Dust Observation by the Radio and Plasma Wave Science instrument during the Cassini Mission

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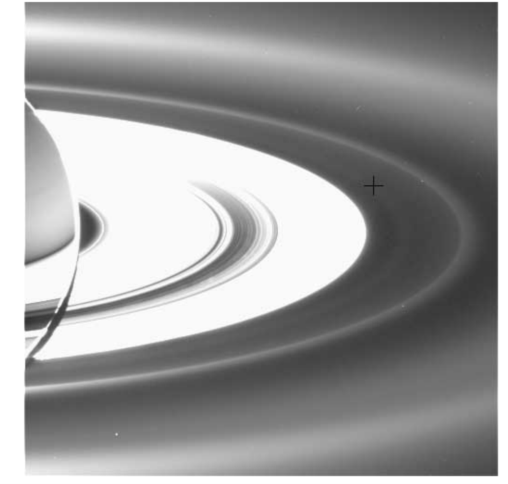
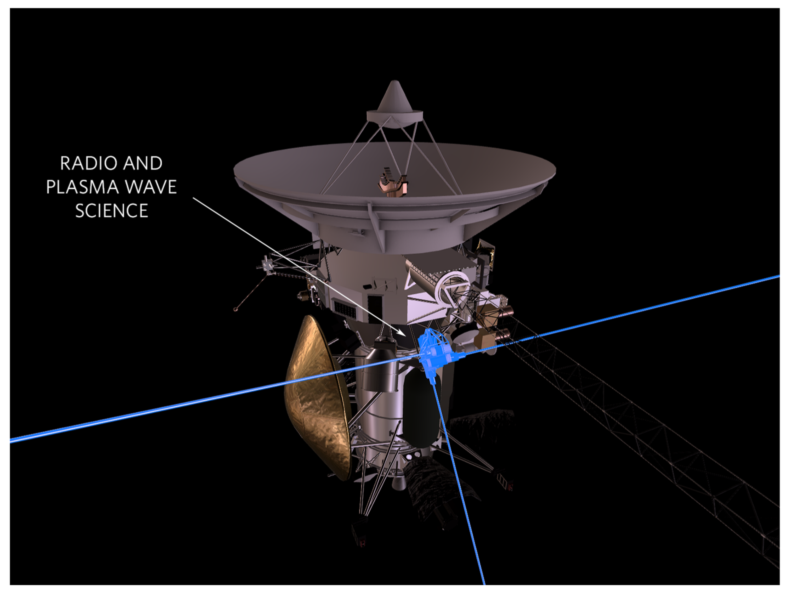
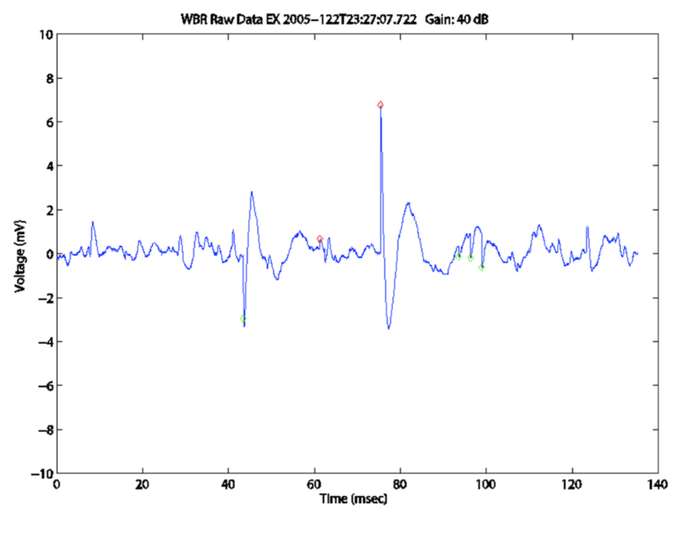


