MULTI-MESSENGER ASTRONOMY WITH ANTARES

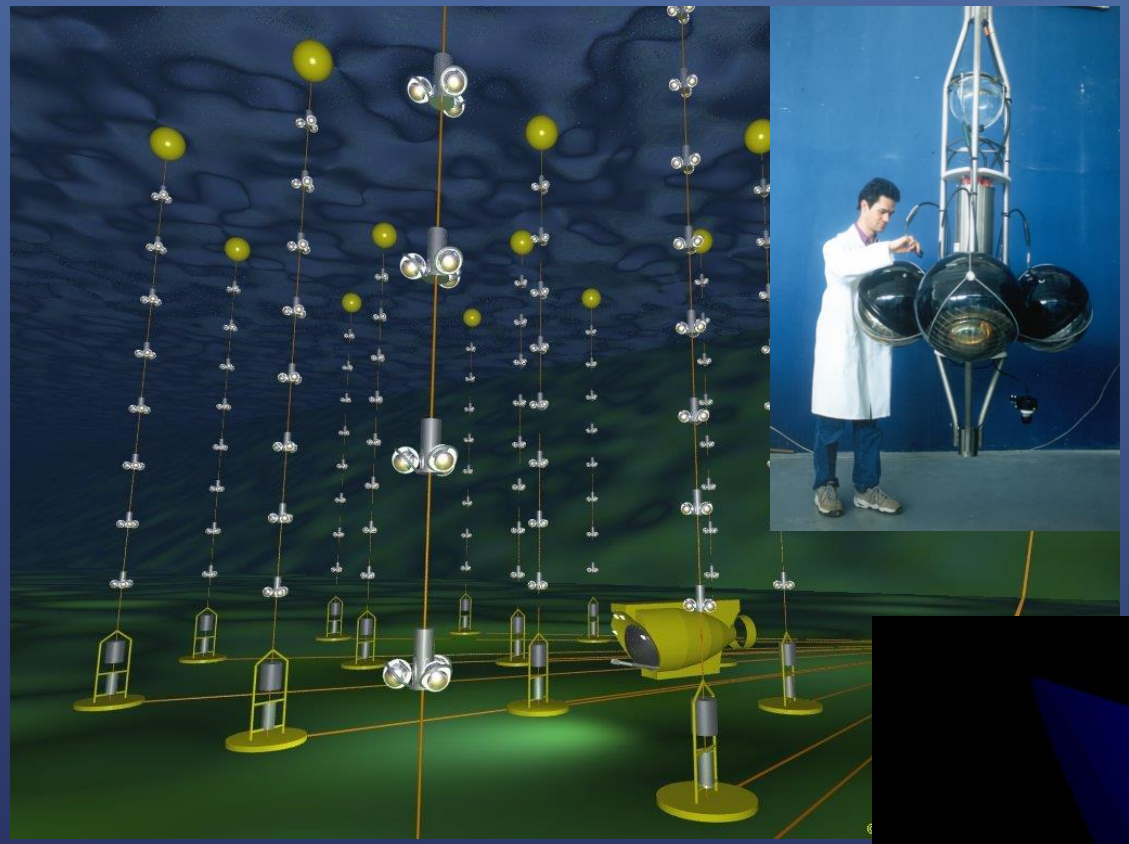
XXXII INTERNATIONAL SEMINAR of NUCLEAR and SUBNUCLEAR PHYSICS "Francesco Romano"

