EPS-HEP Venice 2017

Extending the gravitational waves searches for black holes with intermediate masses and residual eccentricity at merger

Shubhanshu Tiwari
for the LIGO Scientific and the VIRGO collaborations

Trento Institute for Fundamental Physics and Applications

Outline

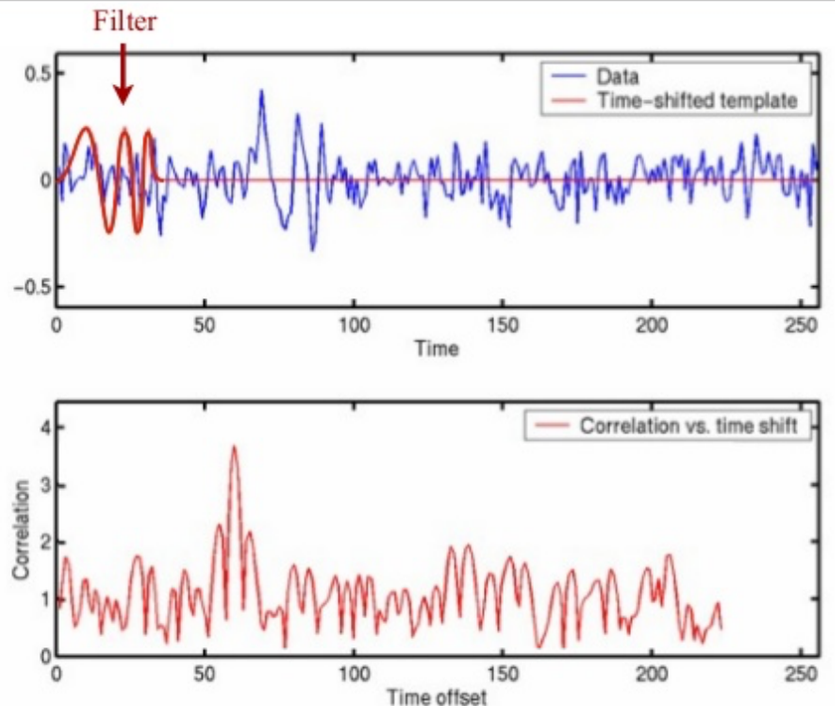
- Searches for gravitational waves from Binaries Black-Holes (BBHs)
  - Modelled search
  - Un-Modelled search
- Limitations of modelled searches for BBHs
  - Effect of eccentricity on BBH searches
- Un-modelled searches for BBHs
- Search for eBBH
- Search for Intermediate mass BHs

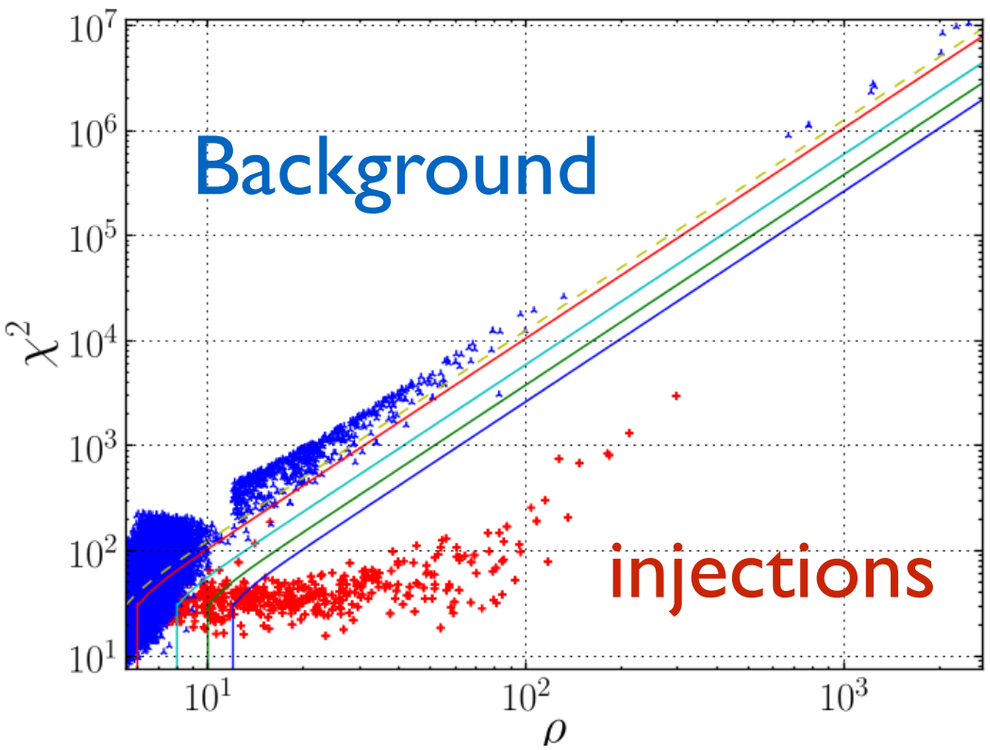
Searches for gravitational waves from Binaries Black-Holes (BBHs)