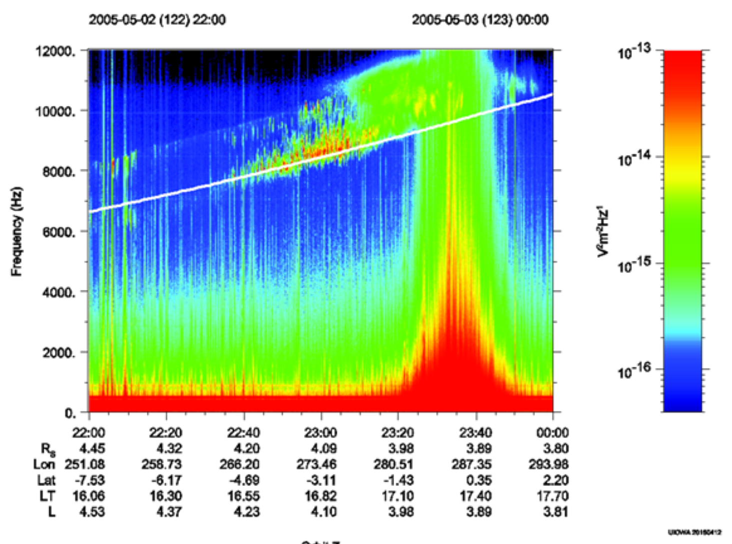
ABSTRACT Wave instruments onboard spacecraft are designed to detect radio and plasma waves in space. However, when spacecraft encounter dust at tens of kilometers per second, the plasma clouds released by energetic dust impacts can couple to the electric antennas and cause either voltage pulses in waveforms or broadband noise in the spectra recorded by the receivers. The impact signals have been simulated in the lab by shooting dust particles onto a spacecraft model with electric field antennas. During the Cassini mission, such signals have been detected by the Radio and Plasma Wave Science (RPWS) instrument in the solar wind and Saturn's magnetosphere. Given the particle velocity and impact charge yield function, the size and density of the particles can be estimated from the measured signals. In various locations, RPWS measurements have been shown to be consistent with the Cosmic Dust Analyzer (CDA), the dedicated dust instrument. RPWS complemented CDA during times CDA couldn't make measurements due to pointing constraints or low dust density. RPWS carried out in-situ dust density measurement during each crossing of the Saturn's dusty rings and Enceladus plume, providing unprecedented data for these dynamic regions. A new plasma oscillation induced by dust impacts at the background plasma frequency was discovered, providing an independent measurement of local electron density in addition to the Langmuir probe and upper hybrid resonance methods. Before the end of mission, RPWS helped quantify the dust hazards posed to the spacecraft and instruments onboard during the proximal orbits, when RPWS made measurements regardless of the spacecraft attitude. The Grand Finale orbits data revealed a surprisingly low density of dust larger than 0.1 micron. Close inspection of the waveforms indicates a possible dependence of the impact signal decay time on the background plasma density.

Dust impact signals



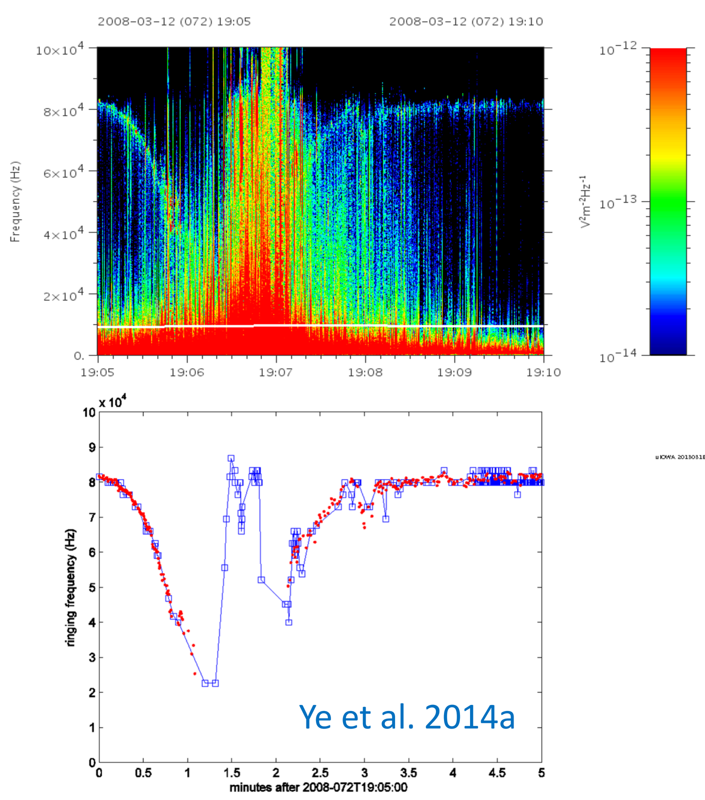
The 3 electric field antennas Eu, Ev, Ew, each 10 m long and 2.86 cm in diameter, and the spacecraft body are sensitive to dust impacts.



