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ELECTROSTATICS OF GRANULAR MATERIAL (EGM): SPACE STATION EXPERIMENT

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ABSTRACT

Aggregates were observed to form very suddenly in a lab-contained dust cloud, transforming (within seconds) an opaque monodispersed cloud into a clear volume containing rapidly-settling, long hair-like aggregates. The implications of such a "phase change" led to a series of experiments progressing from the lab, to KC-135, followed by micro-g flights on USML-1 and USML-2, and now EGM slated for Space Station. We attribute the sudden "collapse" of a cloud to the effect of dipoles. This has significant ramifications for all types of cloud systems, and additionally implicates dipoles in the processes of cohesion and adhesion of granular matter. Notably, there is the inference that like-charged grains need not necessarily repel if they are close enough together: attraction or repulsion depends on intergranular distance (the dipole being more powerful at short range), and the D/M ratio for each grain, where D is the dipole moment and M is the net charge. We discovered that these ideas about dipoles, the likely pervasiveness of them in granular material, the significance of the D/M ratio, and the idea of mixed charges on individual grains resulting from tribological processes --are not universally recognized in electrostatics, granular material studies, and aerosol science, despite some early seminal work in the literature, and despite commercial applications of dipoles in such modern uses as "Krazy Glue", housecleaning dust cloths, and photocopying.

The overarching goal of EGM is to empirically prove that (triboelectrically) charged dielectric grains of material have dipole moments that provide an "always attractive" intergranular force as a result of both positive and negative charges residing on the surfaces of individual grains. Microgravity is required for this experiment because sand grains can be suspended as a cloud for protracted periods, the grains are free to rotate to express their electrostatic character, and Coulombic forces are unmasked. Suspended grains will be "interrogated" by applied electrical fields. In one module, grains will be immersed in an inhomogeneous electric field and allowed to be attracted towards or repelled from the central electrode of the module: part of the grain's speed will be a function of its net charge (monopole), part will be a function of the dipole. Observed grain position vs. time will provide a curve that can be deconvolved into the dipole and monopole forces responsible, since both have distinctive radial dependencies. In a second approach, the inhomogeneous field will be alternated at low frequency (e.g., every 5-10 seconds) so that the grains are alternately attracted and repelled from the center of the field. The resulting "zigzag" grain motion will gradually drift inwards, then suddenly change to a unidirectional inward path when a critical radial distance is encountered (a sort of "Coulombic event horizon") at which the dipole strength supersedes the monopole strength --thus proving the presence of a dipole, while also quantifying the D/M ratio. In a second module, an homogeneous electric field eliminates dipole effects (both Coulombic and induced) to provide calibration of the monopole and to more readily evaluate net charge statistical variance. In both modules, the e-fields will be exponentially step-ramped in voltage during the experiment, so that the field "nominalizes" grain speed while spreading the response time --effectively forcing each grain to "wait its turn" to be measured.

In addition to rigorously quantifying M, D, and the D/M ratio for many hundreds of grains, the experiment will also observe gross electrometric and RF discharge phenomena

associated with grain activity. The parameter space will encompass grain charging levels (via intentional triboelectrification), grain size, cloud density, and material type.

Results will prove or disprove the dipole hypothesis. In either case, light will be shed on the role of electrostatic forces in governing granular systems. Knowledge so gained can be applied to natural clouds such as protostellar and protoplanetary dust and debris systems, planetary rings, planetary dust palls and aerosols created by volcanic, impact, aeolian, firestorm, or nuclear winter processes. The data are also directly applicable to adhesion, cohesion, transport, dispersion, and collection of granular materials in industrial, agricultural, pharmaceutical applications, and in fields as diverse as dust contamination of space suits on Mars and crop spraying on Earth.


Electrostatics of Granular Materials
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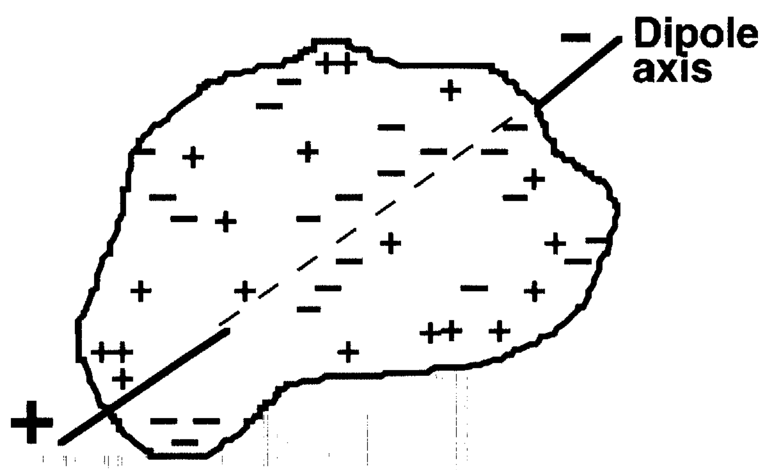
Hypotheses Being Tested

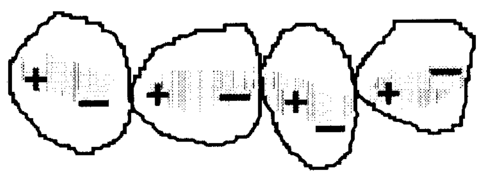
Grains of dielectric material must have a dipole moment, D, if they have a non-uniform distribution of positive and negative surface charges (total net charge determines value of monopole moment, M, regardless of the charge distribution)

