Reports

Pygmy Stars: First Pair

Abstract. *The binary LP 101–15/16 having the proper motion of 1.62 seconds of arc per year has been studied with the prime-focus spectrograph of the 200-inch (508 cm) telescope. Indications are that LP 101–15/16 is the first pair of pygmy stars ever discovered. One of its components, LP 101–16, is probably a blue pygmy star which is at least four magnitudes fainter than the ordinary white dwarfs. Also, two of the Balmer lines in absorption appear to be displaced toward the red by amounts which indicate the existence of an Einstein gravitational red shift corresponding to about 1000 km sec^{-1}. On the other hand LP 101–15 is red and shows an entirely new type of spectrum, which suggests that it may be a first representative of a type of red pygmy star which is 2.5 magnitudes fainter than the M-type dwarf stars of the main sequence.*

In our cooperative search for very compact stars and compact galaxies, Luyten succeeded in locating several blue pygmy stars (*1*) whose spectral characteristics have been previously reported (*2*).

Theoretically at least two types of pygmy stars appear possible, one being stars with radii and densities which are respectively of the order of 1000 km and 1000 tons cm^{-3} and which lie between those of ordinary white dwarfs, and the hypothetical ultimate neutron stars (*3*) that have radii of 10 km and densities of 10^{14} g cm^{-3}. Recently, Luyten (*4*) has found a most interesting binary LP 101–15/16 at right ascension 16^h 33.5^m and declination of $+57°15'$ (1950), the two components of which are respectively very blue and very red, representing the first pair of what are probably individual blue and red pygmy stars. Some of the characteristics of these usual new-type stars, including spectra which were obtained with the prime focus spectrograph of the 200-inch (508 cm) telescope, are as follows.

White Pygmy Star LP 101–16. The two stars, according to Luyten, move with 1.62 seconds of arc per year in position angle 319 degrees. The relative position of the star 16 relative to 15 is 22.3° and 25.7″ (1950). The yearly relative motion of star 15 relative to 16 is 0.042″ (± 0.018″) in 180°.

The apparent photographic magnitude (m_p) of star 16 is about 15.8. A tracing of its essentially featureless spectrum is shown in Fig. 1.

On close inspection, the spectrum appears to show very wide Balmer lines H_α and H_β in absorption, indicating a red shift of about 1000 km sec^{-1} and a line width of about 500 km/sec. These observations, if confirmed, suggest that the red shift observed is due to the Einstein effect and that the star under discussion is massive and small. A star with a mass equal to that of the sun, $M\odot = 2 \times 10^{33}$ g, and radius $r =$ 1000 km would give a red shift $\Delta\lambda/\lambda = 1.5 \times 10^{-3}$, corresponding to a symbolic Doppler shift of 450 km/sec. Its density would be 5×10^8 g cm^{-3}, about 1000 times that of an ordinary white dwarf. Therefore, LP 101–16 is most likely a hot star considerably smaller than the moon and of a density of the order of 10^9 g cm^{-3}. These estimates are in agreement with conclusions to be drawn from the star's spectral type and from its motion. Its proper motion of 1.62 sec yr^{-1} indeed indicates a distance of not more than 6 parsecs or 19 light years. At this distance, with $m_p = 15.8$, its absolute photographic magnitude is $M_p = 16.8$, which is four magnitudes fainter than M_p for ordinary white dwarfs. With this value for the absolute magnitude our star must thus be assigned a surface millions of times smaller and a radius thousands of times smaller than that of blue main-sequence stars of the spectral types A and B. Luyten also remarks that, with the distance given for LP 101–15/16 and a combined mass equal to $M\odot$, the period of revolution of our pair will be of the order of 2000 years, corresponding to an apparent orbital motion of 0.06 sec yr^{-1}. This is in satisfactory agreement with the observed relative motion of 0.042 sec yr^{-1}.

