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DOCUMENT

Vibration Induced Phenomena in Granular Materials (VIP-GRAN)
Experiment Scientific Requirements

Prepared by	**Olivier Minster**
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APPROVAL

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Science Team coordinators on behalf of the team members: Eric Falcon Nicolas Vandewalle Matthias Sperl		
Physical Sciences Unit head: O. Minster		
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1 INTRODUCTION

Project ID: AO-2004-121
Title: Behaviour of Granular Dissipative Gas under Vibration and Cluster Formation (SPACEGRAINS)
And ID: AO-2009-0943
Title: Compaction and Sound Transmission in Granular Matter (COMPGRAN)

Acronym of the instrument: VIP-Gran

Team Members:

Name	Address	email
Eric Falcon Co-coordinator	CNRS-Université Paris Diderot Tel.: +33 1 57 27 62 19	eric.falcon@univ-paris-diderot.fr
Nicolas Vandewalle Co-coordinator	Dept Physique, University Liège, Belgium Tel.: +32 80 880 921	nvandewalle@ulg.ac.be
Matthias Sperl Co-coordinator	Institut fuer Materialphysik im Weltraum, DLR, Cologne Tel.: +49 (02203) 601-3434	matthias.sperl@dlr.de
Yves Garrabos	CNRS-ICMCB, Pessac, France, Tel.: +33 5 40 00 63 37	garrabos@icmcb-bordeaux.cnrs.fr
Carole Lecoutre	CNRS-ICMCB, CNRS Pessac, France	carole.lecoutre@icmcb-bordeaux.cnrs.fr
Angel Garcimartín Montero	University Navarra, Pamplona, Spain Tel.: +34 948425600 ext. 6385	angel@unav.es
Diego Maza Ozcodi	University Navarra, Pamplona, Spain	dmaza@unav.es
Meiying Hou	IoP, CAS, Beijing	mayhou@aphy.iphy.ac.cn
Pierre Evesque	CNRS-Ecole Centrale Paris	pierre.evesque@ecp.fr
Stephan Fauve	Ecole Normale Supérieure	fauve@lps.ens.fr
Sébastien Aumaitre	CEA Saclay	Sebastien.aumaitre@cea.fr
Michaël Berhanu	CNRS-Université Paris Diderot	Michael.berhanu@univ-paris-diderot.fr
Robert Behringer	Duke University	bob@phy.duke.edu
Eric Clement	LMDH – PMMH	Eric.clement@upmc.fr
Stefan Luding	Multi Scale Mechanics, Twente University	s.luding@utwente.nl
Matthias Schroeter	Max Planck Institut für Dynamik und Selbstorganisation	Matthias.Schroeter@ds.mpg.de
Stefan Egelhaaf	Univ. Düsseldorf	Stefan.Egelhaaf@hhu.de
Axelle Amon	Univ. Rennes	Axelle.Amon@univ-rennes1.fr
Jérôme Crassous	Univ. Rennes	Jerome.crassous@univ-rennes1.fr
Douglas Durian	Univ. Pennsylvannia	djdurian@physics.upenn.edu
Xiaoping Jia	LPMDI, Un. Marne la Vallée	jia@univ-mlv.fr
Ralf Stannarius	Otto van Guerike Univeristy Magdeburg	ralf.stannarius@ovgu.de

ESA project scientist: Olivier Minster, HSO-USP, Olivier.Minster@esa.int (+31-71 565 4764)

ESA instrument project manager: Marco.Martella, HSO-UPM, Marco.Martella@esa.int (+31-71 565 4846)

2 GENERAL DESCRIPTION

2.1 Objectives

The aim of SPACEGRAINS and COMPGRAN experiments is to study the dynamical and statistical properties of granular media in low-gravity environment, from dilute to dense regimes. It is of primary interest to better understand rheology, flow and dynamics of granular media subjected to vibrations.

Beyond the spatial interest (management of a granular in space, of powder propellants of rockets, and better understanding of planetary ring dynamics), the motivation for low gravity is to achieve an experimental situation in which inelastic collisions between particles are the only interaction mechanism. The only time scale for such a granular system in low gravity is the period of vibrations that thus strongly simplifies the modelling of the system by using simple dimensional analysis. Long run experiments are also necessary since transient phenomena are of quite long duration for granular systems.

The objective is to perform unique measurements on granular gas (clustering and phase transitions), convection, segregation and jamming in granular materials subjected to vibrations without the symmetry breaking influence of gravity.

2.2 Experiment Specific Objectives

The specific objectives are to experimentally answer to basics questions:
How a granular gas (which is intrinsically dissipative due to inelastic collisions) deviates from the elastic limit of usual gas when dissipation increases?
What is the phase diagram of dynamical states of such an out-of-equilibrium dissipative gas?
What is the spatial distribution of an applied mechanical stress or acoustic deformations within a granular without confinement pressure of grains due to their own weight?
What is the large-scale dynamics of a dense granular medium mediated by a convection-like mechanism (when two walls vibrates with different velocities as a "thermal gradient"-like forcing)?
What is the segregation mechanism in a granular composed of two types of particle species in low gravity?

For this purpose, systematic experiments have to be performed from dilute to dense regimes, as described below (see also http://spacegrains.org/ for recent updates).

2.2.1 Principle of the experiment

The basic principle of the experiment consists in a 3D closed cell containing particles. Two opposite walls of the cell are pistons that vibrate in-phase or out-of-phase. Their opposite motion allows for injection of mechanical energy in the system. It is expected that the balance between this energy input and dissipative collisions of the particles will drive the system towards different stationary out-of-equilibrium regimes.

Four different Working Packages (WP) have been selected. **WP1: Dilute systems (granular gas), WP2: Dense systems, WP3: Convection, and WP4: Segregation and aspherical particles.**

2.2.2 Granular gas (WP1)

A dissipative granular gas differs from a usual gas due to the inelastic collisions between particles. Continuous injection of energy is thus necessary to sustain a stationary state in this dissipative out-of-equilibrium system. We will experimentally study how a granular gas deviates from the quasi-elastic limit (usual gas) when dissipation increases in the system. One way to do that is to increase the volume of the container at a constant particle density all things being equal. Another set

of experiments will be devoted to quantify more precisely the clustering transition in order to establish the phase diagram between gas- and solid-like phases.

2.2.3 Cooling of granular gas (WP1)

The study of the relaxation of a granular gas once the forcing is stopped will be also investigated. Such an experiment is hardly achievable on Earth due to the gravity restoring force, and need, in low-gravity, a very low level of g-jitter such as in ISS. Understanding of such a granular gas "cooling" is important for particle management in Space and to know how an out-of-equilibrium stationary system returns to equilibrium.

2.2.4 Stress distribution in dense granular matter (WP2)

The behaviour of a granular material in dense regimes near the jamming transition is of particular interest at a fundamental and a more applied level. Without confinement pressure of grains due to their own weight, knowing the spatial distribution of stresses or acoustic deformations will be obtained by the use of stress-birefringent beads. In addition, sound (transmission and scattering) shall be measured both internally by stress-birefringence as well as by impact force sensors at the walls.

2.2.5 Convection (WP3)

The large-scale dynamics of a dense granular medium mediated by a convection-like mechanism will be investigated. To mimic a "thermal gradient" forcing, two cell walls will vibrate with different velocities and phases. The corresponding "cold" and "hot" walls are expected to drive the system into a convective-like motion. The relevant parameter that controls convection is not yet established without confinement pressure of grains due to their own weight. Long runs are necessary since convective motions are quite slow.

2.2.6 Segregation (WP4)

Another subject of interest is the segregation mechanism of binary mixtures (particle species of different sizes, shapes or densities). On Earth, segregation is frequently observed due to different mechanisms: convection by friction to boundaries, percolation of small particles under large ones known as "Brazil nuts" effect, etc. In absence of gravity, the segregation mechanism is unknown. Its knowledge will give new insights in the management of particles in weightlessness.

2.2.7 Phase separation (Maxwell's demon) (WP4)

In a dilute regime, the transfer of grains from a compartment to another connected by a slit shall be investigated. This experiment is also called a Maxwell's demon experiment. This experiment shall study, in a dilute regime, how the transfer rate of grains varies with the volume fraction. With gravity, the phase separation is controlled by the ratio between the gravity potential energy at the altitude of the slit and the mean kinetic energy per particle. In absence of gravity, the mechanism of phase separation is an open problem.

2.2.8 2D granular systems (WP1, WP2, WP4)

Similar experiments as in WP1, WP2 and WP4 will be performed in a quasi-2D cell. This cell enables much more simple tracking of each particle with one single camera than with respect to 3D cells.

