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RESULTS TO BE EXPECTED FROM LIGHT SCATTERING DUST ANALYZER DURING A RENDEZVOUS MISSION

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1. General

The light scattering principle for particle detection is customary for the measurement of aerosols (Hodkinson, 1966) and has also been used for space experiments ("Sysiphus" on board Pioneer 10/11). Light scattering techniques can be applied to mixtures of particles (nephelometers) and to single particles as well. Measuring particle mixtures, of course, simplifies detection because of the higher intensity level, however, information concerning the individual particle is lost. To provide well defined conditions over the whole rendezvous period, i.e., constant illumination beam and unchangeable scattering angle, the use of an artificial light source (instead of the sun) and a scattering volume located within the S/C is highly desirable. Considering this and the relatively low particle densities to be expected, the measurement of particle mixtures must be excluded.

2. Aspects of the Choice of Scattering Angle and Light Source

The scattering pattern not only indicates the evidence of a particle but also contains information concerning its physical properties (size, refractive index, and structure), thus in principle the measurement of the complete scattering diagram would be desirable. Weight and size limits of space experiments, however, lead to the restrictions concerning the scattering angle domain. For the selection of a most favorable scattering angle the following aspects must be considered:

Near forward scattering provides maximum intensity, but contains only size information. Near backward scattering produces less intensity and does not allow satisfactory size determination. Additionally both forward and backward scattering measurements would require the highly parallel beam of a laser. Detecting signals scattered by single particles always raises sensitivity problems. These can be minimized by use of light sources with high UV-part, within the range of the maximum quantum efficiency of photomultipliers. Shorter wavelengths are also favorable, because the scattering efficiency of particles depends on the ratio of their size to the illuminating wavelength (Kerker, 1969). Distinguishing features of different particle types also depend favorably on this ratio. As we will see in the next section, for averaging reasons, too, monochromatic light sources are not the optimum choice. All these considerations in connection with weight and power aspects lead to the rejection of a laser source in favor of a customary Hg-lamp. Consequently a scattering angle in the medium range must be chosen. For several reasons the choice of 90° turns out to be optimum: In this range different types of particles have different polarization properties. To take advantage of this effect, the scattered signal must be split into two branches for separate measurement of the components parallel or perpendicular to the scattering plane, respectively. The choice of 90°-scattering angle furthermore simplifies instrumentation for symmetry reasons.

3. Averaging Concept

A scattering pattern of a single particle in one orientation illuminated by a monochromatic light source contains many maxima and minima (especially in the case of dielectric particles, see Kerker, 1969). Scattering analysis based on a distinct scattering angle would lead to unreliable conclusions. Therefore the concept proposed provides three methods of averaging.

a) Average over Scattering Angles

The scattering diagram is smoothed out by measuring an angular interval of scattering angles around 90°. This step also increases the utilizable intensity, but misleading conclusions can still not be excluded safely.

b) Average over Sizes

The scattering properties depend on the ratio of particle size and the wavelength of the light source. Thus, one particle changes its scattering diagram if it is illuminated with different wavelengths. The spectrum of the Hg-lamp selected contains many utilizable lines from the UV to the red. This converts each particle into an artificial polydisperse mixture.

4. Measurement Analysis

The quantities measured are the peak intensities I_1 and I_2 registrated at the two sensors responsible for the two directions of polarization, and the duration T of the scattered light flash. Quantities derived from these data are the degree of linear polarization

$$P = \frac{I_1 - I_2}{I_1 + I_2},$$

the total intensity $I = I_1 + I_2$ (see Kerker, 1969) and the velocity of the particle $v = a/T$ (a is the dimension of the scattering volume in the direction of particle motion).

4.1 Criteria for Distinction Between Different Particle Types

The first step of the data evaluation are conclusions concerning the particle type. Such conclusions are justified by measurements of the scattering properties of nonspherical particle (Zerull et al., 1979; Holland and Gagne, 1970; Pinnick et al., 1976; Perry et al., 1978; Giese et al., 1978).

The polarization measurements proposed allow distinctions concerning the refractive index of the particle material (dielectric or absorbing) and the particle shape (spherical, irregular, or "fluffy"). As a special type of particles, fluffy particles of dielectric and absorbing constituents (as collected by Brownlee, 1978), can also be identified.

