On The Visibility of Bright Venusian Fireballs From Earth

by

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Abstract

The possibility of observing Venusian fireballs from Earth is examined. We estimate the steady-state flux of large, fireball-producing meteoroids at the orbit of Venus, and find that the prospects for observing such events from Earth with small, 'amateur-sized' telescopes are not unreasonable.

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1. Introduction:

The manner in which large meteoroids are distributed within the inner Solar System is not well known (Grinspoon and Lewis, 1988; Wetherill, 1989). Consequently, there are good reasons for pursuing observational programs that may yield an estimate of the average meteoroid flux at well defined distances from the Sun. The flux of meteoroids in the 10^3 to 10^7 kg mass range has, to date, only been directly sampled at the Moon's surface and the Earth. In the Earth's atmosphere large, megakilogram meteoroids produce bright fireballs and meteorite dropping events at the Earth's surface. While it is understood that all planets within the Solar System are liable to impacts from meteoroids, in all mass ranges, attempting to observe the consequences of such impacts is not, in general, a practical exercise for Earth based observers. Of the terrestrial planets, next to Earth itself, Venus offers the best prospects for directly observing fireballs. Venus is well suited to such observations since it has a dense atmosphere, a key pre-requisite to the production of a fireball, and because, as it nears inferior conjunction, the planetary disk that Venus presents to the Earth-based observers is mostly in shadow.

2. The Flux of Fireball Producing Meteoroids at Venus:

An estimate of the steady-state, fireball-producing meteoroid flux at Venus can be made from the observed flux of terrestrial fireballs, $N_E(m)$, and the employment of an appropriate enhancement factor, F. In this way, it is the enhancement factor that accounts for the change in meteoroid flux within the Solar System. The enhancement term is a non-trivial function of radial distance from the Sun (Wetherill, 1989).

Halliday *et al.* (1984) found that the terrestrial fireball flux can be expressed as function of meteorite terminal mass such that

$$N_E(m) = -0.689 \text{ Log } m + 3.76 \qquad \text{(H)}$$

where $N_E(m)$ is the number of actual meteorite falls of mass exceeding m grams per 10^6 km^2 per year. Halliday *et al.*, further argue that the total flux of fireball producing (but not necessarily meteorite dropping) meteoroids is a factor of 3 larger than that given in (H).

A least square fit to the data given by Ceplecha (1992) suggests that in the 10 to 10^{10} g mass range the cumulative flux of meteoroids of mass greater than m grams entering the Earth's atmosphere per year is

$$N_E(m) = -0.64 \text{ Log } m + 6.98 \qquad \text{(C)}$$

Given the many observational difficulties that hinder the determination of the meteoroid flux at the top of the Earth's atmosphere, expressions (H) and (C), when compared over equal areas, are in remarkably good agreement.

Transforming expressions (H) and (C) to a surface area equivalent to that of the Venusian atmosphere we obtain an estimate of the steady-state flux of fireball producing meteoroids at Venus, $N_V(m)$. The expressions for the Venusian meteoroid flux are:

$$N_V(m) = -0.689 \text{ Log } m(g) + 6.92 + \text{Log } F \qquad \text{(H1)}$$

from (H), and

$$N_V(m) = -0.64 \text{ Log } m(g) + 6.96 + \text{Log } F \qquad \text{(C1)}$$

from (C). Recall that F is the flux enhancement factor at the orbit of Venus. Monte Carlo studies by Wetherill (1989) suggest that an enhancement factor of F = 1.5 is appropriate at the orbit of Venus.

3. Venusian Fireball Simulations:

In order to quantify the expected brightness of fireballs in the Venusian atmosphere, a series of single-body (non-fragmenting) ablation calculations have been performed. Of interest to this study is the determination of the pre-atmospheric meteoroid mass, greatest absolute magnitude relation. We shall also be interested in determining the length of time that a given fireball is brighter than an absolute magnitude of $M_V = -20$. A Venusian fireball that exceeds this limiting absolute magnitude in brightness should be observable from Earth with a typical 'amateur-sized' telescope (see section 4).

We have used a standard fourth-order Runge-Kutta routine to numerically integrate the differential equations describing the classical meteoroid ablation process (see e.g., Bronshten, 1983). Pre-atmospheric velocities of 15, and 23 km/s have been adopted in our calculations and a luminosity efficiency of 1% has been assumed. A meteoroid density of 3000 kg/m^3 has also been adopted. The atmospheric model of Seiff (1983) is used to describe the variation of atmospheric density with height. Full details of our calculations will be published elsewhere.

