GW170817/GRB 170817A

An Astronomy/Astrophysics Viewpoint

Deep Chatterjee$^{1,2}$
on behalf of the LIGO-Virgo Collaboration

$^1$University of Wisconsin – Milwaukee

$^2$LIGO–Virgo Collaboration

Rencontres de Moriond, La Thuile
March 26, 2019
Lights, Camera, Follow-up...

GW170817
[Abbott et al., 2017c]
GRB 170817A
[Goldstein et al., 2017, Abbott et al., 2017b]

SSS17a
EM170817
AT 2017gfo
[Abbott et al., 2017d]
Notice Timeline

Unprecedented Follow-up Operations

Radio, X-ray follow-up operations \(~ 1\text{yr.}\)

**Speed of gravity = \(c\)?**

On August 17, it was established correct up to \(15\) decimal places!
The Story it Told...

In this talk

The astrophysics:

- Independent measurement of $H_0$
- Tidal deformability & neutron star equation of state (EoS)
- Physics of “kilonova”
- Progenitor model
- Post-merger remnant
- Stochastic background & merger rates

Multi-messenger astronomy:

- Follow-up operations
- Looking ahead at the third observing run (O3)
GW-GRB Association

- GW170817 - GRB 170817A unambiguous association
- Chance spatio-temporal coincidence, $p = 5 \times 10^{-8} \Rightarrow 5.3\sigma$ significance. [Abbott et al., 2017b]

BNS system are progenitors of, at least, some short GRBs
Parameter Estimates
GW170817 Masses and Spins

Credits [Abbott et al., 2018b]

\[ M_c = 1.186 M_\odot; \quad \Delta \Omega = 16 \text{deg}^2; \quad d_L = 40 \text{Mpc}; \quad \text{SNR} = 33 \]

Chirp mass
Sky loc.
Lumin. dist.
Signal to noise
Parameter Estimates

Tidal Deformability

\[ \Lambda = \left( \frac{2}{3} \right) k_2 \left( \frac{Gm}{c^2 R} \right)^{-5} \]

Effective tidal parameters enter waveform @ 5 PN

Credits [Abbott et al., 2018a]
Neutron Star Equation of State

Low Spin Prior

Low Support for stiff EoS
MS1 like EoS ruled out with $\geq 90\%$ confidence
- Compact NS favored
- For GW170817, $R_1 = 11.9^{+1.4}_{-1.4}\text{km}$; $R_2 = 11.9^{+1.4}_{-1.4}\text{km}$

[Abbott et al., 2018a]
Dynamical Ejecta

GW parameters $\rightarrow M_{ej}$

\[ M_{ej} = M_{ej}(m, m_b, R) \]

\{ \( m, \Lambda \) \} $\xrightarrow{\text{EoS}}$ \{ \( m_b, R \) \}

from GW

NR fitting [Dietrich and Ujevic, 2017]

Credit [Abbott et al., 2017a]
$r$-process Abundance

\[ \rho_{rp} = f_{rp} \times M_{ej} \times R \times \langle T_{\text{mergers}} \rangle \]

\[ X_{rp} = \frac{\rho_{rp}}{\rho_*} \]

$\rho_{rp} \geq 10\%$ accounts for MW abundance [Abbott et al., 2017a]
Post-Merger Remnant

GW Signatures

- Possible scenarios:
  - Prompt collapse into BH; quasi-normal modes
  - Hypermassive NS; collapse to BH $\lesssim 1\text{s}$
  - Supramassive NS; collapse to BH $\sim 10 - 10^4\text{s}$
  - Stable NS

- Absence of template waveform

- Generic search for excess power in spectrogram

- Whatever the scenario, optimistic GW emission @ $\text{SNR} \sim 1 - 2$ in LIGO-Virgo band.

No GW signature found

Signal, if present, is too weak for current sensitivity/searches
[Abbott et al., 2017f, Abbott et al., 2019]
Progenitor of GW170817

Occurrence $\sim 2\text{kpc}$ from center of NGC 4993, constrains:

- Delay time, $T_{\text{delay}}$
- Distance of second CC-SNe, $R_{\text{SN}}$
- Natal kick, $v_{\text{kick}}$

Credits [Abbott et al., 2017e]
Progenitor properties robust if stellar properties of NGC 4993 is older than ∼1 Gyr [Abbott et al., 2017e]

$v_{\text{kick}}^{90\%} \sim 300^{+250}_{-200} \text{ km s}^{-1}; \quad R_{\text{SN}}^{90\%} \sim 2.0^{+4.0}_{-1.5} \text{ kpc}$
Hubble Constant Measurement

Credits [The LIGO Scientific Collaboration et al., 2017]

General agreement with $H_0$ from SNIa’s and CMB
More detections will sharpen posterior
Looking ahead in **O3**

**Implication of Rates**

<table>
<thead>
<tr>
<th>Detector</th>
<th>BNS range (Mpc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIGO</td>
<td>~ 120–140</td>
</tr>
<tr>
<td>Virgo</td>
<td>~ 50</td>
</tr>
<tr>
<td>Kagra</td>
<td>≤ 25</td>
</tr>
</tbody>
</table>

- **Expected Rates** \(^1\):
  - Total BNS count ~ 1–10.
  - BBH candidates are expected once a week.
  - NSBH rates uncertain at this stage.

- **Skymaps:**
  - BNS systems will have median 90% sky areas between 120 – 180 deg\(^2\).
  - 12 – 21% such systems expected to be localized ≤ 20 deg\(^2\).

\(^1\) [https://dcc.ligo.org/LIGO-G1800370/public](https://dcc.ligo.org/LIGO-G1800370/public)
Follow-up campaign

- **GW170817:**
  - First success story of electromagnetic & gravitational-wave (EMGW) astronomy.
  - Follow-up operations were unprecedented.

- **Need for a rapid, robust alert infrastructure:**
  - Semi-automated with low false alarm.
  - Data products from GW side to aid EM follow-up.
  - Crucial to capture the transient at early times.
Public Alerts
For the first time, LIGO-Virgo Alerts will be public!

- All alerts are sent over Gamma-ray Coordinate Network (GCN)
- Retractions might happen at the *Initial* stage
- Circulars are sent during Initial alert
Low-latency Data Products

Skymaps

Chances of EM-counterpart

$P_{\text{astro}}$ by source category

GW-GRB association
GW Inference
EMGW Inference
Follow-up
Combined Skymaps
Will be sent for Fermi and IceCube

(a) GW170817 (HL)  (b) Fermi GBM  (c) Combined
Userguide for alerts in O3

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.

https://emfollow.docs.ligo.org/userguide/

Abbott, B. P. et al. (2017b).

Abbott, B. P. et al. (2017c).

Abbott, B. P. et al. (2017d).

Abbott, B. P. et al. (2017e).

Abbott, B. P. et al. (2017f).


Abbott, B. P. et al. (2019).
Properties of the Binary Neutron Star Merger GW170817.

Modeling dynamical ejecta from binary neutron star mergers and implications for electromagnetic counterparts.
*Classical and Quantum Gravity*, 34:105014.

An Ordinary Short Gamma-Ray Burst with Extraordinary Implications: Fermi-GBM Detection of GRB 170817A.

A gravitational-wave standard siren measurement of the Hubble constant.