2 IN SITU MEASUREMENTS OF INTERPLANETARY DUST

2.3 PARTICLE COLLECTION EXPERIMENTS AND THEIR INTERPRETATION

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2.3.1 Submicron Particles from the Sun

by

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Abstract

A review is given which suggests that cosmic dust theoretical and experimental studies are still beset with uncertainty and inaccuracy. A significant body of interrelated evidence exists which indicates that the solar system has two populations of dust particles, a submicron population generated and emitted by the sun and a larger size population spiraling inward toward the sun. The submicron component may provide the missing coupling mechanism between solar sunspot activity and meteorological activity in the earth's atmosphere.

Troubles with Measurements and Theories

In the attempts to infer the nature of the interplanetary dust particles from Zodiacal Light studies, a single spectral index has been assumed in the size distribution ($dn \propto r^{-c}dr$), even though it is clear from the collection studies, lunar microcrater studies and the interplanetary detection studies that such an assumption is unreasonable. The collection techniques have been questioned from a contamination viewpoint and when inflight-shadowing was introduced to obtain greater reliability of particle identification, a loss in small particle sensitivity resulted. The coincidence techniques currently employed in detection experiments are always limited by the sensitivity of the least sensitive element and thus also sacrifice sensitivity for reliability. The penetration studies, which use foil thicknesses 25 to 50 μ thick, have to be calibrated by extrapolation since electrostatic accelerators cannot accelerate particles larger than

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1 μ to typical interplanetary impact velocities. When we calibrated our S-149 experiment at both the Goddard Space Flight Center and the Max-Planck-Institut für Kernphysik we found that to produce the same microcrater size in the same materials with the same kind of particles, that unexpected factors of 8 in momentum and of 3 in energy appeared. Thus it seems there are problems and limitations with all phases of cosmic dust work and this paper will be no exception. The purpose of this paper is to suggest that some of the observations in the cosmic dust field become more understandable if one views the dust population of the solar system as having two components, a component of relatively large particles ($\gtrsim 10^{-13}$gms) spiraling inward towards the sun and a component of submicron particles ($\lesssim 10^{-13}$gms) flowing outward from the sun,having its origin in sunspots.

Evidence from Collection Studies suggesting a Solar Origin for Submicron Cosmic Dust

Figure 1 shows a core-mantle particle collected during a noctilucent cloud (NLC) display. It will be noted that the small core appears black, which in a transmission electron microscope indicates a large number of electrons per unit volume which in turn requires a high Z material for the core. The mantle is very fragile and is only an ash of its former self. The mantle is consistent with a hydrogen-soaked, carbon mantle which has oxidized[1] in transit through the ionosphere. The reality of these core-mantle particles appears to be confirmed by the existence of submicron penetration holes ("evil eyes") at 230km altitude[1] (Gemini S-012) and at 430km altitude[2] (Skylab S-149). The existence of submicron particles in the solar system has also been shown by the presence of submicron craters in the Skylab S-149 experiment[2].

Figure 2 shows a NLC particle which has experienced a violent thermal experience, probably more violent than entry into the earth's atmosphere. The particle appears to have a high-Z refractory nature and may have encountered a high temperature environment during ejection from the sun's atmosphere. Notice that the particle is curved only on one side and has only a thin mantle. Generally particles smaller than .1 μ have no mantles. The presence of carbon mantles in the larger submicron particles may be nature's way of reducing the average density of the larger particles to permit solar light pressure to approximately balance solar gravity to enable the particles energetically to

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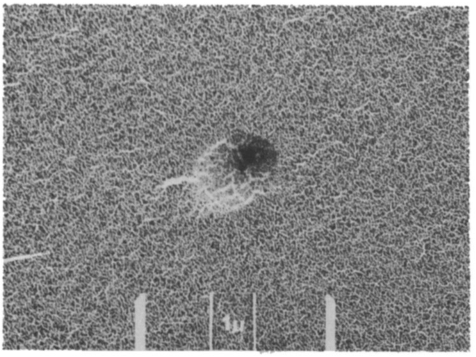
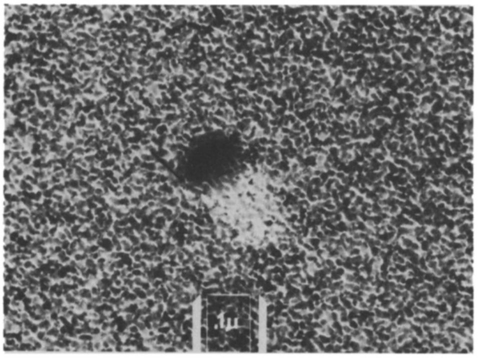
escape from the sun.



