VX SAGITTARII: A VARIABLE AT MANY WAVELENGTHS

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I first observed VX Sagittarii while blinking two plates of the region taken at Nantucket. The star was originally discovered by Henrietta Leavitt in 1904, and has been on the AAVSO observing program since 1935. I was originally interested in comparing its photographic and visual light curves. VX Sagittarii is a semiregular variable with an extremely long period.

THE VISUAL AND PHOTOGRAPHIC LIGHT CURVES

The visual data were provided by the AAVSO (Mayall, 1970) in the form of a computer plot of ten-day mean magnitude estimates. The computer program for this was written by Barbara Welther of the Smithsonian Astrophysical Observatory. Similar light curves have been computed for a number of stars on the AAVSO program. For my photographic estimates I used the NA (Nantucket) plates for JD 36,000 to the present (1957-1973) and a number of Harvard B plates and RB-RH plates for JD 25,000-34,000 (1929-1949).

The technique used for estimating the photographic magnitude of the star on the plates was the standard one of using a nearby sequence of comparison stars. I chose a sequence of seven nearby stars, with magnitude intervals averaging about $0^{m}.8$. I divided each interval into ten subdivisions and estimated the brightness of the variable relative to the comparison stars on each plate.

To convert these estimates into magnitudes, I simply had to find the magnitudes of the stars in the comparison sequence. Then I could draw up a table of magnitude values for the estimates in my comparison sequence, and, when plotting the light curve, could simply read the magnitude off the table. I estimated the brightness of the four brightest comparison stars relative to the stars in Harvard Selected Area 158, and used a nearby sequence of fainter stars for the fainter three. The variable never appeared brighter than $8^{m}.8$, and never much fainter than $12^{m}.0$.

At this point, things were complicated by the fact that VX Sagittarii has a visual companion so close that the images were blended on the Nantucket plates. On the B plates, with a slightly larger scale, the stars were separable at minimum. This meant that I had estimated the combined magnitude of the two stars, rather than the magnitude of VX alone. I estimated the magnitude of the companion on several plates to be $12^{m}.1$. I found the magnitude of VX corresponding to each combined magnitude by converting to luminosities and finding the magnitude corresponding to the sum of their luminosities. When I had completed this table, I could finally, for each value of the estimated combined magnitude, read off the corrected value for the magnitude of VX Sagittarii.

It is important to consider the effect of these corrections on the accuracy of the estimated magnitudes. My original estimates were accurate to about ±1-2 sub-intervals. Translated into magnitudes, this became scatter of about $\pm 0^{m}.1$-$0^{m}.2$. For the brighter values of m_{VX}, the correction for the companion did not have an important effect, since the variable was so much brighter ($9^{m}.0$) than the companion ($12^{m}.1$) that the contribution of the companion was negligible. Here, subtracting the effect of the companion simply added $0^{m}.1$ to the photographic apparent magnitude of the variable. For example, if the combined magnitude was $9^{m}.7$, the magnitude of VX was $9^{m}.8$. When the magnitude of the variable decreased to around 11th magnitude, however, the effect of the companion became much more important. When the estimated combined magnitude fell to $12^{m}.0$, it was clear that the companion was contributing most of the light, so that a change of $1^{m}.0$ in m_{VX} would change the combined magnitude by only $0^{m}.1$ ($11^{m}.9$ to $12^{m}.0$). This accounts for the fact that there is much more scatter - $1^{m}.5$, in fact - at minimum on the light curve than near maximum.

TABLE I

MAGNITUDES OF VX SGR ALONE AND COMBINED WITH COMPANION

Combined Magnitude	Magnitude of VX
9.0	9.1
10.0	10.1
11.0	11.5
11.5	12.5
11.8	13.5
11.9	14.0
12.0	15.0
12.1	<16.0

In fact, the amount of scatter in the photographic estimates is somewhat comparable to the scatter in the visual observations. The visual light curve is the result of means of observations taken by many different observers. Where a point is the mean of a large number of observations, the value is well verified. However, certain parts of the curve are drawn in on the basis of one or two observations in a ten-day interval, which may not necessarily be as reliable. For example, the sharp peak in the visual light curve at JD 28,840-60 (see Fig. 1) is due to only one observation per ten-day interval, and the sharp dip at JD 30,400 is the result of only one observation.

