RESONANCE LINES IN THE SOLAR CHROMOSPHERE

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Abstract. Stigmatic balloon spectra of the Sun in the vicinity of 2800 Å were obtained on September 22, 1968 and April 30, 1969. We compare the observed profiles of the H and K lines of ionized magnesium with the computed profiles of Athay and Skumanich and of Dumont. The discrepancy between observed and computed profiles of the Mg II lines is considerable. It is shown that this is a general fact for all chromospheric resonance lines of abundant elements. A brief review is given of different interpretations of this discrepancy.

1. Introduction

The observation of the H and K lines of ionized calcium has undoubtedly been the basis of most solar and stellar chromospheric investigations. In particular, the discovery made by Wilson and Bappu (1957) of a relation between the width of the central reversal of the lines in the spectra of several stars and the absolute magnitude of those stars increased the interest of such an investigation and initiated a considerable amount of work. The obtaining of high resolution profiles of these lines and other lines of chromospheric origin has been of great importance both for observers and for theoreticians.

Since the publication by Durand *et al.* (1949) of the first rocket solar spectra the investigations have been extended to the H and K lines of Mg II at 2800 Å and to the Lyman α and Lyman β lines of neutral hydrogen. All these lines show central self-reversals but the interpretation has, in general, only been partly successful.

Recent observations of solar Mg II lines by means of a balloon borne instrument are presented in this paper and their correlation with observations of other resonance lines of chromospheric origin is studied.

2. Observations of the H and K Lines of Mg II

The first profiles of the resonance lines of ionized magnesium at 2800 Å were obtained photographically during a rocket firing by Purcell *et al.* (1963) without spatial resolution on the disc. With a spectral resolution of some 3.10^{-2} Å both lines of the resonance doublet exhibit very strong central self-reversals similar to that observed at the centre of the H and K lines of ionized calcium (Figure 2a).

As a consequence of the rapid development of stratospheric balloon technology at the C.N.E.S. (National Centre for Space Research in France) a research programme was set up in France directed toward balloon spectrographic observations of the Mg II lines. A first stigmatic photographic spectrograph recorded centre-to-limb spectra of the lines with a resolving power of 5.10^{-2} Å and a resolution on the solar disc of the order of 2′ of arc (Lemaire and Blamont, 1967).

Houziaux and Butler (eds.), Ultraviolet Stellar Spectra and Ground-Based Observations, 250–255.

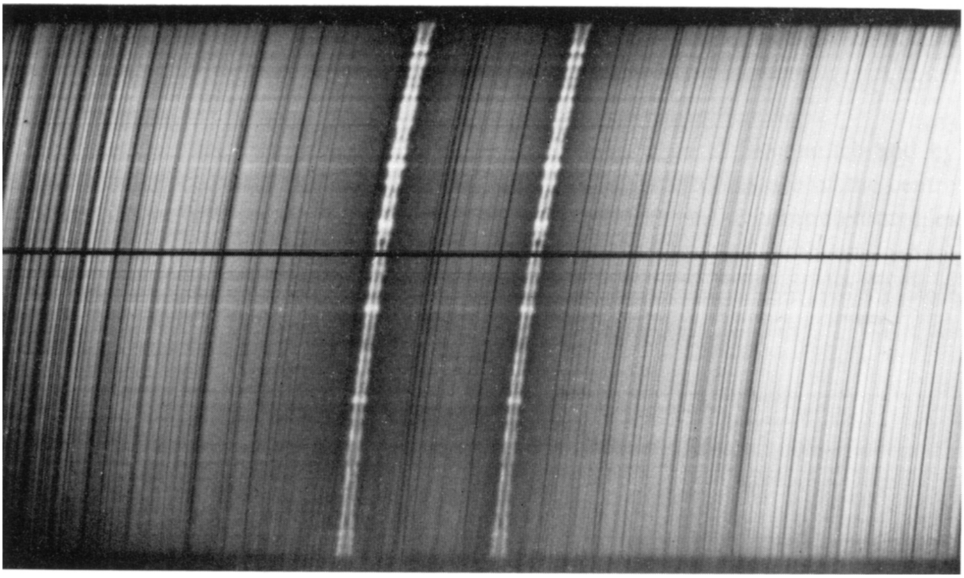

Fig. 1. 15-sec exposure stigmatic balloon spectra in the neighbourhood of Mg II (2795, 2802 Å) lines across a solar diameter (flight of April 30, 1969). The black trace is caused by a guide mark used as a reference for the respective position of the Sun and the slit. The curvature of the line is an instrumental effect. The shortest wavelengths of the spectrum are at the left of the photograph.

