What comes next for LIGO?
Planning for the post-detection era in gravitational-wave detectors and astrophysics

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Why are we here?

• Advanced LIGO detectors, a concept that was part of the original LIGO proposal, will soon discover gravitational waves;

• What happens after Advanced LIGO discoveries?

• Will those discoveries affect…
  ➢ ... the short term R&D for Advanced LIGO detectors improvements?
  ➢ ... the searches for astrophysical sources?
  ➢ ... the plans for multi-messenger astronomy?
  ➢ ... US plans for GW science?
  ➢ ... the dynamics of the international network?

• The answer is YES.

• The real question is HOW those discoveries may affect these aspects: this is what we want to discuss here.
Table 1: Summary of a plausible observing schedule, expected sensitivities, and source localization with the advanced LIGO and Virgo detectors, which will be strongly dependent on the detectors’ commissioning progress. The burst ranges assume standard-candle emission of $10^{-2} M_\odot c^2$ in GWs at 150 Hz and scale as $E_{\text{GW}}^{1/2}$. The burst and binary neutron star (BNS) ranges and the BNS localizations reflect the uncertainty in the detector noise spectra shown in Fig. [1]. The BNS detection numbers also account for the uncertainty in the BNS source rate density [28], and are computed assuming a false alarm rate of $10^{-2} \text{yr}^{-1}$. Burst localizations are expected to be broadly similar to those for BNS systems, but will vary depending on the signal bandwidth. Localization and detection numbers assume an 80% duty cycle for each instrument.
A reminder: Observing Scenario


![Graph showing strain noise amplitude vs frequency for Advanced LIGO and Advanced Virgo](image)

Figure 1: aLIGO (left) and AdV (right) target strain sensitivity as a function of frequency. The average distance to which binary neutron star (BNS) signals could be seen is given in Mpc. Current notions of the progression of sensitivity are given for early, middle, and late commissioning phases, as well as the final design sensitivity target and the BNS-optimized sensitivity. While both dates and sensitivity curves are subject to change, the overall progression represents our best current estimates.
Very rapid commissioning progress

Latest calibrated spectra in https://dcc.ligo.org/LIGO-G1401390/public
Detections are coming

- It will be a milestone discovery!

- Probably followed soon (or preceded) by other gravitational wave detections (pulsar timing, CMB polarization)
What comes next for LIGO?

- We have a “default” plan for LIGO – will need adapting to known sources after we have detections.

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Estimated Run Duration</th>
<th>Estimated Run Duration</th>
<th>$E_{GW} = 10^{-2}M_\odot c^2$ Burst Range (Mpc)</th>
<th>BNS Range (Mpc)</th>
<th>Number of BNS Detections</th>
<th>% BNS Localized within 5 deg$^2$</th>
<th>% BNS Localized within 20 deg$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>3 months</td>
<td>40 – 60</td>
<td>–</td>
<td>40 – 80</td>
<td>0.0004 – 3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2016–17</td>
<td>6 months</td>
<td>60 – 75</td>
<td>20 – 40</td>
<td>80 – 120</td>
<td>0.006 – 20</td>
<td>2</td>
<td>5 – 12</td>
</tr>
<tr>
<td>2017–18</td>
<td>9 months</td>
<td>75 – 90</td>
<td>40 – 50</td>
<td>120 – 170</td>
<td>0.04 – 100</td>
<td>1 – 2</td>
<td>10 – 12</td>
</tr>
<tr>
<td>2019+</td>
<td>(per year)</td>
<td>105</td>
<td>40 – 80</td>
<td>200</td>
<td>0.2 – 200</td>
<td>3 – 8</td>
<td>8 – 28</td>
</tr>
<tr>
<td>2022+</td>
<td>(India) (per year)</td>
<td>105</td>
<td>80</td>
<td>200</td>
<td>0.4 – 400</td>
<td>17</td>
<td>48</td>
</tr>
</tbody>
</table>
Current plan: white papers

LSC Instrument Science White Paper
https://dcc.ligo.org/LIGO-T1400316/public

2 Roadmap 2015-2035 and Executive Summary

2.1 A+ .................................................................
2.2 LIGO Voyager .................................................
2.3 LIGO Cosmic Explorer .................................

