Dust ablation laboratory experiments to measure the plasma and light production of meteoroids in the atmosphere

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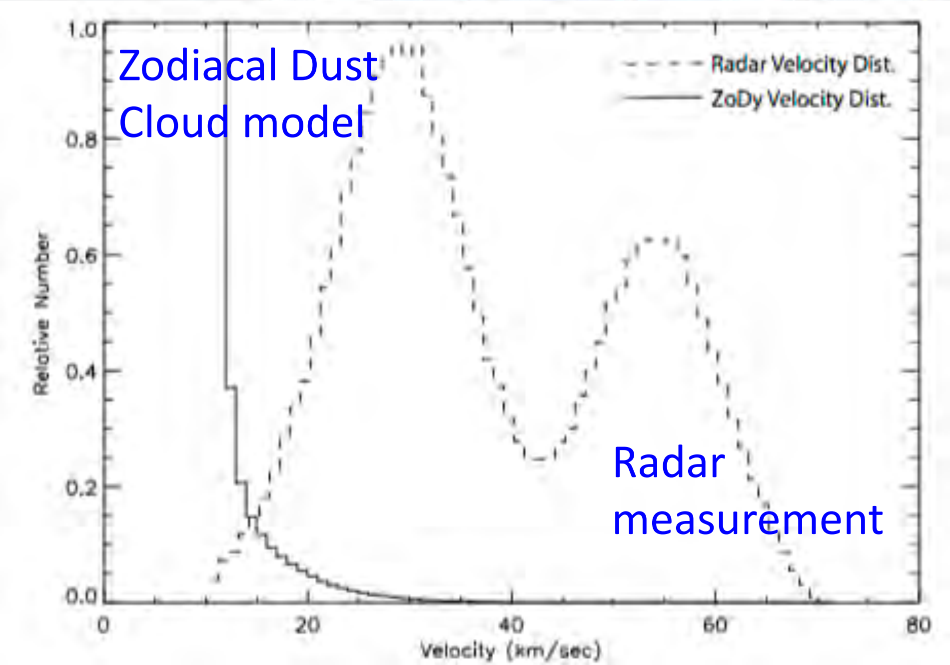
Outline

- The understanding of **microphysical processes in meteoric ablation** is needed for:
  - Interpreting meteor radar measurements
  - Confining the total mass input of cosmic material into the atmosphere
  - Understanding the origin and distribution of interplanetary dust
- The ablation process is studied experimentally at a unique **dust accelerator facility** (Univ. of Colorado)
- Main results from recent measurement campaigns:
  - The ionization efficiencies of Fe and Al measured over the a wide range of velocities, and they are not small.
  - First measurements of particle deceleration and calculating the molecular drag coefficient

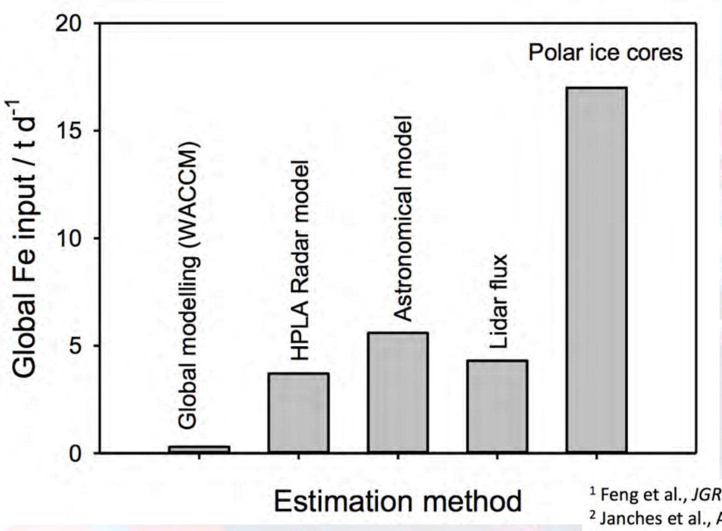
Are meteor radar data interpreted correctly?

Modeled and measured velocity distributions



Nesvorny el al. 2010, Janches et al., 2014

Fe input rates into the atmosphere



[1] Feng et al., *JGR* 2013
[2] Janches et al., Astrophys. J. 2014
[3] Nesvorny et al., 2015
[4] Huang et al., *GRL* 2015
[5] Dhomse et al., *GRL* 2013

- Disagreement between modeled and measured IDP velocity distribution
- Daily cosmic mass influx **3-300 t/d** (Plane, 2012)
  - Radars: ~5 t/d (Mathews et al. 2001)

Ablation/ionization models need experimental verification

State of the art ablation model (after Vondrak et al., 2008)

