SUMMARY OF RESEARCH

NASA Office of Space Science
Planetary Geology and Geophysics Program

Dynamics of Solar System Dust

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Grant Award NAG5-4531
March 1, 1999 – February 28, 2002

Division of Sponsored Research
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May 24, 2002

This is a final report for research supported by the National Aeronautics and Space Administration under grant number NAG5-4531, issued through the Office of Space Science Planetary Geology and Geophysics Program, covering all relevant activities during its period of funding from 03/01/1999 through to 02/28/2002. The ongoing aim of the research supported through this grant, and now through a successor award (NAG5-11643), is to investigate the dynamical and physical evolution of interplanetary dust particles in order to produce a detailed global model of the zodiacal cloud and its constituent components that is capable of predicting thermal fluxes in mid-infrared wave bands to an accuracy of 1% or better; with the additional aim of exploiting this research as a basis for predicting structure in exozodiacal clouds that may be signatures of unseen planets.

Research Achievements and Future Directions

One of several significant accomplishments during the tenure of this award has been the development of the first detailed dynamical model of the "ten-degree" solar system dust band (Grogan et al., 2001a), which incorporates a size-frequency power-law distribution of asteroidal dust particles with diameters of up to $100\,\mu$m. This model has demonstrated that in order to provide a good match to both the amplitude and shape of the IRAS (Infrared Astronomical Satellite) dust band profiles in multiple wave bands, a size-frequency power-law index $q \simeq 1.4$, must be adopted. This low value for q ($< 5/3$) indicates that large particles, with diameters $\sim 10^2\,\mu$m, dominate the total surface area distribution of the dust particles. A result that is consistent with the cratering record on the LDEF (Long Duration Exposure Facility) satellite, which shows a peak in the surface area distribution at 1 AU for particles with diameters $\sim 140\,\mu$m (Love and Brownlee, 1993), and other evidence (see the review by Grün et al., 1985). However, this peak particle diameter will probably be even larger in the main asteroid belt, the source region of the dust band particles that is located between approximately 2 and 4 AU, as we expect that the particles at 1 AU will be collisionally evolved. This conclusion is easily reached by considering that, in the inner solar system, the timescale for a dust particle to be destroyed by inter-particle collisions is comparable to the time taken for the orbit of a particle to decay into the Sun (the Poynting-Robertson, or P-R, drag timescale) for particles with diameters of $\sim 500\,\mu$m (Wyatt et al., 1999a). Many of the large asteroidal dust particles, with diameters $\sim 10^2\,\mu$m, will therefore be broken up by collisions before they reach 1 AU, while only the smaller particles will arrive intact.

It is worth noting here that while a better understanding of the origins and structure of the solar system dust bands is intrinsically valuable in this context, its merit also lies in the fact that the dust bands represent the "tip of the iceberg" of the total asteroidal contribution to the zodiacal cloud and are therefore also a key element in determining the cloud's global structure. The results discussed above therefore provide the motivation for a fundamental goal of the research sponsored by this award, which is to study the dynamical behavior of large asteroidal dust particles. However, the P-R drag timescale for a $100\,\mu$m diameter dust particle initially located at ~ 3 AU is of the order of a million years, approximately an order of magnitude longer than for a similar $10\,\mu$m diameter particle (Wyatt and Whipple, 1950), and for this reason, any comprehensive numerical investigation of the orbital evolution of larger particles is computationally prohibitive using traditional techniques. To achieve this stated goal has therefore required the adoption of novel numerical techniques (Kehoe et al., 2002c) that, when allied with moderate computing resources, have allowed the necessary numerical simulations to be performed, within a reasonable time frame. To date, we have now investigated the orbital evolution of particles up to 500 μm in diameter originating from the Eos asteroid family and, in so doing, have gained valuable insights into the qualitatively different dynamical behavior exhibited by these large particles, as compared to the smaller particles ($< 100\,\mu$m diameter) that we were limited to investigating previously. These differences in orbital evolution are discussed in detail by Dermott et al. (2001; 2002) and Kehoe et al. (2002a; 2002b), and will be incorporated into future models of the zodiacal cloud that will employ realistic size-frequency distributions of particles. Extending this investigation to consider particles from other family and non-family asteroids, as well as cometary particles, is an ongoing and essential component of this research, which is now supported by a successor award. Another important aspect of this new award is to implement an algorithm that allows the effects of collisional fragmentation to be modeled, and hence to investigate the orbital evolution of dust particles with diameters larger than the collisional threshold value of 500 μm.

