Study of Saturn's rings based on analysis of dust impact signals captured by Cassini RPWS

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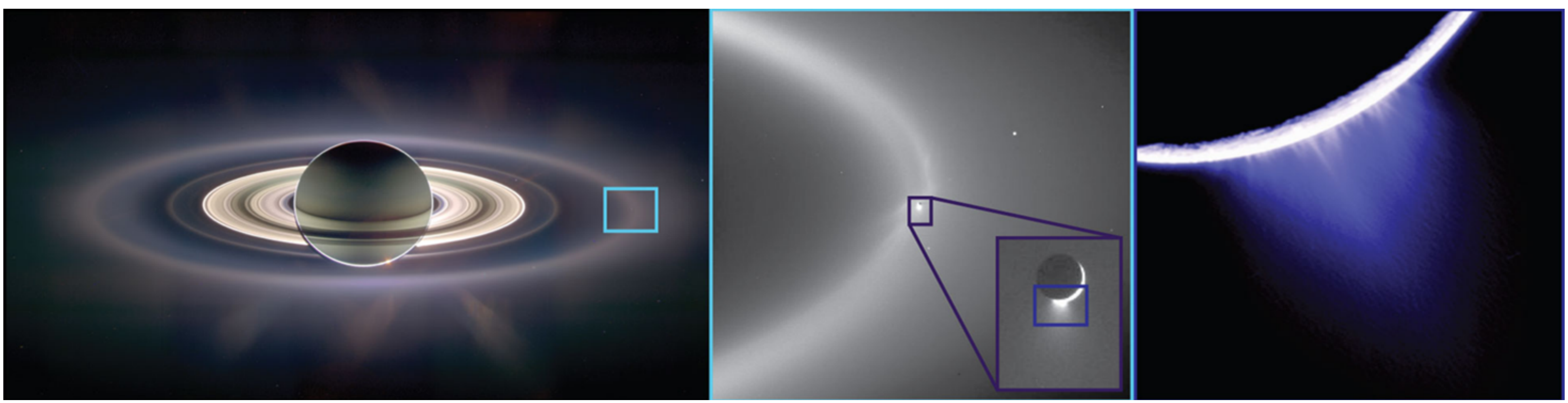
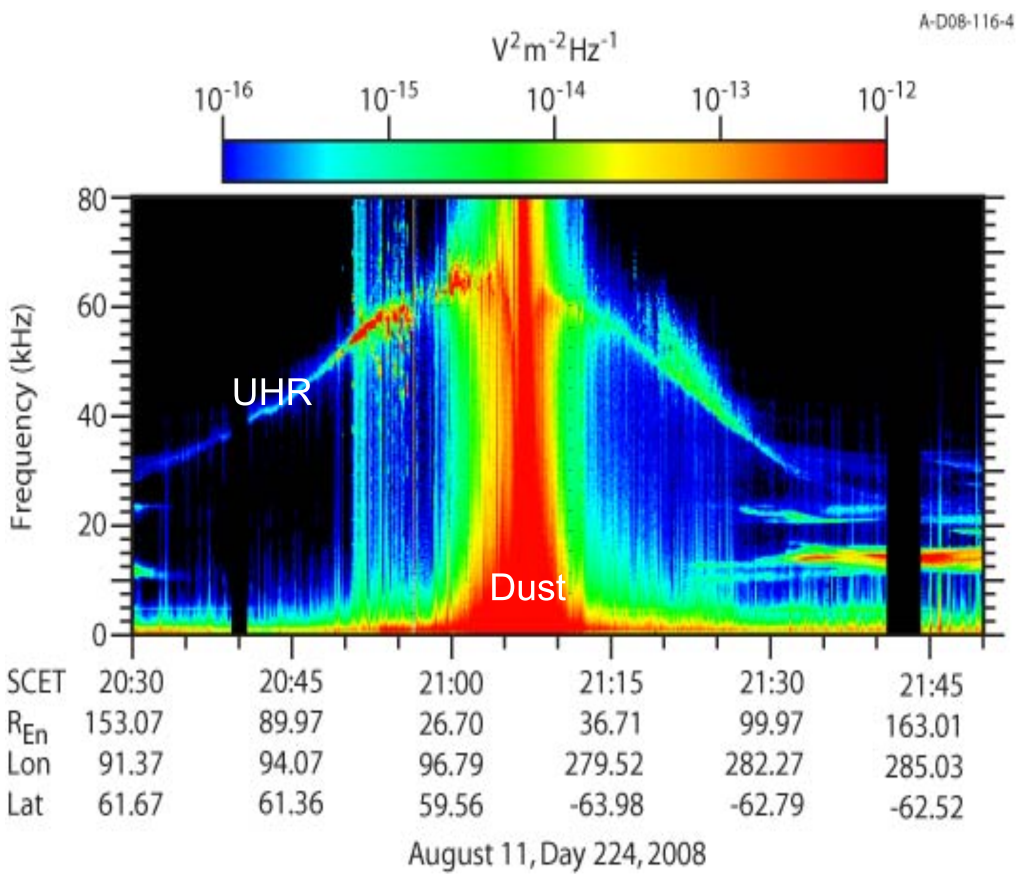
Planetary Rings Workshop, LASP, Boulder, CO, Aug 13, 2014

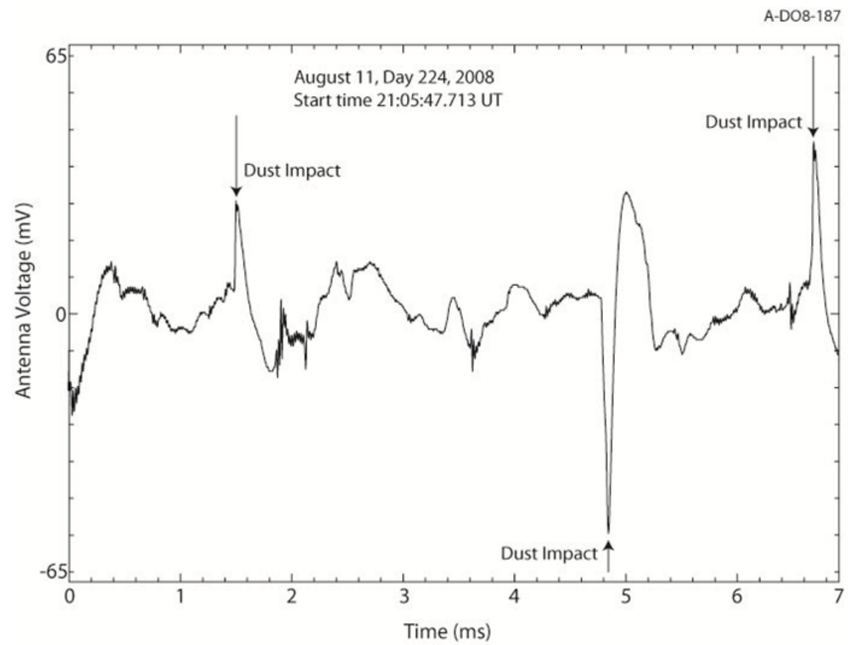
Outline:

1. RPWS dust detection mechanism
2. Dust size distribution and dust density
3. Comparison with CDA
4. Enceladus plume and E-ring dust density profile
5. On-board dust detection
6. Dust ringing -> ambient plasma frequency



RPWS detection of dust impacts during E4 flyby

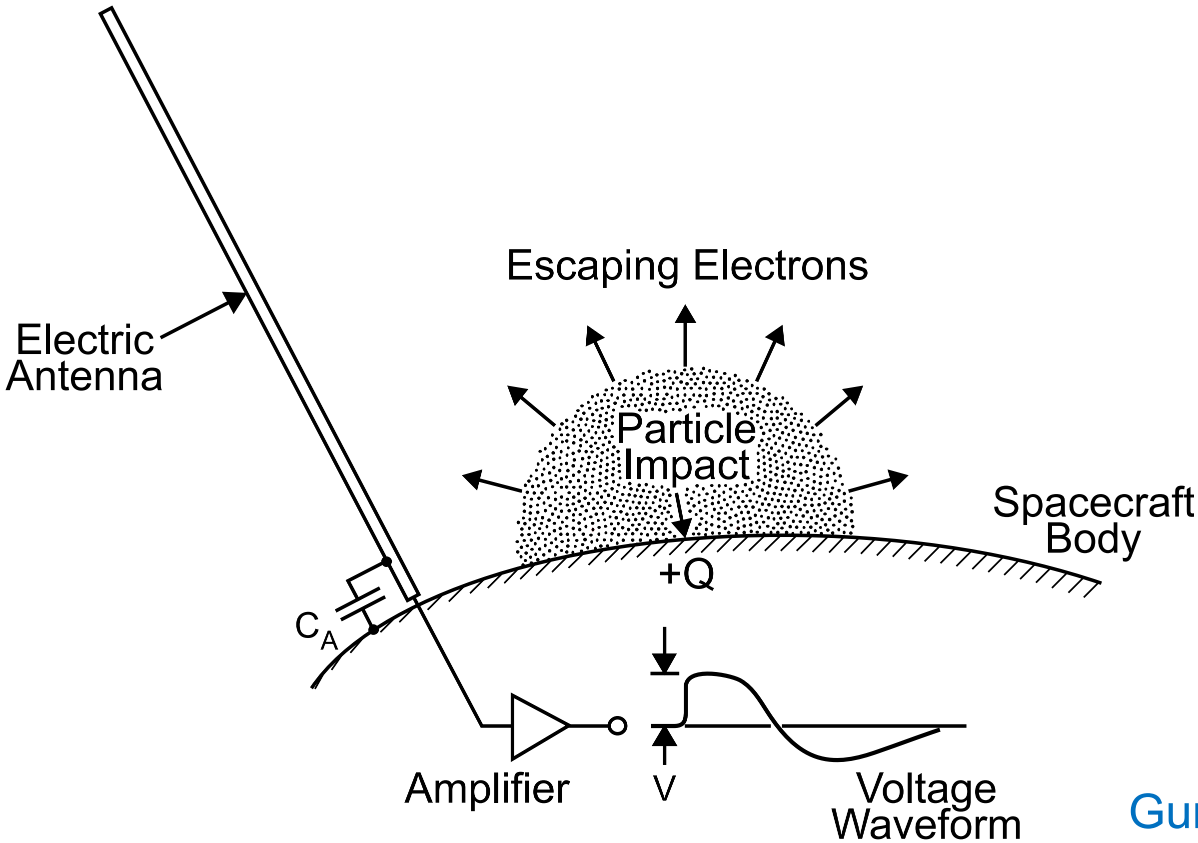




Power spectrum $\propto f^{-4}$ proportional to dust density

The dust impact waveform signatures observed by the RPWS in the 80-kHz mode of WBR using the x-axis dipole antenna. Dust size and impact rate.

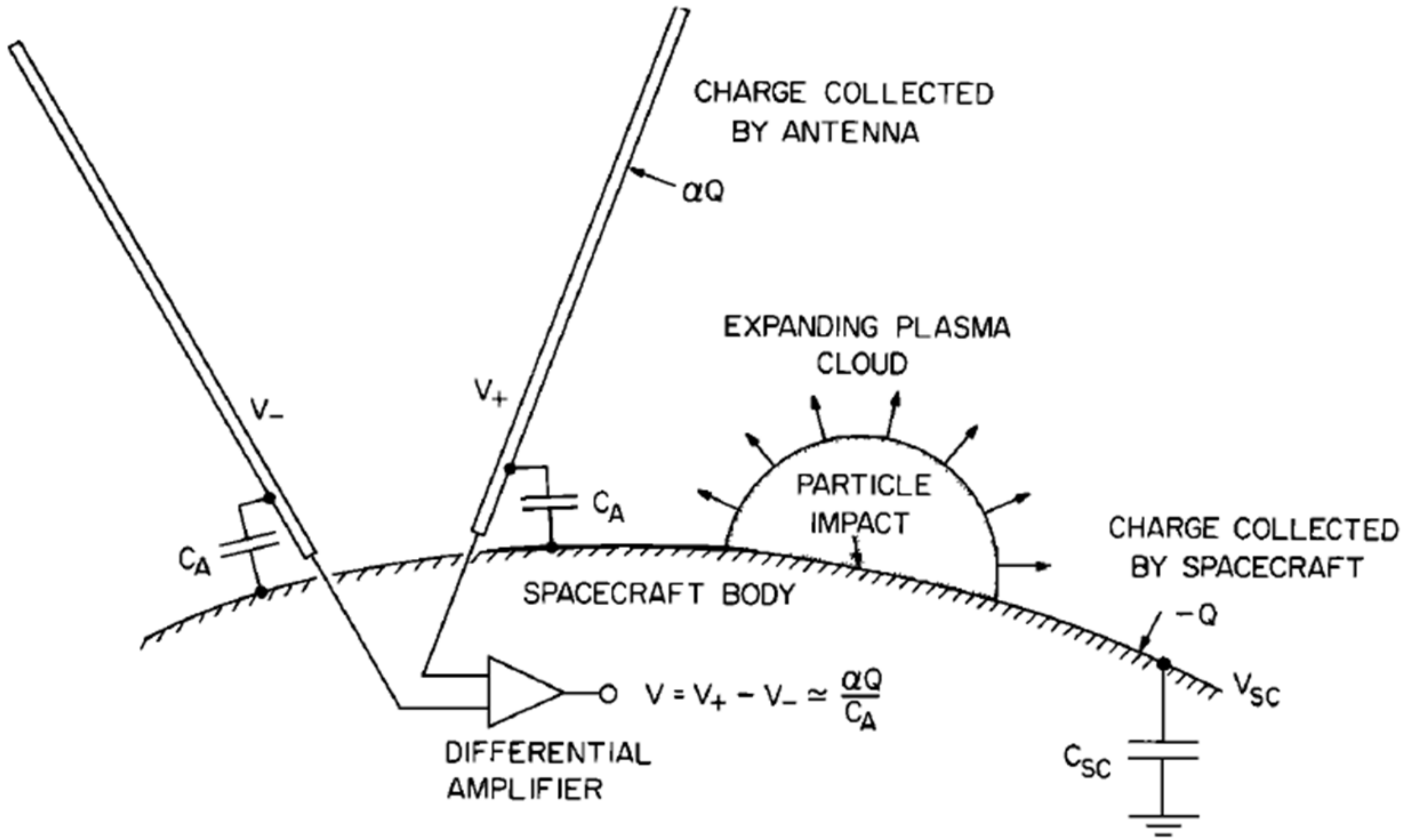
Dust impact detection mechanism (monopole)



