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Jonathan Charles Truax

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A SEARCH FOR RS CVn / BY DRACONIS VARIABILITY IN A SAMPLE OF 11 NEW CaII EMISSION LINE STARS

By

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ABSTRACT

A SEARCH FOR RS CVn / BY DRACONIS VARIABILITY IN A SAMPLE OF 11 NEW CaII EMISSION LINE STARS

By

Jonathan Charles Truax

I present the results of a search for photometric short -period variability in 11 CaII H and K emission line stars. Of these, 4 were found to be variable stars with amplitudes in excess of 0.05 magnitudes and periods of less than 30 days. The photometric search was conducted in the Johnson R band with the M.S.U. 0.6 meter telescope and CCD camera.

The program stars were 11 of the northernmost CaII emission line stars from an objective prism survey of the southern Galactic hemisphere. I present medium resolution (1 angstrom) spectra for these stars as well as for 55 additional late type stars found in the survey. Based on my results roughly 40 percent of the 50 CaII emission stars in the sample are expected to be variable in excess of 0.05 magnitudes. Seven of 50 CaII emission line stars also exhibit Balmer line emission.

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μ = Standard deviation.

Đm = Differential magnitude.

X = Air mass values in atmospheres.

d = Mean deviation.

V = Instrumental magnitude of variable or suspected variable.

C = Instrumental magnitude of comparison star.

Rap = R band apparent magnitude.

I. Introduction:

In the last decade, stars with strong CaII emission have come under the scrutiny of many observers, and a substantial portion of them have turned out to be variable stars with light variations attributable to starspots. The prototype of these stars exhibiting solar-like activity is the RS Canum Venaticorum binary system (hereafter RS CVn). The study of stars in the RS CVn group has been important to the hope of establishing better relationships between stellar rotation and coronal activity (Walter and Bowyer 1981) as well as understanding the activity of starspots.

During an objective prism search for metal poor stars by Beers, Preston, and Shectman (1985, hereafter BPS) a sample of 66 peculiar late-type stars were discovered serendipitously. In this southern Galactic hemisphere survey, candidates were selected based on their appearance in a limited (~ 150 Å) region of spectrum near CaII H and K (3933 and 3968 Å) . The faintest stars in the survey reached to a B magnitude of 16 (see BPS for details). Peculiarities were noticed in 66 late spectral class stars during plate scanning. Subsequent medium resolution (1 Å resolution) digital spectroscopy was obtained of interesting candidates.

In Table 1, the 66 peculiar late-type stars are presented. The table lists star name, positions, and star types. The star types were determined from analysis of the BPS Reticon spectra. Figures 1 through 22 present the spectra. Each spectrum ranges from 3750 to 4450 angstroms. As seen in Table 1, 50 of the stars fall into the category of CaII emission line stars, 11 are CH stars, and 5 are Miras. Many of the spectra appear to be composites of early and late spectral class stars. Stars showing double-peaked emission lines are labeled binary in the comments section of Table 1. Stars with CaII H and K in emission are designated CaII in the star type column. The CaII stars also exhibit many prominent lines of Iron, Cromium, Nickel, and a well defined CaI line (4226 Å) in absorption.

The 11 objects designated CH stars are characterized by strong CH features at 4300 angstroms. Some of these stars may be of the "subgiant CH star" class suggested by Bond (1974). The five stars designated Miras display Balmer emission and CaII H and K absorption lines common to the prototype of this class, and are likely to be long period variable stars. There are 7 stars showing both CaII and Balmer emission typical of dMe stars.

A paper in preparation will present radial velocities, line strengths, and discuss the stellar kinematics of the entire sample of late-type stars.

In a sample of 55 CaII emission line stars, Evans and Koen (1987) found 25 of the sample to vary with amplitudes in excess of 0.09 magnitudes in the V band. All 55 stars showed some degree of variability, showing validity in using CaII as the selection criteria for discovering spotted stars.

In the standard spot model (Eaton and Hall 1979) magnetic fields are presumed to be the origin of dark spots in the stellar photosphere, and the creators of the chromospheric activity leading to the CaII H and K emission lines. The starspots (or inhomogeneities) produce light variations as a result of axial rotation of the stars. The spots are not distributed uniformly or randomly across the stellar photosphere, but are instead concentrated into one or two large groups. As a result of the axial rotation and synchronously rotating binary system, the spotted and unspotted hemisphere is seen alternately. Photometric amplitudes of variation are typically on the order of a few hundredths to a few tenths of a magnitude.

In addition to the RS CVn variables there are the BY Draconis variables. These variables are again spotted stars with light variations due to surface inhomogeneities. BY Draconis variables are intrinsically faint; exhibiting photometric variations ĐV $\geq$ 0.10 magnitudes (Bopp 1981). The observational key in discriminating BY Draconis variables from the RS Cvn stars is found in their spectra. RS CVn systems are subgiants of spectral type of G or K, while the BY Draconis stars have a dK or dM spectra. Both classes have CaII H and K in emission, but only the strongest emitters will be BY Draconis variables (Bopp 1981). Both classes have periods extending from 1 day to several weeks in length, but usually less than a month.

Bopp and Espenak (1977) have stated that all dKe-dMe stars (displaying Balmer and CaII emission) are subject to BY Draconis-like variability. It is also well substantiated that most BY Draconis stars exhibit flaring like the UV Ceti flare stars (Petit 1987). Only about 25 BY Draconis stars and 40 RS CVn stars are known to exist (Petit 1987). This number does not reflect the recent findings of Evans and Koen. D. S. Hall (1981) lists 70 known RS CVn systems. Nevertheless, the known sample of spotted stars is small.

In this paper, I report the findings of a search for new RS CVn or BY Draconis variables using the CaII emission feature as the basis for possible variability. The candidate stars are 11 of the northernmost CaII emitters discovered in the BPS southern survey. Finder charts were prepared using the BPS celestial coordinates and the Palomar sky survey.

II. Observational Data:

Photometric observations were obtained over a total of 7 nights during the period from September 7 to October 6 1988 using the Michigan State 0.6 meter telescope (East Lansing, Michigan). The photometer was a Photometrics CCD camera with a Texas Instruments 4849 CCD (390 X 584 pixel array). All observations were restricted to the Johnson R band only.

On average, two exposures were taken of each program star field a night. Exposure times varied between 24 and 90 seconds depending on the relative brightness of the program star and richness of field stars. An effort was made to select a universal exposure time of 60 seconds for all program star exposures, and 6 seconds for standard star observations. The frames themselves covered approximately 6.0 X 9.0 arc minutes of sky.

In addition to observing the 11 CaII emitters, one CH star and three extinction/transformation stars were observed. The extinction stars were Landolt Standards (Landolt 1983). A description of all program stars and standards is found in Table 2. The table lists star names, celestial coordinates, star types, and magnitude-color index relevant to standard stars. The CS designation is the Curtis Schmidt plate number.

Differential photometry was obtained using several field stars surrounding each program star as comparison stars. One of the seven nights, September 25-26, was a night of nearly Full moon. Data reduction of frames from this night was aborted due to excessive scattered light in the CCD frames. Data from the other 6 nights was reduced as follows. First, the frames were dark and flat corrected, using dome flats and closed shutter exposures taken the beginning of each night. The fully processed frame F is then defined by the relationship:

$$F = (fe - d)/(ff-d/ffa)$$

Where fe is the exposed field, d is the corrected dark frame, ff a flat field exposure, and ffa the mean level of the flat field minus dark. Next, raw instrumental magnitudes for each field star above a defined threshold brightness was calculated using the aperature photometry capability of DAOPHOT, the digital stellar photometry reduction program of the Dominion Astrophysical Observatory (see Stetson 1987).

Having calculated raw instrumental magnitudes for program and field comparison stars, differential magnitudes (Δm) were measured for variable minus several comparison stars, and comparison minus comparison stars. It was assumed in these calculations that both the light from the variable and the comparison stars had passed through the same air mass X, and therefore no extinction corrections were necessary. In Tables 3 through 14 this work is seen beginning in the third column of each table. Each of these tables represents the culmulative data for a single program star.

Upon calculation of the differential magnitudes, a frame-to-frame accuracy estimate of ± 0.050 magnitudes was determined for two frames taken on the same night. This estimate is based on a mean deviation of differential magnitudes equal to 0.042 magnitudes and standard deviation equal to 0.050 magnitudes for 17 pairs of frames. For the nonvariable program stars, night-to-night brightness variations were generally lower than the 0.050 frame-to-frame magnitude dispersion, being instead around 0.040 magnitudes.

It is likely that these magnitude dispersions are due to a combination of small instrumental effects, momentary deteriation in seeing, or bad CCD pixels. Due to the accuracy achieved being less precise than the estimate of error in a single measurement calculated by DAOPHOT, the value of 0.050 magnitudes will be used as the error estimate quoted for each single Ðm observation in Tables 3 through 14. DAOPHOT's estimate of error is derived from star position errors and errors due to sky brightness. It is typically a few hundredths of a magnitude less than the 0.050 accuracy estimate.

Having differential magnitudes, the next step in the reduction process was calculation of extinction and transformation coefficients. Air mass values were found for each frame using the relationship:

$$X = 1 / (\sin d * \sin b + \cos d * \cos b * \cos h)$$

Where d is the declination of the program star, b the observer's latitude, and h the hour angle of the telescope. First order extinction coefficients were determined for each night using multiple observations of the 3 Landolt standard stars, and linear regression. Second order extinction corrections were not made due to the absence of V-R color indices for the program stars; also since this correction is expected to be less than the maximum error in the data.

First order coefficient values determined for each of the 6 nights are listed in table 15. Using these coefficients, appropriate extinction corrections were made to the raw instrumental magnitudes.

Appropriate mean zeropoint and transformation coefficient were next determined to transform the extinction corrected instrumental magnitudes to the Johnson photometric system. The corrections were calculated using data from the Landolt standard stars cumulatively for the 6 observing nights. Unfortunately, using only 3 standard stars yielded values with as much as 0.12 magnitudes difference, when calculated apparent magnitudes were compared with known standard star magnitudes. Program star instrumental magnitudes were then transformed to the same exposure level used to record the standard stars, so as to be in the Johnson system. This transformation amounted to a constant added to the zeropoint.

The complete transformation equation is :

$$Rap = Ie - Zr + T*(V-R),$$

where Rap is an approximate apparent magnitude good to within 12 percent or better, Ie the extinction corrected instrumental magnitudes, and V-R the color index. The transformation coefficient is T = 0.606 and zero point Zr = -3.089.

Due to the precision in apparent magnitudes being lower than the precision of the differential magnitude measurements, it is the differential photometry which defines the variability or nonvariability of the program stars.

Since the V-R colors were not known for the program stars, an estimate of V-R = 0.93 was devised, based on average values found by other observers (Bopp 1984) for spotted stars with K to dM0e spectra. Using this color index with the transformation equation, the approximate apparent magnitude (Rap) is listed in the last column of Tables 3 through 14. In Table 14 for CH star CS 22957-027, a V-R color of 0.50 was chosen appropriate to typical CH stars (Jaschek 1987). The resulting error in apparent magnitude due to a lack of known color indices and extinction/transformation errors is 0.12 magnitudes as seen in the tables.

III. Results and Interpretation:

Using differential photometry data as the basis for variability determinations, a variable star is defined as a program star with $\mu > 0.050$, or variable minus comparison star μ values 2 times higher than the comp-comp differential magnitude dispersions. In the category of CaII emission line stars, 4 out of the sample of 11 stars were found to be variable. They are CS 22886-037, CS 22894-025, CS 22937-037, and CS 22950-027. As expected, the CH star CS 22957-027 was found to be nonvariable with $\mu = 0.038$.

As seen in Tables 3 through 14, residuals have been calculated for differential magnitude measures against a mean differential magnitude. Below each comp/var Dm column there is a value of the mean deviation di and standard deviation μi quoted. In determining variability, an average value of standard deviation $\mu = 1/n\ \mu i + .. + \mu n$ was calculated using individual Đm standard deviation values. This value is listed below the tables.

We now discuss the particulars of each new variable. CS 22886-037 has strong CaII H and K emission lines as seen in its spectra Figure 1-22. The BPS Reticon spectrum shows a strong G band around 4300 angstroms, a well defined CaI absorption line at 4227 angstroms, and many FeI metal lines common to a late K type star of luminosity class IV or V. Looking at Table 6 we see the mean standard deviation for this variable is $\mu = 0.108$. Comparison minus comparison star differential magnitudes show a dispersion of 0.058 magnitudes. From the table it is apparent that the amplitude of variation is 0.20 ± 0.05 magnitudes. A good estimate of the period is not possible without further observations, but examination of Table 6 indicates that there is only two days separating maxima and minima of the Đm measures in the data set. This indicates the variable to be of short period.

CS 22894-025 also has a K IV-V type spectra (Figure 1-31). A look at Table 9 shows that 3 comparison stars were used to determine variability. Comp-comp standard deviation values were approximately $\mu = 0.028$ magnitudes. The mean value of the standard deviation for var/comp Đm measures was $\mu = 0.174$ magnitudes. Using Table 9 data, the apparent amplitude of variation for the variable is 0.22 ± 0.05 magnitudes. The data indicates that the variable star has a period less than the 30 day period in which this work was conducted.

CS 22944-037 is the only variable with a spectrum different from the others. Looking at Figure 1-41 the spectrum has many weak FeI lines, CaII H and K in emission, but possesses a very shallow G band. The CaI line at 4227 angstroms is broad and shallow. The spectrum is a composite of an early K star with a star of spectral class O or B. From Table 10 the mean standard deviation in Đm var-comp measures is μ = 0.067 magnitudes. Comparison star minus comparison star Đm values show a dispersion of only 0.021 magnitudes. The apparent amplitude of variation for this variable is 0.15 ± 0.05 magnitudes.

The last variable, CS 22950-027, again has a K IV-V spectrum as seen in Figure 1-52. The mean standard deviation in Đm var-comp measures found in Table 13 is μ = 0.127 magnitudes. Values of the comp-comp Đm yield a dispersion of μ = 0.067 which is above average for frame to frame measures. The plurality of comparison stars justifies that CS 22950-027 is variable in spite of the high dispersion. From analysis of the data in Table 13 an apparent amplitude of variation for CS22950-027 is 0.24 ± 0.05 magnitudes. The period for this variable is certainly less than 30 days.

More coverage of the 4 variables would have allowed better determinations of photometric amplitudes and periods. Unfortunately, due to above average rainfalls and high demand for telescope time, this was not possible.