Noctilucent Cloud Particle
Figure 1



Noctilucent Cloud Particle
Figure 2

Figure 3 shows the sort of evidence which suggested to us[3] the presence of high Z elements in the cores of the particles. The top scan is a portion of an X-ray probe analysis of the particle shown and the bottom scan of a region about 30μ away. The extra peak best fits hafnium and two additional peaks also fitting hafnium were also found on the same trace. Similar X-ray peaks in other particles have given evidence of Ta, La, W, Th, etc., all high temperature, high Z elements found in NLC collections. Three of the four successful NLC collections found significant particle flux enhancements at times of NLC displays. One did not. Probably both the enhanced particle flux and the hydroxyl-ion mechanism are playing roles in NLC formation.

Figure 4 shows a fission track cluster which shows the presence of uranium in particulate form in a sample of lexan exposed facing the sun during the S-149 experiment[4]. Significantly more such events appear to have been found in the solar facing samples than in the anti solar exposure. More work needs to be done before flux numbers can be given. Their presence does suggest the presence of uranium (a high Z, high temperature refractory material) in significant amounts in the submicron particles of the solar system.

Next we note that the times of NLC displays do not appear to be related to meteor showers and that significant flux enhancements of collected submicron particles have been observed in rocket collection experiments on four occasions. Table I summarizes these data. During these particle enhancements, a constancy of observed particle flux with altitude has been found, suggesting an influx from outside the earth's atmosphere. Also Fechtig[5] has found all particles measured in rocket experiments in the

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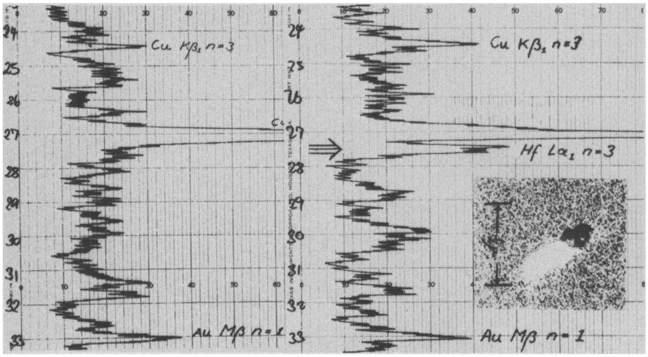
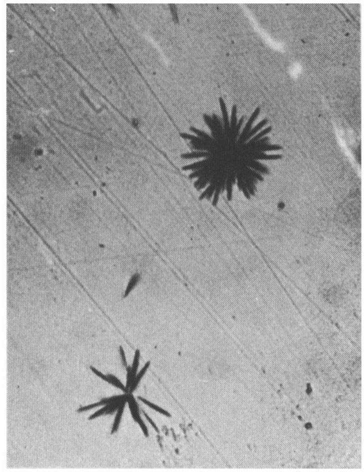


X-ray Probe of
Noctilucent Cloud Particle
Figure 3



Fission Track Clusters
in Lexax S-149 Sample
Figure 4

Location	Date	Enhanced Particle Flux	
Kronogård, Sweden	Aug. 11, 1962	$10^{5.5}$	part/m^2s
White Sands, N.M., USA	Nov. 18, 1965	10^4	"
Kiruna, Sweden	Aug. 8, 1970	10^{4*}	"
Kiruna, Sweden	July 31, 1971	10^{3*}	"

Table I

atmosphere to be falling. These enhancements may be the result of concentrations of particles ejected from the vicinity of sunspots by prominence outbursts in the solar atmosphere.

Table II shows the melting and boiling points of some of the elements or molecules which appear to exist in the NLC particles. It is to be noted that these materials have such low vapor pressures that their boiling points (STP) are so high that their values are not well known. In some cases the oxides or carbides appear to be more stable and have lower vapor pressures than the elements alone. Thus there does appear to exist materials in the NLC particles which could nucleate and grow in the vicinity of sunspots. Furthermore, the composition discrepancy[6] between the solar abundances and, say, the moon might well be the result of material of the refractory elements existing in particulate form in the atmosphere of the sun.

*Estimated flux may be low due to use of inflight shadowing.

Element or Molecule	Melting Point	Boiling Point
W	3683°K	6200°K
Hf	2248 "	5673 "
HfC	4163 "	----
Ta	3500 "	5698 "
TaC	4153 "	5773 "

Table II

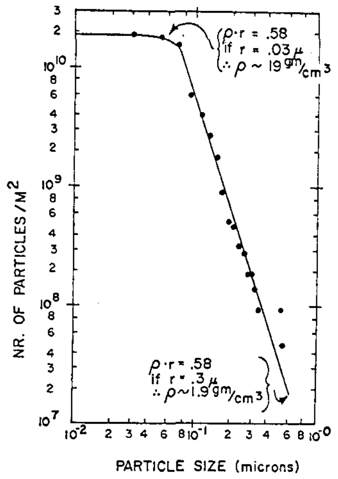
The nose cone collections which were made during the first NLC sampling expedition and the corresponding control collections in the absence of a NLC both showed a particle size-cutoff at about 0.03μ in radius. Figure 5 shows the size distribution[7] of this NLC collection in 1962. Since inflight shadowing was not used and the fluxes were high, it was possible to detect the small particle cutoff in this experiment. Smaller particles have been observed in the rocket collection experiments but always in association with the larger particles. The largest particles observed in most rocket experiments are about .3μ in radius. The integrated size distribution shown in Figure 5 has a slope of -3.2 (differential size distribution, $dn \propto r^{-4.2} dn$). An important question to be explained is why over such a relatively narrow range of sizes is there such an enhancement of the small particle fluxes over the larger sizes. It may be because the particles in this size range are the only ones which can approximately balance solar light pressure and gravity and thus can energetically escape from the sun in relatively large numbers. Under these conditions then