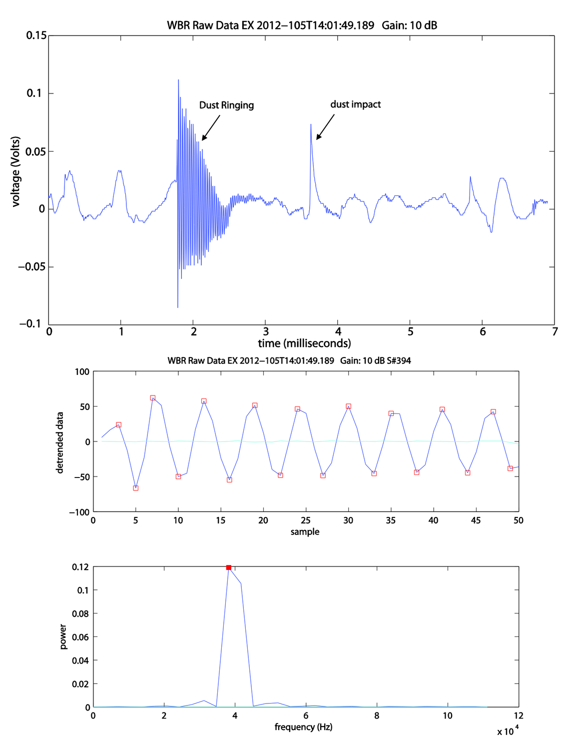


Differential collection of the impact charges by the antenna elements causes potential perturbation measurable in the Wideband receiver (WBR). The potential jump is proportional to the mass of the impacting particle $\delta V \sim mv^{4.5}$ and the power spectrum is a power law function of frequency f^{-4}, with level proportional to dust density.

