

Probing the High Energy Neutrino universe with ANTARES



Thierry PRADIER

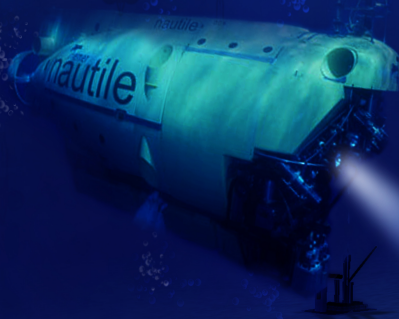
on behalf of the ANTARES Collaboration

pradier@in2p3.fr

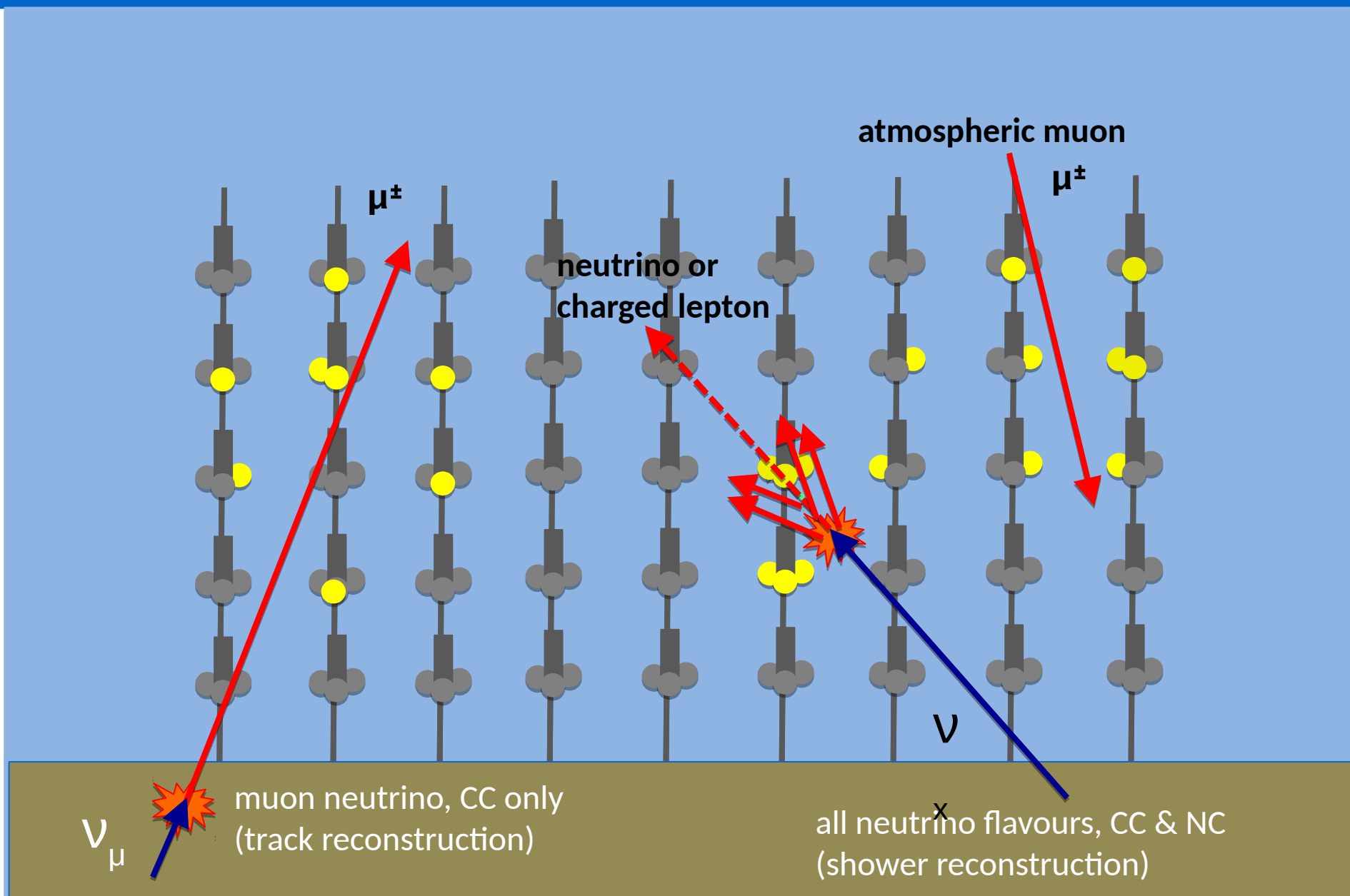
IPHC::Department of Subatomic Research

&

University of Strasbourg (France)



Principles of Neutrino Telescopes

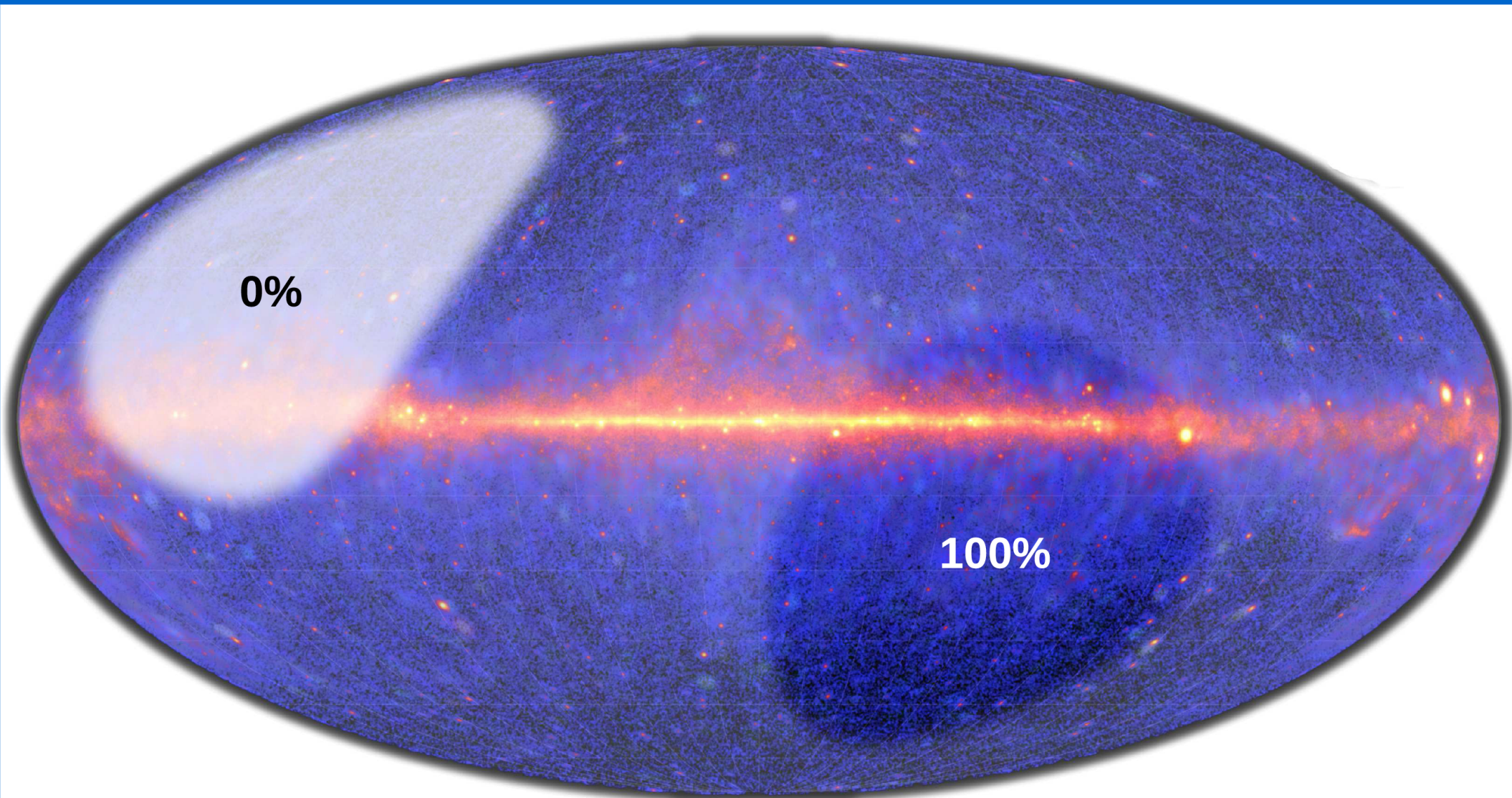


Astronomy with a Neutrino Telescope & Abyss environmental RESEARCH



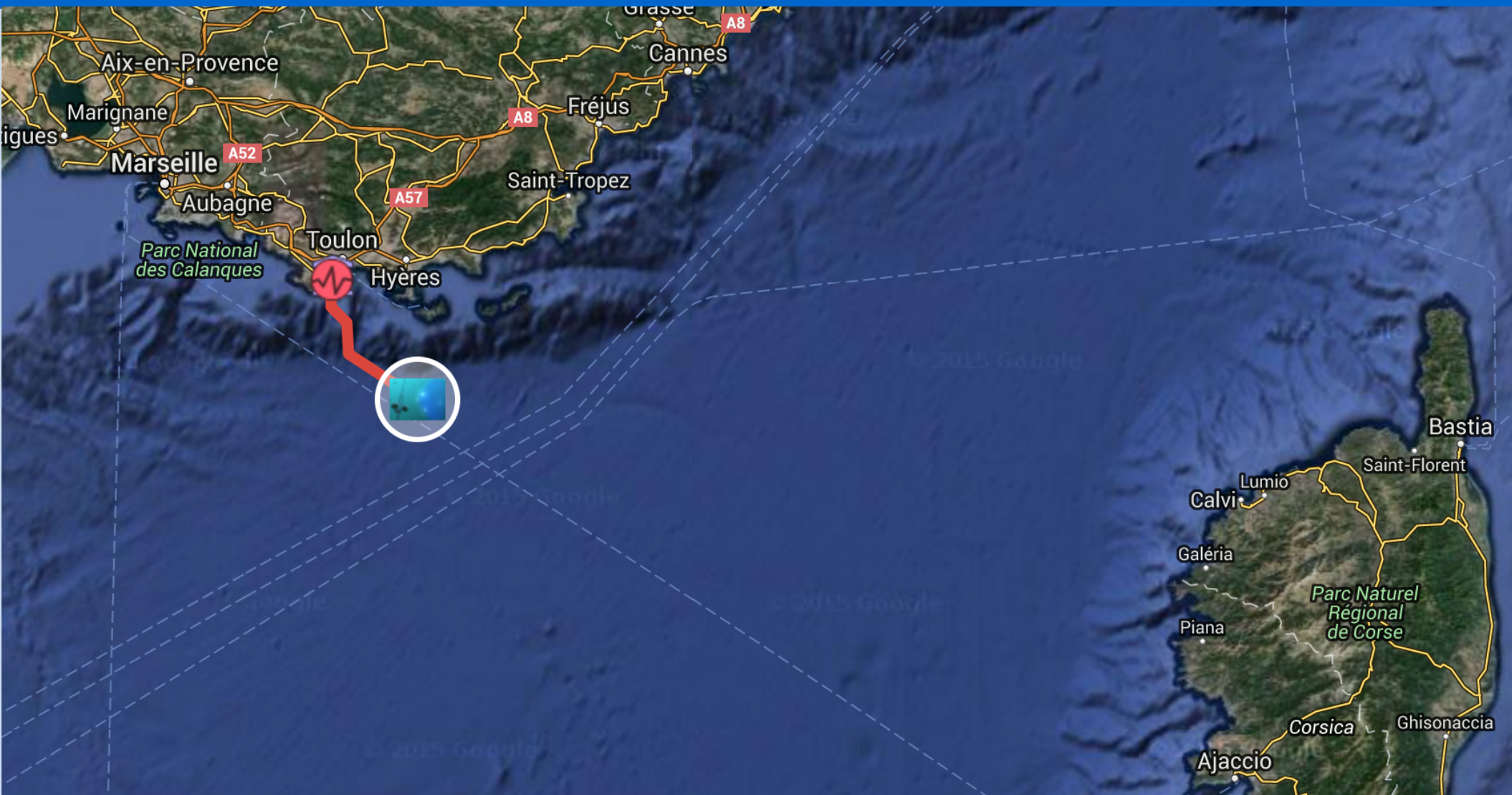
- **Complementarity with IceCube** : visibility of Galactic Plane + Galactic Center
 - 10 % instantaneous overlap - 40 % integrated overlap

