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Concepts for Dust Velocity Measurements on a Cometary Orbiter

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Abstract. We have studied several optical systems for dust velocity measurements on a cometary orbiter using light scattering to detect particles. Two main concepts are considered. The first relies on trajectory imaging, while the second uses time-of-flight measurements between two or more light sheets. Their merits and disadvantages are discussed. The favored system, time-of-flight between two planes with particle localization, is described.

1. Introduction

The independent determination of the velocity of interplanetary dust grains by space detectors has only been recently implemented. The Munich Dust Counter of the MUSES-A mission measures the charges generated by the high velocity impacts of particles on a gold target. The Cosmic Dust Analyser of the CASSINI mission measures the time-of-flight (tof) between two wire meshes which record the charge induced by the crossing of a charged particle (Auer, this volume). Theoretical calculations have shown that cometary particles in the vicinity of the nucleus are slow and neutral, so that the above concepts do not apply in the case of a rendez-vous mission.

Another approach to detecting dust particles is to record the light scattered when they are illuminated. Two main optical concepts have been investigated, trajectory imaging and tof measurements (already introduced in the cancelled Halley-Tempel 2 mission in a proposal headed by J.A.M. McDonnell). In implementing either concept, several severe constraints have to be taken into account: i) the velocity of the dust which range from 1 m/s to 250 m/s, and therefore requires a high speed signal acquisition/processing system that is near the limits of present technologies; ii) the size of the particles which range from less than 1 μm to a few mm, and consequently require the detection system to have a very large (10^6) dynamic range; iii) the small fraction of light scattered by the particles requires that a very efficient photon collection system be used. Actual circumstances are even more unfavorable as small particles, which produce the lowest signals, also are expected to have the largest velocities; iv) a reasonable size for the entrance aperture of the dust collector is about 100x100 mm^2. This imposes the requirement that the optical collection system have both a large field-of-view and a large depth-of-field; v) the spacecraft resources are obviously limited and require the design concept to operate within these resources.

Both concepts, trajectory imaging in section 2 and tof measurements in section 3, with their implementations, are illustrated and discussed in relation to the above constraints. Then the proposed system is described in some detail.

2. Dust trajectory imaging

Imaging the particle at short intervals of time as it travels through an illuminated volume allows the reconstruction of its 3-D trajectory and the determination of its velocity. In practice, two solutions may be considered.

In the first one, sequentially pulsed laser diodes create a segmented light volume. A projection of the particle trajectory is imaged on a CCD-detector by collecting the light scattered at 90^o from the incident light. Proper timing of the pulses and of the detector readout allows the retrieval of both the third spatial component of the velocity vector and its modulus.

In the second solution, the illumination operates continuously. Two objectives project the particle trajectory in two independent directions, a kind of "stereo-imaging" results. This allows the reconstruction of the true trajectory, while the velocity is determined by the detector readout timing.

These systems offer highly redundant information and the possibility of recording simultaneous events. But the very large expansion of the individual laser beams to create the light volume results in a weak irradiation of the particles. The very long optical system imposed by the large field-of-view and depth-of-field leads further to a small collecting efficiency. Altogether, the overall sensitivity in terms of detectable particle size is very low. In addition, the high readout rate required by this system is at the limit of the present technology. Consequently, the trajectory imaging concept is not pursued any further at this time.

3. Time-of-flight measurements

Recording the tof of a dust particle between two parallel planes allows the determination of the velocity component orthogonal to the planes. There are two possible ways to determine the full velocity vector, i) to localize the particle impact point in each plane or ii) to measure the tof in two additional directions.

3.1. Time-of-flight measurements with localization

Imaging the whole plane in order to localize the particle impact is impractical, since the large field-of-view requires a long, and inefficient, optical system. Based on our present understanding that the cometary outflow is essentially radial with respect to the nucleus, a compromise is to emphasize the determi-

