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Low-Latency analysis and alert update

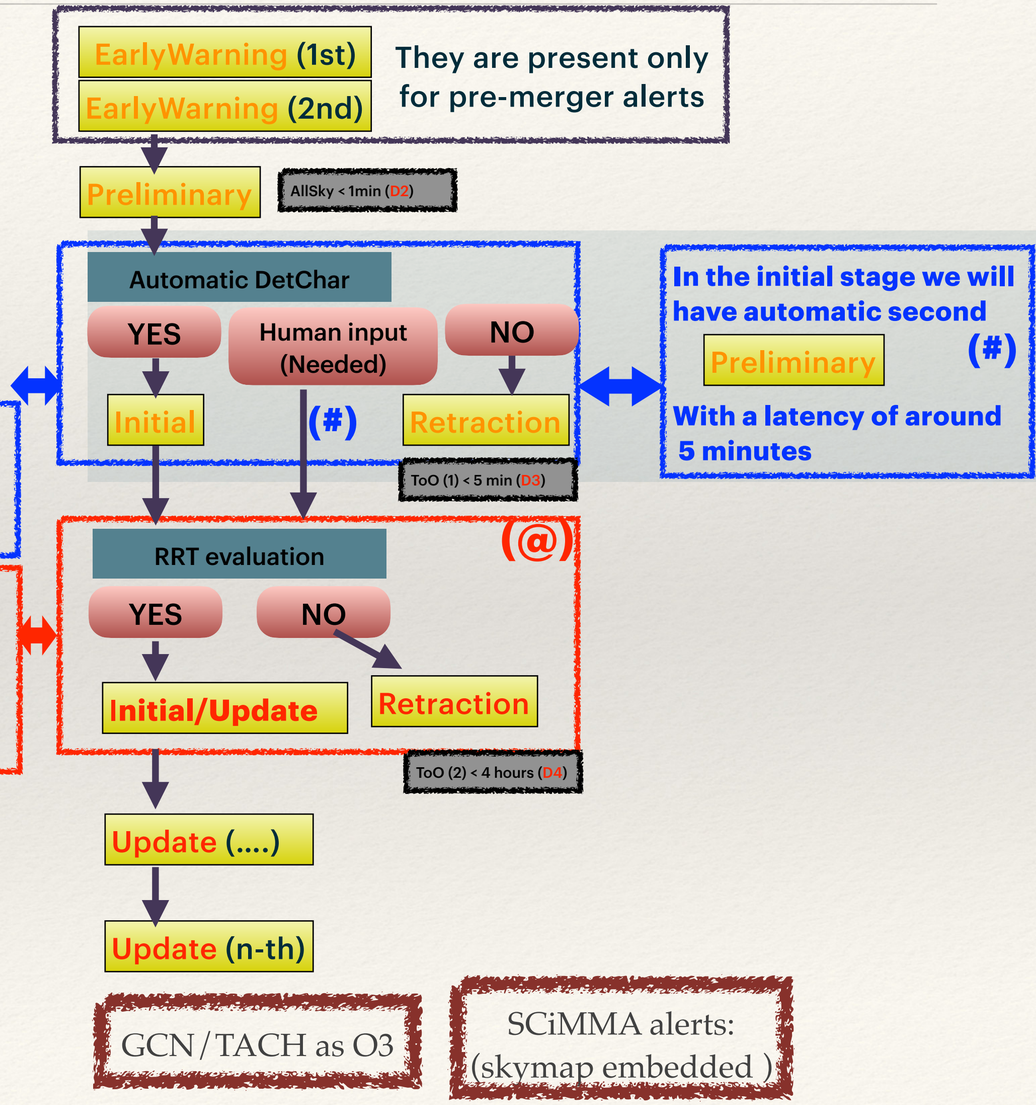
LIGO-Virgo-KAGRA Town Hall
Telecon - Thursday, 21 July 2022

Plan of the talk

- General plan for O4 alerts (stream and content)
  - MassGap classification removed from p_astro and moved to source properties.
