

Low-latency alerts & Data analysis for Multi-messenger Astrophysics Workshop

13-14 January 2022

Report of Contributions

<https://indico.in2p3.fr/e/25290>

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Overview

Antoine Kouchner¹, Stavros Katsanevas²

¹Université Paris Cité, ²European Gravitational Observatory

For more than a decade now, multi-messenger astrophysics has established itself as a distinct discipline. To provide new insights and understand the properties and processes of the most energetic events in the Universe, it leverages the potential of the combined analysis of multiple and complementary information sources: electromagnetic waves (or photons) from radio waves to gamma-rays, neutrinos, gravitational waves and high-energy cosmic rays.

Two major and historical events are at the foundation of this new paradigm: the supernova SN1987A and the binary neutron star merger GW170817. The former was observed through electromagnetic waves and neutrinos, while the latter in gravitational waves and a wide range of electromagnetic counterparts. Both events yielded a long list of scientific discoveries and implications that directly arise from the concomitant observation of different cosmic signals from a single source.

Thanks to the new generation of more sensitive detectors and observatories planned for the coming decade, other multi-messenger observations are expected to take place that will further expand the scope of this new astronomy.

Information access and dissemination between experiments are at the core of this science. As a consequence, interoperable cyberinfrastructures and proper communication networks will play a central role in the rapid identification of candidate events in the very large volume of data, and production of “alerts” associated with these events.

The aim of this workshop is to provide an overview of the existing and future

developments from a data analysis perspective of the space-based and ground-based infrastructures, identify and discuss technical issues and foster new interactions and community building around the multi-messenger data analysis science and tools. The workshop, organized under the auspices of APPEC, is the first of a potential series if deemed useful by the community.

Observatories and Detectors

INTEGRAL

Carlo Ferrigno¹, for the INTEGRAL multi-messenger collaboration², open access paper³

Session Classification: Observatories & alert systems: X-rays, Gamma rays

¹Université de Genève, ²<https://www.astro.unige.ch/cdci/integral-multimessenger-collaboration>

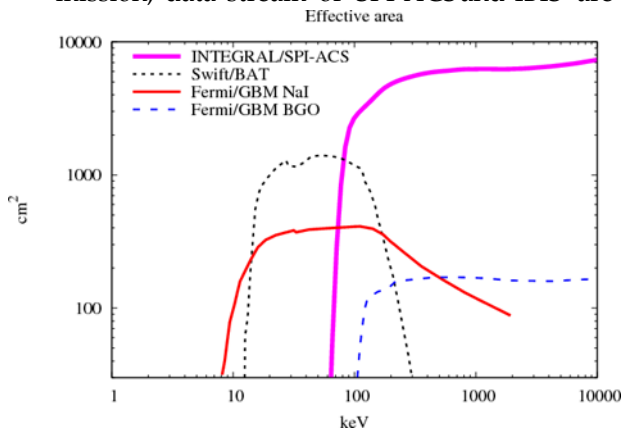
³<https://doi.org/10.1016/j.newar.2020.101595>

INTEGRAL as an efficient full-sky monitor

Launched in 2002, it carries 4 co-aligned instruments: 3keV – 8 MeV plus a V-band small optical monitor.

Thanks mainly to the anti-coincidence Shield of the spectrometer (SPI-ACS) it delivers uninterrupted, unocculted, omni-directional response for 85% of the 2.7-days orbit. Combining the off-axis response of all detectors, it is possible to enhance sensitivity. Within the 30x30 degrees field of view of the pointed instruments, it has higher sensitivity.

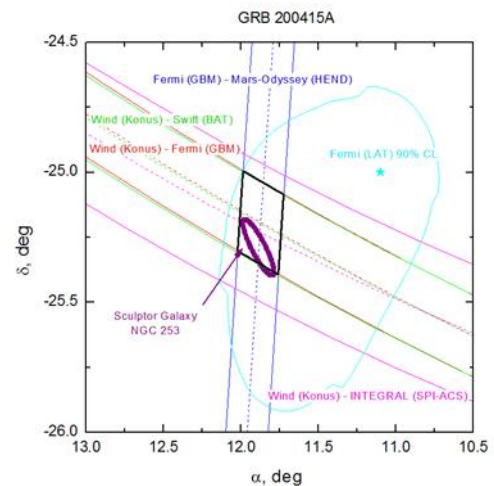
The SPI-ACS has large effective area, and sensitivity on the most of the sky, but no localisation. It has a stable background, which is, however, a high and affected by short (~0.1 s) spikes induced by cosmic-ray hits. INTEGRAL is not triggering on board, but it downloads data in real time to ground. Since the start of mission, data stream of SPI-ACS and IBIS are



scanned for gamma-ray bursts alerts distributed (IBAS system). SPI-ACS: 200 GRBs per year: localisation by triangulation in InterPlanetary Network (IPN). 6-10 GRBs/year detected and localised (3') by IBIS.

Interplanetary network (IPN)

IPN uses spacecraft in both Earth-orbit and elsewhere in the solar system to establish the



locations of gamma-ray bursts and magnetar flares through triangulation. GRB 200415A was localised in the nearby Sculptor galaxy at 3.5 Mpc and classified as a giant magnetar flare with $L=10^{46}$ erg/s.

Kevin Hurley (1942-2021) pioneered the whole multi-mission localizations with IPN also, and worked on improving various gamma-ray instruments for multi-instrument use. Among

other merits, he pushed to have the 50 ms counter on SPI-ACS to be used for triangulation.

Architecture of our transient analysis

Experts can develop test, and integrate the scientific workflows in a reproducible and standardized way. We developed a fully automated triggered analysis to react to neutrino, gravitational waves, and (when possible) FRB. We distribute standard results in Data Papers/Publications. Use these as base for further robust knowledge (to be reported in papers.)

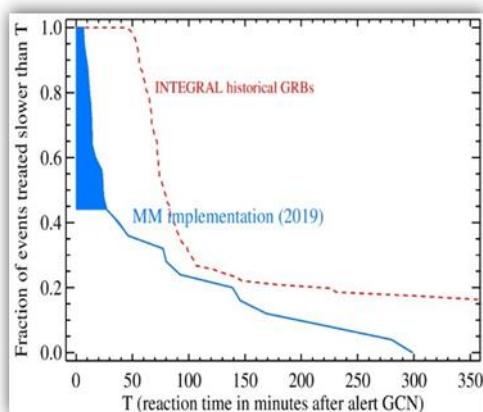
The INTEGRAL Multi-Messenger team and on-line computing interface

- Since 2011 we scanned offline for known events in near real time,
- Since 2018 we scanned for known events in real time (within 20s).

WE developed a fast-responding infrastructure with built-in intelligence: in 2017-2019.

This is a shared effort among the instrument teams that provide round the clock scientists on shift.

The results are ready in one click: it performs a fully automatized data analysis and compiles circulars from a template. It reacts to GW, neutrino, or any other alerts that we will implement (LSST, SKA, ...).



Upper limits on BH-BH mergers

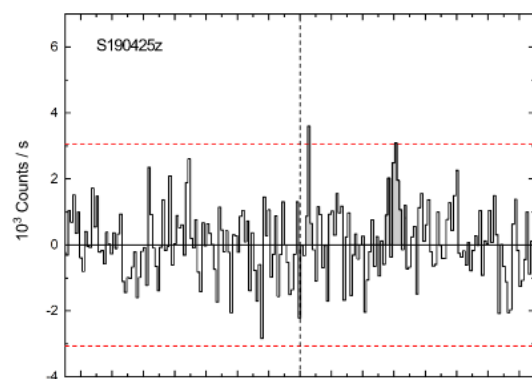
61 upper limits with fluence from 1.3×10^{-7} and 5.3×10^{-7} erg/cm². 11 times INTEGRAL was inactive at the time of the event (15%). 2 pointed follow-up. Our results on LIGO/Virgo O1 O2, and O3 are consistent with the expectation that no matter is involved in the merging of black-holes and, therefore, not electromagnetic emission is possible.

GW 150914: the first of many upper limits on BH-BH mergers

GW150914 was due to the merging of two 30 solar masses Black Holes, localised within 620 deg² at 90% c.l. Fermi-GBM reported a marginal excess 0.4s after the merging (0.22% FAP). INTEGRAL set upper limits on EM emission to be $< 10^{-6}$ the GW energy for a limiting fluence of 10^{-7} erg/cm². Only a corner of parameter space allows the GBM excess to be compatible with INTEGRAL data.

Binary neutron star mergers

On 17 August 2017, INTEGRAL and Fermi-GBM detected a short faint gamma-ray burst following the merging of two neutron star. It was an off-axis GRB and constrained alternative theories of gravity as well as Lorentz invariance. On 25 April 2019, gravitational waves were detected from the merging of two objects, whose total mass exceeded 3.3 Suns. The only, speculative, counterpart was reported by INTEGRAL.



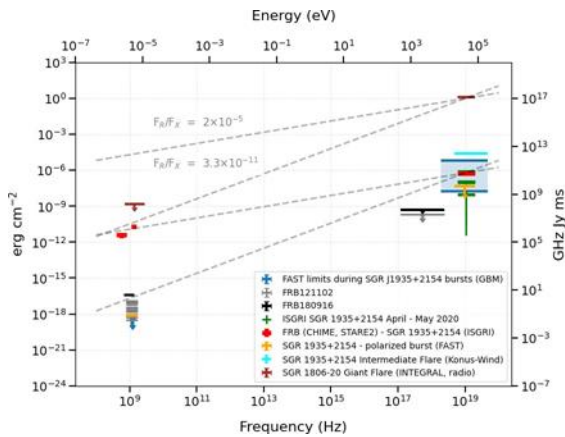
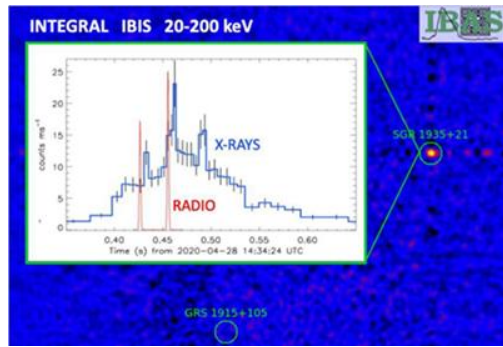
ICECUBE and ANTARES neutrino serendipitous observations

52 upper limits with fluence from 1.8×10^{-7} and 5.2×10^{-7} erg/cm². 5 times INTEGRAL was reported to be inactive at the time of the event

(8%). 2 pointed follow-up without notable source behaviors. INTEGRAL provided spectral constraints on the blazar TXS 0506+056 candidate source of a high-energy neutrino detected by IceCube in 2017.

A magnetar flare produced a galactic Fast Radio Burst

On 28 April 2020, INTEGRAL detected a hard X-ray magnetar flare that was in the field of the IBIS detector; a low-latency automatic alert was sent 5.5 s after the event. We were the first to associate the FRB and the X-ray flare in the morning of 29 April. CHIME and STARE2 radiotelescopes detected a double peaked fast radio burst. Direction and timing show that both X-rays and radio waves come from the magnetar SGR 1935+21. It is the first time that a Galactic Fast Radio Burst is observed.



A rare phenomenon

The ratio of radio to X flux is from 2×10^{-5} of the detection to 1×10^{-11} of several upper limits. It is necessary to continue exploring the parameter space with the new wealth of FRB detectors to understand when and why emission is panchromatic.

Conclusions

INTEGRAL detected the first GRB coincident with a neutron star merger using SPI-ACS on 17 August 2017. Owing to the coincident detection with Fermi-GBM and LIGO/Virgo, and the subsequent kilonova, the era of multi-messenger astronomy was opened. Upper limits on the hard X-ray emission of 85% of gravitational waves and neutrino events were consistently produced over the first three LIGO-Virgo observing runs and current IceCube operations..

A Magnetar flare was detected in temporal and spatial coincidence with a Fast Radio Burst confirming the hypothesis of magnetars being at the origin of (at least some) FRBs. INTEGRAL will operate at least until March 2023 and it might cover part of O4 from LIGO/Virgo. Further extension of INTEGRAL is asked to ESA.

Open access to the full review paper on Multi-Messenger astronomy with INTEGRAL is at: <https://doi.org/10.1016/j.newar.2020.101595>

Fermi-LAT

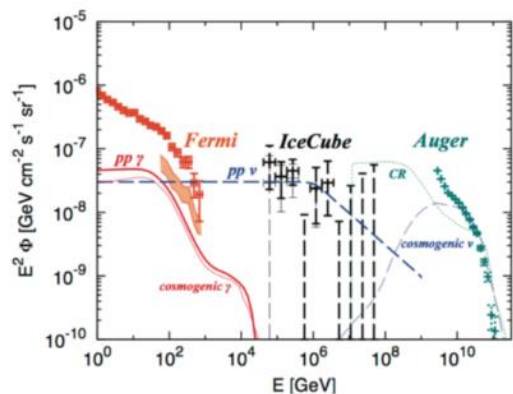
Sara Buson¹, S. Garrappa, on behalf of the Fermi-LAT collaboration², ERC project³

Session Classification: Observatories & alert systems: X-rays, Gamma rays

¹University of Würzburg, ²<https://glast.sites.stanford.edu/>, ³<https://cordis.europa.eu/project/id/949555>

Energy Density in the Universe in γ rays, neutrinos and cosmic rays is similar

Diffuse energy fluxes of sub-TeV γ rays, PeV neutrinos, and UHECRs are all comparable, while particle energy spans over ten orders of magnitude.



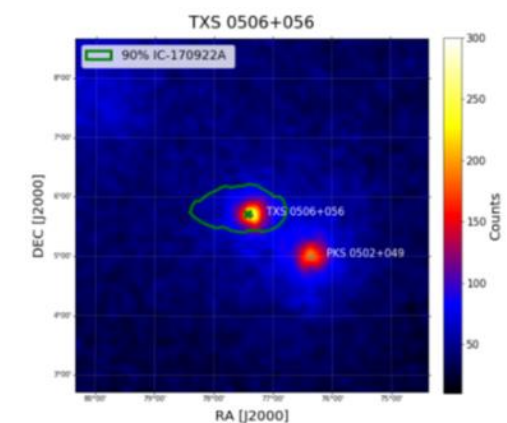
Murase & Waxam 2016

The Persistent Gamma-ray Sky: > 6600 sources ($E > 100$ MeV), dominated by AGN of the blazar class. The Variable Gamma-ray Sky: Flare Advocates daily monitoring; FAVA weekly monitoring. Lightcurve repository enables to track variability of some 4FGL-DR2 blazars: <https://fermi.gsfc.nasa.gov/ssc/data/access/lat/LightCurveRepository/>

Cosmic neutrinos may originate in blazars - a first compelling neutrino candidate

IC 170922A & TXS 0506+056 : Intriguing high-energy Neutrino/Blazar Association. High-energy neutrino event with >183TeV. Flaring γ -

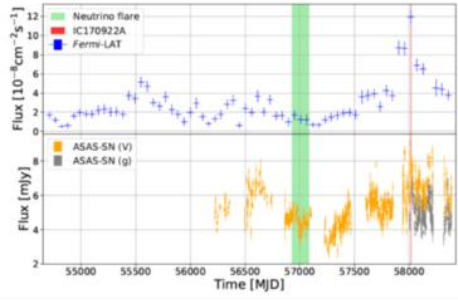
ray blazar (Tanaka, SB+ Atel#10791). $\sim 3\sigma$ post-trial chance coincidence correlation. Lepto-hadronic models can adequately explain the observations (IC170922A) (IceCube, Fermi, MAGIC+ Science 361, 146 2018)



Garrappa, SB+ 2019 ApJ

Observations challenge theoretical interpretation

Substantially different electromagnetic behavior during time periods of putative neutrino emissions. Models producing neutrinos and γ rays require leptonic dominated γ -ray production! Multiple neutrino emission regions in blazar jets? Multiple neutrino physical processes in blazar jets? (e.g. Garrappa, SB et al. 2019, Rodrigues+ 2019, Halzen+ 2019, Petropoulou+ 2020, Kun+ 2020)

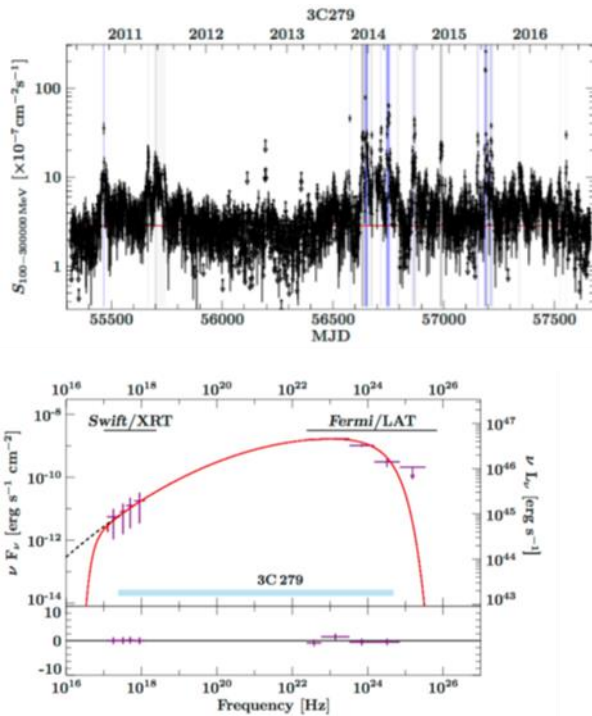


Reimer, Böttcher and SB 2019

High-energy neutrinos from individual blazar flares

Fluence of most individual blazar flares is too small to yield a substantial probability for the detection of one or more neutrinos with IceCube. Absolute neutrino expectation for short-term blazar flares is negligible.

Possible contribution from individual flaring sources to the IceCube neutrino diffuse flux is modest, still possible for long-term flares.

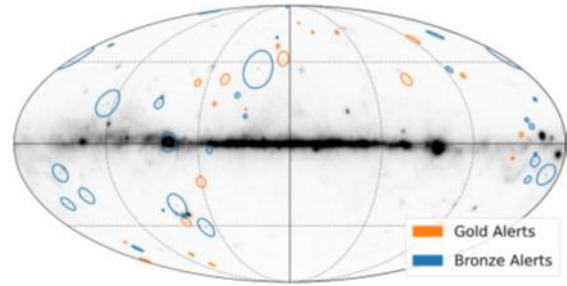


E.g. Kreter, ... SB+ 2020, Oikonomou+ 2019

Follow-up observations with Fermi-LAT

Fermi-LAT all-sky survey: Full sky coverage* every ~3hrs. Point source analysis in 100 MeV - 1TeV band. 4FGL-DR2 catalog containing 5064 sources (10 years of observations). Follow-up of all alerts in the IceCube realtime stream 2.0 (as of Jan 12, 2022): Total of 56 realtime alerts: 22 Gold, 34 Bronze

* Newer observation strategy in place due to solar panel issue leads to exposure gaps up to a ~week



Garrappa, SB et al. ICRC 2021 (arXiv:2112.11586)

Follow-up observations with Fermi-LAT -- Analysis strategy

Systematic analysis of LAT sky regions around the neutrino direction. Investigate 3 timescales during a pre-defined follow-up (T0 = neutrino detection time): One-day before T0: Detect fast, bright transients coincident with the neutrino. One-month before T0: Detect recent transients, sources in bright state (with time lags consistent with the most credited models). Full-mission data: Detect weak gamma-ray sources not (yet) included in LAT catalogs and positionally consistent with neutrino localization.

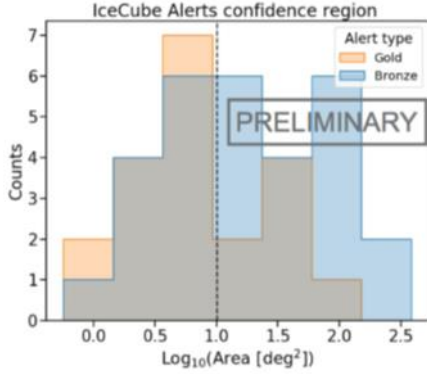
When a transient is detected in the one-day or one-month timescales, dedicated lightcurve analyses are performed up to one-year timescale before T0. In the case of a non-detection at the best-fit position of the neutrino, 95% CL upper limits are reported, corresponding to the detection of a power-law source (index 2.0). Findings released via GCN Circulars/ATels.

Follow-up observations with Fermi-LAT -- Results

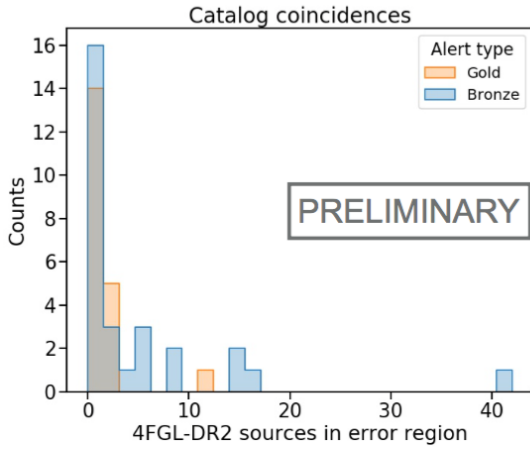
Neutrino 90% containment regions from 0.57 deg² up to 385 deg². Median extension from full

sample: 10.2 deg². 5.5 deg² for Gold alerts, 12.2 deg² for Bronze alerts. 22 events (45%) have no coincident sources in 4FGL-DR2. 8 events have a single 4FGL-DR2 candidate.

With a 4FGL-DR2 source density of ~ 0.12 deg² (~ 0.07 deg² for 4LAC sources) we still expect a non-negligible rate of random chance coincidences (Based on follow up alerts up to Sep 13, 2021).



Garrappa, SB et al. ICRC 2021 (arXiv:2112.11586)



Selection of well-reconstructed alerts: 90% containment smaller than observed median (10.2 deg²). 23 alerts left in the sample (12 Gold, 11 Bronze) Only 7 with at least one 4FGL source coincident.

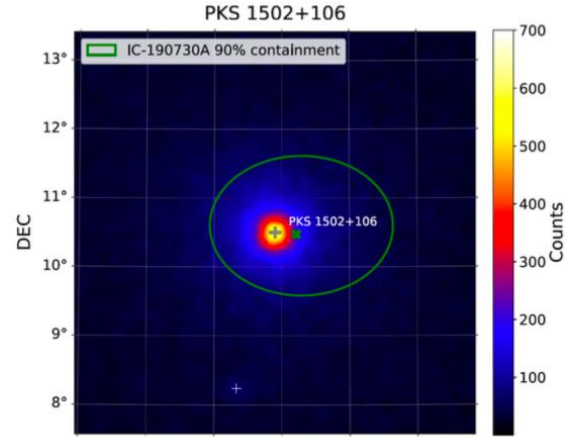
4FGL Name	Class ¹	E.Flux [erg cm ⁻² s ⁻¹]	Redshift	Event	Type	Sig.
J1504.4+1029	FSRQ	$(1.9 \pm 0.02) \times 10^{-10}$	1.84	IC190730A	Gold	0.67
J0946.2+0104	BL Lac	$(2.55 \pm 0.55) \times 10^{-12}$	0.577	IC190819A	Bronze	0.29
J1003.4+0205	BCU	$(1.64 \pm 0.39) \times 10^{-12}$	2.075	IC190819A	Bronze	0.29
J0658.6+0636	BCU	$(3.7 \pm 0.73) \times 10^{-12}$	-	IC201114A	Gold	0.56
J0206.4-1151	FSRQ	$(1.22 \pm 0.06) \times 10^{-11}$	1.663	IC201130A	Gold	0.15
J1342.7+0505	BL Lac	$(2.98 \pm 0.49) \times 10^{-12}$	0.13663	IC210210A	Gold	0.65
J1747.6+0324	unid.	$(7.03 \pm 0.92) \times 10^{-12}$	-	IC210510A	Bronze	0.28

¹Classification in 4FGL-DR2

Garrappa, SB et al. ICRC 2021 (arXiv:2112.11586)

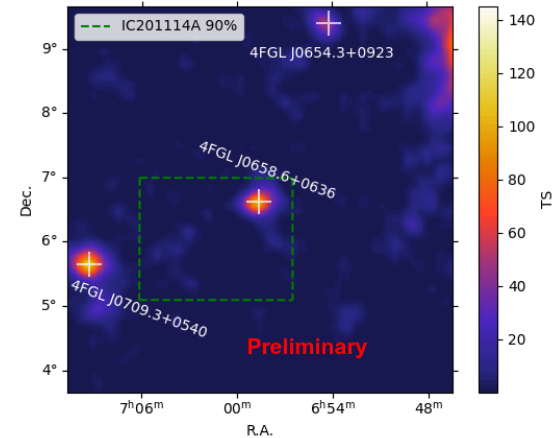
Follow-up observations with Fermi-LAT -- Remarkable coincidences with a single candidate counterpart

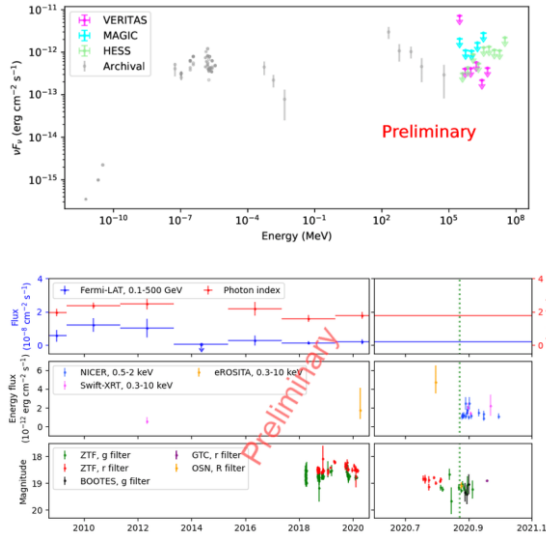
IceCube-190730A and PKS 1502+106: Gold alert with 67% signalness, well-reconstructed. PKS 1502+106, FSRQ at redshift of $z = 1.84$. 15th brightest blazar in the 4LAC catalog. Detected in low gamma-ray state at neutrino arrival. Neutrino production suggested by several works (Rodrigues+2021, Britzen+ 2021, Plavin+ 2021, Oikonomou+ 2021)



Franckowiak et al. 2020, ApJ 893, 2, 162

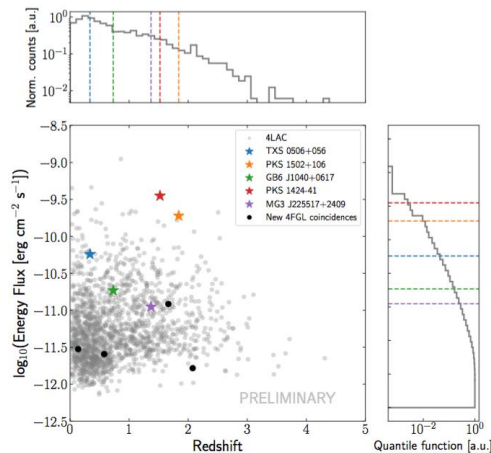
IceCube-201114A and NVSS J065844+063711: Gold alert with 56% signalness, well reconstructed. Known high-energy emitter (3FHL catalog), detection up to 155 GeV. Not significantly detected in LAT data at short timescales. Rich multi-wavelength campaign right after neutrino detection. (Preliminary results in de Menezes, SB et al. (ICRC 2021), de Menezes et al in prep.





Follow-up observations with Fermi-LAT – Results

Patterns in the Behavior of γ -ray-Candidate Neutrino Blazars. Neutrino-emitting blazar candidates are statistically compatible with hypotheses of both a linear correlation and no correlation between neutrino and gamma-ray energy flux.



Garrappa, SB et al. ICRC 2021 (arXiv:2112.11586)
 Adapted from Franckowiak, .. SB et al 2020

Bright g-ray blazars are only the “tip of the iceberg”

It has to be kept in mind that a small fraction of the total observed γ -ray emission of all blazars is associated with the brightest individual objects. Only $\sim 70\%$ of the blazar γ -ray emission has been resolved into point sources so far by Fermi-LAT.

For any high-energy neutrino event, there will always remain a large probability of being associated with the population of faint and/or remote sources, which are not individually resolved.

Forthcoming Decade

KM3Ne T-ARCA

1 km³ volume

$< 0.1^\circ$ angular resolution for tracks

$< 2^\circ$ angular resolution for showers

Baikal-GVD

1 km³ volume

0.25° - 0.5° angular resolution for tracks

3.5° - 5.5° angular resolution for cascades

IceCube-Gen2

10x larger than IceCube

$< 0.3^\circ$ angular resolution for tracks

$< 5^\circ$ angular resolution for cascades

P-ONE

New R&D

Summary

Fermi-LAT keeps playing a key role in the identification of neutrino counterparts. Fermi-LAT is continuously improving its follow-up strategies towards a faster and more detailed reporting of observations. Prompt triggers to multi-wavelength facilities on interesting target candidates. LAT team is also involved in active proposals for multi-wavelength follow-up observations.

Future “wish-list”: Common standards for cross-detectors analysis. Long-term strategy for the release of these data to the broader community (similarly to e.g. g-ray, gravitational waves..). Independent confirmation of constraints / detections. Extension of the sensitivity to higher-neutrino energies also employing new promising detection techniques, e.g. radio-neutrino detectors such as ARIANNA, GRAND, RNO, ..

Enhanced cooperation e.g. GNN:
<https://www.globalneutrino.network>

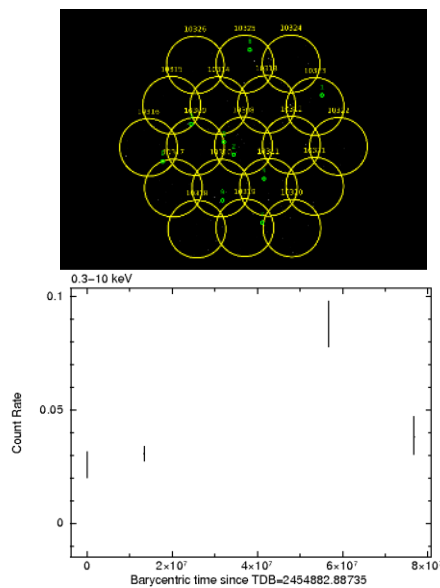
SWIFT

Phil Evans¹

Session Classification: Observatories & alert systems: X-rays, Gamma rays

¹University of Leicester

Two key Swift MMA discoveries to date



UV discovery of GW 170817 and X-ray discovery of IceCube 170922A.

Evans+ 2017



Future MMA/LL options

LIGO/Virgo/KAGRA O4

IceCube

KM3NeT

But it's not just multi-messenger that is giving interesting new time-domain science:

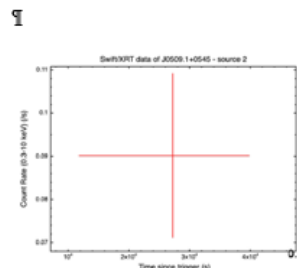
HAWC

CTA

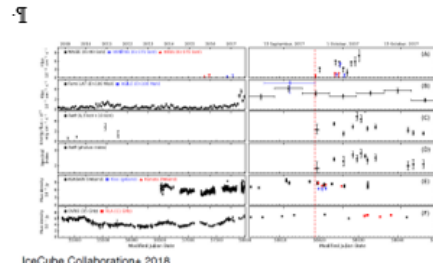
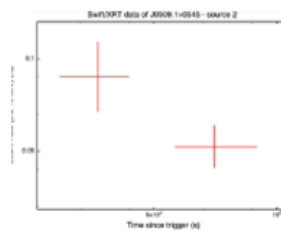
FRB (e.g. CHIME)

VRO/LSST

Some cautionary notes



~~eRosita surveys will be a significant benefit in this area.~~



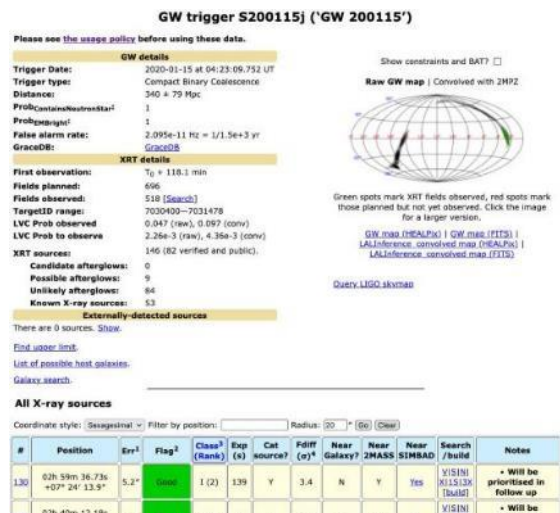
New Swift innovations — operations

GUANO — Gamma-ray Urgent Archiver for Novel Opportunities (Tohuvavohu et al. 2020, ApJ, 900, 1). If notified quickly enough, BAT event data can be saved and then searched offline with greater sensitivity. 35 GRBs so far, arcminute localisation. Automated ToO uploads. ToO submission API (By Jamie Kennea: https://www.swift.psu.edu/too_api/)

Tiling optimisation and “manypoint” upload tool.

New Swift innovations – analysis

For Swift-team / collaboration projects, automated XRT analysis exists.



For any observation: XRT on-demand analysis (https://www.swift.ac.uk/user_objects (Evans et al. 2009).

Select products

To reduce the load on our servers, please select only the independent products you require.

Light curve: ☒ Spectrum ☒ Position ☐ Image ☒ Source detection ☒

[Build products] [Reset form]

Object details

Copied settings from job 42350

*Name: Mkn 421 [Find]
 *Target ID: 00030352
 Time zero: 524467661.8006
 All input times since this? ☐
 *Coordinates: 866.1138, 38.2088

Global options

E-mail address: pae9@leicester.ac.uk
 Remember me ☒
 Email me when complete? ☐
 Details of object to be processed: ☒ try to centroid? ☒
 *Centroid method: Single pass ☐
 *Max attempts: 10
 *Search radius (arcmin): 5
 Super-soft source? ☐
 Show advanced pile-up controls?
 *Use 2SXPS source lists: ☒ (if available)
 Data not in 2SXPS

Light curve details

Binning Method: Time
 *Bin length (s):
 WT: 10 PC: 100
 *Hardness ratio bin length (s):
 Same as main curve ☐
 WT: 20 PC: 200
 Min fractional exposure 0
 Minimum sigma: 3
 Allow upper limits? Yes ☐
 Allow Bayesian bins? Yes ☐
 Use Bayesian when below:
 Counts: 15 SNR: 2.4
 *Time axis unit: seconds
 Energy and grade selection: Default
 Specify observations? ☐
 Use which data: []

Now available through an API (https://www.swift.ac.uk/user_objects/API)

Swift API tools available via: pip install swifttools

Build-the-request

First we need to create an `XRTProductRequest` object, and set some global parameters. By default, the object is created in 'silent' mode: it does not produce any output (unless an error is raised). For interactive use such as in this tutorial, the output can be helpful, so we will create it with `silent=False`.

The RA/Dec must be in decimal degrees, J2000.0. So:

```
In [1]: from swifttools.xrt_prods import XRTProductRequest
In [2]: myReq = XRTProductRequest('YOUR_EMAIL_ADDRESS', silent=False)
In [3]: myReq.setGlobalParams(getTargets='run', centroid='true', name='GRB 200416A', RA=335.6985, Dec=-7.5179,
centMeth='simple', useSXPS=False, T0=608713541.952, postFrac=1)
```

OK, now lets add the products. For the light curve we will request counts binning, with the same settings as the [XRT GRB light curve repository](#) uses. For the spectrum we need to specify that we have no redshift, and beyond this we will accept the defaults. Likewise for the positions, we will accept the default parameters, except that we want to use all available data for the astrometric positions:

```
In [4]: myReq.addLightCurve(binMeth='counts', pcCounts=20, wtCounts=30, dynamic=True)
Successfully created a light curve

In [5]: myReq.addSpectrum(hasRedshift=False)
Successfully created a spectrum

In [6]: myReq.addStandardPos()
Successfully created a standard position

In [7]: myReq.addEnhancedPos()
Successfully created an enhanced position

In [8]: myReq.addAstromPos(useAllObs=True)
Successfully created an astrometric position
```

Forthcoming tool: LSXPS

Several XRT point source catalogues exist (SwiftFT, 1SwXRT, 1SXPS, 2SXPS). All retrospective; good for mining and reference, bad for time-domain response. Swift observes ~75 fields/day = 7.5 sq degrees; lots of scope for discovery if we analysed in real time...LSXPS is updated in ~real time*. Searches for transients with each data delivery. Can often use itself as the best reference catalogue. Data are analysed on receipt, typically 1-4 hours after observation. Transients will be reported ASAP, catalogue is not updated for 28 days (TBD).

Final thoughts

Swift remains a powerful, rapid-response, multi-wavelength facility optimally suited for the MMA/TDA era. Coordination between different facilities and rapid dissemination of information is important. Some means of collating and coordinating results would be very helpful. The Swift team are producing new innovations and tools to make it as easy as possible to use Swift for this science. This is an exciting and fruitful field with a bright and immediate future!

Some cautionary notes

1) Are we going to see things that don't follow expectations? For example: how 'low-latency' should follow-up be? 2) Can we find the needle in a... pot of needles?

Notable lessons

Keep an open mind about appearance. Multiple observations and timescales to probe Challenging with large position uncertainties! Rapid information exchange between facilities is key. GCN / ATEL / TNS?

XMM-Newton

Natalie Webb¹, Erwan Quintin¹, Hugo Tranin¹, for the XMM-Newton Survey Science Center² and the XMM2ATHENA project³

Session : Observatories & alert systems: X-rays, Gamma rays

¹Institut de Recherche en Astrophysique et Planétologie, ²<http://xmmssc.irap.omp.eu/>,

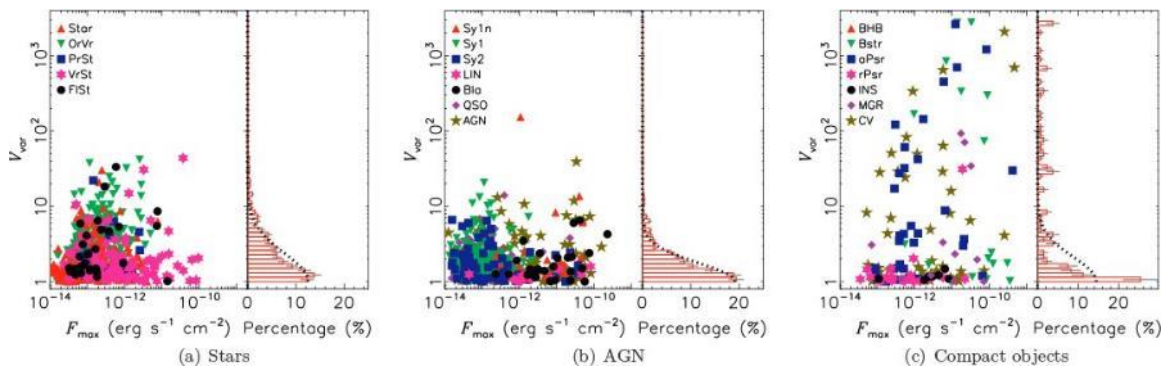
³<https://cordis.europa.eu/project/id/101004168>

X-ray transients

Investigation of 4330 point-like, good signal to noise sources with multiple pointings in 2XMM (Lin, Webb & Baret 2012)

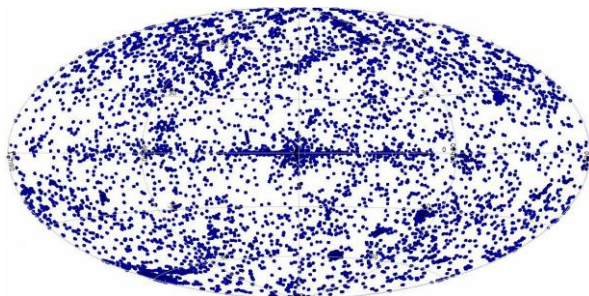
Transient X-ray sources are : gravitational wave events, γ -ray bursts, cataclysmic variables, tidal disruption events, supernovae, X-ray binary outbursts, magnetars...

The XMM-Newton Survey Science Centre was selected by ESA to ensure that the scientific community can exploit XMM-Newton data. Responsibilities: Development of science analysis system (SAS). Pipeline processing of all XMM-Newton observations. Follow-up/identification of XMM-Newton serendipitous sky - the XID Programme. Compilation of the Serendipitous Source Catalogue.



XMM-Newton Survey Science Centre (SC)

4XMM-DR11

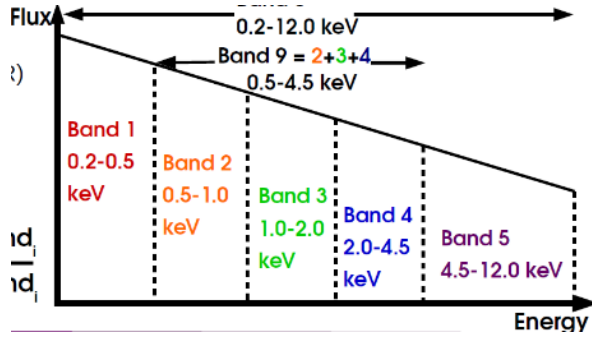


3 February 2000 – 17 December 2020 Released:
 18th August 2021. 895415 detections, 602543
 unique sources - detected up to 80 times. 319292

(36%) sources with spectra and lightcurves.
 112084 extended sources. Cross correlation
 with 222 catalogues. Covers 1239 sq. deg of sky.

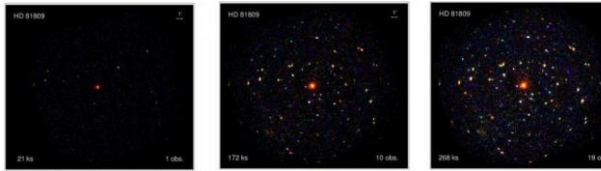
336 columns of information including:

- Identifiers/coordinates
- Observation date/time and observing mode
- Exposure /background info
- Extent
- Counts/fluxes/rates
- Hardness ratios (HR)
- Maximum likelihood
- Quality flags
- Variability



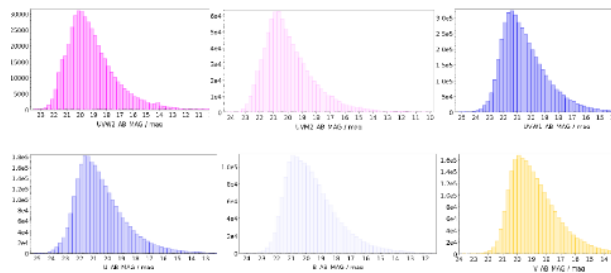
4XMM-DR11s

- 1475 stacks
- 8292 observations
- 335 812 sources
- ~20% new sources with respect to 4XMM-DR11
- Long term variability

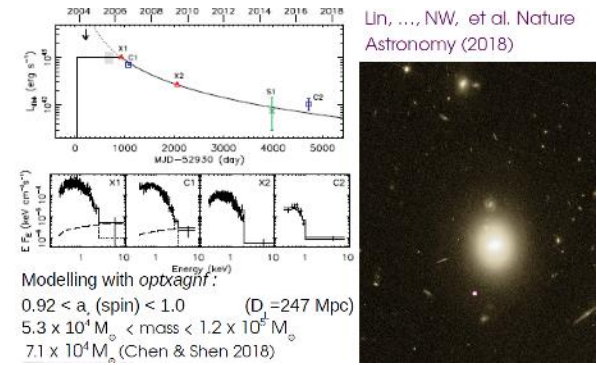


SUSS-5.0

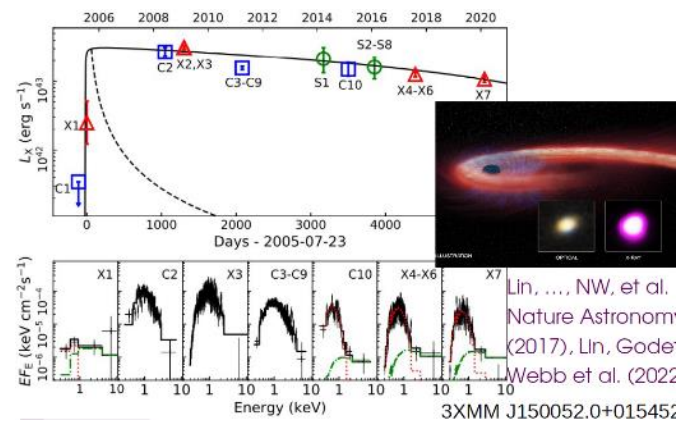
- 10th December 2020
- 10628 observations
- 8863922 detections, 5965434 sources, 1120754 with multiple entries
- 114 columns



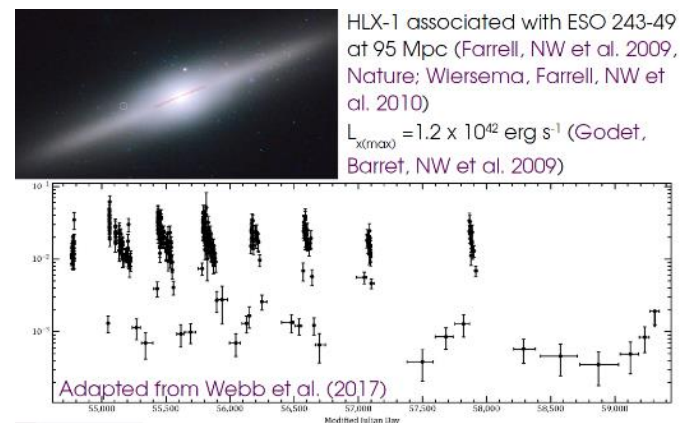
Low mass tidal disruption events



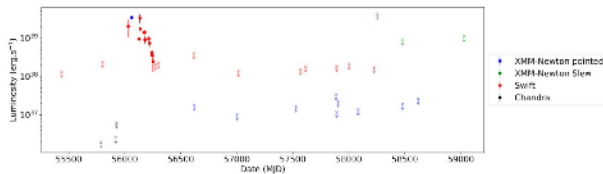
Extreme tidal disruption event



A very bright ULX (HLX-1)



A second neutron star ULX in NGC 7793

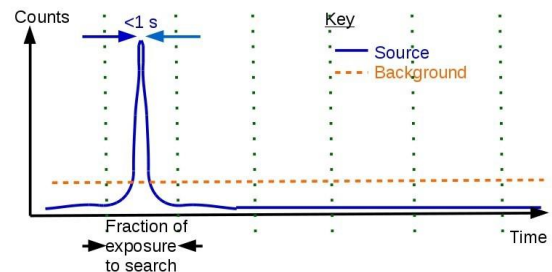


Quintin, Webb et al. (2021)

A new pulsating (0.397 s, 3.4 σ) ULX in NGC 7793 (two confirmed in galaxy)

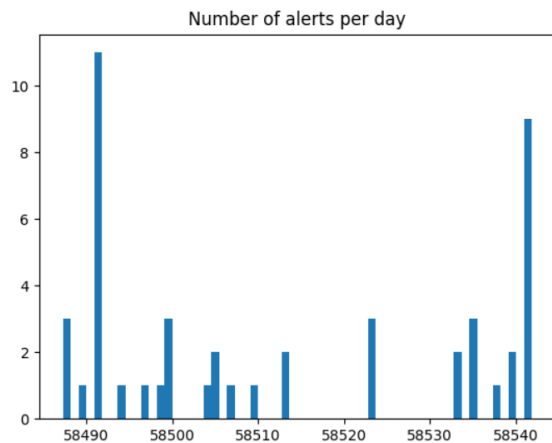
Two other ULXs also highly transient – may also contain neutron stars

discovered. 4 new extra-galactic type I X-ray bursts discovered, only 2 previously known. Recent improvements include using MOS data (confirm bursts) and other observing modes to search all 15000 observations in DR11.



