

# Jupiter dust stream observations with Cassini

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## Abstract

The expected Jupiter flyby of the Cassini spacecraft is on December 30 in the year 2000. This offers the possibility to observe and characterize the Jovian dust stream discovered by the dust detectors onboard Galileo and Ulysses. The flux is expected high enough to be observed at distances as far as almost 2 AU away from Jupiter. The dust stream particles originate in the plumes of Io's volcanoes. Theoretical analysis has shown that the size of the particles is in the range of 10 nm and the speed exceeds 200 km/s. The "Cosmic Dust Analyser" of Cassini offers now the unique opportunity to measure the elemental composition of these dust stream particles and hence the volcanic ash from Io.

## 1 Introduction

In the early times, the planet Jupiter was explored by the flyby missions Pioneer 10, Pioneer 11, Voyager 1 and Voyager 2. Unfortunately, the Voyager spacecrafts did not carry any dust sensors. Only the Pioneer spacecraft were able to observe 10-micron-sized dust particles in the year 1973 [10]. Then no further data were available until Ulysses approached Jupiter in February 1992. The dust detector onboard Ulysses detected collimated dust streams originating from the direction of Jupiter and showing a periodicity. The Jupiter system was immediately suspected to be the source for various reasons (see below) [6]. Ulysses performed a swing-by and was deflected out of the ecliptic to enter a high inclination orbit around the sun. The observation geometry changed during the Jupiter flyby causing a change in impact directions. The detection of the dust streams by the Galileo spacecraft was reported in [4]. These streams were observable from as far as 2 AU and remained observable during the entire Galileo mission. The Galileo observations clearly confirmed the origin of the dust bursts, but the source within the Jovian system remained unclear until the year 1998. Sophisticated data analysis using periodograms rather than common fourier analysis lead to the final conclusion in 1998, that the origin of the dust streams is the moon Io [12][3][11]. Small particles ejected by the vulcanoes on Io charge up in the magnetosphere and are accelerated to very high speeds. Particles with masses as low as  $10^{-18}$  g are able to escape from the Jovian system and start their journey through the planetary system. Once they have left the Jovian magnetosphere, the particles couple to the interplanetary magnetic field (compare with fig. 1).

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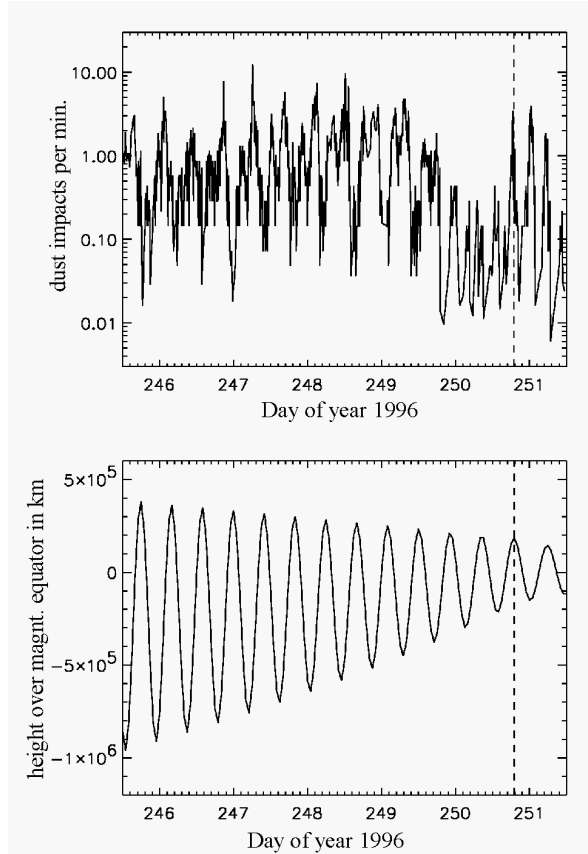


Figure 1: The dust impact rate (top) and the magnetic field (bottom) show a correlation.

