Sensitivity of the Gravitational Wave Detector Network to High Mass Binary Black Hole Mergers in Observing Run 3 and Beyond

LIGO Summer Undergraduate Research Fellowship

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Caltech

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Background/Motivation

- Intermediate Mass Black Hole Binary (IMBHB) mergers
- Pair Instability, Pair Instability Mass Gap
- GW190521: 64 on 85 solar masses
- Astrophysical implications for formation- want to observe more events

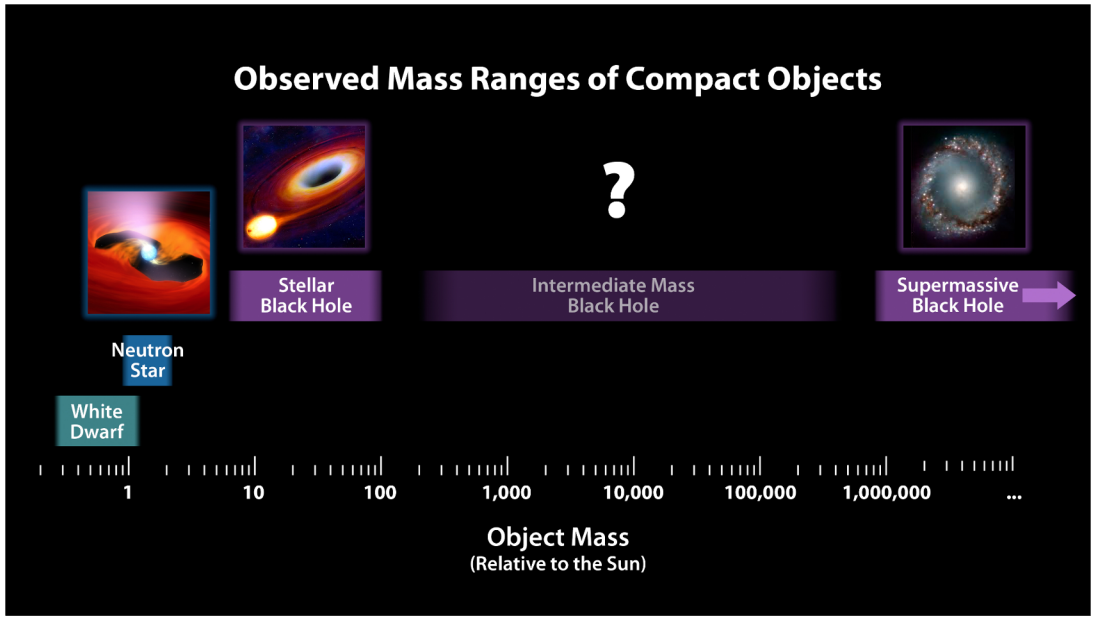


Image credit: NASA/JPL-Caltech

The Fate of the Most Massive Stars: Pair Instability

- Large stars are heated past 10^9K
  - Photons dissociate into electron-positron pairs
  - electron-positron pairs provide less radiation pressure
- Pulsational vs. Supernova Remnants
  - 100-150M⊙ are in the pulsational range
  - 140-260M⊙ have no remnant
- I define the IMBHB mass range as ~ 65 to 250 $M_\odot$

