TECHNOLOGY REQUIREMENTS FOR DEEP SPACE MEASUREMENTS

Report No. S-2

ASTEROID FLY-THROUGH MISSION

by

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SUMMARY

This report defines technical areas in which the development of instrumentation and instrumental techniques are required for satisfying the scientific measurement requirements of an asteroid fly-through mission. The particles contained in the asteroid belt were divided into five size ranges; namely, the sub-micron, micrometeorite*, sub-millimeter to 3-cm, 3-cm to 1-km, and greater than 1-km diameter, for convenience in considering the scientific questions and appropriate measurement techniques. The scientific questions concerning the spatial distribution, structure and composition of each size class were formulated. Existing and proposed experimental techniques were then examined for each class and instrumental areas requiring technological advances were defined.

Only two technical areas appeared to be adequately covered by existing instrumentation, micrometeorite detection and visual observations. Several other technical areas are defined which could be satisfied by modest development programs. Five specific requirements for advanced technology were derived

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* Particles in the size range 1μ to 100μ diameter will be denoted "micrometeorite" particles in this report.

from this study:

1. A direct technique for simultaneously determining the mass, size, velocity, position and direction of a statistically significant sample of sub-micron size particles throughout the asteroid belt.
2. A remote technique for simultaneously determining the mass, size, velocity, position and direction of a statistically significant sample of sub-millimeter to 3-cm diameter particles throughout the asteroid belt. The instrumentation requirements here differ markedly from those in item (1).
3. A technique for collecting particle samples in the asteroid belt. The particles must be collected partially intact for structural studies while the collection of vapors may suffice for compositional studies. Collected samples may be analyzed onboard or returned to Earth for laboratory analysis.
4. A remote technique for determining the structural characteristics of particles in the asteroid belt.
5. A remote technique for determining the composition of particles in the asteroid belt.

Of these, the first three should receive early attention.

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1. INTRODUCTION

This document is the first in a series of reports which will serve as guides for defining technical areas in which development of instrumentation and instrumental techniques are required for satisfying scientific mission objectives. The measurement problems discussed in this report are defined by the scientific objectives for an asteroid fly-through mission.

The desirability of investigating the asteroids and the asteroid belt by means of unmanned space missions has been discussed in previous ASC/IITRI reports (Friedlander and Vickers 1964, Greenspan 1964). The results of those studies concluded that an asteroid belt fly-through mission could provide information on the mass, the spatial distribution and the flux of particles in the asteroid belt. The fact that such a mission has no specific target and hence no launch constraints permits the minimum energy requirement of a Hohmann transfer to be utilized and a relatively inexpensive mission to be accomplished.

The scientific objectives of such a mission were previously considered in a summary fashion (Roberts 1964) and instrument requirements and availability dictated the scope of the measurements. In this report, the scientific questions regarding the asteroid belt were reformulated without regard for the existence of appropriate instrumentation. In this manner, scientific rather than technological constraints define the mission objectives. For example, the majority of the questions which can be asked about the composition and structure of asteroid particles require sophisticated and complex onboard instrumentation for in situ analysis. This fact does not, however, remove such questions from consideration if their scientific merit warrants solution.

This study was performed in three phases: Phase 1 - the relevant scientific questions and instrument requirements were defined. Phase 2 - existing and proposed instrumental techniques were examined. Phase 3 - the scientific instrument requirements were compared with the capabilities of existing technology for the purpose of establishing required technological advances.

This procedure was applied to scientific questions relating to the spatial distribution, the structure and the composition of asteroidal matter. In several cases, alternative approaches to instrument development are suggested. The scientific objectives, measurement constraints and technological requirements are outlined in summary fashion.

2. CLASSIFICATION OF ASTEROIDAL MATTER

The objects comprising the asteroid belt range in size from sub-micron diameter particles (which may result from grinding or accretion in the belt) up to bodies roughly 770-km in diameter (that of Ceres). The spatial densities of these bodies, the way in which they interact with the space environment, the pressing scientific questions and the required measurement techniques differ widely with size. It would therefore be useful to define certain size categories (ranges) for asteroidal matter in which the above problems and features are similar. The following five categories have been chosen to satisfy this requirement. The properties of each of these categories are briefly discussed.

