

Constraining Black-Hole Dipole Radiation

with Multiband Gravitational Waves from Eccentric Binary Black Holes

[arXiv: 2604.27734](https://arxiv.org/abs/2604.27734)

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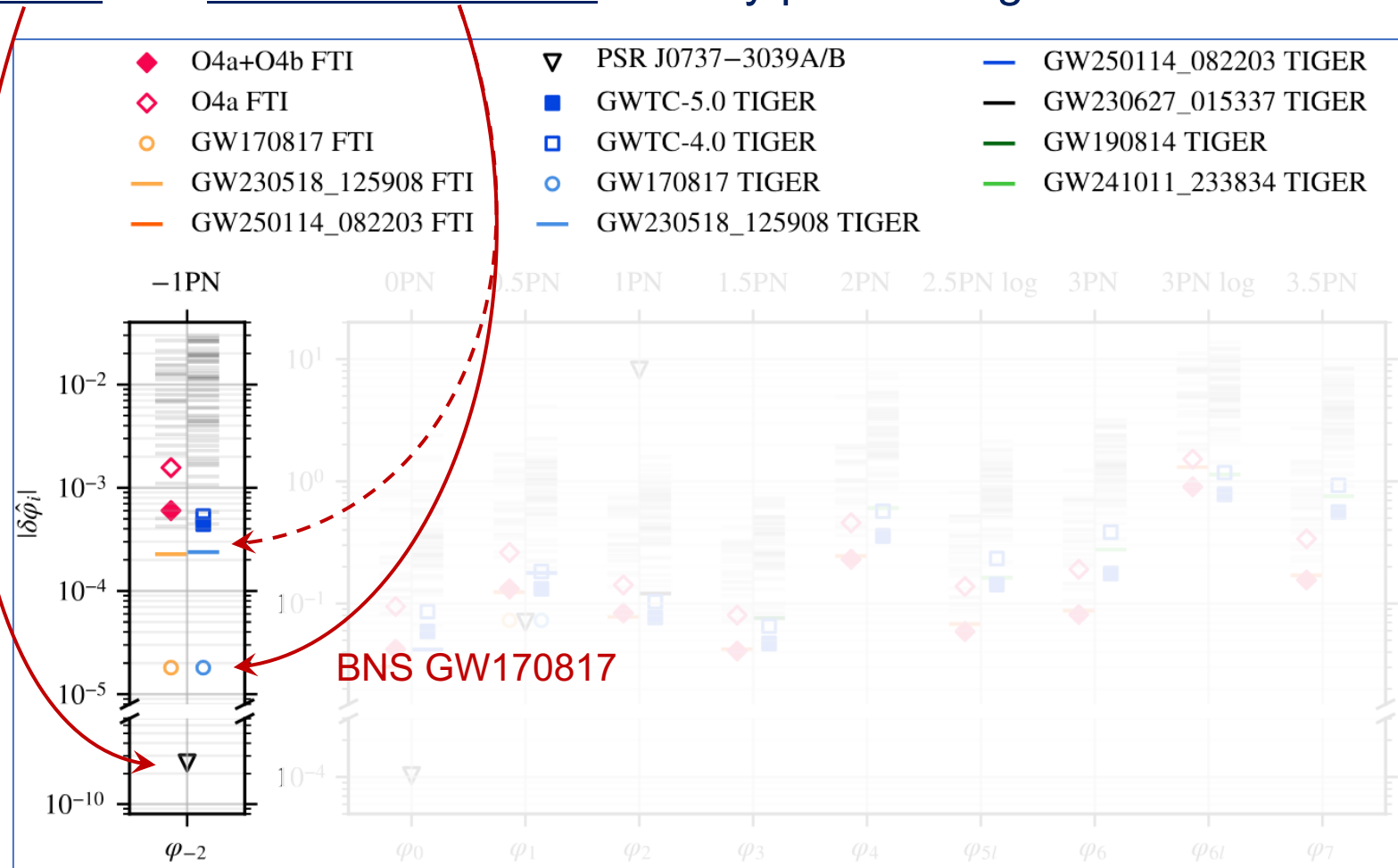
humphreywang.github.io

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Dipole radiation

- Enters at **-1PN** order and accumulates strongly in the early inspiral
- Existing pulsar and GW observations already place stringent bounds

