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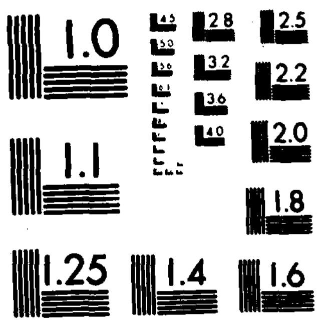

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GEOCORONAL IMAGING WITH DYNAMICS EXPLORER: A FIRST LOOK

by

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Abstract

The ultraviolet photometer of the University of Iowa spin-scan auroral imaging instrumentation on board Dynamics Explorer-1 has returned numerous hydrogen Lyman alpha images of the geocorona from altitudes of 570 km to 23,300 km (1.09 R_E to 4.66 R_E geocentric radial distance). The hydrogen density gradient is shown by a plot of the zenith intensities throughout this range, which decrease to near celestial background values as the spacecraft approaches apogee. Characterizing the upper geocorona as optically thin (single-scattering), the zenith intensity is converted directly to vertical column density. This approximation loses its validity deeper in the geocorona, where the hydrogen is demonstrated to be optically thick in that there is no Lyα limb brightening. Further study of the geocoronal hydrogen distribution will require computer modeling of the radiative transfer.

Introduction

Global properties of the earth's tenuous hydrogen exosphere—the geocorona—have been studied through measurements of the scattered solar Lyman alpha radiation. Initially the observations were made by photometers carried on rockets reaching altitudes not much in excess of 100 km, and measurements were sparse for support of early theoretical work on the high-altitude hydrogen distribution [Chamberlain, 1961, 1963; Thomas, 1963]. Knowledge progressed as photometers were flown into medium- and high-altitude orbits. OGOs 4, 5 and 6 provided measurements from 400 km to 145,000 km altitude, for extensive modeling by Meier and Mange [1970, 1973], Thomas and Bohlin [1972], Vidal-Madjar and Bertaux [1972], Bertaux and Blamont [1973], and Thomas and Anderson [1976]. Numerical solutions for the integrals of radiative transfer [Chandrasekhar, 1952] in spherically symmetric isothermal models of the geocorona have been computed by Anderson and Hord [1977]. Radiative transfer theory is necessary for description of the optically thick inner region.

Directional photometric data was improved upon by the first actual images of the geocorona, "photographed" from the lunar surface by the Apollo-16 crew. From these images global density variations could be observed without the ambiguity of temporal and spatial effects [Carruthers et al., 1976]. No further attempts at geocoronal imaging were made prior to the Dynamics Explorer mission.

Dynamics Explorer Imaging Instrumentation

The Dynamics Explorer satellites DE-1 and DE-2 were launched into coplanar orbits on August 3, 1981. The high altitude DE-1, with an apogee of 4.66 R_E and a perigee of 1.09 R_E geocentric (1 R_E = 6371 km), carries the University of Iowa spin-scan auroral imaging system. This instrumentation consists of three photometers, two operating at visible wavelengths and the third in the ultraviolet. Each photometer has a conical field-of-view with full angle 0.32° and accumulates counts for successive 3.4 ms intervals (separated by ~0.4 ms dead-time) as the spin-stabilized satellite rotates. These data are telemetered as picture elements (pixels) of a scan line. After each full satellite rotation a mirror is stepped to displace the photometer field-of-view by 0.25° perpendicular to the scan direction so that a subsequent scan line may be received. Full displacement is 15° to either side of the spacecraft spin plane allowing images of 30° width containing 120 scan lines, which require 12 minutes to accumulate at DE-1's 10 rpm spin rate.

With all three photometers sharing the telemetry bit-stream three images are transmitted simultaneously in this period, each of angular dimension 30° X 120° and approximately earth-centered. In geocoronal studies it is desirable to obtain scattered Lyman alpha intensities not only in the general direction of earth but over the full sky, as the hydrogen exosphere extends well beyond satellite apogee. For this purpose the two visible wavelength photometers are commanded off-line and the ultraviolet photometer is sampled continuously, sending a panoramic image of dimension 30° X 360°. Each of the 120 scan lines in a complete 360° image contains ~1565 pixels. A detailed description of the optical assembly and its operation is given by Frank et al. [1981].

A wheel containing spaces for twelve filters is located in front of each photometer. It is positioned by ground command. To view the geocorona one position on the ultraviolet filter wheel is fitted with a filter designated "120W", which transmits hydrogen Lyα (121.6 nm) with a photometric sensitivity of 2.18 counts/kilorayleigh-pixel. (One kilorayleigh is an ominidirectional emission rate of 10^9 photons/cm^2-sec in a column of unit cross section along the line of sight.) This filter also transmits atomic oxygen emissions at 130.4 nm and 135.6 nm and LBH band emissions of molecular nitrogen, which are strictly confined to the earth's atmosphere and make no contribution to counting rates in the image beyond a few pixels from the earth's limb. Contributions from oxygen and nitrogen emissions across the disk of the earth may be determined by imaging through another filter, "123W", which is characterized by essentially the same sensitivity versus wavelength curve as filter 120W except that it has a lower cutoff at a wavelength above Lyα (see Figure 1). Thus the net Lyα flux may be obtained by simple subtraction of one image from another.

