Time-Resolved Temperature Measurements in Hypervelocity Dust Grain Impact

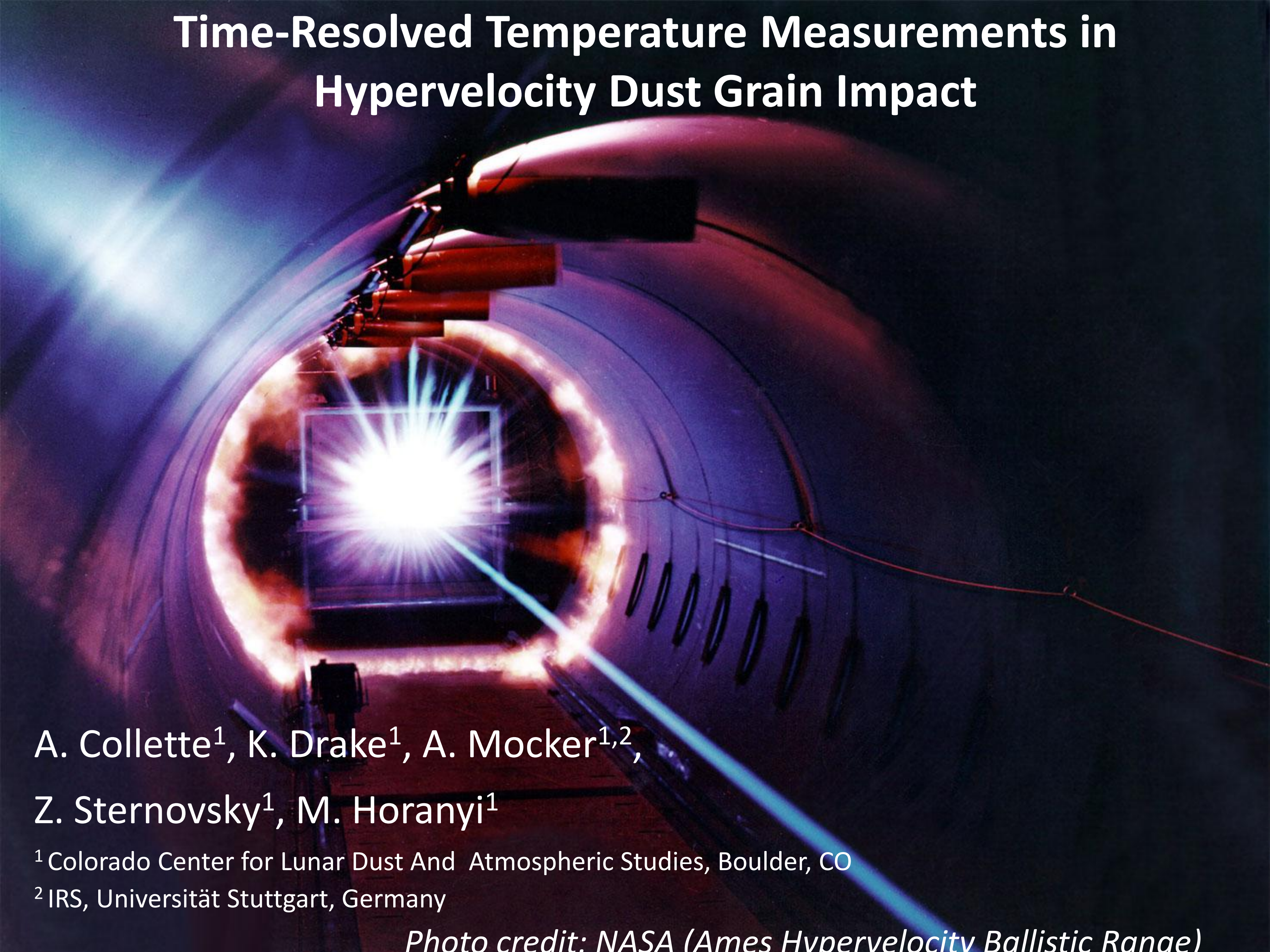

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Photo credit: NASA (Ames Hypervelocity Ballistic Range)

CCLDAS studies on impact physics

The Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS) is an NLSI team focused on understanding properties of the Moon and other airless bodies through a combination of experiment, theory and simulation.

The flagship experimental device at CCLDAS is **an electrostatic dust accelerator** which can be used for basic science investigation or for instrument calibration (e.g. LDEX).

