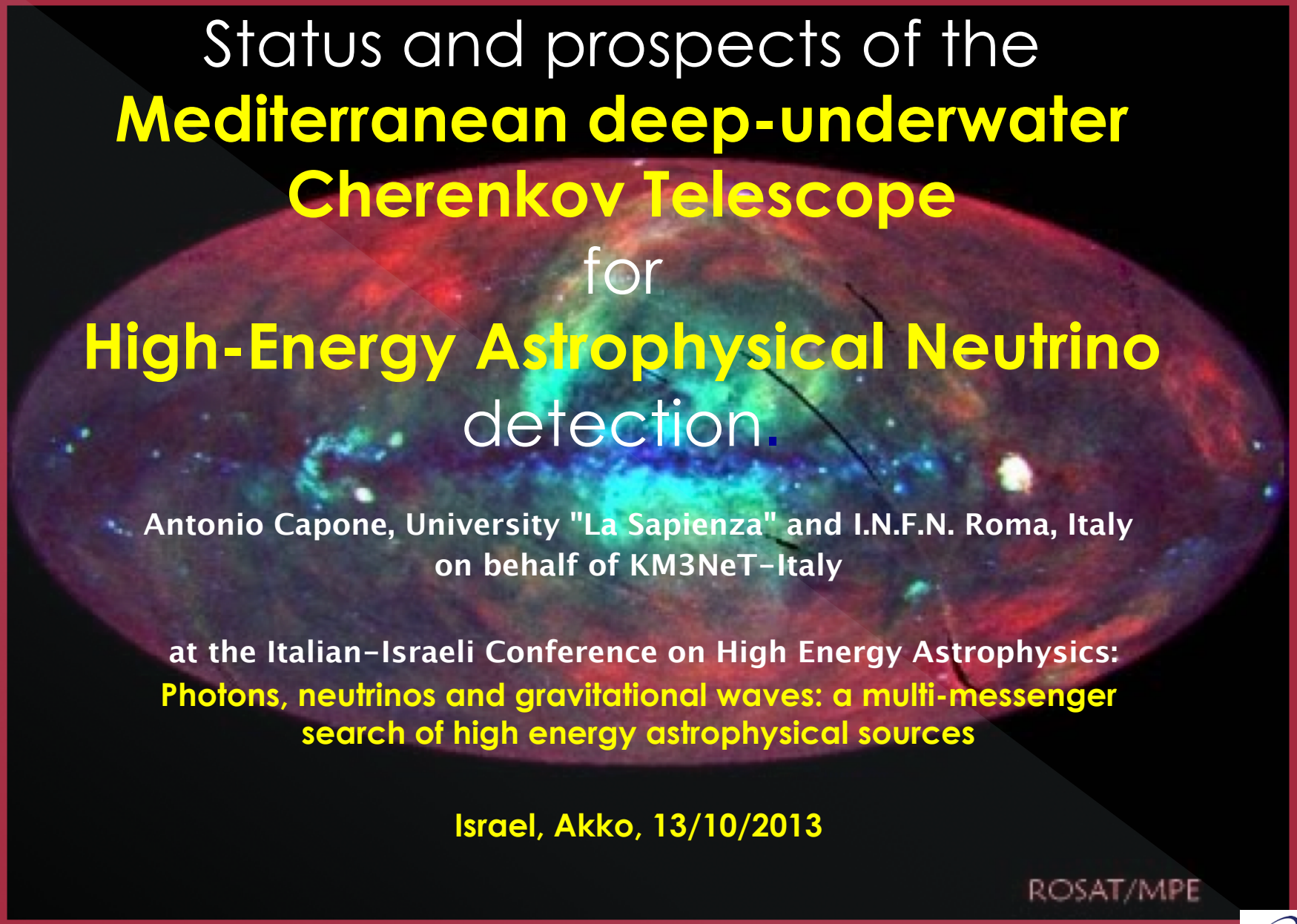
Status and prospects of the **Mediterranean deep-underwater Cherenkov Telescope** for **High-Energy Astrophysical Neutrino** detection.

Antonio Capone, University "La Sapienza" and I.N.F.N. Roma, Italy
on behalf of KM3NeT-Italy

at the Italian-Israeli Conference on High Energy Astrophysics:
Photons, neutrinos and gravitational waves: a multi-messenger search of high energy astrophysical sources

Israel, Akko, 13/10/2013



Outline

- **Physics motivation for a Mediterranean Cherenkov Neutrino Telescope**
- **Aiming at Km^3 Neutrino Telescope in Mediterranean Sea:**
  - KM3NeT (ANTARES + NEMO + NESTOR + …)
  - Joining efforts, design and technologies towards a common project
  - Pan-European coordination of funding agencies and research Institutions

  and at active synergies with marine-sciences deep sea researches
- **Status and perspectives**

KM3NeT-Italy:

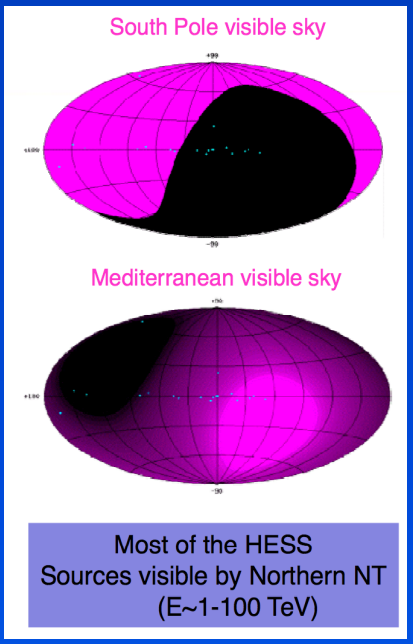
INFN: Bari, Bologna, Catania, Genova, Lab. Naz. Frascati, Lab. Naz. Sud, Napoli, Pisa, Roma, Salerno

IFIC, Instituto de Fisica Corpuscular, Valencia
UPV, Universitat Politecnica de Valencia

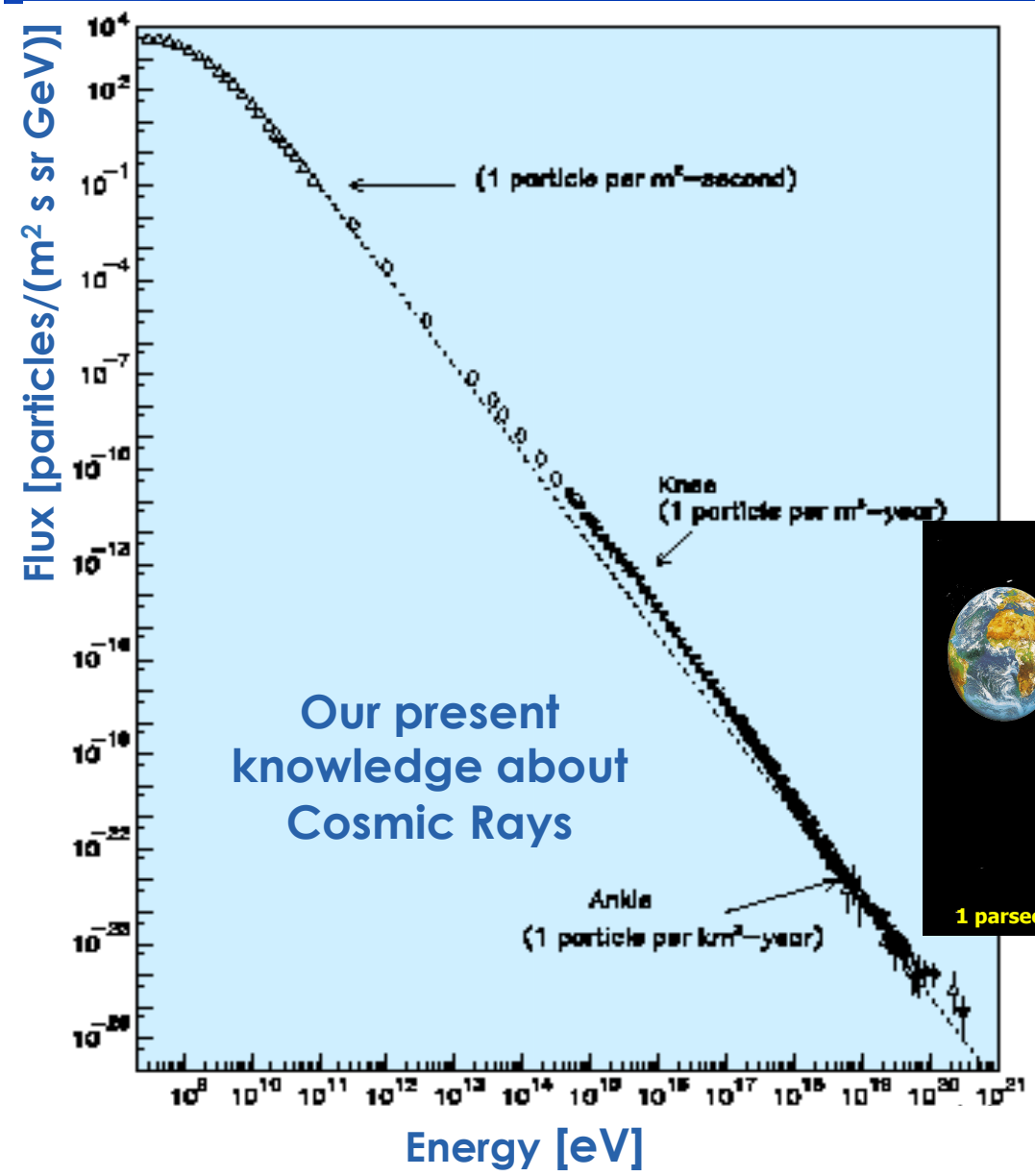
- **Physics with a Mediterranean Neutrino Telescope**
  - Complementarity to the South Pole IceCube detector
  - Multi-km^3 detector exceeding ANTARES and IceCube in sensitivity
  - Central physics goals:
    - galactic neutrino sources ($1 < E_\nu < 100$ TeV, point-like)
    - high-energy diffuse neutrino flux
    - extragalactic sources
    - Dark Matter (indirect detection)
    - Neutrino properties
    - Exotics (monopoles, nuclearites, sterile neutrinos...)

… and in a multi-messenger approach:

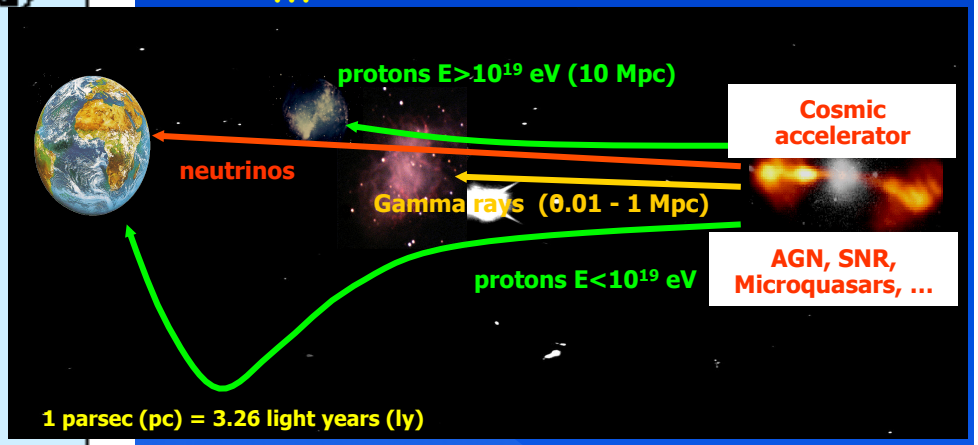
  - origin of cosmic rays, internal dynamics of sources and acceleration processes



The Universe is transparent for UHE neutrinos !

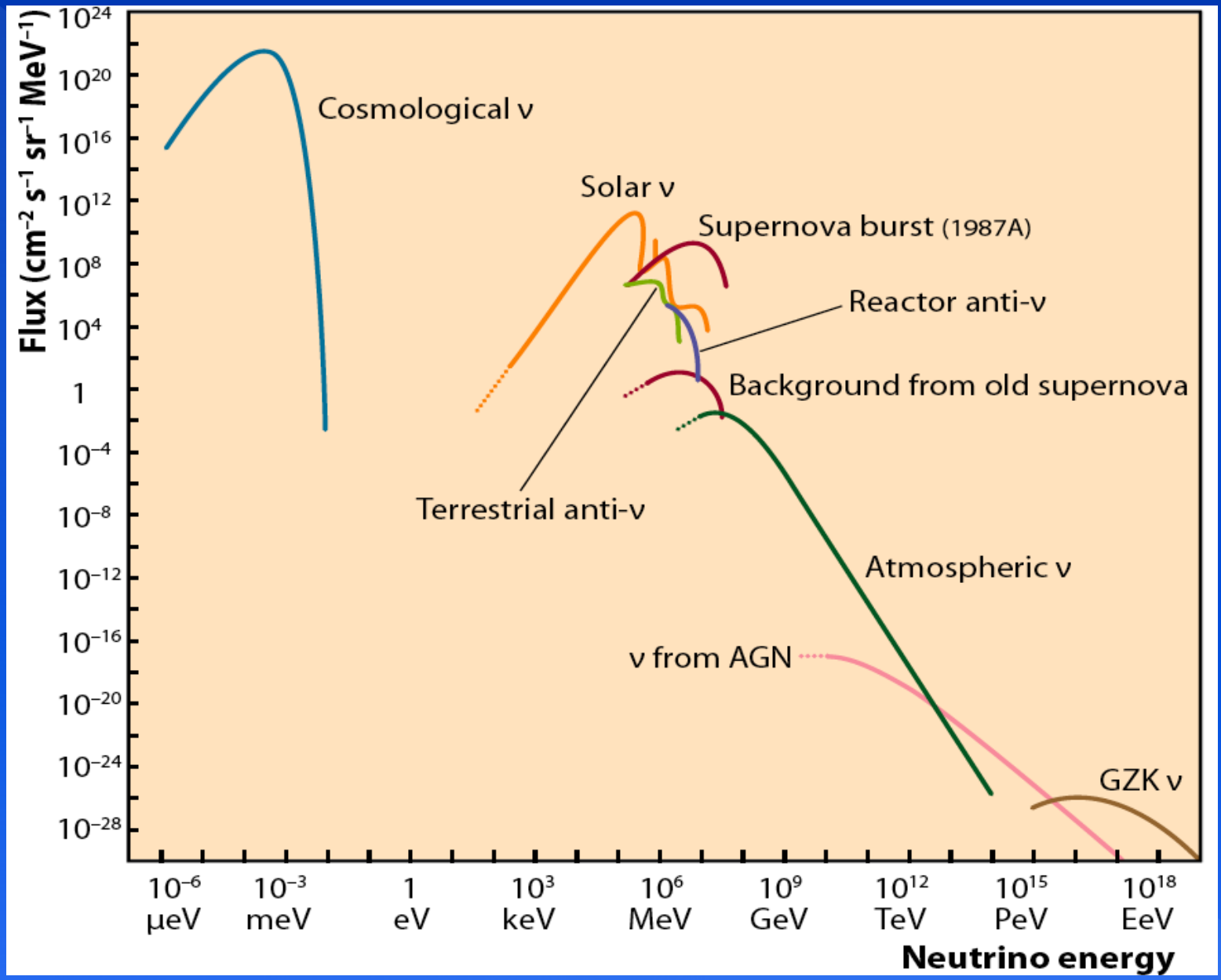


- Observed elementary particles or nuclei carrying a kinetic energy up to 10^{21}eV (like a tennis ball moving at ~150km/h)
- Many open questions:
  - Where they come from ?
  - Which acceleration mechanism ?
  - …



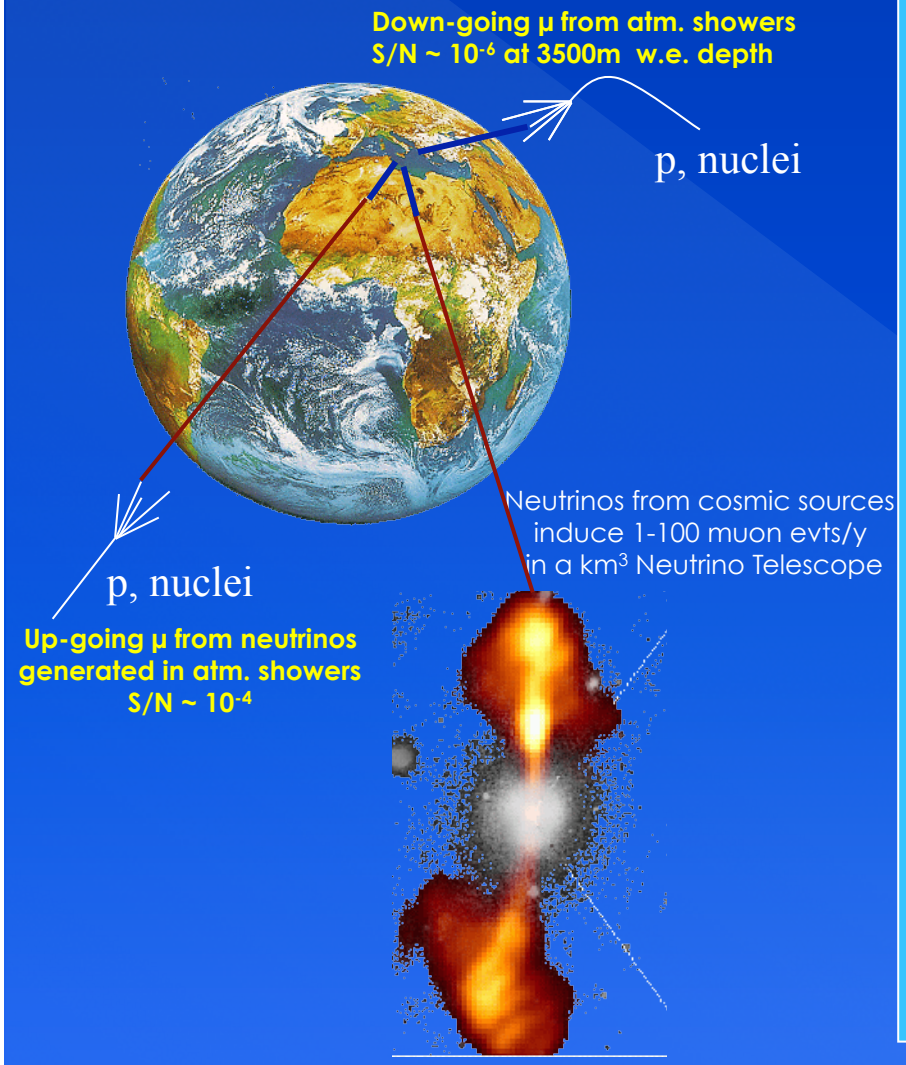
- **UHE astrophysical neutrinos will extend the limits of the "visible" Universe.**
- **Multi-messenger observations**

Neutrino fluxes: what do we know/expect ?