Red Pygmy Star LP 101–15. This second companion of our pair is most interesting. Its spectrum, of which a direct tracing is shown in Fig. 2, indicates that it is the first-known representative of a new class of absolutely very faint red stars. The spectrum shows a number of broad emission

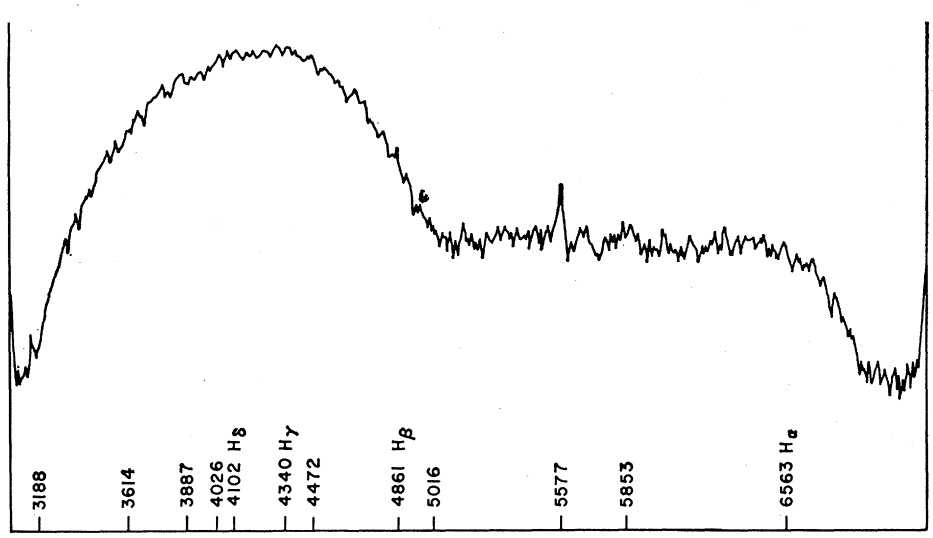

Fig. 1. Direct microphotometer tracing of the spectrum of the blue pygmy star LP 101–16, as obtained with the prime focus spectrograph of the 200-inch (508 cm) telescope on emulsion 103a-F at a dispersion of 400 Å mm^{-1}.

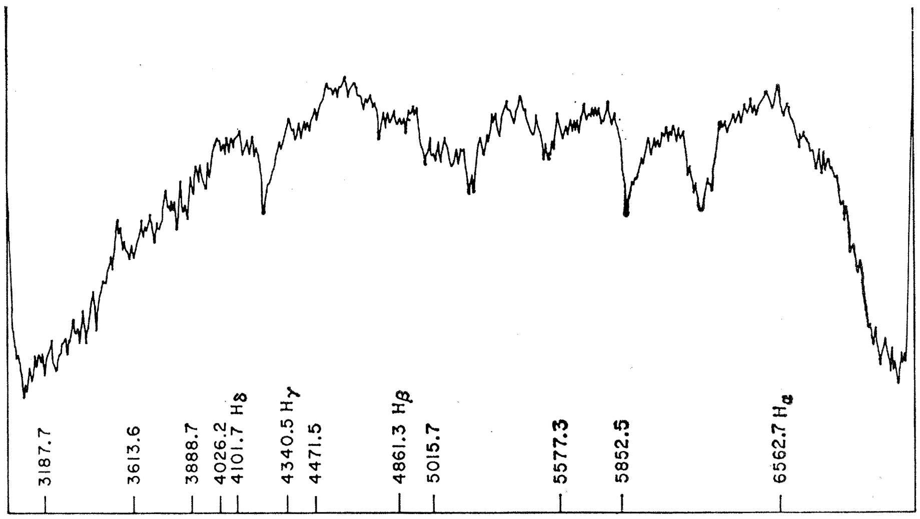

Fig. 2. Direct microphotometer tracing of the spectrum of the red pygmy star LP 101–15, as obtained with the prime focus spectrograph of the 200-inch (508 cm) telescope on emulsion 103a-F at a dispersion of 400 Å mm^{-1}.

bands, many sharp emission lines and a few distinct broad absorption lines. In view of the low sensitivity of the 103a–F emulsions in the green, some of the bright lines and bands in this part of the spectrum are of remarkable intensity.