- We now know that BBHs exists in nature and merge in Hubble time
- Till now we have detected 3 confirmed BBHs mergers GW150914, GW151226 and GW170104 and one lower significance event LVT151012
- This provides motivation to search for BBHs from all possible formation channels, some of the formation channels predict binaries with eccentricities (e>0.1) in LIGO band (like dynamical capture in dense stellar environments, three body interaction etc) or binaries with intermediate mass (>100 M_sun) companion
- The searches for BBHs can be divided into
  - Modelled search
  - Un-Modelled search

Modelled search for Binary Black holes

- Modelled search
  - Uses **matched-filtering** to search for BBH signals in the data
  - Looks for the correlation between the data and various waveforms models called **templates**
- The goal is to find the optimal template which would maximise the **signal to noise ratio** (SNR)
- The signal consistency check is performed by a **chi-squared test**
- Search is optimal if the signal is within the parameter space of the templates used

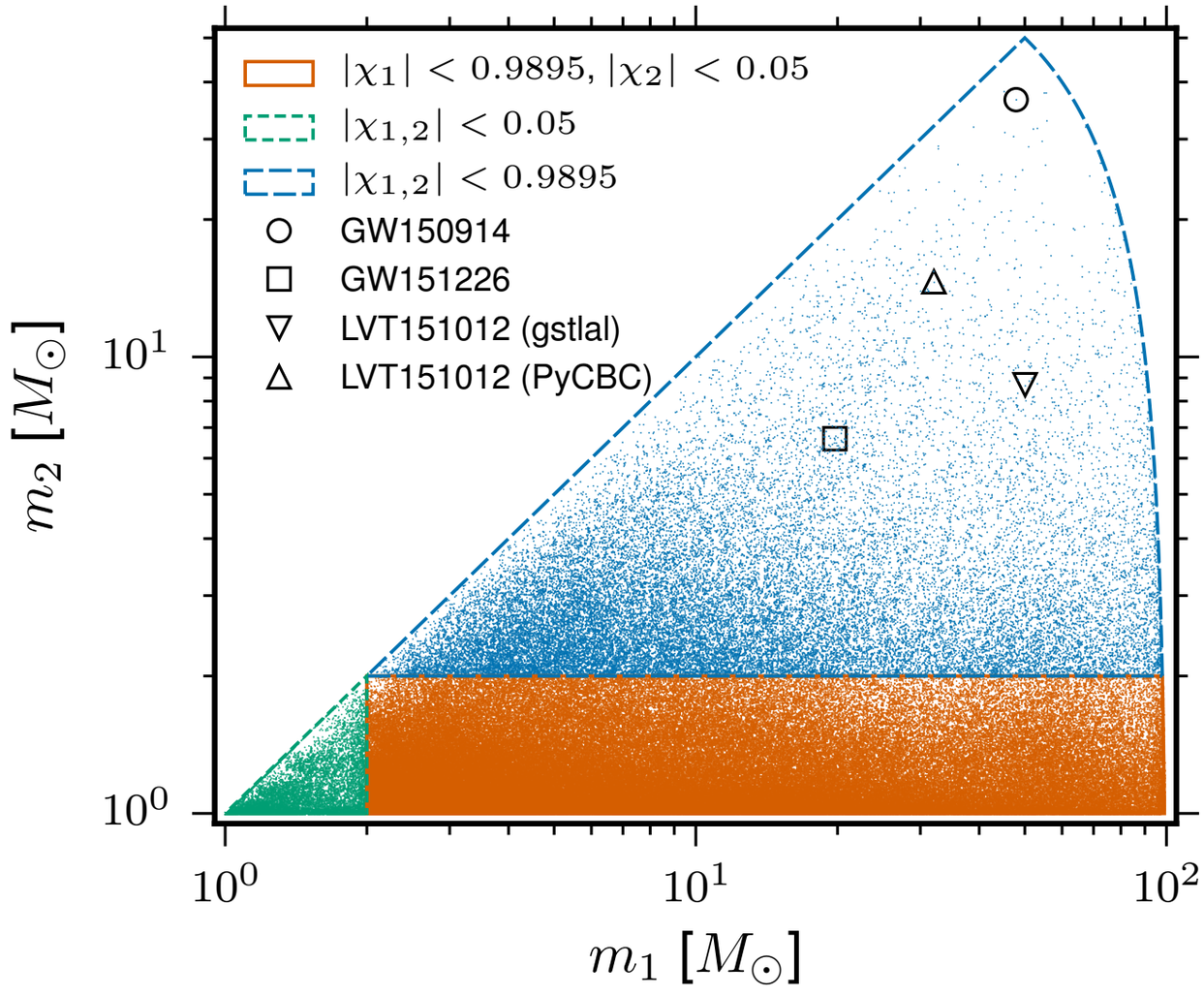




Babak+ PRD 87 024033

Modelled search for Binary Black holes

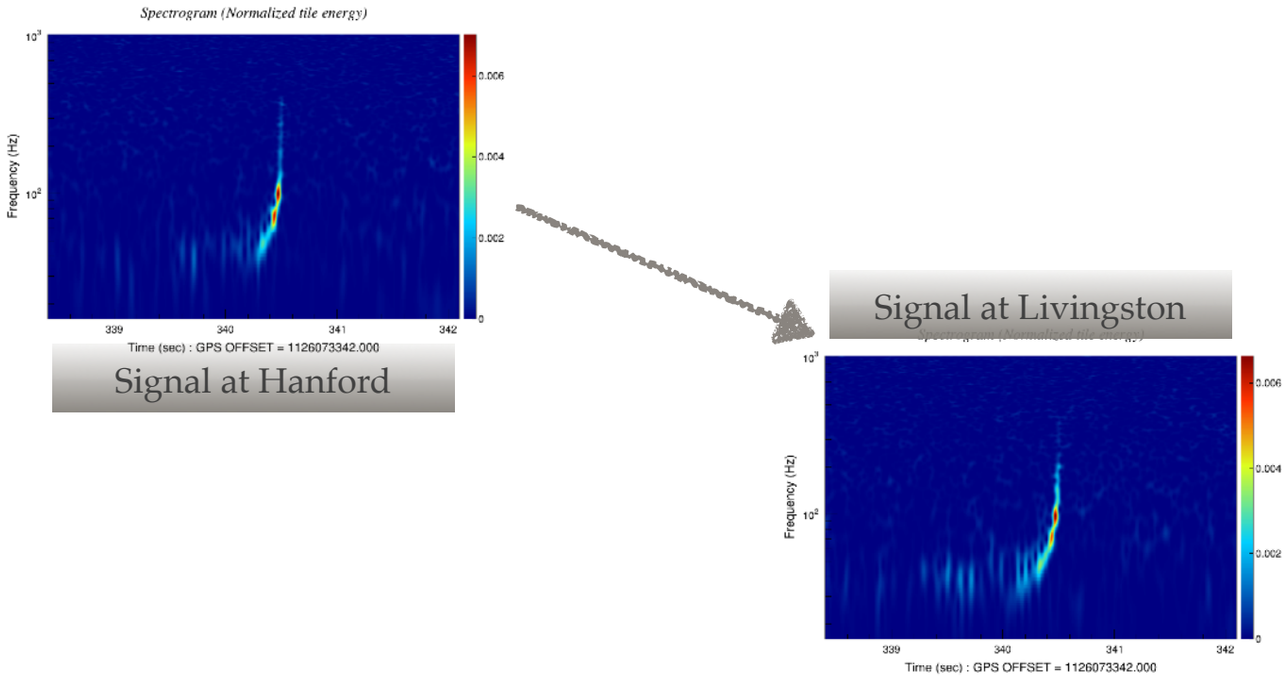
- The four-dimensional search parameter space (component masses and spins) covered by the template bank shown projected into the component-mass plane.
- The colours indicate mass regions with different limits on the dimensionless spin parameters $\chi 1$ and $\chi 2$.
- Although this template bank covers a huge part of the parameter space and most likely BBHs signals , it assumes
  - circular orbits (no eccentricity)
  - no contribution from higher modes (can be important in high mass ratio systems)
  - only aligned spin (no precession)
- Note : the template bank for BBHs search is an evolving process and it keep on expanding like our universe