Detection principle

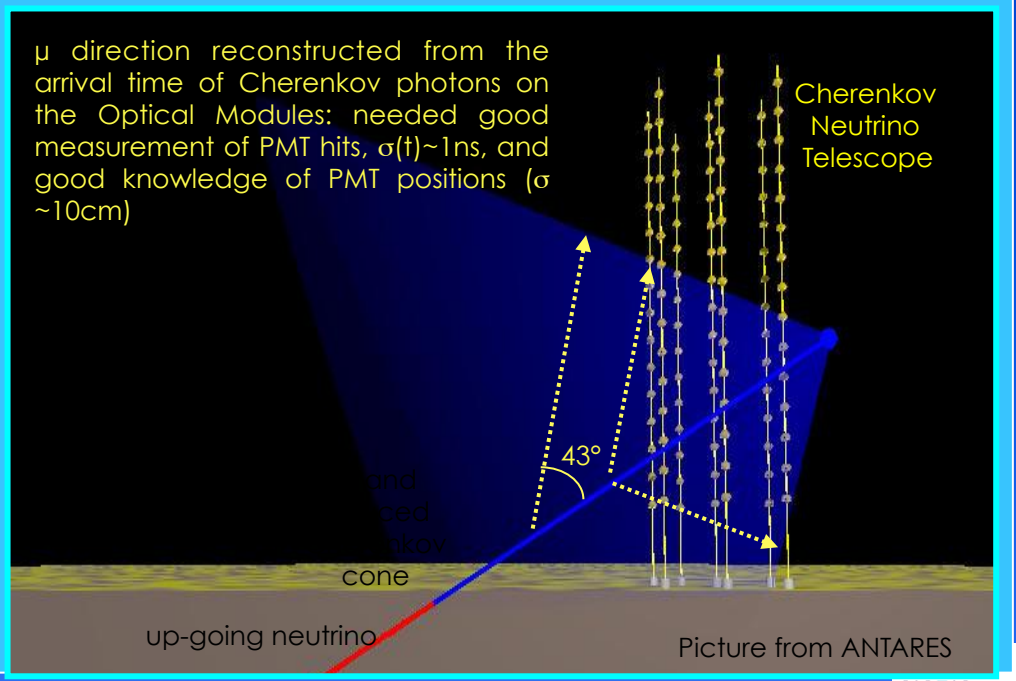
Search for neutrino induced events, mainly $\nu_\mu N \rightarrow \mu X$, deep underwater



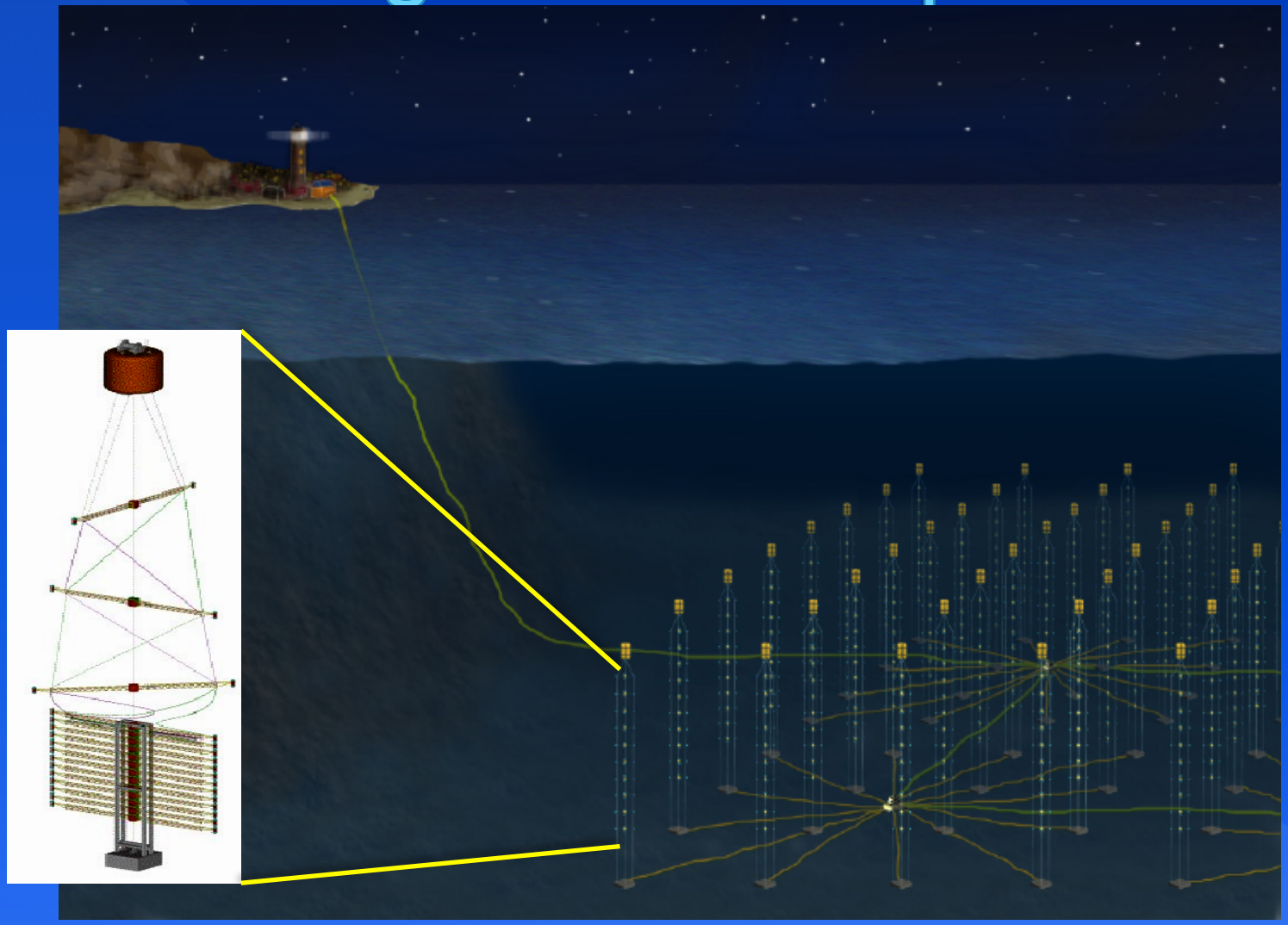
- Atmospheric neutrino flux ~ E_ν^{-3}
- Neutrinos flux from cosmic sources ~ E_ν^{-2}
  - Search for neutrinos with E_ν>1÷10 TeV

- ~TeV muons propagate in water for several km before being stopped
  - go deep to reduce down-going atmospheric μ backg.
  - long μ tracks allow good angular reconstruction

$$For\ E_\nu \geq 1TeV \quad \theta_{\mu\nu} \sim \frac{0.7^\circ}{\sqrt{E_\nu[TeV]}}$$

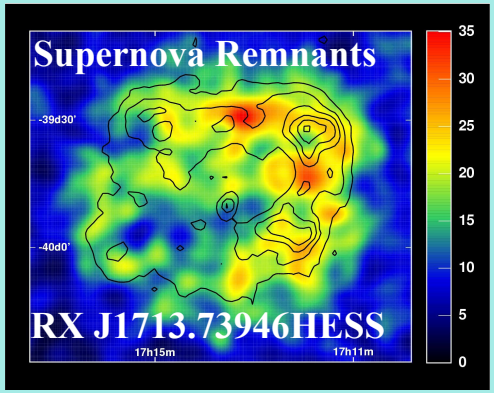


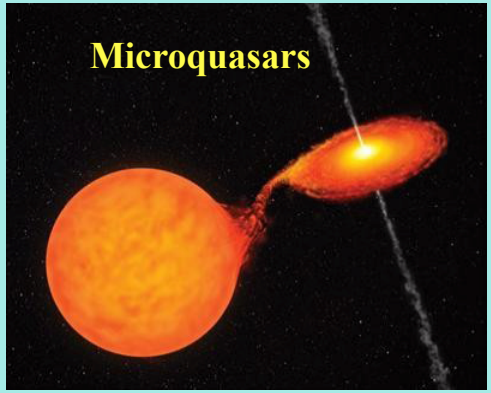
The NEMO-Km^3 Detector concept: a 3D semi-rigid structure holding O.M. in fixed positions



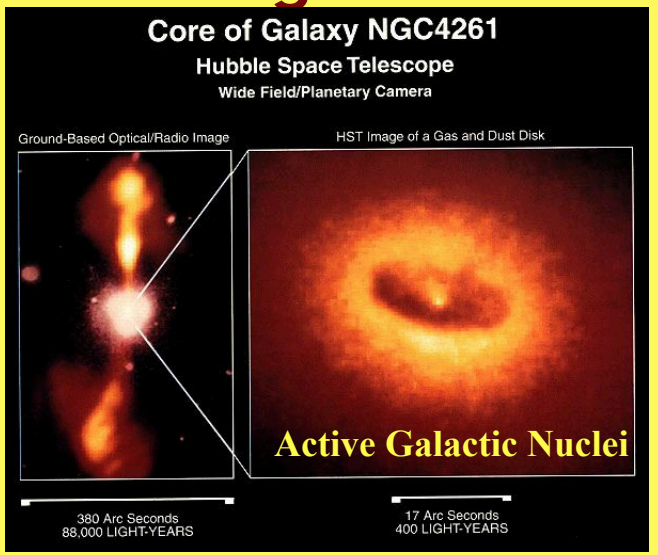
Point like cosmic Neutrino Sources

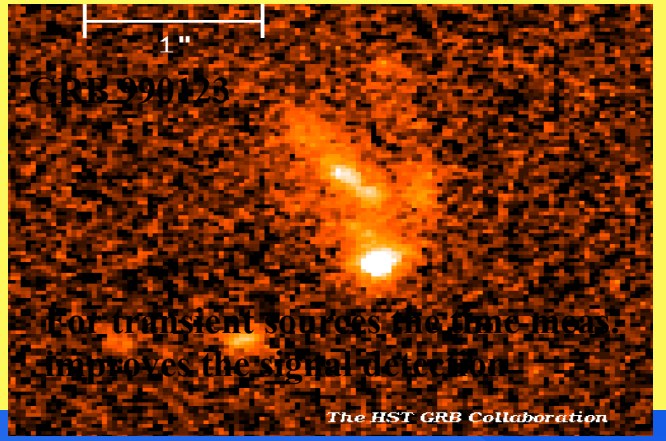
Galactic





Extragalactic





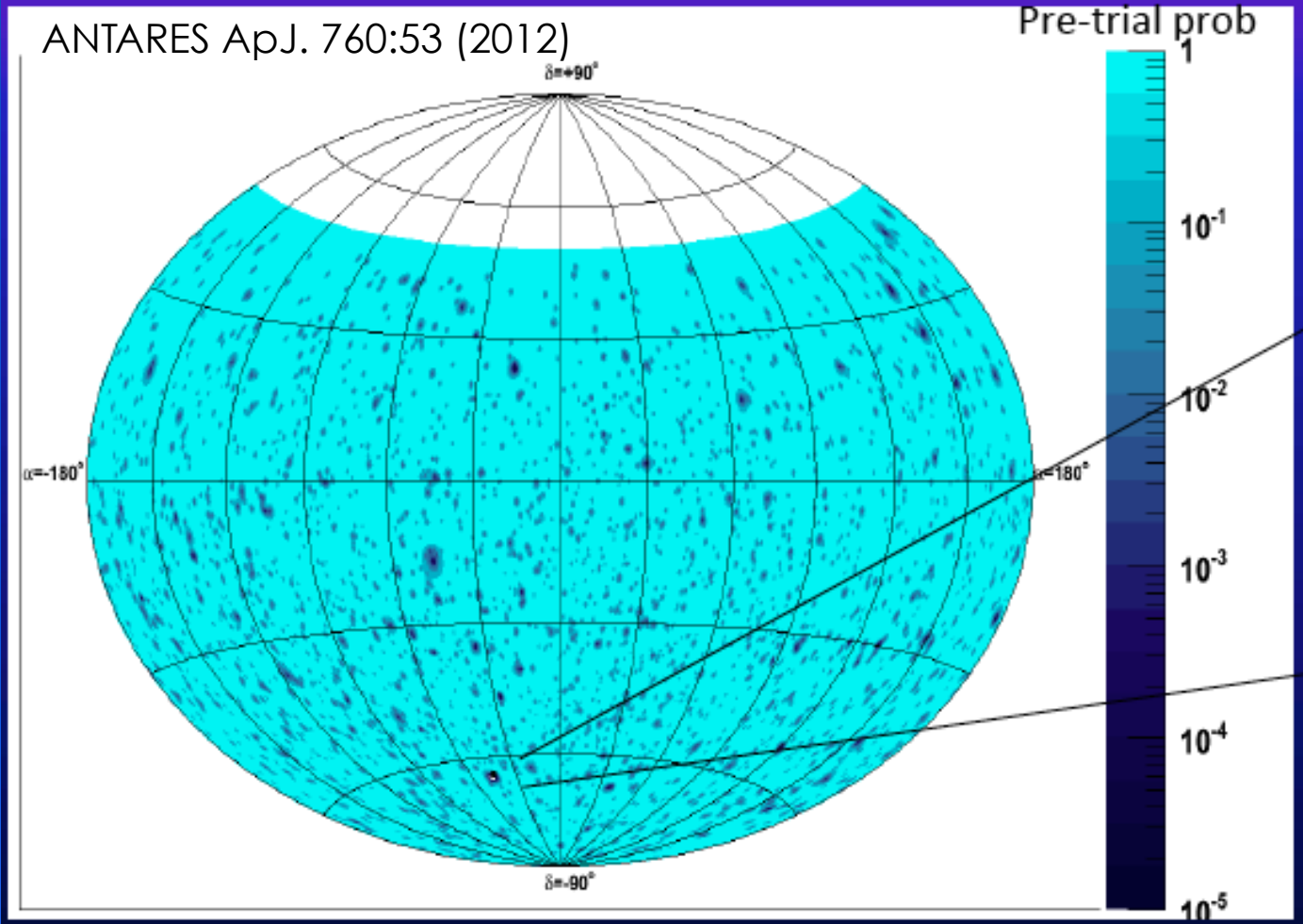
Their identification requires a detector with accurate angular reconstruction

$$\sigma(\vartheta) \leq 0.5^\circ \text{ for } E_\nu \geq 1 TeV$$

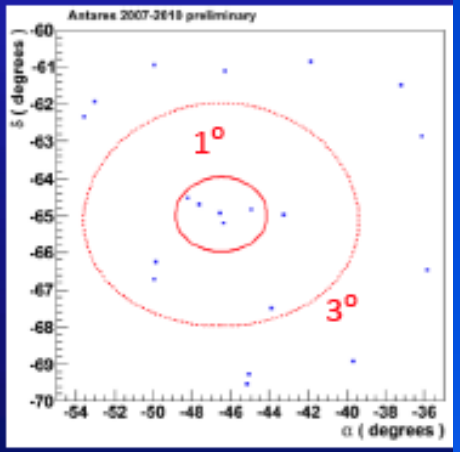
Experimental signal : statistical evidence of an excess of events coming from the same direction

An example: the ANTARES search for point-like sources

ANTARES ApJ. 760:53 (2012)



Most significant cluster at:
$\mathcal{RA} = -46.5°$,
$\delta = -65.0°$



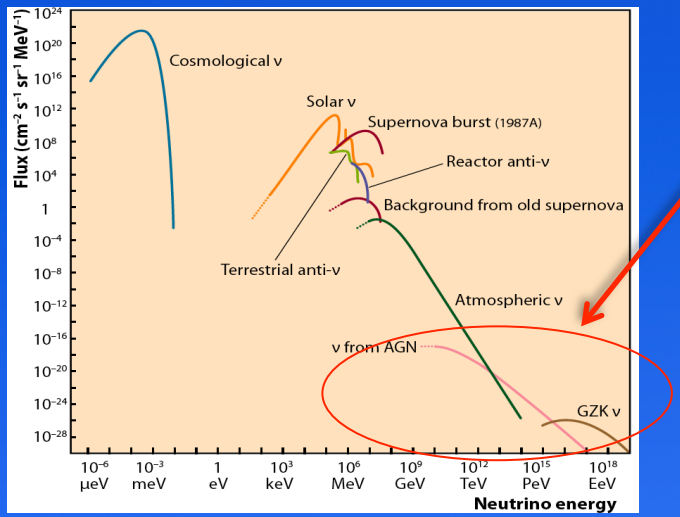
$N_{sig} = 5$
p-value=0.026
(post-trial)
Significance = 2.2 σ

Results compatible with the background hypothesis

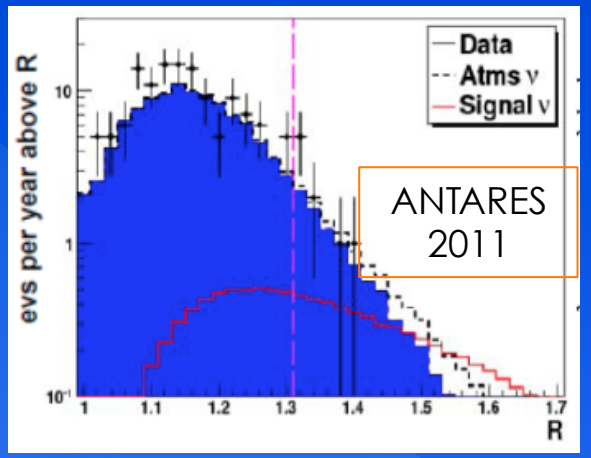
Diffuse Cosmic Neutrino Sources

- Unresolved AGN
- Neutrinos from "Z-bursts"
- Neutrinos from "GZK like" p-CMB interactions
- Neutrinos foreseen by Top-Down models
- ....

