



ANTARES

recent results

with focus on the multi-messenger and
real-time program

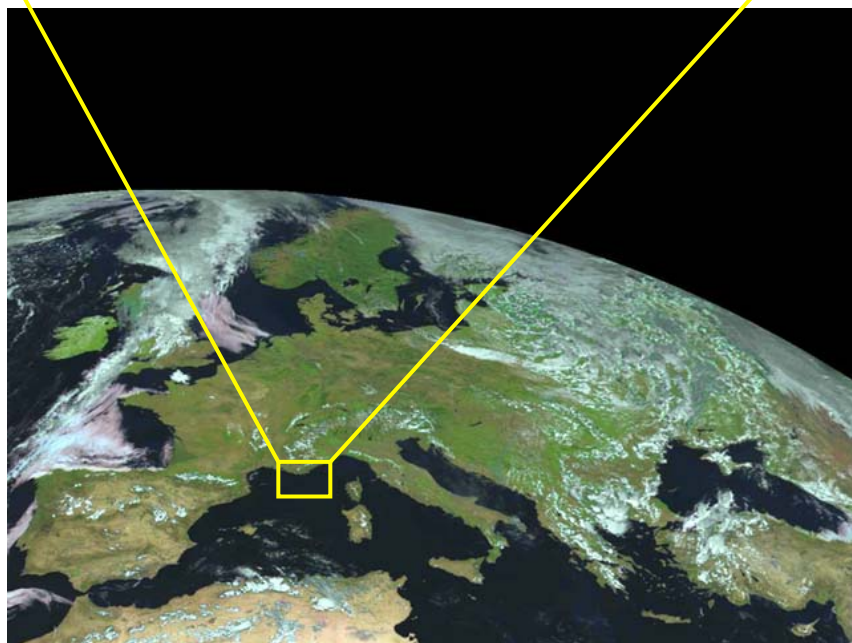
Fabian Schüssler
on behalf of the ANTARES collaboration

fabian.schussler@cea.fr



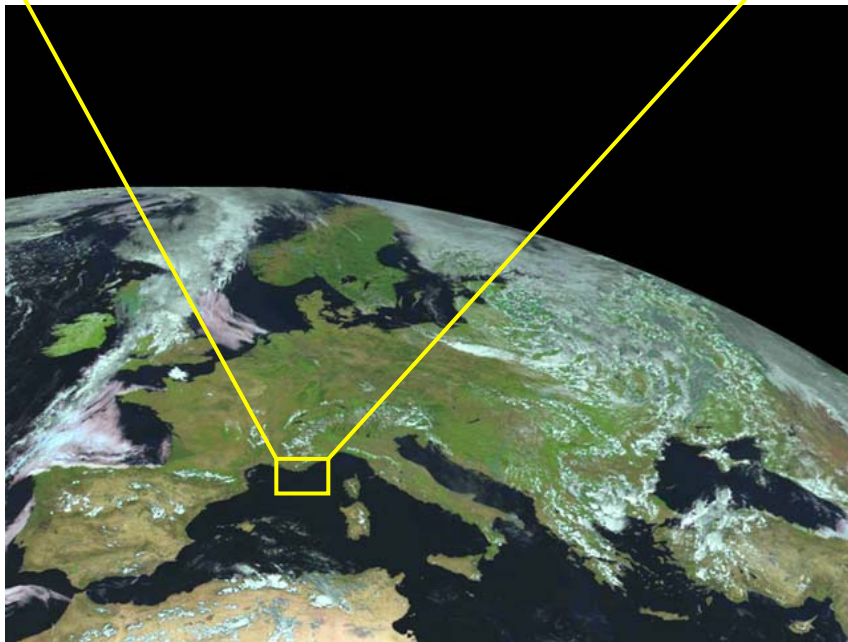
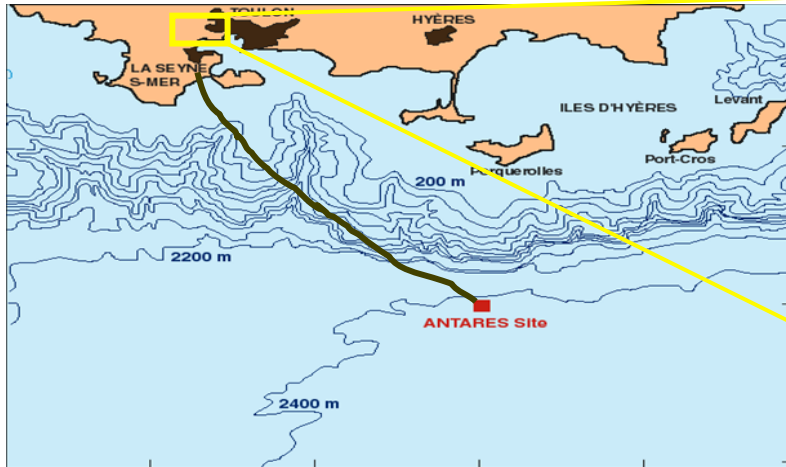


Astronomy with a Neutrino Telescope and Abyss environment RESearch



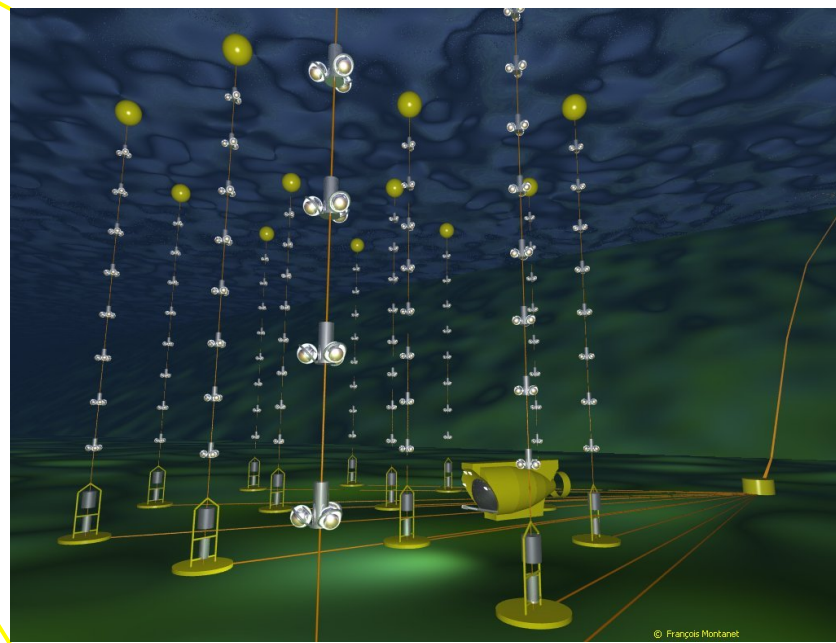
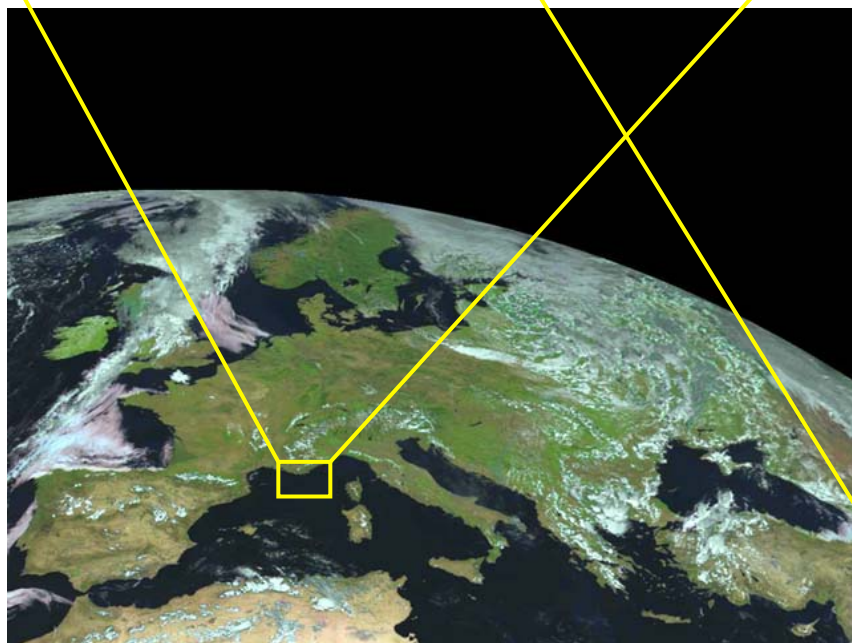
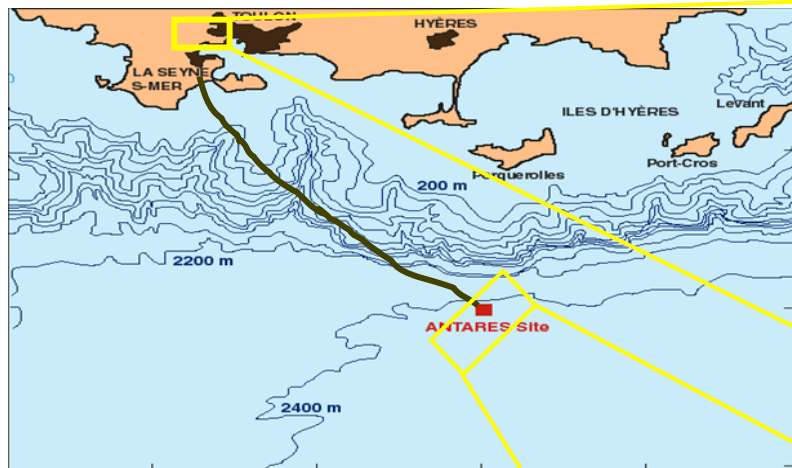


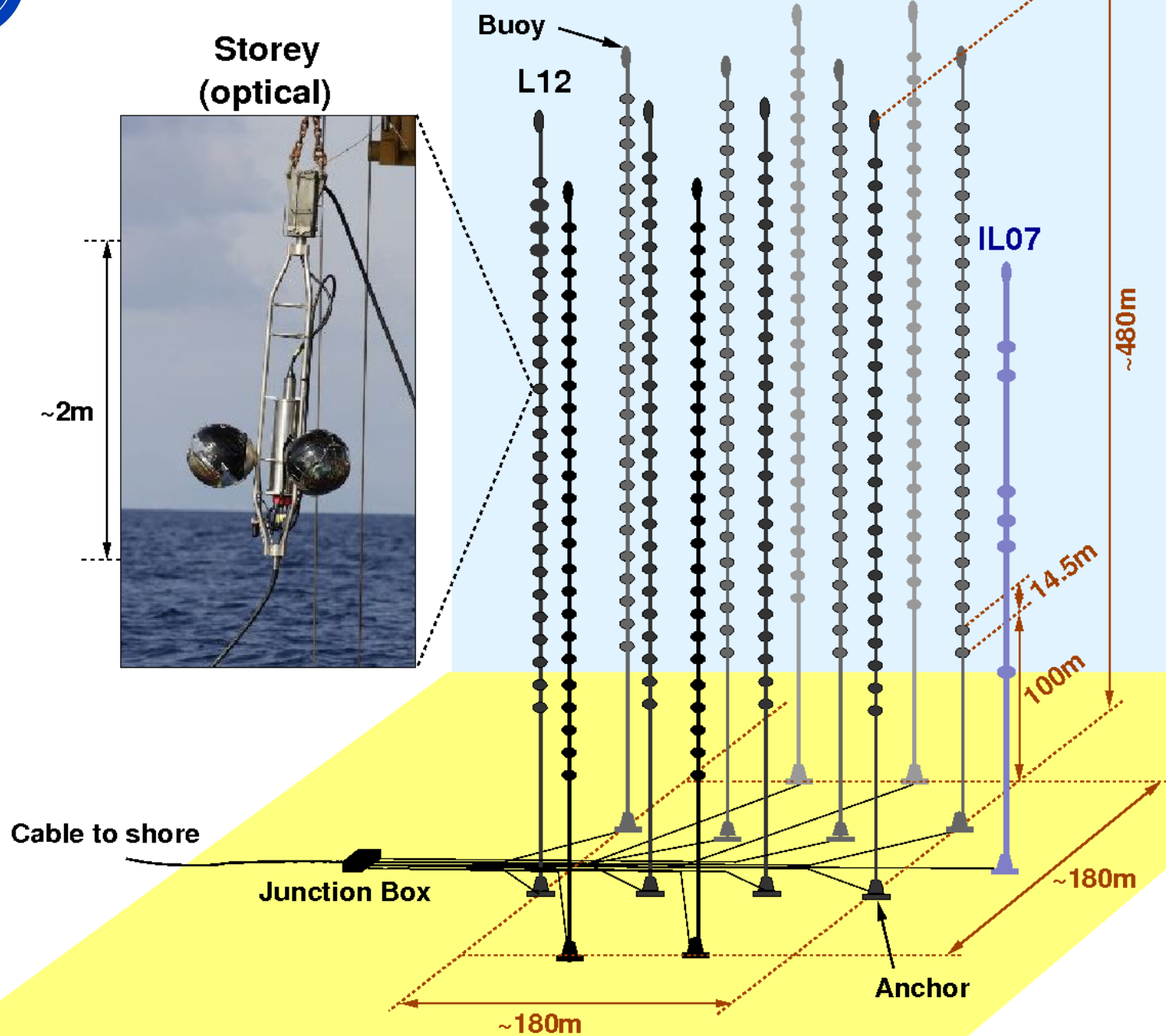
Astronomy with a Neutrino Telescope and Abyss environment RESearch