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

Momentum equation, **Γ = molecular drag coefficient**

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

Energy conservation (heating) equation
Λ – heat transfer coefficient

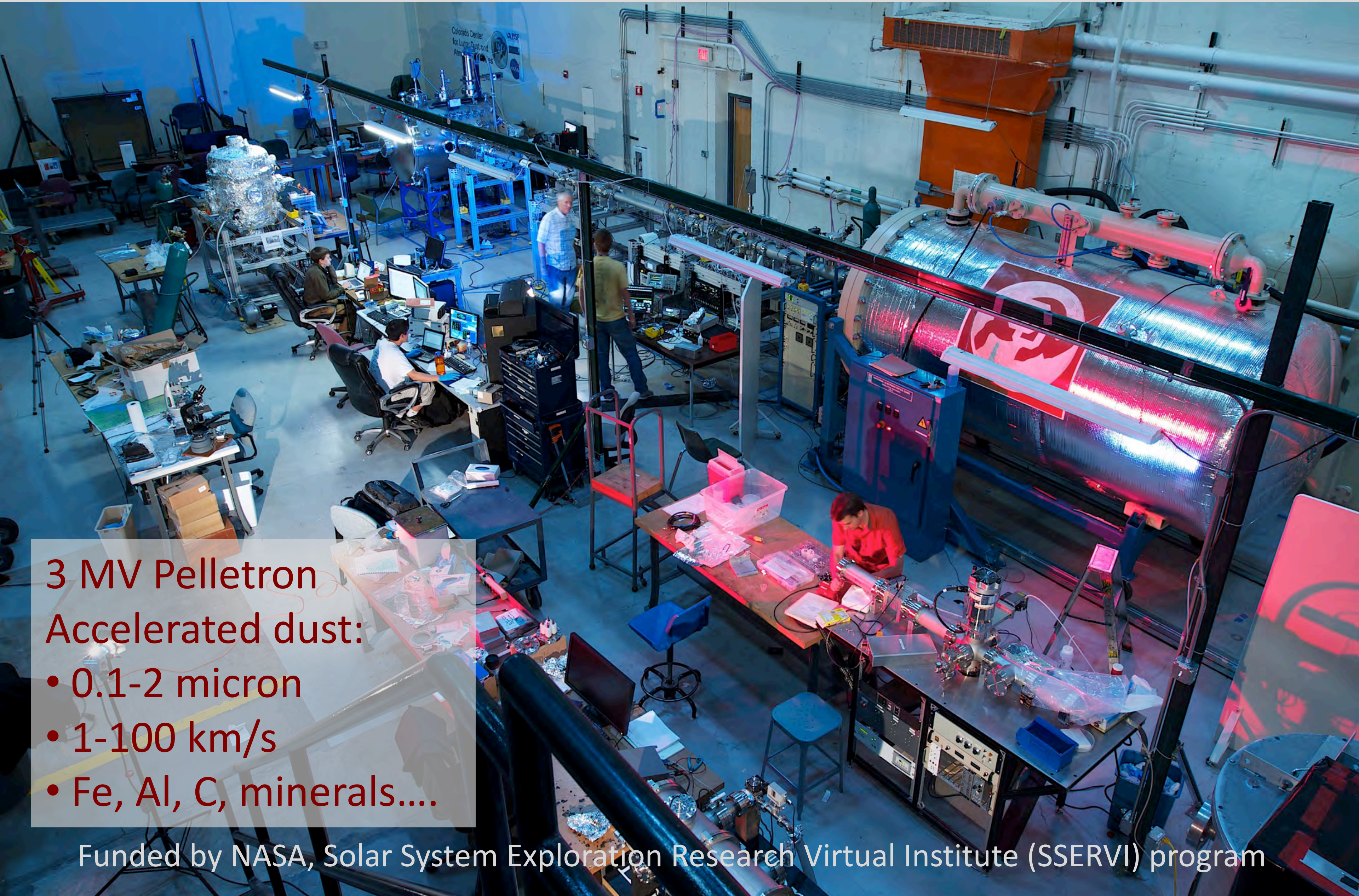
$$\frac{dm_i^A}{dt} = \gamma\, p_i S \sqrt{\frac{\mu_i}{2\pi k_B T}}$$

Mass loss rate, **γ** = uptake coefficient

Ionization rate: (dm/dt) × β(v)

β(v) = Ionization efficiency, function of velocity

The *dust accelerator facility* operated at the Univ. of Colorado



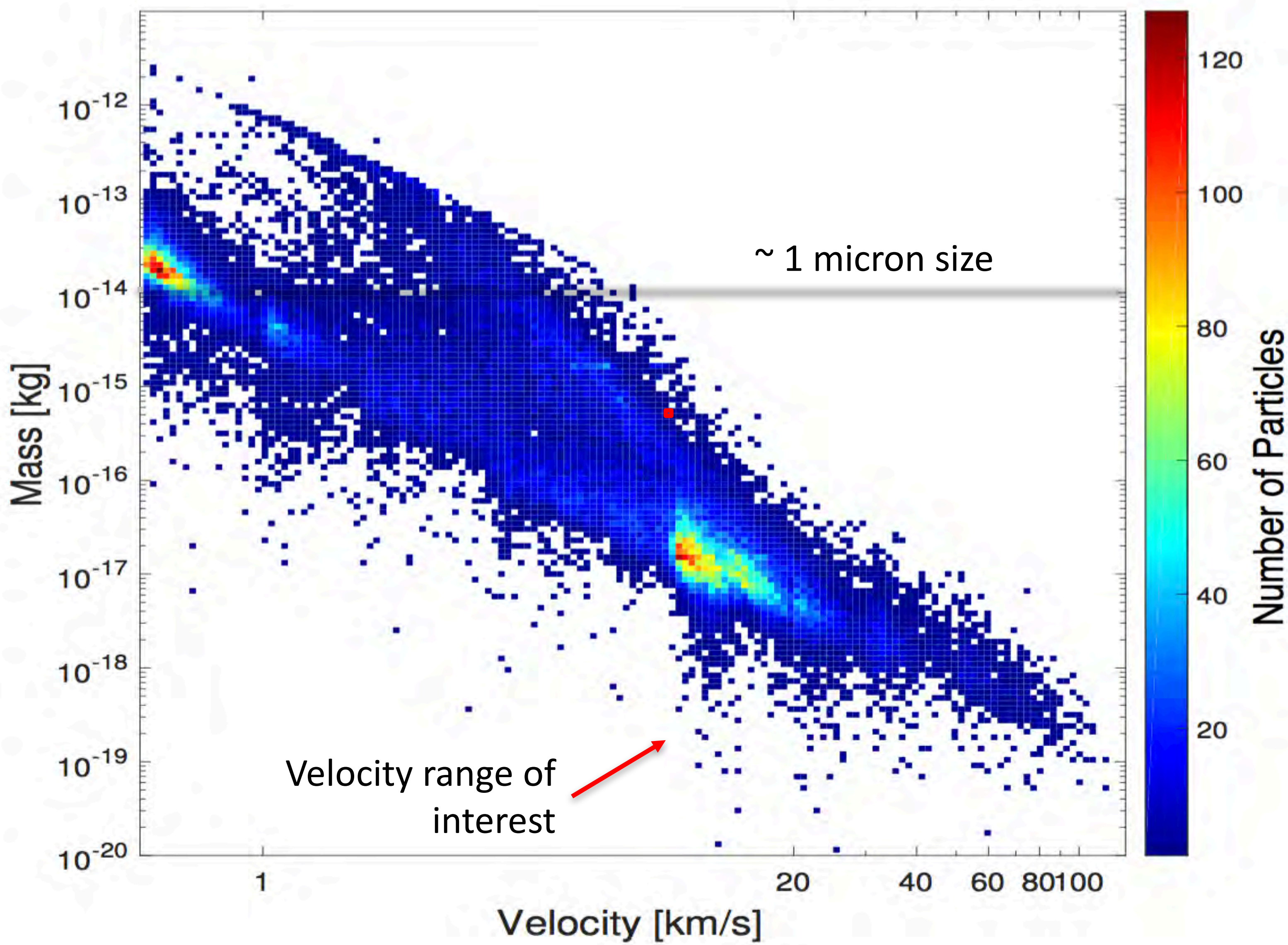
3 MV Pelletron

Accelerated dust:

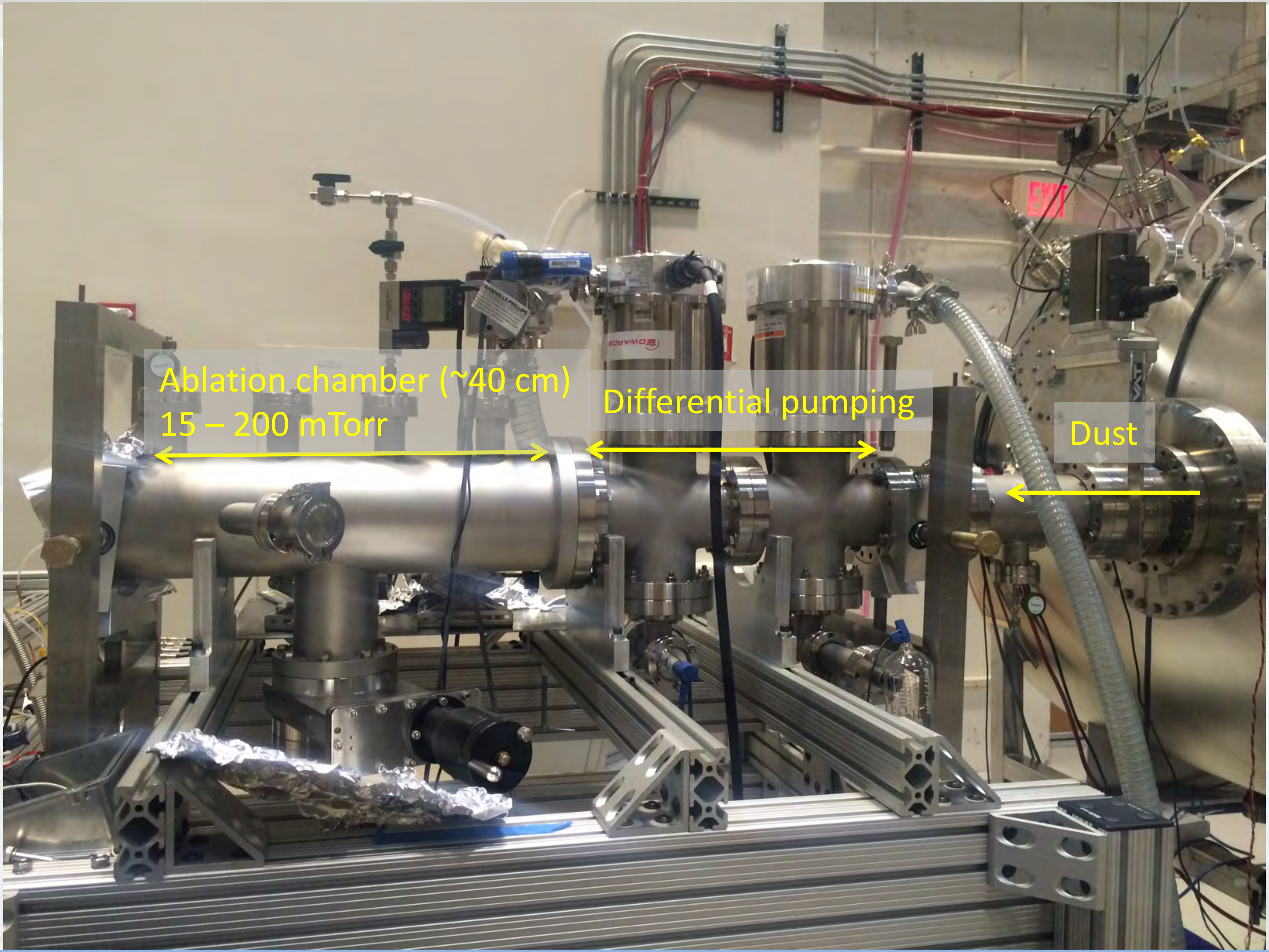
- 0.1-2 micron
- 1-100 km/s
- Fe, Al, C, minerals….

Funded by NASA, Solar System Exploration Research Virtual Institute (SSERVI) program

