
Y. Huang

3G – CBC populations

Salvatore Vitale
MIT

PAX VI, EGO
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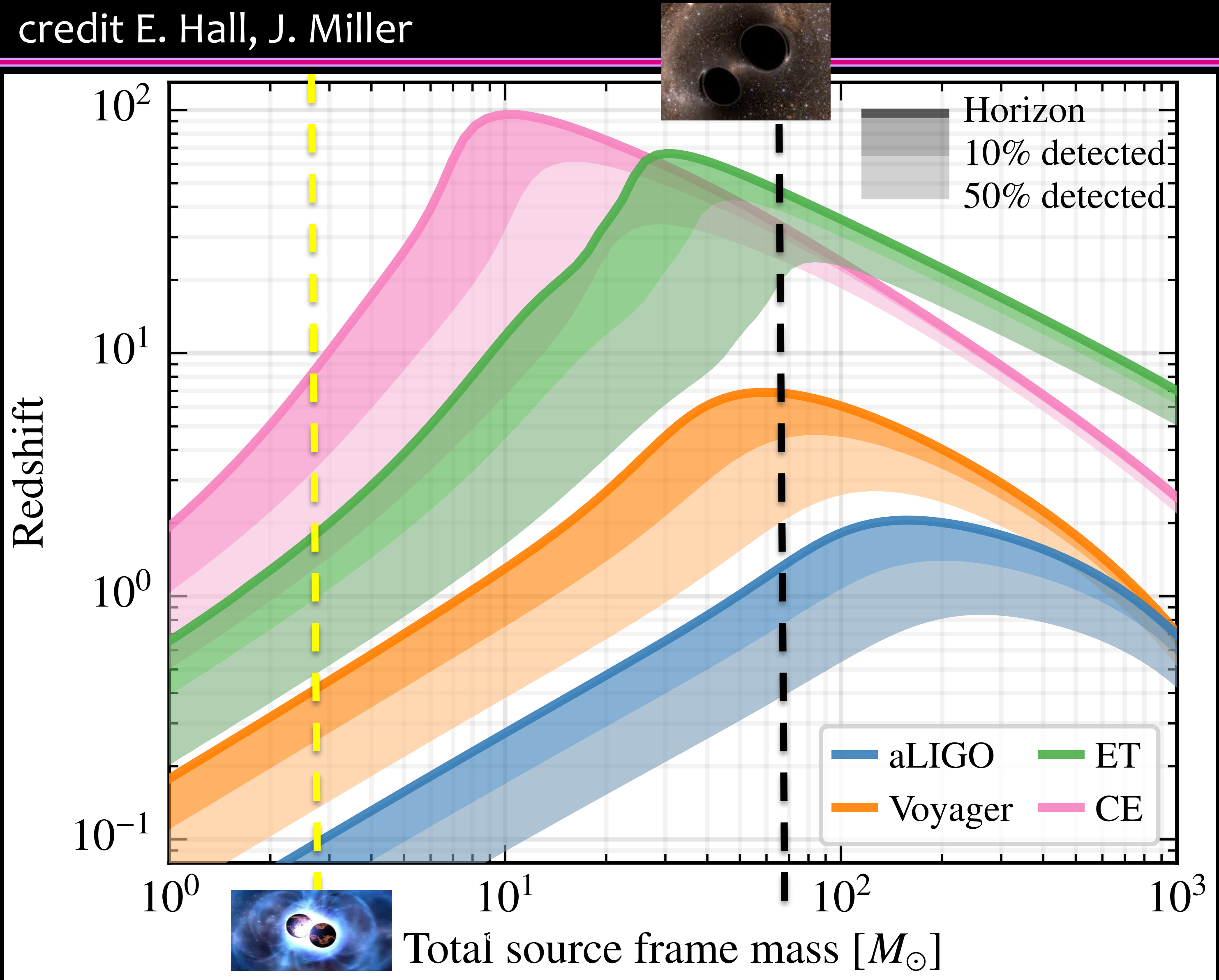
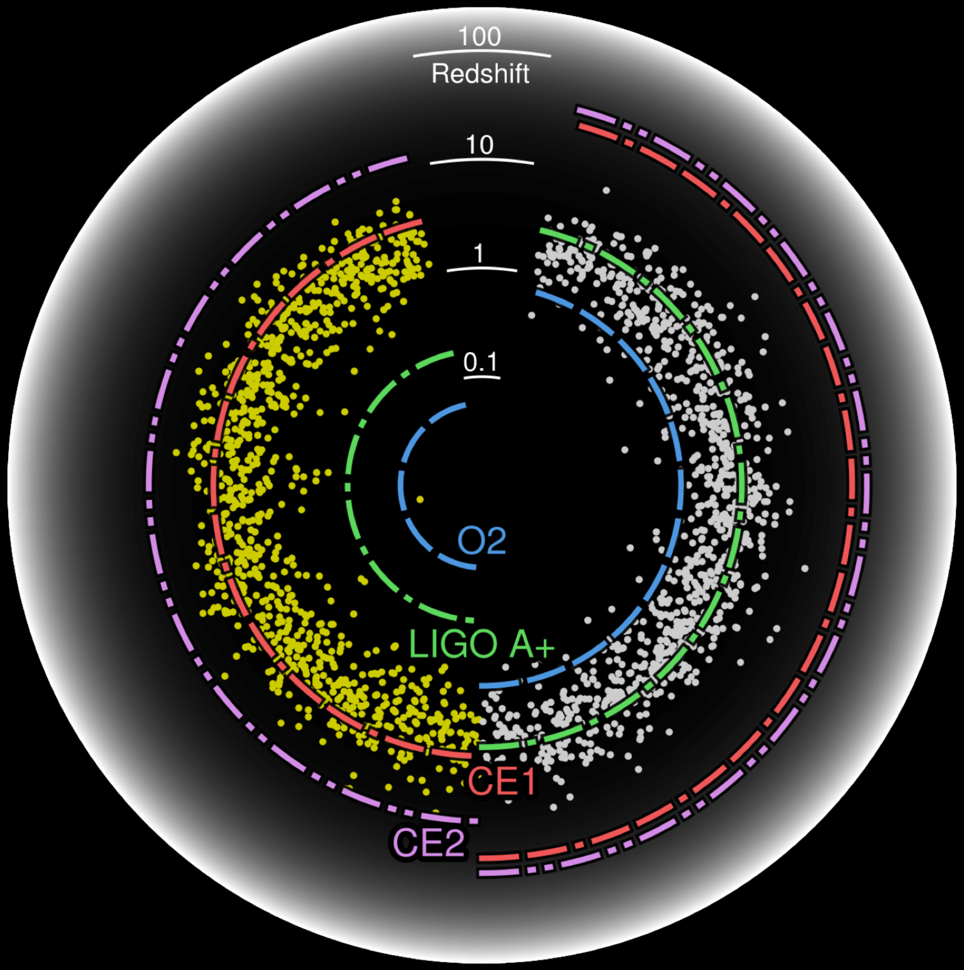
Where do we go from here?

credit E. Hall, J. Miller





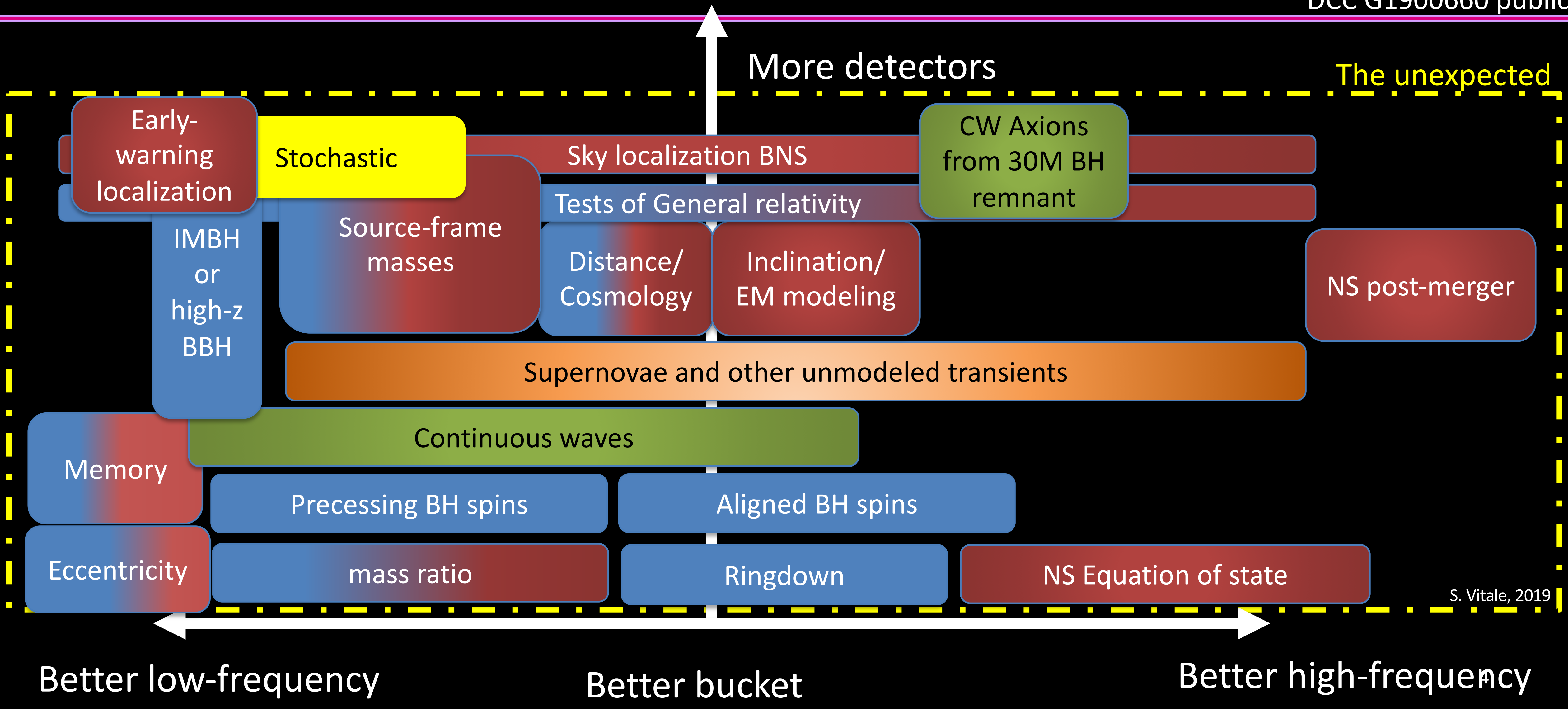
Hall/Vitale

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)

