Numerical Modeling of Cometary Meteoroid Streams Encountering Mars and Venus

A. A. Christou • J.Vaubaillon

Abstract We have simulated numerically the existence of meteoroid streams that encounter the orbits of Mars and Venus, potentially producing meteor showers at those planets. We find that 17 known comets can produce such showers, the intensity of which can be determined through observations. Six of these streams contain dense dust trails capable of producing meteor outbursts.

Keywords Mars · Venus · meteoroid streams · meteors · meteor showers · meteor outbursts

1 Introduction

Although no meteor showers have yet been observed at Venus and Mars, the undertaking of projects such as the U.S. rover Curiosity and the JAXA orbiter Akatsuki leads one to expect that such observations will be made, serendipitously or otherwise, in the near future. In support of these and follow-on missions with some meteor-detecting capability we carried out numerical simulations of cometary streams identified by previous work as potentially Mars- or Venus-encountering. We hope that these results will be used to guide future meteor surveys but also to interpret observations.

2 Method

Our method is that of Vaubaillon et al (2005a; 2005b). The motion of test particles initially ejected from the comet near perihelion according to the model of Crifo and Rodionov (1997) is propagated forward in time by numerical integration. The software then records all particles that approach the planet to within a few hundredths of an AU within the period 2000-2050. The initial sample of cometary candidates, either Intermediate Long Period Comets (ILPCs; $P > 200$ yr) or Halley Type Comets (HTCs; $P < 200$ yr), is taken from Christou (2010). Cometary orbits from HORIZONS (Giorgini et al, 1996) were back-integrated in time, to simulate past perihelion passages. Relevant physical and orbital characteristics of the comets themselves may be found in Tables 2 and 4 of the work by Christou. As these comets' orbital periods span two orders of magnitude, we have varied the number of perihelion passages considered for particle ejection on a case-by-case basis as shown in Table 1. In some cases, we have considered non-consecutive perihelion passages (eg one out of every five) in order to extend the time period over which the comet's, and hence the stream's, orbital evolution can be investigated.

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Table 1. Characteristics of all ILPCs and HTCs from Christou (2010) that satisfied the “shower” criterion in the numerical simulations. Column 2 gives the orbital period in years. Column 3 identifies the relevant planetary body as Venus (V) or Mars (M). Column 4 gives the number of perihelion passages where test particles where ejected from the comet. In cases where a mixture of consecutive and non-consecutive perihelion passages were considered for particle ejection we provide the number of said passages x and the increment y in the format (y)x in Column 5. Column 6 gives the date of the earliest perihelion passage considered in the simulations.

Comet	Period (yr)	Planet	Number of per. pass. considered	Step	Start Year
13P/Olbers	70	M	11	1	1313
27P/Crommelin	27	V	30	5(10) + 1(20)	326
35P/Herschel-Rigollet	155	V	17	1	−6160
161P/Hartley-IRAS	21	M	21	5(6) + 1(15)	1104
177P/Barnard	119	M	10	1	1038
P/2005 T4 (SWAN)	29	V	11	1	1720
P/2006 HR30 (Siding Spring)	22	M	11	1	1751
C/1769 P1 (Messier)	2100	M	9	1	−12087
C/1857 O1 (Peters)	235	V	8	1	−336
C/1858 L1 (Donati)	2000	V	9	1	−18372
C/1917 F1 (Mellish)	145	V	16	1	−5496
C/1939 B1 (Kozik-Peltier)	1800	V	5	1	−4689
C/1964 L1 (Tomita-Gerber Honda)	1400	V	4	1	−3600
C/1984 U2 (Shoemaker)	270	M	10	1	11
C/1998 U5 (LINEAR)	1000	M	5	1	−1989
C/2007 H2 (Skiff)	348	M	4	1	1016
5335 Damocles	41	M	18	5(8) + 1(10)	6

The simulation of the generation and evolution of these meteoroid streams was run on 5 to 50 parallel processors at CINES (France). Three size bins, equally log-spaced from 0.1 mm to 100 mm were considered. Ten thousand (10^4) particles per size bin and per perihelion passage were simulated. In the analysis reported in this work, we do not discriminate between the different particle sizes.

3 Results

The results of the numerical simulations consist of state vectors of planet-encountering particles as defined in the previous Section. If the distribution of the particle orbit nodes on the planetary orbital plane encompasses the planetary orbit then we can say that a shower is present at that planet. This condition was quantified by highlighting all those test particles (TPs) that approached the planetary orbit to within 0.005 AU and binning them in the direction parallel to the planetary orbit in units of time. Bins of angular width corresponding to one hour of time were used. In the resulting distribution plot, the comet tests positive for a shower if any one of the bins contains more than one particle. 17 comets in our sample satisfied this criterion, which we will hereafter refer to as the “shower” criterion.

