ESFRI, Astronomy & Astroparticles Panel
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The KM3NeT Project:

A km^3–Scale Mediterranean Neutrino Telescope and Deep-Sea Research Infrastructure

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on behalf of the KM3NeT consortium

- Scientific Case
- Technical Aspects
- The KM3NeT Design Study and Beyond
- Conclusions and Outlook

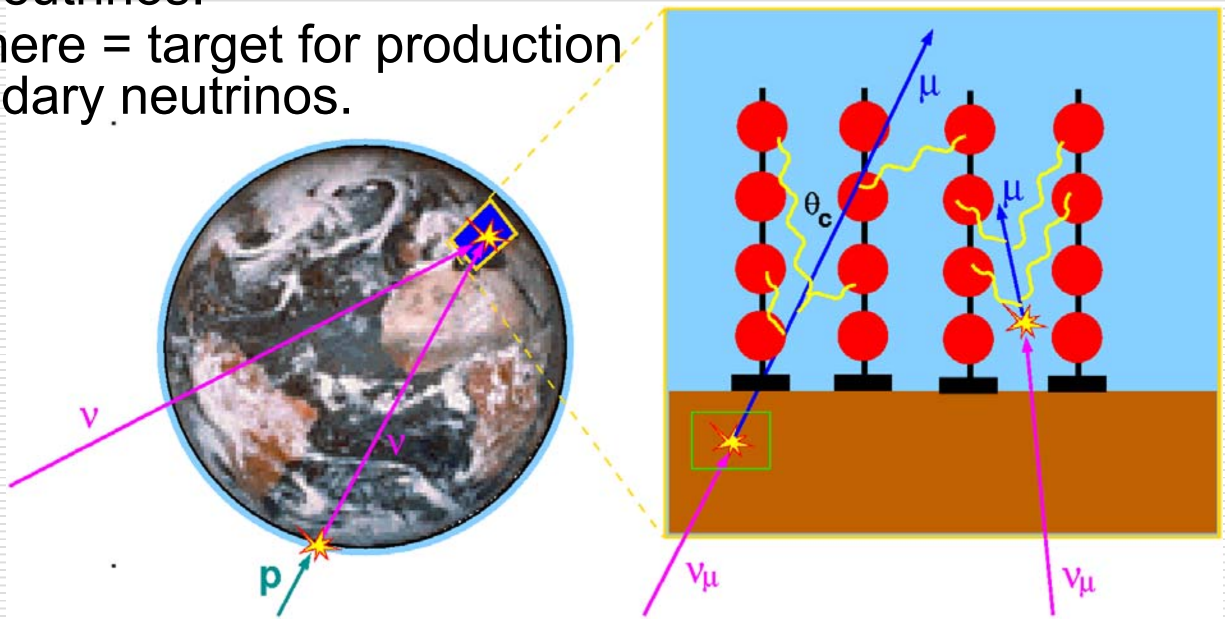
The Principle of Neutrino Telescopes

Role of the Earth:

- Screening against all particles except neutrinos.
- Atmosphere = target for production of secondary neutrinos.

Čerenkov light:

- In water: $\theta_C \approx 43°$
- Spectral range used: ~ 350-500nm.



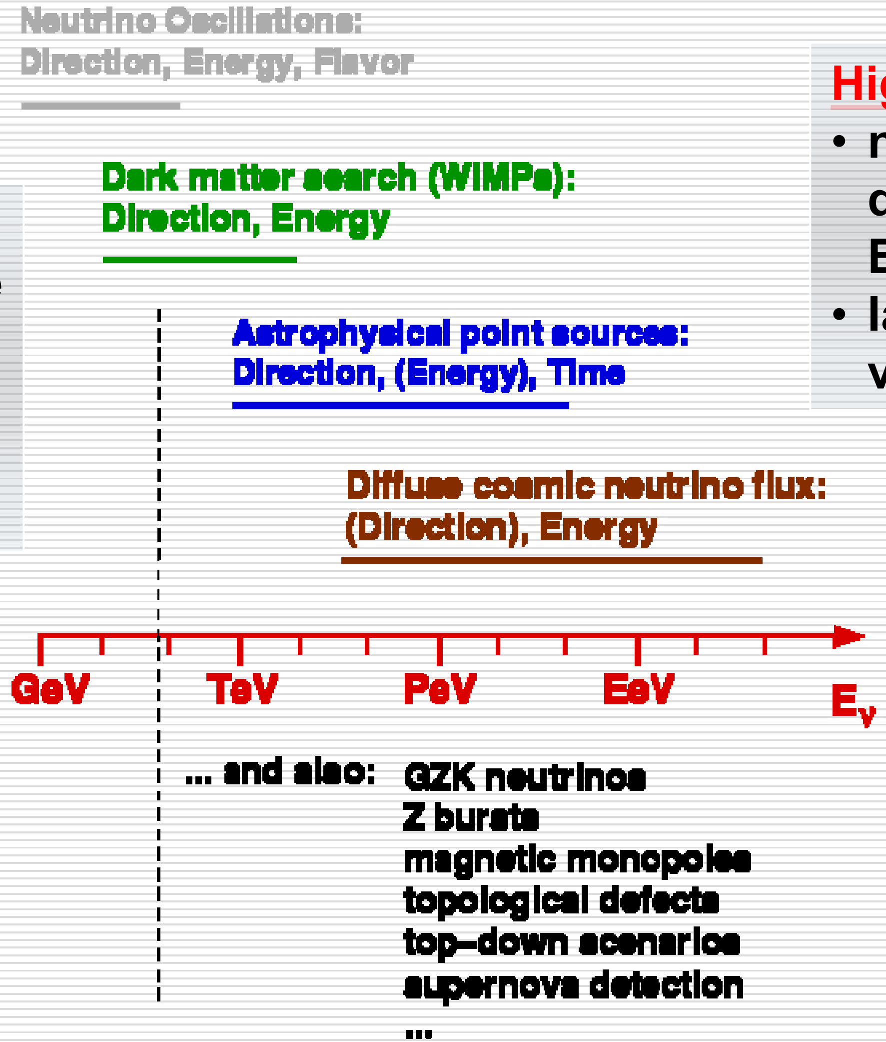
Angular resolution in water:

- Better than ~0.3° for neutrino energy above ~10 TeV, 0.1° at 100 TeV
- Dominated by angle(ν,μ) below ~10 TeV (~0.6° at 1 TeV)

Astro- and Particle Physics with ν Telescopes

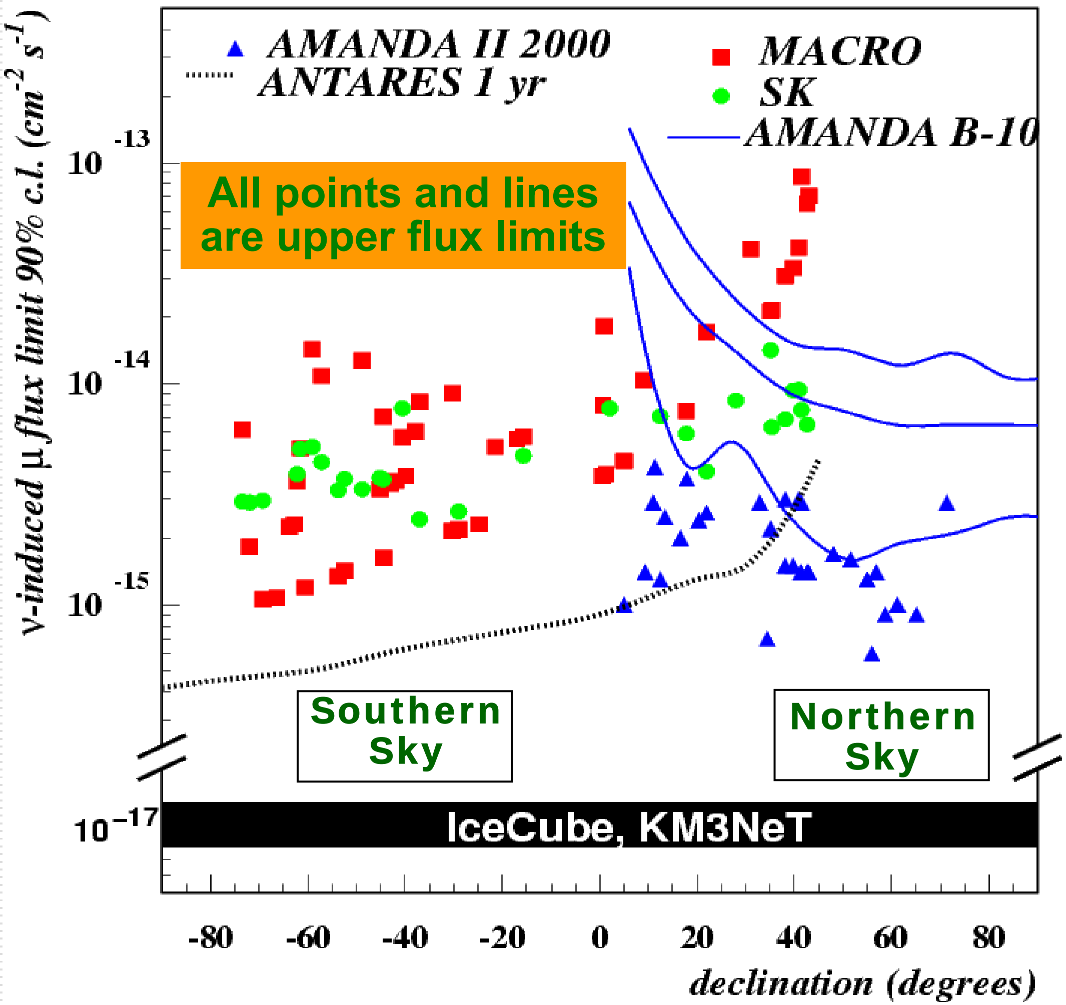
Low-energy limit:
- short muon range
- small number of photons detected
- background light from K40 decays

