Experimental investigation of micrometeoroid ablation using a dust accelerator – preliminary results

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Motivation

Meteors - incoming cosmic material

Mass distribution, detection techniques

Velocity distribution – biased?

Unknowns:
- Total mass input (5-200 tons/day)
- Velocity distribution – what is the bias of radar measurements?
- Origin/composition (cometary/asteroidal)
Ablation model

\[ \frac{dV}{dt} = -\Gamma V^2 \frac{3\rho_a}{4\rho_m R} \]

Momentum equation, \( \Gamma = \text{molecular drag coefficient} \)

\[ \frac{1}{2} \pi R^2 V^3 \rho_a \Lambda = 4\pi R^2 \varepsilon \sigma (T^4 - T_{\text{env}}^4) + \frac{4}{3} \pi R^3 \rho_m C \frac{dT}{dt} + L \frac{dm}{dt} \]

Energy conservation (heating) equation
\( \Lambda = \text{heat transfer coefficient} \)

\[ \frac{dm_i^A}{dt} = \gamma p_i S \sqrt{\frac{\mu_i}{2\pi k_B T}} \]

Mass loss rate, \( \gamma = \text{uptake coefficient} \)

\( (dm/dt) \times \beta(v) = \text{ionization rate} \)

Ionization efficiency
Old ionization efficiency measurements

1- Ionization cross section measurements

Na\(^+\) beam

Na beam, ioniz.

CX coll.

Na, K on N2, O2, etc

Bydin & Bukhteev, 1960
Moutinho et al., 1971
Cuderman et al., 1972
Kleyn et al., 1978

2- Dust accelerator/ablation measurements

Fe, Cu on N2, Ar, CO2, air, etc

(20 – 45 km/s)

Slattery and Friiichtenicht, 1966
Friiichtenicht et al., 1967
Friiichtenicht and Becker, 1971
Experimental setup

![Experimental setup diagram]

Experimental data

\[ \beta = 1 \]

\[ \beta_{Fe} = 5.96 \times 10^{-6} \times v^{-3.12} \]

(measured in air)

\[ 20-45 \text{ km/s} \]
\[ \beta_0 = \frac{c(v - v_0)^2 v^{0.8}}{1 + c(v - v_0)^2 v^{0.8}} \]

Jones (1997)

Minimum ionization speed:

\[ v_0^2 = \frac{2(m + M)}{mM} q_{IE} \]

From Vondrak et al. (2008)
The dust accelerator facility at the Univ. of Colorado

3 MV Pelletron
Accelerated dust:
• 0.1-2 micron
• 1-60 km/s
• Various materials
Particle mass vs. velocity distribution
The ablation facility

Ablation chamber

Diff. pumping
What’s inside

Segmented and biased charge collectors

Accurate velocity measurement
Calibrated charge (mass) measurement

\[ \frac{1}{2}mv^2 = QU_p, \]
Ionization efficiency, Fe + N₂

Fe+N₂ \( \beta \) Measurements and Theory

Complete ablation: \( \beta = \frac{\text{Charge collected (e⁻)}}{\# \text{ of Fe atoms in dust}} \)
Recorded data sample

10.4 km/s
~70 nm in radius

Fit parameters:
Γ = 0.75
Λ = 0.55

β is strongly varying with velocity
Sample solution

10.4 km/s = v
~70 nm = r
Need to consider change of velocity during the ablation process.

The calculation of mass loss over each collection plate is dependent on the ablation model and parameters used (uncertainty).

Need to analyze a large assemble of particles for reliable find the fitting parameters.

\[ \beta \]

\[ \beta \text{ will depend on parameters in the ablation mode and the assumed shape of } \beta(v) \]
Fast particle

18.6 km/s

~50 nm in radius
Fast particle

18.6 km/s
~50 nm in radius

Γ = 0.5 (insensitive)
Λ = 0.9

Better fit not achieved for realistic Γ and Λ values
Fast particle

Graph showing the relationship between velocity (km/s) and ionization efficiency ($\beta$) for the Jones model (Fe). The graph includes a data point labeled as "Measured."
Summary/Conclusions

• There is a need for better $\beta (v)$ data and in particular at lower velocities
• New ablation facility operating at CU (open to collaboration)
• Good quality preliminary measurements already obtained for $> \sim 20$ km/s
• More careful analysis is needed at low velocities

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