## 2 Results

### 2.1 Results by Ulysses

Ulysses discovered the streams during its approach to Jupiter at the end of 1991. The first analysis of the complete flyby data showed six dust streams with a periodicity of  $28 (\pm 3)$  days. Grün et al. [7] reported the discovery of a collimated stream coming from the line-of-sight to Jupiter and suggesting a Jovian source. This suggestion was manifested in [6] proposing either the rings (main, halo or gossamer ring) or the volcanoes on Io as the source. The model in [9] supported the identification of Io as the source. This model already explained the periodicity as a result of the resonance between the Io orbit and the Jupiter rotational period, and confined the particle size to the range of  $0.01 \mu\text{m}$  and  $0.1 \mu\text{m}$  and the speeds to be above  $30 \text{ km/s}$ . Another model by Hamilton and Burns [8] ruled out the main Jovian ring as the source of the streams and suggested the gossamer ring as a source. A later reanalysis of the impact rate by MPI-K showed another five peaks. However, this discovery did not change the obtained understanding.

The tidal disruption of the comet Shoemaker-Levy-9 in the Jovian system in the year 1992 caused new speculations about the source mechanism. However, a detailed analysis came to the conclusion that this event could only add some dust to two of the streams detected by Ulysses.

The work by Zook in [13] came to new results: The stream particles must have

sizes of about 10 nm ( $10^{-18}$  g), and speeds above 200 km/s in order to reach the Ulysses detector at the measured geometry. Their analysis was based on solar wind plasma data and magnetic field data. However, they were not able to resolve the source within the Jovian system.

## 2.2 Results by Galileo

The results from the Galileo mission caused the breakthrough in understanding the dust-magnetosphere interaction. The new dataset of its approach and its inner measurements was used as input for further modelling and data analysis. [1] gives an overview of the history in data analysis whereas the latest results are given in [5]. As an overview a small summary will be given here.

The Galileo dust detector observed the streams with rates of up to 104 impacts/day during its approach and even higher rates within the Jovian system. The impact data suggested only speeds between 30 and 70 km/s, but it has to be mentioned that no calibration of the detector was performed with particles faster than 70 km/s. Therefore, the number given can limit the speed at the lower boundary. The evaluation of the amplitude, risetime, direction and the impact rate of the observed impact signals revealed a 5 as well as a 10 hour periodicity (Fig. ??). This indicates that the dust is modulated by the magnetic field of Jupiter. The axis of the strong magnetic field of Jupiter is tilted by 9.6 degree with respect to the rotation axis of the planet. The rotation of Jupiter with the  $9^h55^{min}$  hour period leads to a 5 hour up-down-variation of the magnetic field direction in the equatorial plane. How does a typical trajectory of a particle leaving Io look like? Let us consider a particle with a charge of +3 Volt and a size smaller than 50 nm originating from Io (distance of Io from Jupiter is  $5.9 R_J$ ). This particle is strongly accelerated by the corotational electric field of Jupiter and reaches about 70% of its terminal speed at a distance of  $10 R_J$  from Jupiter. Then, this particle follows a roughly straight trajectory until it hits the dust detector of Galileo. For the smallest particles that originate from Io's distance the escape speed from the Jovian system is about 350 km/s. This is in good agreement with the results by H. Zook[13]. Dust particles continuously released from a point source within the magnetosphere of Jupiter escape in a warped sheet of dust (fig. 2). The Galileo dust detector in the equatorial plane of Jupiter observes particles when the warped sheet passes over its position leading to the observed periodicity of 5 and 10 hours.

Fig. 2 shows a snapshot of this warped sheet for two different phases of the Jovian magnetic field. In this sheet, the dust particles are separated by their charge to mass ratio, and time of generation as well. The solid lines signify positions of particles released at the same time before the observation, and the dashed lines indicate the positions of particles with the same charge-to-mass ratio. The solid lines are 22 minutes apart from each other and the charge to mass ratio varies from 8 to 984 C/kg. More details are given in [5].

