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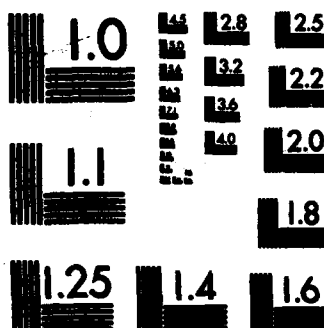
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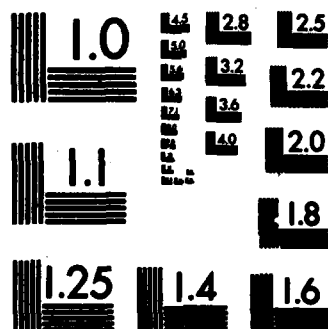
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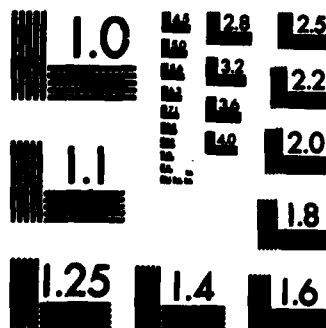
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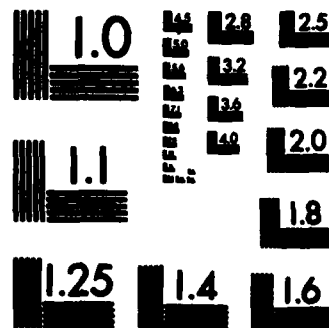
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STELLAR ANALOGS OF SOLAR ACTIVITY

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Final Report
15 December 1979 - 15 December 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A fiber-coupled spectrograph (FCS) for moderate-resolution stellar observations has been designed, fabricated, and tested. The excellent short- and long-term stability of this instrument represents a significant advance in the state-of-the-art for high precision stellar spectrophotometry. A preliminary observational survey of the greatly enhanced analogs of solar activity that exist in flare stars and the RS CVn binaries has been performed using this instrument, and the starspot model for explaining the photometric variability of		

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these latter stars has been verified spectroscopically

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1.0 INTRODUCTION

1.1 Statement of Objectives

The primary objective of this contract is to determine techniques and limiting magnitude for observing stellar analogs of solar-like activity and related phenomena such as rotation and luminosity variations. Pursuant to these goals we have undertaken both instrumental and observational programs.

1.2 Description of Approach

The instrumental program concentrates on those techniques which will allow precise, highly repeatable synoptic data to be obtained from stellar sources. At the onset of this contract very little work had been done in precision stellar spectroscopy. However, Livingston and his collaborators had been synoptically studying the integrated spectrum of the sun using precision spectrophotometry. This work concentrated on the Ca^+ K line and temperature sensitive features of carbon and titanium. The only comprehensive program monitoring stars was the work of Vaughn and his collaborators at Mt. Wilson where they used a specially designed photometer to study Ca^+ K line core emission. They have surveyed a wide variety of objects with an emphasis on solar like (F-K) main sequence stars. Our goal was to develop more generalized techniques which would allow any spectral region to be studied at varying wavelengths and resolutions. The approach that evolved makes use of recent developments in fiber optic technology to provide the environment for precision spectrophotometry.

The observational program has involved two phases. The first of these was the study of greatly enhanced analogs of solar activity such as exist in flare stars and RS-CVn stars. The purpose of this initial phase was to develop spectroscopic diagnostic techniques which might prove fruitful when studying more solar like objects. The second phase was to concentrate on bringing these tools

to bear on main sequence objects with spectral types later than F5. Unfortunately the termination of this contract prevented the pursual of these observations past a few preliminary project studies.

2.0 RESEARCH ACCOMPLISHMENTS

In this section we will detail the work done under this contract. In the first section (2.1) we will deal with the instrumentation in and of itself. In section 2.2 we will discuss the observational program carried out and in section 2.3 we will summarize the current status of the research and goals for any future programs in this area.

2.1 Instrumentation

The major work in this area was development of our Fiber Coupled Spectrograph (FCS) concept. We implemented a breadboard system at Black Moshannon Observatory (BMO) for trial observations in summer 1980 and an upgraded version in late fall 1981. Considerable work has also been done on fiber measurements.

Angel et al. (1977) have discussed the basic properties of fused silica optical fibers along with several potential astronomical applications. In a follow-up study Hubbard, Angel and Gresham (1979) demonstrated the feasibility of a fiber coupled spectrograph. Heacox and Serkowski (1980) report the use of a fused silica fiber coupler for image scrambling on the U. of A. radial velocity spectrometer which was previously used at a cassegrain focus. We report here on the development of a fiber coupled spectrograph for use with the Pennsylvania State University's 62" telescope and our existing detector instrumentation (i.e. a SIT system). Our approach is to build the spectrograph itself in an optical bench fashion. This is housed on the observing room floor and fed by a fiber from the f/11 cassegrain focus of the telescope. Some advantages to such a scheme in addition to the scrambling properties emphasized by Heacox and Serkowski are as follows:

1. Freedom from telescope related flexure
2. High dimensional stability achievable
3. Low implementation cost and effort compared to a Coudé
4. Easier control of detector environment
5. Greatly simplified mechanical design

For the type of observations in this project the stability of the spectrograph and the consistency of illumination is most important. The fiber has provided for identical illumination of the spectrograph optics under all observing conditions which has greatly improved the repeatability of our measurements. In addition, previous uncertainties in flat field correction have disappeared.

2.1.1 Fiber Measurements

The first phase of our project was the testing of useful fiber products. The fiber described by Heacox and Serkowski (1980) is unfortunately not a readily available item in the relatively small quantities needed by most observatories at the present time. We have investigated several alternatives which are current "off the shelf" items.

We considered several fibers during this phase of the project. They are given in Table 2 below. All are step index with fused silica cores.

Table 2

Fiber Mfg.	Core Diameter
Galite (4000-LC)	125 Micron
Galite (4000-LC)	204 Micron
Galite (5020)	125 Micron
Maxlight	250 Micron
Maxlight UV	150 Micron
Valtec	125 Micron

We performed tests on the above fibers similar to those discussed by Angel et al. (1977) and Heacox and Serkowski (1980). Figure 1 shows the results of a test where the prepared end of the fiber was illuminated with an $f/11$ cone from a diffused tungsten lamp through a $500 \text{ \AA}$ interference filter centered at $6500 \text{ \AA}$. The ordinate shows the fraction of the total light within a cone defined by the f number on the abscissa. This was measured by a PMT system where the field lens ($f/2.5$) was imaged on the fiber end. A variable diaphragm changed the effective aperture. The results for the Galite 5020 were typical of the Valtec and Maxlight 250 micron fibers. These results show the Maxlight 150 μ fiber to be acceptable for $f/6$ or faster. This fiber has superior blue ($3000\text{--}5000 \text{ \AA}$) transmission properties compared to the Galite 4000 series. The measurements of the Galite 125 micron fiber displayed here are spurious and have been attributed to distortion caused by the epoxy holding the fiber in the test set-up. This and other experiments we have done convinced us that extreme caution must be used when applying adhesives to these fibers. In Figure 2 the results of more qualitative tests are presented. These were done by using a laser and varying the angle of incidence. The output is annular, as described by Angel et al. (1977). The upper and lower lines in our figure are for the outer and inner diameter of the annulus respectively. The results of Heacox and Serkowski (1980) for the Galite 125 micron fiber are reproduced for comparison as our tests on a 1 meter sample kindly supplied by them confirm their data. We note that all the above described tests were done with fiber ends prepared by cleaving.