Astronomy with a Neutrino Telescope & Abbyss environmental REsearch



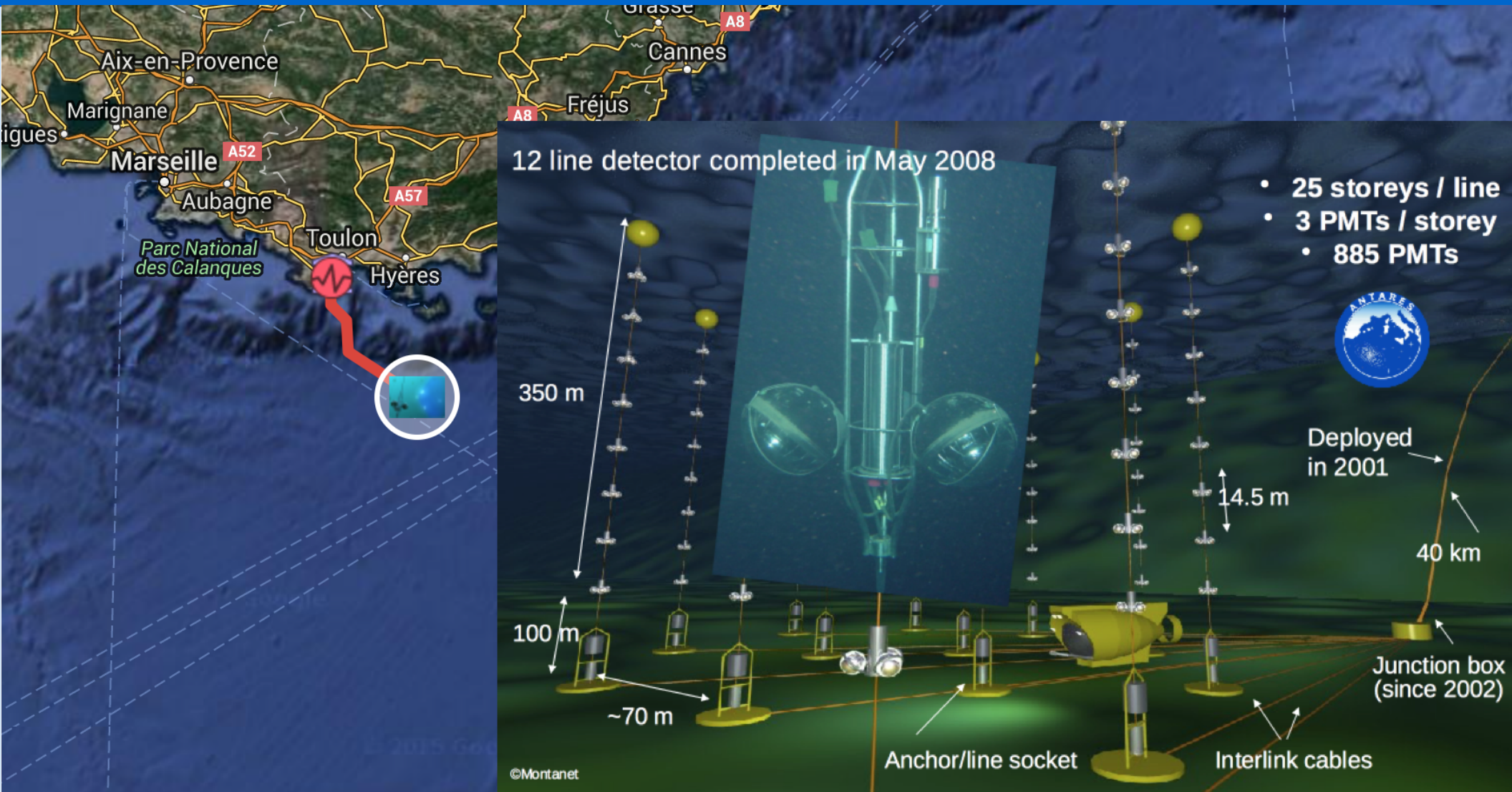
- Fermi 5-year gamma-ray catalogue ($> 1\text{GeV}$) – instantaneous : 50 % overlap

Astronomy with a Neutrino Telescope & Abyss environmental RESEARCH



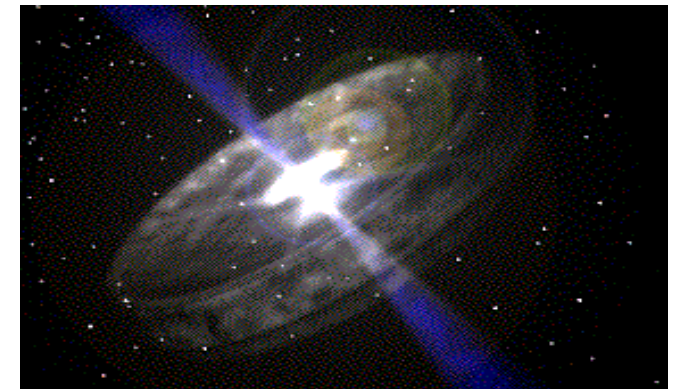
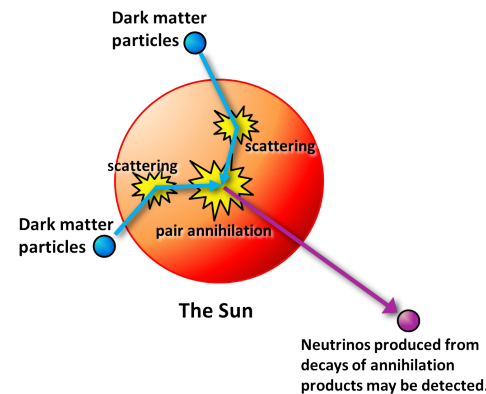
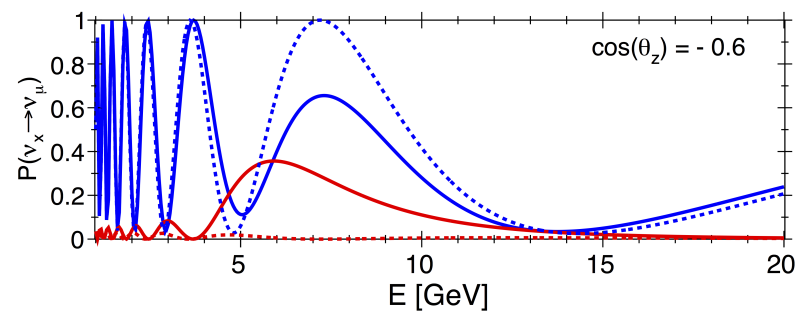
- **Advantages wrt Polar Ice** : Less scattering but more absorption
 - $\Delta\theta$ on reconstructed track $\sim O(0.1^\circ)$ compared to $\sim O(1^\circ)$ in Ice

ANTARES : 10 years of data taking with 12 lines (0.1 km²)



- **Requirements** : Measurements of time (ns), position (10cm), amplitude (10%)
- **Line 1 has celebrated its 10-year anniversary !**

Physics studies with Neutrino Telescopes : from GeV to PeV neutrinos !



Low Energy
 $3 \text{ GeV} < E_\nu < 50 \text{ GeV}$

Medium Energy
 $10 \text{ GeV} < E_\nu < 1 \text{ TeV}$

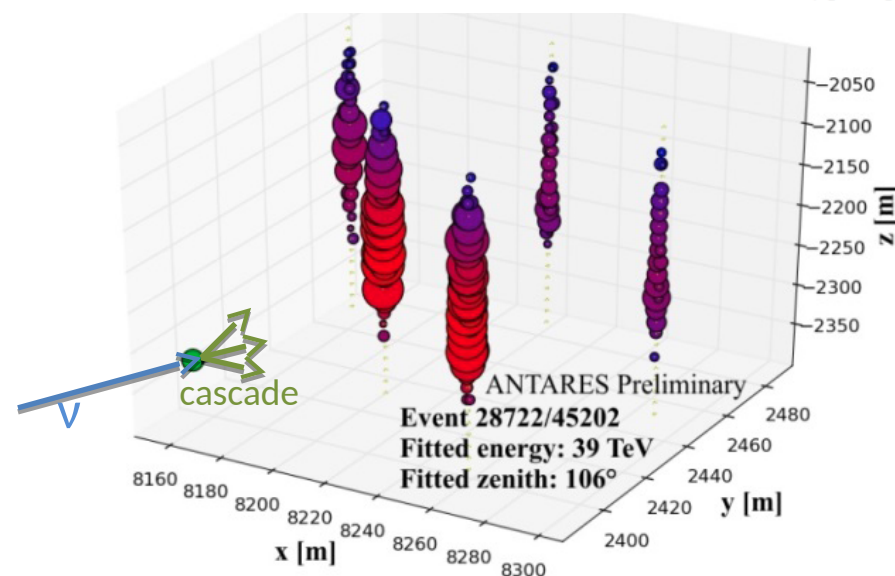
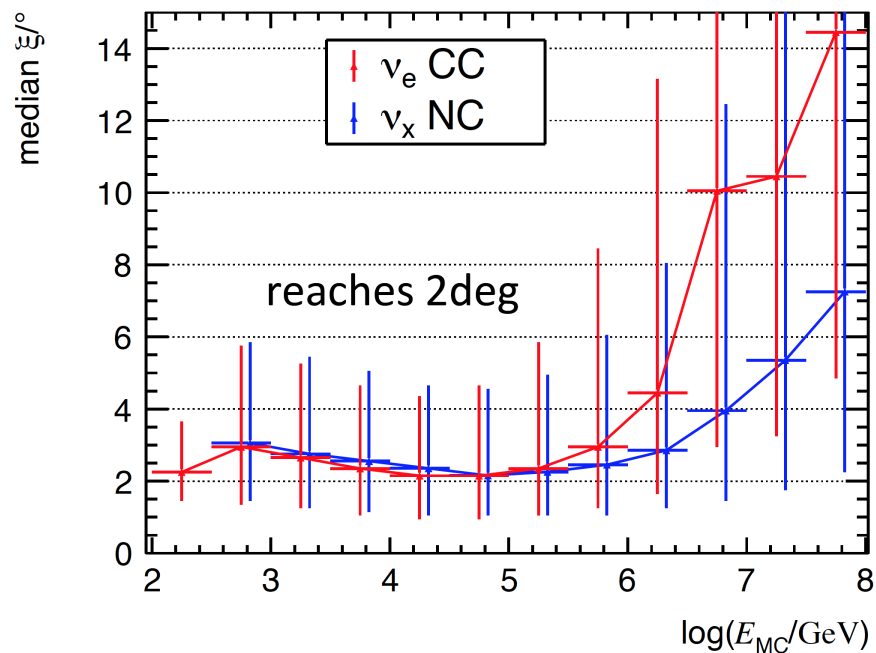
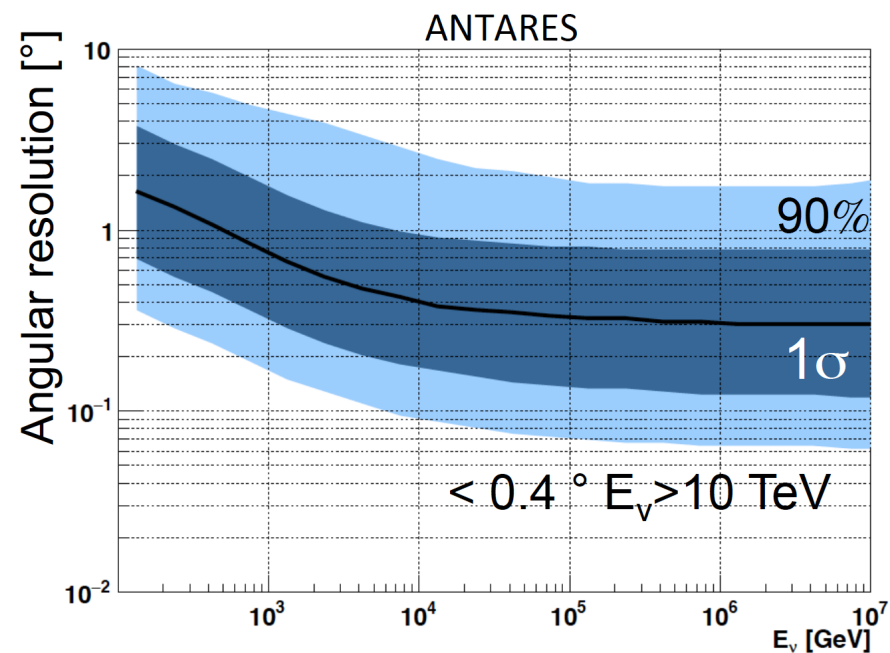
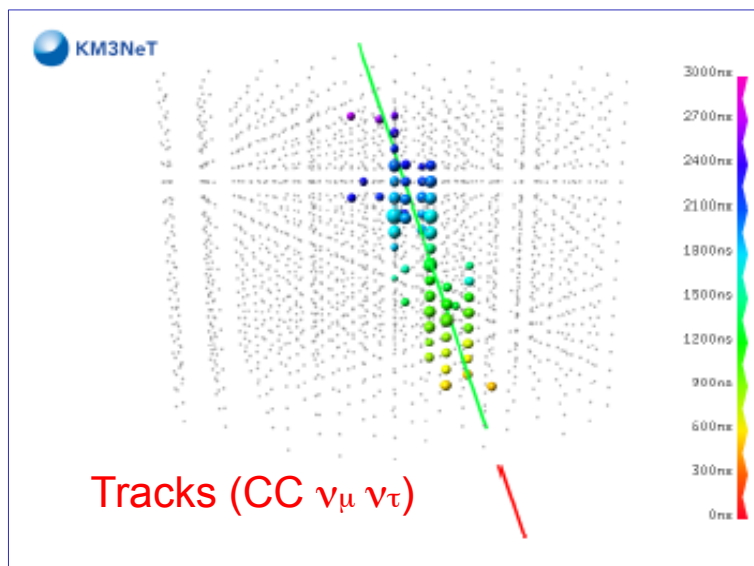
High Energy
 $E_\nu > 1 \text{ TeV}$

Neutrino Oscillations
 [Mass spectrum \rightarrow ORCA]