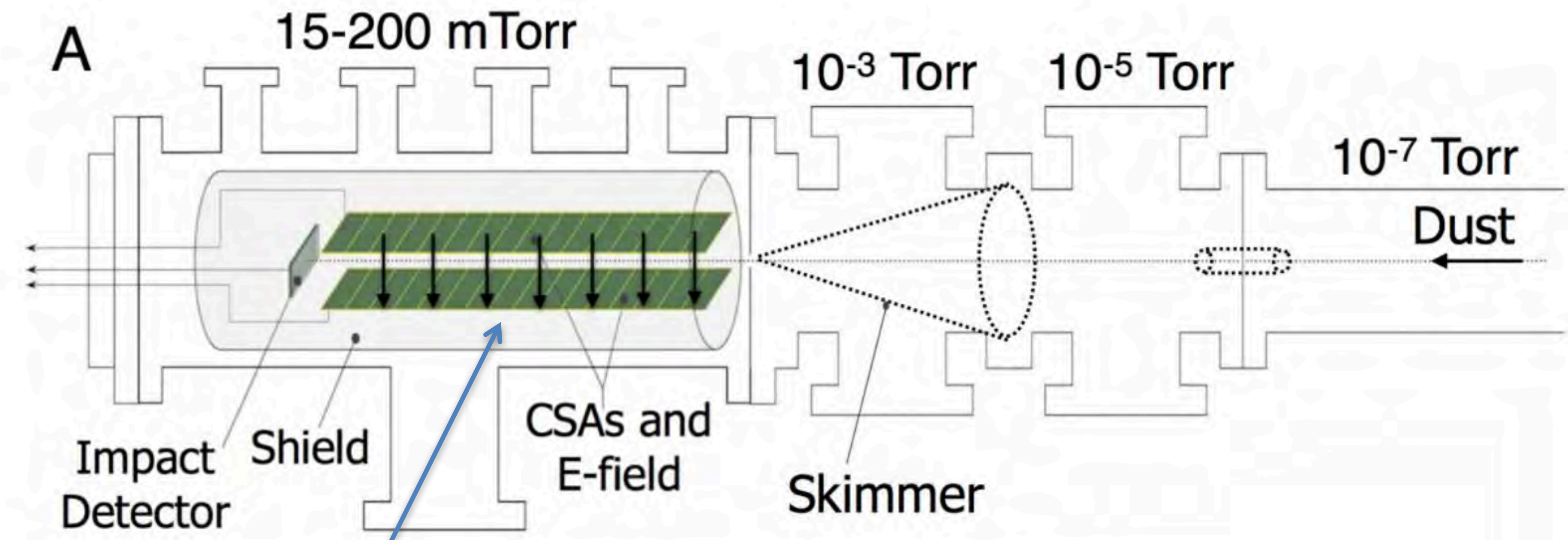
Particle mass vs. velocity distribution



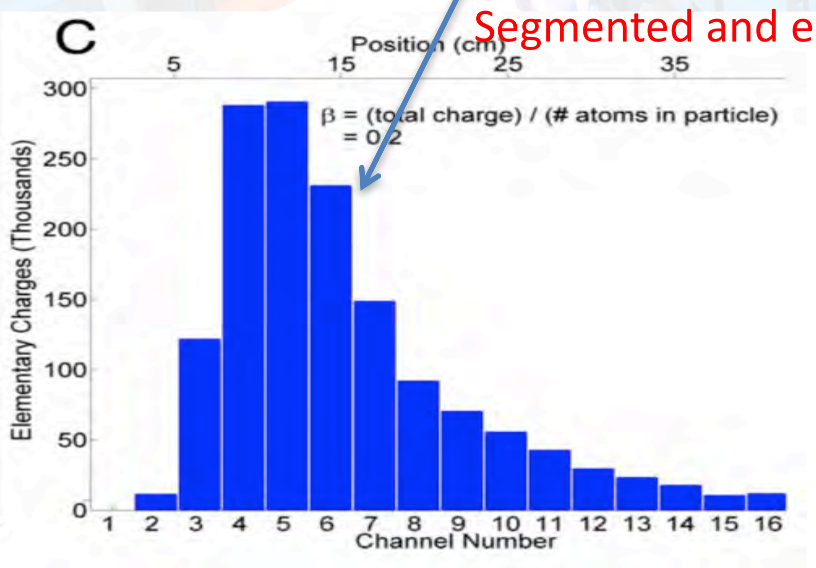
The ablation facility



Measuring the rate of charge generation



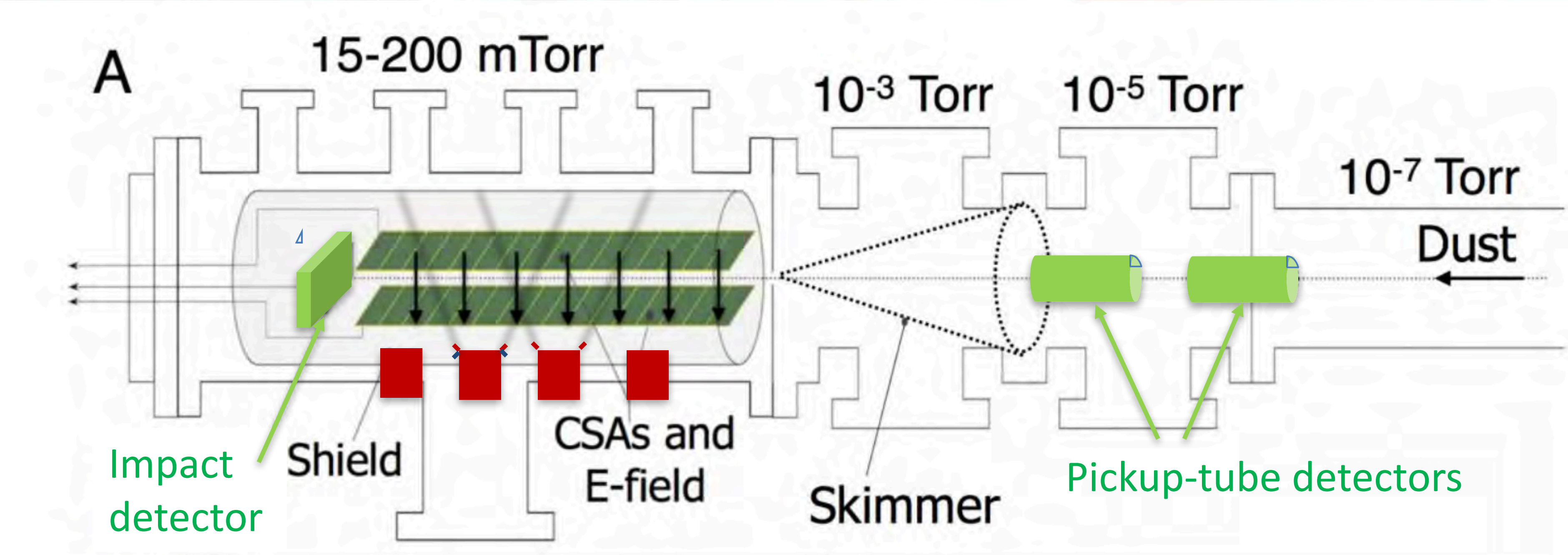
Segmented and electrically biased charge collectors

