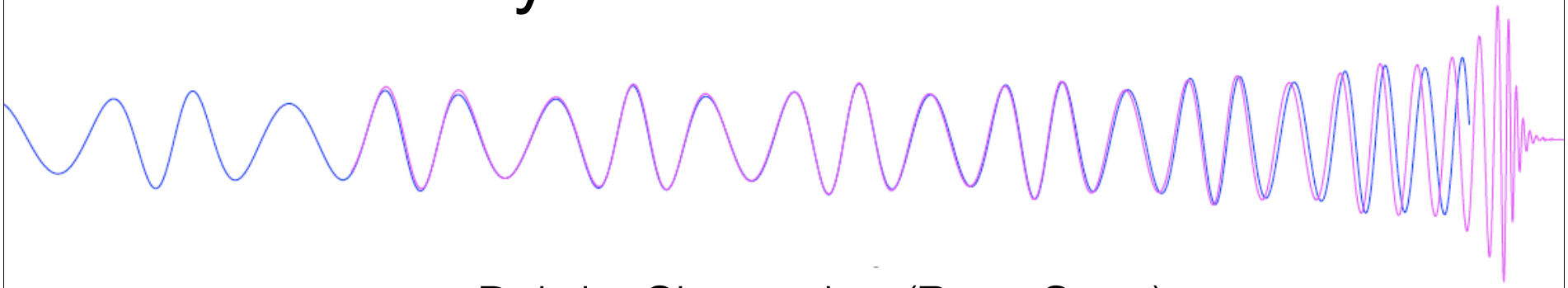
Coupling Simulations with Data Analysis and Observations



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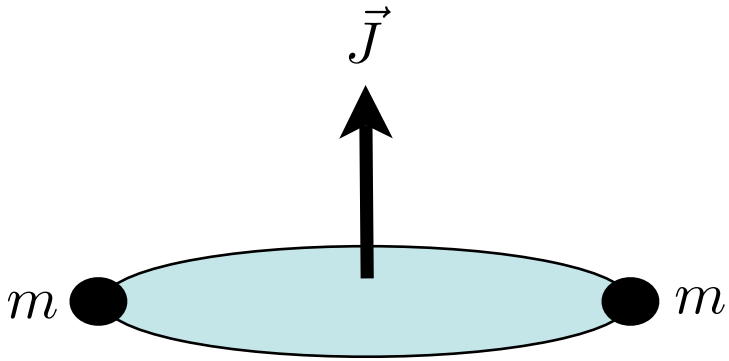
Birjoo Vaishnav
Ian Hinder
Frank Herrmann

1. Are ground based detectors blind to eccentricity?
2. How well will LISA see eccentric waveforms of late inspiral/merger/ringdown?

Binary Black Holes in Eccentric Orbits



- Cactus & Carpet (Schnetter)
- Moving punctures approach (RIT & NASA)
- Kranc (Husa, Hinder, Lechner)
- 6th order finite differencing
- Initial Data: PN parameters in puncture approach and TwoPuncture Code (Ansorg)

