EFFECTS OF STELLAR ROTATION ON SPECTRAL CLASSIFICATION

Arne Slettebak and Thomas J. Kuzma

Perkins Observatory, Ohio State and Ohio Wesleyan Universities

ABSTRACT

Stellar rotation may affect the strengths of lines used in spectral classification because of effects of plate resolution and also because of physical changes in the rotating stellar atmospheres. In the first case, the importance of using standard stars with appropriate rotational line broadening in classifying spectra of relatively high dispersion (resolution) is emphasized. Rotational effects on weak lines in general and on the Balmer lines may cause systematic errors in the assignment of spectral types and luminosity classes unless the standard stars are chosen with line broadening similar to that of the star to be classified. With regard to physical changes in the rotating atmospheres, we have extended the earlier work of Collins to include the Balmer lines plus additional lines of He I and Si II which are important in spectral classification over a wider range of spectral types.

1. INTRODUCTION

That stellar rotation may affect spectral classification has been known for many years. In addition to the effects of using spectra of different resolutions there exist physical effects in the rotating stellar atmospheres which can now be calculated using model atmospheres theory and modern computers. We shall consider these two effects separately.

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2. EFFECTS OF RESOLUTION ON LINE STRENGTHS IN STELLAR SPECTRA

The MKK system of spectral classification employed a dispersion of 125 Å mm^{-1} at Hγ for the early-type stars. With this dispersion, "The varying widths of the spectral lines are not very noticeable, except for a very few stars with exceedingly broad lines" (Morgan, Keenan, and Kellman 1943). More specifically, "With the coarse resolution of the MKK Atlas, all early-type stars with rotational velocities less than 200 km/sec can be satisfactorily intercompared" (remark by Morgan in Abt [1963]).

When the scale of the spectrograms is increased, it becomes difficult to make direct comparisons of broad- and sharp-lined stars. This was the cause of the systematic difference in the Mount Wilson classification of the broad-lined A-type stars relative to the Harvard classification (see Keenan 1963 for references) and relative to the MK classification (Jaschek 1970).

We have examined spectrograms of MK spectral classification standard stars taken with various dispersions with the Perkins 72-inch reflector of the Ohio State and Ohio Wesleyan Universities at the Lowell Observatory in Flagstaff, Arizona, and also spectrograms of 40 Å mm^{-1} dispersion taken at the Kitt Peak National Observatory by Abt. We note two effects of high (relative to the MK system) resolution on wide (rotationally broadened) lines.

2.1 Weak Lines

In line ratios of unequal strength, the weaker line appears still weaker due to rotation. This has the following consequences for spectral classification:

a) Early to middle B-type stars may be classified too early because the Si II 4128-30 lines will appear weaker relative to the He I 4144 line than in sharp-lined stars. The weakening of Mg II 4481 relative to He I 4471 in B5-B7 rapid rotators will have the same effect.

b) Near B9, the weakening of He I 4471 relative to Mg II 4481 should have the opposite effect, resulting in classifying these stars too late.

c) The weakening of metallic lines by rotation in the spectra of A-type stars will result in the classification of such stars as too early. This is the "Mount Wilson effect" referred to earlier.

2.2 Hydrogen and Helium Lines

In sharp-lined stars the extensive wings of Stark-broadened lines such as the Balmer lines of hydrogen will appear weaker relative

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to their sharp, deep cores than in broad-lined stars. The effect of rotation, then, will be to make the Balmer lines look stronger relative to sharp-lined stars. Intrinsically sharp Balmer lines will appear weaker at high resolution and such stars will be classified as too luminous.

This effect will also play a role in the classification of B-type stars in which members of the Diffuse series of helium (e.g., 4026, 4144, 4388, 4471 Å) are used in line ratios. As with the Balmer lines the wings of these lines will be lost in sharp-lined stars observed with high resolution, and the lines will appear weak relative to rapid rotators.

The effects just described will be most pronounced for line ratios far from unity and for resolutions far greater than that used in the MK system. They can be avoided by using standard stars of comparable rotational velocity when classifying stellar spectra at dispersions significantly higher than that used in the MK system.