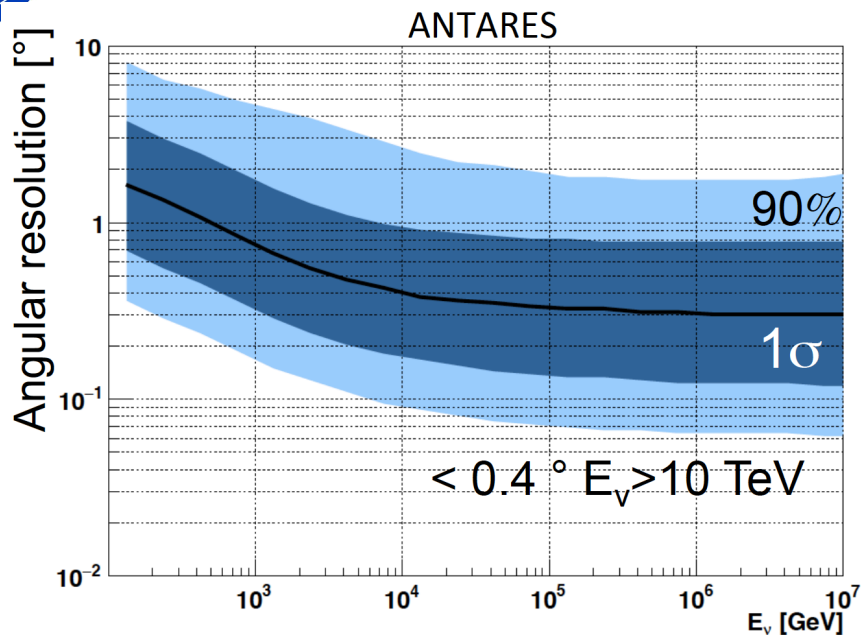
Astronomy with a Neutrino Telescope and Abyss environment RESearch



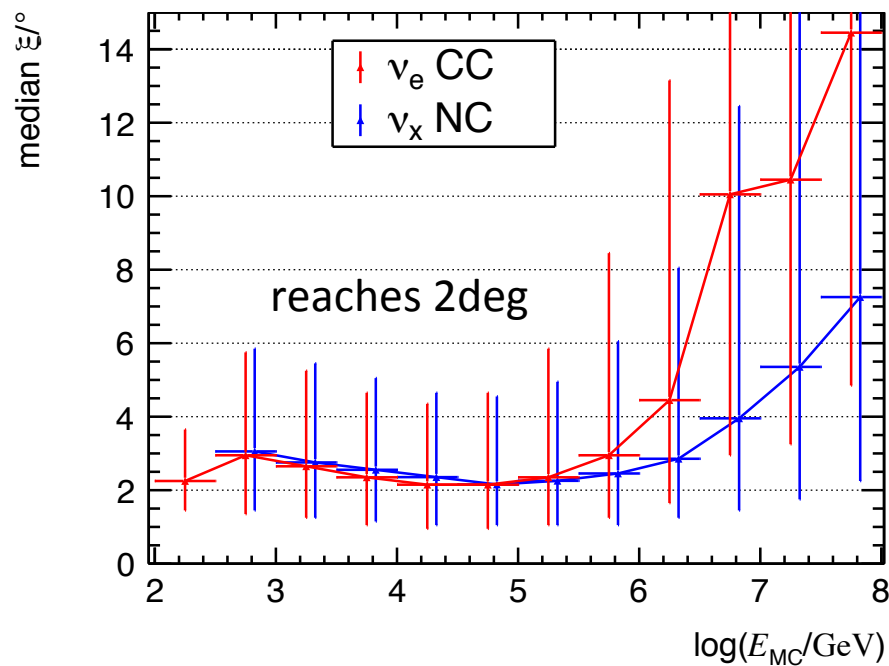
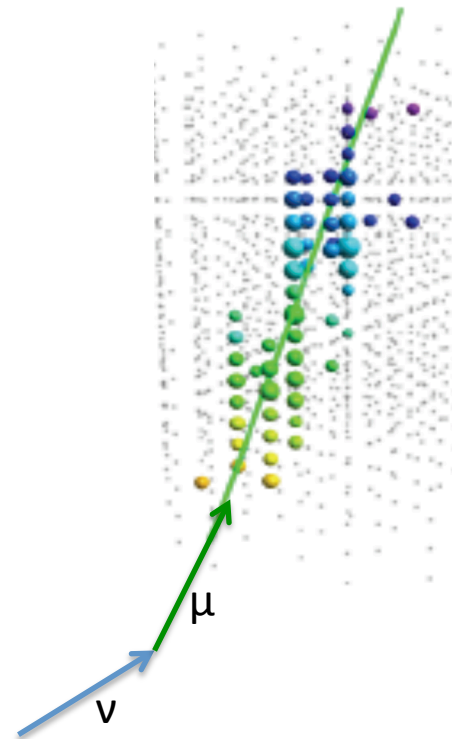




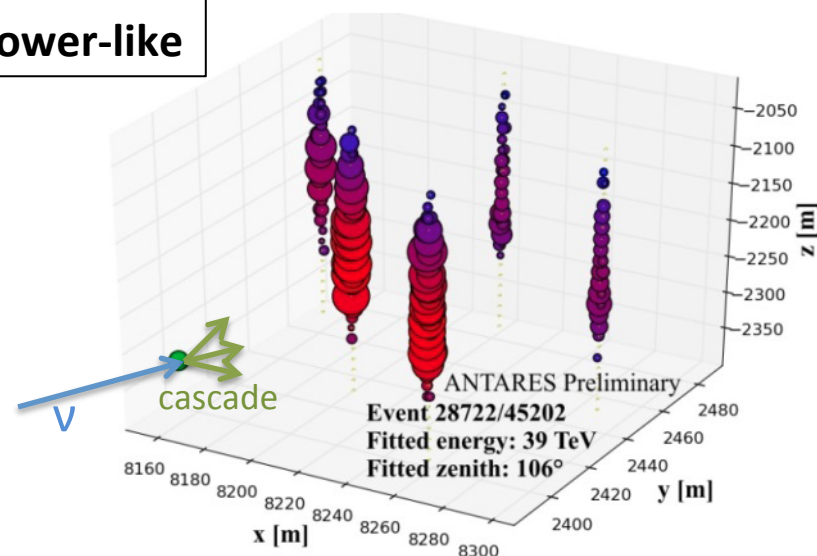
Event topologies



Track-like



Shower-like



Physics with a neutrino telescope

Sources of cosmic rays

- Point sources (steady/transient)
- Diffuse flux, UHE, ...
- CR anisotropies
- Multi-messenger studies

Detection parameters

$100 \text{ GeV} < E < 1 \text{ PeV}$
angular res.: 0.3 deg
Volume: 20 Mt

High energy physics

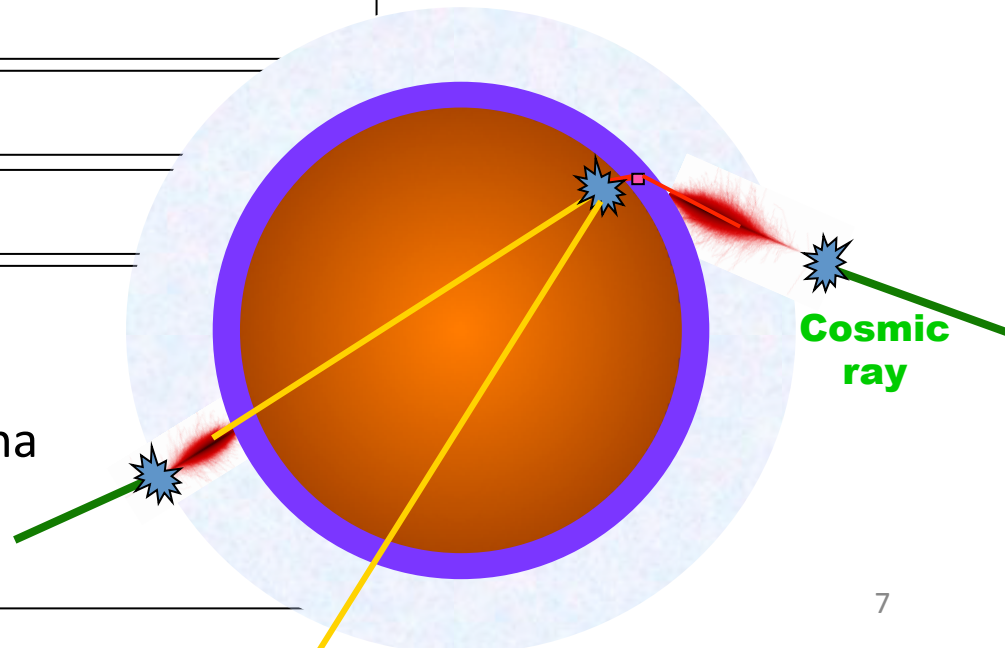
- Atmospheric muons
- Atmospheric neutrinos
- Neutrino oscillations
- ...

Indirect detection of dark matter

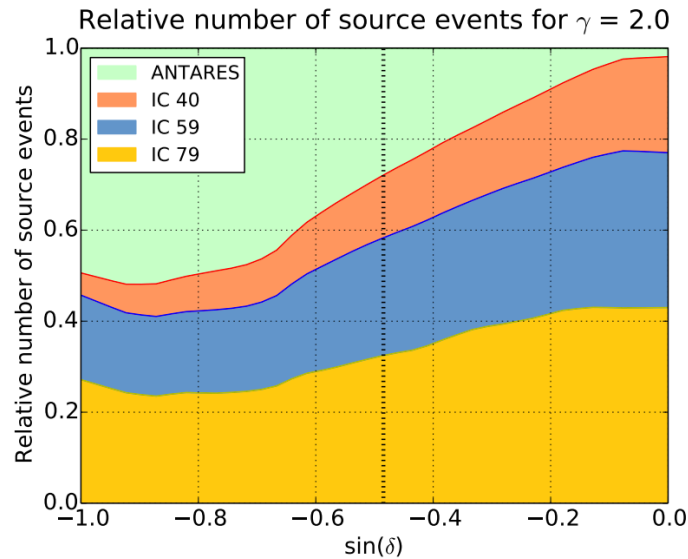
Exotics (monopoles, nuclearites, ...)

Environmental sciences

- Online measurements
- Long periods: exotic phenomena
- Carbon cycle
- ...

