The Laplace project

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for the
Laplace Team

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Objectives for the Laplace experiments

- **How efficient are evolution and growth of dust aggregates in protoplanetary disks?**
  - Brownian-motion driven growth; onset of compaction; evolution of fractal dimension during growth with compaction; occurrence of bouncing; role of cosmic radiation.
- **What are the fundamental aspects of transport phenomena in dust clouds?**
  - Choice of adequate models for rarefied gas dynamic description of particle and gas motion; transition to and manifestation of non-linear response in heavily mass-loaded dust-gas clouds; transition peculiarities of dust-gas clouds to and from granular matter systems.
  - Radiative energy transport in dust clouds.

Microgravity requirement

- **Extremely low collision velocities** (e.g., in Brownian motion driven agglomeration; $v < 10^{-3}$ m/s) and **very long coagulation timescales** (minutes).
- **Gravity-induced compaction** leads to unrealistic agglomerate structures on Earth for agglomerates with more than ~10^5 micron-sized constituents (i.e. with sizes larger than ~100-500 µm).
- **Gravity-induced sedimentation** (or any non-volumetric levitation technique) leads to de-mixing of dust clouds, to alignment and gliding of non-isometric particles and, thus, to unrealistic conditions for zero-gravity environments in space (e.g., protoplanetary disks).

The anticipated Laplace mission

The individual Laplace experiment sequences will be sub-divided into two regimes:

1. Evolution of µm-sized dust particles under Brownian motion and forced agglomeration
   - Evolution of size distribution
   - Fractal dimensions
   - Photo- and thermophoretic properties
   - Two-phase-flow phenomena
2. Collision behavior of individual large dust aggregates
   - Onset of compaction
   - Change in fractal dimension
   - Photo- and thermophoretic properties
   - Fragmentation or mass loss?
   - Does bouncing occur?

Laplace will study ~10 different dust types:

- Dust materials (silicates, oxides, organic materials)
- Monomer sizes (~0.1-1 µm)
- Monomer size distributions (monodisperse, bidisperse, polydisperse)

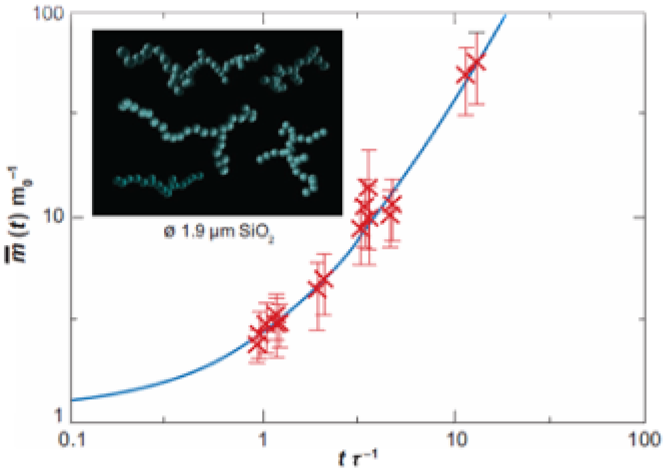
Each sample type will undergo ~10 experiment runs for:

- Statistical significance
- Variation of initial phase of agglomeration (Brownian/forced)

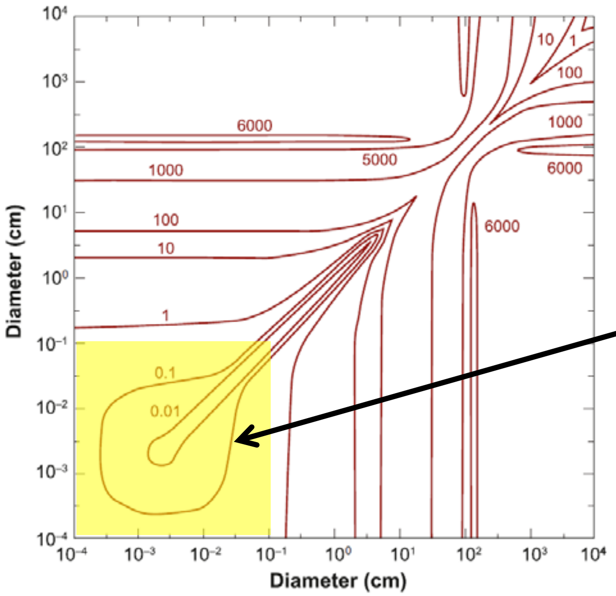
Temporal evolution of a cloud of µm-sized dust particles