Students' presentation session

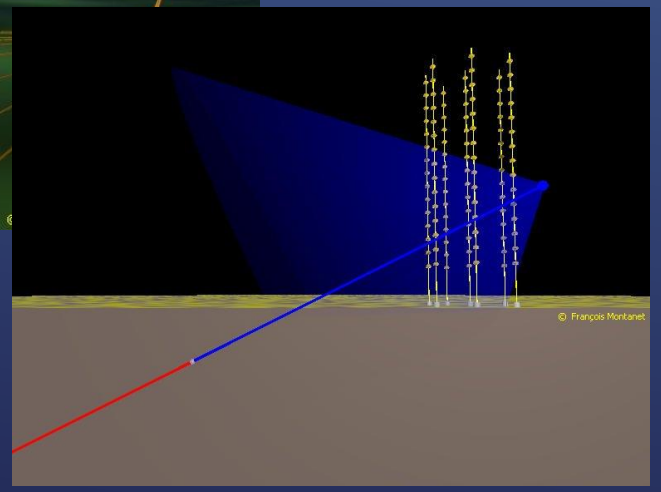
Sergio Alves Garre

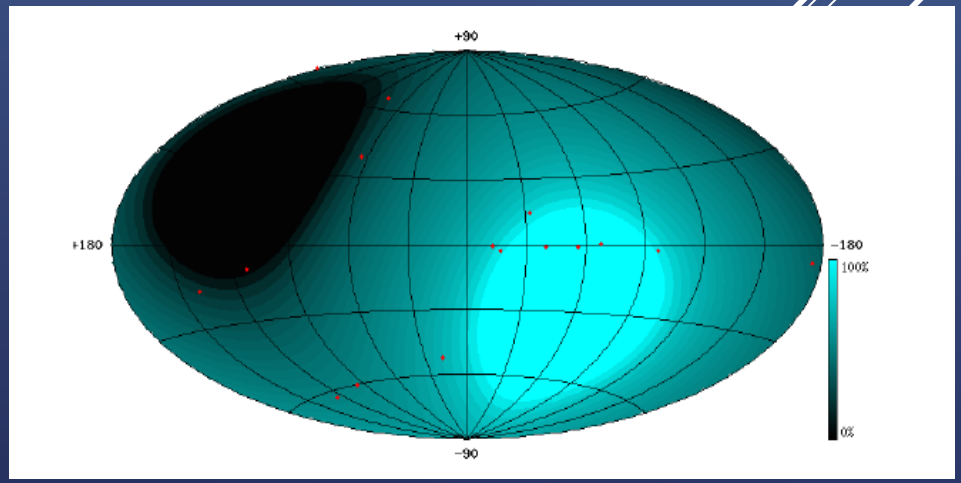
Instituto de Física Corpuscular UV-CSIC

THE ANTARES NEUTRINO TELESCOPE



- Located at 40 km off-shore from Toulon at a depth of 2500 m.
- Composed of 12 lines, with 25 storeys each, hosting 3 down-facing optical modules.
- Detects the Cherenkov light produced by the emitted lepton from neutrino interactions in the vicinity of the detector
- Well suited for observation in the GC and southern sky. Complementary to IceCube.
- Has been operational since 2007.





ANTARES-GVD ALERTS OFFLINE ANALYSIS I

Baikal GVD is a Cherenkov neutrino detector located at lake Baikal, Russia (under construction). We have been sharing alerts with them since 2018: Coincidences found with 3 alerts!!

ANALYSIS METHOD

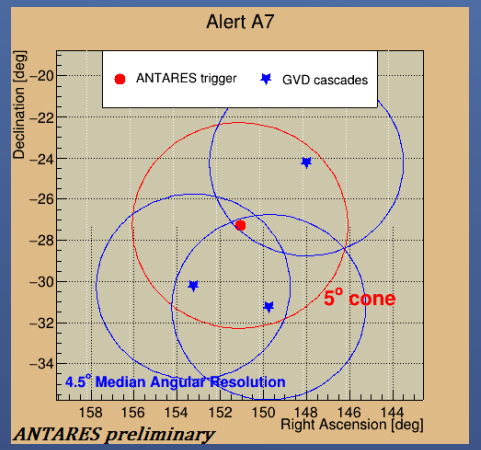
Objetive: Look into ANTARES data for further coincident events.

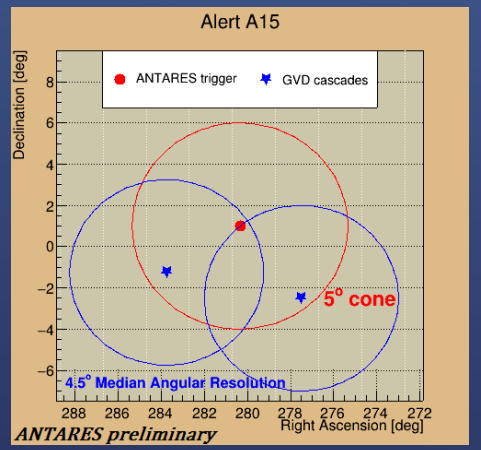
Binned analysis: count & compare.