$$\rho \cdot r = .58 \frac{gm}{cm^3} \cdot \mu \qquad (1)$$

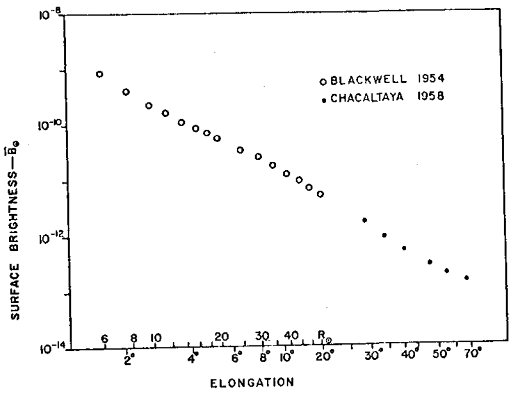
would be expected to hold where ρ and r are the particle density and radius[8]. The minimum particle size observed would represent the point where nature runs out of materials of sufficient mass density ($\sim 20 gm/cm^3$) and the maximum size would be determined by the smallest effective density that the materials can have in particulate form.

Intercomparisons Between Other Techniques to Study Cosmic Dust

Figure 6 shows the work of Blackwell and Ingham[9] which indicated that the brightness of the Zodiacal Light (ZL) as a function of elongation angle matches up with the brightness of the outer Corona. The standard explanation of this matching is by forward scattering of sunlight by large dust particles. However, this explanation encounters difficulties in the inability of the large dust grains to provide sufficient polarization for the ZL. An alternate possibility is that a significant part of the brightness of the ZL is due to scattering by submicron particles flowing outward from the sun.



Cumulative Noctilucent Cloud
Particle Size Distribution
Figure 5



Zodiacal Light and
Coronal Brightness
Figure 6

When the samples were brought back from the moon, the initial conclusion was that there were no submicron particles in the solar system since no small impact craters were found. With more careful work on smoother samples at higher magnification, relatively large numbers of small impact craters were found. Figure 7 shows an example of recent studies[10]. It will be noticed that there is about 2.5 to 3.5 orders of magnitude enhancement of the relatively steep small crater data. This suggests a flux of submicron particles hitting the moon (omitting corrections for particle directivity and small particles impact craters missed) of about 1 particle /m^2s, since these numbers must be added to the relatively flat flux curve of larger particles with masses greater than 10^{-13}gm ($3x10^{-4}$part/m^2s). It will also be noticed that the slopes of the lunar microcrater data are relatively steep. For example, a slope of -4.2 fits the data of sample (15301.79) better than the slope of -3.2, suggesting (assuming a constant impact velocity and that the particle size distribution is that given in Figure 5) that the particle density may increase as the particle size decreases according to equation (1). There is also a suggestion of a small particle cutoff in the data despite the diffi-

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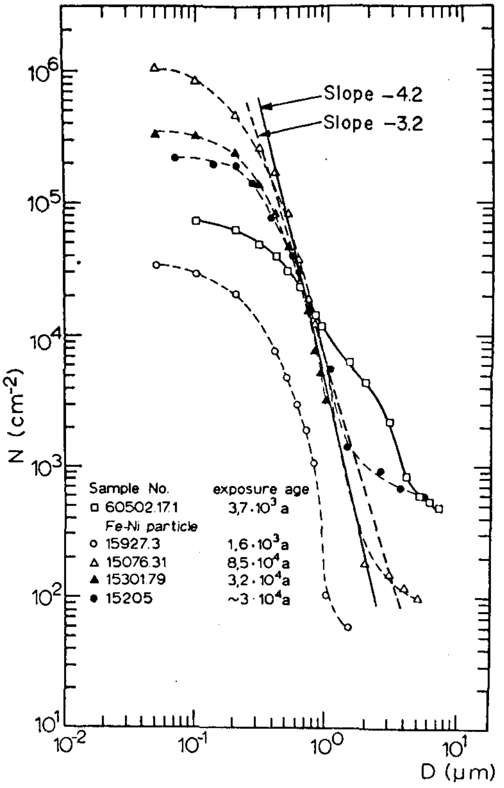
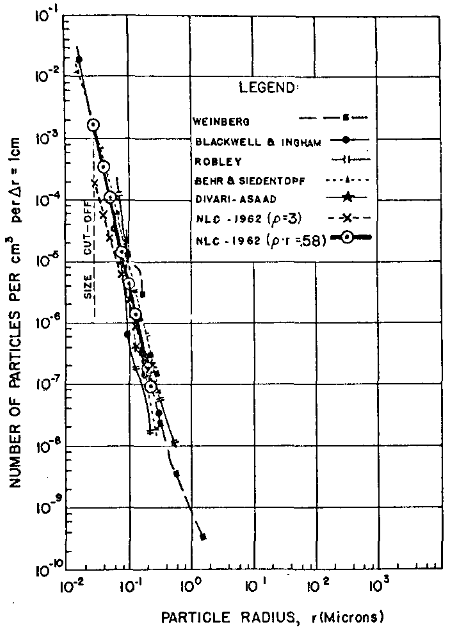
culties of finding very small impact craters.