Based upon their spectral class and strength of emission lines, I believe that all 4 variables belong to the RS CVn group of variables. A more reliable classification of grouping might come from a search for H-Alpha emission in their spectra, since well over 90 % of known BY Draconis variables show such emission (Bopp 1981). Unfortunately, no spectra redward of 4550 angstroms are available. In RS CVn systems, the H-Alpha emission character is not nearly as common (Jaschek 1987). The lack of Balmer emission in the existing spectra of the four variables favors them being RS CVn systems.

The other 7 CaII emitters in the observing program showed no deviation above the μ = 0.05 dispersion selection criteria. Four variables out of eleven CaII emitters yields 36 % of the sample being variable. This compares well with Evans and Koen (1987) findings of 25 out of 55 (45 %) of their CaII emission line stars variable with amplitudes > 0.09 magnitudes.

If better accuracy could have been achieved, perhaps more of the sample, those with photometric amplitudes around 0.05, would have been detected. However, another possibility is that atleast a few of the other 7 CaII emitters are in a stage of quiescence, a period of inactivity suggested by Bopp (1981). During the period there is either an absence of starspots or a uniform distribution in stellar longitude.

IV. Conclusions:

The primary result of this work has been the discovery of 4 new RS CVn / BY Draconis variables. In Table 16, the results of the photometric search are summarized. From the table, the apparent amplitudes of variation are seen to be less than 0.30 magnitudes, which is consistent with the spotted star phenomena. The R band apparent magnitude of the stars ranges between 11th and 13th magnitude.

The discovery of new variables is important from the standpoint that very little is known about the frequency of RS CVn / BY Draconis phenomena in the Galaxy. It would be invaluable to determine if there is a correlation between CaII line intensities and stellar rotation rates (photometric periods) as Bopp has suggested (1981). Vaughan (1983) has already shown that there are definite variations in CaII line intensities over "solar-like" cycles of 10 to 20 years.

In addition to the discovery of new variables, this work confirms the results of Evans and Koen (1987), and Bopp (1981), that the presence of CaII H and K emission lines in a stellar spectra of F through M spectral class is a worthy selection criteria for the discovery of spotted stars. Using the supposition that about 40 % of a sample of strong CaII emitters will be variable with photometric amplitudes in excess of 0.09 magnitudes, one might expect 20 new variables in the BPS sample of 50 CaII emission line stars introduced in this work.

Using a photometric system sensitive to variations as small as 0.01 magnitudes, one might evaluate the entire sample of 50 CaII emitters. The objective being confirmation of the Evans and Koen result that all CaII emission line stars show some degree of variability. This was not possible in this work, since the majority of the BPS sample are southern hemisphere objects.

In the sample subset of 11 stars subjected to a photometric search, a confirmation that all CaII emitters are variable was not possible since the precision of the photometer was sensitive only to variations > 0.05 magnitudes.

In the BPS sample, the seven stars designated as dMe stars in table 1 are good candidates for UV Ceti type flaring and/or BY Draconis variability. Two of these, CS 22184-024 and CS 22886-057 were observed photoelectrically, with no variations above the 0.05 magnitude dispersion level detected. However, looking at Table 7, CS22886-057 may have flared 13 - 14 September 1988, by an order of 0.09 magnitudes. Both differential and Rap measures show an increase in brightness above the average magnitude. An exposure 2 minutes later shows the star at normal brightness. A short duration rise and fall of brightness is consistent with what is observed in the UV Ceti stars. Unfortunately, the author could find no reference works where research was attempted in the R band. Observed flares show greatest amplitudes toward the U band. A flaring of YZ CMi recorded in 1971 was 4 times more intense in the B band than the V band, and 4 times more intense in U than in B (Petit 1987). This ratio, although not always a factor of 4 per band, is typical of most flares. Using an approximation, one might expect R band measurements to be about 1/4 the intensity of those in V. For a 0.09 magnitude increase in R, an approximate flaring of 0.33 magnitudes in V, 0.97 magnitudes in B, and 2.07 magnitudes in U, might be observed.

In 1975, three observatories working together, monitored UV Ceti for 132.5 hours. Out of 77 flares observed in B, 3 had amplitudes greater than 3 magnitudes, 31 were between 1 and 3 magnitudes, and 43 were less than one magnitude (Petit 1987). So a flare recorded in R of 0.09 magnitudes corresponding to a flaring of 0.97 magnitudes in B is a possibility. Without more observations, classification of CS 22886-057 as a UV Ceti flare star is a marginal conclusion.

The UV Ceti stars have the same spectral characteristics as the BY Draconis variables, but need not exhibit photometric variations due to starspots. Only about 120 of these stars are known to exist (Petit 1987). A systematic surveillance of the seven dMe stars introduced in this work attempting to detect flaring might prove fruitful.

In closing, I would like to recommend that the Michigan State 0.6 meter telescope be utilized for more projects like this thesis work and the extension of this work outlined above.

APPENDIX

Table 1 - The B.P.S. late type star sample.

STAR-ID	R.A. (1950)	DEC	STAR TYPE	COMMENTS
22172-038	03 30 17.7	-09 05 38	CaII	dMe,BPM-71214
22174-019	01 18 06.6	-08 40 32	Mira	
22174-036	01 23 02.2	-08 17 04	CaII	
22179-005	00 33 19.3	-05 00 47	CaII	
22183-008	00 52 41.7	-04 10 57	CaII	Binary
22184-015	02 32 50.3	-12 31 31	CaII	
22184-024	02 36 42.9	-10 40 45	CaII	dMe
22184-037	02 46 36.4	-10 41 32	CaII	dMe
22872-076	16 24 58.3	-02 00 34	CaII	
22873-070	19 47 45.0	-61 21 13	CaII	
22874-092	14 44 20.9	-24 13 30	CH star	
22877-001	13 11 17.1	-11 55 48	CH star	
22879-059	20 41 53.8	-41 00 52	CaII	
22879-102	20 42 48.4	-37 48 32	CaII	
22880-074	20 43 09.9	-21 10 14	CH star	
22881-023	21 57 26.1	-39 21 58	CaII	Binary
22882-010	00 22 59.7	-28 51 04	CaII	dMe
22882-037	00 26 22.5	-31 11 31	CaII	
22885-052	20 14 24.8	-38 05 29	Mira	
22885-126	20 24 03.4	-38 03 26	CaII	
22885-184	20 29 55.6	-38 38 09	CaII	Binary
22886-037	22 19 01.9	-12 04 43	CaII	Variable
22886-057	22 17 46.5	-07 42 41	CaII	dMe
22888-053	23 19 19.5	-35 25 03	CaII	
22889-020	13 37 23.9	-10 54 57	CaII	
22890-077	15 21 11.9	-00 33 45	CaII	
22891-171	19 23 45.0	-59 30 31	CH star	
22892-034	22 08 33.1	-17 14 31	CaII	
22892-052	22 14 18.9	-16 54 26	CH star	
22894-016	23 34 14.0	+00 01 07	CaII	
22894-025	23 40 28.3	-02 04 55	CaII	Variable
22896-087	19 34 45.8	-57 01 26	CaII	
22898-027	21 02 55.5	-18 48 55	CH star	
22938-014	22 43 27.8	-63 33 50	CaII	
22938-077	22 59 10.4	-63 10 53	CaII	dMe
22940-072	20 38 55.0	-61 02 07	CaII	
22941-036	23 34 05.7	-32 25 49	CaII	Composite
22942-007	00 47 19.3	-23 07 48	CaII	
22942-019	00 54 52.1	-25 42 19	CH star	
22942-036	01 00 50.6	-23 41 26	CaII	

Table 1 (cont'd)

22944-037	21 43 54.1	-14 43 37	CaII	Variable
22945-061	23 59 21.3	-67 24 26	CaII	dMe
22945-065	23 54 50.0	-65 39 45	Mira	
22946-018	01 14 46.9	-17 49 23	CaII	
22947-286	19 27 16.8	-50 30 08	Mira	
22948-027	21 34 39.3	-39 40 51	CH star	
22948-052	21 40 55.4	-39 57 38	CaII	
22948-089	21 46 04.7	-41 47 26	CH star	
22949-019	23 16 44.3	-06 58 01	CH star	
22949-031	23 19 06.3	-03 30 59	CaII	
22949-035	23 19 50.6	-02 30 06	CaII	
22950-027	20 16 15.1	-14 11 33	CaII	Variable
22950-127	20 26 46.5	-12 31 36	CaII	
22953-024	01 11 27.1	-61 55 45	CaII	
22955-004	20 21 12.6	-27 11 13	CaII	
22957-027	23 56 39.3	-04 10 30	CH star	
22963-001	02 53 01.2	-04 12 52	CaII	
22964-013	19 44 58.0	-40 26 38	CaII	
22964-071	19 50 44.0	-39 43 04	CaII	
22964-088	19 49 03.3	-41 10 12	CaII	
22964-101	19 55 16.8	-41 59 01	Mira	
22968-040	03 15 50.6	-53 11 47	CaII	
22968-047	03 17 31.8	-52 28 04	CaII	Binary
29521-055	23 05 01.5	+07 52 36	CaII	
29521-063	23 03 26.7	+09 26 00	CaII	
29529-106	04 16 20.6	-62 11 28	CaII	

Table 2 - Program stars and standards.

STAR NAME	R.A. (1950)	DEC.	TYPE	V	V-R
22179-005	00 33 19.3	-05 00 47	CaII	...	...
22184-015	02 32 50.3	-12 31 31	CaII	...	...
22184-024	02 36 42.9	-10 40 45	CaII	...	...
22886-037	22 19 01.9	-12 04 43	CaII	...	...
22886-057	22 17 46.5	-07 42 41	CaII	...	...
22894-016	23 34 14.0	+00 01 07	CaII	...	...
22894-025	23 40 28.3	-02 04 55	CaII	...	...
22944-037	21 43 54.1	-14 43 37	CaII	...	...
22946-018	01 14 46.9	-17 49 23	CaII	...	...
22949-031	23 19 06.3	-03 30 59	CaII	...	...
22950-027	20 16 15.1	-14 11 33	CaII	...	...
22957-027	23 56 39.3	-04 10 30	CH	13.56	0.50
111773	19 36 30.0	+00 08 56	Std	8.96	0.12
111775	19 36 30.0	+00 10 02	Std	10.75	0.97
1111496	19 37 36.0	+00 18 39	Std	7.22	0.15

Table 3 - Data for star CS 22179-005.

U.T.	DATE	Dm V-C1 ±.05	Dm V-C2 ±.05	X	Rap±0.12
6:05	09/08/88	...	-0.026	1.537	11.91
6:07	09/08/88	-0.334	-0.015	1.533	11.96
5:35	09/14/88	-0.330	...	1.550	11.85
5:39	09/14/88	-0.314	...	1.542	11.87
5:08	09/15/88	-0.286	...	1.611	11.91
5:20	09/15/88	-0.333	-0.118	1.576	11.88
3:22	10/06/88	...	-0.078	1.697	11.89
3:31	10/06/88	...	-0.090	1.664	11.92
		d1 = 0.019	d2 = 0.047		
		μ1 = 0.029	μ2 = 0.059		

Average μ = 0.044
Nonvariable.

Table 4 - Data for star CS 22184-015.

U.T.	DATE	Đm V-C1 ±.05	Đm V-C2 ±.05	Đm C1-C2 ±.05	X	Rap±0.12
6:58	09/14/88	-1.436	+0.644	-2.080	1.990	13.06
7:10	09/15/88	-1.303	+0.583	-1.886	1.915	13.17
7:20	09/15/88	-1.385	+0.601	-1.986	1.877	13.22
4:16	10/06/88	-1.336	+0.659	-1.995	2.184	13.27
		d1 = 0.061	d2 = 0.040	d = 0.068		
		μ1 = 0.076	μ2 = 0.050	μ = 0.085		

Average μ = 0.063
Nonvariable based on small
number of observations.

Table 5 - Data for star CS 22184-024.

U.T.	DATE	Đm V-C1 ±.05	Đm V-C2 ±.05	Đm C1-C2 ±.05	X	Rap±0.12
6:50	09/14/88	+0.489	-0.559	-1.048	2.089	12.46
6:52	09/14/88	+0.464	-0.605	-1.069	2.074	13.21
7:25	09/15/88	+0.491	-0.619	-1.110	1.785	12.52
7:30	09/15/88	+0.466	-0.585	-1.051	1.770	12.53
4:16	10/06/88	+0.533	...	...	2.601	12.57
4:24	10/06/88	+0.416	-0.645	-1.061	2.487	12.41
		d1 = 0.033	d2 = 0.031			
		μ1 = 0.038	μ2 = 0.033			

Average μ = 0.036
Nonvariable.

Table 6 - Data for star CS 22886-037.

U.T.	DATE	ÐmV-C1 ±.05	ÐmV-C2±.05	ÐmV-C3±.05	ÐmC1-C2±.05	X	Rap±0.12
2:58	09/08/88	-2.625	-1.666	-0.834	-0.959	2.052	12.86
3:17	09/08/88	-2.605	-1.641	-0.880	-0.964	1.940	12.86
3:38	09/08/88	-2.604	-1.650	-0.792	-0.954	1.850	12.84
3:52	09/14/88	-2.482	-1.499	-0.745	-0.983	1.751	12.96
3:54	09/14/88	...	-1.473	-0.736	...	1.748	12.95
3:11	09/15/88	-2.415	...	-0.676	...	1.837	13.00
3:25	09/15/88	-2.367	-1.507	-0.750	-0.870	1.797	12.98
3:23	10/04/88	...	-1.552	-0.720	...	1.731	12.96
3:28	10/04/88	...	...	-0.720	...	1.736	12.96
1:35	10/06/88	-2.666	-1.681	...	-0.985	1.885	12.85

d1 = 0.116　d2 = 0.087　d3 = 0.056　d = 0.036
μ1 = 0.145　μ2 = 0.108　μ3 = 0.070　μ = 0.045

Average standard deviation μ = 0.108
CS 22886-037 is variable.

Table 7 - Data for star CS 22886-057.

U.T.	DATE	Ðm V-C1 ±.05	Ðm V-C2 ±.05	Ðm C1-C2 ±.05	X	Rap±0.12
3:45	09/08/88	-0.659	-0.139	+0.520	1.637	13.29
4:00	09/14/88	-0.772	-0.247	+0.525	1.576	13.10
4:02	09/14/88	-0.675	-0.143	+0.532	1.574	13.31
3:32	09/15/88	-0.624	...	...	1.611	13.22
3:34	09/15/88	-0.741	...	...	1.604	13.22
3:28	10/04/88	-0.735	-0.162	+0.573	1.573	13.23
3:30	10/04/88	-0.750	-0.173	+0.620	1.574	13.21
1:38	10/06/88	-0.704	-0.181	+0.523	1.683	13.19

d1 = 0.048　d2 = 0.032　d = 0.039
μ1 = 0.060　μ2 = 0.040　μ = 0.049

Average standard deviation μ = 0.050
Nonvariable.
Possible UV Ceti flaring on 09/14/88 obs. 1.