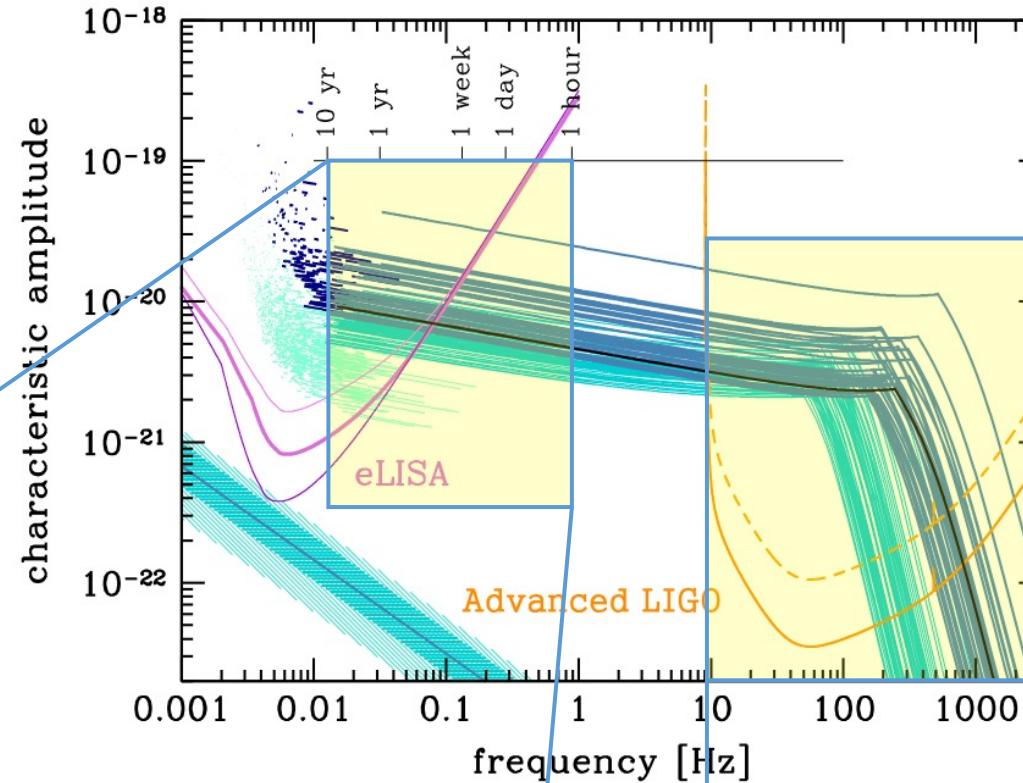


Abac et al. [arXiv:2607.19293](https://arxiv.org/abs/2607.19293)



sBBH: Multiband GW source

Sesana. [arXiv:1602.06951](https://arxiv.org/abs/1602.06951)



