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Dynamics of the Polonnaruwa meteorite fall

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Abstract

The Polonnaruwa meteorite fell over the north east of Sri Lanka on 29 Dec. 2012, with the fireball observed descending at 18.30 local time. Fragments were picked up the following day from paddy fields, sized from 10-15cm down to few mm. Meteorite fragments were readily identifiable on top of the sandy soil and scattered over an area of 1 km scale. The meteorites are unusually fragile and porous, with mean density less than water. A thin fusion crust is found around some cm-sized pieces. From their spatial distribution, we infer the meteoroid survived to an unusually low altitude ~10km.

This does not fit with canonical models for bolides in the atmosphere, in which fragile bolides break up much higher, unless the bolide speed was unusually low and it was protected against the shock-induced pressure gradients by vigorous ablation. Here we suggest that such fragile bodies may survive to low altitudes by a protective outgassing sheath of volatile ices and organics that shields the meteoroid from direct atmospheric heating. The fusion crusts could be formed in the fireball or during the subsequent fall of independent fragments.

We compare the Polonnaruwa meteorite with the meteorite fragments associated with the recent Chelyabinsk fireball and the samples of cometry material recovered from the Comet Wild/2 during the STARDUST mission. In all three cases, analysis of the trajectory of the bodies and the surviving material imply that pristine comets are highly porous and heterogeneous in composition.

1. Introduction

Disintegration of meteoroids descending through the atmosphere is usually described by a process of *continual ablation* where the energy absorbed in heating the bolide is proportional to the cube of its speed (u^3) [1] or by catastrophic fragmentation when the ram pressure ($\propto u^2$) exceeds the tensile strength of the body [2]. Both these models predict that ~ 1m radii, low density meteoroids such reach a minimum altitude of 30-20 km. From analysis of a Leonid meteoroid, Coulson [3] suggested that ~90% of the initial mass of cometary fragments are a composite of low density material with the rest denser stony material.

3. Modelling the bolide fall

Here we assume that the Polonnaruwa bolide was initially composed of volatile ices and organics held within and surrounding a denser, stone core. At a distance of 1 AU, a 1m radius body of this composition has a temperature of ~ 290K [4]. At these temperatures energy losses from the body occur principally by sublimation (radiation losses are lower by several orders of magnitude). The gases from the sublimating material form a sheath around the body which protects it from direct interaction with the atmosphere as it descends at hypersonic speeds.

A bow shock stands-off ahead of the bolide, diverting the atmosphere around it. The two protective properties compared with no sheath are:

♦ The bow shock is not attached, so fracture due to pressure gradients are much lower

♦ The hot shocked gases make no direct contact and their radiative heating of the bolide is reduced.

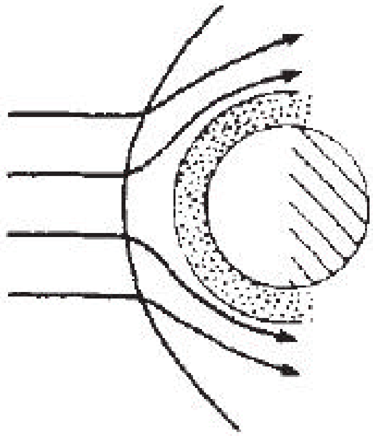

Figure 2: The sheath of sublimating gases serves like the atmosphere of a comet or non-magnetic planet in the solar wind.

4. Sublimation Model - general results

Assumes that the sublimation pressure increases as the bolide descends through the Earth's atmosphere such that the sublimation pressure ˜ ram pressure and that the mass lost by sublimation << than the original mass of the body.

Using a similarequations of motion for a bolide entering the Earth's atmosphere under the influence of atmospheric drag to ReVelle [5] but for a constant mass, the velocity profiles for 1 m radii bolides are calculated.

At altitudes > 60 km, the sublimation pressure raises to counter the increase in ram pressure. At 100 km the sublimation pressure far exceeds ram pressure and the temperature of the bolide is effectively that of free space (290 K).

By 70 km, the ram pressure has risen to ~1.2 kPa and the temperature ~ 400 K for the sublimation pressure balance (depending on ice or organic composition). Radiative heating from bow shock-heated air molecules dominate the heating of the bolide - a physical model will be included in later work.

5. Summary and Conclusions

For a Polonnaruwa type bolide the maximum ram pressure (~0.3 MPa) occurs between 34-24 km above the Earth. Its break-up at ~ 10km altitude implies that the sublimation sheath survived till this height, and the explosive break-up occurred as it weakened and disappeared.

Our samples of the Polonnaruwa meteorite have a thin fusion crust on the largest fragment. It is not yet clear if the fusion crust is created as parts of the bolide lose their volatiles prior to loss of the sheath, or during the deceleration of fragments post-disintegration of the bolide core. Future work will determine the maximum temperature and duration of heating from analysis of the fusion crust.

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