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Hα PROFILE VARIATIONS IN VARIABLE LUMINOUS YELLOW SUPERGIANTS

A. Arellano Ferro[1]

Instituto de Astronomía
Universidad Nacional Autónoma de México

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RESUMEN

Se presentan perfiles Hα de las estrellas supergigantes amarillas variables y luminosas HD 161796, 89 Her, ε Aur, V509 Cas y ρ Cas. Se detectan variaciones en los perfiles en escalas de tiempo de meses y semanas y se discuten sus características y variabilidad. Los perfiles de HD 161796 aparecen peculiares debido aparentemente a la existencia de emisión incipiente centrada en la línea. En la binaria eclipsante ε Aur, el ala azul de Hα muestra variaciones prominentes antes del primer contacto del eclipse de 1982-84. Estas variaciones están posiblemente relacionadas con la pulsación de la estrella primaria.

ABSTRACT

Hα profiles of the variable luminous yellow supergiants HD 161796, 89 Her, ε Aur, V509 Cas and ρ Cas, are presented. Profile variations in time scales of months and weeks are detected. The nature and variability of the profiles is discussed. The profiles of HD 161796 are most peculiar due to incipient emission centered on the line. Spectacular variations are found in the blue wing of Hα in the eclipsing binary ε Aur, even before the first contact of the 1982-84 eclipse, these variations may be connected with the pulsation of the primary star.

Key words: STARS-ECLIPSING BINARIES — STARS-EMISSION LINE STARS — SPECTRUM VARIABLES — STARS-SUPERGIANT

I. INTRODUCTION

From detailed spectroscopic analyses (Sargent and Osmer 1969; Barlow and Cohen 1977; Lambert, Hinkle and Hall 1981) luminous stars have been demonstrated to be undergoing mass loss. Much of the mass ejected is still bound to the stars in the form of circumstellar shells (Lambert *et al.* 1981). Therefore, complicated structures in the Hα profiles may be expected. Indeed, Hα emission has been detected by several authors in many luminous yellow supergiants, although the origin of the emission is not always clear.

In this paper we present Hα profiles of five variable long-period luminous yellow supergiants. The main goal is to survey line profile changes on time scales of months or less, which may provide further insight into the problem of the origin of Hα emission and the nature of the stellar environment.

II. OBSERVATIONS AND REDUCTIONS

The spectra were obtained between September 1980 and June 1981 and in November 1982 with the 1.88-m telescope of the David Dunlap Observatory (DDO). The emulsion was vacuum sensitized 098 which covers the wavelength range 5300-6700 A. The plates were primarily used to measure the stellar radial velocities and the results have been reported elsewhere (Arellano Ferro 1985). The reciprocal dispersion was 16 A mm^{-1} and the projected slit was 24 μm.

The plates were calibrated using a Latham type spot sensitometer (Latham 1969). Calibration and spectral plates were developed together. The spectrograms were digitized by scanning them with the DDO-PDS microdensitometer. Density readings were taken every five microns. Usually two scans were done per spectrum and then averaged.

Continuum points were carefully selected through the whole spectrum. No continuum points were selected within 25 A from the center of Hα. The continuum level is estimated to be correct within 1 percent.

III. DISCUSSION OF Hα PROFILES

The five variable luminous yellow supergiants in our sample are listed in Table 1. Their spectral type, the characteristic time of their variation (semi-period) and the number of profiles acquired are indicated.

The rectified Hα profiles are shown in Figures 1 to 6, and are plotted in the wavelength-residual intensity plane. The wavelength scale of the spectra has been corrected from the photospheric radial velocity, measured from about 32 stellar lines and reported by Arellano Ferro (1985). In consequence, any apparent shift that may exist in Hα should be relative to the stellar photosphere.

1. Investigador Nacional.

TABLE 1

STARS STUDIED

HR/HD	Name	Sp. T.	P (days)	No. of Hα profiles
161796	...	F3Ib	43,62	6
1605	ϵ Aur	F0Ia	123,160	15
6685	89 Her	F2Ia	63	6
8752	V509 Cas	G0Ia	385	12
9045	ρ Cas	F8Iap	483	11