In Figure 8 the number density as a function of particle size of the particles scattering solar photons to form the Zodiacal Light (ZL) is shown as computed from the work of Powell[11]. If one performs a conversion from the NLC particle size distribution shown in Figure 5 for the constant mass density case and the variable mass density case,

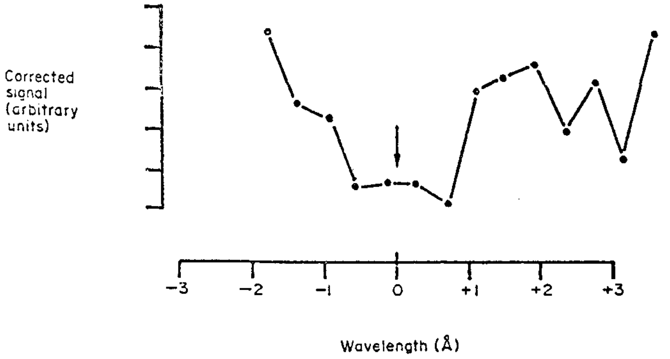


Cumulative Crater Number Densities
N vs. crater pit diameter D
Figure 7



Noctilucent Cloud and Zodiacal Light
Particle Size Distributions
Figure 8

equation (1), one can see that the variable mass density case fits the predictions of Powell better than the constant density case. This fit uses a flux of about 10 particles/m^2s and assumes a constant velocity of outflowing particles from the sun of 120/km/s. At 60km/s the flux to match the ZL brightness is about 5 particles/m^2s. It is also to be noted that the work of Powell provides an explanation of the polarization of the ZL and thus the size distribution of Figure 5 does also. In Figure 9 a high resolution plot of one of the ZL spectral lines given by Ring's group[12] is shown. If the satellite line represents the brightness contribution of an outward flowing submicron flux from the sun, it suggests that about 1/5 of the ZL brightness is due to submicron particles and thus also suggests that about 1 to 2 particles/m^2s should represent the average submicron flux from the sun.



High Resolution Zodiacal Light Spectral Line
Figure 9

We next attempt to intercompare the optical characteristics of the NLC particles and interstellar grains. If one uses a plane slab model and a NLC differential size distribution of dn $\propto r^{-4.2}$dr and assume constant absorption and scattering efficiencies, one gets an extinction approximately inversely proportional to wavelength. In Figure 10 one can see a comparison with the interstellar extinction measurements of Whitford, Boggess and the theoretical estimates of Greenberg[13]. It is to be noted that the prediction from the NLC size distribution is in fair agreement with the interstellar extinction values when converted to the same ratio of magnitude difference units. Furthermore the average size of the NLC particle cores at .044μ obtained from Figure 5 agrees quite well with the .05μ given by Greenberg for the average size of the cores of interstellar grains. This suggests that the process of stars generating submicron particles may be a common process and the difficulties of nucleating interstellar grains in interstellar space may disappear.

In Figure 10 one also sees the wavelength dependence of solar limb darkening[14] converted to the same units and compared with Greenberg's[13] work. It is to be noted that the data also agree remarkably well and a second interesting coincidence has appeared. It may also be shown that the limb darkening data converted to the ratio of magnitude difference units as in Figure 10 is independent of the angle with respect to the center of the sun at which the limb darkening data is taken. This limb darkening agreement