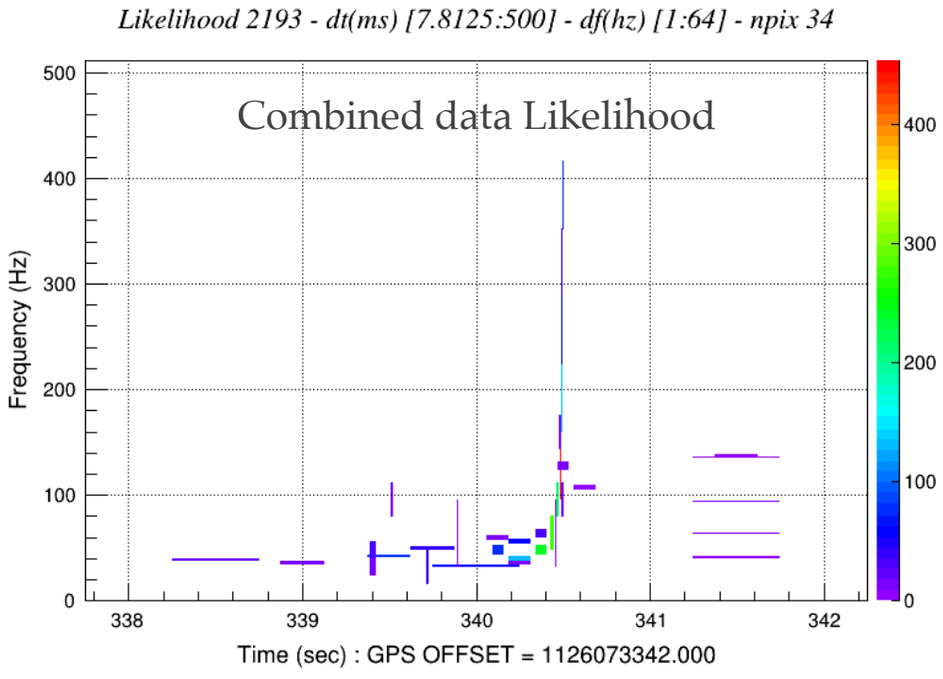


LVC arXiv:1606.04856 (2016) O1 BBH

Un-modelled searches for BBHs

- Un-modelled search
  - Uses the estimation of excess energy in the detectors
  - Exploits the presence of signal (energy) in multiple detectors to appear coherently i.e. consistent in time and sky location
- Data is combined from the networks of detectors
- No templates/waveforms models are required/used
- Can be more affected by the non-gaussian glitches in the data than the modelled search, and hence are not the optimal searches
- This search can be made more sensitive for BBHs by tuning the clustering and requiring some lose and generic condition on the signal model, and hence rejecting background





