

Results from the ANTARES Neutrino Telescope

Agustín Sánchez Losa

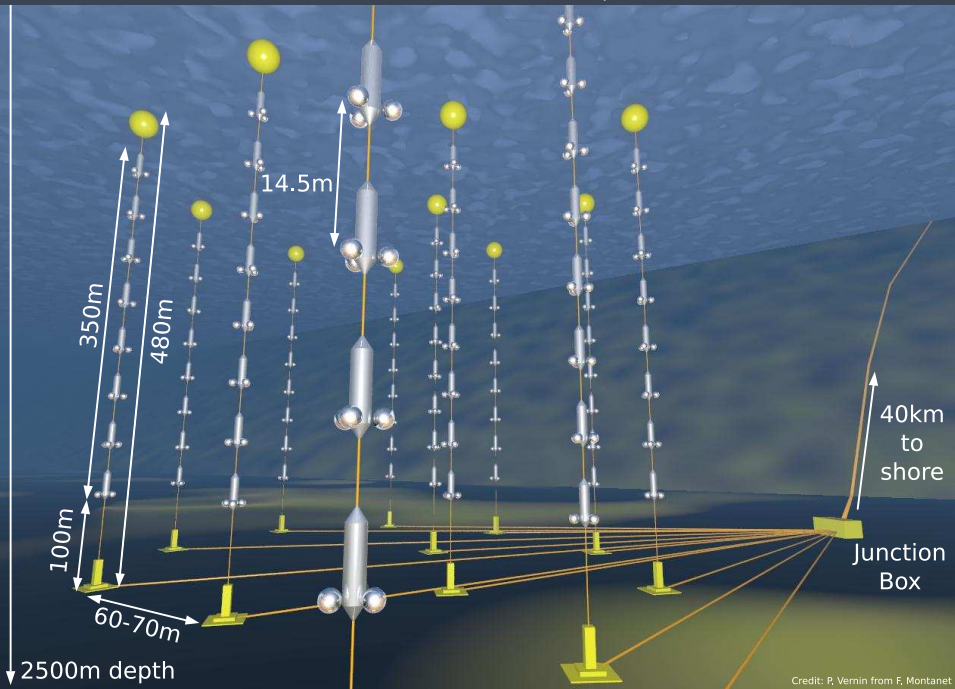
INFN (Sezione di Bari)

