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Pluto–Charon solar wind interaction dynamics

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ABSTRACT

This work studies Charon's effects on the Pluto-solar wind interaction using a multifluid MHD model which simulates the interactions of Pluto and Charon with the solar wind as well as with each other. Specifically, it investigates the ionospheric dynamics of a two body system in which either one or both bodies possess an ionosphere. Configurations in which Charon is directly upstream and directly downstream of Pluto are considered. Depending on ionospheric and solar wind conditions, Charon could periodically pass into the solar wind flow upstream of Pluto. The results of this study demonstrate that in these circumstances Charon modifies the upstream flow, both in the case in which Charon possesses an ionosphere, and in the case in which Charon is without an ionosphere. This modification amounts to a change in the gross structure of the interaction region when Charon possesses an ionosphere but is more localized when Charon lacks an ionosphere. Furthermore, evidence is shown that supports Charon acting to partially shield Pluto from the solar wind when it is upstream of Pluto, resulting in a decrease in ionospheric loss by Pluto.

1. Introduction

Pluto's discovery in 1930 was followed several decades later by that of its companion, Charon, in 1978. Here we will be exploring the role that Charon plays in the system's interaction with the solar wind as a result of the unique properties of the Pluto–Charon system, including those of Pluto's atmosphere. Following the confirmation of its existence through stellar occultation in 1989, Pluto's atmosphere has undergone notable and unexpected change. This consists of a large and sustained increase in estimated surface pressure, from ~ 5 μbar in 1988 (Elliot et al., 1989; Sicardy et al., 2003) to between 6.5 and 24 μbar in 2008 (Lellouch et al., 2009), with surface pressure at the time of the New Horizons encounter measured as ~ 10 μbar (Gladstone et al., 2016). This result was unexpected, as Pluto passed perihelion in 1989 and its atmosphere was therefore expected to be decreasing in surface pressure. Possible explanations for this include a change in albedo due to orbital orientation or changes in surface composition as well as thermal inertia (Elliot et al., 2003). It has long been suspected that Pluto's atmosphere freezes out completely as it approaches aphelion, however, recent simulations done by Olkin et al. (2015) suggest that this is not the case. Pluto's primary atmospheric constituent is N_2 but it also contains 0.25% CH_4 and trace amounts of higher hydrocarbons (Stern et al., 2015b). A thermal inversion is present through much of Pluto's lower atmosphere, the surface temperature being ~ 40 K and the peak atmospheric temperature approaching 100 K (Lellouch et al., 2009). Results from the New Horizons encounter also indicate that Pluto's atmosphere is more compact and slightly cooler than modeling based on stellar occultations had suggested (Gladstone et al., 2016; Stern et al., 2015b). This, in combination with a higher than anticipated solar wind density (Bagenal et al., 2016), resulted in the bow shock created by the interaction of the solar wind with Pluto's ionosphere being closer than expected at 4.5 Pluto radii upstream (McComas et al., 2016). Chemical modeling of Pluto's atmosphere indicates that ionospheric constituents consist of several distinct groups, centered at 1/28, 1/40, and 1/53 q/Da (elementary charge/dalton), the most abundant of which is 1/28 q/Da and is composed of $HCNH^+$ and $C_2H_5^+$ (Krasnopolsky and Cruikshank, 1999).

Charon is over half Pluto's radius (1 $R_P \approx 1187$ km and 1 $R_C \approx 606$ km (Stern et al., 2015b)), orbits 16.5 R_P from Pluto with a period of 6.4 days (Buie et al., 2006), and has a surface that is compositionally distinct from Pluto (almost exclusively H_2O in contrast to widespread N_2 and trace methane ices present on Pluto (Stern et al., 2015b), which are more volatile). Like Pluto (Cravens and Strobel, 2015), Charon is not expected to have an intrinsic magnetic field. This mixture of features results in a unique situation in which a moon might have a large impact on the solar wind interaction of its companion on a continuous basis. Additionally, there are several possible mechanisms that have been proposed through which