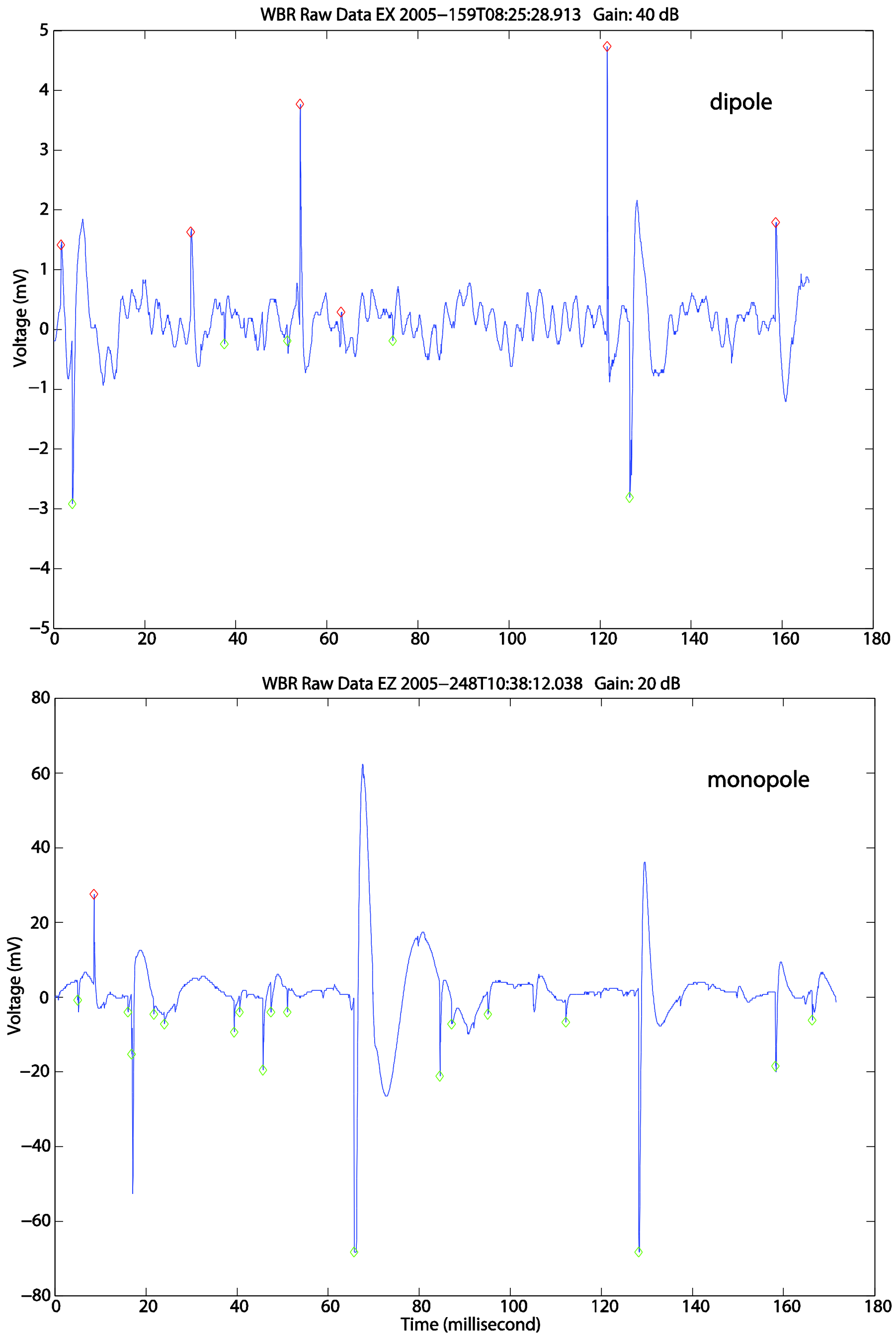
Gurnett et al. [1983]

When dust particles strike the spacecraft with very high velocity, kinetic energy in the collisions vaporizes the particle and part of the target material. The spacecraft body recollects impact charges resulting in a voltage difference between the antenna and the spacecraft.

Dust impact detection mechanism for dipole antenna



For the dipole mode, the same dust impact would induce much smaller signal. One interpretation of the dipole signal is the recollection of impact charges by one of the antennas near the impact site [Gurnett et al., 1987]. Voltage induced on antenna by escaping charges [Meyer-Vernet et al., 2014].



Dipole vs. monopole measurements

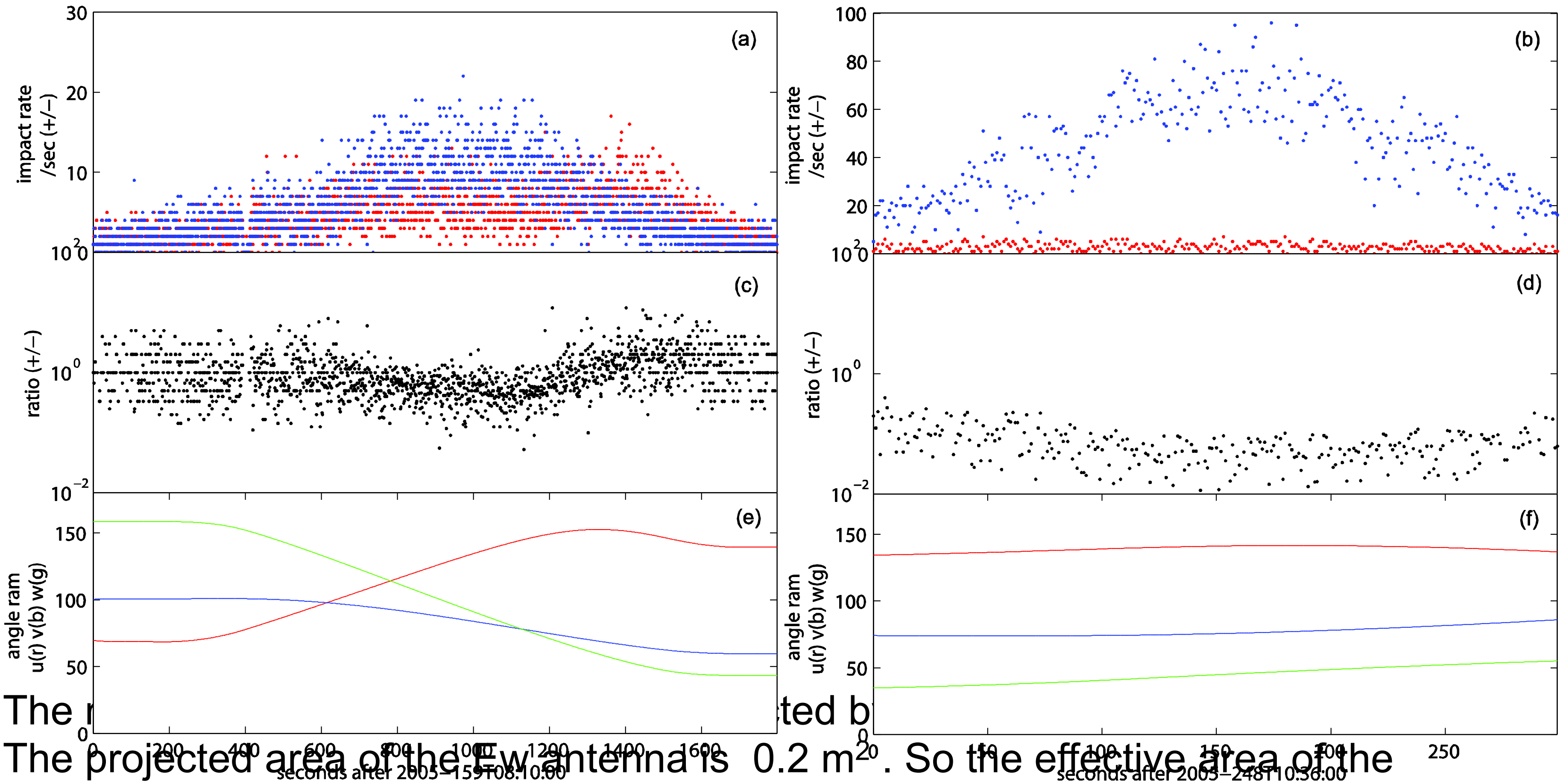
- E-ring crossing
- Approximately equal number of positive and negative pulses
- Polarity determined by impact location [Malaspina et al., 2014; Meyer-Vernet et al., 2014]

- Ring plane crossing at 3 Rs
- Stronger signals
- Negative pulses significantly out number positive pulses
- Negative pulses due to impacts on the spacecraft
- Positive pulse due to impact on the monopole antenna
- Polarity of the pulses indicate spacecraft charging state

Polarity ratio of voltage pulses

dipole

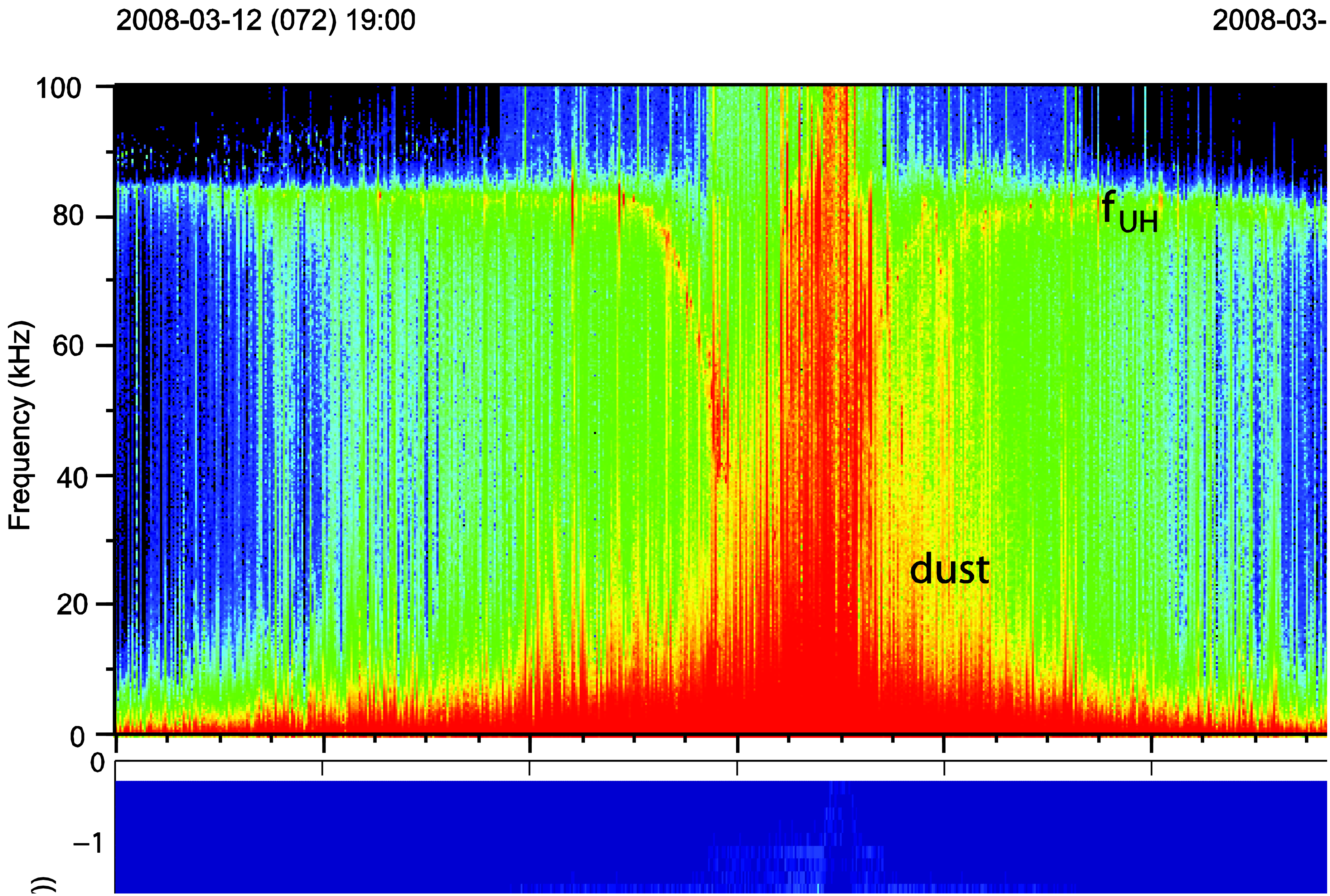
monopole



The r ted b

The projected area of the Ew antenna is 0.2 m^2. So the effective area of the spacecraft body should be ~4 m^2.

RPWS/WBR dust detection during E3 flyby



Voltage to Mass/Size Conversion (monopole)

$$V = \beta \alpha Q / C$$

Spacecraft body capacitance C = 200 pF. $\beta = C_A / (C_A + C_B) \approx 0.4$ is a factor that takes into account the voltage reduction due to the known base capacitance of the antenna [Wang et al., 2006]. α =0.5 is the charge-spacecraft coupling coefficient in the monopole mode, ~100 smaller for charge-antenna coupling in the dipole mode [Gurnett et al., 1983; Gurnett et al., 1987; Tsintikidis et al., 1994].

$$Q/m = 0.01 \times v^{4.6}$$

Q in Coulumb, m in kg, v in km/s, charge yield for iron particles impacting on Kapton [Grün et al., unpublished], 5-10 times smaller than $Q = 0.7 m v^{3.5}$ of MacBride and McDonell [1999] . 7 times larger than Q/m = 55 C/kg for 10 km/s impact velocity by [Collette et al.,2014].