a) *HD 161796*

Six Hα profiles of this star are displayed in Figure 1. Although no obvious emission appears, in contrast to the following four stars, the profiles are outstandingly peculiar. For residual intensities, $r_i < 0.8$, the profiles are too shallow when compared to emission free profiles of short-period yellow supergiants (Arellano Ferro 1984) while the wings, $r_i > 0.8$, look rather normal. These profiles can be represented by the superposition of an absorption line and a nearly centered emission. To show this we subtracted from the average of the six profiles of Figure 1, the emission-free average profiles of the short-period yellow supergiants HR 690 (F7Ib), HR 424 (F8Ib) (see Figure 17 in Arellano Ferro 1984) and HR 8157 (F3II). The short-period stars have higher gravities and the cores may be sensitive to gravity; however, being the gravities not too different and for the purpose of showing the underlying emission, these profiles may be appropriate. The results of the subtraction are shown in Figure 2. The core emission is evident. This emission could be interpreted as produced in a circumstellar cloud of (hot) gas or an extended envelope. The emission appears redshifted by about 25 km s^{-1} and may indicate that the gas is infalling. There is substantial change in the strength of the absorption (or perhaps the emission) between September 1980 and March-June 1981. In 1980 the minimum residual intensity was 0.5 and in 1981 it

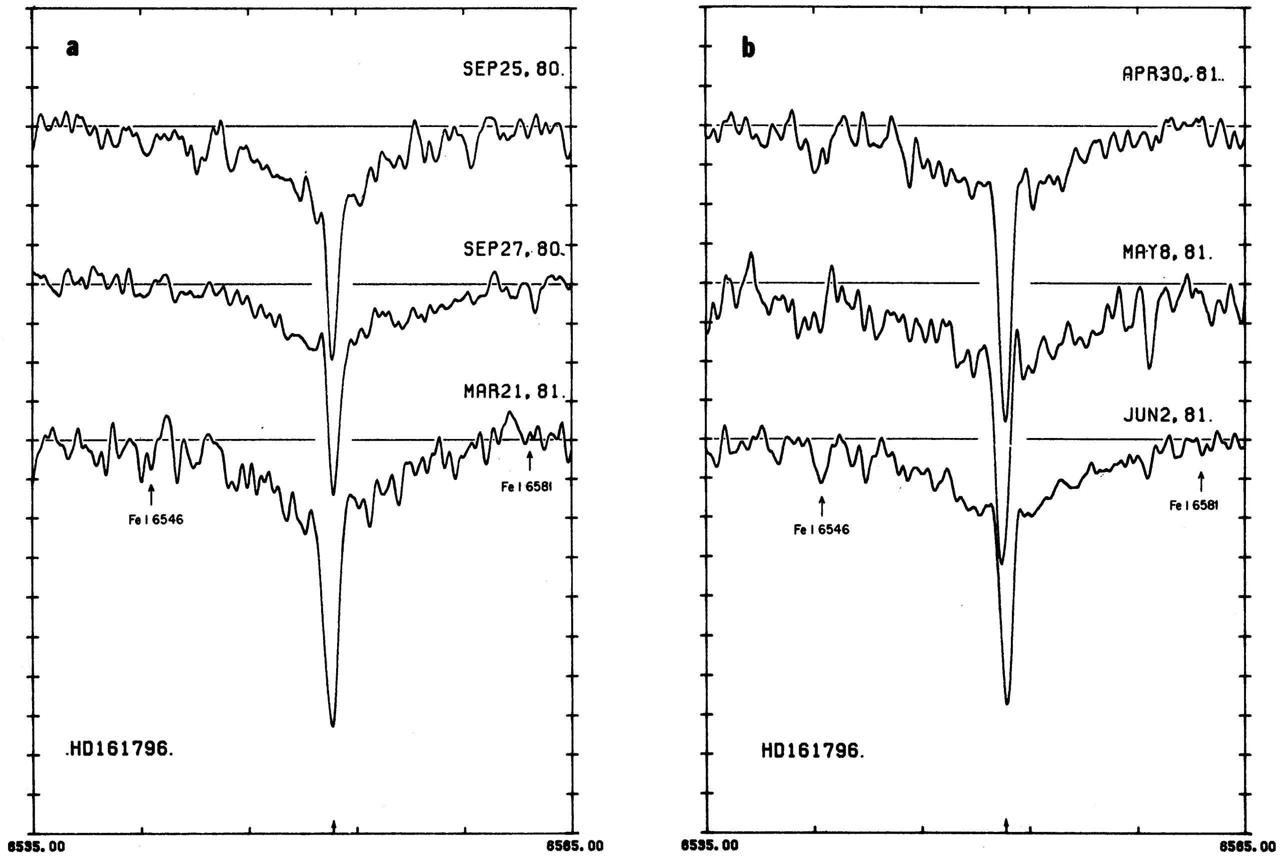


Fig. 1. Hα profiles observed in the spectrum of HD 161796. All spectra have been corrected for the photospheric radial velocity. Fiducial marks on the vertical axis are separated by 0.1 of residual intensity (r_i). The arrow on the horizontal axis indicates the rest wavelength or Hα Note the shallowness of the profiles for r_i < 0.8, and also the substantial change in the absorption strength from 1980 to 1981.