Transient Alerts

Plan to provide transient alerts to community, when PI is in agreement. Developed task to be inserted into pipeline. >30 yrs of XMM-Newton, Swift, Chandra, ROSAT etc data + upper limits. Also exploits the OM data. Test on two months of DR10 data to determine alert rate. Chosen (example) variability of factor 3 (data bars 90%). Consider sources rising, falling, generally variable + short term variability.



4XMM time resolution poor. Faint burst drowned out by background in long observation. Require new way to find short bursts. Pastor Marazuela, Webb et al (2020) devised new methodology to search for sudden bursts and searched whole field of view in short time windows. 5751 pn full frame obs. searched, 2536 rapidly varying sources

XMM2ATHENA*

1st April 2021 – 31st March 2024

Classified X-ray sources (Tranin et al. 2021). Improved upper limit server. Identification + classification of OM sources. Multi-wavelength/messenger counterparts to X-ray sources. Improved source detection in the stacked catalogue. Photometric redshifts. Fits to spectra, including sources with just 5 flux bands. Physically motivated (type/z) spectral fits for best spectra. (Very) short term and long-term variability (+alerts). New outreach material. A single 5XMM catalogue with all the above information (

<http://xmm-ssc.irap.omp.eu/xmm2athena/>)

* This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n°101004168

Future & Catalogue Access

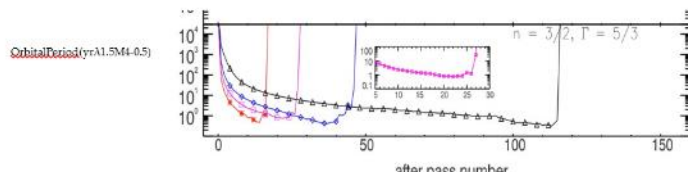
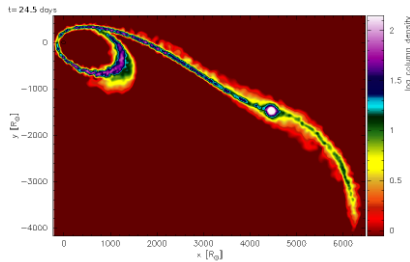
New incremental version planned for 2022 (DR12). Alerts to the community of variable sources in nearly real time. Other XMM2ATHENA products coming.

Catalogue access: XMM-SSC webpages :<http://xmmssc.irap.omp.eu>. But also at : XSA at ESA's XMM-Newton SOC : <http://xmm.esac.esa.int/xsa/> XCAT-DB at <http://xcatdb.unistra.fr/4xmmdr11>

The IRAP catalogue server XSA : <http://xmm-catalog.irap.omp.eu/>
 Browse at HEASARC NASA GSFC:
<http://heasarc.gsfc.nasa.gov/db-perl/W3Browse/w3browse.pl>. ESA sky:
<http://sky.esa.int/> And complimentary optical/UV catalogue using OM data (8.9 million detections, 6 million sources, 6 bands down to 23-25 mag.)

HLX-1 – a failed tidal disruption event

Orbital evolution of a companion, polytrope $n=1.5$, $\Gamma=5/3$ and initial periapsis separation from the IMBH (relative to the tidal radius) of 2.3 (red), 2.4 (magenta), 2.5 (blue), 2.7 (black), $\lambda = R/0.01R_{\odot}$ and $M_4=MBH/104 M_{\odot}$



Low-latency alerts and data analysis for MMA insight

- Each observatory should provide standardised, high quality, virtual observatory compliant, data products allowing the multi-wavelength/messenger identification of a source even if you are not an expert in the observing domains searched. All observatories should be properly credited for the data products provided.
- Coordinating follow-up observations can be very complicated. Avoiding duplicating effort is important. Multiple multi-wavelength facilities could decide to reserve dedicated time

during the year for coordinated multi-wavelength observations (à la EVN). This would imply applying with a single excellent proposal to a Time Allocation Committee (TAC) able to assess the proposal for all facilities. Applicants therefore only need to put together a competent team and an excellent scientific case. Assessment and scheduling would be simplified. What is the best strategy? MoUs? Consortium? Horizon Europe infrastructure?

SVOM

Cyril Lachaud¹, on behalf of the SVOM collaboration

Session Classification: Observatories & alert systems: X-rays, Gamma rays

¹Université Paris Cité, ²<https://www.svom.eu/>

SVOM Observation Programs

The Core Program (GRB). The first objective of the SVOM mission.

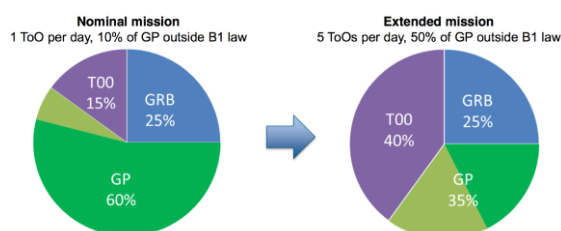
~50-60 ECLAIRs alerts/yr (loc. < 13 arcmin). ~90

GRM only alerts (loc. < 5-10 deg).

~30-40 GRBs/yr with prompt emission over 3 decades + X-ray and V/NIR afterglow + redshift.

General Program (GP). SVOM will be an open observatory : observations will be awarded by a TAC (a SVOM co-I needs to be part of your proposal). 10% of the time can be spent on low Galactic latitude sources during the nominal mission (up to 50% during the extended mission).

Target of Opportunity (ToO) program : alerts sent from the ground to the satellite. Initially 1 ToO per day focussed on time domain astrophysics including multi-messengers. ToO program devoted time increases during extended mission.



Core program (GRB) downgoing telemetry links

VHF: Alert products (ECLAIRs, GRM then MXT, VT). 65% of the alerts received within 30s at the French Science Center.

Beidou: Beidou Navigation Satellite System (BDS). For VHF redundancy and only for high priority alert products. Fast but still under review (recent addition to the SVOM satellite).

First alert notices will be sent automatically within minutes after on-board GRB detection.

X-Band stations: All data are downloaded thanks to X-band stations located in Sanya (Hainan - China). Time between 2 passages strongly depends on the orbit (max=12h).

Circulars with updated analysis will follow the data reception.

Up-going telecommands links (GP & ToO)

GP & ToO-NOM: S-band stations: Standard S-band stations are located in Sanya, Kashi, Qingdao (China). GP Work Plan is uploaded one week in advance. ToO-NOM are uploaded with a typical 48h delay after decision.

ToO-EX & ToO-MM: To reduce the latency for fast ToO (ToO-EX and ToO-MM for exceptional and multi-messenger alerts), Kourou (French Guyana) and Hartebeeshoek (South Africa) can be used as well. We have a delay < 12h between alert and start of observations.

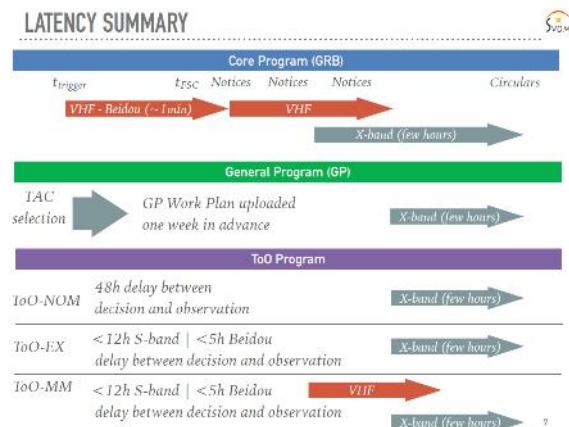
Beidou: Beidou system will be used to reduce the latency with respect to S-band stations for ToO-EX and ToO-MM. Delays still under review. The typical delay between alerts and observations will be ~5 hours at start but will be drastically reduced later.

GP & ToO downgoing links

GP &ToO-NOM: X-band stations: Data downloaded through standard X-band stations in China.

ToO-EX: ToO-EX will use KUX and HBX in addition to the Chinese X-band stations.

ToO-MM: VHF (Beidou): MXT Position packet and photon packets will be sent to the ground through VHF for immediate analysis. Beidou could be used for MXT position packet but it is not confirmed yet.



SVOM Data policy

Core Program (GRB): Real-time VHF scientific products (under the supervision of the Burst Advocates) will be public as soon as they are available => similar to Swift or Fermi-GBM. All the scientific products are public six months after the data production.

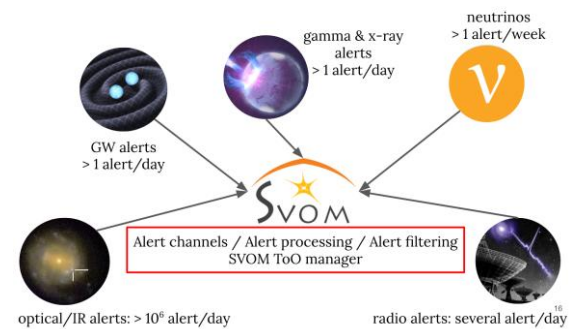
General Program (GP): Semester Call for proposal (in association with a SVOM Co-I), it can include ToO. All the SVOM data will be distributed to the Responsible Co-I. One year of proprietary period before all the scientific products become public.

ToO Program (still under discussion): ToOs triggered by the SVOM CO-Is => we will make publicly available as soon as possible any scientific product that is relevant to perform follow-up observations. The number of products to be publicly released will be

addressed case by case. ToOs triggered by non SVOM CO-Is => all the scientific products will be public as soon as they are available.

SVOM ToO Infrastructure

The future = a large increase of the alert flow asking for transient candidate follow-up observations Our first thought was to deal with the alert flow this way:



SVOM ToO Infrastructure and FINK

We plan to use the FINK broker developed for the Vera Rubin Observatory / LSST which has the capacity to deal with a large volume of alerts to perform the filtering. Thanks to FINK we will trigger our own ground telescopes to enrich promising candidates with data and decide to eventually trigger a ToO for the satellite. SVOM will have also its own channel in FINK so that subscribers can receive our alerts this way (allowing the usage of the FINK filtering mechanisms).

Conclusion

SVOM will be launched mid-2023 and will be an important actor both for alerts and follow-up in space and ground. The recent addition of the Beidou System to the satellite will shorten delays up and down. Still under evaluation by the System team.

POLAR-2

Merlin Kole¹, on behalf of the POLAR-2 Collaboration²

Session Classification: Observatories & alert systems: X-rays, Gamma rays

¹Université de Genève, ²<https://www.unige.ch/dpnc/polar-2>

POLAR-2

POLAR- is a dedicated gamma-ray polarimeter which is confirmed for launch towards the China Space Station (CSS) in late 2024 or early 2025. It is the follow-up mission of POLAR (N. Produit et al. arXiv:1709.07191), which took data from late 2016 until early 2017. POLAR reported a total of 55 GRB observations during this period through GCNs and performed detailed polarization measurements of the GRB prompt emission for 14 GRBs. Its successor POLAR-2 is designed to be approximately one order of magnitude more sensitive than POLAR, thereby allowing it to perform meaningful polarization measurements of GRBs with fluences exceeding 10^{-6} erg/cm² as indicated in figure 1. The large sensitive area required to perform such polarization measurements, in combination with the computing facilities aboard the CSS, makes POLAR-2 also an ideal instrument to provide transient

alerts. The large effective area will allow it to perform spectral and polarization measurements for all GRBs with a fluence exceeding 10^{-7} erg/cm² within its field of view.

In both POLAR-2 and its predecessor POLAR, polarization measurements

of gamma-rays are performed using a plastic scintillator array. When photons Compton scatter, the azimuthal scattering angle depends on their initial polarization vector. Based on this, the polarization of an incoming flux can be measured by selecting photons which Compton scatter in one scintillator bar and subsequently get photo-absorbed in a second scintillator. It is however, important to note that only about 10% of all incoming photons interact like this in the detector while others are either directly photo-absorbed, or undergo multiple Compton scattering interactions in the detector. While not useful for polarization, such photons can be used to perform spectral and localization studies of the transient event and are therefore not discarded from the data. Additionally, in order to compensate for the typically low efficiency for polarization measurements polarimeters have a large geometrical area. For POLAR the geometrical area was approximately 550 cm² (the area depends on

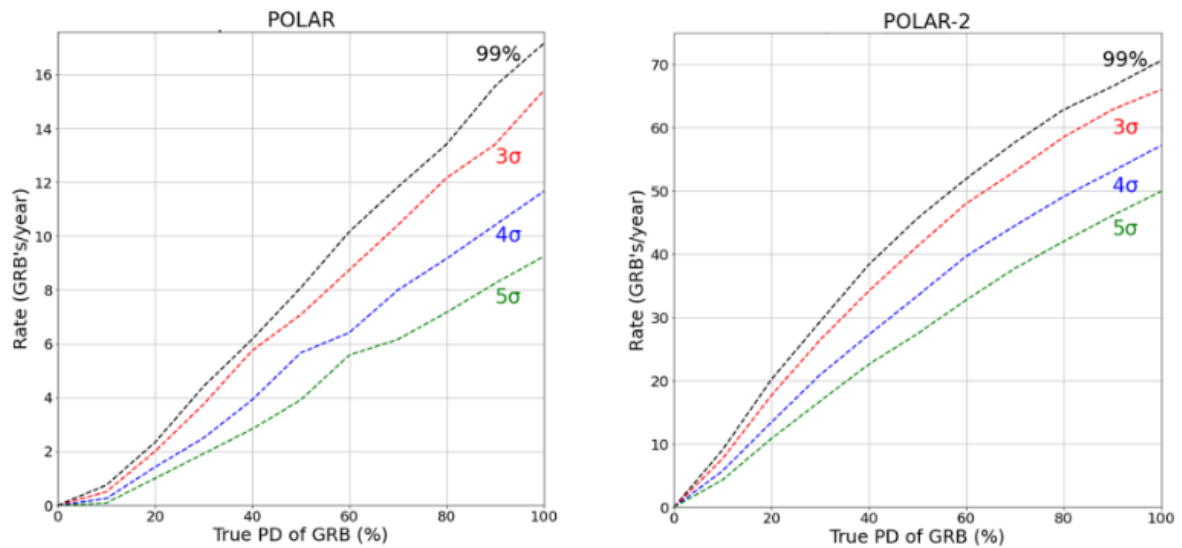


Figure 1: The rate at which POLAR (left) and POLAR-2 (right) are able to detect the polarization of GRBs (with various levels of significance) as a function of the true GRB polarization degree.

the incoming angle of the GRB with respect to the instrument). For POLAR-2 this is 4 times larger, leading to a total geometrical area of approximately 2200 cm².

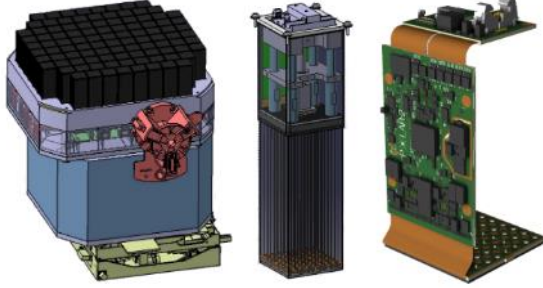


Figure 2: The design of the POLAR-2 instrument (left) containing 100 detector modules, a single detector module is shown in the middle with the front-end electronics shown on the right.

Apart from an increase in the geometrical area technological improvements on the instrument design further increase POLAR-2's sensitivity. The main improvement regards the use of Silicon Photomultipliers (SiPMs) instead of Photomultiplier Tubes (PMTs) which, combined with improvements on the scintillator shape allow for a significant increase in the effective area at energies below 100 keV. The detector design of POLAR-2 is shown in figure 2 while its effective area (for all triggered events) can be seen for three different incoming angles in figure 3.

POLAR-2 is optimized for transient measurements with a field of view of half the sky. This field of view is not occulted by the Earth during any time thanks to the position of POLAR-2 on the CSS. The FoV of half the sky is combined with an operational efficiency only limited by passages through the South Atlantic Anomaly during which the background rate will be too high to allow for meaningful data taking.

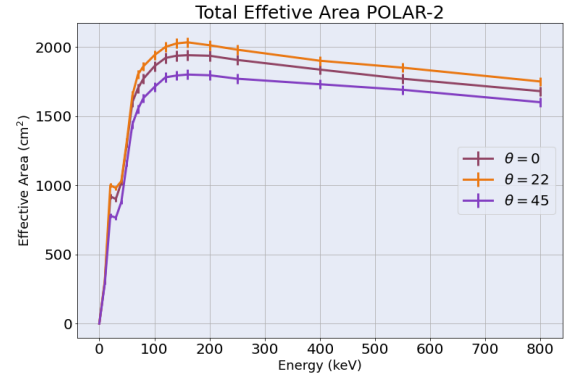


Figure 3: The simulated total effective area of POLAR-2 for 3 different incoming angles.

Localization studies

POLAR-2, like its predecessor POLAR, is sensitive to the incoming direction of the transient event. This is due to the highly segmented detector design which allows to use the dependence in the detector response of the individual detector channels on the incoming direction. For POLAR this method, which is similar to that employed by Fermi-GBM, was tested. It was found that for GRBs with a fluence of $\sim 10^{-5}$ erg/cm² the location on the sky can be measured with accuracy of several degrees (Y.H. Wang et al. NIM.A 988, 2021). The method used for this initial localization study made use of the 'look-up' table method where the response for all detector channels is known for 3 different typical GRB energy spectra. The more complex method, employed by BALROG (J.M. Burgess et al arXiv:1610.07385v1), which performs the spectral and localization fit in parallel to reduce systematic errors on the location, is currently being tested on POLAR data as well. For POLAR-2 the sensitivity to localization is still under study, however, due to the significant increase in effective area and the larger number of detector segments it is expected to be better than that of POLAR.

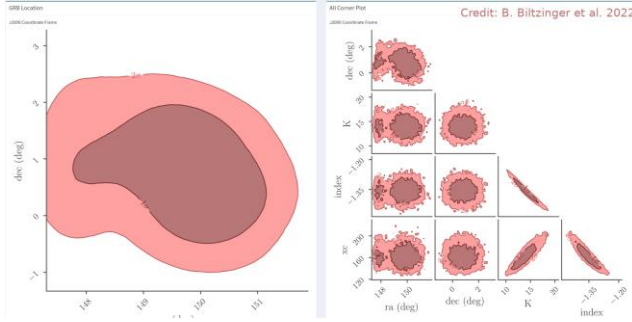


Figure 4: A typical result from the BALROG localization method applied to Fermi-GBM data. The method is currently being evaluated for use on POLAR-2 data after verification on the POLAR data.

Processing and Messages to Ground

All the data from POLAR-2 will be stored and downloaded to ground. The downloads will occur approximately twice a day and allow for a total of approximately 50 GBs/day. This data will cover all data taking allowing for careful background studies throughout the mission and to analyze GRBs reported by other missions.

In order, however, to respond quickly to transient events of interest the instrument will also contain an online trigger algorithm capable of detecting transients with a fluence $> 10^{-7}$ erg/cm². The data from approximately 100 seconds before the online trigger and approximately 10 seconds after will be automatically analyzed using the GPU based computing system on the CSS. The analysis will output a preliminary assessment of the type of GRB, the energy spectra and a basic location on the sky.

The details on the analysis tools to be used are still being evaluated. Although the BALROG method would be ideal for providing an accurate location and spectrum, its adaptability to a GPU based system needs to be understood. The more basic alternative solution of the look-up table based method is a fall-back solution, while machine learning methods more suitable for GPUs are also being evaluated.

The goal is to provide the first basic analysis result within 1 minute of the online trigger. They can subsequently be sent to ground in almost real time using the Beidou satellite system within 560 bit packets. The advantage of this system is that the data can be sent directly to a receiver on ground, without the need for passing through ground stations. A simple automatic ground based analysis is subsequently performed on the incoming alert message before a GCN is sent to the community. The goal of current studies is to be able to send the GCN within 2 minutes of the online trigger.

Schedule and outlook

The POLAR-2 instrument is currently in the final stages of design and the first prototype (consisting of 9 detector modules) has undergone the first scientific evaluation tests as well as calibration tests. The prototype is foreseen to be fully tested by the middle of 2022 followed by the development of the flight model. The flight model will be delivered to China in late 2023 and will be launched towards the CSS in late 2024 or early 2025. The instrument will subsequently start a calibration campaign of approximately 1 month followed by at least 2 years of scientific data taking.

ATHENA

Alexis Coleiro¹

Session Classification: Observatories & alert systems: X-rays, Gamma rays

¹Université Paris Cité

Scientific goals of ATHENA

Athena is the last but one large class mission of the European Space Agency which is expected to fly in 2034. It is designed to investigate two main questions: how does baryonic matter assemble into large-scale structures? How is the matter distributed? How are formed the large-scale structures that we see today? Furthermore, supermassive black holes are hosted at the center of each of those galaxies but the way they grow and interact with their environment is not precisely understood yet. Thus, this leads to the second question that Athena is going to address: how do black holes grow down to the epoch of the reionization and how these black holes shape the Universe?

But Athena will be primarily an observatory: 2/3rd of the observing time during nominal operations will be open to the international community through a standard peer-review call for proposal. It will cover all the topics of astrophysics and in particular for what concerns multi-messenger astrophysics, one of the most important capabilities of Athena will be its fast response since Athena will be able to reach random position in the field of regard within 4 hours, which will allow for fast responses to study multi-messenger transient sources.

Mission profile

In order to achieve these goals Athena includes a unique combination of a scientific payload with a single 12-m focal length telescope and two instruments located at the focal plane of the system: i) a CCD-like wide field imager with a field of view of 40 arcmin and ii) a X-ray integral field spectrometer (X-IFU) which is a microcalorimeter instrument designed to achieve an impressive energy resolution of 2.5 eV at 5 keV. Athena is by far the largest effective

area X-ray telescope which exceeds by at least one order of magnitude the performances of the current generation of X-ray observatories (see Figure 1). And in particular the effective area of the X-IFU spectrometer will exceed around 1 keV by a factor of fifty the effective area of any existing similar instruments or instruments that will flow in the next few years.

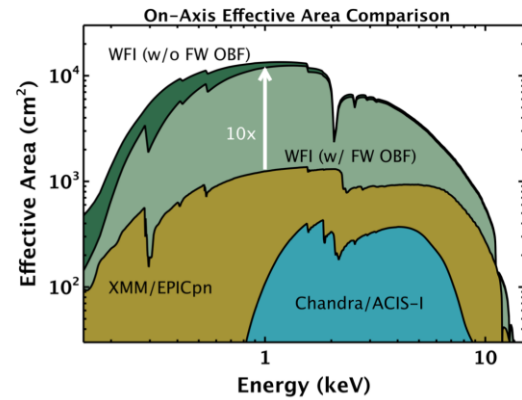


Figure 5.a.: Effective Area of Athena/WFI compared with current generation instruments.

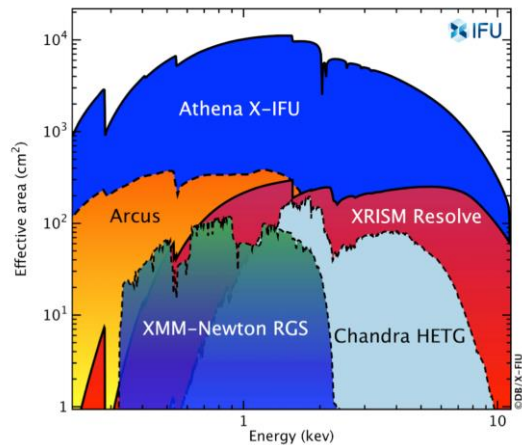


Figure 6.b.: Effective area of Athena/X-IFU compared with current generation instruments.

Multi-messenger synergies

The multi-messenger synergies where Athena will play a major role are diverse and in the

following, we only provide with some examples. The interested reader can refer to the multi-messenger Athena synergy white paper¹ for a more exhaustive discussion.

For what concerns the follow-up of gravitational-wave events from stellar-mass compact objects, Athena will be able to perform a much wider and accurate census of X-ray counterparts, in particular for neutron star - neutron star mergers. Figure 2 shows the predicted X-ray lightcurves of events similar to GW170817 at 41 Mpc for different viewing angles. One can see that for any inclination, Athena will be able to detect the source over a long timescale. But it will also be able to constrain the jet geometry and orientation by following the X-ray lightcurve, probe the relation between jet's orientation and binary inclination, determine the rate of choked jets with more isotropic electromagnetic emission and possibly break the degeneracy on the nature of the remnant.

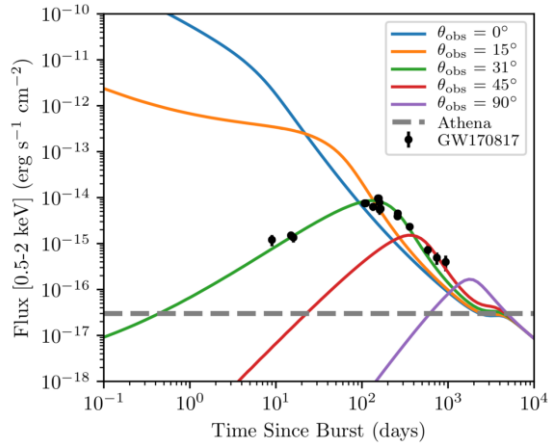


Figure 2: Predicted X-ray lightcurve of gravitational-wave events similar to GW170817 at 41 Mpc with different viewing angles. The Athena sensitivity is shown by the gray dashed line. From Troja et al., 2020, MNRAS, 498, 5643.

Another particularly exciting possibility is the synergy with LISA, the future gravitational wave space interferometer that the European Space Agency will launch in the thirties and which will detect supermassive black hole mergers.

Studying those mergers with both LISA and

Athena is particularly appealing because it would provide a unique opportunity to probe the behavior of matter in such mergers, study the speed of gravity, provide an independent measurement of the Hubble constant and a unique opportunity to probe the physics of Active Galactic Nuclei (AGN) in particular the onset of jets and the formation of a corona surrounding the black hole.

More precisely, Athena might detect supermassive black holes at a redshift up to 2, an horizon at which LISA should detect about 3 events per year. But when searching for the electromagnetic counterpart, the challenge is how to distinguish those mergers from isolated AGNs or other X-ray transients. To answer this question, one needs to rely on theory and numerical simulations which demonstrate that SMBH mergers should emit in soft X-rays due to the presence of different accretion flows (see Figure 3) around the two black holes. This X-ray emission might show clear modulation correlated with the gravitational wave periodicity as we can see in Figure 4. This could be a good signature to search for when looking for X-ray counterpart of LISA events but there are still a lot of unknowns like the X-ray obscuration. The key element to achieve such multi-messenger observations is the localization capability of LISA which should ideally be of the same order as the Athena field of view to avoid tilling a very large region of the sky.

Current studies show that this could be possible a few hours prior to the coalescence for a few very high signal-to-noise ratio events detected by LISA but specific joint observing strategies are still to be improved.

¹ <https://arxiv.org/abs/2110.15677>

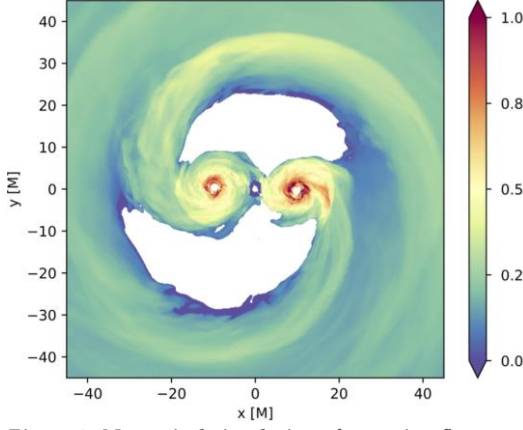


Figure 3: Numerical simulation of accretion flows around a supermassive binary black-hole merger. The simulations shows the presence of a circumbinary disc as well as mini-disks surrounding the two black-holes. These structures are expected to emit in soft X-rays. From d’Ascoli et al., 2018 ApJ 865 140.

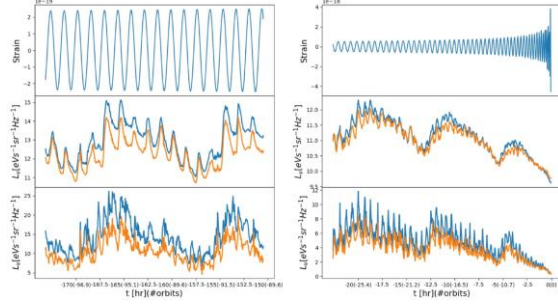


Figure 4: Simulated X-ray lightcurve of a supermassive binary black-hole merger. From Tang, Y. et al., 2018, MNRAS 476

Concerning the origin of the cosmic rays and their acceleration, Athena will work in close synergy with neutrino telescopes as well as with CTA.

Neutrinos are the signature of accelerated baryons and combined observations in X-rays, gamma-rays and neutrinos will allow to disentangle leptonic and hadronic populations and then constrain the origin of the cosmic rays. This is true at the extragalactic scale where we can investigate whether AGNs and in particular blazars are significant neutrino emitters. This is a hot topic since the detection by IceCube of a neutrino coincident with a gamma-ray flare of the blazar TXS 0506+056 in 2017. And in this context, soft X-ray observations have been shown to be really decisive to constrain hadronic or leptohadronic models (see Figure 5) and Athena will play an important role here as well.

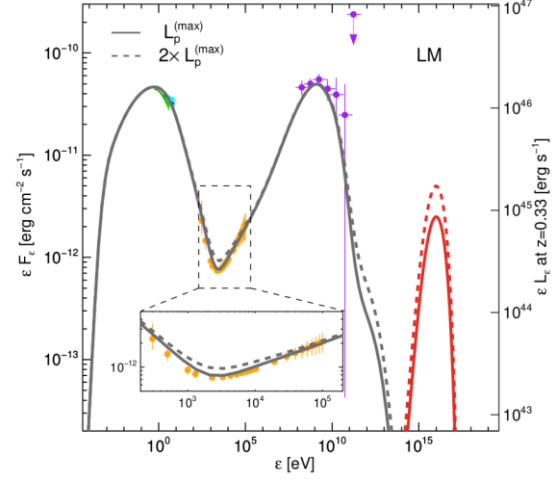


Figure 5 : Spectral Energy Distribution of the blazar TXS 0506+056 fitted with a leptohadronic model, showing the importance of soft X-ray dataset to constrain the proton luminosity. The red curves shows the expected neutrino spectral energy distribution, compatible with the detection of IC190922-A. From Keivani et al., 2018 ApJ 864.

The synergies between neutrino telescopes, CTA and Athena also apply at the galactic scale with the study of supernova remnants that will be one of the main topics addressed with the X-IFU spectrometer. In particular combining multi-messenger data will enable to constrain cosmic ray acceleration in these sources and X-ray data are particularly useful here in order to estimate both the matter density on which cosmic rays interact and the magnetic field intensity.

AGILE

Andrea Bulgarelli¹, on behalf of the AGILE team²

Session Classification: Observatories & alert systems: X-rays, Gamma rays

¹INAF OAS Bologna, ²<https://agile.ssdsc.asi.it/>

The AGILE satellite

AGILE unique combination of two co-aligned X-ray and γ -ray imaging detectors. Excellent for multimessenger counterpart search. Two non-imaging 4π detectors: MCAL (0.3 – 100 MeV), AC (80 keV - 200 keV).

Launch: April 23, 2007. Fully operational, nominal status, and active in:

- gamma-ray astrophysics;
- terrestrial atmosph. & magnetosph. physics;
- solar physics;
- search of GRB, GW counterparts, neutrinos, Fast Radio Bursts and other transients.

AGILE Mission Configuration

Other capabilities for multimessenger counterpart search:

1. GRID ($E > 30$ MeV) very large field of view (2.5 sr)
2. Sensitivity $\sim (1-2) \cdot 10^{-8}$ erg/cm²s in 100 sec.
3. - Spinning observation mode: rotation $\sim 0.8^\circ/\text{sec}$, 200 passes/day with 70-80% of the sky coverage (solar panel constraints) \rightarrow “almost” full sky coverage every ~ 7 min.

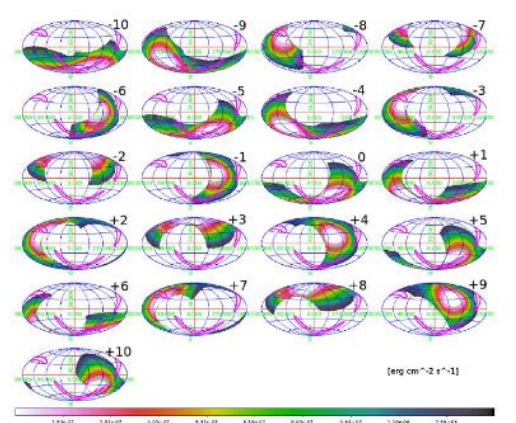


Figure: 100 s interval sequence of ($E > 50$ MeV) maps in Galactic coordinates showing the AGILE-GRID passes with the best sensitivity (in $\text{erg cm}^{-2} \text{s}^{-1}$) over the GW170104 obtained during the period (-1000 s, $+1000$ s) with respect to event time.

From Ground Station to AGILE Science Team

The AGILE data flow and pipelines are distributed between the data center at ASI/SSDC and INAF/OAS in Bologna \rightarrow redundancy/availability.

First scientific results through the Real Time Analysis (RTA) developed by INAF/OAS Bologna are within ~ 25 min from the data downlink to the ASI Malindi ground station \rightarrow software optimization/parallel processing.

AGILE Team organization

The monitoring of the gamma-ray sky is one of the main activities of the AGILE Team. Two roles:

- Flare advocates: GRID data, daily basis.
- Burst advocates: shifts 24/7 to check results on external trigger, but also the check results on AGILE data.

The AGILE Real-Time Analysis workflow

1. The system at INAF/OAS Bologna, with the LV2 data received from SSDC.
2. Alerts are received from the GCN network.
3. GW: two independent wakeup systems call the AGILE Team if a new alert from LIGO/Virgo collaboration is received.
4. PIPELINES ON REAL-TIME AGILE DATA:
 - a) AGILE-MCAL pipeline searches GRB and TGFs. In the presence of a GRB identified by MCAL pipeline, an automated GCN notice is submitted to the GCN network.
 - b) AGILE-RM analyses SuperAGILE, MCAL, GRID and AC ratemeters.
 - c) AGILE-GRID analysis to search flares at daily basis above 100 MeV: SPOT6 at INAF/OAS Bologna and Quick-Look Scientific pipeline at ASI/SSDC with two different methods of analysis.
5. PIPELINES ON EXTERNAL SCIENCE ALERTS: if new alerts are received, the science alert pipeline performs automated scientific analysis of GRID, MCAL and ratemeter data: the pipeline alerts the AGILE Team (SMS, email and call) preparing two templates for the GCN Circulars that the Burst Advocate can use to send an answer to the external science alert.
6. Control Room: to monitor both AGILE technical information (data archive, data flow etc.) and scientific results produced by the pipelines.

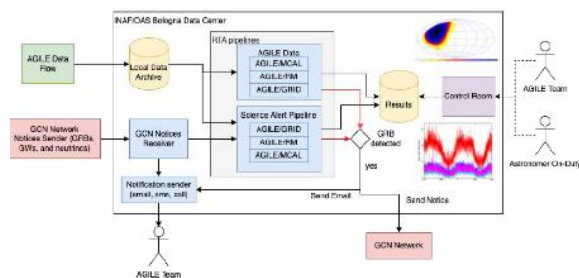


Figure: the general workflow of the AGILE Real-Time Analysis pipeline

Ratemeters pipeline

The AGILE RM (ratemeters) pipeline analyses SuperAGILE, MCAL, GRID and AC ratemeters and performs a detrending of the data.

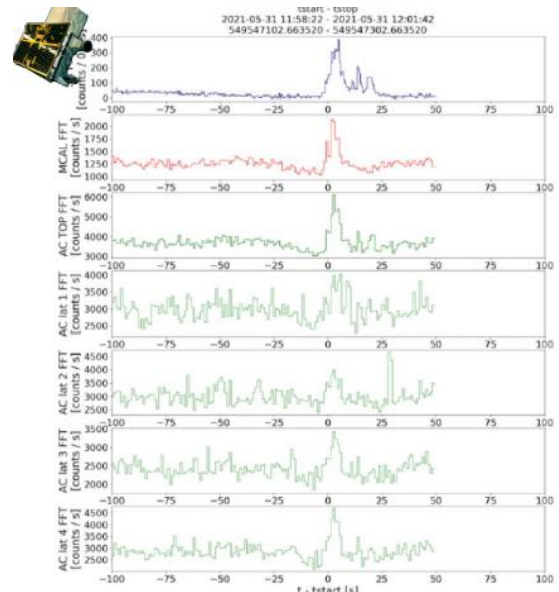


Figure: The AGILE RM (ratemeters) pipeline analyses SuperAGILE, MCAL, GRID and AC ratemeters and performs a detrending of the data.

MCAL pipeline - GRB detection

The AGILE MCAL automated pipeline sends notice to the GCN network when a GRB is detected. Since this implementation (2019) more than 60 automatic notices have been sent.
https://gcn.gsfc.nasa.gov/agile_mcal.html

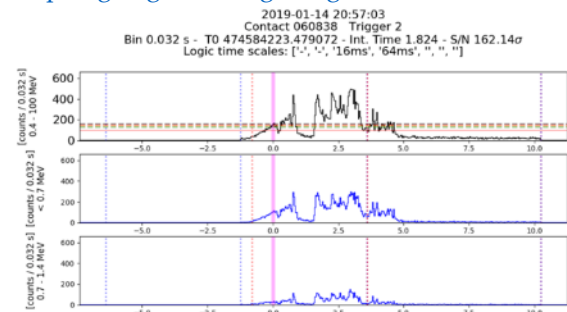


Figure: a GRB detected by the AGILE MCAL automated pipeline.

MCAL pipeline - TGF detection

The AGILE MCAL automated pipeline detect Terrestrial Gamma-Ray Flashes (TGF). From June 2020 about 500 TGF has been detected. Due to its equatorial orbit it is possible to detect multiple TGFs from the same storm.

Science Alert Pipeline

Science alert are received from GCN network and CHIME and the AGILE data is automatically analysed. Automated analysis are performed for triggers from LIGO/VIRGO, Fermi, Swift, Icecube, Integral, FRB.

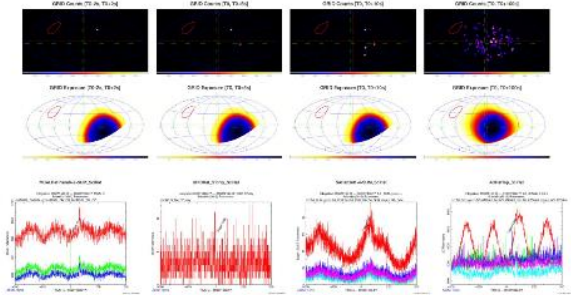


Figure: an example of a report generated automatically with the result from GRID and ratemeters in coincidence with an external trigger.

AGILEScience App

The Team has developed an App to monitor the results of the AGILE satellite and perform GRID analysis: AGILEScience for iOS and Android. The last available gamma-ray sky maps is available for outreach purposes. “Science on the road” functionality allows AGILE team to perform analysis on GRID data with the AGILEScience App.



Figure: From left to right: (i) the Flare Advocate can check the γ -ray sky. If a candidate γ -ray flare is found it is possible to perform a manual scientific analysis to confirm the result. To perform the scientific analysis, (ii) the Flare Advocate goes in the “Scientific Analysis” section, (iii) where is possible to create a new analysis or select an existing one, (iv) some parameters of the analysis must be inserted (e.g. integration time, position in the sky), and (v) the App shows the final result, analysed with the Maximum Likelihood Estimator, and the sky maps.

Many important discoveries. Two examples

1) The first detection of a gamma-ray flare from Crab Nebula in Sept 2010 was performed by these pipelines. AGILE Team was immediately alerted and after few hours the ATEL #2855 was issued. After few hours, the Fermi/LAT confirmed the result (Science, Tavani et al. 2011 → Bruno Rossi Prize 2012).

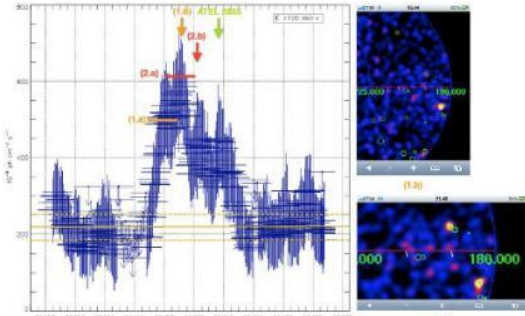


Figure: 96' sliding light curve (with two-day integration time) of the 2010 September Crab nebula flare as seen by the Bologna's AGILE-GRID Science Alert System. Errors are 1σ , and time is given in MJD.

2) AGILE strongly affected by limited ground operations at ASI Malindi due to the COVID-19 pandemic: from March to June 2020 down to 3 pass/day (over ~14 pass/day) → new automatic ratemeter analysis pipeline and burst identification. Two results: 2.1) AGILE become also a solar flare monitor; 2.2) FRB science: very important discovery on April 28, 2020 (ATEL #13686) published in Nature Astr., Tavani et al. 2021 (2021NatAs...5..401T), it shows for the first time that a magnetar (SGR 1935+2154) can produce X-ray bursts in coincidence with FRB-like radio bursts.

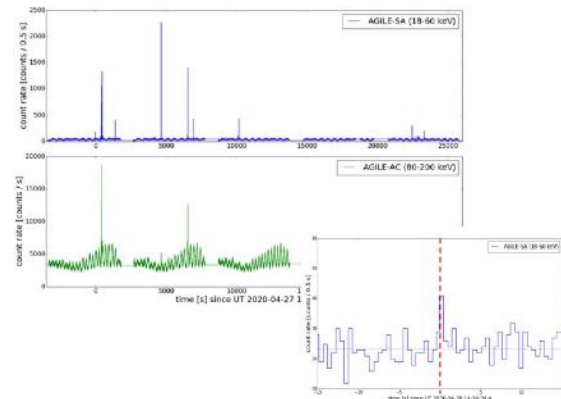


Figure: AGILE ratemeters coincidence with the radio burst reported by CHIME/FRB at $T_0 = 2020-04-28 14:34:33$ UTC.