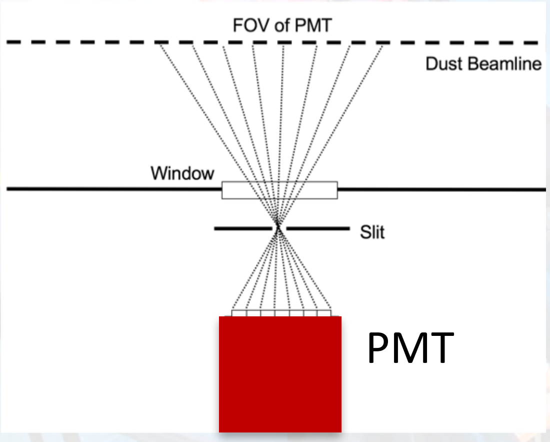


For complete ablation:

$$\beta = \frac{\text{Total collected charge}}{\text{Dust mass (\# atoms)}}$$

Improving the facility with velocity measurement capability





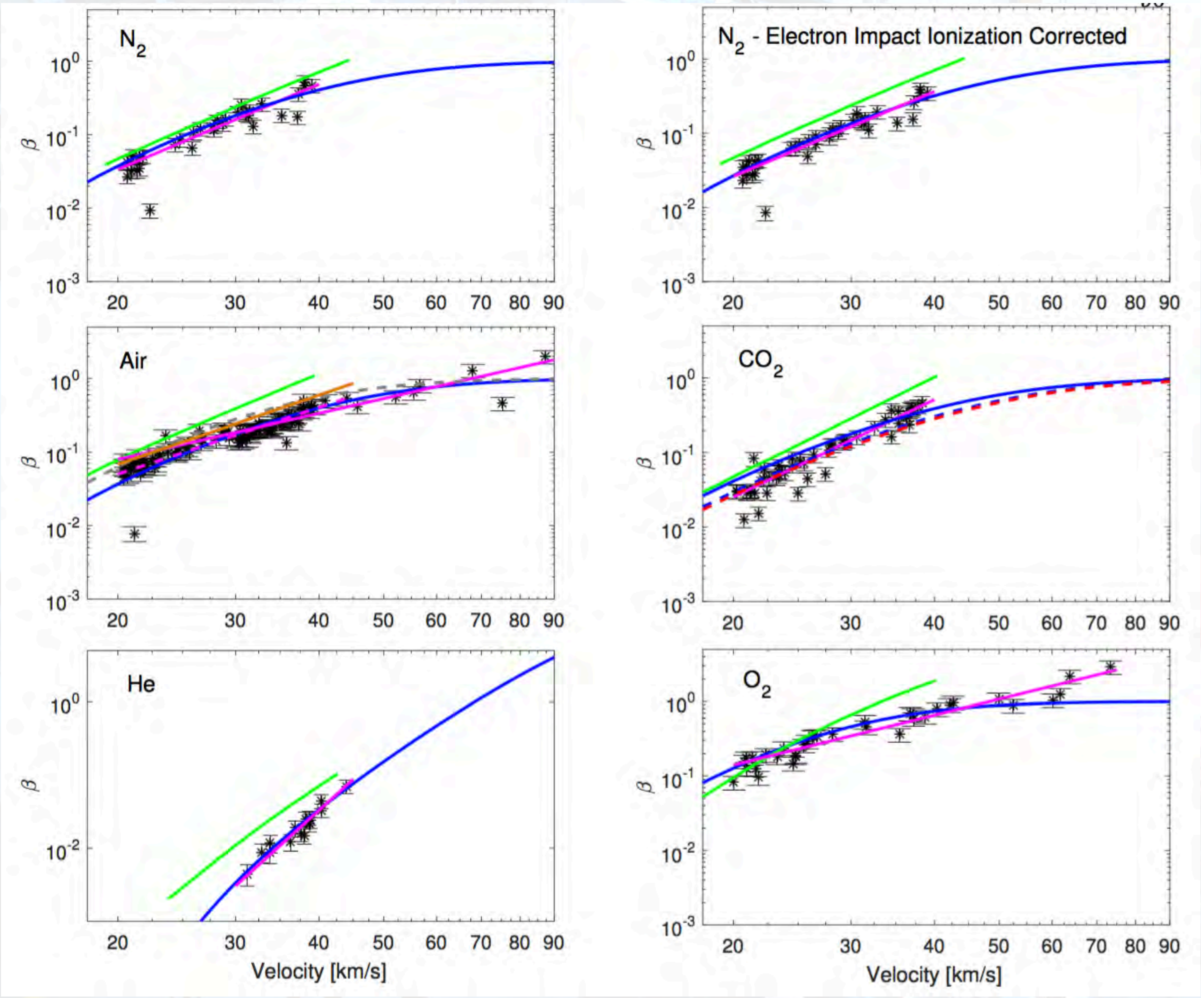
High velocity dust: Four PMT detectors monitor the velocity of the ablating particle

Low velocity dust: Pickup tube and impact detectors provide velocity and slowdown

Thomas et al., *Rev Sci Instrum* 88, 034501 (2017)

DeLuca et al., in preparation (2018)

Initial results of β measurements



- Fe dust particles
- Different target gases
- **Limited to ≥ 20 km/s**

- Previous measurements (Friichtenicht et al., 1967)

