# Music of the Spheres: the gravitational wave signal from exoplanets

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## Abstract

We focus on a class of sources that has been largely ignored in the science case for the Laser Interferometer Space Antenna (LISA), a joint ESA/NASA space-based gravitational wave mission set to launch in 2034: stellar-exoplanet systems. These systems are a billion times closer, if much less massive, than say supermassive black holes, making exoplanets a potentially observable source class. With typical orbital periods of decades, most exoplanets would emit gravitational radiation at much lower frequencies than the current design of LISA. However, exoplanet surveys have unveiled a surprisingly rich variety of systems, from highly eccentric orbits to hot Jupiters to pulsar planets. Here, we investigate the gravitational wave signal from known exoplanets and predict the total signature of exoplanetary systems in the Milky Way.

## Motivating Question

How weak are exoplanets in gravitational waves? If very weak individually, there are so many, and so close to us, will LISA see this as background?

## Theory - GWs from Binaries

Masses in orbit exhibit a time-changing mass quadrupole moment and therefore emit GWs (Peters and Mathews, Maggiore). Averaged over a full orbit, they define the function

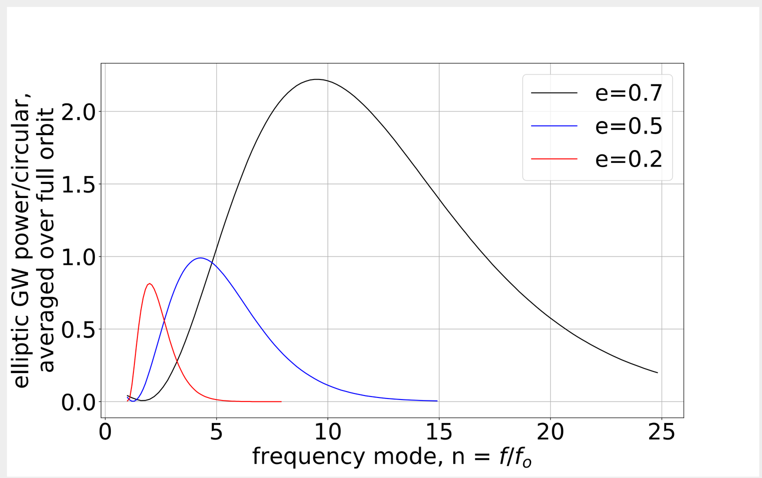
*g(n,e)* = GW Power at $f=n*f_o$ / GW Power Equiv. Circ. orbit at $f=2f_o$

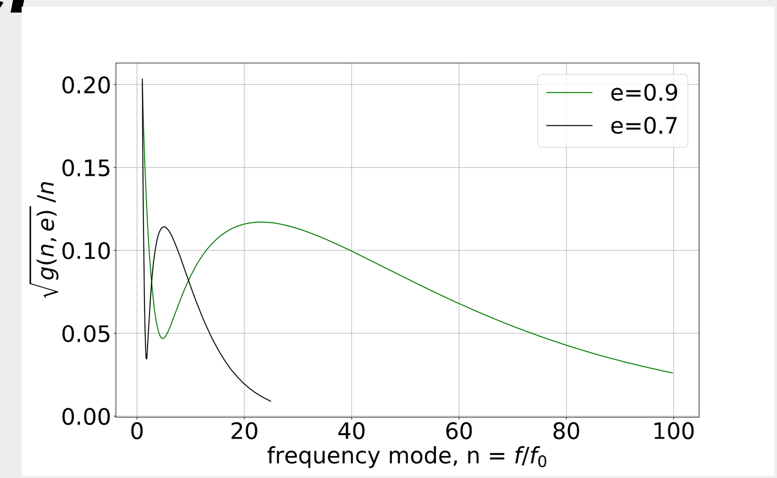
And following Amaro-Seoane et al., the dimensionless strain can be written

$$h_n = \left(\frac{G^{5/3}}{c^4}\right) 2\sqrt{\frac{32}{5}}\,\frac{\mathcal{M}^{5/3}(2\pi f_0)^{2/3}}{r}\,\frac{\sqrt{g(n,e)}}{n}$$

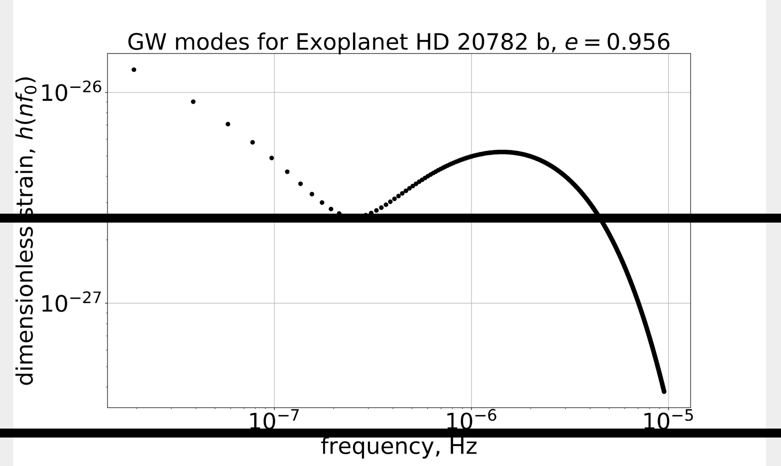
where the mass is the "chirp mass" and is $m_1^{3/5} m_2^{3/5}/(m_1+m_2)^{1/5}$, and $h_n$ is at a multiple of the orbital frequency $f_o$, $nf_o$ and $n=[1,2,3...]$.

