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THE COMRADE EXPERIMENT : A COLLECTION FACILITY FOR COMETARY DUST AND SPACE DEBRIS

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ABSTRACT

The COMRADE experiment,is designed to return minimally degraded particles to Earth along with complete *in situ* information concerning mass, velocity and trajectory of encountered particles. The objectives of the program are very diverse. A set of flight-tested active detectors will be combined in an array to identify some of the physical properties of an incident grain, e.g., velocity vector, momentum, mass. The use of passive detectors gives access to the chemical and isotopical properties of the grains in the micron size range. We are concerned simultaneously with a destructive capture, using metallic collectors, and a nondestructive capture, using a new low density target in which the impacting grains stop, practically intact.

INTRODUCTION

We are interested in the collection and analysis of particles of various origins orbiting around the Earth at low altitudes (between ~300 and ~800 km), where they can be recovered by various spacecrafts. We can roughly divide them into categories of orbital debris, resulting from manmade effects and extraterrestrial particles. It is important to collect these last particles before being processed by the Earth atmosphere.

Since the first NASA U-2 flight collection in 1974 (Ref. 1), the collection and analysis of extraterrestrial particles orbiting around the Earth in Low Earth Orbits (LEO) have been greatly developed.

The main scientific interest in the analysis of extraterrestrial particles, more commonly called Interplanetary Dust Particles (IDPs), is due to the fact that part of these particles could be of cometary origin and thus contain information on the origin of the solar system. Cometary material is likely to be the most primitive material accessible for analysis. It is thought that grains once present in the cometary nuclei and now present as individual grains in interplanetary space are the best candidates for still having present properties they acquired before or during the condensation of planetary objects. A second minor component is also present, originating from the asteroidal belt. The smaller size fraction (grains less than 10 microns in diameter) is supposed to be enriched in grains of cometary origin (Ref. 2). The grains we analyse are thus of various origins from inside the solar cavity and have been subject to various kinds of irradiations, inside the past and present solar cavity. It is now well known that these different irradiations of grains can result in different physical, chemical or isotopical properties (Ref. 3). Also present are orbital debris with velocities of the same order and resulting from manmade activities (paint flakes, aluminium oxide spheres, etc...). The small sized grains are the most frequent ones orbiting around the Earth, manmade debris having, for all sizes, much larger fluences than extraterrestrial grains.

The COMRADE experiment (Collection Of Micrometeorites, Residue And Debris Ejecta) has been selected as a proposal for the EURECA pre-Columbus flight, in order to gain information on all sizes of particles present on Low Earth Orbits, including submicron grains. It has been accepted by ESA authorities for use on the EURECA 2 platform. The purpose of our proposal, apart from studying the various properties of grains and impacts, is to conduct an extensive study into the design of a permanent collection facility to be flown on board Columbus.

We are concerned simultaneously with a destructive capture of orbiting grains, using metallic collectors, improved since the COMET-1 experiment (Ref. 4) and a non destructive capture, using new low density targets in which the impacting grains stop, practically intact. The advantage of the first type of capture is twofold: it allows us to gain information on the smallest size fraction, and to detect the presence of light elements such as carbon. The interest of the second type of capture is to allow the extensive study of intact IDPs. Up to now, this technique has only been applied to short flights of the NASA Space Shuttle, for studies of orbital debris (Ref. 5). Grains a few microns in size can be stopped in those low density materials and recovered for further studies. Our COMRADE experiment will be the first one coupling purpously the two techniques.

The proposed investigation, which will collect micron/submicron particles with a minimum of particle degradation, will at the same time measure the dynamic particle parameters (determination of its mass, velocity, trajectory,and, for some, charge) with a high degree of confidence. Long term *in-situ* dynamic measurements of these particles, in this spatial region, do not exist reliably. The instrument proposed will accomplish this double task using completely flight proven components having a scientific lineage which includes experiments such as COMET, ESA's HEOS and HELIOS and NASA's Shuttle Environment Monitor experiments.

SCIENTIFIC OBJECTIVES

The primary objectives for this mission are: i) to identify the particle remnants of the micron sized grains having impacted on purposely designed metallic collectors, for complete and detailed chemical, isotopic and organic analysis thereby determining grain composition as well as the existence of organic and inorganic molecules, to be related with the possible cometary origin of the grains showing an extraterrestrial signature; ii) to return captured intact particles to Earth for complete and detailed chemical, isotopic, spectral, mineralogical and organic analysis thereby determining grain composition as well as the existence of organic and inorganic molecules; iii) to capture micron/submicron dust grains in a manner that insures minimal particle degradation and guarantees state of the art confidence in measurements of the *in-situ* particle parameters including trajectory, velocity vector, mass and flux distributions.

