

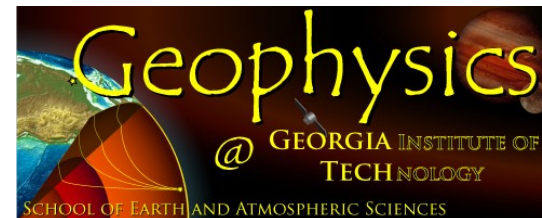


The triboelectric charging of volcanic ash

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Josef Dufek¹

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Tonaltepetl (B. Hernández)

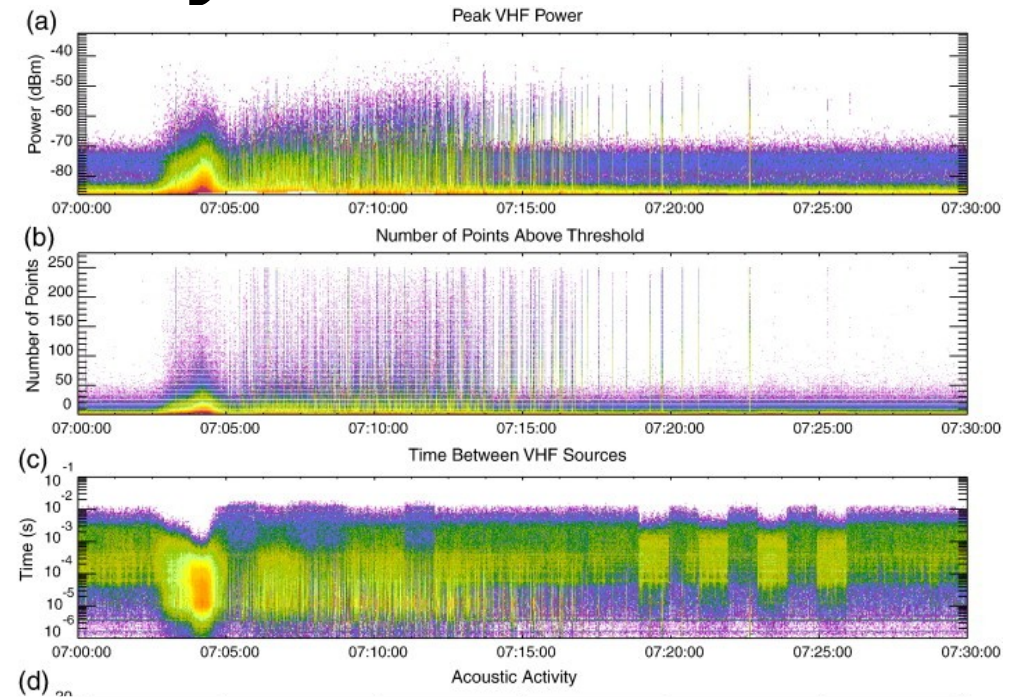


Sakurajima (A. Williams)



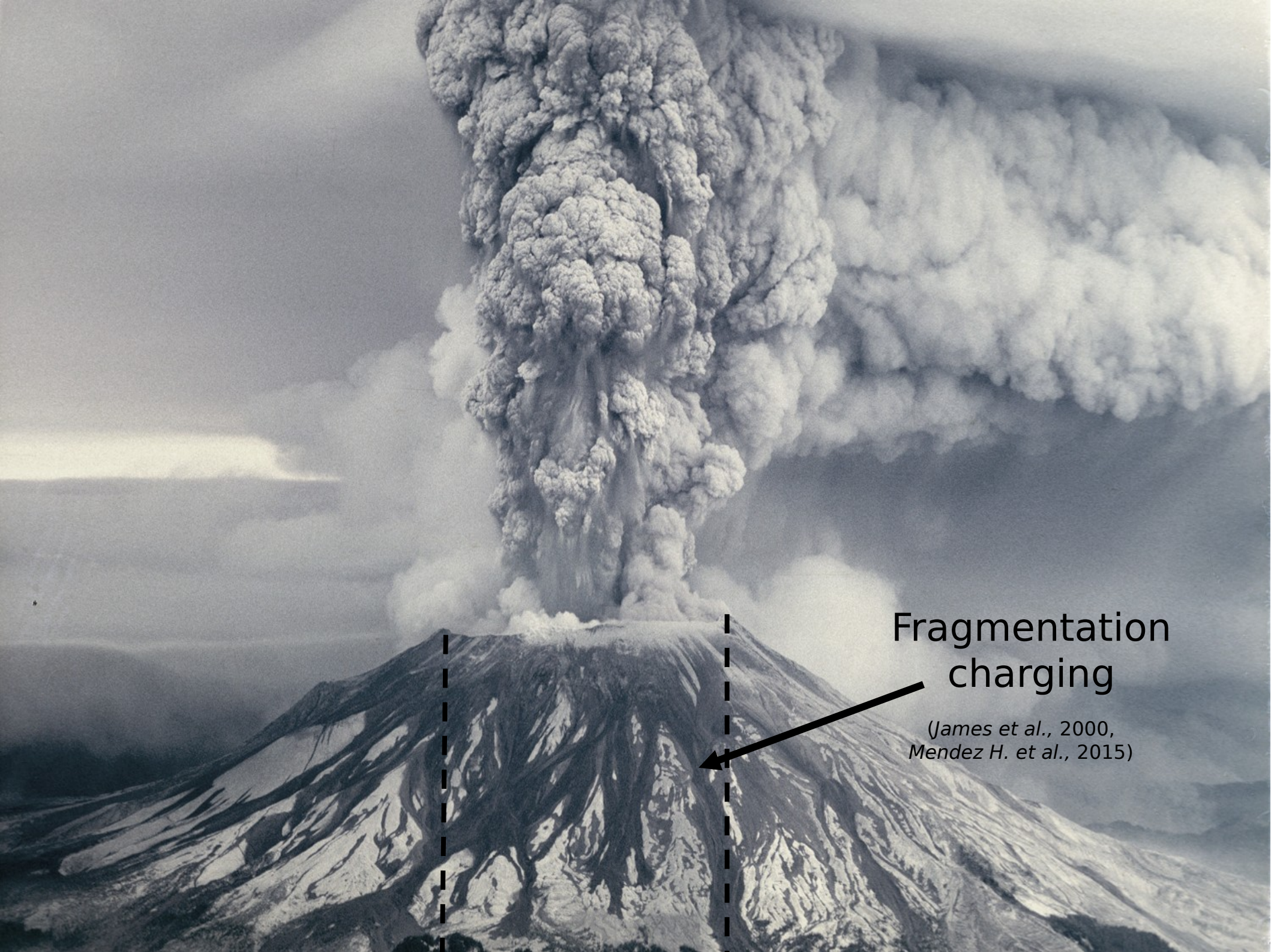
Eyjafjallajökull (Nat. Geo.)

What can charging in plumes tell us about eruption dynamics?





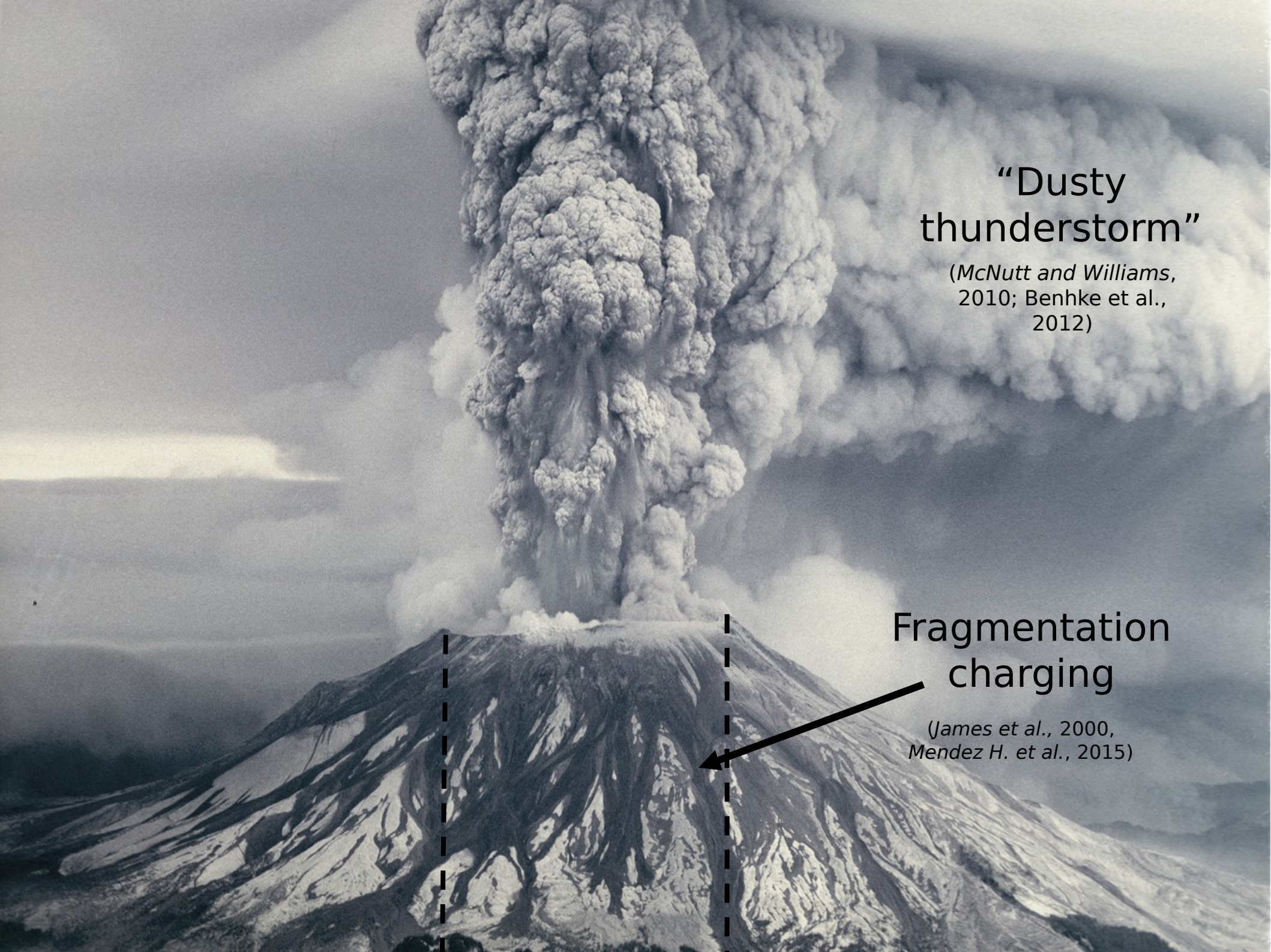
1980 eruption of Mt Saint Helens (USGS)



Fragmentation
charging

*(James et al., 2000,
Mendez H. et al., 2015)*





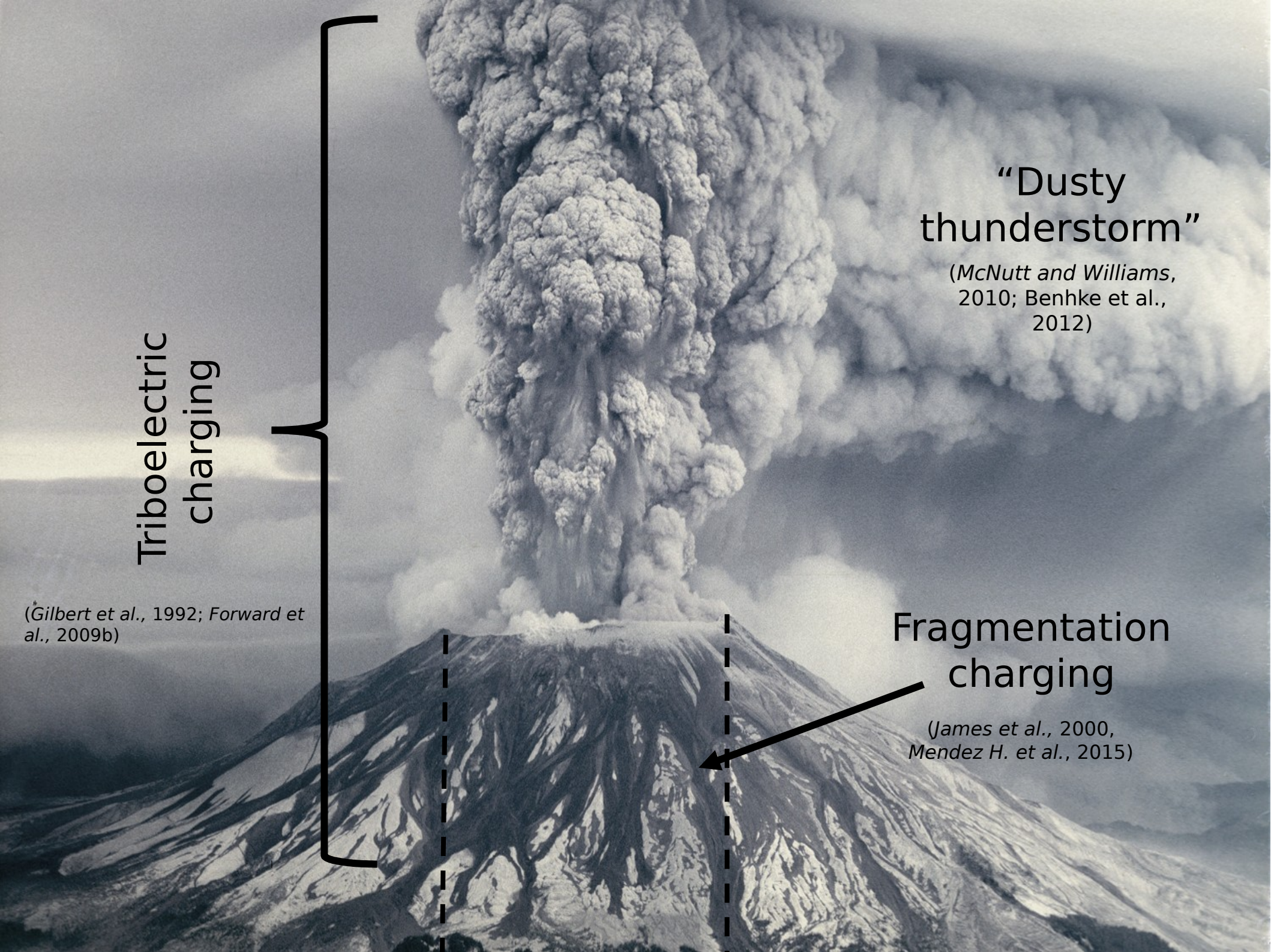
“Dusty thunderstorm”

(McNutt and Williams,
2010; Benhke et al.,
2012)

Fragmentation
charging

(James et al., 2000,
Mendez H. et al., 2015)





Triboelectric
charging



“Dusty
thunderstorm”

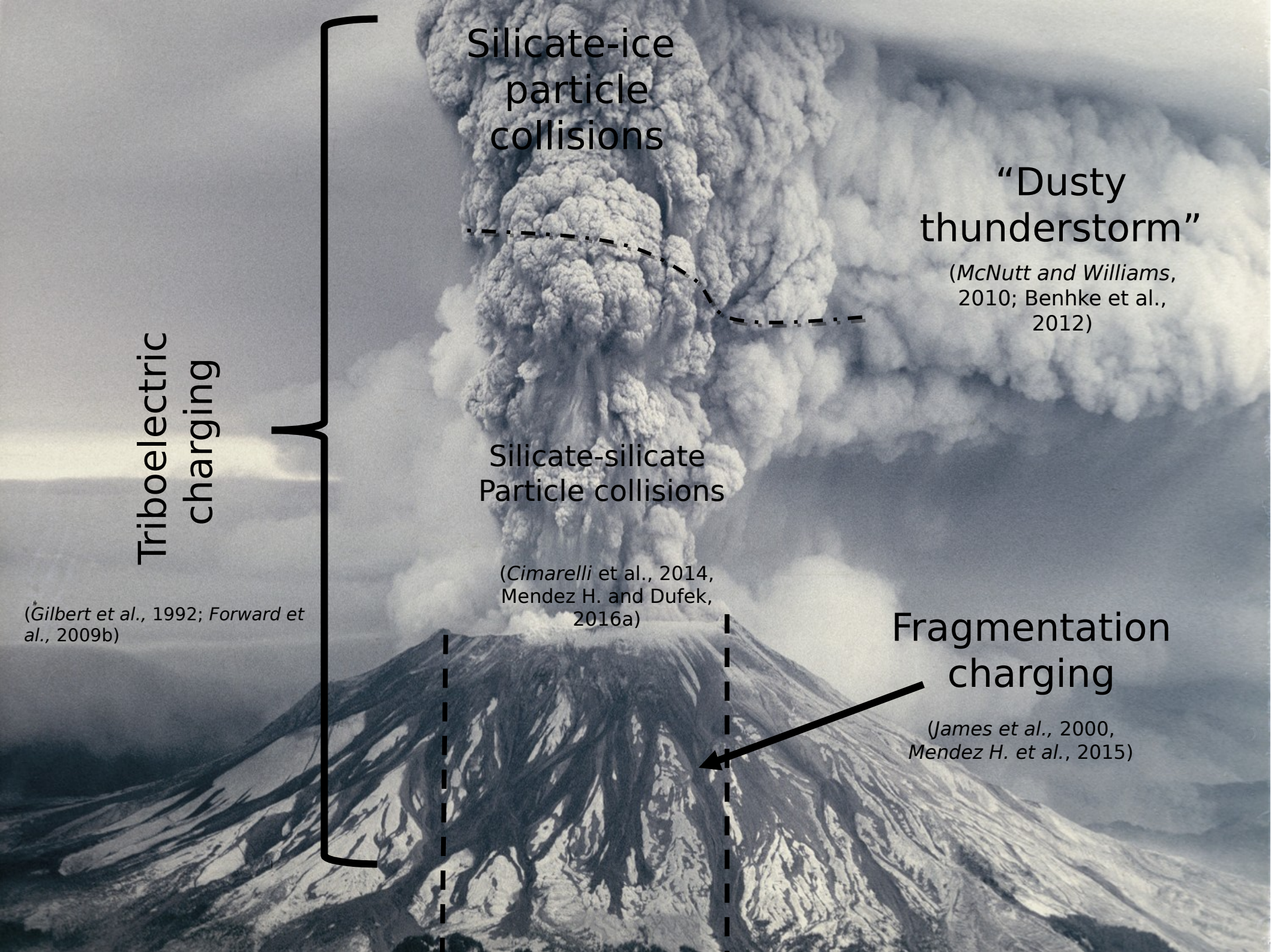
(McNutt and Williams,
2010; Benhke et al.,
2012)

(Gilbert et al., 1992; Forward et
al., 2009b)

Fragmentation
charging

(James et al., 2000,
Mendez H. et al., 2015)





Triboelectric charging

Silicate-ice particle collisions

“Dusty thunderstorm”

(McNutt and Williams, 2010; Benhke et al., 2012)

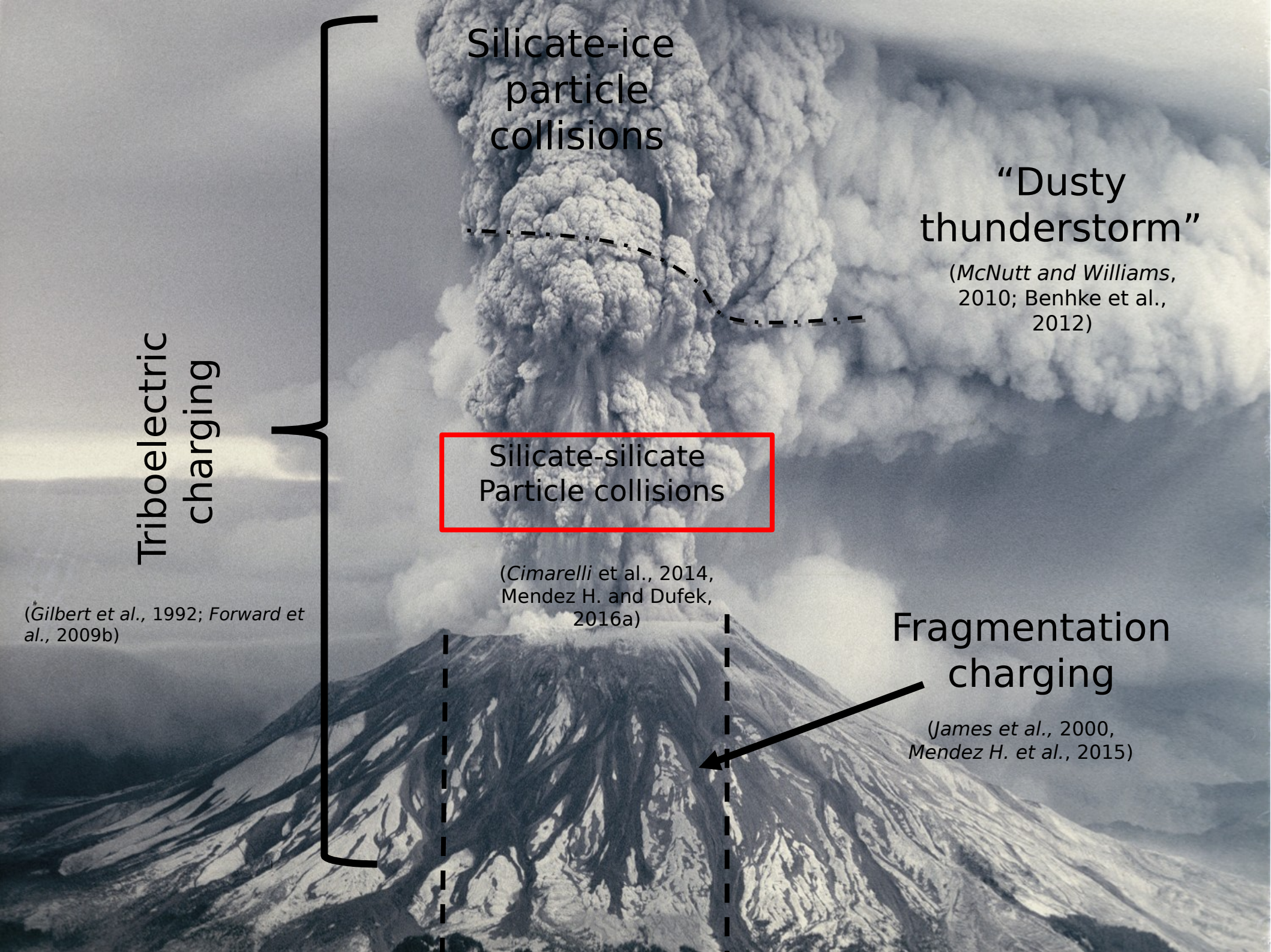
Silicate-silicate Particle collisions

(Cimarelli et al., 2014, Mendez H. and Dufek, 2016a)

Fragmentation charging

(James et al., 2000, Mendez H. et al., 2015)

(Gilbert et al., 1992; Forward et al., 2009b)



Triboelectric charging

Silicate-ice particle collisions

“Dusty thunderstorm”

(McNutt and Williams, 2010; Benhke et al., 2012)

Silicate-silicate Particle collisions

(Cimarelli et al., 2014, Mendez H. and Dufek, 2016a)

Fragmentation charging

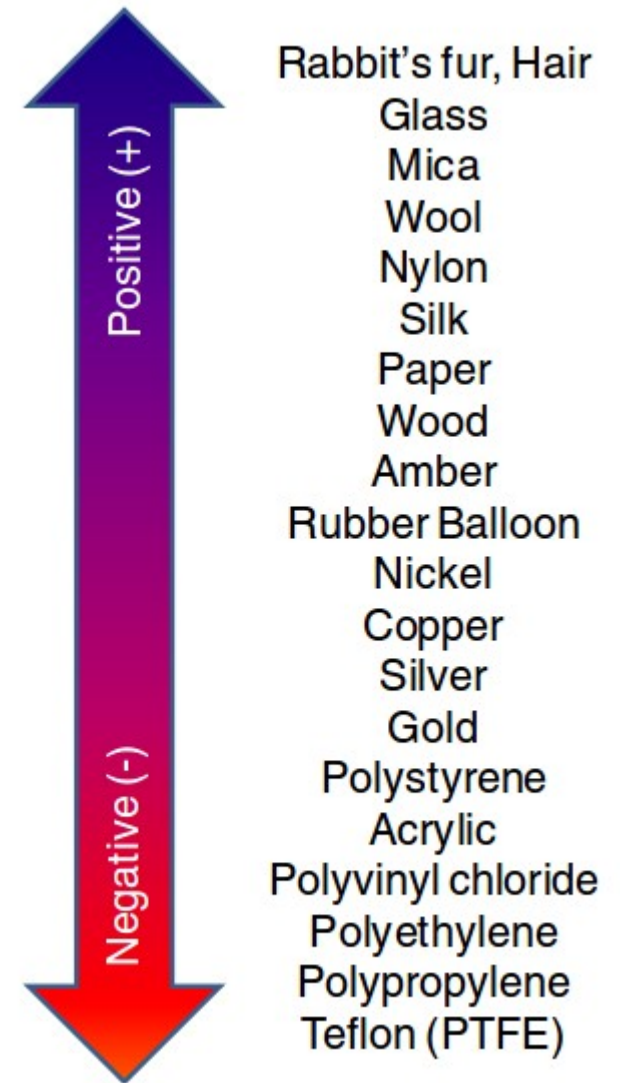
(James et al., 2000, Mendez H. et al., 2015)