High-energy limit:
- neutrino flux decreases like E^{-n} ($n \approx 2$)
- large detection volume needed.



Neutrinos from Astrophysical Point Sources

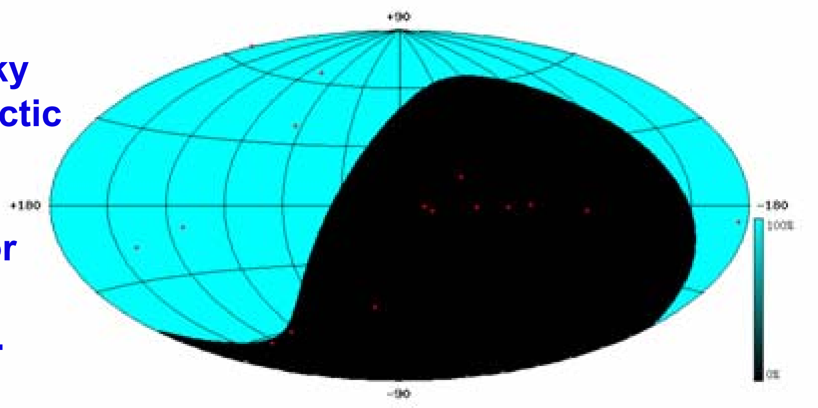
- Association of neutrinos to specific astrophysical objects.
- Energy spectrum, time structure, multi-messenger observations provide insight into physical processes inside source.
- Measurements profit from very good angular resolution of water Čerenkov telescopes.
- km^3 detectors needed to exploit the potential of neutrino astronomy.

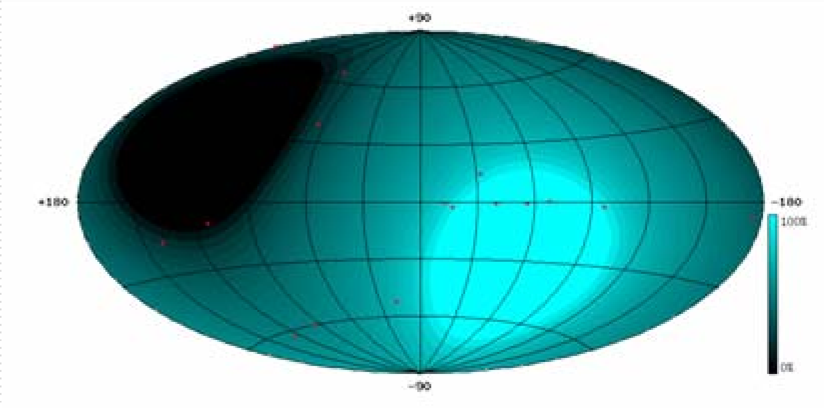


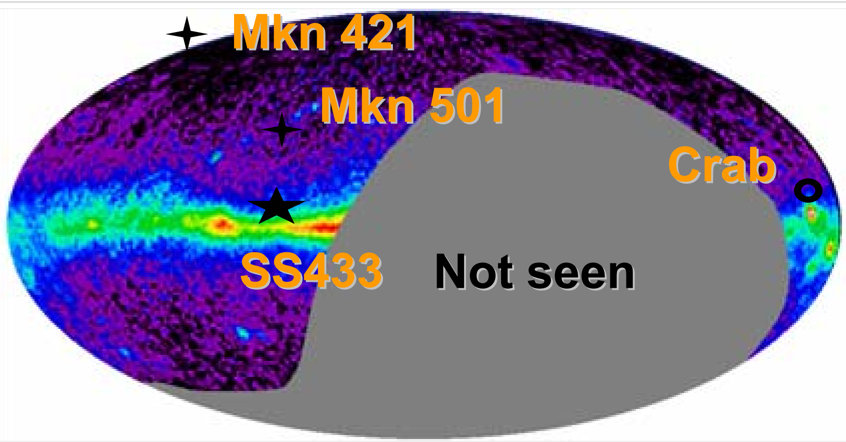
Sky Coverage of Neutrino Telescopes

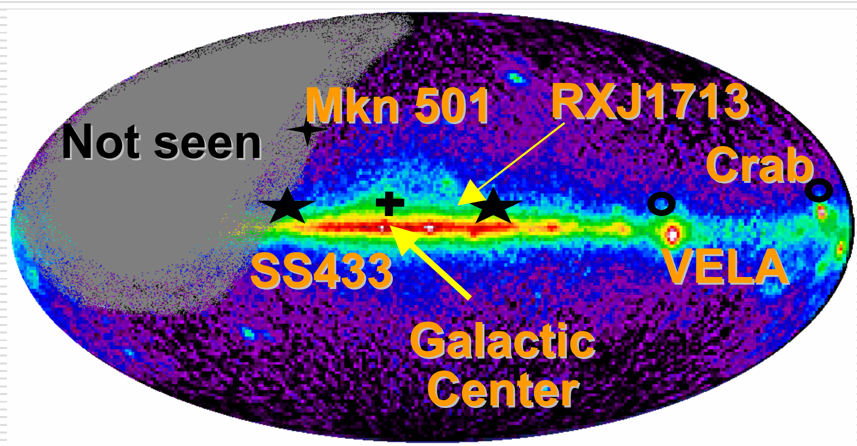
South Pole | **Mediterranean**

Region of sky seen in galactic coordinates assuming efficiency for downward hemisphere.





