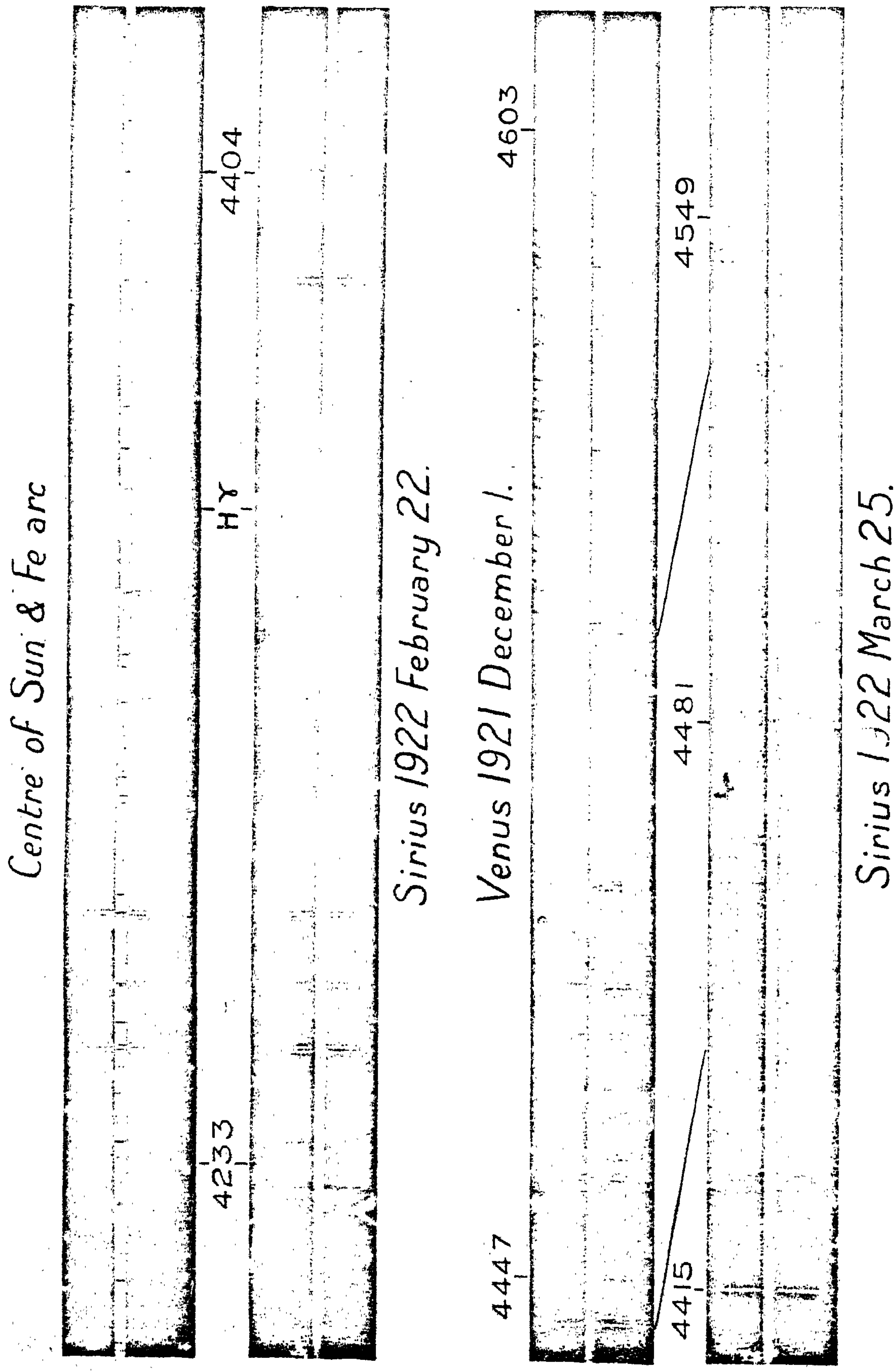
Widened Lines in the Spectrum of Sirius. By J. Evershed.
(Plate 10.)

Photographs of the spectrum of Sirius have been obtained at Kodaikánal with the new auto-collimating prism spectrograph specially built for obtaining high-dispersion Venus spectra. The Sirius spectra reveal a peculiarity which has not, so far as I know, been noticed before. The spectrum, as is well known, consists of very broad hazy hydrogen lines and sharply defined metallic lines, of which the majority are the enhanced lines of the elements. In Lockyer's classification Sirius is on the descending side of the temperature curve, and he states that for stars of this class "the hydrogen lines are relatively broad, and the metallic lines thin."*

Our spectra have a dispersion about five times greater than that employed by Lockyer, the scale ranging from about 1·3 A. per mm. to 2 A. per mm., and they include the spectral region between 4220 and 4700. The hydrogen line Hγ shows a quite definite nucleus and a broad shading extending about 10 A. on either side. But the most noteworthy feature in the spectra is the width of the metallic lines, and the uniformity of this character throughout the range of spectrum photo-

* Memoir on the general spectra of certain type stars.