So far: mass range factor ~100

Laplace: mass range factor ~10^6



Blum et al. 2000, PRL; Krause & Blum 2004, PRL

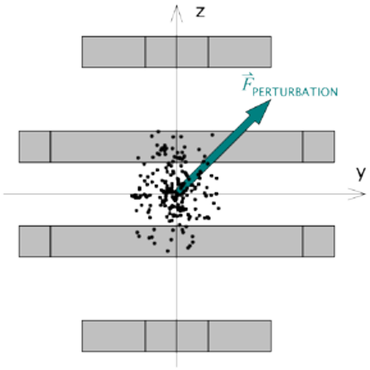


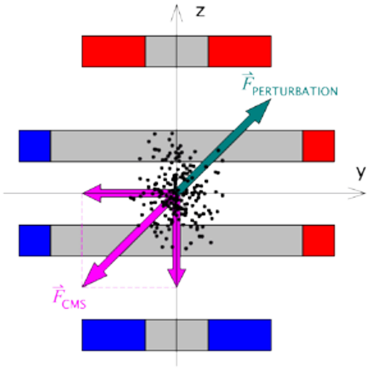
Weidenschilling & Cuzzi 1993

How to achieve this?

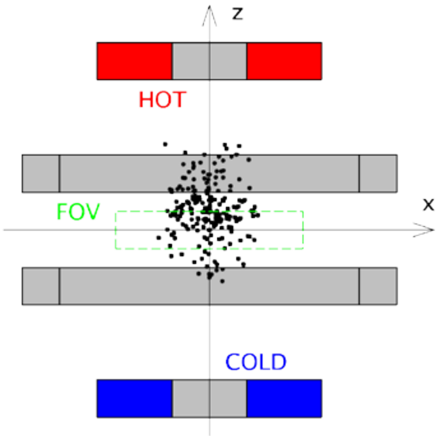
- Compensation of thermophoretic drift
- Dynamical “squeezing” of dust cloud
- Forced low-velocity agglomeration

The cloud manipulation system (static mode)

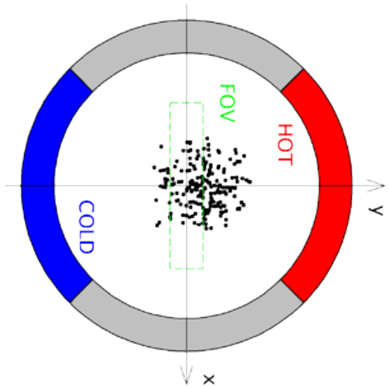




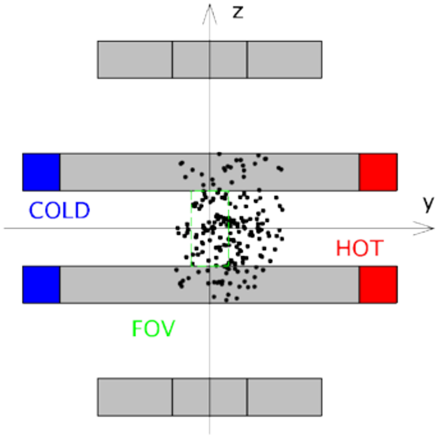
Side view



Top view



Side view



- Compensation of thermophoretic motion of the dust caused by external temperature gradient
- Scanning of dust cloud through the field of view with long-distance microscope and overview camera system.

The cloud manipulation system (static mode)

Movie from drop tower campaign with the CMS showing the positioning mode of the dust cloud. All particles move with the same velocity, regardless of size!

The cloud manipulation system (static mode)

