Waveform Systematics for Black Hole Binary Mergers Models

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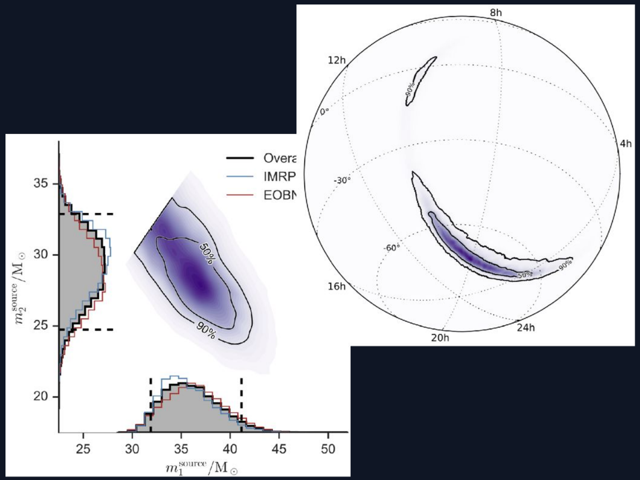
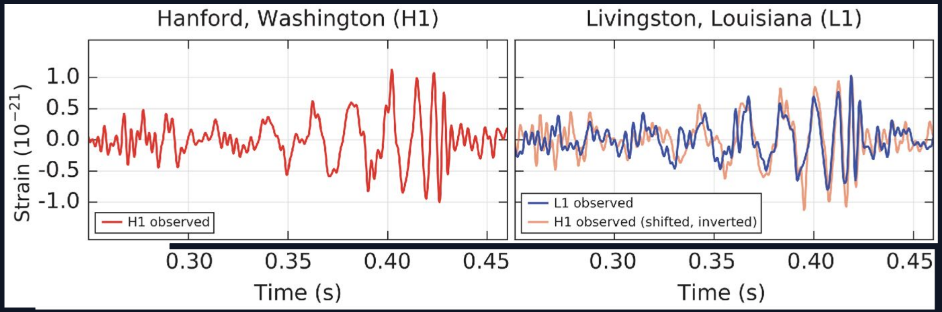
Waveform Systematics for Black Hole Binary Mergers Models

- Black hole mergers can be characterized using gravitational wave data collected at LIGO/Virgo
- Deep Inference for Gravitational-wave observations (DINGO) leverages neural networks to speed up analysis vs traditional methods





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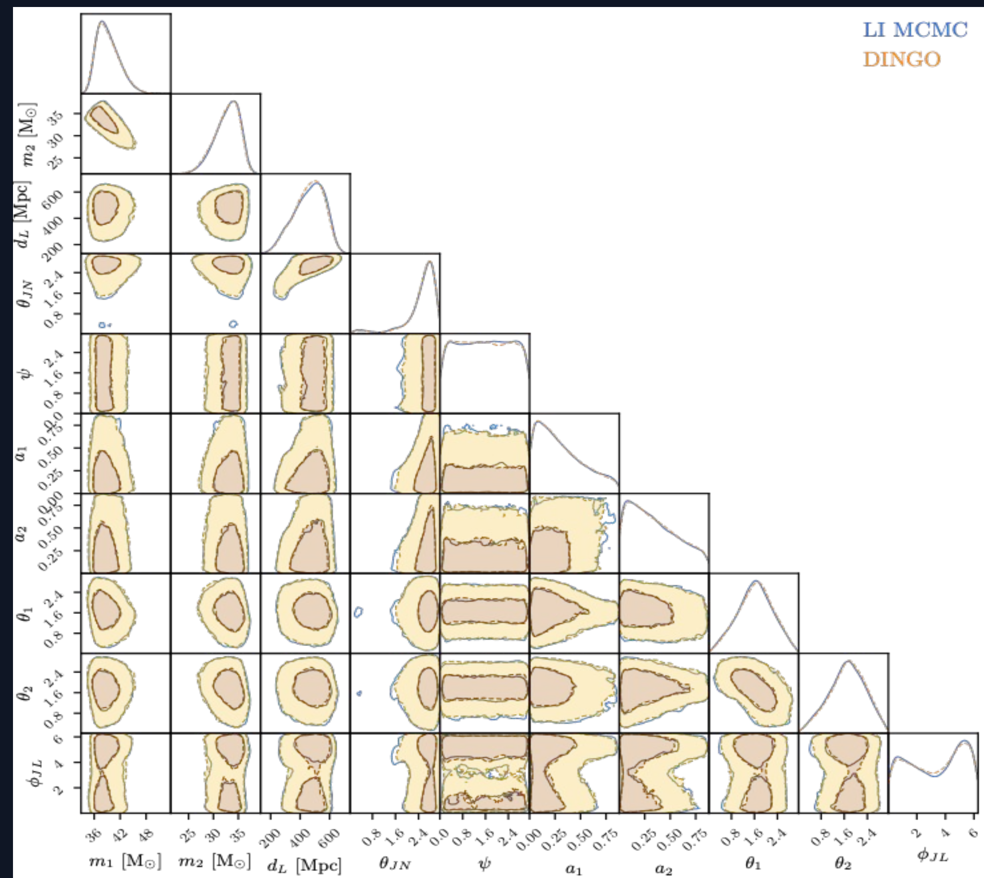
LVC, PRL 116, 2016