  - GCN Notices and Circulars (as in O3)
  - New SCiMMA and GCN alert
  - New format for skymaps (multi-order HEALPix)
- On going MDC testing
- Change with respect to O3 (RAVEN+EarlyWarning)
- Final update (September 2022)

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 localisation information.**
  - **(2nd) EarlyWarning alert (fully automatic) as soon as sensible localisation 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. Targeting < 30s).**
  - **Preliminary alert (localisation information needed)**
- **We target a fully automatic DETECTOR characterisation checks that would allow:**
  - **Initial (Fully automatic) alert, automatic Initial circular sent**
  - **Retraction (Fully automatic) alert, automatic Retraction circular sent**
- **RRT meeting and a fast PE evaluation. Typically within 4 hours for BNS events or 1 day for vanilla BBH.**
  - **(1st) Update alert (human confirmation and evaluation). Update circular sent**
  - **Retraction alert (In case the event should be vetted). Retraction circular sent**
- **Any time a significant new information is collected , verified and approved we will send :**
  - **(2nd) Update notice and circular sent (within 1 day). Update circular sent**
  - **(3rd) Update notice and circular sent (within 2 day). Update circular sent**
  - **(4rd) Update notice and circular sent (within 1 week). Update circular sent**

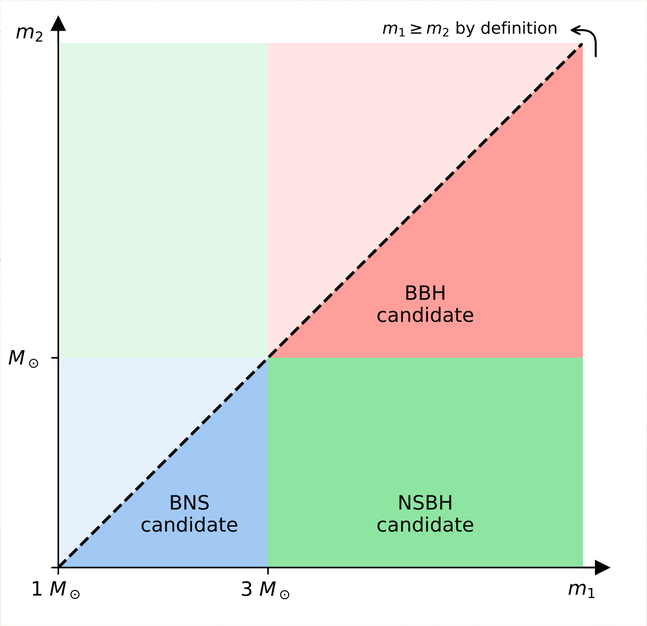


PUBLIC ALERT (notice) CONTENT O4

The alert WILL 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

  Rapid source properties parameter estimations EM-Bright:
  PROB_NS (0…1), PROB_REMNANT(0…1)
- A new EM-Bright probability (**PROB_MassGap**) - removing the probability of mass-gap from p-astro as it led to confusions.
- For each trigger, we will publish in GraceDB the pipeline specific quantities (like p-astro probabilities and FAR) for the search that contributed to the alert.
- We will also provide these information over Kafka topics distributed by SCiMMA and GCN.



O4 classification
- Boundary at $3\,M_\odot$

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//////////////////////////////////////////////////////////////////////
TITLE:            GCN/LVC NOTICE
NOTICE_DATE:      Mon 16 Dec 19 21:50:12 UT
NOTICE_TYPE:      LVC Preliminary
TRIGGER_NUM:      S191216ap
TRIGGER_DATE:     18833 TJD;   350 DOY;   2019/12/16 (yyyy/mm/dd)
TRIGGER_TIME:     77618.472999 SOD {21:33:38.472999} UT
SEQUENCE_NUM:     1
GROUP_TYPE:       1 = CBC
SEARCH_TYPE:      1 = AllSky
PIPELINE_TYPE:    4 = gstlal
FAR:              1.131e-23 [Hz]  (one per 10.....0 days)  (one per 28.....00
years)
PROB_NS:          0.19 [range is 0.0-1.0]
PROB_REMNANT:     0.00 [range is 0.0-1.0]
PROB_MassGap:     1.00 [range is 0.0-1.0]
PROB_BNS:         0.00 [range is 0.0-1.0]
PROB_NSBH:        0.19 [range is 0.0-1.0]
PROB_BBH:         0.81 [range is 0.0-1.0]
PROB_TERRES:      0.00 [range is 0.0-1.0]
TRIGGER_ID:       0x10
MISC:             0x1898405
SKYMAP_FITS_URL:  https://gracedb.ligo.org/api/superevents/S191216ap/files/
bayestar.multiorder.fits,0
EVENTPAGE_URL:    https://gracedb.ligo.org/superevents/S191216ap/view/
COMMENTS:         LVC Preliminary Trigger Alert.