Table 8 - Data for star CS 22894-016.

U.T.	DATE	Đm V-C1 ±.05	Đm V-C2 ±.05	Đm C1-C2 ±.05	X	Rap±0.12
5:30	09/07/88	-1.497	-1.401	+0.096	1.378	12.38
4:30	09/08/88	-1.542	-1.563	-0.021	1.484	12.45
5:00	09/14/88	-1.586	-1.490	+0.096	1.380	12.30
5:02	09/14/88	-1.509	-1.464	+0.045	1.378	12.34
4:08	09/15/88	-1.542	-1.468	+0.074	1.468	12.42
4:11	09/15/88	-1.583	-1.483	+0.100	1.461	12.42
3:53	10/04/88	-1.496	-1.452	+0.044	1.369	12.85 **
2:48	10/06/88	-1.517	-1.447	+0.070	1.461	12.46

d1 = 0.033 d2 = 0.052 d = 0.029
μ1 = 0.041 μ2 = 0.065 μ = 0.036

Average standard deviation μ = 0.053
Nonvariable.

**** Cloud observed near program star.**

Table 9 - Data for star CS 22894-025.

U.T.	DATE	ĐmV-C1±.05	ĐmV-C2±.05	ĐmV-C3±.05	ĐmC3-C2±.05	X	Rap±0.12
6:30	09/08/88	-2.143	...	...	...	1.409	11.70
6:34	09/08/88	...	-3.613	...	...	1.411	11.70
4:50	09/14/88	...	-3.827	-4.515	+0.688	1.453	11.26
4:00	09/15/88	...	-3.579	...	...	1.571	11.51
4:02	09/15/88	...	-3.552	-4.263	+0.711	1.564	11.44
3:47	10/04/88	-2.308	...	-4.480	...	1.430	11.48
2:57	10/06/88	...	-3.606	...	...	1.510	11.62

d1 = 0.165 d2 = 0.096 d3 = 0.157 d = 0.022
μ1 = 0.206 μ2 = 0.119 μ3 = 0.196 μ = 0.028

Average standard deviation μ = 0.174
CS 22894-025 is variable.

Table 10 - Data for star CS 22944-037.

U.T.	DATE	Ðm V-C1 ±.05	Ðm V-C2 ±.05	Ðm C1-C2 ±.05	X	Rap±0.12
3:30	09/07/88	-2.438	...	...	1.906	12.28
2:35	09/08/88	-2.369	-2.228	+0.110	2.109	12.47
3:44	09/14/88	-2.273	...	...	1.850	12.51
2:40	09/15/88	-2.292	...	...	1.960	12.55
2:42	09/15/88	-2.298	...	...	1.954	12.52
2:41	10/04/88	...	-2.105	+0.133	1.852	12.54
2:44	10/04/88	-2.248	...	...	1.853	12.58
0:53	10/06/88	-2.269	-2.143	+0.126	2.064	12.53
0:55	10/06/88	-2.278	-2.127	+0.151	2.053	12.51

d1 = 0.054 d2 = 0.052 d = 0.017
μ1 = 0.068 μ2 = 0.065 μ = 0.021

Average standard deviation μ = 0.067
CS 22944-037 is variable.

Table 11 - Data for star CS 22946-018.

U.T.	DATE	Ðm V-C1 ±.05	Ðm V-C2 ±.05	Ðm C1-C2 ±.05	X	Rap±0.12
6:30	09/14/88	...	-1.524	...	2.100	12.98
6:40	09/14/88	...	-1.529	...	2.074	13.00
6:04	09/15/88	-1.556	-1.547	.009	2.185	13.00
6:36	09/15/88	...	-1.637	...	2.073	13.09
3:45	10/06/88	-1.511	-1.496	.015	2.609	12.97
4:09	10/06/88	-1.557	-1.545	.012	2.383	13.02

d1 = 0.031 d2 = 0.036 d = .003
μ1 = 0.039 μ2 = 0.045 μ = .004

Average standard deviation μ = 0.042
Nonvariable.

Table 12 - Data for star CS 22949-031.

U.T.	Date	Đm V-C1 ±.05	Đm V-C2 ±.05	Đm C1-C2 ±.05	X	Rap±0.12
5:00	09/07/88	+0.263	+0.324	+0.061	1.484	13.16
5:45	09/14/88	+0.216	+0.282	+0.066	1.445	13.15
5:48	09/14/88	+0.197	+0.247	+0.050	1.446	13.12
4:18	09/15/88	...	+0.267	...	1.503	13.19
4:25	09/15/88	+0.290	+0.247	-0.043	1.490	13.17
3:35	10/04/88	+0.167	+0.300	+0.133	1.456	13.22
2:07	10/06/88	+0.135	+0.244	+0.109	1.678	13.10
2:25	10/06/88	+0.127	+0.293	+0.166	1.582	13.10

d1 = 0.057 d2 = 0.028 d = 0.059
μ1 = 0.069 μ2 = 0.035 μ = 0.070

Average standard deviation μ = 0.053
Nonvariable.

Table 13 - Data for star CS 22950-027.

U.T.	DATE	ÐmV-C1	ÐmV-C2	ÐmV-C3	ÐmV-C4	ÐmV-C5	ÐmC2-C1
2:25	09/08/88	-1.296	...	...	...	...	...
3:35	09/14/88	-1.350	-1.805	-2.786	-3.460	-2.975	+0.455
3:37	09/14/88	-1.356	-1.878	-2.862	-3.488	-3.015	+0.522
2:30	09/15/88	-1.544	...	...	...	-3.055	...
2:32	09/15/88	-1.485	-1.868	...	...	...	+0.382
2:36	10/04/88	-1.503	-1.944	-2.958	-3.698	-2.981	+0.441
2:38	10/04/88	-1.513	-1.937	-3.120	-3.644	-3.198	+0.424
0:43	10/06/88	-1.388	-1.775	-2.777	-3.438	-2.916	+0.387
0:48	10/06/88	-1.389	-1.786	-2.888	-3.474	-2.991	+0.397
		d1=0.083	d2=0.071	d3=0.113	d4=0.110	d5=0.131	d=0.042
		μ1=0.104	μ2=0.089	μ3=0.141	μ4=0.138	μ5=0.164	μ=0.053

Table 13 (cont'd)

DATE	ÐmC3-C4	X	Rap±0.12
09/08/88	...	1.839	10.88
09/14/88	-0.674	1.948	10.87
09/14/88	-0.626	1.956	10.84
09/15/88	...	1.831	10.74
09/15/88	...	1.830	10.74
10/04/88	-0.740	2.033	10.84
10/04/88	-0.530	2.042	10.84
10/06/88	-0.661	1.832	11.08
10/06/88	-0.590	1.831	10.94
	d=0.065		
	μ=0.080		

Average value of standard deviation for variable minus comp measures μ = 0.127. Average value of standard deviation for Comp minus Comp measures μ = 0.067. CS 22950-027 is variable.

Note error for all differential measures is ± 0.050 magnitudes.

Table 14 - Data for star CS 22957-027.

U.T.	DATE	Ðm V-C1±.05	Ðm V-C2±.05	Ðm C2-C1±.05	X	Rap±0.12
5:51	09/07/88	+0.096	-0.618	+0.522	1.481	12.93
5:55	09/07/88	+0.035	...	...	1.476	13.23
5:20	09/08/88	+0.016	-0.619	+0.635	1.525	13.24
5:08	09/14/88	+0.068	-0.558	+0.631	1.503	13.76
5:29	09/14/88	+0.034	-0.629	+0.663	1.474	13.14
4:34	09/15/88	+0.055	-0.572	+0.627	1.571	13.12
3:05	10/06/88	+0.049	-0.554	+0.603	1.590	13.15
3:07	10/06/88	+0.065	-0.532	+0.597	1.584	13.18

d1 = 0.021 d2 = 0.039 d = 0.037
μ1 = 0.026 μ2 = 0.049 μ = 0.046

Average standard deviation μ = 0.038
Nonvariable.

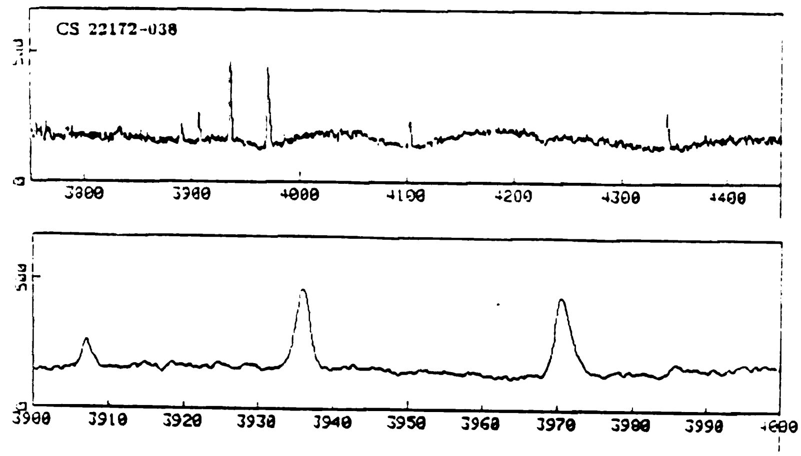
Table 15 - First Order Extinction Coefficients.

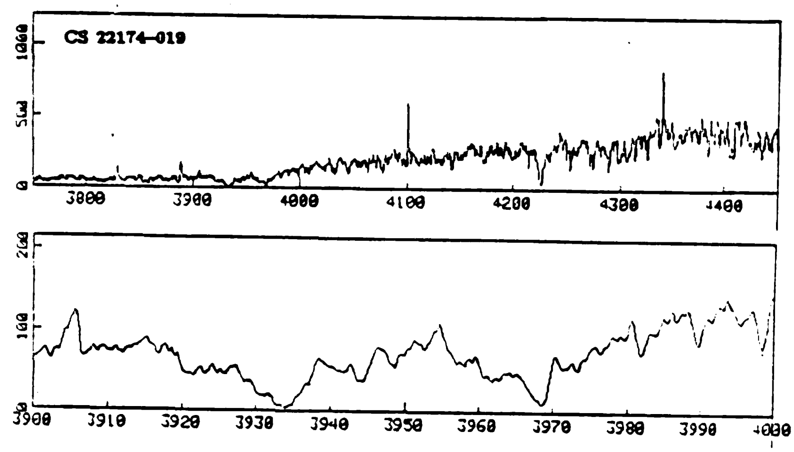
U.T. Date	Coefficient Value
09/07/88	.187
09/08/88	.128
09/14/88	.152
09/15/88	.150
10/04/88	.200
10/06/88	.190

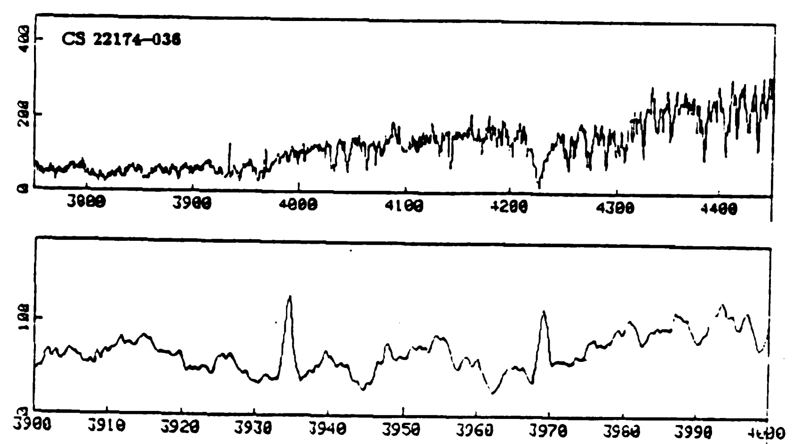
Table 16 - Final Results.

Starname	Rap & Err.	Amplitude & Err.
22179-005	11.89 ± 0.12	0.00 ± 0.05
22184-015	13.22	0.00
22184-024	12.49	0.00
22886-037	12.80 - 13.00	0.20
22886-057	13.23	0.00
22894-016	12.40	0.00
22894-025	11.48 - 11.70	0.22
22944-037	12.30 - 12.40	0.15
22946-018	12.99	0.00
22949-031	13.15	0.00
22950-027	10.76 - 11.00	0.24
22957-027	13.14	0.00

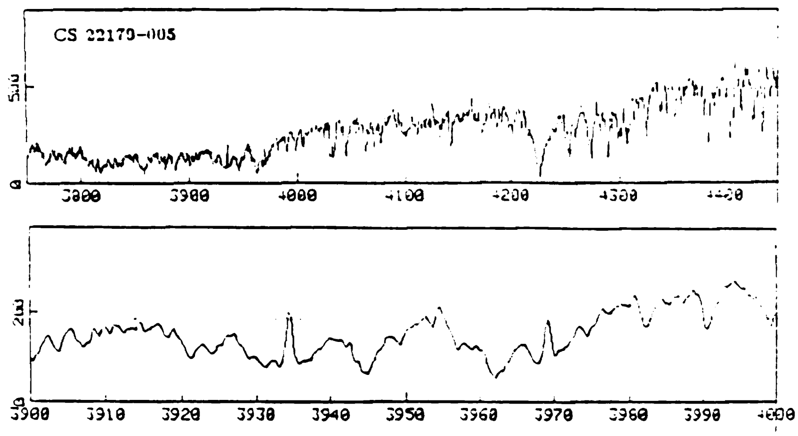
Figure 1 - Medium resolution spectra of the BPS sample. Figures 1-01,02,03.

