Coherent dust cloud observed by three Cassini instruments

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Abstract

We revisit the evidence for a "dust cloud" observed by the Cassini spacecraft at Saturn in 2006. The simultaneous data of 3 instruments are compared to interpret the signatures of a coherent swarm of dust that could have remained floating near the equatorial plane.

1. Introduction

Interplanetary dust clouds are local density enhancements of particles of a specific mass type. Such clouds might usually be relics of a dissolved comet, debris of an asteroidal collision, ejecta from planets or moons, and a few may also go back to jet streams from active bodies, or coronal mass ejections. In the vast range of patterns, the characteristics of dust will vary on all dimensions: size, density, mass, lifetime, and more (see, e.g., Grün et al. (2004)).

Kennedy et al. (2011) looked for a dust swarm in the far-off field at Saturn (>100 Saturnian radii, RS) using Spitzer observations. A large-scale cloud, that could be attributed to an irregular satellite or other cosmic origin, was not found definitely. More recently, Khalisi et al. (2015) reported of one possible dust cloud detected as a persistent feature in the impact rates of the Cosmic Dust Analyser on the Cassini spacecraft. We revisit their data in a broader context and complement it with new evidence. We synchronised the data by the Cosmic Dust Analyser (CDA), the Radio/Plasma Wave Detector (RPWS), and Magnetometer (MAG) to search for patterns that may give evidence for a cloud of particles. Unfortunately, the Plasma Spectrometer (CAPS) did not provide sufficient output in the time slot considered.

2. Data Basis

The key parameters of the instruments on the Cassini spacecraft are stored in the MAPSview database. We employed the following parameters for our study:

- CDA: impact rate $r'_{\text{all}}$ of all the registered dust events per 64 seconds, see [4];
- RPWS: qualitative radio signals in the frequency bands of 1 Hz, 10 Hz, 100 Hz, 1 kHz, and 10 kHz;
- MAG: strength of the magnetic field $|B|$ plus its three spatial components in the kronicentric solar-magnetospheric (KSM) coordinate system.

Most parameters are provided at 1-minute intervals of time, except some very few cases when the instrument was out of nominal operation.

The CDA data depend on the current instrument pointing and reflect the density as well as other states of the dust only partially. RPWS and MAG are not reliant on the spacecraft attitude and have the advantage of a continuous measurement of their respective signals throughout the orbit. In particular, the components of the B-vector give important clues to alignments of the magnetic field or circular currents.

3. The dust cloud of DOY 203/2006

The Cassini spacecraft just changed its sequence of orbits from equatorial to inclined trajectories after a targeted flyby at Titan (T16) on DOY 203.02. It set in for four consecutive revolutions (#26–29, Fig. 1) out of the equatorial plane to traverse almost the same spot in the Saturnian space. The inclination to the ring plane was about 15° for these revolutions (not seen in that projection). The ring plane of Saturn was crossed at DOY 203.11 in a distance of 20.126 RS. The green segments mark the region of the supposed dust cloud.

Figure 2 shows the time-dependent signals of the three instrumental parameters in July 2006. The peak in the dust rate at DOY 203.40 coincides with a depression of $|B|$ (black line), and, in particular, the B$_x$-component (blue) changes its direction. The B$_y$-component (orange) exhibits a decline from positive to negative values and rising back again showing a clear sign of rotation as a ring current was hit. At time $T = 203.50$, the previous B-values were restored acting as
Figure 1: Trajectory of Cassini from outer regions heading to its perikronium. The region of the dust cloud is highlighted green.

if separated by a bulkhead. Goertz (1983) reported of similar plasma tubes from both Voyager flybys. He interpreted that as “plasma blobs” breaking off the magnetospheric sheet.

The RPWS data support the thought of a “magnetic bubble”, for it shows a remarkable tranquility in the 100 Hz and 1000 Hz band (third and fourth curve of RPWS in the middle panel). A dozen "negative peaks" appear in the 1 Hz band (top black curve). These peaks can be considered as micron-sized dust grains impacting on the spacecraft. Similar features in the 10-kHz-band were discussed by Kurth et al. (2006). Moreover, the CDA registered twice as much impacts on the instrument housing than on its sensitive areas, meaning that many particles did not enter from the Kepler-RAM direction. Time stamps of the most conspicuous features are given in Table I.

The same pattern repeated at the next two passages when the spacecraft passed almost the same spot of space. During the Revolution #27 (Fig. 3), the CDA pointed to an unsuitable direction, but the countersink of the magnetic field remained. — At the third return the signals resemble DOY 203 again (Fig. 4). In spite of some changes among minor features, important characteristics of the first passage can be identified. From the time stamps of entering and leaving, the radial extent of that “cloud” or “blob” can be estimated to $\approx 82,500$ km or $1.36 R_S$. Its $z$-location is found $1 R_S$ below the ring plane. — At the fourth passage on DOY 266/2006 (not shown), the CDA data displays even stronger deviations, and the allocation of that cloud turns out uncertain.