This analysis should determine possible particle sources such as interplanetary or interstellar dust, meteorites, comets, lunar ejecta and orbital debris originating mainly from the effluents from solid rocket motors. Correlating the dynamic particle data with the collection analysis data can more confidently determine particle origin and allow advancement of current theories in universe, solar system and cometary evolution, exobiology and the origin of life.

CAPTURE OF REMNANT PARTICLES FOR CHEMICAL ANALYSIS

Grain collection in low Earth orbit had started with the COMET-1 (Collecte en Orbite de Matière ExtraTerrestre) experiment that was designed to allow the collection of grains by impacts on targets installed outside Saliout 7 station, orbiting at 350 km altitude (Ref. 4). The collectors were exposed to space in October 1985, while the Saliout 7 station was crossing the Giacobini-Zinner meteor stream, in order to study the chemical properties of grains of cometary origin.

High purity metallic sufaces are used for the collection of all grains down to submicron sizes. During the impact of a high density impactor, a characteristic crater is formed, with rounded habits and a depth to diameter ratio characteristic of the encountered metal, the velocity and size of the impacting particle; the particle is destroyed and the remnants are mixed with the target material, concentrating in the bottom of the crater or on the surrounding rims. Its chemical and isotopical properties can be identified, by analyzing the rim material. In the case of impacting aggregates of very low density, it seems that the particle sticks to the collector, much less melted (Ref.6).

After tests made at the Dust Accelerator of the Max Planck Institut in Heidelberg, we have found that gold and nickel are metals suitable for such collectors; furthermore, it is possible to obtain these metals at high purity (4 or 5 N). We have also shown that the evaporation of 50 nm of gold on the exposed surface increases noticably the identification of the impacting position, as the tear of the film creates a decoration of the impact position, allowing its easier finding.

The major strength of the metallic collectors lies in the fact that these analytical techniques can be applied without modification to craters ranging from tens of nanometers up to millimeters in size, limited only by the thickness of the plate. Also, identification of carbon and organic material is made possible; this is essential for the study of extraterrestrial material, in search of particles of cometary origin.

The collectors, after their exposure in space, are brought back in clean, sealed boxes to the clean rooms of the lab. There, the impact positions of the grains are identified directly on the surface of the collectors, either by optical microscopy for the larger ones, or by using a scanning electron microscope for the micron-sized impacts, at a magnification that allows to identify crater features down to diameters of $\sim 1\ \mu$m. We can thus analyze the size distribution of the impact features, down to these sizes, allowing the evaluation of the incident microparticle flux in the near Earth environnment. In a second step, it is possible to determine, for each selected crater, the chemical composition down to C of the impacting particles, generally physically destroyed and mixed with target material in the process of crater formation. For grains identified on a chemical basis as being of extraterrestrial origin, this analytical step is to be followed by a high resolution analytical protocol including FESEM (Field Emission Scanning Electron Microscopy) imagery, molecular and isotopical identification.

The main results obtained up to now concern only particle remnants that have been obtained from the COMET-1 experiment, the analysis of a few cm^2 of thick aluminium targets of the FRECOPA tray, directly opposed to the velocity vector on board LDEF and the analysis of collectors exposed during some Shuttle flights (STS experiments).

We found for the number of impact features smaller than 10 microns in diameter a cumulative flux of $\sim 8 \cdot 10^{-2}\ m^{-2}\ s^{-1}$ for COMET and $\sim 2 \cdot 10^{-4}\ m^{-2}\ s^{-1}$ for FRECOPA. The flux measured for COMET consists of $\sim$ 90% orbital debris, while for FRECOPA, the flux value is mainly due to extraterrestrial particles, as confirmed by chemical analysis. This value fits with the previous estimations of the micrometeorite particle mass distribution, while for COMET, we find a large enhancement, attributed to the fact that the collection occurred during the encounter of the Giacobini-Zinner meteor stream.

