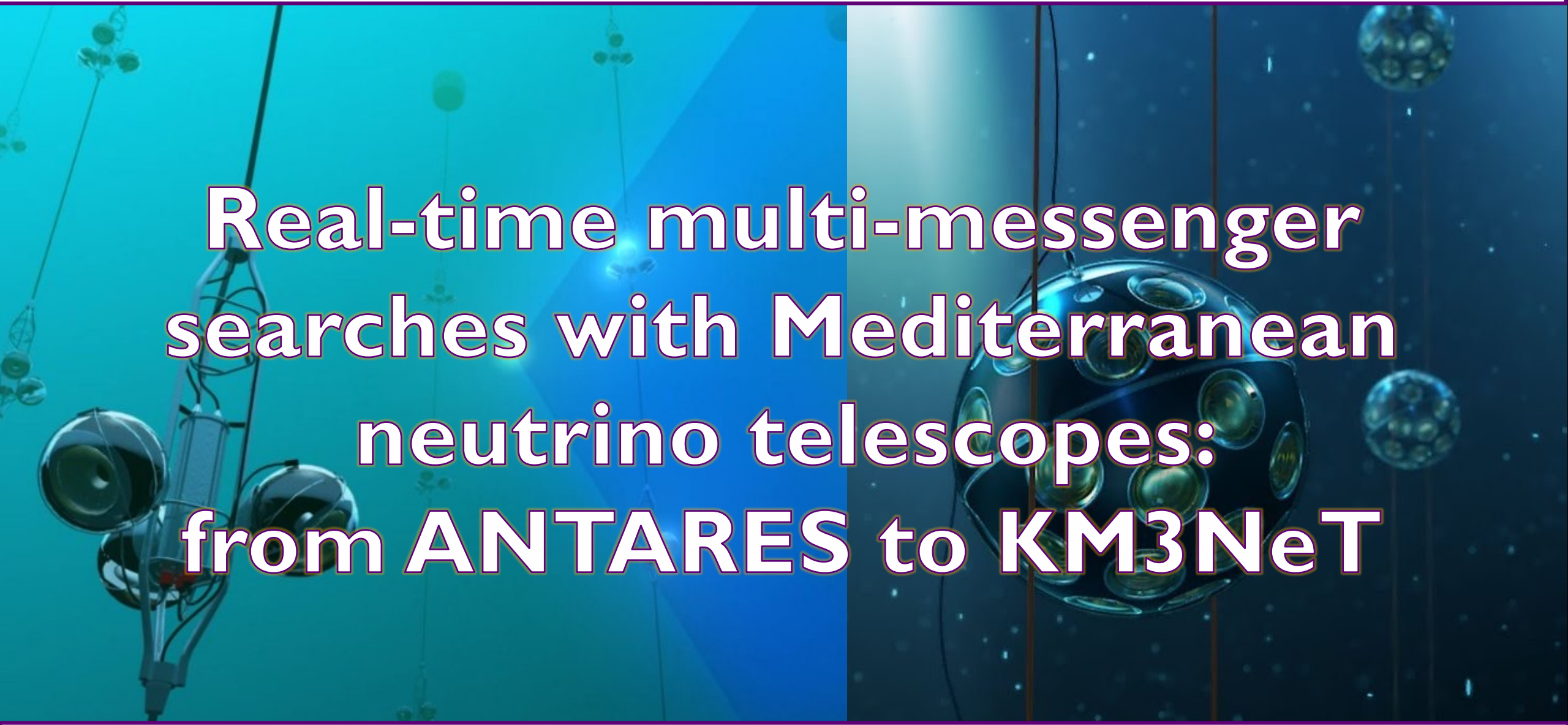
1st Astro-COLIBRI Multi-Messenger Astrophysics Workshop
Bochum, 27/09/2022

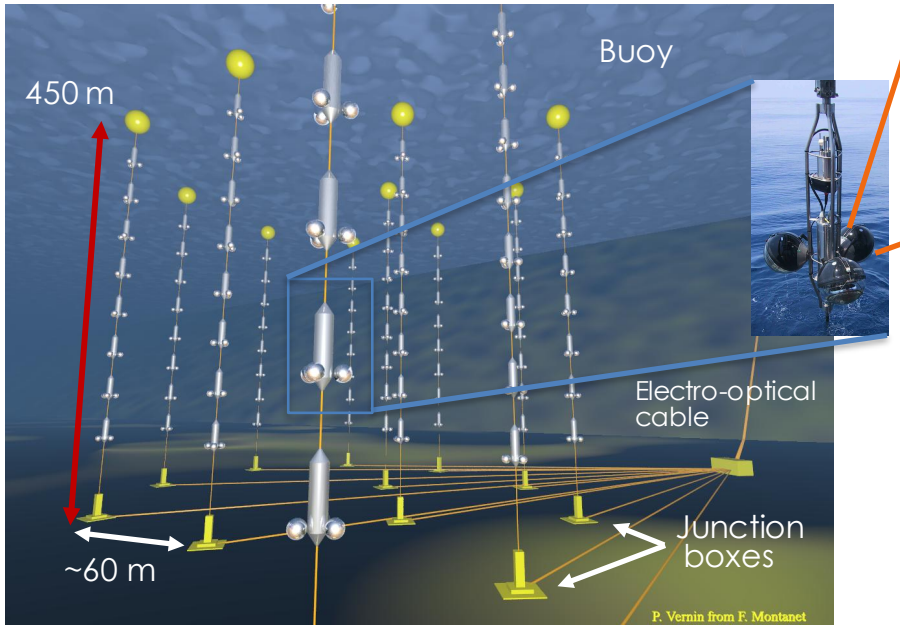


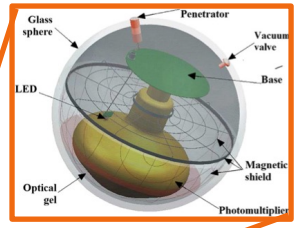
Real-time multi-messenger searches with Mediterranean neutrino telescopes: from ANTARES to KM3NeT

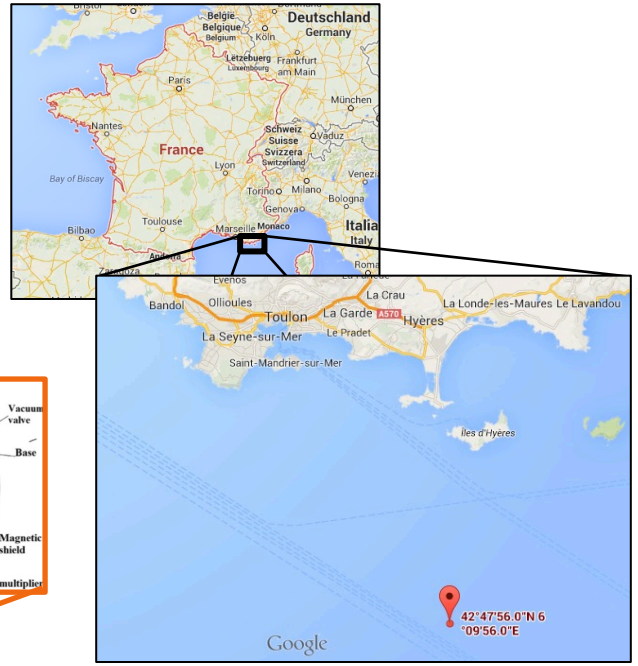
Giulia Illuminati (INFN, University of Bologna)

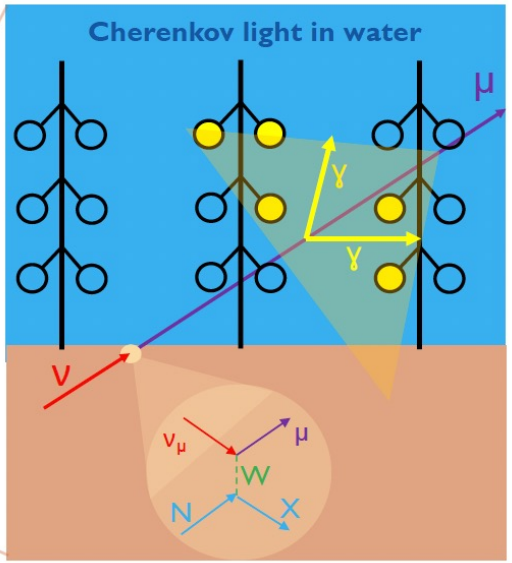
ANTARES telescope

- First detection line installed in early 2006
- **Completed in 2008**
- **Decommissioned in 2022**
- **2475 m depth** in the Mediterranean Sea
- 40 km offshore from Toulon



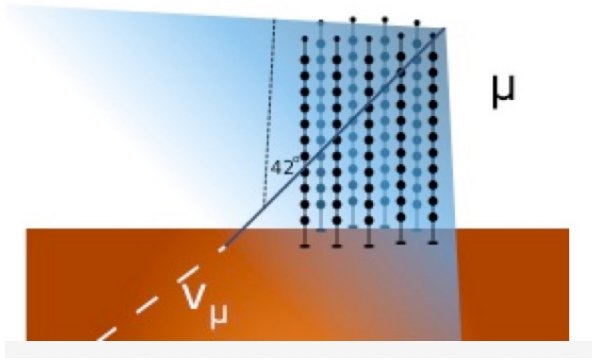






- Three-dimensional array of 885 PMTs
- 12 vertical lines
- **Instrumented volume ~0.01 km^3**

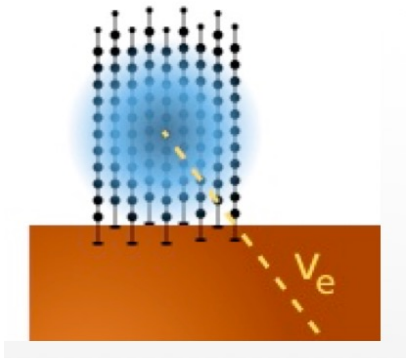
ANTARES telescope



Track-like events:

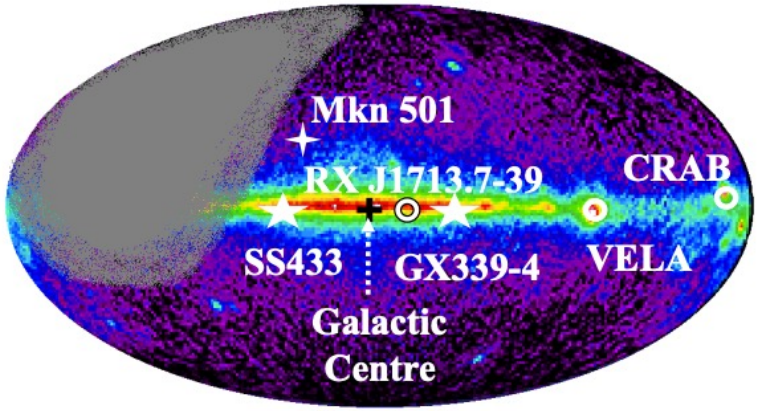
ν_μ (ν_τ) neutrino
CC interaction near the detector

Topology used in online analyses

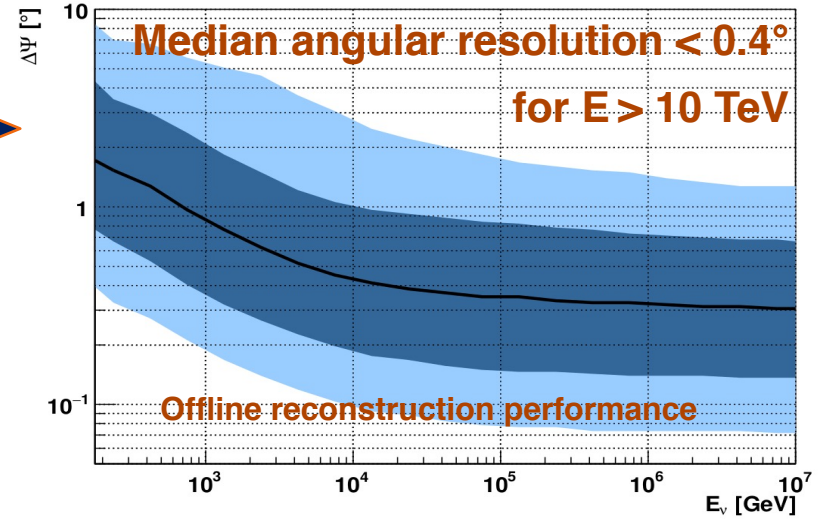


Shower-like events:

all neutrinos NC, ν_e,ν_τ CC interaction
inside or very close to the detector

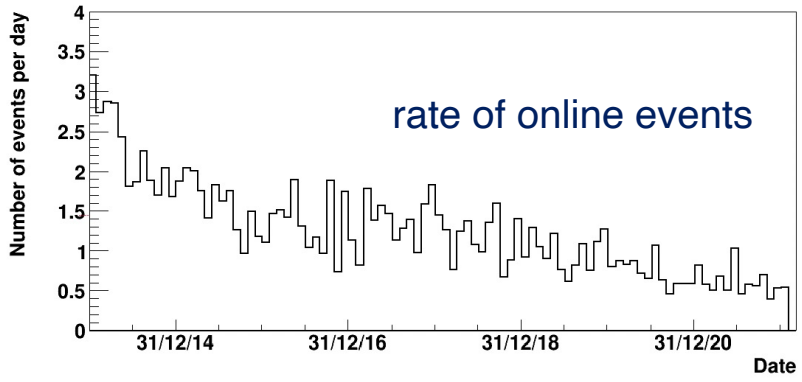


Visibility: ¾ of the sky, most of the Galactic plane
~95% duty cycle

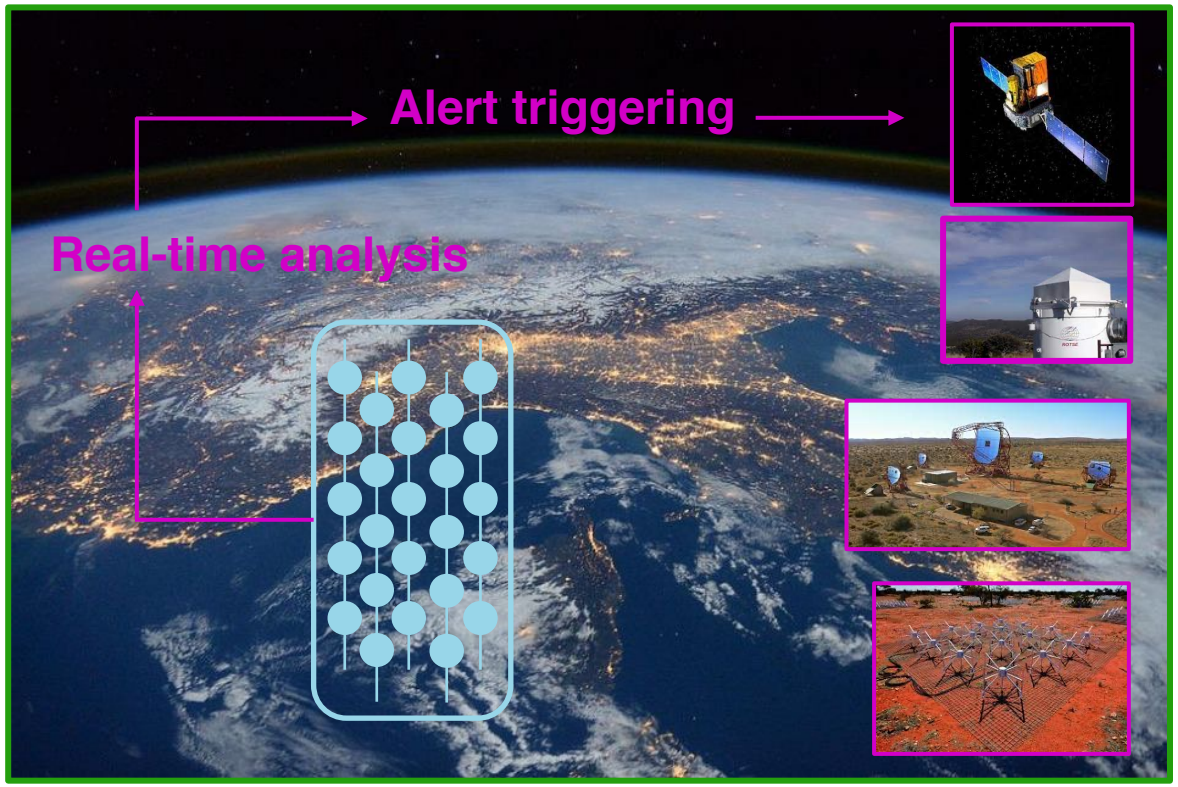


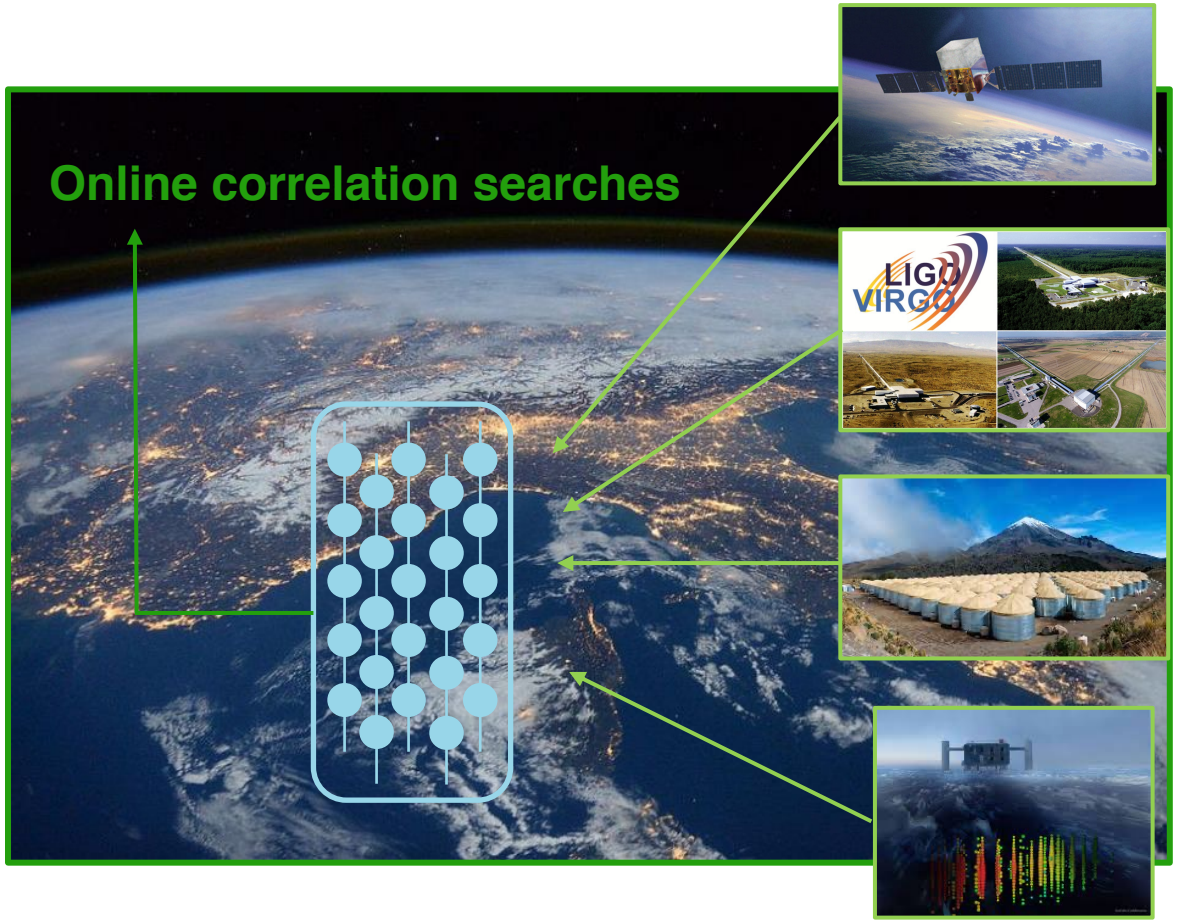
ANTARES sample for online analyses:

- Up-going tracks, good reconstruction quality
- → **0.5° median angular resolution**
- → **<10% muon contamination**

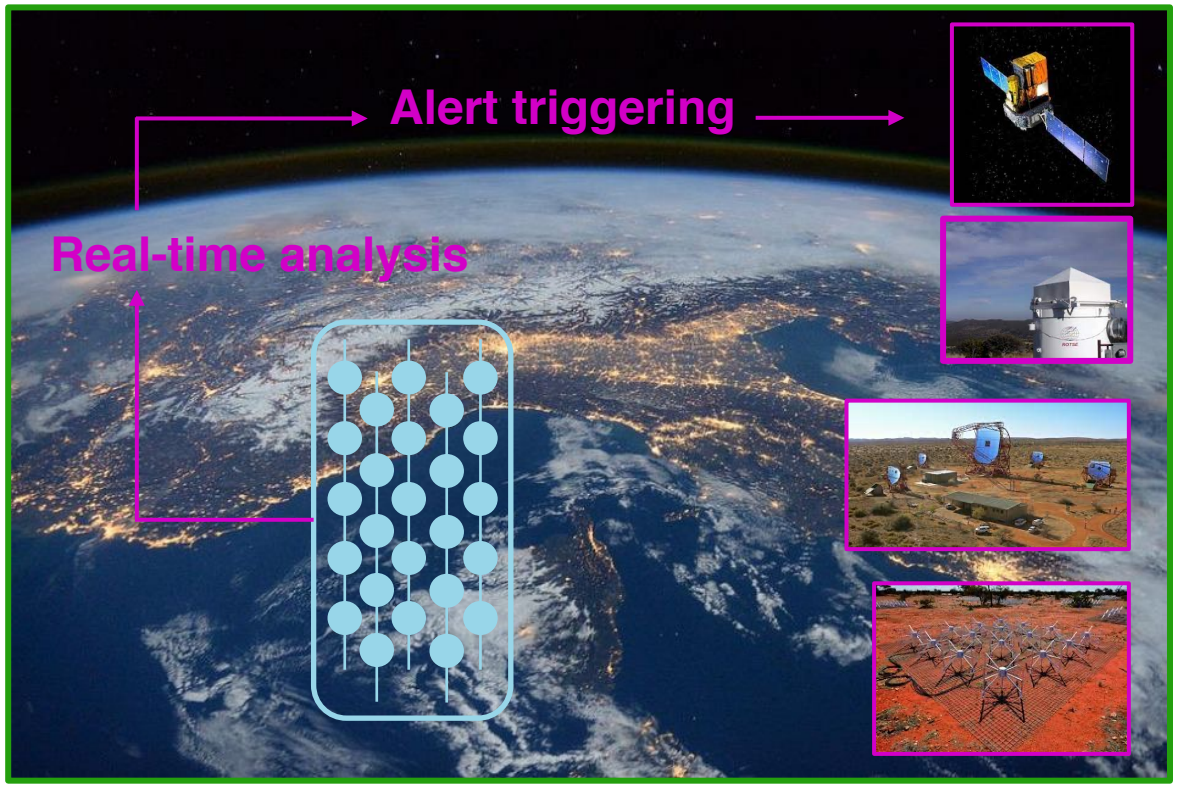


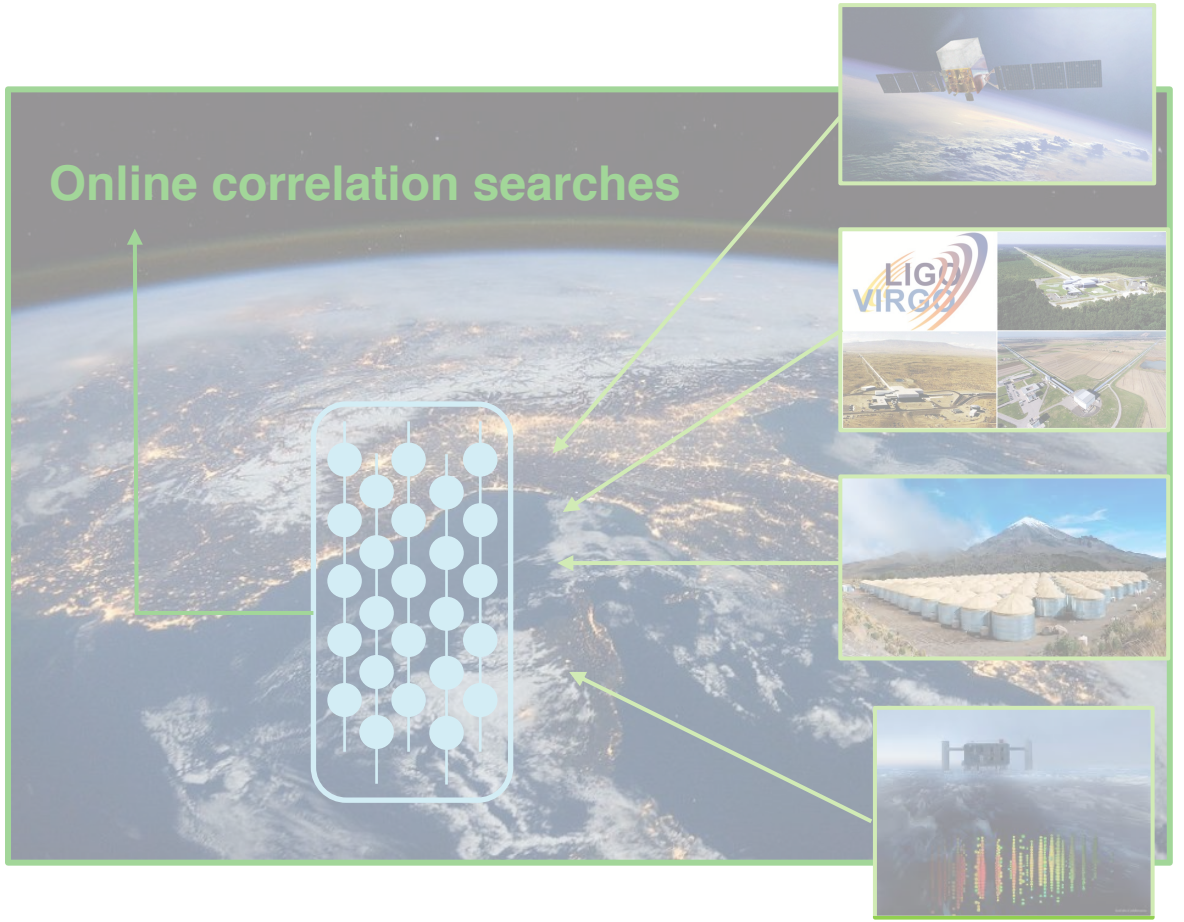
Online activities: 2 approaches



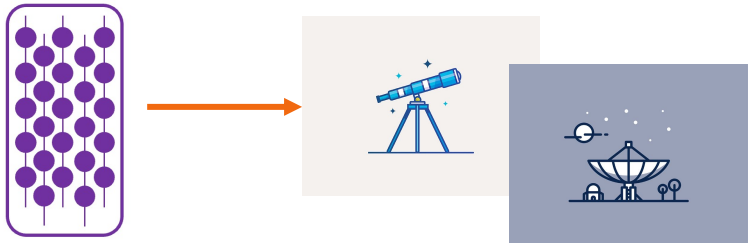


Online activities: 2 approaches





ANTARES alerts



Alert system (**TAToO: Telescopes and Antares Target of Opportunity**) operating since 2009