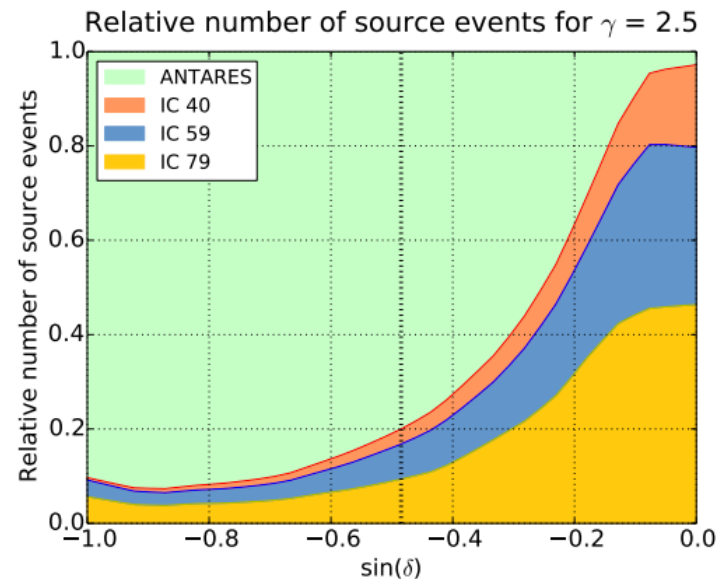
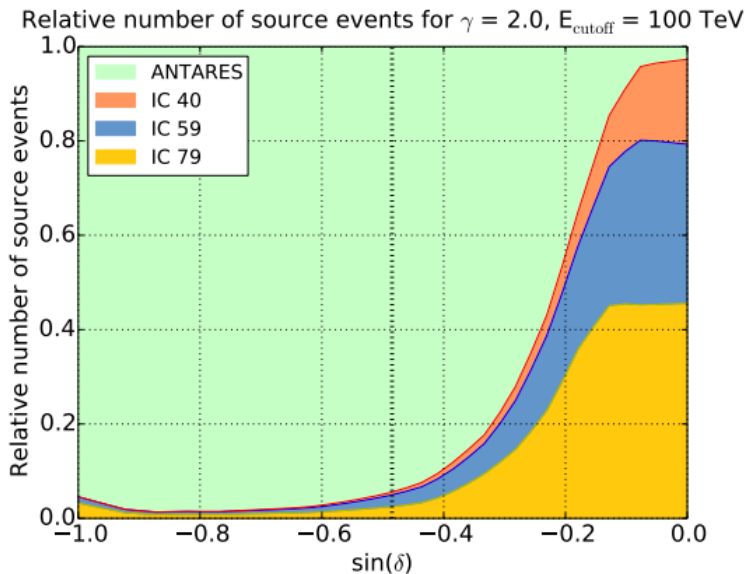


ANTARES vs IceCube



Sensitivities to track like events
assuming an E^{-2} spectrum
within an energy interval

➔ focus on Galactic TeV sources
(and transients)



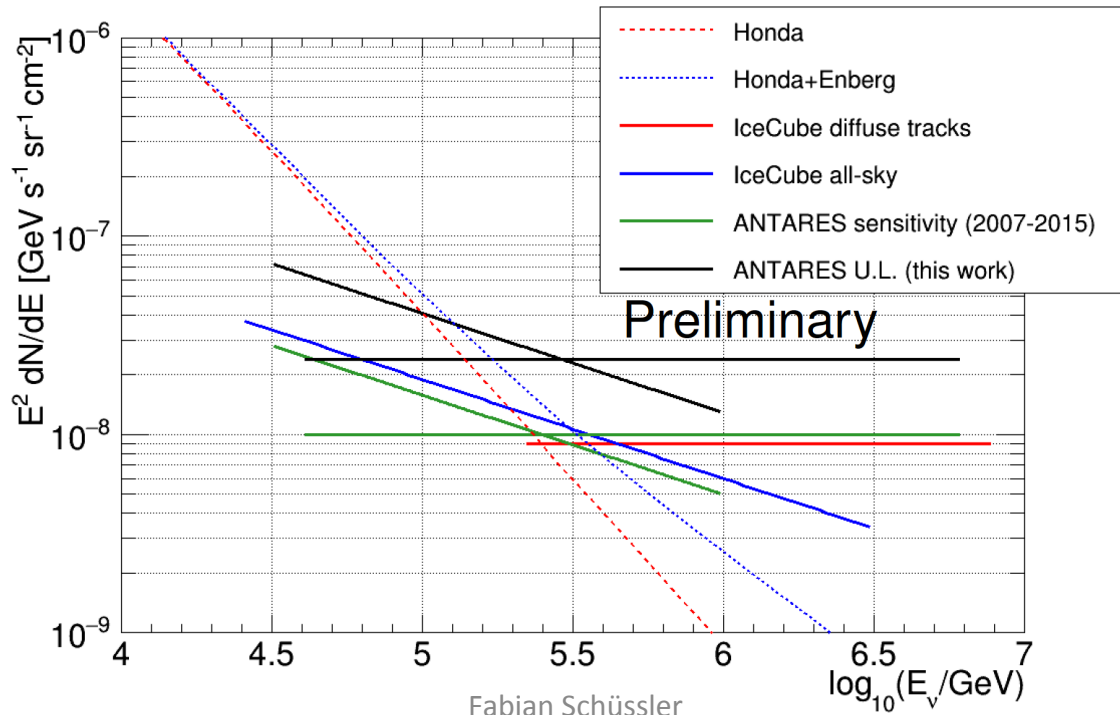


Search for a diffuse, high-energy flux

Blinded analyses, optimizing cuts for $\Gamma=2$ and $\Gamma=2.5$ spectra

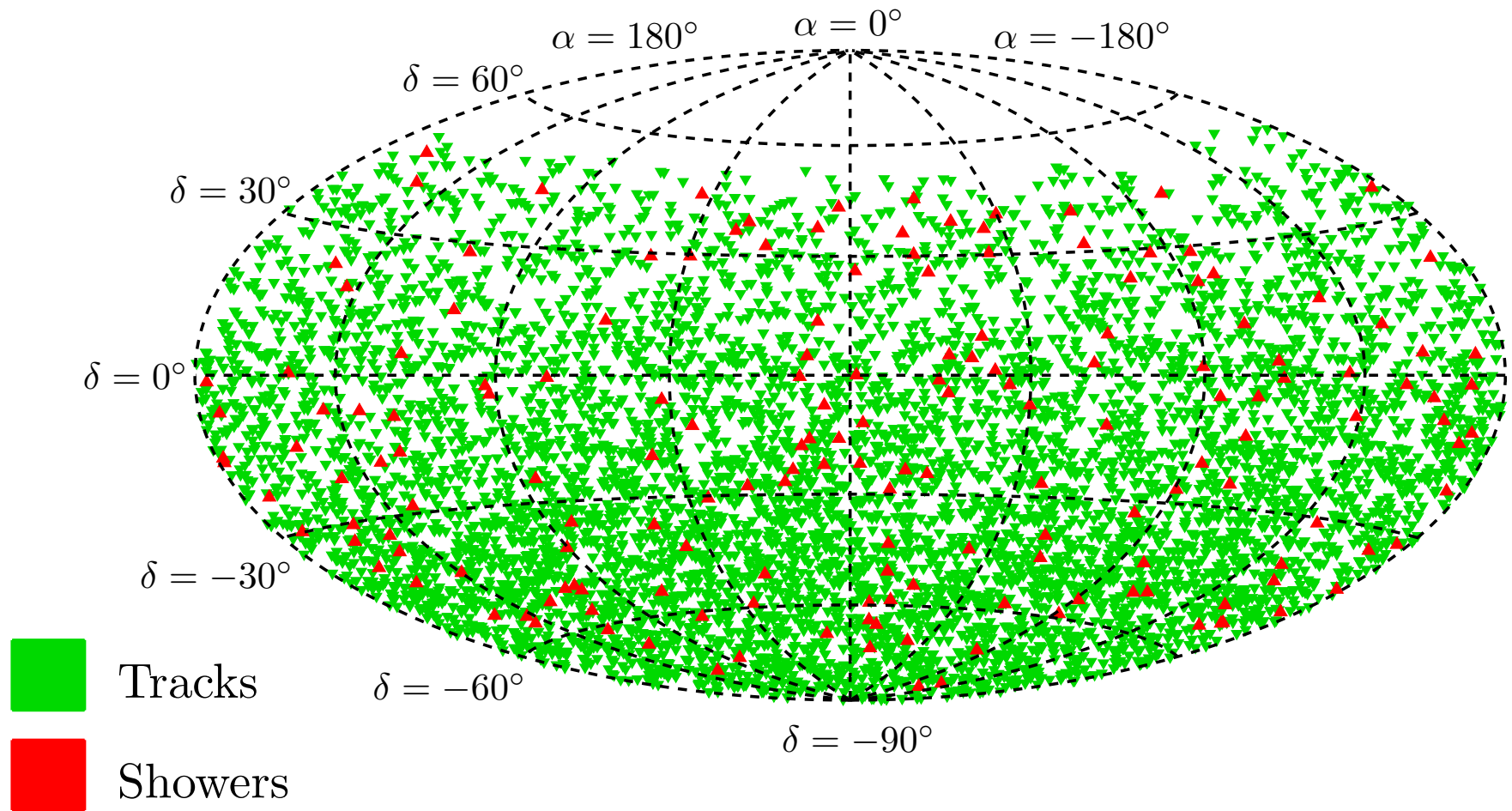
Checks on 10% burn sample

Channel	Period	DATA	Background	IC-flux
Tracks	2007-2015	19	13.5 ± 3	3
Showers	2007-2013	7	5 ± 2	1.5





Searches for neutrino sources



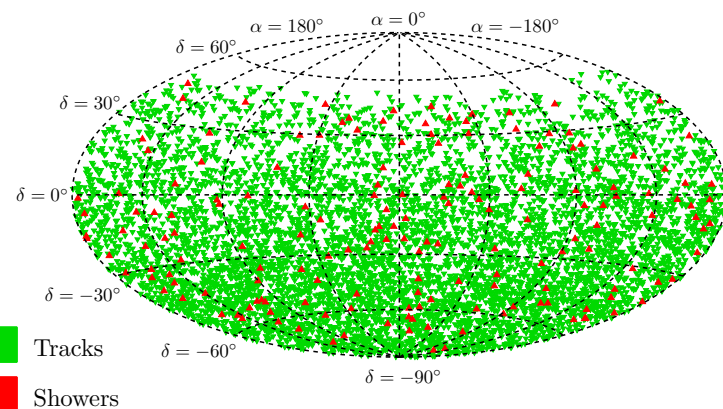


Searches for point-like neutrino sources

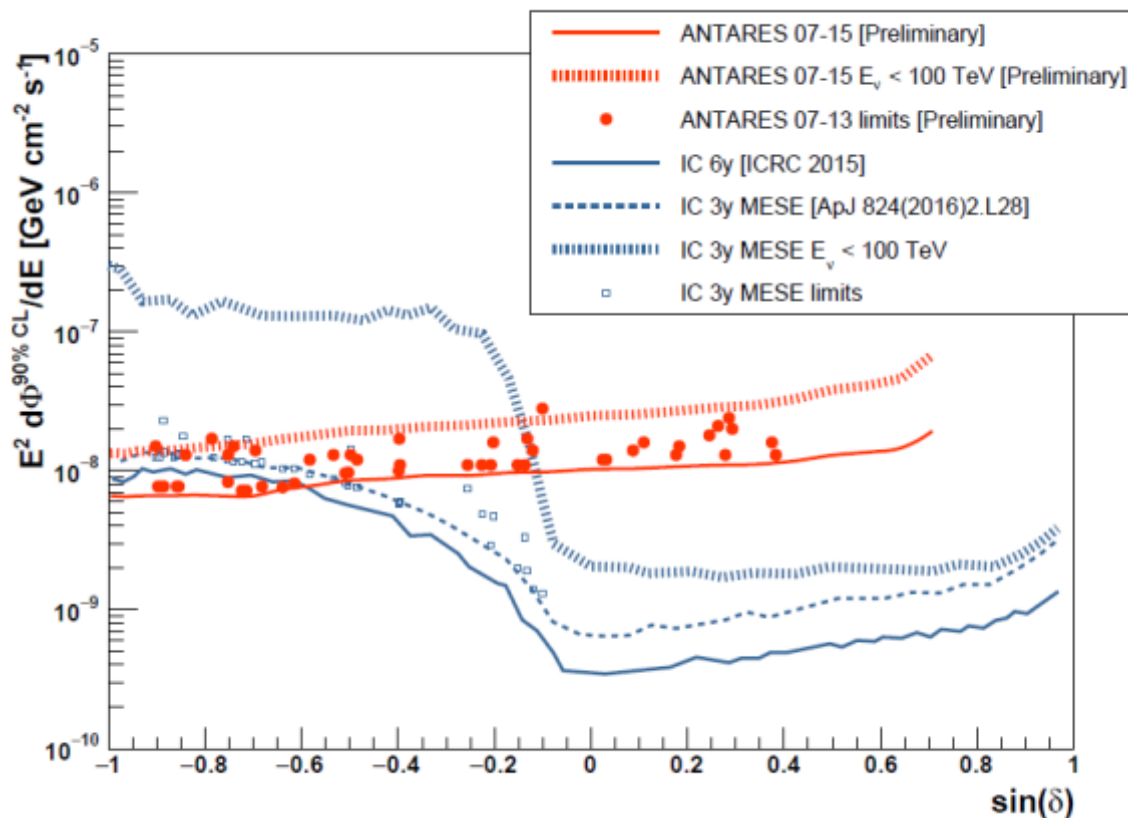
All-Sky + 54 candidate sources + 8 IC HESE-tracks