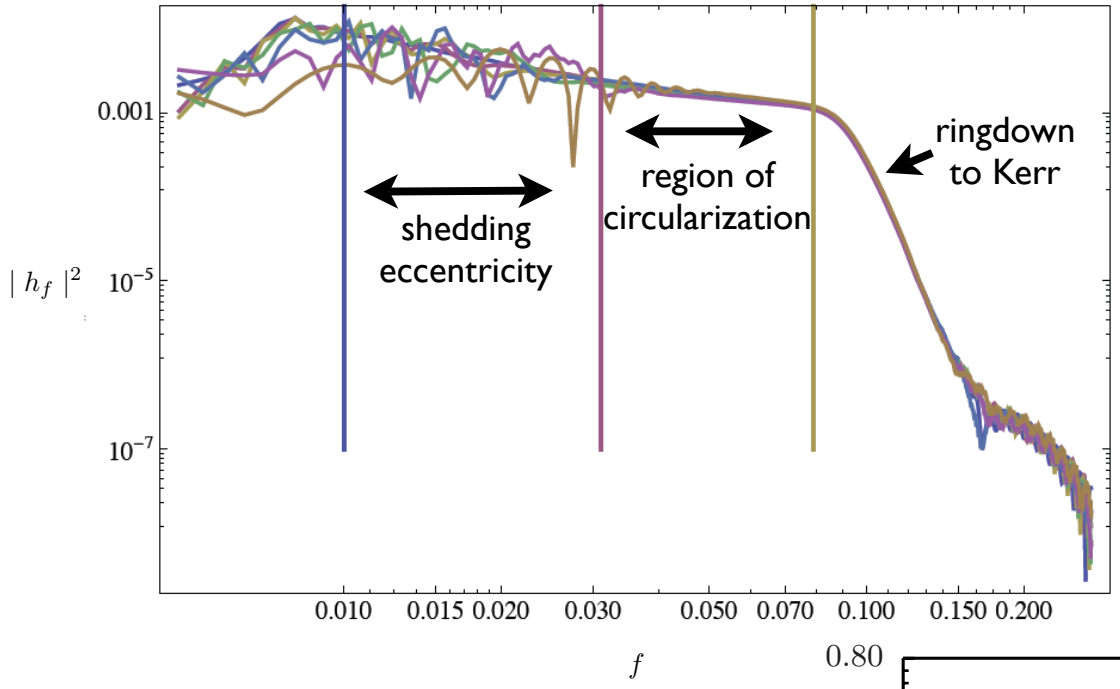
Are eccentric BBHs interesting for Detection of Gravitational Waves?

- BBHs circularize before they reach the LIGO band.
  [Gultekin, Miller, Hamilton ApJ 640 (2006) and Mandel, Brown, Gair, Miller arXiv 0705:0285]

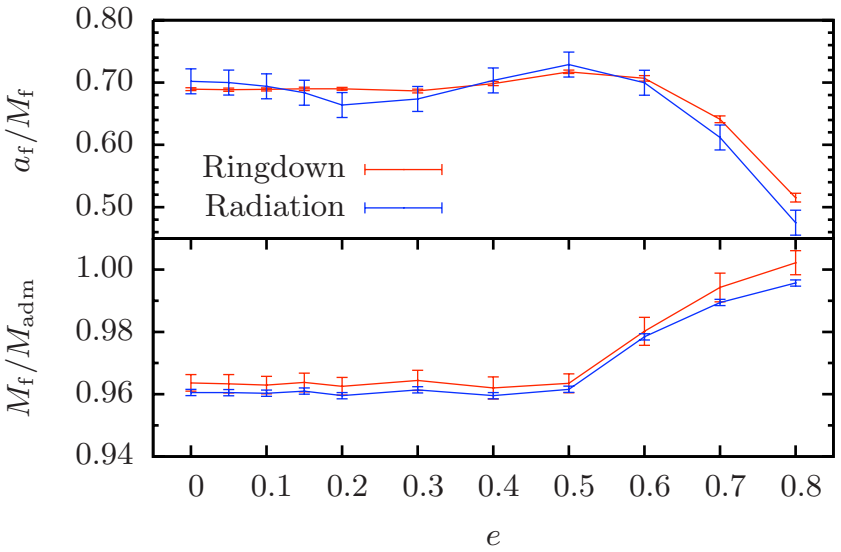
- Some scenarios for eccentric binaries within ground based detector's reach have been suggested.
  [Kozai 1962, Miller and Hamilton 2002, Wen 2003, Campanelli et al 2008, ...]

- More scenarios suggested for LISA.
  [Gultekin, Miller and Hamilton 2004, *Three-Body Dynamics with Gravitational Wave Emission*
  Armitage and Natarajan 2004, *Eccentricities of Supermassive Black Hole Binaries Coalescing from Gas Rich Mergers*,
  Dotti, Colpi, Haardt and Mayer 2006, *Supermassive black hole binaries in gaseous and stellar circumnuclear discs: orbital dynamics and gas accretion*
  Hoffman and Loeb 2006, *Dynamics of Triple Black Hole Systems in Hierarchically Merging Massive Mergers*]

Eccentric Binaries: The Final State



- The eccentricity "hair" is shed almost immediately upon entering plunge.
- The final spin depends weakly with e<0.4.
- Final spin agrees with Sperhake et al.
- For larger eccentricities, there is a peak in spin at about e~0.45.