COMMENTS:         This event is an OpenAlert.
COMMENTS:         LIGO-Hanford Observatory contributed to this candidate event.
COMMENTS:         VIRGO Observatory contributed to this candidate event.
```

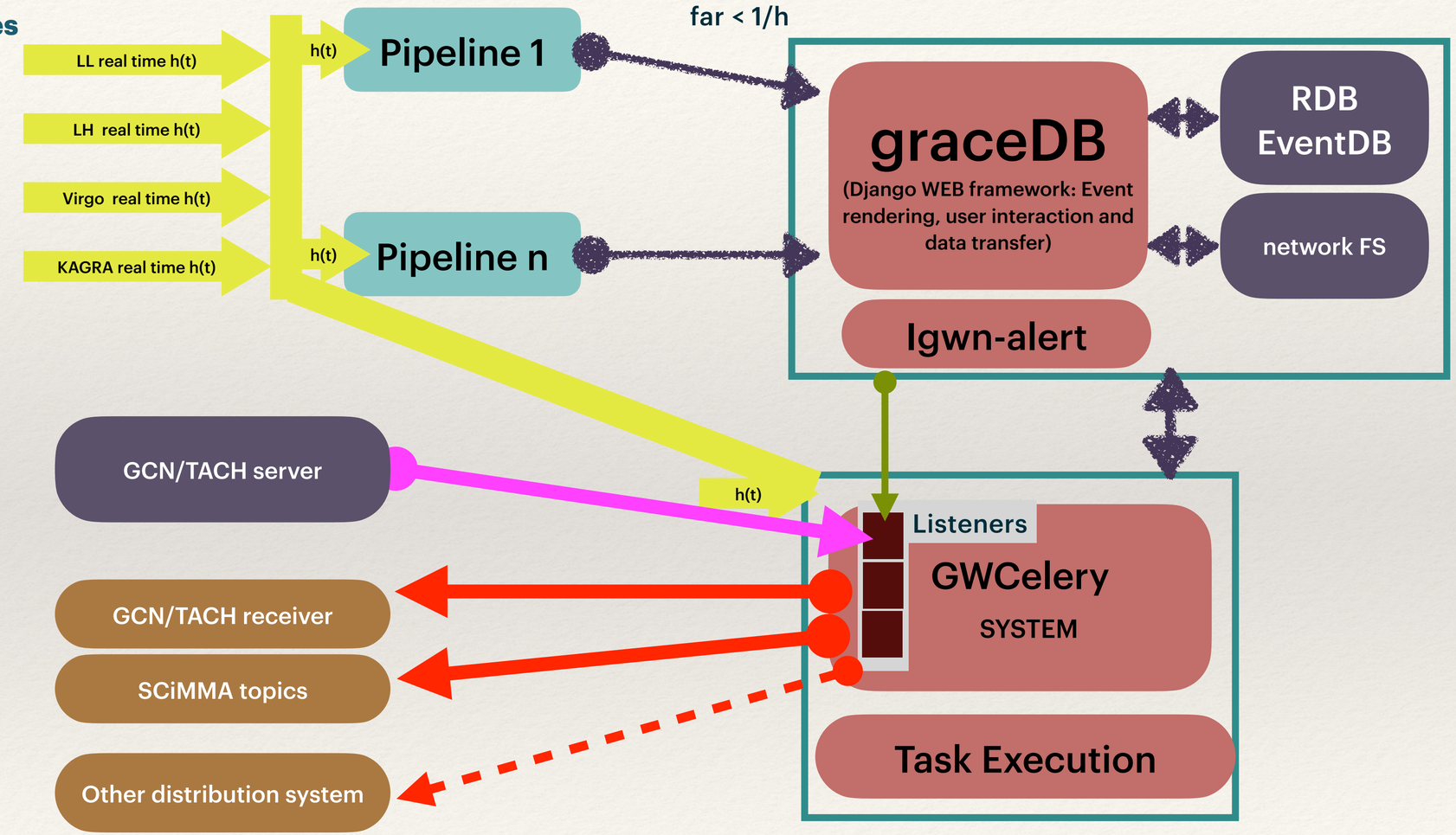
Must sum to 1.0

Skymap format

- We will provide localizations in two HEALPix formats, distinguished by file extension:
- ***.multiorder.fits** (**PREFERRED - change with respect to O3**)
  A new variant of the HEALPix format that is designed to overcome limitations of the *.fits.gz format for well-localized events from three-detector operations and future gravitational-wave facilities (see rationale in LIGO-G1800186). It uses HEALPix explicit indexing and the NUNIQ numbering scheme, which is closely related to multi-order coverage (MOC) maps in Aladin. This is the internal format that is used by the LIGO/Virgo low-latency alert pipeline. **This is the primary and preferred format, and the only format that is explicitly listed in the GCN Notices and Circulars.