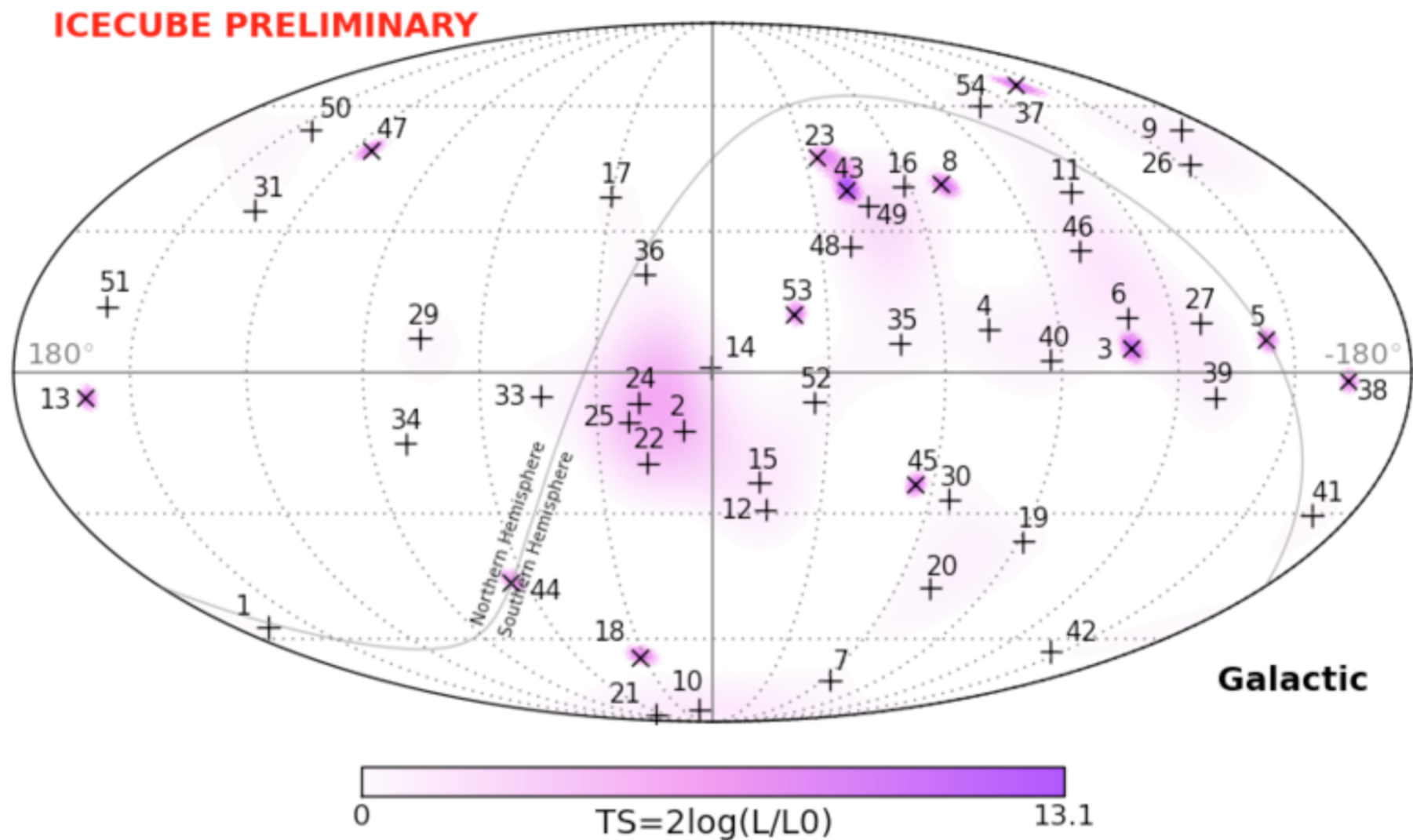
Dark Matter Searches
 Exotics

Neutrino Astronomy
 Origin of Cosmic Rays

Tracks & Showers - topologies and resolutions

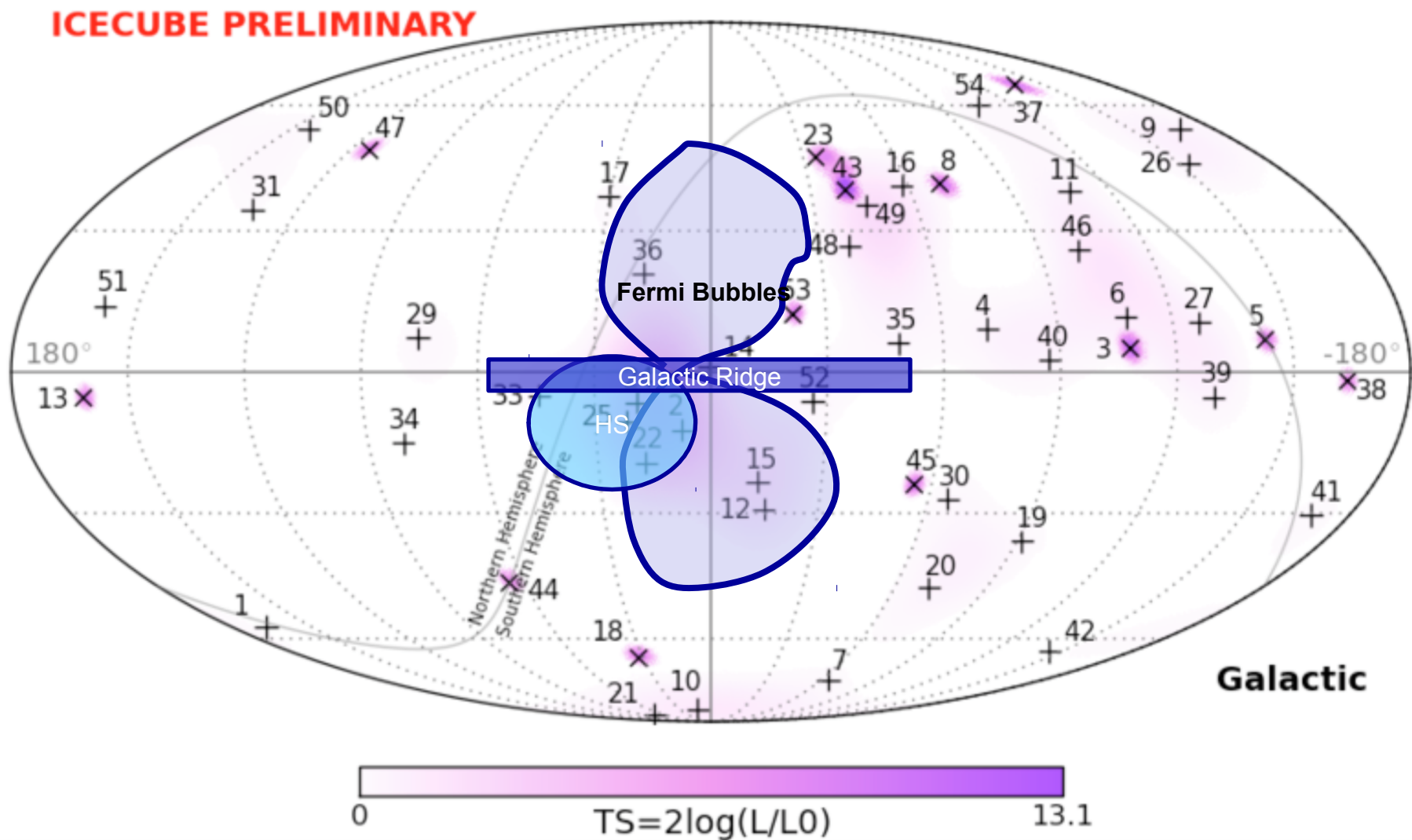


The IceCube signal...and ANTARES dedicated searches



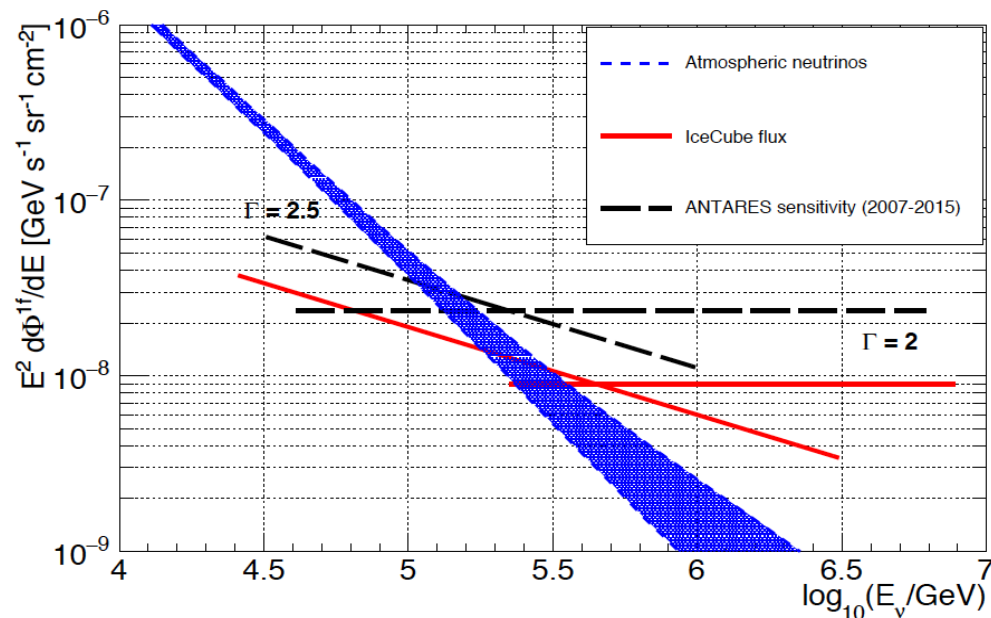
- Spectral index different for HE tracks ($\sim E^{-2}$) and for tracks+showers ($\sim E^{-2.5}$)
- Southern/Northern hemisphere contribution ?
- **Origin : Galactic (Fermi Bubbles, Galactic Ridge,...) or farther ?**

The IceCube signal...and ANTARES dedicated searches



- Spectral index different for HE tracks ($\sim E^{-2}$) and for tracks+showers ($\sim E^{-2.5}$)
- Southern/Northern hemisphere contribution ?
- **Origin : Galactic (Fermi Bubbles, Galactic Ridge,...) or farther ?**

