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Determination of Spectral Types for the Stars in the EXPORT Sample

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EXPORT

Abstract. In this paper we present the results of the spectral classification of stars included in the EXPORT sample and observed during the 1998–1999 International Time campaigns in the Canary Island observatories. Intermediate resolution spectra obtained with the Isaac Newton Telescope (INT) were used in this work. In addition to the confirmation of some spectral types and changes to previous classifications, we report new results for stars whose spectral type had not been accurately assigned before.

1. Introduction and motivation for this work

The determination of spectral types in general, and in particular for the kind of objects we are interested in, is an important and difficult field of work (see Jaschek & Jaschek 1990). The knowledge of all the relevant parameters of stars showing protoplanetary disks, envelopes or any trace of circumstellar material, or planets orbiting around, is a crucial point for understanding the evolution of these objects and the formation processes of planetary systems.

During the four International Time campaigns, the INT was devoted to obtain intermediate resolution spectra of targets of interest for establishing an evolutionary sequence covering from objects with protoplanetary disks in the pre-main sequence, to objects similar to β Pic, stars showing the Vega phenomenon and stars with planets already formed.

One of the goals of these observations was the analysis of the spectral features appearing in the spectra and their comparison with standard, normal stars, leading to a revision of the available results on spectral types for some of the targets and to a classification for stars poorly studied previously.

2. Observations

The observations were taken with the Isaac Newton Telescope (INT) during the four campaigns awarded to EXPORT in the International Time Programme

(14–17 May, 28–31 July, 23–27 Oct 1998 and 28–31 January 1999). See Eiroa et al. (2000) for more information on the EXPORT consortium.

The Intermediate Dispersion Spectrograph (IDS) was used. The spectral ranges covered were 5854–6728 Å (May run) and 5715–6812 Å (July, October and January runs), and the resolutions were 0.707 and 0.475 Å/pixel (corresponding to $\lambda/\Delta\lambda$ =4500, 6600 at 6300 Å) respectively. See Mora et al. (2000) for more information on INT EXPORT observations.

3. Tools for the spectral classification

The spectral classification has been done by using spectra of standard stars with well-determined spectral types, taken during the EXPORT runs. A library of high and mid-resolution INT spectra of standard stars (Montes et al. 1997) was also used to more accurately determine the spectral type of the cool stars in the sample.

First of all, an approximate classification was done by a visual inspection of the spectra. After this step, the comparison spectra were broadened using a rotation profile with the value of $v \sin i$ of the target star. The formalism given by Gray (1992) was applied. Most of the $v \sin i$ values used here were computed by EXPORT members using high resolution observations obtained during the four campaigns with the William Herschel Telescope (see Solano et al. 2000). The broadened standard spectra were then compared with the target spectra, allowing the determination of the spectral type.

3.1. Cool stars

For cool stars several lines, in different spectral intervals, have been used, paying attention to the changes in their relative intensity. In Table 1 we list these lines and the interval of spectral types where their intensity changes are significant for discriminating between two spectral types. In addition to these lines, the TiO molecular bands have been also used; they appear around spectral type K7V and increase their strength as the effective temperature decreases.

3.2. Hot stars

For hot stars we used the He I lines at 5875 Å and 6678 Å to confirm the B type assignation when they are clearly photospheric, i.e. when we do not see any changes from one observation to another in the line profiles or equivalent widths. In those cases when variations are apparent, their origin is assumed to be circumstellar and therefore they are not appropriate for classification.

4. Results and comments

We have very accurately determined the spectral type of 30 stars in the EXPORT sample. Work is in progress to determine the spectral type of the whole EXPORT sample observed with the INT (81 stars).

In Tables 2 and 3 we show the results of our work. In Table 2 the spectral types are listed for those stars whose determination is unambiguous and can be considered as highly reliable. Table 3 shows the spectral types for peculiar stars

Table 1. Lines used for assignation of spectral types for cools stars

Line identification	Interval of spectral types
S II 6102 Å Ca I 6122 Å Fe II 6129 Å	K0 V – K5 V
Fe I 6494 Å Fe I 6546 Å K II 6595 Å	F0 V – F9 V
Na I D_1 D_2 5890,5896 Å Ca I 6162 Å Fe I 6136 Å Fe I 6677 Å Ca I 6494 Å	F0 V – M0 V

in the EXPORT sample whose assignation could not be accurate either because of the presence of very broadened lines, or because they have many circumstellar and interstellar absorption lines that mask the photospheric spectrum or they show a combined spectrum that seems to correspond to a binary system.