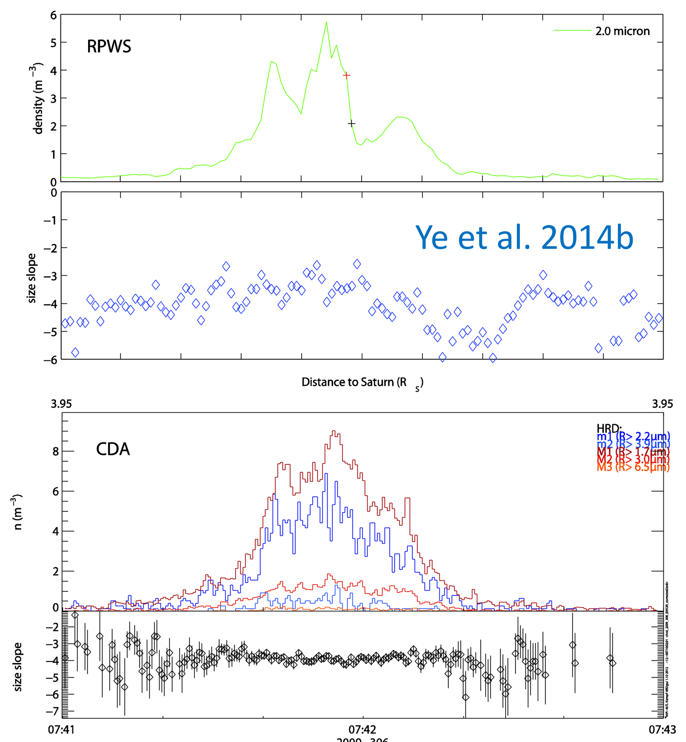
Enceladus plume



Dust ringing events E3



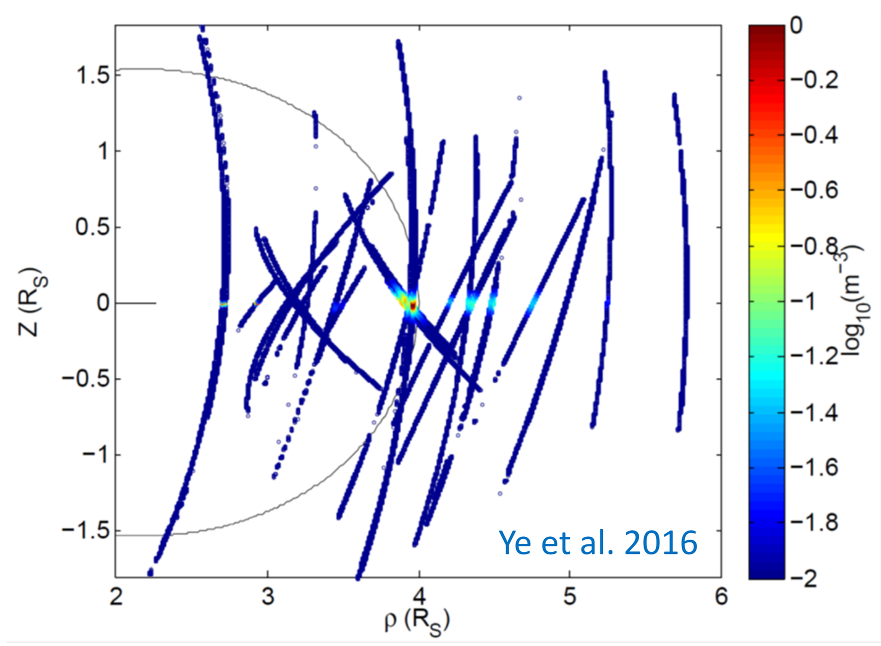
Dust density profile E7



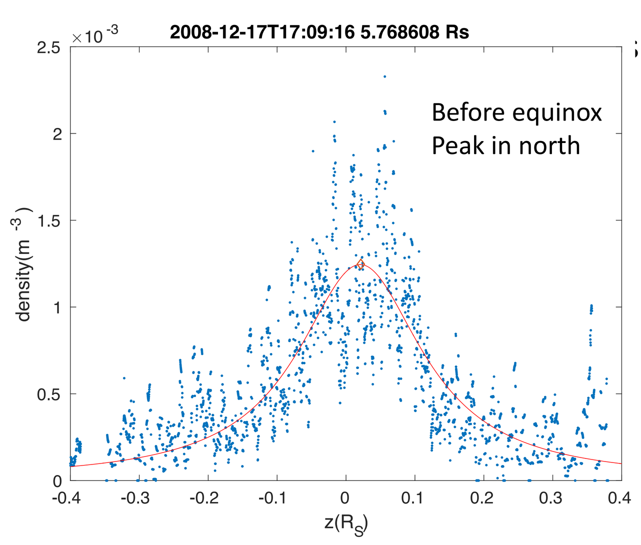
Dust ringing is the plasma oscillation induced by a dust impact probably through electron beam plasma instability. The ringing frequency is consistent with the local plasma frequency. These events can be used to measure the electron density inside Enceladus plume where the upper hybrid resonance is hard to identify.

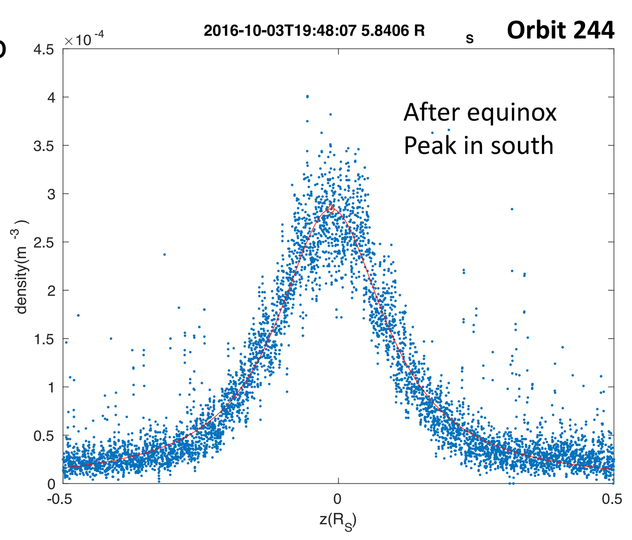
RPWS/WBR and CDA/HRD measured similar density structure and size distribution slopes (β ≈ -4) during the Enceladus plume crossing.