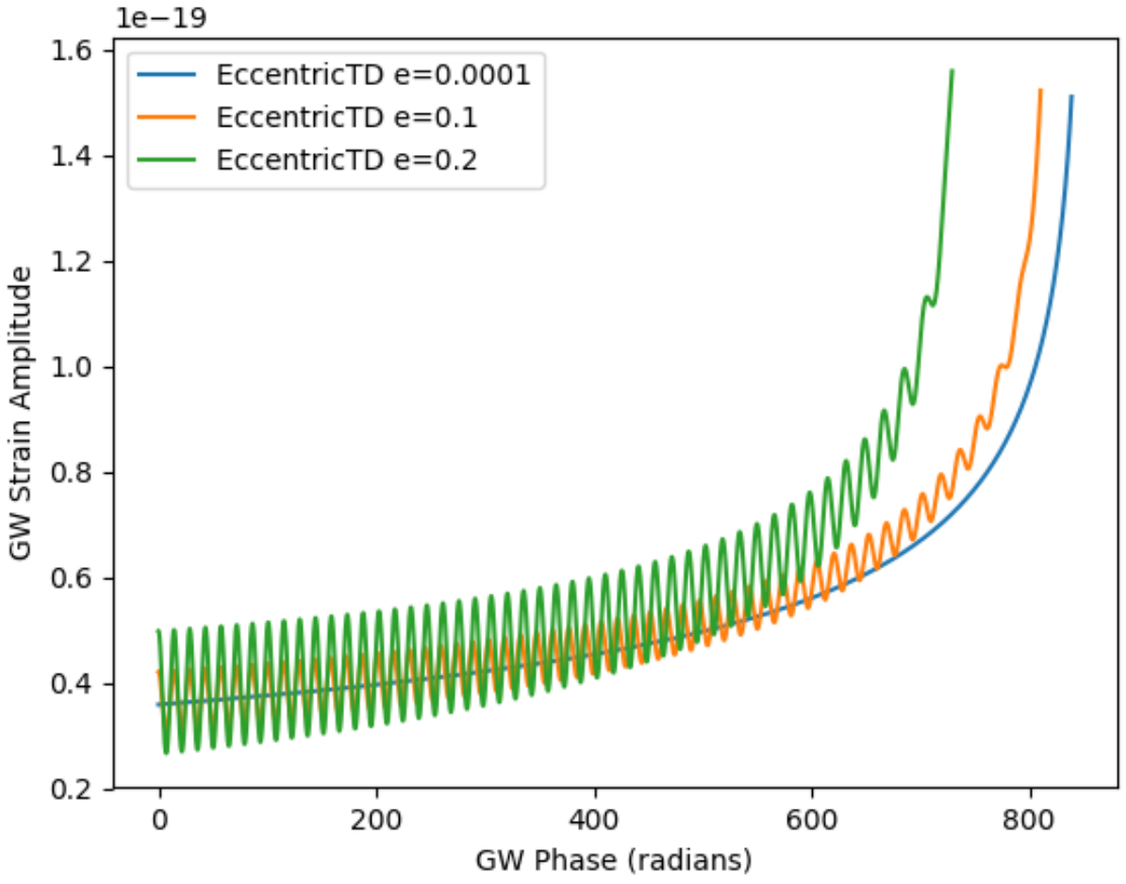
Klimenko+ PhysRevD.93.042004

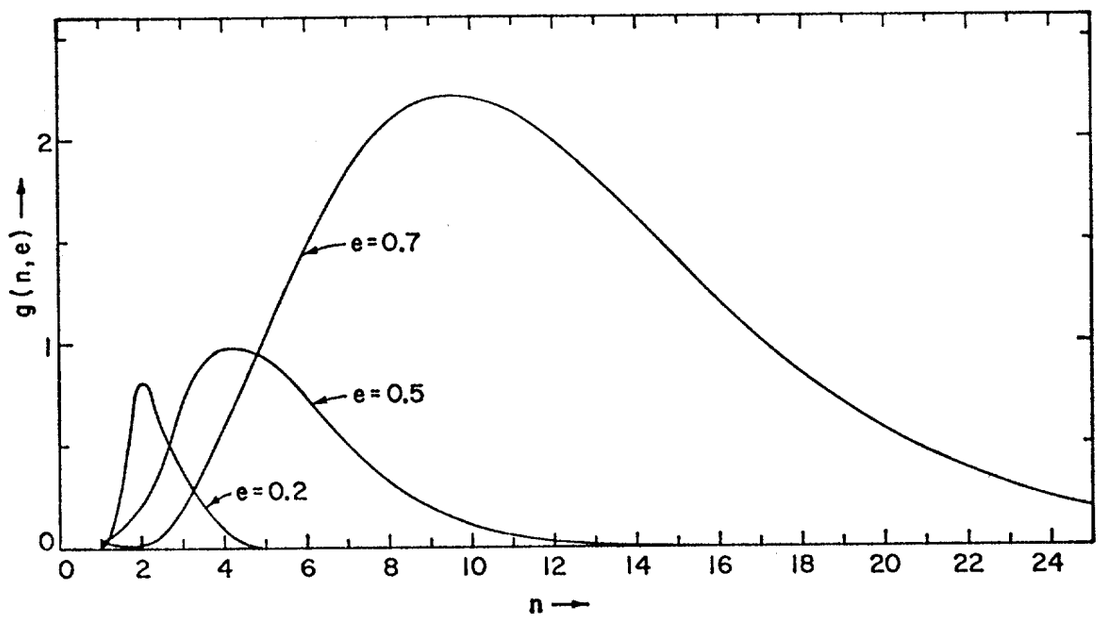
Limitations of modelled searches for BBHs

- As preluded before, the modelled searches don't (yet) cover the part parameter space such as
  - eccentricity in the sensitivity band
  - higher harmonics contributions
  - precession of the orbit
- Also there can be more exotic scenarios like
  - third body interaction
  - BH mimickers etc
- In these situations un-modelled searches for the BBHs will complement modelled searches
- Next : we provide an example for the effect of eccentricity on circular templates

Gravitational waves from eccentric BBH

- Binaries with orbital eccentricity will have periastron advance, this feature is translated as the phase modulation in the GWs waveform
- The waveform are shorter in time, i.e. time to merge is smaller as the eccentricity increases
- The relative power in the higher harmonics are proportional to the eccentricity





