Understanding the Astrophysics of Compact Binaries in the Galaxy with LISA

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Collaborators

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Approach

- Synthesize a Galactic population of white dwarf binaries
- Assume detection criteria
- Explore properties of resolved binaries

Population Synthesis

- Modeling the evolution of binaries:
  - Use outcomes of Nelemans synthesis
    - provides distribution of binary types
    - provides P_{orb} vs M at birth
  - Generate a realization of the Galaxy population using Benacquista, DeGoes, & Lunder
    - Assume constant birth rate
    - Select binary type
    - Select masses
    - Determine P_{orb} at birth
    - Evolve to the present

Galactic Structure

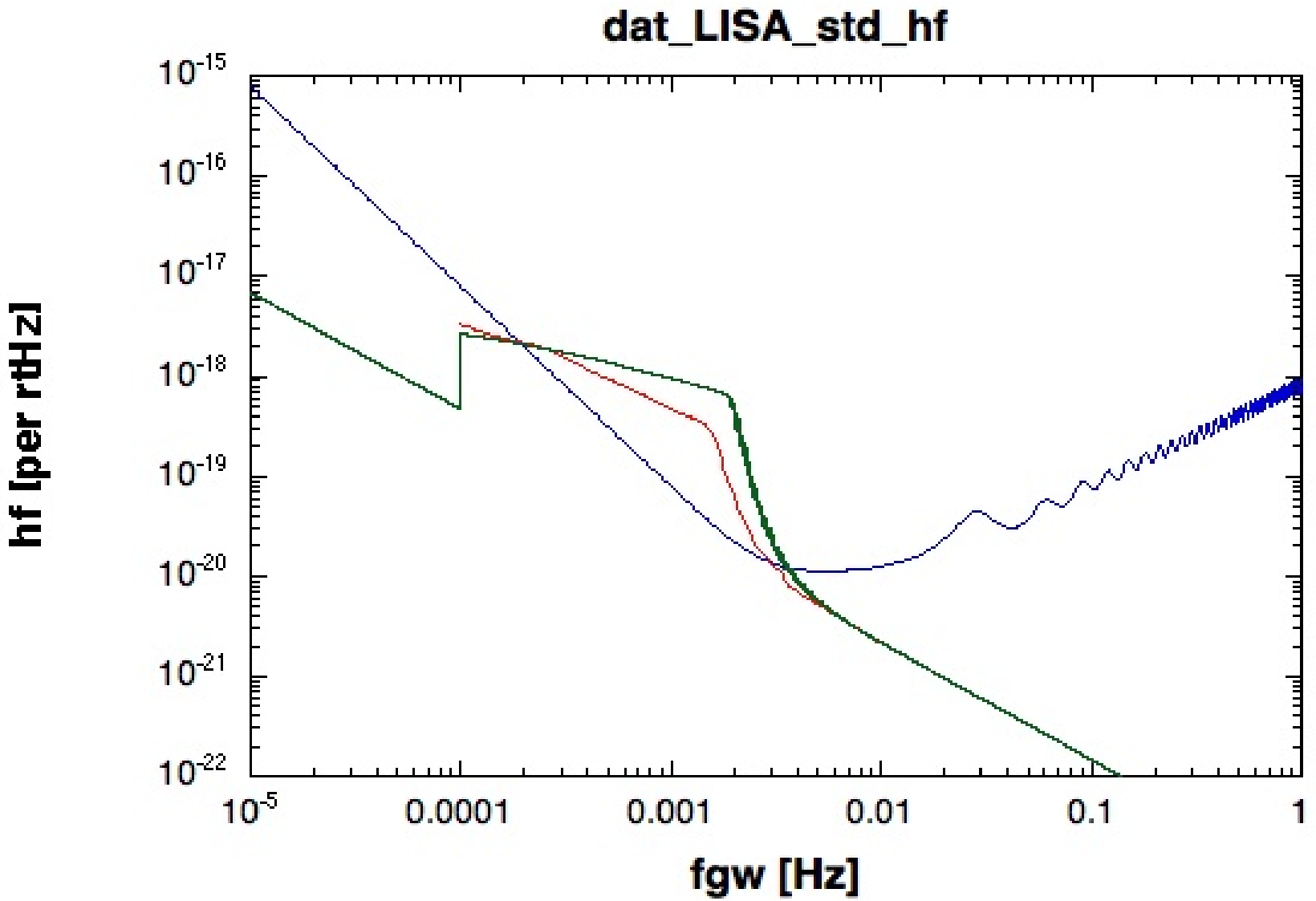
- Use "cuspy" bulge distribution:

$$\rho(\mathbf{r}) = \frac{N}{4\pi R R_0 z_0} e^{-R/R_0} \mathrm{sech}^2(z/z_0),$$

- Vary R_0, z_0 to explore variations in Galactic structure
  - R_0 = 2.0, 2.5, 3.0 kpc
  - z_0 = 100, 200, 300, 500 pc
- Use $N = 30 \times 10^6$