We are in the midst of a measurement campaign aimed at investigating following aspects of hypervelocity impact:

- ❑ Impact-produced ionization
- ❑ Cratering
- ❑ Impact-generated neutral gas
- ❑ Ejecta generation
- ❑ **Temperature measurement (via light flash)**

Summary

We are using the **impact-generated light flash** from **dust grains** moving at speeds from **1-40 km/sec** impacting a **metallic target**

Measures conditions on **microsecond time scales** following impact

- Using a **three-color** technique under the assumption of blackbody radiation
- We get the **blackbody temperature** and **radiant power as a function of time**
- Also **temperature variation with velocity**

Summary of findings:

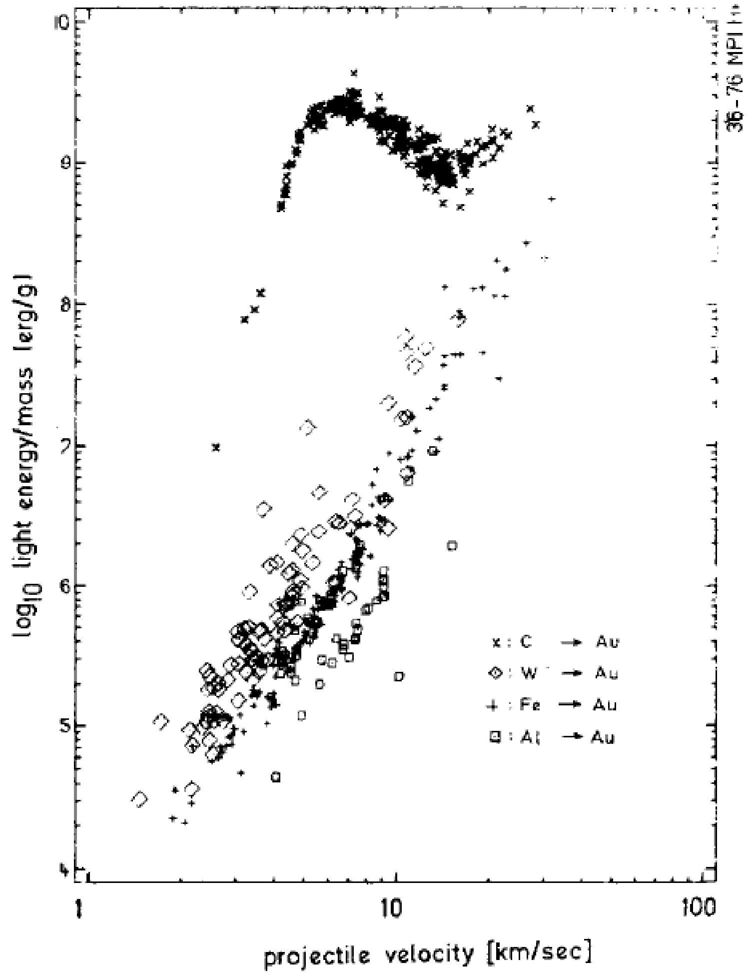
- Time-averaged temperatures **2500K-5000K**, increasing with velocity
- Initial (1µs) temperatures **up to twice the time-averaged temperature**
- Radiant power **does not drop off quickly,** but stays elevated for 10's of µs

Light energy is a strong function of *v*

May experiments undertaken in the **1960s and 1970s** into the physics of dust impact, as part of the Apollo-era concern about the effect on spacecraft and astronauts.

For metal/metal impacts:

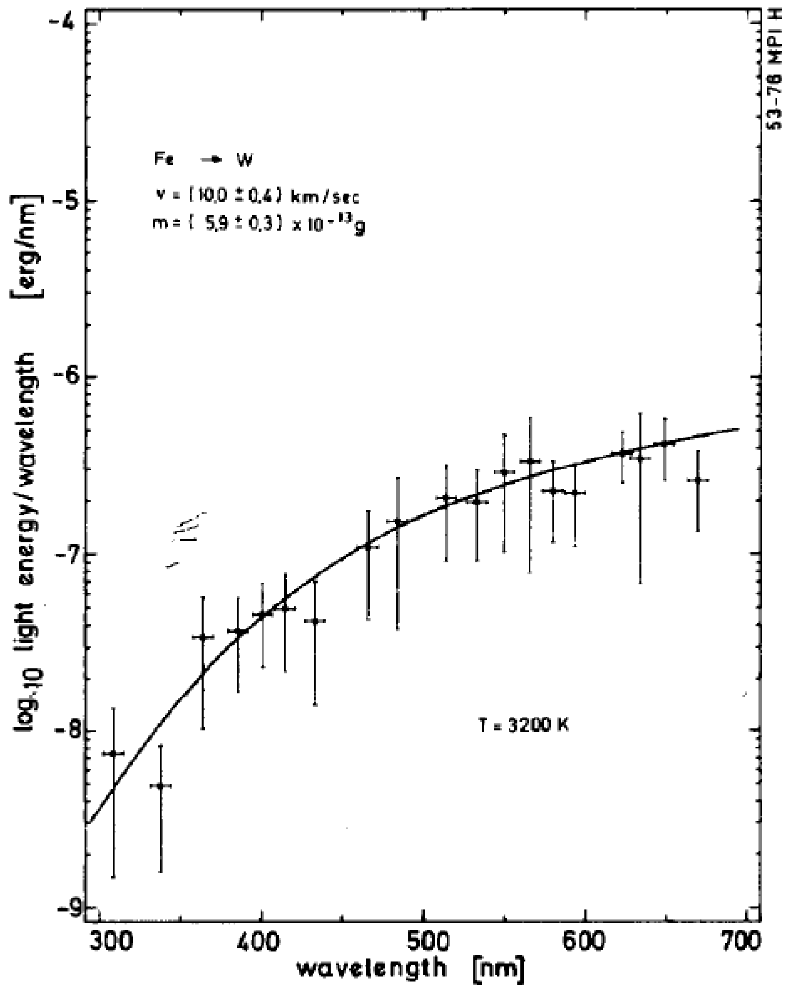
- At most **~0.01% kinetic energy** goes into light energy, depending on the target material
- Blackbody temperatures in the **3000-5000K** range
- Light energy scales linearly with mass, and **strongly with velocity ($v^3 - v^4$)**



