THE JOHNS HOPKINS UNIVERSITY

DEPARTMENT OF PHYSICS

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Final Report

ROCKET AND LABORATORY STUDIES IN AERONOMY AND ASTRONOMY

by

Paul D. Feldman

NASA Grant NGR 21-001-001

Baltimore, Maryland 21218

December 15, 1983

FINAL REPORT

NASA Grant NGR 21-001-001

November 1, 1968-February 28, 1983

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December 15, 1983

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FINAL REPORT

This is the final report for NASA Grant NGR 21-001-001 and covers the period from November 1, 1968 to February 28, 1983. William G. Fastie was Principal Investigator until September 1981, when Paul D. Feldman took over that responsibility. This grant was a continuation of a program in rocket and laboratory studies of ultraviolet astronomy and aeronomy which was supported by NASA grant NsG 193-62 from August 1, 1961 to September 30, 1968, with G. H. Dieke as P. I. until his death in the summer of 1965 when William G. Fastie assumed principal investigator responsibilities. As of March 1, 1983, this program is continuing under grant NAG5-619.

During the period of the grant, semi-annual status reports have been submitted detailing the scientific achievements and current objectives of each six-month period. These will not be repeated here; instead a compilation of data extracted from these reports is attached in the form of several appendices. These include a list of all sounding rocket launches performed under NASA sponsorship (Appendix A), a list of Ph.D. and M.A. degrees awarded to students who worked in these programs (Appendix B), and a summary bibliography of all publications through 1983 (Appendix C).

The rocket program also spawned a number of related NASA programs at Johns Hopkins University including the Apollo 17 Ultraviolet Spectrometer Experiment (W. G. Fastie, P.I.) and observing programs using the _Copernicus_ and _IUE_ satellite observatories. The most recent project to develop from the sounding rocket program is the Hopkins Ultraviolet Telescope (A. F. Davidsen, P. I.) which is part of the ASTRO astronomy payload to be flown on Space Shuttle in 1986. A list of the publications from the IUE program, which has had a significant impact on planetary astronomy, is included in Appendix D. A summary of instrument development supported by the Johns Hopkins sounding rocket program was prepared by W. G. Fastie in 1979 and is reproduced in Appendix E. Appendix F is a list of faculty and post-doctoral research associates whose work was supported by this grant.

A separate financial statement is being forwarded by the Office of Accounting Services of The Johns Hopkins University.

APPENDIX A

SUMMARY OF ROCKET LAUNCHES

SUMMARY OF ROCKET LAUNCHES

LAUNCH NUMBER	DATE	TARGET	ROCKET	COMMENTS	RANGE
X.XX	27 February 1961	Aurora	Aerobee	(AFCRL Support)	Ft. Churchill
4.71	27 June 1962	Nightglow	Aerobee	Twin Experiments	Wallops Island
4.72	27 June 1962	Dayglow	Aerobee	Twin Experiments	Wallops Island
4.XX	13 December 1962	Dayglow	Aerobee	Failed	Wallops Island
4.XX	27 January 1963	Dayglow	Aerobee	Failed	Wallops Island
4.98	7 May 1963	Dayglow	Aerobee		Wallops Island
4.75	20 July 1963	Eclipse	Aerobee		Ft. Churchill
4.76	12 November 1963	Dayglow	Aerobee		Wallops Island
4.124	26 February 1964	Aurora	Aerobee		Ft. Churchill
8.34	5 November 1964	Dayglow	Javelin		Wallops Island
4.125	17 December 1964	Nightglow	Aerobee		White Sands
4.129	18 February 1965	Aurora	Aerobee		Ft. Churchill
4.164	21 October 1965	Comet Ikeya-Seki	Aerobee		Wallops Island
4.162	19 February 1966	Aurora	Aerobee		Ft. Churchill
4.165	21 April 1966	Venus	Aerobee		White Sands
4.163	16 February 1967	Aurora	Aerobee		Ft. Churchill
4.197	5 December 1967	Venus	Aerobee		White Sands
4.217	8 February 1968	Aurora	Aerobee		Ft. Churchill
18.31	31 July 1968	Dayglow	Nike-Tomahawk		Wallops Island
4.206	10 January 1969	Venus	Aerobee		White Sands
4.308	7 February 1969	Venus	Aerobee		White Sands
4.188	11 February 1969	Aurora	Aerobee		Ft. Churchill
4.309	25 March 1970	Aurora	Aerobee		Ft. Churchill
4.318UA	25 January 1971	Venus	Aerobee		White Sands
13.046UA	25 January 1971	Dayglow	Aerobee 170		White Sands

SUMMARY OF ROCKET LAUNCHES (Continued)

LAUNCH NUMBER	DATE	TARGET	ROCKET	COMMENTS	RANGE
4.311UA	2 June 1971	Jupiter	Aerobee		White Sands
17.11UA	10 June 1971	Dayglow	Aerobee 350	Apollo Preprototype	Wallops Island
4.320UA	17 March 1972	Aurora	Aerobee		Ft. Churchill
13.047UP	31 August 1972	Jupiter	Aerobee 170		White Sands
13.096UA	11 December 1972	Solar Spectrum	Apollo 17		White Sands
26.006UP	24 October 1973	Saturn	Aerobee 200		White Sands
26.023UG/UP	4 January 1974	Comet Kohoutek	Aerobee 200		White Sands
S16B	5 March 1975	Aurora	Nike-Apache	Piggyback	ESRANGE, Sweden
4.334UA	10 March 1975	Aurora	Aerobee		Ft. Churchill
26.039UG	15 March 1975	Saturn	Aerobee 200		White Sands
26.050UC	4 March 1976	Comet West	Aerobee 200		White Sands
13.077UA	26 March 1976	Aurora	Aerobee 170	Pointed	Ft. Churchill
NB24.276	1 January 1977	UV Background	Aries A-8	Piggyback (NRL Launch)	White Sands
13.124UG	17 February 1977	Hot Stars	Aerobee 170		WOOMERA, Australia
26.051UG	21 February 1977	α Centaurus A & B	Aerobee 200		WOOMERA, Australia
21.054UG	16 April 1977	3C273	Black Brant VC	FOT I Telescope	White Sands
25.029GA	9 January 1978	Airglow	Astrobee-F	Piggyback	White Sands
21.056 UG	10 January 1978	NGC 4151	Black Brant	FOT II Telescope	White Sands
33.002GA	29 March 1978	Aurora	Taurus-Orion	Piggyback	Ft. Churchill
31.006UE (S27)	13 April 1978	Twilit Aurora	Nike-Orion	Piggyback	ESRANGE, Sweden
25.038UL	1 December 1978	Jupiter	Astrobee-F		White Sands
21.059UG	29 June 1979	Hz Herculis	Black Brant	FOT III Telescope	White Sands

