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# Nanodust in the Heliosphere

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**Abstract.** The NASA Parker Solar Probe and the ESA Solar Orbiter will explore the source region of the solar wind within 20 solar radii. Their unprecedented in-situ measurements are also expected to shed light on the nature of the F-corona and the existence of a halo of nanodust. Such a dust complex might play an important role in the generation of high-speed nanodust grains and the inner-source pickup ions. A brief summary of previous works on this topic is given here to be followed by a sketch on a plan to integrate MHD simulation of solar wind flow dynamics, orbital motion of charged nanodust and the production of energetic neutral atoms (ENAs) in the interplanetary space.

## 1. Introduction

Recent analysis of the HI-1 imaging data from the STEREO A solar telescope indicated the existence of a circumsolar dust belt in the vicinity of Mercury's orbit [1]. The source of such a dust belt could be associated with some small bodies in co-orbital motion with Mercury. The same author team [2] examined the white-light brightness distribution of the F corona inside of this newly discovered dust belt. Clearly, the in-situ measurements of the Parker Solar Probe would provide the first-hand information not just on the heating and acceleration of the solar wind, but also the near-solar dust cloud complex never directly probed by spacecraft. In retrospect, we should remember that there have been a number of intriguing space measurements providing a glimpse of the physical processes involving dust-plasma interaction in the source region of the solar wind. The first one has to do with the detection of the electromagnetic signals generated by high-speed impacts of nano-dust particles on the antennas of the plasma wave and radio science experiment on the STEREO spacecraft [3, 4]. A convenient explanation of the source mechanism of these tiny solid particles of 1-10 nm size has to do with the collisional erosion or breakup of the dust grains in the F corona [5,6,7]. However, an additional source of potential importance is comets – especially the so-called sun-grazing comets - with perihelion distances very close to the sun [8,9].

## 2. Nanodust dynamics

Because of photoemission, interplanetary dust particles would usually be charged to an electrostatic potential of a few Volts. Depending on the size and mass of individual dust grains, the corresponding charge-to-mass ratio in unit of electron charge ( $e$ ) to the proton mass ( $m$ ) can have a wide range of possible values, namely, from  $e/m \sim 10^{-7}$  to  $e/m \sim 10^{-5}$ . As a result, the Lorentz force coupled with the solar gravitational force could generate different types of particle trajectories according to the  $e/m$  values and the injection locations of the nanodust. Computation of the particle trajectories is not as simple as it seems. This is because the details depend on the structures of the solar wind and the interplanetary magnetic fields (IMF) that are quite variable. For most cases of the MHD simulations of



the space weather effects, the inner boundary of the simulation box is larger than  $20 R_{\odot}$ , thus missing the main part of the nanodust source region. To explore the dynamics of the charged nanodust, some special cases with the inner boundary set to be just a few solar radii would have to be run. The advantage is that with the initial condition of the solar wind and solar coronal magnetic field mapped to the solar surface, a more realistic picture of the solar wind structure and interplanetary magnetic field configuration would be available to the corresponding trajectory calculations. In the absence of such a more comprehensive description, the alternative is to use a simple kind of steady state Parker wind model with a prescribed, spherically symmetric, solar wind velocity profile and the resultant 3D Parker spiral configuration of the interplanetary magnetic field. For example, the solar wind speed can be assumed to be constant with  $V_{sw} = 400 \text{ km s}^{-1}$ , and the magnetic field  $B = 4 \times 10^{-4} \text{ G}$  at  $r = 1 \text{ AU}$ . Even in this case, the dust motion is still quite variable. Figure 1 illustrates the orbital structures of the nanodust with  $e/m$  between  $10^{-4}$  and  $10^{-6}$  and injection positions ( $r_i$ ) at three different heliocentric distances from  $10 R_{\odot}$  to  $25 R_{\odot}$ . The nanodust particles are assumed to be initially in circular Keplerian motion in the ecliptic plane before the switch-on of the Lorentz force. Some characteristic features to be noted.