Four ANTARES alert triggers:

- **High energy (HE) trigger:** single neutrino with an **energy ≥ 5 TeV**. → **Rate: ~1/month**
- **Very high energy (VHE) trigger:** single neutrino with an **energy ≥ 30 TeV**. → **Rate: ~3-5/year**
- **Directional trigger:** single neutrino from the **direction (≤ 0.4°) of a local galaxy (≤ 20 Mpc)** of the Gravitational Wave Galaxy Catalogue (GWGC). This trigger was mainly introduced to enhance the chance to detect a local CCSN. → **Rate: ~1/month**
- **Doublet trigger: at least two neutrinos** coming from **close directions (≤ 3°) within** a predefined **time window (15 min).** → No doublet trigger ever been issued

- Alerts sent a **few seconds (~6 s) after ν detection**
- All alerts were sent using the **GCN normalized format** and the standard **VOEvent format**

- ANTARES policy: all alerts were **private** (data exchanged upon MoU). Only if a potential **counterpart was found, the alert became public**

ANTARES partner followers

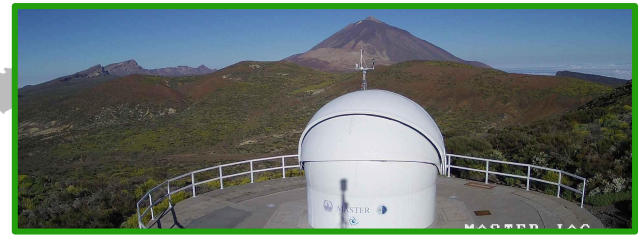
2009 (TAToO starts) 2014 2015 2017 2022

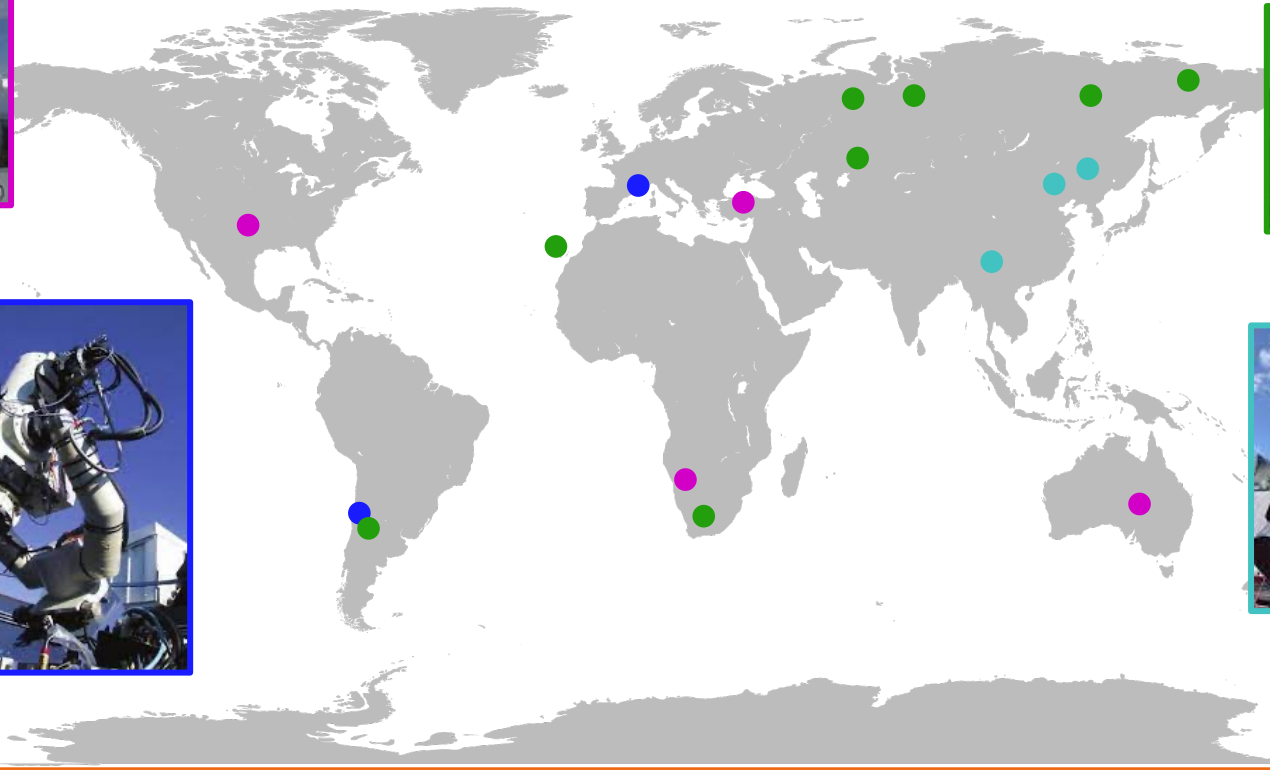
TAROT

ROTSE

MASTER

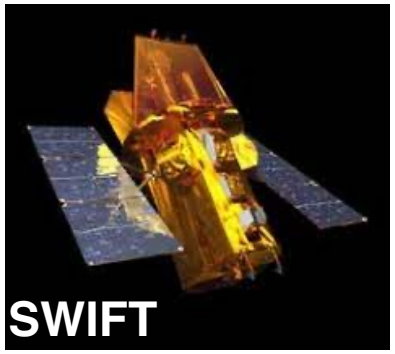
SVOM/GWAC

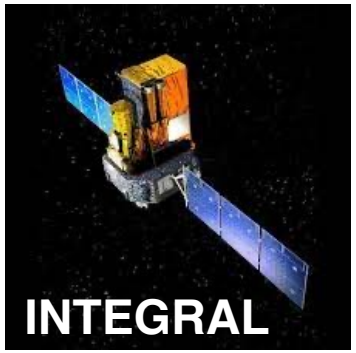




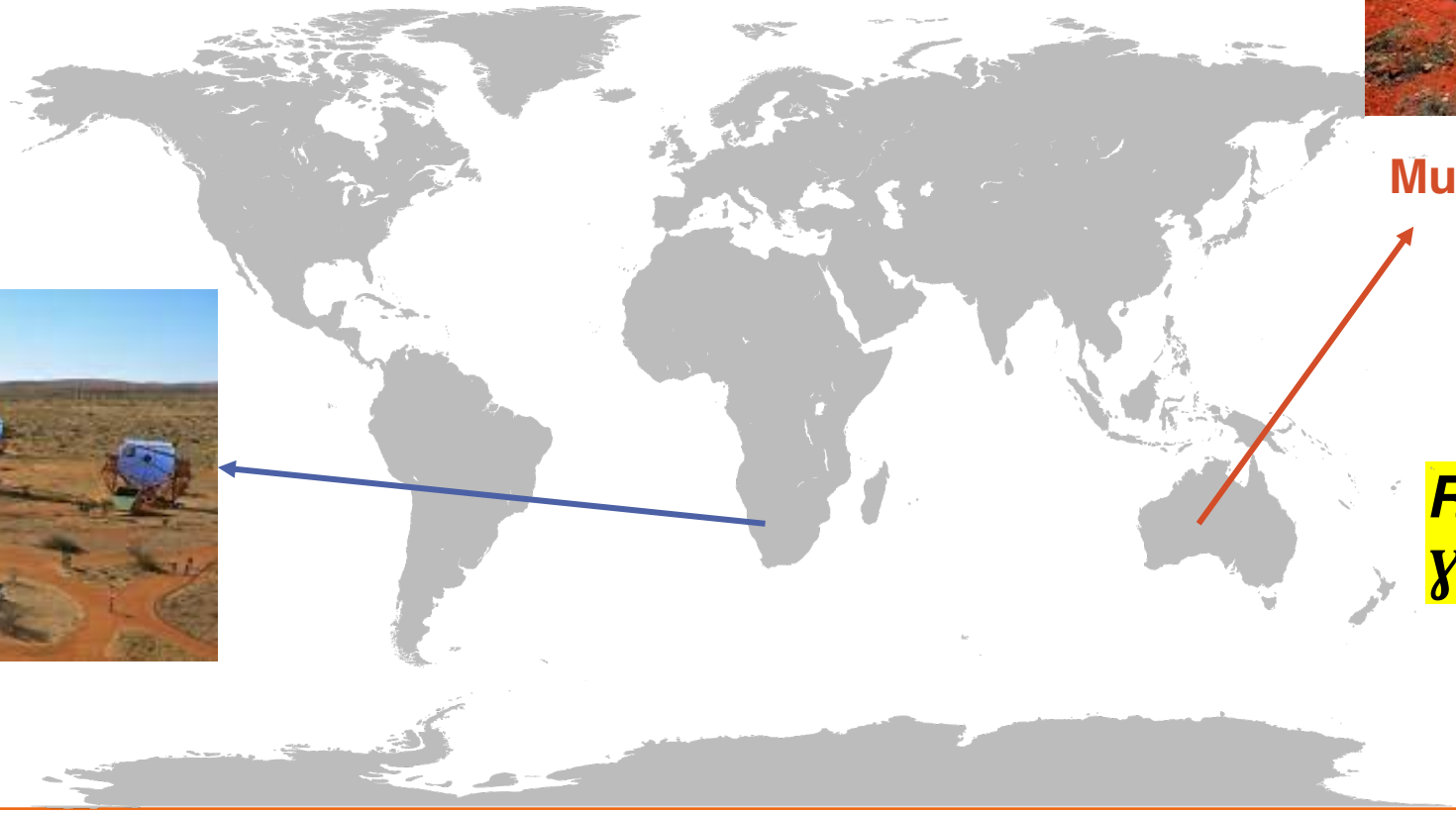
Optical telescopes

ANTARES partner followers





Murchinson Wide Field Array (MWA)

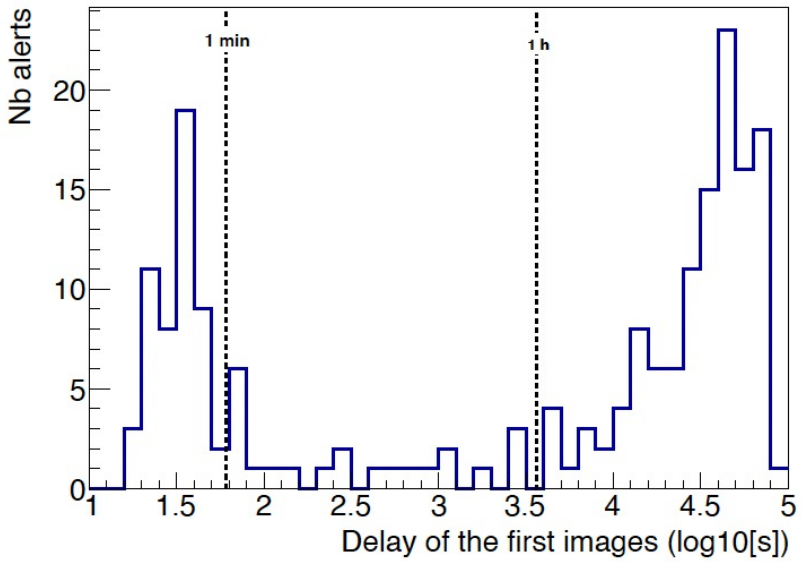


H.E.S.S.

Radio, x-ray and γ-ray telescopes

Statistics of ANTARES alerts

- **322 alerts sent to robotic telescopes**
  - 68% followed within 24h
  - Late follow-up due to bad weather or direction under horizon/close to Sun/Moon
- **26 sent to Swift**
- **15 sent to Integral**
- **20 sent to MWA**
- **2 sent to H.E.S.S.**

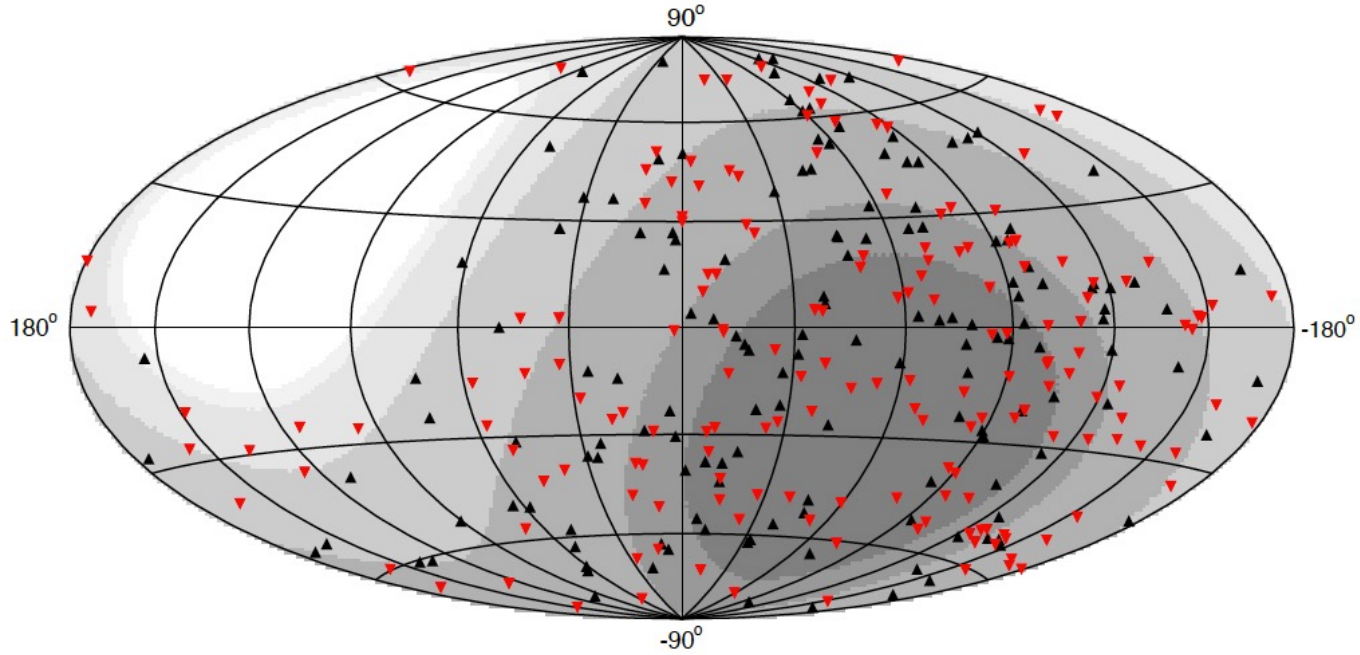


Skymap in Galactic coordinates with the positions of the **directions of all the TAToO alerts sent by ANTARES**

▼ **early follow-up (<24 h)**

▼ **late follow-up**

ANTARES visibility



Time delay between first TAROT/MASTER image and neutrino detection

Summary of ANTARES alert follow-up

Prompt follow-ups
No clear optical transient counterparts found → upper limits on the magnitude of a transient astrophysical source derived

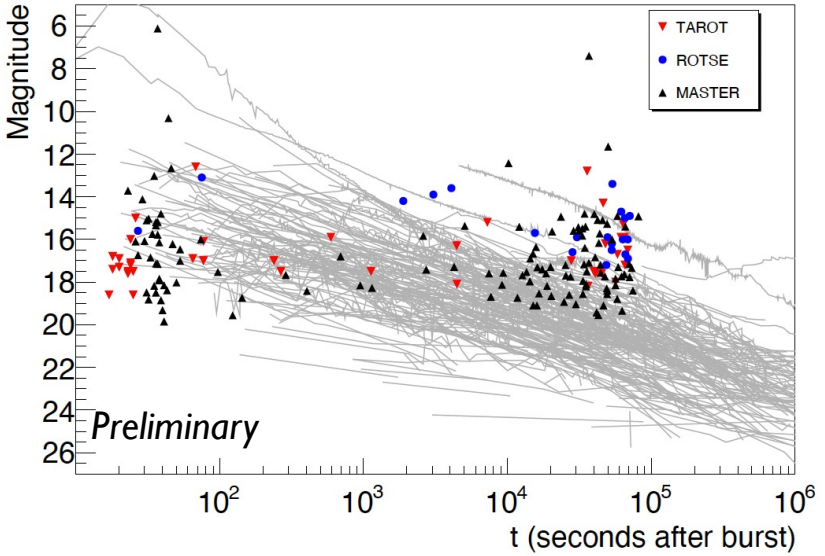
Long-term follow-ups
224 alerts allowed for good optical follow-ups for 2/3 nights
No significant slowly varying optical counterpart found

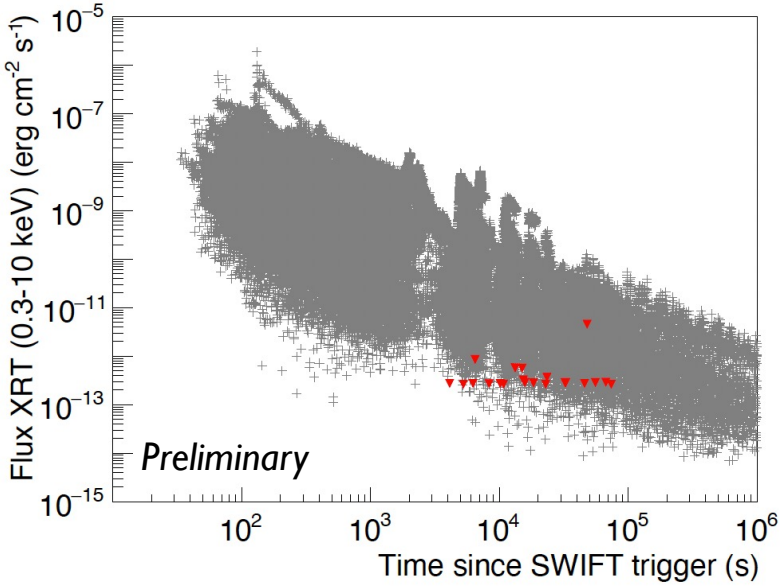
Radio follow-up
2 alerts followed by M.W.A.
No strongly varying radio counterpart identified

H.E.S.S. follow-up
2 alerts followed shortly after ν detection
No VHE candidates associated

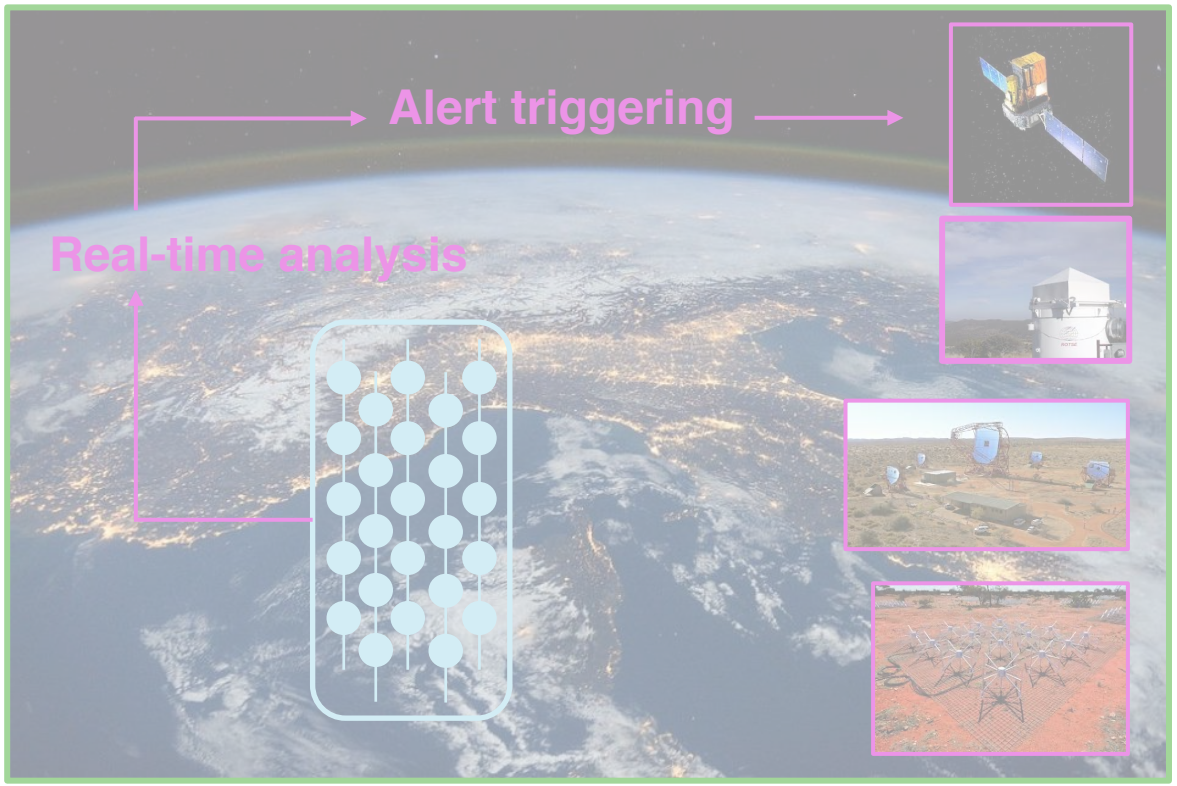
Search for correlation with sources
No significant correlation with GRBs/CCSNs/blazars found