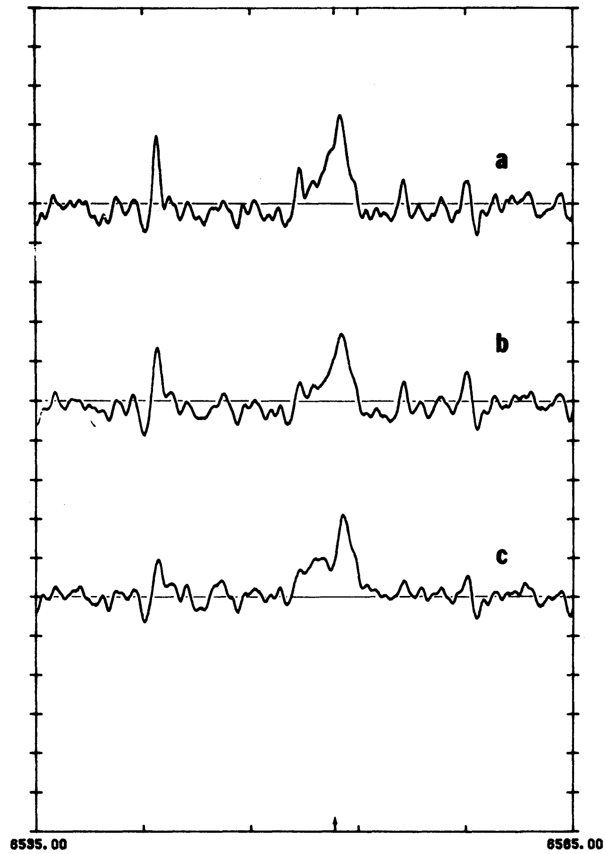


Fig. 2. Subtraction from the average of six Hα profiles of Figure 1, the emission free profiles of a) HR 690 (F7Ib), b) Polaris (F8Ib), c) HR 8157 (F3II). In all cases the subtraction shows an underlying emission shifted about 25 km s^{-1} to the red.

was 0.3 This indicates that substantial changes in the circumstellar material can occur in time scales of months. More subtle changes, occurring probably on shorter time scales can also be noted in the feature Fe I λ6546. More observations are required to see if these changes are subject to some periodicity.

b) *HR 1605 (ϵ Aur)*

Fifteen spectra are presented in Figure 3. Thirteen of them give a very good coverage of the pulsational period between September 1980 and May 1981. As the first contact of the 1982-84 eclipse was not expected until mid 1982, these spectra represent Hα out-of-eclipse. The most striking feature is the substantial variation of the blue emission in a time scale of weeks. It is interesting to note that the time elapsed for the blue emission to return to a particular state, say from October 9, 1980 to about March 21, 1981, is about 163 days which is similar to the characteristic pulsation time identified from photometric and radial velocity variations from 1930 to 1956, i.e., 160 days (Arellano Ferro 1985). The red emission does not show significant changes. One may wonder if the blue emission variation is linked to the pulsation of the F supergiant. Indeed variations in Hα like those in Figure 3 can be produced by a variation in the intensity of the stellar continuum. Another possible explanation is that the profiles out-of-eclipse are not simply formed by two components, one absorption and one emission broadened by rotation of the emitting region as proposed by Morris (1963), but instead that the blue and the red emission are produced in two different and dynamically unrelated regions. In fact it may suggest that the material producing the blue emission is linked with the F supergiant and then is affected by the stellar pulsation while the red emission is produced by material bound to the secondary. The series of spectra in Figure 3 is, to our knowledge, the first in which Hα shows, out of the eclipse, such conspicuous variation. Four spectra prior to the 1956 eclipse (Wright and Kushwaha 1958; Morris 1963) show qualitatively the same shape as those in Figure 3, but they were taken at more than one year intervals and thus do not provide information on whether a similar behaviour of the blue emission prevailed before the 1956 eclipse. Two spectra obtained in the same night in 1971 were reported by Castelli (1977), they show both wings in emission.

