LIGO - Gravitational Wave Detection and Future Plans

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Welcome to the era of GW astrophysics!

2 confirmed BBH mergers in Advanced LIGO first observing run O1 (Sep 2015 - Jan 2016)
Advanced LIGO 1st observing run (O1)

\[ \sqrt{S(f)} \text{ and } 2h(f)/\sqrt{f} \text{ (strain/\sqrt{Hz})} \]

\begin{align*}
\text{Frequency (Hz)} & \quad \text{Strain (10^{-21})} \\
10^1 & \quad 10^{-21} \\
10^2 & \quad 10^{-22} \\
10^3 & \quad 10^{-23}
\end{align*}

- Hanford
- Livingston

\begin{align*}
\text{Time from 30 Hz (s)} & \\
0.0 & \\
0.5 & \\
1.0 & \\
1.5 & \\
2.0 & \\
GW150914 & \\
LVT151012 & \\
GW151226 &
\end{align*}

LVC, PRX, 6, 041015 (2016)
For lower-mass GW151226 and LVT151012, distributions follow curves of constant chirp mass; for GW150914 (SNR equally split between in-spiral and post-in-spiral) distribution shaped more by constraints on total mass.

Luminosity distance to source inversely proportional to signal amplitude. GW150914 and GW151226 comparable distance. LVT151012 at greater distance.
Probable position of source - RA (hours), Dec (deg):
GW150914 → 230 deg² (90%)
LVT151012 → 1600 deg² (90%)
GW151226 → 850 deg² (90%)

Sky area scales inversely with square SNR.

LVC, PRX, 6, 041015 (2016)
GW150914 EM follow-up

- Consortium between LIGO-Virgo and 63 teams using ground and space facilities.
- Gamma-ray, X-ray, optical, infrared, and radio wavelengths.
BBH gamma-ray counterpart?

- γ-ray signal (0.2% FAP) lasting ~1s in Fermi/GBM (>50 keV), 0.4 s after BBH merger (Connaughton et al. 2016, ApJ, 826, 6).


If γ-ray transient is a SGRB associated with GW150914, then it is an outlier in the luminosity-$E_{\text{peak}}$ plane (Li et al. 2016, ApJ, 827, L16).
◆ Second Advanced LIGO run (O2) began on November 30, 2016 - currently in progress.

◆ As of April 23 approximately 67 days of Hanford-Livingston coincident science. Average reach: 70 Mpc for NS-NS, 300 Mpc for 10+10 \( M_\odot \) and 700 Mpc for 30+30 \( M_\odot \) mergers.

◆ As of April 23, 6 triggers identified by online analysis using loose false-alarm-rate threshold of 1/month, and shared with astronomers (via MoUs) for EM follow-up.

◆ A thorough investigation of data in progress; results will be shared when available – http://www.ligo.org/news.php#sthash.bR30qPvX.dpuf
Expected progress in the near future

LVC, Living Reviews in Relativity 19, 1 (2016)
BHs are nice but NSs matter...

- Binary neutron stars (NSs)
- BH-NS star binaries
- Individual NSs and magnetars
- Supernovae (and engine-driven SNe)
A zoo of possibilities, a “bright” future…

Matched filter

Excess power, cross-correlation

Modeled Waveform

Unmodeled Waveform

Short Duration

Long Duration
Current constraints on BNS rates

Dominik et al. pop syn
de Mink & Belczynski pop syn
Vangioni et al. r-process
Jin et al. kilonova
Petrillo et al. GRB
Coward et al. GRB
Siellez et al. GRB
Fong et al. GRB
Kim et al. pulsar
aLIGO 2010 rate compendium

BNS Rate (Gpc$^{-3}$yr$^{-1}$)

Current constraints on BH-NS rates


Dark blue: 5-1.4 $M_\odot$
Light blue: 10-1.4 $M_\odot$
BNS: prospects for improved localizations

2016-2017

BNS system at 80 Mpc

2017-2018

BNS system at 160 Mpc

2019+

2022+

LVC, Living Reviews in Relativity 19, 1 (2016)
Pre-merger emission (?)

Interaction with ISM (optical and radio afterglow, days to months)

(Short) Gamma-ray Burst (seconds), X-ray (secs-days) if on-axis

Kilonova R-process nucleosynthesis: optical-IR (~ 1 day).

Courtesy: Varun Bhalerao
A zoo of possibilities, a “bright” future...

- Modeled Waveform
- Unmodeled Waveform

- Matched filter
- Excess power, cross-correlation

Short Duration
Long Duration
GWs bursts and core-collapse events

$R_{GRB} \approx R_{GRB,obs}(1-\cos\theta_j)^{-1}$

Extreme collapse (optimistic): $\sim 10^{-2} M_\odot c^2$ in GWs $\Rightarrow < 100 \text{ Mpc}$

$R_{LGRB,obs} \approx 1 (\text{Gpc})^{-3} \text{ yr}^{-1}$
$(1-\cos\theta_j)^{-1} \approx 65$ (i.e. $\theta_j \approx 10$ deg)
$R_{LGRB} \approx 0.3 \text{ yr}^{-1}$ at $\leq 100$ Mpc (only 1-2 in 100 with $\gamma$-rays)

$R_{LLGRB,obs} \approx 100-400 (\text{Gpc})^{-3} \text{ yr}^{-1}$ (Virgili et al. 2009, MNRAS, 329, 91).
$R_{LLGRB,obs} \approx R_{LLGRB} \approx 0.4-2/\text{yr at } \leq 100 \text{ Mpc}$

Galactic core-collapse SNe: $R_{SN,MW} \approx 1-3/\text{Century.}$
Radio counterparts to core collapses

Welcome to the era of GW astrophysics!

More BBH detections to be expected (and awesome related astrophysics; Kesden’s talk).

BBH are nice but NS matter… A broad community is looking forward to NSs and EM follow-up!
TO APPLY AND FOR MORE INFO VISIT:
http://www.depts.ttu.edu/phas/Academics/Graduate_Program/Prospective_Students/index.php