Although the common fourier analysis of a two-year impact rate dataset reveals the 5 and 10 hour periodicity, even better results would be obtained by a periodogram. The advantage of this method is that irregularly spaced datasets can be transformed into frequency space without the aliasing effects of a FFT analysis. The received frequencies showed clear evidence for the amplitude modulation of Jupiter's magnetic field frequency and Io's rotational frequency. The periods of the magnetic field and Io modulate each other leading to the conclusion that Io itself is the source of the carrier frequency[2, 12]. This conclusion is best described by Graps et al. in

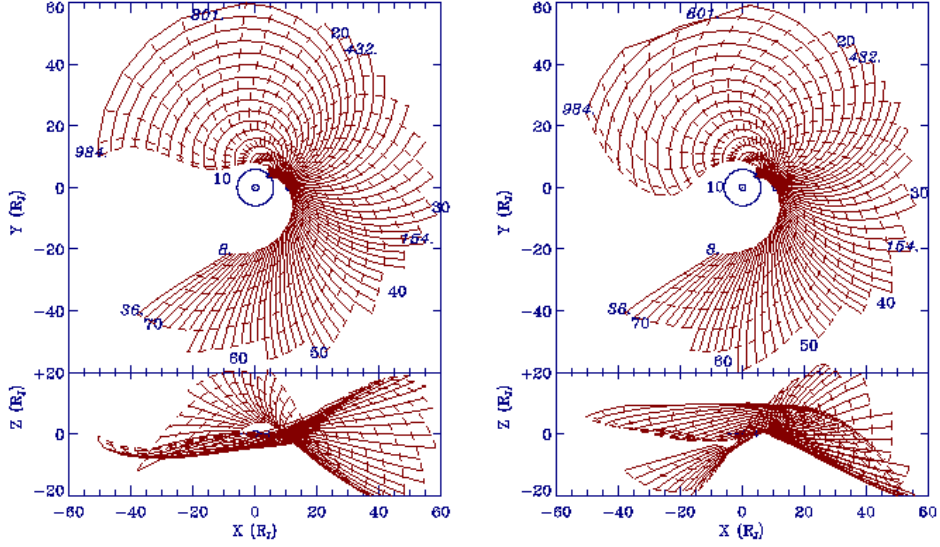


Figure 2: Dust sheet around Jupiter produced by emission from Io. Solid lines give the positions of dust released at the same time, dashed lines indicate positions of particles with the same charge-to-mass ratio. The left diagram shows results with a magnetic field phase of  $0^\circ$ , the right diagram for a phase angle of  $120^\circ$ .

ref. [3].

### 3 Measurements with the Cassini Cosmic Dust Analyser (CDA)

#### 3.1 CDA measurement capabilities

The CDA instrument can measure the mass, speed, charge, elemental composition and the impact direction of dust particles. The corresponding calibrated range is 1-70 km/s for the velocity,  $10^{-17}$  -  $10^{-10}$  kg for the mass and  $10^{-15}$ - $10^{-13}$  C for the electric charge of the particle. The calibration of the even smaller Jupiter stream particles is in preparation. The mass resolution  $m/\Delta m$  of the time-of-flight mass spectrometer increases in mass and is about 20 for masses of 20 amu and 50 for masses of 100 amu. The direction of the particles with a charge above  $10^{-14}$  C can be determined for one plane within 5 degree. The direction of other particles is determined by the field of view of the detector which is  $\pm 45^\circ$  for the big impact target and  $\pm 28^\circ$  for the small chemical analyser target. The new capability with respect to Galileo is a more reliable determination of the particle speed, mass and charge based on internal signal processing. A complete new subsystem is the chemical analyser (time-of-flight spectrometer), which allows the identification of elements of the dust particle. This capability allows the separation of icy, silicate, CHON and e.g. sulfur particles. The measurement of sulfur in the spectra would directly support the conclusion that Io is the origin of the dust stream particles.