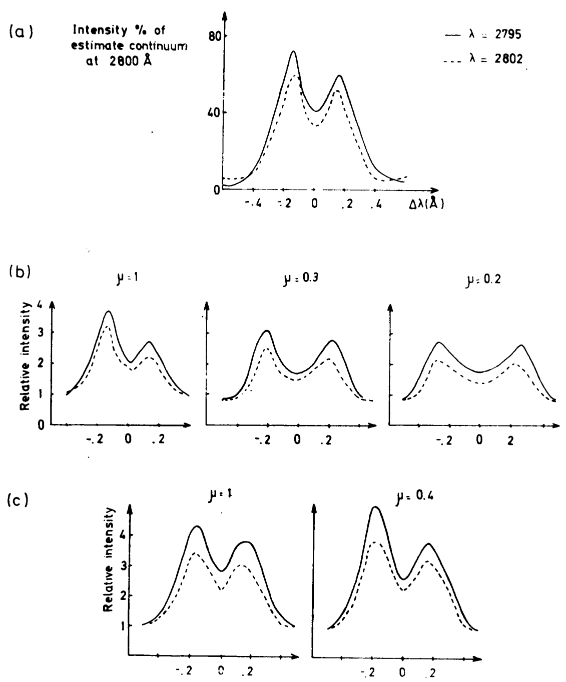

Fig. 2. Observed Mg II H and K profiles. (a) average over the central third of the solar disk on August 21, 1961 (Purcell *et al.*, 1963). – (b) and (c) Balloon spectra of April 1969 with a spatial resolution of 10″ of arc. (b) over quiet regions and (c) over faculae.

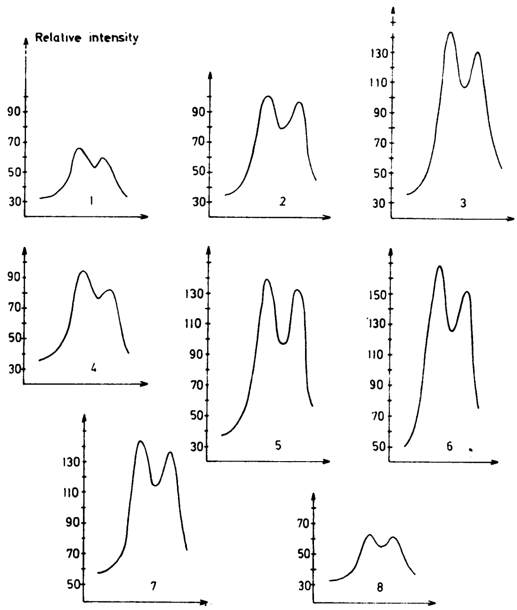

Fig. 3. Observed Mg II K profiles over a sunspot during the flight of September 22, 1968. (1) and (8) are profiles of quiet Sun from both extremities of the spot. (2), (3), (5), (6), and (7) are profiles of the plage region around the spot. (4) is the profile from the umbra to the spot.

An improved instrument increased both spatial and spectral resolutions and two successful flights on September 22, 1968 and April 30, 1969, allowed us to obtain stigmatic profiles along a diameter of the solar disc (Lemaire, 1969).

Figure 1 shows a spectrum obtained on the latter flight with an angular resolution of $\pm 7''$ of arc and a spectral resolution of 35 mÅ.

The following characteristic features can be noticed on those spectra:

(i) The distance between the two emission maxima of a single line increases from the centre to the limb. This variation is also observed for the H and K lines of Ca II.

(ii) The intensity emitted in both lines varies considerably over the disc depending on whether the slit of the spectrograph has cut across active or quiet regions.

(iii) The intensities of the peaks of a single line are unequal at the centre of the disc but become gradually equal as one goes closer to the limb (Figure 2b).

