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LYMAN-ALPHA EMISSION FROM ARCTURUS

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ABSTRACT

The K2 IIIp star Arcturus was observed by a rocket-borne precision-pointing telescope and ultraviolet spectrometer. Only one spectral scan was obtained; it showed a definite enhancement of the H I line at 1216 Å over the geocoronal background. This excess is interpreted as chromospheric Lα emission from Arcturus.

I. INTRODUCTION

Since the discovery of the Earth's ionosphere, it has been realized that even stars as cool as the Sun are capable of emitting a certain amount of hard radiation, radiation that is characteristic of a temperature much higher than the blackbody temperature associated with the bulk of their emission. Until the detection of the 10830 Å line of neutral helium in G and K stars by Vaughan and Zirin (1968), about the only observational evidence for chromospheres in late stars other than the Sun was the presence of Ca II H and K reversal radiation (e.g., Wilson and Skumanich 1964).

The solar chromosphere is at an elevated temperature probably because of energy deposited there by shock waves, which are the result of noise generated by the turbulence that is observed in the photosphere below. The very high turbulence that is observed in a study of the curve of growth of elements in giant stars cooler than the Sun would lead one to expect a stronger energy input to the chromospheres of such stars, but the resulting heated layer might be effectively drained by a stronger stellar wind (Ulmschneider 1966). An unambiguous test for the presence of a chromosphere in cool stars would be the presence of Lyman-series emission, which must be produced either by collisional excitation or by recombination. Study of the amount and nature of such emission should elucidate the structure of the chromosphere of late-type stars. Patterson (1966) has calculated the Lα flux for several types of stars including a late-type giant.

The star α Boo is a particularly good candidate for observation of the H I line at 1216 Å. It is of spectral type K2 IIIp (Hoffleit 1964), has a high luminosity, and is quite close (11 pc). A more distant star might have much of its Lα emission absorbed by interstellar hydrogen. Very little is known about the hydrogen density in the solar neighborhood. The Sun is believed to be situated slightly to the north of the galactic plane as defined by the general vertical distribution of mass (Elvius 1965) or by the position of the neutral-hydrogen layer (Gum, Kerr, and Westerhout 1960). Arcturus is at a high northern galactic latitude ($l^{II} = 15°$, $b^{II} = +69°$). The 21-cm emission in its direction indicates 4×10^{20} neutral hydrogen atoms per cm^2 (Garmire and Kraushaar 1965; Kerr and Westerhout 1965). With a half-thickness of 110 pc for the hydrogen (Kerr and Westerhout 1965), this column density predicts a Lα absorption equivalent width of 4.3 Å for a star at a distance of 11 pc. Experience has shown that Lα absorption lines often indicate densities one-tenth that predicted by 21-cm emission. If this applies in the present case, then the predicted width is 1.4 Å. A scaling of rocket results for much larger distances (Morton 1967; Carruthers 1970) suggests an absorption-line width of $\sim$1 Å. Solar Lα is 1 Å wide (Tousey 1963), and the emission from Arcturus would be expected to have a width similar to that of the Sun (Patterson 1966). Thus, although the interstellar absorption of Lα from Arcturus is probably significant, it is likely not to be total.

Arcturus was the first of three targets programmed for observation from an Aerobee rocket carrying a precision-pointing telescope-spectrometer. Because of a malfunction in the rocket system, the star was observed for only a few seconds. Nevertheless, a scan through Lα was obtained while the telescope was pointed at α Boo, and a definite increase in the signal at 1216 Å was observed.