** (See: https://emfollow.docs.ligo.org/userguide/tutorial/multiorder_skymaps.html)
- ***.fits.gz (They will be available in GraceDB with a latency of order ~10s)**
  A subset of the standard HEALPix-in-FITS format (see semi-official specifications from the HEALPix team and from the gamma-ray community) that is recognized by a wide variety of astronomical imaging programs including DS9 and Aladin. It uses HEALPix implicit indexing and the NESTED numbering scheme. (Will be created for legacy usage)
- Both formats always use celestial (equatorial, J2000) coordinates.

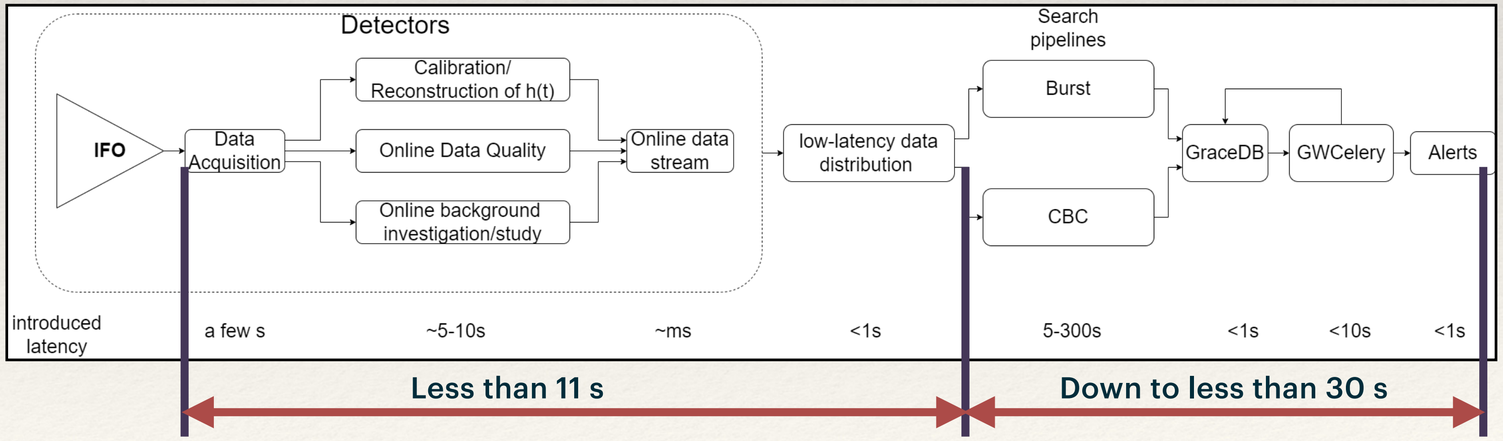
Alert infrastructure

- We operate multiple on-line detection pipelines that upload candidate events (G-event) to a database (GraceDB) if they have a false alarm rate (FAR) of less than 1/hour.
