MCMC PE for “eccentric” CBC inspirals

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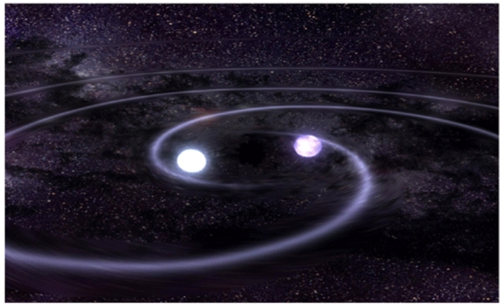
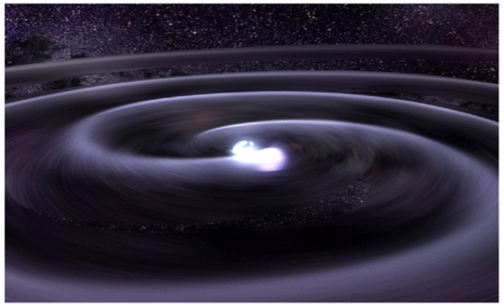
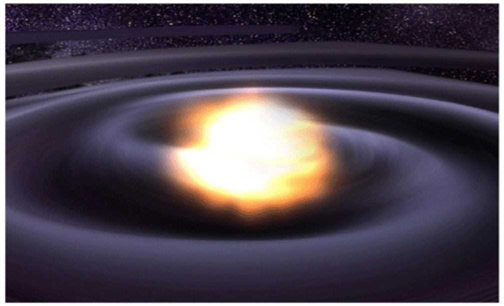
In collaboration with Marc Favata, K.G. Arun, Blake Moore

Motivation







- Eccentric CBC inspirals are most relevant to populations formed by stellar dynamics and those formed with strong supernova kicks

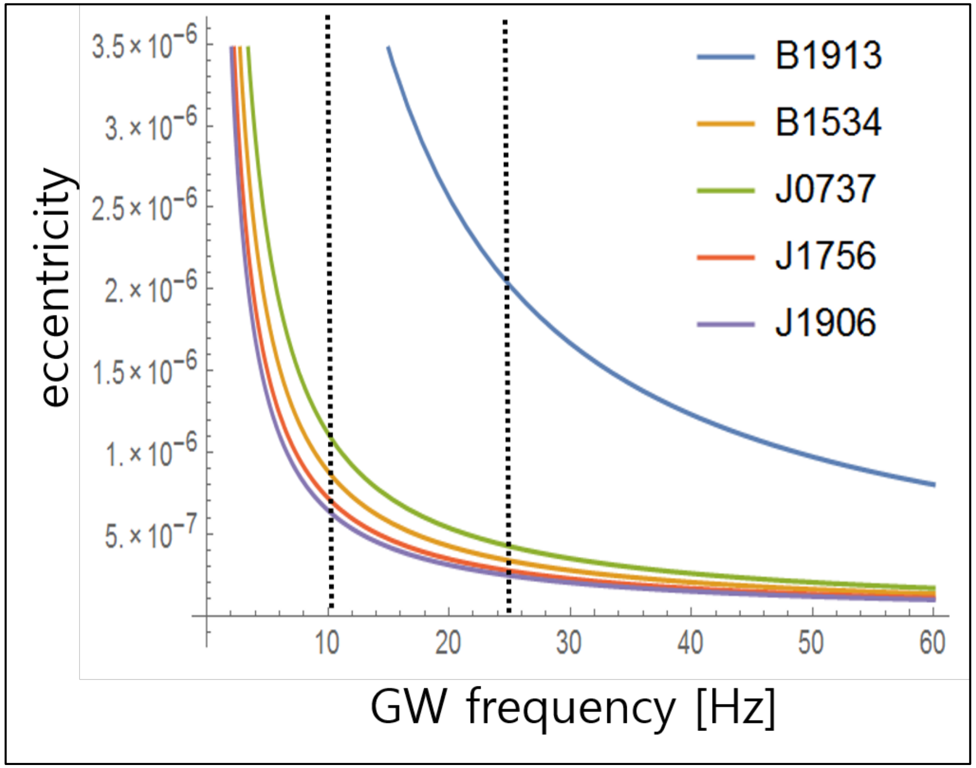
- GW search/PE use “circular” templates. Eccentricity changes the phase of inspiral GW waveform from a circular case. This affects PE accuracy of intrinsic parameters such as masses (Favata 2013)