2.3   Experiment description

As schematically shown in the figure below, the instrument consists of a 3D cell filled with particles where two opposite container walls act as vibrating pistons. Different cells will be used, split into different compartments or not, and will be interchangeable on the instrument. For instance, one cell is adjustable in length. Control parameters are the number of particles N, the cell length L, and the amplitude, a, and the frequency, f, of vibrations. Impact force sensors will be implemented to resolve collisions of particles on cell walls to notably deduce the experimental distributions of particle velocity, of time of flight between two successive collisions with a wall. Accelerometers screwed in the shaft of each vibrating piston will enable to infer mean injected power and the temporal fluctuation of injected power. Two cameras will enable to visualize the system, and perform quantitative measurements from particle tracking in dilute regime and correlations between particle displacements. Several experiments will be performed from dilute to dense fillings.
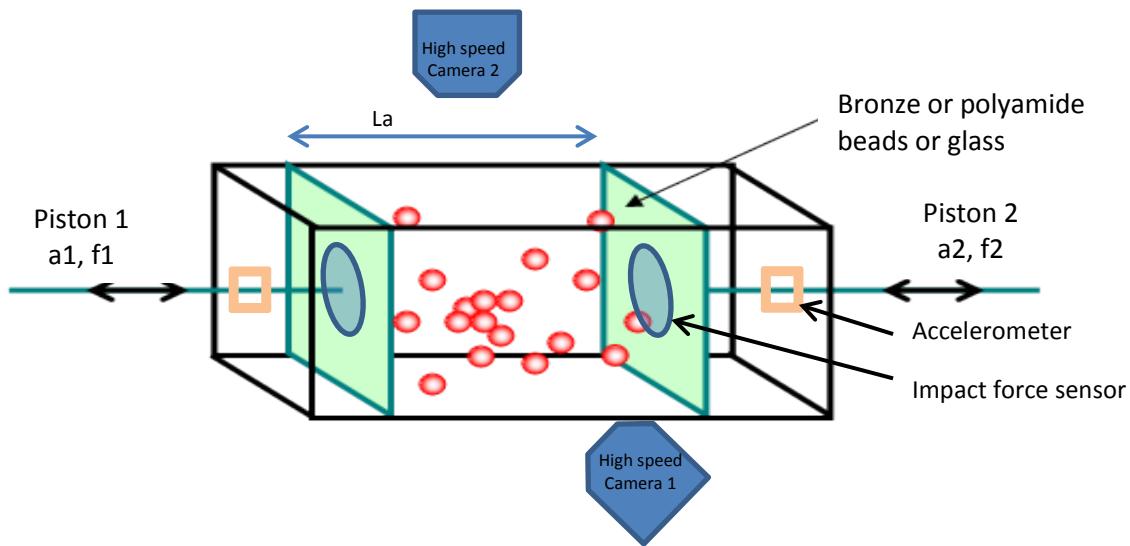
The typical protocol is as follows. At the beginning of a run, one shall "refresh" initial conditions by a slow (or rapid) motion of the pistons in some direction before starting vibrating at a definite amplitude and frequency. Then, different experiments are performed with various forcing parameters and filling (number of beads or type of bead).

2.4   Justification of the need for space experiments

One of the most astonishing properties of granular matter under vibrations is its tendency to form clusters of particles. Although this has probably been known since the early observation of planetary rings, only few experiments have been performed which display cluster formation. Furthermore, ground based experiments are perturbed by gravity and by the coherent friction force which acts on all the particles and which is far from being negligible. Low-gravity environment is thus needed for dilute regimes of vibrated granular medium because it is the only way to achieve the experimental situation in which inelastic collisions are the only interaction mechanism. Low-gravity environment is also needed to better understand the rheology and the jamming transition of dense granular media without confinement pressure of grains due to their own weight. Weak mechanical or acoustic vibrations can be then applied to the granular medium to probe and control its rheology near the onset of jamming.

The time scale for granular matter subject to vibrations to reach a steady state configuration or for mechanism such as segregation to be observed and the study of the transients to reach that configuration calls for long duration experiments in free-fall conditions. On top of acquiring statistically representative observations, the number of parameters that influence the state of granular matter requires to perform numerous consecutive experiments. The ISS is therefore the platform favoured for operating the VIP-Gran facility.

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2.5   Previous flight experiments (precursors)

MiniTEXUS-5

This sounding rocket experiment was performed in 1998 in order to study granular media in low-gravity environment. It led to the first observation of clustering formation in a granular gas in low gravity due to the inelastic collisions between particles. Results were published in Physical Review Letters 83, 440 (1999) and were commented in the American scientific press (Science, Science News and Physics News in 1999)

MAXUS-5

This follow-on experiment was carried out in 2003 to study the dilute regime of granular gases in low gravity. By means of 7 cells filled with different volume fractions, different phases of granular matter under vibration were observed such as gas-, liquid-, and solid-like phases.

MAXUS-7

This sounding rocket mission took place in 2006. The cell was made of one 3D compartment (with visualization on two perpendicular directions), and of one 2D compartment. The goal was to confirm the formation of the 3D and 2D liquid-like clusters.

REXUS-10

This sounding rocket was launched in 2011 to study a granular gas constituted of aspherical particles (rod-like). For such an anisotropic granular gas, the mean free path of particle is considerably reduced with respect to a granular gas of spherical particles at the same volume fraction. No clustering is observed and the principle of equipartition of kinetic energy between rotations and translations is violated. Results were published in Physical Review Letters 110, 144102 (2013).

PARABOLIC FLIGHTS

Parabolic flight experiments were performed by several of the members of the Science Team notably to prepare the above sounding rocket experiments. Some campaigns have shown the ability of impact force sensors to record the collision frequency and of the impulses on a container wall and to give access to several quantities of interest. For instance, contrary to usual gases, the mean collision frequency in a granular gas is found to not scale linearly with the number of particles in the container [see EPL 74, 830 (2006)]. This is due to the dissipative nature of the collisions and is also directly related to the non-extensive behaviour of the kinetic energy (the granular temperature is not intensive). In the parabolic flight campaign DLR-13 in 2009 (Sperl et al), the compaction was demonstrated for a dense stress-birefringent sample in three dimensions, cf. [P. Yu, A. Boerngen, S. Frank-Richter, and M. Sperl, Granular Matter, accepted for publication (2013)].

2.6   Reference publications

E. Opsomer, M. Noirhomme, N. Vandewalle and F. Ludewig, Phys. Rev. E 88, 012202 (2013)

How dynamical clustering triggers Maxwell's demon in microgravity

E. Falcon, J.-C. Bacri, and C. Laroche, EPL 103, 64004 (2013)

Equation of state of a granular gas homogeneously driven by particle rotations

K. Harth, U. Kornek, T. Trittel, U. Strachauer, S. Höme, K. Will, R. Stannarius, Phys. Rev. Lett. 110, 144102 (2013)

Granular gases of rod-shaped grains in microgravity

W. T. Kranz, M. Sperl, A. Zippelius, Phys. Rev. E 87, 022207 (2013),

The Glass Transition in Driven Granular Fluids: A Mode-Coupling Approach,

M. Berhanu, A. Petroff, O. Devauchelle, A. Kudrolli, D.H. Rothman, Physical Review E 86 (2012)

Shape and dynamics of seepage erosion in a horizontal granular bed

T. Bertrand, C. Bonnoit, E. Clément, A. Lindner, Granular Matter 14, 169 (2012)

Dynamics of drop formation in granular suspensions: The role of volume fraction

G. A. Caballero-Robledo, C. Goldenberg, E. Clement, Granular Matter 14, 239 (2012)

Local dynamics and synchronization in a granular glass

A. Janda, I. Zuriguel and D. Maza, Phys. Rev. Lett. 108, 248001 (2012)

Flow Rate of Particles through Apertures Obtained from Self-Similar Density & Velocity Profiles

Y. Li, R. Liu, and M. Hou, Phys. Rev. Lett. 109, 198001 (2012)

Gluing bifurcation and noise-induced hopping in the oscillatory phenomena of compartmentalized bi-disperse granular gases

Y. Li, R. Liu, M. Shinde, M. Hou, Granular Matter 14, 137 (2012)

Flux measurement in compartmentalized mono-disperse and bi-disperse granular gases

C. Lozano, A. Janda, A. Garcimartín, D. Maza and I. Zuriguel, Phys. Rev. E 86, 031306 (2012)

Flow and clogging in a silo with an obstacle above the orifice

C. Lozano, G. Lumay, I. Zuriguel, R.C. Hidalgo, A. Garcimartín, Phys. Rev. Lett. 109,068001 (2012)

Breaking Arches with Vibrations: The Role of Defects

E. Opsomer, F. Ludewig, and N. Vandewalle, EPL 99, 40001 (2012)

Dynamical clustering in driven granular gas

H. S. Sajjad, Y. Li, F. Cui, Q. Zhang, and M. Hou, Chin. Phys. B 21, No.1, P.014501 (2012)

Directed segregation in compartmentalized bi-disperse granular gas

H. S. Sajjad, Y. Li, F. Cui, Q. Zhang, and M. Hou, Chin. Phys. Lett. 29, No.3, P.034501 (2012) *Irregular Oscillation of Bi-disperse Granular Gas in Cyclic Three Compartments*

M. Sperl, W.T. Kranz, A. Zippelius, EPL 98,28001 (2012)

Single-particle dynamics in dense granular fluids under driving

A. Tordesillas, D.M. Walker, G. Froyland, J. Zhang, R.P. Behringer, Phys. Rev. E 86, 011306 (2012) *Transition dynamics and magic-number-like behavior of frictional granular clusters*

M.-J. Dalbe, D. Cosic, M. Berhanu, A. Kudrolli, Physical Review E 83, (2011)

Aggregation of frictional particles due to capillary attraction

C. Yanpei, P. Evesque, and M. Hou, Chin. Phys. Lett. 29, No.7, P.074501 (2012)

Breakdown of Energy Equipartition in Vibro-Fluidized Granular Media in Micro-Gravity

D. Bi, J. Zhang, B. Chakraborty, R.P. Behringer, Nature 480, 355 (2011)

Jamming by shear

A. Garcimartín, I. Zuriguel, A. Janda and D. Maza, Phys. Rev. E 84, 031309 (2011)

Fluctuations of grains inside a discharging two-dimensional silo

R. Harich, T. Darnige, E. Kolb, E. Clément, EPL 96, 54003 (2011)

Intruder mobility in a vibrated granular packing

T. Kanzaki, M. Acevedo, I. Zuriguel, I. Pagonabarraga, D. Maza, R.C. Hidalgo Eur. Phys. J. E 34, 133 (2011) *Stress distribution of faceted particles in a silo after its partial discharge*

