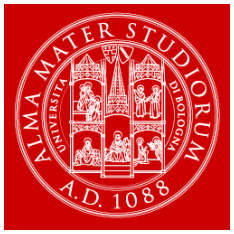
The ANTARES neutrino telescope

Annarita Margiotta
INFN & University of Bologna
on behalf of the ANTARES Collaboration
annarita.margiotta@unibo.it

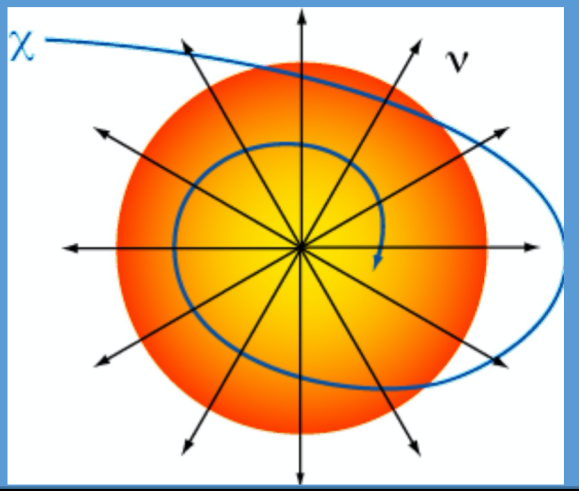


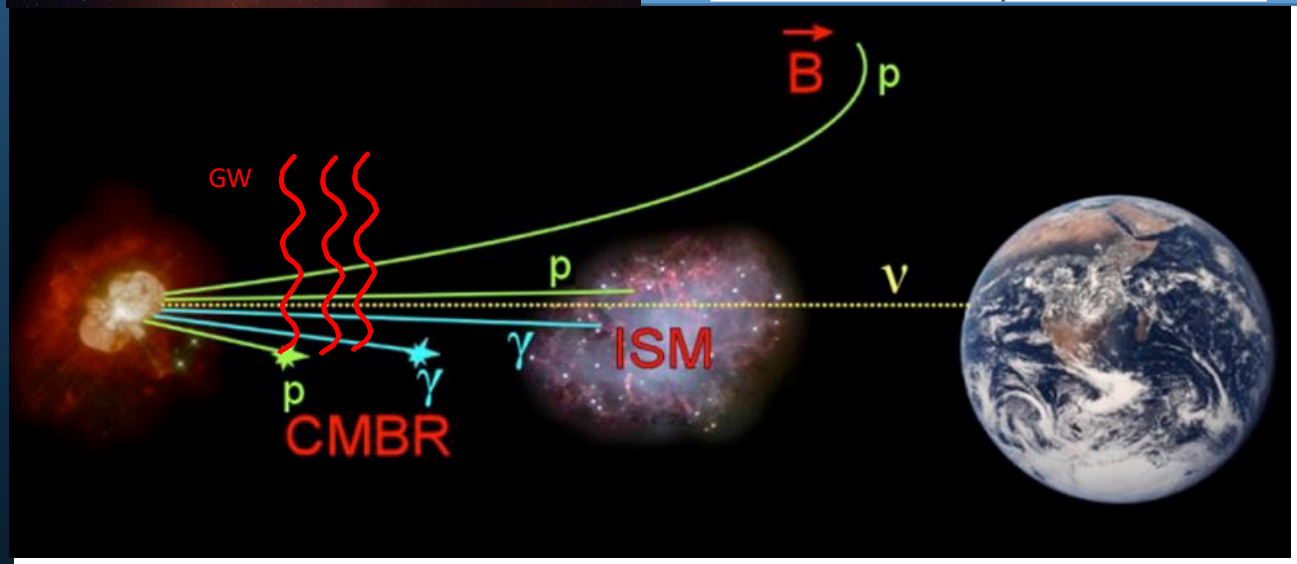
INFN

Neutrino Astronomy

- Perfect probes : undeflected and unabsorbed
- Search for a diffuse flux from unresolved sources
- Search for individual sources
- **Multimessenger search**

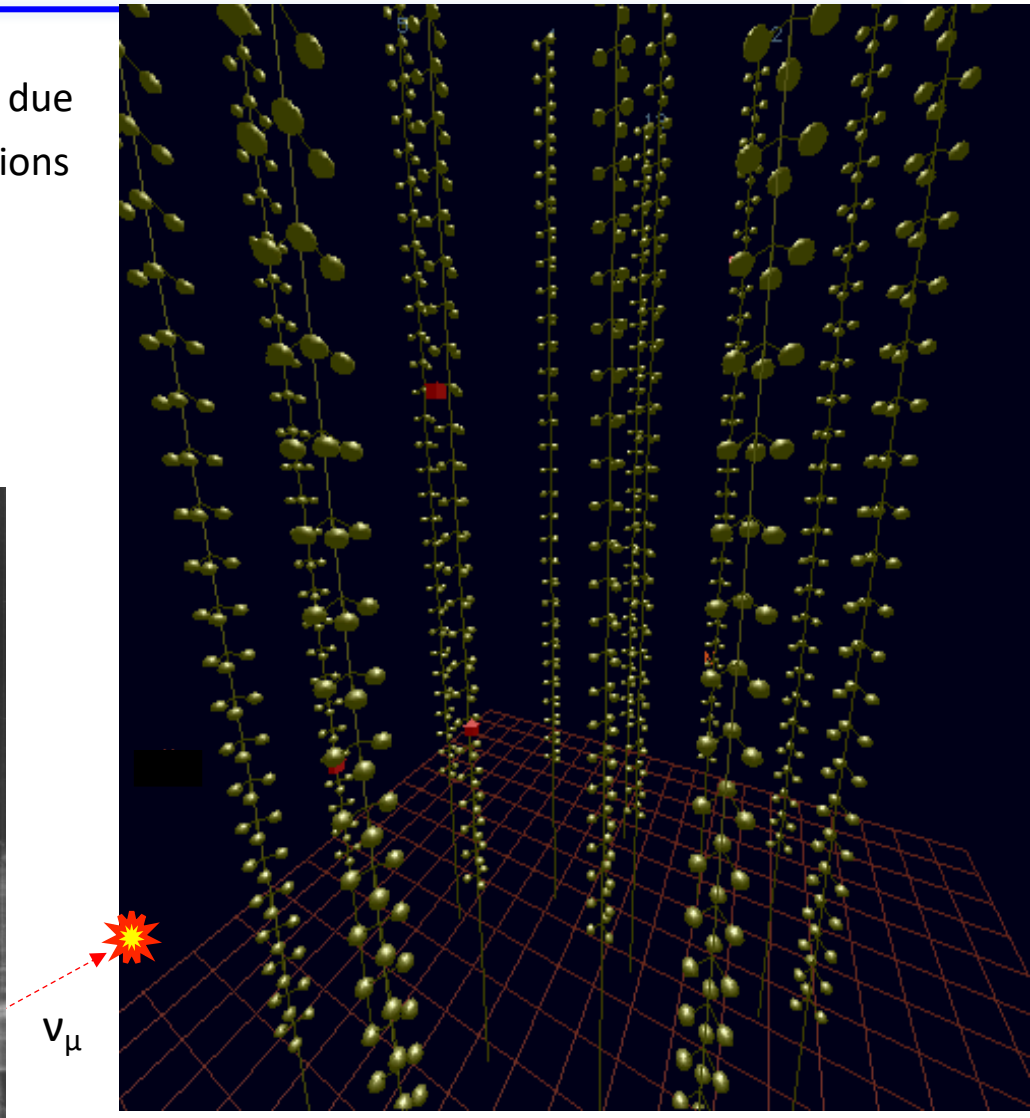
- Cosmic ν
- Origin and production mechanism of HE CR
- Dark matter
- Monopoles, Nuclearites
- Atmospheric neutrino studies