Early inspiral

Late inspiral, merger, ringdown

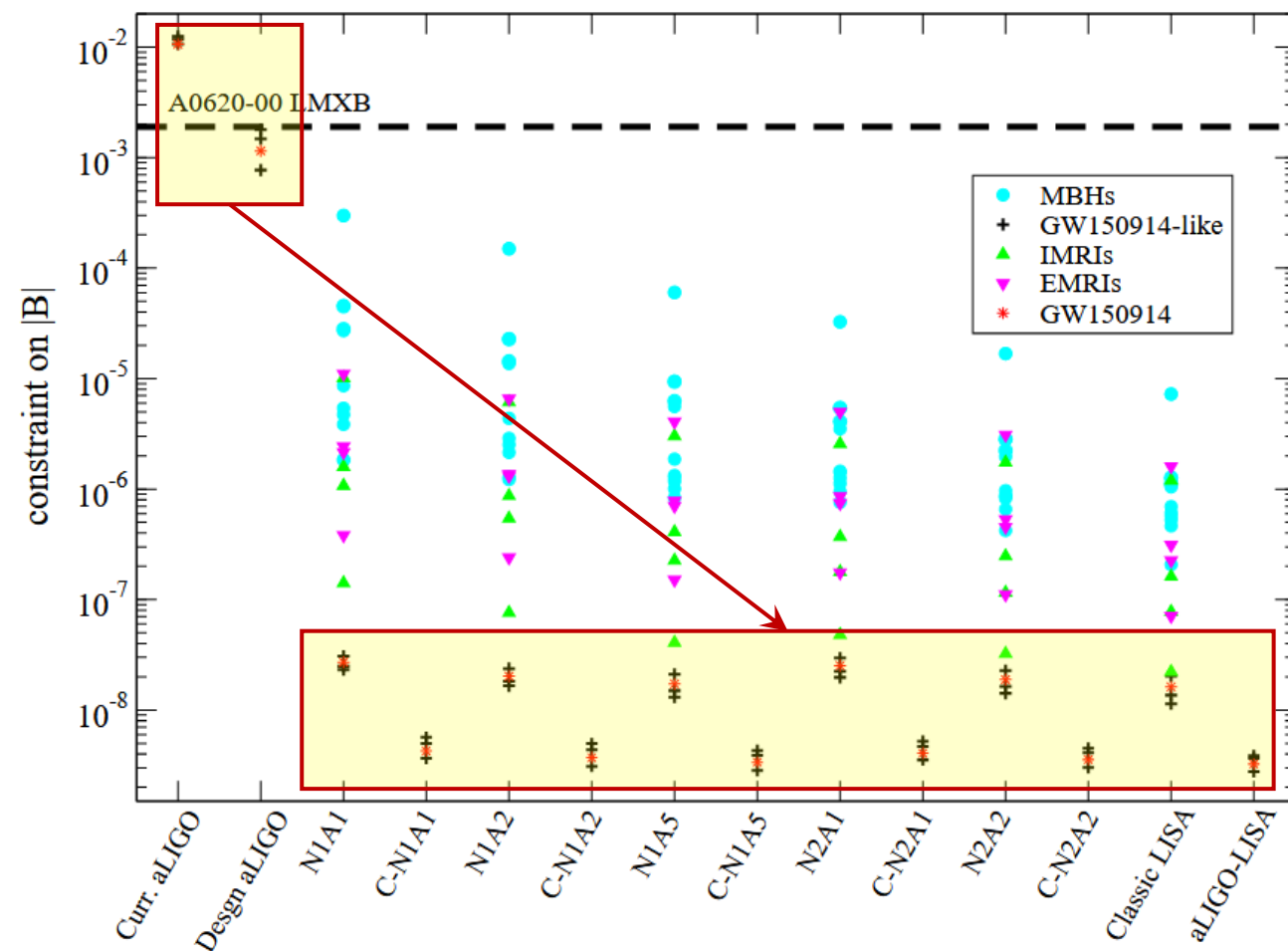


** The waveforms are schematic.

Multiband binary black holes

□ A **distinct** and **complementary** channel for constraining dipole radiation

- Black holes v.s. neutron star
- Years-long mHz inspiral included
- Dipole radiation in BBH system?
 - **Theory-agnostic constraint**

