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PREPARATION, ANALYSIS, AND RELEASE OF SIMULATED INTERPLANETARY GRAINS INTO LOW EARTH ORBIT

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I. INTRODUCTION

Astronomical observations which reflect the optical and dynamical properties of interstellar and interplanetary grains are the primary means of identifying the shape, size, and the chemistry of extraterrestrial grain materials and is a major subject of this workshop. Except for recent samplings of extraterrestrial particles in near-Earth orbit and in the stratosphere (see R. L. Walker, this volume) observations have been the only method of deducing the properties of extraterrestrial particles. In order to elucidate the detailed characteristics of observed dust, the observations must be compared with theoretical studies, some of which are discussed in this volume, or compared with terrestrial laboratory experiments.

Such experiments typically seek not to reproduce astrophysical conditions but to illuminate fundamental dust processes and properties which must be extrapolated to interesting astrophysical conditions. In this report, we discuss the formation and optical characterization of simulated interstellar and interplanetary dust with particular emphasis on studying the properties on irregularly shaped particles. We also discuss efforts to develop the techniques to allow dust experiments to be carried out in low-Earth orbit, thus extending the conditions under which dust experiments may be performed. The objectives of this study are three fold:

1. Elucidate the optical properties, including scattering and absorption, of simulated interstellar grains including SiC, silicates, and carbon grains produced in the laboratory.

2. Develop the capabilities to release grains and volatile materials into the near-Earth environment and study their dynamics and optical properties.

3. Study the interaction of released materials with the near-Earth environment to elucidate grain behavior in astrophysical environments. Interaction of grains with their enviroment may, for example, lead to grain alignment or coagulation, which results in observable phenomena such as polarization of light or a change of the scattering properties of the grains.

II. EXPERIMENT AND DISCUSSION

1. Grain preparation and physical characterization

The grains may be prepared by injecting a gas mixture, including volatile precursors containing the elements of interest, into an inductively coupled plasma system. The volatile precursors, mixed with other reactant gases, for example hydrogen, argon, and N_2O are pyrolized in the high temperature plasma to an elemental gas. The grains are formed by condensation from the gas in the relatively low temperature tailflame of the plasma. For example, SiC or silicate grains may be prepared by mixing combinations of CH_4, $Fe(CO)_5$, and SiH_4 into the plasma feed gases. A schematic of such a plasma system, currently used by Los Alamos researchers to form refractory ceramics is shown in Figure 1 (from Vogt et al., 1984). Nearly any gas mixture can potentially be prepared by using a combination of gaseous, liquid, and powder feed materials. The system shown operates at near atmospheric pressure, and local thermodynamic equilibrium is believed to be maintained throughout the condensation process. Powders can be prepared in the kilogram quantities necessary for release experiments into orbit.

The particles produced occur as tangled strings of submicron grains typical of laboratory produced grains. Figure 2 shows silicate, SiC, and carbon grains prepared by another method, vaporizing a solid into a rarified gas using a laser (Stephens, 1980). The diffraction patterns for the "olivine" silicate, SiC, and carbon grains indicate that the grains are amorphous, highly crystalline B-SiC, and glassy, respectively.

2. Optical characterization of grains

Although the individual grains produced in the plasma are too small to produce significant scattering of visible and infrared radiation, the agglomerated grains have shown measurable scattering to wavelengths at least 10 microns in the infrared (Stephens and Russell, 1979). Such elongated grains could also cause polarization of starlight if they are aligned. A laboratory apparatus is being constructed to study the absorption, scattering, and light polarization properites of these highly irregular particles as a function of scattering angle and wavelength. A schematic of the laboratory apparatus is shown in Figure 3. The apparatus consists of a solar simulator light source with optional monochromator and polarizer which illuminates a scattering chamber of several liters volume in which particles are suspended in a gas. Scattering from the particles is detected by a combination monochromator-optical multichannel analyzer (OMA) which is sensitive over the wavelength range of 300 to 900 nm. The apparatus measures the wavelength and polarization resolved scattering of particles averaged over particle shape and orientation and is complementary to instruments which measure single particle scattering at a single wavelength. Planned enhancements to the system include adding a quartz element mass monitor to measure aerosol mass and a photoacoustic detector to allow measurement of aerosol absorption.