Determine Foregrounds

- Use barycentric frame
- Don't include modulation due to LISA motion
- Calculate a running average
- Assume confusion limit is the running average
- Cut off the running average (a la Bender and Webbink) at high frequencies


dat_LISA_std_hf
hf [per rtHz]
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^-21
10^-22
10^-5
0.0001
0.001
0.01
0.1
1
fgw [Hz]

Resolvable Binaries

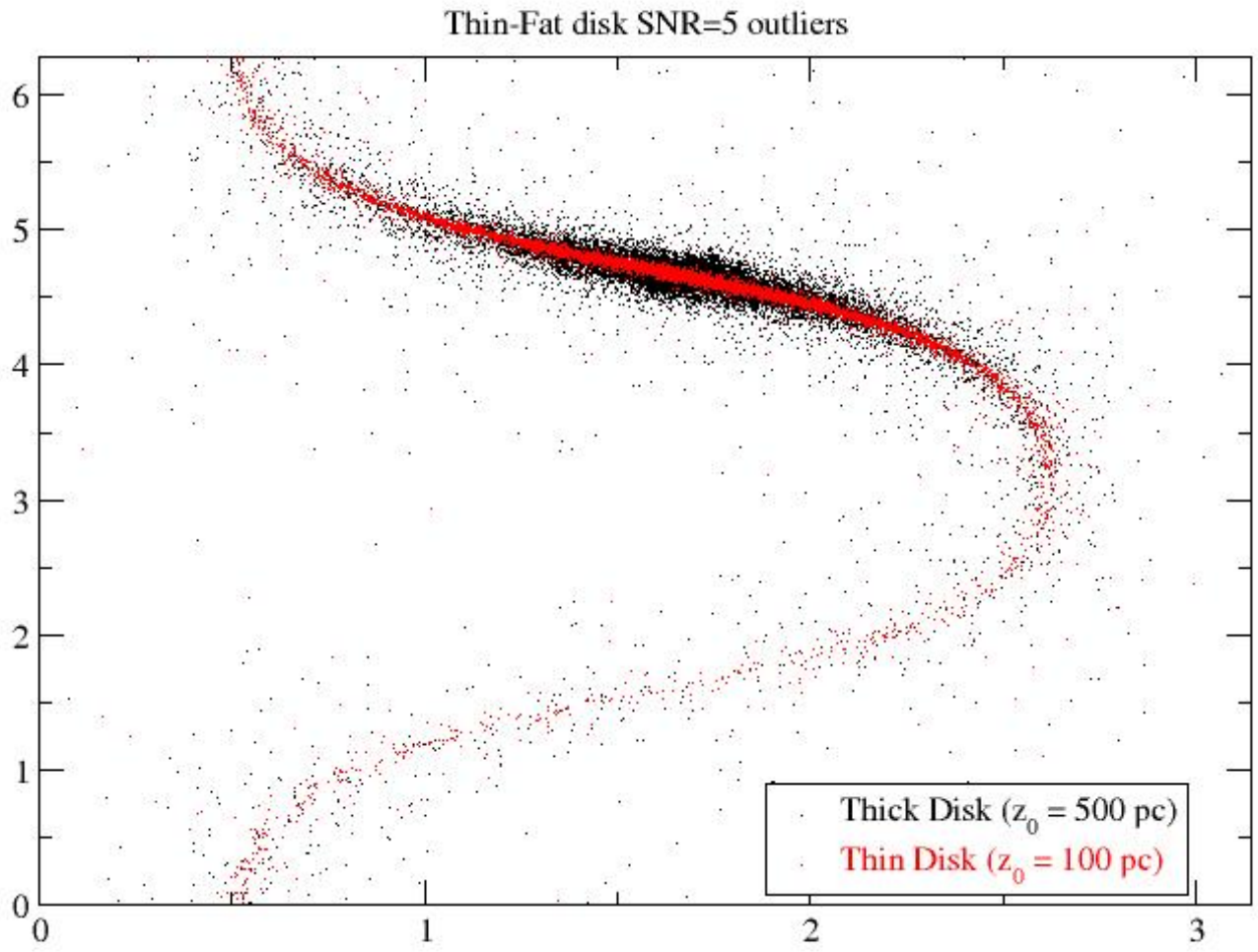
- Assume a demodulation concentrates power into one frequency bin
- Use confusion-limit + instrument as noise
- Assume SNR > 5 necessary to characterize a binary
- Assume *perfect* characterization of binary properties

Properties of Resolved Binaries

- Calculate the chirp df/dt.
- If the frequency changes by more than one frequency bin, assume that the chirp is detectable
- For observation time T, this requires: $df/dt \geq T^{-2}$
- Otherwise the binary is monochromatic