CNN evaluation with real data

We developed a Convolutional Neural Network (CNN) to detect GRBs from the AGILE/GRID counts maps to overcome the limits of the Li&Ma methods:

- We tested the CNN using the Fermi-LAT, Fermi-GBM, and Swift-BAT GRB catalogues.
- These maps are analyzed with both the CNN and the standard Li&Ma methods.
- The CNN detected 21 GRBs with a $\sigma > 3$ from the list of GRBs obtained with Fermi and Swift catalogues. The Li&Ma on the same list and with the same parameters detected only two sources.
- This CNN is implemented into the AGILE GRID real-time analysis pipeline that reacts to external science alerts.

Table 2. List of GRBs detected with CNN and Li&Ma methods.

GRB	CNN			Li&Ma		
	T_{on}	N_{on}	sigma	T_{on}	N_{on}	sigma
100724B	200	9	5			
110530A	200	3	3			
120711A	200	2	3			
121202A	200	2	3.5			
130427A	200	5	5			
130518A	200	2	3.5			
130828A	200	5	5			
131108A	200	11	5	200	11	4.4
141012A	200	3	4			
141028A	200	4	3			
160325A	200	4	4			
160804A	200	2	3.5			
160912A	200	8	4			
170115B	200	4	4			
170127C	200	3	4.5			
170522A	200	5	5			
170710B	200	4	3.5			
180418A	200	2	3.5			
180720B	200	13	5	200	13	4.7
190324B	200	5	3			
190530A	200	6	4.5			

In progress: deep learning methods on ratemeters.

Parmiggiani, N., *Italian National Prize for Artificial Intelligence and Big Data research, WMF and IFAB 2021. Media INAF*

Conclusions

The monitoring of the gamma-ray sky with a rapid and efficient alert system led to the publication of 231 ATels and 114 GCNs circulars: AGILE follow-up of all GW events resulted in 96 GW-AGILE type GCNs.

From May 2019 automatic GCN notices on MCAL: more than 60 notices have been sent to the GCN network about GRBs without human intervention.

Many lessons learned after 15 years of operation on team experience, mission configuration, software optimization, team organisation that are available to the overall community: some part of the system will be reused for the development of the CTA/Science Alert Generation System (see Monica Seglar-Arroyo's talk).

AGILE team is producing new tools available at <https://agile.ssdsc.asi.it/> and Agilepy (see <https://agilepy.readthedocs.io/en/latest/>) to make easier as possible the use of AGILE data, that is publicly available.

Coordination is mandatory. Enhance cooperation with the community, e.g. on sub-threshold events.

THE AGILE SKY SCANNING GOES ON!

*<https://indico.in2p3.fr/event/25290/contributions/104614/>

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Running Imaging Atmospheric Cherenkov Telescopes

Matteo Cerruti¹

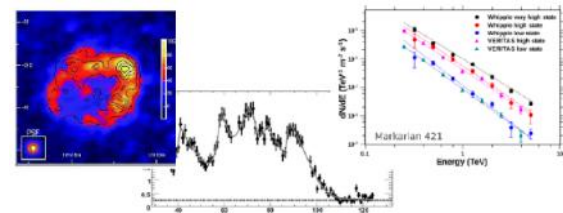
Session Classification: Observatories & alert systems: Gamma rays, Neutrinos, Cosmic rays

¹Université Paris Cité

Imaging Atmospheric Cherenkov Telescopes (IACTs) are gamma-ray detectors that use the Earth's atmosphere to indirectly measure the properties of photons coming from the Universe. They work by imaging the Cherenkov light produced by the particle cascades triggered in the interaction of TeV photons with the nuclei in the atmosphere. The major limit of the detection technique is that photons are not the only particles that can produce cascades: cosmic rays with similar energies also trigger cascade and their Cherenkov light is imaged by the telescopes. The shape of the Cherenkov images is fortunately different, and it is possible to effectively perform a background subtraction and identify gamma-ray candidates. From these, it is possible to reconstruct incoming direction, arrival time, and energy of the photons, and thus do TeV astronomy by producing sky-maps, spectra, and light-curves.

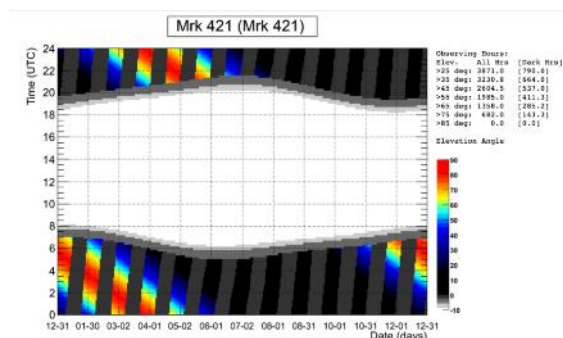
IACTs work in the energy band ~ 100 GeV - 100 TeV, with threshold energy dependent on the zenith angle of the observations. Energy resolution is about 10% at 1 TeV; and angular resolution is about 0.05° at 1 TeV. The field of view of running instruments are 3° to 5° .

There are currently three major IACT arrays: H.E.S.S. (in Namibia), MAGIC (on the Canary Island of La Palma), and VERITAS (in Southern Arizona). Nearby the MAGIC telescopes are installed the FACT telescope, and LST-1, the first telescope of the future CTA-North array.



IACT have some observational constraints that are important for multi-wavelength and multi-messenger campaigns:

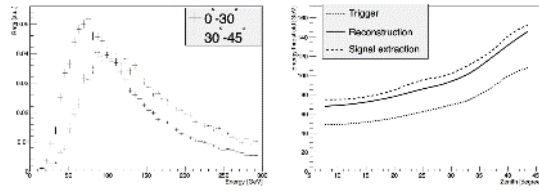
1) standard observations can be performed under dark conditions only. This constraint significantly limit the duty cycle of the observations, and a large effort has been done to extend observing capabilities under moonlight. See [MAGIC Collaboration 2017](#), [VERITAS Collaboration 2017](#) & [2015](#). H.E.S.S. also implemented a moonlight program in the last years. The FACT camera is unique in this sense, being able to regularly observe in moonlit nights.



Visibility plot of Mrk 421 from MAGIC site
 (tevcad.uchicago.edu)

2) the observing capabilities of IACTs depend on the zenith angle of the observations. This has an impact on the capabilities to follow up astronomical transients. The main effect is an

increase of the energy threshold with increasing zenith angle.

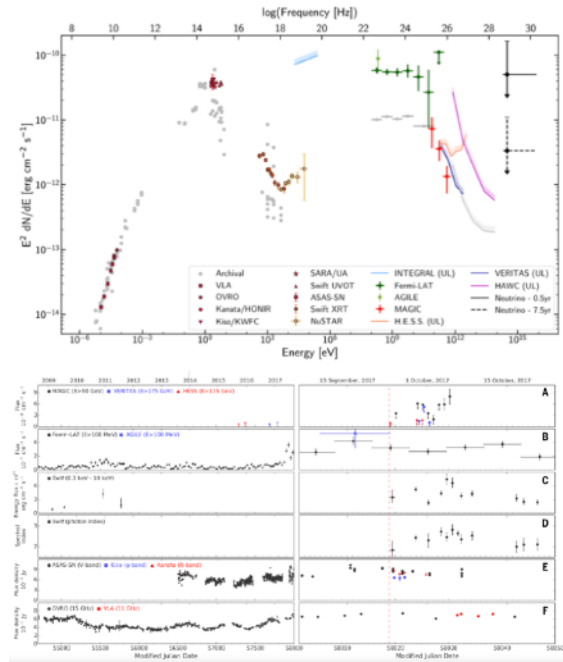
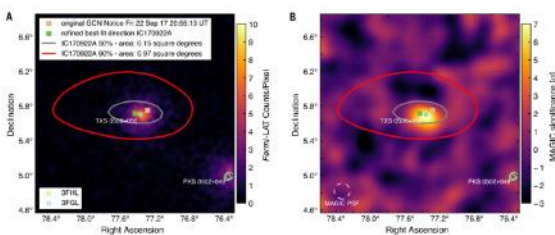


3) the Universe is opaque to TeV photons: they pair-produce on low-energy (infrared and optical) photons that are abundant in the Universe, and constitute the Extragalactic Background Light. This effect results in an absorption in the TeV band. The absorption is energy dependent, so the spectra of extragalactic sources appear softer ('redder') than they intrinsically are. The most distant published detection is from the gravitationally lensed blazar S3 0218+35 ($z=0.95$). The most distant preliminary detections (announced via Astronomer's Telegrams or GCN notices) are GRB 201216C ($z=1.1$), and the blazar PKS 0346-27 ($z=0.99$)

IACTs in the multi-messenger news

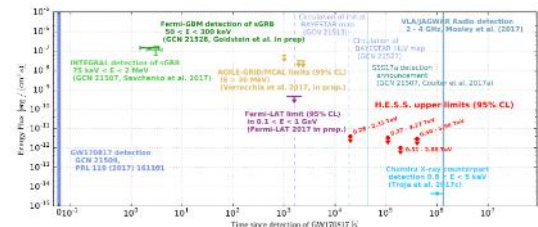
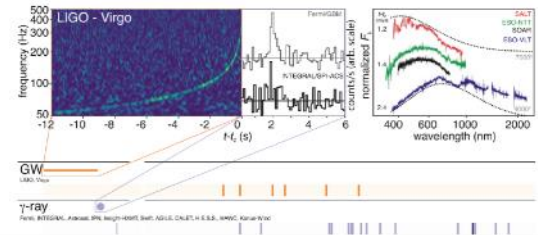
The recent years have seen a fast development in multi-messenger astronomy, and IACTs contributed significantly to two major observing campaigns:

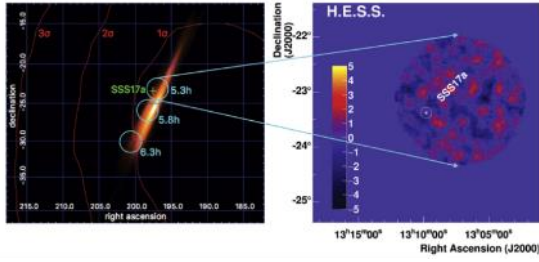
1) In September 2017, the IceCube neutrino detector observed a high energy neutrino (IC170922A, with an estimated energy of 290 TeV), coincident at the 3σ level in space and time with a gamma-ray flare from the blazar TXS 0506+056. This is the most significant association today of a high-energy neutrino with an astrophysical source.



IceCube, Fermi, MAGIC et al. 2018

2) In August 2017 IACTs took part in the multi-messenger campaign that led to the identification of the electromagnetic counterpart to the gravitational wave event GW170817. In particular, the H.E.S.S. telescopes were the fastest telescopes on target besides survey instruments. No TeV counterpart of the event was observed, but upper limits on the flux could be placed.

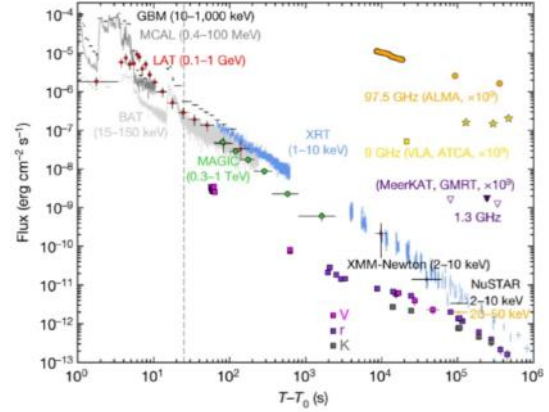




[LIGO-VIRGO+++ 2017](#) ; [HESS Collaboration 2017](#)

3) Although it is not a multi-messenger type of events yet, it is important to mention that in the recent years IACTs have observed gamma-ray bursts (GRBs) in the TeV band, after more than a decade of upper limits. Today 4 GRBs have been observed by IACTs. This type of events show well the capabilities of current instrument to fast reaction to external triggers.

Fig. 1: Multi-wavelength light curves of GRB 190114C.



[HESS Collaboration 2019 & 2021](#) ; [MAGIC Collaboration 2019](#)

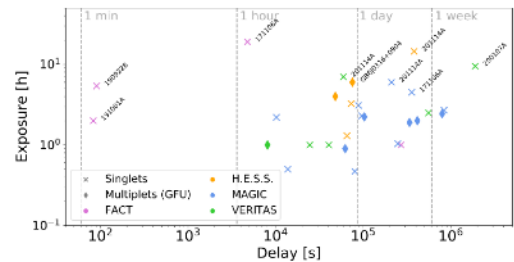
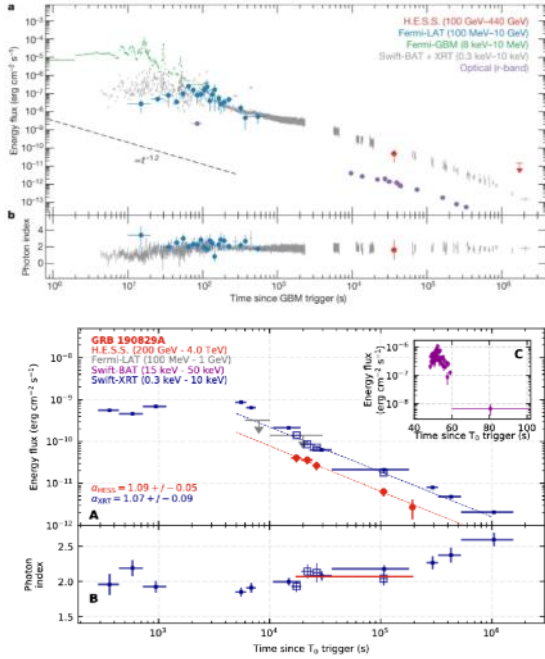
Receiving alerts : neutrinos

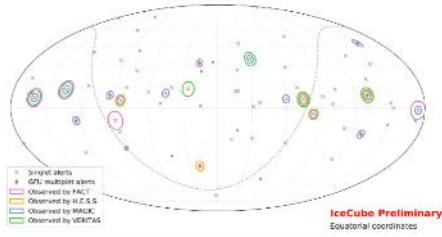
Concerning neutrino alerts from the IceCube detector, IACTs have two main channels:

- 1) Alerts on high-energy single events that are publicly shared on GCN or Astronomer's Telegram.
- 2) Gamma-ray Follow Up (GFU) program. In this case the IceCube collaboration is looking at excesses of events at pre-defined positions in the sky, coincident with known gamma-ray sources.

In both cases IACTs can perform automatic repointing during data-taking if the location is visible in the sky (see previous section). Otherwise observations are scheduled on best-effort.

Fig. 1: Multi-wavelength light curve of GRB 180720B.

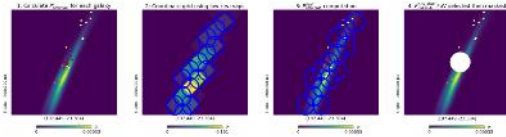




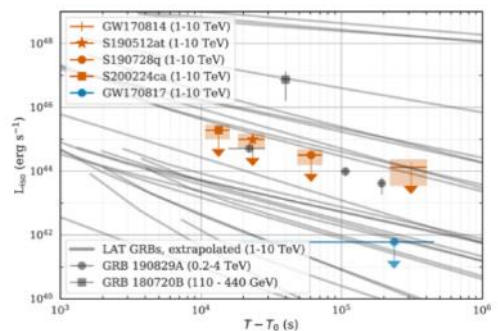
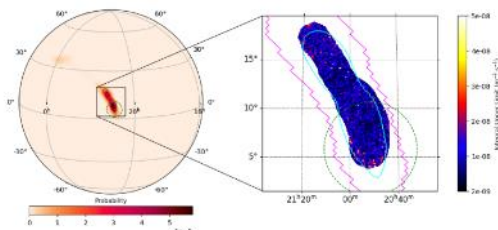
[IACTs+IceCube ICRC 2021](#)

Receiving alerts : GW

Gravitational waves alerts are unique due to the larger uncertainty regions, that usually exceed the field of views of IACTs. In this case the optimal strategy is to map the uncertainty region to test for all possible localizations. The IACT community has developed automatic tools to optimize this mapping. For further details see next talk by Dr. Seglar-Arroyo.



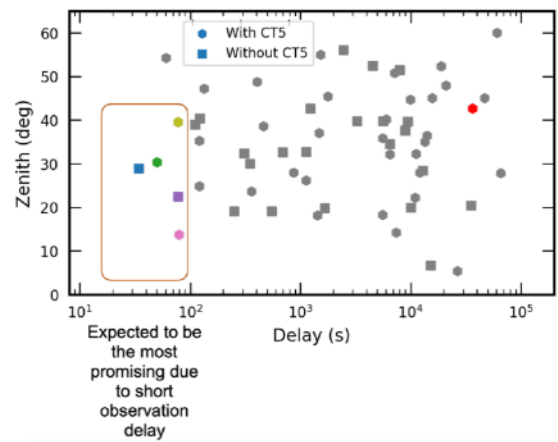
[Ashkar+ 2021](#)



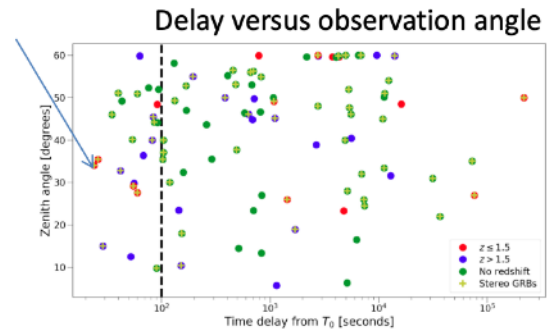
[HESS Collaboration 2021](#)

Receiving alerts : GRBs

The detection of GRBs in the TeV band has been one of the main scientific drivers of IACT science. A lot of efforts have been developed in maximizing the slew speed to be on target as fast as possible. For alerts that are visible during data-taking, IACTs can be on target, taking data, in less than a minute. Updates from GRB follow-ups program by all IACT collaborations have been regularly presented in the last decades. The first detections had to wait until 2019 and show that, interestingly, TeV emission can be observed deep in the afterglow phase.



[HESS Collaboration ICRC 2019](#)



[MAGIC Collaboration ICRC 2019](#)

Receiving alerts : LST

The future of IACTs is CTA, the Cherenkov Telescope Array, that will significantly boost the sensitivity in the TeV band. The first CTA telescope, LST (Large-Size Telescope) is already taking data on the future CTA-North site. At the last ICRC the first results from LST observations have been presented, including follow up observations on GRBs and IceCube neutrinos. Although these results in upper

limits, it shows the capabilities of the new telescope.

events this delay can be reduced, and the fastest ATel from IACTs happened about 4 hours after the detection of the GRB 190114C.

	T_0 [UTC]	T_{90} [s]	z	Start time [UTC]	Zenith [deg.]	Delay [s]	Trigger	VHE
GRB 201216C	23:07:31	48.0	1.1	20:57:03	40	79200	<i>Swift</i>	Y ^a
GRB 210217A	23:25:42	4.2	-	23:40:22	44	880	<i>Swift</i>	N
GRB 210511B	11:26:39	6	-	03:37:54	45	58200	<i>Fermi-GBM</i>	N
IC 210210A	11:53:55	-	-	05:41:54	25	64134	<i>IceCube</i>	N

[CTA-LST Collaboration ICRC 2021](#)

Sending alerts

All IACTs have running real-time analysis tools, that give the observers significance maps in real time, and thus the capability to send alerts to the world. The usual approach is to perform next-day analyses for interested signals picked up by the real time analyses. Astronomer's Telegrams and/or GCN are commonly sent the day after the observations. For bright and out-of-doubts signals, the reaction time can be faster. The fastest reaction time has been for the GRB 190114C, for which the corresponding ATel has been sent about 4 hours after the event.

An exception to this typical reaction times is represented by a memorandum of understanding among IACTs, which gives them the possibility to directly communicate about flares from a pre-defined list of *known* TeV blazars and pre-defined thresholds. In this case communication happens almost in real time via email exchange among shift crews.

Conclusions

All running IACTs have very active transients programs with specific focus on multi-messenger follow-ups. TeV data from IACTs have been included in the major multi-messenger campaigns in the last years.

On the receiving part, IACTs can react down to sub-minute time-scales if the alert is received and visible during data taking.

On the sending part, they rely on real time analysis tools that need validation by humans. Alerts are typically sent the day after the observations, once real time analyses have been validated by offline analyses. For very bright

CTA

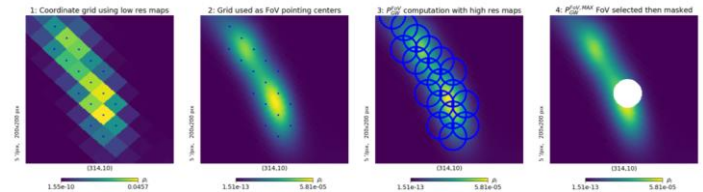
Monica Seglar-Arroyo¹

Session Classification: Observatories & alert systems: Gamma rays, Neutrinos, Cosmic rays

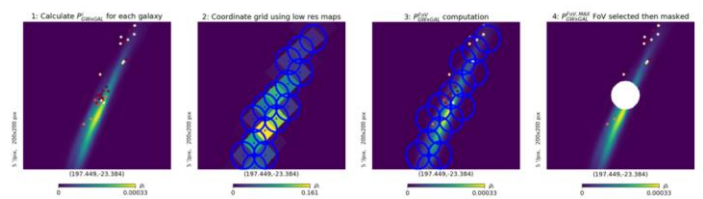
¹Centre national de la recherche scientifique ; <https://www.cta-observatory.org/>

Observe Transients in VHE with IACTs

- The gamma-ray interacts in the atmosphere and produces a shower of particles
- Cherenkov radiation for charged particles at $v > c$
- The Imaging Atmospheric Cherenkov Telescopes (IACTs) faces challenges in transient follow-up
 - Low duty cycle: darkness conditions,
 - Some transients, as in GW localization, may have large uncertainty regions 10-1000 deg²
 - Need of fast alert systems are key for rapid and strategic response

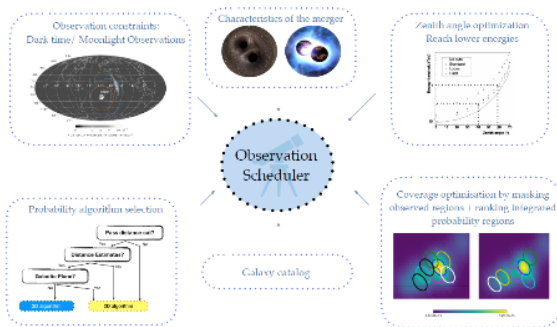


- 3D Algorithms: obtain 3D posterior 'GW x galaxy' probability distribution using GW skymap and galaxy catalogs (e.g. GLADE)



Ashkar, H., SA, M., et al., (2020). *The HESS Gravitational Wave Rapid Follow-up Program.*
 JCAP2021, 2021.03: 045

Rapid Follow-up Observations in IACTs



Seglar-Arroyo, M., Schüssler, F. Moriond VHEPU 2017, PoS 167-174. / Ashkar, H., SA, M., et al., (2020). *The HESS Gravitational Wave Rapid Follow-up Program.*
 JCAP2021, 2021.03: 045

These algorithms, developed at the beginning of O2, used by H.E.S.S. during the second half of O2 and O3 => total of 6 follow-up campaigns, see Abdalla, H., et al., ApJ 923.1 (2021): 109.

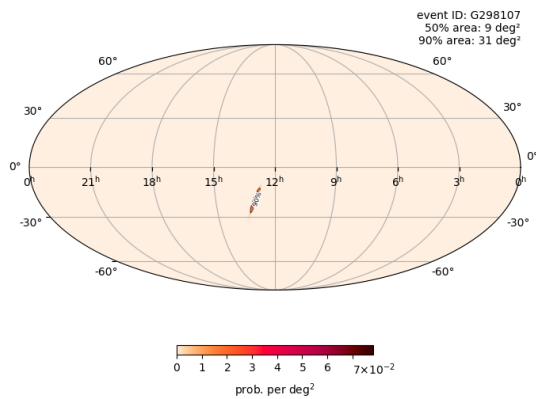
Probability Selection Algorithms

- 2D Algorithms: using 2D localization uncertainty region of GW skymap

H.E.S.S. observations of GW170817

H.E.S.S. was the first ground-based instrument on target

- 5.3 hours after merger
- 5 minutes after the publication of the GW skymap (LV reconstruction)
- Before the discovery of the optical transient SSS17a
- 3 observations from 17:59 - 19:30 UTC.
- 56 % of the GW covered (effective FoV of 1.5deg° radius)
- No TeV emission was detected



First telescope installed of full CTA array: LST telescope being installed (CTA-North site). Suited for short time-scale transients follow-up and high-redshift sources:

- Large effective area: Low energy-threshold
- Fast repositioning (~ 20 s for 180°)

LST-1 telescope currently in its commissioning phase on La Palma, Canary Islands. The First ATel #14783 on a variable, extragalactic object: BL Lacertae in July 202

Real Time Analysis under commissioning

Observation scheduler in LST

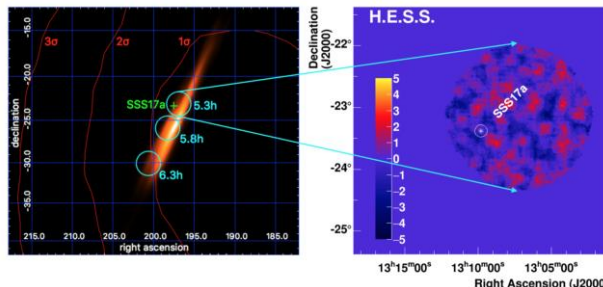
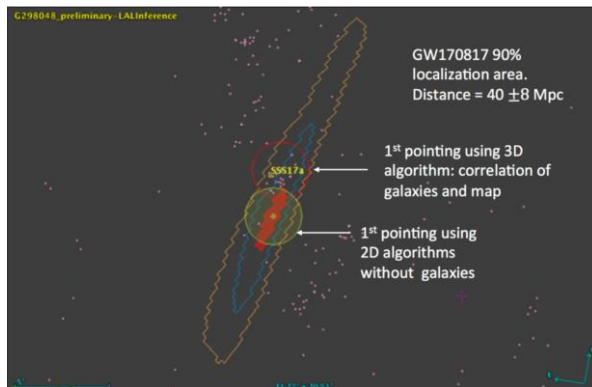
LST-1 transient handler:

- External communication with brokers/facilities providing real-time alerts (currently receiving GCNs)
- Internal communication with Telescope Control Unit, Scheduler and Real Time Analysis
- Automation of the full follow-up procedure ongoing (currently shifter in the loop)
- Reception, parsing, visibility checks < 1 s

Strategies to cover large localization uncertainty region events under commissioning

- GW follow-up strategy based on Ashkar, H., SA,M et al., (2020), JCAP2021, 2021.03: 045 ;
- A similar follow-up strategy implemented for GRBs detected by Fermi-GBM.

Example: GRB 200303A GBM alert ($R_{FoV}=2^\circ$) and GW190915_235702 ($R_{FoV}=2^\circ$)



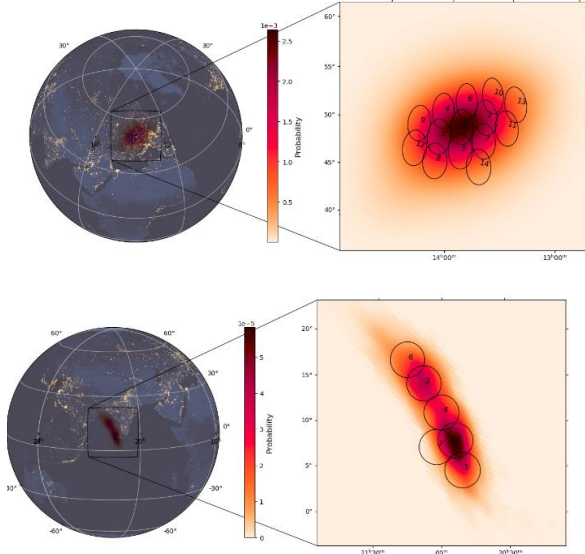
Abdalla, H, et al., *The Astrophysical Journal Letters*, 850(2), L22

Next generation IACTs: the Cherenkov Telescope Array and Large-Sized Telescope

CTA-O Low latency response: assured by the Science Alert Generation (SAG) system in charge of the real time CTA data analyses

Goals:

- Data reconstruction, data quality monitoring, science monitoring and real-time alert issuing: ~ 20 s latency
- Flexible capability, including observations with sub-arrays



Carosi, A., SA, M. et al., First follow-up of transient events with the CTA Large-Sized Telescope prototype, 36th International Cosmic Ray Conference (ICRC2021), PoS838, 2021

GW follow-ups with CTA: Prospects in joint BNS-GRB detections

Goals:

- Assess the detectability of short GRBs from BNS mergers with CTA
 - Study of the optimal exposure of CTA observations to detect the BNS counterpart.
- End-to-end simulation of joint BNS-GRB detections: from simulation of BNS-GRB, follow-up and analysis.
- The observations scheduling algorithms have an extra parameter to compute: The exposure is obtained from the time needed to detect the source at 5 sigma significance level for the instrument response functions.

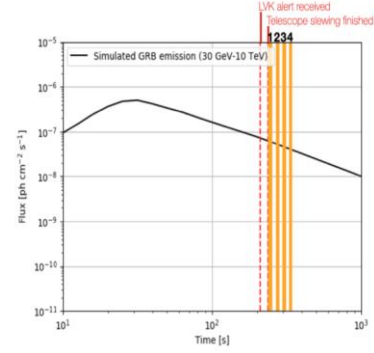
$$\int_{t_0}^{t_0+T_{\text{exp}}} F(t) dt \geq F_{5\sigma}^s(T_{\text{exp}}),$$

Patricelli, B., SA M et al.. Searching for very-high-energy electromagnetic counterparts to gravitational-wave events with CTA, 36th ICRC2021, PoS998, 2021

Prospects in joint GRB-GW rates with CTA

Simulation inputs:

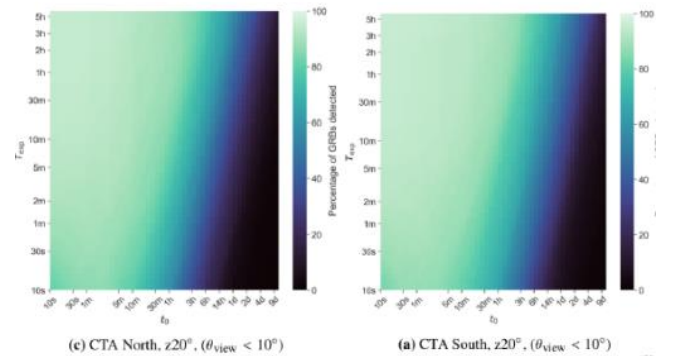
- Realistic BNS systems uniformly distributed in the local universe



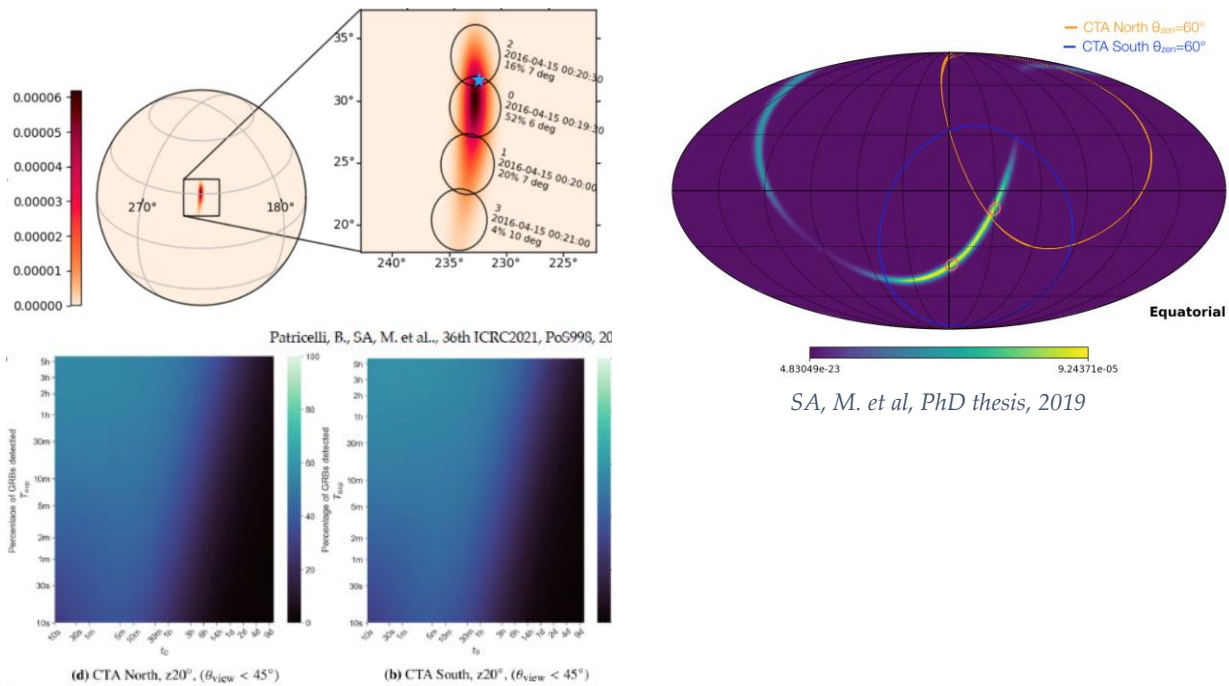
- From GRB 190114C: power law spectra with photon index $\alpha \sim -2.2$
- Lightcurve: PL+decay index from X-ray afterglows of sGRBs
- Structured Gaussian jet for off-axis lightcurves

First results for the detection expectations by CTA if the source was well localized (no latency added by the tiling)

- On-axis GRBs ($\theta_{\text{view}} < 10^\circ$):
 $t_0 \sim 30$ s, ~ 94 % detections with $T_{\text{exp}} \leq 30$ min.
 $t_0 \sim 10$ min ~ 92 % detections with $T_{\text{exp}} \sim$ hours



- On-axis + Off-axis GRBs ($\theta_{\text{view}} < 45^\circ$):
 $t_0 \sim 30$ s: ~ 52 % detections with $T_{\text{exp}} \leq 30$ min
 $t_0 \sim 10$ min: ~ 54 % detections with $T_{\text{exp}} \sim$ hours



What's next?

- First proof of the connection BNS-sGRB with GW170817-GRB170817A.
- Current generation IACTs and LST will perform follow-up observations during O4 (starting ~Dec. 2022)
- Low-latency multi-messenger strategies in place in CTA/LST
- Transient handler: Observation scheduling algorithms to tackle large localization uncertainty regions (GW/GRBs)
- The SAG system: latencies of ~ 20 s detect+issue candidates
- Real Time Analysis & Transient Handler under commissioning at LST-1
- Further studies for strategy optimization
 - Optimize the exposure time in future observations;
 - Sub-array strategy: maximize coverage in low-latency response but decreasing sensitivity
 - Exploit CTA-North CTA-South complementarity

KM3NeT

Damien Dornic¹, for the KM3NeT collaboration²

Session Classification: Observatories & alert systems: Gamma rays, Neutrinos, Cosmic rays

¹Centre national de la recherche scientifique, ² <https://www.km3net.org/about-km3net/collaboration/>

KM3NeT

KM3NeT is the neutrino research infrastructure in the deep Mediterranean Sea.

Main characteristics: - Extended energy range: 1 GeV → 10 PeV (+ 10-40 MeV)

- Full sky coverage with the best sensitivity for the

galactic sources

- High duty cycle (> 95%)

- All-flavor neutrino detection

- Good angular resolutions

Last news of KM3NeT

ORCA: 1 GeV - few TeV (~10% deployed)

10 strings in operation (~1.5 years of ORCA6 data)

⇒ Already better performances at low-energy than ANTARES

and IceCube

⇒ First results on oscillation promising

⇒ Continuous construction: +13 in 2022 (20%)

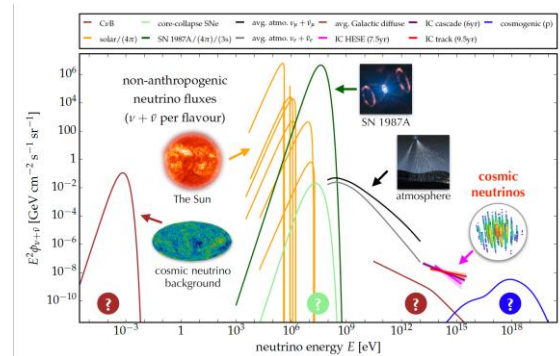
ARCA: 100 GeV - few PeV (~3.5% deployed)

8 strings in operation (6 months of ARCA6 data)

⇒ Almost similar performances than ANTARES

⇒ Continuous construction: +25 in 2022 (15%)

Astrophysical neutrino fluxes



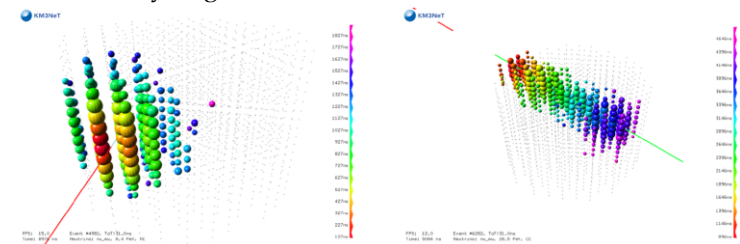
All-flavor neutrino detection

For ARCA:

- Gal. sources: 0.2° at 10 TeV
- Extra-gal. sources: 0.1° at 100 TeV
- VHE: 0.06° at 10 PeV
- Energy resolution 0.2 in Log10(E)

For ORCA:

- 7° at 10 GeV, 2° at 100 GeV, <1° at 1 TeV
- Energy resolution ~20-30%
- Very large statistics

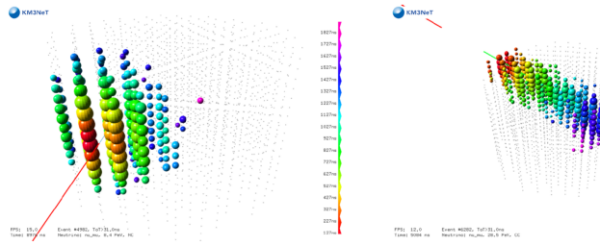


For ARCA:

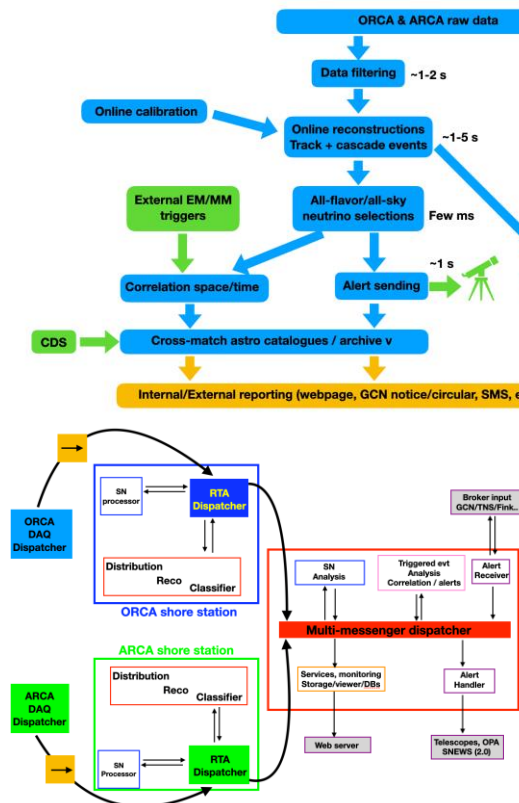
- Vertex: 6-8m (long), 0.5m (perp)
- Direction: ~1.5° for E > 50 TeV
- Energy: 5%

For ORCA:

- Direction: 7° at 10 GeV, 3-4° at >50 GeV
- Energy: ~20-30%

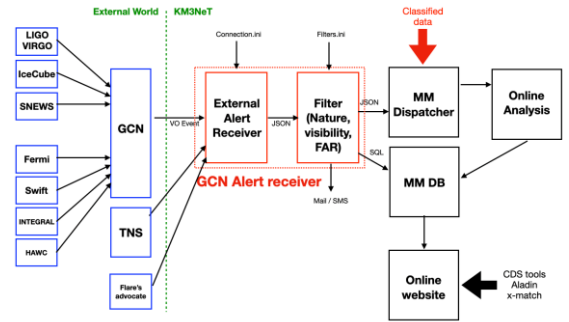


Real-time analysis framework

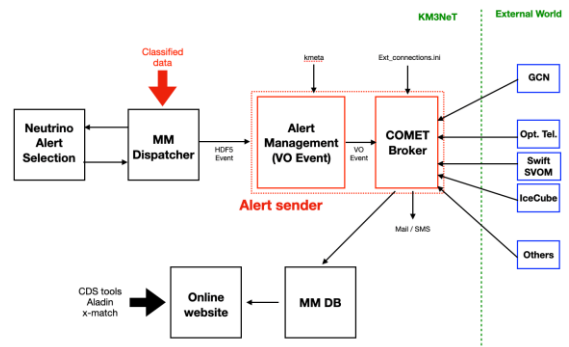


KM3NeT interfaces with the external world

External trigger reception → Connection to different brokers (GCN, TNS, Flare's advocate...); Filtering module to select the triggers (visibility, nature, FAR, delay); GCN chain ready and in operation.

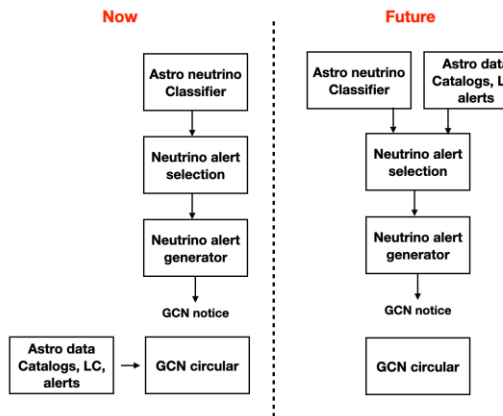


KM3NeT alert sending → Alert distribution performed by Comet using only VO event (XML file); Alert management module validates automatically the content of the VO event using kmeta data; After commissioning, we will start an open public alert program; A test version is in operation.



KM3NeT neutrino alerts >mid 2022

Alert neutrino selection → Neutrino alerts: burst of LE neutrinos, single VHE, single + specific direction, auto-correlation; Move from a pure neutrino selection (a la IC and ANTARES) to a mix neutrino-astro selection. Of course, for the peculiar events, neutrino alerts can be sent whatever its astro content to be not biased; Definition of the astro content: direction crossmatches with astro catalogues (BZCAT, 3HSP, 4FGL, RFC...) and adding the time cross-matches with Fermi-LAT real-time analysis, connection with LSST/ZTF brokers...

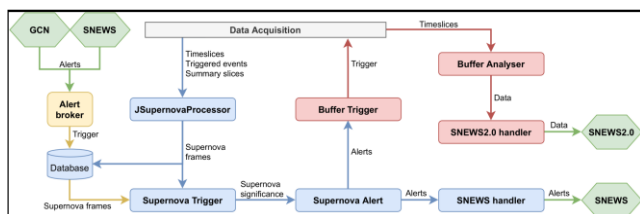


Alert content → Rate: 1-2 per month ;
 Working on the detailed content of the
 VO Event alert message and on the
 automatisisation to obtain all the
 quantity.

VO content:

- * ID
- * Detector (ARCA/ORCA)
- * Type of alert triggers
- * Multiplicity (i.e. number of events in given time and space windows)
- * Flavor PID
- * Energy
- * IsRealAlert
- * Time
- * RA, DEC, Longitude, Latitude
- * Error box 50%, 90% (TBC)
- * Reconstruction quality
- * Probability of neutrino (anti-muons)
- * Probability of astrophysical neutrino
- * Ranking
- * Astro contents

CCSN neutrino alerts



KM3NeT CCN neutrino analyses →
 Very complex software organisation: 3

parallel analyses are in operation: Real-Time Analysis, Quasi-Online Analysis and Triggered analysis ; Connected to SNEWS and send regularly alerts with a FAR of 1/8 days [provide only the time of the neutrino signal] ; Start to upgrade the system to be able to answer to SNEWS 2.0 requirements of the 3 alert tiers. We are now able to provide the time of the alert, the significance at any time on request and the neutrino light curve (1-10 ms time bin depending of the strength of the signal) and the estimation of the time of the neutrino signal ; The triggered analysis allow to provide the significance for a MeV neutrino signal at any time.

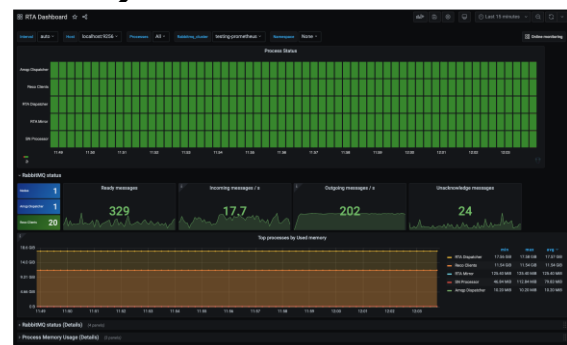
Online shifter organization

Goal: build an online analysis group that will take care of the real-time follow-up of the KM3NeT internal alerts and EM/MM external triggers.