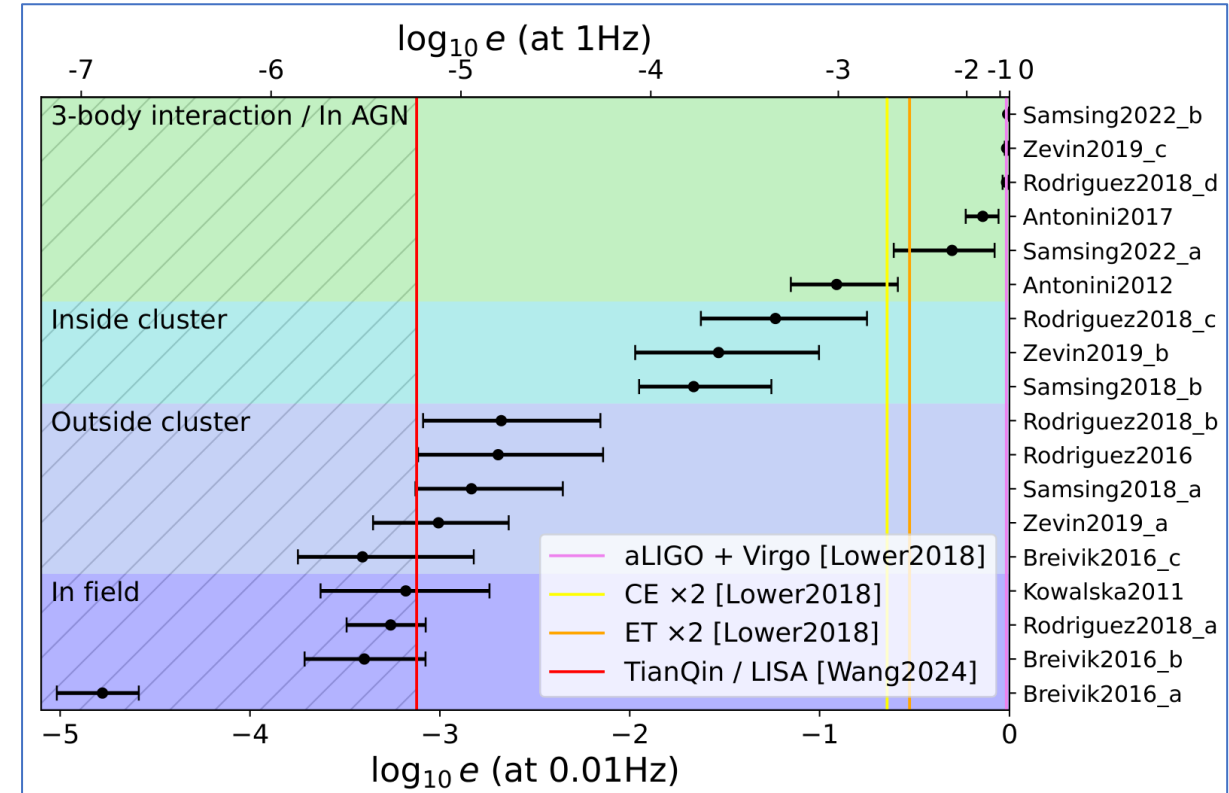


Barausse et al. [arXiv:1603.04075](https://arxiv.org/abs/1603.04075)

Early inspiral preserves eccentricity

HW et al. [arXiv:2304.10340](https://arxiv.org/abs/2304.10340)

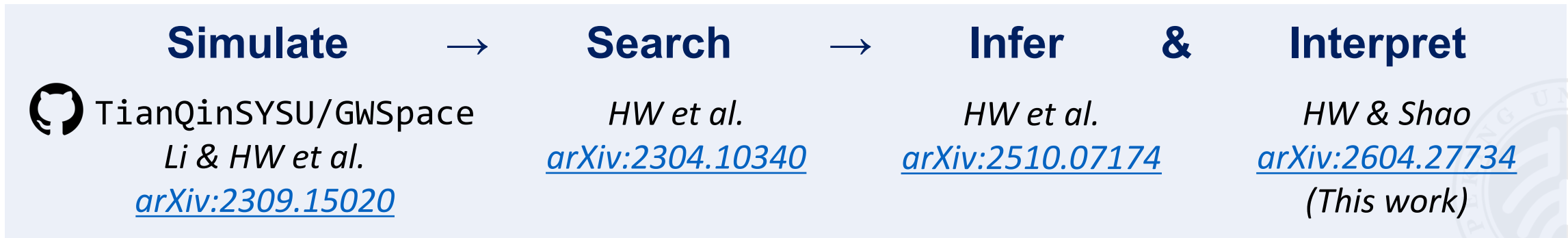
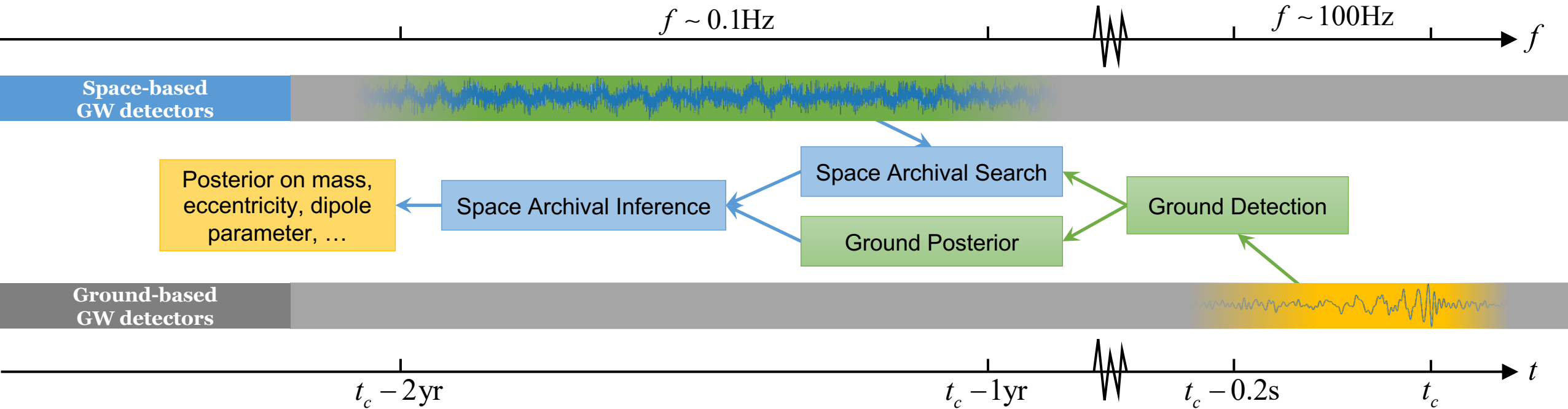
- ❑ The orbital eccentricity also modifies the low-frequency phase used for the dipole-radiation test
- ❑ Can dipole radiation be robustly constrained when eccentricity is inferred simultaneously?



