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ANTICIPATED RESULTS FROM DUST EXPERIMENTS ON COMETARY MISSIONS

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The major scientific objectives of a space mission to a comet have been defined by NASA's Comet Science Working Group in order of priority:

To determine the chemical nature and physical structure of comet nuclei, and to characterize the changes that occur as a function of time and orbital position.

To characterize the chemical and physical nature of the atmospheres and ionospheres of comets as well as the processes that occur in them, and to characterize the development of the atmospheres and ionospheres as functions of time and orbital position.

To determine the nature of comet tails and processes by which they are formed, and to characterize the interaction of comets with the solar wind.

Since dust is a major constituent of a comet, the achievement of these goals requires the intensive study of the particulate emission from a comet. Both NASA and ESA have studied a Halley fly-by mission and established a set of instruments to fulfill the stated objectives (NASA in addition worked on a rendezvous mission, but as it seems very unlikely to get it started in the near future, we shall concentrate on the fly-by mission).

Table 1.1 shows the NASA, Table 1.2 the ESA model payload.

Table 1.1

Model Payload for NASA's Halley Probe

	Instrument	Mass,kg	Power	Maximum Data Rate, kb/s
a)	Dust analyzer	8	10	3
b)	Dust counter	1	1,5	0,3
	Neutral mass spectrometer	7	8	2
	Ion mass spectrometer	7,5	5	1,6
	Electron and proton analyzer	5	5	1
	Magnetometer	3,5	3,5	1
	Plasma wave analyzer	3	3	1
	Imaging system	5	7	2,5
Total		40	43	12,2

Table 1.2

Model Payload for ESA's GIOTTO Halley Fly-By

		Mass (kg)	Power (W)	Data Rate (kbps)
	Camera	10,0	12,0	20,0
	Neutral Mass Spectrometer	10,0	9,0	4,0
	Ion Mass Spectrometer	8,0	10,0	3,2
a)	Dust Impact Mass Spectrometer	9,0	12,0	6,0
b)	Dust Impact Detector System	2,5	2,7	1,0
	Electron/Ion Plasma Analyzer	5,0	5,0	2,0
	UV-Spectrometer	5,5	8,0	1,5
Total		53,0	61,7	38,7

In both payloads, measurements on cometary dust are performed with two instruments, a dust counter (b) and a dust mass spectrometer (a). Both are related to the first scientific objective.

The counter addresses the physical nature as it measures the mass distribution of the dust released from the comet's nucleus, covering a large mass range. To achieve this the instrument has to include a variety of sensors with overlapping ranges for cross correlation such as:

-- impact plasma detectors covering the 10^{-17} g to 10^{-11} g range yielding mass, flux and also density data.

-- penetration detectors covering the 10^{-16} g to 10^{-3} g range by using different layer thicknesses of the barrier to be penetrated.

-- momentum detectors like e.g., microphones used in coincidence covering the 10^{-10} - 10^{-3} g range yielding data on mass and flux.

Depending on the target size allocated to the individual sensors, it is expected to establish the flux in a wide dynamic range within a ± 20 percent accuracy. Moreover density data on the particles become available in a range from 10^{-17} g to 10^{-8} g. Timely variation of the impact rate -- if present -- would indicate the presence of non-continuities in dust emission by the comet.

Last but not least, data in the smallest mass range will clarify whether smallest particles (< 1μm), which cannot be detected optically by ground based measurements are emitted by the comet and provide direct information on the dust environment during comet formation.

The dust mass spectrometer addresses the chemical nature covering the smaller mass range (10^{-16} g to 10^{-10} g). Basd on the ionisation upon impact of particles onto a solid target it produces time of flight spectra of the positive ions in the range from 1 to 110 amu. First Friichtenicht et al. (1971, 1973) have shown that the composition of a fast particle can be measured by the composition of the impact plasma. Later Dalmann (1978) has shown that target contamination greatly influences the composition of the impact plasma. Ion sputtering of a precleaned target, as planned in this instrument, just before the measuring phase, however, greatly eliminates ions of contaminants in the mass-spectrum. Recent work by Braun (1980) has established relative sensitivies of such an instrument for various elements. During his measurements at the Heidelberg dust accelerator he has varied both target and projectile materials. His values are listed in Table 2.