No significant cluster:

- All-sky: 1.3σ at RA:311.7°, Dec=-48.3°
- Candidates: 0.75σ for HESS J°6302+057



6490 tracks + 172 showers



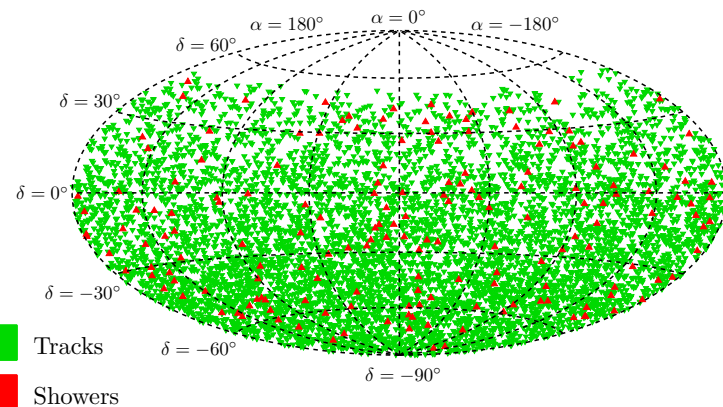


Searches for point-like neutrino sources

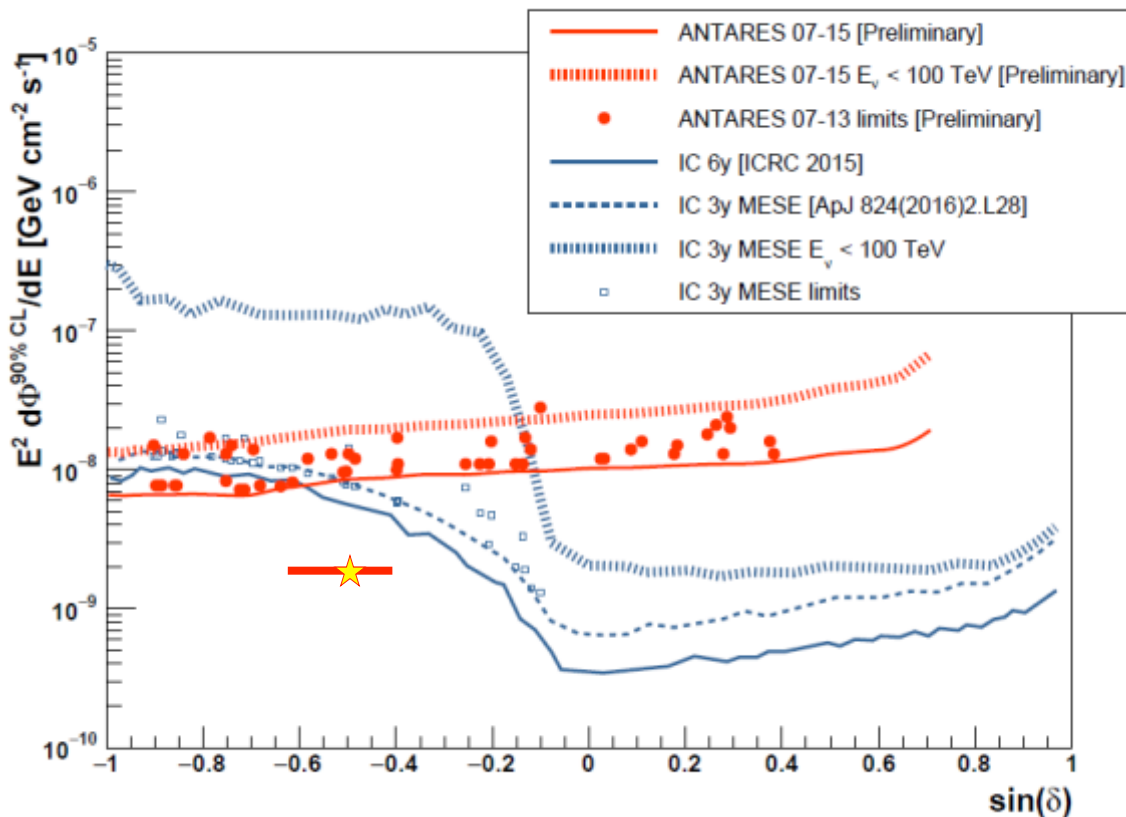
All-Sky + 54 candidate sources + 8 IC HESE-tracks

No significant cluster:

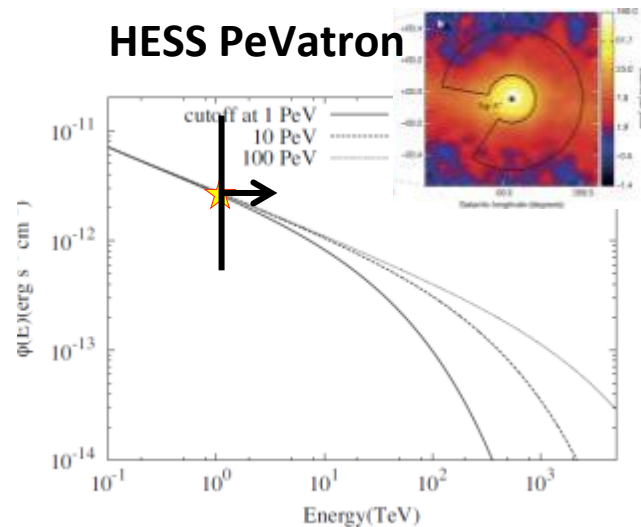
- All-sky: 1.3σ at RA:311.7°, Dec=-48.3°
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6490 tracks + 172 showers



HESS PeVatron

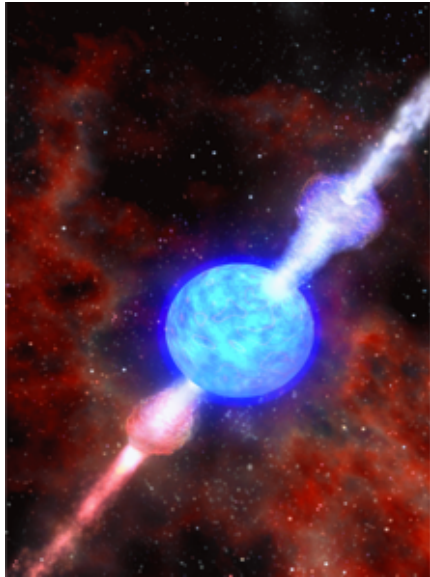


Nature 531 (2016) 476



Using input from EM observations

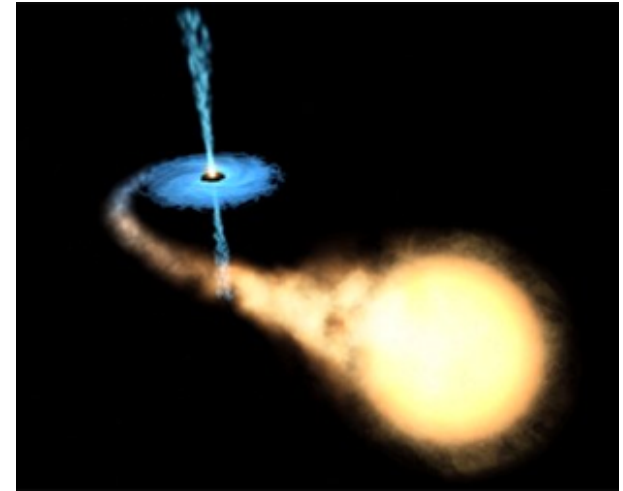
GRBs



AGNs



Microquasars

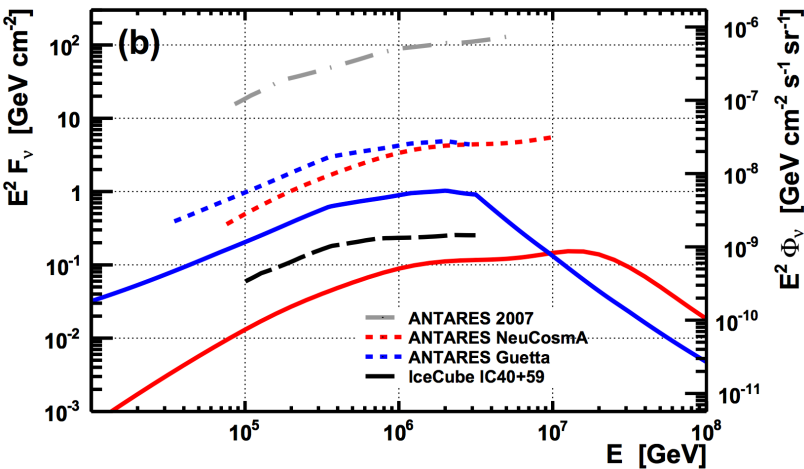


- Spatial and temporal information as input to neutrino searches
 - Optimize search windows
 - Reduce backgrounds
 - Increase sensitivity
- Coincident signals → smoking gun for common source, hadronic origin, etc.



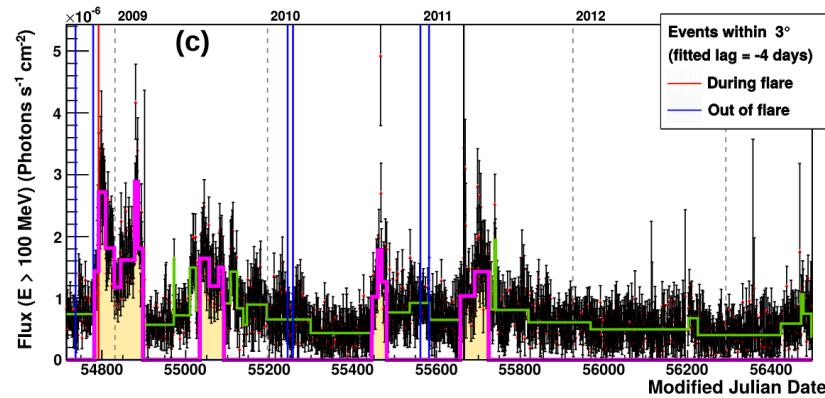
Using input from EM observations

GRBs



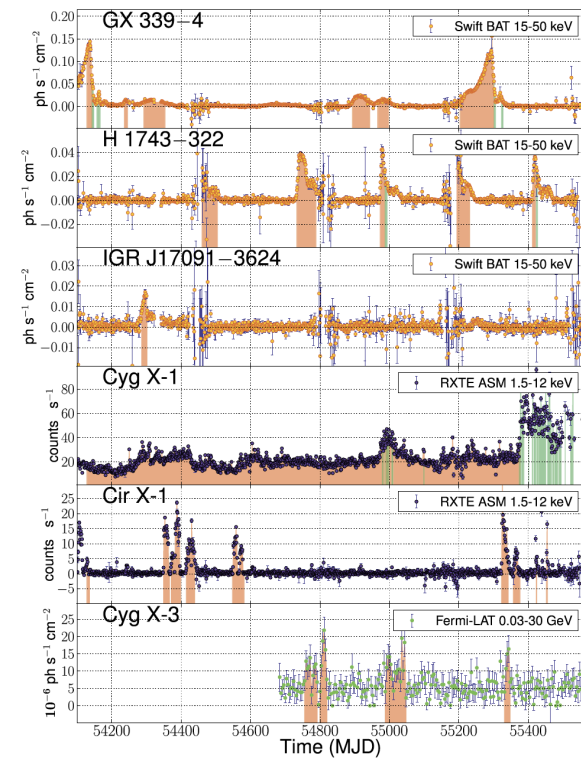
Stacking analysis of long GRBs in 2008-2011 (**A&A 559 (2013) A9**)