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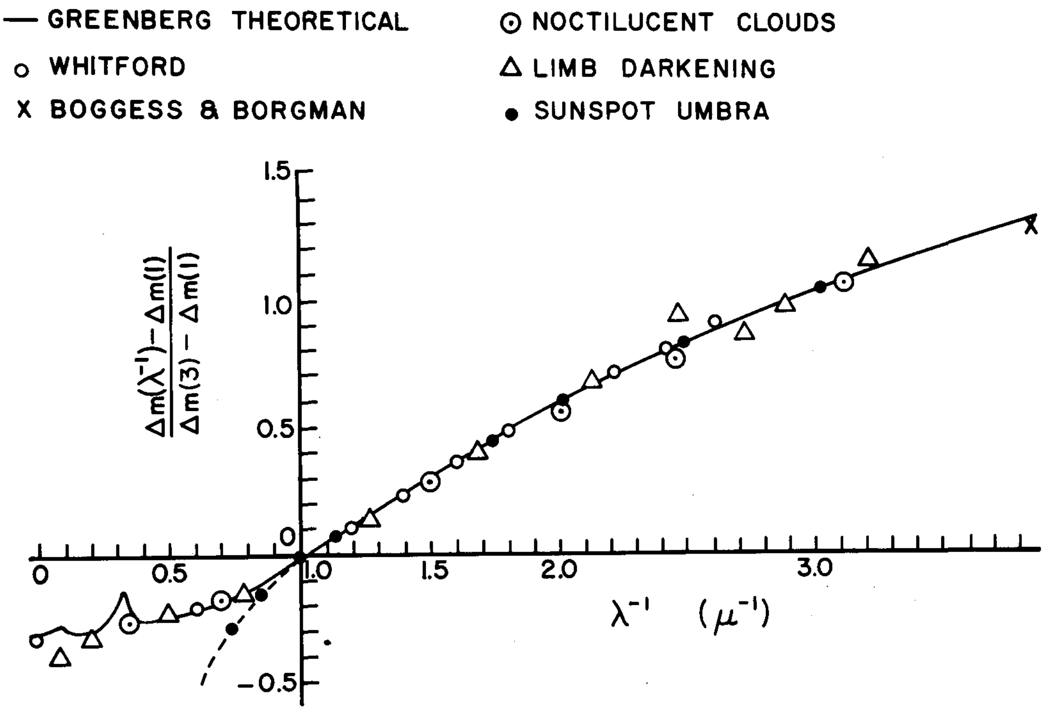

Interstellar Grains, Noctilucent Cloud Particles, Limb Darkening, and Umbra
Figure 10

suggests that high temperature refractory particles having the size distribution given in Figure 5 extending down into the Angstrom range, located in the region of the temperature minimum between the photosphere and the chromosphere could provide an alternate explanation of limb darkening. Chandresekar[15] gives wavelength dependence of solar extinction at the center of the sun and finds significant departures below 4500Å and around 9000Å. Pottasch[16] in a later review article says that an unexplained opacity in the solar brightness still exists in the UV.

Also if one converts the wavelength dependence of the umbral brightness of a sunspot[17] to these ratio of magnitude difference units, one finds fair agreement in the visual but significant departures in the infrared as shown in Figure 10. This suggests that we are dealing with the same particles except that they have not had time to grow to a sufficient size to be significant absorbers in the infrared. Thus there appears to be a four-fold coincidence between interstellar grains, NLC particles, particles sufficient to explain limb darkening and the particles to explain the wavelength dependence

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of the sunspot umbral brightness. If sunspots are particle generators such a coincidenc is not surprising since most of the particles which escape from the sun escape from the solar system. If our sun generates submicron particles which can escape to interstellar space, it is likely that most stars also do.

The temperature of the corona may be estimated by comparing Parker's theory of the solar wind with Vela satellite data to be about 750,000°K. Similar values result from radio and X-ray brightness studies[18]. If one determines the coronal brightness by the width of the Fraunhofer lines, the temperature of the corona becomes 2 to 3×10^6 °K, a significant difference from 750,000°K. Let us assume that the high coronal "temperature is due to doppler shifted photons scattered by submicron particles moving radially from the sun in different directions at the velocity equivalent of 2.3×10^6 °K and estimate the flux of submicron particles to be expected at the earth, ϕ_e, to provide the total corona brightness (Baumbach). We use Mie theory and assume m=2, $\lambda = .5\mu$ and all particles to have the average size of the NLC distribution 0.044μ (Figure 5). The results are given in Table III, where r_m is the minimum distance to the sun along the straight line integration paths. It is interesting that

r_m ($r_\odot$)	ϕ_e (Part/m^2s)
2.0	10.7
3.0	7.4
4.0	7.6
5.0	8.3
6.0	8.9

Table III

the values of ϕ_e are about the same as needed to provide a match between the NLC distribution and Powell's work as might be expected from Blackwell and Ingham's work (Figure 6 Perhaps the flow of submicron particles from the sun can provide an explanation of the temperature inconsistency of the solar corona and the coronal temperature is really only about 750,000°K. It is interesting that the outward velocity of the particle reaches a maximum at $r_m = 3.5(r_\odot)$ of about 200km/sec and appears to decrease linearly with $1/\sqrt{r_m}$ to about 80km/sec at the earth's distance from the sun, suggesting that the balance between solar light pressure and gravity is lost as the particles cool as they move away from th sun and that drag forces are important for small particles in the solar corona. The fluxes are reduced somewhat if one intercompares with the F coronal brightness and the extrapolated velocity at the earth drops to about 60km/sec.

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If one intercompares the steep lunar microcrater data given in Figure 7 with the relatively flat data[10] for larger particles ($\gtrsim 10^{-13}$gm) and inquires how do the submicron solar particle flux enhancements, velocities, fluxes and maximum particle masses vary, the data of Table III result.