II. EXPERIMENTAL DETAILS

The Aerobee rocket was launched from White Sands at 00:00 hours MST on 1970 June 2. In addition to the experimental package, it carried a STRAP III attitude control system which used both inertial guidance and a star tracker to point the rocket. The experiment consisted of a Dall Kirkham telescope (Bottema, Fastie, and Moos 1969) which imaged the star onto an entrance slit of a Czerny-Turner LiF prism spectrometer (Moos *et al.* 1970). The telescope contained a supplementary star tracker which sampled a portion of the telescope beam in order to servocorrect the secondary mirror for bore-sighting errors and for jitter in the pointing by the STRAP III system. Corrections could be made for bore-sighting errors of $\pm 7'.5$ and jitter rates of 130″ sec^{-1}. Data from a previous flight indicate an overall system-pointing accuracy of $\sim$1″. The entrance slit of the spectrometer was rigidly connected to the star tracker. Measurements made before and after four flight-qualifying vibration tests and four rocket flights, including the present flight, indicate that the two do not shift with respect to each other more than 2″. By monitoring the error signal of the star tracker the offset of the image from its centered position was known at any time during the observation. The response time of the error signal was better than 10 msec. The prism spectrometer was provided with dual entrance and exit slits. The stellar image fell in the center of a circular slit 51″ in diameter. (The inclusion of Jupiter in the other targets on the flight necessitated the large aperture.) The terrestrial airglow, primarily Lα, was monitored by a 50″ $\times$ 250″ rectangular slit situated in the focal plane about 500″ from the image slit. The ratio of the terrestrial Lα (caused by the multiple scattering in the geocorona of solar Lα) through the two slits was very accurately determined in flight, and thus the geocoronal contribution through the stellar-image slit could be subtracted for any spectral scan. The region between 1200 and 1900 Å was scanned by partial rotation of the prism with a 4.25-sec period; the spectral resolution at 1216 Å was 12 Å. The signal was detected by two EMR 641G (extreme solar blind CsI cathode) photomultipliers with pulse-counting electronics. The dark-count rates measured in flight prior to nose-cone ejection were $\sim$1 count sec^{-1}, and signals of a few counts per second were considered significant. Similar detection systems have been used on previous flights to measure the weak ultraviolet emission spectra of Venus and Jupiter (Moos, Fastie, and Bottema 1969) and to measure the weak emission of O I $\lambda\lambda$1304 and 1356 in the late evening twilight (Buckley 1969).

III. RESULTS

Due to a malfunction, the STRAP III system was able to hold Arcturus within the field of view of the telescope only for the period from 109 sec to 115 sec after launch. No further targets were acquired for the remainder of the flight, but airglow Lα was monitored for about 250 sec by both the image and the airglow slits. On Arcturus the jitter rate about the yaw axis was quite large, and the servo-control system of the telescope tracker had difficulty following it. However, it could be determined from the error signal of the telescope tracker when the image of Arcturus was actually held within the entrance slit. The spectral regions 1210–1230 Å, 1245–1425 Å, and 1650–1750 Å were scanned during the three periods the image was within the slit. As expected, no signal was observed in the latter two spectral regions. The first region contains all but the very beginning and very end of the Lα line; 92 percent of the signal was observed.

Figure 1 shows the Lα data for the image and airglow slits as a function of altitude in the time period of interest. The ratio of the image-slit to airglow-slit sensitivities was determined in flight to be 0.556 ± 0.018, and this is the ratio of the two ordinate scales in Figure 1. To within ± 0.01, the measured ratio did not change from the beginning to the end of the flight. The photomultipliers and pulse-counting electronics for each slit—the components most susceptible to change—were calibrated before and after the flight. The sensitivity ratio changed by less than 4 percent. The error bars in Figure 1 are $\pm\sqrt{N}$, where N is the number of counts.