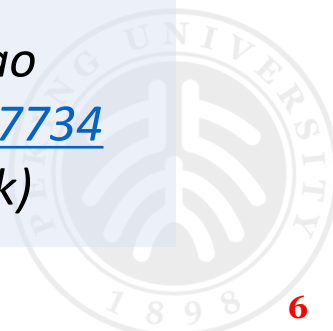
** The waveforms are schematic.

Ground-triggered archival inference

- Make weak space signals tractable



** The waveform, time interval and frequency interval in the figure are for demonstration only.



Model both eccentricity and dipole radiation

- Dipole radiation in eccentric waveform *Ma & Yunes* [arXiv:1908.07089](https://arxiv.org/abs/1908.07089)

- The total GW energy flux of a compact binary

$$\dot{E} = \dot{E}_{\text{GR}} \left[1 + b \left(\frac{M}{a} \right)^{-1} \right]$$



$$\dot{E}^{\text{ecc}} = \dot{E}_{\text{quadrupole}}(e) + b \dot{E}_{\text{dipole}}(e)$$

- Including the eccentric harmonics

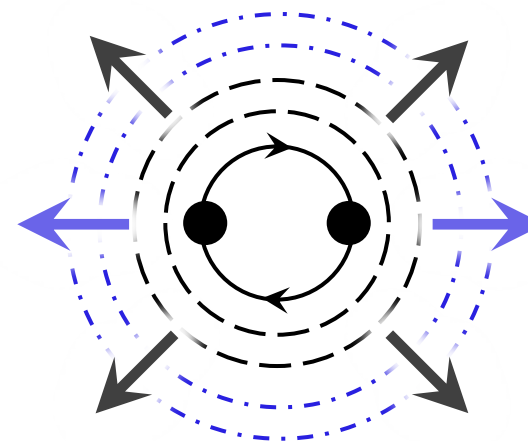
 HumphreyWang/pyEccentricFD

- TDI response calculation via GWSpace

 TianQinSYSU/GWSpace

$$\dot{E}(e, b) \rightarrow \{\dot{F}, \dot{e}\} \rightarrow \{\Psi_j, \xi_j\} \rightarrow h(f)$$

- GR quadrupole + extra dipole radiation



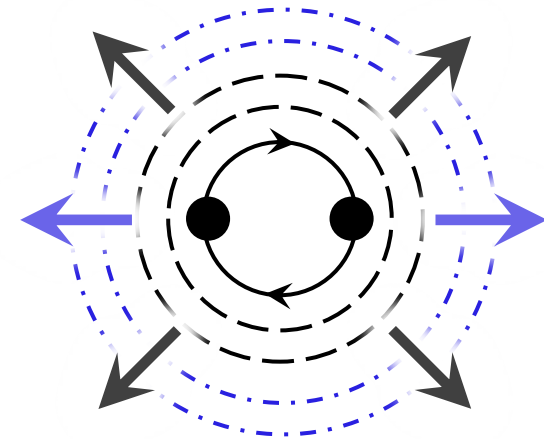
Model both eccentricity and dipole radiation

□ parameter b : what do we constrain?