(Gilbert et al., 1992; Forward et al., 2009b)

Triboelectric charging



Triboelectric charging

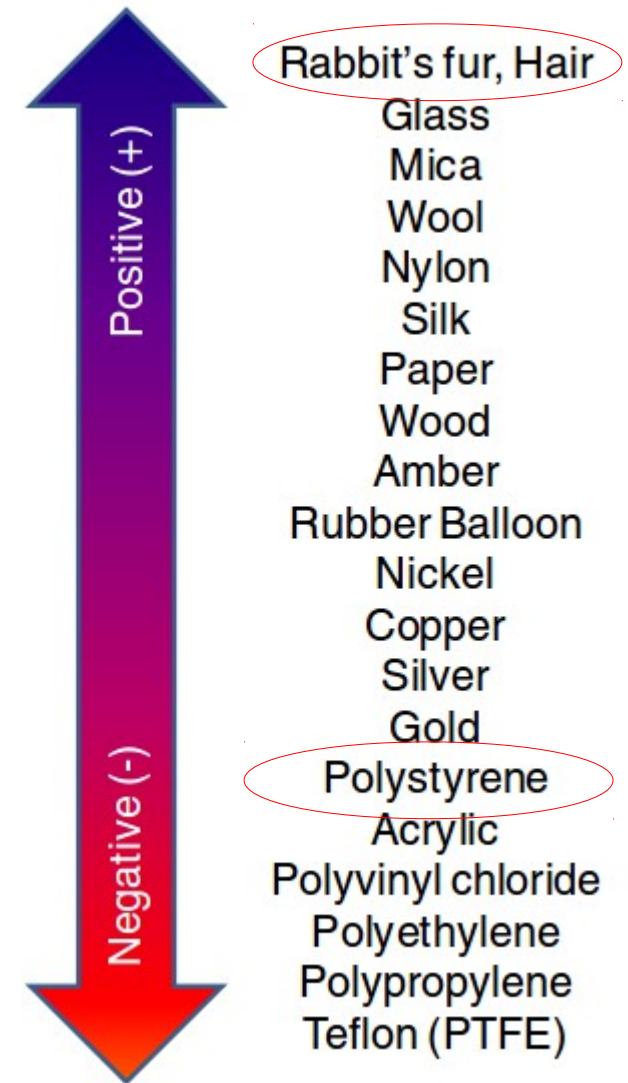


Lacks and Sankaran. [2011]

Triboelectric charging

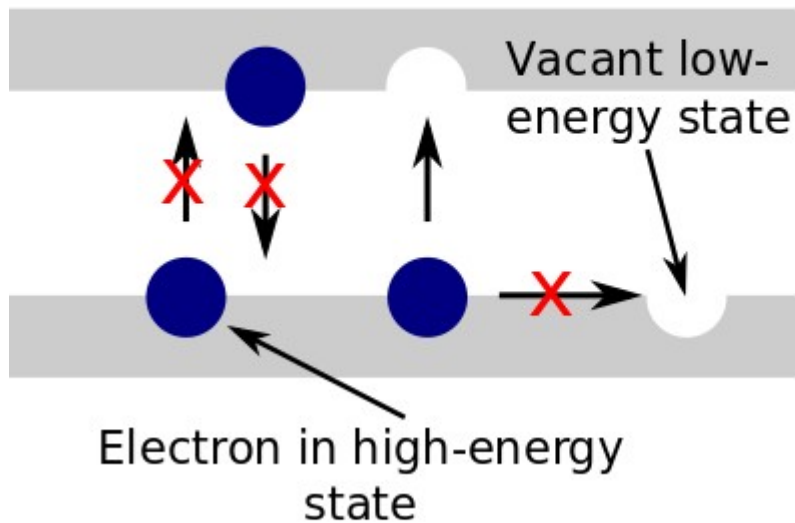
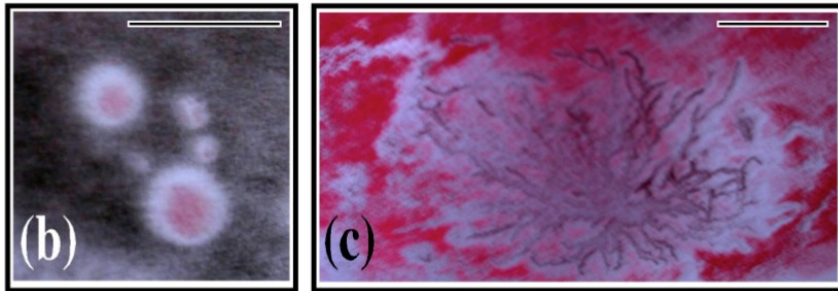
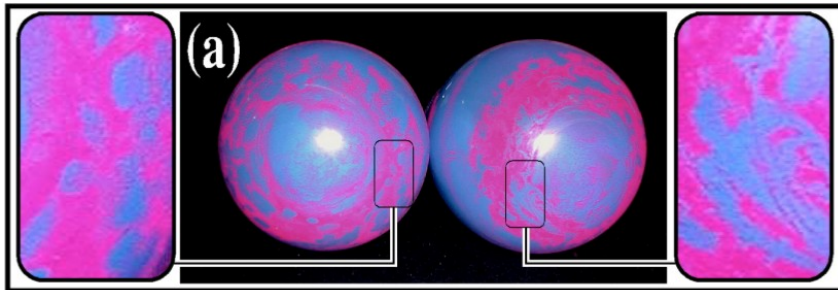


Positive cat,
negative peanuts

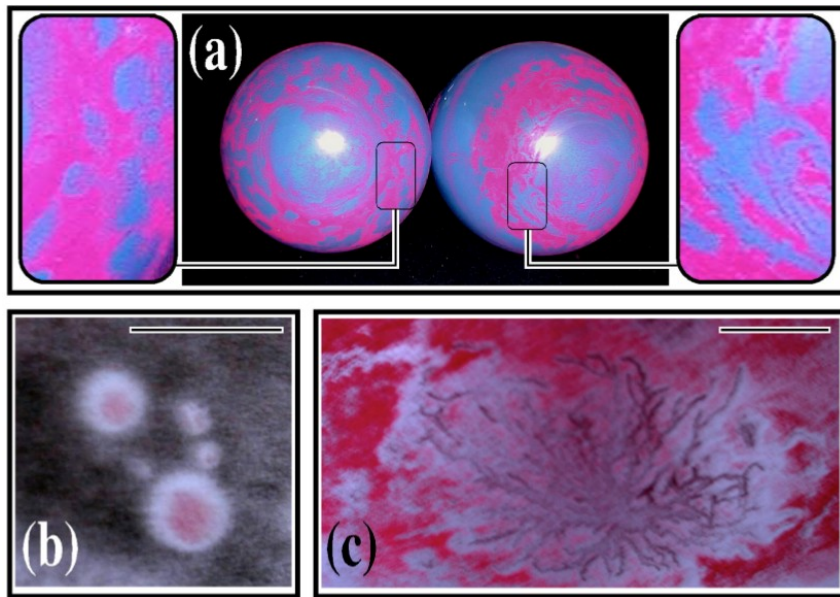


Lacks and Sankaran. [2011]

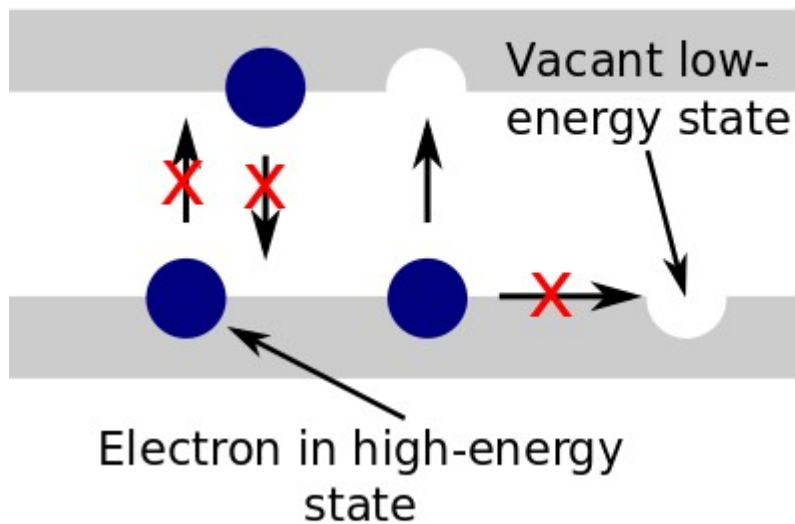
Triboelectric charging of chemically *similar* dielectrics



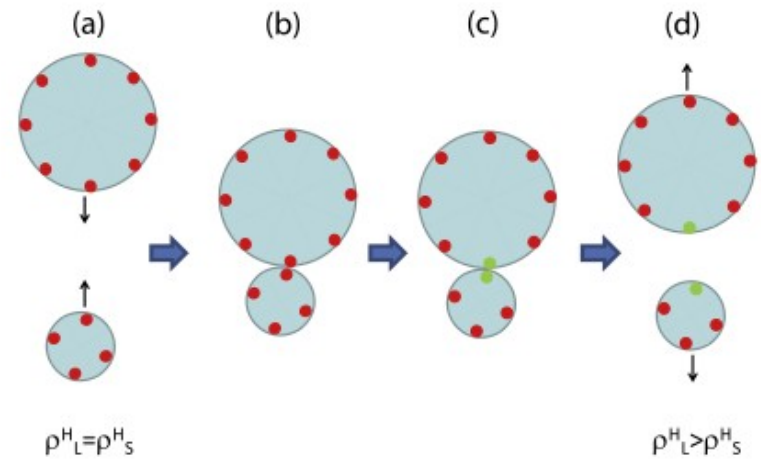
Triboelectric charging of chemically *similar* dielectrics



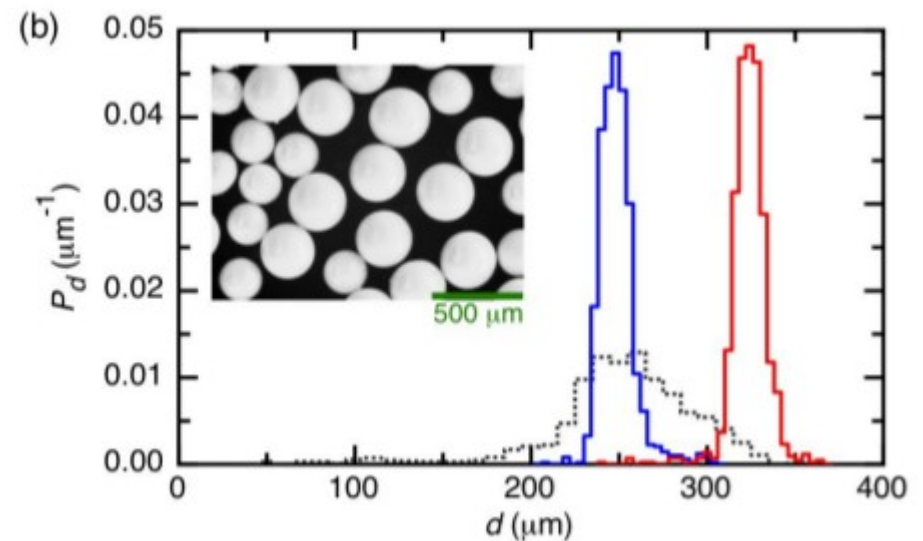
Shinbrot et al. [2013]



First collision

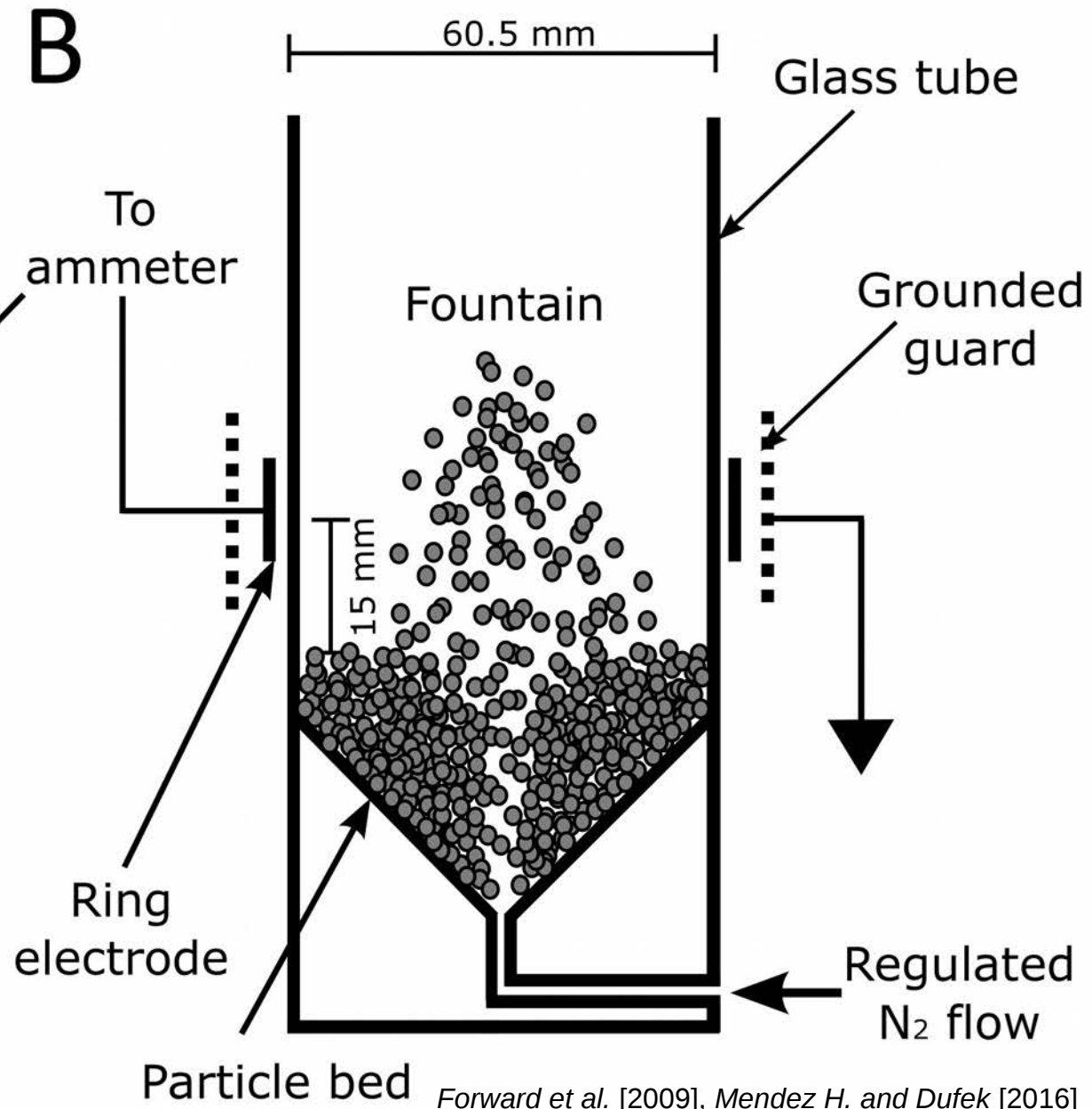
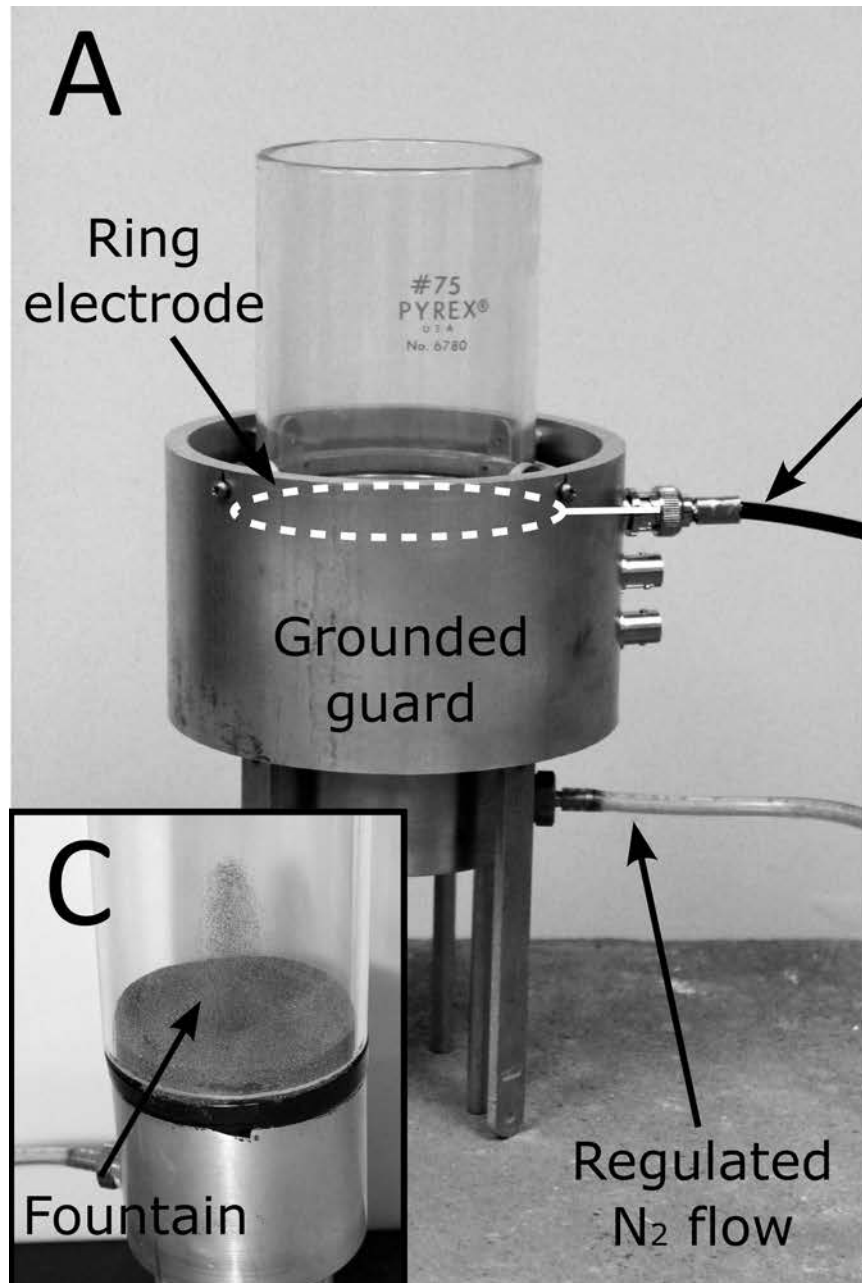


Forward et al. [2009]



Waitukaitis et al. [2014]

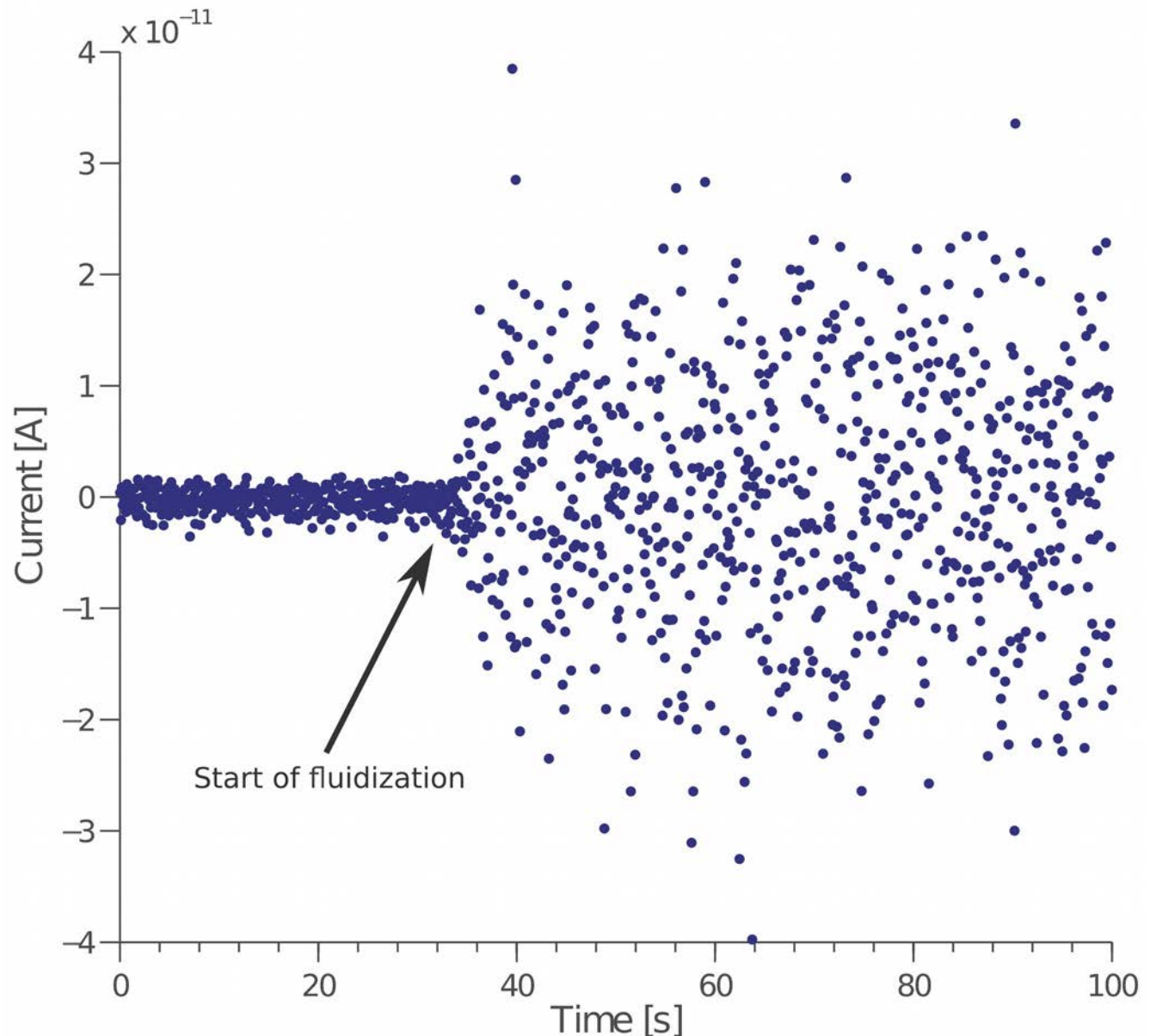
Measuring charging in a chemically-homogeneous granular system



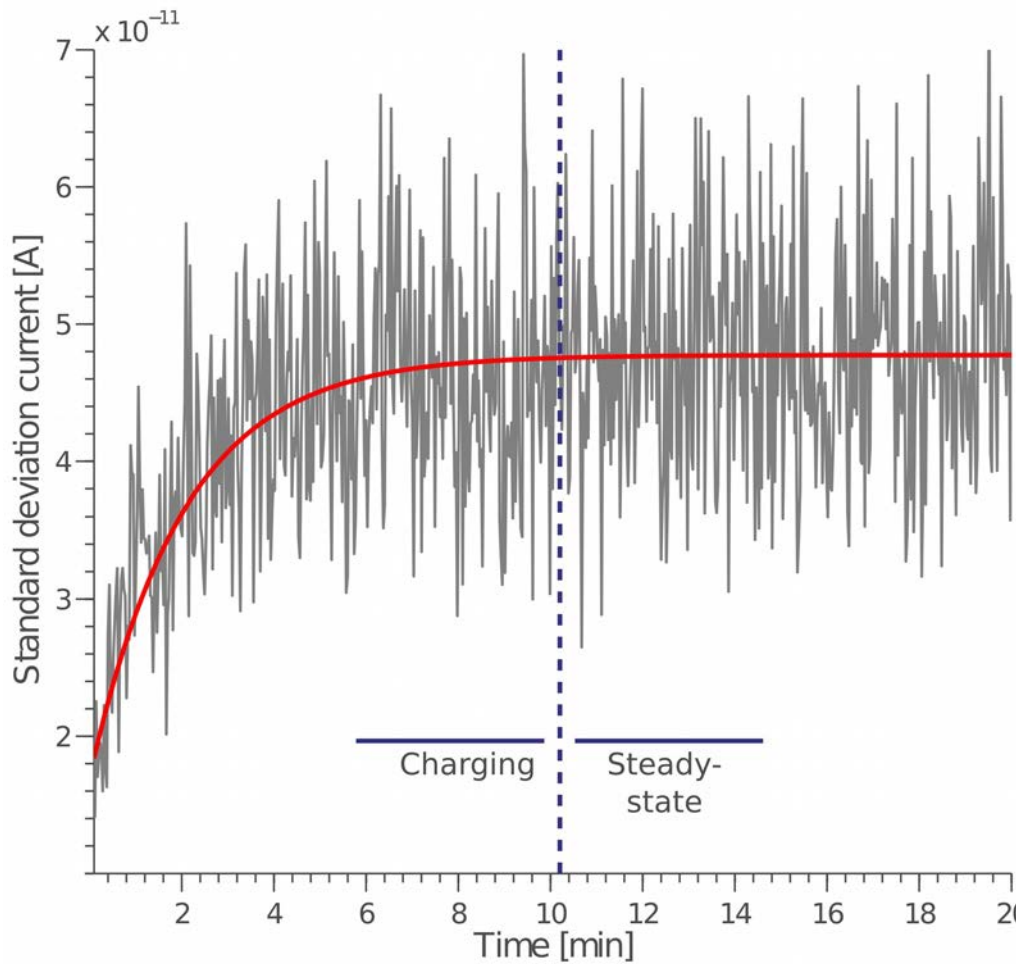
Raw picoammeter data

Charged particles produce currents in the ring electrode as they move up and down in the fountain.