SUMMARY OF ROCKET LAUNCHES (Continued)

LAUNCH NUMBER	DATE		TARGET	ROCKET	COMMENTS	RANGE
S27B	21 August	1979	Twilit Aurora	Nike-Orion	Piggyback	ESRANGE, Sweden
25.039UA	24 September	1979	Airglow, Zodiacal Light, Sirius-B	Astrobee-F		White Sands
27.043AS	16 February	1980	Solar Eclipse	Black Brant	Piggyback	San Marco Platform, Kenya
25.046CE	30 June	1980	Airglow	Astrobee-F	Piggyback	White Sands
24.010UG	27 April	1981	3C273 Background Radiation	Aries	Aries Telescope, 1/4 m Ebert Spectrometer	White Sands
21.067UG	26 May	1981	Io Torus	Black Brant	FOT IV Telescope	White Sands
29.017CE	7 December	1981	Magnetospheric Cleft	Terrier-Malamute	Piggyback Project CENTAUR	Cape Parry, N. W. T.
21.074UG	17 December	1982	Stellar Calibration	Black Brant	Jupiter Telescope	White Sands
4.340 UG	22 August	1983	Day Airglow	Aerobee	HUT Spectrograph/ Detector and 1/8 m Spectrometer	White Sands

APPENDIX B

GRADUATE DEGREES AWARDED

THE JOHNS HOPKINS UNIVERSITY

DEPARTMENT OF PHYSICS

HOMEWOOD CAMPUS

BALTIMORE, MARYLAND 21218

STUDENTS TRAINED IN GRADUATE SPACE SCIENCE PROGRAMS

1969-1982

RODNEY C. ANDERSON
Ph.D. 1979
Dissertation: "Interstellar Matter and Extragalactic Light"
Present Address: Hughes Aircraft Co., Culver City, CA

EDWARD J. BEITING, III
Ph.D. 1978
Dissertation: "Laboratory and Auroral Studies of Molecular Nitrogen"
Last Known Address: Physics Dept., Mississippi State University, Mississippi State, MS

WILLIAM H. BRUNE
Ph.D. 1978
Dissertation: "Ultraviolet Observations of Hot Stars and Diffuse Nighttime Line Emissions"
Present Address: Eng. Sci. Lab., Harvard University, Cambridge, MA

JAY L. BUCKLEY
Ph.D. 1970
Dissertation: "Observation and Interpretation of Far Ultraviolet Emissions in the Late Evening Twilight"
Present Address: General Electric Company, Space Division, Valley Forge Space Ctr., Philadelphia, PA

JOHN T. CLARKE
Ph.D. 1980
Dissertation: "Far Ultraviolet Spectral and Spatial Imaging of Jupiter and Saturn"
Present Address: Space Astrophysics Group, Space Sciences Laboratory, University of California, Berkeley, CA

PATRICIA DAVEY
MA 1979
Master's Essay: "The Production of CO in Comet West (1979 VI)"
Present Address: Computer Science Corporation, Silver Spring, MD

ROBERT J. DAVIDSON	MA 1979	
	Master's Essay:	"Measurement of the X-ray Flux of Sco X-1"
	Present Address:	Hewlett-Packard, Boise, Idaho
THOMAS G. FINN	Ph.D. 1973	
	Dissertation:	"Electron Impact Excitation of Nitrogen: Absolute Cross Sections for the Lyman-Birge-Hopfield System and Elastic Scattering; and a High Energy-Resolution Investigation of the Second Positive System"
	Present Address:	Naval Research Laboratory, Washington, DC
JOHN W. GILES, JR.	Ph.D. 1974	
	Dissertation:	"The Far Ultraviolet Spectrum of Jupiter"
	Present Address:	The Johns Hopkins University Applied Physics Laboratory Laurel, MD
GEORGE F. HARTIG, JR.	Ph.D. 1978	
	Dissertation:	"The Faint Object Telescope: A First Look at the Far Ultraviolet Spectra of Extragalactic Sources"
	Present Address:	AURA, C.T.I.O., Chile
ROBERT D. KOEHLER	MA 1981	
	Master's Essay:	"Excited Oxygen Ions in the Thermosphere"
	Present Address:	Computer Science Corporation, Silver Spring, MD
ROBERT L. LUCKE	Ph.D. 1975	
	Dissertation:	"The far Ultraviolet Albedo of the Moon"
	Present Address:	Naval Research Laboratory, Washington, DC
DAVID MANDELBAUM	Ph.D. 1974	
	Dissertation:	"Infrared Emission Spectra of N_2^+ by Electron Impact Excitation"
	Present Address:	Departamento de Fisica Universidad Simon Bolivar Apartado Postal #5354 Caracas 108, Venezuela
WILLIAM E. McCLINTOCK	Ph.D. 1976	
	Dissertation:	"Chromospheres of K-Type Stars and Local Interstellar Matter"
	Present Address:	Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO

WAYNE McKINNEY	Ph.D. 1974 Dissertation: "The Far Ultraviolet Spectrum of Arcturus" Present Address: Bausch and Lomb, Rochester, NY
CHET B. OPAL	Ph.D. 1969 Dissertation: "Measurements of Nighttime O_2 Densities in the Upper Atmosphere from Far-ultraviolet Absorption" Present Address: Naval Research Laboratory, Washington, DC
HONGWOO PARK	Ph.D. 1977 Dissertation: "A Rocket Study of Vacuum Ultraviolet Auroral Emissions" Present Address: Systems and Applied Science Corp., Riverdale, MD
RUSSELL PARKS	MA 1979 Master's Essay: "The Application of Bit Slice Microprocessors to High Performance Ultraviolet Detector Systems" Last Known Address: Advanced Micro Devices, San Jose, CA
GARY ROTTMAN	Ph.D 1972 Dissertation: "The Far Ultraviolet Spectrum of Venus" Present Address: Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO
ROBERT L. SCHAF	MA 1979 Master's Essay: "An Instrument for the Design of Optical Systems" Present Address: Johnson Space Center, Houston, TX
GULAMABAS G. SIVJEE	Ph.D. 1970 Dissertation: "Spectro-photometry of the Night Airglow and the Aurorae" Present Address: NSF, Washington, DC (Temporary) University of Alaska, Fairbanks, Alaska
WILLIAM SNYDER	Ph.D. 1982 Dissertation: "X-ray Variability of BL Lacertae Objects" Present Address: Naval Research Laboratory, Washington, DC
JAMES SWANDIC	Ph.D. 1978 Dissertation: "Some Problems in Time-Dependent and Nonlinear Particle Transport Theory" No Known Address

PETER Z. TAKACS

Ph.D. 1974
Dissertation: "Far Ultraviolet Atomic and Molecular Nitrogen Emissions in the Day Airglow"
Present Address: TRW, Los Angeles, CA

ROBERT C. VITZ

Ph.D. 1977
Dissertation: "A Rocket Observation of the Far Ultraviolet (1160-1700 Å) Emission Spectrum of Capella"
Present Address: General Electric Company, Space Division, Valley Forge Space Ctr., Philadelphia, PA

HAROLD A. WEAVER, JR.

Ph.D. 1981
Dissertation: "Ultraviolet Spectra of Comets Observed with the International Ultraviolet Explorer Satellite Observatory"
Present Address: NASA Goddard Space Flight Center, Greenbelt, MD

ARTHUR WEINSTEIN

Ph.D. 1976
Dissertation: "A High Sensitivity Sounding Rocket Observation of the Far Ultraviolet (1160-1700 Å) Spectrum of Arcturus"
Last Known Address: Bell Telephone Labs., Murray Hill, NJ

HEINZ WEISER

Ph.D. 1978
Dissertation: "Far Ultraviolet Spectrum of Saturn"
Present Address: Harvard College Observatory, Cambridge, MA

ALBERT J. WILLIAMS III

Ph.D. 1969
Dissertation: "High-Resolution Low-Energy Electron Scattering from Molecular Nitrogen"
Last Known Address: Woods Hole Oceanographic Institute, Woods Hole, MA

JOSEPH R. WOODWORTH

Ph.D. 1974
Dissertation: "Determination of the Spontaneous Radiative Transition Rate of the $2^3S_1 - 1^1S_0$ Transition in Neutral Helium"
Present Address: Sandia Labs., Albuquerque, NM

STUDENTS TRAINED IN GRADUATE SPACE SCIENCE PROGRAMS

1983

RICHARD P. CEBULA — Ph.D. 1983
Dissertation: "Morning Twilight Observations of the Zodiacal Light and Terrestrial Airglow"
Present Address: Systems & Applied Sciences, Corp., Hyattsville, MD

PETER D. TENNYSON — Ph.D. 1983
Dissertation: "The Diffuse Ultraviolet Background: 1700 Å-2900 Å"
Present Address: Department of Physics, The Johns Hopkins University, Baltimore, MD

APPENDIX C

SUMMARY BIBLIOGRAPHY

- APPENDIX C1 -

SUMMARY BIBLIOGRAPHY

(1963-1983)

This list contains papers of research done entirely or partially under NASA grants NsG 193-62 and NGR 21-001-001 but does not contain papers of related work supported entirely by other NASA programs, e.g, Copernicus, Voyager, IUE and Apollo 17.

E. C. Zipf, Jr., A Measurement of the Diffusion Coefficient and Radiative Lifetime of Nitrogen Molecules in the A $^3\Sigma_u^+$ State, J. Chem. Phys. 38, 2034 (1963).

E. C. Zipf, Jr. and Wm. G. Fastie, An Observation of Day Airglow Emission at 6300 Å, J. Geophys. Res. 68, 6208 (1963).

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W. G. Fastie, H. M. Crosswhite and D. F. Heath, Rocket Spectrophotometer Airglow Measurements in the Far Ultraviolet, J. Geophys. Res. 69, 4129 (1964).

W. G. Fastie and H. M. Crosswhite, Far UV Dayglow Measurements: Atomic Oxygen, Planet. Space Sci. 12, 1021 (1964).

T. M. Donahue and W. G. Fastie, Observation and Interpretation of Resonance Scattering of Lyman α and O I (1300) in the Upper Atmosphere, in Space Research IV: Proceedings of the Fourth International Space Science Symposium, P. Muller, ed., North-Holland Pub. Co., Amsterdam, 1964, p. 304.

R. Isler and W. G. Fastie, An Observation of the Lyman-Birge-Hopfield System in an Aurora, J. Geophys. Res. 70, 2613 (1965).

R. E. Miller, High Resolution Emission Vegard-Kaplan Bands of Nitrogen, J. Chem. Phys. 43, 1695 (1965).

D. F. Heath and G. H. Dieke, Vacuum Ultraviolet Instrumentation (High Resolution Vacuum Spectrograph), Jap. J. Appl. Phys. 4, 455 (1965).

