The Effect of Plasma and Dust of Enceladus on Saturn's E Ring

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ABSTRACT

Saturn's E ring was discovered in 1996 and it is associated with materials ejected out (geysers) from particular areas (Tiger Stripes) around the south pole of Enceladus. Our study about activities of the geysers and their influences on E ring was conducted by making use of *Cassini* data of the ejected plasma and dust. The suitable data were recorded by the *Cassini* detectors on three events, i.e. March, August, and October, 2008. Moreover, ephemeris data of Enceladus, *Cassini*, and Saturn are used to figure out orbital configurations across the events. Mean-motion resonance between Enceladus and Dione occurs in equatorial configuration, so this may play an important contribution on Tiger Stripes compared to those caused by other satellites. Analyzing of the plasma and dust data reveals no regular pattern covering Enceladus and the data vary caused by the geysers. Number of ejected dust and mass increases for the three events, while that of plasma decreases. Variation of the data indicates no regular material ejection.

Keywords: Saturn, Enceladus, Ring E, *Cassini*

1. INTRODUCTION

Enceladus is one among inner satellites of Saturn. Geyser plasma and dust may be trapped in the gravity of Saturn and produces the ring E. The geysers, consisting of organic materials, are main constituents of the ring E material. Ammonia detected in geysers suppresses the H_2O freeze point, so that H_2O can be in liquid phase. Besides by Saturn, geological activities on Enceladus are influenced by the 2:1 orbital (mean-motion) resonance of Enceladus and Dione. Examinations to resonances of other satellites (Dione, Tethys, Mimas, Rhea) with Enceladus verified that the Enceladus-Dione resonance occurs at about equatorial region of Enceladus and this may be responsible for the geyser phenomena.

This study focuses on recognizing activities of the geyser around the south pole of Enceladus and weighing up number of geyser's material and mass which develop Saturn's E ring.

2. DATA

Data of plasma and dust were provided by the Planetary Data System (PDS) NASA, and the ephemeris were taken from the JPL-NASA Solar System Dynamics. Plasma data were recorded by *Cassini* RPWS (Radio Plasma Waves) instrument, comprising *Cassini* distances from Enceladus, electron density (N_e), electron temperature (T_e), and spacecraft potential (Sc). Dust data are taken from *Cassini* CDA (Cosmic Dust Analyzer) instrument that records signal on the detector (MP), electron charge on Chemical Analyzer Target (QC), ion charge (QI), inducted electron charge (QP), and electron charge on CDA (QT). After scrutinizing the above data types based on closely available consecutive time occurrences, finally the suitable ones were selected on three events, i.e. 11, 12, 13 March (Event 1); 10, 11, 12 August (Event 2); and 31 October 2008 (Event 3). The events were actually *Cassini* encounters with Enceladus.

3. RESULTS AND DISCUSSION

3.1. *Cassini* Encounters with Enceladus

A configuration of *Cassini* encounter with Enceladus on Event 1 centered on Saturn is illustrated in Figure 1. Other two events showed about the same scheme, coming from the northern hemisphere of Enceladus (arriving phase) and going out from the southern hemisphere (leaving phase). Data of plasma and dust were taken along the cruises and here we report our analyses to the data.

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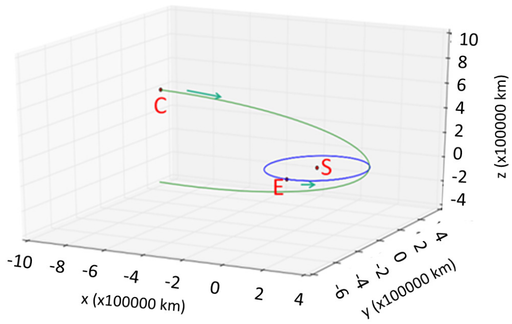

Figure 1. A configuration of *Cassini* (C) encounter with Enceladus (E) on Event 1, while S stands for Saturn at the center.