for RICAP-16 on behalf of
the ANTARES Collaboration

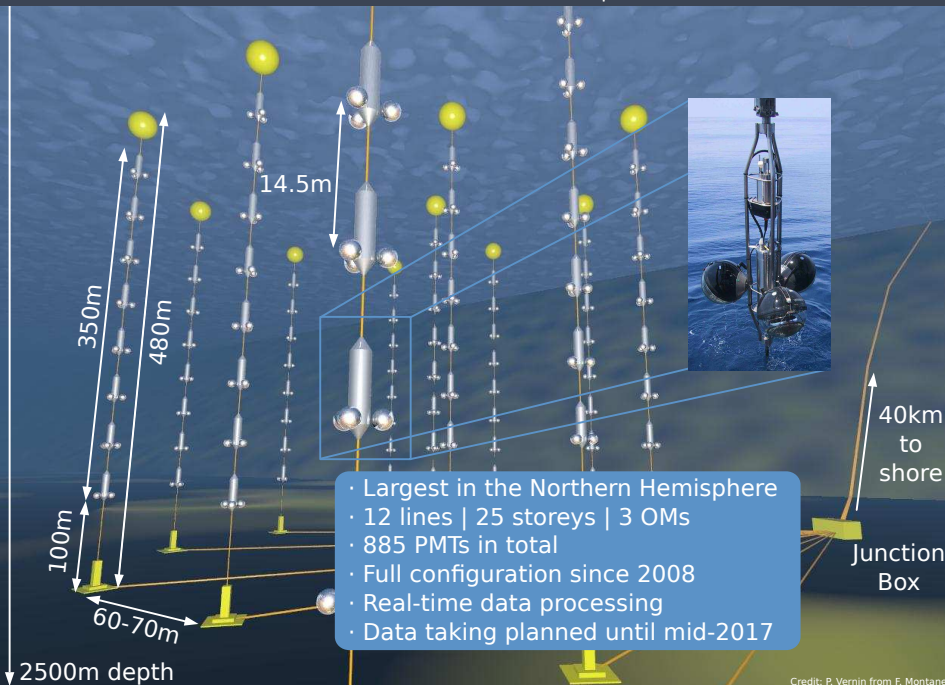
Frascati, June 23rd, 2016



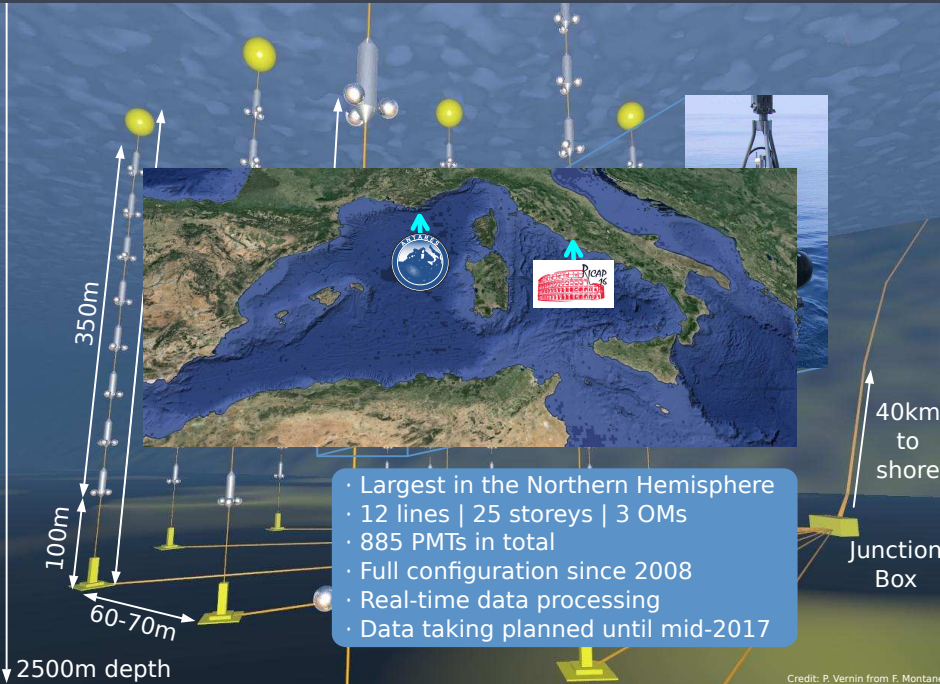
ANTARES neutrino telescope



Credit: P. Vernin from F. Montanet

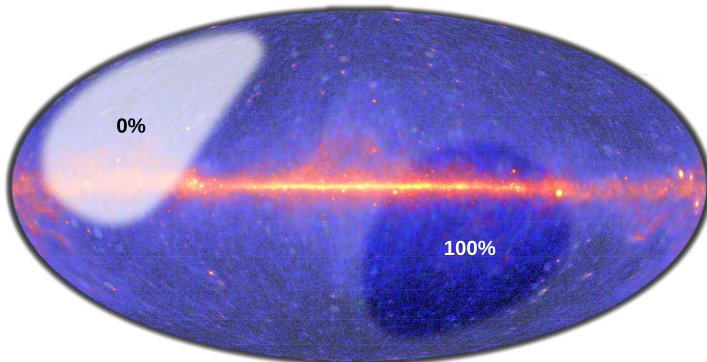


Credit: P. Vernin from F. Montanet



- Largest in the Northern Hemisphere
- 12 lines | 25 storeys | 3 OMs
- 885 PMTs in total
- Full configuration since 2008
- Real-time data processing
- Data taking planned until mid-2017

ANTARES Visibility



Fermi 5-year gamma-ray skymap (>1 GeV) combined with ANTARES visibility

- Instantaneous half sky visibility
- Visibility of $3/4$ of the sky: most of the Galactic Plane

40km
to
shore

nction
Box

from F. Montanet

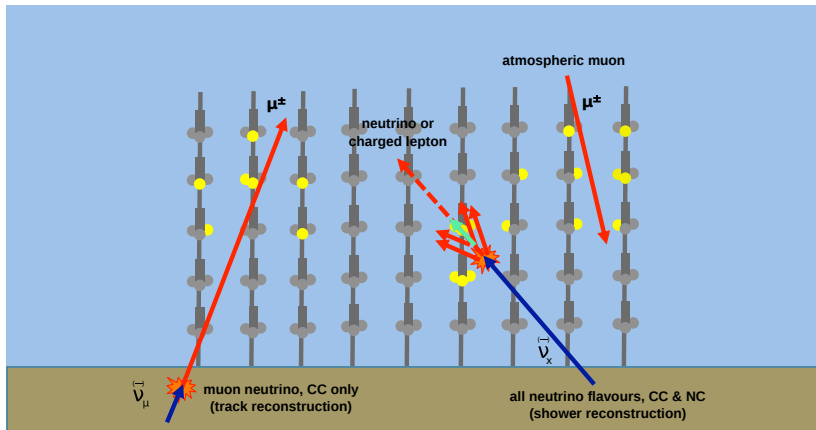
Detection principle

Neutrino interactions:

- **CC:** $\nu_l N \xrightarrow{W} l X$
- **NC:** $\nu N \xrightarrow{Z} \nu N$

Neutrino topologies:

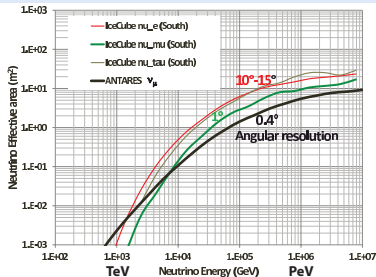
- regarding interaction (CC/NC) and lepton output ($e/\mu/\tau$)
- **tracks** and **showers**



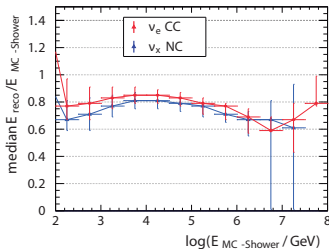
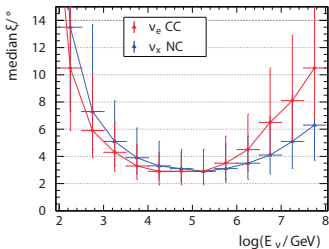
ANTARES Track & Shower Performances

- Median angular resolution for tracks below 0.5° above ~ 10 TeV: 0.4° for E^{-2}
- Effective area $\sim 1\text{m}^2$ @ 70 TeV

Bottom: performance of the shower energy-direction reconstruction (**EM&HS**) for contained events. Left, MC-reconstructed angle vs. neutrino energy. Right, MC-reconstructed energy ratio vs. shower energy. Error bars are 25–75%.



ANTARES – ApJ 760:53(2012)
IceCube – PhysRevD 91(2015)2,022001



Scientific goals

Highlighted topics:

- Point sources: First combined analysis  **IceCube–ANTARES** 
- Diffuse fluxes  Nu#2 | L. Fusco
- Multi-messenger studies:
 - Prompt alerts: TATo0, **GW150914** follow up...  GW | A. Coleiro
 - Transient gamma & X-ray sources
 - GRBs  Nu#2 | M. Sanguineti
- Dark matter indirect searches  DM | C. Tönnes

Also: *(not covered on this talk)*

- Study of: atmospheric neutrinos and oscillations, atmospheric muons, cosmic-ray anisotropy...
- Exotic particles search: nuclearites, monopoles...
- Acoustic neutrino detection techniques
- Earth and Sea sciences

Point Sources

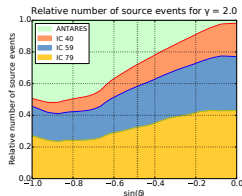


IceCube–ANTARES

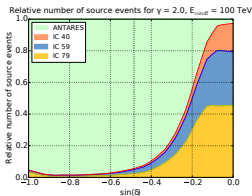


combined analysis

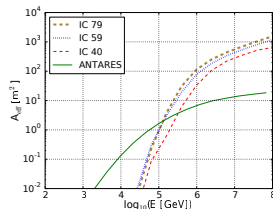
- “**First combined search** for neutrino point-sources in the Southern Hemisphere with the **ANTARES and IceCube** neutrino telescopes , ApJ 823(2016)65
- Southern sky muon tracks
- IceCube 2008–2011 + ANTARES 2007–2012:
 - IC-40: 375 days of livetime with 22779 events
 - IC-59: 348 days of livetime with 64240 events
 - IC-79: 316 days of livetime with 59009 events
 - ANTARES: 1338 days of livetime with 4136 events



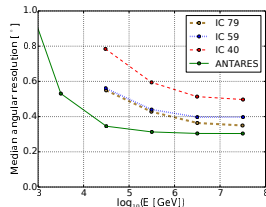
Combined acceptance for
 E^{-2}



Combined acceptance for
 $E^{-2} \exp^{-\sqrt{E}/100\text{TeV}}$



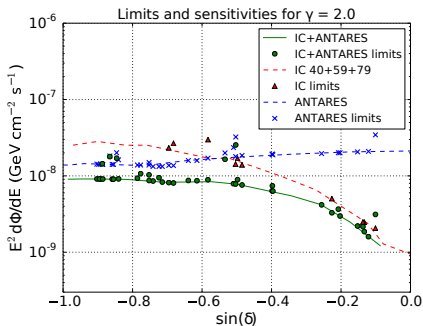
Muon neutrino effective area for a point source at a declination $\delta = -30^\circ$ (top) and median angular resolution (bottom) for this analysis