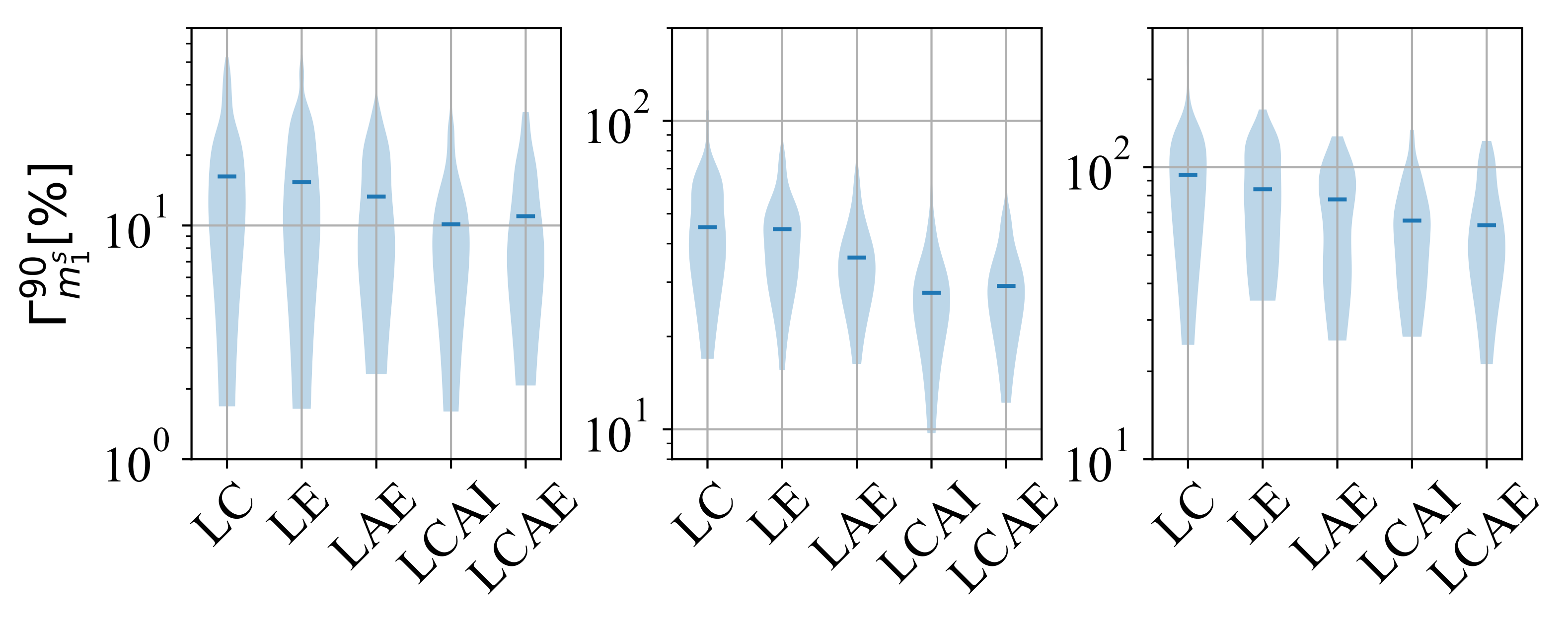
Low/High frequency - Network size trade off

DCC G1900660 public



BBH Source frame masses

- Especially at large redshifts, having more than 2 sites is important to measure component masses
- Uncertainties of [few-10]% for z<3
- Factor 1.5-2 better with 4 IFOs w.r.t. 2 IFOs



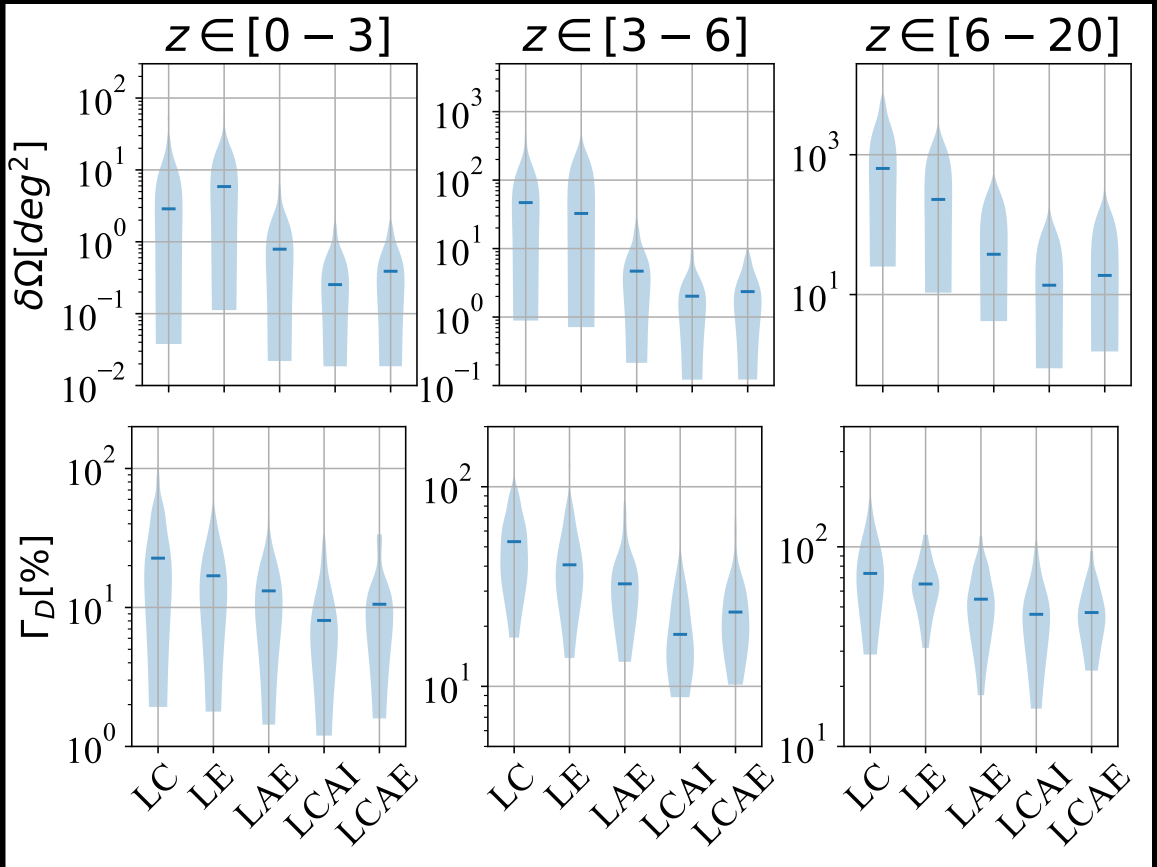
Vitale & Evans, PRD 95 064052

BBH Extrinsic parameters

- Precise distance and sky position:
  - EM (if luminous), isotropy, cosmology

Sky location

Luminosity Distance



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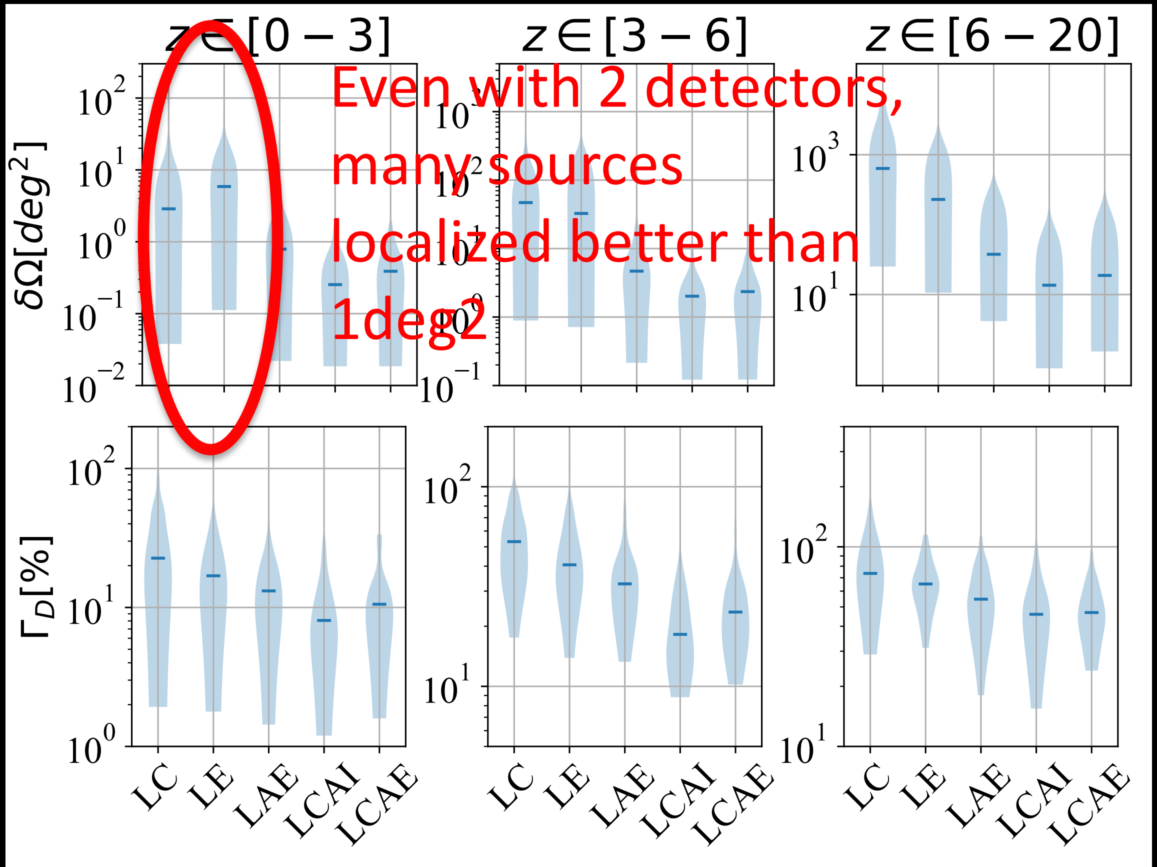