- A phenomenological correction to the radiative energy loss
- A specific theory may map it to charges or coupling constants
- Infer b directly, without assuming any mapping
- Other negative-PN effects may produce similar low-frequency phasing

$$\dot{E}^{\text{ecc}} = \dot{E}_{\text{quadrupole}}(e) + b \dot{E}_{\text{dipole}}(e)$$

- GR quadrupole + extra dipole radiation



Dipole radiation included

- One-year observation
- Stationary Gaussian noise
- GW231123-like
- SNR~7.5 for TianQin or LISA
 - ~11 for TianQin+LISA
- Einstein Telescope + 2 × Cosmic Explorer provides ground-informed priors

Case I: reference analysis **without dipole** radiation

Case II: **full dipole** analysis, both $e_{0.01}$ and b are sampled

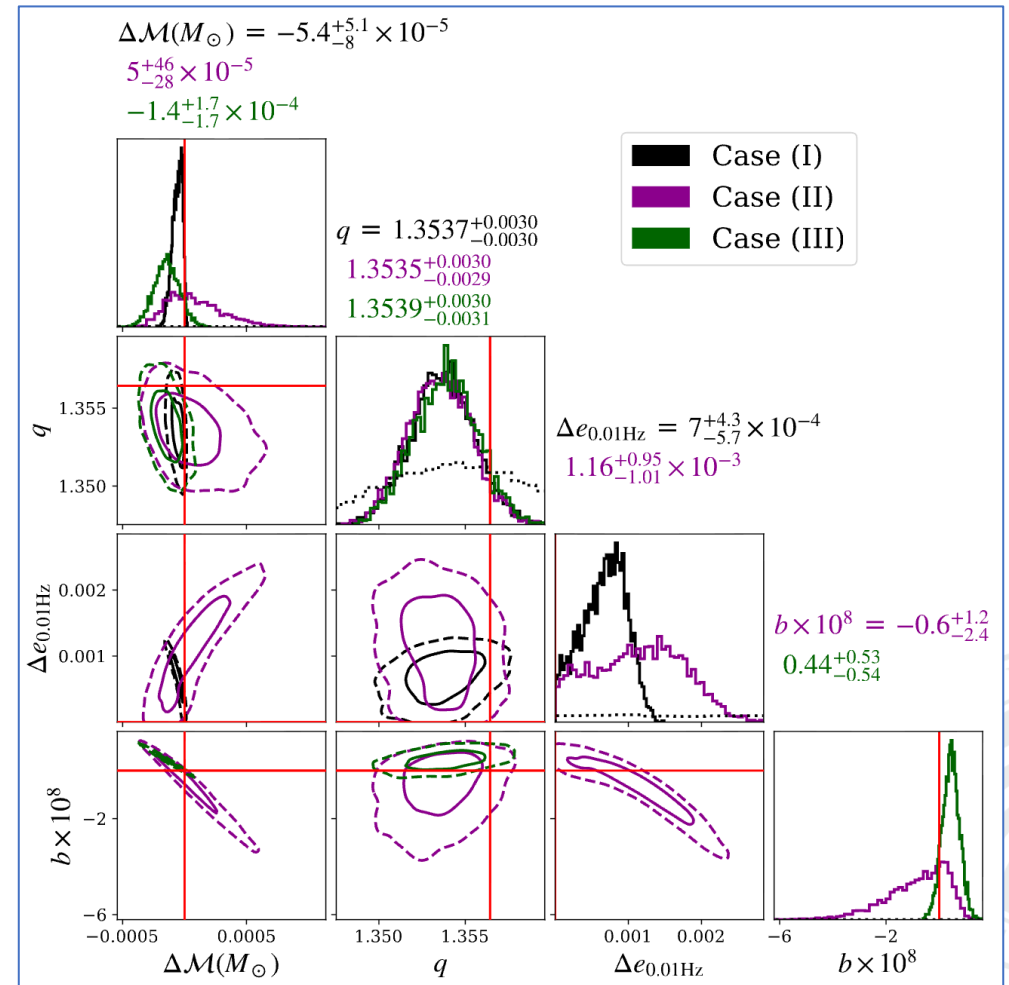
Case III: **restricted dipole** analysis, fixed $e_{0.01} = 0$



Degeneracy between parameters

- TianQin+LISA, $e_{0.01} = 0$
- Eccentricity opens an additional degeneracy direction
- Allowing eccentricity broadens the dipole constraint by $\sim 3\times$

Case I: reference analysis **without dipole** radiation
 Case II: **full dipole** analysis, both $e_{0.01}$ and b are sampled
 Case III: **restricted dipole** analysis, fixed $e_{0.01} = 0$