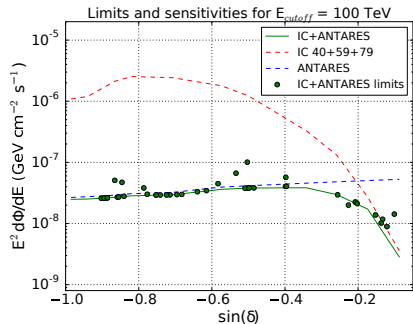
Point Sources

IceCube-ANTARES  combined analysis

- Full sky + 40 sources (17 extra-galactic + 22 galactic + Galactic Centre)
- Upper limits improvement up to a factor ~ 2
- No significant cluster found, largest excesses:
 - Full sky search: 0.7σ significance (post-trial) at (RA: 332.8° , δ : -46.1°)
 - Candidate list: 1.2σ significance (post-trial) for HESS J1741.302



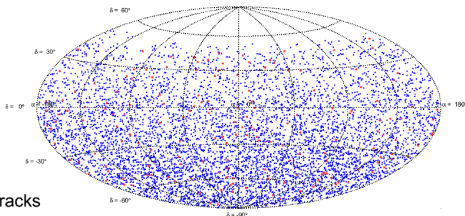
Combined upper limits for E^{-2}



Combined upper limits for $E^{-2} \exp^{-\sqrt{E/100\text{TeV}}}$

Point Sources

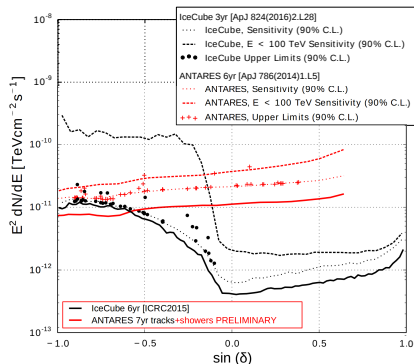
ANTARES 2007–2013 PS update



■ Tracks
■ Showers

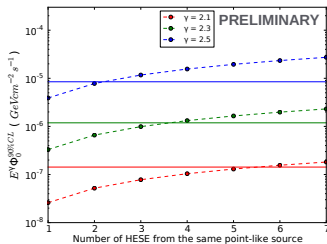
ANTARES 2007–2013 skymap
6490 tracks (*median angular res. 0.3°*)
172 showers (*median angular res. 3°*)

- Michael, ICRC2015 1078
- 1690 live-time days
- tracks + showers analysis ($\sim 10\%$ atmospheric muon contamination)
- Full sky + 54 candidate sources + 8 IceCube μ -tracks (Phys Rev Lett 113(2014)101101) + Galactic Centre (as $0^\circ - 5^\circ$ extension)
- No significant cluster found, largest excesses:
 - Full sky search: 1.3σ significance (post-trial) at (RA: 311.7° , δ : -48.3°)
 - Candidate list: 0.75σ significance (post-trial) for HESS J0632+057

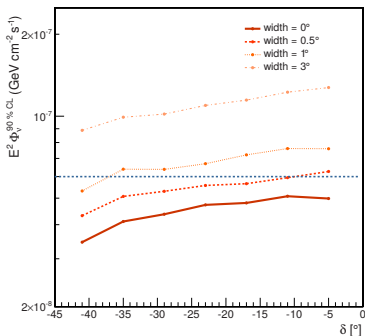


Point Sources

ANTARES 2007–2012 PS about Galactic Centre / IceCube Hot Spot



ANTARES limits (solid lines) on the contribution of point-like sources to the IceCube HESE 3yr sample and the flux required to produce a given expected number of HESE (dashed lines) for source spectra between 2.1 and 2.5 and a source declination of $\delta = -29^\circ$



ANTARES excludes unique source ($\gamma = 2$, up to 1° extension) in a 20° cone as origin of the IC cluster (ApJL 786:L5 2014)

- Barrios-Martí, ICRC2015 1077
- 1338 live-time days and 5516 tracks ($\sim 10\%$ atmospheric muon contamination)
- No significant result found: point-like sources with spectral index closer to 2.5 are more disfavoured than for values closer to 2.0

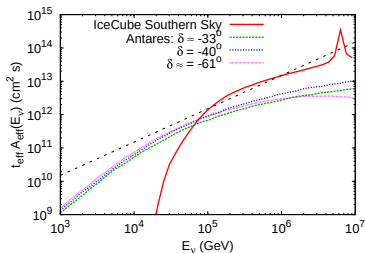
Point Sources



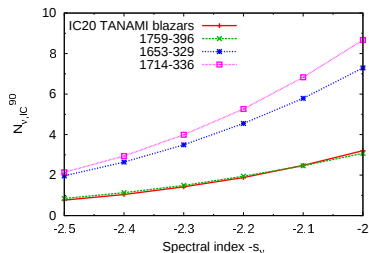
TANAMI-ANTARES



about IC14 and IC20 events



Relative exposures of the ANTARES candidate list search to a flavour-uniform neutrino flux from the characteristic declinations of the six candidate blazars, and the southern-sky-average of the IceCube HESE 3yr analysis


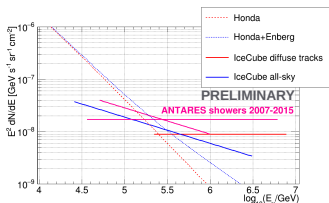


ANTARES limits on the expected number of IceCube events of blazar origin. “IC 20 TANAMI blazars” corresponds to 0235-618, 0302-623, and 0308-611.

