THE EARLIEST INFRARED LIGHT CURVES

DORRIT HOFFLEIT
Yale University Observatory
New Haven, CT 06511

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Abstract

In 1932 John S. Hall, a graduate student at Yale, built a caesium-oxide photoelectric photometer giving an effective wavelength of about 8000Å. With this he observed the Cepheid zeta Gem. Later Dr. A. L. Bennett used the same equipment to observe many variables. His light curves for only AO Cas, S Sge, and RT Aur were published. When Bennett was called for war work by the Navy he left behind observations on 30 long period variables and a few others of short period. As he did not return to astronomy after the war this wealth of observations has never been published.

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Neglected and now forgotten, the first photoelectric determination of an infrared light curve of a variable star was probably that obtained in 1932 by Yale graduate student John S. Hall (now Director Emeritus of the Lowell Observatory at Flagstaff, Arizona) for the Cepheid zeta Geminorum (Hall 1932, 1934). This was at a time when Joel Stebbins and associates in America and other astronomers in Europe had already been measuring variables with photocells at visual and photographic wave lengths. It was a decade before Stebbins and Whitford (1943) initiated their six-color photoelectric system.

John Hall experimented with the use of a caesium oxide photoelectric cell, designing his own photometer. He found it would work well only when cooled to -40°C, and to keep it that cool he cleverly mounted it inside a thermos bottle to protect it from heat and keep it dry chemically. The color curve of the cell ranged from under 3000 to over 12000Å, with maximum sensitivity at about 7500Å and a secondary at 3000Å. With the use of different filters he was able to derive color indices.

The equipment was mounted at the eye-end of the 15-inch Loomis Memorial Telescope. This was a polar telescope with a 10-inch visual refractor mounted parallel to the 15-inch photographic. A 30-inch flat mirror at the base of the tube (the objective end) was mounted on an equatorial drive and directed the starlight up both tubes. That fact that the eye-end, at the top of the tower, was inside a closed room where the heavy photoelectric equipment could remain in a fixed position for all observations made this telescope particularly advantageous for Hall's purposes.

For calibrating his instrument Hall made measurements of the Pleiades. Comparing the magnitudes determined without filter with those using the filters giving effective wavelengths of 8100 and 8800Å, he determined (non-standard) red indices for 347 stars brighter than visual magnitude 5.0 (Hall 1934). These compared well with Bottlinger's (1923) indices obtained with a blue sensitive cell used with blue and yellow filters.

On zeta Geminorum Hall acquired measures on 33 nights between January 28 and November 27, 1932. He compared his light curve at effective wavelength 7400Å with Guthnick's (1921) at 4500Å for 1919-20

and Luizet's (Hertzsprung 1929) at 5500Å for 1898-1918. The amplitudes of the three curves are 0.40 magnitude in the red, 0.55 in the visual, and 0.81 in the blue. At successive wavelengths the observed maxima fall later, the infrared falling 0.024 period later than the visual.

Hall was granted his Ph.D. in 1933, for his thesis on **Photoelectric Photometry in the Infra-Red with the Loomis Telescope.** After leaving Yale he went first to Swarthmore, then to his alma mater, Amherst. From similar observations in the infrared (8660Å) carried out at both of those observatories, he published a light curve of Algol which he compared with a blue photoelectric curve obtained by Stebbins (Hall 1939). Again the amplitude in blue was appreciably greater than that in red.

Between 1932 and 1940 Arthur L. Bennett used Hall's equipment both for determining color indices for 254 stars of all spectral classes with visual magnitudes between 5th and 9th magnitude (Bennett 1937) and also for obtaining infrared light curves for variable stars. Although he observed some 30 long period variable stars (Schlesinger 1937-40) and a few of other types, he published his light curves for only three: AO Cas (Bennett 1938), S Sge (Bennett 1939), and RT Aur (Bennett 1941). Table I summarizes both Hall's and Bennett's infrared results on the variable stars and compares them with the data given in the most recently available **General Catalogue of Variable Stars** (Kholopov et al. 1985), the **Bright Star Catalogue** (Hoffleit 1982), or other sources. The effective wavelengths were not uniform for all the variables and are noted in the bottom line. It may be pointed out that none of these coincides exactly with the modern standards of Stebbins and Whitford (1943), whose R is for effective wavelength 7190Å and I for 10300Å.

