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LISA Pathfinder exceeds expectations

Mission accomplished for the *LISA Pathfinder* spacecraft after only two months of science operations. Not only were the technologies needed for the future *eLISA*[1] gravitational wave space observatory validated, but the performance of the ESA demonstrator also exceeded the project specifications by a factor of five, and was very close to requirements for *eLISA*. These first results, which involved the Astroparticule et Cosmologie laboratory (CNRS/Université Paris Diderot/CEA/Observatoire de Paris), with support from CNES, are published on 7 June 2016 in the journal *Physical Review Letters*. They represent a major step towards space-based gravitational astronomy[2], which will make it possible to study phenomena such as mergers between supermassive black holes.

LISA Pathfinder is a technical and scientific success. After the first 55 days of science operations, the spacecraft's performance has proved to exceed by a factor of five the project specifications for the mission, which aims to test the technologies required for a space-based gravitational wave observatory.

LISA Pathfinder contains two test masses, small cubes made of gold and platinum, which are not mechanically connected to the rest of the spacecraft but 'floating' in cavities 38 cm apart, surrounded by the instrumentation required to measure their position. The scientists have shown that the two cubes can be maintained practically motionless with regard to each other and are only under the influence of gravity, free from external forces such as that of the solar wind.

The spacecraft protects the cubes from external influences by constantly adjusting its position using an ultra-precise micro-thruster system. The cubes thus remain in the center of the cavities in free-fall, following an orbit that is determined only by gravity. In addition, the laser-based system that measures the distance between the two cubes is 100 times more effective than in laboratory results: it can measure a distance to the nearest 30 femtometers[3] (one ten-thousandth the size of an atom). The system evaluates the residual acceleration between the two masses, which is less than half a billion millionth of terrestrial gravity.

This success holds out great promise for the design of *eLISA*, ESA's future space-based gravitational wave observatory. *eLISA* will comprise three spacecraft carrying technologies tested in *LISA Pathfinder*, placed several million kilometers from each other. Laser beams exchanged between the spacecraft will

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[1] *Evolved Laser Interferometer Space Antenna, a future L-class space mission in ESA's 'Cosmic vision' program, with the participation of the US space agency NASA.*

[2] *The first direct detection of gravitational waves, last September, opens the way to using this new cosmic messenger to better understand the astrophysical objects that emit them, explosions of massive stars, and mergers of neutron stars or black holes. Gravitational waves are tiny distortions in spacetime produced by cataclysmic phenomena. See our press release: http://www2.cnrs.fr/en/2701.htm*

[3] *A femtometer (fm) is a million billionth of a meter (10^{-15} meter).*

constantly measure the distance between them (or, more precisely, between the test masses contained in them), and will detect the slightest variation in this distance, indicating a passing gravitational wave.

Gravitational waves are tiny distortions in spacetime produced by some of the most violent phenomena in the Universe. Predicted by Albert Einstein a century ago, they were detected directly for the first time a few months ago at the ground-based observatory LIGO. The LIGO-Virgo consortium, which processes the data, detected a signal characteristic of two orbiting black holes spiralling around each other just before merging. This breakthrough has opened the way to gravitational wave astronomy: gravitational waves provide a new tool for observing the Universe, together with electromagnetic radiation (light, radio waves and microwaves, gamma rays and X-rays) and astroparticles (cosmic rays and neutrinos). They are indeed the only direct signal emitted by certain objects such as black holes.

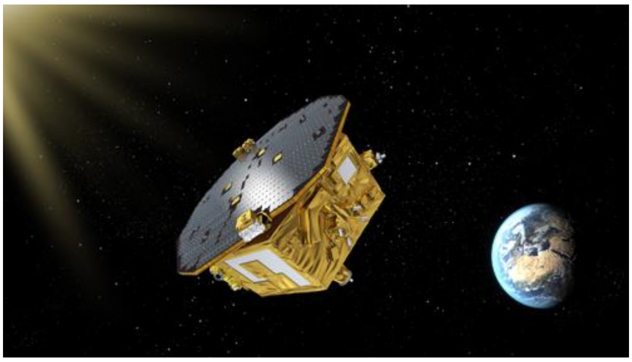
In this new field of gravitational astronomy, *eLISA* will play a complementary role to that of ground-based detectors. It will be able to detect larger objects such as supermassive black holes at the center of galaxies which, when they merge, emit low-frequency gravitational waves that are drowned out by background noise on Earth. However, because of its size, it will scarcely be sensitive to the smaller objects observed by Virgo and LIGO (mergers of pairs of neutron stars or black holes).

The *LISA Pathfinder* mission, launched on 3 December 2015 from Kourou (French Guiana), arrived on 22 January 2016 at its final orbit around the L1 Lagrange point, 1.5 million kilometers from Earth. Over the following weeks, the various instruments were activated. On 15 and 16 February, the test masses were released from the rest of the spacecraft. Science operations began on 1 March 2016 and the level of precision of the project specifications was reached on day one. Performance gradually improved, in particular due to the spacecraft attaining its operating temperature and to the release of residual gas. The scientists took advantage of this to observe very precisely the residual forces acting on the test masses, which proved to be less than the threshold required to measure gravitational waves. Operations are expected to continue until the end of June 2016, with a possible extension until April 2017.

In France, the Astroparticule et Cosmologie laboratory (APC, a laboratory jointly run by the CNRS, Université Paris Diderot, CEA and the Paris Observatory) was actively involved in the data analysis. Several researchers regularly travel to the ESOC, the European Space Operations Centre (Darmstadt, Germany) for initial analysis of the data, while the Centre François Arago (Paris), associated with APC, is one of the complementary data processing centers, directly linked to ESA. CNES supports APC's activity in the *LISA Pathfinder* mission.

To find out more about *LISA Pathfinder* and *eLISA*:

- Consult the APC lab website.
- Read the press release issued for the launch of *LISA Pathfinder*: LISA pathfinder: a step toward gravitational wave detection.
- Other websites: https://www.elisascience.org/ and http://sci.esa.int/lisa-pathfinder/.



LISA Pathfinder ***in space (artist's impression).***

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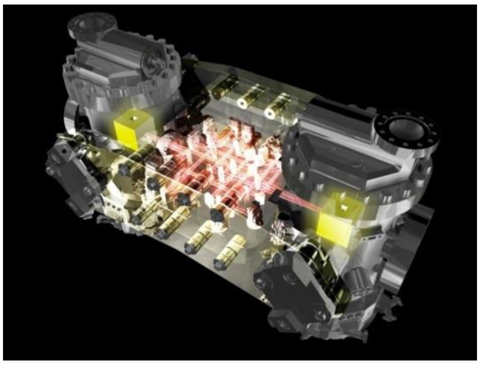

The 'test masses', two identical cubes made of gold and platinum (2 kg, 4.6 x 4.6 x 4.6 cm), float inside the spacecraft, surrounded by the optical bench that measures their position.

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Other images (photographs, videos) of LISA Pathfinder *are available on the* ESA website*.*

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