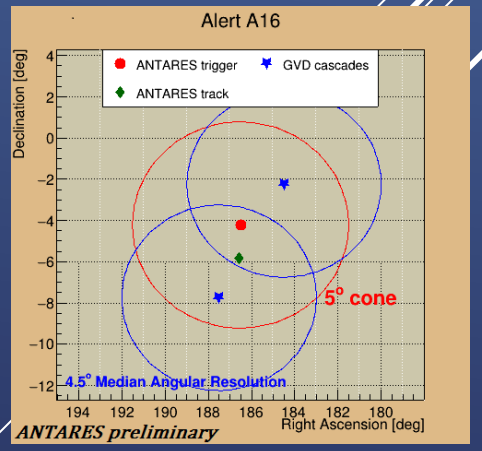
- Pros: Easy to implement.
- Cons: Uses minimal information.

Procedure: Optimize signal vs background cuts for a given significance (3σ)

Optimization target: Acceptance to a E^{-2} flux. Obtained through Monte Carlo generated samples.







Alert A7: Directional trigger
Alert A15 & A16: HE triggers

GVD follow-up time: 48 hours.
GVD RoI: 5 degree cones.

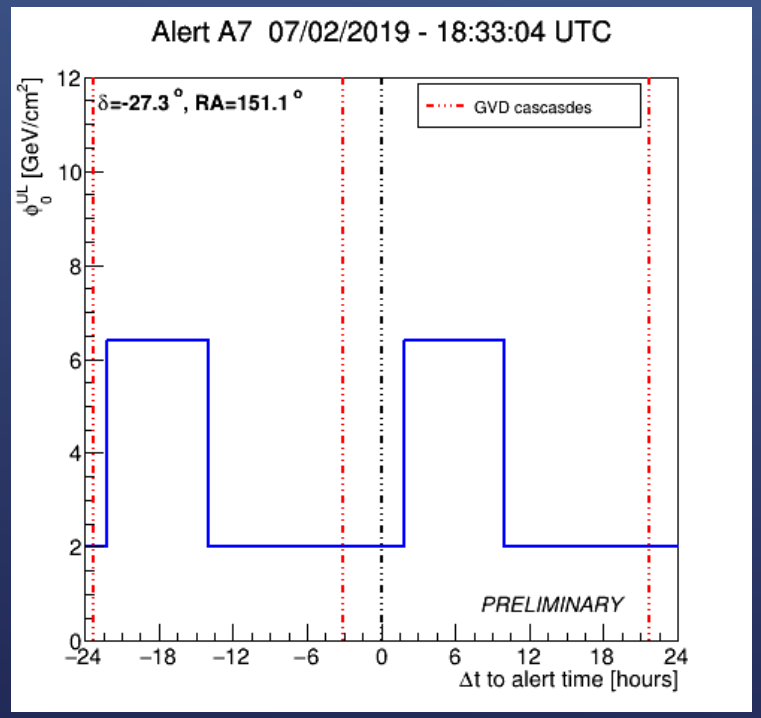
7 cascades found with angular separation smaller than their median angular resolution.