Diffuse fluxes in ANTARES - tracks & showers

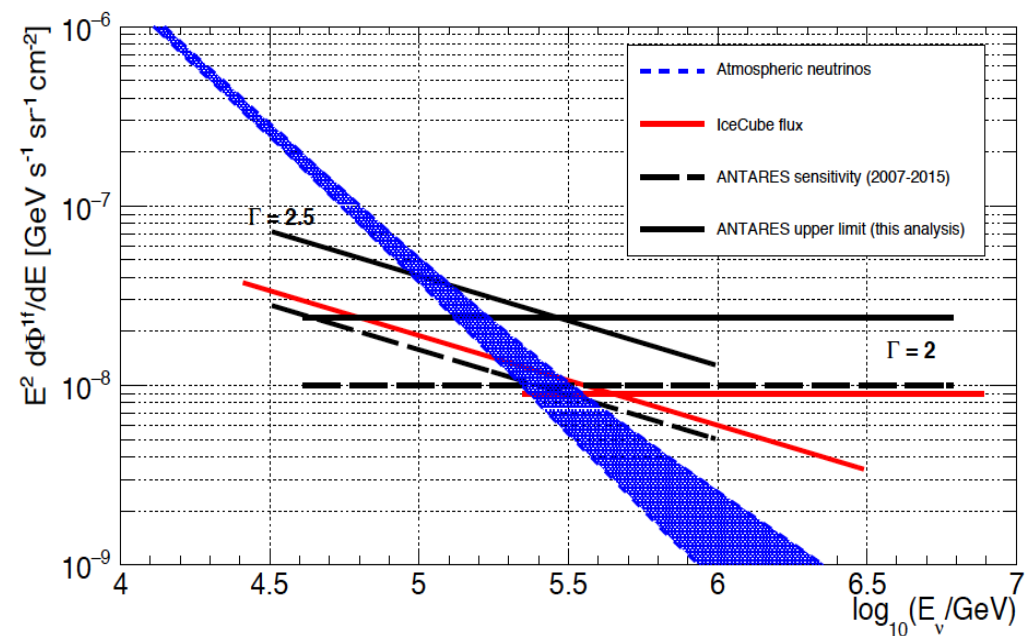


Track channel

Data 2007 – 2015 : 2451 days

Observed : 19

Expected : 13.5 ± 3 from bkg **~3 from IC**



Cascade channel

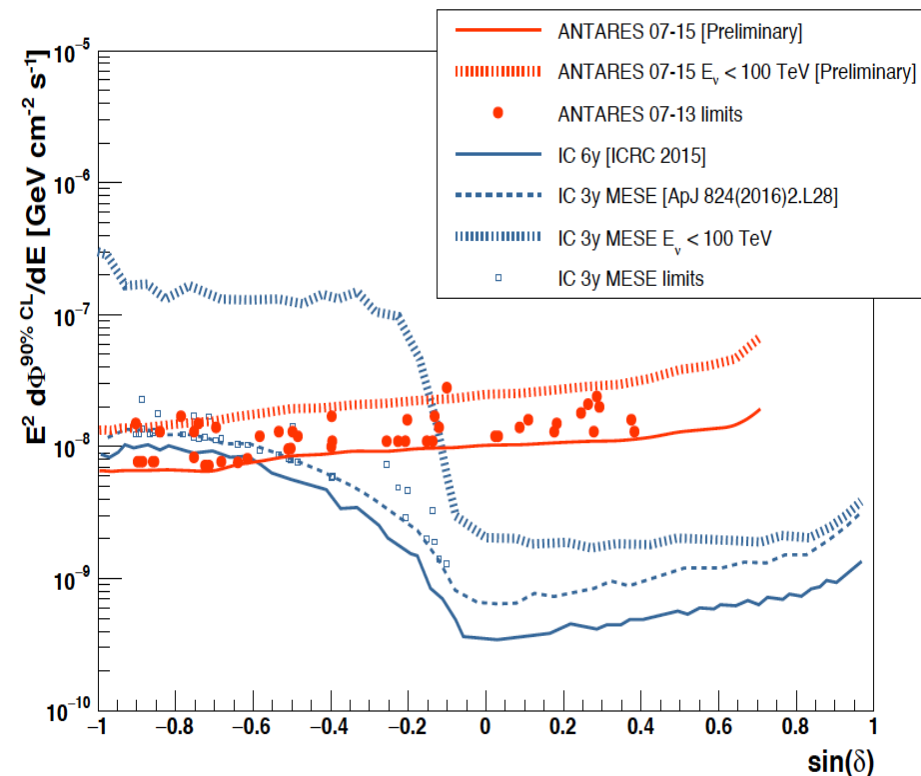
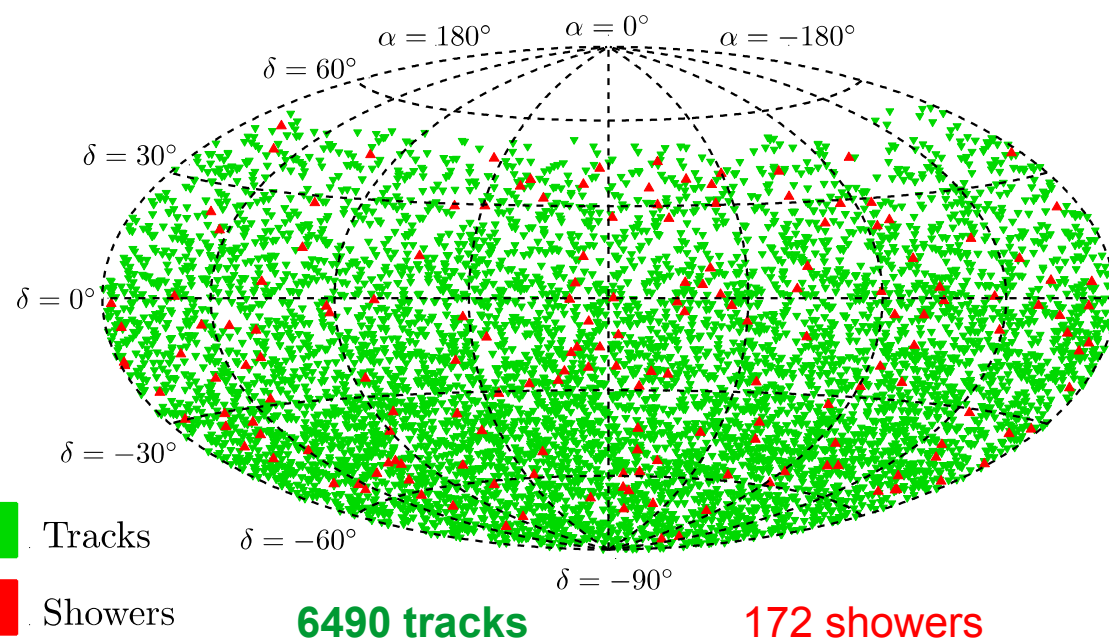
Data 2007 – 2013 : 1405 days

Observed : 7

Expected : 5 ± 2 from bkg **~1.5 from IC**

Volume of instrumented medium is paramount → KM3NeT

Point Source searches in ANTARES - tracks & showers



Best sensitivity below few 10^2 TeV

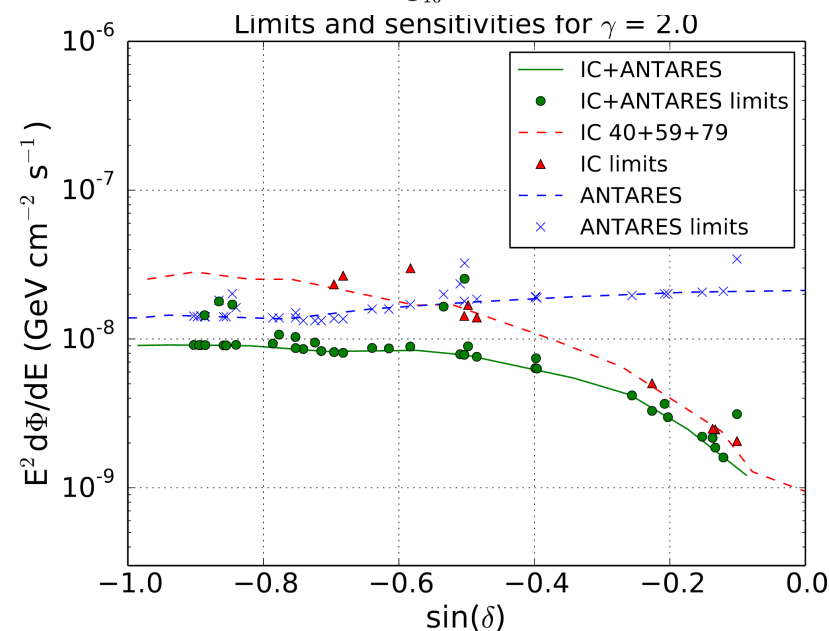
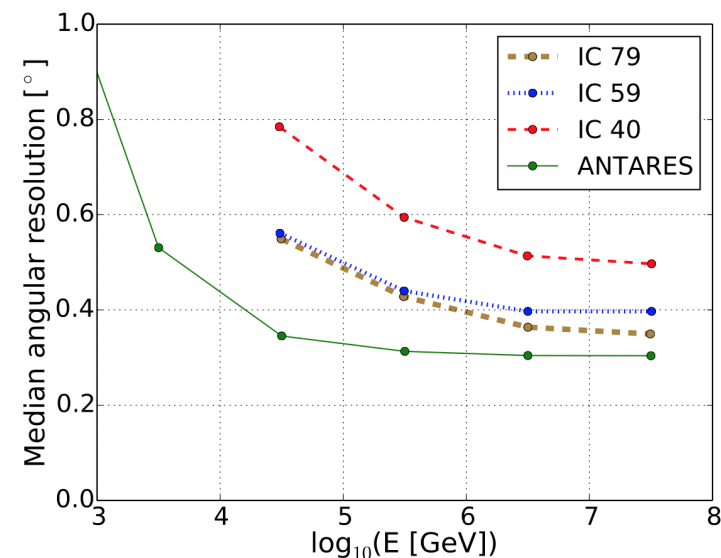
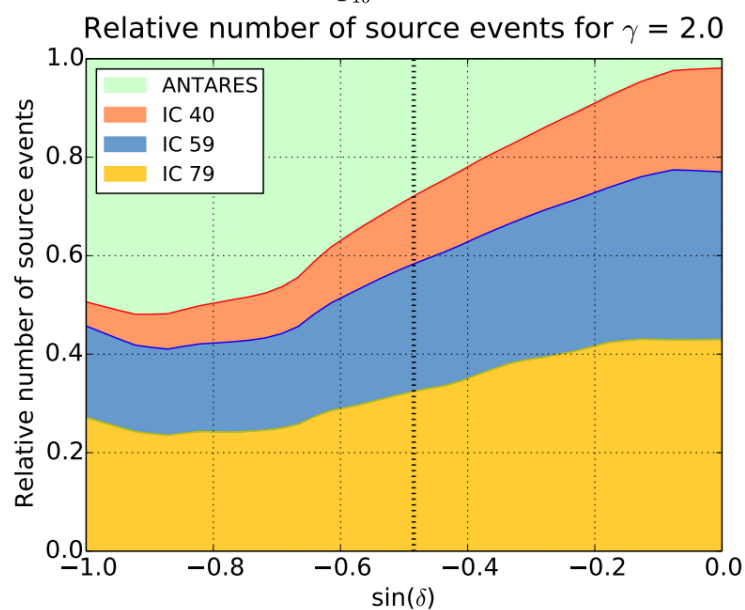
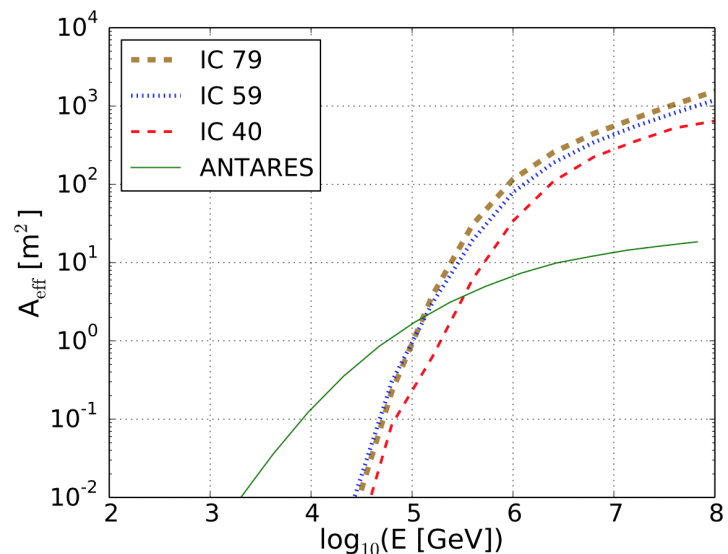
- To identify the origin of the signal :
 - Combine ANTARES and IceCube data
 - Reduce the space search window : identify regions of interest
 - Reduce the space+time window : Multi-Messenger programs

See poster 167 by J. Barrios-Marti on Wednesday 14th

ANTARES/IceCube joint search : complementary telescopes

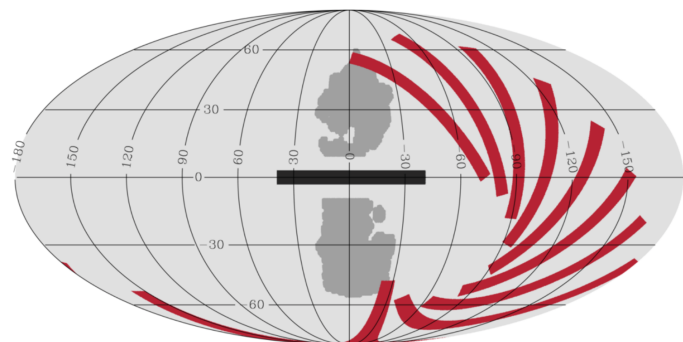
ANTARES 2007-2012 + IceCube 2008-2011

Astrophys.J. 823 (2016) no.1, 65

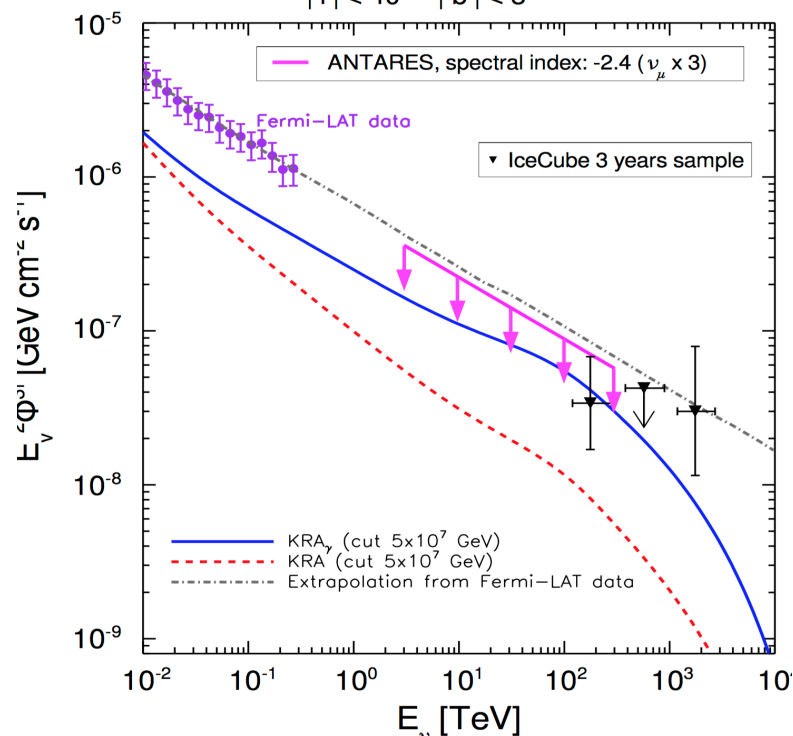


Zero in on the origin of the IceCube signal...

