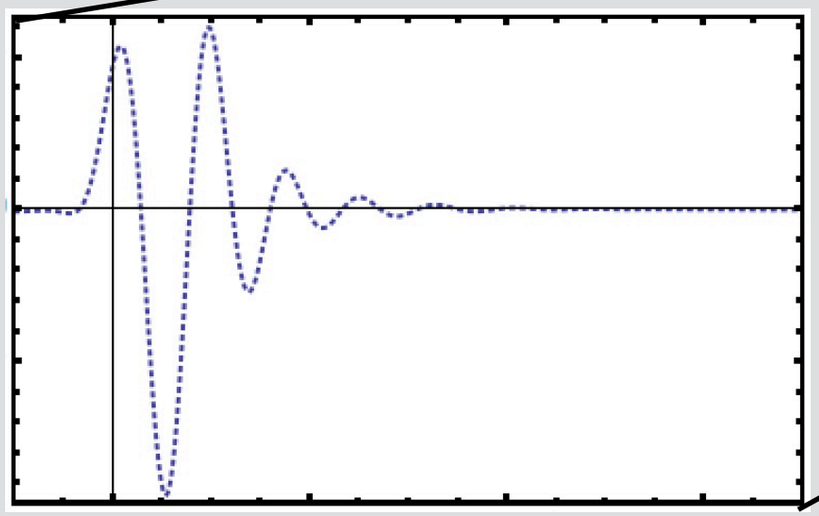
Confusing head-on and precessing intermediate-mass black hole mergers



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LIGO-P1900363, submitted to P&P in early December

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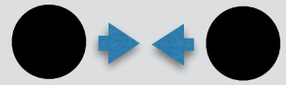
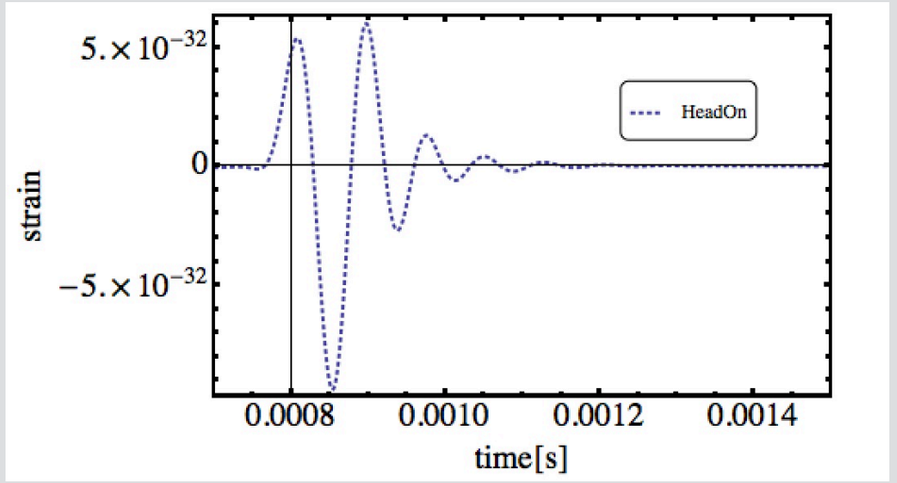
Motivation

- **Head-on** binaries produce merger-ringdowns with **no inspiral**
- **Precession** can lead to a **zero-ing of the inspiral** right before merger
- Can these two effects be confused?
- If so, in what range of masses and signal loudness?
- **Real case: s190521g (not part of the draft)**
  - Very short in the detector band (almost no visible inspiral)
  - Less power in the inspiral than predicted by aligned spin waveforms
  - Precession seems to explain the signal
- Could s190521 be consistent with a head-on?
- Investigations for lower eccentricities point toward high values

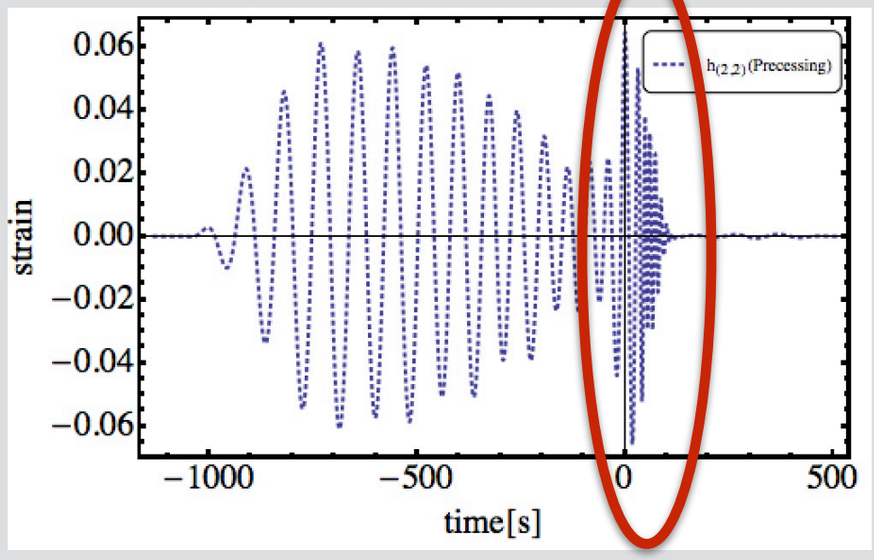
See Isobel Romero-Shaw's slides: https://dcc.ligo.org/DocDB/0164/G1902078/001/S190521g_slides.pdf

- Head-on collision





- Precessing collision



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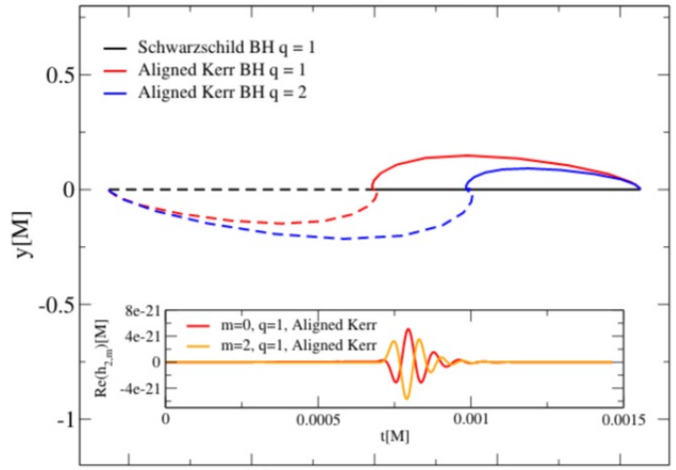
Analysis