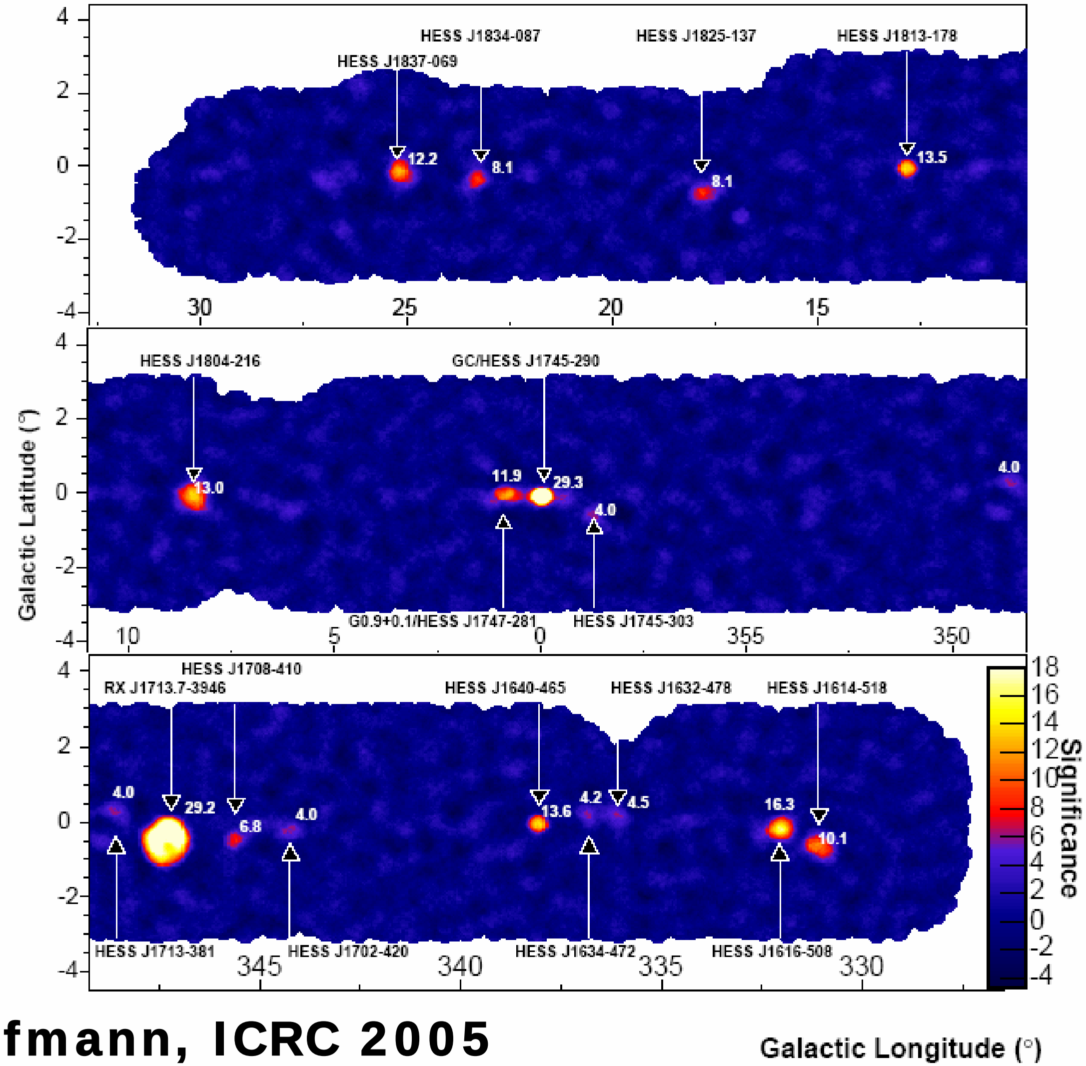




→ We need ν telescopes in both hemispheres to see the whole sky

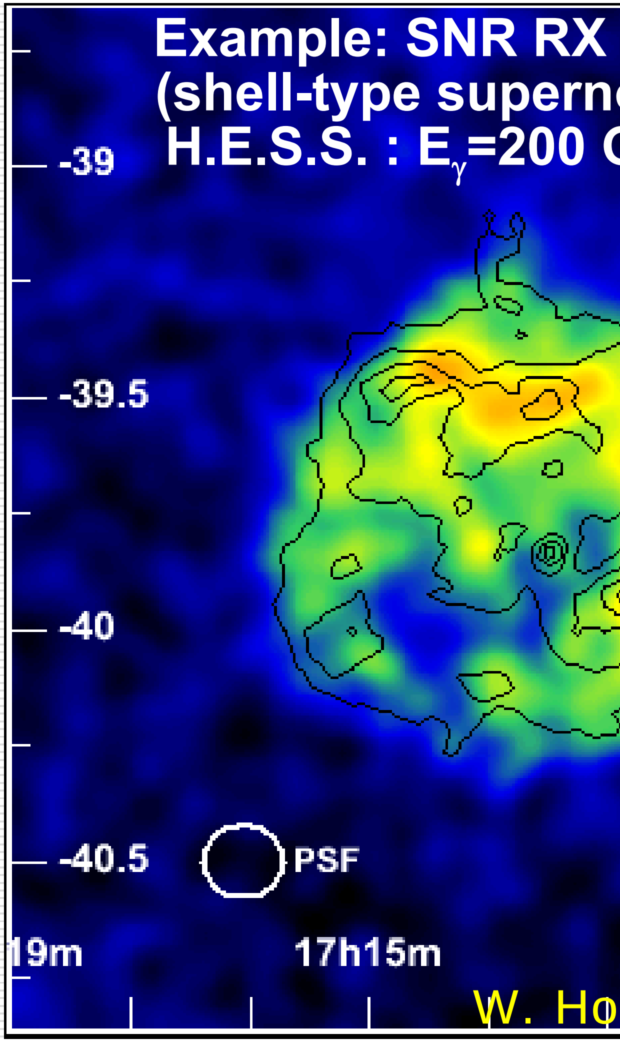
High-energy γ sources in the Galactic Disk

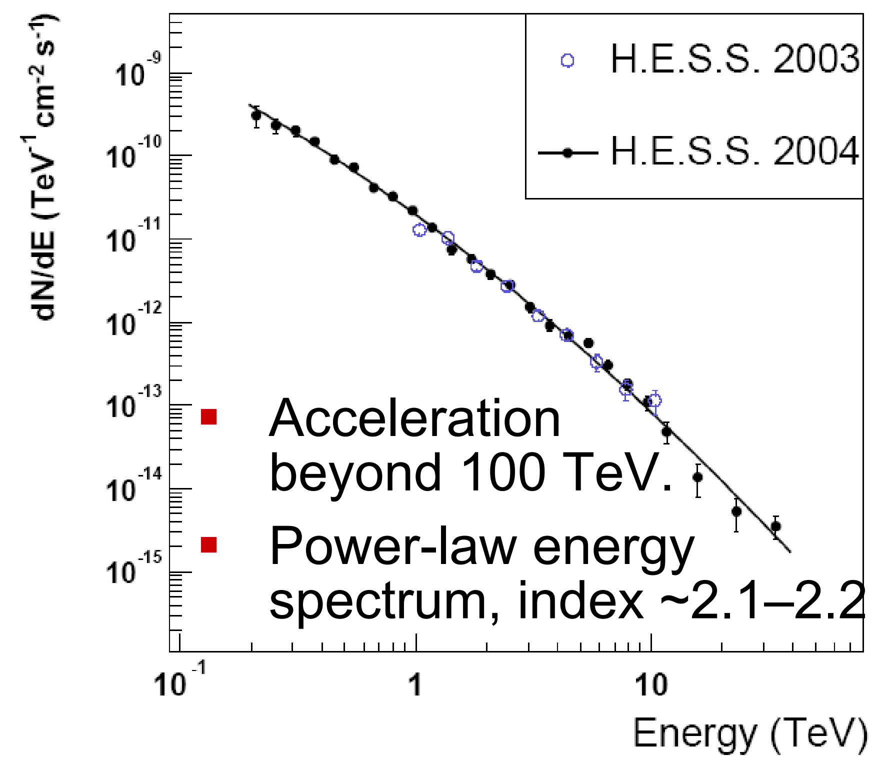
- 5 γ sources could be/are associated with SNR, e.g. RX J1713.7-3946;
- 3 could be pulsar wind nebulae, typically displaced from the pulsar;
- Some coincide with EGRET, ASCA, … unidentified sources;
- 3 have no counterpart known to us.