On the other hand, it is interesting to note that, at JD 36,000-100, the sudden sharp variation in the visual light curve is matched by a similar fluctuation in the photographic magnitude. At JD 36,020, the mean of 8 visual observations was $10^{m}.0$, and at JD 36,040, the mean of 5 visual observations was $9^{m}.6$, which seems to indicate a change of at least $0^{m}.4$. While the scatter in the photographic magnitude is fairly large when $m_{VX} \leq 11^{m}.0$, as discussed above, the points do seem to indicate a real variation. Of course, we cannot say definitely that there is a sudden change in magnitude taking place on the basis of this data, and, in any case, this is only one event. However, perhaps we cannot entirely rule out the possibility that there may be occasional sudden variations in the light curve over time intervals on the order of tens of days.

Superposing the visual and photographic light curves, one notices that the photographic amplitude is greater than the visual. That is, the difference between m_V and m_{pg} is less at maximum than it is at minimum. The color curve is redder at minimum, and bluer at maximum. This is what one would expect from a star as red as VX Sagittarii, of spectral class M4. When the star is at minimum, with a surface temperature of, say about 2000°K, the fall-off between the blue and visual bands is sharper than the fall-off for a maximum temperature of about 3000°K. This is because at the cooler temperature the radiation peaks at a longer wavelength, and the blue and visual bands fall on a steeper part of the black-body curve. This greater fall-off in intensity explains the greater amplitude of the photographic (blue) variation. Figure 2 is a schematic diagram of this phenomenon.

Kukarkin et al. (1969&71) classify VX Sagittarii as SRb, that is, one of a class of "....semiregular variable giants of late spectral class with a poorly expressed periodicity". They give a period of 732 days, which fits the observations reasonably well. A given cycle may vary by as much as ±100 days from this mean period, especially a lower-amplitude cycle where it is very hard to determine the point of actual minimum light.

One readily notices the variation in the amplitude of the cycles. Looking at the visual light curve, we see an amplitude of from $5^{m}_{.}0$ to about $1^{m}_{.}0$. In fact, there seems to be a trend for a high-amplitude cycle to be followed by cycles of gradually decreasing amplitude until they fall off to cycles of around 1 to 2 magnitudes, and then for the amplitude to build up again. It can be seen from Figure 3 that this pattern repeats itself about every five or six cycles, or every 3,500 days. This may be some kind of a beat period, the variation in amplitude being sinusoidal in shape. It would be interesting to investigate more cycles of the star to see if this amplitude variation continues in a regular manner. Future AAVSO observations will continue the visual light curve and provide more information on the amplitude variation of VX.

VARIABILITY AT LONGER WAVELENGTHS

Recently, VX Sagittarii has been observed as a variable source at longer wavelengths. It has been found to emit excess infrared radiation, and, in the last five years, OH and H_2O microwave emission has also been detected.

The infrared emission of VX Sagittarii has been observed at six wavelengths by Bechis et al. (1973a). Their light curves at two wavelengths for the period 1969-1972 are given in Figure 4. There is a phase delay of 0.1-0.2 (of the period) of the infrared curve with respect to the visual. This is a commonly observed phenomenon in long-period red variable stars. The decreasing amplitude of the variations with increasing wavelength (a consistent trend over the six wavelengths) is at least partly due to the decreased temperature sensitivity of the radiation in this part of the black-body curve. The authors conclude that the excess infrared emission is caused by a dust shell around each star which absorbs near infrared (shorter-wavelength) light emitted by the star and reemits it at about 3-10μ.

Emission lines of around 18cm wavelength, due to transitions between different states of the OH molecule, have been observed in a number of infrared stars, including VX Sag. Bechis et al. (1973a) also observed variations in the flux of the OH emission lines from VX in 1969-1972. This variation peaked at about the same time as the infrared variation. More recently still, Bechis (1973b) has observed a similar variation in the strength of the H_2O emission lines of VX. It has been suggested that the OH and H_2O emission is produced in the cool circumstellar dust region by a maser mechanism. The correlation of this emission with the infrared suggests that the maser emission may be pumped by infrared radiation from the star.

The observed OH and H_2O lines also exhibit a Doppler shift, indicating the velocity (relative to the observer) of the material producing the emission. The OH lines are double, giving two velocity values. The velocity of the H_2O-emitting region seems to fall somewhere between these two velocities. This data invites the construction of models to explain it. Different models, suggesting for emission line sources expanding gas shells, stationary shells, clumps of gas in rings, or shells with shock fronts passing through them, have been proposed. In one model, Dickinson and Chaisson (1973) suggest that a low-velocity line could be produced by stationary gas ahead of a shock front (in the outer layers of the shell), and a high-velocity line could be formed in the rapidly moving gas behind the shock front. Since H_2O emission needs a higher energy input than OH, it would be more likely to occur in a hotter region nearer the star, with an intermediate velocity. The details of a model for the observed OH and H_2O emission lines for stars like VX Sagittarii, however, have yet to be worked out.

