Multi-messenger neutrino alerts from ANTARES

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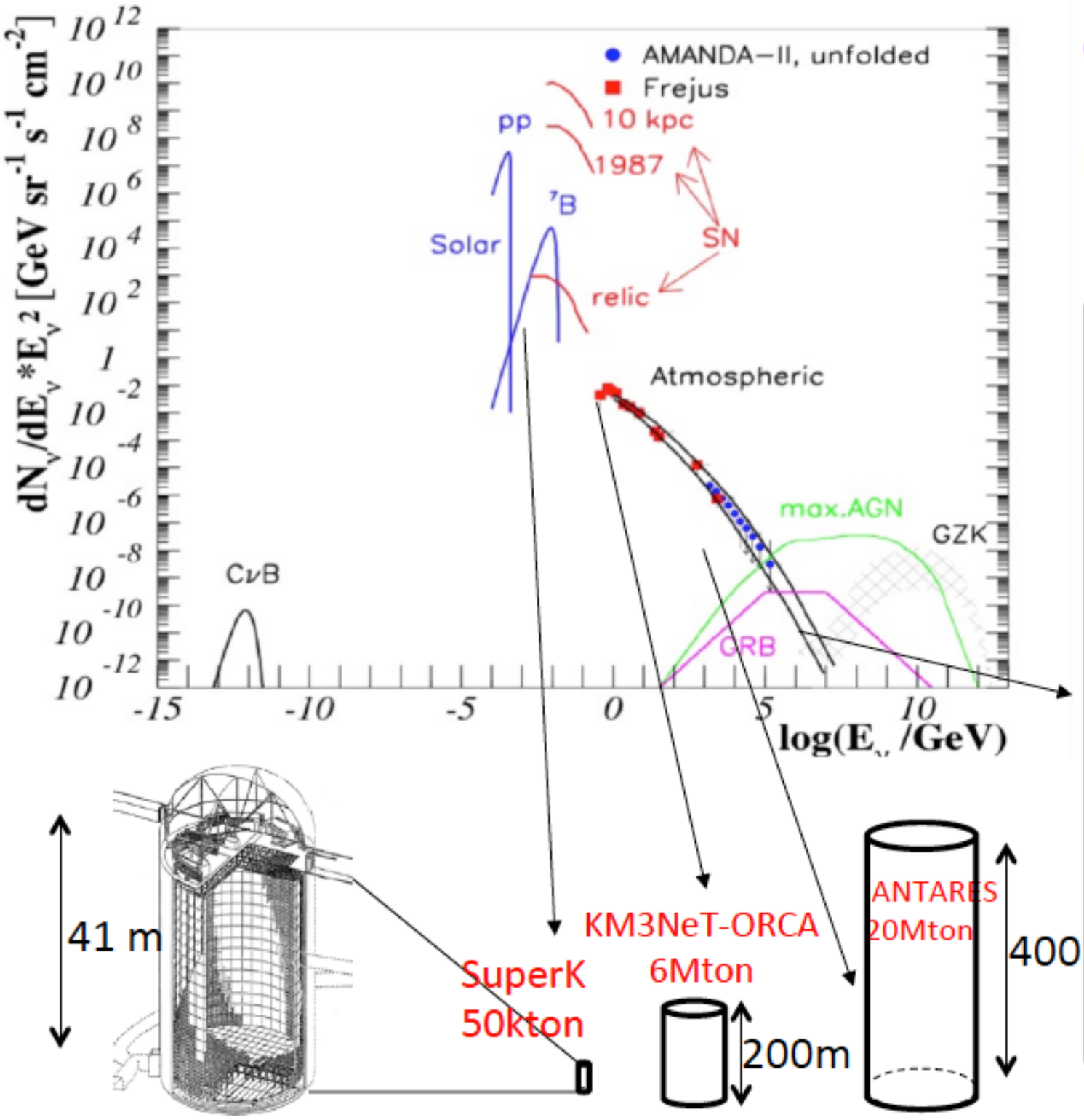
2nd SVOM Scientific workshop - 04/2017

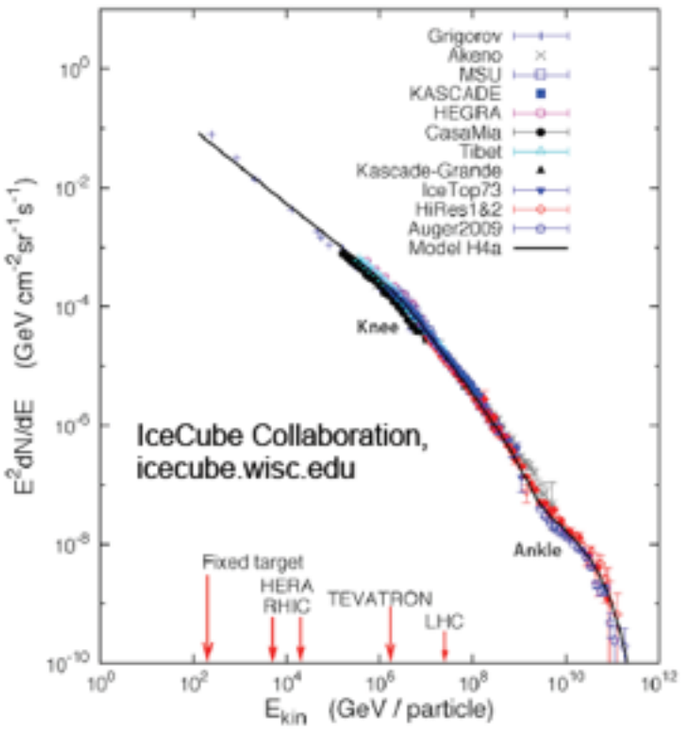
Neutrino fluxes in the Universe



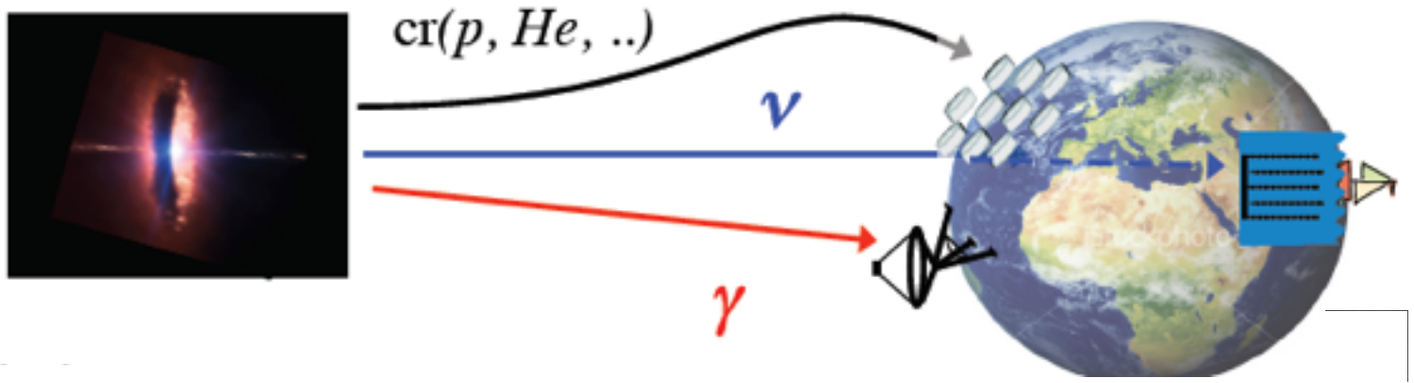
$\sigma(\nu p)/\sigma(\gamma p) = 10^{-7}$ at 1 TeV