3.2. **Plasma**

We infer that electron density (N_e) increases when *Cassini* came closer to Enceladus. However, no periodic or waving pattern has been detected as shown in Figure 2. This indicates a sporadic ejection of the geysers and spreading material in rather short time.

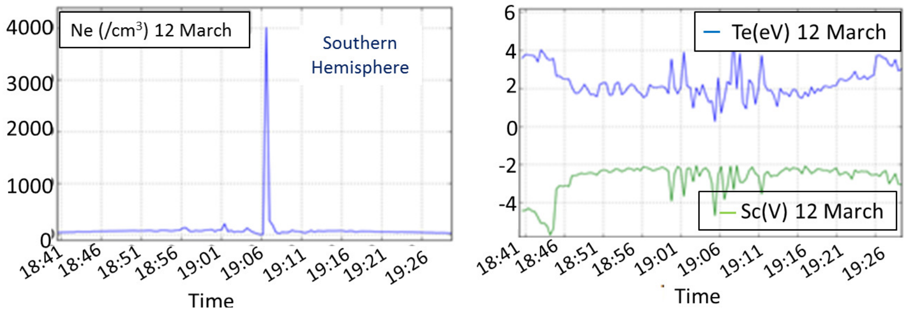

Figure 2. The detected plasma in southern hemisphere on Event 1

Meanwhile, it is verified that when electron temperature increases, the spacecraft potential decreases. This is in agreement with Morooka et al. (2011) that regions having high N_e have negative Sc. Variations of T_e and peak of N_e show that there must be a particular phenomenon occurs in the southern hemisphere.

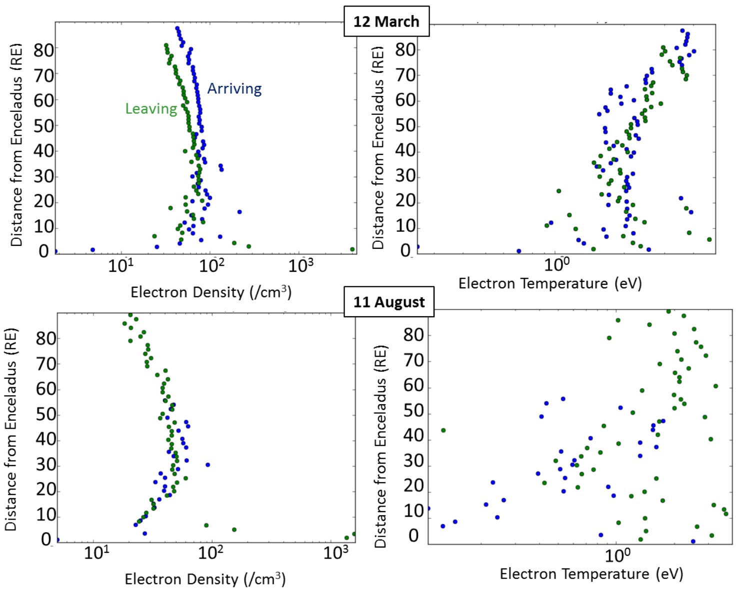

Figure 3. Circumstances of plasma with respect to distances from Enceladus. Upper and lower panels are, respectively, for Event 1 and Event 2.

On 12 March (Event 1), N_e in the northern hemisphere was denser than that in the southern hemisphere. Meanwhile, at very close locations to Enceladus, N_e was more vary influenced by the geysers (Figure 3). It is also found that on Event 1 the detected T_e in northern hemisphere was higher than that on other events. The phenomenon on 12 March (Event 1) differs from 11 August (Event 2), but the latter was about the same manner with that on 31 October (Event 3). This findings convey that the geyser related phenomena are very dynamic.

3.3. **Material Disk of Ring E**

There are disks of materials encircling Enceladus. The materials consist of plasma associated with magnetic field and dust associated with gravitational field. Both plasma and dust build the ring E and the disks configuration depend on rotation phase of Saturn and position of Enceladus along orbiting Saturn. The configuration can be responsible to the plasma and dust data recorded by *Cassini* instruments.