One may well ask: What type of star would have a peculiar expanding shell such as this? While the general opinion is that VX Sagittarii and similar stars are evolved red supergiants, their general characteristics, and therefore, positions on the Hertzsprung-Russell diagram (luminosity-color diagram), are not so different from those predicted for newly forming stars. Determination of the chemical composition from the spectrum of such stars will help decide the question of age. Indeed, we may well look forward to further data providing answers to the many questions raised by previous observations of VX Sagittarii.

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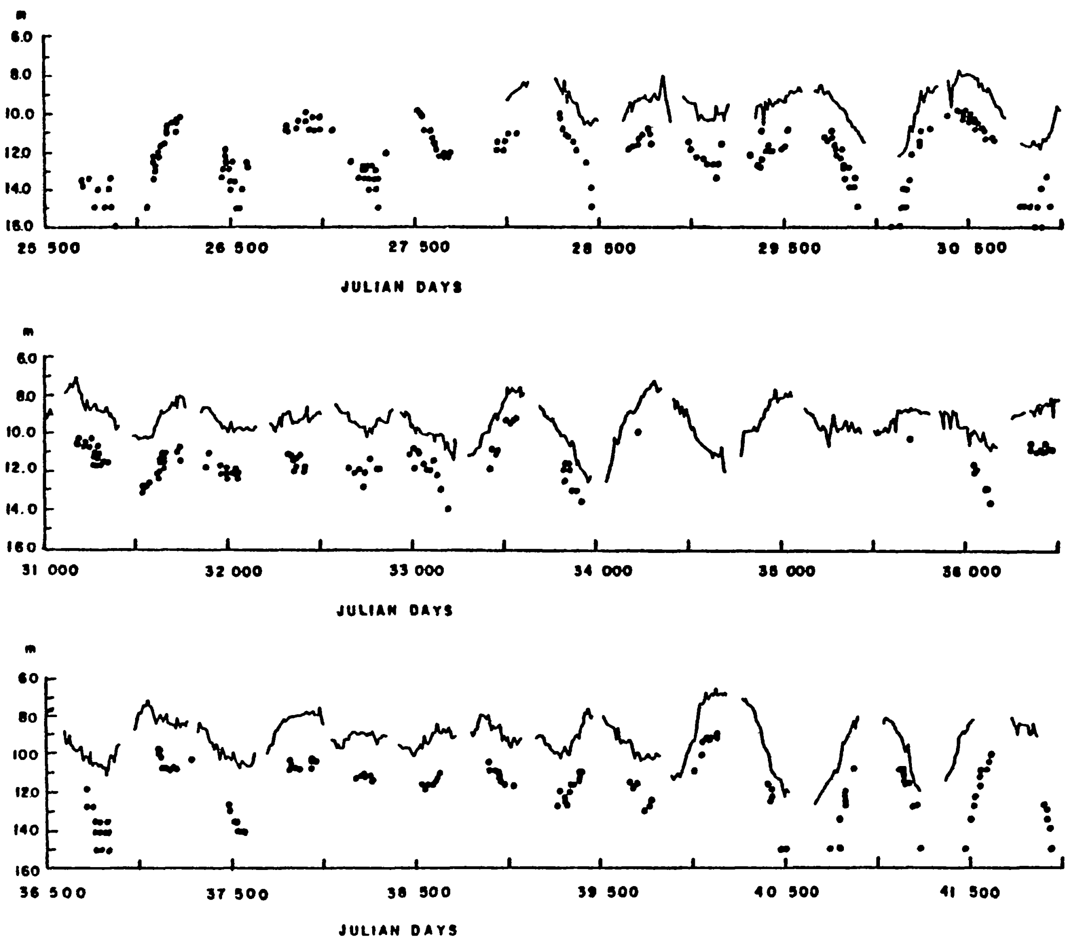

Figure 1: LIGHT CURVE OF VX SAGITTARII. The upper curve is the 10-day mean visual light curve (courtesy of AAVSO), and the points are the estimated photographic magnitudes.