- **We inject in bilby simulated signals from head-on** collisions with parameters**:**

q	a_1	a_2	$\mathrm{D_{ext}}$	e_1^{red}	e_2^{red}	$M_{\mathrm{fin}}/M_{\mathrm{ini}}$
1	0.58	0.58	150	0.14	0.14	0.999
2	0.60	0.56	150	0.09	0.20	0.999
3	0.61	0.55	150	0.06	0.23	0.999
1	0.00	0.00	150	0.00	0.00	0.999



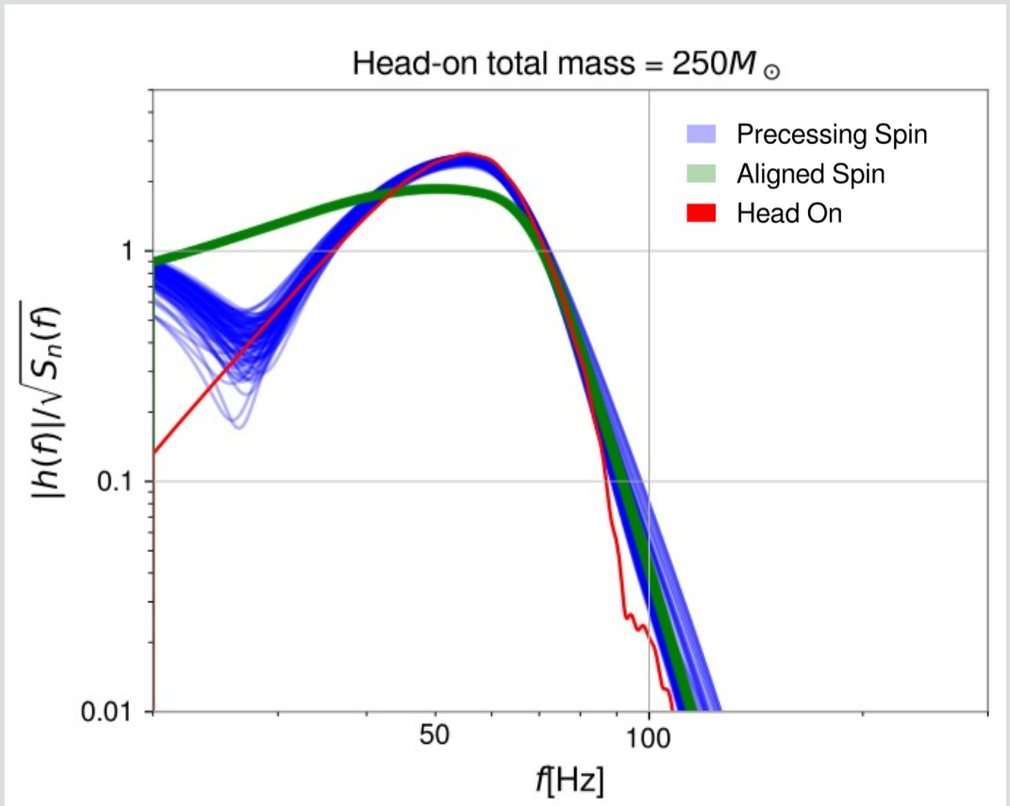
  - Include (2,2), (2,0), (3,2), (3,1) and (2,1) modes. Inject face-on.
  - **Recover it using IMRPhenomPv2** in two configurations:
    - Setting in-plane spins to zero (i.e., IMRPhenomD)
    - Allowing precessing spins.

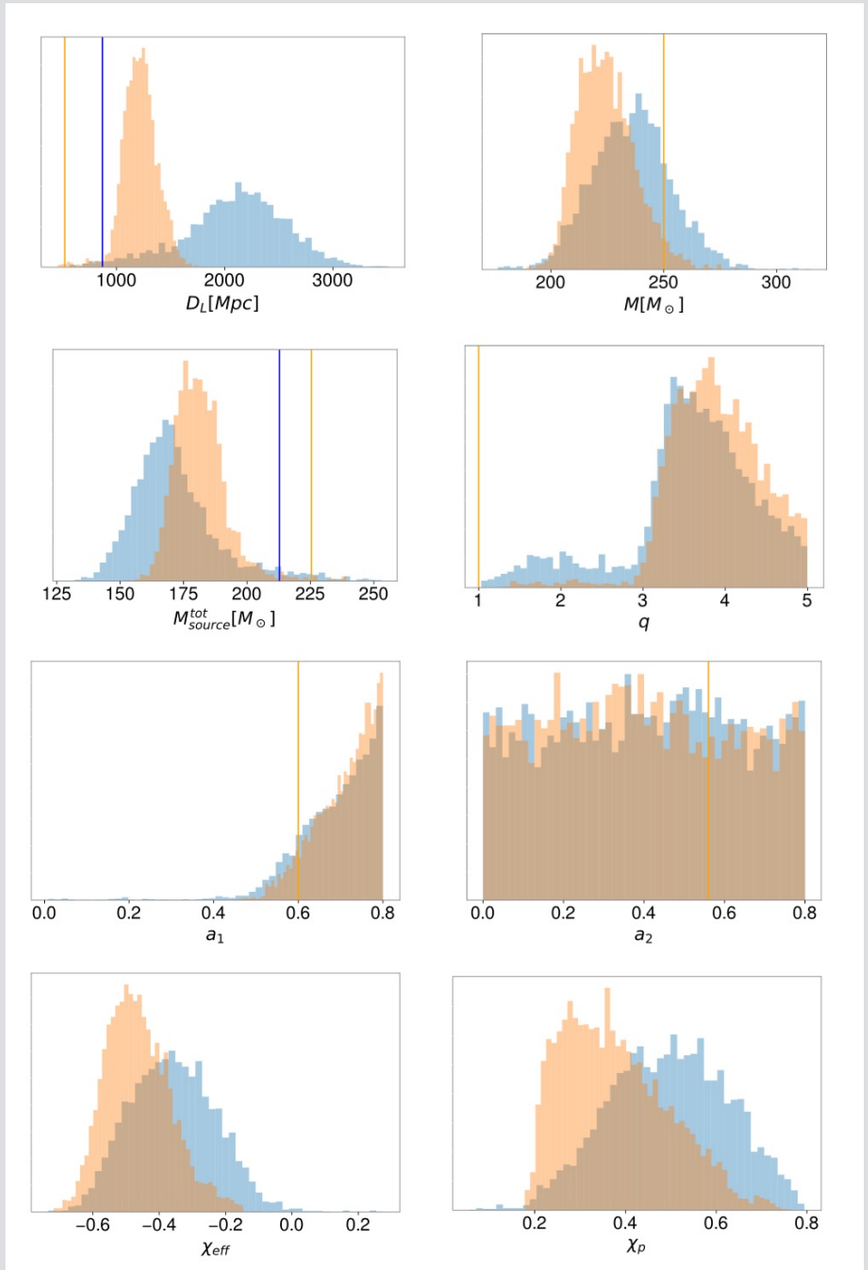
- Use standard priors in all quantities. “Volumetric” prior for spins.
  - Zero noise • Lower freq. cutoff = 20Hz • PSD: Advanced LIGO Zero Detuned High Power • Optimal SNR = 15,25

- **Look at parameter recovery and LogBayes factor** (precession vs. no-precession)
- **Look at the fitting factor:** check if a head-on might be detected by some ``precessing search”.