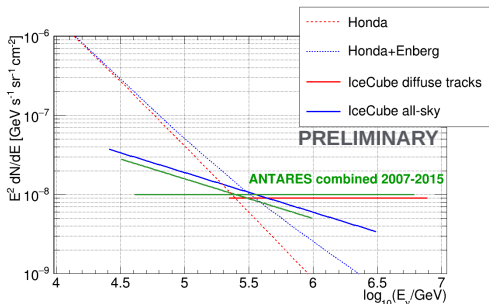
- “ANTARES Constrains a Possible Blazar Origin of the IceCube PeV Neutrino Events”, A&A Lett. 576(2015)L8 (*highlighted in Nature 520, April 2015*)
- TANAMI collaboration reported observations of 6 bright blazars locally compatible with the 2 first PeV IceCube events IC14 (Bert) and IC20 (Ernie)
- ANTARES 2007–2012 data
- Relevant constraints on spectral index of potential source

Diffuse fluxes

ANTARES 2007–2013 diffuse fluxes with showers

( Nu#2 | L. Fusco)

Sensitivity about 1.5 times larger than IceCube best fits (for $\gamma = 2.0$ and $\gamma = 2.5$)


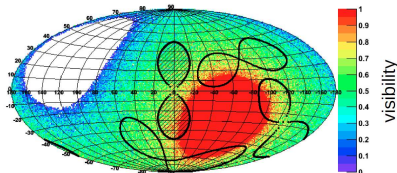


Sensitivity gain by combining both track and shower channels

- A first sample of 1405 days (out of 2007–2013 data) has been unblinded for the shower channel
- MC expectations: **5 background events** (3 atmospheric muons, 2 atmospheric neutrinos) + **2 signal events** (depending on the spectral index, for all flavour)
- **7 events observed** in data: Compatible with expectations for background + signal, excess not significant, but more data are being analysed
- Sensitivities computed for 2007–2015 data with tracks and showers (combined $1/S = 1/S_{tr} + 1/S_{sh}$): could reach IC flux?

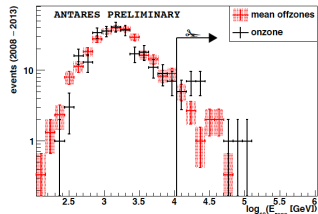
Diffuse fluxes

ANTARES 2008–2013 about Fermi bubbles

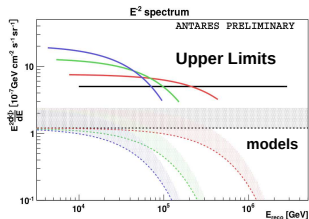
( Nu#2 | L. Fusco)

On/Off zones - Gal. coordinates

- Hallmann, ICRC2015 1059
- Muon tracks in 2008–2013 ANTARES data
- 4 OFF zones selected: same shape, efficiency and coverage than ON zone
- **13 background events** expected and **22 events observed** in data: 1.9 σ excess

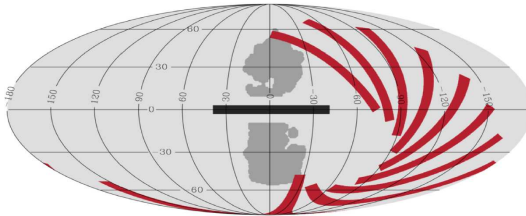


Energy distribution



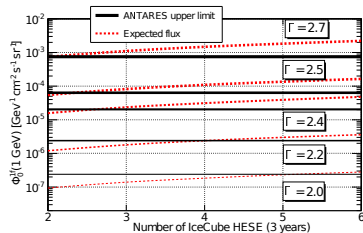
Diffuse fluxes

ANTARES 2008–2013 about Galactic Ridge




On/Off zones - Gal. coordinates

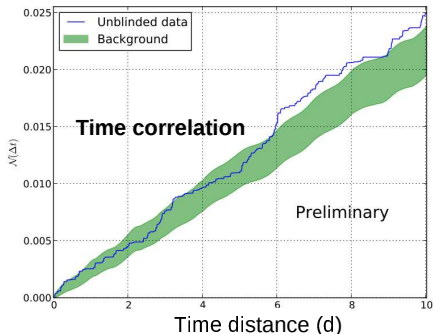
- “Constrains on the neutrino emission from the Galactic Ridge with the ANTARES telescope”, accepted for publication on *PhysLettB*
- Muon tracks in 2007–2013 ANTARES data
- 9 OFF zones selected: same shape, efficiency and coverage than ON zone
- **3.7 background events** expected and **2 events observed** in data: underfluctuation