4.2 Size Determination of Particles

The total intensity $I = I_1 + I_2$ scattered at 90° is a measure for the size of the particles. As the scattering efficiency at 90° depends on the type of particles, the delimitation concerning particle type has to precede the size determination. Reliable size information will be obtained using appropriate calibration curves for the particle type registrated.

4.3 Velocity Determination

The duration of a light pulse registrated at the photomultipliers is inversely proportional to the particle velocity.

5. Compatiblity with Expected Flux Rates and Particle Velocities

The purpose of this section is to point out that the experiment proposed will meet all requirements due to extremely different flux rates and particle velocities to be expected during the rendezvous period depending on the distance comet-sun and S/C-comet. To prove this, extensive calculations have been carried out based on the conditions for the Tempel 2-mission using either the nominal or extreme high model of Newburn (1979), considering the relevant area of the scattering volume and the S/C trajectory proposed, following the procedures given by Eddington (1910), Wallace et al. (1958), and Mendis et al. (1976). Typical excerpts are presented in Table 1. The S/C coordinates x/y/x are centered at the nucleus of the comet with -x pointing to the sun and x/y representing the orbital plane. N and E indicate the use of either Newburn's nominal or extreme high model.

Table 1.

Example No.	Distance Comet-Sun [AU]	S/C Position z = o		Model	Max. Velocity (0.925 μ-p.) [ms^{-1}]	Most Abundant Particles (1.125μ) events [s^{-1}]	Total Number of Events [s^{-1}]	Time between events [s]
		x[km]	y[km]					
1	1.6 pre-P.	-300	100	N	83.6	0.055	0.13	7.58
2	1.6 pre-P.	-1400	545.4	N	15.5*	0.311	0.328	30.5
3	1.6 pre-P.	-100	100	N	90.4	0.296	0.725	1.4
4	1.4 post-P.	-100	500**	N	283	0.346	0.75	1.32
5	1.4 post-P.	-100	300	N	284	16.9	59	0.017
6	1.4 post-P.	-1000	1000	E	399	13.5	30.7	0.036
7	1.4 post-P.	-100	100	E	404	1360	3090	$0.32-10^{-3}$
8	1.4 post-P.	-10000	1000	E	353	0.242	0.562	1.78
9	1.8 post-P.	-100	100	N	172	1.01	2.28	0.439
10	2.2 post-P.	-100	100	N	54.8	0.114	0.261	3.83

* velocity of 1.125μ particles ** z = 500 km; y = 0

As Tempel 2 is no longer a serious rendezvous candidate, it should be pointed out that in case of other candidates the S/C trajectory will probably be chosen appropriately to provide comparable dust conditions.

The comparison of the performance limits of the instrument and the expected values for various mission conditions suggests the following conclusions:

The allowable velocity range ($v = < 500$ ms^{-1}, due to the limited sampling rate) is not even exceeded in the extreme case of example No. 7. The minimum time requested between two events (for data processing and to avoid overlapping of events, altogether about $100\mu s$) is also well observed. On the other hand, the number of events to be expected during less active phases (No. 1, 2, 3, 9, 10) turns out to be highly sufficient for reliable statistic conclusions. Conditions for example No. 2 are chosen appropriately to demonstrate the capabilities of the instrument near the apex distance of certain particles (in this case particles of 1.125μ are extremely dominant at velocities of only 15 ms^{-1}). The especially high data rates expected in the cases No. 5, 6, 7 can be mastered by appropriate choice of measuring intervals and use of buffers for transitory data storage.

6. Summary of Problems of Cometary Physics Addressed by the Instrument

The Light Scattering Dust Analyzer will be able:

a) to determine the size distribution and number density of cometary dust as a function of the position of the S/C within the coma and the comet's activity,

b) to determine the abundance of different bulk materials of the cometary dust,

c) to determine the bulk density of the cometary dust,

d) to measure the velocity of cometary dust particles,

e) to provide the necessary link to imaging experiments and remote measurements, to investigations concerning the chemical structure (photometry of cometary emission, mass spectrometer), and to dynamic studies in order to obtain consistent understanding of the physical processes in comets and the interplay between cometary and interplanetary dust.

7. References

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