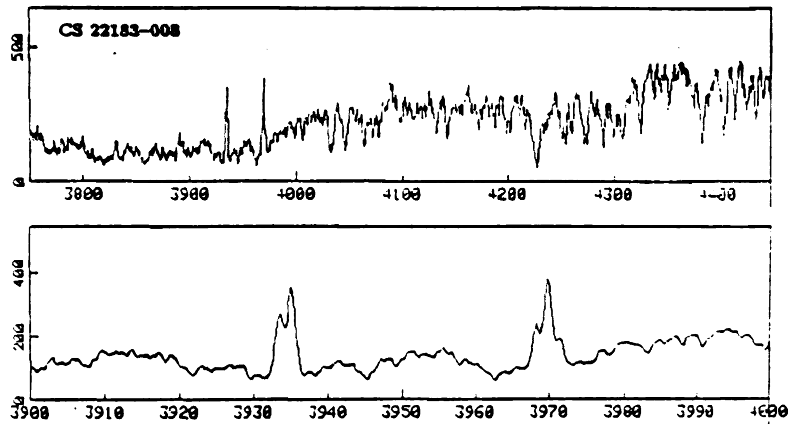


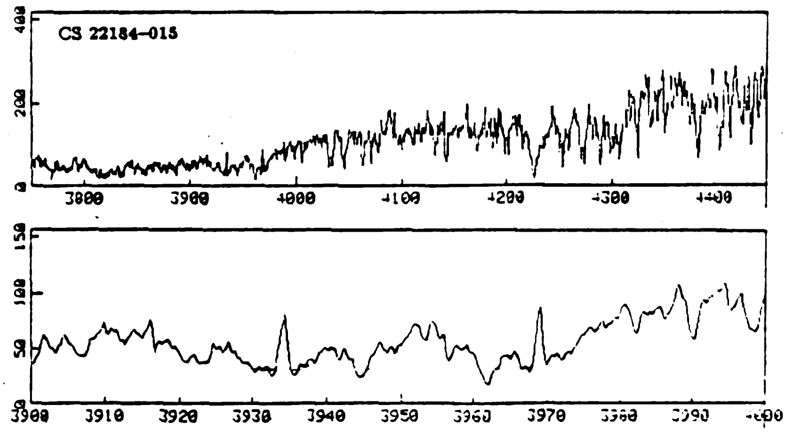




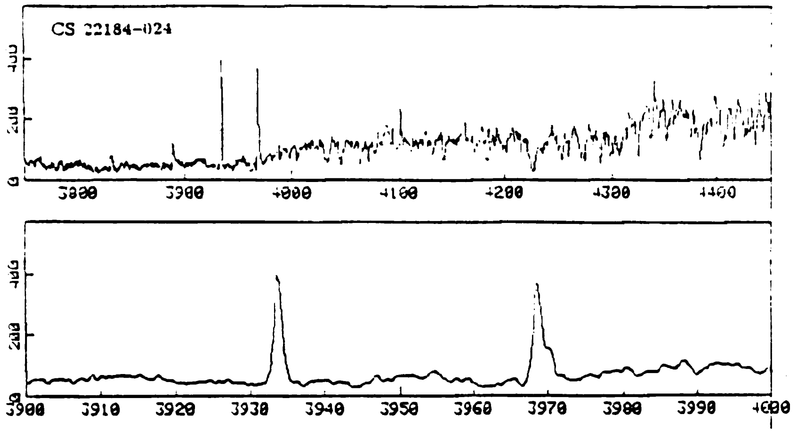
Figures 1-04,05,06.

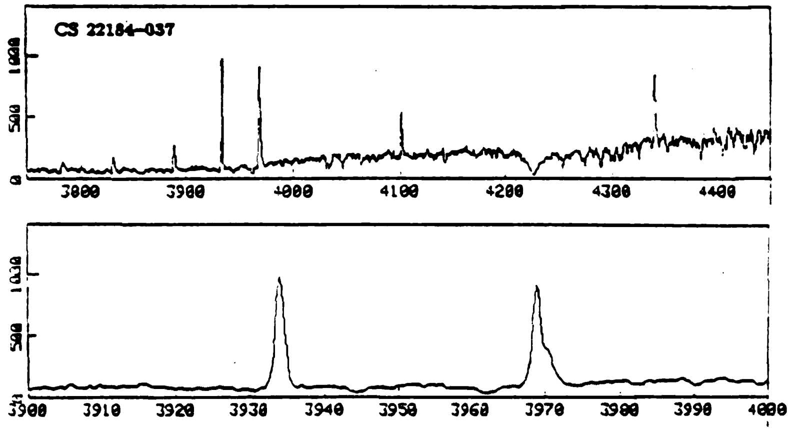


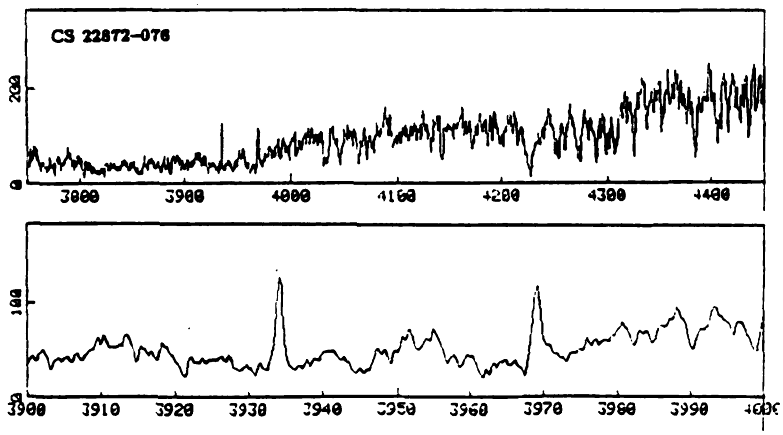




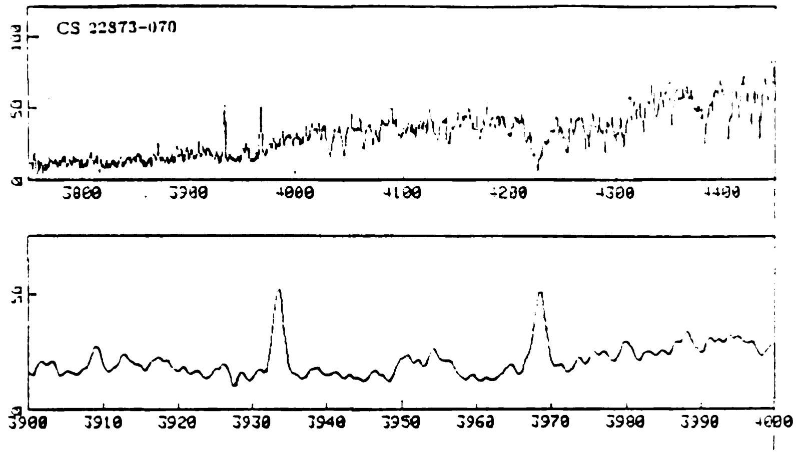
Figures 1-07,08,09.

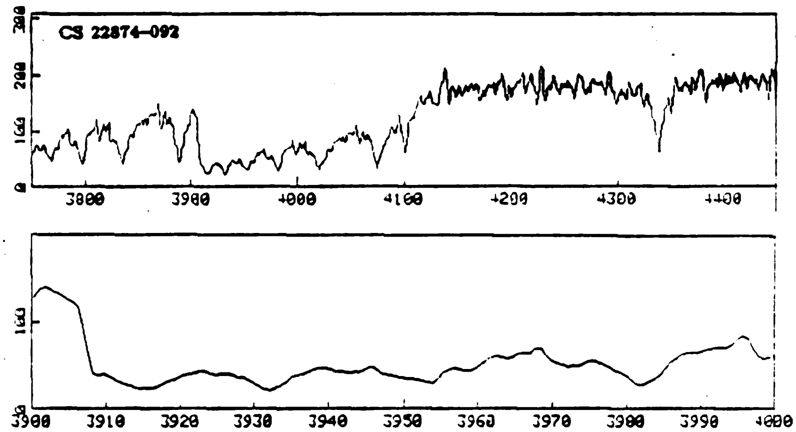


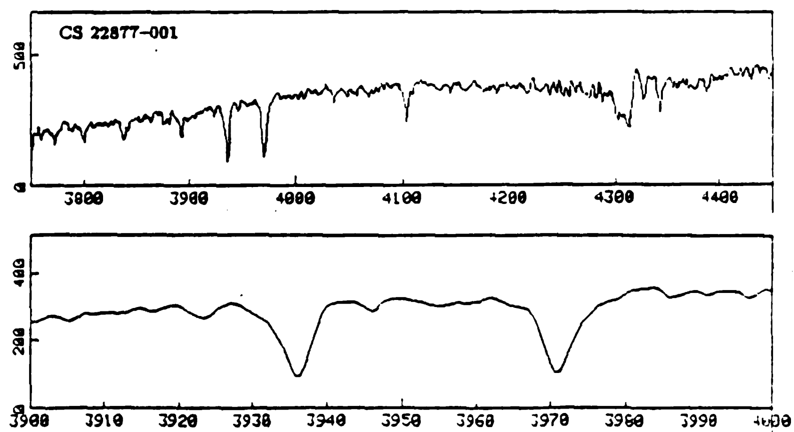




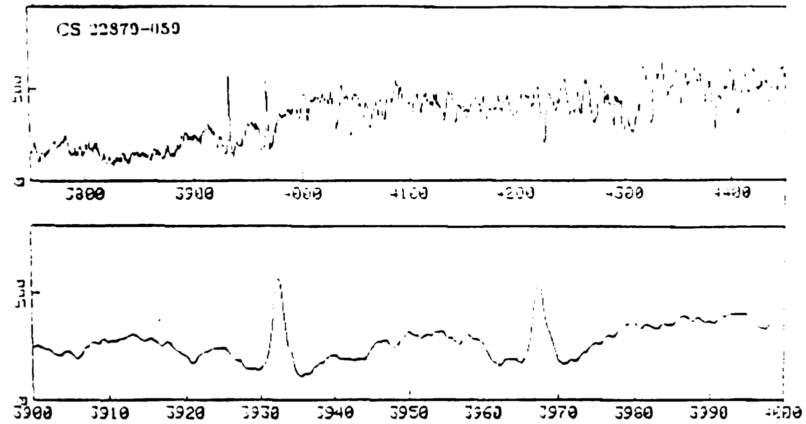
Figures 1-10,11,12.

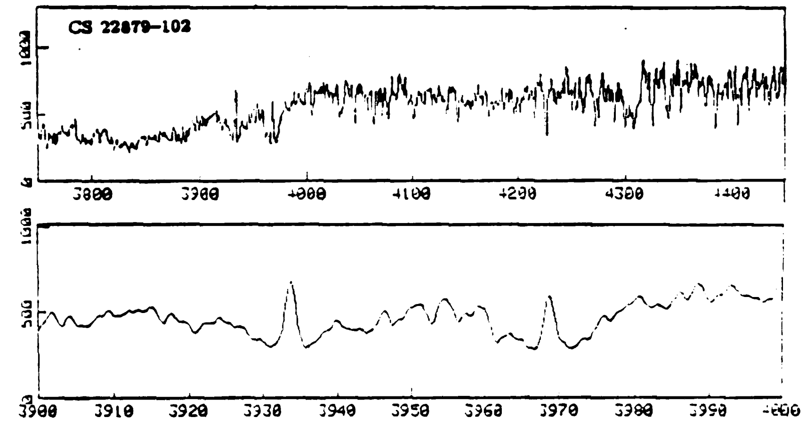


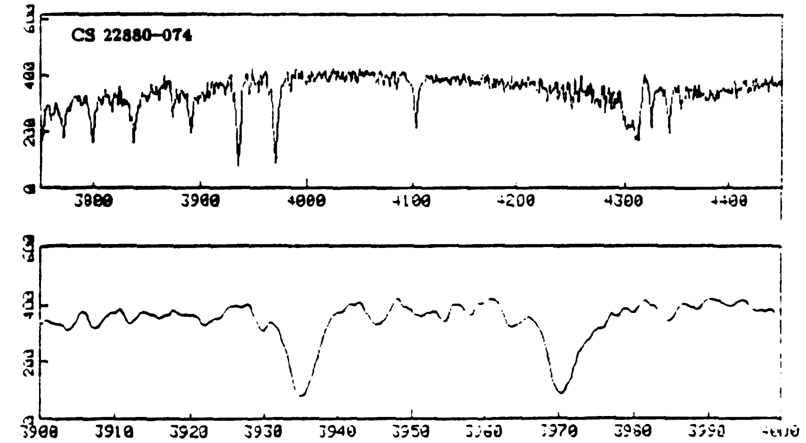




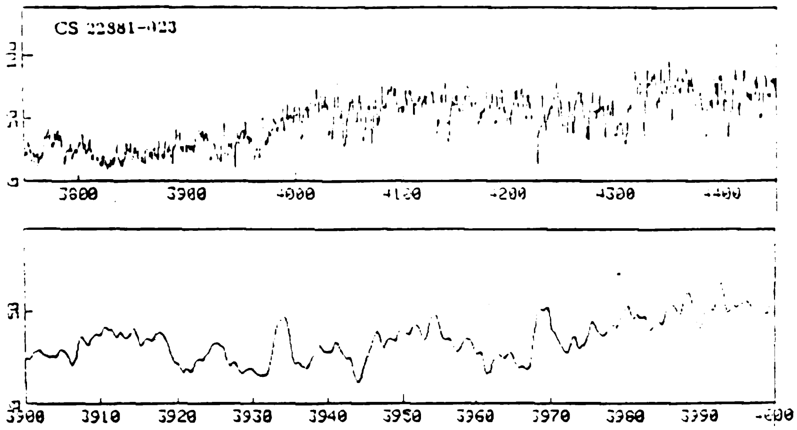
Figures 1-13,14,15.