Duties:

- Monitor the health of the online processes (reco, classifiers, SN processes), the network and the high-level neutrino performances.
- Monitor the outgoing broker
- Organize follow-up for our alerts
- Monitor the EM/MM trigger receptions and the online analyses
- Report the results

→ Website with all required tools
 →



Name	Source	Parameters	Inputs	Results
GRB1002A	GRB	1071488, 20210902T040507, 122.278 -32.388, 0.12, Swift	Linka GCN	Link_res_sma1 / Link_res_sma2
GRB1001A	GRB	652359525, 20210901T140407, 160.238 +2.386, 0.20, Fermi	Linka GCN	Link_res_sma1 / Link_res_sma2
IC1001A	Radio	15891, 36044807, 20211017T060507, 59.788 +34.576, 0.38, IceCube	Linka GCN	Link_res_sma1
SNS10702A	CCSN	210702_040507, 20210702T040507, ., SNEWS	Linka SNEWS	Link_res_sma3
S210702A	GW	S2003169, 20210701T1101507, skyrmag_GW, LIGO	Linka GCN	Link_res_sma1 / Link_res_sma2

Summary

KM3NeT has just arrived at the same or better effective area compared to ANTARES (11 yrs) in less than 1 yr of operation. The construction rate will increase (~15-20% of the detector next year).

KM3NeT is implementing a real-time analysis platform as automatized as possible that includes online correlation analyses with external triggers and the neutrino alert sending. We plan to start the online activity in Spring 2022 (first alerts for Summer).

Simultaneous MWL/MM follow-up is the key to resolve the neutrino sources (too few statistic in the neutrino side).

IceCube and IceCube-Gen 2

Anna Franckowiak¹

Session Classification: Observatories & alert systems: Gamma rays, Neutrinos, Cosmic rays

¹Ruhr-Universität Bochum; <https://icecube.wisc.edu/>

Event Signatures

High-energy neutrinos can be detected by measuring Cherenkov light emitted by secondary charged particles produced in the neutrino-nucleon interaction. IceCube is a cubic-kilometer sized detector located in the clear ice at the geographic South Pole equipped with a grid of 5160 digital optical modules. [1] We distinguish between “track” and “shower” event signatures. Tracks are produced in charged-current interactions of muon-neutrinos while the other is the result of neutral-current interactions and charged-current interactions of electron or tau neutrinos. Track events have good angular resolution, while shower events have good energy resolution.

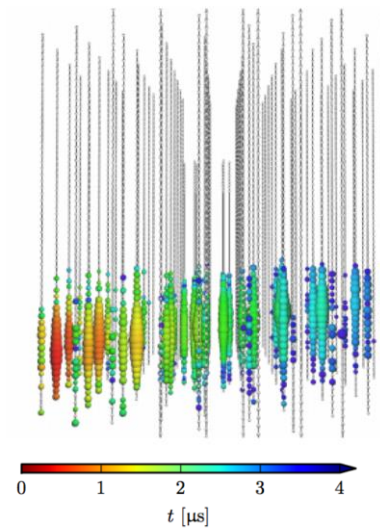
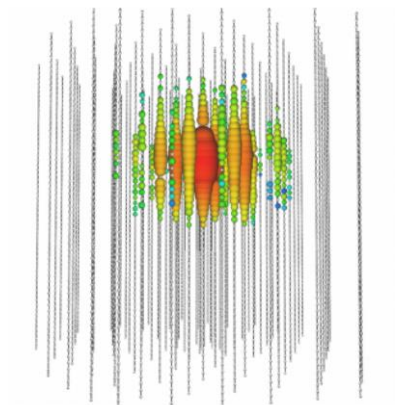


Fig. 1 Event displays for a shower (top) and track event (bottom), from [2].

IceCube Target of Opportunity Program

To identify electromagnetic counterparts to high-energy neutrinos and to increase the sensitivity to transient and variable sources, IceCube has set up a realtime program to act as an input into the target of opportunity (ToO) program of other instruments. Interesting neutrino alerts that are likely astrophysical in origin are made public in realtime. [3]

Neutrino Source Candidates (selection)

Potential source candidates targeted by the ToO program include gamma-ray bursts (GRBs) [4], supernovae with choked jets [5], interacting supernovae [6], active galactic nuclei (AGN) [7] and tidal disruption events (TDE) [8].

Realtime-Searches

Several neutrino alert streams are active:

1. MeV neutrino bursts (Galactic Supernovae) as part of the Supernova early warning system (SNEWS) [9]
2. Cluster of O(1-10 TeV) neutrinos [10]
 - a. All-sky
 - b. Pre-defined source list of promising TeV gamma-ray candidate sources
3. High-energy O(100 TeV) track events with high “signalness” [3]
4. High-energy O(100 TeV) cascade events
5. Neutrino and high-energy gamma-ray (HAWC) coincidences [11]

In addition a fast response analysis was developed to quickly analyze IceCube data triggered by external observations. [12]

High-energy Track Alerts

High-energy track alerts are sent to the public since April 2016 with a median latency of 33 seconds. An initial GCN is broadcasted through AMON without any humans in the loop [3]. The directional information reported in the first GCN is based on a fast online reconstruction. In a second step a more time-consuming likelihood scan is applied which typically takes a few hours. To convert the likelihood landscape to a 90% confidence contour re-simulations of similar events (including systematic uncertainties) are used. The updated reconstruction is issued in a follow-up machine-readable notice and a circular.

A selection of interesting source candidates identified by ToO programs using high-energy alerts include the gamma-ray blazar TXS 0506+056 [13], the radio-bright blazar PKS 1502+106 [14-16] and two tidal disruption events, AT2019dsg [17] and AT2019fdr [18].

Gravitational Waves and Neutrinos

IceCube performs searches for neutrinos from gravitational wave events in a time window of ± 500 sec around the gravitational wave event. So far no significant neutrino counterpart was found [19]. Neutrinos could help to constrain the direction of a source candidate and teach us about the gravitational wave source environment.

Prospects for IceCube-Gen2

IceCube-Gen2 is a planned neutrino observatory at the South Pole with a sensitivity improvement by a factor of 5 compared to the current IceCube detector [20]. This will allow more significant associations with bright neutrino sources (for example the neutrino flare from the blazar TXS 0506+056 would have been detected at 5 sigma level) and at the same time access to dimmer sources.

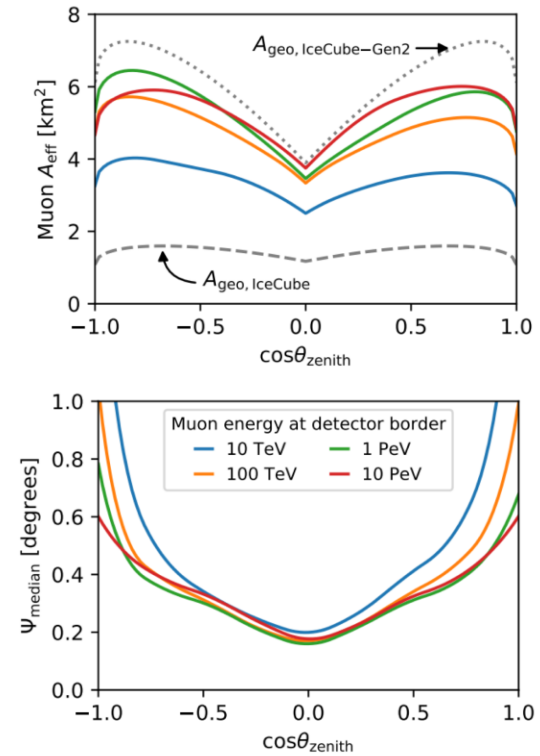


Fig. 2 shows the muon effective area (top) and median angular uncertainty (bottom) for the planned IceCube-Gen2 detector (from [20]).

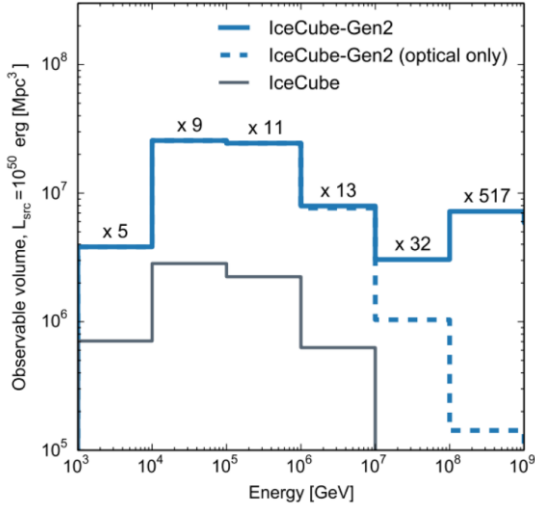


Fig. 3 shows the observable volume for a generic 100s burst with equivalent isotropic emission of 10^{50} erg in neutrinos described by a power law, $dN/dE \propto E^{-2}$ (from [20]).

Conclusion

The IceCube Observatory has various realtime searches implemented, which already enabled the identification of first interesting candidates. The difficulty in the search for electromagnetic counterparts is that many candidate neutrino source classes exist, each with a different signature. The future of multi-messenger astronomy with neutrinos is bright with new neutrino detectors and electromagnetic follow-up instruments on the horizon.

References

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- [14] S. Britzen et al. MNRAS 503 (2021)
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- [20] Aartsen et al. (IceCube Gen2 Coll.), J.Phys.G 48 (2021)

Pierre Auger Observatory

Michael Schimp¹, for the Pierre Auger Collaboration²

Session Classification: Observatories & alert systems: Gamma rays, Neutrinos, Cosmic rays

¹Bergische Universität Wuppertal, ²<https://www.auger.org/>

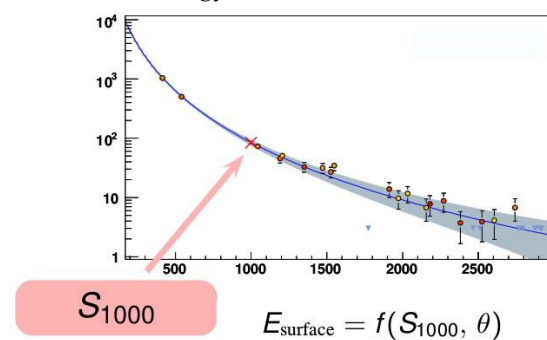
Cosmic ray detection

Calorimetric energy measurement with FD :

Energy loss dE/dX

$E \propto \int (dE/dX) dX$

→ SD energy calibration via S_{1000}



Auger Prime

- World's largest cosmic ray radio detector array
- Electronics upgrade: 40 → 120 MHz sampling, more precise GPS, higher dynamic range, ...
- Add small PMT in WCD to increase dynamic range
- 5 yrs runtime: Distinguish 0% → 10% protons at highest energies with 5σ
- Electromagnetic (EM) → muonic (μ) component → Enhance mass composition measurement

SSD installed w/ PMT (163 stations)

SSD installed w/o PMT (1268 stations)

no SSD installed (236 stations)

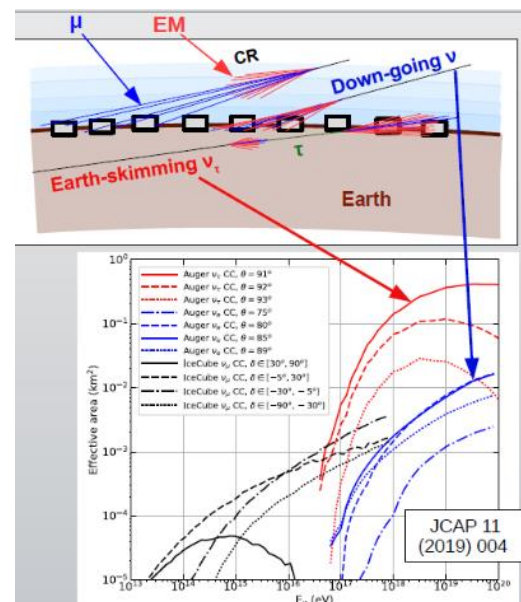
Electronics upgraded (134 stations)

Multi-messenger activities

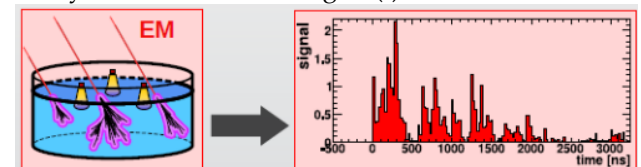
- GW follow-up searches with neutrinos and photons
- Photon real-time stream to AMON
- Deeper Wider Faster

- ANITA follow-up searches for upgoing air shower events
- UHECR-neutrino correlation searches (Auger, IceCube, TA)
- Neutrons from the Galaxy

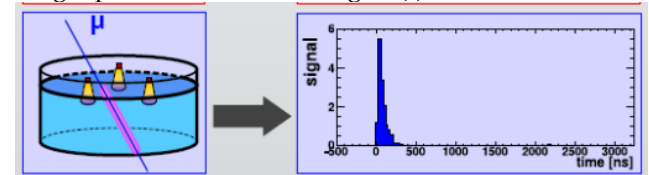
Neutrino detection with the Auger SD



Many cascades → Broad signal(t)



Single particles → Narrow signal(t)



No neutrino candidates identified so far

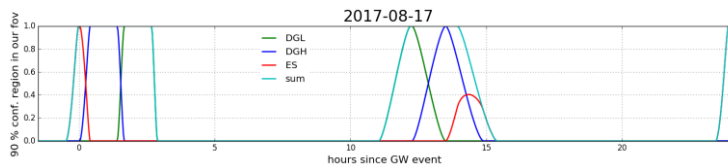
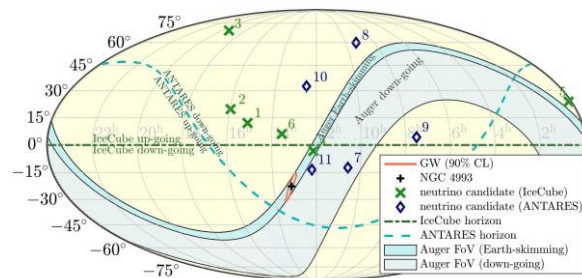
- Limits on
- Diffuse flux
- Point source flux

- Astrophysical and cosmological models
- Flux from followed-up sources

GW170817 - ApJL 850, L35

Excellent visibility of the merger

- Fast LIGO/Virgo + Fermi GCN circular
- Our follow-up routines were not automatized, manual “unblinding”
- Now: Immediate search initiation

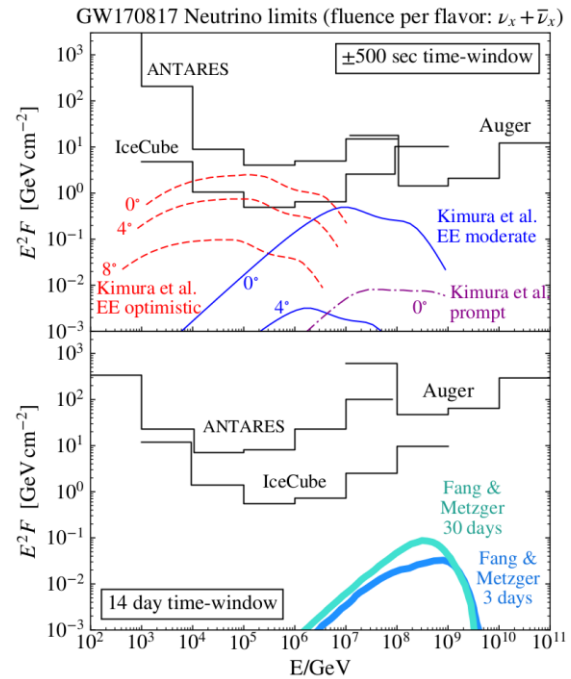


GW170817 neutrino limits - ApJL 850, L35

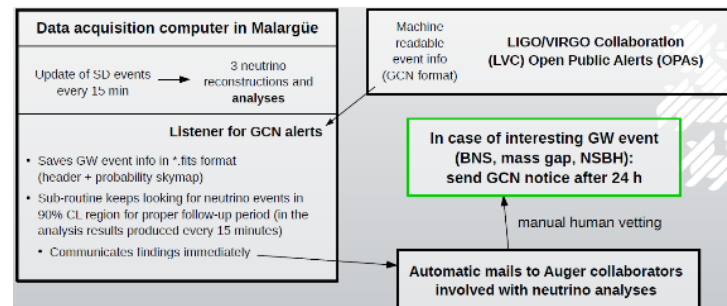
No related neutrinos detected by ANTARES, IceCube, and Auger

Auger sensitivity high for ± 500 s but reduced for 14 days

- Good vs. periodic visibility
- Lesson: Lucky strikes happen, improved preparation (faster follow up) might pay off in the future



Automatic GW follow-up routine



Real-time stream of photon-like events to AMON

Side remark: Auger is already sending SD shower data with certain directional, energy, and quality cuts to AMON. Work in progress. Goal: Stream photon-like candidate events from Auger data to AMON via fast estimator(s)

- MVA for fast and reliable photon discrimination utilizing:
 - Signal risetimes
 - Shower front curvature
 - Station multiplicity
 - Zenith angle

Deeper Wider Faster

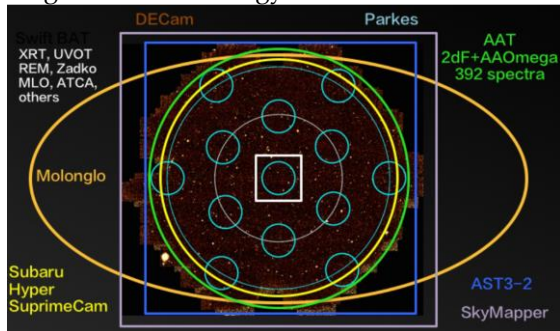
Multi-instrument (> 30) project

- Radio through ultra-high energies

incl. non-photons (Auger)
~ 10 groups observe simultaneously
➤ Deep+wide-field fast (sampling and analysis) multi-wavelength + multimessenger
probing of same field

Auger:

- Full-SD events in DWF field of view shared, no significant coincidences found so far
- Future plan: include smaller sub-arrays of Auger for lower energy events



Pierre Auger Observatory Open Data

Check-it out on opendata.auger.org

LIGO-Virgo-KAGRA

Franco Carbognani¹, on behalf of the LIGO², Virgo³ and KAGRA⁴ collaborations

Session Classification: Detectors, probes & alert systems: Neutrinos, Gravitational waves

¹European Gravitational Observatory, ²<https://www.ligo.caltech.edu/>, ³<https://www.virgo-gw.eu/>,

⁴<https://gwcenter.icrr.u-tokyo.ac.jp/en/>

The common Gravitational Wave detectors distributed cyber infrastructure supporting low-latency alerts

IGWN

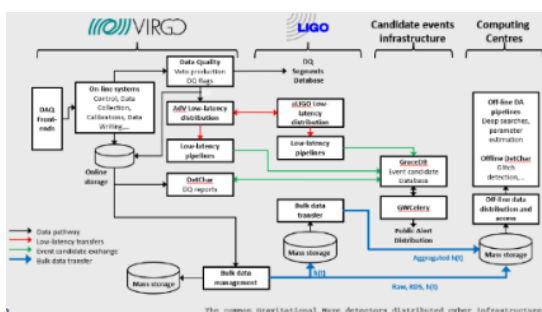
International Gravitational Waves observatory Network (IGWN):

- A coordination effort aimed at jointly discussing the computing policy, management, and architecture issues of LIGO, Virgo, and KAGRA.
- igwn.org will host common Virgo/LSC services, and KAGRA is joining
- Migration planning for common services (GitLab, Wiki, etc.) ongoing
- The effort comprises all computing domains (online, offline, LL), with different levels of engagement.

Plans for migration from legacy tools to common, mainstream tools are being implemented.

- Data management and transfer (CVMFS/StashCache, Rucio and Kafka)
- Software management (GitLab, CMake, Conda, CVMFS)
- The tools (and the general architecture) are chosen to be consistent with many large-scale computing projects such as WLCG

The Data Flow Schema



Data Flow: The O3 case

1. The signal arrives
2. Data composed into frames
3. Calibration of the data
4. Veto, DQ flags production
5. $h(t)$ transfer
6. Low-latency matched-filter pipelines
7. Upload to GraceDB
8. Data written into on-line storage
9. Low-latency data quality
10. Low-latency sky localization
11. GCN Circular sent out
12. Data written into Cascina Mass Storage
13. Data transfer toward aLIGO and CCs

What is needed

GW data analysis (including low-latency) is performed as a joint IGWN effort.

The geographical separation of the detectors and the short timescale involved (current/O3 e2e latency from signal detection to alert generation in the order of 25 sec) imply the creation of a common distributed cyber infrastructure which must guarantee:

- Adequate storage and computing resources for detector characterization, low-latency searches and alerts generation.
- Low-latency data distribution among the different observatories and computing clusters for low-latency searches
- An ubiquitous and uniform running environment

Storage and Computing Resources

Low-latency storage and computing mainly provided by observatory computing centers:

- Low-latency alert infrastructure runs on dedicated resources with high priority to burst out into pool.
- Search pipelines run on dedicated or highly-prioritised resources in an HTCondor-managed resource pool.
- Fast, direct access to small data files / shared memory.
- GraceDB production instance currently deployed in High Availability (HA) on AWS.
- Alternative HA deployment via Kubernetes is being tested on INFN CNAF Cloud.

High Availability (HA) deployment

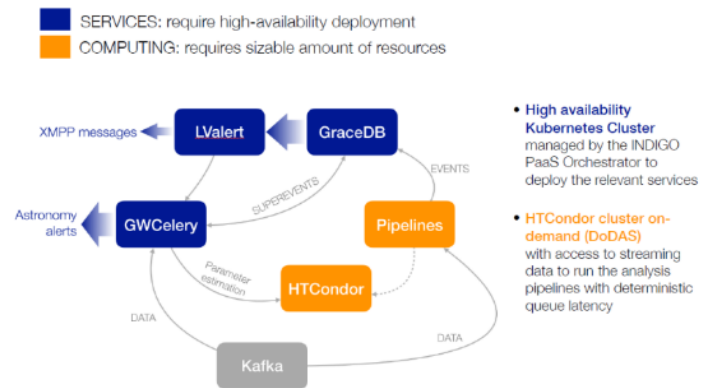
We are developing an High Availability deployment based on Kubernetes (de-facto standard for cloud orchestration) for the alert generation components (GraceDB, GWCelery, LValert) on CNAF Cloud.

- To exploit support from CCs staff and achieve cloud provider independence
- Resources and support for both high-availability deployment using K8S and on-demand HTCondor cluster (at least partially) funded by EGI-ACE project from the INFRAEOSC-07 EU call
- Including also GWCelery in the K8S deployment, to have a fully portable setup.
- Performance and stress tests in progress.

Also, a preliminary step to provide infrastructure to run low-latency searches off-site.



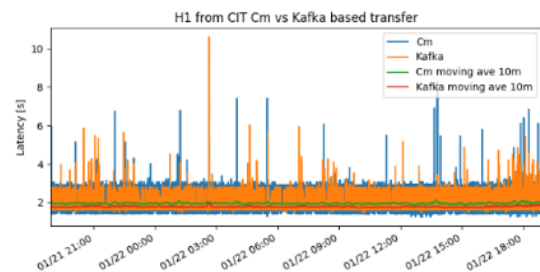
Deployment plan within EGI-ACE



Low-latency data distribution: Kafka

Kafka is a modern high throughput stream processing software, with

- built in redundancy
 - Can survive if stream stops or Kafka broker goes down
 - Replication so no data loss from downed
- and highly scalable and reconfigurable
 - Can easily add additional observatories data (KAGRA being added)



Running Environment: IGWN Conda

Sustainable software development and distribution → CVMFS + Conda

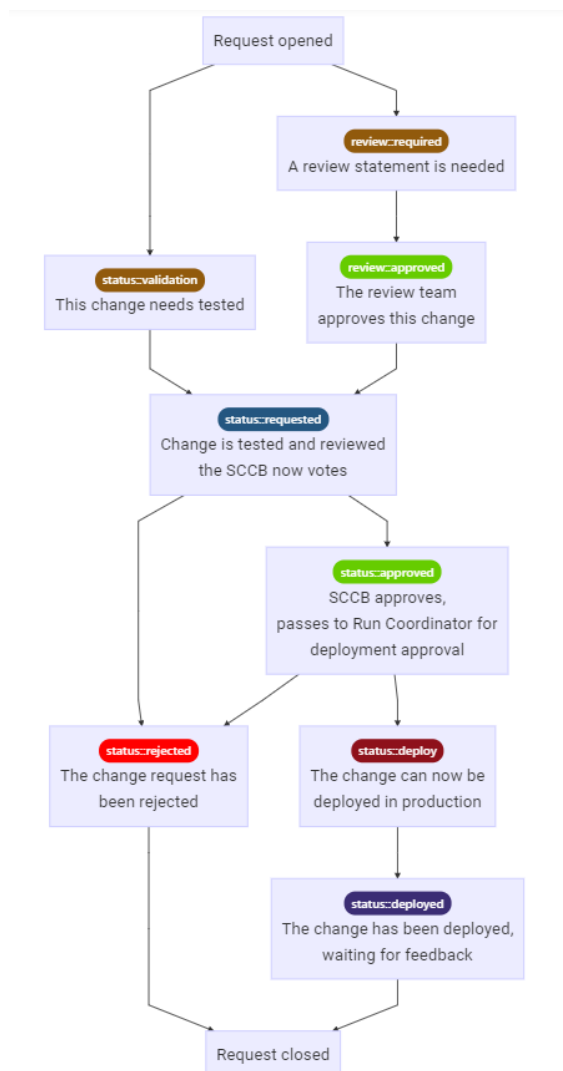
Conda environments are hosted in CVMFS file system available at all IGWN sites and CC

- IGWN Conda Distribution provides pre-built, automatically-distributed environments of approved software.
- available via CVMFS on any machine (no authentication required) can be replicated on any workstation.
- OS-independent
- Leverage on CMake/Meson for software build.

- Provide a very effective solution for unmaintainable number of custom software builds.
- On large part of IGWN sites (including Cascina) the IGWN environment can be activated manually or by default at user login.

Software deployment into IGWN Conda Distribution

Software deployment is controlled via change control board (SCCB). Software must be approved by SCCB and the relevant scientific review committee before being used for production analysis.

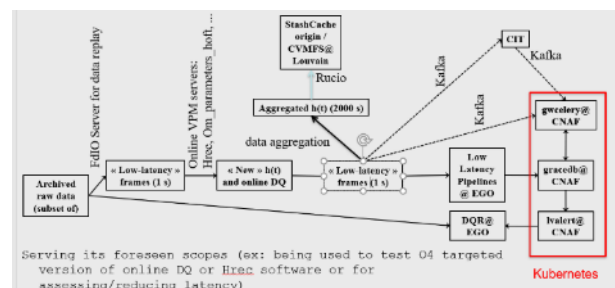


Preparing for O4: The O3 End-to-End Data Replay

Scope, a truly end-to-end one:

- Provide a reasonable representation of low-latency detector data in O4 (to be noted that interferometer data don't grow with sensitivity, but only with the number of "technical" channels)
- Exercise the search pipeline's ability for finding GWs as well as the mitigation of generating event candidates from terrestrial noise; for this, a stretch of data that generated a variety of Bursts, BNS, NSBH and BBH events as well as retractions is desired
- Exercise the calibration pipeline's ability to provide calibrated $h(t)$ in low latency
- Exercise low-latency detector services and their ability to detect and/or mitigate non-stationary/non-Gaussian noise in $h(t)$ using $h(t)$ and/or auxiliary channel information.
- Exercise the alert infrastructure's capability in providing timely alerts and evaluate its full latency.
- This end-to-end setup will constitute the main testbed for O4 on rapid alerts generation and in particular for the standardization of the low latency data distribution using Kafka.

E2E Stage 2 @ EGO + CNAF+ Louvain



Conclusions

IGWN means a coordinated and common infrastructure between the collaborations
 Making a large technological step on many tools

- To provide interoperability between Virgo, LIGO and KAGRA and enable effective convergence towards IGWN

- To reduce maintenance effort on proprietary/legacy solutions
- Tests ongoing satisfactory, working on deployment strategy
- Migration to modern software management tools well underway

Plans for O4

- Most of the planned architecture should be ready for O4. In case of problem we can fall back on O3 proven solutions

Designing a common robust and scalable long-term architecture.

Acknowledgements

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LIGO-Virgo-KAGRA

Roberto De Pietri¹, LVK Collaboration², PD-PR-TN-TR Virgo Group

Session Classification: Detectors, probes & alert systems: Neutrinos, Gravitational waves

¹Parma University, ²<https://www.ligo.caltech.edu/>, <https://www.virgo-gw.eu/>, <https://gwcenter.icrr.u-tokyo.ac.jp/en/>

Discussion of the timeline of the 80 Alerts of O3

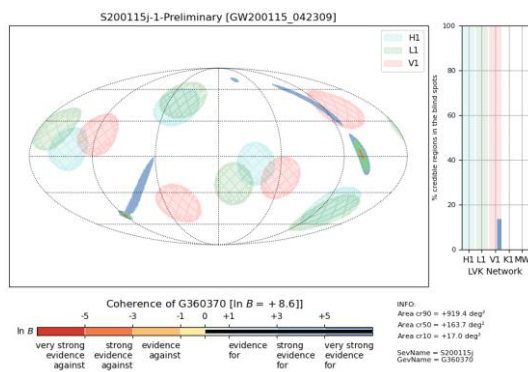
Expectation for O4

The LVK (igwn) alert system

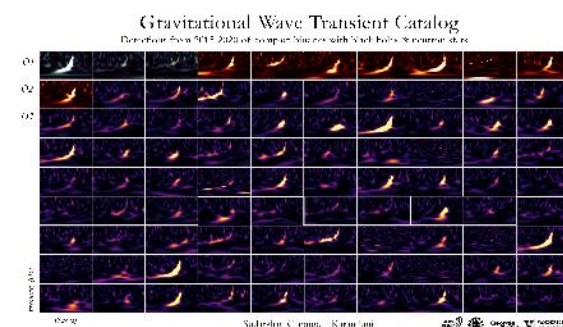
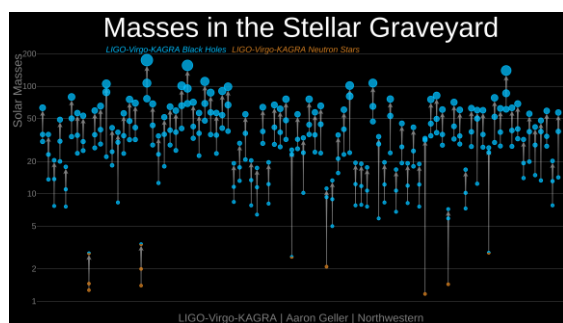
New functionality with respect to O3

The planned main Open Public Alert (OPA) timeline

GW200115_042309 (NSBH)



Distributed 6.3 minutes after merger time



O3 Public Alert Time-line

Seven of O3a open OPAs are discussed in GWTC2 but not confirmed GW, namely:

- S190510g, [S190718y](#), S190901ap, S190910d, S190910h, S190923y, S190930t.

Three of O3b open OPAs are not confirmed GW and one retracted OPA is GW:

- S191205ah: It is classified in the O3b catalog as a low- SNR ($\rho < 10$) single-detector candidate
- S191225q: It was retracted, but it is now classified as an O3 marginal IMBH
- S191213g: It is discussed in the O3b catalog. It was found in low latency by GstLAL in both LIGO Hanford and LIGO Livingston, with low network SNR and a modest FAR of 1.1/yr
- S200213t: It is discussed in the O3b catalog. It was found in low latency by GstLAL as a low-SNR singledetector candidate in LIGO ford with a modest FAR of 0.56/yr

Some GW event in catalog do not have a corresponding OPA

Seven of O3a open OPAs are discussed in GWTC2 but not confirmed GW, namely:

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- S200213t: It is discussed in the O3b catalog. It was found in low latency by GstLAL as a low-SNR single-detector candidate in LIGO ford with a modest FAR of 0.56/yr

12 marginal event

- 9 without an OPA
- 3 with an OPA
 1. S200105ae RETRACT (GW200105_162426 [GWTC-3-marginal])
 2. S191225aq (191225_215715 [O3_IMBH_marginal])
 3. S200114f (200114_020818 [O3_IMBH_marginal])
- 82 events (3 of them has been reclassified)
- 36+2 without an OPA
- 43+1 with an OPA

80 OPA during O3

- 23 Retraction
- 1 Retraction is now Marginal
- 43 Confirmed confident GW
- 4 Confirmed as marginal GW
- 9 not in GW catalogs and not RETRACT

O4 Expectations

LIGO, VIRGO, AND KAGRA OBSERVING RUN PLANS as of 15 November 2021 update; next update by 15 March 2022

- Start of the run in mid-December 2022. Target sensitivity:

- LIGO: 160-190 Mpc
- Virgo: 80-115 Mpc
- Kagra: 1 Mpc with a plan to improve to 3-25 Mpc during O4

- Ligo O3 sensitivity ~115 Mpc Hanford and ~133 Mpc Livingston => $(160/115)^3 \sim 2.7$ in Volume
- Virgo O3 sensitivity ~50 Mpc => ~4 in Volume
- We do expect a factor 3 in the number of events: We should reasonably expect (arXiv:2111.03606 [gr-qc] reported 79 GW events) to have: ~ 240 OPA , ~ 240 GW events. That is almost 1 detection per day.

Localization : O3 Sky-Area

Abbott et al. 2020, LRR

Since Kagra not reaching the sensibility of that simulation the number for O4 will be the same of O3 not having the Advantage of a proper 4-detector improvement.

		BNS	NS-BH	BBH
		Area (deg ²) 90% c.r.	Area (deg ²) 90% c.r.	Area (deg ²) 90% c.r.
O3	HLV	270 ⁺³⁴ ₋₂₀	330 ⁺²⁴ ₋₃₁	280 ⁺³⁰ ₋₂₃
O4	HLVK	33 ⁺⁵ ₋₅	50 ⁺⁸ ₋₈	41 ⁺⁷ ₋₆

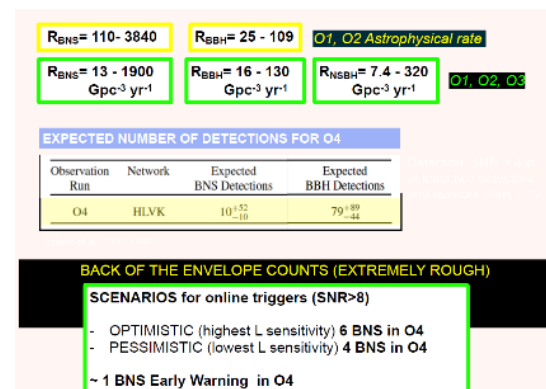
O3a low-latency → median 90% c.r area for BBH detected in O3a = 600 deg² (BAYESTAR)

Larger with reported respected to the O3 predictions, but:

- simulation more conservative SNR threshold (SNRnet=12) vs online (SNRnet of about 8.5) → sky area scale inversely with SNR²
- released single interferometer candidate (while simulation requires a detection of SNR > 4 in at least two instruments)

O4 area ~ 300 deg²

We are performing injection studies to give more accurate number before the start of O4



Alert Infrastructure

We operate multiple on-line detection pipelines that upload candidate events (Gevent) to a database (GraceDB) if they have a false alarm rate (far) of less than 1/hours.

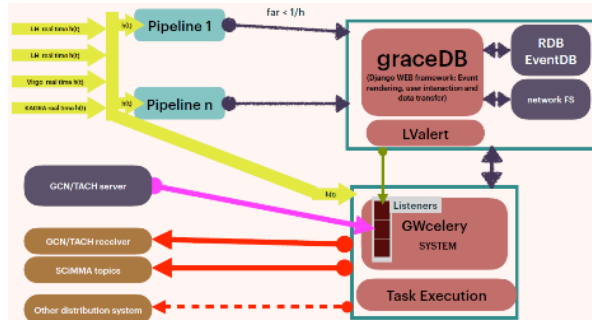
An events database (GraceDB)

The GWcelery system that:

- Ingest GCN/TAC alerts to ingest external events (E-events)
- Aggregate coincident-in-time events into super-events (S-events).

- Generate external alerts if the combined far of the S-events meet publication criteria.

- far < 1/(2 months) for CBC events
- far < 1/(years) for Burst events
- combined spatial-temporal far with external events.

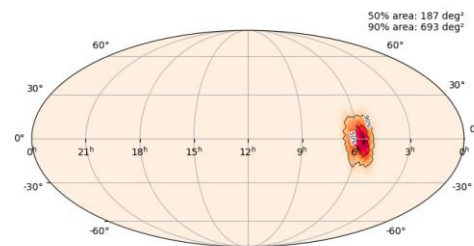
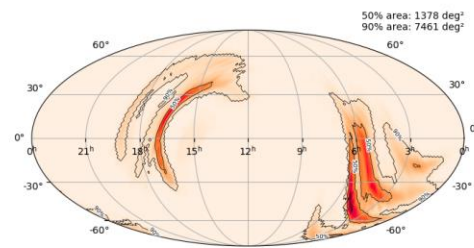


RAVEN (and LLAMA) pipeline

LLAMA: online search pipeline combining LIGO/Virgo GW triggers with High Energy Neutrino (HEN) triggers from IceCube. Looks to temporally-coincident sub-threshold IceCube neutrinos.

RAVEN: Rapid On-Source VOfEvent Coincidence Monitor (RAVEN). It searches coincidences between GW events with alerts for gamma-ray bursts (GRBs) and galactic supernova alerts from the SNEWS collaboration.

- Notice Type Considered:
FERMI_GBM_ALERT,
FERMI_GBM_FIN_POS,
FERMI_GBM_FLT_POS,,
FERMI_GBM_GND_POS,
FERMI_GBM_SUBTHRESH,,
SWIFT_BAT_GRB_ALERT,
SWIFT_BAT_GRB_LC.
- It combines GW+GRB localizations to assist in identifying a counterpart kilonova transient.
- It attributes new significance by computing additional combined Spatio-temporal significance (far) for sub-threshold GW candidates, allowing the distribution of additional alerts.



Search	Pipeline(s)	Untargeted	Targeted
CBC-GRB	Fermi-GBM	[-1, +5]	[-1, +10]
	Swift-BAT	[-1, +5]	[-10, +20]
	INTEGRAL	[-1, +5]	N/A
	AGILE	[-1, +5]	N/A
Burst-GRB	All GRB	[-60, +600]	N/A
Burst-Neutrino	SNEWS	[-10, +10]	N/A

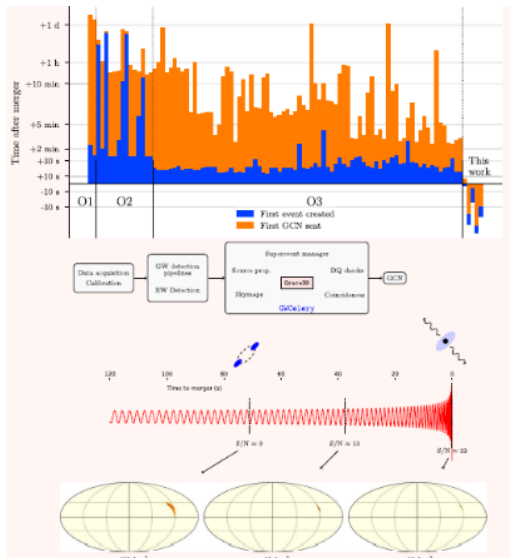
Early Warning Demonstration

"First demonstration of early warning gravitational wave alerts", Ryan Magee et al., 2021 ApJL 910 L21 (<https://arxiv.org/abs/2102.04555>)

Test based on results of an early warning matched- filtering pipeline by considering six different discrete frequency cutoffs: 29, 32, 38, 49, 56, and 1024 Hz to analyze signal recovery at (approximately) 58, 44, 28, 14, 10, and 0 s before the merger.

We recovered 5 injections with latency to notice 7.1 s, -35.2 s, -2.9 s, -51.3 s, -27s. To this latency, one should add the latency (from the arrival of the GW) needed to transfer the signal to the pipeline (< 10s).

Early warning will be available during O4!



Planned PUBLIC ALERT time-line (GCN)

BNS/NSBH early warning pipeline (This stage may not apply and we should expect that an early-warning event is followed by a general all-sky search (need to fix the timing).

- (1st) EarlyWarning alert (fully automatic) with no localization information.
- (2nd) EarlyWarning alert (fully automatic) as soon as sensible localization information is available.

After Detection search is completed by All the pipelines (Including RAVEN) or as soon as sensible information is collected. (Within 1 minutes).

- Preliminary alert (localization information needed)

Fully automatic DET char checks with required latency check that allows for these results to be used as part of a retraction or confirmation that occurs within 10 minutes.

- Initial (Fully automatic) alert, automatic Initial circular sent.
- Retraction (Fully automatic) alert, automatic Retraction circular sent.

RRT meeting and a rapid PE evaluation typically within 4 hours for BNS events or 1 day for vanilla BBH. DQR that have a time scale of 1 hour (see)

- (1st) Update alert (human confirmation and evaluation). Update circular sent.

- Retraction alert (In case the event should be vetted). Retraction circular sent.

Any time significant new information is collected upon RRT (after PE group, and follow advocate suggestion) approval. In a case-by-case basis. Targeting for BNS candidates.

- (2nd) Update notice and circular sent (~ 1 day). Update circular sent.
- (3rd) Update notice and circular sent (~ 2 days). Update circular sent.
- (4rd) Update notice and circular sent (~ 1 week). Update circular sent.

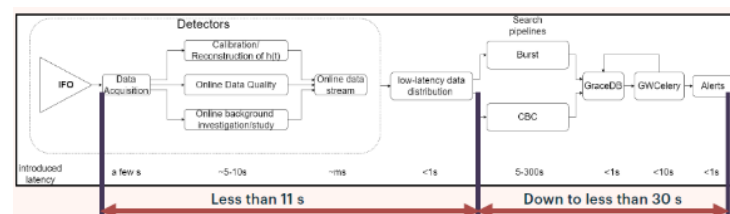
Latency study (from signal to alert)

We are running extensive tests (already started - up to engineering runs) from data acquisitions (synthetic) to alert generation, and we are monitoring latency."

We have the signal ready to be analyzed online in less than 11 seconds from the arrival of the (GW) signal at the detectors.

That makes pre-merger alerts possible (with negative latency) and to have the first preliminary alerts in less than a minute.

The study will also allow us to test the effectiveness of the online pipeline to detect and assess the properties of the signal.



Conclusions

We will provide open public alerts (OPA) also for:

- pre-merger (negative time) early warning alerts.
- alerts based on a coincident external public trigger.

We plan to provide alerts not only in the GCN/TACH infrastructure

Alerts for sub-threshold trigger will be provided on MOA-based agreement.

You should expect one OPA per day.

Acknowledgment

This material is based upon work supported by NSF's LIGO Laboratory which is a major facility fully funded by the National Science Foundation. The authors also gratefully acknowledge the support of the Science and Technology Facilities Council (STFC) of the United Kingdom, the Max-Planck-Society (MPS), and the State of Niedersachsen/Germany for support of the construction of Advanced LIGO and construction and operation of the GEO600 detector. Additional support for Advanced LIGO was provided by the Australian Research Council. The authors gratefully acknowledge the Italian Istituto Nazionale di Fisica Nucleare (INFN), the French Centre National de la Recherche Scientifique (CNRS) and the Netherlands Organization for Scientific Research (NWO), for the construction and operation of the Virgo detector and the creation and support of the EGO consortium. The authors also gratefully acknowledge research support from these agencies as well as by the Council of Scientific and Industrial Research of India, the Department of Science and Technology, India, the Science & Engineering Research Board (SERB), India, the Ministry of Human Resource Development, India, the Spanish Agencia Estatal de Investigación, the Vicepresidència i Conselleria d'Innovació, Recerca i Turisme and the Conselleria d'Educació i Universitat del Govern de les Illes Balears, the Conselleria d'Innovació, Universitats, Ciència i Societat Digital de la Generalitat Valenciana and the CERCA Programme Generalitat de Catalunya, Spain, the National Science Centre of Poland and the European Union – European Regional Development Fund; Foundation for Polish Science (FNP), the Swiss National Science Foundation (SNSF), the Russian Foundation for Basic Research, the Russian Science Foundation, the European Commission, the European Regional Development Funds (ERDF), the Royal Society, the Scottish Funding Council, the Scottish Universities Physics Alliance, the Hungarian Scientific Research Fund (OTKA), the French Lyon Institute of Origins (LIO), the Belgian Fonds de la Recherche Scientifique (FRS-FNRS), Actions de Recherche Concertées (ARC) and Fonds Wetenschappelijk Onderzoek – Vlaanderen (FWO), Belgium, the Paris Ile-de-France Region, the National Research, Development and Innovation Office Hungary (NKFIH), the National Research Foundation of Korea, the Natural Science and Engineering Research Council Canada, Canadian Foundation for Innovation (CFI), the Brazilian Ministry of Science, Technology, and Innovations, the International Center for Theoretical Physics South American Institute for Fundamental Research (ICTP-SAIFR), the Research Grants Council of Hong Kong, the National Natural Science Foundation of China (NSFC), the Leverhulme Trust, the Research Corporation, the Ministry of Science and Technology (MOST), Taiwan, the United States Department of Energy, and the Kavli Foundation. The authors gratefully acknowledge the support of the NSF, STFC, INFN and CNRS for provision of computational resources.

