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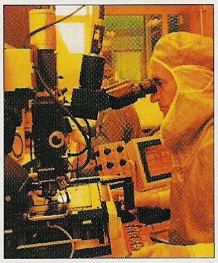
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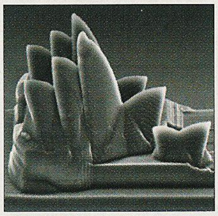
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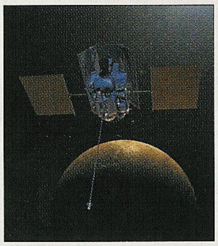
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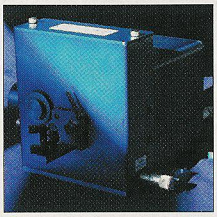
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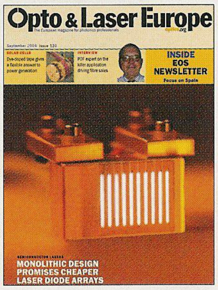

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Mercury altimeter set for warm reception

MESSENGER, NASA's first mission to circle Mercury, was launched in early August. **Jacqueline Hewett** finds out about the laser altimeter that will produce an accurate topographic map of the planet's surface.

As one group of NASA scientists delights in the recent success of the Cassini–Huygens mission to Saturn, another group is now holding its breath. Following a successful launch on 3 August, NASA is on its way to Mercury for only the second time. Carrying a wealth of scientific instrumentation, the mission will see NASA make its first attempt to map the planet's topography with a laser.

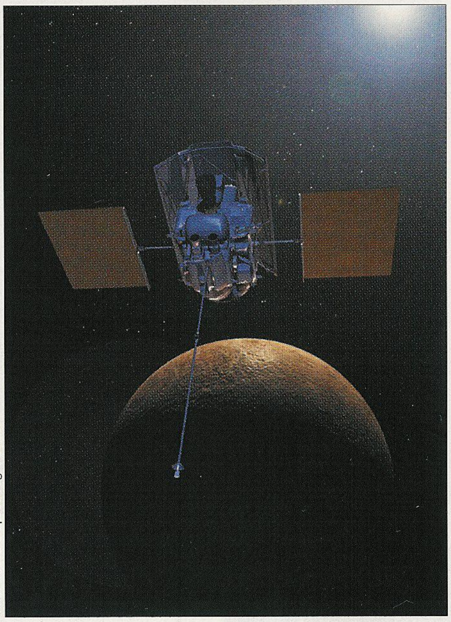
The mission is aptly named MESSENGER, which stands for Mercury Surface, Space, Environment, Geochemistry and Ranging. Launched from Cape Canaveral in Florida, the MESSENGER satellite will travel 7.9 billion km and reach Mercury in 2011. Once there, it will use seven miniaturized instruments to beam back information about the planet's surface, atmosphere and core. The total cost of the mission is around \$427 m (€347.9 m).

One instrument making the journey is the Mercury laser altimeter (MLA), which was built at NASA's Goddard Space Flight Center in Maryland. The MLA weighs 7.4 kg and fits into a box measuring $30\,cm^3$. It uses a nanosecond-pulsed Nd:YAG laser and will map Mercury's surface using time-of-flight measurements.

"The altimeter's main purpose is to make a topographic map of Mercury's northern hemisphere," Xiaoli Sun, an instrument scientist on the MLA project, told *OLE*. "It will also be used to help understand the planet's geophysics, history and evolution as well as determine if Mercury has a liquid or solid core. MLA will also measure surface reflectivity and might help detect possible frozen ice at the bottom of permanently shadowed craters near the polar region."

The more immediate problem, however, is ensuring that the scientific payload survives both the launch and the journey to Mercury. Needless to say, much thought and testing has gone into this aspect of the mission.

NASA gave the go-ahead for MESSENGER in July 1999 and since then scientists in six countries have been putting together the individual components that make up the scientific payload. All seven instruments were installed on MESSENGER in October 2003, and in December the satellite was shipped to Goddard for further testing before launch.