For certain granular regimes, interaction of grains is strongly a function of D/M ratio and its relationship to intergranular spacing. D/M has not been experimentally determined for triboelectrically interactive grain populations

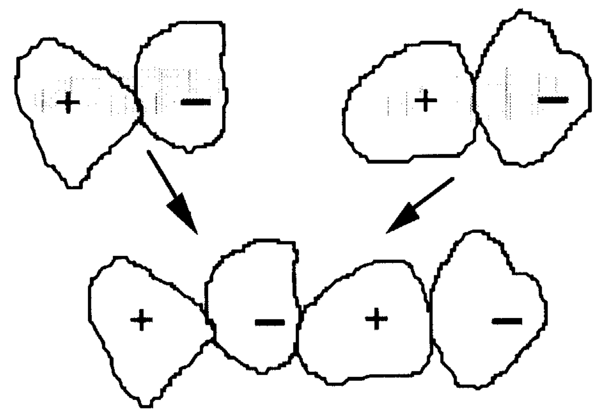


Strength of the dipole is a function of the number of fixed charges, and the distribution of the charges

Current Concepts



Aggregates formed from
discrete dipoles on each grain



Aggregates formed from
dipole couplets of monopoles

EGM versus conventional aggregation concept

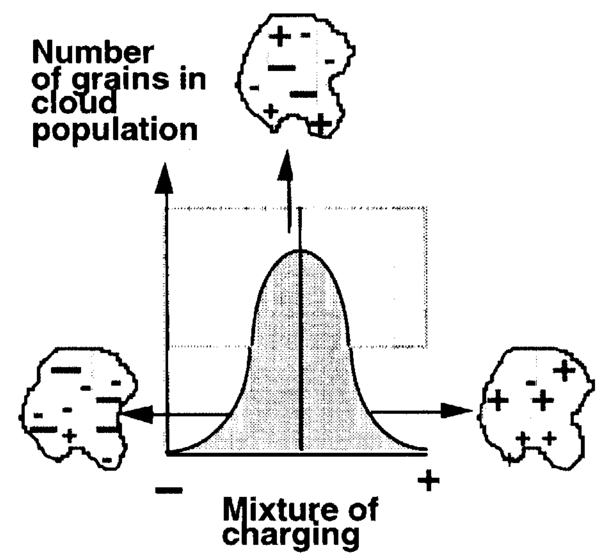
Tribocharging & Dipoles

Grains of like material acquire both + and - charges during grain-grain contact as a result of differential work functions

Causes

- Microscopic surface configurations causing stress field variation
- Structural variation in hardness, surface energy, piezoelectrics, etc
- Protruberance dragged across a surface is dramatically heated compared to scratch line on other surface --thermal discrepancy
- Surfaces transfer material across tribological boundary. For like materials, it is random which grain acquires or loses material

Effects

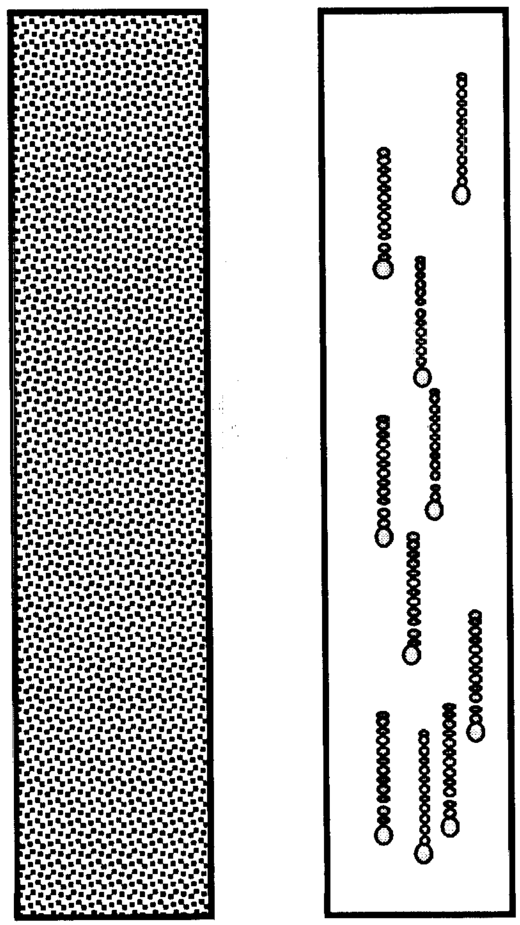


Mixture of monopole and dipole strengths in grain population

Dipoles: *Early Clues*

t = 0

Dense
dust
cloud

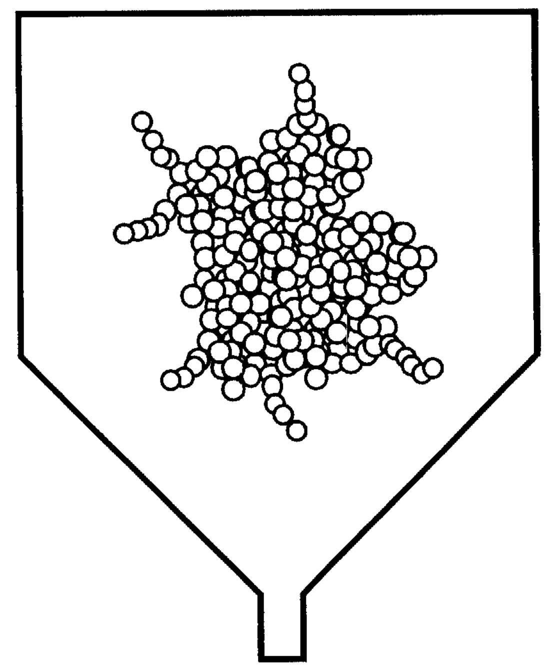


t = 30 seconds

Clear column with
2 cm long settling
filament hairs.
Catastrophic
"phase change"

