Plans for the First Observing Run (O1)

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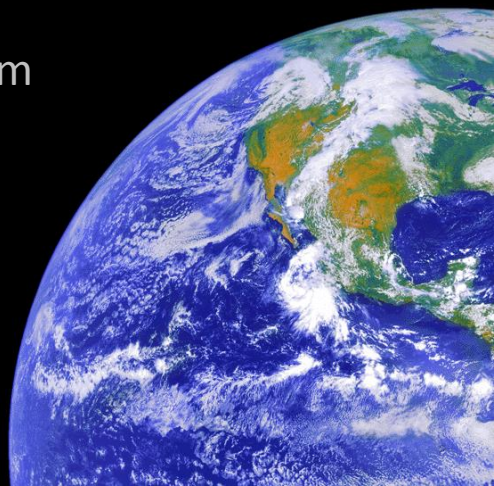
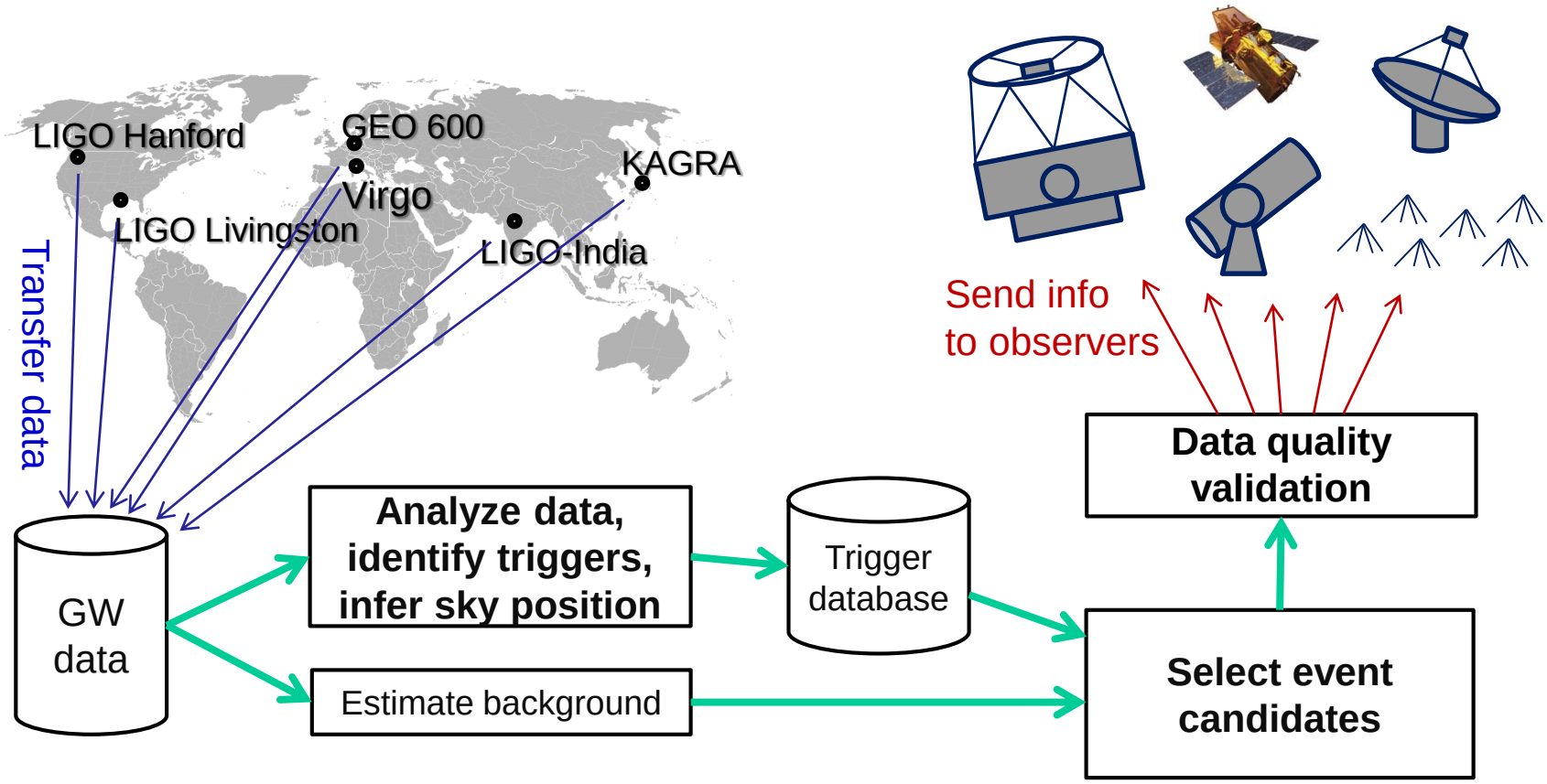
Workshop on the LIGO-Virgo EM Follow-up Program
Cascina — April 23, 2015