2.1 Sub-Micron Particles

Particles of diameter less than one micron should be strongly influenced by solar radiation pressure and should be blown out of the asteroid belt. Their presence in the asteroid belt would suggest the existence of some regeneration mechanism. Detection techniques normally used for micrometeorite particles are not sensitive enough for particles in this size range.

2.2 Micrometeorite Particles (1μ to 0.1 mm diameter)

Particles in this size range should be present in the asteroid belt in large numbers. The Poynting-Robertson effect should cause many of the larger of these bodies to spiral into the Sun.

Techniques have been developed for studying the distribution and composition of particles in this size class in the near-Earth environment.

2.3 Sub-Millimeter to 3-cm Diameter Particles

The maximum expected spatial densities of particles in this size class (and in larger size classes) are so low that the number of bodies swept out by the fly-through spacecraft would not provide for statistically significant distribution studies. Remote detection techniques will be required for most measurements of objects in this class. Such techniques are, in general, not currently available.

2.4 3-cm to 1-km Diameter Particles

Fluxes of these particles will be small, and remote detection will be required. Questions of structure and composition are especially important for these particles. These bodies are large enough that conventional radar techniques can be employed for spatial distribution studies and possibly for size and surface feature studies.

2.5 Bodies Larger than 1-km Diameter

Main belt asteroids of diameter greater than 1-km should be observable telescopically from Earth at magnitude brighter than 21. More than 4500 such bodies have been observed (1600 separate orbit determinations have been made) while Kuiper et al. (1958) estimate that 33,600 bodies brighter than magnitude 19.5 exist. Although much information on these bodies can be obtained from Earth, certain detailed studies must await lander missions to specific target asteroids. Measurements of this type are, however, beyond the scope of this report which treats fly-through missions. Thus, any additional fly-through studies can be considered as extensions of the 3-cm to 1-km diameter class. The larger of these bodies may be of geological interest.

3. SPATIAL DISTRIBUTION OF ASTEROIDAL MATTER

3.1 Scientific Questions and Associated Measurement Problems

All questions relating to the spatial distribution of asteroidal matter would be solved if the mass, size (hence density) and orbital elements of all of the individual particles comprising the asteroid belt were determined. While this goal will not be realized, many pertinent scientific questions on particle distribution can be formulated and partially answered through measurements made during an asteroid fly-through mission. A list of these questions is presented in Table 1.

The answers to some of the questions posed in Table 1 are available for the visible asteroids (diameter greater than 1-km) from Earth-based observations. For the smaller particles, however, very little data exists.

Alfven (1954) points out that by Jeffreys' (1947) hypothesis, collisions between two bodies will rapidly tend to reduce the inclination and the eccentricity of the orbits of both bodies. Thus, one might hypothesize (in analogy to Saturn's rings) that the bulk of the small particle population,

Table 1

SCIENTIFIC QUESTIONS RELATING TO THE SPATIAL DISTRIBUTION OF ASTEROIDAL MATTER

1. How do the size, mass and flux of asteroid particles vary with their orbital elements?

2. Is there a lower limit to the size of particles in the asteroid belt?

3. Do discrete gaps exist in the smaller particle population of the belt? Do these suggest planetary resonances?

4. Is the small particle concentration of the belt denser near the ecliptic plane? Do these bodies in general have orbits of lower eccentricity than the larger asteroids?

5. Is the mean distribution of asteroid mass symmetric about an axis through the Sun and normal to the ecliptic plane or does clustering prevail?

6. Is the size distribution of the smaller asteroidal bodies suggestive of grinding or accretion in the belt?

whose spatial density is high, must possess nearly circular orbits of low inclination as a result of these collisions. The larger bodies, on the other hand, are not in a highly fragmented state (Anders 1965) suggesting relatively few collisions, and they should still nearly possess their original orbital elements. It is therefore important to study the distribution of the small particle population of the belt in the ecliptic plane.

