FINAL REPORT

on

NGR 21-002-219

A STUDY OF THE ORIGIN, NATURE, AND BEHAVIOR OF PARTICULATE MATTER AND METALLIC ATOMS IN THE MESOSPHERE, LOWER THERMOSPHERE, AND AT THE MESOPAUSE

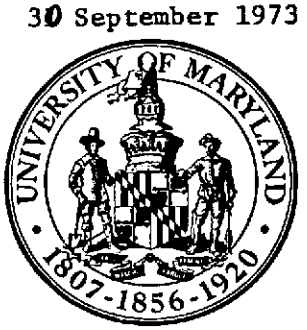
Submitted to

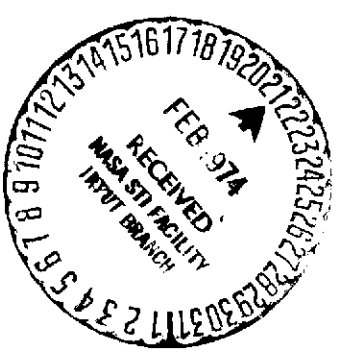
National Aeronautics and Space Administration

by

Sherman K. Poultney

30 September 1973





UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

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ABSTRACT

This report briefly summarizes the results obtained in research under Grant NGR 21-002-219 concerning the origin, nature, and behavior of particulate matter and metallic atoms in the vicinity of the mesopause. Three areas have received the most effort. These areas are the significance of cometary dust influxes to the earth's atmosphere, the relation of nightglows to atmospheric motions and aerosols, and the feasibility of using an airborne resonant scatter lidar to study polar noctilucent clouds, the sodium layer, and fireball dust. Detailed reports on each area of research are available separately; the first as a technical report, the second as a Ph.D. dissertation, and the last as a proposal.

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Section 1

INTRODUCTION

Introduction

Research under Grant NGR 21-002-219 continued in the areas of the cometary dust source for upper atmosphere aerosols and the use of laser radar for studying these aerosols and certain of the metallic atoms also present in this region. The cometary dust source was shown to be a minor contributor to both interplanetary dust and dust entering the atmosphere. However, detection of these transient dust events is of great significance from the point of view of cometary physics and from the point of view atmosphere dynamics and airglows. One such influx has been predicted and observed and a list of other possible events has been drawn up. Research in this area is summarized below and treated in detail in the attached Technical Report 74-015. Development of a laser radar useable for both resonant scatter studies of metallic atoms and back-scatter studies of the atmosphere and atmosphere aerosols was halted in Summer, 1972 due to technical difficulties. Studies of the use of such a lidar for studying details about the summer polar noctilucent clouds, latitude dependence of sodium airglow, and the debris of fireball break-up were, however, pursued. This lidar would be airborne for the necessary spatial coverage. The results of these studies will appear in a proposal to be sumbitted. A summary appears in Section 3. Recent technical advances in laser flash lamps now make such a lidar attainable and the airborne studies of great interest. The halt in the experimental studies of lidar observation of the metallic atom layers led to the search for an alternate area of research for a Ph.D. student. This area was found in the synoptic night airglow data from OGO-4. Explanations of the large longitudinal asymmetries and certain correlations in the airglows were made on the basis of physical atmosphere motions and dust influxes to the atmosphere. Section 4 contains the

abstract and Table of Contents of the Ph.D. dissertation of J. D. Walker. The dissertation discusses this research in detail. Finally, a list of publications and talks supported by this grant is given in Appendix I.

Section 2:

TIMES, LOCATIONS, AND SIGNIFICANCE OF COMETARY MICROMETEOROID INFLUXES IN THE EARTH'S ATMOSPHERE: EXTENDED ABSTRACT OF PAPER SUBMITTED FOR PUBLICATION