The average current remains at zero, but the standard deviation increases as the particle bed becomes electrified.

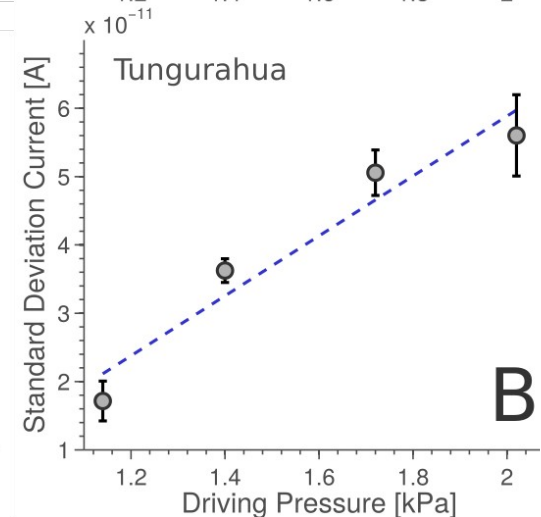
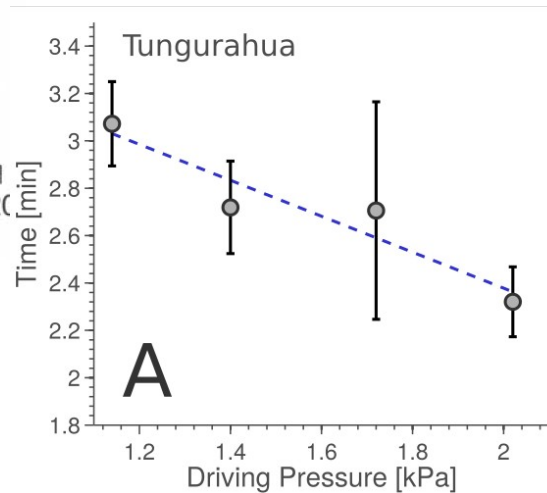
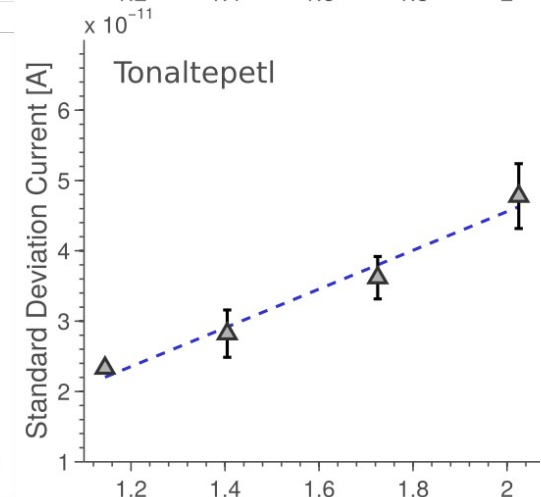
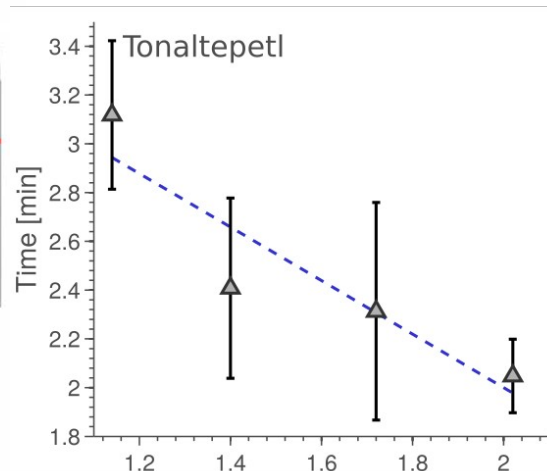
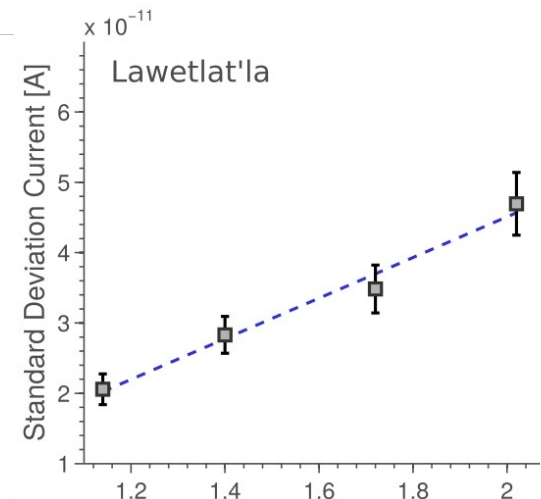
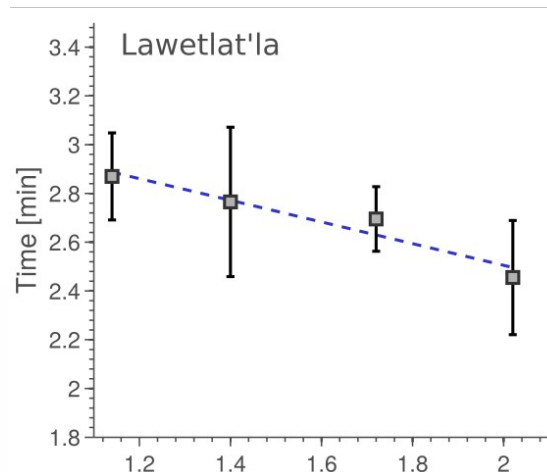


Charging curve



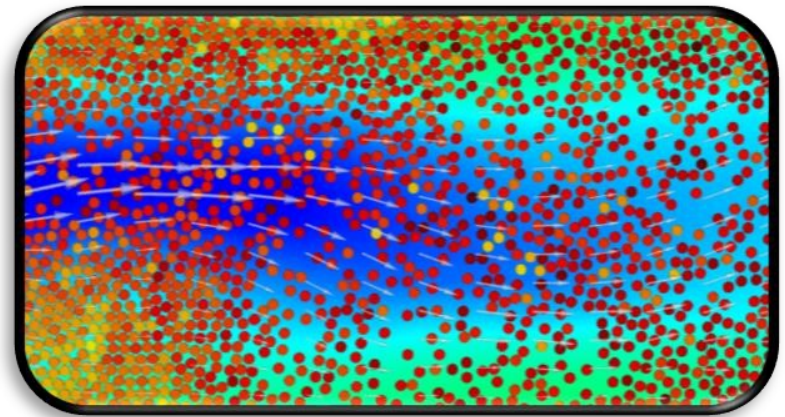
$$I(t) = I_{ss} \left(1 - e^{-\frac{t}{\tau}} \right)$$

Mendez H. and Dufek [2016]



Multiphase Flow with Interphase eXchange

- Model built on open-source **Multiphase Flow with Interphase eXchange** (MFIX) code developed by the National Energy and Technology Lab (NETL)
- MFIX provides robust **two-fluid** (Eularian-eularian) and coupled **DEM-CFD** (Eluarian-lagrangian) modalities
- Written in FORTRAN



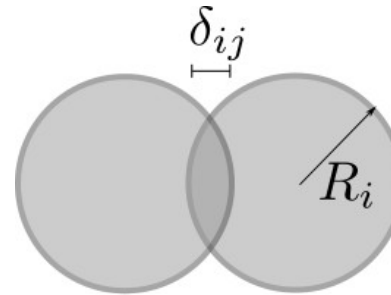
Model Overview: DEM

- Base MFIX-DEM solves momentum, energy, chemical reactions, and species equations
- Easily coupled to gas phases
- Uses soft-sphere approach
- **No support for electrostatics**
- We have updated the base model to integrate:
 - Trapped electron model to simulate charging [*Lowell and Truscott, 1986*]
 - Electrostatic forces based on the model of *Bichoutskaia et al.* [2010]

Charging Model

Particles start out with an initial charge density of trapped species

During each contact an effective contact area is computed based on particle overlap



$$A_{ij} = \pi \frac{R_i R_j}{R_i + R_j} \delta_{ij}$$

The number of potential electrons to be transferred is product of contact area and density of trapped electrons times a scaling constant

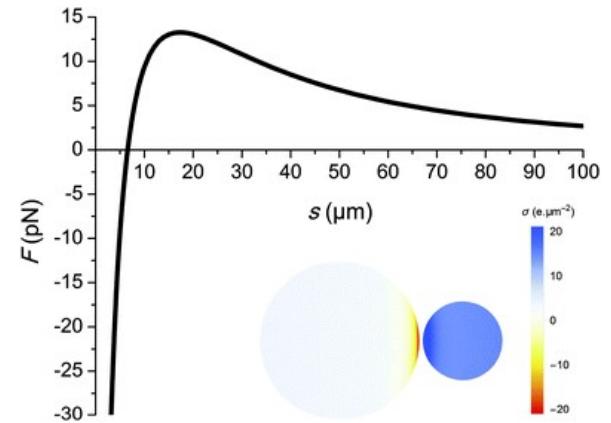
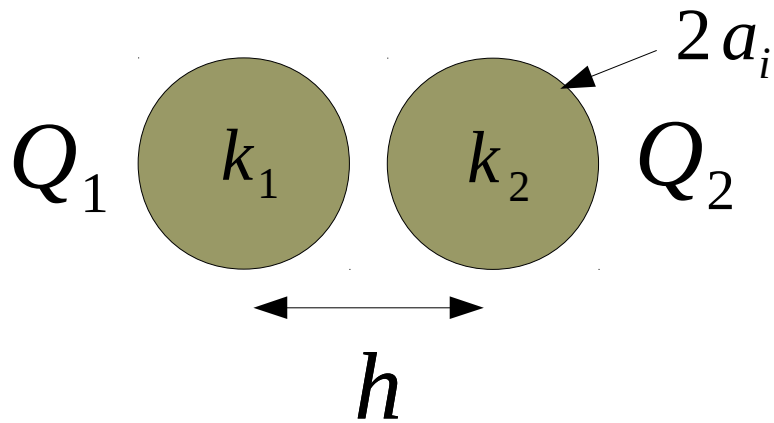
$$\left\{ \begin{array}{l} n_i^H = \begin{cases} 0, & \text{if } \sigma(n_i^H, n_i^L) > 0 \wedge |\sigma(n_i^H, n_i^L)| < \sigma_o \\ C A_{ij} \sigma_i^H, & \text{otherwise} \end{cases} \\ n_i^L = \begin{cases} 0, & \text{if } \sigma(n_i^H, n_i^L) < 0 \wedge |\sigma(n_i^H, n_i^L)| < \sigma_o \\ C A_{ij} \sigma_j^H, & \text{otherwise} \end{cases} \end{array} \right.$$

Transfer of species is proportional to collision energy and contact time

Trapped electron densities are updated

$$Q_i = [(n_i^{H_o} - n_i^H) - n_i^L] q_e$$

Electrostatics Force Model between Two Charged Dielectric Spheres



$$F_E = k_C \frac{Q_1 Q_2}{h^2} - Q_1 \sum_{m=1}^{\infty} \sum_{l=0}^{\infty} \frac{(k_2 - 1)m(m+1)}{(k_2 + 1)m + 1} \frac{(l+m)!}{l!m!} \frac{a_2^{2m+1}}{h^{2m+l+3}} A_{1,l} - \frac{1}{k_C} \sum_{l=1}^{\infty} \frac{(k_1 + 1)(l+1) + 1}{(k_1 - 1)} \frac{A_{1,l} A_{1,l+1}}{a_1^{2l+3}}$$

Coulomb force

Forces due to polarization

$$A_{1,j_1} = a_1 k_C Q_1 - \frac{(k_1 - 1)j_1}{(k_1 + 1)j_1 + 1} \frac{a_1^{2j_1+1}}{h^{j_1+1}} k_C Q_2 + \frac{(k_1 - 1)j_1}{(k_1 + 1)j_1 + 1} \sum_{j_2=0}^{\infty} \sum_{j_3=0}^{\infty} \frac{(k_2 - 1)j_2}{(k_2 + 1)j_2 + 1} \frac{(j_1 + j_2)!}{j_1!j_2!} \frac{(j_2 + j_3)!}{j_2!j_3!} \times \frac{a_1^{2j_1+1} a_2^{2j_2+1}}{h^{j_1+2j_2+j_3+2}} A_{1,j_3}$$

Medium-scale DEM simulation

100,000 particles, 2D

Large: 100 microns

Small: 200 microns

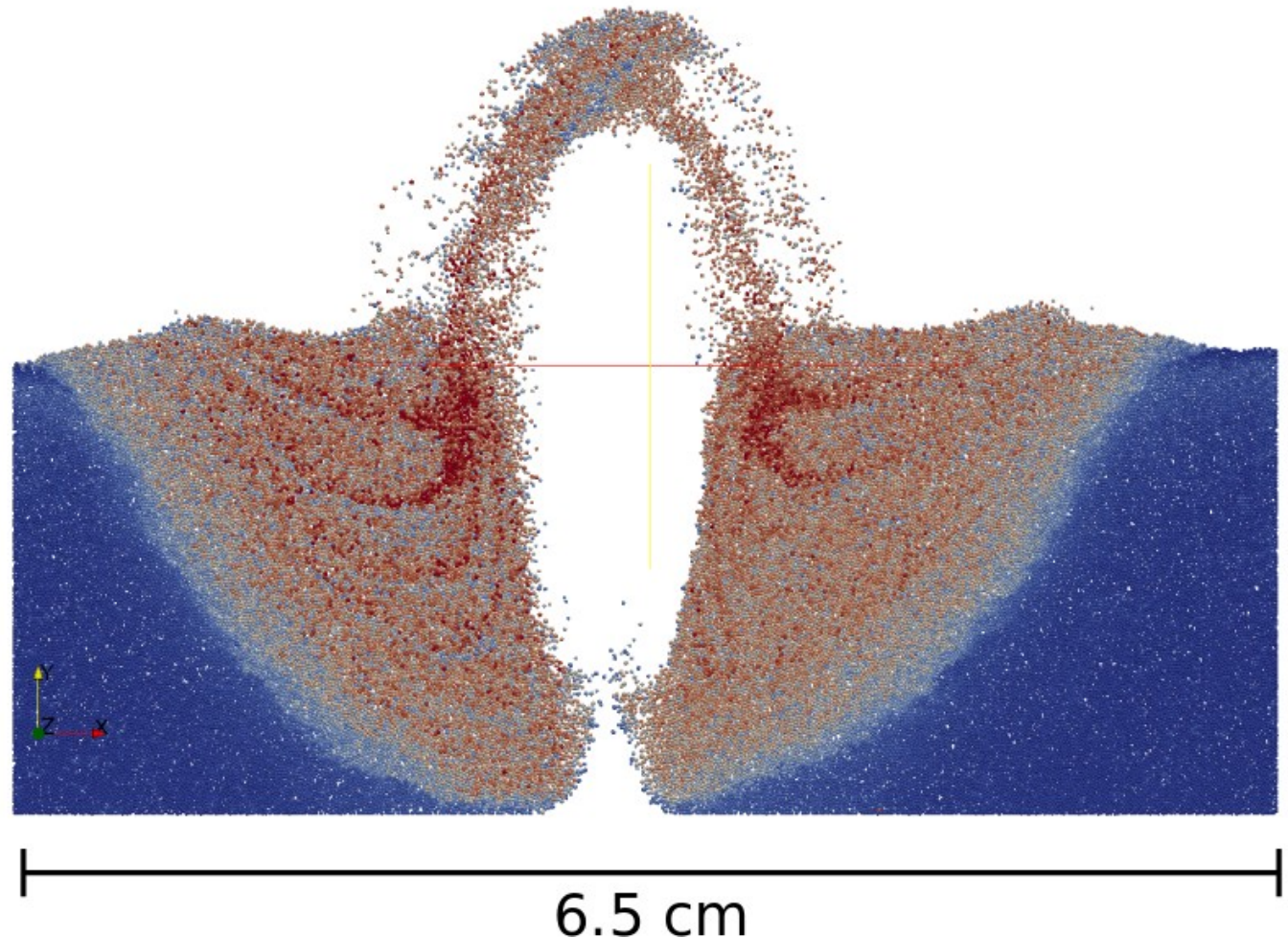
%50 by volume

Fluid grid 0.5 cm resolution
with refined resolution near
the inlet

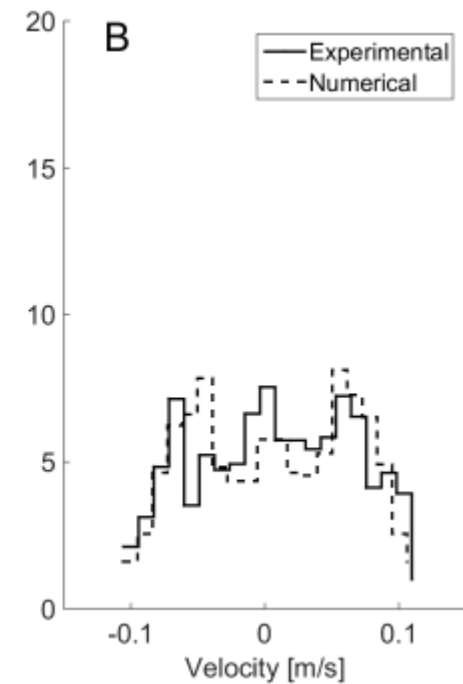
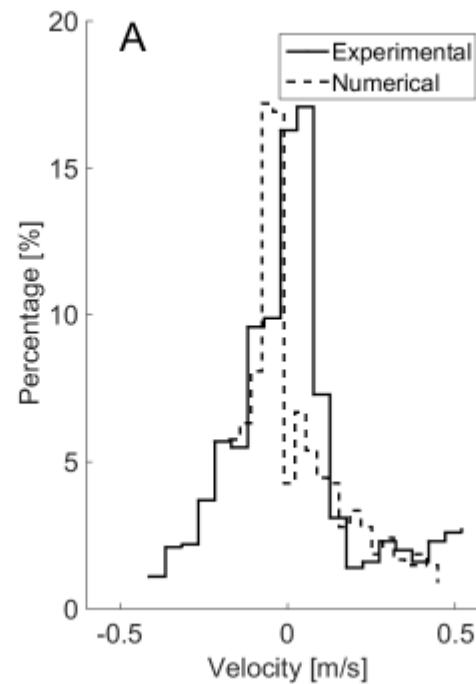
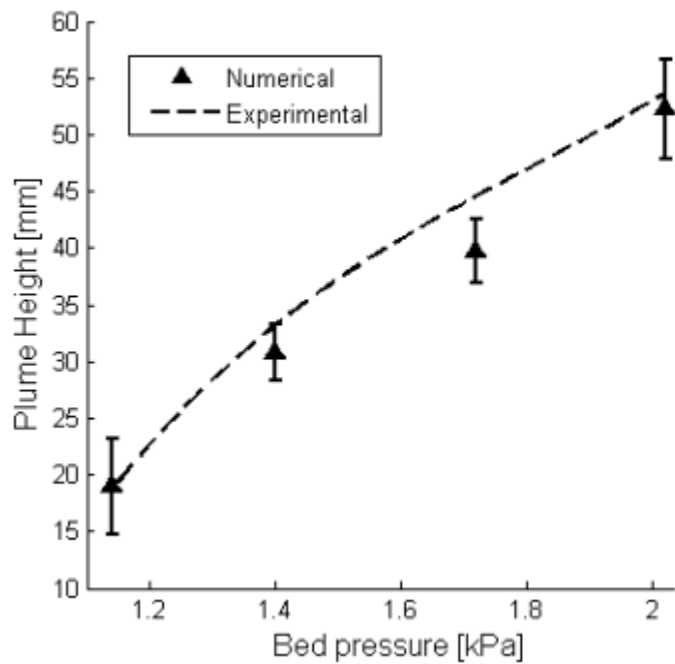
Particle spring constant
set to 1000

Simulations run on 64-128
cores

Runtime ~2.5-3 weeks
Simulation time ~ 10 min



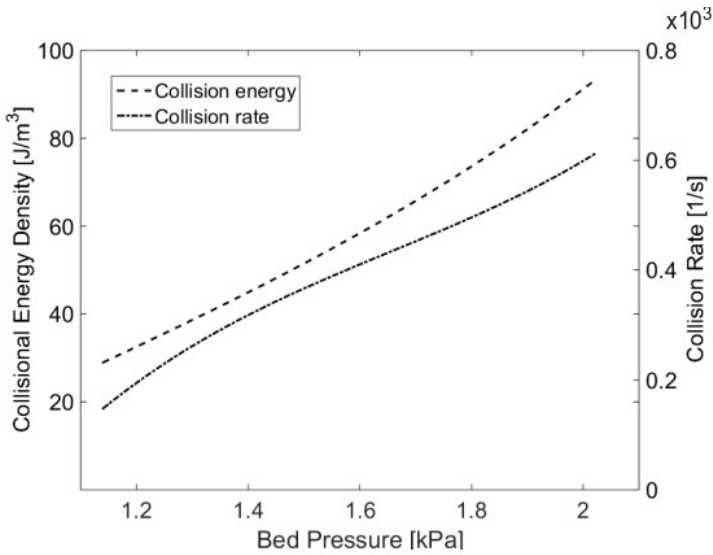
Model validation with experiments



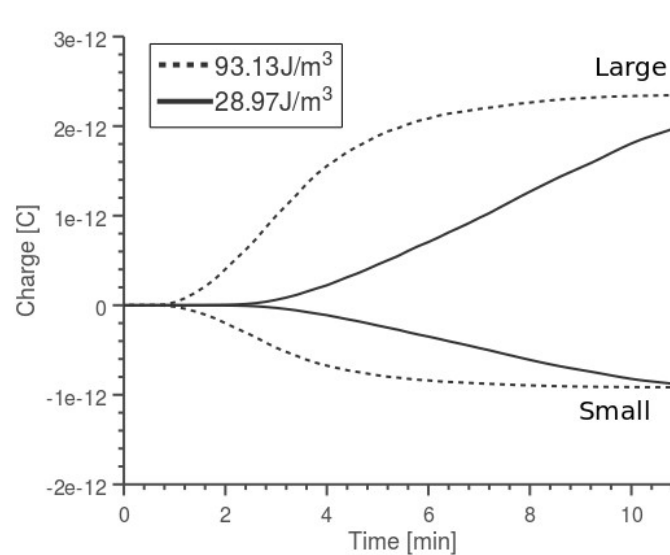
Comparison between experimental and numerical fountains

Comparison between horizontal and vertical velocity distributions between experimental and numerical fountains (lowest energy case)

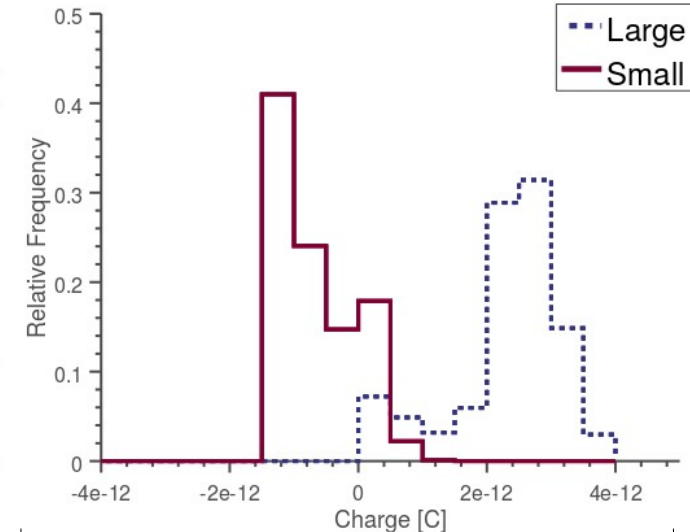
Building constitutive charging relationships



Relating experiment-specific parameters to particle dynamics in the fountain



Evolution of charge on largest and smallest particles in the fountains (lowest -- and highest – energy cases)

