

# Overview on the use of VOevent for gravitational-wave alerts

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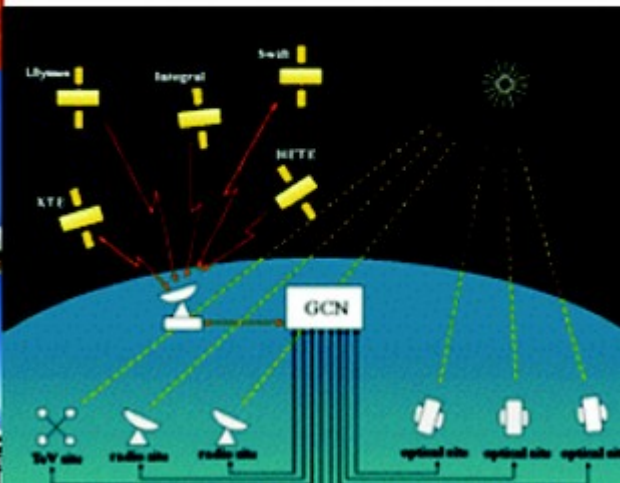
Coalescence of two black holes (credits: SXS)



# Multimessenger astronomy

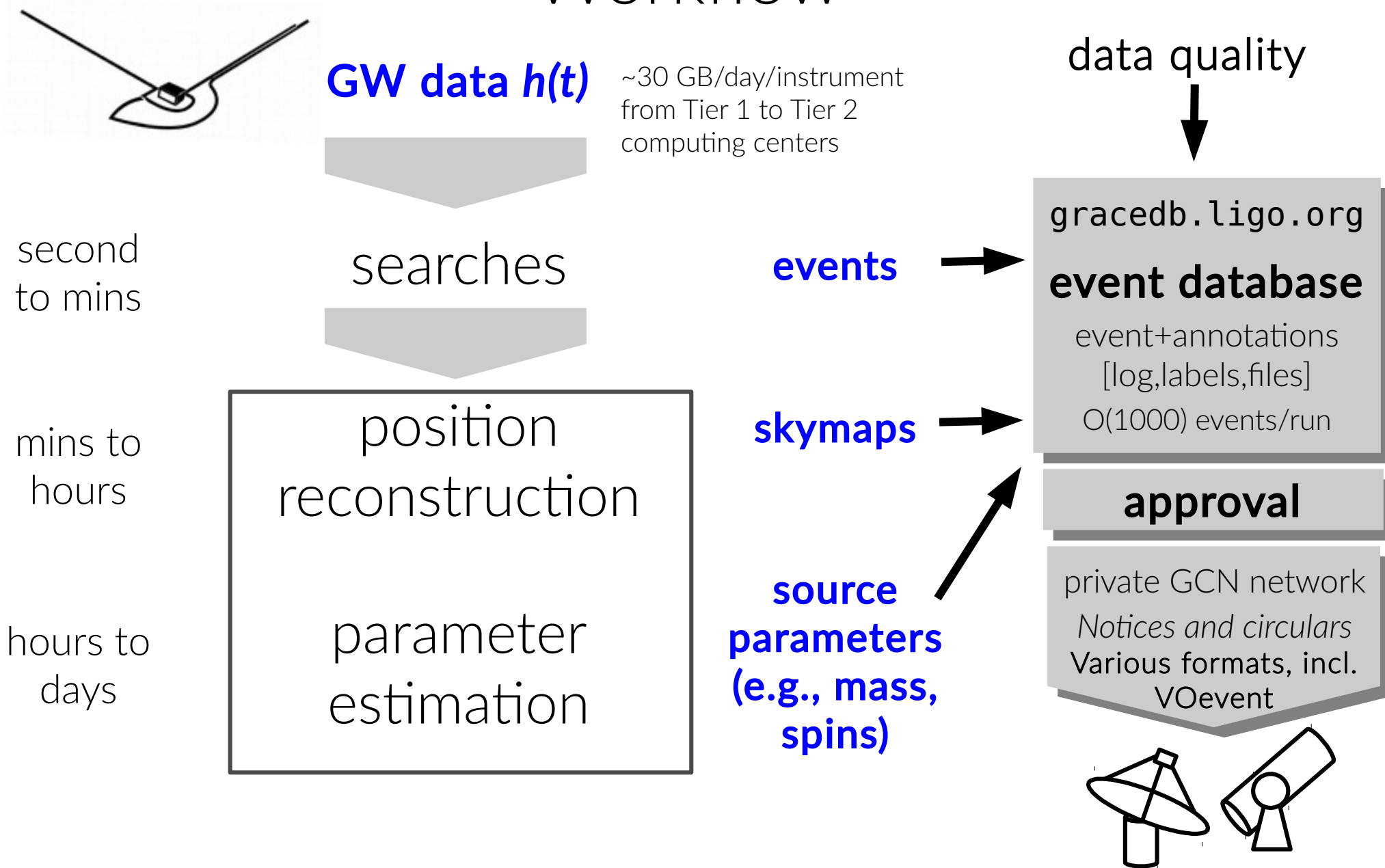
- Two approaches for joint GW and EM search
  - **“Externally triggered” GW searches**
    - Gamma-ray bursts, pulsar glitches, SGR flares, fast radio bursts, nearby supernovae, ... ~20 publications
  - **Electromagnetic follow-up of GW alerts (this talk)**
    - LIGO & Virgo have signed MOUs with **~80 astronomer groups**  
Cover all accessible wavelengths from radio to very high energies
    - MOU = Framework to share information promptly while maintaining confidentiality
    - Alerts are based on loose false-alarm rate threshold (1/month)  
LIGO O1 (Sep 2015-Jan 2016)– 3 alerts  
LIGO O2 (Nov 2016-Aug 2017?) - as of Feb 2016, 3 alerts
    - Once GW detections become routine ( $\geq 4$  published), there will be prompt **public alerts of high-confidence detections**