In conjunction with the optical measurements of laboratory-produced particles, microwave analogue studies, in collaboration with the Space Astronomy Laboratory at the University of Florida at Gainesville and the Ruhr University at Bochum, Germany are planned. The microwave analogue technique uses microwave radiation scattered from cm sized "grains" with the appropriate complex index of refraction to simulate scattering of visible radiation from micron-sized particles. The technique allows accurate measurements of irregular particle scattering to be made which are not possible by direct measurements on real particles. The microwave analogue measurements on scaled single particles complement our measurements on a cloud of particles.

3. Grain packaging, release, and monitoring of grains in low-Earth orbit

The thrust of the orbital release experiments is to monitor the dynamics and optical signatures of well characterized laboratory grains released into near-Earth orbit to elucidate the behavior of grains in astrophysical environments. Several kilograms of laboratory-prepared dust will be required for dust release experiments in orbit. Initially, refractory dusts including silicates, SiC, or carbon are planned for release. Later, releases of mixtures of dust and volatile materials, to simulate a comet nucleus, are possible. It is presently planned to collect the dust immediately upon preparation by the plasma system in a liquid or solid binder to inhibit grain coagulation during storage. A high vapor pressure liquid or subliming binder are being considered. Samples of the grains prepared will be characterized physically and optically, as outlined above, to provide baseline data for the observations of the grains in orbit.

Grain releases will be carried out from the Space Shuttle Orbiter using a Get-Away-Special cannister with the capability of releasing a small satellite (XSAT), which is approximately 45 cm on a side, with a weight capacity of 150 pounds. The XSAT, containing the grains, binder, and supporting electronics is ejected from the Shuttle by a crewmember while in orbit. After the shuttle has deorbited, activity on the XSAT may be initiated by radio. Aerosols are released from the binder using resistive heating or exothermic chemical reaction. The Get-Away Special cannister containing the ejection mechanism has been tested on a recent shuttle flight. The XSAT deployed in the recent shuttle flight was developed by the experimenters. NASA has proposed to develop a generic XSAT with telemetry, limited attitude control, and programmable data controller capabilities. The lifetime in orbit would be up to a year with solar cells. A photograph of the get-away-special ejector is shown in figure 4 in cutaway view with the top open.

Initiation of the grain release from the XSAT and observations will be carried out from the AMOS/MOTIF observatory on Mt. Haleakala on Maui in the Hawaiian Islands. Grain release will be initiated at a time such that the grains pass overhead near the terminator, with the grains illuminated by the sun, but the ground in darkness. Observations will be performed as the grains pass overhead, yielding scattering data as a function of sun-grain-observer scattering angle. Possible observations include total scattered intensity, cloud imaging, and also visible and infrared spectrometry. Polarization resolved observations of scattered light, which may result from grain streaming or alignment by the Earth's magnetic field, will be carried out if the signal is sufficiently strong. Fundamental questions to be answered include the magnitude of the atmospheric drag on the particles, efficiency of grain alignment caused by streaming through the atmosphere or alignment with the Earth's magnetic field, and charging of the particles which can have a major effect on their orbital trajectory.

III. CONCLUSIONS

The above program is aimed at elucidating the scattering properties of irregular, coagulated dust composed of candidate materials for interstellar and interplanetary dust. In addition, this program attempts to extend the physical conditions under which dust may be studied by extending laboratory studies to the near-Earth environment. We have outlined several phenomenon of fundamental interest to the study of interstellar and interplanetary dust which will be investigated. The orbital release studies outlined above represent only a beginning of what is possible. Releasing mixtures of refractory grains and volatiles to simulate comet processes near perihelion is one potentially fruitful avenue of research. Simulated comet releases could be used not only to study cometary processes, but also to test instruments designed for comet rendezvous missions. Such studies would take advantage of the Shuttle as an observation platform for performing space experiments. Suggestions and collaborations involving observations, experiments, and equipment design are welcome.