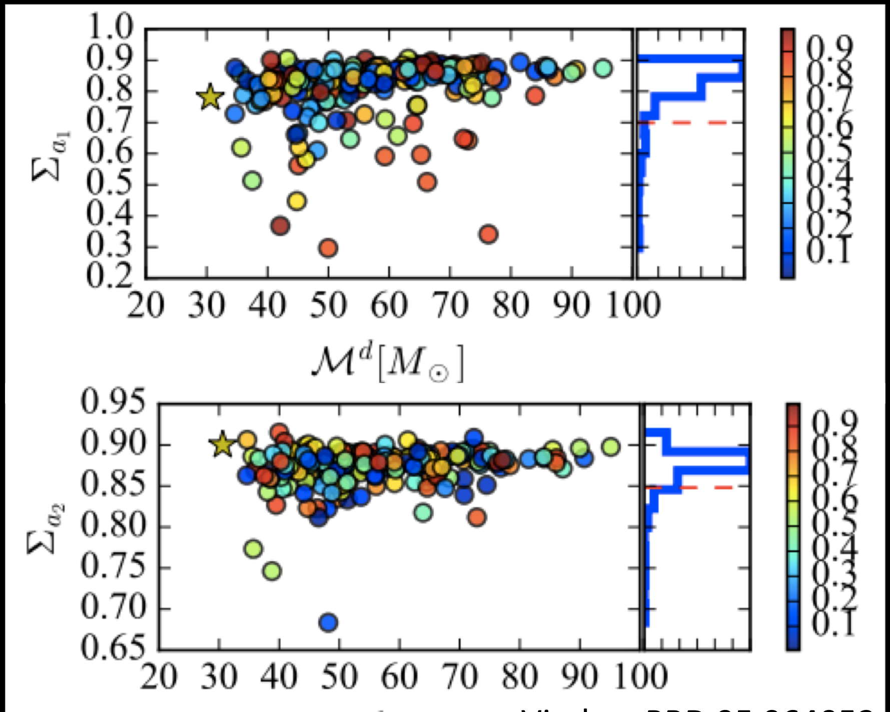
Vitale & Evans, PRD 95 064052

BBH Spins

- Due to larger SNR and isotropic orbital orientation, 3G will get much better spin estimation than 2G

Vitale & Evans PRD 95 064052

2G

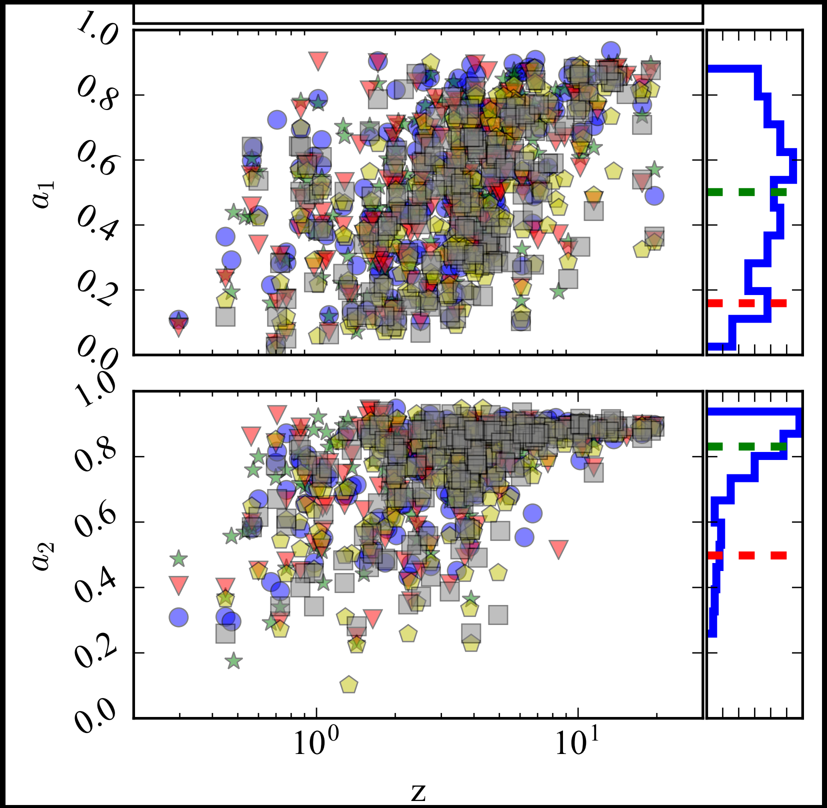


Vitale+, PRD 95 064053

True Chirp mass

Primary spin uncertainty

Secondary spin uncertainty

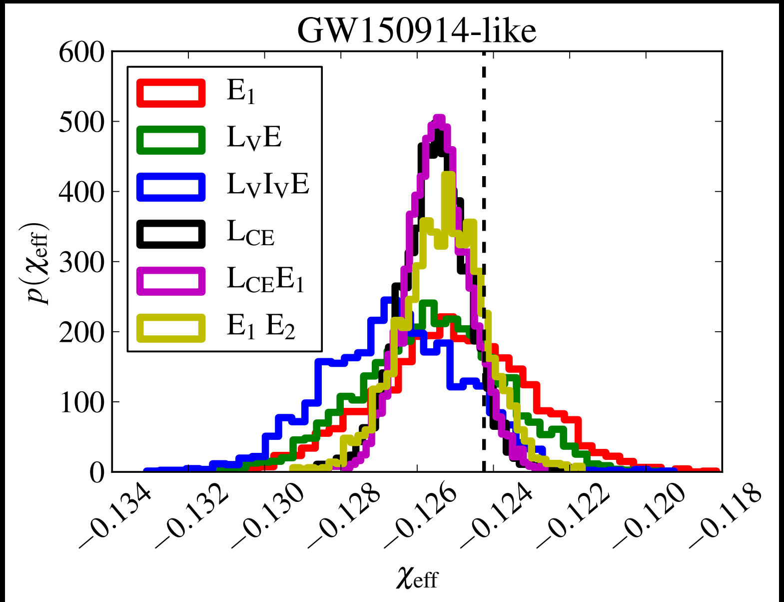


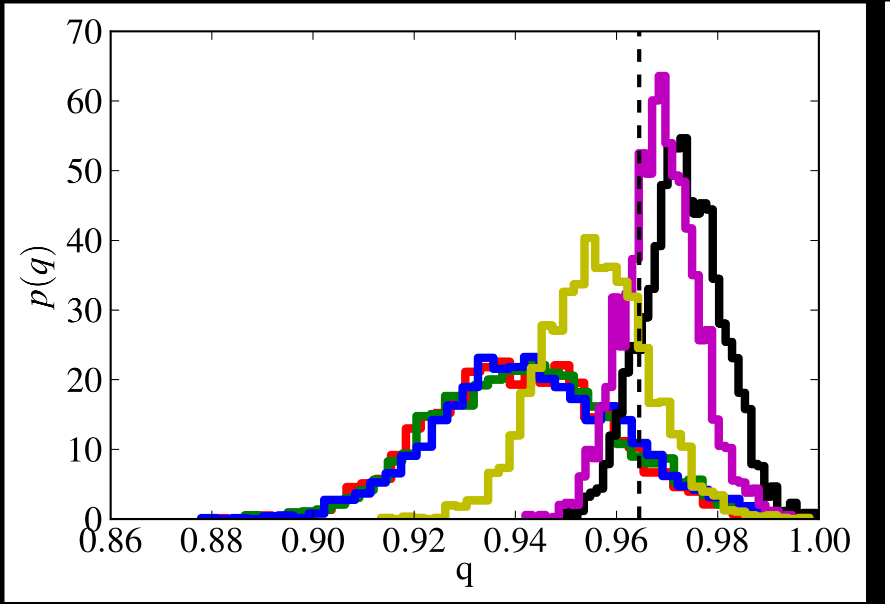
3G

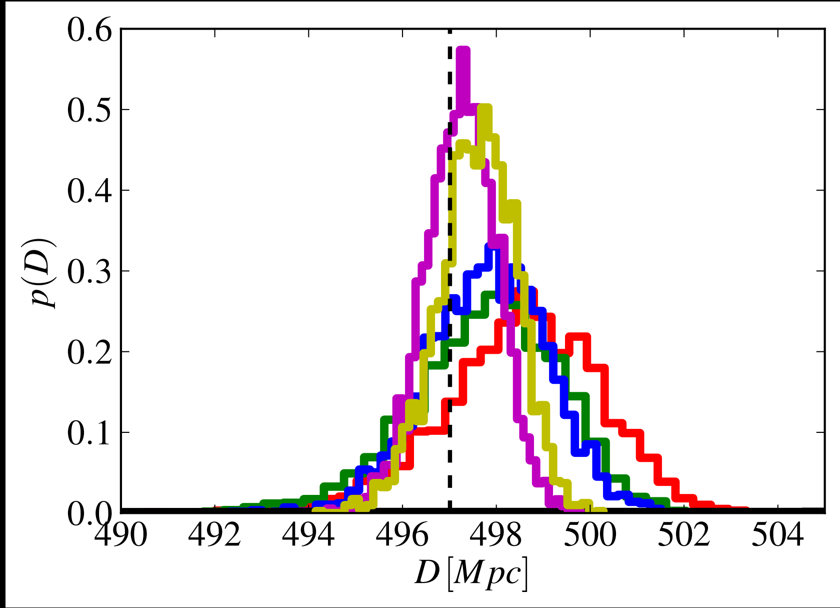
Redshift

Golden BBH events

- A GW150914-like event will have SNR~2000 in a cosmic explorer facility.
- How well can we do?