Their identification out of the more intense background of atmospheric neutrinos (and muons) is possible at very high energies (E > TeV) and implies accurate energy reconstruction.

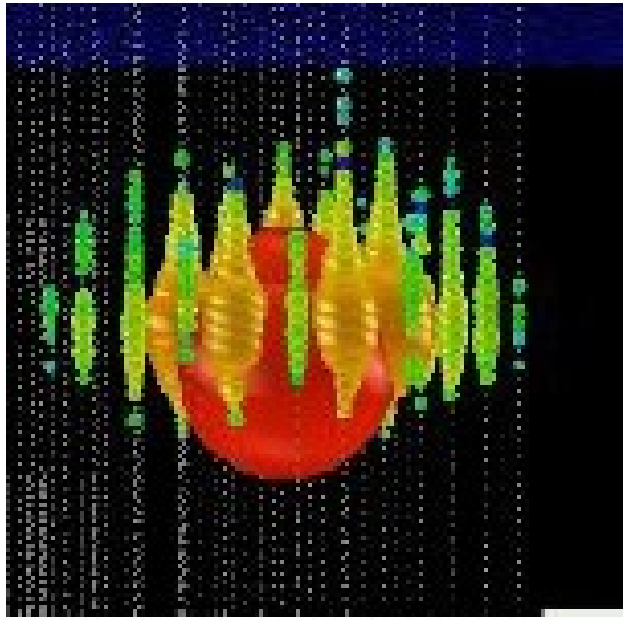


Search here !!!

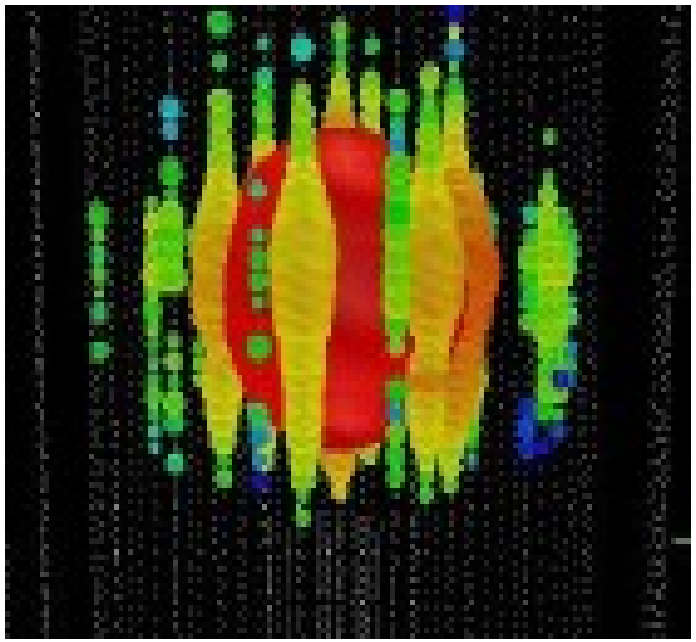


Discovery !!!!

The first two VHE astrophysical ν events observed by IceCUBE



T. Stanev
NOW-2012



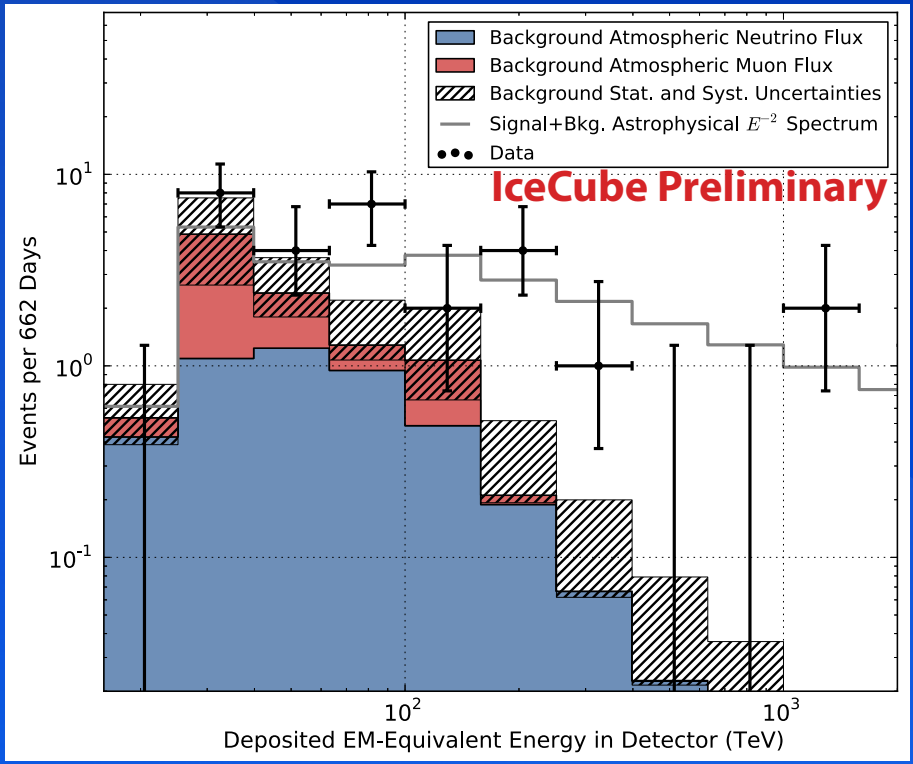
312 DOMs

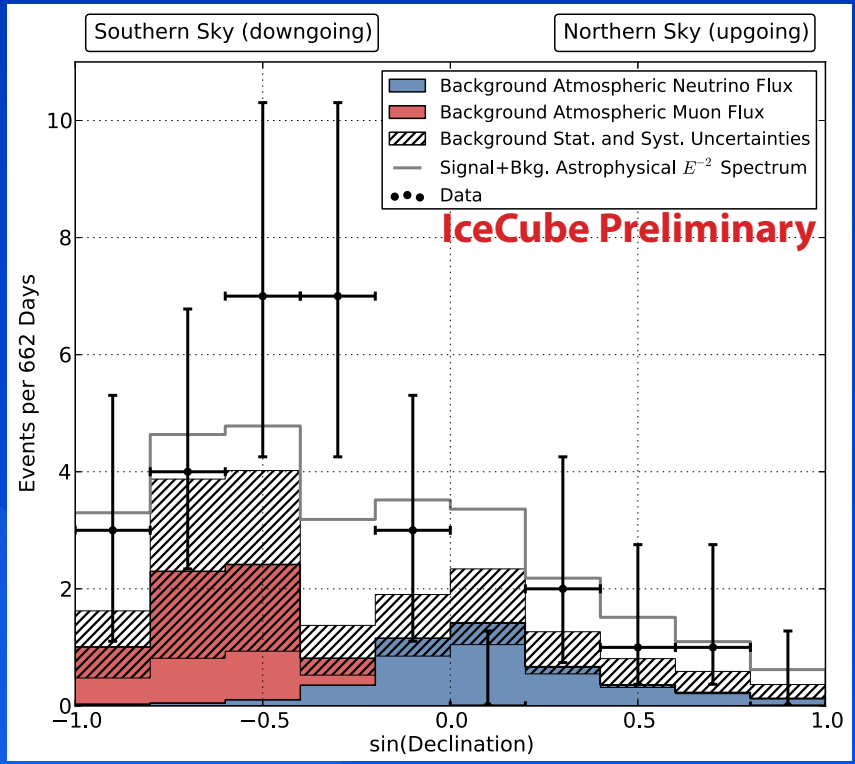
354 DOMs

Two neutrino events of energy above 10^{15} eV detected in IceCube were reported on Neutrino 2012 by **Aya Ishihara**. The first thought was that these events are produced by electron antineutrinos generating the Glashow resonance.

Discovery !!!!

28 contained VHE astrophysical ν events reported by IceCUBE





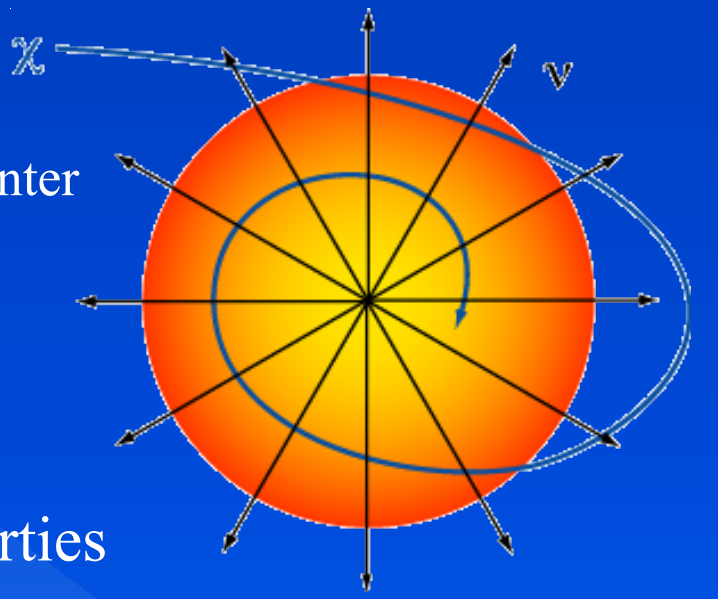
- Observed energy distribution harder that any expected atmospheric background
- Measured event sample compatible with isotropic neutrino flux

THE NEUTRINO ASTRONOMY CHAPTER IS NOW OPEN !!!

… not only neutrino astrophysics…

… also open problems in particle physics …

- Dark Matter searches:
  - Neutralinos from Sun, Earth, Galactic Center
- Monopoles, Nuclearites
- Acceleration mechanisms
- Neutrino interaction Cross sections
- Neutrino oscillations, neutrino properties
- …



Neutralino search: $\chi\chi \rightarrow \nu$+…

ANTARES - Multi-Messenger Searches

Potential astrophysical sources are predicted to emit very faint neutrino signal. The Multi-Messenger Approach increases the **discovery potential**, by observing with different probes; the **significance**, by coincident detection; the **efficiency**, by relaxed cuts.

ANTARES ⟺ VIRGO LIGO

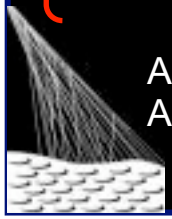
common working group (GWHEN)
5 Line data
S. Adrián-Martínez et al.,
JCAP 06 (2013) 008

AGN Flares
(ν emission from γ-flaring blazars)

ANTARES ⟺ FERMI

S. Adrián-Martínez et al.
Astropart. Phys. 35 (2012) 634

ANTARES ⟺ AUGER



Adrian-Martinez et al.,
ApJ 774 (2013) 008

TATOO
(Telescopes – ANTARES Target of Opportunity)
Optical follow-up of **neutrino alerts** for transient source search (GRBs, SNae).
Analysis in progress!

ANTARES ⟺ Optical Telescopes
TAROT & ROSTE + more

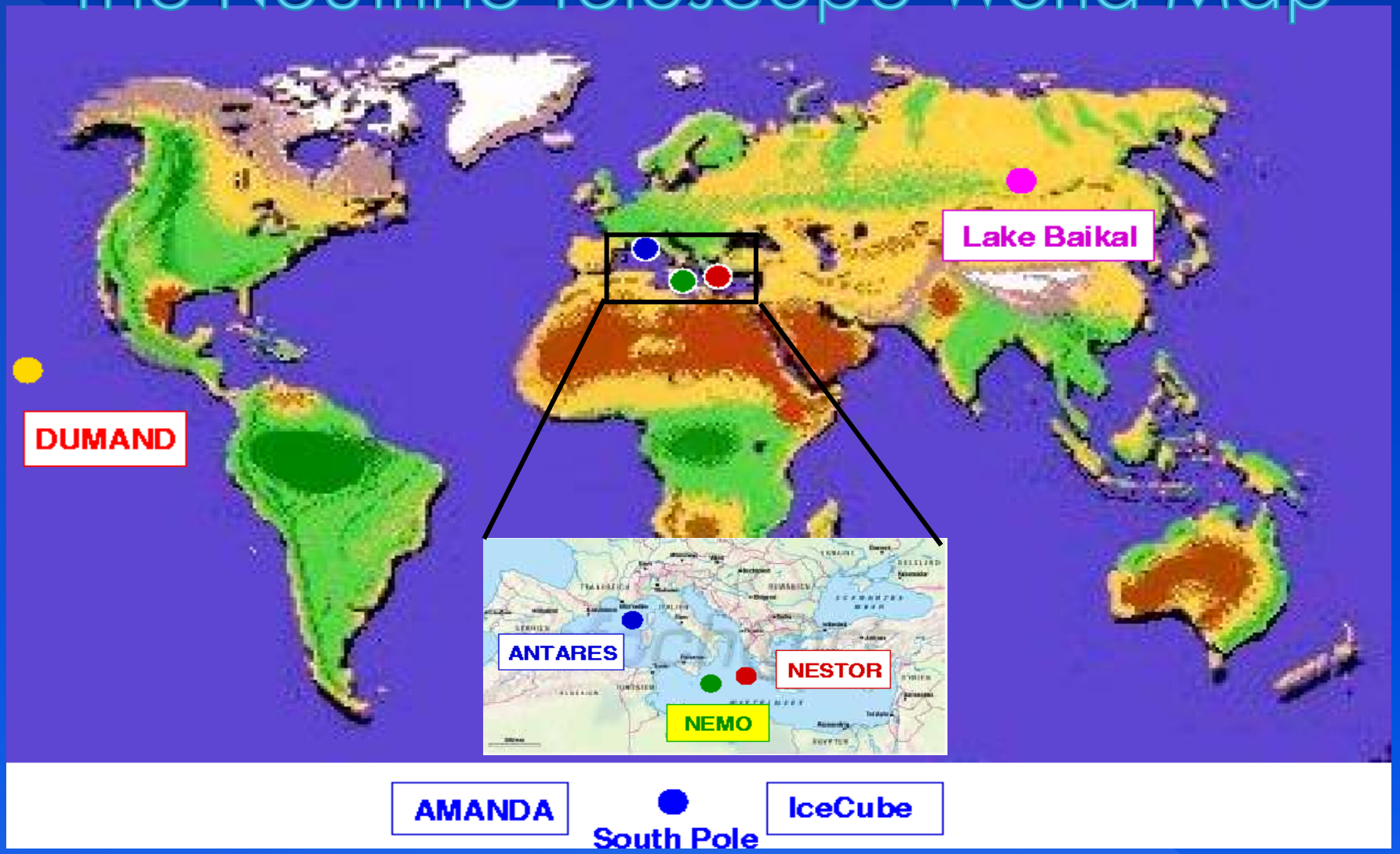
Ageron *et al.*, *Astrop.Phys* 35 (2012) 530-536

