ON THE SOLAR DUST RING(S)

T. Mukai
Kanazawa Institute of Technology
Nonoichi, Ishikawa 921
Japan

ABSTRACT. Based on a mechanism to form the solar dust ring, it is proved that the observed peak in infrared F-corona cannot be explained by silicate type grain alone. Preliminary analysis on the recent infrared data of F-corona by Maihara et al.(1984) has suggested that the ring particle has different physical properties compared with the dust grains, which produce the background F-corona.

1. INTRODUCTION

In the F-corona, Peterson(1967) and MacQueen(1968) independently detected the peaks in infrared intensity for a wavelength λ of 2.2 μm over the range of 4-10 solar radii($R_\odot$) from the sun, and Lèna et al. (1974) confirmed the flux peak at 4 $R_\odot$ in the middle infrared at λ=10μm. Recently, Maihara et al.(1984) obtained the infrared brightness of F-corona at λ=1.25, 1.65, 2.25 and 2.8 μm by balloon observation at the total solar eclipse on June 10, 1983 in Indonesia. Their results have clearly shown the existence of the flux peak near 4 $R_\odot$.

Based on the dynamical behaviour of grains near the sun, Mukai et al.(1974), and Mukai and Yamamoto(1979) proposed a mechanism to form the solar dust ring and explained the observed flux peak as the combination of thermal and scattered light from such a solar dust ring consisting of grains suffering sublimation. Although their model has succeeded to construct the dust ring near the sublimation zone of grains, there still remains some uncertainty in identification of the material of ring particles. In this paper I shall reexamine whether silicate grains alone can produce the observed peak of infrared flux or not, and make a preliminary analysis of multiphotometric data by Maihara et al.(1984).

2. IS SILICATE A CARRIER OF INFRARED FLUX PEAK?

A complete dynamical analysis to form a solar dust ring has already been investigated in Mukai et al.(1974), and Mukai and Yamamoto(1979). I will therefore simply summarize the mechanism here. A radial velocity of the grain spiraling toward the sun under the Poynting-Robertson effect

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suddenly decreases due to an increase of a relative radiation pressure on a grain. This is caused by a decrease of grain radius under sublimation. Consequently, a concentration of grains arises near the sublimation zone in the outer solar corona. The zodiacal cloud is displayed near the ecliptic plane and almost all of its grains fall toward the sun by the Poynting-Robertson effect, keeping its inclination of orbits. Then, such a concentration in number density of circumsolar grains would make a ring structure around the sun. It is called, therefore, the solar dust ring.

To produce a sharp peak of space density of grains, the temperature of grain should be almost independent of grain radius. In other words, when each grain with a different radius begins to sublime at nearly the same distance from the sun, the enhancement of spacial density of circumsolar grains becomes narrow and sharp. It was found in Mukai and Yamamoto(1979) that the ratio of the lifetime of grain with radius s, $t_s=s/|ds/dt|_{sub.}$ to a period of Kepler orbit, t_K becomes a good indicator of the position of the ring, where $|ds/dt|_{sub.}$ denotes a sublimation rate. Namely, the grain suffering sublimation keeps its solar distance from the sun against the Poynting-Robertson effect during $10^2 \sim 10^3$ orbital revolutions till it completly sublimes. This result agrees with the numerical calculations by Lamy(1976).

The shaded area in figure 1 denotes the region between $t_s/t_K=10^2$ and 10^3. For silicate and silicate with impurity, I calculated a ratio of t_s to t_K as follows. That is, based on the Maxwell-Garnet expression the complex refractive index of heterogeneous silicate is derived(see Chýlek and Srivastava 1983). Then using the Mie theory and the energy balance equation for a grain, the temperature of the grain is obtained by the same treatment as shown in Mukai and Schwehm(1981). Finally, referring to the sublimation rate of silicate, a ratio of t_s/t_K is computed as functions of grain radius and solar distance. As shown in figure 1, a ratio of t_s to t_K varies with grain radius because the temperature of silicate strongly depends on grain radius(see Mukai and Schwehm 1981). This unfavorable feature in the formation of a sharp concentration of grains remains even when other materials such as impurities in the silicate matrix are included. Therefore, it can be said that silicate can hardly produce a sharp and narrow structure of ring near 4 $R_\odot$.

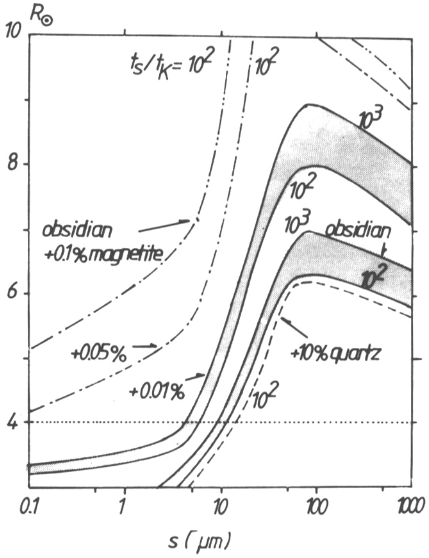

FIG.1. Computed ratio of t_s(a lifetime of a grain) to t_K(its Kepler period) for obsidian, and obsidian with impurity, where number of percentage means a volume fraction of impurity.

