Entering the multi messenger area of Astronomy

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for the LIGO and Virgo collaborations
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Multi-messenger sources

Coalescence of binary system of neutron stars and/or stellar-mass black-hole

Core-collapse of massive stars

Isolated neutron stars
GW point of view

GW answering to counterparts
GW triggering counterparts
A new window to the universe

LVC arXiv:1811.12907
**Ex-triggered**

- GW community perform searches triggered by counterparts
  - GRB
  - Core collapse supernovae
  - FRB
  - Neutrinos
  - …

Combined exclusion distance for 20 short GRBs analyzed with the coalescence search for both a BNS and an NS-BH progenitor (top) and for all 31 GRBs analyzed with the generic transient search for ADI-A and standard siren CSG GW transients at 150 Hz with an energy of $E_{gw}=10^{-2}M_\odot c$ (bottom). We exclude at 90% confidence level cumulative distance distributions that pass through the region above the solid curves.

The different curves show how the probability, or confidence, with which we could exclude a CCSN model is expected to scale with the sample size of observed supernovae (denoted by $p$) and the sensitivity to the waveform amplitude (denoted by $A$). Currently $p=A=1$ so we cannot yet make any statements excluding this model.
GW Followup

- GW candidates triggering counterparts
- In O3 OPA (Open Public Alert) Era begins: no more «Event validation»: trigger automatically sent out (and eventually manually retracted)

See P. Savina poster on Pierre-Augier Observatory
GW150914

• First detection of GW
• Coalescence of Black Holes
• Only LIGO detectors
• Open the GW astrophysics

Simulation of merging black holes radiating gravitational waves
Credits: NASA/Ames Research Center/C. Henze

GW150914 follow-up

- First exercise on a real event event
- Big covered area (230 deg$^2$)
- No found counterparts (as expected)

O1 vs O2 alerts

O1

• 3 alerts:
  • GW150914
  • G194575
  • GW151226

• 2 confirmed detection and 1 rejection

O2

• 11 confident detections

• Consistent with noise

• Rejected by offline analysis

LVC arXiv:1811.12907

Credits: M. Branchesi
GW170814: the first HLV detection

- Blue: two LIGO detectors only (1160 square degrees).
- Orange: Adding Virgo (100 square degrees).
- Green: full parameter estimation analysis with three detectors (80 square degrees).
- Not shown: full parameter estimation using two LIGO detectors (700 square degrees).

Multimessenger detections

And astrophysics discoveries
1987 supernova

• Probably the first multi-messenger detection
  • EM spectrum
  • Neutrino

• No GW observed (Resonant bars)
GW170817

- Coincident detection between GW and GRB
- Ligo-L showing a glitch occurring during the event
- Follow-up campaign found EM counterparts
Short GRB

NS merger

Radio

X-ray afterglow

LHV sky localization

Kilonova

Credits: M. Branchesi

LVC + astronomers, ApJL, 848, L12
First spectral identification of the kilonova emission

- the data revealed signatures of the radioactive decay of r-process nucleosynthesis (Pian et al. 2017, Smartt et al. 2017)
- BNS merger site for heavy element production in the Universe! (Cote et al. 2018, Rosswog et al. 2017)

EJECTED MASS $\sim 0.03 - 0.05 \, M_\odot$

EXPANSION VELOCITY $\sim 0.1 - 0.3 \, c$
GW velocity

Constraining velocity rules out modified gravity models

Considering the delay between GW and GRB, and the distance they travelled

\[ \Delta t = 1.74 \pm 0.05 \text{ s} \]
\[ d \sim 40 \text{ Mpc} \]

we have:

\[ -3 \cdot 10^{-15} \leq \Delta c/c \leq 7 \cdot 10^{-16} \]

LVC 2017, APJL, 848, L13
$H_0$ measurement

Combine distance from GW:

$$d = 43.8^{+2.9}_{-6.9} \text{ Mpc}$$

And NGC4993 recession velocity we have:

$$H_0 = 70^{+12.0}_{-8.0} \text{ Mpc}$$

Abbott et al. 2017, Nature, 551, 85A
Neutrino + EM

- **September 22nd, 2017**: Trigger alert from IceCube of a high energy neutrino event
- **Fermi-LAT** detects a blazar in a high gamma-ray state in the neutrino field of view
- IACTs observations triggered
- MAGIC detected a significant signal (just before the full moon break)

The SED is based on observations obtained within 14 days of the detection of the IceCube-170922A event. The vertical axis is equivalent to a scale Differential flux upper limits (shown as colored bands and indicated as “UL” in the legend) are quoted at the 95% CL, while markers indicate significant detections. Archival observations are shown in gray to illustrate the historical flux level of the blazar in the radio-to-keV range as retrieved from the ASDC SED Builder (62), and in the γ-ray band as listed in the Fermi-LAT 3FGL catalog (23) and from an analysis of 2.5 years of HAWC data. Representative neutrino flux upper limits that produce on average one detection like IceCube-170922A over a period of 0.5 (solid black line) and 7.5 years (dashed black line) are shown, assuming a spectrum of at the most probable neutrino energy (311 TeV).

The 50% and 90% containment regions for the neutrino IceCube-170922A (dashed red and solid gray contours, respectively. Gamma-ray sources in this region previously detected with the Fermi spacecraft are shown as blue circles, with sizes representing their 95% positional uncertainty and labeled with the source names. The yellow circle shows the 95% positional uncertainty of very-high-energy γ-rays detected by the MAGIC telescopes during the follow-up campaign.
The future is now

Waiting for GW+EM+Neutrino…
O3 has started April 1st

FIRST O3 EVENT YESTERDAY!!!

LIGO-VIRGO Joint Run Planning Committee

Working schedule for O3
(Public document G1801056-v4, based on G1800889-v7)

Epoch 2018 – 2019

Planed run duration 12 months

Expected burst range/Mpc

LIGO 75 – 90
Virgo 40 – 50
KAGRA —

Expected BNS range/Mpc

LIGO 120 – 170
Virgo 65 – 85
KAGRA —

Achieved BNS range/Mpc

LIGO —
Virgo —
KAGRA —

Estimated BNS detections 1 – 50

Actual BNS detections —

90% CR % within

5 deg^2 1 – 4
20 deg^2 12 – 21
Median/deg^2 120 – 180

Searched area % within

5 deg^2 20 – 26
20 deg^2 42 – 50

GEO ~70% observing mode

Detector operational, commissioning mode (small fraction of observing mode time)
Detector in observing mode for a fraction of the time during Engineering Runs (ERs), possible GW alerts with human vetting
Detector not producing data (downtime)
24/7 observing mode (Observing Run, Open Public Alerts in low-latency)

ER13: from 8am PT Dec 14 to 6 am PT Dec 18
ER14: up to four weeks, starting at the earliest March 1st, 2019 O3 to follow

O3: one calendar year long