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NASA Lyndon B. Johnson Space Center, Houston, Texas 7708

8 Mar 1977

CR 151242

Measurements of Far-Ultraviolet Photographs from Skylab 4 and Apollo 16

FINAL REPORT on S201 Data Analysis, NASA DPR T-9602 B

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Abstract: This report is a compilation of papers published in scientific journals on the analysis of over 700 far-UV photos obtained with the S201 electrographic camera on Skylab 4 (27 Nov 1973 - 28 Jan 1974) and from the Apollo-16 lunar site (21 - 23 Apr 1972). Data analysis on the 189 Apollo frames was delayed by the Skylab mission, and further work is continuing under contract NASW-3023 until Dec 1977. The investigators under NASA DPR T-845C included Drs. George R. Carruthers, Robert R. Meier, and Chet B. Opal at the Naval Research Lab, and Dr. H. U. Keller in West Germany, as well as the Principal Investigator. Valuable assistance was provided by Richard E. Hill of the Lockheed Electronics Co. Aerospace Systems Div. in Houston. The list of our 19 publications is given in Appendix A.

(NASA-CR-151242) MEASUREMENTS OF
FAR-ULTRAVIOLET PHOTOGRAPHS FROM SKYLAB 4
AND APOLLO 16 Final Report (Naval Research
Lab.) 5 P HC A02/MF A01
CSCL 14E
G3/43
UNCLAS
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N77-21516

The major achievements of the project are these:

- The Lyman-alpha geocorona was found to fit R. R. Meier's model
- The tropical airglow belts were measured quantitatively
- The history of Comet Kohoutek's Ly- α halo (and lack of an oxygen halo) was followed from 32 days before to 13 days after perihelion passage, and fitted to a model of hydrogen production from the comet
- Far-UV emissions from the Large Magellanic Cloud have been measured quantitatively and compared with ground-based measurements of stellar associations and nebulae
- Computer programs have been developed to contour the densities measured by microphotometer on the original film and to locate and sum density-volumes in each starlike image
- Thousands of stars have been identified and their far-UV flux measured in two band-passes (1050 - 1600 A, 1250 - 1600 A). Work continues under NASW-3023 to publish a catalogue of these stars, nebulae, galaxies, and peculiar objects
- All of the data and computer programs have been provided to NSSDC, and there are two summary files in the ICCA Astronomy Data File under the headings CONTOUR PLOTS and STAR IMAGES

Part I. The Data

The S201 Far-UV Camera is an f/1 Schmidt electrograph of 75 mm aperture designed and built by Carruthers. Two corrector plates were provided, one of LiF transparent above 1050 A, and one of CaF₂ transparent above 1250 A. The KBr photocathode is sensitive to wavelengths shorter than 1600 A. The photoelectrons are focused on special photographic film to record imagery or spectra in the two band-passes 1050 - 1600 and 1250 - 1600 A. A few spectra were taken with no corrector plate and recorded images down to 580 A. After being aimed by an astronaut, the camera took an automatic sequence of exposures until interrupted by the astronaut.

At the Apollo-16 lunar site the camera was deployed on a tripod and pointed at 10 different pre-selected targets. The field of view on these photos is a circle 20° in diameter, and the 1-, 3-, 10-, and 30-min exposures show images of blue stars as faint as 9.5 mag. In Skylab 4 the camera was used on EVA to photograph Comet Kohoutek with similar results but shorter exposures. Most of the Skylab-4 photos were taken through the Scientific Air Lock viewing an adjustable mirror which limited the field of view to 7° diameter. The reflectivity of this mirror was degraded by a factor of 20 during the Skylab-4 mission (due to vented condensates) and the photographic densities had to be corrected for this loss in sensitivity.

At the Apollo-16 lunar site there was only a very small sensitivity change from the pre-flight calibration. The Apollo camera was rotated automatically 90° downward to view a plane reflection grating through a collimator and photograph spectra of a strip across the imagery field. All imagery and spectra had to be corrected for distortion in the camera's magnetic focussing of the photoelectrons.