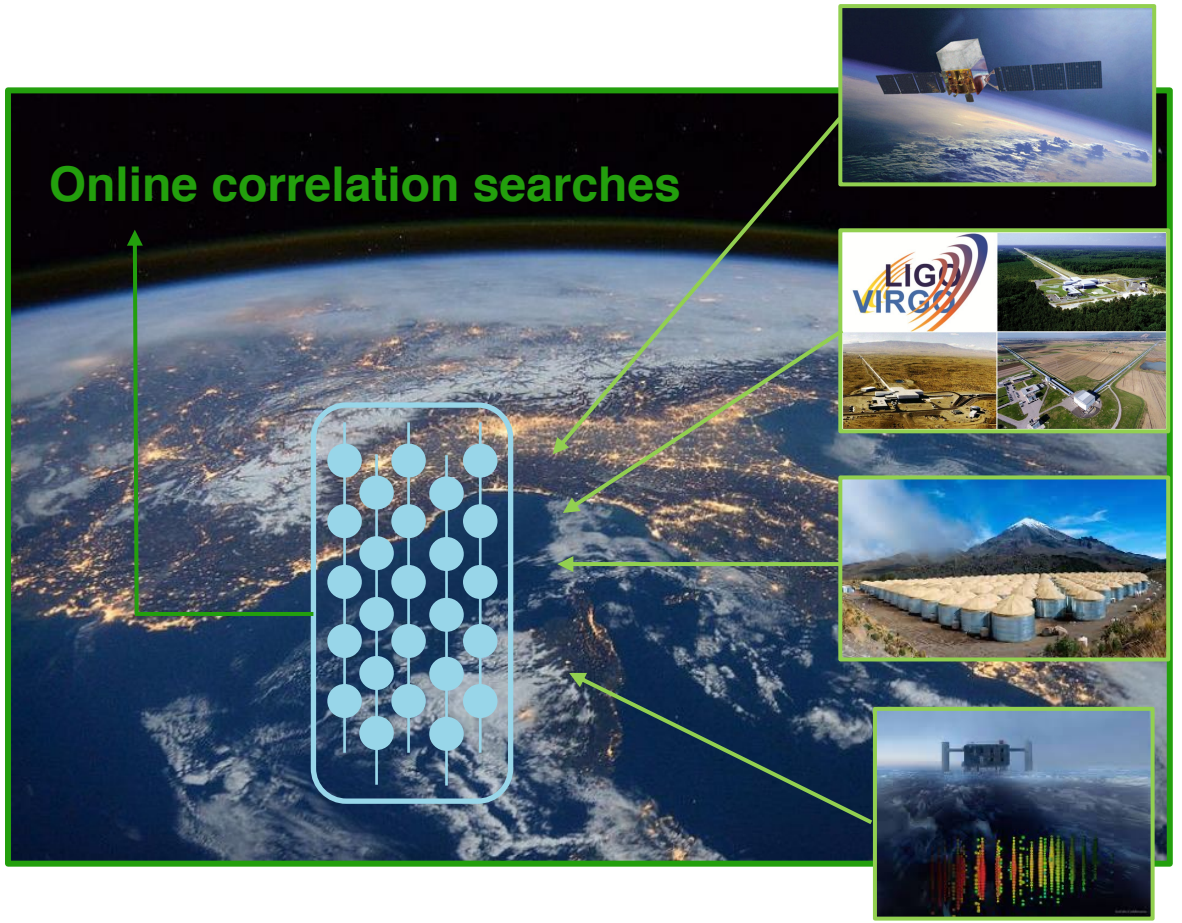
+ANT150901: only public alert with a complete MWL follow-up



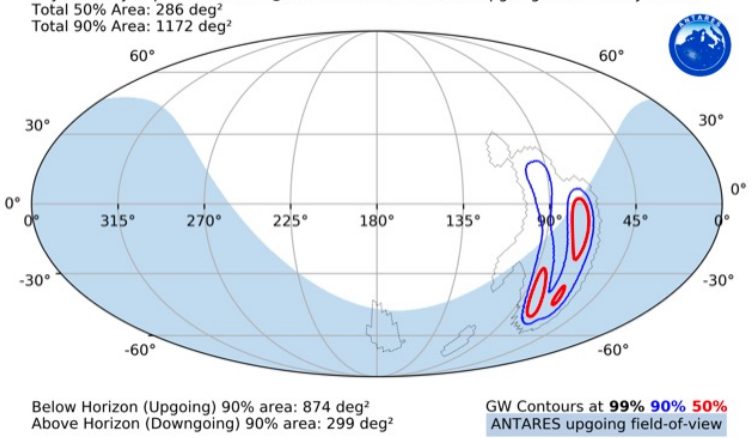


Online activities: 2 approaches

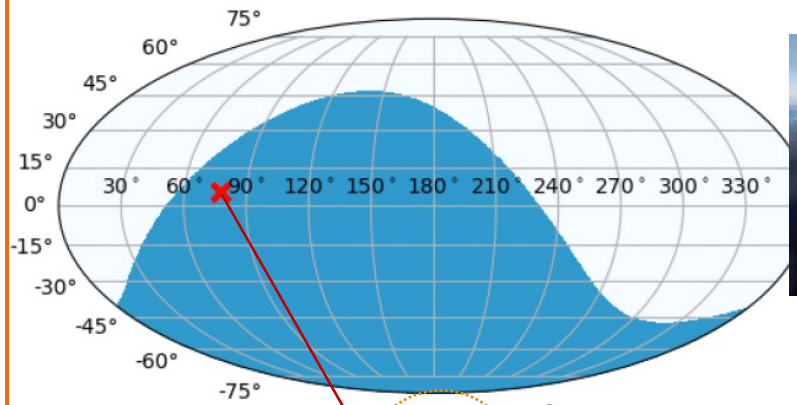


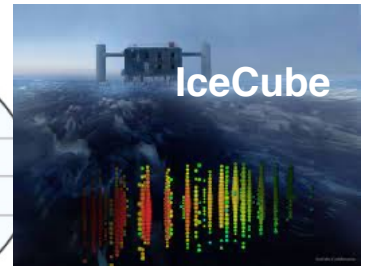


Examples of online ANTARES analyses



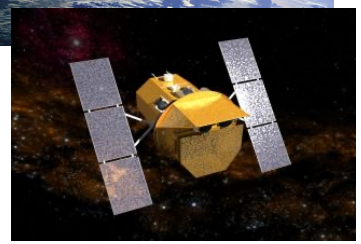
Search in
Spatial overlap between
90% GW contour and
ANTARES visibility region
±500 s and **±1 hour**

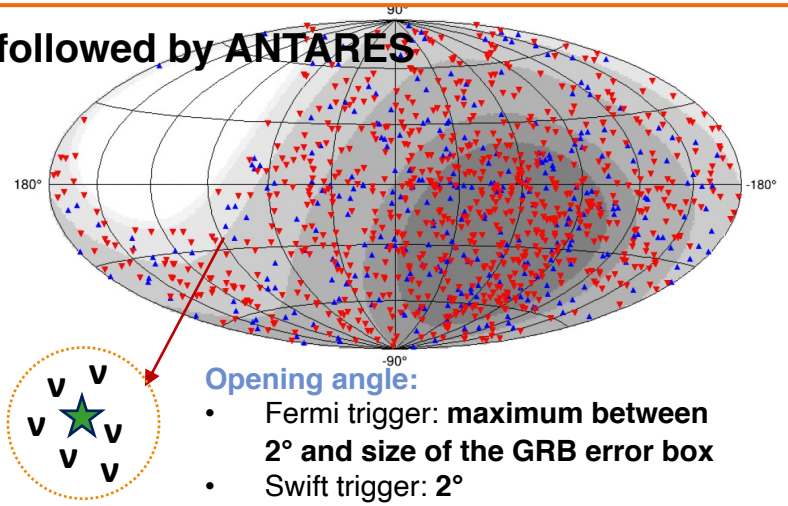




Search in
3° cone
±1 hour and **±1 day**

Fermi and Swift GRBs followed by ANTARES



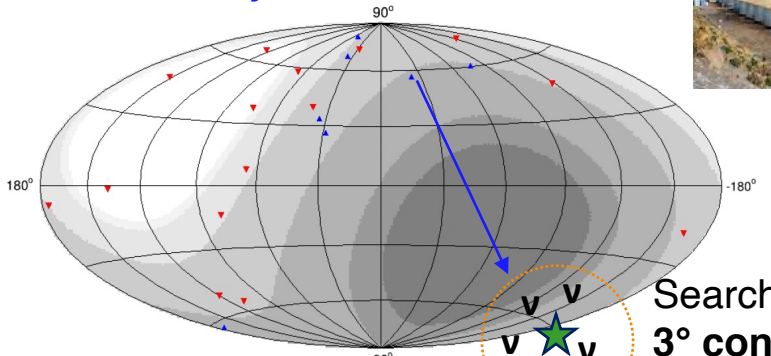


Opening angle:
- Fermi trigger: **maximum between 2° and size of the GRB error box**
- Swift trigger: **2°**

Time window:
[–250 s; +750 s] around the GRB time

HAWC alerts:

Not followed by ANTARES
Followed by ANTARES

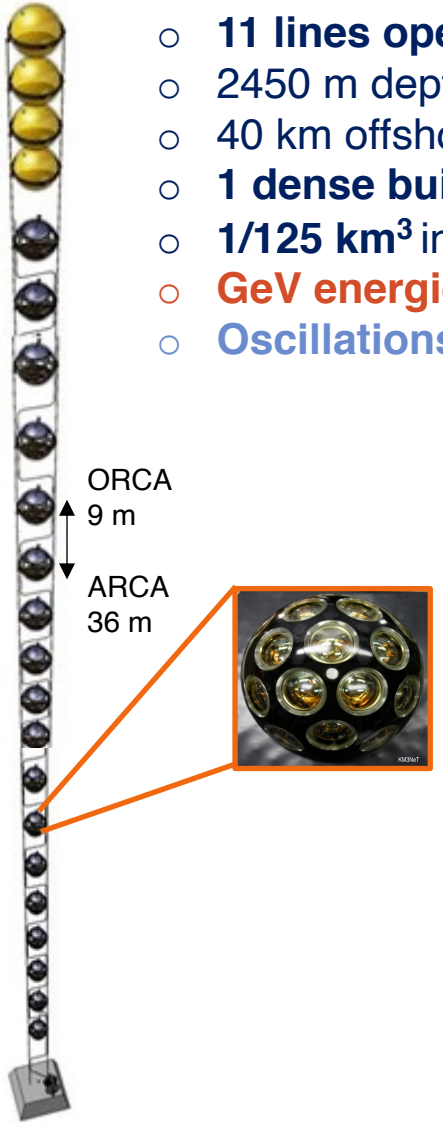


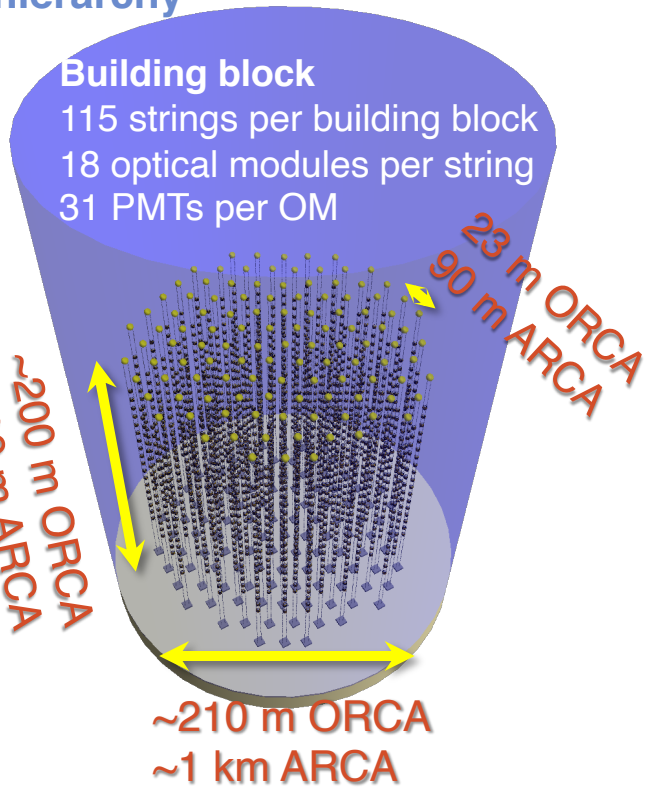
Search in
3° cone
±1 hour and **±1 day**

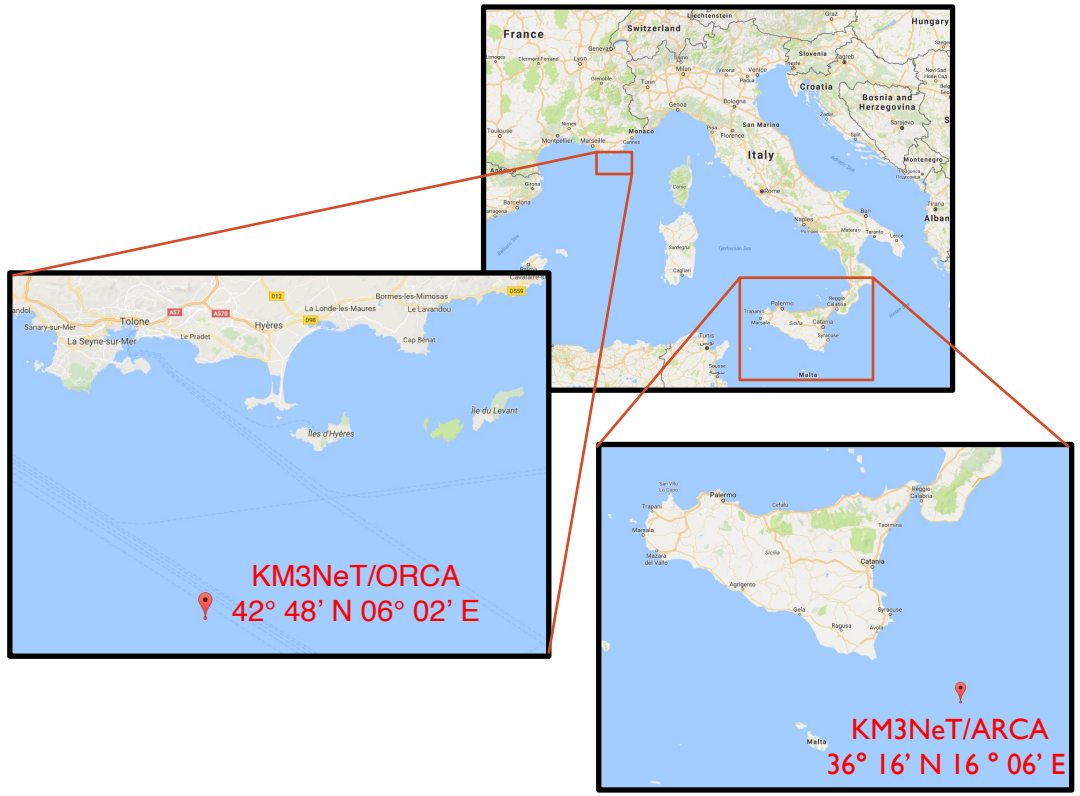
KM3NeT

KM3NeT/ORCA

- **11 lines operating**, 115 lines foreseen
- 2450 m depth in the Mediterranean Sea
- 40 km offshore from Toulon
- **1 dense building block**
- **1/125 km^3** instrumented volume
- **GeV energies**
- **Oscillations, mass hierarchy**







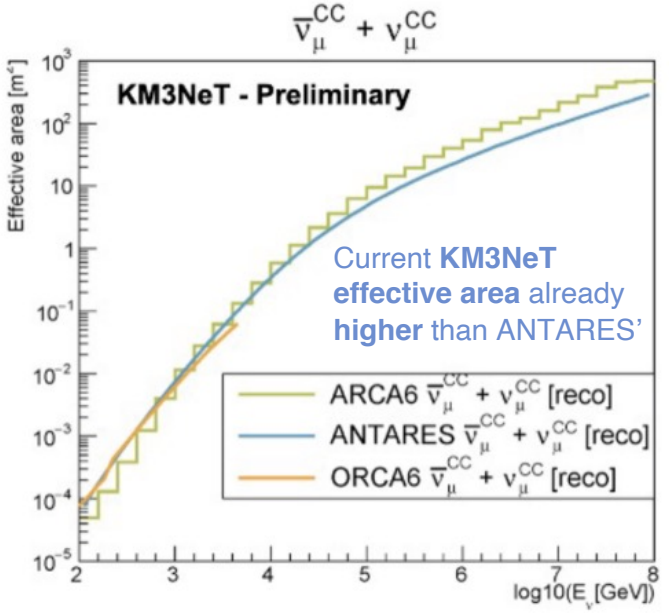
KM3NeT/ARCA

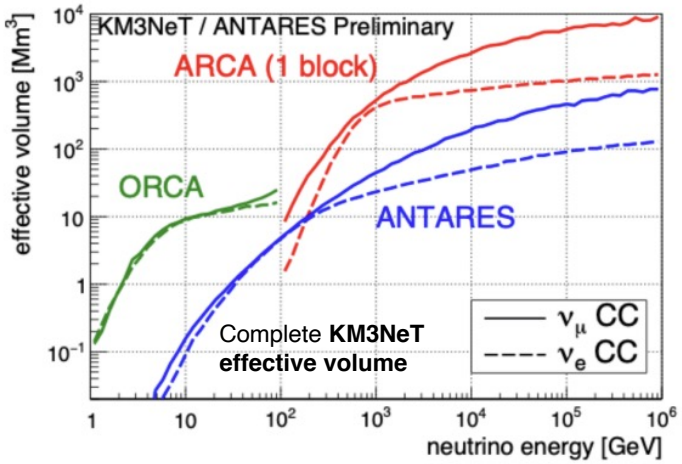
- **21 lines operating**, 230 lines foreseen
- 3500 m depth in the Mediterranean Sea
- 100 km offshore from Sicily
- **2 sparse building blocks**
- **1 km^3** instrumented volume
- **1-10 TeV energy threshold**
- **High-energy neutrino astronomy**

KM3NeT

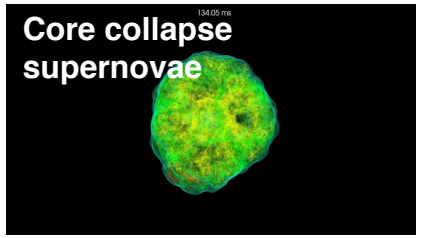
- Same **sky visibility** and **duty cycle** as ANTARES
- **Better** median **angular resolution**:
  - ARCA: **0.1° (1°) @1PeV for tracks (showers)**
  - ORCA: **< 5° @50GeV, 1° @1TeV**

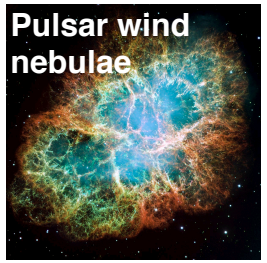
  - **Both ORCA and ARCA employed for astronomy**
    → Extended energy range:
    1 GeV → 10 PeV (+ 10-40 MeV)
    → vast **variety** of astrophysical sources

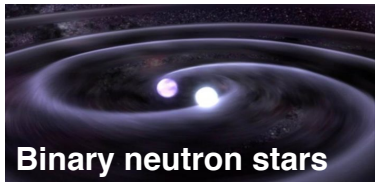


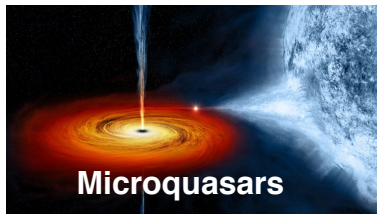


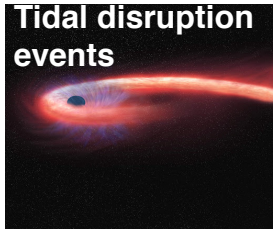
MeV **GeV** **TeV** **> PeV**











From ANTARES to KM3NeT: lessons learned

Online processing:

- Quite large difference between the online calibrations used for the reconstruction and the offline ones used in the offline analyses (no dynamical positioning)
- No online shower reconstruction => need to implement it (important discovery channel)
- Reduce the systematics on the angular direction of the alerts (good control of the pointing accuracy)

Neutrino alert selection:

- As the results were not so good, better neutrino selections
- Increase the scientific interest of the neutrino alerts (provide more astro content)
- Automatize the astro counterpart search directly at the alert level (crossmatch catalogs, LC…)
- Private / public neutrino alerts (how to optimize the follow-up)
- Uniformise the alert format: only VO event

Real-time correlation analysis:

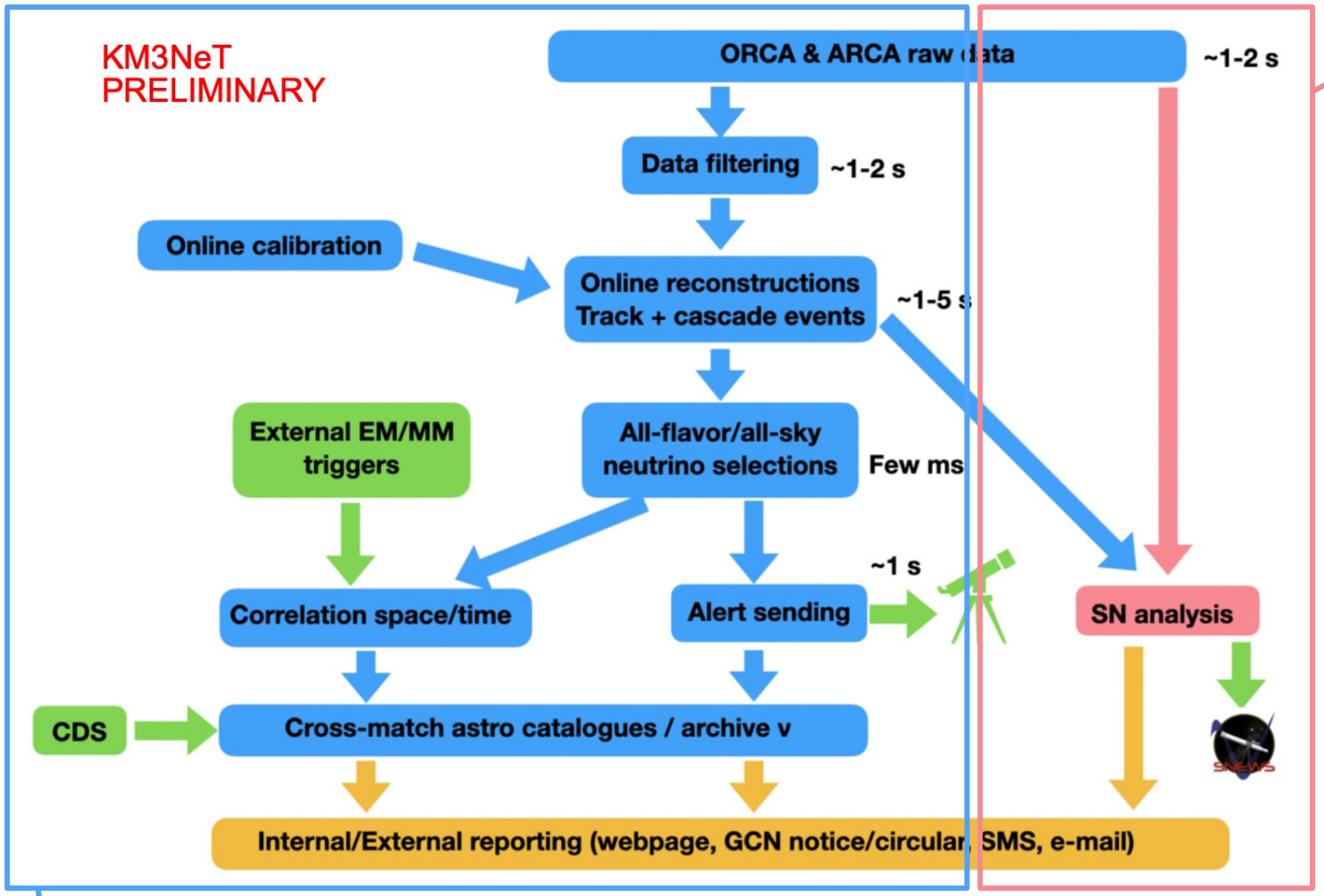
- Automatize the analyses as much as possible