# Low-latency GW analysis

## Workflow



# Sep 14, 2015 09:50:45 UTC

## GraceDB — Gravitational Wave Candidate Event Database

HOME	SEARCH	CREATE	REPORTS	RSS	LATEST	OPTIONS	DOCUMENTATION
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3 mins later

### Basic Info

UID	Labels	Group	Pipeline	Search	Instruments	GPS Time Event Time	FAR (Hz)	Links	UTC Submitted
G184098	H1OK L1OK	Burst	CWB	AllSky	H1,L1	1126259462.3910	1.178e-08	<a href="#">Data</a>	2015-09-14 09:53:51 UTC

### Analysis-Specific Attributes

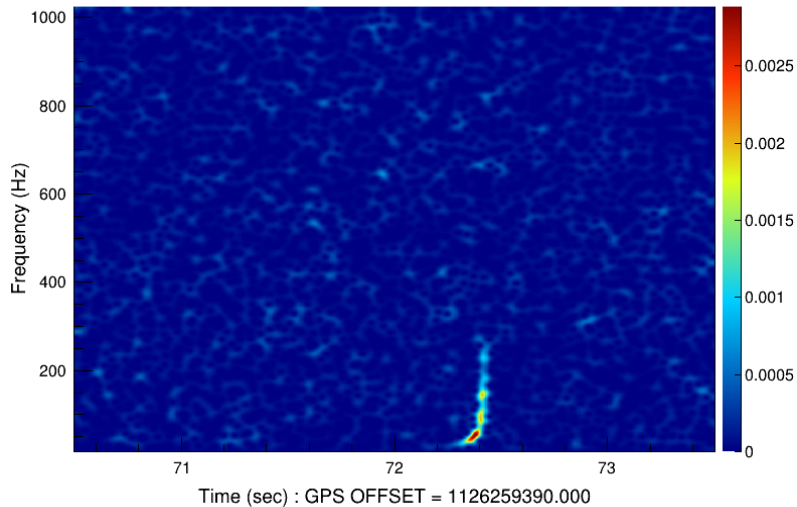
start_time	1126259461	central_freq	123.8285	false_alarm_rate	
start_time_ns	750000000	bandwidth	51.8386	ligo_axis_ra	130.9219
duration	2.477e-02	amplitude	1.410e+01	ligo_axis_dec	4.4808
peak_time	None	snr	23.4521	ligo_angle	None
peak_time_ns	None	confidence		angle_sig	None

