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Probing the Milky Way with LISA: Extracting astrophysics from the compact binary population

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PROBING THE MILKY WAY WITH LISA:

Extracting astrophysics from the compact binary population

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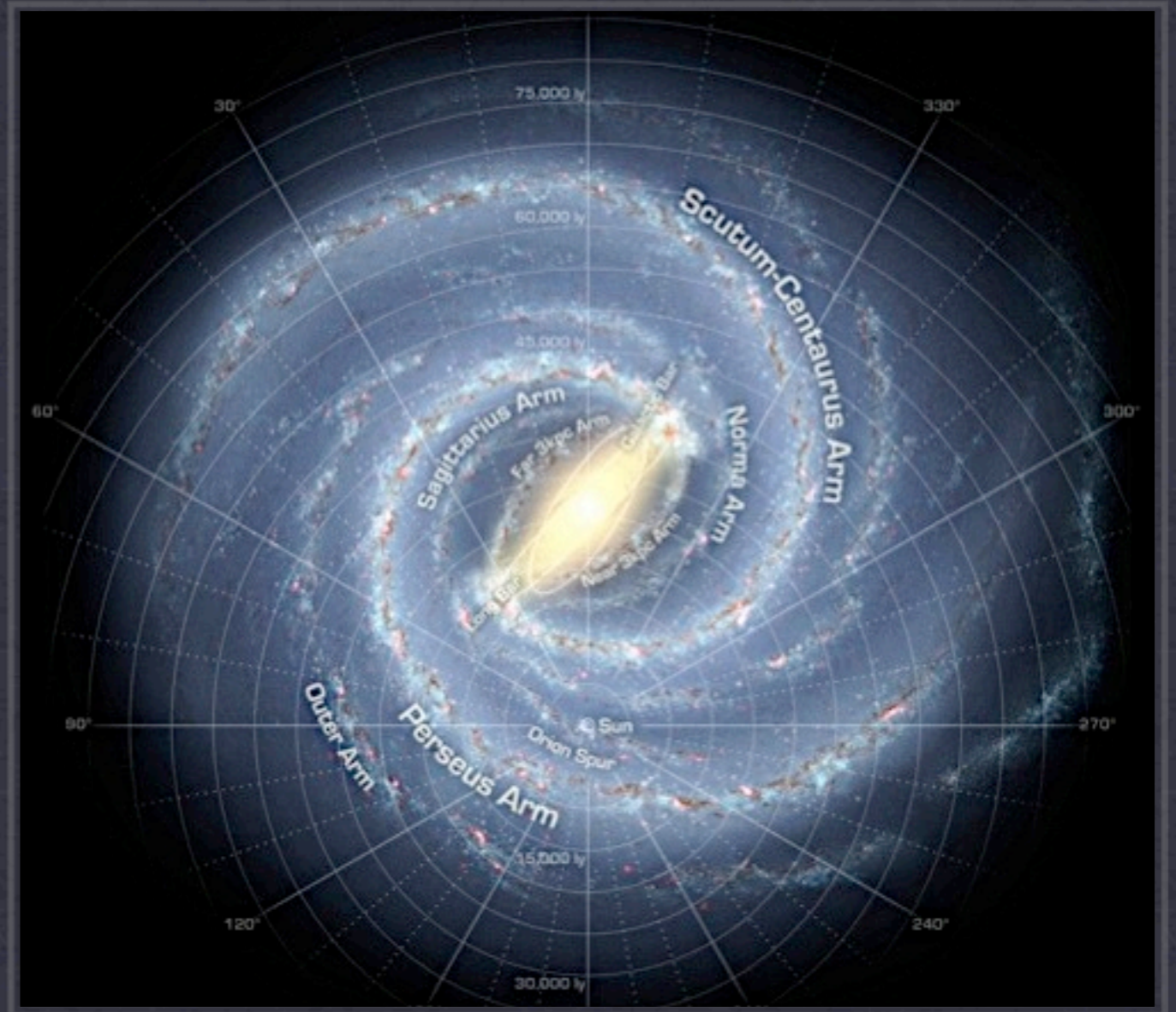
Gravity Seminar
Washington State University
7 February 2011

Storyline

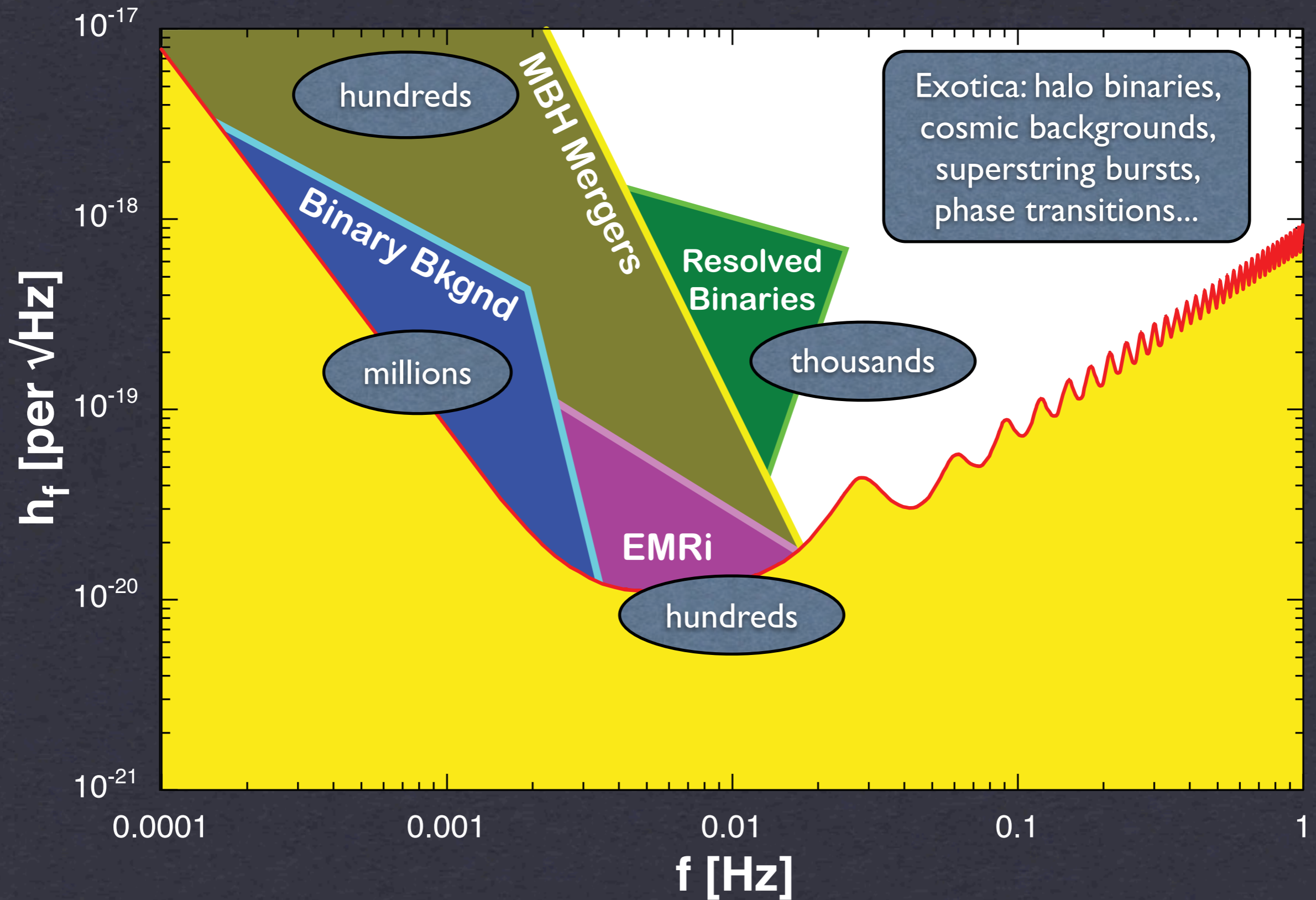
- Some info about the Milky Way
- Some info about the Ultracompact Binaries
- Vignettes
 - Mass-Transferring Binaries (Ruiter et al. [2010])
 - The Shape of the Galaxy (in progress)

The Milky Way

- SBc barred spiral galaxy
 - Diameter: 100,000 lightyears
 - Mass: $7.0 \times 10^{11} M_{\odot}$
 - Number of stars: ~200 billion
- **10-80 million ultracompact binaries in LISA band**



