ATMOSPHERIC ENTRY HEATING OF COSMIC DUST. G. J. Flynn, Dept. of Physics, SUNY-Plattsburgh, Plattsburgh, NY 12901

The process of atmospheric deceleration and heating of micrometeorites was modeled by Whipple (1950) and extended by Fraundorf (1980) to predict the distribution of temperature maxima reached by micrometeorites with any given velocity distribution prior to atmospheric entry. The cosmic dust particles collected from the stratosphere in the NASA Cosmic Dust Sampling Program contain volatile elements, minerals of low stability, and solar flare ion "tracks" all of which undergo alteration or loss at certain established temperartures. Flynn (1987) used these three internal temperature indicators and the Whipple/Fraundorf entry heating calculations to suggest that the peak temperature distribution of the cosmic dust collected from the stratosphere was more consistent with the entry velocity distribution expected if the majority of the particles were derived from main belt asteroids than from comets. However the distinction between particle sources rests on calculated peak temperatures differing by only a few hundred degrees C.

To assess the validity of the Whipple/Fraundorf entry heating model, a computer simulation of the atmospheric entry process was developed. This simulation follows the Whipple (1950) assumption that in any given time interval the particle must radiate away all of the energy added to it by collisions with the air molecules. The temperature of the particle is then determined from Stefan's thermal radiation equation. To solve the peak temperature equation in closed form Whipple (1950) made three assumptions:

1) the atmospheric density varies exponentially with height (as it would for a homogeneous, isothermal atmosphere),

2) there is no gravitational acceleration during atmospheric entry, and

3) the energy going into raising the temperature of the particle is negligible compared to the radiated energy during each interval.

In this computer simulation none of these assumptions are required. The exponential approximation to the atmospheric density is the most serious difficulty with the Whipple/Fraundorf model. Figure 1 compares the U.S. Standard Atmospheres (1962) atmospheric density profile, used in this simulation, with the exponential atmosphere used by Fraundorf (1980). Although both are in good agreement below 130 km, the tabulated values exceed the exponential extrapolation by an order of magnitude at 170 km.

For large or dense particles the dilute atmosphere above 130 km produces negligible deceleration. However in the computer simulation, an incoming 20 μm diameter particle of 1 gm/cm^3 density having a velocity at infinity of 10 km/sec and normal incidence reached its peak velocity at 176 km. Thus the atmospheric deceleration exceeded the gravitational acceleration at this high altitude. A direct comparison of the two models for this particle gave a peak temperature of 1185 K using the Whipple/Fraundorf model* versus 1159 K in the computer simulation. Though the difference between the peak temperatures predicted by the two models is small in this case, it would be expected to increase for lower density particles (which experience more deceleration above 130 km) and for particles with larger impact parameters (which have a longer path through the upper regions of the atmosphere).

Direct comparison of the predicted peak temperatures over the entire range of impact parameters which result in earth collection is complicated by

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* Since the Whipple/Fraundorf model does not include the gravitational infall acceleration, the entry velocity was calculated using energy conservation as:

$$v_{entry} = (v_{escape}^2 + v_{infinity}^2)^{1/2}.$$

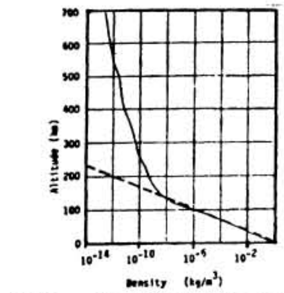

Fig. 1: Atmospheric Density Profile. U.S. Std. Atm. (solid line), Expon. Approx. (dash)

Table I: Fraction of Particles Not Heated Above T
(Particle: 20 μm Dia, 1 gm/cm^3 Dens, 10 km/s at ∞)

Temp T (^oC)	Fraundorf (1980)	This Work
236	0.1%	2%
406	1%	4%
471	2%	6%
545	5%	10%
615	10%	16%
680	17%	26%
781	39%	50%
841	57%	75%
870	75%	90%
887	90%	100%

the fact that the Whipple/Fraundorf model does not include the gravitational infall acceleration. In their model a velocity characteristic of the particle's entry into the "deceleration region" is chosen. However two particles starting at infinity with the same velocity but different impact parameters do not arrive at any fixed altitude with equal velocities when the deceleration in the upper atmosphere is significant. In Table I the peak temperature distribution predicted by each model is compared by taking as the Whipple/Fraundorf entry velocity the velocity expected at 100 km by energy conservation in the absence of atmospheric deceleration. The two models are seen to be in relatively good agreement, though the temperatures in this simulation are generally tens of degrees lower than calculated using the earlier model. The most striking difference is the large fractional increase of particles entering with very low temperatures. The fraction not heated above 236 ^oC, for example, is 2% in this simulation but only 0.1% using the Whipple/Fraundorf model. This reflects the substantial deceleration above 130 km for particles entering near grazing incidence. The particles in this catagory, however, constitute only a small fraction of the total number collected from the stratosphere.

Comparison of this simulation with the Whipple/Fraundorf model indicates that the earlier model accurately assesses the entry heating experienced for particles of moderate or higher density and for entry angles near the normal. As the particle density decreases or the entry angle approaches a grazing condition, the Whipple/Fraundorf model systematically overestimates the peak temperature reached on entry due to the low atmospheric density above 130 km used in that model. For particles of density 1 gm/cm^3 or higher the differences between this simulation and the earlier model are not large enough to alter the conclusion in Flynn (1987) that, based on the peak temperature reached on atmospheric entry, a large fraction of the chondritic cosmic dust collected from the stratosphere entered the atmosphere with relatively low velocity, consistent with a main belt asteroid origin.

REFERENCES: Flynn, G.J. (1987) Atmospheric Entry Heating: A Criterion to Distinguish Between Asteroidal and Cometary Sources of Cosmic Dust (submitted to Icarus). Fraundorf, P. (1980) Geophys. Res. Lett., 10, 765-768. U.S. Standard Atmospheres (1962) U.S. Govt. Printing Office. Whipple, F.L. (1950) Proc. Nat. Acad. Sci., 36, No. 12, 687-695.

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