A more extensive series of tests were done on the beam preservation properties by Barden, Ramsey and Truax (1981). These results provide an initial guide to selecting fibers for use in astronomical spectroscopy.

2.1.2 Test Fiber Coupled Spectrograph (FCS)

The next step was the construction of a test instrument. Our initial effort was a breadboard system built in a light tight enclosure on the floor in the telescope area. This version, called FCS I, was constructed on a I-beam reinforced 1" plywood 4 x 8' table.

The spectrograph geometry was rather conventional (Figure 3). The 150 mm f/6 collimator is a paraboloid illuminated $\sim 7^\circ$ off axis. The 100 mm grating was the aperture stop of the system and effectively limited the input beam to f/9. The Galite 4000-LC 204-micron core 15-meter long fiber cable used had an f/6 emergent beam. A transfer lens to reduce light losses due to overfilling the collimator was used. There were two camera "tracks". One is at an angle of 12° to incident angle for use with an echelle grating ($\theta_B = 63^\circ 26'$, 316 λ/mm). The other track at a 45° angle was optimized for our lower blaze angle gratings ($\theta_B \leq 21^\circ$).

Two cameras were tried and could be placed on either track. Both were spherical lens systems and we focused on the sagittal astigmatic image. The short focal length camera (305 mm) was a surplus Aero-Ektor F/2.5 lens and the long focal length camera was a commercial 762 mm., 6" achromat. These cameras limit the unvignetted field somewhat but both are more than adequate for our SIT format of 12.5 mm. The following table shows the inverse dispersion available with these cameras and gratings. Changing from one configuration to another took about 15 minutes.

Table 1

Grating	θ_B	Order	λ	Long Focus Camera	Short Focus Camera
1200 λ/mm	$17^\circ 27'$	1	5000	11 $\text{\AA}/\text{mm}$	27 $\text{\AA}/\text{mm}$
316 λ/mm	$63^\circ 26'$	11	5000	2.0 $\text{\AA}/\text{mm}$	5 $\text{\AA}/\text{mm}$
300 λ/mm	$4^\circ 30'$	1	5000	43 $\text{\AA}/\text{mm}$	110 $\text{\AA}/\text{mm}$

The slit, of course, was defined by the fiber core and is circular for the single fibers tested so far. For ease of alignment and interchangeability of fibers the output end of the fiber was held by a pin vise mounted on a 5-axis holder for alignment purposes. A test exposure of a Ne-Ar lamp through the fiber using the 305 mm camera yield an FWHM line profile of 2.7 channels. This performance is very close to what can be expected from the projected image of a .2 mm circular aperture in this system.

The fiber input was in the cassegrain focal plane of the telescope which has f/11 beam. Figure 4 is an optical schematic of the fiber viewing system. Acquisition was done with the wide field viewer. A pellicle beam splitter which transmits 90% of the incident light was used along with a transfer lens assembly to image the fiber head on an image-tube/T.V. guider.

This version of the FCS was initially tested at the telescope during the summer of 1980. It has proved to be somewhat slower ($\sim 3\times$) than the cassegrain echelle system previously used when the dispersion difference is accounted for ($1.5 \text{ \AA/mm}$ for the echelle vs $5.5 \text{ \AA/mm}$ for the FCS). Much of this loss has been traced to the poor efficiency ($\sim 50\%$) of the surplus Aero Ektor Camera lens system. Other losses took place at the input end of the fiber as well as in the transfer lens system. However, given its limitation, useful data were obtained and the viability of the concept tested. The telescope trials of the FCS during the June, July and August observing runs were very successful especially considering its breadboard nature. The stability of the system was nearly as good as the detector system ($\sim 1-2\%$ for our SIT vidicon). Short term stability was much better than the detector and the long term (weeks) was slightly worse ($\sim 5\%$).

2.1.3 Implementation of FCS II

During late fall 1980 we installed a completely new system designated FCS II to replace FCS I. The new system is not conceptually significantly different than the prototype previously described. It does, however, have substantially improved long term stability due to its construction and location. The optical

schematic for this system is given in Figure 5. The entire spectrograph is mounted on a research grade optical table in a room remote from the dome on a sealed concrete floor. While the table is not vibration isolated no significant problems are expected due to the remoteness of the observatory site. A 25 meter 204 micron fiber is used to feed the spectrograph. The new spectrograph optics are completely refracting and are much more efficient than those in the previous system. This system was implemented in late November 1980 and test results indicated an increase in system speed by about a factor of four. This is interesting especially in view of the longer fiber used here. An additional modification involves a new fiber holder/head assembly which is illustrated in Figure 6. This assembly places less stress on the fiber and leads to better beam preservation characteristics as well as less insertion loss.

Some of the expense for the FCS implementations were supported by NSF grant under the supervision of Lawrence W. Ramsey.

2.2 Observations

The observational research under this contract has concentrated heavily on spectroscopy and in particular on spectroscopy of RS CVn stars and related systems concomitant to our goal of establishing diagnostic techniques for solar like phenomena. In the latter stage of the contract study of solar-like stars was initiated.

2.2.1 Spectroscopy and Photometry of RS CVn stars

RS CVn binaries have come under increasing study due to their discovery as strong radio emitters (eg. Spangler et al., 1977; Owen and Gibson 1978) with occasional radio flaring (Feldman et al., 1978). Also RS CVn's have been detected as both flaring and quiescent soft X-ray sources (White et al., 1978; Walter et al., 1978a, 1978b). Walter et al. (1980) developed a coronal model for it. Hard x-rays associated with RS CVn systems have also been observed (Crampton et al., 1979, Schwartz et al., 1979 and Garcia et al., 1980). Swank et al., (1981) suggest that a component up to 10^8 K may be needed to explain the X-ray spectrum. RS CVn

are among the most intense soft X-ray emitters in the cool half of the diagram. RS CVn systems are defined by Hall (1976, 1978) as a binary in which the hotter component is spectral type F or G and strong Ca II H & K emission is outside eclipse. The RS CVn systems are classified in two broad groups. The short period group has orbital periods between one day and two weeks and the long period group contains those systems with periods longer than two weeks. We have not studied the latter group much as they tend to be giant stars. This class of variables exhibit a variety of other peculiarities such as wave-like distortions in their light curve and H α emission. Hall (1976) extensively tabulates these properties. The operational hypothesis for understanding much of the observed phenomena in RS CVn systems is based largely upon our solar experience. The dominant photometric variability in the form of a distortion wave is modeled by hypothesizing a thermal inhomogeneity with appropriate latitude and longitude distributions (e.g., Eaton and Flare, 1979). This "starspot" model has gained wide support. The ultraviolet emission is also modeled by analogy to the solar chromosphere and transition region (Simon and Linsky, 1980). A solar corona-like phenomena is also invoked to explain the soft X-ray emission (Walter *et al.*, 1980, Walter and Bowyer, 1981). We have surveyed various spectral features with diagnostic potential. As RS CVn stars are generally cooler than the sun we have and will continue to emphasize the ultraviolet and near IR regions of the spectrum. This is especially crucial as it is in these regions that we have the greatest potential contrast between the spot spectrum and the surrounding photosphere. Observations of the TiO δ system at 8860 Å in HR 1099 (Ramsey and Nations, 1980) proved productive in this respect, as they along with similar data on II Peg (Vogt, 1979, 1981a) have removed any questions concerning the starspot model as a viable hypothesis for understanding the photometric variations in this class of objects. In these observations the temperature of the TiO feature underwent a dramatic enhancement when the photometrically darker hemisphere was facing the observer, as is illustrated in Figure 7. Simultaneously the H α strength increased, reminiscent of the solar plage phenomenon. Analysis of the H α emissions in HR1099 (Figure 8) shows that a component of the H α emission is very