GCN
(**GRB** Coordinat. Network)

ANTARES ⟺ GCN

1.S. Adrián-Martínez et al.,
JCAP 1303 (2013) 006

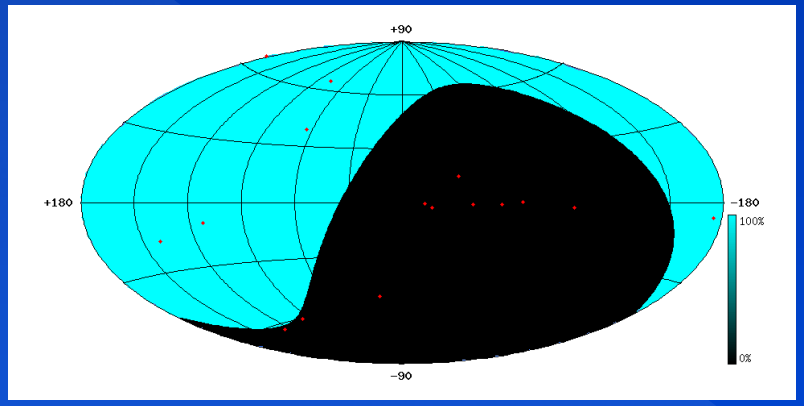
The Neutrino Telescope World Map

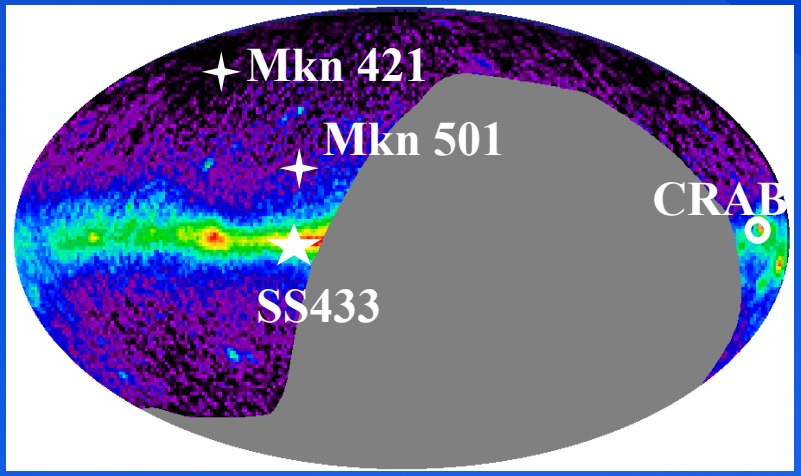


ANTARES + NEMO + NESTOR joined their efforts to prepare a km^3-scale Cherenkov neutrino telescope in the Mediterranean → **KM3NeT Collaboration**

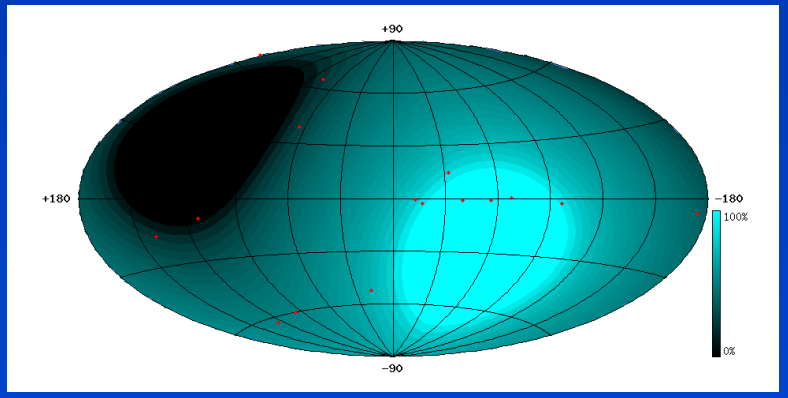
Locations for Neutrino Astronomy

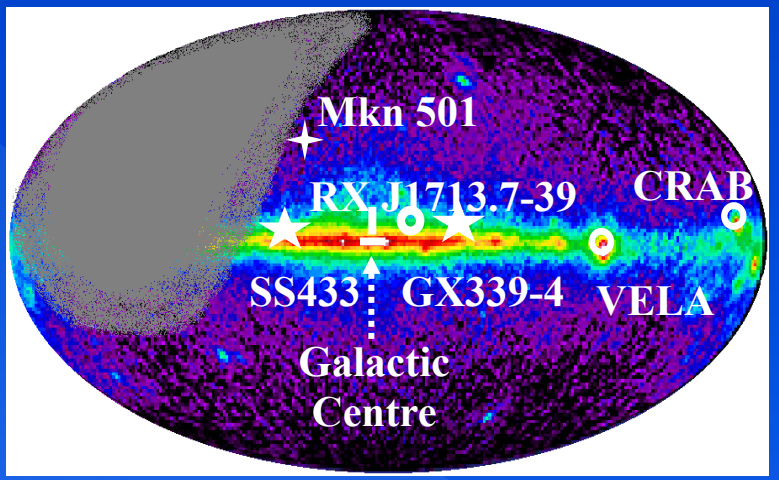
From Antartica





From Mediterranean Sea



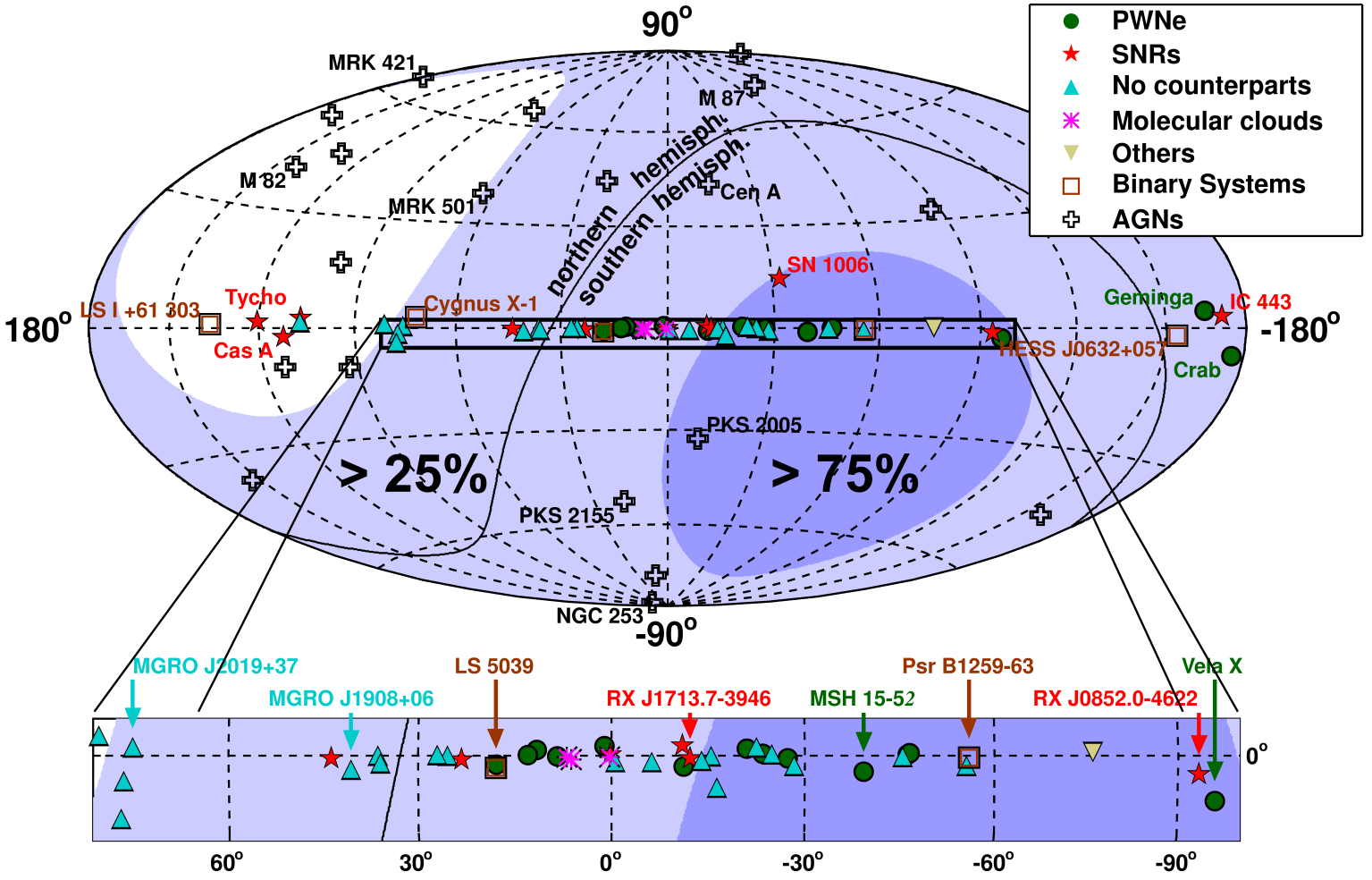


Mediterranean location provides a 3π sr sky coverage, 0.5π sr instantaneous common view with IceCube, and about 1.5π sr common view per day. The Galactic centre is visible 2/3 of the time.

A Km³ Neutrino Telescope in Mediterranean Sea will be complementary to IceCube and … will search for neutrino sources in the Galactic centre

Mediterranean Sea ν Telescope Sky Coverage

Observed sky, in galactic coordinates, by a detector efficient to tracks from below the horizon (up-going tracks).



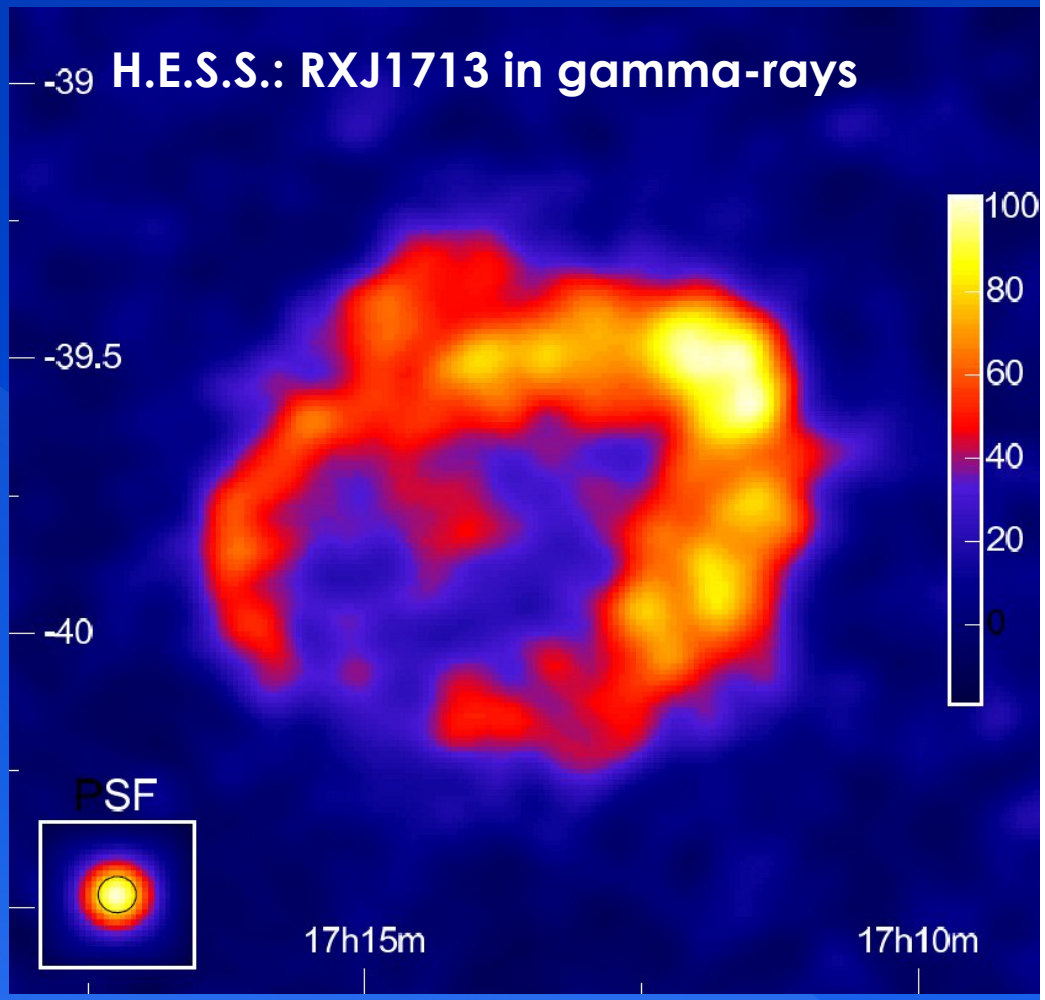
→ We need a km³ Northern ν Telescope to cover the Galactic Plane

Sensitivity to galactic source for a Mediterranean ≈5km^3 Cherenkov ν Telescope

For a galactic Supernova Remnant:
RXJ1713.7-3946

5σ discovery in less than 5 years
(50% probability)

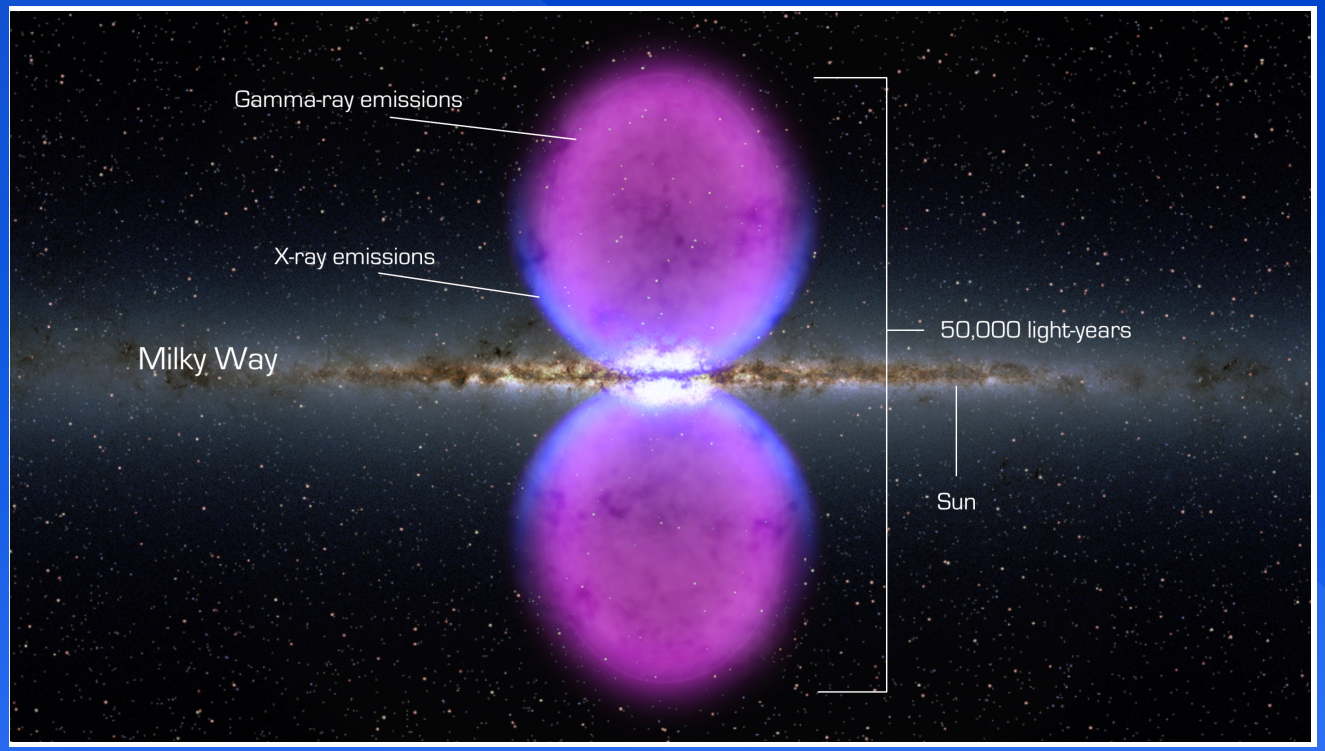
Further candidate sources with similar or better discovery chances: Vela X, …



Neutrinos from "FERMI Bubbles" ??