Two spectra were obtained in November of 1982 (Figure 3*e*), i.e., these spectra represent Hα during ingress. The blue emission is strong as in September 1980 and the red emission is probably slightly diminished. The most prominent change is the broadening and the asymmetry developed in the central absorption. Similar structures were observed during ingress to the 1956 eclipse (Morris 1963) and to the 1982 eclipse (Boehm and Ferluga 1983), and have been explained in terms of combined rotations of the primary star and the eclipsing body and inhomogeneities of their shells.

c) *HR 6689 (89 Her)*

The six spectra obtained of this star span just over a month (Figure 5). A P-Cygni profile persisted and no significant changes can be detected, except those on the blue wing which are due to telluric effects. The core of the blue-shifted absorption component has an average velocity of about −30 km s^{-1} and the redshifted emission has an average velocity of about 40 km s^{-1} relative to the photosphere.

Similar Hα profiles were observed between 1960 and 1967 by Sargent and Osmer (1969). These authors observed abrupt profile changes in a time scale of a month. Such rapid changes are not observed here. The Hα profiles have been interpreted by Sargent and Osmer as being due to an optically thick expanding shell. The blue-shifted absorption is produced by the material between the star and us, while the red-shifted emission is caused by some stellar light "reflected" by the material behind the star and moving away from us. The outflow velocity measured on several spectra by Sargent and Osmer ranges between 10 and 150 km s^{-1} relative to the photosphere.