Organisation:

- Have a real organized team to manage the online analyses, not only a few persons. Reinforce the MWL follow-up expertise in the collaboration. Provide some centralized tools for the shifters

Slide Credit: Damien Dornic

KM3NeT online analysis framework

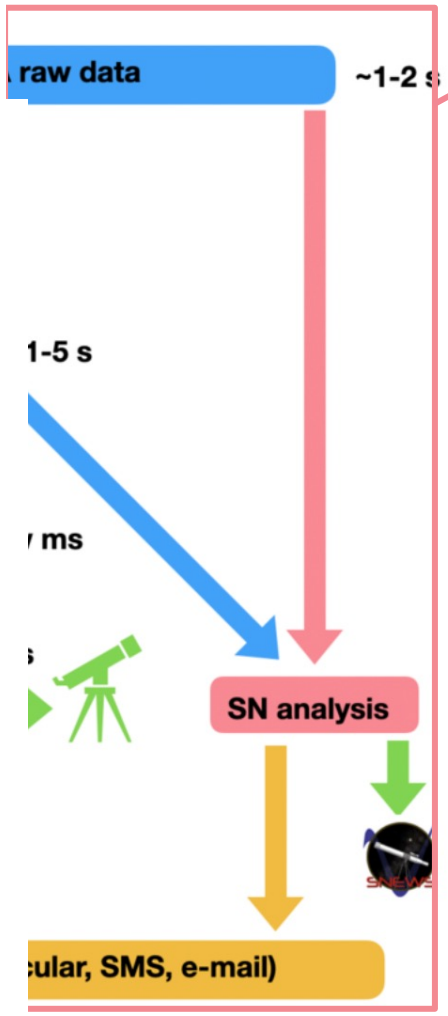


MeV Core-Collapse
Supernova Neutrino Pipeline
In place

High-energy Pipeline
Work in progress

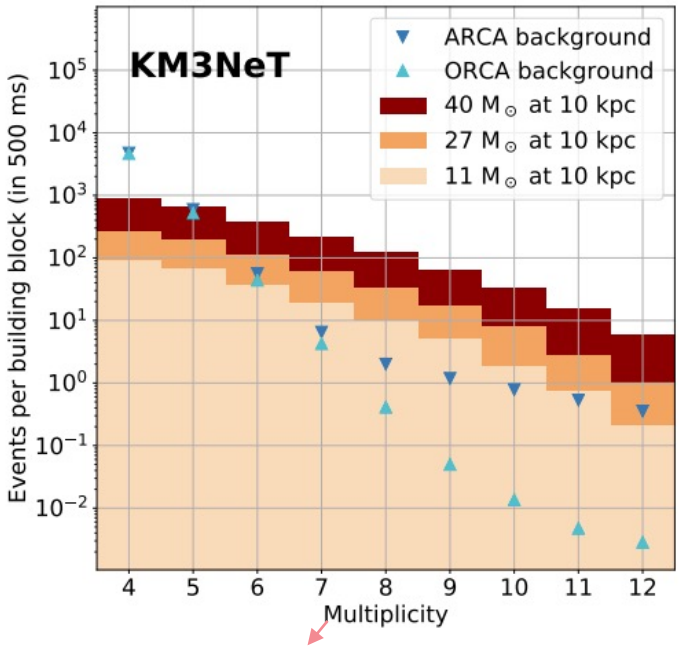
KM3NeT online analysis framework

PoS(ICRC2021)941
Eur. Phys. J. C 81, 445 (2021)
Eur. Phys. J. C 82, 317 (2022)

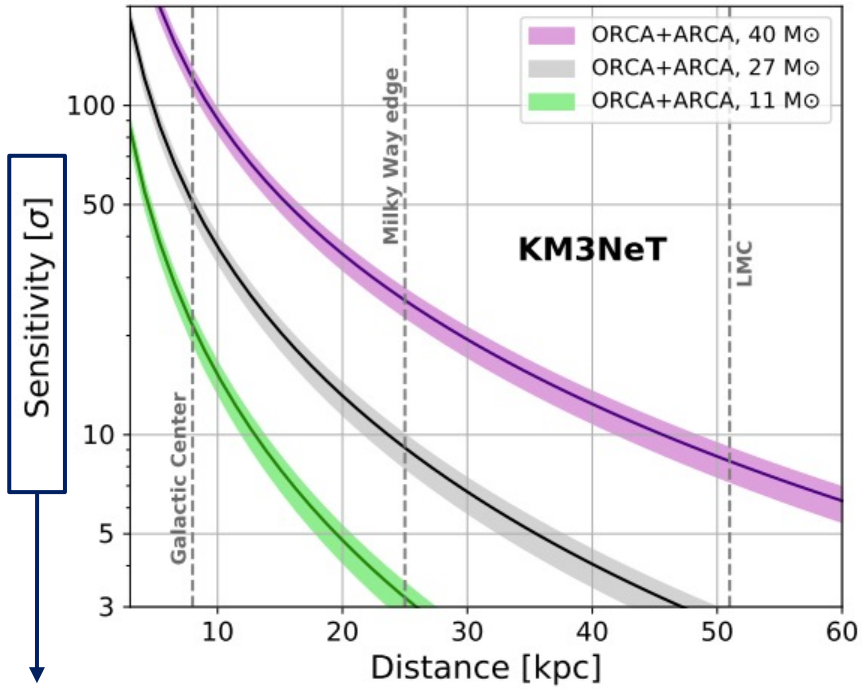


MeV Core-Collapse Supernova Neutrino Pipeline
In place

MeV neutrinos → no event-by-event reconstruction possible
Strategy: exploit collective increase of multiplicity rates in the detector



Number of PMTs in coincidence



With today's configuration (ARCA21+ORCA11) → 0.3*Sensitivity

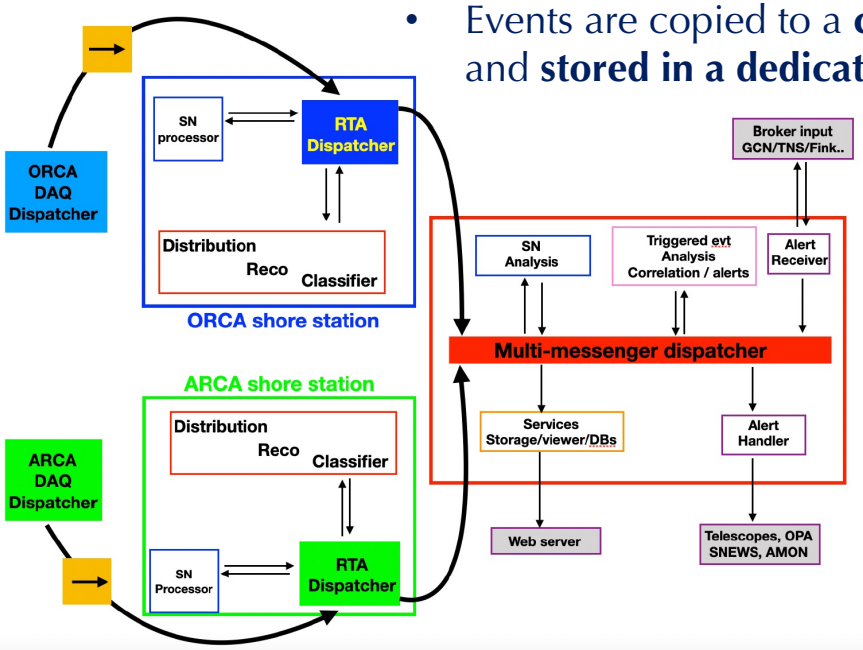
CCSN monitoring fully operational and connected to SNEWS

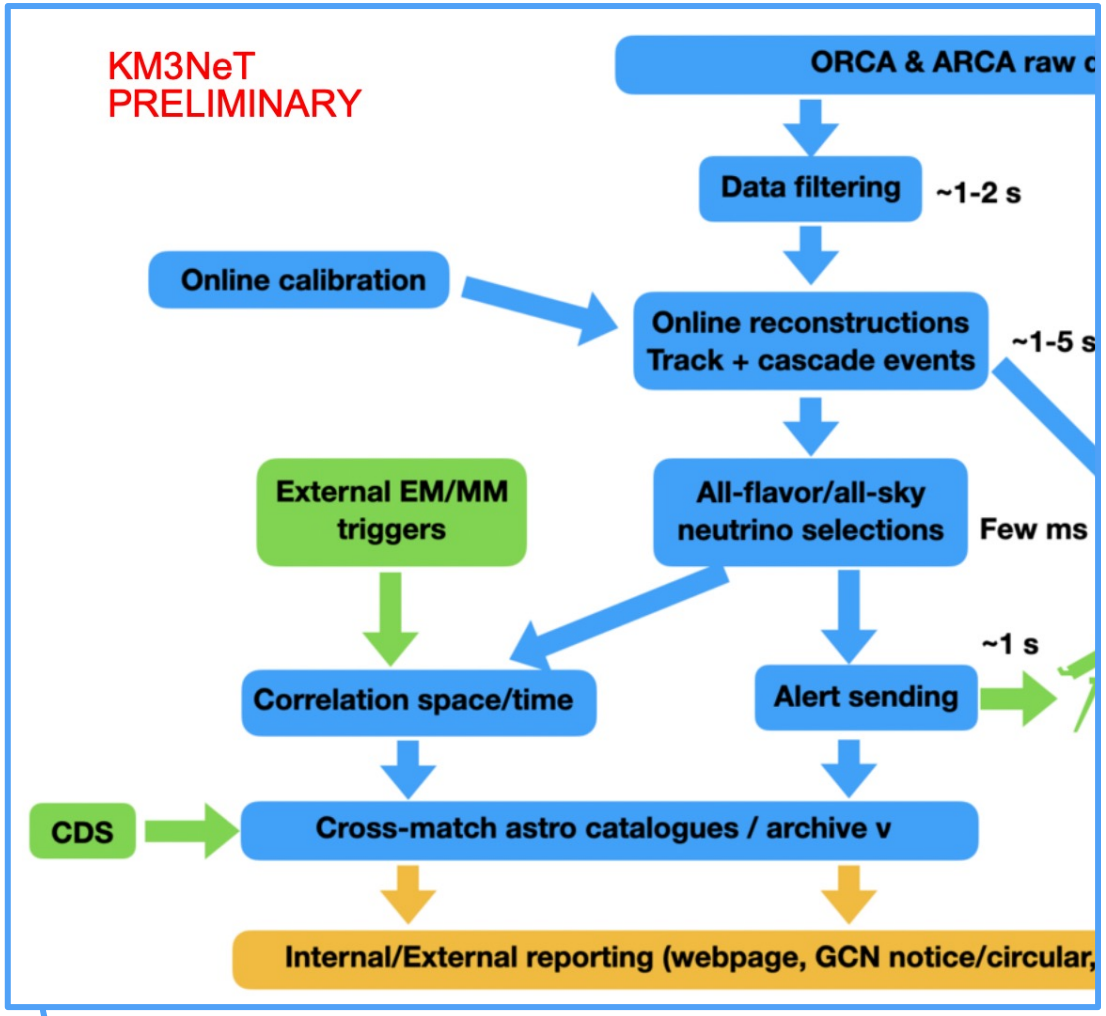
KM3NeT online analysis framework

Event processing:

- **Online calibration** -> working on including **dynamical positioning** (otherwise limited angular accuracy ~1-2 deg at HE, ~2-5 deg at LE)
- **Track & shower reconstructions** -> similar algorithms as offline, shower channel not yet in operation
- **Event classification** -> atmospheric muons-neutrinos, track-shower, atmospheric/cosmic neutrinos
- **Processing time:** 30 s –> 10-15 s after removing buffer

- Events from each detectors **processed separately**
- Events are copied to a **common event dispatcher** and **stored in a dedicated DB**



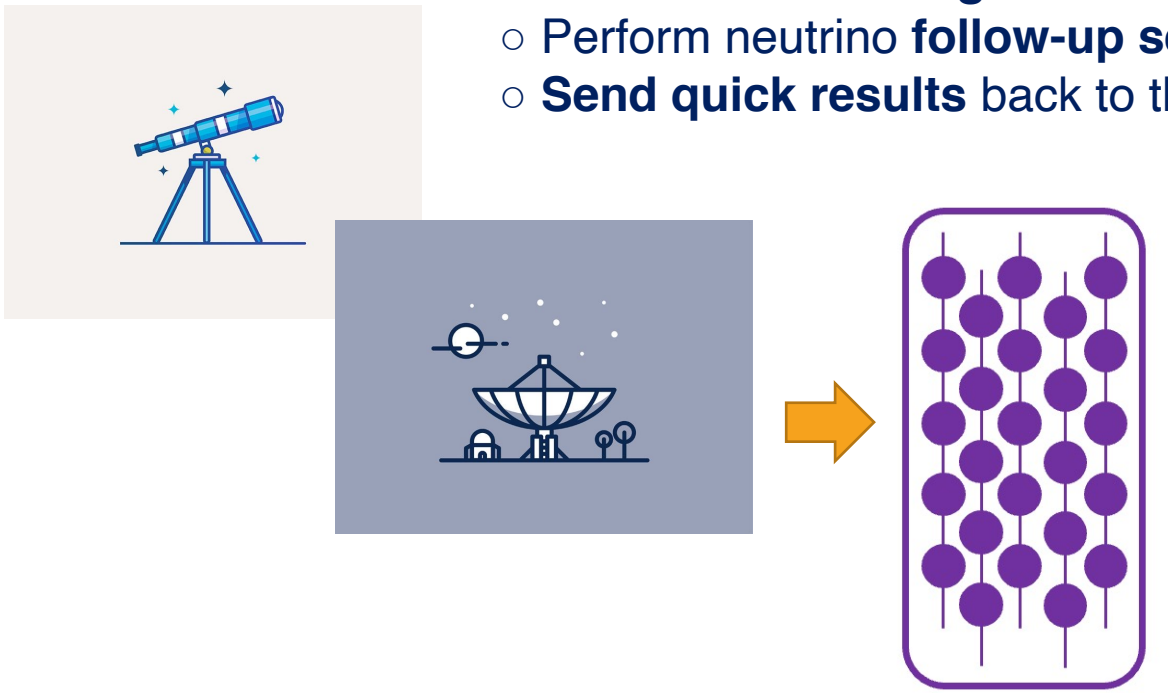


High-energy Pipeline
Work in progress

KM3NeT real-time follow-up pipeline

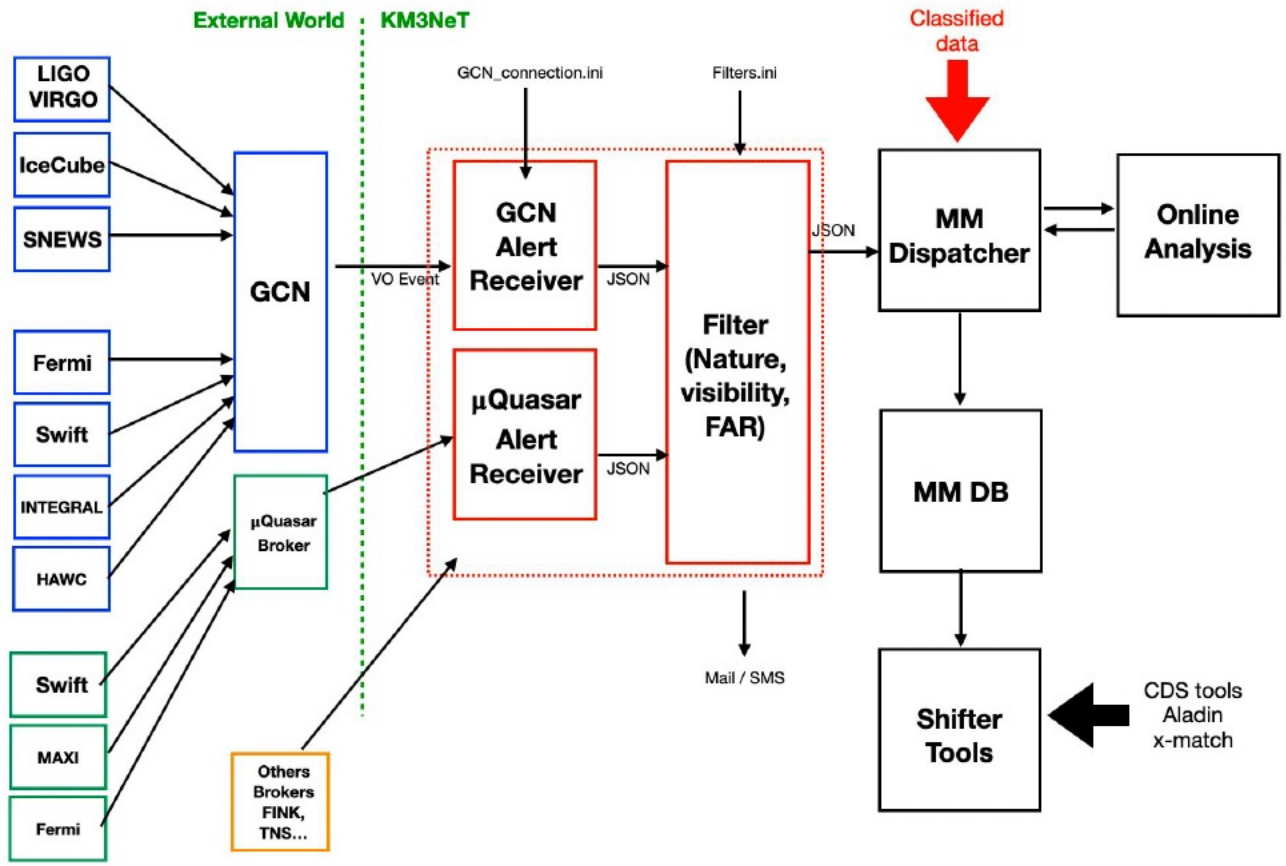
Goals:

- Find **multi-messenger** correlated signal
- Perform neutrino **follow-up search from external alerts**
- **Send quick results** back to the public



KM3NeT real-time follow-up pipeline

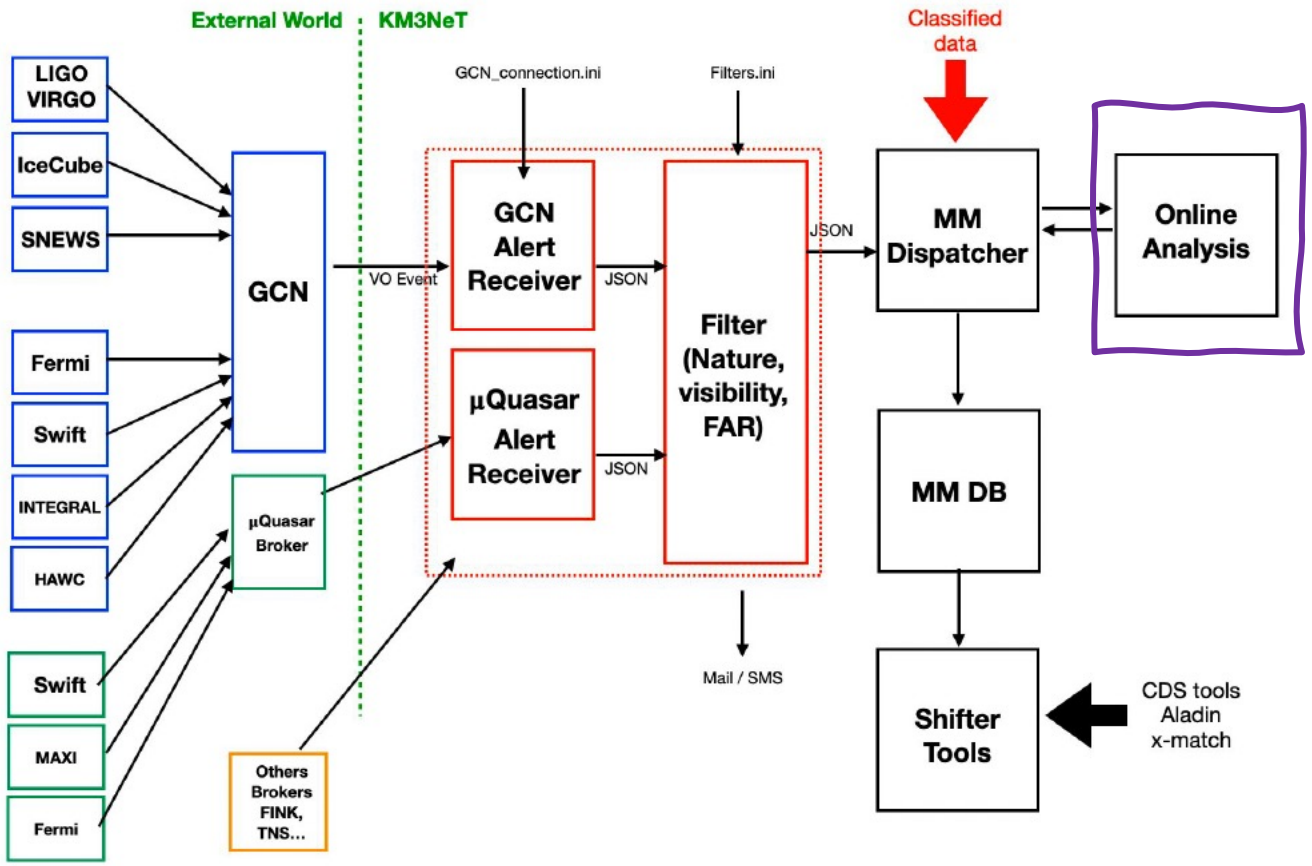
Framework overview



Plot Credit: Sébastien Le Stum

KM3NeT real-time follow-up pipeline

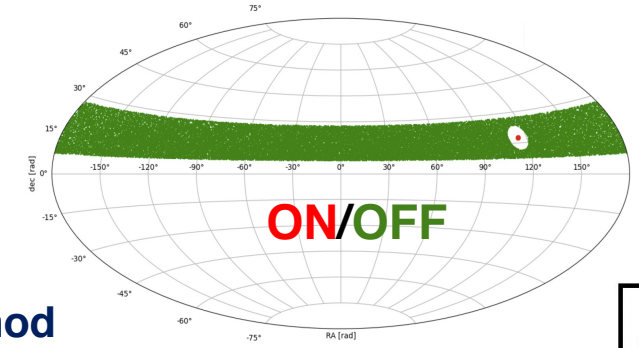
Online analysis



Plot Credit: Sébastien Le Stum

KM3NeT real-time follow-up pipeline

Online analysis



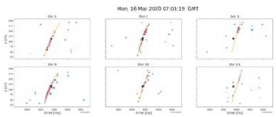
- Binned analysis with an **ON/OFF method**
- **Regions definition:**
  - **ON:** Cone around the source (ROI)
  - **OFF:** Declination band containing the source declination
- **Event selection**
  - Optimisation: **MRF/MDP**
  - Parameters:
    - ROI size
    - Neutrino purity: simple cuts, BDT score
- **Time window:** +/- 24h around the alert
  - Analysis starts at alert reception and is updated for 24 hours

Example of analysis output

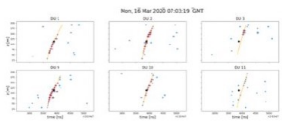
Results:

N_S :	2
N_B :	1.04
μ_B:	1.5
P-value :	0.23
U.L. (90% C.L.):	0.12 GeV/cm²

Detector stability:



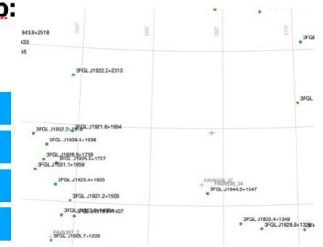
Event 1
IO_SCORE values



Event 2
IO_SCORE values

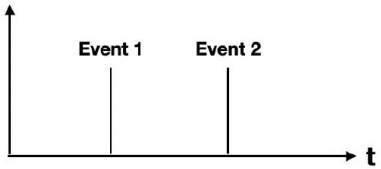
Skymap:

Aladin
TNS
FAVA
Fink



Aladin skymap
+ include source list from Aladin/TNS/...