## g(n,e) Ratio GW Power elliptical to circular




$$h_n \propto \sqrt{g(n,e)}/n$$




## NASA Exoplanet Archive

https://exoplanetarchive.ipac.caltech.edu/

**3711** Confirmed Planets as of 8 April 2018

For GW strain calculation we need the following attributes:

$m_1$ stellar mass, st_mass

$m_2$ planet mass, pl_bmassj

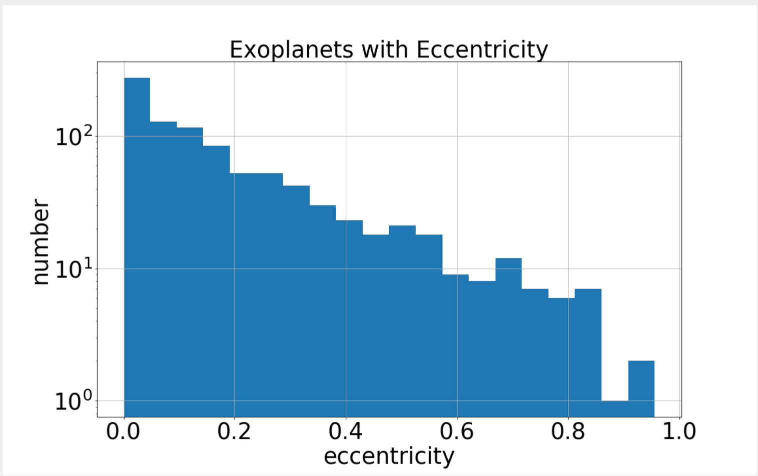
*r* distance to system, st_dist

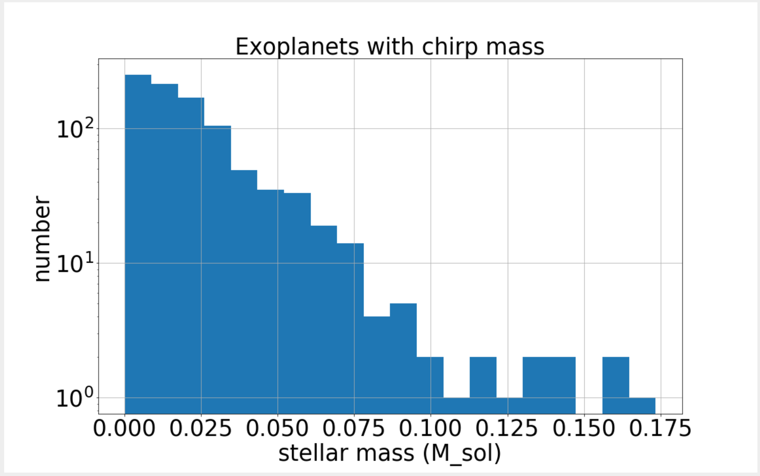
*e* orbital eccentricity, pl_orbeccen

*P* orbital period, pl_orbper

*a* orbital semi-major axis, pl_orbsmax

Which leaves **910** exoplanets that we can use for GW calculations.




## LISA Sensitivity / Noise

Following Cornish and Robson (2018) on the LISA sensitivity curve with the following caveats:

•exoplanet GW frequencies are much less than laser round trip time (16.7s) or f_star (19mHz), in the "LIGO Limit";
•no frequency evolution assumed over the four year integration time;
•factors of order a few from sky and polarization averaging not included, no \cal R factor included.

## Future Work

•Refine the noise/sensitivity curve analysis;
•Consider errors in exoplanet parameters for the SNR and noise/sensitivity analysis;
•Stellar and planetary synthesis to estimate possible total numbers of exoplanets in the neighborhood of Earth;
•Consider what parameters would make a single planet detectable for LISA;
•Work our way up the mass scale: brown dwarf binaries, etc.

## References

**P. C. Peters and J. Mathews**, "Gravitational Radiation from Point Masses in Keplerian Orbit," Phys. Rev. 131 (1963) 435;
**M. Maggiore**, "Gravitational Waves: Volume 1: Theory and Experiment," Oxford Univ. Press, 2008;
**Amaro-Seoane et al.**, "Triplets of supermassive black holes: astrophysics, gravitational waves and detection," Mon. Not. Royal Astro. Soc. **402** (2010) 2308;
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**N. Cornish and T. Robson**, "The construction and use of LISA sensitivity curves," 2018, arXiv:1802.01944;
**A. Ain, S. Kastha, and S. Mitra**, "Stochastic Gravitational Wave Background from Exoplanets," Phys. Rev. D, **91** (2015) 124023, arXiv:1504.01715v2.

**junk like my 8.5x11 rectangle for layout**
**Darn my TexMaths is not working**
**Three rectangles on previous slide are guides, delete when done**
**Lose the Abstract and put in bullet points maybe??**
**What would a “mode” scale look like for Planet HD xxxx b?**

stuff

and more stuff

$h_n \propto \sqrt{g(n,e)}/n$

# Abstract

$h_n = \frac{1}{12} s(u,e,g)$