Highlights from the ANTARES detector

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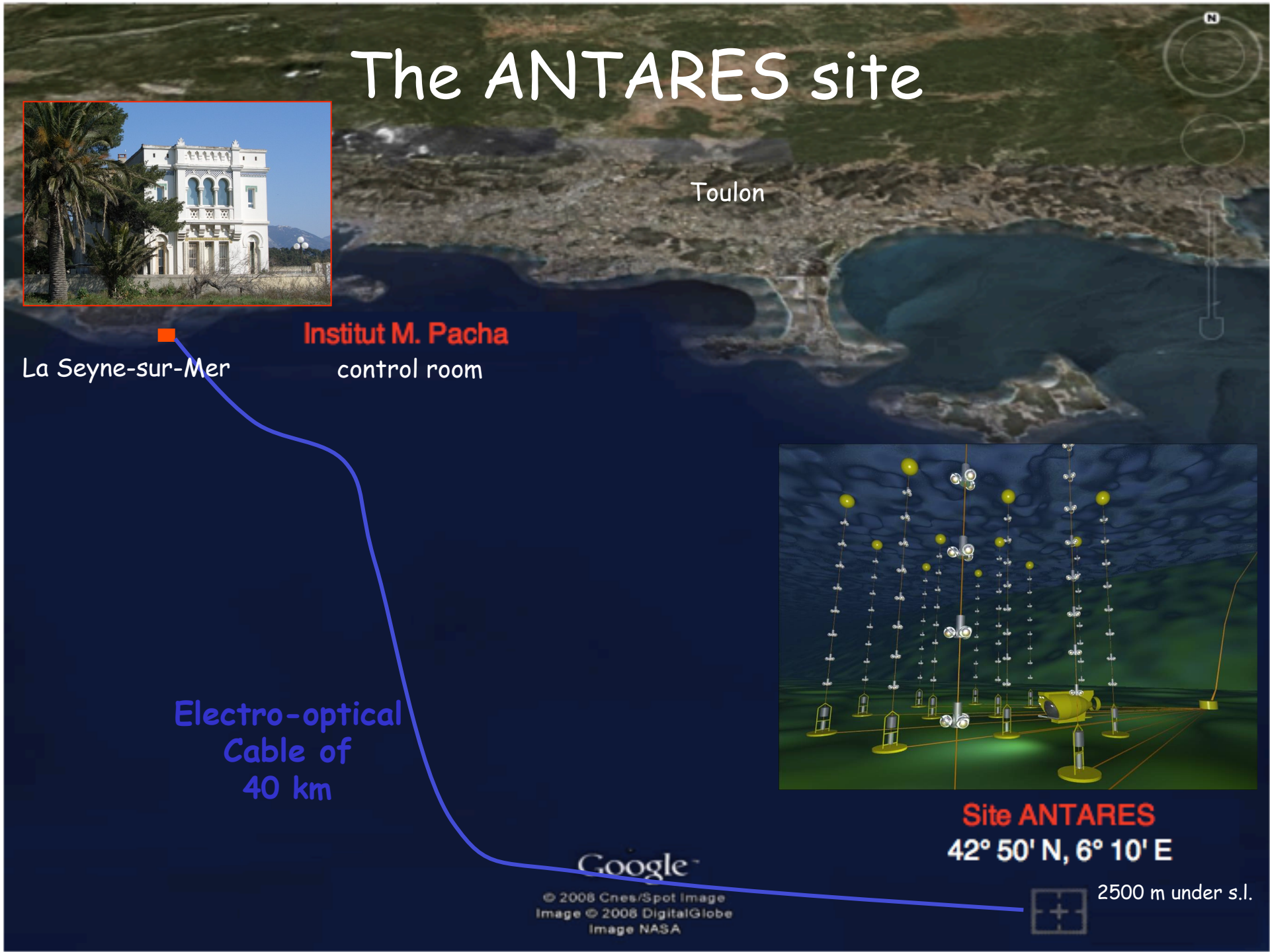
ANTARES: the largest Northern neutrino telescope

Scientific goals

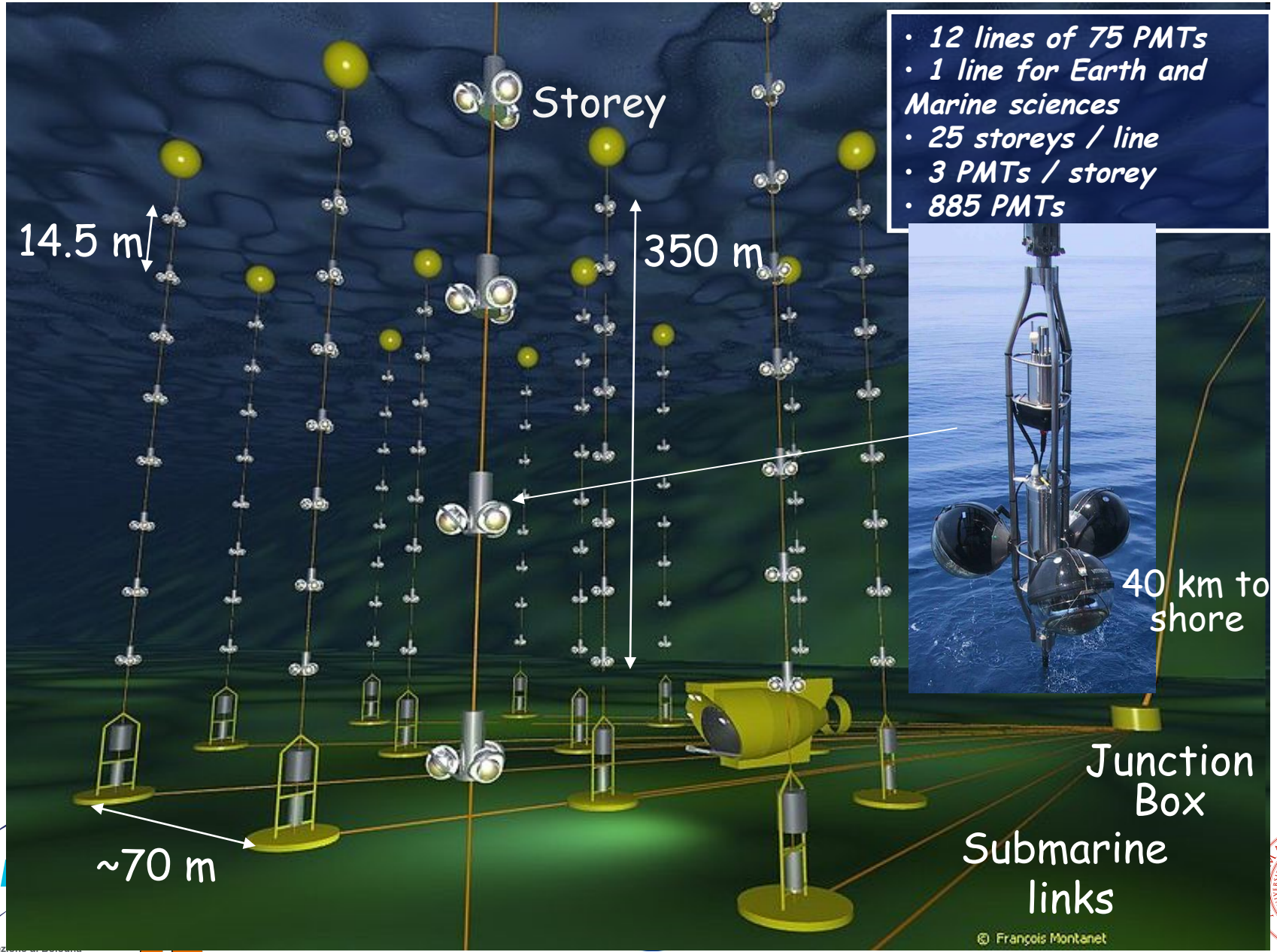
- Neutrino astrophysics
- Multi-messenger studies
- Dark matter searches
- Atmospheric neutrinos
- Exotic particles search: nuclearites, monopoles
- Acoustic neutrino detection
- Earth and Sea sciences

The origin of the IceCube signal: what can ANTARES say ?