- 2^{nd} and 3^{rd} G detectors can be capable of observing “eccentric” CBC inspirals. Low frequency band (f_{gw}= 10 – 30 Hz) is important.

- This work: MCMC PE for GW151226-like BBH inspirals assuming different eccentricities (e=0.0001 - 0.2)

CBC inspirals and eccentricity

Circular templates are ok
for CBCs like known NS-NS mergers.
$e < 10^{-5}$ at 10 Hz or higher
(e.g. Hulse-Taylor binary)



Some exotic CBCs may be "eccentric"
O(0.1%) – O(1%) of disk population
(Kowalska, Bulik, et al. 2011)

We examine systematic error in eta
(systematic mass ratio) due to "eccentricity"

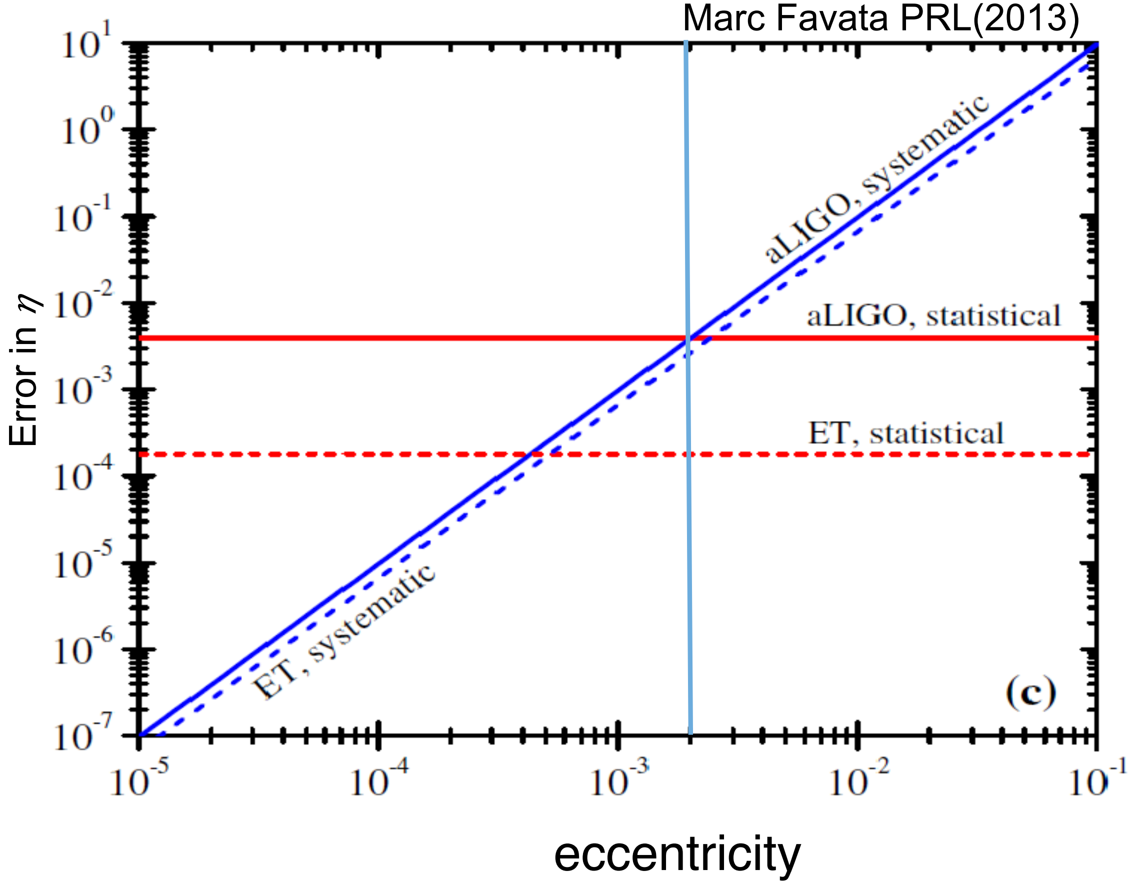
Systematic bias in the symmetric mass ratio due to neglecting eccentricity [Fisher Matrix study]

