Planetary and Space Science 85 (2013) 250–260

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

The extreme ultraviolet spectroscope for planetary science, EXCEED

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ARTICLE INFO

Article history:
Received 8 March 2013
Received in revised form
10 June 2013
Accepted 20 June 2013
Available online 29 June 2013

Keywords:
EUV observation
EXCEED
Io plasma torus
Planetary science
Spectroscope

ABSTRACT

The extreme ultraviolet spectroscope EXtrem ultraviolet spetrosCope for ExosphEric Dynamics (EXCEED) on board the SPRINT-A mission will be launched in the summer of 2013 by the new Japanese solid propulsion rocket Epsilon as its first attempt, and it will orbit around the Earth with an orbital altitude of around 1000 km. EXCEED is dedicated to and optimized for observing the terrestrial planets Mercury, Venus and Mars, as well as Jupiter for several years. The instrument consists of an off axis parabolic entrance mirror, switchable slits with multiple filters and shapes, a toroidal grating, and a photon counting detector, together with a field of view guiding camera. The design goal is to achieve a large effective area but with high spatial and spectral resolution. In this paper, the performance of each optical component will be described as determined from the results of test evaluation of flight models. In addition, the results of the optical calibration of the overall instrument are also shown. As a result, the spectral resolution of EXCEED is found to be 0.3–0.5 nm Full Width at Half Maximum (FWHM) over the entire spectral band (52–148 nm) and the spatial resolution achieve was 10". The evaluated effective area is around 3 cm^2. Based on these specifications, the possibility of EXCEED detecting atmospheric ions or atoms around Mercury, Venus, and Mars will be discussed. In addition, we estimate the spectra that might be detected from the Io plasma torus around Jupiter for various hypothetical plasma parameters.

1. Introduction

The extreme ultraviolet (EUV) is an important spectral band for planetary science as it includes many interesting emissions from plasmas and atmospheres. However, it is not easy to observe there because to begin with the observing site must be outside of the Earth's atmosphere in order to avoid absorption. And because the emissions from many of the targets are very faint, the effective area of the detector should be as large as possible and long observation times are required.

Beginning more than 30 years ago, a number of satellites and orbiters have made planetary observations in the EUV. The first attempt to observe planetary EUV emission was made by the spectrometer on board Mariner-10 (Broadfoot et al., 1977). The instrument took the spectra from the atmosphere of Mercury and Venus. Several years later, the EUV imager on board the Planet-B spacecraft took the first images of a part of the Earth's plasmasphere capturing the EUV emissions from the helium ions (30.4 nm) there (Nakamura et al., 2000; Yoshikawa et al., 2000). The Ultraviolet Imaging Spectrograph on board the Cassini spacecraft made both imaging and spectroscopic observations of Jupiter and Saturn (Esposito et al., 2004). The Erath orbiting EUVE satellite also made EUV observation of the Mars and Jupiter (Krasnopolsky et al., 1994; Herbert and Hall, 1998). In addition, the KAGUYA spacecraft observed the Earth's plasmasphere from the orbit of moon using EUV emissions (Yoshikawa et al., 2008; Murakami et al., 2013). Although these observations have delivered much valuable scientific information, it has limitations due to limited observation windows, narrow fields of view and spectral bands, and low spectral resolution; all of which create serious constraints on what we can say about of the respective planetary plasmas with respect to long period variations or phenomena with wide dynamic range.

EXtrem ultraviolet spectrosCope for ExosphEric Dynamics (EXCEED) is an EUV spectroscope on board the Japanese small scientific satellite, “SPRINT-A” which is dedicated to planetary science. It will be launched in the summer in 2013 and carry out spectroscopic and imaging observation of EUV emissions from the plasmas and atmospheres around the solar system planets. The spectral range of EXCEED is wide enough to include the majority of planetary EUV emissions (52–148 nm) and its spectral resolution is high enough to separate those lines (Full Width at Half Maximum,

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http://dx.doi.org/10.1016/j.pss.2013.06.021

FWHM: 0.3 nm). Since EXCEED is developed mainly for planetary science, its observation window can be dedicated to the solar system planets limited only by the allowable geometrical angles of the observing Sun–Spacecraft–target system.

In this paper, the specifications and performance of EXCEED as measured during the flight model calibration is summarized, and possible observation scenarios will also be discussed.

