# DID SU UMa UNDERGO A CLASSICAL NOVA OUTBURST?

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ABSTRACT

Recent observations of an apparent soft X-ray halo around the dwarf nova SU UMa have led to speculation that this may well be evidence of the object having undergone a classical nova-like outburst within historical times (Cordova and Mason 1980). By combining the relationship between quiescent X-ray luminosity and speed class for classical novae and the observed X-ray luminosity of SU UMa we derive a distance dependent apparent magnitude at outburst for the object. Distance estimates for SU UMa and absolute magnitude ranges for classical novae then determine the apparent magnitude of an outburst more exactly. From the angular size of the halo and the absolute magnitude - ejection velocity relationship for classical novae we derive the approximate date of any outburst. Comparison with historical records does not reveal any promising candidates. An alternative interpretation of the halo in terms of scattering of soft X-rays from dwarf nova outbursts by interstellar grains is suggested.

## 1. INTRODUCTION

The dwarf nova SU UMa was observed by Cordova and Mason (1980) to possess a soft X-ray halo, the properties of which are suggested as being consistent with the interaction with the interstellar medium of material ejected in a classical nova outburst several centuries ago. If this is the case then it is potentially an important clue to the evolution of cataclysmic binaries (see Vogt, 1982). However, the detection of the halo was marginal and we therefore set out in this paper to determine how bright a classical nova eruption at the distance of SU UMa might have appeared; we also estimate its duration of visibility and the most likely outburst date, and compare this with the historical record.

## 2. DISTANCE

As a first step we require a good estimate of the distance of SU UMa.



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Bruch (1981) has used two independent methods to derive this quantity and the first of these, and potentially the most accurate, relies on the findings of Vogt (1981 ) that dwarf novae at outburst maximum have essentially the same visual luminosity. The absolute magnitude measured by a distant observer then depends in a well known way only on the inclination of the system which in this case is $\sim 21°$. Thus with $m_V$ = 14.51 ± 0.23 (taking the average of a variety of observations) and neglecting interstellar extinction, which will be small for an object at the distance and Galactic latitude of SU UMa, we find $213 \lesssim d$ (pc) $\lesssim 421$ and $M_V \simeq 7.2 \pm 0.8$ at minimum. As classical novae at outburst have $-5 < M_V < -9$ (Bath, 1978) then if SU UMa underwent such an outburst it would have had $m_V \simeq 3$ at worst. Stephenson (1981) has suggested that objects of this magnitude and brighter are highly likely to have been noted in Eastern records. Lundmark (1921) does indeed cite such records of possible novae of this magnitude and brighter. We now proceed to define the probable apparent magnitude of any outburst more exactly and to determine its observable duration and date

## 3. BASIC RELATIONSHIPS

Recently Becker and Marshall (1981) have discussed a relationship between the X-ray (0.15 keV - 4.5 keV) luminosity of classical novae at quiescence $L_X$ and their optical luminosity at outburst $L_O$ (more specifically their speed class $\dot{m}_V$), the common factor apparently being the accretion rate onto the white dwarf. These authors show that evidence for such a relationship is provided by X-ray studies of old classical novae by Cordova et al (1981). Although the nova DQ Her does not appear to follow the general run of the $L_X$ - $\dot{m}_V$ relationship, Becker and Marshall (1981) note that its high inclination may suppress any X-ray emission. However, we note here that the soft X-ray luminosity that is required (cf. Ferland and Truran, 1981) to maintain the excitation of the nebula surrounding DQ Her is significantly greater than the upper limit obtained by Cordova et al (1981). While the X-ray luminosity of HR Del ($\dot{m}_V \simeq 0.008$ mag $d^{-1}$) adjusted from the data of Hutchings (1980) to the same waveband follows the general trend of the Becker-Marshall relationship well, with $L_X \sim 3 \times 10^{31}$ erg $s^{-1}$. The data presented by Becker and Marshall (1981)are suggestive of a $L_X$ - $\dot{m}_V$ relationship and the additional data presented above seem to strengthen their argument. The Becker-Marshall relationship plays a central role in the estimation of the date of, and apparent magnitude at, any classical nova outburst SU UMa may have undergone.