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JSPS Grant-in-Aid for Scientific Research on Innovative Areas 2905: JP17H06358, JP17H06361 and JP17H06364, JSPS Core-to-Core Program A. Advanced Research Networks, JSPS Grant-in-Aid for Scientific Research (S) 17H06133 and 20H05639, JSPS Grant-in-Aid for Transformative Research Areas (A) 20A203: JP20H05854, the joint research program of the Institute for Cosmic Ray Research, University of Tokyo, National Research Foundation (NRF) and Computing Infrastructure Project of KISTI-GSDC in Korea, Academia Sinica (AS), AS Grid Center (ASGC) and the Ministry of Science and Technology (MoST) in Taiwan under grants including AS-CDA-105-M06, Advanced Technology Center (ATC) of NAOJ, Mechanical Engineering Center of KEK.

Einstein Telescope

Patrice Verdier¹

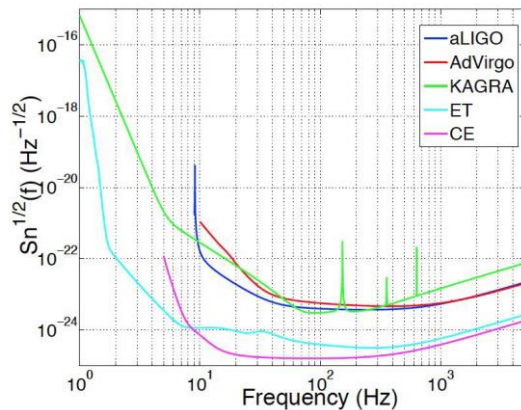
Session Classification: Detectors, probes & alert systems: Neutrinos, Gravitational waves

¹Centre national de la recherche scientifique; <http://www.et-gw.eu/>

The Einstein Telescope project

Einstein Telescope is the project aiming to realize the European 3rd generation ground-based GW observatory:

- A huge improvement in sensitivity compared to nominal sensitivity of 2G interferometers, especially at low frequencies (few Hz –10Hz)
- High reliability and improved observation capability



ET science programme

ASTROPHYSICS

Black hole properties: origin (stellar vs. primordial) evolution, demography

Neutron star properties: interior structure, equation of state, demography

Multi-band and –messenger astronomy: joint GW/EM observations (GRB, kilonova,...); multiband GW detection (LISA); neutrinos

Detection of new astrophysical sources: core collapse supernovae; isolated neutron stars; stochastic background of astrophysical origin

FUNDAMENTAL PHYSICS AND COSMOLOGY

The nature of compact objects: near-horizon physics, tests of no-hair theorem; exotic compact objects

Tests of General Relativity: post-Newtonian expansion, strong field regime

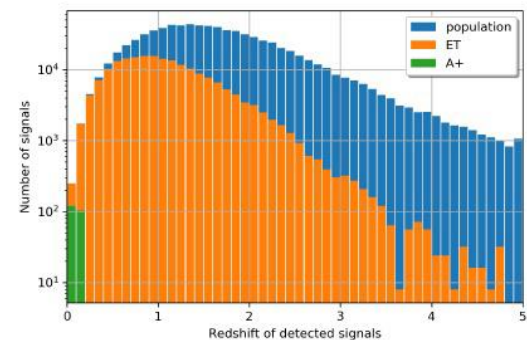
Dark matter: primordial BHs; axions, dark matter accreting on compact objects

Dark energy and modifications of gravity on cosmological scales: dark energy equation of state, modified GW propagation

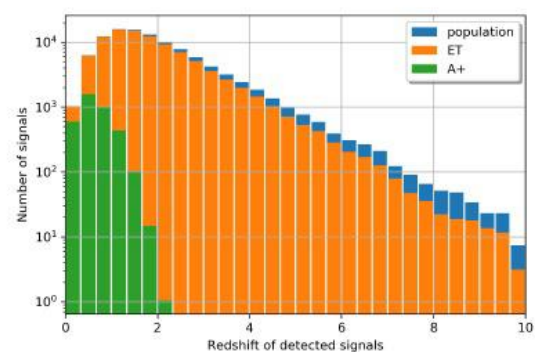
Stochastic backgrounds of cosmological origin: inflation, phase transitions, cosmic strings

ET sensitivity

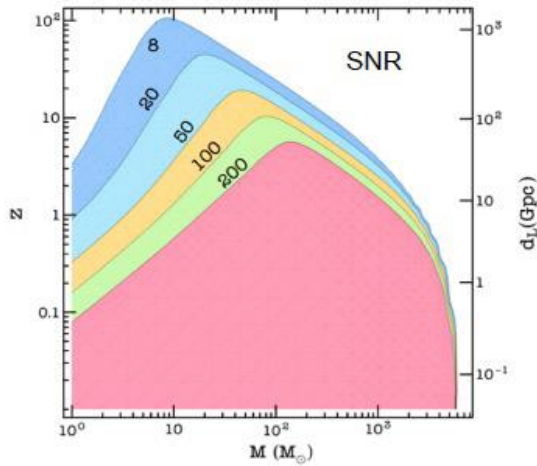
BINARY NEUTRON-STAR MERGERS



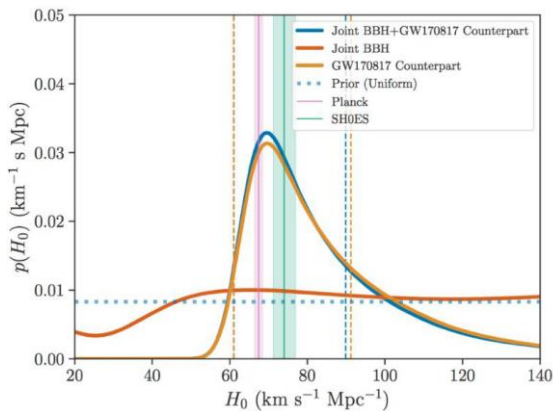
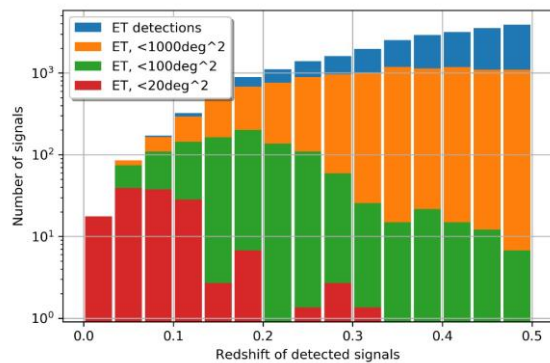
BINARY BLACK-HOLE MERGERS



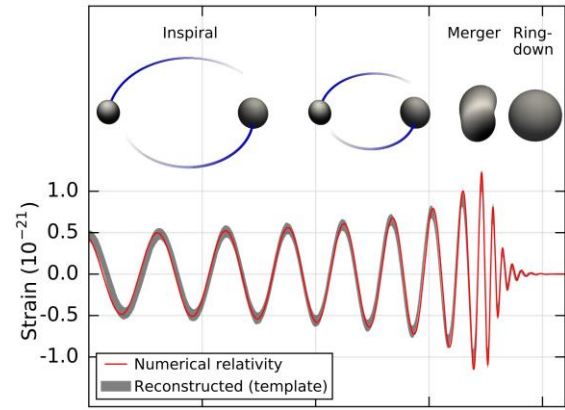
- 105-106 BBH detections per year
- 105 BNS detections per year among which ~100-1000 with EM counterparts
- High SNR events
- Overlapping events
- ~1 detection every 30s



- BNS detection with EM counterparts and localization precision $< 20 \text{ deg}^2$: ~ 100 per year
- Overlap with many BBH signals
- Potentially, very long signals
- ET will be able to provide alerts few hours before the merger



Identify early the inspiral and provide alert before the merger phase



- And with ~ 600 BNS-EM detection, we can reach Planck resolution on H_0 measurement

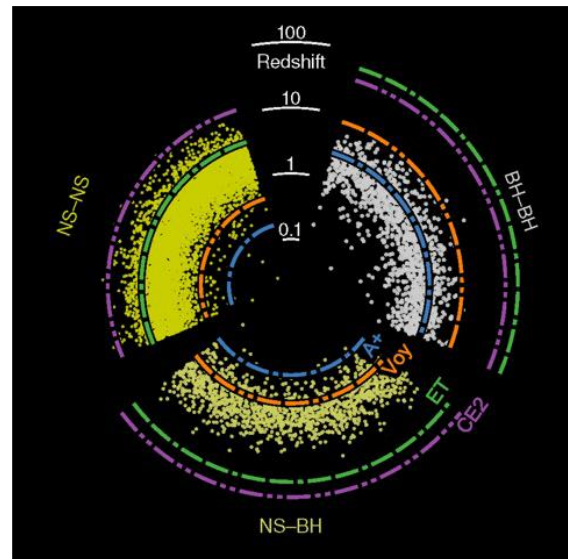
ET data

- Despite the large increase in the expected number of events (105-106 events/year) compare to 2G

interferometers, ET raw data will represent only few tens of PB per year. ET data will however need

to be distributed to a much larger number of users.

- Data processing in ET is the highest challenge, especially parameter estimation of CBC (ET CPU will represent $\sim 10\%$ of ATLAS in the HL-LHC era) : plenty of margin for improvements with R&D !

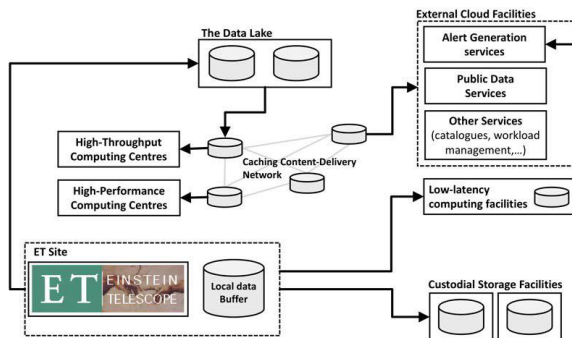


ET will use a distributed computing infrastructure largely based on existing infrastructures: network and national

computing centers, mainly HTC, but also HPC (GPU, FPGA) for numerical relativity simulations & Deep Learning techniques.

Global Computing Infrastructure for ET

ET will use a distributed computing infrastructure largely based on existing infrastructures: most of the computing (data processing and services) might run off-site.



1. Data collection in a local circular data buffer. A local computing infrastructure is used to pre-process and reduce the data to the format used for low-latency and offline analyses
2. Data are transferred to the low-latency search facilities, where search pipelines are automatically run
3. Data are also shipped to the Data Lake for subsequent offline analyses [It may be possible for the low-latency processing sites to exploit the data lake, reducing the complexity of the computing infrastructure]
4. A reduced version of raw data are transferred to archival sites for safekeeping
5. All data (raw, processed, public) is registered in a general catalogue database that functions as a single front-end both for data discovery and access
6. Low-latency processing facilities run search pipelines and send triggers and candidate information to the low-latency alert generation and distribution services
7. Candidate event alerts are generated and distributed by the relevant services. Data segments to be distributed with the alert are not copied again but tagged in the database as "public"
8. Offline analyses (parameter estimation, deep searches etc.) and all scientific computing (numerical relativity simulation, Machine

Learning model training, etc.) are run on available HTC, HPC or even "Big Data" facilities optimised for Machine Learning, depending upon the optimal type of technology

9. Publicly released data are not copied again, but tagged in the database and made available through public discovery and access services.

Global Computing Infrastructure for ET

ET data policy and computing model definition: ET will follow the path created by LIGO and Virgo (c.f. today's talk by Franco Carbognani)

- Open and Public Access to alerts
- Limited period of property data (18 months) : Calibration, data quality, internal analysis
- Releasing short chunk of data around published gold events
- Open Access to data implementing the F.A.I.R. indications

And when ET will be taking data:

EOSC will be operational

- Infrastructures, services and tools for Low Latency Alerts and multi-messenger analysis will be available
 - And several experiments will be already using these : CTA, Vera Rubin Observatory, DUNE, Hyperkamiokande, KM3Net, SKA ...
- ET is willing to contribute from the beginning. Possibilities to develop next generation solutions using advanced technologies.

Advanced Computing Technologies

- Handling ET data volume (~10 PB/year) should be under control, but what will grow compared to 2G GW detectors is
 - the amount of scientific information encoded in the data
 - the complexity of this information
 - the number of users accessing this data (including for MMA)
- Huge work and improvements are expected from using ML/AI and new techniques which will be developed during the next ~10 years

- Most ET needs can be addressed with High-Throughput Computing, however the role of HPC is expected to increase (numerical relativity, templates production, parameter estimation) : the use of GPU and FPGA architectures will also be considered (for online/offline)
- Most of the computing aspects of ET will have to be organized in order to be able to run on various computing centres and in an automated way
- ET foresees technology tracking of leading-edge computing technologies
- ET computing model will be tested with early data challenges

ET proto-collaboration

<http://www.et-gw.eu/index.php/et-steering-committee>

ET is now an ESFRI project:

Renewed interests and sharp increase in participation

The ET proto-collaboration is currently in construction

Works towards the definition of the Infrastructure and Project governance is starting

Conclusion

- Einstein Telescope will provide enhanced sensitivities to GW detection compared to 2G experiments, enabling a very rich scientific program in astrophysics and fundamental physics
- ET has to tackle many challenges in the fields of computing and algorithms development in order to meet the needs for analyses, in particular multimessengers
- ET is willing to contribute to current developments of tools and services for Low Latency Alerts & Multi-Messenger Analysis
- ET project timescale also allows to start innovative R&D to develop advanced technologies for the 2030's

LISA

Sylvain Marsat¹, in collaboration with J. Baker², T. Dal Canton¹, S. Babak¹, A. Toubiana¹, M. Katz³, A. Mangiagli¹, H. Inchauspé¹, R. Cotesta⁴, ...

Session Classification: Detectors, probes & alert systems: Neutrinos, Gravitational waves

¹Centre national de la recherche scientifique, ²NASA GSFC, ³Albert Einstein Institute, ⁴Johns Hopkins University;
<https://www.elisascience.org/articles/lisa-consortium>

Massive black hole mergers observed by LISA and their localization
 L2IT, CNRS/IN2P3, LISA Consortium in collaboration with J. Baker (NASA GSFC), T. Dal Canton (LAL), S. Babak (APC), A. Toubiana (APC), M. Katz (AEI), A. Mangiagli (APC), H. Inchauspé (APC), R. Cotesta (J. Hopkins), ...

The LISA mission

Status

- Provisional launch date around 2034
- Successfully finished phase A, entered phase B1

Success of LISA pathfinder !

Specificities of LISA response

Features in the instrument response that give us the localization:

Time and frequency-dependency

Time: motion of LISA on its orbit

Frequency: departure from long-wavelength

Time and frequency-dependency

Time: motion of LISA on its orbit

Low-f approximation: two LIGO-type detectors in motion [Cutler 1997]

High-f: more complicated

Data acquisition, low-latency

[Preliminary, in discussion]

- Scheduled gaps: ~5hrs every 15 days, longer gaps ~1/year
- Unscheduled gaps

- Target duty cycle > 75%
- Protected periods: 6 days continuous operations
- Data downlink: 8hrs every day
- Real-time data downlink?

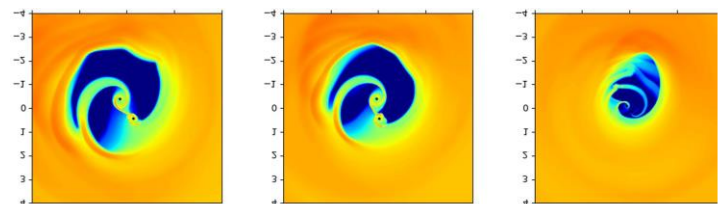
The LISA sources

A rich landscape at low frequencies

- MBHBs: massive black hole binaries
primary candidates for EM counterparts
- EMRIs: extreme mass ratio inspirals (tidal disruption EM counterpart?)
- SBHBs: stellar-mass black hole binaries
- + astrophysical and cosmological stochastic backgrounds, other transients (TDE)

Electromagnetic counterparts from MBHB mergers

Surrounding disk pre- and post-merger [from Tang&al 2018]



Pre-merger emission

- Circumbinary disk, lump
- Minidisks
- Accretion

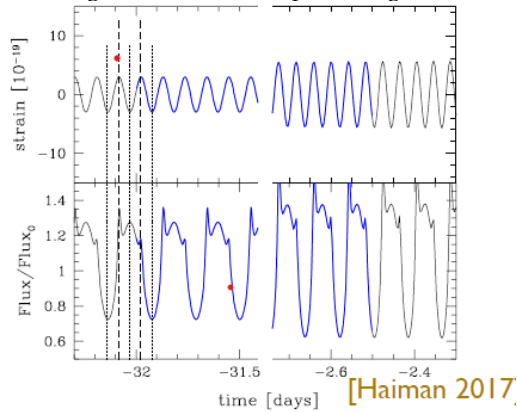
Post-merger emission

- Shocks close to merger

- Formation of jets
- Effect of mass-energy loss
- GW recoil kick
- Reorientation of AGN jet

[Review: Bogdanovic & al 2021]

Phasing of GW and EM pre-merger emission



Active area of research

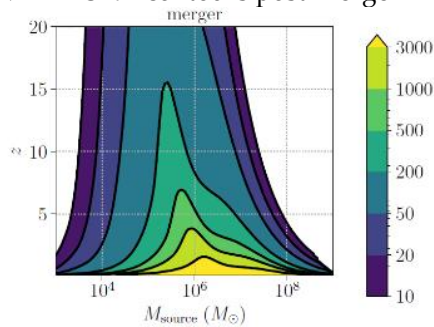
Multiwavelength counterparts: X, optical, radio

Future instruments: Athena, LSST, SKA

LISA MBHB – localization crucial

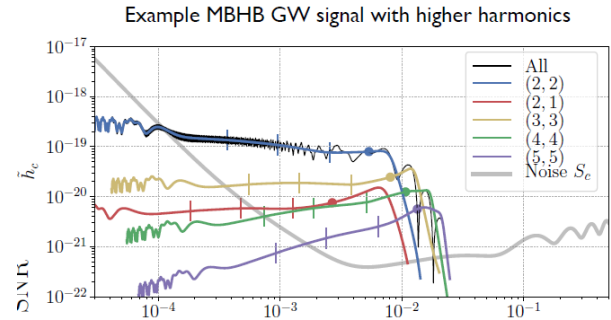
Massive black hole binaries

MBHB SNR contours post-merger



Extremely loud signals...

Example MBHB GW signal with higher harmonics



Ticks:

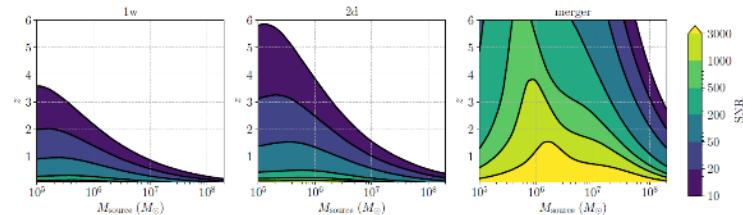
- SNR/64 (40h)
- SNR/16 (2.5h)
- SNR/4 (7min)
- merger

Higher harmonics strong at merger (break degeneracies)

Data analysis simulations still missing precession, eccentricity

MBHB signals are merger-dominated in SNR

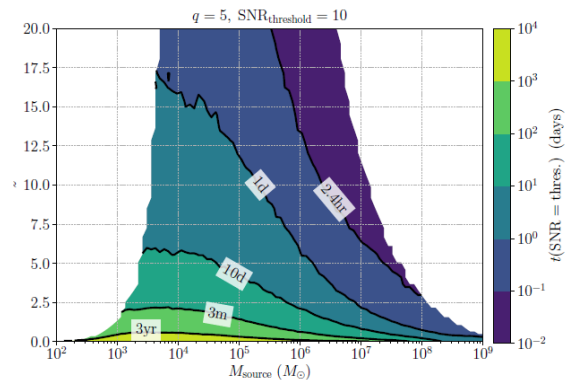
MBHB SNR contours pre-merger and post-merger



Most of the SNR accumulates in the last hours before merger

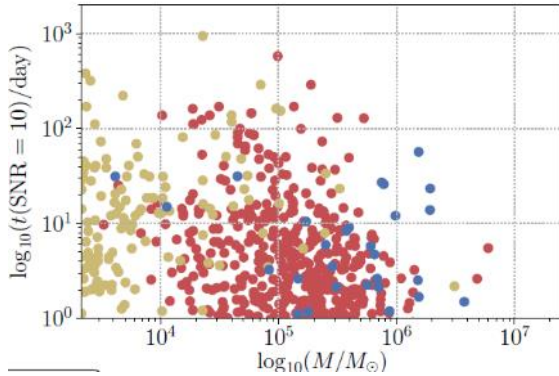
The length of MBHB signals

- How long before merger can we detect the signal ?
- SNR=10 to claim detection



Astrophysical models [Barausse 2012]:

- Heavy seeds - delay
- Heavy seeds - no delay
- PopIII seeds – delay

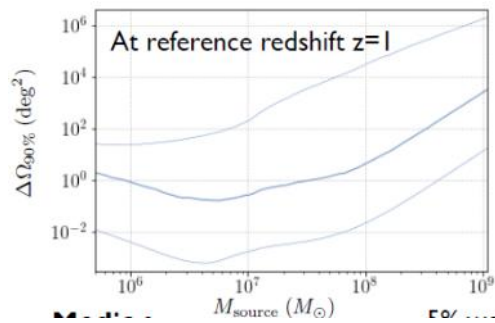


MBHB detected signals:
 Bulk shorter than ~10days
 Tail extending to ~3months

MBHB localization at merger

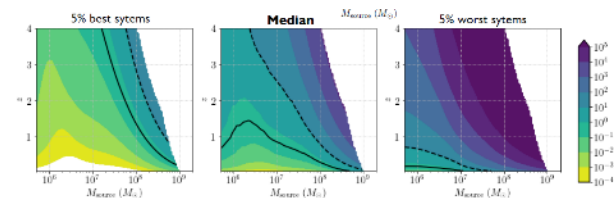
Fisher matrix analysis (with merger and HM)

Randomizing over mass ratio, spin, orientation



[Preliminary]

Large variations of sky localization depending on orientation!



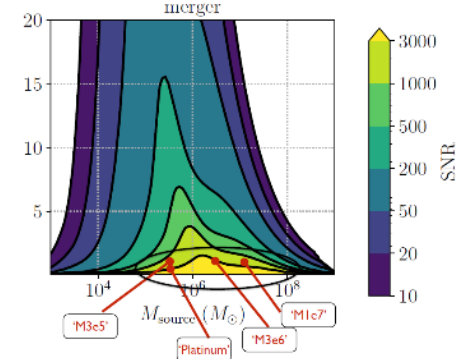
[Preliminary]

- -10 sq. deg.: LSST field of view
- 0.4 sq. deg.: Athena Wide Field Imager

[See also McGee&al2018, Mangiagli&al 2020]

Example MBHB signals: ‘golden’ sources

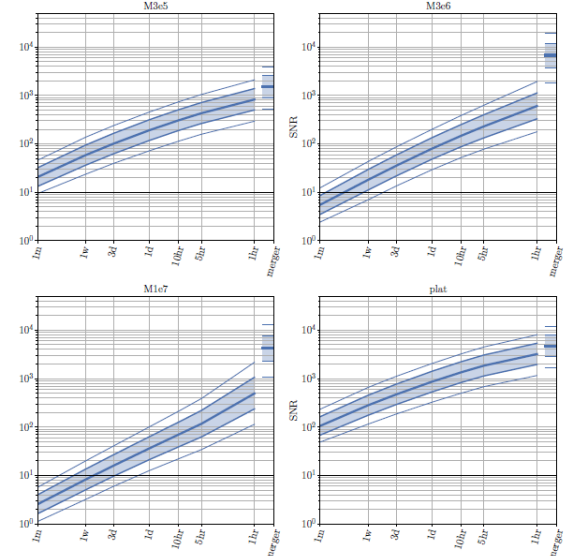
Examples of good candidate systems for an advance localization :



- M3e5 z=1
- M3e6 z=1 (‘Gold’)
- M1e7 z=1 (‘Heavy’)
- M3e5, z=0.3 (‘Platinum’)

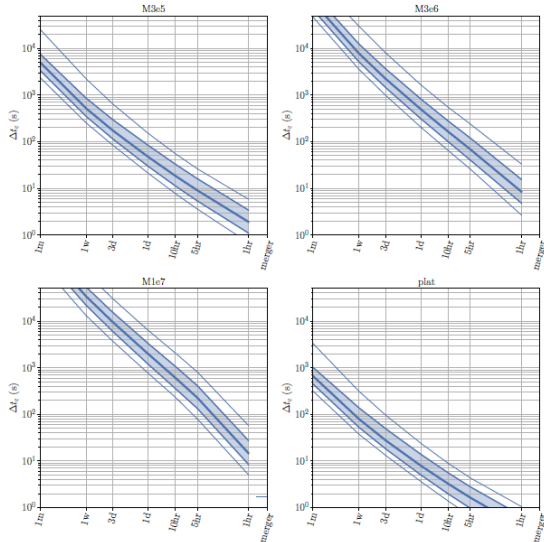
Early detection for ‘golden’ sources

SNR pre-merger and early detection



Early detection easy for golden sources

Time of coalescence measurement error



Allows protected observation periods

[See also Mangiagli&al 2020]

Pre-merger analysis: can we localize well enough for EM observatories?

Here: sky area of main mode of the posterior

LISA-EM synergy

- 10 sq. deg. : LSST field of view
- 0.4 sq. deg.: Athena Wide Field Imager

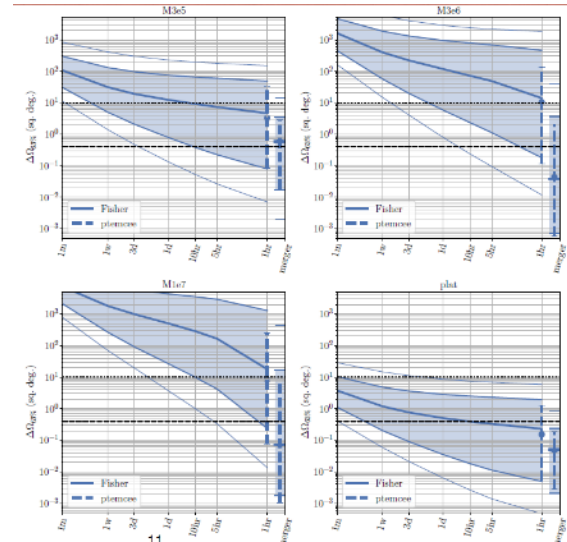
Fisher-MCMC comparison

[See also Mangiagli&al 2020]

- Fisher matrices: 10000 random parameters
- MCMC (ptemcee): 100 random PE runs

[Preliminary]

- LSST
- Athena



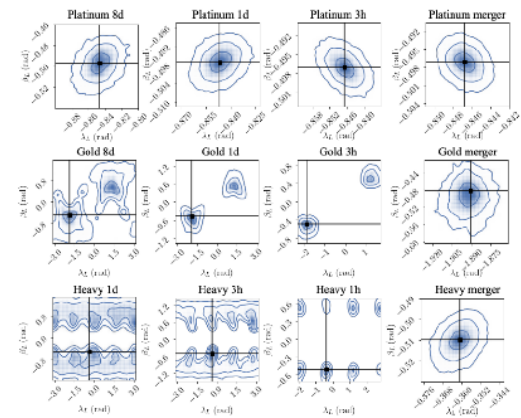
Advance localization challenging, much better post-merger

Large dispersion in sky area, ~4 orders of magnitude

Localization of 'golden' MBHB sources: degeneracies

Bayesian sky localization cutting at different times

[Preliminary]



- 'Gold': M3e6, $z=1$
- 'Heavy': M1e7, $z=1$
- 'Platinum': M3e5, $z=0.3$

- Wide range of multimodalities dep. On parameters
- Post-merger localization unimodal

Highlights

- LISA localization capabilities for MBHBs crucial for multimessenger science
- Many MBHB systems might be short, subset of low- z events could be observed for months
- MBHB signals are merger-dominated, post-merger localization can be very good
- Pre-merger localization can be challenging, except for the very best events
- Degeneracies in the sky position can occur, notably pre-merger

Outlook

- Better explore LISA's localization capability across the parameter space
- More realistic analysis: superposition of multiple signals, realistic noise, data gaps, glitches...
- More realistic waveforms: precession and eccentricity.

Alert systems

SNEWS

Kate Scholberg¹

Session Classification: Detectors, probes & alert systems: Neutrinos, Gravitational waves

¹Duke University

The core-collapse neutrino signal

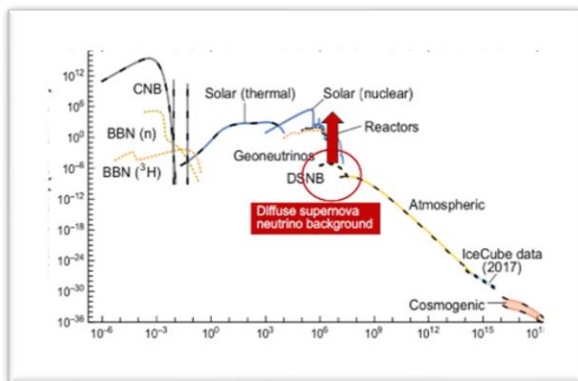
When a star's core collapses, ~99% of the gravitational binding energy of the proto-nstar goes into n's of all flavors with ~tens-of-MeV energies.

(Energy can escape via ν 's). Mostly ν -antiv pairs from proto-vstar cooling.

The core-collapse neutrino signal: Timescale: prompt after core collapse, overall $\Delta t \sim 10$'s of seconds.

The Steady State Neutrino Spectrum @ Earth

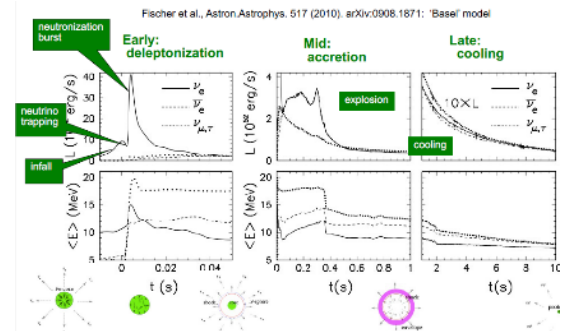
During a ~10s Galactic burst, SN flux can increase 9-10 orders of magnitude.



Grand Unified Neutrino Spectrum at Earth

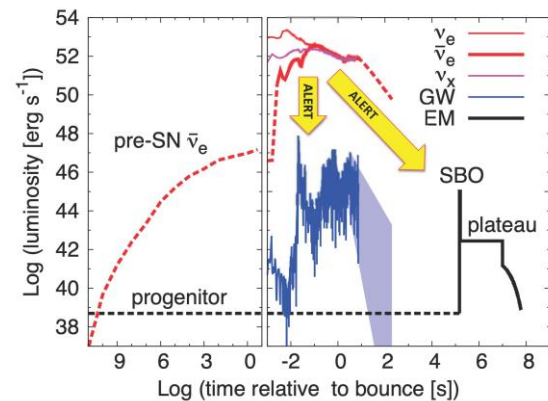
Edoardo Vitagliano, Irene Tamborra, Georg Raffelt. Oct 25, 2019. 54 pp.
MPP-2019-205
e-Print: [arXiv:1910.11878](https://arxiv.org/abs/1910.11878) [astro-ph.HE] | [PDF](#)

Expected neutrino luminosity and average energy vs time
Vast information in the flavor-energy-time profile.



Visible supernova may not show up for hours or days.

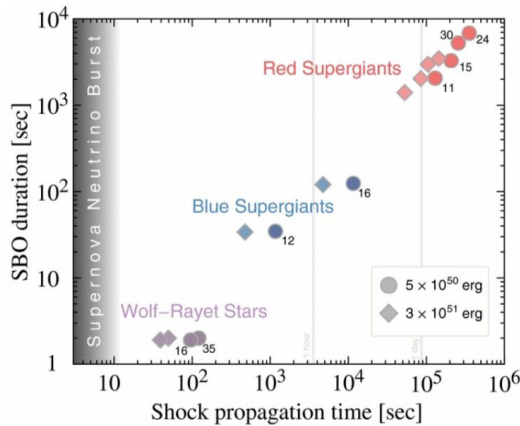
Multimessenger signals from core collapse



K. Nakamura et al., MNRAS 2016

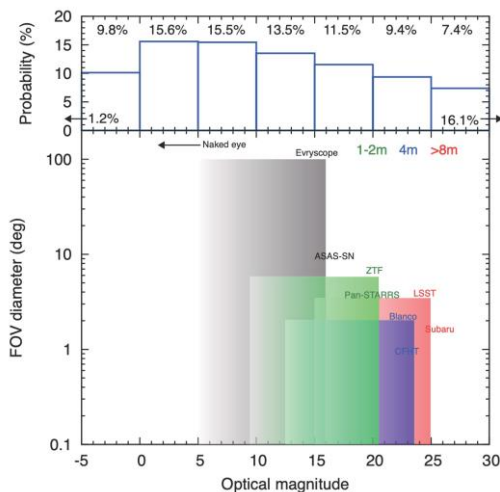
If we see a neutrino burst... where's the supernova??

We're racing the shock! May have less than a half hour, or even just minutes.



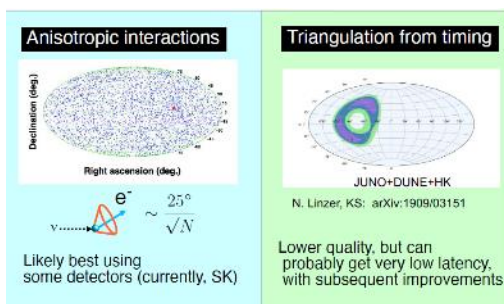
Matthew D. Kistler, W. C. Haxton, and Hasan Yüksel. Tomography of Massive Stars from Core Collapse to Supernova Shock Breakout. *ApJ*, 778:81, 2013, [arXiv: 1211.6770](https://arxiv.org/abs/1211.6770).

Optical follow-up requirements for the next Galactic supernova



Adapted from Nakamura et al., *MNRAS* 2016

Neutrino Pointing Approaches

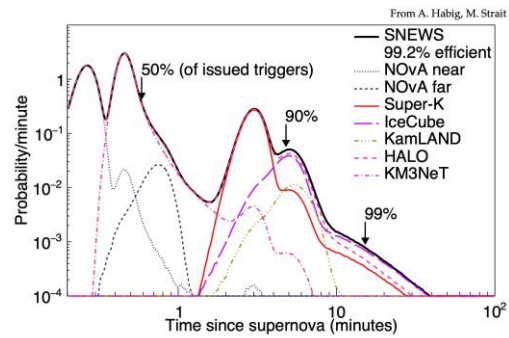


The Supernova Early Warning System 1.0

Simple 10-sec coincidence → email alert + socket connection +GCN

Running in automated mode since 2005 (no nearby CCSNe...)

SNEWS Alert Latency



(will improve with SNEWS 2.0) [arXiv: 2011.00035](https://arxiv.org/abs/2011.00035)

Current effort: upgrade to SNEWS 2.0

- improved latency
 - neutrino-based pointing, including triangulation
 - "fire drills"
 - presupernova r
- snews2.org

Real-time alerts and followup

Alert Tier – send an alert when more events than background detected. This includes the current detector data-taking mode.

Significance Tier – send signal significance periodically or when the significance changes rapidly.

Timing Tier – send time series or time distribution of events for each channel.

Collaborating with: SCIMMA (using Hopskotch) (Baxter et al., [arXiv:2101.07779](https://arxiv.org/abs/2101.07779)), AMON, AAVSO, GRANDMA

WUN2K (What You Need To Know)

Core-collapse neutrinos

- ~10 second prompt burst of all flavors, few tens of MeV

Current & near future detectors:

- ~Galactic sensitivity (SK reaches barely to Andromeda)
- can get some pointing from neutrinos
- SNEWS 1.0 network is waiting, SNEWS 2.0 in near future

Long term future

- huge statistics: extragalactic reach
- richer flavor sensitivity (e.g. ne in LAr!)
- multimessenger prospects

The Transient Name Server (TNS)

Ofer Yaron¹

Session Classification: Detectors, probes & alert systems: Neutrinos, Gravitational waves

¹Weizmann Institute of Science

The Transient Name Server - overview

In operation since Jan 1 st, 2016. The official IAU mechanism for reporting new astronomical (extra galactic) transients and specifically for official name designation. (Set up by the IAU in order to provide a modern, automatic mechanism to archive and distribute alerts about transients, replacing the manual CBAT system.)

[As of Jan 2022] holds: ~90k reported transient candidates ("ATs"),
>9k (10%) classified SNe (in addition the full catalog of all pre-2016 SNe),
>1k registered users, >120 groups

The basic TNS object is an Astronomical Transient (AT) with a unique identifier of the form AT YYYYx (x=A..Z, aa..zz, aaa..zzz,...). The prefix "AT" can be later changed to indicate a classification (e.g., "SN") but the unique identifier is always kept.

Most reports are submitted automatically by "bots" of the major surveys & brokers (PS1, ZTF, Gaia, ATLAS...), but it is also possible to submit reports interactively using forms. Discovery reports are called AT-reps whereas classification reports (supported by a spectrum, for the "normal" transients) are called Class-reps.

The system naturally handles multiple reports on the same event (e.g., discoveries of the same object by different surveys) and keeps a (fully searchable) record of "internal names" that are associated with each AT-rep.

The system supports a service for short astronomical announcements (AstroNotes) which is a superior version of the ATEL system (e.g., searchable; hyperlinked to the specific objects).

All reports and AstroNotes are indexed by the ADS and are citable.

Currently all alerts/notifications from the TNS (discoveries/classifications/AstroNotes) are distributed via emails to the registered users, according to their defined preferences. (Additional staging/alerting mechanisms (e.g. Kafka streams) may be added.)

Some data can be reported as proprietary for a certain period of time; e.g. securing a name designation without official release of the details yet, or not exposing a classification spectrum.

Groups, Bots and memberships are all self-managed (by the users/group-owners), thus enabling flexible handling of access permissions, controlling the discovery credits etc.

The system resides on the AWS cloud, increasing its high-availability capacity and scalability.

On Mar 2020 the Fast Radio Bursts (FRB) community joined the TNS. An additional subsystem was tailored for handling the specific requirements of FRBs – including a separate naming engine (FRB YYYYMMDDx), a separate report form (for the specific FRB properties), and enabling specification of area localizations ("area transients").

Adaptations for the Gamma-Ray Bursts (GRB) community are now in design phase. (Requiring a separate GRB naming engine, and several additional challenges, e.g. the editing of many properties after the initial report...)

Two major requirements/guidelines of the TNS

To provide quick (low-latency) and robust processing of the incoming reports, and in strict order of arrival.

- No downtime is allowed (downtimes are kept on the level of a few hours per year).
- A high-availability and scalable system configuration is provided.
- The TNS is dynamic - constantly adapted to meet the needs of the community and its working protocols, as well as the inclusion of new communities and system components.

APIs, Bulk downloads

A Sandbox environment exists for experimentation with the APIs (both for submission and retrieval of info)

All API development must be performed against the sandbox : <https://sandbox.wis-tns.org> <https://sandbox.wis-tns.org/api> •

APIs are in place for:

- the submission of Discovery (AT) and Classification reports.
- Searching of objects (by coords, names – IAU/internal)
- Retrieving object details

CSV/TSV downloads are available from the Search page (also in a scriptable way) e.g. https://www.wis-tns.org/search?&&classified_sne=1&date_start%5Bdate%5D=2021-01-01&format=csv&num_page=100&page=0
←[0..N]

A CSV of all public objects (as well as daily “delta” lists) are available for download, in order to allow for easy local managing of the TNS data and to perform “heavy” operations locally (such as cross-matching entire catalogs

or long object lists) https://www.wis-tns.org/system/files/tns_public_objects/tns_public_objects.csv.zip Or using curl (with User-Agent and api_key) for a daily csv: `curl -X POST -H 'user-agent: tns_marker{"tns_id":YOUR_BOT_ID,"type": "bot", "name":" YOUR_BOT_NAME"}' -d 'api_key=YOUR_API_KEY' https://www.wis-tns.org/system/files/tns_public_objects/tns_public_objects_20220112.csv.zip` > `tns_public_objects_20220112.csv.zip`

Clarifications / to summarize

The TNS manages discovery & classification information (data), NOT extended LCs, spectral sequences etc... For this, data repositories such as WISEREP are relevant. Initiated mainly for SN candidates, the TNS also handles other extra-galactic transients, including novae (CVs), AGN flares, TDEs, Kilonovae... BUT NOT variable stars, asteroids or other such galactic/local variable/moving sources. PLEASE DO NOT submit varstars/moving objects but only secure extra-galactic transient candidates!!!

“Area Transients” are also officially joining the TNS: FRBs, and soon also GRBs, GW events. (In future more sophisticated cross-matching and association capabilities should be implemented – both on the TNS, and hopefully also by the additional utilities being developed.)

Classifications must be supported by a spectrum (not relevant for the area transients), and currently the TNS only switches the prefixes from AT to SN. (TDEs, Kilonovae... remain AT until an official decision will be made.)

API sample codes are available for download on the help page.

For any questions/feedback/suggestions related to the use of the TNS, its APIs, AstroNotes, please do not hesitate to contact us: www.wis-tns.org/content/contact-us (or me in person)

Overview of the Transient Name Server (TNS), in light of the advancing MMA realm

With the emergence and growth of robotic, wide-field high-cadence optical sky surveys during the last two decades (e.g. PTF, Pan-STARRS, ATLAS and more), the discovery of supernovae has considerably grown from a few tens per year to the hundreds and thousands domain. It became apparent to the members of the extragalactic transient community that in order to be able to reliably and rapidly inform the community about discovered events, an automatic name server and platform for reporting potential supernovae (and other transients of interest) must be put in place. With these needs in mind, the IAU SN working group was revived, and the TNS was developed and began full operation on January 1st, 2016, immediately replacing the previous almost entirely manual/human-managed mechanism that has been in operation until that point.

Besides operating as a name server that provides unique and unified names for transients (that are often discovered by several facilities independently, and have different internal survey names), the TNS manages and addresses a variety of related aspects – such as deciding whether a submitted discovery report should create a new object/event or be associated with an existing one, the official crediting and ADS indexing of the discovery/classification entries, distribution of the discovery alerts (to registered users, based on their defined preferences), self-management of reporting groups, memberships and bots, enabling search queries and retrieval of data using both scripted solutions (APIs, staged CSVs) as well as web interfaces, and the AstroNotes notifications platform that has been serving the community since 2019.

Currently all major optical sky surveys, as well as individuals and amateur transient hunters, report their discoveries and classifications to the TNS; the vast majority of the reports are submitted by computer-to-computer (bot) communication, utilizing the provided APIs.

As a central hub that collects in real time discovery reports of astronomical transients

and provides the official IAU designations of the events, two major requirements and guidelines of the TNS are:

- To provide quick (low-latency) and robust processing of the incoming reports, and in strict order of arrival. In this respect, the requirements from the web application are that no downtime is allowed (downtimes are kept on the level of a few hours per year), and that a high-availability and scalable system configuration is provided.

- Continuous adaptation to the needs of the community and its working protocols, as well as the inclusion of new communities and system components. Regarding the latter; whereas the TNS was originally aimed to meet the needs of the “optical” extragalactic transient community (mostly SN-related), the exploding emergence of multi-messenger astronomy in recent years has naturally led to expansions of the TNS. The Fast Radio Bursts (FRB) community has joined the TNS during 2020; the required adaptations for the Gamma-Ray Bursts (GRB) community are now in design phase, and discussions have been initiated with the Gravitational-Wave collaboration.