E-ring



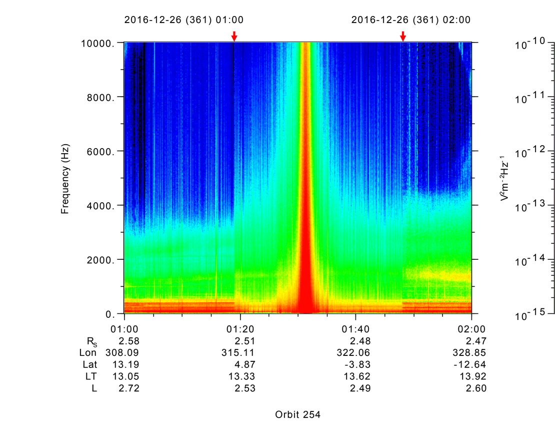
During the ring plane crossings before equinox, RPWS measured the vertical and radial structure of the dusty E-ring, which showed a warping of the outer edge towards north, possibly caused by the solar radiation pressure (Hedman et al. 2012).

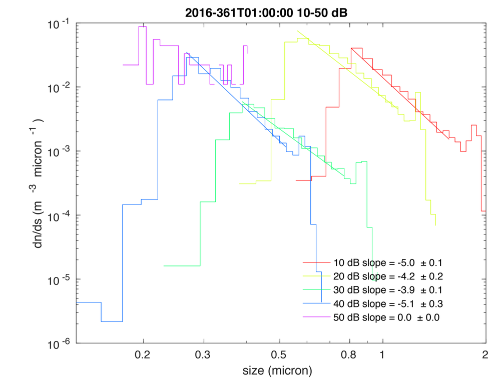




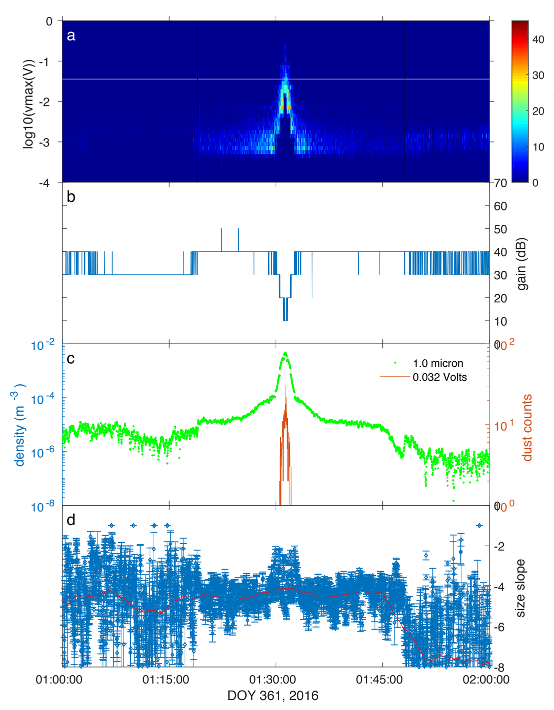
Comparison of the E-ring vertical profiles measured by RPWS before and after equinox showed that the peak location of the outer E-ring moved to the south, supporting the seasonal control of the E-ring warping.