The size calculation applies to monopole antenna measurement. For dipole antenna measurement, a correction factor ~40 for the voltage needs to be applied. There are uncertainties in α and β , which affect the derived sizes.

Number Density:

$$n = R / UA_{eff}$$

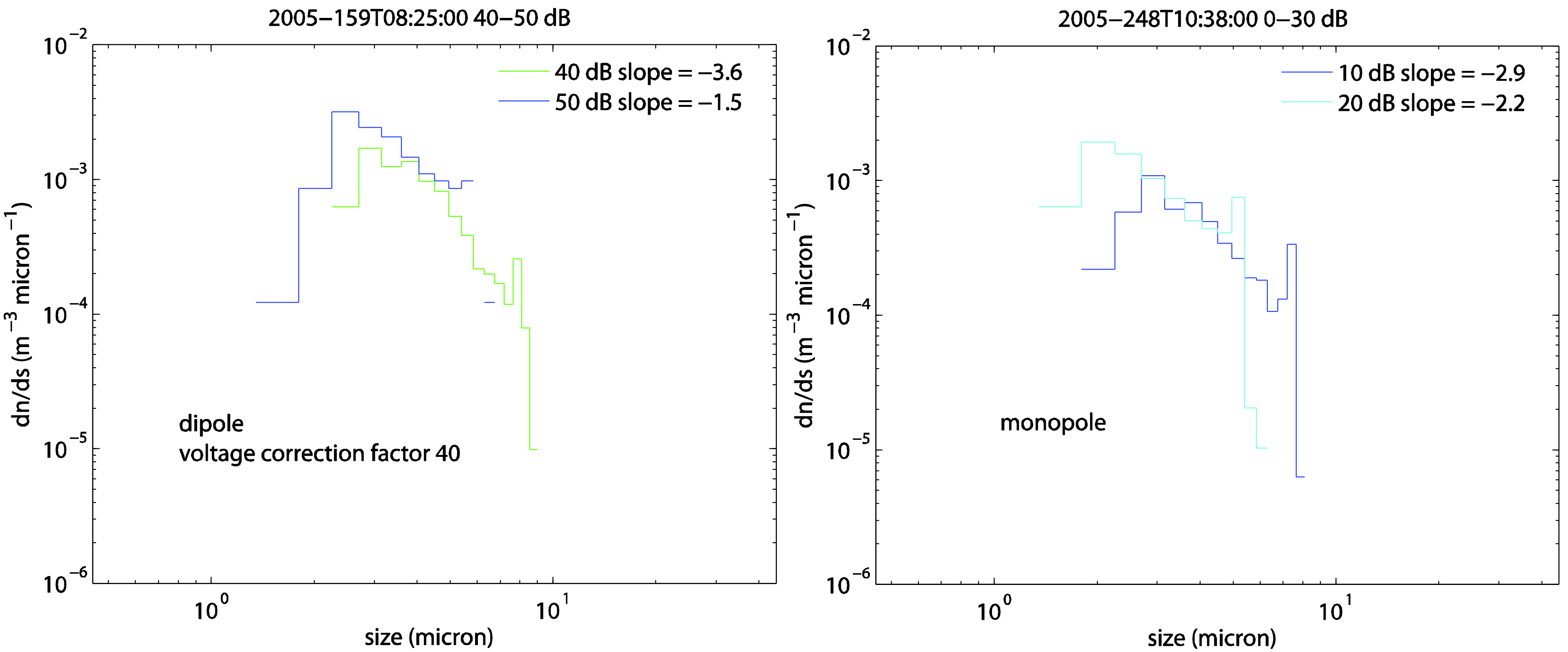
✓ R the impact rate

✓ U the relative speed between the spacecraft and the dust grains

- between 6.35 (E9) and 18 (E5) km/s

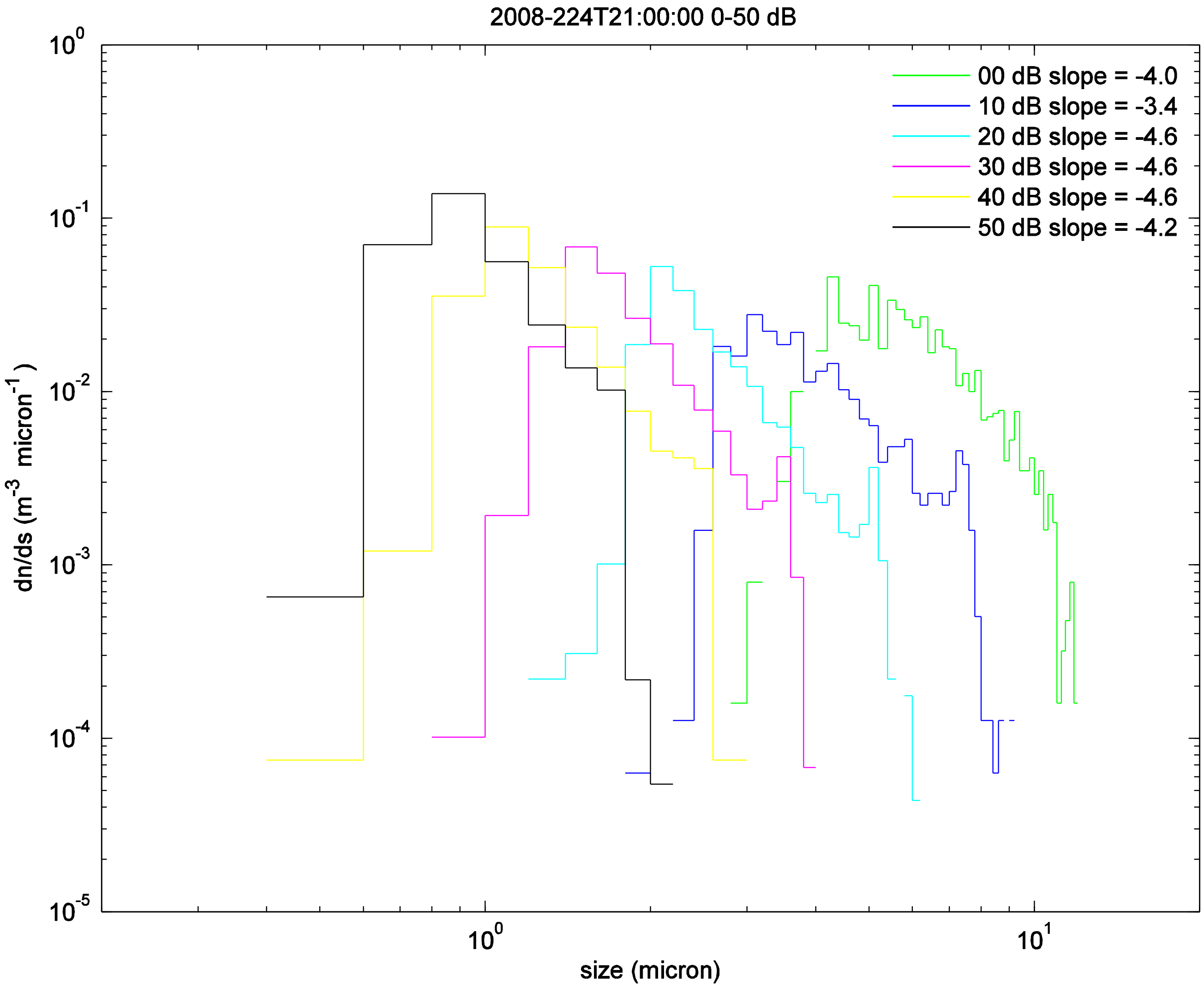
✓A_{eff} the effective impacting area used in this study was 4 m^2 for monopole antenna (derived from the polarity ratio of voltage pulses in the monopole data) and 1.5 m^2 for dipole mode (smaller due to common mode rejection).

Size calculation applied to dipole (left) and monopole (right) measurement during the E-ring crossings



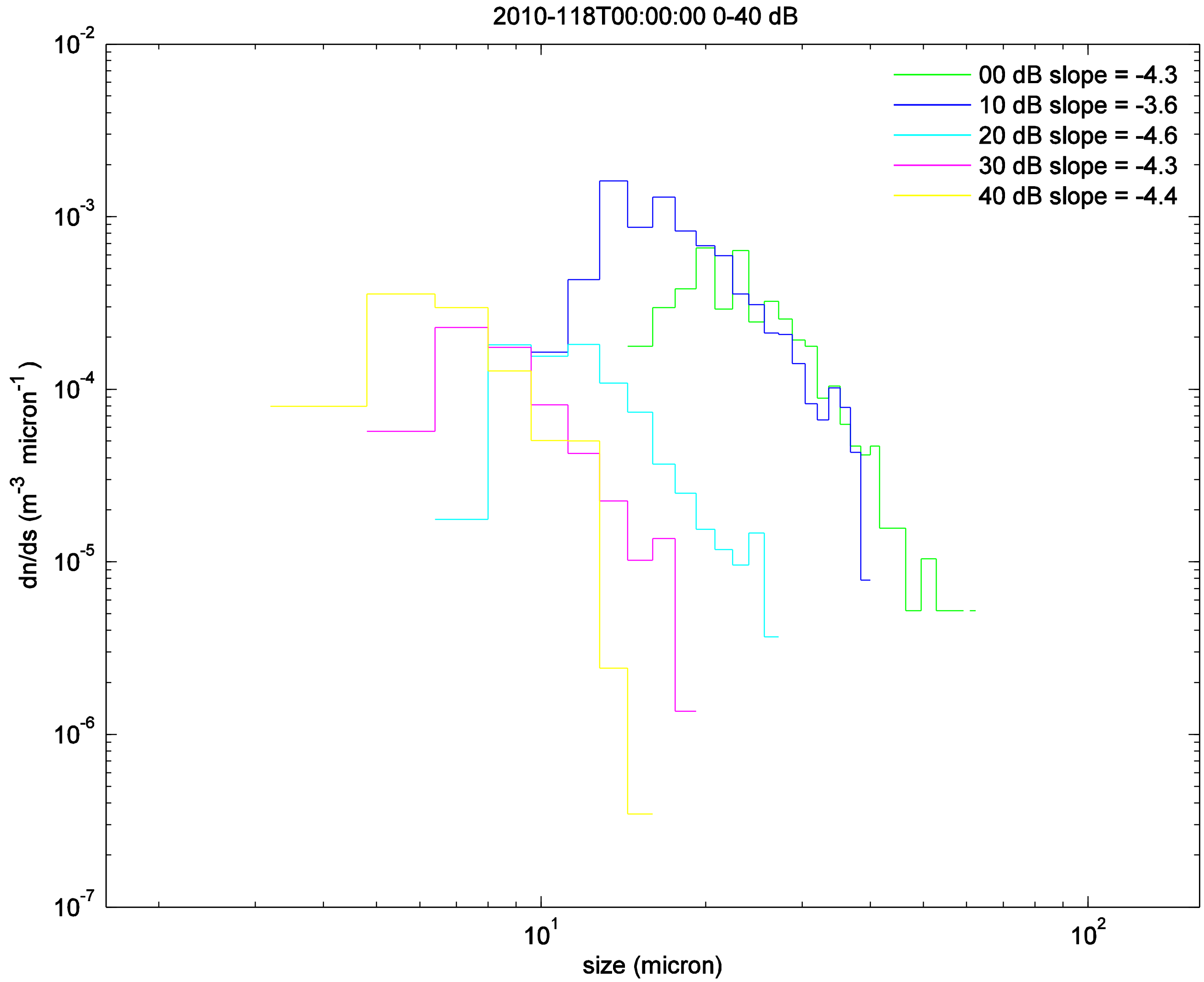
The dipole mode voltages are multiplied by a correction factor 40 (and for all the dipole data in this talk) when calculating the sizes. The resulting size ranges are generally consistent with each other and CDA measurement [Kempf et al., 2008].

Dust size distribution for E4 flyby



The size distribution within each gain level shows power law distribution with -4 slope. Lower gain level corresponds to larger size and higher density level.

Dust size distribution for E9 flyby



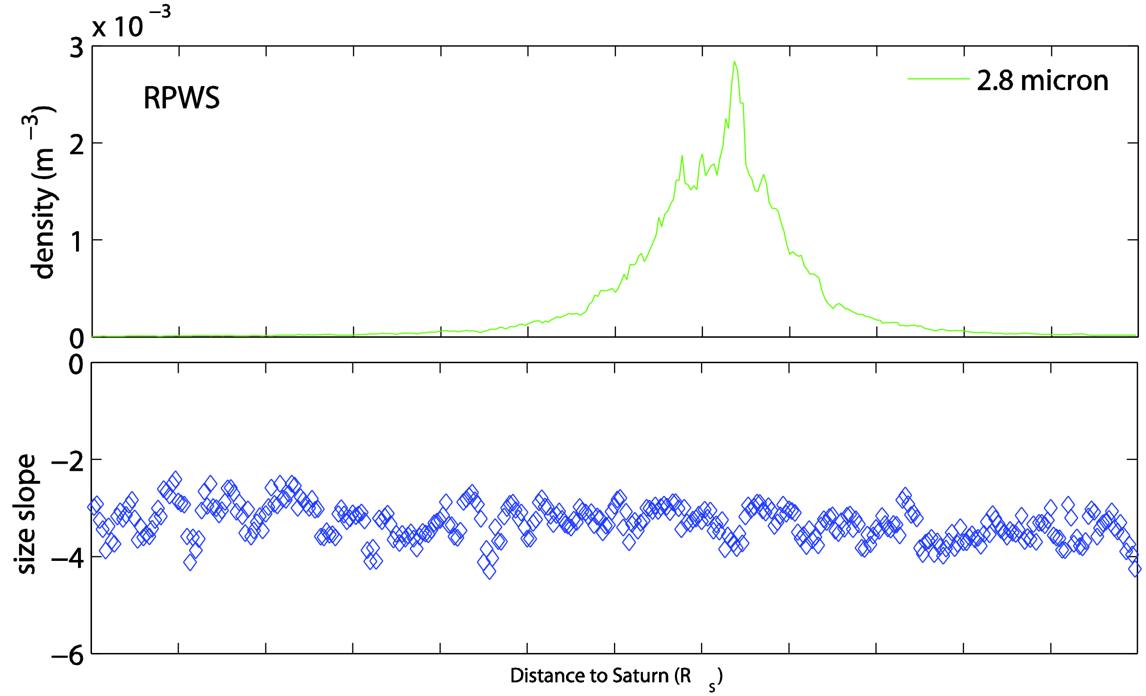
E9 trajectory was a horizontal cut through the base of the plume. The power law size distribution still holds above 10 micron, contrary to VIMS measurement that particles above 4 micron are depleted [Hedman et al., 2009].

