

# A Numerical Study of Micrometeoroids Entering Titan's Atmosphere

M. Templeton • M. E. Kress

**Abstract** A study using numerical integration techniques has been performed to analyze the temperature profiles of micrometeors entering the atmosphere of Saturn's moon Titan. Due to Titan's low gravity and dense atmosphere, arriving meteoroids experience a significant "cushioning" effect compared to those entering the Earth's atmosphere. Temperature profiles are presented as a function of time and altitude for a number of different meteoroid sizes and entry velocities, at an entry angle of 45°. Titan's micrometeoroids require several minutes to reach peak heating (ranging from 200 to 1200 K), which occurs at an altitude of about 600 km. Gentle heating may allow for gradual evaporation of volatile components over a wide range of altitudes. Computer simulations have been performed using the Cassini/Huygens atmospheric data for Titan.

**Keywords** micrometeoroid • Titan • atmosphere

## 1 Introduction

On Earth, incoming micrometeoroids (~100  $\mu\text{m}$  diameter) are slowed by collisions with air molecules in a relatively compact atmosphere, resulting in extremely rapid deceleration and a short heating pulse, often accompanied by brilliant meteor displays. On Titan, lower gravity leads to an atmospheric scale height that is much larger than on Earth. Thus, deceleration of meteors is less rapid and these particles undergo more gradual heating. This study uses techniques similar to those used for Earth meteoroid studies [1], exchanging Earth's planetary characteristics (e.g., mass and atmospheric profile) for those of Titan. Cassini/Huygens atmospheric data for Titan were obtained from the NASA Planetary Atmospheres Data Node [4].

The objectives of this study were 1) to model atmospheric heating of meteoroids for a range of micrometeor entry velocities for Titan, 2) to determine peak heating temperatures and rates for micrometeoroids entering Titan's atmosphere, and 3) to create a general simulation environment that can be extended to incorporate additional parameters and variables, including different atmospheric, meteoroid and planetary data.

The micrometeoroid entry simulations made using Titan atmospheric data assume that, as on Earth, micrometeors are heated by collision with molecules in the atmosphere. Unlike on Earth where heating pulses last a few seconds and reach temperatures sufficient to melt silicates ( $> 1600$  K [1]), micrometeors on Titan experience a more gradual thermal exchange lasting several minutes and the particles do not reach such high temperatures. The long duration of this gradual heating and cooling may allow ices and volatile organic species (such as small PAHs) to be evaporated throughout Titan's upper atmosphere.

---

M. Templeton (✉) • M. E. Kress

Dept. of Physics & Astronomy, San José State University, San José, CA 95192-0106. Phone: +1-408-924-5255; E-mail: templeton100@gmail.com

## 2 Atmospheric Entry Model

The method used in these simulations is that of Love & Brownlee [1] for micrometeoroids entering Earth's atmosphere. Meteoroids are assumed to be spherical and of uniform composition and density,  $\rho_{met} = 3 \text{ g/cm}^3$ , with a starting radius  $r$  of  $100 \text{ }\mu\text{m}$  and an entry angle of  $45^\circ$ .  $g$  is the acceleration due to gravity for Titan,  $1.352 \text{ m/s}^2$ . A full two-dimensional simulation is performed to correctly account for Titan's curvature.

The change in velocity due to atmospheric drag and gravity is

$$d\mathbf{v} = \left( -0.75 \frac{\rho_{atm} v^2}{\rho_{met} r} \hat{\mathbf{v}} + \mathbf{g} \right) dt \quad (1)$$

where  $\rho_{atm}$  is the local density of Titan's atmosphere calculated from the Huygens probe's pressure and temperature data and  $v$  represents the velocity of the meteoroid with respect to the atmosphere. Heating of meteoroids is due to the impacts with atmospheric molecules, in this case primarily nitrogen and methane. The rate of energy transfer,  $P_{in}$ , to the meteoroid is described by:

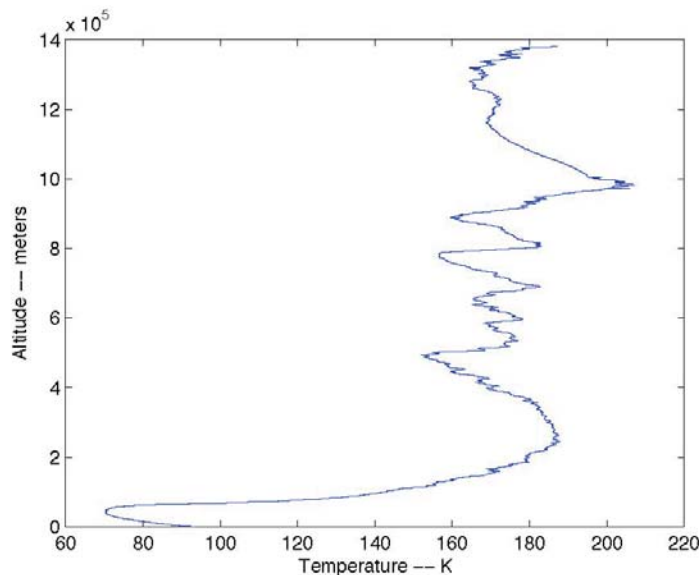
$$P_{in} = 0.5 \rho_{atm} s v^3 \quad (2)$$

