The LVK Alert System and the use of IVOA standard.

DISCLAIM: I am not speaking on behalf of the LVK collaboration

Roberto De Pietri, University of Pama. (Member of the Virgo Collaboration and cochair of the LowLatency group)

Preliminary consideration

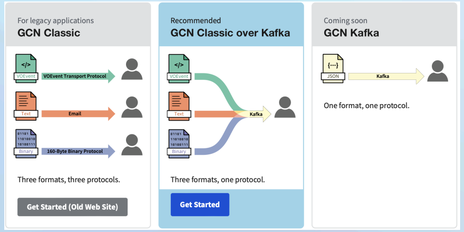
DISCLAIM: I am not speaking on behalf of the LVK collaboration

- **The IVOA standard used by the LVK collaborations**
  - **VOEventTransport** https://www.ivoa.net/documents/VOEventTransport/20170320/index.html
  - **VOEvent** https://www.ivoa.net/documents/VOEvent/20110711/index.html
  - **MOC** https://www.ivoa.net/documents/MOC/20220727/index.html
- **In the "User Guide," we have a complete reference to the following tools and technology**
  - The **ALADIN** IVOA tool [See our User Guide], **MOC** and **HiPS** standard.
  - The use of FITS Format for **Multi-Order Sky Maps** [See our User Guide]. That it is based on MOC standards enriched with additional information.

Timing and Kind of LVK Public Alerts

Alerts provided by the LVK collaboration

- VOEvent using GCN Classic
- kafka-JSON Alerts using GCN - KAFKA
- Kafka-avro Alerts using hopskotch services provided by SCiMMA



https://gcn.nasa.gov/

HOPSKOTCH

https://scimma.org/

- **EarlyWarning** **Associated to EW pipeline**

— Trigger time —

- **Preliminary (1)** **median latency ~30s**
- **Preliminary (1a)** **in case of new significance**
- **Preliminary (2)** **final in ~320s**

— Rapid Response team decision —

- **Initial/Retraction Alert**
- **Update (1)**

Complete information in the UserGuide

The false alarm rate threshold for public alerts is **2/day** (on the FAR reported by the pipeline).

Significant gravitational-wave alerts with false alarm rate less than 1/month for CBC and 1/year for bursts that pass automated and **manual verification tests**. All other alerts have low-significance.

The thresholds on the reported pipeline FAR are indeed:

CBC **1/(6 months)** – trial factor six

BURST **1/(3 years)** - trial factor three

The pipeline FAR based thresholds may change if we change the active pipelines.