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T. M. Donahue, T. Parkinson, E. C. Zipf, J. P. Doering, W. G. Fastie and R. E. Miller, Excitation of the Auroral Green Line by Dissociative Recombination of the Oxygen Molecular Ion: Analysis of Two Rocket Experiments, Planet. Space Sci. 16, 737 (1968).

W. G. Fastie, Far Ultraviolet Day Airglow Studies, Planet. Space Sci. 16, 929 (1968).

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H. W. Moos, W. G. Fastie and M. Bottema, Rocket Measurement of Ultraviolet Spectra of Venus and Jupiter between 1200 Å and 1800 Å, Astrophys. J. 155, 887 (1969).

C. B. Opal and H. W. Moos, Nighttime Molecular Oxygen Densities in the 100 to 130 km Region from Schumann-Runge Absorption, J. Geophys. Res. 74, 2398 (1969).

A. J. Williams, III and J. P. Doering, An Experimental Survey of the Low Energy Electron Scattering Spectrum of Nitrogen, Planet. Space Sci. 17, 1527 (1969).

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J. P. Doering, W. G. Fastie and P. D. Feldman, Photoelectron Excitation of N_2 in the Day Airglow, J. Geophys. Res. 75, 4787 (1970).

K. A. Dick, Some Spectrometric Results from the NASA 1968 Airborne Auroral Expedition, J. Geophys. Res. 75, 5605 (1970).

K. A. Dick, Tentative Identification of Several N_2 $c' \, {}^1\Sigma_u^+ \rightarrow a \, {}^1\Pi_g$ Bands in Auroras, J. Geophys. Res. 75, 5609 (1970).

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H. W. Moos and G. J. Rottman, O I and H I Emissions from the Upper Atmosphere of Venus, Astrophys. J. 169, L127 (1971).

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G. G. Sivjee, K. A. Dick and P. D. Feldman, Temporal Variations in Night-Time Hydroxyl Rotational Temperature, Planet. Space Sci. 20, 261 (1972).

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H. W. Moos and G. J. Rottman, The Far-Ultraviolet Emission Spectrum of the K2 III Star, Arcturus, Astrophys. J. 174, L73 91972).

T. G. Finn, J. F. M. Aarts and J. P. Doering, High Energy-Resolution Studies of Electron Impact Optical Excitation Function. I: The Second Positive System of N_2, J. Chem. Phys. 56, 5632 (1972).

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P. D. Feldman, Daytime Ion Chemistry of N_2^+, J. Geophys. Res. 78, 2010 (1973).

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H. W. Moos, Comparison of the Far Ultraviolet Spectra of Venus and Mars, J. Geophys. Res. Letters 79, 685 (1974).

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W. G. Fastie, H. W. Moos, R. C. Henry and P. D. Feldman, Rocket and Spacecraft Studies of Ultraviolet Emissions from Astrophysical Targets, Phil. Trans. Roy. Soc. Lond. A 279, 391 (1975).

P. D. Feldman and J. P. Doering, Auroral Electrons and the Optical Emissions of Nitrogen, J. Geophys. Res. 80, 2808 (1975).

J. W. Giles, W. R. McKinney, C. S. Freer and H. W. Moos, An Image-Stabilized Telescope-Ten Channel Ultraviolet Spectrometer for Sounding Rocket Observations, Space Sci. Instrumentation 1, 51 (1975).

P. D. Feldman and P. Z. Takacs, A Search for Molecular Hydrogen Fluorescence near 100 km, J. Atmos. Sci. 32, 2209 (1975).

P. D. Feldman, P. Z. Takacs, W. G. Fastie and B. Donn, Rocket Ultraviolet Spectrophotometry of Comet Kohoutek (1973f), in Comet Kohoutek, NASA SP-355 (1975), P. 109.

J. R. Woodworth and H. W. Moos, Experimental Determination of the Single-Photon Transition Rate between the 2^3S_1 and 1^1S_0 States of He I, Phys. Rev. A 12, 2455 (1975).

T. G. Finn and J. P. Doering, Elastic Scattering of 13 to 100 eV Electrons From N_2, J. Chem. Phys. 63, 4399 (1975).

R. C. Henry, A. Weinstein, P. D. Feldman, W. G. Fastie and H. W. Moos, Low Resolution Ultraviolet Spectroscopy of Several Hot Stars Observed form Apollo 17, Astrophys. J. 201, 613 (1975).

P. D. Feldman and P. Z. Takacs, Twilight Observation of the Forbidden O^+ (^2P-^4S) Transition at 2470 Å, J. Geophys. Res. 81, 260 (1976).

P. D. Feldman, Nitric Oxide Gamma Band Emission in an Aurora, Geophys. Res. Letters 3, 9 (1976).

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W. R. McKinney, H. W. Moos and J. W. Giles, The Far-Ultraviolet (1180-1950 Å) Emission Spectrum of Arcturus, Astrophys. J. 205, 848 (1976).

R. C. Vitz, H. Weiser, H. W. Moos, A. Weinstein and E. S. Warden, Spectroscopic Survey of the Far-Ultraviolet (1160-1700 Å) Emissions of Capella, Astrophys. J. (Letters) 205, L35 (1976).

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APPENDIX D

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- APPENDIX D1 -

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APPENDIX E

INSTRUMENTATION DEVELOPMENT

- APPENDIX E1 -

A Summary of Space Instrumentation Developments in Optics and Spectroscopy at The Johns Hopkins University

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March 1979

I. Introduction

During the past two decades a program of space science research in the field of Optics and Ultraviolet Spectroscopy has been supported at JHU almost exclusively by the National Aeronautics and Space Administration. This research has covered a broad area including the aurora, the day and night time ionosphere, lunar, planetary and cometary spectroscopy, solar terrestrial relationships including zodiacal light, spectroscopy of stars, extra galactic objects and studies of the diffuse galactic background. One goal of our program has been to measure spectral emissions from astrophysical targets with the highest possible absolute photometric accuracy in the spectral region 900 to 3200 A. Another goal has been the continual evolution of improved instrumentation -- optical, spectroscopic and photometric detecting systems for space research. This latter facet of the program is the subject of this report which reviews the current status and our future plans with particular emphasis on the applicability of these developments to space research in the Shuttle era.