In 1940 Bennett was called away for war work for the Navy, not to return to astronomy. The bulk of his observations on variable stars has remained unpublished, although he had converted them to magnitudes. Comprising 20 note books for the years 1933 through 1940, they are stored in the Archives of the Yale University Library. I sampled these for the two variables, W And (6.7-14.6v) and R Lyn (7.2-14.3v), variables with S-type spectra and periods of 395.93 and 378.75 days, respectively. The observations are plotted in the upper parts of Figures 1 and 2; the middle curves are the visual magnitudes made by AAVSO observers in the same time interval (Campbell 1936-39). The lowest curves in the figures represent the color indices, infrared minus visual, which range from slightly less than four to over eight magnitudes. These estimates are comparable with results of a somewhat earlier similar investigation by Hetzler (1936), who also compared his observations at about 8500Å with visual AAVSO curves. He found infrared minus visual indices from 5 at maximum to 8 near minimum for W And and 3 to 6 for R Lyn.

Already in his annual report for 1935-36 Schlesinger wrote, "The useful way in which photoelectric cells have been employed on the Loomis Telescope since 1930, first by Mr. Hall and now by Mr. Bennett, is a source of satisfaction to all the friends of the observatory." Later, in 1940, Ejnar Hertzsprung was to write Schlesinger, "Though I do not know if Dr. Arthur L. Bennett is still active at your observatory I want to put down a few remarks concerning his interesting work on color indices observed photoelectrically with the Loomis Telescope. The fact that Dr. Bennett has obtained good results down to nearly 9th visual magnitude opens possibilities for further applications of this promising method." Alas! World War II put an end to this fruitful pioneering research at Yale.

Bennett's observations with the Hall photometer at the Loomis Telescope were the last infrared observations carried out at Yale. After World War II the telescope was refurbished for an entirely different project (D. Brouwer's investigations into the variation of

the pole of rotation of the earth) for photographing exclusively the polar region. From July, 1946, until June, 1953, Dr. Joseph Ashbrook made both visual and photographic estimates of variable stars at Yale, but with other instruments and none photoelectrically or at red wavelengths. Still later, Dr. Harlan J. Smith used the 10-inch Butler refractor at Yale for photoelectric observations of short period variables, but only in **UBV**.

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TABLE I

Variable Stars With Early IR Light Curves

Name	zeta Gem	Algol	AO Cas	S Sge	RT Aur
BS	2650	936	65	7609	2332
Max	3.62V	2.12V	5.96B, 6.07V	5.79B, 5.28V	5.02V
Min	4.18	3.40	6.11 6.24	7.05 6.04	5.82
Type	Cep	EA	Ell	Cep	Cep
Period (days)	10.15	2.87	3.52	8.38	3.73
Spectra	F7-G3	B8+B8	O9+O9	F6-G5	F4-G1
PEP amplitudes:					
red	0.40	0.9	0.143	0.459	0.521
visual	0.56	1.28	0.17	0.76	0.87
blue	0.81	1.25	0.15	1.26	1.18
λEff	7400	8660	8000	8000	7500

