A Solution to LISA's Galactic Binary Problem

Kyle Gersbach

UNIVERSITY *of* WASHINGTON | BOTHELL

Global Analysis of the Gravitational Wave Signal from Galactic Binaries

Tyson B. Littenberg,[1] Neil J. Cornish,[2,3] Kristen Lackeos,[4] and Travis Robson[2]

[1] *NASA Marshall Space Flight Center, Huntsville, Alabama 35811, USA*
[2] *eXtreme Gravity Institute, Department of Physics, Montana State University, Bozeman, Montana 59717, USA*
[3] *Artemis, Université Côte dAzur, Observatoire Côte dAzur, CNRS, CS 34229, F-06304 Nice Cedex 4, France*
[4] *NASA Postdoctoral Program Fellow, NASA Marshall Space Flight Center, Huntsville, Alabama 35812, USA*

Galactic ultra compact binaries are expected to be the dominant source of gravitational waves in the milli-Hertz frequency band. Of the tens of millions of galactic binaries with periods shorter than an hour, it is estimated that a few tens of thousand will be resolved by the future Laser Interferometer Space Antenna (LISA). The unresolved remainder will be the main source of "noise" between 1-3 milli-Hertz. Typical galactic binaries are millions of years from merger, and consequently their signals will persist for the the duration of the LISA mission. Extracting tens of thousands of overlapping galactic signals and characterizing the unresolved component is a central challenge in LISA data analysis, and a key contribution to arriving at a global solution that simultaneously fits for all signals in the band. Here we present an end-to-end analysis pipeline for galactic binaries that uses trans-dimensional Bayesian inference to develop a time-evolving catalog of sources as data arrive from the LISA constellation.