Degeneracy between parameters

□ TianQin+LISA, $e_{0.01} = 0.1$

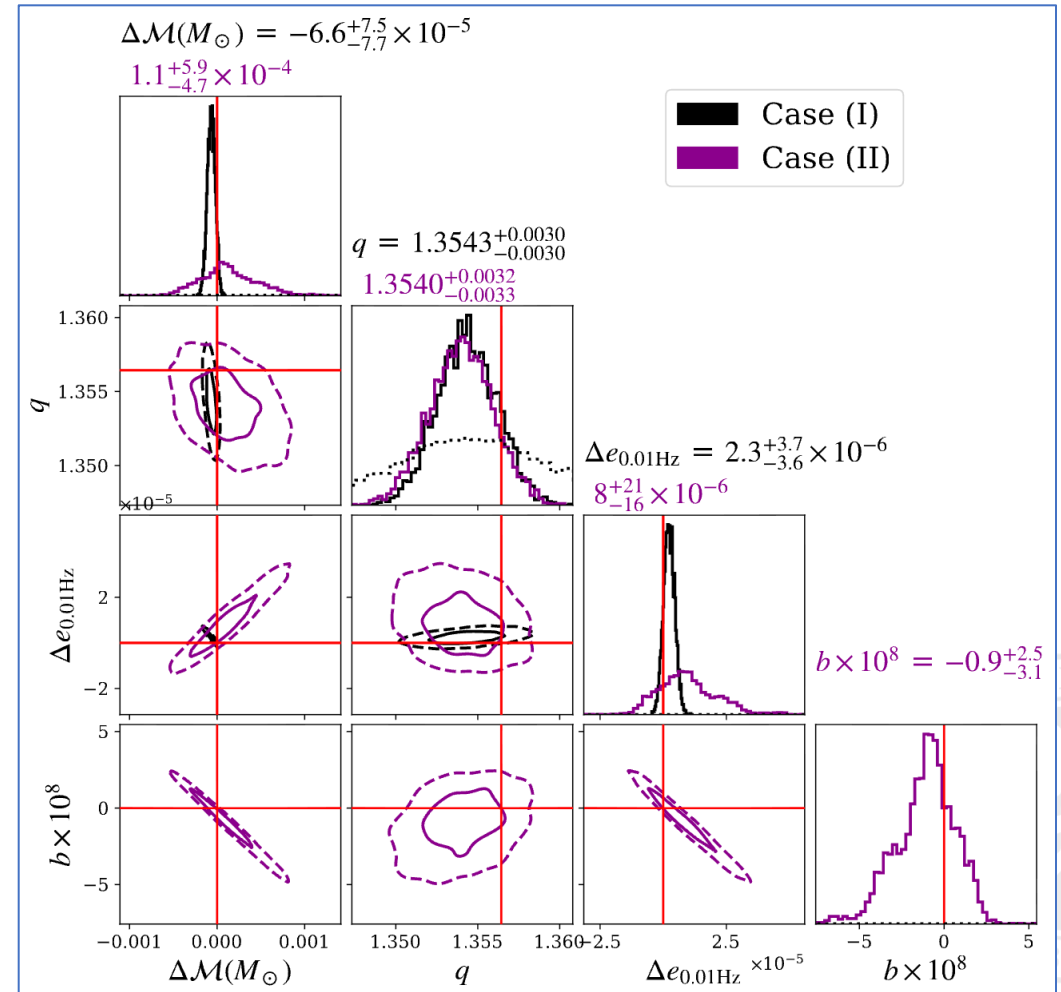
□ How to understand the degeneracy?

□ Over a finite low-frequency band, changes in **dipole radiation** and **eccentricity** can both be partially absorbed by shifts in the phase scale set by **chirp mass**

$$\begin{aligned}\Psi_{\text{GR}}(f) &\propto (\pi M f)^{-5/3} \\ \Delta\Psi_b(f) &\propto b\eta^{2/5}(\pi M f)^{-7/3} \\ \Delta\Psi_e(f) &\propto e_0^2 f^{-19/9}\Psi_{\text{GR}}(f)\end{aligned}$$