likely originating in a plage-like region. We have in turn studied the TiO γ system in the $\lambda 7120 \text{ \AA}$ region. Image tube observations in March 1981 at KPNO, though noisy, definitely show phase dependent variations of a γ system bandhead in the RS CVn system BD+61° 1211 which is also a hard X-ray source (Crampton *et al.*, 1979). SIT observations at Penn State have also indicated the presence and variation of this feature in II Peg (Figure 10). A program to observe a calibrating sequence of K and M dwarfs and giants at the $\lambda 7120$ TiO bands was also carried out at BMO. Approximately 30 spectra of these stars were obtained and reduced to provide a calibration of the TiO band equivalent widths vs spectral type (or effective temperature) for dwarfs and giants over the range G8-M2. This data will later be used in semi-empirical starspot modeling of the $\lambda 7120$ data obtained for the program RS CVn stars. Figure 11 shows a few samples from this survey.

We also completed analysis of BVRI photometric observations of the RS CVn-like system II Peg. Figure 12 shows the evolution of the light curve of this star for the period 1974-1977. The data is from Vogt (Ap.J. 1981). Our 1979 V data is shown in Figure 13. The general shape of the light curves presented here indicates that a dramatic change in the longitudinal distribution of the starspots on II Peg has recently taken place. The spots are now much more widely distributed in longitude than previously.

It is particularly interesting to compare the observations from 1977 and 1979. In 1977 the minimum in the V band observations occurred about 0.10 in phase earlier than did the primary or deeper minimum of the 1979 observations while the secondary or brighter minimum in 1979 occurred ~ 0.45 in phase later than did the primary minimum. There are two simple, competing scenarios which can most easily explain this behavior. The first is simply that the spot group responsible for the 1977 variations "dissipated" in the intervening two years with two new spot groups forming at the appropriate stellar longitudes to account for the 1979 observations. The second possible explanation for the evolution in the light curves is that the quite large spot of 1977 fragmented, possibly due to the shearing action of

differential rotation, with the two largest fragments drifting to the positions observed in 1979. Unfortunately, the data are not sufficient to choose between these two scenarios (or any others), especially since observations from 1978 apparently do not exist.

During the summer of 1981 approximately 70 image tube plates of RS CVn stars were obtained at the coudé feed telescopes at KPNO. The object here was to further study the usefulness of the TiO band at $\lambda 7120 \text{ \AA}$ as a diagnostic for discovery and paramertization of starspots. In all cases H α spectra were obtained to search for modulation of the equivalent by active regions hypothesized to be coincident with the starspot complexes in analogy to the solar case. The stars observed included SZ Psc, II Peg, HR1099, UXAr1, HD155638, and HD166181, among others.

Reduction of these spectra indicate that II Peg went through a period of extremely weak H α emission during this observing run, with the rotational modulation of active regions into and out of the line of sight being a possible explanation for this behavior.

Bopp (1981) has noted a peculiar H α outburst on SZ Psc in 1978. He has attributed the time behavior to a possible mass transfer event. However, an analysis of photometry covering the interval of Bopp's observation show the system to be substantially underfilling its Roche Lobe (Eaton et al., 1981). Ramsey and Nations (1981a) observed an even stronger event in 1979 which persisted from early August through the end of September. It is an interesting question whether such events are precipitated by localized surface activity or a more global phenomenon as suggested by Bopp. Our results indicate a curious phase dependence which may indicate a localized source.

2.2.2 Coronal lines in W UMa systems

IUE observations of cool stars have demonstrated the existence of high temperature regions similar to the sun in their outer atmospheres (Dupree et al. 1979, Linsky et al. 1979). Particularly interesting have been the close binaries of the RS CVn and W UMa classes. These stars have been shown to have surface fluxes

of 10 to 100 times greater than the solar value in lines which are transition region lines ($\sim 10^5$ °K) in the sun. In addition, X-ray observations indicate that many have a high temperature ($\sim 10^6$ °K) corona. Our observations were based on the operating hypothesis that lines which are visible in the solar corona via ground based instrumentation will also be greatly enhanced in these stars and may be detectable against the stellar continuum. In particular we have studied the FeXIV line at 5303 Å and the Fe X line at 6375 Å. The 5303 Å line is generally more prominent on the active sun and reaches intensities of or 10^{-4} disk intensity. Enhancements of a few times 10^2 could give rise to integrated emission a few percent above continuum in the candidate stars.

This experiment concentrated on detection of these visible coronal lines in active binaries. We mostly observed W UMa stars as they exhibit relatively higher UV emission line surface fluxes but some RS CVn stars were also observed. Reasonable resolution was required as the thermal broadening for Fe is not large even at 10^6 °K (~ 3 Å) and we have no guarantee that a corona like region in these stars will share in the orbital motion of the components. Our procedure was to expose the continuum weakly on high contrast (IIIaJ) plates using the S-20 image tube on Camera #5 in the 84" coude spectrograph.

The program objects ranged in magnitude from $V \sim 7-10$ with most between $V = 8.5$ and 9.5. The periods of the systems ranged between 0.22^d and 0.8^d . Thus multiple exposures at various phases with a duration of $\lesssim 30^m$ were obtained. A cursory inspection of the photographic plate material did not reveal outstanding emission on any of the sources. We would not expect to see pronounced emission features if the emission was coming from an extensive corona co-rotating with the star as the emission line would be appreciably rotationally broadened. If this is the case then any emission lines will be difficult if not impossible to detect by visual inspection. Detection of broadened lines requires a different technique using high S/N spectra which will have to be pursued at some future time.

2.2.3 Solar like Stars

The ultimate goal of our research is to study the very low levels of activity expected on solar-like stars. We have completed an initial feasibility study phase of a program to compare the H α profiles in solar-like stars with strong and weak Ca⁺K emission. The program involves obtaining spectra at H α for stars with large mean K line emission fluxes. These so-called program stars are then compared with "standard" objects which have low K line fluxes but are matched in spectral type with the program stars. The observational program in Table I has been completed to date.

All these observations were made with the FCS I fiber system. Analysis of this data has been done by ratioing the program and standard stars to determine if there is an "emission excess" or filling in of H α in the program objects. This would be manifested as an emission line in the ratio spectra. Figure 14 shows that an emission excess is observed and is roughly correlated with the Ca K line emission strengths. Figure 15 shows that the emission excess is also greater for the active or strong K line emission stars with cooler spectral type. Both these correlations are expected and indicate that H α strength is a good diagnostic for active chromosphere stars.