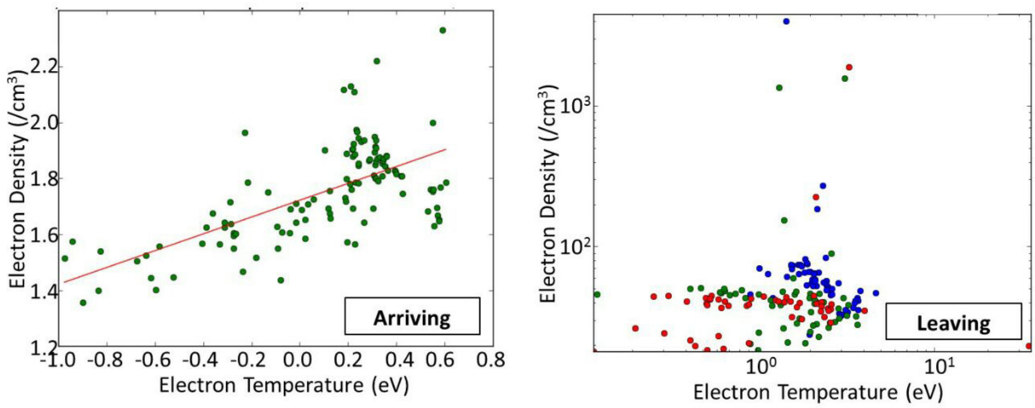

Figure 4. Relation of electron density and temperature electron is obvious in arriving phase, which is indicated by the slope line on the left panel. However, there was no such trend for leaving phase (right panel).

For arriving phase, there is a relation between N_e and T_e, which is estimated using a linear regression to the data, i.e $T_e \simeq N_e^{\gamma-1}$. Figure 4 shows that the polytropic index $\gamma = 3.44$. This implies that the plasma expands adiabatically and releases energy. The positive correlation means that the plasma jet goes out directly from the lower layers above the surface of Enceladus (Edberg et al. 2010). However, such relation did not occur in leaving phase, which was dominantly altered by the geyser's ejection.

3.4. **Dust**

Figure 5 shows samples of sporadic releases of dust with no regular and periodic pattern.

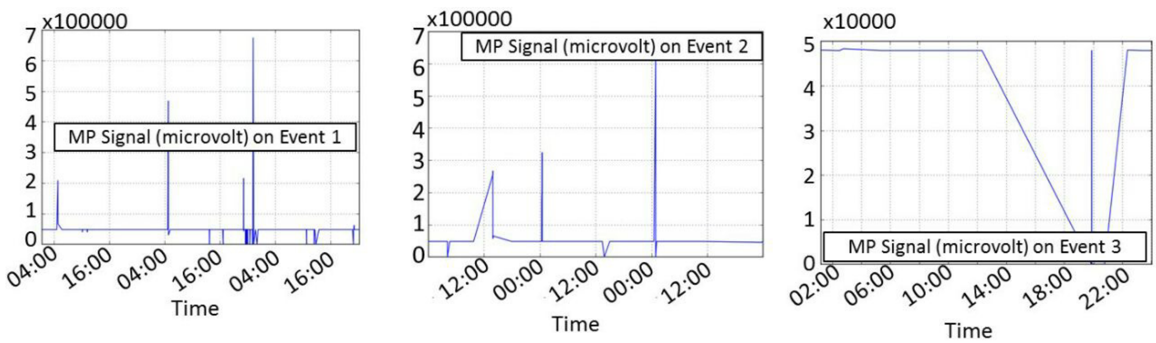

Figure 5. Character of dust in time for all the three events.

The detected signals (only MP signal is shown in Figure 6) increase in southern hemisphere and at distances of ~550–700 $\times 10^3$ km above Enceladus were the densest dust layer. Assuming homogeneous dust size of 3 micron and *Cassini* velocity during the recording time, we estimate number of dust received at the collecting area of the detector (Figure 7).

