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Encounters of the dust trails of comet 45P/Honda-Mrkos-Pajdusakova with Venus in 2006

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ABSTRACT

Aims. We aim to investigate the dynamical fate of meteoroids ejected during past perihelion passages of comet 45P/Honda-Mrkos-Pajdusakova that intersect the orbit of Venus. Of particular interest is the possibility, borne of previous work, that a significant flux of these particles will reach the planet during early June and late August 2006, when the *Venus Express* spacecraft will be operating in orbit around Venus.
Methods. We have simulated the generation of meteoroid trails ejected by the comet at some past perihelion passages, and numericaly integrated them forward in time until they approach Venus in 2006.
Results. On the inbound leg of the comet's path towards perihelion, we find a trail composed of dust particles ejected between 1943 and 1980 that encounters Venus on 9 June 2006 at a distance of 0.009 AU. On the outbound leg, we observe a dense trail of particles ejected between 1985 and 2001 that measures 3.4×10^{-4} AU (5×10^4 km) in half-width, and passes under the planet at a distance of 1.72×10^{-3} AU (2.6×10^5 km) on 30 August. Based on these results, we conclude that, on both occasions, the incident flux at Venus will likely be too low to allow for the detection of a shower by optical means. We discuss the circumstances under which *Venus Express* may encounter a significant flux of small particles detectable through impact ionization or disturbances in the interplanetary magnetic field.

Key words. comets: individual: 45P/Honda-Mrkos-Pajdusakova – meteors, meteoroids – planets and satellites: individual: Venus

1. Introduction

Meteoroid streams of sufficient flux density to cause meteor showers on Earth are usually the subject of intense observational campaigns utilizing a variety of methods (CCD, video, radar, etc.). These observations offer us information that is crucially needed to understand the physical and chemical properties of meteoroids, both individually and at the population level, as well as their parent comets, by proxy. Such streams, also potentially hazardous to spacecraft (Caswell et al. 1995; Cameron et al. 2005), are not restricted to the vicinity of the Earth; although no showers have been observed to occur in the atmospheres of other planets to-date, it is nevertheless predicted that they exist (Christou & Beurle 1999; Christou 2004; Selsis et al. 2004). Furthermore, individual events attributable to meteors on Venus and Mars have already been identified (Huestis & Slanger 1993; Selsis et al. 2005). The realisation that the evolution of meteoroid trails can be deterministic over several orbits of the parent comet has led to reliable meteor storm forecasting (Kondrateva & Reznikov 1985; McNaught & Asher 1999; Asher 1999; Vaubaillon 2002) and the new methods developed on that basis are readily applicable to other planets as well.

Here, we utilise such a method to examine the particular case of comet 45P/Honda-Mrkos-Pajdusakova (hereafter 45P). This comet is a double Venus approacher, with its orbit intercepting that of Venus both at the inbound (0.01 AU) and the outbound (0.0016 AU) legs of its trajectory through perihelion (Christou 2004; Selsis et al. 2004). 45P particles entering the Venusian atmosphere at the interception points would give rise to meteors of comparable brightness to those from the same comet in the atmosphere of the Earth (McAuliffe & Christou 2006). During its 2006 apparition, when the *Venus Express* spacecraft will be operating in Venusian orbit, the comet comes to within 0.1 AU of Venus during the first week of June, with its closest approach at 0.085 AU on the 4th. Our aim is to determine whether trails of meteoroids ejected from 45P during past perihelion passages will produce meteor displays in the Venusian atmosphere that will be detectable by *Venus Express* instruments as well as to calculate any direct or indirect effects of the stream on the spacecraft itself.

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Table 1. Orbital elements and physical parameters of comet 45P/Honda-Mrkos-Pajdusakova. $[Af\rho]$ and r_n are taken from Lamy et al. (1999), q from Rocher (see: `http://www.imcce.fr/en/ephemerides/donnees/comets/FICH/CIA0028.php`), $Q_{\mathrm{H_2O}}(q)$ from A'Hearn et al. (1995), and f is computed from Crifo & Rodionov (1997, Appendix A, Eq. (9)), while s is assumed.

