LISA Pathfinder

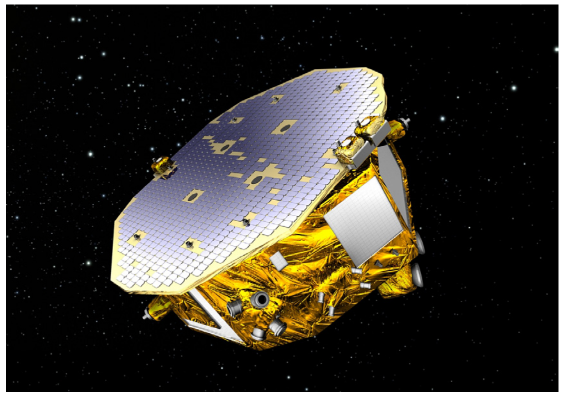
Laying the foundation for gravitational wave detection in space

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 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 inform 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 detectors and at lower frequencies with pulsar timing arrays, 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 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.



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

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 residual relative acceleration is less than 30 femtometer/s^2/$Hz^{1/2}$ at frequencies from 1 to 30 mHz
- Demonstrate optical metrology of freely-falling test masses with precision of 10 picometer/$Hz^{1/2}$ in the same frequency band
- Demonstrate precision spacecraft attitude control using microthuster technologies with micronewton/$Hz^{1/2}$ force noise in the same frequency band
- Test the endurance of the different instruments and hardware in the space environment

NASAfacts

Spacecraft and Payload

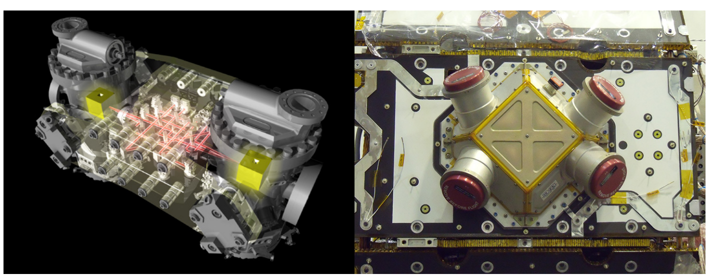
Led by the European Space Agency, LISA Pathfinder includes major hardware contributions from several European national agencies as well as a contribution from NASA. The European Space Agency, in partnership with an industrial contractor, has provided the spacecraft, which includes a cold gas micro-propulsion 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. Funded as the Space Technology 7 mission under the New Millennium Program, the DRS consists of a colloidal micro-pro- pulsion 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.

Mission Design

After launch aboard a Vega rocket from Kourou, French Guiana, LISA Pathfinder will use 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 will separate from the LISA Pathfinder science spacecraft and be discarded. Approximately two months after launch, LISA Pathfinder will begin a two-week commissioning period followed by six months of science operations, the first three with the LTP and the latter three jointly with the DRS. The spacecraft and mission design, as well as the available consumables, allow for the possibility of extended science operations of up to one year.



Left: LISA Technology Package (LTP) payload. (Credit: ESA)
Right: One DRS colloidal thruster cluster integrated into the LISA Pathfinder spacecraft. (Credit: NASA)

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: July 2015 (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/s^2/$Hz^{1/2}$
Thrust noise: $<$ 0.1 micronewton/$Hz^{1/2}$
Spacecraft position control: $<$ 10 nanometers/$Hz^{1/2}$

For more information:

ESA project website: http://www.esa.int/Our_Activities/Space_Science/LISA_Pathfinder_overview

eLISA mission: https://elisascience.org

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

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

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