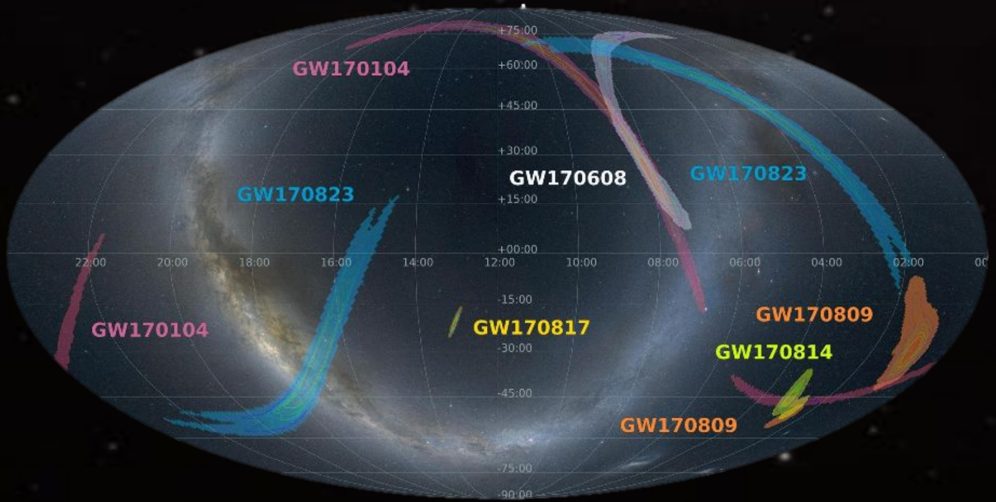
LSC LIGO Scientific Collaboration VIRGO

Low Latency gravitational wave alerts of the advanced LIGO and Virgo collaboration



Sarah Antier, *CNES, APC*, Paris

The New Era of Multi-Messenger Astrophysics

SCIOPS, Nov, 2019

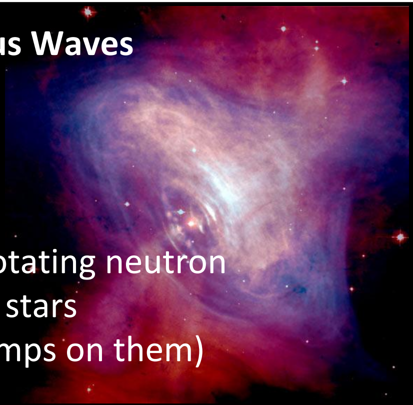
LIGO-Virgo analyses for sources of gravitational waves

Sources can be transient or of continuous nature, and can be modeled or unmodeled

Coalescence of Compact Sources
(e.g. black holes, neutron stars)

EM: Short GRBs, Kilonova

Continuous Waves

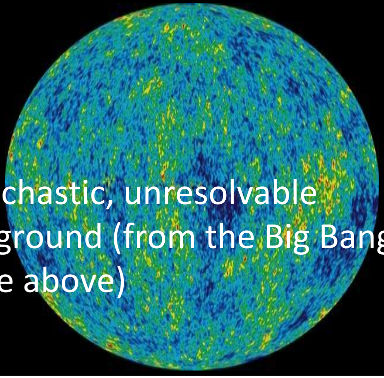


Rapidly rotating neutron stars
(with lumps on them)

Burst
Asymmetric core collapse supernovae

EM: supernovae emission, long GRBs

Stochastic



A stochastic, unresolvable background (from the Big Bang, or all of the above)

Multi-messenger astronomy with LIGO/Virgo : since 10 years !

Coïncidence Search

Compare sets of candidates events

Triggered analysis

Search that uses EM or neutrino observations to drive the detection of GWs

GRB prompt emission, SN explosion in local galaxies, flares SGR, pulsar glitches, low and high energy neutrino

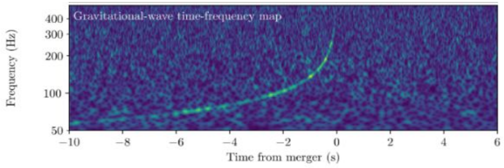
Known event time and sky position

- reduction in search parameter space for GW searchs
- gain in search sensitivity

