Music of the Spheres: the gravitational wave signal from exoplanets

William Gabella[1], Katelyn Breivik[2], Yilen Gomez Maqueo Chew[3], Kelly Holley-Bockelmann[1,4], Brittany Kamai[5]

1-Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235 USA
2-Department of Physics and Astronomy, Northwestern University, Evanston, IL 60202 USA, also Center Interdisciplinary Exploration and Research in Astrophysics (CIERA), Evanston, IL 60202 USA
3-Instituto de Astronomía, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, Ciudad de México, México
4-Department of Physics, Fisk University, Nasville, TN 37208 USA
5-Division of Physics, Math and Astronomy, California Institute of Technology, Pasadena, CA 91125 USA

Motivating Question

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

from the Abstract

- We consider exoplanets as a source of Gravitational Waves (GW) for the LISA space-based 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 (Peters and Mathews, Maggiore). Averaged over a full orbit, they define the function

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

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_0, nf_0 with $n=[1,2,3...]$.

planet and star graphic with parameters

Observed Population of Exoplanets

https://exoplanetarchive.ipac.caltech.edu/
**3711** Confirmed Planets as of 8 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, a orbital semi-major axis.
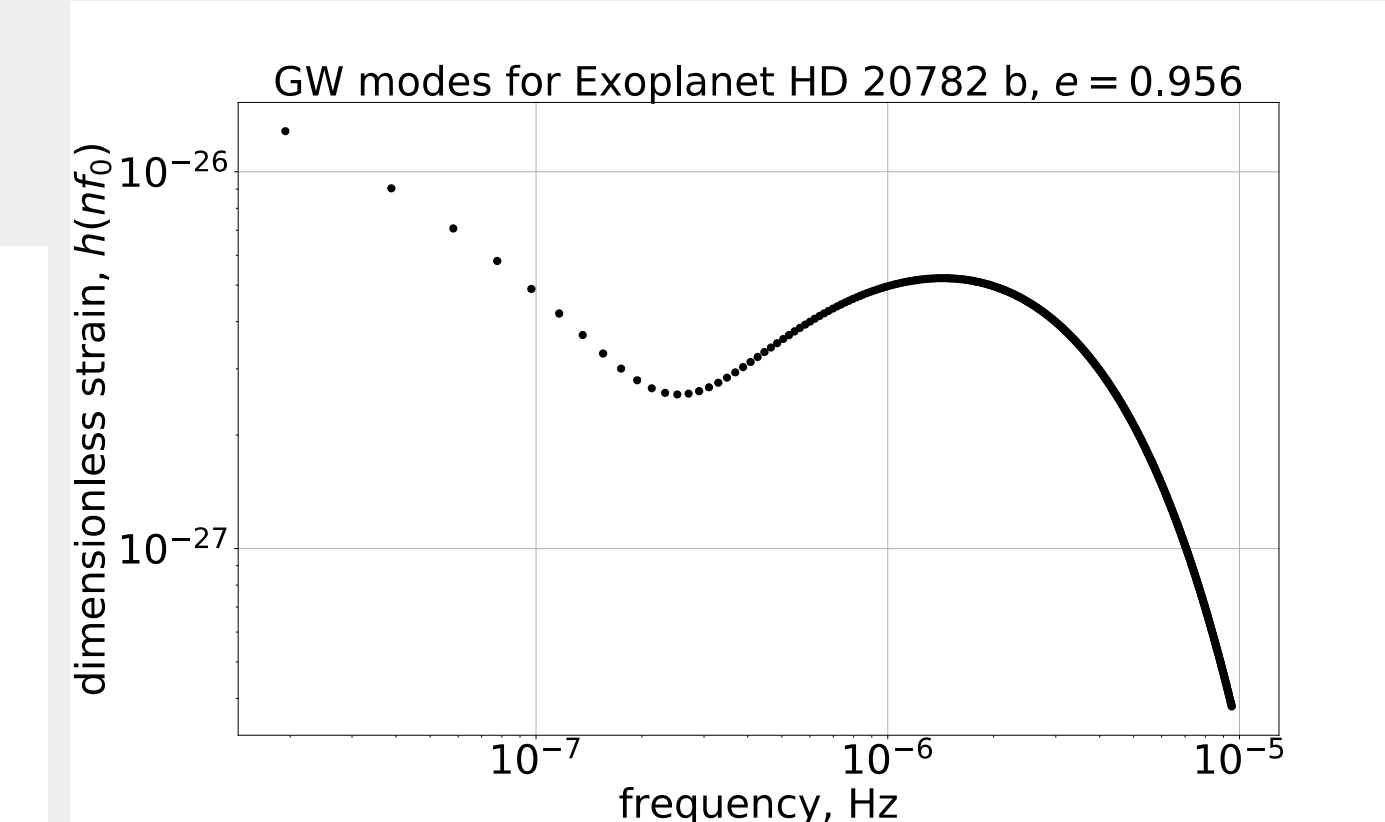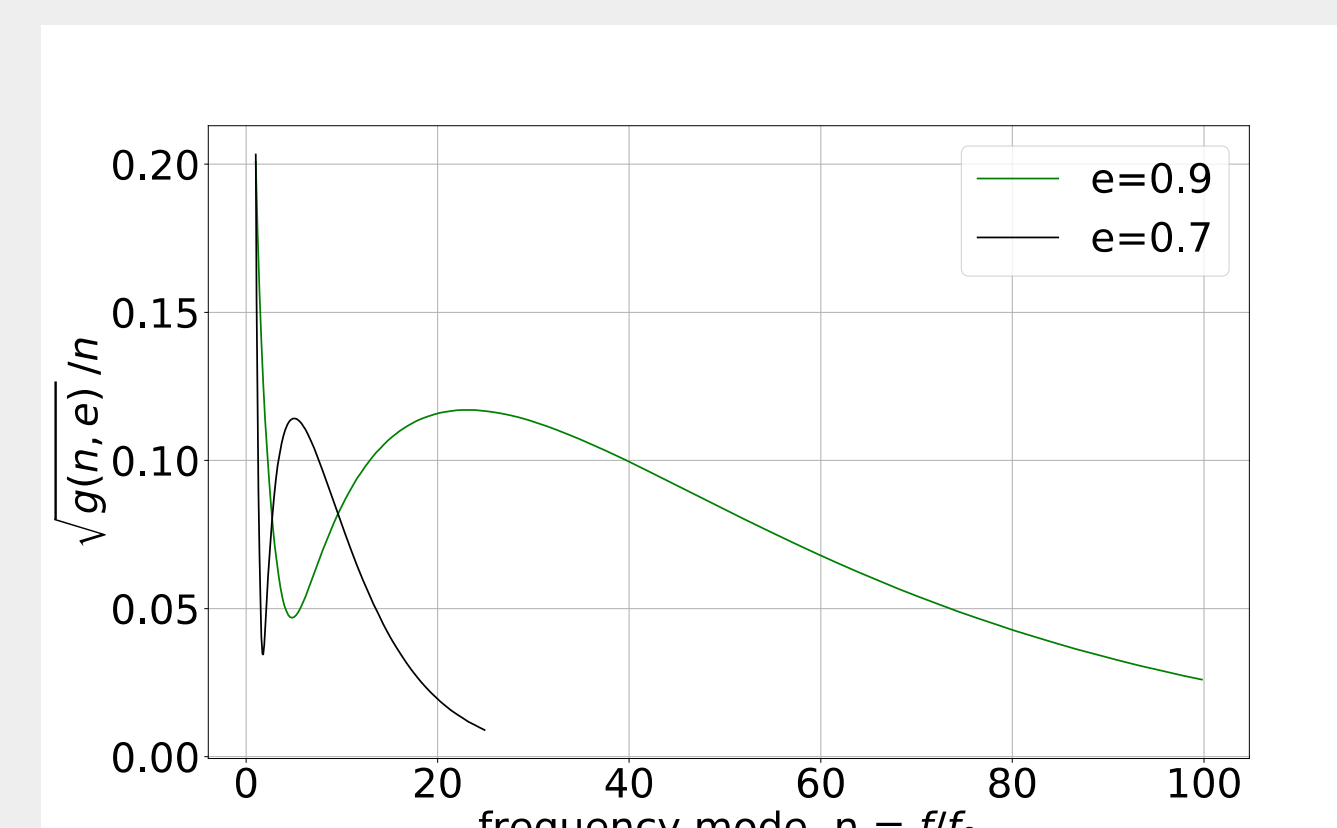Which leaves **910** exoplanets that we can use for GW calculations.