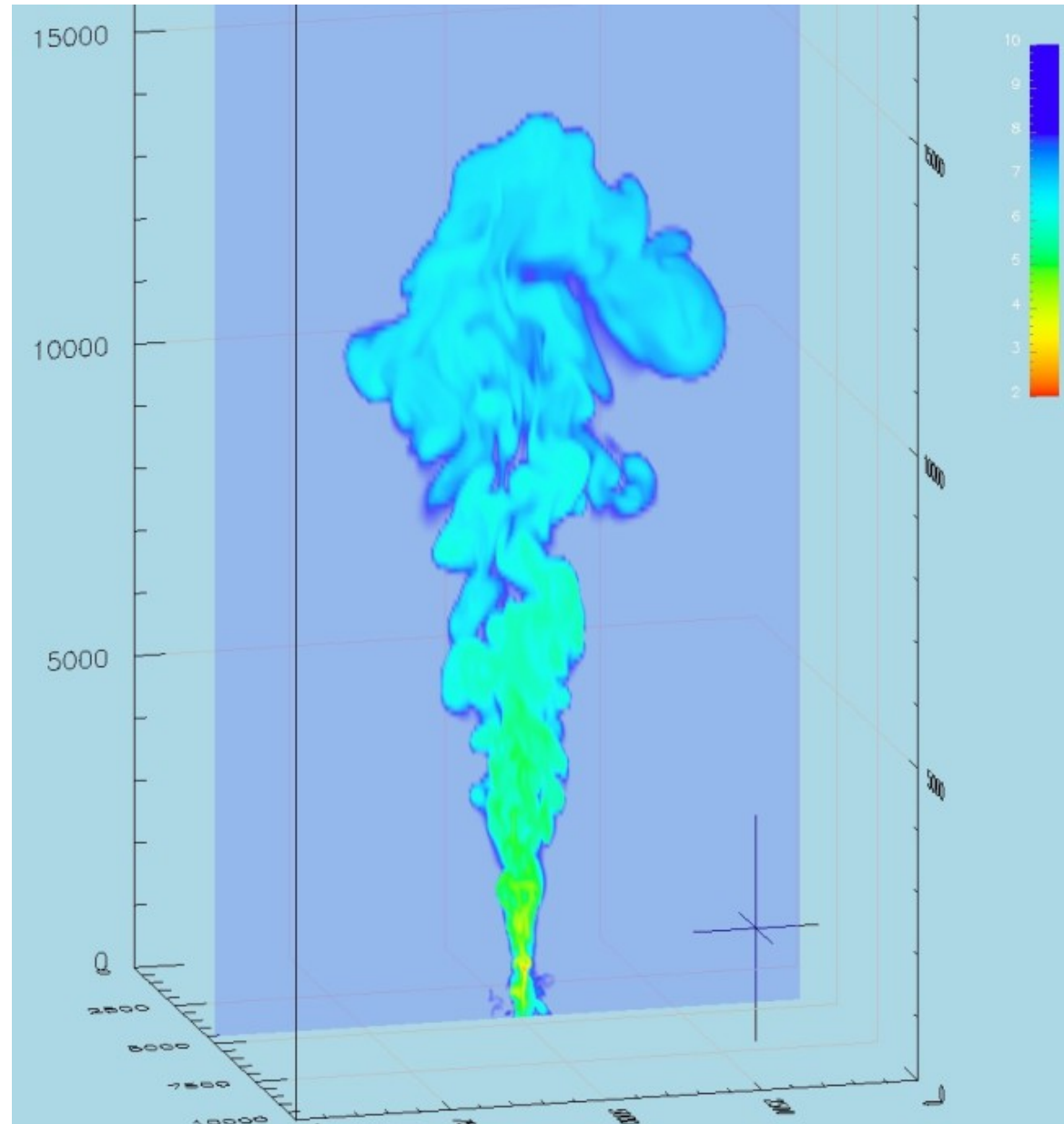
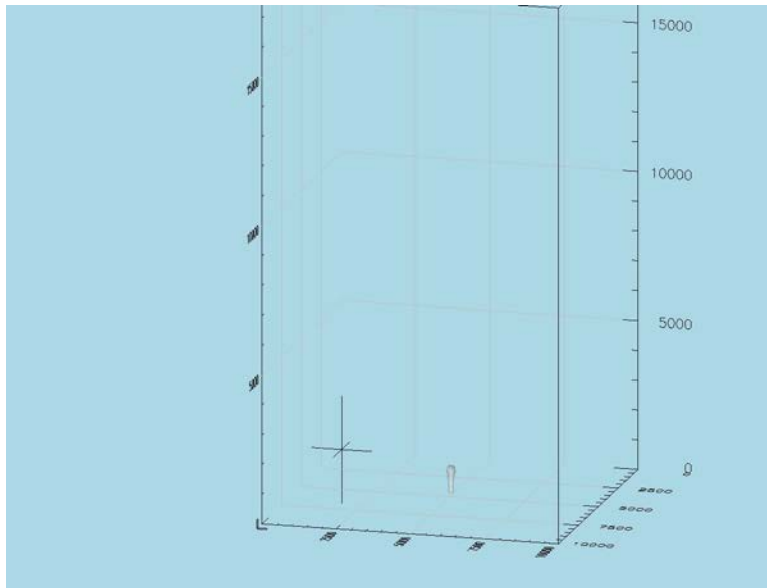


Size-dependent charge segregation (highest energy case)

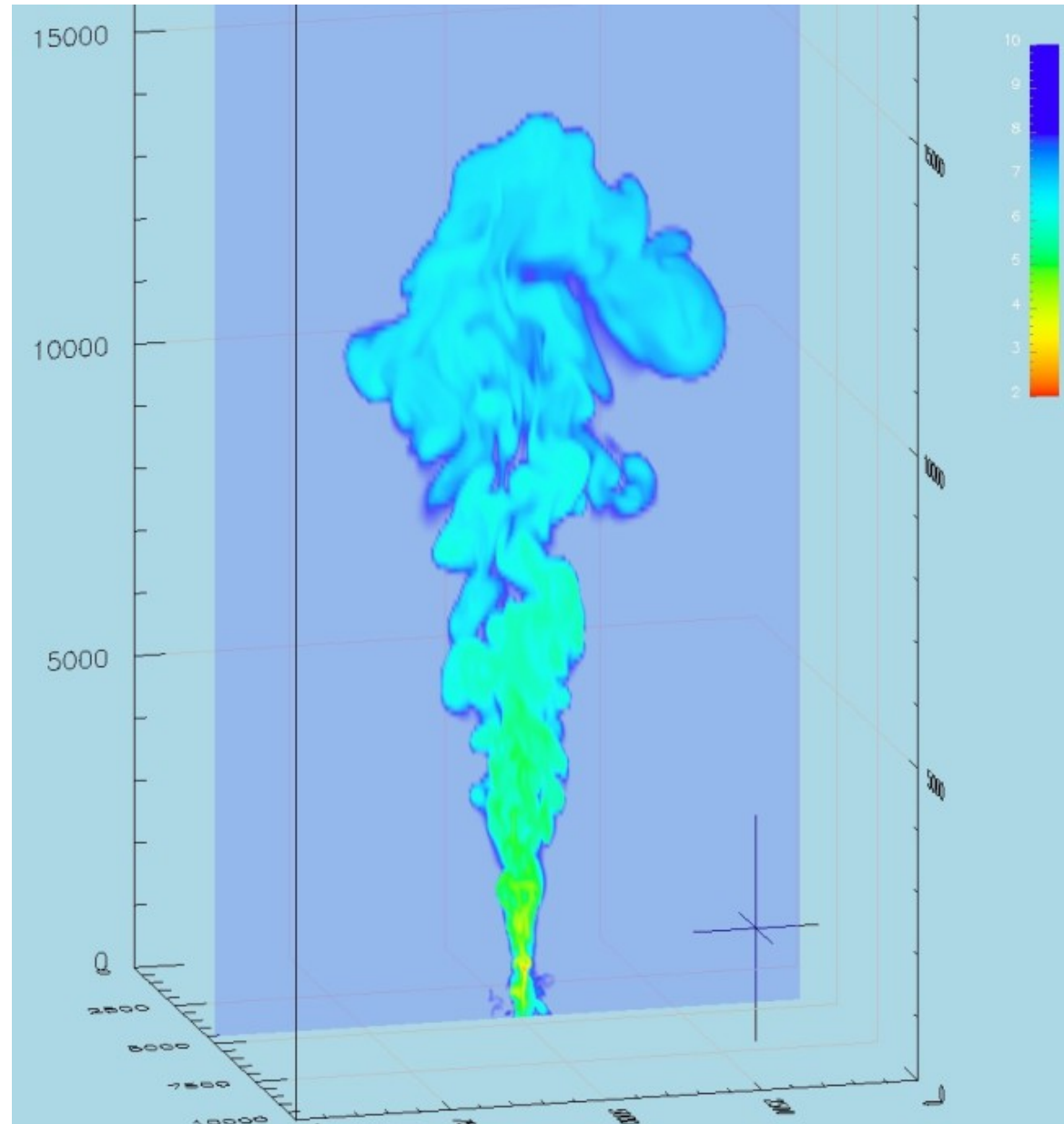
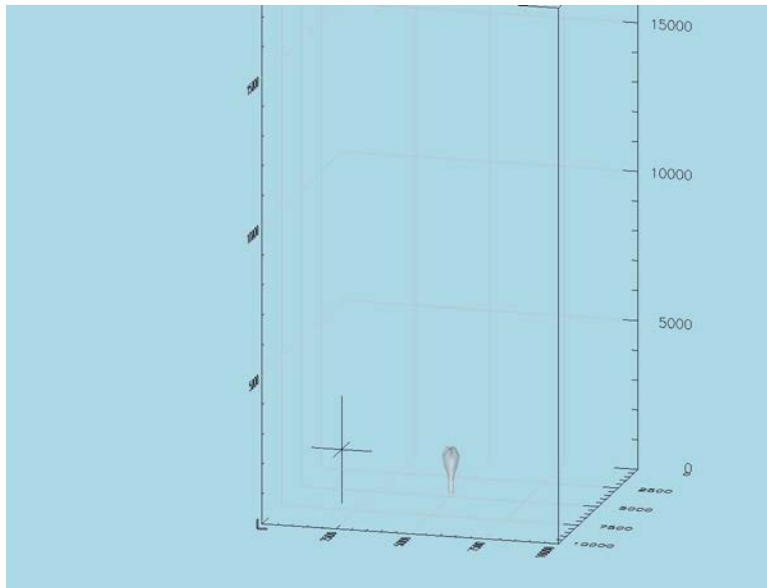
Moving to plume-scale simulations

- Combination of experiments and DEM model allows us to establish constitutive relationships that can be used in multiphase plume model
- Moving from a scale of several cm^3 to several 100 km^3
- Cannot treat solids as discrete particles → We treat particle phases as inter-penetrating fluids each described by separate conservation equations
- Particle properties (size, velocity, charge) are averaged over each grid cell

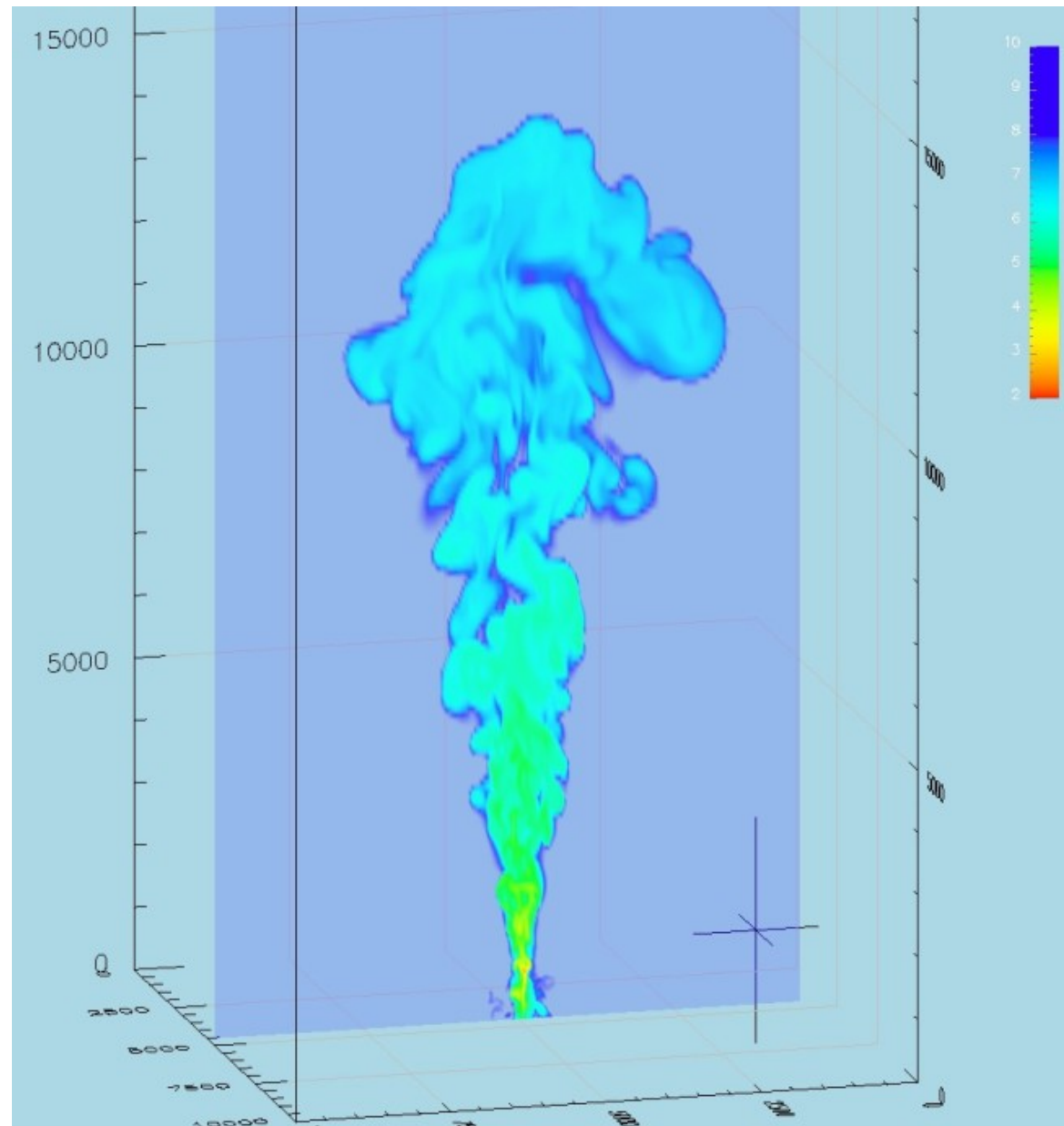
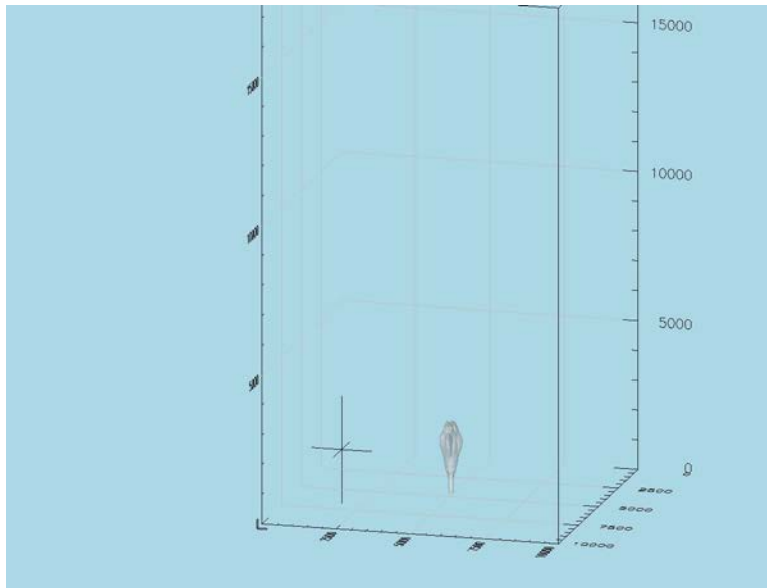
Integrating charging rates into large-scale plume models