Parameter estimation (example q=2, M=250Msun)

- Preference for unequal masses and precessing spins, and negative chi_effective
- Primary spin hits the prior boundary
- Slight bias in the detector frame mass
- Gigantic distance bias
- Bias in the source frame mass





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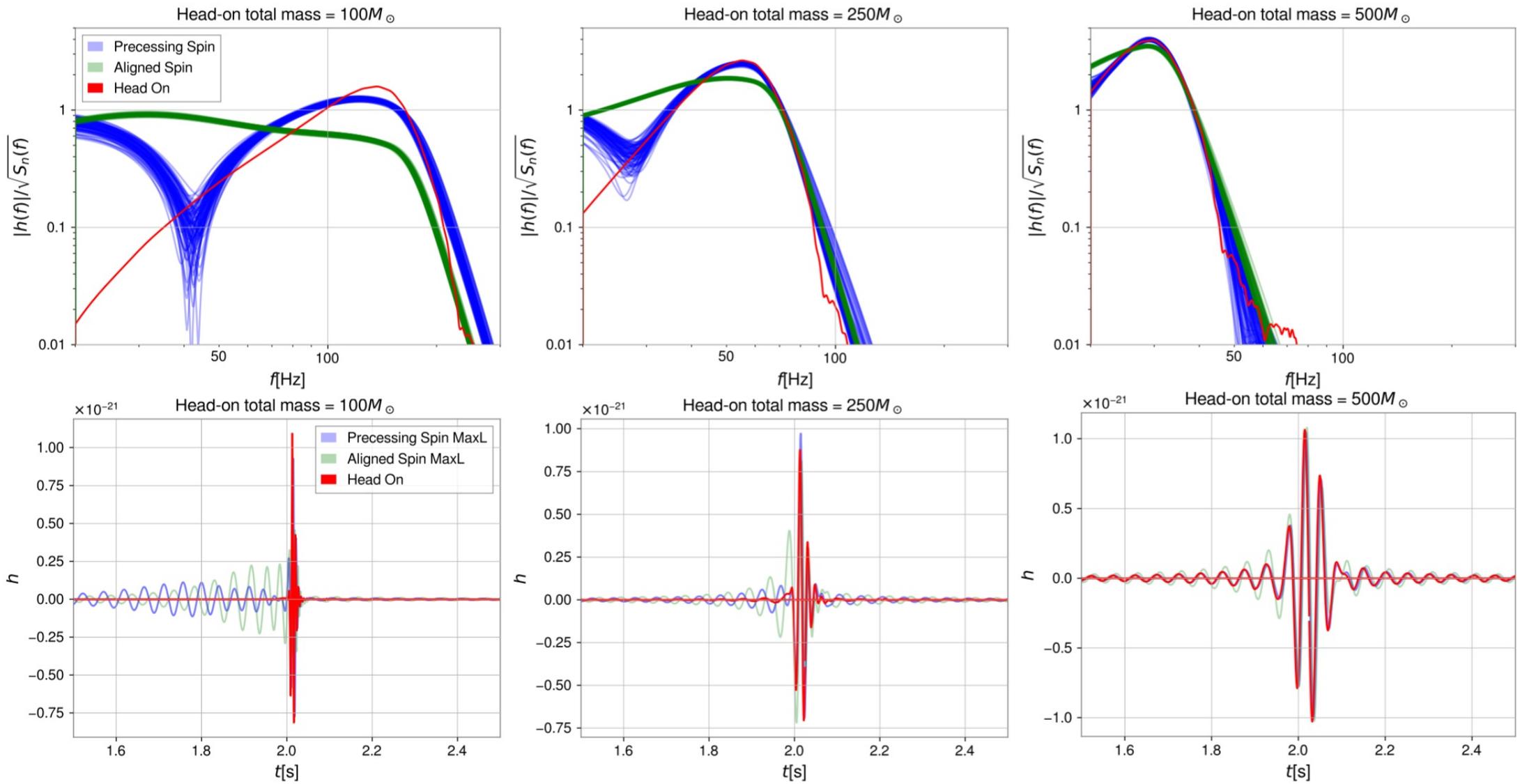
Parameter estimation (effect of total mass)



Can head-on collisions pass as preccesing ones?