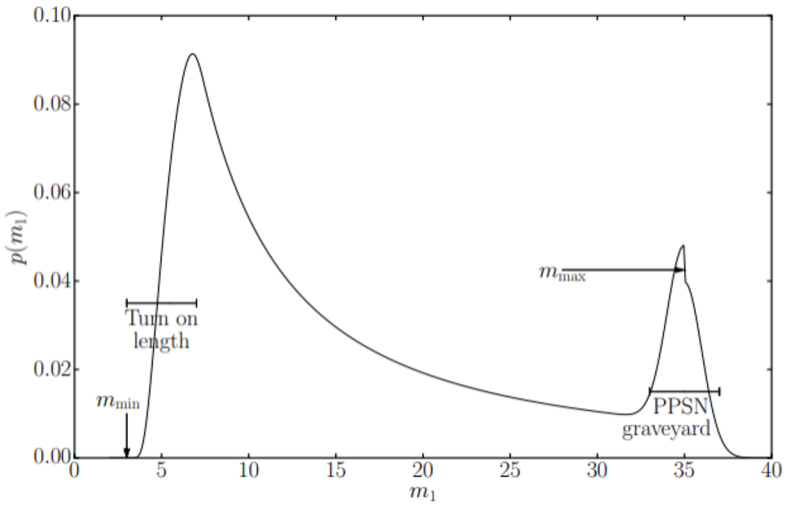


Image Credits: Colm Talbot and Eric Thrane

Goal: Determine The Sensitivity of the Detector Network to High Mass Systems

- Question: How sensitive is the detector network to IMBHB mergers?
  - With effects such as precession and higher order modes?
  - In O3? In the future? With more detectors?

- Express the sensitivity as a rate of events per space-time volume

$$N = RVT$$

Number of Observed Events and Distance Sensitivity

$$N = RT \int dz \frac{dV_c}{dz} (1+z)^{-1} \epsilon(z|\theta)$$

$$V_s = \int dz \frac{dV_c}{dz} \epsilon(z|\theta)$$

N = Number of Detected Events

V_s = Sensitive Volume

dV_c/dz = Comoving Volume

R = Rate of IMBHB mergers (assumed constant)

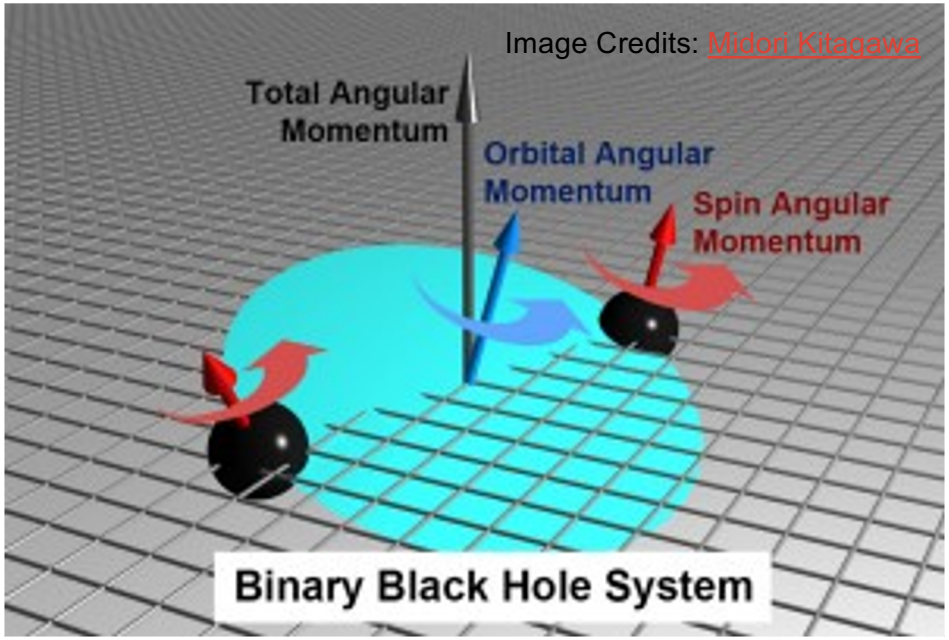
T = Time (without dilation factor)

ε(z|θ) = efficiency function

z = redshift

Parameters Affecting Detector Sensitivity: θ

- Masses, spins, precession, sky location, orbital orientation
  - Not eccentricity or tidal deformation
- Antenna pattern of the detectors
- Detectors in the network