Symbol	Name	Value
T	epoch (JD)	2 453 833.5
a	semi-major axis	3.0227318819 AU
e	excentricity	0.8245702722
i	inclination	4.2533061566 (°)
Ω	Long. of Asc. Node	89.114123791 (°)
ω	arg. of perihelion	326.10832699 (°)
r_n	radius of nucleus	0.34 km
q	perihelion distance	0.529 AU
$[Af\rho]$	$[Af\rho]$ at 0.97 AU from the Sun	3.7 cm
$Q_{\mathrm{H_2O}}$	gas production rate at perihelion	4.07×10^{27} mol.s^{-1}
f	fraction of active area at perihelion	0.2
s	diff. size population index	2.5

Table 2. 2006 encounter parameters of meteoroid trails ejected from 45P. "Maximum" refers to the population mean for all Venus-approaching particle orbits, as described in Sect. 2. The population median is also given in parentheses where appropriate. Column 1 identifies the range of perihelion passages of the comet corresponding to each composite trail with the number of passages given in parentheses. Column 2 gives the encounter date, and Col. 3 gives the time of the trail's closest approach to Venus. Columns 4 and 5 show the duration during which the particle flux exceeds one tenth of the maximum flux (10% max.) before and after the peak respectively. Column 6 gives the orbit-to-orbit closest approach distance Δ between the trail and Venus. Column 7 gives the half-width of the trail on the B- or impact plane.

Trail ID	Date	UT time of max. (dec)	Interval from 10% max. to max. (h)	Interval from max. to 10% max. (h)	Δ at max. flux (AU)	Distance from max. to 10% max. (AU)
			June 2006			
1900−1927 (6)	2006-06-09	7.62 (7.68)	3.17	1.92	0.02378 (368)	0.00350
1943−1980 (8)		22.92 (22.92)	0.25	0.28	0.00898 (900)	0.00065
1985−2001 (4)		22.86 (22.68)	0.63	1.21	0.01007 (007)	0.00009
			August 2006			
1900−1980 (16)	2006-08-30	2.17 (2.97)	2.83	3.17	0.01093 (087)	0.00180
1985−2001 (4)		19.00 (19.62)	7.67	2.50	0.00173 (174)	0.00034

2. Method

The method used here was developed by Vaubaillon et al. (2005a,b). The orbital elements and physical properties of the comet are summarised in Table 1. The simulation of the generation and evolution of the meteoroid stream formed by comet 45P was run on five to fifty parallel processors at CINES (France). Five size bins from 100 μm to 10 cm were considered. Ten thousand particles per size bin were simulated, for thirty four perihelion returns (begining in 1811 A.D.) and a total of 1.7×10^6 particles. The code was modified to consider meteor showers on a planet other than the Earth. We recall that the initial method detects the ecliptic nodal crossing of particles to store the position of particles close enough to the planet (Earth). Here, we used the crossing of the orbital plane of Venus instead to filter out particles that do not approach the planet. We then calculated the closest approach conditions in three dimensions for all Venus-approaching particle orbits using a method described in Christou & Beurle (1999). This second step is necessary since the relative inclination between the comet's and the planet's orbital planes is only a few degrees. To further visualise the encounter configuration, we followed the method introduced by Vaubaillon et al. (2006) to compute the 3-D view of the stream relative to the planet. During this process, it was found that particles ejected prior to 1900 do not approach Venus in significant numbers. In what follows, we concentrate on the most recent perihelion passages of the comet starting from 1900. To avoid confusion, we introduce the following terminology: we refer to a trail of particles resulting from ejection during a single perihelion passage of the comet as an *individual* trail to distinguish it from a *composite* trail that follow the same orbit, consisting of particles ejected during several perihelion passages.

