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Surface charging and electrostatic dust acceleration at the nucleus of comet 67P during periods of low activity

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ABSTRACT

We have investigated through simulation the electrostatic charging of the nucleus of Comet 67P/Churyumov–Gerasimenko during periods of weak outgassing activity. Specifically, we have modeled the surface potential and electric field at the surface of the nucleus during the initial Rosetta rendezvous at 3.5 AU and the release of the Philae lander at 3 AU. We have also investigated the possibility of dust acceleration and ejection above the nucleus due to electrostatic forces. Finally, we discuss these modeling results in the context of possible observations by instruments on both the Rosetta orbiter and the Philae lander.

1. Introduction

Comets are constantly exposed to incoming solar wind plasma, which in the rest frame of the comet is supersonic. Due to solar insolation, cometary volatiles at the surface and within the subsurface may sublimate and be expelled from the nucleus. A large fraction of these ejected neutrals become ionized and are "picked up" by the solar wind motional electric field, transferring momentum and energy from the solar wind, causing it to decelerate near the nucleus (e.g. Coates, 1997, 2004). Eventually, as outgassing rates increase, the solar wind may be sufficiently decelerated ("mass loaded") for several plasma structures to form, including a weak bow shock (Biermann et al., 1967) and a diamagnetic cavity where the plasma is purely cometary in origin (Ip and Axford, 1987). However, as cometary gas production rates typically vary by several orders of magnitude depending on the comet–Sun distance, the interaction between the comet and the solar wind will change substantially depending on its activity phase (e.g. Cravens and Gombosi, 2004; Hansen et al., 2007; Rubin et al., 2014). In the case of a comet that is weakly outgassing, either intrinsically so, or when a productive comet is far from the Sun, the resulting mass loading rate will be insufficient to form these plasma boundaries, and the un-shocked solar wind will be able to flow directly onto the nucleus.

Comet 67P/Churyumov–Gerasimenko is a relatively weakly outgassing comet, with a predicted outgassing rate at perihelion ($\sim$1.29 AU) of $\sim 10^{27}$ molecules/s (Snodgrass et al., 2013), in comparison to that of comet 1P/Halley during its most recent apparition ($\sim 10^{30}$ molecules/s) (Huddleston et al., 1990; Weaver et al., 1986). The Rosetta spacecraft rendezvoused with comet 67P in August 2014, when the comet–Sun distance was roughly 3.5 AU. During this initial stage of the encounter, the comet was expected to be only weakly outgassing, with a predicted gas production rate of $\sim 10^{25}$ molecules/s (Snodgrass et al., 2013). Koenders et al. (2013) investigated the predicted evolution of plasma structures around 67P during the Rosetta escort phase using MHD and hybrid models. Their work predicted that 67P's cometary bow shock is only fully established when the comet–Sun distance is less than 1.35 AU, and that the magnetic pile up region and diamagnetic cavity appear when the comet–Sun distance is less than 2 AU, which occurs in April 2015. Thus, early in the Rosetta escort phase and during the touchdown of the Philae lander, it is expected that the un-shocked solar wind may flow directly onto the cometary nucleus.

Objects exposed to inflowing plasma and solar UV photons experience charging currents due to electron and ion bombardment, photoemission, and secondary electron emission (Whipple, 1981).

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For typical solar system materials, the electrical conductivity is sufficiently low that different regions on the surface may charge to different electrostatic potentials, depending on the local solar insolation and plasma flow geometries, as illustrated in Fig. 1. Although predicted to occur on a number of planetary bodies, this effect has so far only been reported to be observed in-situ at the Earth's moon (e.g. Freeman and Ibrahim, 1975; Halekas et al., 2002) and at Saturn's moons Hyperion (Nordheim et al., 2014) and Rhea (Jones et al., 2011; Santolík et al., 2011). The effect is also well-established to occur on spacecraft themselves. It has been predicted that surface charging may also occur on cometary nuclei during periods of low outgassing activity, when solar wind plasma and solar UV photons are allowed direct access to the nucleus (Mendis et al., 1981). It has also been suggested that surface charging of the nucleus may lead to electrostatic levitation of small dust particles (Flammer et al., 1986; Juhász and Szegő, 1998; Mendis et al., 1981) and that electrostatic dust blow-off may explain sudden changes in the observed brightness of comet Halley at large heliocentric distances (Flammer et al., 1986). As suggested in the recent review given by Mendis and Horányi (2013), the nucleus of comet 67P may exhibit surface charging and dust levitation during the initial part of the Rosetta escort phase when the comet is expected to be only weakly outgassing. The present work considers surface charging of the 67P nucleus during periods of weak activity, such as was the case during the initial encounter and early escort phase of the Rosetta mission. Thus we aim to provide context for the interpretation of data from the Rosetta orbiter and Philae lander, the latter which landed on comet's nucleus on November 12th 2014, when the comet–Sun distance was ~3 AU.