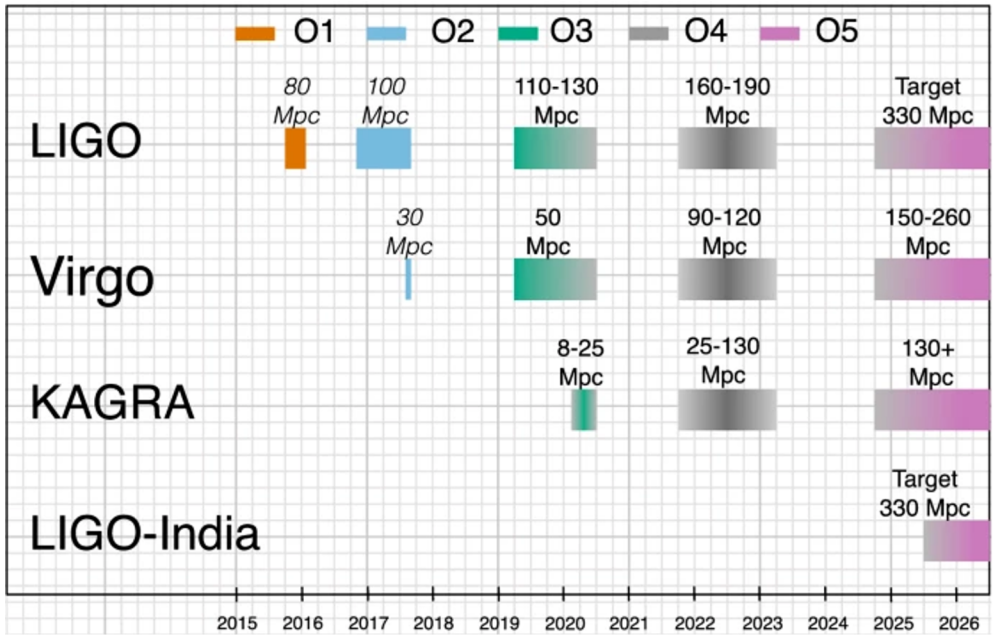


Image Credits: Paper

Averaged Parameters vs Sampled Parameters

Searching for overall sensitivity of the network

Average the Extrinsic Variables

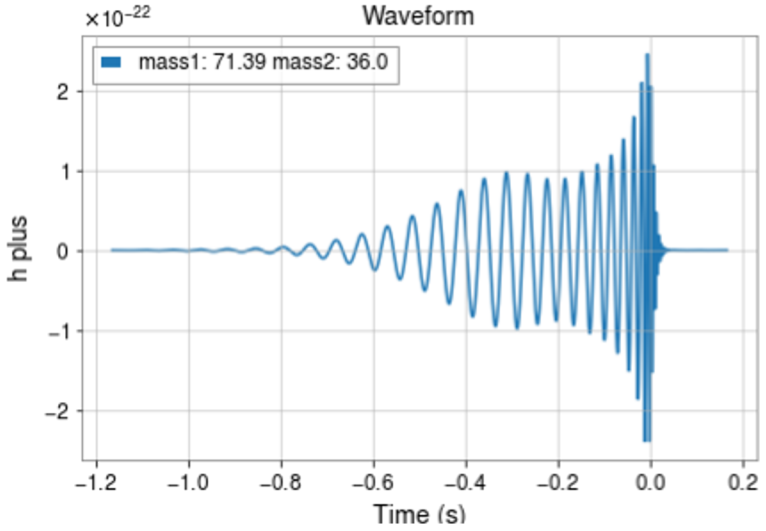
- Sky location/orientation
  - Assume uniformly random
- Spin values
  - Assume gaussian distributions
- Presence of precession/higher order modes

Sampled

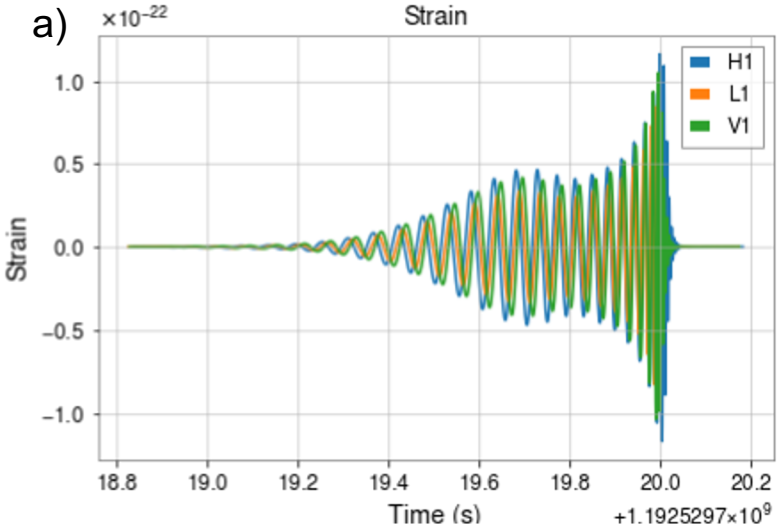
- Masses
- Precession
- Network Configurations
- Redshift/ luminosity distance

