Spurious Acceleration on LISA Due to Solar Irradiance

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Background on Gravitational Waves

Gravitational waves are essentially small undulations in spacetime, manifesting themselves by slightly oscillating the distance between objects (see Figure 1). Gravitational waves are created whenever a system is accelerating without spherical symmetry.[3] Common astrophysical examples of this are binary systems, spinning non-spherical objects, and supernovae.

Methods

To calculate force, we expanded the basic equation of force by photon pressure by compensating for geometry and materials, given by

\[ F = \frac{E \cdot A}{c^2} \]  

where \( E \) is the energy flux or irradiance (\( \text{Watts/m}^2 \)), \( A \) is area (\( A = \pi r^2 \cos \alpha \), where \( \alpha \) is the angle between the normal and sun), and \( c \) is the speed of light.[4] Of course, we aren't interested in force in general but only if force oscillates for frequencies within those within the LISA sensitivity range (10^{-4} - 1Hz). We can calculate force but this will inevitably be a time-dependent quantity. This means that we must examine a Fourier transform of force.

We used the 60 second averaged total solar irradiance data, from 1996-2014, measured by the VIRGO (Variability of solar Irradiance and Gravity Oscillations) experiment aboard the SOHO (Solar and Heliospheric Observatory) spacecraft, which measures solar irradiance at the L1 (first Lagrangian) point. The major problem with our data is the fact that there is many missing data points, or 'gaps', that must be dealt with since a fourier transform requires a complete data set. These gaps come from periods where the instruments were not taking data, due to failure, or the data was considered to be unreliable by the VIRGO research team. After and exhaustive study, we chose to use an averaging filtering method. This means that we took the first value from either side of the gap and set every value in the gap to the average. Visually this looks like figure 3.

Results

In the figure above, we can clearly see much of the oscillatory noise that will be affecting LISA's signal. Below, we can clearly see three large spikes within the desired frequency range. This first is right around 0289Hz which is somewhat near "5-minute oscillations" frequency that patches of the surface of the sun will move radially in and out. The other two higher frequencies are second and third harmonics to this frequency.

Applications of LISA

The Laser Interferometer Space Antenna (LISA) is a configuration of three satellites that will precisely measure the distance between each other in order to detect gravitational waves.[1] Therefore, the stability of LISA satellite configuration will be crucial to its ability to measure gravitational waves, as will understanding the noise introduced in the measured gravitational wave signal from various environmental accelerations. Although solar irradiance will certainly be a large source of noise in the desired frequency band and will attempt to disrupt the satellite configuration, previous research has only considered zeroth order calculations of force by irradiance in static systems. To remedy this, we used a geometric and material based approach to calculate the force on the satellites’ solar arrays, the only component facing the sun. Running our simulation of LISA based on irradiance data from the VIRGO (Variability of solar Irradiance and Gravity Oscillations) satellite, we examined the Fourier transform of force to find the associated acceleration noise within the LISA frequency band due to solar irradiance. This research will help isolate the gravitational wave signal when LISA is flown.

Abstract

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Basics of LISA

The LISA spacecrafts orbit in a triangular formation (constellation) around the sun about 20° behind the earth with approximate distance of 5 million km between each craft.[2] LISA will detect gravitational waves by calculating the distance between each spacecraft, done essentially by measuring the intensity of laser signals sent from one craft to another. When a signal is received the spacecraft references the position of a test mass, free-floating and located inside, and measures the phase difference between the signal is sending out and the one it received. Combining this information from the three arms comprises the gravitational wave signal. Essentially the outer sections of the satellite are created to protect and house the test mass in order to prevent any external environmental accelerations. Each spacecraft can compensate for constant accelerations by firing thrusters to keep itself centered on the test mass but even changing the center of mass will cause the test mass to accelerate, creating noise in the signal. Therefore, it is crucial to understand the force of the largest external influence, the sun, and whether this force will have any periodicities within the LISA band and what this noise will look like.

References