Galactic Ridge – 2008-2013

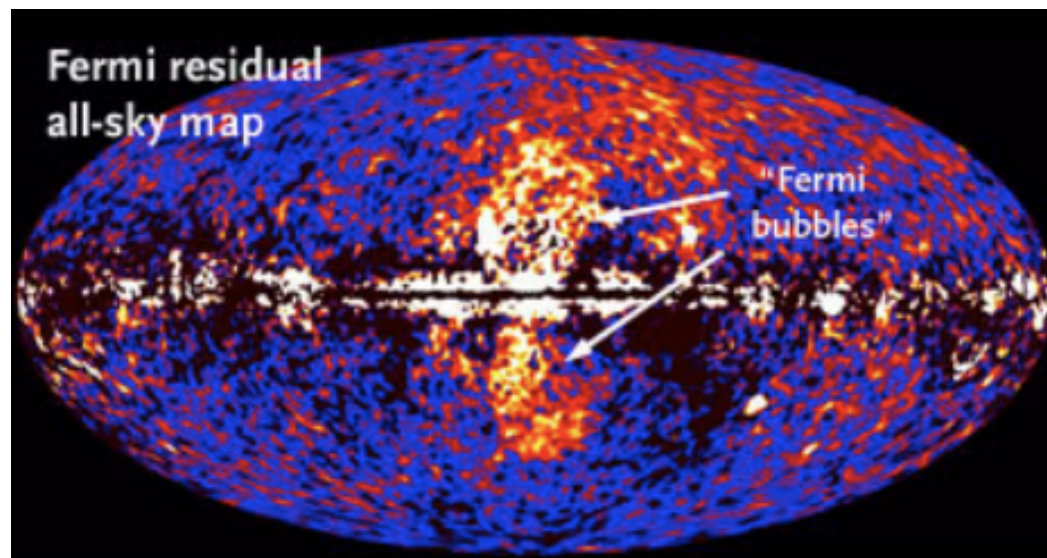


$||l|| < 40^\circ$ $|b| < 3^\circ$

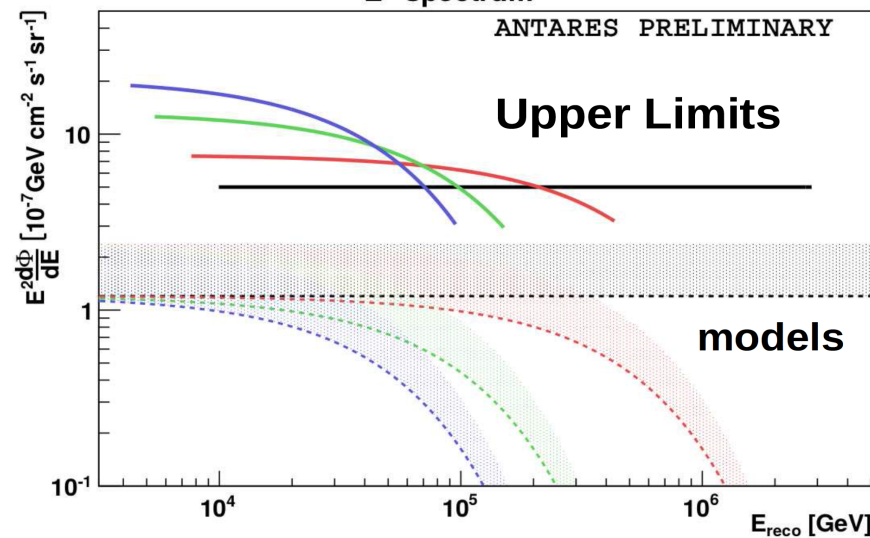


PLB 760(2016)143

Fermi Bubbles – 2008-2013

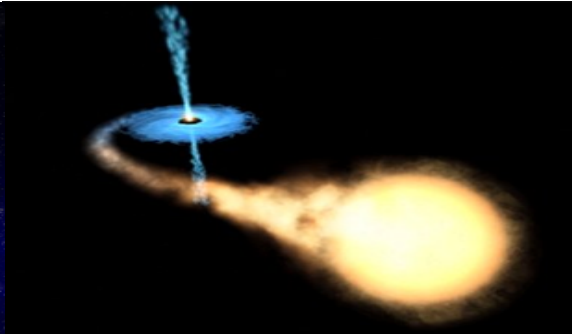
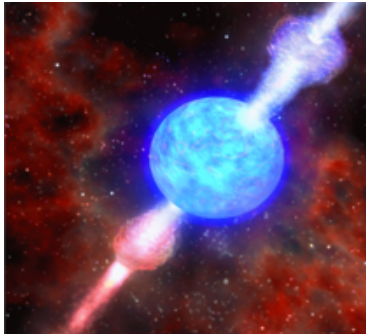
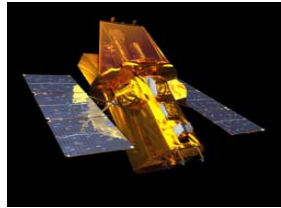
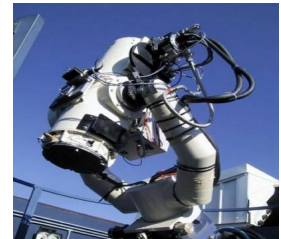
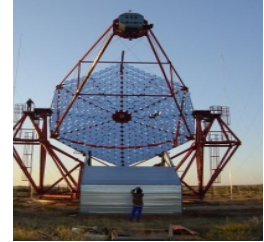
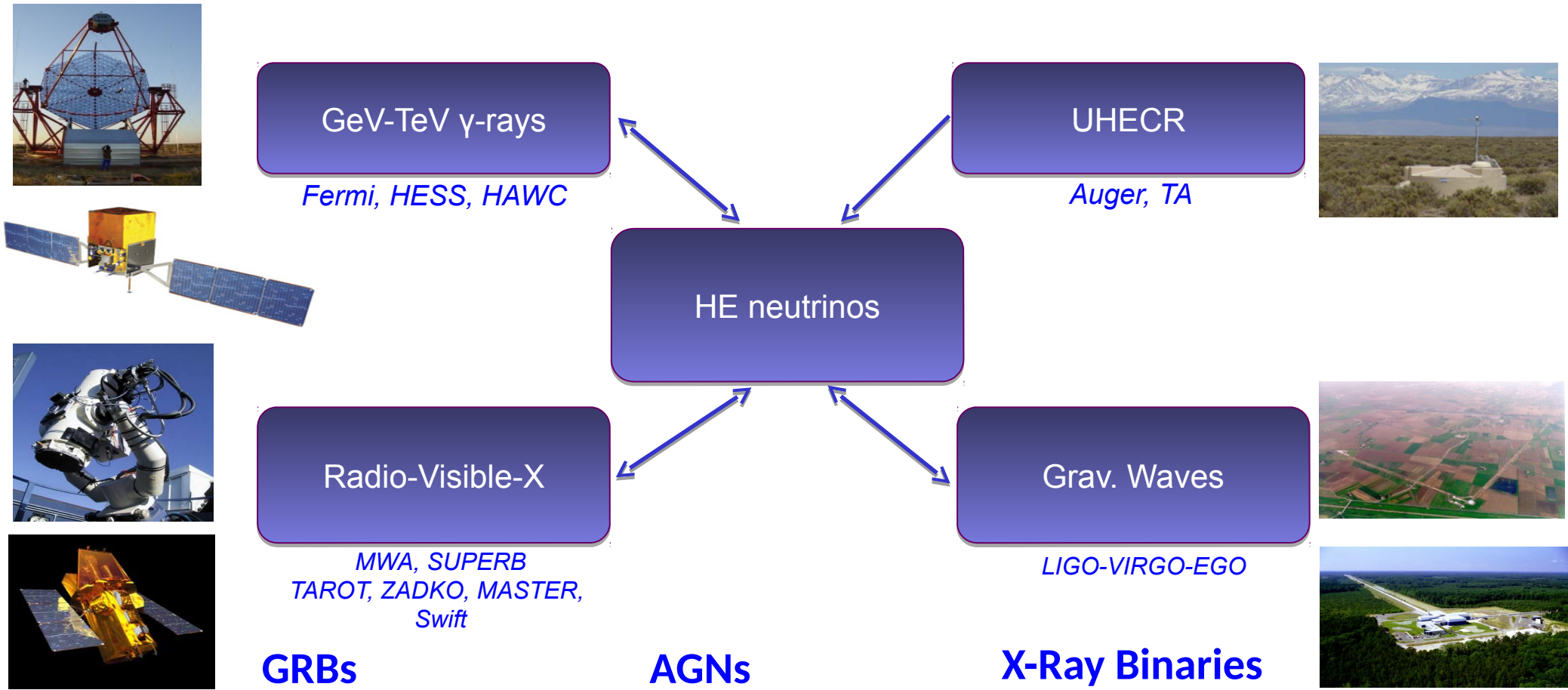


E^2 spectrum



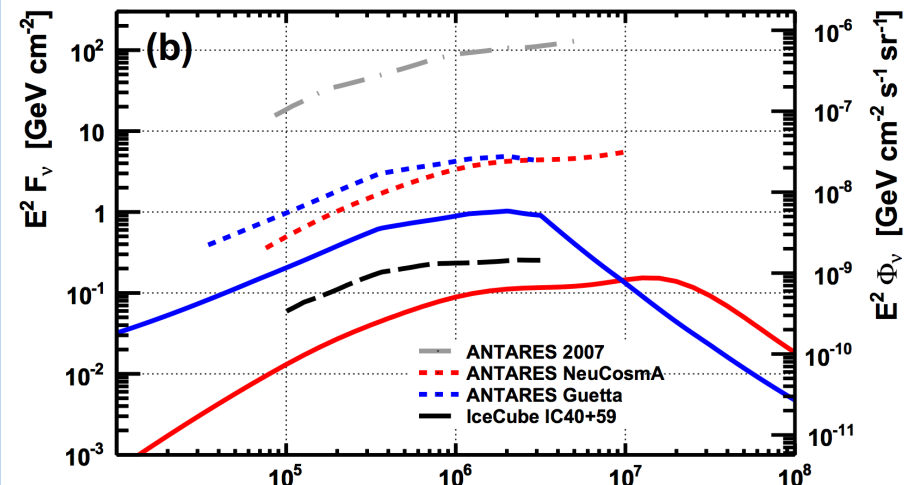
EPJ C (2014) 74:2701

Multi-Messenger Astronomy - Reducing the time+space search window



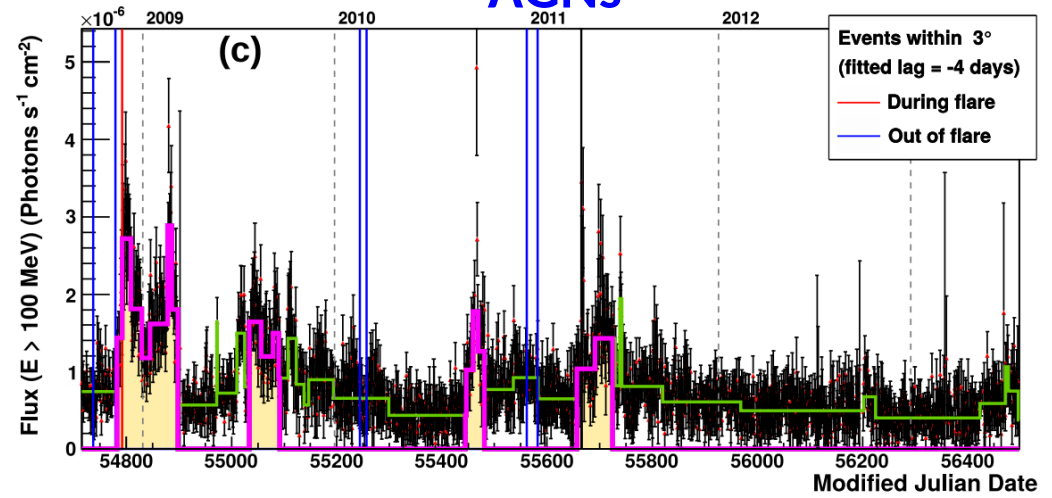
From EM observatories to ANTARES

GRBs

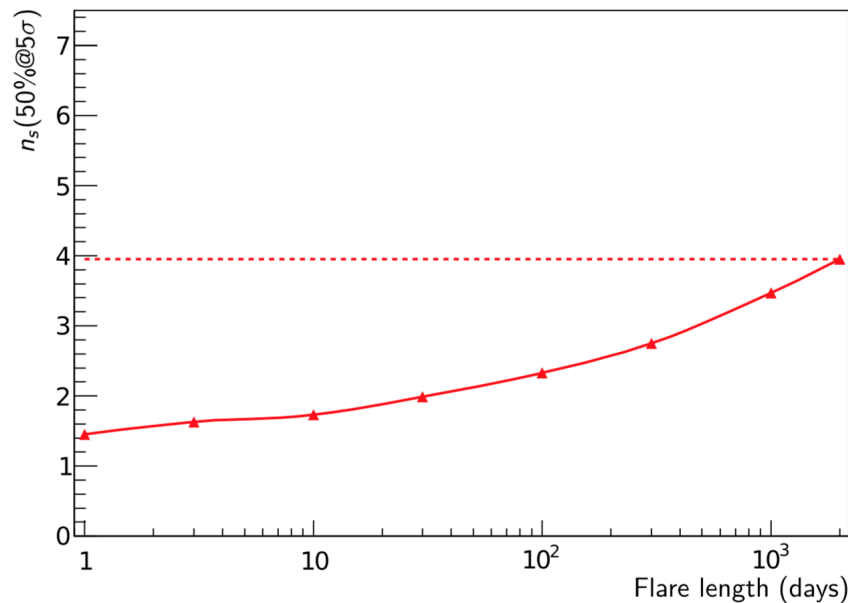


Stacking analysis of long GRBs in E [GeV]
2008-2011 (A&A 559 (2013) A9)