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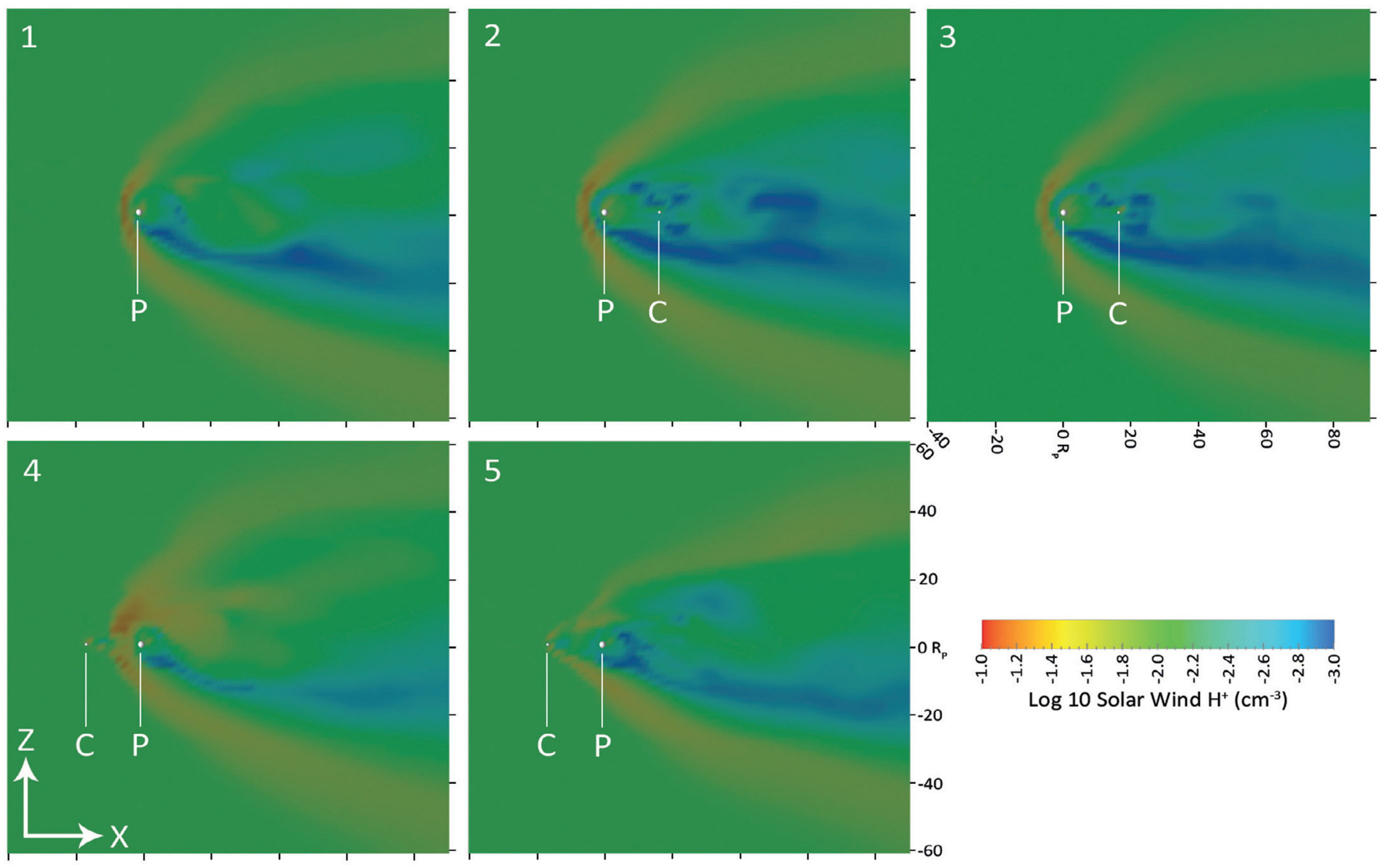

Fig. 1. Number density of H^+ from the solar wind for each test case is shown in the XZ plane (Y is pointing out of the plane). Solar wind flow is in the positive X direction and the IMF is pointed in the negative Y direction. Positions of Pluto and Charon are labeled in each case and each body is at Y = 0.

Table 1
Plasma parameters used for Solar Wind, Pluto, and Charon. *Temperatures are incorporated through the state equation. **Peak ion density for the Charon sourced species is not set to exactly 0 cm^{-3} due to numerical constraints.

Parameter	Value(s) Used
Magnetic field (nT)	0.2 (Bagenal et al., 1997)
Solar wind speed (km/s)	380 (Bagenal et al., 2015)
Solar wind density (cm^{-3})	0.01 (Bagenal et al., 1997)
Solar wind temperature (K)*	9000 (Richardson and Smith, 2003)
Pluto peak ion density (cm^{-3})	750 (Krasnopolsky and Cruikshank, 1999)
Pluto ion temperature (K)*	130 (Sicardy et al., 2003)
Charon peak ion density (cm^{-3})	25, ~ 0**
Charon ion temperature (K)*	40

Table 2
Simulations performed. All cases were run for 1500 s of simulated time in order to allow for a quasi-steady-state to be reached.

Charon absent	(1)	
Charon without Ionosphere	Charon downstream (2)	Charon upstream (4)
Charon with Ionosphere	Charon downstream (3)	Charon upstream (5)

Charon could at times possess a trace atmosphere and therefore ionosphere. These include a water group atmosphere sourced from cryovolcanism (Cook et al., 2007), a parasitic N_2 atmosphere derived from material escaping from Pluto (Tucker et al., 2015), and a transient, impact-sourced atmosphere (Stern et al., 2015a). The average age of Charon's surface (Moore et al., 2016) makes it unlikely that cryovolcanism has recently occurred on Charon. Similarly, measurements by the Alice UV spectrometer aboard New Horizons appear to preclude Charon currently possessing an atmosphere (Gladstone et al., 2016). However, the craters which appear to rule out recent cryovolcanic activity on Charon reaffirm that large impactors periodically hit Charon, demonstrating that Charon must go through phases of possessing an ionosphere (Stern et al., 2015a). This means that, during these periods in which Charon possesses an ionosphere, an ion source distinct from that of Pluto is moving through the Pluto system. In addition to this, the presence of an ionosphere around Charon must appreciably increase any alteration or obstruction of plasma flows within the system that are caused by Charon. While in the freestream upstream of Pluto – as the compact Plutonian atmosphere reported by Gladstone et al. (2016) suggests that Charon is for much of its orbit – Charon is likely to significantly modify conditions of the flow incident upon Pluto's ionosphere. This possibility is intriguing, as, while many moons locally alter the shock of their parent bodies while crossing the shock (Nishino et al., 2011), the only similar occurrence in which the moon was directly upstream of the parent body that has been observed within the solar system was during Cassini's T96 flyby of Titan, when Titan was determined to be outside of Saturn's bow shock (Bertucci et al., 2015). However, Charon's large size relative to Pluto compared to Titan's relative to Saturn indicates that any effect would be more significant on a global scale. A plausible result of this is that Charon could cause a decrease in atmospheric loss from Pluto through shielding from the solar wind. Another possible effect of Charon on Pluto's plasma environment is the modification of Pluto's plasma wake structure. This could be due to either physical obstruction by Charon itself or by the introduction of plasma into the region.

Previous work on the Pluto-solar wind interaction performed by Delamere has focused on instabilities using a 3D hybrid model (Delamere, 2004, 2009), while work by Harnett has compared

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