SNR = 23.45

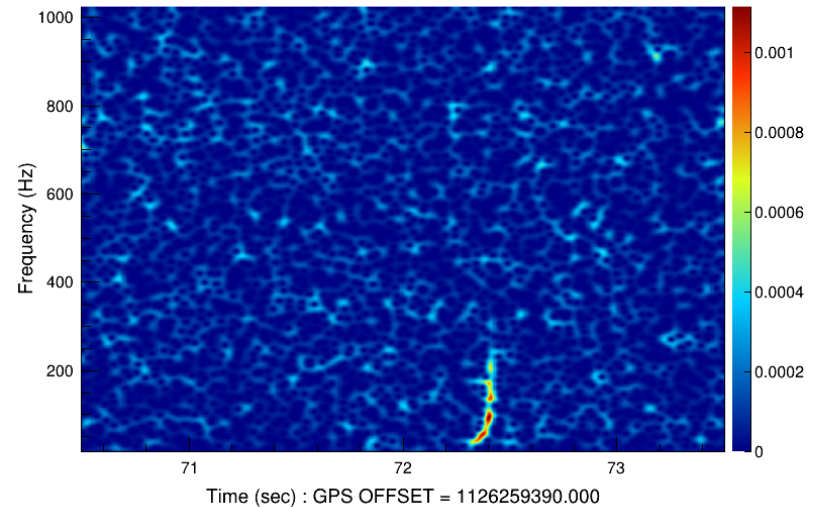
Hanford H1

Livingston H1

Spectrogram (Normalized tile energy)



Spectrogram (Normalized tile energy)





# How is the information communicated?

GraceDB – Gravitational Wave Candidate Event DB

Source parameters

Alert updates or retraction within hours

HOME	SEARCH	CREATE	REPORTS	RSS	LATEST	OPTIONS	AUTHENTICATED AS: ERIC CHASSANDE-MOTTIN
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**Basic Info**

UID	Labels	Group	Pipeline	Search	Instruments	GPS Time Event Time	FAR (Hz)	Links	UTC Submitted
G158249		CBC	MBTAOnline		H1,L1	1117621400.2060	1.372e-06	<a href="#">Data</a>	2015-06-06 10:24:49 UTC

**Coinc Tables**

End Time	1117621400.2060
Total Mass	9.2271
Chirp Mass	3.0849
SNR	13.6718
False Alarm Probability	

**Single Inspirals Tables**

IFO	L1	H1
Channel		
End Time	1117621400.219121932	1117621400.206010103
Template Duration	None	None
Effective Distance	177.7525	459.68568
COA Phase	-0.2746053	-1.0825006
Mass 1	7.365417	7.365417
Mass 2	1.861673	1.861673
$\eta$	0.16105389	0.16105389
F Final	None	None
SNR	12.637432	5.2167654
$\chi^2$	None	None
$\chi^2$ DOF	None	None
spin1z	-0.2383012	-0.2383012
spin2z	0.0005419254	0.0005419254

Neighbors [-5,+5]

No neighbors in range.

Low latency analysis  
Preliminary alert in 3-5 mins

Rapid preliminary sky position  
Initial alert issued in 5-10 mins  
includes: time, significance, sky map

Event Log Messages [\(add\)](#)

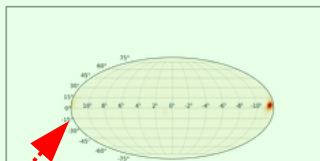
Analyst Comments

LLO Local Log Entry Created	Submitter	Comment
Jun 7, 2015 5:18:52 PM	GDB Processor	No unblind injections window [-5,+5] seconds
Jun 7, 2015 5:06:33 PM	GDB Processor	No unblind injections window [-5,+5] seconds

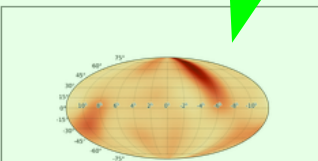
Noise Curves

LLO Local Log Entry Created	Submitter	Comment
Jun 6, 2015 5:24:54 AM	MBTA Alert	PSDs <a href="#">psd.xml.g</a>

Sky Localization



[skymap.png](#), Submitted by GDB Processor on Jun 7, 2015 10:06:16 PM



[LALInference\\_skymap.png](#), Submitted by GDB Processor on Jun 7, 2015 10:18:34 PM

LLO Local Log Entry Created	Submitter	Comment
Jun 7, 2015 5:18:25 PM	SkymapViewer	<a href="#">LALInference_skymap.ison</a> <a href="#">View in SkymapViewer!</a>
Jun 7, 2015 5:06:01 PM	SkymapViewer	<a href="#">skymap.ison</a> <a href="#">View in SkymapViewer!</a>
Jun 7, 2015 5:05:55 PM	GDB Processor	INFO: BAYESTAR: uploaded sky map <a href="#">skymap.png</a>