Peter Mathews (1964) PRL

Effect of eccentricity on the templated search for BBHs

- The circular template bank are not a good match for the binary neutron star (**BNS**) having eccentricity, e > 0.05 *Huerta, E. A. and Brown, Duncan A. PRD (2013)* plot on the right shows the fitting factor (FF) as a function of eccentricity for BNS

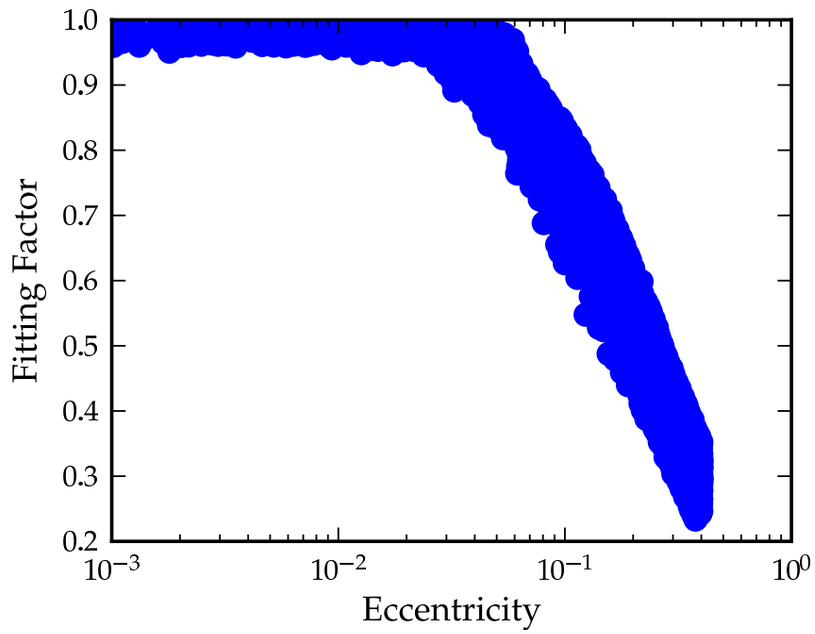
- Bottom right we do the same for the **BBH**, we can conclude for ~ e > 0.2 the FF falls below 0.9 (this is done with the inspiral only waveform and templates) *Tiwari et al in preparation* , full inspiral merger ringdown models are not available yet

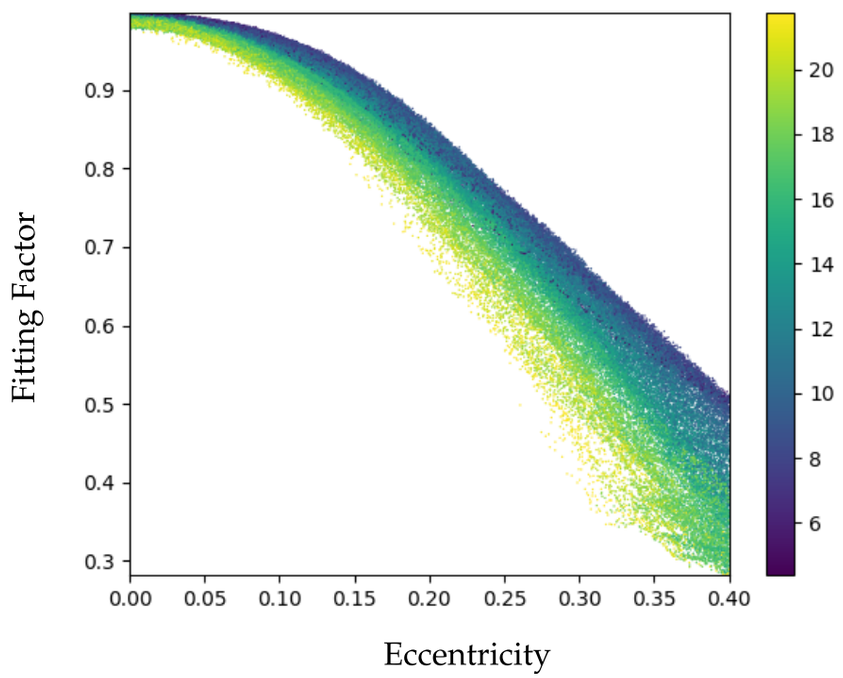
- Fitting factor is the measure of how much waveform accuracy contributes to the collection of optimal SNR

- Hence, searching for eBBH with the circular template bank will be quite suboptimal

- For such scenarios un-modelled search targeted for BBHs can complement the modelled searches