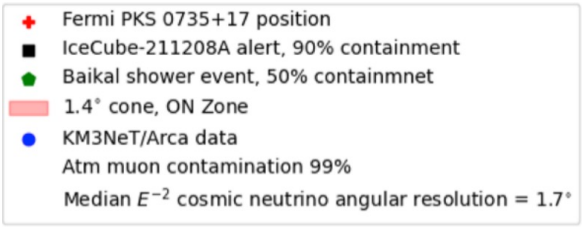
Lightcurve:



Update LC background with FAVA LC,...

KM3NeT real-time follow-up pipeline

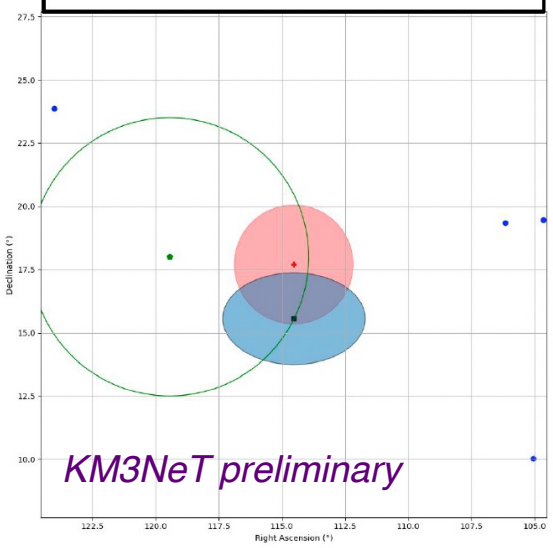
Online analysis



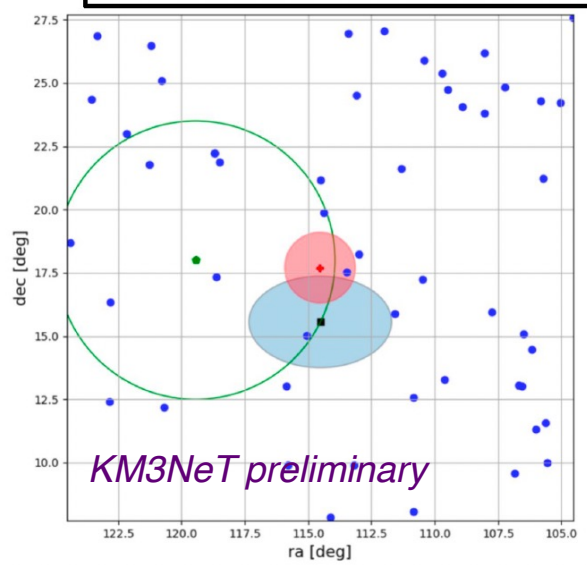
⇒ Same analysis method applied "offline" on multiple IceCube alerts associated with blazars:

- TXS0310 (IC220304A-GOLD)
- PKS0215 (IC220225A-BRONZE)
- PKS1741 (IC220205B-GOLD)
- PKS0735 (IC211208A-BRONZE, GVD211208A, Baksan)
  - Additional 1 month time window motivated by FERMI flare

ORCA PKS0735 1 month skymap



ARCA PKS0735 1 month skymap



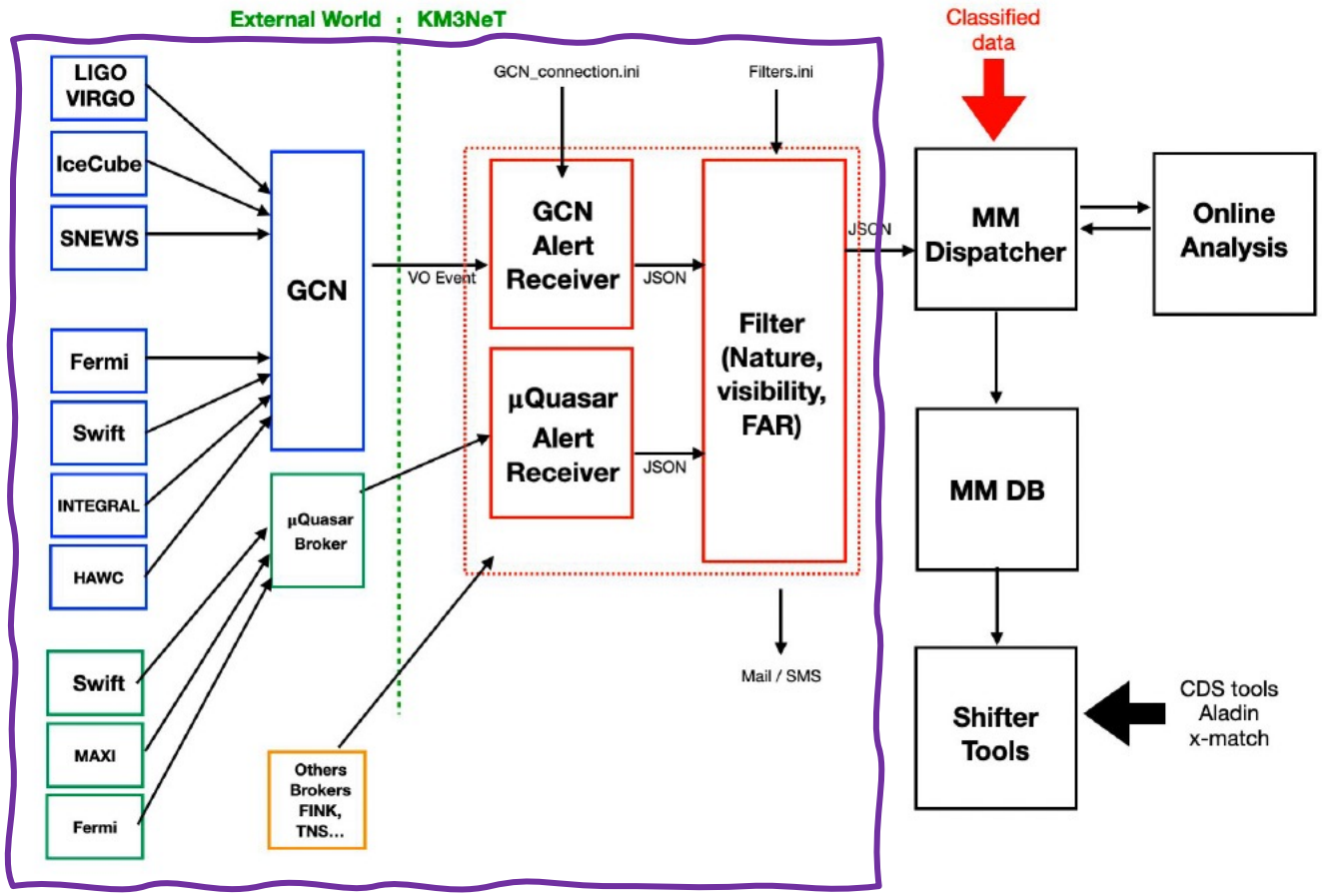
Results:

- **1 associated ARCA neutrino** candidate with **PKS0735** in the one-month time window, p-value = 0.14
- No association for the other blazars
- Reported in ATel #15290

⇒ Implementation in the online framework in progress

KM3NeT real-time follow-up pipeline

Alert handler



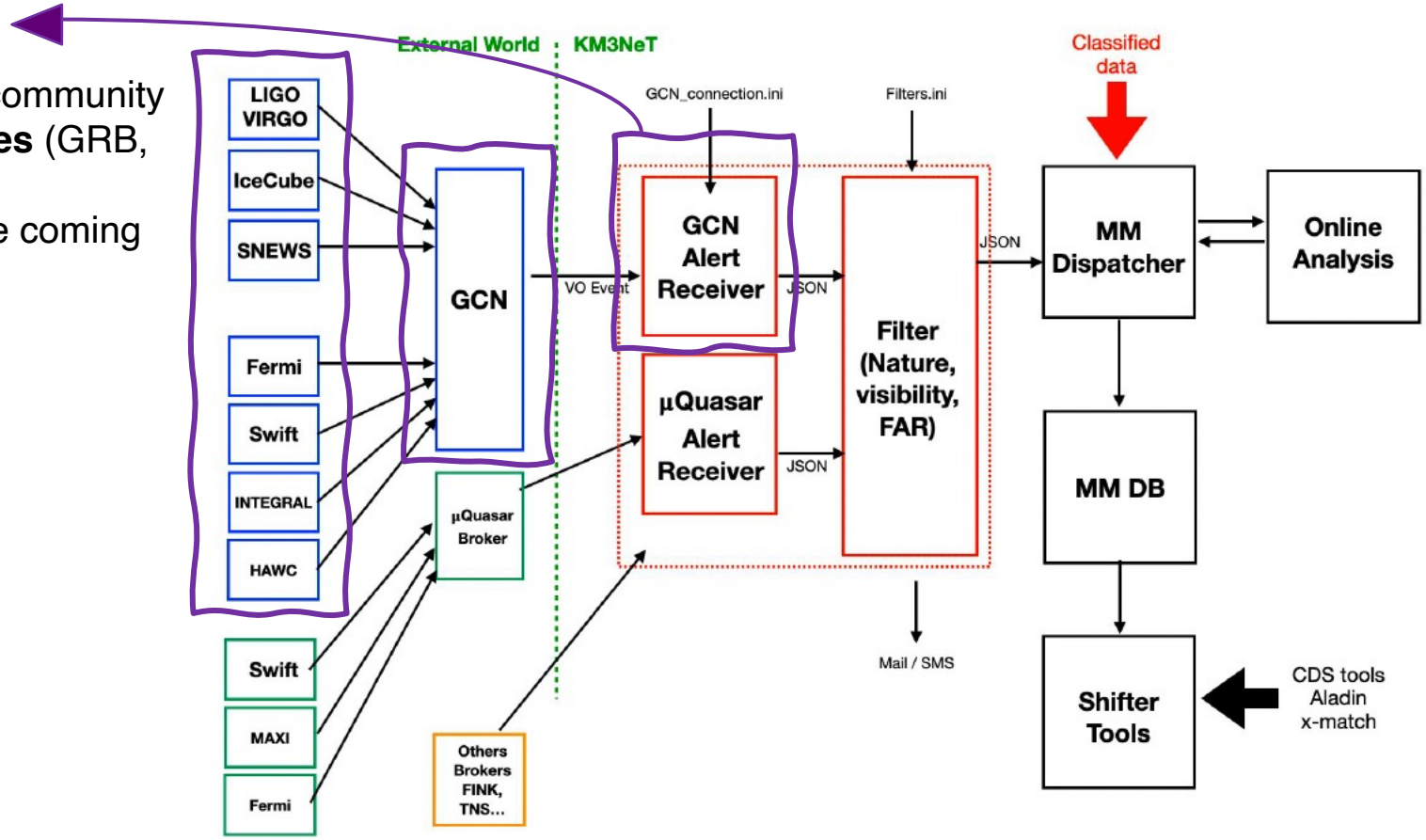
Plot Credit: Sébastien Le Stum

KM3NeT real-time follow-up pipeline

Alert handler

From public GCN notices:

- Commonly used in the transient community
- **Multiple sources and event types** (GRB, GW, Neutrino events, …)
- Volume of alerts to increase in the coming years ⇒ **need for filtering**



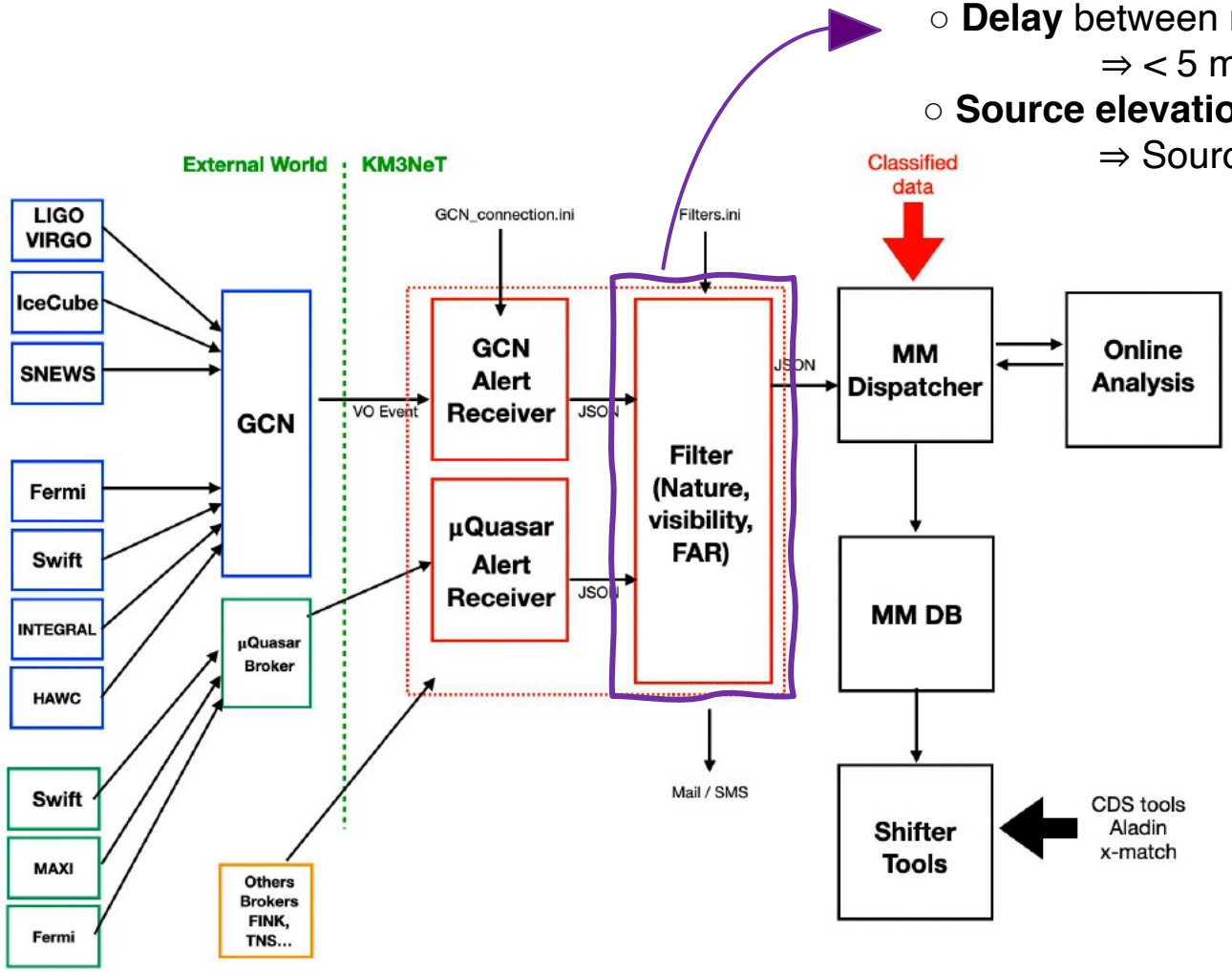
Plot Credit: Sébastien Le Stum

KM3NeT real-time follow-up pipeline

Alert handler

GCN notices filtering:

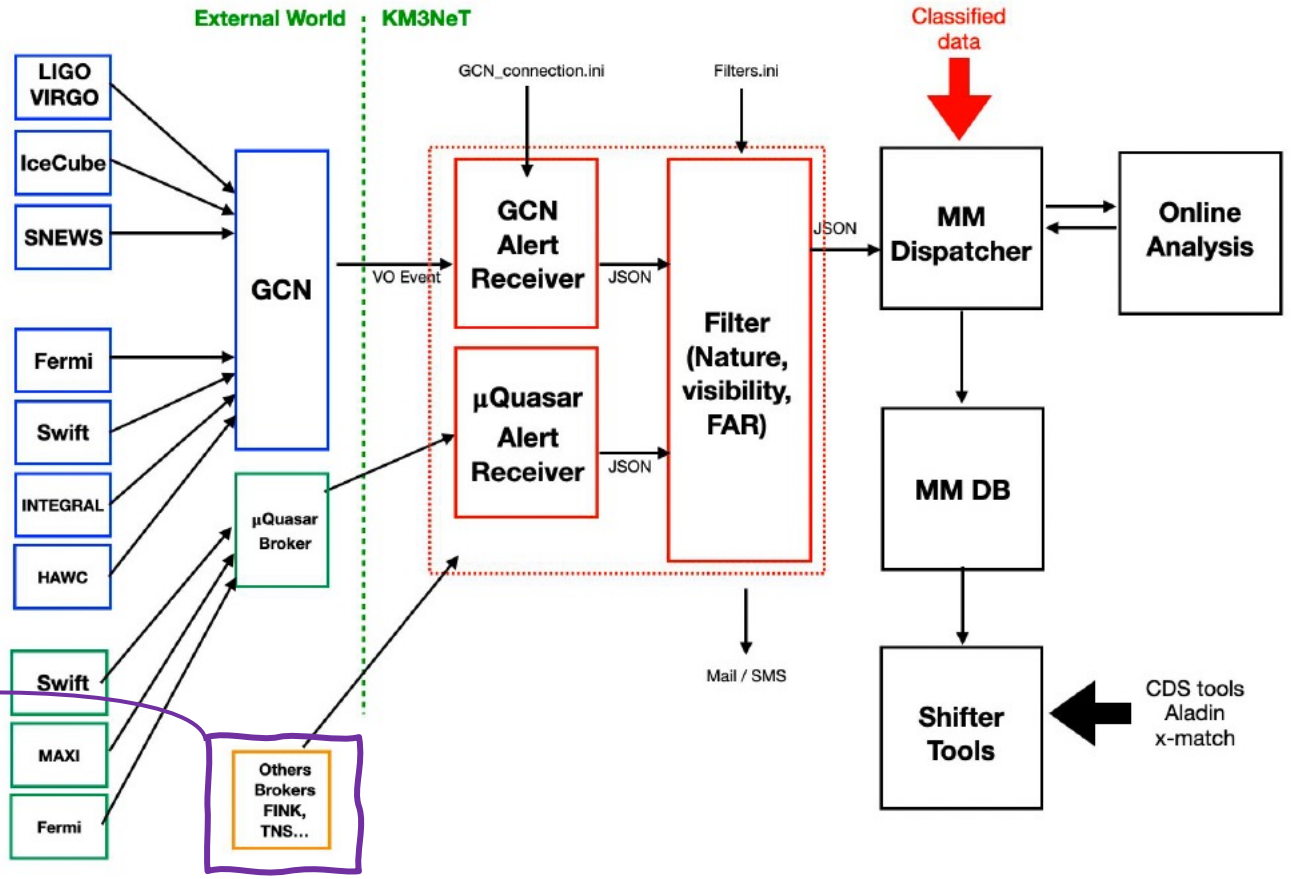
- **Delay** between notice and event
  ⇒ < 5 minutes for GRBs
- **Source elevation** (observability)
  ⇒ Source below horizon
- **FAR**



Plot Credit: Sébastien Le Stum

KM3NeT real-time follow-up pipeline

Alert handler



Additional brokers:

Alert handler from other brokers to be implemented to follow-up on more channels/phenomena

- **FINK (ZTF/LSST) - Optical**
- **TNS - SNs/FRBs**

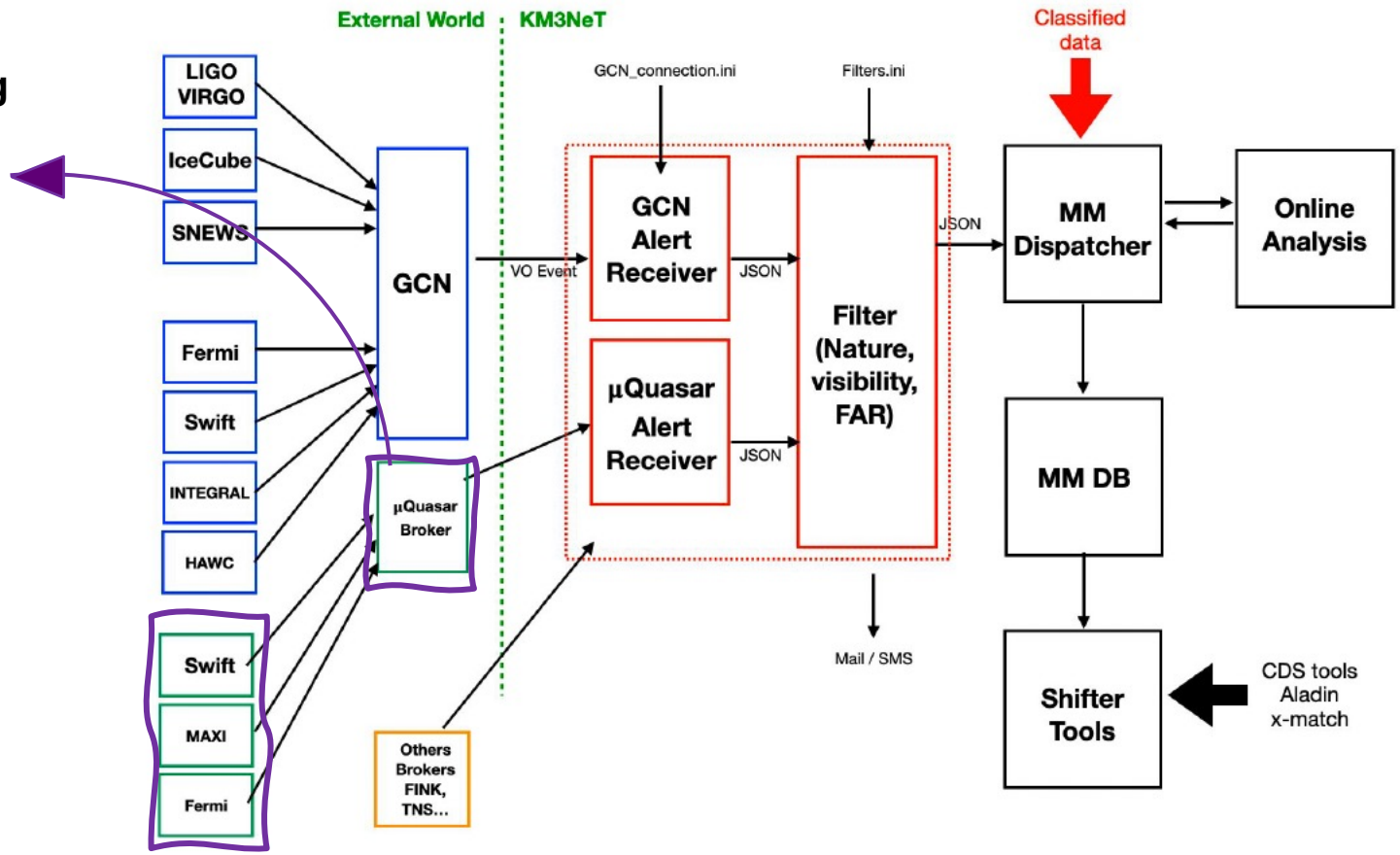
Plot Credit: Sébastien Le Stum

KM3NeT real-time follow-up pipeline

Alert handler

MicroQuasar broker

- **Goal: multiwavelength monitoring** of a list of known sources
- Looks for **new flares** from a list of microquasars
- Use publicly available **SWIFT/BAT** and **MAXI** lightcurves and **FERMI-LAT** data
- Search for **neutrinos during flares**

