STUDIES OF THE LOCAL INTERSTELLAR MEDIUM

Final Report

1 May 1979 - 30 September 1979

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NASA Grant NSG 5293

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INTRODUCTION

This grant covers studies of the local interstellar medium from absorption lines observed in the spectra of nearby, late-type stars. Since the resonance lines of interstellar hydrogen and deuterium appear in absorption against the strong chromospheric emission line of hydrogen Lyman-α, it is both useful and necessary to study the chromospheric structure as well.

During this reporting period, activity included analysis of existing ultraviolet and optical data on late-type stars, preparation and publication of results, and acquisition and reduction of additional ultraviolet and some simultaneous ground-based observations. The stars studied were Alpha Centauri A and Lambda Andromedae. The results for each of these stars are discussed below as related to the topics of stellar chromospheres or to the interstellar medium.

STELLAR CHROMOSPHERES AND CORONAE

Lambda Andromedae: In collaboration with Harvard graduate student, S. Baliunas, the Copernicus ultraviolet and ground-based spectroscopic observations of this 20-day-period late-type binary system have been analyzed. This recently discovered soft X-ray source also exhibits extreme chromospheric activity. Showing as it does intense and variable Ca II emission in our accumulated spectra, the chromosphere of Lambda And has been modeled extensively.

A paper concerning our simultaneous ground-based and Copernicus observations has appeared in the Astrophysical Journal. An abstract of the paper, and some of the figures are attached. Some major results discussed in the paper are:

(1) The disk-averaged Ca II profiles resemble those of the active Sun in appearance; additionally, the surface fluxes of the H-Lα and Mg II emission features are similar to those seen in the active Sun (see Fig. 1).

(2) Circumstellar material emitting at Ca II may be present in variable amounts in the binary system (see Fig. 2).

(3) Chromospheric models may require sonic turbulent velocities to describe the Ca II features.

(4) The time-variability of the chromospheric features has implications for and provides constraints on chromospheric models (see Figs. 3 and 4).

The spectra we obtained are being employed in semi-empirical models of the chromospheres, constructed with an extensive computer code. The high-resolution profiles of Ca II, Mg II, and Hα are predicted by specifying the chromospheric temperature rise and micro-turbulent velocity fields with atmospheric densities. A paper containing the initial results of model calculations for λ And has appeared in the Astrophysical Journal (Letters). An abstract of this paper is attached. A major result of this paper concerns a caveat for generalizations of previous models of stellar chromospheres to all stars. Earlier models were overly restrictive in the exploration of the range of reasonable physical assumptions and parameters. The success of our models, which rely on observational constraints provided by several optical and ultraviolet regions, casts doubt upon

previously-published "scaling laws" of chromospheric density with stellar gravity. Unlike the results of earlier attempts, our models are gratifyingly compatible with stellar analogies to solar activity.

Alpha Cen A: Our previous observations have been reduced and the final analysis is proceeding in collaboration with W. Hagen, a Postdoctoral Fellow at the Center for Astrophysics. It appears that Alpha Cen A is not as similar to the sun as has been previously supposed. In particular, the surface flux of the Si III line at 1206 Å is lower by an order of magnitude as compared to predictions based on the Ca K lines and scaling by solar models.

We re-observed α Cen A with Copernicus in May 1978 and received the data tape from Princeton some months later. This data is being analyzed in collaboration with Harvard Postdoctoral Fellow S. Baliunas.

We obtained ∿ 200 scans of the region of the O VI feature (1032 Å) with the low-resolution U2 detector. The data were processed by eliminating those scans contaminated by electronic interference from the U1 carriage slews. Due to both the number of scans eliminated and the degradation in efficiency of the Copernicus satellite, our upper limit of non-detection was not as sensitive as had been expected. For the O VI feature, our upper limits to the surface flux is $\lesssim 1 \times 10^{14}$ photons cm^{-2} s^{-1} for a 3σ detection. By comparison, this is a factor of ∿ three times the quiet sun value, or a factor of ∿ two times the surface flux for an active region.

The observations pertaining to the interstellar medium, which were also obtained in May 1978, will be discussed below.

