Rev. Lett. **81** (1998) 1158.
6. ANTARES proposal : astro-ph/9907432, ANTARES Collaboration, ``A deep sea telescope for high energy neutrinos''.
7. ANTARES Conceptual Design Report

8. Optimisation et caractérisation des performances d'un télescope sous-marin a neutrinos pour le projet ANTARES, April 1999,*Fabrice Hubaut,* CPPM - Marseille
   Caractérisation des performances à basse énergie du futur télescope sous-marin à neutrinos ANTARES et leur application à l'étude des oscillations des neutrinos atmosphériques
   Decembre 1999, *Cristina Carloganu*, CPPM - Marseille

Detector Description



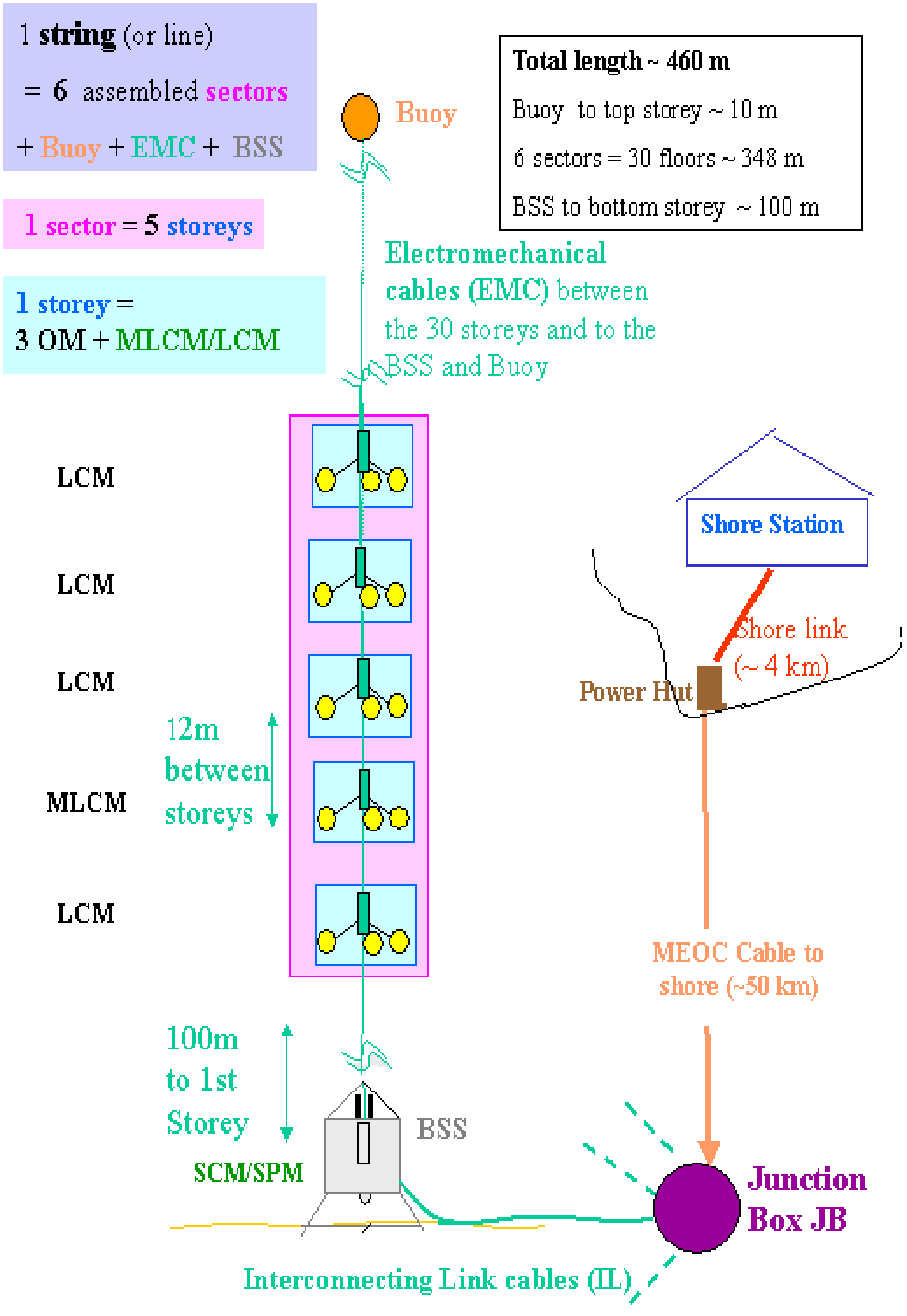
Artist's view of the 0.1 km^2 ANTARES detector