(a)  $r_i = 10 R_{\odot}$

Nanodust of different  $e/m$  ratios would all be deflected to inward trajectories. At the boundary of  $5 R_{\odot}$ , the dust grains reach a radial speed of nearly  $200 \text{ km s}^{-1}$ . This means these fast-moving nanodust could be very efficient in eroding the F-corona dust cloud. The accelerated particles are generally confined to a flat disk with the vertical distance  $z < 1 R_{\odot}$ .

(b)  $r_i = 15 R_{\odot}$

The trajectories are still generally inward except for  $e/m = 10^{-5}$  in which case a large fraction of the nanodust is temporarily trapped. The dust population is still confined in a flat disk.

(c)  $r_i = 20 R_{\odot}$

Depending on the magnetic field polarity, the highly charged nanodust with  $e/m \sim 10^{-4}$  could be either deflected inward or outward. For the outward-moving component, their vertical distances could reach  $z \sim 50 R_{\odot}$ . The above-mentioned trend is followed by the dust grains with  $e/m \sim 10^{-5}$ . Interestingly, the radial and vertical distances could be larger than  $100\text{-}200 R_{\odot}$  thus filling the whole heliosphere. For those dust particles with  $e/m \sim 10^{-6}$ , they would be trapped in oscillatory motion in an ellipsoidal-shaped zone.

(d)  $r_i = 25 R_{\odot}$

At the outer edge of the nanodust source zone, the dust particles with large  $e/m$  values would be injected either inward or outward depending on the polarity of the IMF. For those reaching the orbital distance of the Earth at  $r \sim 200 R_{\odot}$ , the speed could be as high as  $400 \text{ km s}^{-1}$ . However, they also have rather large vertical distance ( $z \sim 70 R_{\odot}$ ). They hence do not necessarily account for the dust impact effect detected by the STEREO experiment (Bougerete et al., 2008; Meyer-Vernet et al., 2009). For  $e/m \sim 10^{-5}$ , all the dust grains would be ejected outward and upward to  $r > 200 R_{\odot}$  and  $z > 100 R_{\odot}$ . The gravitational force becomes more significant at  $e/m \sim 10^{-6}$  so that the charged nanodust would be trapped in orbital motion forming a kind of “knitting ball” surrounding the sun.

These numerical results are qualitative similar to the results of Mann, Murad and Czechowski [10] who also showed how charged nanodust in certain  $e/m$  range ( $\sim 5 \times 10^{-6}$ ) could be trapped in different orbital configurations according to their original injection positions near the sun. It is therefore expected that the Parker Solar Probe and the Solar Orbiter of ESA would enter this nanodust zone as they move inside the orbital region with  $r < 0.2 R_{\odot}$ .

The fluxes of the high-speed nanodust are quite variable according to Meyet-Vernet et al. [4]. There could be a number of physical reasons. The first one, more exotic in nature, has to do with the occasional passages of sun-grazing comets with perihelion distances of a few solar radii [8, 11]. The charged cometary nanodust originally in near-parabolic orbits could be accelerated to very high speed in escaping trajectories. On the other hand, changes in the solar wind structures or solar activity could also be an important factor. Czechowski and Kleimann [6] using a MHD model of a coronal mass ejection from the solar surface to a radial distance of  $0.14 R_{\odot}$  to compute the trajectories of charged nanodust. These authors found that a speed as high as  $1000 \text{ km s}^{-1}$  could be achieved by some dust particles.

### 3. Discussion

In the above, a very brief summary is given to the topic of the existence and dynamics of nanodust in the near-solar region overlapping the F-corona. In-situ measurements and remote-sensing observations of the Parker Solar Probe and the Solar Orbiter related to dust impacts and dust cloud distribution might provide first-hand information on the near-sun dust environment. It can be seen that a lot remains to be done in this relatively unexplored area. Our plan is therefore to systematically assemble a set of numerical data from 3D MHD model calculations of (1) solar wind flow during quiet-sun condition (cf. [12]), (2) the time evolution of the corotating interaction region of the high-speed solar wind and the low-speed solar wind (cf. [13]), and (3) expansion of the coronal mass ejection events from the solar corona to the interplanetary space (cf. [14]). These data sets providing detailed information on the solar wind plasma velocity, temperature, number density and interplanetary magnetic field in different regions of the heliosphere would allow us to simulate the orbital motion of nanodust with different  $e/m$  values.