LIGO-G1500517-v2



GOES-8 image produced by M. Jentoft-Nilsen, F. Hasler, D. Chesters (NASA/Goddard) and T. Nielsen (Univ. of Hawaii)

The Big Picture



Swift: NASA E/PO, Sonoma State U., Aurore Simonnet

Event Candidate Selection and Validation

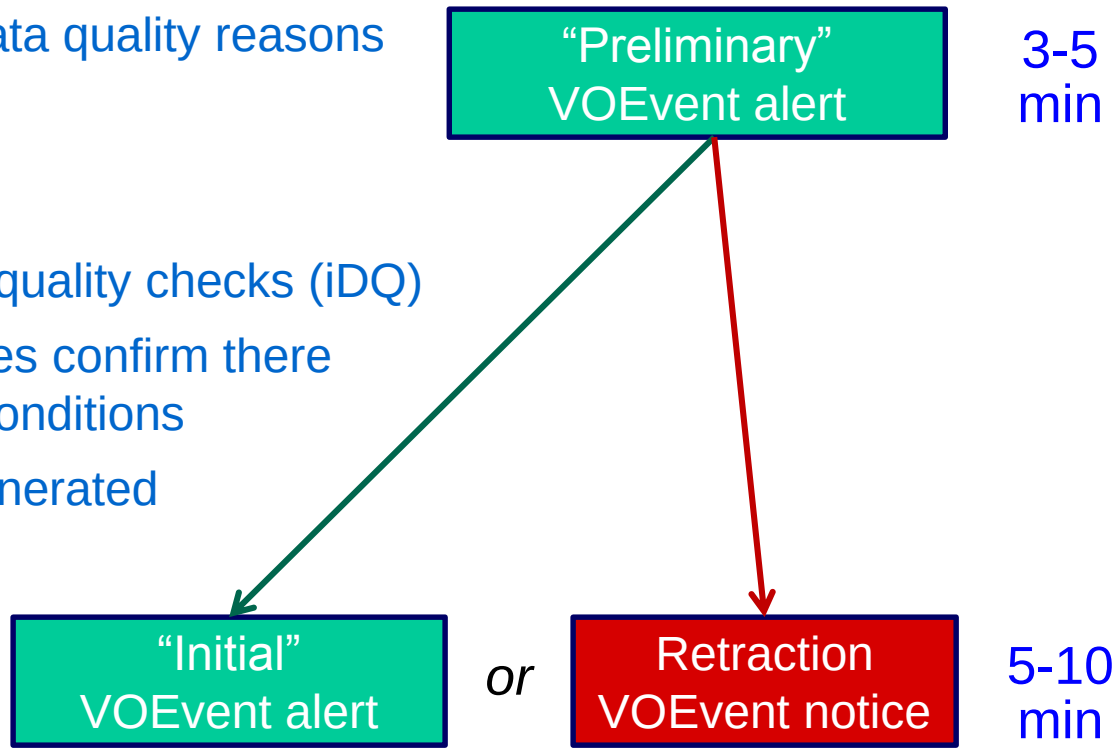
Software component:
"Approval Processor"

Preliminary identification

- Trigger found by low-latency CBC or Burst search
- Estimated FAR below some threshold
- Not a (non-blind) hardware injection
- Not already vetoed for data quality reasons

Data quality validation

- More sophisticated data quality checks (iDQ)
- Operators at observatories confirm there were no anomalous conditions
- Skymap file has been generated



