

LISA Pathfinder: experiment details and results

Martin Hewitson on behalf of the LPF Collaboration

Abstract

On December 3rd 2015 at 04:04 UTC, the European Space Agency launched the LISA Pathfinder satellite on board a VEGA rocket from Kourou in French Guiana. After a series of orbit raising manoeuvres and a 2 month long transfer orbit, LISA Pathfinder arrived at L1. Following a period of commissioning, the science operations commenced on March 1st, beginning the demonstration of technologies and methodologies. This phase was followed by a 3 month period of operations of the NASA payload items. Since then, the mission has been in its extension phase, and will continue to operate until the end of June 2017. The results from LPF pave the way for a future large-scale gravitational wave observatory in space. This talk will describe the LISA Pathfinder mission in detail, looking at many aspects of the experiments that have been performed, all of which lead to the exceptional performance. The results from the main mission period will be discussed in detail, and contrast against the improved results gained in the mission extension.

GW Detection in Space: An Overview

Wei-Tou Ni

Abstract

Gravitational wave (GW) detection in space is aimed at low frequency band (100 nHz – 100 mHz) and middle frequency band (100 mHz – 10 Hz). The science goals are the detection of GWs from (i) Supermassive Black Holes; (ii) Extreme-Mass-Ratio Black Hole Inspirals; (iii) Intermediate-Mass Black Holes; (iv) Galactic Compact Binaries and (v) Relic GW Background. In this paper, we present an overview on the sensitivity, orbit design, basic orbit configuration, angular resolution, orbit optimization, deployment, time-delay interferometry and payload concept of the current proposed GW detectors in space under study. The detector proposals under study have arm length ranging from 1000 km to 1.3×10^9 km (8.6 AU) including (a) Solar orbiting detectors -- ASTROD-GW (ASTROD [Astrodynamical Space Test of Relativity using Optical Devices] optimized for GW detection), BBO (Big Bang Observer), DECIGO (DECi-hertz Interferometer GW Observatory), e-LISA (evolved LISA [Laser Interferometer Space Antenna]), LISA, other LISA-type detectors such as ALIA, TAIJI etc. (in Earth-like solar orbits), and Super-ASTROD (in Jupiter-like solar orbits); and (b) Earth orbiting detectors -- ASTROD-EM/LAGRANGE, GADFLI/GEOGRAWI/g-LISA, OMEGA and TIANQIN.

LISA: A Gravitational Wave Observatory in Space

Martin Hewitson on behalf of the LISA Consortium

Abstract

The Laser Interferometer Space Antenna (LISA) is a gravitational wave observatory in space, targeting the millihertz frequency band where a large number of astrophysical and cosmological sources of gravitational waves is expected. In 2013, the European Space Agency selected the science theme “The Gravitational Universe”, which focuses on this rich science. In 2016, a call was issued by ESA for missions to address this science, and the LISA Consortium responded to that call with the LISA mission. This talk will review the LISA mission as a whole, highlight the outstanding science that it will deliver. We will also look at the technical aspects of the design, as well as the strong heritage from the LISA Pathfinder mission, all of which leads to an expected performance able to deliver the science of “The Gravitational Universe”.

The preliminary analysis of TIANQIN mission and the development of key technologies

