Waveform modeling to meet the needs of LISA and beyond

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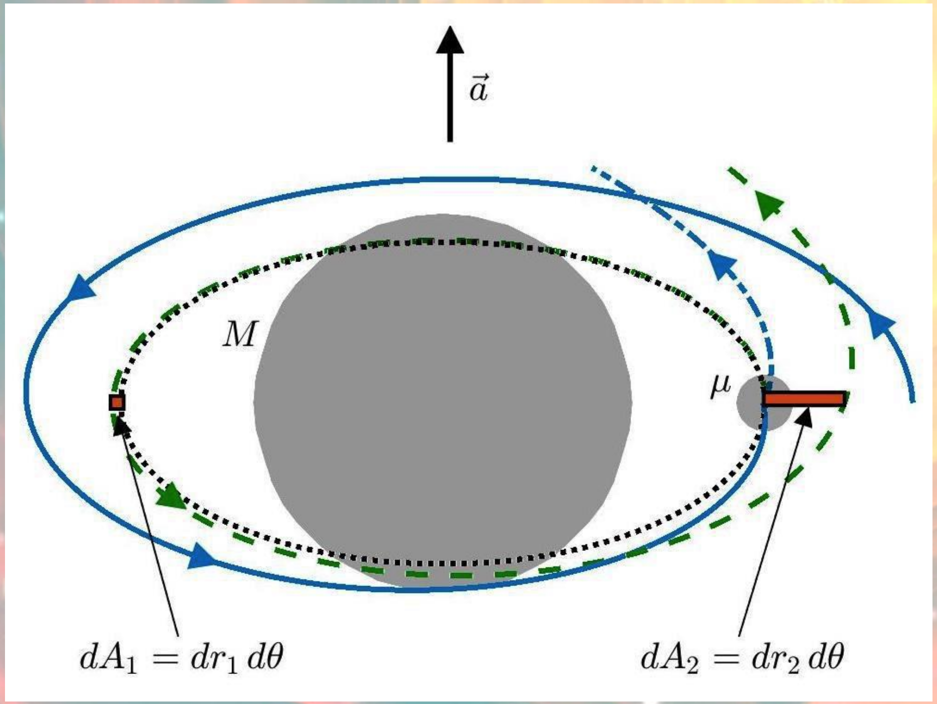
Analytic black-hole binary mergers from first principles

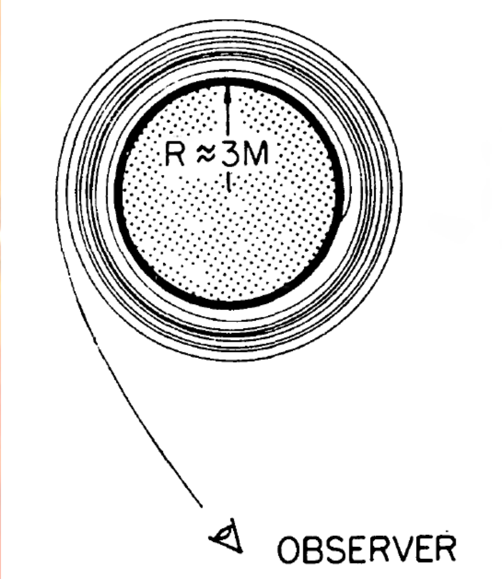
- As sensitivities of GW detectors improve, greater demand to minimize waveform systematic errors
- NR simulations are not error-free, and take a long time to generate
- Available phenomenological models introduce dofs to tune to NR results
- Poorly controlled systematics, interpolation can smooth over interesting features
- Ringdown attachment procedures not always robust
- Goal: develop a physically motivated, highly efficient ***late inspiral***-merger-ringdown model

First, a question…

- In merger modeling, the peak strain amplitude is usually associated with the light ring (e.g. peak “orbital” frequency).
- Meanwhile, in the eikonal approximation, ringdown is associated with null orbits at the light ring.
- How can both be true?