Need very large detectors

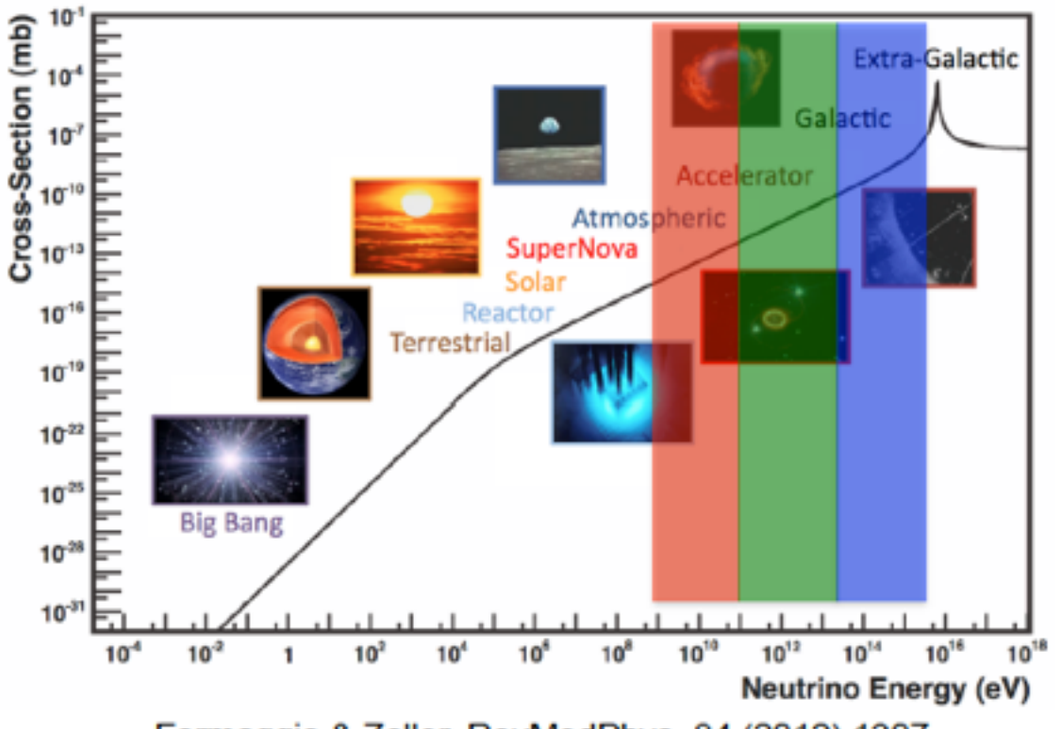
Multi-messenger paradigm



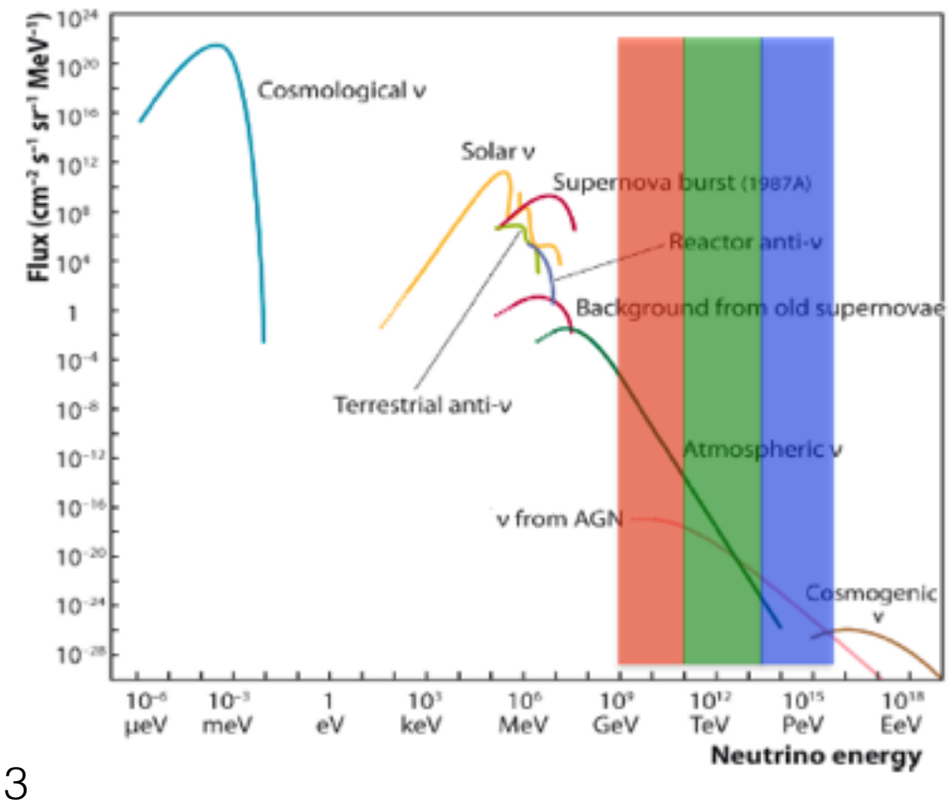
Neutrinos: smoking gun for cosmic-ray interactions



- 1 – 100 GeV: atmospheric neutrinos, dark matter… ORCA
- 100 GeV - 30 TeV: various galactic (TeV gamma) sources ANTARES
- 30 TeV – 3 PeV: IceCube signal (astrophysical flux) ARCA



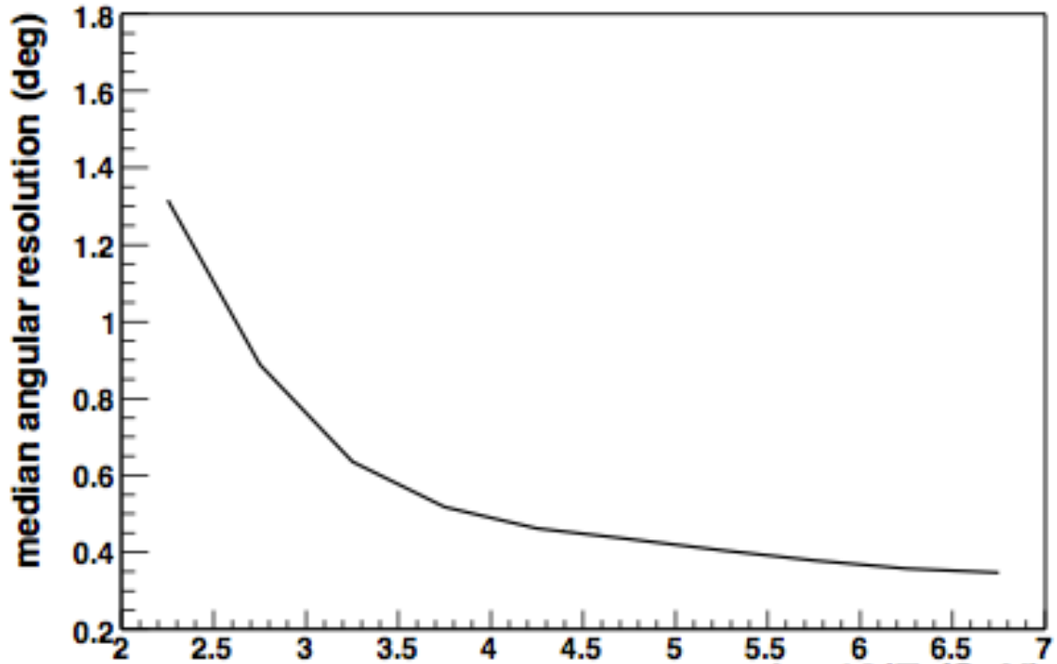
Formaggio & Zeller, RevModPhys 84 (2012) 1307

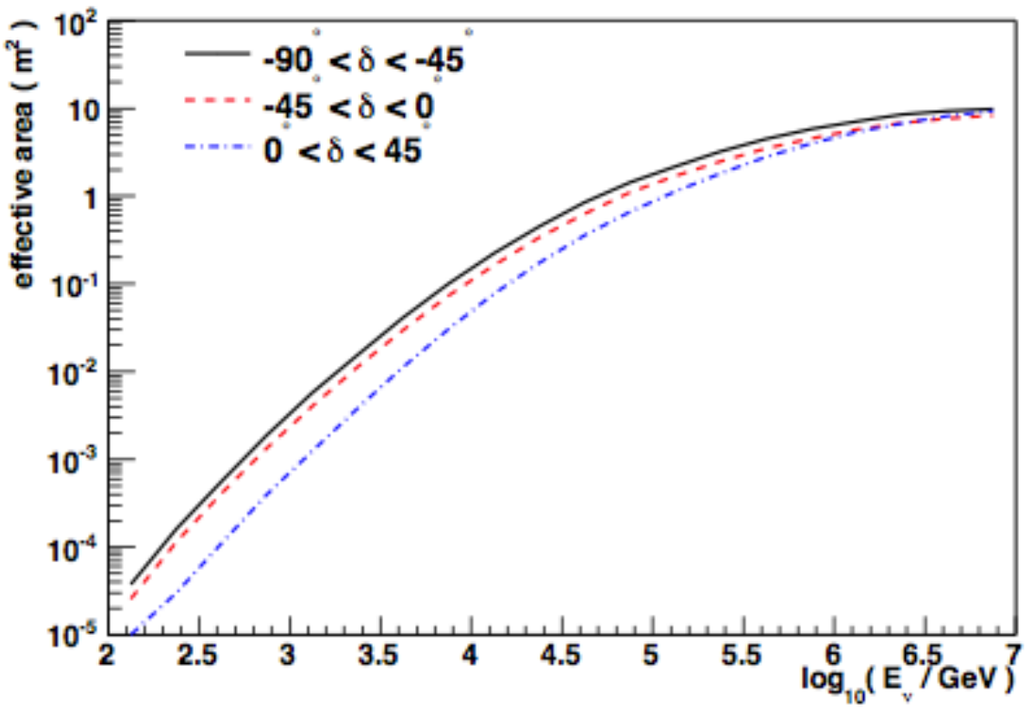


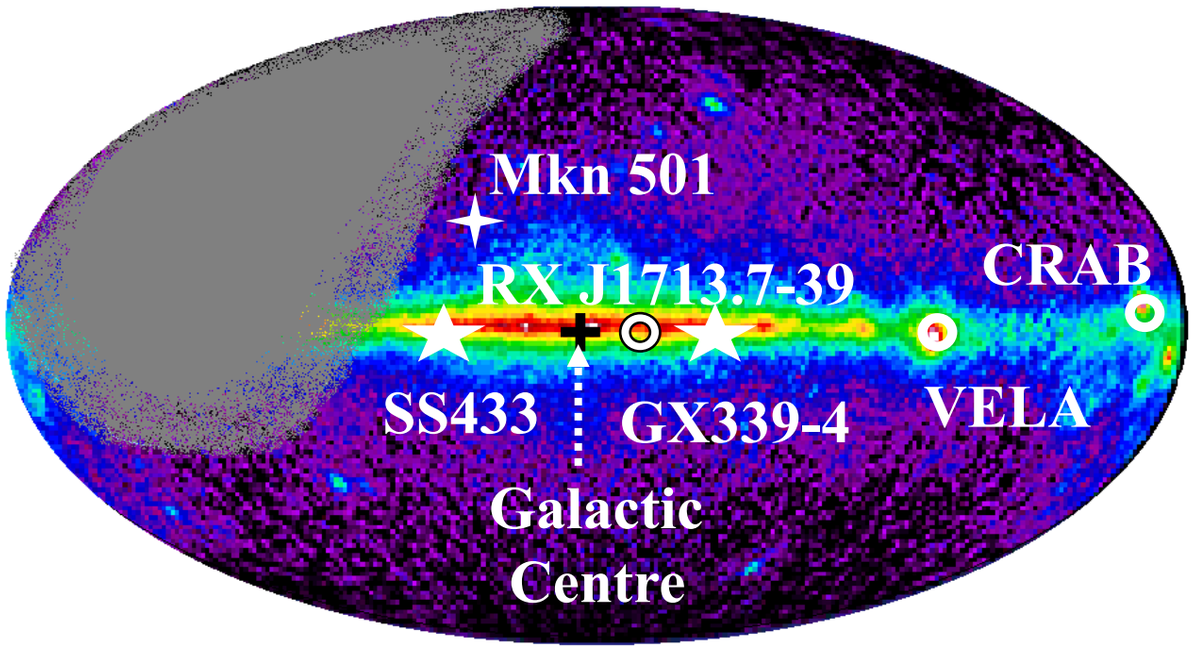
ANTARES

ANTARES in numbers:

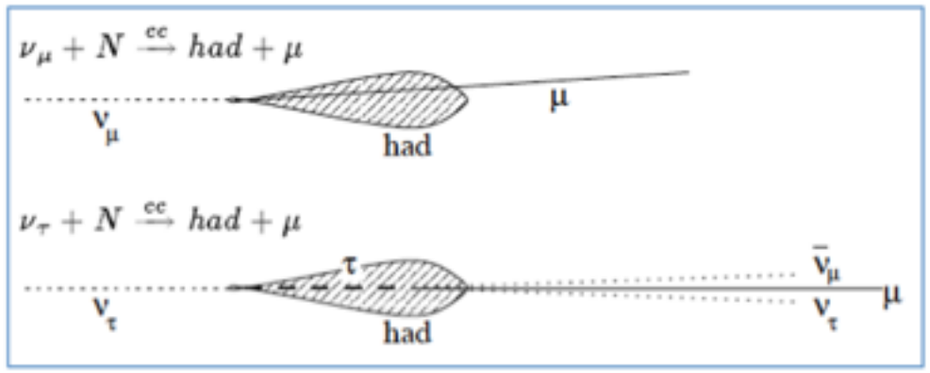
- 12-line data taking since 2008
- o(11000) detected neutrinos
- Angular resolution: 0.3-0.4° (median)
- Effective area: ≈1m² @ 30 TeV
- Visibility: ¾ of the sky, most of the galactic plane
- Real-time data processing