AGNs

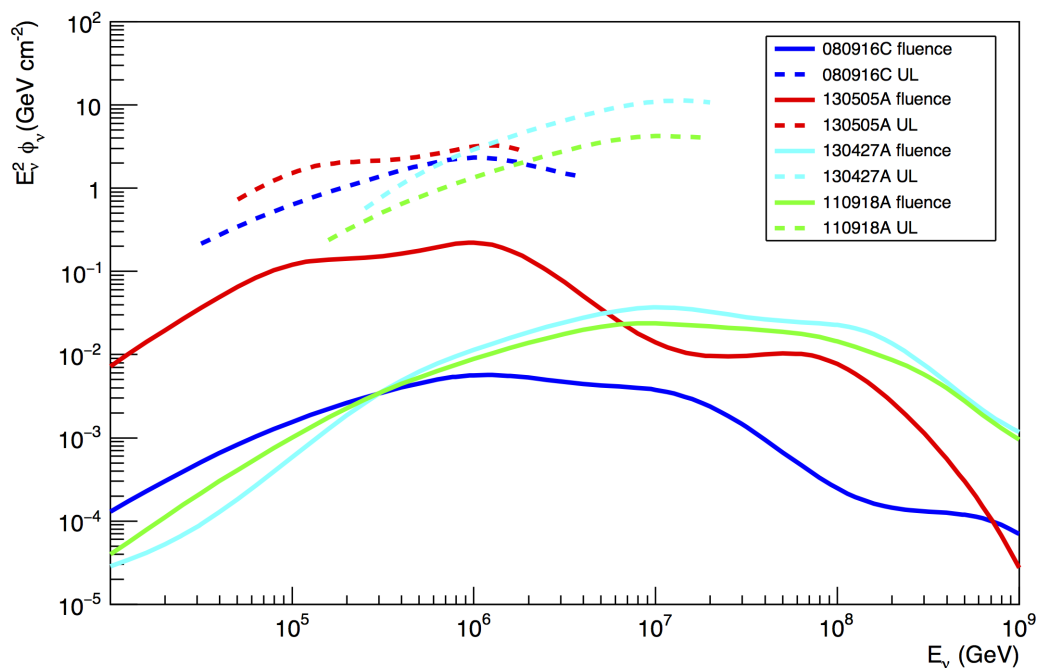
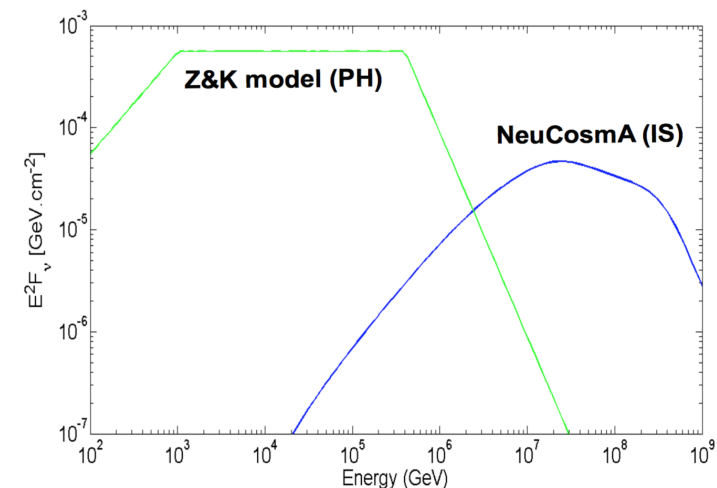
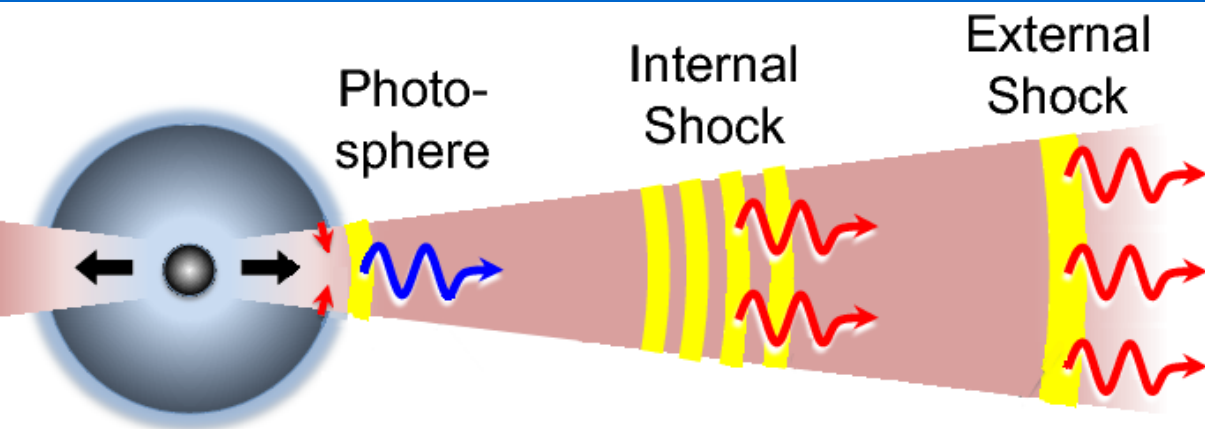


Blazars monitored by FERMI-LAT and Cherenkov
Telescopes (JCAP 1512 (2015), 014)

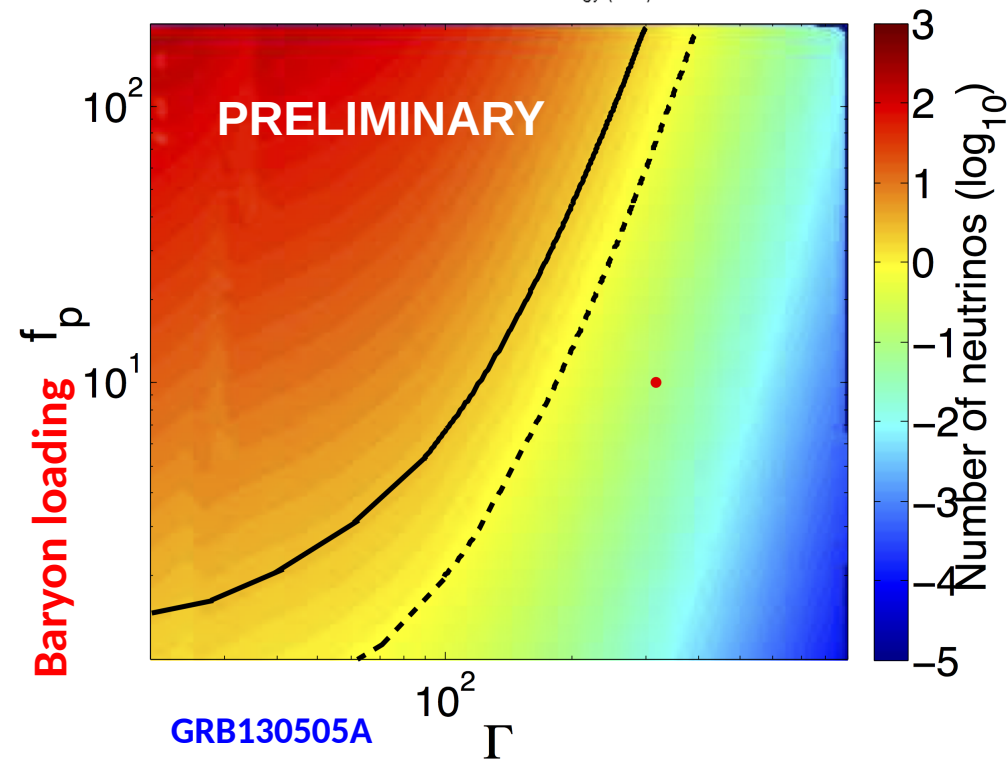


$\langle N_{\text{events}} \rangle$ for a 5σ discovery
 $\delta = -40^\circ$, E^{-2} spectrum

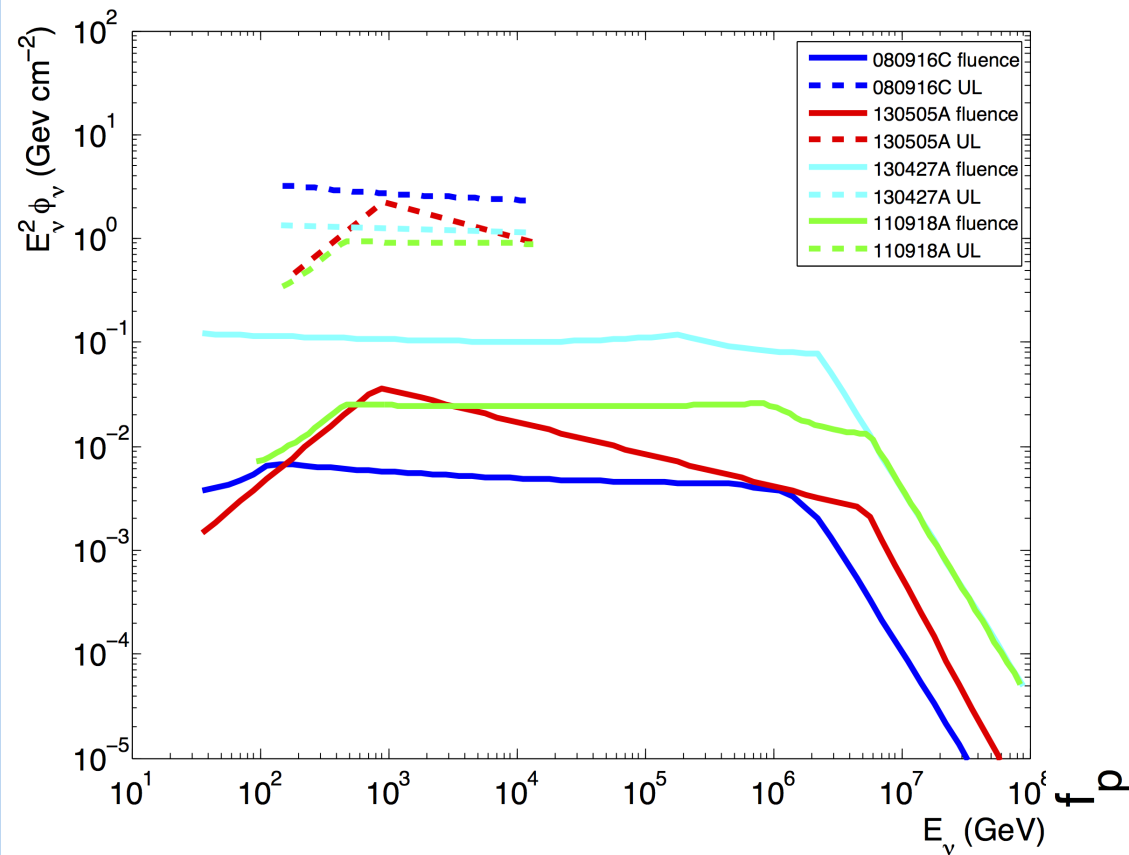
ANTARES and the brightest GRBs - Models & constraints