The Lα from the terrestrial hydrogen geocorona increased slowly with altitude due to the decrease in optical thickness of terrestrial H and possibly slight outgassing of water vapor from the rocket. The solid curve in Figure 1 represents a best fit to the Lα data from the airglow slit. Except at Arcturus, where the enhancement is apparent, the image-slit data agree extremely well with the curve. From the solid curve, the expected mean terrestrial-airglow signal through the image slit for the spectral scan in which Arcturus was observed should have been 31 ± 3 counts. The value ± 3 represents the uncertainty in the predicted mean and was determined from the fit. Specifically, the deviation of the airglow data from the curve for the three altitudes centered on the observation altitude of Arcturus were used to determine this uncertainty. We are not certain that the star was within the slit for two short periods of time at the very beginning and very end of the Lα line. During the period when the star was certainly within the slit, the mean airglow contribution to the image slit should have been 28 ± 3 counts. The observed signal during this period was 46 counts. The probability that such a value or larger be a statistical fluctuation was ≤ 0.3 percent, thus highly unlikely. In the other forty-seven spectral scans, no percentage deviation this large was observed. The next

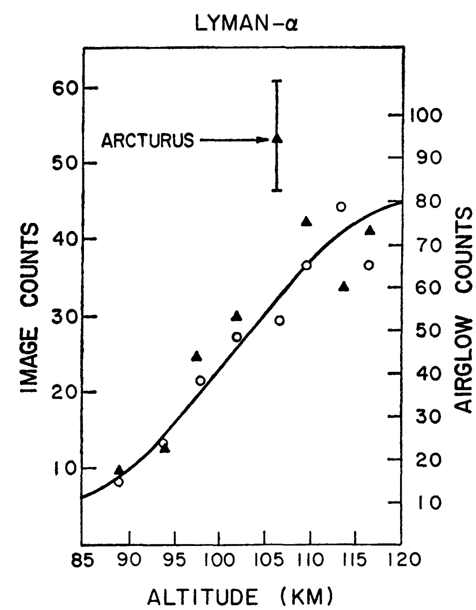

FIG. 1.—Counting rates as a function of rocket altitude for Lα from the airglow detector (*open circles* and *solid fitted curve*) and for Lα from the image detector (*solid points*). Ordinate scales have been so adjusted as to produce agreement. The one spectral scan taken with Arcturus present on the entrance slit of the image channel gives a point significantly above the expected mean Lα from the terrestrial hydrogen geocorona. The error bars are $\pm\sqrt{\langle N \rangle}$, where $\langle N \rangle$ is the number of counts.

largest was 2σ with a probability of occurrence of 4.5 percent ($\sigma = \sqrt{\langle N \rangle}$, where $\langle N \rangle$ is the mean counting rate). Particle showers and hard radiation can be ruled out by the fact that the excess occurred only during the Lα scan and only on one photomultiplier. The most plausible conclusion is that the excess was due to Lα emission from Arcturus. The excess of 18.0 ± 7.4 counts (i.e., $46 \pm \sqrt{6}$ counts minus 28 ± 3 counts) corresponds to a net flux of 4.0 ± 1.6 photons cm^{-2} sec^{-1} at the Earth. In addition, there is an uncertainty in the flux of a factor of 2.0 due to possible errors in the calibration of the experiment.

IV. DISCUSSION

The observed Lα flux from Arcturus of ~ 4 photons cm^{-2} sec^{-1} at the Earth is to be compared with the solar Lα flux of 3×10^{11} photons cm^{-2} sec^{-1} (Hinteregger 1970). Without correction for interstellar absorption, this implies a Lα luminosity for Arcturus about 70 times the solar value. Because of interstellar Lα absorption, the true Lα luminosity may be even greater. The model used by Patterson (1966) for a late-type giant [log $(R_{\alpha \mathrm{Boo}}/R_{\odot}) \approx 1.43$, where R is the radius (Pease 1945)] at a distance of 11 pc would predict a Lα luminosity on the order of 22 times the solar value. Although the uncertainty in the measured value precludes a definitive estimate of the Lα emission from Arcturus, the agreement with Patterson's model is reasonable.

It is unfortunate that only one spectral scan was obtained. Although it is highly unlikely that the Lα enhancement on the Arcturus scan was a chance fluctuation in the geocoronal background signal, it is clear that further observations should be made.

The Lα signal observed from Arcturus is sufficiently large to permit higher-spectral resolution observations. Such an observation might give a line shape containing information not only on the stellar chromosphere but also on the interstellar density of neutral hydrogen.

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