The ANTARES site

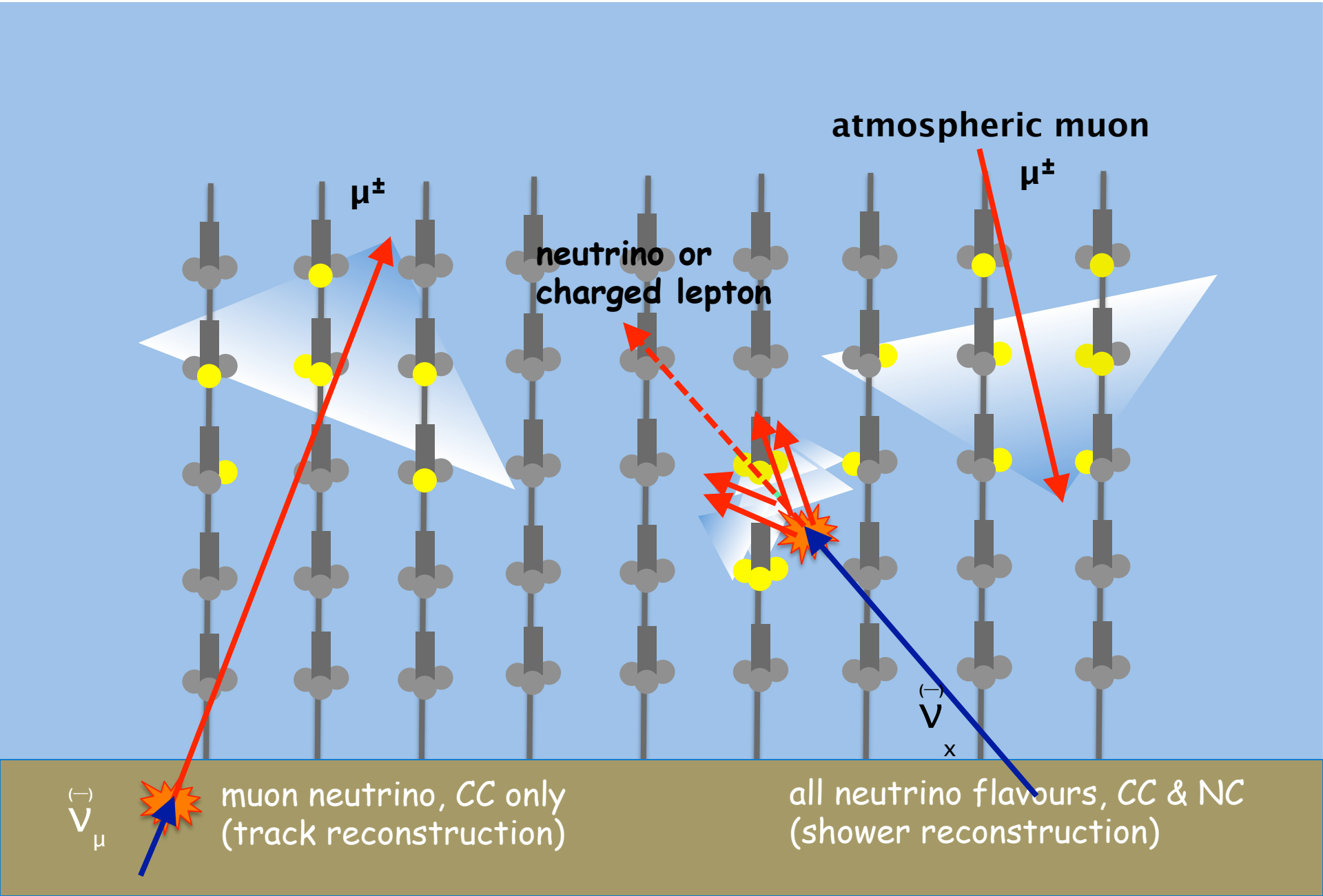


The telescope: full configuration since 2008

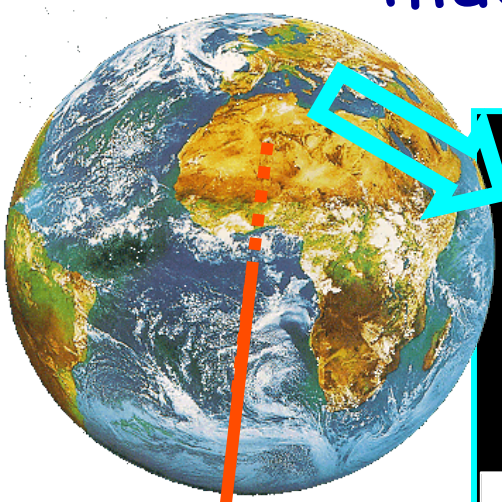


- 12 lines of 75 PMTs
- 1 line for Earth and Marine sciences
- 25 storeys / line
- 3 PMTs / storey
- 885 PMTs

How does a neutrino telescope work?



muon tracks = golden channel



HE muons from ν_μ CC-interaction

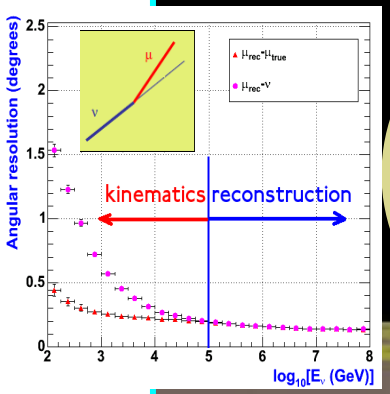
Energy threshold ~ 10 GeV

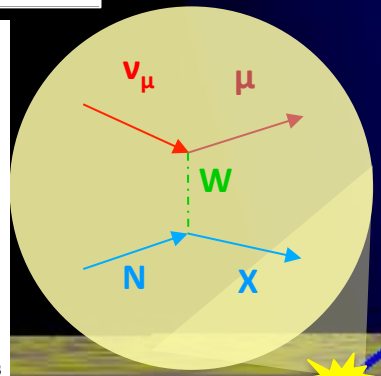
$$\frac{dN_\gamma}{dx} = 3.5 \times 10^4 m^{-1}$$

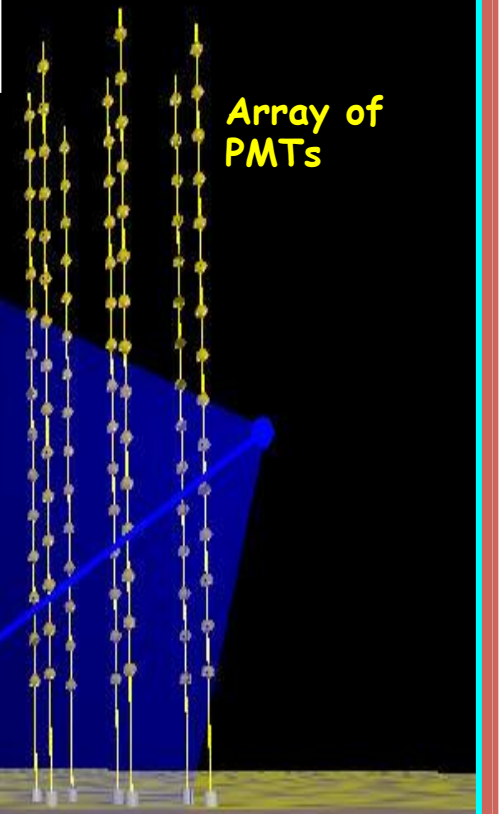
$$\theta_{\mu\nu} \sim \frac{0.7°}{\sqrt{E_\nu[TeV]}}$$

Cherenkov photons

θ_{Ch}~42° in water







muon

neutrino

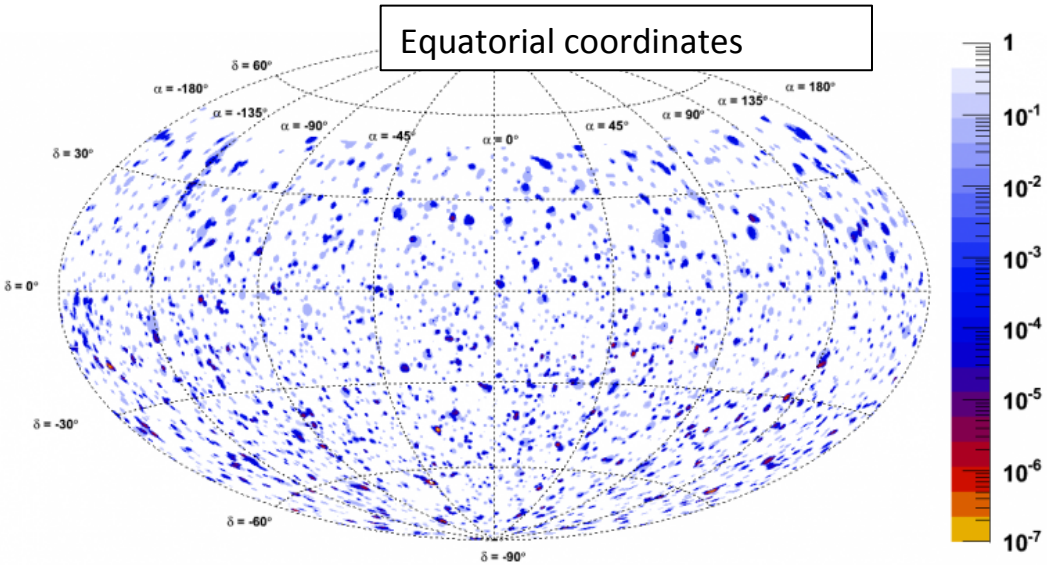
Reconstruction of μ trajectory (~ ν) from timing and position of PMT hits

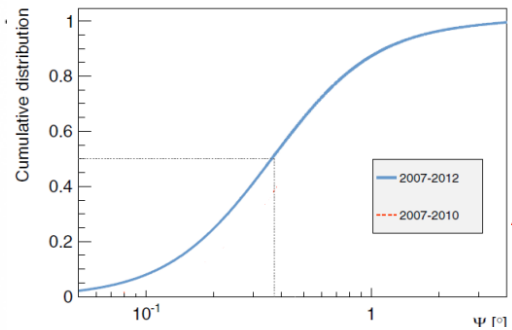
Point-like sources

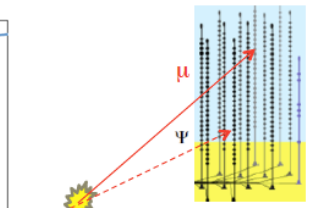
5516 events

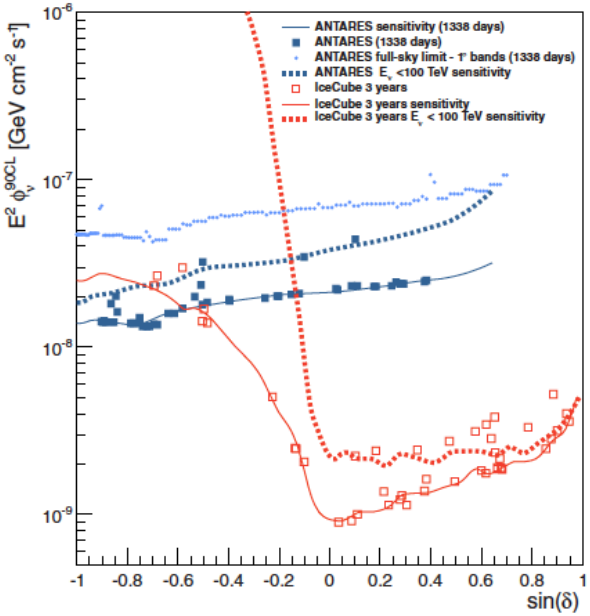
10% μ_{atm} contamination

0.38° angular resolution









- ν_μ channel→ ANTARES behaves like a telescope
- 50% ν_μ are reconstructed within 0.4° (for E^{-2})
- ANTARES dedicated study of 50 pre-selected sources using data set 2007-2012 (no significant excess)
- Unbinned searches: no excess (most significant at 2.2σ)