How to Interpret a “Preliminary” Alert

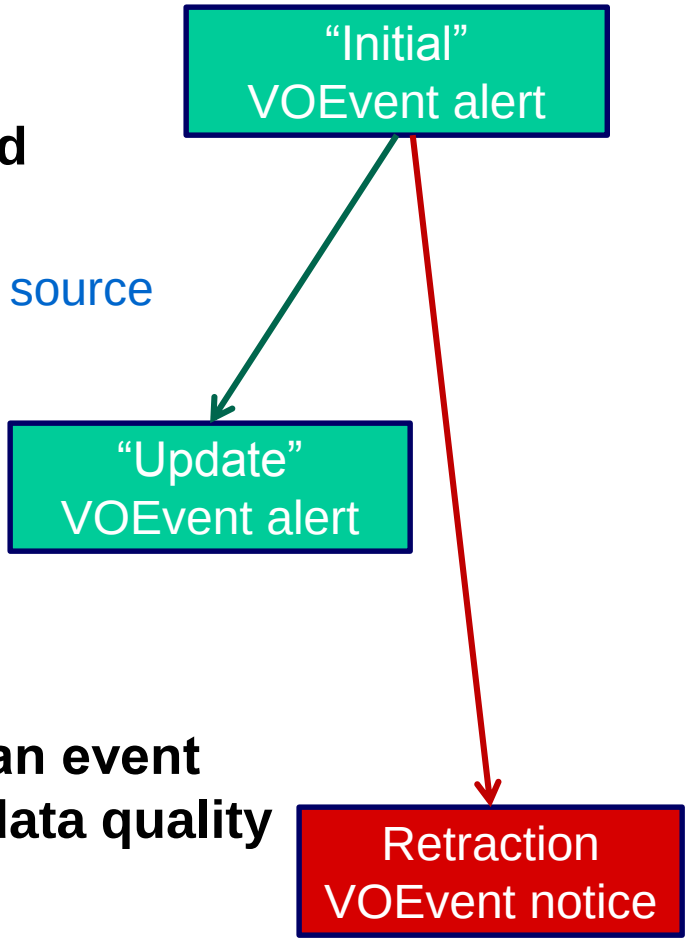
The “Preliminary” alert type is intended to help observers prepare to *possibly* follow up an event candidate

- May be useful to wake up a human or a scheduling computer
- For some instruments, could initiate buffering of data
- It should not be considered a validated GW candidate
- We don’t know yet what fraction of Preliminary alerts will pass the validation checks and produce “Initial” alerts
  - *[During the LIGO/Virgo science run in 2009-10, about 1/3 were rejected at this stage]*

Updated Information

Identifying an event candidate will also launch software to do more sophisticated parameter estimation

- Sky position and physical parameters of the source
- Can require many hours (MCMC)
- Produces updated skymap
- Potentially could refine FAR estimate too
- → One or more “Update” alerts



It’s possible that further examination of an event candidate could discover an issue with data quality or estimation of the FAR (significance)

FAR Threshold / Alert Rate for O1

We will generate alerts from CBC and Burst low-latency searches

We propose to set the FAR threshold so that we expect ~1 CBC alert and ~1 Burst alert per calendar month during O1

➔ Total of about 6 alerts expected during O1

Note: the event type and FAR is included in the alert, so you could apply a tighter cut on the alerts you receive, if you want

Caveats:

Estimated corrections for livetime and rate of surviving data quality checks

Poisson statistics

Low-latency FAR estimation could have some systematic issues

Position reconstruction is a bit worse for weaker events

We're saying we will generate alerts for ~6 false event candidates, *plus* however many real event candidates are loud enough to pass the FAR threshold too (which could be zero during O1)

Real Events vs. FAR Threshold

In O1, *assuming* 60 Mpc ranges, "realistic" BNS merger rate is exact, and background model in "Prospects" paper (arXiv:1304.0670):

1 per 100 years	$\rho_c \geq 12$	0.10 events selected
1 per year	$\rho_c \geq 11$	0.13 events selected
1 per month	$\rho_c \geq 10.46$	0.15 events selected

With full range of possible BNS merger rates:

0.001 to 1

0.0013 to 1.3

0.0015 to 1.5

Probably

➔ **Very small additive gain of real events in O1**

(Despite large difference in number of false events!)

Fractional gain will be more valuable in later runs

Note: any 1-per-100-years event will be selected with *any* of these thresholds; and even with the loose 1-per-month threshold, 2/3 of real events selected will have FARs of 1-per-100-years or better

Rationale for the Loose FAR Threshold

Practice!