Diffuse fluxes

ANTARES May/2010–Nov/2012 time correlation with IceCube HESE 3yr

( Nu#2 | L. Fusco)

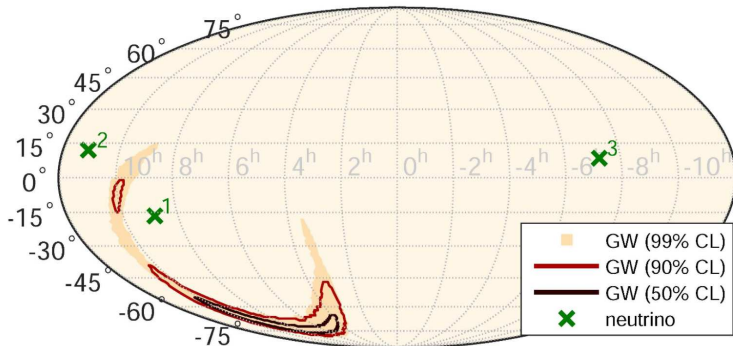



Upper limits from null observation:
exclude that 2 or more IceCube HESE
3yr originate from the region around the
GC for flares ranging from 0.5 to 0.01
days in duration for $E^{-2.5}$ to E^{-2}
spectra

- Coleiro, ICRC2015 1073
- Transient source at Sgr A* might be the origin of a few IceCube events (Bai et al. 2014)
- Searched for time correlation between 9 IceCube HESE 3yr and ANTARES events close to the GC
- No significant time correlation was found

Multi-messengers

ANTARES GW150914 follow up

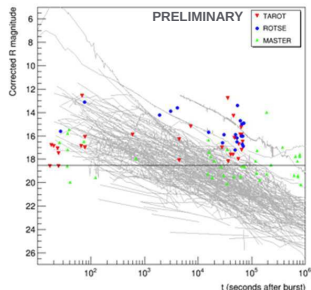
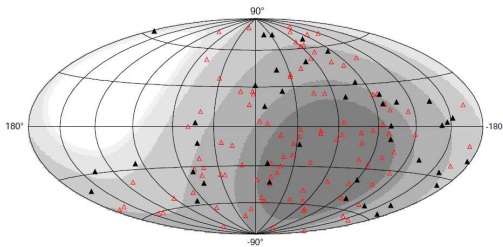
( GW | A. Coleiro)

- Alert triggered by LIGO on 14/SEP/2015: first Gravitational Wave detected
- “High-energy Neutrino follow-up search of Gravitational Wave Candidate GW150914”, accepted by Phys Rev D (Apr 22nd 2016), arXiv:1602.05411
- ...see  GW | A. Coleiro talk a bit later!


Multi-messengers

ANTARES TAToO GRB search update

( GW | A. Coleiro)

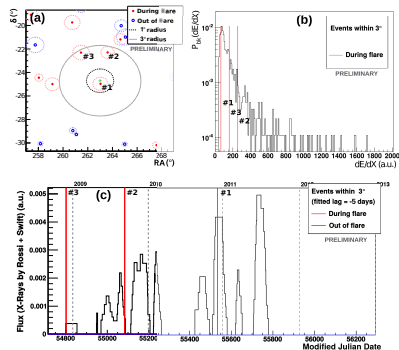
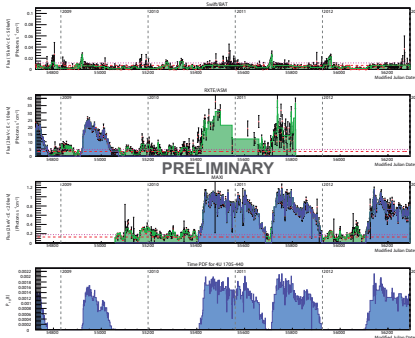


Skymap of triggers with (black triangles) and without (red triangles) early optical follow-up.

- TAROT–ANTARES Target of Opportunity: electromagnetic follow up of neutrino alerts
- Optical (TAROT, ROTSE and MASTER) and X-ray (Swift-BAT) telescopes
- Update of the GRBs limits
- ...also covered on  GW | A. Coleiro talk a bit later!