THE ASTROPHYSICAL JOURNAL LETTERS, 786:L5 (5pp), 2014 May 1

Joint analysis ANTARES-IC

ANTARES data sample + IceCube (IC-40, IC-59, IC-79) data samples

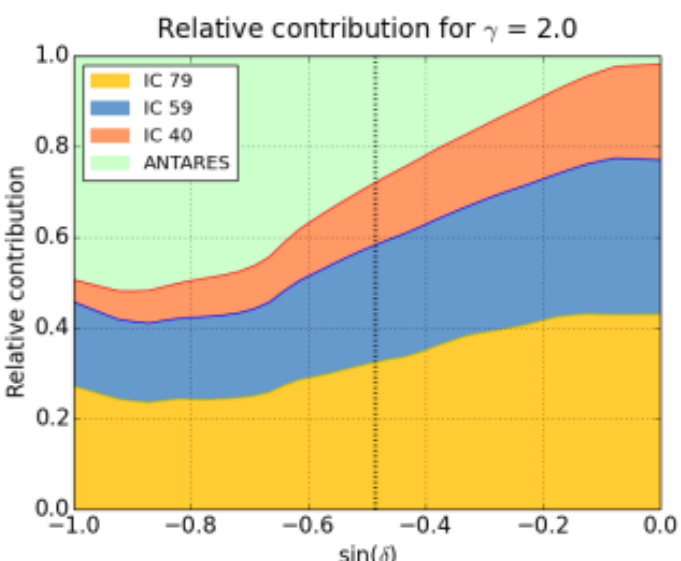
1) Search for an excess over a BG in the Southern Sky, for E^{-2} spectrum (unbinned)

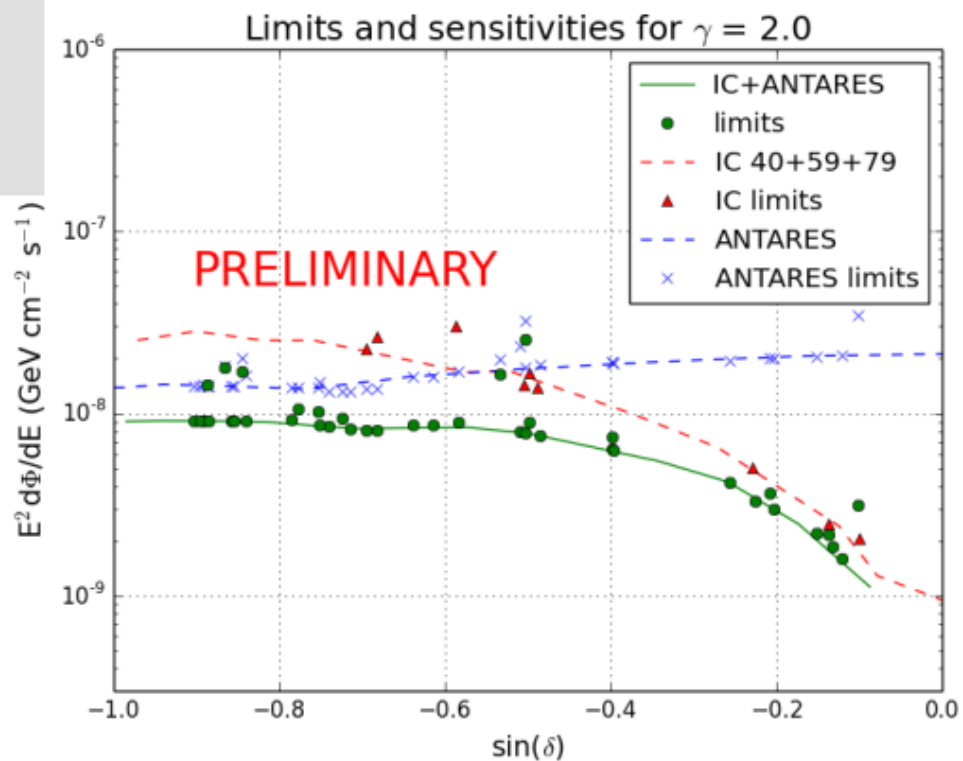
2) Search over a pre-selected list of candidate sources with : γ= 2, 2.5;
energy cutoffs at 1 PeV, 300 TeV, 100 TeV

- ANTARES has better angular resolution (less scattering in seawater)
- IceCube has more events with better energy resolution (it's bigger!)
- Different declination dependencies – complementary regions

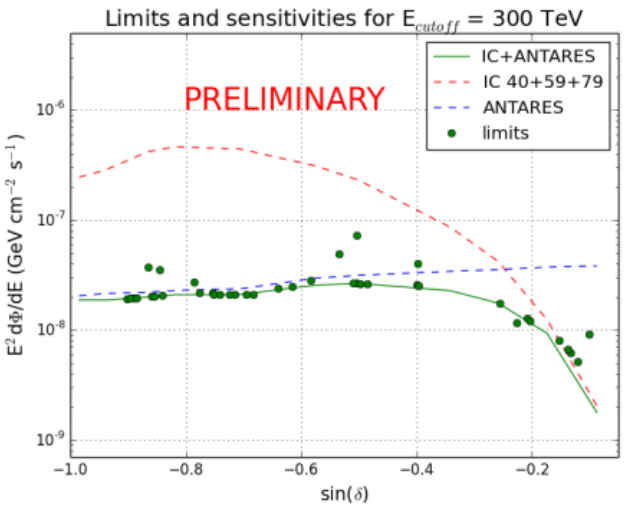
Paper in preparation

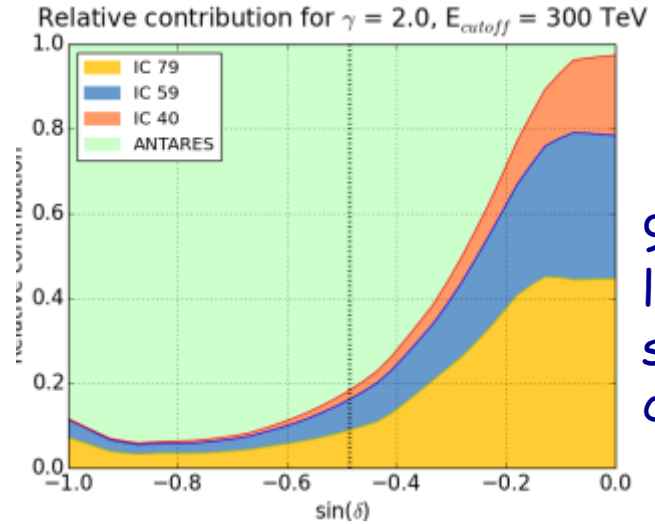
Combined 90% CL sensitivities (green line) and limits (points) for an E^{-2} source spectrum. Blue (Red) curves/points indicate ANTARES (*IceCube*) sensitivities/limits



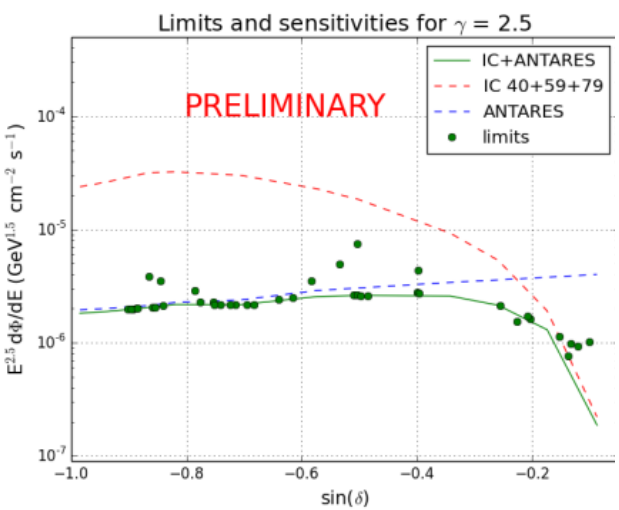


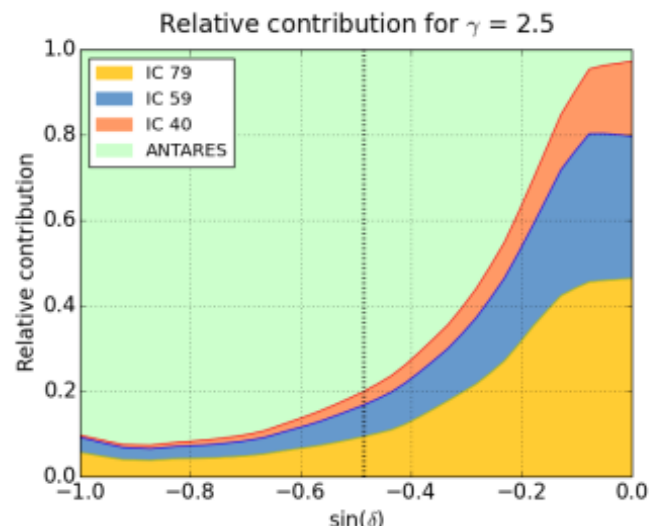
Joint analysis ANTARES-IC





90% CL sensitivities and limits for an E^{-2} source spectrum and exponential cutoff at E = 300 *TeV*.