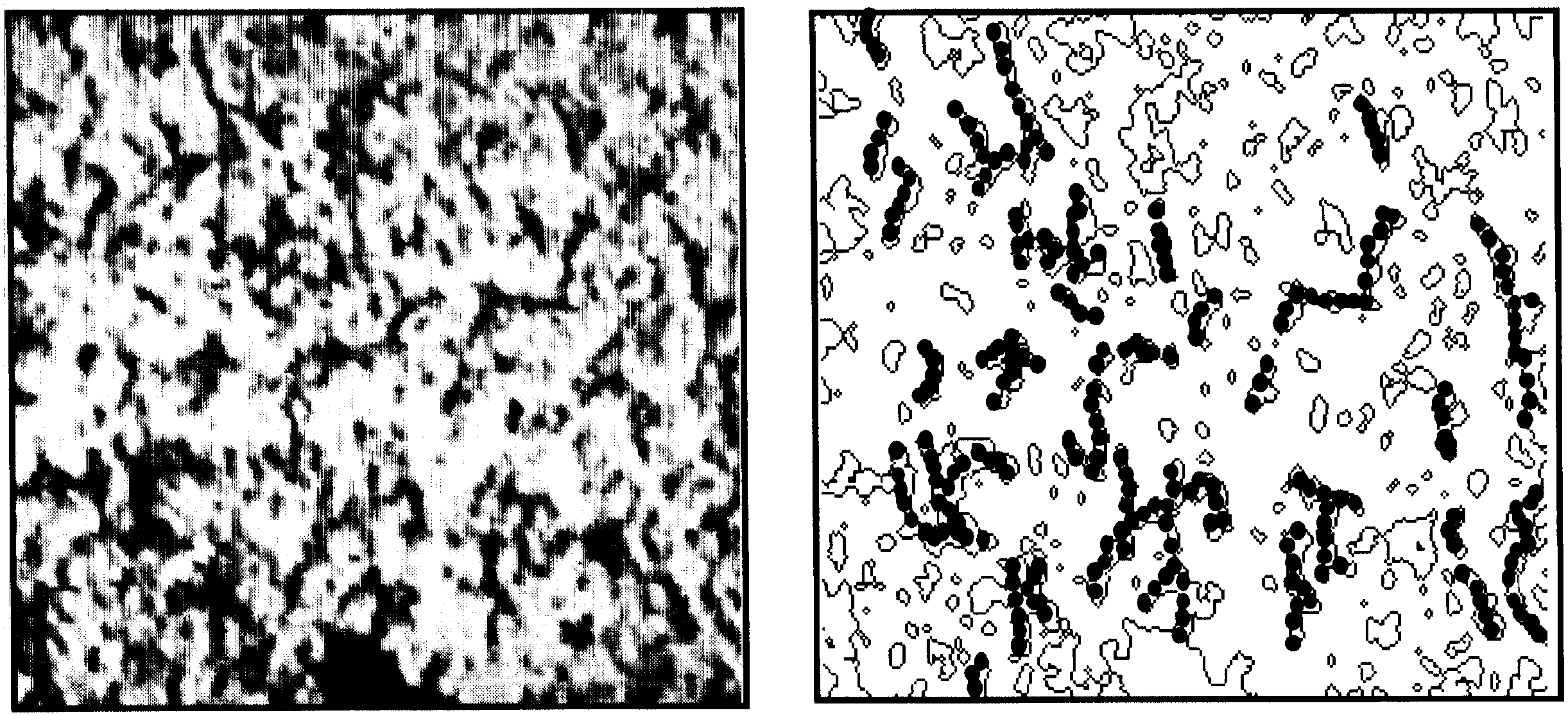
1 m settling column of dust in 1 g

Undispersable sand mass
with filamentary attachments



10 liter container in KC-135 zero-g

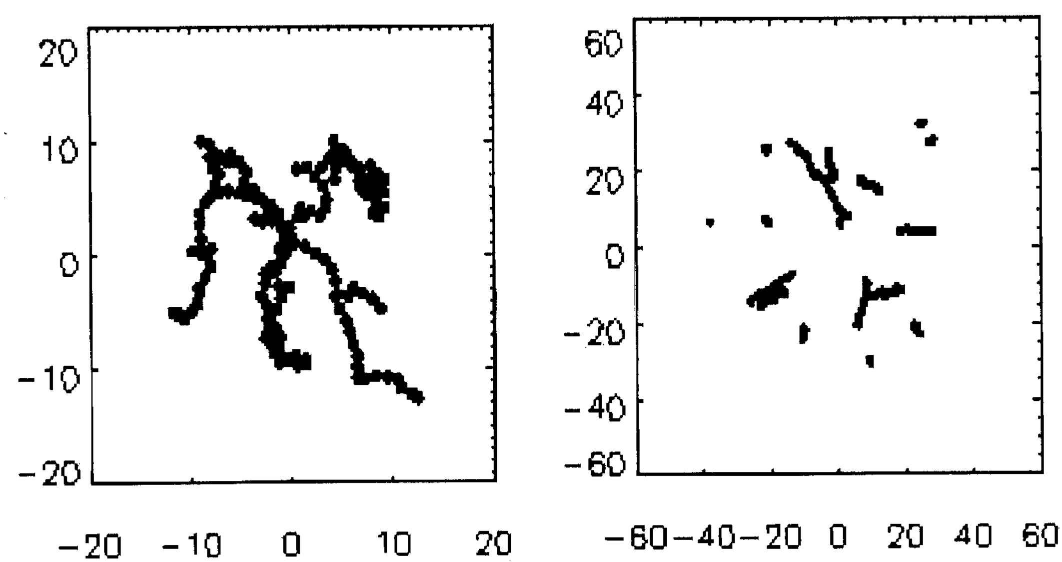
USML-2 Evidence for Dipoles



Filamentary aggregates from dense grain cloud in USML-2 Glovebox. Angular grains of 400 micron diameter quartz

Dipoles in Modeling

- 3-D computer modeling produced same results as USML experiments
- Grains "dispersed" with fixed surface charges, randomly distributed. Each charge just a monopole with corresponding Coulombic force