eta (η) : symmetric mass ratio

$$\eta = \frac{m_1 m_2}{(m_1 + m_2)^2}$$

systematic error becomes larger than statistical error in eta measurement for CBCs
with **e > 0.002 at 10Hz (aLIGO)**
with **e >~ 0.0004 (ET)**

Marc Favata PRL(2013)

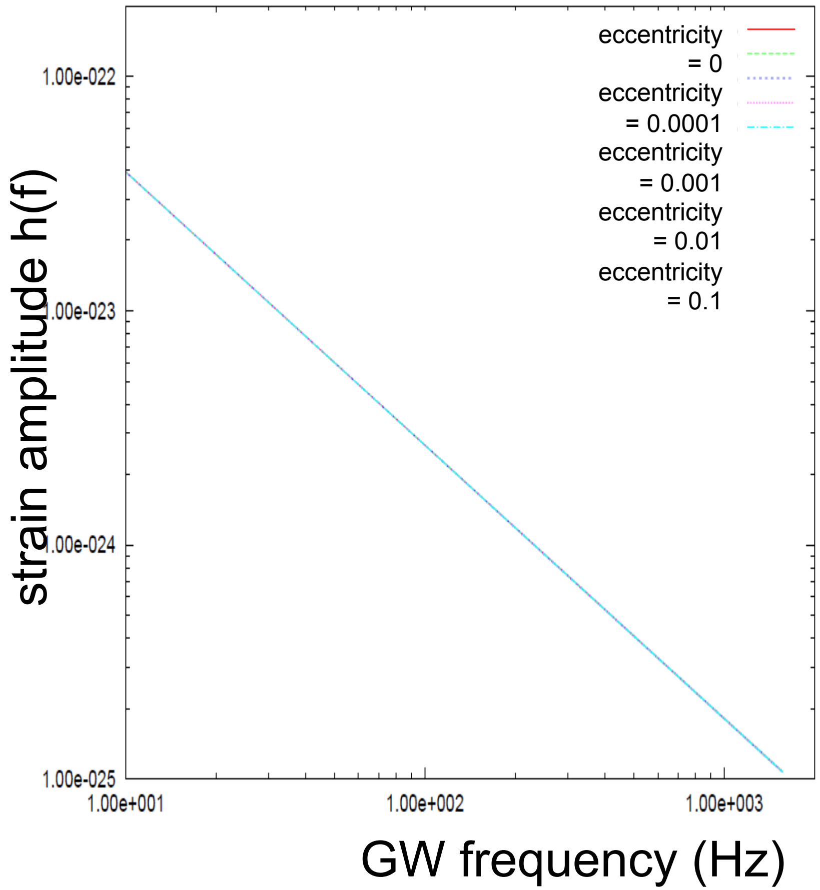


“eccentric” GW waveform (inspiral)

- Waveform model: TaylorF2 (restricted, non-spinning) [Favata et al. in prep]

- Phase term = 3.5pN SPA
  + 3.0pN secular phase corrections
  for eccentricity

- We implemented eccentricity corrections to TaylorF2 (in LALSuite/LALSimulation). No spin, No amplitude corrections.