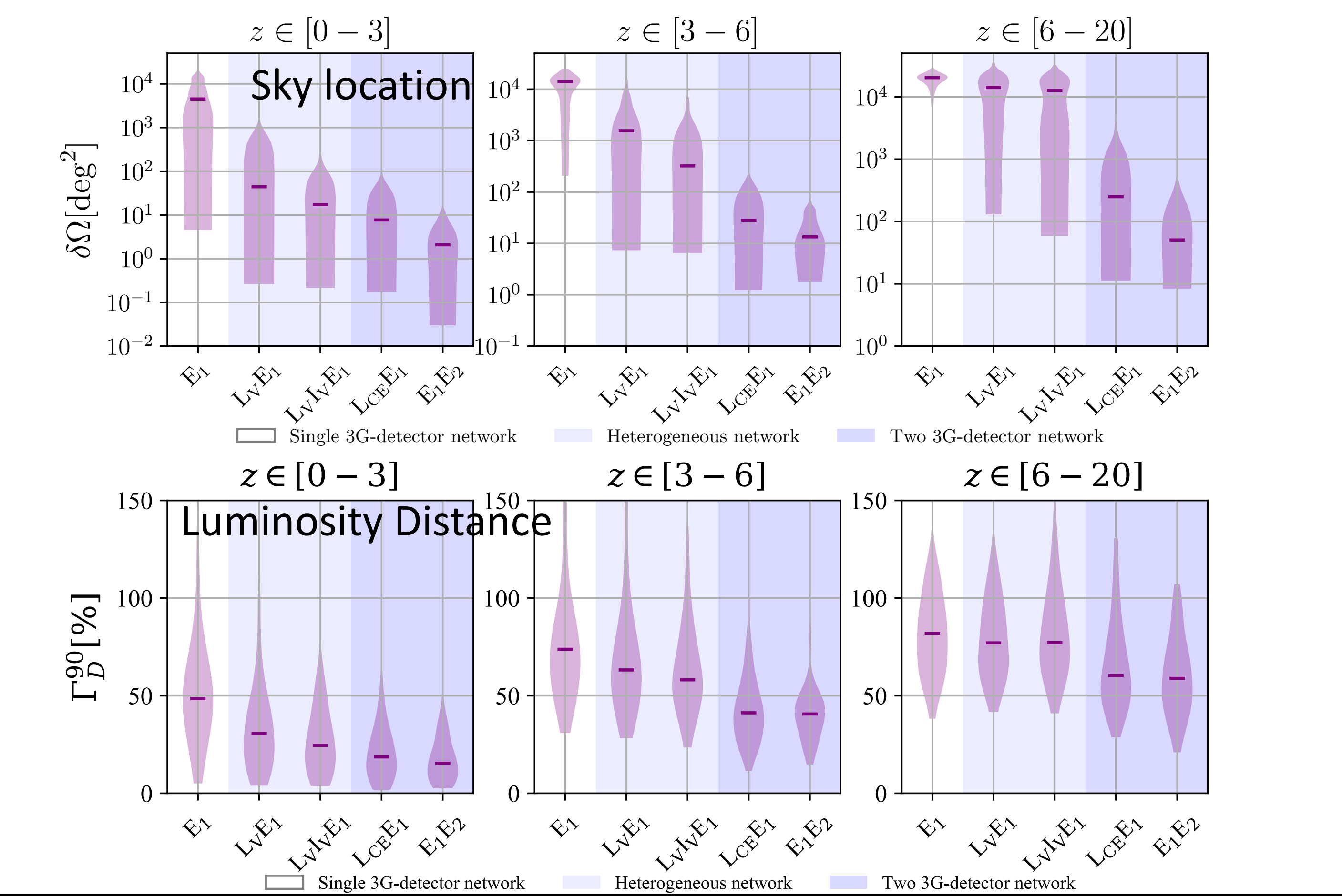


Vitale, Whittle, PRD 98, 024029

Extrinsic parameters (2.5G+3G)

- Adding a Voyager significantly improves sky localization - factor ~100
- See Mills+ for BNS sky localization precision
- However with only 1 3G will rarely have localizations better than 1deg2

- Smaller improvement in distance estimation

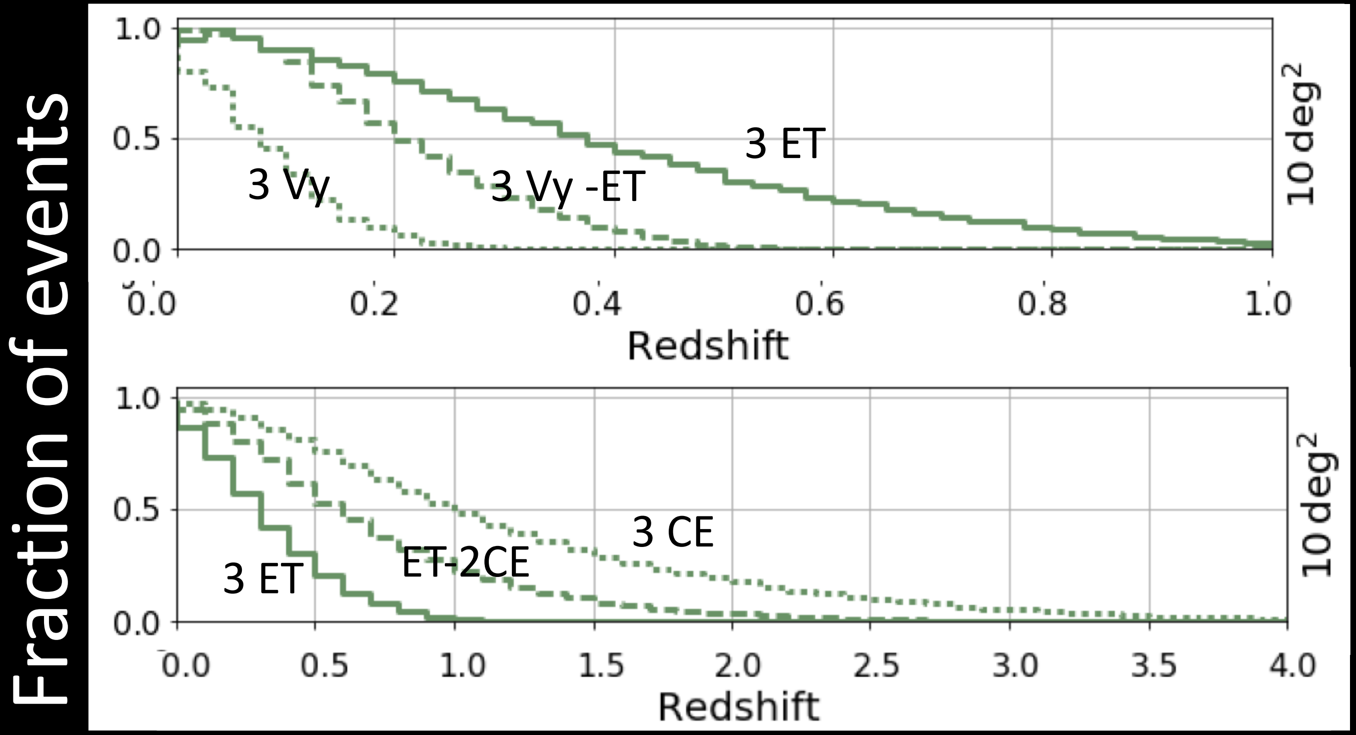


Vitale+, PRD 98 024029

Binary neutron stars - Localization

- Will detect BNS at large redshifts
- A significant fraction of which can be localized to a few deg2
  - H0, dark energy EOS (Sathyaprakash+ Arxiv: 0906.4151; Del Pozzo+ Arxiv:1506.06590; many more)