Figure 2: Timeline for A+, LIGO Voyager and LIGO Cosmic Explorer.
Current plan: white papers

<table>
<thead>
<tr>
<th>Priority Level</th>
<th>Burst</th>
<th>CBC</th>
<th>CW</th>
<th>SGWB</th>
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</thead>
<tbody>
<tr>
<td>All-sky search for generic GW transients, in low latency for EM followup and deep, online for 4+ detection confidence</td>
<td>All-sky matched-filter search for binary neutron star (BNS) systems, deep and low latency</td>
<td>All-sky search for isolated neutron stars, both as a quick-look on owned resources and as a deep/broad search on Einstein@Home</td>
<td>Targeted search for high value, known pulsars</td>
<td>Isotropic search for stochastic GW background</td>
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<tr>
<td>Parameter estimation for the astrophysical interpretation of detected burst events</td>
<td>All-sky matched filter search for binary neutron-star and black-hole (NSBH) systems, deep and low latency</td>
<td>Directed searches for Cas-A</td>
<td>Constraints of a detected background of astrophysical origin with long transients</td>
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<tr>
<td>Search for GW bursts triggered by outstanding GRB alerts</td>
<td>All-sky matched filter, deep search for binary black-hole (BBH) systems</td>
<td>Directed searches for X-ray binaries SGR-X1 and J1751-305</td>
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<tr>
<td>Searches triggered by outstanding astrophysical events (a galactic supernova, neutron star transients, an exceptional high energy neutrino alert)</td>
<td>Parameter estimation of detected CBC events</td>
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<tr>
<td>Search for cosmic string kinks and cusps</td>
<td>CBC searches triggered by all GRB alerts</td>
<td>Tests of General Relativity with CBC events</td>
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<tr>
<td>Searches triggered by high energy neutrinos, extragalactic supernovae, and GRB observations</td>
<td>All-sky search for spinning binary neutron star systems (deep and low latency)</td>
<td>Targeted search for other known pulsars</td>
<td>Long transient follow up of CBC and burst candidates</td>
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<td>Burst search for intermediate mass and eccentric black hole binary systems</td>
<td>Matched filtered search for intermediate mass black hole binary systems</td>
<td>Directed searches for other isolated stars and X-ray binaries</td>
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<td>All-sky search for long bursts of &gt; 10s duration</td>
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<td>GRB-triggered search for long-duration bursts and plateaus</td>
<td>Exploring effects of detector noise on parameter estimation</td>
<td>All-sky search for isolated stars (alternative approaches)</td>
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<td>Hypermassive neutron star followup</td>
<td>All-sky search for binaries</td>
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<td>Burst searches triggered by radio transients and by SGR/SGR-QPO</td>
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<td>Burst tests of alternative gravity theories</td>
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**LIGO-T1500055 - Table 2, page 2**
Current plan: astronomy partners

- More than 70 agreements signed from 20 countries, with about 150 instruments covering the full spectrum, from radio to high-energy gamma-rays.
- Shortly after a few detections, LSC/Virgo will publicly release GW triggers for follow up: dcc.ligo.org, LIGO-M1200055.
Current plans have multiple paths

• How will first few detections influence paths in the years that follow? In short term, different paths may compete with each other…

• How can the community be prepared with appropriate plans? We may consider different scenarios if they depend on the nature of the first detections.

• Five sessions on plans for:
  - multi-messenger astronomy;
  - data analysis;
  - aLIGO improvements;
  - international network;
  - GW science in the context of US science.
What’s next?

• Expect from each session active discussion, converging in consensus (of attendants) or description of plans following detections.

• A brief write-up of results of discussions will be compiled by session chairs and circulated within ~ a month; later posted in conference website.

• Let’s get to work!