The responsibility for conducting our future rocket and shuttle experiments will be borne by Physics Department faculty members currently active in the astrophysics area, who in order of seniority are H. Warren Moos, Paul D. Feldman, Richard C. Henry and Arthur F. Davidsen. The above will act as principal investigators for the individual experiments. The writer's responsibility for these future experiments will be in the area of instrumentation -- particularly the evolution of improved instrumentation in cooperation with the above principal investigators.

II. Historical Review

Our first space age effort began in 1959 under Air Force Cambridge Research Laboratory (AFCRL) support. We developed a rocket Ebert Scanning UV Spectrometer to study emissions from the aurora borealis in the spectral range 1750 to 3500 A. We performed one rocket flight under AFCRL support in early 1960 which successfully observed the first auroral spectrum below 3000 A. A follow-on program initiated under a NASA grant with the late G. H. Dieke, Physics Department Chairman, as principal investigator expanded the research effort to include studies of day time and night time ionospheric and exospheric emissions. During the early years of the NASA support instrumentation improvements included an increase in speed of the Ebert spectrometer from f/10 to f/5, which today still appears to be its optimum speed, and the use of LiF windowed photocathodes which are solar blind to replace sodium salicylate fluorescing films on blue sensitive photomultiplier tubes. These tubes had much higher photon detection efficiency and in addition very effectively reduced sensitivity to scattered near UV and visible radiation. They were developed by Electromechanical Research, Inc. under the support of Dr. Laurence Dunkelman at Goddard Space Flight Center.

A parallel activity which started in 1962 was the writer's consulting work with Jet Propulsion Laboratory which consisted of conceptual designs for the Mariner Far UV Ebert Scanning Spectrophotometers in cooperation with Dr. Charles Barth who later moved to the University of Colorado.

Our very early daytime ionospheric studies were not understandable in terms of the extant theory. These results led to a rocket experiment by John P. Doering, Chemistry Department, JHU, to study the very low energy spectrum of ionospheric electrons with instrumentation which he had developed to study auroral electrons as part of our NASA research. The ionospheric electron rocket experiment during which simultaneous spectrophotometric observations were made, confirmed the earlier rocket results (C. A. Barth had performed one definitive rocket experiment in this area) and provided a much more complete understanding of ionospheric processes. The early electron studies of the aurora and daytime ionosphere by Doering led to his involvement in the Atmospheric Explorer Satellite. Doering's experiment on AE has produced a plethora of new data and much improved understanding of ionospheric physics.

The instrumentation for auroral and airglow studies was also used in several expeditions aboard NASA's airborne observatory (Convair 990) to study solar eclipses, auroral displays under constant solar angle and at local noon, and night airglow as a function of time and latitude. These studies were conducted in the visible and near ultraviolet region. Dr. Kenneth Dick, a postdoctoral fellow was responsible for much of this work.

With the death of G. H. Dieke in the summer of 1965 the writer assumed principal investigator responsibilities. In the fall of 1965 the apparition of the sun grazing comet Ikeya Seki presented a new opportunity. We interfaced the two-mirror coronagraphic type telescope which C. A. Barth had developed for Mariner planetary flyby instruments with the 1/2 meter f/5 Ebert scanning spectrophotometer which had become the work horse of our program. We employed an Aerobee rocket with an early version of a pointing control system which had been developed by the Sounding Rocket Division at Goddard Space Flight Center. The experimental equipment worked fine but scattered solar light completely inundated the comet signal. However, the experiment alerted us to the potential of pointing systems for astrophysical research. It also introduced H. W. Moos into the space program.

During the next few years Moos developed a 35 cm diameter astronomical telescope with a servocontrolled secondary mirror to provide sub second of arc pointing stability. This activity was enhanced by Murk Bottema who later joined Ball Brothers Research Corporation.

Moos's further instrumentation contributions have included the introduction of photo-electron pulse counting techniques to lower the level of light detection and the use of multiple detectors in the focal plane of spectrographs to increase the total data yeild. This development was in several steps -- first the use of a gang of small photomultiplier tubes, each with a separate detector and then the use of far UV sensitized microchannel plates with a resistive strip pulse position readout system of the type described by Bowyer, and finally and more recently the use of a microchannel plate with a resistive plate to provide two-dimensional pulse locating capability, also described by Bowyer. The resistive plate development has been a joint development with Paul D. Feldman and with Chet B. Opal, a former student in our program who is now at the Hulbert Center for Space Research of the Naval Research Laboratory. Although we anticipate that better two-dimensional systems for reading the output of microchannel plates will soon become available, the resistive plate readout is the only state-of-the-art system as of this writing. It should be noted that for some applications it can provide much better information than any one-dimensional system now available and can have a significant role in the near future.

Moos has used the fine pointing telescope with focal plane spectrographs and pulse counting multiple element detector systems to study planetary far UV emissions (Venus, Jupiter, Saturn and Saturn's Rings) and far UV emissions from cool stars, which exhibited much brighter line emissions than anticipated and led to a series of observations with the Copernicus Spectrometer/Telescope Satellite in cooperation with R. C. Henry, and J. B. Linsky at the Joint Institute for Laboratory Astrophysics at Boulder, Colorado.

In 1975 Moos assumed the additional responsibility under Department of Energy support of conducting a laboratory study of far UV, extreme UV and soft x-ray emissions from large plasma machines. This new program was expedited by the initial use of our space instrumentation but currently feedback from the plasma program is providing new techniques for our space program.