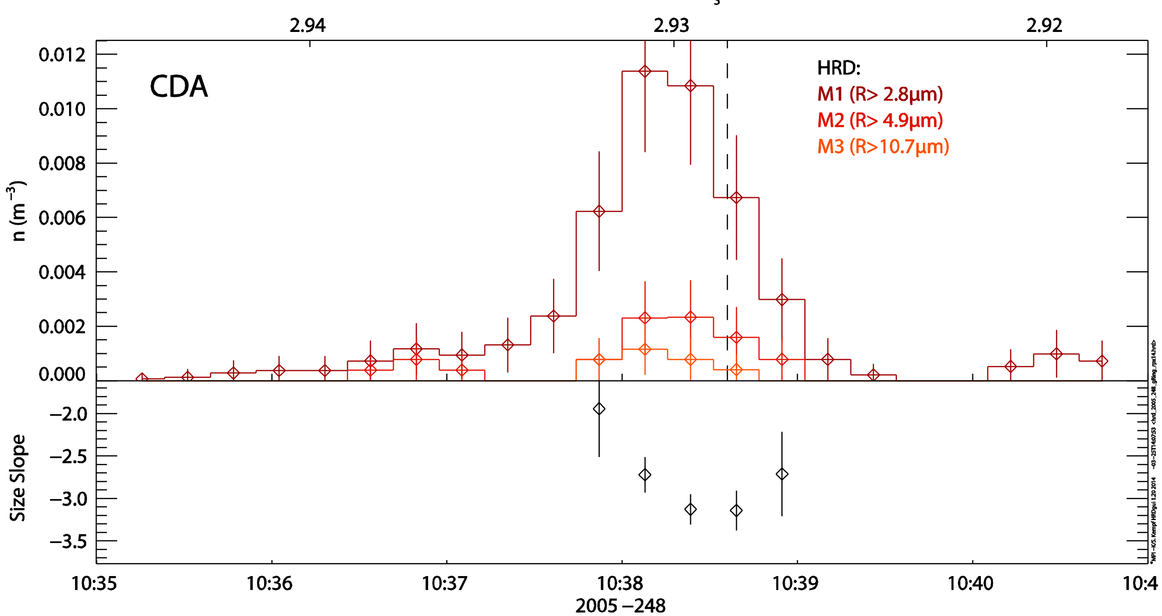
RPWS monopole data compared to CDA

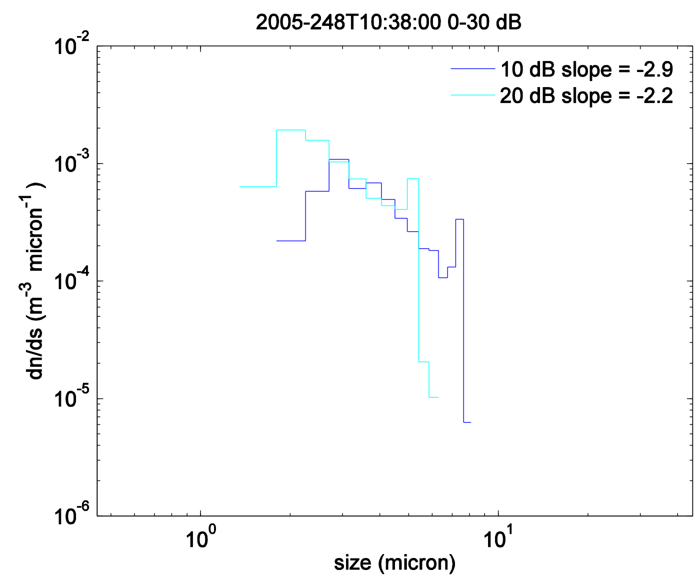
$$n=R/AU$$

$$dn/dm \propto m^{-2}$$

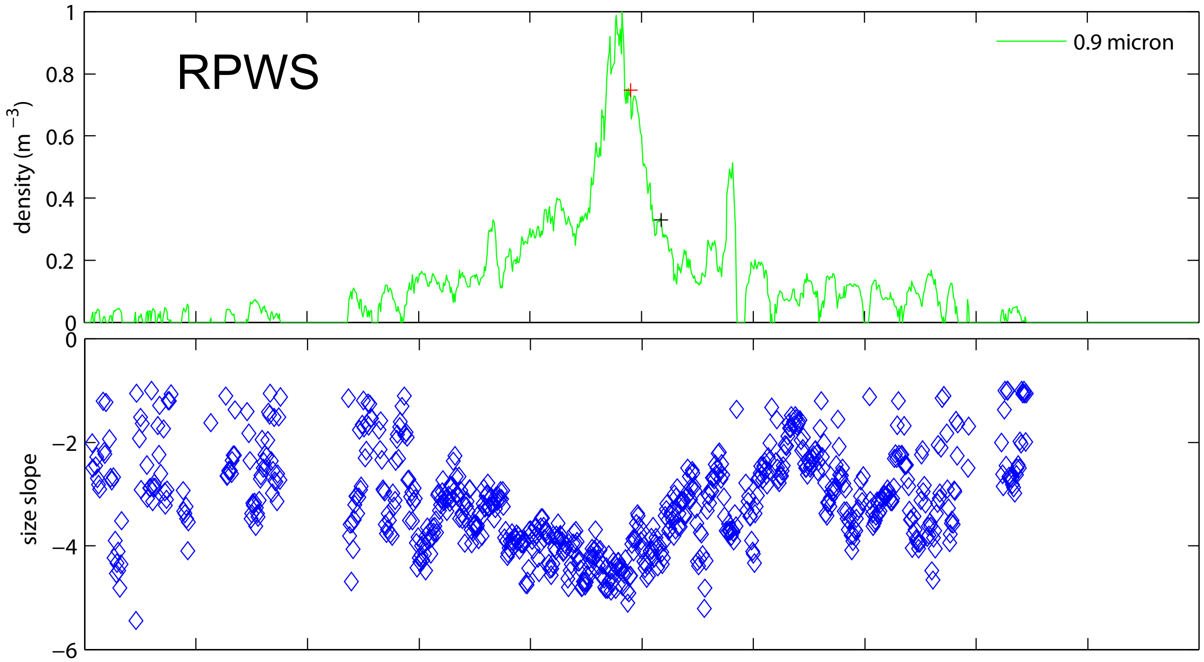
$$n(m>m1) \propto 1/m1$$

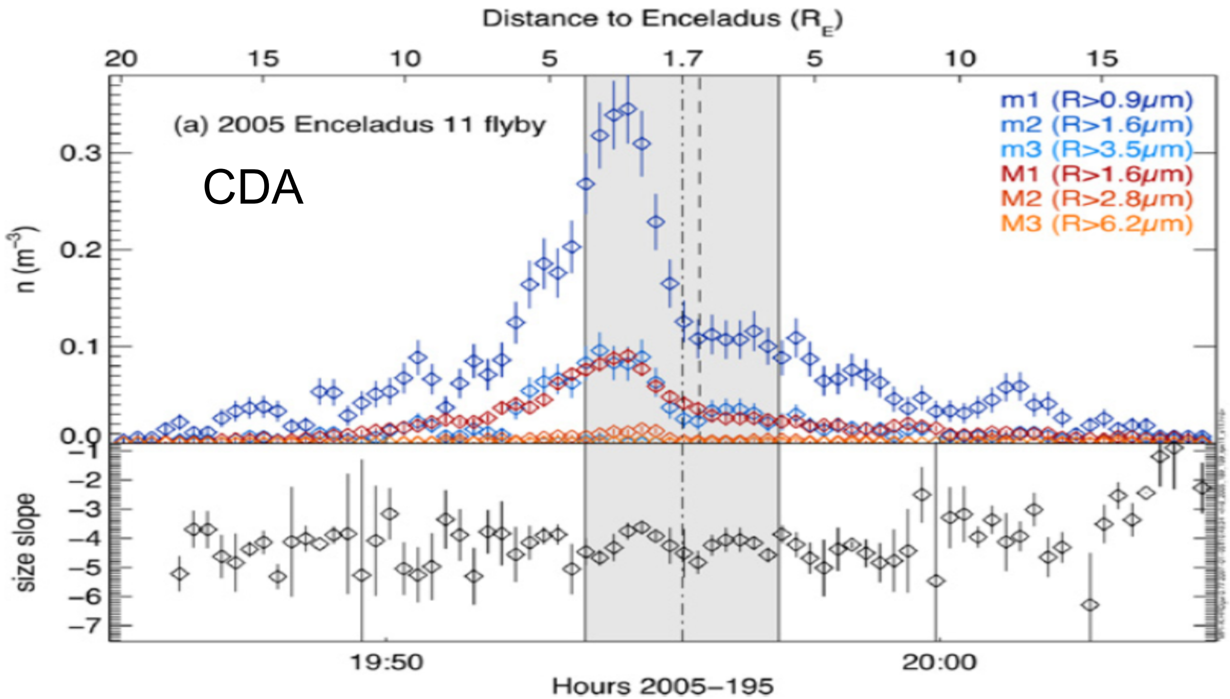






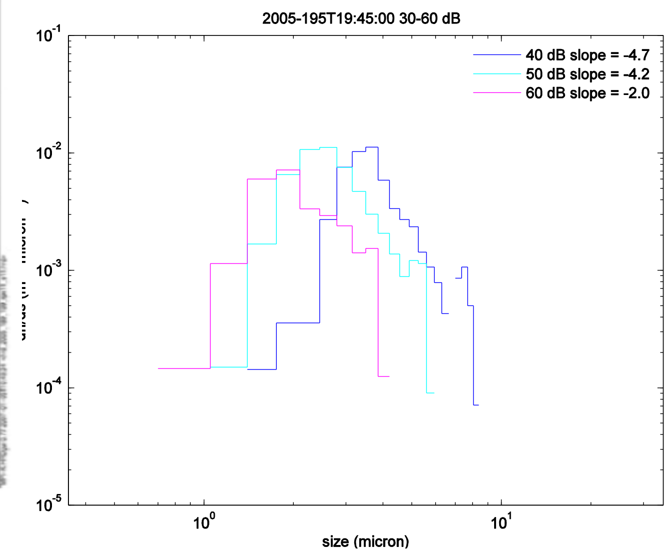
Dust density measured by RPWS and CDA during E2 Flyby



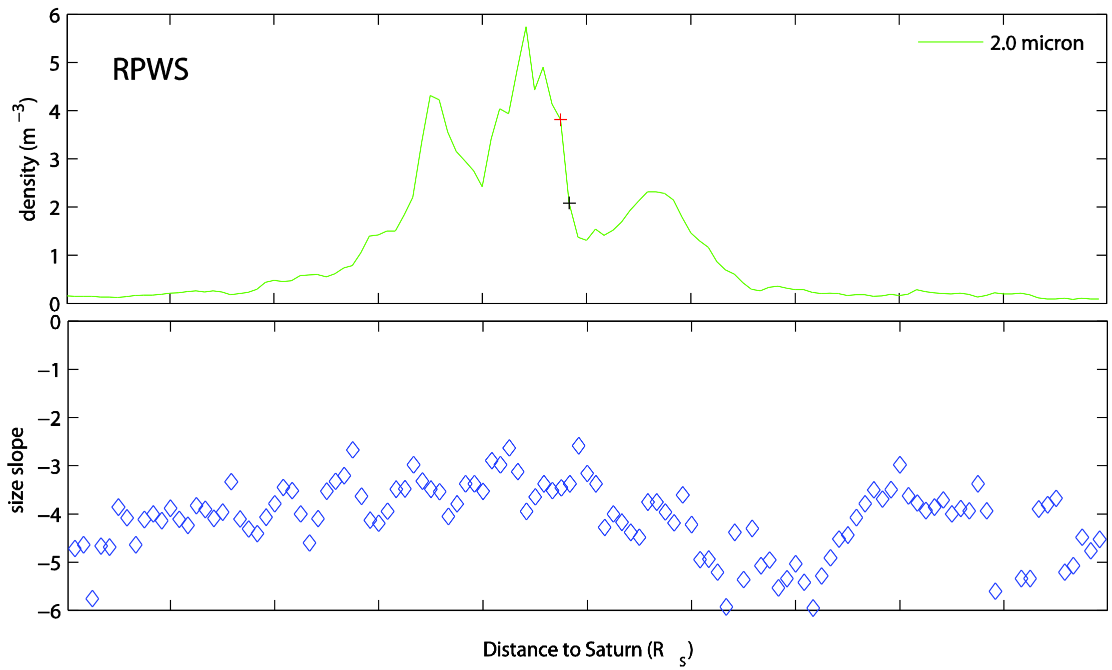


similar structures as CDA/HRD

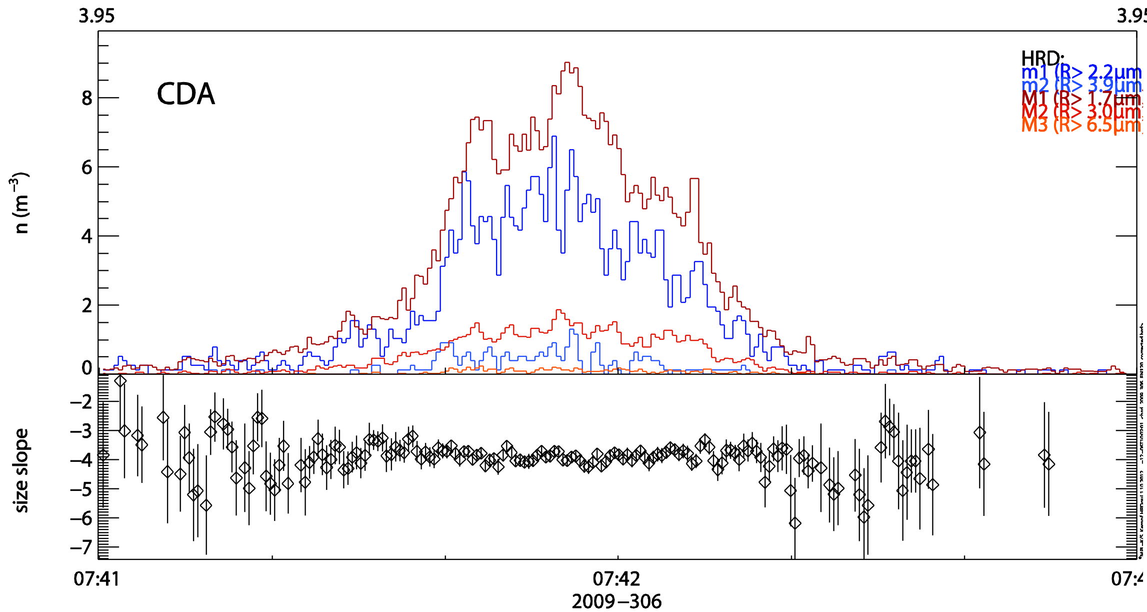
Difference within the uncertainty range. The effective area could be off by a factor of three. The charge yield factor could be off by a factor of ten.