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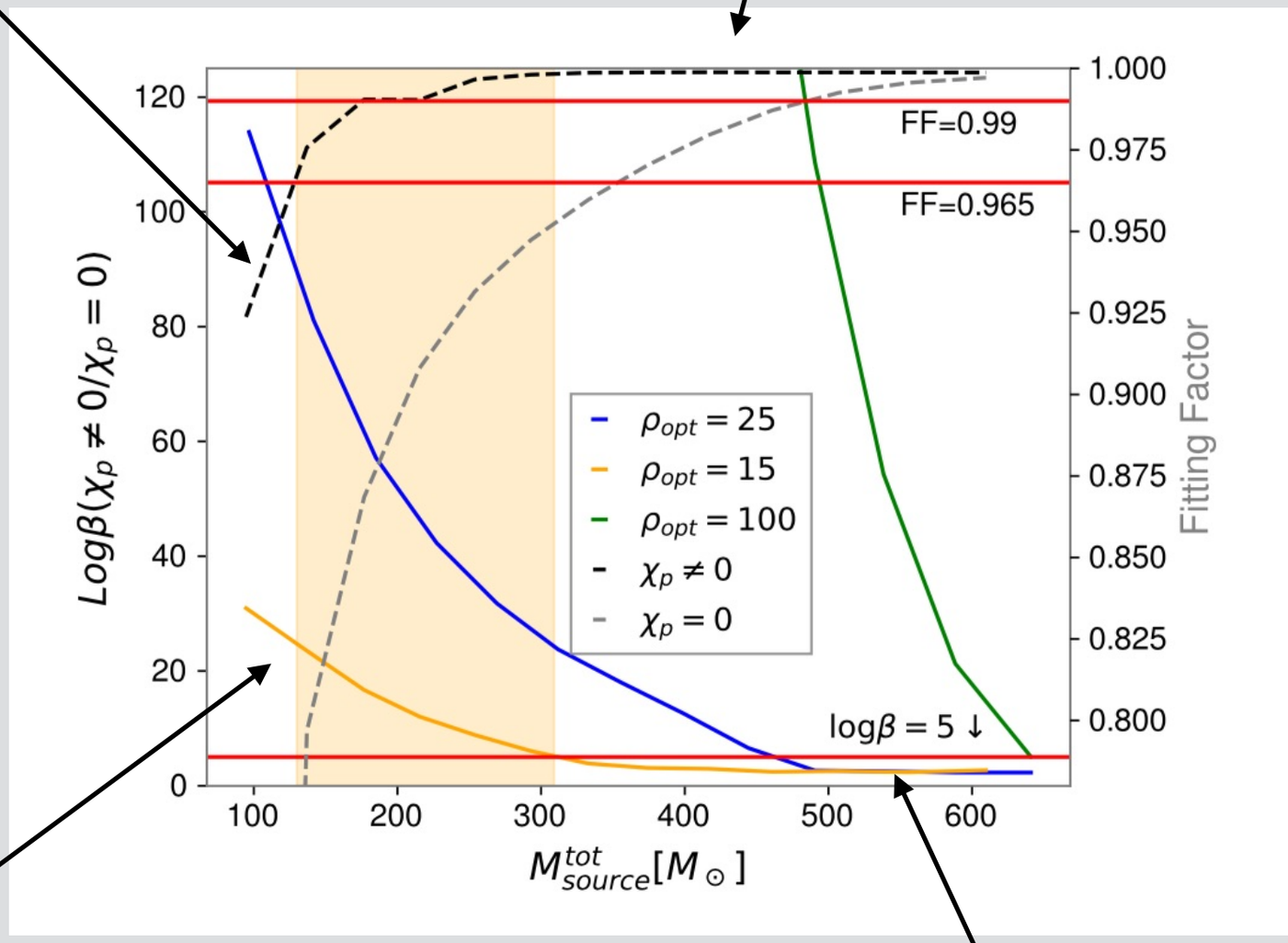
Bayes' Factors (q=2 case)

Low fitting factor: large residuals, easy to discard a BBH origin

Large fitting factor: the head-on would be detected. The BBH can mimic the head-on

Orange region: large beta and large fitting factor (SNR=15)



Large beta: precession is strongly preferred

Low beta (below 5): impossible to decide between aligned-spin or precession

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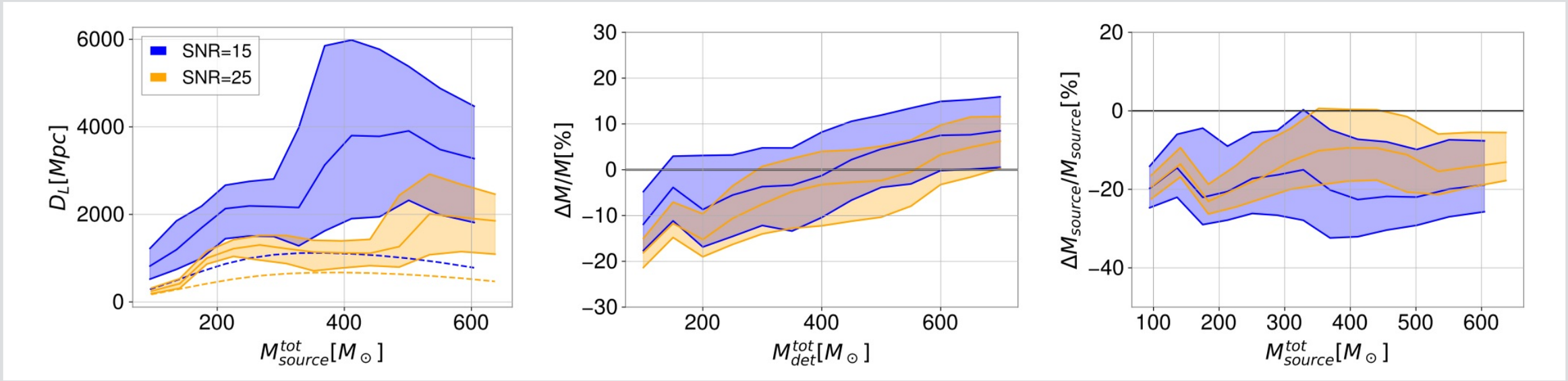
Parameter recovery (q=1)



Head-on collisions are less luminous than BBHs

For large mass: both head-on and BBH show the same ringdown (equal final mass)

Bias toward larger distances + Slight bias to larger detector frame mass. Not too bad. = Bias toward lower source frame mass

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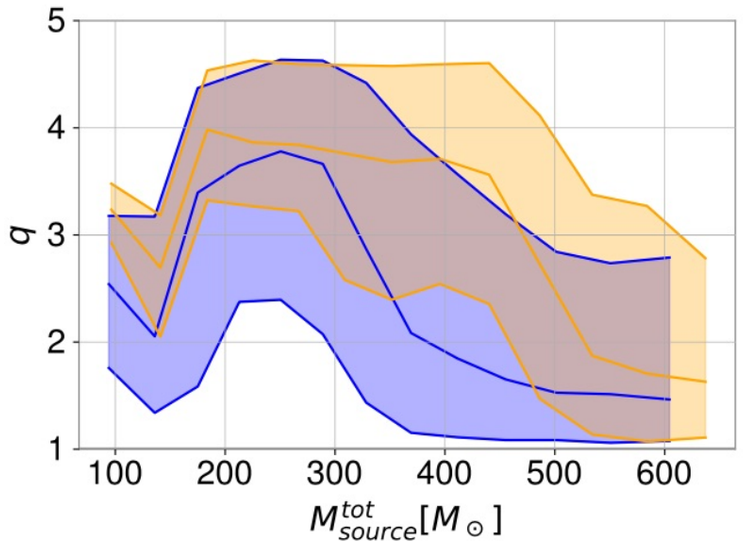
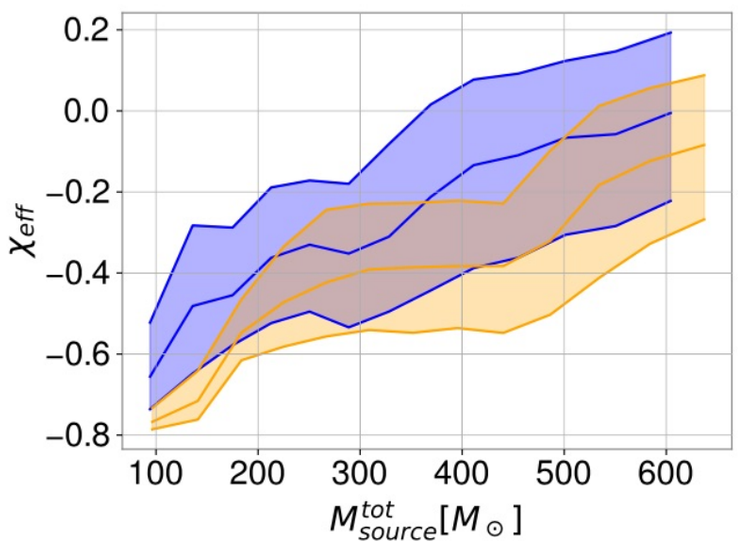
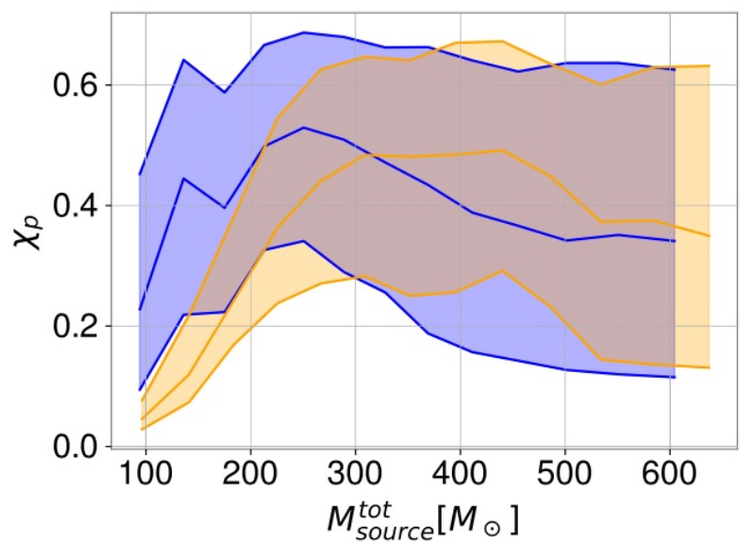
Parameter recovery (q=1)