Extrapolating the estimated number of dust down to the surface of Enceladus, we obtain that number of dust increases from Event 1 to Event 3. Number of dust on 12 March (Event 1) was low, while the plasma was high (opposite trend). On the other hand, we find about the same trends of dust and plasma on 11 August (Event 2) and 31 October (Event 3). We suggest that this is because of different configuration of the disk materials between Event 1 and both Events 2 and 3.

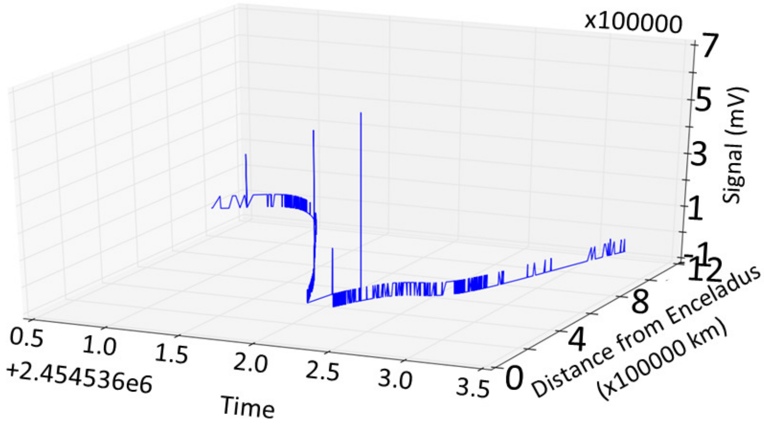

Figure 6. Nature of dust with respect to distances from Enceladus on Event 1.

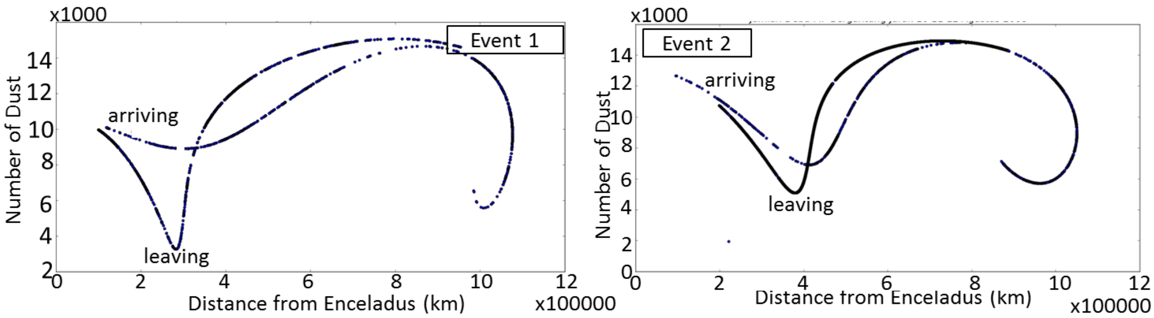

Figure 7. Variations of number of dust (MP Signal) during *Cassini* encounters on Event 1 (left panel) and Event 2 (right panel).

Using estimated Tiger Stripes area of 2.6×10^8 m^2 (Porco et al. 2006), total ejected mass on Event 1 was ~36.3 kg and about the same mass (~46.5 kg) for Events 2 and 3. Recent results by Steele (2013) and Waite et al. (2017) show that very primitive form of supporting condition of life may occur in Enceladus.

4. CONCLUSION

Plasma was more abundant in the northern hemisphere, while dust was more abundant in the southern hemisphere of Enceladus. The number and mass of dust increase but the plasma decreases for the three events (March, August, and October 2008) of *Cassini* encounters with Enceladus. Different number of dust and plasma along the three events is indicative of different disk configuration encircling Enceladus and probably geology activity around Tiger Stripes.

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