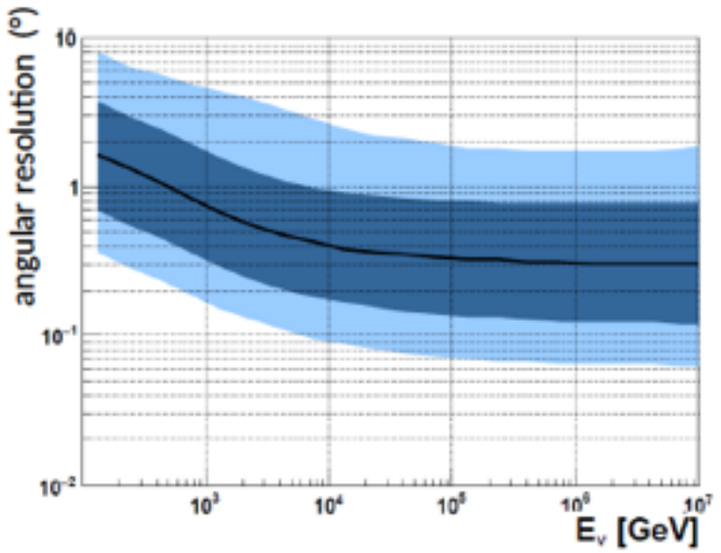




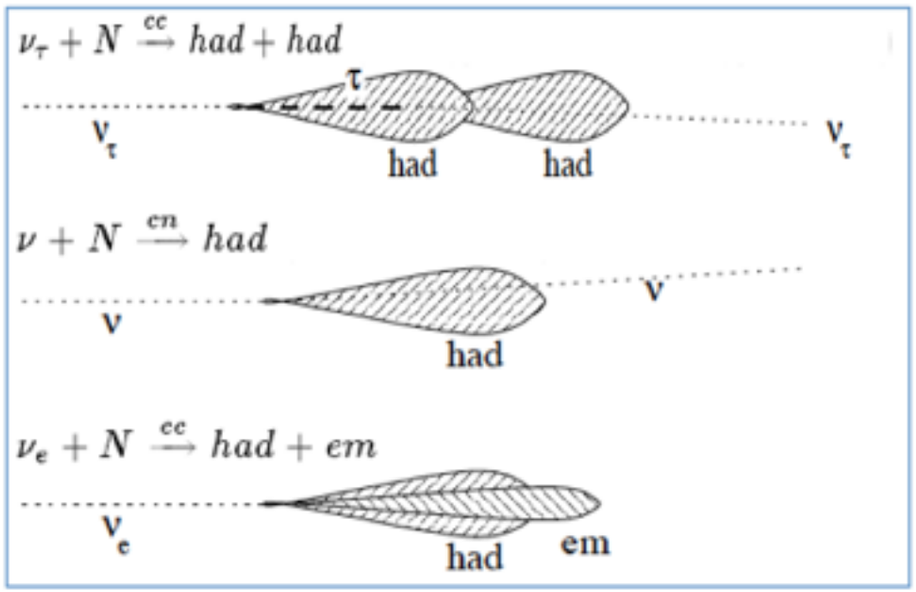


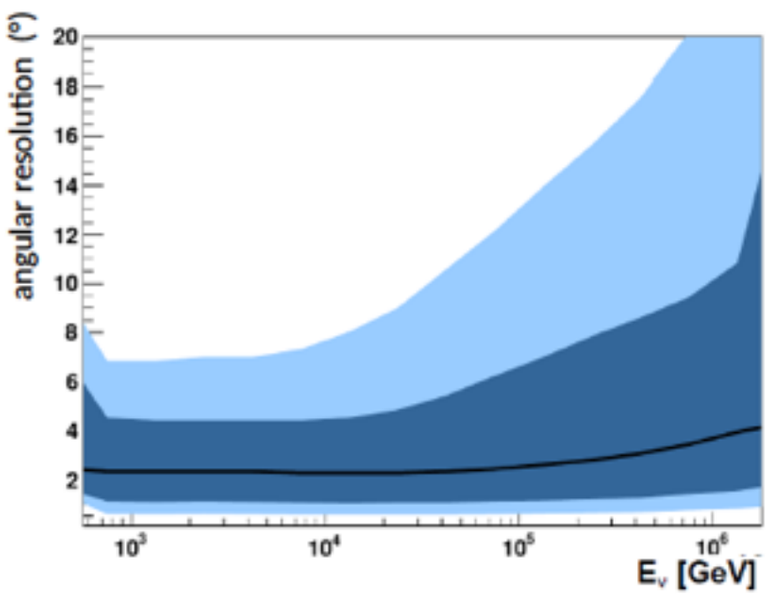
Neutrino event topologies





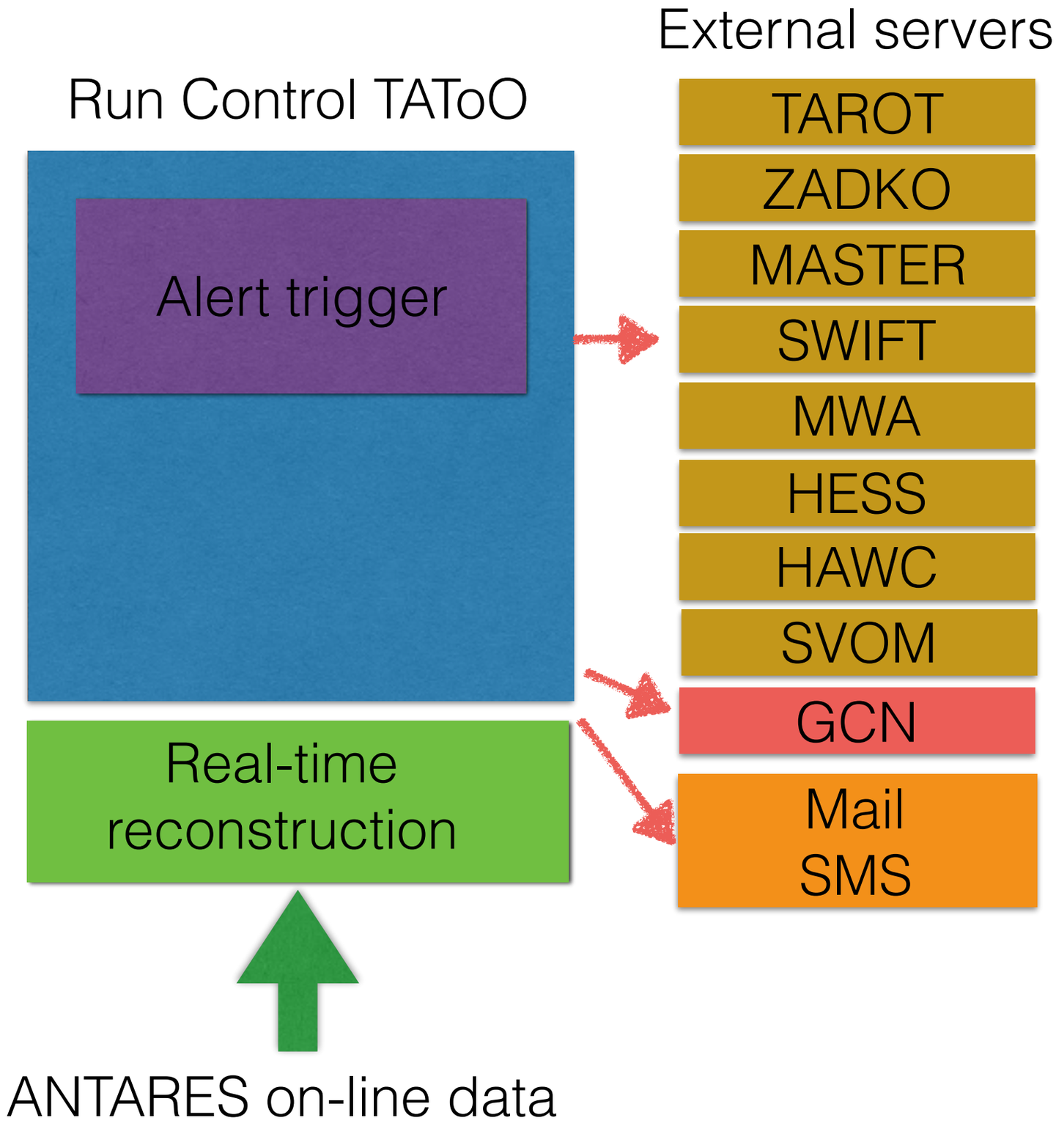
Tracks:
Angular resol: ~0.3°
Energy resol: factor 3
Large detection volume
=> Ideal for astronomy
=> but large atm bkg