In both experiments, extraterrestrial particles, supposed to be mainly of cometary origin, show chondritic proportions of various elements : Na, Al, Mg, Si, S, Ca and Fe, associated in most cases with various proportions of C and O. For some extraterrestrial particles, C and O are found alone. The systematic presence of low Z elements, either exclusively or associated with other elements whose abundances reflect a chondritic type composition, can be compared to results obtained by the PUMA and PIA experiments (Ref. 7). These experiments analyzed the grains in the close environment of Halley nucleus and demonstrated that at least 50% of the grains within the nucleus contain a phase made of C,H,O and N atoms, called CHON phase. The existence of grains with similar compositions, close to the nucleus and in terrestrial orbit means that they are stable and refractory enough to survive up to thousands of years in the intense solar UV field. Such refractory phases might be accounted for by an irradiation origin.

We have also exposed our collectors during some flights of the NASA Space Shuttle (STS flights). These flights last a few days and are not related to specific meteor streams. The specificity of our previous COMET experiment, that was due to the exposure of collectors related to cometary events is replaced by a larger frequency of flights, allowing us to accumulate results on submicron particules orbiting around the Earth. A first flight took place in 1990 (STS 32), during the mission of recovery of the LDEF satellite. Again, during the STS 42, 44, 46 and 52 missions, a few cm^2 of metallic collectors were exposed to space. Up to now, no IDP impact has been identified ; the number of identified orbital debris impacts is consistent with a non enrichment in the micron size range, even when a large enrichment has been observed for larger events, as is the case for the STS 44 flight (Ref. 8).

INTACT CAPTURE OF HYPERVELOCITY IMPACT PARTICLES

The return of extraterrestrial material to the laboratory is a primary goal of this investigation. Traditionally, this has been achieved in low Earth orbit by use of the capture cell or its variant. The proposed investigation intends to retrieve relatively unshocked material by impacting three types of "underdense" capture devices. Shuttle experiments (STS 41-B, 41-D and 61-B) have shown that both organic foam and aerogel materials can be successfully used to capture intact particles (Ref. 9). These underdense capture devices will also be complemented by two well established techniques: namely the foil/substrate capture cell and the witness plate.

The impact of a hypervelocity projectile (> 3km/s) is a process which subjects both the impactor and the impacted material to a large transient pressure distribution. The resultant stresses cause a large degree of fragmentation, melting, vaporization and ionization (for normal densities). The pressure regime magnitude, however, is directly related to the density relationship between the projectile and target materials. As a consequence, a high density impactor on a low density target will experience the lowest level of damage.

Historically, there have been three different approachs towards achieving the lowest possible target density. The first employs a projectile impinging on a foil or film of moderate density but whose thickness is much less than the particle diameter. This results in the particle experiencing a pressure transient with both a short duration and a greatly reduced destructive effect. A succession of these films, spaced to allow nondestructive energy dissipation between impacts, will reduce the impactor's kinetic energy without allowing its internal energy to rise to the point where destruction of the projectile mass will occur.

A second alternative uses aerogel as the capture medium. This material, in its silicon form, is commonly produced for the nucleonics industry as a Cherenkov radiator, and has in fact been used in both space (HEOS, Ulysses and STS-32) and balloon instrumentation. Other, analytically more desirable, compounds may also be processed to form this microporous structure, and these are currently being investigated. In comparison with polymer foams however, the extremely low densities ($\rho = 0.035$) cannot be achieved in any aerogel without producing great fragility.

Polymer foams have been employed as a third method of capturing particles with minimum degradation. The manufacture of extremely low bulk density materials is usually achieved by the introduction of voids into the material base. It must be noted, however, that a foam structure only has a true bulk density of the mixture at sizes much larger than the cell size, since for impact processes this is of paramount importance. The scale at which the bulk density must still be close to that of the mixture is approximately equal to the impactor. When this density criterion is met, shock pressures during impact are minimized which in turn maximizes the probability of survival for the impacting particle. Polymer foam has been used currently as collecting material on various STS flights. Intact particles, mainly of terrestrial origin, as small as 0,4 microns in size have been recovered. They are often recovered by encrusted pyrolized foam easily removed, leaving an undegraded specimen.

MEASURE OF FUNDAMENTAL PARTICLE PARAMETERS

The reliable determination of the trajectory of each individual dust particle is a high priority of the proposed investigation. Historically, particle trajectories (as well as particle time of flight) have been determined using the thin film/plasma technique. This technique is based on the fact that a cosmic dust particle which impacts an extremely thin film will create a minute plasma cloud. The collection of this plasma cloud then allows for the analytic determination of dynamic particle parameters. The use of multiple thin films thereby yields a method whereby particle trajectories and time of flight can be determined.