For greater sensitivity in the upper geocorona the filter wheel may be commanded to the "aperture", a location containing no filter. This location is designated "117A" after the lower wavelength cutoff of 117 nm, the limit for the photocathode substrate. The corresponding photometric sensitivity to Lyα is 7.0 counts/kR-pixel.

Plate 1a is a 30° X 360° ultraviolet image taken with filter 117A on October 14, 1981. The image is presented in three 120° segments as indicated on Plate 1b. Scan lines were acquired from left to right over a period of 12 minutes during which the spacecraft traveled from 2.44 R_E to 2.77 R_E geocentric radial distance along its orbit. Hence the earth appears somewhat wider on the left even though nadir is centered in the frame. The northern auroral auroral oval is visible along the earth's bottom edge. Spacecraft latitude is ~20°N and local time is 09:20. Geocoronal isophote contours for this image are shown on Plate 1b. Another set of contours indicates the angle through which photons from the sun have been scattered to enter the photometer in the geometry of this image.

During the year since launch numerous geocoronal images have been collected in a variety of viewing geometries and scattering angles, establishing an unprecedented data set for quantitative study of the earth's exosphere. The following section presents an elementary treatment of some early images to obtain a measure of the hydrogen densities as interpreted in terms of a spherically symmetric model.

Zenith Intensities

In an optically thin exosphere the intensity of Lyα emission viewed in any direction will be proportional to the integrated column density of geocoronal hydrogen in that direction. A rough conversion from rayleighs to atoms/cm^2 column density requires only the hydrogen resonant scattering cross section in Lyα and the intensity of the solar Lyα emission line. Although the earth's exosphere is optically thin only to a certain depth this is a good approximation for initial estimates of the hydrogen distribution.

A plot of Lyα zenith intensities versus spacecraft geocentric radial distance (Figure 2) illustrates the hydrogen density gradient with altitude. These zenith intensities asymptotically approach the galactic Lyα background values, which range from ~200R to 500R depending on viewing direction. To obtain the net geocoronal contribution we subtract background intensities derived from isophote contour maps published by Bertaux and Blamont [1973] and Thomas and Krassa [1971, 1974] in their analyses of Ogo-5 Lyα measurements at altitudes up to ~24 R_E.

In the optically thin case of single scattering the hydrogen column density L_H is given by

$$L_H = 4\pi I/g$$

where $4\pi I$ is the scattered Lyα intensity and g is the number of photons scattered per second per atom:

$$g = \pi F_0 \left(\frac{\pi e^2}{mc}\right) f_{12}$$

[Brandt and Chamberlain, 1959]. πF_0 is the solar Lyα flux in photons/cm^2-sec-Å and $f_{12} = 2.03 \times 10^{-13}$ is the transition oscillator strength. The solar Lyα flux can be estimated as a function of the Zurich or International sunspot number R_I [Thomas and Anderson, 1976], and

$$\pi F_o \approx [2.25 + (7.38 \times 10^{-3})\, R_I] \times 10^{11} \text{ photons/cm}^2\text{-sec-Å},$$

with a standard deviation of ~10%. Taking $R_I \approx 190$ [Solar-Geophysical Data prompt reports, November 1981] we obtain

$$\pi F_o \approx 3.65 \times 10^{11} \text{ photons/cm}^2\text{-sec-Å}$$

and

$$g \approx 1.96 \times 10^{-3}.$$

Using this value of g as a conversion factor we have converted the zenith intensities in Figure 2 into the vertical column densities shown in Figure 3.

Limb Brightening

As described earlier, the Lyα flux observed across the disk of the earth can be determined by an appropriate subtraction of the oxygen and nitrogen contributions. In this section we apply the technique to an investigation of the observed limb brightening at ultraviolet wavelengths. Three consecutive images from September 28, 1981 are used: one through filter 120W (with Lyα), bracketed by the previous and subsequent images through filter 123W (without Lyα).

The ten central scan lines of each image have been averaged and smoothed to give intensity profiles crossing the earth's sunlit limb perpendicularly. The relevant portions of these are shown in Figure 4, representing ~6 degrees in the direction of scan (note one earth diameter subtends ~26 degrees at these radial distances). DE-1 latitude is ~67°N at a local time of 10:20, and the sun-limb-detector scattering angle is ~95°.