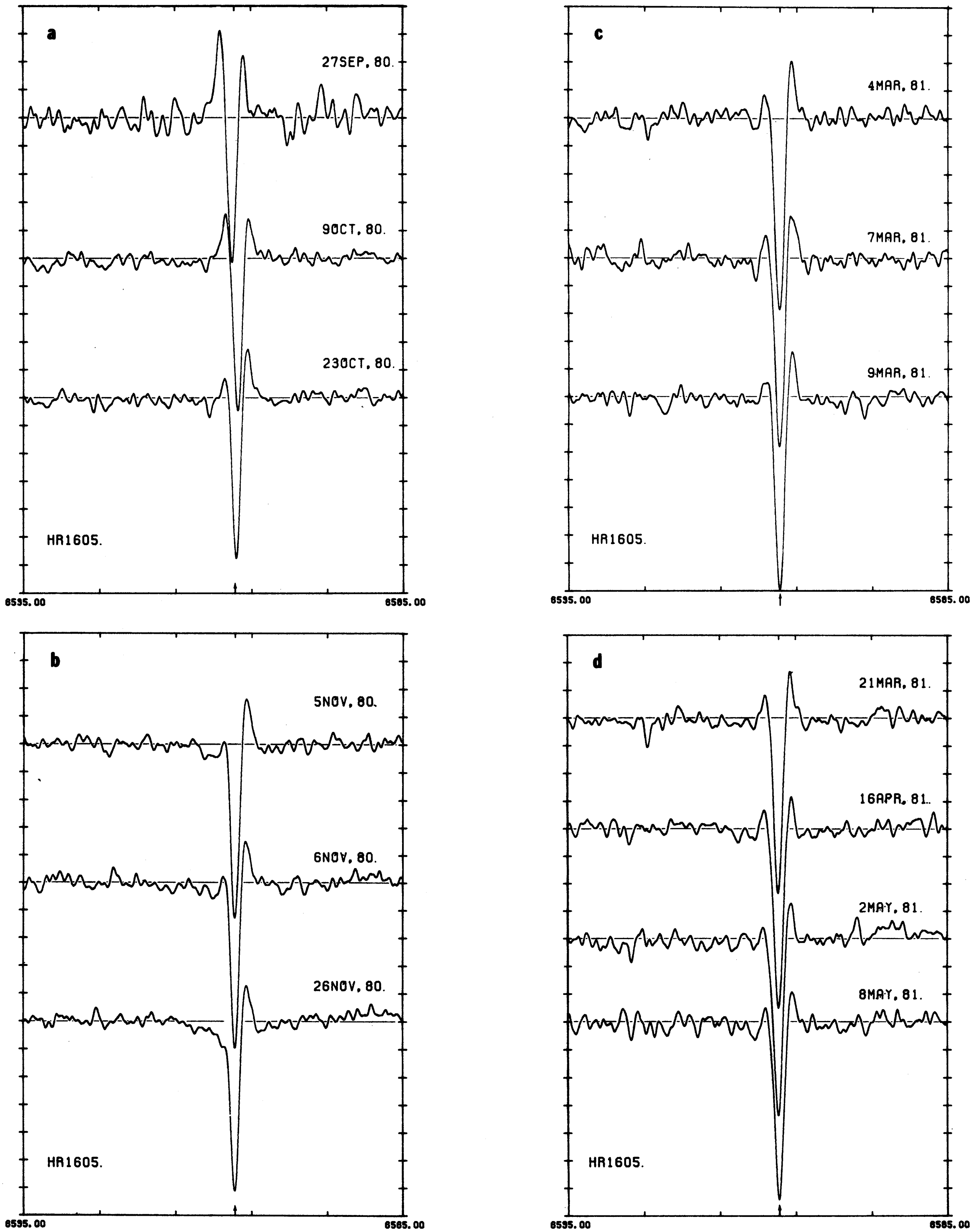


Fig. 3. Same as Figure 1 for the star HR 1605 (ϵ Aur). The most striking feature is the variation of the blue emission wing. This change may be associated to the underlying stellar pulsation (see text). Frames a), b), c) and d) have Hα profiles out-of-eclipse.

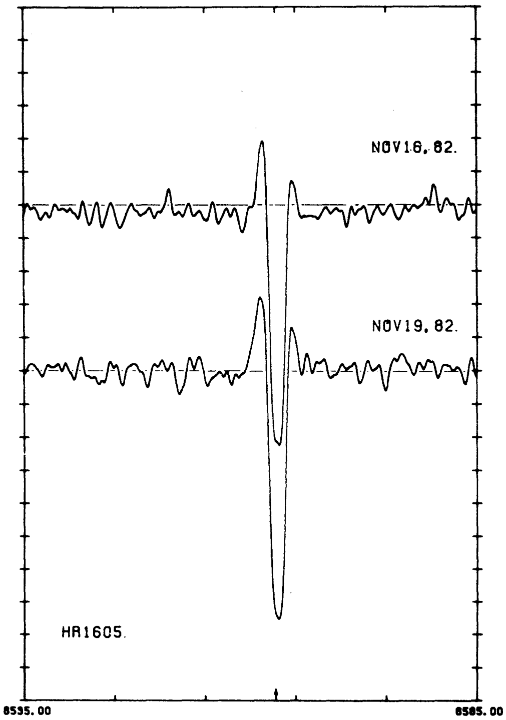


Fig. 4. These two profiles were obtained during ingress to the 1982-84 eclipse. The line appears significantly broader than out-of-eclipse.

d) *HR 8752 (V509 Cas)*

Eleven spectra taken between September 1980 and June 1981 are displayed in Figure 6. All these spectra show qualitatively the same structure as those of high dispersion (1.2 A mm^{-1}) obtained between July 1979 and January 1980 by Barden and Ramsey (1980). Although in our 16 A mm^{-1} spectra we cannot distinguish some of the more subtle changes found by these authors, such as the rapid variations in strength of the Ca I λ6572 emission feature, we can see the substantial strength variation of the red emission in a time scale of months as observed by Barden and Ramsey. Asymmetries in the blue absorption –due to Ti II– of the type described by Lambert and Luck (1978) that can occur in hours (Barden and Ramsey 1980), can be observed in some of our spectra, e.g., in October 13, 1980 and March 7 and May 2, 1981.

One spectrum was obtained in November 1982. It shows the most prominent changes. The blue emission has diminished down below the continuum level or probably disappeared while the red emission is spectacularly strong. In two 10 A mm^{-1} spectra obtained in May 4 and September 27, 1982 by Smolinski *et al.* (1982), the blue emission is also not present. Barden and Ramsey (1980) noticed that the blue emission diminishes parallel to the red emission over six months. Our data clearly show that the red to blue emission ratio does not remain constant on time scales of years.

