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Final Technical Report

NASA-GRANT NAGW-89

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(NASA-CR-180593) THE SIZE DISTRIBUTION OF
INSTELLAR GRAINS Final Technical Report
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I. Objectives

This program of astrophysical investigations was designed to explore the role, in interstellar space, of particles in the size range between that of the classical interstellar grains (size $\sim 10^{-5}$ cm) and that of macromolecules (10^{-7} cm). Such particles, when illuminated by the UV radiation from a close-by star, reveal their presence by scattering with a near-isotropic phase function or by becoming subject to single-photon heating/excitation processes. The latter lead to the emission of characteristic spectral features as well as of a continuum in the red and near-IR wavelength range. The relative abundance of such small particles in the size distribution of interstellar grains also has a pronounced effect on the wavelength dependence of interstellar extinction in the UV. This program, therefore, consisted of investigations in three major areas involving interstellar grains:

1. Studies of scattering in reflection nebulae with the goal of deriving scattering characteristics of dust grains such as the albedo and the phase function asymmetry throughout the visible and the UV.
2. Studies of the wavelength dependence of interstellar extinction designed to demonstrate the wide range of grain size distributions naturally occurring in individual clouds in different parts of our Galaxy.
3. Studies of the UV-powered emission of dust grains in the $0.5\mu-1.0\mu$ wavelength range in reflection nebulae.

II. Results

The results of these investigations are contained in the publications listed in Section III. These publications consist of refereed papers in the open scientific literature and of papers presented at national or international meetings. Further dissemination of the results took place through a series of colloquia presented by the Principal Investigator.

Here we will highlight findings considered of major importance and will indicate in parentheses the publication numbers relevant in the context.

1. Demonstrations of Significant Phase Function Variations in the UV (2,3,5,9,11,14,18,19,21,26)

We have accumulated strong observational evidence showing that in a number of reflection nebulae the scattering phase function in the UV is measurably more isotropic than is observed at visual wavelength in the same objects. We have interpreted this result as indicating that particles of size $\sim 10^{-6}$ cm and smaller play a much more important role than indicated by accepted models for interstellar dust. Our conclusions have received dramatic

support through IRAS discoveries of the widespread occurrence of dust emission from grains with temperatures in the 10^2 - 10^3 K range. This can be understood if one accepts non-equilibrium heating processes occurring in a vast population of grains in the 10^{-7} size range.

2. Variation of Interstellar Extinction in the Galaxy
(1,8,14,20,23,24)

Through our UV observations of early-type stars embedded in reflection nebulae we vastly increased the data base of observations of UV extinction produced by single clouds. We demonstrated that the wavelength dependence of UV extinction in interstellar space varies widely from cloud to cloud in our Galaxy, and what is often promoted as "anomalous" extinction is simply a more extreme example out of this naturally occurring range. The implication is that dust size distributions vary from cloud to cloud and, therefore, that processing of interstellar dust and its size distribution inside clouds is an important phenomenon.

3. Demonstration that the diffuse Interstellar Band of 4430A is not Caused by Small Interstellar Grains (4,22)

For about 10 years it had been thought, mainly based on a process of exclusion of other likely possibilities, that the unidentified diffuse interstellar band at $\lambda 4430\text{\AA}$ (as well as others of its type) was caused by very small interstellar grains. We were the first to show that the relative strength of the 4430A band is unrelated to the presence or absence of small grains in the size distribution of grains along the line-of-sight. This result, unfortunately, still leaves the 4430A band unidentified.

4. Discovery of Scattering in the 2175^oA Interstellar Feature
(12,22)

In two reflection nebulae, IC 435 and CED 201, we discovered significant increases in the dust albedo in the long-wavelength wing of the interstellar 2175^oA extinction feature, indicating enhanced scattering associated with that feature. The central wavelength of the 2175^oA band observed in the spectra of the two illuminating stars involved was well within the narrow range normally observed. These results have been interpreted to indicate that graphite is not a likely material responsible for the 2175A feature, as proposed by most currently fashionable models.