Waveform Systematics for Black Hole Binary Mergers Models

DINGO

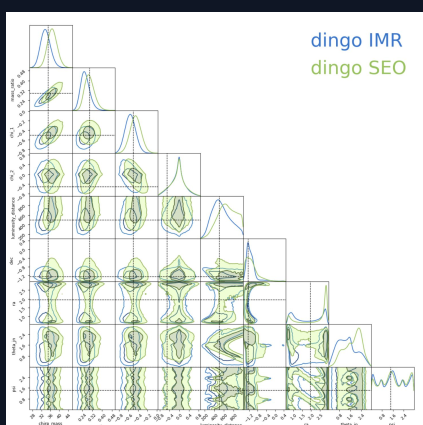
- Train on simulated data (Gaussian noise + GW signal)
- Training: ~1 week (NVIDIA A100)
- Inference: ~ 1 minute [GPU]; ~ hours with *importance sampling* [CPU]
- Posterior and evidence match with traditional samplers (~ 1 nat)



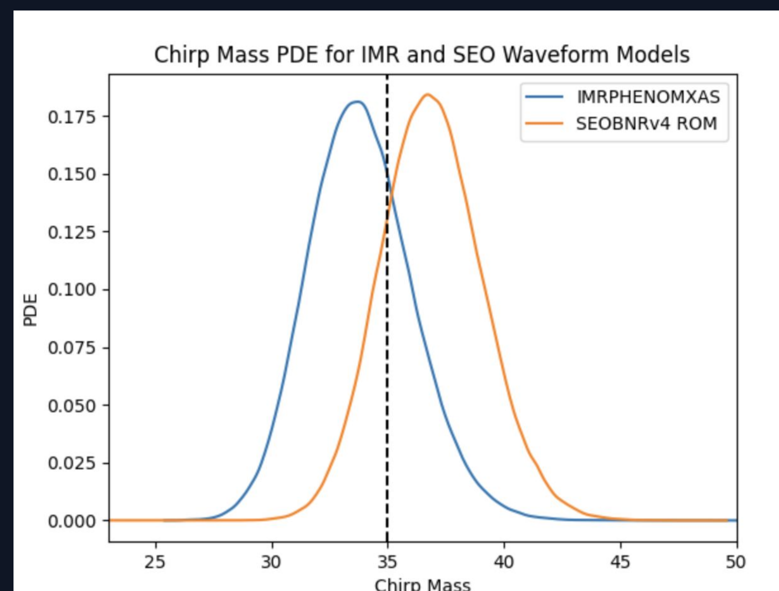
Code: https://github.com/dingo-gw/dingo

Waveform Systematics for Black Hole Binary Mergers Models

- Imperfections in gravitational waveform models can lead to significant bias in estimating parameters
- Goal: create a visual map of discrepancies between the posteriors for different models to guide model improvements
- Method: Analyze grid of 100 mock injections varying mass ratio from 1 to 8 and varying spin from -0.9 to 0.9 using simple waveform models



