Astronomy

Mapping the topography of Mercury with MESSENGER laser altimetry

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The Mercury Laser Altimeter onboard MESSENGER involves unique design elements that deal with the challenges of being in orbit around Mercury.

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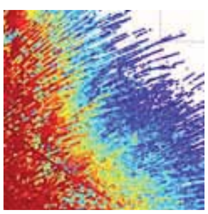


The Mercury Laser Altimeter (MLA) is one of seven instruments on NASA's MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft. MESSENGER was launched on 3 August 2004, and entered into orbit about Mercury on 18 March 2011 after a journey through the inner solar system. This involved six planetary flybys, including three of Mercury. MLA is designed to map the topography and landforms of Mercury's surface. It also measures the planet's forced libration (motion about the spin axis), which helps constrain the state of the core. The first science measurements from orbit taken with MLA were made on 29 March 2011 and continue to date. MLA had accumulated about 8.3 million laser ranging measurements to Mercury's surface, as of 31 July 2012, i.e., over six Mercury years (528 Earth days).

Although MLA is the third planetary lidar built at the NASA Goddard Space Flight Center (GSFC), MLA must endure a much harsher thermal environment near Mercury than the previous instruments on Mars and Earth satellites. The design of MLA was derived in part from that of the Mars Orbiter Laser Altimeter on Mars Global Surveyor. However, MLA must range over greater distances and often in off-nadir directions from a highly eccentric orbit.

In MLA we use a single-mode diode-pumped Nd:YAG (neodymium-doped yttrium aluminum garnet) laser that is highly collimated to maintain a small footprint on the planet. The receiver has both a narrow field of view and a narrow spectral bandwidth to minimize the amount of background light detected from the sunlit hemisphere of Mercury. We achieve the highest possible receiver sensitivity by employing the minimum receiver detection threshold. Figure 1 and Figure 2 show the instrument, laser, and receiver specifications and capabilities.

Laser pulse energy	*20 mJ, 8 Hz, 6 ns FWHM*
Wavelength	*1064.30 ±0.05 nm*
Beam divergence	*80 μrad (TEM00)*
Receiver aperture	*11.5 cm diameter, ×4*
Receiver field of view	*400 μrad*
Receiver optics transmission	*77%*
Receiver optical bandwith	*0.7 nm FWHM*
Detector quantum efficiency	*>35%*
Receiver noise equivalent power (NEP)	*35 fW/$Hz^{1/2}$ (averaged over 33 MHz)*
Receiver timing accuracy	*<1 ns*
Data rate while in operation	*2.4 kbits/s*
Weight	*7.4 kg*
Electrical power consumption	*23 W*

Figure 1. *Photograph of the Mercury Laser Altimeter (MLA) and a list of key instrument parameters. The instrument is 25cm across and 28cm tall. FWHM: Full width at half-maximum.*

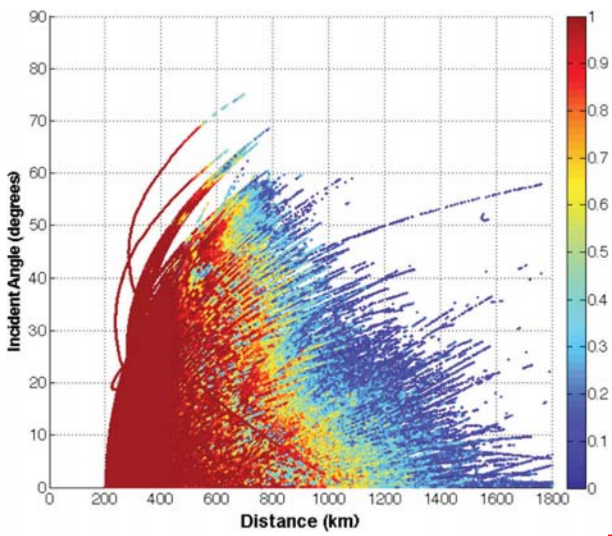
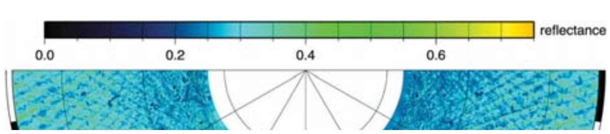