5. Discovery of UV-Excited Grain Emission in the 0.5 -1.0 μ Spectral Region in Reflection Nebulae (7,10,13,15,16,17,25,27,28,29)

First through photometric studies, then through spectroscopy, we discovered that there is extended red emission present in reflection nebulae in the 0.5 μ -1.0 μ spectral region. The principal source of this emission is fluorescence by hydrogenated

amorphous carbon. We identified this substance on the basis of the characteristics of the broad emission band peaking near 0.67 (FWHM \sim 0.12 μ), observable in about 2/3 of all bright reflection nebulae. The source of excitation of this luminescence process is the short-wavelength radiation from the illuminating stars of the nebulae. These results show that amorphous carbon appears to be a very common substance in interstellar grains. This, with the result listed in §4, raises even greater doubts about the role of graphite in interstellar space, so favored in many theoretical model studies.

III. Publications

Completed with partial support from NASA grant NAGW-89

1. "The ULtraviolet Interstellar Extinction Curve in the Pleiades," by A. N. Witt, R. C. Bohlin, and T. P. Stecher, Astroph. J., 244, 199, 1981.
2. "High Resolution Photographs in the Rocket Ultraviolet of the Orion Nebula," by R. C. Bohlin, J. K. Hill, T. P. Stecher, and A. N. Witt, Astroph. J., 255, 87, 1982.
3. "The Scattering Phase Function of Interstellar Grains: the Case of the Reflection Nebulae NGC 7023," by A. N. Witt, G. A. H. Walker, R. C. Bohlin, and T. P. Stecher, Astroph. J., 261, 492, 1982.
4. "The Diffuse Interstellar Feature at 4430 A and Interstellar Extinction in the Far UV," A. N. Witt, R. C. Bohlin and T. P. Stecher, Astroph. J. Letters, 267 L47, 1983.
5. "The Surface Brightness of Reflection Nebulae: NGC 1432 and the 17 Tau Nebulosity," M. J. Cottrell and A. N. Witt, Astron. J., 88, 418, 1983.
6. "On the Contributions of the Orion Reflection Nebulosity to the Continuous UV Spectrum of the Herbig-Haro Objects HH 1 and HH 2 and of the C-S Star," R. Mundt and A. N. Witt, Ap. J. Lett., 270, L59, 1983.
7. "Photometric Study of NGC 2023 in the 3500 A to 10,000 A Region: Confirmation of a Near-IR Emission Process in Reflection Nebulae," A. N. Witt, R. E. Schild, and J. B. Kraiman, Ap. J., 281, 708, 1984.
8. "The Variation of Galactic Interstellar Extinction in the Ultraviolet," A. N. Witt, R. C. Bohlin and T. P. Stecher, Ap. J., 279, 698, 1984.
9. "Colors of Reflection Nebulae I. Phase Function Effects in the Merope Nebula," A. N. Witt, Astroph. J., 294, 216, 1985.
10. "Colors of Reflection Nebulae II. The Excitation of Extended Red Emission," A. N. Witt and R. E. Schild, Astroph. J., 294, 225, 1985.
11. "Colors of Reflection Nebulae III. UV Scattering by Small Particles in the Reflection Nebulae Associated with 17, 20 and 23 Tau," A. N. Witt, R. C. Bohlin, and T. P. Stecher, Astroph. J., 302, 421, 1986.
12. "Detection of Scattering in the 2175 A Interstellar Band," A. N. Witt, R. C. Bohlin, and T. P. Stecher, Astroph. J. Letters, 305, L23, 1986.

13. "CCD Surface Photometry of Bright Reflection Nebulae", A. N. Witt and R. E. Schild, Astroph. J. Suppl., 62, 839, 1986.

B. Papers Submitted or to be Submitted for Publication

14. "The Unusual Dust Scattering Properties in the Reflection Nebula CED 201," A. N. Witt, R. C. Bohlin, T. P. Stecher and S. H. Graff, Astroph. J. (Oct '87) in press.
15. "Hydrogenated Amorphous carbon Grains in Reflection Nebulae," A. N. Witt, and R. E. Schild, Astroph. J., (to be submitted) 1987.
16. "Near-IR Scattering Properties of Interstellar Grains and the Density Profiles of Globules," A. N. Witt, M. Oliveri and R. E. Schild (in preparation 1987).
17. "Near-IR Spectra of Reflection Nebulae: Luminescence from Hydrogenated Amorphous Carbon," A. N. Witt and T. A. Boroson (in preparation 1987).