Multi-messengers

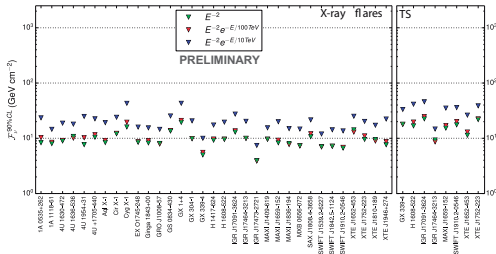
ANTARES 2008–2012 about X-ray binaries




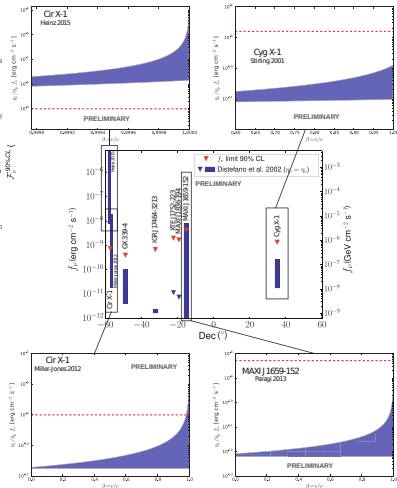
- Sánchez-Losa & Dornic, ICRC2015 1075
- 1044 days of livetime of muon tracks during 2008–2012
- Study of 33 XRBs during X-ray flares, 8 of them also during hardness transition states
- Time signal: X-ray light curves from Swift-BAT, RXTE-ASM and MAXI, transition states from “The Astronomer’s Telegram” alerts
- No significant excess: best post-trial 72% for GX 1+4

Multi-messengers

ANTARES 2008–2012 about X-ray binaries


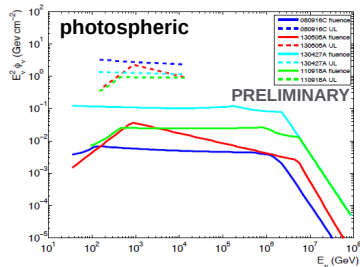
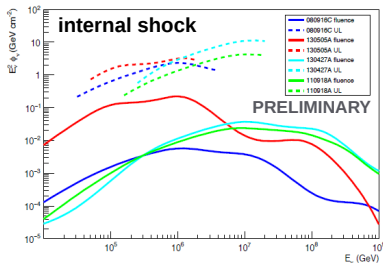


- Upper limits on neutrino fluence during studied periods
- Constrains on model parameters
- ...also covered on  GW | A. Coleiro talk a bit later!

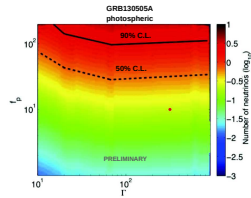
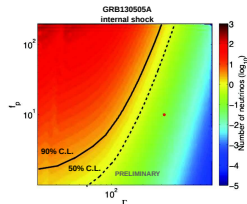


Multi-messengers

ANTARES 2008–2013 Brightest GRBs

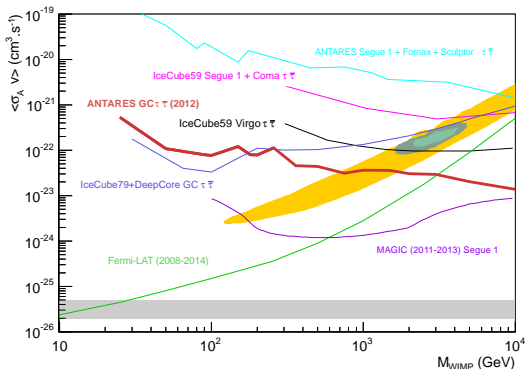
( Nu#2 | M. Sanguineti)

- Brightest GRBs detectable from ANTARES within 2008 and 2013: **GRB080916C**, **GRB110918A**, **GRB130427A** and **GRB130505A**
- Two neutrino production models studied: internal shock and photospheric
- 10° around GRB during its detection (7s–100s) $\pm 2s$ around
- No neutrino in coincidence: upper limits and constrains on baryonic loading factor and bulk Lorentz



Dark Matter

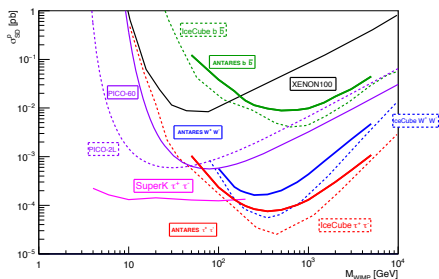
ANTARES 2007–2012 about Dark Matter on the Galactic Center