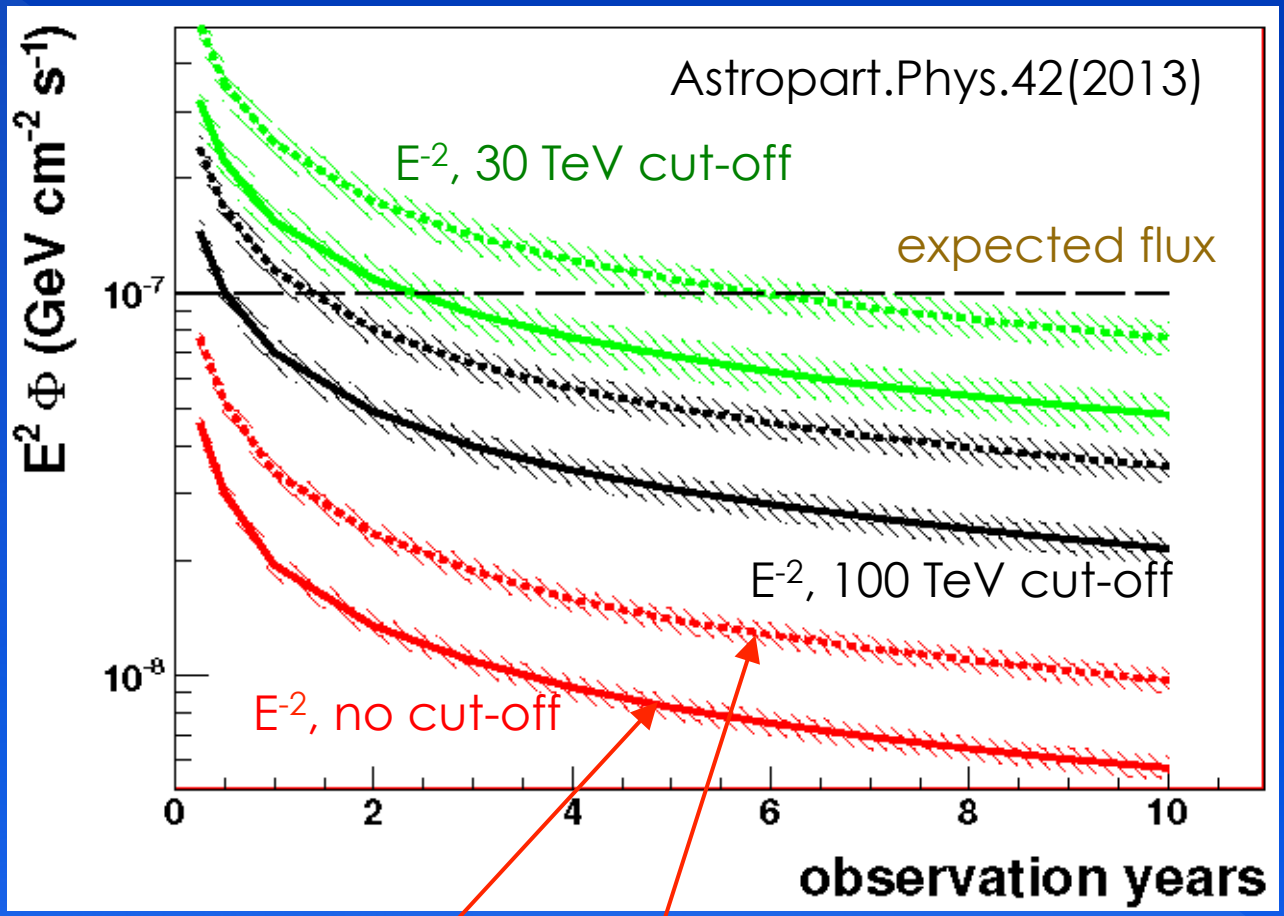
Search possible for a Mediterranean Cherenkov ν Telescope

- FERMI detected hard γ emission (E^{-2}) up to 100 GeV in extended "bubbles" around Galactic Center, hard spectrum not compatible with Inverse Compton mechanism, M.Su et al., Ap.J.724 (2010).
- Models involving hadronic processes (e.g. Crocker & Aharonian, PRL 2011) predict significant neutrino fluxes.
- This could be one of the first neutrino "source" for the Mediterranean ν Telescope.



Sensitivity to H.E. ν from "FERMI Bubbles"

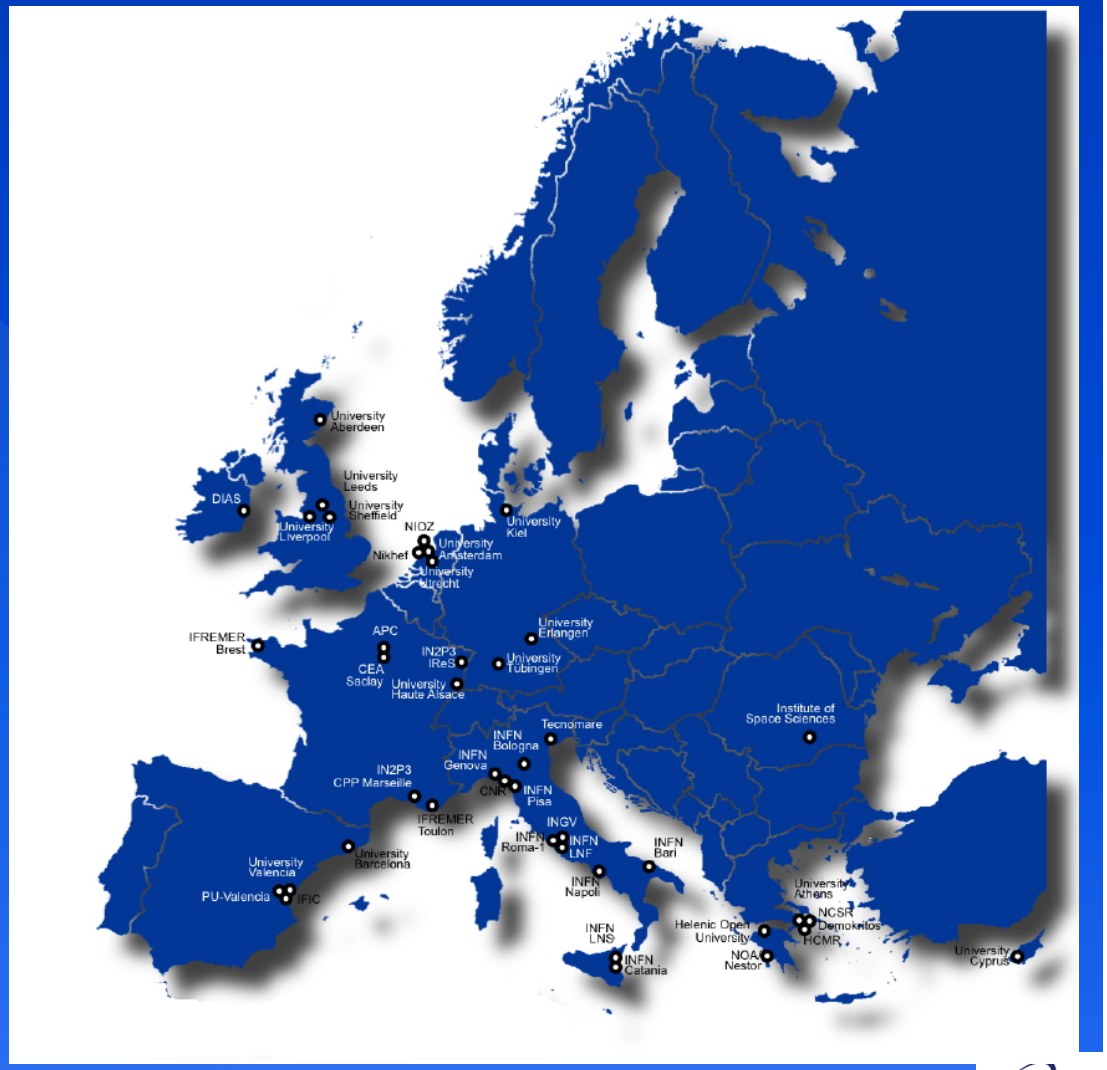
for a ≈ 5km³ Mediterranean Cherenkov ν Telescope



International Collaboration involving more than 300 scientists from 10 EU countries (CY, DE, ES, FR, GR, IE, IT, NL, RO, UK)

KM3NeT

- Objective: to build the most sensitive high energy neutrino telescope in the Northern Hemisphere
- KM3NeT is on the ESFRI roadmap since 2006



A Brief History of KM3NeT

- Started in February 2006 with the Design Study project co-funded with 9 M€ under the 6th EC Framework Programme
  - Coordinated by University of Erlangen, Germany (U. Katz)
- In 2007 included in the roadmap of the European Strategy Forum of Research Infrastructures (ESFRI)
- In 2008 co-funded with 5 M€ for a "Preparatory Phase" under the 7th EC Framework Programme and concluded in February 2012
  - Coordinated by INFN-LNS, Italy (E. Migneco)

A Brief History of KM3NeT

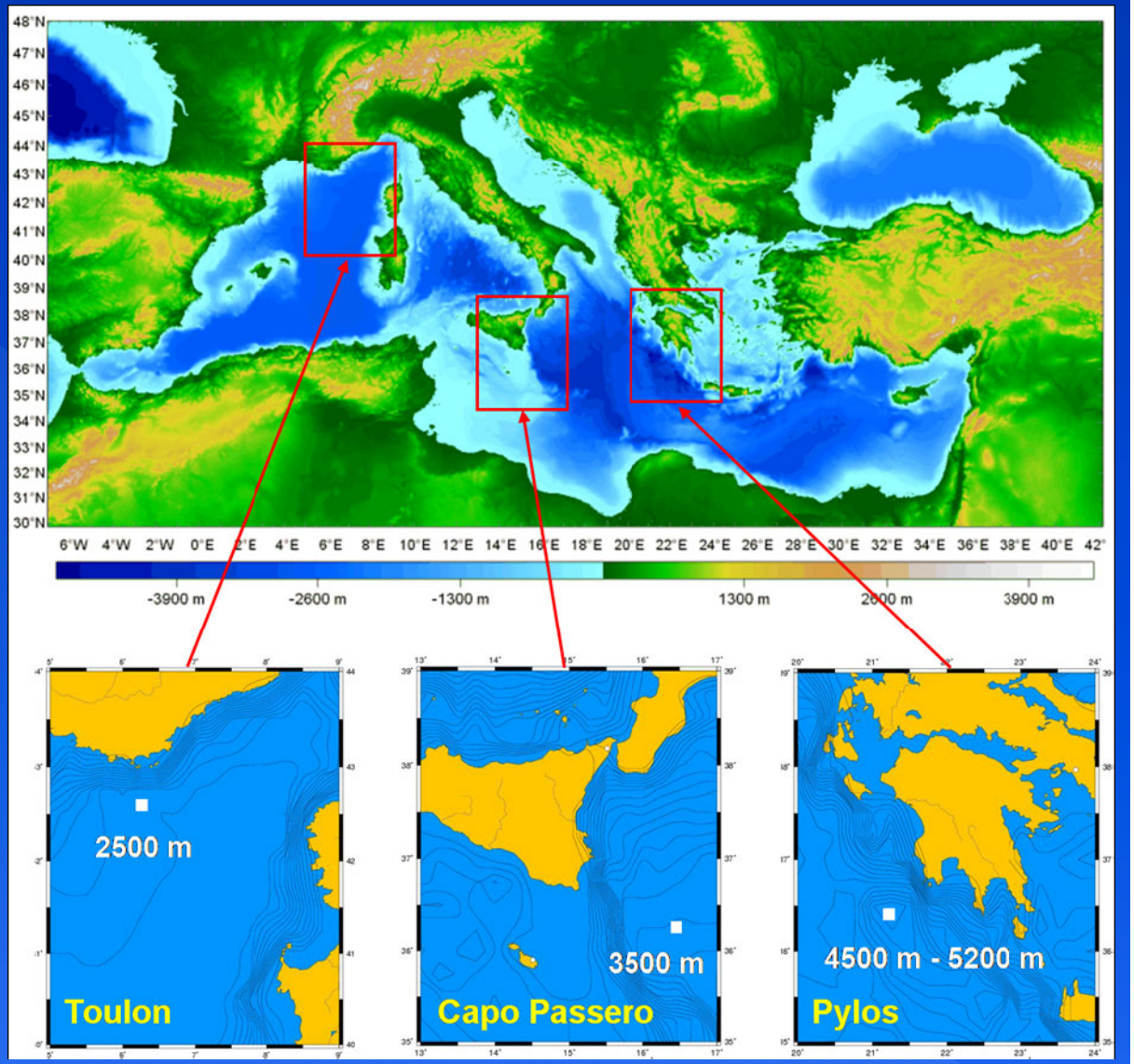
- End of 2011
  - **IT: 20.8 M€ PON budget for detector construction to be spent before end 2014. A full-proved DU technology needed to start the construction !!!**
- Funds available
  - FR: for sea/shore infrastr. and DUs in Toulon
  - NL: for DUs and DU-production site in Amsterdam
- March 2012: KM3NeT-PP ends, TDR released
- Decision: detector realised in a "multisite" option

KM3NeT multisite construction

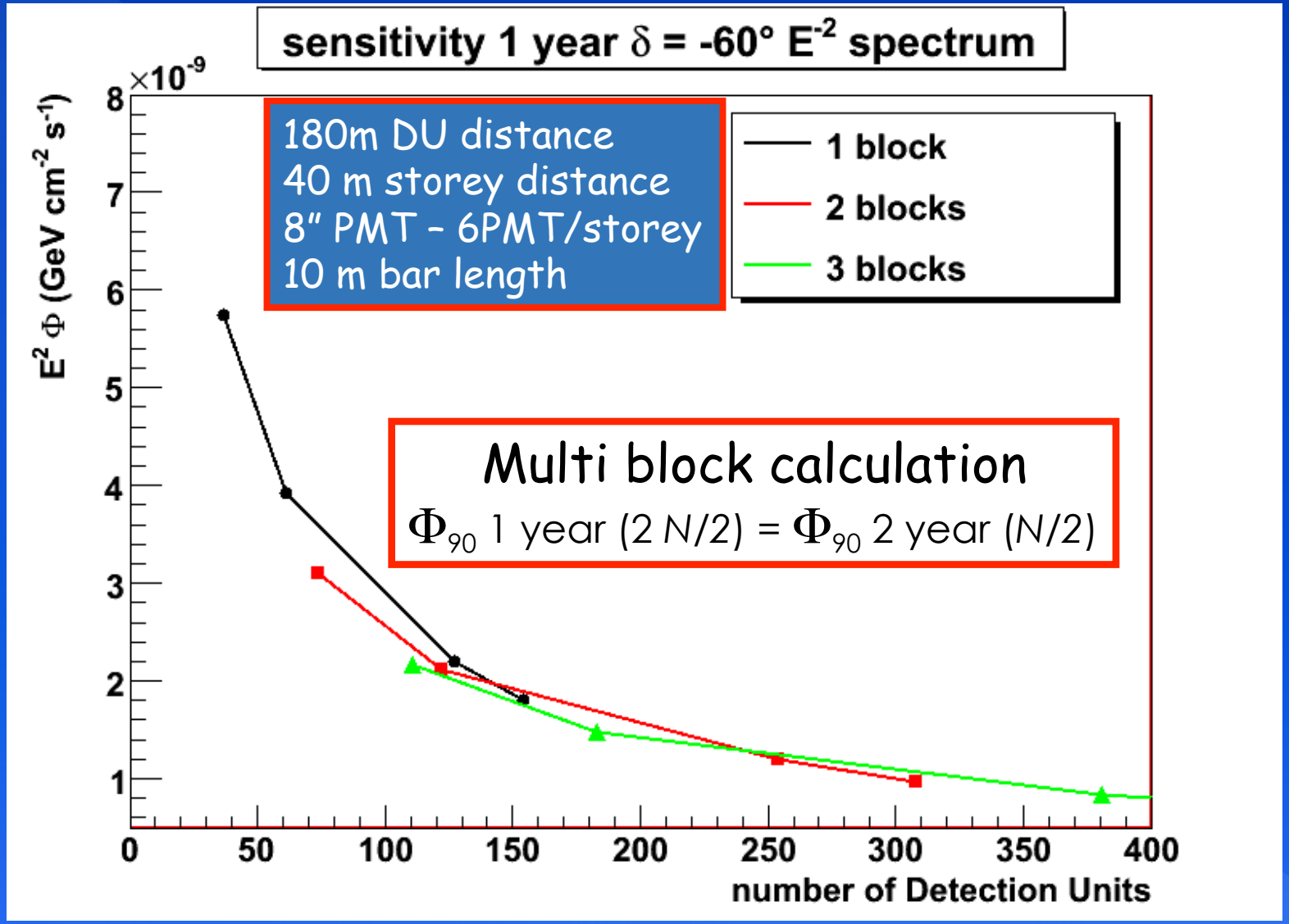
- 3 detectors, each ~2km^3 in 3 sites
- KM3NeT-France: Toulon

  KM3NeT-Italy: Capo Passero

  KM3NeT-Greece: Pylos
- Long-term site characterisation measurements performed



Multi-site approach: sensitivity to a Point-like source as a function of DU number



KM3NeT status

- KM3NeT phase-1 **(~3 times ANTARES, ~1/4 IceCube)**
  - Collaboration (since Feb 2013)
    - 40 institutes
    - 185 members
  - KM3NeT Funding Agencies (KFA)
    - in place
  - Scientific & Technical Advisory Committee (STAC)
    - in place

