3G – low-frequency & populations

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Where are we?

• In the first two science runs advanced detectors have detected
  – 10 binary black holes (BBH)
    LVC, Arxiv:1811.12907
  – And 1 binary neutron star (BNS), LVC
    PRL 119, 161101, PRX 9 011001
    • Electromagnetic emission also detected!

• First 50 days of O3:
  – ~10 BBH, 1 BNS, 1 NSBH (?)
    candidates shared with the public

5/21/19
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Where do we go from here?

Total source frame mass [$M_\odot$] vs. Redshift

- aLIGO
- ET
- Voyager
- CE

Horizon
10% detected
50% detected

Redshift

100
10

Hall/Vitale

credit E. Hall, J. Miller
How many events?

• Using the rates calculated with O2 events and projecting...
• 3G detectors will detect
  – ~ $10^5$ BBH per year (Regimbau+, PRL 118, 151105)
  – ~ $10^6$ BNS per year (LVC, PRL 120, 091101)
• They will overlap in time, which leads to interesting challenges (Regimbau+, Arxiv: 1201.3563; Meacher+ Arxiv:1511.01592)
Low frequency – computational challenges

- We would love to know how well CBC parameters can be measured in 3G. However...
- The duration of waveforms (and hence the computational time required) blows up
  - As flow decreases
  - As the chirp mass decreases
- With current methods, we cannot run parameter estimation codes on binary neutron stars for 3G
Chirp mass extrapolation

- Run actual PE (meaning MCMC, not Fisher matrix) for decreasing true chirp mass
- See if the results can be extrapolated to the BNS mass region

Whittle+, preliminary
Lower-frequency extrapolation

- Run actual PE (meaning MCMC, not Fisher matrix) for decreasing lower frequency
- See if the results can be extrapolated to the BNS mass region
- Ongoing: 2D mass/flow extrapolation
- Caveat: don’t have time dependent antenna patterns
  – Does anybody?
What gets better and what doesn’t

Mass ratio (but careful, $q_{\text{true}}=1$)

Whittle+, preliminary
Early warning for BNS

- Early warning that a BNS is about to merge -> better chances to understand the energetics of EM emission, pre-merger emission
- Lots of work by many people (UWA, PSU, Glasgow)
- Especially for network with >=ET+CE, can get significant fractions of nearby events with early warning
  - Question: can EM successfully follow-up 100deg2 at >200Mpc?

### Table

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\(^1\) Uniformly distributed in the comoving volume.

Chan+, PRD 97 123014 (sky<100deg2, snr>12)
Memory effect

• Very challenging to detect with advanced detectors

• Lasky+ showed that one might make a statistical detection given $\gg 1$ sources
  – Somewhat optimistic assumptions

• Yang+ focuses on 3G and quantifies SNR in the memory phase
IMBH, multibanding

- The space-based LISA GWs detector can observe heavy BBH and intermediate-mass BBH
- Some of those signals will also be visible from the ground (years later)
- Complementary information! (Sesana PRL 116, 231102; Vitale PRL 117, 051102; Barausse+ PRL 116, 241104)
- For nearby IMBH, LISA might provide Mchirp info, but not for z>~0.3
  - Still need decent f-low
  - But do IMBH exist...?
BBH Formation channels

• Many methods have been proposed to study the formation channels of BBH (and compact binaries in general)
  – Shown to work for advanced detectors in the local universe [Refs1]

• With 3G:
  – Study how the fraction of CBC from each channels evolve with redshift
  – Accessing thousands of BBH per year we can study the explosion mechanism of SNe (O'Shaughnessy+, PRL 119 011101 shows what can be learned with GW151226 alone)
BBH formation channels

- Depending on relative abundances, might be able to distinguish populations and calculate branching ratios.

There might be more sub-populations (e.g. AGN disks, Bartos+ Nature Com, 8 831)
Reality is always harder

- Considered a fraction of sources coming from galactic fields (as before)
- And the rest coming from globular clusters
- Madau-Dickinson template for the star-formation rate in galaxies
- Log-Normal for globular clusters (based on Carl Rodriguez’ simulations.
- Measure characteristic parameters of each population, plus branching ratios between populations.
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Time-delay distribution for BNS

\[ \dot{n}(z) = \int_{z_b=10}^{z} \lambda \frac{dP_m}{dt} (t - t_b - t_{\text{min}}) \psi(z_b) \frac{dt}{dz} (z_b) dz_b \]

\[ dP_m/dt \propto t^\Gamma \]
Time-delay distribution for BNS

Safarzadeh+, 1904.10976

All BNS

2G detectable

Merger Rate Density $[\text{Mpc}^{-3}\text{year}^{-1}]$

Detection rate $[\text{year}^{-1}]$

redshift ($z$)

redshift ($z$)
Time-delay distribution for BNS

Safarzadeh+, 1904.10976

3G detectable
More from populations

• These are just examples of what can be done with large numbers of CBCs

• Others examples include
  – Cosmology
  – Measurement of mass and spin distributions
    • Do these vary with z? How?
  – Features in the mass function
  – Higher probability of getting rare events/outliers
Rare events

• Together with populations, one gets rare events, showing peculiar properties

• However, those might not be super loud
  – Don’t expect SNR of 1000s with eccentricity with spin precession with XYZ (replace with your secret dream)
Thanks!
References

- [Refs2]: Del Pozzo+ PRL 111 071110; Chatziionannou+ PRD 97 104036; Lackey+ PRD 91 043002; Read+ PRD 79 124032
- [Refs3]: LVC ApJL, 833, 1; Wysocki+ Arxiv: 1805.06442; Farr+ , PRD 91, 023005; Gaebel+ Arxiv:1809.03815
- [Refs4]: Gossan+, PRD 85 124056; Berti+, Arxiv:1801.03587; Yang+ PRL 121, 071102; Vitale+, PRD 95 064052
Inferring the BH mass distribution

• Can use hierarchical methods to infer the underlying properties of the BH mass function
• Used 3 models, increasing complexity (and number of parameters!) [Refs5]
• No strong preference for any one model