- No dipoles or D/M ratio artifically embedded in the code
- Chain aggregates always produced, implicating dipoles

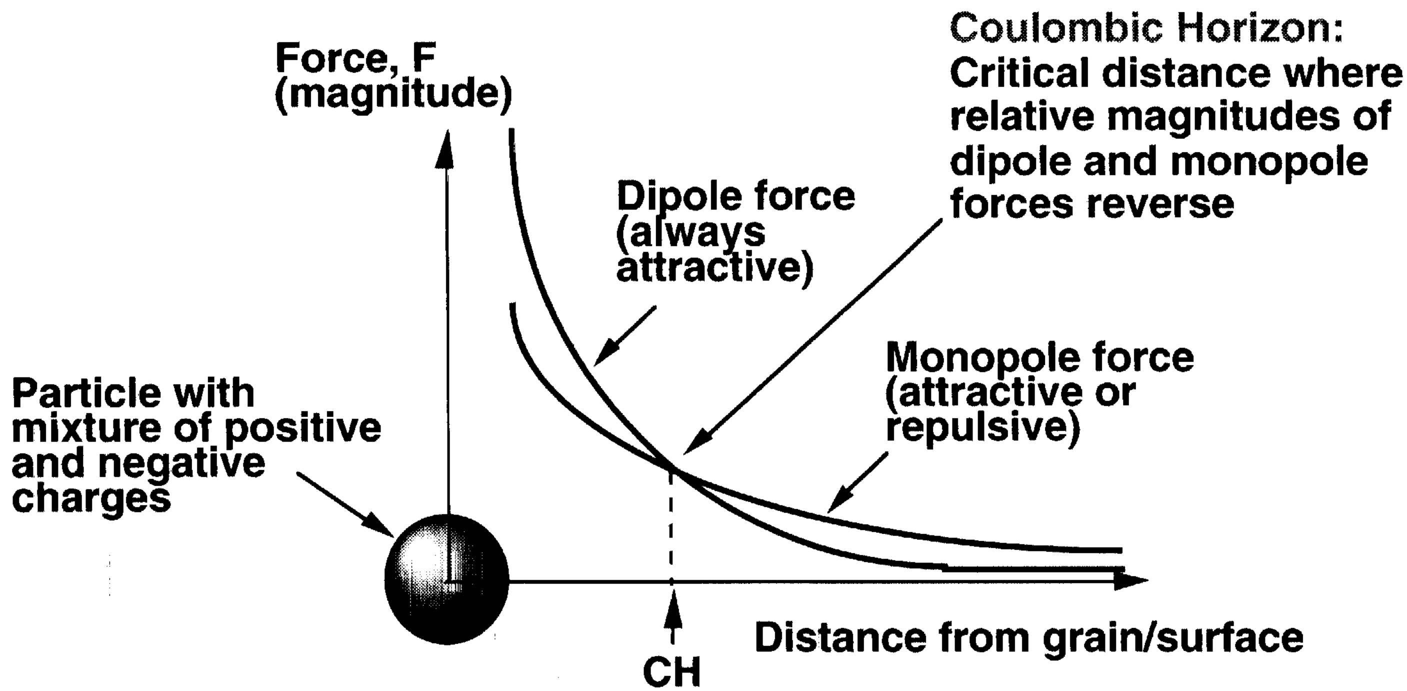


Left: Aggregate from cloud collapse ("neutral" charge-balanced grains with dipoles)

Right: Aggregates (formed by dipole interactions) being dispersed by monopole forces (cloud net charge). Units = grain diam.

Coulombic "Event Horizon"

Interaction of a grain with other grains or with surfaces is function of dipole to monopole (net charge) relationship, and distance between grains and surfaces. Need both D and M