The LISA Discovery Space



LARSON, HISCOCK & HELTINGS (2000)

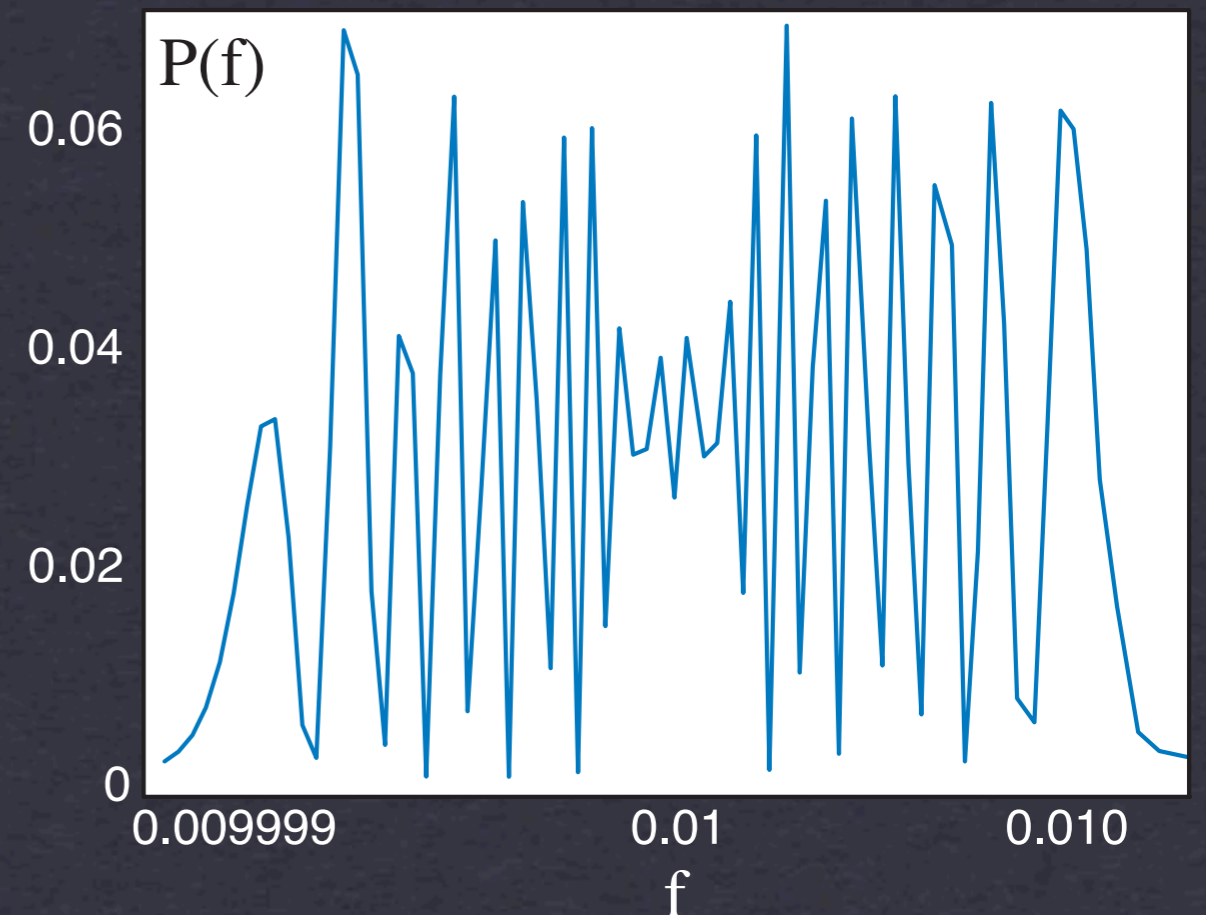
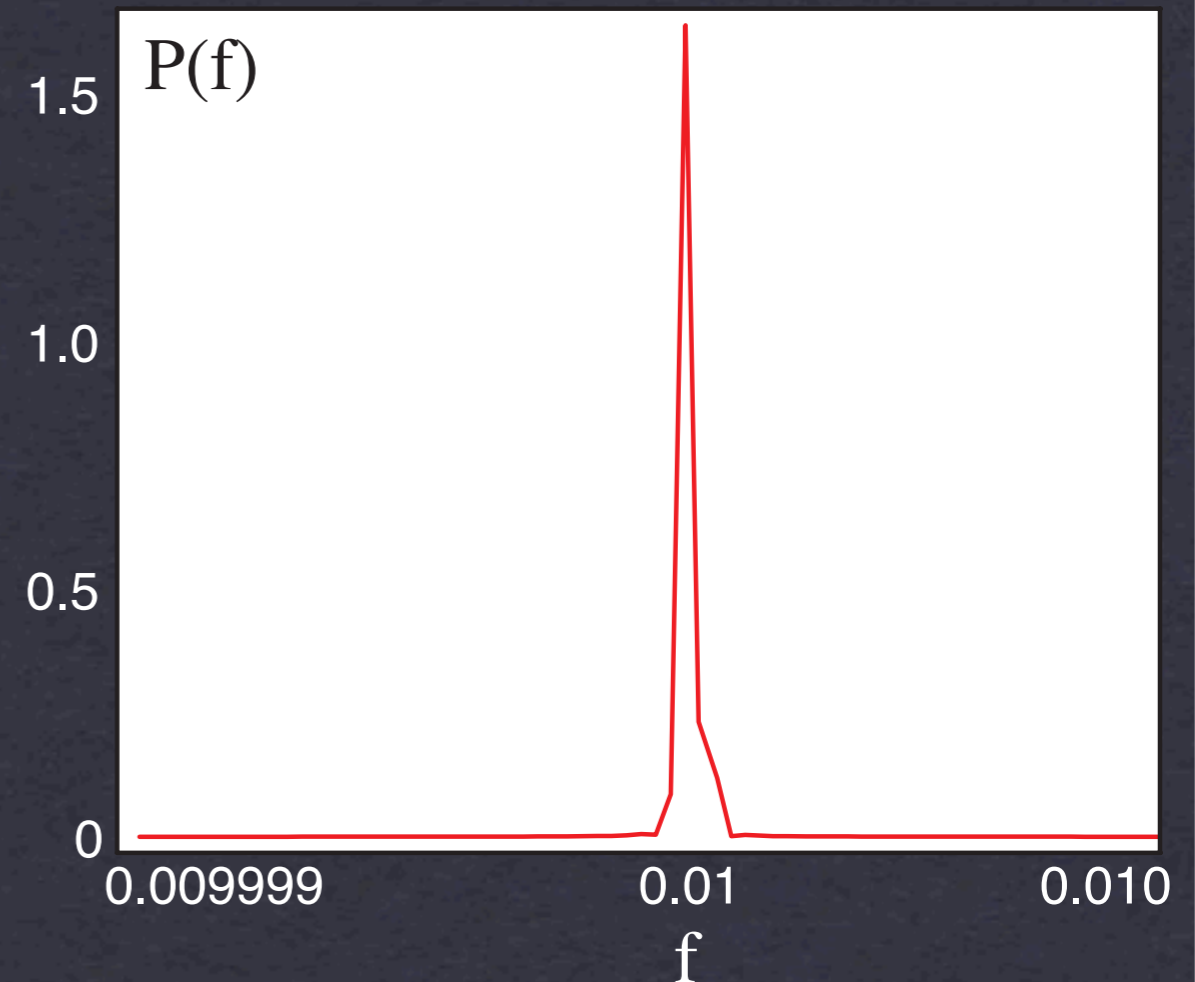
The Close Binaries

- There are so many binaries, their signals overlap, and it is difficult to tell them apart
- This is called the “**confusion limit**”, and is analogous to a cocktail party
 - You can hear people **nearby**
 - You can hear **loud people**
 - All else is a **dull noise**



The Close Binaries

- Most of the close binaries are **monochromatic** over a LISA observation time
 - The power is gathered in single lines in the power spectrum
- The signals are **modulated by LISA's motion** (that's how we point)
 - Spreads the signal power over many bins in frequency
 - In order to be **separable**, the binary central frequencies must be separated by “several” bins
 - “3 bin rule”