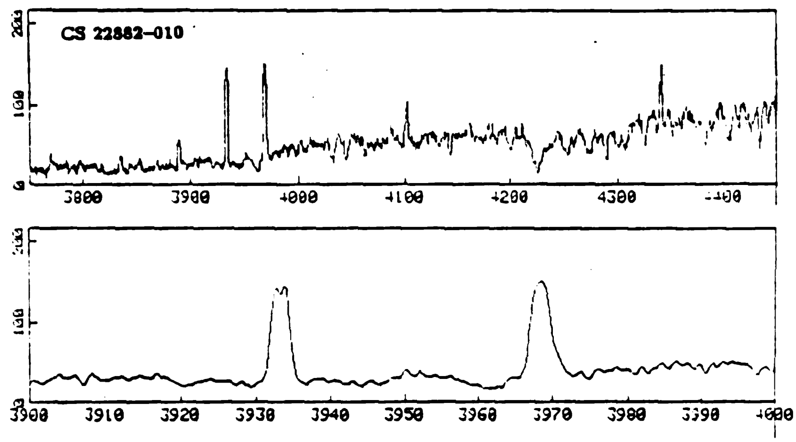


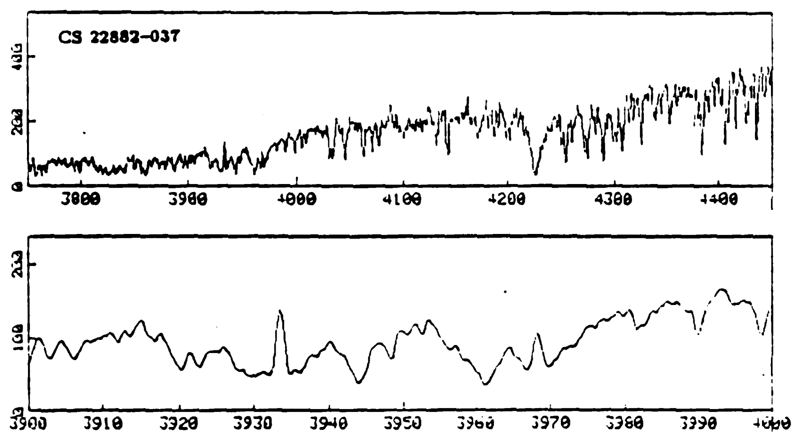




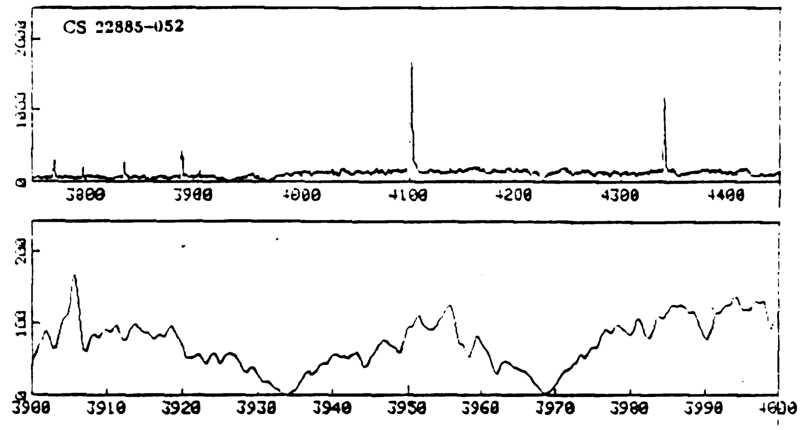
Figures 1-16,17,18.

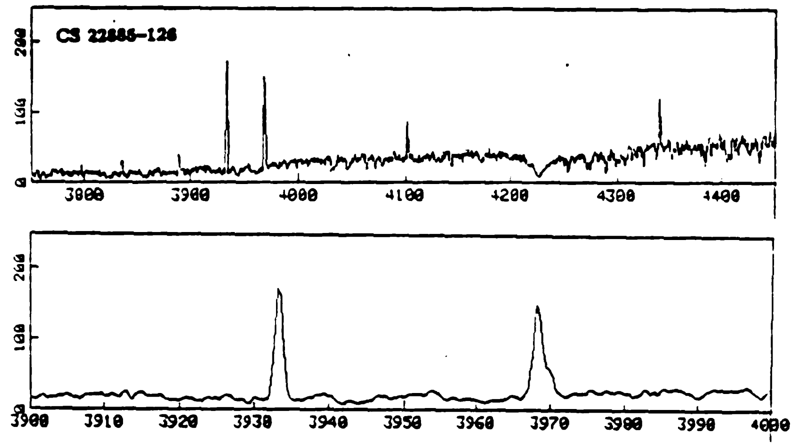


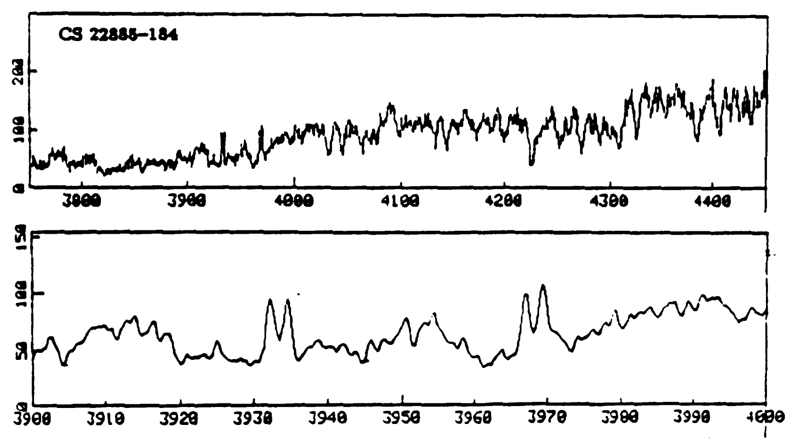




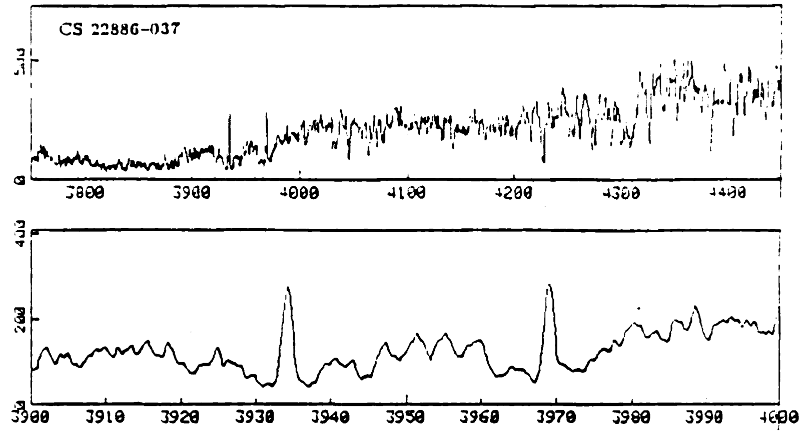
Figures 1-19,20,21.

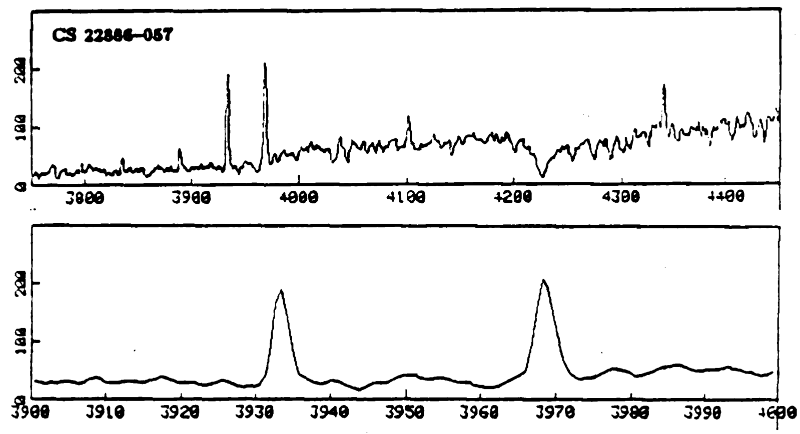


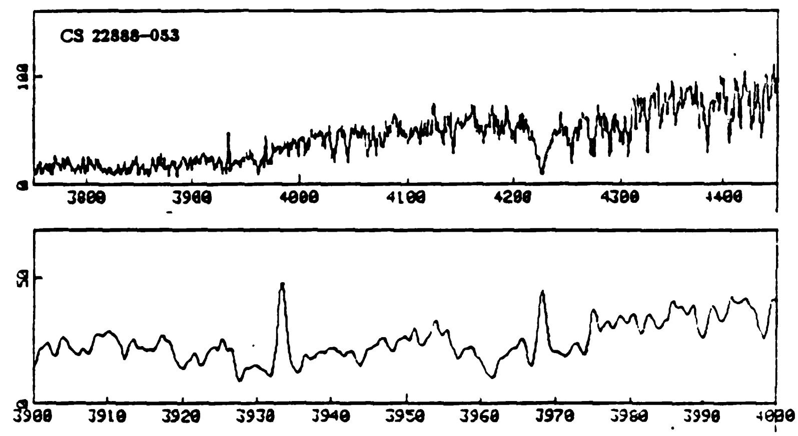




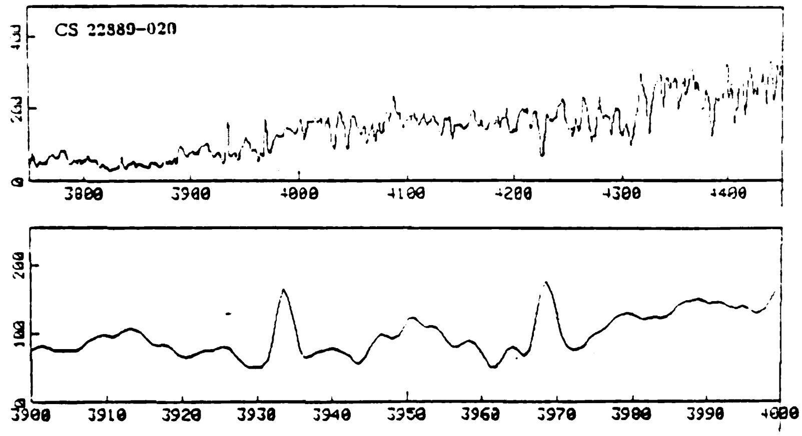
Figures 1-22,23,24

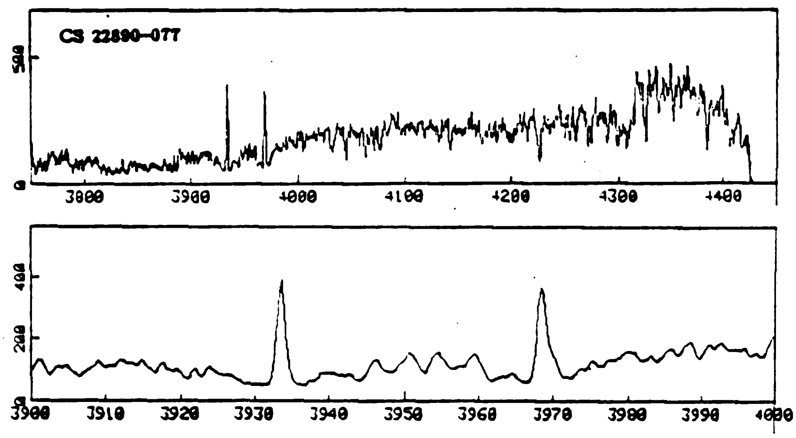


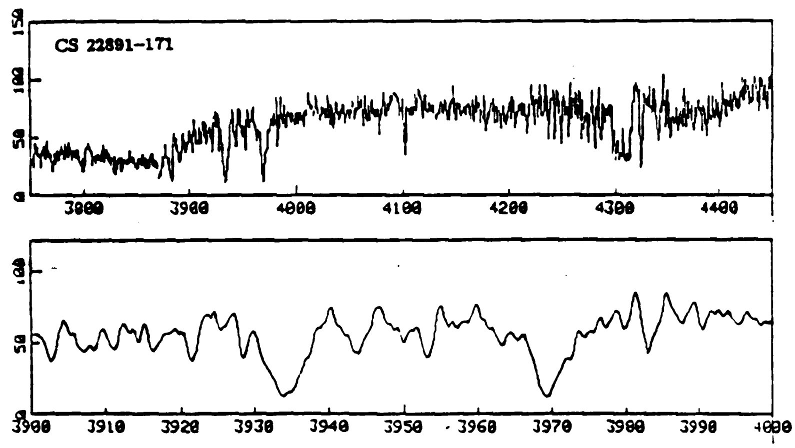




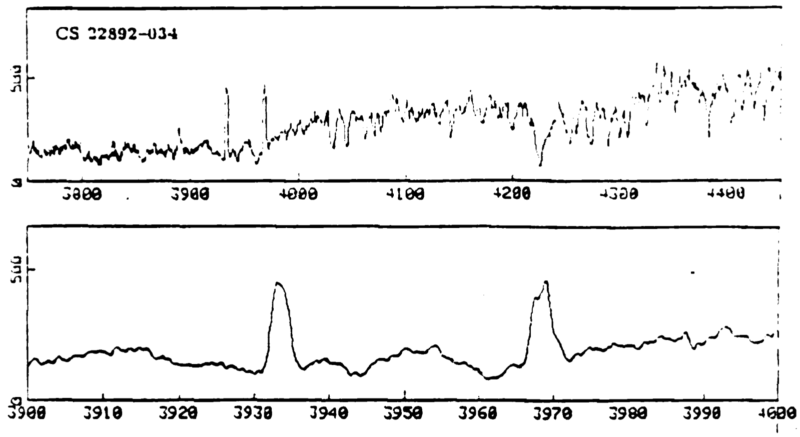
Figures 1-25,26,27.

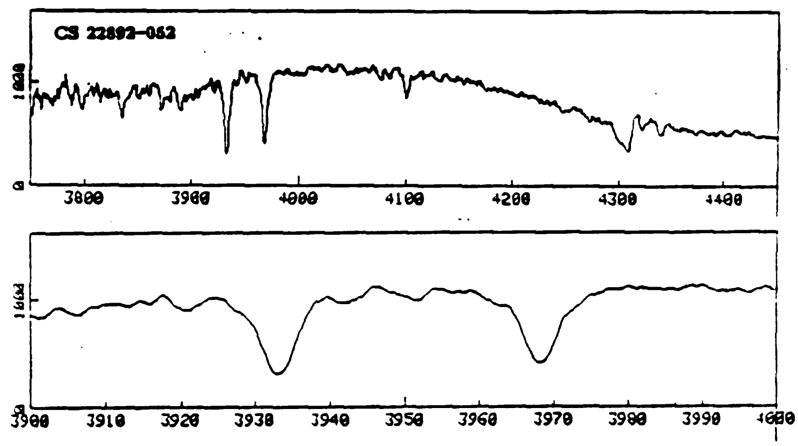


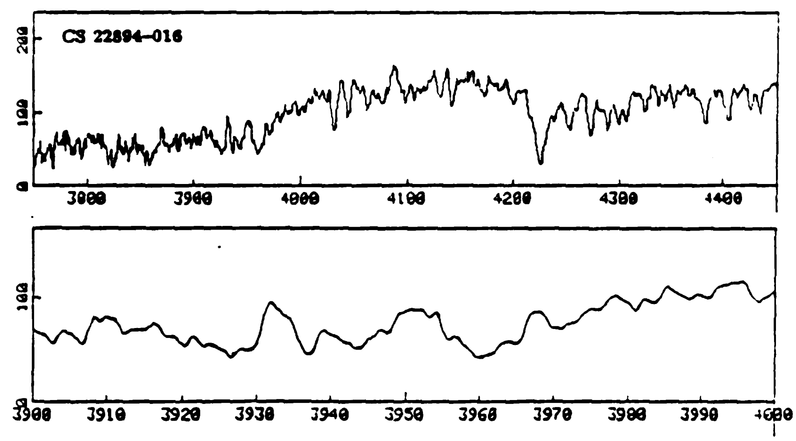




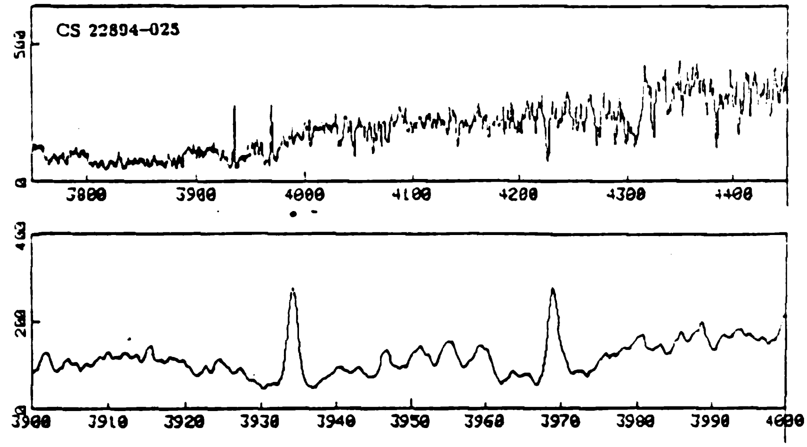
Figures 1-28,29,30.