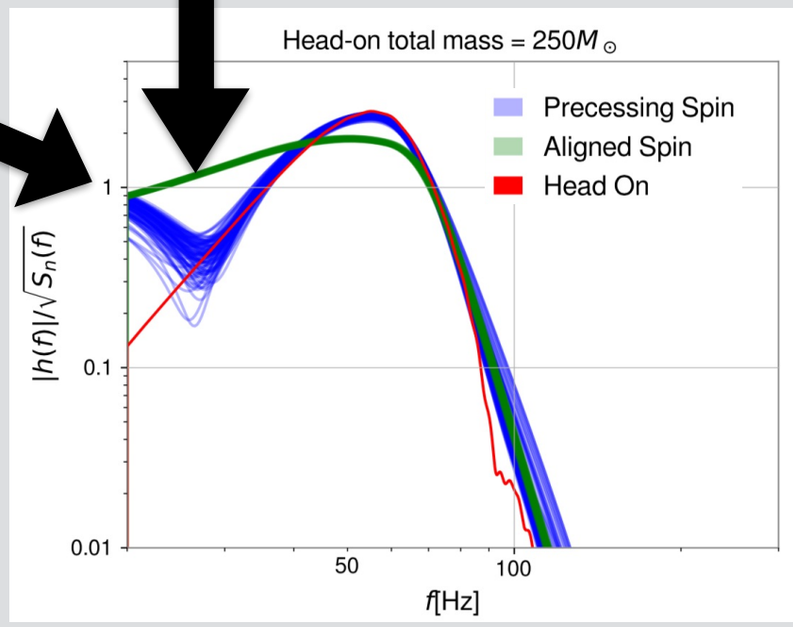






A large mass ratio and negative chi_eff make the waveform shorter in band, leaving the precessing BBH inspiral our of band

Precessing spins to mimic the power lack at low frequencies



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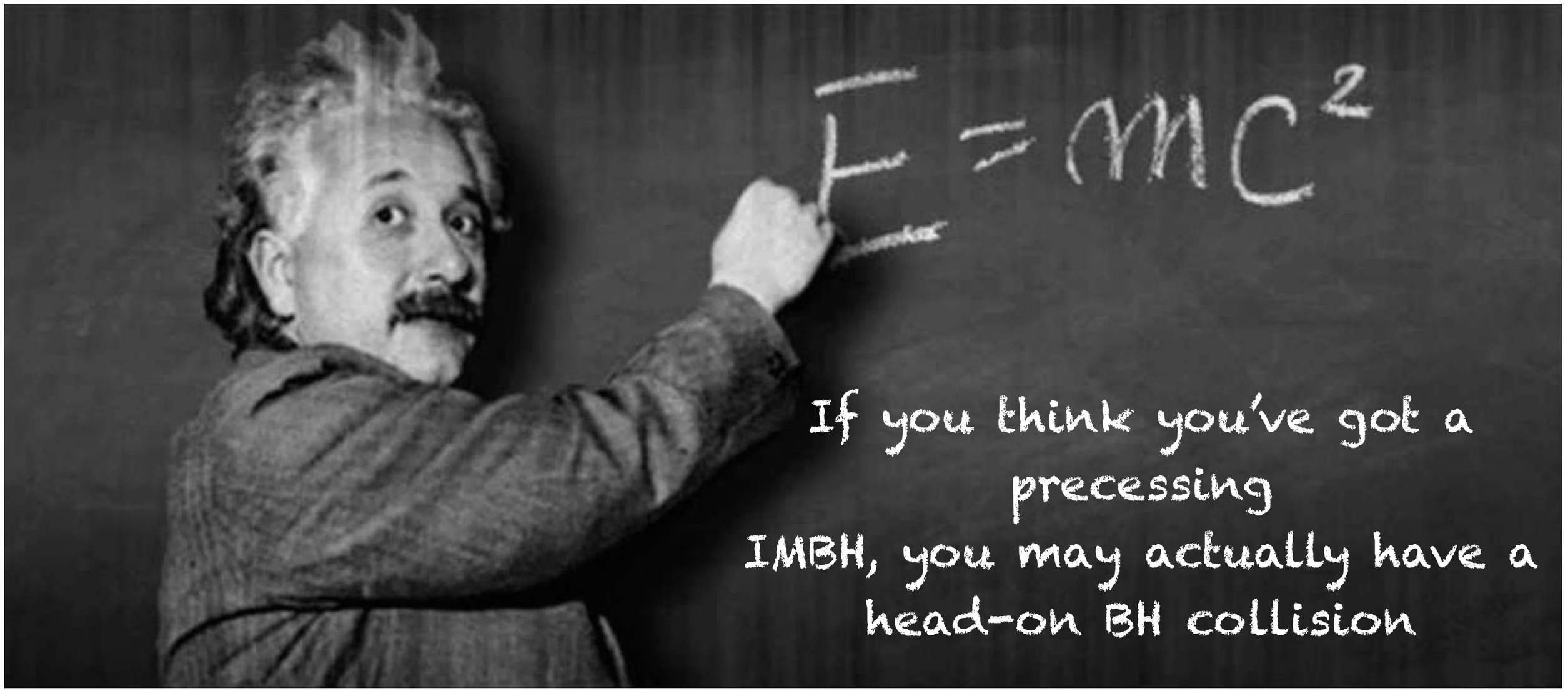
Take home message so far