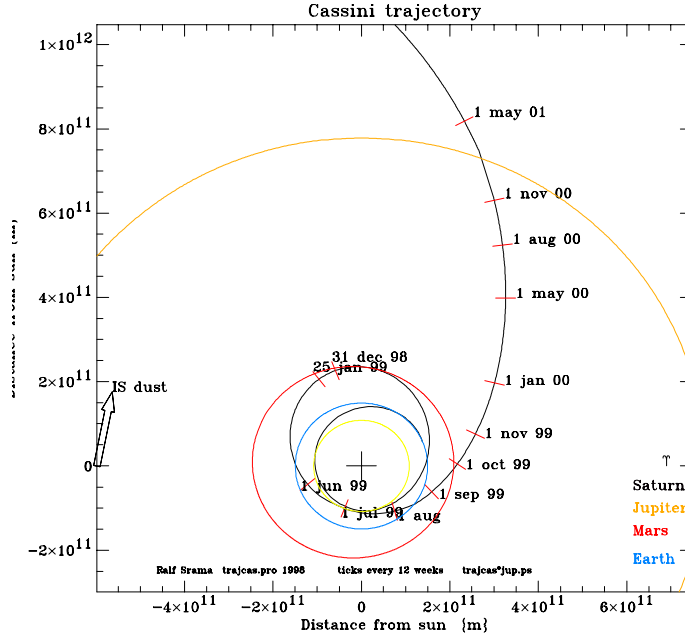


Figure 3: Trajectory of Cassini (black) and the orbit of Jupiter (orange).

### 3.2 Combined Galileo and Cassini measurements

Cassini is on its way to Saturn and passes Jupiter on December 30 in 2000 with a distance of  $137 R_J$  (Fig. 3). At this time, it is likely that the Galileo spacecraft is still operable (Galileo-Extended-Mission). The planned geometry is such that Cassini measures outside the magnetopause, whereas Galileo measures inside the magnetopause at a much closer distance to the Jupiter (Fig. 4). This geometry has the benefit of allowing simultaneous measurements of both dust detectors at different locations. Additional measurements of the solar wind and magnetic fields would allow a reconstruction of dust stream trajectories leading to insights of dust-plasma-magnetosphere interactions, especially in the important transition region from the magnetosphere to interplanetary space.

Of special interest are simultaneous measurements of Galileo and Cassini when both spacecrafts are linked by a single dust trajectory. This condition occurs on day 364 (December 29, 2000) and is shown in figure 5. Particles ejected by Io on day 364 (2000) intersect with both spacecraft. The impact rate measured by the Galileo- and Cassini-dust detector on this day will constrain the dynamics of the Io dust stream particles within the jovian magnetosphere. This observation is already planned onboard Cassini: the high gain antenna (-z axis) points towards the Sun and the spacecraft roll angle<sup>1</sup> is  $160^\circ$ . The CDA articulation angle will be set to  $60^\circ$ . In addition to this observation, Cassini-CDA will observe the dust stream particles between day 17 and day 20 in 2001 using a -x to Sun orientation. Long integration times in the order of days are necessary to accumulate a significant amount of dust impacts which are expected with rates between  $10^{-5}$  and  $10^{-1} \text{ m}^{-2}\text{s}^{-1}$  with strong statistical variations.

<sup>1</sup>The roll angle is defined by the angle between the ecliptic north pole and the spacecraft +y-axis (MAG boom).