The concept of Cherenkov neutrino telescopes

- Photomultipliers collecting Cherenkov photons due to relativistic charged particles from ν interactions
- Parent ν direction reconstructed using time & position



Event topologies in a ν telescope

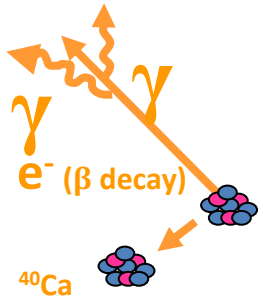
Environmental background

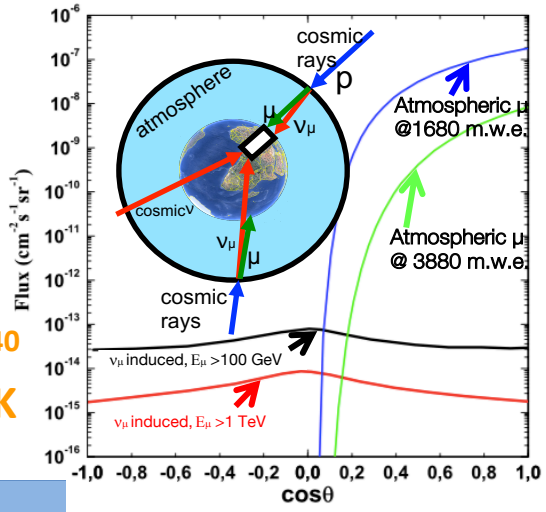
^{40}K decay

bioluminescence

rejection :

causal correlation of the signals





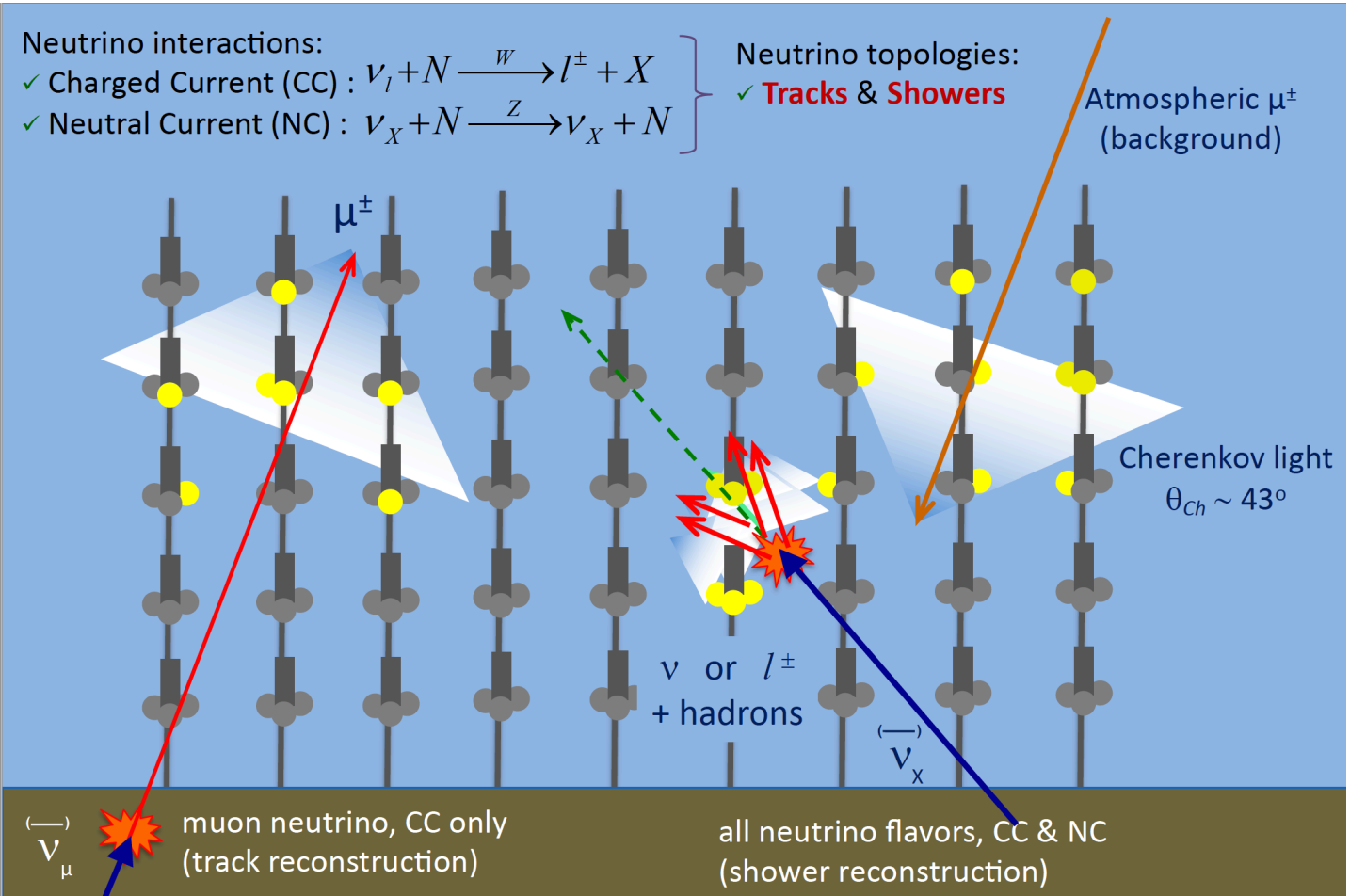
Neutrino interactions:

✓ Charged Current (CC) : $\nu_l + N \xrightarrow{W} l^{\pm} + X$

✓ Neutral Current (NC) : $\nu_X + N \xrightarrow{Z} \nu_X + N$

Neutrino topologies:

✓ Tracks & Showers



Physics background

Atmospheric muons

direction cut → upward going events

BUT

detector calibration

Atmospheric neutrinos

irreducible background

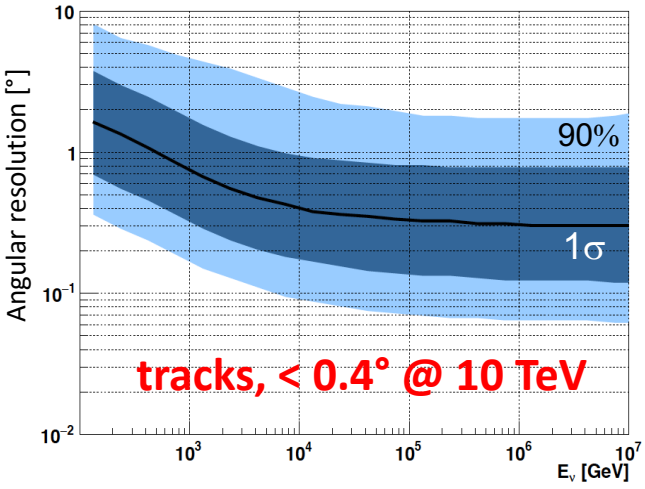
BUT

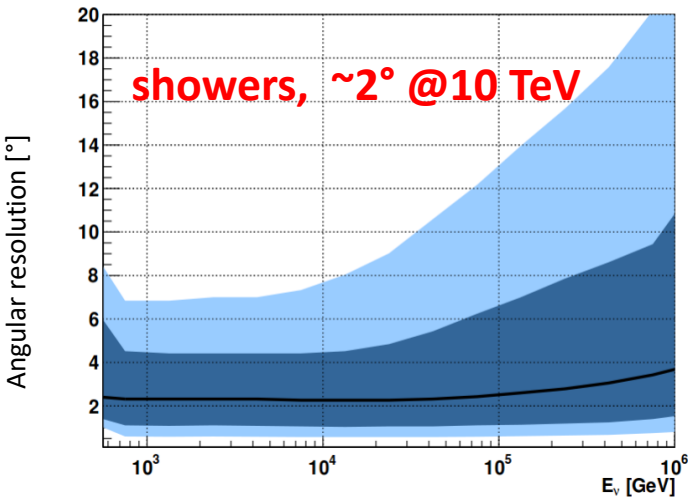
neutrino oscillations

energy spectrum

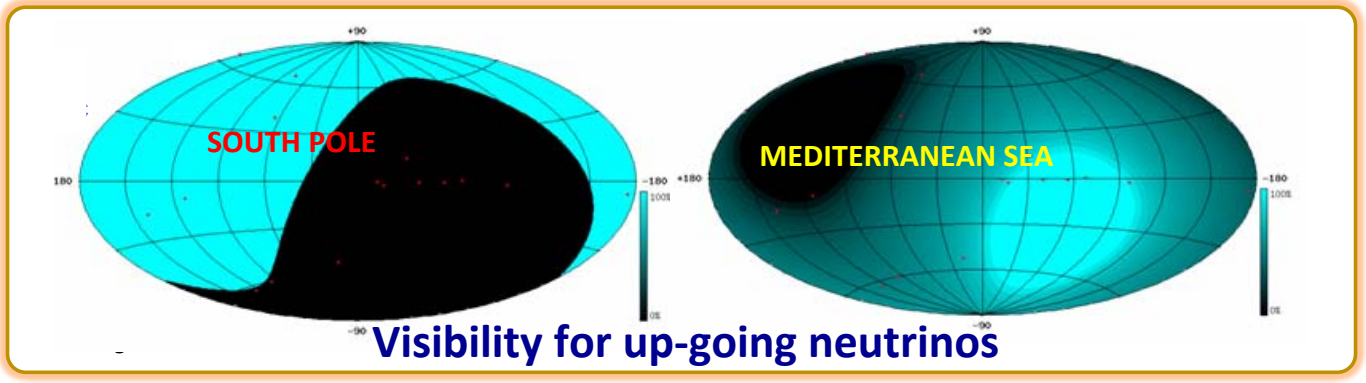
Why the Mediterranean Sea

Optical properties of water → Mapping the **Southern sky** with excellent angular resolution

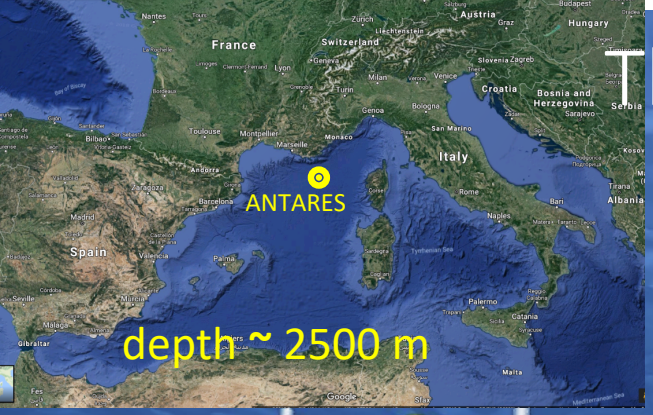




Visibility of the Galactic region



The ANTARES neutrino telescope



- In operation since 2007
- 885 10” PMTs
- 12 lines
- 25 storeys/line
- 3 PMTs / storey
- all-data-to-shore
- Volume 0.01 km^3

