SS CYGNI

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The term, "catacylsmic" refers to three classes of eruptive variables: dwarf novae, novae and supernovae, arranged in order of increasing integrated energy of outbursts. U Geminorum type stars are dwarf novae with integrated energies in the range of 10^{38} to 10^{39} ergs.(Kraft 1963). In general they have long intervals of apparent quiescence at minimum with sudden rises to maximum. The range of outbursts is between 2 to 6 magnitudes, depending upon the star. It is a well established fact that most of the members of this group are spectroscopic binaries with short periods, in the order of a few hours(Kraft, Luyten 1965).

SS Cygni is the brightest and the most observed U Geminorum type variable. Its variability was discovered in 1896 by L.D. Wells of Harvard Observatory. Since then it has been so closely observed that not one of its outbursts has passed undetected. In general, the star is usually faint at minimum at around 12th magnitude. It brightens about 3.5 to 4 magnitudes every 50.0 days, in the average; although the individual intervals between maxima may vary from 20 to 100 days. It stays at maximum about 10 to 20 days and then goes back to its "quiet" state. Statistical studies of Sterne and Campbell(1934)have shown that the frequency of distribution of the cycles follow a law of errors and that one cannot make exact predictions of dates of maxima and minima.

In 1934 Leon Campbell collected all the existing observational data on this variable and did an extensive study of the characteristics and peculiarities of its light curve(Campbell 1934). These findings still hold for more recent observations and will be pointed out below.

Figures 1 and 2 show the AAVSO light curve of SS Cygni from discovery till 1974. Particularly the data till 1934 contain contributions of several other organizations(Campbell 1934)and the more recent light curve includes observations of Astronomiske Selskab kindly provided by Ole Klinting, and observations by members from Werkgroep Veranderlijke(Reports of Kapteyn Astronomical Laboratory). Figure 2 is the light curve of the daily means of the observations,computerized as of 1971. Both figures show clearly that the rise to maximum is generally quite rapid, however this by no means is uniform. The light curve of the outbursts is at times quite flat for several days, then it gradually slopes until more rapid decline sets in(see max 490, 507, 514, 556)and at times a suggestion of double max with a slight dip as secondary minimum occurs(see max 497, 533, 551). At times there is a slight brightening before the actual maximum(see max 490, 504)and at other times there is a change from a steep slope to a more gradual one during the decline(see max 485, 489, 492, 493, 528, 533, 535, 551, 555).

The minimum is the star's quiescent time. At times the light curve is quite flat(see intervals between maxima 546 and 549, 559 and 560). At other times the curve is quite irregular, with occasional rises in magnitude, preceding regular max of at least 10.0 mag or above(see interval between 483 - 495, 556 - 558).