To emphasize, the inclusion of various communities within the scope of the TNS means that for each type of event a specific set of properties and functionalities must be tailored and implemented. Also, several separate “naming wheels” clearly have to co-exist in parallel, be it of the AT/SN YYYYxyz format, or the FRB/GRB/GW... YYYYMMDDxyz format, which relates to events/bursts that, by definition, are being designated to the day (DD) level. The envisioned goal to be able to manage and directly associate and couple different “messengers” of an astronomical event (like we’ve experienced with the GW170817/AT2017gfo kilonova), all within the scope of a unified system, is a very challenging one, but certainly has many advantages and a potential to be beneficial to all the relevant communities. <https://www.wis-tns.org/>

Computing Centers

CC-IN2P3

Eric Fède¹

Session Classification: Software tools & platforms for data analysis

¹Centre national de la recherche scientifique

Mission

CC-IN2P3 : French National Computing Centre of IN2P3.

Mission : Providing computing resources and services for experiments supported by IN2P3.

85 agents. Most of them are engineer.

Providing resources (Computing/Storage/DB)

Providing services.

- For our institute (mail, backup,....)
- For developer (GitLab, forge,....)
- For users/experiment (Dirac, squid,....)

Providing infrastructure (Cloud, Network connection,...)

Involving on a large landscape of collaboration (~80)

- Small (few user) to large collaborations (many thousand of people)
- Short lifetime (few months) to more decade (LHC,LSST,...)
- Regional collaboration to international (the main part of them)

Raw data storage site for some experiments.

Infrastructure

2 computing rooms for a total of 1500 m²

Computing Facilities

- HTC (High Throughput Computing) : ~50 000 slots
- HPC (High Performance Computing) : ~ 512 physical cores.
- GPU cluster : 20 K80 GPUs, 72 V100 GPUs
- Storage
-

Tapes : ~ 110 PB

HDDs : ~45 PB (different technologies: dCache, XRootD, CEPH...)

Network

- LHCOPN : 100 Gb/s (dedicated to LHC data)
- LHCONE : 100 Gb/s (LHC, Belle2, Juno,...)
- Specific link : LSST (40Gb/s), French HPC (100Gb/s)
-

Service

- Mail, GitLab, web, institutional services, cloud infrastructure,....

Activities at CC-IN2P3

High Energy Physics

- WLCG : CC IN2P3 is Tier1 for whole LHC experiments and is providing around 10% of the Tiers 1 capacities.
 - A long term engagement.
 - High level of availability/reliability.
 - Today ~60 % of the CC resources.

- BELLE2, JUNO, DUNE,....

- All this experiments are based on distributed/Grid computing model.

- CC IN2P3 involved on analysis and simulation. A part of raw data of this experiments are available at CC.

Nuclear

- A small set of experiments

GW Activities at CC-IN2P3

Today

- Virgo/LIGO
 - Historical computing site (with CNAF) for Virgo collaboration.

- A full copy of Virgo Raw Data at CC IN2P3.
- Support analysis job via
- Local submission (Virgo)
- Grid submission (Virgo/Ligo)

Tomorrow ?

- Einstein Telescope
 - A strong interest of IN2P3 to this collaboration and for the CC IN2P3 on computing aspect (computing model, resource requirement,...).

Astroparticles activities at CC IN2P3

Activities decreasing (but again with some analyses activities and raw data available at CC IN2P3).

- AMS (cosmic ray)
- Antares (neutrino)
- Hess (cosmic ray)

Currents and futures activities (analysis, simulation, raw data storage)

- Km3net (neutrino)
 - Provide already a large set of resource (CPU, GPU, DB, storage,...)
 - Discussion ongoing concerning the role of CC IN2P3 on the computing model.
- Pierre Auger (cosmic ray)
- CTA (cosmic ray)
 - Today CC is involved on grid activities (job scheduling, simulation) and provide some central grid services (Job scheduler Dirac, monitoring DB)

Cosmology activities at CC IN2P3

Old activities still active on analysis task.

- Planck
- Super novae

Current and future

- LSST/Vera Rubin
 - Will be one of the major experiments supported at CC IN2P3 during the next decade (and more).
 - 50 % of the data at CC IN2P3.

- Needs to satisfy a large set of resources requirement : CPU, storage, network
- Needs to provide new set of services and/or technologies: Notebooks, GPU usage,...

- Euclid (launch mid 2023)

- Involved on data reduction and pipeline preparation.
- ...

Broker

CC IN2P3 will provide the infrastructure for a LSST brokers (Fink)

Fink prototype is providing by IJCAB/IN2P3 laboratory

- Expected to move on production before end of 2022 on CC IN2P3 cloud infrastructure.
- ~500 vcpu and 1 PB of disk storage during one decade.
- A strong constraint on availability of the service.
- Not operate by CC but by Fink team (see talk later).
- But infrastructure evolution (aka performance) has to be considered to ensure
- the broker service efficiency (low latency,...).

Conclusion

CC IN2P3 provide computing resource (analysis, storage and services) for a large set of experiment involved on Astrophysics/Cosmology which provide multi-messenger

- Neutrino, Cosmic ray, GW, deep sky,...

CC IN2P3 is not involved on the science itself but provide computing tools and services for the experiments.

May be a good place to provide new services (broker,...) to the scientific communities

- Data (a part) are here.
- Computing facilities are here.
- Analysis (a part) is done here.

Fink (LSST Broker) is a first use case for us.

Software tools and platforms for data analysis

INTEGRAL Science Data Center

Volodymyr Savchenko¹

Session Classification: Software tools & platforms for data analysis

¹Université de Genève

INTEGRAL/ISDC and the world at lower latency

Data available with 20 s delay. Extra 10 min time to quantify the background (interplay between latency and quality). More dirty results faster? IBAS (especially ACS) does not wait and produces plenty of false alerts. Is this about building better automation/pipelines? In part, but also why this is hard, especially with available manpower. Complementary approach is to share more data, and we will very soon share 20 s latency data with the community.

Development space: help scientists make robots

There are much more scientists who can make a jupyter notebook than write organized code. Google-collab, binder, ESA DataLabs

We use Swiss-made Renku platform, to:

- Continuous integration and testing
- Supports in publishing of data and code (e.g. in zenodo)
- Support in annotation for scientists and robots reuse! FAIR!

<https://github.com/oda-hub/>

Develops and integrates metadata in a Knowledge Graph

Add “creativity”: Linked Open Data Knowledge Graphs

People know a lot, and form free associations. Robots have much information too. E.g. much insight is reported in GCN Circulars but only accessible to people.

- Global linked identifiers - URI (ivo://, http://, ..): building common vocabularies. URIs point to documents, workflows, data, astro objects
- Explain possible relations in ontologies
- Embedding and following references, to express connections between different URIs

We develop tools:

- scrobbling gcns, atels, tns, arxiv: I wish people would put more references to structured data like URL to json, but we try to consume graciously
- for annotating and publishing integrate code/workflows with data: making sure we produce cautiously
- Using graph relations to rank and optimize publication production

With this, we recently wrapped up INTEGRAL FoV calibration. We publish next INTEGRAL MM (GWTC3, recent IceCube) catalog with RDF metadata.

FAIR INTEGRAL Astrophysical Transient Analysis

Multi-messenger transient astronomy puts especially high demands on confusion-free low-latency interoperability, which we addressed by developing two key components:

- Environment to develop, test, and integrate data reduction, theoretical models, statistical methods, spacecraft operation tools

- Knowledge-Graph-enabled engine finds combinations of data, adapters, statistical methods, publishers, planning, and disseminates provenance-tracked standard results along with public data and code

Conclusions

Low-latency is hard to reconcile with high-quality and especially high-creativity, and costs development effort. Sharing is key, and low-latency, real time SPI-ACS data (20 s latency, in 8 s blocks) soon available on <https://www.astro.unige.ch/mmoda/> will be announced by a GCN. We make open tools for data centers (other projects also do) focused on added value analysis, aligned with software industry developments and EOSC:

- Online analysis tools and tools and components: to help non-developers explore
- Development, testing, benchmarking, integration tools: to help non-developers contribute
- Building KG-enabled knowledge base, integrating papers, workflows, data, and learning from this graph

Let's interoperate based on standards and tools! <https://github.com/oda-hub>

GRANDMA

Sarah Antier¹, on behalf of the GRANDMA collaboration²

Session Classification: Software tools & platforms for data analysis

¹Observatoire de la Côte d'Azur, ²<https://grandma.ijclab.in2p3.fr/who-we-are/partners/>

Created in April 2018 by IJCLAB and Observatoire de la Côte d'Azur

30+ institutes/groups. Including within Europe
 CNRS – Univ. Amsterdam – Univ. Louvain –
 Univ. Postdam – FZU – INFN - IAA

30 observatories

More than 85 scientists

PI. S.Antier (Artémis), Co-PI. A. Klotz (IRAP)

Project manager: T. Midavaine (Inst. Optique)

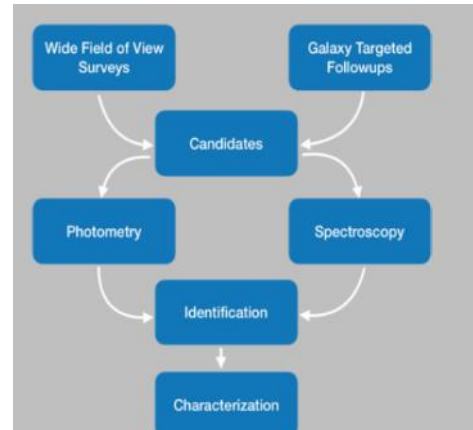
Work Packages :

- Consortium (Antier)
- Data Base (Perus)
- Follow-up (Tosta e Melo)
- Data reduction (Karpov)
- Online Infrastructure (Leroy)
- Observation plan (Coughlin)
- Citizen science (Turpin)

Present in 18 countries

GRANDMA : GW program (lead. Antier)

What are the properties of cold, ultra dense matter ? What are the properties of ejecta in compact binary mergers? What does the population of kilonovae look like? How are heavy elements produced ? Can we use these mergers for precision cosmology?



Challenge	Solution
Short lived	Speed
Faint - Peak at 20.5 mag at 200 Mpc	Deep Observations
Rapid Color Evolution	Observation in g and r bands (adding i if possible)
Large localisation uncertainties + Many alerts to follow + Well sampled lightcurves	No duplication Coordination of Observations Choosing alerts

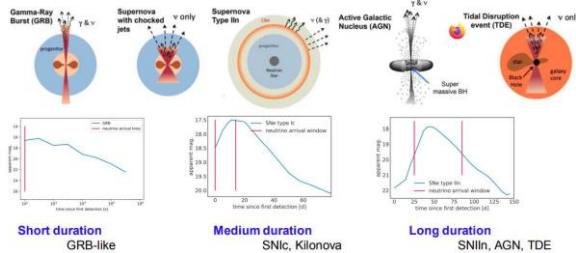
Identify and characterize GRB afterglows and kilonovae associated to gravitational-wave events.

Network and challenges

Requires a network of telescopes : common observational strategy, generic data reduction tools, spectroscopy and photometry, web platform and a centralized data base
 + expertise in transient follow-up (Postigo, Klotz, Stargate, TAROT)
 + Filtering alert streams in collaboration with FINK

- + expertise on compact binaries (GRB with SVOM France Daigne, Kilonovae with GRANDMA)
- + expertise on gravitational-wave physics (Virgo members)
- + GW pipelines GstLAL, Caudill + LVK low latency (Antier)
- + expertise on nuclear physics (Tews, Khan)

GRANDMA with HEN (lead: Pradier)



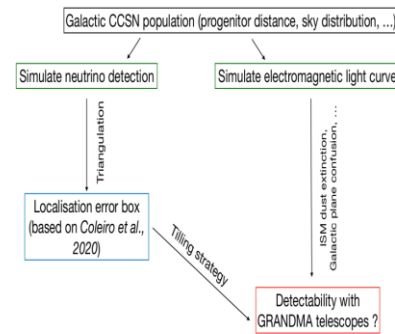
What is the origin of astrophysical neutrinos?
 GRANDMA has been creating a follow-up strategy at both early times and longer term:
 ~2-3 neutrinos / month, only 30% followed by e.g. ZTF; 80% by Master for counterpart identification

Medium/Long term follow-up needed for counterpart (s) classification+characterization
 → Requires expertise on KM3Net/ IceCube alerts (Dornic, De Wasseige) and on neutrino physics together with follow-up expertise developed during gravitational-wave follow up

GRANDMA with SNEWS (lead: Coleiro)

- Study the mechanisms of the explosion of core collapse supernovae
- Study the equation of state of ultra dense matter
- Study the nature of the remanent (neutron star vs black hole)
- Study properties of neutrinos (mass hierarchy)

Work in progress (APC, Purdue University)
 • build the framework to receive SNEWS alerts and trigger follow ups
 • Optimize the follow-up strategy to rapidly find the counterpart



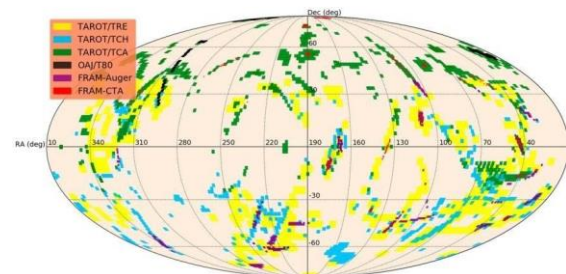
⇒ Run Monte-Carlo simulations to optimize the follow-up strategy

Questions

- How to prioritize observations within a network?
- How can a network composed of both amateurs and professionals interact?
- How can we use the distribution of massive stars in the Galactic plane as a prior to constrain the source localization?
- How can we maximize the chance of detecting the shock breakout?
- How do we deal with very bright CCSN which may saturate CCD detectors?

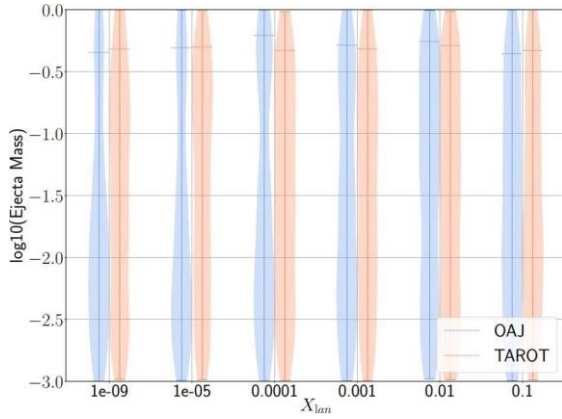
GRANDMA GW O3 observations

All O3 observations done by GRANDMA wide field of view telescopes.



87% of O3 alerts follow up by GRANDMA
 49/56 alerts for O3a
 90 minutes delay between first Obs and GW trigger for 50% of the alerts
[Reference article, MNRAS, 2020](#)

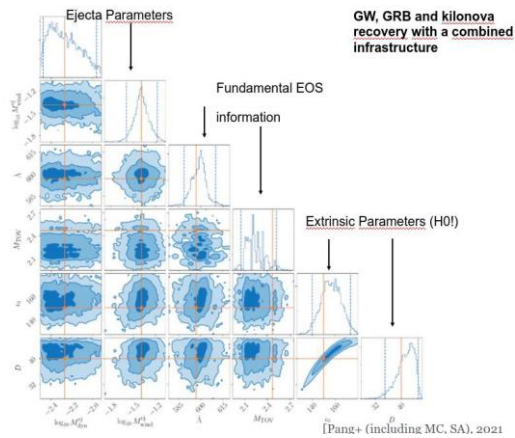
Minimal delay only 15 min for the first observation after the merger time
 Coverage on average per alert: 200 sq. deg down to 18 mag
 In case of interesting candidates, we can trigger OAJ and CFHT covering 100 sq. deg down to 22 mag



Constraints on the ejecta mass in terms of lanthanide fractions. X_{lan} for the BNS candidate. S200213t based on the OAJ and TAROT observations.

NMMA: Fully Bayesian Joint Inference Pipeline GW events

Lead: T. Dietrich (Postdam) with P. Pang , G. Raaijmakers (Amsterdam, Nikhef)



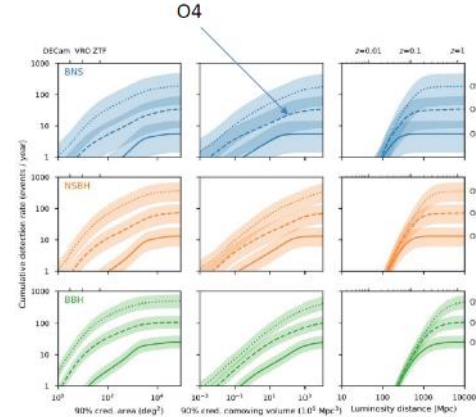
GRANDMA Citizen science: Kilonova catcher (lead Turpin)

<http://kilonovacatcher.in2p3.fr/>
 Reference article, MNRAS, 2021

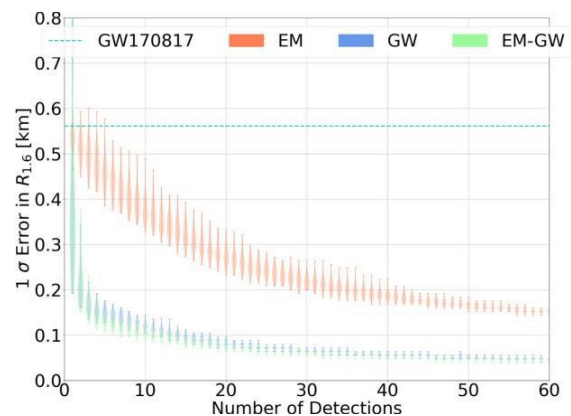
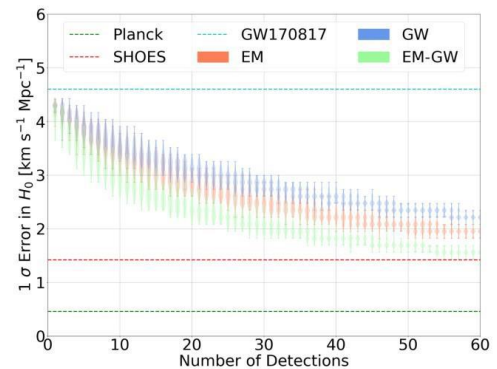
More than 130 participants and telescopes (from 15-60 cm)
 Observations made for NS BH and BNS candidates; more than 100 galaxies observed
 Observations of 12 Fink kilonova and supernova candidates
 30 amateurs participated in the ReadyforO4 campaign (April-September 2021); more than 1000 observations.

Participation to ZTF/LSST- LIGO Virgo SNEWS- KM3NET - IceCube and SVOM alerts

O4 observational campaign: Rate and Prospects



Petrov, Singer, et al., APJ 2022 : Updated observing scenarios based on O3



Coughlin, SA et al., in preparation : Prospects for H_0 and EOS based on observing scenario updates

Abstract for my talk

GRANDMA is a world-wide network of telescopes with the primary scientific goal of discovering and characterising electromagnetic counterparts of gravitational waves. It brings together an heterogeneous set of already-existing telescopes that operate in a coordinated fashion as a single observatory. Within the network, there are wide-field imagers that observe large areas of the sky, looking for optical counterparts; there are also narrow field of view instruments that do targeted searches of a predefined list of possible host galaxies, and larger telescopes that are devoted to the characterisation and follow-up of the identified counterparts.

The GRANDMA network is managed through a central system that distributes alerts and the desired observing sequences to each observatory in a coordinated way, to maximise the coverage. The collaboration provides the software for data reduction and analysis that allow to identify counterparts and report them in real time to the system. Further follow-up observations can be then performed in a way that optimises the use of resources and avoids duplicities. The network also includes a collaboration with amateur astronomers which can also receive alerts and report their observations.

Comments related to the workshop

Various tools are produced to face challenges in multi-messenger astronomy. However, we clearly see two types of approaches. Tools developed by a groups of astronomers for which other participants need to adapt the software (and sometimes with difficulty to modify them for their own purpose). However, those tools belong to a project and a large commitment can be allocated, but the project will not be maintained at longer-term if the

project ends. The second approach are tools developed for the community; these are generic but the failure is sometimes they are disconnected from the application and practice and barely used. SA has the impression that the bridge between neutrino/gravitational-wave experiments and the electromagnetic community is not filled and it is hard to interact with both. The same point of tension is present between ground and space missions, especially gamma-ray and optical. SA has also the impression that some grants obtained at the European level to serve the whole European community have not sufficiently consulted the broader community for their needs. SA hope in the future this community born in APPEC will be consulted.

MMO

Andrii Neronov¹

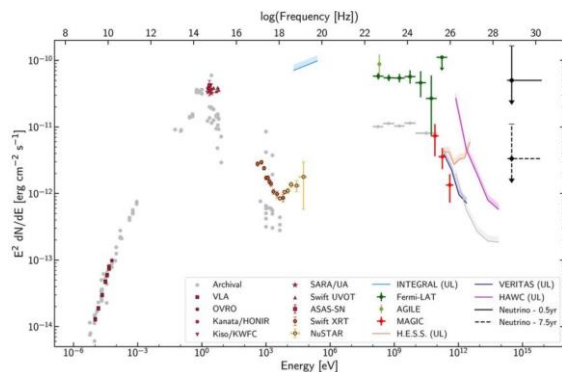
Session Classification: Software tools & platforms for data analysis

¹Université Paris Cité

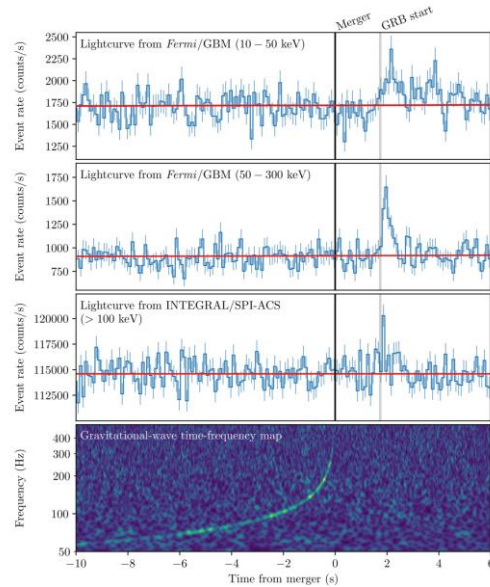
Multi-Messenger Observatory (MMO)

A wealth of astronomical sources emit over very broad energy range. Understanding of emission mechanisms requires astronomical data collected with many different types of telescopes.

A wealth of unprocessed data relevant for specific source may be residing in instrument archives and can be processed to extract relevant information on the source-of-interest “on demand”.



A wealth of astronomical sources appears on the sky for a short period of time (down to milli- and microseconds in the case of “fast radio bursts”). Understanding of emission mechanisms requires “fast reaction”, to observe the source with multiple telescopes, while it is “in action”.



Variety of multi-messenger data and analysis methods

Scientific publications conventionally report “static” results. This was justified when publications were published on paper. Rigidity of published information limits the potential of their re-use for a large variety of analyses (e.g. source of interest is not in the table, but can be added “on demand”?).

Individual astronomers cannot master all possible telescopes at once and, contrary to the high-level data products, raw telescope data may be not directly publicly exposed.

A system that helps multi messenger analysis and extracts data analysis results in automatic way would be useful.

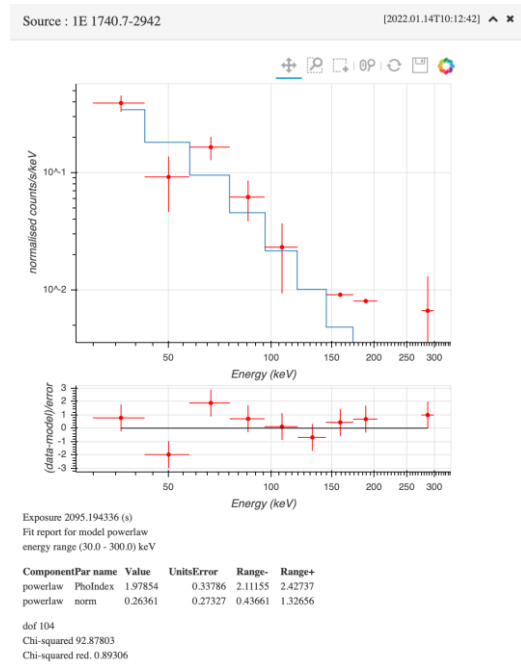
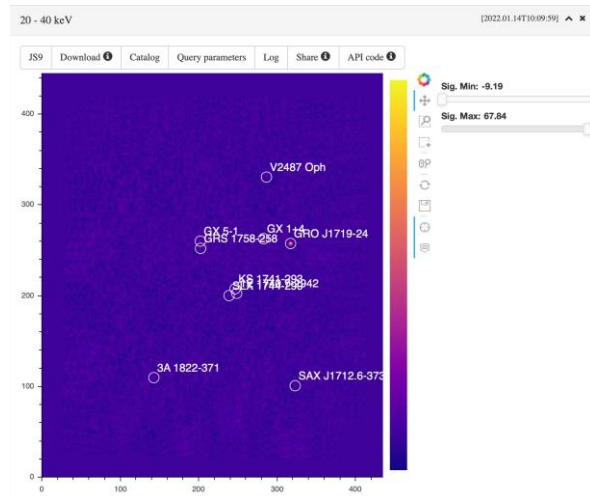
Multi-Messenger Online Data Analysis

Cloud computing opens a possibility to provide telescope data analysis “as a service”. Customizable data products (catalogs, images,

spectra, lightcurves) do not need to be static. They can be adjustable to the needs of specific multi-instrument / multi-messenger task.

<https://si-apc.pages.in2p3.fr/face-website/service/mmo/>
<https://www.astro.unige.ch/mmoda/>

Offline Science Analysis (OSA) for INTEGRAL telescope “as a service”. Allows to generate images, spectra, lightcurves using intuitive web interface (no need to download and install OSA locally on user machines).



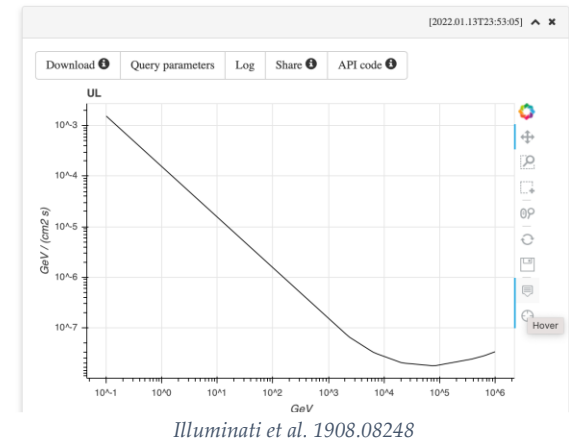
AN, Savchenko, Tramacere, Meharga, Ferrigno, Paltani,
arXiv:2002.12895

API for on-the-fly analysis can be integrated into further services, e.g. automatically generating relevant data products for multi-messenger analysis for transient sources.



API for on-the-fly analysis can be integrated into further services, e.g. automatically generating relevant data products for multi-messenger analysis for transient sources.

ANTARES neutrino flux upper limits for any spectral slope and any source on the sky.



Data for different instruments can also be generated via requests through a Python API and embedded into multi-instrument / multi-messenger analysis workflows on user laptops.

They appear in the formats directly suitable for further analysis (tables, arrays with all relevant metadata).

MMODA architecture

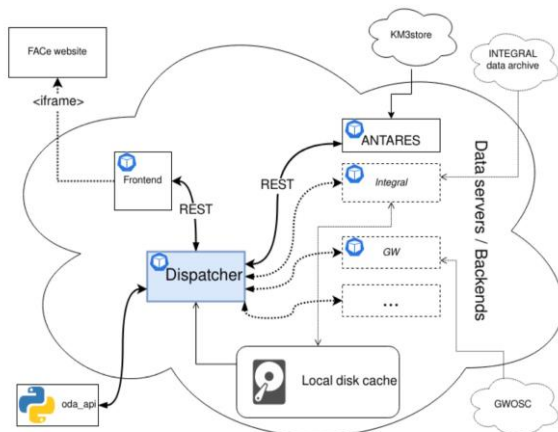
The platform uses a mixture of HPC and cloud resources, the French part is deployed on OpenStack infrastructure provided by France Grilles.

Services of MMO are deployed in containers (Docker, Singularity), easy and fast to create and remove. The containers are managed by Kubernetes (k8s), container orchestrator system.

Some of the containers work in “service” mode: they listen to requests of users of the platform, and respond to this requests: interpret them, deploy “worker” containers that do data analysis, return the results to the users.

User requests (from frontends or via API) are interpreted by a “dispatcher” that deploys “worker” containers for specific analysis, close to the data, and collects results.

The results are also stored in cache, so that repeated requests do not generate multiple processing.



MMODA service development

The platform is extendable: (almost) any analysis in a notebook or an analysis system in

a container can be converted into a service and added to MMODA.

Example: next development for gravitational wave data analysis workflows:

- most of the data of the latest O3 run of LIGO-VIRGO are publicly available.
- analysis notebooks are available at <https://www.gw-openscience.org>

LIGO-VIRGO collaboration has published results for selected “events” (high significance detections). Not only “positive” detections, but also “negative” results may be useful for analysis of multi messenger sources. Added value to the data can be generated if the GW notebooks are deployed for “analysis as a service”.

- on-going interaction with GW team at APC on service development.

Further contributions are welcome!

ENGRAVE

Nial Tanvir¹

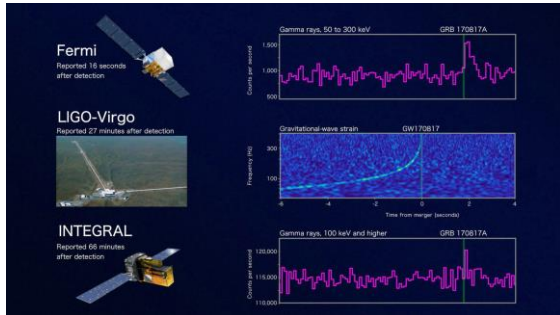
Session Classification: Software tools & platforms for data analysis

¹University of Leicester

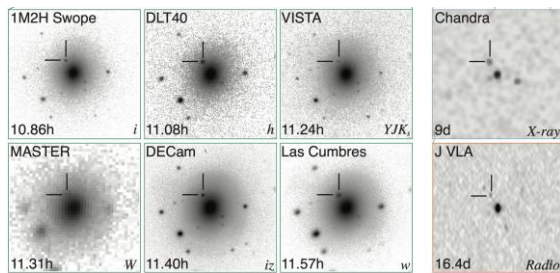
Electromagnetic follow-up of GW sources: successes and challenges - - the ENGRAVE experience

GW 170817

Within weeks of Virgo joining network, located first BNS merger accompanied by a short gamma-ray flash!!



O/IR (X/Radio) counterpart discoveries. Host NGC4993 @ 40 Mpc
 Combination of mapping and galaxy targeting
 → AT2017gfo

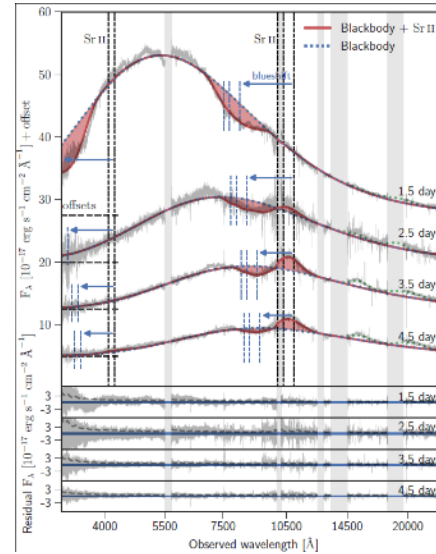


Spectral analysis

Superb sequence of spectra obtained, particularly with VLT/X-shooter (Pian et al. 2017).

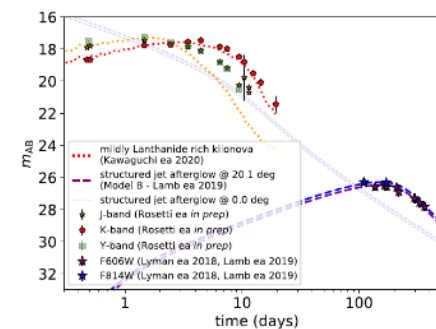
Note very broad optical/NIR spectral range.

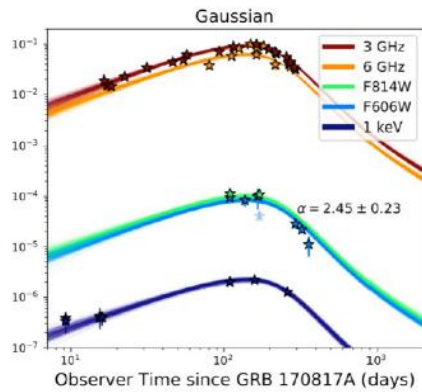
Potential evidence for (light) r- process from Sr II (Watson et al. 2019)



Ongoing behaviour

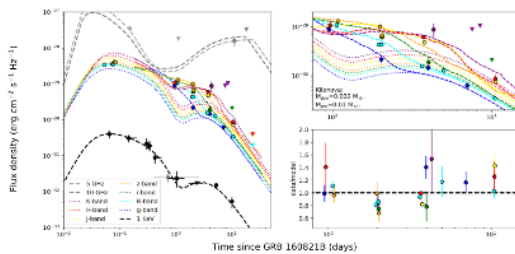
Late-time observations show still visible in optical (HST), radio (JVLA) and X-ray (CXO). Best explained as afterglow emission from off-axis structured jet.





But, diversity is expected, and seen

SGRB 160821B: In this case, fainter KN suggests lower ejecta mass $\sim 10^{-2} M_{\odot}$



Lamb et al. 2019 (also Troja et al. 2019)

ENGRAVE

A (primarily) European collaboration for detailed observational follow-up of gravitational wave EM counterparts, based particularly around the European Southern Observatory VLTs and their state-of-the-art instrumentation, but bringing in other major facilities, such as ALMA, HST, JWST...

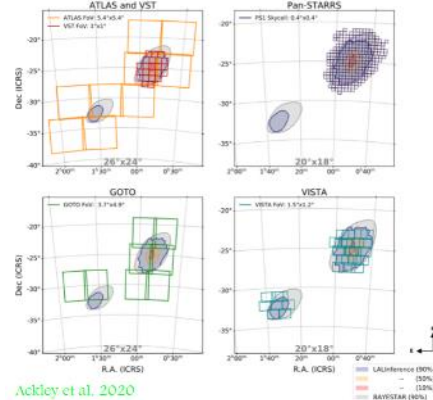
Significant overlap with major search campaigns e.g. PanSTARRS, BlackGEM, GOTO, VINROUGE, GRAWITA, ATLAS...

<http://www.engrave-eso.org>

Large allocations of time spanning O3 science run.

GW 190814: High confidence NSBH merger, but no good counterparts found, despite extensive, rapid searches (mainly mapping, although also some galaxy targeting).

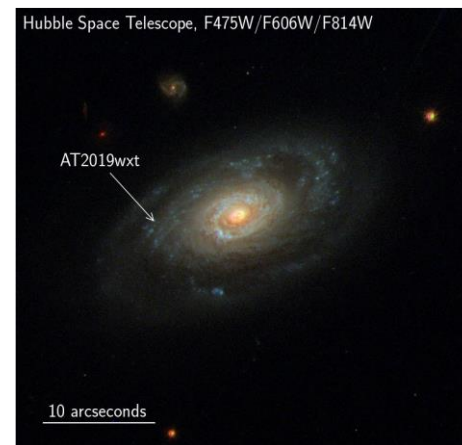
Unsurprising, given the high mass ultimately reported for the BH component.

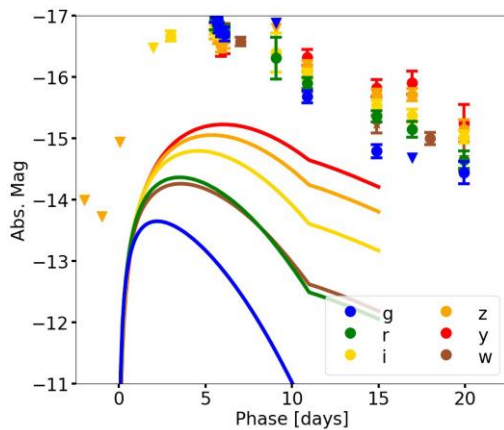


Ackley et al. 2020

See also Thakur et al. 2020, Adreoni et al. 2020, Kasliwal et al. 2020

S191213g: Candidate (low significance) BNS merger. No compelling counterparts, but discovery of AT2019wxt in error region provided an example of a possible class of rapidly evolving "imposter" which may turn up in kilonova searches.





In fact a faint, supernova from an ultra-stripped, dusty progenitor star.

ENGRAVE, Pan-STARRS + others, in prep.

Lessons from O3 run

Several more candidate (and confirmed) NS-containing events, but:

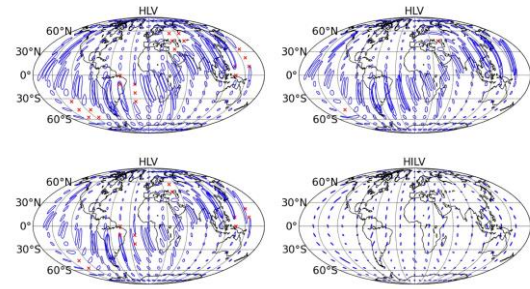
- Still quite rare (compared to BBH, at least)
- Typically quite far (~200 Mpc) – hence expect counterparts to be faint – challenging to find candidates and also to confirm/study them.
- Typically large error regions (100s of sq-deg)

(One candidate “burst” event)

GW future : O4

Many positives:

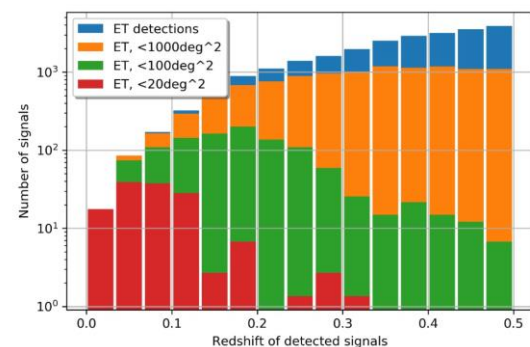
- Enhanced sensitivity will increase rate further, and time on sky will give chance for more nearby events.
- LSST may play significant role in rapid localisation of optically bright events, even at large distance.
- JWST and 30 m class telescopes provide deep follow-up.
- We plan to continue ENGRAVE at least through the O4 science run.



GW future : ...beyond

Positives and negatives:

- Beyond O4, inclusion of LIGO India, in particular, should result in smaller error regions.
- Ultimately, 3G detectors may largely depend on coincident SGRBs to provide EM counterparts.... And...there’s a risk that there may be no sensitive high-energy mission flying that will provide good localisations of these.



Insight

An issue I’d like to highlight is the challenge of coordination between facilities, collaborations and funding agencies. Multi-messenger astrophysics, above all, requires uniquely close involvement of multiple facilities and real-time communication, and therefore benefits from efficient coordination operationally, but in the longer run, also “joined up thinking” in terms of funding and designing future facilities and infrastructure. This should push us, at least to some extent, towards a change of mindset from bottom-up (how can we best work with what we have) to top-down (what infrastructure and facilities will be required to exploit MMA in the future).

Perhaps the most critical issue is that of persuading funding agencies to support development of, for example, new satellite missions for which a major part of the science case is MMA. Such missions have a very long lead-time (~decade), but the other facilities with which they will coordinate cannot be guaranteed, e.g. because they are also not yet built, or because time is awarded competitively. Again, a change of mind-set is required if we are to realise the promise of MMA.

Similarly important “meta-problems” are how to work efficiently and fairly together within and between large (and small) collaborations. Internal operation is hard enough, but there are now well-established models, not least that of LVK itself. Ways of working externally, between collaborations is an important part of the whole project life-cycle, and in particular for low-latency. Some marriages have been increasingly forced on us, and we have models from transient astrophysics that have enjoyed good success (e.g. GCN system), but has not been without pain (e.g. writing the primary MMA paper on GW170817!), and paths forward are still not clear, particularly in an era where rates will be higher.

Astro-COLIBRI

Fabian Schüssler¹

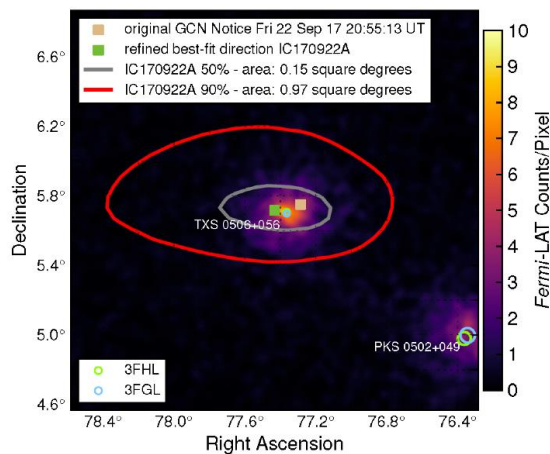
Session Classification: Software tools & platforms for data analysis

¹Commissariat à l'énergie atomique et aux énergies alternatives

COincidence LIBrary for Real-time Inquiry for multi-messenger astrophysics

IceCube-170922A and TXS 0506+056

22/09/2017: Detection of another high-energy neutrino of about 300 TeV by IceCube: automatic and public alert distribution to follow-up observatories at all wavelengths
 28/09/2017 Fermi-LAT: Detection of an active blazar within the neutrino uncertainty region ATEL #10791



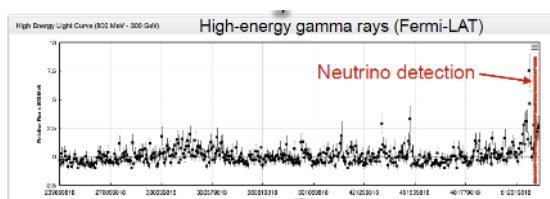
Behind the curtain

It took 6 days between the neutrino detection and the realization that there is a flaring blazar within the localisation uncertainty!

Cone search within the neutrino uncertainty => TXS 0506+056

Check state of the source(s) in FAVA

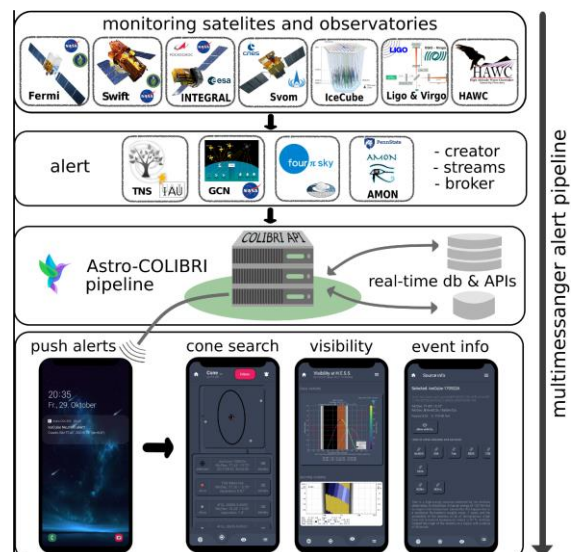
Many tools are available but need for automatisation + interfaces



Astro-COLIBRI

automatic pipeline providing easy access to

- transient detections (GRBs, FRBs, TDEs, SNe, OTs, high-energy neutrinos, GWs, etc.)
 - interfaces: <https://astro-colibri.com> + [Android](#) + [iOS](#)
 - a central API with publicly available endpoints for cone searches, etc.
 - Version 1.0 released in August (>500 users at the moment)
 - new releases / new features every 1-2 months
- Paper published: P. Reichherzer et al., 2021 ApJS 256 5 ([link](#))



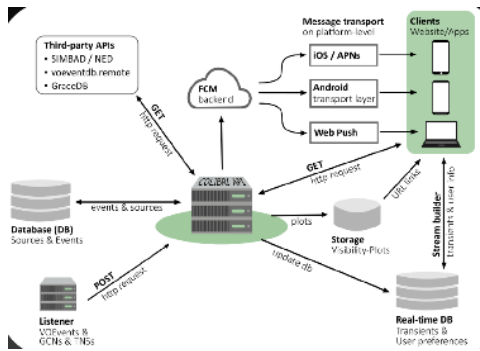
Android + iOS : alert notifications in real-time

Contact/feedback: astro.colibri@gmail.com

Web interface: <https://astro-colibri.com>

API (incl. documentation): <https://astro-colibri.herokuapp.com>

Architecture



Insight

The multi-messenger revolution is building on a strong foundation of a huge amount of effort towards rapid and largely automatic dissemination of data analyses and results. These publicly accessible tools include alert distribution networks and brokers (e.g. GCN, TNS, ATEls, etc.), visualization tools like ALADIN and ESA-Sky, databases like SIMBAD and NED, as well as portals to information of individual observatories (e.g. FAVA and Fermi-LCR for Fermi-LAT, the ZTF and Vera Rubin Observatory brokers, etc.). These tools are run by experts and provide access to the wealth of information obtained by the worldwide networks of observatories. Timedomain (and multi-messenger) astronomy has become more and more relevant for many observatories over the years. This naturally led to an increased in the number of detections, alerts, and follow-up opportunities. Combined with the need for reactions in real-time to catch the most violent explosions in the universe, many traditional and largely manual procedures to get informed about and react to new phenomena reached saturation. The need for novel approaches and new, modern tools has become urgent.

