POSSIBLE DISTORTION OF THE INTERPLANETARY MAGNETIC FIELD BY THE DUST TRAIL OF COMET 122P/DE VICO

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Received 2003 March 10; accepted 2003 September 15; published 2003 October 8

ABSTRACT

Interplanetary field enhancements are unexpected localized increases in the heliospheric magnetic field magnitude. Four such enhancements, detected by the Pioneer Venus Orbiter and Ulysses spacecraft, have been found to be very close to the orbital plane of comet 122P/De Vico. Analysis of the magnetic field during these events revealed that the field perturbations were close to those expected if the interplanetary magnetic field draped at the comet's orbit and that the field enhancements represent crossings of a "sheet" of disturbed solar wind in the comet's orbital plane. The results suggest that a dense dust stream may occupy at least part of the orbit of De Vico and that its effects on the solar wind are apparent almost 1.4 AU downstream. One field enhancement suggests the existence of an annulus of dust extending upstream of the comet itself.

Subject headings: comets: general — comets: individual (122P/De Vico) — interplanetary medium — meteors, meteoroids

1. INTRODUCTION

Interplanetary field enhancements (IEFs) in the solar wind were first reported by Russell et al. (1983). These uncommon events are characterized by a magnetic (B) field magnitude increase, often with a toroid-shaped profile, and are usually accompanied by a discontinuity in the field direction. Russell, Arzougarian, & Luhmann (1984a) and Arzougarian et al. (1985) cataloged several tens of IEs near Venus and Earth. Although IEs were initially suggested to be cometary signatories, it was later proposed that they were due to interactions between dust and the solar wind (Russell 1990). This was supported by correlations between IEs near Venus and times when the orbital path of asteroid 2201 Olgaga, whose plane is close to Venus's, was closest to the planet (Russell et al. 1984b). Although no production mechanism was determined, this correlation, and other nonrandom IEF clustering in inertial space, suggested a link with material co-orbiting with minor solar system bodies. No similar relationship between IEs and a known body has been reported since.

A particularly strong and clear IEF was detected by the Ulysses spacecraft in 1990 July. The possibility of this event being a cometary ion tail crossing was explored by Jones et al. (2002), who concluded that this interpretation could not be supported in full by the data. A survey of other strong events at Ulysses was carried out subsequently (Jones et al. 2003). In the latter study, the possibility was explored of a link with cometary dust trails (e.g., Sykes & Walker 1992). The discovery of an association between IEs and the dust trail of a known object would strengthen the case for the dust trail link considerably. Here we report on such a case, where a correlation has been found between the locations and characteristics of one IEF at Pioneer Venus Orbiter, three at Ulysses, and crossings by those spacecraft of the orbital plane of comet 122P/De Vico.

2. OBSERVATIONS

An investigation was carried out to test the hypothesis that, by some undetermined process, the B-field magnitude () is increased when the solar wind encounters a dense dust trail. This region of enhanced would be carried antisunward by the near-radial solar wind flow. One would therefore expect a correlation between the occurrence of IEs and crossings of the orbital planes of comets that possess dust trails, as long as the comet's orbit is sunward of the IEF locations. We compared the locations of IEs at Ulysses and the crossings of the orbital planes of all known short-period comets listed in the IAU Catalogue of Cometary Orbits and of several minor planets with comet-like characteristics. The results indicated that several IEs coincided with crossings of the orbital plane of comet De Vico. The comet's orbital elements, from the IAU Catalogue of Cometary Orbits, are given in Table 1. The profiles of the IEs of interest shown in Figure 1, and several of their spatial and temporal characteristics, are listed in Table 2. Another IEF very close to De Vico's orbit was reported in the survey of Russell et al. (1984a). The IEF durations in terms of field directional deflections are somewhat longer than those inferred from . The relative positions of the IEs and of De Vico's orbit are shown in Figure 2. The relationship between each IEF and the De Vico orbit is now briefly described.

2.1. 1983 October 31

De Vico's orbit was the closest to the Sun-IEF line in this case. At a slightly greater separation was the path of 45P Honda-Mrkos-Pajdusáková. At the time of the IEF, the latter was not near perihelion. Observed dust trails initially form near the positions of the nuclei (Rath et al. 2000), and as the latter comet's orbit has undergone several changes in the recent past (e.g., Lamy et al. 1999), it is doubtful that material could have migrated far enough around its current orbit to be the source of this IEF.

2.2. 1990 November 30

In this case also, De Vico's orbit was the closest to alignment, but we note that the orbit of 122P/FraW-Broms was also close. This latter comet is also in a high-inclination, stable orbit, with...
TABLE 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit date</td>
<td>1995 Oct 6:2322</td>
</tr>
<tr>
<td>e</td>
<td>0.680694 62</td>
</tr>
<tr>
<td>w</td>
<td>0.96278 62</td>
</tr>
<tr>
<td>Revolution period</td>
<td>74.9 yr</td>
</tr>
<tr>
<td>Argument of perihelion</td>
<td>1279.753</td>
</tr>
<tr>
<td>Longitude of ascending node</td>
<td>797.173</td>
</tr>
<tr>
<td>Inclination</td>
<td>873.898</td>
</tr>
<tr>
<td>Epoch of perihelion</td>
<td>1995 Oct 10:0</td>
</tr>
</tbody>
</table>

a 70.97 yr orbital period. As reported by Jones et al. (2003), two IFSs were detected at 12TP on this day. One may thus have been related to 12TP and the other to 12TP/Smith-Brooks.