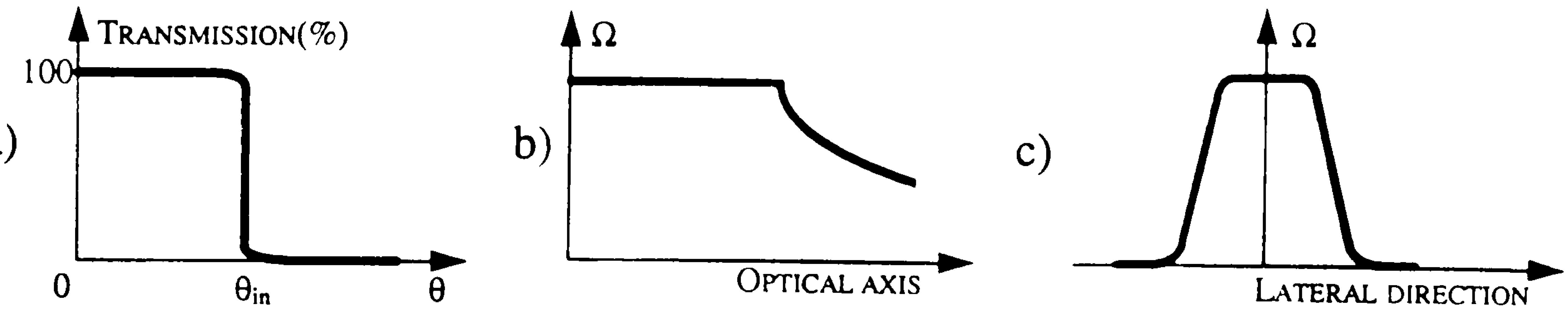

Figure 1. Properties of a concentrator: a) limited field-of-view, b) acceptance angle along the concentrator optical axis, c) acceptance angle orthogonally to the optical axis

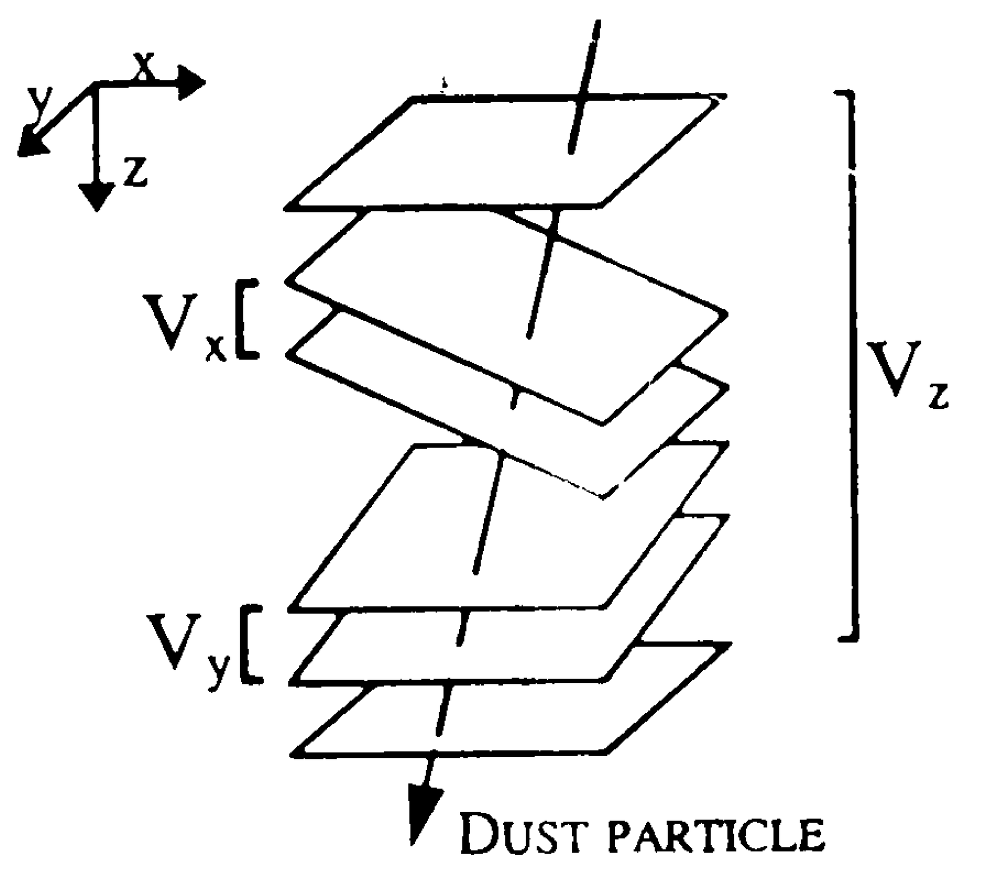

Figure 2. Geometry of inclined planes concept.

nation of the radial component by a tof measurement between two planes and to approximately localize particles impacts in these planes.

The localization is achieved by segmenting the planes in two orthogonal directions thus defining square sub-areas. Individual, sequentially pulsed laser diodes with appropriate collimating optics define first contiguous rectangular sub-areas. Second, self-baffling, adjacent concentrators of light (Welford 1989), of limited field-of-view (Fig. 1), complete the segmentation in the direction orthogonal to the propagation of the laser light. Furthermore, because of their potential proximity to the measurement area, concentrators have a large collection acceptance angle (about 20 times that obtained with an imaging system).

3.2. Inclined planes concept

To remedy the coarse localization of the particle, the complete determination of the velocity vector can be performed by tof measurements using one pair of parallel planes for each component, so that three pairs of parallel planes are necessary. A practical implementation is shown in Fig. 2. With such an arrangement, a very high accuracy for all the velocity components can be obtained. However a single collecting device that covers the whole field-of-view is impractical, so that multiple detectors as proposed in section 3.1 are required.