Hsien-Chi Yeh

Science and Design of DECIGO and B-DECIGO

Masaki Ando

Abstract

ASTROD-GW

Wei-Tou Ni

Abstract

We present an overview of Astrodynamical Space Test of Relativity using Optical Devices (ASTROD-GW) optimized for Gravitational Wave (GW) detection mission concept and its studies. ASTROD-GW is an optimization of ASTROD which focuses on low frequency GW detection. The detection sensitivity is shifted by a factor of 260 (52) towards longer wavelengths compared with that of the new LISA. The mission consists of three spacecraft, each of which orbits near one of the Sun–Earth Lagrange points (L3, L4 and L5), such that the array forms an almost equilateral triangle. The three spacecraft range interferometrically with one another with an arm length of about 260 million kilometers. The orbits have been optimized resulting in arm length changes of less than ± 0.00015 AU or, fractionally, less than $\pm 10^{-4}$ in 20 years, and relative Doppler velocities of the three spacecraft of less than ± 3 m/s. In this paper, we present an overview of the mission covering: the scientific aims, the sensitivity spectrum, the basic orbit configuration, the simulation and optimization of the spacecraft orbits, the deployment of ASTROD-GW formation, Time Delay Interferometry (TDI) and the payload. The science goals are the detection of GWs from (i) Supermassive Black Holes; (ii) Extreme-Mass-Ratio Black Hole Inspirals; (iii) Intermediate-Mass Black Holes; (iv) Galactic Compact Binaries and (v) Relic GW Background. For the purposes of primordial GW detection, a six spacecraft formation would be needed to enable the correlated detection of stochastic GWs. A brief discussion of the six spacecraft orbit optimization is also presented.

Deployment Optimization for Various Gravitational Wave Missions

An-Ming Wu

Abstract

Space Gravitational Wave (GW) mission proposals often use constellation or formation flying for the required interferometry implementation. The spacecraft of most of these mission proposals go to deep space and many have Earthlike orbits around the Sun. ASTROD-GW, Big Bang Observer and DECIGO have spacecraft distributed in Earthlike orbits in formation. LISA has three spacecraft arranged in a nearly equilateral triangle formation with 2.5 Mkm arms, inclined by 60° with respect to the ecliptic and flying along an Earth-like heliocentric orbit trailing Earth by 20° . ALIA-Descope (Taiji) are proposed to work on time delay interferometry for 3, 4, 6 Mkm arm-length LISA-like orbits. ASTROD-GW has 3 spacecraft near Lagrange points to range interferometrically with one another with arm length about 260 Mkm. Since the deployment is related to the spacecraft mass and travel time, it is critical for the mission cost. LISA is proposed to be launched on 2030.12.18 with transfer time of 400 day to arrive mission orbits. After specifying the initial states of three spacecraft on mission orbits according to JPL DE431 solar ephemerides, we use the multi-segment compact finite-difference method for the orbit equation to calculate the delta-V for deployment of LISA from LEO. The deployment of 3 spacecraft to 3 mission orbits has slight different delta-V for each. Furthermore, the deployment is optimized for delta-V with the launch date and the transfer time for LISA and LISA-like missions.

Orbit design and TDI simulation for LISA, TAIJI and other LISA-like GW missions

Gang Wang and Wei-Tou Ni

Abstract

In order to attain the requisite sensitivity, laser frequency noise must be suppressed to below the secondary noises such as the optical path noise, acceleration noise etc. In early investigations, we have performed the numerical simulation of the time delay interferometry (TDI) for original LISA, ASTROD-GW and eLISA together with a LISA-type mission with a nominal arm length of 2×10^6 km using the CGC 2.7.1 ephemeris framework. In this talk, we follow the same procedure to simulate the time delay interferometry numerically for the new LISA mission and the TAIJI mission together with LISA-like missions of arm length 1×10^6 km, 2×10^6 km, 4×10^6 km, 5×10^6 km and 6×10^6 km. To do this, we work out a set of 2200-day (6-year) optimized mission orbits of each mission starting at March 22, 2028 using the CGC 2.7.1 ephemeris framework. We then use numerical method to calculate the residual optical path differences of first-generation TDI configurations --- Michelson X, Y & Z; Sagnac α , β & γ ; Relay U, V & W; Beacon P, Q & R; Monitor E, F & G --- and the second

generation TDI configurations --- 2 arm type [ab, ba]'s; [aabb, bbaa]'s; [abab, baba]'s; [abba, baab]'s; Sagnac-type α 12-1, α 12-2 & α 12-3. We compile and compare the resulting differences of various TDI configurations due to the different arm lengths for various LISA-like mission proposals and for the ASTROD-GW mission proposal.