- 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/(year) for Burst events
    - combined spatial-temporal far with external events.



Latency Study (from signal to alert) MDC

- **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 (target < 30s).**
- **The study will also allow us to test the effectiveness of the online pipeline to detect and assess the properties of the signal.**



RAVEN and LLAMA pipelines

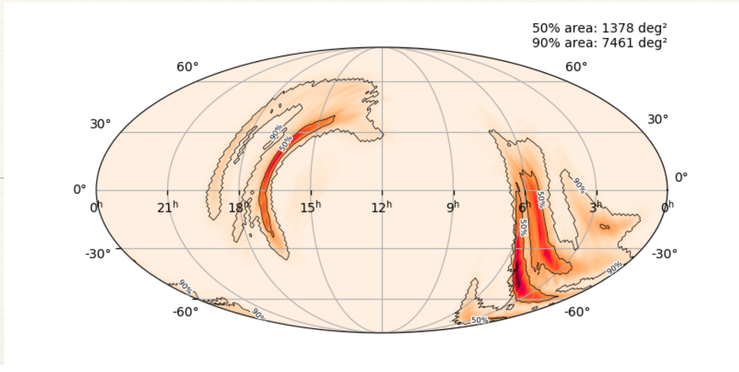
- **LLAMA**: online search pipeline combining LIGO/Virgo GW triggers with High Energy Neutrino (HEN) triggers from IceCube. Looks to temporally-coincident sub-threshold IceCube neutrinos.

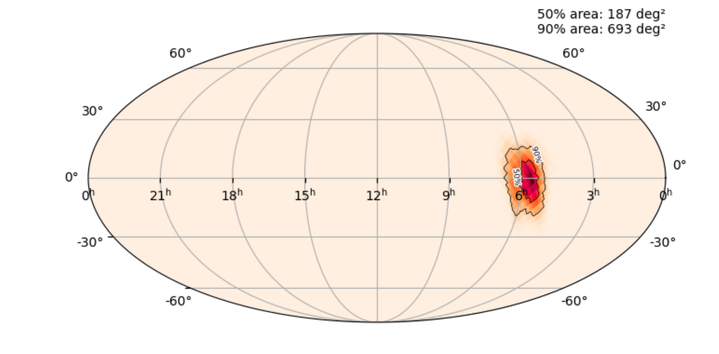
- **RAVEN**: Rapid On-Source VOEvent Coincidence Monitor (RAVEN). It searches confidences between GW events with alerts for gamma-ray bursts (GRBs) and galactic supernova alerts from the SNEWS collaboration.

  - 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 localisations 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.