Posterior plot example for single grid point



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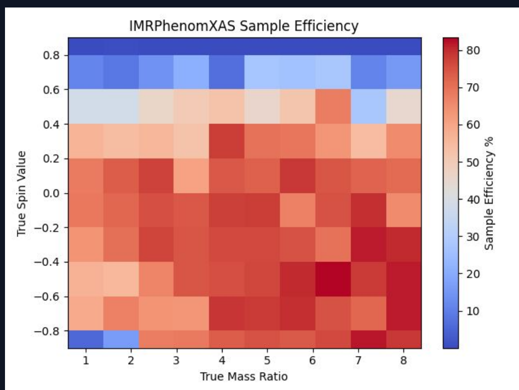
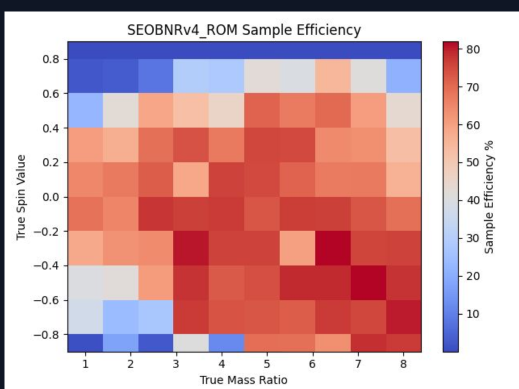
- Timeframe
- Start Date: October 1, 2023
  - End date: March 31, 2024

Waveform Systematics for Black Hole Binary Mergers Models

Results





- Trained networks conditioned on two waveform models (IMRPHENOMXAS and SEOBNRv4_ROM
- Used *importance sampling* to verify grid space where models perform well
- Results here indicate at very high spins neither network performs well

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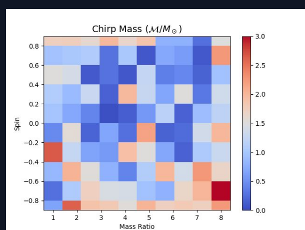
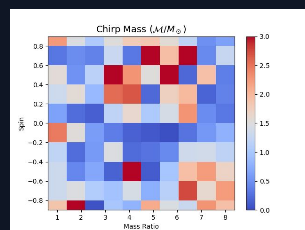
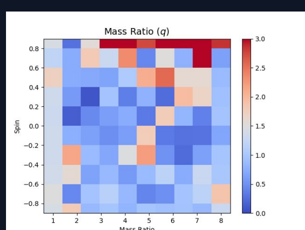
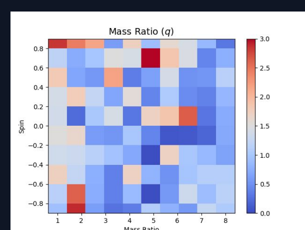
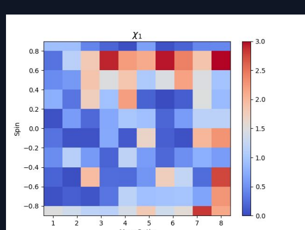
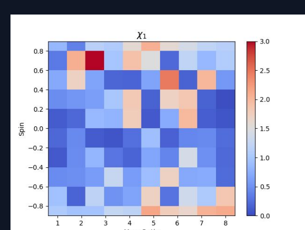
IMRPhenomXAS	SEOBNRv4 ROM
	
	
	

- For both models biases in a number of parameters are high for large spin magnitudes
- biases tend to be small for moderate spins, irrespective of mass-ratio.
- Biases at high spin magnitudes may be partly due to the spin prior used to train networks being constrained to [-0.9, 0.9] which can cause railing.

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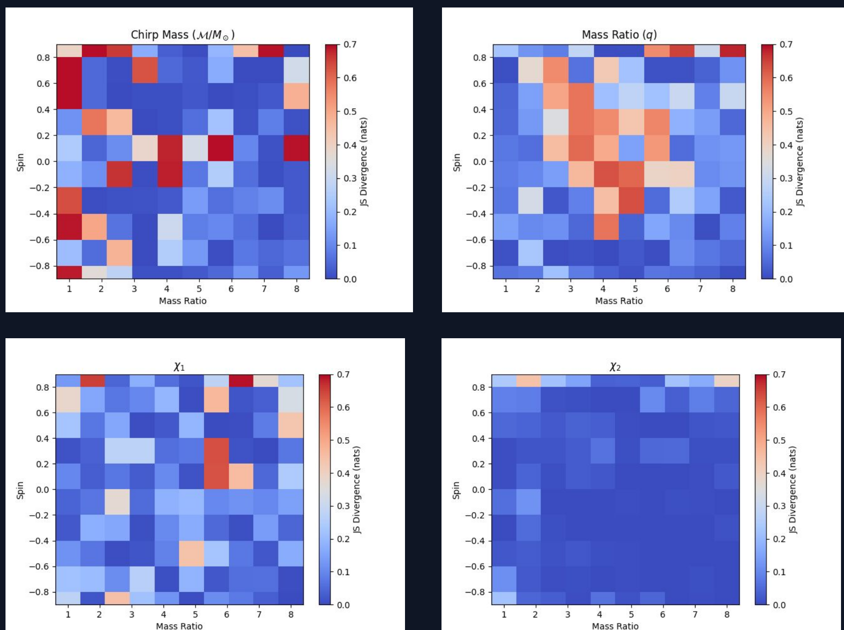