An interesting potential byproduct of the planned study is the examination of the process of solar wind charge exchange with the interstellar neutral gas. By the same token, the dust-related source mechanism of the so-called inner source pickup ions [15-18] might be investigated in more detail once the orbital distribution and dynamics of the charged nanodust is better understood.

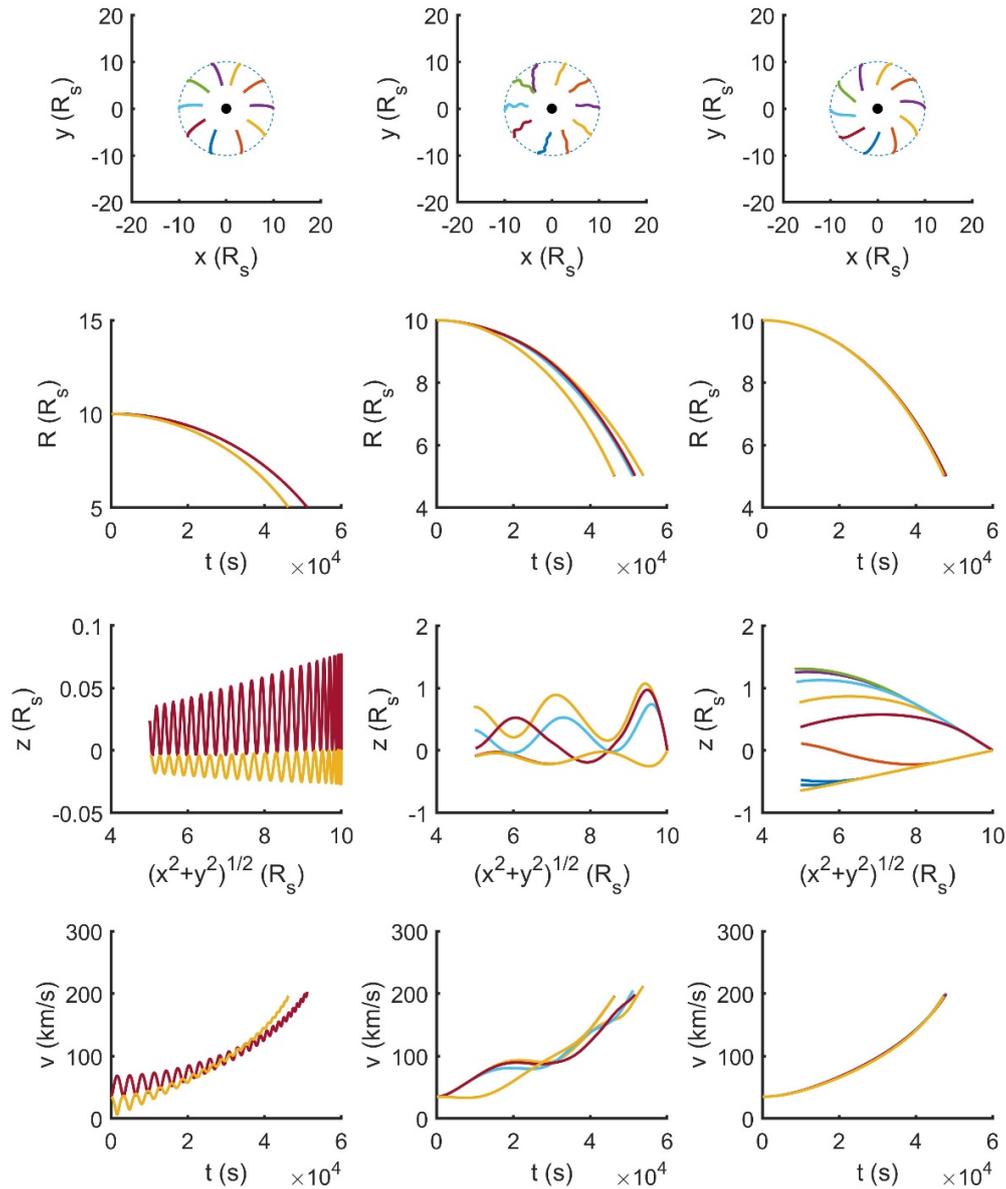


Figure 1. Orbital dynamics of charged nanodust with  $r_i = 10 R_\odot$  and three different values of  $e/m$  (e.g.,  $10^{-4}$ ,  $10^{-5}$  and  $10^{-6}$ ). First row: 2D projections of the particle trajectories on the ecliptic plane; second row: the changes of the heliocentric distance; third row: the changes in the vertical distances; fourth row: the time profiles of the particle speeds after ejection.