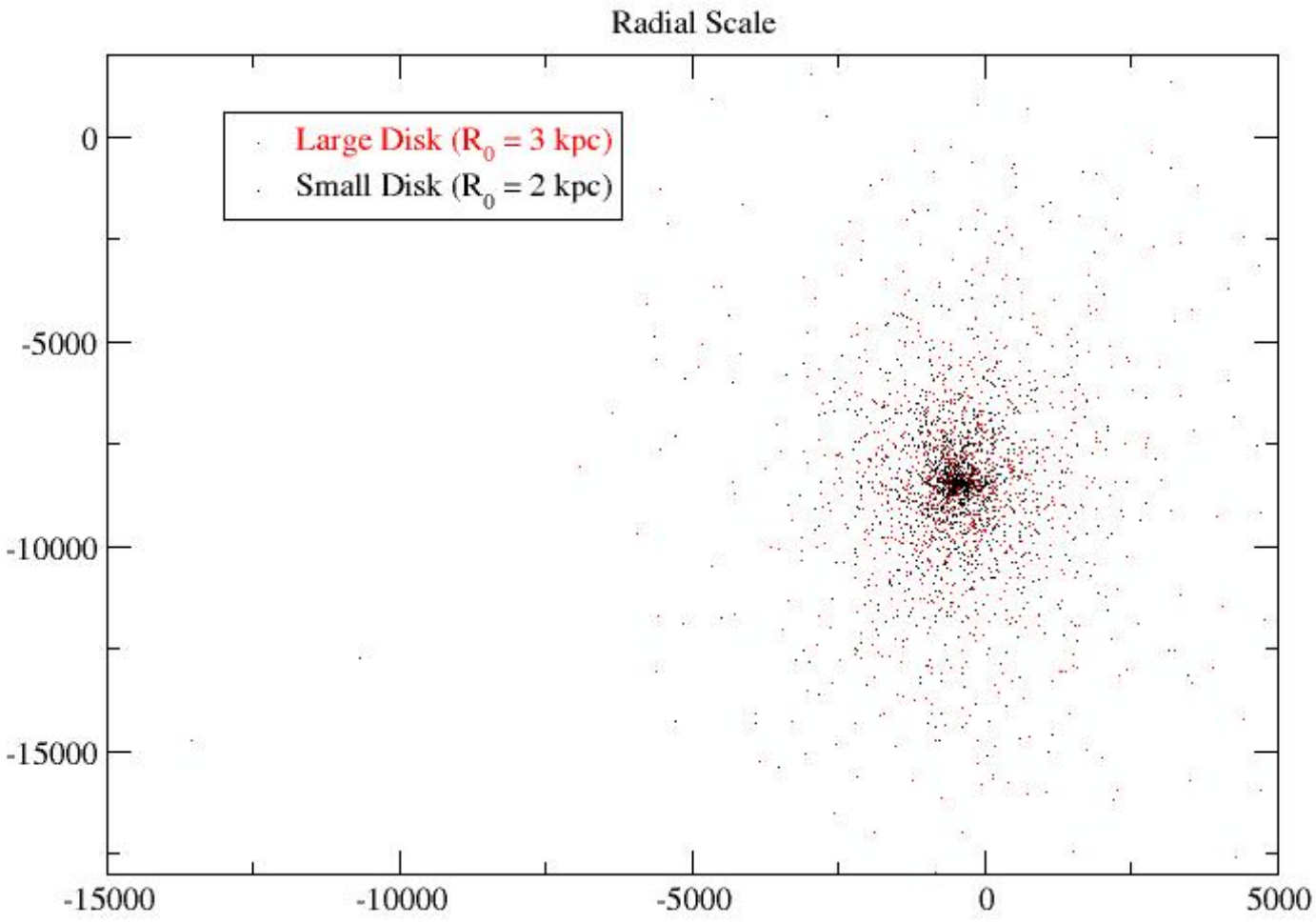
Monochromatic Binaries

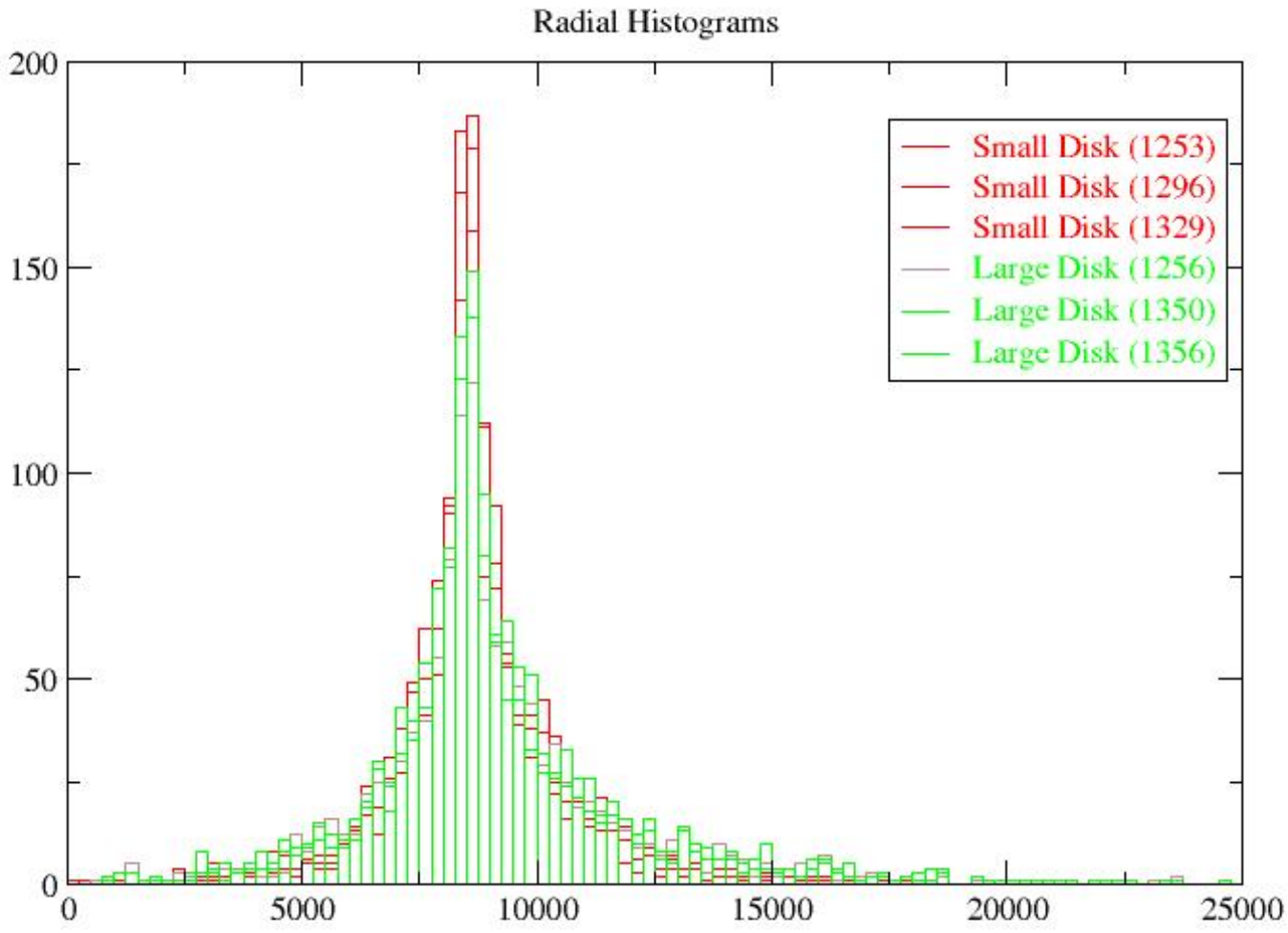
- The population of monochromatic binaries provides structural information only through sky position
- Consequently, monochromatic binaries can provide scale height information.
- ~ 25,000 resolved monochromatic binaries


Thin-Fat disk SNR=5 outliers
Thick Disk (z_0 = 500 pc)
Thin Disk (z_0 = 100 pc)
0
1
2
3
4
5
6