Extended Abstract of COSPAR Contributed Talk C.1.7

TIMES, LOCATIONS, AND SIGNIFICANCE OF COMETARY MICROMETEOROID INFLUXES IN THE EARTH'S ATMOSPHERE

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A number of comets during the last seven years have had orbits that make it possible for micrometeoroids released from their nuclei upon approach to the sun to travel directly to the vicinity of the earth under the action of radiation pressure. The micrometeorites collect in the upper atmosphere and fall at a rate determined by the radiation parameter allowed by their orbital elements. One such falling cloud has been reported by the Jamaica laser radar group in May 1970 in an event related to comet Bennett (1970 II). Due to the young age of the micrometeoroids and the small thickness of a comet dust tail emitted before its coma develops, the micrometeoroids impinge on the earth at a definite time and geographical location. Table I gives theoretical predictions for the radiation parameters, times of influx, and geographical locations of the micrometeoroid influx for comets 1971 II, 1970 II, 1969 IX, 1969 V, 1968 IV, 1967 VIII, 1967 VII, 1967 IV, and 1967 II.

On average, about one comet a year injects micrometeoroids equalling the normal one day influx of interplanetary dust in a period shorter than a day. The contribution of comet micrometeoroids to the total extra-terrestrial dust input to the earth is therefore minor. Its permanent

contribution to the interplanetary dust population is also minor except possibly in the case of certain short period comets. However, the existence and detectability of these micrometeorite showers are important with respect to comet structure and with respect to studies of aerosol phenomena near the mesopause. The mechanism for these direct cometary micrometeoroid showers to reach the earth is quite sensitive to the micrometeoroid properties and requires a definite release distance from the sun. Detection of this influx to the atmosphere by a means sensitive to particle size (e.g. laser radar) would yield significant information about the activity of a comet nucleus at the release distance, about the size of the micrometeoroids given off there, and about the state of coma development. Most of the influx events considered here are due to emissions before the comet coma develops and so bear a closer resemblance to the "forward spike" of comet Arend-Roland (1957 III) than to the thicker dust tails of comets Arend-Roland and Bennett which have been analysed by Finson and Probstein and Sekinina and Miller respectively.

Injection of the micrometeoroids into the atmosphere at a given time and location(s) in significant amounts (10^2 to 10^4 tons) could yield information on the behavior of the micrometeoroids in near-earth space, information, on the behavior of aerosols in the upper atmosphere, and information on competing mechanisms for the origin of the free sodium near 90 Km. An indication of the potential in the latter case is the report of Visconti and Fiocco of an increase in Na twilight emission related to a comet P/Encke (1971 II) event (among other comet events). They use this data to support their hypothesis that the Na is produced by sublimation from recently-fragmented, incoming dust particles and indicate that this method is a more sensitive dust detection method than the laser radar method being able to detect the lower amount of material quoted above.

Their reports suggest the examination of synoptic observations of airglows by the OGO-4 and OGO-6 satellites for correlations of airglow enhancements with the times and locations of cometary showers (as well as meteor showers). A recent study by J. D. Walker of the OGO-4 data spanning the period Sept. 1967 to Jan. 1968 shows promise for a correlation only with the comet 1967 VII event.

Detection of the cometary micrometeoroid showers in space by interplanetary space probes is much less probable due to the much smaller cross-sections of their particle detectors. Each passage of a Pioneer 8/9 detector through a shower in space would only be expected to yield one detected particle. These types of direct micrometeoroids are therefore only a minor constituent of the actual Pioneer dust events. However, since the time and trajectory of such an event can be predicted, a correlation with space probe data still may yield identifications with particular comets. It should also be clear that the earth makes a good space probe to one of these comet dust tails due to its large collection cross section. A Pioneer-type sampling mission would collect very few particles unless orbiting in the comet plane itself.

Despite the minor contributions that direct cometary micrometeoroid showers make to both the interplanetary dust population and the dust influx to the earth, their existence and detectability are important with respect to comet structure and with respect to studies of aerosol phenomena near the mesopause. This work has been supported by NASA Grant NGR 21-002-219 and will be reported on more fully in the Journal of Geophysical Research.