Averaging the bracketing images to compensate for spacecraft motion and subtracting the result from the filter 120W profile yields a flat profile of Lyα emissions (~14 kR) across the limb. This absence of a Lyα signature at the limb is the expected result for an optically thick hydrogen geocorona.

Discussion

We have presented a sample image of the geocorona returned by the University of Iowa spin-scan imaging system on board Dynamics Explorer-1, along with quantitative information in the form of an isophote contour map. Hydrogen Lyman alpha zenith intensities from several points around the orbit have been plotted against geocentric radial distance to illustrate their decrease to values approaching celestial background intensities as DE-1 nears apogee. These zenith intensities were then converted to vertical column densities of atomic hydrogen under the assumption of single scattering of the photons, which is a good approximation at the higher altitudes for these initial studies of the outer geocorona. The inner geocorona becomes optically thick, however, as is seen by the absence of limb brightening at the Lyα wavelength. This necessitates the use of computer modeling of the radiative transfer problem for further investigation of the hydrogen distribution.

Exospheric models, e.g., Anderson and Hord [1977], have vertical optical depths of 2 to 3 above the exobase (~500 km). Since the cross-section for Lyα scattering is 1.6×10^{-13} cm^2, one optical depth of hydrogen is ~6×10^{12} atoms/cm^2. Two to three optical depths are then 1 to 2×10^{13} atoms/cm^2 of vertical column density and correspond to the measurements at perigee with DE-1, but are a factor of 5 to 10 higher than indicated in Figure 3. The single-scattering approximation used here is not expected to be valid at these optical depths.

For comparison with models at larger radial distances the first derivative of the vertical column density as a function of radial distance yields density in atoms per unit volume. Evaluated at 3 R_E geocentric radial distance, for example, we find 400 atoms/cm^3. A 1250°K model used by Thomas and

Anderson [1976] in their analysis of OGO-6 data, when extrapolated upward to 3 R_E, gives a density of ~600 atoms/cm^3. Bertaux and Blamont's [1973] analysis of OGO-5 data extends down to 4.5 R_E, where they found 70 to 120 atoms/cm^3. The preliminary DE-1 result at 4.5 R_E is 70 atoms/cm^3.

Acknowledgments

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Plate Captions

Plate 1a. Vacuum-ultraviolet image of the earth and geocorona from DE-1, 22:44 UT, 14 October 1981. This 30° X 360° image is presented in three 120° segments.

Plate 1b. Isophote contours at 1 kilorayleigh intervals for this image. Angles for single scatter of photons from sun into the photometer field-of-view are also shown.

Figure Captions

Figure 1. The absolute sensitivities of vacuum-ultraviolet photometer C as functions of wavelength for filters 120W and 123W. Hydrogen Lyα (λ121.6) and atomic oxygen (λ130.4 and λ135.6) emission wavelengths are indicated [from Frank et al., 1981].

Figure 2. Zenith intensity of hydrogen Lyα versus radial distance for images with filter 120W (S(Lyα) = 2.18 counts/kR-pixel) on 28 September 1981, and for images in the aperture mode (S(Lyα) = 7.0 counts/kR-pixel) on 14 October 1981. The average value of Lyα galactic background for these zenith look directions is shown (~290 rayleighs).

Figure 3. Geocoronal hydrogen vertical column density versus radial distance as computed from the observations of Figure 3 after background subtraction.

Figure 4. Counts per pixel along the central scan lines of three consecutive images across the sunlit limb. The profile for image UC 1519 is a sum of hydrogen, oxygen and nitrogen emissions, while those for images UC 1518 and UC 1520 are taken with filter 123W which rejects Lyα. Subtraction yields a Lyα profile which shows no limb brightening.