THE LOCAL INTERSTELLAR MEDIUM

Along with the chromospheric features in our spectra, the interstellar L-DI and L-HI lines appear. The abundance of deuterium has substantial implications for many areas of astrophysics - the most notable being its use as a probe of the early stages of the universe. Our results of the analysis towards the nearby stars Alpha Aur and Alpha Cen A indicate that there may be substantial local variations in the ratio of the abundances of deuterium to hydrogen. Our analysis of Lambda And (combined in the paper concerning chromospheric analysis) shows an interstellar deuterium line that appears weakly, and yields a ratio of abundances of DI to HI lower than that of any other local measurement. A variation of the deuterium abundance implies a local scale of astration, galactic production of deuterium, or concentration anomalies in the galaxy. A galactic mechanism for production of deuterium may contaminate the use of this isotope as a test of the primordial density of the university.

We requested and were granted additional time to reobserve these interstellar features with Ul towards Alpha Cen A. The data were acquired in May 1978. The data reduction and analysis are being carried out in collaboration with Harvard Postdoctoral Fellow S. Baliunas.

Careful handling of the background emission was necessary in the data reduction; the weak stellar signal is affected by both the wavelength and time dependence of the background emission (the latter due in part to increased solar activity) during the observations. Approximately half of the scans were discarded when stringent requirements on the smooth behavior of the backgrounds for each scan were applied. The final profile

for Lα from α Cen A is appended. The quality of this profile, especially in the region of the DI feature, is improved over that of our original data.

In order to determine the density of hydrogen and deuterium in the interstellar gas towards α Cen A, we will use two different methods of analysis. We have developed computer programs which analyze the data in both ways. Our "forward-backward" scheme approaches the possible solutions from two different directions:

(1) We start with assumed profiles which describe the interstellar hydrogen and deuterium gas. These calculated profiles are divided into the observed profile. The resulting stellar profile is compared to an expected range of intrinsic Lα H-I emissions.

(2) We start with an assumed Lα HI stellar profile. Upon this stellar profile, we superpose absorption profiles of the interstellar HI and DI gas. Matches to the observed profile are sought.

The key to this scheme is its flexibility in the determination of a range of acceptible solutions. We will test the expected range of several parameters. For example, the intrinsic Lα profile for α Cen A should not be far from solar. However, a somewhat wider emission may be expected since the chromospheric Ca II-K profile is wider than that of the sun. The possible asymmetric appearance of the profile is being tested. For example, the solar Lα profile changes asymmetry with activity cycles. The strength of any underlying asymmetry will affect the appearance of the observed profile and hence the deduced abundance of interstellar gas. An examination of published Mg II and Ca II data may provide evidence for any

asymmetries since the cores of these profiles are formed in close proximity in the atmosphere.

The deuterium feature in α Cen A appears puzzling in the high resolution data. The line is either broader than expected or there are two absorption features near the expected DI wavelength. It is possible that the end of a Ul scan that occurs near the position of the DI line affects the line profile.

We will endeavor to remeasure this absorption feature again, by using 1 standard routine centered on the DI line. We have 24 hours of unused scanning time on Copernicus that could be used for this purpose.

Publications and Presentations

During this reporting period, the following papers were published that incorporated scientific results from this Grant. In addition, many of the results of the ultraviolet observations from Copernicus were incorporated in the Ph.D. thesis of Harvard graduate student S. Baliunas.

"Ultraviolet and Optical Spectroscopic Studies of Lambda Andromedae: The Chromosphere and Interstellar Medium", S.L. Baliunas and A.K. Dupree. Astrophysical Journal, 227, 870, 1979.

"High-Pressure Transition Regions in Stellar Model Chromospheres", S.L. Baliunas, E. Avrett, L. Hartmann, and A.K. Dupree. Astrophysical Journal (Letters), 233, L129.

"The Interstellar Medium in the Solar Vicinity", A.K. Dupree and S.L. Baliunas, invited review talk at IAU Comm. 34, General Assembly of the IAU, 1979.

"Ultraviolet and Optical Studies of Stellar Chromospheres of λ Andromedae and Other Late-type stars", S.L. Baliunas, Ph.D. Thesis, Harvard University, 1979.