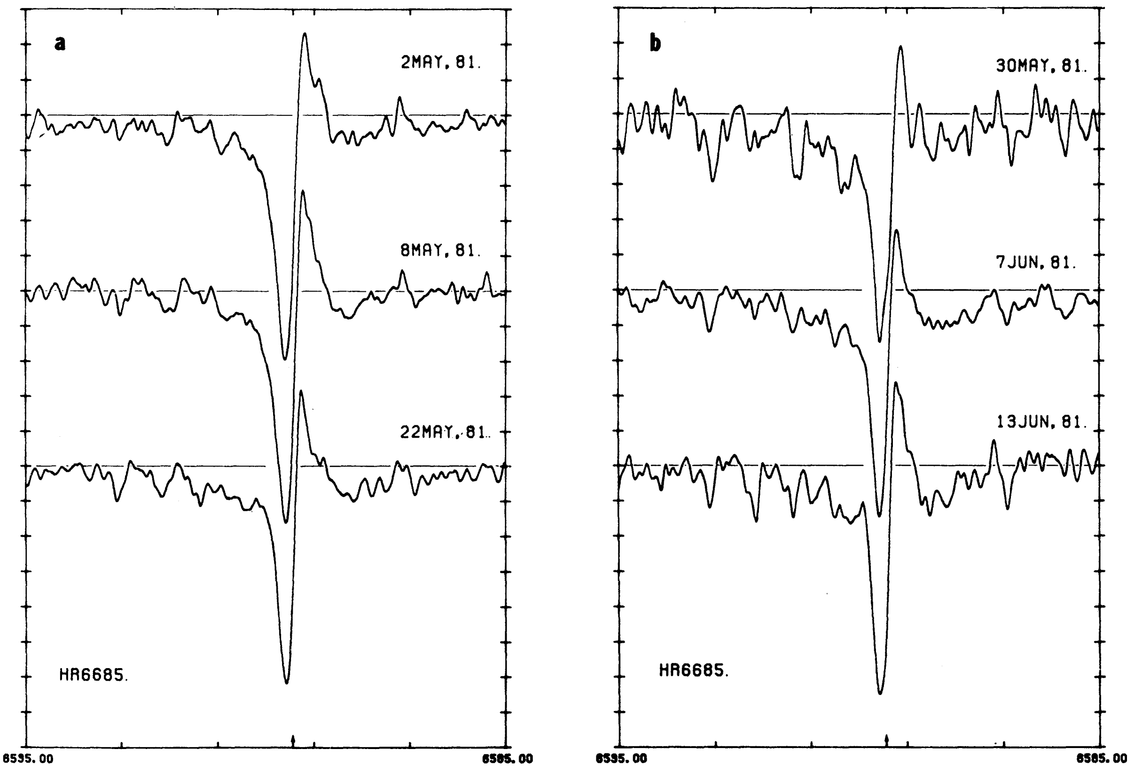
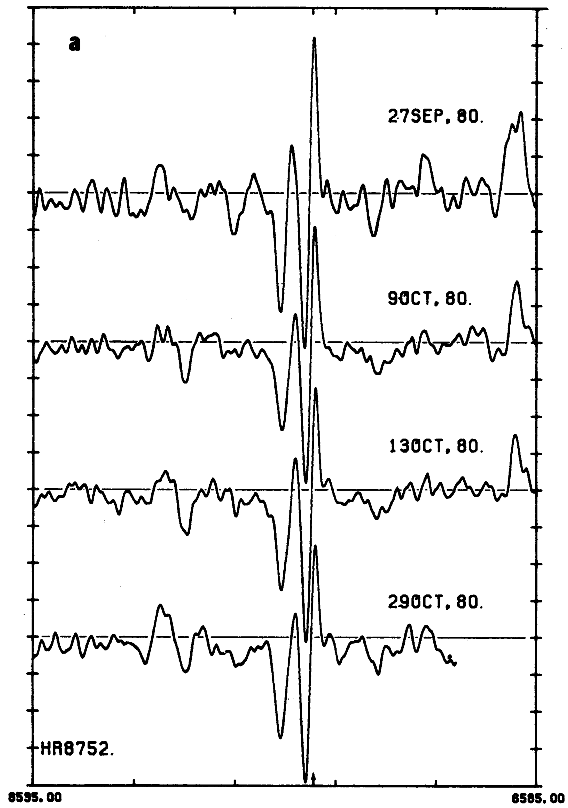


Fig. 5. Same as Figure 1 for the star HR 6685 (89 Her). See text for discussion.



Several absorption components in the Hα region found by Smolinski *et al.* (1982) are not distinguishable in our lower dispersion spectra. However, the emission (E2) on the red wing of Hα (see spectrum of May 2, 1981 in Figure 6*c*) observed by Smolinski *et al.* in September 27, 1982, and that according to these authors may be due to the binary nature and/or the pulsation of the star, was definitively present in our data in May 2, 1981 and insinuated in March 7, June 2, 1981 and November 19, 1982. This series of spectra shows that the variation of this feature occurs in time scales of weeks.

e) *HR 9045 (ρ Cas)*

Ten spectra taken between September 1980 and June 1981 are shown in Figure 7. Substantial spectral changes are evident. The most remarkable are: the growth of emission on the red wing of Hα from September-November 1980 to May-June 1981; the line doubling of Fe I λ6546 in early October disappearing by October 19, and reappearing in November 26 of 1980. By May 1981 the line appears well developed and persists until June 1981, although it often shows asymmetries. Similar and parallel changes can also be observed in the feature Fe I λ 6581. The line doubling of these, probably of photospheric origin features, may result, according to Lambert *et al.* (1981), from the propagation of a shock passing