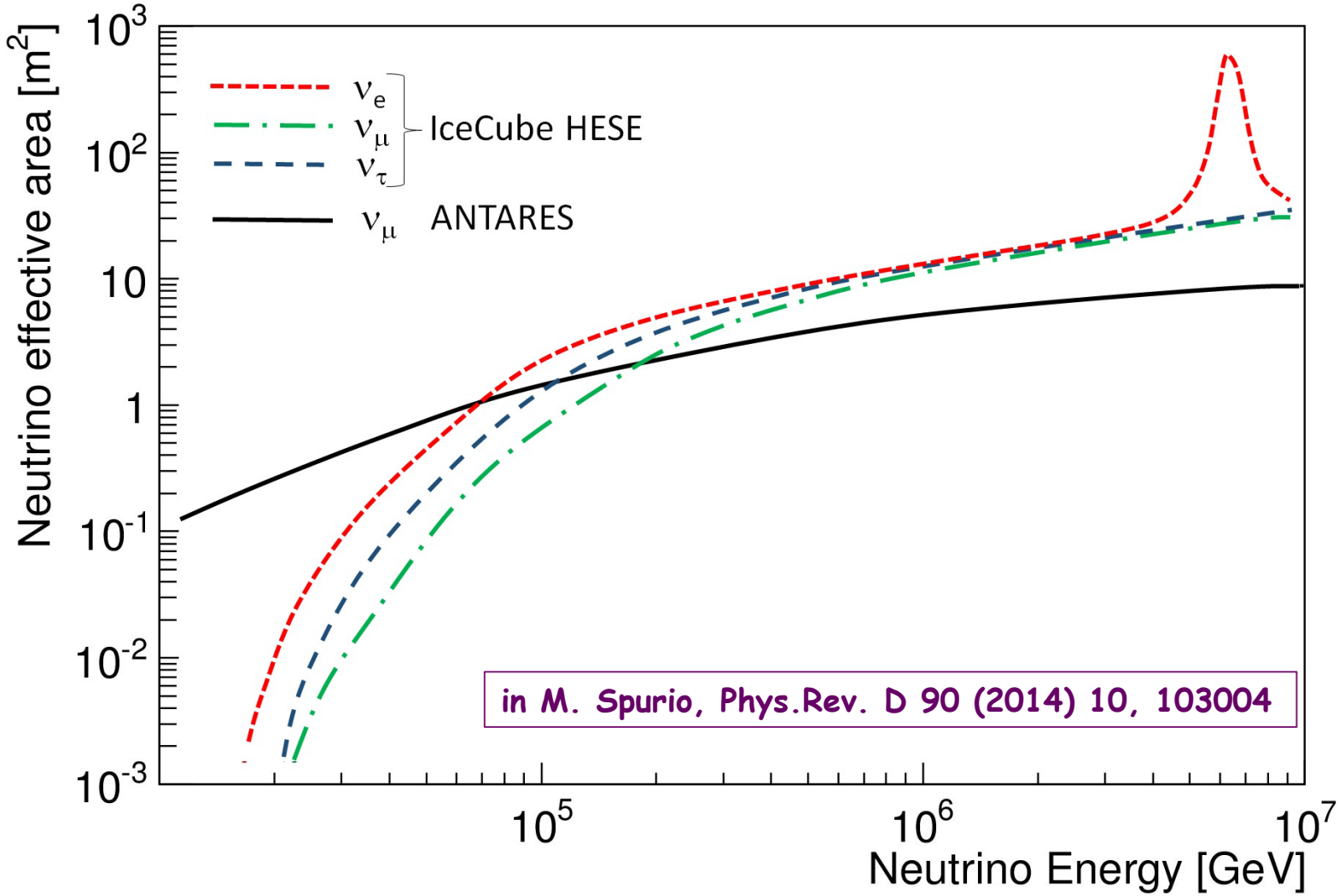




spectral index Υ=2.5

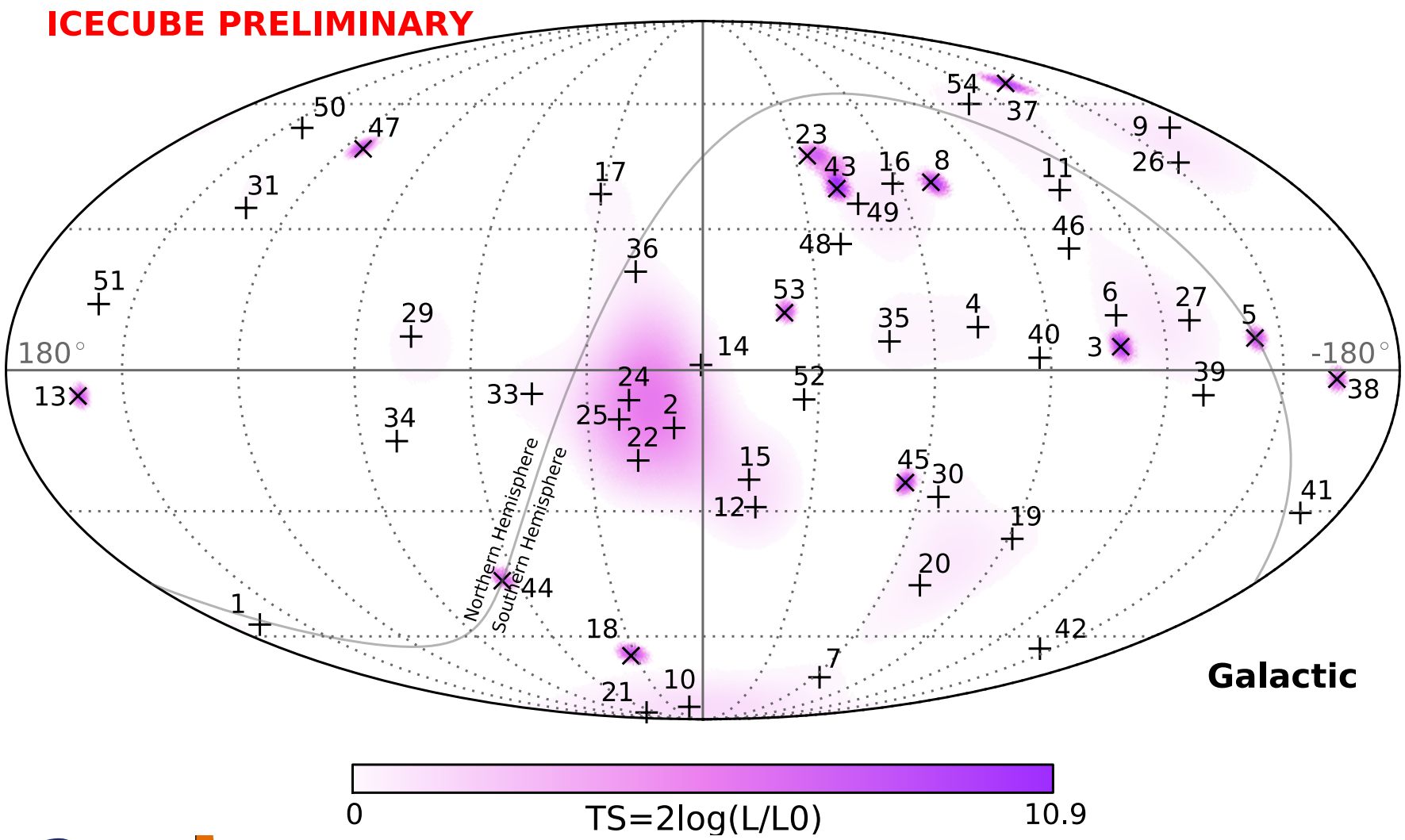
Effective areas

evaluated starting from:
IceCube - Science 342, 1242856 (2013)
ANTARES - ApJ 760:53 (2012)

