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Dust Near the Sun

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Abstract. Yielding the inner continuation of the interplanetary dust cloud, the dust at about 0.3 AU and closer to the Sun is studied under observing conditions different from those of the Zodiacal light. The F-coronal brightness indicates its optical particle properties as well as its overall spatial distribution. The present knowledge is based on visible and near infrared F-coronal observations and may be improved from data of the SOHO satellite in the near future. Some dynamical effects become particulary important for sub-μm particles in the solar vicinity. However, these particles seem to have only a small effect on the observable corona brightness, but are more accessible to in-situ experiments.

1. Introduction

From the viewpoint of astronomical scales the whole interplanetary dust cloud is "near the Sun". As far as the physics of the solar system is concerned at least two specifications are possible. From the dust dynamics interactions with the solar magnetic field and heating of dust particles have significant effect near the Sun, however it is not evident where this is exactly the case. For remote observations we can define the dust near the Sun as the region that is not detectable in the Zodiacal light of the nightsky, i.e. a region of about 0.3 AU around the Sun.

Mainly produced at larger solar distances, the dust approaches the Sun under deceleration from the Poynting-Robertson effect, yielding the inner continuation of the Zodiacal cloud. The composition of the dust cloud (cf. Mann 1995) as well as the properties of single particles may change with solar distance. Moreover the existence of sungrazing comets (Sekanina 1982, Marsden 1989, MacQueen & StCyr 1991) may provide a temporal contribution, which however could not be determined from remote observations. Effects of charged dust particles and interactions with the solar wind can be expected to be particularly important in the solar vicinity (Morfill & Grün 1979, Scherer et al. 1995) and to produce dust rings (Mukai & Yamamoto 1979, Mukai et al. 1974).

2. The Solar F-Corona

The solar Fraunhofer (F) corona has long been attributed to the scattering of sunlight by interplanetary dust particles along a line-of-sight (LOS) (van de Hulst 1947). The contribution from thermal emission was early suggested by Russell (1929) and shown in quantitative calculations by Över (1958) and then Peterson (1963) and Röser & Staude (1978). The reddening of the solar corona is also influenced by the change of the scattering properties (Mann 1993), which depends on the size distribution of particles. Model calculations based on findings concerning dust scattering properties and "reasonable" size distributions show, that the contribution of dust within 0.2 AU around the Sun makes up between 50 and 70% of the total brightness (Mann 1992).

3. Results from Brightness Observations

A review of previous F-corona observations was given by Blackwell et al. (1967) and then by Koutchmy & Lamy (1985). A general continuous slope from the Zodiacal light into the F-corona for small elongations of the LOS shows the connection of the two phenomena (Fechtig et al. 1981). Since the mid 1960s near infrared observations have also been attempted, some of which showed variations in the slope of the infrared brightness ("feature", MacQueen 1968, Peterson 1967, 1969). More recent observations during the 1991 eclipse benefit from the development of IR detectors and describe the brightness of the near infrared solar corona (Hodapp et al. 1992, Kuhn et al. 1994, Lamy et al. 1992, Tollestrup et al. 1994) over a relatively wide coronal range from 3 to 9 $R_\odot$. However no features could be identified during the 1991 eclipse. Some recent observations also covered the F-coronal polarization (Maihara et al. 1985). Further knowledge about the dust orbital motion is obtained from the observation of Doppler shifts in the coronal Fraunhofer lines (Beavers et al. 1980, Dürst 1982, Shcheglov et al. 1987, see also Shestakova et al. this volume and Clarke, this volume.)

3.1. Near Infrared Features

The observed infrared features were initially interpreted to be a region of enhanced dust concentration (Mukai & Mukai 1973; Mukai 1985; Mukai & Yamamoto 1979) and later by a geometric effect that is expected when the LOS crosses the beginning of the dust free zone around the Sun (Mann 1992). Both 1991 observations show no evidence for the existence of a feature at the time of observation (Hodapp et al. 1992, Lamy et al. 1992) and the beginning of the dust free zone could not be identified within the region of distances larger than 3 $R_\odot$ around the Sun, which points to a large extended zone of nearly constant number density near the Sun (Mann & MacQueen 1993).