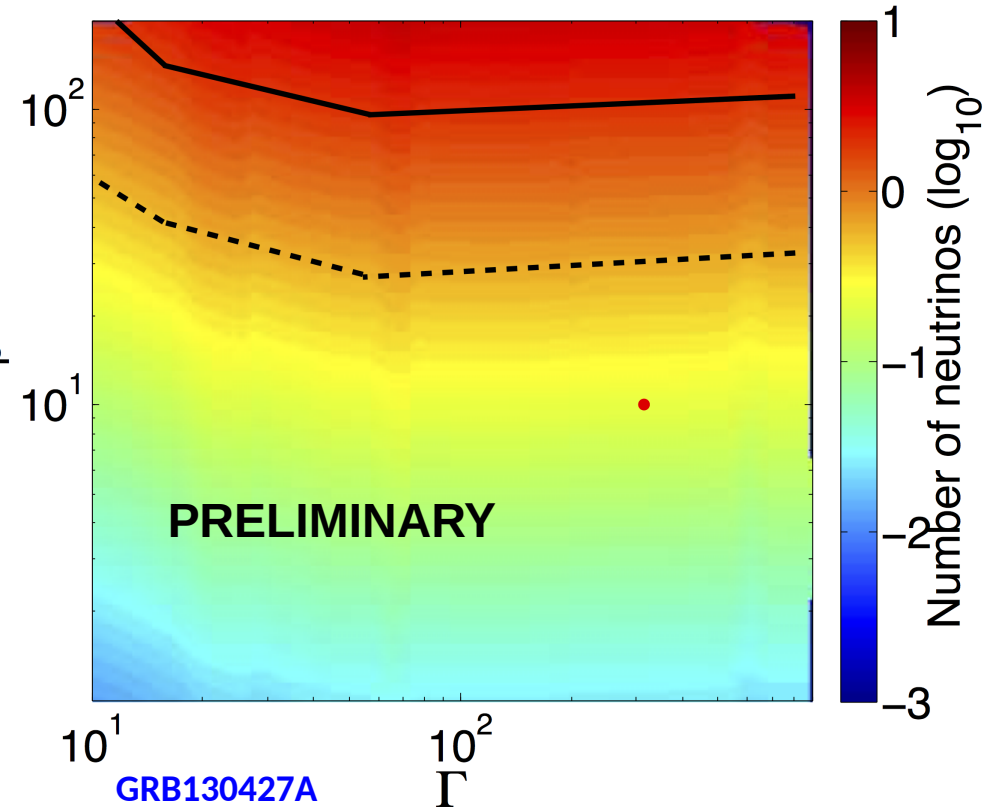
ANTARES – 2008-2013



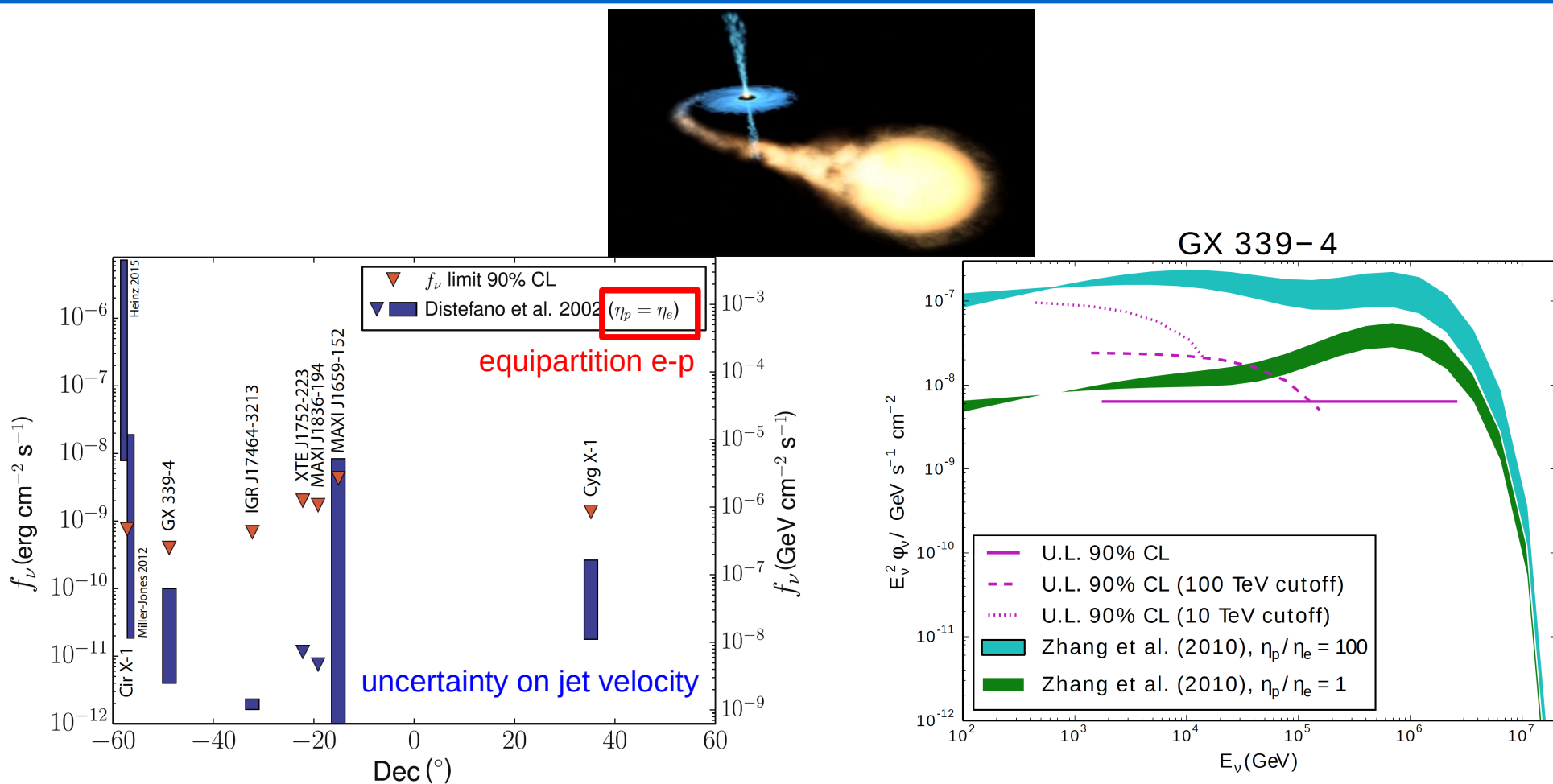
ANTARES and the brightest GRBs - Models & constraints



ANTARES – 2008-2013



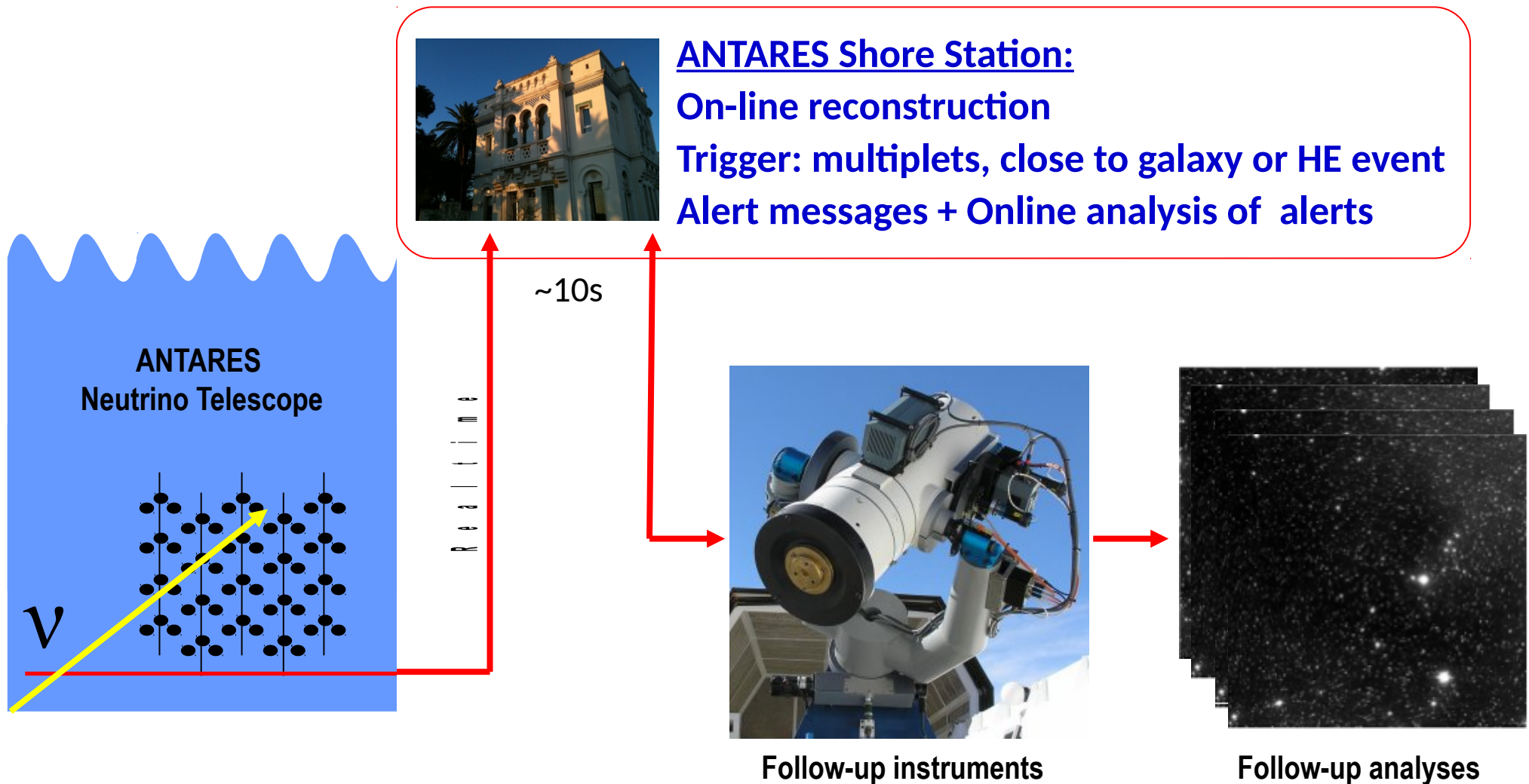
X-Ray Binaries during flaring states



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

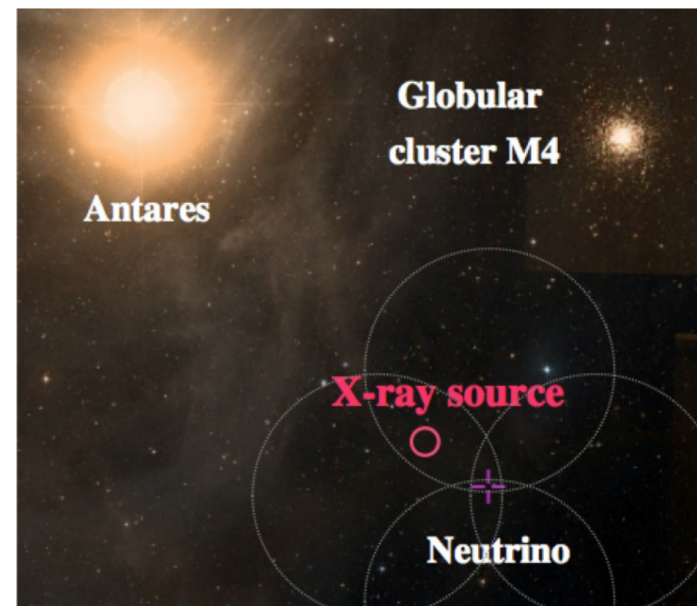
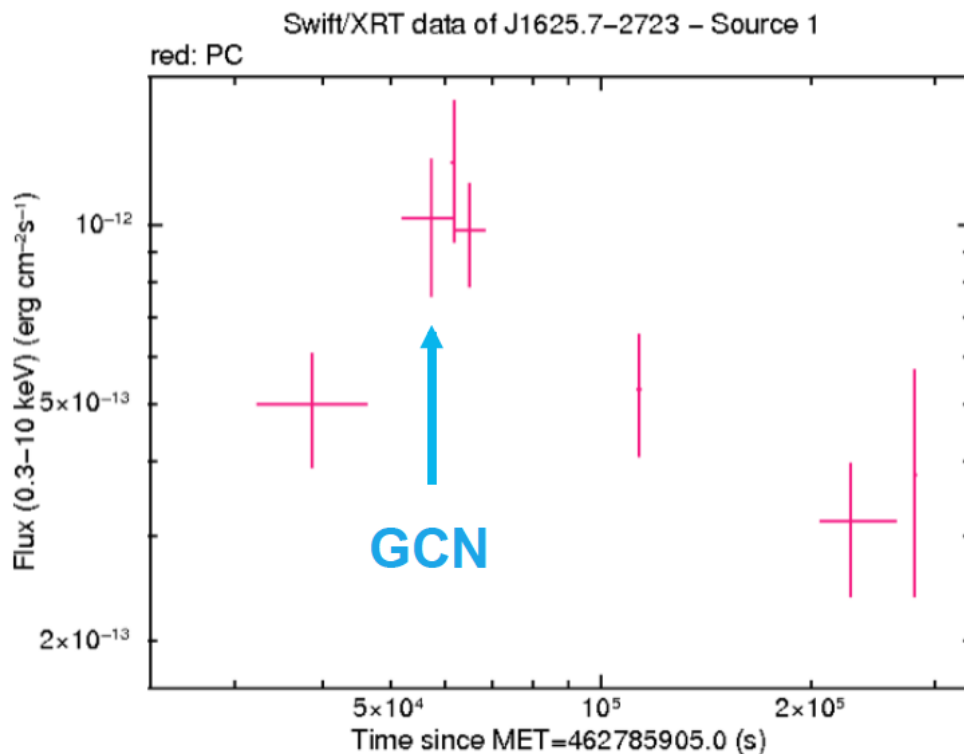
From ANTARES to EM observatories : Target-Of-Opportunity [TAToO]



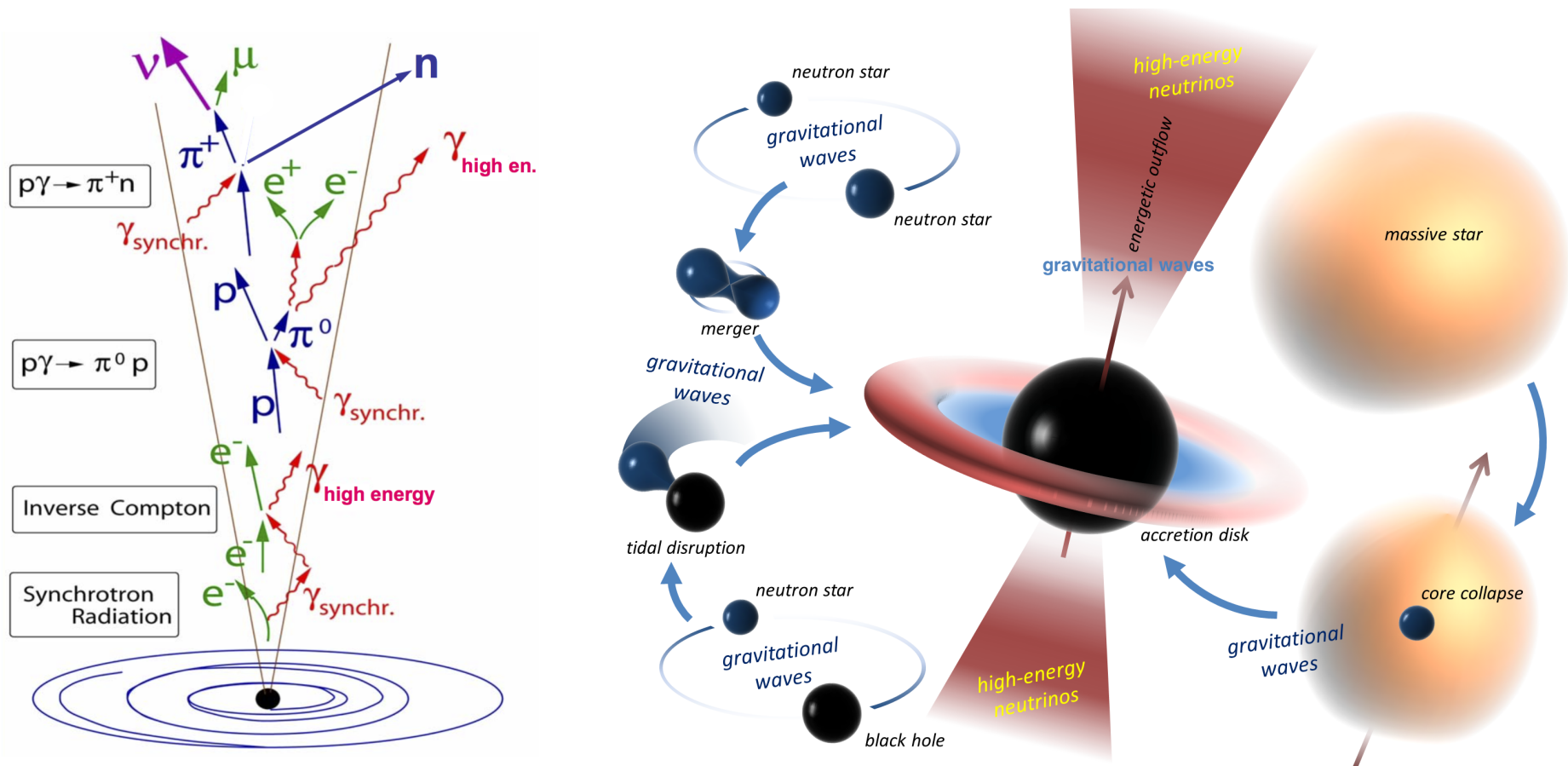
The ANTARES Telescope Neutrino Alert System
 Astroparticle Physics 35 (2012) 530-536, arXiv:1103.4477

One interesting alert from ANTARES...