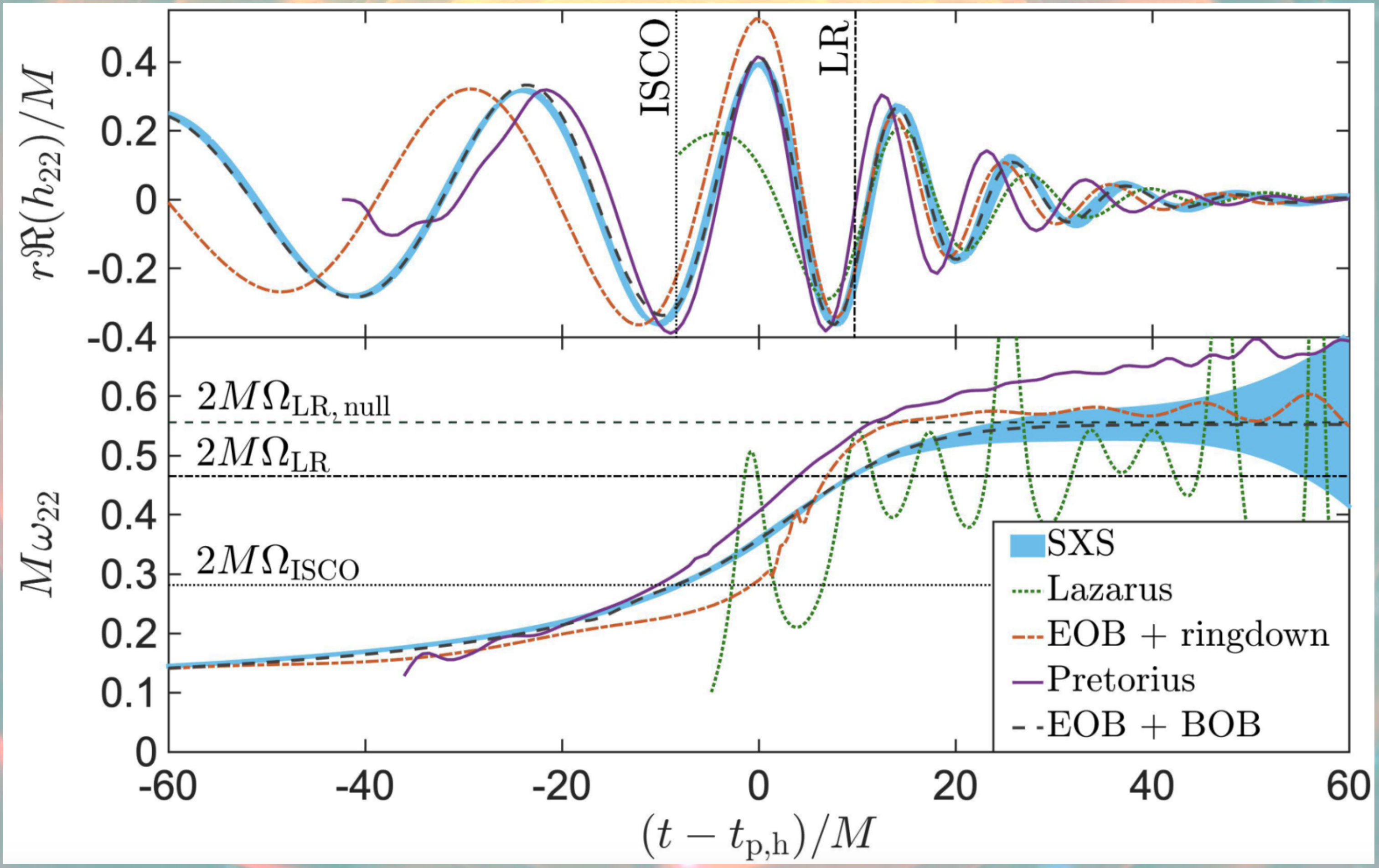
- In an EOB-like treatment, emission is coming directly from effective perturber orbiting throughout inspiral
- Approaching merger, emission reflects off curvature potential
- As perturber passes light ring, emission generated with a range of ang. mom. between the perturber’s and the null circular value
- lowest frequency rays have lowest ang. mom., escape in least time. Approaching null circular rays, emission moves to higher frequencies and longer time delays to reach distant observers.