Memorandum of Understanding

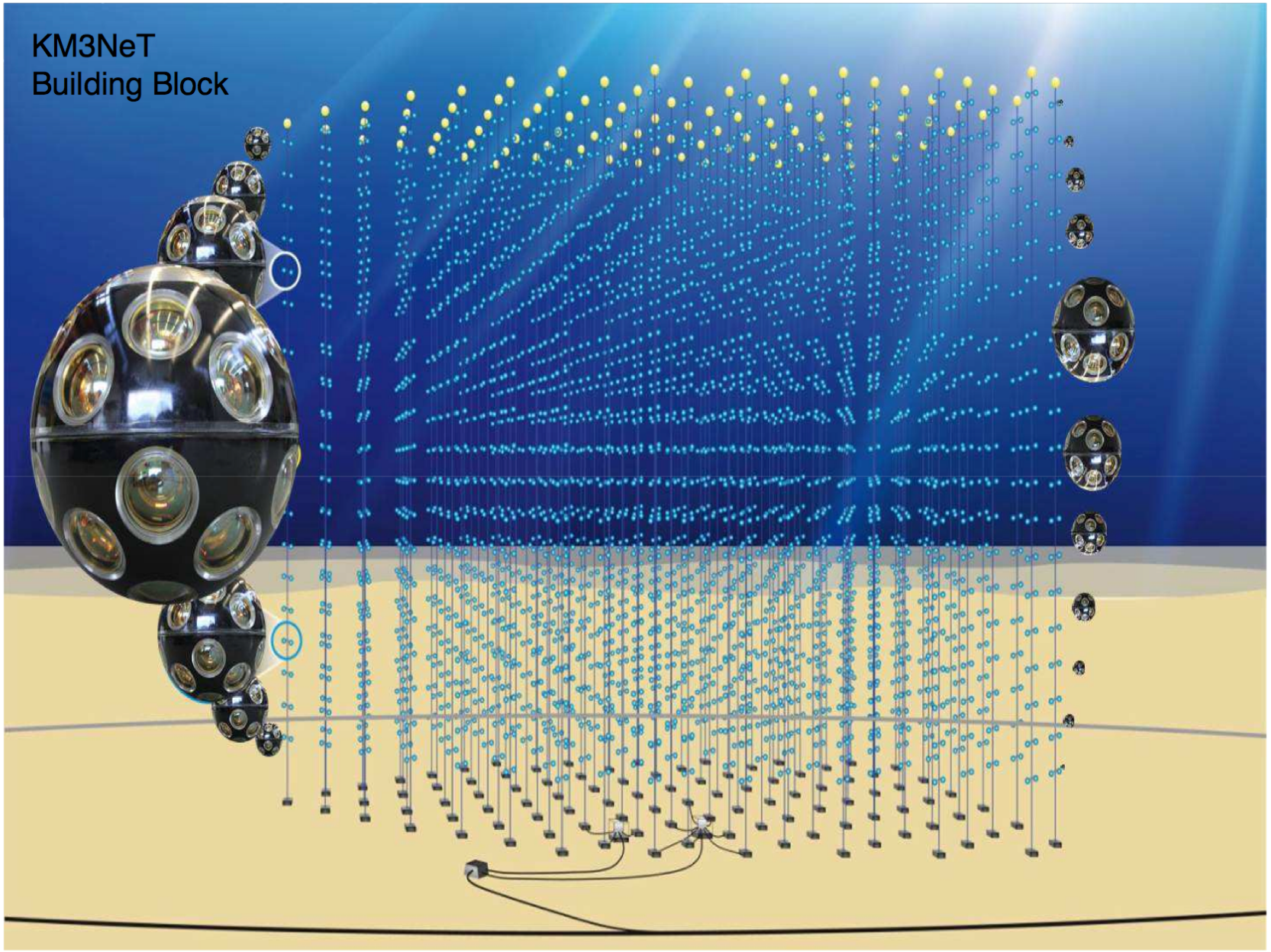
- 185 scientists, 40 institutes

- Commitments/expenditures of acquired funds
  France (7M€), Italy (16M€); Netherlands (8M€)
  + Germany, Spain, Romania, Ireland, Cyprus, Greece, UK

- Local funds constrained in time (end 2014) and location

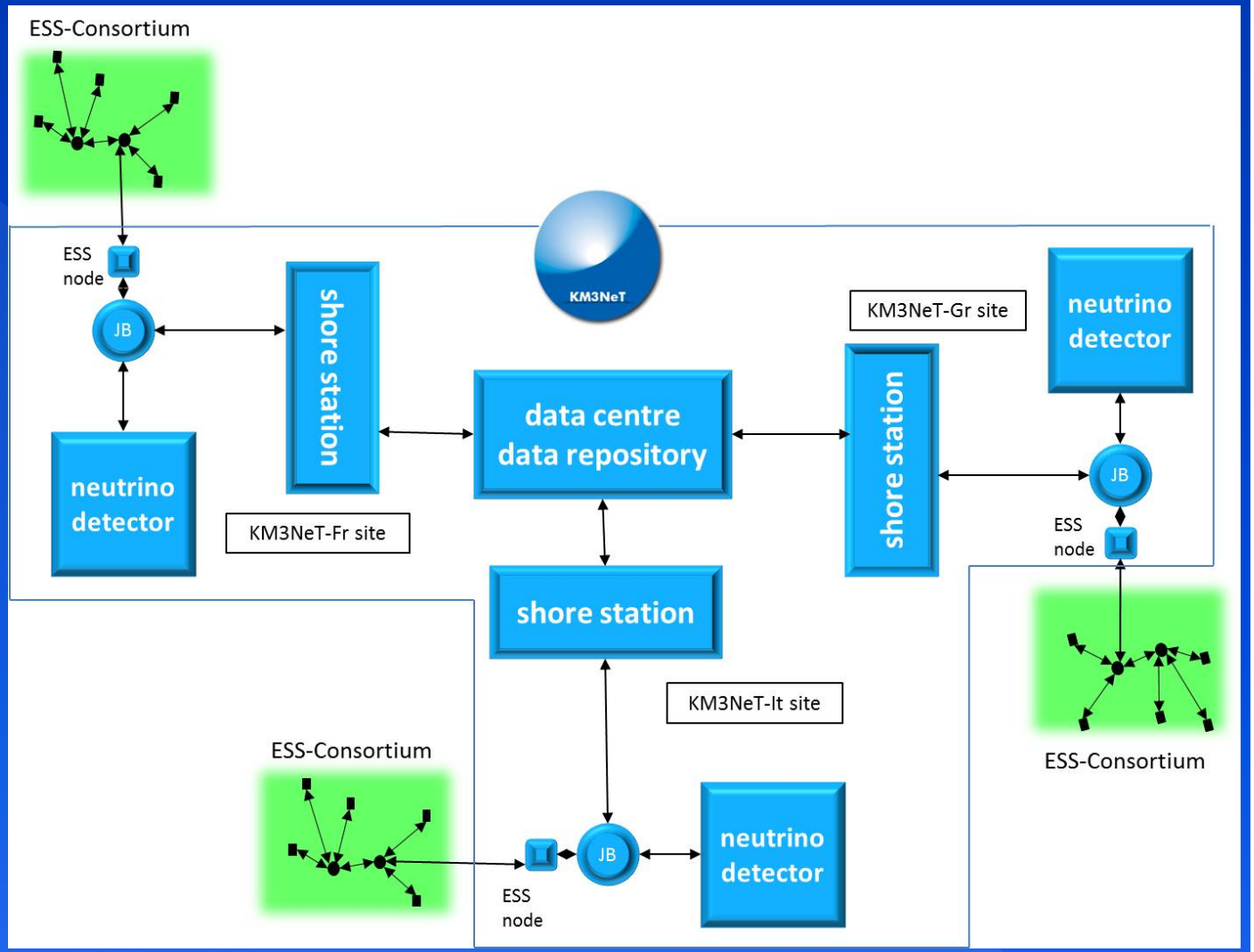
- Agreement on string sharing (total: 31 strings)
  - PPM-DU — Capo Passero
  - string 1 — Toulon
  - strings 2–25 — Capo Passero
  - strings 26–31 — Toulon

- Approved by KM3NeT Institute Board, 13 Oct 2013
- Next step: signature of funding agencies


KM3NeT
Building Block

KM3NeT: a distributed Research Infrastructure

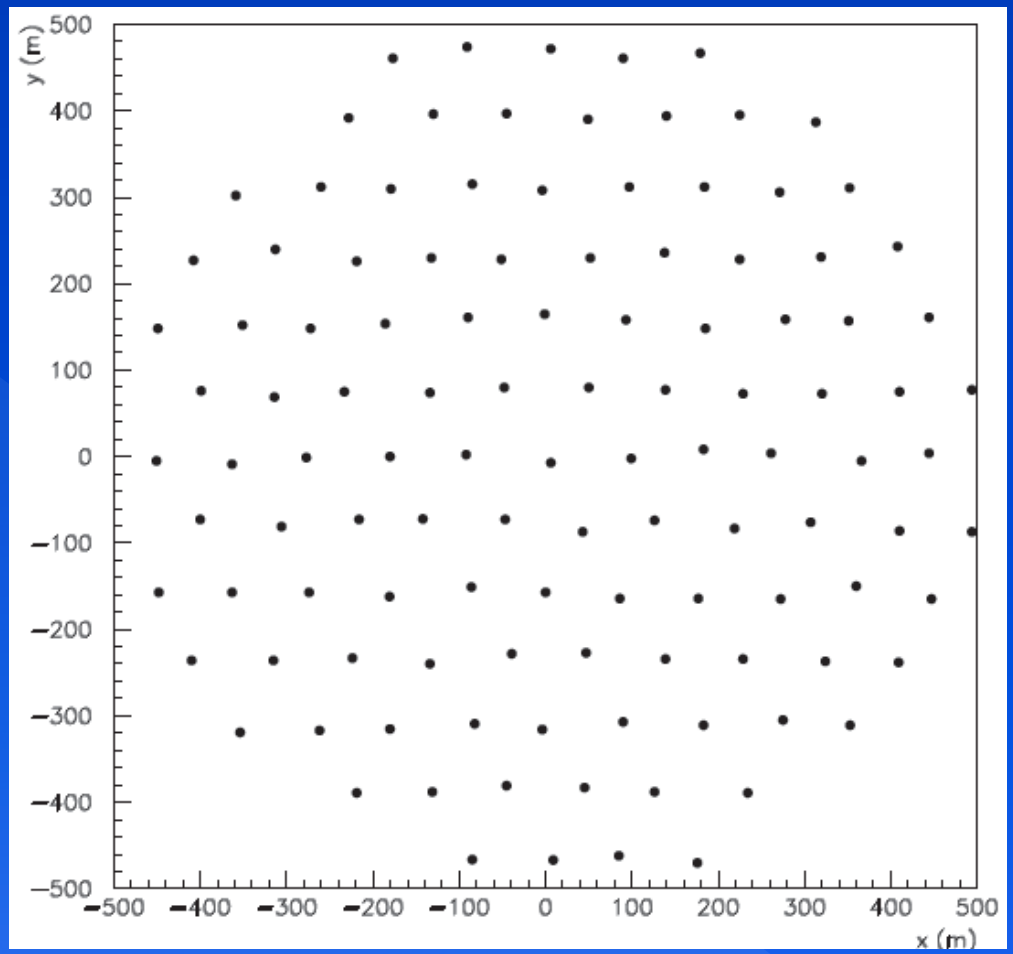
- Centrally managed
- Common hardware
- Common software, data handling and operation control
- Sites in France, Greece, Italy
- Consistent with funding structure (regional sources)



The building block concept

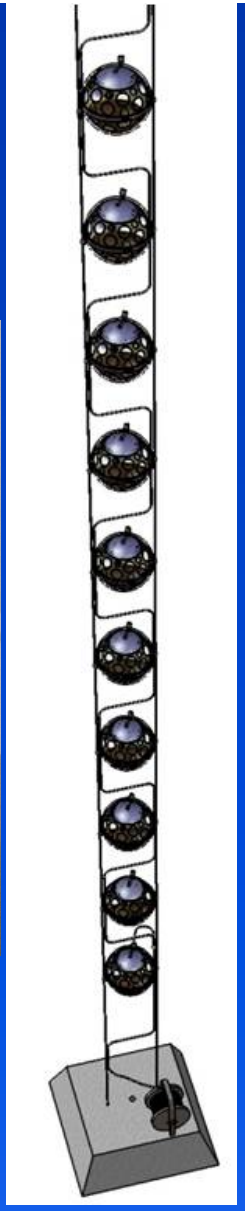
Simulated configuration:
115 DUs, 90m distance on average

- Building block:
  - 115 detection units
  - Segmentation enforced by technical reasons
  - Sensitivity for muons independent of block size above ~75 strings
  - One block ~ half IceCube
- Geometry parameters optimised for galactic sources (E cut-off)
- Technical feasibility verified
- **KM3NeT includes 6 building blocks (2 blocks/site)**



KM3NeT decision taken:

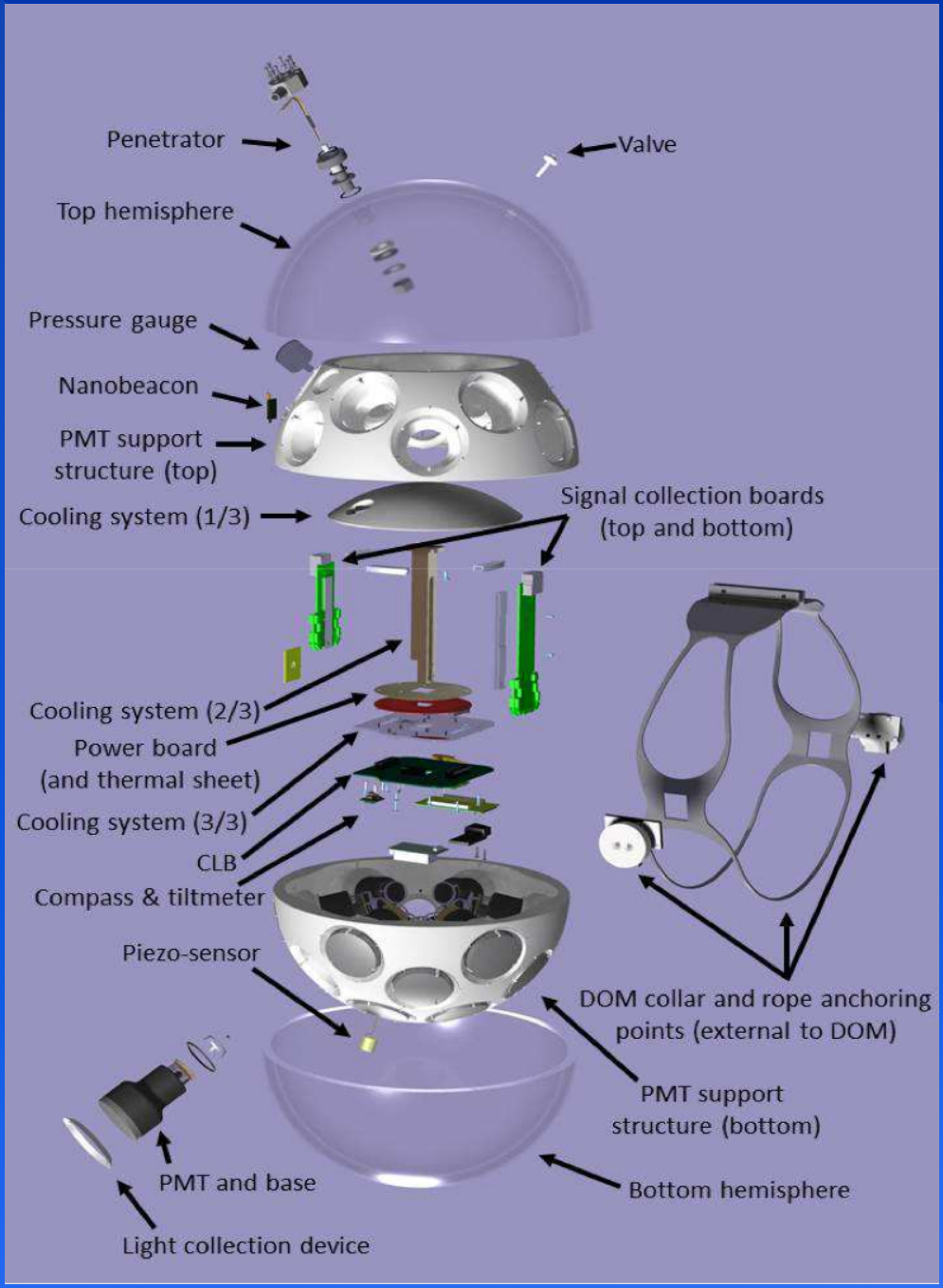
- **Detection Units made by Strings equipped with**
- **Multi-PMT Digital Optical Modules**



- Mooring line:
  - Buoy (probably syntactic foam)
  - 2 Dyneema© ropes (4 mm diameter)
  - 18 storeys (one OM each), 36m distance, 100m anchor-first storey
- Electro-optical backbone (VEOC):
  - Flexible hose ~ 6mm diameter
  - Oil-filled
  - fibres and copper wires
  - At each storey: connection to 1 fibre+2 wires
  - Break out box with fuses at each storey: One single pressure transition

This technology is not yet full-proved: in order to match the spending profile required by the PON Italian funding we started the construction of the KM3NeT-Italy detector with 8 “Towers” like the NEMO-Phase2 one.