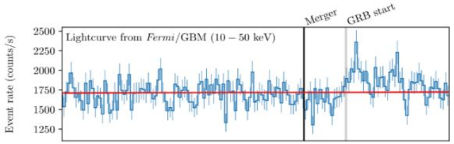
EM Follow-up

Search EM/neutrino counterpart candidates after GW identification

GW170817 multi-messenger discovery

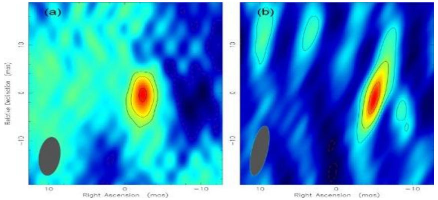


Gravitational waves

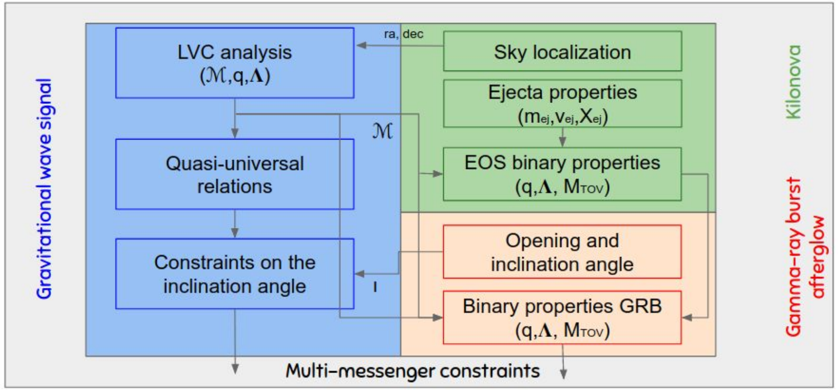


GRB

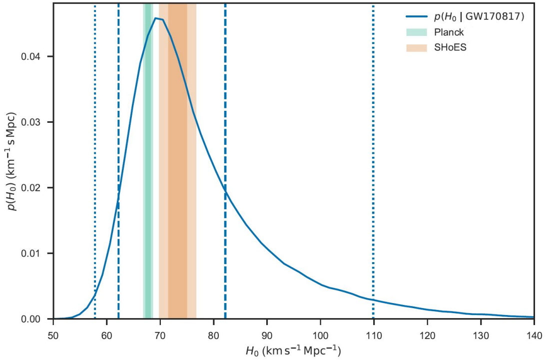
Kilonova



Afterglow

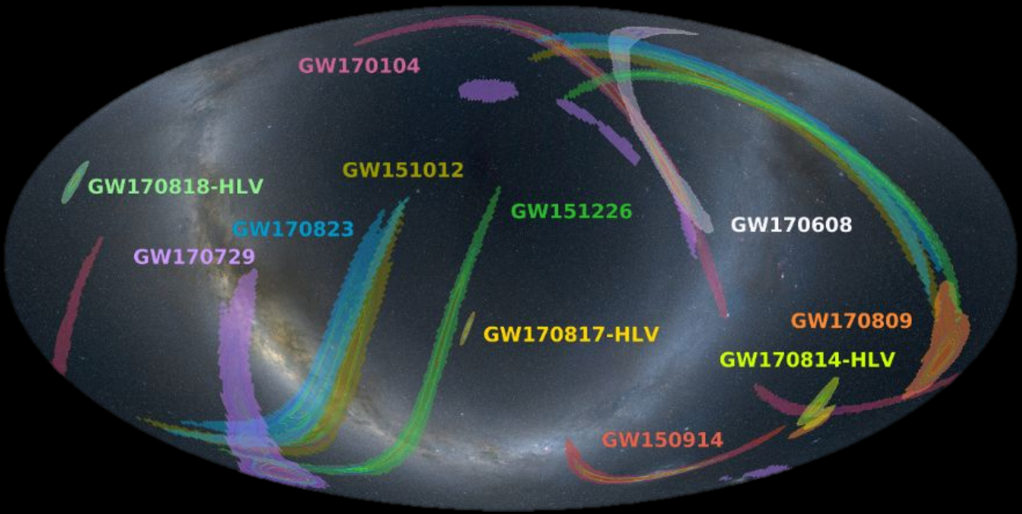


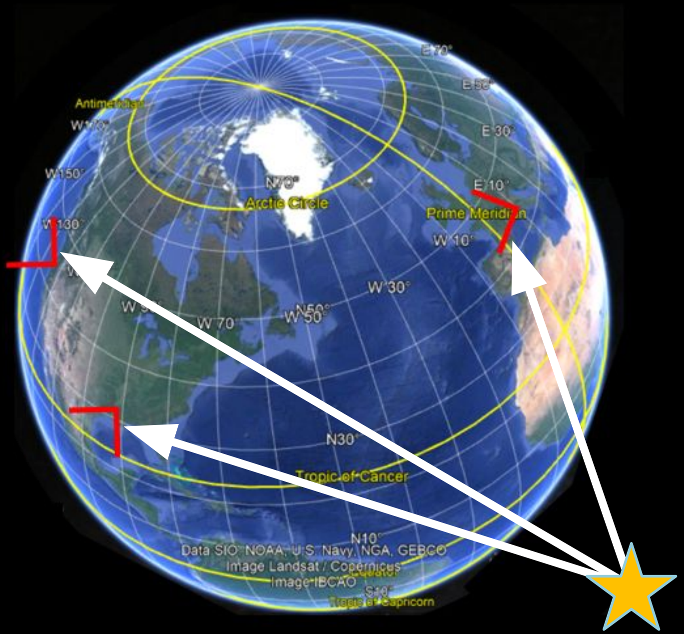
Multimessenger Bayesian parameter inference of a binary neutron star merger, Coughlin et al., 2019



A gravitational wave standard siren measurement of the hubble constant, LVC et al., 2017

O2 Multi-messenger campaign



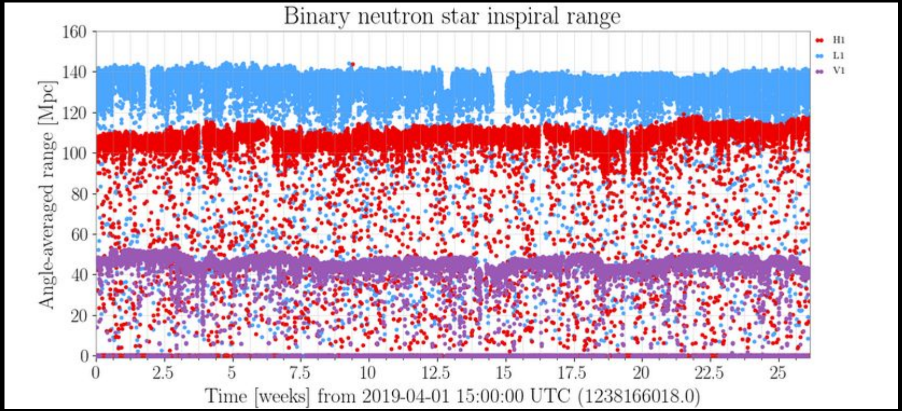


14 alerts sent during O2, 6 confirmed !
GW170817 first arrived at Virgo, after 22 ms it arrived at LLO, and another 3 ms later LLH detected it

Virgo allowed source location via triangulation

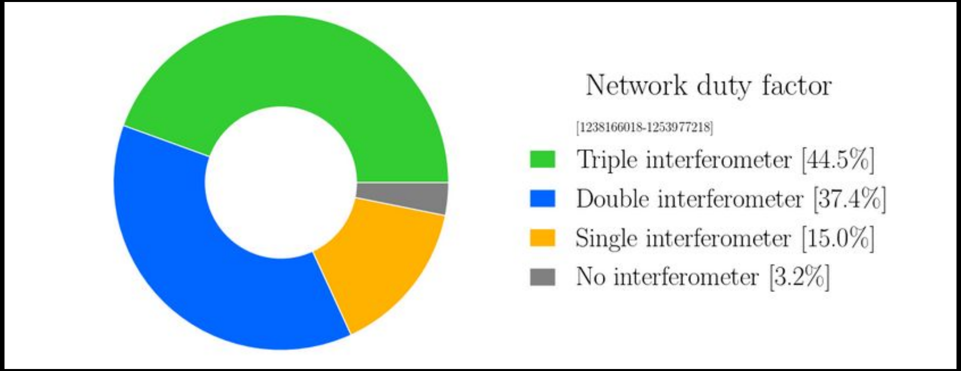
Low latency gravitational wave alerts for multi-messenger astronomy during the second advances LIGO and Virgo observing runs APJ, 2019