Answers to the scientific questions listed in Table 1 can be obtained if the mass, size and orbital elements of a large enough sample can be measured. The problems of detecting and measuring these parameters simultaneously vary markedly for the different particle sizes as discussed briefly in Section 2.

In order to treat the above problems in a quantitative fashion, we can estimate the maximum particle densities and impact rates in the asteroid belt. A first order calculation of particle number densities has been performed (Friedlander and Vickers 1964) by assuming that there are 0.06 gms/km^3 of matter uniformly distributed in a belt containing 6 x 10^{24} gms total mass. A mean density of 3 gm/cc is also assumed. Table 2 gives the results of this calculation in which maximum estimates are obtained by assuming that all particles are of a single size. While this assumption is certainly not valid, meaningful conclusions about the detection problem can be derived from these data. Another approach to estimating particle number densities involves the extrapolation of the asteroid size distribution curve (Kuiper et al. 1958), obtained for the visible asteroids, to the smaller bodies. Not enough data exists on the smaller bodies however, to justify such an extrapolation.

Table 2

ESTIMATED PARTICLE DENSITIES AND IMPACT RATES

Particle size	Max. number density of particles	Impacts/m^2/sec for VHP (12 km/sec)	Impacts/m^2/year for VHP (13 km/sec)
1μ radius	$6 \times 10^9/km^3$	7.8×10^4	2.46×10^{12}
10μ radius	$6 \times 10^6/km^3$	7.8×10^1	2.46×10^9
100μ radius	$6 \times 10^3/km^3$	7.8×10^{-2}	2.46×10^6
1 mm radius	$6 \times 10^0/km^3$	7.8×10^{-5}	2.46×10^3
1 cm radius	$6 \times 10^{-3}/km^3$	7.8×10^{-8}	2.46×10^0

3.2 Existing Experimental Techniques

The greatest developments in particle detection techniques have been made in the area of micrometeoritics. Micrometeorite detectors have been flown in balloons, rockets, scientific satellites, and on interplanetary probes (Alexander 1963). Extensive development programs are currently being carried out (Berg 1965) to increase their sensitivity and range and to provide more accurate calibrations. This work, however, is directed toward the near-Earth measurement problem and existing instruments do not appear completely suitable for an asteroid fly-through mission.

Micrometeorite detectors are of several basic types:

3.2.1 Microphone Detectors

These employ either piezoelectric or capacitance detectors. Sensitivities of up to 10^{-10} dyne-sec can be obtained. The detected signal is nearly proportional to the momentum of the particle.

3.2.2 Velocity Grids

The time of flight of the impacting particle between two separated foils is measured. The penetration into the second foil gives the kinetic energy MV^2. Thus, mass, velocity and direction are measured.

3.2.3 Light Screens

The particle passes through one or more light screens. The scattered light is detected and gives a measure of size. Time of flight between two screens gives velocity and direction (from the orientation).

3.2.4 Pressure Cans

Particle penetrates wall of a pressurized can. Pressure loss indicates an impact.

3.2.5 Photomultiplier (PM) Detectors

In one type of detector, the particle can penetrate an opaque covering on a PM tube window permitting an external source of illumination to be detected. In a second type of detector the particle impacts on a target which is viewed with a PM tube. The intensity of the light flash is proportional to MV^2 over the range 3-15 km/sec. Particles from 1μ to 1 mm diameter may be detected by this technique.

3.2.6 Conduction Detectors

The impacting particle penetrates two conducting films separated by an insulator. The penetration causes momentary conduction between the films generating a pulse.

3.2.7 Size Detectors

The impacting particle penetrates the wall of a detection chamber allowing an external source of illumination to fall upon the detector. The intensity of the light gives the hole size which is 2-3 times the particle diameter at 30 km/sec.

The current and prospective status of micrometeorite instrumentation was discussed with personnel (Berg 1965) of the Goddard Space Flight Center. While existing instrumentation, capable of meeting the scientific objectives, is not currently available in flyable form (suitable for an asteroid fly-through mission), the development required should not present much of a problem. The possibility of employing composite detectors was also discussed and several detector combinations showed good promise. For example, a series of light screens followed by a capacitance detector which is viewed with a PM tube could give mass, size, velocity and direction.