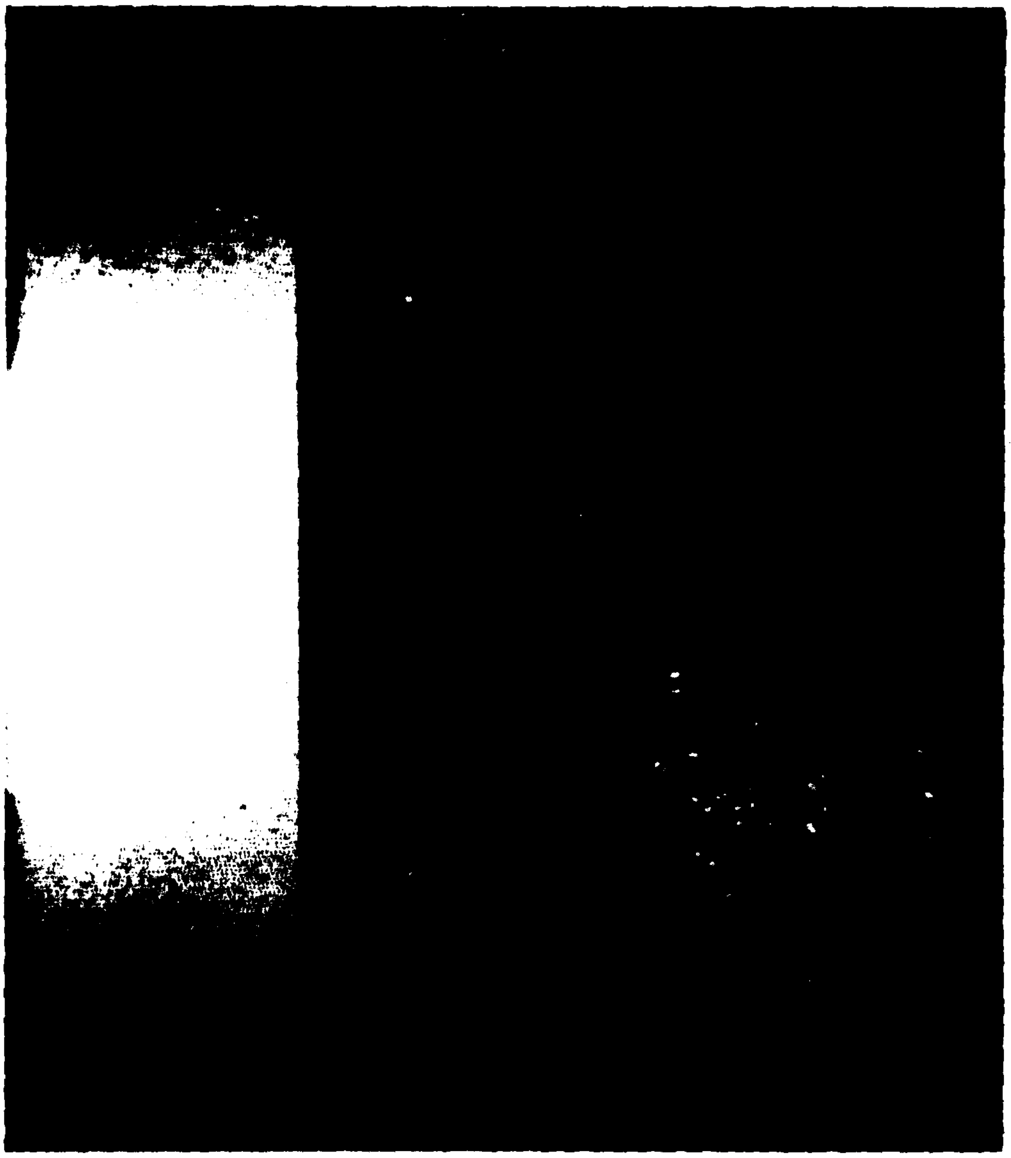

Plate 1a

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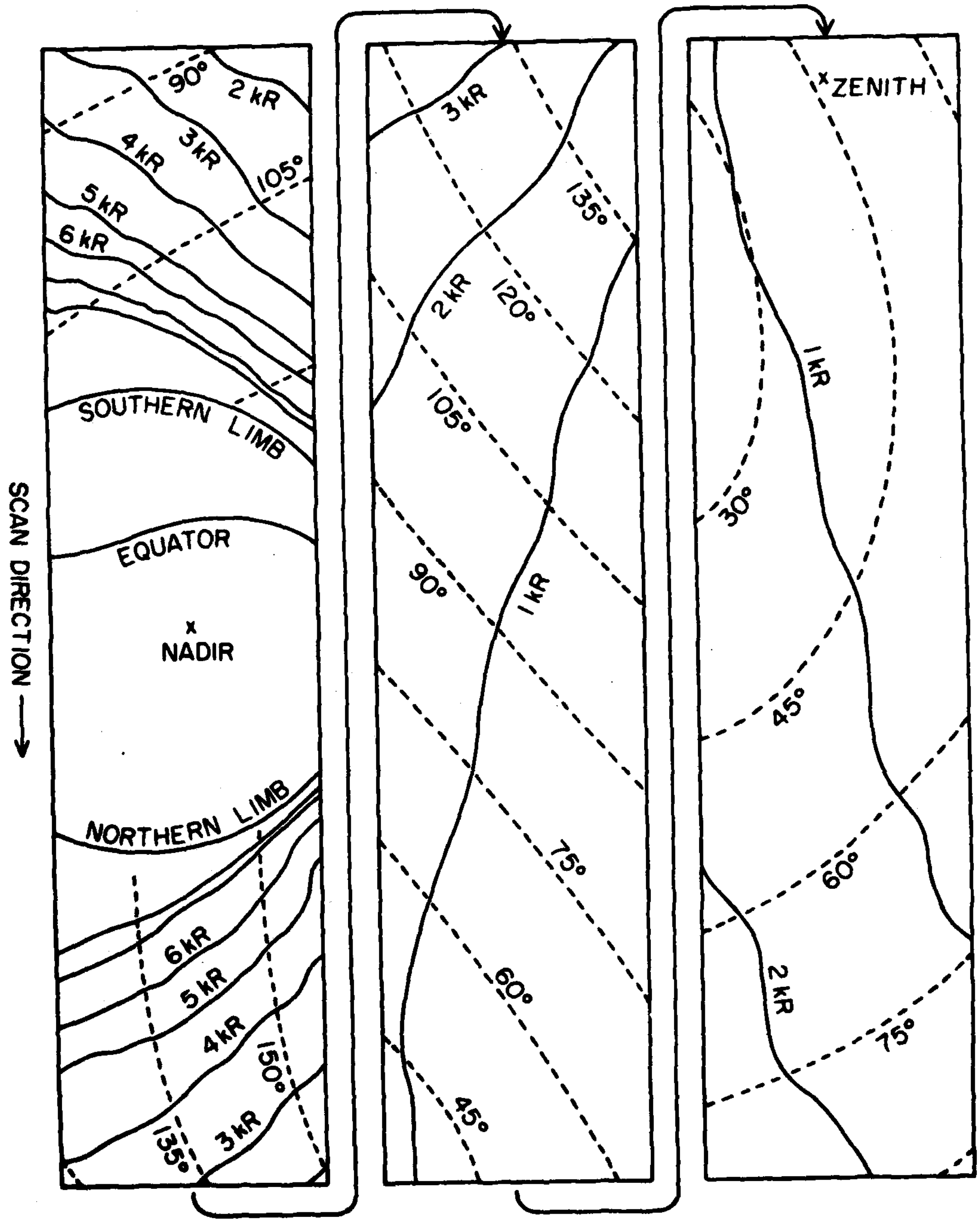