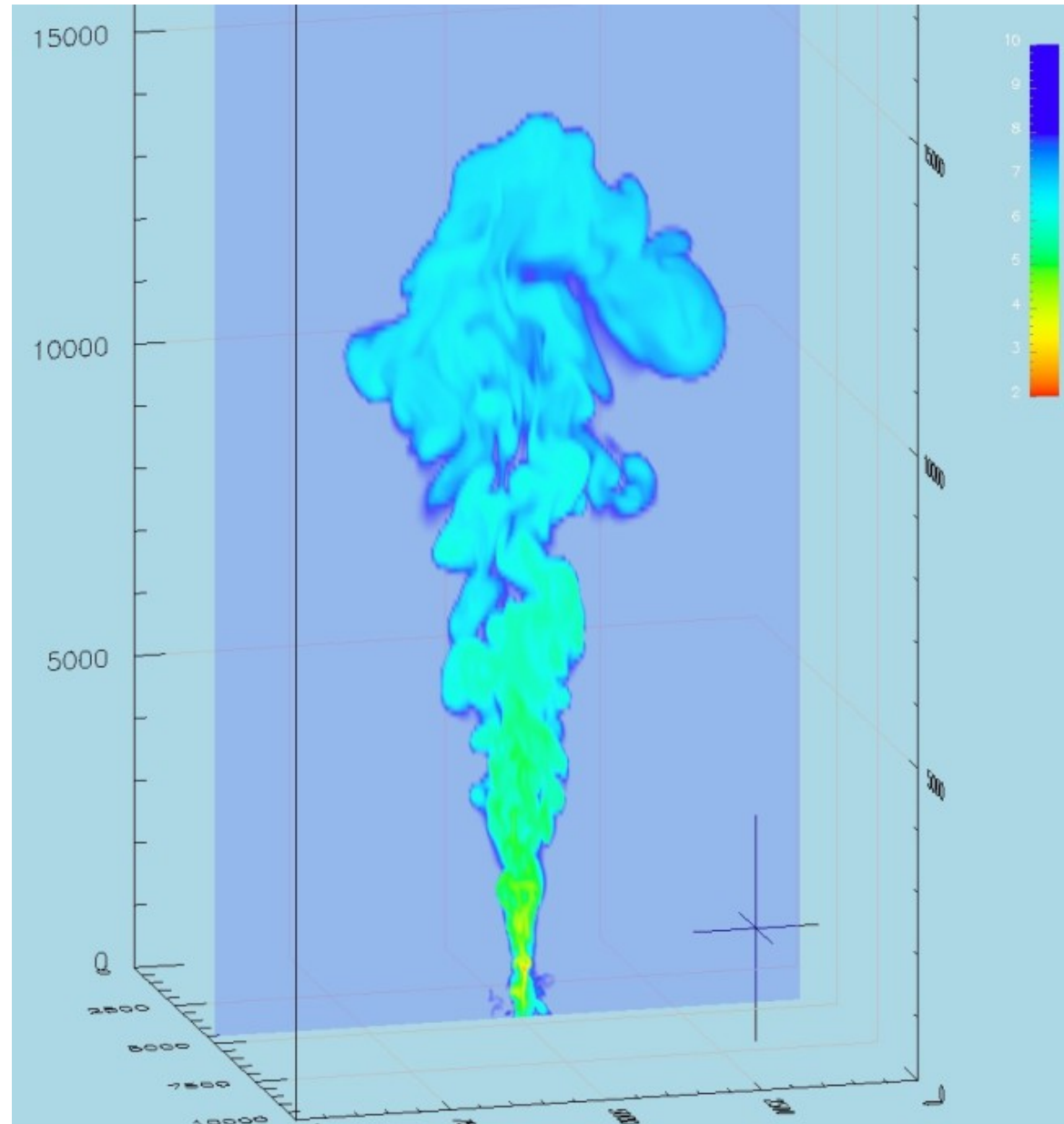
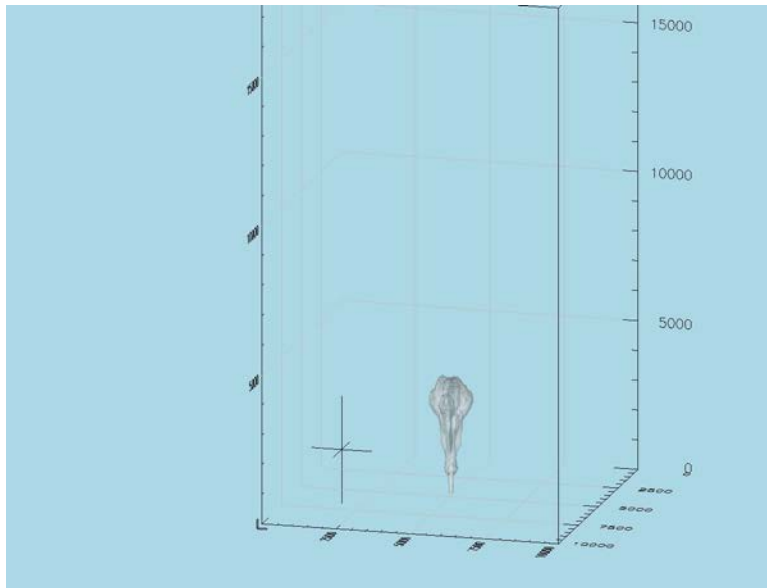
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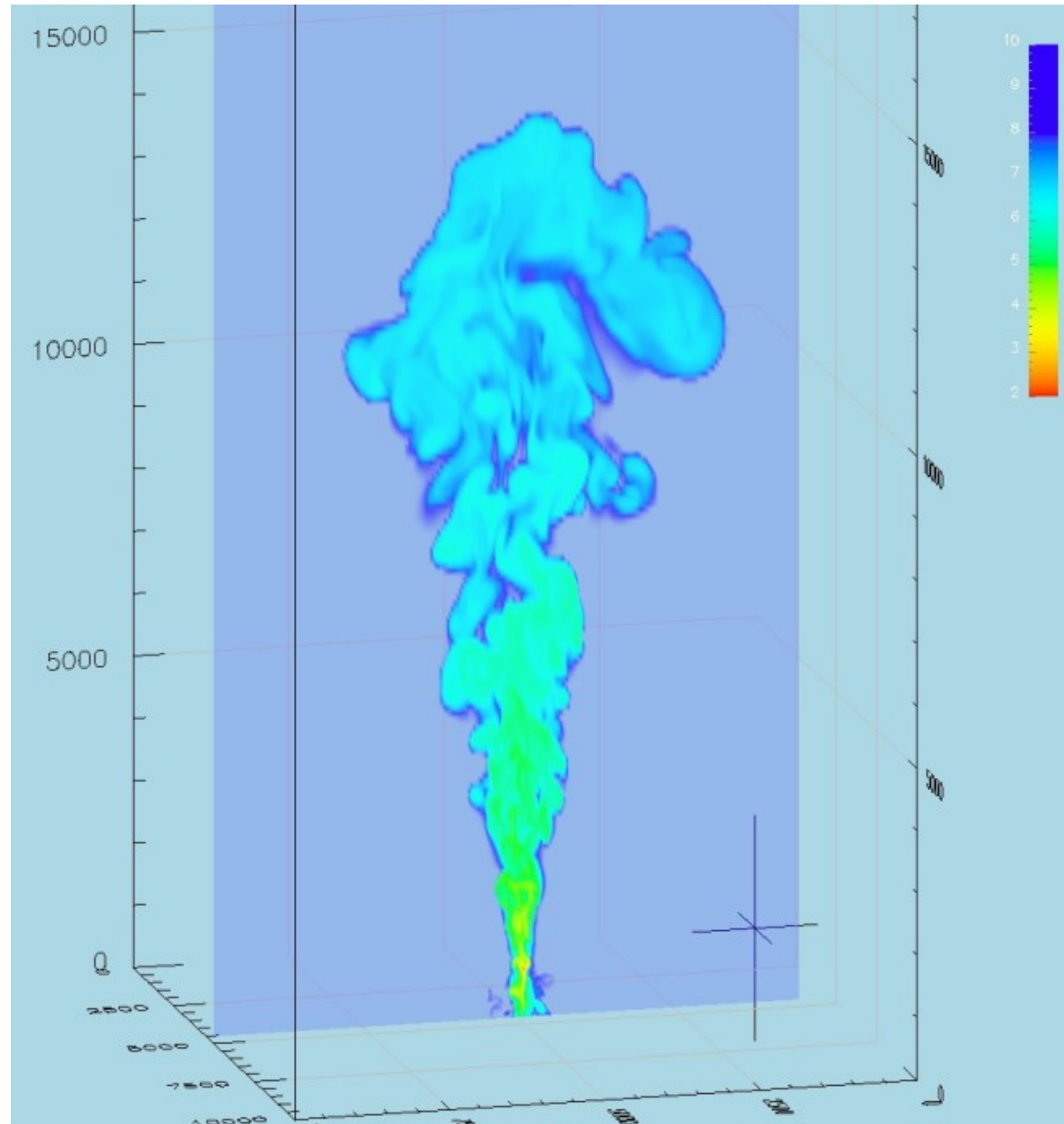
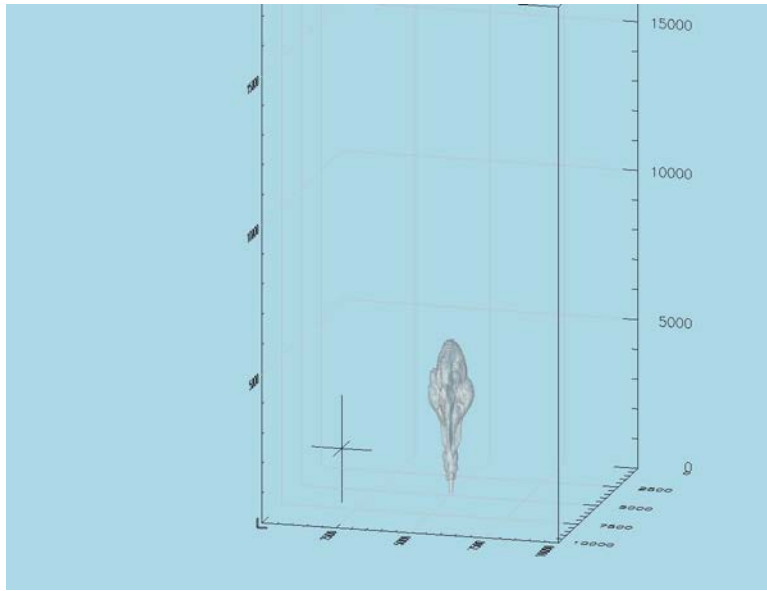
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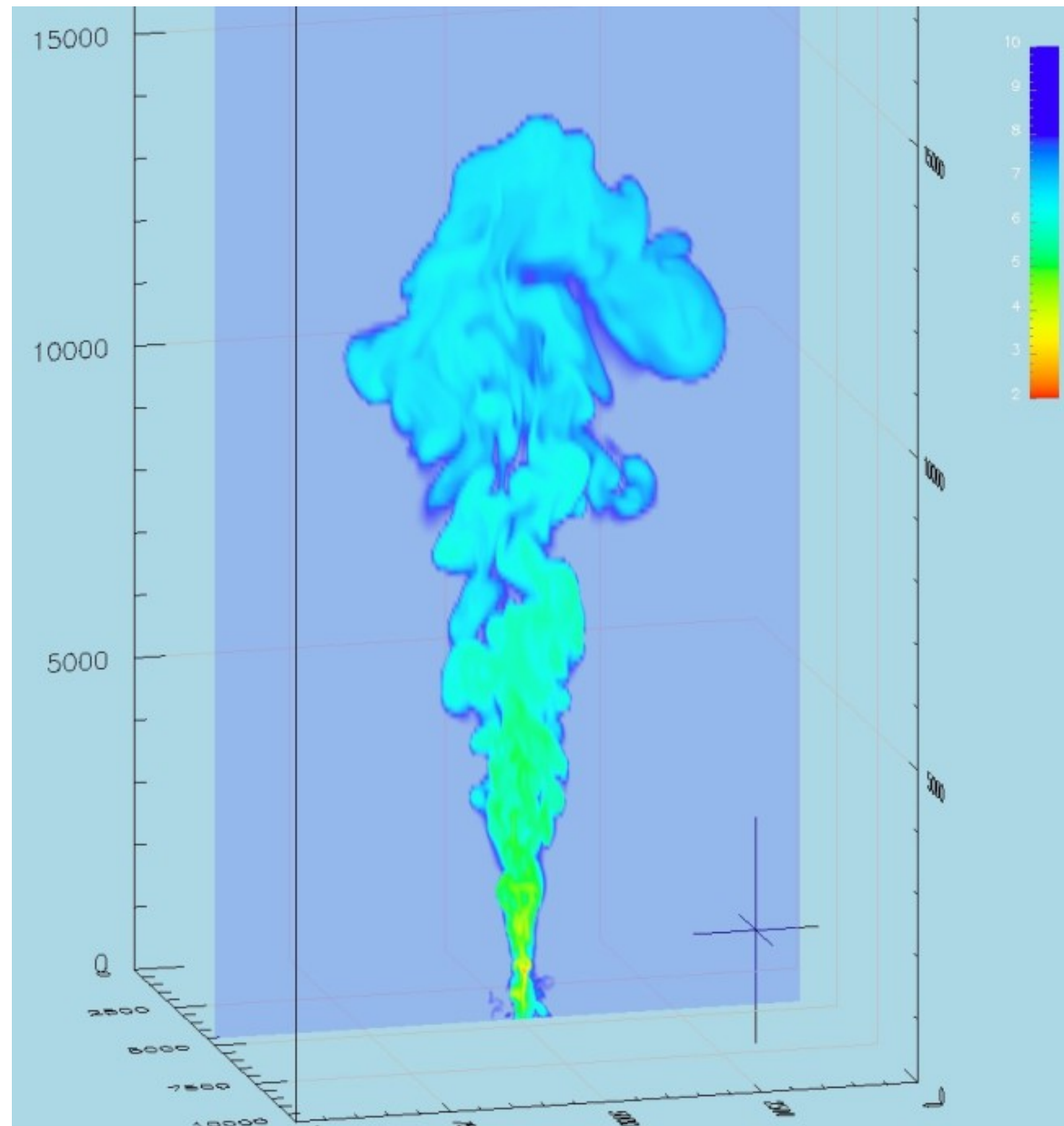
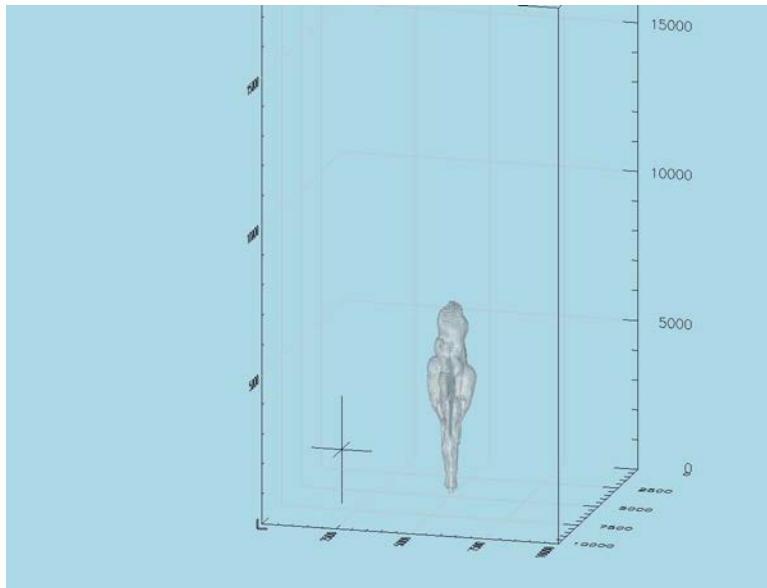
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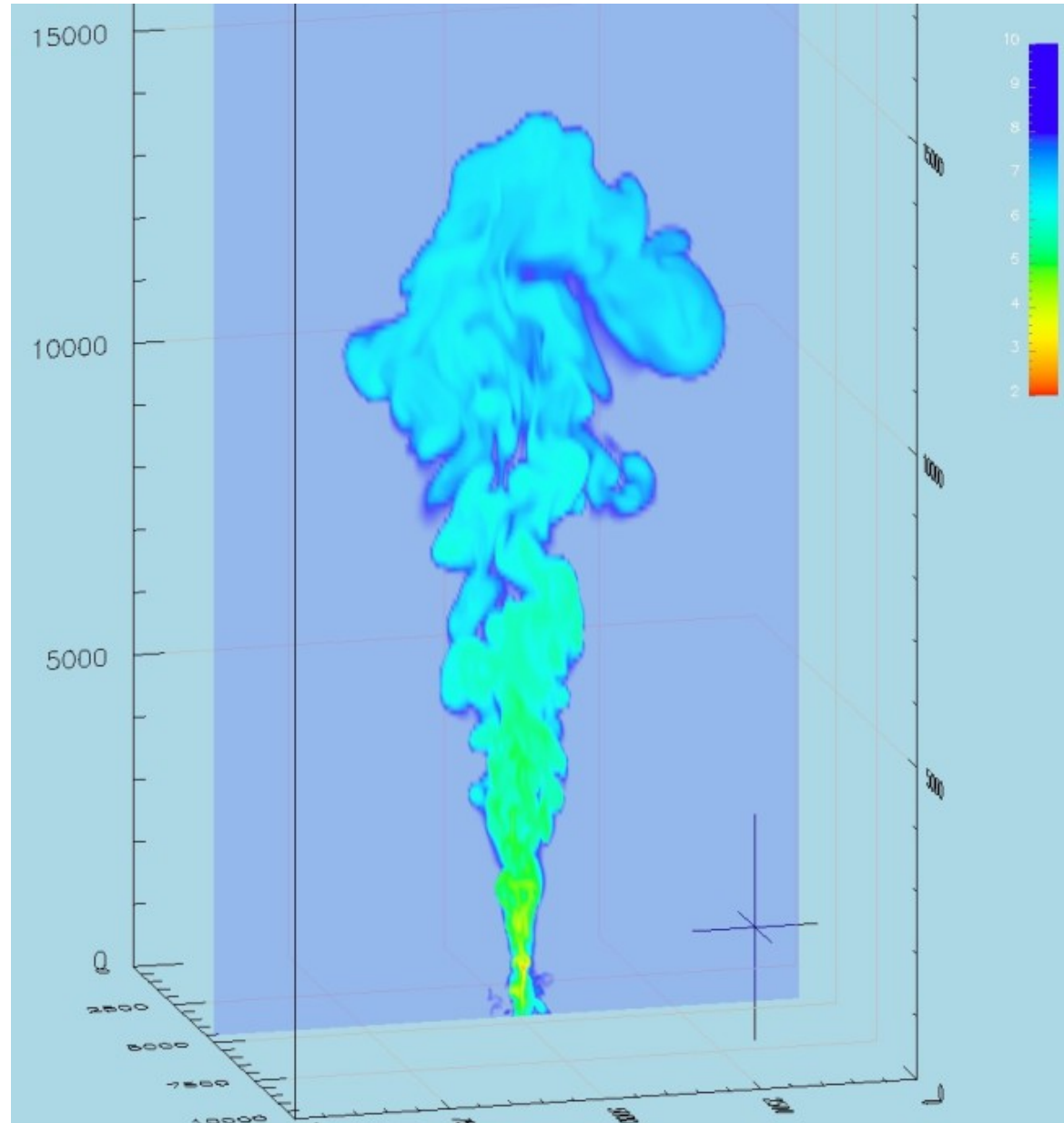
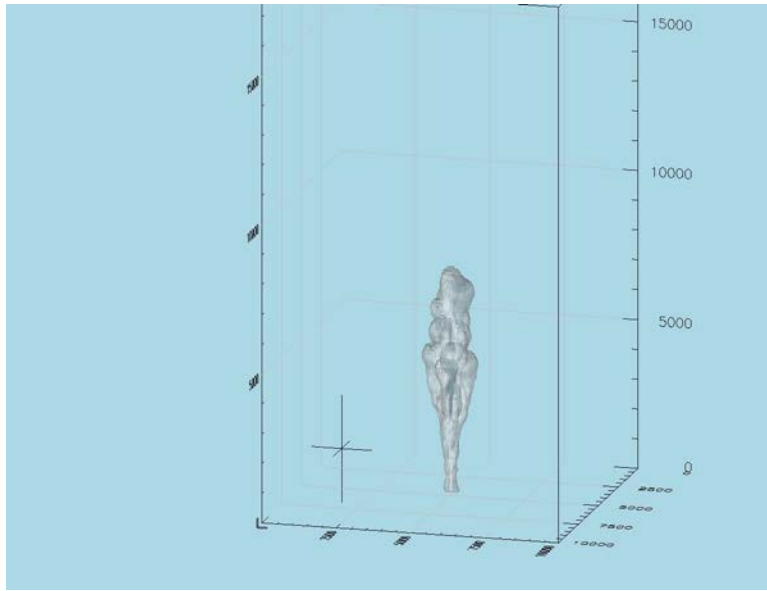
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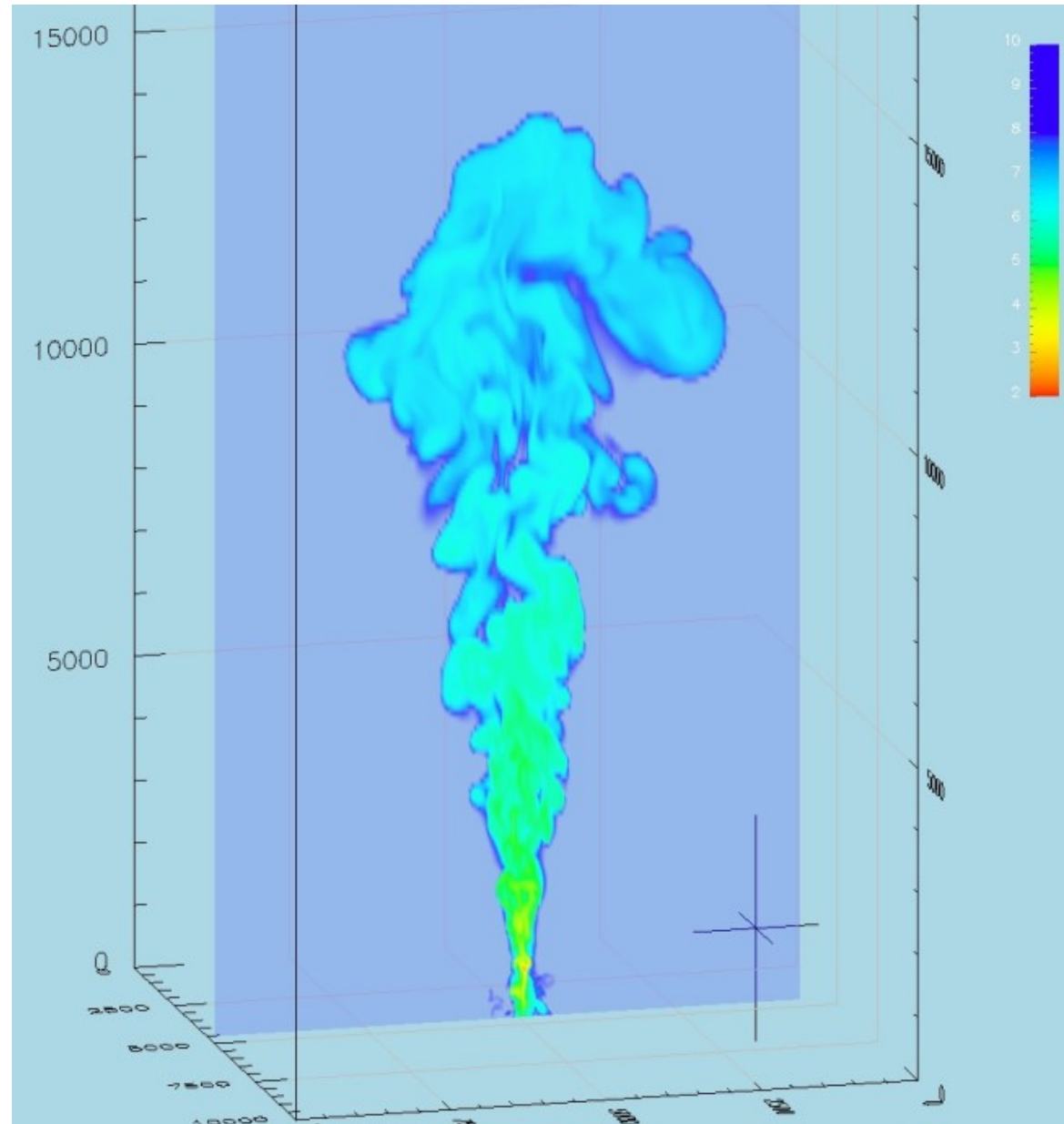
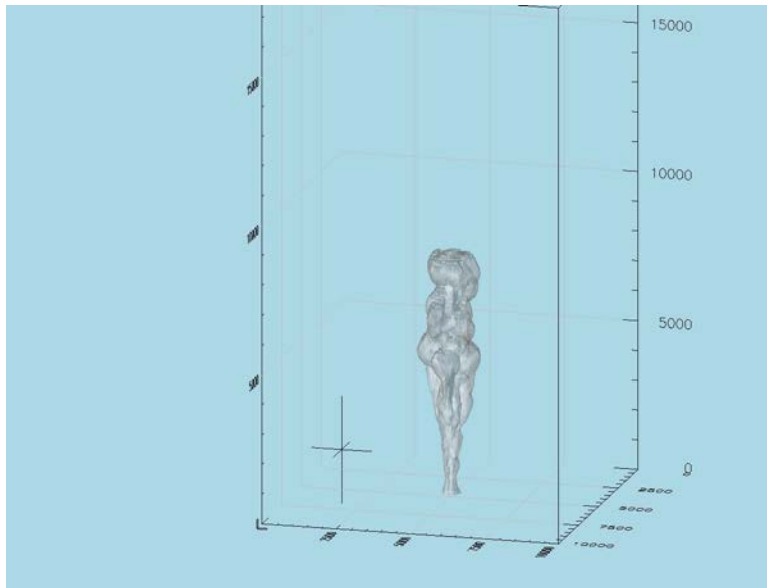
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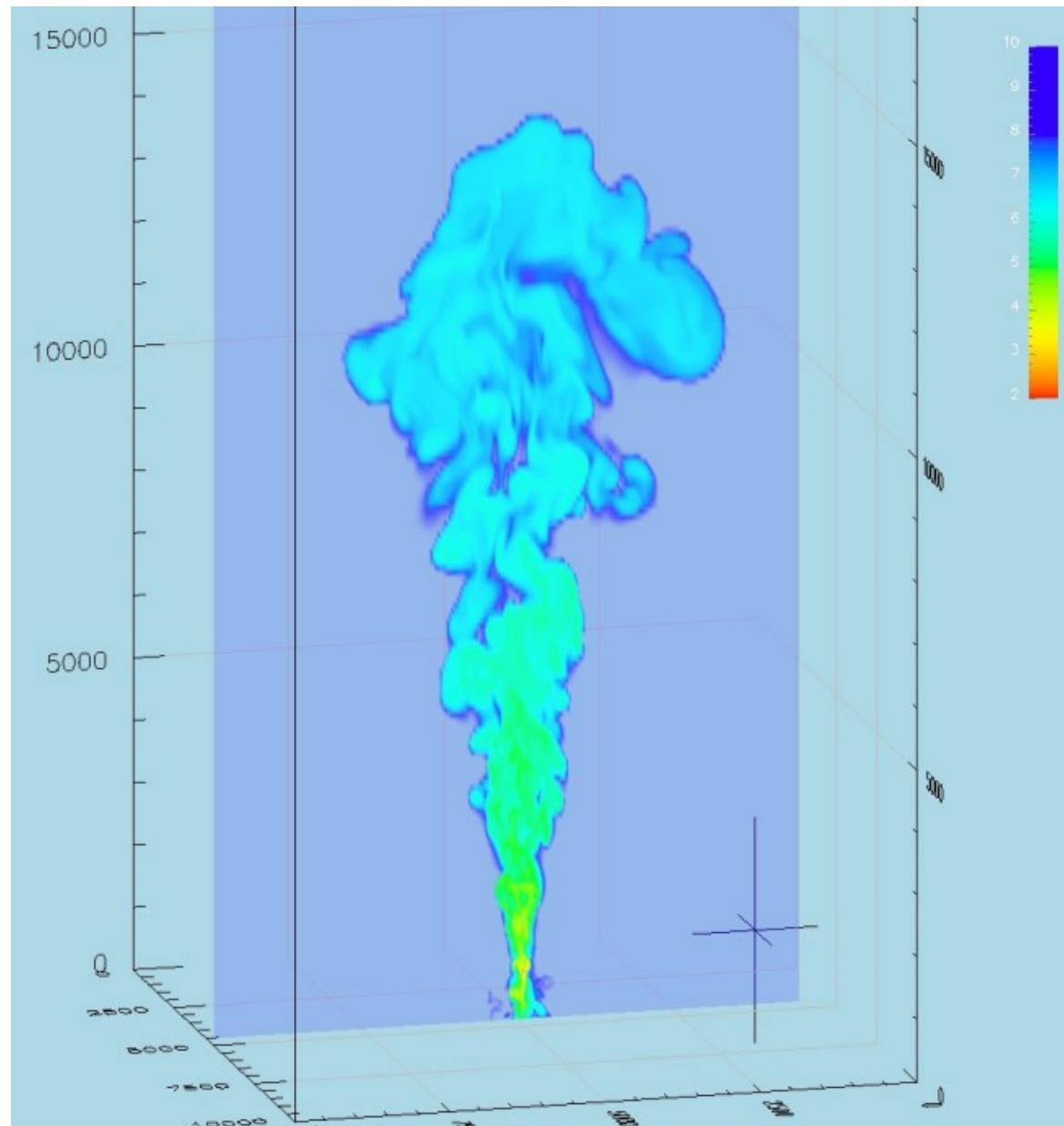
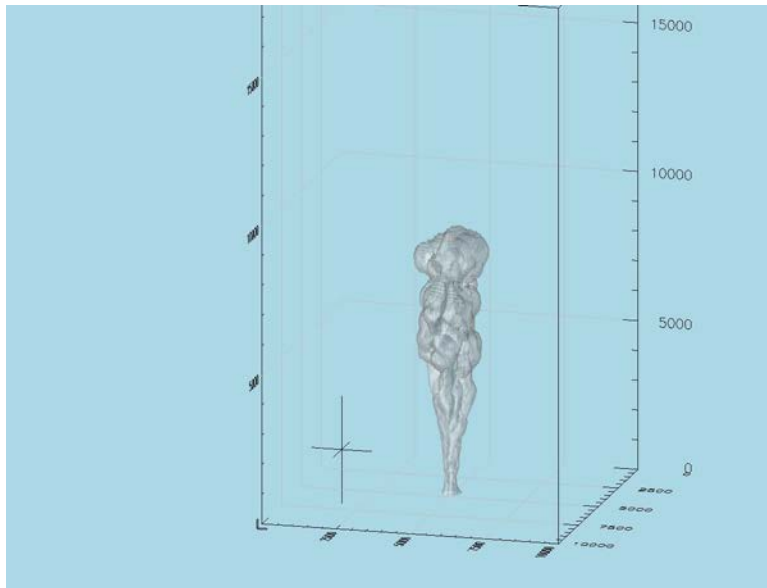
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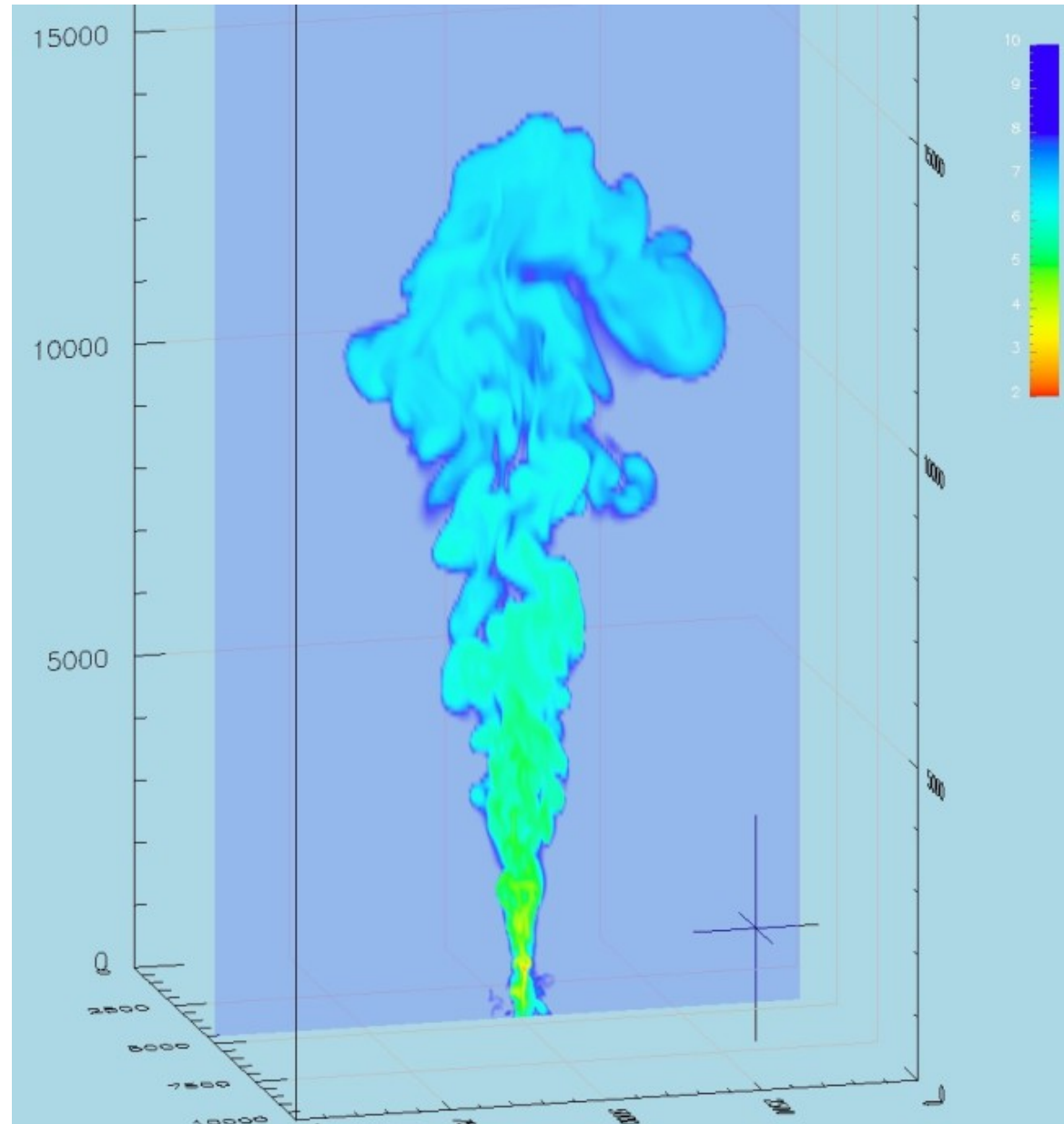
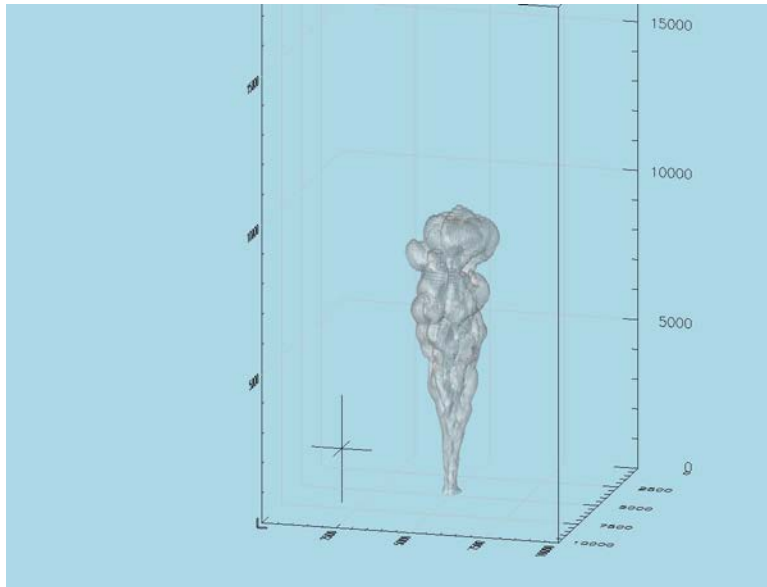
