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PREDICTING MARTIAN AND VENUSIAN METEOR SHOWER ACTIVITY

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Abstract. Based on the number of planet-approaching cometary orbits at Mars and Venus relative to the Earth, there should be ample opportunities for observing meteor activity at those two planets. The ratio of planet-approaching Jupiter family comets (JFCs) at Mars, Earth, and Venus is 4:2:1 indicating that JFC-related outbursts would be more frequent at Mars than the Earth. The relative numbers of planet-approaching Halley-type comets (HTCs) implies that the respective levels of annual meteor activity at those three planets are similar. We identify several instances where near-comet outbursts (Jenniskens, P.: 1995, *Astron. Astrophys.* **295**, 206–235) may occur. A possible double outburst of this type at Venus related to 45P/Honda-Mrkos-Padjusakova may be observable by the ESA *Venus Express* spacecraft in the summer of 2006. Similarly, the Japanese *Planet-C* Venus orbiter may observe an outburst related to 27P/Crommelin's perihelion passage in July 2011. Several additional opportunities exist to observe such outbursts at Mars from 2019 to 2026 associated with comets 38P/Stephan-Oterma, 13P/Olbers and 114P/Wiseman-Skiff.

Keywords: Mars, meteor outbursts, meteor showers, meteors, Venus

1. Introduction

Meteor astronomy employs the atmosphere of the Earth as a large area detector for 0.1 mm to decimeter-sized meteoroids. These are smaller than can be detected individually in space with Earth-based telescopes but of too low flux density to make their detection with conventional space-based dust detectors practical. Monitoring the atmospheres of other planets for meteor activity offers the opportunity to study the parent bodies of as yet undetected meteor showers as well as providing better statistics on the spatial distribution and dynamical evolution of such meteoroids in the solar system. It provides opportunities to test ablation models on atmospheres of different structure and composition than the Earth's. Finally, predicting enhancements of large meteoroid flux associated with planet-intercepting streams allows interplanetary spacecraft operators to mitigate the risk of impact and potential loss of mission.

Both Mars and Venus have atmospheres dense enough to ablate meteoroids as bright meteors. Adolfsson et al. (1996) have shown that fast (>30 km s^{-1}) meteoroids would be of similar brightness in the atmospheres of Mars and the Earth while lower speed meteoroids would be fainter at Mars. Martian meteors would reach their maximum luminosity 10–20 km lower than at the Earth. A probable meteor trail was recently detected by the *Spirit* rover on Mars (Bell et al., 2004).

Christou (2004) has argued that, based on the venusian atmospheric structure, meteoroids would reach their maximum ablation rate, and thus their maximum meteor luminosity, between 100 and 120 km, above the cloud and haze layers that surround Venus (Esposito et al., 1983). They would also be intrinsically brighter, typically by one or two magnitudes, than at the Earth, rendering them readily detectable from orbiting spacecraft. Indeed, the UVS instrument onboard the *Pioneer Venus Orbiter* spacecraft detected a meteor-trail-like phenomenon in February 1979 (Huestis and Slanger, 1993).

2. Relative Abundance of Shower Parents

A small minimum orbit-to-orbit distance or MOOD (Christou and Beurle, 1999), hereafter denoted as Δ, offers a necessary, but not sufficient, criterion for a comet to produce an observable meteor shower in the atmosphere of the Earth. Indicators of this type have been used to identify possible meteor shower parent bodies at Venus (Beech, 1998; Christou, 2004; Selsis et al., 2004) and Mars (Chirstou and Beurle, 1999; Treiman and Treiman 2000; Larsen, 2001; Selsis et al., 2004). Such results, taken as a statistical population, may also be used to make statements on the relative abundance of meteor showers at the three planets. In a sample of 158 multi-apparition comets available within the JPL DASTCOM database, the respective number of comets approaching Mars, Earth and Venus to within 0.1 AU is 34, 15 and 9, mostly consisting of Jupiter family comets (JFCs – $P < 20$ yr) but also including Halley-type comets (HTCs – $P > 20$ yr) in all three cases (3, 3 and 5, respectively – Figure 1). Earth has two very-close-approaching ($\Delta < 0.01$ AU) HTCs, namely 55P/Tempel-Tuttle and 109P/Swift-Tuttle, parents of the Leonid and Perseid meteor showers respectively. All three HTCs (including 1P/Halley in addition to the above) are parent bodies of prominent annual showers (η Aquarids/Orionids – 1P/, Perseids – 109P/) or intense outbursts (Leonids – 55P/) compared to only a quarter of the Earth-approaching JFCs (Ursids – 8P/Tuttle, Draconids – 21P/Giacobini-Zinner, π Puppids – 26P/Grigg-Skjellerup). The number of Mars-approaching JFCs is 31 compared to 12 at the Earth, three of which (9P/Tempel 1, 114P/Wiseman-Skiff, 146P/Shoemaker-LINEAR) approach to within 10^{-2} AU (Christou and Beurle, 1999; Selsis et al., 2004). Thus, JFC-associated meteor