W. Hofmann, ICRC 2005

Neutrinos from Supernova Remnants

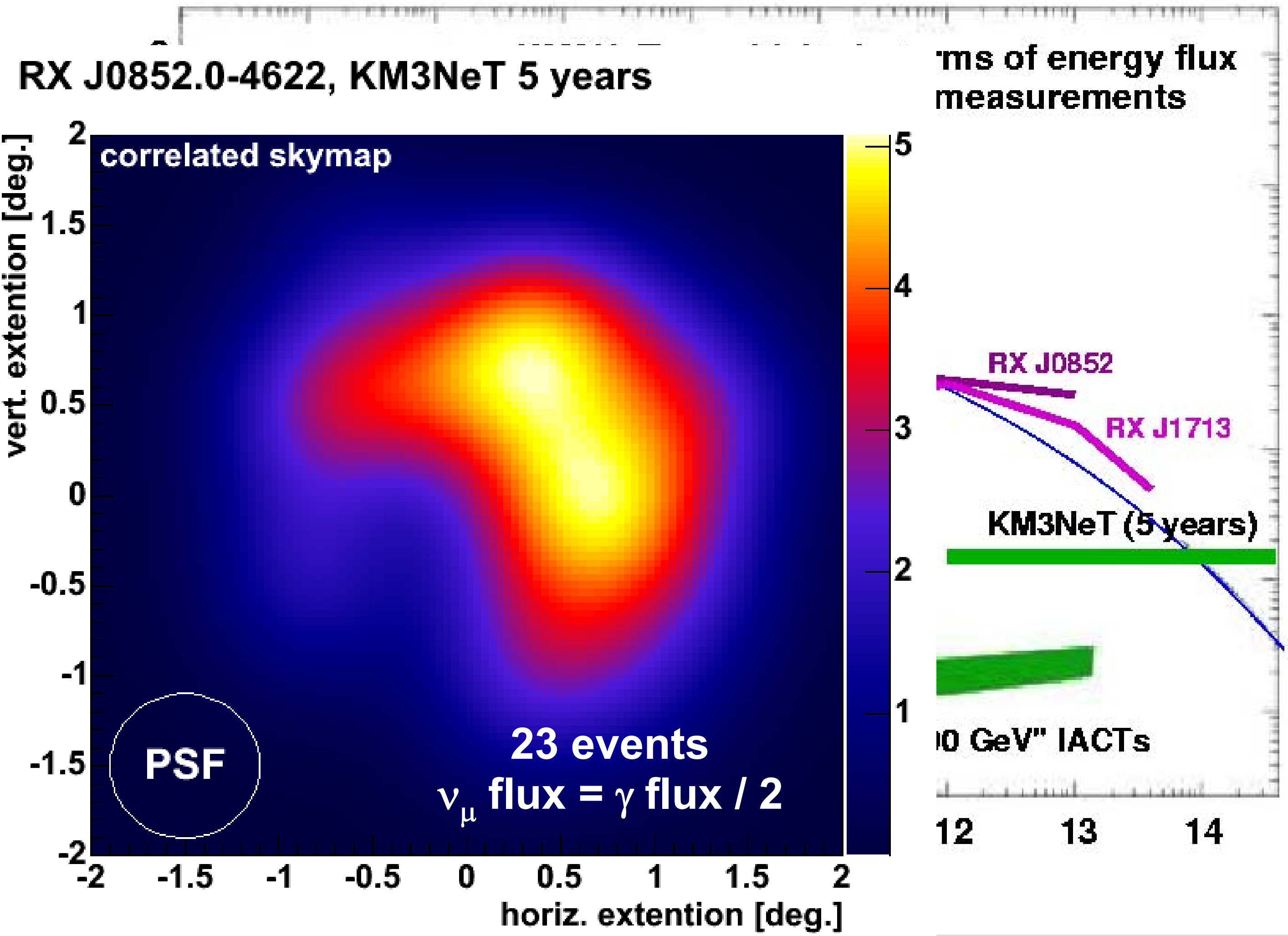




- Acceleration beyond 100 TeV.
- Power-law energy spectrum, index ~2.1–2.2.

- Spectrum points to hadron acceleration → ν flux ~ γ flux
- Typical ν energies: few TeV

E Flux Sensitivity of the KM3NeT ν Telescope



KM3NeT sensitivity estimated for

- **requirement: 10 hits/event**
- **80% duty cycle**
- **ν_μ flux**

Very preliminary !

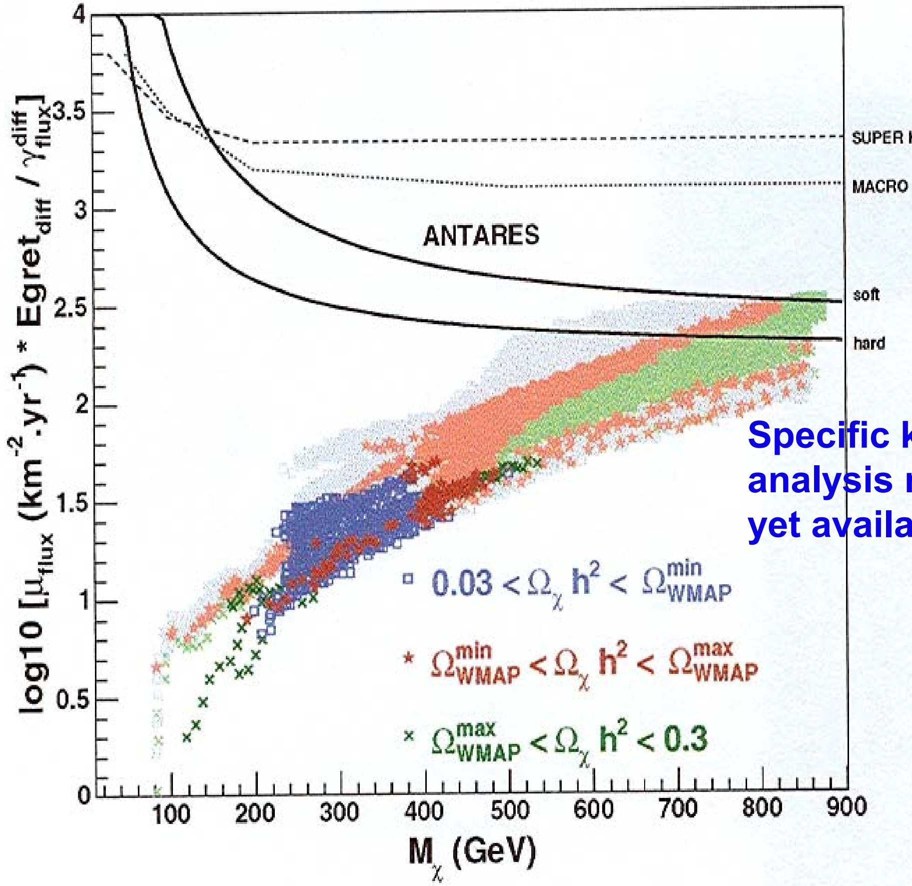
Indirect Search for Dark Matter

- WIMPs can be gravitationally trapped in Earth, Sun or Galactic Center;
- Neutrino production by

$$\chi\chi \rightarrow \nu + X$$

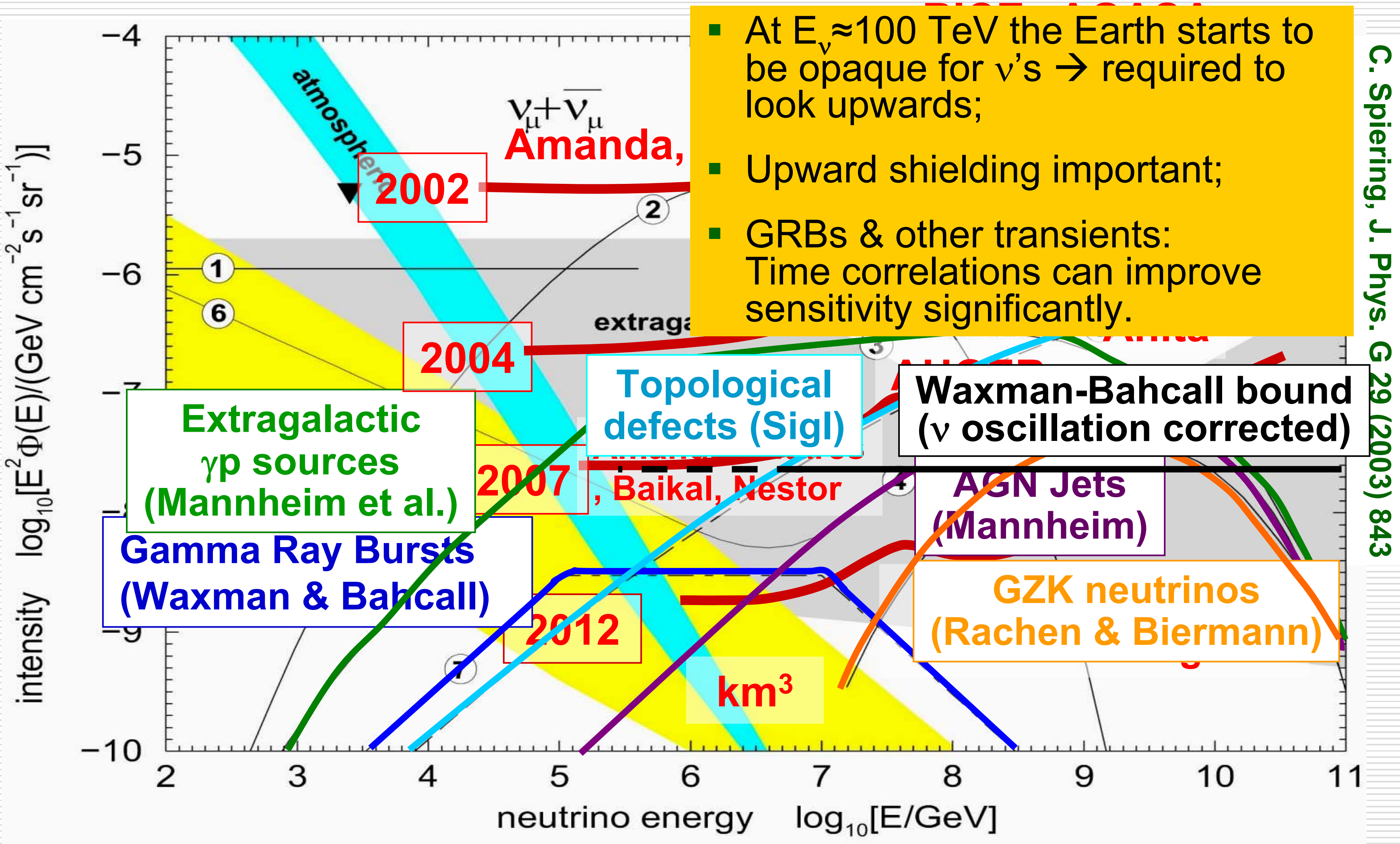
- Detection requires low energy threshold (O(100GeV) or less).
- Flux from Galactic Center may be enhanced if a Black Hole is present → exciting prospects for KM3NeT [see e.g. P. Gondolo and J. Silk, PRL 83(1999)1719].
- But: model uncertainties on ν flux are orders of magnitude!