In order to proceed, we write:-

$$\log L_X = \alpha_X \log \dot{m}_V + \beta_X \quad (1)$$

$$\log L_O = \alpha_O \log \dot{m}_V + \beta_O \quad (2)$$

where equation (1) represents the Becker-Marshall relationship and equation (2) is the usual relationship between optical luminosity at maximum and speed class for classical novae (cf. McLaughlin, 1960). We

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take $\beta_X = 32.2$, as suggested by a linear least squares fit to the data on novae detected at X-ray wavelengths as illustrated in figure 2 of Becker and Marshall together with that on HR Del from Hutchings (1980), and $\alpha_0$ and $\beta_0$ from the standard relationship in McLaughlin (1960). The X-ray flux of SU UMa at quiescence is $1.3 \times 10^{-11}$ erg cm$^{-2}$ s$^{-1}$ (Cordova and Mason, 1980). We can now use equations (1) and (2) to compute the value of $m_V$ at maximum of classical nova outburst. Similarly we can compute the date of outburst by means of the relationship between ejection velocity V and speed class (cf. McLaughlin, 1960):

$$\log V = \alpha_V \log \dot{m}_V + \beta_V \qquad (3)$$

In the equation (3) we take for $\alpha_V$ and $\beta_V$ the values appropriate for the principal spectrum (McLaughlin, 1960), as this generally contains the bulk of the ejecta (e.g. Gallagher, 1977).

## 4. RESULTS

Although the data presented by Becker and Marshall (1981) suggest a value $\alpha_X \sim 0.4$, more X-ray data on slow novae at quiescence are required to determine the exact form of the relationship, and here we compute $m_V$ and V at maximum for various values of distance d and $\alpha_X$. The relationship between $m_V$ at classical nova maximum and distance is shown in Figure 1 for several values of $\alpha_X \gtrsim 0$. For $\alpha_X = 0$, the distance (d = 316 pc) is uniquely determined by the X-ray properties of SU UMa at quiescence; while for $\alpha_X = \infty$, the distance is determined by the optical properties alone, $m_V \propto 5 \log d$. The effect of any uncertainty in $\beta_X$ is indicated in Figure 1 by the short horizontal arrow : an uncertainty of 0.2 in $\beta_X$ results in an uncertainty of $\sim$ 25% in the distance and a corresponding shift of all lines by the amount indicated. Also indicated on Figure 1 is the region of the $m_V$ - d diagram most probably occupied by SU UMa. The limits delineated by the parallelogram are determined by (a) the distance estimates for SU UMa and (b) the range of visual absolute magnitude of classical novae at outburst (see above).

Figure 1 suggests that values $\alpha_X \gtrsim 0.5$ are ruled out. The least squares fit suggests $\alpha_X \simeq 0.4$ and we find from Figure 1 that, at maximum, SU UMa had $-2.1 \gtrsim m_V \gtrsim -2.3$ at classical nova outburst; the corresponding distance is 213 <d(pc) <224. Also, we note that this distance range implies a visual decay rate of 0.24-0.31 mag d$^{-1}$ typical of fast novae (Payne-Gaposchkin, 1957). Such novae normally have rather smooth light curves, and SU UMa would have faded to naked eye invisibility in $\sim$ 1-2 months.

The relationship between ejection velocity at classical nova outburst and distance is shown in Figure 2, in which similar considerations apply to the values $\alpha_X = 0, \infty$. The range of V values for classical novae lies in the range 200 km s$^{-1}$ for slow novae to 2000 km s$^{-1}$ for fast (McLaughlin, 1960). These limits on V, together with the limits on d from Figure 1, define the parallelogram in Figure 2 in which SU UMa is most likely to lie. Again Figure 2 suggests that large values of $\alpha_X$ are ruled out, although the upper limit in this case is $\alpha_X \lesssim 2$. Taking

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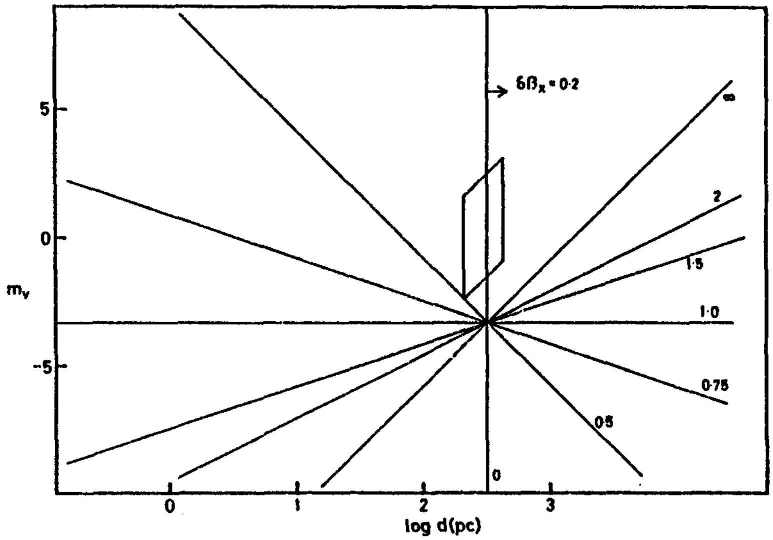


Fig. 1 Relationship between apparent visual magnitude at classical nova maximum and distance for SU UMa; $\alpha_X$ values as indicated. See text for details.