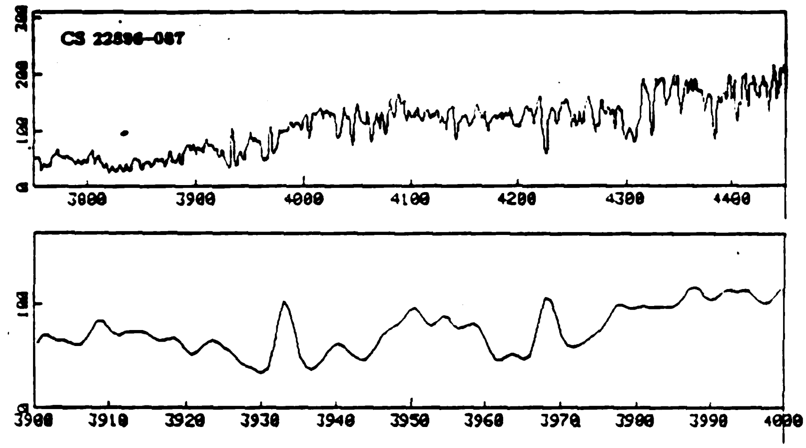


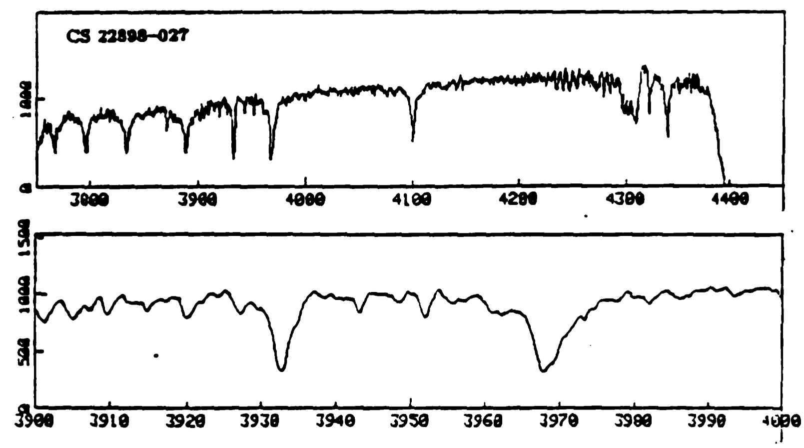




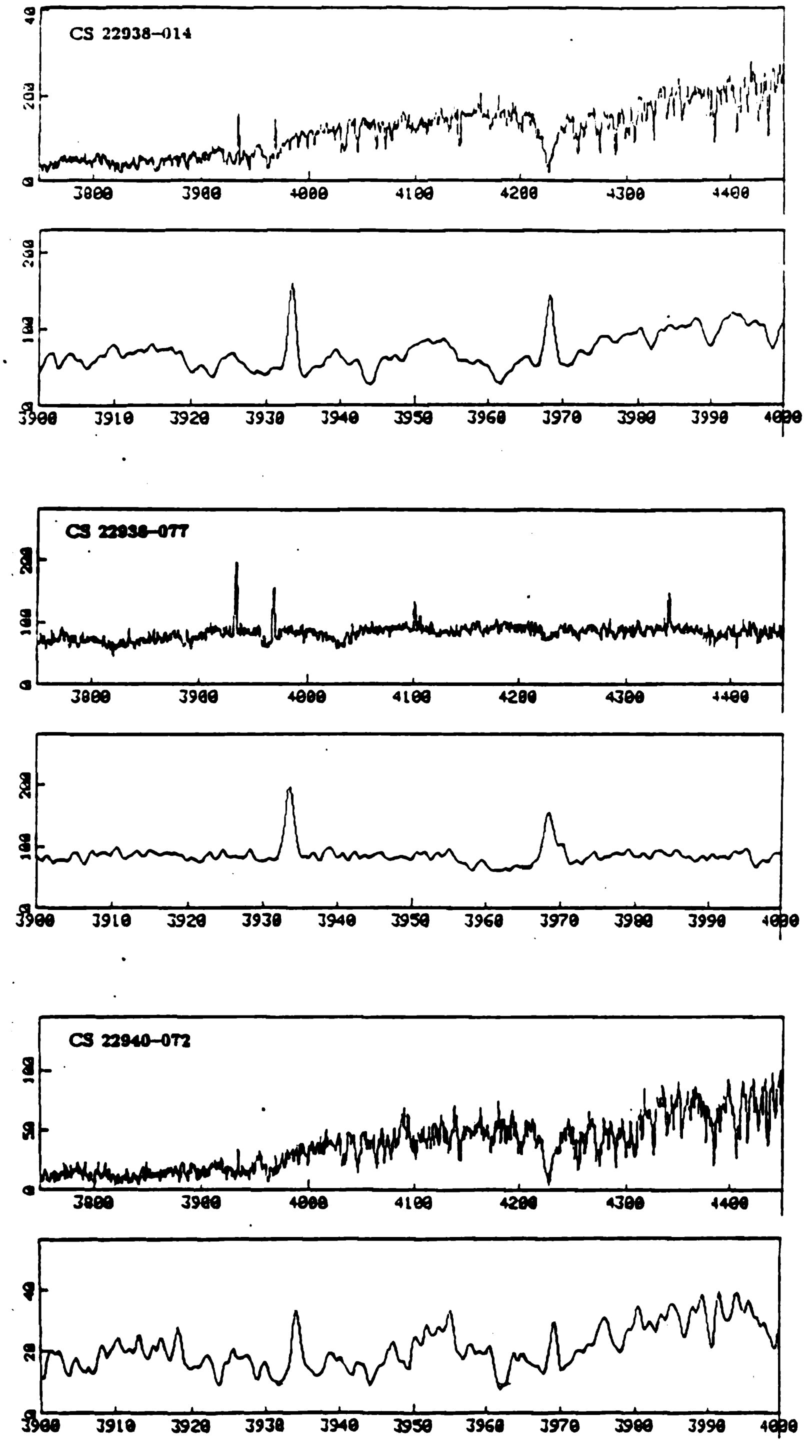
Figures 1-31,32,33.



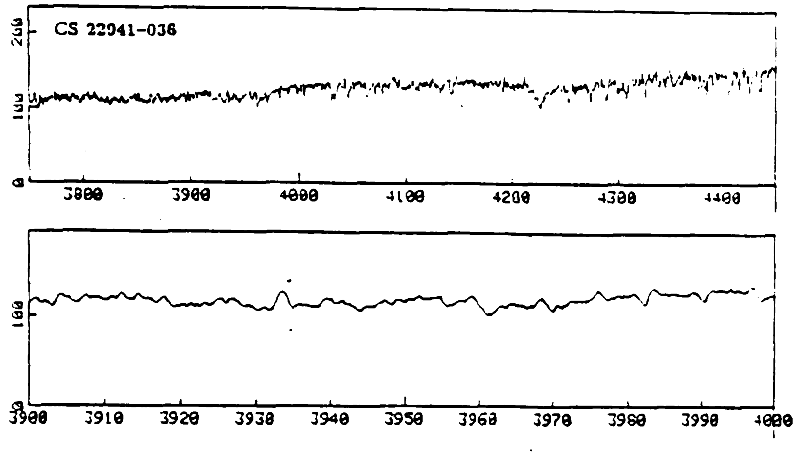


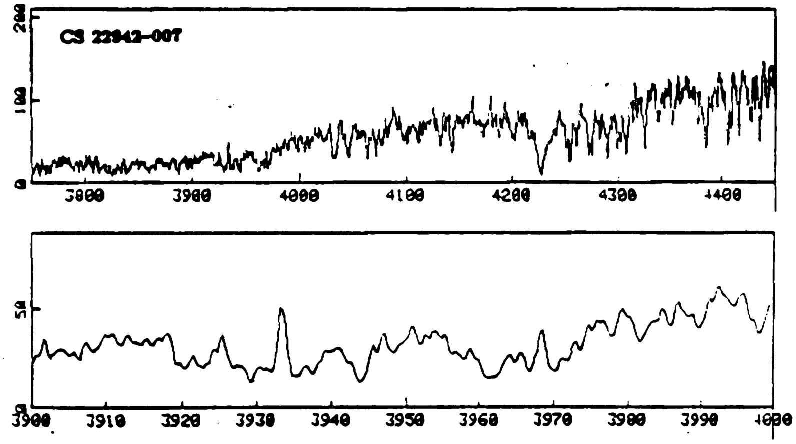


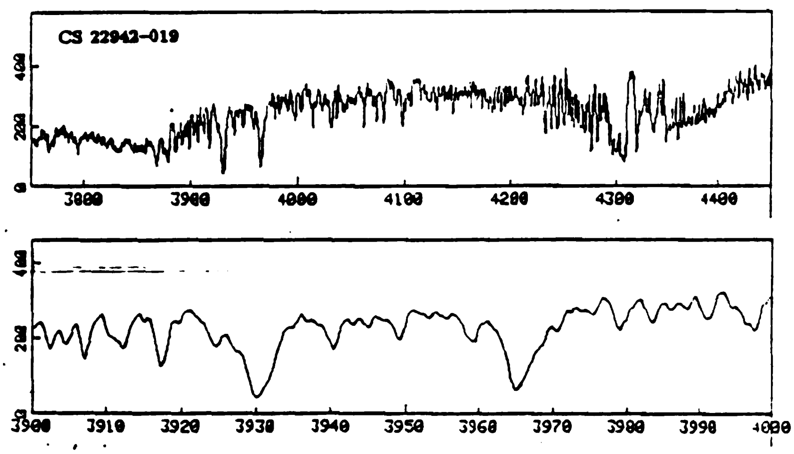
Figures 1-34,35,36.



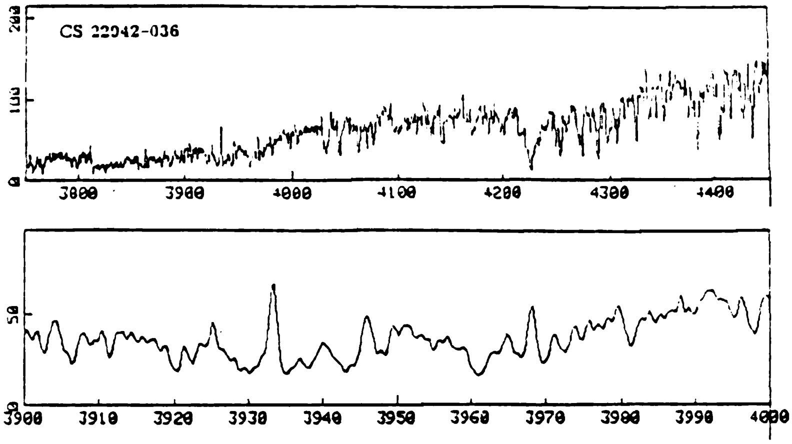
Figures 1-37,38,39.

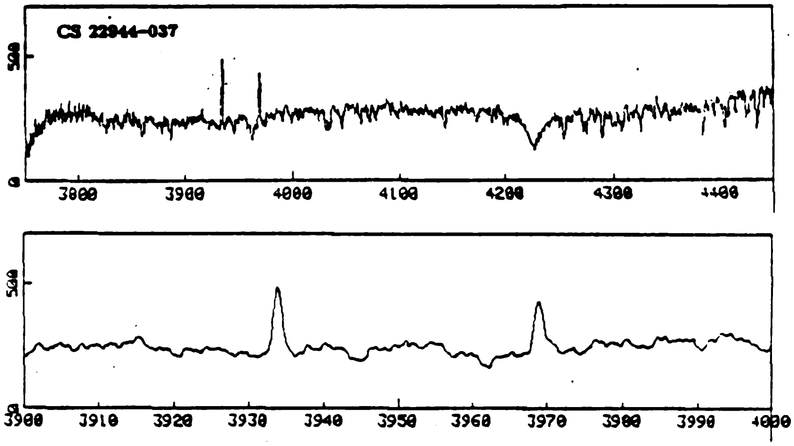


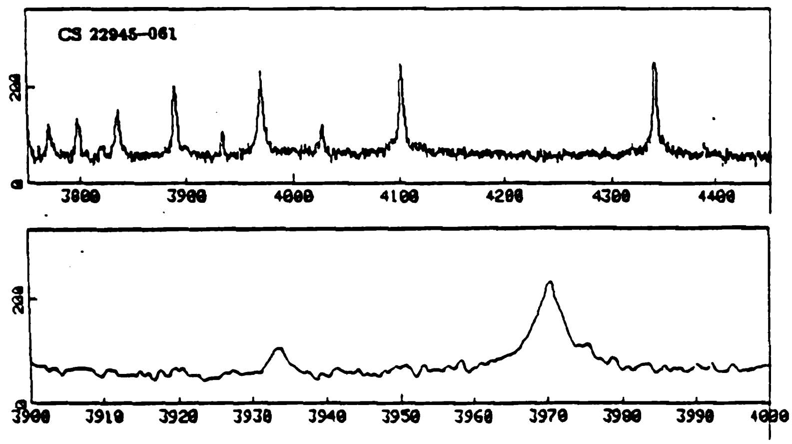




Figures 1-40,41,42.