Campbell(1934)by intercomparing and superposing the individual

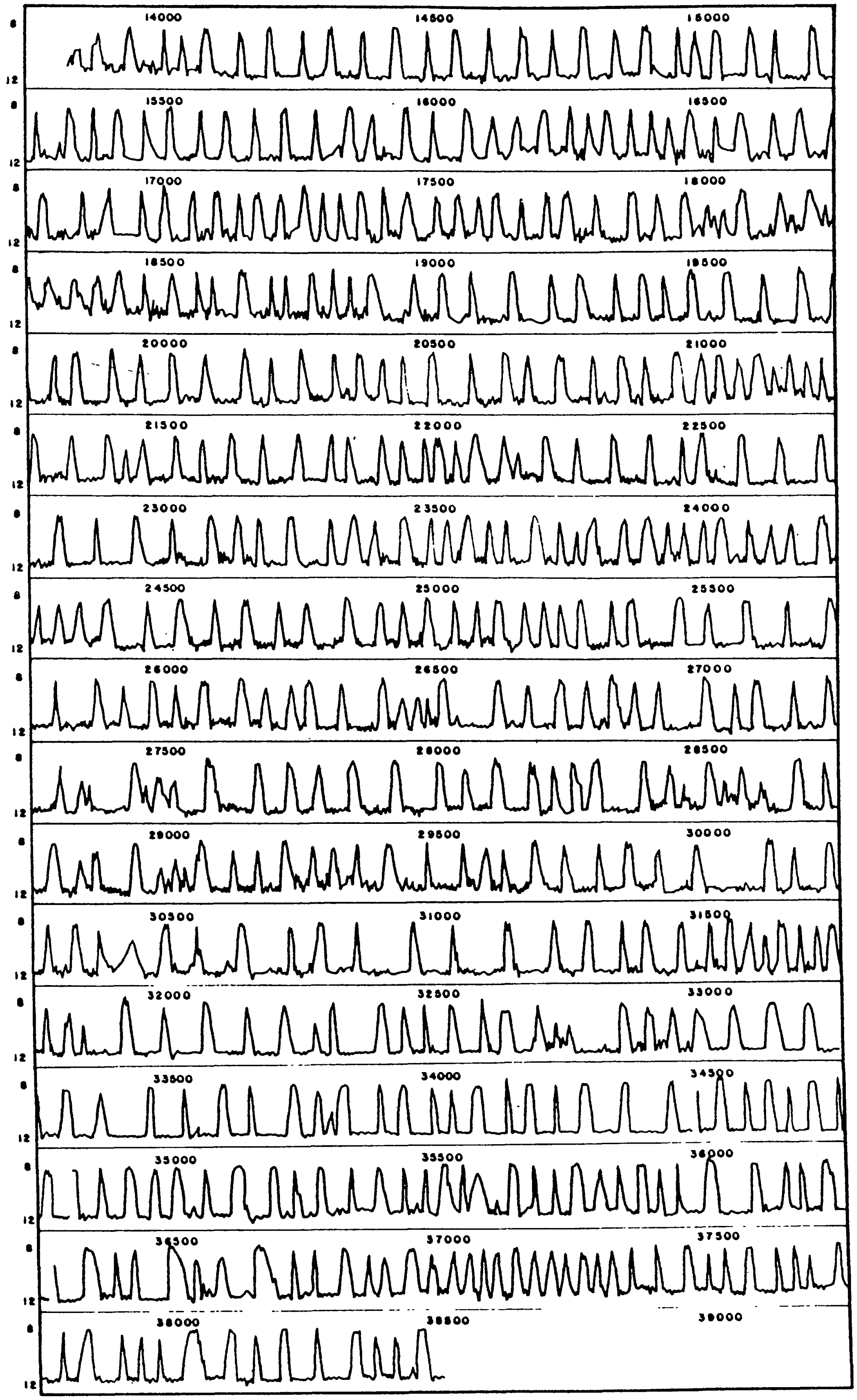

Figure 1. AAVSO light curve of SS Cygni from 1896 to 1964.