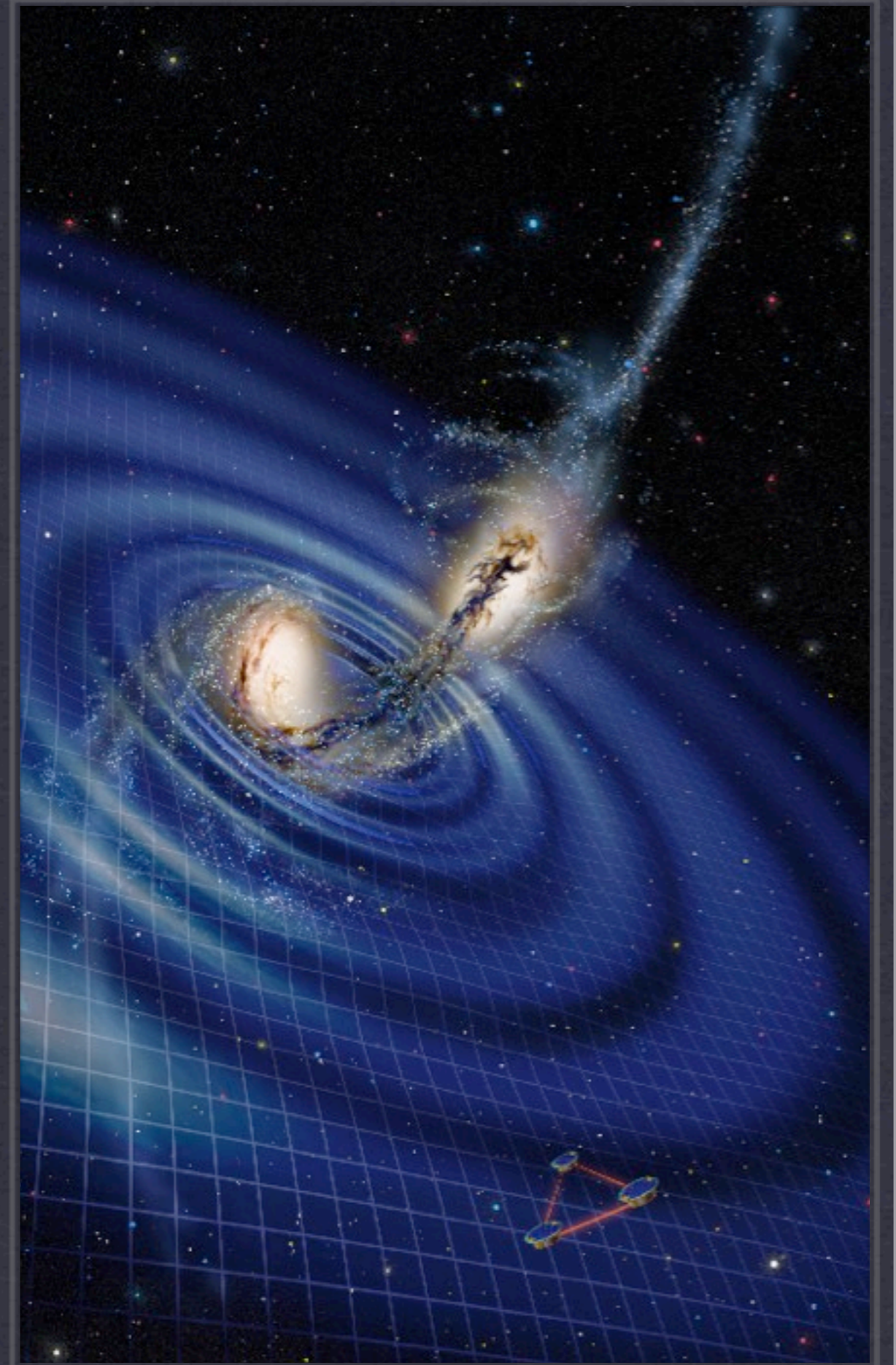
The Close Binaries

- There are so many binaries, their signals overlap, and it is difficult to tell them apart
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 - You can hear people **nearby**
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- ~10,000 binaries will be **separable** from the confusion (depends on method)
- A subset of the 10,000 will be **visible in telescopes** (some are already known)



Perspectives...

- The binaries are generally viewed from two common perspectives:
 - The nearby known resolvable binaries are strong and will be visible almost immediately
 - **VERIFICATION BINARIES**
- The sum of the galactic close binaries are an irreducible astrophysical foreground that impedes other LISA observations
- **CONFUSION FOREGROUND**

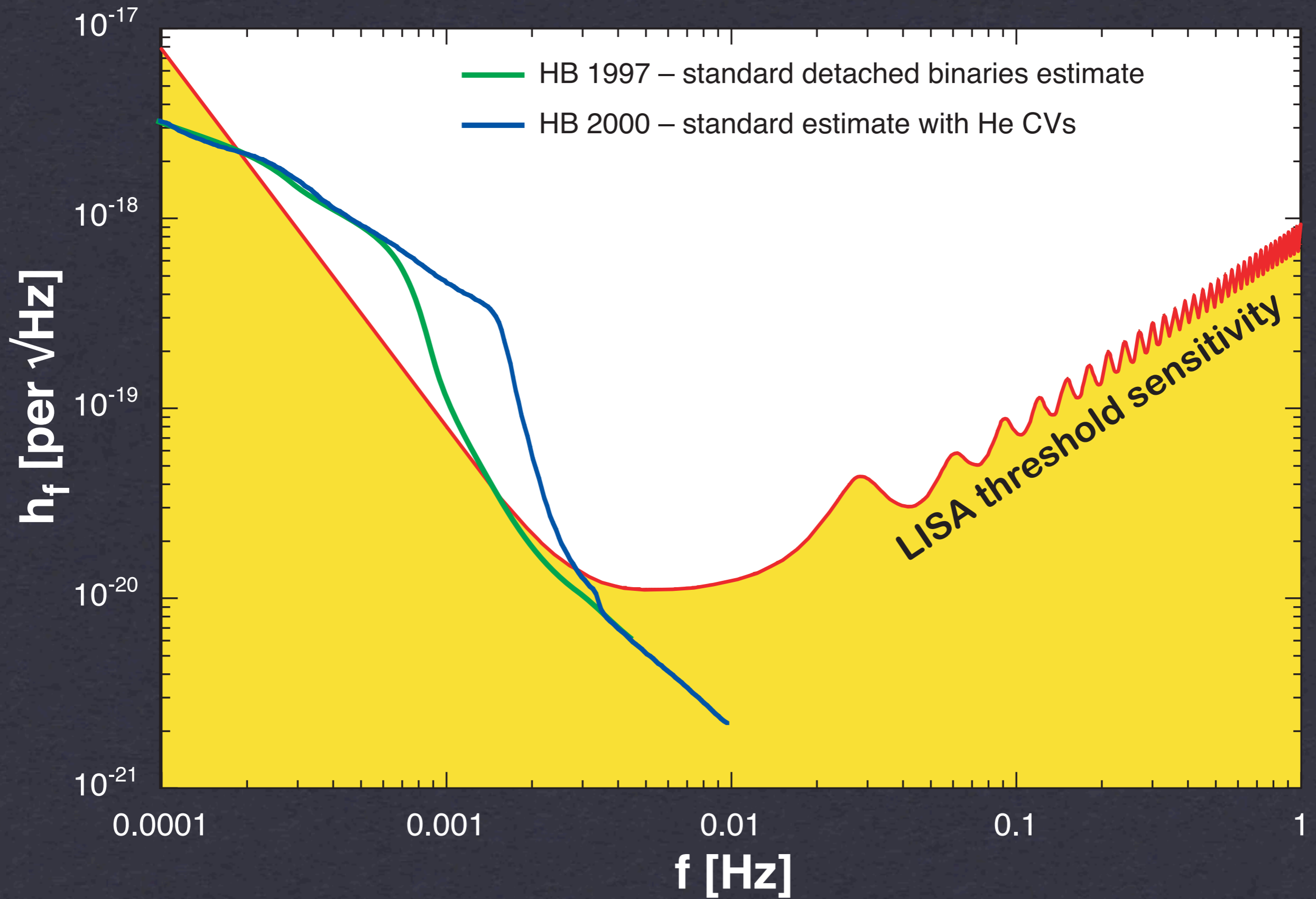


Questions to ask...

- The binaries are the single largest population of sources LISA will see
- What can we learn from and about the binaries?
 - Don't ask questions about **data analysis** and extracting signals
 - Ask what information is encoded in the extracted information (**science analysis**)
- What do the binaries tell us about binary evolution?
- What do the binaries tell us about the Milky Way?