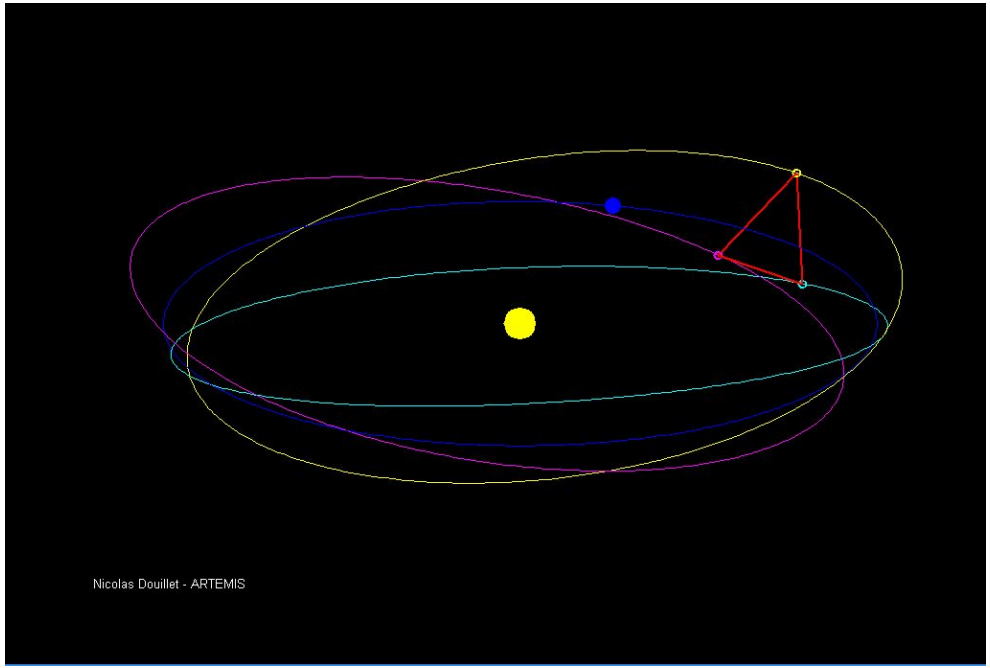
https://arxiv.org/pdf/2004.08464.pdf

Shamelessly stolen from one of Tyson's slides

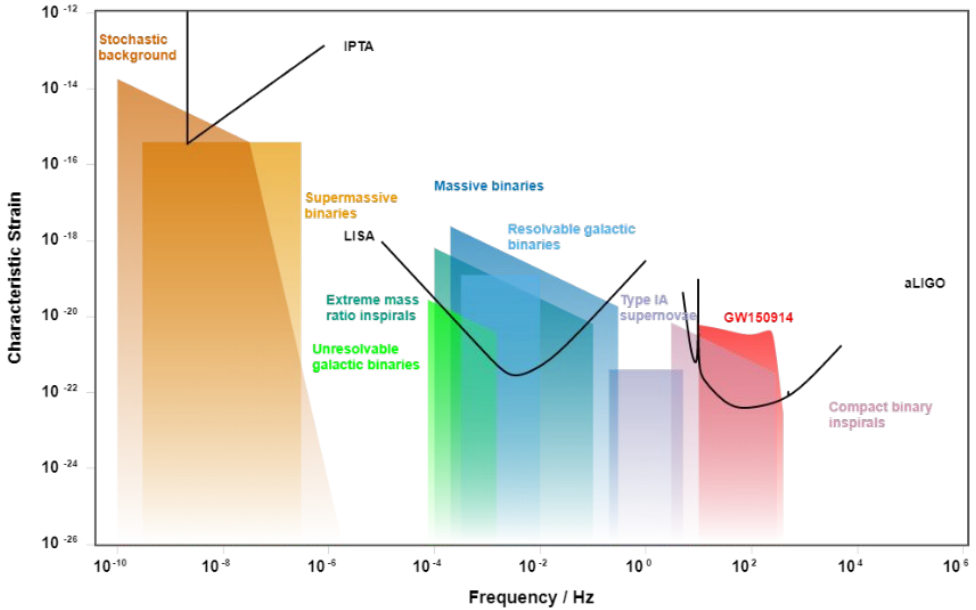
What is LISA?

Laser Interferometer Space Antenna

- **Launching in 2034**
- **2.5 million km beam arms**
- **Simulated LISA data from the LISA Data Challenge**



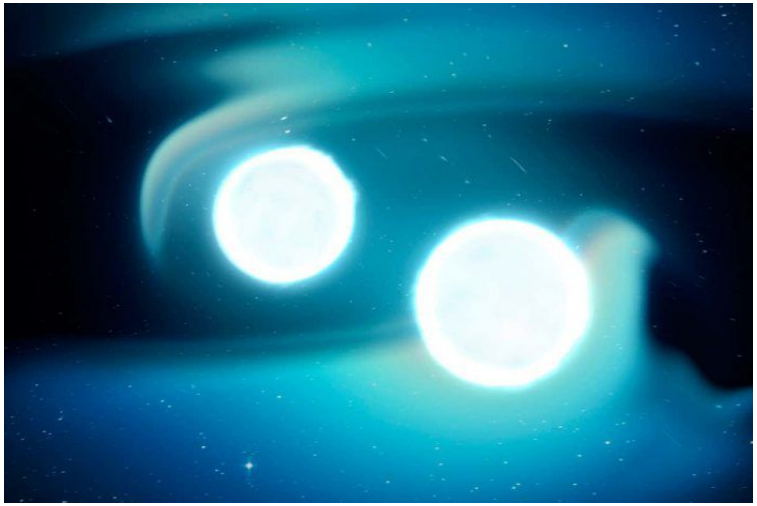
The Gravitational Wave Spectrum



Spectrum of gravitational waves with estimated sources and strain *Credit: Christopher Moore, Robert Cole & Christopher Berry*

Ultra-Compact Binaries (UCBs)

- Often a white dwarf binary
- Close enough to have periods on the order of minutes for LISA
- Signals will dominate in the LISA GW band
- Possibly Millions of UCBs in our Galaxy