phase corrections

TaylorF2 phase = SPA + phaseEcc + etc.

phaseEcc depends on e_0, v_0 and eta

e_0 : eccentricity@f_0

$v_0 = (\pi M f_0)^{1/3}$

$M = m_1 + m_2$

f_0 is set to be 10Hz

$$\psi = 2f\pi t_0 - 2\phi_0 + \psi_0 + \frac{3}{128}\frac{1}{\eta v^5}\Big\{1 + v^2\left(\frac{3715}{756} + \frac{55}{9}\eta\right) - 16\pi v^3 + v^4\left(\frac{15293365}{508032} + \frac{27145}{504}\eta + \frac{3085}{72}\eta^2\right)$$

$$+ v^5\left(\frac{38645}{756}\pi + \frac{38645}{756}\pi\ln\left[v^3\right] + \eta\left(-\frac{65\pi}{9} - \frac{65}{9}\pi\ln\left[v^3\right]\right)\right) + v^6\left(\frac{11583231236531}{4694215680} - \frac{6848}{21}\gamma_e - \frac{640}{3}\pi^2\right.$$

$$\left. + \left(-\frac{15737765635}{3048192} + \frac{2255}{12}\pi^2\right)\eta + \frac{76055}{1728}\eta^2 - \frac{127825}{1296}\eta^3 - \frac{3424}{21}\ln\left[16v^2\right]\right)$$

$$- \frac{2355}{1462}e_0^2\left(\frac{v_0}{v}\right)^{19/3}\Big[1 + v^2\left(\frac{299076223}{81976608} + \frac{18766963}{2927736}\eta\right) + v_0^2\left(\frac{2833}{1008} - \frac{197}{36}\eta\right) + -\frac{2819123}{282600}\pi v^3 + \frac{377}{72}\pi v_0^3$$

$$+ v^4\left(\frac{16237683263}{3330429696} + \frac{24133060753}{971375328}\eta + \frac{1562608261}{69383952}\eta^2\right) + v^2 v_0^2\left(\frac{847282939759}{82632420864} - \frac{718901219}{368894736}\eta - \frac{3697091711}{105398496}\eta^2\right)$$

$$+ v_0^4\left(-\frac{1193251}{3048192} - \frac{66317}{9072}\eta + \frac{18155}{1296}\eta^2\right) + v^5\left(-\frac{2831492681}{118395270}\pi - \frac{11552066831}{270617760}\pi\eta\right) + v^3 v_0^2\left(-\frac{7986575459}{284860800}\pi + \frac{555367231}{10173600}\pi\eta\right)$$

$$+ v^2 v_0^3\left(\frac{112751736071}{5902315776}\pi + \frac{7075145051}{210796992}\pi\eta\right) + v_0^5\left(\frac{764881}{90720}\pi - \frac{949457}{22680}\pi\eta\right) + v^6\left(-\frac{436031538670725770087}{1326585351168000000} + \frac{536803271}{19782000}\gamma_e\right.$$

$$+ \frac{15722503703}{325555200}\pi^2 + \left(\frac{299172861614477}{689135247360} - \frac{15075413}{1446912}\pi^2\right)\eta + \frac{3455209264991}{41019955200}\eta^2 + \frac{50612671711}{878999040}\eta^3 + \frac{3843505163}{59346000}\ln[2]$$

$$\left. - \frac{1121397129}{17584000}\ln[3] + \frac{536803271}{39564000}\ln\left[16v^2\right]\right) + v^4 v_0^2\left(\frac{46001356684079}{3357073133568} + \frac{253471410141755}{5874877983744}\eta - \frac{1693852244423}{23313007872}\eta^2\right.$$

$$\left. - \frac{307833827417}{2497822272}\eta^3\right) - \frac{1062809371}{20347200}\pi^2 v^3 v_0^3 + v^2 v_0^4\left(-\frac{356873002170973}{249880440692736} - \frac{260399751935005}{8924301453312}\eta + \frac{150484695827}{35413894656}\eta^2\right.$$