Irreducible Astrophysical Foreground



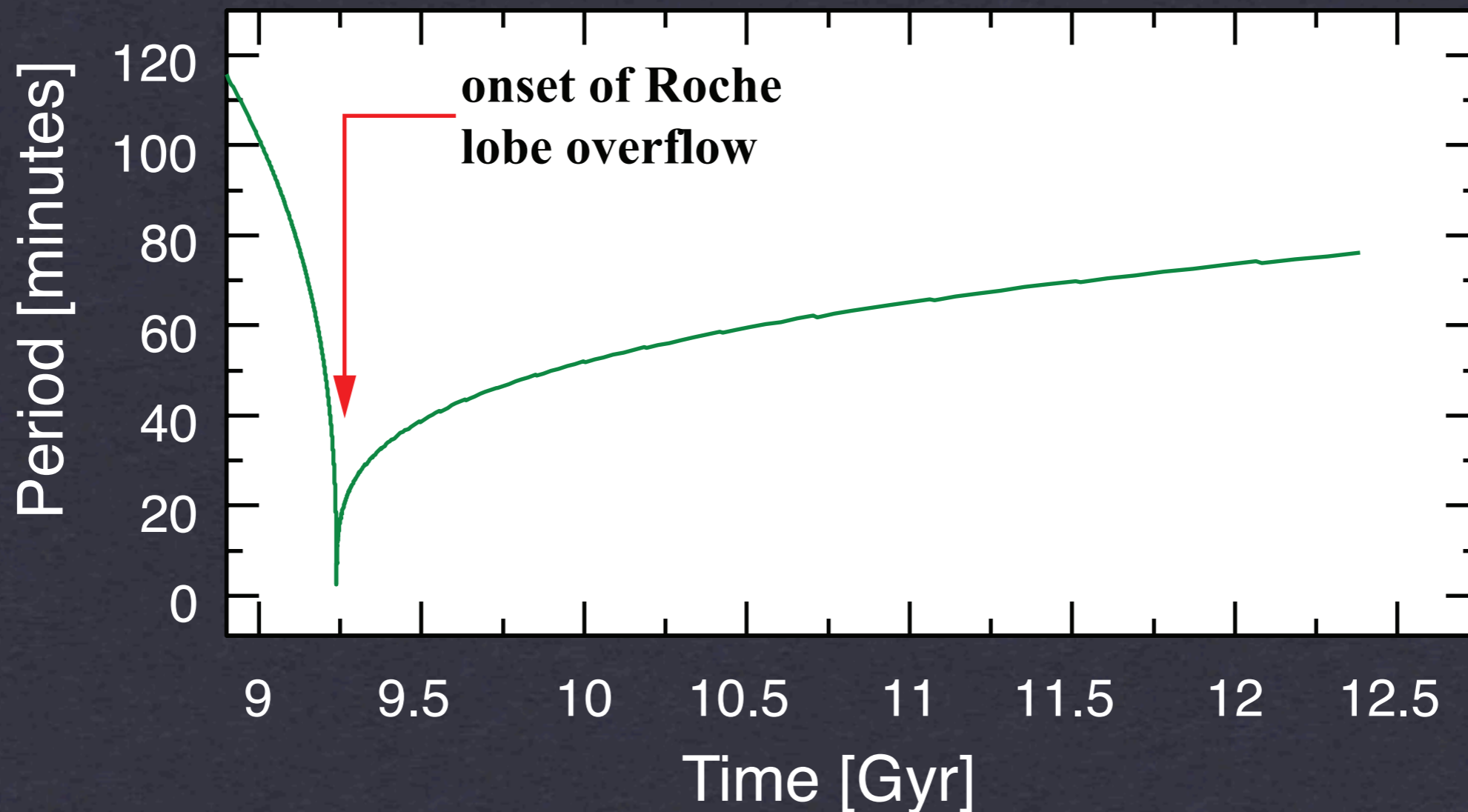
Population Synthesis

- Our knowledge of GW binaries is limited to those close by that can be seen by (lame) photon telescopes
- ~40 known, ~6 well studied
- Randomly generate **initial populations** of stars and **evolve them in time**
- Track mass transfer, period evolution, gravitational wave emission, tidal effects
- Result: population of stars we use to compute the gravitational wave signal from the entire galaxy



Binary Evolution

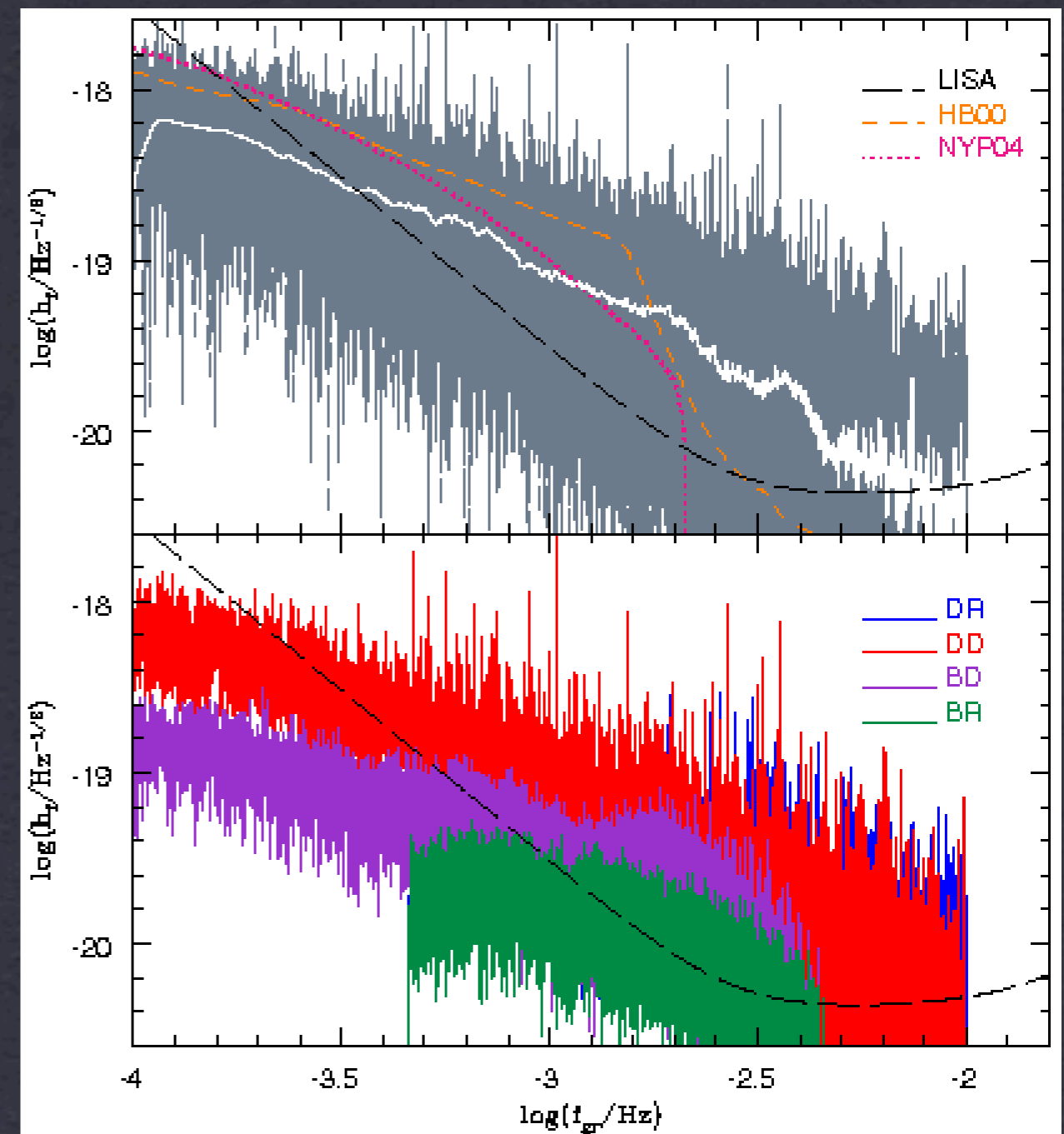
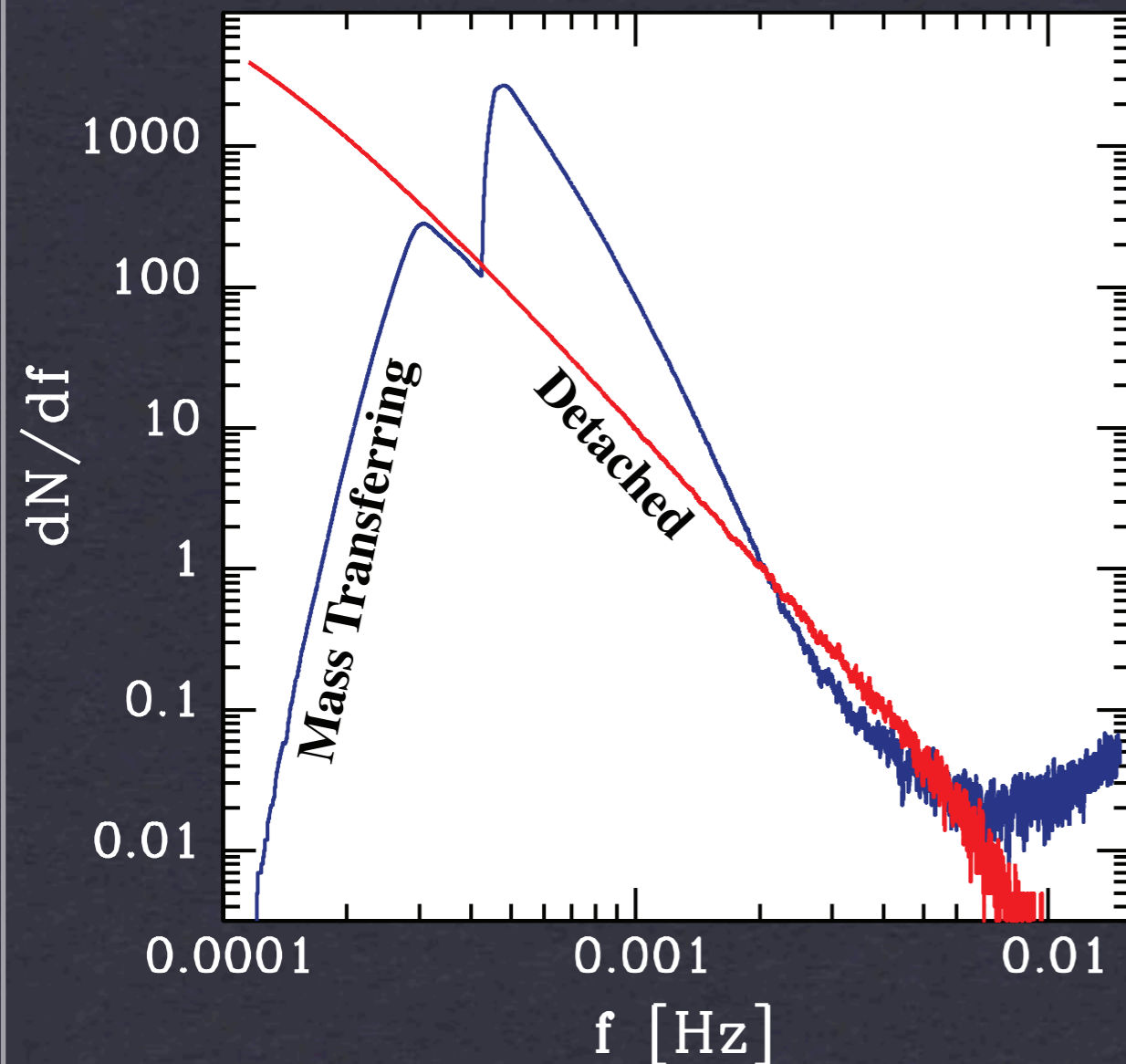
- Standard estimates of the background only include **detached binaries**
- Mass transfer has significant effect on period evolution
- At any given period, there are **two distinct populations** of binaries contributing to the overall gravitational wave signal