2.3. 1993 September 13
This is arguably the event with the most convincing link with de Vico. It is the only known comet with an orbital path within 5° of alignment with this IFE. As shown in Table 2, the event also occurred very close to the passage of the comet's nucleus past the Sun-IFE line.

2.4. 2001 January 11
No known comet orbit was close to the Sun-IFE line in this case. However, the IFE was very close to the orbital plane of the de Vico orbit, with the IFE located between the Sun and the orbital path. Clearly, this IFE cannot have been formed at the comet's orbit. However, further analysis revealed more evidence of a link to de Vico, as described below.

3. CORRELATION OF B-FIELD BEHAVIOR WITH COMET DE VICO
From a study of cometary orbital alignments alone, as associated with comet de Vico cannot be established with any great certainty. However, analysis of the B-field characteristics of the IFEs, described below, does strengthen the case for an association considerably.

Apart from the 2001.01.01 event, the correlation with de Vico's orbital plane is suggestive of agreement with the hypothesis that the interplanetary magnetic field (IMF) is disturbed at the comet's orbit and that the distortion propagates outward with the wind (see Fig. 1). The IFEs' separations from the cometary orbital plane are well within observed ranges of nonradial wind flow. The characteristics of each IFE's B-field were examined in more detail, to determine if there was a common link between the events that were possibly related to de Vico. Minimum variance analysis (MVA; Sornson & Cahill 1967) provides a means of determining the directions in which a set of vectors, in this case B-field vectors of IFEs, vary the most and least. The MVA results are given in Table 3. The results were determined to be meaningful by the high values in each case of the maximum intermedium: minimum eigenvalue ratios. On close inspection, it was found that the maximum variance direction of each IFE was close to parallel to the orbital plane of de Vico. To illustrate this, the vector products of the maximum variance directions and the antisunward vectors at each IFE are shown in relation to the 'x' of perpendicularly to the de Vico orbital plane (Fig. 4). The angular separation of the vector products and this latter vector are also given in Table 3. The probabilities of vectors in isotropically random distributions being close to this particular direction are 7.9%, 0.1%, 1.0%, and 0.03%, respectively. The likelihood of all vectors being close to de Vico's orbital plane is thus very low. The IFEs thus appear to possess B-field variations consistent with the IMF's distortion mostly in the plane of the putative de Vico dust trail.
FIG. 2.—Locations of the UVS in June 1990, with respect to the ecliptic plane and the exoatmospheric orbit of 12989s Venus and Earth. The orbits of Venus and Earth, and the orbital plane of 12989s, are shown close to the exoatmospheric orbit.

For an elongated neutrals source, e.g., outgassing particles occupying a comet's orbit, the above scenario no longer holds. A current sheet downstream of it, when formed, would not necessarily be perpendicular to the upstream field. Assuming that draping occurs with approximately equal strength along part of the orbit, most field direction would be parallel to the orbital plane. This analogy does suggest that a process that would confine the maximum variance direction to the dust trail is conceivable. However, how the maximum variance direction could remain confined to the orbital plane for a considerable distance downstream is unclear.

The existence of an IFE on 2001.011, closer to the Sun than de Vico’s orbital path, but very close to the orbital plane, suggests that a dust sheet may exist upstream of the comet’s orbit. This could be formed by the circulation and reduction in the orbital paths of dust trail particles originating along de Vico’s orbit, by the Pyonning-Robertson effect (e.g., Maks & Yamamoto 1962). IFEs may result from the cumulative effect on the solar wind of a sheet of material lying in the parent comet’s orbital plane, rather than being formed only at the dust trail itself.

4. DISCUSSION

Cometary dust trails are composed of millimeter-sized particles visible in the thermal infrared (Sykes & Walker 1993). Typical trail widths are less than 1.5 x 10^5 km, i.e., very similar to IFEs’ scales. Particle concentrations leading the comet are generally smaller than those following (Sykes & Walker 1993). These structures eventually develop into more diffuse and lower density enzone sheets. If the “sheet” hypothesis is correct, IFEs’ directions indicate the formation region’s site. The spacecraft velocity transverse to the upstream direction indicates the maximum sheet thickness. Taking into account the wind’s radial expansion and the dust sheet’s broadening with heliocentric distance, the dust trail width at perihelion (0.65 AU) would have been as listed in Table 2. We note that the apparent trail widths for the 1995 and 2001 IFEs were greater than for the two IFEs presumably formed by material leading the comet along its orbit. A trail along de Vico’s orbit was not among those observed by IRAS during 1983 (Sykes & Walker 1993), but the trail’s non-detection by IRAS does not prove its nonexistence. Visible