G. Eichhorn (1975)

Light source treated as a blackbody

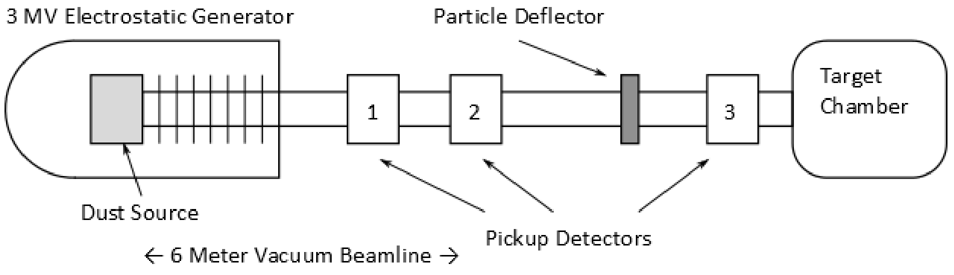
- Strictly speaking, it's not; line emission has been measured for large projectiles in light gas gun experiments
- Very difficult to perform spectroscopy on *dust impacts*, because of the limited light available
- Unclear on what timescales line emission is dominant for dust impacts
- Measurements by Eichhorn and (earlier) Friichtenict indicate blackbody radiation is a reasonable approximation
- Full spectra of the flash is planned to be measured in future experiments at CCLDAS

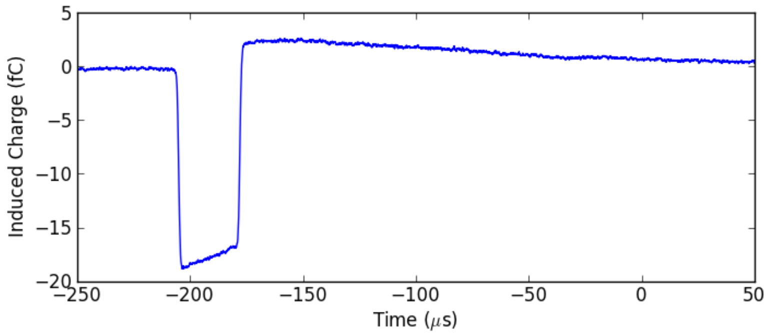


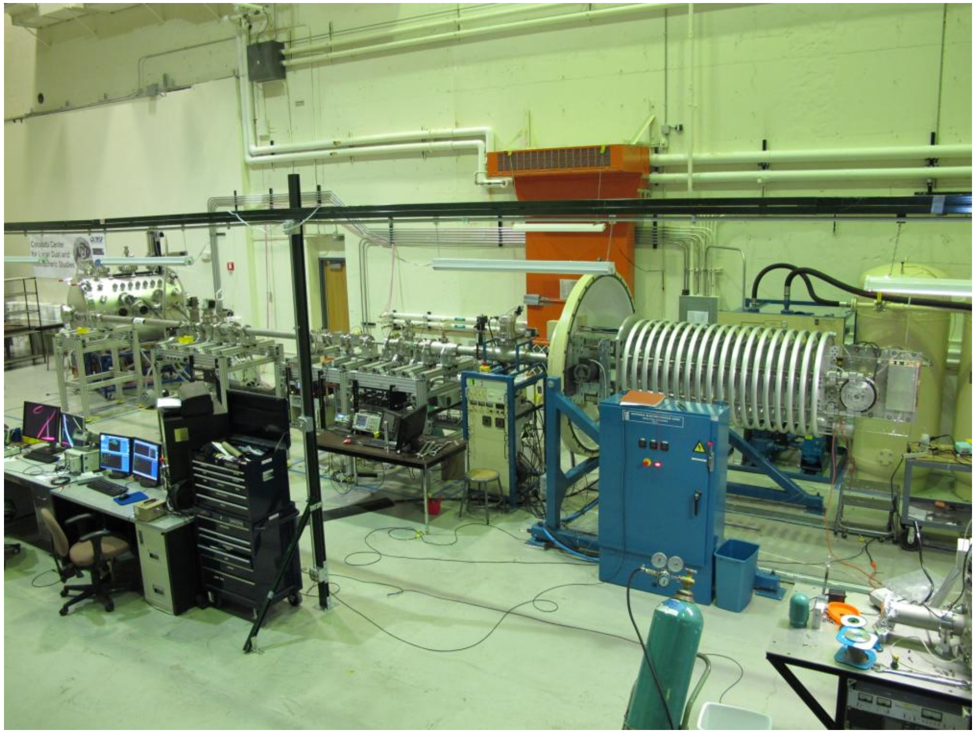
G. Eichhorn (1976)