3. Simulation results

3.1. June 2006

Our results regarding dust trail encounters, both for June and August, are summarised in Table 2, where the statistics of the closest approach epochs and distances for all Venus-approaching particles are presented. During early June, the comet is physically close to Venus. The stream encounters the planet five days after the comet's closest approach, appearing to radiate approximately from the anti-Sun direction (RA = 338°, Dec = −12°, in Earth-equatorial J2000 coordinates), as it crosses the Venusian orbit from the outside towards perihelion. We find that particles ejected prior to 1927 result in a diffuse composite trail passing ~0.024 AU above the

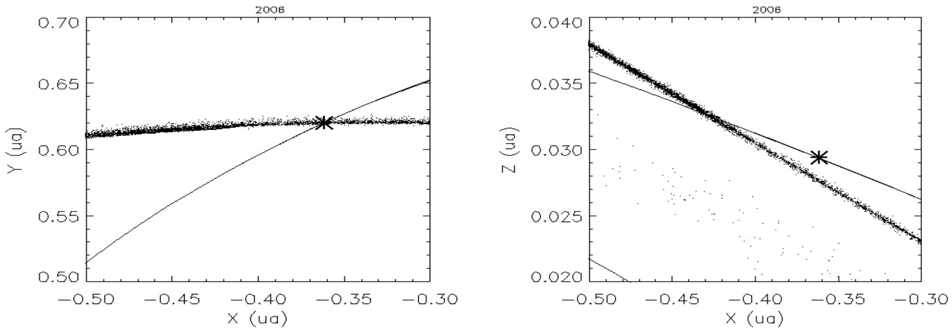

Fig. 1. Three-dimensional view of the 1985−2001 composite trail encounter with Venus in August 2006. The asterisk marks the position of Venus on 29 August (1900 UT), when the two orbits intersect on the *XY* plane (*left panel*). At that time, the trail will be under the planet, moving upwards and outwards towards its ascending node on the Venusian orbital plane. Its closest approach to Venus occurs a day later at ∼19:00 UT on 30 August.

planet on the morning of 9 June. As would be expected for a relatively "old" population, these are predominantly large (>1 mm) particles. No significant flux of 1933−1938 particles approaches the planet, probably due to a 1935 encounter of the comet with Jupiter at 0.08 AU. After 1938 a new, narrower, composite trail was created that encounters the planet between 2200 and 2300 UT, passing ∼0.009 AU below the Venusian orbital plane. This second trail consists of large particles ejected between 1943 and 1980, and mainly between 1969 and 1980. Ejections between 1985 and 2001 result in a third particularly narrow composite trail populated by large as well as intermediate-sized particles with the same encounter geometry as for the pre-1980 particles. The stream is, in effect, formed anew after a recent close encounter of the comet with Jupiter (0.11 AU in 1983).

3.2. August 2006

On the outbound leg of the comet's orbit, a diffuse composite trail of cm-sized particles ejected before 1938 passes 0.01 AU under the planet during the first few hours of 30 August. Material ejected between 1938 to 1980 makes up a more compact structure essentially following the same geometry. Smaller particles (≤5 mm) dominate the individual trail population for the more recent ejections. From 1985 onwards, the particles follow the new, post-1983 Jupiter encounter orbit of the comet, passing 0.0017 AU under Venus. Figure 1 illustrates the encounter geometry in ecliptic J2000 coordinates. The closest approach to the planet for this trail occurs between 11:00 and 22:00 UT on the 30th. It consists of particles <0.5 mm in size and has a radiant at (RA = 318°, Dec = −21°), near the solar direction. This encounter happens 38 days after the cometary closest approach to the Venusian orbit.

4. Expectations for *Venus Express*

As a result of this work, we have found that trails of particles ejected at each perihelion passage of 45P since 1900 pass either above or below Venus when the latter is at the critical points of its orbit on 9 June and 30 August, 2006. Thus, in spite of the comet being physically near Venus at the time, our expectations for strong meteor activity in the Venusian atmosphere are low, with a predicted Zenithal Hourly Rate of less than 1 (the ZHR definition used here is the same as for the Earth; see Koschack & Rendtel 1990; Jenniskens 1994).