Exoplanets with Eccentricity

Exoplanets with Orbital Frequency
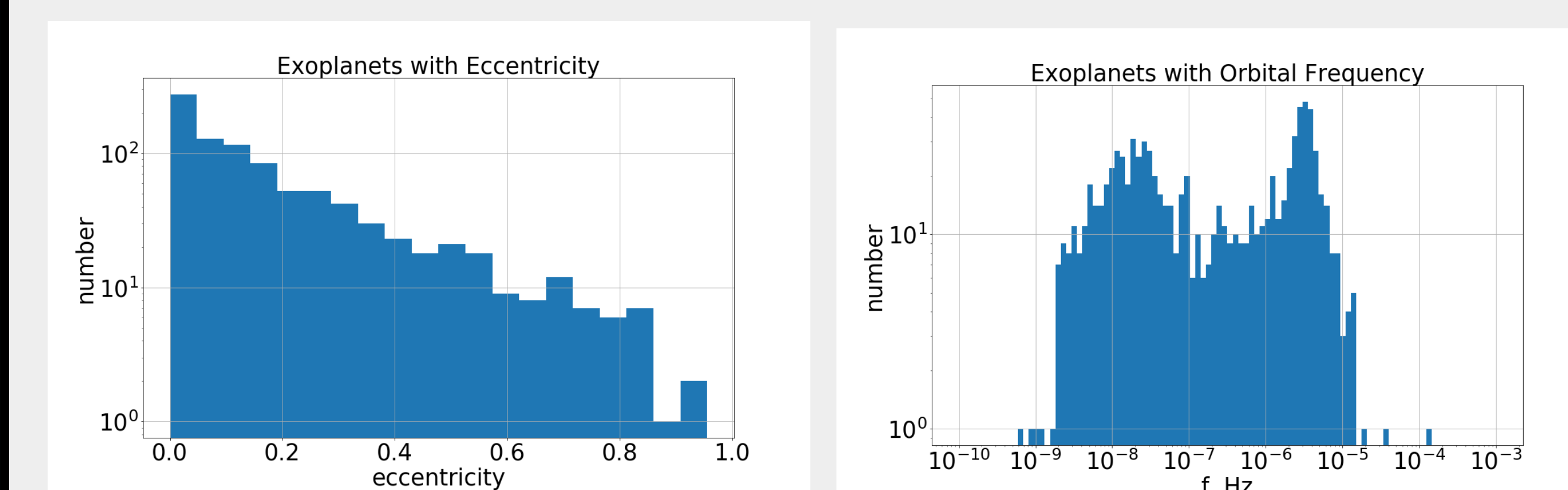
Eccentricity Increases GW Frequency