The ANTARES detector is based on independent **strings** (called also **lines**), deployed at 2400 m depth on the Mediterranean sea bed, each supporting a total of 90 photo-multipliers **(PMT).**

The photo-multipliers are contained inside glass spheres, which stand the pressure of about 250 bars. The assembly of PMT, glass sphere and related electronics is referred to as an **Optical Module (OM).**

Three Optical Modules are grouped symmetrically together by an **Optical Module Frame** (**OMF**) which also holds the local electronics container (**Local Control Module** or **LCM**), to give one **storey**, (or **floor**) in the detector.

The vertical distance between storeys is 12 m. The adjacent OMFs are connected by Electro-Mechanical Cables (**EMC**) of 10 m length. Storeys are grouped by 5 to form a **sector**, which is the unit that is assembled and tested. Six sectors are then grouped together to form a **string (line)**. The full line contains 30 storeys with an active length of 348 m for a total string length of about 460 m.



(not to scale)

Schematic view of the detector with the main sub-systems and objects

The string is maintained vertically by a **buoy** at the top of the string. The horizontal displacement of the buoy relative to the bottom will be less than 10 m for a sea current of 20 cm/s, the maximum observed in the site measurements.

The lines are anchored to the seabed by a **Bottom String Socket (BSS)** such that the active length starts at a distance 100 m above the bottom of the sea. The **BSS** also supports two local containers, called **String Control Module** (**SCM**) for electronics and **String Power Module** (**SPM**) for the power distribution to the photo-multipliers and electronics in the string.

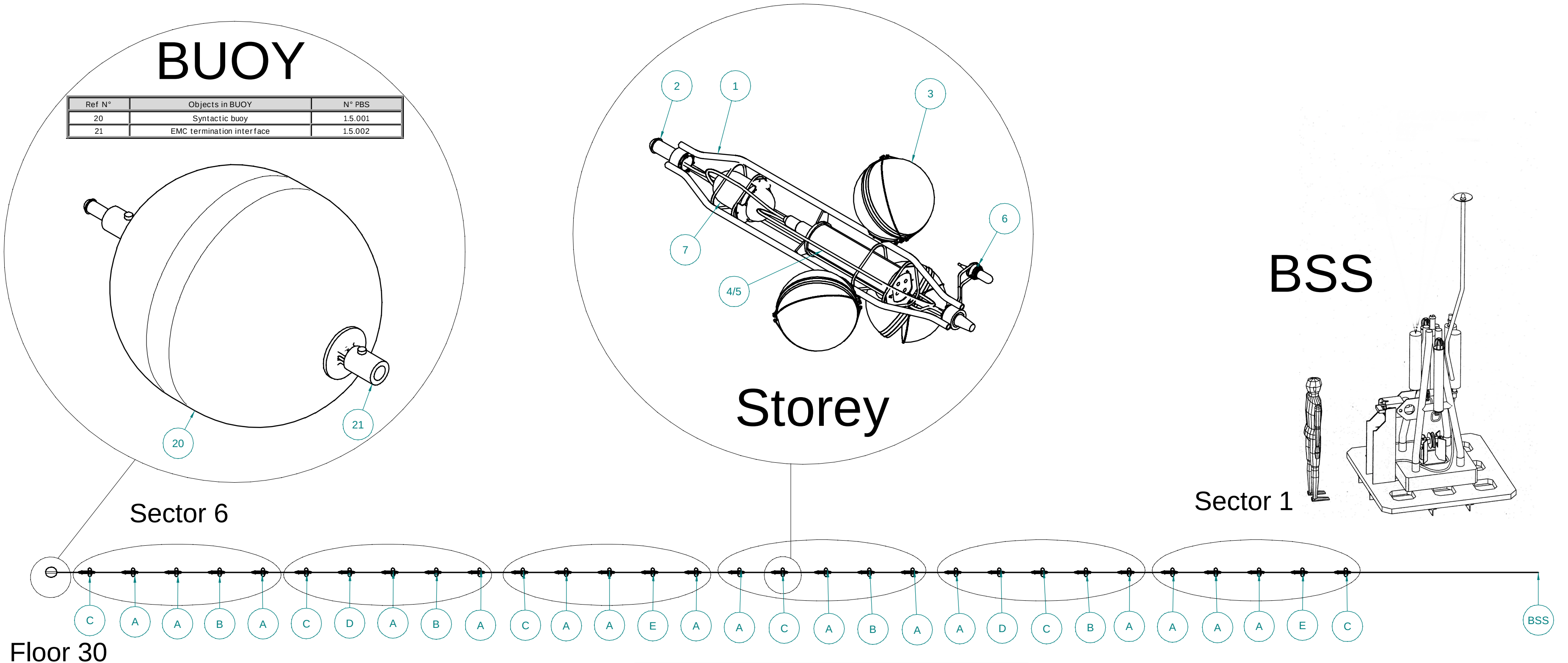
The detector is built, tested and controlled on shore, at La Seyne sur Mer, . A **Shore Link** of about 4 km with optical fibres connects the control room at the **Shore Station** to the **Power Hut** on the beach. Power to the detector is transferred from the beach by a 50 km long **Main Electro-Optical Cable** (**MEOC**), which has also the capability to ensure data transmission via fibre optics from and to the shore. The power is then transformed inside a **Junction Box** (**JB**) and distributed to each line by the String Power Module (SPM).