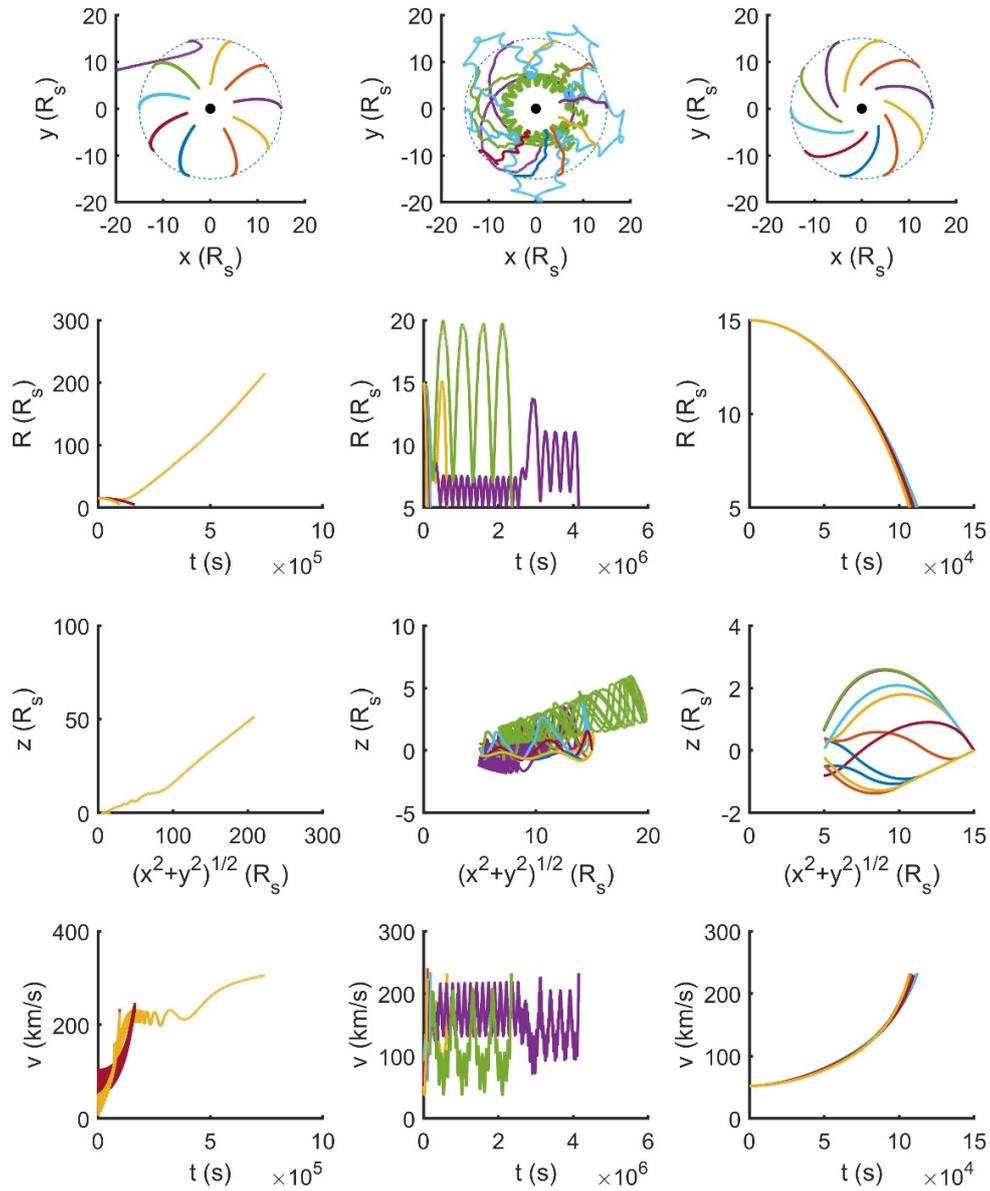


Figure 2. Same as Figure 1 but for  $r_i = 15 R_\odot$ .