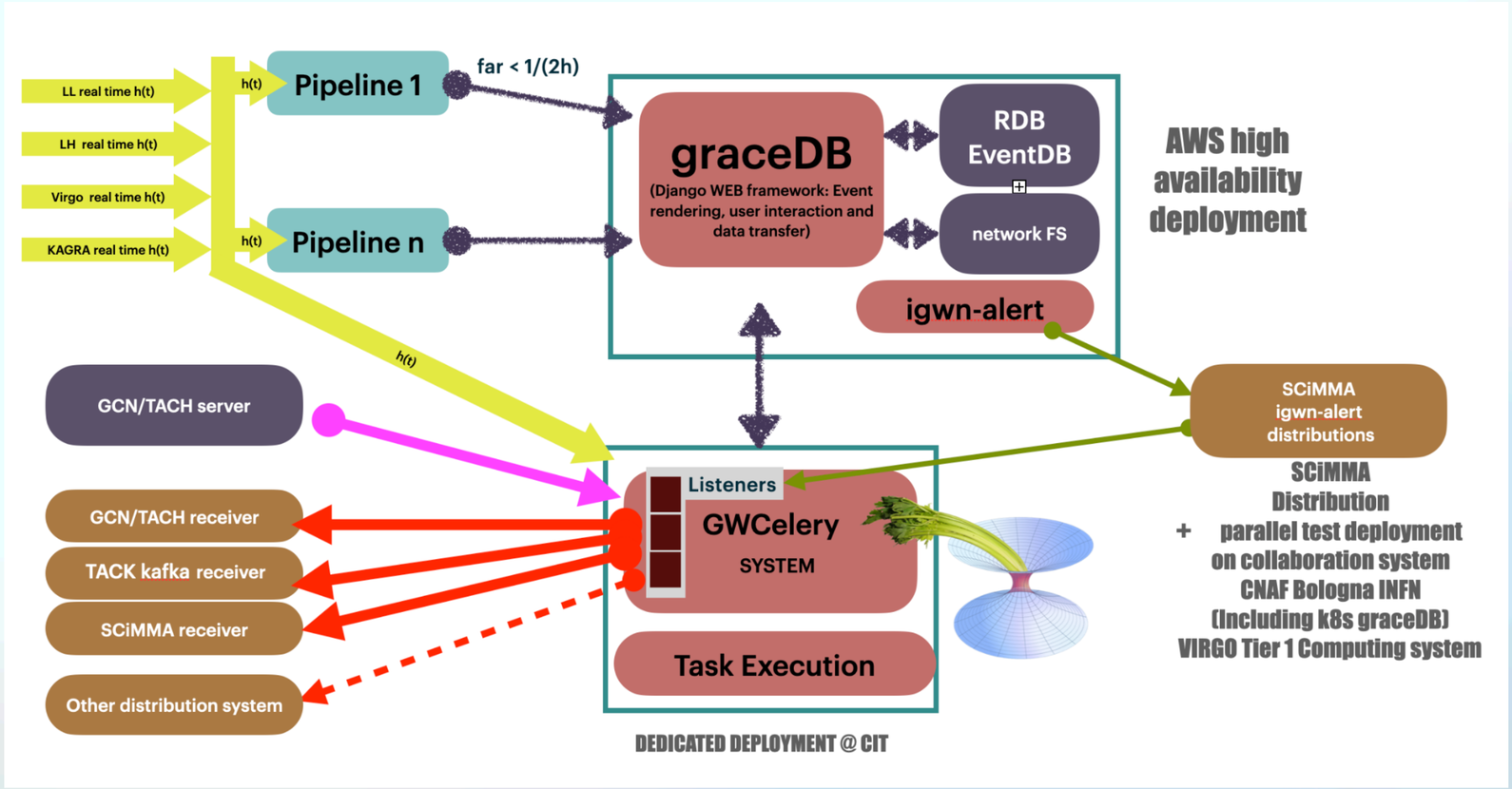
Only for sigificant Alerts

Preliminary (3) for - S230831e 23.9s – 36.9s – 314.9s

The LVK Low Latency Architecture

The components are distributed all around the world....

- Analysis Pipeline operated in different data centers (Euro/USA) on h(t) data transferred from the observatory using Kafka
- Trigger data are uploaded using internal LVK format to a centralized database deployed in AWS
- Triggers are elaborate and enrinched on a dedicated system (GWCelery) deployed at Caltech. The system:
  - Receive information on DBChange using SCiMMA infrastructure and **VOevent** from the GCN/TACH server (mainly using the legacy GCN system 'VOEventTransport' and some kafka-JSON private chanels)
  - Send out allert using:
    (1) Legacy GCN services (**VOEvents**)
    (2) GCN JSON Notices
    (3) Avro encoded alerts usining SCiMMA infrastructure