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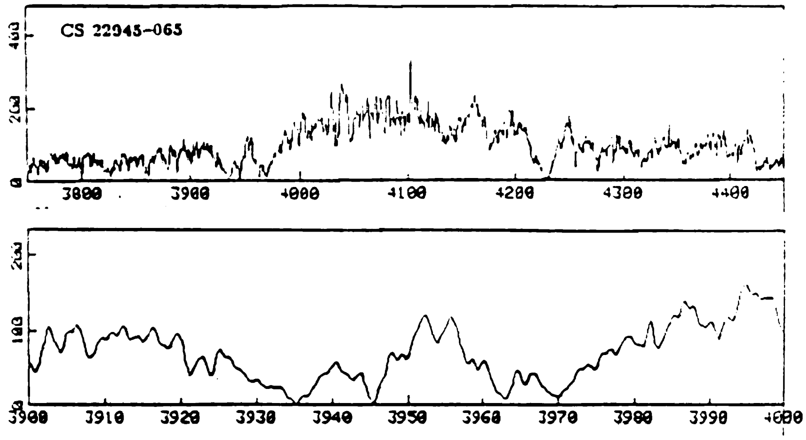
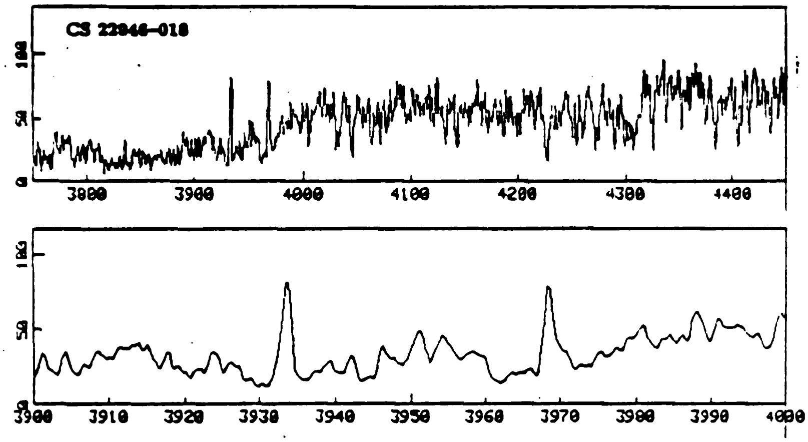
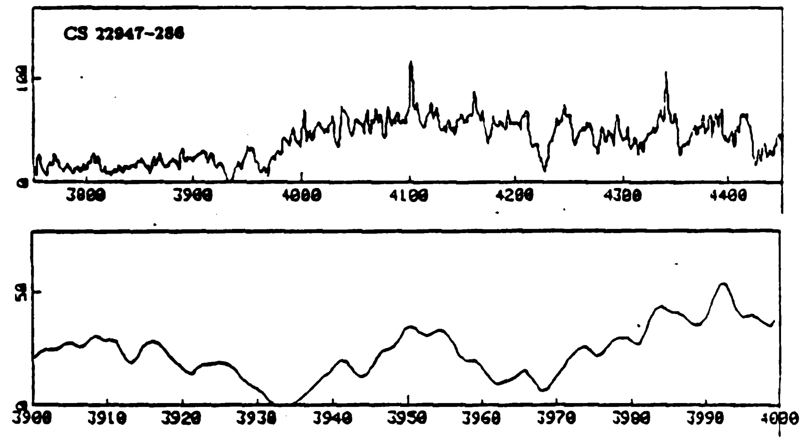
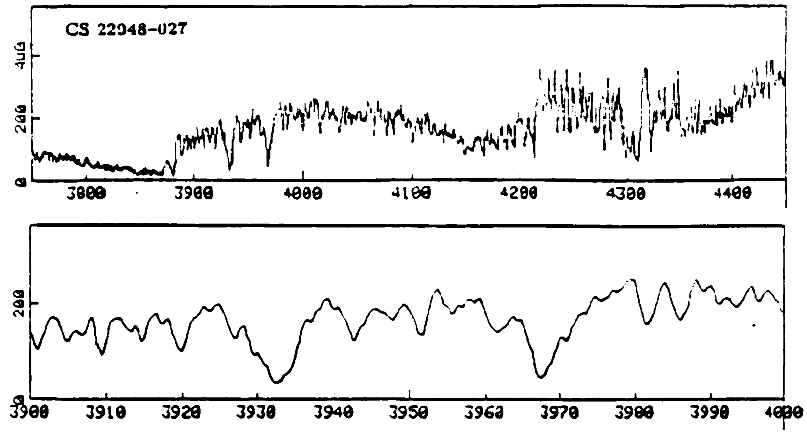
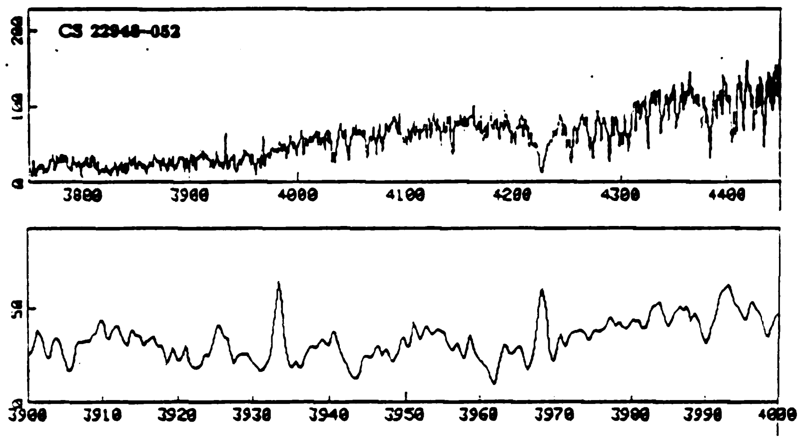


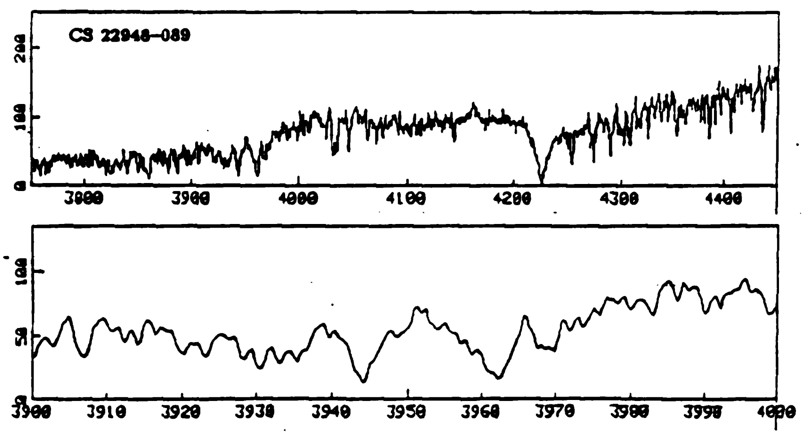




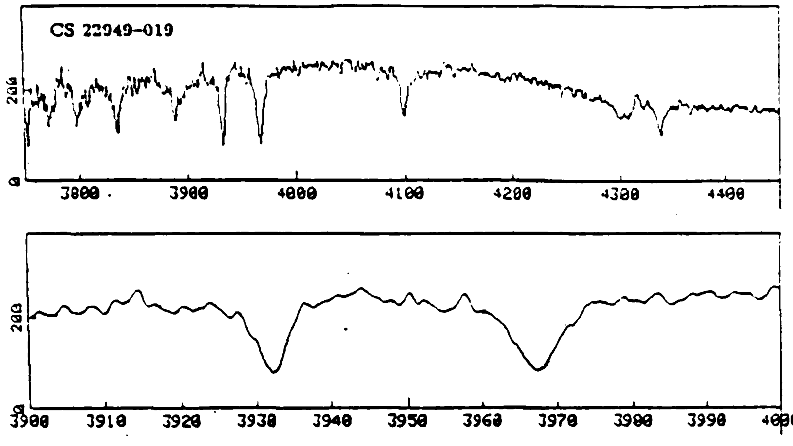
Figures 1-46,47,48.

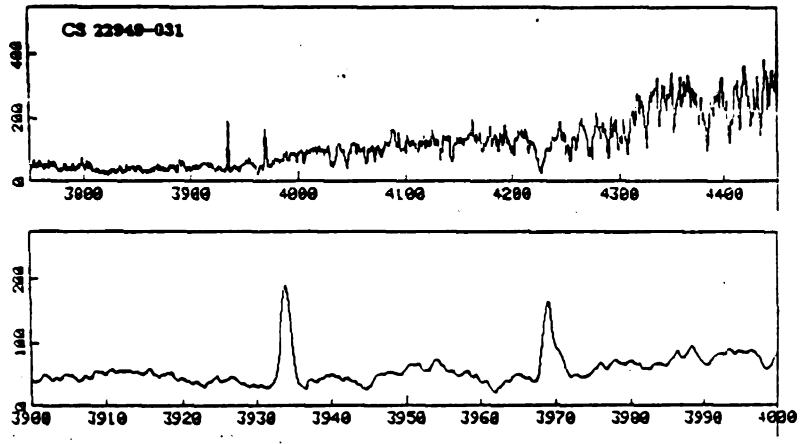


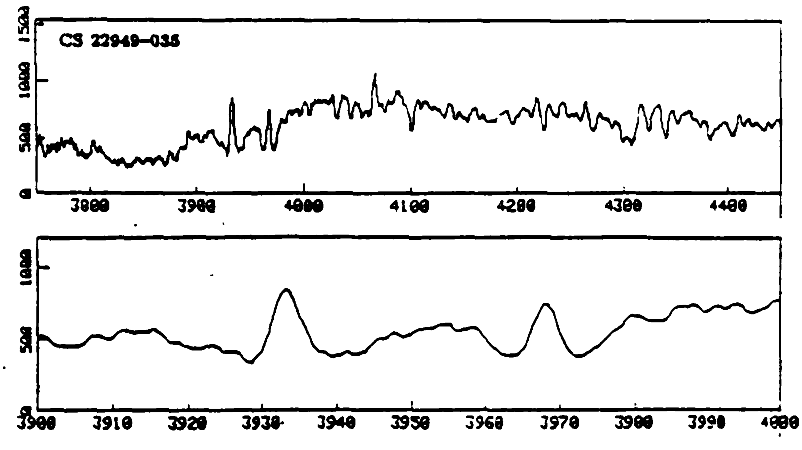




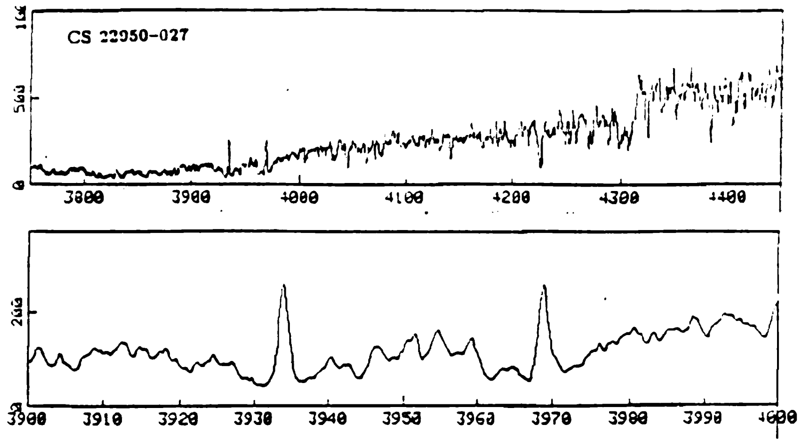
Figures 1-49,50,51.

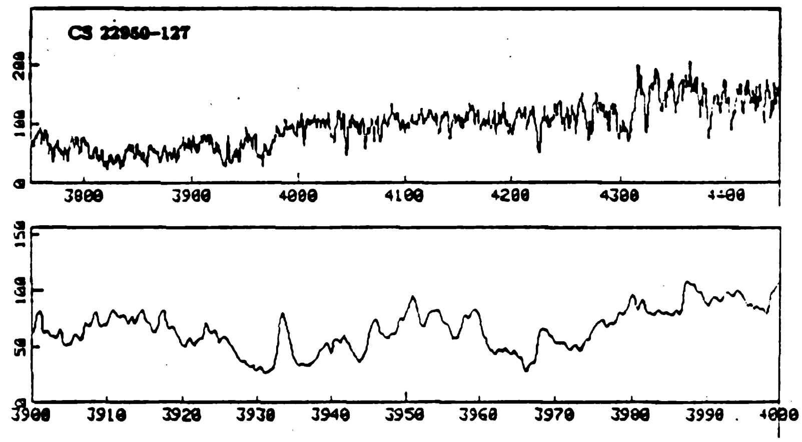


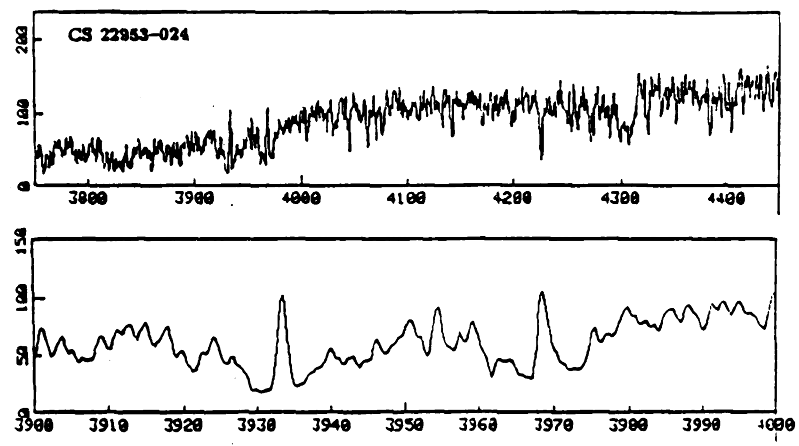




Figures 1-52,53,54.