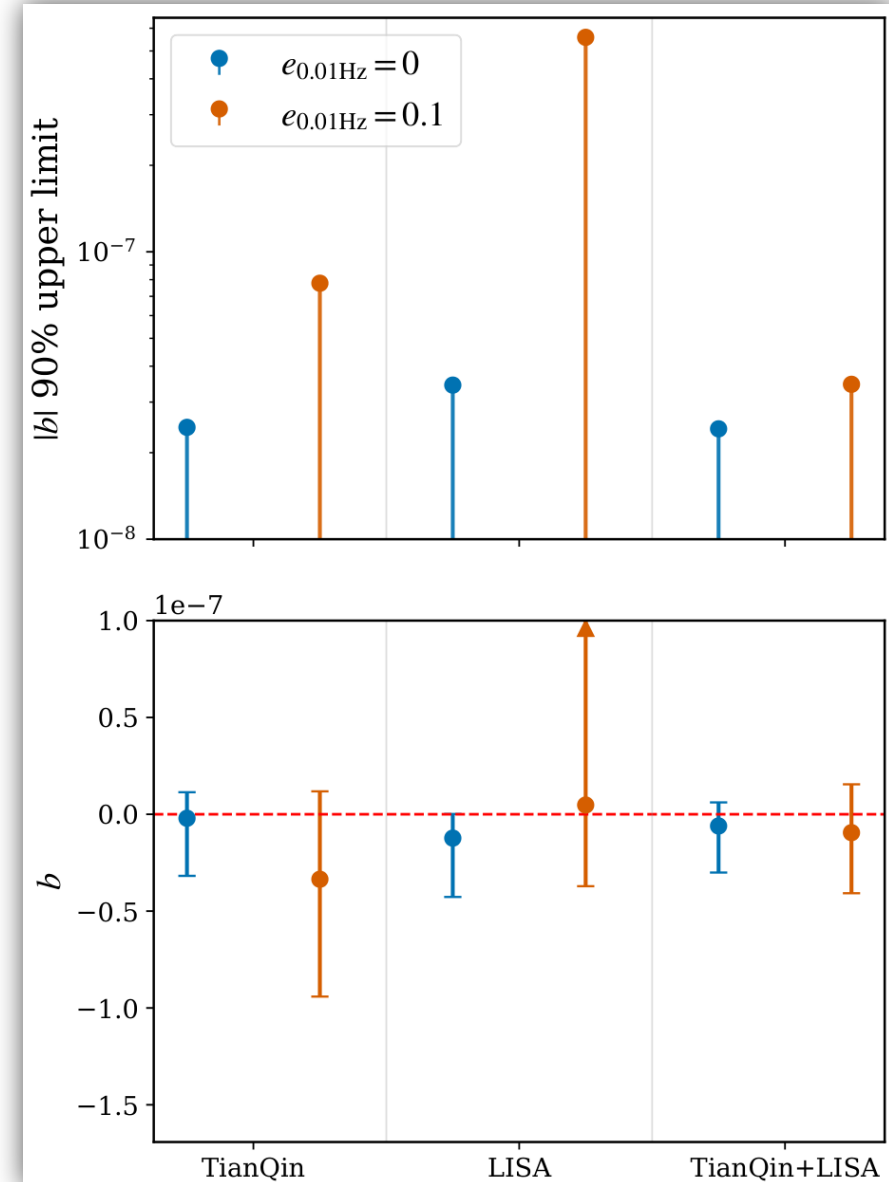
Case I: reference analysis **without dipole** radiation

Case II: **full dipole** analysis, both $e_{0.01}$ and b are sampled



Constraints overview

- Eccentricity generally weakens the bound
- The LISA eccentric case is the least constrained
- Joint network gives the most robust result
- Typical constraints remain at $|b| \lesssim \mathcal{O}(10^{-7})$
 - *Weaker than idealized circular forecasts*
 - *But more robust because eccentricity is inferred simultaneously in noisy data*



Take-home messages

□ Distinct and complementary regime

Multiband sBBHs probe black-hole sources during a years-long low-frequency inspiral and complement pulsar/BNS tests for dipole radiation

□ Physical degeneracy

Eccentricity introduces a physical ($\mathcal{M} - e - b$) degeneracy and can broaden and reshape the inferred posterior

□ Robust constraints remain

For a GW231123-like source, the multiband analysis can still reach $|b| \lesssim \mathcal{O}(10^{-7})$

□ Future Work

- **Model completeness:** precise waveform (spin...), other causes of false GR violations, ...
- **Data realism:** duty cycle, overlapping signals, ...