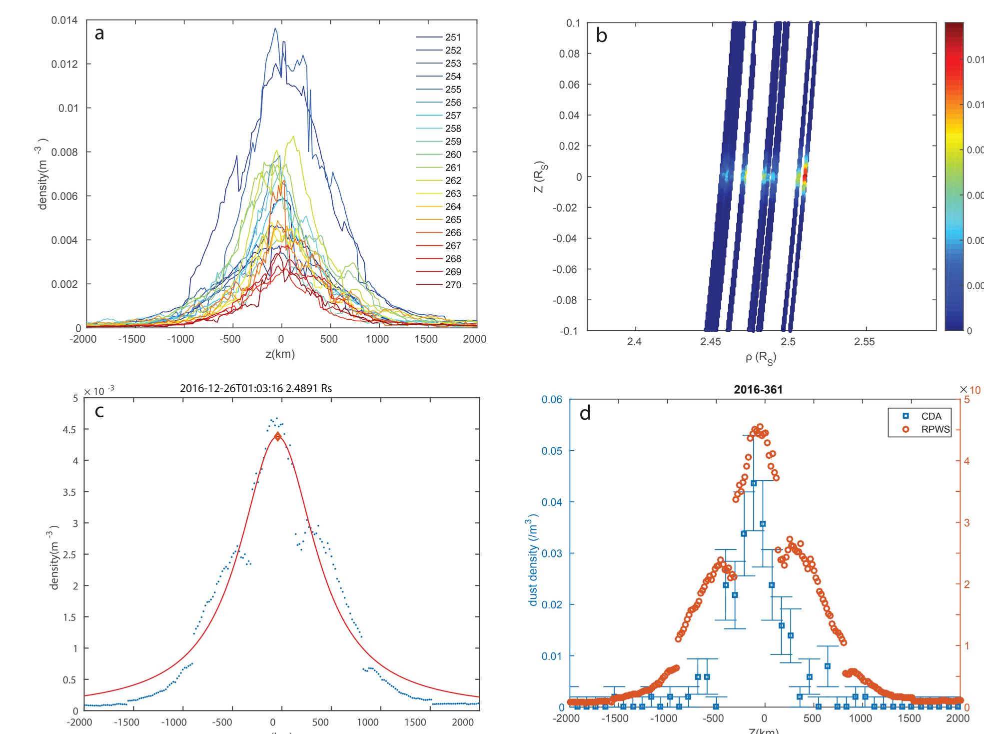
Ring Grazing orbits





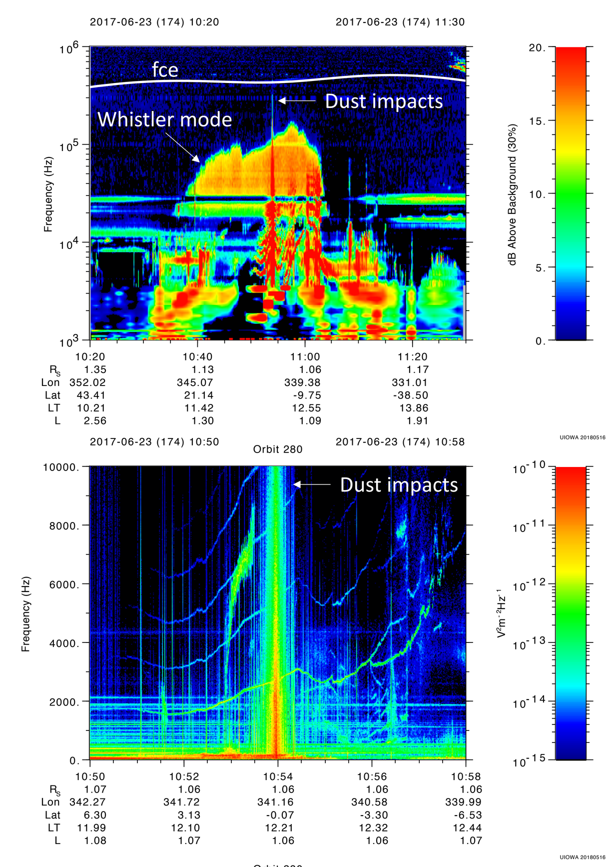
RPWS/WBR dust measurement during the ring plane crossing on DOY 361, 2016 (Ye et al., 2018).