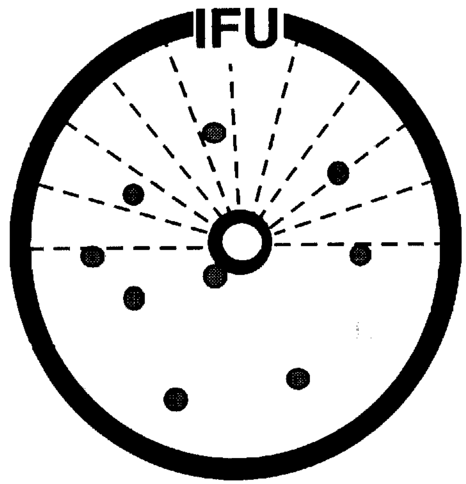


CH can be orders of magnitude larger than grain itself

Experiment Concept

E-Field Manipulation of Suspended Sand Grains

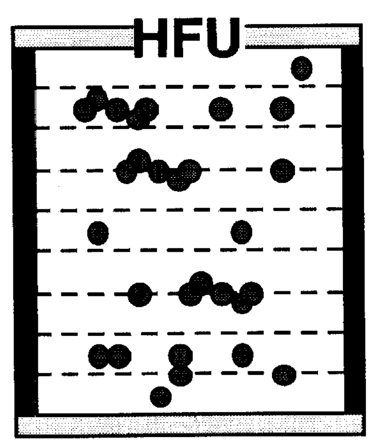
Module Characteristics



- Inhomogeneous radial (2D) field lines
- Dipoles only move to center. Monopoles can move in or out

Prime Measurements & Function

- Radial speed indicates D and M
- Event horizon (r) gives D/M ratio
- Forces expressed:
  Dipole
  Monopole
  Induced polarization



Module Characteristics

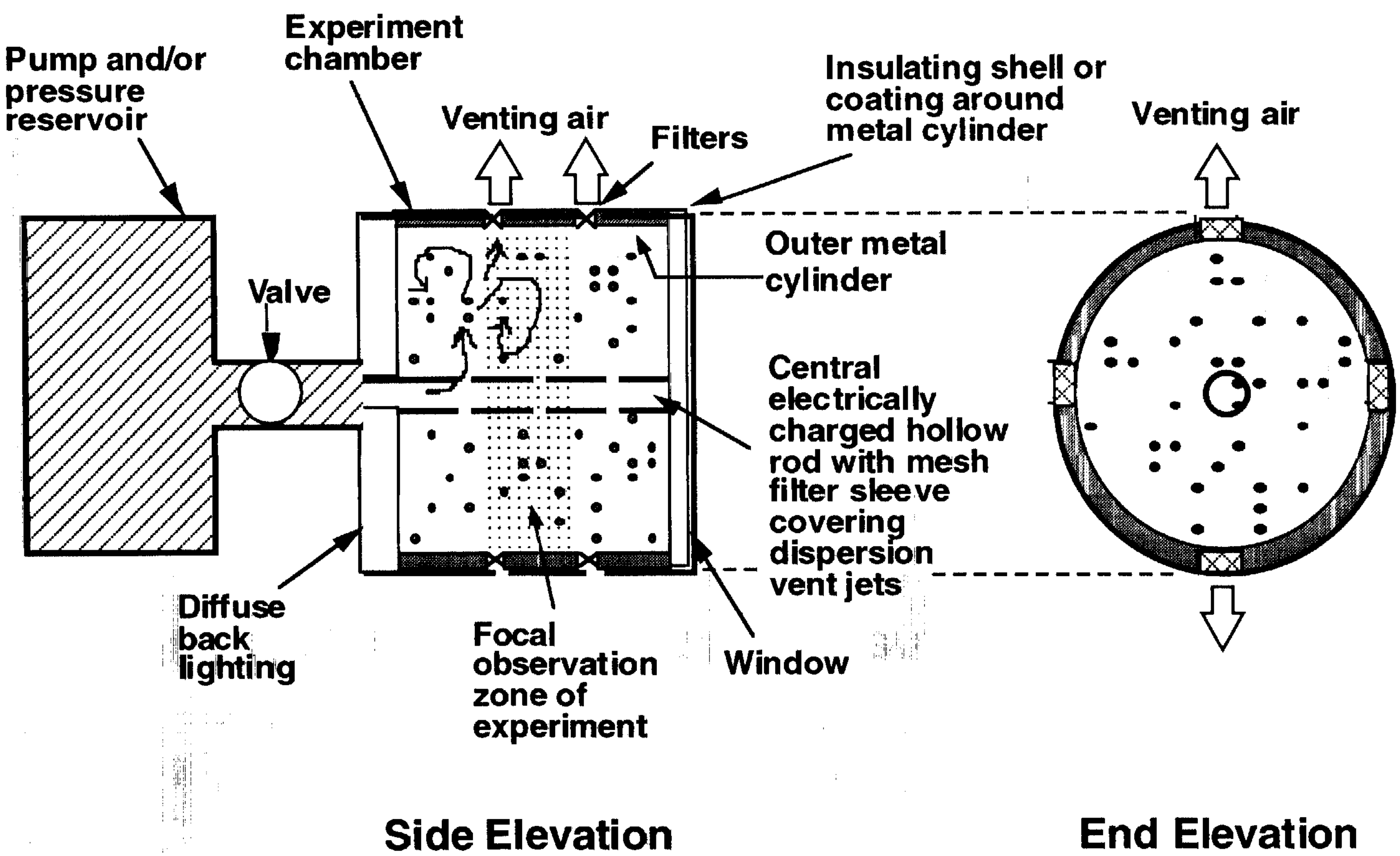
- Homogeneous parallel field lines
- Both aggregates and single grains studied
- Dipoles cannot move in either direction. Monopoles can move both ways

Prime Measurements & Function

- Drift speed of grains & aggregates indicates monopole
- Torque/alignment on aggregates indicates cluster dipole
- Long range forces expressed:
  Monopole