Paul D. Feldman joined our program in 1967. His intial interests were aurora and ionospheric emissions. At that time we had initiated a joint program with Edward F. Zipf (a former student and post doctoral fellow in our program) and Thomas M. Donahue (an earlier JHU Ph.D. in Physics) at the University of Pittsburgh. The joint program combined our spectrometric and photometric instrumentation with the University of Pittsburgh developed mass spectrometers and with Doering's electron spectrometers to produce an integrated package to more broadly study auroral, ionospheric and exospheric phenomena. The use of multiple instruments in the then available rocket systems squeezed the Ebert spectrometer to smaller dimensions, at first 1/4 meter focal length and culminating in a current version which is still f/5 but which has a 1/8 meter focal length, weighs 2 pounds and required 2 watts to operate. This smaller instrument is inherently less sensitive for observing terrestrial phenomena but improved optical and detector system efficiency has maintained the requisite sensitivity. A companion development has been to build a 1/4 meter focal length scanning concave grating spectrograph based almost entirely on the 1/8 meter hardware. This instrument has the great advantage that only one optical element is needed (the Ebert system requires three) to study auroral and ionospheric emissions in the EUV region below 1150 A where lower optical reflectivity is achievable than at longer wavelengths.

Feldman has participated less in instrumentation development than in concocting unique combinations of our instruments and their subsystems to perform new experiments and in using computer techniques to analyse the data and to develop theoretical models of atmospheres to compare with the experimental data. For example has has used the 1/8 meter spectrograph in the Solrad Satellite to monitor the sun in search of solar-terrestrial interactions. He has utilized the scanning concave grating system with a single element telescope to measure the absolute brightness of several stars in the spectral range 900 to 1250 A. He has adapted a 1/4 meter Ebert and a 1/8 meter Ebert to form a bore-sighted two barrel array of telescopes to study the spectra of comets Kouhoutek and West. He is currently studying cometary coma models from which an optimum observing program can be deduced and which will assist in defining cometary UV payloads for rocket, shuttle and rendezvous missions to study Eneke, Halley and cometary targets of opportunity.

R. C. Henry joined the group in 1968. His research interests include stellar atmospheres, particularly of cool stars, diffuse galactic background, lunar albedo and absolute calibration of stars in the far UV. Henry's role has been to propose advanced experiments which fall within our measuring capabilities rather than instrumentation per se, and to analyse the results from such experiments. For example he generated an observing program for our Apollo 17 experiment (to be described later) and directed the scientific analysis of the results in three areas -- the far UV lunar albedo, absolute stellar calibrations and diffuse galactic background. This analytical work led to further rocket studies of stellar brightness and the diffuse galactic background. A two year tour of duty at NASA headquarters is now complete, and he is continuing experiments of the type described above.

In 1969 our group was given the responsibility for conducting a far UV spectroscopic experiment on Apollo 17 with the writer as principal investigator and with C. A. Barth, G. E. Thomas and C. F. Lillie at the University of Colorado and T. M. Donohue, The University of Pittsburgh, as co-experimenters. The prime purpose of the experiment was to search for a residual lunar atmosphere (which was not detected) but there were many other facets including a study of interplanetary hydrogen, fluorescence of gases discharged from the spacecraft, the lunear albedo, the measurement of the absolute spectral brightness of stars, and the measurement of the UV spectrum of the diffuse galactic background.

The instrumentation for the Apollo 17 experiment was substantially identical to the 1/2 meter focal length Ebert spectrometer developed at the outset of our NASA program except the the addition of a reflector system at the exit slit to enhance the sensitivity. The Applied Physics Laboratory of the Johns Hopkins University took the responsibility for preparing the flight hardware and managing the pre-launch program.

By the late 1960's a need had developed for more precise measurement of the absolute brightness of UV and far UV spectral emissions from astrophysical targets. In the earlier period discovery of new emissions, for which precise theory did not exist, was the area of emphasis. Accordingly, as part of the Apollo 17 program we devised and installed a calibration facility in our laboratory which for nearly a decade has permitted our laboratory (and several other laboratories which have used the facility) to make precision ultraviolet photometric observations on space vehicles to the limits which can be achieved in the laboratory. The late Donald E. Kerr of the Physics Department contributed to the calibration facility by developing a stable UV source. In the two year period prior to his death in 1975 Kerr also contributed to the space telescope program described below.

In 1975 Arthur F. Davidsen came aboard. His activity has been the study of far UV emissions from extra galactic objects, in particular Quasars. For these studies we have developed a very advanced spectrometer-telescope rocket system which includes a dual star finding system that can point the telescope to within one arc minute of any point in the sky (developed by the Sounding Rocket Division, GSFC), a TV camera to present an instantaneous picture of the star field to which the telescope is pointing, and ground command capability to make fine adjustments of the rocket pointing system so that the star field can be quickly centered on the desired target to within 5 arc seconds.

The new telescope system has been flown on two rocket missions (both successful), the first flight producing the first far UV spectrum of a Quasar (3C 273) from which many very significant scientific results have been deduced.

The success of Davidsen's telescope has inspired the development of a much larger telescope for future rocket and space shuttle astrophysical experiments. The new telescope, currently in the design phase will have a primary mirror diameter of 90 cm and will be designed in a modular fashion so that new detecting systems, new spectrometers and new TV camera systems can be incorporated in the telescope package as they evolve from our ongoing instrumentation studies.

These developments, along with the development of advanced specialized optical devices for studying planets, comets and diffuse emissions represent our current concept of our future program as outlined in Sec. IV.

In 1975 George H. Mount accepted a three year appointment as a post doctoral fellow to study the UV properties of diffraction gratings of potential interest to Space Telescope and to the

International Ultraviolet Explorer. His work has resulted in a better understanding of grating properties which in turn has resulted in much better inflight performance than originally anticipated for IUE and will have a similar positive impact on ST.