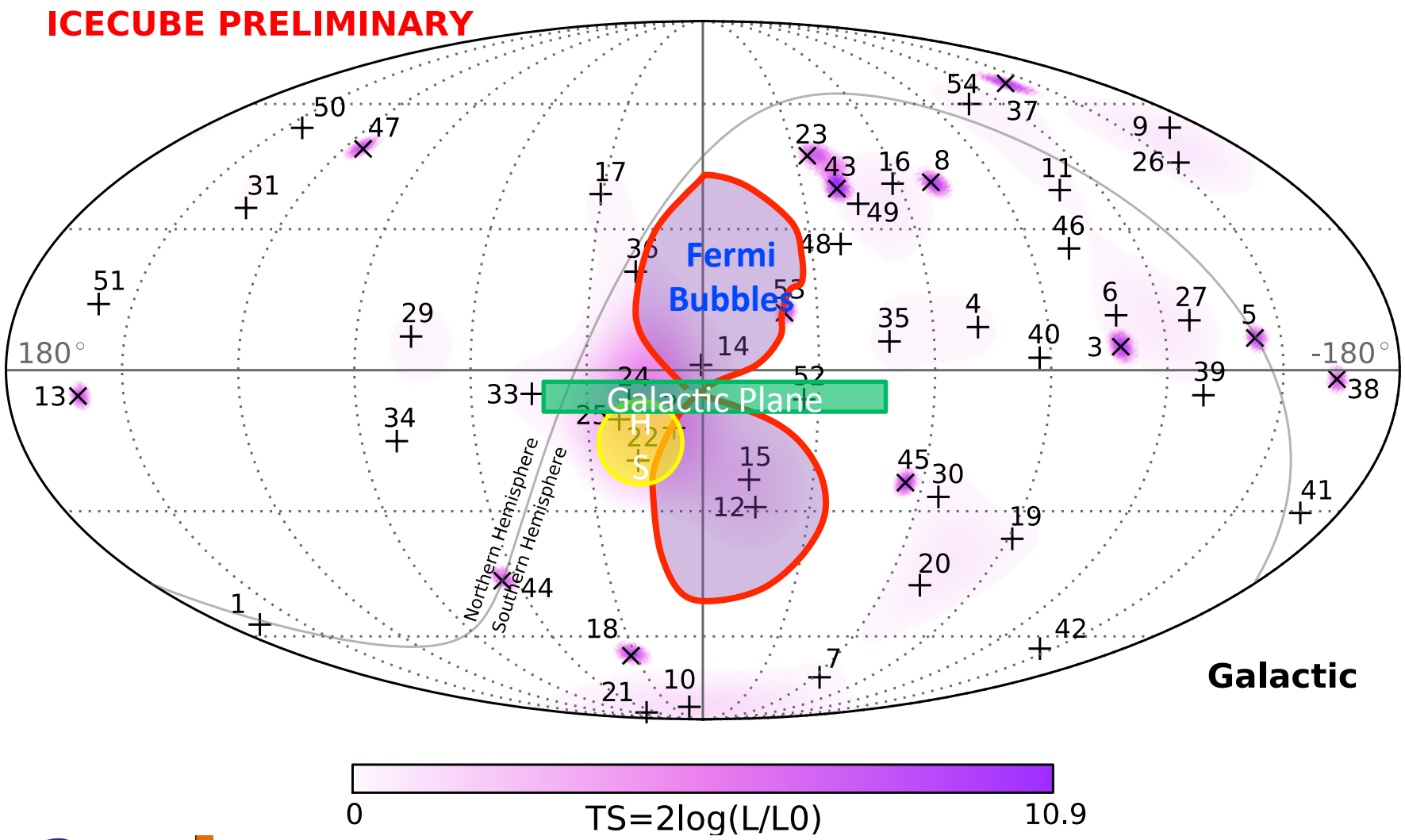


in M. Spurio, Phys.Rev. D 90 (2014) 10, 103004

the HotSpot in HESE : enhanced diffuse flux

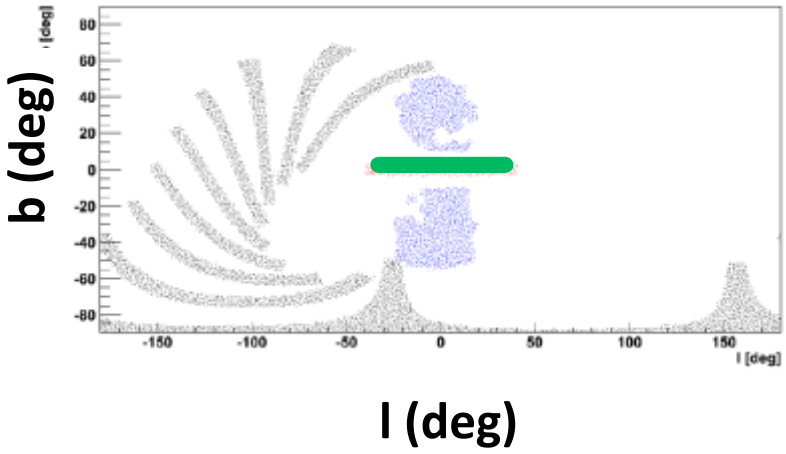


the HotSpot in HESE : enhanced diffuse flux



the HotSpot in HESE : enhanced diffuse flux

CR propagating through the Galaxy can produce ν and γ-rays



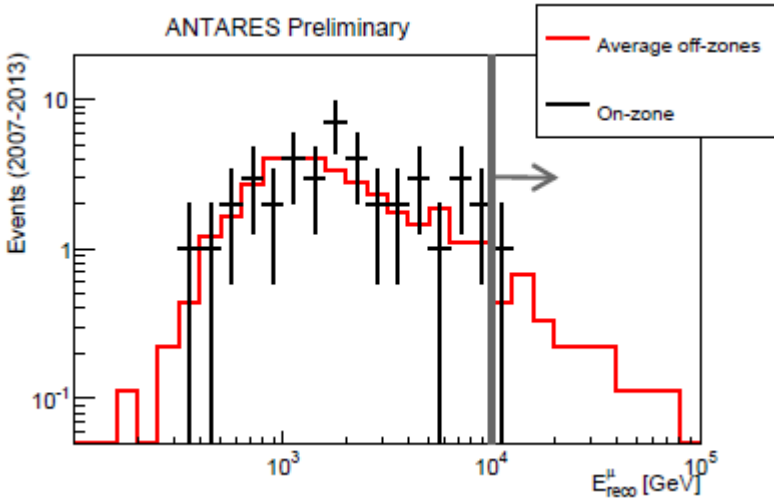
$$p_{CR} + p_{ISM} \rightarrow \pi^0 \, \pi^{\pm} \ldots$$

$$\pi^0 \rightarrow \gamma\gamma, \; EM \; cascade$$ **Fermi-LAT**

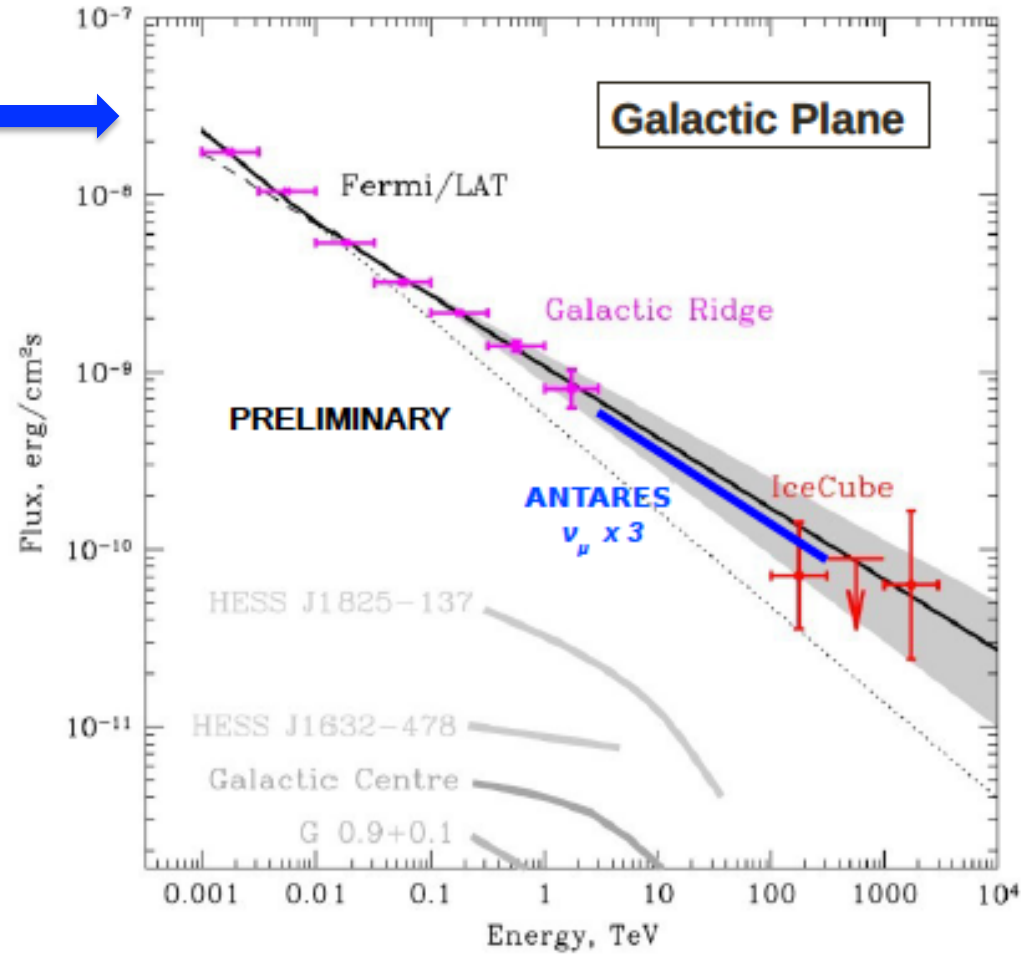
$$\pi^{\pm} \rightarrow \nu_{\mu}, \nu_{e} \ldots$$ **IceCube** **ANTARES**

A diffuse flux in the shower channel in IC might appear as an enhanced diffuse emission from a defined region.

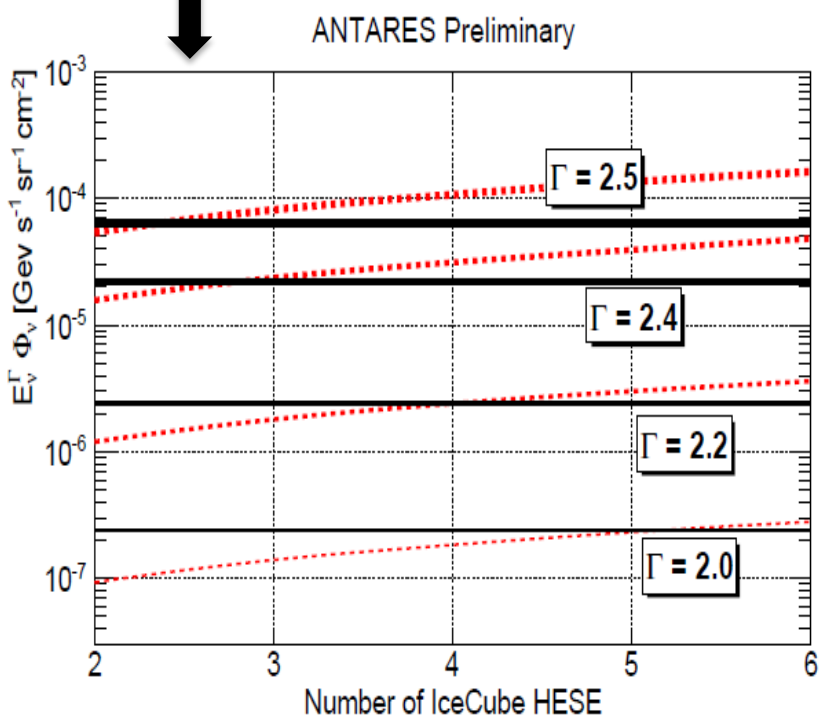
- Search for ν_{μ} using data from 2007-2012
- Search region $|l|<30^{\circ}$, $|b|<4^{\circ}$
- Counts in the signal/off zones
- No excess in the HE neutrinos
- 90% cl upper limits in the $3<E_{\nu}<300$ TeV region



ANTARES sensitivity compared with Fermi-LAT and IceCube in the ON region for γ =2.4

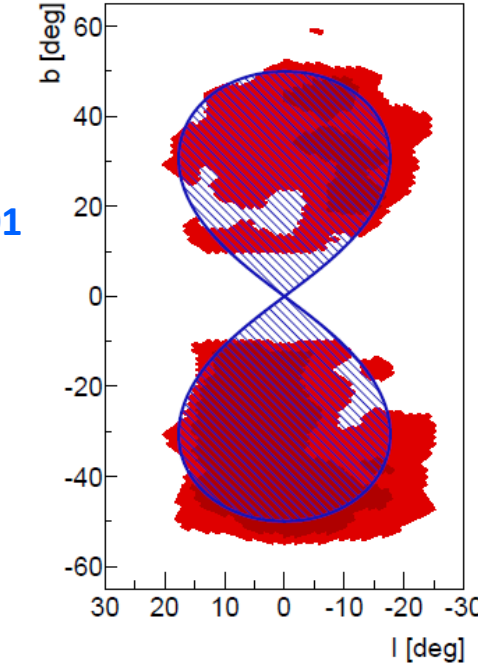


90% cl limits from the Galactic Plane compared to the expected flux producing a n_p IceCube HESE events vs. γ.

