INTERACTIONS IN COSMIC AND ATMOSPHERIC PARTICLE SYSTEMS (ICAPS) – EXAMPLES OF THE RESEARCH PROGRAMME

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ABSTRACT

We describe a new international microgravity research program on the ISS. Interactions of solid and liquid particles with other particles, with gas, and with light are intended to be investigated, including aggregation phenomena, light scattering properties, evaporation and condensation cycles, and phoretic effects. Compared to several previous attempts to build a multi-user microgravity facility for particle experiments in microgravity, ICAPS is the most modern approach and has, after being judged scientifically “outstanding”, good chances to become reality. Preparational laboratory work is in progress.

INTRODUCTION

In the past decades, various attempts were made to design an experimental facility to be used for a variety of experiments with small particles in microgravity. In the 1980s, for example, NASA investigated a concept for a “Gas Grain Simulation Facility” (Zamel and Petach 1993). However, this project never became funded and was finally cancelled. In 1995, the European Space Agency ESA called for proposals in order to install “Topical Teams”, which were intended to define future microgravity research, primarily with respect to ESA’s participation in the International Space Station (ISS). The work done by the ESA-funded Topical Team “Particle Aggregation and Dispersion” resulted in a proposal entitled “Interactions in Cosmic and Atmospheric Particle Systems (ICAPS)” (Blum et al. 1999) on which this contribution is based. ICAPS is a seven-years scientific programme to simulate, under microgravity conditions, cosmic and atmospheric particle systems, i.e. particle-particle, particle-gas and particle-light interactions. At submission of the proposal, the ICAPS team comprised 21 scientists from Austria, Belgium, Canada, Finland, France, Germany, Italy, Japan, and the USA. The team is open to further expansion in the future. In July 1999, the scientific evaluation of the proposal resulted in the mark “outstanding”, upon which ICAPS officially became part of the ESA MAP (“Microgravity Application Programme”). Funding for preparational work is already available in Finland, Germany, Japan, and USA, where laboratory work is currently in progress.

SCIENTIFIC OBJECTIVES

Following extensive discussions during the preparation of the ICAPS proposal and during the Topical Team meetings, the basic scientific objectives of ICAPS were defined to be the following:

1. Study mutual interactions between solid or liquid particles.
2. Study interactions between solid/liquid particles and the ambient (neutral) gas.
3. Study interactions between solid/liquid particles and electromagnetic radiation.

For the realisation of these objectives, we defined so-called Central Research Topics (CRT’s), in which different aspects of the main objectives are treated. The six CRT’s which were identified in the proposal are the following:
In Fig. 1, the relationship between the six CRT's and the main scientific objectives is illustrated, and Table 1 summarises the individual scientific disciplines and presents keywords for the applications of the research to be performed by ICAPS.

**AN EXAMPLE OF A DETAILED SCIENTIFIC PROGRAMME**

Due to space limitations, we cannot present the complete current scientific programme of ICAPS. Here we will concentrate on a single, representative (however biased) example of a research project that will be performed with ICAPS. This project deals with research on high-porosity macroscopic bodies, ranges in applications from astrophysics to material sciences, and comprises CRT3 - CRT6.

**Formation of High-Porosity Macroscopic Bodies**

The formation of planetesimals in the young Solar System is marked by orderly dust growth, followed by a runaway growth process, during which the largest dust aggregates in the ensemble accrete the free-floating smaller dust grains (Weidenschilling and Cuzzi 1993). This latter, theoretically-predicted process has never been experimentally investigated, particularly not under solar-nebula conditions, i.e. in a rarefied gas and in a
Table 1: The scientific programme of ICAPS. P-P, P-G, and P-L refer to particle-particle, particle-gas, and particle-light interactions, respectively.