[Hinder, Vaishnav, Herrmann, Laguna, Shoemaker PRD 77, 081502 (2008)]

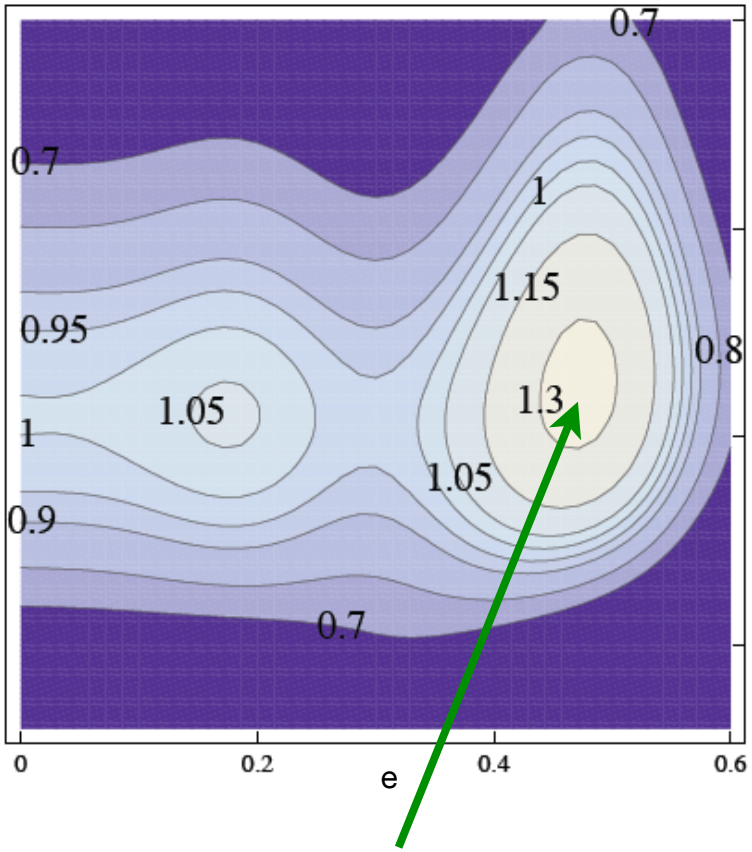
How Blind are Interferometers to Eccentricity?

Signal to noise ratio from waveforms of eccentric binaries
with initial LIGO noise curve