Radar techniques can be employed* for the detection of particles larger than 3-cm diameter. A pulsed system with peak power of 1 kw would only consume a few watts (on average) and could detect particles of 3-cm diameter at distances up to

* This assumes that 1 cm wavelength radars, which are within the current state of the art, will be used.

10 km (Friedlander and Vickers 1964). In this case, the effective cross sectional area of the experiment would be $\sim 3 \times 10^6$ m^2 and, by Table 2, detection of up to 30 particles per hour could be expected. Since the effective detection cross-section increases as the 4th power of the target diameter and the expected impact rate decreases as the 3rd power, the situation should improve for larger objects. The radar return should provide information on the size of the target, the range, and the radial velocity component. If the particle can be tracked (observed several times) it should be possible to reconstruct the orbital elements. Although radar techniques are felt to be within the state of the art, flyable radar systems do not currently exist. Such systems have been proposed, however, for other space applications (Moore et al. 1965).

3.3 Technological Requirements

The two basic existing detector types, micrometeorite particle analyzers and radar, can respectively provide data on the spatial distribution of micrometeorite particles and bodies larger than 3-cm diameter in the asteroid belt. Some development will be required for both types of instrumentation to provide optimal effectiveness in studies of the distribution of asteroidal matter. The micrometeorite detectors can give the mass, size, velocity, density and orbital elements of impacting particles. The radar techniques can, in principle, give the size, velocity and orbital elements but cannot determine mass or density.

A 35 gc radar system ($\lambda \approx 0.86$ cm) employing an 8 foot by 1 foot antenna array could scan space with a 0.2 degree resolution. A system with 40 kw peak power would weigh roughly 65 pounds (15 pounds for antenna and 50 pounds for transmitter and receiver without display or telemetry) and would require roughly 160 watts input power. Similar K-band systems such as the APQ 97 are currently being flown on aircraft.

The momentum imparted by sub-micron size particles is below the limit of sensitivity of micrometeorite detectors although the flux of particles should be sufficient for the utilization of direct counting techniques if the particles can be detected. Light screen techniques utilizing ultraviolet radiation may be applicable to the larger particles in this class; however, the complex scattering laws may render this technique useless.

Remote detection techniques must be employed for particles in the sub-millimeter to 3-cm size class. Radar techniques ($\lambda \geq 1$ cm) are unsuitable since the target size approaches the radar wavelength. One possible developmental approach would be to consider optical (laser) radar. Application of this technique would provide data similar to that obtainable with radar for larger particles.

4. STRUCTURE OF ASTEROIDAL MATTER

4.1 Scientific Questions and Associated Measurement Problems

Structural studies of asteroidal matter are concerned with surface state, shape, crushing strength, thermal characteristics, phase, and construction (crystalline, powder, loose agglomeration, compact solid) of individual particles in the asteroid belt. Specifications of the particle structure has great implications to the origin and evolution of the asteroid belt.

Anders (1965) has recently presented a description of the fragmentation history of the asteroid belt from the absolute magnitude distribution of visual asteroids between 2.0 and 2.6 AU in which he tentatively concluded that the asteroid belt is not in a highly fragmented state. He also deduced an average crushing strength of $\sim 2 \times 10^8$ dyne/cm^2 for the asteroids. It is important to examine the fragmentation state of the asteroids in situ in order to verify or reject these hypotheses and to extend our knowledge to the smaller objects in the belt which would more likely be fragmentation products. Studies of particle structure in the asteroid belt also have direct application to the spacecraft hazard problem. A short list of scientific questions relating to asteroid structure is given in Table 3.