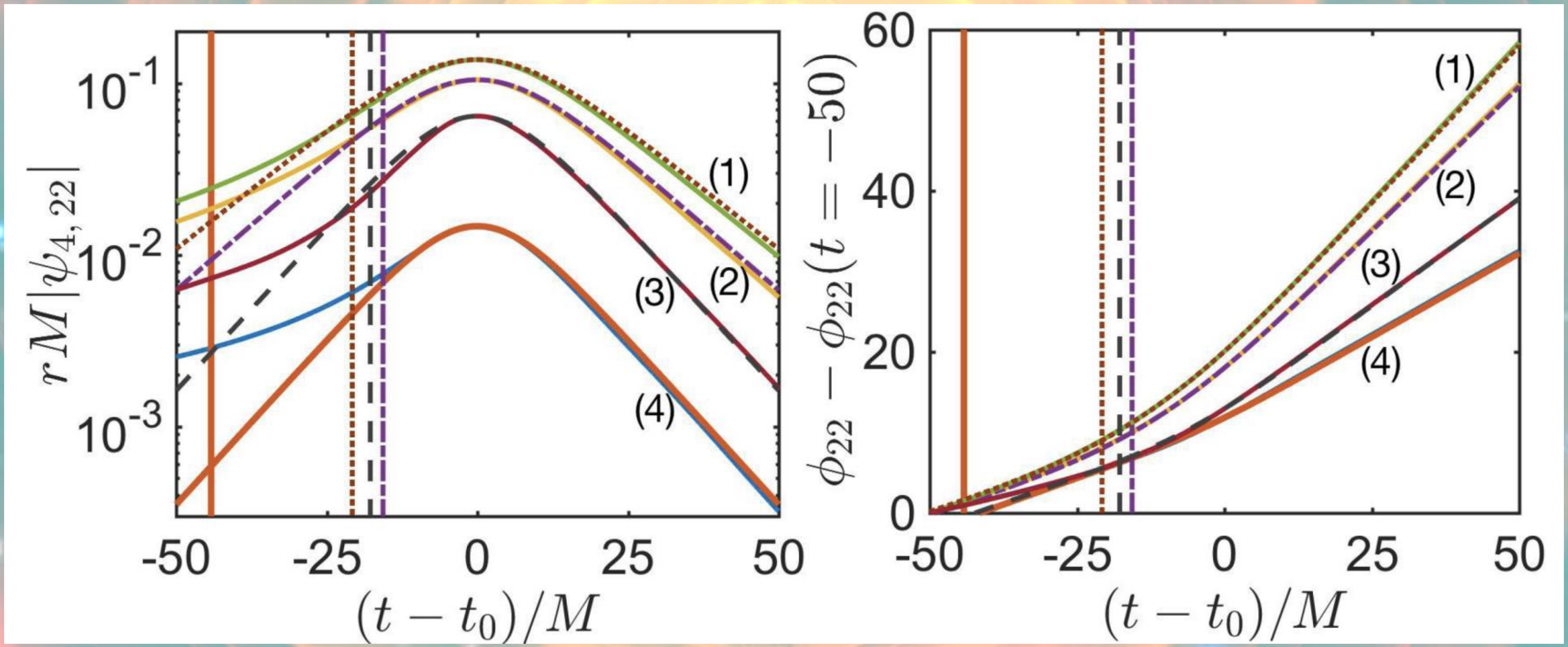


Ames and Thorne (1968)

– Behavior of null congruence tells us amplitude behavior
– Rigid rotation allows calculation of frequency from amplitude
– Model needs merger-remnant mass and spin, can use NR fits or other models
– Can reproduce equal mass, nonspinning to within SXS errors



- Can reproduce l=2, m=2 *of the merger-ringdown* to within SXS errors for most (all?) cases
- Can extend back to ISCO of merger-remnant spacetime for q >~1/6, would still need NR-calibrated EOB for q < ~1/6
- Can model higher harmonics to < SXS errors, need better NR to actually characterize BOB error for HH



(1) q=1, a_1= a_2=0.9, (2) q=2/3, a_1=0.991, a_2=0.2 (misaligned), (3) q=1, a_1= a_2=0.6 (misaligned), (4) q=1/10

