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Planetary and Space Science 54 (2006) 645–660
Planetary and Space Science
www.elsevier.com/locate/pss

A laser altimeter for BepiColombo mission: Instrument design and performance model

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Received 20 May 2005; received in revised form 13 March 2006; accepted 22 March 2006
Available online 9 May 2006

Abstract

This paper presents a definition study of a laser altimeter for the topographic exploration of Mercury. The reference scenario is the BepiColombo mission, a cornerstone mission of European Space Agency (ESA) planned for 2012. BepiColombo will offer the chance to make a remarkable new contribution to our knowledge of the Solar System, by venturing into the hot region near the Sun and exploring Mercury, the most enigmatic of the earth's sisters among the terrestrial planets. First images of Mercury surface were acquired by Mariner 10 in 1974 and 1975 offering a coverage and resolution comparable to Earth-based telescopic coverage of the Moon before spaceflight. BepiColombo mission can be very beneficial by using an optical rangefinder for Mercury exploration. In fact starting from the first missions in 1970s until today, laser altimeters have been demonstrating to be particularly appropriate as part of the scientific payload whenever the topography of earth, lunar and planetary surface is the scientific objective of a space mission.

Our system design is compliant to Mercury Polar Orbiter (MPO) of the mission. System performance analysis is carried out simulating main hermean topographic features and the potential targets on the planet by means of analytical models and computer codes and several plot are presented to analyse the performance of the instrument.

Keywords: Mercury; Topography; Laser altimeter; BepiColombo mission

1. Introduction

Recently a laser rangefinder has been considered for an European Space Agency (ESA in the following) cornerstone mission: the BepiColombo mission to Mercury (Murphy et al., 2003).

The main scientific objectives of BepiColombo mission are (ESA, 2000):

- morphology, geology, cratering and surface composition of Mercury;
- planetary magnetic field, rotational state and interior structure of Mercury and
- general relativity and gravitation.

The mission will send to the planet two orbiters:

- Mercury Polar Orbiter (MPO) dedicated to planet wide remote sensing, radio science and asteroids observations and
- Mercury Magnetospheric Orbiter (MMO) accommodating mostly the field, wave and particle instruments.

BepiColombo will be the first mission with dual Mercury orbiters and the first European deep-space probe using electric propulsion.

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0032-0633/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pss.2006.03.003

The MPO and the MMO composites will be launched in 2012 and will reach Mercury in 3.5 years. First images of Mercury surface were acquired by Mariner 10 in 1974 and 1975 (Neukum et al., 2001; Watters et al., 2001; Robinson and Lucey, 1997). The best resolution of 2500 images was around 100 m but less than 1% of the surface was covered at a resolution of better than 500 m and less than 50% coverage was obtained at a resolution between 1 and 1.5 km. This coverage and resolution is modest and comparable to Earth-based telescopic coverage of the Moon before spaceflight.

BepiColombo mission can be very beneficial by using an optical rangefinder for Mercury exploration. The technique can provide accurate information on the surface profile in a fast and cost effective manner in comparison with RF system (Mattei et al., 2006), and allowing, within the characteristics of spacecraft orbit, global coverage of the planet surface.

The basis of the laser altimeter measurement is the timing of short pulses for round-trip propagation at the speed-of-light between the space probe and the surface to be measured (Bufton, 1989; Forrester and Hulme, 1981). Laser altimetry can provide measurements of the structure and albedo of the target surface in addition to the straightforward range measurement (Gardner, 1992; Abshire et al., 2000). Surface structure (i.e. the height distribution or slope within the laser footprint) is determined by the analysis of the backscattered laser pulse shape through analogue processing or high-speed digitisation. The transmitted laser pulse width is typically optimised to be very short (1–10 ns) for high-precision ranging. After interaction of the laser footprint with a rough or sloping surface, the backscattered pulse may contain several nanoseconds or more of pulse spreading or distortion. The application of gigahertz bandwidth digitisation to this received pulse waveform provides pulse shape data. The backscattered pulse width (or rms pulse spreading) that is derived from these data is usually a sufficient measure of surface structure. The total area under the received pulse is proportional to the pulse energy and it is a measure of surface albedo at the monochromatic laser wavelength. Effective use of this albedo data requires at least a calibration of laser backscatter from different surfaces and a normalisation by laser transmitter energy.

From 1971 to 72, when three Apollo missions carried laser altimeters to the Moon, to the Mars Global Surveyor mission operating the MOLA (Mars Orbiter Laser Altimeter) instrument for nearly 1000 days, the number of planetary ranges has increased by more than five orders of magnitude, and accuracy by nearly three orders. High-resolution Moon contour maps were created from Apollo orbiters metric camera stereo images, using control from laser altimeters (Margot et al., 1999). Coverage was modest, laser transmitters were short-lived but the Apollo altimeters were adequate for their primary purpose, giving ranges for photographs, with a precision of about 4 m. Two decades after the Apollo orbiters, a Laser Image Detection and Ranging (LIDAR) experiment was designed to measure the distance from the spacecraft to a point on the surface of the Moon (Nozette et al., 1994; Smith et al., 1997) and flown on Clementine, a joint mission of NASA (National Aeronautics and Space Administration) and the Ballistic Missile Defence Organisation. This allowed an altimetric map to be made, which can be used to identify the morphology of large basins and other lunar features. SLA-01 was the first of four planned flights to precisely measure the distance to the Earth's surface from the Space Shuttle. SLA-02 emitted laser pulses and measured their echoes from the Earth to determine the shape of land surfaces and vegetation canopies. SLA-01 and SLA-02 demonstrated the effectiveness of orbital laser altimeters for terrestrial geodesy despite relatively short flights and the inconvenience of using the shuttle as an orbital platform (Garvin et al., 1998). In February 2000 the NEAR (Near-Earth Asteroid Rendezvous) spacecraft, which carried the NEAR Laser Range (NLR), reached the asteroid 433 Eros, one of the largest and most intensively studied near-Earth asteroids (Cheng et al., 2000; Cole, 1998). The overall NEAR mission objective was to provide information about the origin and nature of near-Earth asteroids, whose characteristics are suspected to provide clues about the formation of the inner planets, including the Earth. The NLR made highly accurate measurements of asteroid's shape and detailed surface capability. In September 1997, the Mars Global Surveyor (MGS) entered into orbit around Mars. One of the four scientific instruments on MGS was the Mars Orbiter Laser Altimeter (MOLA) which mapped the topography of the planet to unprecedented accuracy (Abshire et al., 2000; Neumann et al., 2001). The primary objective of the MOLA investigation was to determine the global topography of Mars for addressing fundamental questions in planetary geology and geophysics. Secondary objectives was the study of the 1064 nm surface reflectivity of Mars, to contribute to analyses of global surface mineralogy and seasonal albedo changes, to assist in addressing problems in atmospheric circulation, and to provide geodetic control of topography for assessing future Mars landing sites. In August 2004, NASA's Discovery programme launched MESSENGER (MErcury Surface, Space, ENvironment, GEochemistry and Ranging) spacecraft with Mercury Laser Altimeter (MLA) and other six scientific instruments on board. The goal of MESSENGER mission is to analyse the planet Mercury in order to understand how terrestrial planets formed and evolved (Solomon et al., 2001). MLA will start its observations on 2011 measuring the topography of the Mercury northern hemisphere via laser pulse time-of-flight (TOF). The primary science objectives are to provide a high-precision topographic map of the polar region, measure the long-wavelength topographic features of the mid-to-low latitude region, and to detect and to quantify the planet's forced librations (Sun et al., 2004). The laser design is on the heritage of MOLA technology but incorporates peculiar thermal management features