The measurement problems associated with structural studies differ from those encountered for the distribution question. For direct detection, large numbers of impacts would not be required to yield significant results. Thus, with a detector of moderate size, samples of particles smaller than 3-cm diameter should be detectable by the spacecraft. For the

Table 3

SCIENTIFIC QUESTIONS RELATING TO THE STRUCTURE OF ASTEROIDAL MATTER

a. What are the shapes of asteroid particles? e.g., spherical or irregular.

b. Are the asteroid particles compact solids, crystalline, powdery, loose agglomerations, fluffy, etc.?

c. What is the surface state of asteroid particles? e.g., smooth, fragmented, dust covered, eroded, etc.

d. What are the thermal characteristics of asteroid particles?

e. Are compositional layerings revealed on fracture surfaces?

f. What is the impact strength of an asteroid particle?

g. What are the electrical characteristics of asteroid particles? Are the particles changed?

h. Are asteroid surfaces stable or is collisional erosion constantly taking place?

larger particles remote sensing techniques would have to be relied upon.

For direct studies of asteroidal structure, the particles must first be collected at least partially intact. Considering the hypervelocities (10 km/sec) expected for spacecraft-particle encounters, the collection of even the fragments or vapors of impacting particles poses a severe problem. The hypervelocity penetration into normal collection devices is usually small and particle fragments are seldom retained in the crater.

For remote studies of structure, the high relative particle-spacecraft velocities impose fast time response constraints on any detector scheme which might be proposed.

4.2 Existing Experimental Techniques

Existing remote detection techniques can provide information on the shape and possibly on the surface features of asteroidal matter. Photometric studies have suggested irregular shapes for many visual asteroids (Kuiper et al. 1958). Additional data has been obtained from spectral reflection and polarization observations. These techniques will require some development, however, for application in an asteroid fly-through mission.

For direct measurement of asteroid structure, numerous existing techniques can be employed once the particle is collected partially intact and placed in an analyzer. For example, conventional microscopy or X-ray diffraction techniques could be modified for spacecraft operations.

Numerous particle collection techniques are available for use in the Earth's atmosphere where the impact velocities are low. Many of the so-called particle collectors are actually crater collectors which record the impacts without retaining any of the fragments or vapors (Berg 1965). These generally involve the destruction of an opaque film surrounding a transparent container. In these cases the craters are counted photoelectrically by the transmission of light through the holes. Geltains, glycerine and fiber pads destroy the low velocity particles on impact but do retain the fragments. This may not be the case for the higher velocity impacts. Millipore filters are currently being investigated as a means of trapping fragments from high velocity particles. In this technique the particle penetrates several layers of the filter before impact. The layers above the impact layer then trap, at least partially, the fragments and vapors.

4.3 Technological Requirements

For remote sensing, photometric, radar, television and polarimetric techniques can in principle be applied for obtaining minimal data on particle structure. None of these techniques have been developed in flyable form suitable for an asteroid fly-through mission. New types of remote structure analyzers could be employed very profitably during a mission of this type.

Direct analysis of particle structure depends entirely upon a solution to the collection problem. Since this constraint will also apply to compositional analysis, particle collection should definitely receive early and concentrated attention. If a non-destructive collection technique can be found, a means of transferring collected samples into onboard analyzers (and the analyzers themselves) will have to be developed.

An alternative to the development of sample transfer and analysis techniques involves the return of collected material to Earth for laboratory analysis. A Hohmann transfer orbit with a 3-year period would: (1) penetrate to 3.2 AU from the Sun, (2) remain in the belt for about 650 days, (3) provide for direct communication with Earth (RC = 2.2 AU) at maximum penetration, (4) require only 46,700 ft/sec ideal velocity at launch and (5) rendezvous with the Earth 3 years from the launch date which is unconstrained.