FIGURE CAPTIONS

Fig. 1 - Simultaneous satellite (Mg II, H-Lα) and ground-based (Ca II) observations for 1974 Oct. The Ca II profiles have been normalized in the photospheric wings, in a region free of identifiable features. The ultraviolet spectra have had constant continua removed. For H-Lα, dashed lines indicate the deletion of contamination by geo-coronal emission ($\nu\lambda$1215) and electronic interference ($\nu\lambda$1212). The central reversal, absorbed in part by interstellar hydrogen, probably reaches zero intensity. The wavelength scales for Mg II and Lα are relative to the systemic velocity of λ And (γ = +6.8 km s^{-1}).

Fig. 2 - Lyman alpha interstellar and stellar hydrogen, and interstellar deuterium. The low-resolution (U2) profile is from Fig. 1. The solid line is the high-resolution (U1) profile of 1976 Oct. The wavelength scale is relative ot the systemic velocity of the U1-phototube. The U1-scale has been shifted towards longer wavelengths to account for the difference in radial velocity of the primary star at the two spectroscopic phases, and the temperature-dependence of the velocity-scale of the U1-phototube. The efficiency of the U2-and U1-phototubes is approximately the same due to the degradations of the sensitivities of the two phototubes between the observation dates.

Fig. 3 - Lyman alpha interstellar and stellar hydrogen and interstellar deuterium profiles of May 1978 for Alpha Cen A.

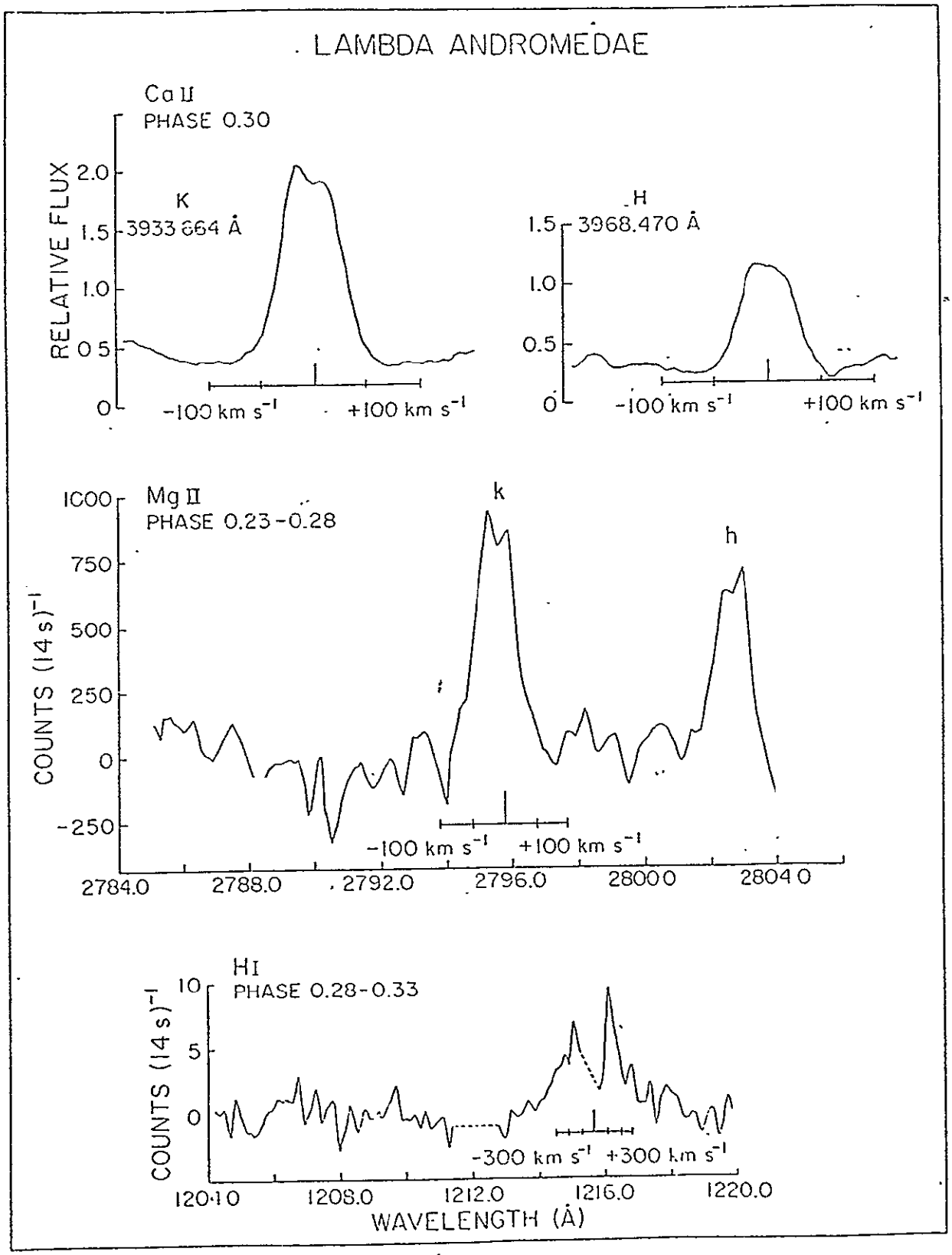
LAMBDA ANDROMEDAE
Ca II
PHASE 0.30
K
3933.664 Å
H
3968.470 Å
RELATIVE FLUX
2.0
1.5
1.0
0.5
0
-100 km s⁻¹
+100 km s⁻¹
Mg II
PHASE 0.23-0.28
k
h
COUNTS (14 s)⁻¹
1000
750
500
250
0
-250
2784.0
2788.0
2792.0
2796.0
2800.0
2804.0
HI
PHASE 0.28-0.33
10
5
-300 km s⁻¹
+300 km s⁻¹
1204.0
1208.0
1212.0
1216.0
1220.0
WAVELENGTH (Å)