3. EFFECTS OF PHYSICAL CHANGES IN ROTATING STELLAR ATMOSPHERES ON LINE STRENGTHS.

In addition to the aforementioned instrumental effects, physical changes in rotating stellar atmospheres may also affect line strengths in stellar spectra. During recent years, a number of writers have considered the effects of stellar rotation on spectrum lines (e.g., Collins and Harrington 1966; Collins 1968a, 1968b, 1970, 1974; Collins and Sonneborn 1977; Hardorp and Strittmatter 1968; Hardorp and Scholz 1971; Friedjung 1968; Stoeckley and Mihalas 1973; Balona 1975; Warren 1976).

Collins (1974) in particular calculated line profiles for He I 4471, Mg II 4481, and Fe I 4476 for a set of rotating model 09-F8 main-sequence stars. Using the ATLAS model atmosphere program and taking shape distortion (assuming a Roche model) and gravity darkening into account, Collins obtained line profiles for various values of the angular velocity and various values of the angle of inclination of the rotation axis. He found that the helium and iron lines are extremely sensitive to the amount of stellar rotation while the magnesium line is not, which results in some ambiguity in spectral classification for stars in the range B7-B9.

We have extended Collins' calculations to include the Balmer lines, the He I lines 4009, 4026, 4121, 4144, and 4388, and the Si II lines at 4128-30 Å, using the model atmosphere code ATLAS V and the most recent edition of the Griem broadening theory (Gieske and Griem 1969; Griem 1974). Although this work will be reported in detail in a paper elsewhere, we can make a few generalizations which are relevant for spectral classifications:

1. Increasing rotation always has the effect of lowering the observed effective temperature and effective gravity.

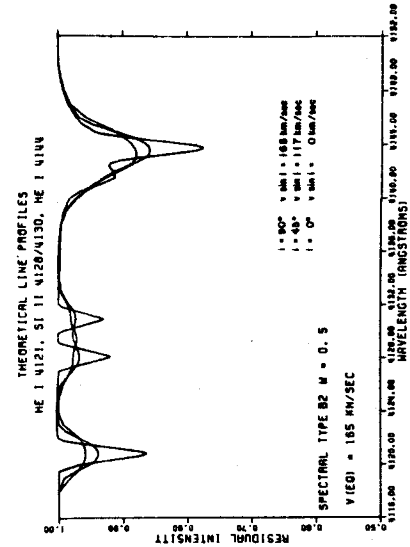
2. This decreased temperature and gravity will affect different lines in different ways. Some typical line profiles at various spectral types and rotational velocities are shown in Fig. 1. Measurements of the equivalent widths of these and other line profiles lead to the following conclusions:

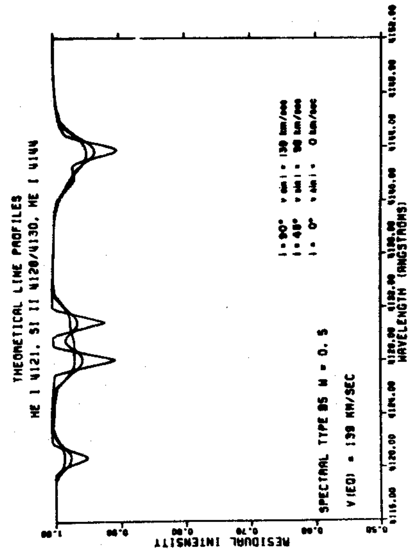
   a. He I lines of the Diffuse series are much more sensitive to the amount of stellar rotation than are the Si II 4128-30 and Mg II 4481 lines. For B stars of type B2 and later, this means that rapid rotation weakens the He I 4144 line relative to the Si II 4128-30 lines, and weakens the He I 4471 line relative to the Mg II 4481 line (as Collins [1974] had found earlier), and these stars will be classified too late. In other words, a rapidly rotating early B-type star may simulate a middle B-type, and a middle B-type rapid rotator may look like a late B-type star.

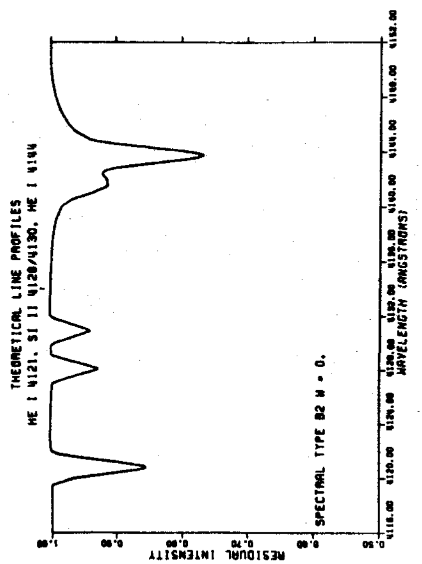
   b. Rapid rotation may decrease or increase the equivalent widths of Balmer lines depending upon whether the temperature or luminosity dependence of the line is dominant at a particular spectral type. The B-type stars show stronger Balmer lines with increased rotation, while the Balmer lines tend to become weaker in rapidly-rotating A-type stars. Inclination effects may produce appreciable differences in the Balmer line profiles for rapid rotators, as shown for the A2 model in Fig. 1.