2. Scientific targets

EXCEED has two main scientific goals. One is to estimate the atmosphere escaping rate from the terrestrial planets. Although, heretofore there have been several in-situ observations by orbiters, the knowledge obtained from them has been limited (e.g., Shizgal and Arkos (1996)). VENUS EXPRESS and MARS EXPRESS measured physical parameters such as velocity and temperature along the orbits. They allowed good estimations of these flows based on their in-situ measurements (Lundin et al., 2008; Lammer et al., 2006). These orbiters measured local physical parameters such as velocity and temperature, but global aspects such as the total amount of outward-flow plasma are not straightforward to determine with a few exception such as Rosetta–Alice observation for Mars (Feldman et al., 2011). EXCEED will be able to deduce the density distribution of the planetary plasmas and determine the quantity of the escaping atmosphere. Its field of view is wide enough that we can get an image from the interaction region between solar wind and planetary plasmas all the way through to the tail at any one time. This will enhance our knowledge of the characteristics of outward-flowing plasmas, e.g., their composition, rate of flow, and dependence on solar activity. For Mercury, the first observation of its exosphere was made by the Mariner-10 spacecraft (Broadfoot et al., 1976). They found three atomic species there (H, He, and O). After later observations by ground-based telescopes, atomic sodium, potassium, and calcium have also been detected (Potter and Morgan, 1985, 1986; Bida et al., 2000). Next, the ultraviolet spectrometer on board NASA's MESSENGER detected atomic magnesium (McClintock et al., 2009). In addition, a distribution of magnesium, calcium, and sodium around the tail region of Mercury has been found (Vervack et al., 2010). The sodium imager with Fabry–Perot interferometer MSASI (Yoshikawa et al., 2010) and UV spectrometer PHEBUS (Chassefiere et al., 2010) on board the European Space Agency (ESA) and Japan Aerospace Exploration Agency's (JAXA) BepiColombo mission which will be launched in 2016 will improve our knowledge of the spatial variations of atmosphere around Mercury. Through EUV emissions, EXCEED will be able to map possible density distributions of other atomic species such as neon or sulfur which have bright emissions in the EUV. Such information will help us to understand the evolution of Mercury and the generation process of its exosphere.

The other study objective for EXCEED is the plasma dynamics around the Jovian inner magnetosphere. This can be monitored by using the EUV emission surrounding the Io plasma torus which is located in the Jovian inner magnetosphere. The neutral volcanic ejecta from Io, one of the Galilean satellites is the main source of plasma for the torus, and drives the shape and dynamics of the rapidly rotating Jovian inner magnetosphere. Major ions such as sulfur and oxygen have many allowed transition lines in the EUV, and their radiation easily escapes to become observable from outside the plasma region (Delamere and Bagenal, 2003; Steffl et al., 2004a). EXCEED will carry out both spectroscopic measurements as well as making imaging observations, together they will enable us to deduce the radial distribution of the ion densities and surrounding electron temperatures through the spectral diagnosis (see Section 6.2).

In addition, EXCEED will also observe the Jovian aurora. The radiation from the aurora comes from excitation by the precipitating electrons along the magnetic field line in the foot print of the middle (~20 Jovian radii from the planet center) magnetosphere (Gerard et al., 1994; Bhattacharya and Thorne, 2001). Furthermore, it is thought that the electrons around the equatorial plane move toward inside through the process of injection (Mauk et al., 2002) or interchange instability (Russel et al., 2005). Therefore, since EXCEED can observe both the torus and aurora at same time, we will be able to discuss about the plasma transport process around the Jovian magnetosphere by comparing the spectra of the torus (inner magnetosphere) to that of the aurora (corresponding to the middle magnetosphere).

3. Launch date and orbit

The EXCEED satellite will be launched in the summer of 2013 by the new Japanese solid propulsion rocket Epsilon (Morita, 2012). Epsilon has been developed to provide a more reliable and responsive space launch system with a lower life cycle cost for various small satellites. The rocket has 3 stages and is designed to provide flexible capabilities for various orbits and weights. The SPRINT-A is the first satellite that will be launched by Epsilon. The nominal mission life is 1-year but it could be extended to several years. As shown in the previous section, EXCEED will address various fundamental scientific questions pertaining to planetary plasma science through its capability for observations covering wide dynamic ranges and long time periods. Fig. 1 shows the Sun–spacecraft–planet angles from the beginning of 2013 to the end of 2015. Thanks to its entrance baffle, EXCEED can observe planets as long as the separation angle exceeds 20°. After the launch and in-flight calibration, we will start to observe Venus for several weeks. Then the target will shift to Jupiter. After 2 months of observing Jupiter, Mars and Mercury will be selected. The orbital altitude has a 950 km perigee and 1150 km apogee. These come from optimizing the tradeoffs between contaminating emissions from the Geocoronal emission and Van Allen radiation belt (Yoshioka et al., 2010). The orbital period is 105 min and the inclination is 31°.

4. Design and performance of the EXCEED (efficiency)

EXCEED consists of an entrance mirror, a slit plate with changeable filters, a grating, and a photon counting device together with an FOV guiding camera (Fig. 2). The incoming photons from the targets (planetary emissions) are incident onto

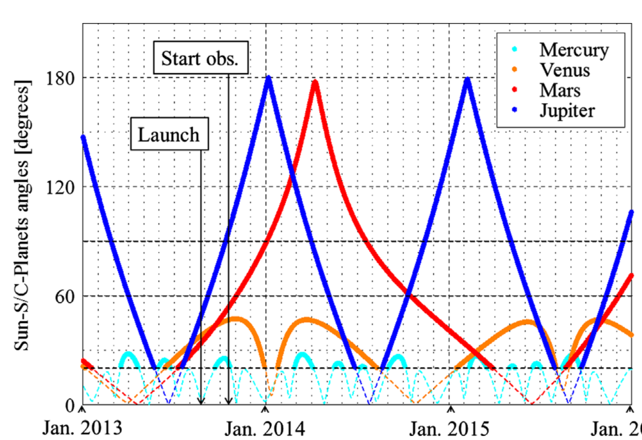

Fig. 1. The Sun–spacecraft–planet angle as a function of time. The angle must be larger than 20° before targets can be observed (bold lines).