CCLDAS Dust Accelerator

- Launches charged micron-sized and smaller conducting dust grains
- Design range 1-100 km/sec (1-40 km/sec in this talk)
- In-line detectors measure particle velocity and charge (also giving mass) on particle-by-particle basis

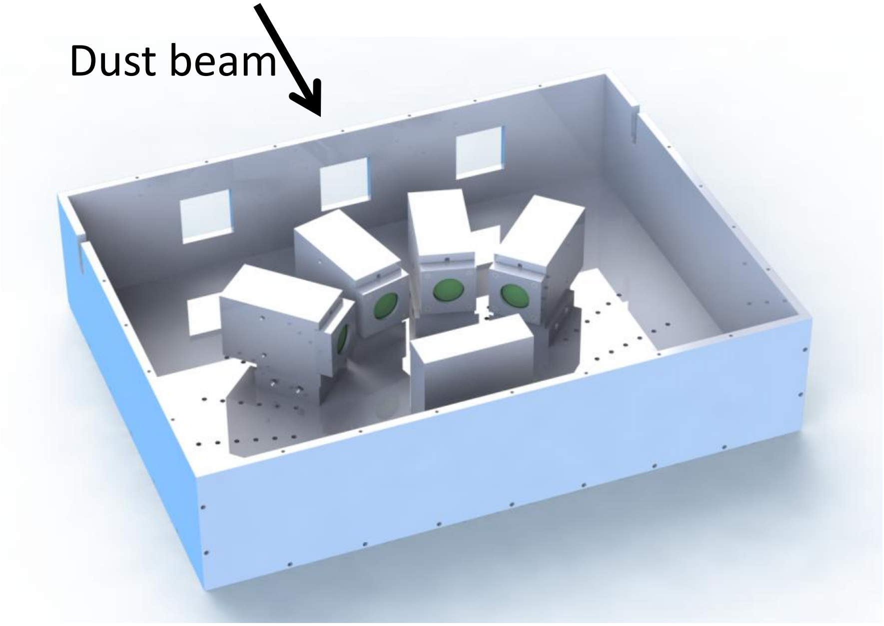


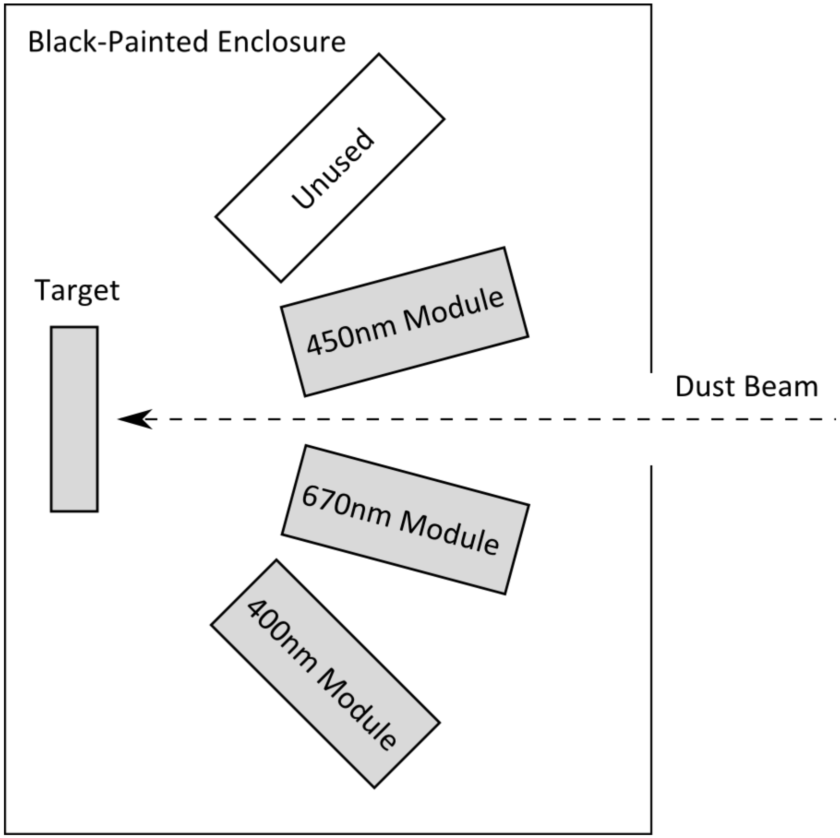




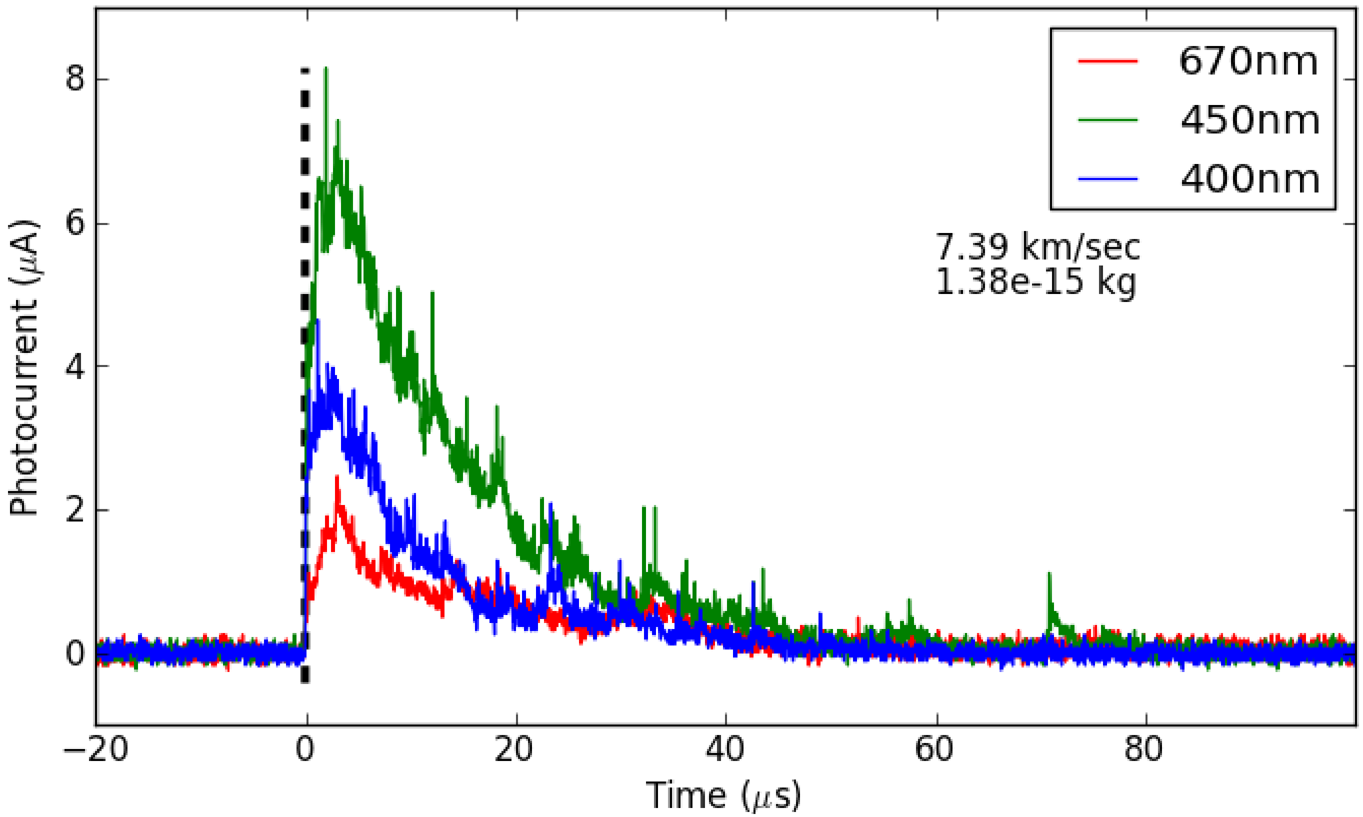
Experimental Setup

- Incoming dust grains strike a tungsten target, producing a light flash
- Up to four photomultiplier modules can observe the flash simultaneously (3 in this experiment)
- Each photomultiplier has a 40nm FWHM bandpass filter; center wavelengths are at 400, 450, 670 nm.
- Phototubes use 1us integration time





PMT Output (3 filters)