Methodology: How Parameters Affect the Waveform

a)



a)



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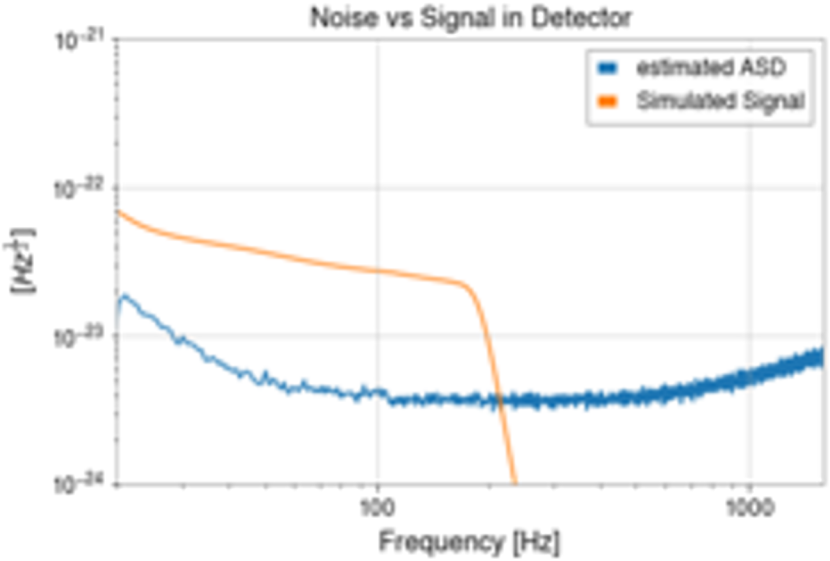
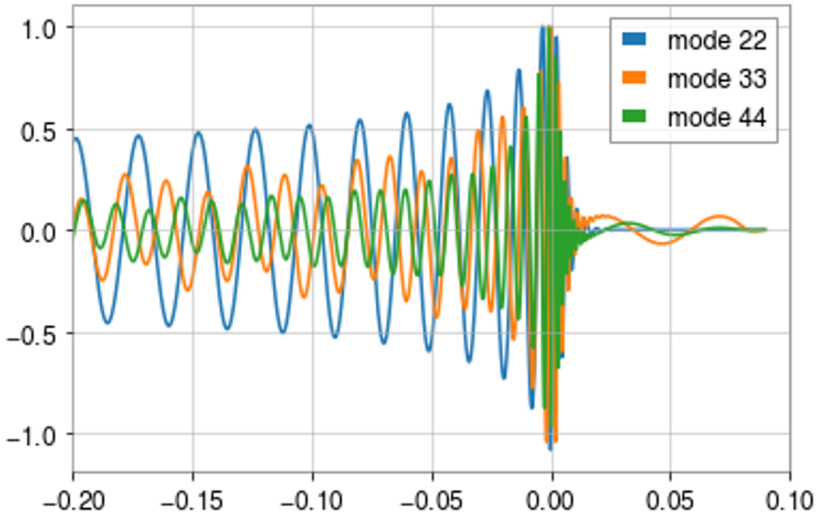