O3 observational campaign, starting April 2019

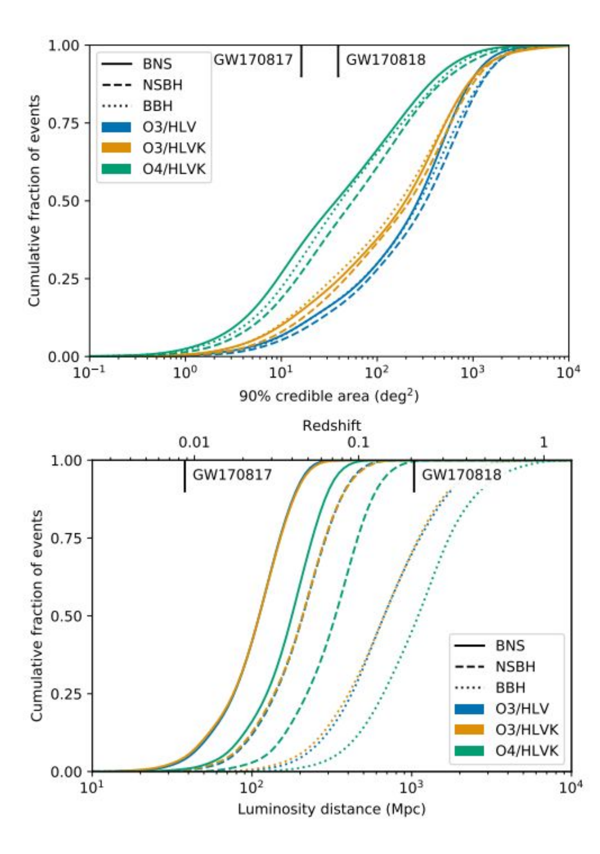


O3a summary status
V1: 50 Mpc - H1: 100 Mpc - L1: 140 Mpc

O3a summary status
Triple duty cycle (45%) compared to 60% during the August 2017



O3 observational campaign: Rate and Prospects



Anticipated GW sky localization for CBC signals during O3 and O4.
Up: Cumulative fractions of events with sky-localization area, luminosity distance asmaller than the abscissa value.

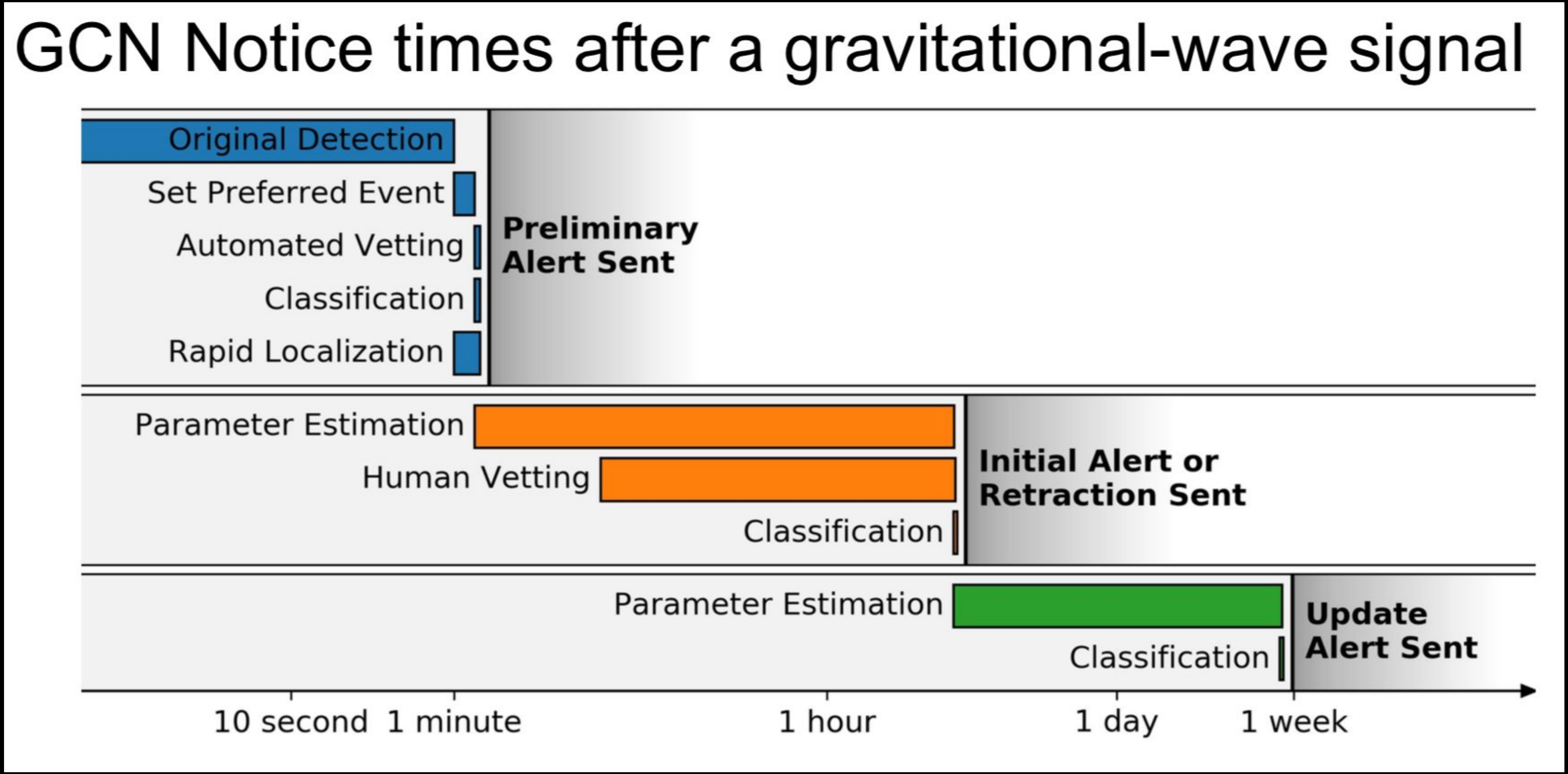
Around 10% of the event having a 90% credible region smaller than 20 deg2
The 90% median credible region is 250-340 deg2