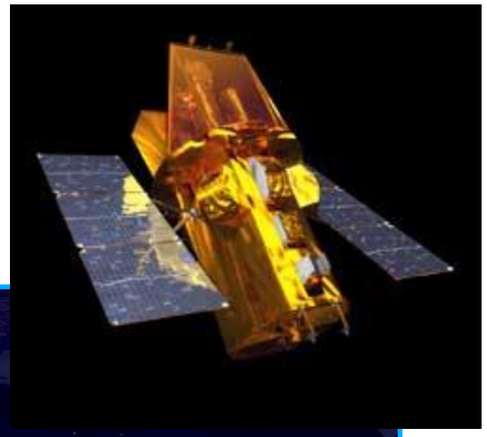


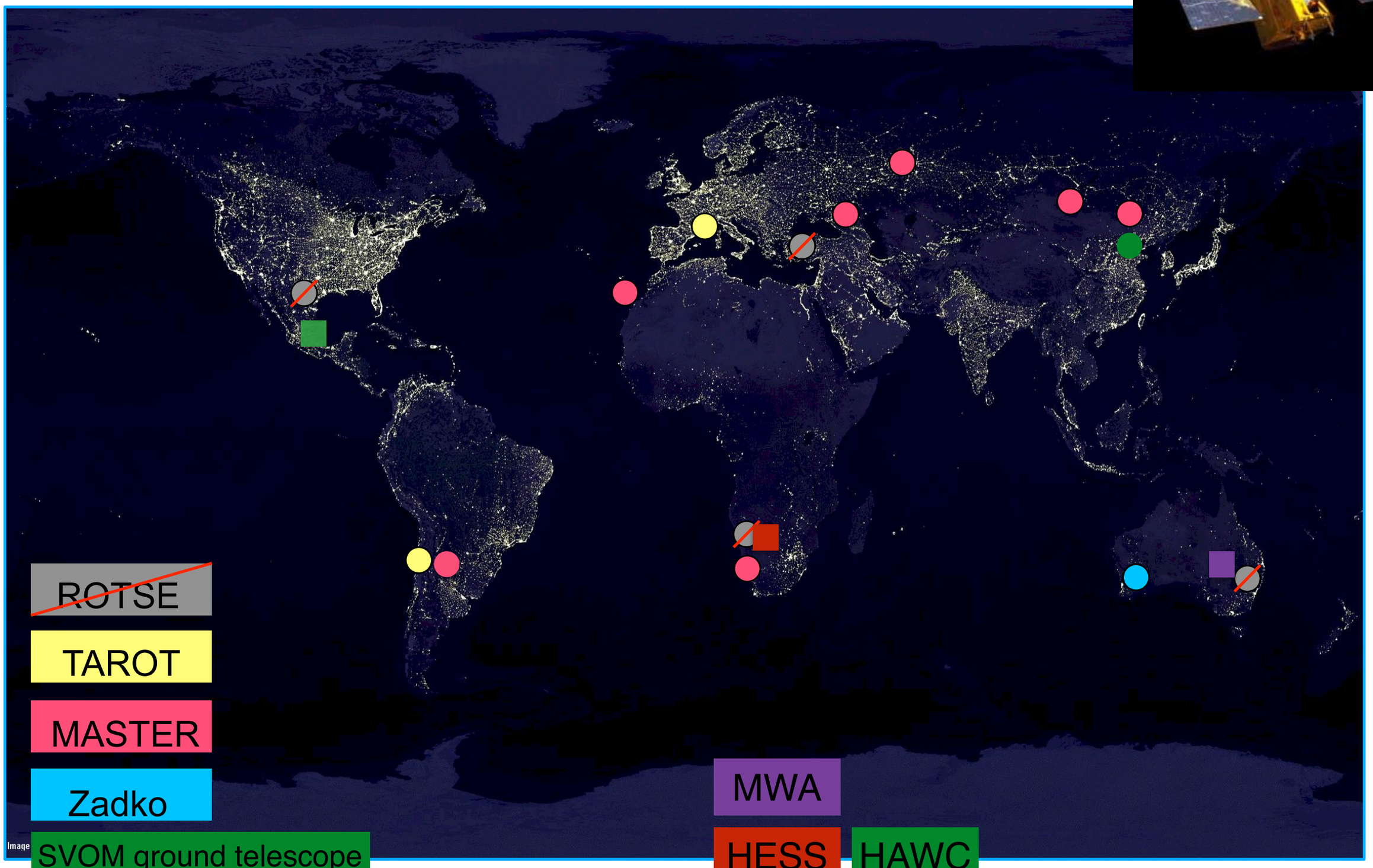
Cascades:
Angular resol: ~3°
Energy resol: 5-10%
Contained event
=> Almost no atm bkg

TAToO alert system



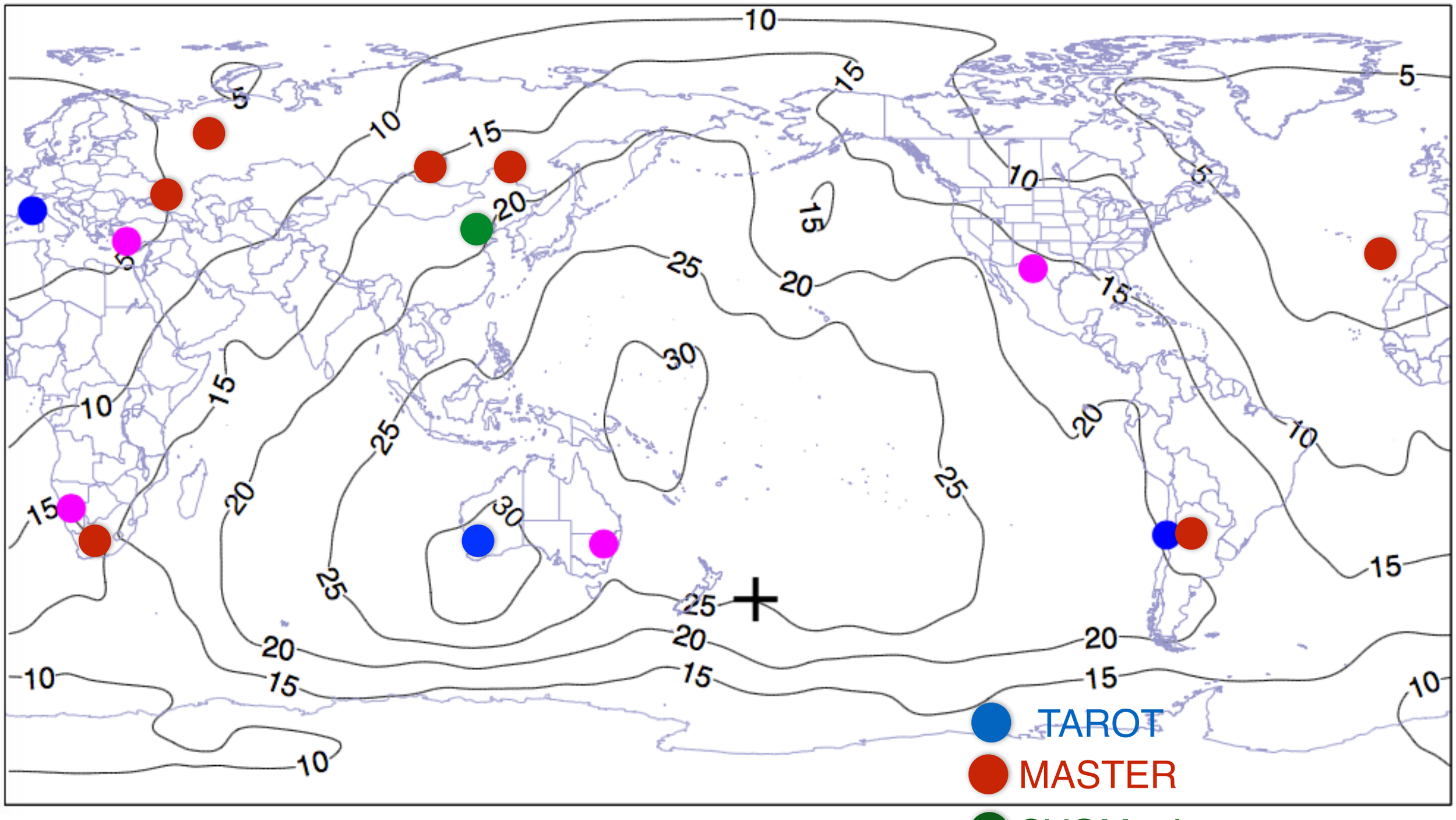
Telescopes:



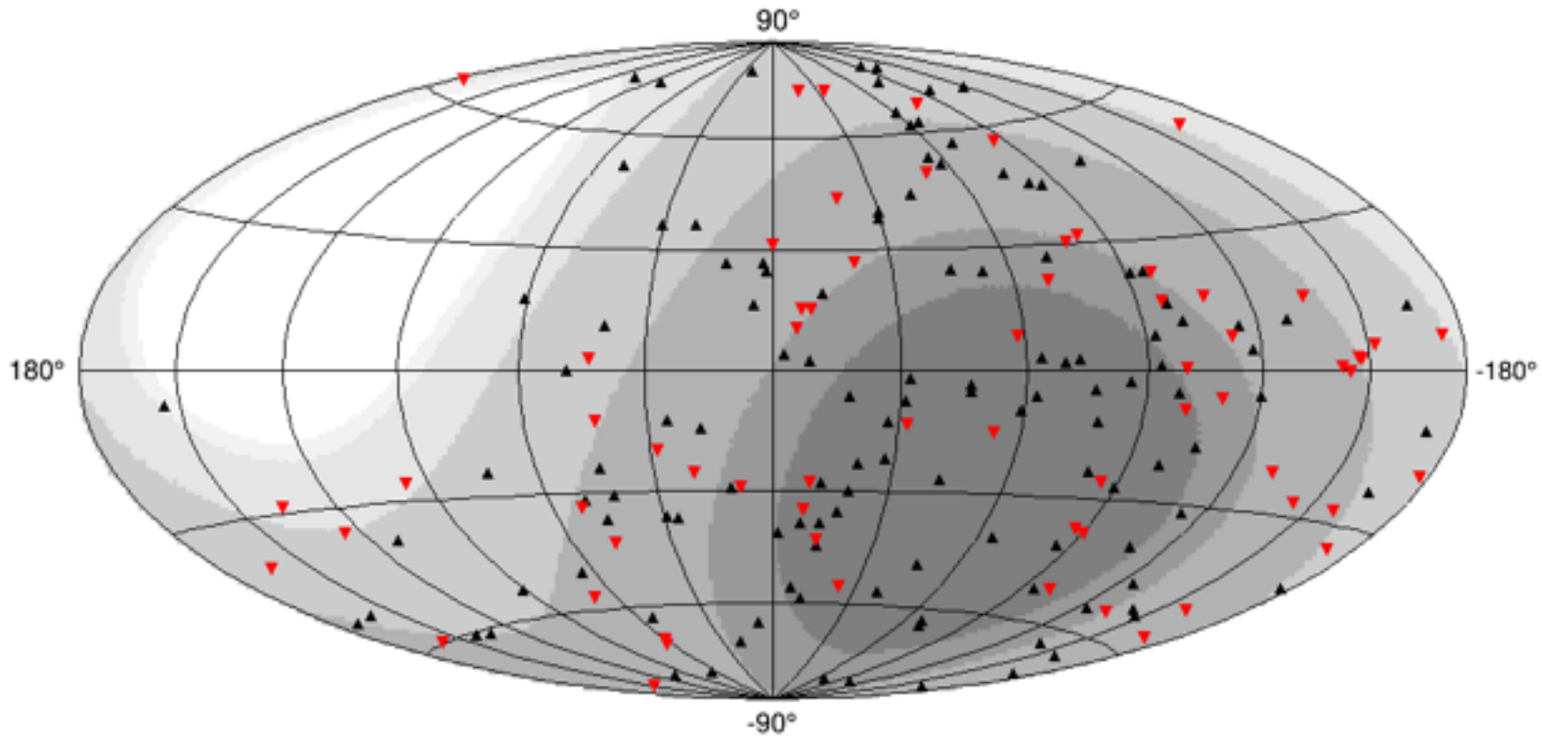

ROTSE
TAROT
MASTER
Zadko
SVOM ground telescope
MWA
HESS
HAWC

Telescopes:

Efficiency of prompt observations vs location on the Earth



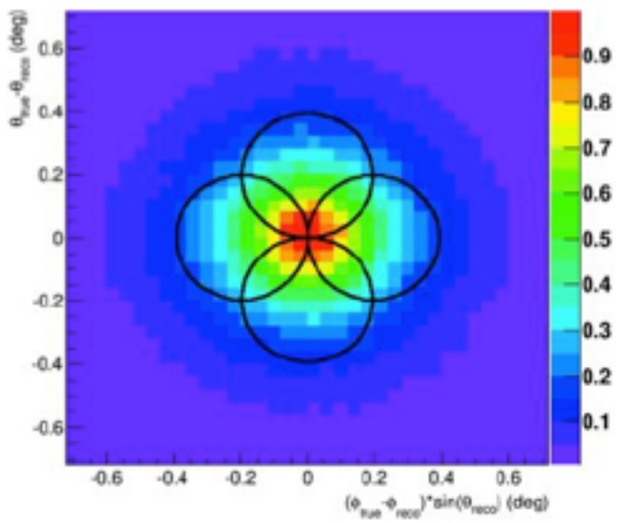
TAToO alert triggers



Triggers: Single HE neutrinos (~10 TeV), single neutrino with direction close to local galaxies (~1 TeV), doublet of neutrinos