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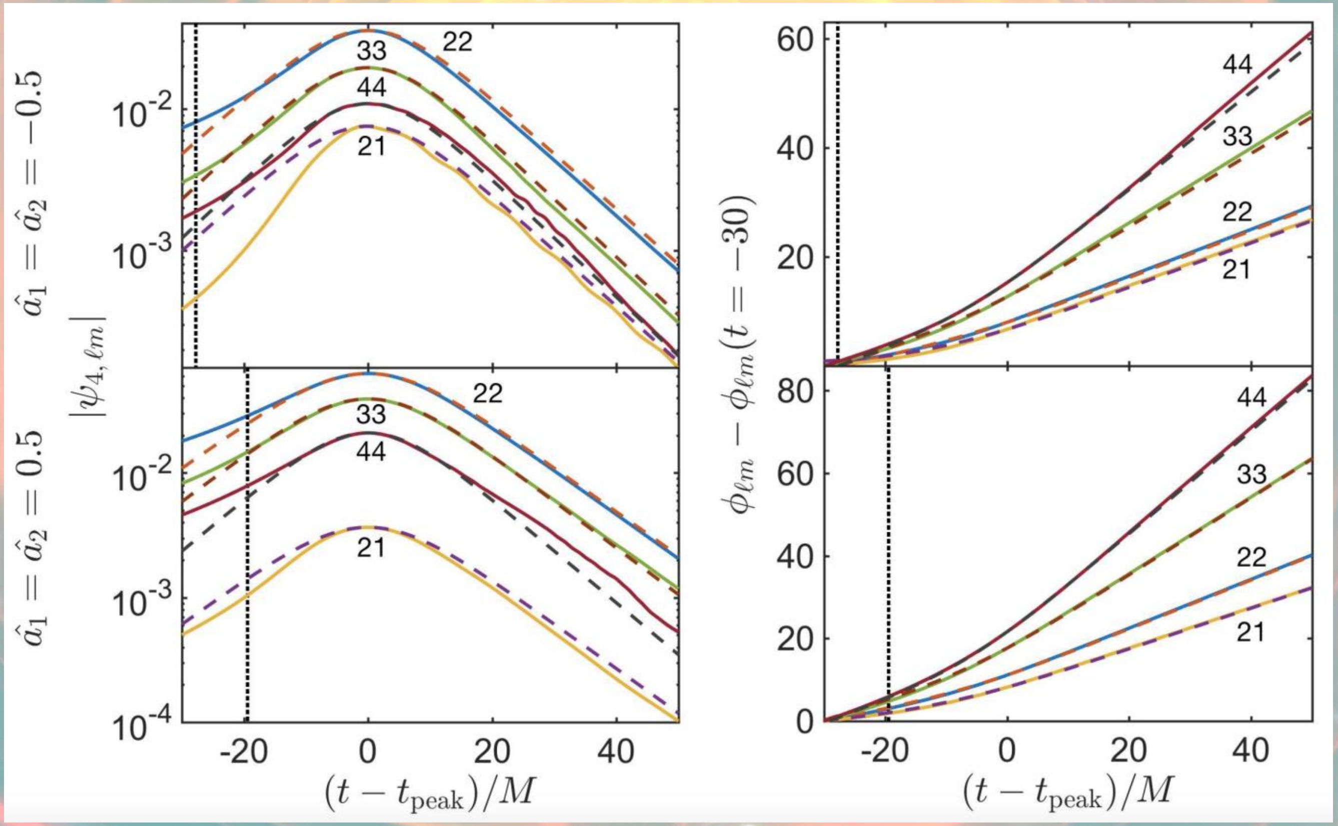