O3 aLIGO 110 – 130 Mpc, AdV 50 Mpc, KAGRA 8 – 25 Mpc
The BNS search volume V is 2.5 × 106 Mpc3 yr

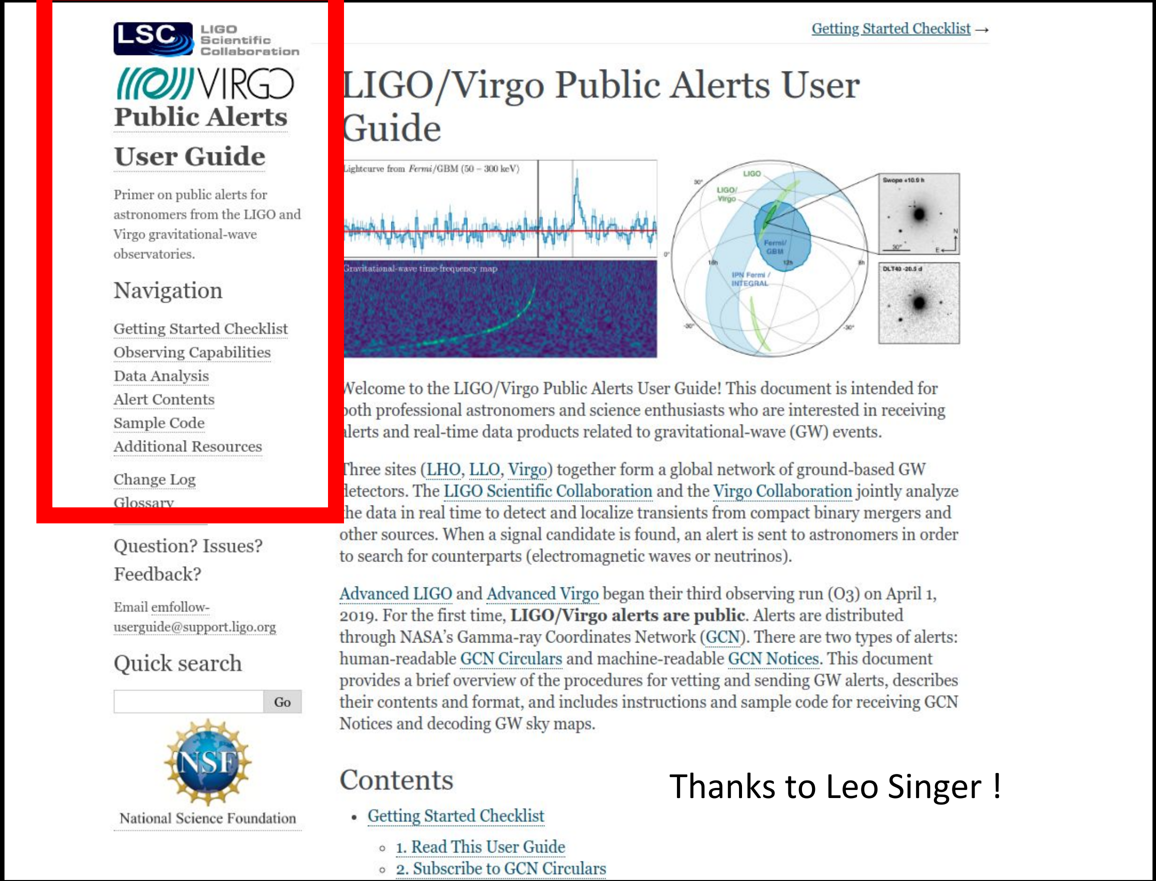
2 (+8 −2) expected BNS detections

[Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO, Advanced Virgo and KAGRA]

O3 LIGO-Virgo PUBLIC alerts



LIGO-Virgo Userguide



LSC LIGO Scientific Collaboration

VIRGO

Public Alerts User Guide

Primer on public alerts for astronomers from the LIGO and Virgo gravitational-wave observatories.

Navigation

- Getting Started Checklist
- Observing Capabilities
- Data Analysis
- Alert Contents
- Sample Code
- Additional Resources
- Change Log
- Glossary

Question? Issues? Feedback?

Email emfollow-userguide@support.ligo.org

Quick search

Go

National Science Foundation

Getting Started Checklist →

LIGO/Virgo Public Alerts User Guide

Welcome to the LIGO/Virgo Public Alerts User Guide! This document is intended for both professional astronomers and science enthusiasts who are interested in receiving alerts and real-time data products related to gravitational-wave (GW) events.

Three sites (LHO, LLO, Virgo) together form a global network of ground-based GW detectors. The LIGO Scientific Collaboration and the Virgo Collaboration jointly analyze the data in real time to detect and localize transients from compact binary mergers and other sources. When a signal candidate is found, an alert is sent to astronomers in order to search for counterparts (electromagnetic waves or neutrinos).

Advanced LIGO and Advanced Virgo began their third observing run (O3) on April 1, 2019. For the first time, **LIGO/Virgo alerts are public**. Alerts are distributed through NASA's Gamma-ray Coordinates Network (GCN). There are two types of alerts: human-readable GCN Circulars and machine-readable GCN Notices. This document provides a brief overview of the procedures for vetting and sending GW alerts, describes their contents and format, and includes instructions and sample code for receiving GCN Notices and decoding GW sky maps.

Contents

- Getting Started Checklist
  - 1. Read This User Guide
  - 2. Subscribe to GCN Circulars

Thanks to Leo Singer !