TABLE 3

<table>
<thead>
<tr>
<th>Date</th>
<th>Day of Year</th>
<th>Angular Separation (deg)</th>
<th>Magnetic Period (UT)</th>
<th>Angular Separation (deg)</th>
<th>Likelihood (%)</th>
</tr>
</thead>
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<tr>
<td>1995 Oct 31</td>
<td>334</td>
<td>0.3</td>
<td>15.64 - 17.24</td>
<td>2.3</td>
<td>22.3</td>
</tr>
<tr>
<td>1995 Nov 3</td>
<td>334</td>
<td>3.0</td>
<td>17.46 - 19.15</td>
<td>28.6</td>
<td>7.6</td>
</tr>
<tr>
<td>1995 Sep 13</td>
<td>326</td>
<td>0.4</td>
<td>04.08 - 07.15</td>
<td>9.4</td>
<td>8.1</td>
</tr>
<tr>
<td>2001 Jun 11</td>
<td>011</td>
<td>1.6</td>
<td>19.36 - 00.00</td>
<td>23.1</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Note: Angular separation is between the closest point along the comet’s orbit to the Sun-Earth line, \( \lambda _m \), maximum and intermediate eigenvalues, noted such that the maximum eigenvalue \( \lambda _m \) = 180°. Angle between \( \lambda _m \) direction vector and \( \lambda _d \) direction perpendicular to orbit. Likelihood ratio to that of a constant variance direction vector being as close as determined to the orbital plane of 12989s, Venus in an isotropically random distribution.
Figure 4.—Minimum variance results, plotted on a sphere in solar ecliptic coordinates. The ecliptic plane, north ecliptic pole, and various equators are shown for reference. The sector perpendicular to 123.94° Venus’ orbital plane (dotted) and the inferred decretion precession arc of the earth containing the IFEs (Allen circles, labeled) is shown. To demonstrate the close proximity of the result to that expected for events originating at 123.94° Venus’ orbit, concentric circles have been added that contain the circles 5%, 10%, 15%, and 20% of a population of non-originally random vectors in the direction normal to the comet’s orbit.

Observations indicate that de Vico is gas-rich (Kawakita, Ayani, & Matsubara 1998; Cochran & Cochran 2002). As comets’ actual dust–gas ratios are sometimes an order of magnitude greater than implied by visible observations (Reach et al. 2000), the existence of a dust trail is not precluded.

If the above IFEs do originate at de Vico’s orbit, one would expect similar events at Earth annually around December 11–12, during the orbital plane crossing. Continuing searches of data from several near-Earth and interplanetary spacecraft during de Vico orbital plane crossings have not yet revealed IFEs as clear as those presented. Likewise, the 1983 event was the only near-Venus IFE reported near the de Vico orbital plane (Russell et al. 1984a), and Ulysses did not detect a strong IFE when it returned to the 1995 IFE’s location in late 2001. Although IFEs could have been missed owing to data gaps, etc., it is unlikely that they all evaded detection by several spacecraft over numerous years. This suggests that IFEs do not always form, or that they are detectable only under certain conditions. A thorn-shaped IFE (St) profile may require conducive conditions, e.g., certain anti-orientations. IFEs may also occasionally be swamped by B-field features inherent to the wind. Russell et al. (1986) showed that IFEs’ signatures may vary significantly over small distances. Finally, IFEs’ clarity could be sensitive to trail dust number density and size distributions. Although studies show cometary surface brightness decreases with increasing nuclear distance, some structuring may exist, possibly owing to orbital resonances. Separate broad and narrow trail components have been detected (Reach et al. 2000).

Processes potentially responsible for IFE formation, including outgassing by dust grains, pickup of charged grains, and the neutralization of solar wind particles, are discussed by Jones et al. (2003). Whatever the physical process responsible, it is likely to be some dust–solar wind interaction.

5. SUMMARY AND CONCLUSION

Evidence has been presented that suggests a link between several IFEs and the dust trail of a known comet. This agrees with the suggestion of such a link by Russell (1990) and the link between other IFEs and the putative dust trail of asteroid Olijato.

We encourage other workers to search for similar field enhancements close to de Vico orbital plane crossings. Such events near Earth should occur around December 11–12 annually. We encourage the observation of the orbital path of de Vico in the infrared by the STIS spacecraft, to attempt to detect the putative dust trail. Given the recently proven viability of detecting dust trails at visual wavelengths (Ishiguro et al. 2002), we suggest that similar observations also be attempted at longer wavelengths.

A major implication of the above results is that the solar system’s dust population may significantly affect the solar wind’s characteristic. Once the IFE formation mechanism is determined, IFEs may provide a means of remotely studying the characteristics of sometimes undetectable cometary dust trails.

Ulysses research at Imperial College London is supported by the UK Particle Physics and Astronomy Research Council. The authors thank T. S. Horbury and M. Neugebauer for useful comments.

REFERENCES

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