We separate those into two groups. The first group consists of those streams which exhibit a smooth distribution of particles on the planetary orbit plane, in other words a smooth “background” flux of meteoroids. An example of such a stream is shown in Figure 1. The left panel shows the spatial distribution of Venus-encountering particles from comet C/1858L1 (Donati). The orbit of Venus, indicated by the black curve, passes well within the distribution of particles in its orbit plane, indicating that this planet samples the core of the Donati stream. The right panel shows the distribution of particles that satisfy the shower criterion along the Venusian orbit as a function of the astronomical solar longitude λ_S .The profile of this shower, and all other showers in Group I, appears to be well-behaved, in the sense that the distribution is fairly symmetric with a gradually varying slope and a single maximum. From this information, basic properties of the shower can be predicted.

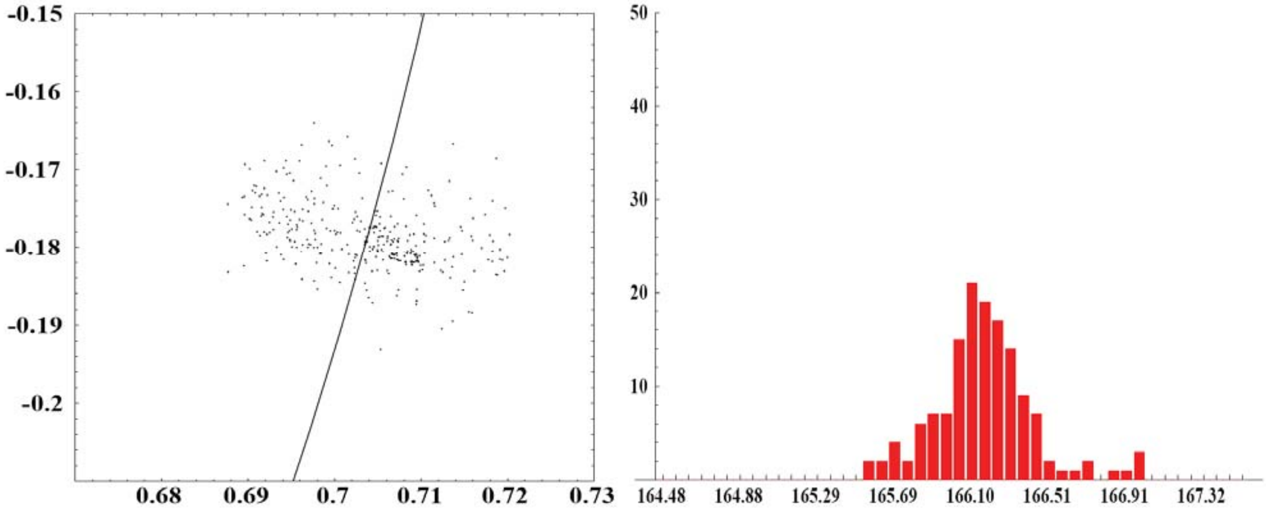

Figure 1. Left panel: Distribution of test particles ejected from comet C/1858 L1(Donati) that encountered Venus between the years 2000 and 2050. The points represent the locations of the particles, in cartesian heliocentric J2000 coordinates and units of AU, as they cross the orbital plane of the planet. The black curve represents the orbit of Venus, with the direction of motion of the planet being from bottom to top. Right panel: Histogram of those particles shown on the left panel that approach the planet's orbit to within 0.005 AU as a function of solar longitude in units of degrees. The size of each bin corresponds to one hour of time.

In Table 2 we provide such properties in the form of the solar longitude of the peak of the histogram (Column4), the shower duration in terms of the solar longitudes at which the first and last bins with more than one TP are encountered (Column5), the peak count of test particles per bin (Column6) and the total number of TPs that satisfied the shower criterion for that comet (Column7).

Group II, also listed in Table 2, consists of those cometary streams, six in total, containing multiple density enhancements orders of magnitude higher than the background value. The fact that these enhancements only appear on certain years lead us to conclude that they correspond to individual dust trails which can yield meteor outbursts at the corresponding planet. An example of such a case, for comet C/2007 H2 (Skiff), is shown in Figure 2. A number of planet-approaching trails are embedded in the background (left panel) resulting in at least two maxima in the corresponding shower density histogram (right panel). For two cases belonging to this group, that of 13P/Olbers and C/1998 U5 (LINEAR), the background component is not well defined as its particle density is too low. These are indicated by a question mark (?).

Table 2. Simulation results for all ILPCs and HTCs from Christou (2010) that satisfied the "shower" criterion. Whether a stream tested positive for membership in Group I or II as defined in the text is indicated in Columns 2 and 3 respectively.