3.2. Optical Properties of Near Solar Dust

The local albedo and local degree of polarization could be derived from the F-coronal brightness and compared to findings about the dust properties at larger solar distances, as presented in Figure 1. The left panel shows the local polarization values derived from the visible F-coronal polarization according to the Blackwell model as squares and the values derived from the visible Zodiacal light polarization as triangles. The right panel shows the local albedo derived from a comparison of thermal emission and scattered light brightness. Triangles refer to the data derived from the F-coronal observations, squares and diamonds refer to models based on different infrared observations of the Zodiacal light. The squares are based on ZIP rocket data and the diamonds are based on IRAS

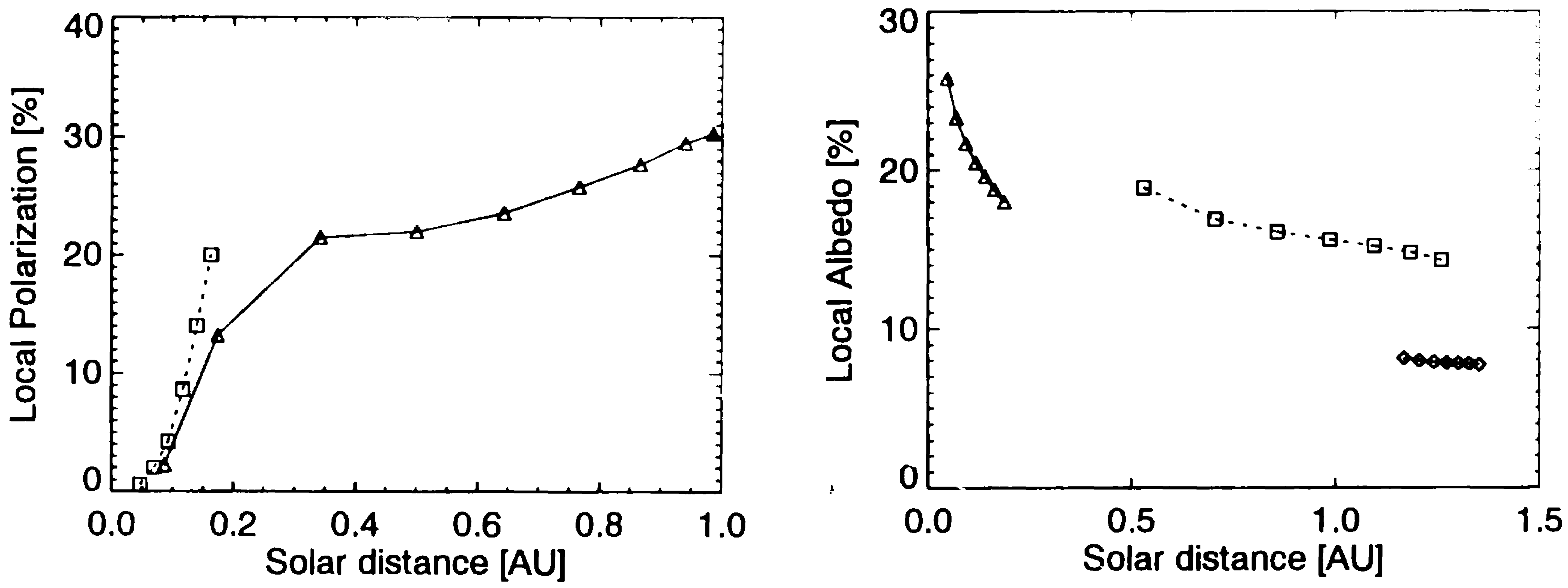

Figure 1. Average local degree of polarization and geometric albedo of particles at solar distance r: F-coronal data (Mann 1992) in comparison to Zodiacal cloud models (Levasseur-Regourd et al. 1991).

data (Levasseur-Regourd et al. 1991). All data show in quality a tendency to low polarization values and high albedo values with decreasing distance from the Sun. Observational data of the polarization in the visual coronal brightness according to Blackwell et al. 1967, are mainly affected by the high polarization of the K-corona. Previous model calculations can only explain the derived F-coronal polarization, if the polarization of near solar dust were zero (Mann 1992). Although a trend to smaller polarization values can be explained qualitatively and would support the trend seen by Renard et al. (1991) in the analysis of the inner Zodiacal light data, a quantitative understanding could not be achieved (Mann 1993).