Chirping Binaries

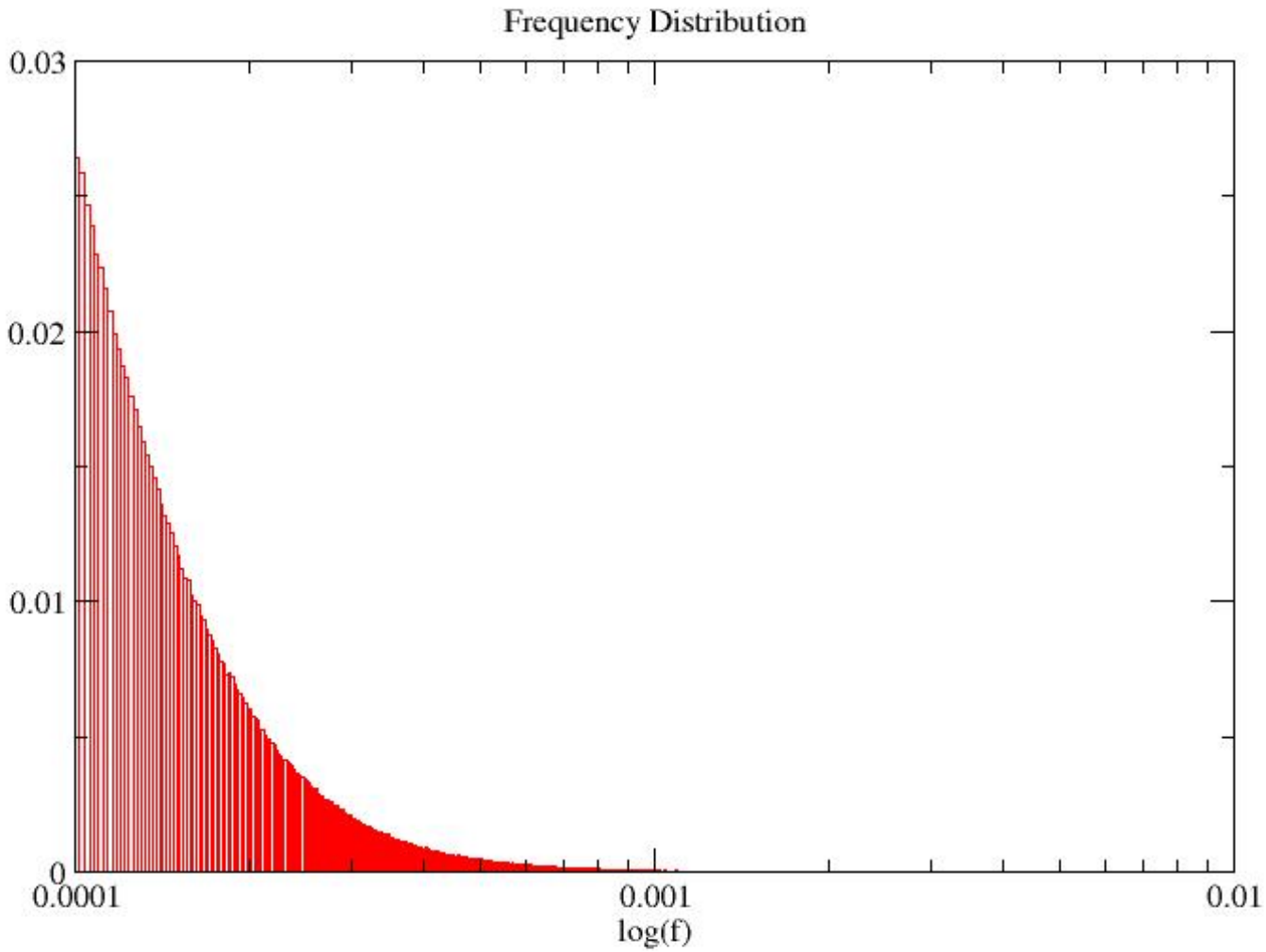
- Measurement of the chirp allows for the measurement of distance
- The population of resolved chirping binaries can be used to determine the radial scale
- ~ 1300 resolved chirping binaries

