LISA Pathfinder

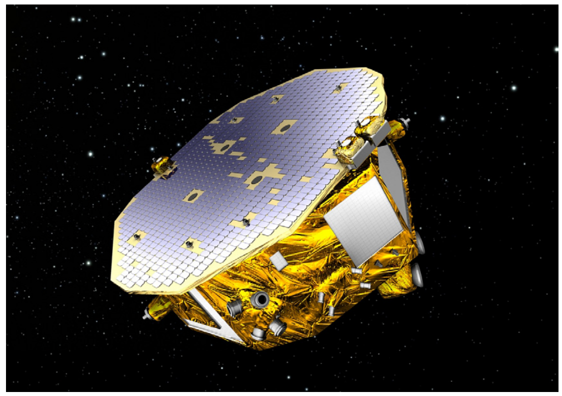
Laying the foundation for gravitational wave detection in space

Overview

LISA Pathfinder is a European Space Agency (ESA) mission to validate key technologies for space-based detection of gravitational waves in the millihertz (mHz) frequency band. LISA Pathfinder and its two science payloads, the European LISA Technology Package (LTP) and the NASA-provided Disturbance Reduction System (ST7-DRS), will demonstrate the technique of drag-free control to maintain an inertial reference mass in near-perfect gravitational free-fall. Drag-free control is a key element of the Laser Interferometer Space Antenna (LISA) mission concept that has been under development in the U.S. and Europe for several decades.

A prediction of Einstein's General Theory of Relativity, gravitational waves are undulations in the fabric of space-time produced by energetic events in our universe and propagate at the speed of light. The mHz frequency band, corresponding to waves with periods of minutes to hours, is expected to be the most source-rich in the gravitational wave spectrum. A mission based on the LISA concept will detect gravitational waves from colliding supermassive black holes at the edge of the observable universe, the capture of compact objects by massive black holes in the cores of nearby galaxies, and millions of compact-object binaries in our own galaxy. These observations will impact several areas of physics and astrophysics research including galaxy formation and evolution, black hole growth, the end states of stars, cosmology, and the nature of gravity itself. Observations in the mHz gravitational wave band will complement existing efforts at higher frequencies by ground-based interferometers and at lower frequencies by precision timing of radio pulsars, much as infrared astronomy complements both high-energy and radio astronomy.

LISA-like instruments observe gravitational waves by measuring small changes in the distance between pairs of freely-falling test masses on widely-separated spacecraft that are caused by passing gravitational waves. A key requirement is that the motion of these test masses is determined entirely by gravitational effects and not by other stray forces. To accomplish this, the test masses are allowed to drift freely inside a cavity within the spacecraft while a control system steers the spacecraft around the test masses using a micro-propulsion system. The LISA Pathfinder mission



Artist's impression of the LISA Pathfinder spacecraft. LISA Pathfinder will test in-flight the concept of low-frequency gravitational wave detection by putting two test masses into near-perfect gravitational free-fall while controlling and measuring their motion with unprecedented accuracy. Credit: ESA

can be viewed as a miniaturized version of a LISA measurement arm: two drag-free test masses separated by 38 cm on a single spacecraft with the relative acceleration between the test masses measured using laser interferometry.

LISA Pathfinder Objectives

The aim of the LISA Pathfinder mission is to demonstrate, in a space environment, the technique of drag-free control as an implementation of a freely-falling test mass. Specifically, it must:

- Demonstrate drag-free and attitude control of a spacecraft with two freely-falling test masses
- Mitigate stray forces on the test masses so that their relative acceleration fluctuates by less than 1 femtometer per second squared, or one tenth of one quadrillionth of the gravitational acceleration on Earth's surface, over a measurement period of 1000 seconds
- Demonstrate optical distance measurement of freely-falling test masses with a drift of less than 0.1 picometer, or about one hundredth the diameter of a hydrogen atom, over a measurement time of 1000 seconds
- Demonstrate precision spacecraft attitude control using microthuster technologies with

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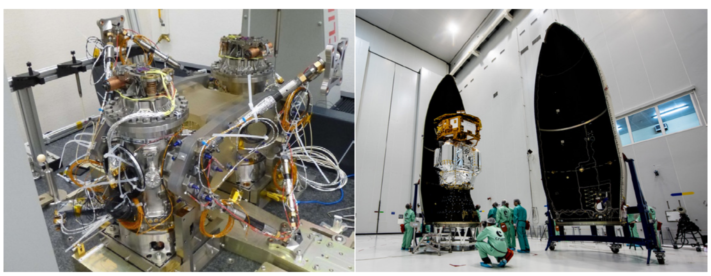
micronewton thrust precisions, equivalent to the weight of a mosquito's antennae in Earth's gravity
- Test the endurance of the different instruments and hardware in the space environment