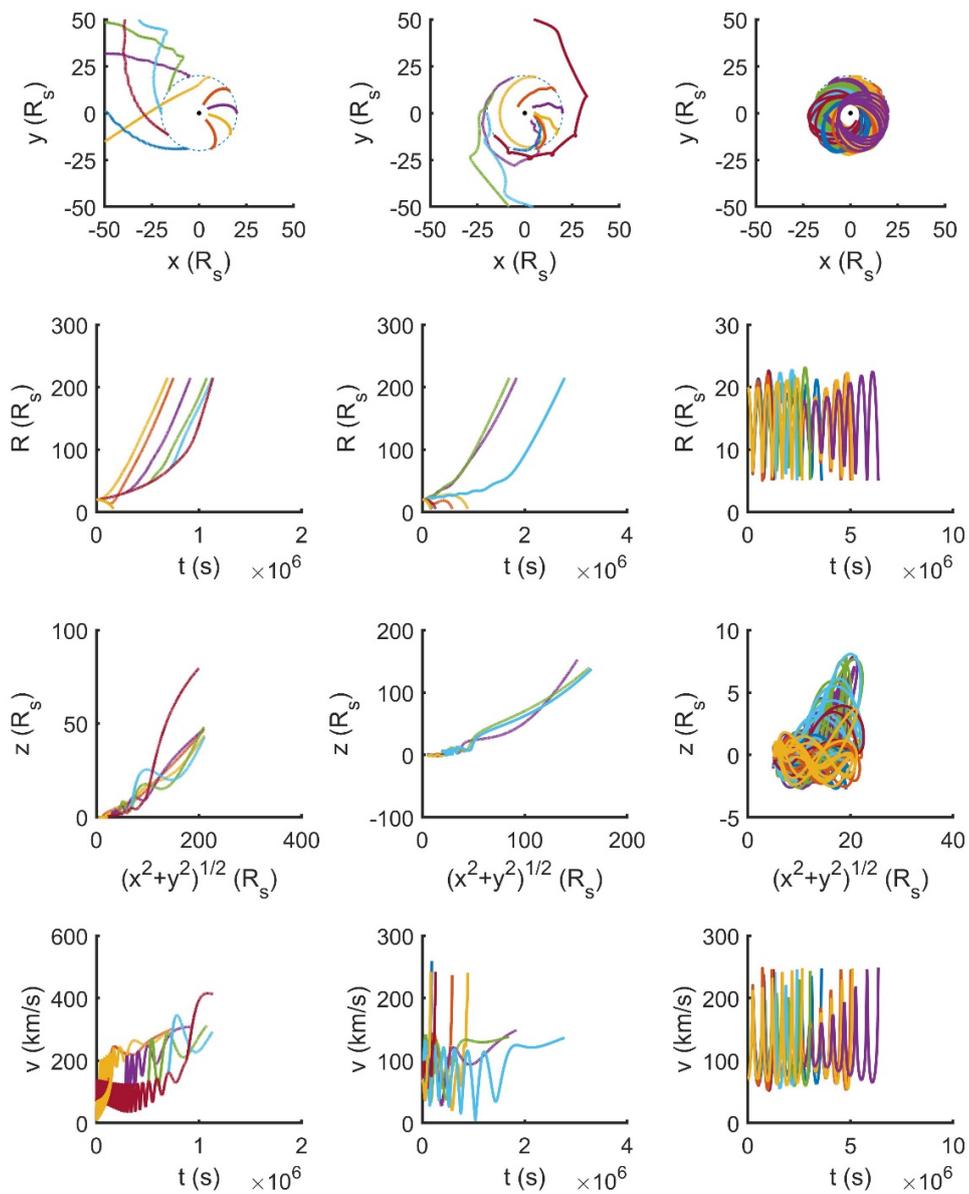


Figure 3. Same as Figure 1 but for  $r_i = 20 R_\odot$ .