<table>
<thead>
<tr>
<th>CRT#</th>
<th>Name of CRT</th>
<th>Fields</th>
<th>Disciplines</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT1.1</td>
<td>Particle behaviour in a nonconvective gas</td>
<td>P-G, P-P</td>
<td>Heat/mass/momentum transfer</td>
<td>Diffusion, coagulation</td>
</tr>
<tr>
<td>CRT1.2</td>
<td>Microphysics of clouds</td>
<td>P-G, P-P, P-L</td>
<td>Planetary/climatology</td>
<td>Evolution of cloud nuclei and droplet spectra, rain initiation</td>
</tr>
<tr>
<td>CRT2.1</td>
<td>Phoretic effects with phase transition of water</td>
<td>P-G, P-L</td>
<td>Aerosols, light scattering/radiative transfer</td>
<td>Particle scavenging in clouds, influence on optical properties of droplets and crystals</td>
</tr>
<tr>
<td>CRT2.2</td>
<td>Phoretic effects without phase transition of water</td>
<td>P-G, P-L</td>
<td>Aerosols, light scattering/radiative transfer</td>
<td>Abatement of industrial effluents, industrial sampling bias</td>
</tr>
<tr>
<td>CRT3.1</td>
<td>Restructuring of dust agglomerates</td>
<td>P-P, P-G</td>
<td>Astrophysics, aerosols, planetary science</td>
<td>Planetesimal formation (early phase), metamorphosis of atmospheric particles, planetary rings and cometary comae</td>
</tr>
<tr>
<td>CRT3.2</td>
<td>Run-away growth process</td>
<td>P-P, P-G</td>
<td>Astrophysics, aerosols, planetary science</td>
<td>Planetesimal formation (intermediate phase), precipitation formation</td>
</tr>
<tr>
<td>CRT3.3</td>
<td>Large-aggregate collisions</td>
<td>P-P</td>
<td>Astrophysics, planetary science (comets, rings)</td>
<td>Planetesimal formation (late phase)</td>
</tr>
<tr>
<td>CRT4.1</td>
<td>Morphological and mechanical properties of regoliths</td>
<td>P-P, P-L, P-G</td>
<td>Planetary science</td>
<td>Weathering of small Solar-System bodies, sampling on small Solar-System bodies, gas diffusion in regoliths</td>
</tr>
<tr>
<td>CRT4.2</td>
<td>Optical properties of regoliths</td>
<td>P-L</td>
<td>Light scattering/radiative transfer, planetary science</td>
<td>Small Solar-System bodies: remote sensing, taxonomy, variegation</td>
</tr>
<tr>
<td>CRT5</td>
<td>Optical and morphological properties of dust aggregates</td>
<td>P-L</td>
<td>Light scattering/radiative transfer, planetary science, aerosols of dust particles and aggregates</td>
<td>Interplanetary, cometary, and preplanetary dust particles, particles in planetary rings, light-scattering characterisation of particles and aggregates, optical properties of dust aggregates, database for optical constants of dust particles and aggregates</td>
</tr>
<tr>
<td>CRT6</td>
<td>Validity of classical radiative transfer theory and various light scattering methods</td>
<td>P-L</td>
<td>Light scattering/radiative transfer</td>
<td>Influence of inter-particle distance (inhomogeneous media)</td>
</tr>
</tbody>
</table>
microgravity environment.

The runaway growth process of dust aggregates will be studied in ICAPS CRT3.2 (see Table 1). A beam of single or aggregated dust grains will be directed onto a porous target substrate (Fig. 2). For sufficiently low impact velocities, the impinging dust grains will stick to the target and to the subsequently growing dust layer without impact compaction (Blum and Wurm 2000). Thus, a very porous, macroscopic (i.e. cm-sized) dust agglomerate will form with which further experiments will be conducted. Due to the absence of gravity, the porous body will not collapse under its own weight as would be the case on Earth. The initial porosity of the macroscopic dust agglomerate is dependent on the impact velocity of the dust grains in the jet (Blum and Wurm 2000) and on the aggregation stage of the impinging particles. As primary dust grains, micron-sized silicate particles will be chosen whenever the astrophysical process of runaway growth is studied. For other applications (see below), different materials and grain sizes will be used. The basic technology of dust jet formation (Poppe et al. 1997, Blum and Wurm 2000) has been demonstrated, and a laboratory setup for the study of runaway growth phenomena is under construction.

**Figure 2: The formation of macroscopic dust agglomerates.**

**Mechanical Properties of High-Porosity Macroscopic Bodies**

Once the macroscopic dust agglomerate has formed, its “bulk” physical properties will be evaluated (Fig. 3). One of these measurements will deal with the determination of the overall mass density (or porosity) of the aggregate. The total mass of the macroscopic body will be determined by examining the eigenfrequency of a spring on which the agglomerate is mounted (Fig. 3a). With the aid of the ICAPS camera system, the total volume, and thus the mass density can be derived.