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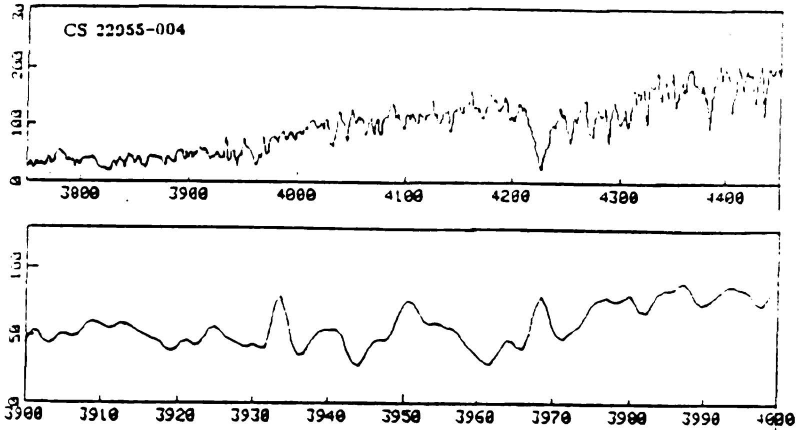
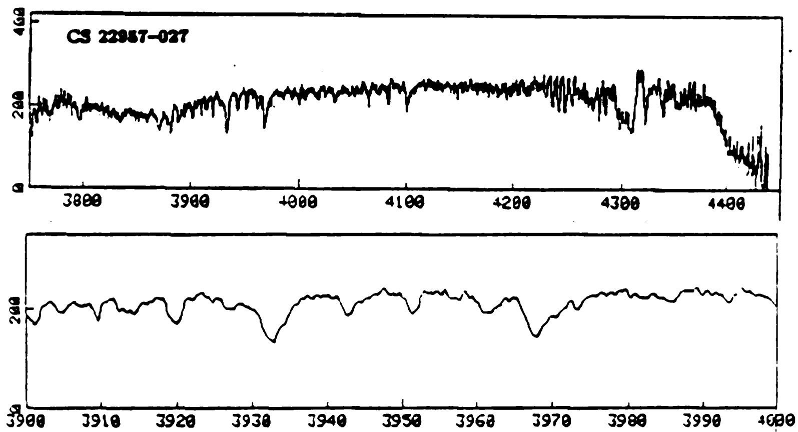
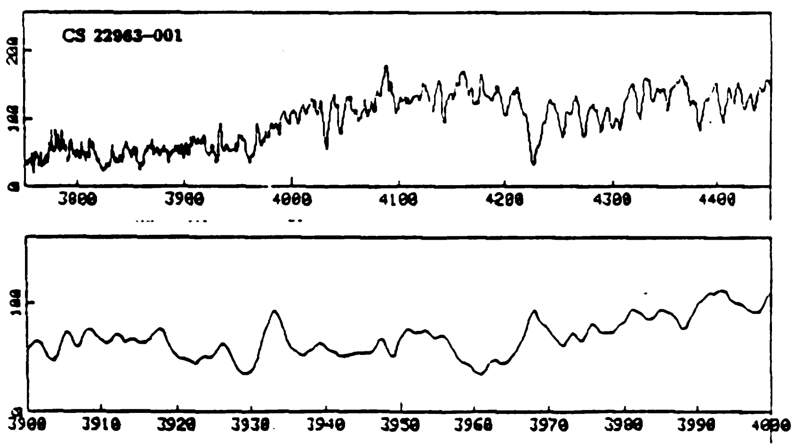
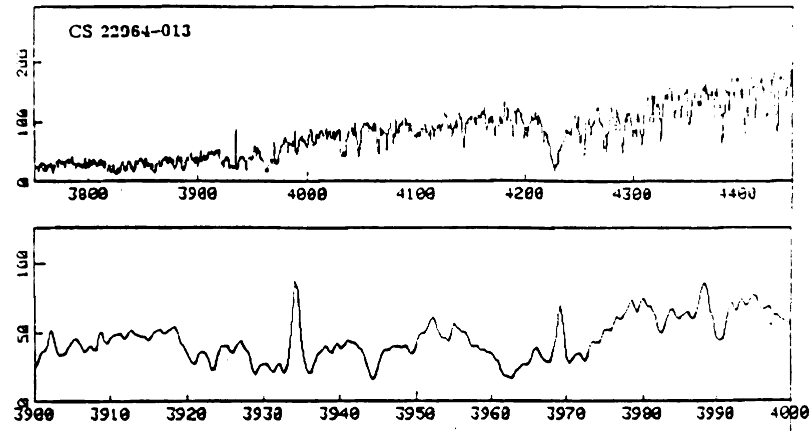
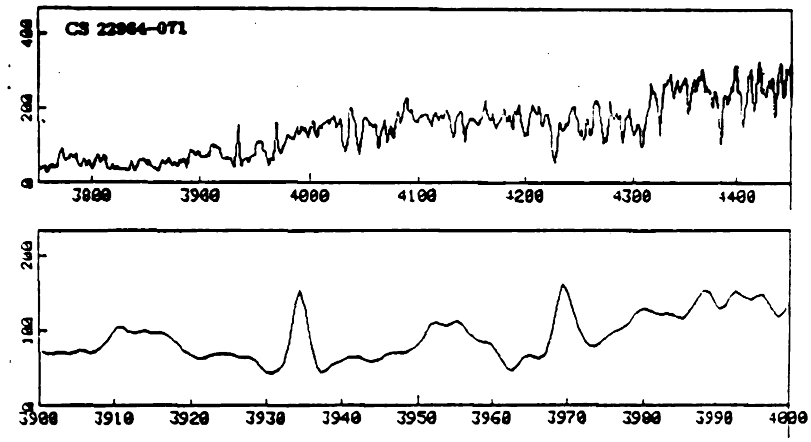


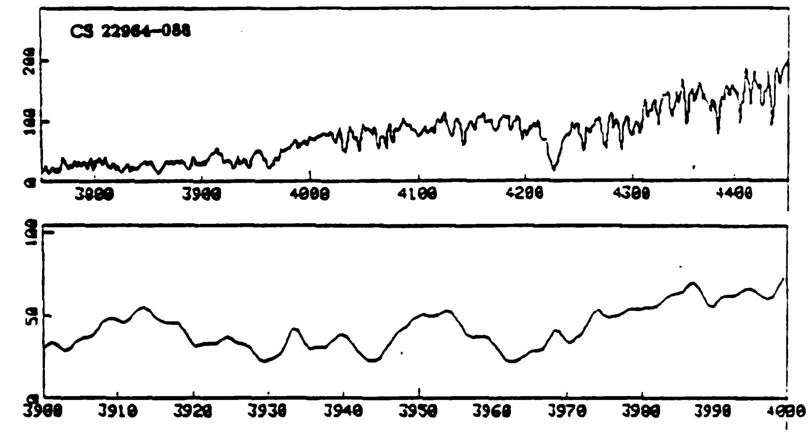




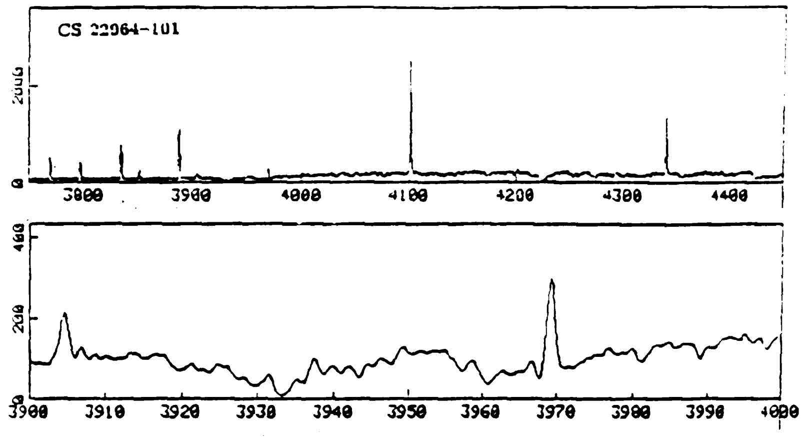
Figures 1-58,59,60.

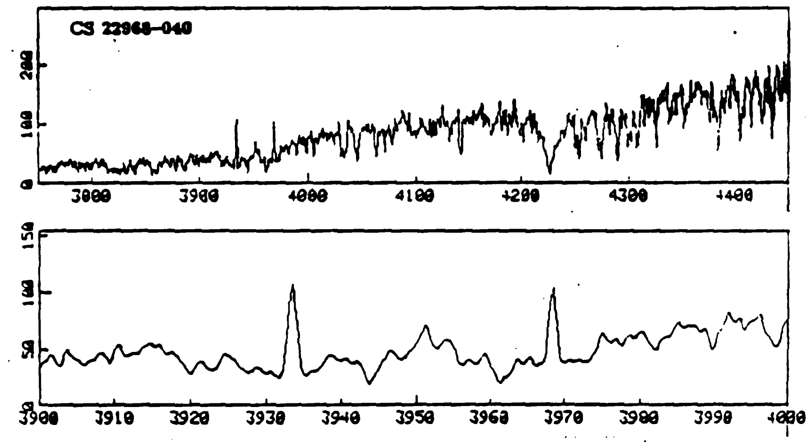


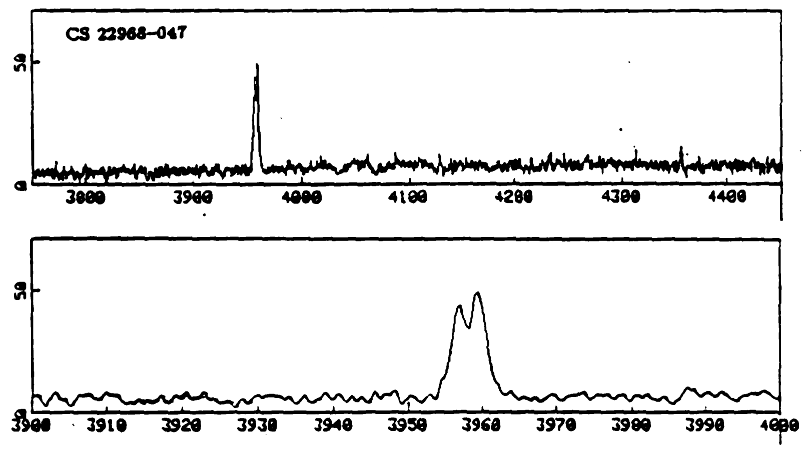




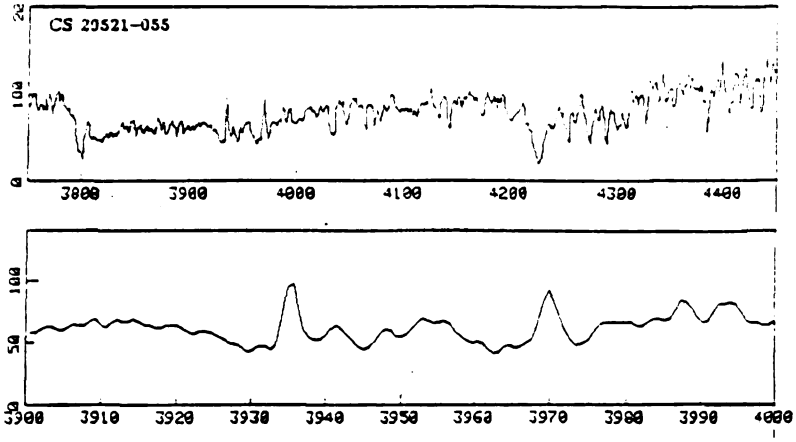
Figures 1-61,62,63.

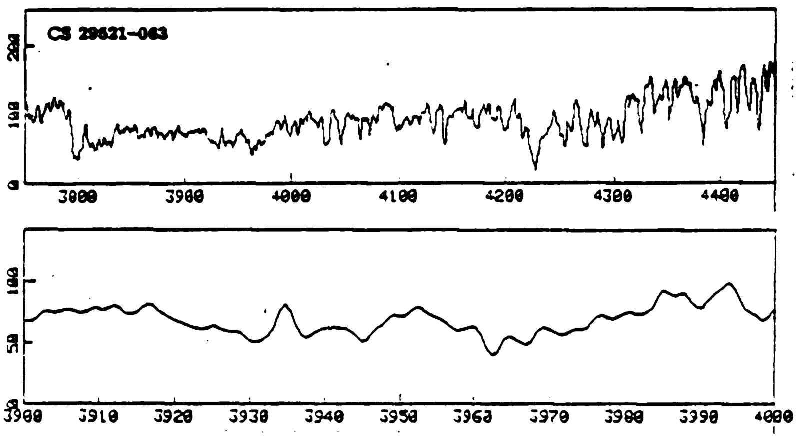


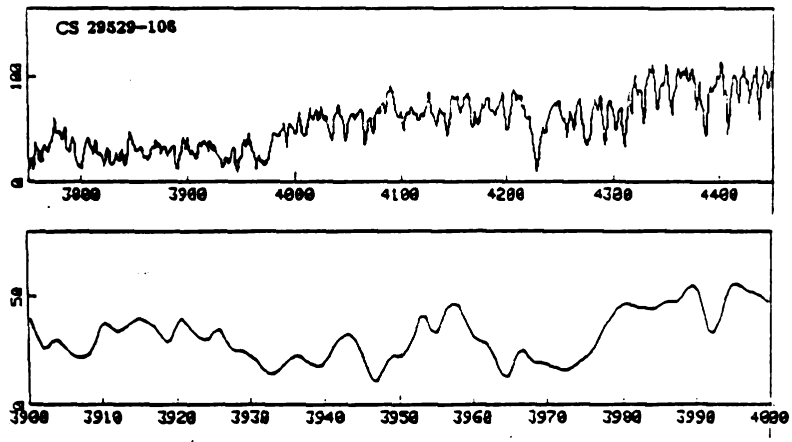




Figures 1-64,65,66.







BIBLIOGRAPHY

BIBLIOGRAPHY

Beers, T. C., Preston, G. W., Shectman, S.A.(1985). Astronomical Journal, Vol. 90, page 2089.

Bond, H. E. (1974). Astrophysical Journal, Vol. 194, page 94.

Bopp, B. W., and Espenak, F., (1977). Astronomical Journal, Vol. 82, page 916.

Bopp, B. W., Noah, P. V., Klimke, A., Africano, J., (1981). Astrophysical Journal, Vol. 249, page 210.

Eaton, J. A.,and Hall, D. S., (1979). Astrophysical Journal, Vol. 227, page 907.

Evans, T. L., and Koen, M. C. J., (1987). South African Astronomical Observatory Circulars, No. 81. page 21.

Hall, D. S., (1981). in Solar Phenomena in Stars and Stellar Systems.

Jaschek, C., and Jaschek, M., (1987). The Classification of Stars. Cambridge University Press.

Landolt, A. U., (1983). Astronomical Journal, Vol. 88, No. 3.

Petit, M., (1987). Variable Stars., John Wiley and Sons.

Stetson, P. B., (1987). Bulletin American Astronomical Society., Vol. 19, page 745.

Vaughan, A. H., (1983). I.A.U. Symposium, Vol. 102, page 113.

Walter, F., and Bowyer, S., (1981). Astrophysical Journal, Vol. 245, page 671.