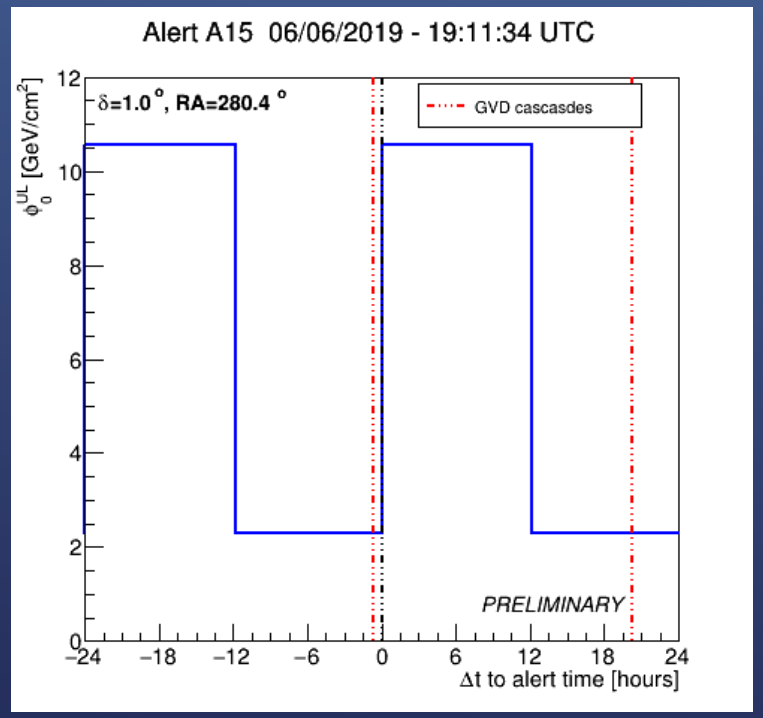
ANTARES-GVD ALERTS OFFLINE ANALYSIS II

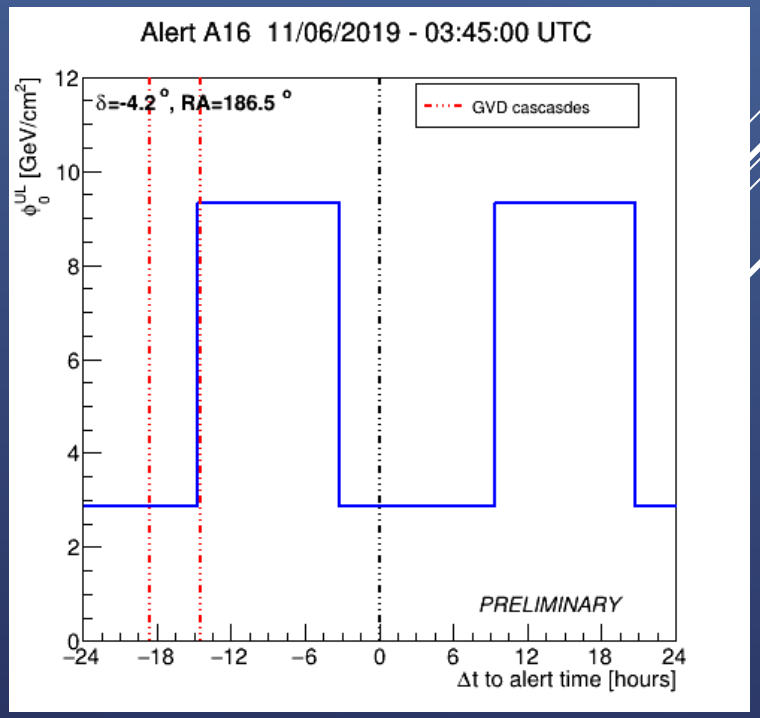
After optimization, complete unblinding of the ANTARES data was done during the 48 h time window.

NO ADDITIONAL TRACKS OR SHOWER WERE DETECTED

Upper limits on the neutrino fluence to a E^{-2} spectrum over the time search are presented.







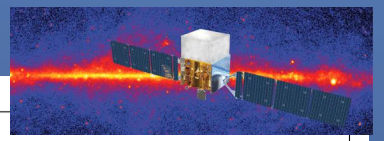
ANTARES FLARING ANALYSIS (IN PROGRESS)