Mills+ PRD 97 97, 104064

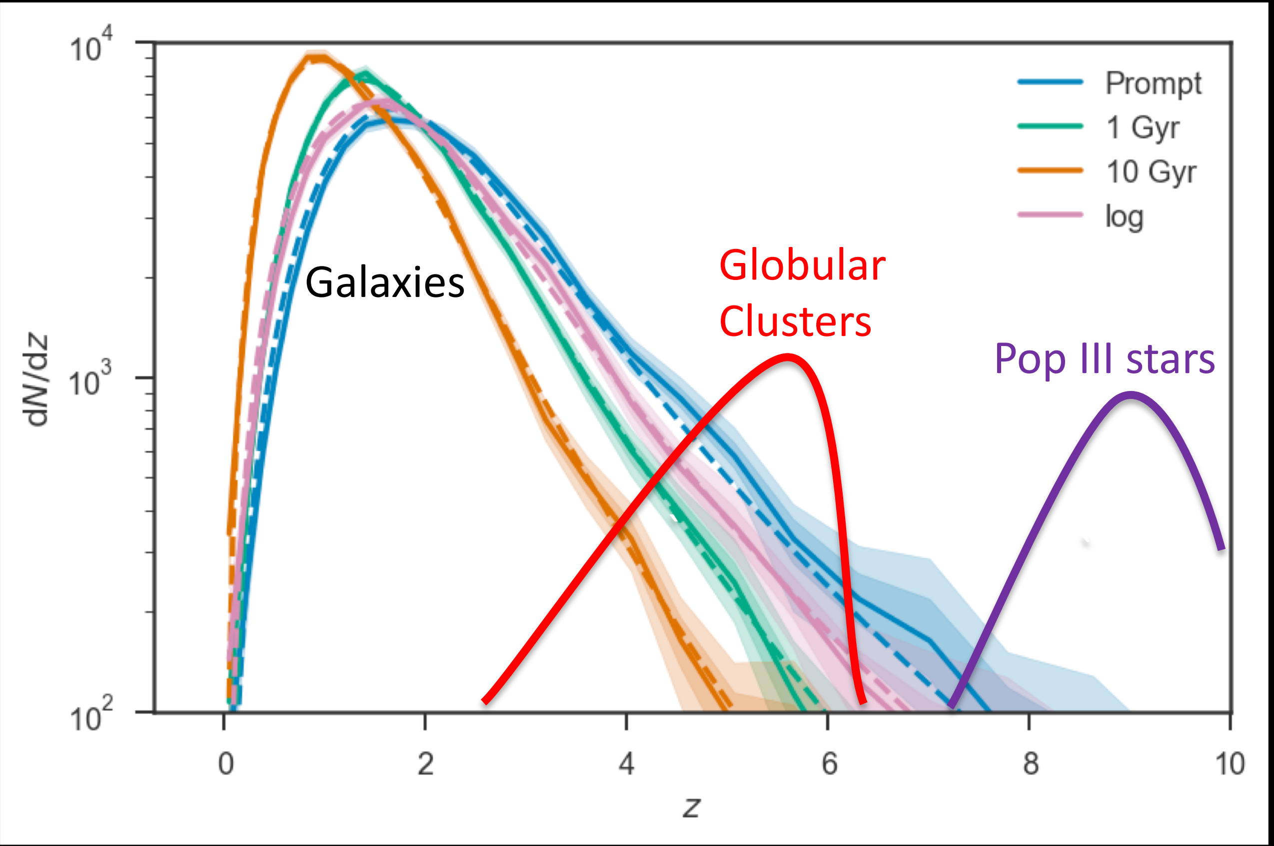


BBH Formation channels

- 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

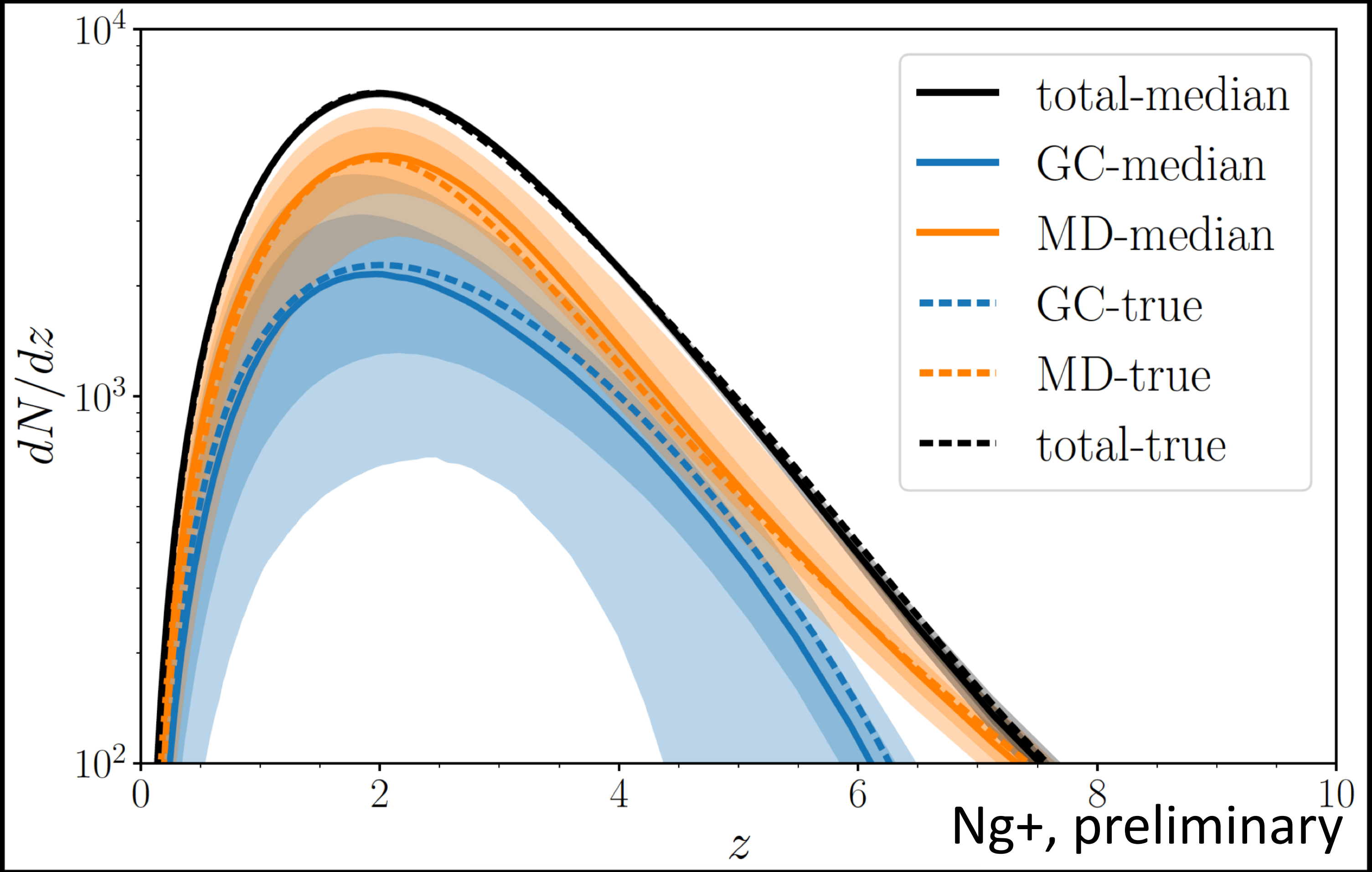


There might be more sub-populations
(e.g. AGN disks,
Bartos+ Nature Com, 8 831)

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.



But still…

- Considered a fraction of sources coming from galactic fields (as before)
- And the rest coming from globular clusters

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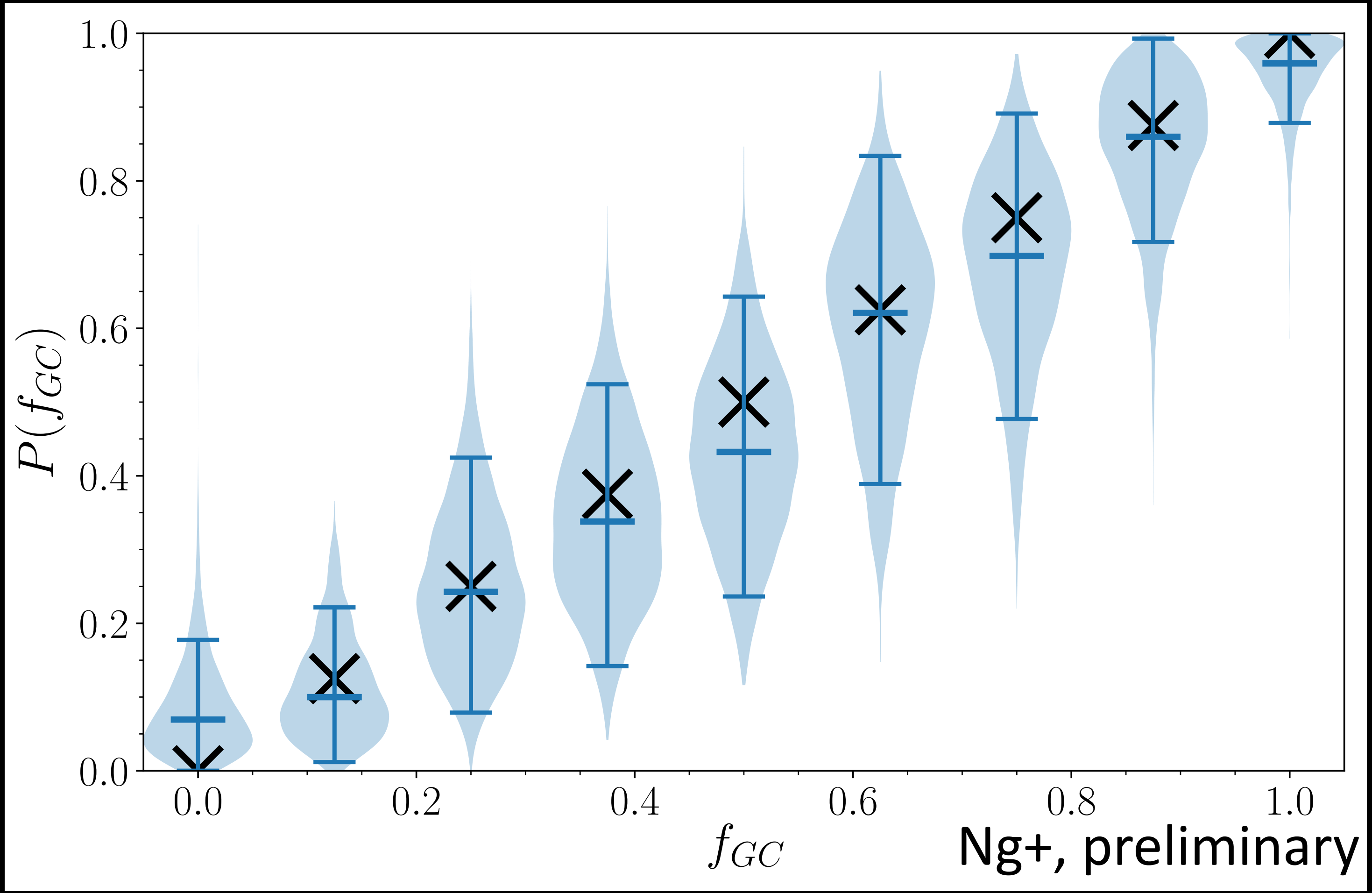
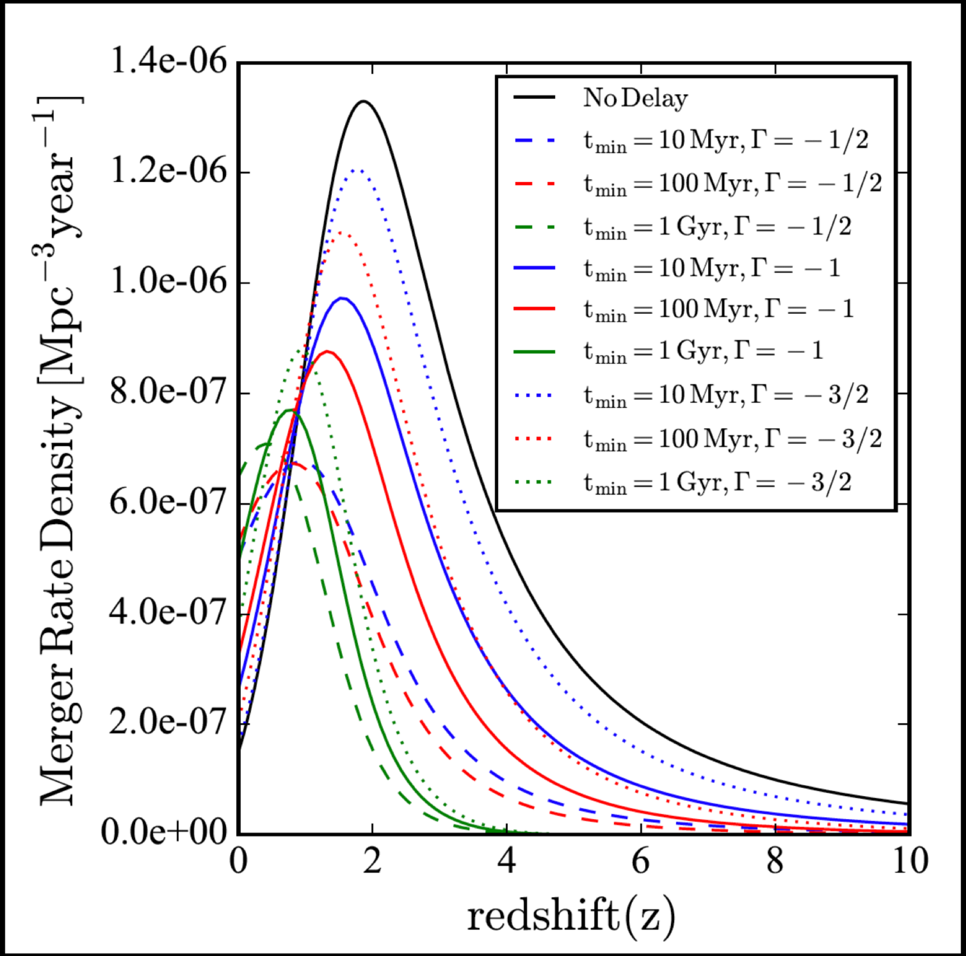