10” PMT

450 m

Detector completed in 2008
13 years data taking
duty cycle ~95%

40 km to shore

JunctionBox

Interlink cables

70 m

Many searches and activities

Only some selected recent results are presented

- Diffuse flux search
- Atmospheric neutrino energy spectra
- Cosmic neutrino sources
- Multi-messenger studies (space-time coincidences) – the intriguing case of radio blazars

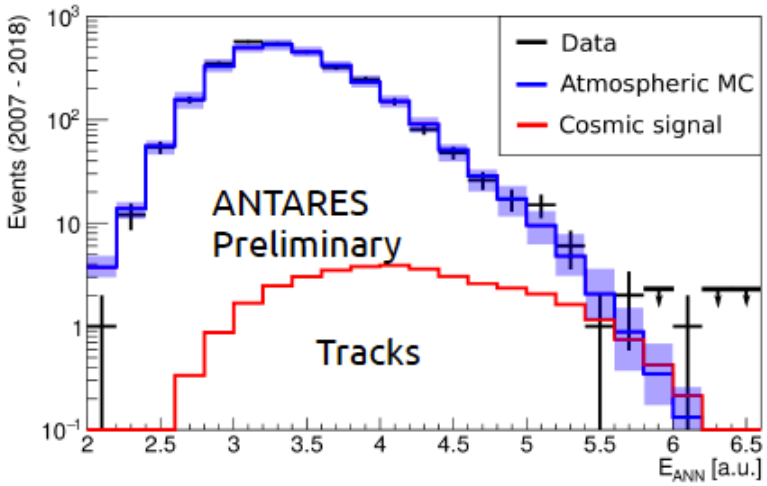
- Dark matter – **talk of Daniel Lopez-Coto: tomorrow July 28th**

No time to discuss today

- Exotics: magnetic monopoles and nuclearites
- Moon and Sun shadows of cosmic rays arriving at the Earth
- Oceanography, biology, geophysics….
- https://antares.in2p3.fr/ complete list of publications

Diffuse cosmic flux

Results presented at ICRC2019 : 2007-2018 (3330 days) – PoS(ICRC2019) 891



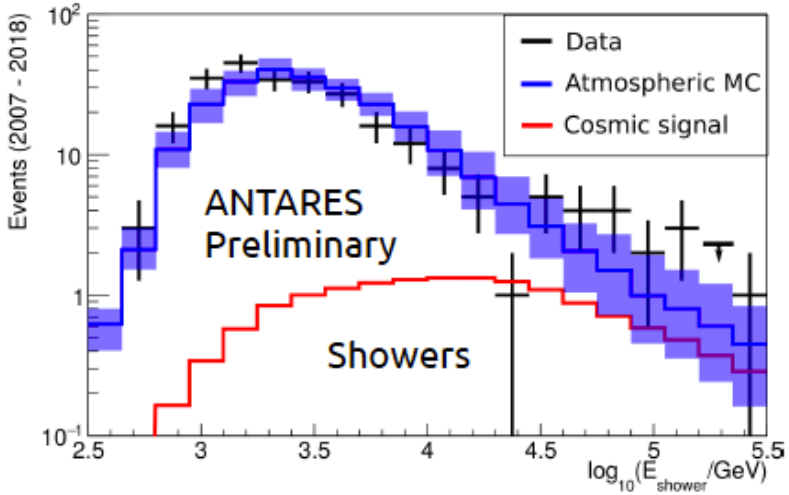
data: 50 events **(27** tracks **+ 23** showers**)**
bkg MC **expected**: **36.1 ± 8.7** (stat. + syst.)

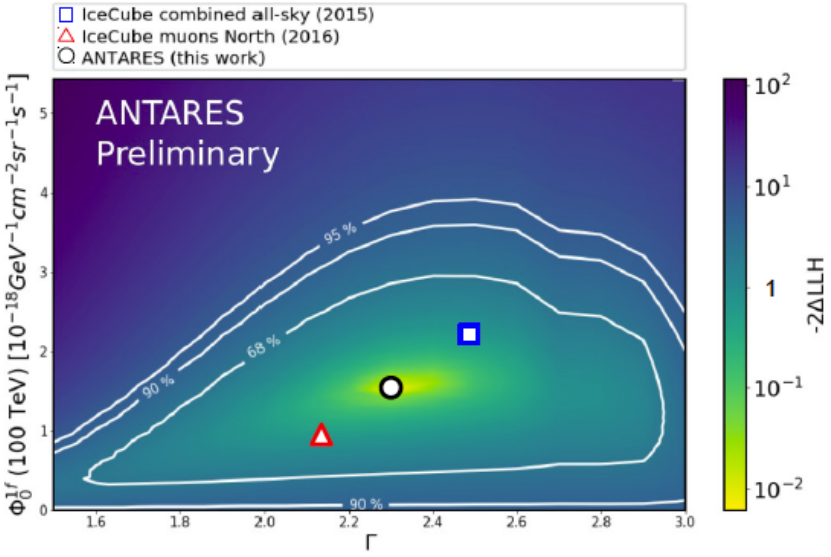
mild excess of HE ν observed (1.8 σ)
0-cosmic excluded c.l. >90%

Atmospheric $\Phi_{atm} = 1.25 \times (\text{Honda} + \text{Enberg})$

Cosmic $\Phi_{100\ \text{TeV}} = (1.5 \pm 1.0) \times 10^{-18}\ \text{GeV}^{-1}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$