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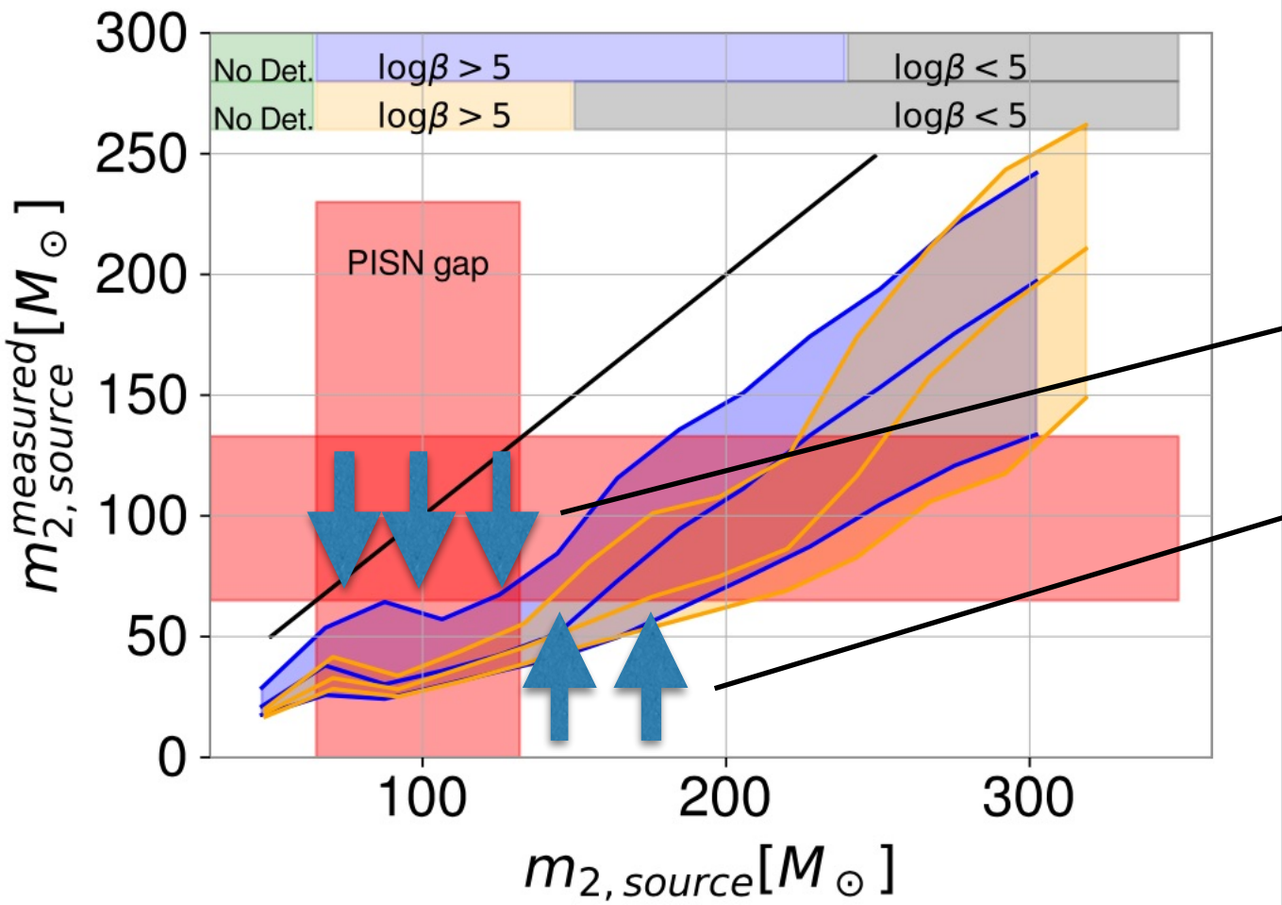
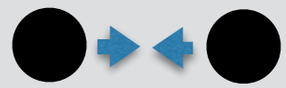
Astrophysical implications: mind the gap

- In principle, black holes in the range ~(60,130)Msun can not form from stellar collapse (PISN gap)
- We find that, in some cases BBH and head-on PE lead to different conclusions about the presence of BHs in the mass gap