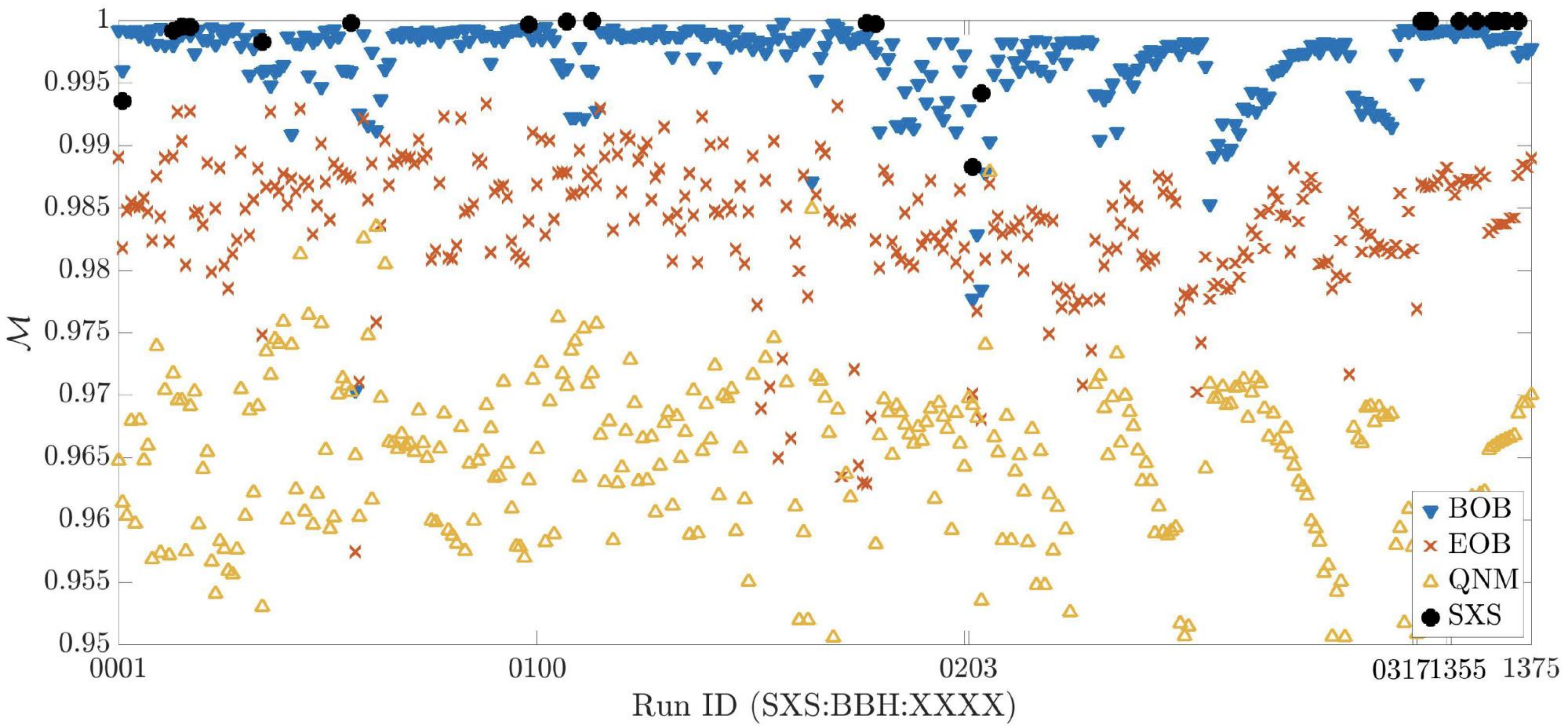
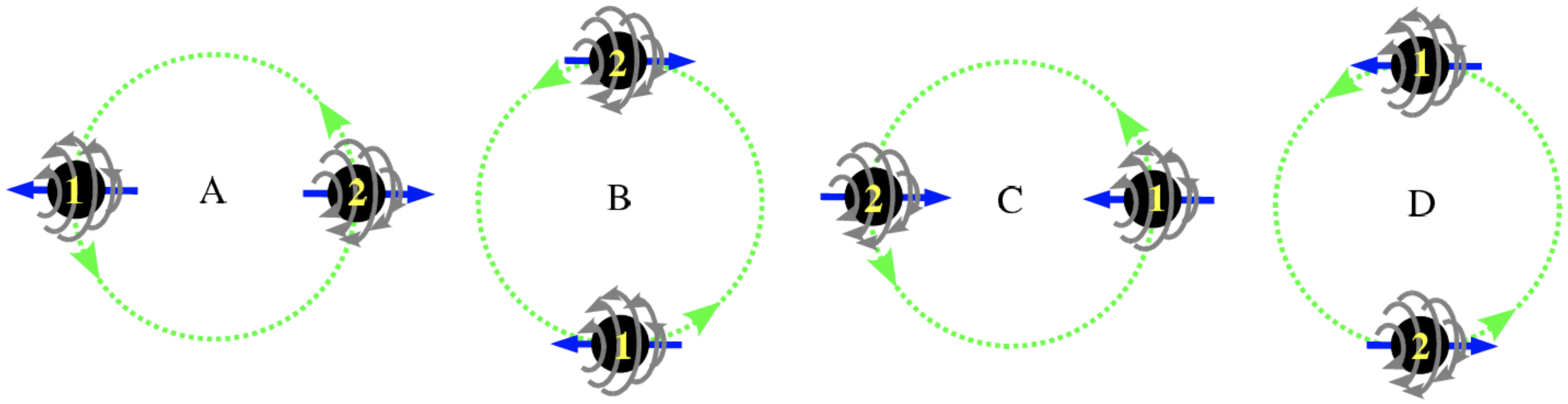