TABLE I: TIMES AND LOCATIONS OF POSSIBLE COMETARY MICROMETEORITE SHOWERS

Comet Name	β	R_o	Time	Hem.Cap Location	Remarks
1971 II	0.85	1.1	1971 23 Feb 1840	105°W, 2.5°S	$\pm$1 day
1970 II	0.6	2.1	1970 5 May 0340	90°E, 43°S	Observed.
1969 IX	1 (?)	---	1970 2 Jan 0240	--, --	?
1969 V	0.5	2.1	1969 15 Nov 1800	90°W, 16°N	Sharp
1968 IV	0.3	5	1968 13 May 0936	52°W, 60°S	Sharp
1967 VIII	0.7	1.2	1968 24 Feb 0100	180°E, 1.9°S	$\pm$ 1 day
1967 VII	1 (?)	6	1967 25 Oct 0800	120°E, 50°S	Sharp
1967 IV	0.45	$\geq$7	1967 14 Oct 0230	60°E, 54°N	Sharp
1967 II	1 (?)	?	1966 8 Dec	-- , --	---

Section 3:

A STUDY OF NOCTILUCENT CLOUDS IN POLAR REGIONS, LATITUDE DEPENDENCE OF THE HEIGHT AND BEHAVIOR OF THE SODIUM LAYER, AND THE LOCATION OF FIREBALL ENTRY DUST CLOUDS USING AN AIRBORNE PORTABLE LASER RADAR: SUMMARY OF PROPOSAL TO BE SUBMITTED

PROPOSAL

FOR A GRANT IN SUPPORT OF

A STUDY OF NOCTILUCENT CLOUDS IN POLAR REGIONS, LATITUDE DEPENDENCE OF THE HEIGHT AND BEHAVIOR OF THE SODIUM LAYER, AND THE LOCATION OF FIREBALL ENTRY DUST CLOUDS USING AN AIRBORNE LASER RADAR

submitted to

National Aeronautics and Space Administration

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UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
COLLEGE PARK, MARYLAND

September 1973

SUMMARY

It is proposed that a portable dye laser radar be flown on a long range aircraft to investigate three phenomena recently receiving attention in the literature. First, the height and thickness of noctilucent clouds which appear in the summer polar regions with surprising regularity and coverage can be determined along one or more latitude lines in the polar regions. Second, the height, profile, and areas of correlated accumulations of the sodium layer near 90 km can be determined as a function of latitude from equator to the pole. Third, the collection of fireball entry dust can be made more certain by the aircraft if the dust cloud is located by the laser radar. The first two measurements would yield valuable information on the dynamics and chemistry of the atmosphere in the 70 to 90 km region in the least and perhaps on the origin of both noctilucent cloud particles and sodium. The last investigation would allow collection of a sample of important interplanetary material. A budget of is requested over a two year period for this study starting 1 October 1973. The study would have to be supplemented by operational aircraft groups and fireball dust collection groups. The Principal Investigator would be Sherman K. Poultney.

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Section 4:

THE EFFECTS OF EXTRATERRESTRIAL DUST, STRATOSPHERIC WARMINGS, AND LOWER THERMOSPHERIC PRESSURE SYSTEMS ON OGO-4 MEASURED NIGHTGLOWS IN THE EARTH'S ATMOSPHERE (80 to 100 km): SUMMARY OF PH.D. DISSERTATION OF J. D. WALKER

ABSTRACT

Title of Thesis: The Effects of Extraterrestrial Dust, Stratospheric Warmings, and Lower Thermospheric Pressure Systems on OGO-4 Measured Nightglows in the Earth's Atmosphere (80-100 km)

Jearl D. Walker, Jr., Doctor of Philosophy, 1973

Thesis directed by: Sherman K. Poultney

Photometric measurements of four upper D and lower E region nightglows --- Na (5890 Å), OH (9-3 Band), O_2 (UV, Herzberg), and O (5577 Å) --- were made from August 1967 to January 1968 from the OGO-4 satellite. World-wide maps of the nightglow distribution and deviations from daily zonal averages are given here, and analysis of the variation in nightglow intensities is made. From this distribution, pressure systems operating in the nightglow altitudes are deduced, though the source of these systems is not determined. Horizontal winds at these altitudes are geostrophic in the extratroptical regions, non-geostrophic in the tropics. The sodium nightglow is greatest in the winter hemisphere but is extensive in the autumn tropics. Horizontal transport of free sodium and sodium-sublimating extraterrestrial dust is deduced. In the autumn tropics this transport results in a general anticorrelation of the sodium with the two oxygen nightglows. This anticorrelation is further enhanced by what can only be rapidly developing pressure changes, with vertical winds in excess of 10 cm/sec in some cases. The source of the tropical atmospheric free sodium so affected by vertical winds is found to be small, light dust particles (0.1μ in radius and 0.3 g/cc in density) which are produced near 100 km