Head-on mass

BBH inferred mass

Gap —> no Gap

no Gap —> Gap

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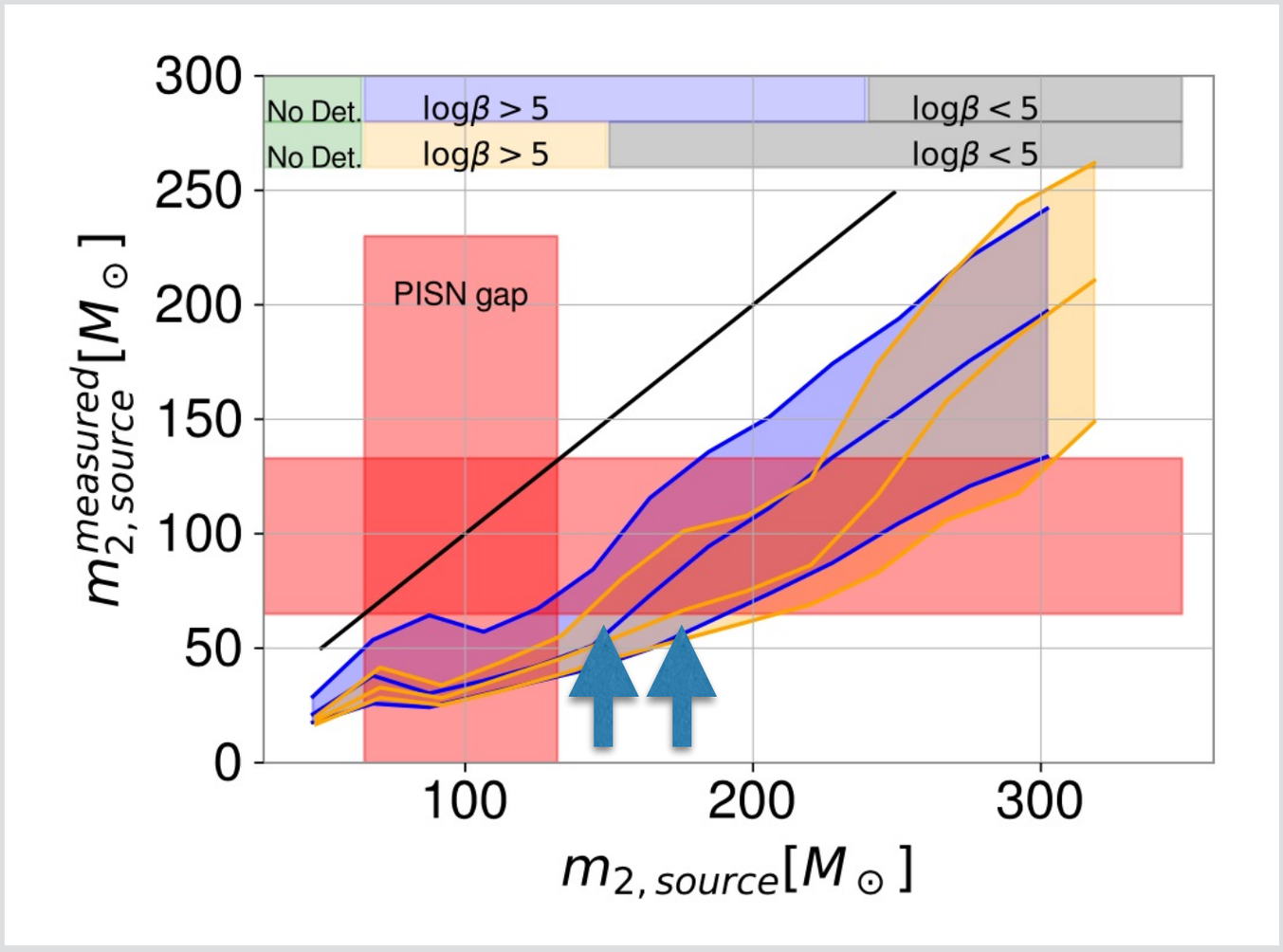
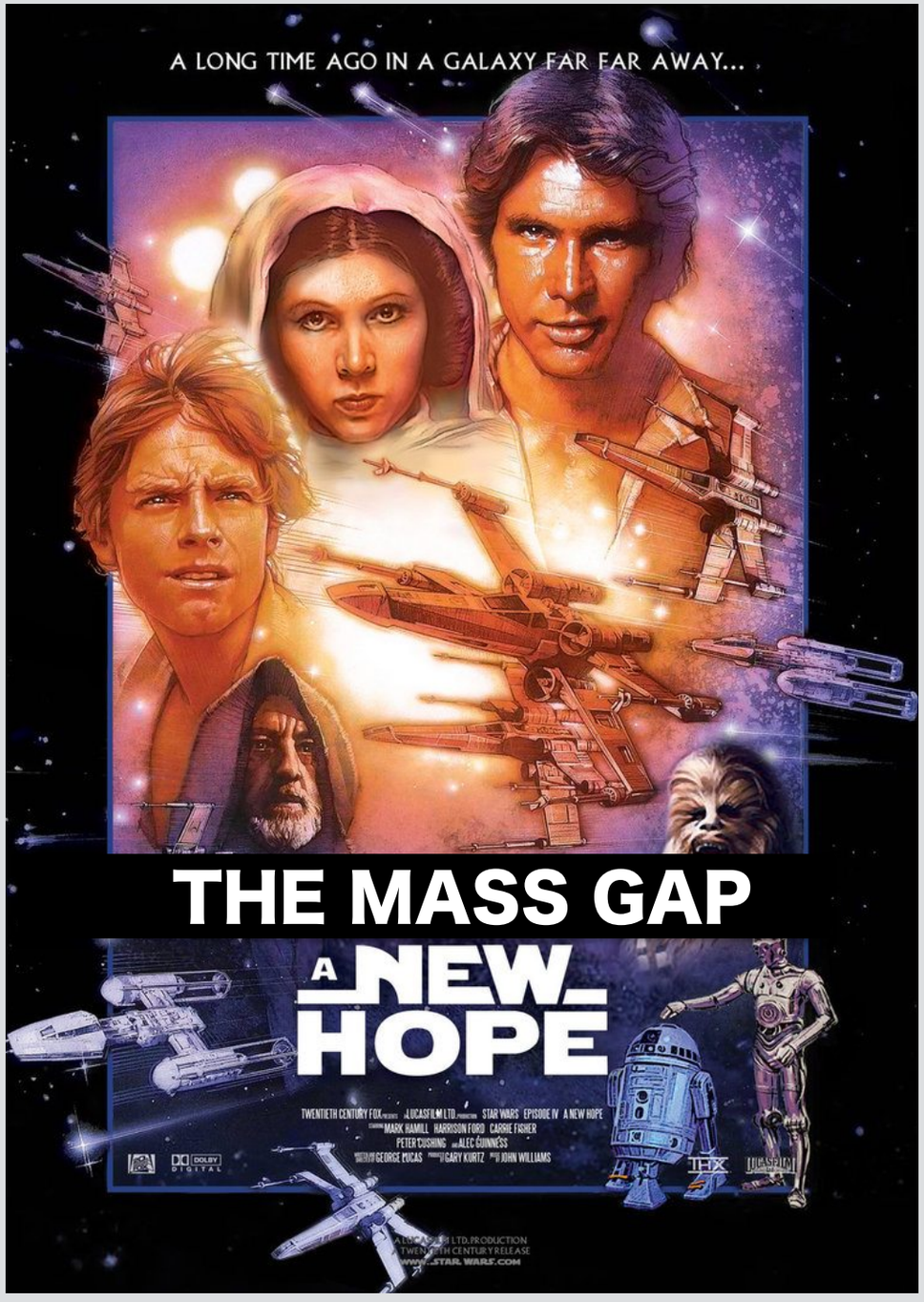
Sorry, I could not help it