L. Kondic, X. Fang, W. Losert, C.S. O'Hern, R.P. Behringer, Phys. Rev. E 85, 011305 (2011) *Microstructure evolution during impact on granular matter*

Y. Li, M. Hou, and P. Evesque, J. Phys. Conf. Ser. 327, 01203 (2011)

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Directed clustering in driven compartmentalized granular gas systems in zero gravity

V.B. Nguyen, T. Darnige, A. Bruand, E. Clement, Phys. Rev. Lett. 107, 138303 (2011)

Creep and fluidity of a real granular packing near jamming

E. Opsomer, F. Ludewig and N. Vandewalle, Phys. Rev. E. 84, 051306 (2011)

Phase transitions in vibrated granular systems in microgravity

E. Opsomer, F. Ludewig and N. Vandewalle, J. Phys.: Conf. Ser. 327, 012035 (2011)

Dynamical regimes of a granular gas in microgravity: a molecular dynamics study

L. A. Pugnaloni, José Damas, I. Zuriguel, D. Maza, Papers in Physics 3, 030004 (2011)

Master curves for the stress tensor invariants in stationary states of static granular beds. Implications for the thermodynamic phase space

C. Yanpei, P. Evesque, M. Hou, C. Lecoutre, F. Palencia, Y. Garrabos, J. Phys. Conf. Ser 327, 012033 (2011)

Long range boundary effect of 2D intermediate number density vibro-fluidized granular media in micro-gravity

I. Zuriguel, A. Janda, A. Garcimartín, C. Lozano, R. Arévalo, D. Maza, Phys. Rev. Lett. 107, 278001 (2011) *Silo Clogging Reduction by the Presence of an Obstacle*

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3   SCIENTIFIC REQUIREMENTS ON THE HARDWARE

Each requirement has been prioritised as follows:

Priority 1 is essential (unless otherwise specified, requirements are Priority 1)

Priority 2 is optimal

Priority 3 is nice to have

Justifications and/or comments are provided for explanation and information.

List of parameters:

Symbol	Unit	Denomination
a	mm	amplitude of a stimulus
d	mm	diameter of a bead
D	mm	depth of the cell
H	mm	height of the cell
L	mm	total inner length of the cell hosting the experiment
La	mm	length of the experimentally active part of the cell (the one that contains the beads)
Ra	Hz	frame rate of the camera
$f = \omega/2\pi$	Hz	frequency of a stimulus
θ	rad	phase of the oscillation

3.1   General concept

The requirements for different cells are provided below. The cell geometry as well as the stimuli characteristics depend of the studied phenomena. The different configurations are then detailed.

3.1.1   Concept for the cells

The cells shape shall be a parallelepiped featuring a static core closed at the two ends by two pistons. The depth of the cell will depend on the experiments, as defined below.
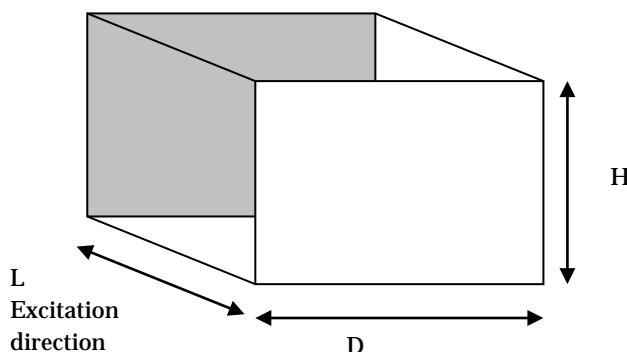
Some cells shall contain beads in air (so-called "dry cells", see 3.2 to 3.5) while other cells shall contain beads in a liquid (so-called "wet cells", see 3.6).

3.1.2   Characteristic dimensions of the cells

The excitation axis is defined to be along the actual physical length L of the cell that shall be at least 60 mm.

The length La of the active part of the cell that actually confines the beads shall be selectable (see 3.7).
The depth of each cell is specific for each cell and shall be fixed.
The inner height of each cell shall be 30 mm TBC with the wet cell.

3.1.3   Observation requirements

The observation system shall enable the recording of video sequences with a field of view including the full active volume of the cell (that is the volume occupied by the beads including the walls that confine them).

3.1.4   Excitation requirement
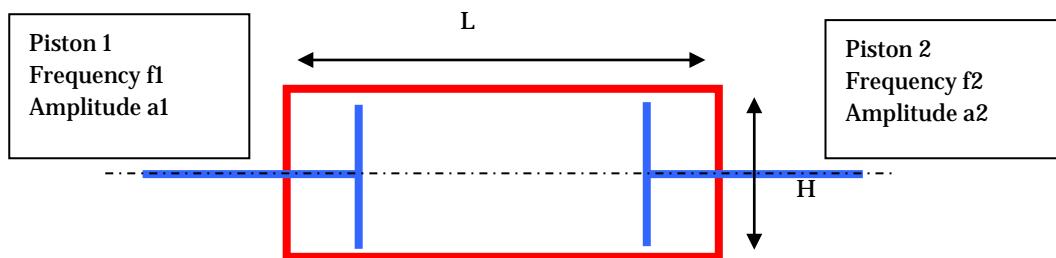
It shall be possible to activate the pistons at independent frequency and amplitude (see section 3.9.1).
A controllable phase shift between the pistons is assumed.
The shape of the stimuli shall be a modifiable parameter (see section 3.9.3).
The surface roughness of the pistons shall be selectable (either smooth or roughened, see 3.2.2).

Justification: The weight of the moving mass is strongly reduced with respect to moving the entire cell. Both pistons will be driven at different frequencies, or at the same frequency, either in phase ($\theta_1=\theta_2$) or out of phase ($\theta_1\neq0\neq\theta_2$), or in opposite phase ($\theta_1-\theta_2=\pm\pi$), with same or different amplitudes a_1, a_2 of vibration and frequencies $f_1=\omega_1/(2\pi)$, $f_2=\omega_2/(2\pi)$ of vibration.

Comments: The case $f_1=f_2$, $a_1=a_2$ and $\theta_1=\theta_2$ is interesting since it limits the vibration transmitted to the ISS.
Since θ can vary with time t, care has to be taken to impose enough space remaining in the cell for the granular matter all along during shaking. This can be ensured using a piezoelectric sensor which measures the force on each piston in order to detect a strong increase of force.
The pistons could move at will according to, typically, a sinusoid with varying amplitude and frequency range within the limits defined in 3.9.1.

3.2   Cell type "3D systems" characteristics
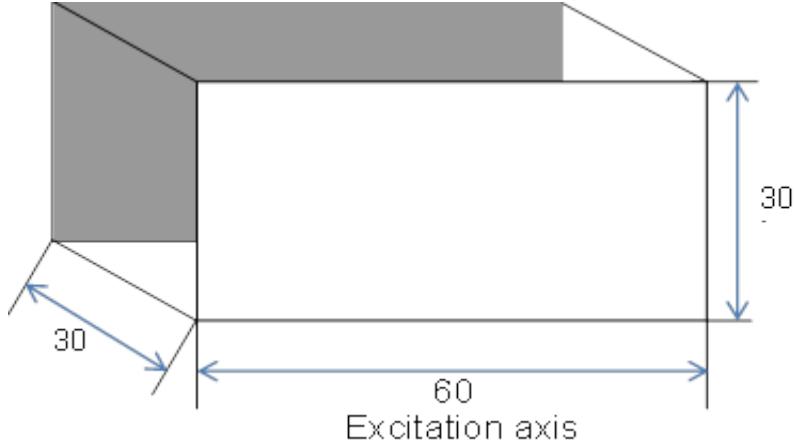
Schematic of cell type "3D systems" (dimensions in mm)

3.2.1   Dimensions

Cell with a fixed square section (30mm x 30mm)
The cell type "3D systems" shall have the following dimensions:
H= 30 mm
D= 30 mm
L= 60 mm

3.2.2   Piston roughness TBC after parabolic flight tests

The surface roughness of the piston shall be selectable (either smooth or with a roughness of the order of the grain size in both height and lateral extent).
In a given cell, both pistons shall feature the same surface characteristics.
The parameters describing the roughness are the following ones: TBD

3.2.3   Bead feeding device

Up to two bead feeding device(s) (see 3.8) are required to add to a given volume fraction of monodisperse beads additional beads of different size or shape.

3.2.4   Impact force sensors and accelerometers

Both pistons shall each be equipped with an impact force sensors on the piston wall (see 3.10.5) and an accelerometer on the shaft (see 3.10.6)

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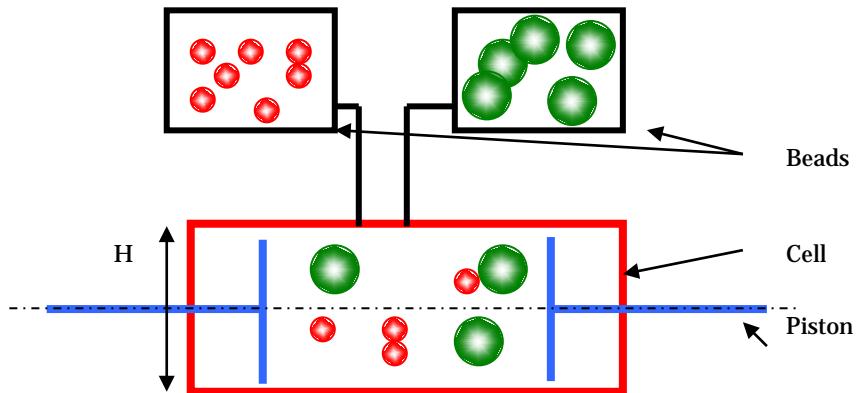
Justification for this cell type:
The aim is to study dynamical states of granular gases as well as segregation effects in a dilute regime (WP1 and WP4). In a dense regime, the cell can be used to study convection-like motions induced by vibration (WP3). Roughening the piston aims to deliver a more stochastic spatial forcing than smooth pistons do. Control parameters will be the number of beads, the amplitude and frequency of the forcing, and the cell length. By means of cameras, impact force sensors and accelerometers, particle tracking and correlations, local density, collision frequency, velocity distribution, mean injected power and its fluctuations will be inferred.