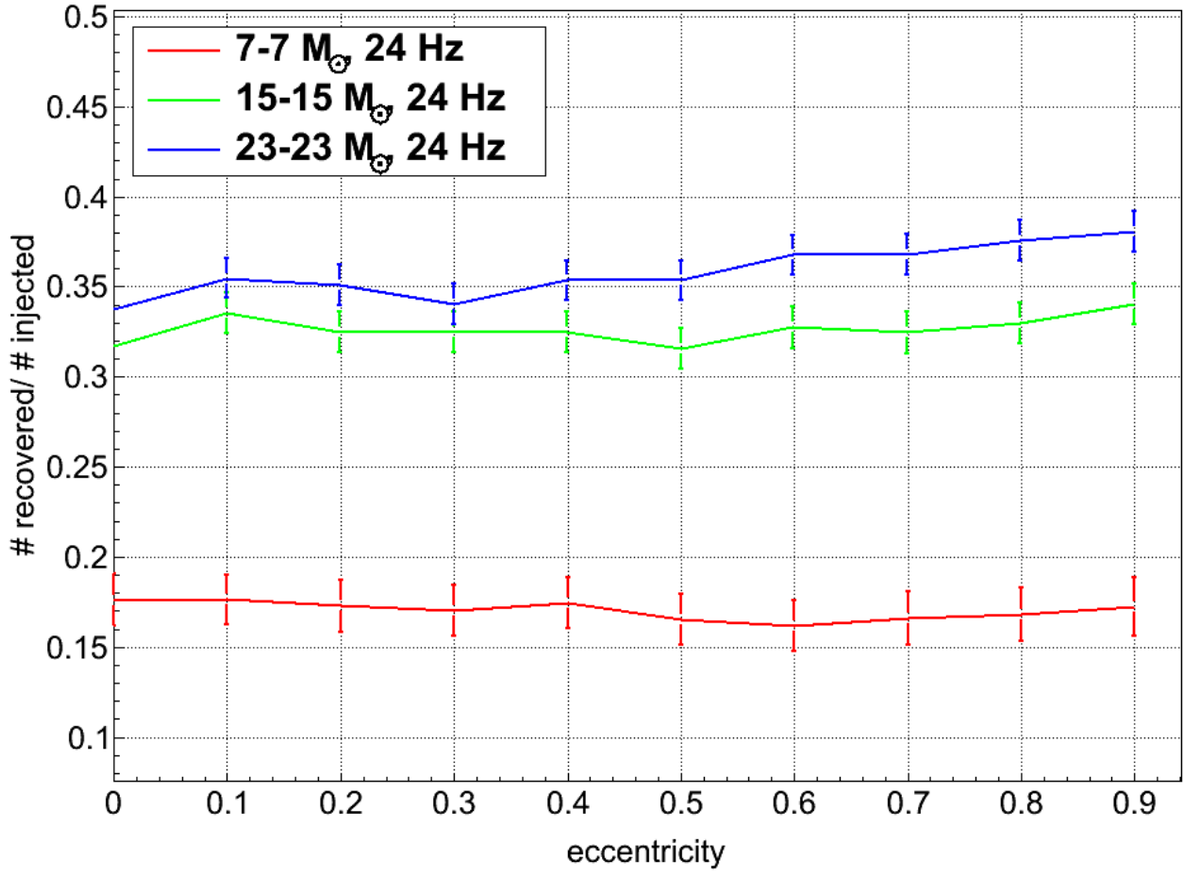
$$\mathcal{FF} = \max_{b \in \text{bank}} \mathcal{O}(h^e, h_b^T)$$





