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Vortex-Related Plasma Boundary in the Venus Wake

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Measurements conducted with the ASPERA instrument in the Venus Express spacecraft (VEX) show that the planetary O+ ions dragged by the solar wind from the Venus ionosphere form a corkscrew vortex structure detected across a plasma boundary within the Venus wake. That structure is southbound directed reaching larger distances away from the ecliptic plane as it moves downstream from Venus,

VEX DATA

Measurements conducted with the Venus Express spacecraft (VEX) have led to the detection of a vortex in the Venus plasma wake. The data have shown that similar features merge to form a corkscrew structure that extends along the Venus wake. A suitable example of the density and speed profiles of planetary O+ ion fluxes together with the profile of the magnetic field intensity measured across a corkscrew is that for the Sept. 21-2009 VEX orbit shown in **Figure 1**.

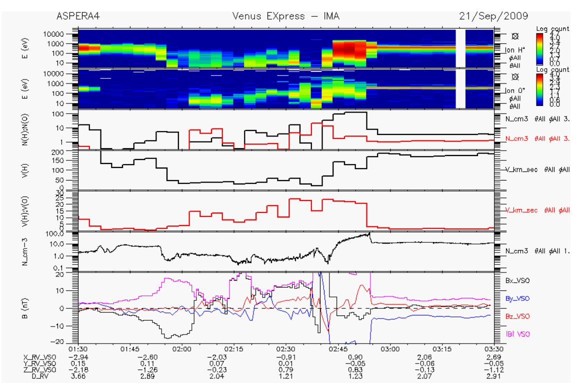

Figure 1. Energy spectra of the H+ and O+ ions (top panels) measured during the Sept. 21-2009 VEX orbit in the Venus wake by the midnight plane (small Y-values). Between 02:03 UT and 02:13 UT there are decreased values of the magnetic field intensity (bottom panel) at the time when the O+ density and speed values (middle panels) are enhanced**.**

The density and speed profiles of the O+ ion fluxes exhibit a correlation with low values of the magnetic field intensity when they are enhanced. In particular, the magnetic field intensity profile exhibits a valley between a boundary at 02:03 UT and at 02:13 UT when the density and the speed of the O+ ion fluxes display enhanced values. Similar variations are also encountered in the profiles of other orbits with oscillations in the components of the magnetic field suggesting the presence of vortices. It is to be noted that across the corkscrew structure in Figure 1 (between 02:03 UT and 02:13 UT) the B_x and the B_z components display brief variations in their magnitude before B_x changes polarity at the end of that period.

Suitable examples of data in VEX orbits that probed by the midnight plane in the Venus wake are presented in **Table 1** to estimate the manner in which a corkscrew structure formed by vortices that merge in the Venus wake are displaced in that region. A collection of 10 orbits in that table describes the VEX position at the time when the spacecraft entered and left a corkscrew structure together with the peak density and speed values of the O+ ion fluxes measured within that feature. Those values lead to the kinetic energy density **ρv^2 of** the O+ ion fluxes that are then compared with the magnetic energy density $B^2/8\pi$ derived from the magnetic field intensity both indicated in the last two columns of **Table 1**. From the values of both energy densities indicated in the eight and ten columns there is a near balance condition between them with fluctuating differences.

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*Added note: A correction is noted for the Introduction of the manuscript ¨Measurements of plasma channels in the Venus wake¨ by Pérez-de-Tejada et al., in the ICARUS (321, 1026, 2019) publication where at the bottom in the right side column in p. 1028 it is wrongly stated that by 2009 a ¨minimum¨ of the solar cycle was approaching rather than having used instead the word ¨maximum¨.

Table 1. VEX coordinates indicated by pairs (in R_V) at the time of crossing (in UT) into and away from a corkscrew structure detected in 9 orbits across the Venus wake. Together with the measured density (cm^{-3}) and speed v (km/s) of planetary O+ ions in each orbit values are shown for the their kinetic energy density ρv^2 (10^{-10} ergs/cm^{-3}). The average value of the magnetic field intensity B(nT) measured across each crossing and its magnetic energy density $B^2/8\pi$ (10^{-10} ergs/cm^3) are indicated in the last two columns.