Neutrino flux from the Galactic Center (from G. Bertone et al., astro-ph/0403322)



Specific km³ analysis not yet available.

Diffuse ν Flux: Models, Limits and Sensitivities



- At $E_\nu \approx 100$ TeV the Earth starts to be opaque for ν's → required to look upwards;
- Upward shielding important;
- GRBs & other transients: Time correlations can improve sensitivity significantly.

Summary of KM3NeT physics goals

- Search for astrophysical point sources
  - "Smoking gun" for identification of hadronic accelerators and investigation of acceleration mechanisms;
  - Neutrino part of multi-messenger observations to correlate radiative and hadronic processes;
  - Study of transient sources (e.g. Gamma Ray Bursts);
  - Unique chance to study neutrinos from galactic disk.
- Measurement of the diffuse neutrino flux
  - Information on cosmological source densities/distributions;
  - Search for Big Bang relics.
- Dark Matter
  - Search for neutrinos from WIMP annihilations.
- Particle physics & cosmology
  - Magnetic monopoles, topological defects, Z bursts, nuclearites, …

Marine sciences

- Large interest for long-term, real-time measurements in the deep sea:
  - Marine biology
  - Geology and geophysics (seismology, tsunamis, …)
  - Environmental sciences
  - Oceanography
  - …
- KM3NeT will be associated to European deep-sea observatory network projects (ESONET, EMSO).
- Marine science communities are actively involved in the project preparation.

Technical aspects

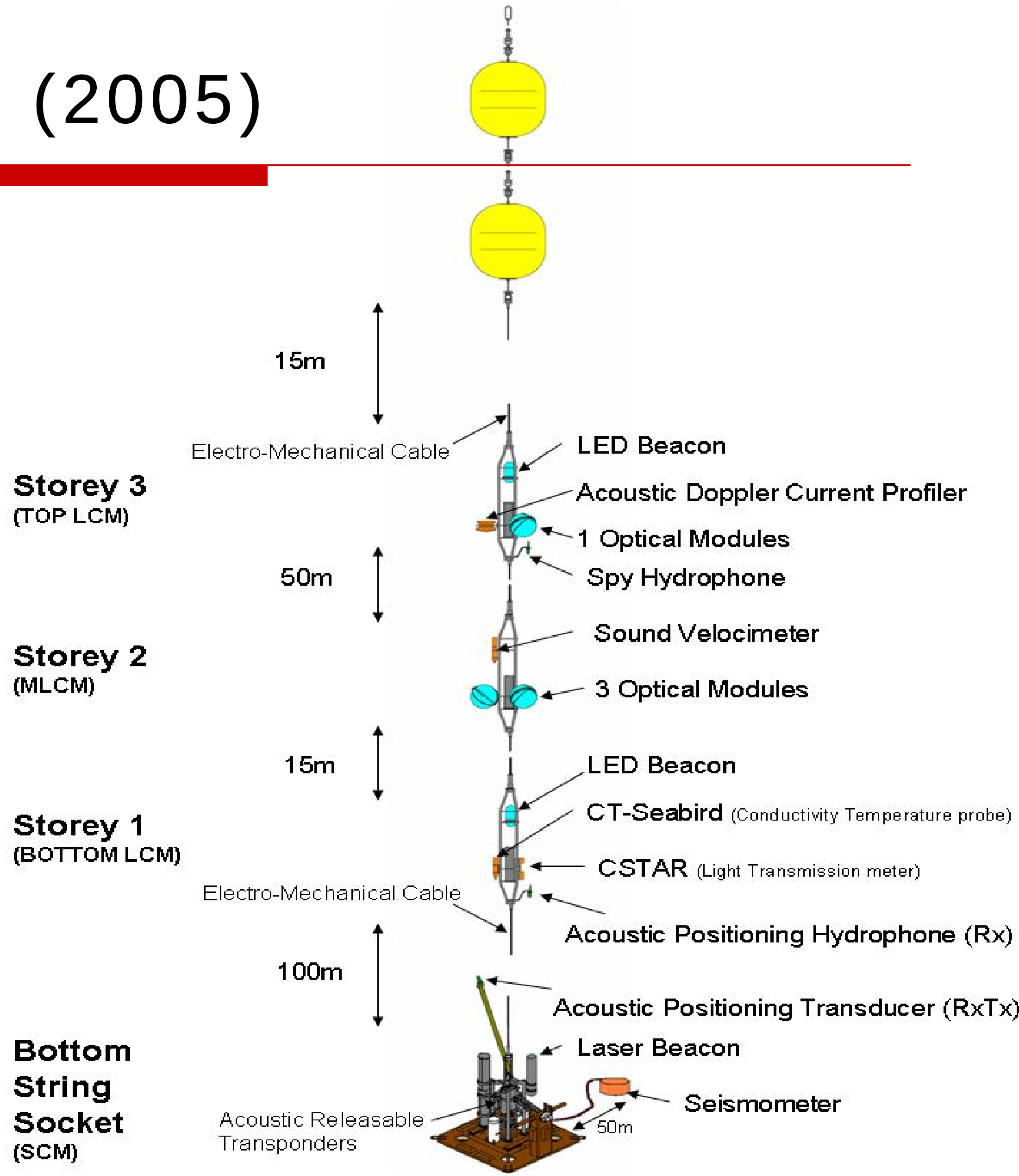
- 3 current projects in the Mediterranean Sea provide
  - Proof of feasibility;
  - The world expertise in deep-sea neutrino telescope technology;
  - A huge reservoir of technical experience and solutions;
  - Extensive exploration of 3 candidate sites.
- The technical design of the KM3NeT ν telescope will be worked out in an EU-funded 3-year Design Study
  - Participation of all current deep-sea ν telescope groups as well as "newcomers" and marine science institutes;
  - EU contribution 9 M€, overall budget ~20 M€ (contract signature in progress);
  - Project start: February 1, 2006.

ANTARES: Detector Design

- String-based detector;
- Underwater connections by deep-sea submersible;
- Downward-looking photomultipliers (PMs), axis at 45° to vertical;
- 2500 m deep.

ANTARES: MILOM (2005)

- Successful operation over several months
- Major progress:
  - **Validation of final design;**
  - **Validation of time calibration ($\Delta t < 1$ ns);**
  - **Validation of acoustic positioning ($\Delta x < 10$ cm);**
  - **Measurements and long-term monitoring of environmental parameters;**
  - **Tests and improvements of data acquisition.**



NESTOR: Rigid Structures Forming Towers

- Tower based detector (titanium structures).
- Dry connections (recover−connect−redeploy).
- Up- and downward looking PMs.
- 3800 m deep.
- First floor (reduced size) deployed & operated in 2003.