$\Gamma = 2.3 \pm 0.4$





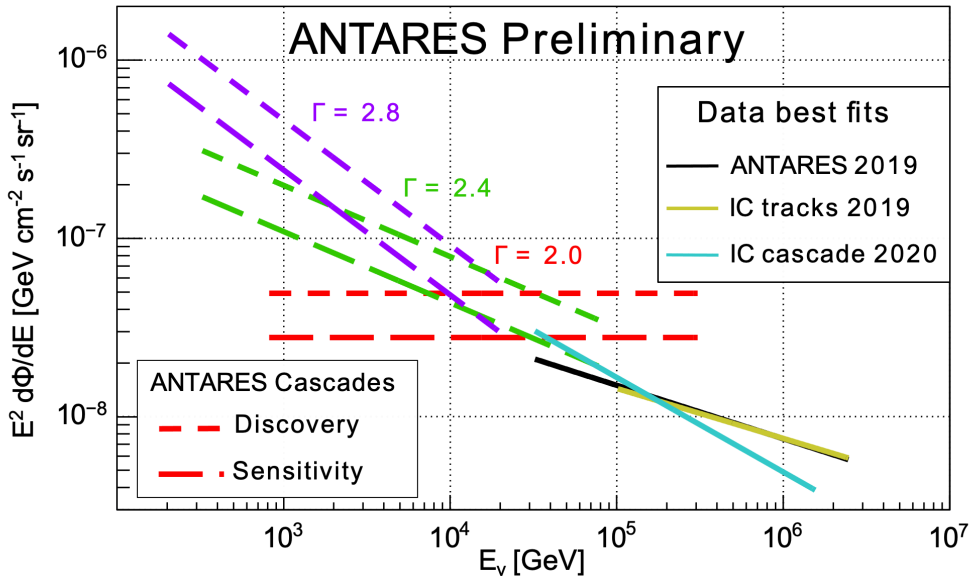
Diffuse cosmic flux

New ways to improve the result are under study → new shower selection strategy

- Boosted Decision Tree (BDT)
  -> low-energy showers
  -> atmospheric ν_e CC

- **A new powerful tool to select cascade-like events in cosmic neutrino search**

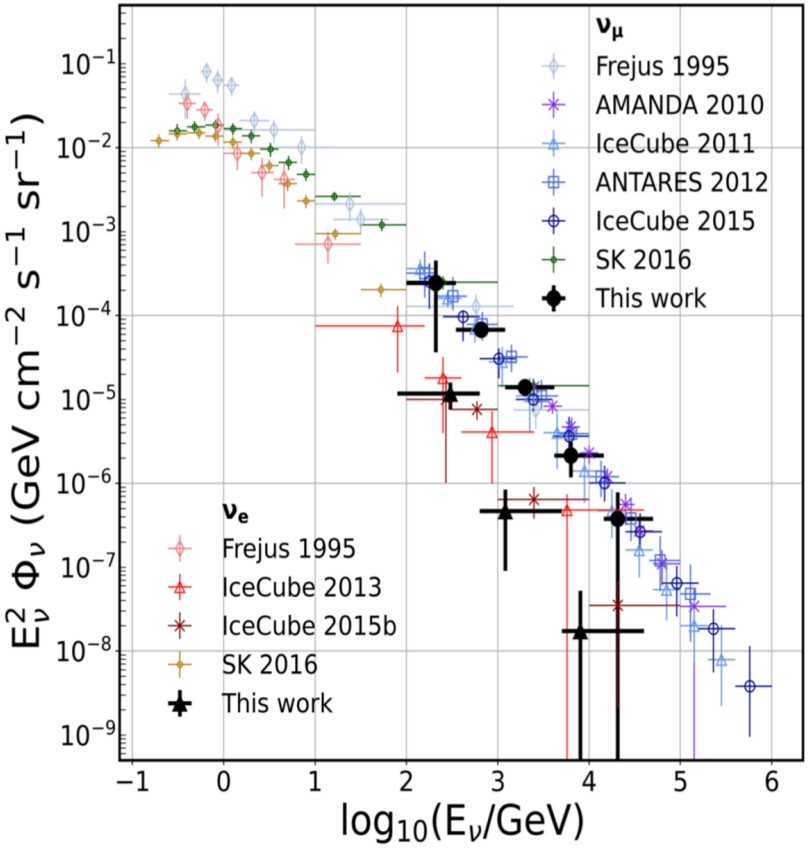
- Unfolding of energy spectrum
- In agreement with existing measurements
- Excellent rejection of atmospheric muon bkg