Data returned by the IRAS and COBE (Cosmic Microwave Background Explorer) missions have revealed several interesting large-scale features of the zodiacal cloud that require a dynamical explanation: namely the offset of the center of symmetry of the cloud from the Sun (Kelsall et al., 1998; Dermott et al., 1999a), and the tilt and warping of the plane of symmetry of the cloud with respect to the ecliptic (Dermott et al., 2001). Modeling supported through a predecessor award has shown that the central offset of the zodiacal cloud from the Sun results from the forced eccentricity imposed on the dust particles that constitute the cloud due to the effects of secular gravitational perturbations by the planets (Dermott et al., 1998; Holmes et al., 1998). Reasons for the tilt and warping of the symmetry plane of the cloud are discussed in detail in the review chapter by Dermott et al. (2001).

An important development supported through this award has been the application of techniques developed to model the structure of the zodiacal cloud, to explain large-scale structures that have been observed in certain zodiacal cloud analogues suspected of harboring planetary systems in debris disks around other stars. A particular example of the success of this approach has been the modeling undertaken of the disk around HR4796A, images of which have shown an asymmetric double-lobed feature, with one lobe brighter than the other (Telesco et al., 2000). This brightness asymmetry can be explained as the result of the gravitational influence of a planet in an eccentric orbit imposing a forced eccentricity on the dust particles in the disk, and hence shifting the center of the disk away from the star in the direction of forced pericenter, causing one lobe to glow brighter than the other (Wyatt et al., 1999a).

The results discussed above are just some of the highlights of the important research carried out through the support of this grant, research that is now continuing with the support of a successor award. A full discussion of the results obtained through this research has now recently been published in two substantial review articles (Dermott et al., 2001; 2002).

Publications and Presentations Relevant to this Award

In summary, as a result of support through this proposal, we have published a total of 3 chapters in books, 3 articles in refereed journals, and 12 papers in conference proceedings, many of which were also refereed. We have also presented papers and communicated our research at several prestigious international and domestic scientific meetings, workshops, and review panels.

Book Chapters

Dermott S. F., Grogan K., Durda D. D., Jayaraman S., Kehoe T. J. J., Kortenkamp S. J., and Wyatt M. C. (2001) Orbital evolution of interplanetary dust. In *Interplanetary Dust* (E. Grün, B. Å. S. Gustafson, S. F. Dermott, and H. Fechtig, eds.), pp. 569–639. Springer-Verlag, Berlin.

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Journal Articles

Grogan K., Dermott S. F., and Durda D. D. (2001a) The size-frequency distribution of the zodiacal cloud: evidence from the solar system dust bands. *Icarus*, 152, 251–267.

Telesco C. M., Fisher R. S., Piña R. K., Knacke R. F., Dermott S. F., Wyatt M. C., Grogan K., Holmes E. K., Ghez A. M., Prato L., Hartmann L. W., and Jayawardhana, R. (2000) Deep 10 and 18 micron imaging of the HR 4796A circumstellar disk: transient dust particles and tentative evidence for a brightness asymmetry. *Astrophys. J.*, 530, 329–341.

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Conference Papers

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Grogan K. and Dermott S. F. (1999) Observing the solar system dust bands with SIRTF. In *Astrophysics with Infrared Surveys: A Prelude to SIRTF*, ASP Conf. Series 177 (M. D. Bicay, C. A. Beichman, R. M. Cutri, and B. F. Madore, eds.), pp. 385–388. Astron. Soc. Pacific Press, San Francisco.

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