(iv) In active regions this inequality can either completely vanish or be completely reversed.

It is to be noticed that the profiles given in Figure 3 are identical with those observed in the H and K lines of Ca II (Engvold, 1967). The Lyman-α profiles obtained by Tousey *et al.* (1964) are also in good agreement with these characteristics.

3. Comparison with Computations

Several successful computations of the H and K lines of Ca II and Mg II have been made, especially by Dumont (1967a, b) and Athay and Skumanich (1968a, b). These authors made the assumption that the chromosphere is homogeneous and computed the source function and optical depth at a given point in the lines by solving simultaneously the equations of statistical equilibrium and radiative transfer.

In Figure 4, we compare the results obtained by Athay and Skumanich and by Dumont with the observed profiles of the Mg II lines. The profiles are of the centre of the disc. The distance between the two peaks appearing on the computed profiles is in good agreement with the observations. However, the lack of symmetry cannot be reproduced by the computation and the same is true for the width of the emission

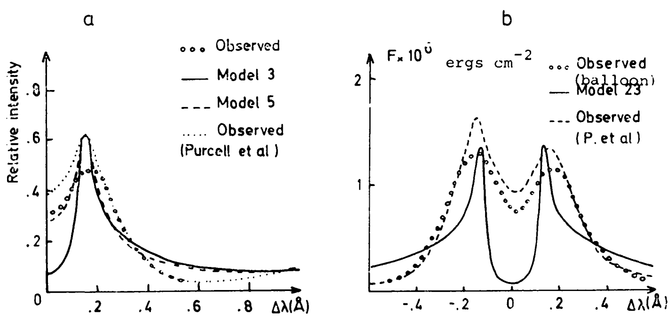

Fig. 4. Comparison of computed and observed Mg II K profiles. (a) Athay and Skumanich (1968). – (b) Dumont (1967).

peaks. Further, the computed centre-to-limb variation of the intensity ratio between the two peaks of a single line does not represent the progressive disappearance of the asymmetry toward the limb. Similar discrepancies in the theoretical and observed profiles appear for the Ca II lines (Dumont, 1967a, b; Athay and Skumanich, 1968a, b) and for the Lyman-α line (Cuny, 1968).

The explanation for these discrepancies seems to be due to the use of a homogeneous chromospheric model which is obviously a very coarse approximation to the problem. If it is assumed that the emission and absorption occur in descending and ascending cells whose velocities are normal to the atmospheric layers of different temperatures, then it is possible to explain the appearance of non-symmetrical profiles.

This assumption is reinforced when one examines very high space-resolved profiles of the H and K lines of Ca II such as those obtained by Zirin (1966) and Dodson-Prince and Mohler (1966). When the resolution is close to 1″ of arc, the emission occurs in totally inhomogeneous areas and the profiles for a single element are composed of a central emission line shifted preferentially toward the short wavelengths with reabsorption occurring in the wings. Each element therefore does show an unsymmetrical reversal and observing the disc with a resolution inadequate to separate these elements leads to a general blurring which gives the profile the appearance of a self-reversed line.

It is likely that the same thing occurs for both Mg II and H I resonance lines but at

TABLE I

References related to observations and computations of H and K lines of Ca II

Observations	
Very high spatial resolution ($\simeq 1''$)	Other observations
Zirin (1966) Dodson-Prince and Mohler (1966)	Goldberg *et al.* (1959) Zirker (1968) Linsky (1968) White and Suemoto (1968)
Computations	
Unsymmetrical profiles	Symmetrical profiles
Miyamoto (1957) Kulander (1967)	*Thin chromosphere:* Zirker (1968) Linsky (1968) *Thick chromosphere:* Dumont (1967a, b, 1969) Athay and Skumanich (1968a, b)

a different altitude.* As a consequence, the interpretation of resonance line spectra emitted in the chromosphere in terms of only LTE departures seems highly questionable.

Table I reviews recent observations of the H and K lines of Ca II. We indicate also the different interpretations that have been advanced by different authors to explain the shapes of the lines. Among them two do account for unsymmetrical lines. Both introduce model atmospheres with macroscopic velocity fields:

(1) Miyamoto (1957) assumes that the upper part of the chromosphere is moving down with respect to the lower part.