Implementing two bead feeders enables the study of the competition of two different particle species. Clustering may occur for one species, the other one remaining in a gas state. The presence of a second species may therefore induce clustering, which is of high interest. Segregation is expected when both species form a cluster in the middle of the cell, which can be investigated by optical means.

The accelerometers on the pistons' shaft enable to measure the acceleration of each piston, and thereby its velocity by numerically integrating the signal. This will provide the mean power injected by the piston into the system as well as temporal fluctuations of injected power due to the bead collisions on the piston. Both quantities are of primary interest to describe systems driven far from equilibrium such as granular gases.

Comments: When pistons apply a mean stress, one can also use the cell with a sound emitter at a piston and a sound detector on the other piston to study sound transmission through a dry granular medium (WP2). If this mean stress varies slowly with time oscillating around an average, one can study the effect of small variations on the speed of sound. The suitability of the piston driver and the impact force sensor to perform such measurements should be assessed.

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3.3   Cell type "quasi-2D" characteristics

Schematic of cell type "quasi-2D" (dimensions in mm)
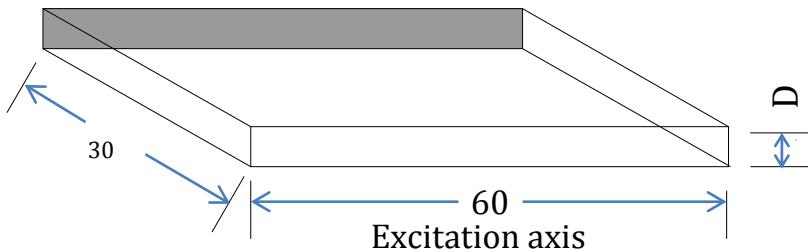
3.3.1   Dimensions

The cell type "quasi-2D" shall have the following dimensions:
H= 30 mm
D= 5 mm
L= 60 mm

3.3.2   Bead feeding device

A bead feeding device (see 3.8) is required to add to a given volume fraction of mono-disperse beads additional beads of different size or shape (if compatible with the bead feeding device).

Justification for this cell type: Similar experiments as in WP1, WP2 and WP4 will be performed in a "quasi-2D" cell. The "quasi-2D" cell enables much simpler tracking of each particle with one single camera than in the case of "3D systems" cells.

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3.4 Cell type "3D systems with partition" characteristics
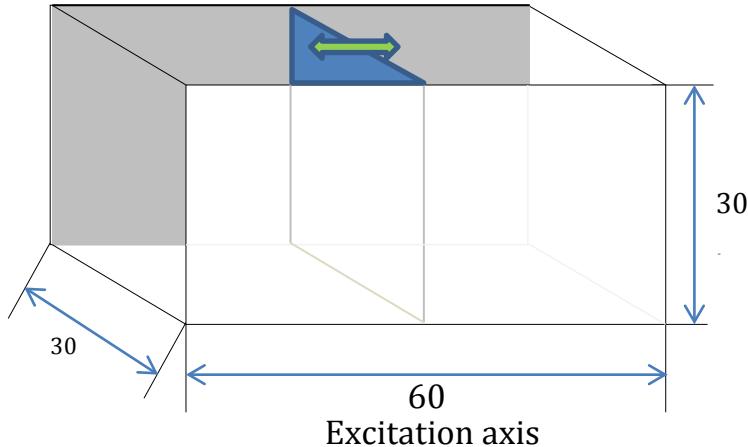
Schematic of cell type "3D systems with partition" (dimensions in mm)

3.4.1 Dimensions

Cell with a square section (30mm x 30mm)
The cell type "3D systems with partition" shall have the following dimensions:
H= 30 mm
D= 30 mm
L= 60 mm

3.4.2 Piston roughness TBC

The surface roughness of the piston shall be selectable (either smooth or with a roughness of the order of the grain size in both height and lateral extent).
In a given cell, both pistons shall feature the same surface characteristics.
The parameters describing the roughness are the following ones: TBD

3.4.3 Freely mobile partition wall

A partition parallel to the pistons but freely mobile shall be accommodated around the centre of the cell, with dimensions such that beads cannot cross over.
It shall be possible to implement different partition inertia in the range TBD.
The maximum friction (static, and dynamic) for its translational movements shall be TBD.

3.4.4 Bead feeding device

A bead feeding device is required on each side of the mobile partition wall to locally change the bead volume fraction or to add beads of different size or shape (if compatible with the bead feeding device, see 3.8)

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Justification for this cell type: To test the granular effective temperature on each side of the partition for cases where the number and type of grains are different on both sides of the partition. Since the number of grains is far smaller than the thermodynamic limit, the partition position will fluctuate. This will be measured and compared to the simple Gaussian expectation. The partition kinetic energy will be compared with the granular effective temperatures.

Priority 2

3.5 Cell type "Maxwell's demon" characteristics
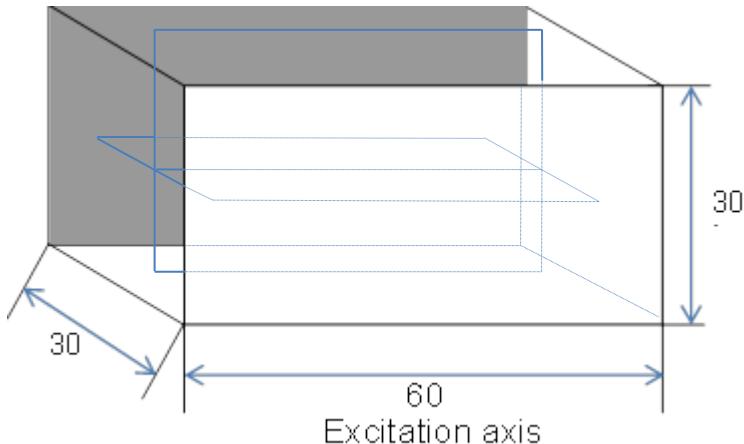
Schematic of cell type "Maxwell's demon" (dimensions in mm)
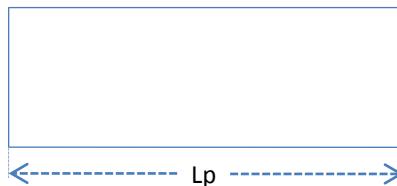
Schematic of half a partition wall

This cell is designed to enable studies of the Maxwell's demon effect. The cell shall be split in four identical compartments by two fixed perpendicular partition walls, themselves perpendicular to both the side walls of the cell and the pistons. The length Lp of the two partition walls shall be 30 mm. The motion of the pistons at the extremities of the walls shall leave enough space for the exchange of particles between the compartments.

3.5.1 Dimensions

The cell type "Maxwell's Demon" shall have the following dimensions:
H= 30 mm
D= 30 mm
L= 60 mm
The length of a partition wall shall be:
Lp= 30 mm

The cross-sections of the four compartments shall be identical within 1% and the parallelism between the partition walls and the wall of the cell shall also be within $1°$. The thickness of the partitions are expected not exceed 2 mm and their extremities facing the pistons shall be rounded.

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3.5.2 Bead feeding device

A bead feeding device is required to change the bead volume fraction or add particles of a different size or shape (see 3.8)

Justification for this cell type: Enables the study of Maxwell's demon effects that causes beads to transfer from one compartment to the others until it reaches extremely low densities.

If in addition two kinds of grains can be used at the same time, one could also study the Maxwell's demon effect with segregation. Two particle sizes may provoke oscillations in the exchange currents between compartments.

Experiments on the Maxwell's demon effect will be performed by Prof Hou of the CAS on the SJ-10 mission. Refinement of the requirements may occur in the light of the results of her experiment.

Priority 2

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3.6 Cell type "dense granular matter" characteristics

This cell type is dedicated to the study of dense clouds of beads.
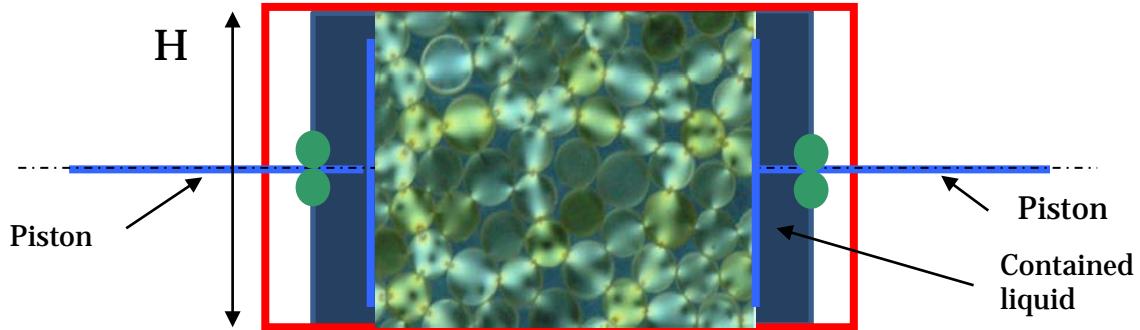
Schematic of the cell type "dense granular matter"

3.6.1 Dimensions

The cell type "dense granular matter" shall have the following dimensions:
H= 30 mm
D= 30 mm
L= 60 mm

3.6.2 Pressure

The average pressure inside the cell can be the same as the ambient pressure.
The design of the cell shall however limit the amplitude of pressure fluctuations in the liquid upon 10% compaction to less than 5% of the average pressure.
This design requirement can be verified on the ground so that it is not required to monitor the cell pressure in space.