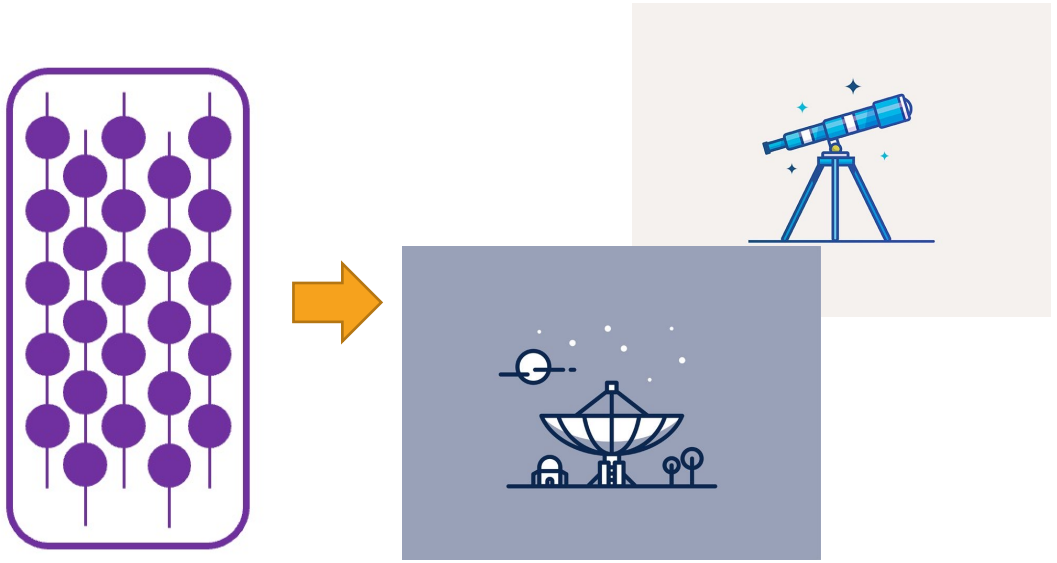


Plot Credit: Sébastien Le Stum

KM3NeT neutrino alert pipeline

Goals:

- Find **multi-messenge**r correlated signal
- Look for promising cosmic neutrino signature in real-time
- **Send quick alerts**

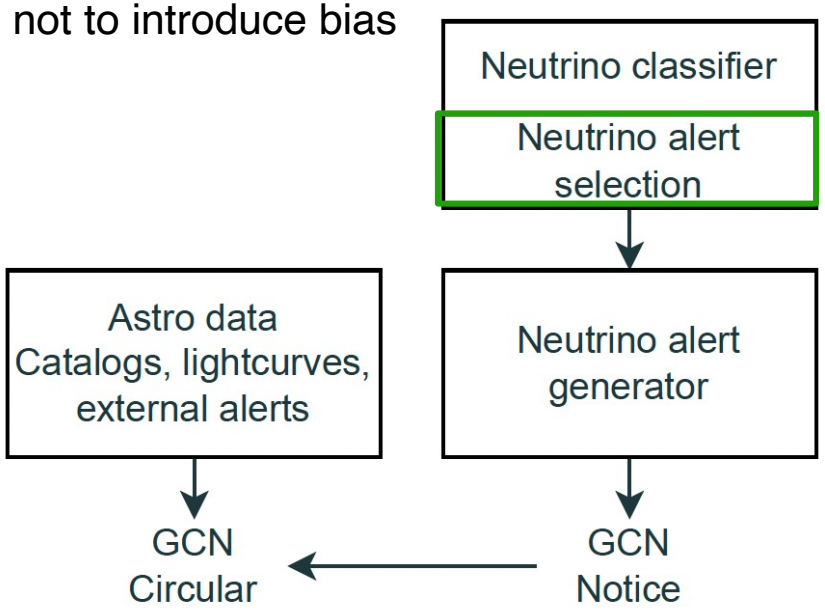


KM3NeT neutrino alerts: new strategy

- Between **100 and 200 neutrinos per day expected** (with full detector)
- From hundreds of neutrinos per day, a few **alerts** per month **to be selected**
- → **two parallel selections**

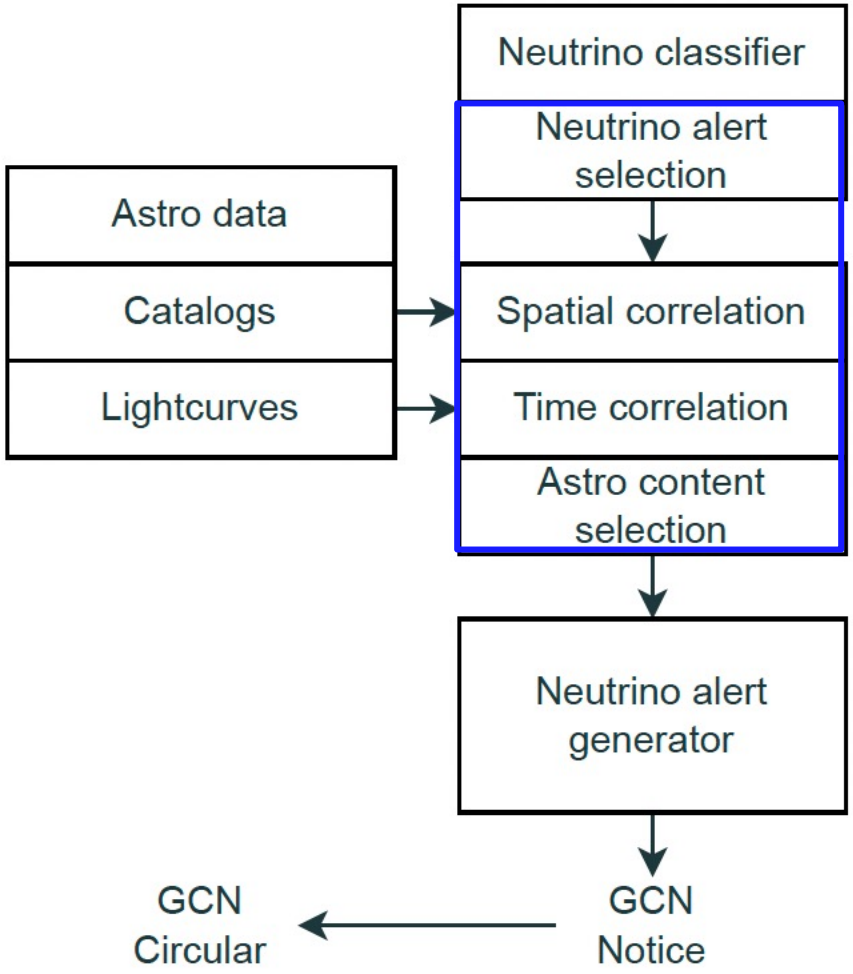
Pure neutrino selection

- based **only** on properties of **neutrinos**
- **VHE** and **multiplet** triggers
- kept not to introduce bias



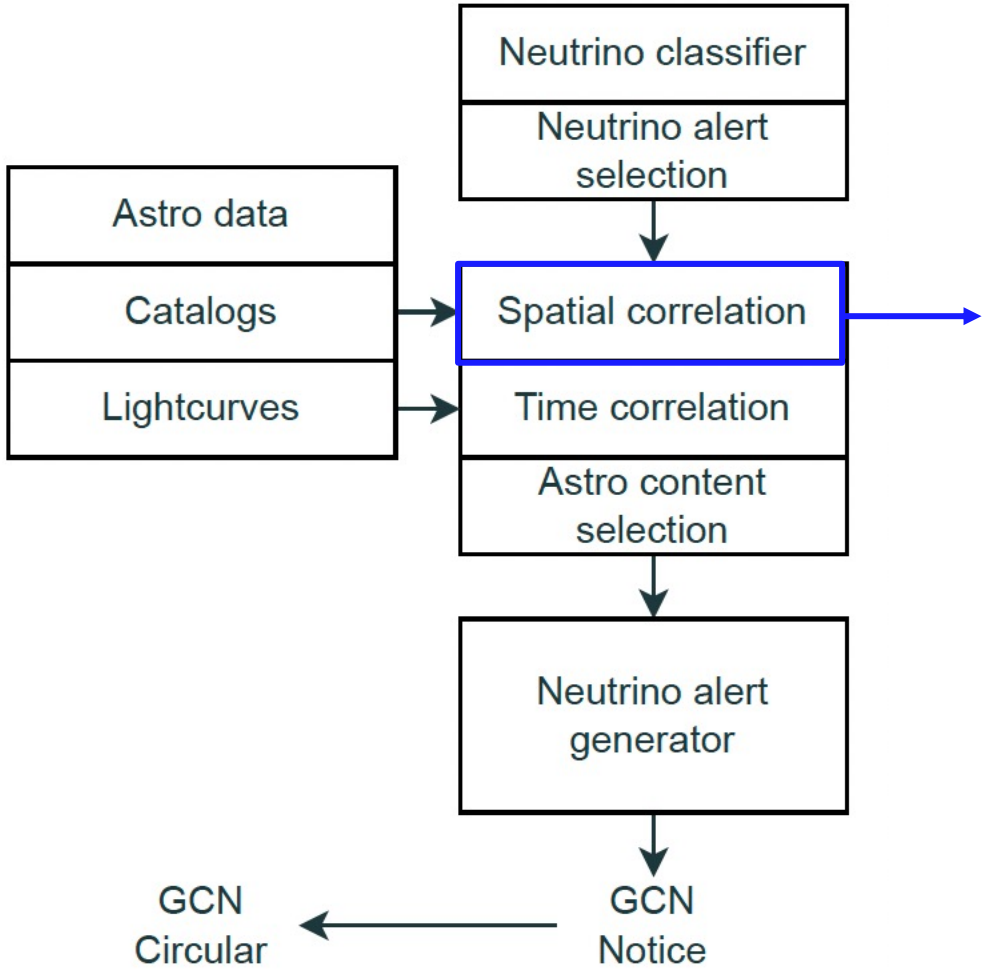
Mixed neutrino-astro selection

- based on the properties of **both neutrinos and potential associated source**



Plot Credit: Godefroy Vannoye

KM3NeT neutrino alerts: new strategy

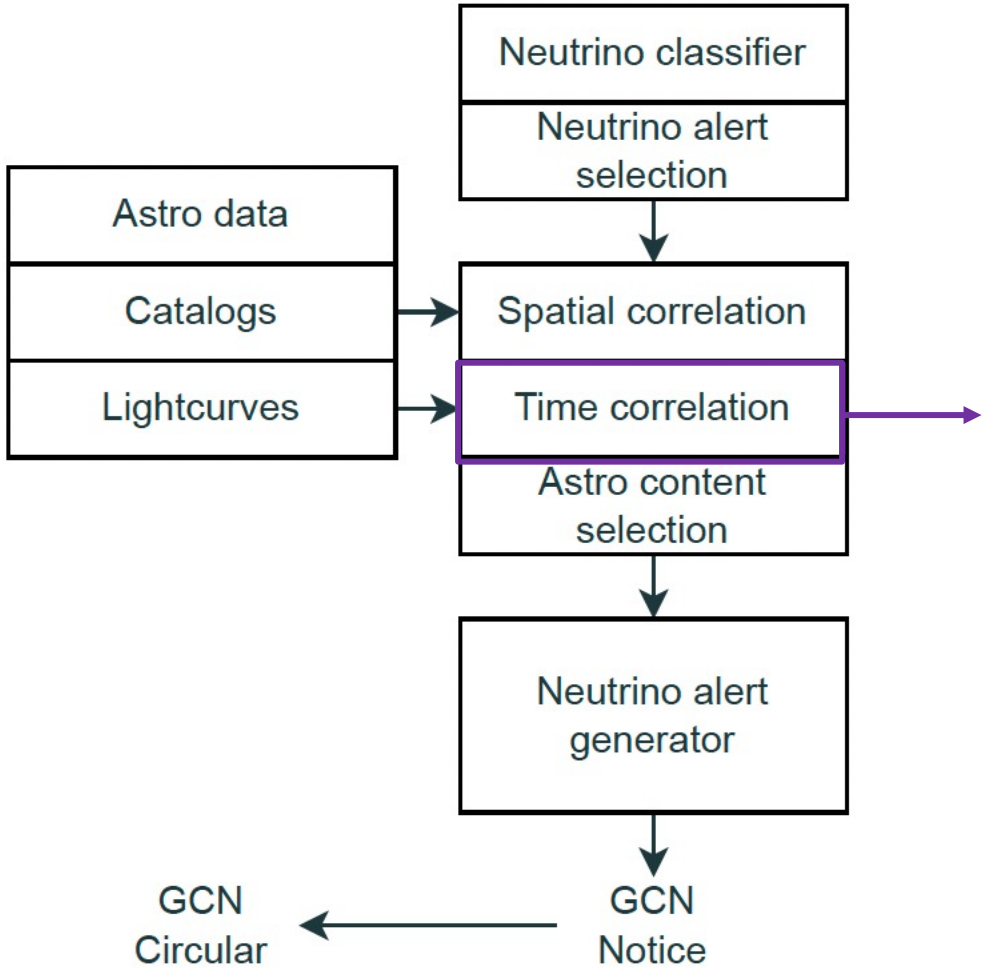


Spatial correlation scan

- Spatial **crossmatch with** sources of the **Strasbourg astronomical Data Center** (CDS) and specific catalogs **for each neutrino alert**
- **Selection of interesting sources** based on optical, gamma and radio properties ⟹ **derive source ranking**
- **Proof of concept with AGNs** planned for next months

Plot Credit: Godefroy Vannoye

KM3NeT neutrino alerts: new strategy

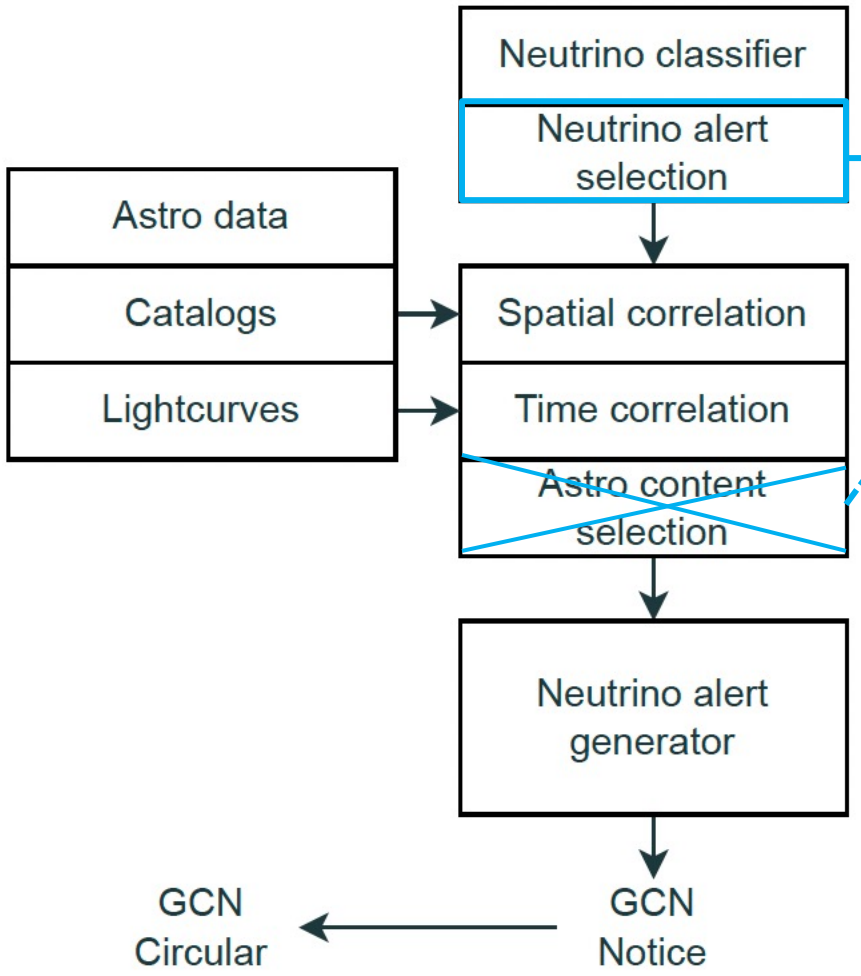


Time correlation scan

- For each interesting source, send request to **ZTF/LSST** via the Fink broker for **optical lightcurves and FAVA** (Fermi All-sky Variability Analysis) to check for (lack of) flares
- **Reranking of the sources** accordingly

Plot Credit: Godefroy Vannoye

KM3NeT neutrino alerts: new strategy



Pure neutrino alert selection

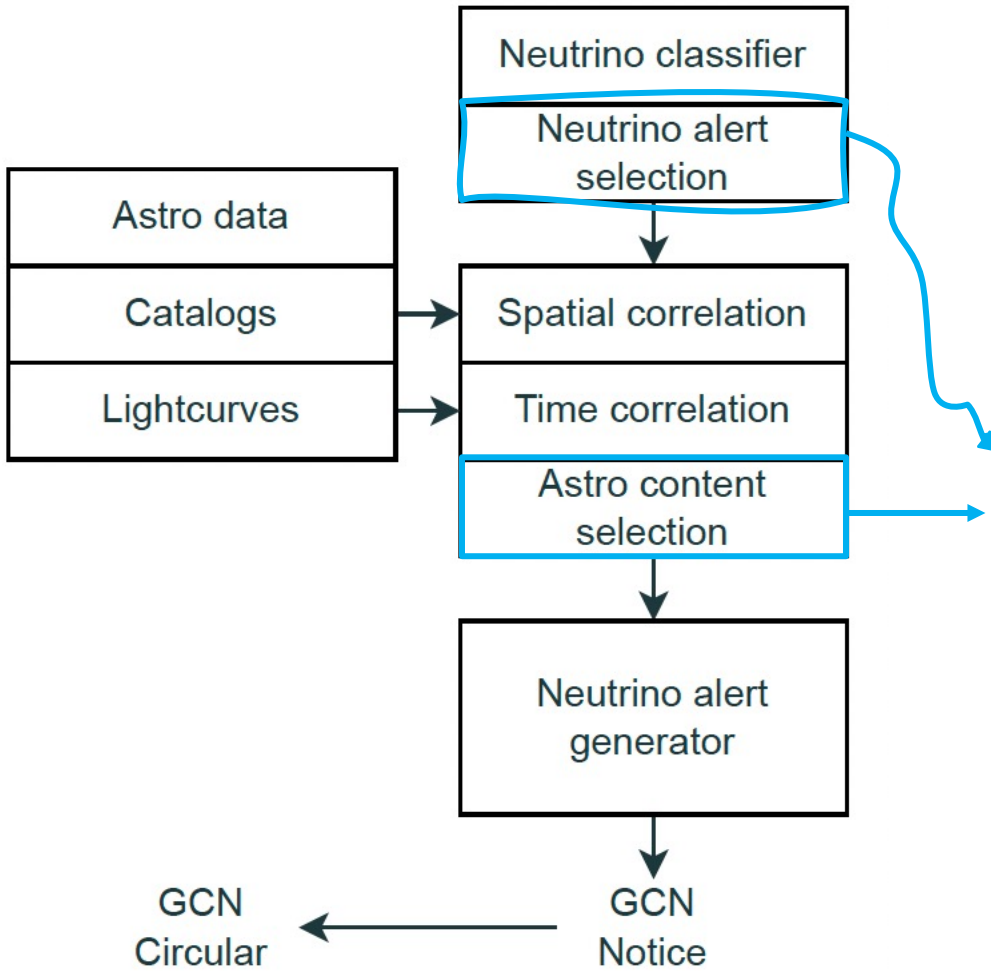
As a first step:

- **only selection** based on **neutrino properties**
- no selection on astrophysical content
- include astrophysical information in the GCN

- **VHE events**
- **Multiplets**

Plot Credit: Godefroy Vannoye

KM3NeT neutrino alerts: new strategy



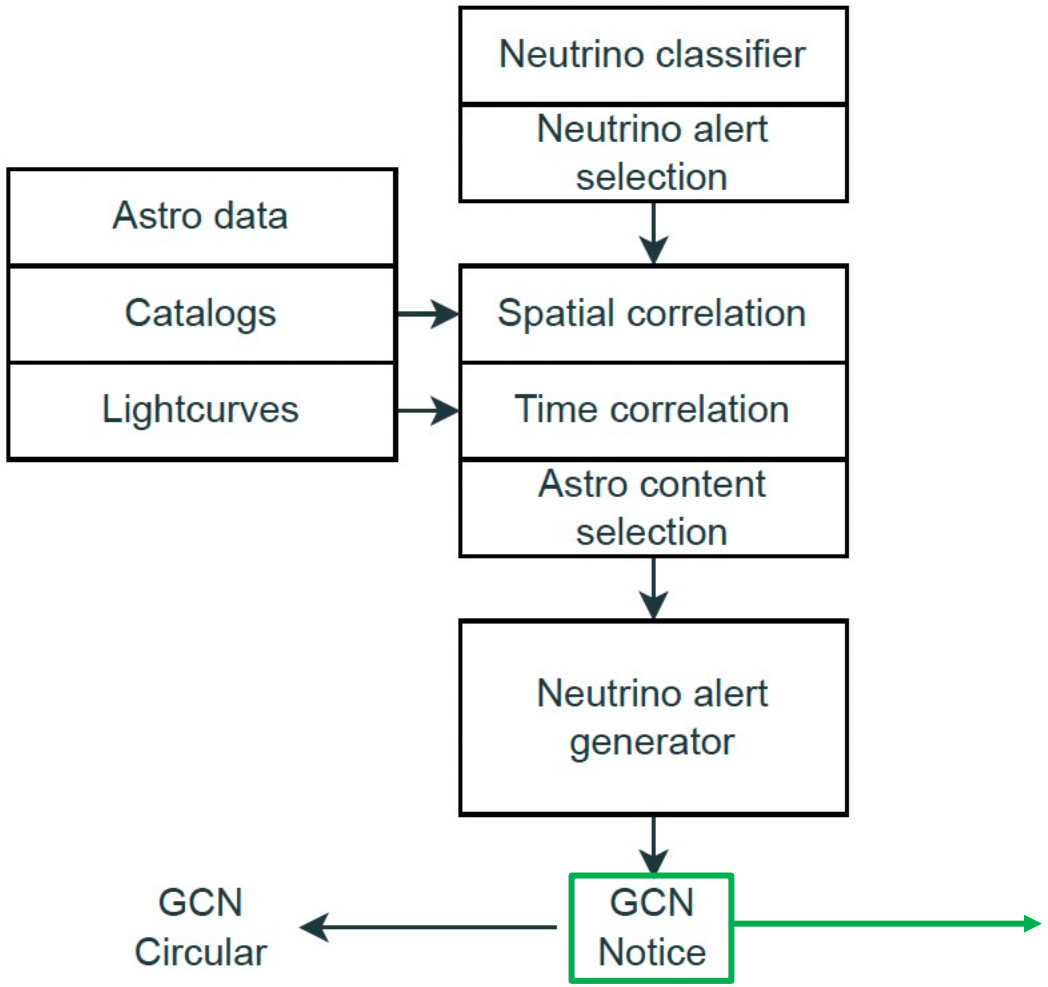
Mixed neutrino-astro selection

- **relax** selection on **neutrino properties**
- **apply selection** on **astrophysical** content
- keep an alert rate of 1-2 per month

- **Avoid bias** depending on which **estimator** is used
- **Recover** lower energy but **still interesting** neutrinos
- Help **maximize** the chances of **follow-ups**