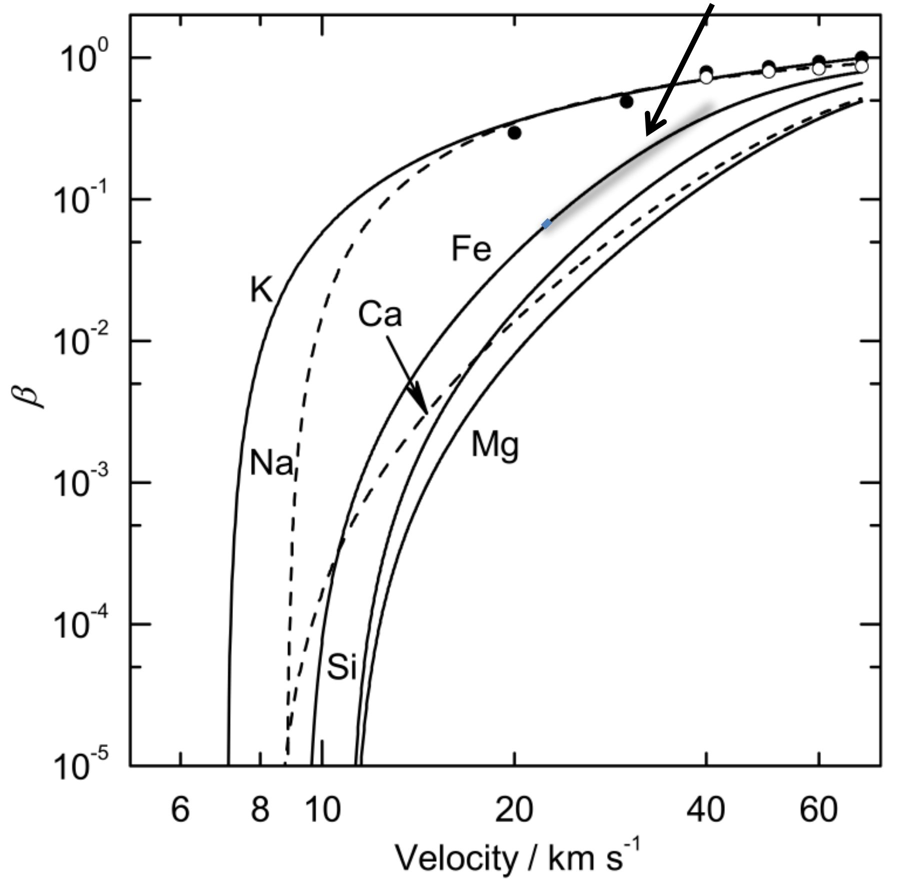
- Fitting data with the Jones model (1997)

E. Thomas et al., GRL (2016) & RSI (2017)

β - state of the art (Vondrak et al., 2008)

From Vondrak et al., 2008,
for ionization in N2

Slattery and Friichtenicht (1967) data



The Jones model (1997)

$$\beta_0 = \frac{c(v - v_0)^2 v^{0.8}}{1 + c(v - v_0)^2 v^{0.8}}$$

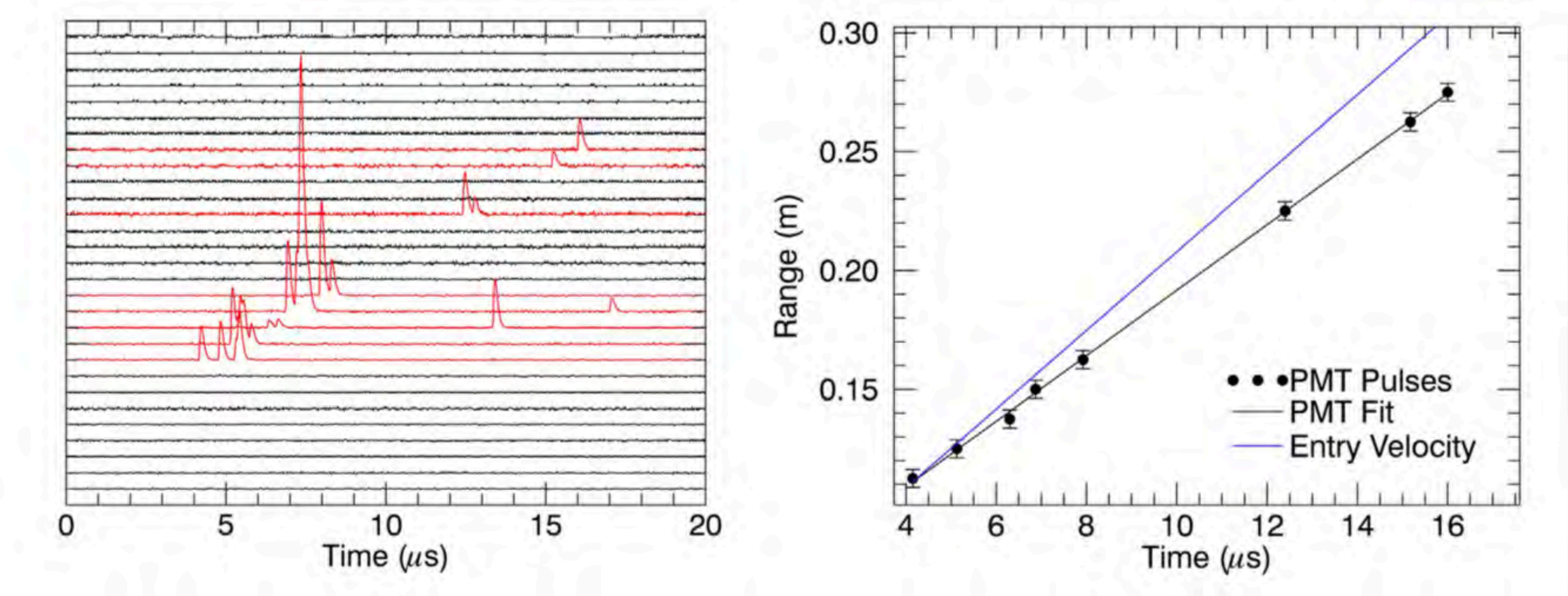
$$v_0^2 = \frac{2(m + M)}{mM}\varphi_{IE}$$

Table 1. Ionization parameters for elements assumed to be present in the composition of a cometary meteoroid.

