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THE RELATIVITY DISPLACEMENT OF THE SPECTRAL LINES IN THE COMPANION OF SIRIUS

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The remarkable character of the companion of Sirius and the almost unique position it occupies as an object which might be expected to yield a very large gravitational displacement of the spectral lines on the theory of generalized relativity has been discussed in an interesting paper by Eddington.[1] In this article he has shown the extraordinary values of the density of the material composing the star which would follow as a consequence of a confirmation of a relativity displacement of the order predicted.

The possibility of deriving results of such interest for this star is, of course, due to the fact that it is at the same time a "white dwarf," that is, an early type star of very low intrinsic brightness, and a component of a visual binary system with well-determined elements. From the elements of its orbit its mass and velocity relative to the principal star may be derived, and the well-known parallax of Sirius in combination with the apparent magnitude of the companion provides a knowledge of its absolute magnitude. The spectral type of the star is a matter of direct observation, and results for surface brightness, size and density follow as a consequence of what is known regarding stars of similar spectral class.

The first observations of the spectrum of the companion of Sirius were made at Mount Wilson with the 60-inch reflector in 1914[2] and showed that the spectrum was of an early type and not widely different from that of Sirius itself. The difficulties of such observations are evident. The brightness of the two stars is nearly in the ratio of 1 to 10,000, and at a distance of 10″ the scattered light of Sirius produces a spectrum which overlies that of the fainter star on all the photographs. Accordingly, it is necessary to select times of excellent seeing and to make the duration of the exposures as short as possible. For this reason the photographs obtained with the 100-inch reflector, with which the brightness of the fainter star relative to the illuminated field is greater than with the 60-inch telescope, are considerably superior. In the case of the more recent photographs diaphragms with circular apertures have been used to reduce the effect of the diffraction rays produced by the supports of the auxiliary mirrors. This has led to a marked improvement. All of the spectrograms have been made at the Cassegrain focus of the telescope at an equivalent focal length of 135 feet. A single-prism spectrograph with an 18-inch camera has been used for the observations, the average exposure time being about 40 minutes.

There seems to be little doubt that the spectrum of the companion is in some respects peculiar. The enhanced lines so prominent in the spectrum of Sirius are faint, λ4481 of magnesium being especially noteworthy in this respect. This agrees with the results found for other white dwarf stars. The arc lines are also faint, and the hydrogen lines form the principal feature of the spectrum. The distribution of the light in the continuous spectrum is noticeably different from that of the scattered light from Sirius and resembles that of an F-type star in being considerably more intense toward longer wave-lengths. As a result, the spectrum of the companion may be obtained nearly free from the spectrum of Sirius at $H\beta$, while at $H\gamma$ the superposition is very pronounced. At wave-lengths shorter than $H\delta$ the spectrum of the companion can hardly be seen upon that produced by the scattered light of Sirius. A consideration of these various features indicates that a classification of the spectrum as F0 is probably not seriously in error, although the line spectrum by itself would indicate a somewhat earlier type. It should be noted, moreover, that the increase in the amount of scattering toward shorter wave-lengths would tend to make the violet portion of the continuous spectrum from the scattered light somewhat more intense than in the case of Sirius itself. This may well account for a part of the difference observed. It seems probable, therefore, that the spectrum of the companion should be classed as earlier rather than later than F0.

For the purpose of measuring the relative velocities of Sirius and the companion a selection has been made of the spectrograms secured under the most favorable conditions and showing the spectrum of the companion most clearly. Four spectrograms have been found especially suitable, two of which are of exceptionally good quality. Since direct measurements are difficult on account of the diffuse character of the lines, they have been supplemented by an extended study and measurement of the two best spectrograms with the large registering microphotometer. For this purpose direct enlargements were made from the original negatives, and intensity curves of the more important spectral lines in both the spectrum of Sirius and that of the companion were traced with the microphotometer from these enlargements. The measurements, which were carried out by Miss Ware, who has had extensive experience with such photometric curves, consist in determining the centers of the chords of the curve of each spectral line at a large number of points between its base and vertex. The spectrum of Sirius lying on either side of that of the companion, the mean of the two curves for Sirius is compared with that of the fainter star. The horizontal scale of these curves is about 53 times that of the original negatives.