3.6.3 Sound pulses generation and detection

A shock wave shall be generated at the location of one piston and shall be detected at the location of the other piston in order to measure the time of flight.
The shock wave can be characterised as a single pulse corresponding to a one oscillation cycle with an acceleration of the piston of typically 4 g for a duration of 20 ms and return of the piston to the initial position with similar characteristics.

Comment: The generation of sound pulses across the beads could make use of the piston position control capability (see 3.9.1).
It should be verified if an impact force sensor (see 3.10.5) can suitably detect the transmitted sound pulse at the other piston.
In a recent parabolic flight experiment, scientists at DLR made use of a pressure compensation device to limit pressure changes in the liquid upon compaction of the beads

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3.6.4   Liquid tightness

The cell shall provide for full containment of the liquid.
The cell shall be filled without bubbles in the liquid.

3.6.5   Bead feeding device

This cell does NOT require a bead feeding device

Justification for this cell type: the birefringent beads are immersed in an index matching liquid and observed with linearly polarised light to reveal the distribution of stresses in the pack. Controlled compaction along with stimulation of the beads by sound pulses from one end of the cell and sound measurements at the other end will enable to study how sound waves propagate in the pack and how fast.

3.7   Length of the active part of the cells

3.7.1   Length of the active part of the dry cells

The length of the active part, 'La', of the dry cells (cell types "3D systems", "quasi-2D", "3D systems with partition" and "Maxwell's demon") shall be adjustable at will by moving the mean position of each piston, such that:
- when the pistons are fully retracted, La ≥ 60mm, and
- when the pistons are fully extended, La ≤ 5 mm.

For the cell type "Maxwell's demon", the piston shall not come any closer to the partition walls than 1.5 times the diameter of the biggest beads present in the cell..

Justification: Changing the length of the active part of the cell enables to change the volume fraction of the beads without changing the number of beads.

For the cell type Maxwell's Demon, the distance between the piston and the partition walls is required to allow the exchange of beads between compartments. Resetting the experiment will be performed by applying a "thermal gradient" across the length of the cell (accumulation of the beads on the cold side).

3.7.2   Length of the active part of the wet cells

The length of the active part, 'La', of the wet cells (cell type "dense granular matter") shall be adjustable at will by moving the mean position of each piston, such that:
- when the pistons are fully retracted, La ≥ 50 mm, and
- when the pistons are fully extended, La ≤ 30 mm.

The level of compaction of the beads will be controlled by controlling the positions of the pistons (see 3.10.3).

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3.8   Bead feeding system

It shall be possible to increase, in a controlled manner[1], the number of beads inside some cells (see characteristics of cell types above) in an incremental fashion.

The numbers of beads to be added in a controlled manner shall be selectable between N_{mini} and N_{maxi} beads at a time.

The bead feeding system shall be able to inject spherical bronze and polyamide beads of Ø2mm (**priority 1**). This system shall also be tested with beads of Ø1mm (**priority 2**)

A bead feeder shall enable to inject large numbers of beads, N_{mini} = 10 beads N_{maxi} = 250 beads (Ø 2mm, **priority 1**) or 1000 (Ø 1 mm, **priority 2**).

When adding any number of beads up to 100 beads, the tolerance shall be +/-2 beads.

When adding any number of beads above 100 beads, the tolerance shall be +/-2% of the added number.

A bead feeder of individual beads (N_{mini} = N_{maxi} = 1 bead) is nice to have (**priority 3**).

The maximum volume fraction of beads in a dry cell equipped with a bead feeding system will not exceed 50% (that means that when packed in FCC arrangement, the beads effectively occupy half of the maximum possible active volume of the cell).

Objective: To study the effect of volume fraction in both dilute and dense systems. To study segregation effects between beads of different diameter by way of adding beads of a different diameter. To study segregation effects between beads by way of addition beads of a different diameter or different shape.

3.9   Requirements on the motion of the pistons

3.9.1   Amplitude, frequency and acceleration of the pistons

3.9.1.1 Amplitude

The amplitude 'a' shall be selectable between 0.2 and 25 mm peak-to-peak.

Comment: If it is possible to achieve amplitudes below 0.2 mm, the Science Team will make use of this capability within the limitations of the instrument.

3.9.1.2 Frequency

The frequencies of vibration of the two moving/oscillating pistons shall be selectable between 1 and 50 Hz.

It shall be possible to operate the pistons at different frequencies (asymmetric oscillations) within the microgravity perturbations limits allowed by the instrument and its accommodation constraints.

Comment: In the great majority of experiments, the pistons will be driven at the same frequency and in phase shift of π.

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[1] i.e. selectable numbers of additional beads, at controlled times (while the pistons are not in motion)

3.9.1.3 Accelerations

During an experiment run, the accelerations of the oscillating pistons shall range from 0 to 5g. This means that the relation between frequency and amplitude shall satisfy the condition: $a.(2.\pi.f)^2 < 5\ g = 50\ m/s^2$.

However it shall be possible to apply larger accelerations to the piston (up to 10 g) in order to destroy any structure of the beads in the cell and re-initialize the experiment ("refresh" run). In fact, the maximum acceleration of the pistons shall be determined such that the amplitude of each of them will depend on the acceleration and the frequency.

The ability of the system to produce singular pulses should be determined, particularly for the generation of sound pulses in cell type "dense granular matter" (see 3.6.3).

3.9.2 Displacement accuracy

For sinusoidal oscillations, the difference in position of any piston as measured by the observation system shall at no time deviate from an ideal sinusoidal displacement curve by more than ±0.2 mm, with the assumption that the origin of both curves is taken at the point of maximum speed of the piston (i.e. the zero displacement line of the theoretical curve).

3.9.3 Other shapes of oscillations

Beyond sinusoidal oscillations at different amplitudes and frequencies per 3.9.1.3, the system shall also enable periodic non-sinusoidal oscillations as well as single pulses

Comment: Ground tests should be performed to characterise the full capabilities of the system including the defining parameters (e.g. frequency, amplitude) for non-sinusoidal periodic oscillations and single pulses, with respect to the above-mentioned capabilities

3.10   Diagnostics requirements

3.10.1 Temperature measurements

The cell temperature shall be known. The temperature shall be measured on the internal or external wall of the cell with an accuracy of less than 1 K.

3.10.2 ISS acceleration measurements

A three-axis acceleration measurement located at a position close to the experiment cell shall be provided so as to measure the background acceleration of the ISS when experiments are running in VIP-Gran.
The positioning of the accelerometer shall be such that there is no appreciable attenuation/amplification with respect to the experiment cell accelerations in the frequency range of interest. The frequency range for the acceleration measurement shall be between 1Hz and 1000Hz. The required resolution of the acceleration measurement is $10^{-6}\ g_0$.

3.10.3 Piston displacement measurements

The position of the pistons shall be known to an accuracy better than 10^{-2} mm.
The acquisition rate shall be above 1000Hz for each piston.

Comments: This implies that the position of each piston is coded with 12 bits since 4096 is greater than 30 mm/0.01 mm.

3.10.4 Time synchronisation

The time-tagging of data, such as acceleration data, piston force, impact force sensors, shall be synchronised with the image acquisition and the piston displacement with a resolution better than 10^{-4} sec.

3.10.5 Impact force sensor

Two impact force sensors consisting of disk-shaped piezoelectric devices are required (one on each vibrating wall) for the cells of types "3D systems" and "3D systems with partition".

The sensing surface could be fixed behind each vibrating wall on the vibrating piston. The sensor axis being collinear with the vibration axis.

The sensor shall be able to resolve the collision of one bead impacting on it lasting typically few microseconds. The sensor shall be able to resolve the collision of one bead impacting on it lasting typically five microseconds. To accurately describe the peak duration and amplitude, at least 10 points shall be recorded for one collision, i.e. a minimum sampling rate of 2MHz is needed (10 / 5μs = 2MHz).
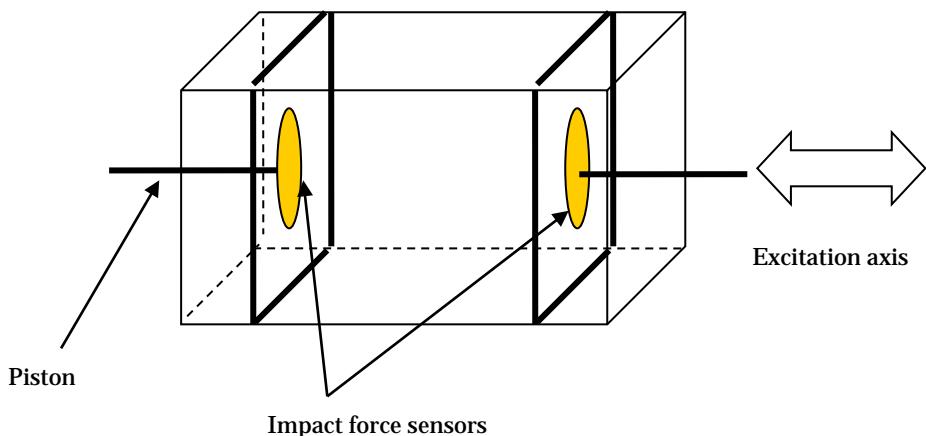
Schematic of the disposition of impact force sensors

Objective: To resolve the collisions of beads on the vibrating walls of the cell. To count the amplitude and the number of impacts. To infer the distribution of particle velocity near a wall, and the distribution of time of flight between two successive collisions with a wall.