AGNs



Blazars monitored by FERMI-LAT and IACTs (**JCAP 1512 (2015), 014**)

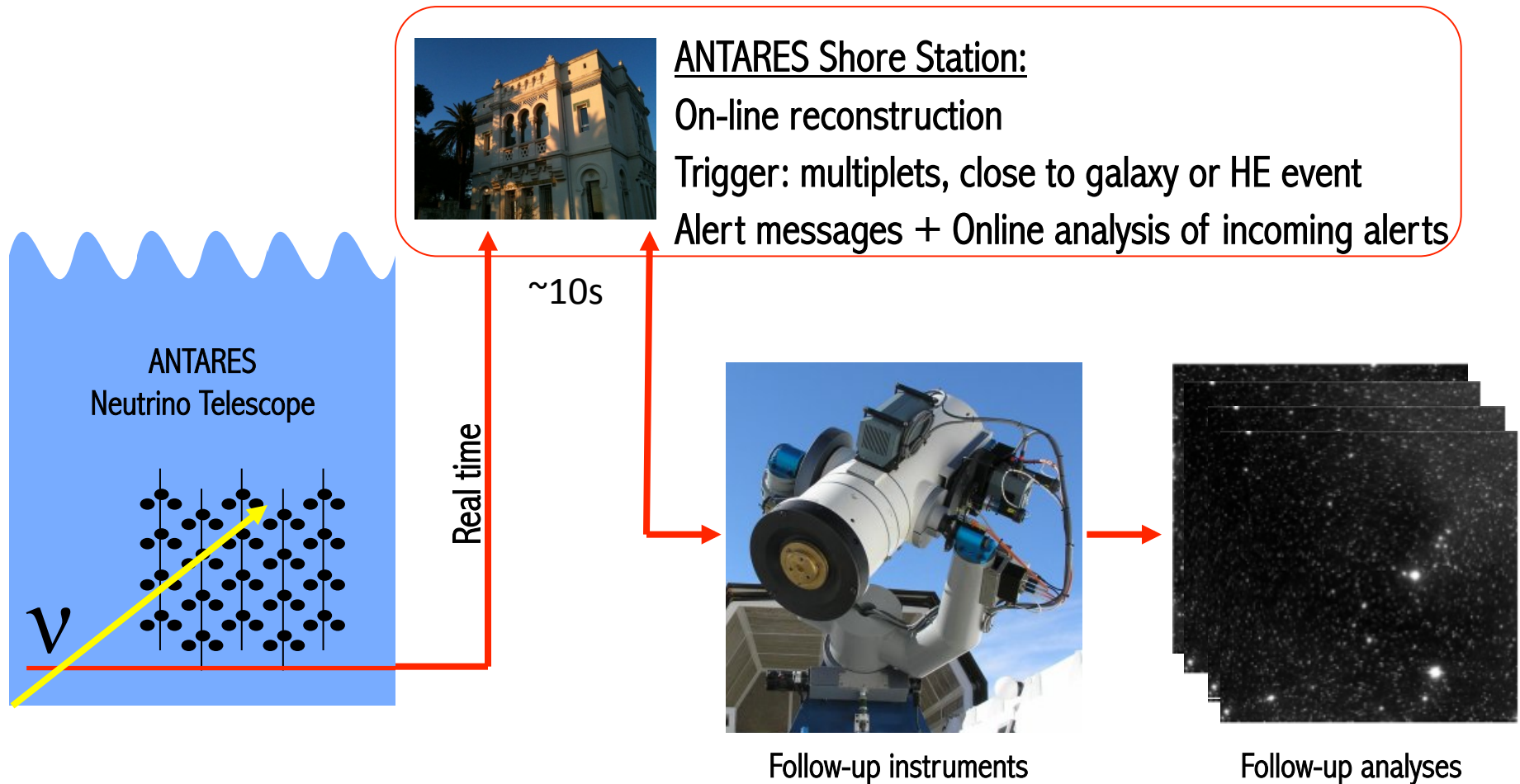
Microquasars



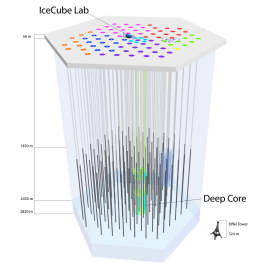
hard X-ray states + hard to soft transitions (**JHEAP 3-4 (2014) 9**)



Multimessenger + alert program: TAToO



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



Multi wavelength follow-up of neutrinos

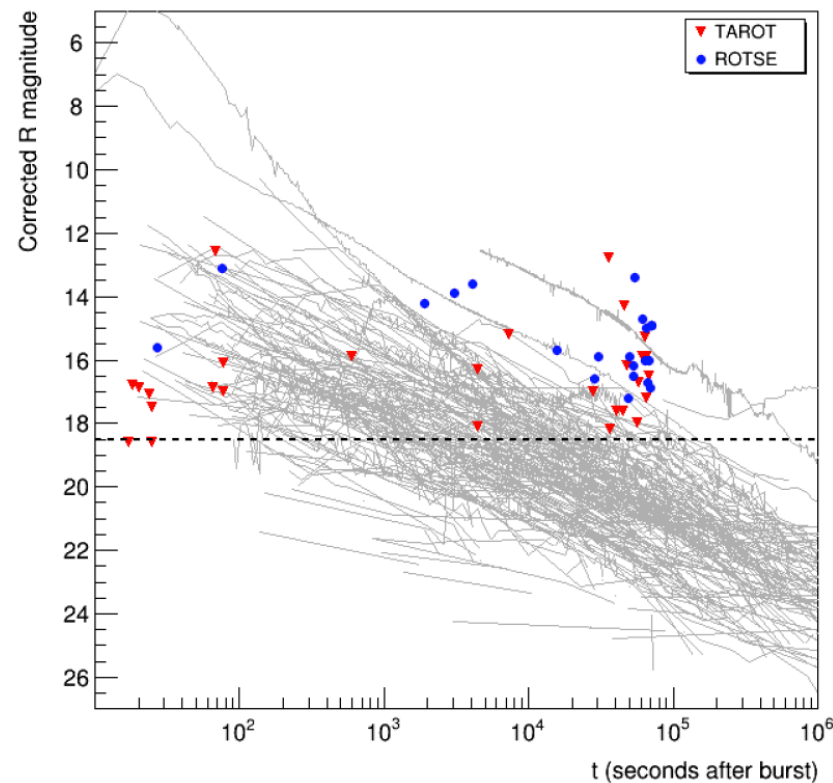


Radio	Visible	X-ray	GeV-ray	TeV-ray	GW	ν
MWA (Parkes)	TAROT ZADKO MASTER	Swift	Fermi-LAT (Offline)	HESS HAWC (1-10/yr)	Ligo Virgo (Offline)	IceCube (joint analyses)
12/yr	30/yr	6/yr				
FRBs		GRBs, AGN flares, etc.			GW events	HESE + EHE

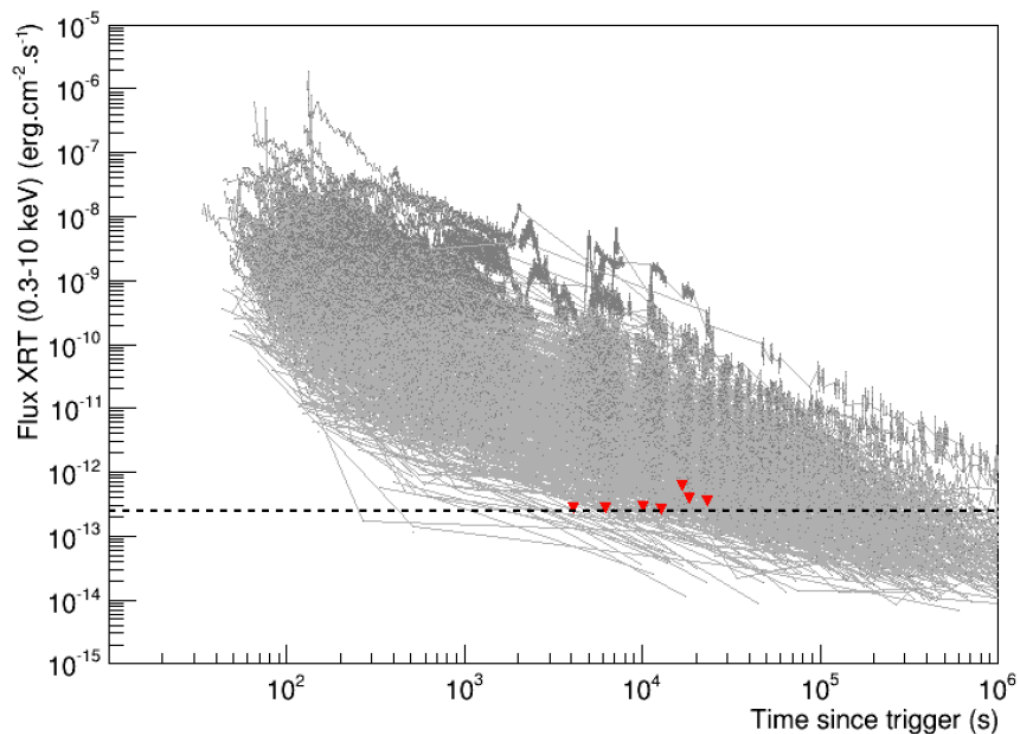


Outgoing: Optical follow-up analysis

- Follow-up optimized for GRBs (min-hours) and SNe (days-weeks)
- Image analysis: search for variable sources



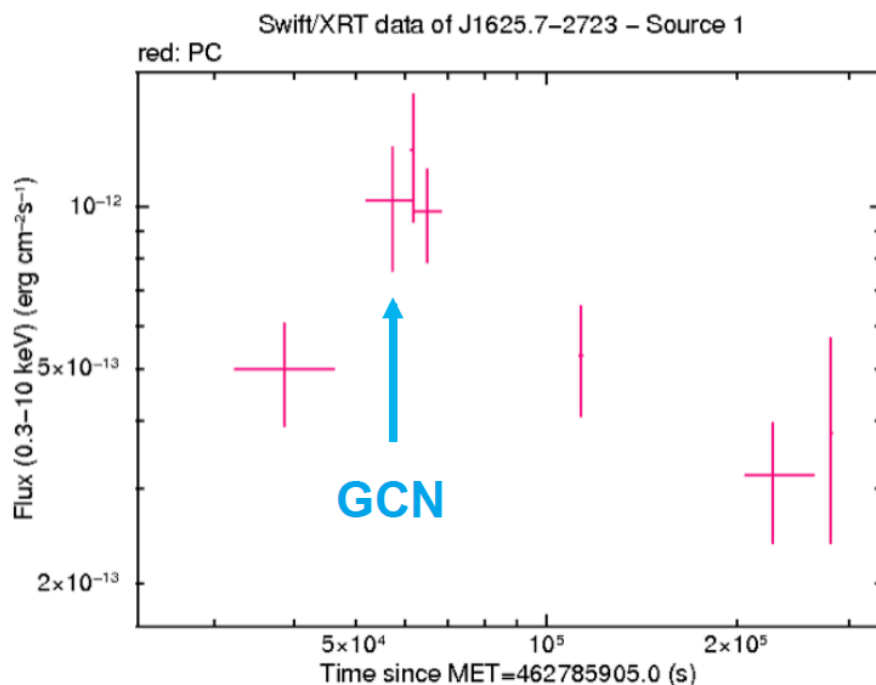
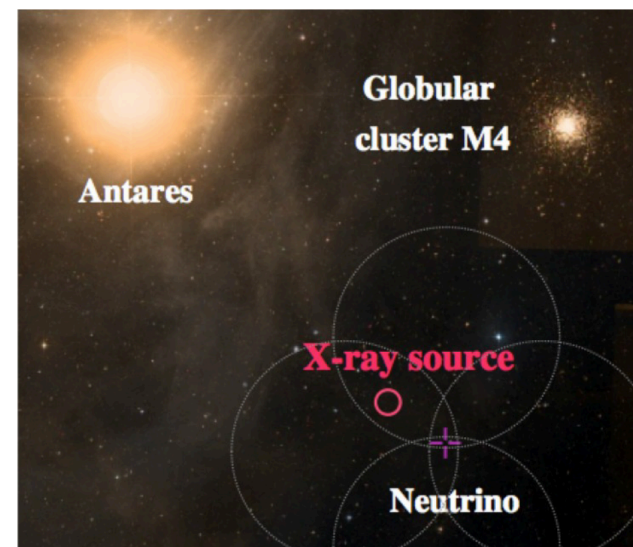
Upper limits compared to the optical GRB afterglow (Kann et al 2010)