In this context we have developed “Astro-COLIBRI”, a platform that evaluates alerts of transient observations in real time, filters them by user-specified criteria, and puts them into

their multiwavelength and multimessenger context. The aim is not to replace the existing landscape of systems and platforms but to provide a central entry point that allows to keep track of the ever-increasing alert rate, provide easy access to the expert systems and thus facilitate multi-messenger follow-up observations.

Through fast generation of an overview of persistent sources as well as transient events in the relevant phase space, Astro-COLIBRI contributes to an enhanced discovery potential of both serendipitous and follow-up observations of the transient sky. The software's architecture comprises an Application Programming Interface (API), both a static and a real-time database, a cloud-based real-time alert system, as well as a website (<https://astro-colibri.com>) and apps for iOS and Android as clients for users. The latter provide a graphical representation with a summary of the relevant data to allow for the fast identification of interesting phenomena along with an assessment of observing conditions at a large selection of observatories around the world. Astro-COLIBRI combines information traditionally scattered across several platforms (e.g. FRBs, SNe, TDEs and other optical transients from TNS as well as GRBs, GWs and high-energy neutrinos announced on GCN). For each event dedicated links provide direct access to a large number of additional and external services. Using cutting edge mobile technology, Astro-COLIBRI has become a central point of accessing information about astrophysical sources and transient events.

Continuous feedback, input of new ideas, as well as contributions to further developments and improvements from the community (comprising both professional and amateur astronomers) are highly welcome.

Contact: astro.colibri@gmail.com

Twitter: @AstroColibri

Gammapy

Régis Terrier¹, for the Gammapy team²

Session Classification: Software tools & platforms for data analysis

¹Centre national de la recherche scientifique, ²<https://gammapy.org/>

Multi-instrument analysis: formats and tools

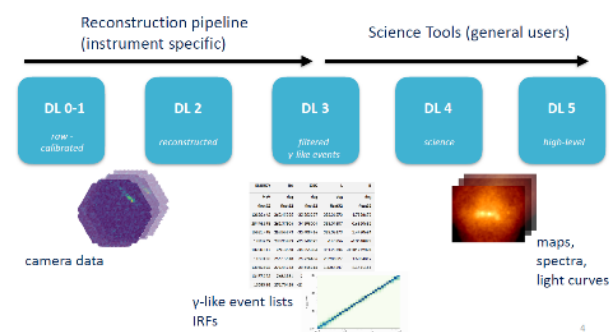
All VHE gamma-ray instruments have their own proprietary formats and tools making joint analyses impossible.

Currently all multi-instrument analyses (and de facto multi-messenger analyses) combine high-level results such as fluxes, SEDs lightcurves etc. This approach does not allow a proper joint analysis as it fails to take into account, eg.

- the instrument-based assumptions on the underlying physical spectrum
- the existence of inter-instrument systematics effects
- the treatment of low statistics

Moreover, multi-instrument analysis requires interoperability & reusability hence common open data formats and common open tools.

This is made possible once the data flow in VHE astronomy is clearly separating instrument specific data treatment from common use cases and methods. While event reconstruction and selection are usually instrument specific the analysis performed with gamma-ray like events lists (or Data Level 3, DL3) is more standard.



Towards common data formats beyond gamma-ray astronomy

A community initiative is currently formed to provide open data formats for VHE astronomy in general.

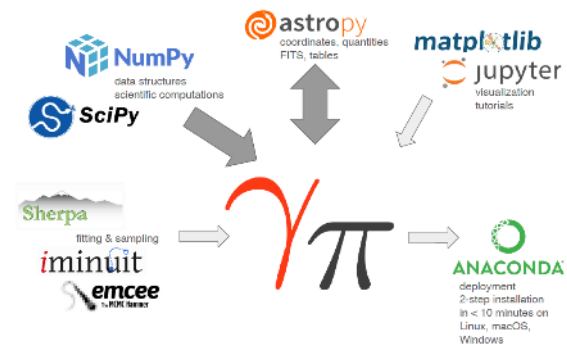
The [g.a.d.f. \(gamma-ray astro data formats\)](#) can serve as a prototype format. But the formats should be able to support at least:

- pointing Cherenkov telescopes (e.g. CTA, Veritas, MAGIC etc)
- drifting telescopes (e.g. HAWC, SWGO and Km3Net, IceCube)
- Fermi-LAT

The gammapy concept

Gammapy is a astropy-affiliated python package for high-level γ -ray astronomy based on [common data formats](#) such as those implemented in the gamma-astro-data-format open initiative.

Gammapy is relying on the extensive scientific python ecosystem. It is a very flexible library allowing to build numerous complex use cases but it can also be used as a configurable high level tool. Gammapy has been selected as the library for the CTA science tools.



Science validation & maturity

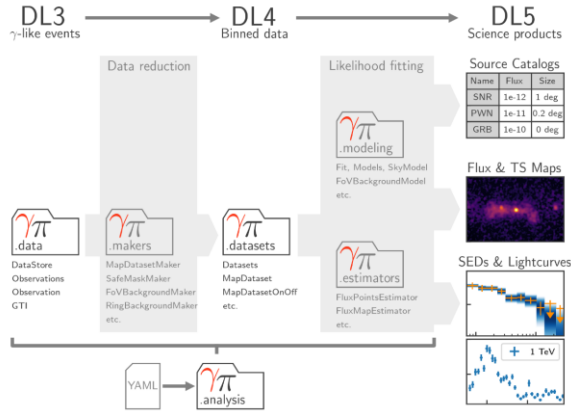
Gammapy has been validated for science usage using the H.E.S.S. DL3 test data release. It is now widely used for science publication within the H.E.S.S. collaboration. It has been selected as science tool library by the CTA Observatory and is used for LST-1 data analysis. A prototype analysis using HAWC data has also been developed ([Olivera-Nieto et al, 2021](#))

Data workflow and package structure

The analysis workflow is split in two different steps:

- data aggregation and reduction (DL3 to DL4)
- modeling / fitting (DL4 to DL5)

The following figure shows how various sub-package are connected within this workflow. The central element in this structure is the Dataset object which represents the DL4 data. Because it bundles binned counts, reduced response functions and sky models, it can easily provide a framework for joint data modeling at DL4 level. This is a crucial point for multi-instrument modeling and fitting.



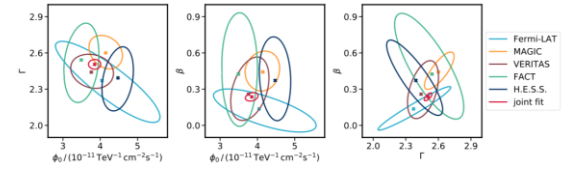
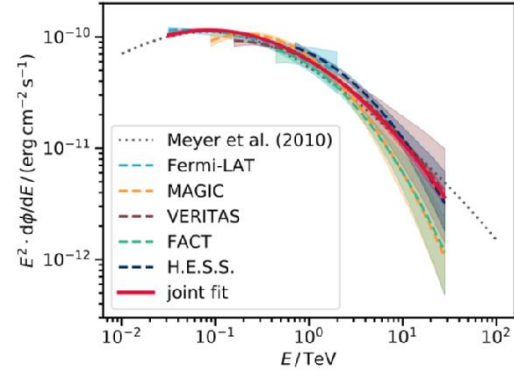
Multi-instrument modeling and fitting

Because Gammapy's Dataset structure allows heterogeneous data modeling and fitting, joint analysis of various instruments is made simple. This can be applied to non gamma-ray data. As an example, [Unbehaun \(2020\)](#) has built a prototype analysis of joint analysis of CTA and KM3NeT data using Gammapy. This work demonstrates the gain of performing combined analysis of CTA and KM3NeT to constrain physical processes.

joint-crab paper

The most complete example of such an multi-instrument analysis is the joint-crab paper. Small set of observations from MAGIC, HESS,

FACT, Veritas and Fermi-LAT were reduced using classical ON-OFF region analysis from DL3 level and jointly fit. The broad band modeling and fitting offer a significantly improved set of constraints on the spectral parameters. It also allows to perform inter-calibration studies to evaluate the amplitude of systematic effects. For instance, in [Nigro et al \(2019\)](#), the level of uncertainty in the absolute energy scale is evaluated.



This paper also provides details on the required environment as well as all analysis notebooks to allow full reproducibility see e.g. [this notebook](#) or [this one](#).

Summary

Multi-messenger analysis requires joint multi-instrument analysis. This requires common and open high level data formats and tools. Together with existing initiatives to provide common VHE data formats, Gammapy is a step in that direction. Its usage is already large, and it has been already used for several multi-instrument gamma-ray analyses from IACTs to Fermi and HAWC. While prototype tools for Km3Net neutrino data analysis are already existing, a larger effort will be needed to fully support high level analysis of VHE neutrino telescope data.

IVOA

Ada Nebot¹

Session Classification: Software tools & platforms for data analysis

¹Centre de données astronomiques de Strasbourg; <https://ivoa.net/>

The VO and the IVOA: what?

A multi-wavelength digital sky that can be searched, visualised and analysed in new and innovative ways".

What is the Virtual Observatory?

Framework for astronomical datasets, tools, services to work together in a seamless way.

What is the International Virtual Observatory Alliance?

A science driven organisation that builds the technical standards, a place for discussing and sharing VO ideas and technology to enable science and promoting and publicising the VO

The VO and the IVOA: why?

Clear benefits : Growth in the scientific return of data. Capability to discover and fuse multiple data sets. Application of the VO in planning new observations and observing strategies.

The VO and the IVOA: who?

Who is the IVOA? - <http://ivoa.net/>

- Exec, Tech Coordination, Standards & processes, Media, Science priorities
- 6 Working Groups: Applications, access, models, grid & web services, registry, semantics
- 8 Interest Groups : Time-domain, radio, solar system, education, data curation, knowledge & discovery, theory
- Completely open to participation

Want to join the IVOA?

- Meetings: 2 interoperability meetings per year
- Email list:

<https://www.ivoa.net/members/index.html>

- GitHub: <https://github.com/ivoa-std>
ada.nebot@astro.unistra.fr

The VO and the IVOA: where?

Existing global framework: populated by major data providers (space and ground based) that is heavily used by the community (e.g. Gaia data access is fully VO).

The VO and the IVOA: how?

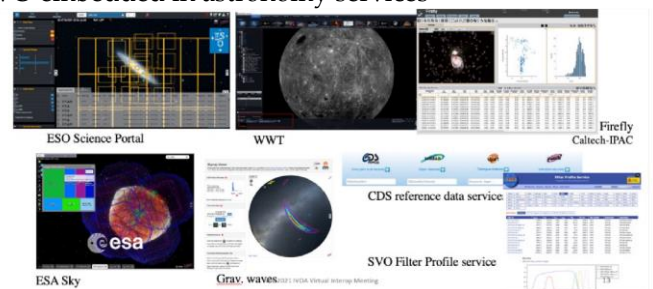
Through the development and adoption of common standards scientifically driven, as an international community effort where astronomers, software engineers and documentarists are involved.

(Some) identified needs of the multimessenger Community

To characterise and classify sources...
Multi-wavelength / messenger approach is needed
Follow-up observations and reaction time for that can be crucial
Coordination & transmission of information
Visualisation & navigation through the data
The IVOA should match user's needs

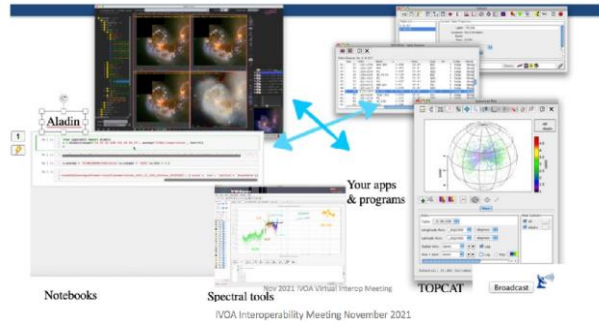
How is the IVOA easing user needs?

VO embedded in astronomy services



How is the IVOA easing user needs?

Interoperable applications and services



- Multi-wavelength / messenger approach
- Combining data from missions covering different wavelength ranges through data curation
 - Source identification (e.g. Simbad, NED)
 - Cross-matching techniques (e.g. CDS xmatch service)
- Enabling access to different types of data defining similar language to access data
 - simple things: Cone search
 - complex things: TAP + ADQL, ...

Follow-up observations, and coordination

- Transmission of alerts using a common standard format (VOEvent)
- Planning observations
 - When is this area of the sky visible from this place?
 - Definition of a common standard for object visibility (ObjVisSAP)
- Coordination of observations:
 - What area of the sky is planned to be observed, when and at which wavelength?
 - Definition of a common standard for observatories to share that type of information (ObsLocTAP)

Visualisation & navigation through the data

- Fast access and navigation through large images and catalogs is possible using a hierarchical way HiPS, MOC (see G. Greco et al. 2022)
 - MOC allows us to e.g. find the intersection in space and in time of

different surveys (existing or planned) and filter catalogs by the area of interest (<https://cds-astro.github.io/mocpy/>)

- Send / receive (share) data among services & tools with SAMP

What are the challenges of the IVOA

Some challenges

- New projects coming up
- PB scale missions coming up
- Support science platforms with analysis close to data
- Support new data-types driven by growth in size and complexity of data sets

Do you want to publish your data into the VO?

Starting point:

<https://wiki.ivoa.net/twiki/bin/view/IVOA/PublishingInTheVO>

email: ada.nebot@astro.unistra.fr

To summarise

Interoperability is possible thanks to the definition and / or adoption of standards which set the common language and technology between services and tools.

- To improve involvement of different communities in the discussion, development and improvements of the standards we need to support meetings (like this one) between technical and scientific community to tackle specific questions
 - & missions involvement
- Training schools for interoperability aimed at early career scientists
 - Having feedback sessions to report and collect requirements
- Share with others at international level through the IVOA channels
- Networking during the IVOA interoperability meetings — meetings 2/yr
- IVOA email — <http://ivoa.net/members/index> to register
- GitHub <https://github.com/ivoa-std>

ESCAPE-ESAP

John D. Swinbank¹

Session Classification: Software tools & platforms for data analysis

¹Netherlands Institute for Radio Astronomy

The ESCAPE² Project brings together the astronomy, particle physics, and astroparticle physics communities to develop a shared digital infrastructure to address fundamental challenges in data-intensive research, inspired by the needs of major European research infrastructures (ESFRIs).

ESCAPE aims to enable multiwavelength and multimessenger science by promoting interoperability between facilities and co-development of shared data processing and analysis capabilities. We are addressing these challenges by developing a range of services, including data distribution and management systems, software and services repositories, virtual observatory integration, and citizen science projects.

ESAP, the ESFRI Science Analysis Platform, is being developed as the primary user-facing interface to the ESCAPE service portfolio. It is designed to provide a friendly and consistent gateway to the full range of project-provided capabilities, while being extensible to incorporate new services in the future, and customizable to address the particular needs of individual ESFRIs.

A toolkit, not a single platform

We envision ESAP not as a single instance of one comprehensive platform, but as a toolkit that can be used to build science platforms that are customized to their particular environments. For example, individual ESFRIs could use ESAP to assemble a platform that integrates the services that are of relevance to their particular user community, while larger consortia could use

ESAP to integrate services drawn from across a range of ESFRIs or other infrastructures. Each of these individual platforms can be integrated with the European Open Science Cloud (EOSC).

ESAP Architecture

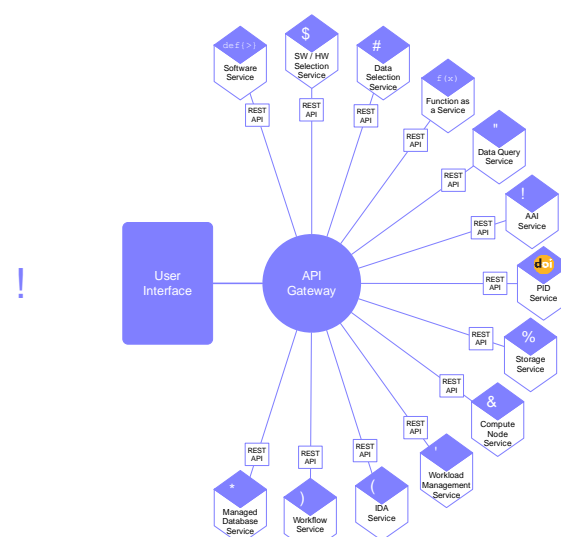


Figure 7: the high-level ESAP structure. At the heart of the system the API Gateway brokers requests across a range of independent services, while the User Interface presents results to the user in a consistent and approachable way.

The high-level architecture of ESAP is illustrated in Figure 7. The core system consists of an API Gateway, which acts as a form of broker at the heart of a cloud of microservices, communicating over REST³ interfaces. Each microservice provides access to a different externally-provided service: these include data discovery, computing, software repositories, and so on. The interface between the external services and the API Gateway is standardized, so that it is straightforward to extend ESAP's

² <https://www.projectescape.eu>

³ Representational State Transfer.

capabilities by “plugging in” new service connectors. Each ESAP instance can be customized to its particular environment by selecting the range of services which are connected to the API Gateway.

Users access ESAP through the User Interface. This presents all the services registered with the API Gateway to the user in a convenient and accessible way.

Anticipated Workflows

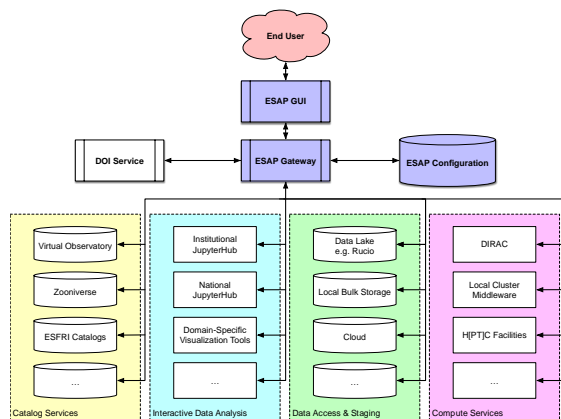


Figure 8: ESAP in its environment, modulating user interactions with a variety of service types.

By design, ESAP is not prescriptive about user workflows or the types of science it enables. Rather, it is designed to be flexible and responsive to the needs of a variety of research infrastructures and their user communities. However, it is designed to support the user through a putative research workflow which might include:

- The user accesses ESAP’s data discovery interface and submits queries to multiple archives and catalogues using a single consistent ESAP interface. Search results are presented to the user in a single, coherent form.
- ESAP helps the user identify appropriate interactive analysis services such as Jupyter notebook systems and dispatches selected query

results to those systems for further analysis.

- Based on the results of interactive analysis, ESAP helps the user discover batch processing workflows that can be used to re-analyze the data in bulk to address specific science questions.
- ESAP facilitates the user in matching data, compute, and storage services to run the selected batch workflow, taking into account issues such as user access rights and data locality.
- Results are made available through the ESCAPE Data Lake, and ESAP guides the user to appropriate services which can be used to assign a persistent identifier for publication.

Current Status

Although ESAP currently exists only in prototype form, it already provides a range of capabilities including:

- Data discovery through multiple bespoke archive types (for example, Zooniverse, or Apertif⁴). The data discovery interface adapts to the details of the specific archive being interrogated.
- Support for a range of Virtual Observatory protocols.
- Interfaces with the Rucio⁵ data management system which underlies the ESCAPE Data Lake.
- Interactive data analysis support, including the ability to discover Jupyter notebooks and a Python⁶ client which integrates them with the ESAP data management system.
- A managed database service which can integrate with archives discoverable through ESAP to enable complex queries such as cross-matching.

Future Prospects

⁴ <http://www.apertif.nl/>;
<https://www.zooniverse.org/>

⁵ <https://rucio.cern.ch>

⁶ <https://www.python.org>

The ESCAPE team continues to develop ESAP, with a particular focus on:

- Closer integration with bulk storage managed by Rucio through the ESCAPE “Data-Lake-as-a-Service” system.
- Advanced matching of users, data, and workflows, taking account of data locality, resource needs, etc.
- Upgraded ESAP internal architecture, including support for asynchronous queries.

The ESAP team is committed to open development and standards-based interfaces. We would be happy to work with other teams to understand how ESAP could be adapted to your needs.

Downloads & Further Information

ESAP is developed in Python, Django, and React⁷. It is available under the Apache license, version 2.0.

Development of the core components takes place in the repositories at:

- <https://git.astron.nl/astron-sdc/esap-api-gateway>
- <https://git.astron.nl/astron-sdc/esap-gui>

An unsupported test system is available at <https://sdc-dev.astron.nl/esap-gui>. You are welcome to experiment, and we value your feedback!

⁷ [https://www.djangoproject.com](https://www.djangoproject.com;);
<https://reactjs.org>

AMON

Hugo Alberto Ayala Solares¹

Session Classification: Software tools & platforms for data analysis

¹Penn State

The Astrophysical Multimessenger Observatory Network

The AMON idea

- Discovery of transient multimessenger sources
- Trigger follow-up observations to identify and study counterparts
- Archival Analyses in search of multi-messenger activity

AMON: a framework to perform multi-messenger searchers

- Real-time coincidences
 - Use of sub-threshold data
- Archival Studies
 - Store events
 - Coincidence analyses
- Partners:
 - Triggering Observatories
 - Follow-up Observatories
- Pass-Through
 - Broadcast directly to GCN/TAN and SCIMMA

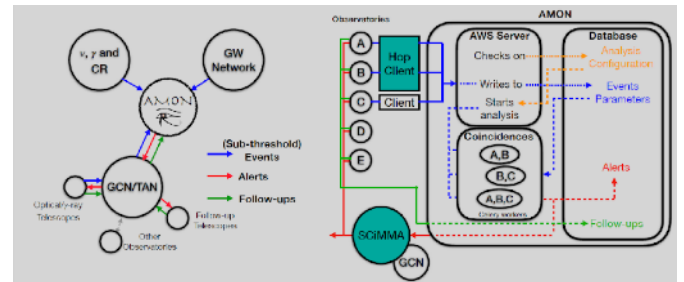
Joining AMON

MoU link: amon.psu.edu/join-amon/

- “As simple as possible, but no simpler”
- Follow-up as you will and report results internally (if private)
- Do not publish on someone else’s private alert without their participation or permission
- Ultimately: Joint or separate (but coordinated) publication

Each observatory retains full rights over use of its data (see AMON MoU). All coincidence analyses require explicit permission of each participating collaboration.

AMON Network and Hardware

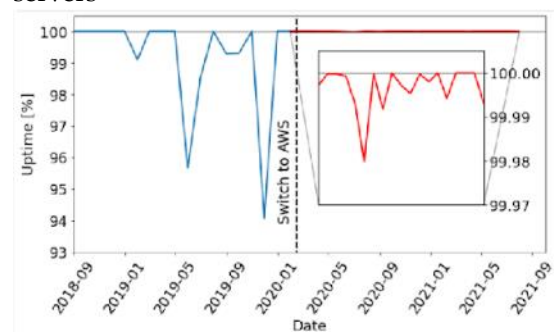


Technical Implementation: AMON uses an asynchronous distribution system to calculate coincidence searches in real-time.

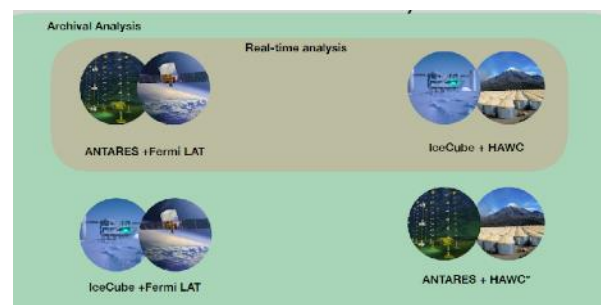
AmonPy software in GitHub:
<https://github.com/AMONCode/Analysis>

AMON Server

Recently transitioned from PSU servers to AWS servers



The NuEM channel: analyses



Coincidences in the NuEM Channel

False alarm rate threshold to send alerts is < 4 coincidences per year.

Archival coincidences have a false alarm rate threshold of < 1 coincidences per year.

Name	R.A. [°]	Decl. [°]	$\Delta\theta$ [°]	FAR [yr^{-1}]	Time UTC
Real-time alerts					
NuEM-211020A	99.76	9.07	0.17	0.86	2021-10-20 14:13:38
NuEM-210515A	93.64	14.66	0.15	3.93	2021-05-15 00:20:43
NuEM-210515B	93.93	12.51	0.20	1.90	2021-05-15 00:19:27
NuEM-210111A	162.34	19.46	0.37	3.85	2021-01-11 13:06:41
NuEM-201124A	134.99	7.74	0.23	2.96	2020-11-24 14:13:37
NuEM-201107A	140.20	29.76	0.15	3.49	2020-11-07 15:55:31
ANTARES-Fermi 200704A	255.42	-34.48	0.43	0.98	2020-07-04 15:53:48
NuEM-200202A	200.30	12.71	0.17	1.39	2020-02-02 14:07:52
ANTARES-Fermi 191011A	49.96	18.80	0.40	1.21	2019-10-11 15:54:32
Archival Coincidences					
ANTARES-Fermi	248.00	-7.7	0.07	0.09	2012-11-21 20:19:52
ANTARES-Fermi	279.68	-5.05	0.10	0.09	2014-08-05 11:13:33
HAWC-IceCube	4.93	2.96	0.16	0.99	2016-12-12 04:38:41
HAWC-IceCube	173.99	2.27	0.53	0.026	2018-04-12 07:54:51
HAWC-ANTARES	25.6	25.0	0.2	0.7	2016-01-08 04:39:38
HAWC-ANTARES	222.8	-0.8	0.2	0.87	2017-09-07 01:21:22
HAWC-ANTARES	85.4	3.4	0.2	0.41	2019-03-29 03:01:18

AMON NuEM channel is active

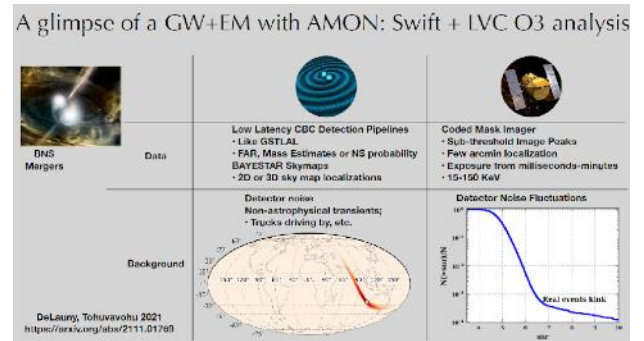
- Searching for high-energy gamma-ray and neutrino coincidences
- Using sub-threshold data

We encourage follow-up observations of these coincidences

Name	Followed by
NuEM-211020A	ANTARES, Swift-XRT
NuEM-210515A/B	ANTARES
NuEM-210111A	ANTARES, INTEGRAL, MAXI
NuEM-201124A	ANTARES
NuEM-201107A	Fermi-LAT
NuEM-200202A	MASTER, ANTARES
FERMI-ANTARES-191011A	MASTER

Visit the <https://amontom.science.psu.edu/> to query alerts

A glimpse of a GW+EM with AMON: Swift + LVC O3 analysis



AMON server is up and running

AMON greatly simplifies multimessengers searches:

- Common data format, transfer protocol, event database, MoUs.

Past:

- Archival analyses, help in the discovery of TXS 0506+056.

Present:

- AMON is issuing alerts from sub-threshold data for multimessenger searches in real-time.
- Pass-through alerts

Future:

- Updating to SCIMMA cyber-infrastructure
- New participants are always welcome!

DWF

Jeff Cooke¹

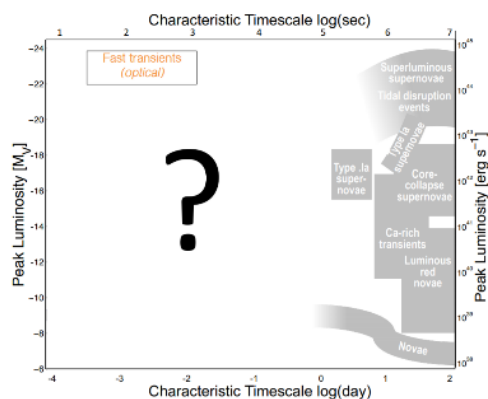
Session Classification: Software tools & platforms for data analysis

¹Swinburne University of Technology

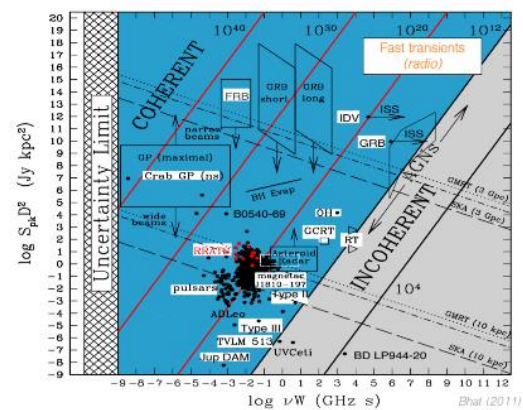
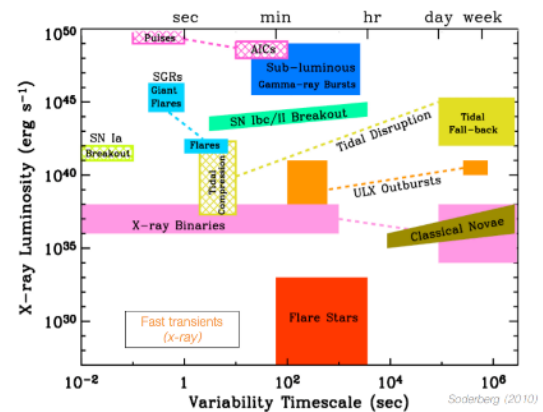
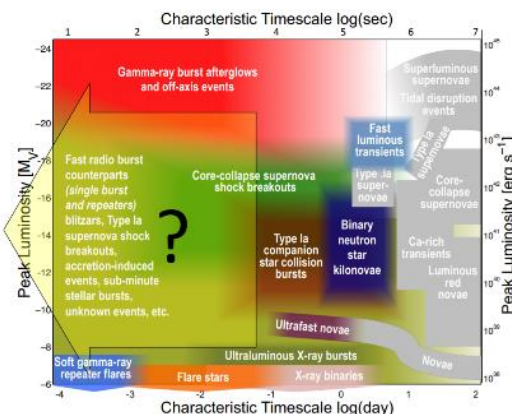
The Deeper, Wider, Faster program

A new approach to observational astronomy to detect the fastest transients and solve the nature of FRBs.

A coordinated program with telescopes on all continents and in space, operating at all wavelengths including particle detection, performing simultaneous coordinated observations, real-time data processing and analysis, rapid-response and later-time follow up, for a complete search for fast transients.



Unexplored optical fast transient space



Fast transients occur and are expected at all wavelengths

Fast transients

Occur at all wavelengths

- Occur in one, multiple, or all wavelength regimes
- Some emit at unknown wavelengths (e.g., theorized events)
- Some include high-energy particles and gravitational waves
- Some arrive BEFORE their detection in their discovery wavelength (e.g., FRB counterparts)

Need to act fast to catch and identify them

- Fast exposures needed to sample their evolution (= shallow)
- Simultaneous all-wavelength coverage to get all possible information for the fastest events before they fade
- Need to process, analyse, and identify events fast to trigger follow up before the 'slower' fast transients fade
- Need deep rapid-response spectroscopy and imaging

All this needs to be done in minutes (or faster) from the moment the light hits the telescopes.

Facilities

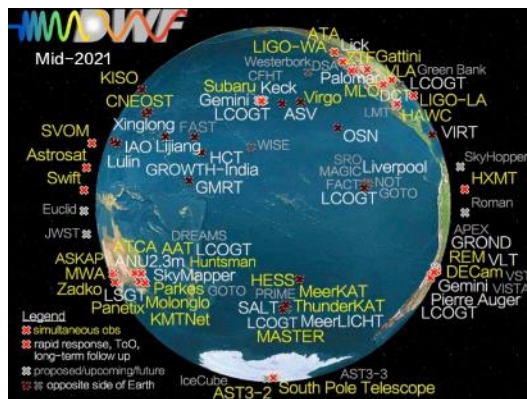
Simultaneous observing facilities, rapid response facilities, ToO, long-term follow up and proposed/upcoming/future facilities



Some conventional ToO facilities



Some field monitoring facilities

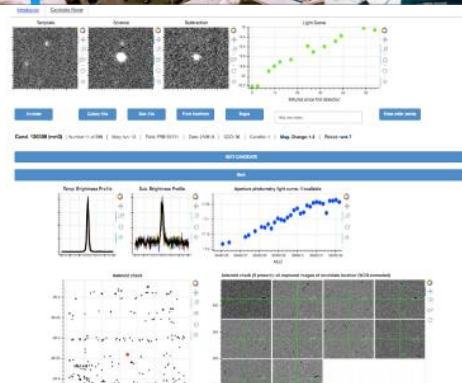


Facilities participating in DWF as of mid-2021



Some rapid-response facilities

Real-time analysis – data visualisation and web tool





Flow-chart of an example DWF run

Some discoveries

Gravitational wave kilonovae research

DWF contributed 14 of 70 telescopes for GW170817 search/follow up. The field set in Australia just before the alert was released. We triggered and coordinated optical, infrared, radio observations. Early wide-field imaging, first optical spectrum, follow up (Australia, Antarctica, Chile, US, US Virgin Islands, South Africa). 12 publications on GW search and follow up.

Fast Radio Burst counterpart searches

DWF contributed FRB counterpart search/follow up since 2014. We performed early wide-field optical searches (DECam) runs since 2014. We detected 2 FRBs in Sept. 2020 (Zhang et al. in prep). We're also mapping line-of-sight galaxies to FRBs to constrain ionised IGM. 4 publications on FRB search and follow up (others in prep).

Deeper, Wider, Faster program

Not a typical transient search program, nor typical reactive follow up.

DWF is 'proactive' and is on field **before, during, and after** the bursts. Being on field before the bursts is essential for coherent

bursts where shorter wavelengths arrive to Earth before the longer wavelength detections, e.g., FRBs.

DWF coordinates facilities at ALL wavelengths and particle detectors. For simultaneous observations that are: deep (the most sensitive wide-field facilities), wide-field (to sample large volumes and catch rare events) and fast-cadenced to sample fast transient evolution and catch early longer-duration events.

Real-time data analysis and fast transient identifications. Using supercomputer processing and data visualisation analysis techniques.

Rapid-response follow up using proposed or DWF collaborating facilities. Including optical (VLT, Gemini, SALT), high-energy (e.g., Swift) and radio (e.g., ATCA).

Conventional (hrs-later) ToOs using proposed or DWF collaborating facilities. Using 1-10m-class optical globally, radio and high energy facilities.

Field monitoring over weeks. Some fast transients are associated with longer duration events (e.g., supernova shock breakouts, SNe Ia ejecta collision with companion stars)

Jeff Cooke and the DWF team

<https://www.swinburne.edu.au/research/centres-groups-clinics/centre-for-astrophysics-supercomputing/our-research/data-intensive-astronomy-software-instrumentation/deeper-wider-faster-program/>

ZTF

Michael W. Coughlin¹

Session Classification: Vera C. Rubin Observatory: Alert brokers

¹University of Minnesota

The Zwicky Transient Facility And SkyPortal/Fritz

The Palomar Time Domain Astronomy Landscape of Optical TDA

The night sky is imaged at 17.5 mag by ASAS-SN (both hemispheres)

- The northern sky is covered by ATLAS, ZTF, and PS-1 to 19, 20.5, 21.5 over roughly two nights (ZTF issues real time, data-rich alerts)
- BlackGEM (21-22 mag; Chile) will start routine operation within this year
- Rubin is expected to become operational in a few years

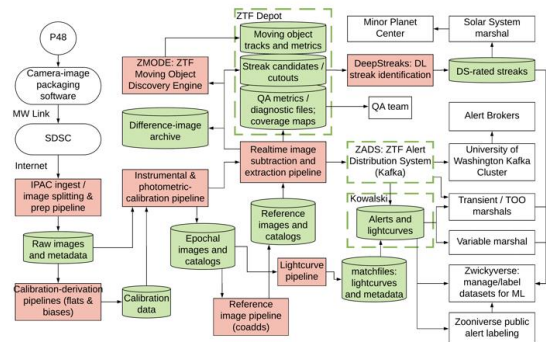
Observing Nights

The most complex time-domain survey ever scheduled

- ZTF-I: 40% MSIP, 40% partnership, 20% Caltech:
- Cadenced surveys, time constrained, deep drilling, ...
- 88+ survey configurations over Phase I
- >3 changes / month
- 4137 filter exchanges
- 3121 ToOs

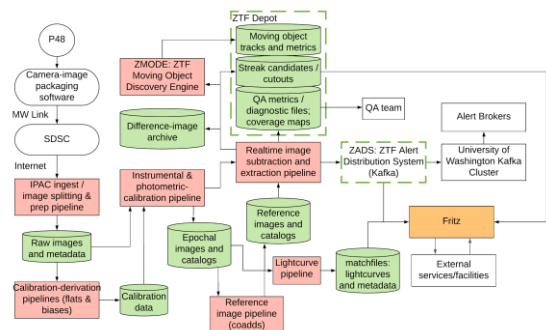
ZTF = 1/10 LSST

ZTF-I: data/processing flow



See Masci+ 2019

ZTF-II: data/processing flow



Fritz: science data platform for ZTF-II

Scalable, API-first system, with fine-grained access control

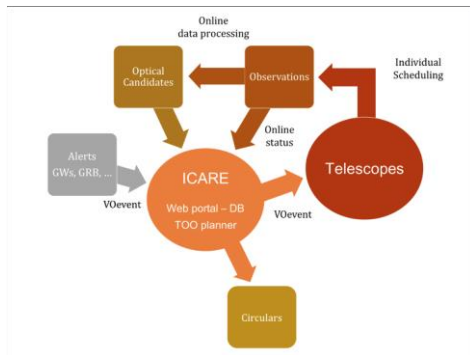
- Multi-survey data archive and alert broker
- Interactive, mobile-friendly collaborative platform for transient, variable, and Solar system science cases
- Workhorse for ML applications: classification and labeling at scale
- Follow-up observation management: robotic and classical facilities

<https://github.com/fritz-marshall/fritz>

<https://docs.fritz.science>

MMA Development

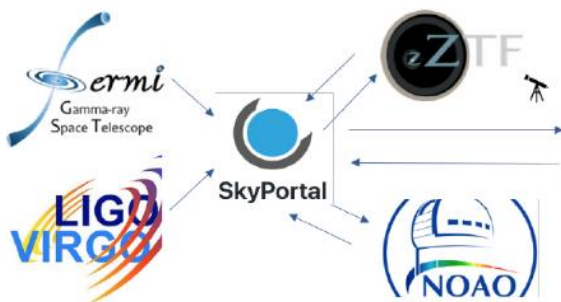
Inherits from two very successful projects during O3 and beyond: GRANDMA's iCARE and GROWTH's ToO Marshal



Ahumada et al. 2105.05067, Anand and Coughlin et al. 2009.07210, Andreoni and Goldstein et al. 1910.13409, Antier et al. 1910.11261, 2004.04277, Coughlin et al.: 1907.12645, etc.

A vision for the O4 workflow

Goal: Inform follow-up decisions.

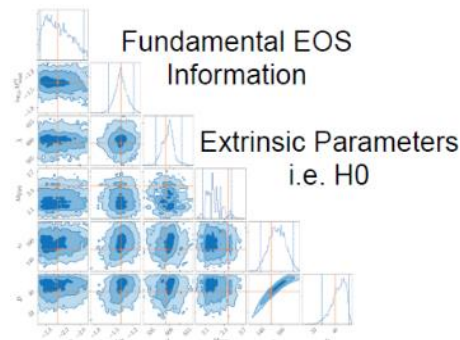


Goal: Remove difference between code we use to vet candidates in low latency and code we use to do science.

New features in development

- MOC-healpix Postgres 14 based object / galaxy cross-matches with skymaps: <https://github.com/skyportal/healpix-alchemy>
- Existing ACL's for telescope triggering interfaces / programs
- Observation Planning page with network level scheduling
- One stop shop for light curves (and therefore light curve fitting suite) and telescope limits (and therefore parameter constraints)

Ejecta Parameters



Epic tracking MMA work: <https://github.com/skyportal/skyportal/issues/2051>

Hope to finish by summer and stress test on active neutrino and GRB programs

Lessons Learned and Conclusions

open source is ♥

- Fritz/SkyPortal/Kowalski is open source : A huge part of devs is volunteer labor of love. While the core dev team is relatively small (in terms of effective person-hours), dozens of people have contributed meaningfully.
- Leveraging what GitHub/OSS has to offer : Issues to track bugs and feature requests. PRs + thorough code review. GitHub Actions as the CI/CD platform. Don't argue about style, enforce pre-commit hook (black, flake8, eslintrc...)
- Project management tool: ZenHub : Should be as close as possible to GH

Testing!

- You are not testing your code enough : From unit testing to integration testing through API and frontend, every bit is essential. Is that docker image still building from scratch? Note the word "continuous" in CI. Never underestimate the scale of a disaster that six innocently-looking lines of code can bring. Database migrations should be tested both ways - roll-backs are more common than we'd wish. Understand (and embrace!) flakiness.
- Staging environment
- Helps catch a lot of bugs before they have a chance to reach production, e.g. innocently-looking migrations that can take forever

Team and community is ♥

- Extraordinary individuals with a broad range of expertise : Critical but fair and open-minded review of ideas and code allows to iterate fast, converging on better solutions. Staying in sync: Slack + Daily 15-min stand-ups + weekly 1h meetings.
- Constructive community feedback is essential for success : Enormously useful for finding/fixing bugs and implementing new features. Need to be clear about the communication channels: a dedicated Slack channel for smaller issues + GH issue templates for larger stuff. Critically important: prioritization + clear big picture for the project.

Production is really hard!

- Even harder is to deliver updates/new features to prod
- Testing is your friend, but it won't catch everything that can happen : Running a subset of the test suite on a read-only replica of the prod db
- Weekly (at least) deployment to prod
- Resilient infrastructure for deployment. Monitoring the performance of the different components. Query Insights on the GCP. API endpoint response times, temporal evolution

Vera C. Rubin Observatory Alert Brokers

Rubin Observatory Alert systems

Eric Bellm¹

Session Classification: Vera C. Rubin Observatory: Alert brokers

¹University of Washington

Rubin Observatory will enable a powerful new survey

9.6 square degree field of view
 6.67 m effective aperture

Key Science Drivers

Probing Dark Matter & Dark Energy

- Strong & Weak Lensing
- Large Scale Structure
- Galaxy Clusters, Supernovae

Inventory of the Solar System

- Comprehensive small body census
- Comets & ISOs
- Planetary defense

Mapping the Milky Way

- Structure and evolutionary history
- Spatial maps of stellar characteristics
- Reach well into the halo

Exploring the Transient Optical Sky

- Variable stars, Supernovae
- Fill in the variability phase-space
- Discovery of new classes of transients

Observatory construction continues to advance rapidly, a powerful Data Management system will provide science-ready data products on rapid timescales

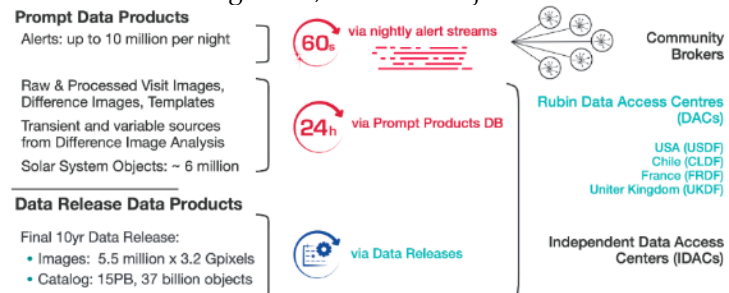
1. Raw Data: 20TB/night:
 - ➔ Sequential 30s images covering the entire visible sky every few days
2. Prompt Data Products
 - ➔ Alerts: up to 10 million per night (60s

via nightly alert streams to the community brokers)

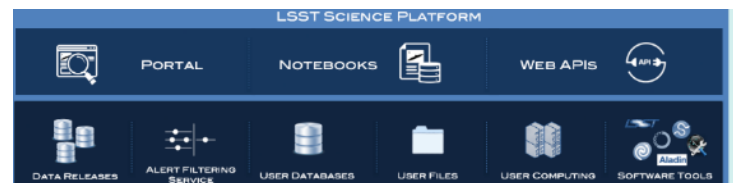
- ➔ Raw & Processed Visit Images, Difference Images, Templates
- ➔ Transient and variable sources from Difference Image Analysis
- ➔ Solar System Objects: ~ 6 million

Data Release Data Products

- ➔ Final 10 yr Data Release:
 - Images: 5.5 million x 3.2 Gpixels
 - Catalog: 15PB, 37 billion objects



Access to proprietary data and the Science Platform require Rubin data rights → LSST Science Platform provides access to LSST Data Products and services for all science users and project staff.