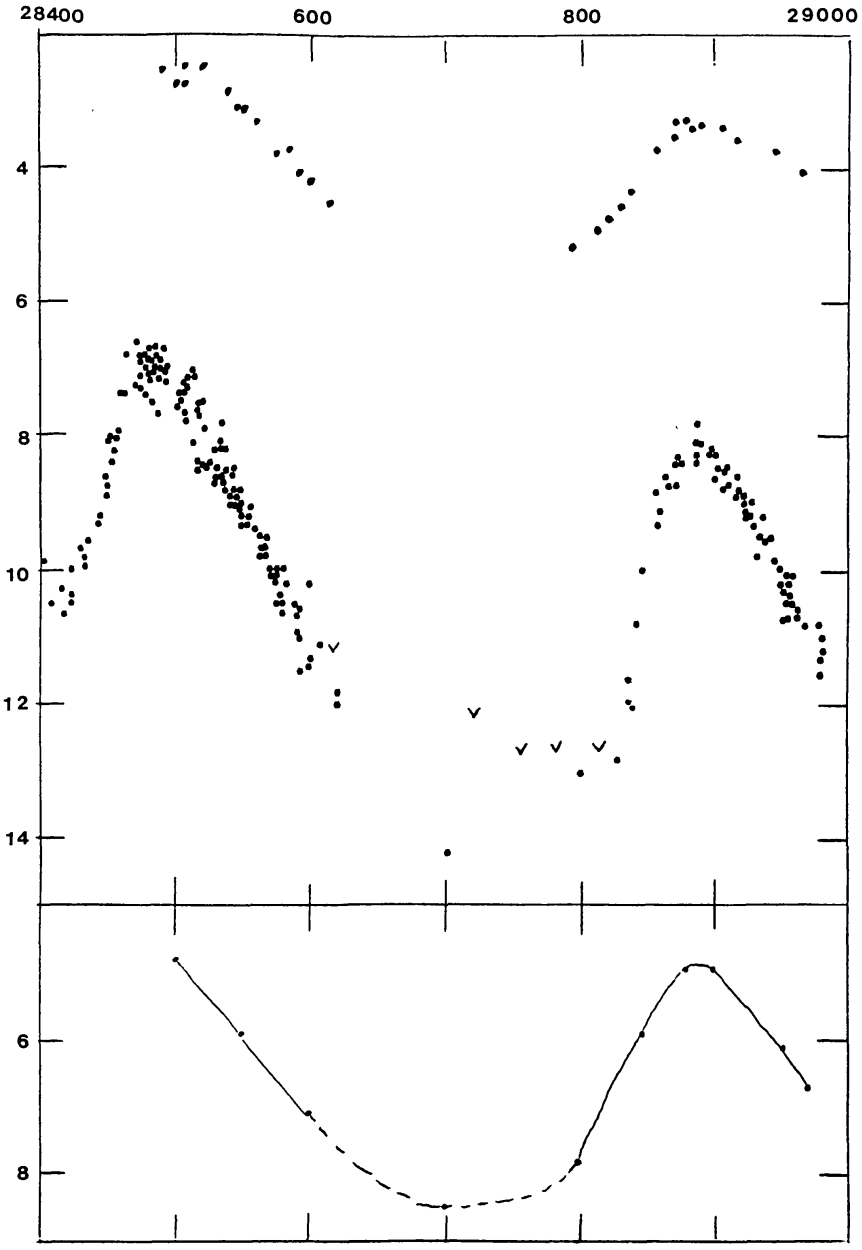

Figure 1. Light and color curves for W And. Upper plot, Bennett's infrared (IR) observations; middle plot, corresponding AAVSO visual observations; bottom plot, color curve, visual minus IR. Ordinates are magnitudes, abscissae JD-2400000.

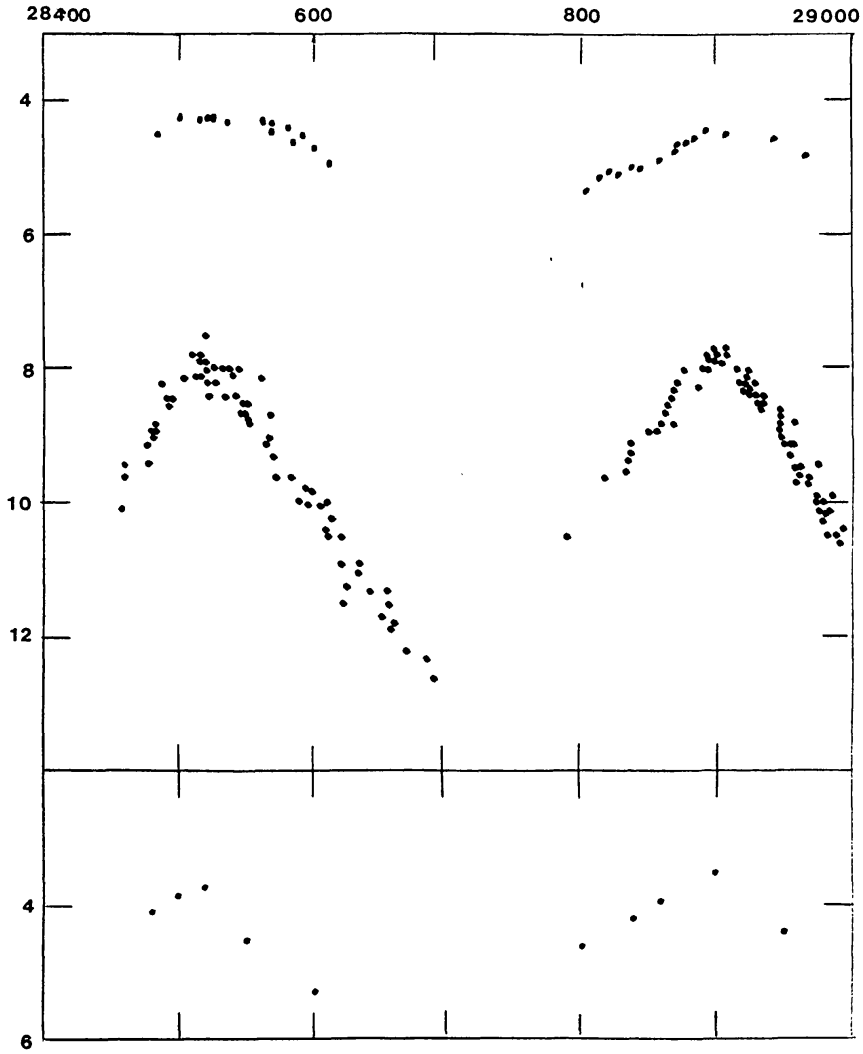

Figure 2. Light and color curves for R Lyn. Upper plot, Bennett's IR observations; middle plot, corresponding AAVSO visual observations; bottom plot, visual minus IR.