Upper limits compared to Swift GRB observations

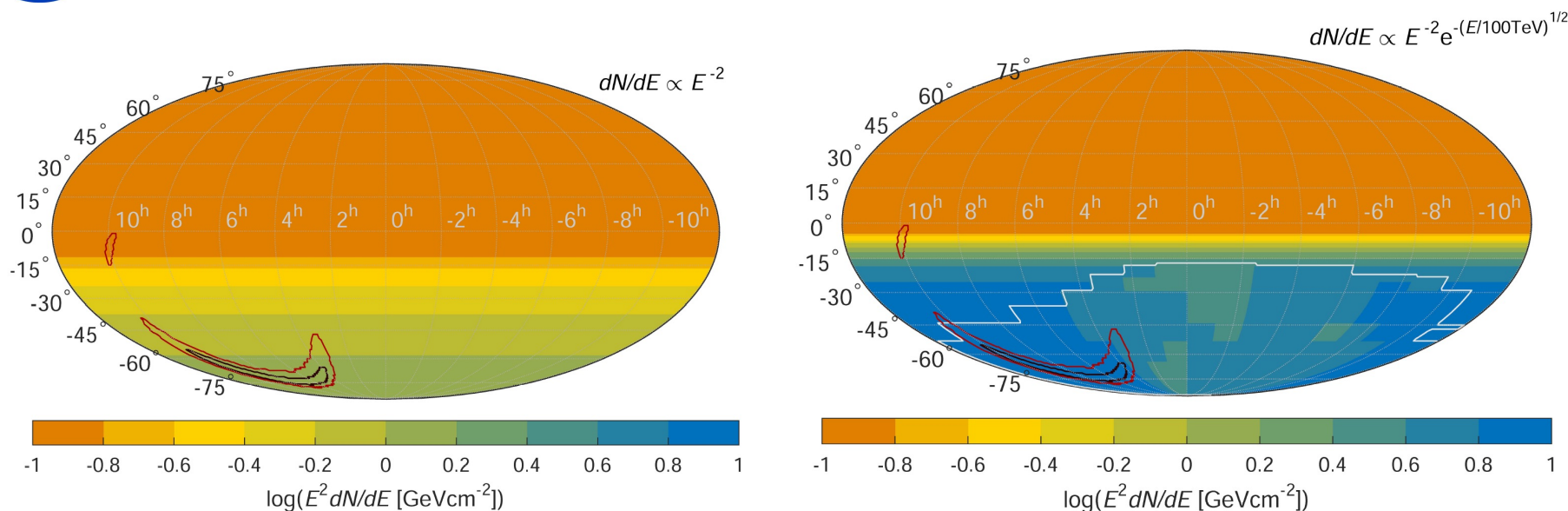
Outgoing: X-ray + VHE follow-up

- September 1st, 2015: TAToO single HE-alert to optical telescopes + Swift
- Unknown, bright and variable X-ray source detected by Swift
- ATEL 7987
 - Extensive follow-up (radio – optical – X – VHE)
 - No gamma-ray source (e.g. HESS-MM talk)
 - Identification as variable star





Incoming: Neutrino follow-up of GW150914



- Size of GW150914 : 590 deg^2 / ANTARES resolution: $<0.5 \text{ deg}^2$
- Searches for coincident neutrinos ($\pm 500\text{s}$): compatible with atmo. backgrounds
- Limits from ANTARES dominate below $O(100 \text{ TeV})$ (white line)
- Limits on total energy radiated in neutrinos: $<10\% \text{ GW}$
- Currently commissioning: Receive + analyze GW alerts in real time

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

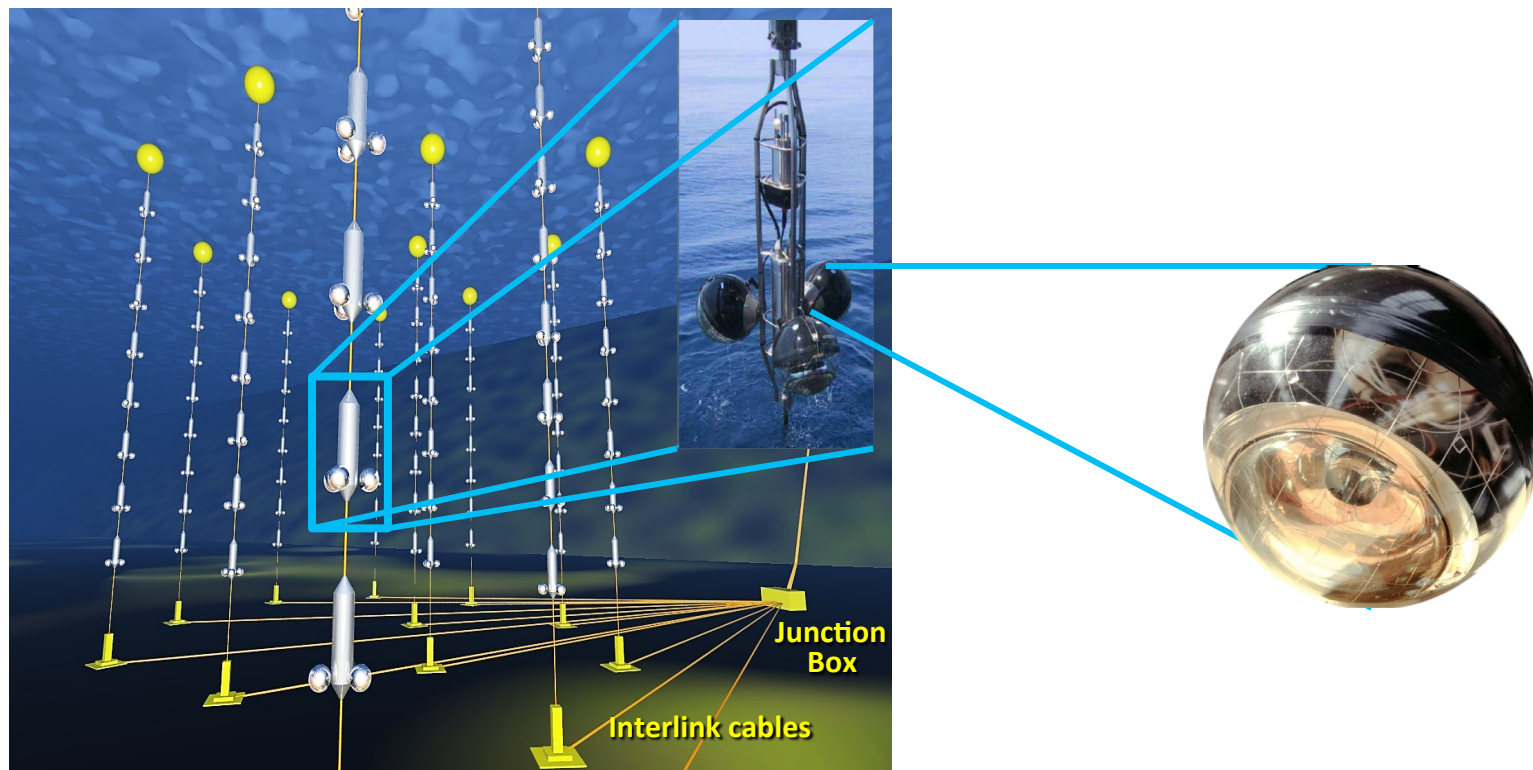
$$E_{\nu,\text{tot}}^{\text{ul}} \sim 10^{52} - 10^{54} \left(\frac{D_{\text{gw}}}{410 \text{ Mpc}} \right)^2 \text{ erg}$$

Summary

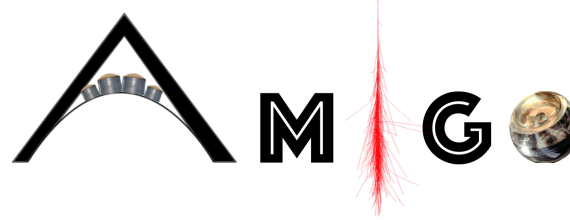
- Northern hemisphere detectors mainly sensitive to Galactic TeV sources
- Extensive searches for neutrino sources
 - neutrino sky (still ?) isotropic
- Extensive multi-messenger program
 - Correlation studies with catalogs of source candidates
 - Time domain important
 - enhanced sensitivity due to background reduction
 - online reconstruction → real-time coincidences + alert emission
 - TAToO: online analysis and alert emission
 - Alerts within a few seconds
 - Extensive follow-up program covering 20all wavelengths

Outlook and a personal note

- KM3NeT under construction (see talk by S. Hallman)
- ANTARES will be de-commissioned in 2017 after more than 10 years of successful operation

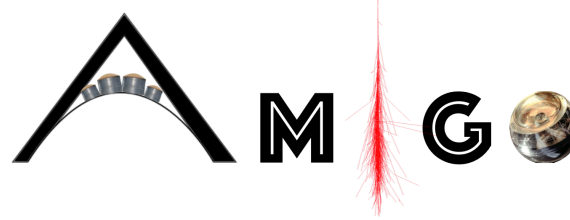


One possibility:



- **Antares Modules In a Gamma-ray Observatory**
- Building on the success of Milagro and HAWC: a next generation water Cherenkov detector in the Southern Hemisphere would allow to do extremely interesting science:
 - Monitoring the TeV gamma-ray sky
 - new sources
 - extended sources
 - variable sources (e.g. triggering CTA)
 - multi-messenger observations (high-E neutrinos, GWs, etc.)
 - ...