Date	UT	X	Y	Z	n	v	**ρv^2**	B	**$B^2/8\pi$**
22/08/2006	01:38	-3.05	-0.15	-1.12	10	20	10	15	**9**
22/08/2006	01:55	-2.58	-0.15	-0.40	10	20	15	15	**9**
23/08/2006	01:40	-3.16	-0.07	-1.30	10	15	**6**	10	**4**
23/08/2006	02:05	-2.59	-0.07	-0.44	10	15	**6**	10	**4**
24/08/2006	01:57	-2.88	0.01	-0.83	10	30	23	18	**18**
24/08/2006	02:18	-2.03	0.01	0.20	10	30	23	18	**18**
28/08/2006	02:22	-2.49	0.28	-0.38	20	20	20	15	**9**
28/08/2006	02:53	-0.87	0.07	0.91	20	20	20	15	**9**
14/11/2007	01:05	-2:31	-0.14	-0.28	10	20	6	10	4
14/11/2007	01:06	-2.28	-0.14	-0.25	10	20	6	10	4
4/07/2008	03:49	-2.08	0.37	-0.14	5	15	**3**	10	**4**
4/07/2008	03:55	-1-80	0.31	-0.20	5	15	**3**	10	**4**
19/09/2009	01:54	-2.51	-0.04	-1.04	10	15	6	10	4
19/09/2009	02:03	-2.20	-0.05	- 0.55	10	15	6	<5	<1
21/09/2009	02:03	-2.30	0.08	-0.65	10	15	**6**	15	**9**
21/09/2009	02:13	-1.95	0.06	-0.12	10	15	**6**	15	9
25/09/2009	02:15	-2.15	0.33	-0.45	10	20	10	15	**9**
25/09/2009	02:27	-1.60	0.23	0.21	10	20	10	15	**9**
26/09/2009	02:05	-2.47	0.46	-1.06	10	2	10	10	**4**
26/09/2009	02:25	-1.83	0.32	-0.01	10	15	6	<5	**<1**

A study of the geometry of the region with enhanced values of the density and speed of the O+ ions in the Venus wake can be carried out by plotting the position of the plasma transition listed in the 10 VEX orbits of **Table 1** as a function of their distance X downstream from Venus. A plot of that position in the XZ plane is presented in **Figure 2** to show a general tendency of the plasma transition to shift to lower negative Z values with increasing X distances downstream from the planet in the -0.5 > X > - 3.5 range. That variation is peculiar in that it applies separately to the position of the plasma boundary measured in 2006 and in 2009 with lower values by the latter year as solar maximum conditions approach. Arguments that lead to that displacement are available from the direction of the vorticity vector which is the rotational of the flow velocity vector. The latter vector is mostly on the XY plane as a result of the solar wind velocity and the direction of the Magnus force and thus the vorticity vector becomes oriented in the Z direction driving the O+ ion fluxes towards the southern hemisphere.

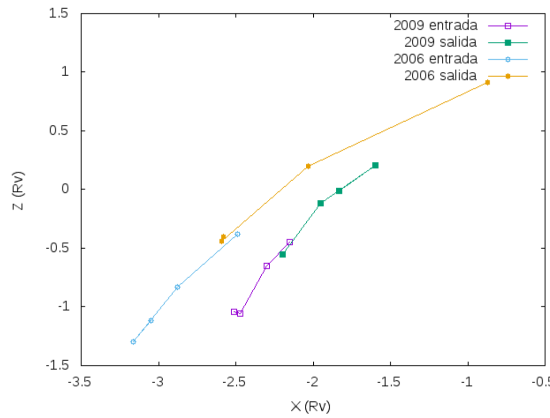

Figure 2 - Position of the VEX spacecraft projected on the XZ plane during its entry and exit through a corkscrew plasma structure in the orbits shown in Table 1. The two traces correspond to 4 crossings in 2006 and in 2009*

Calculations of the width **r** = $\sqrt{(\Delta x^2 + \Delta z^2)}$ of the corkscrew were made by combining the different ΔX and ΔZ values obtained by VEX during its entry and exit in selected orbits in Table 1 (Δx and Δz are differences in the position of the boundary between the two crossings measured in each orbit). As a whole the width r becomes smaller in the 2009 measurements indicating that the corkscrew becomes thinner as solar wind maximum conditions approach*

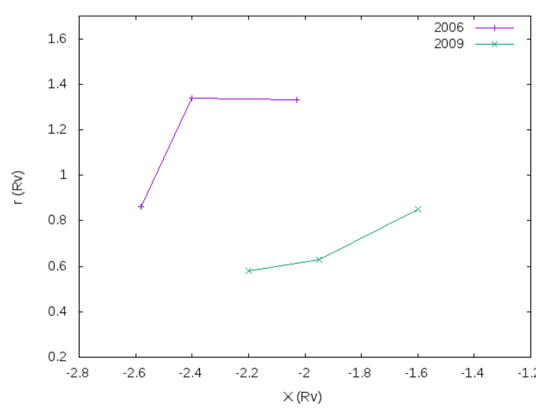

Figure 3. Values of the width r = $\sqrt{(\Delta x^2 + \Delta z^2)}$ of the plasma corkscrew derived from selected orbits in Table 1 corresponding to 2006 and 2009 as implied from measurements along the distance X downstream from Venus*

*Pérez-de-Tejada, H., and R. Lundin, Vortex-related plasma boundary in the Venus wake, (submitted 2019),