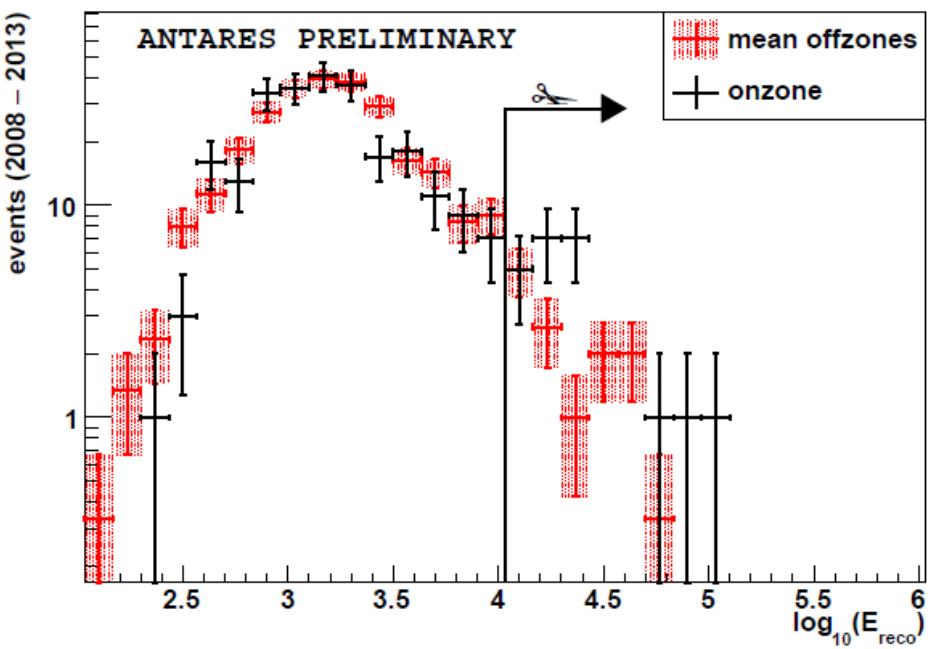


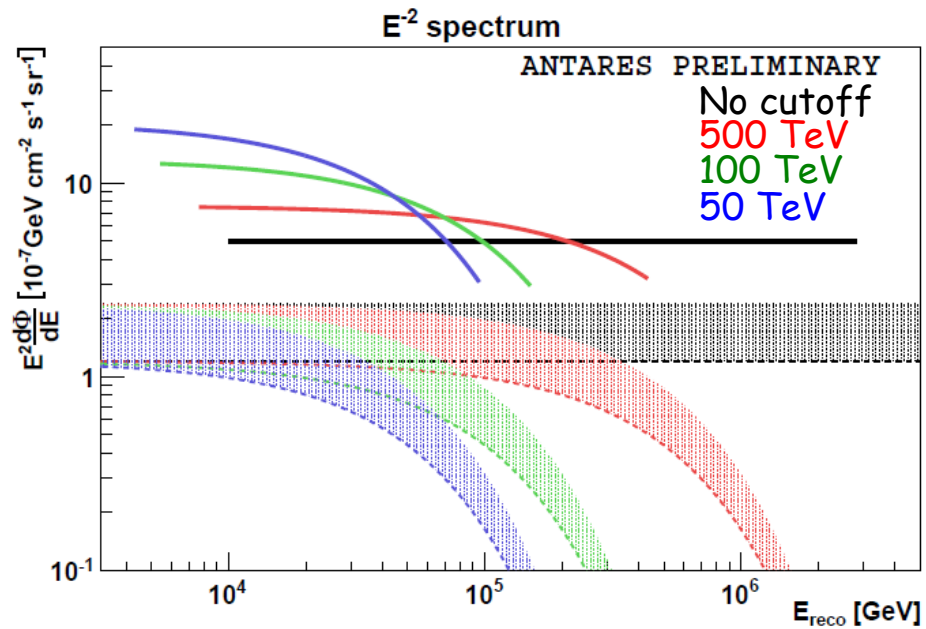
Fermi Bubbles

ANTARES EPJ C (2014) 74:2701



- Hadronic origin for the bubbles?
- E^{-2}, $E^{-2.18}$ spectra and different cutoff [Lunardini et al. PRD92 (2015) 2,021301]
- comparison on-zones/off-zones (3) of $\Delta\Omega$=0.66 sr
- 2008-2013 data analyzed (806+366 days).
- 22 events observed /13 background expected (1.9 σ)





the HotSpot in HESE : single point-like source

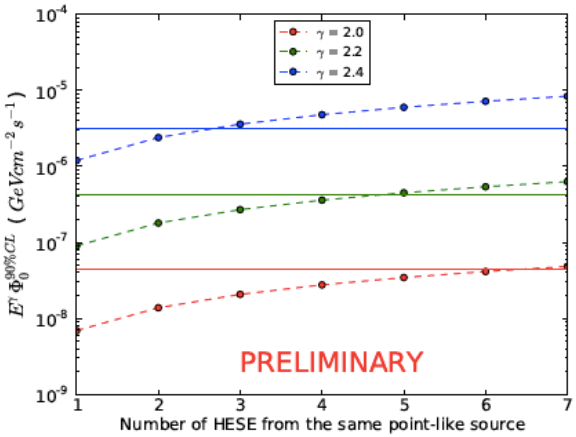
Analysis around the GC for energy spectra between 2.0 and 2.5.

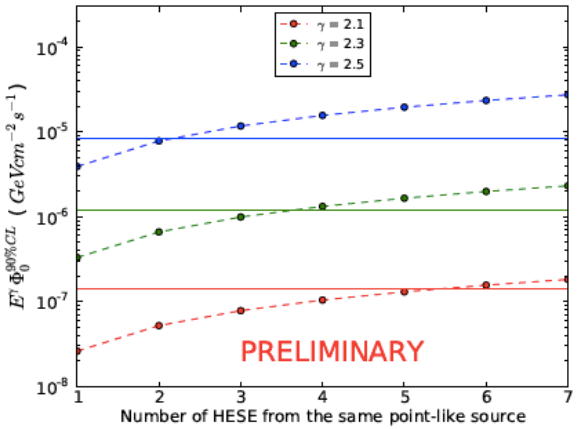
The ANTARES 90% C.L. upper limit excludes that a single point-like source produces n_p>6 HESE, assuming γ=2.0.

A search in a region of 20° around the HotSpot : α, δ= (-79°, -23°)

A single point-like source yielding n_p>3 is excluded for γ=2.3

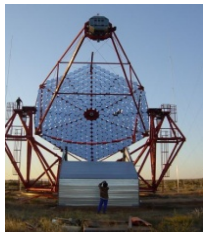
values above the solid lines disfavoured

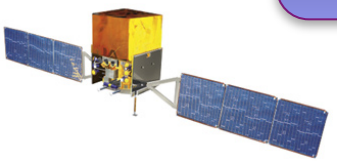


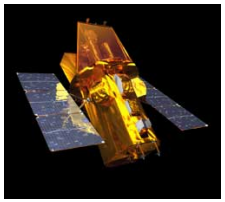


Solid lines: 90%c.l. upper limits for source spectra;
Dashed lines: expected flux normalisation vs the number of HESE events

Multi-messenger







GeV-TeV γ-rays
Fermi / HESS…

📖 JCAP 03(2013) 006
📖 A&A 559 (2013) A9
📖 JCAP 05 (2014) 001

UHECR
Auger

📖 APJ 774 (2013) 19

HE neutrinos

Optic / X-ray
TAROT,
ROTSE /
Swift, ZADKO

📖 APP 36 (2012) 204
📖 A&A 559 (2013) A9

Gravitational
Waves
Virgo / Ligo

📖 JCAP 06 (2013) 008

- Common sources for different messengers.
- Limits searches in time and space, low backgrounds.
- Uncorrelated backgrounds and systematics.

Increased chances of detection

Can blazars produce the HESE PeV events?

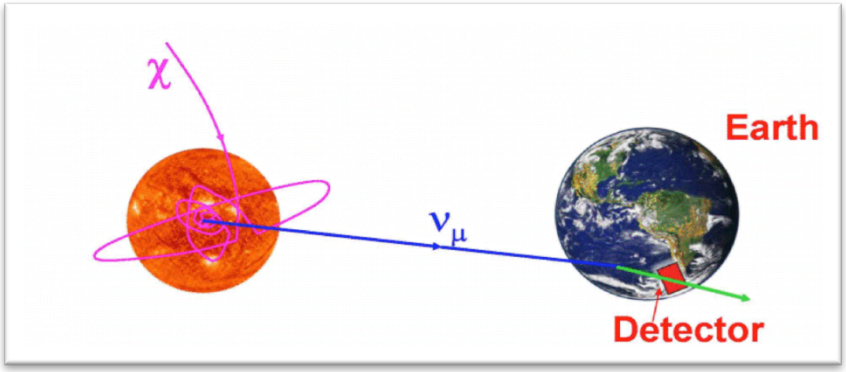
a multiwavelength program that monitors extragalactic jets of the Southern Sky.
Krauß, et al. 2014, A&A, 566, L7

- Blazars associated with IC14 (Bert) and IC20 (Ernie)
- In the FoV of ANTARES
- **Photon flux $\Phi_\gamma \rightarrow \nu_e$ in IceCube ν_μ ANTARES**
- After analysis, one event in the direction of two of the blazars (IC14)
- Consistent with the blazar-origin hypothesis of the IceCube event IC14 for a broad range of blazar spectra, but atmospheric origin cannot be excluded.
- No ANTARES events from BigBird
- **PKS B1424–418: A high-fluence blazar in the IC 35 field (BigBird)**