PLB 816 (2021) 136228

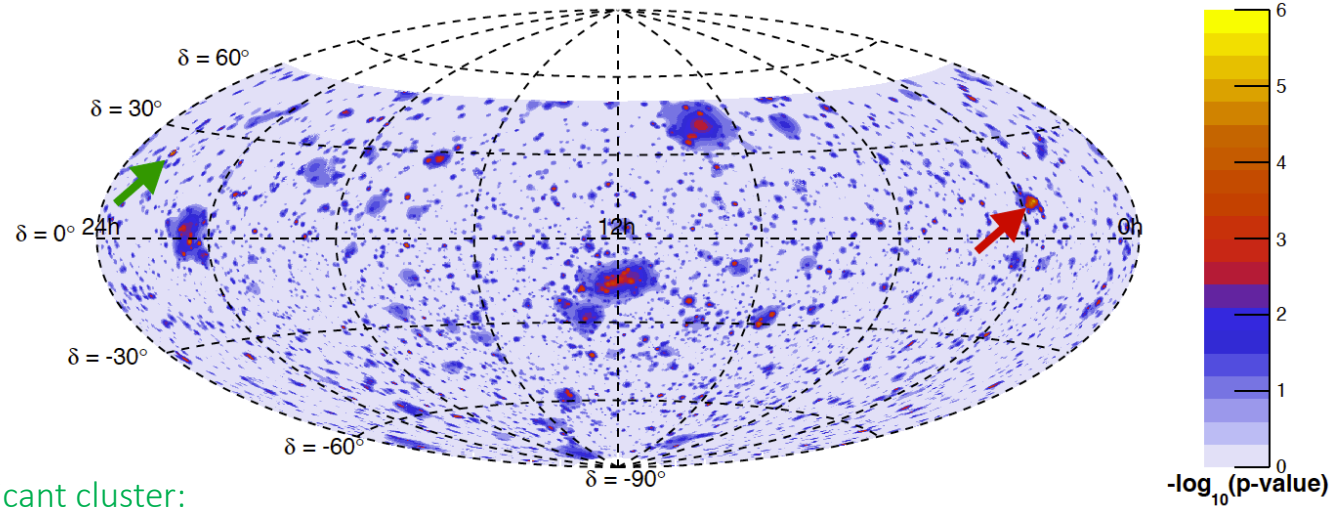
Atmospheric neutrino flux

ANTARES data 2007-2017

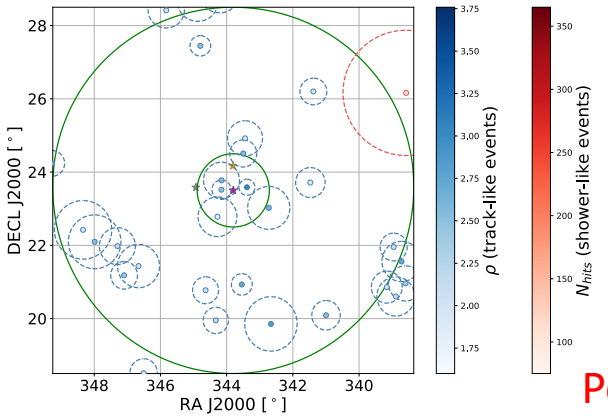


Point-like sources – search for clustering events

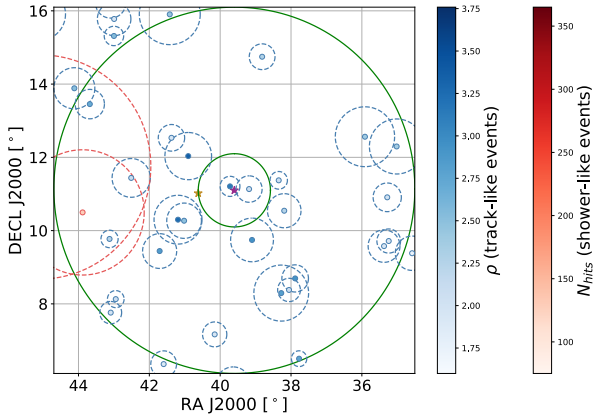
ANTARES 13 years (3845 days of livetime) 10162 track and 225 showers



2nd most significant cluster:
RA=343.8° δ=+23.5°
pre trial: 4.2 σ
Hotspot in a previous ANTARES analysis
Close to blazar MG3 J225517+2409 and to a HE IeCube muon track (ID3) (orange stars)

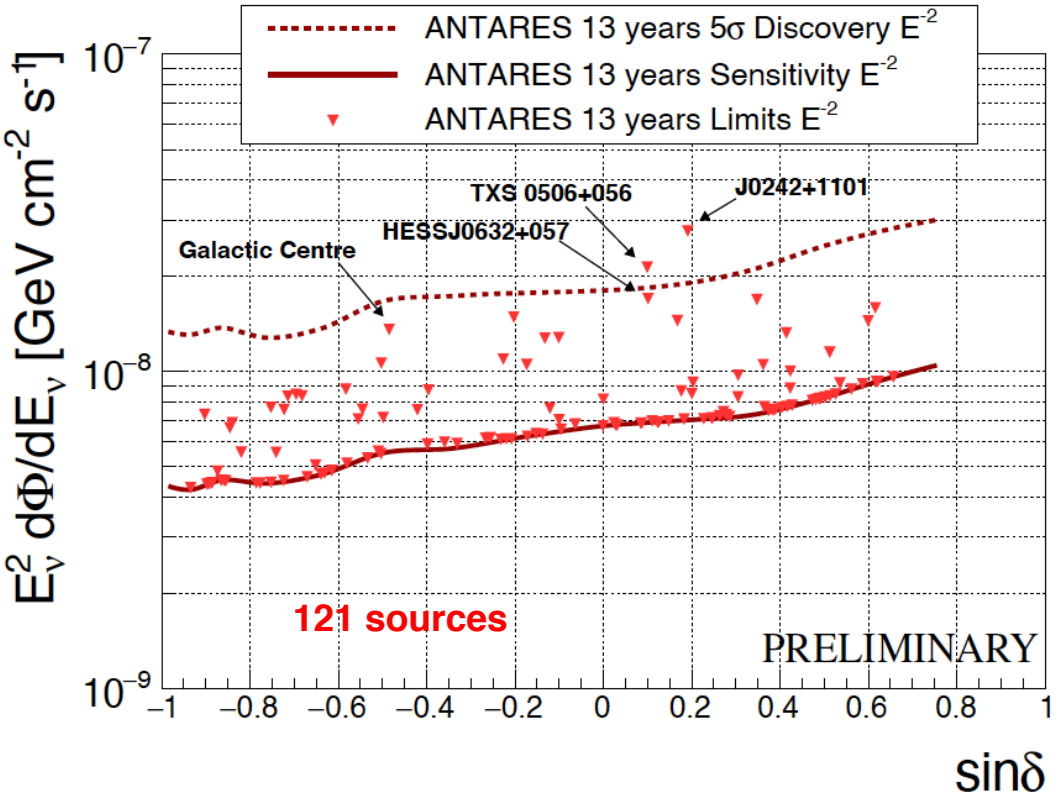


The most significant cluster:
RA=39.6° δ=+11.1°
pre trial: 4.3 σ
Within 1 degree of J0242+1101 (orange star)