Spacecraft and Payload

Led by the European Space Agency, LISA Pathfinder includes major hardware contributions from several European national agencies as well as a contribution from NASA. The European Space Agency, in partnership with an industrial contractor, has provided the spacecraft, which includes a cold gas micro-propulsion system and drag-free control software. The spacecraft is specially designed to minimize thermal, magnetic, and gravitational disturbances.

A consortium of European national space agencies and research institutions have provided the key science payload, known as the LISA Technology Package (LTP). The main components of the LTP are two gravitational reference sensors, an optical metrology system, and a thermal-magnetic diagnostics subsystem. Each gravitational reference sensor consists of a 46mm gold-platinum test mass, an electrostatic housing providing six-axis sensing and control, a UV charge control system, and a mechanical caging and release mechanism.

NASA's Jet Propulsion Laboratory is responsible for the Disturbance Reduction System (DRS) payload on LISA Pathfinder. The DRS consists of a colloidal micro-propulsion system developed in collaboration with Busek Co., Inc., and drag-free control software developed in collaboration with NASA's Goddard Space Flight Center and implemented on an Integrated Avionics Unit built by Moog Broad Reach. During DRS operations, the LTP will be used to provide measurements of the position and attitude of the test masses to the DRS control software.



Left: The LISA Technology Package during the late stages of integration in January 2015. Visible in the foreground is an ultra-stable optical bench that will be used to measure the relative position of the two gold-platinum test masses with a precision of a few picometers. The surface of one of the test masses is just visible inside the vacuum window in the background. Image Credits: ESA / Airbus Defense & Space Systems / CGS (inertial sensor) / U. Glasgow (optical bench) Right: LISA Pathfinder being encapsulated within the half-shells of the Vega rocket fairing on 16 November 2015, at the Centre Spatial Guyanais in Kourou, French Guiana (Credit: ESA–Manuel Pedoussau)

Mission Design

After launch aboard a Vega rocket from Kourou, French Guiana, LISA Pathfinder used its propulsion module to travel to the First Earth-Sun Lagrange point (L1), located 1.5 million kilometers away from the Earth in the direction of the Sun. After injection into a 500,000 km by 800,000 km Lissajous orbit about L1, the propulsion module separated from the LISA Pathfinder science spacecraft and was discarded. Approximately two months after launch, LISA Pathfinder began a two-week commissioning period that will be followed by six months of science operations, the first three with the LTP and the latter three jointly with the DRS. Science operations officially began on March 1, 2016. The spacecraft and mission design, as well as the available consumables, allow for the possibility of extended science operations of up to one year.

Operations

Operations for LISA Pathfinder consist of a series of experiments to measure and characterize the relative acceleration noise between the two test masses. These include direct measurements of the noise as well as measurements of various physical couplings. For example, the effect of thermal fluctuations on acceleration of the test masses will be measured by modulating the temperature of the environment of the test masses at various frequencies and measuring the acceleration response. These measurements will be used to validate a physics-based model of the LISA Pathfinder acceleration noise performance. Such a model will be a valuable tool for designers of future LISA-like missions with different environmental and spacecraft conditions.

Mission Parameters

Launch: Launch: December 3, 2015 at 04:04 UTC (Kourou, French Guiana)

Launch vehicle: Vega rocket

Orbit: 500,000 km x 800,000 km Lissajous about Sun-Earth L1

Science operations: Six months (nominal) to one year (extended)

Measurement band: 1-30 millihertz

Acceleration sensitivity: 30 femtometer/s^2/$Hz^{1/2}$

Displacement sensitivity: 10 picometer/$Hz^{1/2}$

Thrust noise: < 0.1 micronewton/$Hz^{1/2}$

Spacecraft position control: < 10 nanometers/$Hz^{1/2}$

For more information:

ESA project website: http://sci.esa.int/lisa-pathfinder

eLISA mission: https://elisascience.org

NASA LISA website: http://lisa.nasa.gov/

NASA ST-7 website: http://science.nasa.gov/missions/st-7/

NASA Physics of the Cosmos (PCOS) website: http://pcos.gsfc.nasa.gov/

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