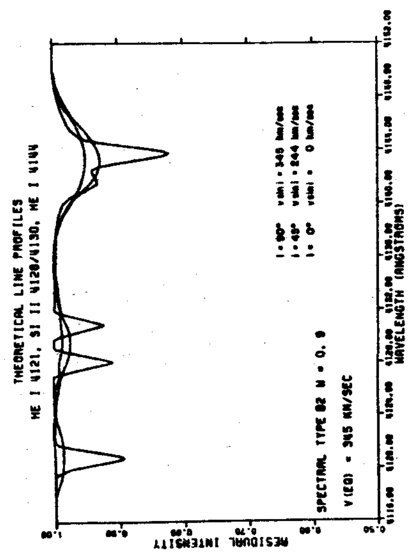
3. Unfortunately, as Collins (1974) has pointed out, rotational color effects would be expected in the same direction as the line strength effects discussed above, which make spectral type ambiguities very difficult to detect.

4. Fortunately, all of the effects discussed above are small for low-to-moderate rotation, and become significant only for the rapidly-rotating stars. Unfortunately, the class of most rapidly rotating stars, the Be stars, are difficult to study because their spectra are complicated by emission and shell effects.









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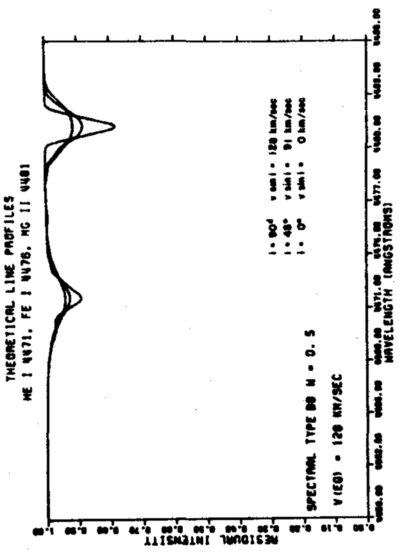

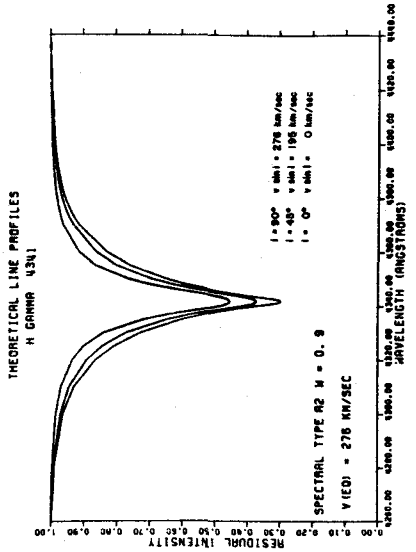

Fig. 1. Typical theoretical line profiles for some of the lines considered in this study. The parameter W is the fraction of the critical angular velocity for which the centrifugal force at the star's equator balances the gravitational force. All profiles have been convolved with an instrumental profile of half-intensity width 1 Å.

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DISCUSSION

Houziaux: Was there any microturbulent velocity included in the stellar models? Were the computer profiles folded with instrumental profiles and, if so, with which profiles?

Slettebak: Turbulent velocities were not considered. The rotational velocities considered are very large with respect to any microturbulent velocities which might be present. The computed profiles were convolved with a triangular instrumental profile of half-intensity width 1 Å.

Andersen: I understand you to mean that one cannot do two-dimensional classification of B and A stars at high dispersion, but must include rotation as well as temperature and luminosity classes, and that among the three, rotation may easily produce the largest effect in the spectrum. Having recently looked at a lot of 20 A/mm plates of B and A stars, I entirely agree, but for a proper three-dimensional classification the available set of standards is not adequate, i.e. even in your own catalogue there is not a fine enough grid of rotations for a given MK type.

Slettebak: I agree. A finer grid of rotational velocity standard stars would be very desirable.