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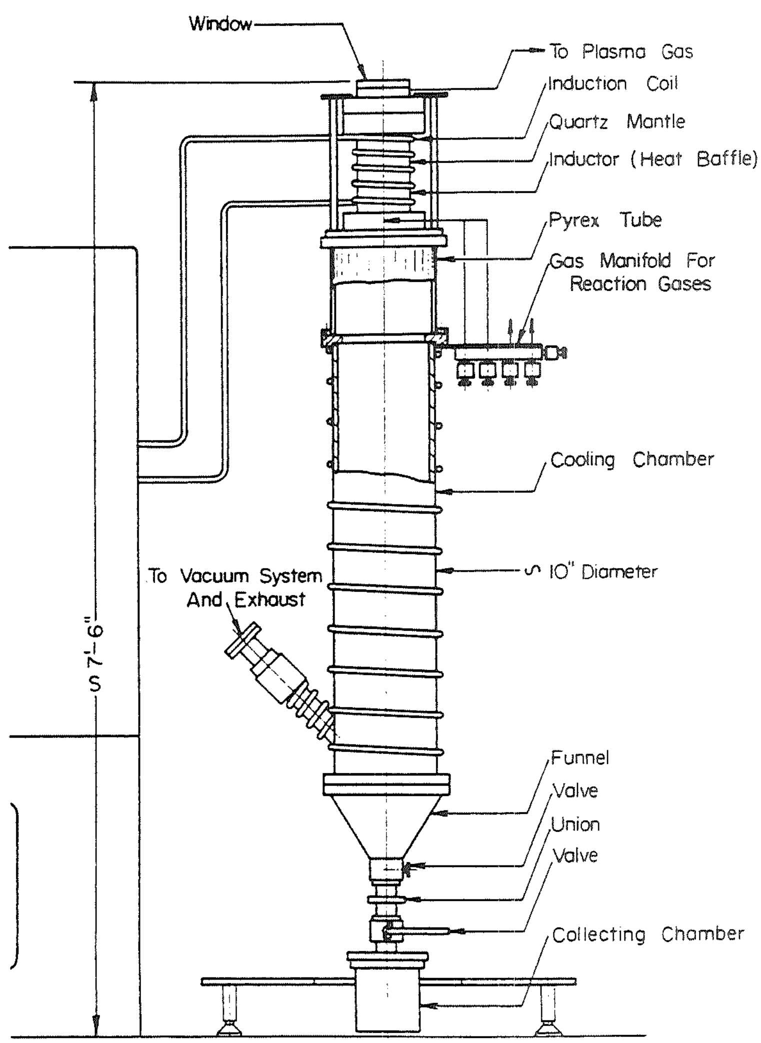


Figure 1

Schematic of plasma system used to generate grain materials. The reaction gases are injected below the plasma induction coil. Grains form in the cooling chamber and are collected in the collection chamber.