Comet	Background	Outbursts	Peak λ_S (°)	Width (°), (hr)	Peak Count	Total Count
13P/Olbers	Y?	Y	256.0	255.8-256.6 (33)	20	175
27P/Crommelin	Y	N	251.7	250.0-253.2 (47)	12	205
35P/Herschel-Rigollet	Y	N	175.1	175.0-175.2 (4)	2	11
161P/Hartley-IRAS	Y	Y	176.9	176.7-177.4 (31)	20	124
177P/Barnard	Y	Y	100.1	100.1-100.4 (16)	20	57
P/2005 T4 (SWAN)	Y	Y	210.5, 213.4	210.1-213.8 (56)	130	869
P/2006 HR30 (Siding Spring)	Y	N	303.1	− (1)	2	30
C/1769 P1 (Messier)	Y	N	175.6	− (1)	2	6
C/1857 O1 (Peters)	Y	N	207.6	206.6-208.0 (22)	28	273
C/1858 L1 (Donati)	Y	N	166.1	165.6-166.9 (21)	25	143
C/1917 F1 (Mellish)	Y	N	271.7	270.2-272.6 (35)	5	30
C/1939 B1 (Kozik-Peltier)	Y	N	289.1	288.8-289.6 (12)	25	133
C/1964 L1 (Tomita-Gerber Honda)	Y	N	139.2	137.8-139.8 (27)	6	43
C/1984 U2 (Shoemaker)	Y	N	214.6	214.3-214.6 (11)	10	51
C/1998 U5 (LINEAR)	Y?	Y	235.7	235.4-235.9 (21)	100	524
C/2007 H2 (Skiff)	Y	Y	32.7	32.2-32.8 (28)	420	1526
5335 Damocles	Y	N	308.7	308.4-308.8 (18)	5	35

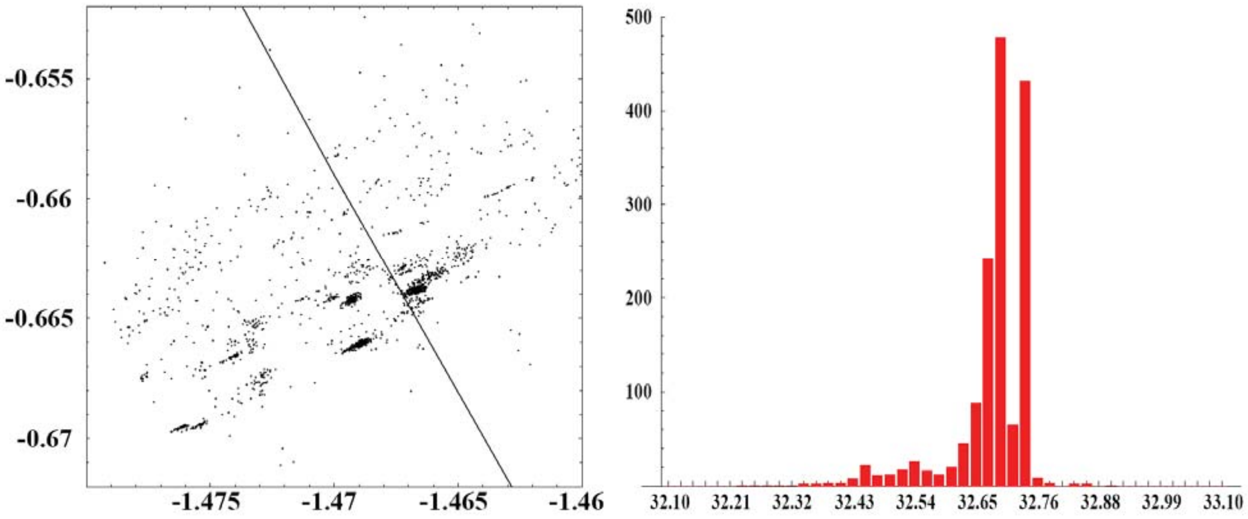

Figure 2. As Figure 1 but for Mars-encountering test particles ejected from comet C/2007 H2 (Skiff). In the left-hand panel, the direction of the planet's motion is from top to bottom. Note the numerous concentrations of particles within the stream's cross-section. These result in multiple maxima well above the background intensity of the shower in the histogram on the right-hand side.

4 Conclusions and Future Work

In this work we have simulated numerically the structure of meteoroid streams that encounter the orbits of Mars and Venus. We have highlighted seventeen of those streams where the planet-encountering density of test particles is sufficiently high to allow estimation of the solar longitude of maximum meteor activity, constrain the duration of said activity and determine whether the stream cross-section as sampled by the planet contains denser trails of particles that could give rise to meteor outbursts.

To convert the density histograms into actual meteor activity profiles would require observations of these showers at Venus and Mars (Vaubaillon et al, 2005b). In the meantime, we intend to use the information in Tables 1 and 2 in combination with available knowledge of the properties of these comets from observations and dynamical studies to calibrate these histograms in the relative sense and conduct intra-sample comparisons.

We also intend to follow up on our discovery of outburst activity from some of these comets by initiating a new series of numerical experiments to model any such outbursts occurring in the near future. These would be prime targets for meteor searches at those planets in coming years.

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