C. Papers Presented at Meetings

18. "Long-Slit Spectroscopy of the Orion Nebula," (with R. C. Bohlin, J. K. Hill, and T. P. Stecher), B.A.A.S. 11, 622, 1979.
19. "Dust Properties in the Reflection Nebula NGC 7023", (with M. J. Cottrell), B.A.A.S., 11, 644, 1979.
20. "Evidence for a Second Class of Interstellar Extinction Curves in the Ultraviolet", A. N. Witt, R. C. Bohlin, T. P. Stecher, B.A.A.S., 12, 446, 1980.
21. "Scattering Properties of Interstellar Grains," Invited Lecture, Workshop on Far-UV Background Radiation, Tenth Texas Symposium on Relativistic Astrophysics, Baltimore, Maryland, Dec. 1980.
22. "The 4430 Diffuse Interstellar Feature and Far-UV Extinction Characteristics," A. N. Witt, R. C. Bohlin and T. P. Stecher, B.A.A.S., 14, 894, 1982.
23. "Variation of Galactic Interstellar Extinction in the UV," A. N. Witt, R. C. Bohlin, T. P. Stecher, B.A.A.S., 15, 989, 1983.
24. "Variation of Galactic Interstellar Extinction in the UV," A. N. Witt, R. C. Bohlin, T. P. Stecher. Symposium "Future of UV Astronomy Based on Six Years of IUE Research," April 3-5, 1984, Goddard Space Flight Center.

25. "BVRI Colors of Reflection Nebulae and the Near-IR Excess," A. N. Witt and R. E. Schild, B.A.A.S., 16, 466, 1984.
26. "UV Colors of Reflection Nebulae and the Scattering Phase Function of Interstellar Grains," A. N. Witt, B.A.A.S., 17, 571, 1985.
27. "Spectroscopy and CCD Photography of Extended Red Emission in Reflection Nebulae," A. N. Witt and R. E. Schild. Summer School on Interstellar Processes, Jackson Hole, WY, 1986, NASA TM 88342, p. 119.
28. "Hydrogenated Amorphous Carbon Grains in Reflection Nebulae," A. N. Witt and R. E. Schild, B.A.A.S., 18, 1030, 1986.
29. "Emission from Interstellar Hydrogenated Amorphous Carbon Grains," A. N. Witt, T. A. Boroson, and R. E. Schild, 2nd Haystack Meeting on Interstellar Matter, MIT, 1987.

D. Invited Colloquia

- 1981: E. O. Hulbert Center for Space Research, NRL, Washington, DC.
- 1981: Gettysburg College, Gettysburg, Pennsylvania.
- 1982: Max Planck Institut fur Radio-Astronomie, Bonn, W. Germany.
- 1982: Max Planck Institut fur Astronomy, Heidelberg, W. Germany.
- 1982: Ruhr Universitat, Bochum, W. Germany
- 1982: Astron. Institute, University of Heidelberg, W. Germany
- 1982: Universitat Tubingen, Tubingen, W. Germany.
- 1983: The University of Toledo, Dept. of Physics & Astronomy.
- 1984: The University of Michigan, Dept. of Astronomy, Ann Arbor, MI
- 1985: The University of Rochester, Rochester, NY, Dept. of Physics and Astronomy.
- 1985: Center for Astrophysics, Harvard College Obs., Cambridge, MA.
- 1985: Ohio State University, Columbus, OH.
- 1986: Center for Astrophysics, Harvard College Obs., Cambridge, MA.
- 1986: Astron. Inst., University of Bonn and Max-Planck-Institut fur Radio Astronomie, Bonn, Fed. Rep. of Germany.

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Final Report of Patent/Inventions

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No patents or inventions emerged from
the research performed under this grant.

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Final Property Inventory

Adolf N. Witt, P.I.
The University of Toledo

No equipment over \$1,000 value was acquired
nor was any GFP received.