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

GW Strain

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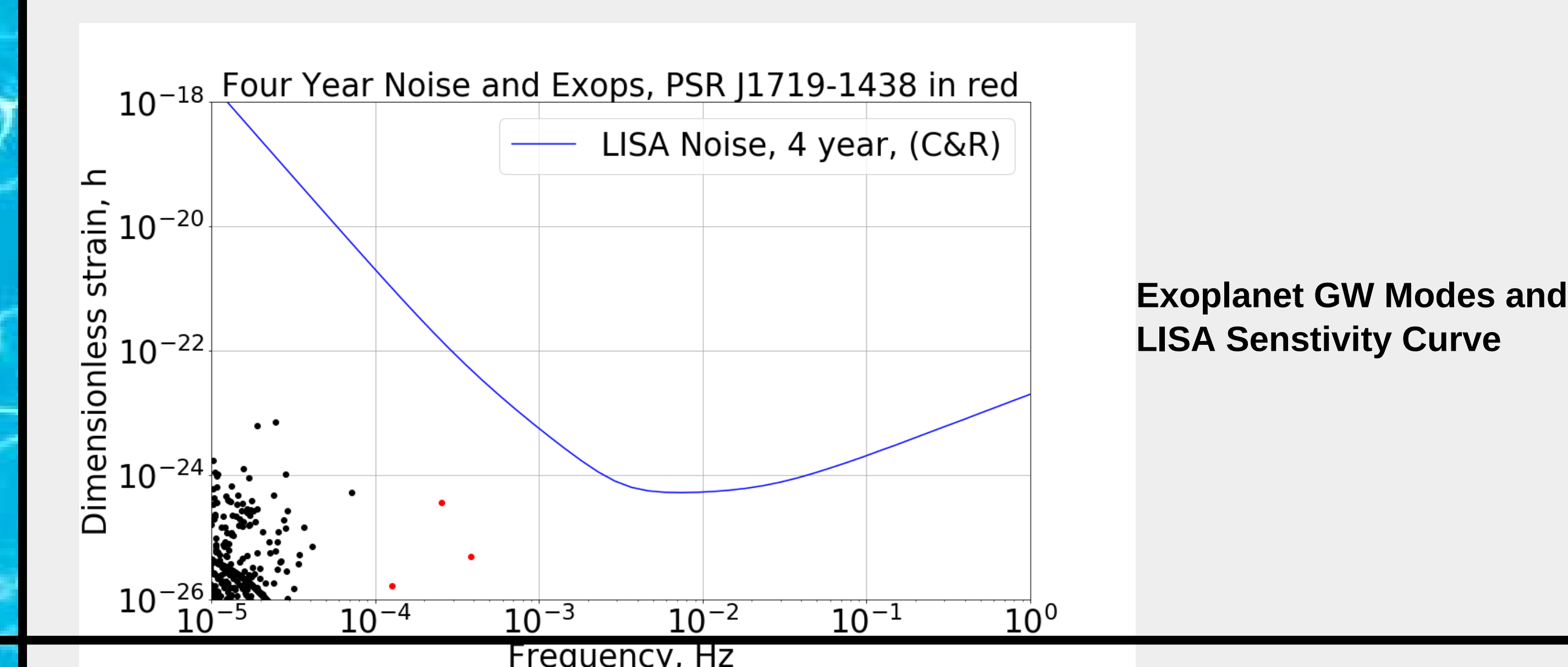