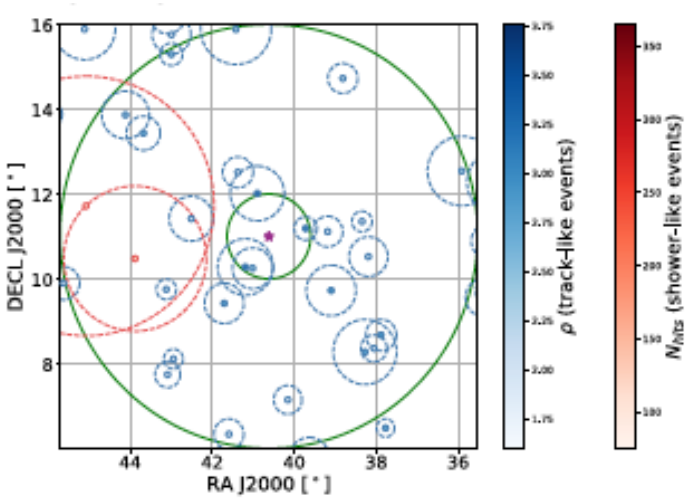
PoS(ICRC2021)1161

Point-like sources – catalog search



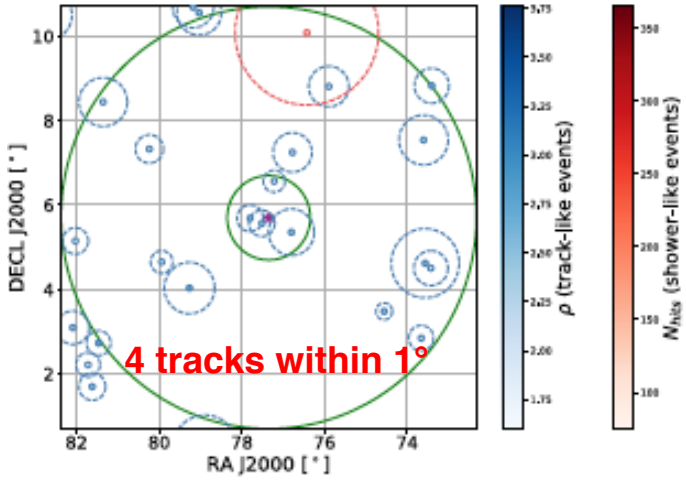
PoS(ICRC2021)1161

1st: J0242+1101



Pre-trial: 3.8σ Post-trial: 2.4σ

2nd: TXS 0506+056



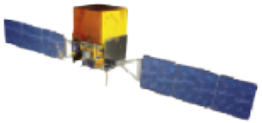
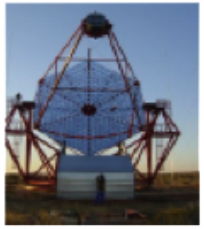
Pre-trial: 3.1σ Post-trial: 2.6σ

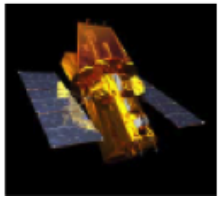
Multimessenger studies with ANTARES

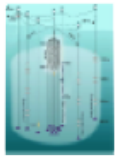
Intense multi-messenger activity

APP35 (2012)530
JCAP02(2016)062

Gamma-ray Coordinates Network (GCN) https://gcn.gsfc.nasa.gov/



neutrinos
IceCube, GVD, SNEWS

GeV-TeV γ-rays
Fermi, HESS, HAWC, CTA

UHECR
Auger, TA

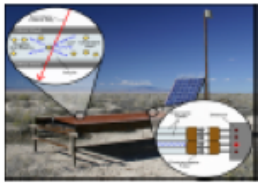
only spatial coincidence

ANTARES

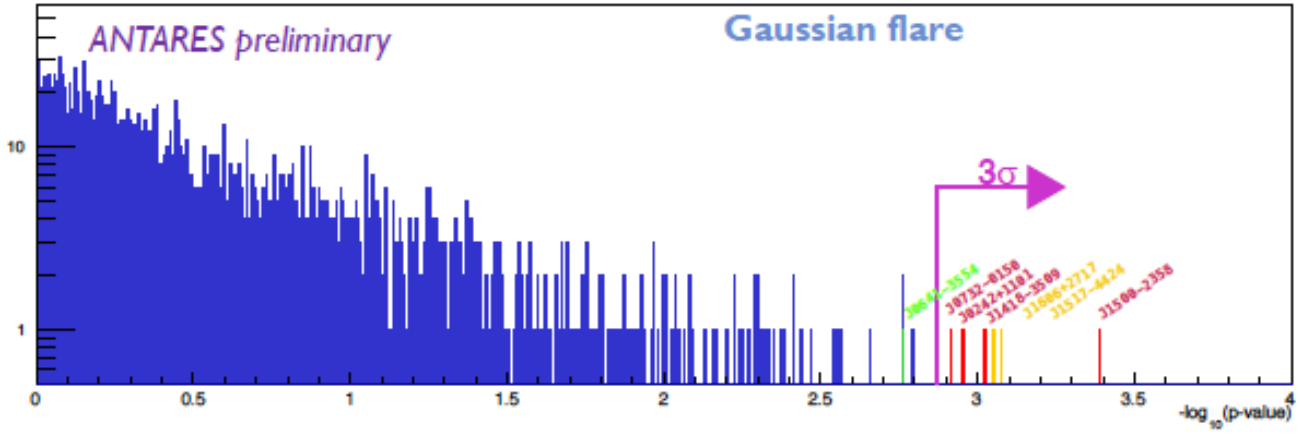
Radio/Optic /X-ray
TAROT, MASTER, Swift, INTEGRAL, MWA

real-time alerts
$\Delta t \sim 5s$
median resolution 0.5°
A few 10 alerts per year

Gravitational Waves
VIRGO, LIGO

VLBI radio loud blazars (2774 sources)

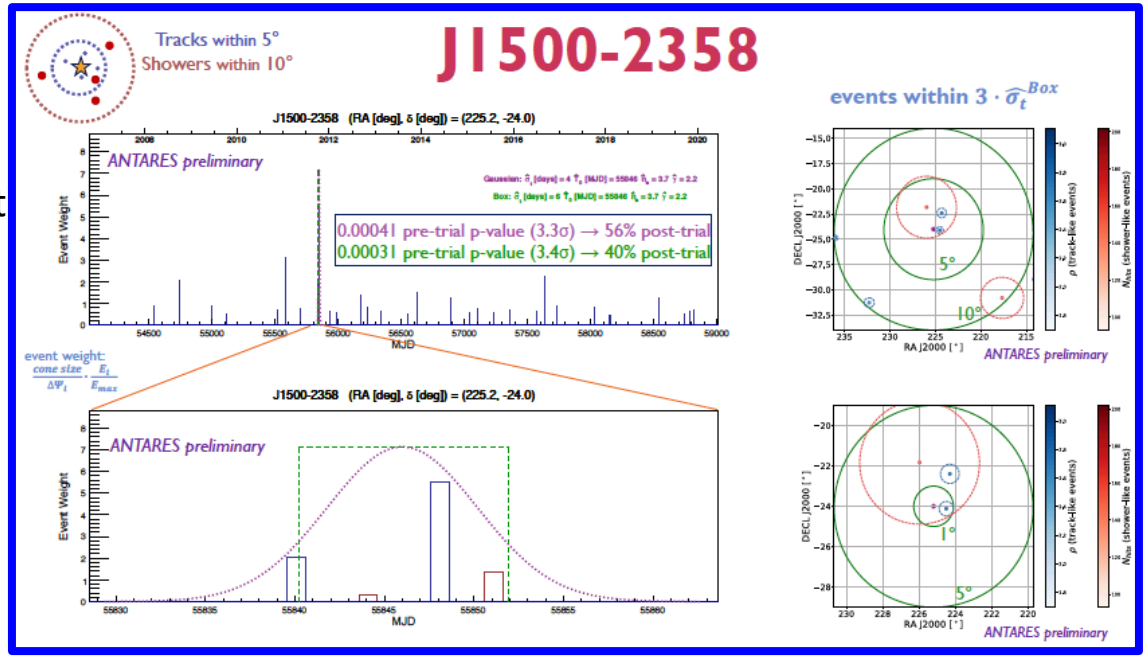


J1500-2358 **The most significant**
J1517-4424
J1606+2717
J1418-3509
J0242+1101 **The most intriguing**
J0732-0150
J0641-3554