where  $s$  is the geometric cross section of the meteoroid under study. The temperature  $T$  of the particle is determined by a balance of frictional heating and radiative cooling:

$$T = \left( \frac{P_{in}}{4\pi r^2 \sigma \varepsilon} \right)^{1/4} \quad (3)$$

where  $\sigma$  is the Stefan-Boltzman constant and  $\varepsilon$  is the meteoroid's emissivity.

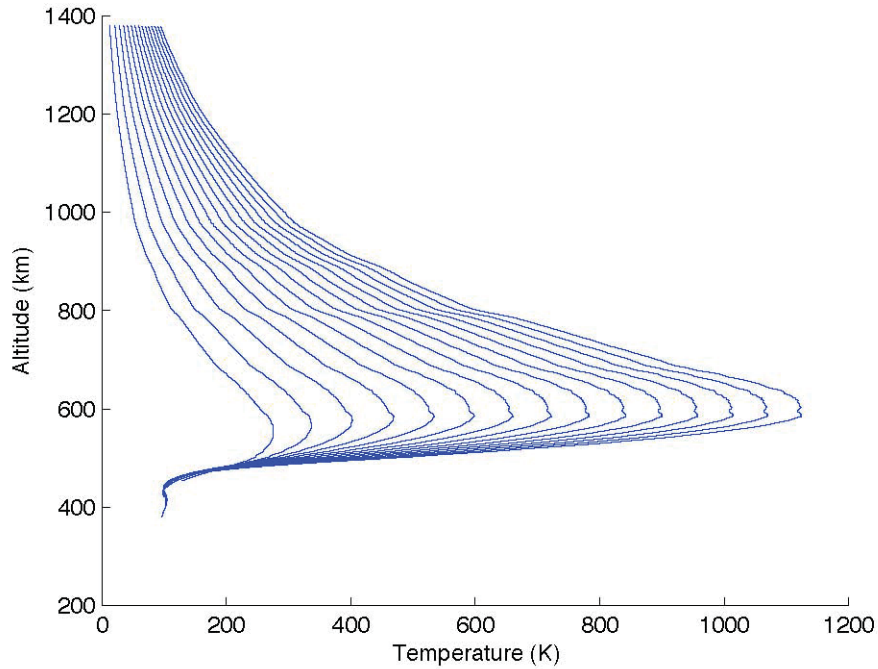
Atmospheric data were obtained from NASA's Planetary Data System Atmospheres Node website. The data set id is HP-SSA-HASI-2-3-4-MISSION-V1.1 [4]. Figure 1 shows a plot of atmospheric temperature versus altitude for the combined Huygens data set.



**Figure 1.** Temperature profile of Titan's atmosphere from the Cassini Huygens mission [4]

### 3 Results

In this analysis, the only parameter that is varied is the entry velocity of the micrometeoroid. Figure 2 shows altitude versus temperature for meteoroid entry velocities from 1 to 15 km/s, chosen to span the range from Titan's escape velocity (2.6 km/s) and orbital velocity (5.6 km/s) to Saturn's orbital velocity (9.7 km/s).



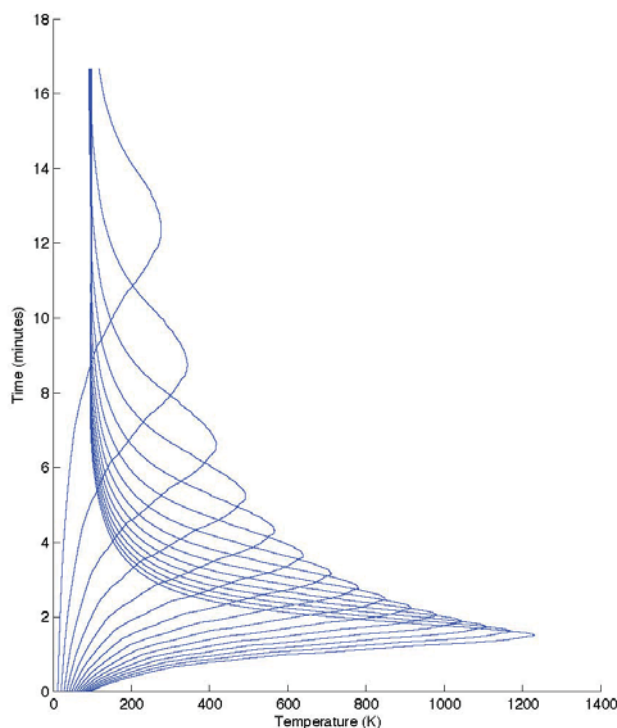
**Figure 2.** Micrometeoroid temperature as a function of altitude for entry velocities of 1 to 15 km/s. The curve that peaks at the highest temperature is 15 km/s.