Plot Credit: Godefroy Vannoye

KM3NeT neutrino alerts: content



- ID
- Detector (ARCA/ORCA)
- Type of alerts triggerrs
- Number of events in given time and space widows
- Flavor
- Energy
- IsRealAlert
- Time
- RA, Dec, Longitude, Latitude
- Error box 50% and 90%
- Reconstruction quality
- Probability of neutrino
- Probability of astrophysical neutrino

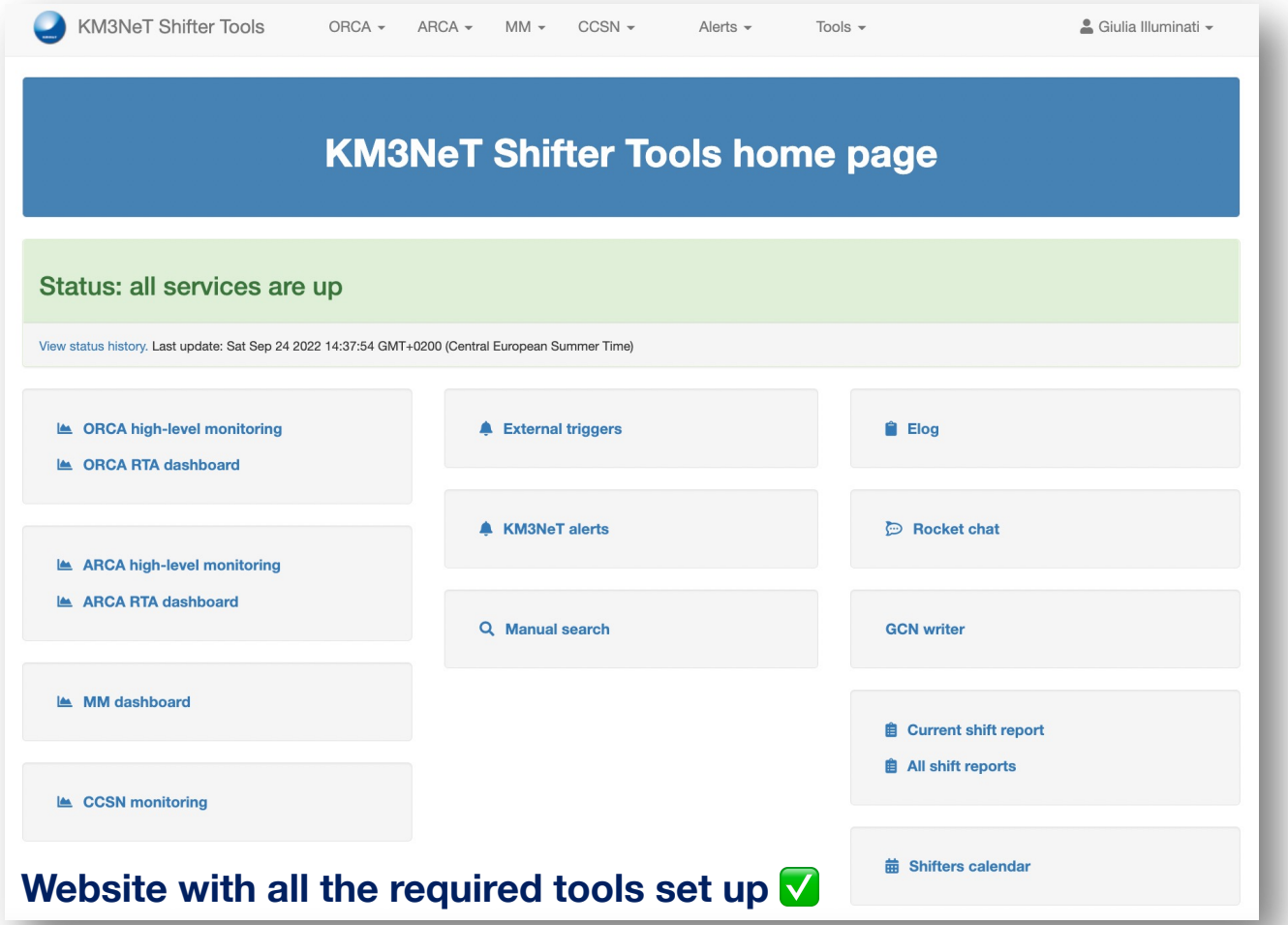
Alert content

- Usual properties of neutrinos
- "Astro contents", including **results of the spatial and time crossmatch**
- General template (**VOEvent**) filled automatically and checked before sending
- Alert distributed through a broker (COMET)

Plot Credit: Godefroy Vannoye

Getting ready to enter the online MM game

- KM3NeT online activities to be **fully operational soon**
- **Online group** ready to be on shift



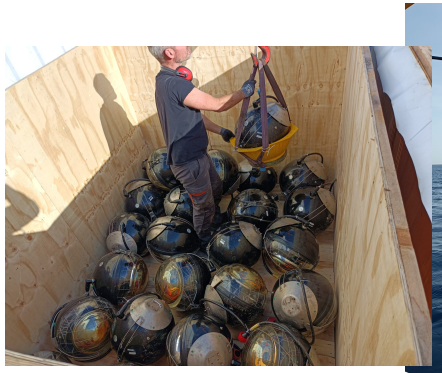
Website with all the required tools set up ✅

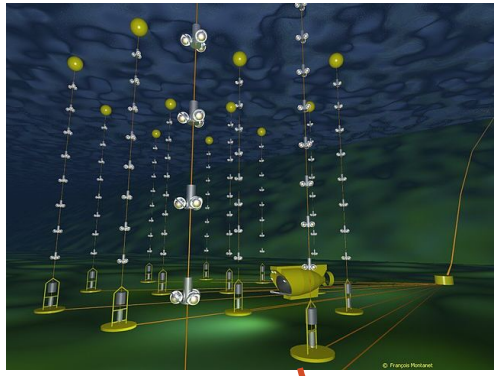
- **Shifter duties:** monitoring of automated follow-up results, manual alert reporting back to the public through GCN or ATels
- **Dedicated website** built to facilitate the task for non-experts

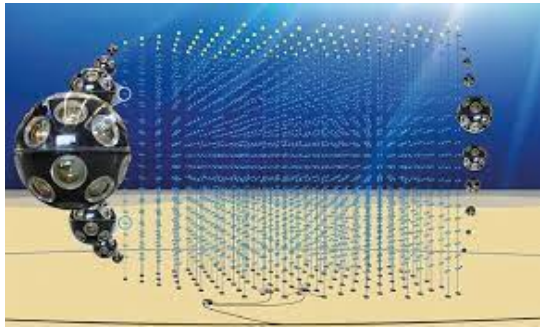
- **Commissioning period: October 2022 – Spring 2023**
  - **Dynamical positioning**
  - **Online shower reconstruction**
  - **Improve ν selection (BDT, GNN)**
- **Online analysis shifts starting in October 2022 to test the system**
- **Start with GCN follow-ups**

- **Follow-up system fully operational by Spring 2023**
- **Alert sending to start in Spring 2023**

Summary and outlook

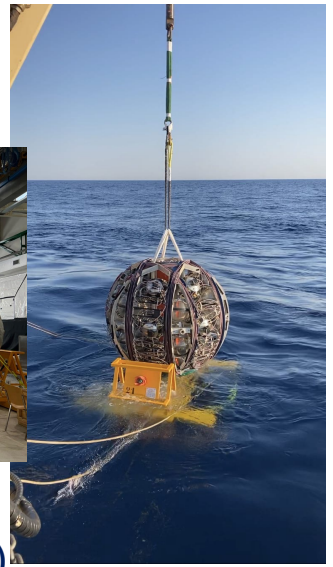






ANTARES

- Run for 15 years with high duty cycle (~95%)
- More than **a decade of multi-messenger real-time activities**
- **Over 300 ANTARES alerts were followed** by multi-wavelength observatories
- **Over 500 alerts** received by multi-wavelength observatories were **followed by ANTARES**
- **No significant correlation found, but important return of experience for KM3NeT**



KM3NeT

- Next generation neutrino telescope in the Mediterranean Sea
- Under construction: currently running with 21 DUs (ARCA) and 11 DUs (ORCA)
- Has **already reached ANTARES's effective area (at least x3 higher)**
- Better **median angular resolution (~0.1° @1 PeV) and x100 ANTARES instrumented volume** (ARCA)
- Will allow **multi-flavour neutrino detection in real-time** over an **extended energy range** (ARCA+ORCA)
- **Real-time framework in preparation, will enter the multi-messenger game soon**
- **Great interest in collaborating with the multi-messenger transient community!**

Backup

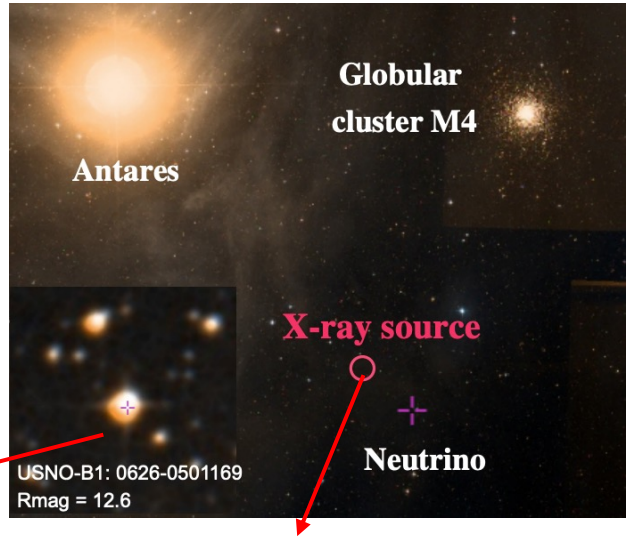
ANT150901A: multi-wavelength follow-up

VHE trigger (E ~ 87 TeV)
Sept. 1, 2015
RA=246.31°; dec=-27.47°

Follow-up by partner telescopes
- **Swift-XRT (after 9h)**
- **MASTER (after 10h)**
- **H.E.S.S. (after 11h)**

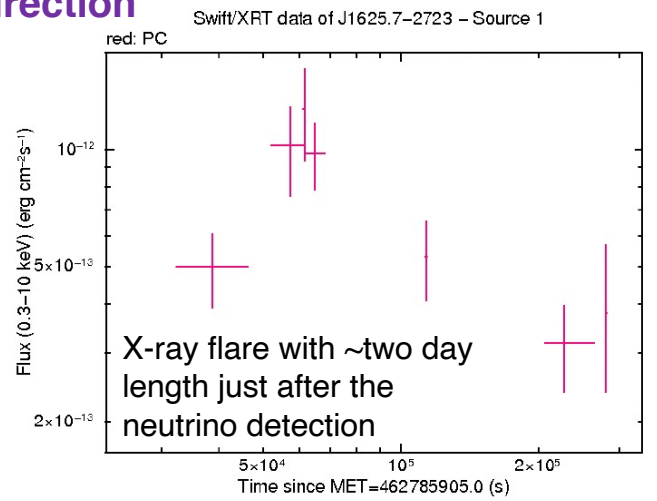
H.E.S.S.:
No VHE transient source
Flux U.L. F(E > 320GeV) < 2.4×10^{-7} m^{-2}s^{-1}

bright star (USNO-B1.0 0626-0501169) identified by MASTER



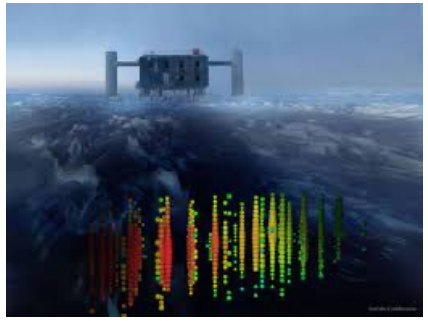
Uncatalogued, relatively bright and variable X-ray source
$(0.5\text{-}1.4)\times10^{-13}$ erg cm^{-2} s^{-1} detected by Swift-XRT
0.11° from neutrino direction

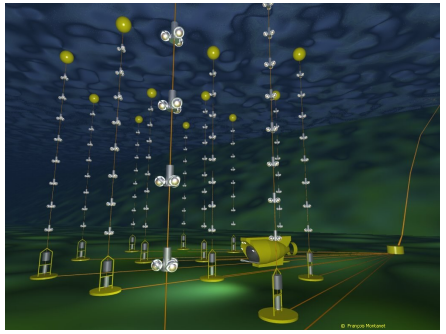
Analysis of **optical and IR archival data** point to **USNO-B1.0 0626-0501169** being a young accreting G-K star or a binary system of chromospheric active stars (RS CVn), undergoing a flaring episode that produced the X-ray emission → **unlikely (3% chance association) to be the origin of ANT150901A**



Great interest in the community (15ATels+6 GCN)
A total of 20 observatories answered to this trigger: one **radio**, 11 **optical/IR**, four **X-ray** satellites, four **VHE gamma-ray** and one **neutrino** observatory

Follow-up of IceCube neutrinos





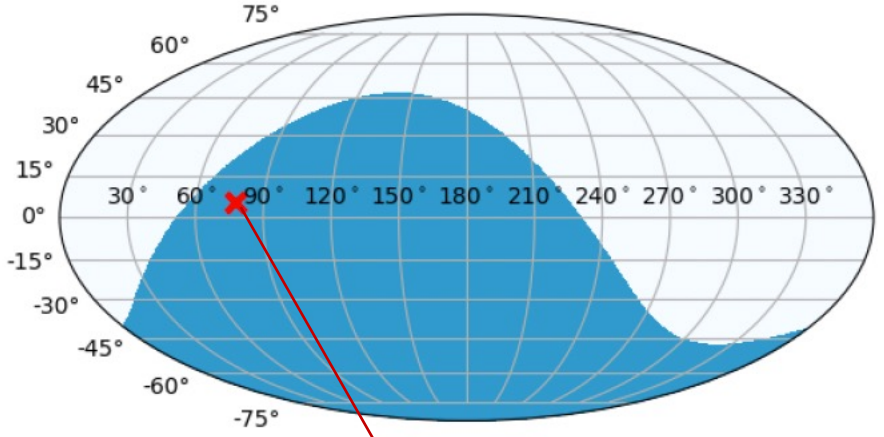
→ 115 neutrino IceCube triggers received, **37 analysed**
(7 HESE, 3 EHE, 10 gold and 17 bronze)
→ **No neutrino candidates found compatible** with any of the alerts
→ 90% confidence level **upper limits on the neutrino fluence**:

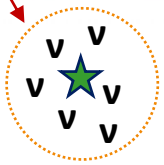
~15 GeV/cm2 in [2.8 TeV, 3.3 PeV] for E^{-2}
~30 GeV/cm2 in [0.4 TeV, 280 TeV] for $E^{-2.5}$

IceCube event	Elevation	Fluence U.L. (GeV cm^{-2}) at 90 % C.L. $dN/dE \propto E^{-2}$	Fluence U.L. (GeV cm^{-2}) at 90 % C.L. $dN/dE \propto E^{-2.5}$	GCN Id	ATels Id
IC160731A (EHE/HESE)	-28°	14 (2.8 TeV - 3.1 PeV)	27 (0.4 - 280 TeV)	/	9324
IC160814A (HESE)	-26°	16 (2.9 TeV - 3.3 PeV)	43 (0.5 - 250 TeV)	19885	9440
IC161103A (HESE)	-26°	13 (3.8 TeV - 3.8 PeV)	22 (0.7 - 370 TeV)	20134	9715
IC170321A (EHE)	-57°	16 (2.5 TeV - 2.5 PeV)	26 (0.5 - 220 TeV)	20926	10189
⋮					
IC211216A (bronze)	-8°	16 (5.0 TeV - 5/0 PeV)	49 (1 - 450 TeV)	31252	15121
IC211216B (bronze)	-4°	17 (5.0 TeV - 5.0 PeV)	40 (1 - 450 TeV)	31262	15127
IC220205B (gold)	-51°	16 (3.0 TeV - 3.3 PeV)	30 (0.6 - 300 TeV)	31556	15207

Published in **GCN circulars** and **Astronomer's Telegrams**

ANTARES visibility sky-map for IC170922 (TXS 0506+056)



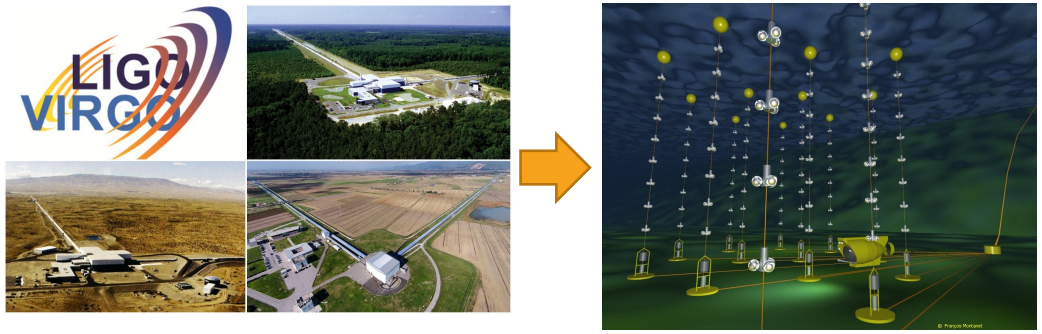


Search in
3° cone
±1 hour and **±1 day**

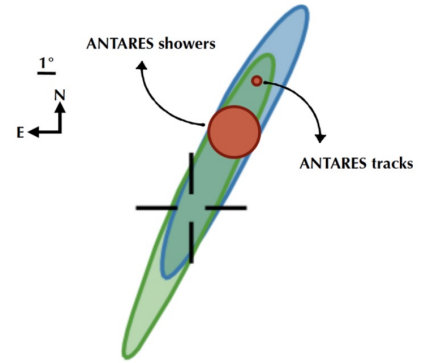
Dedicated offline follow-up:

- **TXS0506+056**
  → *Astrophys.J.Lett.* 863 (2018) 2, L30
- **AT2019dsg and AT2019fdr**
  → *Astrophys.J.* 920 (2021) 1, 50
- **HESE and EHE events**
  → *Astrophys.J. 879 (2019) no.2, 108*

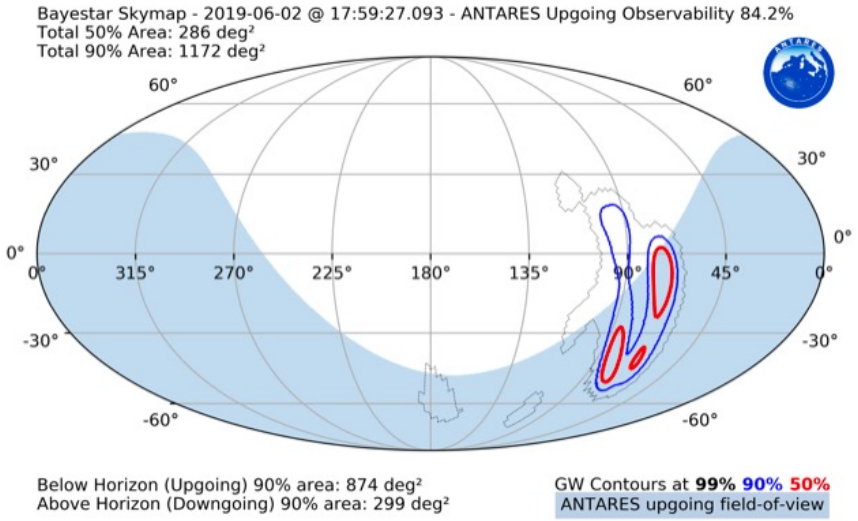
Follow-up of LIGO/Virgo GWs



Neutrinos would
- help **understand physics** of the merger, jets
- significantly **constrain the location** of the source

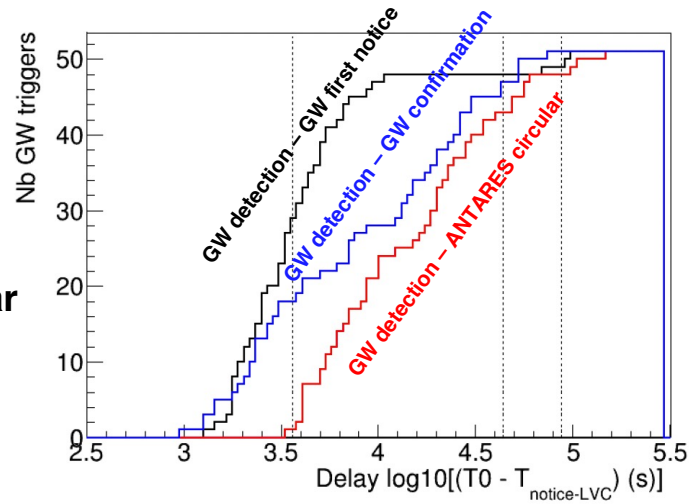


- RunO1 (2015): **3 GW events** detected, all followed **offline (online analysis not ready)**
- RunO2 (2016-2017): **15 GW alerts**, all followed **online (manually)**
- RunO3 (2019-2020): **78 GW alerts** (22 retracted, 3 terrestrial noise, 2 non visible) → **51 followed online (fully automatised)**



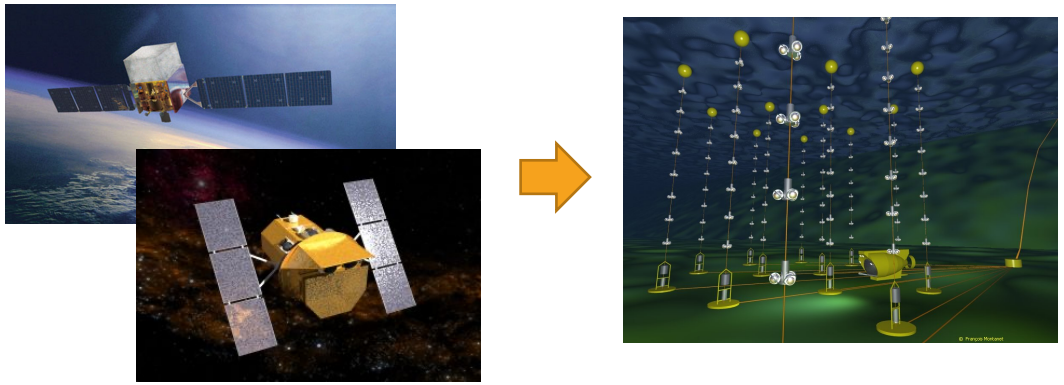
Search in
Spatial overlap between 90% GW contour and ANTARES visibility region
±500 s and **±1 hour**

- **No** time&space **coincidence found**
- Results communicated through **GCN circular**
- **~4.5h from GW detection**
- **< 2h from GW signal confirmation**



Refined offline analyses:
→ Phys.Rev. D93 (2016) no.12, 122010, → Phys.Rev. D96 (2017) no.2, 022005
→ Eur.Phys.J. C77 (2017) no.12, 911, → Astrophys.J. 850 (2017) no.2, L35

Follow-up of Fermi-GMB and Swift GRBs



Fermi/Swift alert message sent via the **GCN** within a **few tens of seconds** after GRB detection