Centre of Sun & Fe arc
4404
Hγ
4233
Sirius 1922 February 22.
Venus 1921 December 1.
4603
4447
4549
4481
4415
Sirius 1922 March 25.

graphed. The lines are rather well defined at their edges, and many of them give the impression of being superposed on a broader bright line, but this may possibly be an effect of contrast. If we place side by side with the Sirius spectrum a plate of the Venus or solar spectrum, taken with the same apparatus and the same slit-width, we note the very much greater width and less intensity of the Sirian lines compared with the solar lines. Measurements show that while the finer single lines in the solar spectrum in this region are from 0·05 A. to 0·10 A. in width, nearly all of the Sirius lines, whether weak or strong lines, are between 0·3 A. and 0·4 A. in width. Again, while the majority of the solar lines are intensely dark, showing in fact no photographic action at all, the Sirius lines for the most part are not black but grey, the intensity within them being perhaps one-third or one-half of that of the continuous spectrum.

There are two notable exceptions in the region photographed, the enhanced line of magnesium at 4481·3 and the line at 4549·8: these appear nearly black and cut the spectrum in two at these points. Were it not for the exceedingly narrow lines of the comparison spectrum of the iron arc photographed simultaneously, it might be thought that the star spectrum had been photographed with a very wide slit. The measures give an average width of 0·37 A. for a normally exposed plate, and the variation from line to line is quite small, but the line 4481 is wider, about 0·5 A., with ill-defined edges. The nucleus of the hydrogen line γ is not very much wider, being about 0·6 A., but, owing to the intensity of the shading, the plate is, of course, underexposed here, and the line probably appears wider than it would if projected on a bright background. (Compare the Sirius and solar lines in Plate 10.)

Several hypotheses may be advanced to explain the widening. The broad shading of the hydrogen lines might suggest that there was considerable pressure in the star's atmosphere, and that this may be responsible for the widening of the metallic lines. But it is easy to show that this cannot be. Measures have been made of the extreme widths of the hydrogen lines β, γ, δ, and ϵ in a low-dispersion spectrum of Sirius taken with two 45° prisms and a 5-foot camera. In this the dispersion varies from 18 A. per mm. at H_β to 8 A. per mm. at K, and it is found that the increased dispersion at the violet end just compensates for the apparent increase of width of the more refrangible lines, so that expressed in angstrom units all the four lines are approximately the same width, which is about 20 A.; but the intensity of the continuous spectrum in this plate is greater near H_β where the spectrum is slightly overexposed, and decreases largely towards the violet end where it is underexposed. This no doubt tends to erroneous estimates of the relative widths, and were the spectrum uniformly exposed all along, the width of the bands would probably be found to increase towards the red end, as is also the case with the much narrower hydrogen lines in the Sun.

The fact that the widths do not increase considerably towards the violet shows that it is not a pressure effect, for, according to the experiments of Rossi, the broadening of the hydrogen lines under pressure varies as the inverse third or fourth power of the wave-length, and, even at a pressure of half an atmosphere only, the line δ was found to be 1·8 times wider than the line β.*

The wings of the hydrogen lines are in all probability produced in the deeper parts of the star's reversing layer, where the density of the hydrogen gas is comparatively great, and if there is no appreciable pressure effect here it cannot occur in the region of iron absorption.

Again, the effect of pressure exceeding an atmosphere on the iron lines is to produce hazy edges and to broaden some lines more than others; but the iron lines in Sirius are all about equally broadened and with defined edges.

The effect of a magnetic field in widening lines by reason of the Zeeman effect may also be ruled out for the same reason: the apparent widening due to the splitting up of the lines into several components would vary greatly from line to line.

It appears that the widening can most probably be explained as a Doppler effect, but this may be due to several causes. If Sirius were a spectroscopic double star there would be a periodical change in the width of the lines, if not an actual doubling, at times of greatest relative velocity in the line of sight. Now in a plate taken on 1922 February 21, the iron arc lines at 4308, 4425·9, and 4404·9 appear to show signs of resolution into two, especially 4404; but none of the other iron lines show this, and it may be due to some accidental alignment of the silver grains. The double star hypothesis may be tested by comparing photographs taken on different dates. We have available plates taken on 1922 January 4, February 18, February 21, March 14, and March 25, and in addition two underexposed grating spectra, one obtained on 1917 February 4 and the other on 1920 March 17. Comparing all these plates, there appears to be no sensible variation in the width of the lines, and only on the plate of 1922 February 21 is there a slight indication of doubling. It is not probable therefore that the light is derived from two stars in relative motion.