$$SNR = \langle h(f) \mid h(f) \rangle$$

h(f): one of a range of numerical, eccentric waveforms

SNR
where SNR(e=0)=1
100 Msun



total mass
of the binary

B.Vaishnav

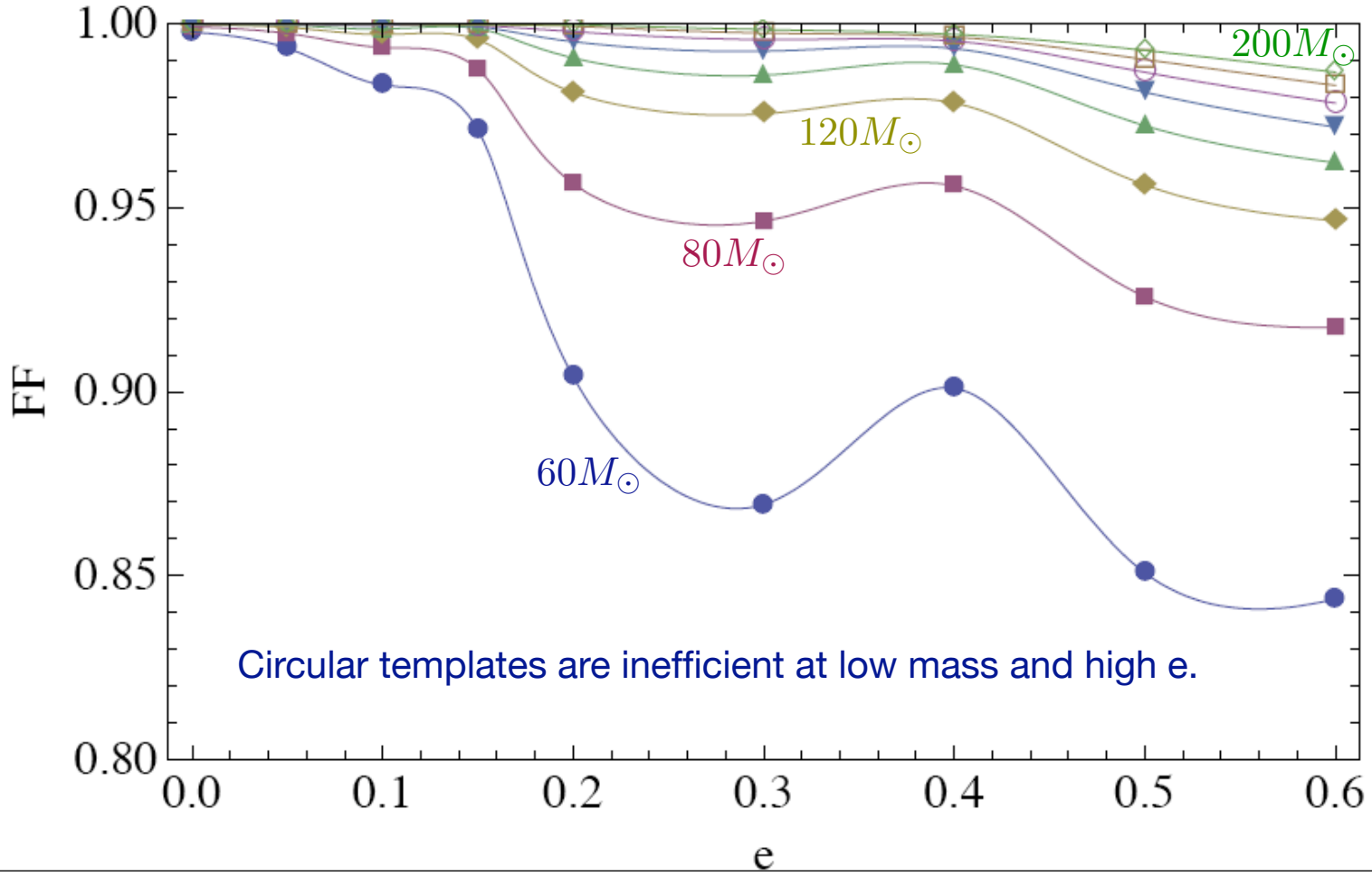
LIGO is 30% more sensitive at eccentric binaries (e=0.45) than circular, implying a greater reach in detection volume

Can we see the unexpected with circular templates?

Interferometric detectors use matched filtering to optimize the detection of inspiraling signals.
If InLIGO assumes no eccentric binaries will be merging, will they miss a signal?

$$FF \equiv max_{m_T} min_{\phi_S} max_{t_0,\phi_T} \frac{\langle S|T\rangle}{\sqrt{\langle S|S\rangle\langle T|T\rangle}}$$