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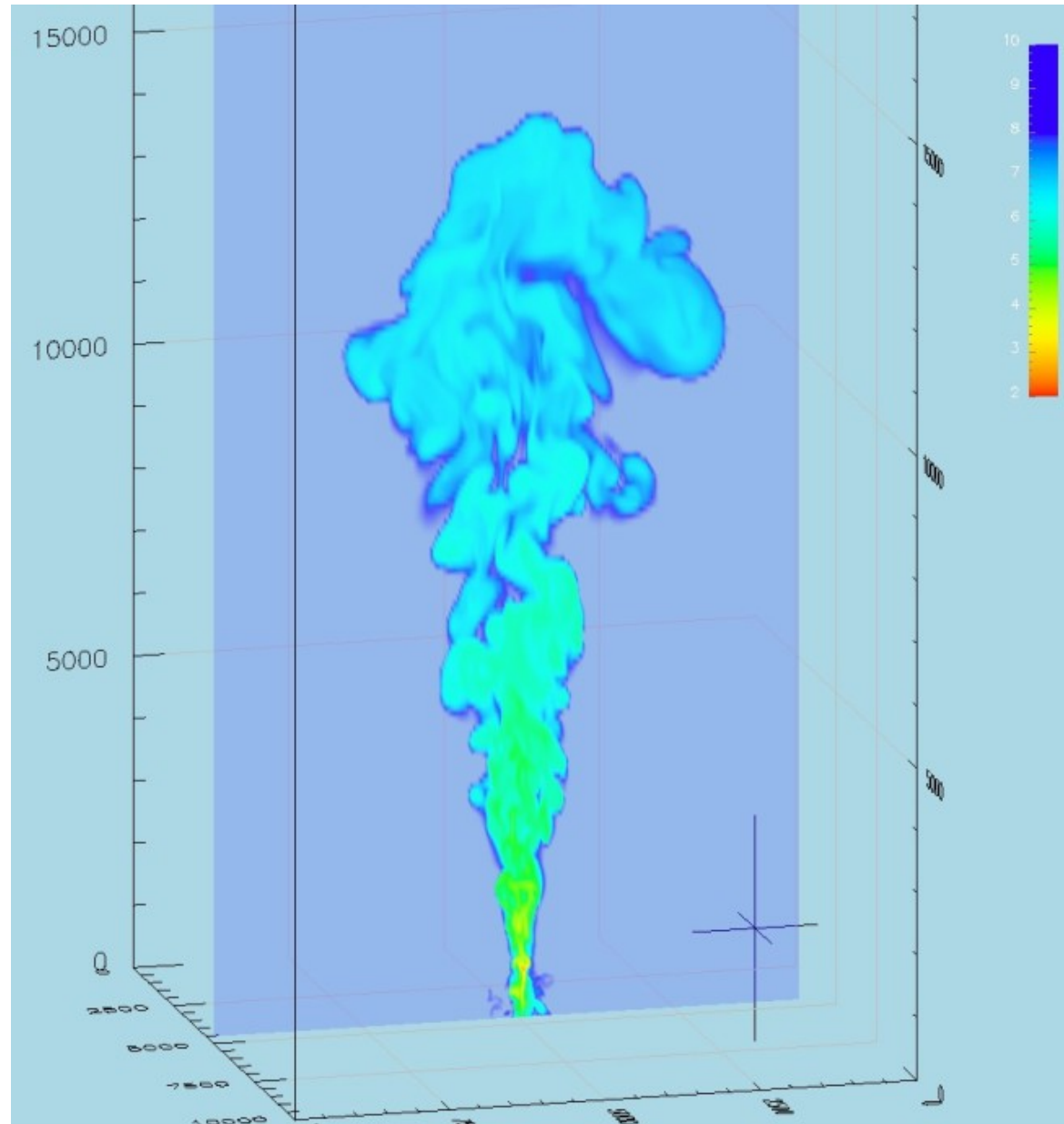
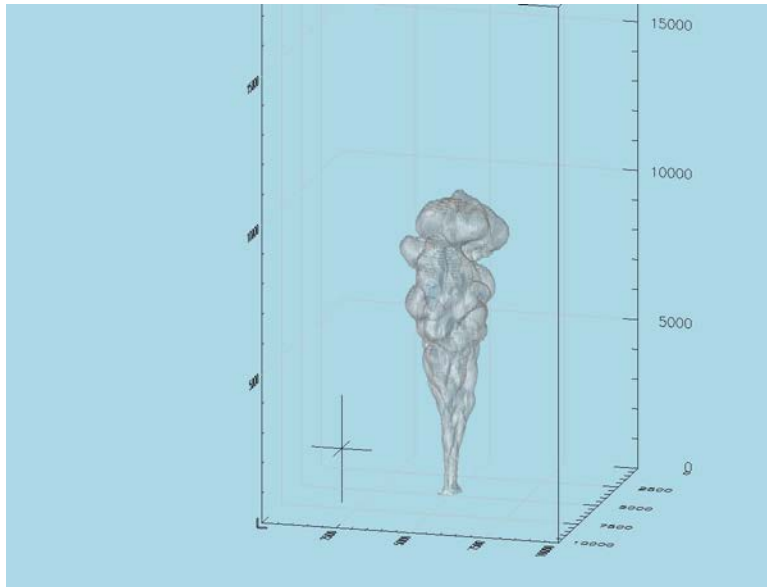
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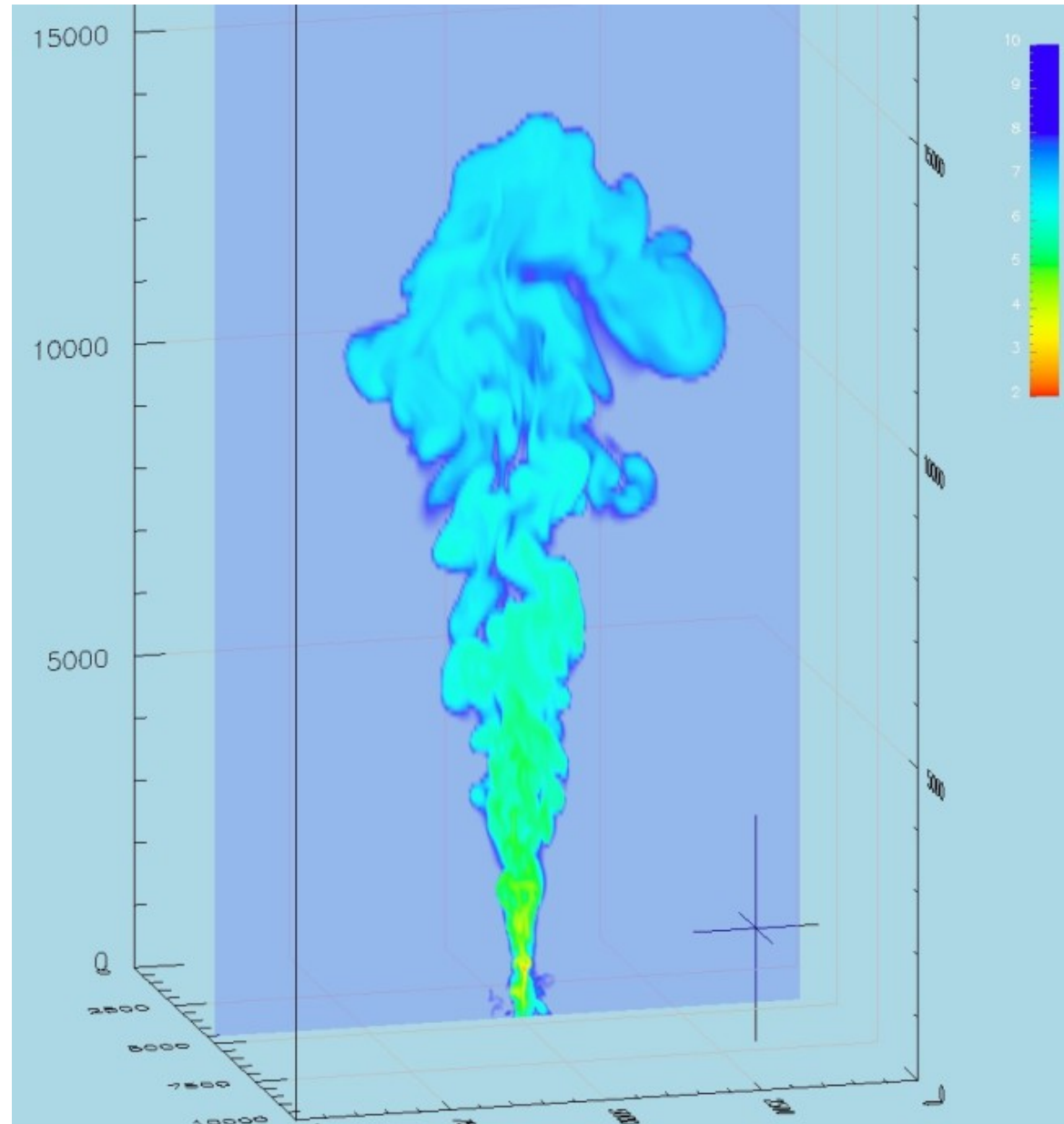
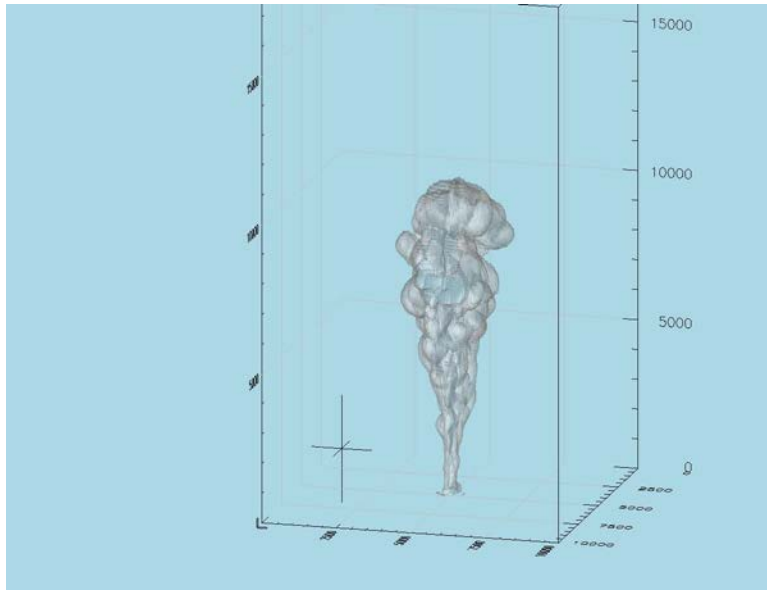
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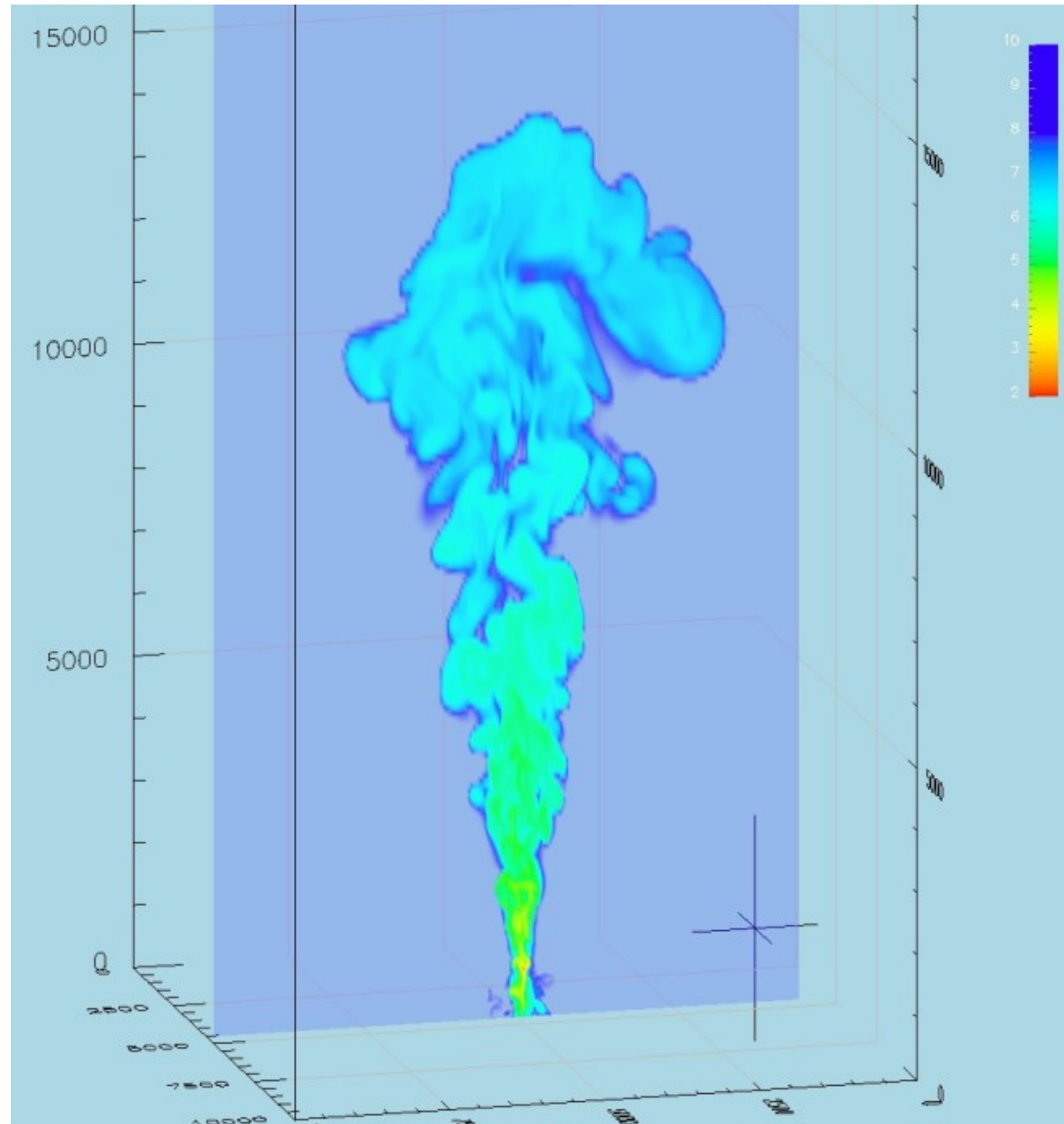
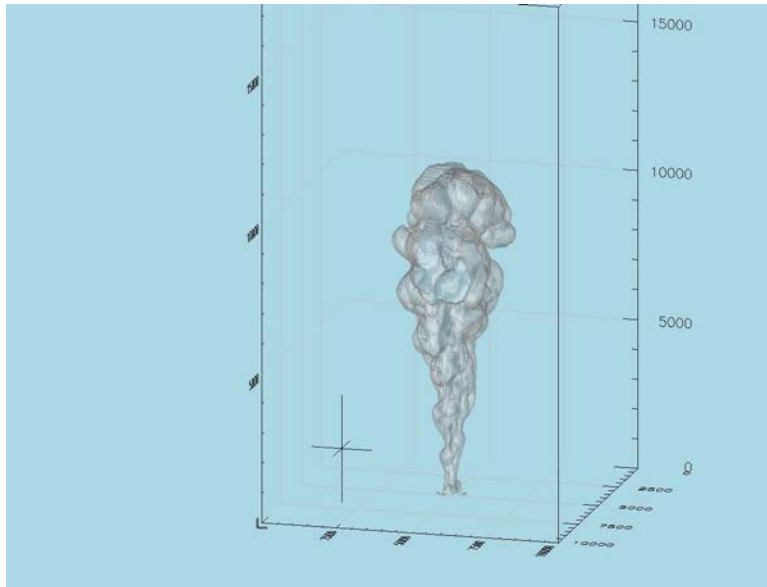
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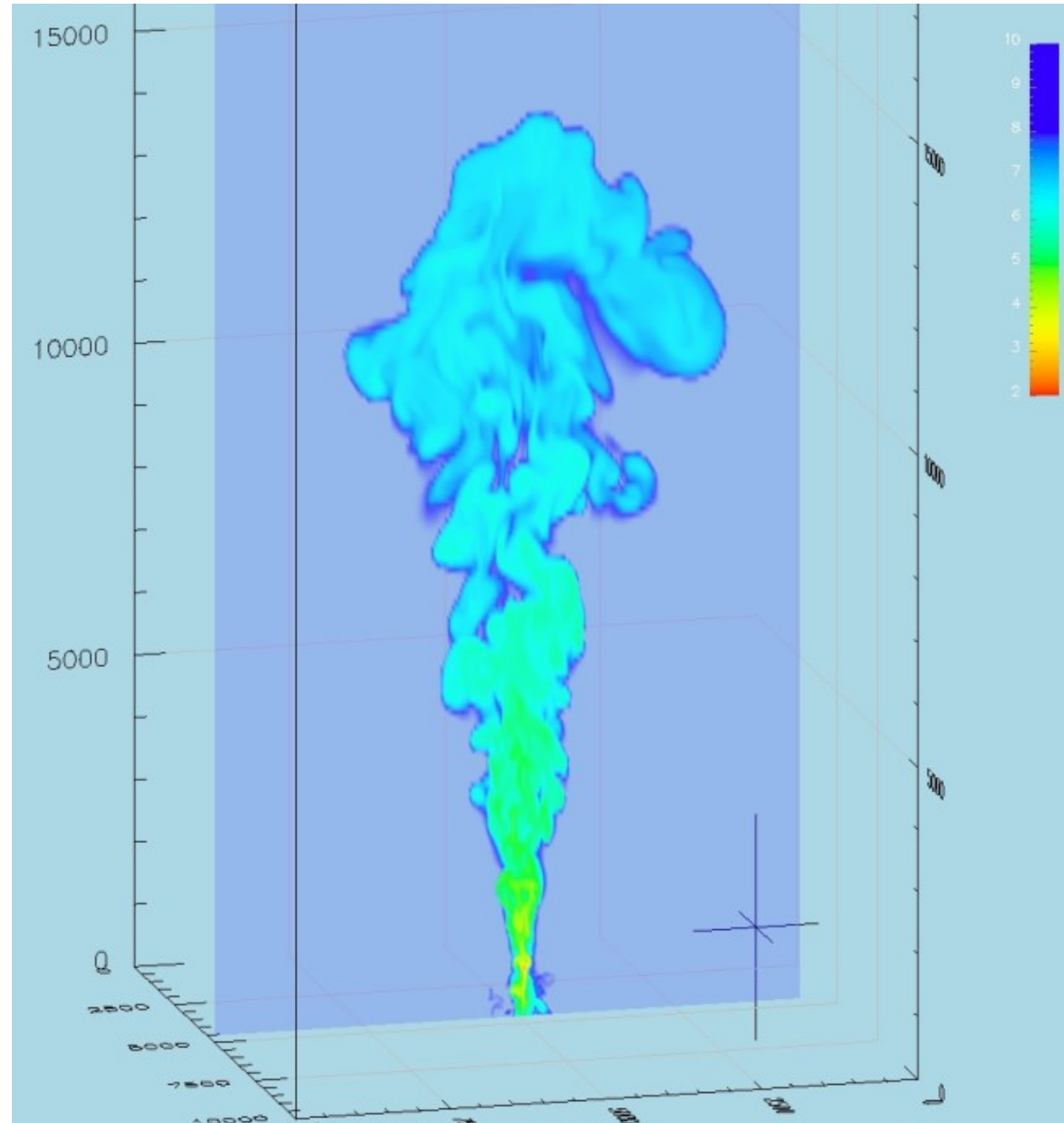
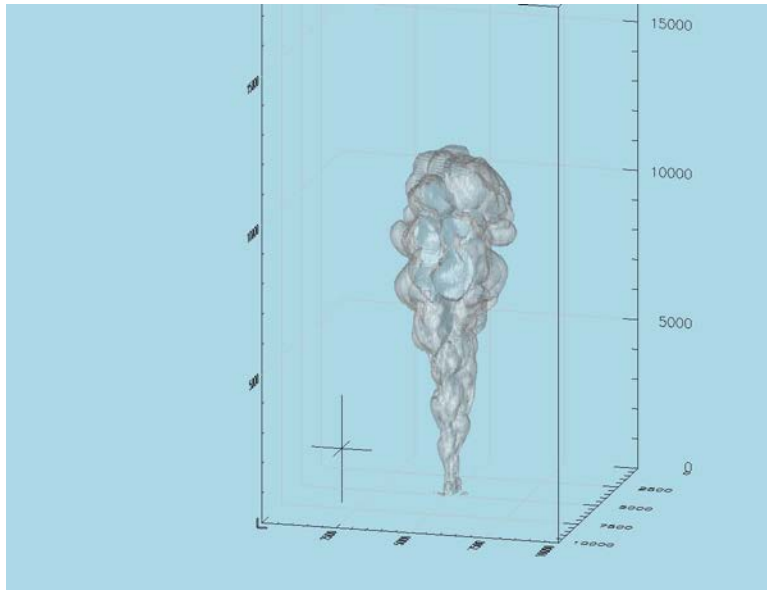
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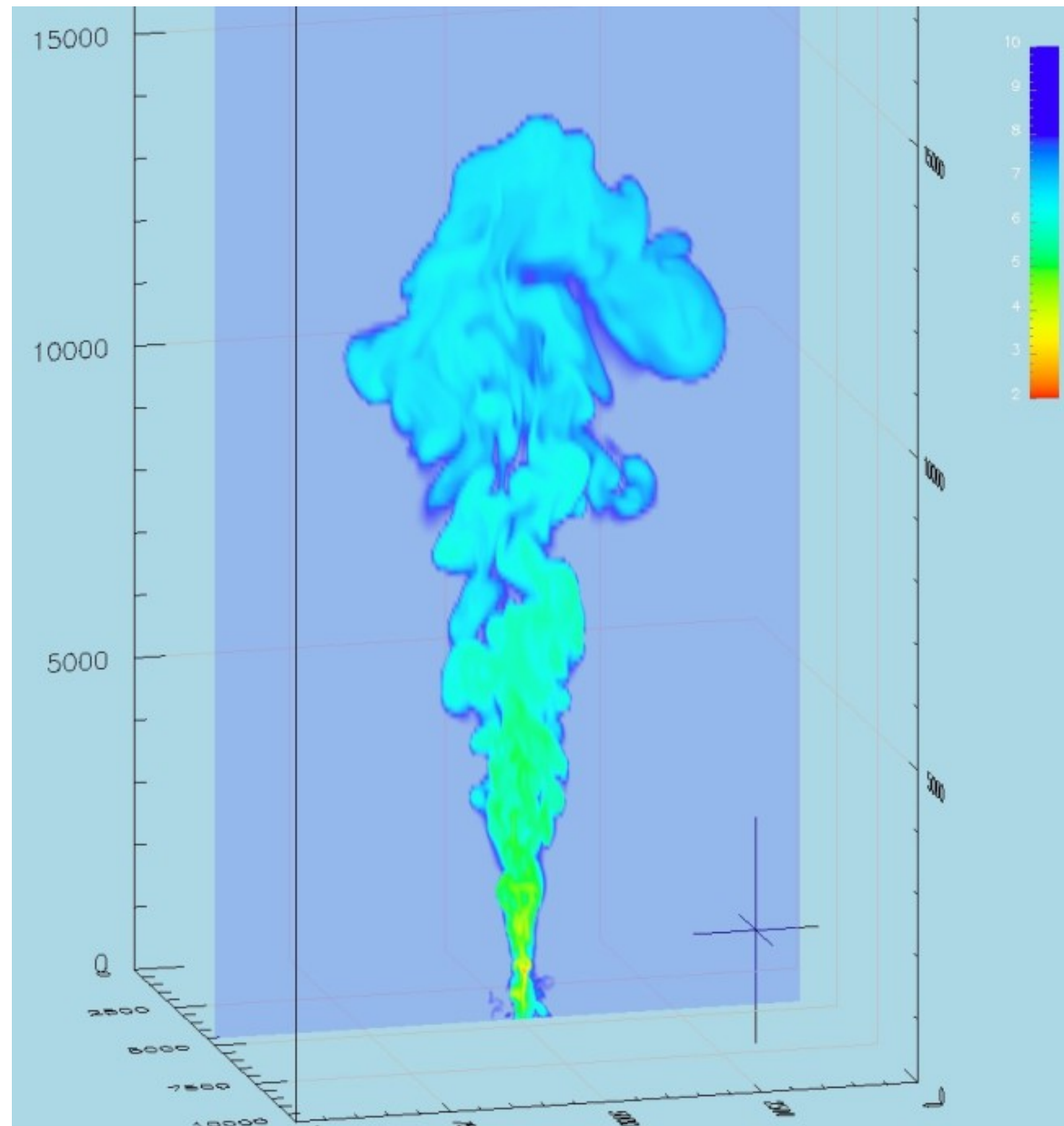
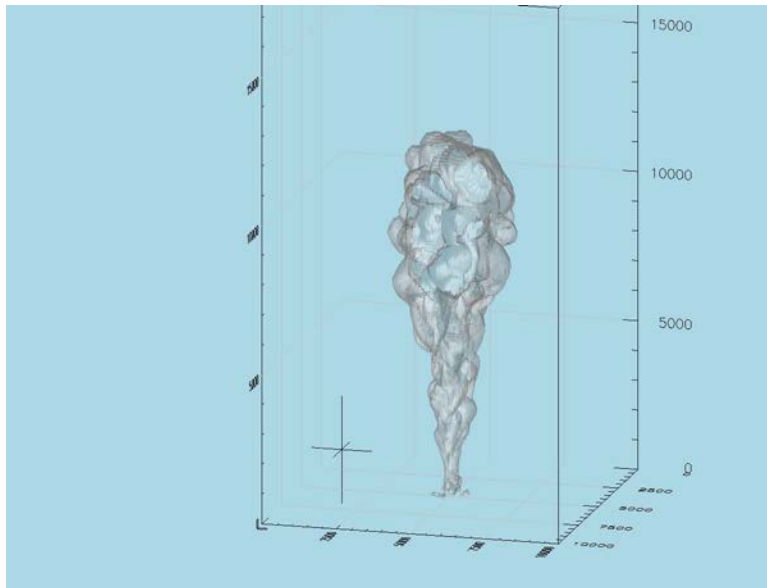
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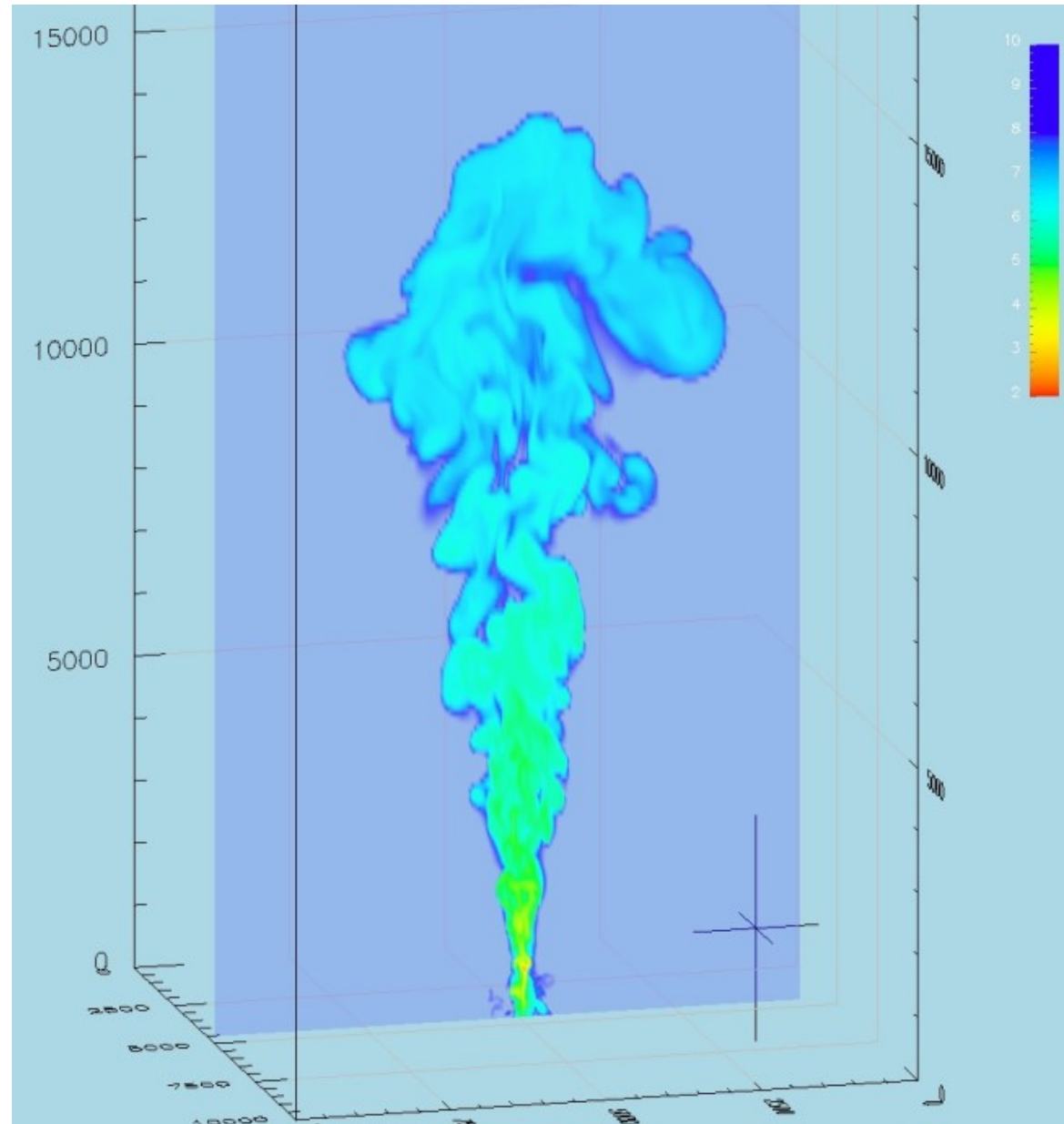
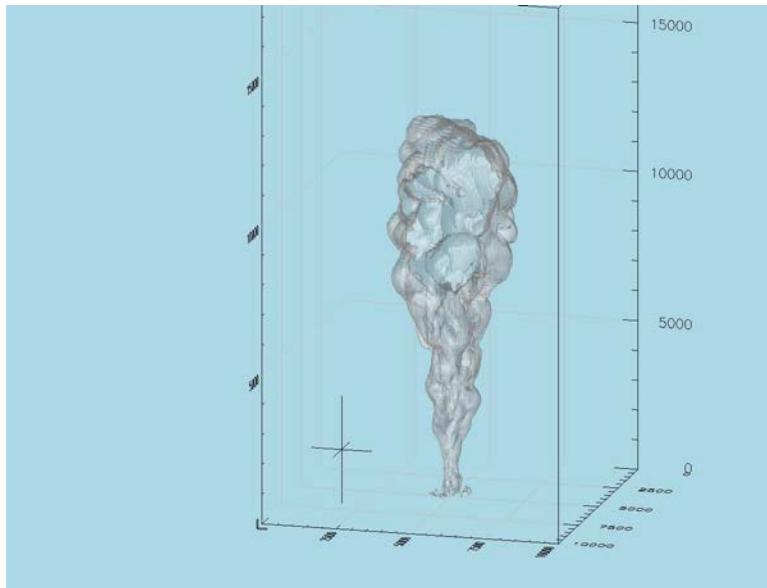
Integrating charging rates into large-scale plume models