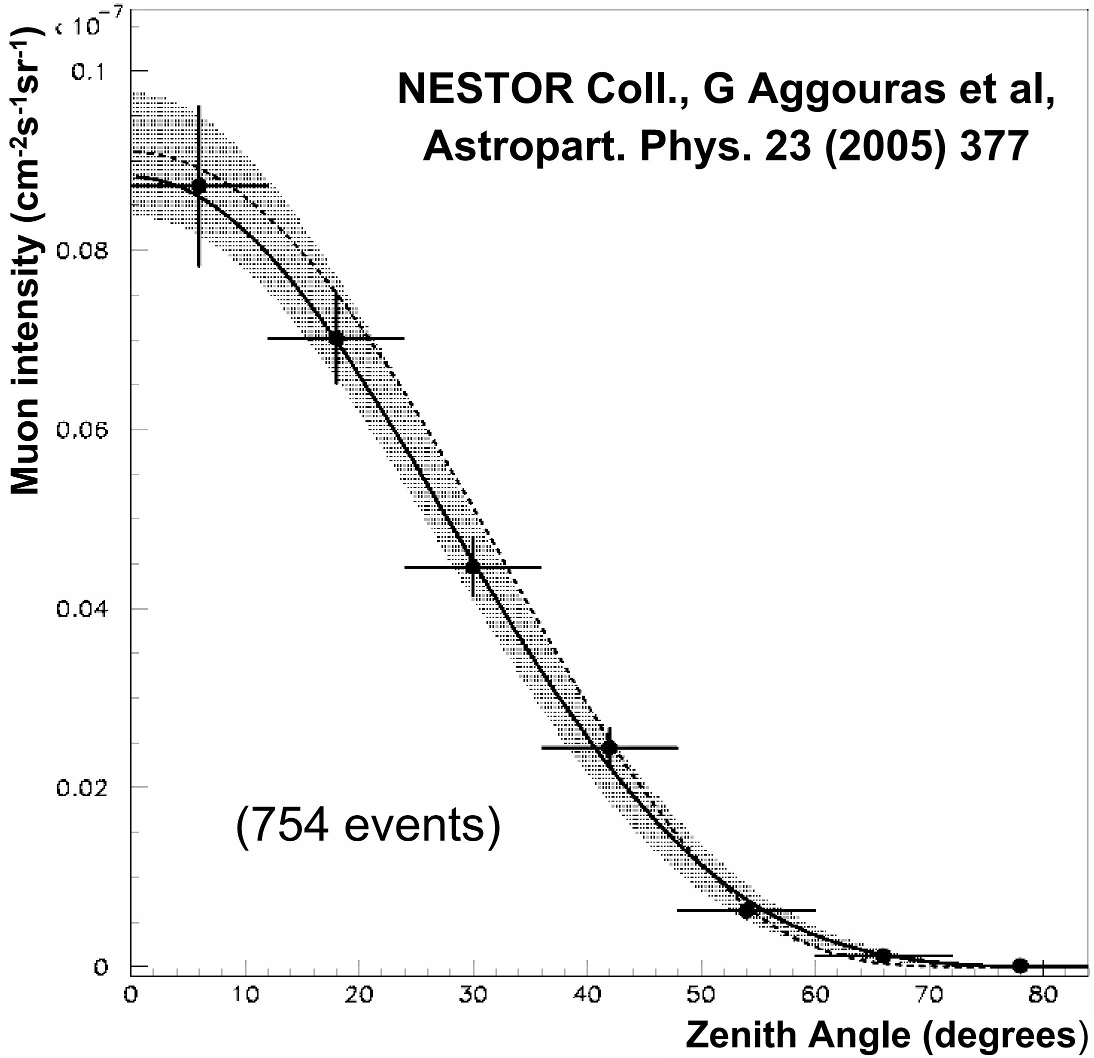
Plan: Tower(s) with12 floors

→ 32 m diameter

→ 30 m between floors

→ 144 PMs per tower

NESTOR: Measurement of the Muon Flux



Atmospheric muon flux determination and parameterisation by

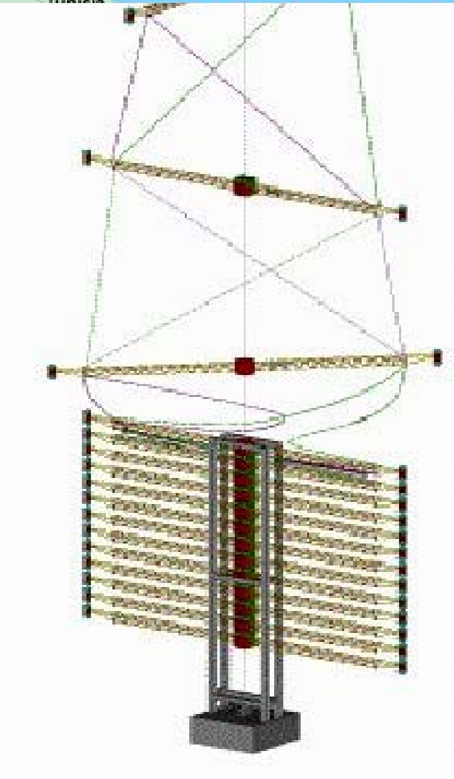
$$\frac{dN}{d\Omega \cdot dt \cdot ds} = I_0 \cdot \cos^\alpha \theta$$

α = 4.7 ± 0.5(stat.) ± 0.2(syst.)
I_0 = 9.0 ± 0.7(stat.) ± 0.4(syst.) x 10^{-9} cm^{-2} s^{-1} sr^{-1}

Results agree nicely with previous measurements and with simulations.

The NEMO Project

- Extensive site exploration (Capo Passero near Catania, depth 3500 m);
- R&D towards km^3: architecture, mechanical structures, readout, electronics, cables ...;
- Simulation.



Example: Flexible tower

- 16 arms per tower, 20 m arm length, arms 40 m apart;
- 64 PMs per tower;
- Underwater connections;
- Up- and downward-looking PMs.

NEMO Phase I

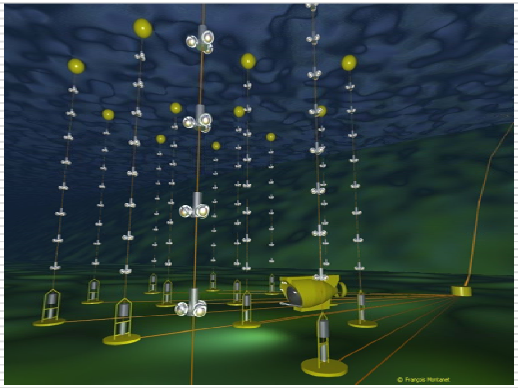
Geoseismic station

Aiming at a km^3-Detector in the Mediterranean

HENAP Report to PaNAGIC, July 2002:

- "The observation of cosmic neutrinos above 100 GeV is of great scientific importance. ..."
- "... a km^3-scale detector in the Northern hemisphere should be built to complement the IceCube detector being constructed at the South Pole."
- "The detector should be of km^3-scale, the construction of which is considered technically feasible."

How to Design a km^3 Deep-Sea ν Telescope



scale up

dilute

new design

Existing telescopes “times 30” ?

- Too expensive
- Too complicated
  (production, maintenance)
- Not scalable
  (readout bandwidth, power, ...)

R&D needed:

- Cost-effective solutions
  to reduce price/volume by factor ~2
- Stability
  goal: maintenance-free detector
- Fast installation
  time for construction & deployment less than detector life time
- Improved components

Large volume with same number of PMs?

- PM distance:
  given by absorption length in water (~60 m) and PM properties
- Efficiency loss for larger spacing

The KM3NeT Vision

- KM3NeT will be a multidisciplinary research infrastructure:
  - Data will be publicly available;
  - Implementation of specific online filter algorithms will yield particular sensitivity in predefined directions → non-KM3NeT members can apply for observation time;
  - Data will be buffered to respond to GRB alerts etc.
  - Deep-sea access for marine sciences.
- KM3NeT will be a pan-European project
  - 8 European countries involved in Design Study;
  - Substantial funding already now from national agencies.
- KM3NeT will be constructed in time to take data concurrently with IceCube.
- KM3NeT will be extendable.