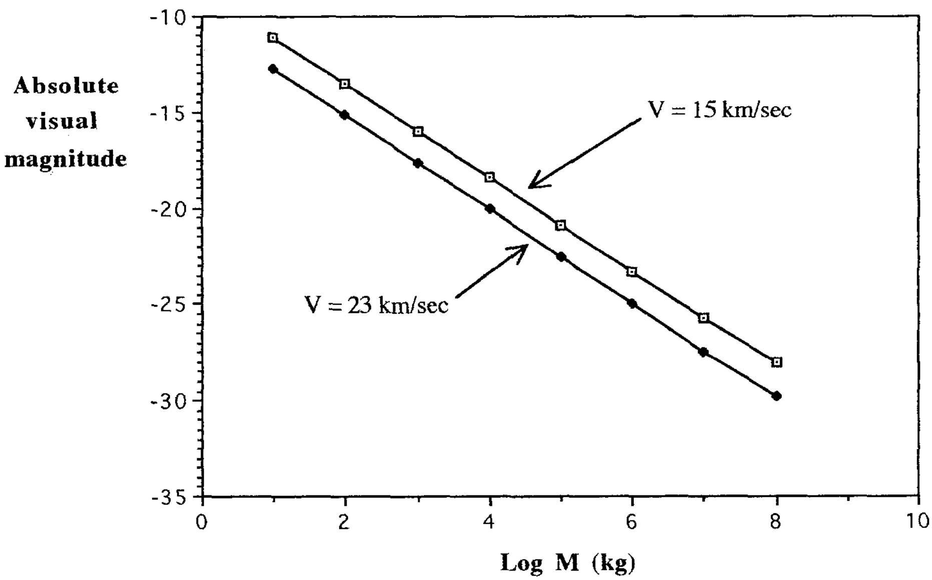

Figure 1: Absolute visual magnitude (M_V) versus initial meteoroid mass. The initial velocities are chosen according to: 1) 15 km/s corresponds to the encounter velocity if the meteoroid is derived from the 3/1 resonance zone in the main asteroid belt and collides with Venus when at perihelion. 2) 23 km/s is, according to the numerical simulations carried out by Wetherill (1989), the average velocity with which Apollo asteroids collide with Venus.

The variation of absolute fireball magnitude, as a function of initial meteoroid mass and encounter velocity is shown in figure 1. The optical transparency of the Venusian cloud deck is extremely low at heights below ~60 km (Seiff, 1983). Our calculations indicate that meteoroids less massive than ~10^7 kg reach their maximum brightness at heights above 60 km. Assuming a tensile strength equivalent to that of stony chondritic material, meteoroids more massive than ~10^6 kg are likely to fragment before reaching their maximum brightness (as predicted by classical theory). For these meteoroids a more detailed analysis, in the manner of that described by Zahnle (1992), or Hills and Goda (1993) should be used to investigate the meteoroids' encounter characteristics.

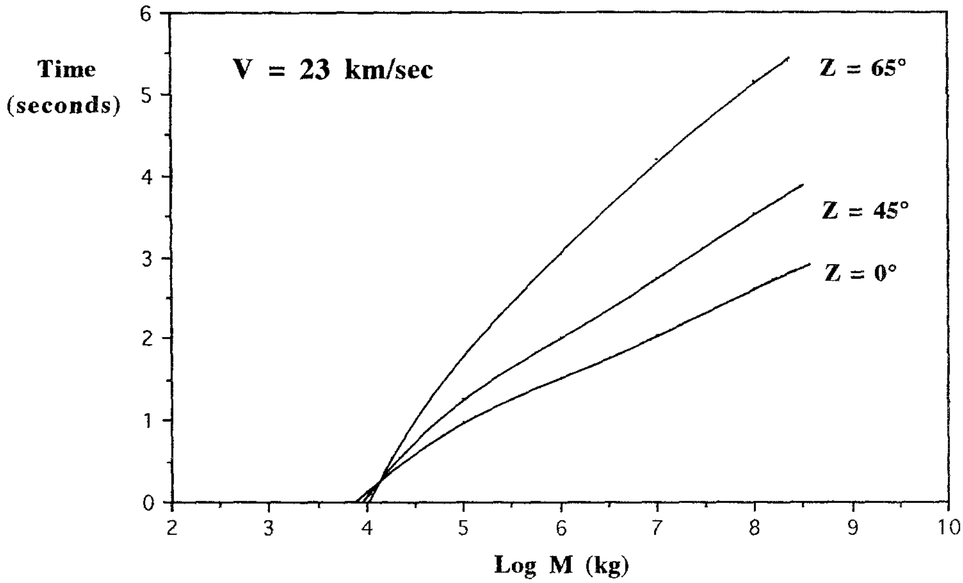

Figure 2: T20, the time that a fireball has an absolute magnitude brighter than M_V = -20, versus initial meteoroid mass. In order to produce a Venusian fireball that is brighter than M_V = -20, for more than one second, the parent meteoroid must have an initial mass in excess of ~10^5 kg (at an encounter velocity of 23 km/s). The more shallow a meteoroids angle of entry, the greater the amount of time, for a given initial mass, the fireball will be brighter than M_V = -20.

The amount of time, T20, that a fireball is brighter than an absolute magnitude of $M_V = -20$, as a function of the initial meteoroid mass and the zenith angle of encounter is shown in figure 2.