5. COMPOSITION OF ASTEROIDAL MATTER

5.1 Scientific Questions and Associated Measurement Problems

A list of scientific questions relating to the composition of the asteroids is presented in Table 4. These questions, and most considerations of asteroid composition, are based upon the assumption that meteorites represent samples of asteroid material. Although there is good evidence supporting this assumption, both from the observations of meteor trajectories (Kresak 1965) and from direct observations of particles in solar orbit (Nilsson 1965), it is important to study the composition of collected particles in situ. Measurements of this type will reveal the mineralogical composition of asteroids

Table 4

SCIENTIFIC QUESTIONS RELATING TO THE COMPOSITION OF ASTEROIDAL MATTER

a. Are the asteroid particles iron or stony or some combination?

b. What information on age and composition can be deduced from radioactivity measurements?

c. What is the ratio of silicon, iron, nickel, oxygen, etc. in asteroid particles?

d. Does the composition vary in any regular way with particle size or with average orbital parameters?

e. Do asteroid particles possess a magnetic moment?

f. What is the mineralogical composition of asteroid particles?

g. Do some of the asteroid particles represent primordial matter?

before they are modified (oxidized) during entry through the Earth's atmosphere. It is also important to determine the ratios of the various elements in asteroid material.

For basic elemental composition studies, the collection constraints are not as severe as those imposed for analysis of asteroid structure. In this case, even the analysis of impact vapors can provide significant data.

If the collection requirements for structural studies can be satisfied, more sophisticated compositional studies can be performed either onboard the spacecraft or following return to Earth.

5.2 Existing Experimental Techniques

The state of the art of collection devices has been reviewed in Section 4. Following collection, mass spectrographs as well as chemical or spectroscopic techniques can be employed for compositional studies.

An onboard compositional analyzer (pulsed mass spectrograph) is currently available (Dubin 1965) in flyable form and could be modified for use in an asteroid fly-through mission. In this instrument the particle impacts on a gold or silver film and is vaporized. The ionized vapors are accelerated and analyzed in a mass spectrograph. The main difficulty encountered in the use of this instrument is in the analysis of pulsed mass spectra.

It is not difficult to envisage the application of optical spectroscopy to similar measurements. In that case, the ionized vapors could be passed through an arc and the spectral information would be telemetered to Earth. In a similar approach, A. G. Hanson (1965) at AVCO/RAD is currently directing a program for the development of gas filled balloons which will be deployed from satellite booms. Particles penetrating the balloon are aerodynamically heated by the inert gas fill and the emission is piped by fiber optics to a spectrograph for analysis.

There are no immediately obvious techniques for studying the composition of asteroid matter with remote sensors with the possible exception of gamma ray or infrared reflection spectroscopy for surface materials. If however the compositional properties of collected particles can be related to their optical, radar or orbital parameters, then limited direct data could be extrapolated to the large group of remotely sensed particles.

5.3 Technological Requirements

All of the existing measurement techniques outlined above will require additional development before spacecraft instruments can be supplied. If the collection problem is successfully attacked, the development requirements for such compositional analyzers should not be too extensive.

Perhaps the most important technological development requirement here is for a remote compositional sensor.

6. SUMMARIZED TECHNOLOGICAL REQUIREMENTS AND CONCLUSIONS

The preceding sections of this report have outlined the major scientific questions relating to the spatial distribution, the structure, and the composition of matter in the asteroid belt. Through the joint consideration of the scientific objectives for an asteroid fly-through mission and the performance of existing instrumentation and instrumental techniques,it was possible to delineate the areas in which technological advances are required.

None of the existing instrumentation reviewed was felt to be in suitable form for direct inclusion in an asteroid belt fly-through spacecraft. In many cases, however, the required development would only involve the modification of existing techniques to provide optimum performance in a fly-through mission. Such development requirements are not classified as advanced technology and are not included here. For example, while existing micrometeorite detector types should be combined to provide an instrument which will simultaneously give the mass, size, and orbital elements of impacting particles, the development requirements are not severe.

In many of the technological areas discussed in this report, flyable instruments are not currently available, and in some cases the basic detection techniques have not yet been specified. In these instances, major technological advances will be required and long lead time development programs should be initiated. The following subsections summarize the pertinent scientific questions and measurement constraints and indicate the required technological advances.

6.1 Spatial Distribution of Sub-Micron Size Particles

Scientific Objective

Determine the mass, size and vector velocity of a large sample of sub-micron size particles throughout the asteroid belt.

