Detecting Exoplanets and Brown Dwarfs with LISA

- Vaidehi Gupta

Collaborators:
Dr. Michael Katz, Dr. Camilla Danielski, Dr. Nicola Tamanini, Professor Michael Coughlin, Dr. Martina Toscani

UNIVERSITY OF MINNESOTA
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P-type sub-stellar objects that orbit a Double White Dwarf Binary

Abundance of DWDs emitting in the LISA band.

What type of exoplanets and brown dwarfs are we talking about and Why?

Tamanini & Danielski 2019

White Dwarf Pollution – supports the existence of a planet around a WD.

Planets can survive more around post-AGB binary than a single WD.

What evidence, if any, do we have to believe we would detect something?

C. Danielski et al, Dec 2019

Main Questions Addressed

We simulate GW from: (1) DWD system (2) DWD + injected SSO

We conduct statistical tests to verify the detectability of SSOs

How do we verify the detectability of these sources with LISA?

Katz et al, 2022

What are the implications of this work on other astrophysical sources?

Third Body Priors

- 8 scenarios – based on semi-major axis and mass distributions.
- 3 realizations – to mitigate bias and statistical fluctuations.

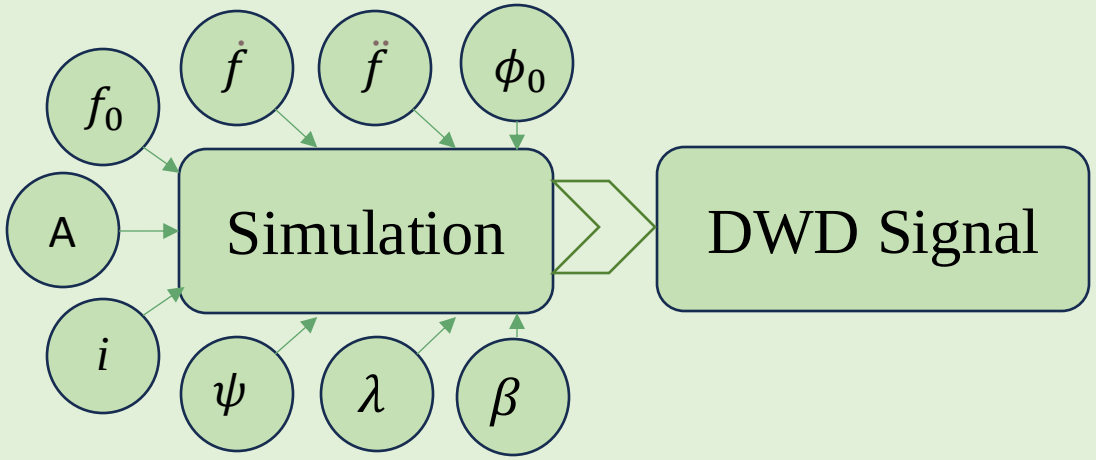
- Semi-major axis distribution:
  - Uniform distribution - $\mathcal{U}_a(0.1 - 200\ au)$
  - $\log_{10}$ uniform distribution - $\log \mathcal{U}_a(0.1 - 200\ au)$
  - log-normal distribution - $f(x) = A\ e^{\ln x - \mu/2\sigma^2}/x2\pi\sigma$
  - Power-law distribution - $a^{-.61}(0.1 - 200au)$