Time-delay distribution for BNS

Safarzadeh+, 1904.10976, press ApjL



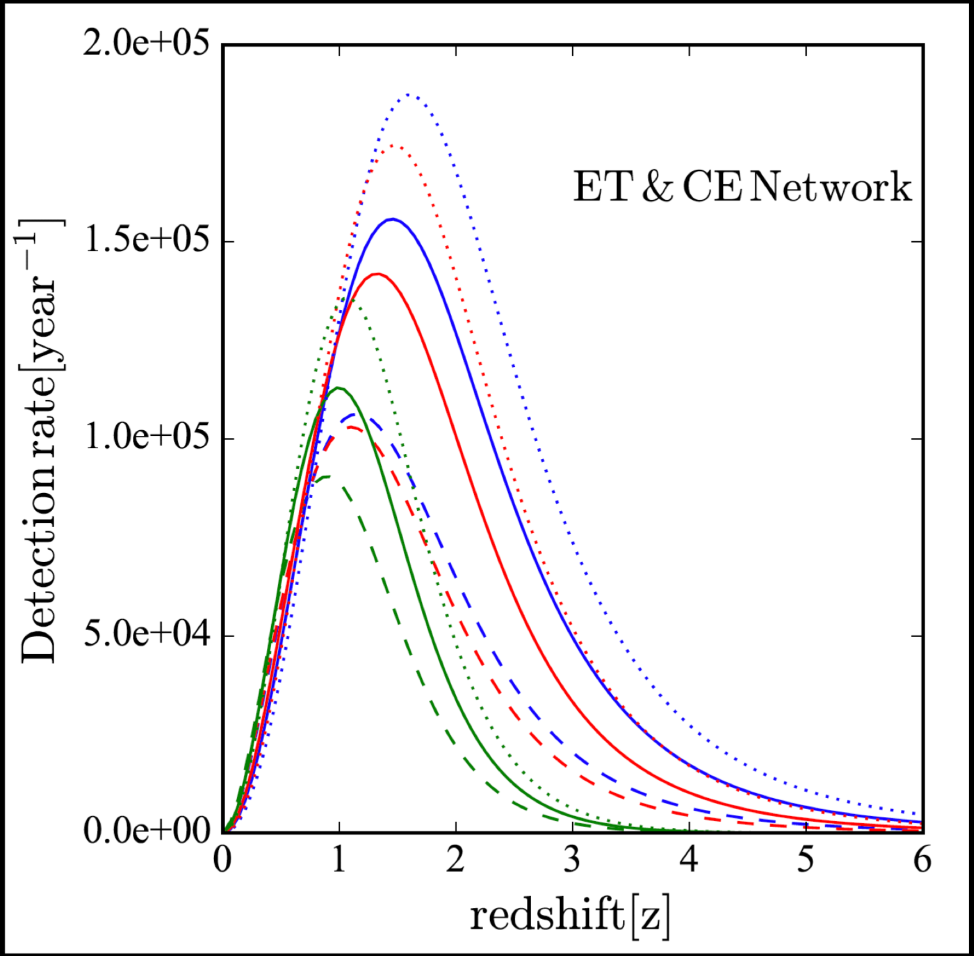
All BNS

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

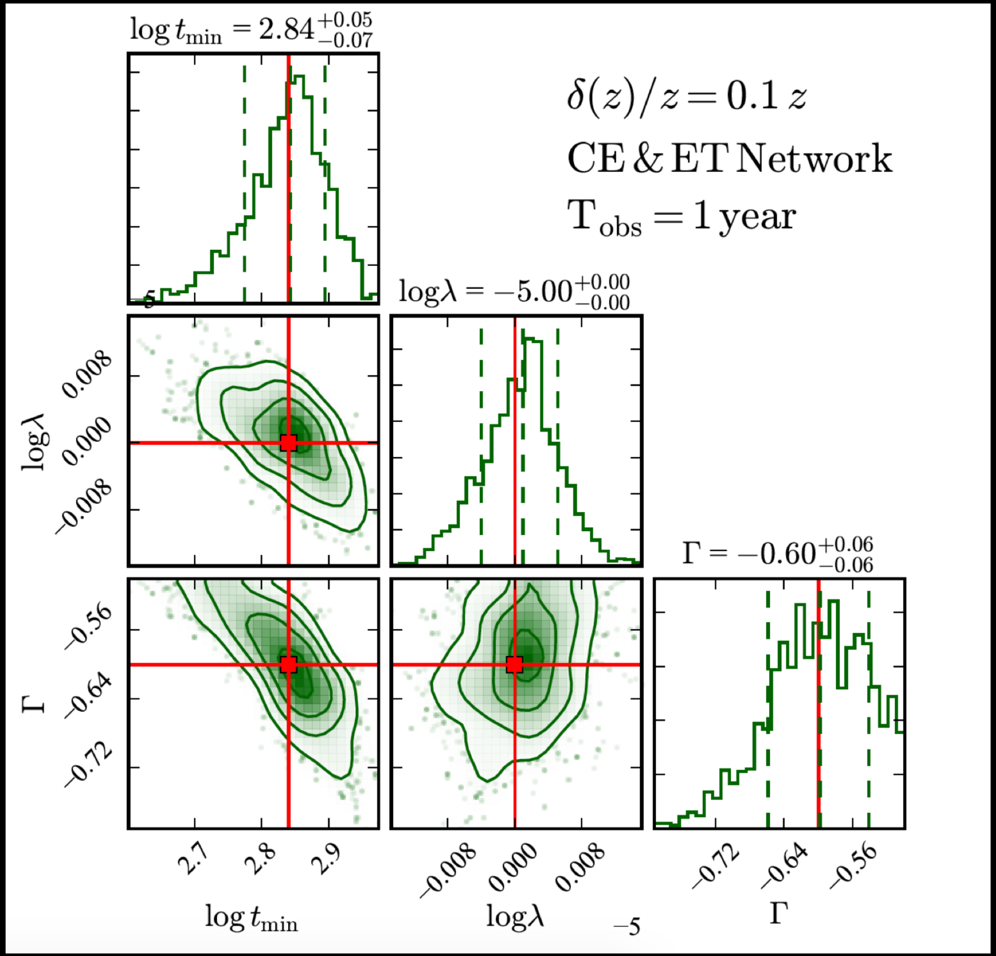
$$dP_m/dt \propto t^{\Gamma}$$

Time-delay distribution for BNS

Safarzadeh+, 1904.10976, press ApjL



3G detectable

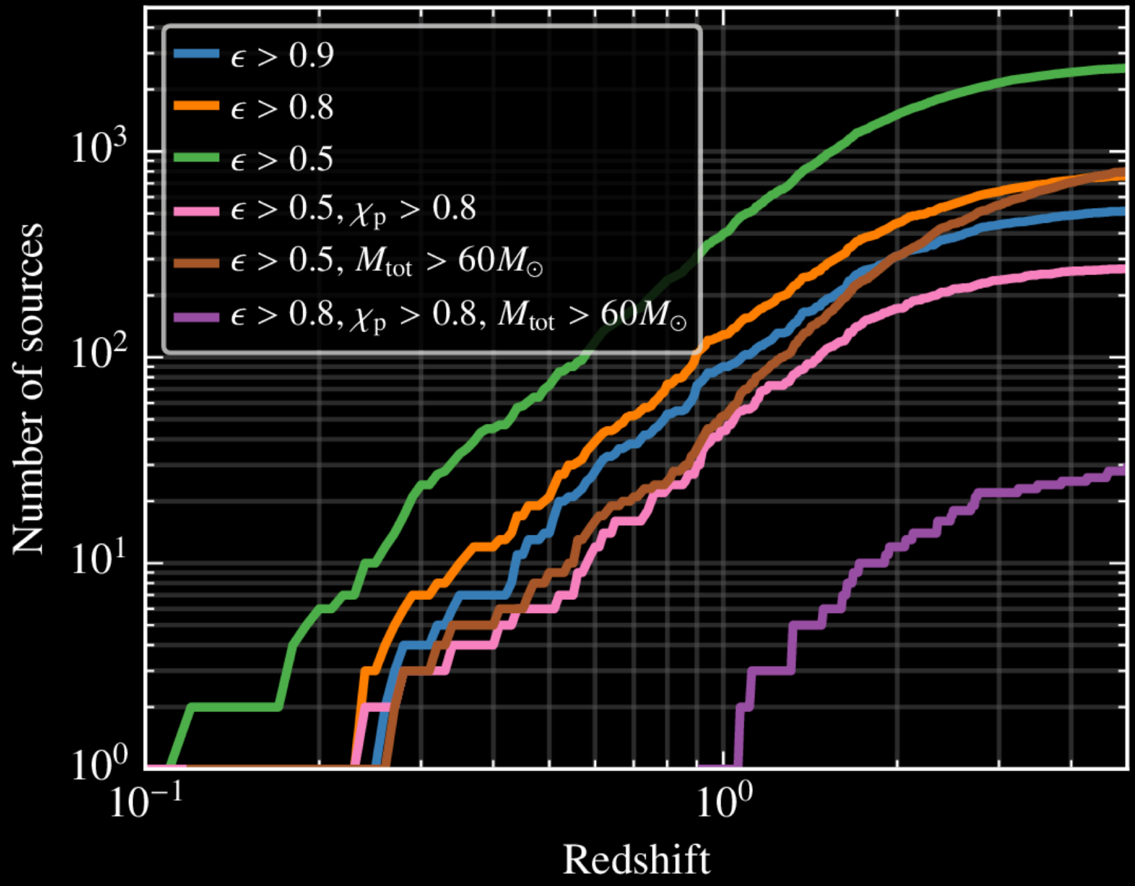


More from populations

- 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

w/ E. Hall and C. Rodriguez; (slowly) in prep



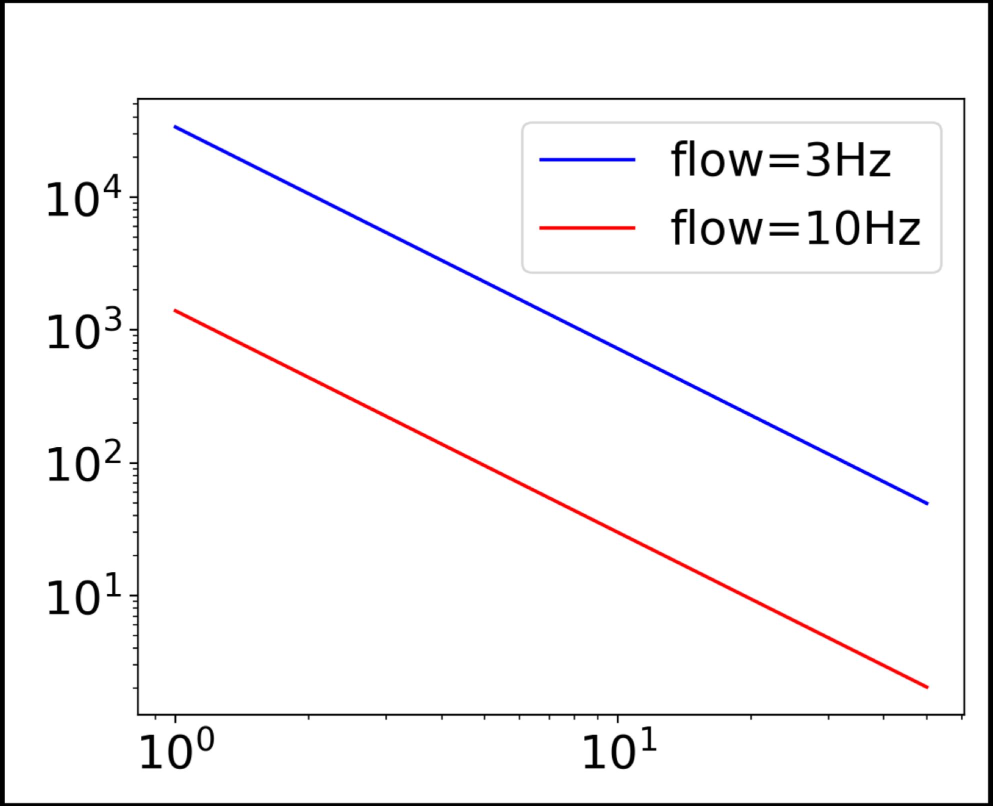
- Together with populations, one gets rare events, showing peculiar properties
- However, those might not be super loud
  - Don't expect SNR of 1000s with eccentricity with spin precession with XYZ (replace with your secret dream)