The evaporation of meteoroid material due to heating was modeled by the Langmuir formula using a variety of values for the vapor pressure as have been used in other meteor evaporation studies [3]. Varying the vapor pressure value over this range did not significantly alter these results.

This result agrees well with previous studies [2] in that the micrometeors reach peak heating at approximately 600 km, and are heated over a timescale of minutes. The slowest particles (1 km/s) only reach a temperature of about 200 K, whereas the fastest particles (15 km/s) are heated to 1200 K.

### 4 Discussion

Meteors decelerate once they have encountered roughly their own mass of atmospheric molecules. Compared to Earth [1], micrometeors entering Titan's atmosphere will experience significantly less severe heating, because Titan's gravity is only  $\sim 14\%$  that of Earth. Titan's atmospheric scale height is thus larger than Earth's, making it a more diffuse medium through which to decelerate and allowing for more time to radiate away the frictional heat of atmospheric entry.



**Figure 3.** Micrometeoroid temperature as a function of time for entry velocities of 1 to 15 km/s. The curve that peaks at 200 K and ~ 12 minutes is that for 1 km/s and the curve that peaks at ~ 1200 K at 2 minutes is for 15 km/s.

A 12 km/s micrometeor of 100 $\mu$ m diameter and 45° entry angle will reach a peak temperature of 1800 K after 13 seconds [1]. By comparison, the same micrometeor entering Titan’s atmosphere will not exceed 1000 K and will require about two minutes to reach its peak temperature.

Detailed knowledge regarding ranges of input velocities, size distribution, average composition, etc. is incomplete for meteor sources in the neighborhood of the outer planets. The assumptions made here assume similarity to the situation observed in our part of the solar system. If meteoritic material in the area of the outer planets is more cometary in origin with a higher percentage of water ice, then a lower meteoroid density and a modified entry velocity range may be more appropriate. The specific heats of vaporization and melting are very different for water ice compared to that used in Earth-based meteor studies [1]. This difference will keep the particle’s temperature lower since energy is more efficiently partitioned into melting and evaporation. The slowest micrometeors may possibly retain some water ice, while the fastest will likely lose all of the ices and most of their organic compounds.

## 5 Conclusions

Titan’s low gravity and large scale height means that micrometeors undergo relatively slow heating and cooling compared to those entering Earth’s atmosphere. Molecules liberated from meteoroids during their descent will likely be able to participate in photochemical and heterogeneous reactions

Recent experiments have shown that flash-heated CM chondrite micrometeorites will evolve organic compounds, including PAHs and light hydrocarbons, at temperatures from 500 to 1000 K [5]. Similar experiments should be conducted at slower heating rates to observe what organic compounds

may be released under the more gentle heating expected in Titan's atmosphere. These compounds can be incorporated into chemical models for Titan's atmosphere. In particular, micrometeorites may be involved in the presence of oxygen-bearing compounds and also small polycyclic aromatic hydrocarbons in Titan's atmosphere.

### **Acknowledgements**

MEK acknowledges research support from the NASA Astrobiology Institute's Virtual Planetary Laboratory (PI: V. Meadows).

### **References**

1. S.G. Love and D.E. Brownlee, Heating and thermal transformations of micrometeoroids entering Earth's atmosphere. *Icarus* 89, 26-43 (1991)
2. S.G. Love and D.E. Brownlee, Heating and thermal transformations of micrometeoroids entering Earth's atmosphere. *Icarus* 89, 26-43 (1991)
3. E.J. Öpik, *Physics of Meteor Flight in the Atmosphere*. Wiley-Interscience, Hoboken, NJ
4. NASA Planetary Atmospheres Data Node, Data Set ID: HP-SSA-HASI-2-3-4-MISSION-V1.1 (2006)
5. M.E. Kress, C.L. Belle, G.C. Cody, A.R. Pevyhouse and L.T. Iraci, Atmospheric chemistry of micrometeoritic organic compounds, NASA Conference Proceedings from Meteoroids 2010, D. Janches, editor (2010)