IMPROVED DATA REDUCTION TECHNIQUES FOR THE ESO CES PLUS RETICON SPECTRA.(*)

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ABSTRACT.

We developed routines for intensity, equivalent width, and radial velocity measurements on CES plus reticon spectra obtained with the ESO 1.4m telescope. In order to achieve the optimal recovery of the signal, the noise has to be minimized by removing any parasitical effect. Special care has been devoted to the correction for remanence effects in the reticon dark counts. Typical results are presented and discussed.

INTRODUCTION.

Since October 1983 we have been carrying out a comprehensive study on the chromospheres of solar-like dwarfs, including (i) multi-component modelling; (ii) the investigation of chromospheric variability in active stars; (iii) the diagnostics of velocity fields and the detection of plages. (See Beckman et al., 1984; Crivellari et al. 1987.)
The most valuable observations for this purpose include H alpha, the H and K lines of Ca II, the infrared triplet of Ca II, and the h and k lines of Mg II.

All the visible observations relevant to our programme have been obtained using the 1.4 m Coude' Auxiliary Telescope (CAT) of the European Southern Observatory at La Silla (Chile), equipped with the Coude' Echelle Spectrograph (CES) and the reticon. High resolution (R up to 10**5) and high signal-to-noise (S/N) spectra are obtained,

Two different kinds of measurements are required by our

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program: (a) accurate spectrophotometry, both absolute to determining chromospheric emission fluxes, and relative for line variability detection; (b) precise wavelength calibration for velocity field diagnostics.

Among the spectral features under study, the H and K resonance lines of Ca II deserve special consideration for the wealth of physical information one can derive from them. On the other hand some specific problems arise from their intrinsic shape: their complex structure requires high spectral resolution; the intensity of the lines at the bottom of the broad photospheric absorption is very faint.

Both facts make long exposures necessary (some times as long as three hours) which necessarily produce contamination of the true signal by parassitic effects. Especially reticon dark counts are a severe source of errors.

AN ESTIMATE OF THE NOISE IN CES SPECTRA.

The recorded spectrum can be expressed as

$$F'(x) = \frac{\beta}{a} s(x) f(x) + b(x) + D(x) \quad , \tag{1}$$

where $f(x)$ is the true stellar spectrum, $s(x)$ the instrumental sensitivity function and β/a the conversion factor from the incoming photons to the digitized recorded signal. $b(x)$ is the total read-out noise, due to the combined effect of the instrumental electronic noise and the periodic noise introduced by the use of four independent lines for recharging the diode array. $D(x)$ is the signal due to the dark counts of the reticon. The image lag phenomenon (remanence effect) can easily be identified as the prime cause of dark counts. (See Maurice and Maugis, 1981.) The independent variable x is a monotonic function of wavelength.

In order to extract $f(x)$ from the recorded signal $F'(x)$ one should know the quantities $s(x)$, $b(x)$ and $D(x)$. The instrumental response of the reticon can be derived experimentally by recording an uniform "flat-field" exposure of intensity C. The recorded flat field is in the form

$$S'(x) = \frac{\beta}{a} s(x) C + b(x) \quad . \tag{2}$$

An empirical estimate of $b(x)$ is also easily obtained. A mean read-out signal $\overline{b(x)}$, found by averaging a limited number (typically five) of independent read-out spectra, can be assumed as a good estimator for $b(x)$. To determine a good estimator for $D(x)$ is a much more difficult problem. A thorough discussion of the correction for remnant effects in the reticon dark counts is contained in the paper by Crivellari et al. (1987). On the basis of the results of our analysis, when correcting the recorded signal for the dark counts contaminations, we use as an estimator the quantity $\overline{D} = m \cdot t_{exp} + q$, where m and q are experimentally determined.

The normalized signal i(x) can be expressed as

$$(3) \qquad i(x) = \frac{\beta/a\, s(x) f(x) + \eta(x) + \varepsilon(x)}{\beta/a\, s(x) C + \eta(x)}$$

where $\eta(x)$ and $\varepsilon(x)$ are defined as

$$(4a) \quad \eta(x) \equiv b(x) - \overline{b(x)} \qquad\qquad (4b) \quad \varepsilon(x) \equiv D(x) - \overline{D}$$

If $\overline{b(x)}$ and $\bar{D}$ were the correct estimators for b(x) and D(x) respectively, the expectation values of $\eta(x)$ and $\varepsilon(x)$ would both be identically zero. Then we can conclude that i(x) is the true stellar spectrum, but for a multiplicative constant. From eq. (3) it is easy to derive the error i(x) in terms of each contributing variable. We have

$$(5) \qquad \Delta i(x) = \left\{ \frac{\Delta^2 F(x)}{\sigma^2(x)} + \frac{[S(x)-F(x)]^2 \Delta^2 \eta(x)}{\sigma^4(x)} - \frac{\Delta^2 \varepsilon(x)}{\sigma^2(x)} - \frac{F^2(x) \Delta^2 S(x)}{\sigma^4(x)} \right\}^{1/2} ,$$

where $\sigma(x)$ is defined as $S(x)+\eta(x)$. F(x) and S(x) are β/a s(x) times f(x), and C respectively.

In Table 1 we present a set of typical S/N values for a sample of Ca II H profiles, obseved in October 1985.

We asume that the errors ΔF(x) and ΔS(x) derive from the statistical fluctuations of the corresponding signal (Poisson statistics). The error on $\varepsilon(x)$ is directly related to the rms fluctuation of the read-out spectrum. From our study of the remanence effect we can derive $\Delta\eta(x)$. When evaluating the errors ΔF and ΔS, s(x) and C must be known. Actually in the present analysis we had to determine them indirectly from the recorded S(x), in lack of exact values from literature. In particular the estimate of C, necessary to detemine s(x), is quite crude. This could have led to an overestimate of Δi(x). Consequently the relative error and S/N values must be taken as conservative.