Low latency R&D infrastructure team

- Erik Katsavounidis
- Shaon Ghosh
- Stuart Anderson
- Deep Chatterjee
- Giuseppe Greco
- Shasvath Kapadia
- Soichiro Morisaki
- Alex Pace
- Roberto de Pietri
- Brandon Piotrzkowski
- Leo Singer

With the support of many others including Data analysis groups and Detchar groups

Alert Generation

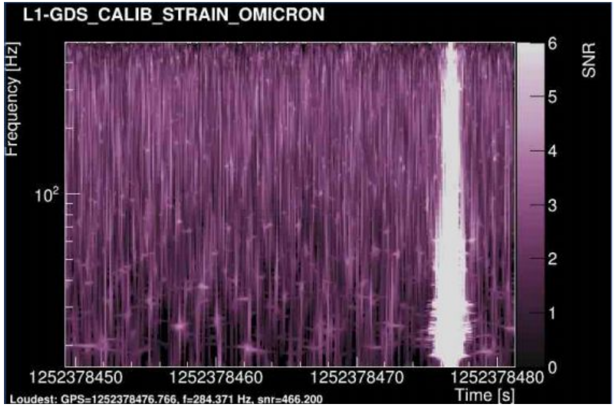
- Several pipelines, each can make several detections with **1-min latency**
  - Modeled searches: GstLAL, PyCBC, MBTA, SPIIR
  - Unmodeled searches: OLIB, cWB
- Detection FAR :
  - CBC : 1 event / 2 months
  - Burst : 1 event / year
- Based on a given criteria, one is chosen as being the **Preferred Event** starting with **BIG S for Superevent** for the public alert (criteria depends on the type of search but also number of interferometers involved)

Automatic alert vetting

Before sending the GCN notice

- Check if the basic status of the IFO are ok
- If there is no injection

Medium latency tools
Omega and Omicron scans



Human vetting to estimate if a glitch

- may mimic a GW candidate

→ alert retractation

- may bias the candidate properties

→ alert update

Human Vetting

Machine learning for Gravity Spy: Glitch classification and dataset

GCN Notices content

Root		
IVORN	ivo://nasa.gsfc.gcn/LVC#[{T,M}]SYYMMDDabc-{1,2,3}-{Preliminary,Initial,Update,Preliminary-Retraction}	
Role	{observation,test}	
Who		
Date	Time sent (UTC, ISO-8601), e.g. 2018-11-01T22:34:49	
Author	LIGO Scientific Collaboration and Virgo Collaboration	
WhereWhen	Time of signal (UTC, ISO-8601), e.g. 2018-11-01T22:22:46.654437	
What		
GraceID	GraceDb ID: [{T,M}]SYYMMDDabc. Example: MS181101abc	
Packet Type	GCN Notice type: {Preliminary,Initial,Update}	
Notice Type	Numerical equivalent of GCN Notice type: {150,151,152}	
FAR	Estimated false alarm rate in Hz	
Sky Map	URL of HEALPix FITS localization file	
Group	CBC	Burst
Pipeline	{Gstlal,MBTAOnline,PyCBC,SPIIR}	{cWB,oLIB}
CentralFreq	N/A	Central frequency in Hz
Duration		Duration of burst in s
Fluence		Gravitational-wave fluence in erg cm^{-2}
BNS, NSBH, BBH, Noise	Probability that the source is a BNS, NSBH, NSBH merger, or terrestrial (i.e., noise) respectively	N/A
HasNS, HasRemnant	Probability, under the assumption that the source is not noise, that at least one of the compact objects was a neutron star, and that the system ejected a nonzero amount of neutron star matter, respectively.	

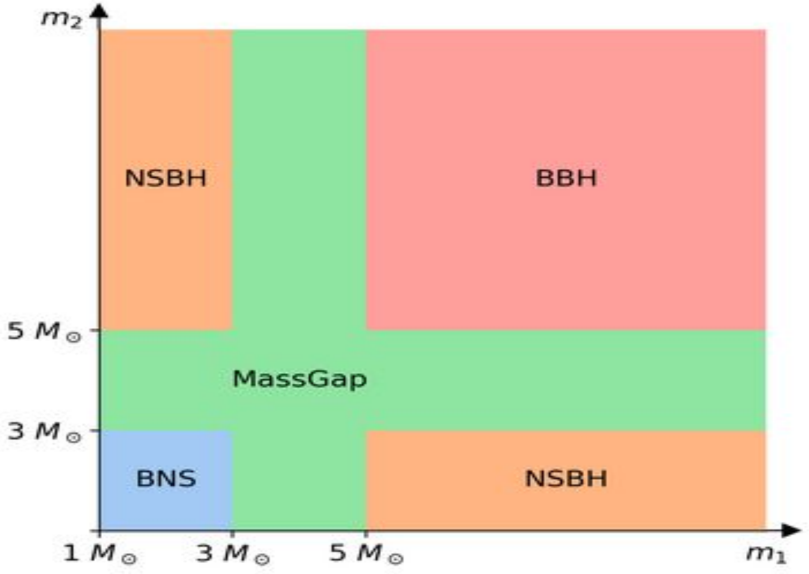
Alert notices send within 5-10 minutes with

- delivery of a first skymap
- False Alarm Rate
- Classifiers of the nature of the source

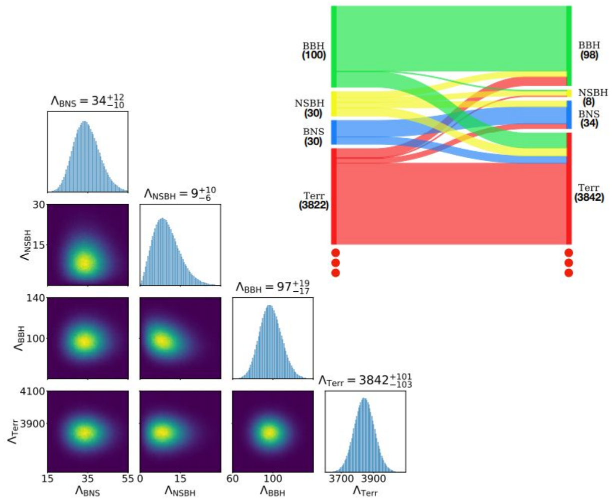
Initial notices sent after validation
Updates notices sent couple of hours later