2. Modeling approach

In this section we present our approach for modeling of surface charging of the 67P nucleus as well as emission of charged submicron dust grains from the surface. In Section 2.1 we give the modeling approach for calculating the surface potential on the dayside nucleus. In Section 2.2 we expand on this by presenting a treatment of the solar wind plasma wake, which allows us to calculate surface potentials on the nightside (downstream) nucleus. In Sections 2.3 and 2.4 we outline how charged dust grains may be electrostatically accelerated away from the nucleus and how the flux of electrostatically emitted charged nanodust may be calculated.

2.1. Surface charging of the dayside nucleus

In order to calculate the electrostatic potential on the surface of the 67P nucleus, we have made use of the formulation of Manka (1973) for the Earth's Moon in the solar wind as implemented by Roussos et al. (2010), which for a given Solar Zenith Angle (SZA) solves the current balance

$$I_{ion} + I_{electron} + I_{photoelectron} + I_{secondary} = 0$$

Due to the large thermal velocity of solar wind electrons compared to the solar wind flow velocity, at every point, they are nearly isotropically incident on the surface of the nucleus and the electron current is proportional to the local electron temperature and density. The gyroradius of the relatively cold solar wind protons will be much larger than the size of the 67P nucleus. However, since the solar wind velocity is much greater than the thermal velocity of the ions, the ion current depends on the flow angle as well as the ion temperature and density.

For the solar wind parameters during the initial Rosetta encounter and Philae landing, we have taken those of Stubbs et al. (2014) at 1 AU and scaled these according to the radial scaling relations provided in Table 1. The photoelectron current is taken from that of Sternovsky et al. (2008) at the subsolar point of the Earth's moon and scaled to the orbital distance of the comet. The current due to emission of secondary electrons depends on the

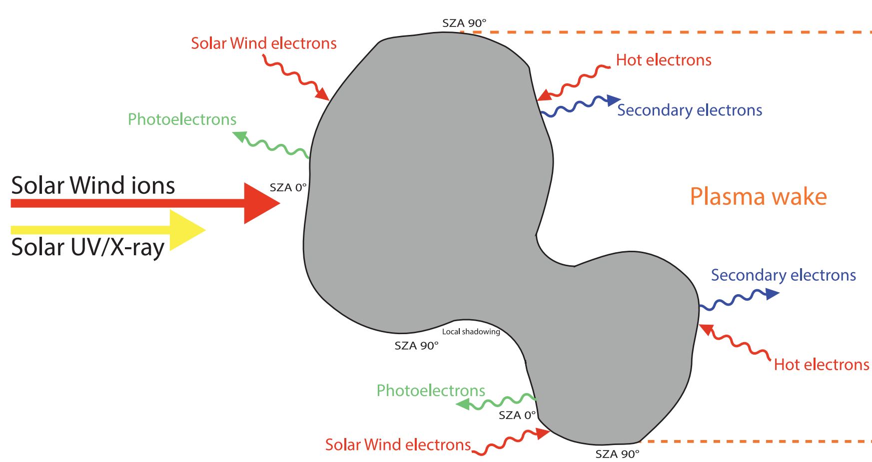

Fig. 1. Plasma interactions and surface charging of a weakly outgassing or inert cometary nucleus with a "double-lobe" structure.

Table 1
Model input parameters for Rosetta initial rendezvous (3.5 AU) and lander touchdown (3.0 AU).

Parameter	1 AU	3.0 AU	3.5 AU	Scaling	Note
T_e [eV]	12.1	4.45	3.87	$R^{-0.91}$	Scaling: Phillips et al. (1995)
T_i [eV]	8.6	3.99	3.58	$R^{-0.7}$	Scaling: Gazis and Lazarus (1982)
V_{flow} [km s^{-1}]	400	400	400		Negligible change – McComas et al. (2000)
Plasma density [cm^{-3}]	10	1.11	0.82	R^{-2}	Scaling: McComas et al. (2000)
E_{max} [eV]	420 eV	420	420		Tiersch and Notni (1989)
δ_{max}	2.5	2.5	2.5		Tiersch and Notni (1989)
I_p [A m^{-2}]	5.05E^{-06}	5.61E^{-07}	4.12E^{-07}	R^{-2}	Sternovsky et al. (2008)