by fragmenting extraterrestrial particles ~ 100μ in radius. We eliminate as possible sources of atmospheric sodium all extraterrestrial particles which are smaller than 10μ before entering the atmosphere. There is, however, no apparent visual or radio meteor shower enhancement of sodium nightglow in the OGO-4 data. Thus, the possible size range of the extraterrestrial particles responsible for the observed autumn nightglows is 10 to 100μ before entrance to the atmosphere. Finally, the O_2 and OH nightglows indicate that a major stratospheric warming of the 1967-68 winter is associated with out-of-phase mesospheric and in-phase lower-thermospheric temperature variations, hence indicating a direct coupling between the stratosphere and the lower thermosphere.

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Appendix I

LIST OF PUBLICATIONS AND TALKS SUPPORTED BY THIS GRANT

Appendix I: List of Publications and Talks Supported by This Grant

A Study of the Origin, Nature, and Behaviour of Particulate Matter in the Mesosphere and at the Mesopause, Semi-annual Report for NASA Grant NGR 21-002-219, University of Maryland, Department of Physics and Astronomy, Tech. Report No. 70-082, 1970.

Rapid Prediction of Cometary Source Dust Influx Times and Amounts for Newly-Observed Comets with N. Forster and E. Silverberg. Paper presented at Third Conference on Laser Studies of the Atmosphere, September, 1970.

A Study of the Origin, Nature, and Behavior of Particulate Matter in the Mesosphere and at the Mesopause, Contribution to the Report to COSPAR 1970, University of Maryland, Department of Physics and Astronomy, Tech. Report No. 71-052, November 1970.

Micrometeorite Showers Related to Comets Bennett and Encke, with E. Silverberg and N. Forster, Trans. Am. Geophys. Union 52, 261 (1971).

Laser Radar Studies of Upper Atmosphere Dust Layers and the Relation of Temporary Increases in Dust to Cometary Micrometeoroid Streams, in Space Research XII (A. Stickland, ed) pps 404 to 421, Akademie-Verlag, Berlin 1972. Also invited talk at COSPAR, Seattle, 1971.

The Capabilities of High-Repetition Rate Laser Radars for Measurement of Atmospheric Properties above 30km, J. Atmosph. Terr. Phys. 34, p. 339 (1972).

Times and Locations of Cometary Dust Influxes in the Earth's Atmosphere, Trans. Amer. Geophys. Union, 54 p. 353, (1973).

Time, Locations, and Significance of Cometary Micrometeoroid Influxes in the Earth's Atmosphere, contributed talk at Symposium on Noctilucent Clouds and Interplanetary Dust held in conjunction with COSPAR 1973 in Konstanz, West Germany, extended abstract to appear in "Space Research XIV", and paper in preparation for J. Geophys. Res., Fall 1973. Also University of Maryland, Department of Physics and Astronomy Technical Report 74-015, September 1973.

Meeting Report on the Symposium on Noctilucent Clouds and Interplanetary Dust (Held in May 1973 in conjunction with COSPAR at Konstanz, FRG), Applied Optics, to be published Fall 1973.

Appendix II: Meeting Report on May 1973 Symposium on Noctilucent Clouds and Interplanetary Dust.

For Applied Optics Meeting Report Section
S. K. Poultney, Dept. of Phys. & Astron., Univ. of Md., College Park, Md.