External Coincidence

Parameter Estimation

EM Observations

Full Event Log

Coincident astrophysical event  
or EM follow-up observations

# Preliminary notice

A preliminary notice is issued after basic sanity checks and approval by operators on sites and on-call EM follow-up advocates.

```
TITLE:                GCN/LVC NOTICE
NOTICE_DATE:          XXXXXX
NOTICE_TYPE:          TEST LVC Preliminary
TRIGGER_NUM:          XXXXXX
TRIGGER_DATE:         XXXXXX
TRIGGER_TIME:         XXXXXX
GROUP_TYPE:           X           [Analysis group: CBC or Burst]
SEARCH_TYPE:          X           [Type of search e.g., Allsky]
PIPELINE_TYPE:        X           [Name of the pipeline]
FAR:                  XXXXXX [Hz]
TRIGGER_ID:           XXX
MISC:                 XXX
```

# Initial notice

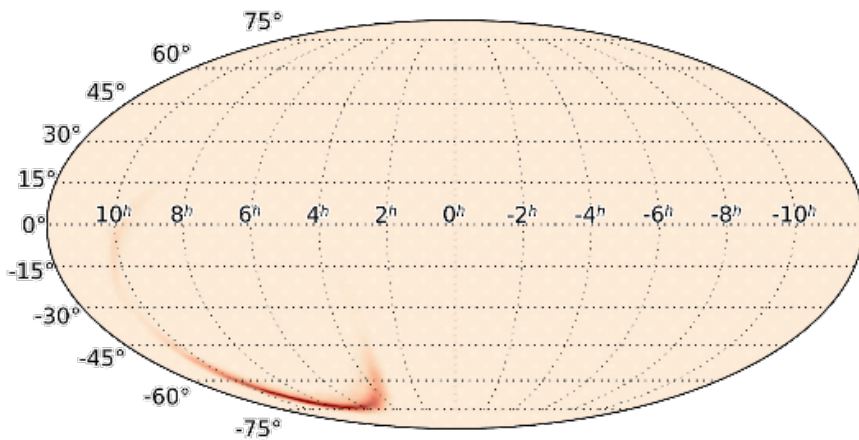
An initial notice is issued after the probability skymap is available.  
The VOevent includes links to skymaps files.

```
TITLE:                GCN/LVC NOTICE
NOTICE_DATE:          XXXXXX
NOTICE_TYPE:          TEST LVC Initial Skymap
TRIGGER_NUM:          XXXXXX
TRIGGER_DATE:         XXXXXX
TRIGGER_TIME:         XXXXXX
GROUP_TYPE:           X
SEARCH_TYPE:           X
PIPELINE_TYPE:        X
FAR:                  XXXXXX [Hz]
TRIGGER_ID:           XXX
MISC:                 XXXXXX
SKYMAP_URL:           https://gracedb.ligo.org/XXX
SKYMAP_BASIC_URL:     https://gracedb.ligo.org/XXX
EVENT_URL:            https://gracedb.ligo.org/XXX
```

Now (O2), includes a model-based event classification “EM-bright” that indicates how likely an EM counterpart would be (probability of a NS in the binary)



# Source localization - Skymap



- Large localization errors ( $>$  few 100 sq degrees)
- Localization in a non-trivial sky region
  - ✓ More complicated than RA, dec + error
- Posterior probability skymap
- Now (O2) includes skymap with position dependent distance estimate

# Update and retraction notices

Update notices are issued when more information is available, e.g., when the skymap from full event parameter estimation is available.

The notice layout is identical to that of initial notices.

Retraction notices are issued when detailed data quality assessment concluded that the candidate event is due to Background.

# Follow-up reporting

- Mandatory (MOU) for follow-up observers to tell which part of the sky has been covered – GraceDB
  - Follow-up observations have to be decided “one-the-fly” – Very little time for coordination
- Report on analysis (upper-limits or transient candidates) through GCN notices
  - Not intended for machines
  - Although this may be produced automatically for few observing groups

# Status so far

- Alerts working fine so far
  - Don't have statistics about which alert format is preferred
- No major issue with GCN-based event distribution
  - Well accepted by follow-up observers
  - Continuous streams of fake events for testing
- Don't expect major changes to the technical scheme nor to the data rate in the futur (  $< \times 10$  ?)
- Plan to switch to “public” alerts in the next year