Visible as well on gracedb public page

Classification



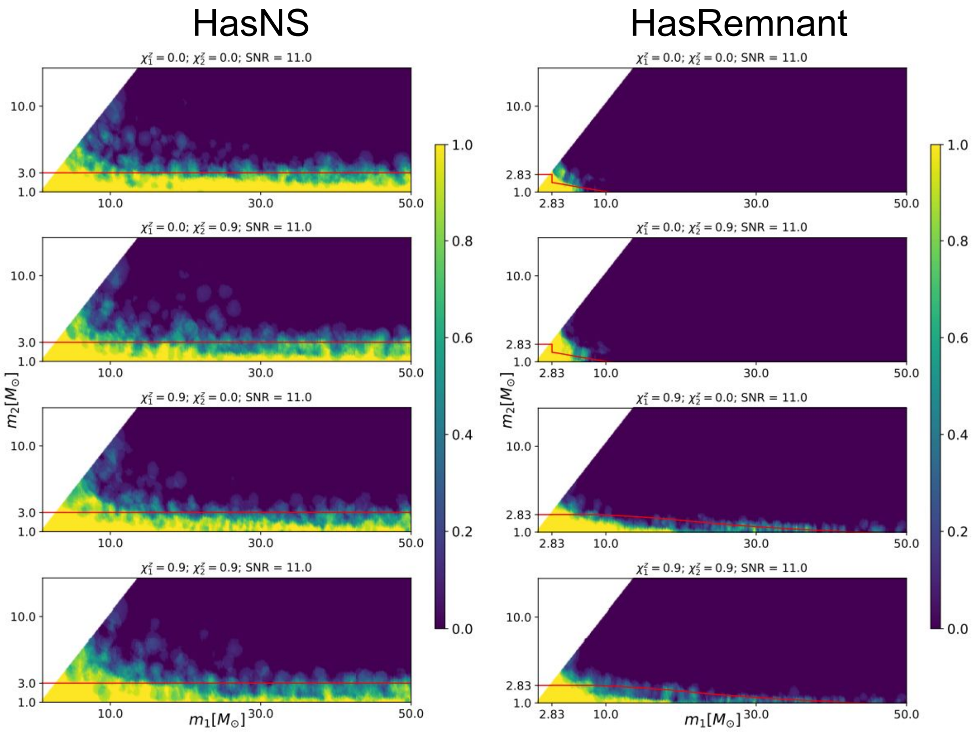
Visual representation of the multi-component posterior on the Poisson counts for BNS, NSBH, BBH, Ter



[Machine Learning Base A self-consistent method to estimate the rate of compact binary coalescences with a Poisson mixture model], Kapadia et al, 2019

Has-Remnant

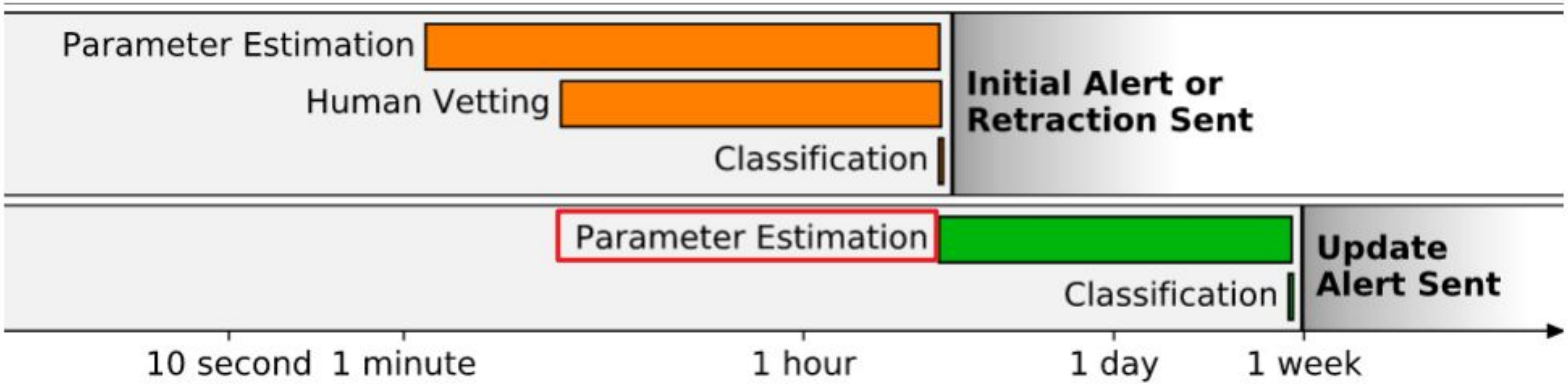
"EM bright" the binary is expected to have at least one neutron star (NS) component



Predictions of the trained binary classifier upon performing a parameter sweep on the (m1, m2) values.

A Machine Learning Based Source Property Inference for Compact Binary Mergers, Chatterjee et al., 2019

Parameters estimations



Bayesian parameter estimation Markov Chain Monte Carlo (MCMC) or Nested sampling

15 parameters (2 Masses, Lum Distance, Inclination angle, …)
Frequency Domain vs Time Domain with different post-newtonian waveforms and EOS for BNS or NSBH