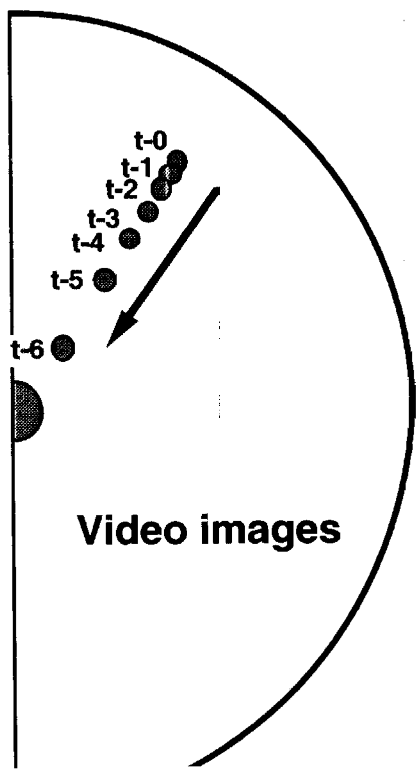
Experiment Description

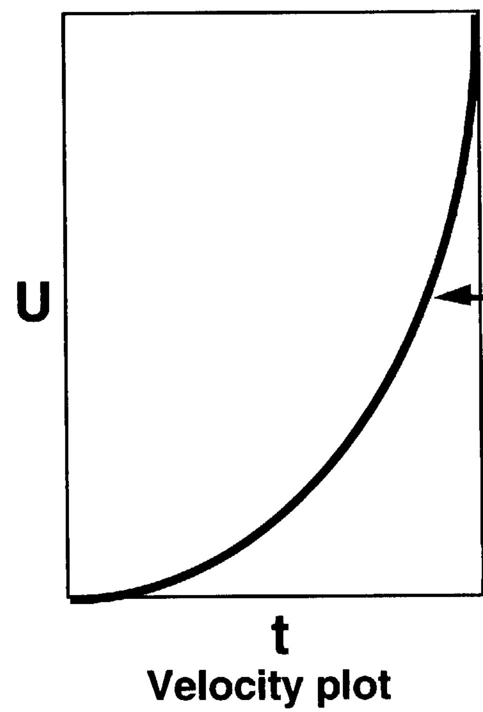
Preliminary Engineering Concept for the IFU



IFU: Grain Interrogation

Method I: Fixed-Polarity Field ------------ Data Acquisition





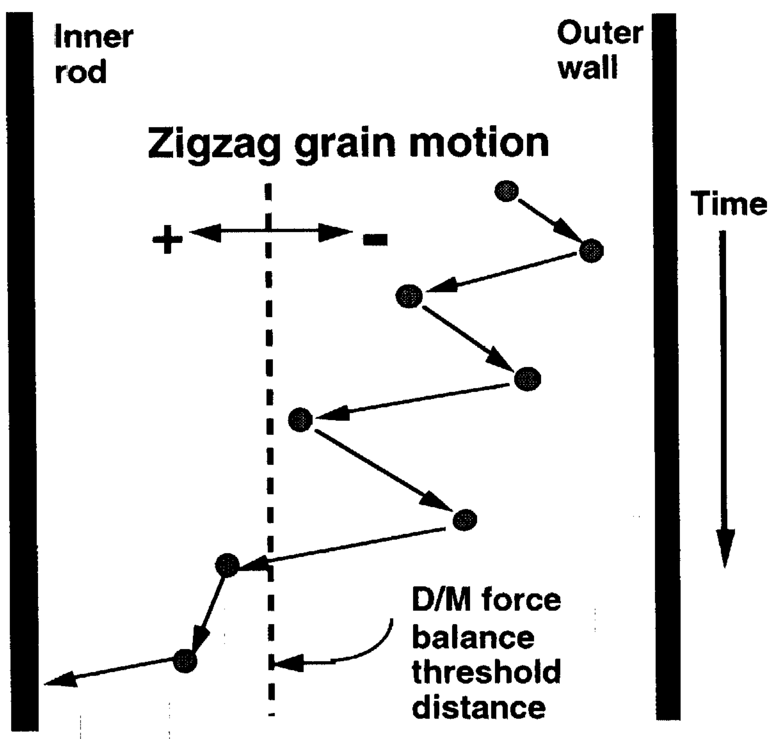
Shape of curve reflects acceleration contributions from: monopole and dipole forces

$1/r$ and $1/r^2$ components

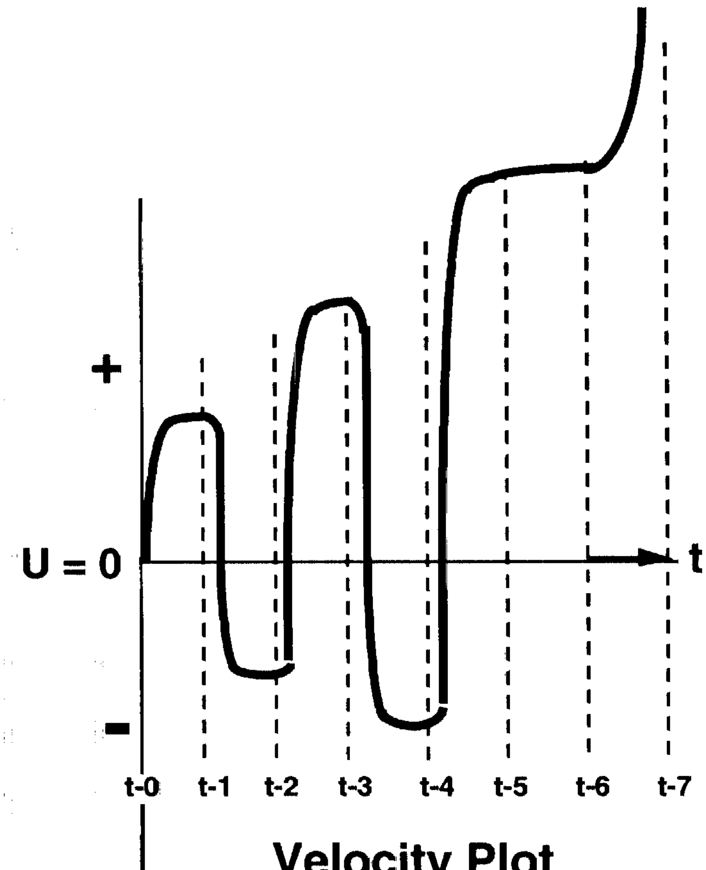
Grain with a dipole rotates dipole axis in alignment with field and is pulled inward. Net charge on grain adds increase or decrease of speed, depending on sign. Depending on distance, net charge can cause drift away from center, but at close range, dipole can override net charge