The suffixes in the spectral types mean: 'e' emission lines, 'v' variable spectrum, 'p' peculiar spectrum (some non-standard features appear), 'n' very broad or nebulous lines and 'm' metallic lines when not expected or stronger than expected.

In the second and third columns we give, for each star, the spectral type and the class of object according to previous works; the latter can be taken, in general, as a good classification, however, some stars like e.g. HD 34700 may be a different kind of object following the results of our work. The pre-main sequence types are abbreviated as follows: TT (T Tauri), HAeBe (Herbig Ae/Be), UXOR (UX Ori type) and ZAMS (Zero Age Main Sequence-Herbig Ae/Be). The main sequence types are: MS (Main Sequence star with planets), Vega (Vega-type), PTT (Post T Tauri) and Ash (A Shell).

Diffuse interestellar bands appear in many spectra and had to be ruled out in performing the visual inspection. These are found at 5780 Å, 5797 Å, 5850 Å, 6196 Å, 6234 Å, 6270 Å, 6284 Å, 6369 Å, 6376 Å and 6614 Å (Mouton et al. 1999; Schmidt-Kaler 1982).

Almost all the pre-main sequence stars in the sample present some kind of variations in the spectra. Many show variable Hα in emission. Some of them show some forbidden emission lines ([OI] 6300 Å, [OI] 6363 Å, [SII] 6716 Å, [SII] 6731 Å, [NII] 6583 Å, [NII] 6548 Å and [NII] 6527 Å; see Osterbrock 1989) which may be related to winds.

The stars HD 34700 and HD 233517 show a deeper-than-expected Li I 6708 Å line in their spectra although they where supposed to be Vega-type main sequence stars before this work.

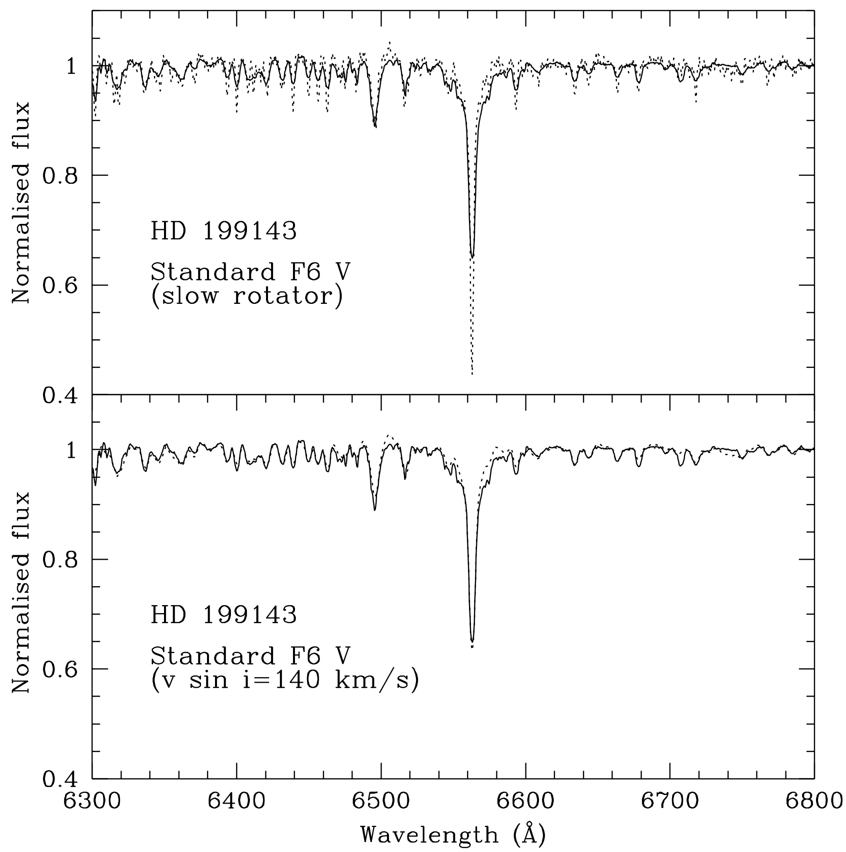

Figure 1. An example of the spectral type determination for the star HD 199143. In the top panel the spectrum of the target star (solid line) is compared with that of HR 4606, a F6V standard star with slow rotation (dotted line). In the bottom panel, the standard spectrum has been broadened with a profile $v \sin i = 140$ km/s; the agreement is remarkable.