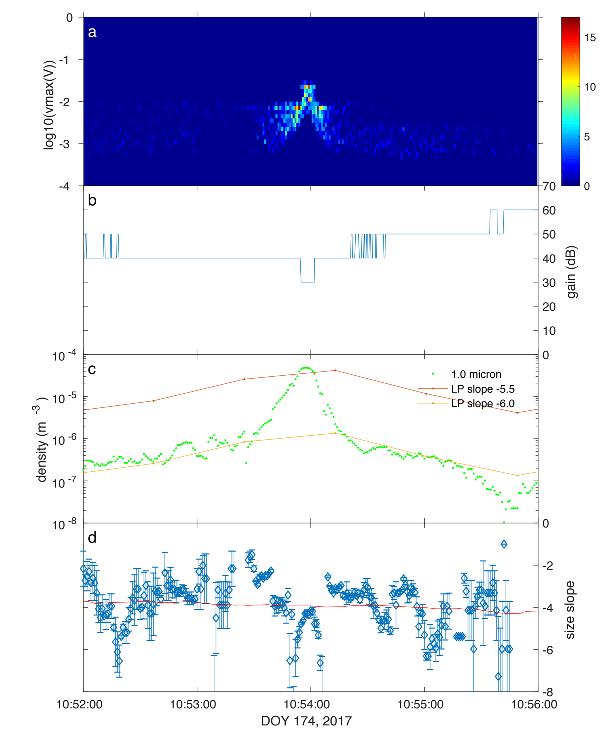




a) RPWS dust density profiles measured during 20 Ring Grazing orbits. **b)** Cassini trajectories color coded with RPWS dust densities (> 1 micron). **c)** Lorentzian function fit of the density profile for the ring plane crossing on DOY 361, 2016. **d)** Comparison of vertical dust density profiles measured by RPWS and CDA HRD.