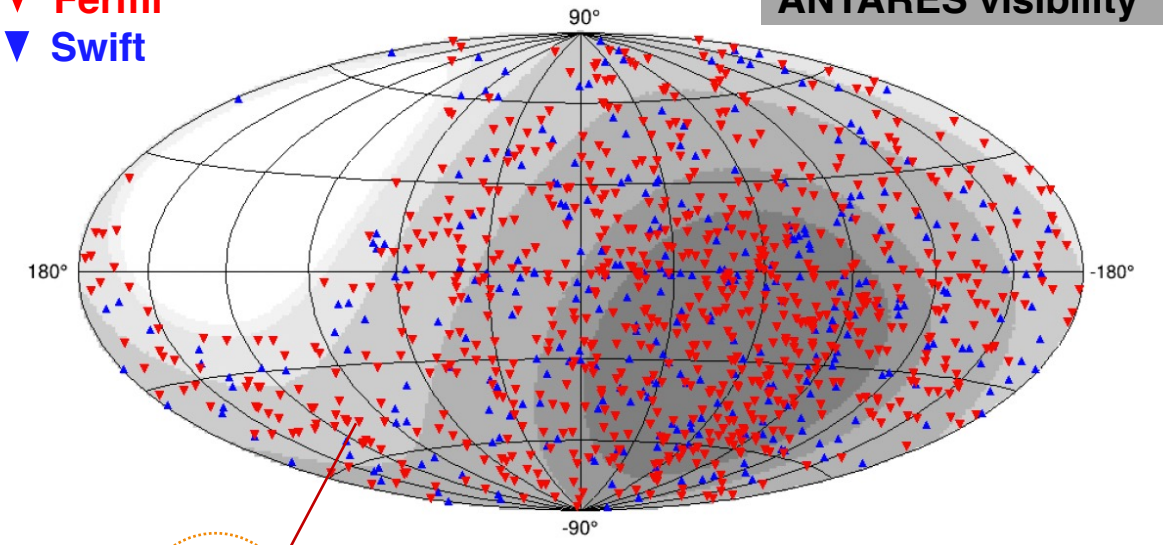
- **Automatic** analysis of ANTARES online data
- Run for **9 years** (01/2014–02/2022)
- **317** Swift and **230** Fermi-GBM bursts followed
- **No** significant **coincidence** detected

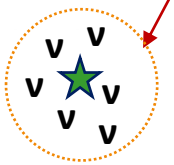
Offline analyses:
→ Eur. Phys. J. C 77.1 (2017)
→ Mon. Not. Roy. Astron. Soc. 469 (2017)
→ MNRAS 500 (2021) 5614

Skymap in Galactic coordinates with the positions of the **GRBs followed by ANTARES**:

▼ Fermi
▼ Swift

ANTARES visibility





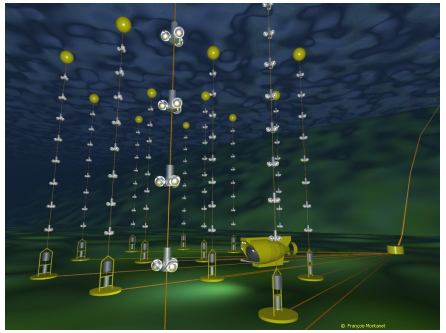
Search in

Opening angle:
- Fermi trigger: maximum between 2° and size of the GRB error box
- Swift trigger: 2°

Time window:
[–250 s; +750 s] around the GRB time

→ **One coincidence event = p-value of 2-5×10^{-5}**

Follow-up of HAWC alerts

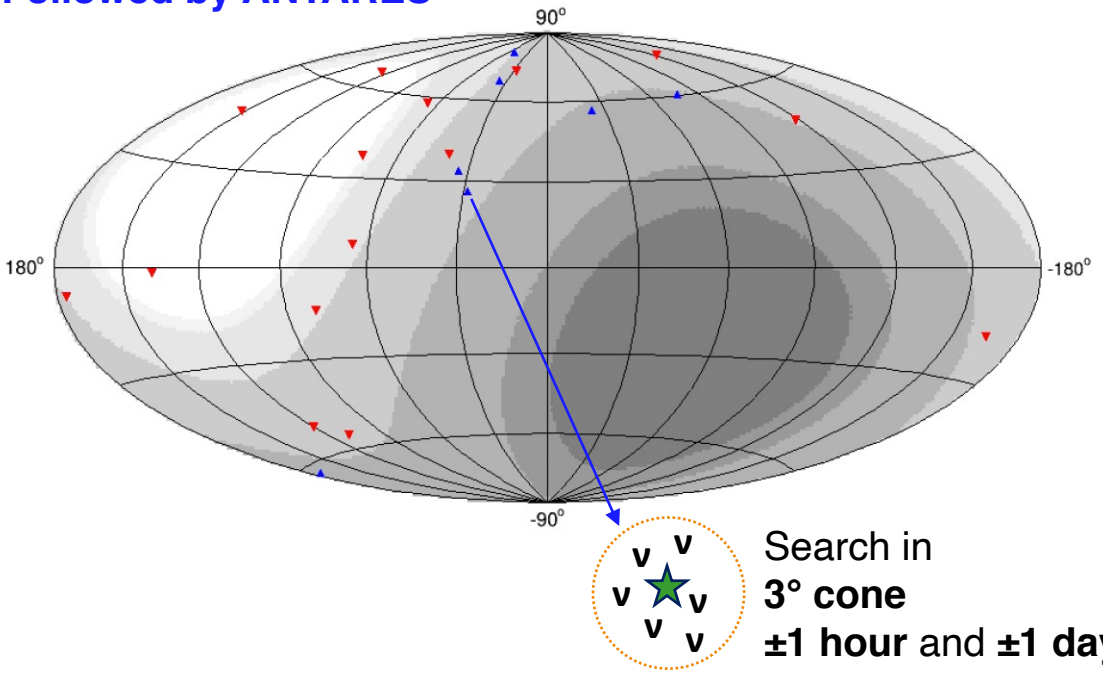


Skymap in Galactic coordinates with the positions of the **HAWC alerts**:

▼ **Not followed by ANTARES**

▼ **Followed by ANTARES**

ANTARES visibility

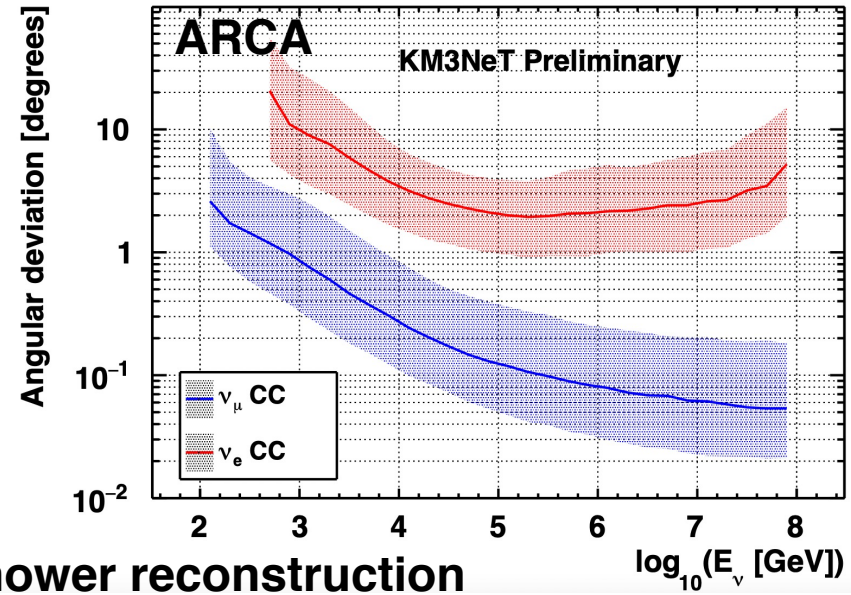


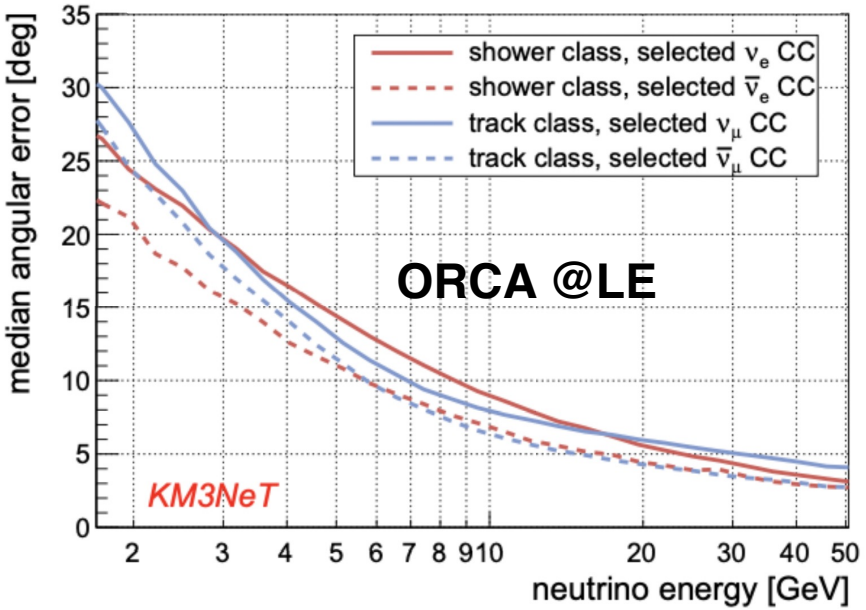
Search in
3° cone
±1 hour and **±1 day**

- Alerts of **short (0.2 to 100 s) TeV transients** sent by the **HAWC** Collaboration since mid 2019 (→ link to alert list)
- Targeting in particular GRBs
- Alerts channeled via the **AMON** framework and then distributed by the **GCN**
- Up to Feb. 2022, 22 triggers sent, **7 followed by ANTARES (in FoV)**
- No coincidence found

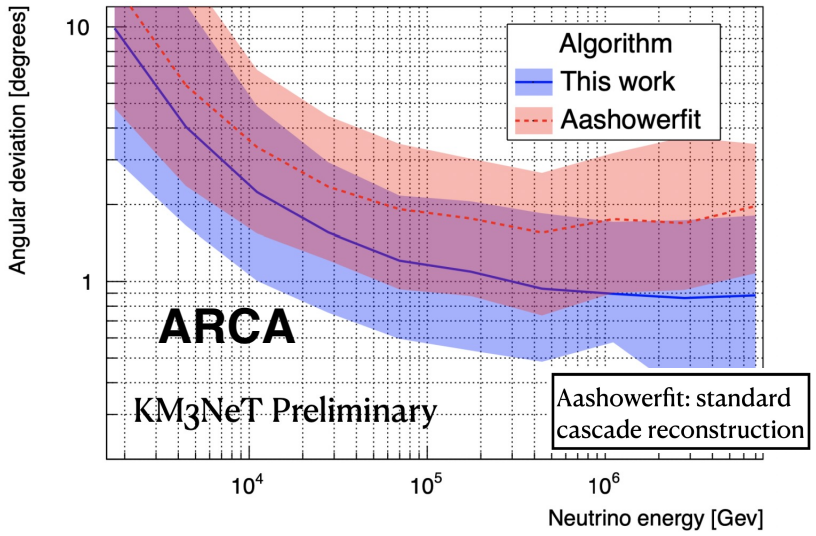
- Additional follow-up of **the IceCube + HAWC coincidences** (NuEM) provided by AMON (→ link to alert list)
- No coincidence found

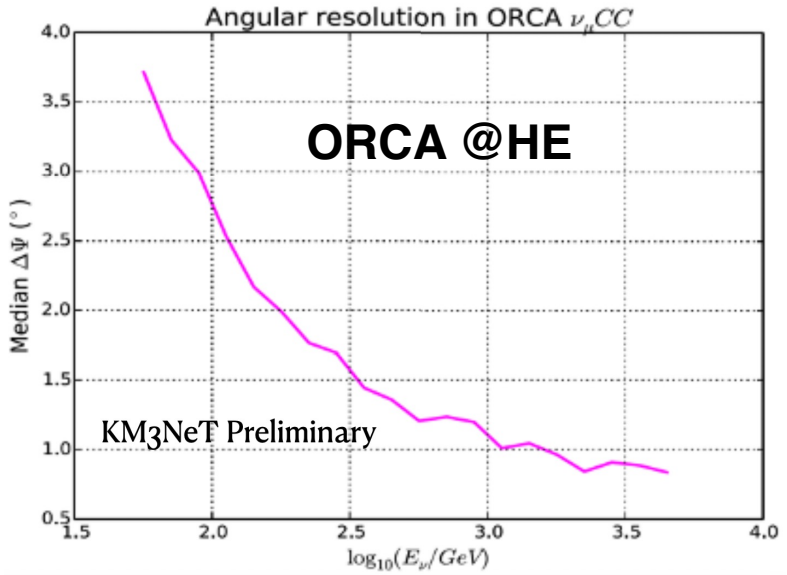
Full KM3NeT angular resolutions





Improved shower reconstruction





Microquasar broker

Dedicated sources multiwavelength monitoring: Microquasar broker

- Goals:
  - Multiwavelength monitoring of a list of known sources
  - Have an broker **independent** from GCN or ATels reported by other collaborations
  - Potentially trigger joined analysis between HESS and KM3NeT

- From a list of microquasar sources
  - Microquasars: X-Ray binaries with accretion-ejection (jets) phenomena
  - Transient sources with flare periods and spectra state transitions
- Continuous MWL monitoring
- Neutrino search follow-up during flares

V4641 Sgr
XTEJ1550-564
GRO J1655-40
GRS 1915+105
GX339-4
H1743-322
IGRJ17091-3624
V404 Cyg
MAXI J1535-571
MAXI J1348-630
MAXI J1820+070
GRS1716-249
4U1630-472

Slide Credit: Sébastien Le Stum

Microquasar broker

Microquasar X-Ray flares detection

⇒ Monitoring new flares from a list of sources

- From publicly available SWIFT/BAT and MAXI lightcurves
- Evaluate signal baseline in a 6 month window before current date
- Check if the most recent flux data point verifies:

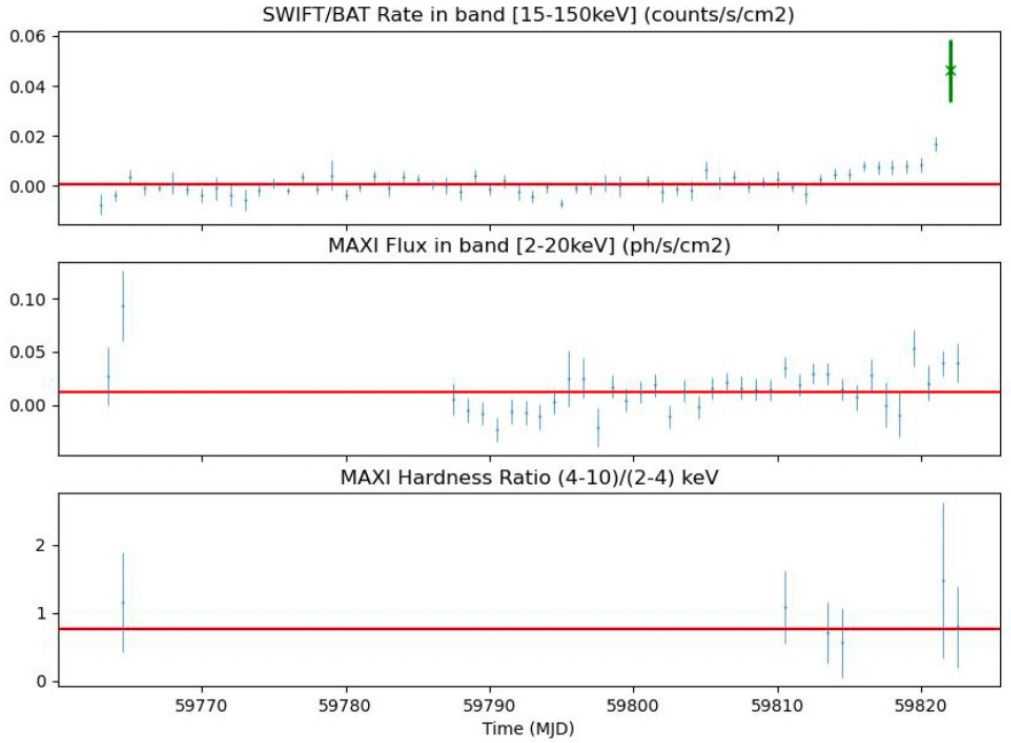
$$F - \delta F > \mu_{BL} + N\sigma_{BL}$$

Flux, error	Baseline mean	Baseline Std. Dev

- And if hardness ratio (between 2 energy bands):

$$|H \mp \delta H| > |\mu_{BL} \pm N\sigma_{BL}|$$

(State transition)



GX339-4 recent flare (reported in ATel#15578)
Baseline is shown in red, alert sent from green data point

Slide Credit: Sébastien Le Stum

Microquasar broker

Microquasar flares detection

If an flare is detected, send alert as a VOEvent through a COMET server

⇒ Follow-up with FERMI/LAT Analysis (HE gamma)

- Binned Likelihood Analysis
- Search for new, uncatalogued, source at the alert position
- Time window: 24h before alert time up to last available data

Alert levels:

- Level 1: X-Ray flux increase OR hardness ratio transition
- Level 2: X-Ray flux increase AND hardness ratio transition
- Level 3: FERMI HE gamma signal

⇒ KM3NeT follow-up analysis

- Time window: +/- 1 day around alert time (TBD with alert level)

Slide Credit: Sébastien Le Stum

KM3NeT neutrino alerts: overview

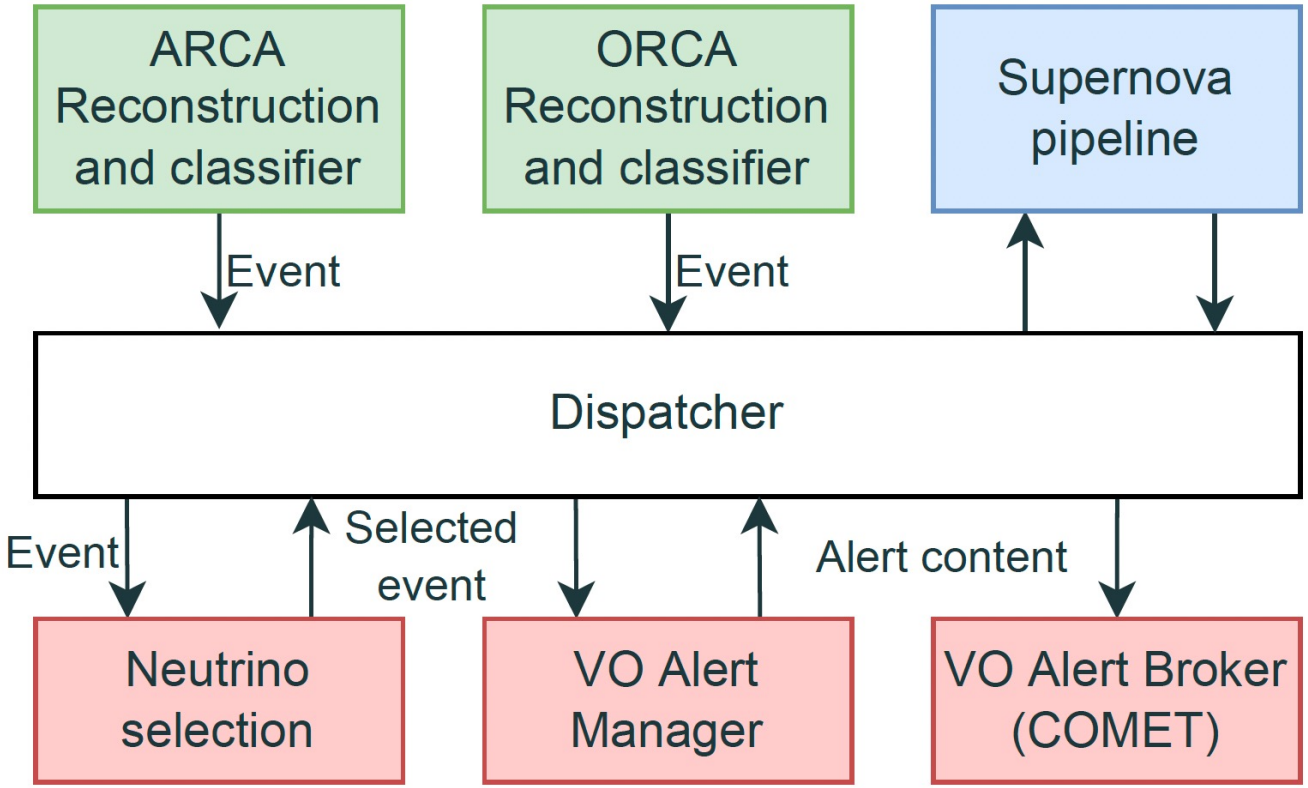
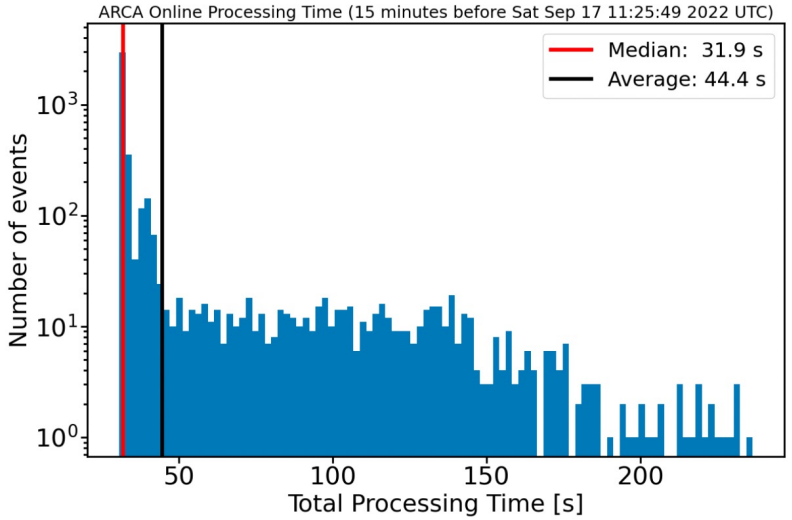


Diagram describing the alert generation

Plot Credit: Godefroy Vannoye

KM3NeT neutrino alerts: reconstruction



Total processing time of events with ARCA

- **Full** reconstruction of **track and shower** direction and energy in **less than 1 minute**
- **Classifier:**
  - **Neutrino/Muon**
  - **Track/Shower**

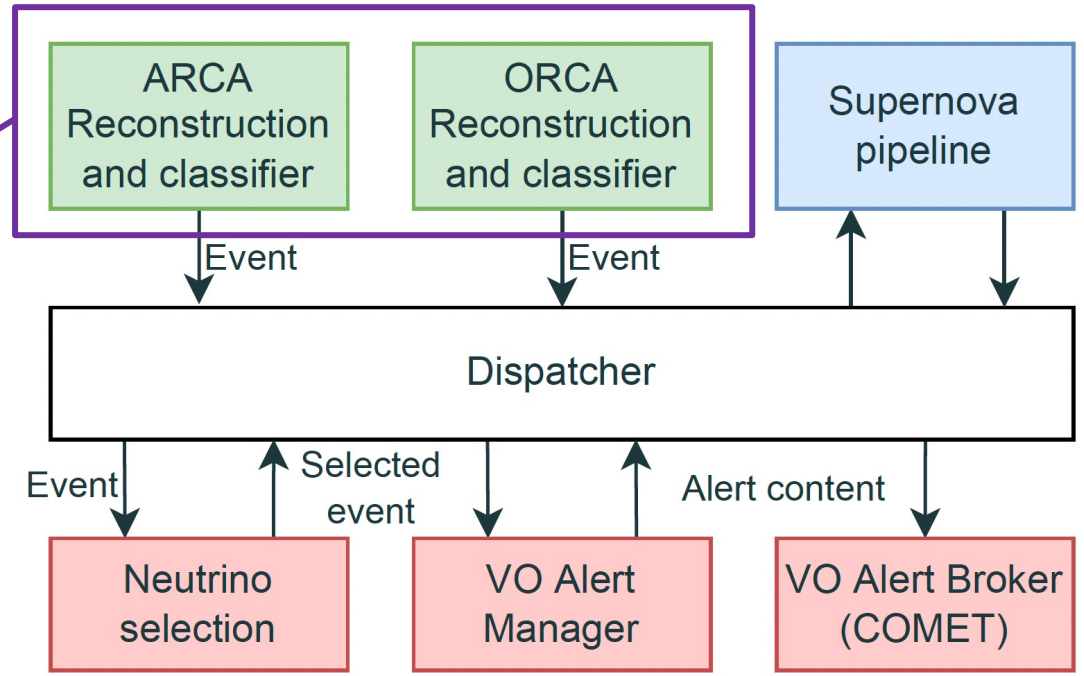


Diagram describing the alert generation

Plot Credit: Godefroy Vannoye