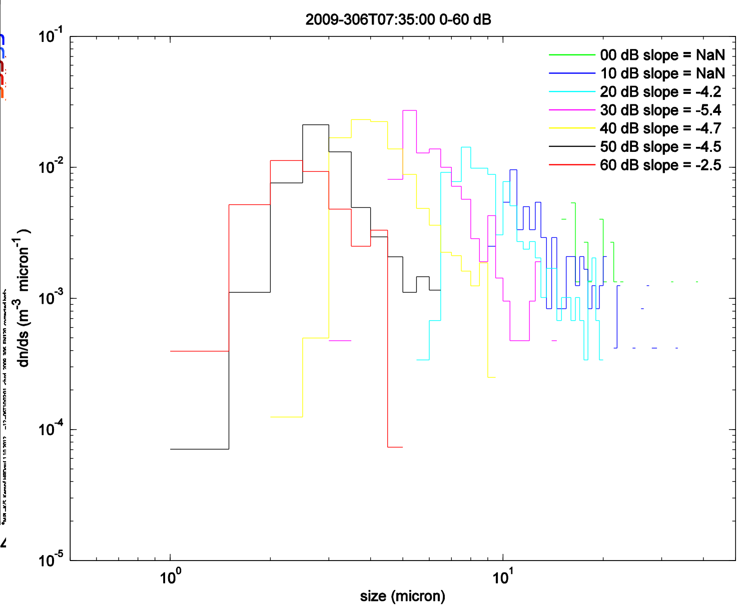
Dust density measured by RPWS and CDA during E7 Flyby