The relative positioning of the detector elements is measured by a High Frequency Long BaseLine (HFLBL) acoustic positioning system, and a set of tiltmeter compasses. The absolute geographic positioning of the detector is ensured by a Low Frequency Long BaseLine (LFLBL) acoustic system, coupled to a DGPS.

Relative time calibrations are foreseen using Laser and LED Optical Beacons (OB). Some lines are equipped with instruments that can monitor the basic parameters of the environment (sound velocity, sea water temperature, salinity, pressure).

The position of the instruments on the string is given in the line schematic view (in pdf format).

A dedicated string, called the **Instrumentation line** is built with specific instrumentations to provide more precise measurements and monitoring. Another dedicated object, the General Purpose Experiment Platform, will be built and deployed by IFREMER for oceanographic studies.



Ref N°	Objects in BUOY	N° PBS
20	Syntactic buoy	1.5.001
21	EMC termination interface	1.5.002

Class	Ref N°	Objects in OMF	N° PBS
A	1	OMF	1.3.001
	2	OMF interface with EMC	1.3.006
	3	OM support	1.3.004
	4	LCM	1.3.002
B	1	OMF	1.3.001
	2	OMF interface with EMC	1.3.006
	3	OM SUPPORT	1.3.004
	5	MLCM	1.3.002
C	1	OMF	1.3.001
	2	OMF interface with EMC	1.3.006
	3	OM support	1.3.004
	4	LCM	1.3.002
	6	Hydrophone support	1.3.005
D	1	OMF	1.3.001
	2	OMF interface with EMC	1.3.006
	3	OM support	1.3.004
	4	LCM	1.3.002
	7	Led Optical Beacon support	1.3.007
E	1	OMF	1.3.001
	2	OMF interface with EMC	1.3.006
	3	OM support	1.3.004
	5	MLCM	1.3.002
	7	Led Optical Beacon support	1.3.007
F	1	OMF	1.3.001
	2	OMF interface with EMC	1.3.006
	3	OM support	1.3.004
	4	LCM	1.3.002
	8	Celerimeter	1.3.008
G	1	OMF	1.3.001
	2	OMF interface with EMC	1.3.006
	3	OM support	1.3.004
	4	LCM	1.3.002
	9	Celerimeter - CTD	1.3.008

Ref N°	Objects in String	Nb / String
1	OMF	30
2	OMF interface with EMC	60
3	OM support	90
4	LCM	24
5	MLCM	6
6	Hydrophone support	6
7	Led Optical Beacon support	4
8	Sound Velocimeter support	0 or 1
9	Sound Velocimeter - CTD support	0 or 1

SYNOPTIQUE LIGNE
ANTARES

Matiere :
Tolerance gen. :
Rugosite gen. :

Protec. : Sans

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	Nom	Date	Ech.
Controle	JAQUET	14/02/01	3/10
Dessine	LAGIER	14/02/01	A0

N|B Pl. Rempl.
Plan : 1/1

Projet :
Sous Projet :