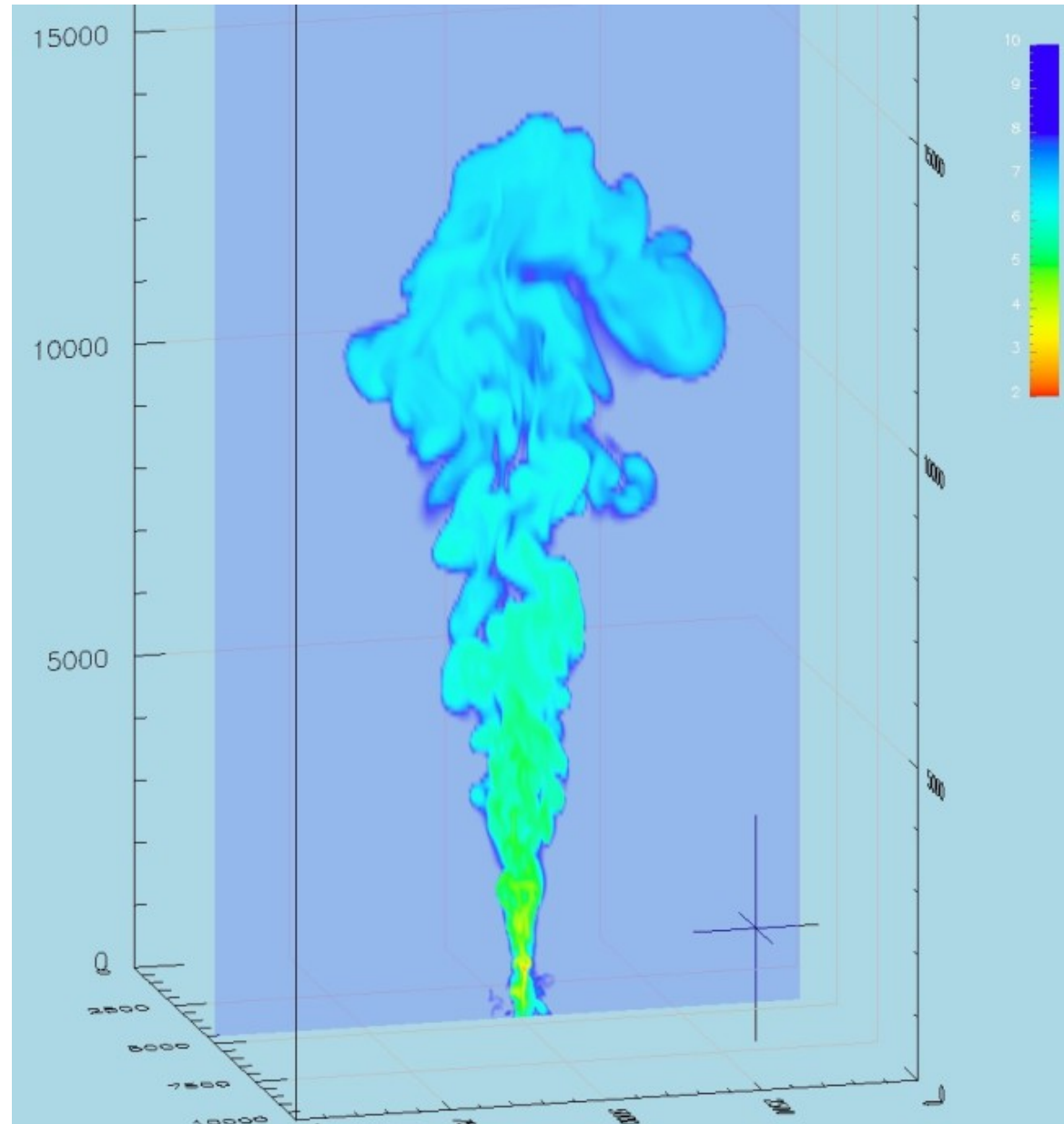
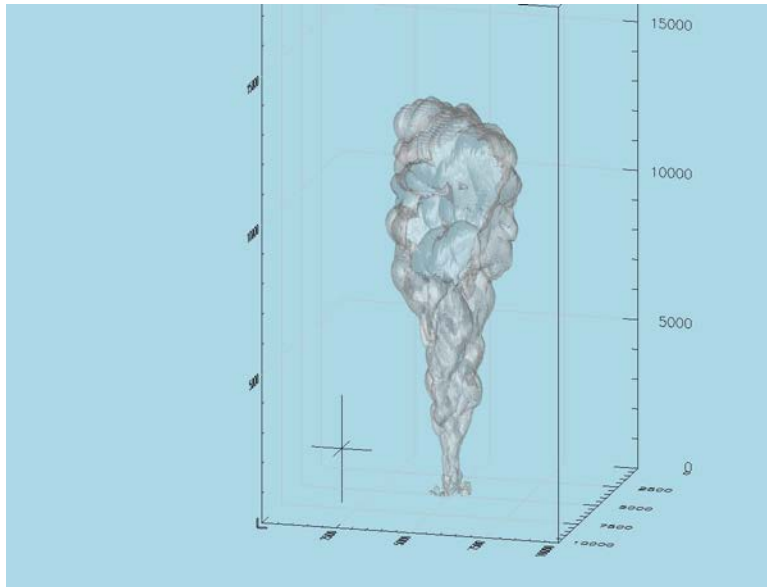
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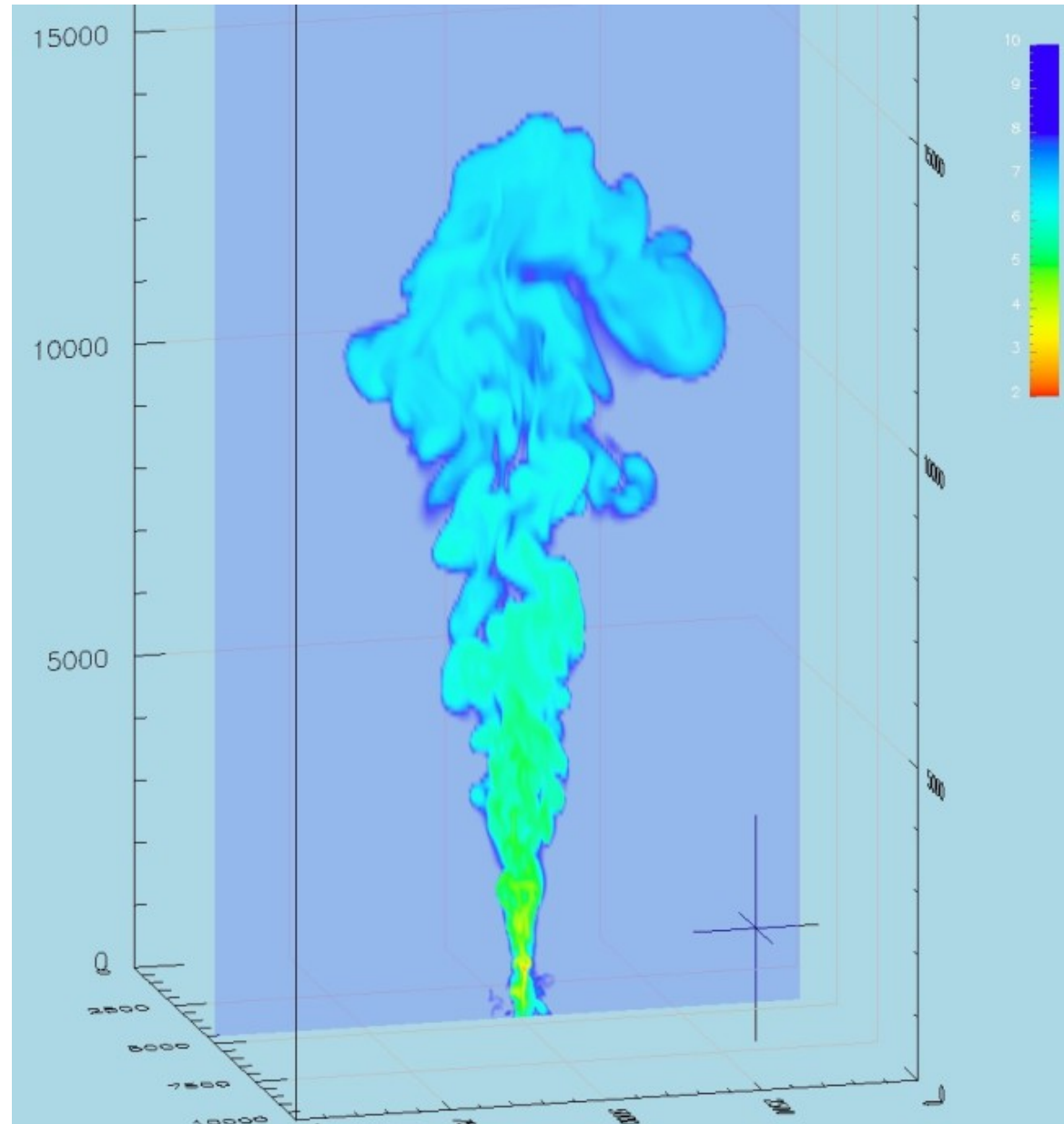
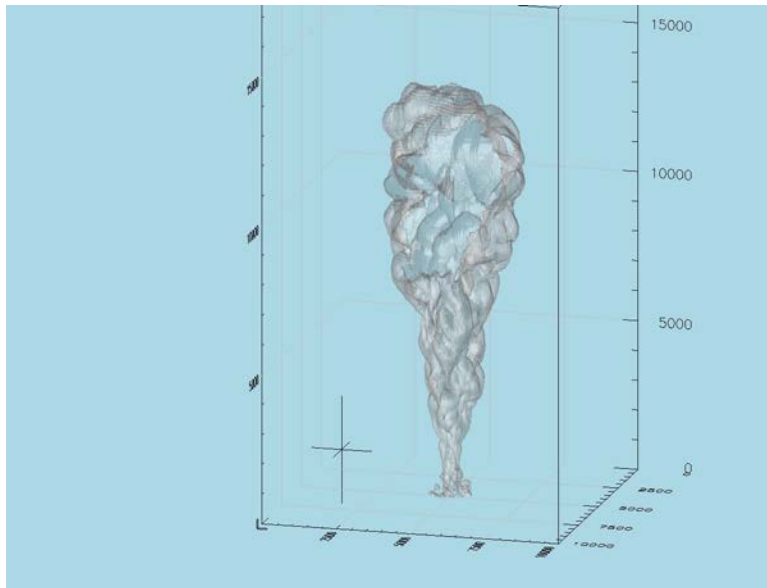
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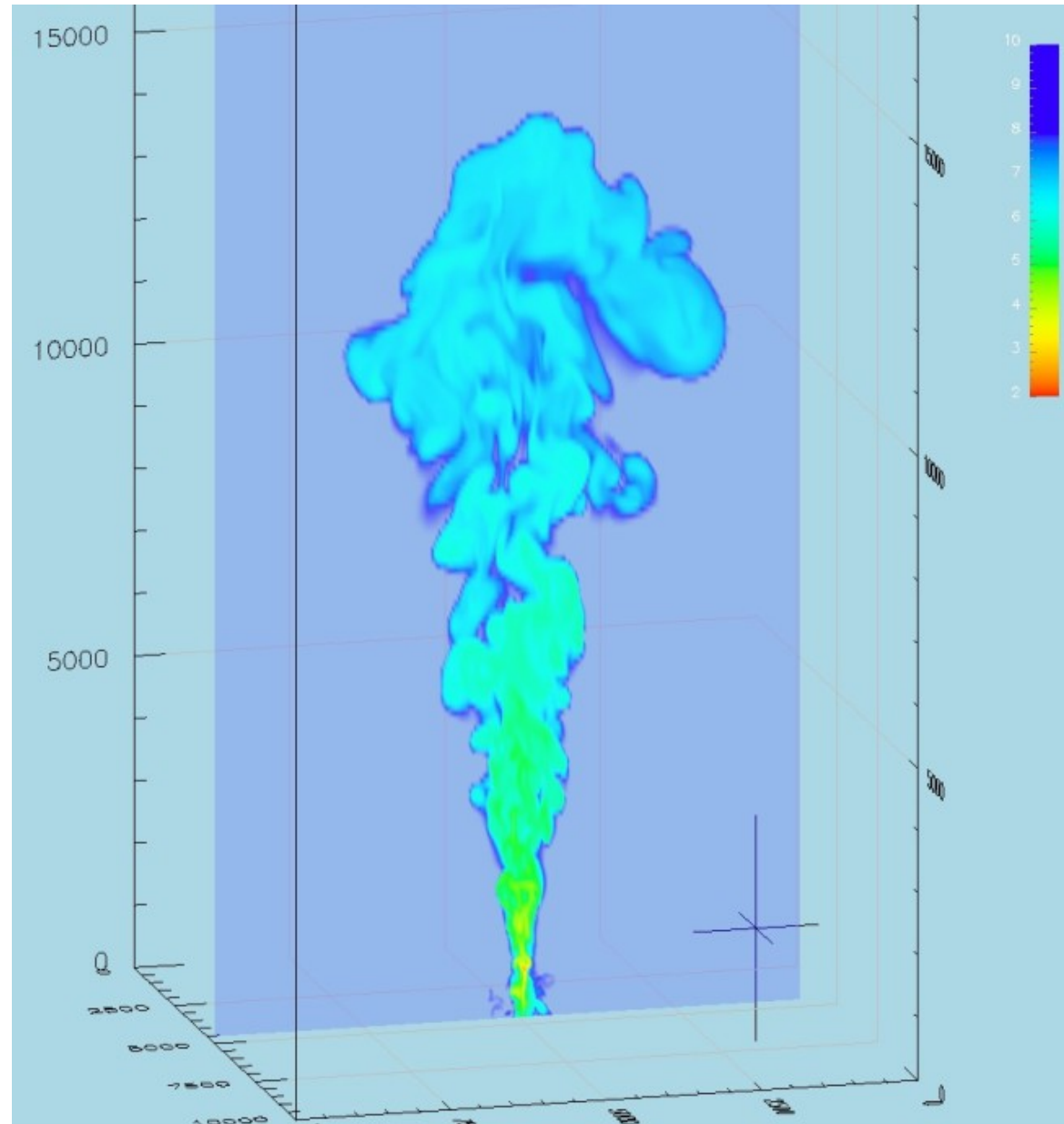
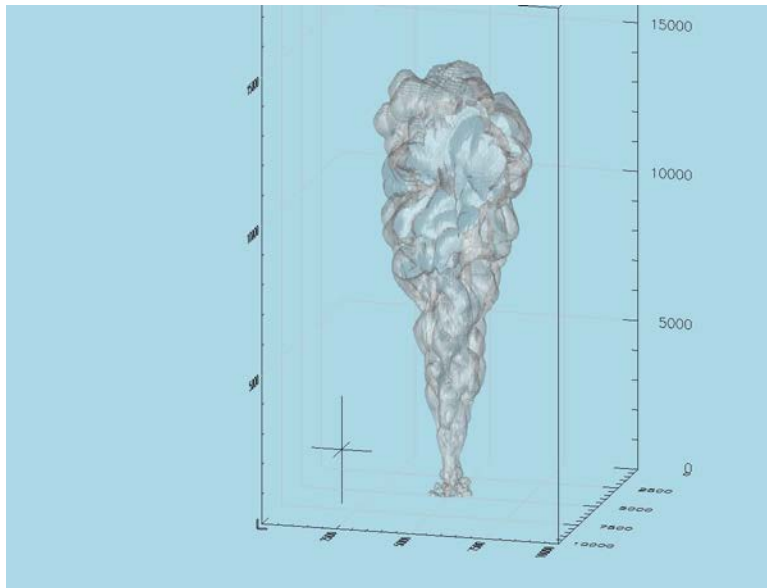
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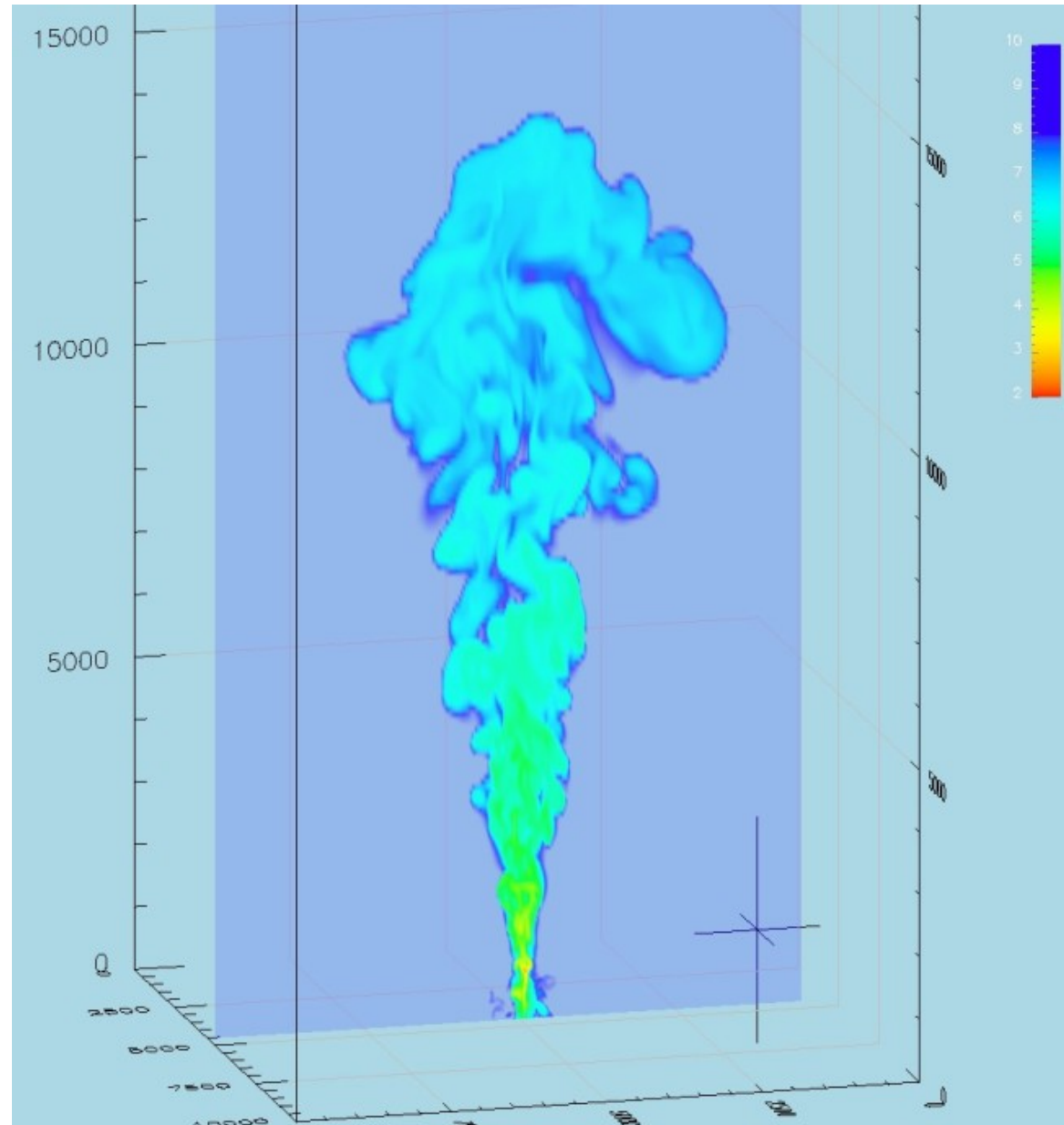
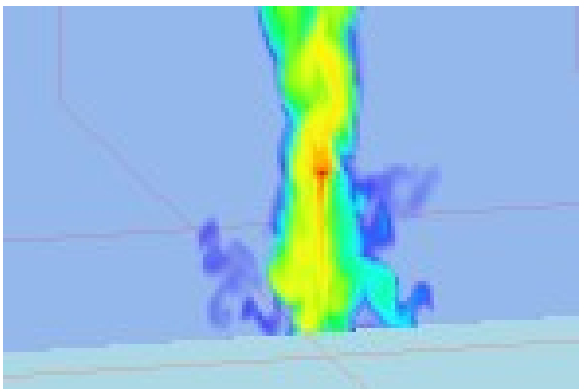
Currently running with three phases: gas, solid 1 (200 microns) and solid 2 (50 microns)