A separate issue is whether the spacecraft itself, scheduled to arrive at Venus on 11 April 2006, will encounter any of these trails. Upon arrival, the nominal mission scenario calls for the spacecraft to be inserted into a ∼250×350 000 km capture orbit. The apocentre will be subsequently lowered to ∼66 000 km by early May to achieve a final, 24 h period operational orbit. The apocentres of these orbits will be at high southern latitudes. This is significant since the 1985−2001 composite trail will pass 260 000 km under the planet on 30 August. Combining our numerical results with the comet's known $Af\rho$ quantity (defined and measured for this comet by A'Hearn et al. 1995 and Lamy et al. 1999) we find that the flux in the center of this trail is 4×10^{-2} particles $\mathrm{km}^{-2}\,\mathrm{h}^{-1}$, for particle sizes greater than 0.1 mm.

Assuming that the average flux per hour is half that over a period of ten hours, and that the spacecraft surface area incident to the flux is 15 m^2, then the probability of single-particle impact is 3×10^{-6}. A power-law fit to the numerical results, extrapolated to 10 μm and 1 μm particle sizes, yields single-particle impact probabilities of 10^{-4} and 4×10^{-3}, respectively. These fluxes, and especially the latter, should be treated with caution for two main reasons. First, these extrapolations depend on the size distribution index we assumed in the simulations (Table 1). Moreover, it is likely that radiation pressure will have removed micron-sized grains from the trail even for material ejected in 2006. Post-ejection fragmentation of large grains, as observed during the *Giotto* encounter with 1P/Halley (Simpson et al. 1986) and the *Stardust* encounter with 81P/Wild 2 (Tuzzolino et al. 2004), may act as an additional source of small grains in the stream. However, whether this mechanism is effective as far from the nucleus as Venus will be in the summer of 2006 is unclear.

Thus, we conclude that *Venus Express* is not likely to encounter a flux of dust particles large enough to be hazardous to mission operations. However we cannot discount the possibility of impact with smaller particles (≤10 μm) in early June and late August. For the latter case, the spacecraft will encounter a dust trail composed of particles ejected from the comet during its last four perihelion passages on 30 August, if its orbit apocentre at that date is higher than 210 000 km. This will not be the case for the nominal mission timeline as described earlier in the paper. It is relevant in the event of either a higher-than-expected apocentre for the operational orbit or a significant delay in the apocentre-lowering orbit manoeuvre. In any case, high enough particle fluxes may be detectable through the process of impact ionization (Scarf et al. 1982; Gurnett et al. 1983) by the Neutral and Energetic Particle Analyzer (ASPERA-4).

A dust trail in the vicinity of Venus may, in addition, produce a significant distortion of the interplanetary magnetic field downstream of the trail (i.e. in the anti-Sun direction) due to "dust-shadowing" of the solar wind; statistical associations have been made in the past between so-called Interplanetary Field Enhancements (IFEs) detected by *Pioneer Venus Orbiter* and *Ulysses* and passages of asteroid (2201) Oljato (Russell et al. 1984) and comet 122P/de Vico through perihelion, though the precise mechanism is not yet clear (for further details, see Jones et al. 2003, Fig. 3). The asteroid is thought to be an extinct or dormant cometary nucleus (McFadden et al. 1993) while the comet is one of those identified by Christou (2004) as Venus-crossing. The orbital similarities between (2201) and 45P lead us to speculate that IFEs related to the latter may be picked up by the magnetometer (MAG) instrument aboard *Venus Express* immediately following the stream's inbound crossing of the Venusian orbit on 9 June 2006 or immediately preceding its outbound crossing on 30 August. In conclusion, it appears that *Venus Express* will be in a position to make observations that will test our understanding of the short-term evolution of cometary dust and its interaction with the interplanetary medium. We therefore encourage the instrument teams to consider the possibility of detecting the effects of 45P dust in the vicinity of the spacecraft in the summer of 2006.

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