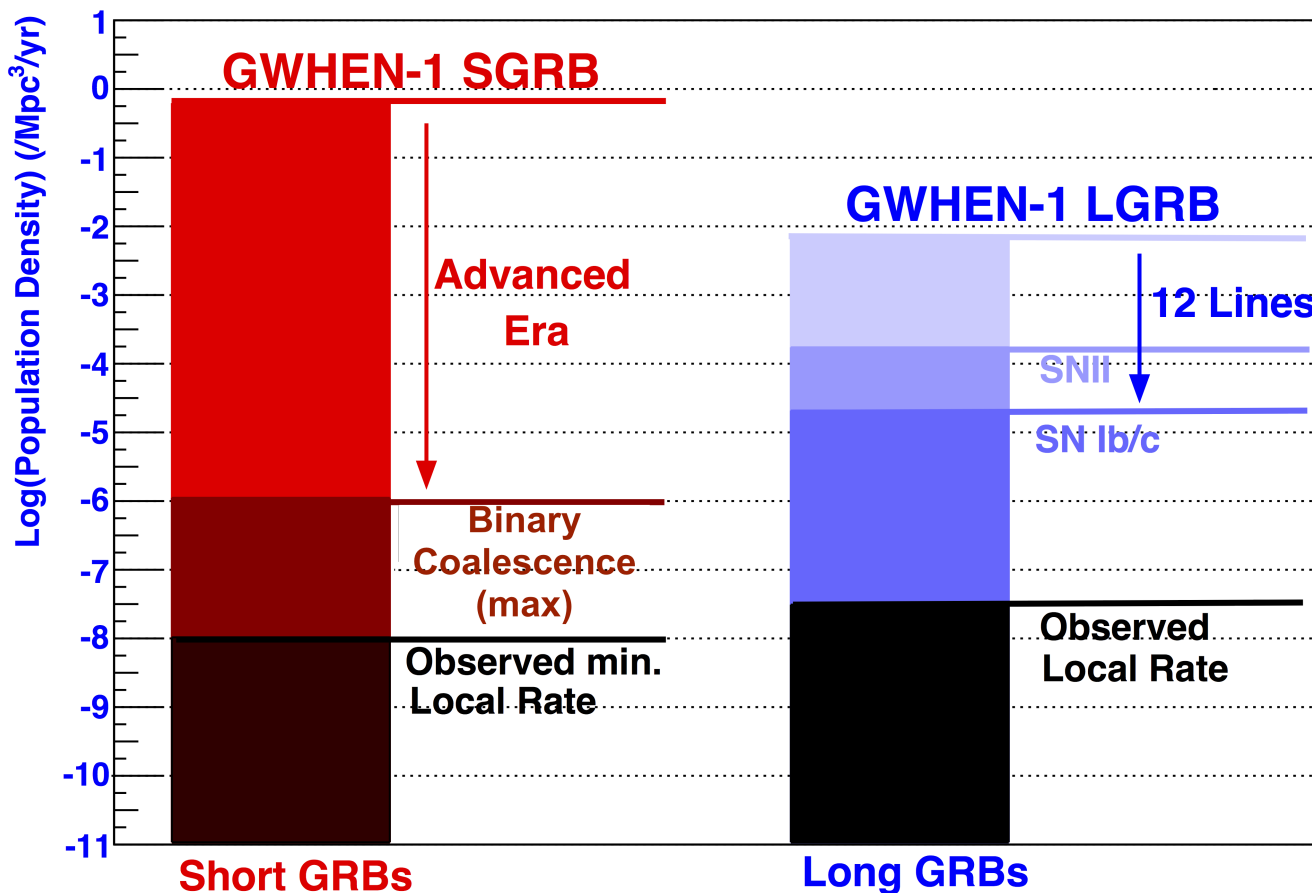
- September 1st, 2015: TAToO single HE-alert to optical telescopes + Swift
- Unknown, bright and variable X-ray source detected by Swift
- **ATEL 7987 issued**
 - Extensive follow-up (radio – optical – X – VHE) → No γ -ray source
 - Identification as variable star



Gravitational Waves + HE Neutrinos : GWHEN program



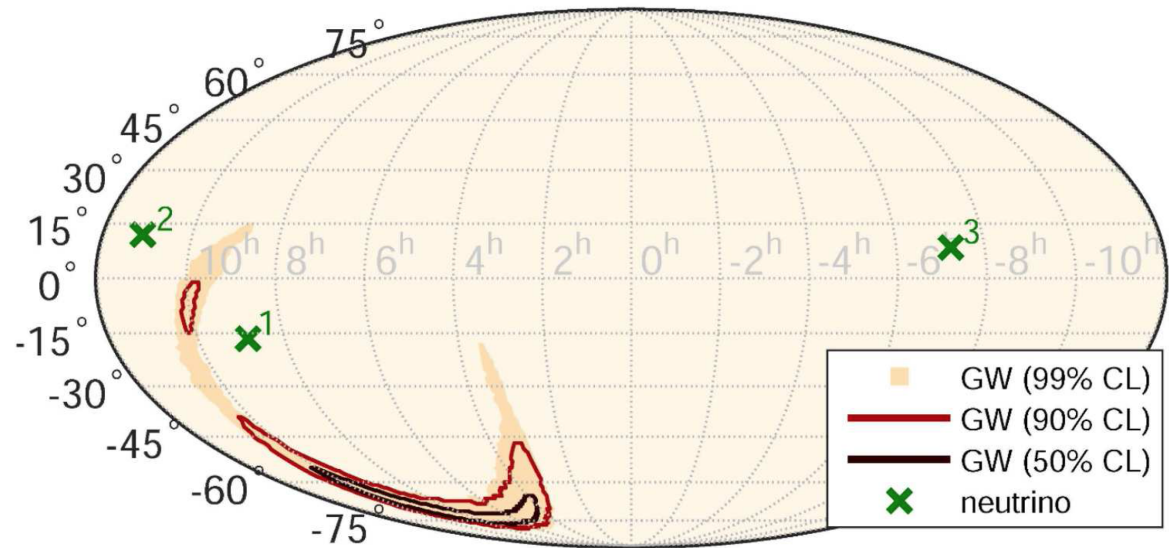
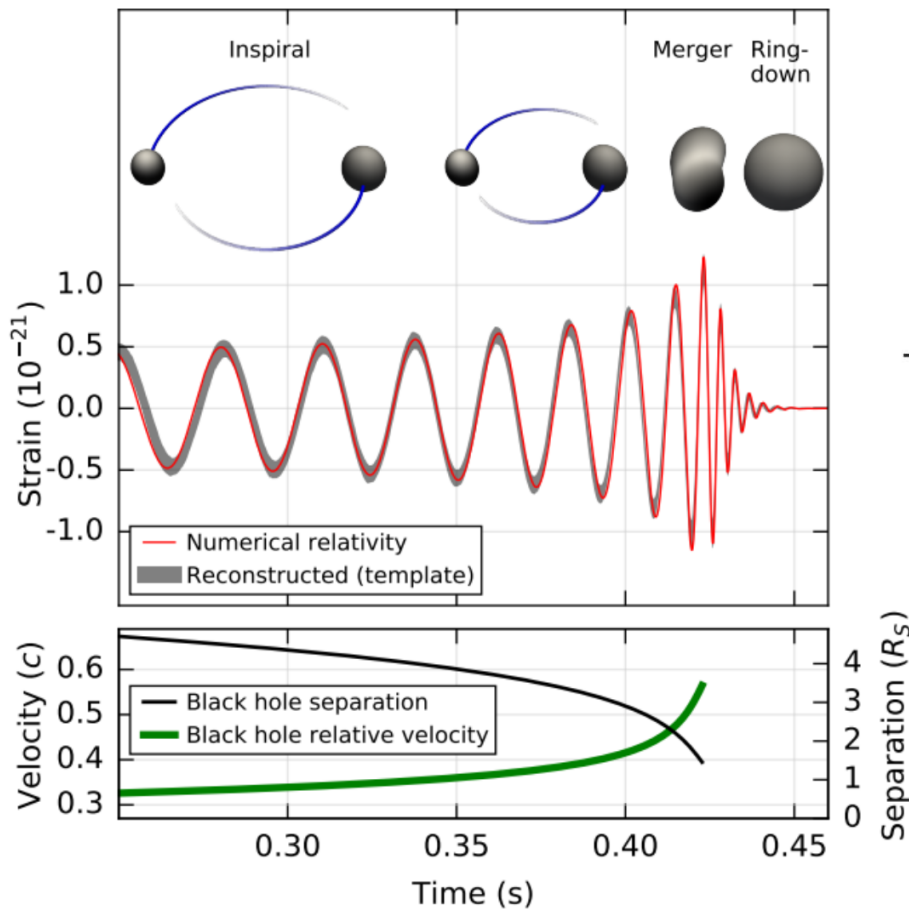
Gravitational Waves + HE Neutrinos : « initial » GWHEN analyses



JCAP 06 (2013) 008

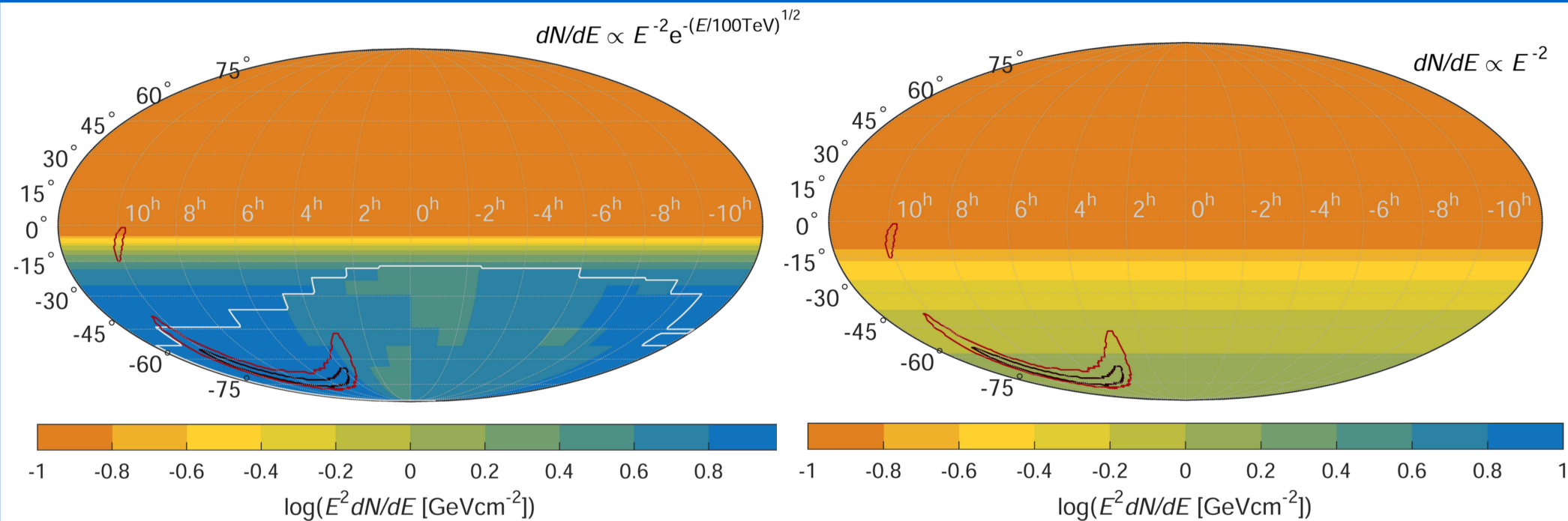
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
ANTARES	5L	10L	12L						KM3NeT			
IceCube	9s	22s	40s	59s	79s	Ice Cube 86 strings						
LIGO	S5			S6					advanced LIGO			
VIRGO	VSR1		VSR2	VS R3	VS R4					Adv. VIRGO		

Advanced GWHEN & the discovery of LIGO : GW150914



With only 2 interferometers, the position of the GW signal is not well known !

Advanced GWHEN & the discovery of LIGO : GW150914





- Size of GW150914 : 590 deg² wrt ANTARES resolution: <0.5 deg² !
- Searches in ± 500 s \rightarrow compatible with atmospheric background
- Limits from ANTARES dominate below 100 TeV (white line)
- Limits on total energy radiated in neutrinos <0.2 %-20% of energy in GW

$$E_{\nu, \text{tot}}^{\text{ul}} \sim 10^{52} - 10^{54} \left(\frac{D_{\text{gw}}}{410 \text{ Mpc}} \right)^2 \text{ erg}$$

Phys.Rev. D93 (2016) no.12, 122010

Conclusions...

- **The sources of IceCube Neutrinos are still to be identified...**
- **ANTARES, in operation for more than 10 years, until mid-2017**
- **Extensive Multi-Messenger program to zero in on their origin(s) !**
 - Time+Space correlations would allow to identify the HEN origin(s)
 - « Underwater » angular resolution crucial → Reduction of background
 - Fast processing of HEN signal → Alert emission towards EM observatories
 - Follow-up programs covering all wavelengths, from visible to HE γ -rays
- **GWHEN and the LIGO discovery**
 - First limits on HEN emission from BH-BH coalescence
 -  Results for GW151226 and LVT151012 published soon...
 -  Reception of GW alerts by ANTARES being installed !