KM3NeT Design Study: Participants

- Cyprus: Univ. Cyprus
- France: CEA/Saclay, CNRS/IN2P3 (CPP Marseille, IreS Strasbourg, APC Paris-7), Univ. Mulhouse/GRPHE, IFREMER
- Germany: Univ. Erlangen, Univ. Kiel
- Greece: HCMR, Hellenic Open Univ., NCSR Demokritos, NOA/Nestor, Univ. Athens
- Italy: CNR/ISMAR, INFN (Univs. Bari, Bologna, Catania, Genova, Napoli, Pisa, Roma-1, LNS Catania, LNF Frascati), INGV, Tecnomare SpA
- Netherlands: NIKHEF/FOM (incl. Univ. Amsterdam, Univ. Utrecht, KVI Groningen)
- Spain: IFIC/CSIC Valencia, Univ. Valencia, UP Valencia
- UK: Univ. Aberdeen, Univ. Leeds, Univ. Liverpool, Univ. Sheffield

Particle/Astroparticle institutes (29) – Sea science/technology institutes (7) – Coordinator

Objectives and Scope of the Design Study

Establish path from current projects to KM3NeT:

- Critical review of current technical solutions;
- New developments, thorough tests;
- Comparative study of candidate sites (figure of merit: physics sensitivity / €);
- Assessment of quality control and assurance;
- Intensify and assess links to industry;
- Investigation of funding and governance models.

Major objectives:

- Conceptual Design Report by summer 2007;
- Technical Design Report by February 2009;
- Limit overall cost to 200 M€ per km^3 (excl. personnel).

Some Key Questions

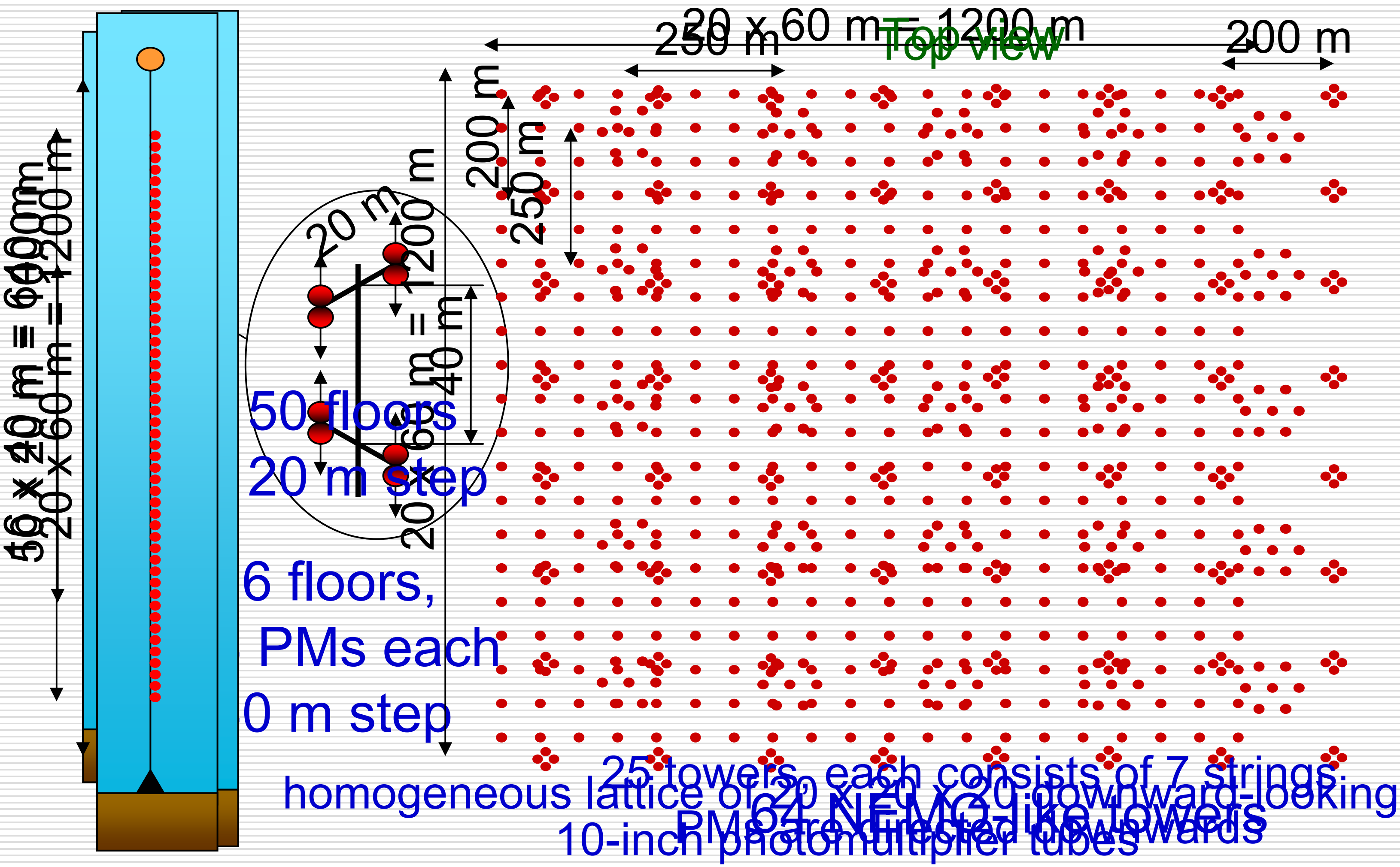
- Which architecture to use?
(strings vs. towers vs. new design)

All these questions are highly interconnected !

- How to get the data to shore?
(optical vs. electric, electronics off-shore or on-shore)
- How to calibrate the detector?
(separate calibration and detection units?)
- Design of photo-detection units?
(large vs. several small PMs, directionality, ...)
- Deployment technology?
(dry vs. wet by ROV/AUV vs. wet from surface)
- And finally: path to site decision.

Detector Architecture

(D. Zaborov at VLVνT)



Sea Operations

- Rigid towers or flexible strings?
- Connection in air (no ROVs) or wet mateable connectors?
- Deployment from platform or boat?