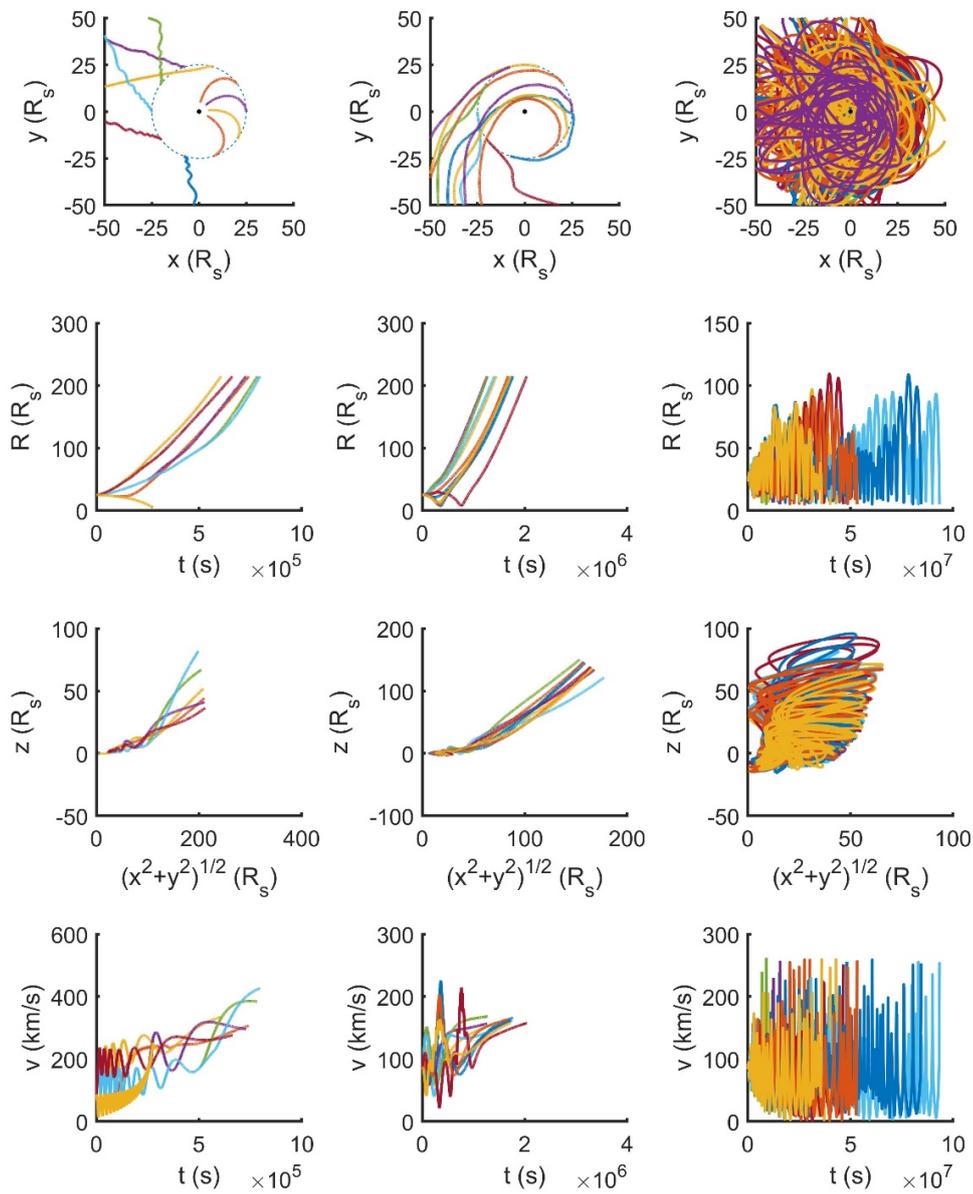


Figure 4. Same as Figure 1 but for  $r_i = 25 R_\odot$ .

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