Domain size: 10 x 10 x 20 km

Resolution: 100 of meters

Run on 512 processors (32 nodes, 16 processes each)

Can start to resolve fine flow detail such as pyroclastic flows



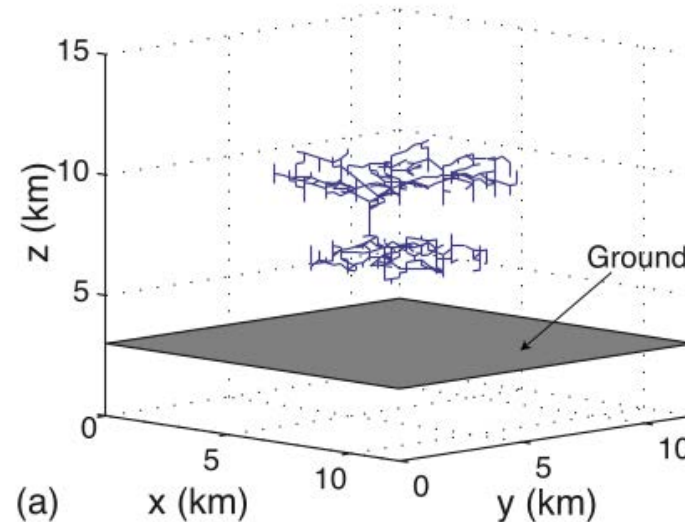
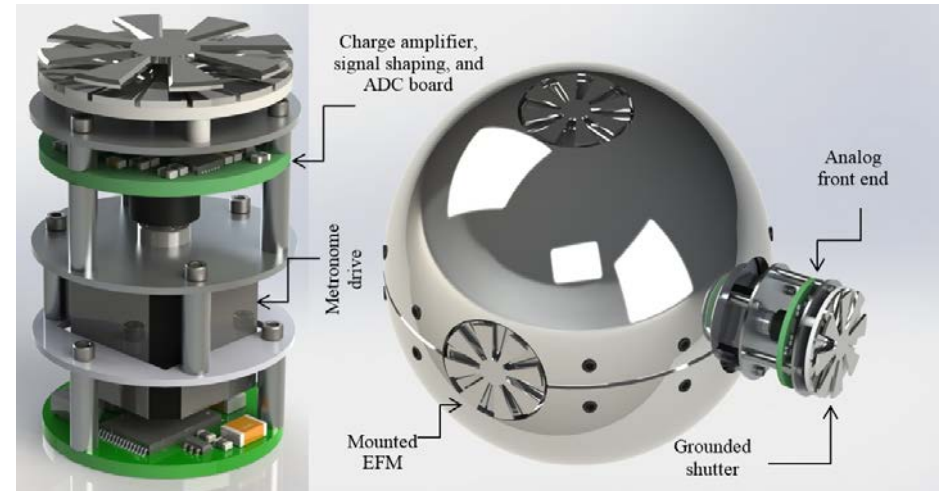
Continuing work

Integrate a fractal lightning model based on the work of Rioussset et al. [2009].

Increase resolution of model near vent → Need submeter grid spacing to resolve near-vent lightning

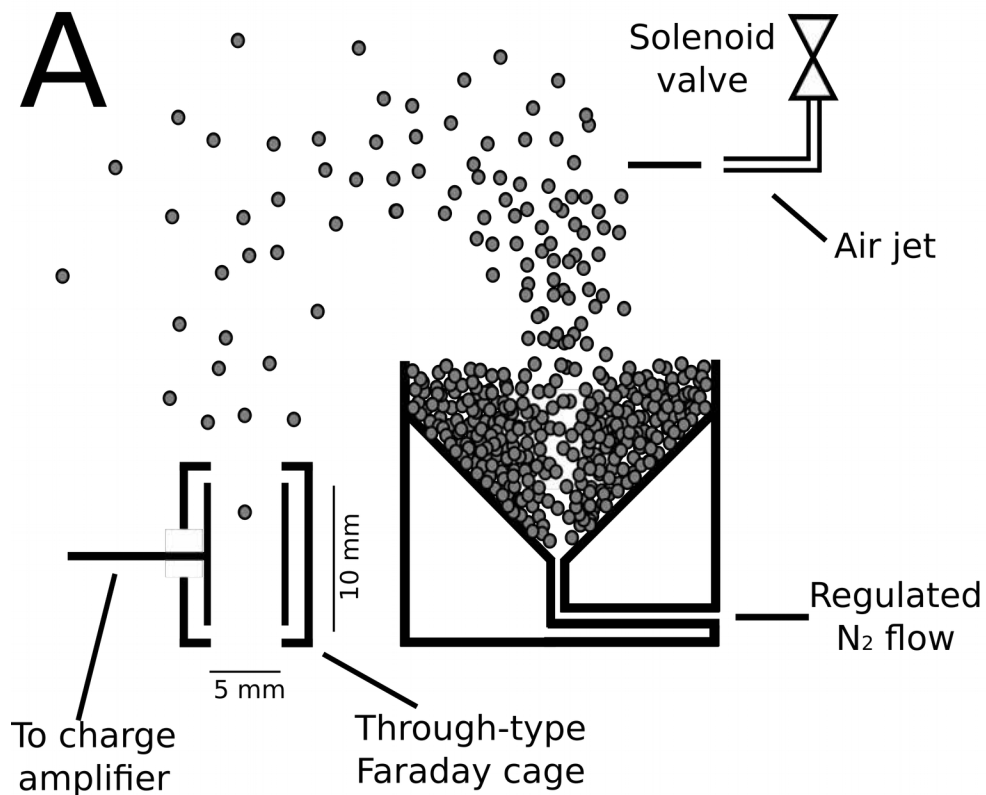
Begin to think about adding other charging mechanisms such as fragmentation charging and ice-based charging

Complete instrument development to perform field validation studies at active volcanoes

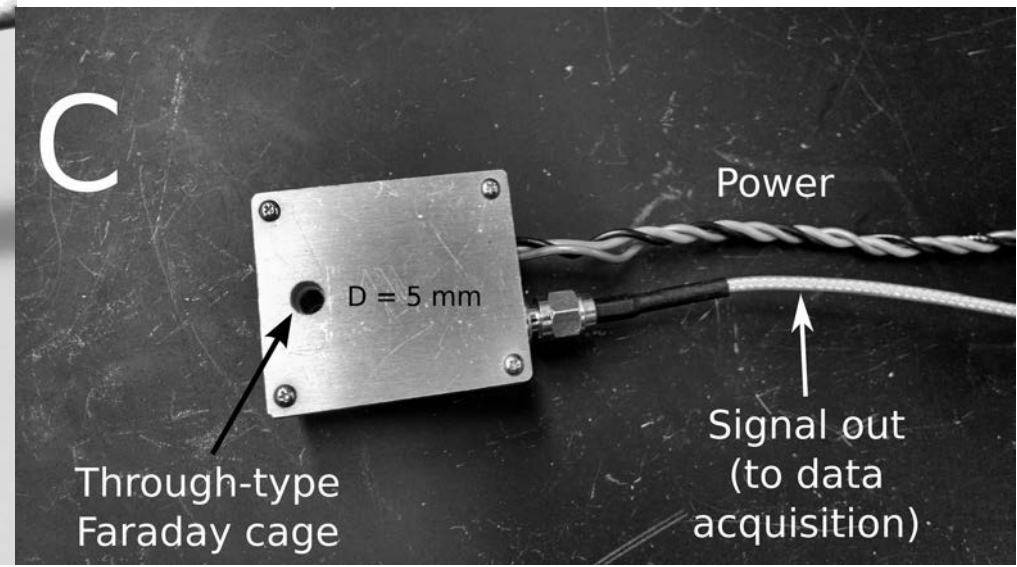
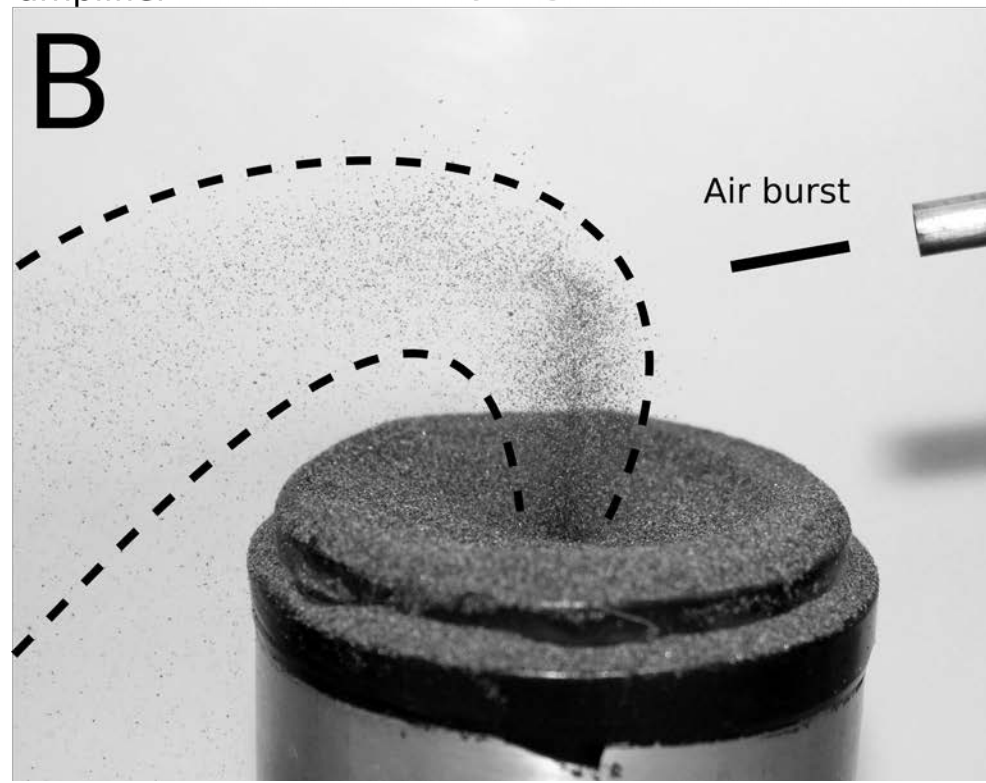


THANKS!

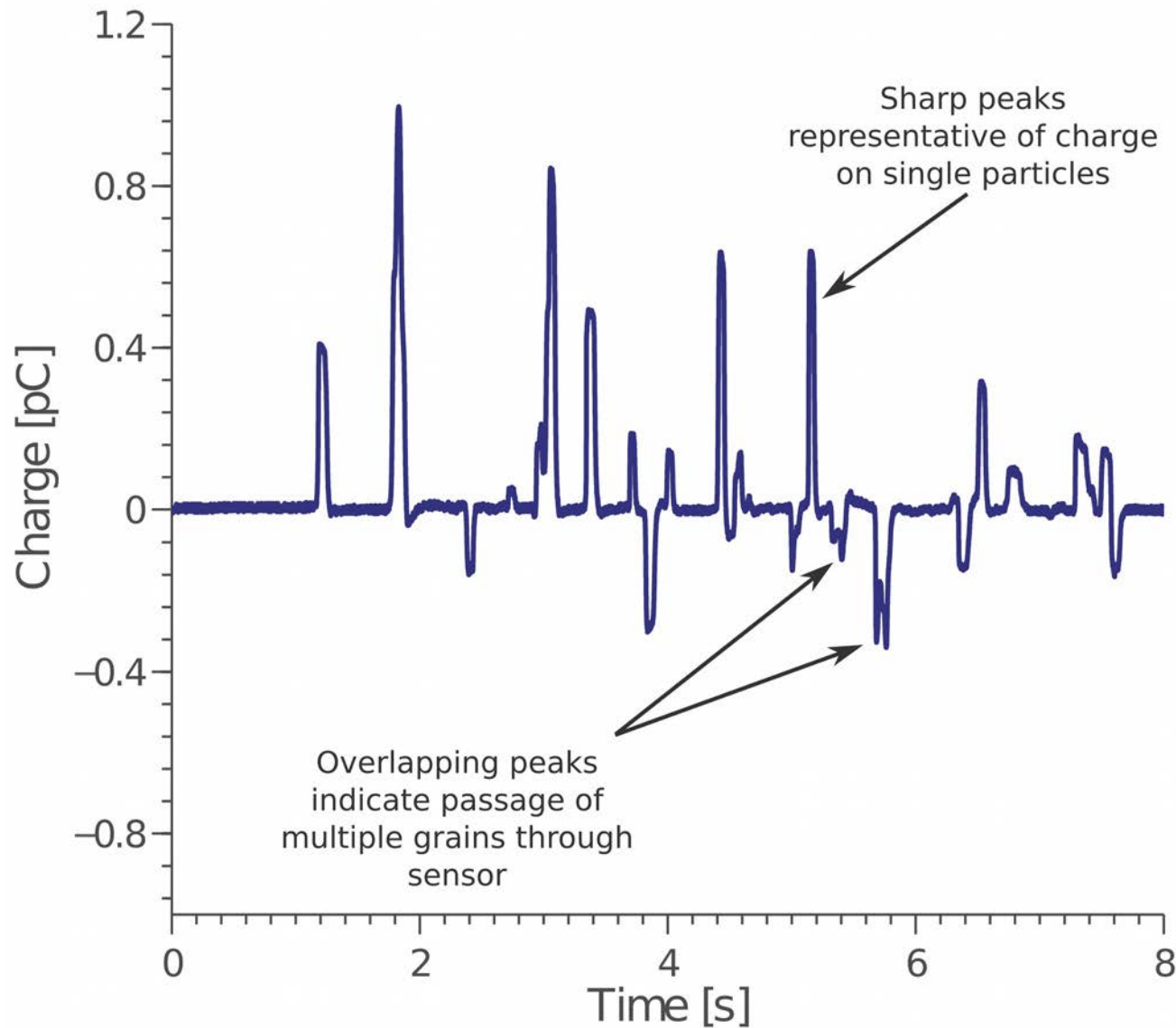
- I would like to acknowledge the Blue Waters Fellowship program, Galen Arnold (my point of contact), and Dr. Mary Benage for their support getting MFIX running.



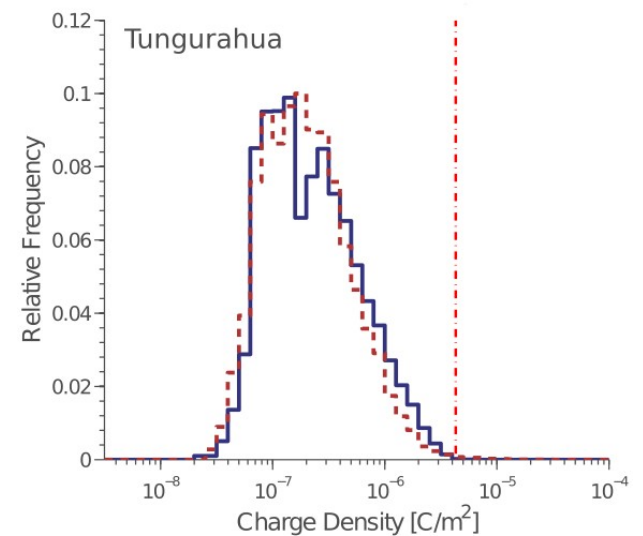
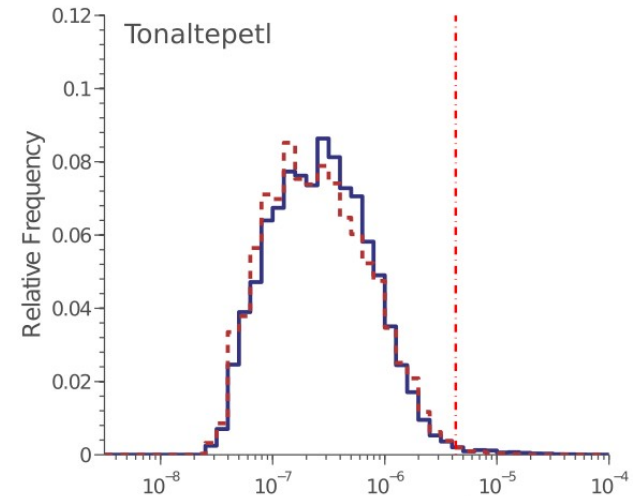
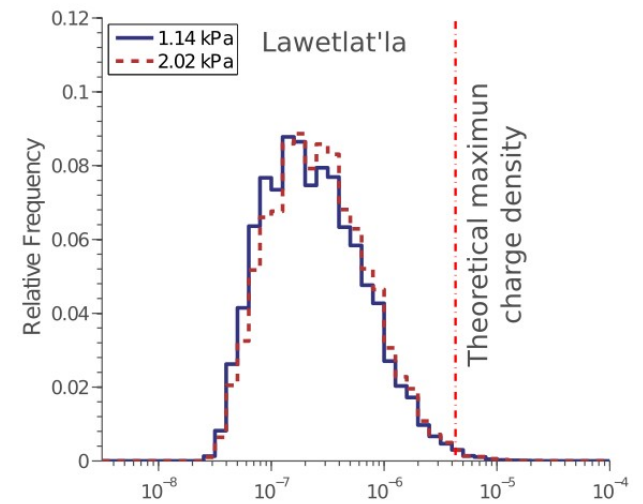
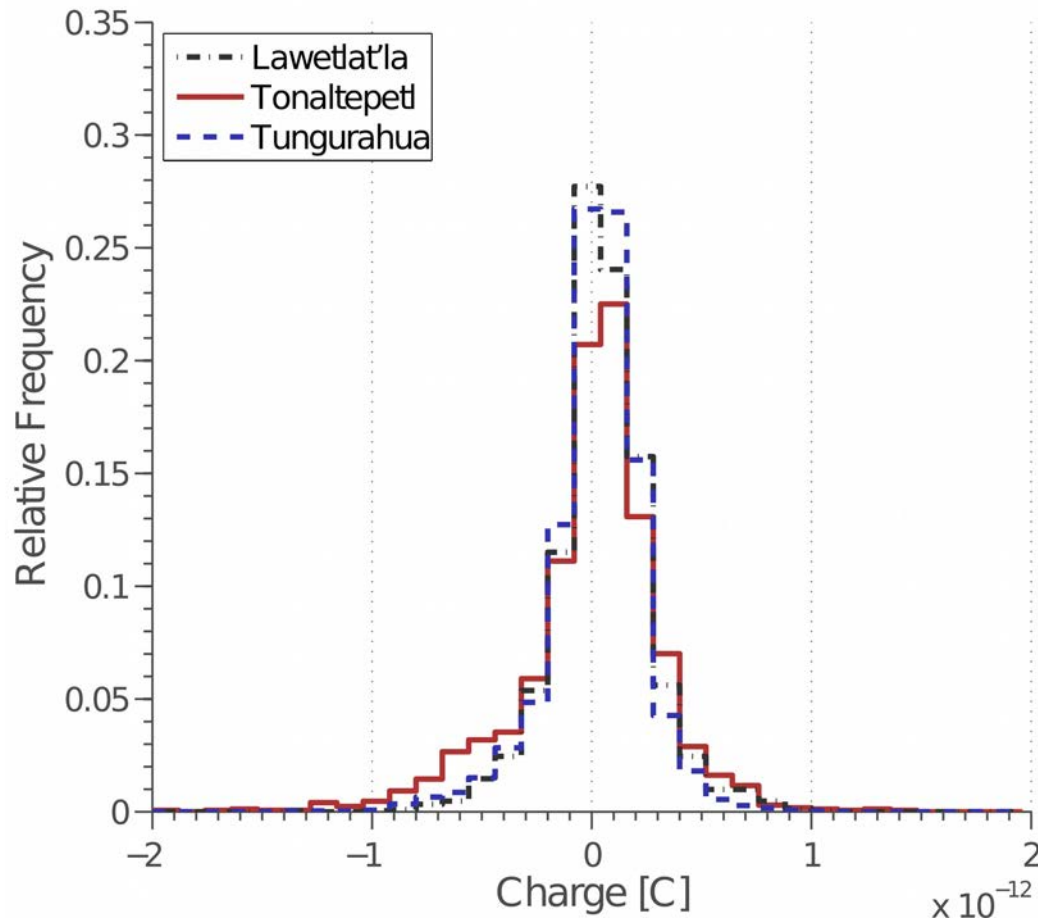
Sampling particles from spouted bed



Measuring charges on single grains



Charge and charge density distributions



The effect of atmosphere