Comment: The Science Team has experience with piezoelectric devices with a sensing surface diameter of 12.7 mm with a sensitivity better than 11V/kN (±15%).
In order to strongly reduce the amount of relevant data to be downlinked or stored to typically 10 kHz, an analogic

filtering of the sensor output may also be proposed in coordination with the Science Team. The filtering stages are made of an offset cancelling (to remove the continuous component of the signal), a notch filter near the forcing frequency ± few Hz (to remove residual sensitivity of the sensor to vibrational acceleration), and an Hilbert filter (to detect the envelope of the signal of each impact).

3.10.6 Accelerometers

Two accelerometers are required to be fixed on the shafts of the pistons for the dry cells "3D systems", "quasi-2D" and "3D systems with partition" to measure the acceleration of each piston in the direction of vibration, and also its velocity (by numerically integrating the acceleration signal), and thus to infer the mean power injected by each piston in the system as well as temporal fluctuations of injected power due to the bead collisions on the piston.

The accelerometer shall be able to resolve the collision acceleration of one bead impacting on the piston lasting typically five microseconds. To accurately describe the peak duration and amplitude, it shall be possible to record at least 10 points for one collision; i.e. a minimum sampling rate of 2MHz is required (10 / 5µs = 2MHz).

It shall be possible for the scientists to select the frequency at which these data are actually recorded during the run (between 1 kHz and 2 MHz) as part of the parameters set for a run.

Objective: to measure accelerations of both pistons, and to infer the mean injected power by each piston (<P>=<F(t)xV(t)> force applied to the piston times the piston velocity) as well as the temporal fluctuations of injected power.
The science team has positive experience with accelerometers with a sensitivity of the sensors between 0.1 V/g and 1 V/g or (±10%) and a frequency range between 0.1 to 8000 Hz.

3.11 Video requirements

3.11.1 Illumination level

The illumination level shall be sufficient to resolve the beads in any location in the cell.

Comment: Back illumination is a common way to measure local densities. Particle tracking may require front illumination.
Often, electronic devices provoke slight oscillations of light sources. Such oscillations should be avoided. Laboratory experiments make use of LED illumination.

3.11.2 Filming and lighting orientation

Observation shall be made in 2 perpendicular directions, themselves perpendicular to the vibration axis. The observation directions are represented by the blue arrows on the schematic below.

The cell shall be preferentially illuminated from the back. Front illumination (where the fast camera sits) should also be foreseen. The illumination is schematically shown below by the red arrows.

The direct reflection of the light to the observation camera shall be avoided. Bright spots on particles shall be avoided.

The angle between the observation axis and the back/front illumination axis shall be between 0 and 90 degrees.

It shall be possible for the scientists to select (see 4.3.1 and 4.3.2):
- which illumination is activated (one of the two or both), and
- the intensity of the illumination on the basis of actual images delivered by the instrument.

Excitation axis

Back illumination

Front illumination
at e.g. 45 deg angle

Secondary observation axis

Primary observation axis
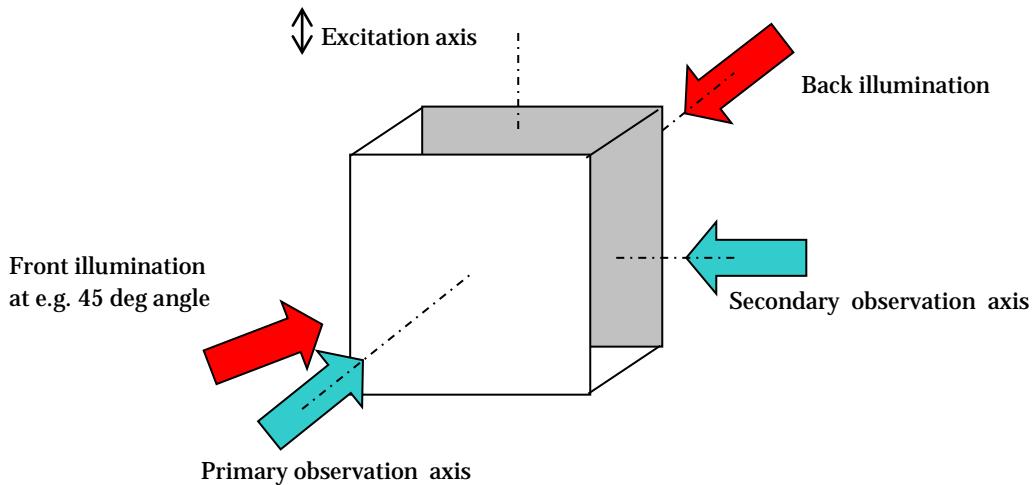
Schematic of the illumination and observation requirements

Justification: Two cameras with a corresponding illumination are important to visualize particle dynamics, and perform quantitative measurements from particle tracking in dilute regime and correlations between particle displacements.

Comment: For particle tracking, two back light illuminations by LED located on the same axis as the one of the camera should make particles better appearing in dark on white background and similar conditions on both cameras.

3.11.3 Depth of field

The depth of field shall be such that the entire depth of the cell can be observed at the resolution defined below for both the primary and secondary observation paths.

Comment: The camera resolution (see section 3.11.5) should be high enough for resolving particles on pictures with the entire cell depth.

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3.11.4 Field of view

The field of view shall cover the full window during vibrations.

For viewing particles close to the front window, it shall be possible to digitally focus on smaller regions of interest **(Priority 3)**

3.11.5 Camera characteristics

The frame rate of the camera shall be selectable between 1 and 1000 frames/s.

The resolution of the camera shall be at least 1024 x 1024 pixels (particle diameter corresponding to 20-30 pixels).

The selected zone to be acquired shall be selectable.

3.11.6 Image colour mode

The pixels' grey levels shall be recorded at minimum 8 bit resolution.

3.11.7 Data acquisition

Data acquisition shall allow 3 Gbytes video recording in one single shot.

Comment: One shot of 3Gbytes means for example 3 seconds of video recording at 1000 frames/s with 1000 x 1000 pixels resolution, or 3000 seconds at 1 frame/s and 1000 x 1000 pixels resolution, or 12000 seconds at 2 frames/s and 250 x 500 pixels resolution.

3.11.8 Subset of data

It shall be possible to extract from the video recordings 20 images per camera for both cameras over the duration of a "run" in order to enable a quick look assessment of the conditions and usability of images for scientific analysis (see section 4.3.2.1).

3.11.9 Image compression

If a compression algorithm turns out to be necessary for data downlinking or storage purposes, it shall maintain the clear visibility of the beads outlines on the compressed images or videos.

3.11.10 Light polarisation

Birefringence phenomenon enables to see the stress field. The visualisation of the stress induced light refraction by beads of cell type "dense granular matter" requires linear+ ¼ λ polarisers located on both sides of the cell (right circular polariser at the entrance and left circular polariser at the exit) (see schematic below). These polarisers can laminated directly onto the windows of the cell.
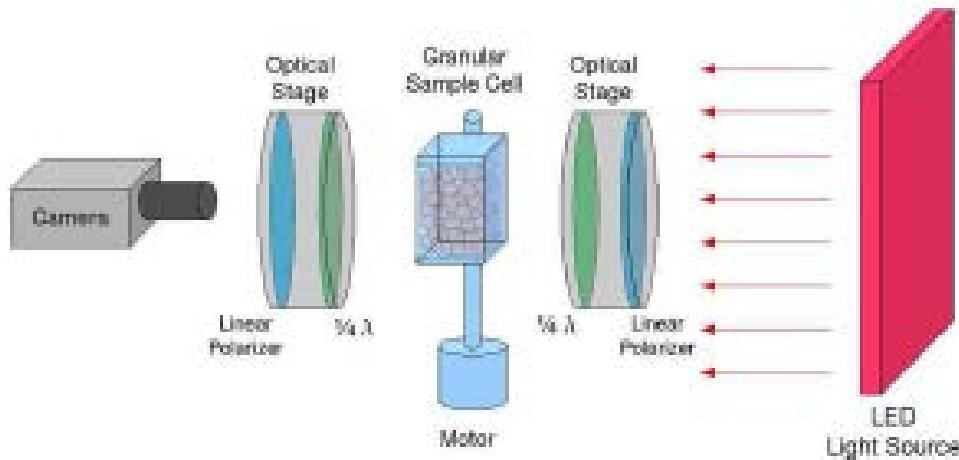
3.12   Fluids and materials

3.12.1 Beads for dry cells

For dry cells, the beads shall be made of bronze or polyamide or glass and shall be spherical with a diameter as detailed in the Table 1 below.

Bead type	Particle shape	Size	Material
M	Medium sphere	Ø1 mm	Bronze
L	Large sphere	Ø2mm	Bronze
D	Deformable sphere	Ø1mm	Polyamide
G	Sphere	Ø1mm	Glass

Table 1: Particles denominations

The beads shall be procured, characterised and provided to the project team by the members of the Science Team.

Purpose: Two different sizes are considered in order to test finite-size effects (through the ratio bead radius / cell size) dissipative mechanisms, as well as segregation phenomena (for mixtures). Medium and Large particles are made of a conducting solid material (bronze) which prevents the accumulation of electrical charges in the cell. The Polyamide and bronze spheres have different restitution coefficients, leading to possibly different dissipative phenomena.