( DM | C. Tönnis

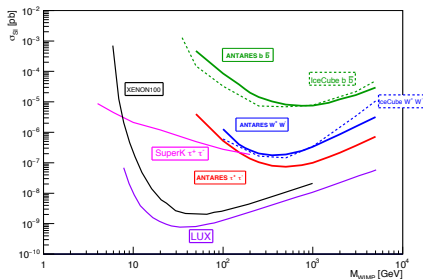
- “Search of Dark Matter Annihilation in the Galactic Centre using the ANTARES Neutrino Telescope”, JCAP10(2015)068
- 1321 days of livetime of muon tracks during 2007–2012
- Competitive results, constraining SUSY dark matter... upcoming new data

Dark Matter

ANTARES 2007–2012 about Dark Matter on the Sun

( DM | C. Tönnis)

spin dependent

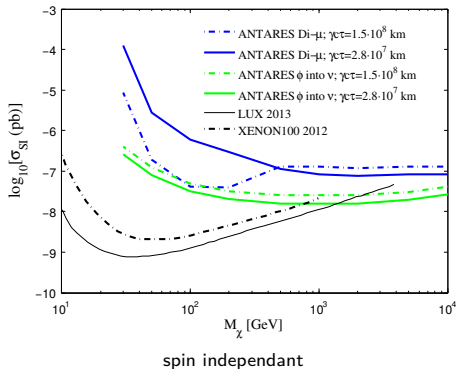
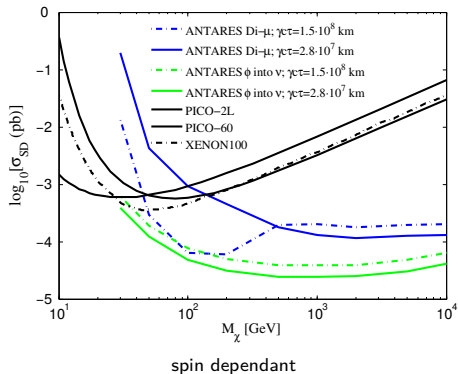


spin independent

- “Limits on Dark Matter Annihilation in the Sun using the ANTARES Neutrino Telescope”, accepted by PhL B (May 6th 2016), arXiv:1603.02228
- 1321 days of livetime of muon tracks during 2007–2012

Dark Matter

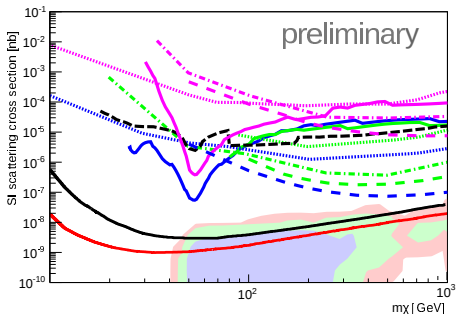
ANTARES 2007–2012 about Secluded Dark Matter



- “Results of the search for Secluded Dark Matter in the Sun with the ANTARES neutrino telescope”, JCAP05(2016)016
- Dark matter secluded by a mediator: detection by mediator eventually decays in neutrinos
- Sun as the source candidate
- 1321 days of livetime of muon tracks during 2007–2012
- Limits inferred in the absence of excess of signal

Dark Matter

ANTARES 2007–2012 about Dark Matter search from the Earth



Blue lines: $\tau^+\tau^-$ channel

Magenta lines: $b\bar{b}$ channel

Green lines: W^+W^- channel

Solid lines: ANTARES (2007–2012)

Dotted lines: BAKSAN (1978–2009)

Dot-Dashed lines: IceCube (2010–2011)

Black line: XENON100 (2012)

Red line: LUX (2013)

- Gleixner & Tönns, ICRC2015 1110
- 1191 days of livetime of muon tracks during 2007–2012
- In this search no equilibrium between annihilation and capture can be assumed

Summary

1 ANTARES is the biggest neutrino telescope underwater and the biggest in the northern hemisphere



2 High duty cycle and an instantaneous field of view of 2π

3 Good visibility of the GC and most of the GP

4 Presented analysis:

- First combined IceCube–ANTARES analysis
- PS update including showers
- GC/IC-HS PS studies
- TANAMI–ANTARES about IC HESE
- Diffuse fluxes with showers
- Fermi bubbles
- Galactic Ridge
- Time correlation with IC HESE
- GW follow up
- TAToO update
- XRBs time-dependant
- GRBs
- DM from GC
- DM from Sun
- SDM from Sun
- DM from Earth

5 Important highlights:

- First results on diffuse flux with showers in ANTARES
- IceCube signal confirmation seems around the corner
- Many promising **tracks** + **showers** analysis with data up to 2015 are on going... keep tuned!
- ...and future is today: see talk on  KM3NeT
by  CR& γ | J. Brunner!