In another series of observations we have perfected a technique for removing an emission line profile from the normal photospheric spectrum. Figure 16 shows an application of the strange object FK Comae. By selecting a standard star of nearly the same spectral type one can recover an estimate of the pure emission profile. This will be extremely interesting to apply to both flare stars and our solar like stars to obtain estimates of what the true emission lines are like. The stability of illumination afforded by the Fiber Coupled Spectrograph substantially enhance the potential of such observations.

TABLE I

PROGRAM STARS

HD No.	No. of Observations*	SPECTRAL CLASS
16160	1	K4 V
16673	1	F6 V
17925	1	K0 V
20630	2	G0 V
25998	1	F7 V
26923	3	G0 V
33608	1	F5 V
35246	2	F8 V
88757	1	F5 V
141004	1	G0 V
149661	2	K0 V
154417	2	F8 V
165341	5	K0 V + K5 V
201091	4	K5 V
201092	3	K7 V
206860	2	G0 V
214834B	1	K2 V

*An observation consists of 3-5 co-added spectra taken on one night.

STANDARD STARS

HD No.	No. of Observations*	SPECTRAL CLASS
13421	2	F6 V
29645	2	G3 V
45067	2	F8 V
89744	1	F6 V
142373	1	G0 V
143761	1	G0 V
159332	1	F4 V
161239	3	G6 V
187013	1	F5 V
187691	3	F8 V
207978	3	F0 V
212754	2	F5 V
216385	2	F7 V

*Defined as per program stars.

2.3 Suggestion for Further Research

A continuing program should focus on main sequence stars with convective envelopes. A major thrust of such an observational program could be H α spectroscopy of G and K type dwarfs. Stars could be selected from those being currently studied in Ca⁺ K by Vaughan and his co-workers at Mt. Wilson. A scheme of comparing more active and less active stars as discussed in section 2.2.3 could be employed. A subset of objects should be intensively studied for short-time low amplitude fluctuations in H α strength which might be related to flaring activity. The enhanced sensitivity of H α vs. the K line to flares is of some importance here. The goal for these types of observations is, of course, to obtain some feel for possible flaring activity in non-dMe stars. One would expect the best results from the later K stars but some active G stars may indicate activity in integrated light. Of particular interest here is any correlation between rotation, mean K line flux and short term H α variations which are of direct relevance to solar cycle studies.

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2.5 Figures Captions and Figures

- Fig. 1 Measured beam profiles for selected fibers.
- Fig. 2 Mean beam divergences for several fibers with varying input $f/\#$. The Galite 125 micron measurements are taken from Heacox and Serkowski 1980.
- Fig 3 Optical Configuration in the breadboard FCS system.
- Fig 4 Optical Configuration of the telescope coupler.
- Fig 5 Optical configuration for the second generation FCS system.
- Fig 6 Mechanical Schematic of the fiber head which is in the telescope focal plane.
- Fig 7 This figure illustrates the diameter variation of the T10 8860 Å feature as a function of phase. The top spectrum was taken at phase (ϕ) ~ 0.47 while the second spectrum was obtained at $\phi \sim 0.81$ near photometric minimum. The third spectrum of a normal M giant is for comparison purposes.
- Fig. 8 The rough anti-correlation of H α emission strength with the photometers brightness variation is presented here.
- Fig. 9 This figure shows the spectrum of II Pegasus in the region of the T1 0 γ system. The middle spectrum of II Peg shows several T1 0 features substantially enhanced. The bottom spectrum is a normal red giant for comparison purposes.
- Fig. 10 A sequence of giant stars in the region of the T10 γ system bandheads is shown.
- Fig. 11 This Figure, from Vogt, shows the variation in the light curves of II Peg during the period 1974-1977.
- Fig. 12 This 1979 light curve of II Peg shows the evolution of two minimum which can be accounted for by two spot groups.

Fig. 13 We present here the measured H α emission excess as a function of spectral type for solar like stars.

Fig. 14 The same emission excess plotted in Figure 13 is shown here against the Ca⁺ K line index "Log S".

Fig. 15 This figure illustrates the procedure proposed for obtaining an estimate of the emission component in a spectrum. A standard star of of similar spectral type (or the program star itself at an inactive phase) is matched and normalized to the program star. In the above case the program star is FK Comae and the smooth line is a comparison star HR4932 whose spectrum has been artificially broadened to match FK Comae. The bottom spectrum is the difference and is an estimate of the pure emission line profile.