Computing temperature

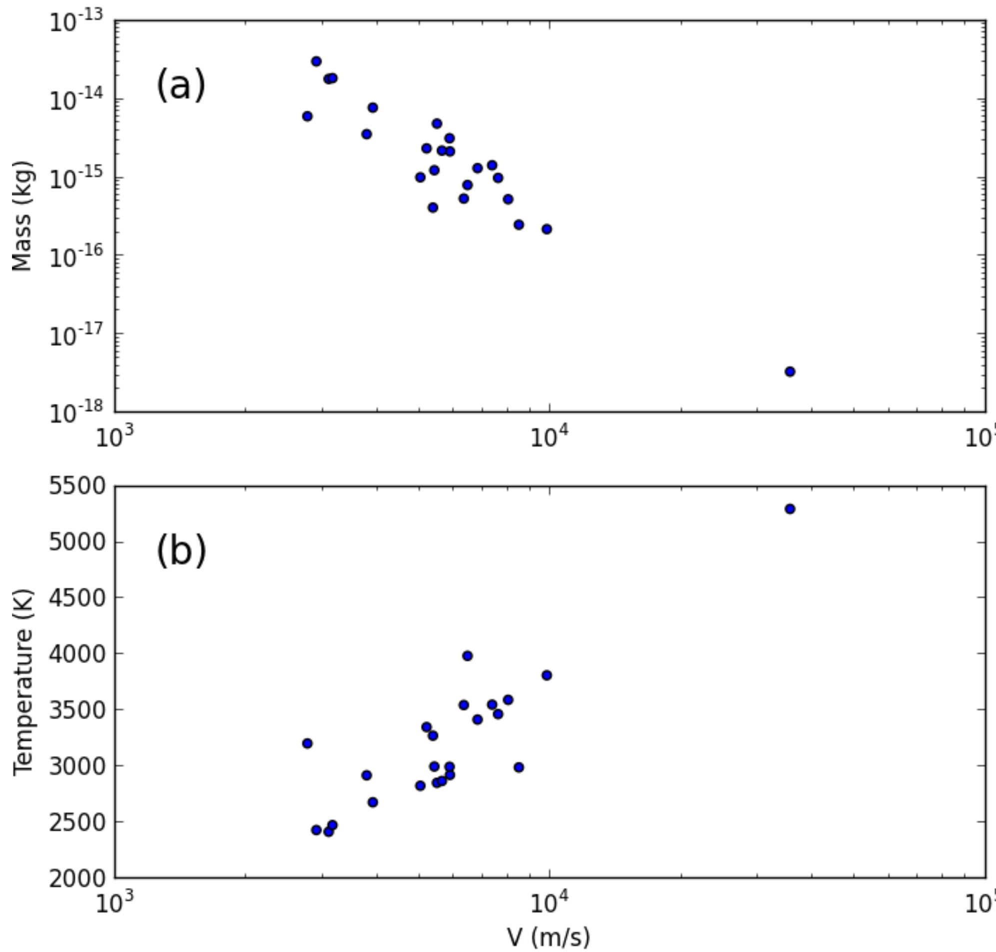
Temperature computer **per-particle**, and as a **function of time.**

- 3 photocurrent time traces acquired from 400, 450 and 670 nm modules
- Each module calibrated to a NIST-calibrated photodiode, providing **photocurrent as a function of spectral irradiance (W/m^2/nm), at several wavelengths across the width of the filter**
- Source is modeled as a **blackbody** with **temperature T** and **radiating area A**, emitting isotropically into 2pi
- A **time window of interest** is selected, and the mean of each photocurrent is computed in that window (producing three photocurrent values)
- The filter calibration is used to compute the photocurrent generated by each module for at a given (A,T) combination
- A two-parameter **least-squares fit is used to find the (A,T) pair** which best reproduces the observed photocurrents
- We compute a goodness-of-fit characteristic (R^2) which can be used to identify cases in which the fit is unreliable

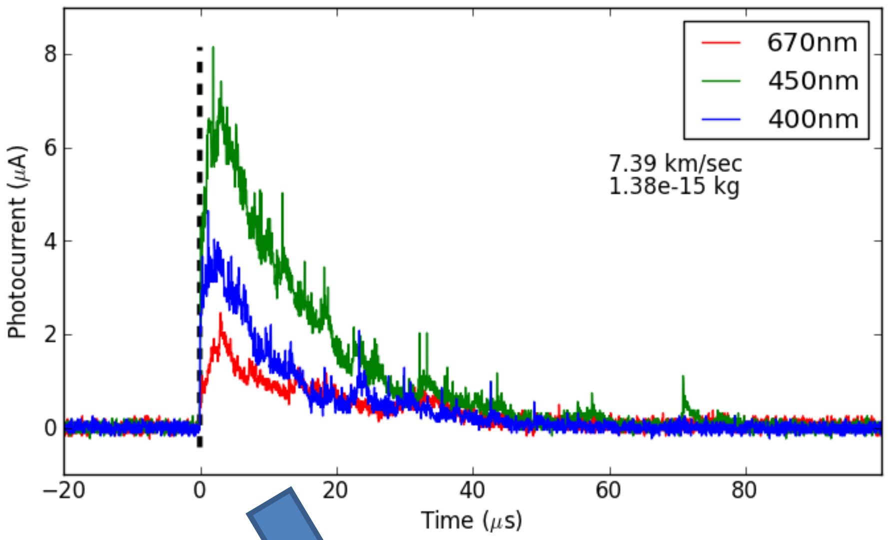
Time-average *T* increases with *v*

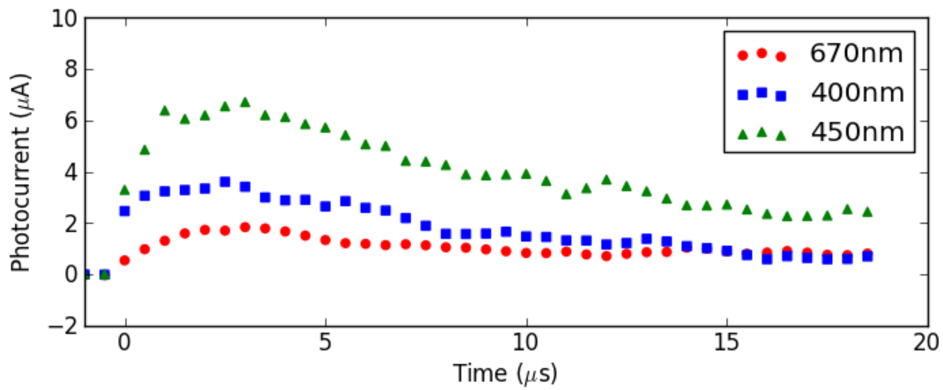
An ensemble of data was collected for particles with speeds ranging from 1-40 km/sec