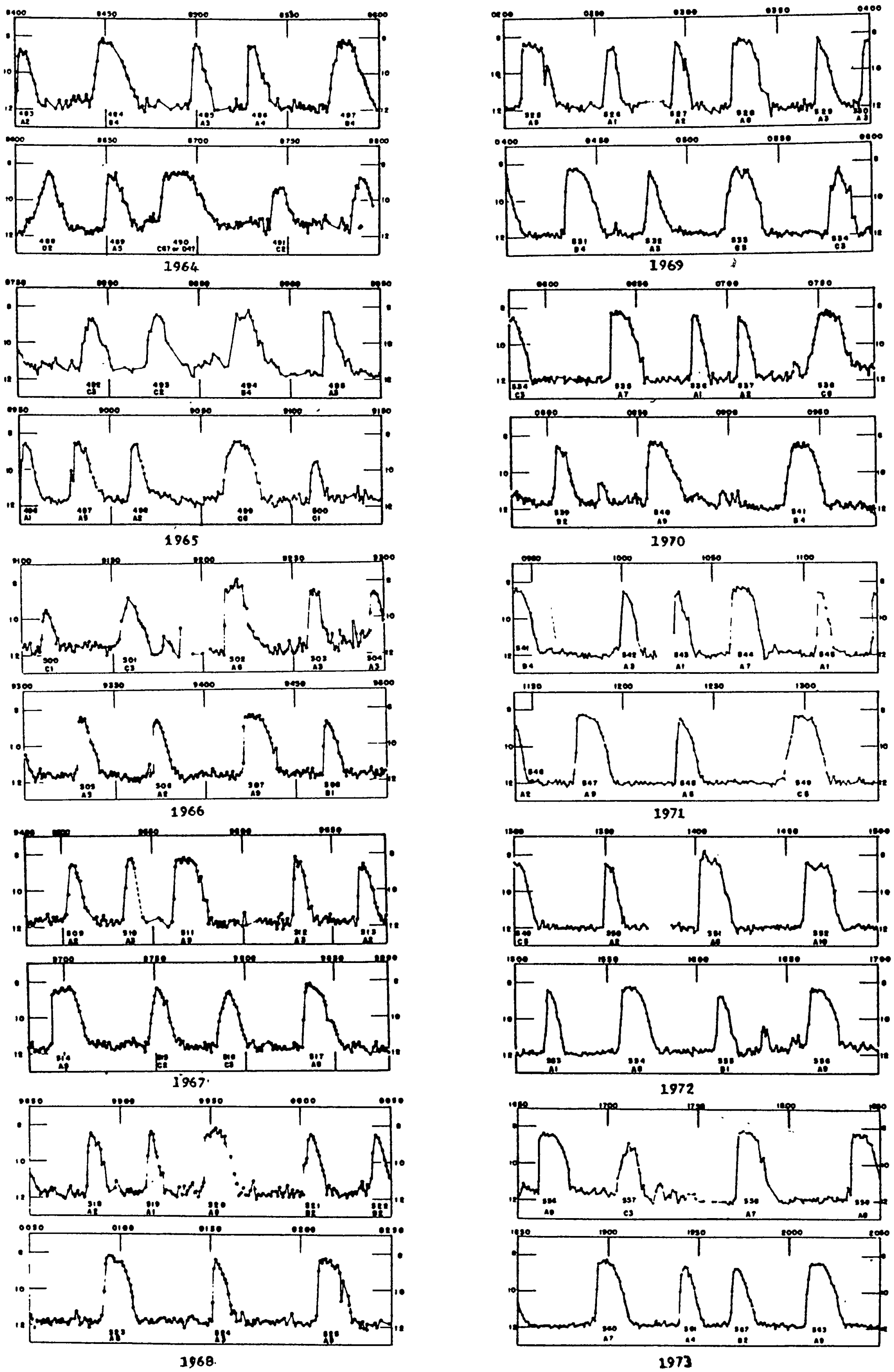

Figure 2. AAVSO light curve of daily means of SS Cygni from 1964 to 1974.

maxima concluded that the curves can be classified into four groups according to the steepness of the rise and the width at 10.0 magnitude phase. Thus, depending on the rapidity of the rise four classes were established: most rapid, Class A; slightly slower increase in magnitude, Class B; a moderately slow rise, Class C; and extremely slow rise, Class D. To distinguish those of the same class with increasing width, numerical subdivisions were established, where the smaller the subdivision, the narrower was the curve of the class. Figure 2 shows the individual outbursts since 1964 consecutively numbered, classified and subdivided, using Campbell's classification. Every maximum since discovery has been numbered, classified, and subdivided as in Figure 2. The data up to 1934 have been published in the Annals of Harvard College Observatory (Campbell 1934). Following data have been published in Popular Astronomy under Variable Star Notes and since 1951 in the third issue of each volume of the Royal Astronomical Society of Canada each year, again under the same title as before.

The existing data indicate that Class A is the prevailing class, up to date, i.e. most of the maxima show a rapid rise.

Several correlations were found to exist from the statistical study of Sterne and Campbell (1934). The analysis on 266 cycles indicated that there are positive correlations between the length of a cycle and the height of the following maximum; the height of a maximum and the length of the following cycles; the length of two consecutive cycles; the width of maximum and the length of the following cycle; the height of two consecutive maxima; the width and height of a maximum. A negative correlation was found between the width of a maximum and the width of the following maximum.

Spectroscopically, the studies of this star have been limited due to the peculiar variable character of its spectrum and its faintness, except when it is at maximum. Early spectroscopic investigations had been carried out by Fleming (1912), Adams and Joy (1922), Elvey and Babcock (1940, 1943) and Hinderer (1949). However, it was the observations of Joy (1956) that revealed a very interesting feature about this star. Variations of radial velocities derived from weak, narrow absorption lines and from wide, strong emission lines, during minimum indicated that the variable was a spectroscopic binary consisting of a dwarf G and a subdwarf B spectral class components. The observations revealed a period of $0\overset{d}{.}276244$ (6^h38^m), for the system. No eclipses were observed (Grant 1955) which led to the conclusion that the inclination of the orbit to the tangential plane to be small, i.e. the plane of the orbit must be considerably inclined to the line of sight. Recent observations of Holm and Gallagher (1974) in the far ultraviolet with the Orbiting Astronomical Observatory-2 (OAO-2) indicated $30\overset{\circ}{.}3$ to be the lower limit for the inclination of the orbit for this system.

In view of Joy's (1956) discovery of the duplicity of the system, the anamolies in the earlier observations became clear. Spectroscopically, the system alternates between the spectrum of the dwarf G during minimum and the subdwarf B component during maximum. At minimum the absorption spectrum is classified to be dG5 (Elvey and Babcock 1943) with a corresponding color temperature of 5520°K. It is veiled by blue, faint continuum and strong emission spectrum with wide lines, (20Å or more), of hydrogen and fainter bright lines of HeI and CaII (Joy 1956) and a broad bright line of HeII at λ4686 (Hinderer 1949). The K line of CaII is occasionally doubled in emission. This feature has been attributed to a rotating ring or shell of material surrounding the hot star (Walker and Chincarini 1968).