One possibility:



- Proposal to the ANTARES collaboration ready
- To be submitted in two weeks
- If interested, talk to me in the coffee break or contact me: fabian.schussler@cea.fr



AMIGO* Proposal

**Use of ANTARES optical modules in a
high-altitude water Cherenkov observatory**

From the bottom of the sea to the top of the mountain

* Antares Modules In a Gamma-ray Observatory

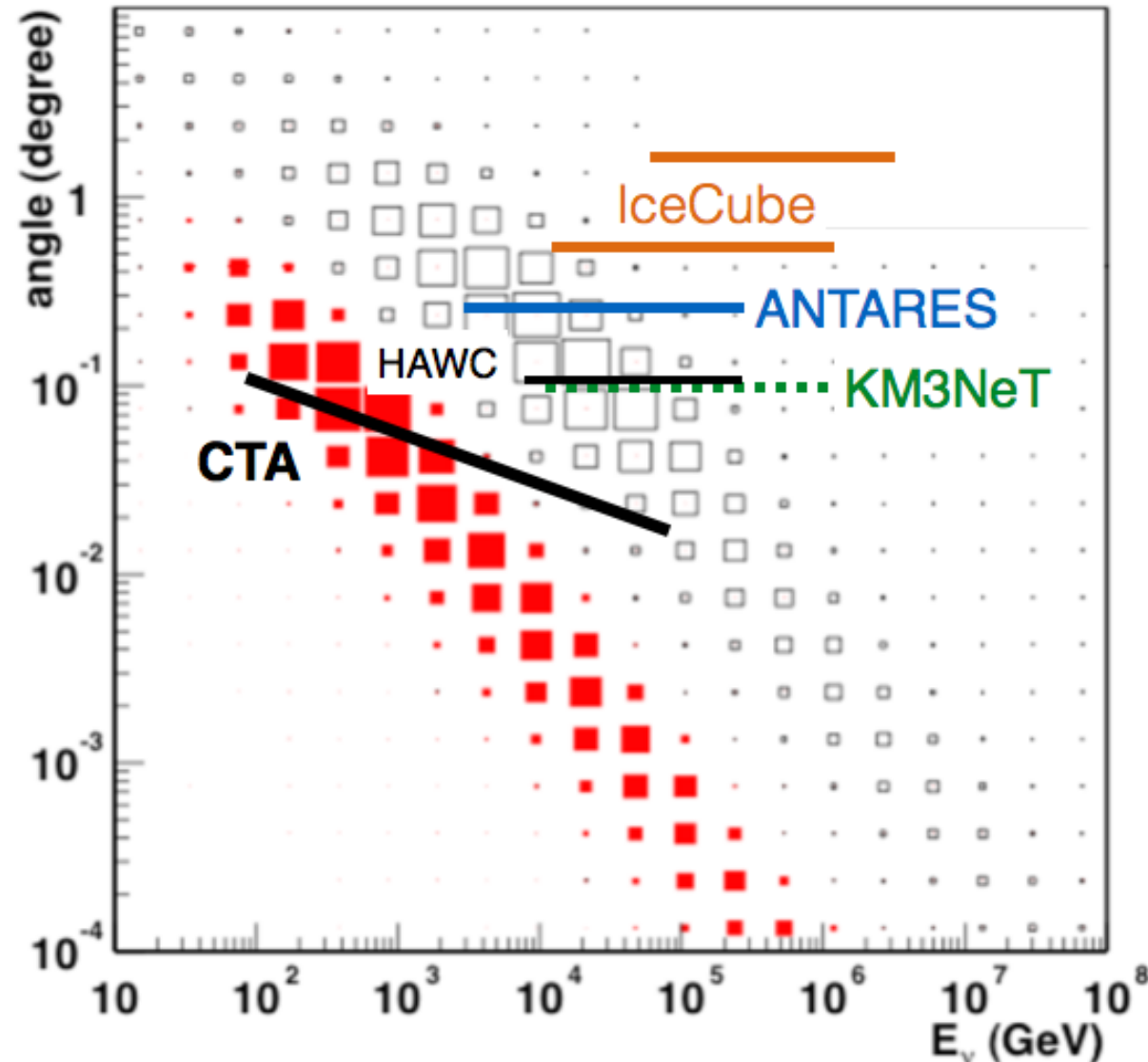
Abstract

After the success of the HAWC high-energy gamma-ray observatory, an extension of the "high altitude water Cherenkov" technique to the Southern Hemisphere is currently being discussed. The following document provides an introduction to the scientific interest and aim of this project. We discuss several proposed detector designs and illustrate preparatory work. In this context, we put forward the AMIGO proposal: the use of the optical modules of the ANTARES high-energy neutrino telescope in this next generation water Cherenkov gamma-ray observatory.

Backup

Neutrino astronomy

A. Heijboer



Interaction: angle between neutrino and muon

Scattering: angle muon is scattered between interaction point and reaching the detector

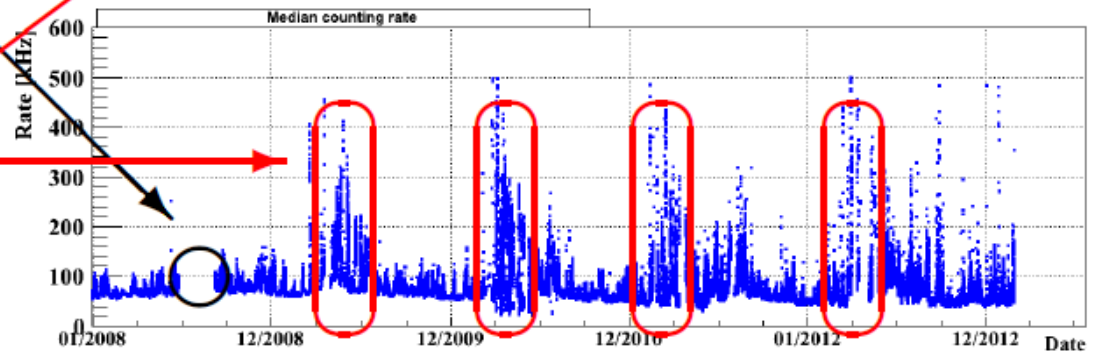
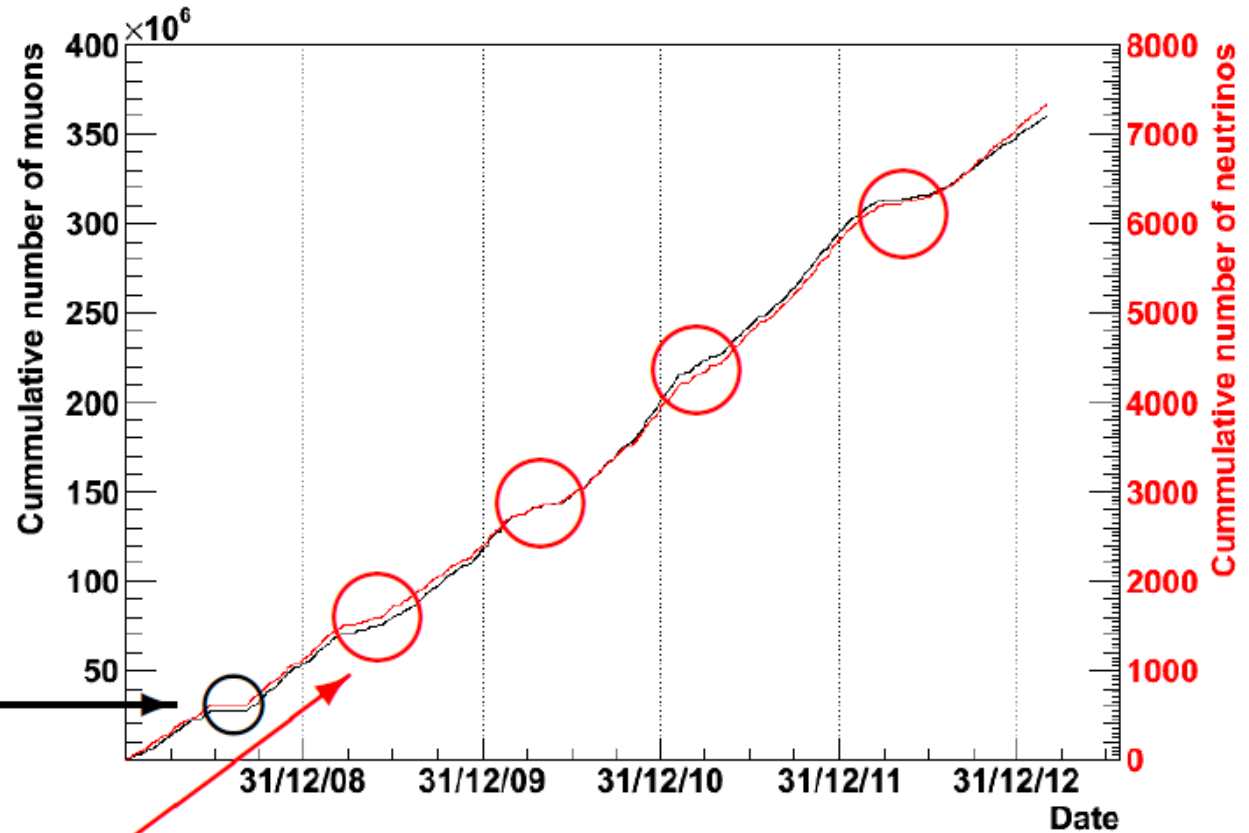


Detector operation

since 2008:
12 lines
0.85 duty cycle

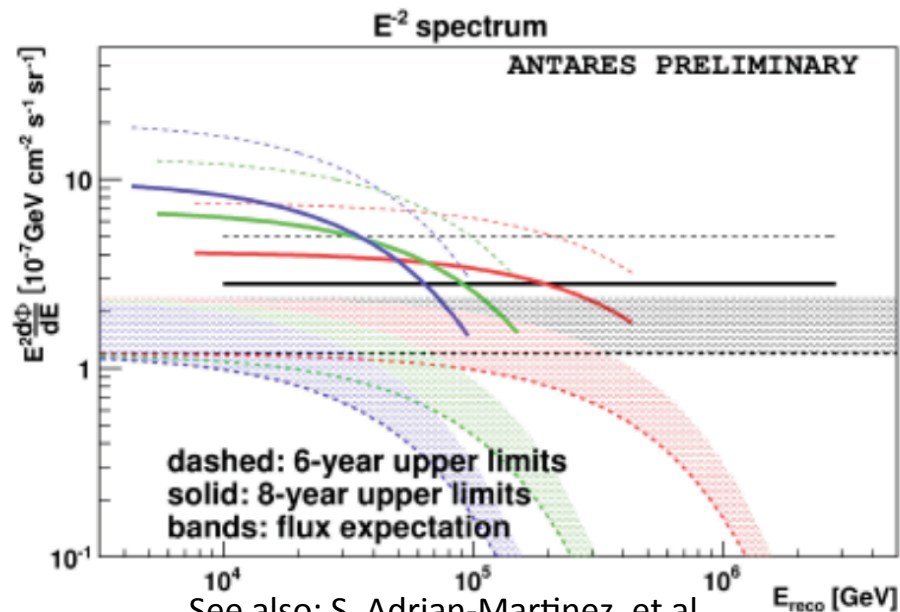
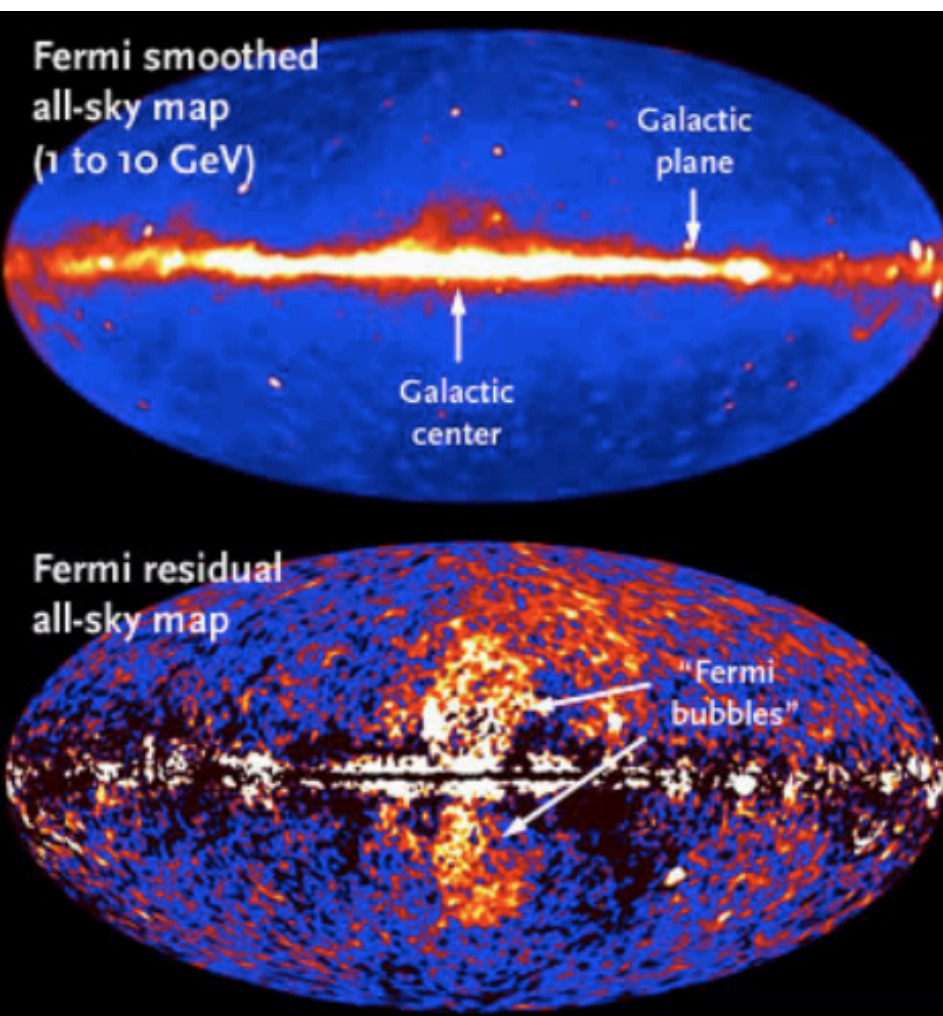
cable failure