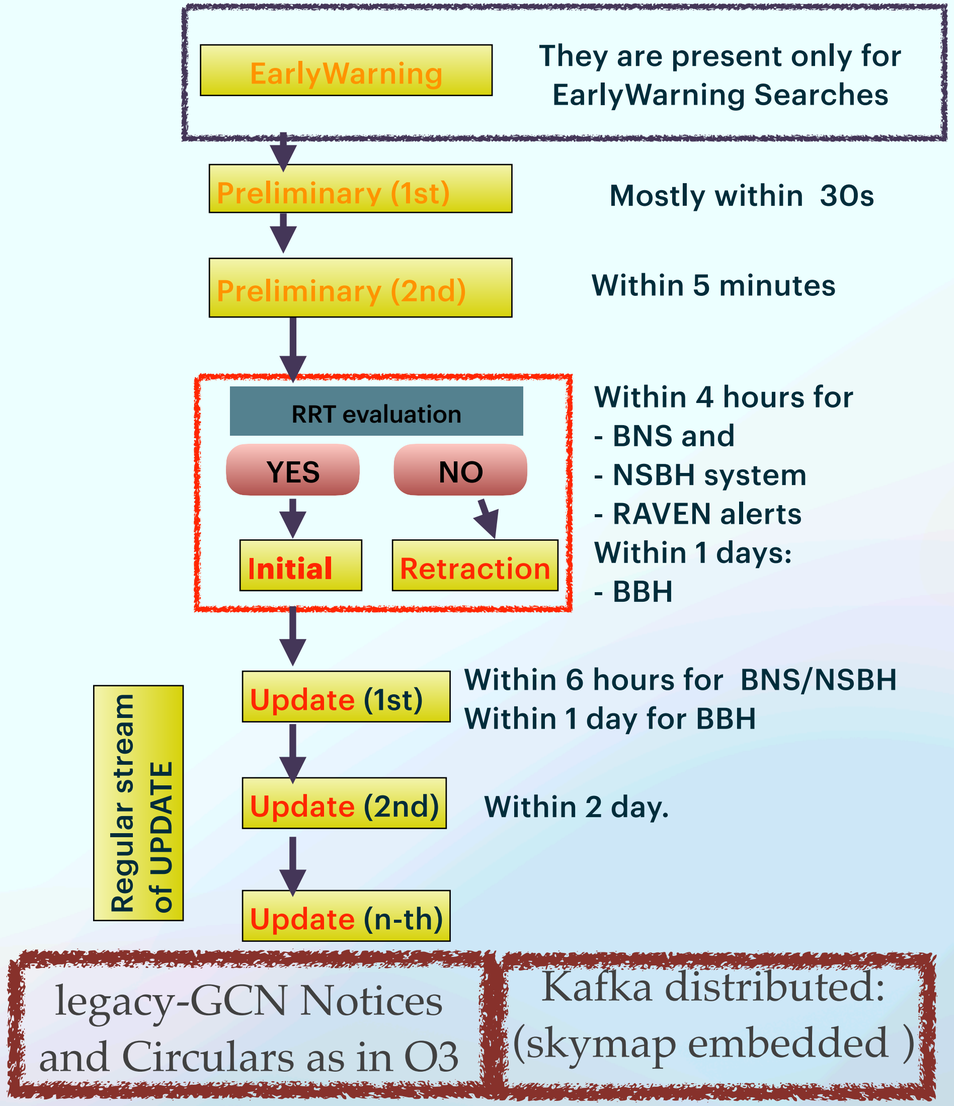
Information in the Alerts

VOEvents + non-standard-ones sent using kafka

The VOEvent of the alert provide the following information:

- **SKYMAP_FITS_URL**: Localisation information using the multi-order fits format (no-flatten) since it is NOW supported by VO-standards
  - The name of the file will include the **SEQUENCE_NUM**
  - The first early waring alert will be without localisation information.
- **FAR**: The False Alarm Rate (i.e.,
- **GROUP_TYPE**, **SEARCH_TYPE**, **PIPELINE_TYPE**: (Relative to the trigger that was used to determine the localisation information)
- Search pipeline based probabilities p-astro probabilities: **PROB_BNS**+ **PROB_NSBH+PROB_BBH**+**PROB_TERRES**=1.0
- EM-Bright probability: Rapid source properties parameter estimations PROB_NS (0...1), PROB_REMNANT(0...1), PROB_MassGap (0..1)

SEQUENCE_NUM and **SKYMAP_FITS_URL** are not provided for the other format while the skymap is embedded in the alerts using an enerched MOC format enchapsuled using the multi-order fits format provided by bayestar



Complete information in the UserGuide

EXAMPLE HERE: https://gracedb.ligo.org/apiweb/superevents/S241113p/files/S241113p-1-Preliminary.xml,0


```
<voe:VOEvent xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:voe="http://www.ivoa.net/xml/VOEvent/v2.0"
xsi:schemaLocation="http://www.ivoa.net/xml/VOEvent/v2.0 http://www.ivoa.net/xml/VOEvent/VOEvent-v2.0.xsd" version="2.0"
role="observation" ivorn="ivo://gwnet/LVC#S241113p-1-Preliminary">
```


Not much use of it, yet.

FITS Format for Multi-Order Sky Maps

Define a new format for defining enriched MOC data?