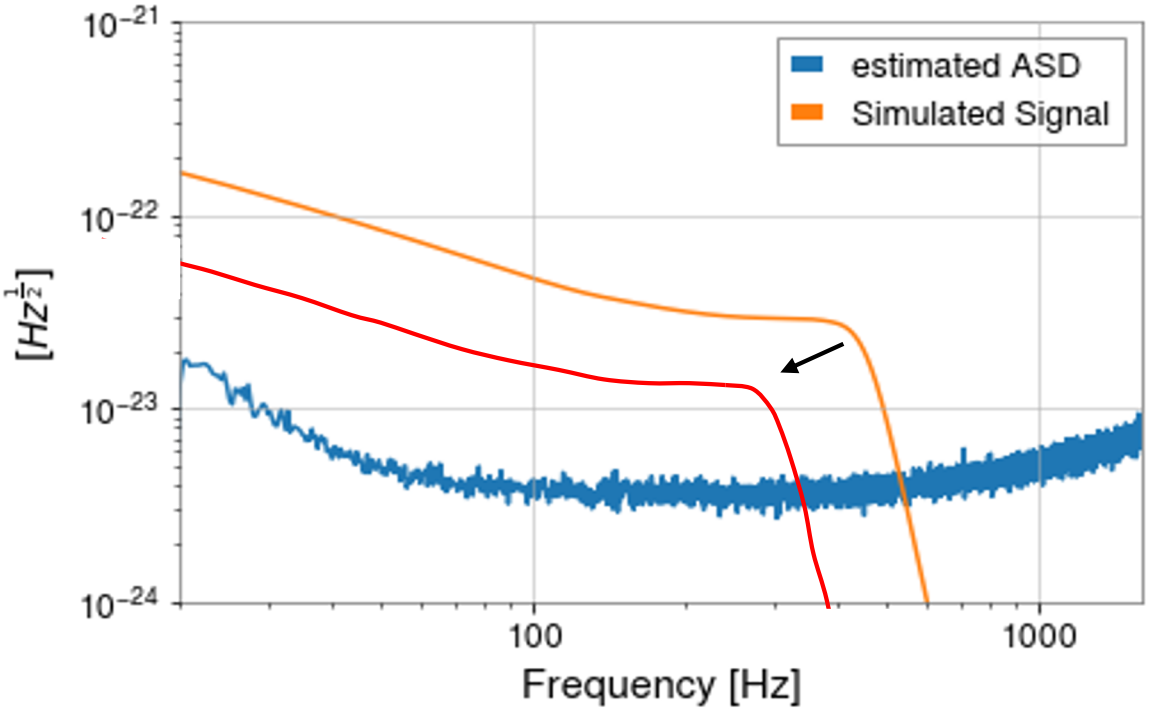
b)



Redshift and Cosmology

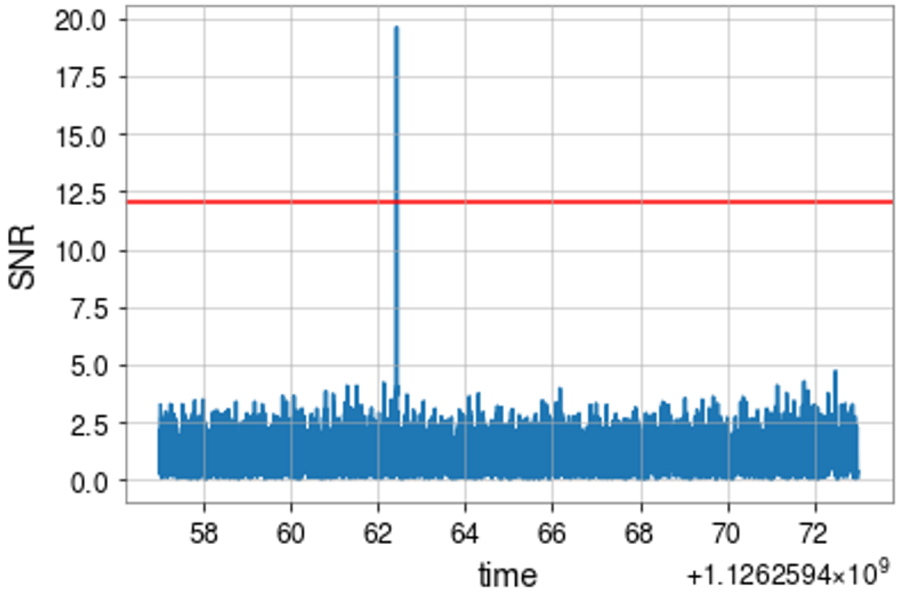
- Frequency is shifted to lower wavelengths
  - Frequency band is 20-2000 Hz
  - Masses are therefore redshifted

- Time dilation of the rate per spacetime volume
  - Rate is proportional to the comoving volume