The Symposium on Noctilucent Clouds and Interplanetary Dust which met on the 24 and 25 of May 1973 gave new inputs into the perennial problems of the field; the nature and origin of interplanetary dust and the observable manifestations of this dust near the earth and in the atmosphere. The Symposium was convened on the island of Reichenau near Konstanz, West Germany where the sixteenth plenary meeting of COSPAR was being held. This island in the lower Bodensee is considered to be one of the birthplaces of western european civilization after the migration of nations, but is now given over to vegetable farming. The symposium program was planned by B. A. Linblad (Sweden) with the aid of E. Hesstvedt (Sweden). R. K. Soberman (USA), Ch. Willman (USSR), and was jointly sponsored by COSPAR and IAMAP/IUGG.

A relation between the topics of the symposium has never been proved although many people believe that interplanetary dust (IPD) entering the atmosphere acts as the nuclei of the noctilucent cloud (NLC) particles. The NLC as observed optically from the ground form sporadically near the mesopause (85 km) at high latitudes in the summer season. T. M. Donahue (USA) dealt at length with his satellite photometry data which indicates (surprisingly) extensive, bright NLC over the whole polar region in the summer season. The normally observed NLC are lower latitude fringes of these polar NLC. Some IPD source people consider the IPD to be of at least two populations; multi-micron-size cometary particles spiraling in toward the sun and sub-micron remnants being accelerated back out; both under the action of radiation pressure. M. Dubin (USA) invoked this second component to explain the blue haze on Mars and the blue clearings at opposition much

as he might have invoked it to provide nuclei for the polar NLC. Other workers doubt that enough (or any) nuclei are supplied in this manner. G. Witt (Sweden) reported new work on the formation of NLC and their relation to the presence of water vapor and to the sodium airglow based upon the simultaneous in situ optical measurements of both NLC and sodium airglow later explained by G. Witt, T. J. Stegman, and H. C. Wood (Sweden). F. Rossler (France) described in situ optical measurements of NLC and gave evidence for a permanent dust remnant which could serve as condensation nuclei. There are, of course, other sources of extraterrestrial material to the atmosphere in addition to IPD. Hughes (UK) gave estimates of the increased influx of dust during major meteor showers (assuming the larger meteoroids fragment into dust), Link (France) reported on additional optical measurements of such correlations, and Poultney (USA) pointed out possible occurrences and the significance of influxes of dust direct from new comets. All of these latter dust sources are probably minor contributors compared to IPD and "sporadic" meteors.

The space density of micrometeoroids measured in near-earth space by all but penetration or cratering detectors has always shown a discrepancy (either real or instrumental) on the high side compared with interplanetary (and even lunar) space. Plasma impact measurements of micrometeoroids by H. J. Hoffman, H. Fechtig, E. Grun, and J. Kissel (FRG) from the Heos 2 satellite may resolve this discrepancy if the observed micrometeoroid swarms can be interpreted as lower velocity fragments of meteors passing obliquely through the upper atmosphere. The only report of a rocket collection of dust in the upper atmosphere (at the node of comet Giacobini-Zinner) was unfortunately not presented due to the absence of the authors. Convincing optical observations from a satellite of the counterglow from particles at the earth-moon libration points were modestly reported by J. R. Roach (USA)

at a light level an order of magnitude below previous reports by others. The particles are in unstable orbits about the libration point and must be continually replenished from some source.

A wide variety of measurements on the lunar surface (e.g. rock erosion, crater formation, the passive seismometer) place serious constraints on the flux of interplanetary particles to the moon. A whole session was devoted to the examination of microcraters on lunar samples (especially glass-surfaces) for use as micrometeoroid detectors. Laboratory impact studies of hyper-velocity projectiles are needed for the size interpretation. Horz et. al. presented data indicating that particles with diameters from 0.1 to 100 μm were silicates of density about 3 without any fluffy structure, had a distinct possibility of a two population distribution, and had a flux which was consistent with other lunar surface studies and which was roughly constant for the last billion years. J. Hartung and D. Storzer (FRG) gave additional evidence for the bimodal size distribution (minimum near 5 μm) and also for a present-day flux (which agrees with satellite penetration experiments) ten times the average over the past 10^5 years. E. Schneider (FRG) et. al. reinforced the concept of large numbers of small micrometeroids, ruled out lunar secondary ejecta as the cause, and allowed that the present flux measured by satellite was higher than the long term averages. The many uncertain elements in microcrater studies were discussed by a number of other authors. Finally, in a paper presented later at COSPAR, G. Latham (USA) concluded from his lunar seismometer signals that the influx of large meteoroids to the moon may be between one and three orders of magnitude lower than previous estimates from earth-based measurements and closer to that inferred from new crater formation.