Variable lines of He I 5877 Å, He I 6678 Å and Na I D_1 D_2 5890,5896 Å that may be produced in the circumstellar disk or envelope appear in many spectra. In some cases these lines show very peculiar and variable profiles.

The method used here to determine the spectral types of the stars in the EXPORT sample leads to very acceptable results. One important fact we would like to remark is that the presence of a number of interestellar lines and also variable circumstellar and shell lines in the spectra can lead to erroneous classifications if a small number of observations is used. Therefore, for this kind of stars, it is highly desirable to work with as many spectra as possible in order to disentangle the nature of each line. In future work we will carry out a determination of the spectral type in the ultraviolet range using observations taken with the International Ultraviolet Explorer (IUE) by fitting Kurucz atmospheric models. Also a determination of the absolute magnitude using the results from the Hipparcos mission will be very valuable to bracket more accurately the luminosity class of each object.

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Table 2. Results for the assignation of spectral types

Star	Previous determinations	Type	This work
HD 23362	K2 V, K2	Vega	K5 IIIm
HD 34700	G0 V	ZAMS	G0 IVe
HD 34282	A2 Ve+sh, A0e, A0	HAeBe	A3 Vne
HD 109085	F2 V, F3 V, F2 III-IV	Vega	F2 V
HD 142764	K5	Vega	K7 V
HD 144432	A7 Ve, A9/F0 V, A7 Ve	ZAMS	A9 IVev
HD 199143	F6 V	ZAMS	F6 V
HD 233517	K2, A2	Vega	K0 V
HR 10	A2 V-A5 V, A6 Vn	Ash	A4 Vn
HR 4757 B	K0 V, K2 Ve, K1 V	PTT	K2 V
HR 5422 A	A0 V, B9.2p , B9 Vp	PTT	A0 V
HR 5422 B	K1 V	PTT	G5 V
HR 9043	A5 V, A3 Vn	Vega	A5 Vn
BM And	K5 V	TT	K5 Ve
BH Cep	A/F5 Vea, F5 IVvar	HAeBe	F5 IIIev
24 CVn	A5 V, A4 V, A5.5 V	Ash	A4 V
KK Oph	B3, B,Ae, A5 Ve, A6	UXOR	A8 Ve
T Ori	A3/4e, A3, B9, A5 e	UXOR	A3 IVev
BF Ori	A5/6 IIIe+sh, A5e, A6e	UXOR	A2 IVev
CO Ori	F9/G Ve, F9: e, F8	UXOR	F7 Vev
NV Ori	F0/8 IVe, F4/8 III,V	HAeBe	F6 IIIev
RY Ori	F6/Gep, F8:pe	TT	F6 Ve
UX Ori	A3e, A2/3 IIIe, A1-3IIIe	UXOR	A4 IVe
51 Peg	G5 V, G2 V, G2.5 V	MS	G2.5 V
DK Tau	M0 V:e, K7 V, K7	UXOR	K5 Ve
RY Tau	F8V:e, K1 IV, G5e, K7	UXOR	F8 IIIev
PX Vul	F0 V:e, F0, F5	HAeBe	F3 Ve
WW Vul	A3e, A0/3 Ve, A0, A1e	UXOR	A0 Ve
LkHα 200	K1 V, Ke, dK0	TT	K3 Ve
LkHα 234	B5.7e, B5/7, B9/A0e, A7	HAeBe	B5 Vev

Table 3. Results for the assignation of spectral types: Peculiar Stars

Star	Previous determinations	Type	This work
HD 58647	A0 IVe, B9 II-IIIe, Be3	ZAMS	B9 IVep
HD 141569	A0 Ve, B9.5 Ve, B9e	ZAMS	A0 Vev
HD 163296	A3 Vep+sh, A1 V, A0-A2	ZAMS	A1 Vepv
HR 2174	A3 Vn, A1 IV-sh, A3 V	Vega	A2 Vnv
VX Cas	A0/3e, A0, A3, A0ea	HAeBe	A0 Vep
VY Mon	B9/A0e, B8, B-A	HAeBe	A5 Vep
HK Ori	A5, A4, G:ep, B8/A4ep	UXOR	G1 Vepv
VV Ser	A2e, B1-3e:, B1/3e/A2:	HAeBe	A0 Vev
RR Tau	F:e, A2II-IIIe, B8ea	UXOR	A3 IVev