SPECTROSCOPIC MEASUREMENTS OF STELLAR ROTATION

DAINIS DRAVINS
Lund Observatory
Box 43
S-221 00 Lund
Sweden

1. Effect of a Star's Rotation on its Spectrum : current and future challenges

This section title is identical to that of the first paper where the broadening of absorption lines in response to stellar rotation was discussed: Abney (1877).

More accurate measurements now reveal also the details of stellar line *shapes*, making it possible to segregate the signatures of rotational and other broadening mechanisms: e.g. Gray (1992) and Smith & Gray (1976). To determine the rotation, fits can be made to line profiles (e.g. Anders et al., 1993), to their Fourier transforms (e.g. Dravins et al. 1990; Smith & Gray 1976), or to extended spectral regions (e.g. Kurucz et al. 1977).

This review, however, concerns issues for [single-epoch] spectroscopic observations only, no temporal aspect will be discussed.

What is observed is a rotationally broadened profile, the accuracy begins to get limited by the incomplete *physical understanding* of stellar line profiles and of the nature of stellar rotation. In order to disentangle the rotational broadening from other effects, one needs to know the 'intrinsic' (i.e. rotationally unbroadened) profile of the non-rotating star. How does this profile change with latitude and longitude across the stellar disk? What effects besides rotation are broadening the lines? What about mass loss, radial pulsation, non-radial oscillations, magnetic fields, spots, etc.? And the star might not even rotate as a rigid body, but perhaps differentially with respect to latitude and/or atmospheric height. All this has to be deduced from the often blended lines in complex spectra. And, finally, one

I. Appenzeller (ed.), Highlights of Astronomy, Vol. 10, 403–406.

has to understand the instrumental effects on measured line profiles, and on continuum levels.

2. The signature of no rotation

A prior knowledge of the *unbroadened* profiles can be obtained either empirically or theoretically. For a random orientation of rotation axes, some fraction will be viewed [almost] pole-on, and thus have [almost] negligible rotational broadening. For examples of such sharp-lined stars among others with more rapid projected rotation, see e.g. Holweger et al. (1986).

Another possibility involves a numerical deconvolution of the observed spectrum for the rotational broadening, thus uncovering the 'intrinsic' line profiles (Dravins et al. 1990).

A third option involves the observation of *subrotational features*. They arise because the rotational broadening has sharp limits in wavelength (corresponding to the Doppler shifts of the approaching and receding limbs of the stellar disk). If there are spectral lines closer together that the width of this broadening, the superposition of different (sharp-edged) lines causes slight 'ripples' or 'bumps' in the resulting spectrum. The shape of each such 'bump' carries information on the *unbroadened* line profiles, even if all lines are blended. Observations of such features are shown in Dravins et al. (1990), while Carpenter et al. (1984) give synthetic spectra where the phenomenon is visible, even for very rapid rotators close to the critical (break-up) velocity.

A fourth option, presently possible for solar-type stars, involves applying detailed hydrodynamic model atmospheres to compute 'intrinsic' line profiles (Dravins & Nordlund 1990).

3. The signature of non-trivial rotation

The Sun rotates *differentially*: its angular velocity changes with latitude. Further, solar rotation depends upon atmospheric height and differs among magnetic and non-magnetic features. Other stars can also be expected to have such non-trivial rotation patterns. The searches are limited by the extra free parameters which are not easy to constrain (Bruning 1981; Dravins et al. 1990; Gray 1977a, 1982).

4. Stars viewed at various inclination angles

Rapidly rotating stars may reach rotation comparable to the critical mass-shedding velocity of perhaps 300 km/s. Gravity darkening implies that the continuum brightness, and spectral line strengths change across the stellar disk. Now the rotational broadening function also depends on the

https://doi.org/10.1017/S1539299600011540 Published online by Cambridge University Press

inclination angle under which the star is observed. This may be deduced by comparing lines of different properties (ionized vs. neutral; ultraviolet vs. visual) with different dependences across the disk, or to make very accurate studies of individual line profiles (e.g. Gulliver et al. 1994; Ruusalepp 1982).

5. Signatures of non-rotational broadening

Most stars are not static, but show various degrees of mass loss, radial pulsation, non-radial oscillations, evolving magnetic fields, spots, etc. For examples of such effects, see Aerts & Waelkens (1993) or Piskunov et al. (1990).

6. Other rotational signatures: Line asymmetries

Besides for line broadening, rotation also has effects on spectral line *asymmetries* (due to e.g. stellar winds or photospheric convection patterns). For discussions of this effect in solar-type stars, see Dravins & Nordlund (1990), or Smith et al. (1987).