NASA Goddard Space Flight Center


NASA Goddard Space Flight Center

Mercury rising: (top) an artist's impression of the MESSENGER satellite orbiting Mercury. The as-built MLA with its four 11.5 m diameter receiver telescopes surrounding the central beam expander.

Tests included checking the spacecraft's structural strength using large vibration tables, and its balance and alignment using speakers that simulated the noise-induced vibrations of launch. The satellite also survived a month-long thermal-vacuum chamber test that replicated the extreme heat, cold and airless conditions of space.

The anxious scientists will now have to wait at least 16 days to find out if their instruments have survived the launch. "All the instruments will be turned on one at a time to make sure they are working," explained Sun. "Some will be calibrated then."

Seven-year journey

Although MLA's laser will be fired about 3 weeks after launch, Sun says that it will be 12 months before the team knows if the kit is fully functional. "A year after launch MESSENGER will do an Earth fly-by," he explained. "A month before that, as it approaches Earth, we will aim its laser at Earth and see if we can detect it. We will also shoot a laser at the MLA and check the detectors." This long-range test will also be used to calibrate the MLA.

The Earth fly-by is just the start of the satellite's seven-year journey to Mercury that will see it perform fly-bys of Venus in October 2006 and June 2007, and Mercury in January and October 2008 and September 2009. If all goes well, MESSENGER will enter an elliptical orbit around Mercury in March 2011.

Then the science will really start to hot up – quite literally. The Sun is up to 11 times brighter at Mercury than on Earth, and surface temperatures swing from above 450 °C to below –212 °C.

The scientific payload has been designed to fit behind a 2.5 × 2 m ceramic-fabric sunshade that will protect it from direct heat from the Sun. While temperatures on the front of the shade could reach up to 370 °C, behind it the instruments will operate ▷

at room temperature.

The biggest problem for all the development teams has been dealing with the heat radiated from the planet. "The thermal environment is the biggest challenge," said Sun. "The MLA has no on-board cooling. The instrument is heated by its own power and by heat from the planet. During the measurement there is nowhere to dump the heat and we expect the laser temperature to rise by 10 °C."

The MLA has been designed to balance the repetition rate of the laser and the heat it generates. Further constraints were a maximum power consumption of 23 W and the need to fit the system into a small space.

As well as the Nd:YAG laser, the main components of the MLA are a laser-beam expander, four receiver telescopes, timing electronics and a microprocessor. Sun says that a key consideration was choosing optics that could withstand and radiate heat. "We decided to use a sapphire exit window on the laser-beam expander and sapphire objective lenses because of sapphire's ability to withstand thermal shock, resistance to radiation darkening and high emissivity," he said. "The lenses will act as radiators to radiate heat in deep space."

He added that sapphire lenses were not

MESSENGER's scientific payload

The only previous spacecraft to visit Mercury was NASA's Mariner 10 when it flew by the planet three times in 1974 and 1975. Much of what we know about Mercury today is based on data from these fly-bys, even though they imaged only 45% of the planet at a resolution of roughly 1 km.

Mercury is on average 36 million miles from the Sun, about two-thirds closer to the Sun than Earth. This makes astronomical observations from the ground and from near-Earth space orbits difficult. The Hubble Space Telescope does not view the planet because of the risk of damage from looking towards the Sun.

MESSENGER will enter an elliptical orbit around Mercury and travel 36.5 million km, recording data for one Earth year. Two single-sided 1.5 × 1.65 m solar panels will charge up a nickel-hydrogen battery and power the scientific instruments. The panels are 67% mirrors and 33% triple-junction solar cells with an efficiency of 28%. To prevent damage, MESSENGER's on-board computer will tilt the panels away from the Sun when the battery is fully charged.