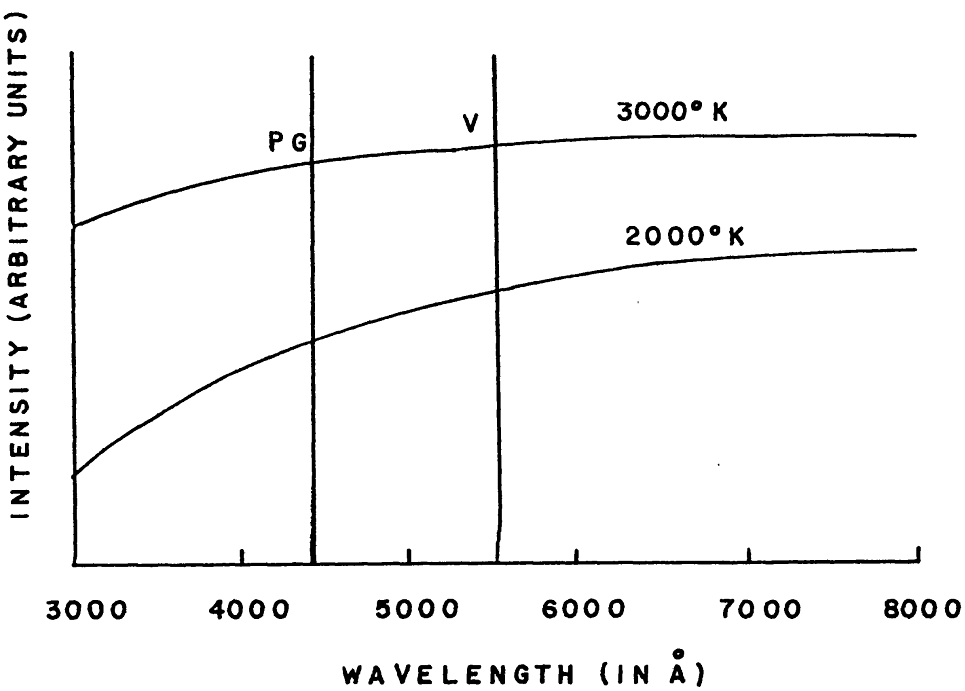

Figure 2. Difference in fall-off between the blue (pg) and visual (V) bands for the black-body curve of a red star. The intensity is in logarithmic units.

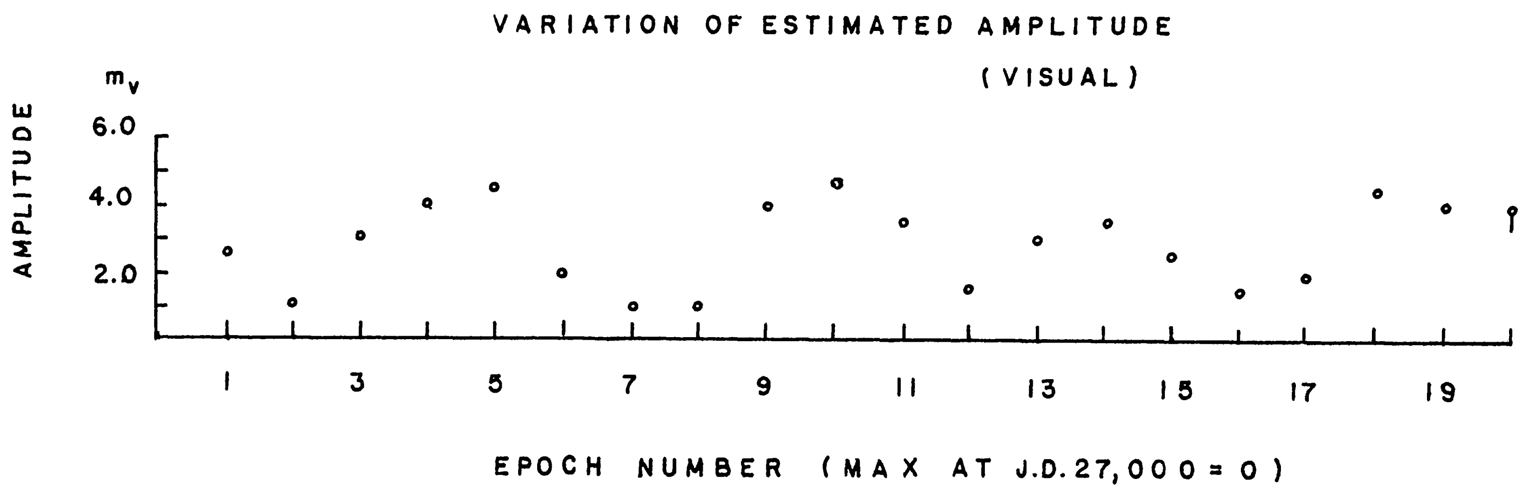

Figure 3. Estimated visual amplitude of each cycle (difference between maximum and minimum) plotted against the epoch, starting from epoch 0 at JD 27,500.