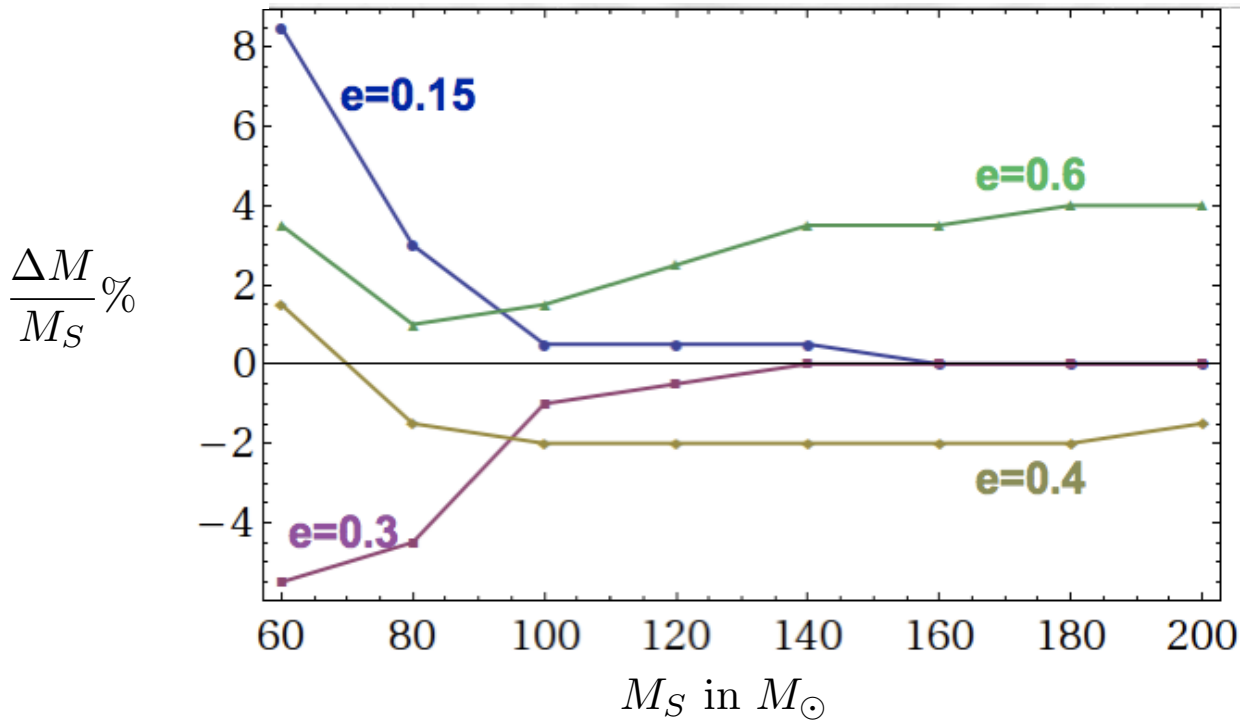
S: signal is one of a range of numerical, eccentric waveforms
T: template is a numerical, circular waveform



Circular templates are inefficient at low mass and high e.