higher harmonics for q=1/3, $a_1 = a_2 = -0.5$

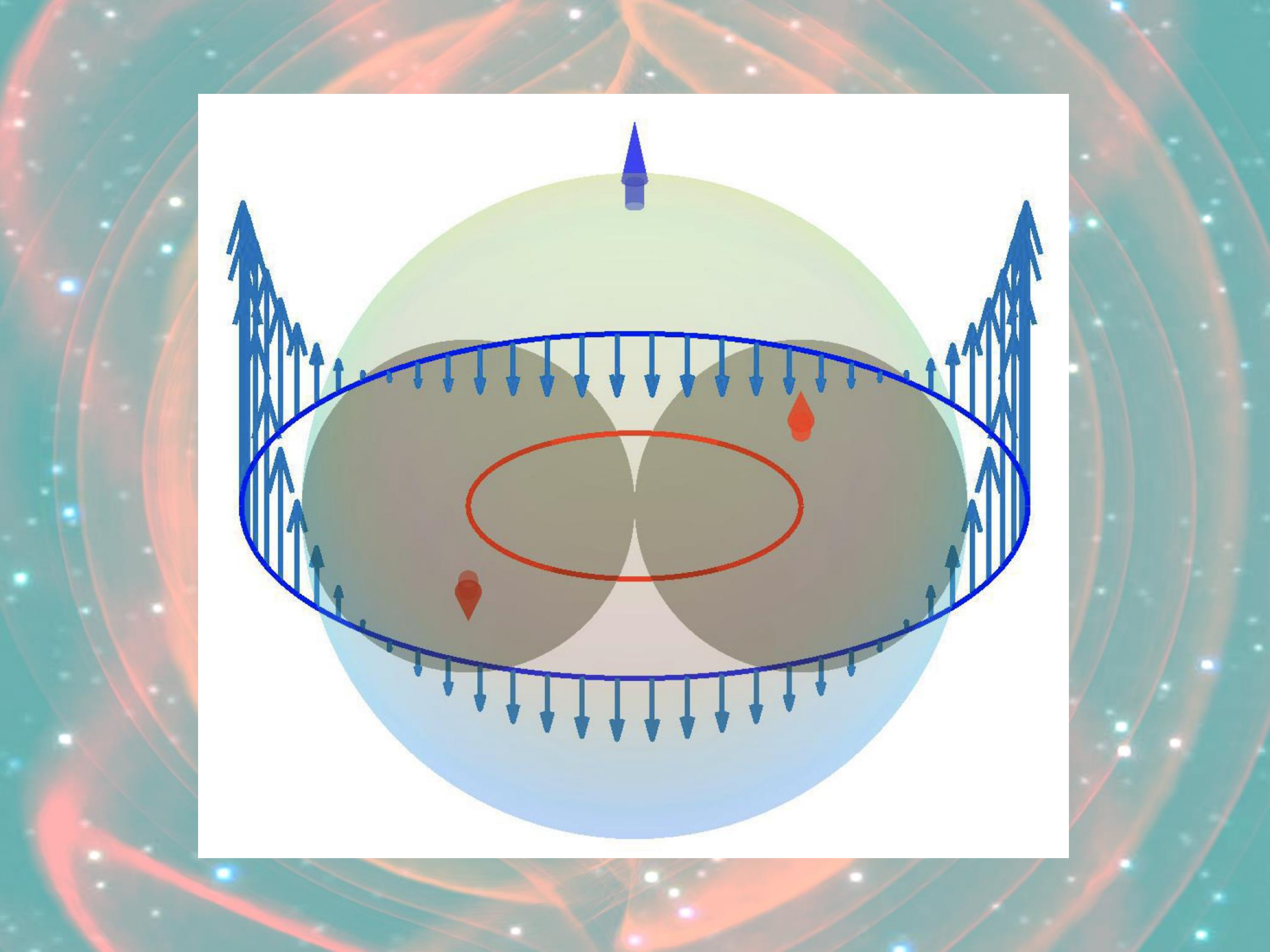
- Data analysts use the “match” or ”fitting factor”, basically the fraction of recovered SNR, to represent the usefulness of a template for detection
- BOB is the best model available, difference with NR is consistent with NR errors for at least a large subset of parameters