For the determination of the mechanical stability of planetesimals in the young Solar System and of comets (which are thought to be large conglomerates of dust and ice) and regolith layers (ICAPS CRT4.1) in the present Solar System, their tensile strength and compressibility need to be known. By fast rotation of the agglomerate sample, we will determine the gross cohesive strength of the aggregates (Fig. 3b). The determination of the compressive force as a function of the displacement of the dust sample under compression will give information on the compressibility of the dust agglomerates (Fig. 3c). With the compressed and compacted samples, further experiments (see below) will be conducted.

**Collisions between High-Porosity Macroscopic Bodies**

Collisions between similar-sized macroscopic dust agglomerates play an important role for the evolution of
proto-planetary nuclei in the solar nebula (ICAPS CRT3.1 and CRT3.3). The outcome of low-velocity (0…1 m/sec) collisions among those bodies is completely unknown. Expectations range from simple sticking to fragmentation (Fig. 4). In the ICAPS facility, two cm-sized highly porous dust agglomerates will be accelerated (with acceleration levels ≤ 1 m/sec²) such that they collide with a velocity in the above-mentioned interval. The outcomes of the collisions will be observed using high-resolution (and probably high-speed) video cameras, so that an unambiguous distinction between the different expected phases can be determined (see Fig. 4).

**Collisions into High-Porosity Macroscopic Bodies**

Impacts into regoliths or onto small planetary bodies (asteroids, ring particles) are ubiquitous in the Solar System. With ICAPS, we plan to study low-velocity (0…10 m/sec) impacts of solid impactors into macroscopic bodies of various porosities. First microgravity experiments, which studied low-velocity impacts into relatively dense dust samples, showed that the coefficients of restitution of the impactors were very low (typically 2-3%) and that only a small fraction of the dust sample was ejected during the impacts (Colwell and Taylor 1999). Here, we intend to study those impacts into more realistic (i.e. much more porous) dust samples (Fig. 5). Dust ejecta, crater size, and the coefficient of restitution of the solid impactor (or its embedding into the dust sample) will be measured.

**Light-Scattering Properties of High-Porosity Macroscopic Bodies**

For the comparison of simulated and real surfaces of small Solar-System bodies (ICAPS CRT4.2, CRT5, CRT6), we will measure the light-scattering efficiency of artificial regoliths for a wide range of phase angles, for different monomer grain sizes, shapes, and materials, and for different porosities of the samples (Fig. 6). A laser diode represents the solar irradiation and a detector system is used for measuring the phase function of the scattered intensity and polarisation.

**Hardening/Solidification of High-Porosity Macroscopic Bodies**

Of general interest to the material sciences, in particular to the understanding of the formation process of ceramics, we intend to perform sintering experiments with high-porosity macroscopic agglomerates, consisting of mineralic entities (Fig. 7a). After an extended exposure to a high-temperature environment (e.g. in the furnace of the JEM module), we will repeat the tensile and compression tests described above, or, for sufficiently stable samples, the sintered materials will be returned to the ground. Complete melting of a formerly porous dust sample may yield information about chondrule-formation processes in the solar nebula.

Another approach for studying potential hardening of “soft matter” is by allowing chemical surface reactions to take place. If the end product of the chemical reaction occupies a larger volume than the primary constituents, the macroscopic agglomerate may break apart or may be considerably solidified (Fig. 7b). Such reactions may
Figure 4: Possible outcomes of collisions between macroscopic dust agglomerates.

Figure 5: Impacts into simulated regoliths.
Figure 6: Light-scattering measurements on simulated regoliths.

Figure 7: Solidification of "soft matter". (a) Sintering and melting. (b) Chemical surface reactions.
have played a considerable role during the cooling phase of the solar nebula.

DEVELOPMENT OF ICAPS TECHNOLOGIES AND METHODS

Due to the widespread microgravity experience of the ICAPS team members, a variety of diagnostic and conditioning hardware has already been developed and space-qualified. Currently, a two-years laboratory development programme is ongoing, in which the different ICAPS groups will develop the crucial technologies and methods, in particular in the field of sample handling and manipulation. Prototype hardware and technology demonstration for the six ICAPS CRT’s are expected for 2001/2002.

ICAPS ONBOARD COF

In 2001, ESA will conduct a Phase A study for the feasibility and accommodation of ICAPS in the Columbus Orbital Facility (COF). Currently, the baseline for the accommodation of ICAPS is the European Drawer Rack (EDR), but alternatives, such as the Fluid Science Laboratory (FSL) are also under consideration. Due to various hardware similarities, a joint ICAPS-IMPF (International Microgravity Plasma Facility) accommodation in COF/EDR will also be studied.

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REFERENCES