Multi-PMT Digital Optical Module



31 x 3" PMTs
- Hamamatsu, ETL, HZC

Light collection ring
- 20-40% gain in photocathode

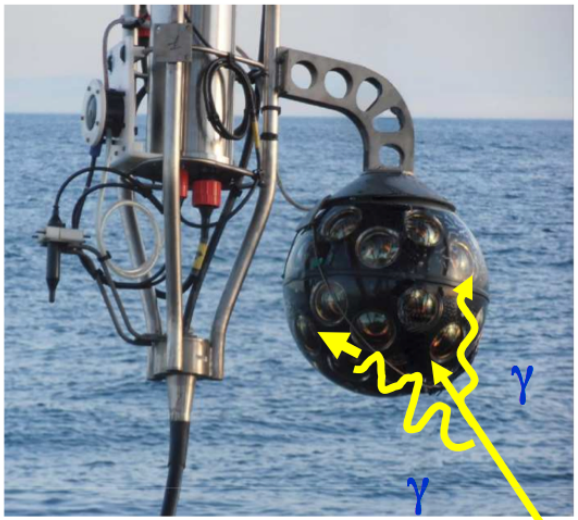
Low power
- < 10 W/DOM

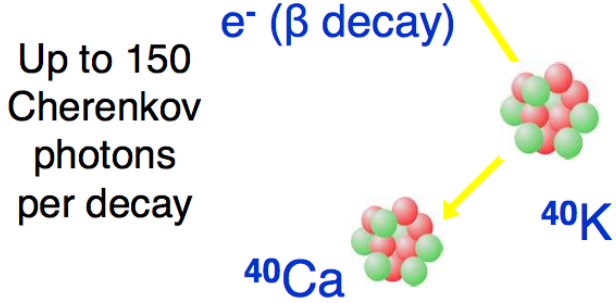
FPGA readout
- sub-ns time stamping
- time over threshold
- all data to shore
- White Rabbit synchronization

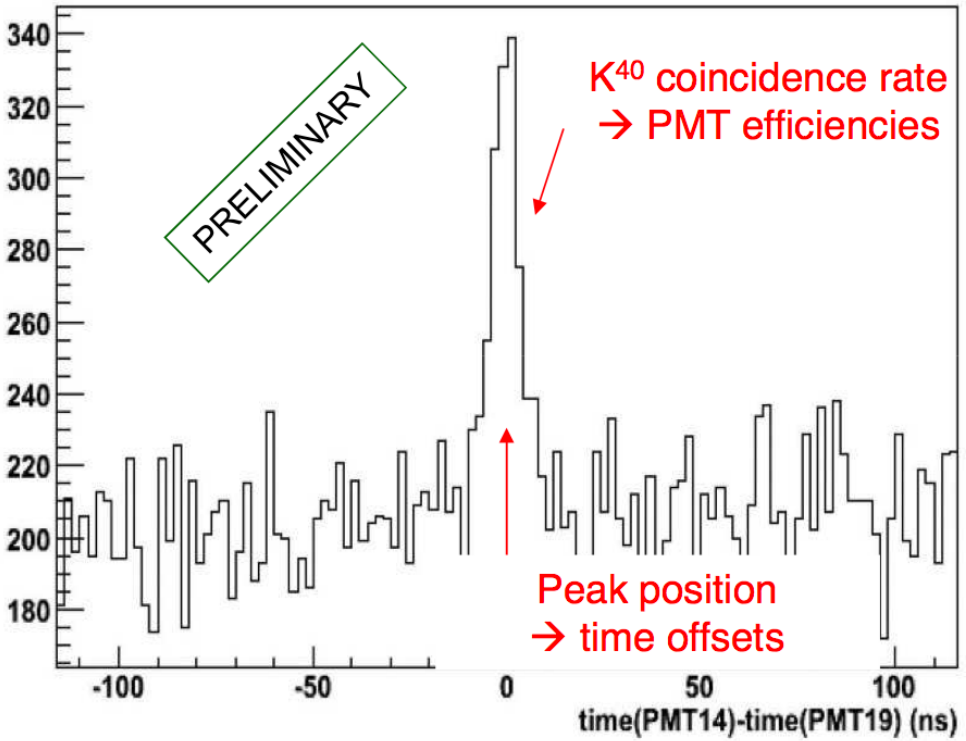
Calibration
- < LED & acoustic piezo in sphere

Optical fibre data transmission
- DWDM with 80 wavelengths
- Gb/s readout

A pre-production D.O.M. in ANTARES

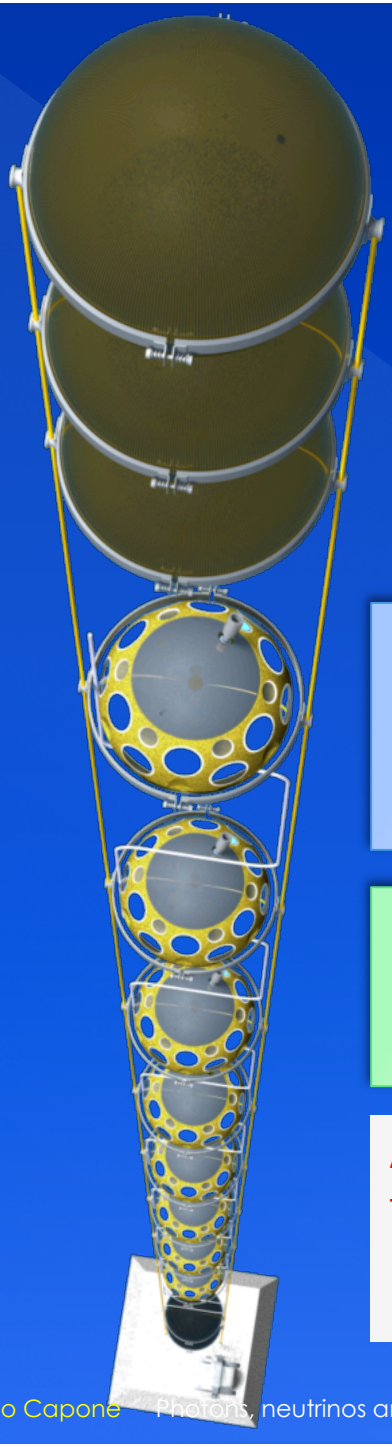






Concentration of ^{40}K is stable
(coincidence rate ~5 Hz on adjacent PMTs)

The String Technology



Digital Optical Module

31 small, 3", PMTs in one glass sphere

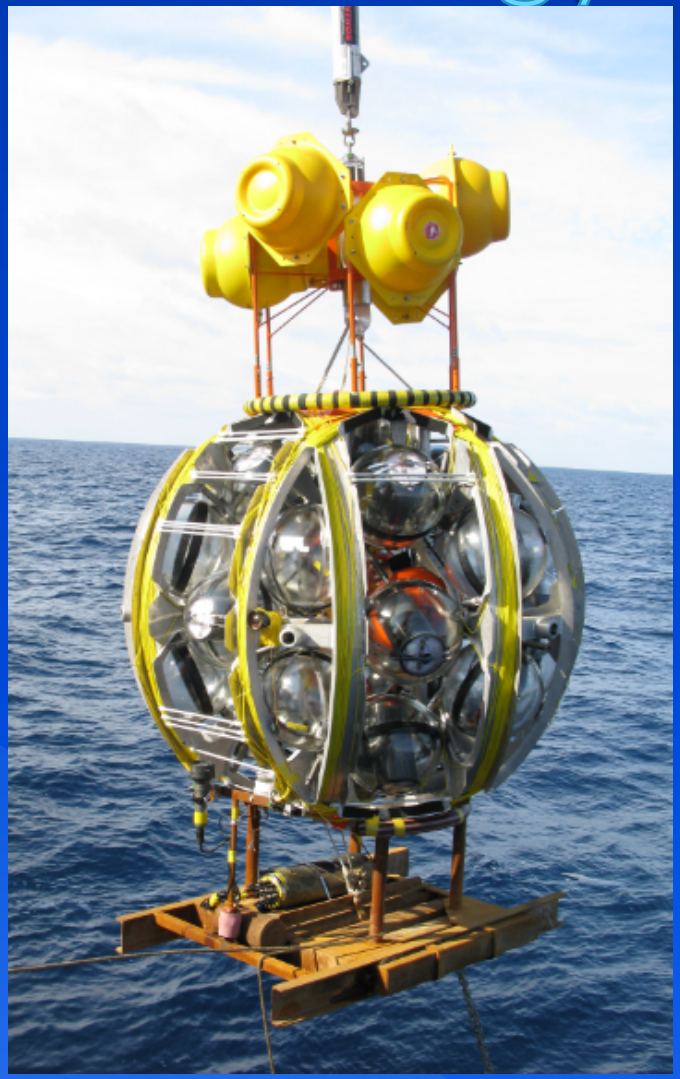
Photon counting

Detection Unit with 18 storeys

36 m inter-storey distance

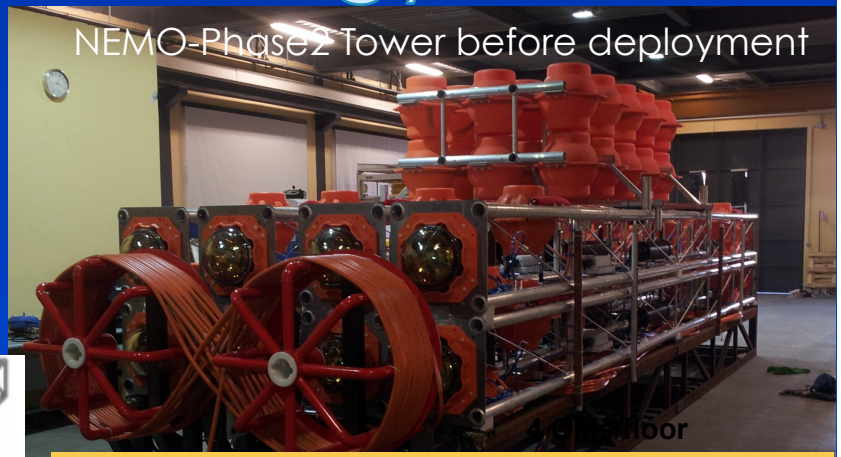
Compact deployment

A multi-PMT OM mounted on the ANTARES Instrumented line allows to study its behaviour



The Tower technology

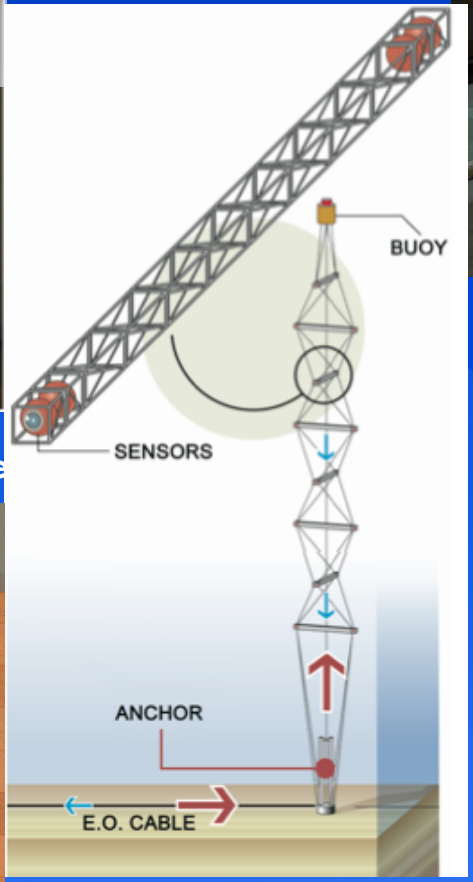
NEMO – Phase2
8 floors, 4PMTs/Floor, 2 hydrophones/Floor
8 m bars, vertical dist. = 40 m, H_{tot} = 450 m
oceanographic instruments
Deployed at 3500m depth in March 2013



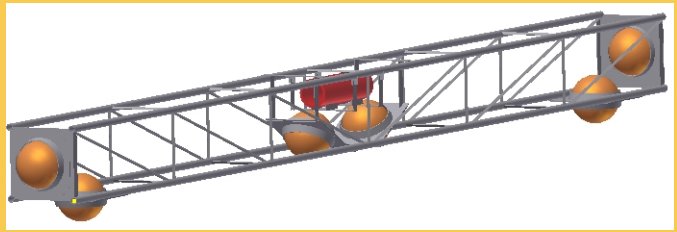
The OM: 10" Hamamatsu R7081, Front End Module, Time Calibration, LED beacons

32 OMs, all fully tested and calibrated.
2 OMs equipped with piezo-hydrophone

Hydrophones: acoustic positioning and bioacustics



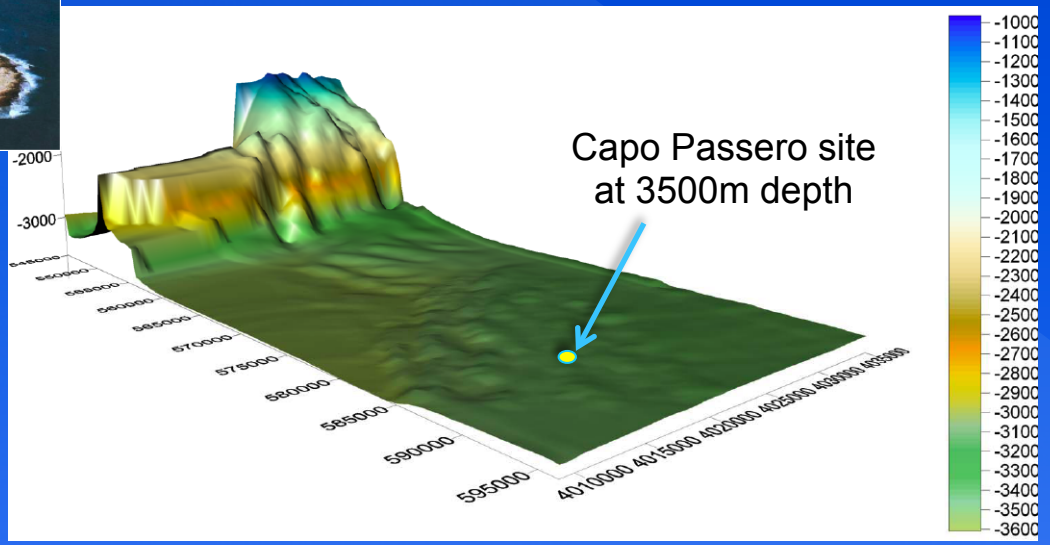
KM3NeT – Italy Towers
14 Floors
8 m bars, vertical dist. = 20 m
H_{tot} ~ 400 m

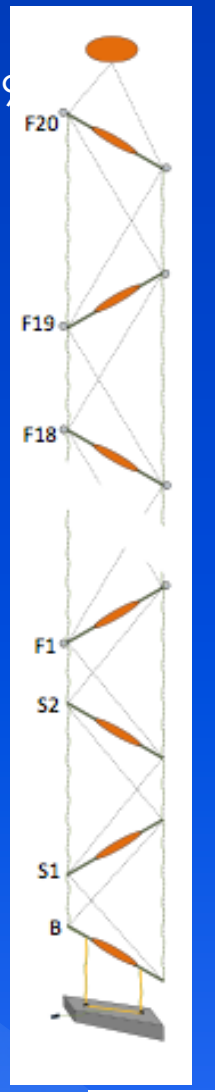


6 OMs + 2 hydrophones / Floors
Oceanographic Instruments
Towers at ~100m hor. dist.

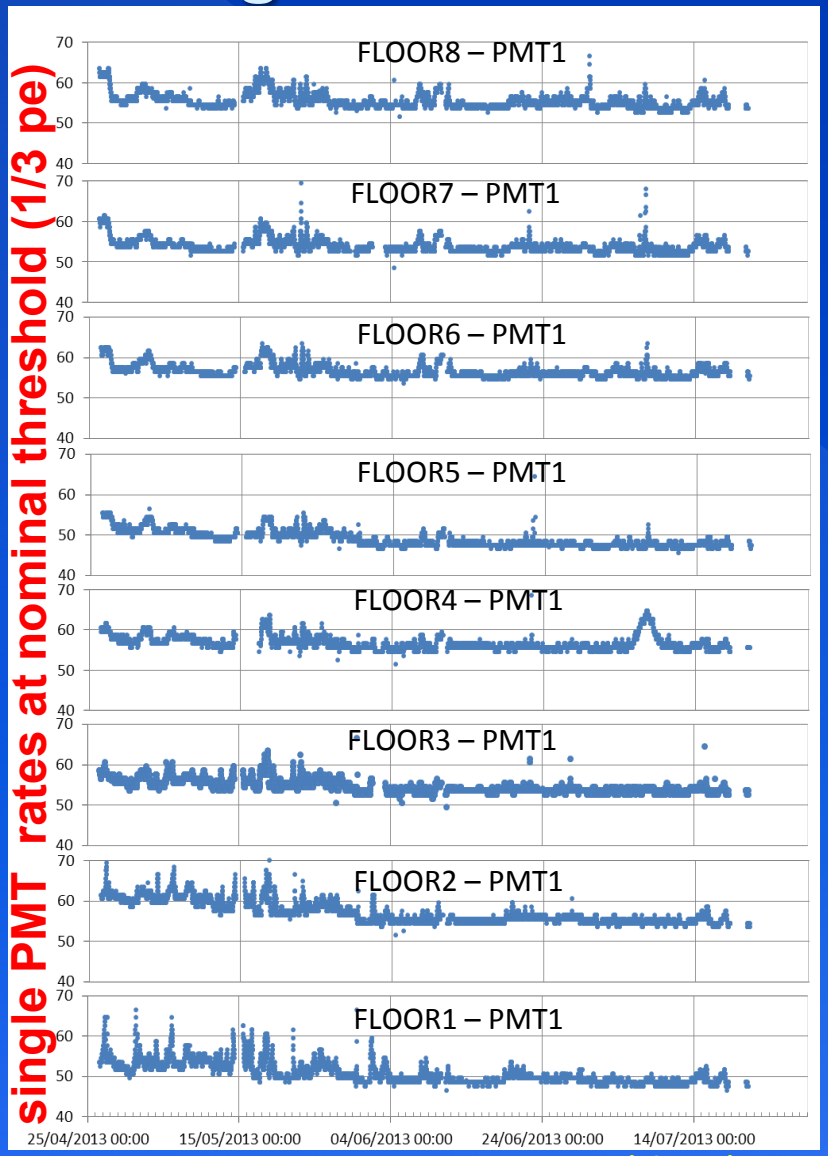
NEMO-Phase2 Tower @ the Capo Passero Site