Thanks!

References

- [Refs1]: Mandel+ CQG 27, 114007; Vitale+ CQG 34, 03LT01; Farr+ ApJ, 854, L9; Farr+ Nature, 548, 426; Stevenson+ MNRAS, 471, 280; Talbot +PRD , 96, 023012
- [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
- [Refs5]: Fishbach+, ApJ, 851, L25; Wysocki+ Arxiv: 1805.06442; Kovetz+, PRD 95, 103010; Talbot +PRD , 96, 023012;

Low frequency – computational challenges



WF duration (s)

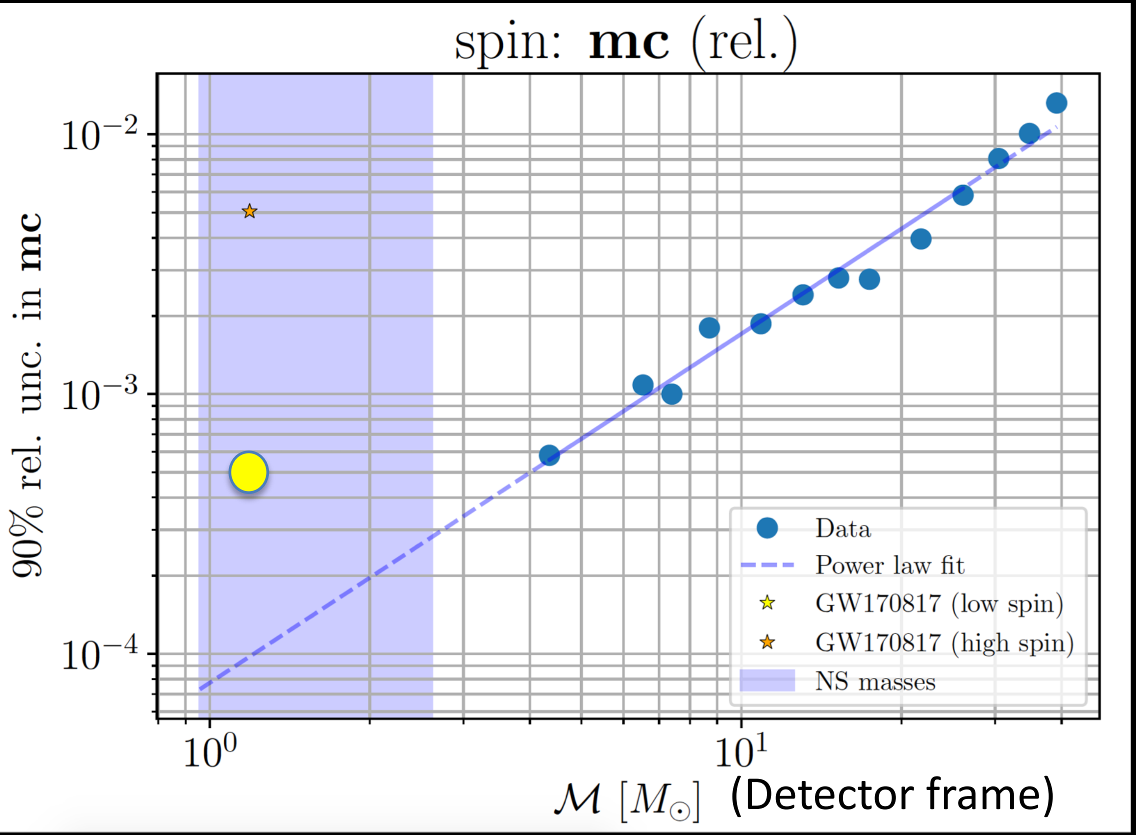
Chirp mass (Msun)

- 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

SNR=32, CE

flow=10

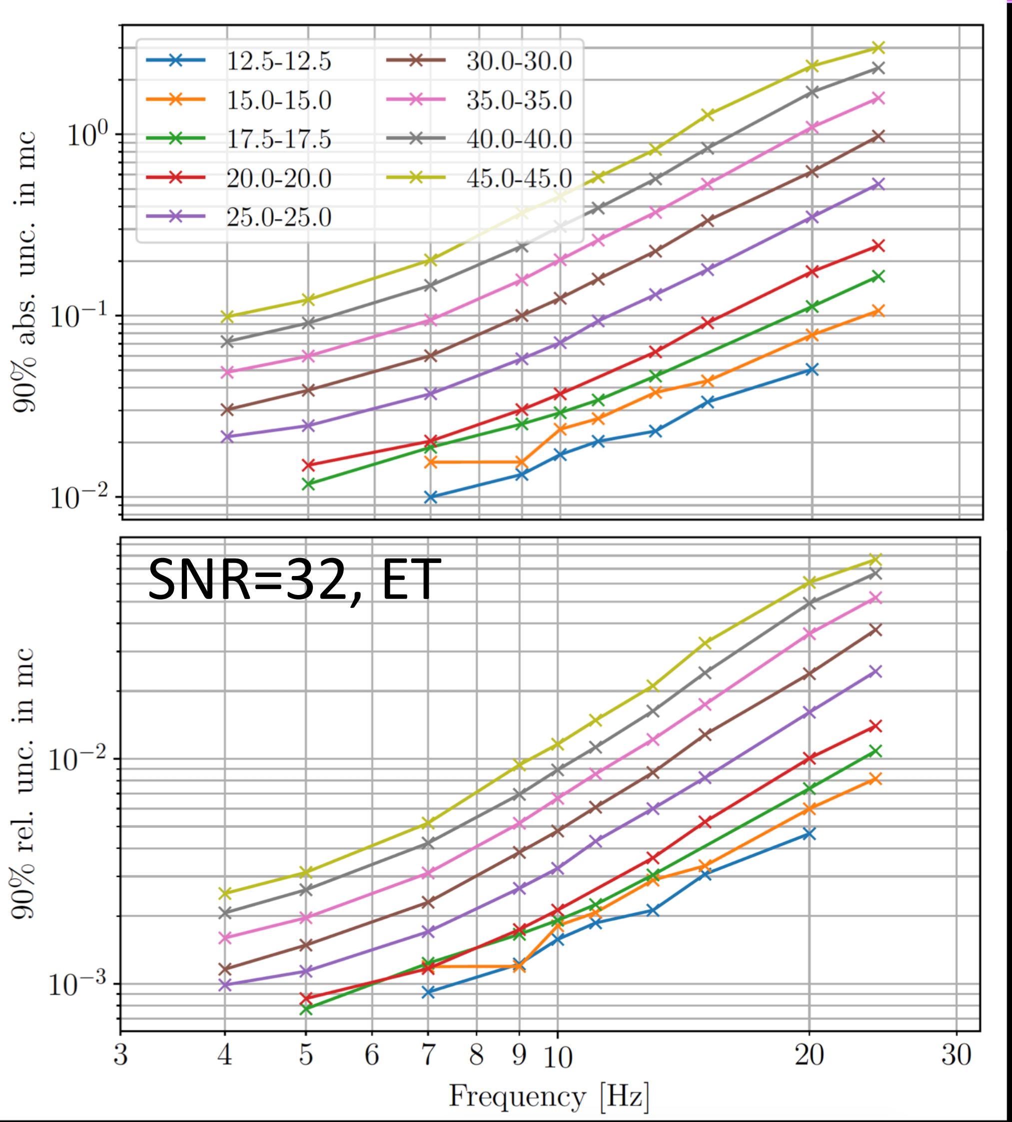


Whittle+, preliminary

- 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
  - Sathya working on similar ideas