A second method of measurement makes use of the lines of the comparison spectrum as traced with the microphotometer. The curves of the lines in the spectrum of the companion are measured with reference to the curves of neighboring comparison lines, and the results are reduced by the usual method for stellar spectra after correction for the enlargement factor. The known radial velocity of Sirius is then subtracted from the value derived for the companion.

The spectrograms have also been measured directly with a comparator by one or more observers. In most cases only the spectrum of the companion has been measured and the resulting radial velocity has been compared with that of Sirius. Toward the violet end of the spectrum, however, it has been possible to measure some of the lines in both spectra and thus obtain differential values directly.

The following table gives the results of all the measures for the individual lines, the detailed values being listed in order to provide material for an estimation of the accuracy of the final results. The methods used in measurement are indicated and the relative displacements between the companion and Sirius are given for convenience as radial velocities in kilometers per second. The displacements in angstrom units may be obtained by dividing these values by 69 at $H\gamma$ and 62 at $H\beta$. The positive sign indicates a displacement toward the red of the lines in the spectrum of the companion relative to those in Sirius. The results for $H\beta$ and $H\gamma$ are entitled to by far the highest weight, the other lines being faint and difficult of measurement.

METHOD OF MEASUREMENT

PLATE NO.		COMP. *minus* SIRIUS KM./SEC.
	$H\beta$	
C776	Microphotometer	+31
C776	Microphotometer (Comparison lines)	23
C776	Comparator	24
C3110	Comparator	17
C3141	Comparator	31
C3156	Microphotometer	27
C3156	Microphotometer (Comparison lines)	28
C3156	Comparator	25
	$H\gamma$	
C776	Microphotometer	+13
C776	Microphotometer (Comparison lines)	17
C776	Comparator	2
C3141	Comparator	4
C3156	Microphotometer	8
C3156	Microphotometer (Comparison lines)	14
C3156	Comparator	12

ADDITIONAL LINES

λ	ELEMENT	PLATE NO.	METHOD	COMP. *minus* SIRIUS KM./SEC.
4215	Sr^{+}	C3156	Comparator	+4
4233	Fe^{+}	C3156	Comparator	5
4271	Fe	C776	Comparator	10
4290	Ti^{+}	C3156	Comparator	6
4300	Ti^{+}	C3156	Comparator	2
4404	Fe	C776	Microphotometer	37
4404	Fe	C776	Comparator	8
4481	Mg^{+}	C776	Microphotometer	20
4481	Mg^{+}	C776	Comparator	21
4549	Fe^{+}, Ti^{+}	C3156	Comparator	25

The outstanding features of these results are the definite character of the positive displacement and its change in amount with wave-length. The greater relative intensity of the spectrum of the scattered light of Sirius toward shorter wave-lengths and the increasing influence of the superposition of the lines in its spectrum upon those of the companion evidently will tend to reduce the amount of the measured displacement. Although the correction for this effect cannot be determined rigorously, some approximation to it can be gained from photometric measures of the relative densities of the continuous spectrum of Sirius and of Sirius *plus* companion at selected points throughout the spectrum. These have been made with the registering microphotometer and give the following values of the ratio of the photographic density of the continuous spectrum of the companion to that of Sirius at five regions in the spectrum:

λ4200	0.8	λ4400	1.2	λ4600	1.7
$H\gamma$	1.1	4500	1.4		

If we may assume, as seems justified from observation, that the relation of line intensity to continuous spectrum is the same for the hydrogen lines both for Sirius and its companion, the above numbers will also represent the ratios of the intensities of the lines. For $H\gamma$, where the ratio is nearly 1, the measured displacement will require multiplication by a factor of nearly 2 to correct for the effect of superposition. At $H\beta$, on the other hand, the spectrum of Sirius is relatively so faint that no correction should be necessary. For the other lines the uncertainty is greater because the relationship of line intensity to continuous spectrum is probably different in the two stars. Under the same assumption as for the hydrogen lines, however, values for the correction factor may be found, when the displacement is small as compared with the widths of the lines, from the approximate formula

$$a = 1 + \frac{k_1}{k_2}$$

in which $k_1 = 1$ is the density of the spectrum of the scattered light of Sirius, and k_2 that of the companion. The correction factors would be larger the fainter the lines in the spectrum of the companion relatively to those in Sirius. Applying corrections obtained by this formula, and assigning double weight to the measures with the registering microphotometer on the hydrogen lines, we find the mean values

	KM./SEC.
$H\beta$	+26
$H\gamma$	21
Additional Lines	22
	+23

The relative velocity of Sirius and its companion may be computed readily from the elements of the visual orbit. For the mean epoch of the observations this is found to be 1.7 km./sec., the companion showing a motion of recession from Sirius. Applying this correction to the observed value, the final result for the displacement of the lines in the spectrum of the companion is +21 km./sec., or +0.32 angstrom. This value, interpreted as a relativity displacement, gives a radius for the star of about 18,000 km. If we use the values derived by Seares[3] for surface brightness, we find for the companion of Sirius, on the alternatives of F0 or A5 for its spectral type,

	F0	A5
Surface brightness	—0.88	—1.45
Radius (km.)	24000	18000
Density (water = 1)	30000	64000
Relativity Displacement (angstrom)	+0.23	+0.32

Eddington has calculated a relativity shift of 20 km./sec. on the basis of a spectral type of F0 and an effective temperature of 8000° for the companion. The resulting density is 53,000 for a radius of 19,600 km.

Although such a degree of agreement can only be regarded as accidental for observations as difficult as these, the inherent accord of the measurements made by different methods, and in particular with the registering microphotometer, is thoroughly satisfactory. The results may be considered, therefore, as affording direct evidence from stellar spectra for the validity of the third test of the theory of general relativity, and for the remarkable densities predicted by Eddington for the dwarf stars of early type of spectrum.

[1] *Monthly Notices*, **84**, 308 (1924).

[2] *Publications of the Astronomical Society of the Pacific*, **27**, 236 (1915).

[3] Contributions from the Mount Wilson Observatory, No. 226; *Astrophysical Journal*, **55**, 165 (1922).

THE BASIN RANGE PROBLEM

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Earlier and Later Views: King, Gilbert, Powell. The Great Basin of our Cordilleran region, including all of Nevada and parts of Utah, Arizona, California and Oregon, is occupied by many separate mountain ranges from 10 to 50 miles or more in length. They were explained 50 years ago by King in a then orthodox manner as the unconsumed residuals of much greater mountains that had been produced in late Jurassic time by the horizontal compression of a heavy series of stratified formations and their Archean foundation; and at about the same time in a then heterodox manner by Gilbert as eroded fault blocks, unequally uplifted on vertical fissures with more or less deformation but without horizontal compression. Gilbert's chief evidence for this novel view was based on a new physiographic principle, to the effect that if a mountain range has a relatively simple base line which transects the range structures, as he found to be the case in typical examples of the Basin Ranges, it must be limited by a fault, even though the down-faulted continuation of the transected structures in the adjoining less uplifted block cannot be seen by reason of its burial under the detritus eroded from the higher block.

Powell entered the discussion thus aroused by briefly announcing, apparently on deductive rather than observational grounds, that, before the production of the vigorous Basin Ranges by the dislocation and erosion of fault blocks, the Great Basin region had been degraded from the mountainous altitudes given to it by late Jurassic deformation and thereby reduced to "a comparatively low plain," thus implying a long erosional