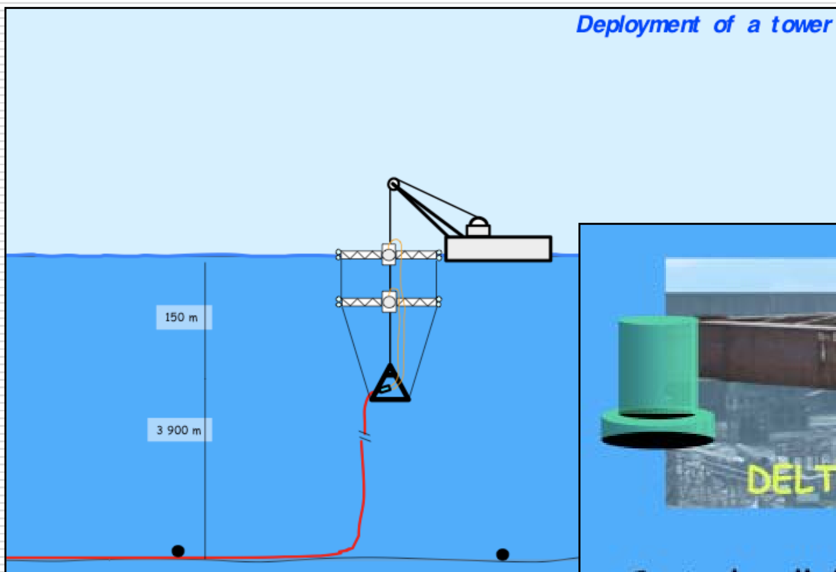
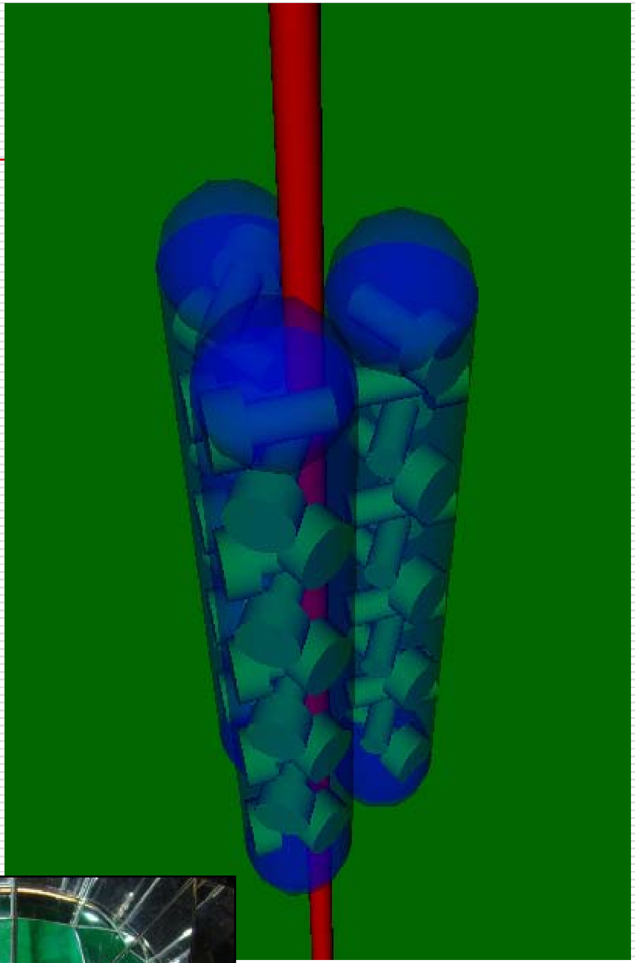
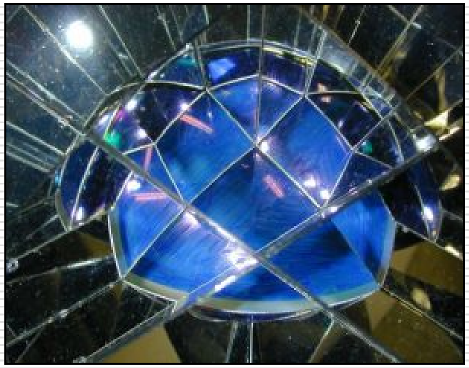
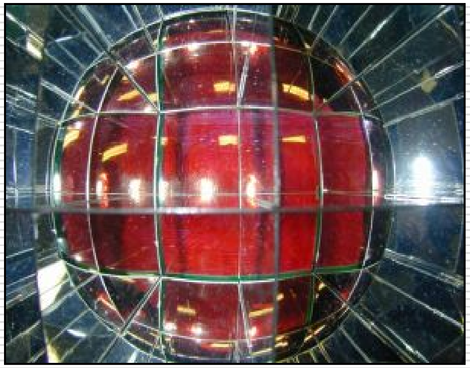
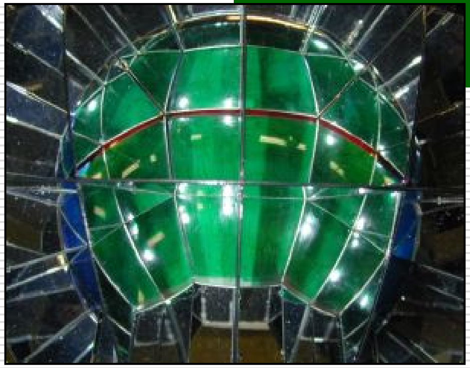


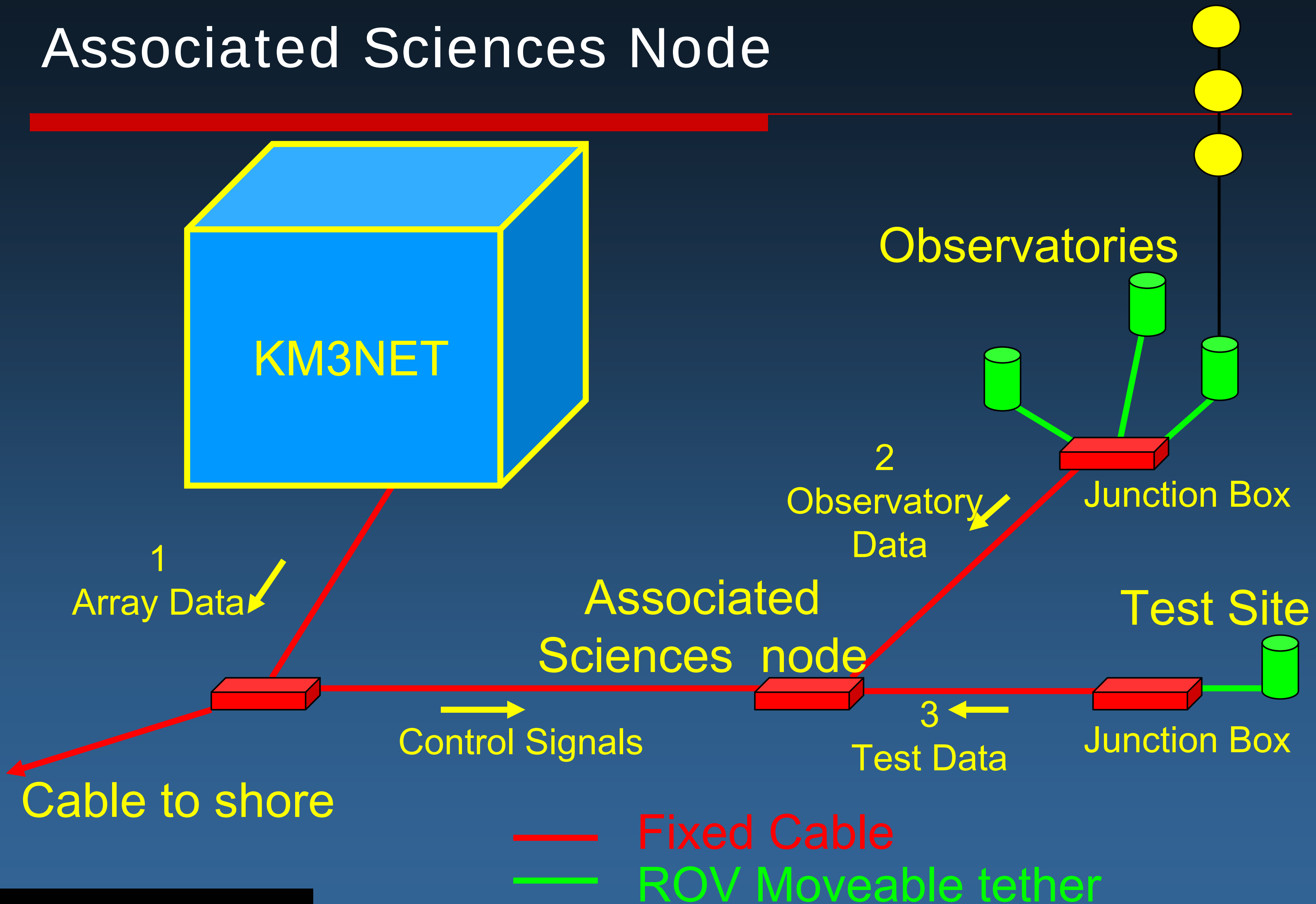
Photo Detection: Options

- Large photocathode area with arrays of small PMs packed into pressure housings – improved timing and amplitude resolution.
- Determination of photon direction, e.g. via multi-anodic PMs plus a matrix of Winston cones.
- But: phase space for developments from scratch is too tight.



Associated Sciences Node



M. Priede, Sept. 2005

KM3NeT: Towards a Site Decision

- Final site decision involves scientific and political arguments (funding, host country support, …).
- Objective of Design Study:
  Provide scientific input and stimulate political discussion.
- Possible scenario: Similar to Pierre Auger Observatory (two candidate sites, decision based on commitment of host country).
- Relation of funding options to site choice will be explored in Design Study.

KM3NeT: Path to Completion

Time schedule (partly speculative & optimistic):

01.02.2006	Start of Design Study
Mid-2007	Conceptual Design Report
February 2009	Technical Design Report
2009-2010	Preparation Phase (possibly in FP7)
2010-2012	Construction
2011-20xx	Data taking

Conclusions and Outlook

- A km^3-scale neutrino telescope in the Mediterranean is required to exploit the potential of neutrino telescopy.
- The pilot projects prove the feasibility of deep-sea neutrino telescopes and provide a huge source of experience and technical solutions.
- The technical design will be worked out in a 3-year Design Study.
- KM3NeT will be a pan-European, interdisciplinary research infrastructure open to the entire community and the marines sciences.
- With KM3NeT, Europe will take the lead in neutrino astronomy.