Mass transferring binaries

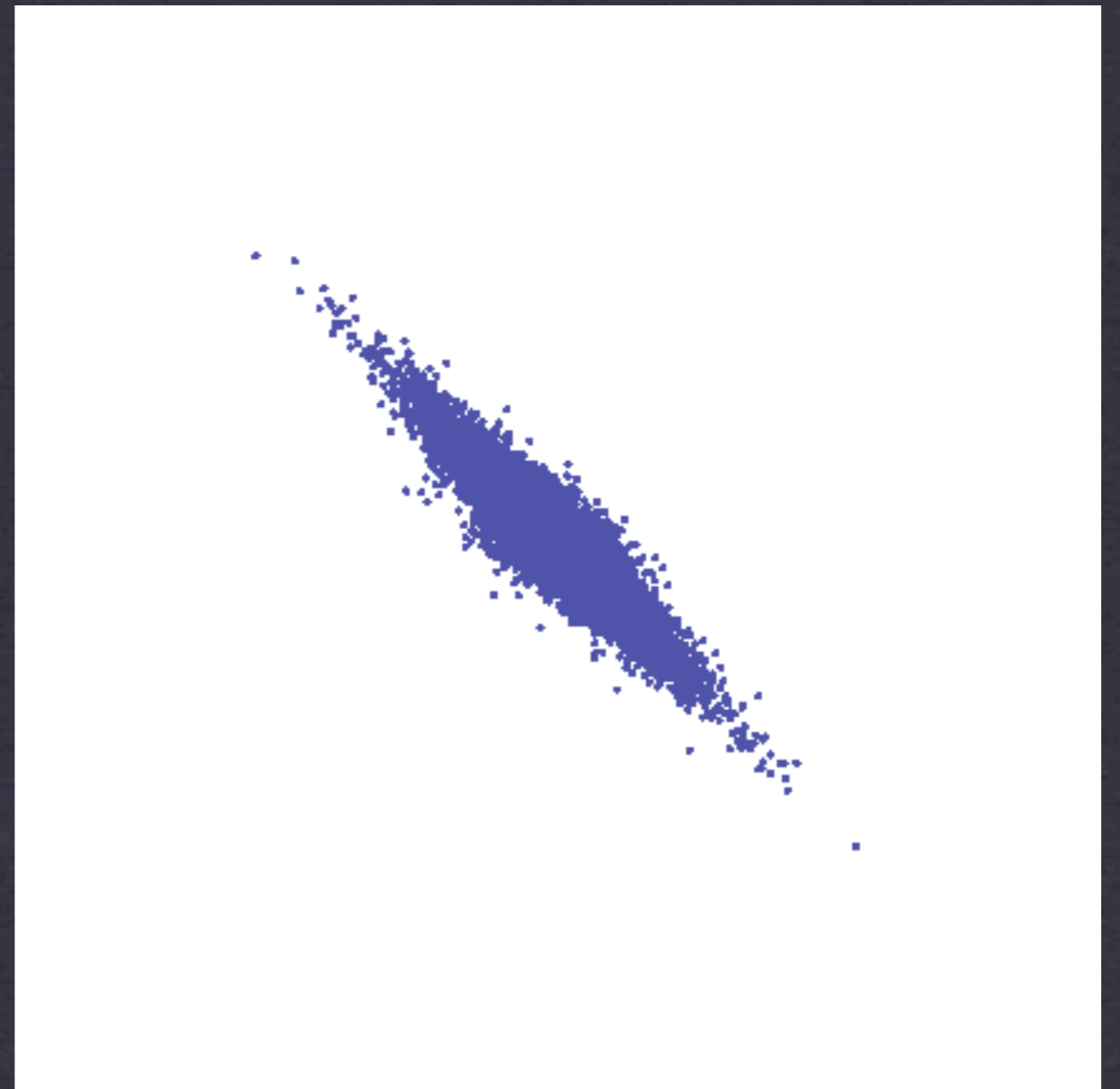
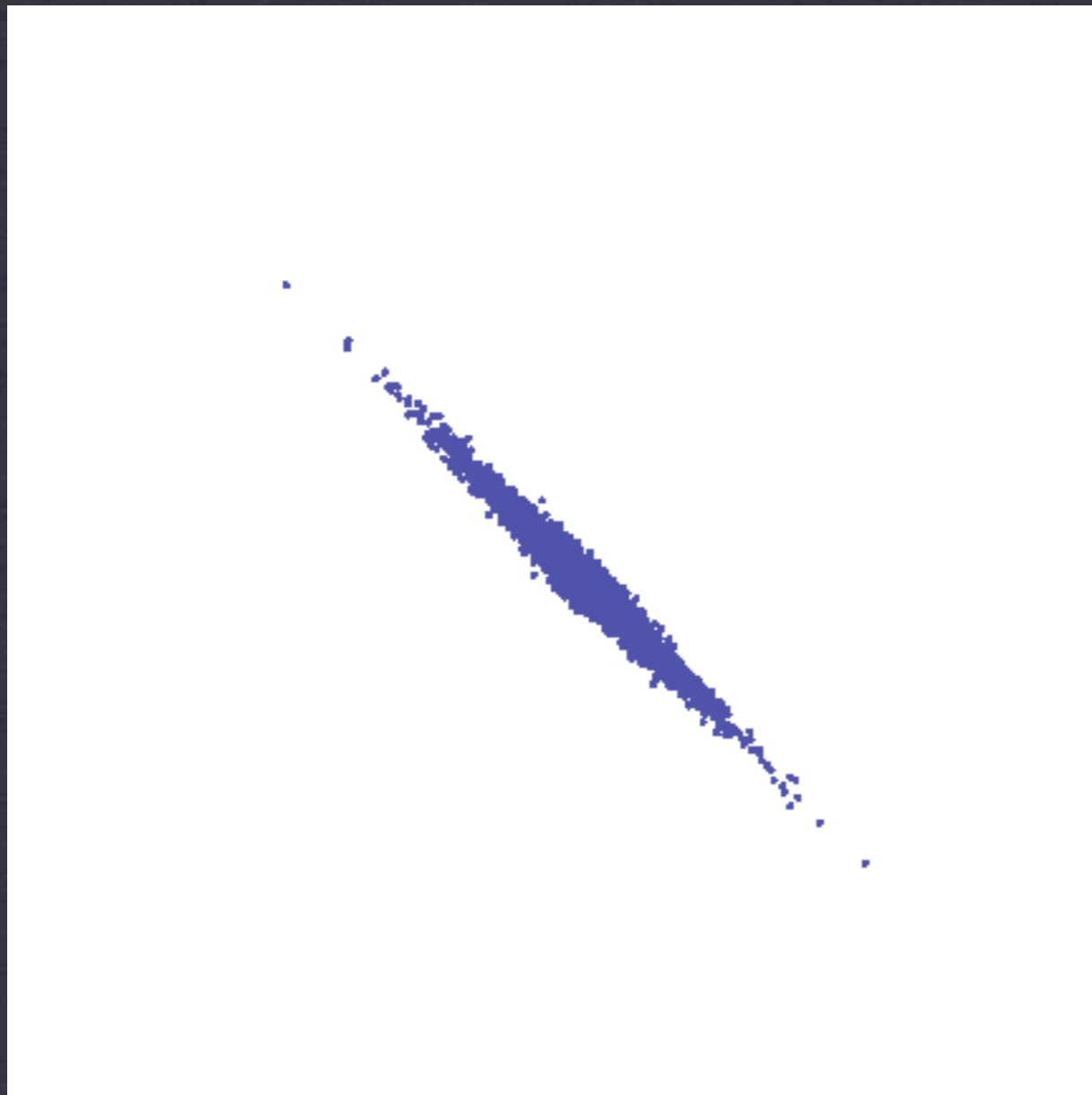
RBBLW [2010]