Search for BBH using un-templated analysis : eBBH

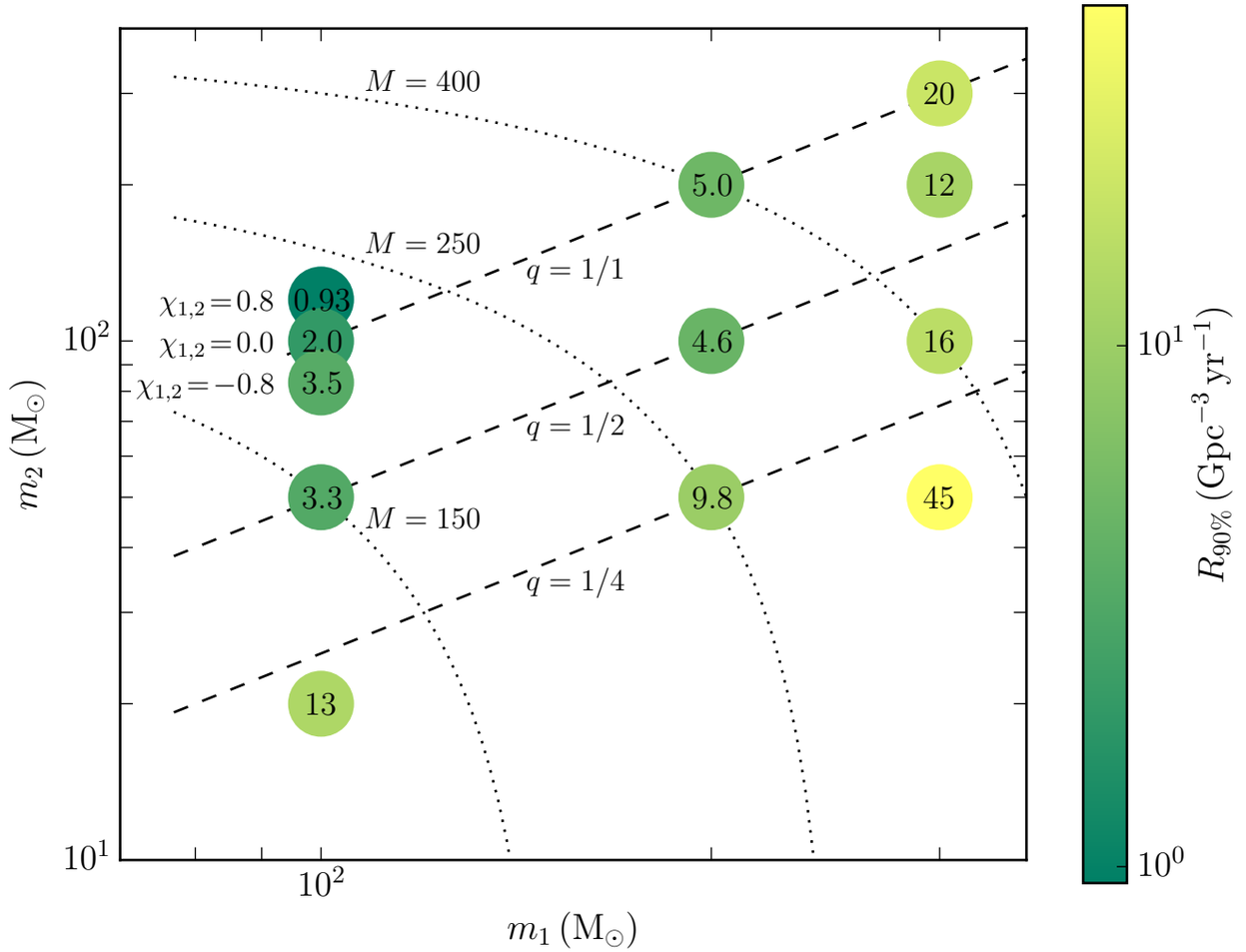
- Search for eBBH is done using un-modelled search, which requires no templates
  - the efficiency of this algorithm is invariant of the eccentricity
- If detected such sources can enrich our understanding of the dense stellar environments and formation channels of BBH
- The results for the early LIGO -VIRGO sensitivity have been published and upper limits were obtained
- We are working on the results of the search for advanced LIGO first and second observing run



V Tiwari+ Phys.Rev. D93 (2016) no.4, 043007

Search for BBH using un-templated analysis : IMBHB

- Search for Intermediate mass BBH is done using both the methods
  - Modelled search : using inspiral merger ringdown template bank with aligned spins till total mass between 50-600 M_sun and effective spins -0.99 and 0.99 and mass ratio less extreme than 1:10
  - Un-modelled search tuned in the parameter space of IMBHB (lower frequency, requires signal to be chirping up etc)
- The results for this search for the first observing run of the LIGO detectors is now published, the highlights are
  - There were no GWs found from IMBHB
  - The rate upper limit at 90% confidence was found to be 0.93 for 100-100 M_sun at 0.8 aligned effective spin



Rate upper limit

LVC arXiv:1704.04628(O1 IMBHB)

Conclusion

- Un-modelled searches are complementary to the modelled searches for BBHs and can potentially help to extend the search parameter space
- Un-modelled searches found BBH like GW150914 and GW170104 with high significance (although lower than the modelled search)
- Some of the interesting formation channels can predict binaries with parameters such eccentricity, extreme precession etc where where un-modelled searches play an important role