OBJETIVE

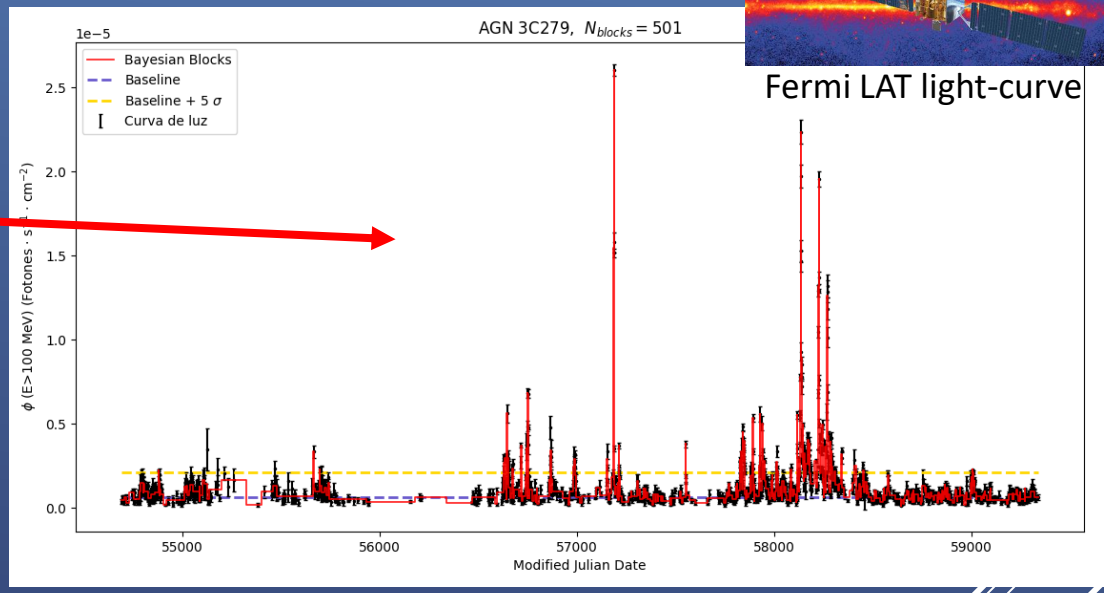
Search for neutrinos that might have been emitted together with gamma-rays from a source in flaring state:

$$p + \gamma \rightarrow \pi^0 + \pi^+ + \pi^- + \dots$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu \rightarrow e^+ + \nu_e + \bar{\nu}_\mu + \nu_\mu$$
$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu \rightarrow e^- + \bar{\nu}_e + \nu_\mu + \bar{\nu}_\mu$$
$$\pi^0 \rightarrow \gamma + \gamma$$



Fermi LAT light-curve



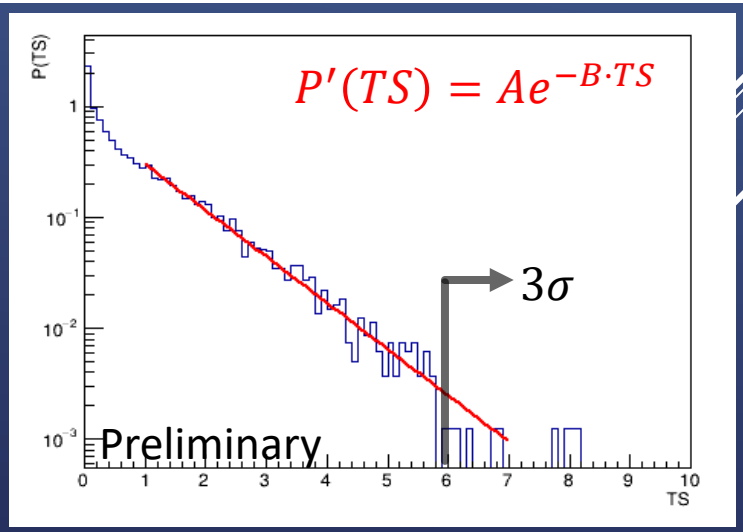
ANALYSIS METHOD

Unbinned Analysis: Uses a likelihood function to estimate the amount of signal coming from a given source.

$$\log \boldsymbol{L^{ML}(n_s)} = \sum^{\boldsymbol{N}} \log\left(\frac{\boldsymbol{n_s}}{\boldsymbol{N}} \boldsymbol{S_i(\theta_i, E_i, t_i)} + \frac{\boldsymbol{N - n_s}}{\boldsymbol{N}} \boldsymbol{B_i(\delta_i, E_i, t_i)}\right)$$