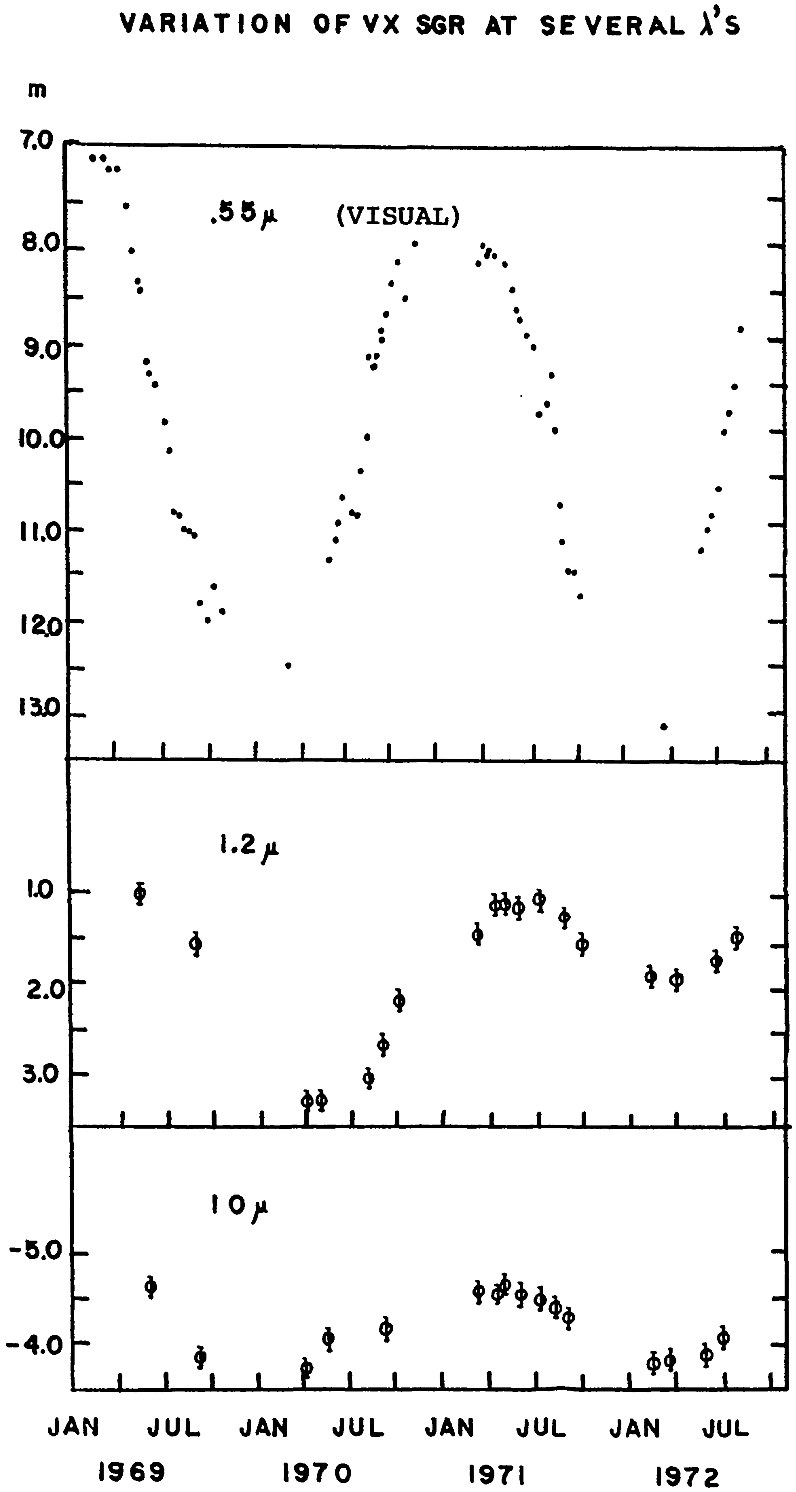

Figure 4. Variation of VX Sgr at several wavelengths. The light curves at .55μ, 1.2μ, and 10μ are compared for 1969-1972. The infrared data are from Bechis et al. (1973a); the visual from the AAVSO.