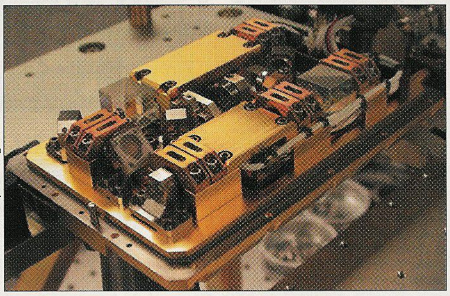
The scientific payload comprises:

- Mercury Dual Imaging System – a camera with wide and narrow fields-of-view for monochrome, colour and stereo imaging of Mercury's surface;
- Gamma-Ray and Neutron Spectrometer – maps the elements present in Mercury's crust;
- X-Ray Spectrometer – also maps the elements in Mercury's crust;
- Magnetometer – maps the detailed structure and dynamics of Mercury's magnetic field, and searches for regions of magnetized crustal rocks;
- Mercury Laser Altimeter – measures the planet's topography and determines whether Mercury has a fluid core;
- Mercury Atmospheric and Surface Composition Spectrometer – measures the abundance of atmospheric gases and detects minerals in surface materials;
- Energetic Particle and Plasma Spectrometer – measures the makeup and characteristics of charged particles within and around Mercury's magnetosphere.

All seven instruments are shielded by a thin 2.5 × 2 m sunshade. The shade comprises front and back layers of Nextel cloth and several inner layers of Kapton plastic insulation.

used in the laser-beam expander because the alignment of the beam is critical. "The receiver is more tolerant of defocusing," he explained. "If you misalign then you miss a fraction of the signal. But on the laser-beam expander, if you misalign then you significantly change the beam divergence and this is critical."

A second consideration was finding materials with high strength and low thermal expansion coefficients. Much of the MLA's mechanical housing, its receiver telescope tubes and laser-beam expander are made of beryllium. "We chose beryllium for its high stiffness and because it is lightweight," said Sun. "The thermal expansion is reasonable." A few key components, such as the MLA's aft optics housing and the instrument mounting flexures are made of titanium, which has a better thermal expansion than beryllium.



NASA Goddard Space Flight Center

Lightweight laser: the laser weighs 0.56 kg without the beam expander and consumes 8.7 W of power.

Mapping Mercury

The Nd:YAG laser emits 6 ns, 20 mJ pulses at 1064 nm. The team settled on a repetition rate of 8 Hz to minimize heating. The laser will operate for about 30 minutes per orbit, and the rest of the 12-hour orbit will be spent radiating excess heat into deep space.

The pulses leave the MLA in a 25 mm square beam which diverges at 80 μrad. This will result in a footprint of 20–100 m on the planet's surface, depending on the altitude of MESSENGER.

The satellite's elliptical orbit around Mercury will see its altitude vary from 200 km to 15 000 km. The maximum range of the MLA, however, is expected to be 1500 km. Photons are expected to take from 4 to 12 ms to return, and will be collected by four 11.5 cm-diameter receiver telescopes and detected using silicon avalanche photodiodes.

"We expect to receive about 100 photons per pulse when we are at 1500 km. This is around the minimum detectable signal," said Sun. "But when we are closer to the planet we expect to detect up to thousands of photons." After a pulse has been detected, timing electronics will perform time-of-flight measurements to build up the topographic map of the planet's surface.

Every pulse represents a pixel in the topographic map. "We expect to achieve a sample rate of 150–450 m per pixel along a path for latitudes of 40° or above," said Sun. "At the end of the mission there will be one track along the planet's surface for every half degree in longitude."

The scientific instruments will make measurements for one Earth year, the equivalent of four Mercury years. "The amount of fuel the spacecraft carries dictates this length of time," explained Sun. "Each Mercury year we have to do a burn to correct the orbit, and we carry enough fuel to do at least three burns."

After eight years in space, the MESSENGER mission will end when the satellite crashes into the planet's surface. But all this is in the future. Today, all thoughts are turned to the state of the scientific payload after launch. "If we can survive the launch then we will be fine," said Sun. "It will be a sweet feeling when it starts sending back data." □

Further details about the MESSENGER mission can be found at: http://messenger.jhuapl.edu/.