(2) Kulander (1967) introduces a discontinuity in the variation of the macroscopic velocity with height, which corresponds to the level in the atmosphere where the lines originate.

The schematic models which do not take into account the chromospheric inhomogeneities could certainly be improved by introducing a network, spread all over the disc, of hot and cold cells, each pair of them possessing its own differential velocity or discontinuity in velocity. Such cells might well be the spicules and interspicular areas.

4. Conclusion

The observation of strong asymmetries in the shape of Ca II as well as Mg II and H I resonance lines cannot be explained with LTE departures only. It seems therefore necessary to introduce upward and downward moving cells, which is a reasonably

* According to Zirker (1968) and Thomas and Athay (1961) the Ca II, Mg II and H I resonance lines are emitted in layers located, on the average, at heights of 2000, 3000 and 4000 km respectively.

realistic hypothesis. It is more likely that a better agreement between observations and computations might be reached by solving simultaneously the equations of radiative transfer and statistical equilibrium for each cell of the chromospheric network. This is obviously a gigantic task.

We suggest that a better knowledge of both dynamical movements and physical properties of the chromospheric layers could be reached by

(i) High resolution ($\sim 1''$) simultaneous observations in Ca II, Mg II and H I resonance lines for a given point on the disc.

(ii) Computations of the shapes of the three lines, using inhomogeneous models, accounting simultaneously for the observations in the three kinds of lines.

This programme cannot be undertaken without the use of rocket or satellite observations.

Acknowledgments

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References

Athay, R. G. and Skumanich, A.: 1968a, *Solar Phys.* **3**, 181.
Athay, R. G. and Skumanich, A.: 1968b, *Solar Phys.* **4**, 176.
Cuny, Y.: 1968, *Solar Phys.* **3**, 204.
Dodson-Prince, H. and Mohler, O. C.: 1966, *The Fine Structure of the Solar Atmosphere*, Franz Steiner Verlag, Wiesbaden, pp. 98–101.
Dumont, S.: 1967a, *Ann. Astrophys.* **30**, 861.
Dumont, S.: 1967b, *Ann. Astrophys.* **30**, 421.
Dumont, S.: 1969, *Astron. Astrophys.* **2**, 45.
Durand, E., Oberley, J. J., and Tousey, R.: 1949, *Astrophys. J.* **109**, 1.
Engvold, O.: 1967, *Solar Phys.* **2**, 234.
Goldberg, L., Mohler, O. C., and Müller, E. A.: 1959, *Astrophys. J.* **129**, 119.
Kulander, J. L.: 1967, *Astrophys. J.* **147**, 1063.
Lemaire, P. and Blamont, J. E.: 1967, *Astrophys. J.* **150**, L129.
Lemaire, P.: 1969, *Astrophys. Letters* **3**, 43.
Linsky, J. L.: 1968, Smithsonian Astrophysical Observatory, Special Report **274**.
Miyamoto, S.: 1957, *Publ. Astron. Soc. Japan* **9**, 146.
Purcell, J. D., Garrett, D. L., and Tousey, R.: 1963, in *Space Research*, vol. III, p. 781.
Thomas, R. N. and Athay, R. G.: 1961, *Physics of the Solar Chromosphere*, Interscience, New York.
Tousey, R., Purcell, J. D., Austin, W. E., Garrett, D. L., and Widing, K. G.: 1964, *Space Research*, vol. IV, p. 703.
White, O. R. and Suemoto, Z.: 1968, *Solar Phys.* **3**, 523.
Wilson, O. C. and Bappu, M. K.: 1957, *Astrophys. J.* **125**, 661.
Zirin, H.: 1966, *The Solar Atmosphere*, Blaisdell Publishing Co., London, pp. 228–230.
Zirker, J. B.: 1968, *Solar Phys.* **3**, 164.

Discussion

Deutsch: Can one estimate the magnitude of the differential velocities that would be required to reproduce the asymmetry observed in K_2?

Hearn: The paper by Miyamoto gives a calculation of the effect of velocities on the asymmetries of the Ca, He, K lines and this leads to an estimate of the magnitude of the velocities required.

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