We (LIGO/Virgo) and you (EM observers) need practice

- Observing strategies
- Data analysis
- Really confronting the statistical issues

Best to do this during the course of O1, rather than concentrating it in a short test period

- Time for us to make adjustments to procedures
- Spacing to do multi-night follow-up observing
- The purity will probably be very low, but at least these are the best GW event candidates we'll have so far – and hey, we could get lucky
- You can always be more selective by making a tighter cut on FAR

~6 alerts seems like enough for every group to probably be able to follow up one or more

Pre-O1 Testing

We will provide test alerts, generated at programmed times to simulate the approval process, distributed through GCN/TAN

Including during our ER7 engineering run (first ~2 weeks of June)

A few example VOEvents are now posted in the LV_EM wiki* at https://gw-astronomy.org/wiki/LV_EM/VOEventExamples

Maybe not quite the final formatting

* Anyone not yet registered for the LV-EM Forum & wiki:
see https://gw-astronomy.org/wiki/LV_EM/RegistrationInstructions

(this page is viewable even if you haven't yet registered)

Be sure to select your "project" at the bottom of the web form

Blind Injections

From the MOU: "… a small number (up to 3 blind injections per run) of simulated signals may be injected into the GW interferometer data, and may lead to GW candidate alerts. No LIGO and VIRGO members (aside from the few people entrusted to carry out the program in secrecy) or <partner group> members will know that those events are not of astrophysical origin until after they have been fully vetted by LIGO and VIRGO."

Won't be un-blinded until the result/preprint is ready to be made public

The LIGO-Virgo blind injection committee has stated that they intend to do this at a rate "comparable to astrophysical expectations". For O1, that means:

- There could very well be no detectable blind injection
- Chance of having >1 detectable blind injection is probably extremely small

In any case, the blind injection program will end when the first GW event is published

General LIGO/Virgo Criteria for Interpreting and Publishing Events

1. **Above ~5 sigma (false prob $\lesssim 10^{-6}$): "detection" paper**

   Unlikely (but possible!) that we will get a golden event like this in O1

2. **Above 3 sigma (false prob $\lesssim 0.003$): "evidence" paper**

   For O1, corresponds to FAR ~ 1 in 100 years

EM counterpart too? Hooray!

3. **Above 2 sigma: describe as outlier in end-of-run upper limits paper, but inconclusive evidence**

   In this case, a reasonably significant EM counterpart (false coinc prob $\lesssim 0.05$) could make this scientifically more interesting, and worth publishing a joint paper

4. **Loudest trigger is consistent with background: just describe briefly in upper-limit paper**

   Unlikely that an apparent EM counterpart could make this interesting, unless it's a short GRB or otherwise exceptionally distinctive (would need convincing demonstration)

Reminder of Publication Constraints

From the MOU: "Any apparent counterpart to the GW event candidate, that was identified due to the GW candidate alert, is strictly *embargoed*: it may not be published or presented prior to the public announcement or publication of the GW event candidate by LIGO and VIRGO. LIGO and VIRGO will share detailed information with all partners who observed the counterpart prior to publishing or presenting the GW event results."

The embargo is important to LIGO/Virgo

- We need to be the ones to present the GW data, after careful vetting
- We will keep you updated on any findings as we check a candidate

***Baseline* plan is that LIGO/Virgo will publish GW event candidates according to their significance based on the GW data alone**

- Follow-up observations will then add to the story
- Frees us from trying to write huge joint papers unless it's really necessary to establish the reality of an event in the first place
- We'll be happy to share drafts and coordinate with companion papers
- Normal co-authorship/acknowledgment etiquette if any unpublished proprietary information is used in a paper

More About Publications

LIGO+Virgo intend to publish *something* routinely reporting all alerts sent out during O1, even if consistent with background

- Lifts the embargo, so you can refer to that information and write concretely about your follow-up observing attempts, if you want
- Timeline: aiming (optimistically?) for 3 months after the run ends

We urge due caution when considering whether an EM transient is really likely to be a true counterpart

- Statistical significance of any apparent counterpart needs to be carefully evaluated in light of the large GW sky regions and background population of EM transients
- Especially for the first detection of GW signals, observation of a new signature calls for convincing evidence

Recall that no restrictions are intended on the publication of EM transients which were not triggered by a GW alert

- But you can't hint that there was a GW counterpart (even if we know there is one!!!), if the embargo is still in effect

Any questions or comments?

Some Questions for Discussion

Does follow-up strategy need something more than FAR and sky map?

Will your observing strategy depend on CBC vs Burst? Other parameters?

Could/should we skip the human validation step before issuing "Initial" alerts?

Would still have the ability to retract later if humans find some anomaly

Do you expect to coordinate with other observers? If so, how?

Are other EM observations useful (or essential) for planning yours?

How will you evaluate the significance (i.e., low chance of false coincidence) if you find an apparent counterpart?

And how low of a false coincidence probability could to demonstrate with your specific instrument(s) and analysis?

Any specific suggestions or requests for testing?