Figure 2: Data comparison of three Cassini instruments at Revolution #26 in July 2006. Uppermost panel: Dust impact rate $r_{all}$ (black line) and the sensitive area (yellow) of the CDA exhibited to the Kepler-RAM. Middle panel: Five frequencies of the radio and plasma data (RPWS). Bottom panel: Magnetic field strength $|B|$ (black) as well as the 3 B-components in the frame of kronocentric-solar-magnetospheric coordinates.

Figure 3: Data of CDA, RPWS, and MAG for Revolution #27. The main feature of the supposed dust cloud resides from $T = 227.11$ to 227.42.

The MAG-data suggests that the cloud has broadened by $15,000$ km from Revolution #26 through #28. It could also have moved outwards from $18.5 R_S$ to $18.9 R_S$, though this might be an effect of the spacecraft hitting the cloud at different parts. The slightly different trajectory can also be the reason for the discrepancies in the data at the second return (DOY 227). The increase of size, however, is supported by the drop of $|B|$ by 2–5 nT. The magnetically “quiet” region in front of the onset of the cloud ($\approx 250.92–251.14$) has
also diminished by 1 nT. The bulk of solid particles (CDA) appears compressed and shifted further from the deepest point of the magnetic field. This deviation seems to grow.

There exist indications for two more clouds during the Revolution #26: from $T = 202.95$ to 203.05 and from $T = 203.65$ to 203.95. Both can be re-discovered at the next but one flyby: in Revolution #28, they peak around 250.80 and 251.50, respectively.

Table 1: Time stamps $T$ of the dust cloud as seen by different instruments. $D = \text{distance of the pattern peak from Saturn.}$ Brackets reflect very uncertain data.

| Instr. | $T$ (enter) | $T$ (leave) | $D [R_S]$ |
|--------|-------------|-------------|-----------|
| CDA    | 203.32      | 203.52      | 17.69     |
| MAG    | 203.33      | 203.50      | 17.64     |
| RPWS$_{1\text{Hz}}$ | 203.36 | (203.53)    |           |
| RPWS$_{100\text{Hz}}$ | 203.36 | 203.56      | 17.64     |
| RPWS$_{10\text{kHz}}$ | 203.31 | 203.56      | 17.71     |
| CDA    | (227.10)    | (227.39)    | (18.78)   |
| MAG    | 227.11      | 227.42      | 18.93     |
| RPWS$_{1\text{Hz}}$ | (227.06) | (227.28)    |           |
| RPWS$_{100\text{Hz}}$ | 227.09 | 227.39      | 18.70     |
| RPWS$_{10\text{kHz}}$ | (227.00) | 227.31      |           |
| CDA    | 251.11      | 251.25      | 18.48     |
| MAG    | 251.13      | 251.29      | 18.34     |
| RPWS$_{1\text{Hz}}$ | (251.13) | (251.26)    |           |
| RPWS$_{100\text{Hz}}$ | —       | —           |           |
| RPWS$_{10\text{kHz}}$ | —       | —           |           |

4. Discussion

It is still not certain whether or not such coherent swarms of dust can exist for long in the magnetosphere of Saturn. From the theoretical point of view, small dust particles are quickly ionised (UV-radiation, solar wind) and carried away by the magnetic field. Various other effects like shock waves, gravitational drags, evaporation, and Kepler shear will also lead to a disruption of the cloud. It will preferably be the debris larger than $\approx 1 \text{ mm}$ in size that may endure several crossing times, $r/v$, where $r$ is the projected radial distance and $v$ the velocity dispersion of the particles. Such larger particles are not recorded though. However, the most intriguing evidence for the supposed clouds of small dust particles comes from the CDA. Further detailed investigation is envisaged and more cases like this one have to be found. Since the trajectory of Cassini changes too frequently, it will be challenging to trace a particular cloud for more than two or three revolutions of the spacecraft. Within that period of time, we expect the cloud to change its shape. More evidence for the dust clouds is in preparation.

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References

[1] Goertz C.K. (1983): Detached Plasma in Saturn’s Front Side Magnetosphere. Geophysical Research Letters 10, p455–458.
[2] Grün E., Dikarev V., Frisch P.C., Graps A., Kempf S., Krüger H., Landgraf M., Moragas-Klostermeyer G., Srama R. (2004): Dust in Interplanetary Space and in the Local Galactic Environment. ASP Conference Series 309, p245–263.
[3] Kennedy G.M., Wyatt M.C., Su K.Y.L., Stansberry J.A. (2011): Searching for Saturn’s dust swarm: limits on the size distribution of irregular satellites from km to micron sizes. Monthly Notices RAS 417, p2281–2287.
[4] Khalisi E., Srama R., Grün E. (2015): Counter data of the Cosmic Dust Analyzer aboard the Cassini spacecraft and possible ”dust clouds” at Saturn. Advances in Space Research 55, p303–310.
[5] Kurth W.S., Averkamp T.F., Gurnett D.A., Wang Z. (2006): Cassini RPWS observations of dust in Saturn’s E-Ring. Planetary and Space Science 54, p988–998.