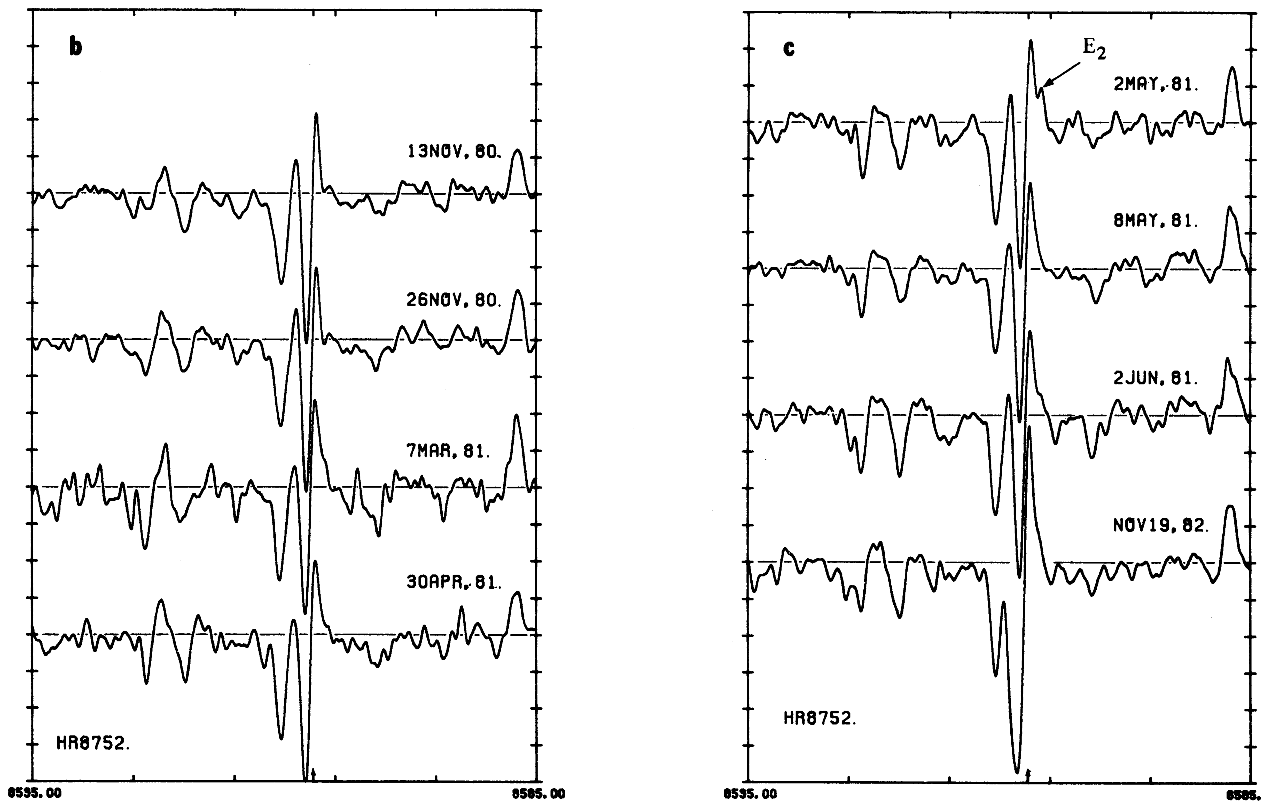
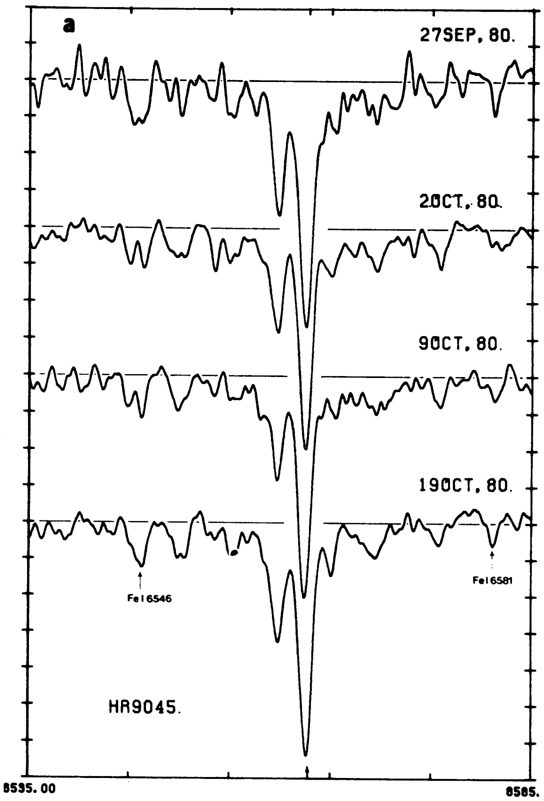


Fig. 6. Same as Figure 1 for the star HR 8752 (V509 Cas). See text for discussion.



through the atmosphere and originated by the underlying stellar pulsation.