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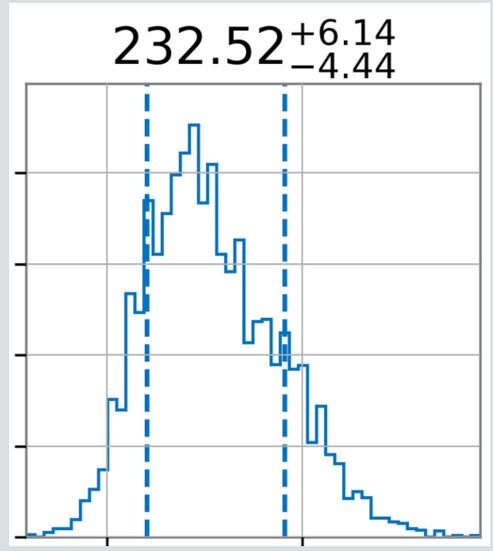
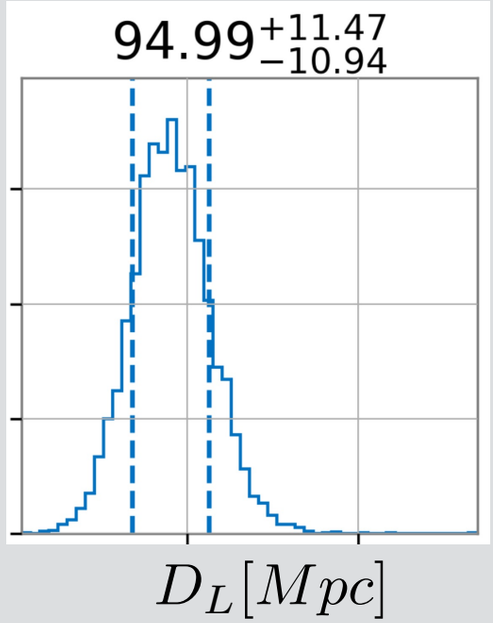
s190521g (not part of the P&P submission)

- **s190521g seems to have several properties discussed so far:**
  - Strongly precessing
  - Unequal masses (according to some models)
  - IMBH remnant
  - Masses in the PISN gap

- **Run PE using several head-on simulations** (low sampling etc…. ALL PRELIMINAR)
  - HLV with C01 SUB60Hz data.
  - Best matched-filter **SNR so far for head-on** (HLV): **15.28**, for the q=1 source in slide 3.
  - Best **PhenomP SNR** so far: **15.55**
  - Best **PhenomD SNR** so far: **14.88**
  - **LogB(**PhenomP vs. best head-on simulation) **~18** 
    - This might be due to the intrinsic weakness of the signal
- **Note we have only explored ~15 points in the mass-ratio & spins space!**





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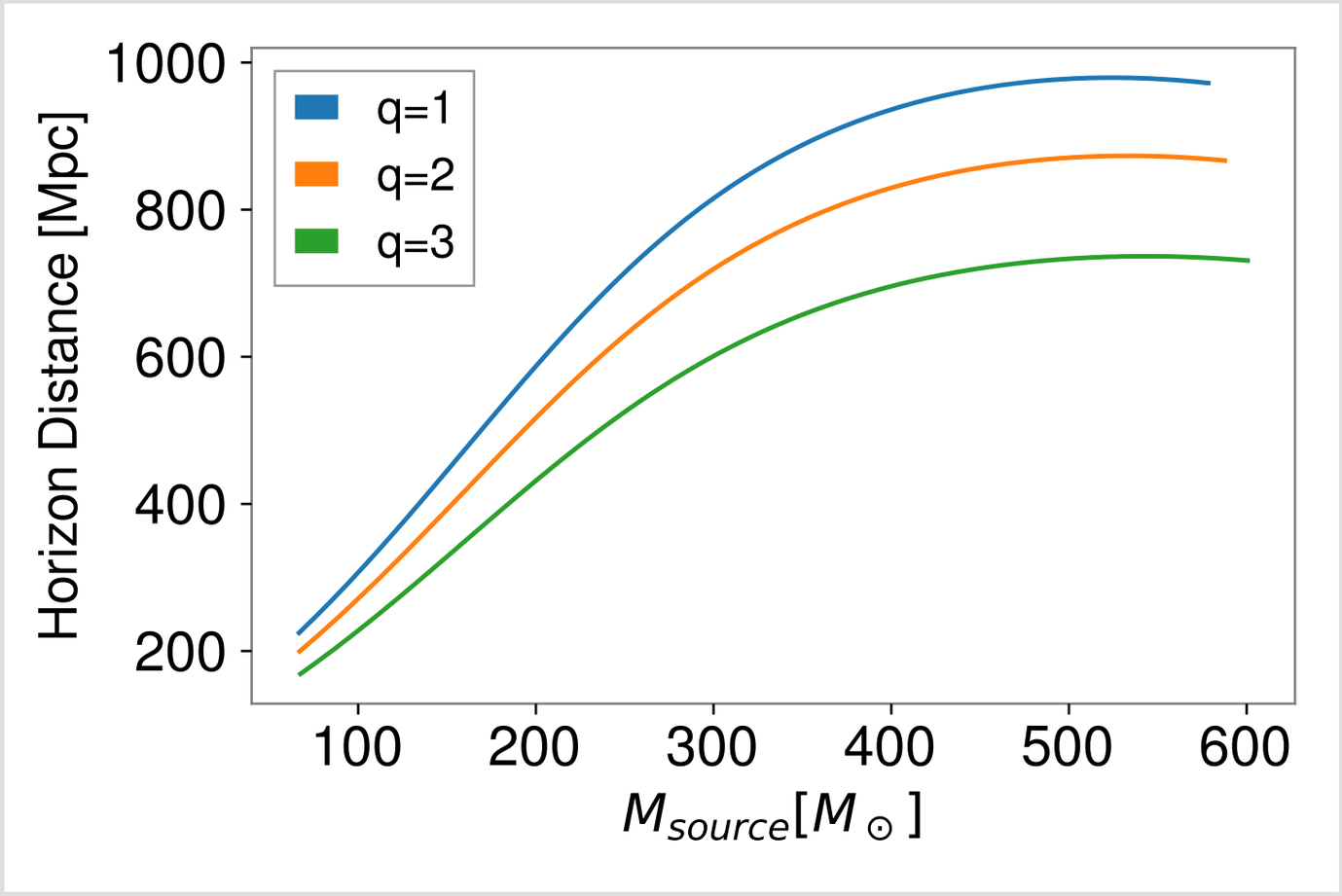
Observability

- Horizon distance for an SNR of 12
  - Averaged over sky-loc, orientation and polarisation
  - Considered a three detector network formed by HLV working at design sensitivity



Conclusions

- **Precession can cause a suppression of the inspiral power just before merger:**
    - For a certain mass range, this can be mimicked by head-on collisions
- **A signal from a head-on IMBHB might pass as a strongly precessing IMBHB with unequal masses:**
    - Distance is biased toward large values
- **Astrophysical implications: (when running PE with BBH waveforms on a Head-on)**
    - Source masses outside (inside) the PISN gap, may be put inside (outside) the PISN gap
    - A remnant IMBH may be interpreted as a less massive BH (see draft)
- **S190521g:**
    - Run PE using several head-on simulations.
    - Recover more SNR than aligned-spin waveforms, but less than PhenomP
    - We will try way more head-on simulations!