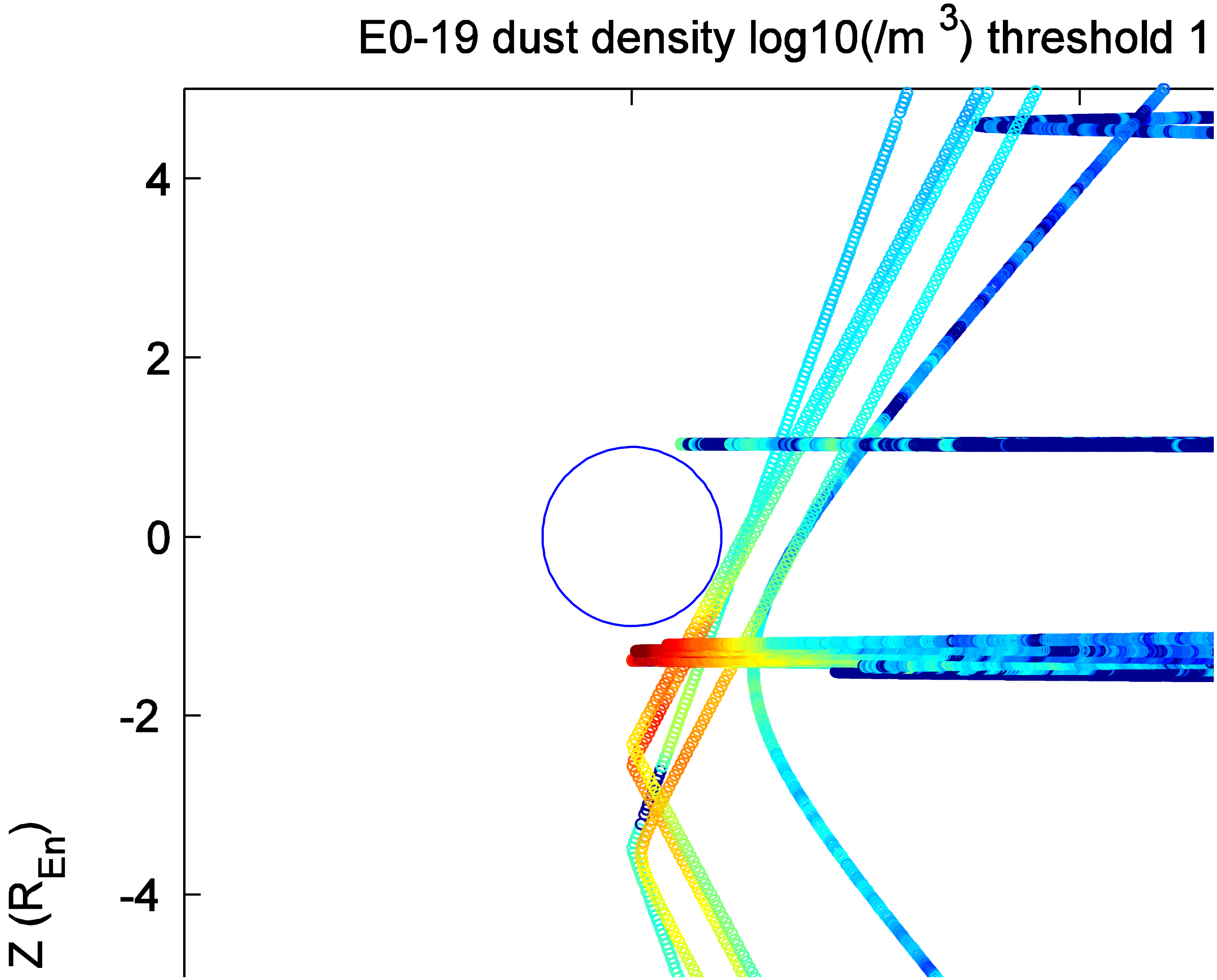
similar structures



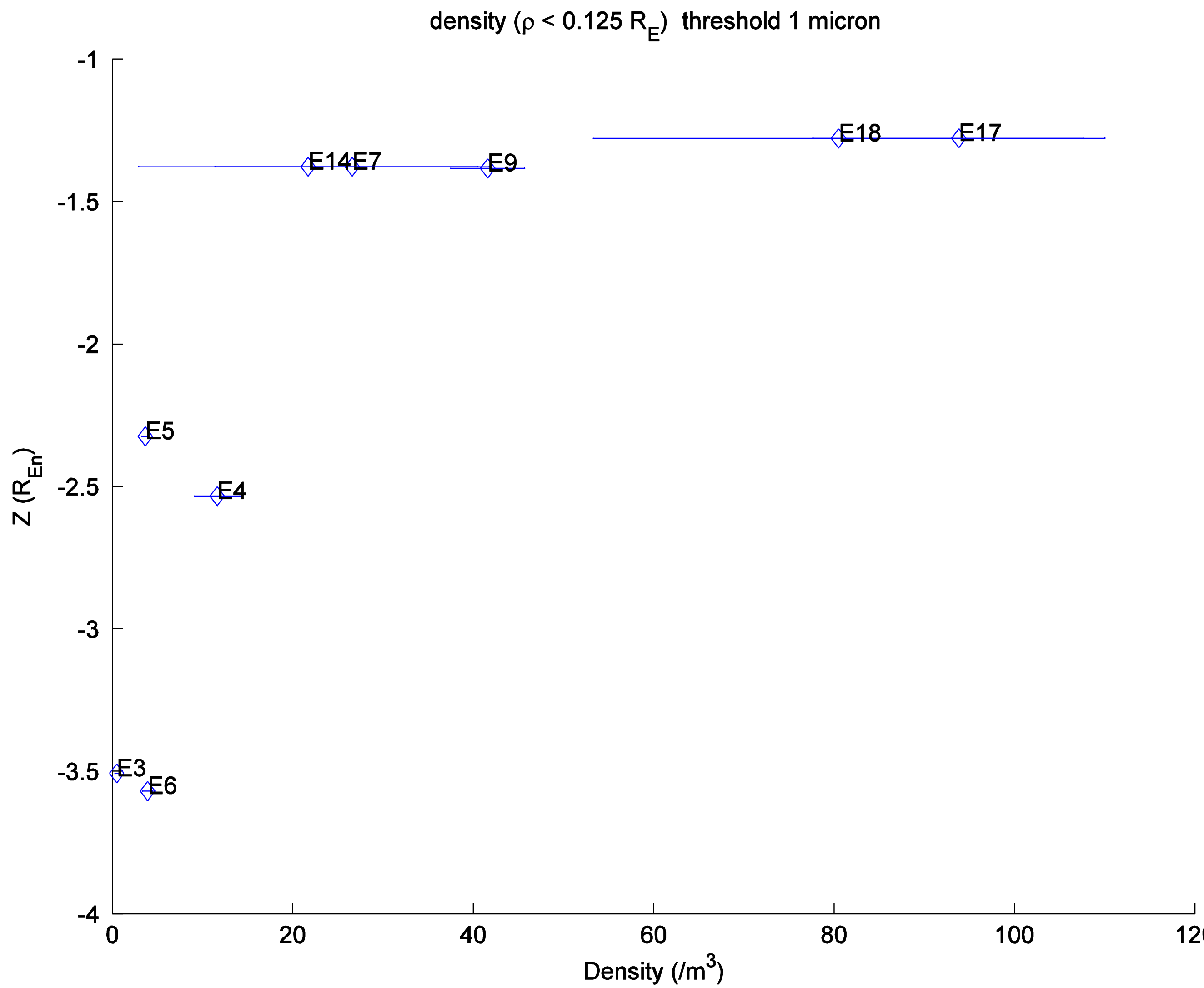
Similar slopes of size distribution



Dust density for all Enceladus flybys

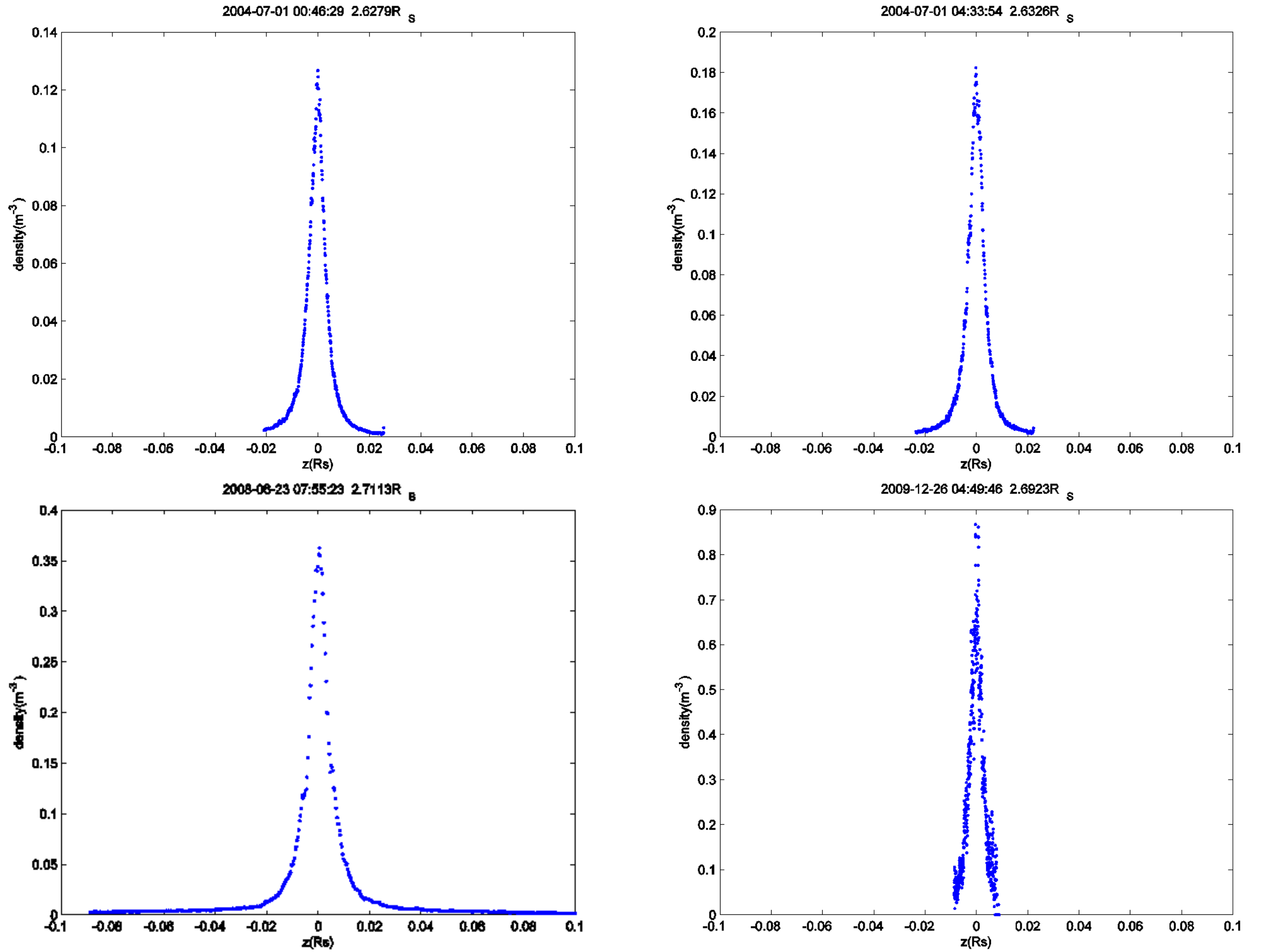


Dust density variation of the Enceladus plume

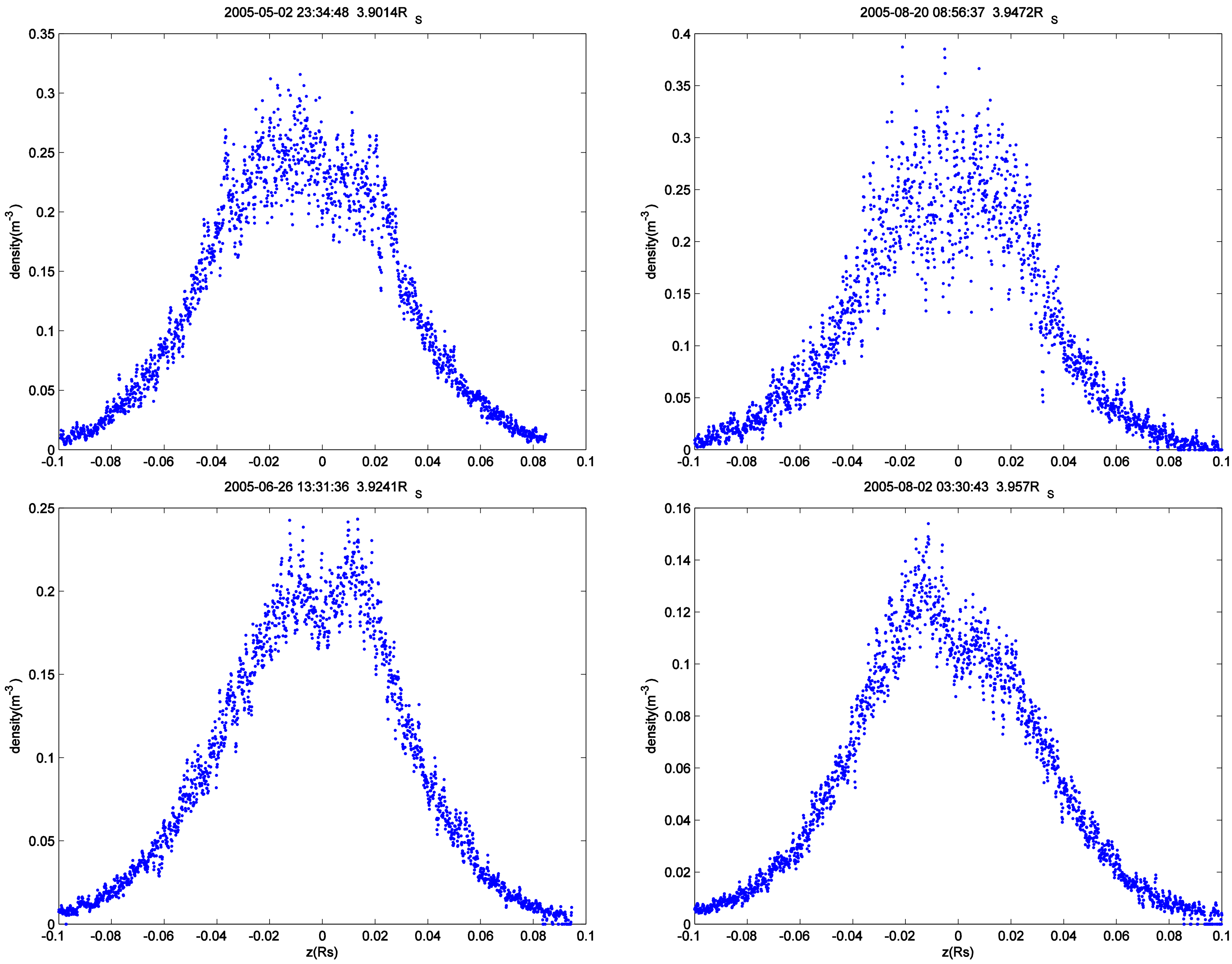


For similar trajectories, the dust densities vary by factor 2 or more

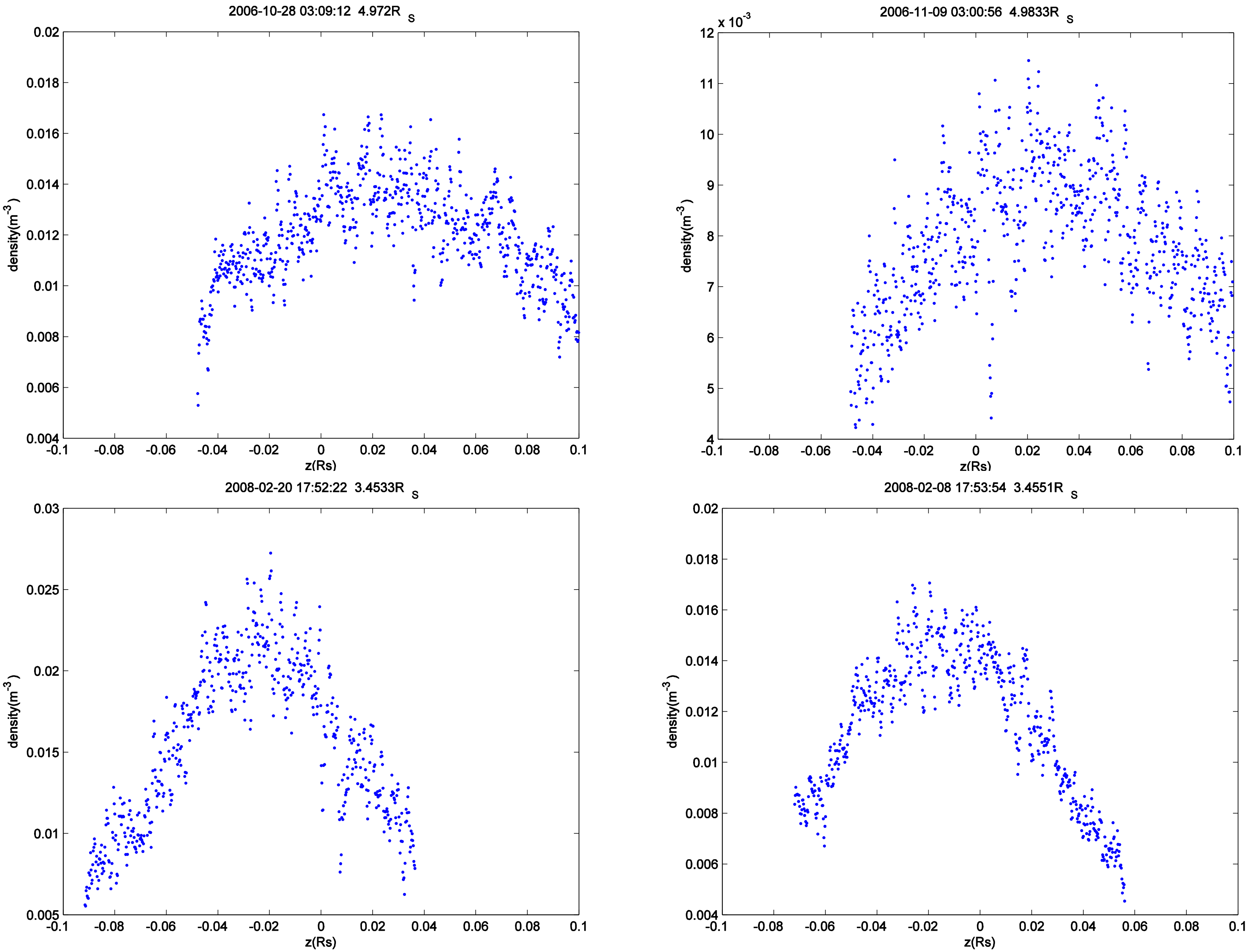
Vertical profile ring plane crossings < 3 Rs