Jensen-Shannon Divergence Values		
Parameter	Median	St.Dev
Chirp Mass($\mathcal{M}/M_\odot$)	0.072 nats	0.237 nats
Mass Ratio(q)	0.120 nats	0.201 nats
Spin 1(χ_1)	0.096 nats	0.158 nats
Spin 2(χ_2)	0.008 nats	0.075 nats

- Used Jensen Shannon divergence to compare models
- Moderate JS-Divergence value, suggesting similar posteriors
  - indistinguishability threshold of 0.002

$$JS(P||Q) = \frac{1}{2}KL(P||\frac{(P+Q)}{2}) + \frac{1}{2}KL(Q||\frac{(P+Q)}{2})$$

$$KL(P||Q) = \sum_x P(x)\log(\frac{P(x)}{Q(x)})$$

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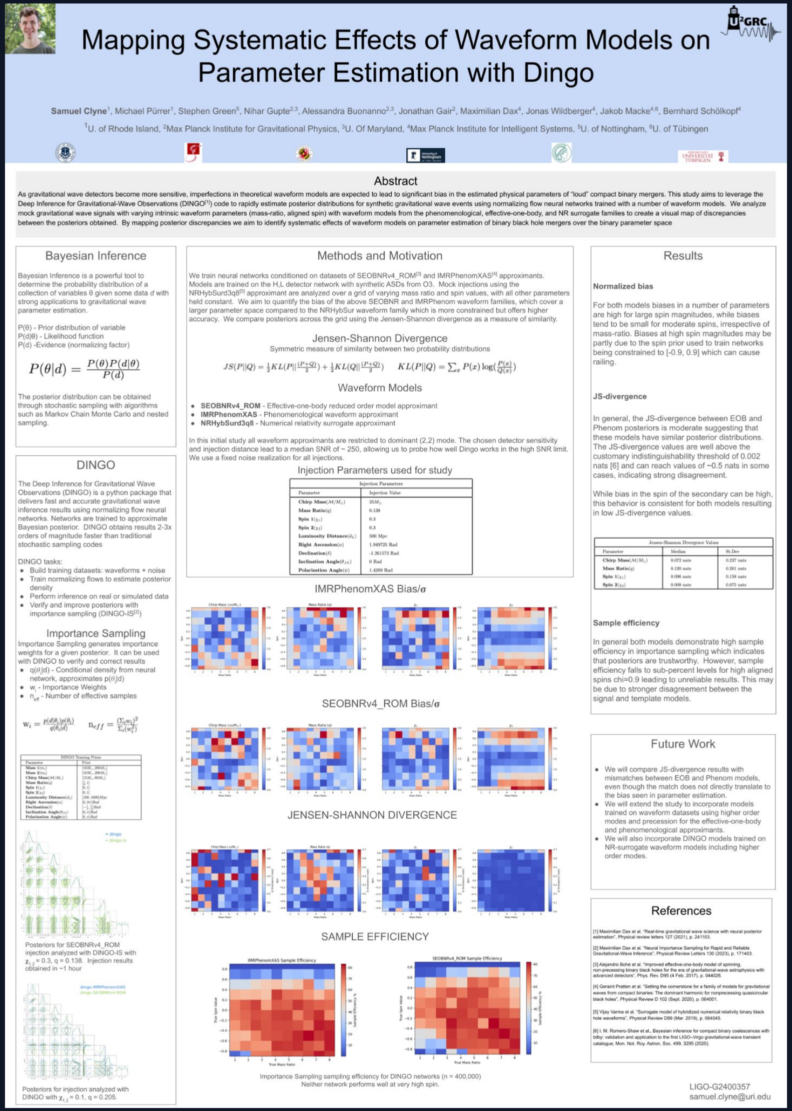
Publications/Contributions

- Poster presentation at LIGO-VIRGO-KAGRA March Meeting in Baton Rouge, LA
- URI AI Lab Poster Competition (April 29)



Challenges

- Initial plan to compare 3 models, but could not get reliable results within timeframe
- Low sample efficiency at high spins limit the scope of study

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Lessons Learned

- Much Stronger understanding of Black Hole Binary Parameter Estimation
- Gained Practical experience training neural networks on HPC resource
- Learned to write efficient scripts to run in HPC
- Ready to apply skills learned during study to more complex models

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