Search from the direction of 2774 radio-bright blazars selected on the basis of Very Long Baseline Interferometry radio flux (flux density integrated over VLBI images at 8GHz >150mJy)

13 years of ANTARES data: 2007-2020
10162 tracks + 225 showers

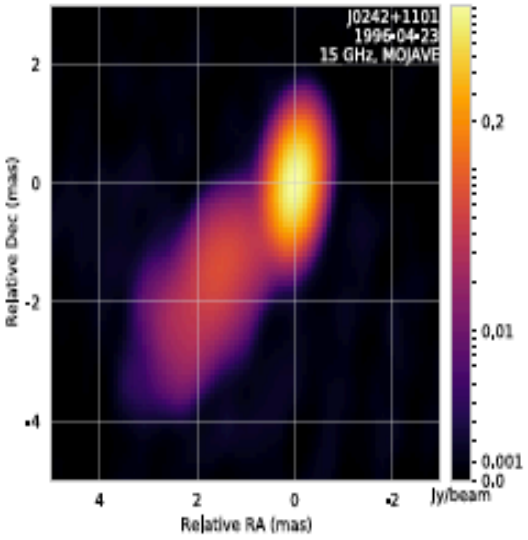
2 signal time profiles:
Gaussian shape
Box shape



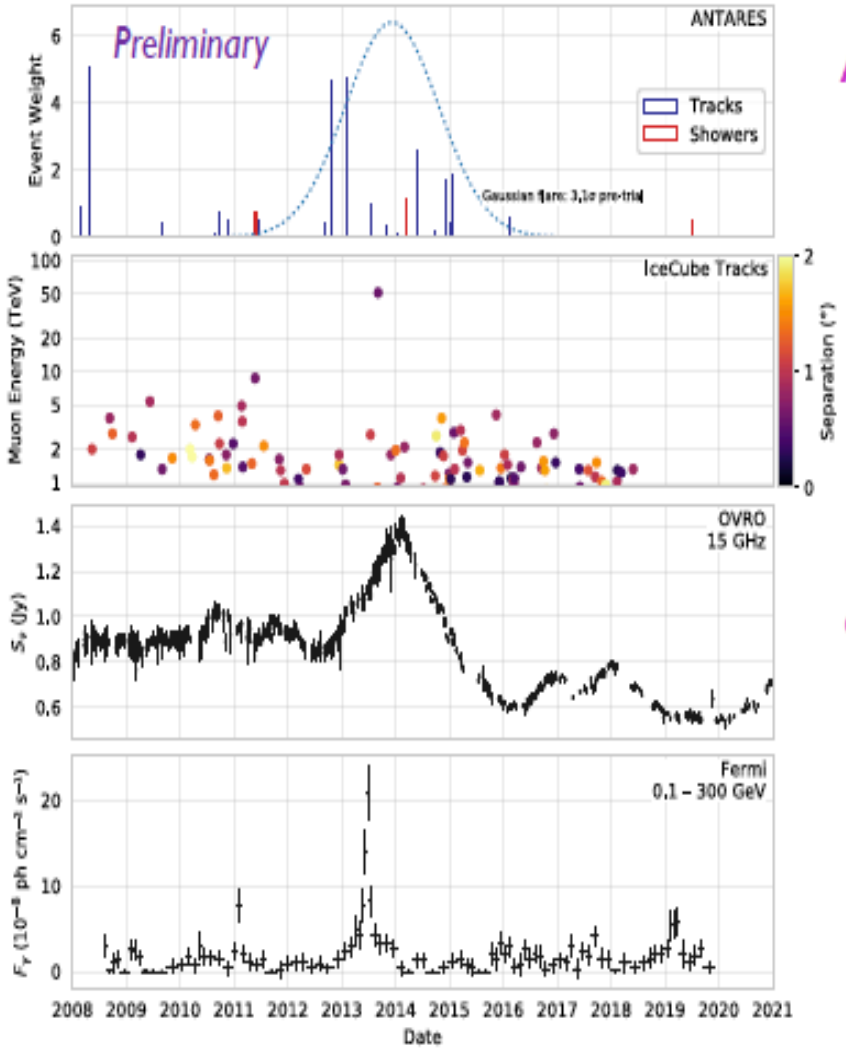
Details can be found in PoS(ICRC2021)972

J0242+1101 (PKS 0239+108)

VLBI image at 15 GHz



Chance probability of the multi-messenger association under study



ANTARES best-fit flare for this source

IceCube tracks from 10-years point-source sample
- Tracks within 90% angular error from source
- angular error < 10deg^2

OVRO radio light-curve

Adaptive binned gamma-ray light-curve obtained from Fermi LAT data

Conclusions

- ANTARES paved the way to Mediterranean neutrino telescopes:
  - Confirmed that
    - the Mediterranean Sea is an excellent location to look at the Southern sky
    - water properties allow for good angular resolution
  - Showed the feasibility of the technique
  - Tested advanced technologies
  - Created a software framework for simulations and data analysis
  - Measured the effects of environmental background
- Produced interesting physics results:
  - Hints for diffuse flux of HE neutrinos
  - Identification of potentially interesting point-like sources of neutrinos
  - Possible association between neutrino candidates and flaring radio sources
  - Atmospheric neutrino spectra of ν_e and ν_μ measured
- Many studies in progress:
  - Dark matter
  - Magnetic monopoles and nuclearites
  - Multimessenger studies in coincidence with GRB, Gravitational Waves, transient phenomena.
- Smooth and continuous data taking since 2008 – decommissioning foreseen in 2022

ANTARES will pass the torch to the KM3NeT telescopes