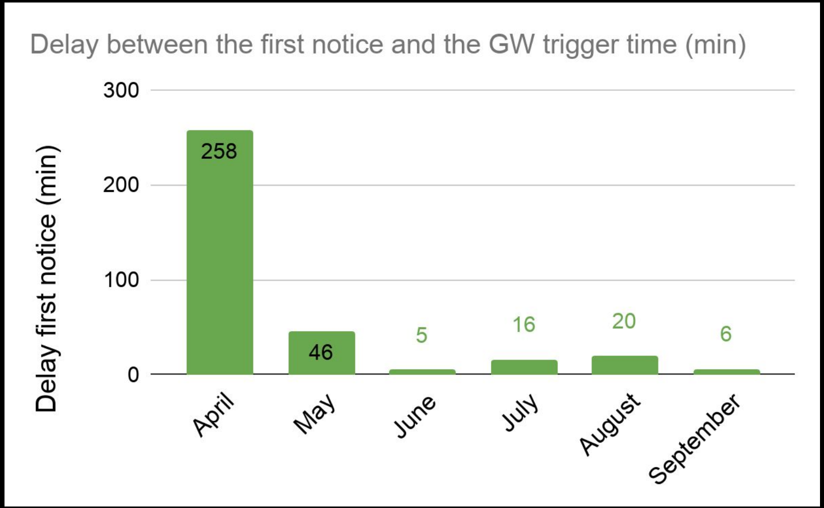
O3a-b alerts summary

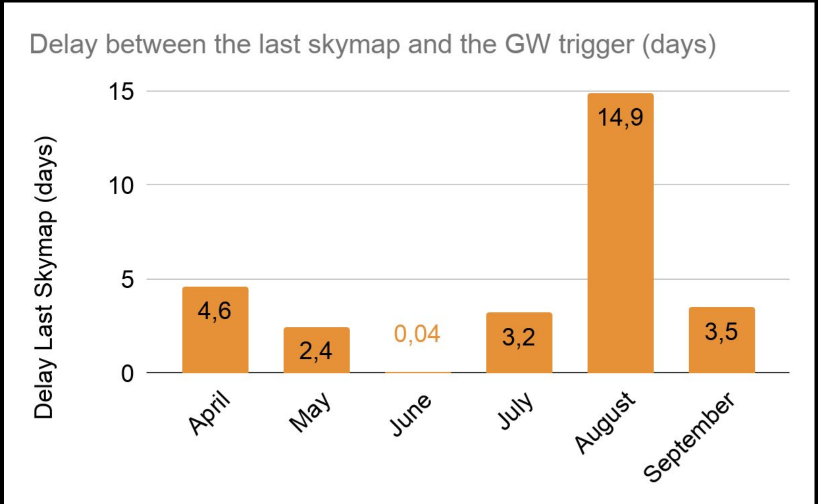
48 PUBLIC GW ALERTS

6 BNS 4 NS-BH 25 BBH MERGERS CANDIDATES

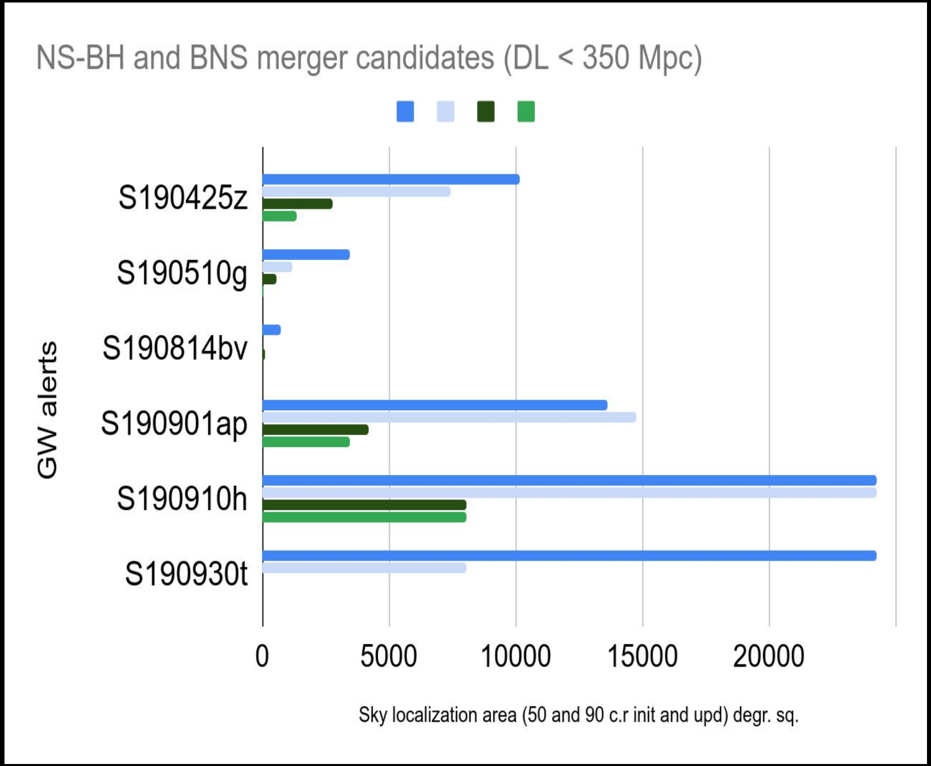
13 RETRACTATIONS

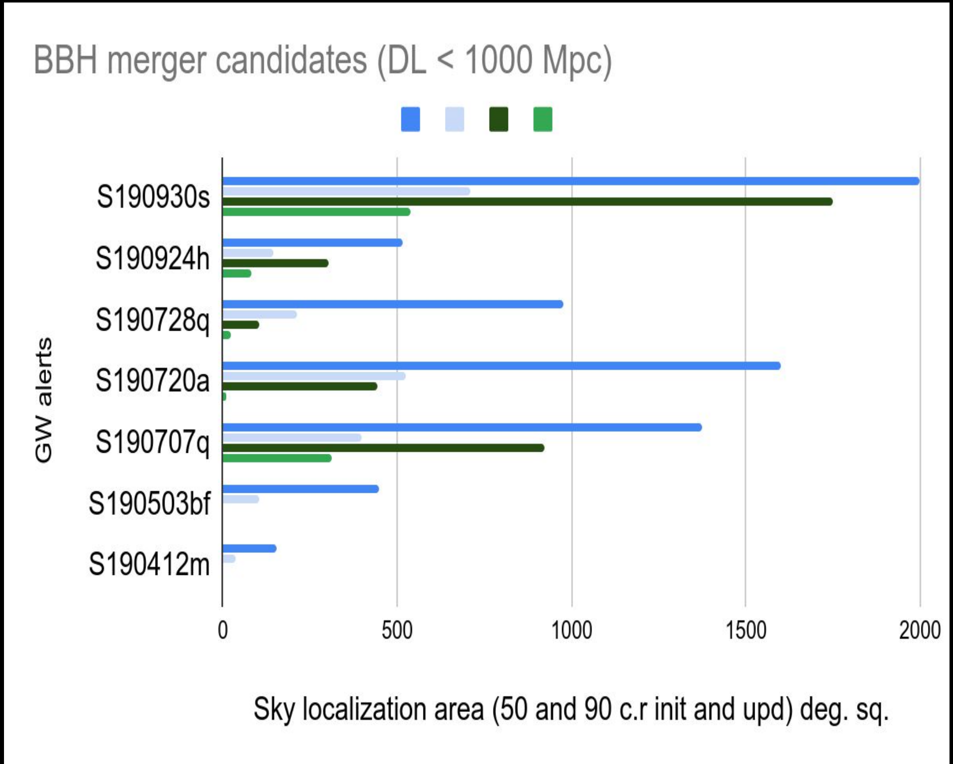
FINAL CONTENT MAY DIFFER !