Submicron Radial Velocity	Enhancement	Solar Part. Flux (ϕ_e)	Max. Part. Mass
20km/s	8×10^4	32 part/m^2s	2×10^{-12}gm
60 "	7×10^3	3 "	2×10^{-13} "
→ 80 "	3×10^3	1.5 "	3×10^{-13} " ←
100 "	1×10^3	.4 "	1×10^{-13} "

Table III

These estimates assume that the NLC size distribution data of Figure 5 is applicable for the submicron solar particles with its small and large particle size cutoffs (.03μ to .3μ radius) that equation (1) applies and that the large inwardly spiraling particles $\gtrsim 10^{-13}$gms hit the moon with an average velocity of about 8km/s. It is to be noted that 3×10^{-13}gm is the mass of a spherical particle of radius .3μ having the density of carbon. The intercomparison data of Table III with that of Figure 7 suggests an outward flowing velocity of submicron particles of about 80km/s at the earth's distance from the sun and a flux of about 1 particle/m^2s.

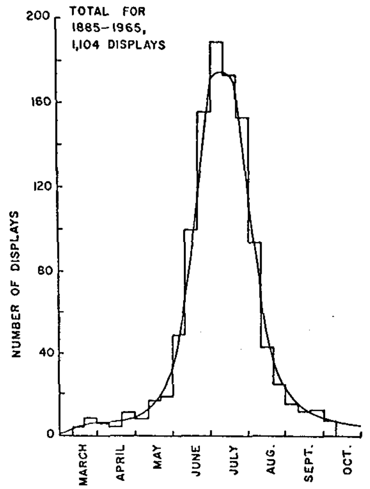
The velocity of the outward bound solar submicron particles may be estimated by direct integration, assuming an injection velocity of about 20km/s, that light pressure and solar gravity balance at the solar surface, and neglecting coronal gas drag. Table IV shows the results of such an estimate. This estimate suggests that if solar light pressure and gravity are in balance at the solar surface, then the imbalance which results as the particles move away from the sun and are struck by photons in a more radial manner, can accelerate particles to velocities of the order of 100 km/s. If one were to take into account coronal gas drag and the change in the index of refraction of the particles as they cool whyle moving away from the sun, then lower velocities would be expected for the solar submicron particles at the earth's distance from the sun. It is interesting that this estimate is independent of particle size (0.03μ to .3μ particle radii) if equation (1) holds.

An additional way of estimating the average particle radial velocity (v_r) at the

Height Above the Sun (r_o)	(Solar Light Pressure-Solar Gravity)/Solar Gravity	Velocity
.025	0.000	20.0Km/s
.055	.000	20.0 "
.125	.001	20.4 "
.25	.006	25.1 "
.50	.016	37.4 "
1.5	.038	69.6 "
2.5	.057	81.4 "
4.5	.075	94.2 "
8.0	.086	105.9 "
35	.096	113 "
75	.098	115 "
150	.103	116 "

Table IV

earth is to analyze the frequency of NLC data[19] as a function of time of year (Figure 11). It will be noted that the peak frequency occurs approximately 18 days after the summer solstice, which is the time that the earth's pole tilts in the plane of the ecliptic about 17.7° away from the sun. If one assumes the peak frequency time is the time that



Time Distribution of Noctilucent Cloud Displays
Figure 11

the greatest number of submicron particles from the sun are intercepted by the high latitude, northern hemisphere region of the earth, then because of the earth's motion

$$v_r = \frac{29.8\text{km/sec}}{\tan 17.7^\circ} \approx 90\text{km/sec}. \qquad (2)$$

Thus this crude parallax estimate appears to be consistent with the earlier velocity estimates. It is to be noted that NLC displays peak in the southern hemisphere six months later than in the northern hemisphere.

Sunspots and Submicron Particles

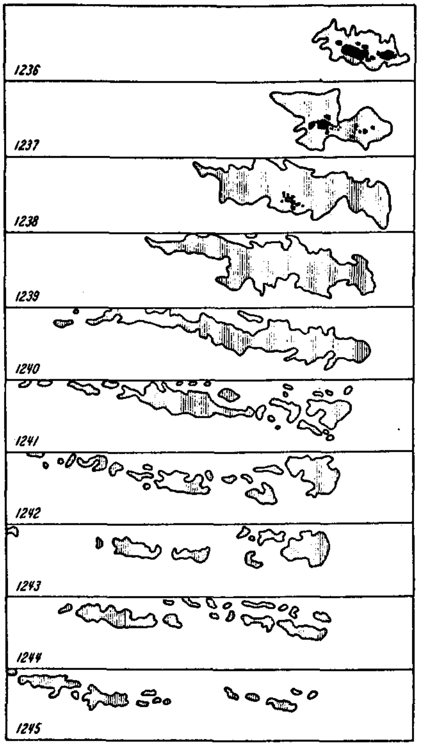
An important question is can the cool regions above the observable sunspot umbra nucleate particles? Let us estimate the magnitude of the cooling to be expected by computing the adiabatic lapse rate; we note that the partially conducting gas is carried to greater heights over sunspots (by virtue of the strong magnetic fields in the vicinity of sunspots by the Evershed effect-300 meters/sec outward velocity), than the heights the photospheric gases can reach by convective mechanisms over the normal photosphere. If one uses the solar gravity at the surface of the photosphere and assumes the gas to be mostly hydrogen, then