Community alert brokers are essential for Rubin's real-time science.

Rubin has agreed to send the full alert stream to seven brokers; Others will operate downstream.

Seven brokers were selected for direct access to the full alert stream:

- [ALeRCE](#)
- [AMPEL](#)
- [ANTARES](#)
- [Babamul](#)
- [Fink](#)
- [Lasair](#)
- [Pitt-Google](#)

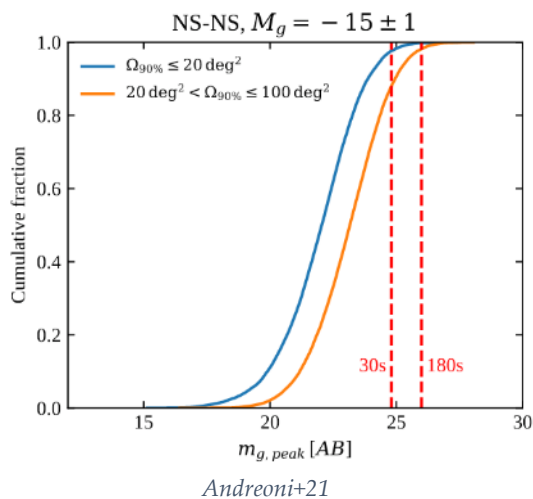
Two additional brokers were recommended to operate downstream:

- SNAPS
- POI/Variables

Connection & protocol testing have begun in January 2022.

We expect Rubin to support TOO observations; EM/GW is a particularly promising source of triggers

Compelling MMA science appears achievable with TOOs using 1-2% of Rubin observing time.



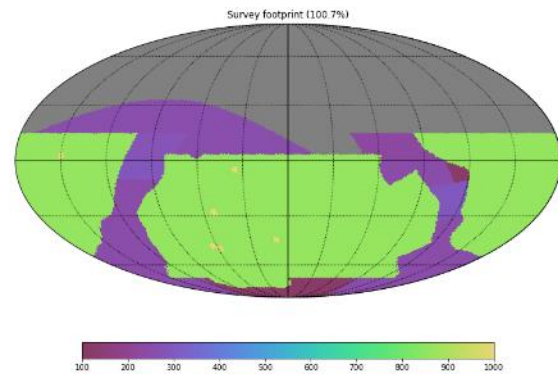
Both political and technical aspects are still being investigated.

- likely to be a proposal-driven process, i.e. through the NOIRLab TAC
- most timely dissemination of data will be through alert stream

Planning a virtual workshop for further discussion later this year.

Correlative/serendipitous MMA observations will of course also be possible

Draft new survey footprint (see [ls.st/doc-37922](#) and [ls.st/lhq](#)):



Cadence optimization will continue through 2022

Commissioning is expected to begin in 2023, with the full survey beginning in 2024

Full survey Operations planned start is April 1, 2024

- Planning date for proposal based on Construction rebaseline
- Still significant uncertainty (this is a “midpoint” between Construction Early and Late Finish)
- We will continue to work closely with the Construction team throughout commissioning and pre-operations to manage the transition.
- Transition happens at the team level

The current Rubin timeline poses challenges for follow-up of the O4 LVK run

Bulk of the O4 run appears likely to overlap with ComCam and LSST commissioning.

During this period, I expect:

- strong schedule pressure for the Rubin team
- ongoing integration of data processing systems and pipelines

- limited template coverage
- live alert distribution only as we approach full operations
- agency-imposed restrictions on early public data release

However, there could be more scheduling flexibility during commissioning, and there is an appetite for early science--we could be lucky!

Conclusions

Rubin Observatory will provide a uniquely powerful resource for optical followup and correlative observations of MMA sources.

Community alert brokers will be vital to identifying EM counterparts.

Rubin commissioning will begin next year, with the full survey (and broader scope for MMA observations) expected in 2024.

FINK

Julien Peloton¹

Session Classification: Vera C. Rubin Observatory: Alert brokers

¹Centre national de la recherche scientifique

Fink scientific objectives

Objective: studying transient sky as a whole, from solar system objects to galactic and extragalactic science.

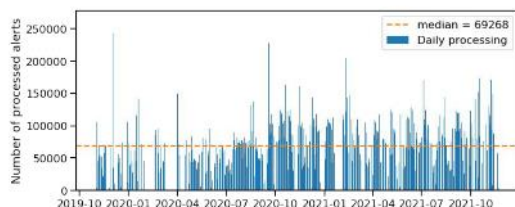
<https://dx.doi.org/10.1093/mnras/staa3602>

Currently deployed at VirtualData (Paris-Saclay). Production services for Rubin under deployment at CC-IN2P3.

Processing ZTF data

Fink is already operating on real alert data

- Listening to Zwicky Transient Facility (ZTF) since end of 2019
- ~200,000 alerts received per night (~20GB/night) -- 1/3 survives our quality cuts



Fink science output

More than 120 million alerts collected since 2019. Cross-matching (e.g. with the CDS xmatch service) + classification (machine learning based algorithms).

Each night, we transmit to the community:

- ~10,000 known variable stars
- ~10,000 known Solar System Objects (SSO)
- ~10 (un)identified satellite glints or space debris
- ~100 new SSO candidates
- ~100 new supernovae & core-collapse candidates
- ~10 new SN Ia candidates
- ~1 new fast transient candidate (KN, GRB, CV ...)

- ~1 new microlensing candidate

Accessing Fink data

Two entry points for users:

- Live streams (Kafka streams)
 - User-defined filters to select objects/parameters of interest
 - Data received “live” (+processing delays)
 -

<https://github.com/astrolabsoftware/fink-client>

- Science Portal & REST API
 - All data will remain accessible for the full survey duration
 - <https://fink-portal.org>
- TOM module
 -

https://github.com/TOMToolkit/tom_fink

If you are a user of the Lasair broker, see also Roy’s talk for accessing some part of Fink’s classification products through their system.

MMA projects in Fink

MMA effort started early, as there are many challenges: data models, interoperability of tools,

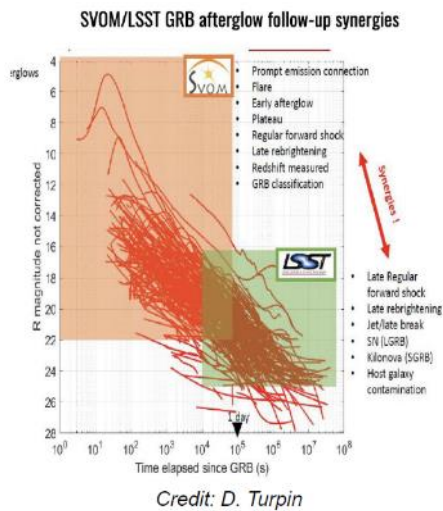
diversity of backgrounds, large infrastructures to develop for low-latency operations...

- Detection of fast fading on-axis GRB afterglows and slow-evolving off-axis GRB afterglows with the SVOM mission (See Cyril Lachaud’s talk)
- Search for Kilonova with the network of telescopes GRANDMA (see Sarah Antier’s talk)

GRB science with LSST & SVOM

SVOM & Rubin will probe different aspects of an event: prompt vs late emission. Rubin thanks to its cadence and limiting magnitude (~24), it

will be able to follow the signal over several days (several weeks for the brightest events). Rubin can localise precisely an event, assuming we can find it in the deluge of alerts!



Credit: D. Turpin

Goal: detection of fast fading on-axis GRB afterglows and slow-evolving off-axis GRB afterglows

Fink should enable at minimum:

- Online response to a query and ToO program
- Complementary observations (with the ground segment)
- Subthreshold analysis and post-processing

Three ongoing efforts

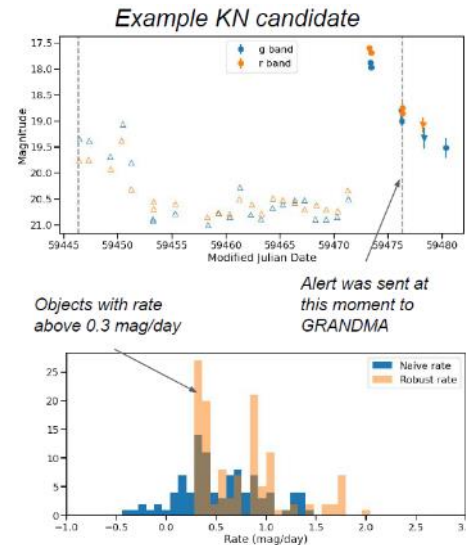
- Integration with SVOM – interoperability (lead D. Turpin)
- Orphan GRB afterglows detection in ZTF/Rubin (lead J. Bregeon)
- Modeling GRB (incl. orphans) & kilonova at Rubin scale (lead J.G. Ducoin)

Kilonova science

Difficulty: we have very little data to compare with... Fink has several ways to select likely kilonova candidates from optical data:

- Simple arguments (e.g. slope of the lightcurve)
- Machine learning based light-curve classification

- Contextual information (criteria on host galaxy, distance, absolute magnitude, etc.)
- All selected candidates are sent real-time to GRANDMA for potential follow-up.



Science with amateurs

Part of our mission is also to open astronomy to a larger community – larger than the professional astronomers. Thanks to GRANDMA, we participate to the Kilonova Catcher that brings professional astronomers and amateurs together to search for kilonovae. Each Friday, Fink sends its KN candidates to the amateur astronomy community so that follow-up observations can be performed over the week-end. Huge success so far, but a lot of challenges! Coordination, photometry, interpretation...

Fink Team - <https://fink-broker.org/members/>

ALeRCE

Paula Sánchez-Sáez¹, on behalf of the ALeRCE team : F. Förster; G. Cabrera-Vives; P. A. Estévez; P. Sánchez-Sáez; J. Arredondo; F. E. Bauer; R. Carrasco-Davis; M. Catelan; F. Elorrieta; S. Eyheramendy; P. Huijse; G. Pignata; E. Reyes; I. Reyes; D. Rodríguez-Mancini; D. Ruz-Mieres; C. Valenzuela; I. Álvarez-Maldonado; N. Astorga; A. Bayo; J. Borissova; F. Chabour; A. Clocchiatti; M. Contreras; R. Dastidar; D. De Cicco; C. Donoso-Oliva; M. J. Graham; L. Hernández-García; R. Kurtev; A. Mahabal; R. Molina-Ferreiro; A. Moya; A. Muñoz-Arancibia; W. Palma; M. Pérez-Carrasco; A. Papageorgiou; J. Pineda; P. Protopapas; M. Romero; L. Sabatini-Gacitua; A. Sánchez; J. San Martín; K. Sharma; J. Silva; E. Vera; J. R. Vergara; C. Ashall; A. Belinski; Th. de Jaeger; G. Folatelli; L. Galbany; S. González-Gaitán; N. Ikonnikova; A. Mourao; B. Safonov; N. Shatsky; A. Tatarnikov; D. Tsvetkov; O. Vozyakova; S. Zheltouhov

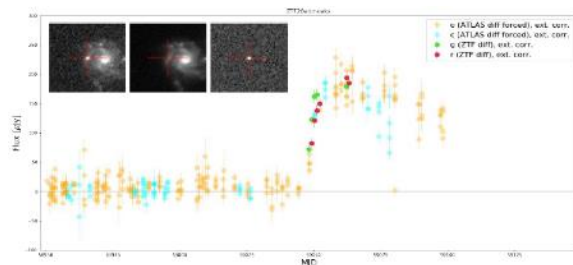
Session Classification: Vera C. Rubin Observatory: Alert brokers

¹Universidad de Chile

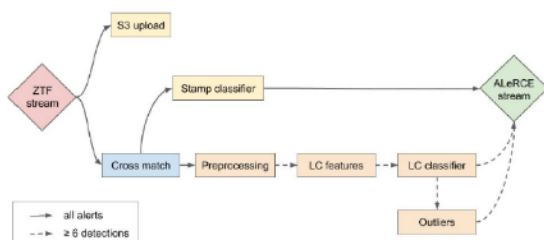
ALeRCE is a Chilean-led broker officially selected as one of the Community Brokers for the Vera Rubin Observatory and its Legacy Survey of Space and Time (LSST).

ALeRCE highlights

Ingesting the ZTF alert stream since early 2019. Bridging ZTF - ATLAS: Collaboration with ATLAS and Lasair, building multi-stream broker.



Modular pipeline in AWS, using Docker containers and scaling with Kubernetes.

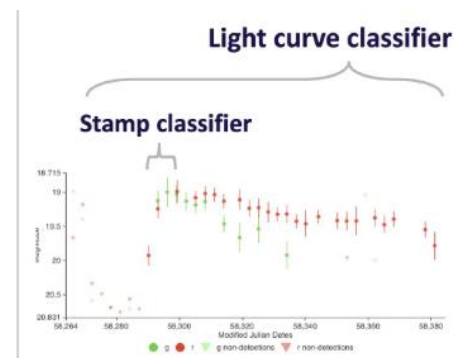


ALeRCE classifiers

Two machine learning classifiers:

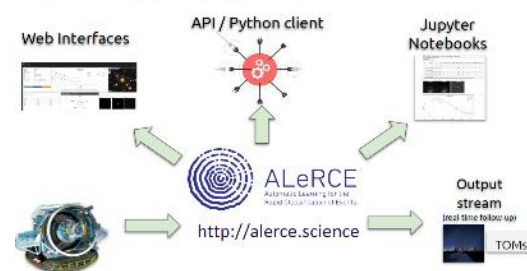
Stamp based (Carrasco-Davis+2021) (fraction of a sec.)

Light curve based (Sánchez-Sáez+2021) (few tens of secs.)



ALeRCE tools and services

ALeRCE tools and services



ALeRCE Explorer - <https://alerce.online/>

ALeRCE SN Hunter -

<https://snhunter.alerce.online>

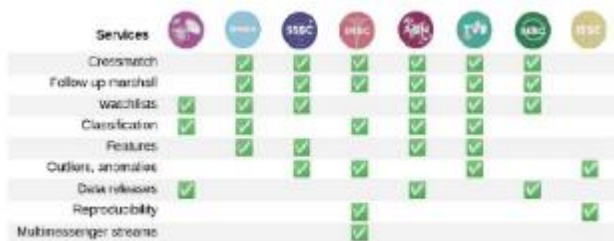
New features

Simple watchlist interface. Submit list of targets, explore and wait for notifications :
<https://watchlist.alerce.online>

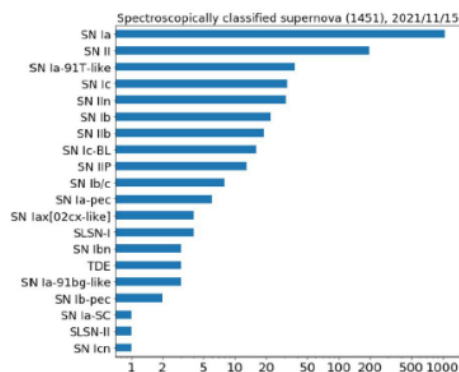
Integration with ZTF Data Releases. Enables outlier exploration: changing state AGN as outliers (Sánchez-Sáez+2021b) and study of outlier detection algorithms (Pérez-Carrasco, in preparation).

ALeRCE user community

ALeRCE tutorial workshop and LSST Enabling Science Broker Workshops (with FINK).
 Feedback from science collaborations, notebooks focused on science cases, 76 recordings available!
<http://workshops.alerce.online/>



User community from 125 countries!



Enabling spectroscopic follow-up of more than 1620 SNe via SN Hunter and TNS reports. More than 12700 early SNe candidates reported to TNS.

AMPEL

Jakob Nordin¹ & the AMPEL team

Session Classification: Vera C. Rubin Observatory: Alert brokers

¹Humboldt-Universität zu Berlin

AMPEL: An analysis platform as broker

AMPEL is a modular and scalable platform with explicit provenance tracking, suited for systematically processing large - possibly complex and heterogeneous - datasets in real-time or not. This includes selecting, analyzing, updating, combining, enriching and reacting to data.

AMPEL can be used to optimize future observations, provide autonomous real-time reactions to data streams as well as doing offline reruns of archived datasets.

AMPEL “consists” of:

- A core set of public libraries.
<https://github.com/AmpelProject/Ampel-core>
- Scientific analysis units contributed by users.
- A live instance hosted by DESY Zeuthen.

Standard Work-Flow: Limited Scalability

Projects in astronomy/astrophysics has traditionally followed a linear path:

1. Retrieve data
2. Run analysis software
3. Evaluate result

However, this workflow scales poorly with increasing data volume, data heterogeneity and more complex analysis schema. Summarized, in an era with near-infinite potential data combinations we cannot anymore first “retrieve data” and then “analyze”.

Code-To-Data

The established industrial solution in the “big data” era is to first produce tested and documented software which is then exported and exposed to data:

3. Define expected result
2. Develop and push software
1. Connect to data streams

This work methodology has been challenging to implement in astrophysics due to the typically splintered research environment. The AMPEL framework has been developed to fully enable Code-To-Data in the regime of time-dependent Astronomy and Astrophysics and provide an interface where the kind of (e.g. python) data workflows scientists develop can be exported, shared and executed on data streams.

Example: POSSIS kilonova search in LIGO

As a brief template for how this can work for a simple analysis we will use the development of a live pipeline for finding the optical counterpart (kilonova) belonging to a NS merger according to a particular model. We do this through going through the three “Code-To-Data” steps outlined above. Steps for repeating the analysis can be found here: <https://github.com/AmpelProject/Ampel-HU-astro/blob/v0.8.2-dev/examples/ligo-kilonova.yml>

3. Define expected result

Goal: Count all ZTF kilonova candidates compatible with an optical model.

Steps:

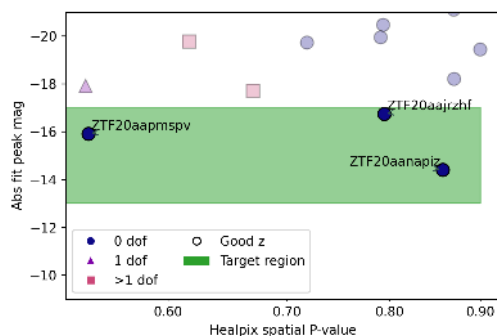
- Select all alerts within LIGO map

- Fit by POSSIS kilonova models
https://github.com/mbulla/kilonova_models
(replace with your favorite model)
- Select from intrinsic peak brightness

2. Develop and upload software

We here implement an analysis which we eventually would like to test on all potential GW counterpart transients:

1. Develop python interface class for POSSIS fit (allows AMPEL to execute fit):
<https://github.com/AmpelProject/Ampel-HU-astro/blob/v0.8.2-dev/ampel/contrib/hu/t2/T2RunPossis.py>



2. Perform local test based on sample data:
3. Distribute through e.g. github.
4. Notify the AMPEL ZTF live instance operators that a new unit is available for AMPEL to host.

1. Connect to data streams

In this final stage we trigger execution of the analysis unit. In this case we submit a manual trigger (through a particular skymap), but a real-time search would autonomously run this on new GW alerts :

1. Find (new) skymap (path)
2. Post path through API:

```
curl -X 'POST' \
  'https://ampel.zeuthen.desy.de/api/ztf/job/runpossis' \
  -H 'accept: application/json' \
  -H 'Content-Type: application/json' \
  -d '{
    "map": "https://gracedb.ligo.org/api/superevents/S200112r/files/LALInference.fits.gz",
    "channel": "my_program",
    "pvalue_limit": 0.9,
  }'
123456
```

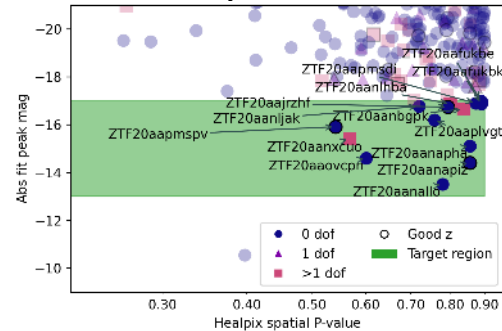
3. [await processing]

```
curl -X 'GET' \
  'https://ampel.zeuthen.desy.de/api/live/jobstatus/123456' \
  -H 'accept: application/json'
completed
```

4. Get result

```
curl -X 'GET' \
  'https://ampel.zeuthen.desy.de/api/live/job/123456/t3/HealpixCorrPlotter' \
  -H 'accept: application/json'
```

We can now inspect the result of the analysis carried out remotely at AMPEL:



In a real-time search, this output could be used for immediately selecting potential candidates for further follow-up.

Sample current projects

The AMPEL Code-To-Data processing framework is already in use for several large scale real-time science programs: Multi-messenger searches looking for counterparts to GWs or Neutrinos, searches for nearby supernovae or rare objects (e.g. TDES), automatic triggers of follow-up telescopes or where large, consistently created transient samples are investigated:

Summary and Further information

AMPEL is now operating as the first Code-To-Data platform in astronomy, and will in the future process multi-messenger data from all large observatories, which will be processed by custom analysis schema designed by user groups.

To explore the code:
<https://ampelproject.github.io/>
Try it out:
<https://github.com/AmpelProject/Ampel-contrib-sample>

For other questions, contact us at: ampel-info@desy.de, jnordin@physik.hu-berlin.de
Reference: Transient processing and analysis using AMPEL: alert management, photometry, and evaluation of light curves, Nordin et al, A&A 631, A147 (2019)

Lasair

Roy Williams¹, Ken Smith², Stephen Smartt², Andy Lawrence¹, Gareth Francis¹

Session Classification: Vera C. Rubin Observatory: Alert brokers

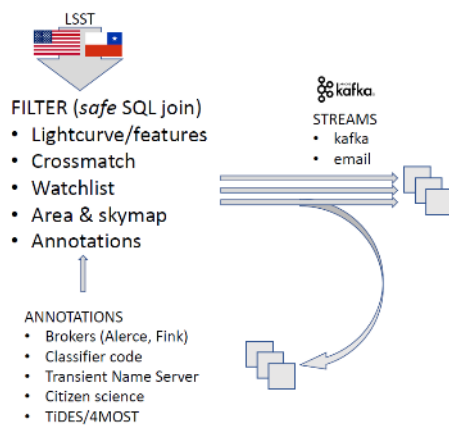
¹University of Edinburgh, ²Queen's University Belfast

Time for Streaming Data (instead of running queries) Send email when a property satisfies my query

Lasair Concepts

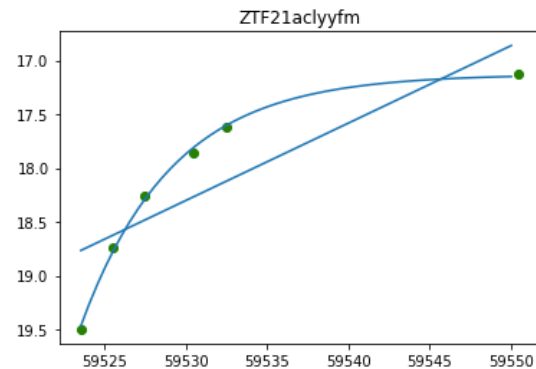
CONTROL

- Web
- API
- Streams
- Notebook
- Mining
- Sharing



Lightcurve Features

Example: curve fitting for rapidly emerging transients



Crossmatch

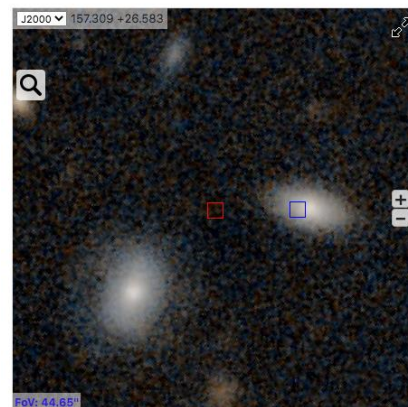
Sherlock

- Classified as SN, at 10.11 arcsec.
- Best crossmatch is galaxy
- The transient is possibly associated with [SDSS J102915.05+263508.6](#); a J=15.28 mag galaxy found in the SDSS/2MASS/PS1 catalogues. Its located 0.02" S, 10.25" E from the galaxy centre.

TNS

- TNS name is AT [2021adpp](#)
- discovered by ALeRCE
- discovery magnitude 20.8156

PanSTARRS



Watchlist example

Choose alerts from likely TDE galaxies (Nichol and Arcavi)

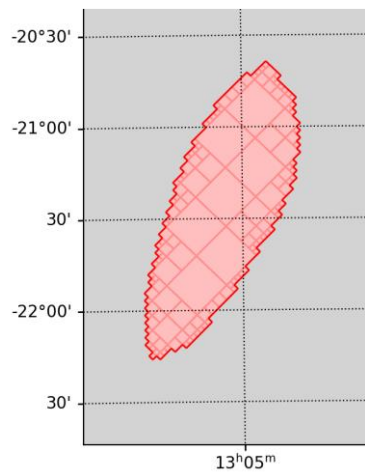
<https://arxiv.org/abs/1810.09507>

Lasair Sky Area

- Upload a MOC
- Can make MOC from Healpix contours
- Events in the area are tagged

GW170817

10% inner contour



Annotations

- Copy of Fink “early SN”

fink_early_sn

```
SELECT /* MAX_EXECUTION_TIME(300000) */ objects.objectId, fink_early_sn.timestamp,
fink_early_sn.classdict FROM objects, annotations AS fink_early_sn WHERE
objects.objectId=fink_early_sn.objectId AND fink_early_sn.topic="fink_early_sn" ORDER BY
fink_early_sn.timestamp DESC LIMIT 1000 OFFSET 0
```

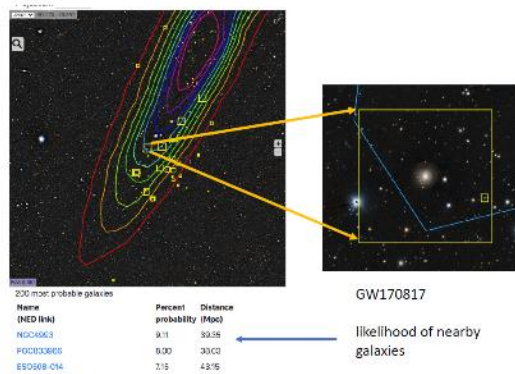
- Alerce classifications
- “Fastfinder” classifier

Fastfinder

```
SELECT /* MAX_EXECUTION_TIME(300000) */ objects.objectId, fastfinder.timestamp,
fastfinder.classdict FROM objects, annotations AS fastfinder WHERE
objects.objectId=fastfinder.objectId AND fastfinder.topic="fastfinder" ORDER BY
fastfinder.timestamp DESC LIMIT 1000 OFFSET 0
```

Skymaps

- area tag for 90% contour
- likely galaxies
- GW, neutrino, gamma, ...



Pitt-Google

Troy Raen¹ on behalf of the Pitt-Google Collaboration

Session Classification: Vera C. Rubin Observatory: Alert brokers

¹University of Pittsburgh

Pitt-Google broker will be a full-stream alert broker for LSST. We are currently running the ZTF alert stream and planning to run gravitational wave alert streams. We add value to the alerts (e.g., SNe Ia classifications) and publish/store to the Google Cloud Platform services Pub/Sub (streaming message service), BigQuery (data warehouse with SQL access) and Cloud Storage (object store). All data is available to pull/query in real-time via APIs, with latencies around one second. During the MMA workshop, I (Troy Raen) presented a process by which users will be able to listen to a gravitational wave stream and trigger their own real-time analysis of LSST data in search of an event's electromagnetic counterpart. The search can immediately look both forward and backward in time. Users can compute next to the data with minimal infrastructure management using (e.g.,) Google Cloud Run which includes automatic scaling and fault tolerance.

Researchers are often concerned about the cost of cloud computing, and similar concerns were raised during this workshop. I presented a cost estimate for my example user-analysis process which totaled approximately \$800 per year. This allows for a relatively large amount of data every night: processing 10^5 LSST-sized alerts, querying 250 GB of data, and egress of 10^3 LSST-sized alerts (US to Europe). Cloud computing can greatly reduce the workload required to implement scientific analyses since the majority of infrastructure management can be handled by the cloud provider. However, organizational budgets will need to evolve. Currently, many are scoped to pay their own employees to perform these tasks, but are not scoped to pay a cloud provider.

An example of Real-time user analysis of MMA streams

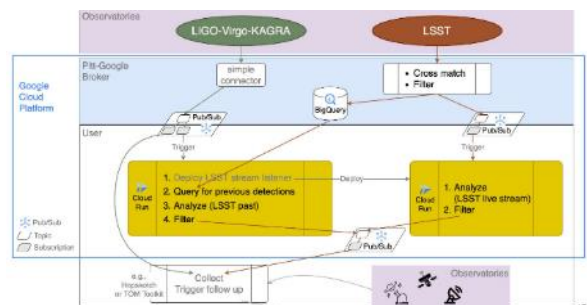
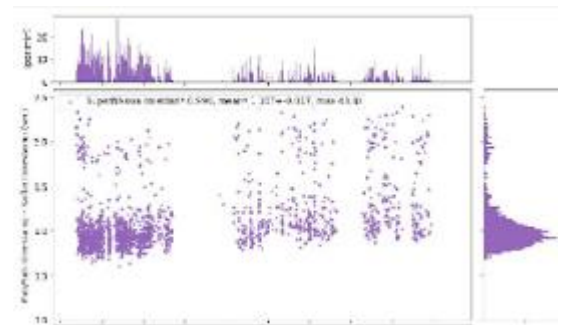
Low-Latency Processing

Time delta between:

- ZTF alert production at IPAC (Kafka timestamp)
- Pitt-Google message production after processing thru the indicated module (Pub/Sub timestamp)

SuperNNova classification

- ~1 sec median latency
- Includes transfer from ZTF, ingestion to Pitt-Google, and 2 previous pipeline modules (running on Cloud Functions)



<https://pitt-broker.readthedocs.io/en/latest/>

Annex 1 – Infrastructures table

Probe	Field of View (°)	Angular resolution (°)	Sky localization (deg ²)	Slew speed (°/min or hrs)	Survey speed (daily of sky coverage)	Observatory alert response time (min or hrs)	Community alert processing time (min or hrs)	Energy band (eV)	Sensitivity (erg/s/cm ²)	v-band GW (Hz)	Real Time Analysis tool (Y/N)	Data analysis Tool (url)	Date of start of data taking	Date of projected end of data taking
XMM-Newton					1°/ day	~hrs	~days				N	https://www.cosmos.esa.int/web/xmm-newton/sas	3 feb 2000	2032
- EPIC-MOS	0.5	0.0015	~0.0003	90°/h	~1°/ day			200-12000	1e-15 (0.2-12 keV)					
- EPIC-PN	0.5	0.0015	~0.0003	90°/h	~1°/ day			200-12000						
- RGS	1 source	-	~0.0003	90°/h	~1°/ day			200-12000						
- OM	<0.15 – depends on mod	~0.0004	<0.00001	-	~0.2°/day			~12, ~6, ~4, ~3, ~2.5 ~2	~23 mag					

	e													
ATHENA														
- WFI	40'x 40'	< 5 arcsec		?	-	4h	?	0.1 – 15 keV	3x10 ⁻¹⁷ erg/s/cm ²	-	-	-	2034	?
- X-IFU	5' dia mete r	< 5 arcsec		?	-	4h	?	0.3 – 10 keV	3x10 ⁻¹⁷ erg/s/cm ²	-	-	-	2034	?
Polar-2	Half the sky	N.A.	~degrees (for 10 ⁻⁵ erg/s/cm ² events)	N.A.	Full sky	minute s	minutes	8'000 - 2'000 '000 (8 keV- 2 MeV)	10 ⁻⁷	N.A.	Y (data availa ble withi n day)		Early 2025	2028
INTEGRAL				2 deg/m in		3 hours	12 hours					https://www.astron.uni-erlangen.de/data/	17/10/2002	TBD
- OMC	5x5	0.01						V band	16 mag		N			
- IBIS	20x20	0.05						20- 2000 keV	1e-12 (in 1 day)		Y			
- JEM-X	7.5	0.02						3-30 keV	1e-11 (in 1 day)		N			
- SPI	30x3	2.8						20-	1e-11 (in 1		N			

	0							4000 keV	day)					
-SPI-ACS	AllSky	N/A						75-2000 keV	3e-7 (in 1 s)		Y			
- IBI S-Veto	AllSky	N/A						75-2000 keV	3e-7 (in 1 s)		Y			
SVOM	Partly described in https://arxiv.org/abs/1610.06892													
AGILE		*depends on energy and off-axis angle	**depends on sky region and S/N level	NA	~ 80%	NA	~ 25 min after TM download		*** depends on exposure and energy: GRID: $E > 100 \text{ MeV}$, 5° in 10^6 s ; SA: 18–60 keV, 5° in 1 day	NA	Y		ongoing (since 23/4/2007)	(at least) up to May 2023
- GRID	~ 2.5 sr	~ 1.2° @400 MeV	~ 15 arcmin					30 MeV - 50 GeV	$3 \times 10^{-7} \text{ ph cm}^{-2} \text{ s}^{-1}$			https://agilepy.readthedocs.io/en		

												/latest/ https://agile.ssdsc.asi.it/publicsoftware.html		
- MCAL	4π	NA	NA					0.3–50 MeV						
- SA	~ 1 sr	~ 6 arcmin	~ 2 -3 arcmin					18–60 keV	15 mCrab					
- AC Sys	4π	NA	NA					80–200 keV						
Fermi														
- LAT	2.4 sr	<0.15deg, on-axis, 68% space angle containment radius for $E > 10$ GeV; < 3.5deg on-axis, 68% space angle containment radius for $E = 100$ MeV	<0.5 arcmin for high-latitude source	-- --	Whole sky coverage in ~ 90 min, in nominal operation mode	-- --	Minutes for automated alert system, few hours for human-based follow up	20 MeV up to >1 TeV	Sensitivity limit depends on the region of the sky and on the hardness of the spectrum. <6x10 ⁻⁹ ph cm ⁻² s ⁻¹ for $E > 100$ MeV, 5 σ detection after 1 year sky survey	2.4x10 ²¹ Hz to 2.4x10 ²⁵ Hz	Y	Several resources, see e.g. https://fermi.gsfc.nasa.gov/sc/data/access/	2008-08-04 15:43:36 UTC	Depends on NASA Senior review, approval required every 3 years. Next review planned in 2022.

		(single photon)												
- GBM	>8sr	Initial GRB Alert location ~15 deg	<15deg. Thanks to improvements it may be reduced to ~2deg to ~4.4 deg	--	Whole sky every ~90min	-- --	Minutes for automated alert system, few hours for human-based follow up	~10keV up to ~20 MeV	< 0.5 cm ⁻² s ⁻¹	2.4x10 ¹⁸ Hz up to 2.4x10 ²¹ Hz	Y	Several resources, see e.g. https://fermi.gsfc.nasa.gov/sc/data/access/	2008-08-04 15:43:36 UTC	Depends on NASA Senior review, approval required every 3 years. Next review planned in 2022.
H.E.S.S.	5°(3.2° for CT5)	~0.08° @ 1 TeV (energy dependent and event-reconstruction dependent)	-	1.7°/s (3.3°/s for CT5)	-	<1 min	<24h	~0.1-100 TeV (Threshold is zenith angle and moon illumination dependent)	~10 ⁻¹² @ 1 TeV (50h exposure, energy dependent)	-	Y	-	2003 (CT1-4) (2012 for CT5)	TBD

MAGIC	3.5°	~0.08° @ 1 TeV (energy dependent and event-reconstruction dependent)	-	4-7°/s	-	<1 min	<24h (Best case is 4 hrs for GRB190114C)	~0.1-100 TeV (Threshold is zenith angle and moon illumination dependent)	~10 ⁻¹² @ 1 TeV (50h exposure, energy dependent)	-	Y	-	2004 (2009 in stereo)	TBD
VERITAS	3.5°	~0.08° @ 1 TeV (energy dependent and event-reconstruction dependent)	-	1°/s	-	<1 min	<24h	~0.1-100 TeV (Threshold is zenith angle and moon illumination dependent)	~10 ⁻¹² @ 1 TeV (50h exposure, energy dependent)	-	Y	-	2007 (2009 array reconfigured)	TBD

CTA		~0.05 @1TeV https://www.cta-observatory.org/science/ctao-performance				Goal : <min	Goal : ~20 s Bulgarelli, A. et al,PoS(ICR C2021)937	t)	5 10 ⁻¹¹ @1TeV, 30min obs https://www.cta-observatory.org/science/ctao-performance		See Bulga relli, A. et al,PoS (ICR C2021)937	https://gamma-astro.org/		
- SST	10.5		-	60	-			5- 300T eV		-	Y			
- MST	7.5- 7.7		-	90	-			150G eV- 5TeV		-	Y			
- LST	4.3		-	30	-			20- 150G eV		-	Y			
KM3NeT														
- ORCA	4pi	Track: 7° at 10 GeV, 3-4° at ~50 GeV, 1° at >1 TeV Cascade: at 10 GeV, 3-4° at ~50 GeV, 2° at >10 TeV			Instantan eous	~10s	~15min	3 GeV - 5 TeV			Y	Not publi c yet	2019	
- ARCA	4pi	Tracks : 0.2° at 10 TeV, 0.1° a 100 TeV, 0.06° at 10			Instantan eous	~10s	~15min	200 GeV - 10 PeV	6-8 10 ⁻¹² erg/cm2/s for 3 yrs in ARCA		Y	Not publi c yet	2020	

		PeV Cascades : 2.5° at 10 TeV, 1.5° at 100 TeV,												
IceCube	All sky	Resolutio n for track events at declinatio n delta=0 and E=100 TeV: 20 arcmin		--	--	<1min	<1min (for GW events)	100G eV – 10 PeV	Peak sensitivity at declination delta=0 (E^- 2 spectrum, 90%CL) : 8*10^-13 erg/cm^2/s	--	Y	--	Data taking with partial detector since May 2006, full detector since May 2011	
IceCube- Gen2	All sky	Resolutio n for track events (delta=0, E=100 TeV): 10 arcmin		--	--	<1min	<1min	1TeV – 10 EeV	Peak sensitivity at declination delta=0 (E^- 2 spectrum, 90%CL) : 1.6*10^-13 erg/cm^2/s	--	Y	--	2029 (partial), 2034 (full detector)	
Pierre- Auger Observatory														
- SD	2 pi sr (one hemi sphe re)	Depends on N _{stations} and shower inclinatio n; typical: <		Does not apply (s. FoV)	Does not apply (s. FoV)	~15 mins	~15 mins	10^1 7..10 ^21		Does not apply	Y (→ strea m of quick ly analy zed	«Offli ne»(n ot publi c)	01.01.200 4	unknown

		1									subthreshold events to AMON)			
- FD	2 pi sr (one hemisphere)	Depends on shower lever arm; typical: 0.5		Does not apply (s. FoV)	Does not apply (s. FoV)	no alert systems active. Feasible: ~minutes	no alert systems active. Feasible: ~minutes	$10^{18..10^{21}}$		Does not apply	N	«Offline»(not public)	01.01.2004	unknown
- HEAT-FD	2 pi sr (one hemisphere)	s. FD		Does not apply (s. FoV)	Does not apply (s. FoV)	no alert systems active. Feasible: ~minutes	no alert systems active. Feasible: ~minutes	$10^{17..10^{19}}$		Does not apply	N	«Offline»(not public)	September 2009	unknown
LIGO										20-5000			Start O4 Observing Run in March 2023	
VIRGO										20-5000			Start O4 Observing Run in March 2023	
KAGRA										20-5000			Start O4 Observing Run in March	

													2023	
ET													2036	

References:

<https://www.mpi-hd.mpg.de/hfm/HESS/>

<https://magic.mpp.mpg.de>

<https://veritas.sao.arizona.edu>

<https://www.cta-observatory.org/science/ctao-performance>

Annex 2 – Tools & platforms table

Platform/ Software	Alert type (BBH, SN, GRB analysis, etc.)	Alert provider (s), if different .	Informat ion publicly available (Y/N)	Distributed information						Alert emiss ion latenc y (sec)	Coinc idenc e analy sis time (sec)	Alert format	API available (if yes, specify)	Code source for the processin g available (url)	Web interface (url)
				Locali zation (deg ²)	Image (Y/N)	Spectr a (Y/N)	Time series (Y/N)	Distan ce (Y/N)	Other informati on? Specify						
Follow-up observatories & consortia															
DWF (coordinated all-wavelength and particle search, detection, and follow-up observing program)	All milliseco nd-to- days duration sources at all wavelen gths	-	Y/N (some days/we eks-long transient s are publicly reported . Howeve r, sub- day transient s	Multi ple - from sub- arcsec to ~deg, depen ding on radio, mm, IR, optica	Y	Y	Y	Y (for subset with approp riate spectra)	Simultan eous wide- field multiple waveleng th imaging and detection observati ons. Coordina ted	Varie s minut es to days.	-	-	No	No	No

			typically are not, with some reported later, after their fast burst e.g., FRBs)	l, UV, X-ray, gamma-ray, or high-energy particle facility					rapid-response (sec/min) and conventional (hr/day) ToOs, and late-time follow up. Spectra include IFU and other formats.						
GRANDMA	GW/Neutrino EM counterpart		N	arcsec	N	N	N	N	CFHT data for ToO publicly available	-	-	VOEVENTs	yes	https://gitlab.in2p3.fr/icare	https://skyportal.io/
ENGRAVE	Primarily responding to BNS and NSBH nearby kilonova candidates, although other targets,	Primarily responding to wide area GW triggered searches.	Results publicly announced. Data available from observatory archives (esp. ESO archive)	Only targeting arcsec - localised sources.	Y	Y	Y	Y		N/A	N/A	GCN free format	No	Yes for pipeline reduction codes.	http://www.engrave-eso.org

	and KNe found in blind surveys if strongly motivated														
Vera Rubin Observatory brokers															
FINK	Incl. Solar System objects, variable stars, microlensing events, supernovae & core collapse, GRB, ...	ZTF, Rubin (future)	Y	1e-6 deg ² (arcsec scale)	Y	N	Y	N	Classification label, closest known object, machine learning scores from user-defined analyses.	1-2 minutes after ZTF processing.	Variable (from few minutes to hours).	Apache Avro (default), voevent (on-demand)	Yes REST: https://finkportal.org/api Livestream: https://finkbroker.readthedocs.io/en/latest/fink-client/	https://github.com/astrolabsoftware	https://finkportal.org/
ALeRCE		ZTF-ATLAS	Y	5.5e-7	Y	N	Y	N	ML classification of ZTF alerts	~10	n/a	Avro, web interface, email, DB	Yes, more details in http://api.alerce.online/ztf/v1	https://github.com/alercebroker	http://alerce.science https://alerce.online https://snhunter.alerce.online

															ne
AMPEL	User configured. Most frequent: SNe, GW/Neutrino counterparts.	User configured.	Y	Y	Y	(Not yet).	Y	Y	Model fits (user configured).	~60s	User configured.	User configured.	yes. Archive: https://ampel.zeuthen.desy.de/api/ztf/archive/docs . Live: https://ampel.zeuthen.desy.de/api/live/docs .	Yes. https://github.com/AmpelProject/	Mainly API driven. https://ampelproject.github.io/astronomy/ztf/index#services
Lasair	All	ZTF (LSST)	Y		Y		Y	Y		15 min			Yes		Lasair.roe.ac.uk
Pitt Google	ZTF	ZTF	Y		Y	N	Y	N		1		Avro, JSON	Y Google Cloud APIs and pittgoogle-client	https://github.com/mwvgroup/Pitt-Google-Broker	in development
General tools & consortia															
ISDC	See INTEGRAL table														
SNEWS 1.0	SN	Aso forwarded by GCN	Y	In some cases; hemisphere	N	N	In some cases	N		Minutes to hours	Few	json and API for parsing	Y but not public	N/A	N/A

				to few degrees											
SNEWS 2.0 (future)	SN	SCIMM A/Hops kotch	Y	In some cases; hemis- phere to few	N	Possi- ble	Y	Y		Sec- onds to hours	TBD	json and API for parsing	Will be, TBD	TBD	TBD
AMON	Multime- ssenger neutrino + gamma rays		Y	0.314	N	N	N	N	False alarm rate	<2160 0sec	~1sec	Emails, GCN notices	Y (pygcN)	https://git hub.com/ AMONC ode/Anal- ysis	https://a montom. science.p su.edu
Astro-COLIBRI	GW, neutrino s, GRBs, SNe, OTs, FRBs, etc.	GCN, TNS, VoEvent brokers, AMON	Y	Depen- ding on the alert	N	N	N	Y	Cone searches + links to other platforms + visibility	<1s	n.a.	Smartphon- e notificatio- ns (FCM)	Yes Cf. https://astr- o- colibri.hero- kuapp.com /document- ation	n.a.	https://as- tro- colibri.co m
Gammapy															
Cyber infrastructures															
ESCAPE-ESAP	N/A	N/A	Depends on provider	N/A	N/A	N/A									