Figure 1

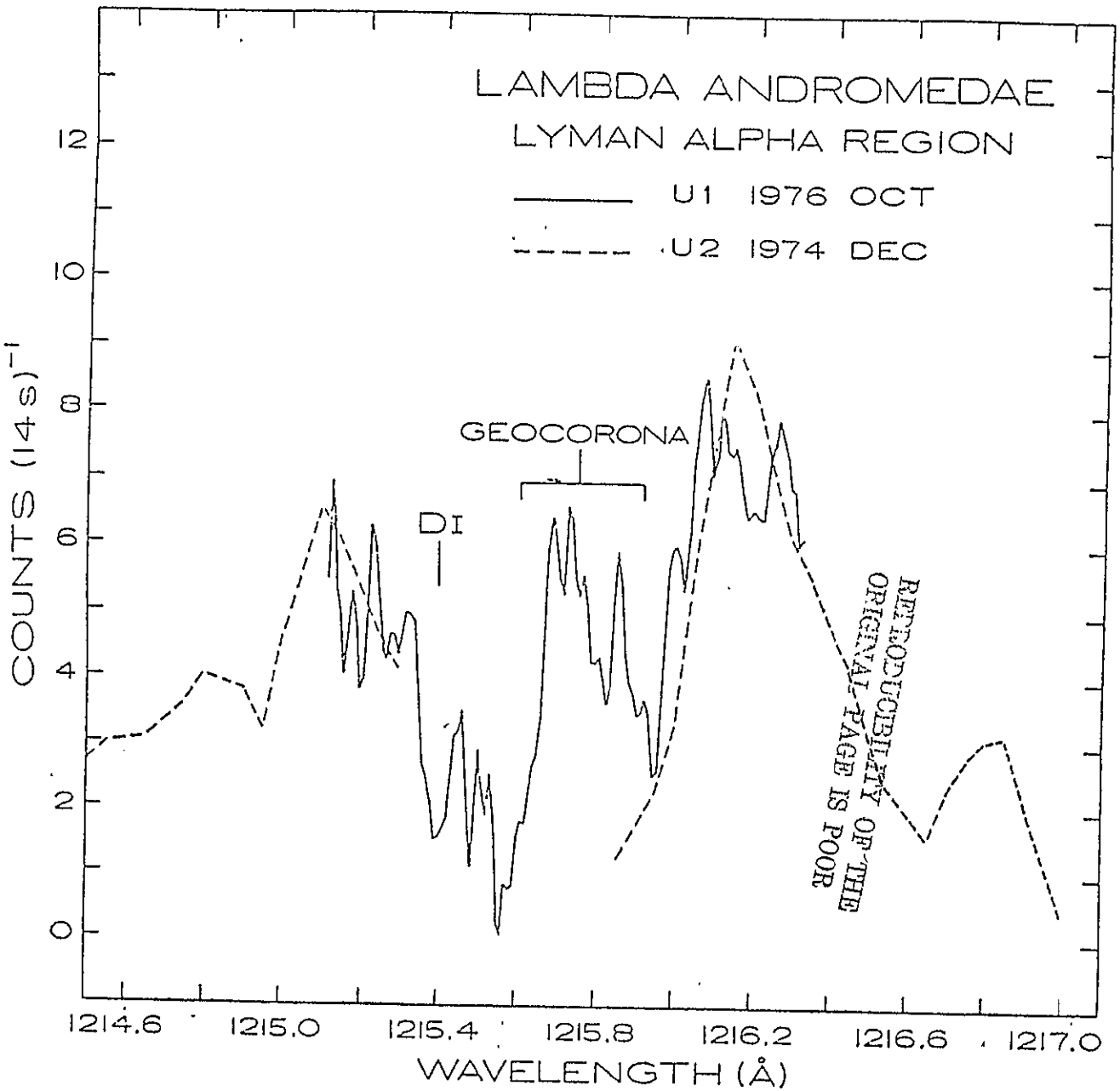
LAMBDA ANDROMEDAE
LYMAN ALPHA REGION
U1 1976 OCT
U2 1974 DEC
GEOCORONA
DI
COUNTS (14 s)$^{-1}$
WAVELENGTH (Å)
0
2
4
6
8
10
12
1214.6
1215.0
1215.4
1215.8
1216.2
1216.6
1217.0
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Figure 2