- Clever extension of the **fits** format to provide muti-resolution information about full-sky.
- It is not yet a standard, but it has extended support from Python libraries, ALADIN, and astropy. A new IVOA standard?
- A significant advance for very well-localized GW observations.
- It will be the standard for skymap distribution from the LVK collaboration and, in O5, it will be the only used format.

```
$ fitsheader bayestar.multiorder.fits
# HDU 0 in bayestar.multiorder.fits:
SIMPLE  =                    T / conforms to FITS standard
BITPIX  =                    8 / array data type
NAXIS   =                    0 / number of array dimensions
EXTEND  =                    T

# HDU 1 in bayestar.multiorder.fits:
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / array data type
NAXIS   =                    2 / number of array dimensions
NAXIS1  =                   40 / length of dimension 1
NAXIS2  =                19200 / length of dimension 2
PCOUNT  =                    0 / number of group parameters
GCOUNT  =                    1 / number of groups
TFIELDS =                    5 / number of table fields
TTYPE1  = 'UNIQ      '
TFORM1  = 'K         '
TTYPE2  = 'PROBDENSITY'
TFORM2  = 'D         '
TUNIT2  = 'sr-1      '
TTYPE3  = 'DISTMU    '
TFORM3  = 'D         '
TUNIT3  = 'Mpc       '
TTYPE4  = 'DISTSIGMA'
TFORM4  = 'D         '
TUNIT4  = 'Mpc       '
TTYPE5  = 'DISTNORM'
TFORM5  = 'D         '
TUNIT5  = 'Mpc-2     '
```

The array of the identifier of the cells that are in the MOC maps

A series of values associated with each cell of the MOC maps

The problem with VOEvent

—- not a data fiels for skymap ——

- There needed to be a more straightforward way to distribute **Skymap** (multiorders fits files) using the VOEvents xml-format.

- Request to include the **embedded** localization information inside the Alerts packets to avoid the need to download localization information from a file server. We face the same issue in integrated (in the RAVEN pipeline) external localization from SWIFT/Fermi/.. alerts to produce joint coincidence alerts.

- **Solution**: create two parallel streams of data (using a not-standardized format) that provide **embedded Skymap** into the alert packets. **Problem:** not a standard format for the packets.

VOEvents in the O5 LVK Alerts ?

Discussion items have already started inside the LVK collaboration.

- **PREVIOUS TALK ABSTRACT**: In this talk, I will present the status of the migration from the legacy GCN Classic system to the new GCN, recent and upcoming features, the GCN JSON Notices schema and relationship to VOEvent, and the status of onboarding new observatories.

- **IMPLICATION 1**: We are starting listening (even in O4) private GCN streams based on “GCN JSON Notices”.

- **IMPLICATION 2**: In the LVK (during the break between O4 and O5), we will discuss how we will distribute alerts and the format and what will be provided in the O5 observing run. It seems we will not follow “VOEvent Transport Protocol Version 2.0” but perhaps use kafka-based transport: GCN-Kafka and/or SCiMMA or, perhaps, a **“VOEvent Transport Protocol Version 3.0”** if it is defined!

VOEvent standard issues

Very nice but difficult to use in real life

- Scientists are not computer science experts; most people involved in developing tools, data analysis software, and processing alerts are graduate students and early career scientists.

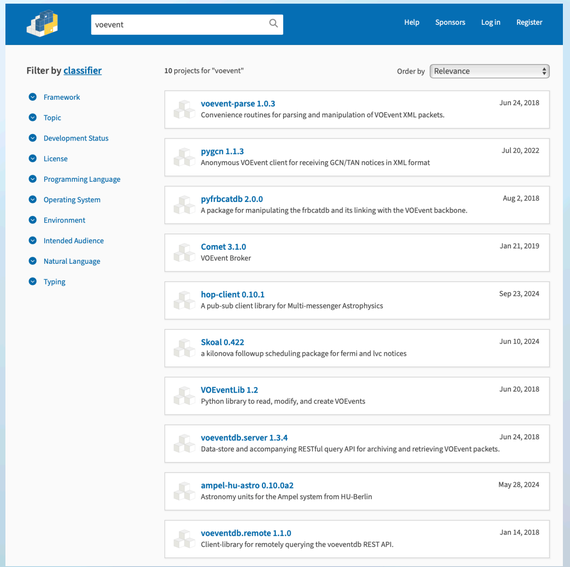
- Most of the software is developed in Python, and there are no easy tools to read VOEvents, convert them into Python data, or create VO events from Python data.

- How the alert distribution service will deal with this standard needs to be more transparent, and a reference library needs to be associated to teh standard.

- Support of VOEvent into **astropy** needed for wide adoptions.

- **Expand it to include localization information.**

SEARCH RESULTS FROM PYPI



Conclusion

LVK will create a new Alet System after the end of o4 (June 2025)

- We have yet to decide on the transport mechanism that will be used to distribute alerts.
- Need to send localization embedded in Alert Packets
- Need to receive Alert Packets (from other “observatories”) that include localization information
- We would love a standard (an IVOA one?) to transmit and receive alerts.
- The collaboration would try to distribute the alerts to any infrastructure that would maximize the scientific output coming from our observation.