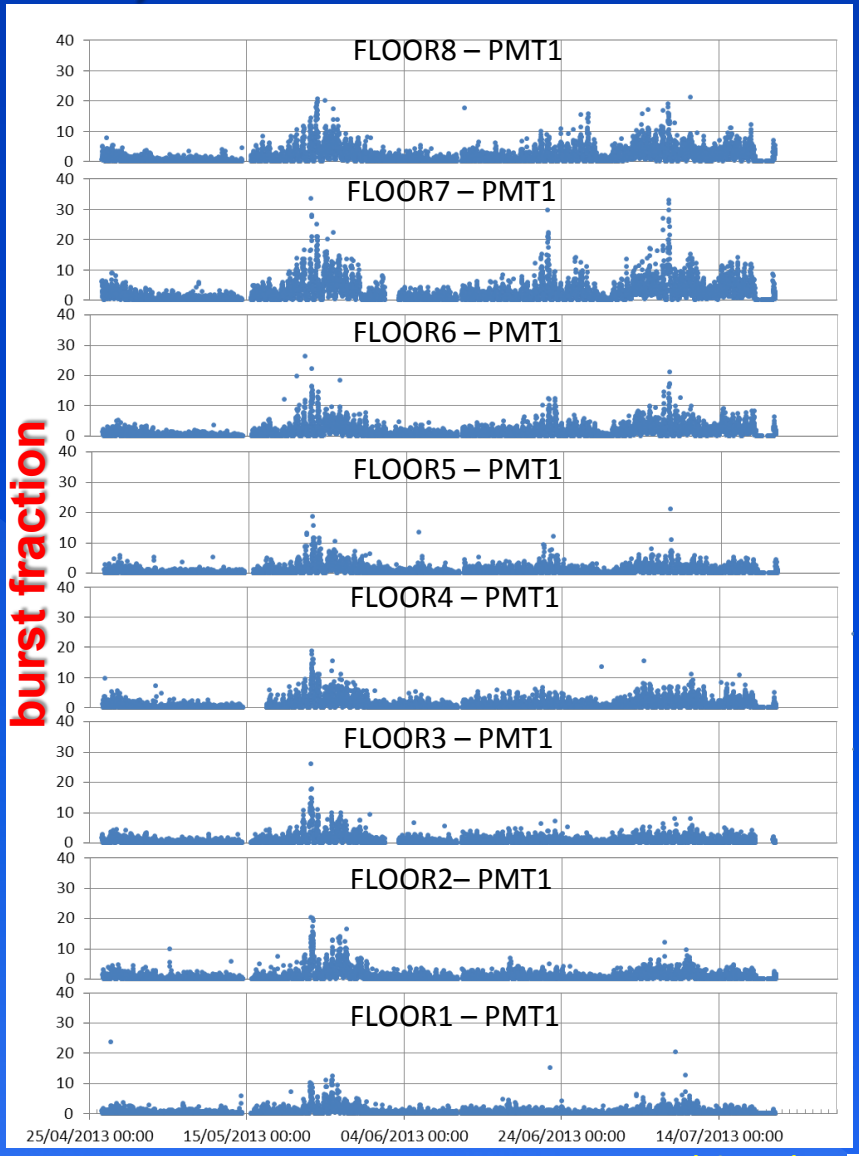
- On-shore infrastructure available (on-shore building completion at beginning 2008)
- 100 km Electro-Optical cable (>50 KW, 20 fibres) deployed (summer 2007)
- On shore Power Feeding System operational
- ALCATEL DC(10kV) / DC(400V) converter deployed and connected (winter 200
- NEMO-PHase2 Tower deployed March 2013:
  - validation of the Tower technology
  - long time measurement of deep-sea environmental conditions





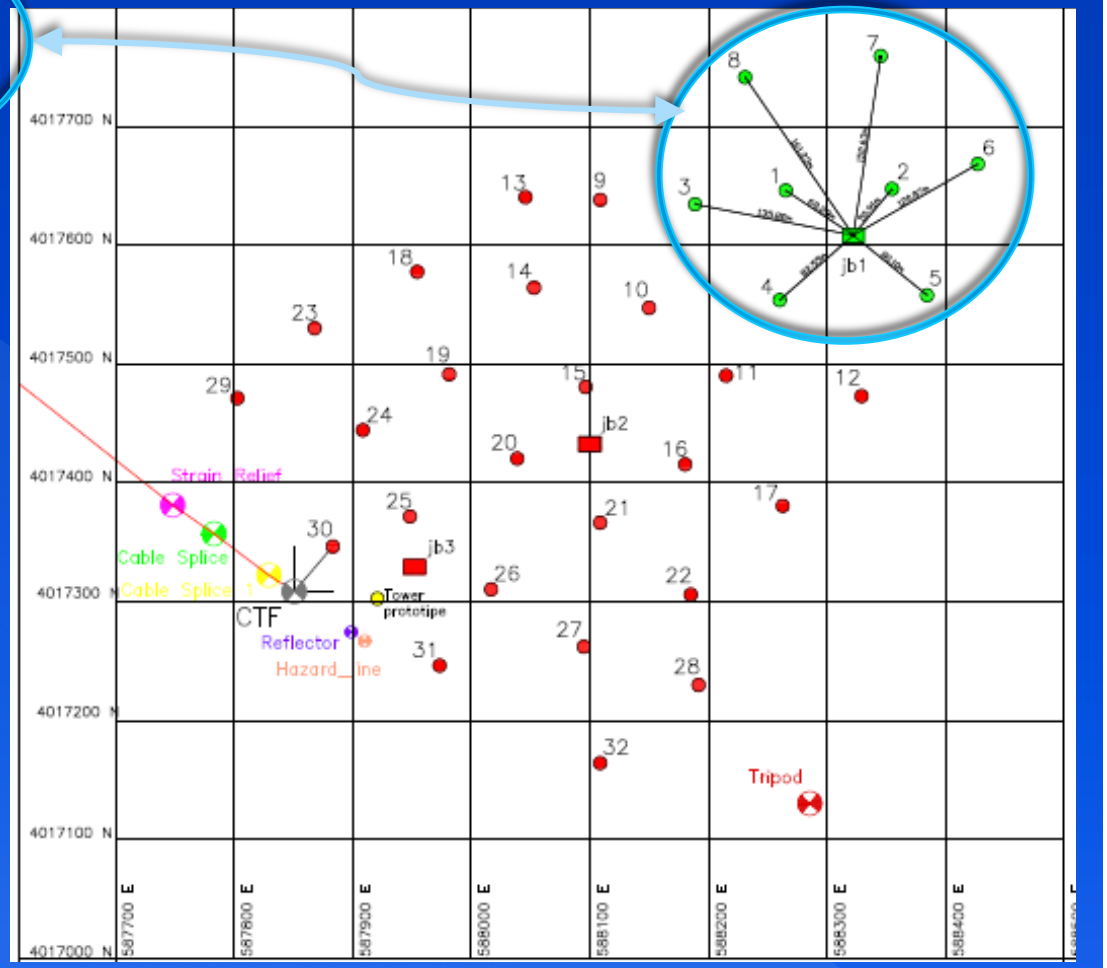
Capo Passero site, 3500 m depth
single PMT rates: ~55kHz, burst fraction ≤ 5%



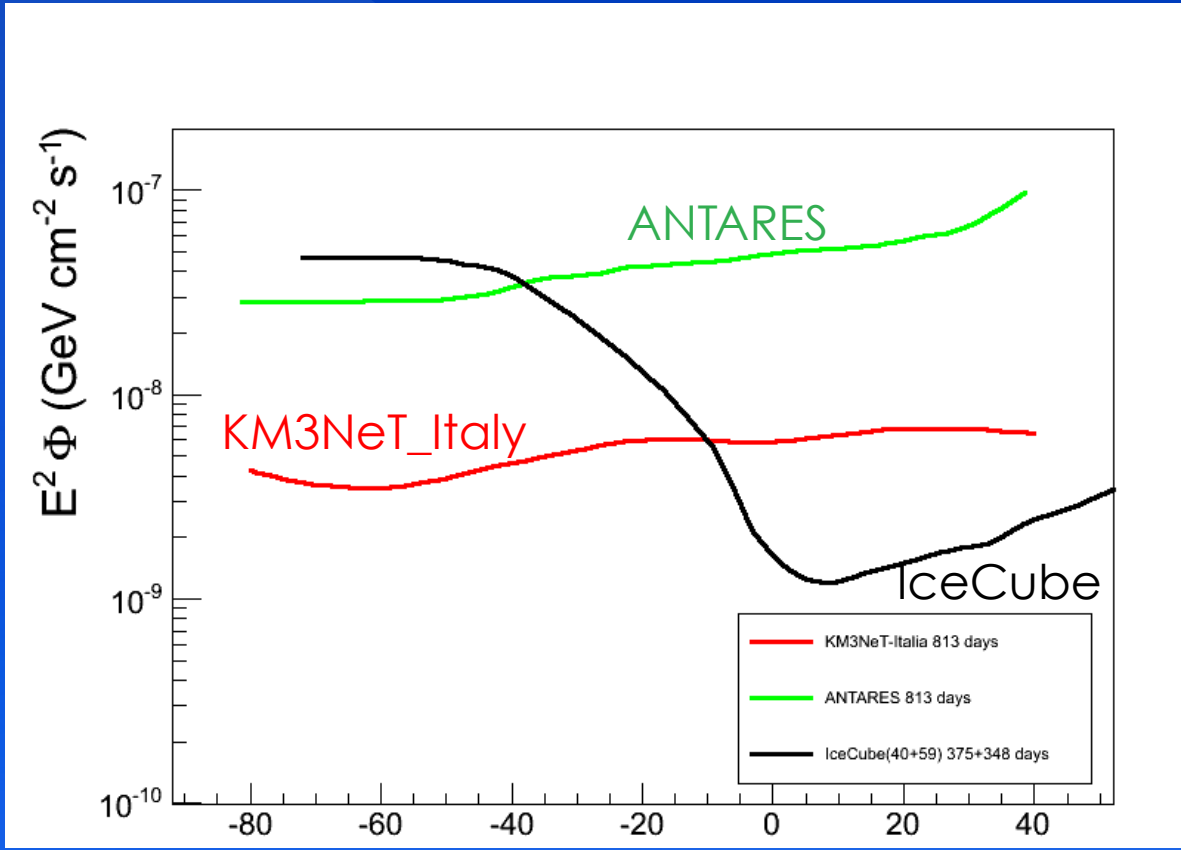


KM3NeT-Italy installation plans (phase-1)

- Start with 8 towers (end 2014)
- Add 24 strings until 2015
- Deep-sea infrastructure (power + cables + Junction Boxes) available for 32 Towers +Strings in 2015



Sensitivity at 90% C.L. for 30 Towers at Capo Passero

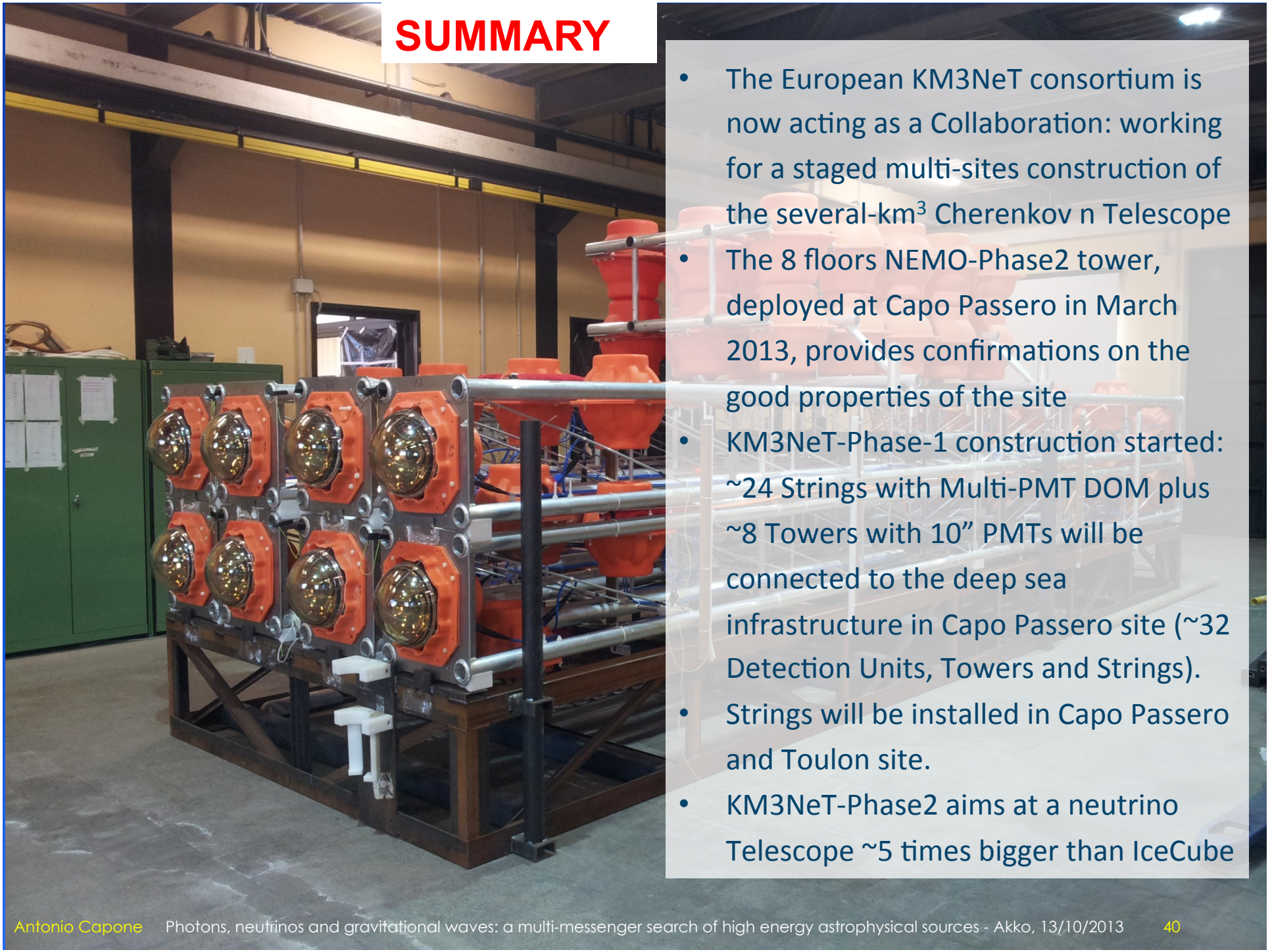


ANTARES, Neutrino 2012
IceCube, ICRC 2011

KM3NeT_Italy 30 Towers
130m distance between DU
20 floors
40m distance between floors

At declination -60° the KM3NeT-Italy project, the one funded by PON, will have a sensitivity 8 times larger than ANTARES

SUMMARY



- The European KM3NeT consortium is now acting as a Collaboration: working for a staged multi-sites construction of the several-km^3 Cherenkov n Telescope
- The 8 floors NEMO-Phase2 tower, deployed at Capo Passero in March 2013, provides confirmations on the good properties of the site
- KM3NeT-Phase-1 construction started: ~24 Strings with Multi-PMT DOM plus ~8 Towers with 10” PMTs will be connected to the deep sea infrastructure in Capo Passero site (~32 Detection Units, Towers and Strings).
- Strings will be installed in Capo Passero and Toulon site.
- KM3NeT-Phase2 aims at a neutrino Telescope ~5 times bigger than IceCube