Table 2.

Relative Ion Yield for Impact Ionspectroscopy (Baum, 1980) and Secondary Mass Spectroscopy (Sparrow, 1976/1971)

Relative Ion Yields	Element									
Arbitrary Units	Mg	Cr	Mn	Fe*	CO	Ni	Cu	Mo	Pd	Ag
Braun, 1980	180	45	90	18	32	13	16	3,8	5	12
Sparrow, 1976, 1977	130	30	47	18	19	13	17	2	3	15

*Normalized for Fe, the standard projectile material.

Taking into consideration that his instrument had no energy focussing device nor electrostatic lenses this has to be considered a good agreement with Sparrow's values. With respect to other elements, so far not yet measured by impact spectroscopy, it is planned to use Sparrow's relative yields as first order approximation, which is thought to match the quantitative abundances within a factor of 3. In order to show which variations might be expected for a single grain analysis, elemental abundances in various minerals found in meteorites and their possible significance are listed in Table 3. It is obvious that they can be identified from composition data. Such the composition of some 10^3 - 10^4 particles in the mass range 5×10^{-16} - 5×10^{-10} g (sizes, 0,1...10um) will become available. The number of spectra available depends on the comet's activity, the probe's miss distance and the data rate allocated to the instrument.

Selected feature, like specific isotopic ratios ^{6}Li/^{7}Li, ^{10}B/^{11}B, ^{12}C/^{13}C of additional up to 1000 particles will be available (e.g. Ca/Si, Al/Si).

Composition of selected particles with unusual element ratios will be available. Data analysis will allow to find variations of the composition with the size of the particles and with the distance from the comet. The composition of dust is largely unknown. Fragmentary information comes from infrared observation of a 10 micron emission feature, which is attributed to silicates (Ney, 1974), from spectroscopic evidence on some metals (especially sodium and iron) far from the nucleus in comets with small perihelion distances, from spectra of meteors which can be correlated to the producing comet (Millmann, 1977), and, in a more qualitative fashion, also from high repulsive accelerations on particles in some comet's tails, indicative of the presence of (electrically) conducting materials. This is one major question to be clarified by this investigation. It may also be possible to find larger (>> 0.2μ ∅) particles dominated by individual minerals One might, for instance, envision refractory element rich objects as they occur in some carbonaceous chondrites (notably Ca-Al-rich inclusions in Allende). Their presence would indicate that such large refractory grains indeed exist in the diffuse interstellar space. Similarly, the presence of other minerals like magnetite or iron particles would suggest analogous conclusions. It would exclude extensive melting and recondensation of pre-cometary material thus placing strong constraints to the formation of comets.

It is uncertain whether individual cometary particles are single crystals or aggregates of crystals. In the latter case one may envision larger crystals surrounded by the very fine grained "matrix" material, particles similar to those collected by Brownlee (1978). In either case, it is possible to identify cosmochemically important minerals if they are present at all (see Table 3). An interesting consequence of the chemical heterogeneity of the nucleus is that less-volatile ices may be dragged away from its surface together with dust by outgassing of more-volatile ices. Delsemme and Wenger (1970) observed stripping of grains from a body of clathrate snow in their laboratory experiment. The continuous spectrum of Comet 1960 II was interpreted by Delsemme and Miller (1971) also in terms of an ice grain halo, whose extent at heliocentric distances around 1 AU is small and recognizable by its steep erate of decrease of its radial brightness profile. The chemical heterogeneity of the nucleus mentioned above suggests that less-volatile ice grains may be expelled the same way dust is ejected. The variation in the composition data will yield a great body of information on ice grains, provided the miss distance is within its nominal value.