3.3. Proposed system

A comparison between the systems discussed in sec. 3.1. and 3.2., both with a segmentation of 4x4 square sub-areas (a good practical compromise), shows that the velocity determination is much more accurate for all the components in the inclined planes option. But the large number of components, and conse-

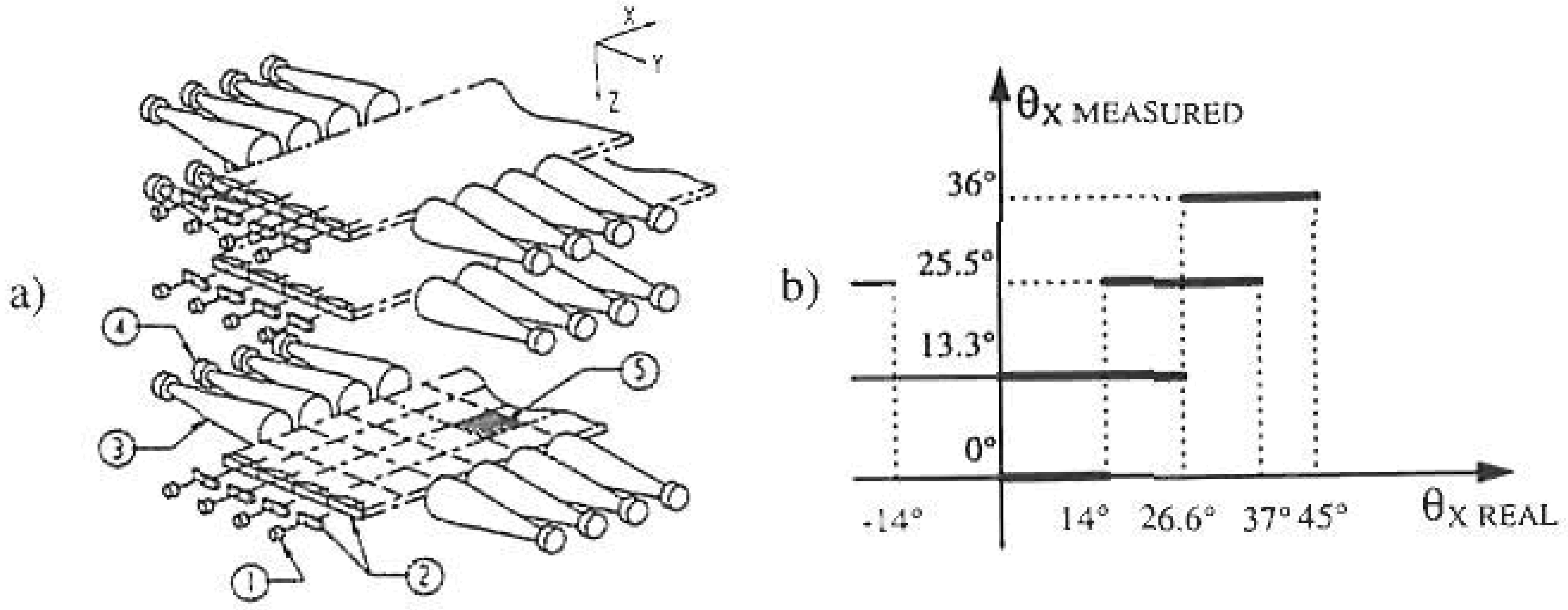

Figure 3. Recommended solution: a) implementation, with 1: laser diode, 2: collimating optics, 3: concentrator, 4: PIN photodiode and 5: basic measurement area, b) accuracy on the velocity direction projected on the x-axis

quently the mass of this solution, leads to the concept of tof measurements with localization as the favored means to measure the dust velocity vector during a cometary orbiter mission.

This solution (Fig. 3a) is composed of three segmented (4x4) light screens of area 100x100 mm^2 and thickness 4 mm. An alert screen, which detects incoming particles, initializes the operation of the next stages. The two velocity screens localize the particle, record the crossing times to determine the tof and perform photometric measurements. For each screen, an illumination of 500 mW/cm^2 is produced by 4 collimated laser diodes (λ = 830 nm). Light collection is achieved by two facing rows of 4 hollow concentrators with diameters 20 mm at the entrance and 8 mm at the exit apertures, the latter being matched with a PIN silicon photodiode (the acceptance angle is approximately 0.2 sr). The operation rate of 6 μs, or 166 kHz, represents a trade-off between the S/N ratio and the maximum detectable velocity.

The overall characteristics of the proposed system are a field-of-view of 30°, a velocity range of 1 to 200 m/s, and a particle size range of about 5 μm to a few mm. The accuracy on the radial velocity component is very good, from 0.01% for V=1 m/s to 2% for V=200 m/s. However the determination of the velocity direction, as shown in Fig. 3b, is rather crude.

4. Conclusion

We have described a novel system to measure dust velocity vectors on a cometary orbiter. Its study is in progress and a laboratory test system will be built to validate its performances.

References

Welford, W. T., & Winston, R. 1989, High Collection Nonimaging Optics, New-York