springs:
bio-luminescence

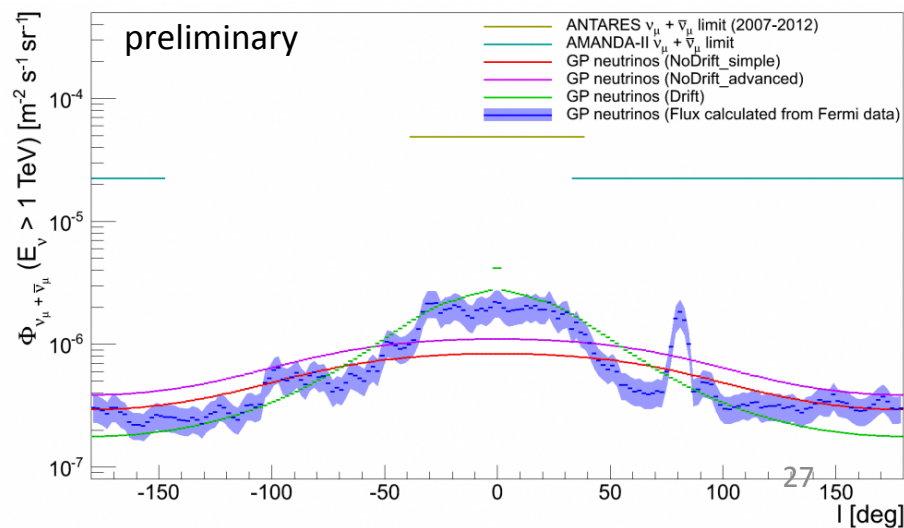




Fermi-Bubbles and diffuse emission



See also: S. Adrian-Martinez, et al.,
Eur. Phys. C 74 (2014) 2701

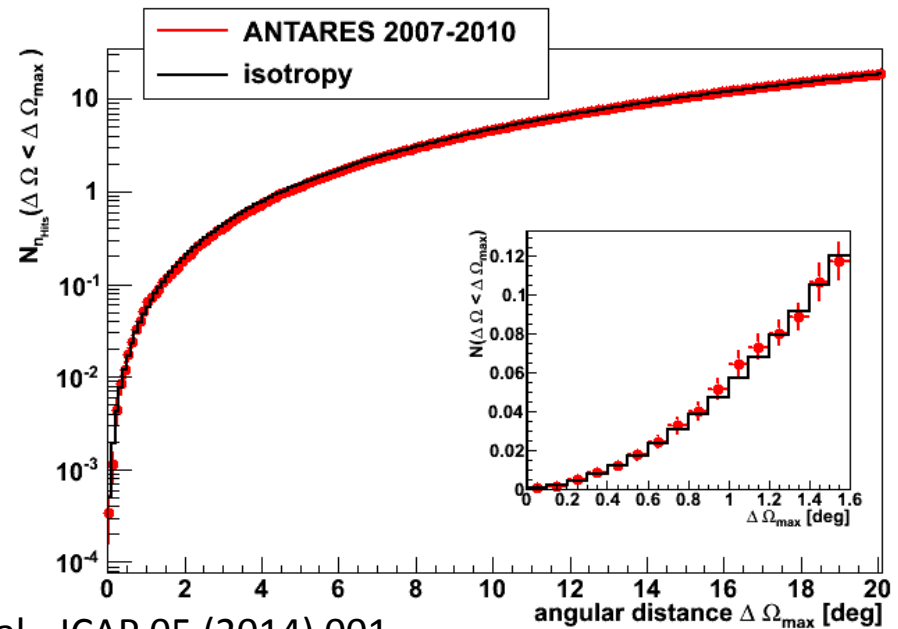
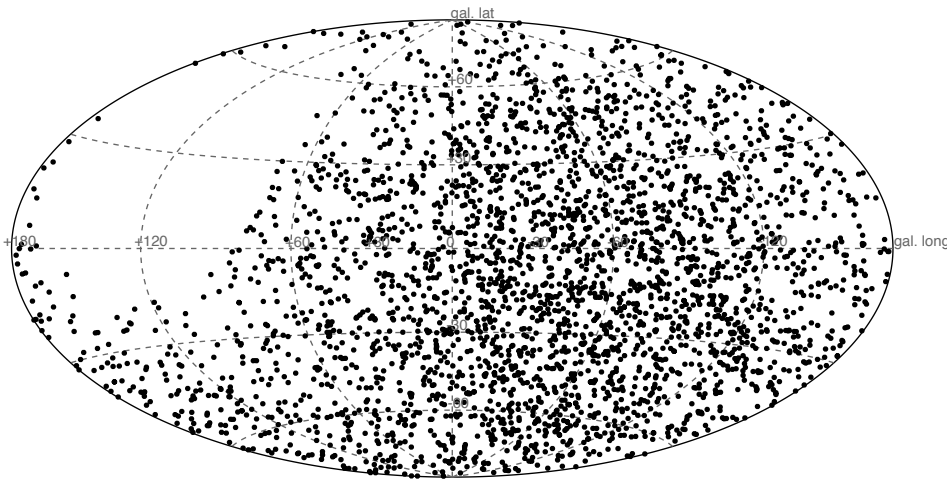




2pt correlations

- Improved auto-correlation analysis
 - Number of event pairs $\mathcal{N}$ as function of their mutual angular distance $\Delta\Omega$, **weighted with the estimated energy of the events**

$$\mathcal{N}_p(\Delta\Omega) = \sum_{i=1}^N \sum_{j=i+1}^N w_{ij} \times H(\Delta\Omega_{ij} - \Delta\Omega)$$



S. Adrian-Martinez, et al., JCAP 05 (2014) 001

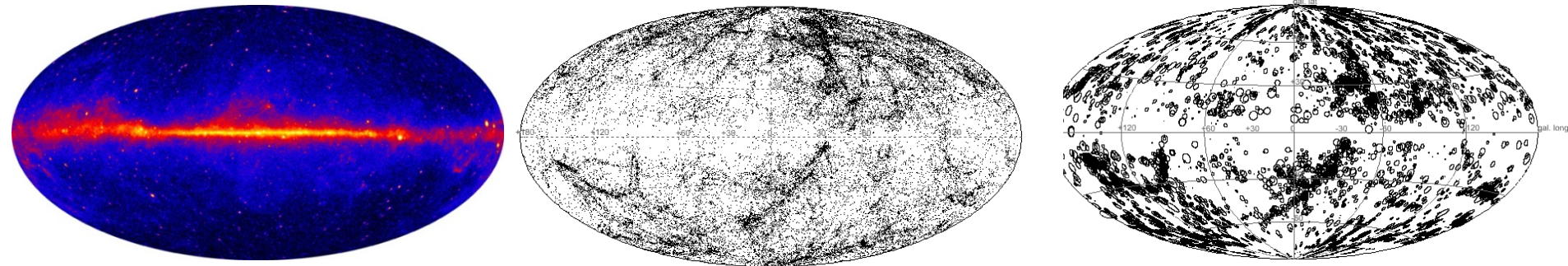
Fabian Schüssler

2016-09-01

28

2pt cross-correlations

- Cross-correlation with external messengers
 - High energy gamma-rays (2FGL, Nolan et al. 2012)
 - Matter distribution in the local universe (GWGC, White 2011)
 - Massive black holes (Caramete&Biermann 2010)

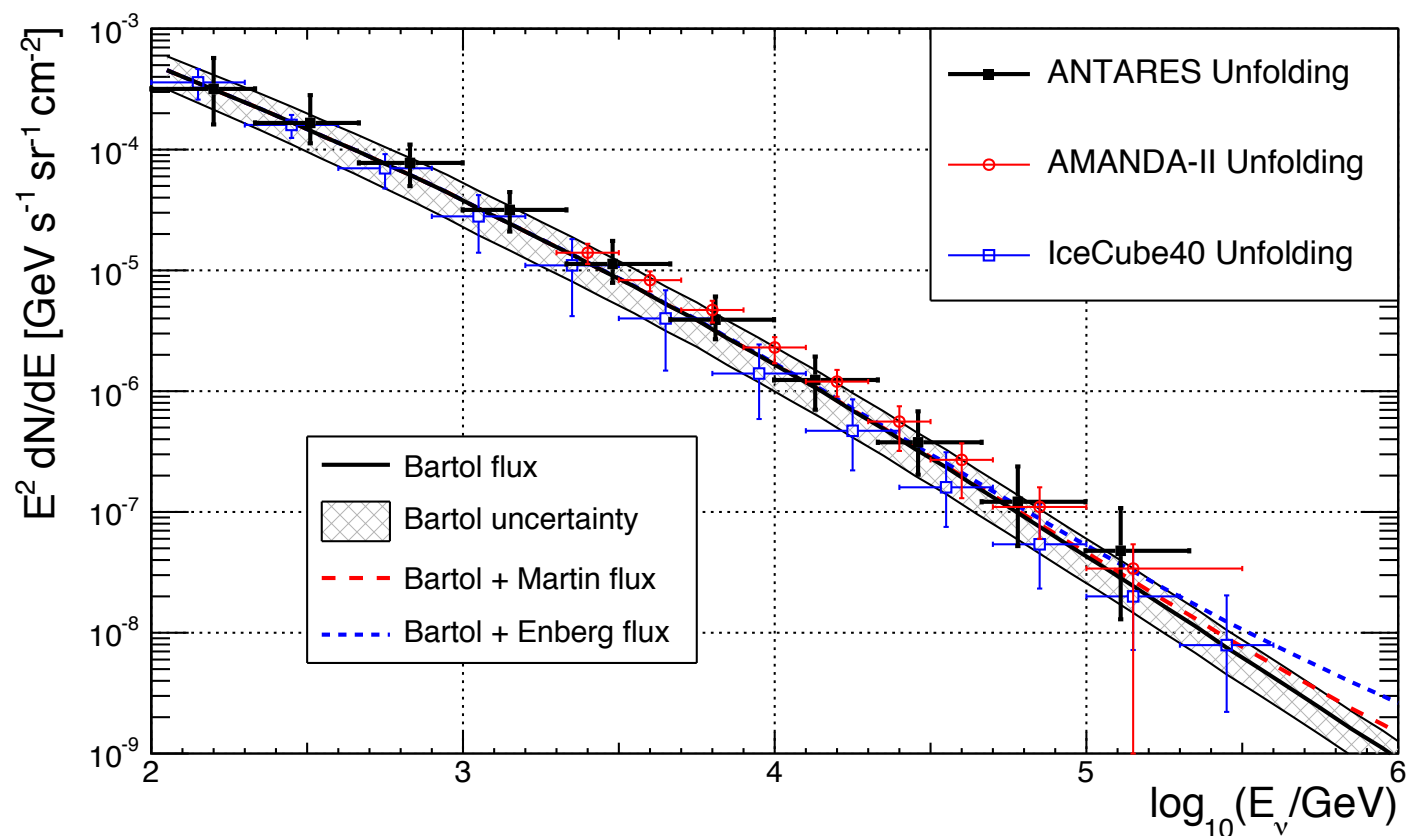


- No significant correlation observed



Atmospheric neutrinos

- main background in searches for astrophysical neutrinos
- access to high energy flavor physics ('prompt' component)
- soft energy spectrum
 - excess at high E → diffuse, astrophysical flux (e.g. Phys. Lett. B 696 (2011) 16)
 - use energy information as discriminant variable in analyses





Temporal search windows: Sensitivity gain