IFU: Grain Interrogation

Method II: Alternating-Polarity Field --- Data Acquisition For Direct D/M Ratio



Video images



Velocity Plot

IFU: Grain Interrogation

Definition of the D/M ratio

At the event horizon, where Fd and Fm are equal, and the grain is about to enter the "always attractive" zone, it follows that:

$$-M\ k\ V / r + D\ k\ V / r^2 = 0$$

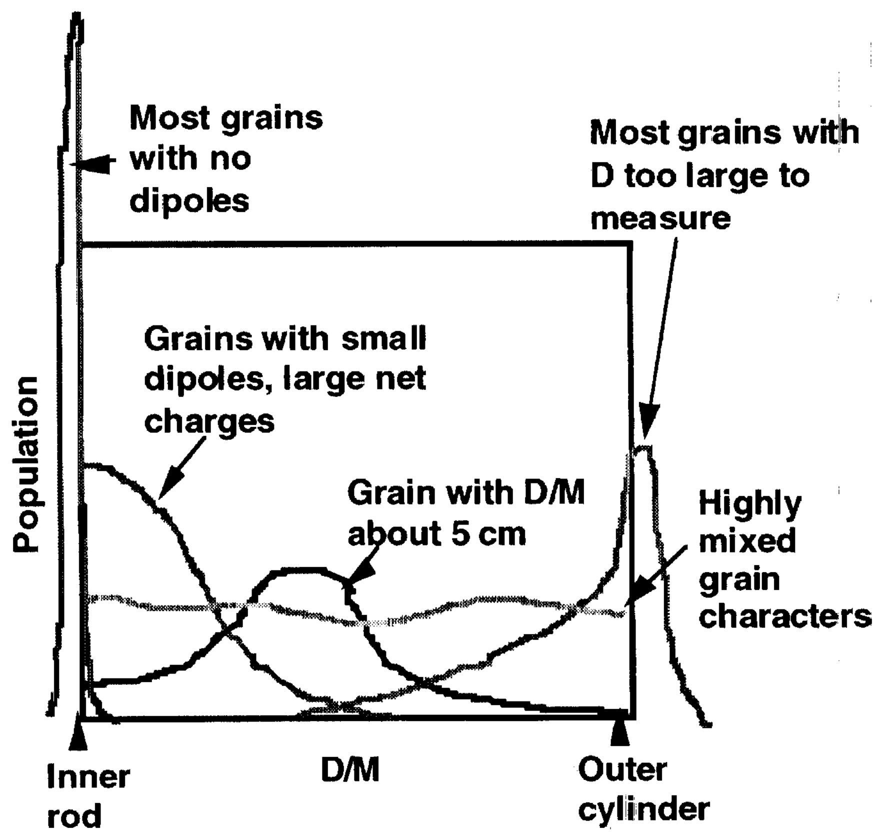
This solves to: $r = D / M$

Thus, the event horizon for a grain is the grain's D/M ratio, by definition, measured in units of length, r

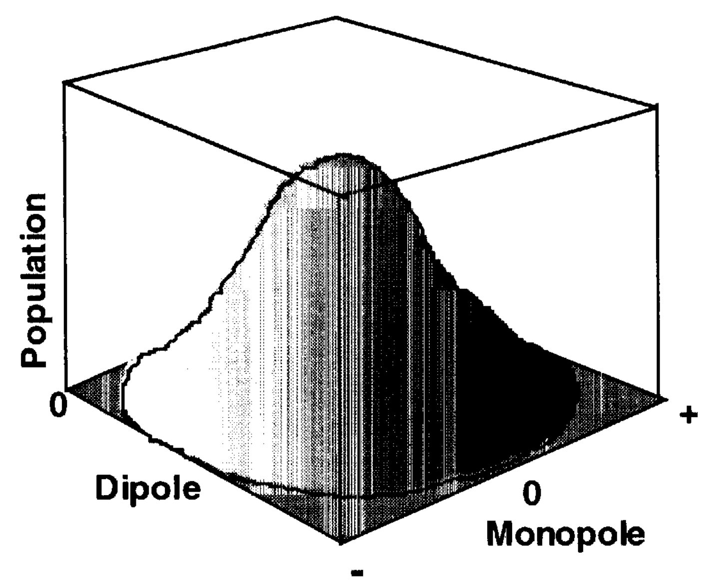
Example Data Product

Scenarios For IFU Population Statistics

Possible D/M Population Statistics for Methods I & II. (Data Sets Directly Comparable in Units of 'r')