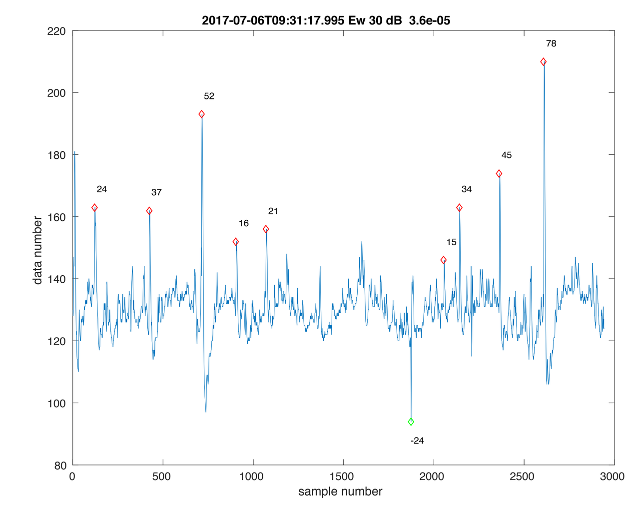
Grand Finale orbits



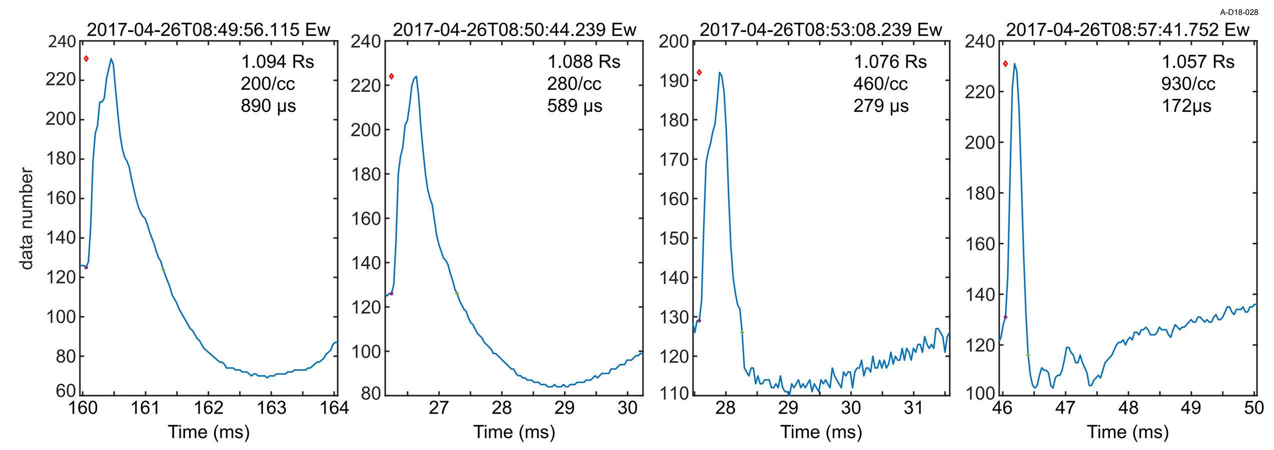


Cassini RPWS electric field power spectrograms and dust analysis for the ring plane crossing on DOY 174, 2017 (orbit 280). The dipole antenna was used. (**a**) Impact counts as a function of voltage and time. (**b**) Gain of the receiver. (**c**) Dust density (1 micron size (radius) threshold) calculated from the WBR impact rates and the difference in ion and electron densities measured by the Langmuir probe. (**d**) Power law index of the differential size distribution.

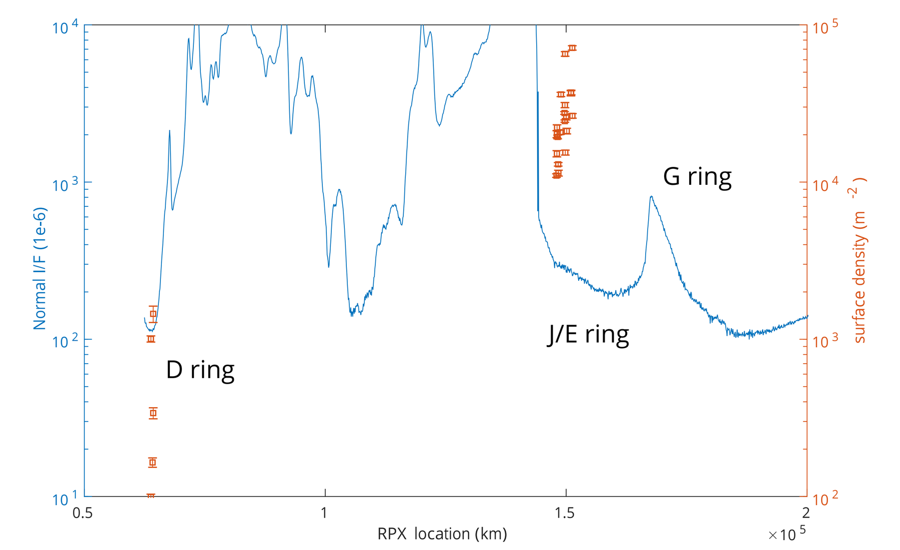
During Cassini's first dive between the D ring and Saturn (orbit 271) on April 26, 2017, no intense broadband signal typical of dust impacts was observed near the ring plane. Close inspection of the waveforms revealed only a few dust impacts, not enough for characterizing the density profile or the size distribution function.



WBR waveform snapshot near the ring plane crossing of orbit 282 (DOY 187, 2017). The receiver was in monopole mode, which measures the voltage between the E_w antenna and the spacecraft. The mostly positive impact signals seem to indicate the spacecraft potential was positive, supported by Langmuir probe data.



Dust impact waveforms observed during the first Grand Finale orbit around the ring plane crossing. The decay time scales of the impact signals, obtained from fitting with the Zaslavsky (2015) model, seem to depend on background plasma density, which increases with decreasing altitude. The top right of each panel lists the radial distance of detection, background plasma density, and the fitted decay time scales.



Comparison of a radial brightness profile from optical observations at 178.5° phase angle [Horanyi et al., 2009] and the RPWS measurements of micron-sized dust surface density (integrated vertically) in the Janus/Epimetheus ring and around 64000 km radial distance, where orbits 276-282 ring plane crossings took place. The brightness measured between 62000 and 64000 km radial distance is close to the background noise level.