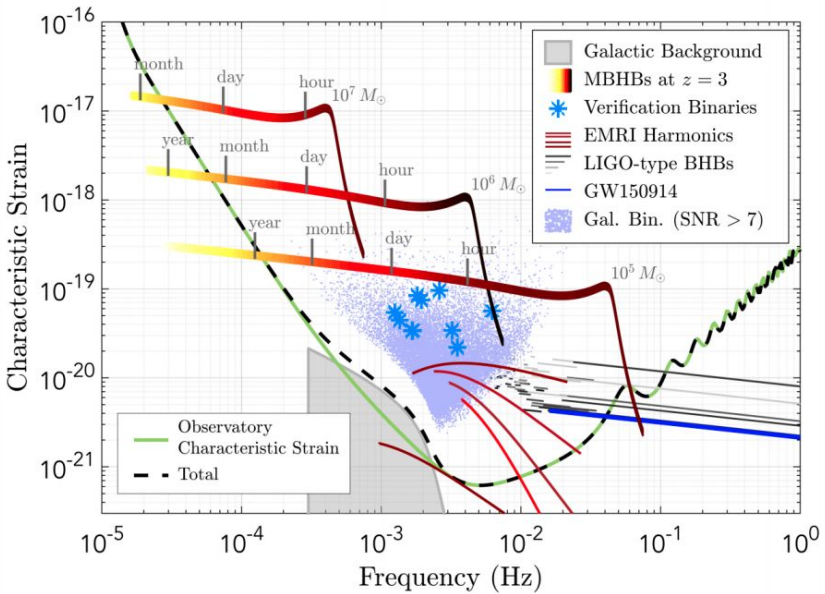


Artist impression of a white dwarf Binary
Credit: NASA/SPL

Why are UCBs important?

For LISA to see much of anything else, you need to identify the UCBs

- **Continuous sources**
  - **Roughly monochromatic**
- **Potentially thousands of resolvable UCBs in the LISA band**
- **Even more UCBs with less strain making up a confusion-limited foreground**



Credit: LISA Mission Proposal for L3 submitted to ESA

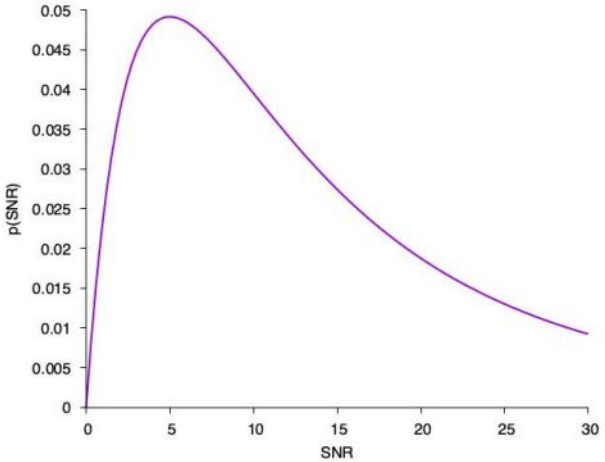
How do we identify UCBs in LISA data?

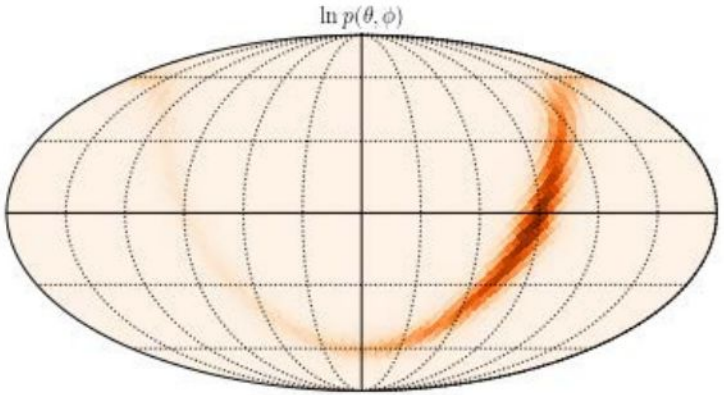
RJMCMC in the Frequency Domain

- Informed Priors
  - Estimate UBC population
- Time Evolving Strategy
  - Analyzing the data as it comes in
    - High SNR sources get cataloged
    - Naturally “annealed”
- Transdimensional MCMC
  - Any amount of sources can be modeled
  - Penalty for higher dimensional models