In addition, as shown in figure 2, thermal emission from silicate is about 10^2∿103 times smaller than the scattered radiance in the near infrared. Figure 2 comes from the model calculations for obsidian grains with 0.05% volume fraction of magnetite inclusions, where it is found that K-coronal radiance is roughly one tenth of scattered light by obsidian grains having a size distribution of s^{-4} between 0.01 μm and 1000 μm.

This result implies that in the near infrared, silicate cannot make a sharp peak of infrared flux because scattered light by ring particles is diluted by a large amount of light due to low angle scattering of grains far from the sun, and subsequently the flux peak becomes ambiguous.

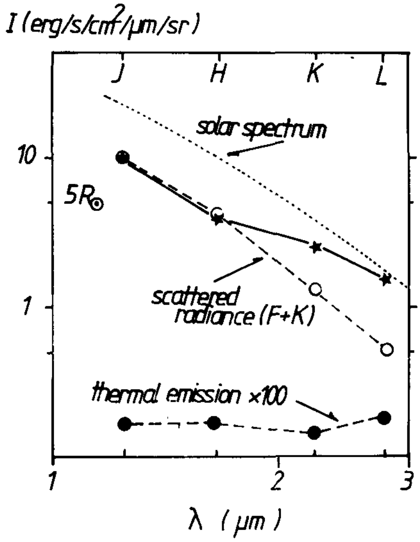

FIG.2. Energy spectrum from model calculations(circles) and observed results(stars).

3. PRELIMINARY ANALYSIS OF INFRARED F-CORONA OBTAINED BY BALLOON

Figure 3 shows the observed energy spectrum at each solar distance (Maihara et al. 1984). A similarity of these spectra to the solar energy spectrum(dotted curve), except at 4 $R_\odot$, strongly suggests that the observed flux in the near infrared outside the flux peak comes from the scattered light formed by grains extended between the sun and the earth.

Furthermore, a color ratio of J(1.25 μm) to H(1.65 μm) bands normalized by that of solar spectrum is applied to examine the observed results(see figure 4).

It is found that there is a weak 'dip' of color ratio near 4 $R_\odot$, which is mainly caused by the observed remarkable peak of flux in H band. Model calculation for the same silicate dust cloud(without dust ring structure) as that in figure 2, where a spatial distribution takes a $r^{-1.3}$-dependence, provides nearly constant value of $(J/H)/(J/H)_\odot \sim 1.4$ (solid line in figure 4).

Since outside the peak region the observed ratio does not vary with solar distance(see figure 4), it can be confirmed that the scattered light plays an important role in the coronal radiance.

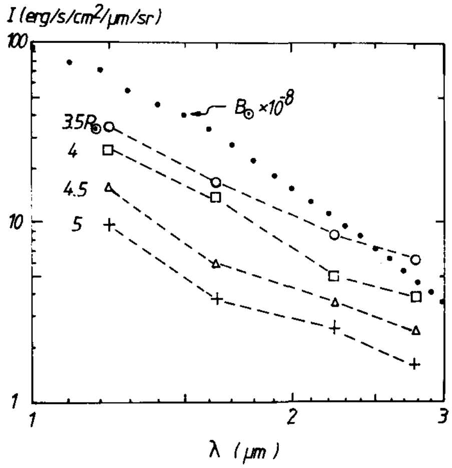

FIG.3. Observed energy spectrum of the infrared F-corona by Maihara et al.(1984).

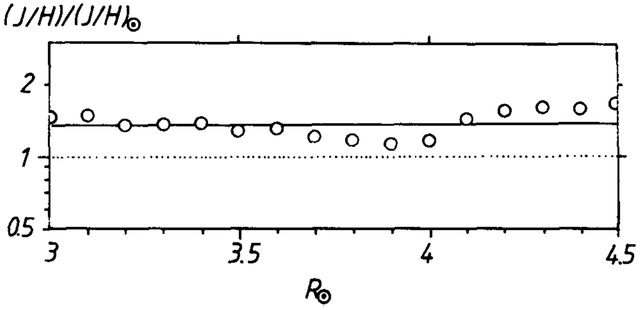

FIG.4. Color ratio of J(1.25μm) to H(1.65μm) normalized by its solar value. Open circles show the observed results by Maihara et al.(1984). Solid line comes from the model calculations presented in the text.

This ratio approaches unity near the dip. There are alternative possibilities to interpret this feature, i.e. (a) if the scattered light produces this dip, ring particles might be larger and/or darker compared with background F-coronal particles, which seem to be silicate grains, and (b) if the thermal emission makes the dip, ring particles have the temperature of about 1800 K at 4 R⊙.

The infrared observations reported by Maihara et al.(1984) have confirmed the existence of flux peak near 4 R⊙. Preliminary analysis of their multiphotometric data considered here has suggested that the ring particles have a different nature compared with the grains existing outside the ring, which are perhaps silicate. Further measurements, especially polarimetric observations in the near infrared, and simultaneous observations at both near and middle infrared, are urgently needed.

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Remarks by S.F.Singer(edited by T.Mukai);Liouville's theorem to describe the orbital evolution of an assembly of particles may lead us astray because the P.R.-effect is dissipative, and the evolution of the size distribution should be considered.