$$\frac{\Delta T}{\Delta z} = \frac{g}{C_p} = \frac{2.7 \times 10^4 \mathrm{cm/s}^2}{4.08 \ \mathrm{cal/gm} \times 4.2 \times 10^7 \mathrm{ergs/cal}} = 1.6 \times 10^{-4}\,{}^\circ\mathrm{K/cm} = 16\,{}^\circ\mathrm{K/km}, \qquad (3)$$

where g is the solar gravity and C_p the specific heat.

Thus in equation (3) a cooling of about 16°K/km is estimated. This means that one need only to elevate the umbral gas through a distance of 100 km (a distance small compared to the diameters of typical sunspot umbra) to drop the temperature of the umbral gas from a temperature of 3600°K to a temperature of about 2000°K. At such temperatures Wickramasinghe[20] and others have suggested that carbon can nucleate in the atmosphere of M stars provided the nucleation occurs on ions. It is to be noted that, despite their much smaller abundances, high Z refractory elements or molecules might nucleate at higher temperatures since they are much more easily ionized and have very much smaller evaporation rates from solid surfaces. It is to be noted that the abundance of high Z refractory elements determined in the solar atmosphere by atomic spectral line amplitude estimates are relatively low compared to other abundance evidence, such as from lunar abundances[6]. The relatively low solar abundances might result from the high Z refractory elements existing in the solar atmosphere in molecular form and the resulting bands being too weak to be detected in the noisy solar spectrum. In addition, the ease with which high Z elements can be ionized might lead to some concentration of the high Z refractory elements in the vicinity uf sunspots. It can be shown that the thermal conductivity is negligable for the temperature lapse rate given by equation (3) if an Evershed velocity of 300 meters/sec is used for the outflowing of solar gas from the vicinity from the umbra of a sunspot.

Figure 12 displays a diagram showing the presence of faculae[18] (white light,



Faculae Duration
Figure 12

higher brightness areas) around a sunspot group. These faculae were observed to persist around a sunspot group for about 9 solar rotations. It is to be noted that all sunspots have faculae and that faculae are best observed near the solar limb. It is suggested that faculae are regions where clouds of high Z refractory particles nucleated above sunspot umbra have grown to a size sufficient to scatter light and that the brightness observed in faculae is the result of increased photon scattering toward the direction of the observer. The average life of a faculae is given by Allen[14] to be 15 days, De Jager[18] says 80 days.

If one takes the high temperature region of the corona to be located within a distance of two solar radii from the solar surface and assumes a constant velocity of 50km/sec for the velocity of the submicron particles traveling radially outward from the solar surface, then a time of about .3 day is required for transit, as shown below.

$$\frac{1.4 \times 10^6 \text{km}}{50\text{km/sec}} = 2.8 \times 10^4 \text{sec} \approx .3 \text{ days} \qquad (4)$$

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Since the particle is cooler in the solar corona than in the interface region between the photosphere and chromosphere (since the temperature of the particle in the corona is determined mostly by photon absorption from the sun and reemission, the high temperature gas pressure being very low), the evaporation rate of the material from the particle in the corona is much reduced and it appears that for transit times of the order of a day the solar particles can readily survive transit through the sun's corona, particularly if the faculae are clouds of high Z, refractory, low-vapor pressure particles.

It is interesting to estimate the evaporation rate (gm/cm^2s) for the particles which we assume are responsible for faculae. We let

$$dm = 4\pi r^2 \rho\, dr = \omega\, 4\pi r^2 dt \qquad (5)$$

where dm is the mass of a spherical shell, r the particle radius, ρ the mass density of the particle, ω the evaporation rate from the particle and dt the time for a spherical shell to grow or disappear. Integrating equation (5) gives

$$t = \frac{\rho r}{\omega} = k_w \frac{\rho r}{\omega_w} \qquad (6)$$

where ω_w is the evaporation rate for tungsten and k_w the constant necessary to convert ω_w to the evaporation rate of the real particle. If the temperature of the interface between the photosphere and the chromosphere is taken to be $4300^{\circ}K$, $\omega_w = 7 \times 10^{-2} gm/cm^2s$ and taking 15 days for the average life time of a faculae gives in equation (6)