Measurement Constraints

Although large numbers of these particles should be swept out by the spacecraft, the momentum imparted in collision is below the threshold of sensitivity for conventional micrometeorite detectors. Light scattering techniques are uncertain because the particle sizes encompass the visible and near ultraviolet wavelengths.

Technological Requirements

Develop a detection technique which will simultaneously provide information on the mass, size, velocity and direction of particles in the asteroid belt smaller than 1 micron diameter.

Comments

The use of vacuum ultraviolet light screens should be investigated as one possibility.

6.2 Spatial Distribution of Sub-Millimeter to 3-Cm Diameter Particles

Scientific Objective

Determine the mass, size and vector velocity of a large sample of sub-millimeter to 3 cm diameter particles throughout the asteroid belt.

Measurement Constraints

The maximum expected spatial density of these particles precludes impact detection for statistical studies of spatial distribution and remote measurement techniques are indicated. Conventional radar detection is unsuitable since the particle size is smaller than normal radar wavelengths and complex scattering laws apply.

Technological Requirements

Develop a remote detection technique which will simultaneously provide information on the mass, size, velocity and direction of asteroid belt particles between sub-millimeter and 3 cm diameter. The effective range of such a system should be as great as possible.

Comments

The possibility of employing optical (laser) radar should be investigated. The determination of particle mass poses the greatest problem with remote detection schemes.

6.3 Direct Analysis of Particle Structure

Scientific Objective

Determine structural characteristics of particles in the asteroid belt by means of direct analysis of captured matter.

Measurement Constraints

Individual particles must be captured (or collected) at least partially intact. Due to the high particle-spacecraft closing velocities, normal micrometeorite collectors would destroy the particles and even ionized vapors would not be retained. Following collection, the particle must either be transferred to an onboard structure analyzer or stored for return to Earth.

Technological Requirements

Develop collection techniques for hypervelocity particles which leave the collected sample intact. Develop technique for introducing collected samples into structure analyzers. Consider the possibility of developing a retrievable collection package for Earth-based analysis. If onboard analyzers are desired, existing instruments must be modified for spacecraft use.

6.4 Remote Analysis of Particle Structure

Scientific Objective

Determine the structural characteristics of asteroid particles by remote detection techniques.

Measurement Constraints

Because of the difficulty in collecting particles intact and because of the low expected spatial densities of the larger particles, remote detection will be required. The high approach velocities imply systems with fast response and reasonably long range.

Technological Requirement

Develop remote techniques for determining the structural characteristics of particles in the asteroid belt.

Comments

Photometry, radar, television and polarimetric techniques should be investigated.

6.5 Direct Analysis of Particle Composition

Scientific Objective

Determine the composition of particles in the asteroid belt by means of direct analysis of captured matter.

Measurement Constraints

As for the direct structural studies (Section 6.3) the particle samples must be collected, however in this case, not necessarily intact. Following collection, the vapors or fragments must either be transferred to onboard compositional analyzers or stored for Earth return.

Technological Requirements

Develop collection technique for hypervelocity particle which retains fragments or vapors. Develop technique for storing sample or for transferring collected sample into analyzer. If onboard analyzers will be used, existing instruments must be modified for spacecraft use.

Comments

Explore possibility of employing improved version of pulsed mass spectrograph for these problems.

6.6 Remote Analysis of Particle Composition

Scientific Objectives

Determine the composition of particles in the asteroid belt by remote measurement techniques.

Measurement Constraints

Because of the low expected spatial densities of the larger asteroid particles, remote detection is indicated. The high relative velocities require fast systems.

Technological Requirement

Develop remote techniques for determining the composition of particles in the asteroid belt.

Comments

Infrared reflection spectroscopy is one possible approach for studying surface composition of the larger particle (or bodies).

One additional problem should be mentioned here; namely that of spacecraft failure analysis. One should be able to determine conclusively whether or not the failure of any spacecraft component is due to asteroid impact. This requirement should be met even for incomplete failure; e.g., partial loss of sensitivity. Several techniques are available for such studies, one of which involves surrounding the entire spacecraft with particle detectors. This would increase the effective detection area and would permit damage evaluation in terms of impacting particle parameters.

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