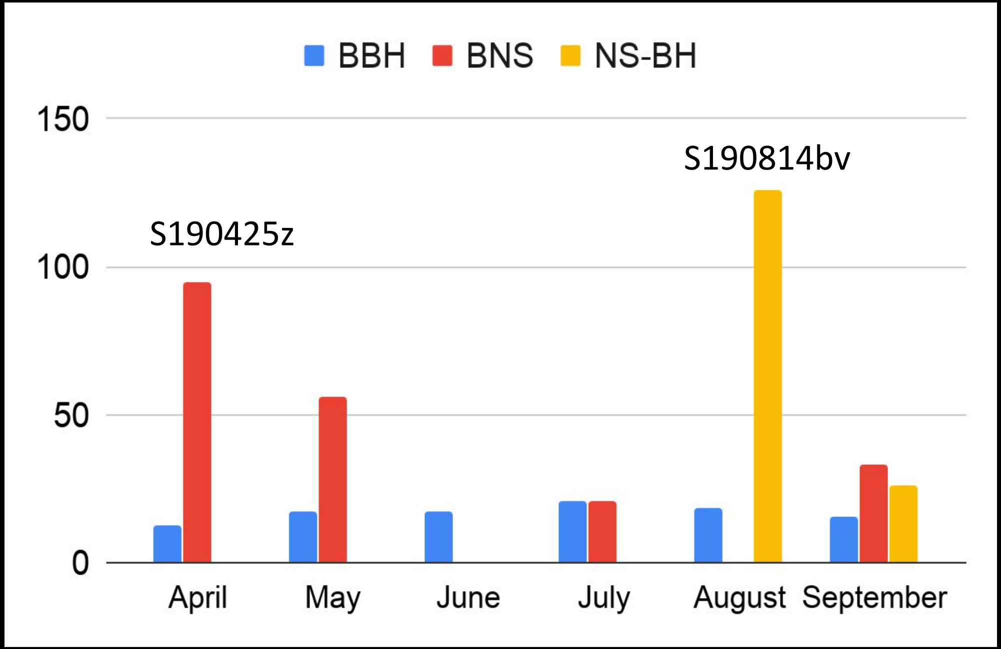
Low latency parameters estimations





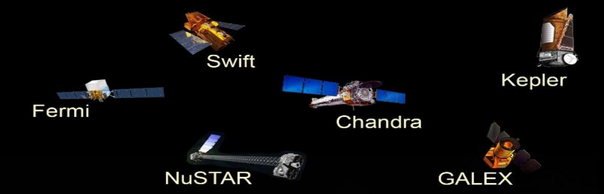
GCN traffic during O3a

LIGO-Virgo candidates currently generate ~50% of GCN circular traffic
Traffic is getting lower ...



- S190425z (BNS) and S190814bv (NSBH) generated ~120 circulars
- S190728q (MassGap then BBH) generated ~40 circulars
- Fermi GBM-190816 generated ~20 circulars

Who is following the alerts ?



30% of the GCN traffic is due gamma-ray observations

IceCube

Master

Growth

8% from neutrino and high energy observations

14% by GRANDMA, GROWTH, MASTER and GTC follow-up

GTC

Grandma

ASKAP

40 % by other groups as radio or optical teams

What is new in O3b ?

Two preliminary alerts (for most of the events) sent via GCN to observing partners.

- The first will be sent out as soon as we have a publishable event with all relevant data products that we share.
- Upon receipt of first preliminary, the second preliminary alert generation process will be launched after a timeout.
- Accumulating and revising the preferred event.
- A second preliminary GCN will then be sent, even if the preferred event did not change.

If the event is retracted before second preliminary, no further second preliminary notice will be sent. Only a retraction GCN will be sent.

Unexpected/Exceptional situation: A manual preliminary alert triggered by human before Initial Notice. Help potential time-sensitive case

RAVEN alert system online

- Automated alerts for coincident GW candidates associated with a GRB or SNEWS event (RAVEN pipeline).
  - GW candidates that may not be significant on their own
  - Have an associated GRB or supernova
  - Resulting increases in joint significance to meet the current established threshold.
- RAVEN-specific preliminary GCN Notice under work; expected development by November.
  - Until then a preliminary LIGO-Virgo GCN notice would be sent.
- Containing usual data products: GW sky-maps; classification & properties.
- The association will be clarified in the following GCN circular.

Perspectives

Toward real time gravitational wave astronomy

- Alerts produced during the inspiral sequence ?
- Robustness of the low-latency classifiers for low masses objects
- Easing digestion of the multiple pipelines search “Super-event”

Toward sub-threshold event alert distribution

- Single of Multiple IFOs in coïncidence with EM signal ?

Toward a 4-detector network

Toward a multi-messenger searchs

Extension of RAVEN to other Gamma-ray surveys and neutrinos

Targeted searches case by case

Question of X-ray/Optical surveys under debate (estimation of GW T0 emission)

Infrastructure linked to alerts in O4 and beyond connected to a new/update alert broker ?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VIRGO
Thanks
Image Credit: LSC/Sonoma State University/Aurore Simonnet