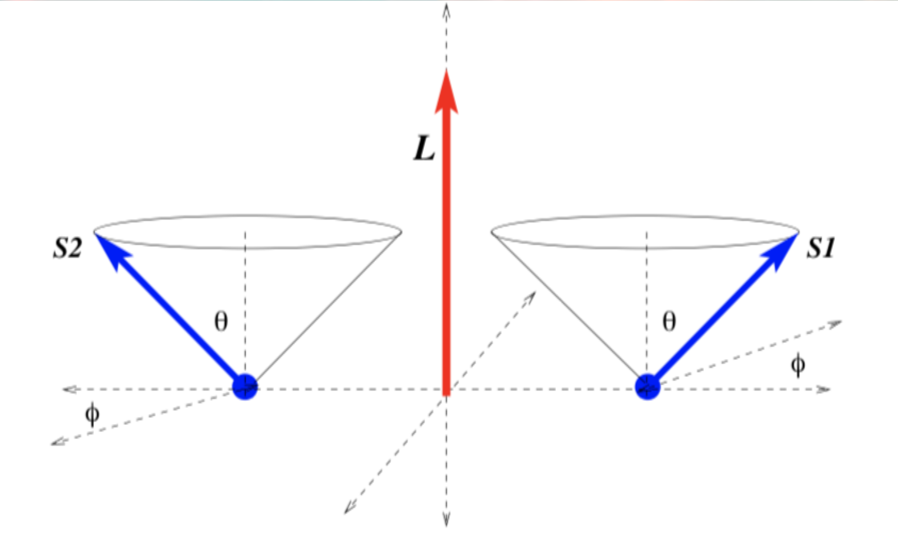


- Since kicks occur mostly during the merger, we can try to understand them with BOB
- Frame-dragging has been used to explain spin kicks
- Newton's 3rd law + no gravitational aberration, but…
- GWs can be frame-dragged, explain kicks