Performances:

* Time to send an alert: ~5s
* First image of the follow-up: <20s (with TAROT few alerts in 15s)
* Median angular resolution: 0.3-0.4°
* Dedicated optical image analysis pipeline



TAToO: early follow-up

Visible:

93 alerts analyzed 01/2010-01/2016 from TAROT, ROTSE, MASTER

=>13 alerts with delay <1min (best: 17s)

=> no transient candidate associated to neutrinos

X-ray:

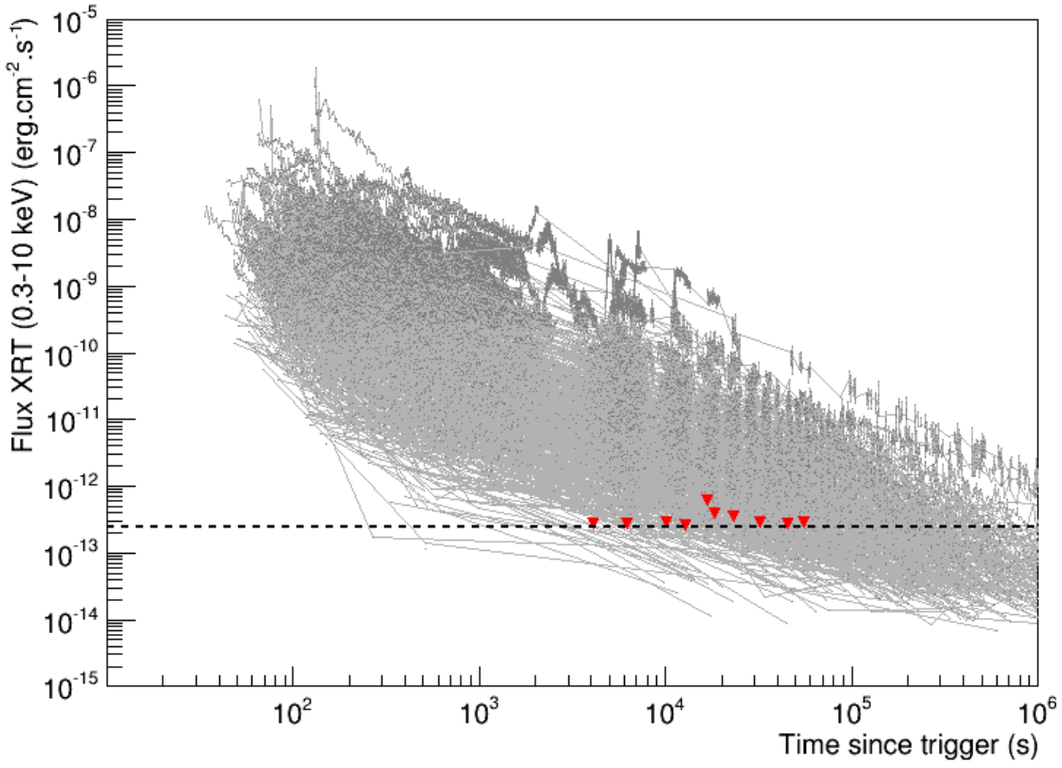
12 alerts analyzed 06/2013-01/2016

=> average delay ~5-6 hours

=> no transient candidate associated to neutrinos

=> Constrains on origin of individual neutrinos

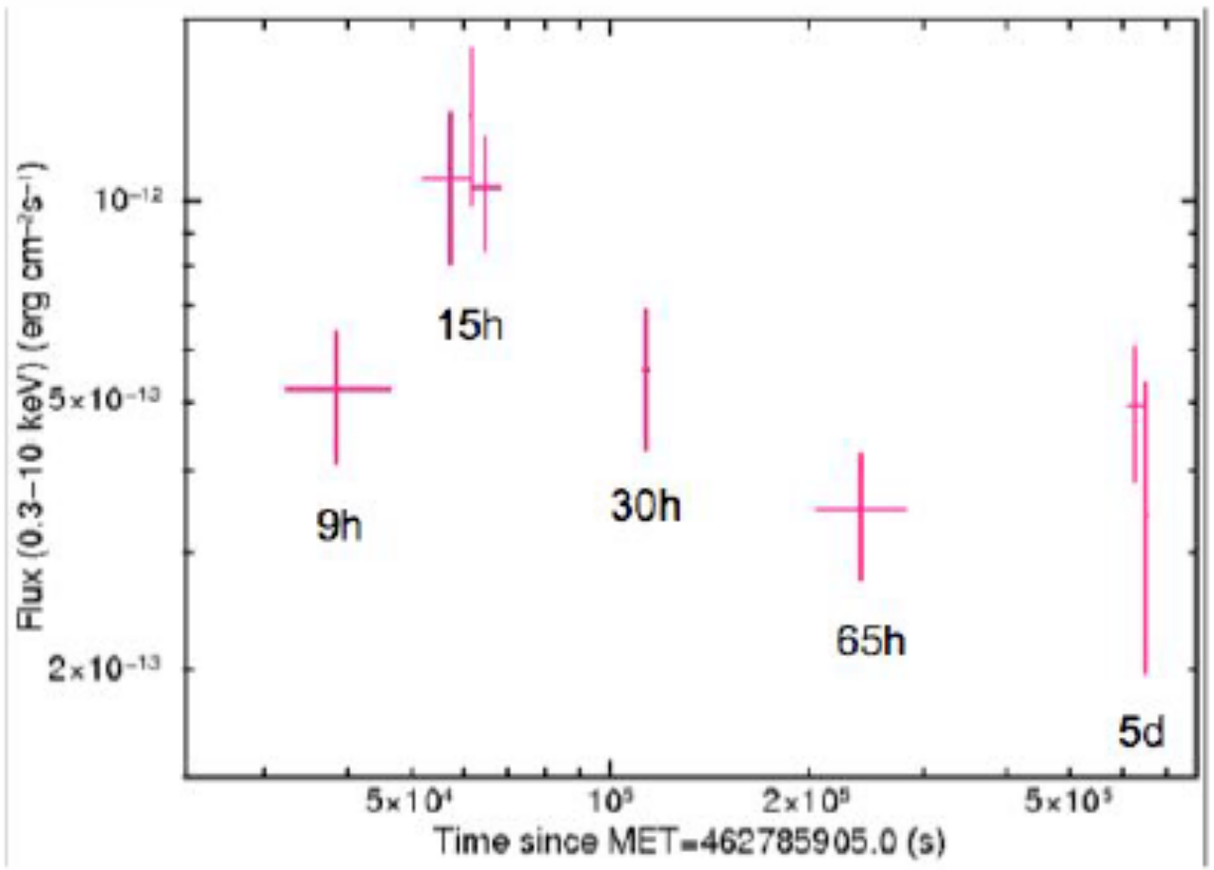
=> Interpretation of the UL in the case of GRB afterglow

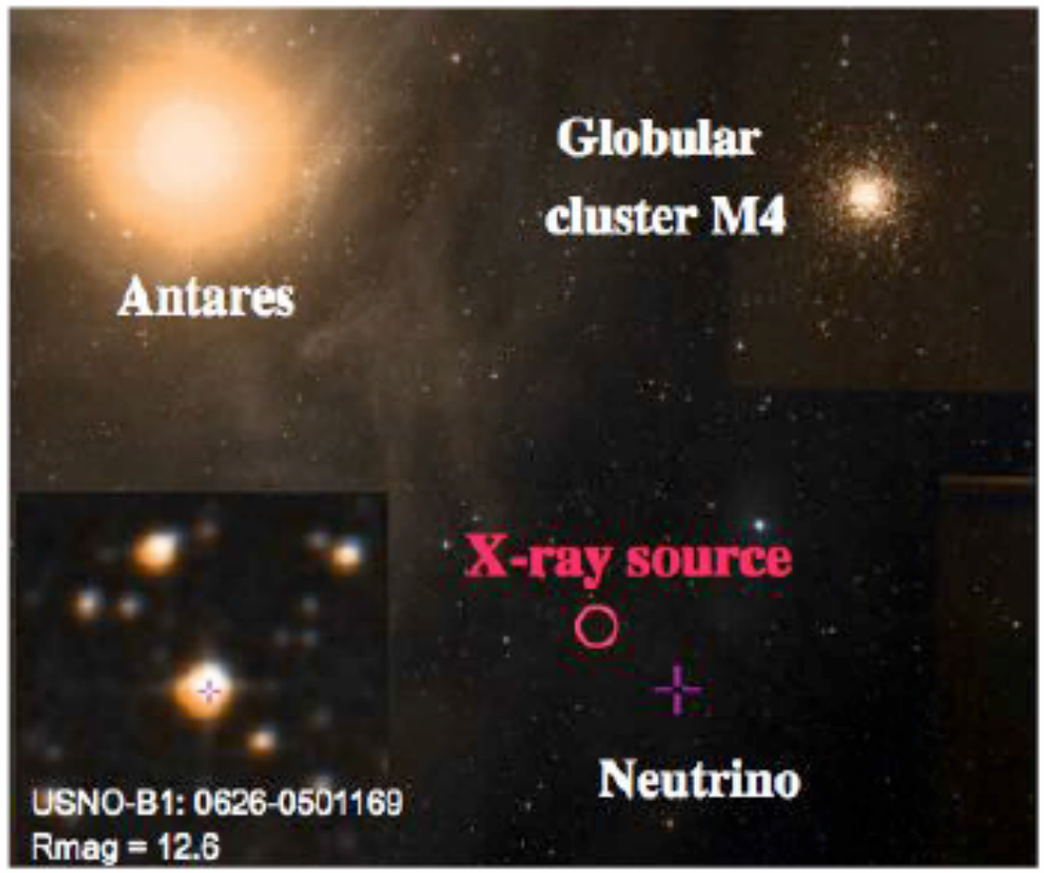


TATOO: ANT150901

➜ Alert **VHE (Sept. 1, 2015)**
E ~ 50-100 TeV
RA=246.306°; dec=-27.468°
Uncertainty: ~18 arcmin (radius, 50%)

Sent after 10 s to MASTER, Swift-XRT
Follow-up with **Swift-XRT after 9h**
Follow-up with **MASTER after 10h**





GCN #18231
ATEL #7987

➜ 16 ATEL + 6 GCN: multi-λ observations
+ few non-reported results

GCN 18236: optical/NIR spectroscopy from NOT
*"All this points to USNO-B1.0 0626-0501169 being a **young accreting G-K star,** undergoing a **flaring episode** that produced the X-ray emission."*
Confirmed by Jansky VLA radio observation (Atel 7999) + X-Shooter observations