Very distinct and deep absorption lines appear at 5890.2 Å and 4227.5 Å which must be identified with the lines λ5889.95 and 5895.92 of sodium and 4226.7 of calcium.

The Balmer lines H_α, H_β, H_γ, H_δ, and H_ϵ and the H and K lines of calcium appear in sharp emission. Unidentified remain the sharp emission lines at wavelengths equal to 6832.8, 6763.3, 6740.0, 6700.8, 6670.9, 5583, 3788, as well as broader and blended emission features at 3884.1, 6162.8 to 6287.8, and 3544.7.

None of the emission bands has been identified with certainty except the one at wavelength 4959.5 which is probably coincident with the band head of TiO at 4955. There remain, however, the features at 5175, 5208, 5445, 5487, and 5583 which might be the ZrO bands at 5185, 5439, 5456, and 5552. In this connection the sharp lines at 6832.8 and 6763.3 could be interpreted as being the ground level lines 6832 and 6762 of ZrI. If the presence of ZrO and Zr could be confirmed, this would suggest that LP 101–15 is the first dwarf representative of the interesting class of S-type stars in the spectra of whose giant members Merrill (*5*) first found the ZrO bands. No other dwarfs showing zirconium bands have been found.

A comparison of the spectrum of LP 101–15 with those of ordinary M dwarfs gave negative results. In particular its spectrum appears quite different from Wolf 47 (right ascension 0^h 57^m, declination $+61°51'$ Epoch 1900) which is an M5 dwarf of large proper motion (0.8 sec yr^{-1} in position angle 80°) and absolute visual magnitude $M_v \cong 12.6$. The apparent photographic magnitude of LP 101–16 is about + 15.3.

On the preliminary distance of 6 parsecs adopted in the preceding, its absolute magnitude therefore is of the order of + 16.3, making it visually about + 15.0 or 2.5 magnitudes below the main sequence.

From the discoveries of pygmy stars made during the past year it is to be expected that some still fainter (absolute) ones will be found to be nearer than any of the nearest stars. If the masses of these new stars are not all greatly inferior to that of the sun, they thus may contribute materially to the mass of the galaxy.

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References and Notes

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6. I thank Dr. A. H. Joy for assistance in the interpretation of the spectral features of the red pygmy star LP 101-15.

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Chondrules: Suggestion Concerning the Origin

Abstract. *The millimeter-sized, sometimes glassy spheroids called chondrules that occur abundantly in stony meteorites may have been produced by lightning in the primitive Laplacian-type nebula while earthy materials were condensing and collecting to form the asteroids and the terrestrial planets.*

Stony meteorites contain small silicate inclusions, called chondrules, of the order of a millimeter in dimension (Fig. 1). The shape of the chondrules varies from almost perfectly spherical droplets to highly distorted figures. The occurrence of glasses indicates a quick cooling from the molten state. In some meteorites chondrules constitute a major fraction of the bulk. Sorby (*1*) thought that they came from Sun in the form of a "fiery rain." Suess (*2*) has suggested that they represent the most primitive material in meteorites, condensed in protoplanets. Wood (*3, 4*), and Levin and Slonimskii (*5*) proposed that chondrules condensed directly from the gaseous solar nebula that is believed to have predated the planets. In the Levin and Slonimskii process, solid chondrules were formed directly, a process that is difficult to support mineralogically, while in Wood's process liquid droplets were condensed and quickly chilled. The massive occurrence of chondrules in most of all known meteorites, in spite of the great losses that such small particles must have sustained owing to subsequent heating and metamorphosis, proves that chondrule formation must have been a nearly universal process, basic to the development of stony meteorites and, presumably, the asteroids. That the bulk composition of the chondrules is very similar to that of the matrix supports this concept. Thus, chondrule formation must have been essentially omnipresent near the asteroid belt or near the asteroids at some early period in the formation of the solar system.

Specialized mechanisms for chondrule formation, such as volcanic action or even hypervelocity-impact spraying, appear inadequate on the grounds that an insufficient fraction of the basic material could be so treated. Direct condensation as droplets from a cooling solar gas requires vapor pressures of about 10^2 to 10^3 atmospheres (*4*), too high to be likely in a Laplace