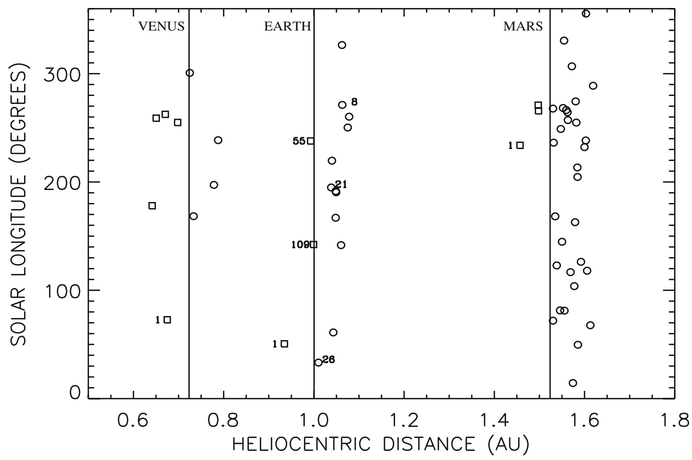

Figure 1. Cometary approach circumstances for Venus, Earth and Mars. Planetary orbits are depicted as vertical lines. Halley Type Comets (HTCs) are denoted as boxes at the left of each orbit while Jupiter Family Comets (JFCs) are shown as circles at the right. The apparent separation between a given comet and planetary orbit is the true minimum distance Δ between the keplerian orbits. Numbered comets correspond to known meteor shower associations at the Earth.

outbursts (also discussed in Section 3.2) may be a more common phenomenon on Mars than the Earth.

3. Individual Shower Predictions

Barring an all-out effort to fully characterise the venusian and martian meteor "years", the first aspects to be observed and studied will likely be occasions of strong recurring ("annual") or episodic ("outburst") activity, for example a Perseid, Geminid or Quadrantid-strength shower in the first instance, and a Leonid- (HTC) or Draconid-type (JFC) outburst in the second. These studies would be carried out mainly from orbiting probes but Earth-based detection may be possible for fireball-rich streams (Beech and Brown, 1995; P. Jenniskens, private communication). Predictions on individual showers is, therefore, a topical issue and can be addressed initially through the Δ quantity.

3.1. Annual showers

Strong annual activity is usually associated with Halley-type comets (Jenniskens, 1994). Their orbits are stable for several tens of orbital revolutions, allowing a complete stream to form. In Table I, we provide a list of HTC

TABLE I

Circumstances of Halley-type comet orbits approaching those of Mars, Venus and the Earth

Comet	Planet	v (km s^{-1})	Δ (AU)	$\lambda_{\odot}$ (degrees)
1P	M	54	0.0670	231
13P	M	27	0.0266	268
38P	M	13	0.0260	263
1P	E	67	0.0662	48
55P	E	72	0.0078	235
109P	E	60	0.0015	139
1P	V	80	0.0487	70
12P	V	53	0.0731	256
27P	V	28	0.0255	252
35P	V	46	0.0821	175
122P	V	59	0.0530	260

The quantity denoted as v is the atmospheric impact velocity at the planet while Δ is the minimum orbit-to-orbit distance and $\lambda_{\odot}$ is the solar longitude.

orbits that approach the orbits of Earth, Venus and Mars. The Δ cutoff is 0.1 AU. This is larger than the value used in Selsis et al. (2004). Also, unlike Christou and Beurle (1999) we do not impose an impact speed restriction. We see that comet 1P/Halley is the only triple-planet HTC approacher in the list raising interesting possibilities for comparative studies of its meteoroid stream. It approaches the venusian orbit slightly closer (0.05 AU) and slightly faster (80 km s^{-1}) than the Earth's. One would also expect related meteor activity at Mars, although the stream particle density there is expected to be lower than at the Earth due to it being further away from perihelion. Venus-approachers 12P/Pons-Brooks, 27P/Crommelin and 122P/de Vico form a cluster in solar longitude spanning 8° across which translates into up to three distinct meteor showers within a period or five Earth days. The most promising candidate for an annual meteor shower on Mars appears to be 13P/Olbers, combining a relatively high impact velocity (27 km s^{-1}) and a small value for Δ (0.03 AU).