MEASUREMENTS ON THE CES SPECTROGRAMS.

a) Intensity measurements.

A calibration law to convert the CES arbitrary intensity scale into absolute flux units is not available. Indirect methods must be used when absolutely calibrated profiles are required, e.g. for comparison with theoretically synthetized spectral feature. (See Castelli et al., 1988, these proceedings.)

However the immediate request of our investigation is a reliable relative spectrophotometry. Either we intercompare spectra of stars with the same overall physical properties, but different level of chromospheric activity to define quantitative activity indexes, or we analyze spectra of the same star, taken at different phases, to look for variability brought about by stellar rotation.

To do that we choose the spectrum of one star as the reference spectrum and bring all the other into registration with it by means of a least-squares fit (program NEWSUM). The basic idea of the method is that after registration we have a set of spectra whose fluxes are expressed on a common (even if arbitrary) scale. A direct comparison is then possible, without the need of a normalization (not always reliable over the limited wavelength range of a single echelle order) to a refernce continuum.

NEWSUM also offers the possibility to co-add several spectra, irrespective of their signal level, to produce averaged spectra with improved S/N ratio.

When the object of the investigation is the search for variability, a statistical analysis of the spectrograms is automatically performed (program JERKA), to spot out locii of possible variations.

The detailed description of our suite of computer codes (namely NEWSUM and JERKA) has been already published. (Ramella et al., 1980; Beckman et al., 1980; Franco et al., 1984.)

Two kinds of measurements are usually performed on the spectrograms: i) The intensity of individual features in the profiles; ii) the integrated flux in selected pass bands to mimic narrow band spectrophotometry.

A good example of the application of these techniques is contained in the paper by Crivellari et al. (1987). Here we have the place only to recall that the scattering of the integrated fluxes around their average is typically of 0.5%. That proves the very high quality of CES plus reticon spectrograms.

b) Wavelength measurements.

Any profile of the spectral features under study is the result of integrating contributions from different layers of the stellar atmosphere. We present in a separate paper (Vladilo et al., 1988, these proceedings) our technique to determining the accurate position of selected features within the complex profile of the H (K) Ca II lines. The method is based on the reconstruction of the observed line profile with two gaussian bands.

Combining the errors which affect the measurement of each single step of the calibration procedure, starting from the standard IHAP routines, we claim a conservative error of +4 mA for each single measure.

CONCLUSIONS.

We intend to present this paper as a cue for a discussion about the real needs (in terms of spectral resolution and S/N) for detailed diagnostics from line profiles.

The choice of the Ca II H (or K) line as a test of our data reduction procedure has been deliberated. Among all the available examples, we selected a line which (i) is intrinsically faint, with a portion of its profile almost saturated, (ii) demands very high resolution to show up its complex structure, (iii) falls in a spectral region where the reticon sensitivity is low. Compared with these severe drawbacks, the performances of the CES are really outstanding. Let the reader go to Table 1, where the S/N values relevant to 9 Cet are reported. For a G2 star of m 6.4 it is possible to obtain a high resolution spectrum (R=8.10**4) with a relative error at the minimum H1 less than 5% within a still reasonable exposure time (240 min).

Our analysis proved the high stability of spectrophotometry with the CES plus reticon. After registration via NEWSUM, the scatter of individual spectra around the mean is a few percent of the signal level.

The results on variability and velocity field diagnostics, presented in our previous paper (Crivellari et al., 1987) clearly show that also in case of low S/N ratio a wealth of useful information can be obtained, when a careful data processing is performed. We claim that, by using proper measurement techniques, it is possible: (a) to detect variations in the normalized fluxes down to some 3% in the most critical cases; (b) to measure velocity gradients within an accuracy of 300 m*s-1.

Table 1.

Star	Sp.type	m	t (mn)	D	feat.	F'(x)	S'(x)	S/N
β Hyi	G2 IV	2.8	90	13	λ3950	830	665	190
					H1	150	830	30
					λ3980	1010	890	230
τ Cet	G8 V	3.5	120	14	λ3950	710	340	160
					H1	170	410	40
					λ3980	890	430	200
α CenB	K1 V	1.3	20	10	λ3950	450	260	100
					H1	100	310	20
					H2	160	310	35
					λ3980	480	325	110
o^2 Eri	K1 V	4.4	100	13	λ3950	420	190	95
					H1	125	210	25
					H2	150	210	30
					λ3980	500	220	110
ε Eri	K2 V	3.7	60	12	λ3950	380	265	85
					H1	130	305	30
					H2	290	220	65
					λ3980	460	220	100
9 Cet	G2 V	6.4	240	19	λ3950	250	200	50
					H1	110	230	20
					H2	150	230	30
					λ3980	270	230	60
Sun	G2 V				λ3950	2335	2290	510
					H1	280	2220	65
					λ3980	1910	890	430

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DISCUSSION.

G. Cayrel. What are you doing with cosimc rays spikes if you have long exposure?

L. Crivellari. We check the spectrograms for possible cosmic events. Then we remove the bad pixel(s), if we have been lucky enough to spot out spikes.

J.E. Beckman. I believe that you did refer indirectly to the point that the long dark counts are not only dependent on the present exposure, but also on the history of the reticon chip, that is on the previous exposure.

L. Crivellari. Of course. The main source of the reticon dark counts is ascribed to the remanence effect.