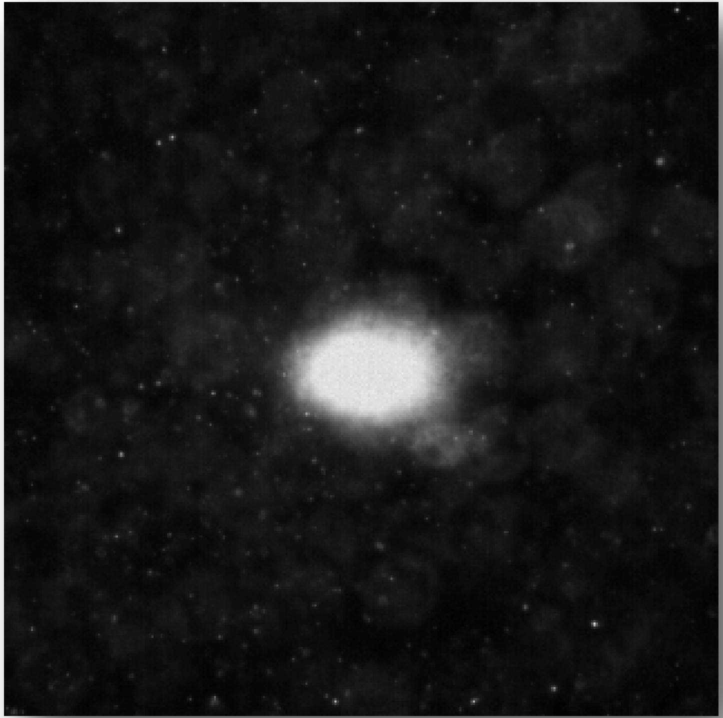
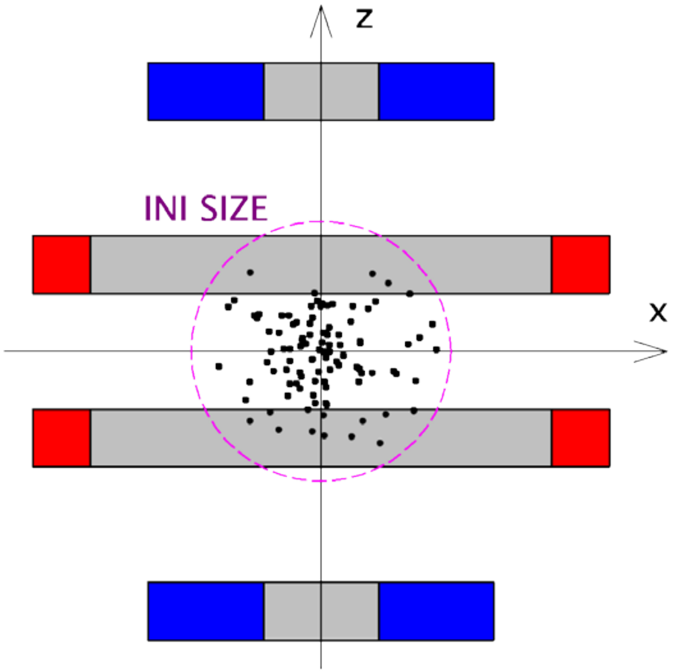


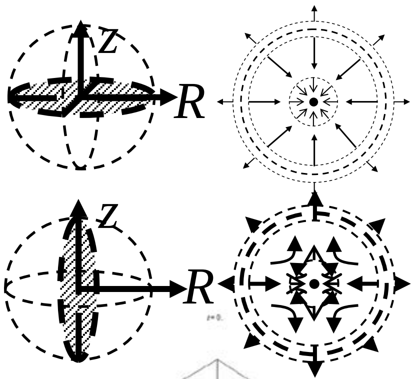
Image sequence from drop tower campaign with the CMS (June 2016) showing a “scan” through the dust cloud with a large agglomerate in the center; the optics were not moved!

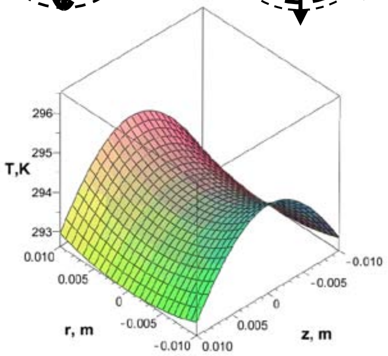
→ 3D information on particle morphology

→ Determination of particle number density

The cloud manipulation system (dynamic mode)