According to the kinetic theory of gases the velocity of the luminous atoms will be proportional to the square root of the absolute temperature. This movement causes a Doppler widening of spectrum lines, which for homogeneous radiations will be proportional to $\sqrt{\frac{T}{M}}$, T being the absolute temperature and M the atomic weight or mass. Taking the absolute temperature of the Sun's atmosphere at 6000°, and that of Sirius at 10,000°, we find that the Sirius lines will be widened in the ratio of 1·3 only compared with the solar lines; also that the hydrogen lines should be $7\frac{1}{2}$ times wider than the iron lines. Actually the measures show that the Sirius lines are nearly 4 times wider than the corresponding solar lines, and the nucleus of the hydrogen line γ is only about 1·6 times the width of the neighbouring iron lines; whilst the wings of the hydrogen lines are over 50 times the width of the iron

* R. Rossi, *Astrophysical Journal*, 34, 301, 302. The significance of these experiments with regard to pressure in solar or stellar atmospheres does not appear to have been realised. They show that pressures exceeding half an atmosphere do not exist in the reversing layers of Sun or any stars showing distinct hydrogen lines.

lines. Evidently the high temperature of Sirius will not account for the widened lines.

Another hypothesis which may be suggested is a rapid rotation of the star. If Sirius is rotating on an axis lying nearly normal to the line of sight, we might expect that the integrated effect of the line-of-sight velocities over the disc would widen the lines. In the case of the Sun, we find that the lines in general sunlight when photographed under very high dispersion have practically the same widths as lines in light from a limited region of the Sun, as the centre of the disc: the only difference is a slight haziness at the edges, which is seen on comparing close double lines. The relative velocity at the equatorial limbs of 3·9 km./sec. has apparently no effect in widening the lines. If, however, we block out the centre of the Sun, and integrate the light from a narrow annulus, the lines are widened on the average about one and a third times. The actual increase of width for the region about 4427 is, according to my measures, about 0·034 A., equivalent to 2·3 km./sec. Thus, even in this case, we do not get the full widening due to the equatorial rotation velocity.

General sunlight differs only very slightly from light taken from the centre of the Sun's disc because of the great falling off in intensity near the limb, so that in a properly exposed plate only the light from the central part of the disc is effective. But it would appear that in Sirius the density of the reversing layer is probably so low that atomic scattering of the photospheric light does not reduce the intensity near the limb of the star to the same extent. The line-of-sight velocities near the east and west limbs may therefore be much more effective in widening the lines than in the case of our Sun. There is no doubt that the relative intensity of the ultra-violet part of the spectrum in stars of class A compared with those of class G indicates the absence of the so-called smoke-layer (atomic scattering) in the former class.

The actual measured widths of the Sirius lines would imply a linear speed of over 12 km./sec. at each limb. But, judging by the experiment with the light from an annulus of the Sun, this must be largely under-estimated, and there is the probability that the axis is not exactly normal to the line of sight. Recent estimates of the diameter of Sirius indicate a value about 1·9 times that of the Sun, so that taking 12 km./sec. as representing the minimum value of the equatorial velocity, the angular speed will be over three times that of the Sun, a complete rotation taking eight days or less. This high speed of rotation seems improbable considering that Sirius is in an earlier stage of evolution, and is therefore less condensed than the Sun: one would expect too that the lines would be more diffused at the edges than they actually are.

The only remaining hypothesis I can suggest is that the Sirian atmosphere is subject to much more violent convection than is the solar atmosphere. If there are radial convection currents with velocities of over 12 km./sec. rising and falling, the lines in the light from the central part of the star disc would be widened to the amount shown.

An analogy can be found in the Sun, but on a very much smaller scale. A high-dispersion photograph of the spectrum when the slit lies across a well-defined image of the Sun reveals innumerable small displacements of the lines equivalent to velocities of the order of a few tenths of a kilometre per second. These irregularities tend to widen the lines in general sunlight, but to an extent probably not exceeding 0·008 A.

Light on the question could be obtained by photographing high-dispersion spectra of other bright stars of the same class to ascertain whether the widening of the lines is peculiar to Sirius or is a feature common to stars of type A.

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