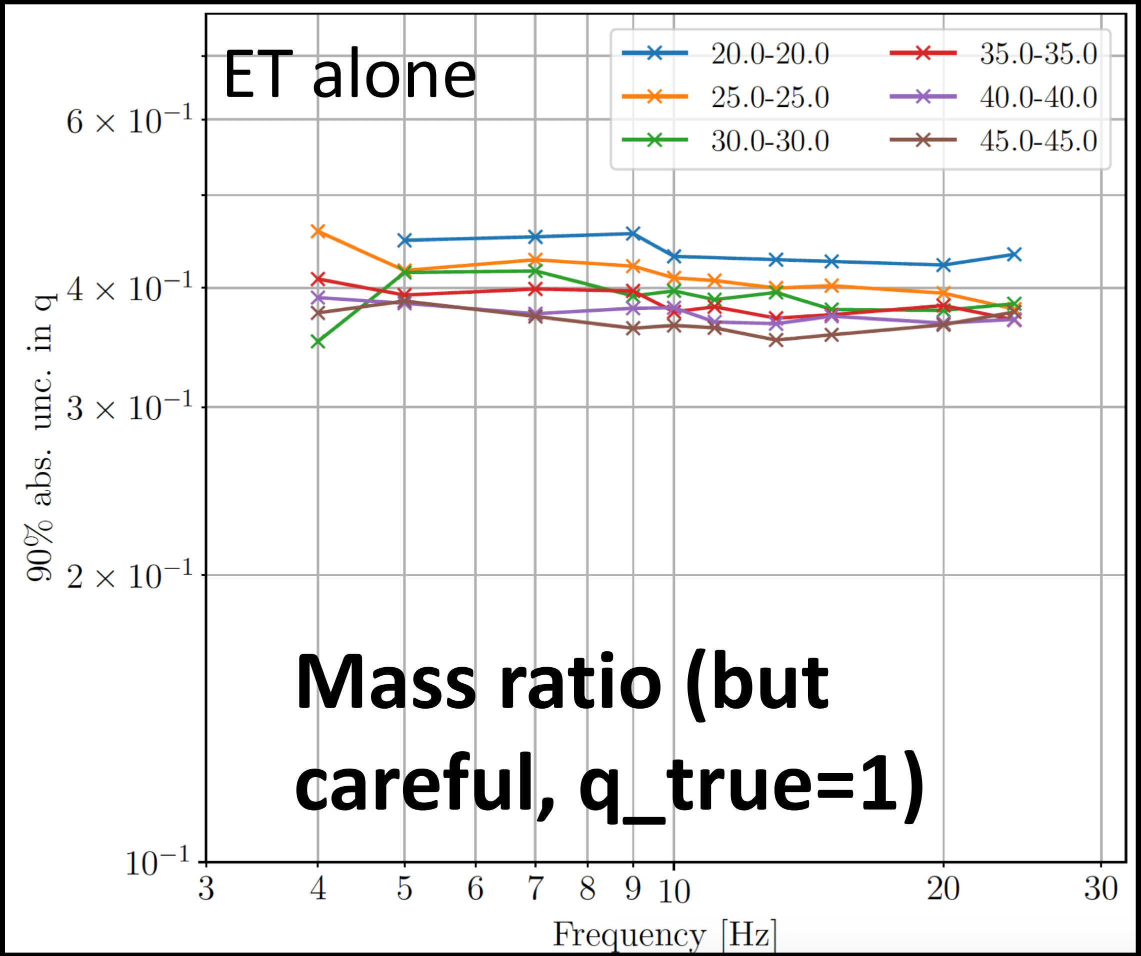
Lower-frequency extrapolation

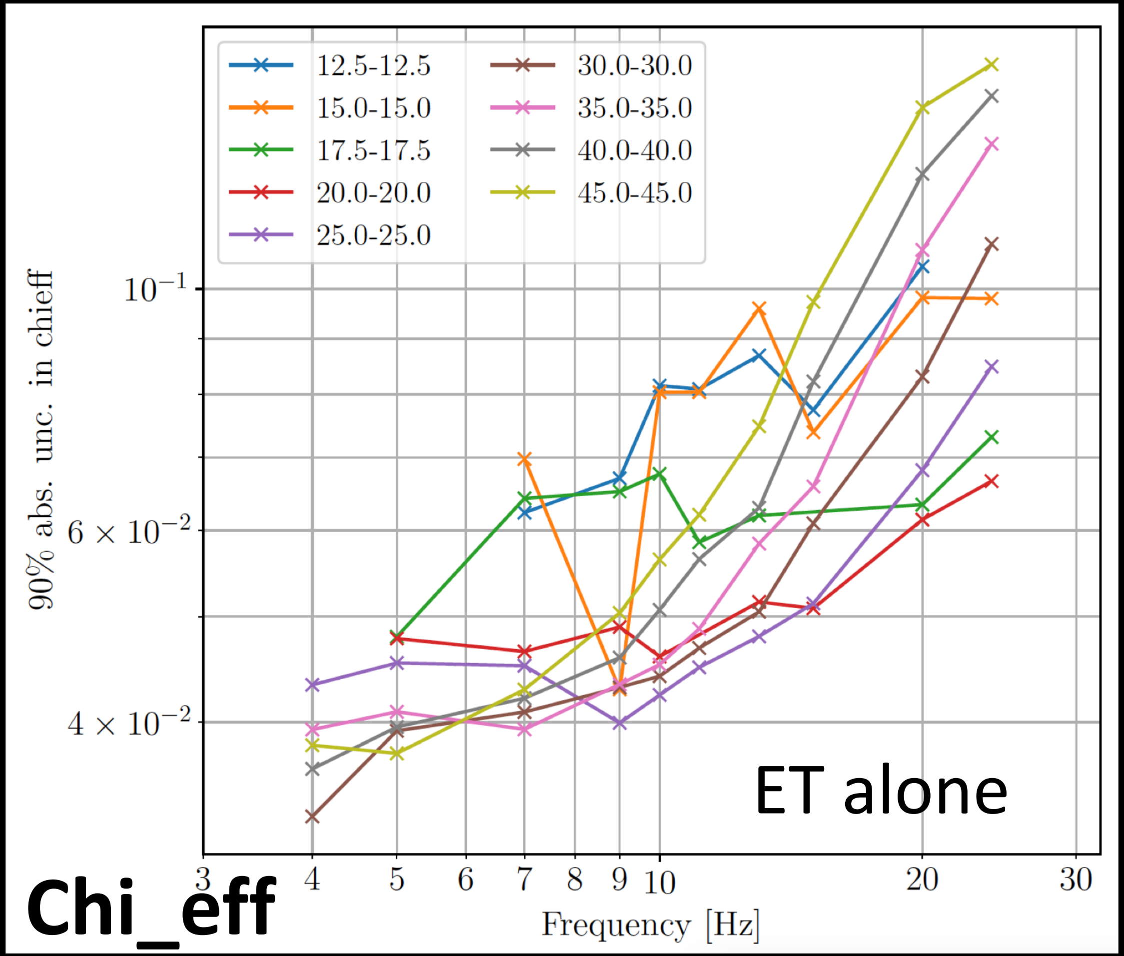
Whittle+, preliminary



- 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

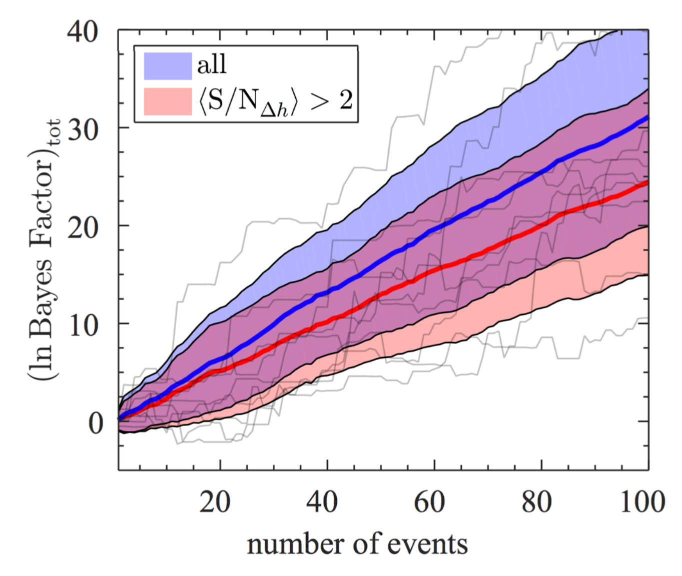


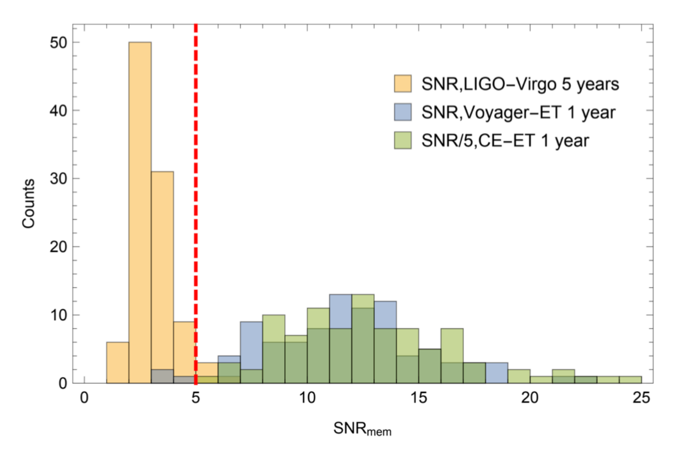


Whittle+, preliminary

Memory effect

Lasky+, PRL 117, 061102





Yang+, PRL 121, 071102

- Very challenging to detect with advanced detectors
- Lasky+ showed that one might make a statistical detection given >>1 sources
  - Somewhat optimistic assumptions
- Yang+ focuses on 3G and quantifies SNR in the memory phase