The Apollo-16 Preliminary Science Report gives a fairly complete account of the targets and the frames obtained on the Apollo mission. Table 1 gives a simplified listing of the objects observed both from Skylab and Apollo. It lists the numbers of frames scanned with a specially tuned PDS microdensitometer at the Boller-Chivens plant in S. Pasadena, Cal. (A complete list of all 700 frames is on file at NSSDC.) The PDS recorded densities from 0 to 5.1D (a remarkably large range). Measured density was found to vary linearly with exposure from 0 to 3.0D, but saturated at higher densities.

Part II. Reduction Techniques

The PDS scans, recorded digitally on magnetic tape, were smoothed to reduce noise, then analysed by the Univac 1108 programs described in the Lockheed Tech Memo 6040 (see App. A). These programs are:

- (1) Contour plots of density at selectable density intervals and selectable magnification
- (2) Detection of star images with selectable parameters defining the size of images to be recorded, separation of close pairs or groups, averaging background density, etc. This program outputs the density-volume of each detected image
- (3) Fit of celestial coordinates to image positions, after correcting for camera distortion and inputting coordinates of three or more identified stars
- (4) Identifying other images with stars in the SAO Star Catalog, using selectable tolerances in R.A. and declination.
- (5) Printing out mosaics of density values in units of 0.01D over a selectable region on any scanned frame
- (6) Correcting densities for non-linear response

Mosaic printouts were used to study details of the Earth's airglow, and of the stellar associations and nebulae in the LMC. Background density was estimated by the average of edge values at four points around the periphery of such a region.

Contour plots were used to spot lines in spectra and to eliminate defects from the star-detection output. They were also used to check background density values used in the calculation of density-volumes. Of course, they are used directly in studies of the geocorona and comet halo.

Table 1. List of S201 Targets under study in two spectral bands
1050-1600Å and 1230-1600Å

<u>Objective</u>	<u>Separate Occasions</u>	<u>No of Frames</u>	<u>Frames Scanned</u>	<u>Contour Plots</u>	<u>Remarks</u>
a) Comet K	14	123	46	501	Determined H-generation rate on 10 dates from 26 Nov 1973 to 10 Jan 1974
b) Geocorona	3	70	51	271	Also measured at centers of frames to check sensitivity change
c) Airglow	4	45	21	114	Inside view of airglow bands not yet studied.
d) Moon	6	29	17	42	Possible evidence of lunar hydrogen
e) Stars	18	357	136	1000	Over 10,000 stellar images detected
f) Nebulae	6	56	27	157	Includes Gum, Cygnus Loop, Crab, N. America nebulae
g) Magellanic Clouds	2	30	16	>200	Distribution of hot stars and hydrogen nearly completed.
h) Other Galaxies	8	89	24	16	Galaxy images on these and other frames not yet identified.
i) Clusters of Galaxies	14	176	51	48	No obvious concentrations of redshifted Lyman-alpha near cluster centers

Part III. Results and Conclusions

The Apollo-16 S201 far-UV photos showed for the first time the tropical airglow belts, the 584-A line of He, the 834-A line of O⁺, the Lyman-beta 1030-A line of H, and the general shape of the geocorona. R. R. Meier has shown that the measured brightness of the geocorona in the Lyman-alpha and -beta lines fits a consistent model.

Similarly, the Skylab-4 S201 observations of Comet Kohoutek fit a model of that comet's hydrogen halo. The measured Lyman-alpha brightness as a function of distance from the nucleus gives quantitative estimates of the hydrogen production rate and how it varied from 32 days before to 13 days after perihelion passage. A puzzling result is that the oxygen emission at 1354 A was barely detected and indicates that there was virtually no oxygen production in Comet Kohoutek. The long, thin tail observed in 1250 - 1600-A light on 26 Dec 1973 has not been explained.

The far-UV imagery of the Large Magellanic Cloud obtained on Apollo 16 deserves further study. The ratio of far-UV starlight to Henize's measures of visible Balmer-alpha (6563 A) varies in an interesting way across the LMC. The measured spectra of hot star associations are consistent with effective temperatures of about 30,000°K and reddening $E(B-V) = 0.3$ mag.