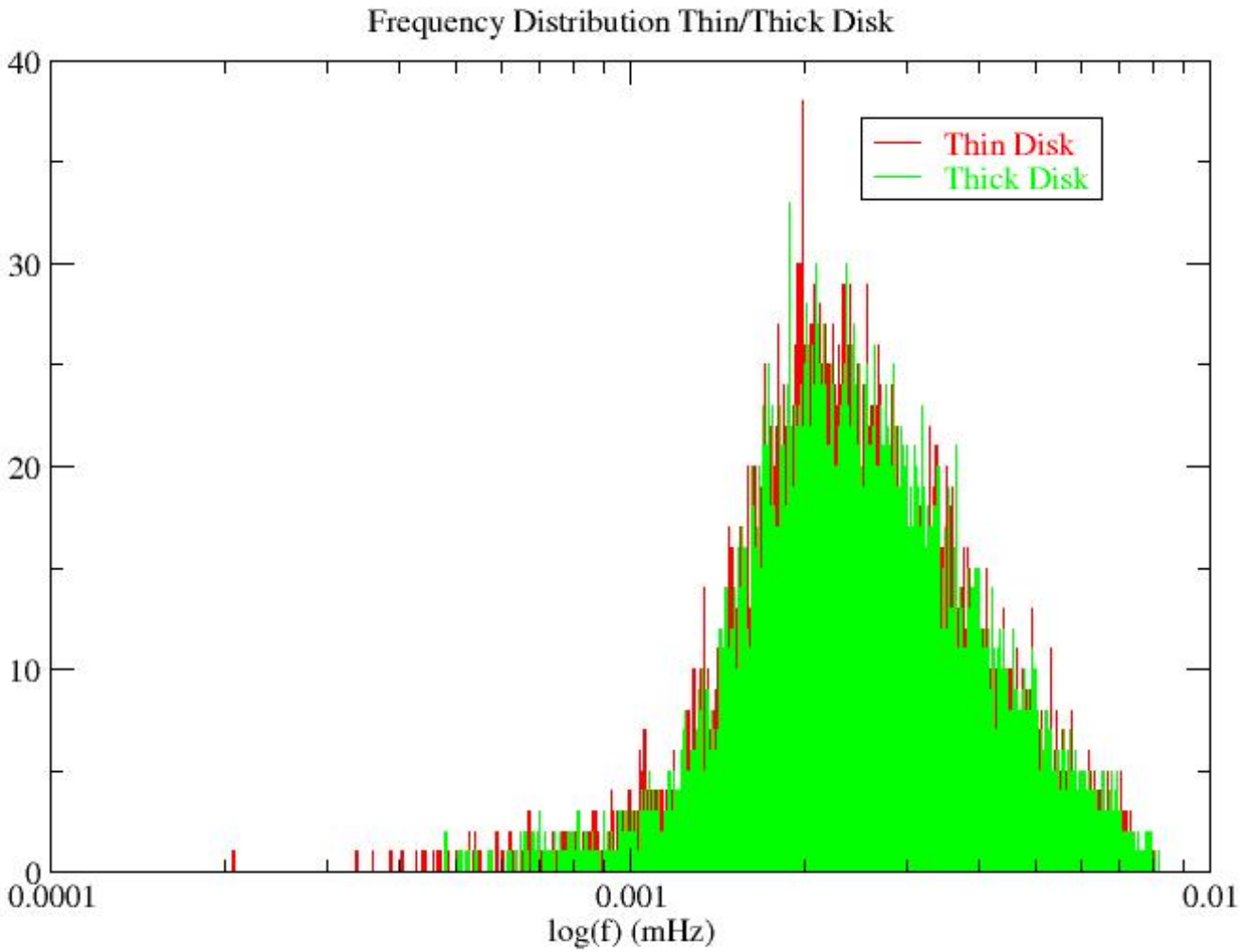

Radial Scale
Large Disk (R_0 = 3 kpc)
Small Disk (R_0 = 2 kpc)
0
-5000
-10000
-15000
-15000
-10000
-5000
0
5000

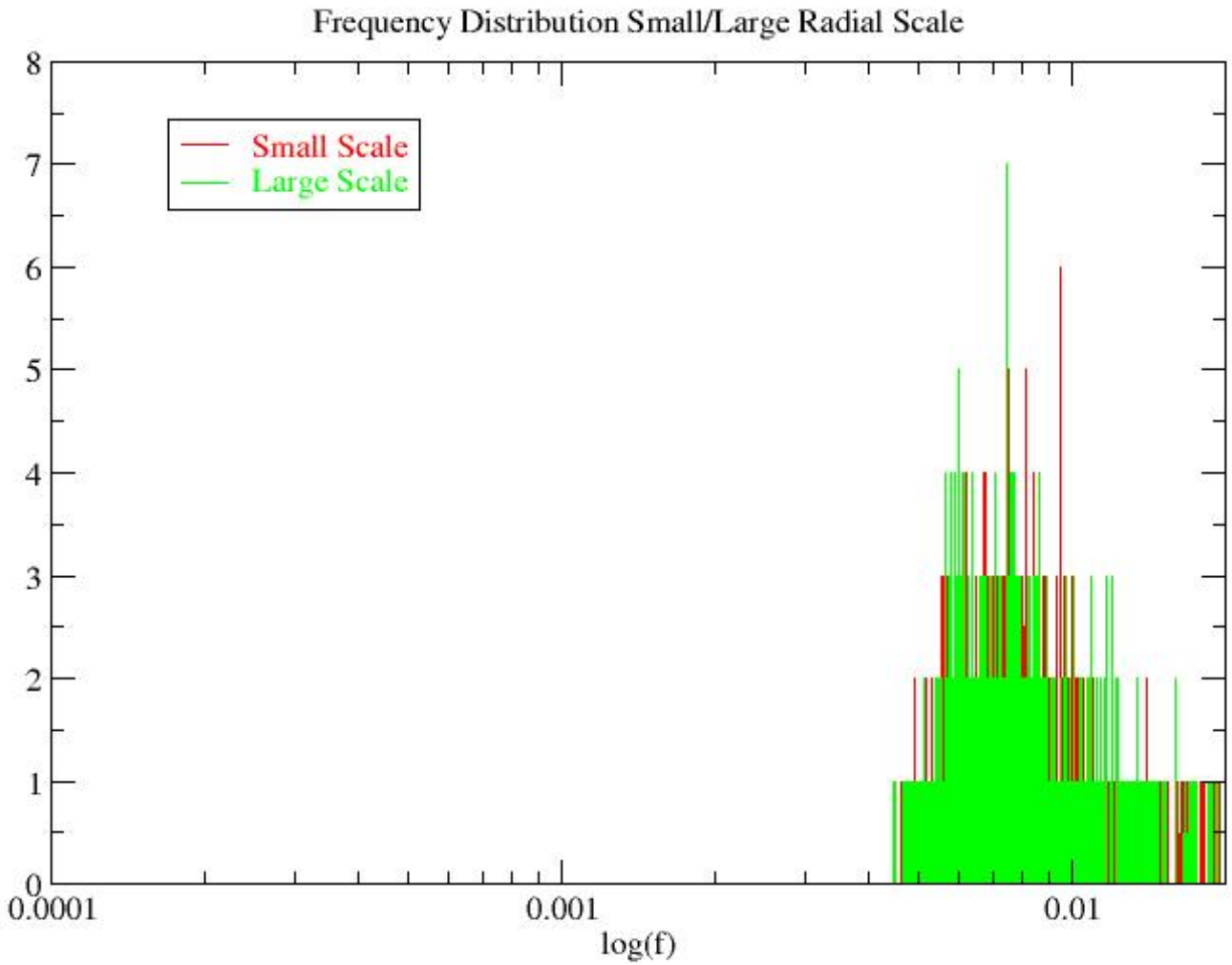

Radial Histograms
200
150
100
50
0
0
5000
10000
15000
20000
25000
Small Disk (1253)
Small Disk (1296)
Small Disk (1329)
Large Disk (1256)
Large Disk (1350)
Large Disk (1356)