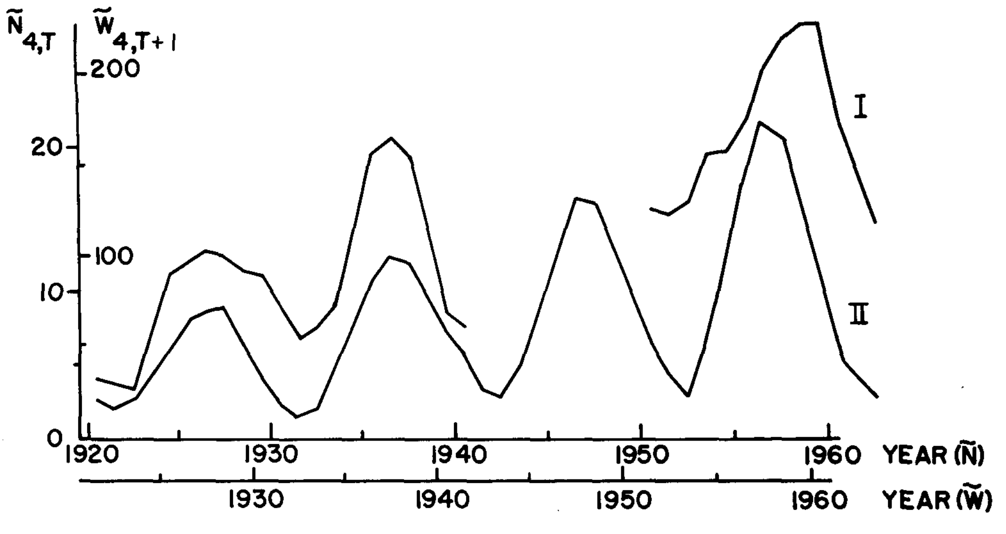
$$15 \text{ days} \times 86400 \text{sec/day} = k_w \frac{19 gm/cm^3 \times 0.03\,\mu \times 10^{-4} cm/\mu}{7 \times 10^{-2} gm/cm^2 s} . \qquad (7)$$

$$k_w = 1.6 \times 10^7$$

This says that the effective evaporation rate of the particle is a factor of about 1.6×10^7 lower than the evaporation rate a .03μ radius tungsten particle would have at a temperature of $4300^{\circ}K$. There are several possible reasons for this large factor: (1) the particle may have a lower temperature if it is not able to absorb all of the photons incident upon it, (2) the particle is probably charged negatively by excess electron accretion and the easily ionized high Z atoms evaporated from the particle are returned to it in significant numbers electrostatically, (3) the particle materials may well have lower evaporation rates than tungsten and (4) the particle is accreting atoms from the solar photosphere and the effective k_w is the result of the difference between the accretion rate and the loss rate of the atoms. The problem of how particles accrete and lose atoms or molecules in a stellar atmosphere needs much further work.

Possible Meteorological Implications of Solar Submicron Particle Enhancements

Many people have attempted to correlate weather phenomena with sunspot activity. Bowen[21] has suggested that the average latitude of "high" tracks across Australia varies with the sunspot cycle. Roberts[22] has suggested that droughts in the midwest of the USA are related to sunspot cycles. Douglas[23] has related tree ring widths and hence tree growth to sunspot activity. The problem has been how to relate sunspot activity physically to meteorological phenomena. We note that if greater numbers of sunspots are present, that a greater area of the sun is covered with faculae particles and the numbers of submicron particles ejected from the sun of a type suitable for NLC formation could be increased. Figure 13 shows how NLC numbers are correlated with sunspot numbers if one averages over 4 year periods. If greater numbers of NLC are formed during high sunspot activity it suggests that the number of particles entering the earth's atmosphere suitable for serving as centers for ice crystal growth in the mesopause vary with sunspot numbers. These particles must fall through the earth's atmosphere and eventually be swept out by rain. It can be shown that the average submicron particle flux is approximately constant



Sliding 4-year curves of the number of nights with noctilucent cloud displays (according to observations in the USSR in 1921 - 1940 and 1953 - 1963) (I) and of Wolf numbers (II).

Figure 13

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from 430km to 25km (alt.) and that the fall-time through the earth's atmosphere is independent of particle size if equation (1) holds (under free molecular conditions).

Rosinski[25] has measured the particle elemental compositions in clouds at an altitude of 9km. A preliminary look at his data suggests the presence of significant excess abundances of Hf, Ta and Th with respect to Fe whereas Ni appears to have normal abundance with respect to Fe.

If the earth encounters enhancements of submicron particle fluxes from the sun as the NLC data suggest, then these particles entering the troposphere in variable amounts might well be the missing variable for long and short range weather forecasting.

Conclusions

There exists a substantial body of interrelated data concerning studies of the Zodiacal Light, the collection and detection of cosmic dust, solar coronal, photospheric and sunspot studies consistent with the view that the sun generates and emits submicron particles. However, much more theoretical and experimental work needs to be done before the sun and most stars can be considered to be submicron particle generators and the source of interstellar grains. It will be particularly interesting to study the polarization characteristics of the photospheric white-light faculae near the solar limb and also to look for polarization in Waldmeier's blue rings[26] around sunspots. Better evidence is needed for the existence of high temperature, refractory materials in the submicron particle complex and can be obtained from rocket collection studies. The meteorological implications of flux enhancements of submicron particles of solar origin may become important for both long and short range weather forecasting.

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