Some 10,000 star-like images have been detected on the S201 far-UV imagery, and over half of them identified with stars in the Smithsonian Star Catalog. In general, density-volumes of the identified stars have been measured on three or four different frames. Using the techniques described in Part II, these lists of identified stars are being corrected and arranged in catalogue format. It is planned to publish the S201 Far-UV Catalogue within a year. Of particular interest are about 100 images not identified with SAO-Catalog stars. Some of these are probably known nebulae and galaxies, but several may be new peculiar objects.

It is concluded that the S201 far-UV imagery and spectra contain a wealth of data of astrophysical importance, and are worth more study than has been possible under DPR T-~~9602B~~. For this reason, all the data have been submitted to the National Space Science Data Center at the Goddard Space Flight Center, and the Density Contour Plots and Star Catalogue are on file at the ICCA Astronomy Data File at GSFC.

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APPENDIX A follows

Appendix A: Publications based on S201 Data Analysis

- The S201 Experiment, George R. Carruthers & Thornton Page, Chap. 13 in the Apollo-16 Preliminary Science Report, NASA SP315, 1972
- Apollo-16 Far-UV Camera/Spectrograph: Earth Observations, G. R. Carruthers & T. Page, SCIENCE 177, 788, 1972
- Comet Kohoutek Images and Spectrograms, G. R. Carruthers, R. R. Meier & D. K. Prinz, SCIENCE 185, 702, 1974 Aug 23
- Lyman-Alpha Imagery of Comet Kohoutek, and Far-UV Magnitudes of Stars, Thornton Page, AIAA Paper No. 74-1247, 1974 Nov 1 (also a chapter in Proceedings of Comet K Workshop, NASA MSFC, 1976)
- Lyman-Alpha Imagery of Comet Kohoutek, G. R. Carruthers, C. B. Opal, T. L. Page, R. R. Meier, & D. K. Prinz, Icarus 23, 526-537, 1974
- Electrographic Camera for the Vacuum Ultraviolet, George R. Carruthers, Electrography and Astronomical Applications, pp 94-113, Univ. of Texas, Austin, 1974
- Far-UV Observations of Comet Kohoutek and other Targets with the S201 Electrographic Camera, Thornton Page, *ibid.* pp 297-304
- Apollo-16 Lyman-Alpha Imagery of the Hydrogen Geocorona, George R. Carruthers, Robert R. Meier & Thornton Page, Jour of Geophys Research, 81, 1664, 1976 Apr
- Apollo-16 Far-UV Imagery of the Polar Auroras, Tropical Airglow Belts, and General Airglow, George R. Carruthers & Thornton Page, JGR 18, 483, 1976 Feb 1
- Apollo-16 Far-Ultraviolet Spectra of the Terrestrial Airglow, George R. Carruthers and Thornton Page, JGR 81, 1683, 1976 Apr 1
- Far-Ultraviolet Brightness of Nebulae in Cygnus, George R. Carruthers & Thornton Page, Astrophys Jour 205, 397-404, 1976 Apr 15
- User's Guide to UV Camera Data Analysis Program, Richard E. Hill, Lockheed Electronics Co Tech Memo 6040, 1976 June
- Apollo-16 Far-UV Imagery and Spectra of the Large Magellanic Cloud, Thornton Page and George R. Carruthers, COSPAR XIX, 1976 June 15
- Space Science and Astronomy -- Escape from Earth, Thornton Page & Lou Williams Page, Macmillan, N. Y. 1976 Oct
- Hydrogen Production Rates from Lyman-Alpha Images of Comet Kohoutek, R. R. Meier, C. B. Opal, H. U. Keller, T. L. Page & G. R. Carruthers, Astronomy & Astrophysics, 52, 283, 1976
- Apollo-16 Far-UV Spectra in the Large Magellanic Cloud, George R. Carruthers & Thornton Page, ApJ 211, 728-736, 1977 Feb 1
- Geocoronal Lyman-Beta and Balmer-Alpha Emissions Measured During Apollo-16 Mission, R. R. Meier, G. R. Carruthers, T. L. Page & A. C. Levasseur, JGR 82, 737, 1977 Feb
- Looking at the Solar System in the Far Ultraviolet, R. R. Meier, Astronautics and Aeronautics 18, 18, 1973 Sept
- A Survey of the Ultraviolet Airglow from 1216 to 304 A, R. R. Meier, Ann. d' Geophys. 30, 96, 1974 Jan