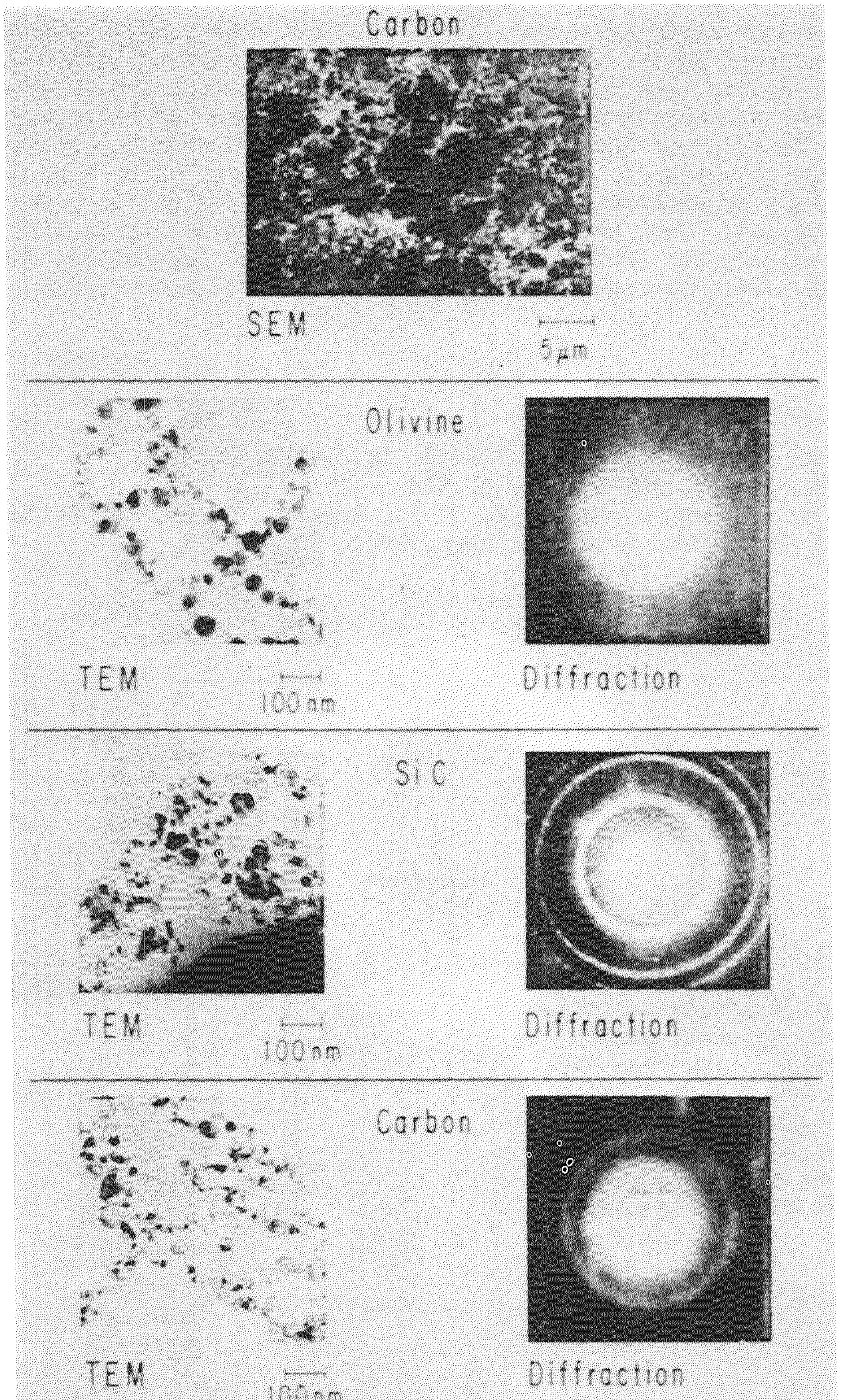
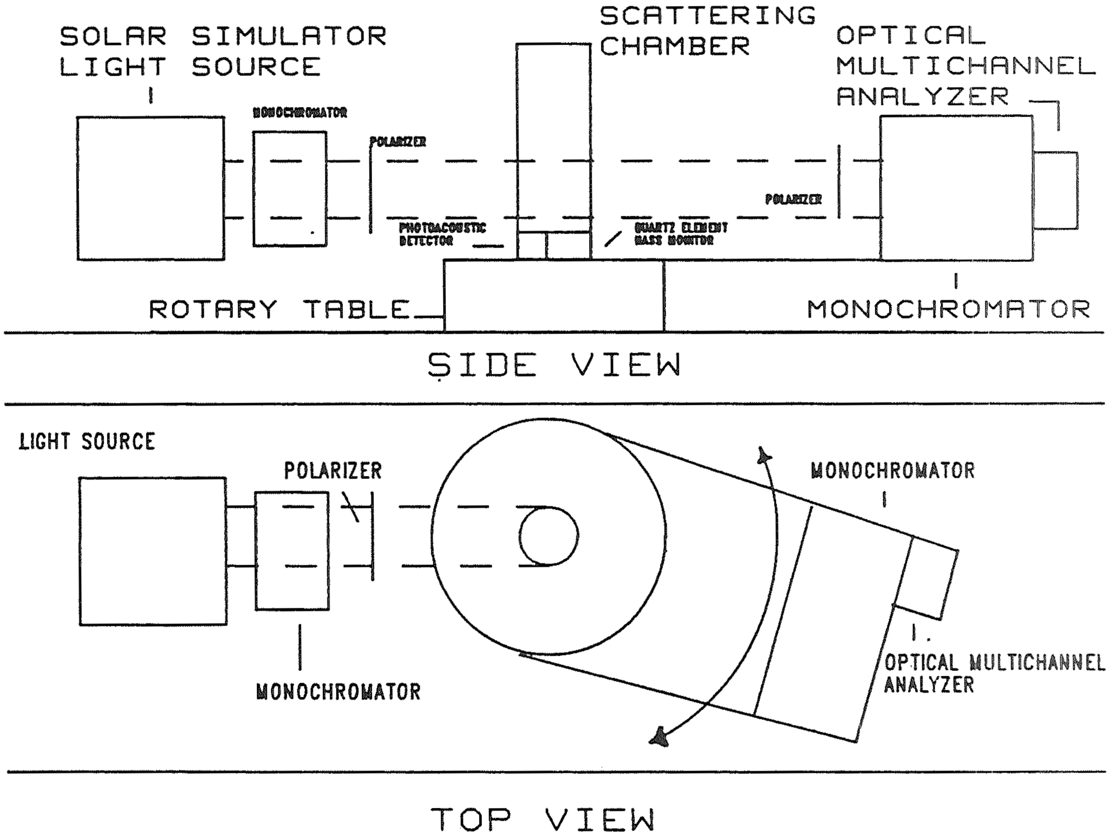