Mount also developed and studied the performance properties of a flight calibration lamp which is flying on IUE and will be used on ST. The lamp work was performed in cooperation with Goddard Space Flight Center and the Westinghouse Corporation.

Mount also conducted a laboratory study of the absorption properties of gases of interest in the study of planetary atmospheres and assisted in a rocket study of the absolute brightness in the UV of bright stars

There are several ancillary programs not supported or indirectly supported by NASA which have enhanced our space research program. The original Air Force support, consulting support by Jet Propulsion Laboratory and Department of Energy support, are described above. For a short time in the late 1960's the writer was a consultant to Ball Brothers Research Corporation and contributed the conceptual design of a solar UV rocket spectrograph which has been successfully flown several times by Harvard College Observatory. The writer has also provided consulting services to two Air Force Geophysical Research Laboratory (formerly AFCRL) experiments, one to study UV emissions in the ionosphere from a satellite, the other to study UV solar emissions from a high altitude balloon. Moos has provided consulting serivces to another Air Force experiment to study soft x-ray solar emissions. Feldman has consulted with the Hulburt Space Research Center at the Naval Research Laboratory, notably in conducting the Solrad experiment described above. Both Henry and Davidsen have also participated in Hulburt Center Research in the area of scientific analysis of x-ray data from astrophysical targets. All of these extra curricular activities have provided extremely valuable feedback to our instrumentation program and to our space research studies.

Another activity of our astrophysics group, as it is generally referred to within the Physics Department, is to provide counsel to NASA through general committee work, scientific experiment selection committees, science working groups and direct administrative support. For example, the writer has served on committees to evaluate and/or select proposed experiments for four solar missions, for two interplanetary missions and for Space Lab II, on the initial working group that defined the International Ultraviolet Explorer (IUE) which is a stellar telescope/ spectrometer system currently operating in geosynchronous orbit, was a member of an instrument identification team for the Space Telescope and is currently one of the two telescope scientists and a member of the science working group for the Space Telescope which will be launched in 1983.

Moos was a rotating member of the International Ultraviolet Explorer and is currently a member of the Mission Operations Working Group, the top committee which advises the astronomy office at NASA headquarters.

Feldman has been a member of proposal evaluation teams, a member of the AMPS (Atmosphere, Magnetosphere and Plasmas in Space) Science Working Group and Definition team and a member of the CLIR (Cryogenic Limb-Scanning Interferometer/Radiometer) Definition team.

Henry, as mentioned above was on leave of absence and completed a two-year tour of duty at NASA headquarters where he served as deputy to the director of the astrophysics division. This is the highest level administrative job to which NASA has appointed a research astronomer.

Davidsen has served on a NASA investigative committee which made an on-site study of state-of-the-art multiple element detectors (one and two dimensional imaging detectors) which might be candidate detectors for cameras and spectrometers aboard the Space Telescope. The report of the detector committee had a major impact on the selection of experimental groups which will provide instruments for the Space Telescope. Davidsen is currently serving as a co-experimenter on the Faint Object Spectrograph team to which he was selected by NASA as a member at large, i.e., he was not an original member of any of the scientific instrument teams which the detector committee reviewed. Davidsen is also a member of the committee that is advising NASA on a permanent space x-ray observatory.

We have recently completed a special study for NASA to define the applicability of rocket experimentation for astronomical studies to use aboard the shuttle. In our report (NASA contract NAS 5-23695) we identify several aspects of the shuttle interface with such experiments and propose generic solutions. In particular, we have proposed that all such experiments should be carried in a sealed universal container which provides a thermal and mechanical interface with the shuttle system.

The committee work of the astrophysics group has been extensive and can therefore be assumed to have been of significance to NASA. The feedback effect has provided the JHU astrophysics group with a much broader view of space astrophysics than would otherwise have occured and has therefore had a very positive effect on the JHU program.

In concluding this historical review it is important to emphasize that in this research program, as in all others, the most important end product is the students (doctoral and post doctoral) that support it and emerge from it. Their names, not mentioned above are generously distributed throughout our scientific publications. It should be understood that the asterisks above refer only to the highlights of our published research. The total publications list totals over a hundred scientific journal publications. We make special note of the following individuals whose names do not appear in the scientific publications and who have had a significant input to the program at the support level.

	Length of Service Through 1979
Mrs. Elsa Clark, executive administrator	10 years
Mrs. Linda Bihun-Werner, executive administrator	1
Mr. Myron D. Chedester, research engineer	10
Mr. Leo Hruska, research engineer	3

Mr. Milton Nemec, Physics Dept. Shop foreman and instrument maker	18
Mr. Bernard Lawrence, instrument maker	10
Mr. Thomas Shipley, instrument maker	7
Mr. Robert Crabbs, instrument designer	2
Mr. Robert Richardson, research technician	3
Mr. Kenneth Wolfram, research technician	3
Mr. Russell Pelton, research technician	1

III. Current Instrumentation

In designing our latest instrumentation for rocket research we have incorporated modular design in our hardware subsystems and have employed space qualified components. This approach has provided flexibility, reliability and economy in assembling a rocket experiment and the same advantages will accrue to our future shuttle program. This policy is reflected in our choice of subcontractors, all of whom have broad experience in providing components and subsystems for satellite experiments as shown below.

Sub Contractor	Product	Example of Satellite Experience
Spacom Electronics	System wiring	Mariners
	H.V. Supplies	Solrad
	Electronic Design	OGO
	Pulse Counting Units	GRL Satellites
	Servo Systems	
	Ground Support Systems	

Sub Contractor	Product	Example of Satellite Experience
Research Support Instrumentation	Optical Mechanical Design	Apollo
	Optical Mechanical Construction	Solrad
	Field Support	GRL Satellites
	Laboratory Support Equipment	
Muffolette Optical Co.	Precision Optics	A.T.M
		Apollo XVII
		Mariners
Electromechanical Research (EMR)	P.M. Tubes	Apollo
	Integrated P.M. Systems	Mariners
		OGO
Westinghouse Corp.	S.I.T. Vidicon	Apollo
	UV Calibration Lamps	IUE
Applied Physics Lab/JHU	Management Support	Apollo
	Field Support	Atmospheric Explorer
	System Design	
	Environmental Testing	Transit Satellites
	Data Analysis	Explorers
		GEOS

The best way to define our current space equipment is to describe a few of our latest rocket payloads. Because of modular design some subsystems are or can be used in several payloads as indicated.