Simplifying Assumptions

- Power Spectral Densities are Estimates
- SNR Threshold is the basis for detection
- Duty Cycle is assumed to be 100%
- Precession and higher order modes are not used in search pipeline template banks



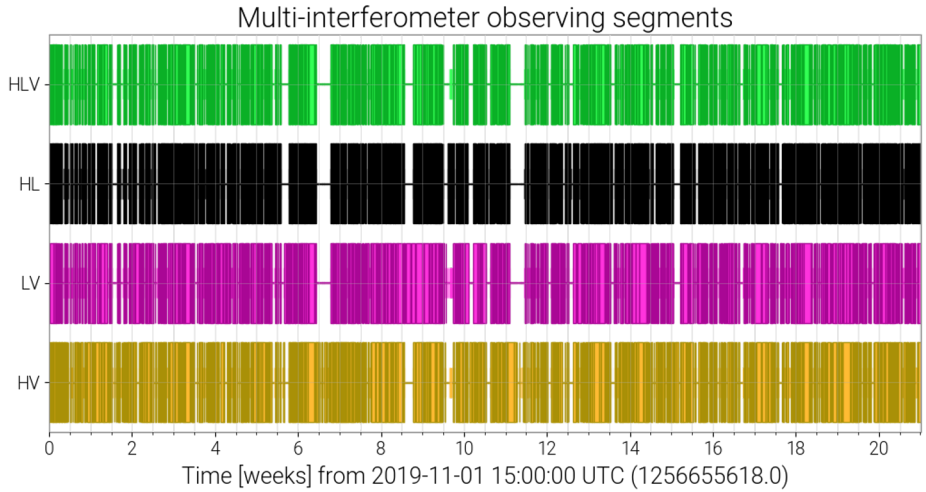
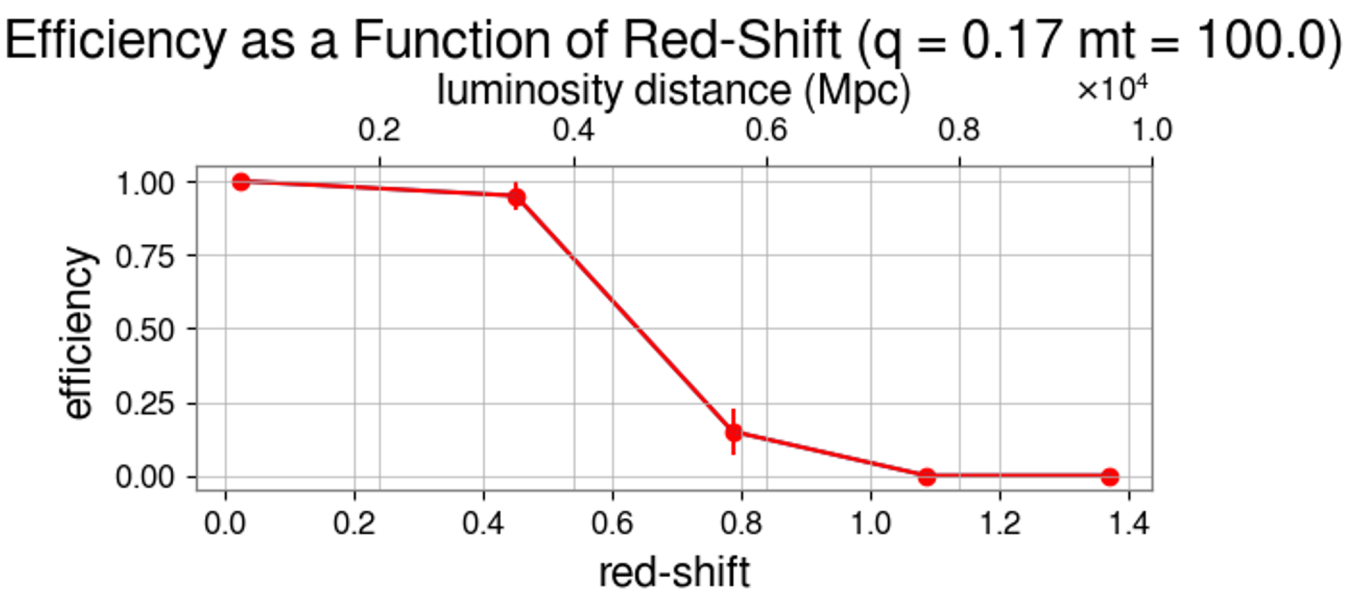
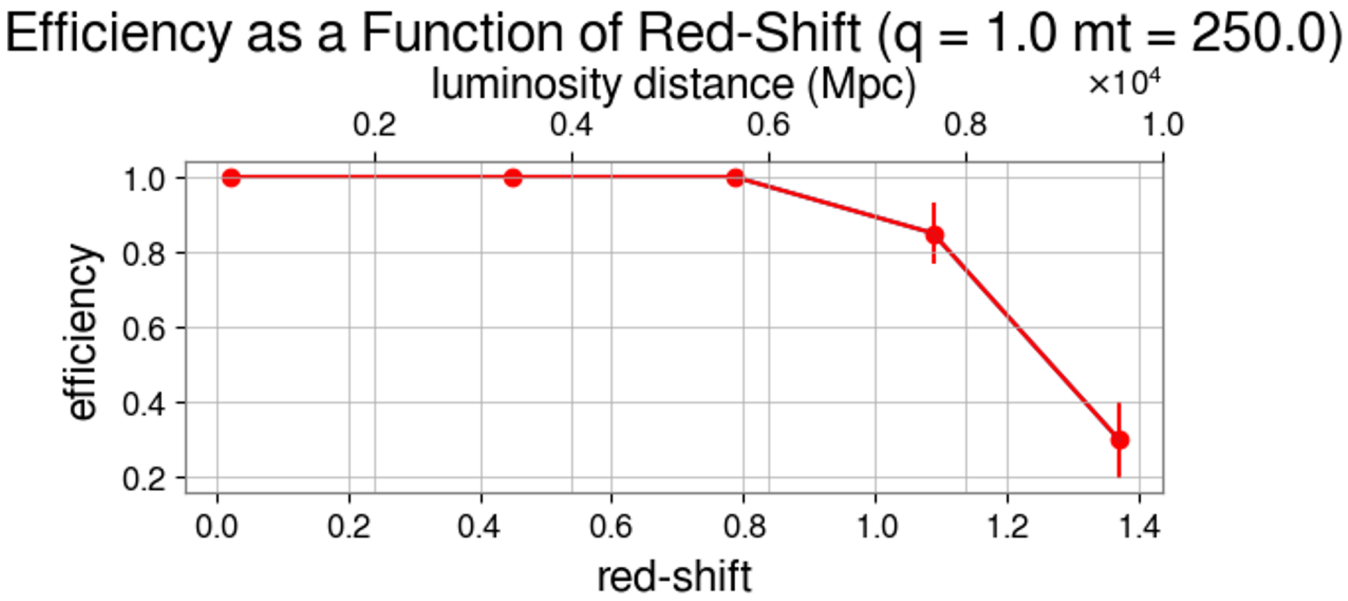


Image Credits: Detchar Summary Pages

Results: Efficiency Curves





No! Wrong Colloms!

Sensitive Distance by Total Mass

Sensitive Distance		
Parameters	Total Mass/ Mass Ratio	Sensitive Distance (z)
Net = O3, no precession/HOMs	$M_t = 50$, q = 0.17	0.63
Net = CE, no precession/HOMs	$M_t = 50$, q = 0.17	1.01
Net = CE, no precession/HOMs	$M_t = 50$, q = 1	1.30
Net = CE, precession/HOMs	$M_t = 50$, q = 1	1.30
Net = O3, no precession/HOMs	$M_t = 250$, q = 1	1.55
Net = CE, no precession/HOMs	$M_t = 250$, q = 1	1.56

$$V_s = \frac{4\pi}{3} D_s^3$$

Conclusion

- Precession/HOMs don’t seem to significantly affect sensitivity
- IMBHB merger rates will help us infer the formation methods of high mass black holes
- Developing a sensitivity range for IMBHBs will be useful for further studies

Acknowledgements

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My fellow SURF students!