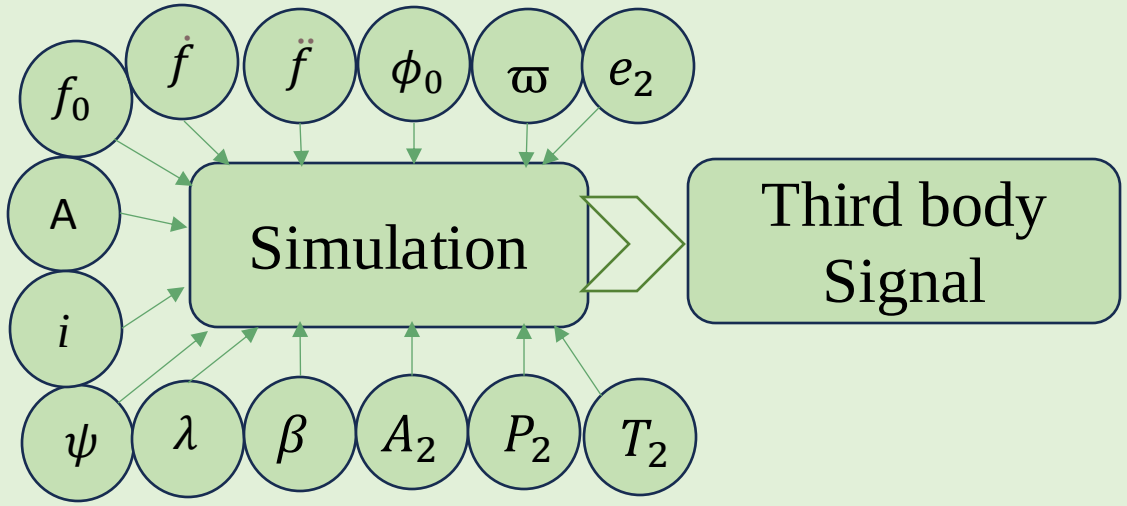
- Mass distribution:
  - Uniform distribution - $\mathcal{U}_M(1M_\oplus - 0.08\ M_\odot)$
  - Combination of power law - $M^{-1.31}$ between $1M_\oplus - 16M_J$ and uniform for $16M_J - 0.08M_\odot$