As the star rises to maximum, the spectrum changes progressively. The underlying continuum strengthens and the maximum intensity shifts toward the violet. The spectrum is that of a subdwarf B star with a color temperature corresponding to 12000°K. The emission lines of minimum light get weaker. The line of HeII 4686 slowly fades and at maximum it vanishes. Broad shallow absorption lines of hydrogen appear along with the doubled K line of CaII in absorption. The spectrum varies depending upon the type of maxima. The variation is particularly displayed in the duration of the absorption lines of hydrogen where short, peaked maxima have briefer displays (Gaposchkin 1964).

Photoelectrically, rapid irregular fluctuations of brightness during minimum have been observed by Grant (1955). They have amplitudes in the order of 0.2 mag, with periods less than 10 minutes. At times a wave of 2-3 hour period is superimposed on these fluctuations, with a similar amplitude, and at times flarelike increases with amplitudes of 0.3 - 0.4 mag are recorded. Grant attributed these rapid fluctuations to the intensity fluctuations of the emission lines.

During the simultaneous photometric and spectroscopic observations of Walker and Chincarini (1968) the variable again exhibited rapid, irregular variations at minimum in the scans of spectra between λ4266 and λ3632 and photoelectrically in the U band. The variations appeared to be in phase in all three regions of the spectra. They concluded those rapid variations of light during minimum to be the result of changes of brightness in the continuum belonging to the B component. These could be attributed either to the changes of effective temperature of the hot component or to the turning on and off of another source of continuous emission.

In recent years this variable has been studied in the regions beyond the visual spectrum.

During the sounding-rocket flight on 30 March 1973, soft X-ray emission at 0.25 keV has been detected from this U-Geminorum variable when it was at its maximum (Rappaport et al 1974). With a possible exception of η Carinae, this is the only stellar source emitting soft X-ray with energy below 0.5 keV. All previous soft X-ray observations of this region (Coleman et al 1971; Garmire and Riegler 1972; Burginyon et al 1973; Bleeker et al 1972; Borken et al 1972) have been carried on during minimum light of SS Cygni and have failed to detect soft X-ray emission due to the low luminosity of the source, at the time.

Explosive nuclear burning of hydrogen-rich material, accreting onto the surface of a collapsed or degenerate star, is generally assumed to be the cause of outbursts of dwarf novae. If there is accretion of this kind, the system may be expected to be an X-ray source. However SS Cygni is not listed as an X-ray source in the Uhuru Catalog (Giacconi et al 1972) which was formulated by scanning almost the entire sky for X-ray sources with an X-ray detector on Small Astronomy Satellite, Explorer 42, named Uhuru -- meaning Freedom in Swahili. The fact that Rappaport and his colleagues detected soft X-ray emission may indicate that the radiation emitted is in the lower energy region than what Uhuru can detect (Holm and Gallagher 1974).

Observations in the far ultraviolet region obtained by OAO-2 at maximum, minimum and during rise to maximum revealed that the ultraviolet radiation from SS Cygni is approximately in phase with the visual outbursts. Observations indicated effective temperature $T_e \approx 19200^{\circ}K \pm 3000^{\circ}$ at maximum which is in reasonably good agreement with ground base observations of Walker and Chincarini(1968) of $T_e = 16000^{\circ}K$. Holm and Gallagher determined the mass of the hot component, the sdB, to be no larger than 1.4 $M_{\odot}$ and the distance of the system to be between 140 and 330 parsecs.

Although this fascinating system has been continuously observed in the visual since discovery and studied in various spectrum ranges, the question still exists on the real cause of the outbursts. Kraft(1962)believes that the late type cool component fills its lobes of inner Lagrangian surface - a stability limit of two components - and ejects material which forms a ring or a disk around the hot, blue component. Szkody (1974)who has made studies of this system in the infrared and correlated observations from soft X-ray to the IR regions also suggests the presence of a hot disk. He believes the onset of the outburst to be caused by rapid heating of the ring or disk by a shock wave to a temperature of $4\times10^{5\circ}K$ and emitting energy by thermal bremsstrahlung - a process in which a free electron emits a photon as it is accelerated by the electric field of an ion.

In order to understand the "real" nature and evolutionary sequence of this and other U Gem variables, observations must go on in the X-ray, ultraviolet, visual, infrared and radio regions of the spectrum. The continuation of the visual observations by variable star observers is particularly necessary to correlate the findings in other regions, with the visual.

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