Additional bead types Hollow (H), Anisotropic (A) will undoubtedly be proposed if compatible with the instrument design. Anisotropic particles could be dimers or trimers (glued spheres) made of the same bronze material.

Glass spheres will be employed primarily for sound propagation measurements in dense dry granular materials.

3.12.2 Beads and liquids for wet cells

For cell type "dense granular matter", the beads shall be made of stress birefringent material such as PDMS or PL-3.

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Spherical beads shall have a diameter of optimally 0.5 mm, however beads of 1 mm are also acceptable. Other shapes might be considered with their smallest features larger than 0.5 mm.

The corresponding liquids with (partial) index matching shall be selected amongst the following mixtures:
- water/glycerol mixtures
- water/ethanol mixtures
- silicon oil
- cassia oil
- water/DMSO

The beads shall be procured, characterised and provided to the project team by the members of the Science Team

3.12.3 Cell and pistons materials

The materials of the dry cells (types "3D systems", "3D systems with partition", "Maxwell's demon" and "quasi-2D") and of the corresponding pistons shall not lead to electrostatic charging of the beads.

The cells shall be mounted on a grounded surface or attached to a grounding point such that all surfaces impacted by the beads shall be at ground potential.

The material employed for the pistons shall optimally be the same as the materials of the beads present in the cell.

The structure of the piston shall aim to minimise its deformation and its intrinsic vibrations caused by bead impacts.

Justification: To avoid electrostatics as much as possible and dust deposition on the windows.
Comment: The Science Team proposes to coat the cell with FTO (tin oxide with fluorine), used in the laboratory of Liège: http://www.solaronix.com/products/tcolayers/tco308/
The ageing of this material with respect to numerous bead-wall collisions should be tested.

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4 SCIENTIFIC REQUIREMENTS ON OPERATIONS

Definitions:

A RUN is an experiment with one set of parameters of stimuli: frequency and amplitude of oscillations. See section 4.1.5

An EXPERIMENT is a series of RUNs with one configuration [cell type / bead type /bead volume fraction]. See section 4.1.5

Assumptions: The protocol hereafter assumes that:
- The cell and pistons are compliant with the requirements listed in the Chapter 3
- The bead feeding system allows to increase the number of beads
- An on-board computer allows data treatment and video compression
- It will be possible to remotely control during in-orbit operation the acquisition time, frame rate, illumination intensity and run parameters.
- Some data can be downlinked after each run for quick look assessment of the results.

4.1 Experiment protocol

4.1.1 Protocol philosophy

The protocol depends on the density (number of beads) and the phenomena to be studied (impact, sound propagation...). The different kinds of run are listed in the section 4.1.5
- Step 1, Runs: Explore the vibration domain by varying the density, the number of beads, the frequency and the amplitude.
- Step 2, Data treatment and Replay of step 1 with different parameters. Some data shall be downlinked (cf. section 4.1.5). The Science Team shall assess the preliminary results before an injection of beads, because the increase of beads is irreversible.
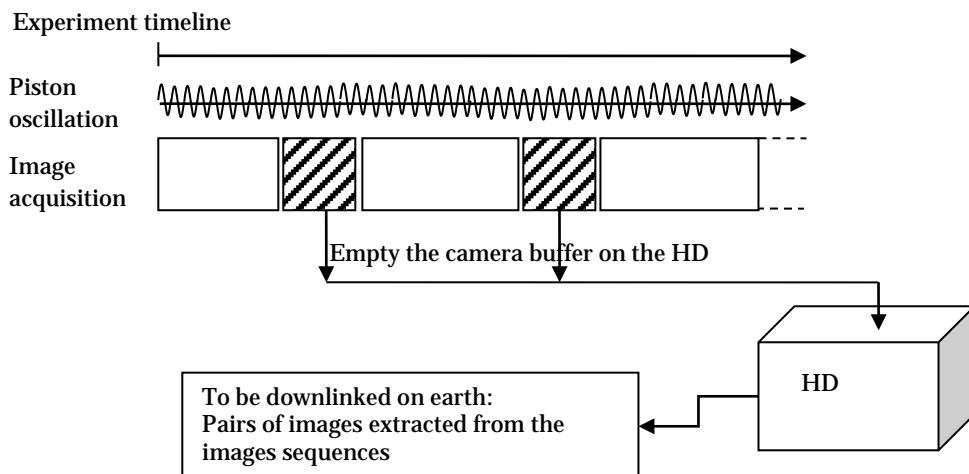
Figure 1: Timeline of one experiment
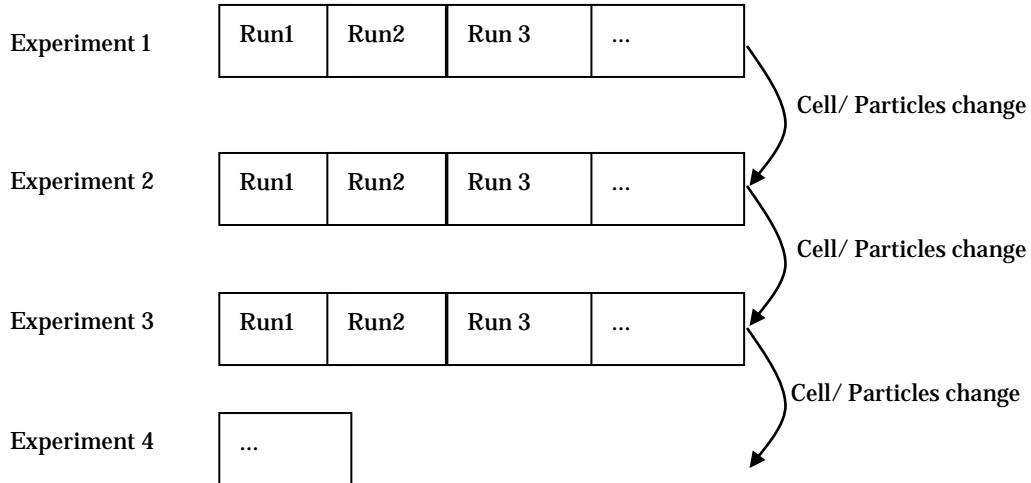
Figure 2: After each experiment the particles number/size and/or the cell geometry is changed.

4.1.2 Run Parameters

Run parameters	
Forcing parameters	see 3.9.1
Fillings or volume fractions	see 4.1.3
Particle types	see 3.12.1 and 3.12.2

Table 2: Run parameters

4.1.3 Cell fillings

The feeding system is defined in the section 3.8. However, the bead volume fraction can also be varied by changing the average positions of the opposite moving walls. The volume of the active part of the cell is then defined by the average distance between the opposite moving walls.

One layer at rest corresponds to the number of beads covering the piston surface. For a 30 mm x 30 mm piston area, one layer is 900 beads (Ø1mm) or 225 beads (Ø2mm).

Filling range	Volume fraction range	Number of fillings	Maximum number of beads	Tracking	Comments
A	0.01 to 2 layers	12	1800 (Ø1mm) 450 (Ø2mm)	YES	Particle tracking is used for this density.
B	0.5 to 6 layers	5	5400 (Ø1mm) 1350 (Ø2mm)	YES	Particle tracking is used for this density.
C	15% to 40%	5	-	NO	Length of the active part of the cell can be varied to change the volume fraction
D	Around 50%	3	-	NO	Length of the active part of the cell can be varied to change the volume fraction

Table 3: Cell fillings (volume fraction means ratio between total solid and gas)

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4.1.4   Measurements

Three measurement methods are used: cameras, impact force sensors and accelerometers.

Cell type	Image analysis		Impact force sensors	Accelerometers
	Correlations	Particle tracking		
"3D systems"	YES	YES	YES	YES
"Quasi-2D"	YES	YES (1 camera)	NO	YES
"3D systems with partition"	YES	YES	YES	YES
"Maxwell's demon"	YES	NO	NO	NO
"Dense granular matter"	TBC	TBC	NO	NO

Table 4: Diagnostics used for each cell

4.1.4.1 Video sequences frame rate

The frame rate shall be tuned in the range 1 Hz ≤ f ≤ 1000 Hz.

4.1.4.2 Intermediate mode

Duration for intermediate (minutes) and long (hours or days) times. Frame rate: 1 or 2Hz up to 50Hz.

4.1.4.3 Fast mode

Duration of few seconds maximum.
In the same way, 2 images at 1ms interval may allow to measure a bead speed when beads are seen 1 by 1 and to look for the possible "nucleation" of the cluster at short times.

Comment: The zone of the video sensor to be used can be adjustable, in order to have the average speed of the beads. 2 pixel lines can count the number of beads crossing a barrier and their speed => this plays the role of a pressure transducer; but this is possible only for a limited number of beads.

4.1.5   Protocol details

The protocol of one run is defined by 4 steps detailed below and in Table 5.
Experiments are planned for various densities and stimuli as defined in Table 6.

4.1.5.1 Step 1

At the beginning of a run, the system will be initialised in order to establish the initial conditions, which implies destroying any structure of the beads in the cell. This is particularly important in the case of large filling (larger than 3 layers of grains in the cell section). It can be required between two runs.

a) Refresh run: Vibrate the cell via a "fast" or "slow" motion of one of the pistons in order to restore initial conditions.

b) Calibration run: In order to check the synchronization of the imaging system and the pistons excitations.

4.1.5.2 Step2

For each set of parameters (frequency and amplitude), the Science Team looks for the possible "nucleation" of clusters at short times (within a few seconds after starting the experiment) with the fast video mode (see 4.1.4.3). The fluctuations of the local density (measured on the images) will provide key information on how to describe such a physical process.
Each run will provide high resolution (1 Mpixels) images which could be compressed. A complete step 2 would provide 1 sec x 1000 fps= 1000 images.