- The confusion limit extends higher than the standard limit
 - Detached binaries: **$f_c \leq 3$ mHz**
 - RLOF binaries: **$f_c \leq 6$ mHz**

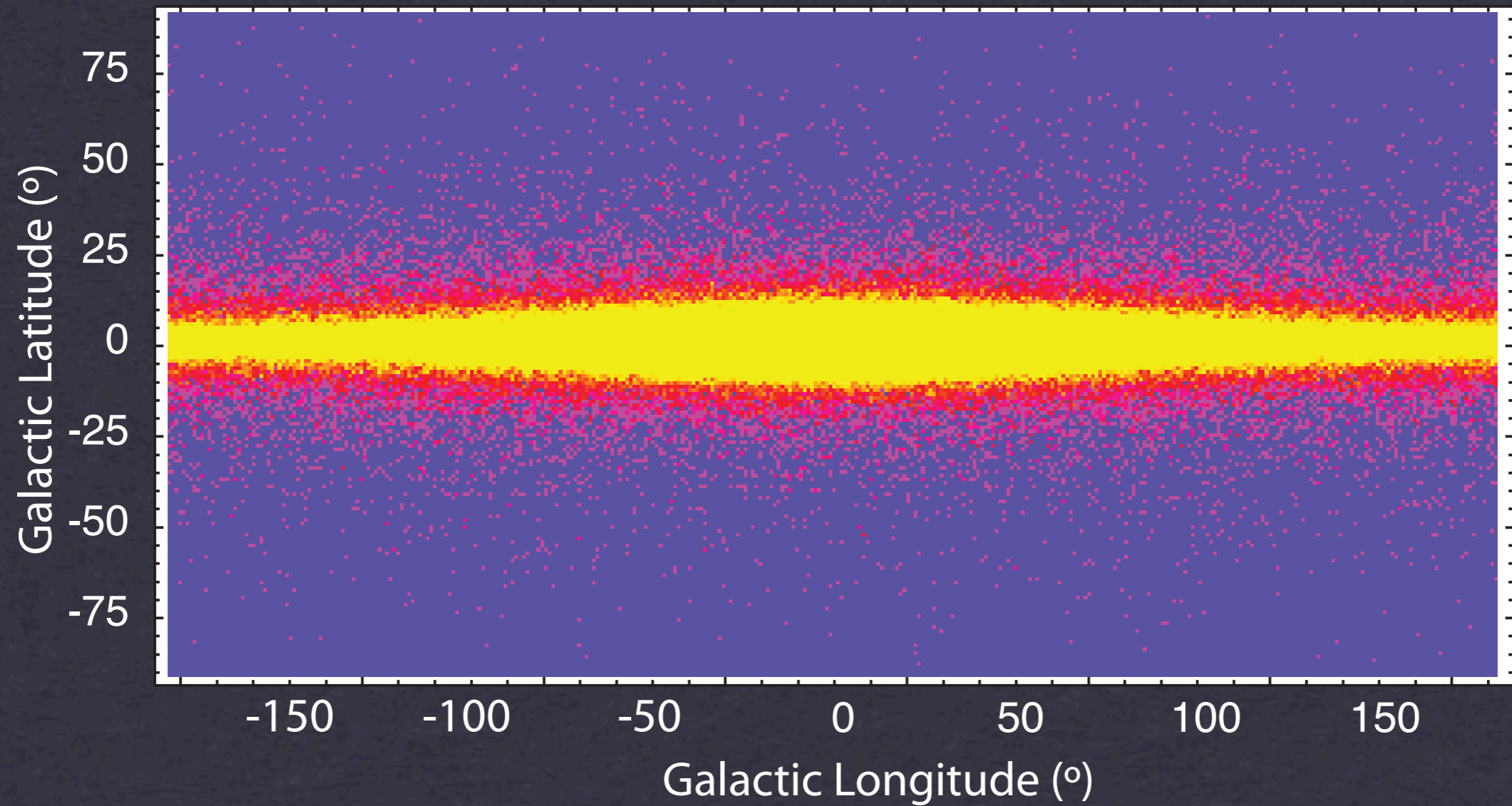


Galactic Distribution

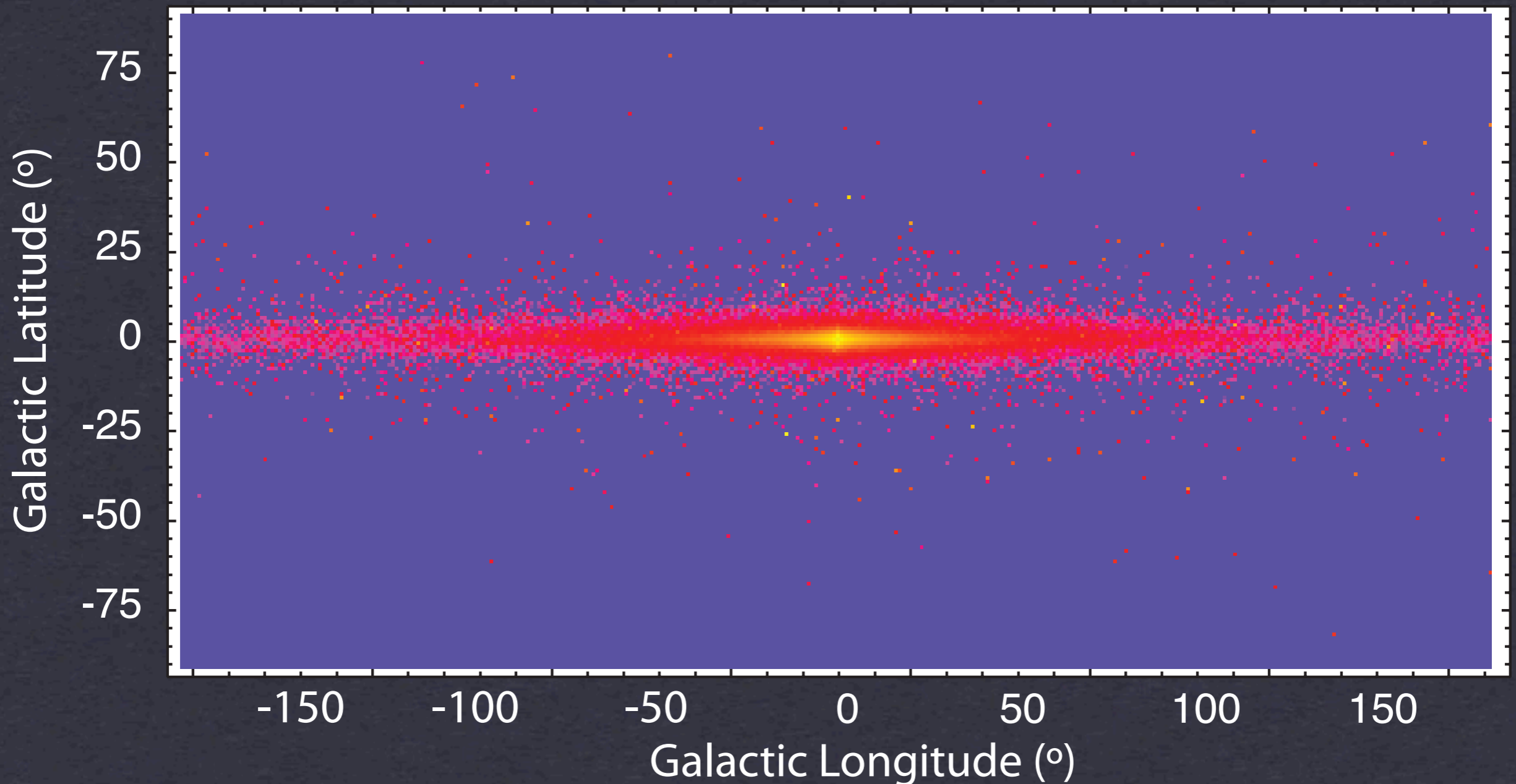
- In addition to distributing the astrophysical parameters of the binaries, we have to also place them spatially in the galaxy
- The parameters that describe the shape of the galaxy are unknown because we can't see through the entire galaxy



The Low Frequency Galaxy