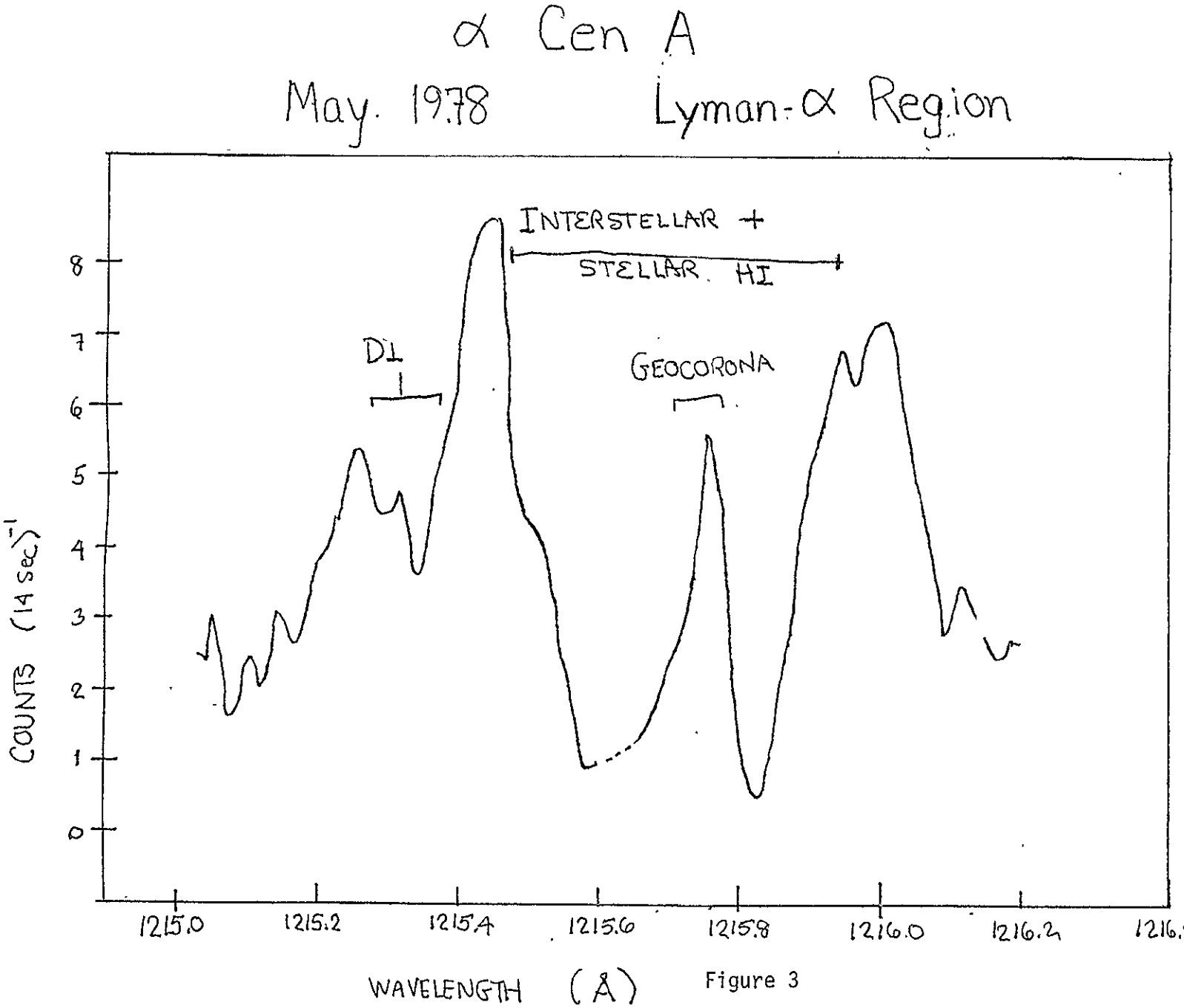

Figure 3

THE ASTROPHYSICAL JOURNAL, 227:870–883, 1979 February 1

ULTRAVIOLET AND OPTICAL SPECTROSCOPIC STUDIES OF λ ANDROMEDAE: THE CHROMOSPHERE AND INTERSTELLAR MEDIUM

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Received 1978 May 15; accepted 1978 August 9

ABSTRACT

Chromospheric lines of, and interstellar lines toward, the spectroscopic binary λ And (primary component G7–G8 III–IV) have been observed in the ultraviolet with the spectrometer and telescope on board the *Copernicus* satellite. An extensive, high-resolution spectroscopic study of the Ca II H and K profiles has also been undertaken. Some of these optical spectra were obtained simultaneously with the ultraviolet data.

The ultraviolet emission lines of λ And are compared to the Sun and to stars of similar spectral type. The star λ And resembles the active Sun in surface brightness of chromospheric emissions and in appearance of the Mg II and Ca II profiles. The largest variations in the integrated calcium emission cores amount to an 80% increase in the K core and a corresponding 40% increase in the H core between observations two years apart. Variations in the cores may show a dependence on spectroscopic phase, and may be contributed to by circumstellar matter in the binary system. Previously unreported, transient emission features have also been observed, at a velocity of -70 km s^{-1} with respect to the Ca II emission cores.