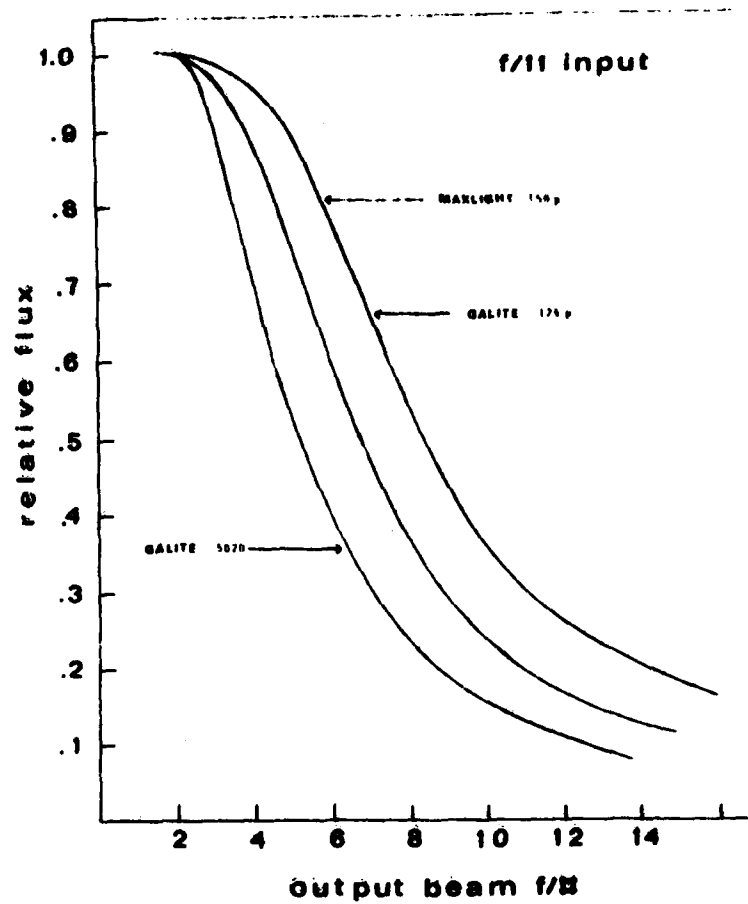


Fig. 1

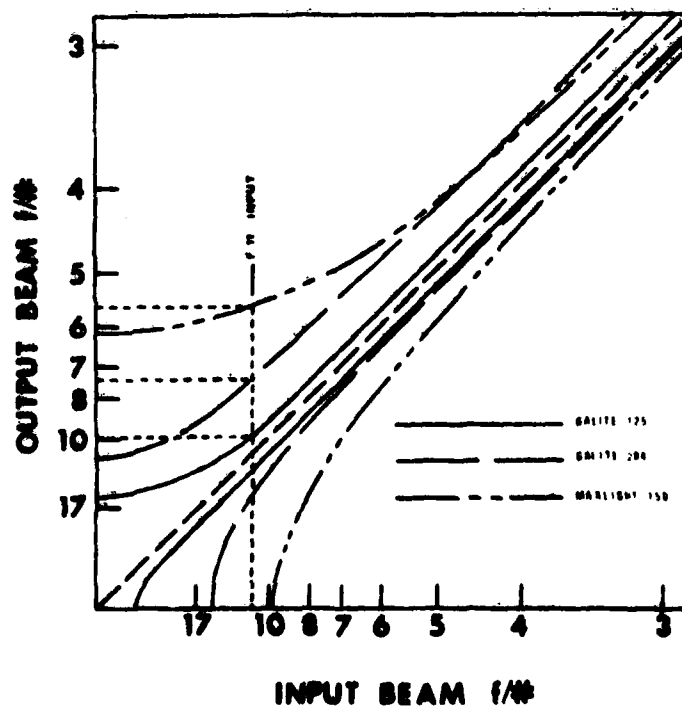


Fig. 2

F. C. S. I

1. FIBER AS ENTRANCE SLIT
2. 150 mm. $f/8$ COLLIMATOR ILLUMINATED AT $f/9$.
3. GRATING CHOICE OF 1200 λ/mm 27 λ/mm diap.
(ECHELLE) 316 λ/mm 2.0 λ/mm
4. 122 mm. $f/2.5$ CAMERA
5. S.I.T. DETECTOR AND COLD BOX SET UP ON ECHELLE RAIL.
6. OPTIONAL RAIL FOR LOW DISPERSION GRATINGS

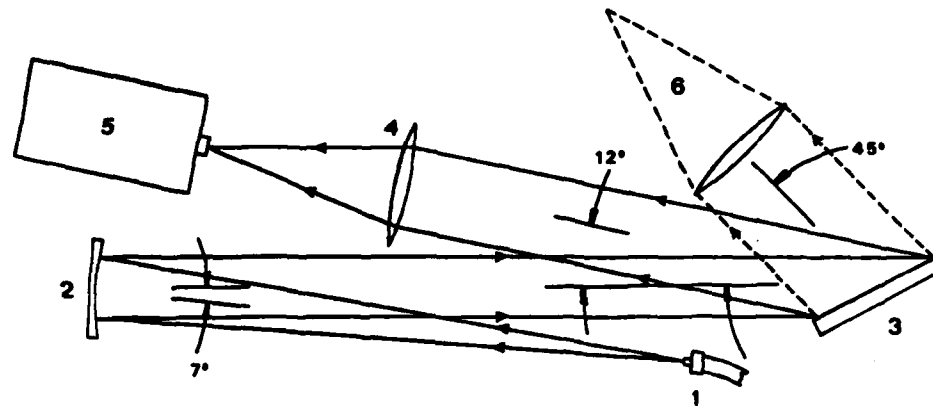
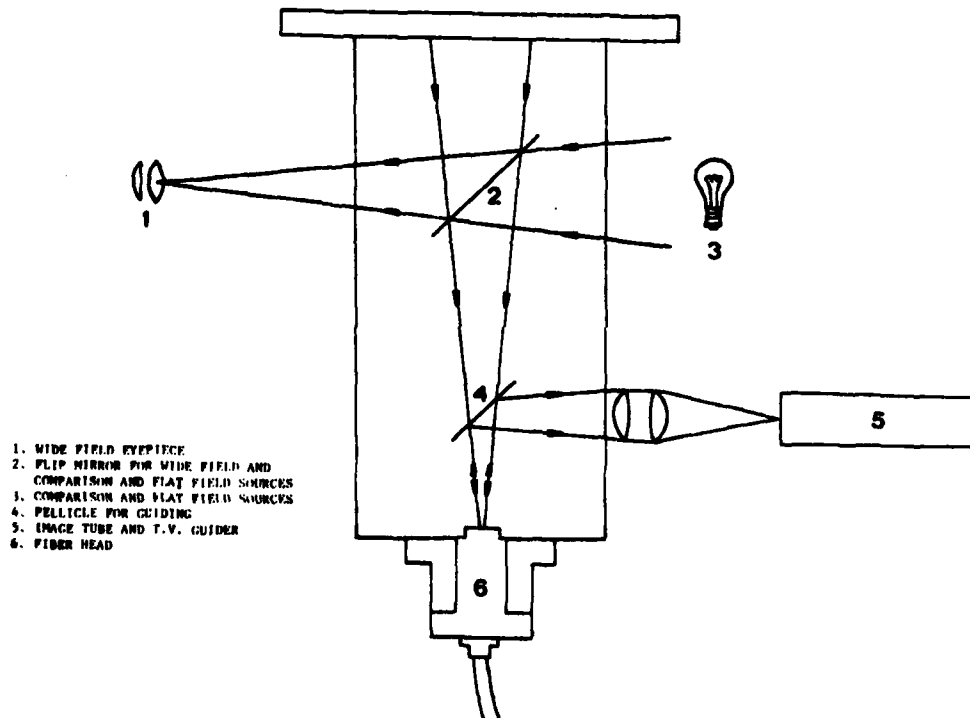


Fig. 3

TELESCOPE COUPLER



1. WIDE FIELD EYEPIECE
2. FLIP MIRROR FOR WIDE FIELD AND
COMPARISON AND FLAT FIELD SOURCES
3. COMPARISON AND FLAT FIELD SOURCES
4. PELLICLE FOR GUIDING
5. IMAGE TUBE AND T.V. GUIDER
6. FIBER HEAD

Fig. 4

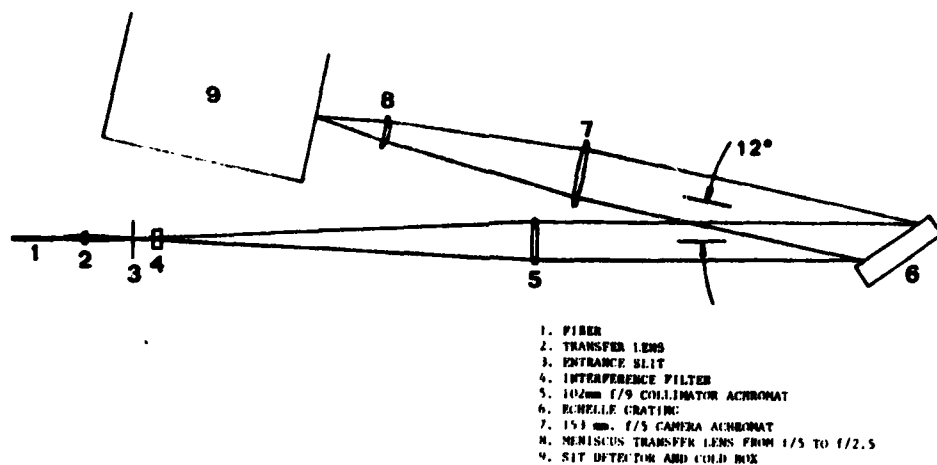


Fig. 5

FIBER HEAD

1. ALUMINUM HEAD
2. ALUMINIZED PLEXIGLASS FOR GUIDING
3. FIBER
4. PROTECTIVE CLADDING
5. INNER FIBER JACKET
6. OUTER FIBER PROTECTIVE JACKET
7. BRASS FIBER FERRULE
8. EPOXY BONDING FIBER CABLE TO FERRULE
9. PROTECTIVE FLEXIBLE STIFF CONDUIT
10. CONDUIT CONNECTOR
11. SET SCREW HOLDING FERRULE AND ALLOWING FIBER ADJUSTMENT