Significance is given by a **Test Statistic:**

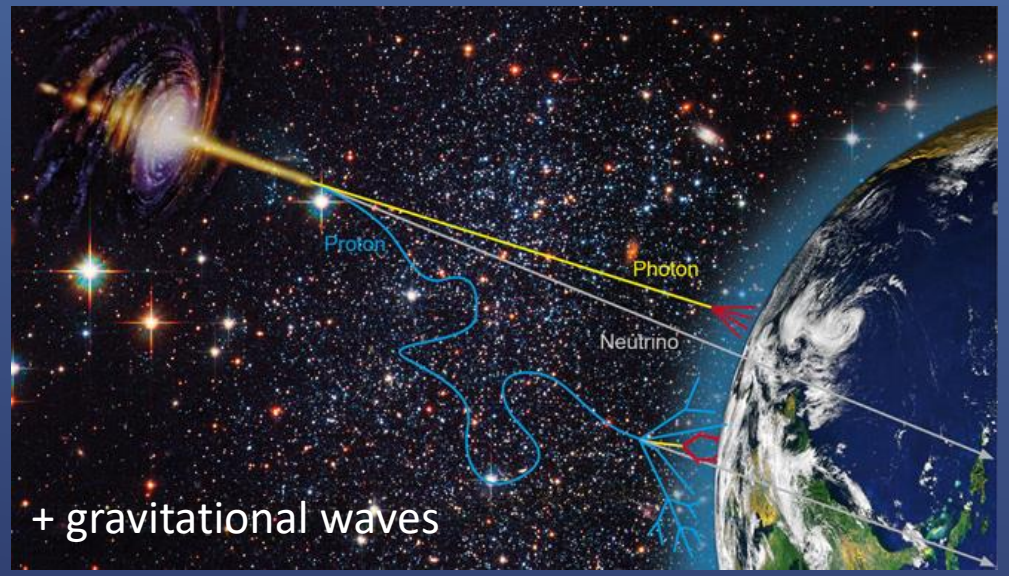
$$\boldsymbol{TS} = -\boldsymbol{2} \log\left[\frac{\boldsymbol{L(n_s = 0)}}{\boldsymbol{L(n_s)}}\right]$$



SUMMARY

- The ANTARES-GVD alerts analysis is a good example of a joint multi-messenger effort. It is complementary to the online analysis, however no additional signal was found.
- Nevertheless, the future of multi-messenger astronomy lies on the constant cooperation of all the available observatories regardless the messenger they follow so a forward step in the right path.
- The source flaring analysis is still in progress. The addition of temporal information depends on the source but greatly reduces the threshold for a significant detection.
- Recently, the models in favour of neutrinos + gamma-rays have been questioned in favour of neutrinos + radio emission so further research must be done in order to answer these questions.

ANTARES IN THE MULTI-MESSENGER ERA



GeV – TeV γ-rays: Fermi, HESS, HAWC, CTA, LHAASO

Neutrinos: IceCube, GVD

WG: VIRGO, LIGO

UHECR: Auger, TA

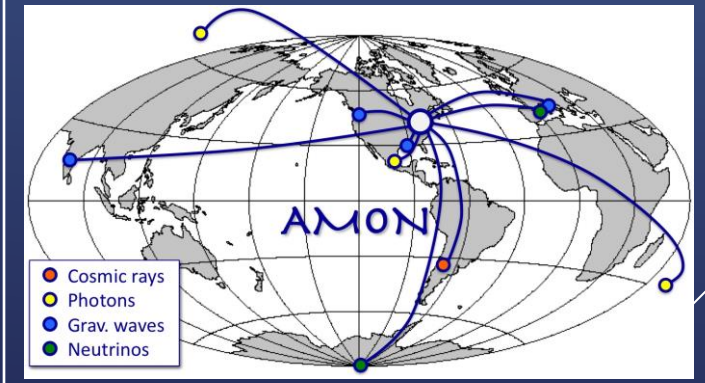
R/O/X-rays: TAROT, MASTER, SWIFT, INTEGRAL

Offline framework: (This talk)

Analysis of the available data after a long time of exposure.

Search for possible coincidences (space/time) among the events collected from different experiments.

Online framework: Real time follow-up



SNEWS