The Resolvable Galaxy



- Resolvable binaries can be separated from the background, and retain information about the distribution of systems on the sky (**2D information**)

Chirping Binaries

- Of the 10,000 resolvable binaries, a couple of thousand will be chirping

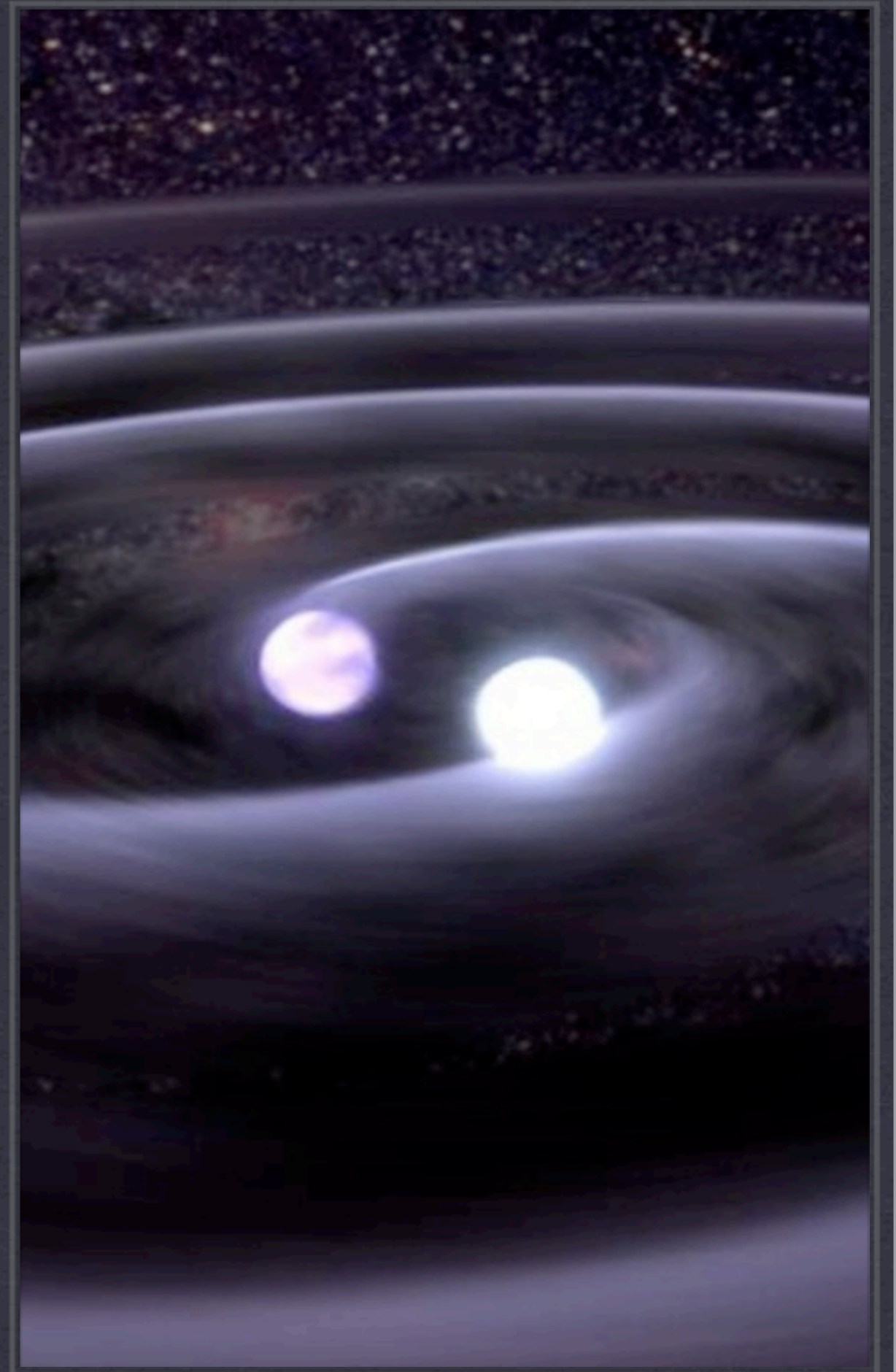
$$h = \frac{\mathcal{M}_c}{D} (\pi f \mathcal{M}_c)^{2/3}$$

$$\dot{f} = \frac{96}{5} \frac{f}{\mathcal{M}_c} (\pi f \mathcal{M}_c)^{8/3}$$



$$D = \frac{5}{96\pi^2} \frac{1}{h} \frac{\dot{f}}{f^3}$$

- 3D information!