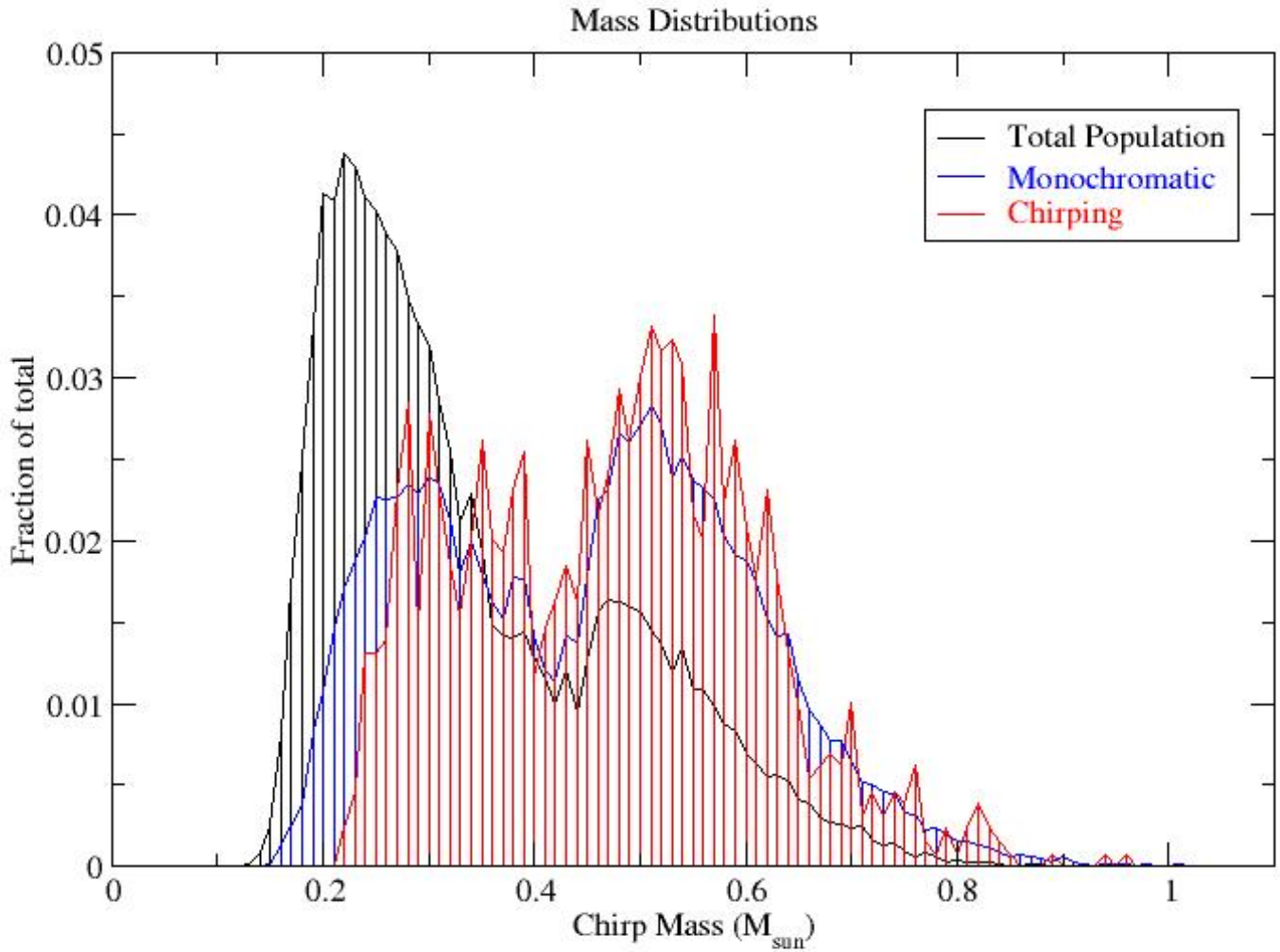
Selection Effects

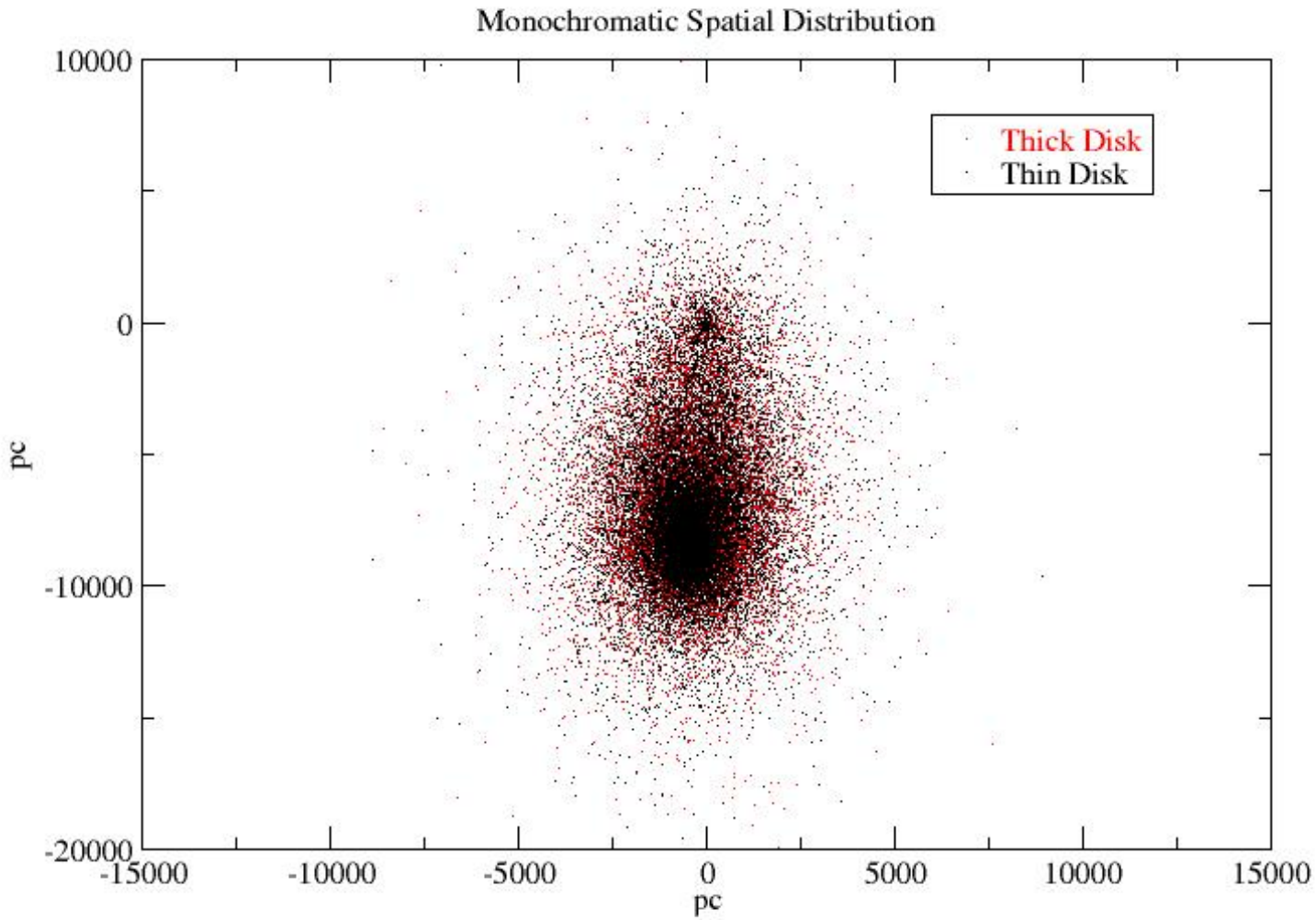
- Resolved population is not a random sampling of underlying population.
- Resolved monochromatic binaries
  - Distant binaries are the high chirp mass tail of the population
  - Nearby binaries sample a larger part of the mass distribution, but mid-frequency distribution
- Resolved chirping binaries
  - High chirp mass tail
  - High frequency distribution


Frequency Distribution
0.03
0.02
0.01
0
0.0001
0.001
0.01
log(f)


Frequency Distribution Thin/Thick Disk
Thin Disk
Thick Disk
40
30
20
10
0
0.0001
0.001
0.01
log(f) (mHz)


Frequency Distribution Small/Large Radial Scale
Small Scale
Large Scale
8
7
6
5
4
3
2
1
0
0.0001
0.001
0.01
log(f)


Mass Distributions
Total Population
Monochromatic
Chirping
Fraction of total
Chirp Mass (M_{sun})
0.05
0.04
0.03
0.02
0.01
0
0
0.2
0.4
0.6
0.8
1


Monochromatic Spatial Distribution
Thick Disk
Thin Disk
10000
0
-10000
-20000
pc
-15000
-10000
-5000
0
5000
10000
15000
pc

Conclusions

- Galactic structure and binary evolution can be constrained by the resolved population of white dwarf binaries
- Selection effects on resolved binaries explore massive, high frequency end of the population
- Need work on data analysis techniques to determine actual capabilities

Data Analysis Websites

- Testbed for LISA Analysis (TLA)
  - http://tla.gravity.psu.edu/index.shtml
- Mock LISA Data Challenge (MLDC)
  - http://www.tapir.caltech.edu/dokuwiki/listwg1b:home
- Task group on Galactic Binaries
  - http://www.tapir.caltech.edu/dokuwiki/listwg1a:home