Figure 2. *MLA target detection rate as a function of the distance traveled by the laser beam and its incidence angle, for data collected during the first nine months of orbit around Mercury.*

Whereas previous laser altimeters used a single lightweight reflective telescope to maintain focus, we use four 11.5cm-diameter refractive telescopes to deal with the large and rapid temperature changes that MESSENGER experiences as it moves from flying over the sunlit side of Mercury (>700K) to the night side (90K). We used a sapphire window on the top of the laser transmitter telescope and sapphire lenses for the receiver telescopes. We selected sapphire as the material because of its ability to withstand rapid thermal changes, its low absorption of IR light, and its resistance to darkening by space radiation. We used four multimode optical fibers to combine the light from the four telescopes onto a single silicon avalanche photodiode.

The receiver has two detection thresholds and records the times of threshold crossings at both the rising and falling edges for up to 10 pulses after an outgoing laser pulse. The onboard software determines the target return based on the continuity of the surface profile and on a histogram of data from successive laser shots. For near ranges and strong signals, the two-threshold detection technique gives four samples of the received pulse waveform. This can be used to estimate the received pulse energy and to give a measure of surface reflectance at the laser wavelength. For longer ranges and weak signals, the return pulses can still trigger the low threshold and give range measurements. More details about the MLA instrument have been provided elsewhere.[1–3]



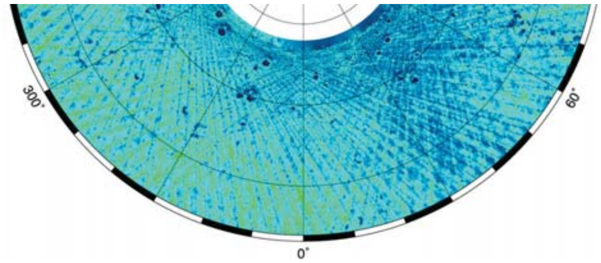


Figure 4. *Surface reflectance of Mercury at 1064nm wavelength measured by MLA. The data are interpolated between tracks, and are presented in polar projection to 72°N.*[8]

MLA has performed well during interplanetary cruise, the first two Mercury flybys in 2008, and in Mercury orbit.[4, 5] This included a successful two-way laser ranging test in 2005 between MLA and the satellite laser ranging station at GSFC over a distance of 24 million kilometers. We have successfully mapped the northern hemisphere of Mercury using MLA during the one-year MESSENGER primary orbital mission.[6, 7] More than half of the 15 million shots completed through 13 September 2012 resulted in valid range measurements. The instrument is coping well with the large temperature gradients. The laser bench temperature changed by up to 20°C over a 40 minute operating period. The laser transmitter telescope experienced a 30°C temperature swing over the same period. MESSENGER's orbital period was changed from 12 hours to 8 hours in March 2012, which put MLA in an even hotter operating environment. The MLA optics remain aligned and in focus throughout the temperature excursions.

MLA measurements have also reached south of the equator, as shown in Figure 3, despite MESSENGER's eccentric orbit and high northern periapsis (closest approach). A map of surface slopes, generated from our topographic measurements, allows volcanic smooth plains to be distinguished from older and more cratered terrain.[7] With MLA we are also mapping surface reflectance, including regions of permanent shadow in Mercury's north polar region (see Figure 4) that may contain deposits of water ice.[8] We will continue measurements with MLA through MESSENGER's extended mission to refine the topography and surface reflectance measurements and to complete our coverage of the polar region.

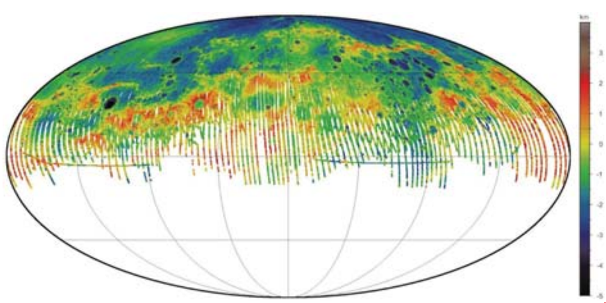


Figure 3. *MLA measurement coverage of Mercury, as of 13 September 2012. The two ground tracks almost following the equator were made from pre-orbital flyby measurements.*

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