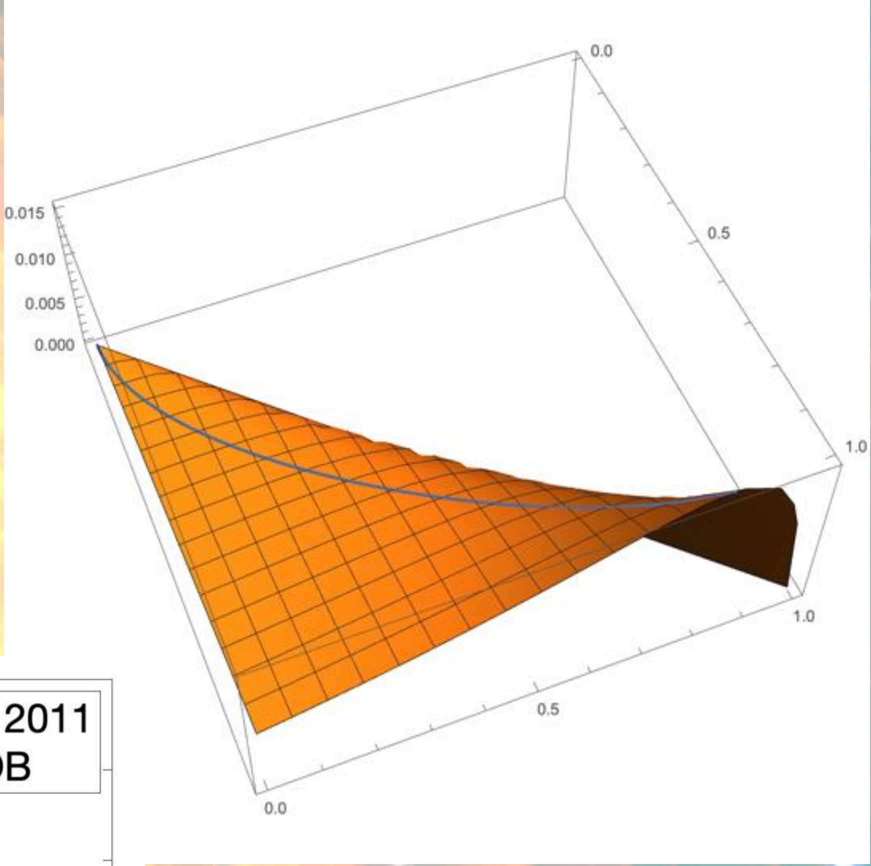


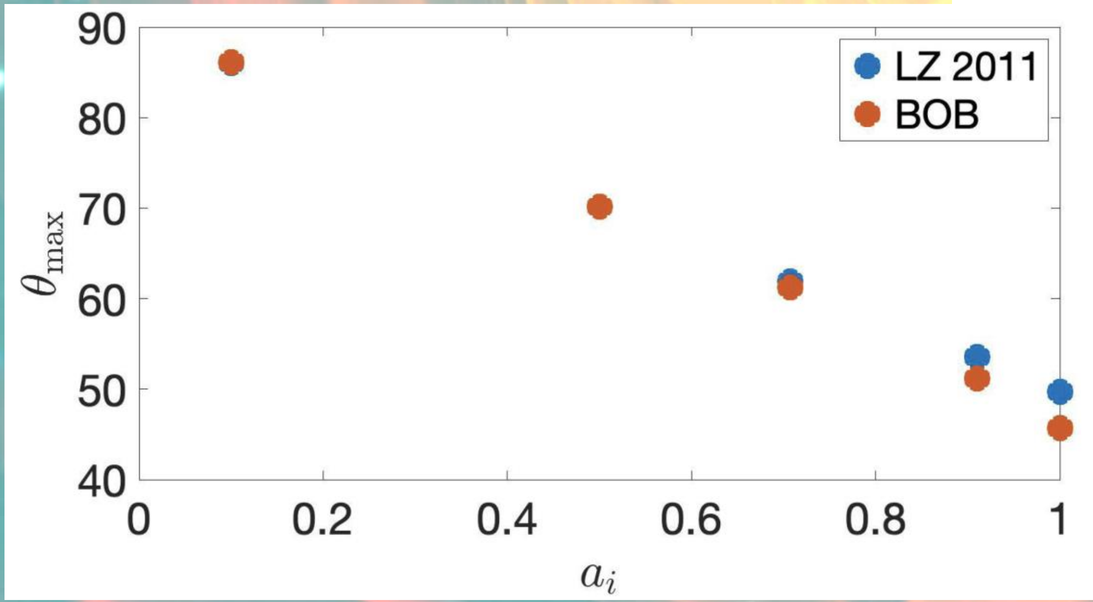
Pretorius (2007)





Lousto and Zlochower (2011)





- As ground-based detectors improve, and space-based like LISA and TianQin become a reality, demands on model accuracy will be far beyond current state-of-the art
- BOB may good enough for merger, still need better/faster inspirals
- Currently implementing BOB with a better inspiral
- BOB methodology can apply to any theory with a BH-like solution

TianQin = GADFLI