Element	%	p	v_0	$c \times 10^6$	μ
O	45	0.617	16.7	4.66	0.57
Fe	15	0.059	9.4	34.5	2.0
Mg	9	0.082	11.1	9.29	0.86
Si	31	0.242	11.0	18.5	1.0
Cu	–	–	9.1	15.3	2.25

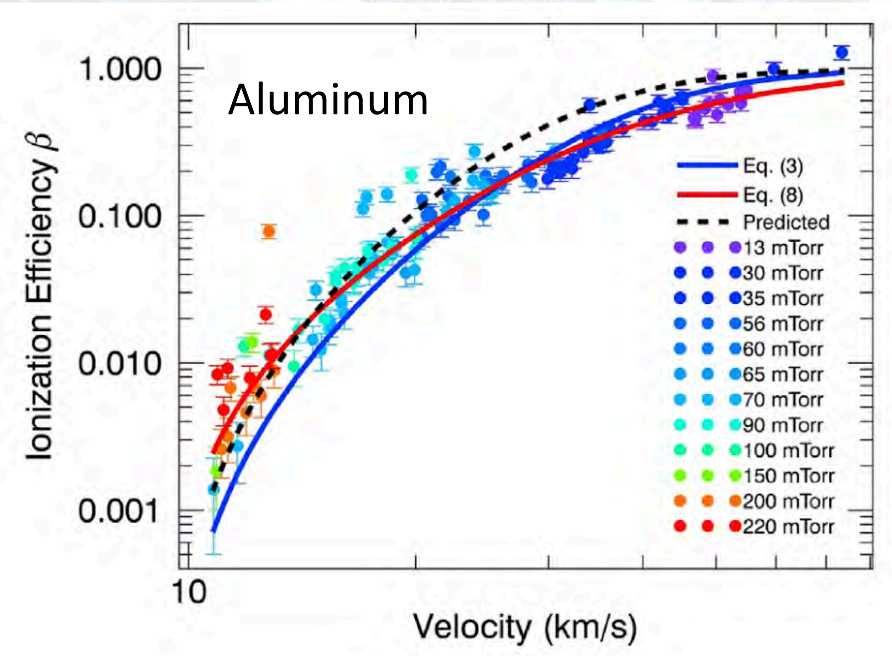
PMT measurements confirm limited slowdown

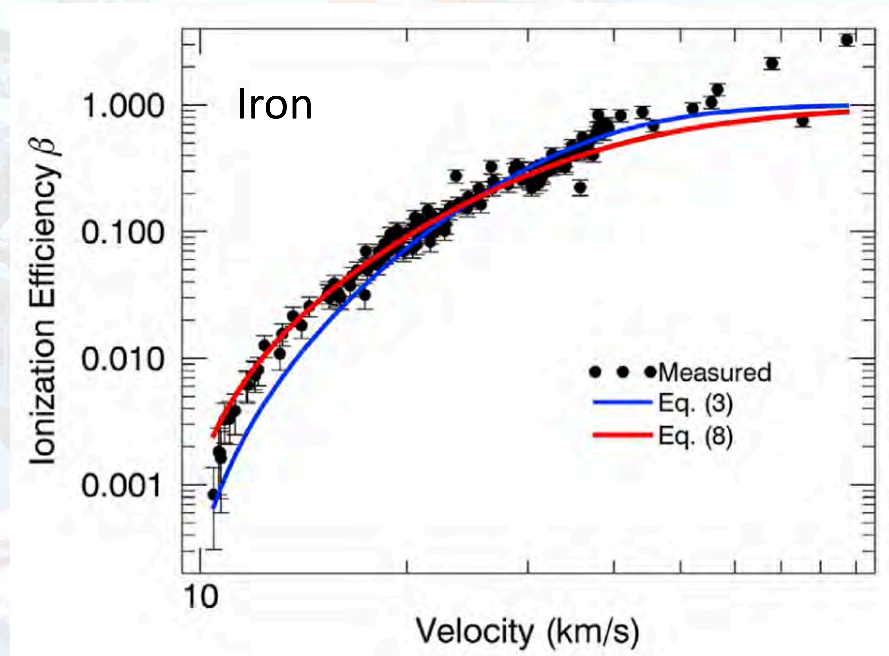
PMT channels in sequence



Measurement confirm that the particle slowdown is small (< 1-2 km/s)

β measurements extended to lower velocities (in air)



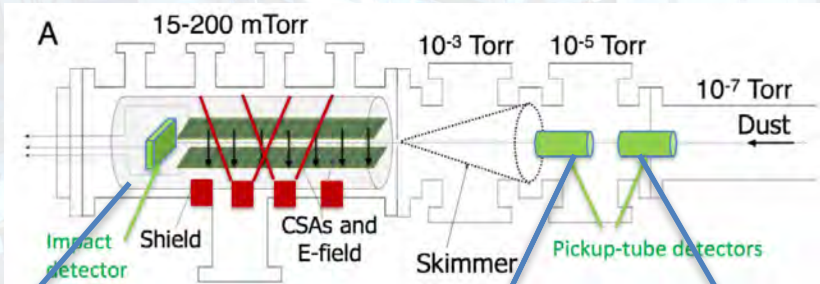


$$\beta(v) = \frac{c(v - v_0)^n v^{0.8}}{1 + c(v - v_0)^n v^{0.8}}$$

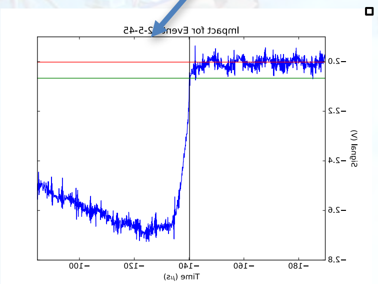
- n = 1.6 is good fit for Al & Fe
- v_0 = 9.1 km/s (Al)
- v_0 = 8.95 ks (Fe)
- c – fitting parameter

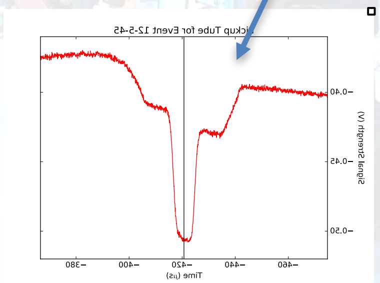
DeLuca et al., PSS (2017)