Figure 2
Scanning (SEM) and transmission (TEM) electronmicrographs and electron diffraction patterns of an amorphous silicate (olivine), SiC, and carbon condensate grains. The silicate, SiC, and carbon grains are amorphous, crystalline β-SiC, and glassy, respectively.



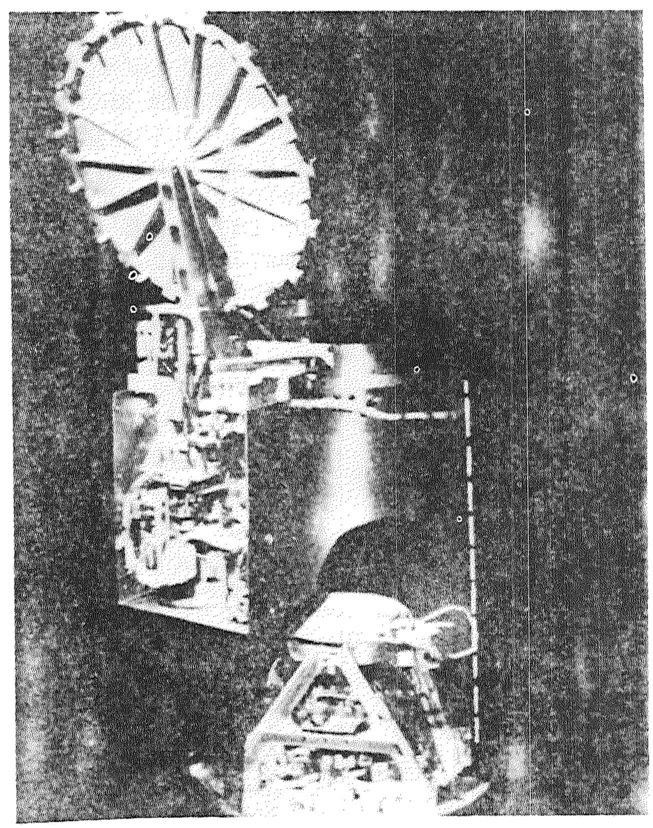


Figure 3
Schematic of laboratory apparatus for measuring light scattering from grains as a function of wavelength and angle. For details see text.

Figure 4
Photograph of Get-Away-Special ejector for launching a small satellite from the Space Shuttle Orbiter. The ejector is shown in cutaway with the top open.