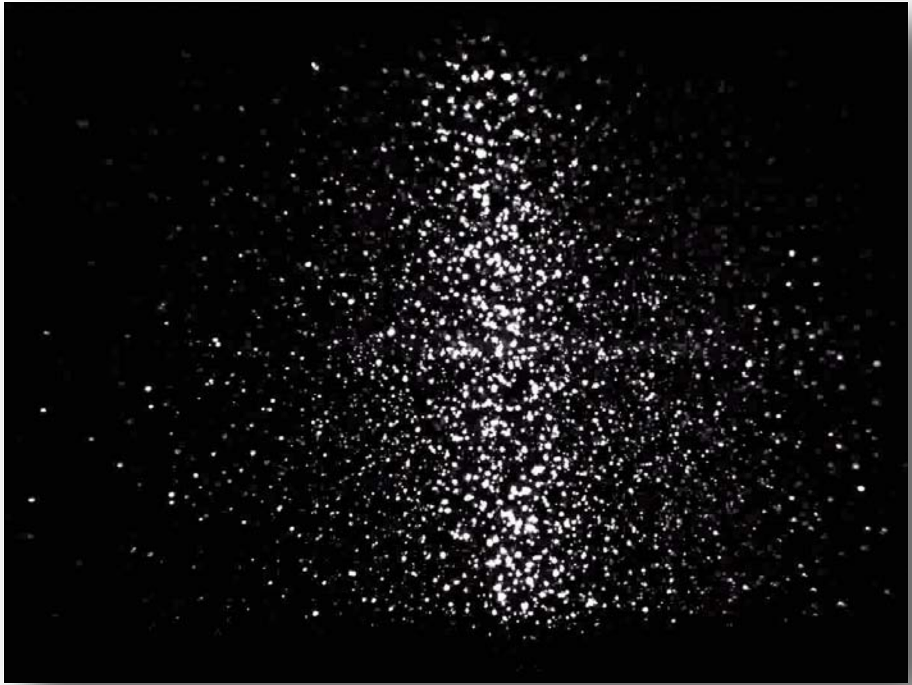






- System works like classical Paul trap
- Compensation of diffusive losses of dust cloud
- Spatial concentration of dust cloud:
  - Shorter collision timescales
  - Higher collision velocities
  - Transition from gas-dominated to dust-dominated flow regime

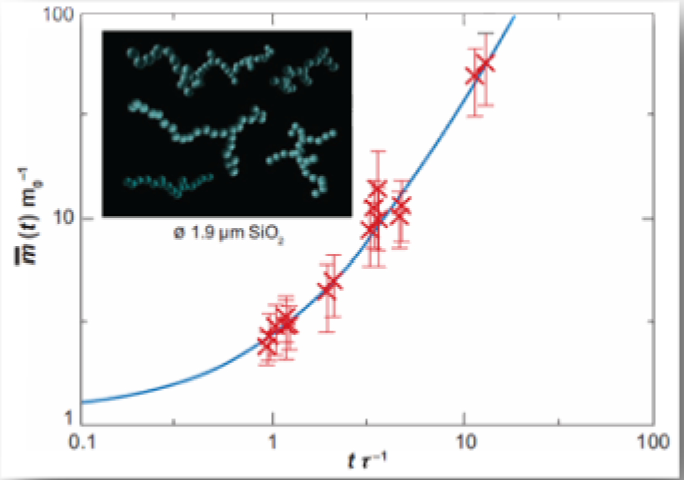
The cloud manipulation system (dynamic mode)



Movie from drop tower campaign with the CMS in dynamic mode showing the cloud reaction to the oscillating temperature field

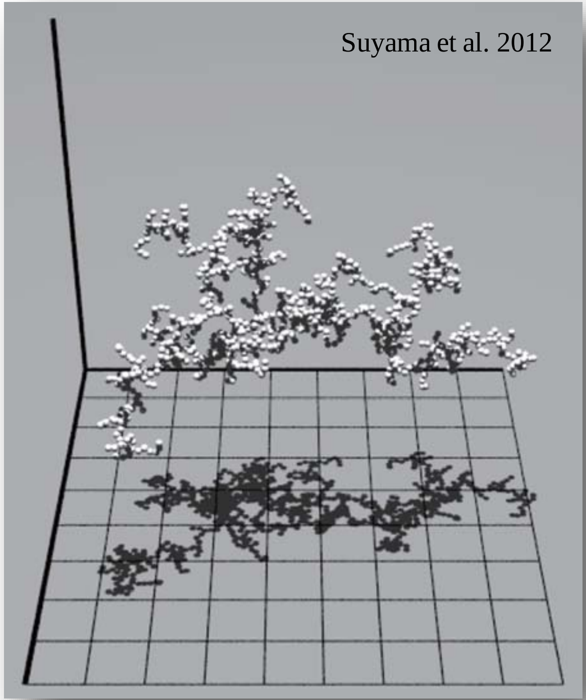
Temporal evolution of a cloud of µm-sized dust particles