- "Average temperature": take the mean photocurrent values over a **20μs window**
- Goodness-of-fit $R^2 > 0.90$ required for the fit to pass
- Temperature of highest-speed impact only 5400K
- More high-speed particles are needed to assess functional dependence



Time-Resolved Photocurrent

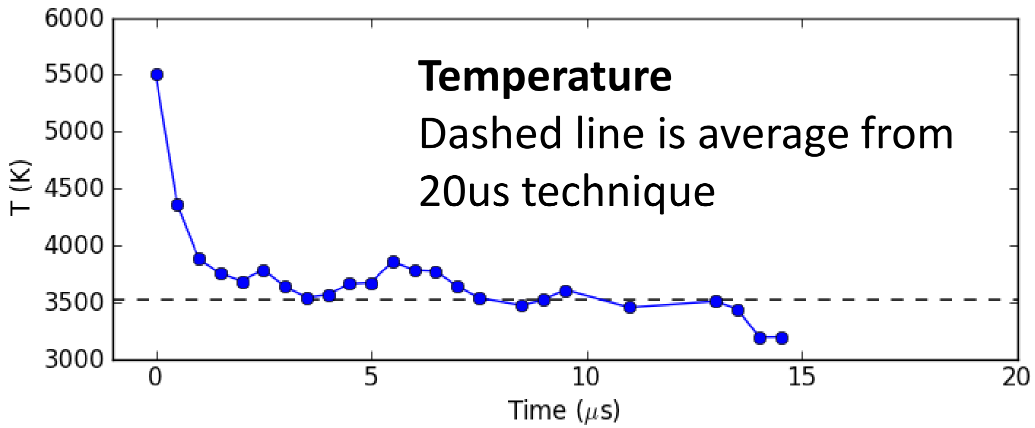


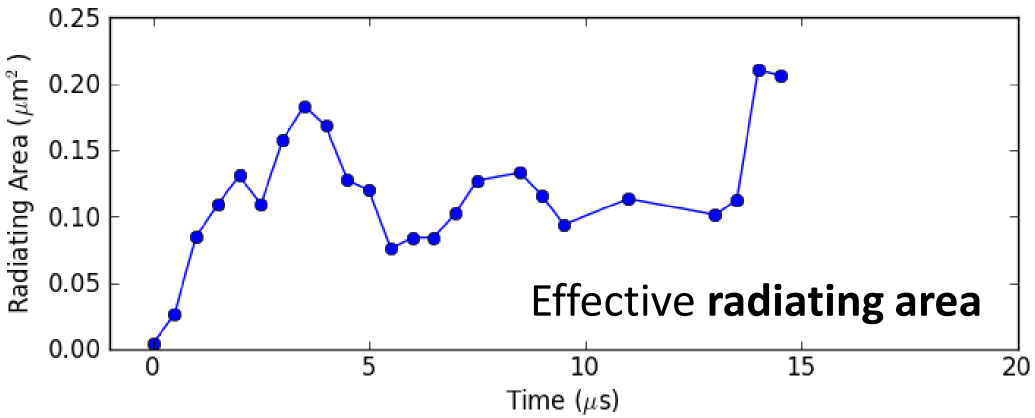


- Photocurrent time series is divided into 0.5us time intervals
- At each time interval, the area and temperature of the radiator is computed subject to R^2 test
- Fit succeeds for about the first 20us of the flash, when the signal enters the noise level

Time-Resolved Temperature/Area

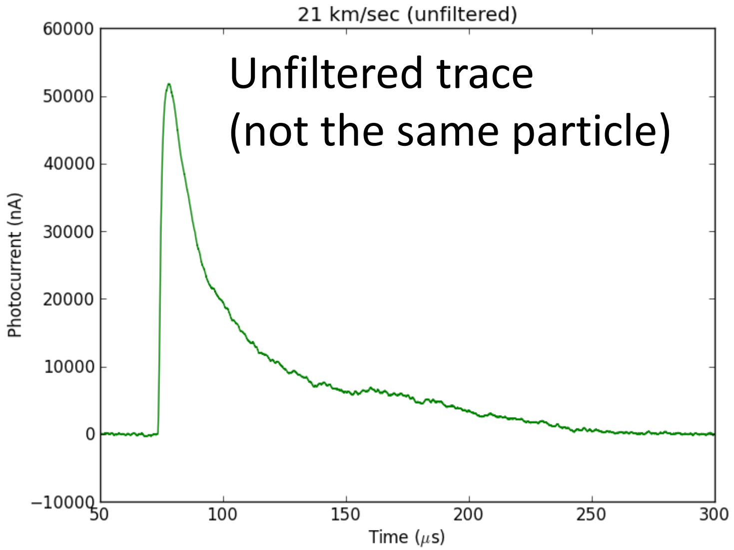
- Dashed line shows time-averaged (20us) temperature used in velocity plot
- At early times, temperature is substantially enhanced
- After initial fast decay, temperature slowly drops from about 3700K to 3200K
- Radiating area starts small but then surprisingly constant over the life of the flash