$$\left. + \frac{340714213265}{3794345856}\eta^3\right) + v_0^6\left(\frac{26531900578691}{168991764480} - \frac{3317}{126}\gamma_e + \frac{122833}{10368}\pi^2 + \left(\frac{9155185261}{548674560} - \frac{3977}{1152}\pi^2\right)\eta - \frac{5732473}{1306368}\eta^2\right.$$

$$\left. - \frac{3090307}{139968}\eta^3 + \frac{87419}{1890}\ln[2] - \frac{26001}{560}\ln[3] - \frac{3317}{252}\ln\left[16v_0^2\right]\right)\Big]\Big\}$$

PE for GW151226-like BBH [preliminary]

Software injection simulation

GW151226 mass parameters

m_1= 15.6 M_{sun} , m_2= 8.2 M_{sun} , **eta= 0.2258**

Assign eccentricity @ 10 Hz, overlap calculation f_{gw}=[25 Hz, ISCO]

To examine PE accuracy,
we consider a single detector (**aLIGO**) ;
set SNR ~ 20 (distance = 500 Mpc)

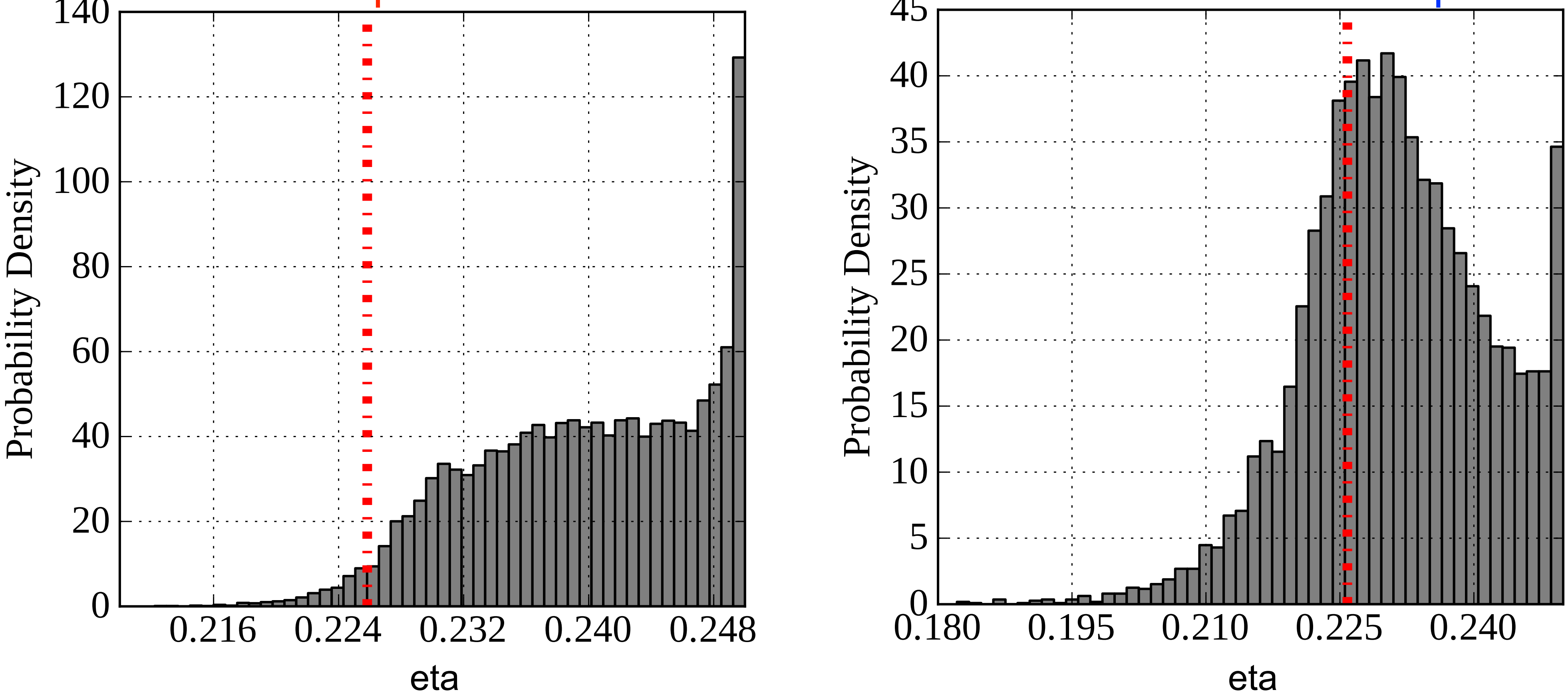
Systematic error in "eta" due to eccentricity