The one spectrum taken in November 1982 shows the most striking change in Hα. The line is nearly completely filled in by emission while the Fe I features have not suffered substantial variations.

In summary, forty eight Hα profiles of variable yellow supergiants of high luminosity have been obtained. Profile variations in time scales of months and even weeks were detected. Although some of these variations may be periodic if the circumstellar material is affected by the underlying stellar pulsation, the present data are not sufficient to prove it. Further observations of Hα of these and other luminous supergiants are in progress.

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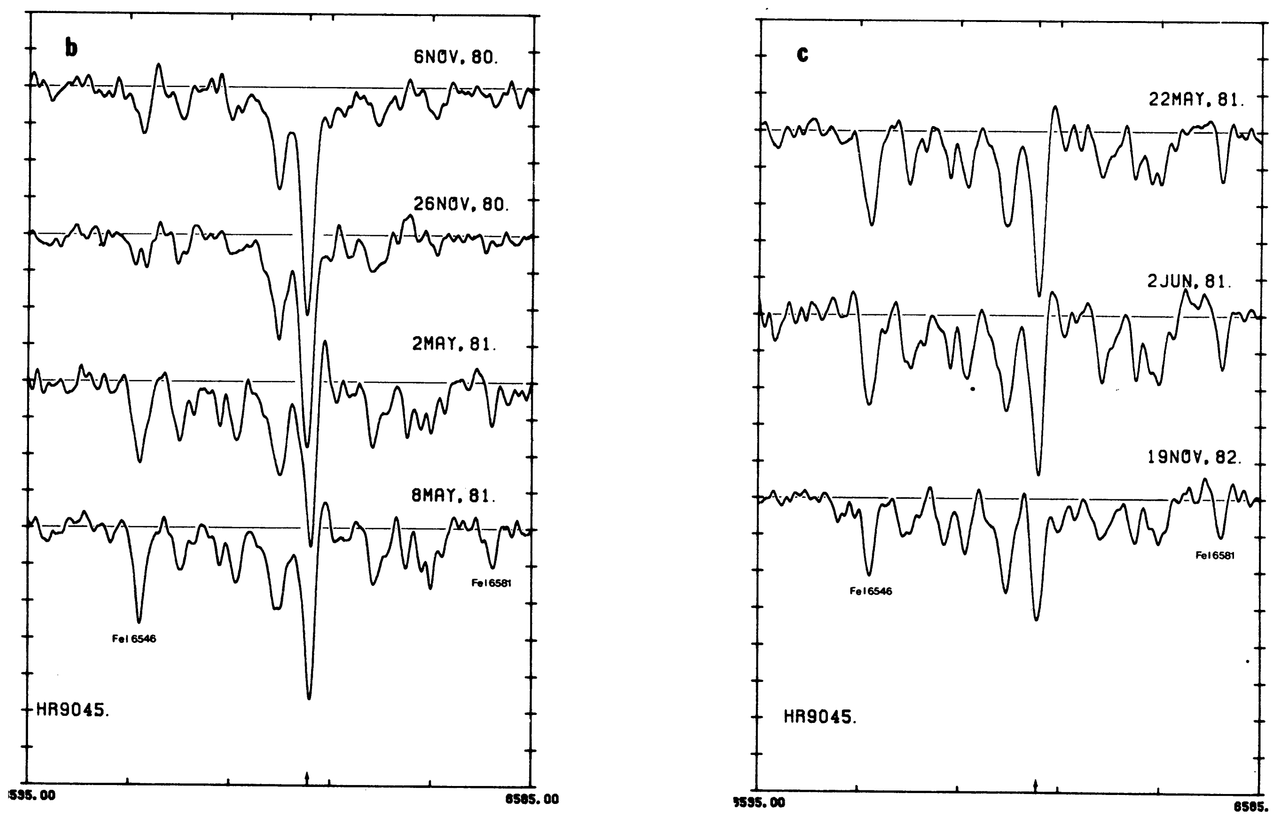

Fig. 7. Same as Figure 1 for the star HR 9045 (ρ Cas). See text for discussion.

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Armando Arellano Ferro: Instituto de Astronomía, UNAM, Apartado Postal 70-264. 04510, México, D.F., México.