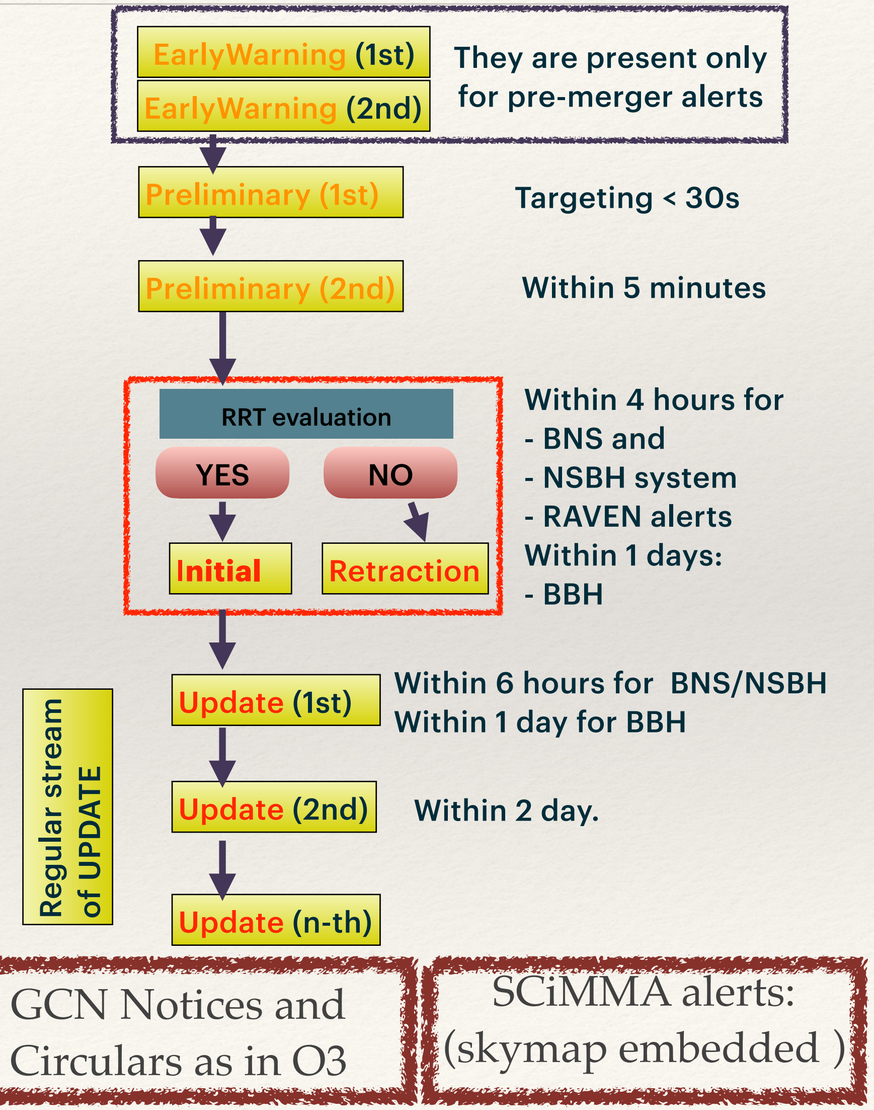




Search	Pipeline(s)	Untargeted	Targeted
CBC-GRB	Fermi-GBM	[-1, +5]	[-1, +10]
	Swift-BAT	[-1, +5]	[-10, +20]
	INTEGRAL	[-1, +5]	N/A
	AGILE	[-1, +5]	N/A
Burst-GRB	All GRB	[-60, +600]	N/A
Burst-Neutrino	SNEWS	[-10, +10]	N/A

What to expect (O4a)

- MassGap moved from P_ASTRO to source properties section of GCN
- EM-Bright probabilities (HasNS and HasRemnant) will be quantities marginalized over large number of equation of neutron star models (instead of single 2H Equation of State from O3)
- Skymap information will be provided using “multiorder” MOC based fits format. Flattened skymap will be available in GraceDB for legacy usage.
- EarlyWarning (negative time) alert will be provided
- Coincident alerts (RAVEN+LLAMA) will be publicly distributed
- MULTIPLE DISTRIBUTION CHANEL for alerts:
  - GCN Notices and Circulars as in O3.
  - Kafka based one with embedded skymap via SCiMMA and GCN
- LIVE STREAM OF (MDC) ALERT WILL BE DISTRIBUTED starting September 2022.



EXAMPLE of skymap availability (Both format are already available for O3 events and will be available during O4):
(PRIMARY) https://gracedb.ligo.org/api/superevents/S191216ap/files/bayestar.multiorder.fits,0
(SECONDARY) https://gracedb.ligo.org/api/superevents/S191216ap/files/bayestar.fits.gz,0

Conclusions

- Expected latency of the alerts will be set and communicated in September
- Starting September we will stream MDC alerts !
- Looking forward to an exciting O4 Multi Messenger observation period !
- Here to have your feedback !