A. Auroral Package

For general auroral research:

1. ¼ meter focal length Infra red scanning Ebert spectrophotometer
   a. No slit illuminator
   b. Cryocentrically cooled Lithium drifted germanium detector
2. Concave grating EUV scanning spectrophotometer
   a. No slit illuminator
   b. Scanning grating (near normal incidence)
   c. Osmium coating to provide sensitivity to 500 A
   d. Windowless PM tube-pulse counting electronics
3. Narrow pass band multiple photometer
   a. Interference filters
   b. Wide dynamic range electronics
   c. Selected PM tubes (5 channels)
   d. Tilting interference filters (2 channels)
4. Mass spectrometer (provided by E. Zipf, U. of Pittsburgh)
   a. Low level detection
   b. Detects ions and neutrals
5. Dual electron spectrometer (J. P. Doering)
   a. Measures secondary electron spectrum to a few volt limit
   b. Measures primary electron spectrum of 40 kev
6. Far UV scanning Ebert spectrometer
   a. Measures auroral emissions in range 3100 A to 1100 A
   b. Employs pulse counting electronics to measure intensities

B. Comet Research Package

(This payload has also been used to absolutely calibrate bright stars in the spectral range 900 A to 3100 A.)

1. ¼ Meter focal length (f/5) scanning Ebert spectrophotometer
   a. Employs f/5 off axis parabolic telescope (½ meter focal length) to illuminate entrance slit
   b. Photo-electron pulse counting electronics
   c. Covers 1700 to 3100 A range
2. 1/8 Meter focal length scanning Ebert spectrophotometer
   a. Covers 1200 to 1700 A range
   b. Otherwise same as 1.
3. ¼ Meter focal length concave grating scanning spectrophotometer
   a. Covers 500 to 1300 A range
   b. Uses off axis parabolic osmium coated slit illuminator
   c. Otherwise same as A-2.
4. BASD (Ball Aerospace Science Division) Startracker (provided by GSFC Sounding Rocket Division)
   a. Is boresighted with 1, 2 and 3
   b. Points rocket at target stars or comet
   c. Limited to 4th magnitude or brighter stars

C. Fine Pointing Telescope

1. Employs BASD star tracker (see B-4) to bring targets into FOV of telescope
2. Dahl-Kirkham 2 mirror optics (35 cm diameter primary, f/16 secondary image, 5.6 meter effective focal length). Invar structure provides thermal stability of focus
3. Servo system articulates secondary mirror to provide image motion compensation to sub arc second stability; part of target light in telescope is used to actuate EMR quadrature star sensor system which controls secondary mirror position
4. Focal plane compatible with most of our scanning spectrophotometer subsystems
5. Prism spectrometer with microchannel plate detector at the focused spectrum provides high throughput with simultaneous detection of entire Far UV spectrum
6. Resistive strip pulse locating system reads out spectrum presented to μ channel plate
7. Resistive plate detector gives two dimensional read out capability for micro channel plates. This detector system is currently used in combination with an objective LiF prism to provide a monochromatic image of Jupiter and its near environs at Ly α

D. Far UV Diffuse Background Experiment

1. Uses ¼ meter focal length Ebert scanning spectrometer with oversize grating
2. Uses EMR strip photocathode solar blind PM tube to provide very low dark current
3. Uses very wide entrance slit (low resolution) to permit detection of very weak signals
4. Needs boresighted BASD tracker or equivalent pointing capability

E. Faint Object Telescope

1. Uses Dahl-Kirkham two mirror optical system (40 cm diameter primary, f/16 secondary images, 5.6 meter effective focal length). Invar tower in central obscuration zone supports secondary mirror and provides thermal stability of focus
2. Employs 2 BASD star trackers to guide on two bright stars so that the telescope can be pointed at very faint objects. Rate integration gyros are used to reduce pointing system jitter. The Sounding Rocket Division at GSFC provides the tracker and gyro system.
3. The spectrometer entrance slit is a hole in a mirror which directs the stellar field to a SIT Vidicon system which provides a real time star field image to the experimenter in the block house. The experimenter

has a quick response "joy stick" to correct the rocket pointing from the ground if necessary

4. A concave grating Rowland type spectrograph is used to record the spectrum. A microchannel plate with a resistive strip readout system (See C-6) is placed on the Rowland circle to provide simultaneous readout of each feature of the system

APPENDIX F

FACULTY AND POST-DOCTORAL RESEARCH ASSOCIATES SUPPORTED BY NASA GRANT NGR 21-001-001

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FACULTY:

Henry M. Crosswhite	1968-1974
Paul J. Dagdigian	1974-1977
Arthur F. Davidsen	1975-Present
John P. Doering	1970-1979
William G. Fastie	1968-Present
Paul D. Feldman	1968-Present
Richard C. Henry	1969-Present
Donald E. Kerr (deceased)	1969-1975
H. Warren Moos	1968-Present

POST DOCTORAL RESEARCH ASSOCIATES:

J. F. M. Aarts	1971-1972
Ronald A. Bell	1983
Kenneth A. Dick	1966-1969
Sammuel T. Durrance	1980-1982
Charles Freer, Jr.	1971-1972
George F. Hartig, Jr.	1978-1980
Frederick Herrero	1970-1972
Joseph A. McClintock	1978
George H. Mount	1975-1978
Robert C. Schaeffer	1970-1972
Earl Warden	1975-1977