"Eccentric" templates are necessary for e >~ 0.2 (@10Hz)

Injection:	Detector:	prior for e:
e=0.2, eta=0.2258	aLIGO (single IF) f_{low}=25Hz	uniform e=[0.0, 1.0]

eccentric injection
circular templates

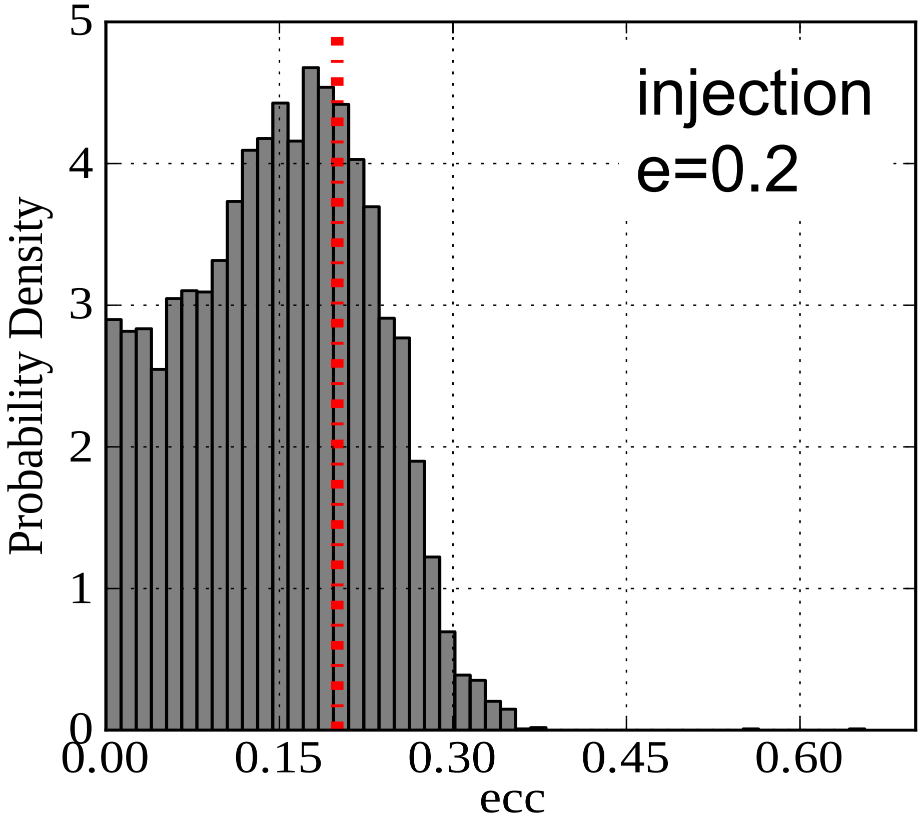
eccentric injection
eccentric templates

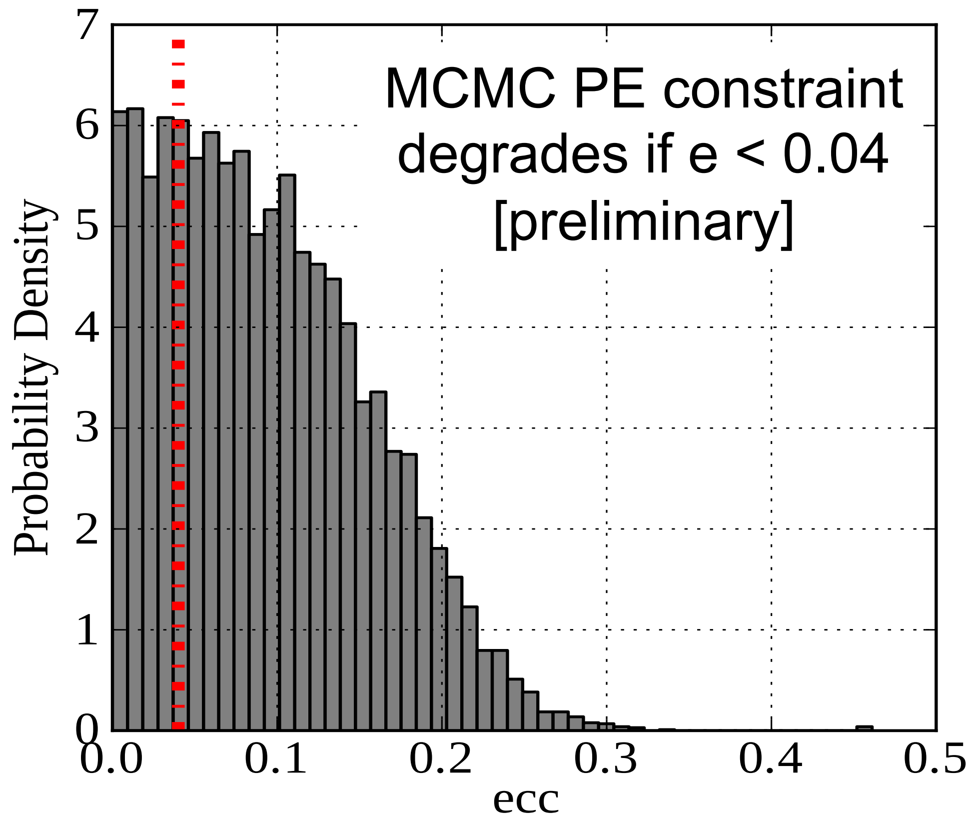


Can we constrain eccentricity from CBC inspirals?

With **aLIGO (25Hz low cut-off frequency)**, e~O(0.01) can be constrained.
Search/PE for small e inspirals are expected to be computationally expensive

[eccentric injection vs eccentric templates]





Summary

- We implemented up to 3.0 pN phase corrections due to eccentricity for TaylorF2 in LALSuite (local branch).
  LALSimulation, LALInference_mcmc can utilize this waveform model

- We examine PE accuracy for symmetric mass ratio and eccentricity for GW151226-like BBH inspiral assuming different eccentricities ($0.0001 < e < 0.2$ @ 10Hz)

- With aLIGO, inspirals with e~O(0.04-0.1) can be interesting for PE purposes (f_{low}=25 Hz) preliminary

- MCMC PE results are roughly consistent with the Fisher matrix prediction preliminary

Future work

- We will extend MCMC PE for “eccentric” CBCs varying masses and low cut-off f_{gw} = [10, 30] Hz (computationally expensive, though)
- Eccentric taylorF2 inspiral waveform will be included in KAGALI

CBC PE for KAGALI

- Additioning pN corrections for amplitude, eccentricity (TaylorF2)
- CBC PE for software AND hardware injection
- KGWG DAS members: Hyung Won Lee, Jeongcho Kim,
  Chunglee Kim

  Yeong-Bok Bae (new postdoc at KASI) will join from 2016.09