# CONVECTION CURRENTS IN STELLAR ATMOSPHERES

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In 1909–10 high-dispersion spectrograms of Sirius, Procyon and Arcturus were obtained by Adams and Babcock, the linear scale being 1.4 *A* per mm at λ 4300. The plates were measured by Adams, Miss Lasby, and Miss Ware. The principal result of the investigation at that time, which was the red displacement of enhanced lines relative to arc lines, was discussed by Adams.[1] In the meantime, studies of the relative behavior of solar and arc lines, the recognition of pole-effect, the classification of spectral lines into pressure and temperature groups, the theory of ionization, and the recognition of differences in level at which Fraunhofer lines have their origin have provided more adequate analytical methods of interpreting solar and stellar spectra, and a rediscussion of the original measures has accordingly been undertaken.

It has been shown that the displacements toward the red in the solar spectrum are larger for high-level than for low-level lines. This appears to be due to differences in radial velocity at different levels. At high levels the absorption produced by the cooler, downward-drifting vapors is the predominating influence in the spectrographic integration, while at low levels the ascending currents are chiefly effective in forming the lines. The great body of data yielded by the early spectrograms of high dispersion provides a means of testing whether similar conditions prevail in the atmospheres of stars.

Two groups of arc lines were formed, one of lines which, in the flash spectrum, according to Mitchell,[2] extend upward 600 km or more, and the other of lines whose heights are below 600 km; these are designated respectively, by the terms "high" and "low." The relative displacements of these groups are given in the last column of table I. For the stars, these differences represent the excess of the relative displacements of the same high-level lines in star and sun over those of the low-level lines in star and sun. Further, the stellar and solar wave-lengths of large groups of enhanced and arc lines were compared in the same way. The resulting differences, enhanced *minus* arc, are in the fifth column of table I. In the case of the sun, the displacements compared were those relative to laboratory values.

The striking features are, first, the close agreement of the differences between enhanced and arc lines with those between high- and low-level lines; and second, the decrease in these differences from Sirius through Procyon to Arcturus. Since the lines of ionized atoms are known to occur at greater heights in the atmosphere than those of neutral atoms, the greater red-displacement of enhanced lines relative to arc lines can be attributed to the same cause as the differences between high- and low-level arc lines. In both cases the differences appear to represent the influence of a variation in convection currents with level.

TABLE I

RELATIVE DISPLACEMENT OF ENHANCED AND ARC LINES IN STELLAR SPECTRA COMPARED WITH DISPLACEMENTS OF ARC LINES OF HIGH AND LOW LEVEL

| | NO. PLATES | NO. OF LINES ENHANCED | NO. OF LINES ARC | ENHANCED *minus* ARC | NO. OF LINES HIGH LEVEL | NO. OF LINES LOW LEVEL | HIGH *minus* LOW |
|---|---|---|---|---|---|---|---|
| Sirius | 4 | 141 | 176 | +0.016A | 64 | 113 | +0.015A |
| Procyon | 4 | 107 | 278 | +0.008 | 73 | 222 | +0.006 |
| Arcturus | 14 | 316 | 1070 | +0.001 | 80 | 666 | +0.002 |
| Sun | | 4(Ti) | 13(Ti) | +0.004 | Mean, Fe Lines | | +0.003 |

The displacement of the stellar lines in table I, which are relative to those of the same lines in the solar spectrum, can be reduced to absolute values by combining them with the solar displacements relative to laboratory values. The results for the high- and low-level lines, are given in table II, together with the equivalent velocities in kilometers. The spectral types are added for comparison, as well as the temperatures according to Seares.[3]

TABLE II

RELATION OF DISPLACEMENT TO TEMPERATURE

| | TYPE | TEMPERATURE | DISPLACEMENT HIGH LEVEL *minus* LOW LEVEL | |
|---|---|---|---|---|
| Sirius | $A_2$ | 8800° | +0.018A | +1.20 km/sec. |
| Procyon | $F_3$ | 6400 | +0.010 | +0.67 |
| Arcturus | $K_0$ | 3900 | +0.005 | +0.34 |
| Sun | $G_0$ | 5800 | +0.003 | +0.20 |

The displacements given in table II, interpreted as Doppler shifts, are in general agreement with the assumption that convection currents are the more pronounced the higher the temperature of the star. There is, possibly, also an influence depending on density.

The principal lines used in the determination of the radial velocities of the B-type stars are high-level lines of elements such as H, He, Mg, Si, O, and N. In the spectrum of Sirius the relative displacement of arc lines for moderate differences of level is 0.018 $A$ at $\lambda$ 4500, or 1.2 km, while for $H\gamma$ it is equivalent to 2.0 km. From these data it seems quite reasonable to conclude that at the still higher temperatures of the B-type stars the downward velocities may have a value of the order of 4 km, the amount of the $K$-term. These results strongly favor the hypothesis suggested several years ago by Campbell[4] that convection currents are a possible explanation of the $K$-term.

The pressures in the atmospheres of these stars may be referred directly to the pressure in the sun's atmosphere by determining the relative displacements, star *minus* sun, for groups of lines whose pressure coefficients differ by determined amounts. Table III shows the results of a comparison of lines of classes *c* and *d* having large pressure-shifts with lines of classes *a* and *b* whose pressure-shifts are smaller.

TABLE III

RELATIVE DISPLACEMENT OF LINES WITH LARGE AND SMALL PRESSURE COEFFICIENTS

| | NO. PLATES | NO. LINES | CLASS | DISPLACEMENT | PRESSURE (ATMOSPHERES) |
|---|---|---|---|---|---|
| Sirius | 7 | 70 | *c,d* | +0.001 | +0.4 ± 1.1 |
| | | 87 | *a,b* | | |
| Procyon | 4 | 71 | *c,d* | −0.003 | −0.8 ± 0.9 |
| | | 158 | *a,b* | | |
| Arcturus | 11 | 175 | *c,d*(*Mn*) | −0.002 | −0.5 ± 0.8 |
| | | 247 | *a,b* | | |
| Sun | — | — | — | —— | +0.13 ± 0.06 |

The inference from these results is that the pressures in the atmospheres of these stars are low and of the same order as that in the sun. A similar investigation by Salet, based upon a much smaller number of lines, gave provisional values of about three atmospheres for Arcturus and one or two atmospheres for Procyon.[5]

A fuller account of this investigation will appear in *Mount Wilson Contribution*, No. 279.

[1] *Mt. Wilson Contr.*, No. 50; Astroph. J. **33**, 1911 (64).
[2] Astroph. J., **38**, 1913 (107).
[3] *Mt. Wilson Contr.*, No. 226; Astroph. J. **55**, 1922 (165).
[4] Lick Obs. Bull., No. 257, 1914.
[5] Astroph. J., **53**, 1921 (327).

# *A STATISTICAL DISCUSSION OF SETS OF PRECISE ASTRONOMICAL MEASUREMENTS, III; MASSES OF THE STARS*

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Inasmuch as present-day conceptions in physics identify mass and energy through the relation $E = mc^2$, and both mass and energy are found in their greatest concentrations only in the stars, there is physical and astronomical interest in the study of the relation of stellar mass to radiant energy. Neither the mass nor the radiant energy has been directly measured for many stars; both have for the most part been estimated by various devices of a statistical and hypothetical nature aiming chiefly at reasonableness of astrophysical assumption and self-consistency of statistical