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Current status of Development of Mercury Dust Monitor for BepiColombo MMO

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Abstract

The Mercury dust monitor (MDM) will be the BepiColombo/Mercury magnetospheric orbiter (MMO) and be operated to clarify the dust environment around Mercury. The MDM employs lightweight and heat-resistant piezoelectric ceramic sensors made of lead zirconate titanate (PZT). This paper describes the current status of MDM development and ground calibration test using a dust accelerator facility.

1. Introduction

Interplanetary dust particles have been investigated by in-situ observations using space probes. Dust environment in the inner heliosphere, however, has been not known precisely. Helios was the first and the last to measure dust fluxes in the inner solar system between 0.3 and 1.0 AU from the Sun in 1970s. Helios detected dust particles with masses between 10^{-14} and 10^{-10} g, however, the detected flux was not large enough around perihelion for discussing dust mass (size) distribution, since the measurements were mainly performed near the aphelion around the Earth's orbit [1].

To elucidate the dust environment around Mercury (0.31-0.47 AU), we have been developing Mercury Dust Monitor (MDM) to be installed on the side panel of Mercury Magnetosphere Orbiter (MMO) of the ESA - JAXA joint Mercury exploration mission Bepi-Colombo [3]. The spacecraft will be launched in 2015, and, after arriving at Mercury in 2020, will observe Mercury for 1 year and more. In the 6-years' cruising time, all scientific instruments will be dormant because the spacecraft will be covered by the sun shield. One of the expected achievements is to determine the fluxes of low-eccentric Keplerian dust particles moving inward due to the Poynting – Robertson effect, beta-meteoroid particles and possibly ejecta from the surface of Mercury as a result of micro-meteoritic impacts, which might form the sodium atmosphere of Mercury, as well as interstellar dust. In situ measurements of dust particles should clarify whether the size shift by dust–dust collision is ongoing in the Mercury region [2].

2. MDM Instrument

The MDM system is composed of a piezoelectric ceramic sensor unit (MDM-S) attached to the outside of the side panel and the electronics unit (MDM - E) installed inside the MMO. The advantages of this type of detector include: (1) simple configuration, (2) large sensitive area compared with the mass of the system, (3) high-temperature tolerance up to +230 °C, and (4) no bias voltage needed. The MDM-S consists of four square plates of lead zirconate titanate (PZT) piezoelectric ceramic sensors (40mm × 40mm × 2mm) coated with heat resistant white paint to reflect solar light. As the piezoelectric material generates voltage signals through the stress caused by the impact of a dust particle, the number of dust impact events, the crude incident direction and the particle momenta can be evaluated with this instrument. We have estimated the number of impacts on the monitor to be 0.5 to 1 hit/day and the minimum detectable mass of dust particles to be approximately 10^{-13} g assuming the dust impact velocity of 30 km/s. The MDM-E is composed of four charge sensitive pre-amplifiers (CSA) for each sensor, gain controller, filter unit and logic circuit. Voltage signals from the four PZT sensors amplified by the CSAs are added by a summing amplifier, and then digitized by an 8-bit ADC with a sampling rate of 40 MHz. The resource limitation allows us to store 1000 sampling points from the timing of triggering for individual impact event. In this case, 30 events can be stored in a memory and be downlink to ground as waveform signal during daily operation. Those waveform signals are used for identification of signal and noise, and for determination of momenta of incident dust particles.

3. Calibration Experiments

For calibration of dust observation with MDM, we have implemented a dust acceleration test campaign using a high voltage Van de Graaff dust accelerators at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany, in April 2012. This experiment was implemented for the selection of flight sensors and the evaluation of functionality of MDM system. Four flight PZT sensors were selected out of whole sensor sets that we made including spare sensors and to evaluate the functionality of electronics of MDM-E in terms of sensitivity. This experiment was significant to determine the lower limit of the dynamic range of dust momenta. In the experiments, the dust particles of iron were accelerated with the speeds in the range between 0.5 and 10 km/sec and with the sizes of up to 2μm. To estimate the physical parameters of impacting dust particles, such as velocity, mass and momentum, from the impact signals of the sensors, empirical formulae is obtained through calibration experiments. The waveforms of impact signals from PZT sensors of MDM are processed with Fast Fourier Transformation to make frequency spectra. The spectra have a strong resonance peak for real dust impact event and the intensity of the resonance peak around 1MHz has linearity with the momentum transfer of an incident dust particle. For future data analysis of observation data, calibration curves will be produced from the relation between the momenta of dust particle measured in accelerator and the resonance peak intensity for individual sensors.

4. Summary

To clarify the dust environment around Mercury, we have proposed that the Mercury dust monitor (MDM) will be onboard the BepiColombo/Mercury Magnetosphere Orbiter. The main objective of the project is to obtain new data on the flux and momentum of the interplanetary meteoroid complex near Mercury (0.31–0.47AU). The MDM uses light weight and heat-resistant piezoelectric ceramic sensors made of lead-zirconate-titanate (PZT). Four square plates of PZT will be installed on a side panel of the MMO. The piezoelectricity of PZT generates a transient voltage signal by impact with a dust particle. It is easy to determine the time of the impact event from which the incident direction is roughly estimated using the spin angle of the MMO. To extract kinetic information on incident particles from the output signals of the PZT sensor, calibration experiments have been carried out with hypervelocity dust particles from two Van de Graaff dust accelerators.

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