Using priors based on observation

Vast majority of detectable UCBs will be within our galaxy

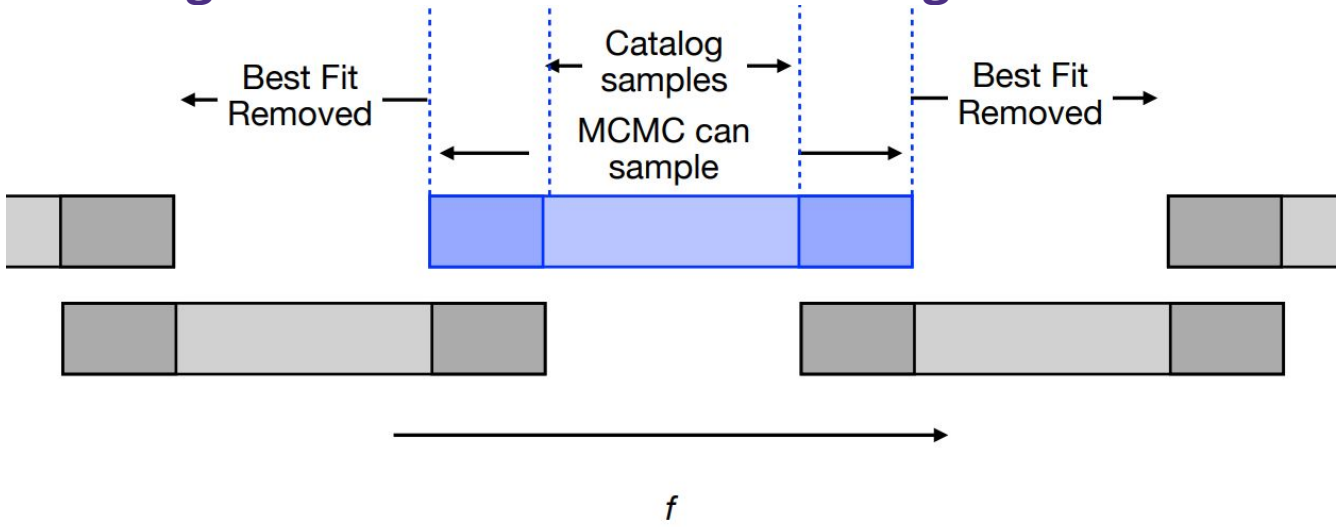




Credit: Tyson Littenberg

Analyzing in separate frequency bins

- Better multi-threaded performance
- Uses catalog to filter loud sources from edge of bins



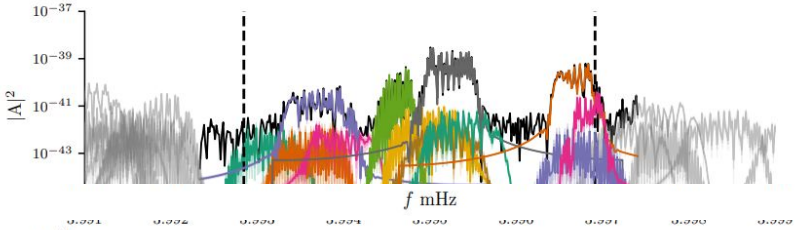
Credit: Tyson Littenberg

Turning the data into a catalog

- Improve data accessibility for astronomers
- Catalog evolves as more sources are found or parameters change

Benefits of this tool

- Probe other side of the Milky Way
- Population analysis
- Multi-messenger astronomy
- Residuals for other pieces of the analysis



Credit: Tyson Littenberg

My background and role

My background

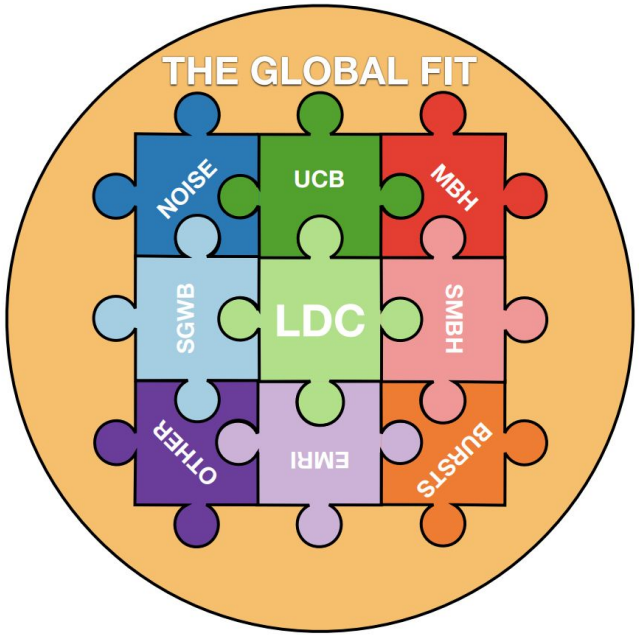
- Majoring in both CSSE & Physics
  - Bring CSSE principles to physics software
  - Developing new skills

The plan so far

- Parallelization
  - Parallelizing the MCMC
    - Parallel Tempering
    - Frequency Bin
- Optimization
  - Software analysis tools: profilers, linters, etc.
  - Apply CSSE skills to prioritize for distributed computing

MPI & OpenMP are both potential parallelization libraries with benefits and tradeoffs

Just one piece of the puzzle



Credit: Tyson Littenberg