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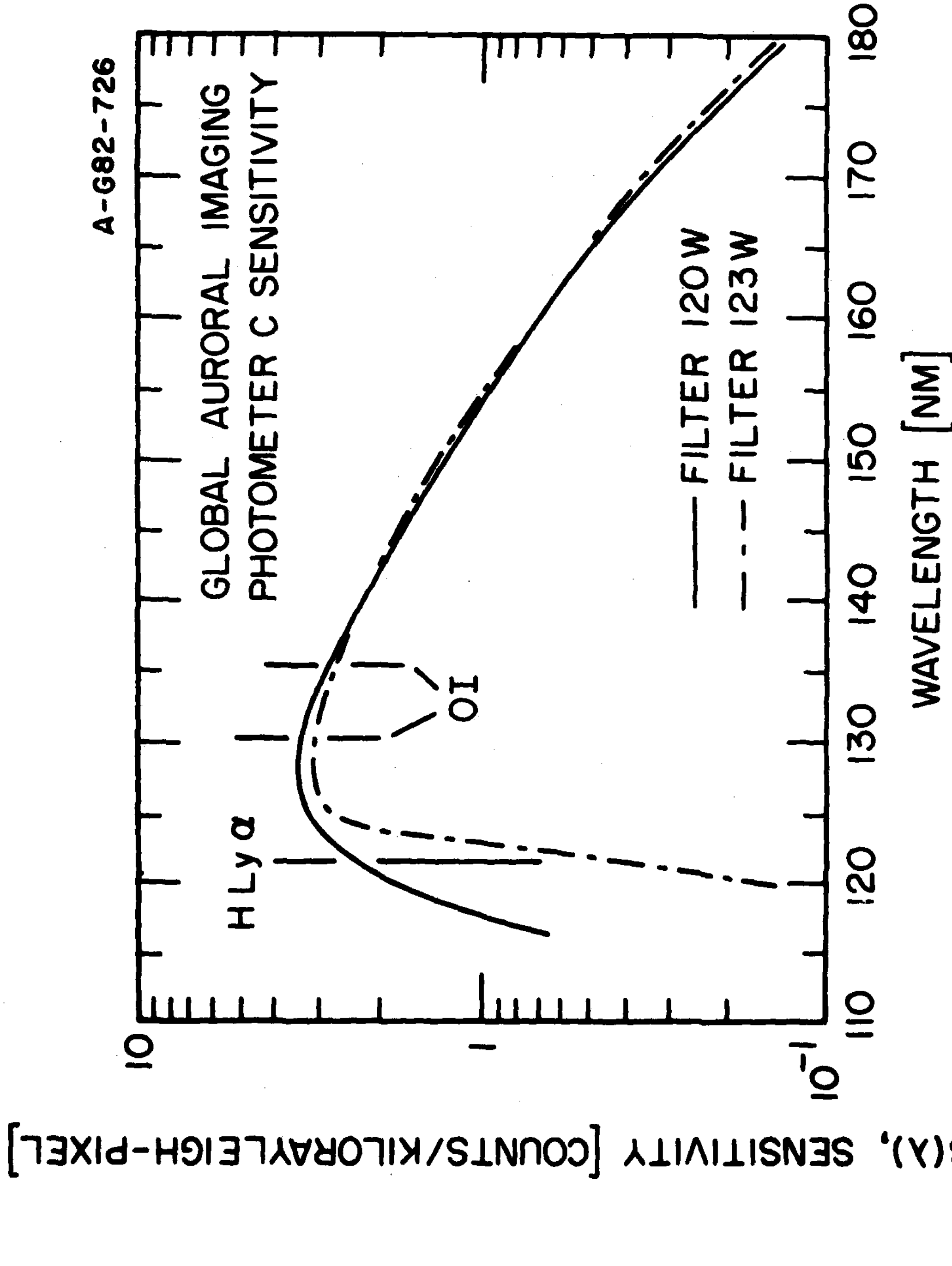
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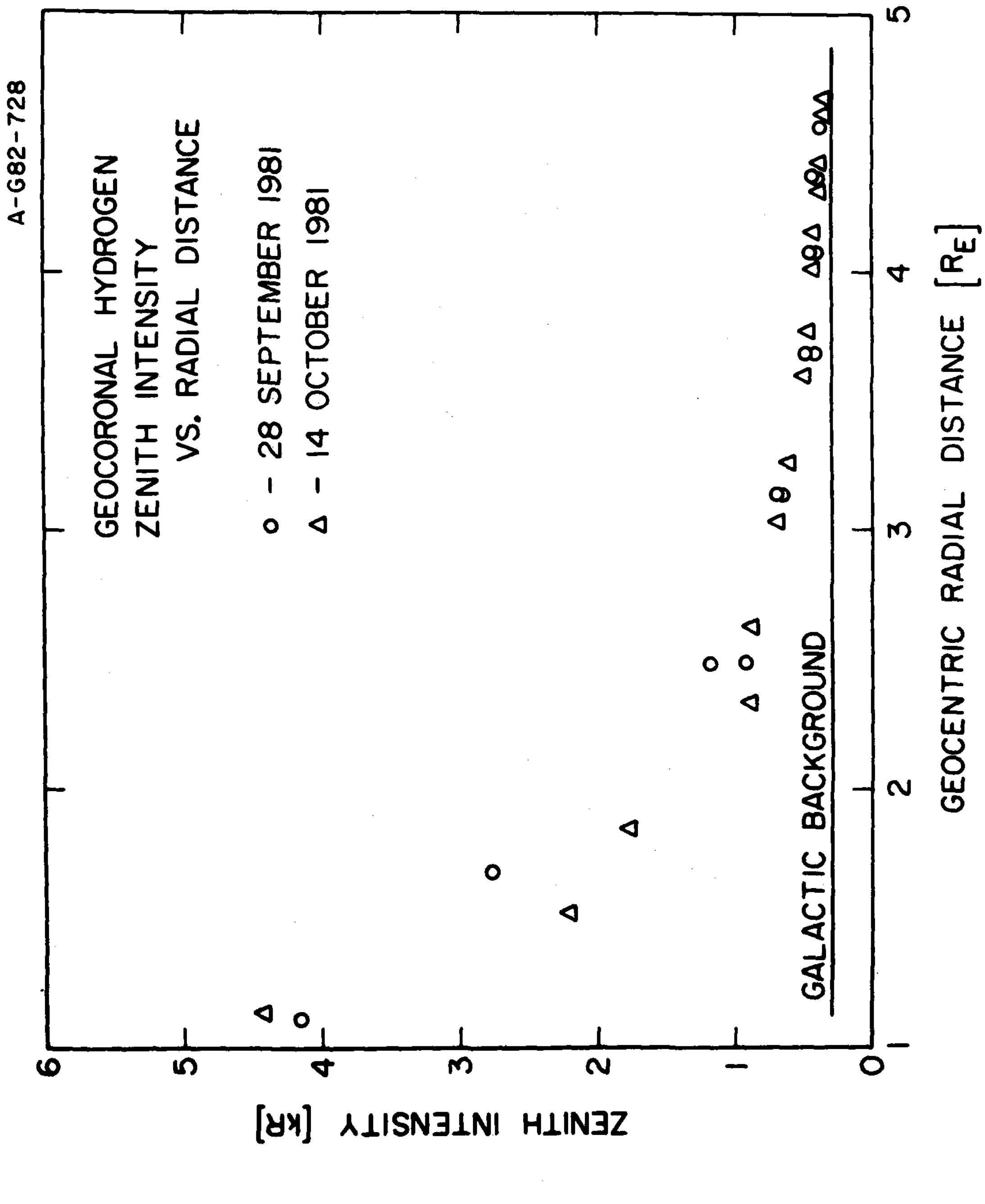
GLOBAL AURORAL IMAGING
PHOTOMETER C SENSITIVITY
H Ly α
OI
FILTER 120W
FILTER 123W
10
1
10^{-1}
110
120
130
140
150
160
170
180
WAVELENGTH [NM]
S(λ), SENSITIVITY [COUNTS/KILORAYLEIGH-PIXEL]