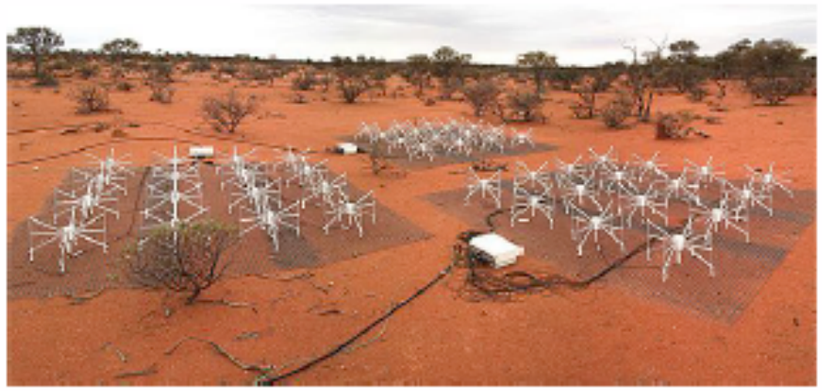
TAToO: ANT150901

- Neutrinos
  - IceCube: ATel 8097
- Optical
  - Pan-STARRS: ATel 7992, 8027
  - SALT: ATel 7993
  - NOT: ATel 7994 GCN18236
  - WiFeS: ATel 7996
  - CAHA: ATel 7998, GCN18241
  - MASTER: ATel 8000 GCN18240
  - LSGT: ATel 8002
  - NIC: ATel 8006
  - ANU: GCN18242
  - GCM: GCN18239
  - VLT/X-shooter
- X-rays
  - Integral: ATel 7995
  - MAXI: ATel 8003
  - Swift: ATel 8124, GCN18231
- Radio
  - Jansky VLA: ATel 7999, 8034
- Gamma-rays
  - MAGIC: ATel 8203
  - Fermi-GBM: GCN18352
  - HAWC
  - HESS

Great interest by astro-community

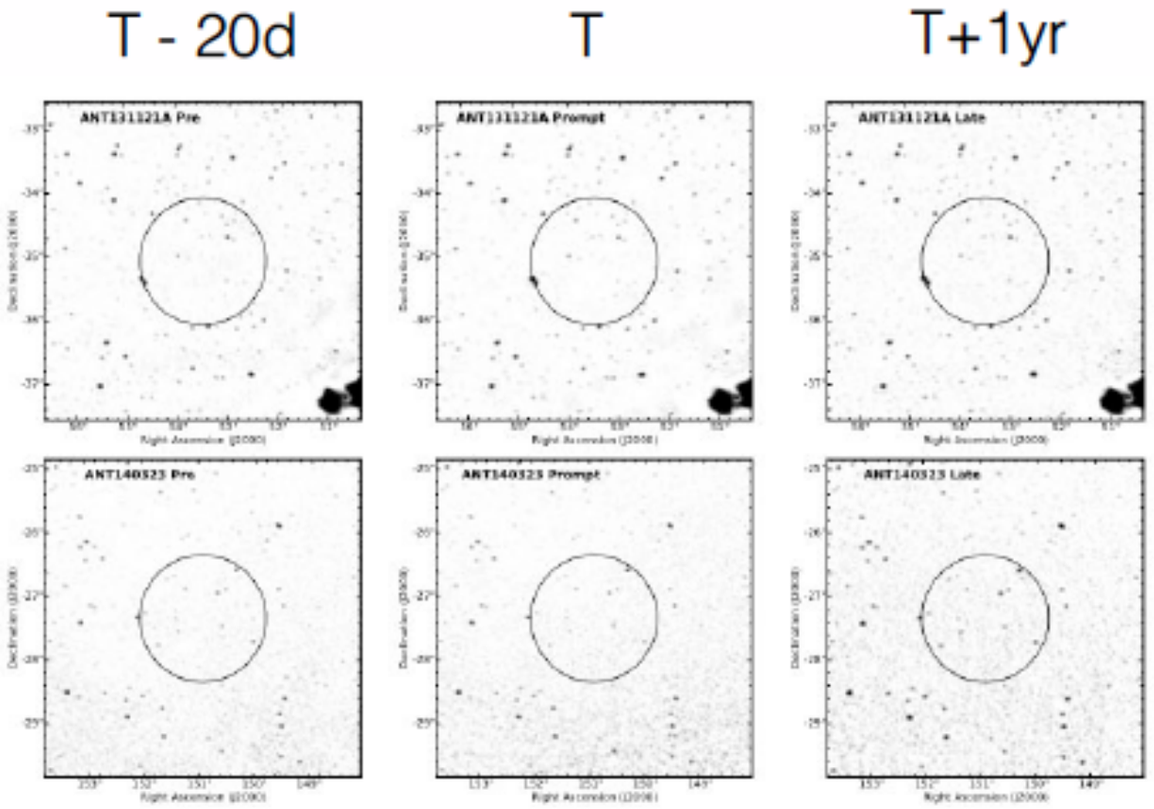
TAToO: radio follow-up

Murchidson Widefield Array: radio telescope (Australia, 80-300 MHz):
2 alerts (directional trigger, local galaxies <20 Mpc)



Radio follow-up of 2 neutrino candidates:

Trigger ID	UT date	UT time	RA (deg)	Dec (deg)	Energy (TeV)
ANT131121A	2013 Nov 21	14:58:28	53.5	−35.1	~ 1
ANT140323A	2014 Mar 23	15:31:01	150.9	−27.4	~ 4



Croft et al, ApJ, 820 (2016) 65

Results: no radio transient/variable sources

➜ Limits on progenitors if we assume neutrinos are cosmic

If source at 20 Mpc, UL(5σ) = 90−340 mJy –> $L_{150\,MHz} < 10^{29}$ erg/s/Hz ($<10^{37}$ erg/s)

If NS-NS coalescence ➜ limit on the distance z>0.2 (>1 Gpc)

TAToO

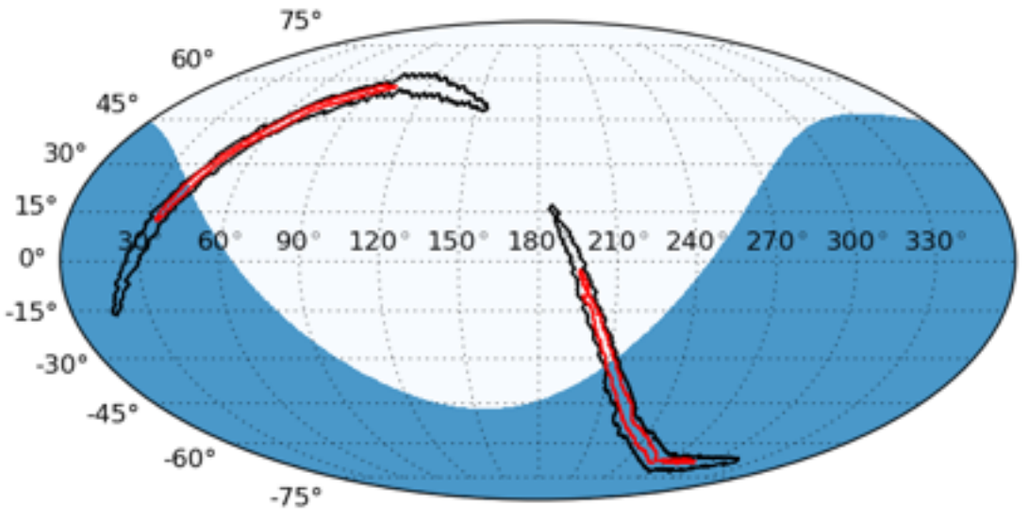
* **TAToO:** multi wavelength follow-up of neutrinos

Radio	Visible	X-ray	GeV-ray	TeV-ray	TeV-ray
MWA	TAROT	Swift	Fermi	HESS	HAWC
(12/yr)	ZADKO	(6 alerts/yr)	(Offline)	(1+1 alert/yr)	(10 alerts/yr)
	MASTER				
	SVOM GT				
	(30 alerts/yr)				

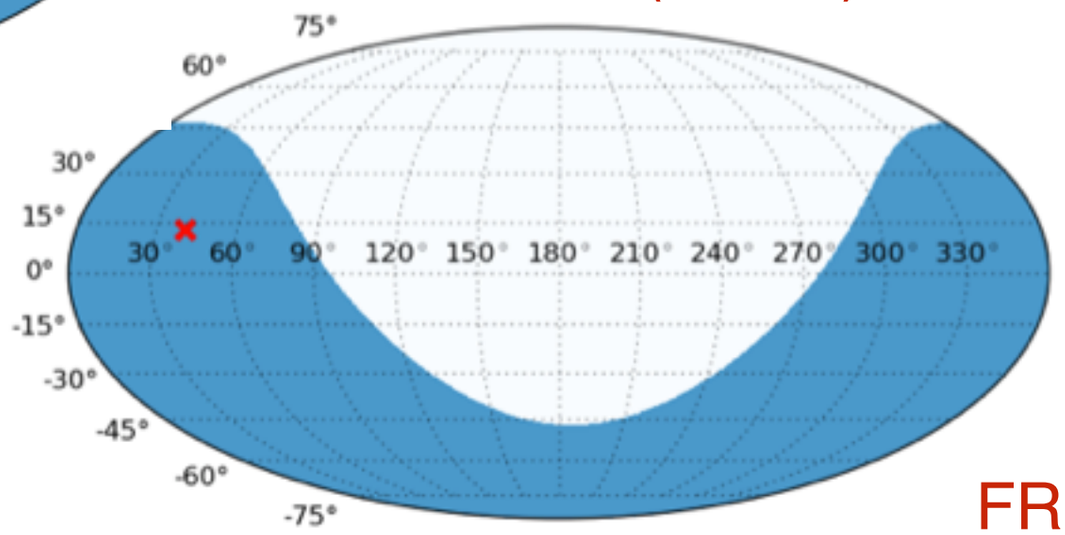
Nb alerts: 221 alerts sent to optical telescopes since mid 2009 +12 to the X-ray telescopes since mid 2013 + 4 to M.W.A since 2016 + 2 to HESS in the last year