In the interstellar medium toward λ And, the volume density of neutral hydrogen is $\sim$0.03–0.08 cm^{-3}. The absorption feature of deuterium appears weakly.

Subject headings: Ca II emission — interstellar: abundances — stars: binaries — stars: chromospheres — stars: individual — ultraviolet: spectra

THE ASTROPHYSICAL JOURNAL, 233:L129–L133, 1979 November 1

HIGH-PRESSURE TRANSITION REGIONS IN STELLAR MODEL CHROMOSPHERES

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Received 1979 April 26; accepted 1979 July 19

ABSTRACT

We have investigated the implications of recent ultraviolet observations of stellar transition-region lines for calculations of the Ca II and Mg II resonance lines. We find that the adoption of high transition-region pressures for stars with active chromospheres, such as λ And and α Aur, can be consistent with observed Ca II fluxes, contrary to the results obtained by Kelch *et al.* for α Aur. Furthermore, the adoption of the high-pressure models removes a long-standing difficulty in the line profile calculations, since the deep central absorption present in earlier calculations is less pronounced or absent, in closer agreement with observations. We also discuss the apparent contradiction between these models and the recent density diagnostic of Doschek *et al.*

Subject headings: line formation — stars: atmospheres — stars: chromospheres — ultraviolet: spectra

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