Figure 1



A-G82-728
GEOCORONAL HYDROGEN
ZENITH INTENSITY
VS. RADIAL DISTANCE
o - 28 SEPTEMBER 1981
Δ - 14 OCTOBER 1981
GALACTIC BACKGROUND
ZENITH INTENSITY [kR]
GEOCENTRIC RADIAL DISTANCE [R_E]
0
1
2
3
4
5
6

Figure 2

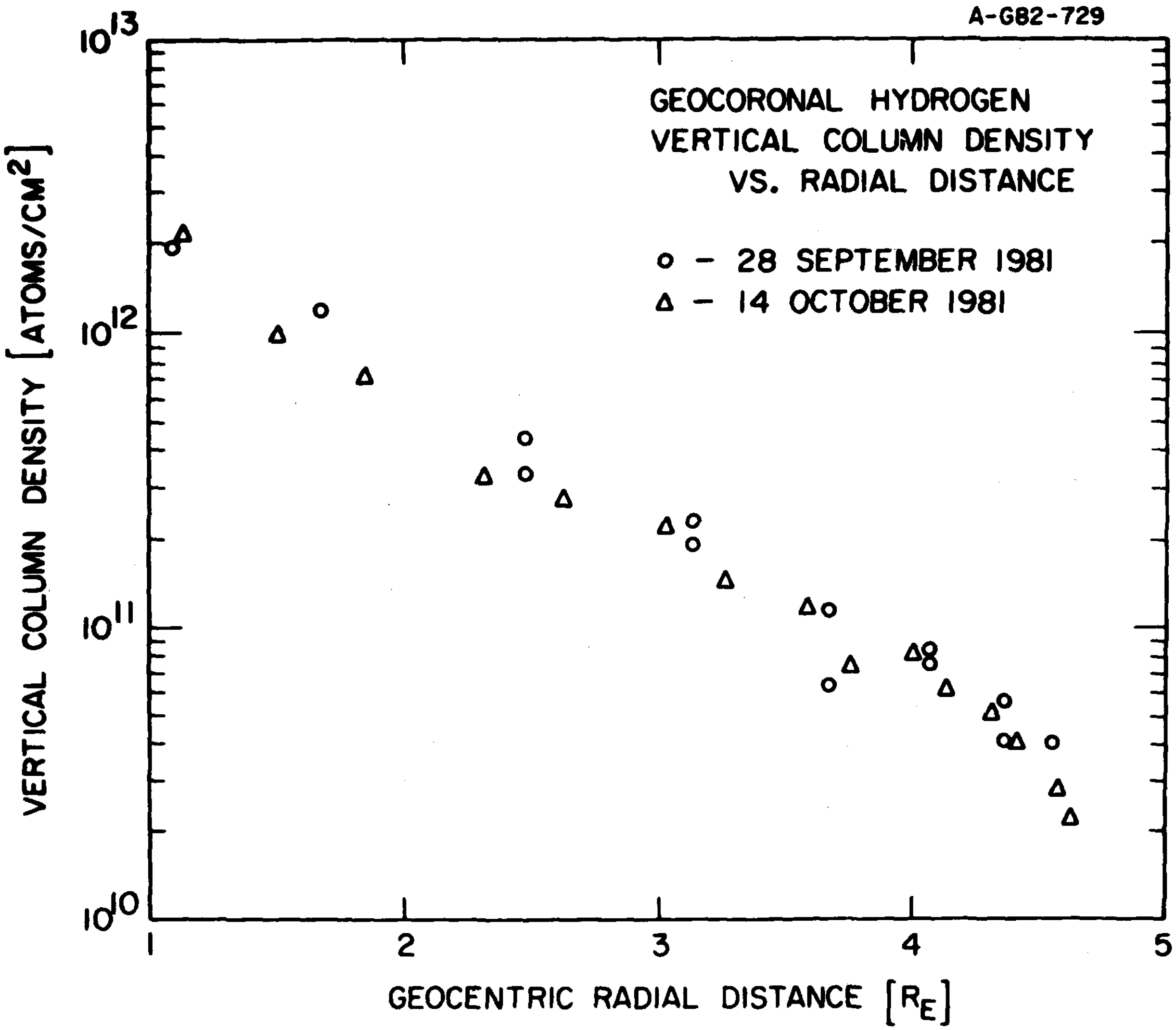

A-G82-729
GEOCORONAL HYDROGEN
VERTICAL COLUMN DENSITY
VS. RADIAL DISTANCE
o – 28 SEPTEMBER 1981
Δ – 14 OCTOBER 1981
VERTICAL COLUMN DENSITY [ATOMS/CM^2]
10^{13}
10^{12}
10^{11}
10^{10}
1
2
3
4
5
GEOCENTRIC RADIAL DISTANCE [R_E]