Adrián-Martínez et al. - A&A Lett. 576 (2015) L8

Source	Cat. Name	F_γ [GeV cm^{-2} s^{-1}]	N_{ν_e} IceCube	IC	N_{sig} ANTARES	p ANTARES
0235–618	PKS 0235–618	$(6.2^{+3.1}_{-3.1}) \times 10^{-8}$	$0.19^{+0.04}_{-0.04}$	20, 7	0	1
0302–623	PKS 0302–623	$(2.1^{+0.4}_{-0.4}) \times 10^{-8}$	$0.06^{+0.01}_{-0.01}$	20	0	1
0308–611	PKS 0308–611	$(4.7^{+1.8}_{-1.8}) \times 10^{-8}$	$0.14^{+0.05}_{-0.05}$	20	0	1
1653–329	Swift J1656.3–3302	$(2.8^{+0.3}_{-0.3}) \times 10^{-7}$	$0.86^{+0.10}_{-0.10}$	14, 2, 25	1.1	0.10
1714–336	TXS 1714–336	$(1.5^{+0.3}_{-0.4}) \times 10^{-7}$	$0.46^{+0.10}_{-0.12}$	14,2,25	0.9	0.04
1759–396	MRC 1759–396	$(7.5^{+1.9}_{-1.9}) \times 10^{-8}$	$0.23^{+0.50}_{-0.40}$	14, 2, 15, 25	0	1
	PKS B1424–418		**many**	**35**	**0**	

Indirect Dark Matter searches



$$X_{\mathrm{WIMP}}\bar{X}_{\mathrm{WIMP}} \rightarrow \nu\bar{\nu},\ \mathrm{b}\bar{\mathrm{b}},\ \mathrm{W}^-\mathrm{W}^+,\ \tau^-\tau^+,\ \mu^-\mu^+$$

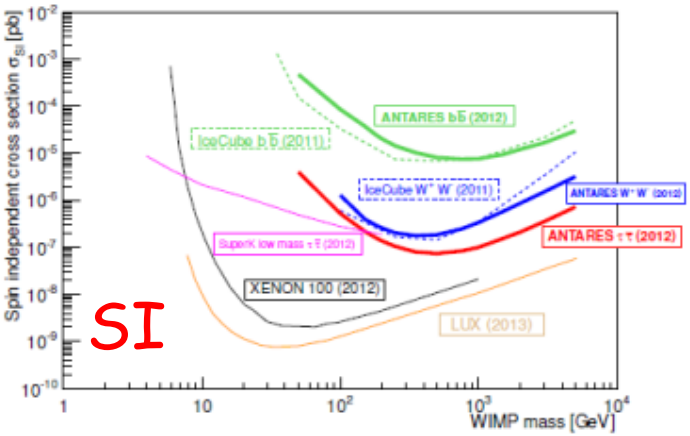
Searches for a ν_μ flux from the Galactic center, the Sun core, the Earth nucleus due to DM annihilation

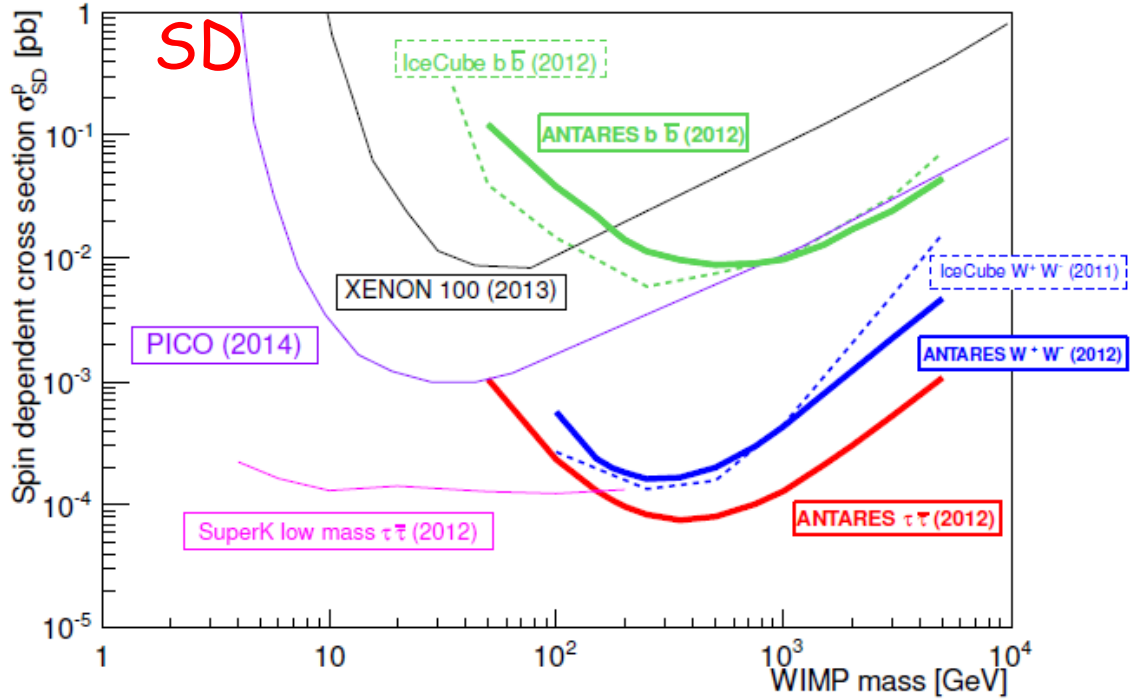
ν_μ spectrum from Earth and Sun → WIMPSIM [Blennow,Edsjö,Ohlsson,arXiv:0709.3898]
from GC and galaxy clusters → M.Cirelli et al., arXiv:1012.4515

BG estimation from time scrambled data

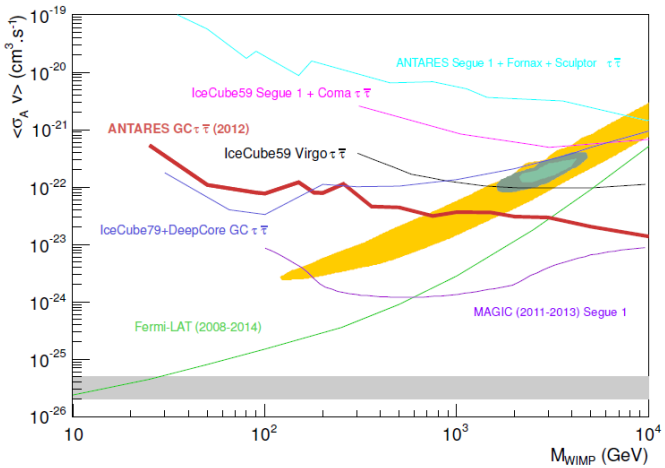
No excess measured

The Sun





ν telescopes → excellent results for Spin Dependent cross section



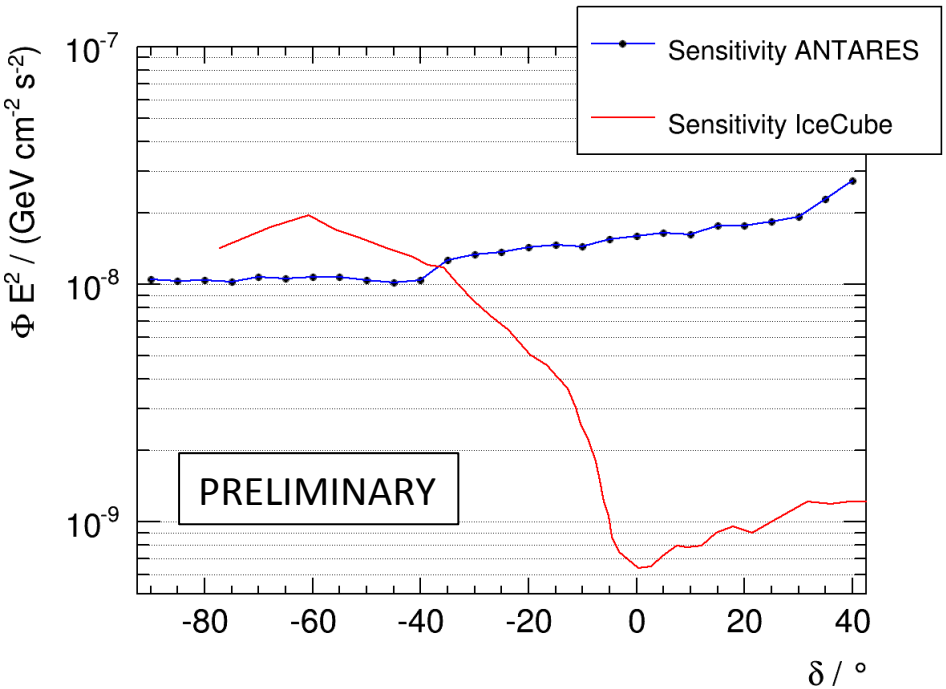
Galactic Center

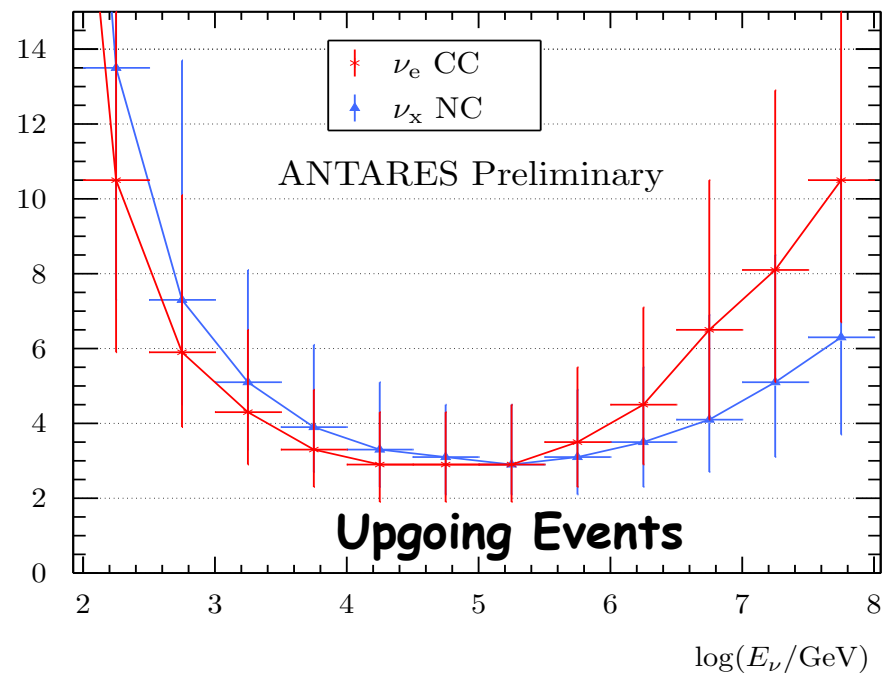
ANTARES: arXiv:1505.04866
IceCube : arXiv:1505.07259