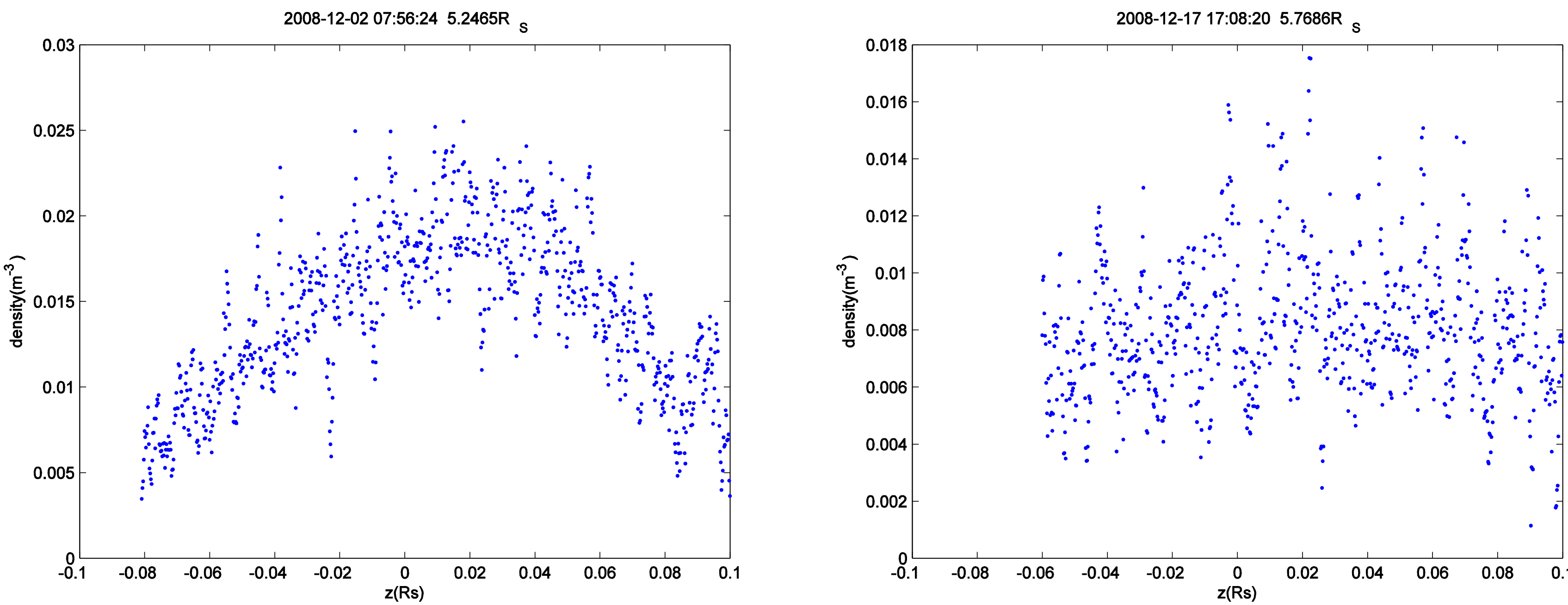
E-ring vertical profile at 4 Rs



E-ring vertical profile outside and inside 4 Rs

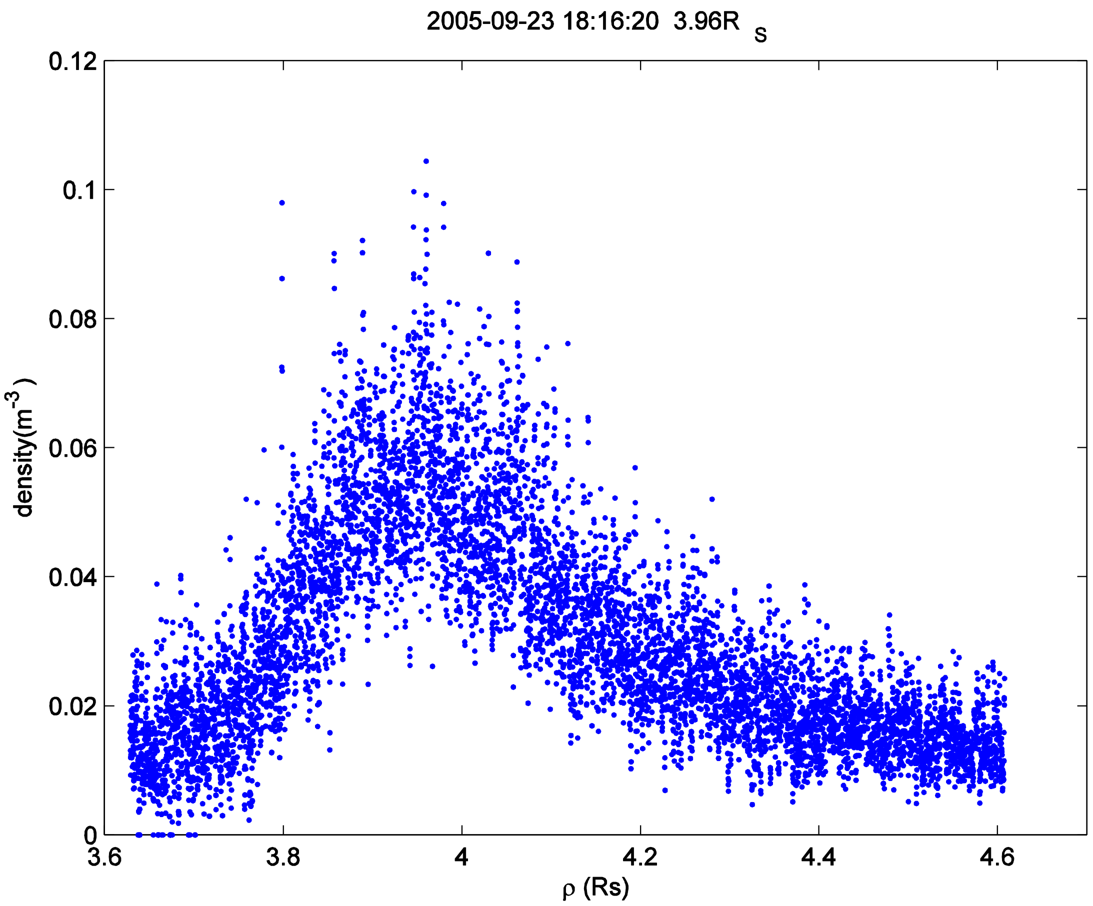


E-ring vertical profile > 5 Rs

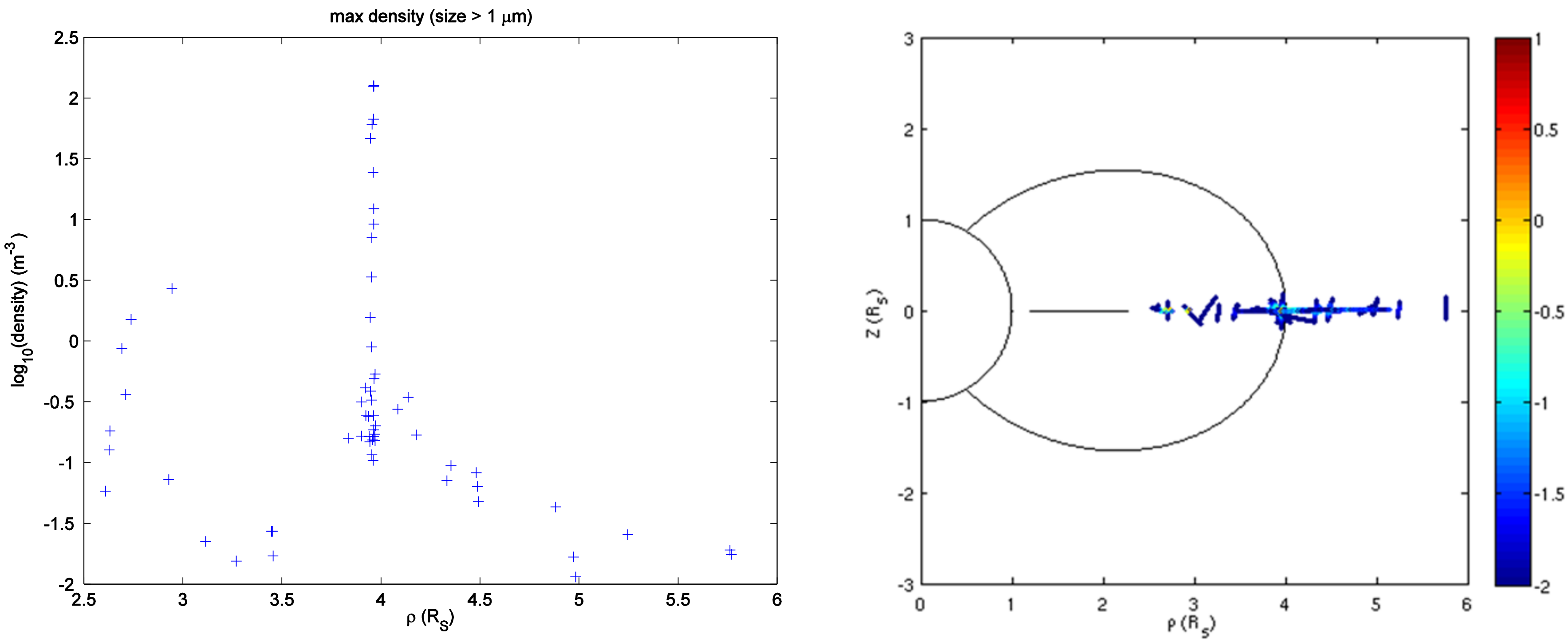


Density peak at north of the ring plane
Scale height increases with radial distance outside 4 Rs

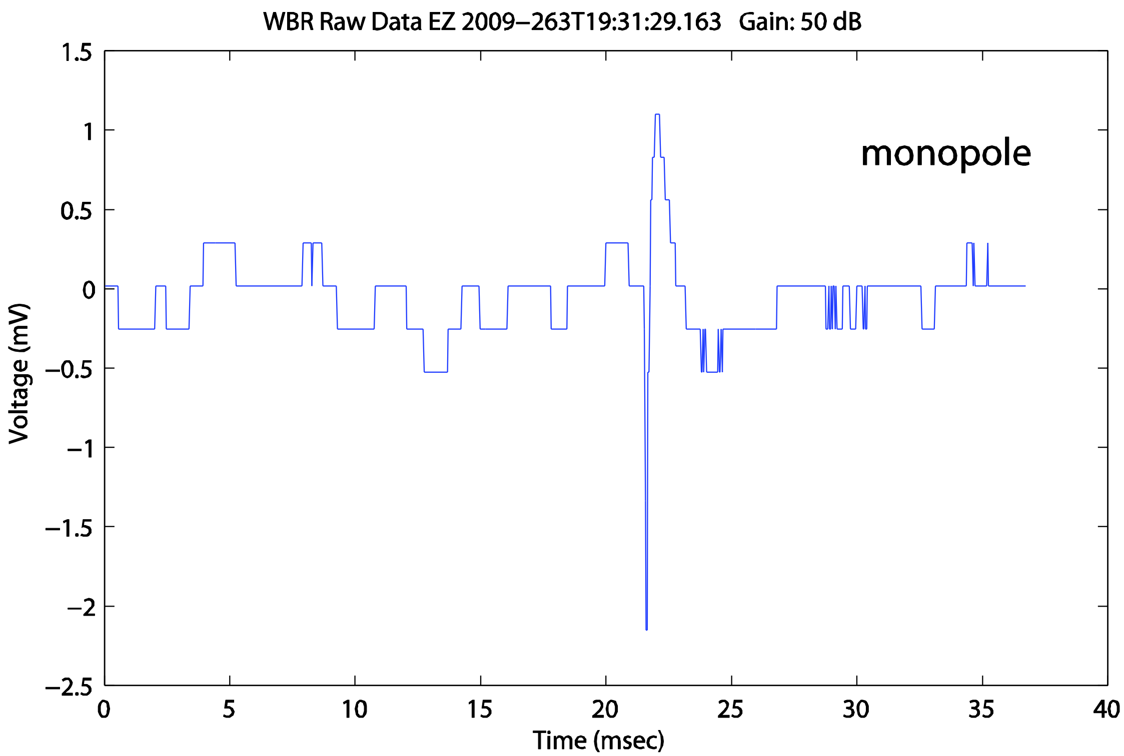
E-ring radial profile

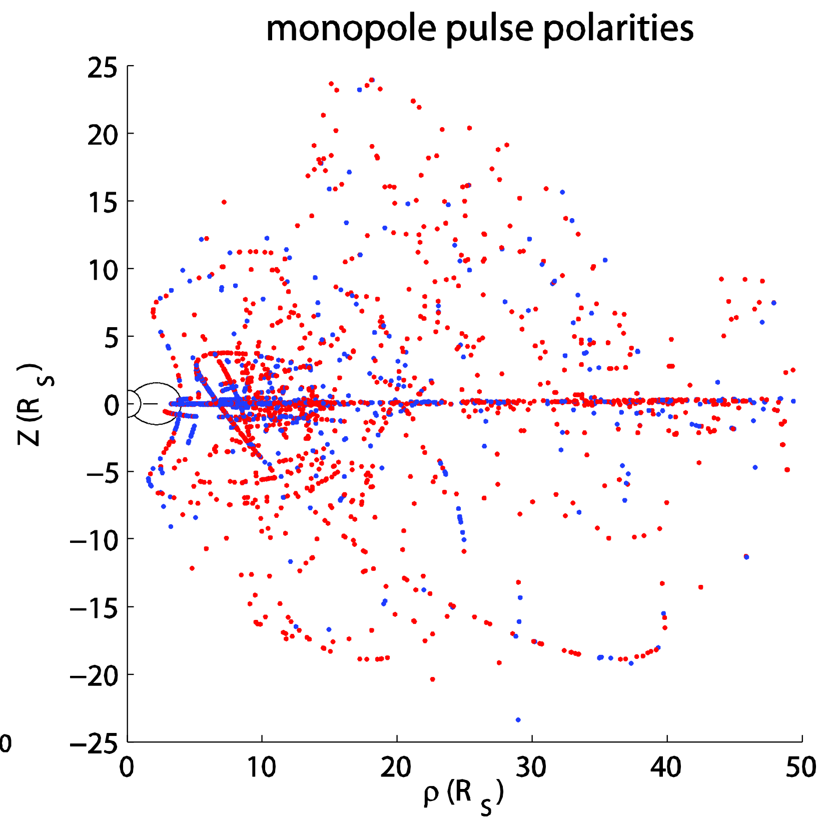


Ring plane crossings (SOI ~ 2012)