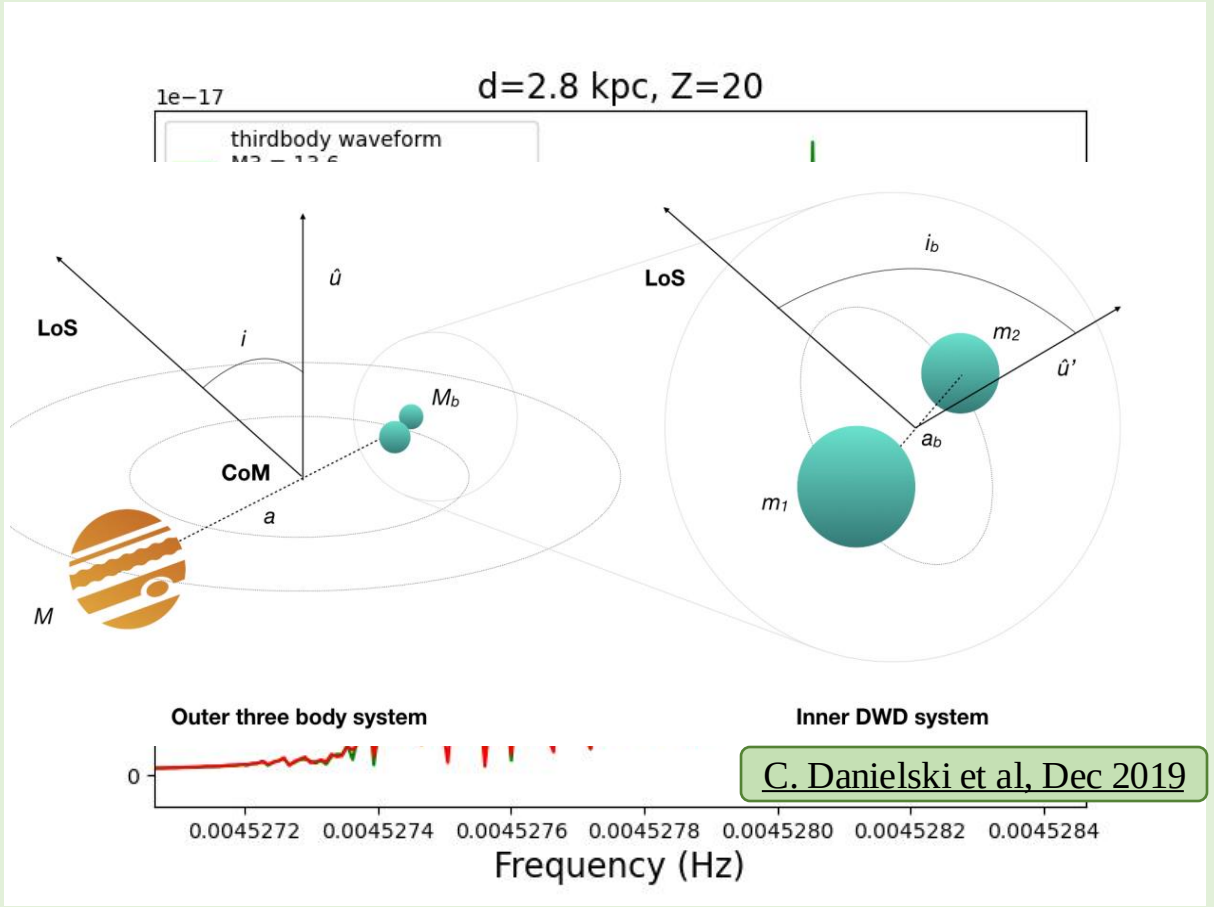
Upper and Lower Values of Realizations

	Min	Max
Period (days)	0.00098	0.248
d (kpc)	0.32419	27.102
WD1 Mass	0.15577	1.3794
WD1 Radius	0.00269	0.022
WD2 Mass	0.19276	1.3773
WD2 Radius	0.00274	0.0205
M3	0.00315	83.816

Simulating Waveforms







C. Danielski et al, Dec 2019

First Step

Likelihood calculation at the injection of the third body.

To see if the two waves are different enough to be detected.

$$\ln \mathcal{L} = -\frac{1}{2} < h_b - h_t | h_b - h_t > = -\frac{\mathbf{1}}{\mathbf{2}} (< \boldsymbol{h_b} | \boldsymbol{h_b} > + < \boldsymbol{h_t} | \boldsymbol{h_t} > - \mathbf{2} < \boldsymbol{h_b} | \boldsymbol{h_t} >)$$

Second Step

Allowing the DWD parameters to evolve.

- Using MCMC, the likelihood between the DWD and the injected third body waveform is maximized.
- Performed to filter out sources before a computationally extensive Evidence calculation.

Third Step

Calculating the bayes factor through evidence calculations. Katz et al, 2022

- The Evidence is computed through thermodynamic integration.
- The Bayes factor is the ratio of the evidence for the two models. $2 \log BF > 5 \Rightarrow$ surely detectable $0 < 2 \log BF < 5 \Rightarrow$ marginal, and $2 \log BF < 0 \Rightarrow$ non-detectable.

Preliminary Results

Estimated detectable Exoplanets

	A1	A2	B1	B2	C1	C2	D1	D2
Realization 1	44	7	32	34	87	15	44	10
Realization 2	46	13	22	7	94	13	43	18
Realization 3	39	9	34	6	66	21	63	8

Estimated detectable Brown Dwarfs

	A1	A2	B1	B2	C1	C2	D1	D2
Realization 1	2552	400	1217	1159	2678	382	2339	343
Realization 2	2432	366	1190	160	2632	396	2344	359
Realization 3	2464	361	1182	168	2647	382	2363	303

Number of Sources with ‘ll diff’ < - 20

To add a plot of P2 vs M3 soon

Future Prospects

Coming Soon!

- Generating final results from evidence runs and publishing the analysis.
- Applying the pipeline for different astrophysical sources.
- Investigating how to adapt the analysis in the global fit.
- Analysing the posterior distributions for sources that make it through the evidence cut.
- Performing the analysis for multiple planets or brown dwarfs.

Questions?

Thank you
for your time and
attention!

Evidence for Existence of Planet Around WD

- Multiple Post common envelope planets detected – Planets survived one CE phase.
- Planets survive more around compact binaries than around single stars. Kostov et al, 2016
- 23-32% of P-type exoplanets survive and orbit DWDs. Columba et al, 2023
- Planets can also form a second generation disc around DWDs. Ledda, Danielski & Turrini et al, 2023
- Second generation exoplanets, i.e., those that form after first CE phase, formed around DWDs, tend to be more stable.

Nigioni et al, submitted

Second Step

Allowing the DWD parameters to evolve.

- **Methodology:**

- Using eryn, an advanced MCMC sampler, the likelihood between the DWD and the injected third body waveform is maximized.

- Often likelihood maximization returns a biased DWD waveform template, but with a higher likelihood than the injection parameters.

- Likelihood maximization is performed to filter out sources before a computationally extensive Evidence calculation.

Third Step

Calculating the bayes factor through evidence calculations.

- **Methodology:**

- The Evidence is computed through thermodynamic integration after locating maximum likelihood values.

- The log of the evidence relative to the prior at $T = 1$ is given by:

$$\log Z\,(1) = \log Z\,(0) + \int_0^1 d\beta \langle \log \mathcal{L} \rangle_\beta$$

- The Bayes factor is the ratio of the evidence for the two models. If:

$2 \log BF > 5 \Rightarrow$ surely detectable

$0 < 2 \log BF < 5 \Rightarrow$ marginal, and $2 \log BF < 0 \Rightarrow$ non-detectable.