Taming systematics in distance and inclination measurements with gravitational waves: role of the detector network and the higher modes

(*Based on arXiv:2504.12473*)

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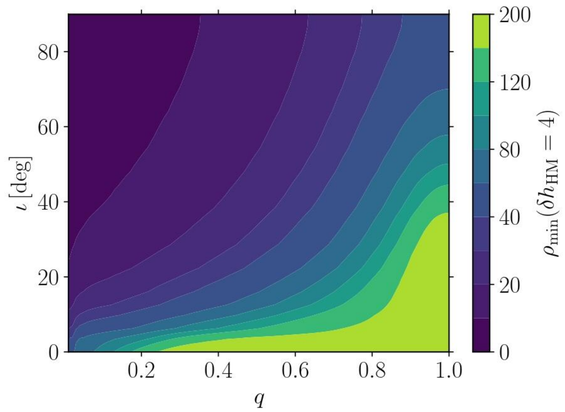
Background

THE DISTANCE-INCLINATION DEGENERACY

- **Distance (redshift) and inclination** are key parameters for **cosmology, multi-messenger astronomy, high-energy astrophysics** etc.;
- A **degeneracy** limits their recovery;
- **Statistical correlation** in the low-inclination limit (**face-on binaries**);
- Difficulty in **detecting both polarizations**: a triangular-shaped **Einstein Telescope** helps mitigate this issue.

BREAKING THE DEGENERACY: ROLE OF HIGHER-ORDER MODES

- If **an electromagnetic** counterpart is available, we have prior information on redshift (GW170817…).
- Otherwise, consider minor effects, such as **including higher order modes in the waveforms.**



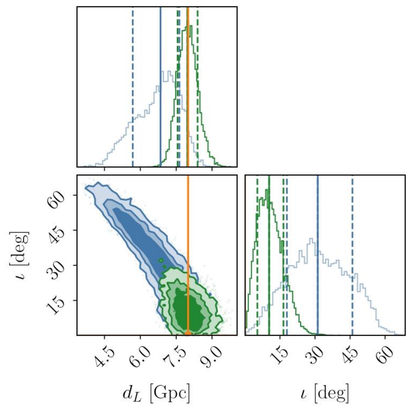
*The **greener** regions are where **higher modes are weaker**, in the Inclination-Mass Ratio plane.*

Main results

BINARIES WITH MASS IMBALANCE

✓ **Higher modes**, if detectable, provide a way to **break the correlation** between distance and inclination;

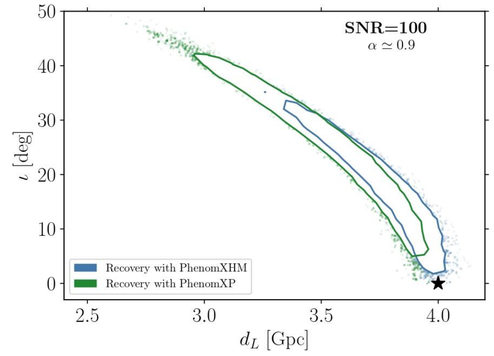
✓ **Stronger** effect for low-mass-ratio systems.



Distance-inclination simulated posterior : mass ratio $\mathbf{q} = \mathbf{0.1}$, SNR=20, with and without higher modes. Inference simulations done with **Bilby**.

QUASI-EQUAL-MASS BINARIES

❖ Moderate improvements.



Distance-inclination simulated posteriors : mass ratio $\mathbf{q} = \mathbf{0.8}$, SNR=100.

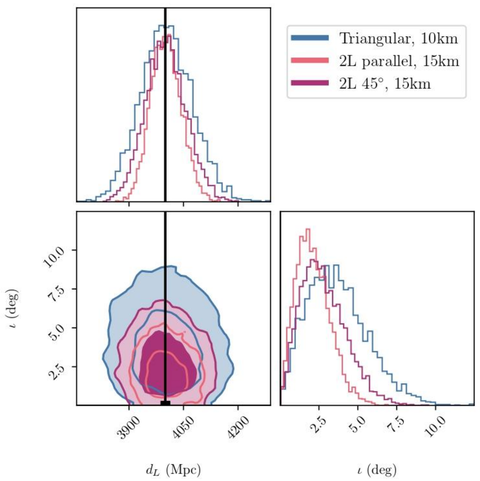
Role of ET design

THREE POSSIBLE DESIGNS (CFR. [1])

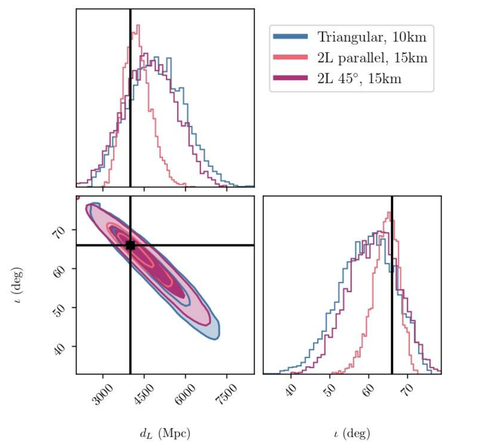
- Triangular, 10 km arms;
- 2L parallel, 15 km arms;
- 2L 45°, 15 km arms.
- Same source, different SNRs, two inclinations.

MAIN MESSAGE

❑ The parallel 2L configuration is slightly favored;
❑ This is explained by the higher SNR in this setup.



Simulation for a face-on binary.



Simulation for a 66° inclined binary.

Main conclusions

- The **distance-inclination** degeneracy affects **slightly inclined** binaries;
- **Higher modes** provide a way to mitigate the effect with GW data only;
- **Promising** for asymmetric-in-mass systems (some BBHs, NSBHs…);
- **Different ET design** respond slightly differently.

What's next?

a) Including **precession effects** (paper in preparation);

b) Further **investigations** on the impact of **different ET designs**.

References

[1] Usman, S. A., Mills, J. C. & Fairhurst, *Astrophys. J.* **877,** 82. (2019).

[2] CoBA: Branchesi, M. *et al.* JCAP **07**, 068 (2023)

[3] Ashton, G. *et al. Astrophys. J. Suppl.* **241,** 27 (2019).

[4] Pratten, G. *et al.* Physical Review D **103** (2021),

[5] Abbott, B. P. *et al. Phys. Rev. X* **9,** 011001. (2019).