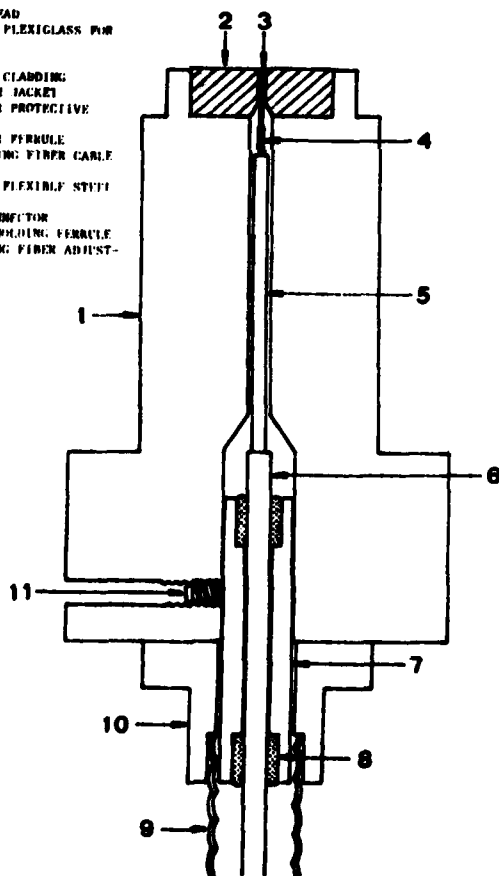


Fig. 6

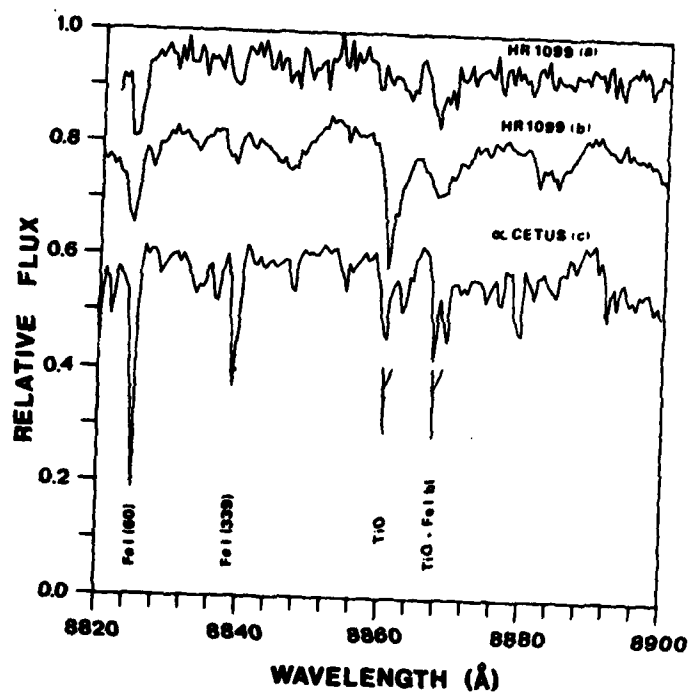


Fig. 7

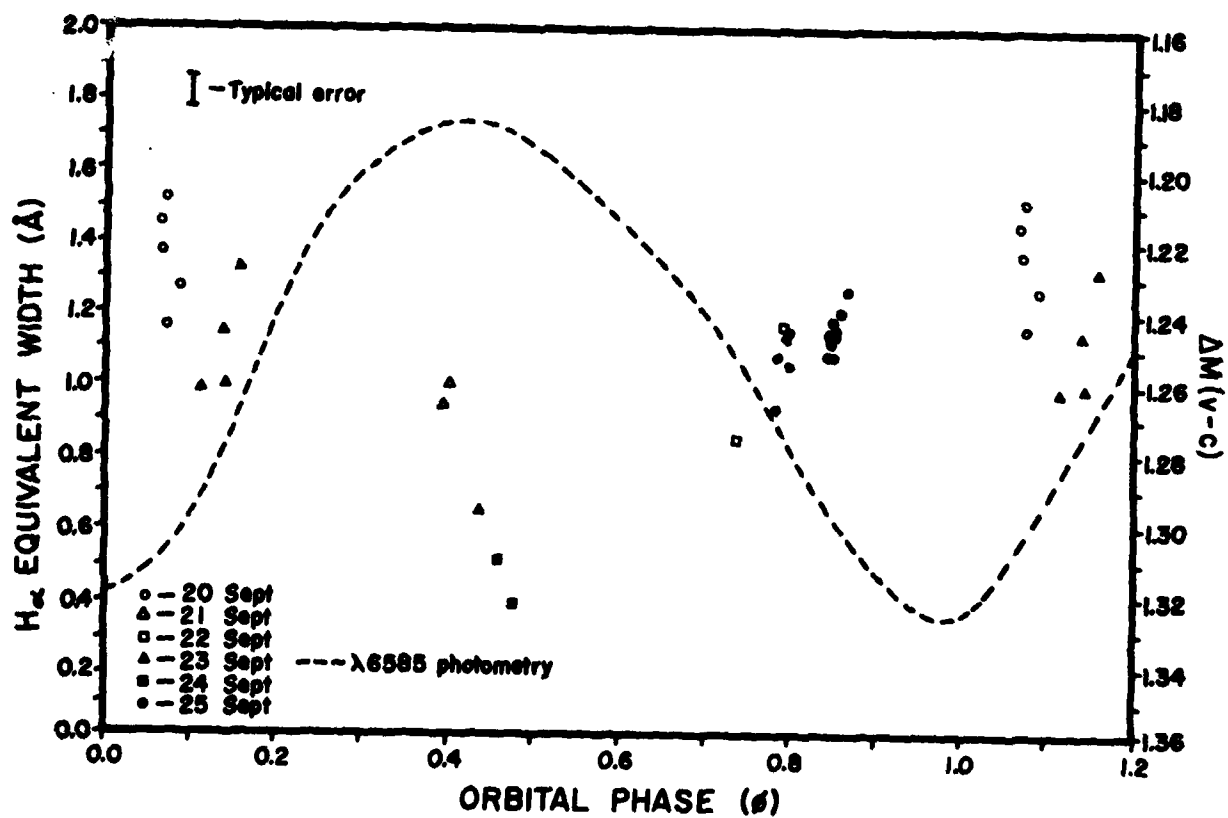


Fig. 8

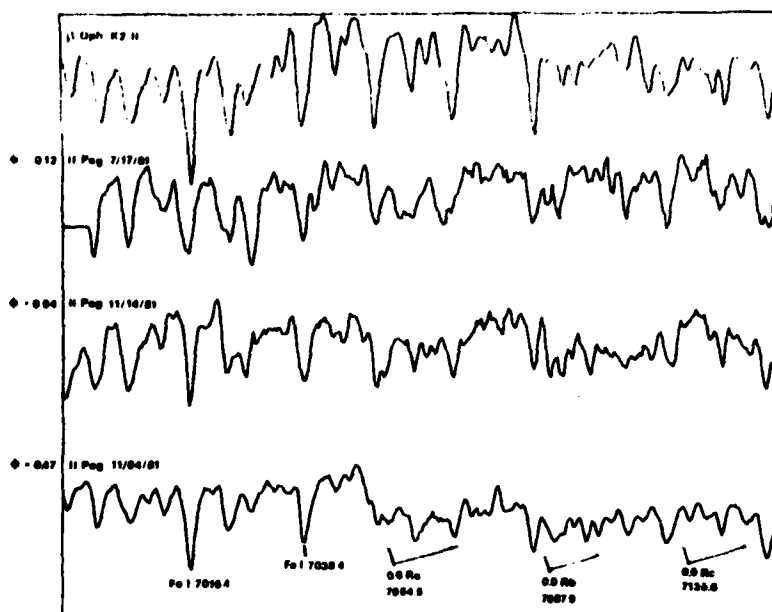


Fig. 9

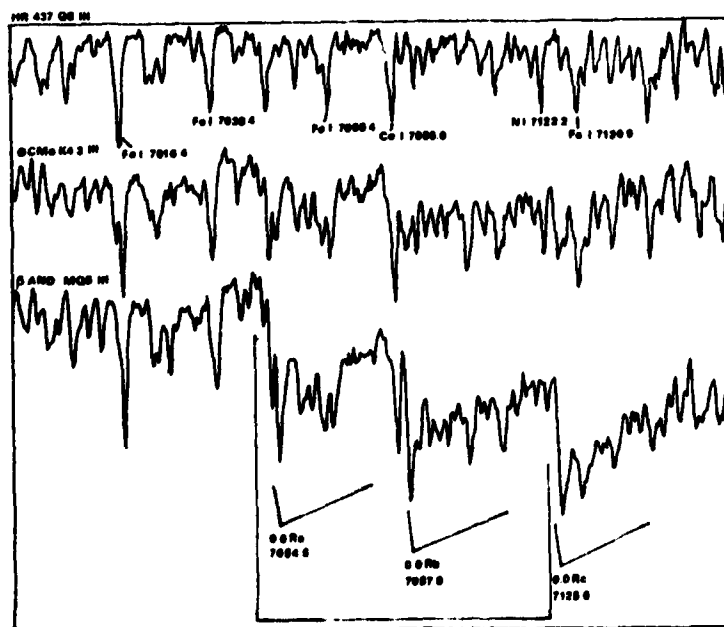


Fig. 10

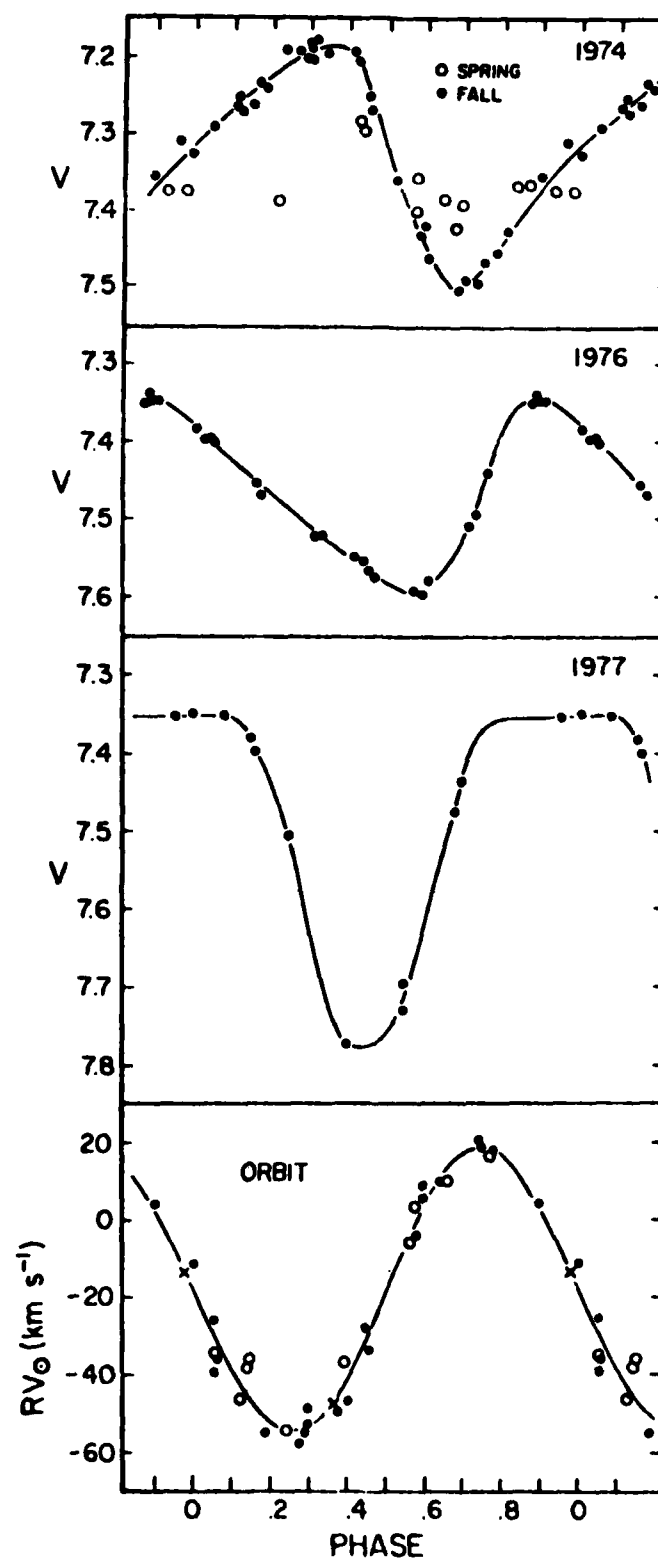


Fig. 11

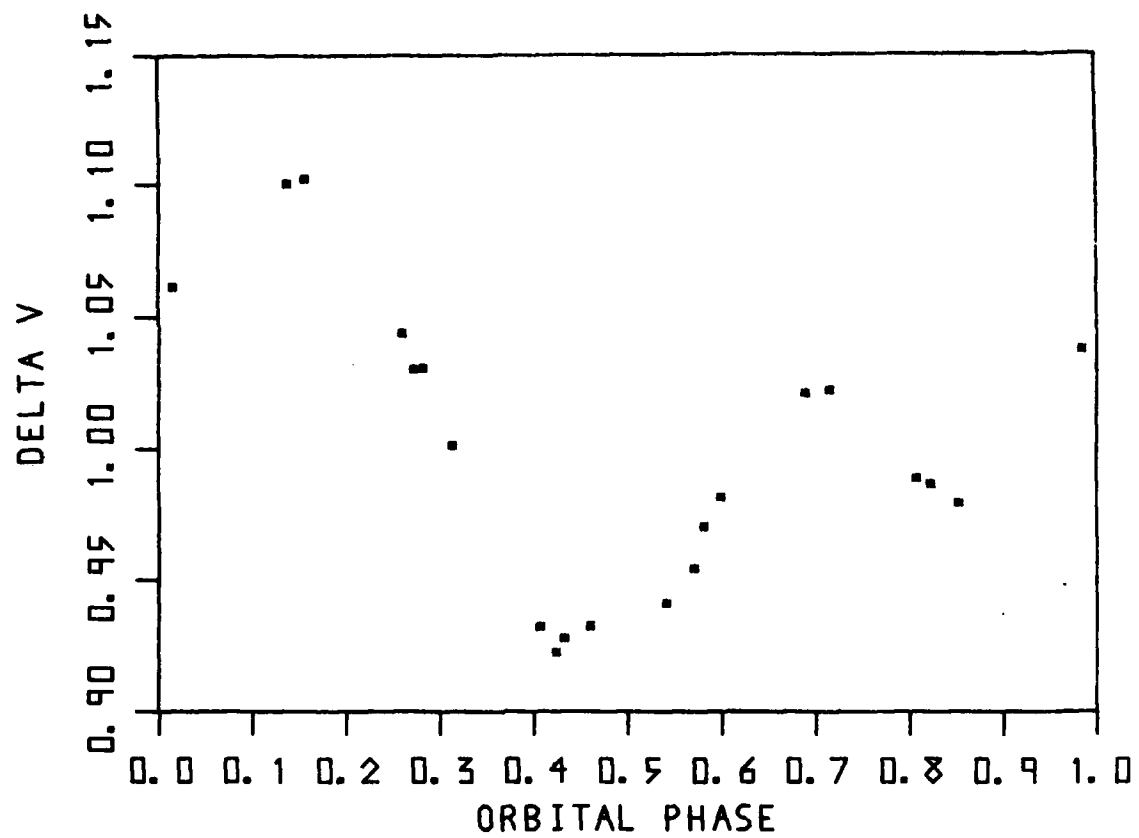


Fig. 12

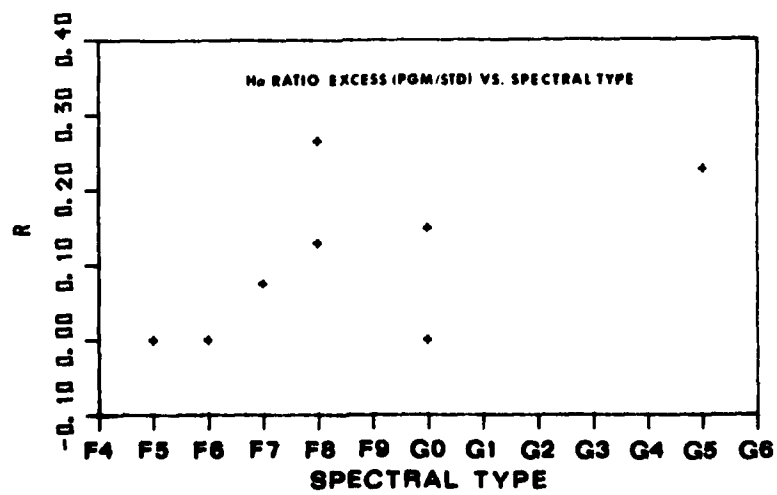


Fig. 13

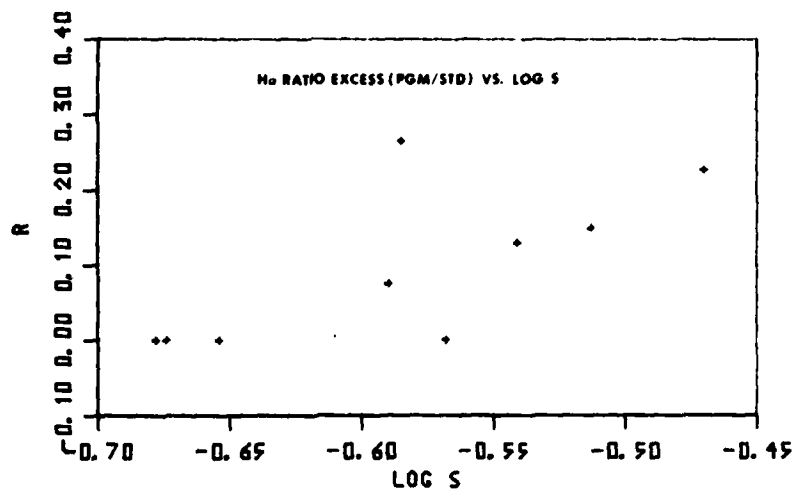


Fig. 14