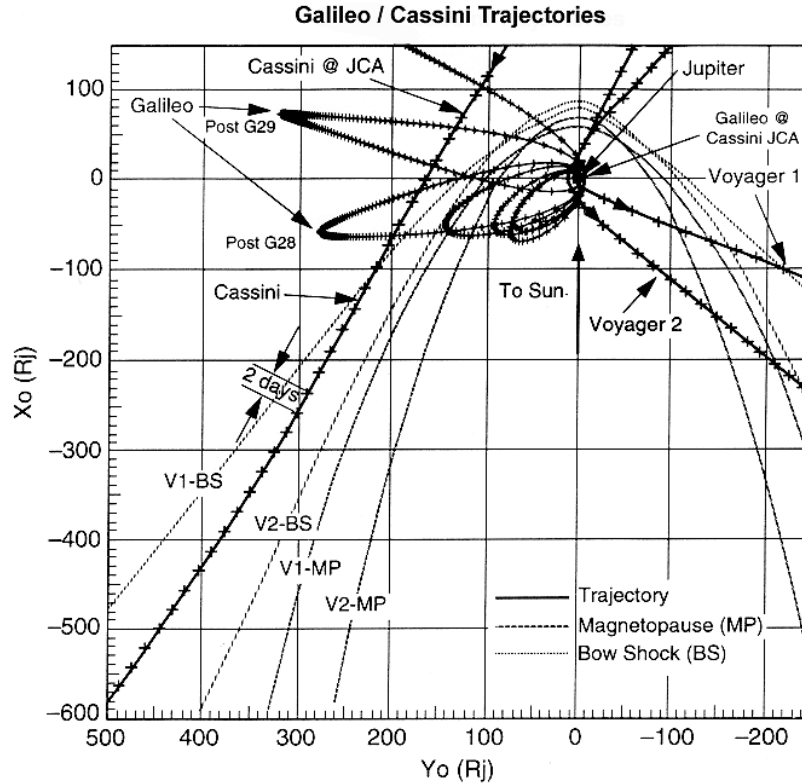


Figure 4: The figure shows the Galileo and Cassini trajectory at Jupiter.

## 4 Summary

Measurements with the Cassini Cosmic-Dust-Analyser will help resolve the question about the origin of the Jovian dust streams discovered by Ulysses and Galileo. There is already clear evidence that Io acts as the source of this phenomena and that the escaping particles are accelerated in the inner Jovian system before they leave on almost straight trajectories. The nanodust particles couple to the magnetic field of Jupiter causing the observed periodicity. The possibility of a combined investigation of two operating dust sensors onboard Galileo and Cassini will even improve the understanding of this phenomena. The combined measurement is planned between December 29, 12:30 and December 30, 1:30 UTC.

The capability of the CDA instrument to determine the elemental composition of the dust will give direct information about the geology of the dust source (Io).

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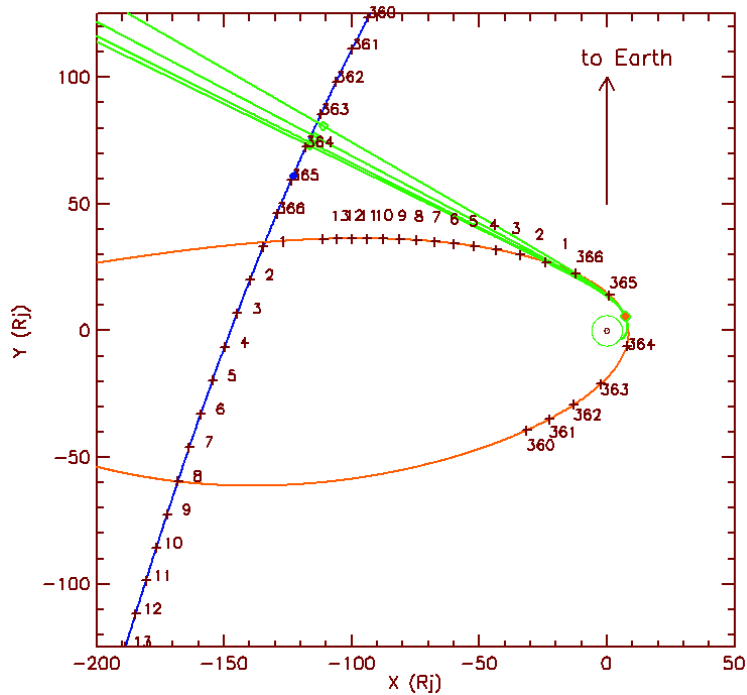


Figure 5: Combined measurements of the Galileo dust detector and the Cassini dust detector of the Io dust streams are possible on day 364, 2000. The Cassini-CDA instruments starts the dust stream observations on December 29 at 12:00 UTC. The observation takes 12 hours.

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