3.3. Size Distribution

Essential for the understanding of dynamical effects near the Sun is the knowledge of the size distribution of particles. Some knowledge about the size distribution of interplanetary dust is given from in-situ experiments up to a solar distance of about 0.3 AU (Grün et al. 1985). According to these results particles of sizes from 1 to 100 μm give the main contribution to the geometric cross section and to the scattering cross section. Also the lack of a bluening in the zodiacal light brightness, that would stem from the influence of sub-μm dust particles supports this model (Saxarra 1987). Models of the F-coronal brightness, which implicitly assume the interplanetary dust size distribution mentioned above, can give a good fit to the brightness data (Mann 1992, Mann & MacQueen 1993), however there is no direct evidence for the validity of the size distribution. The increased number densities and flux rates and resulting collision rates may change the size distribution of particles near the Sun. A detailed study by Davidson et al. (1995, see also this volume) has shown, that the scattered light component in the F-coronal brightness can be explained with different size distributions and especially it can also be explained with a size distribution suggested by Lamy & Perrin (1986), which contains a significant contribution of sub-μm dust to the scattered light brightness. At this point, further observations in a wide spectral range may yield a better understanding.

4. Models for the Most Inner Dust Distribution

4.1. Spatial Distribution

According to present visible light observations the F-corona approaches a spherical shape with decreasing solar distance, which indicates the existence of dust particles above the solar poles. This was recently shown as well for the near infrared brightness (MacQueen & Greeley 1995). Mechanisms to eject particles from the ecliptic plane into the solar pole regions (cf. Morfill & Grün 1979) are not very effective for the bigger particles that make up the coronal brightness and hence cannot explain this polar component. This may indicate an out of ecliptic dust component that has a steeper increase with decreasing solar distance and becomes increasingly important near the Sun (cf. Kneißel & Mann 1991). Different attempts have been made to explain the spatial distribution of dust in the most inner solar vicinity (see also Mann et al., this volume), namely the fact, that the radial density slope is not proportional to 1/r as expected from the Poynting-Robertson drift for particles in circular orbits, but is flatter from about 9 $R_\odot$ inward. Model calculations of temperature profiles have shown, that irregularly shaped particles, can have temperatures significantly cooler than the black body and hence can survive the strong radiation in the solar vicinity (Mann et al. 1994). Also different types of particle compositions may sublimate subsequently when approaching the Sun and thus cause such an extended zone of constant dust number density. Another attempt is to explain the spatial distribution due to the survival probability of particles on orbits with different eccentricity during their perihelion passage.

4.2. Local Dust Fluxes

Table 1. Components of dust in the solar vicinity, further explanations are given in the text (from Mann & Grün 1995).

component	particle size	detection	orbits
ecliptic	0.01 – 100 μm	remote	prograde / circular
spherical	0.01 – 100 μm	remote	random / elliptic
β-meteoroids	≤ 1 μm	in situ	random / hyperbolic
rings	≤ 1 μm	in situ	in ecliptic / elliptic ?

Further components are expected to be limited to the smaller particles and, hence are not necessarily detectable in the coronal brightness. These are the β-meteoroids leaving the solar system on unbound orbits and the dust rings which may exist as a fourth component around the Sun. The local number density in a circum-solar ring was estimated by Mukai & Yamamoto (1979) to increase by a factor of 5 to 10 compared to the overall dust density. As shown by Mann (1992), such a dust ring is not necessarily detectable in the F-corona brightness.

5. Future Investigations

Present knowledge about dust near the Sun is to a large extent based on model calculations and needs further clarification. Essentially two size ranges with different dominating effects exist in the dust cloud. Particles of μm-size and larger are accessible to remote observation and can be investigated by further dedicated experiments, such as near infrared detection in a wide spectral range. The white light observations from the SOHO satellite will yield useful information, as well as the analysis of Doppler shifts will gain information about orbital velocities. The second component of sub-μm sized dust particles is better to detect with in-situ instruments. For these particles further dynamical effects can be expected which are to be investigated by impact detectors (Mann & Grün 1995) and would benefit from near solar space missions (cf. Marsch & Roux 1995, Tsurutani & Randolph 1991). Finally, the inner solar system dust cloud is still a region for promising future investigations.

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