So far: mass range factor ~100



Blum et al. 2000, PRL; Krause & Blum 2004, PRL

Laplace: mass range factor ~10^6



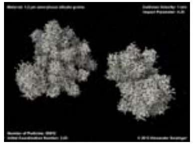
Suyama et al. 2012

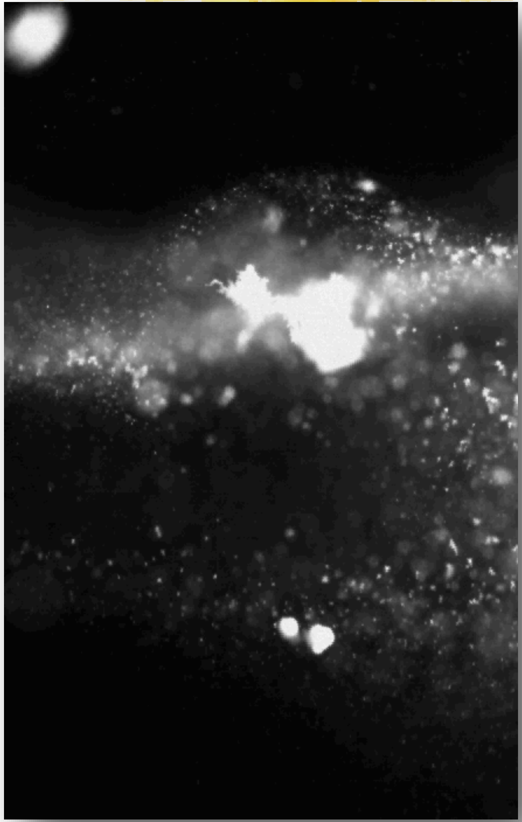
Growth of individual large dust aggregates

Formation of single mm-sized dust aggregate in a drop-tower experiment with extreme settings of the CMS

Collision behavior of individual large dust aggregates

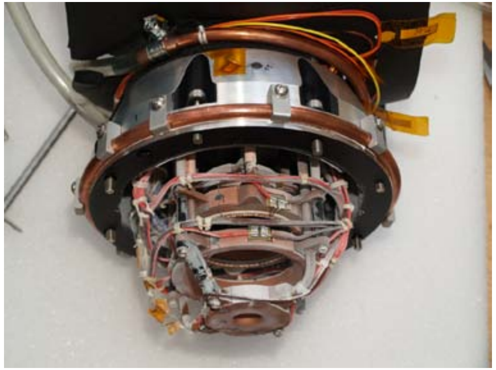
© Alexander Seizngmer

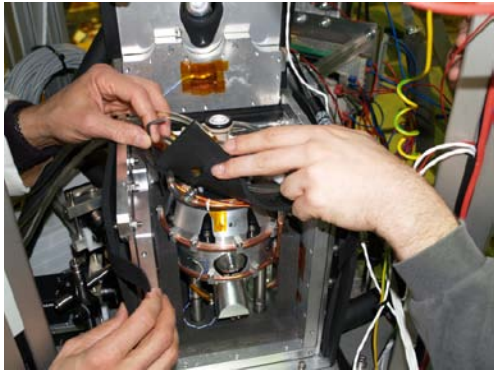




Movie from drop tower campaign with the CMS in dynamic mode showing the collision of a compact agglomerate (projectile) with a fluffy target

The CMS hardware





- Hardware consists of fast micro-Peltier elements.
- Design and performance were optimized in drop tower experiments in 2008, 2010, 2011, 2012, 2016.
- Hardware shall also be equipped with electrostatic unit to determine the charge state of the particles.

Experiment sequence

- Dust cloud injection
- Science sequence I:

  Brownian motion and low-velocity agglomeration; two-phase-flow phenomena; photo- and thermophoresis (~5-100 min)
- Science sequence II:

  Investigation of largest agglomerate grown by Brownian motion and low-velocity agglomeration (~1 min)
- Science sequence III:

  Forced agglomeration; two-phase-flow phenomena; photo- and thermophoresis (~2-10 min)
- Science sequence IV:

  Investigation of the largest 2-3 agglomerates grown by forced agglomeration (~2 min)

The Laplace mission architecture

- Mission Configuration:
  - 12U hosted payload (ISS)
  - 24U free-flying small satellite in low Earth orbit
- Experiment Configuration:
  - Experiment chamber (purged with N_2 at 100 Pa pressure), passively thermally stabilized
  - Cogwheel-type dust dispenser with dust-storage containers
  - Cloud manipulation system (CMS)
  - Long-distance microscope (LDM), ~1 µm spatial resolution, with high-speed camera (1 Mpixel, 1000 fps); FOV: ~ $1 \times 1\ mm^2$
  - Overview cameras (OOS); FOV: ~ $1 \times 1\ cm^2$
  - Laser/LED illumination for LDM, OOS and photophoresis experiments
  - Software/hardware for automatic positioning of individual dust aggregate into the FOV of LDM/OOS

The Laplace team

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