Work in Progress: KDE and Shape Recovery

- Can LISA determine the radial and vertical scale height of the galaxy?

$$\rho(\mathbf{r}) \propto e^{-R/R_0} \operatorname{sech}^2(z/z_0)$$

- **Simulate different models of the galaxy**, look at the chirping binaries
- Heuristically: histogram the 3D distributions, look for scale heights
- Histograms depend on choice of bin width, so use **Kernel Density Estimation**



Galactic Models: Parameter variation

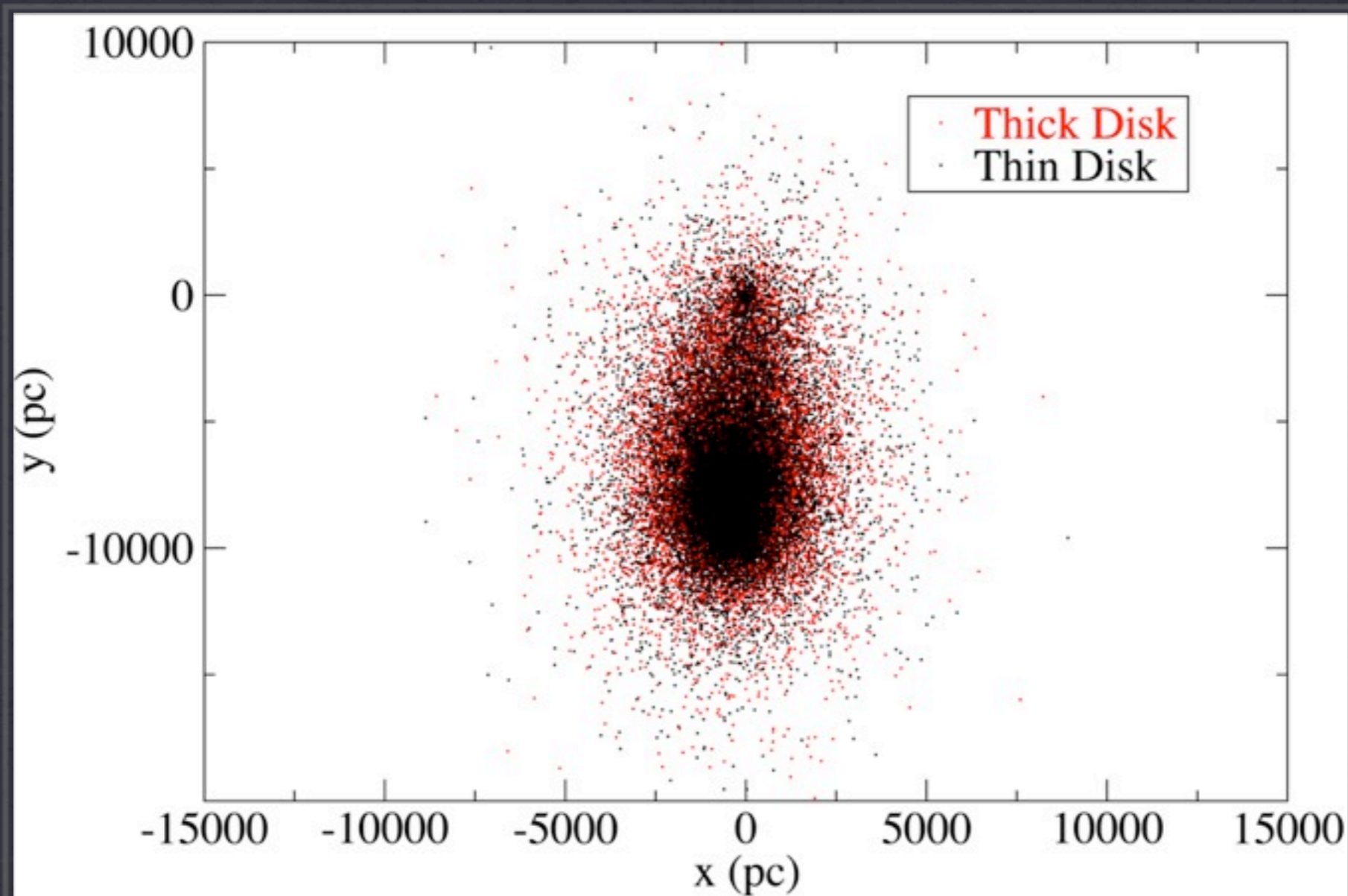
$$\rho(\mathbf{r}) \propto e^{-R/R_0} \operatorname{sech}^2(z/z_0)$$

N^*	r_0 (kpc)	z_0 (pc)
30 MB	2.0	200
30 MB	2.5	100
30 MB	2.5	200
30 MB	2.5	300
30 MB	2.5	500
75 MB	2.5	500
30 MB	3.0	200

- Even though spatial parameters might be the same, other parameters (like local space density) drastically affect the total number of systems

Work in Progress: Beware of dangers...

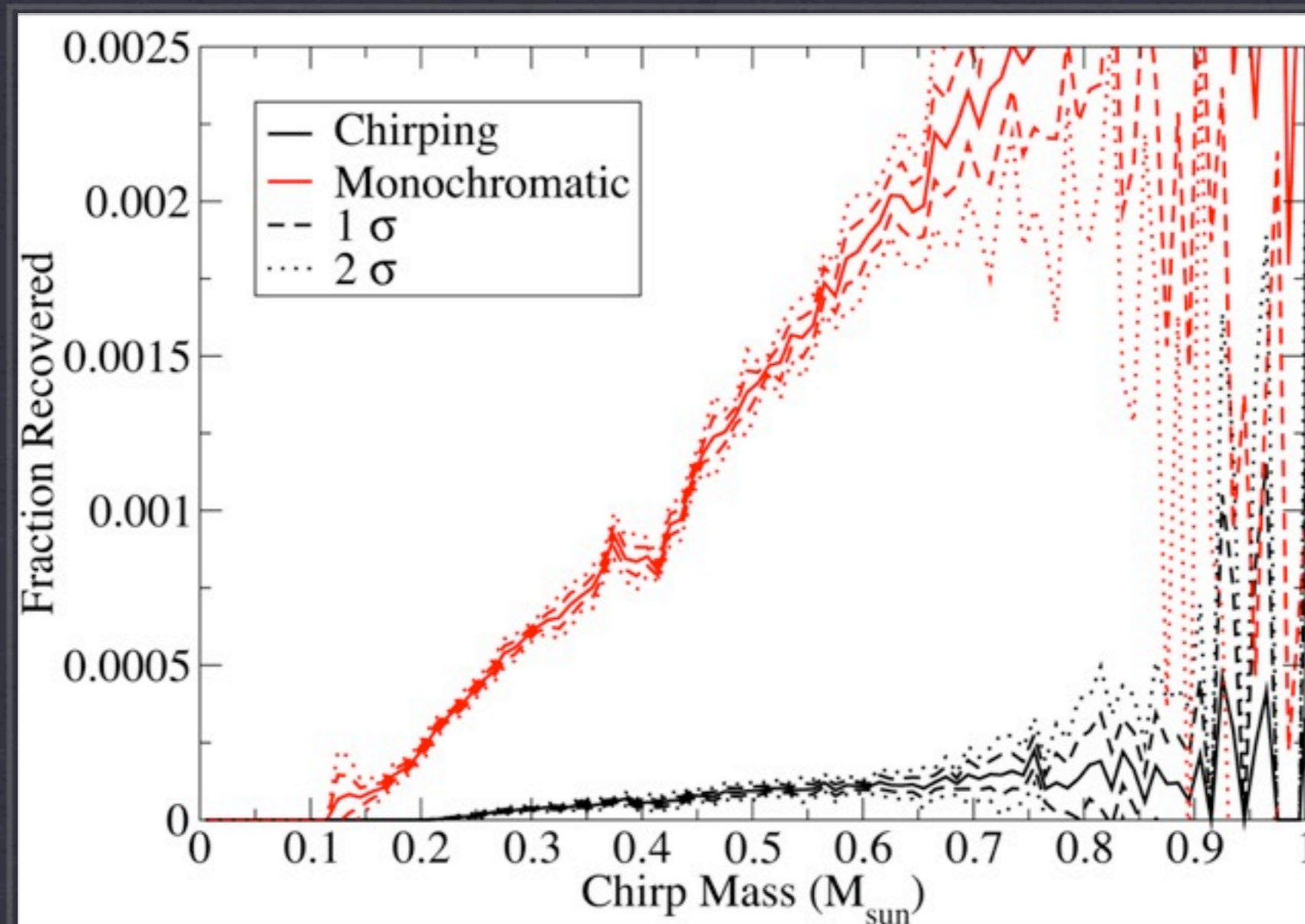
- Care must be taken interpreting the distribution of detected binaries:
bias toward nearby sources
- The total number of sources is dominated by the galactic bulge
 - The local overdensity (sample bias) is axially aligned with the bulge



BENACQUISTA,
LARSON,
TAYLOR
[2007]

Work in Progress: Beware of dangers...

- Care must be taken interpreting the distribution of detected binaries: **bias toward higher chirp masses**
- The total number of sources is dominated by the low mass binaries, but we recover high fractions of high mass binaries



Work in Progress: Beware of dangers...

- Care must be taken interpreting the distribution of detected binaries: **bias toward higher frequencies**
- The source recovery is best above the confusion limit; it is unknown how the higher frequency binaries track with the rest of the population