Figure 3

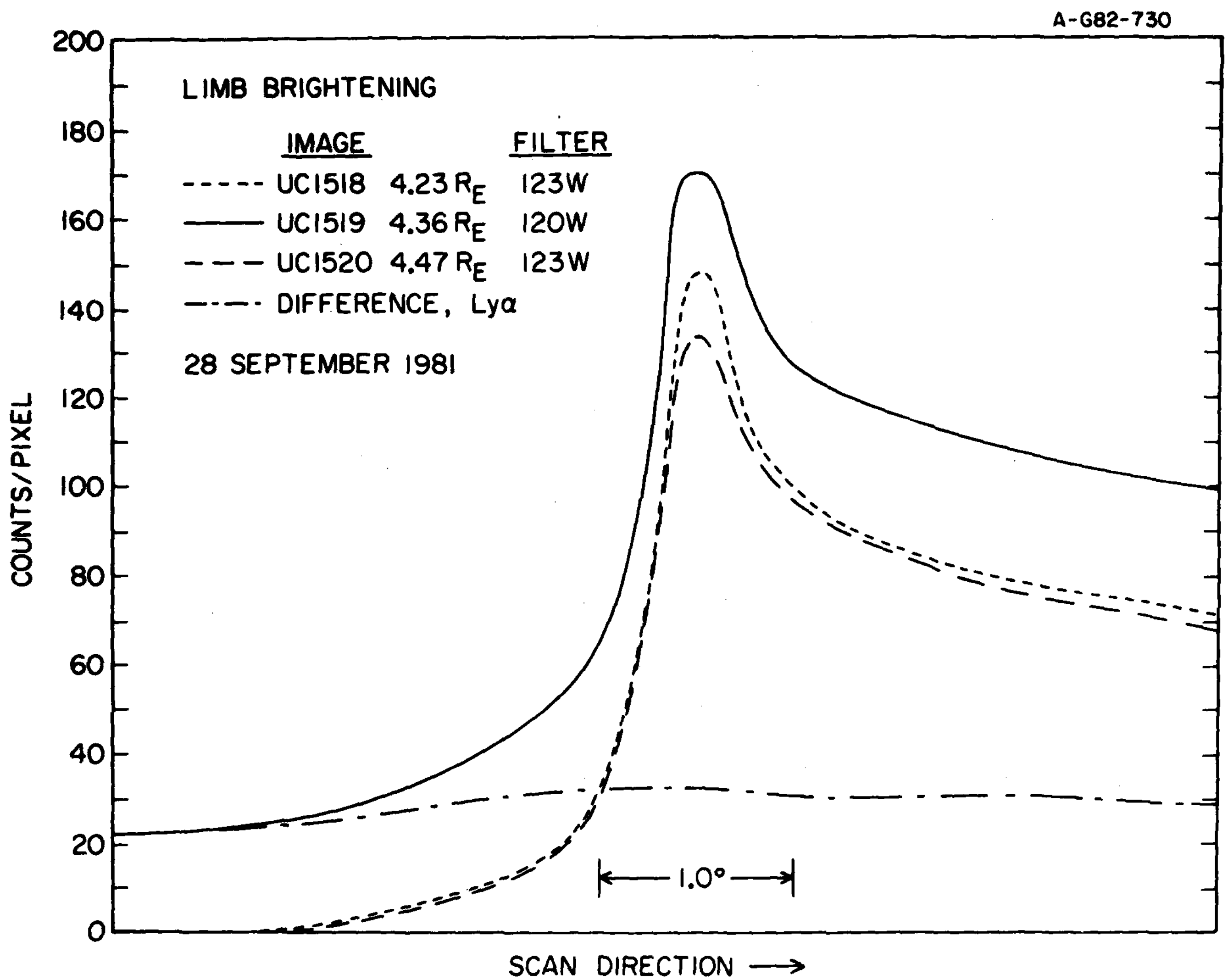

A-G82-730
LIMB BRIGHTENING
IMAGE
FILTER
UC1518 4.23 R_E 123W
UC1519 4.36 R_E 120W
UC1520 4.47 R_E 123W
DIFFERENCE, Lyα
28 SEPTEMBER 1981
1.0°
COUNTS/PIXEL
200
180
160
140
120
100
80
60
40
20
0
SCAN DIRECTION →

Figure 4

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