4.1.5.3 Step 3

Then, the Science Team studies the slow evolution of the cluster with the intermediate video mode (see 4.1.4.2) during 15 minutes.
Each run will provide high resolution (1 Mpixels) images which could be compressed. A complete step 3 would provide 15 min x 60 sec x 2 fps= about 1800 images minimum, or 15 min x 60 sec x 25 fps= about 22500 images optimum.
During the step 3, the buffer of the camera would eventually be transferred on the storage media.

4.1.5.4 Step 4

Pairs of images have to be extracted from the videos/images taken during the run. See section 4.3.2.1.

Step	Duration	Sensors	Vibration	Video mode	Pictures minimum	Pictures optimum
1-Initialization	5 min	OFF	ON: Calibration and Refresh run	10 pictures	10	20
2-Beginning	1 to 3 sec	ON	ON	Fast mode	1000	3000
3-Run	15 min	ON	ON	Intermediate mode	1800	22500
4-End:		OFF	OFF	OFF	N/A	N/A
TOTAL	20 min				2810 Pictures	25520 Pictures

Table 5: Run steps

Priority	Particle tracking	Cell type	Bead type*	Filling range**	Number of fillings	Run per fillings	Total runs	Total Hours
1	Yes	3D systems	L	A	12	12	144	48
1	Yes	3D systems	L	B	5	12	60	20
1	No	3D systems	L	C	5	12	60	20
1	Yes	3D systems	M	A	3	12	36	12
1	Yes	quasi-2D	L	A	12	12	144	48
1	Yes	quasi-2D	L	B	5	12	60	20
1	No	quasi-2D	L	C	5	12	60	20
1	No	quasi-2D	L	D	3	12	36	12
1	Yes	3D systems	M	B	12	12	144	48
2	Yes	3D systems with partition	L	B	5	12	60	20
2	No	3D systems with	L	C	5	12	60	20

Priority	Particle tracking	Cell type	Bead type*	Filling range**	Number of fillings	Run per fillings	Total runs	Total Hours
		partition						
1	Yes	3D systems	M&L	A	5	12	60	20
1	Yes	3D systems	M&L	B	5	12	60	20
1	No	3D systems	M&L	C	5	12	60	20
2	No	Maxwell's demon	M	A	5	12	60	20
2	No	Maxwell's demon	M	B	3	12	36	12
2	No	Maxwell's demon	M	C	5	12	60	20
1	No	dense granular matter	TBD	C	3	12	36	12
1	Yes	3D systems	G, H, A or D	A	12	12	144	48
1	Yes	quasi 2D	H, A or D	A	12	12	144	48
	TOTAL						1524	508

* M: Medium sphere, L: Large sphere, D: Deformable sphere, G: Glass sphere, H: Hollow, A: Anisotropic (see 3.12.1)
*** A (0.01 to 2 layers), B (0.5 to 6 layers), C (15 to 45%), D (around 50%) (see 4.1.3)

Table 6: Indicative planning of experiments

4.1.6   Ground reference experiment(s)

Tests shall be performed on the image and video compression with representative sample cell (size, beads and pistons oscillations).

Objective: To adapt the protocol with the duration of compression and the duration of camera buffer transfer to the storage disk.

4.2   Science constraints during operational phases

4.2.1   Transportation requirements (between lab and launch)

No scientific requirements.

4.2.2   Pre-flight BDC / Operations / Late Access

The feeding activities could be done far before the launch. To be confirmed by the manufacturer.

4.2.3   Upload science constraints

No scientific requirements.

4.2.4   In-flight science activities

The crew may have to exchange cells between the experiments.

Storage media may have to be exchanged by the crew.

4.2.5 In-flight science constraints

4.2.5.1 Microgravity requirements

High microgravity disturbances (i.e. docking) shall be avoided.

4.2.5.2 Humidity level

Measurement of the ambient humidity level in the ISS module where the experiment is located is nice to have (Priority 3), if possible once per run.

4.2.5.3 Experiment duration

See section 4.1.5 and Table 6.

4.2.6 Possibility to interrupt the experiment

4.2.6.1 STOP condition

Interruption between runs can be done without loss of science.
During a run, the acquisition can be stopped but the on-going sequence will be lost.

4.2.6.2 Re-START condition

The run shall be re-started, and the pending sequences processed.
Criteria of successful run:
The run is successful when all the foreseen stimuli have been processed. The data will be checked by the Science Team after each run.

4.2.6.3 START condition of the next run

If the next run does not change the beads numbers, there is no condition and the requirements on telemetry (section 4.3.2 TBC) can be fulfilled later.
If the next run has to increase the beads numbers, all the scientific data of previous runs will need to be checked by the Science Team. This is mandatory since the beads injection is irreversible.

4.2.7 Download science constraints (including samples)

Data of the experiments that are not or cannot be downlinked shall be downloaded.

4.2.8 Post-flight BDC / Operations / Early Retrieval

N/A

4.2.9 Transportation requirements (between landing and lab)

N/A

4.3 Communications requirements

4.3.1 Requirements on commands uplink

During in-orbit operation, it shall be possible to remotely control:
- Choice of illumination and corresponding intensity
- Stimuli characteristics: Amplitudes, shape, phase and frequency of each stimuli for each piston
- S/W; update for image treatment
- Acquisition time, frame rate

4.3.2 Requirements on data downlink

4.3.2.1 Data to be downlinked for each run

- Minimum (Priority 1): Pairs of images shall be extracted from the video sequence, about 20 pairs of images during the run.
- Optimum (Priority 2): in addition to the images above, the following data shall be provided: the acceleration data (both at the pistons and the local residual acceleration of ISS), position of pistons, impact force sensors.

> **Justification**:
> -to determine the beads velocity, particle motion can be measured in low density zones. The time delay between the selections of successive pairs of images is dependent on the specific experiment, but it is estimated that approximately 20 pairs will be requested per experiment run.
> - to assess the performance of the run. In a granular gas, density will be measured if the cell is transparent or from the reflection if the light comes from the front. The Science Team can evaluate if it is possible to perform particle tracking or not.

4.3.2.2 Frequency of downlinking data

All the scientific data of previous runs shall be downlinked before any increase of beads number (see 4.2.6.3). Any increase of beads number is irreversible (no emptying system) and sufficient time shall be allowed for the Science Team to check the data prior to such increase.

4.3.3 Requirements on storage

The data listed below shall be stored:
- The images / video (section 3.11)
- Impact force sensors (section 3.10.5)
- Accelerometers data (section 3.10.6
- Microgravity measurements (section 3.10.2)
- Time (section 3.10.4)
- Piston position (section 3.10.3)
- Temperature measurements (section 3.10.1)

5 EXPERIMENT OUTPUTS (TO BE UPDATED AT A LATER DATE)

Goal: summarizes the scientific outputs expected from the experiment and the rights and obligations of the Science Team members.

5.1 Science deliverables

In this Section, please provide the exhaustive list of scientific experiment deliverables (e.g. samples, etc.) that you expect after successful experiment execution. This list shall be understood as what is needed to perform the post-flight analysis in order to achieve science publication(s).

5.2 Data sharing policy

The data obtained will be made available to all of the Science Team members. The applicable data policy is detailed in **Error! Reference source not found.**.

5.3 Planned analyses

Wet cell: image analysis; integrated 3D stress birefringence

5.4 Publications

Describe how the Science Team defines authorship and reviewing of the papers before submission.

The acknowledgement rules are described in **Error! Reference source not found.** in sections 4.3 and 5.2. All publications shall be provided to the ESA project scientist in electronic format.

5.5 Reports

The Science Team members commit to
– providing to the project scientist on his/her request a one-page report on the scientific activities connected with the experiment
– providing a 30 days post flight report (form will be provided)
– providing a 1 year post flight report (form will be provided)
– providing and maintaining up to date the information related to the experiment for the ESA Erasmus experiment archive starting from the end of flight operations;

Abbreviations and Acronyms

AD	Applicable Document
BDC	Baseline Data Collection
COMPGRAN	Compaction and Sound Transmission in Granular Matter
DMSO	Dimethyl sulfoxide
ESA	European Space Agency
ESR	Experiment Scientific Requirements
ESTEC	European Space Research and Technology Centre
FCC	Face Centred Cubic
HSO	Human Spaceflight and Operations
ISS	International Space Station
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
PB-HSR	Human Spaceflight, Research and Applications Programme Board
PDMS	Polydimethylsiloxane
PDR	Preliminary Design Review
PF	Parabolic Flight
PFC	Parabolic Flight Campaign
PL-3	Materials for the stress birefringent materials (property of Vishey company)
RD	Reference Document
SPACEGRAINS	Behaviour of Granular Dissipative Gas under Vibration and Cluster Formation
SPOT	Science Payload and Operations Team
TBC	To Be Confirmed
TBD	To Be Determined
UIB	Utilisation Implementation Board
VIP-Gran	Vibration Induced Phenomena in Granular Materials

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Appendix 1 - SUMMARY TABLE OF THE TBCs AND TBDs **TO BE COMPLETED by OlivierD**

Experiment item	Requirement	ESR §	Open Issues
		3.2.2 3.4.2	TBC + TBD
		3.4.3	TBD
		3.6.3	TBD
		3.7.1	TBD
		3.7.2	TBC
		3.8	TBC
		3.9.3	TBC
		3.10.2	Specify
		3.10.3	Clarify
		3.10.5	Clarify
		3.10.6	Reformulate in m/s^2
		3.11.4	TBD
		3.12.2	TBD
		4.1.3	Clarify

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