GW modes for Exoplanet HD 20782 b, e = 0.956
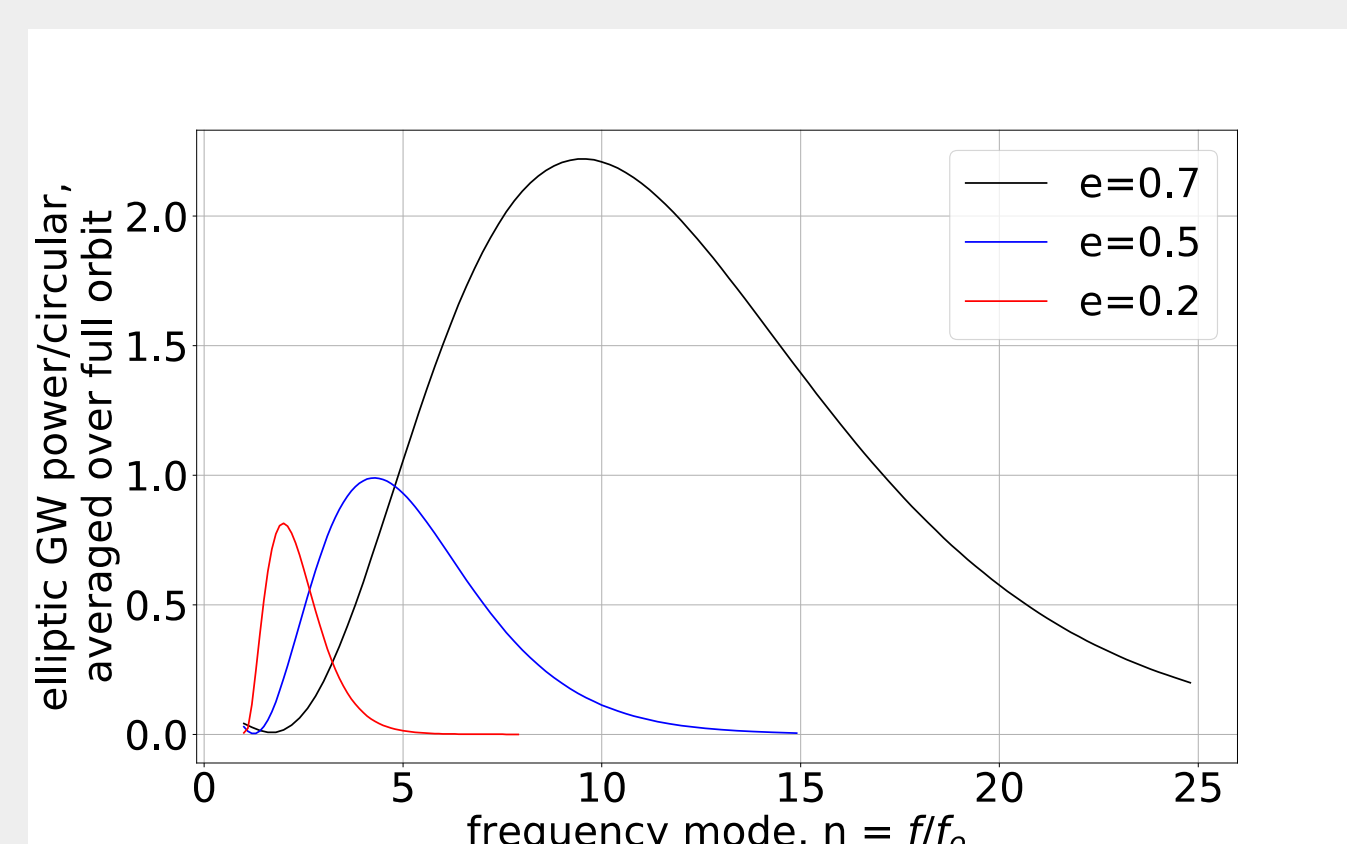
Strain modes for one planet and its star

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, 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.

Four Year Noise and Exops, PSR J1719-1438 in red
LISA Noise, 4 year, (C&R)

Exoplanet GW Modes and LISA Sensivity Curve

Signal-to-Noise for top few planets

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

- 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.

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;
NASA Exoplanet Archive, This research has made use of the archive, which is operated by the California Institute of Technology, under contract with the National Aeronautics and Space Administration under the Exoplanet Exploration Program;
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?

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.

	pl_hostname	pl_orbeccen	pl_orbper	SNR
492	PSR J1719-1438	0.06	0.09071	0.001331
336	PSR J2322-2650	0.0017	0.323	4.899E-05
156	WASP-18	0.0092	0.9415	2.654E-05
1465	KELT-1	0.0099	1.218	1.106E-05
575	WASP-43	0	0.8135	6.012E-06
157	WASP-19	0.002	0.7888	1.734E-06
298	HATS-18	0.166	0.8378	1.649E-06
1174	KELT-16	0	0.969	1.618E-06
1524	KELT-9	0	1.481	1.223E-06
623	WASP-77 A	0	1.36	1.119E-06

stuff

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

and more stuff

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