3.2. Meteor outbursts

Intense meteor activity also manifests itself in the form of *outbursts* (Jenniskens, 1995), caused by trails of material ejected during a previous perihelion passage. Dense trails may typically be found in the vicinity of the comet, producing near-comet outbursts when the comet itself is near perihelion (e.g., 109P/Swift-Tuttle and the 1991–1994 Perseids). Alternatively, older trails or trail segments can produce outbursts by remaining cohesive within mean motion resonances with the giant planets e.g., the 1998 Leonids (Asher et al., 1999) or the 1945/1986 Ursids (Jenniskens et al., 2002). Both JFCs and HTCs can produce outbursts, the main difference being that JFC-related annual activity is typically weak.

We have computed instances up to 2030 when (a) planet-approaching HTCs return to perihelion (b) planet-approaching JFCs return to perihelion and are physically close to the planet. This is quantified through P-C, the interval in days between the comet and the planet passing through the planetary longitude at which Δ is achieved. These are necessary conditions for a near-comet outburst to occur (Jenniskens, 1995). The calculation is carried out in two steps. First we use the JPL DASTCOM ephemerides to calculate approximate encounter conditions. We then repeat the process using an osculating cometary orbit for the critical epoch generated though numerical integration under the action of planetary perturbations and available through the JPL HORIZONS on-line ephemeris service (Giogini, 1996). This additional step improves on the work by Christou (2004) and Selsis et al. (2004) by removing a major source of (deterministic) error in the orbit. We have also checked that none of the comets which we discuss here undergo close approaches to the planets prior to these epochs. As far as non-gravitational forces are concerned, the main effect of which would be a change of the P-C quantity, we estimate, based on a Selsis et al. (2004) upper bound of 3 h until 31/12/2015, that our P-C error is no more than 12 h. In any case, trail lengths are usually a few hundred days (e.g., Giacobinids – Rendtel et al., 1995) so even several days' error is not significant.

The results of this procedure are given in Table II. Comet 45P/Honda-Mrkos-Padjusakova is a relatively dust-poor Jupiter family comet (Lamy et al., 1999) that is also the closest Venus-approacher at present. Its orbit

TABLE II
Circumstances of possible near-comet meteor outbursts at Venus and Mars

Comet	Planet	Δ (AU)	v (km s^{-1})	P-C (days)	Date
45P	V	0.0017	26	+5	9/6/2006
45P	V	0.0101	26	+38	30/8/2006
27P	V	0.0389	28	−24	3/7/2011
38P	M	0.0417	13	+120	18/3/2019
12P	V	0.0800	53	+55	5/6/2024
13P	M	0.0217	27	+211	17/11/2024
114P	M	0.0077	11	+15	5/10/2026

At those instances the planet may encounter a trail of fresh meteoroids from a previous perihelion passage. Enhanced meteor activity related to Halley-type comets may occur on several planetary years surrounding the comet's perihelion passage. P-C is the interval, in days, between the comet and the planet passing through the critical solar longitude while "date" refers to the epoch when the planet is at that longitude approaches Venus at two distinct longitudes, once before and once after perihelion (Christou, 2004; Selsis et al., 2004). During its 2006 perihelion passage, the comet will be physically close to Venus on both occasions. This presents an opportunity to observe a venusian meteor outburst as the ESA *Venus Express* spacecraft will be orbiting the planet at that time (Svedhem et al., 2003). The stream encounter geometry is particularly favourable for the August opportunity, where the theoretical stream radiant is near the local midnight direction. The radiant of the June opportunity is near the direction of the Sun thus rendering meteors difficult to observe. An opportunity to observe strong venusian meteor activity associated with a HTC occurs during 27P/Crommelin's 2011 perihelion passage. In analogy to the Earth, increased meteor activity should be expected for a few venusian years surrounding this perihelion passage, with the best opportunity possibly on 3 July 2011, when Venus precedes the comet by only 24 days. The Japanese *Planet-C* Venus orbiter may be still operating within that timeframe (Nakamura and Imamura, 2002). Including meteor observations within its scope of investigations would allow the characterisation of Crommelin-related meteor activity and its variation over the years. Comet 38P/Stephan-Oterma's 2019 perihelion passage provides the first opportunity to observe a meteor outburst at Mars. However, due to the low impact velocity, these meteors may be exceedingly faint (Adolfsson et al., 1996), and thus difficult to detect with methods other than radio/radar. A more favourable opportunity would occur during comet 13P/Olbers' perihelion return in 2024 owing to its higher impact speed on Mars. That same year also sees a possible outburst at Venus related to comet 12P/Pons-Brooks' perihelion return. Finally, an outburst of faint meteors at Mars may occur during comet 114P/Wiseman-Skiff's close approach in October 2026.

The above predictions rely on the comets' osculating orbits at each critical epoch instead of a common epoch of reference (e.g., J2000) to estimate the encounter geometry accurately. Especially in the case of outbursts, however, in order to ascertain whether, and exactly when, a trail will encounter a planet, numerical simulations of trail formation and evolution from past perihelion returns are required. This will be the subject of future work.

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