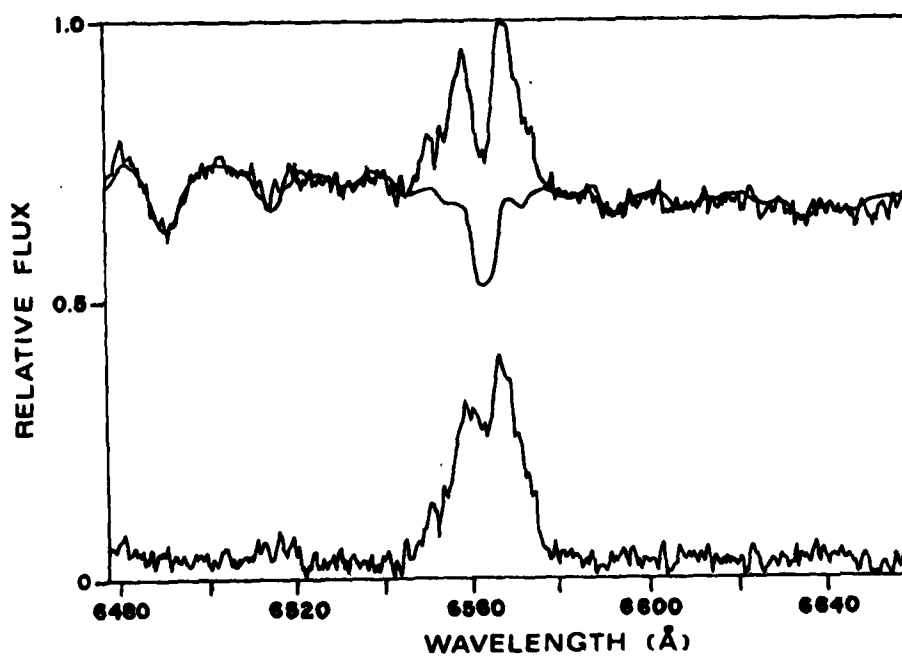


Fig. 15

3.0 Summary of Publications

All publications resulting from this contract fully or partially are listed in order of submission below.

"HR 1099 and the Starspot Hypothesis for RS Canum Venaticorum Binaries," L. W.

Ramsey and H. L. Nations, Ap. J. Letters 239, L55, 1980.

"H α Variability in HR 1099 and Other RS CVn Stars," H. L. Nations and L. W.

Ramsey, A.J. 85, 1086, 1980.

"Evaluation of Some Optical Waveguides for Astronomical Instrumentation," S. C.

Barden, L. W. Ramsey and R. J. Truax, PASP 93, 154, 1981.

"BVRI Photometry of the RS CVn Binary II Peg.," H. L. Nations and L. W. Ramsey,

A.J., 86, 433, 1981.

"On the Nature of H α Outbursts in the RS Canum Venaticorum Binary SZ Piscium,"

L. W. Ramsey and H. L. Nations, PASP 93, 732, 1981.

"Regular Variations in the H α Profile of FK Comae," L. W. Ramsey, H. L. Nations

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