7. Limits set by the spectrum itself

Irrespective of the quality of observations, or of the modeling, certain physical limits are set by the spectrum itself. In some stars, the lack of sharp spectral features makes determination of rotation difficult. In other stars, very rich and complex spectra make the calculation of the intrinsic spectrum awkward (i.e.Kurucz & Furenlid 1979). In one encouraging example, narrow features have been found in otherwise broad-lined white dwarfs: there are sharp cores inside the Balmer lines (caused by non-LTE effects), being very useful for rotation determinations (Koester & Herrero 1988).

8. The limit of very slow rotation

It seems that, with precise observations, the noise in $V \sin i$ can be pushed down to 0.3 km/s or less, at least for solar-type stars (Soderblom 1982). The broadening in the solar spectrum ($V \sin i \simeq 1.8$ km/s) is readily seen in data of sufficient quality (Gray 1977b, Pikalov 1993). Even in noisier data, rotation can be measured above $\simeq 3$ km/s (e.g. Marcy & Chen 1992).

9. Instrumental limits

Obviously, high-quality observations are needed. This holds both for the photometric signal-to-noise ratio (Gray 1988), the placement of the spectral continuum (Dravins et al. 1990), and in understanding the instrumental effects that may distort the spectrum (Dravins 1994).

10. Conclusions

From the above discussion, optimistic conclusions can be drawn concerning the prospects for increasingly accurate determination of stellar rotation. Although numerous effects do influence line profiles, virtually all such effects seem understandable, and can be modeled. The historical trend seems clear: an increased accuracy in determining stellar rotation now calls for a better physical understanding of the line-forming processes, and not merely an improvement of the signal-to-noise ratios in the detectors.

11. Acknowledgements

This work is supported by the Swedish Natural Science Research Council.

References

Abney, W.W.: 1877, MNRAS **37**, 278
Aerts, C., Waelkens, C.: 1993, A&A **273**, 135
Anders, G.J., Jeffries, R.D., Kellett, B.J., Coates, D.W.: 1993, MNRAS **265**, 941
Bruning, D.H.: 1981, ApJ **248**, 274
Carpenter, K.G., Slettebak, A., Sonneborn, G.: 1984, ApJ **286**, 741
Dravins, D.: 1994, in C.Sterken, M.de Groot, eds. *The Impact of Long-Term Monitoring in Variable Star Research*, Kluwer, p. 269
Dravins, D., Lindegren L., Torkelsson, U.: 1990, A&A **237**, 137
Dravins, D., Nordlund, Å.: 1990, A&A **228**, 203
Gray, D.F.: 1977a, ApJ **211**, 198
Gray, D.F.: 1977b, ApJ **218**, 530
Gray, D.F.: 1982, ApJ **258**, 201
Gray, D.F.: 1988, in G. Cayrel de Strobel & M. Spite, eds. *The Impact of Very High S/N Spectroscopy on Stellar Physics*, IAU Symp. **132**, 185
Gray, D.F.: 1992, *The Observation and Analysis of Stellar Photospheres*, 2:nd ed., Cambridge Univ. Press
Gulliver, A.F., Hill, G., Adelman, S.J.: 1994, ApJ **429**, L81
Holweger, H., Steffen, M., Gigas, D.: 1986, A&A **163**, 333
Koester, D., Herrero, A.: 1988, ApJ **332**, 910
Kurucz, R.L., Furenlid, I.: 1979, *Sample Spectral Atlas for Sirius*, Smithsonian Astrophys. Obs. Spec. Rep. **387**
Kurucz, R.L., Traub, W.A., Carleton, N.P., Lester, L.B.: 1977, **217**, 771
Marcy, G.W., Chen, G.H.: 1992, ApJ **390**, 550
Pikalov, K.N.: 1993, Kin.Phys.Cel.Bodies **9**, 29 = Kin.Fiz.Nebesn.Tel **9**, 37
Piskunov, N.E. Tuominen, I., Vilhu, O.: 1990, A&A **230**, 363
Ruusalepp, M.: 1982, in M. Jaschek, H. G. Groth, eds, *Be Stars*, IAU symp. **98**, p. 303
Smith, M.A., Gray, D.F.: 1976, PASP **88**, 809
Smith, M.A., Huang, Y-R., Livingston, W.: 1987, PASP **98**, 297
Soderblom, D.R.: 1982, ApJ **263**, 239