The sessions on observations of interplanetary dust from deep-space vehicles were eagerly awaited because of the new results from Pioneer 10 which passed through the asteroid belt. S. Neste and R. K. Soberman (USA) measured the spatial concentration and orbits of the small meteoroid and asteroid environment (i.e. mean particle size of 200 μm by optical means. Between 1.0 and 3.2 a.u., 200 events were detected with their concentration rising to a peak at 1.2 a.u., dropping to a minimum near Mars, and then, somewhat surprisingly, fluctuating in coincidence with the Kirkwood gaps in the asteroid belt. Absolute concentration, size distributions and orbit determinations are still preliminary. W. H. Kinard, et. al. (USA) gad a meteoroid penetration experiment on board sensitive to 10^{-9} gm (20 μm diameter for density 3) particles and larger. They reported a near constant particle spatial density (about $10^{-9}/m^3$) out to and through the asteroid belt based upon about 40 events. The source of the particles could then probably be cometary out beyond the asteroid belt. The author has calculated that short-period comets preferentially inject micrometeoroids into orbits near their aphelia beyond the belt. A summary of old Mariner IV microphone data by W. M. Alexander and J. L. Bohn (USA) indicated a small increase in particle flux, low inclination orbits, and little dependence on solar longitude between Earth and Mars. Continued analysis of Pioneer 8 and 9 micrometeroid detectors by J. A. M. McDonnell (UK), O. Berg (USA), F. Richardson (USA) supports a purely random occurrence of event times (300 events in several years) with the flux continuing to increase down to 10^{-13} gm sizes. The smaller particles appear to come from the direction of the sun. O. Berg and H. Zook (USA) theoretically pursued the source of the smaller particles to release from unseen comets inside 0.2 a.u. and subsequent ejection by radiation pressure.

An additional source of information about the size and distribution of the small particles (about 1 μm) of IPD is data on the zodiacal light and the gegenschein. The imaging Photopolarimeter on Pioneer 10 is being used to map the inner zodiacal light in two colors and both polarizations by M. S. Hanner and J. L. Weinberg (USA). Its absolute brightness at a given elongation in the ecliptic plane fits an inverse square distribution between the earth and asteroid belt in agreement with gegenschien observations. In and beyond the asteroid belt, the brightness decreases much more slowly. Pending further details on particle distribution in size and spatial concentration, one could tentatively conclude that there are two IPD sources; one inside 1 a.u. and one outside 3 a.u. Basic color models of the zodiacal light calculated by R. Giese, C. Leinert, and M. Hanner to support optical observations favor slightly-absorbing, micron-size particles in the zodiacal dust cloud. In the past, many workers were forced to invoke sub-micron particles to explain polarization observations. S. Hayakawa et. al. (Japan) reported zodiacal light measurements out to 2.2 μm and concluded that reflections from particles with sizes of several microns were responsible.

The reports of new measurements on NLC and IPD sent many attendees back home to puzzle over them in relation to what had been previously known or thought. One especially awaits size and flux results from the Pioneer IPD experiments. Interested readers can immediately obtain copies of the abstract program from either B. A. Linblad (Sweden) or their national COSPAR representative. Copies of individual papers are available from the respective author or the national representative. This year the authors were urged to publish in an appropriate journal rather than in Space Research for prompt communication to other workers. A summary of extended abstracts will be collected by W. M. Alexander (USA) and E. Grun (FRG) and published there, however.

NASA Grant NGR 21-002-219 supported the writing of this report.

Figure Caption

M. Dubin (USA), Chief, Cosmic Dust and Cometary Physics, OSS, NASA Headquarters. Supporter of many of the IPD and NLC experiments.
(in dark glasses)

B. Y. Levin (USSR), well-known theorist in astronomical, astrophysical, and cosmogonic problems.