Estimate of mass parameter bias for InLIGO

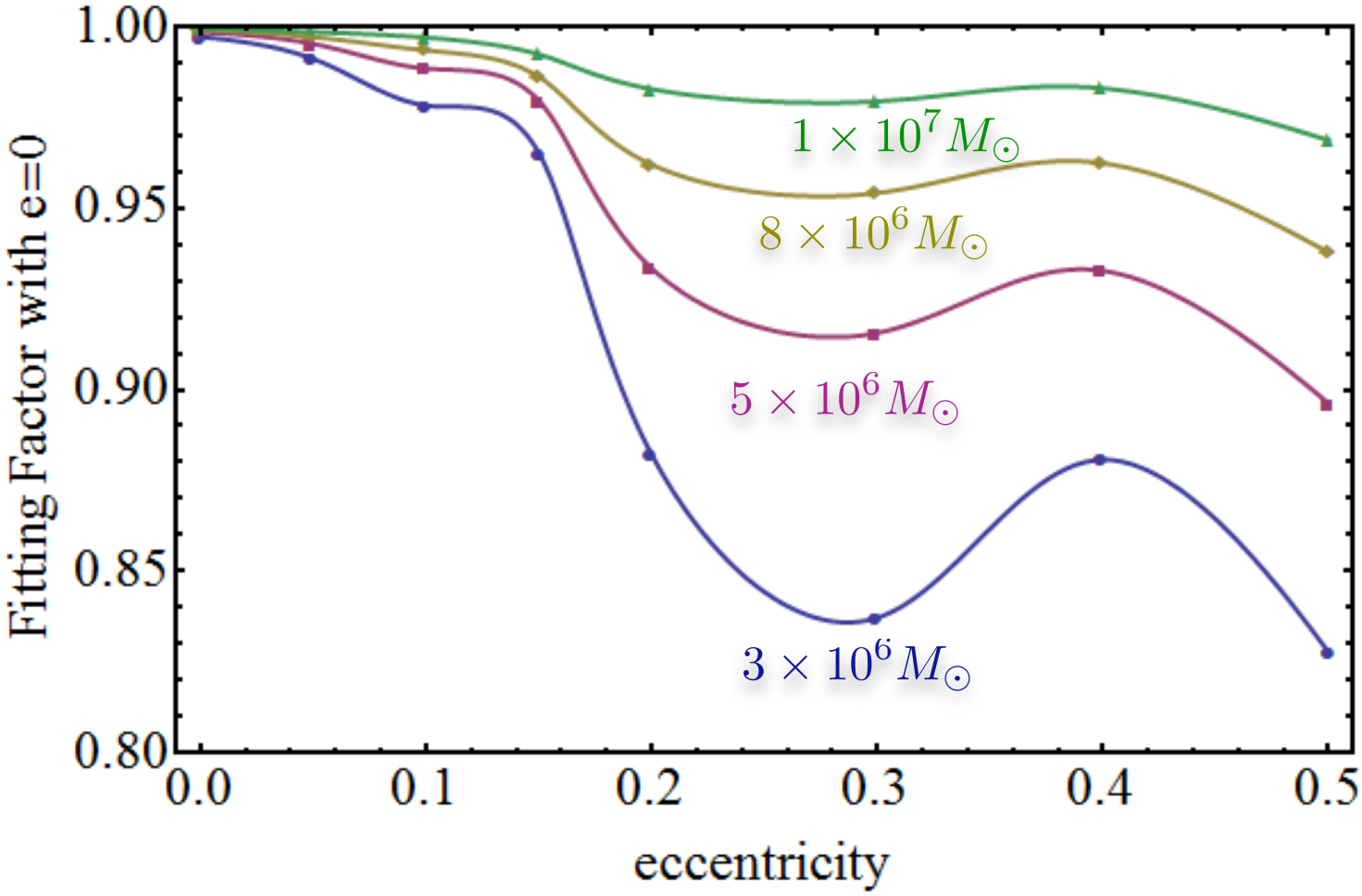
$$\Delta M \equiv M_S - M_T$$



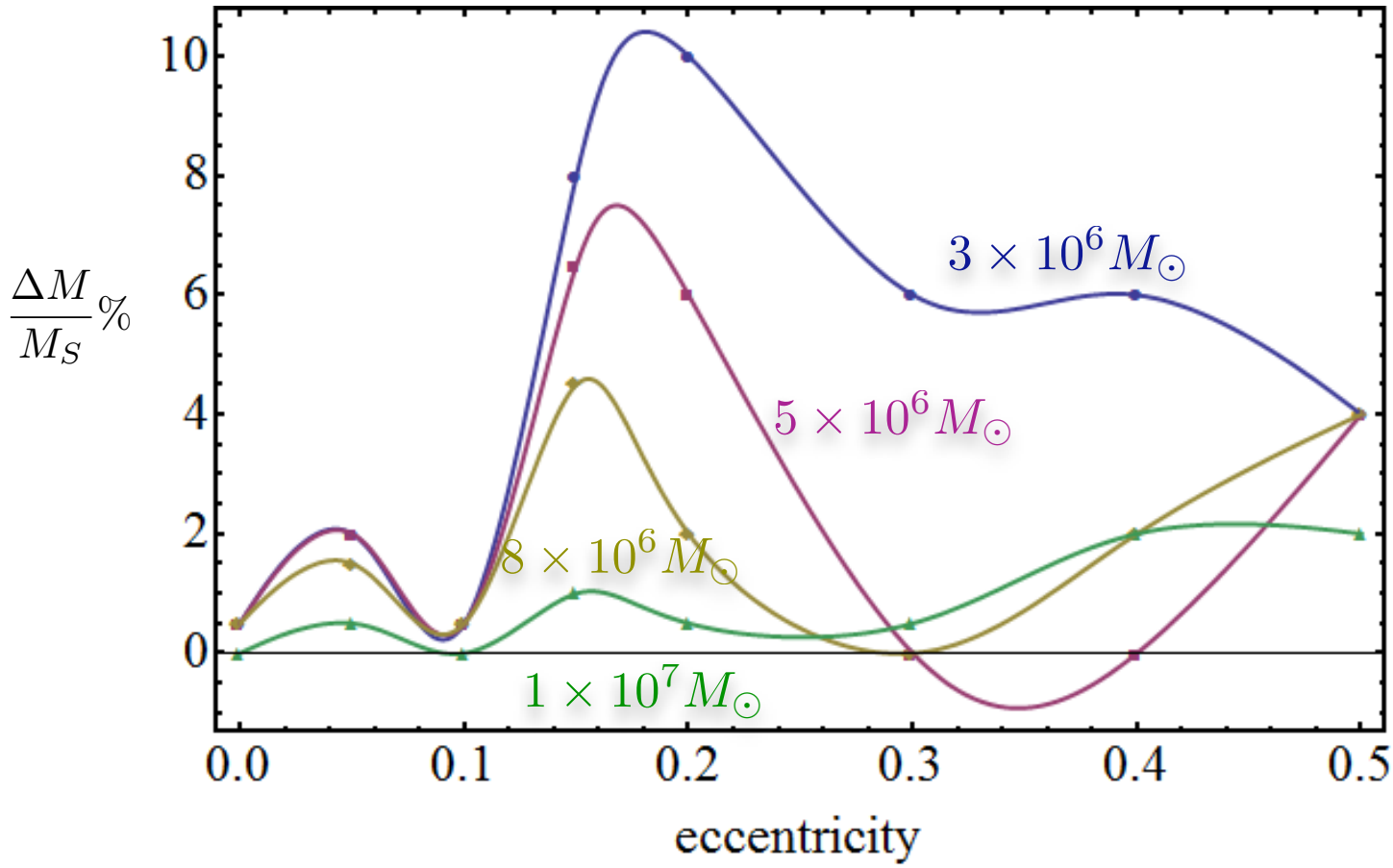
At low e, error decreases with increasing mass.
At high e, error increases with increasing mass.

How well do circular templates work with LISA?

$$FF \equiv max_{m_T} min_{\phi_S} max_{t_0,\phi_T} \frac{\langle S|T\rangle}{\sqrt{\langle S|S\rangle\langle T|T\rangle}}$$

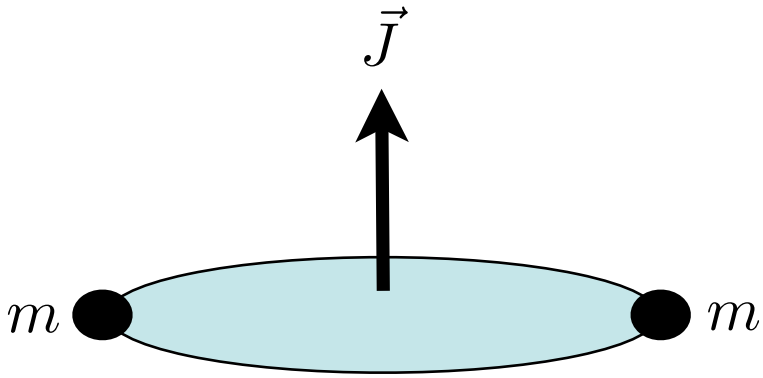


Estimate of mass parameter bias for LISA



- At lower masses, the inspiral plays the strongest role and the mass bias is bigger.
- As mass increases, the ringdown plays the strongest role and we see the circularization at e<0.4 with a smaller mass bias.

Conclusions for Binary Black Holes in Eccentric Orbits



- Are ground-based detectors blind to eccentricity for intermediate mass binaries?
  - biased toward eccentric binaries if they exist in LIGO range at peak in spin
  - yes for e<0.1 when including only dominant mode
- How well will LISA see eccentric waveforms of late inspiral/ merger/ringdown?
  - likely LISA will need eccentric templates to get accurate parameter estimations
  - in future, we will conduct an estimation for e and use hybrid PN/NR templates