On-board dust detection using monopole E_w antenna

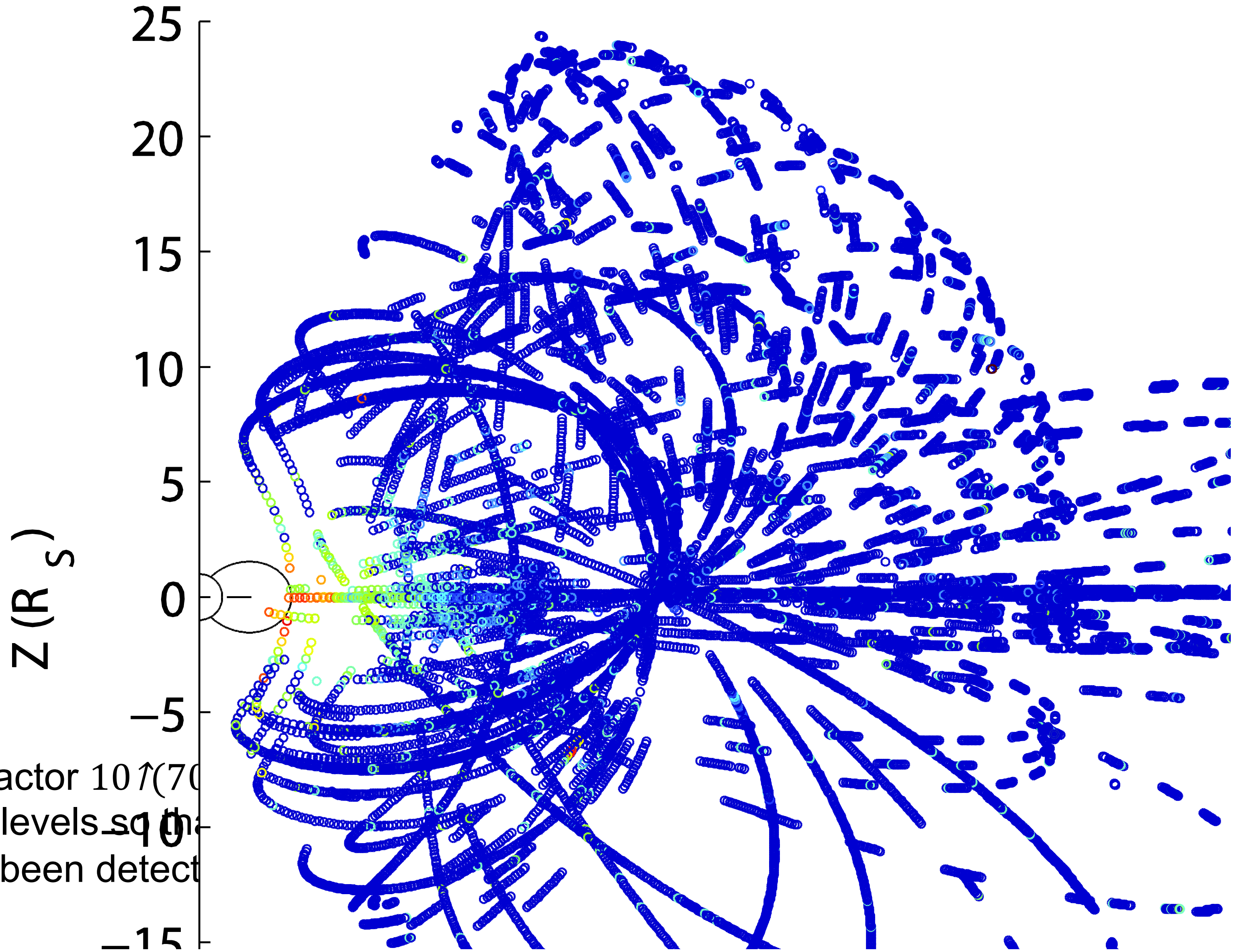




WBR low rate mode, dust detection by on-board program

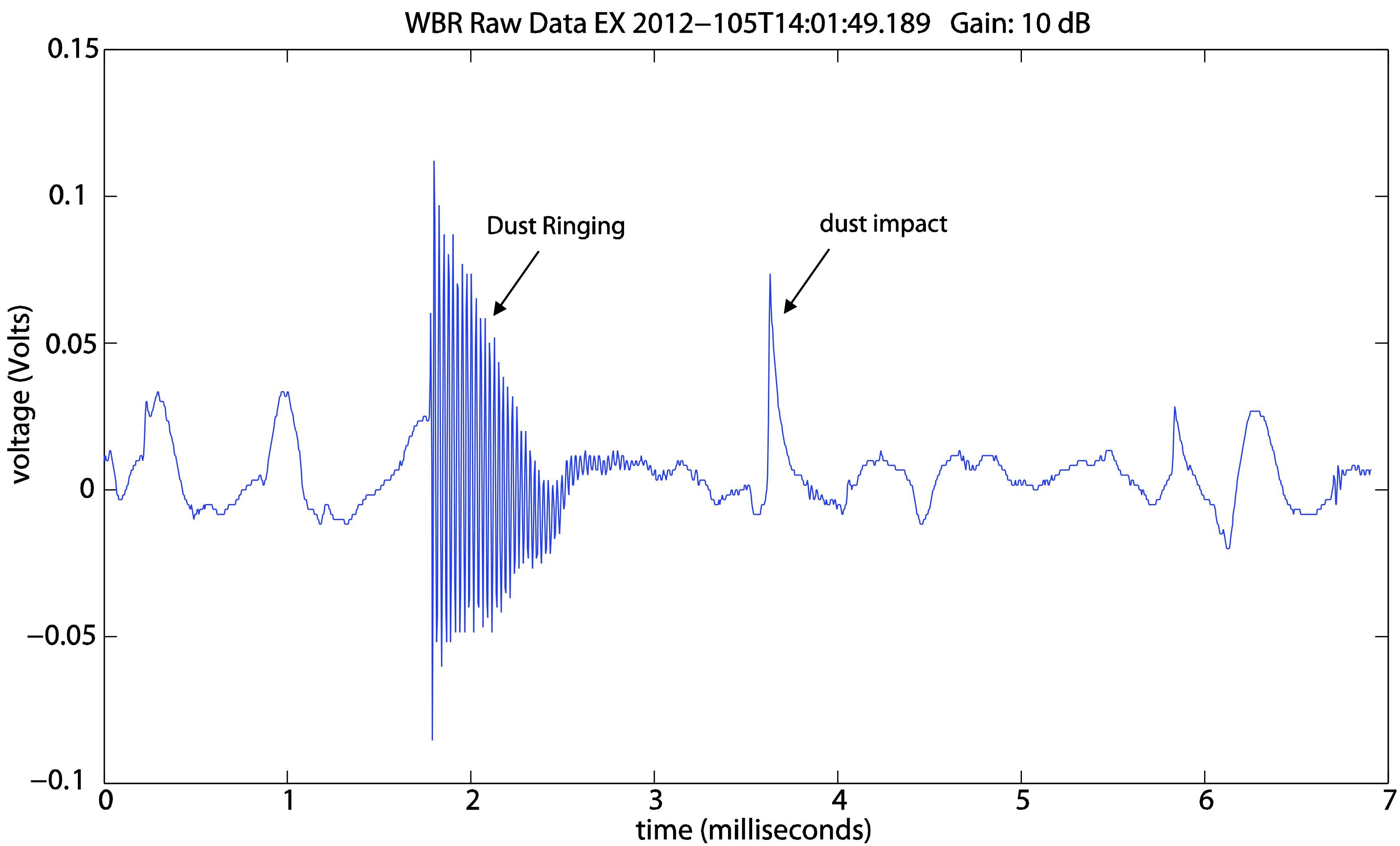
Polarity of the voltage pulses determined by spacecraft potential

On-board dust impact rate monopole E_w antenna

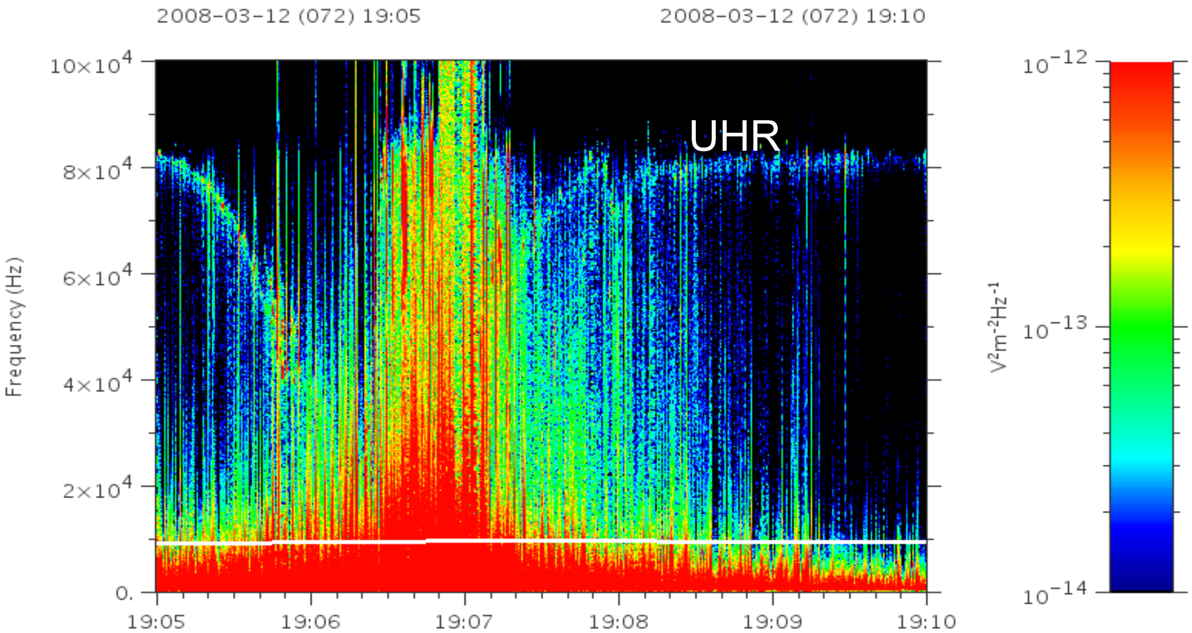


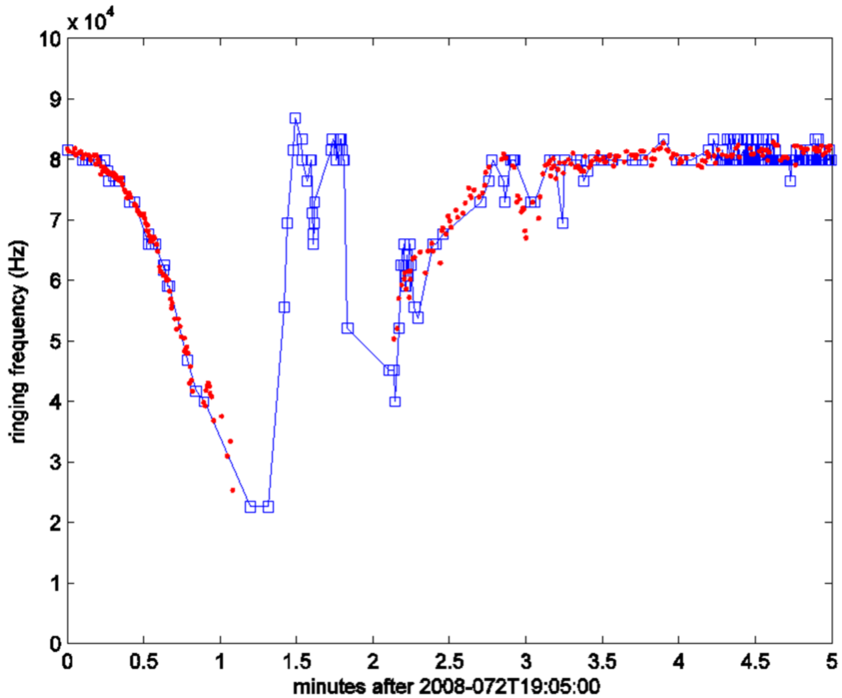
Correction factor 10↑(70
different dB levels so tha
would have been detect
of 70 dB).

Dust ringing effect and plasma frequency

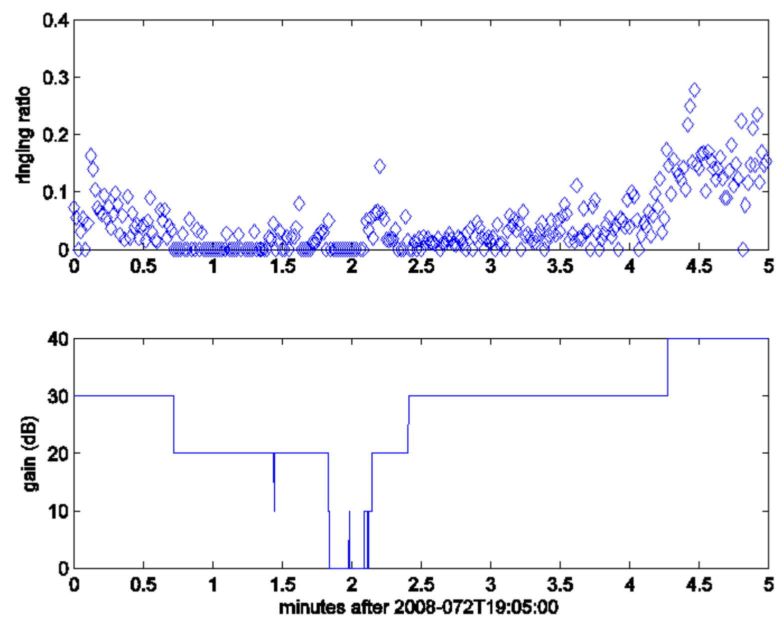


Electron Density Profiles derived from dust ringing frequency for E3

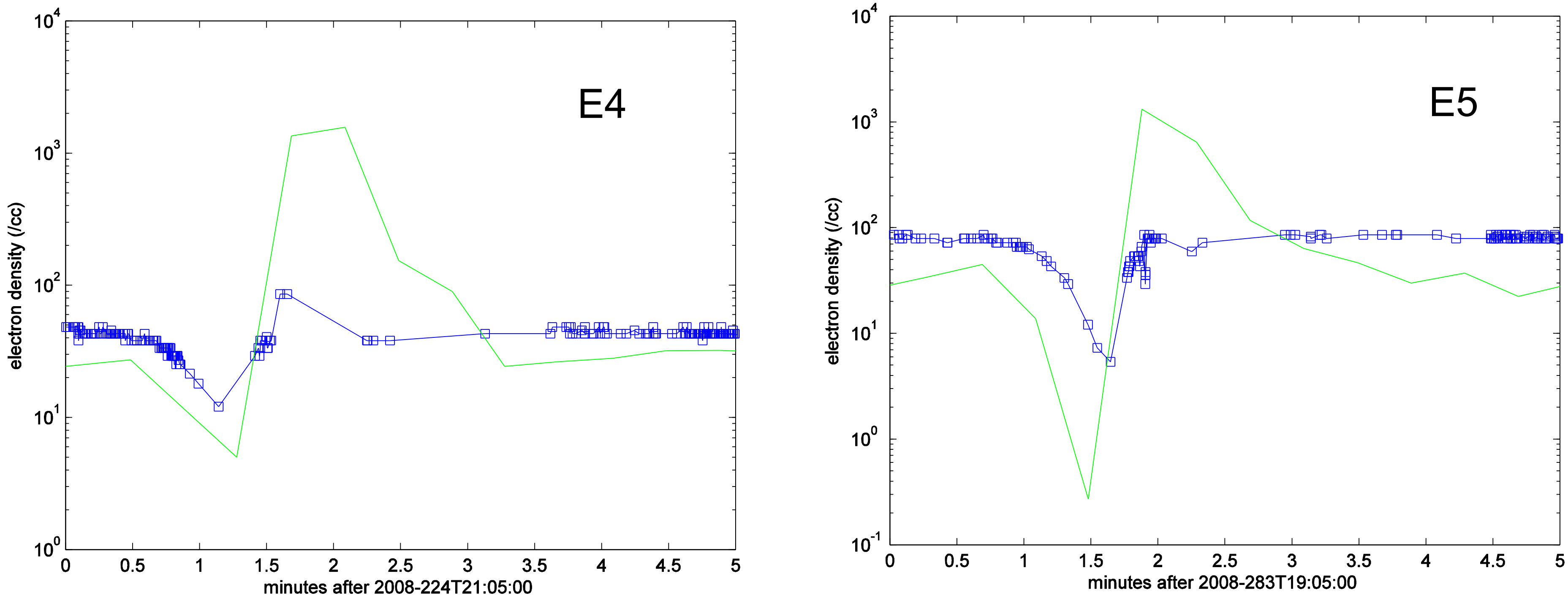




Ringing ratio increases with dB



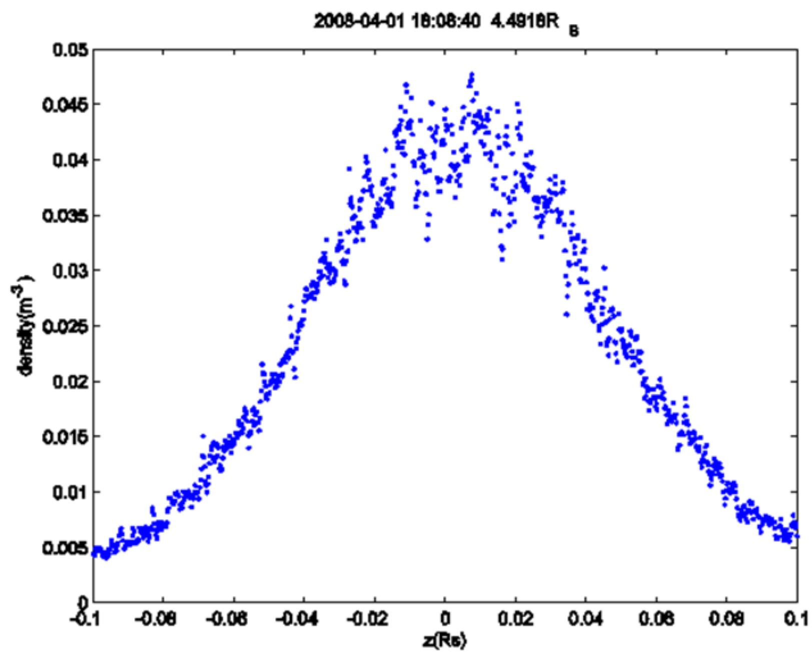
Electron density vs. Langmuir probe measurement



Note that the upper limit of the density measurement via dust ringing is ~ 100 cm^{-3} as imposed by the anti-aliasing filter.

Summary

- At around 10 km/sec impacting speed, RPWS is sensitive to micron-sized dust impacts. The range of detectable size depends on impact velocity and the gain level of the receiver.
- The dipole and monopole measurements of the dust impacts are compared, from which the effective impact area of the spacecraft is estimated to be 4 m^2.
- WBR provides continuous measurements of impact rates, number densities and size distribution of the dust grains in Saturn's rings.
- RPWS and CDA observed similar density profiles and similar size distribution slope.
- The dust size distributions observed during the E-ring crossings and Enceladus flybys show that E-ring particles are characterized by power law distribution $dn/dr \propto r^{\mu}$, where $\mu \sim -4$ and r is the particle radius.
- A new phenomena called dust ringing is applied to determine the plume electron density. The result agrees with LP measurement.


2008-04-01 16:08:40 4.4916R s
density(m^-3)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
z(Rs)