In progress - Cascade analysis

Cascade + muon tracks ➔ sensitivity improved by 30%

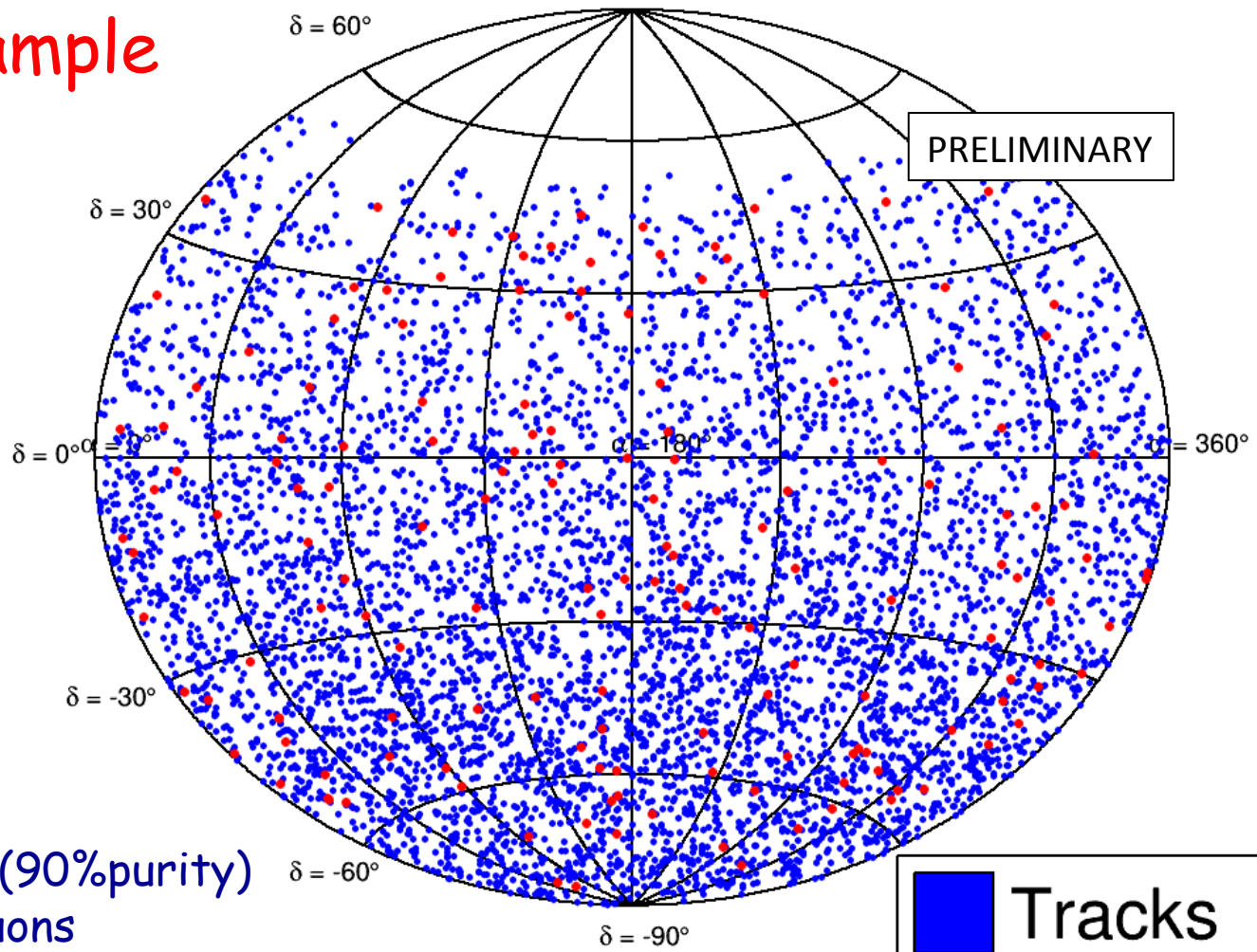
Cascade reconstruction : angular resolutions better than 4° from 10 TeV to 1 PeV





Point source : tracks + showers - New skymap!

2007-2013 sample



6261 muon tracks
156 cascade events (90%purity)
10% atmospheric muons

Tracks
Shower

INFN Istituto Nazionale di Fisica Nucleare
Sezione di Bologna

Summary

- ANTARES: the largest underwater neutrino telescope good angular resolution + Southern Sky direct observation
- Constraints on the possible origin of the IceCube signal
- Several analyses exploiting mainly the track-channel
- Analyses with showers in progress : good angular resolution (better than 4°) but small effective area.
- Data taking until 2016

THEN

KM3NeT

Backup slides

ANTARES neutrino detection and possible Swift X-ray counterpart

ATel #7987; *D. Dornic (CPPM), S. Basa (LAM), P. A. Evans (U. Leicester), J. A. Kennea (PSU), J. P. Osborne (U. Leicester) and V. Lipunov (MSU)*
on 3 Sep 2015; 12:18 UT
Credential Certification: Phil Evans (pae9@star.le.ac.uk)

Recent alert

ANALYSIS IN PROGRESS

Subjects: Optical, X-ray, Neutrinos, Request for Observations

Referred to by ATel #: 7992

On September 1st, 2015, at 07:38:25 UT, ANTARES has detected a bright neutrino at a location of:

RA(J2000) = 16h 25m 42s
DEC (J2000) = -27d 23m 24s
with an uncertainty of 18 arcmin (radius, 50% containment)

A target of opportunity alert has been sent immediately to Swift. The XRT onboard Swift followed the ANTARES error box 10 hours after the neutrino detection. An uncatalogued X-ray source has been detected above the limit of RASS, with the flux varying between 5e-13 and 1.4e-12 erg cm^-2 s^-1 (0.3-10 keV), at location:

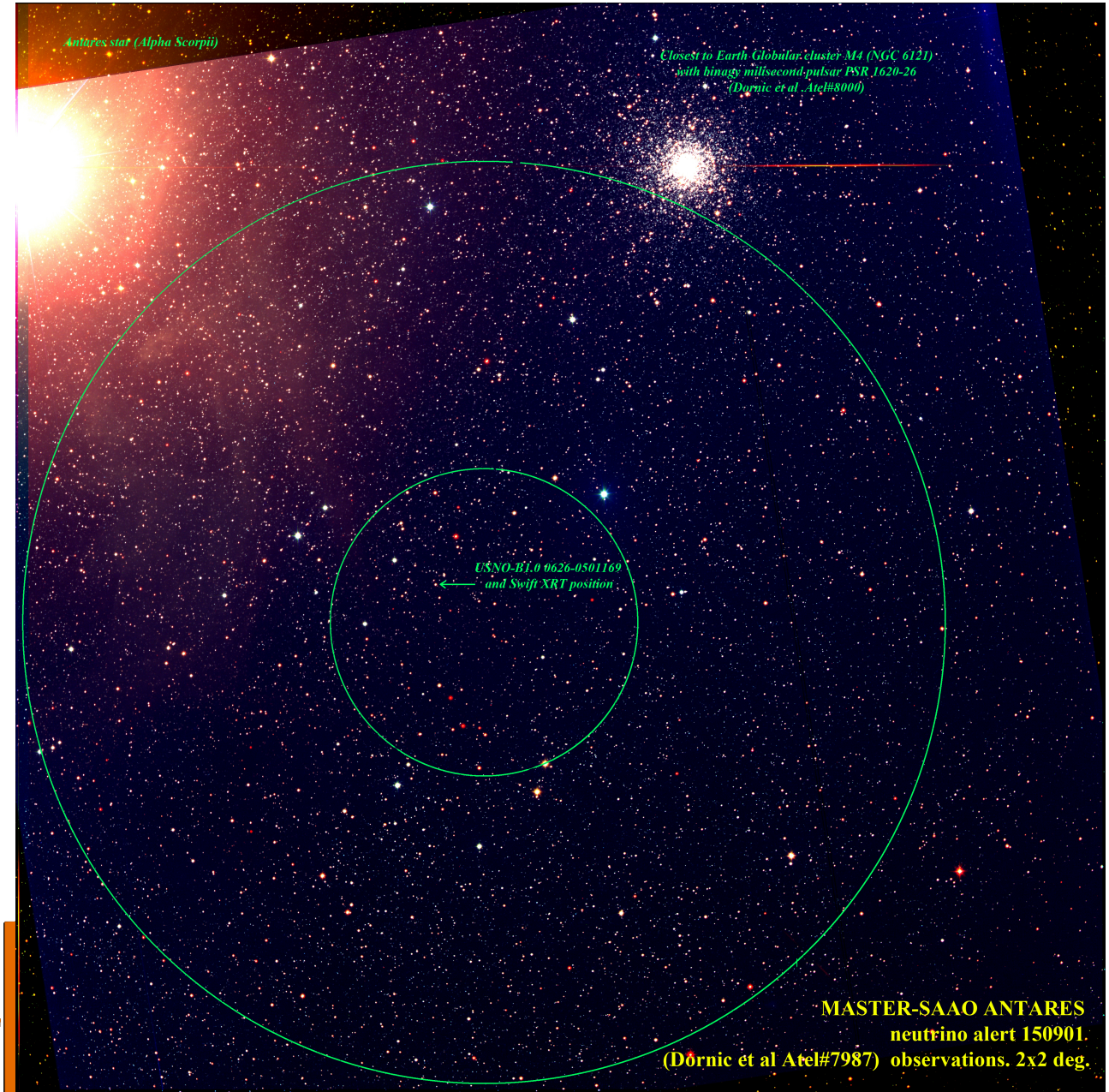
RA(J2000) = 16h 26m 2.12s
DEC (J2000) = -27d 18m 14.8s

with an uncertainty of 2.4 arcsec (radius, 90% containment).

The detected X-ray source seems to be variable. By contrast no transient source in the visible domain with MASTER SAAO has been observed so far until the magnitude 18.5 with a galactic extinction of 2 (Schlegel et al). Further Swift observations have been planned.

We encourage strongly further multi-wavelength observations to identify this X-ray source.

Field of view of the neutrino alert



Effective areas