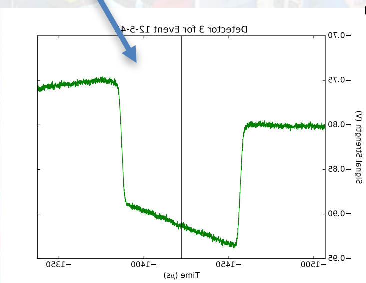
Slowdown experiments – measuring the drag coefficient



$$\frac{dv}{dt} = -\frac{3\Gamma v^2 \rho_{air}}{4R\rho_{meteor}}$$

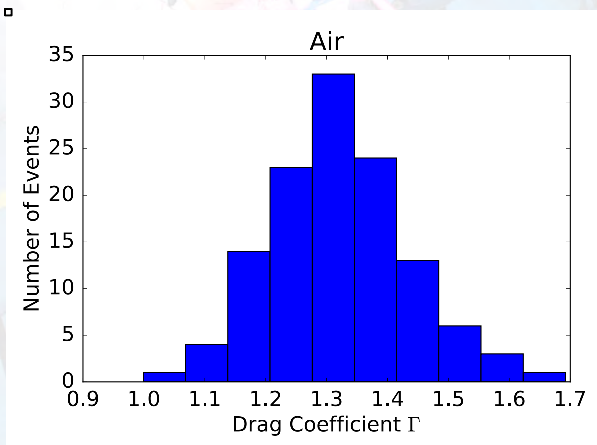






- Γ = 0.5 – 1 assumed
- Aluminum particles
- 1 – 10 km/s

Timing of the events w/wo gas filling yields Γ



Measured data

Air: $\Gamma = 1.32 \pm 0.12$

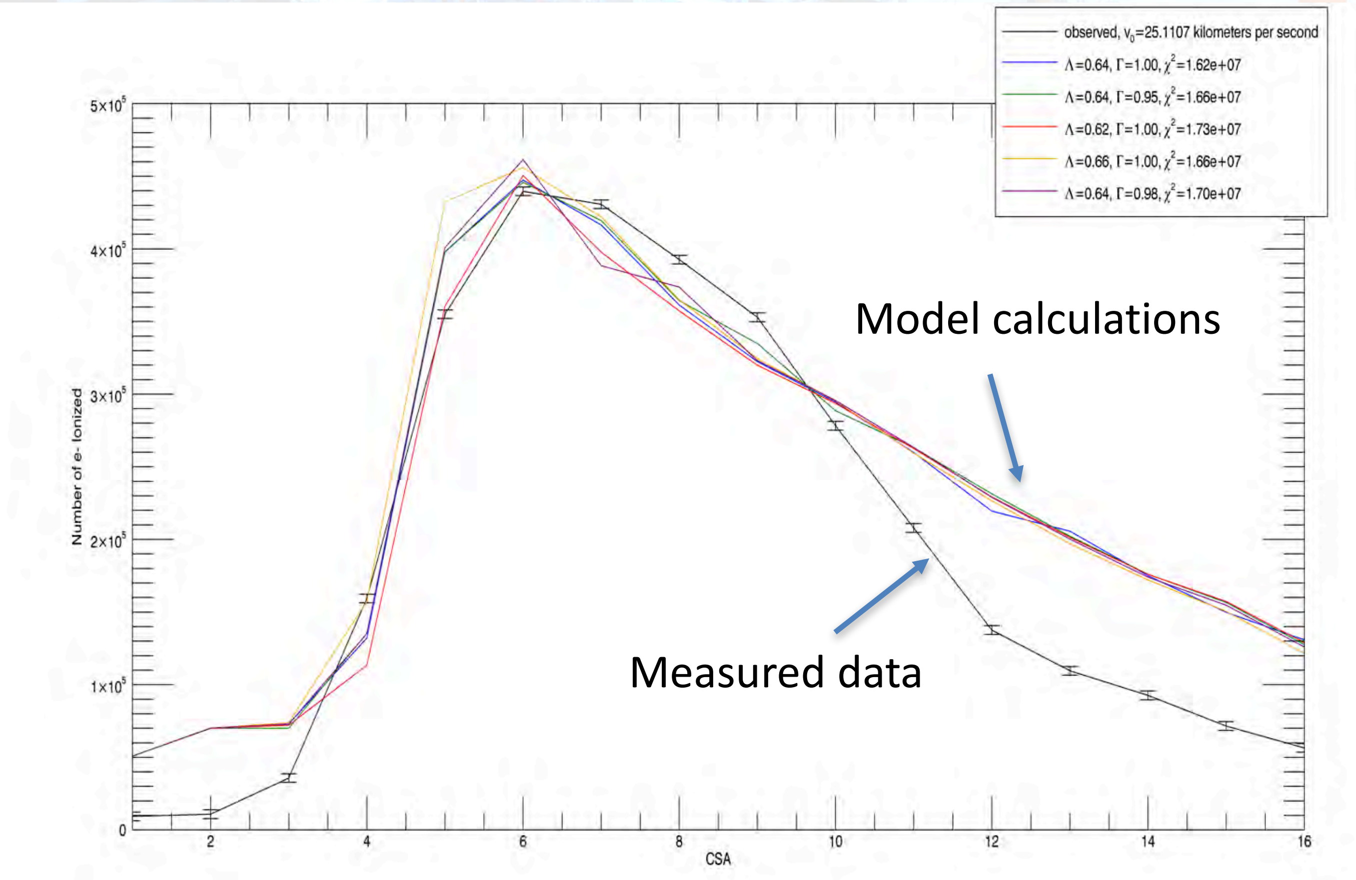
N_2: $\Gamma = 1.34 \pm 0.08$

Ar: $\Gamma = 1.29 \pm 0.10$

CO_2: $\Gamma = 1.28 \pm 0.13$

DeLuca et al., in prep. (2017)

Next challenge: matching the measured ablation profiles with models



- Velocity: 25.1 km/s
- Radius: 58 nm
- Material: Fe
- Gas: N_2
- Pressure: 49 mTorr

Summary/Conclusions

- Dust accelerator facility - enabled the experimental investigation of the ablation process
- Ionization efficiency can be directly measured
- Low ionization efficiency is not the reason for radar insensitivity
- Drag coefficient measurements in progress
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