RIPS 2006: NASA/Goddard Project Description

Proposed Summer Student Project for the RIPS program at IPAM

This goal of this project is to develop methods for detecting gravitational wave signals in LISA data.

Introduction

Gravitational waves are predicted by Einstein's 1915 General Theory of Relativity but are yet to be detected. However, the era of gravitational wave astronomy is set to open in the next decade. Ground-based detectors such as LIGO (in the US), GEO (in Germany), and Virgo (in Italy) are operating or commissioning and the NASA-ESA collaborative space-based detector LISA should be in operation shortly after the centenary of Einstein's paper.

The major types of sources expected are pairs of compact objects either in close orbit or merging. The ground-based detectors are sensitive to neutron star-neutron star mergers while LISA, which operates at longer frequencies, can detect inspiral and merger of pairs of supermassive black holes (SMBH), the capture by a supermassive black hole of a smaller compact object (EMRI), and white dwarf binary systems (WDB). Of course, as with any new way of looking at the Universe there will be surprises so we need to be able to identify the unexpected in the data.

The LISA data analysis challenge is to find characteristic signals in a time series. Some of these signals can be predicted precisely (eg nearby WDB) while others have many possible signatures (eg EMRI). A further complication is that gravitational wave detectors observe the whole sky all the time so that the observed signal is a superposition of all sources in the Universe. A major portion of the background is thus many WDB from our own galaxy.

Project Overview

In order to try out data analysis techniques the LISA Science Team has created a set of challenge datasets. The first sets have just been released and will be open for attack till December of this year. These datasets do not reflect the complete LISA data analysis problem however we expect to build up to that over the next couple of years. The project is to take one or more of the challenge datasets and devise a technique to detect and characterize the gravitational wave signals therein.

One possible method, described in the references below, is chirplet path pursuit. This is particularly good for looking for signals which are not well-characterized such as the EMRI data analysis challenge.

Deliverables

The following deliverables are expected at the end of the program

- A written report on the project including detailed description of the method developed for solving the problem and performance comparison with pre-existing methods such as matched filtering or time-frequency searches.
- Code which implements the method and data resulting from the project
- Documentation for the code

References:

- LISA specific links:
  http://lisa.jpl.nasa.gov/ -- the official website for LISA
  http://astrogravs.gsfc.nasa.gov/docs/mldc -- the website for the Mock LISA Data Challenge

- Existing methodology:
  eg J.Gair & L.Wen *http://arxiv.org/abs/gr-qc/0506116*

- A useful book on signal processing:
  S. Mallat. "A Wavelet Tour of Signal Processing." Academic Press, 1998

- Articles related to chirplets and nonparametric detection and estimation of chirp signals:

  E. Candes, P. Charlton, H. Helgason. "Detecting highly oscillatory signals by chirplet path pursuit.", arXiv/gr-qc/0604017

  E. Candes. "Multiscale Chirplets and Near-Optimal Recovery of Chirps"

- Useful websites:
  www.chirplab.org -- a website with a collection of MATLAB routines for the detecting chirp signals in noisy data

  http://www-stat.stanford.edu/~wavelab/ -- WaveLab is a collection of Matlab functions that implement a variety of computational algorithms related to wavelet analysis