Music of the Spheres: the gravitational wave signal from exoplanets

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Motivating Question

With more than 3700 exoplanets discovered to date, could any individual planetary system or **population of planetary systems** be detected by LISA?

Overview

•We consider exoplanets as a source of **gravitational waves** (GW) for the **LISA space-based gravitational wave detector**
•LISA is the Laser Interferometer Space Antenna, a joint ESA/NASA project expected to launch in 2034
•The rich variety of exoplanets include many with **high eccentricity** which moves their GW spectrum to the LISA band.

Theory - GWs from Binaries

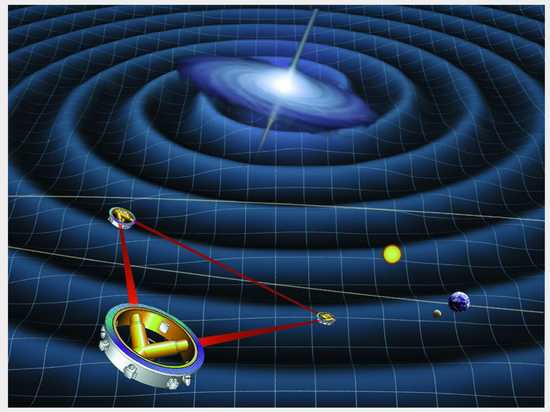
Masses in orbit exhibit a **time-changing mass quadrupole moment** and therefore emit GWs [1,2]. **Averaged over a full orbit**, the dimensionless strain can be written[3]

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

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_0**, *n* f_0 *with n=[1,2,3...]*, and **eccentric orbits** emit more GW power than similar circular orbits,

g(n,e) = (GW Power at $f=n\,f_0$ Elliptical orbit) / (GW Power Equiv. Circ. orbit at $f=2\,f_o$)

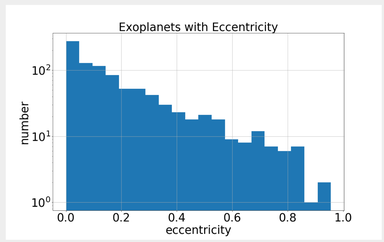
LISA Constellation

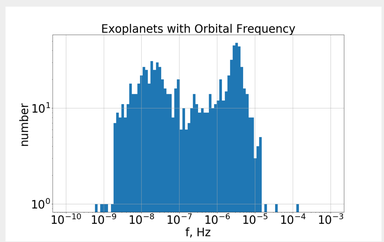


(credit NASA)

Observed Exoplanets

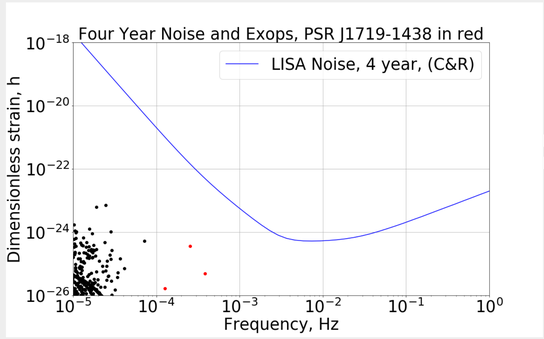
https://exoplanetarchive.ipac.caltech.edu/
3711 Confirmed Planets as of 12 April 2018
For GW strain calculation we need the following physical attributes of the planetary system: m_1 stellar mass, m_2 planetary mass, *r* distance to system, *e* orbital eccentricity, *P* orbital period. Which leaves **910** exoplanets that we can use for GW calculations.





Exoplanets and LISA

We compare the current exoplanet population GW strains to the most up-to-date LISA noise curve[5] with the following caveats:
•exoplanet GW frequencies are much less than laser round trip time (16.7s, equiv 60mHz) or f_star (19mHz), so in the "LIGO Limit"
•no frequency evolution assumed over the four year integration time
•using the *R* function, so nominally sky position and polarization averaged



Exoplanet GW Modes and LISA Sensitivity Curve

Signal-to-Noise for top few planets

$$\left(\frac{S}{N}\right)^2 = 2\,T \sum_{n=1}^{n_\star} \frac{|h_n(n\,f_0)|^2}{S_n(n\,f_0)}$$

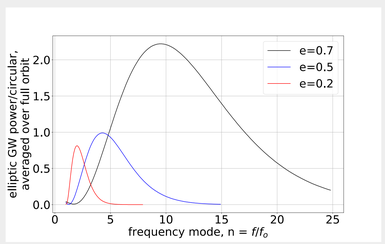
host star	eccentricity	orbital period(d)	SNR
PSR J1719-1438	**0.06**	**0.09071**	**0.001331**
PSR J2322-2650	0.0017	0.323	4.899E-05
WASP-18	0.0092	0.9415	2.654E-05
KELT-1	0.0099	1.218	1.106E-05
WASP-43	0	0.8135	6.012E-06
WASP-19	0.002	0.7888	1.734E-06
HATS-18	0.166	0.8378	1.649E-06

Future Work

•Consider **collections of planetary systems** on GW signal
•Refine the noise/sensitivity curve analysis
•Consider **errors in exoplanet parameters** for the SNR and noise/sensitivity analysis
•Consider what parameters would make a planetary system detectable for LISA
•Work our way up the mass scale: brown dwarf binaries, etc.

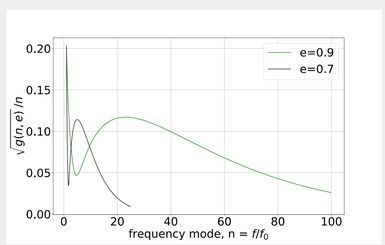
Eccentricity Increases GW Frequency

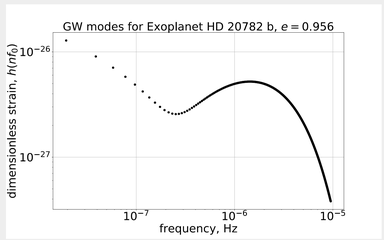
g(n,e) Ratio GW Power elliptical to circular



GW Strain

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





Strain modes for one planet and its star

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