In addition to the particle trajectory, it is vital that dynamic particle parameters also be measured with a high degree of reliability. The basic parameters which the proposed experiment will measure and/or determine are the particles velocity and mass. The particle charge and time of flight can be measured by examining the thin film/plasma technique discussed previously. Also, by examining the amplitude of the plasma pulse produced, the kinetic energy of the particle can be obtained which in turn enables a determination of the particle's mass. Since one of the major goals of the proposed instrument is to capture the particle while causing minimum particle degradation, it is necessary that extremely thin films be used in this sensor. The thinner the foil, the smaller the plasma produced and the more difficult it is to capture the signal produced. However, the experiments previously listed, along with the production and collection of ions and electrons from current laboratory hypervelocity impact studies have yielded the data necessary to optimize the collection ability of the proposed instrument .

Collection of plasma from rear plate hypervelocity impact will imply penetration of thin films by an incident dust grain. Thus a lower bound on particle mass is set which depends on inferred density (Ref. 10), and the penetration mass limits established during calibration studies conducted using materials with various densities ($m_g \geq m_{pen}$). Impact impulse measurements of hypervelocity impact piezoelectric transducers (PZT) will provide, through calibration, the momentum transferred if and only if trajectory can be established from other sensors. With these measurements and an accurate velocity vector measurement ($v_g \pm$ 1-2%), a value for mass will be deduced via calibration established look-up tables. An accurate mass value which possesses only the uncertainty attending measurement of impulse, trajectory, and velocity ($m_g \pm 1\%$) will be given by impulse detection. With precise knowledge of the plasma collected at the PZT impact plate, and with accurate measurement of velocity vector, one can with calibration data from hypervelocity impacts on PZT plates establish an upper bound on the particle mass. The accuracy of this method depends on the composition of dust grains utilized in laboratory simulation studies ($m_g \leq m_Q$). Therefore one may establish a lower bound and an upper bound on the mass of the dust grain encountered: $m_{pen} \leq m_g \leq m_Q$.

CONCLUSION

It is in the context of research of cometary particules down to submicron sizes that our proposal of exposing materials in LEO must be perceived. The detection of these particles combines active detectors, to determine the physical properties of the grains in LEO, with types of passive detectors (metallic collectors and low density material). Any collection facility designed for a long term exposure should contain some high purity metallic targets for chemical and isotopical identification of particles. The coupling of metallic collectors and low density material is an unique opportunity to complete information on all sizes of grains from submicron sizes to a few microns. The perspective of long duration flights is important in order to recover individual grains. The probability of recovering grains larger than 10 microns, while much less frequent, is very much improved in comparison with, for instance, the short exposure collections on board the NASA Space Shuttle. Such short collections are altogether very important for the study of manmade debris evolution in time; they can also be a harvest of cometary grains, if the shuttle flight is correlated with a given meteor stream.

All grains down to submicron sizes can be collected on our metallic targets. Because of their high relative velocity (≥ 5 km/s), the impacting grains are physically destroyed, leaving a melted remnant that is mixed with the crater material. This process is more favorable for the smaller grains, with sizes in the micron size range; the larger grains can vaporise, leaving no analysable remnant. Our previous results have shown that gold and nickel collectors are favorable for the collection and analysis of the small sized-grains orbiting around the Earth. For the less frequent larger grains, their collection is possible in large surfaces of low density material.

The analysis of the grains, either remnants or entire, will be performed with the high resolution instruments we have access to (optical microscopy, SEM, EDS, FESEM, ionprobe). By the time the collectors will be back from space, new techniques will have been developed and accessible for our analysis; for instance IR spectroscopy of individual grains, or double laser probe, promising techniques for identifying eventual organic molecular species present inside the grains. The possibility, offered for the first time with the EURECA platform to recover IDPs of cometary origin, in which the organic phase can be analysed, is a very exciting one, as the comet grains remain privileged witnesses of the beginning of the solar system.

The COMRADE proposal expands upon a program initiated a few years ago, with the COMET-1 experiment. It provides the collections of cometary dust and space debris as well as the characterisation of their dynamic properties. It will consist in exposing a variety of detectors and captors on board spacecrafts orbiting around the Earth.

The opportunities in the future might include EURECA-2, LDEF-2 and possibly the MIR station to which an improved version of the COMET experiment could be attached. This latter flight opportunity would open the possibility to collect material at any given period and for any duration chosen.

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