4. International Venus Watch:

A summary of our model calculations is presented in table 1. It can be seen from the table that the prospects for observing Venusian fireballs, from the Earth, are not unreasonable during the times that Venus is near inferior conjunction. Our calculations suggest that one Venusian fireball of intrinsic maximum brightness $M_V \approx -20$ should be observable once every three to four days. From the Earth such fireballs will appear as faint, transient flashes on the nightside of the Venusian disk. Clearly, the more massive an impacting meteoroid is the brighter the Venusian fireball that will be

Log m(kg)	$< N_V >$	$< M_{V,23} >$	$M_{E,135}$	N_{ex} (day)
3.5 - 4.5	530	-19	15	2
4.5 - 5.5	117	-22	12	9
5.5 - 6.5	52	-24	10	21
6.5 - 7.5	6	-27	7	183

Table 1. Summary of model calculations. $< N_V >$ is the estimated yearly flux of meteoroids (in the mass range given in column 1) at the top of the Venusian atmosphere. The average is based upon equations (H1) and (C1). $< M_{V,23} >$ is the average maximum absolute magnitude for meteoroids in the given mass range assuming an encounter velocity of 23 km/s. $M_{E,135}$ is the apparent magnitude of a Venusian fireball (absolute magnitude given by $< M_{V,23} >$) as seen from the Earth when Venus is at a phase angle of 135°. N_{ex} is the expected time interval, in days, between successive fireball events produced by meteoroids in the given mass range. N_{ex} is calculated on the assumption that only $\approx 1/3$ of the Venusian atmosphere can be monitored, on any given night from the Earth, as Venus passes from greatest eastern to greatest western elongation.

produced and the brighter the transient flash seen from Earth. While brighter transients might be easier to observe from Earth, the rare occurrence of such events (on a time scale of weeks to months) mitigates against their likely detection.

It is well within the bounds of possibility that the Venusian fireball rate might be much higher than the average suggested in table 1 at certain epochs. This being especially so if their is a significant population of fireball-producing meteoroid streams that intersect the Venusian orbit. Only careful, long-term monitoring will reveal whether or not such fireball-rich streams exist.

In principle it should not be difficult to operate a Venusian fireball detection program. All an observer has to do is monitor the planet's nightside for transient flashes. Such monitoring, of course, is far easier said than done, but a diligent and co-ordinated amateur campaign certainly has the potential for yielding scientifically useful results.

While astronomers have carefully scrutinized Venus for a century and more, no convincing evidence for the sighting of a Venusian fireball has been reported in the literature (Corliss, 1985). There are, however, numerous accounts of transient bright 'spots' being observed on the planets disk (Richard Baum, and Detlev Niechoy, personal communications). The time scale of these phenomena, however, is typically of the order of tens of minutes, and consequently they are unlikely to be fireball related events. Corliss (1985) describes one account (from 1878) in which 'flickering lights' were seen on the dark side of Venus. The 'flickering' phenomena was observed for at least 30 minutes, however, and it is once again highly unlikely that the observations are attributable to meteoritic activity.

In principle the best way to detect fireballs in the Venusian atmosphere is to monitor the planets atmosphere with satellite borne instruments. While several in-orbit mapping surveys have been made of Venus, the instruments and/or detectors employed in these surveys have not been well-suited to the detection of transient fireball events. To this date no *in situ* gathered data has been presented for the unambiguous detection of a fireball in the Venusian atmosphere.

The star sensor onboard the Pioneer Venus Orbiter (PVO) was used on several occasions to look for optical pulses resulting from lightning activity on the nightside of Venus (Borucki *et al.*, 1981; and Borucki *et al.*, 1991). No optical flashes attributable to lightning, or for that matter any other atmospheric phenomena, were detected, however. Likewise, no optical pulses were 'seen' by either of the Vega middle-atmosphere balloon experiments (Russell and Scarf, 1990; Taylor and Cloutier, 1994). The Venera 9 lander did detect a series of optical pulses on the nightside of Venus in October of 1975, but it is believed that these flashes were produced by intra-cloud lightning (Krasnopolski, 1983). That the *in situ* measurements made to date have not detected fireballs in the Venusian atmosphere is not too surprising. Either the instruments employed were not designed to do fireball survey work, as in the case of the PVO star sensor, or the instruments were onboard landers or flown below the upper cloud deck, as in the case of Venera 9 and the Vega balloon experiments. Consequently the *in situ* data that is presently available places no useful constraint on the flux of large meteoroids at Venus.

Given the not unreasonable chances of observing Venusian fireballs from Earth, with small telescopes, an International Venus Watch has been set-up by amateur observers in Europe, the United States and Canada. This program has been initiated with the hope of observing faint, transient events on the nightside of Venus. At the present time an amateur-run survey offers the best prospects for observationally constraining the arrival rate of large meteoroids at Venus.

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