Possible D and M Population Statistics from Method I

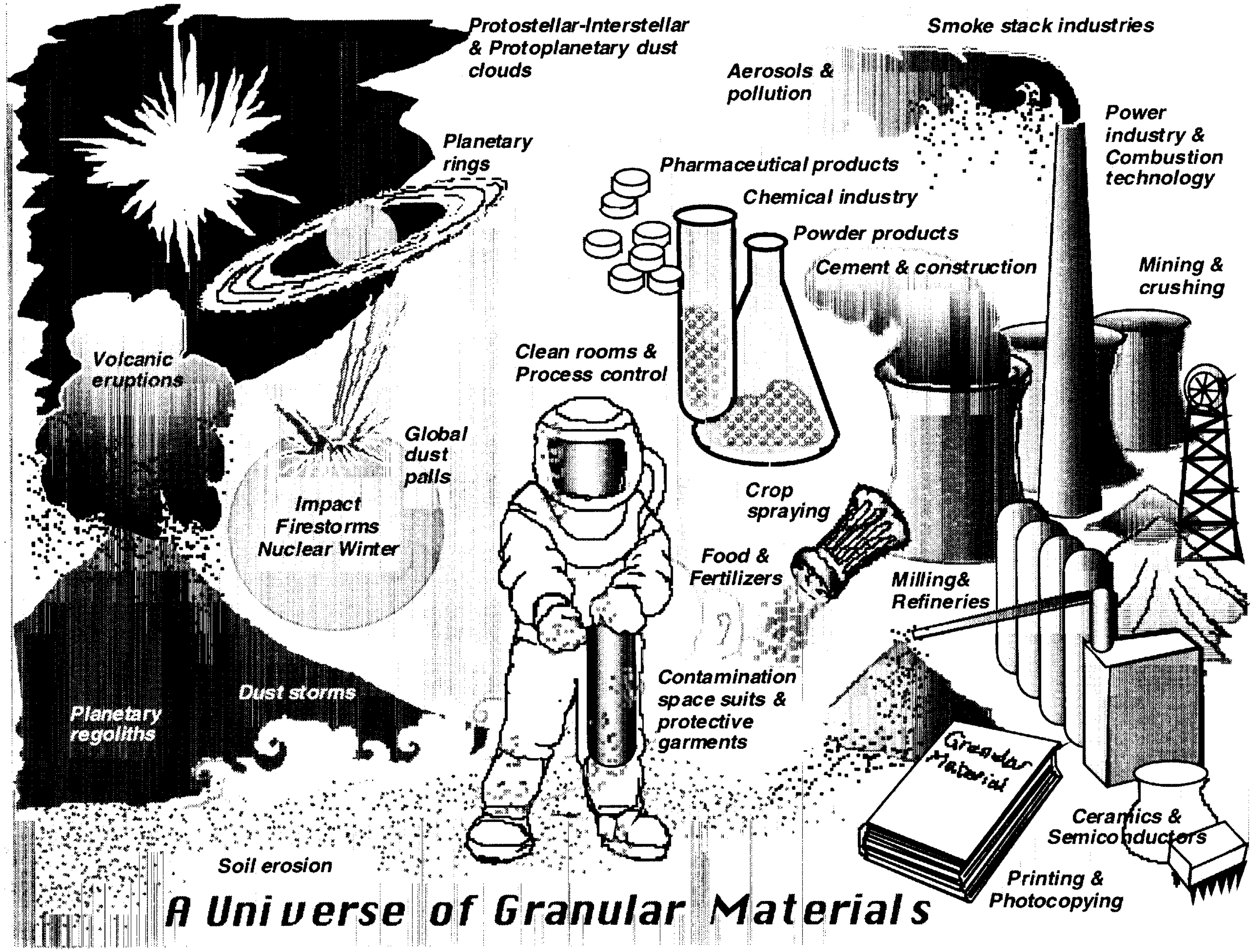


Verification of Hypothesis

- **Measurable values of D in IFU Method I:**
  Proof of dipoles (of magnitude affecting cloud behavior)

- **Measurable D/M ratios in IFU Method II:**
  Proof of dipoles
  Proof of charge mixing on single grains if D/M >grain diameter

- **D/M values too large to measure by IFU Method II:**
  Proves dipoles and that even greater than expected


Protostellar-Interstellar & Protoplanetary dust clouds
Planetary rings
Volcanic eruptions
Global dust palls
Impact Firestorms Nuclear Winter
Planetary regoliths
Dust storms
Soil erosion
Smoke stack industries
Aerosols & pollution
Power industry & Combustion technology
Pharmaceutical products
Chemical industry
Powder products
Cement & construction
Mining & crushing
Clean rooms & Process control
Crop spraying
Food & Fertilizers
Milling& Refineries
Contamination space suits & protective garments
Granular Material
Ceramics & Semiconductors
Printing & Photocopying
A Universe of Granular Materials

Benefits of Research

- Provides fundamental knowledge for electrostatics, granular materials, surface science. Concept of largely unrecognized adhesive/cohesive force

- Knowledge enables modeling of cloud behavior in protostellar and protoplanetary dust-debris systems, planetary rings, planetary dust palls and aerosols created by volcanic, impact, aeolian, firestorm, nuclear winter processes, and atmospheric pollution

- Data directly applicable to adhesion, cohesion, transport, dispersion, and collection of granular materials in industrial, agricultural, pharmaceutical applications, and in fields as diverse as dust contamination of space suits on Mars and crop spraying on Earth