Others real-times MM analysis

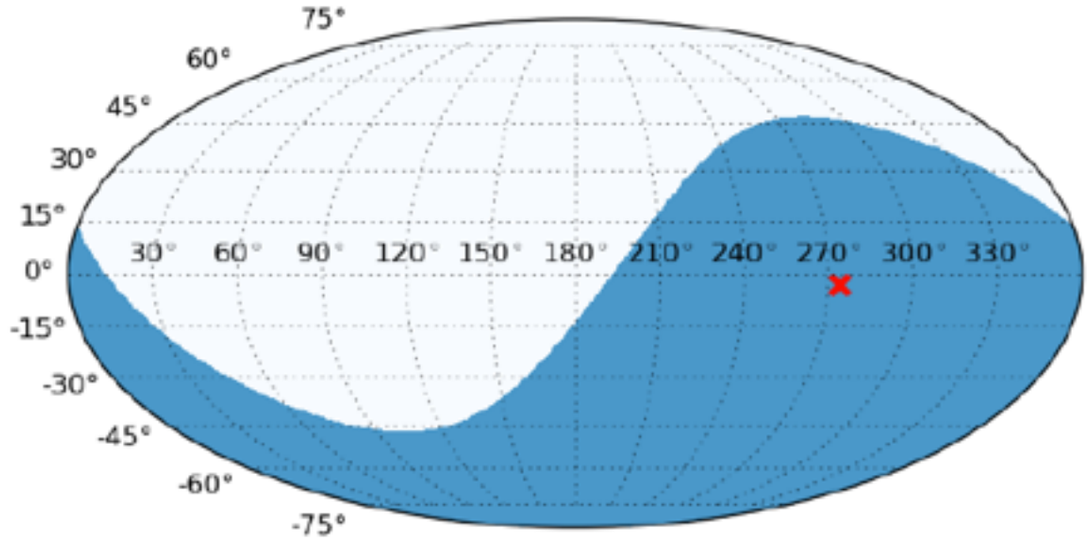
GW151226



IC161103 (HESE)

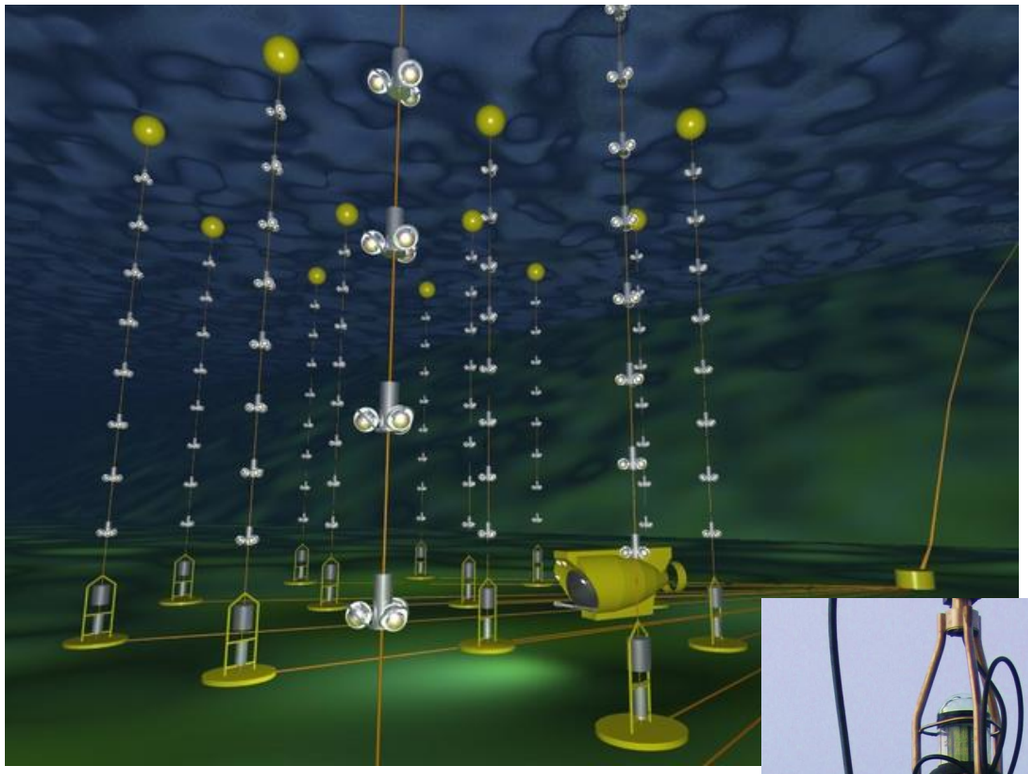


FRB 15.... (Parkes)

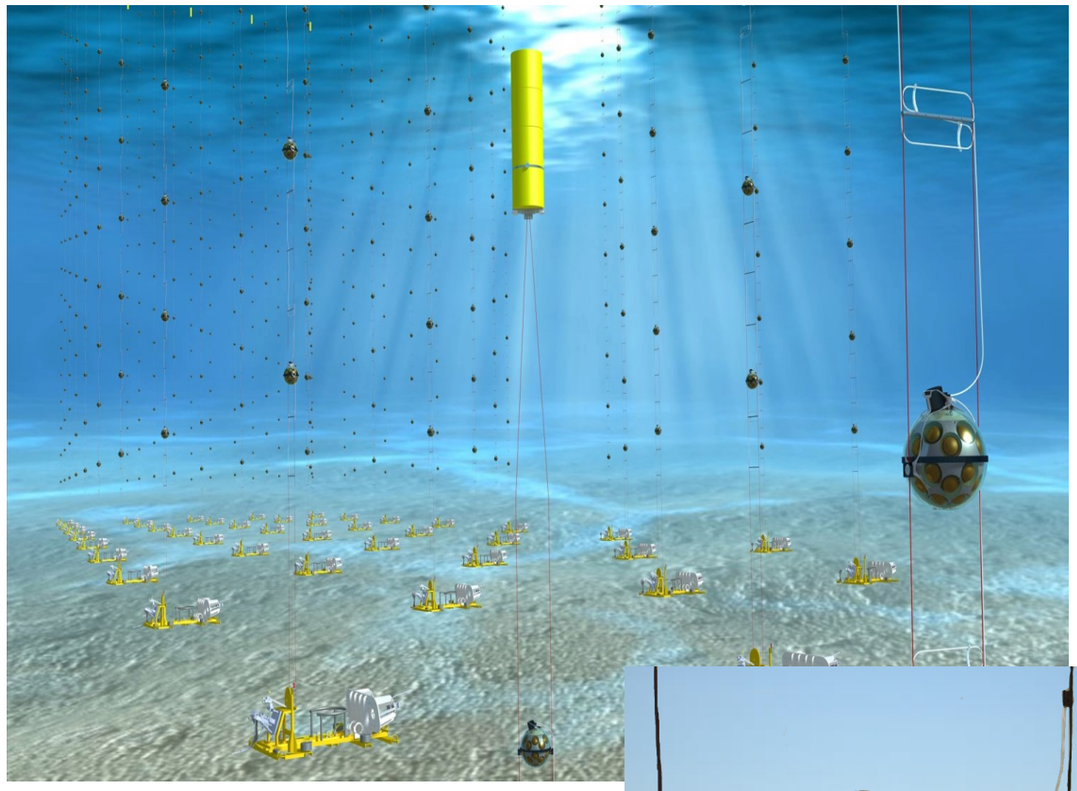


ANTARES => KM3NeT

12 lines, 885 OMs



3 Building Blocks on 2 sites: 3*115 lines, ~6210 OMs, ~45200 PMTs



Performances KM3NeT ARCA

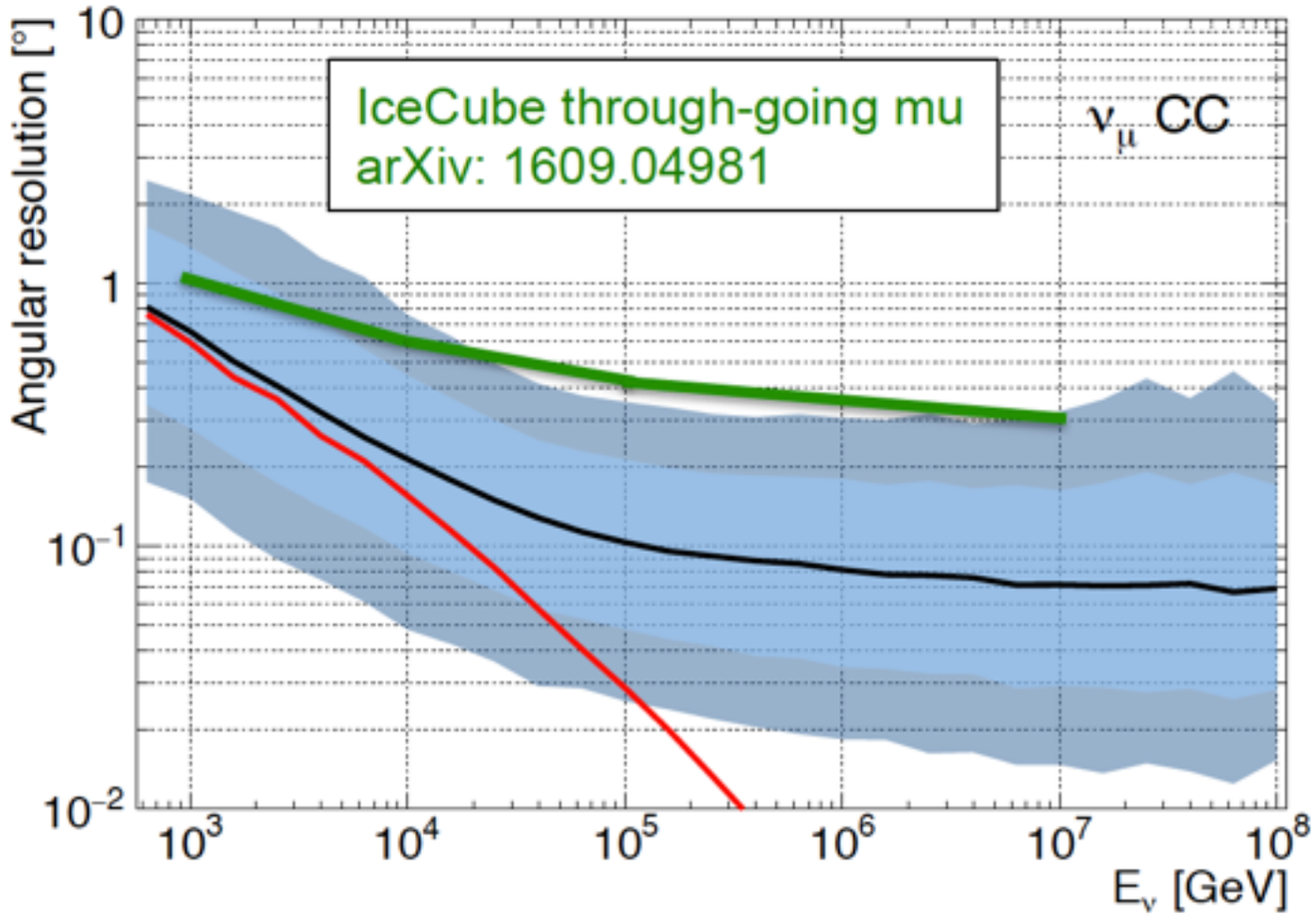
<u>Tracks</u>:

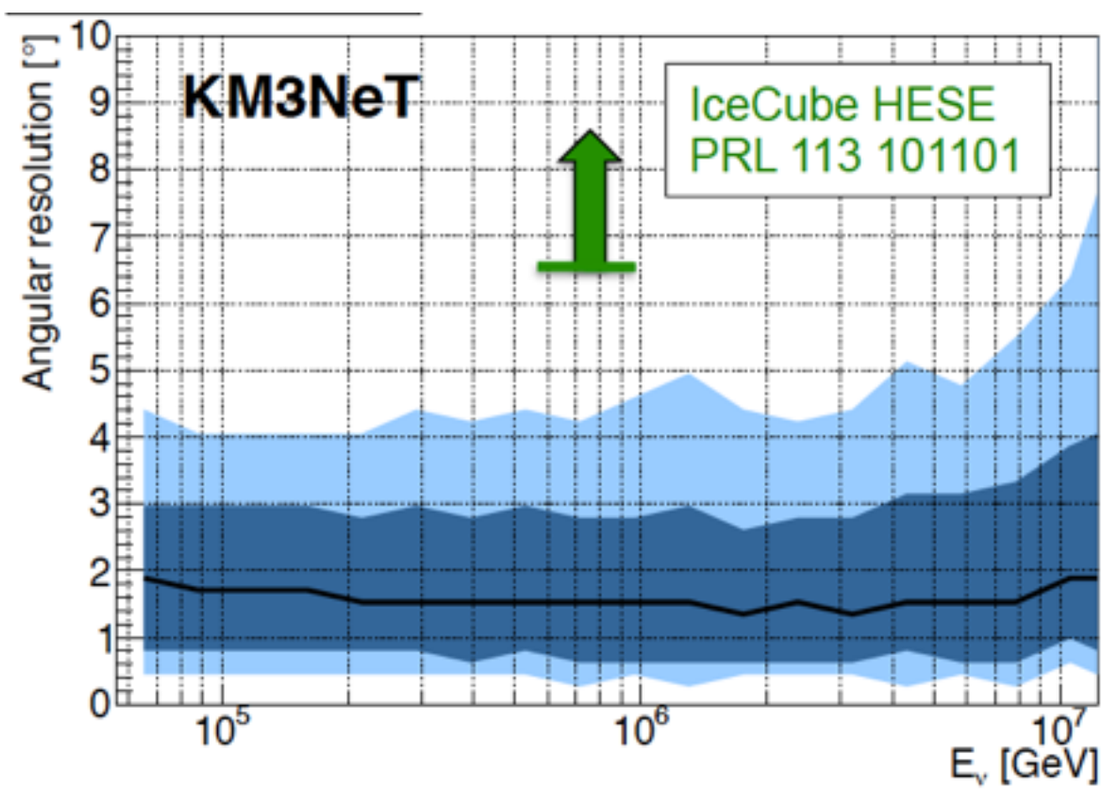
- Direction:

➡ Gal. sources: 0.2º at 10TeV

➡ Extra-gal. sources: 0.1º at 100TeV

- Energy: 0.27 in Log10(E)

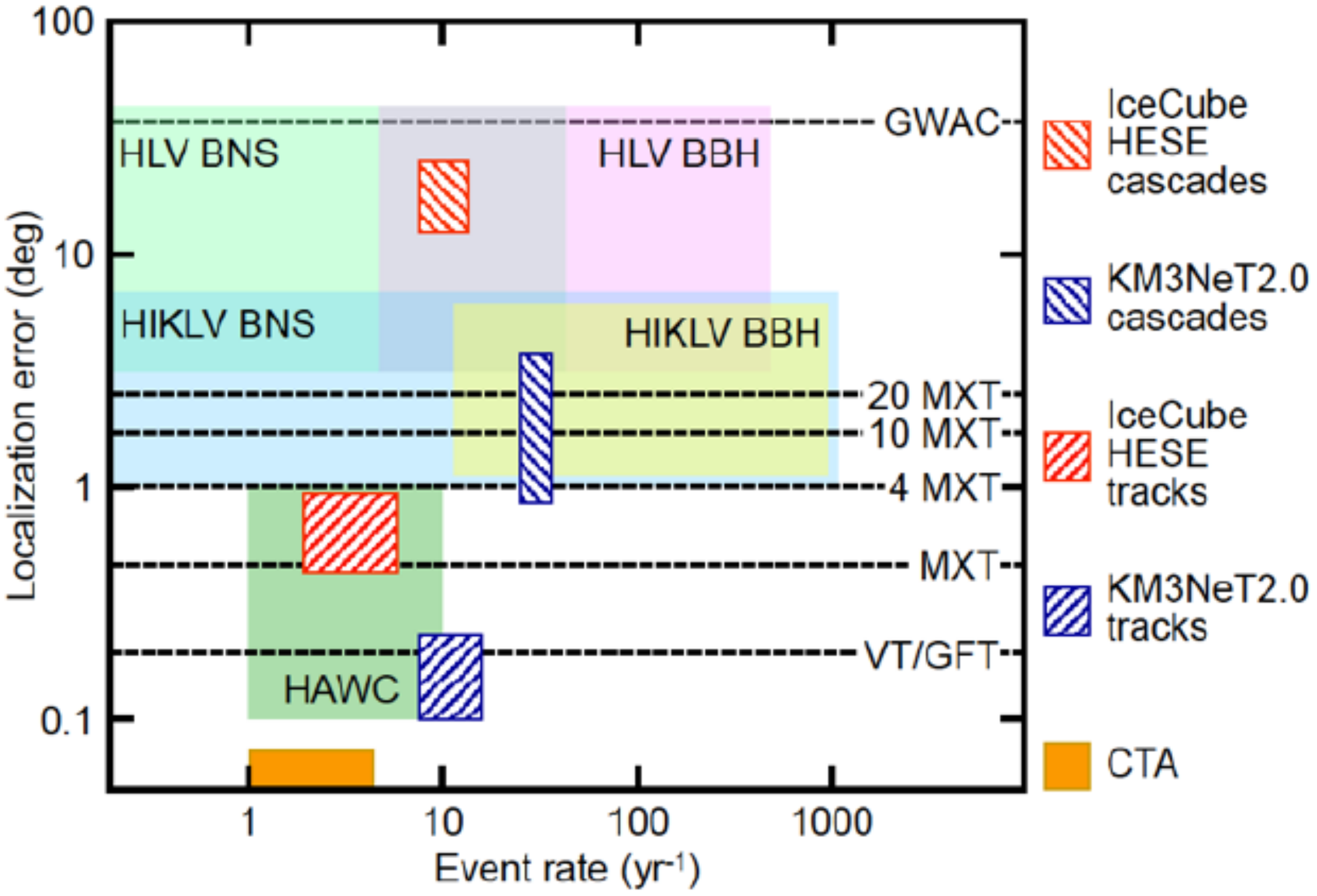


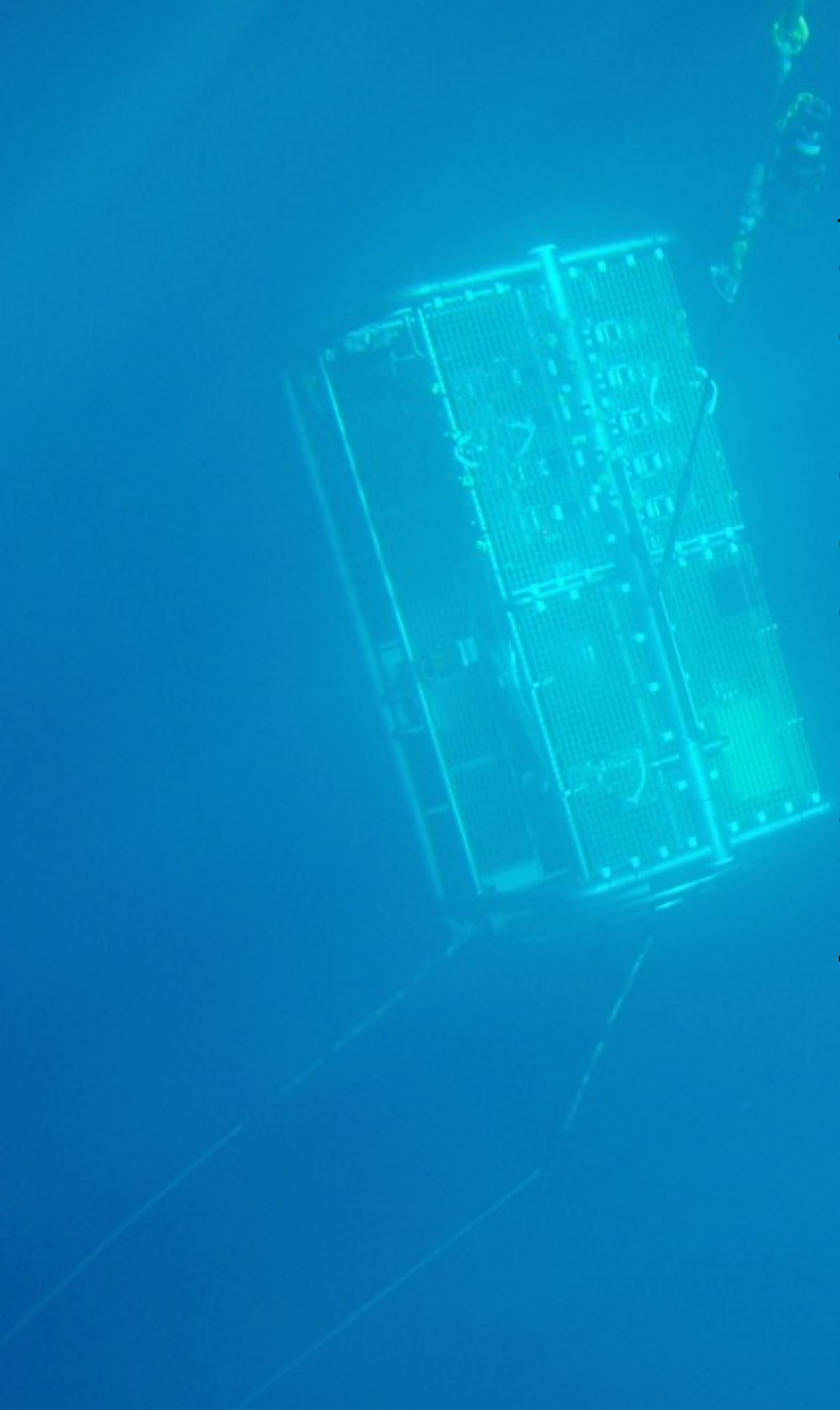


<u>Cascades</u>:

- Vertex: 6-8m (long), 0.5m (perp)
- Direction: ~1.5º
- Energy: 5%

Muliti-messenger alerts @ SVOM





Summary:

- 10 years of continuous data-taking
- Small excess in all diffuse analysis (final ANTARES sensitivity <=> IC signal flux)
- Update with 2016 data @ ICRC
- Competitive results on the Southern sky
- Huge multi-messenger effort

- ANTARES will be decommissioned end of 2017, then smooth transition to KM3NeT
- KM3NeT is under construction in Europe (2 sites South of Italy and South of France).

Last picture of the ORCA node in its way to the abyss

In the KM3NeT Fr site, few months ago…