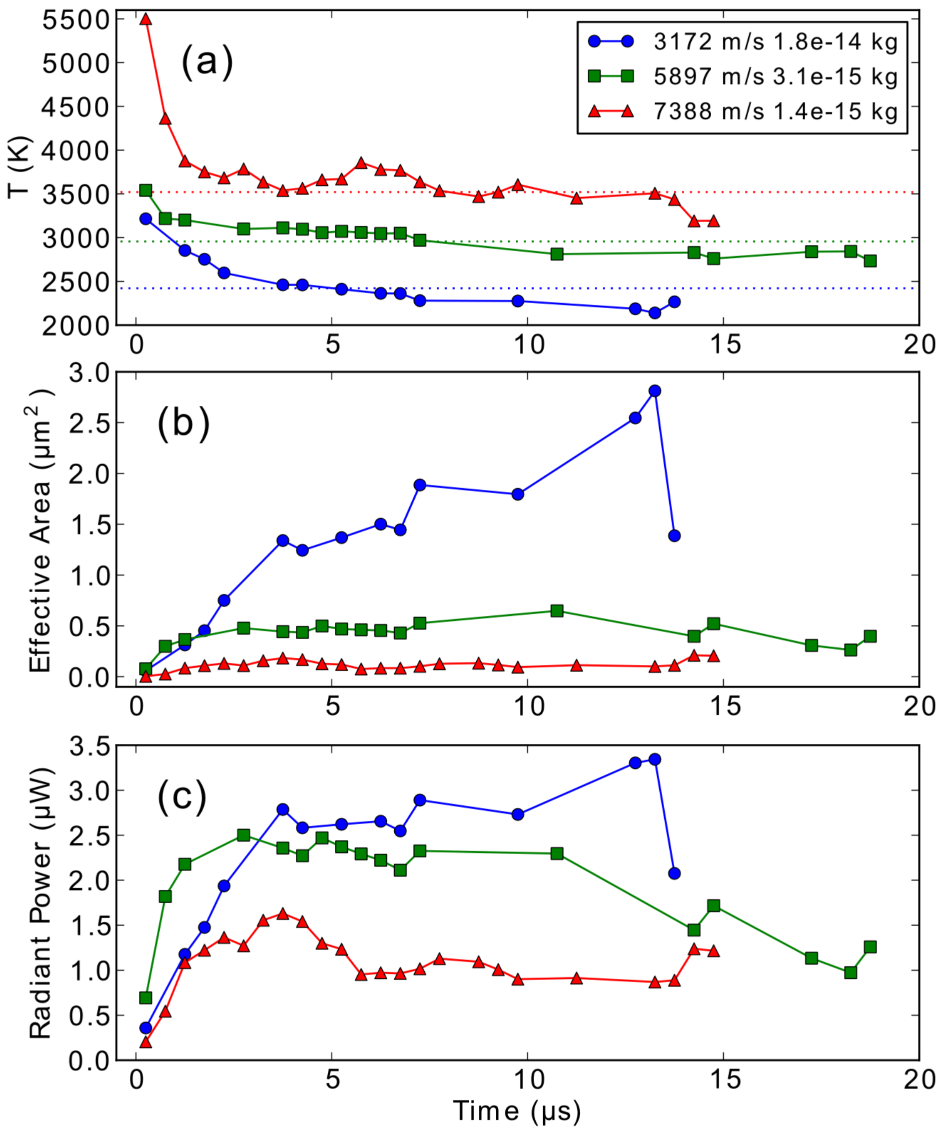




Radiant Power

- We can compute the total power as a function of time from the Stefan-Boltzmann law
- It had been inferred from photocurrent traces that the light power peaked sharply and then fell off on the 10us timescale





Summary & Future Work

- We used the **impact-generated light flash** from **dust grains** moving at speeds from **1-40 km/sec** impacting a **metallic target** for temperature measurement
- The flash is diagnosed using a **three-color** technique with photomultipliers coupled to narrowband interference filters, under the assumption of blackbody radiation
- We find
  - (1) **temperatures in the range 2500K-5000K**, increasing with velocity,
  - (2) **substantially increased initial temperatures on the 1us timescale** (roughly twice the time-average temperature), and
  - (3) that the **radiant power** remains elevated on the timescale of the flash (tens of microseconds)

Future work (**data collected, now in analysis stage**):

- Collection of more particles to make **statistically meaningful statements about velocity scaling, cooling of the cloud, and temperature variation** with impactor mass
- An additional PMT module allowing **a 4-color fit**
- Changes to mounting system to give all 4 PMTs the same angle to the target
- Temperature/power variation with **different target materials**