If the surface of a comet were perfectly homogeneous, the comet's activity would be symmetrical with respect to the subsolar point. The nucleus rotation and the existence of heterogeneities produce unpredictable local variations in the production of both gas and dust, which, in turn, are responsible for the frequently observed deviations of the coma from symmetry and for a complicated coma structure, including such features as jets, fans, halos, secondary condensations, etc. The composition data clarify whether there are groups of particle of similar composition related to those phenomena.

Individual grains may show rather different isotopic compositions for several elements. Such differences exist in meteorites (isotopic anomalies), again most pronounced in Allende. However, the "anomalies" as known today, are largest in the noble gases (> 10 percent) not accessible to the PIA instrument or oxygen and magnesium (< 10 percent) not measurable either. Averaging over many grains there are some interesting bulk properties in the abundances of some light elements. Bulk composition is closely similar in carbonaceous chondrites and the sun. Still there are notable exceptions. For example lithium in the sun (Muller et al., 1975) is underabundant by a factor ~ 10^{-2} relative to C1, C2, and C2 carbonaceous chondrites (Nichiporuk and Moore, 1974), enstatite chondrites (Mason, 1971), and pre-main sequence stars and young cluster (Zappala, 1972) as well stellar and interstellar medium (Reeves and Meyer, 1978). Since stellar and interstellar abundances are about a factor of 2.2 below meteoritic ones it will be interesting to see where the cometary values tend to. Similar enhancement between carbonaceous chondrite abundances and solar vs. stellar values do exist for beryllium (~ 2.8) and boron (~ 9.3). Meyer (1978) has discussed the idea that these Li, Be, B-enhancements in meteorites might be spallogene due to energetic particle irradiation after formation of the sun. Even so, if comets originated far outside the meteorites, they would be less effected anyway, unless a particle source other than the sun existed.

Since the $^{11}B/^{10}B$ ratio on earth, moon and meteorites is about 4.05 ± 0.1 (Mason, 1971) it cannot be explained by β-production through high energy cosmic ray spallation reaction within the lifetime of the galaxy. This would only give $^{11}B/^{10}B$ ~ 2.5. A postulated low energy (~ several 10 MeV/n) component would yield the ratio observed. It is however not obtainable by demodulation of the galactic cosmic ray intensity observed near the sun (e.g., Morfill et al., 1976). A cometary observation would lend suppport (or exclude in the case of a small ratio) to the relative large scale nature of such a low energy component.

The $^{7}Li/^{6}Li$ ratio is observed to be about 12.5 (Krankowsky and Muller, 1967; Balsiger et al., 1968) in different meteoritic and terrestrial rocks. A spallation source from demodulated high energy cosmic rays could quantitatively produce the observed ^{6}Li over the age of the galaxy, but would only lead to $^{7}Li/^{6}Li$ ~ 1.8. Various forms of low energy cosmic ray components would bring this ratio up to ~ 6 (Reeves and Meyer, 1978). Also discussed is the role of extragalactic matter, containing ^{7}Li produced in the "big bang" (see also Reeves et al., 1979). Since the ^{7}Li abundance is strongly related to big band conditions this measurement of the $^{7}Li/^{6}Li$ ratio outside the inner solar system would be very important.

The $^{12}C/^{13}C$ ratio in the gaseous coma of comets was found to be > 100 (Vanysek and Rahe, 1978), somewhat larger than the terrestrial value and about 2-3 times larger than the value found in interstellar clouds (e.g., Liszt, 1978). If this low interstellar cloud value is due to low temperature fractionization, as is probably true for the D/H enhancements there (Watson, 1977) a distinction between the $^{12}C/^{13}C$ ratios in the dust and gas of comets would shed some light on interstellar gas-grain chemistry.

As far as molecules are concerned it might be very interesting to look for very large molecules (or their fragments) in grains. Laboratory experiments by Greenberg and his associates (Greenberg, 1979), irradiating NH_3 and CO-mixtures (which are expected to form ice mantles on interstellar grains) has produced molecular material with evaporation temperatures of 400 to 600 K and molecular weight possibly in the thousands. Assuming the mantles of interstellar grains to consist of such photochemically processed material, it should be seen in cometary material rather than in meteoritic material where they might not have survived heating during formation.

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