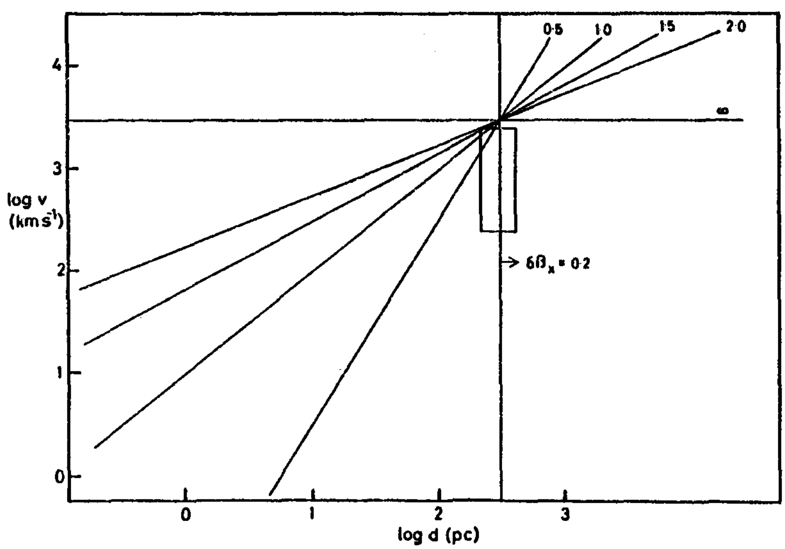


Fig. 2 Relationship between ejection velocity at classical nova maximum and distance for SU UMa; $\alpha_X$ values as indicated. See text for details.

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as above, the specific value $\alpha_X \simeq 0.4$ suggested by the Becker-Marshall (1981) relationship, we find the limits $1100 \lesssim V(\mathrm{km\ s^{-1}}) \lesssim 2000$ and $213 \lesssim d\ (\mathrm{pc}) \lesssim 280$. The limits on V are consistent with the above classification of SU UMa as a fast nova.

From the point of view of confirming a historical classical nova outburst of SU UMa, the quantities of interest are the apparent magnitude at, and date of, eruption. The determination of the latter requires the angular radius of the X-ray halo around SU UMa, given by Cordova and Mason (1980) as $\phi$ = 14 arcmin. Obviously the uncertainties in our numerical results (date and $m_V$) will arise mainly from the intrinsic scatter in the relationships (1)-(3); while the uncertainty in the date will be further aggrevated by our assumption of uniform outflow since outburst.

The dependence of $m_V$ at classical nova maximum on date of outburst is shown in Figure 3; we note that the uncertainty induced by the uncertainty in $\alpha_X$ is eliminated as this relationship is fortuitously independent of $\alpha_X$. However, Figure 3 shows one unfortunate trend : as the classical nova outburst goes further into the past the apparent magnitude at maximum increases. Even so, an outburst at 1 A.D. would have had $m_V \simeq 0.4$ and SU UMa would have ranked fifth in brightness in the northern sky.

## 5. COMPARISON WITH THE HISTORICAL RECORD

The above limits on $m_V$ and V together with Figure 3, suggest an outburst in the period 1360-1410 (it is of interest to note that Cordova and Mason 1980, arrived at an expansion age $\sim$ 500 y). Unfortunately none of the objects in the list of Lundmark (1921) for this period meets the positional requirement. A recent discussion by Imaeda and Kiang (1980) does however suggest the occurrence of several "guest stars" in the relevant period. Alternatively Stephenson (1981) has expressed the view that the only known candidate may be an object classified by Lundmark as being very probably a classical nova, which was observed in A.D. 369. This had naked-eye duration of six months and $m_V \simeq -3$. According to Figure 3 SU UMa should have had $m_V \simeq -0.1$ and duration $\sim$ six years in A.D. 369. Also, although the declination of the A.D. 369 nova is in satisfactory agreement with that of SU UMa the right ascension is more uncertain and is likely to differ from that of SU UMa by $\sim 8^h$ (cf. Lundmark, 1921).

If the dwarf nova SU UMa did indeed undergo a classical nova outburst sometime in the past then the evidence for a generic relationship between these two types of cataclysmic binary would be greatly strengthened. However the apparent lack of historical records of a long duration ($\sim$ two month ) bright ($m_V \simeq -2.2$) outburst in the most likely period can only add to doubts about the origin of the Cordova-Mason (1980) halo.

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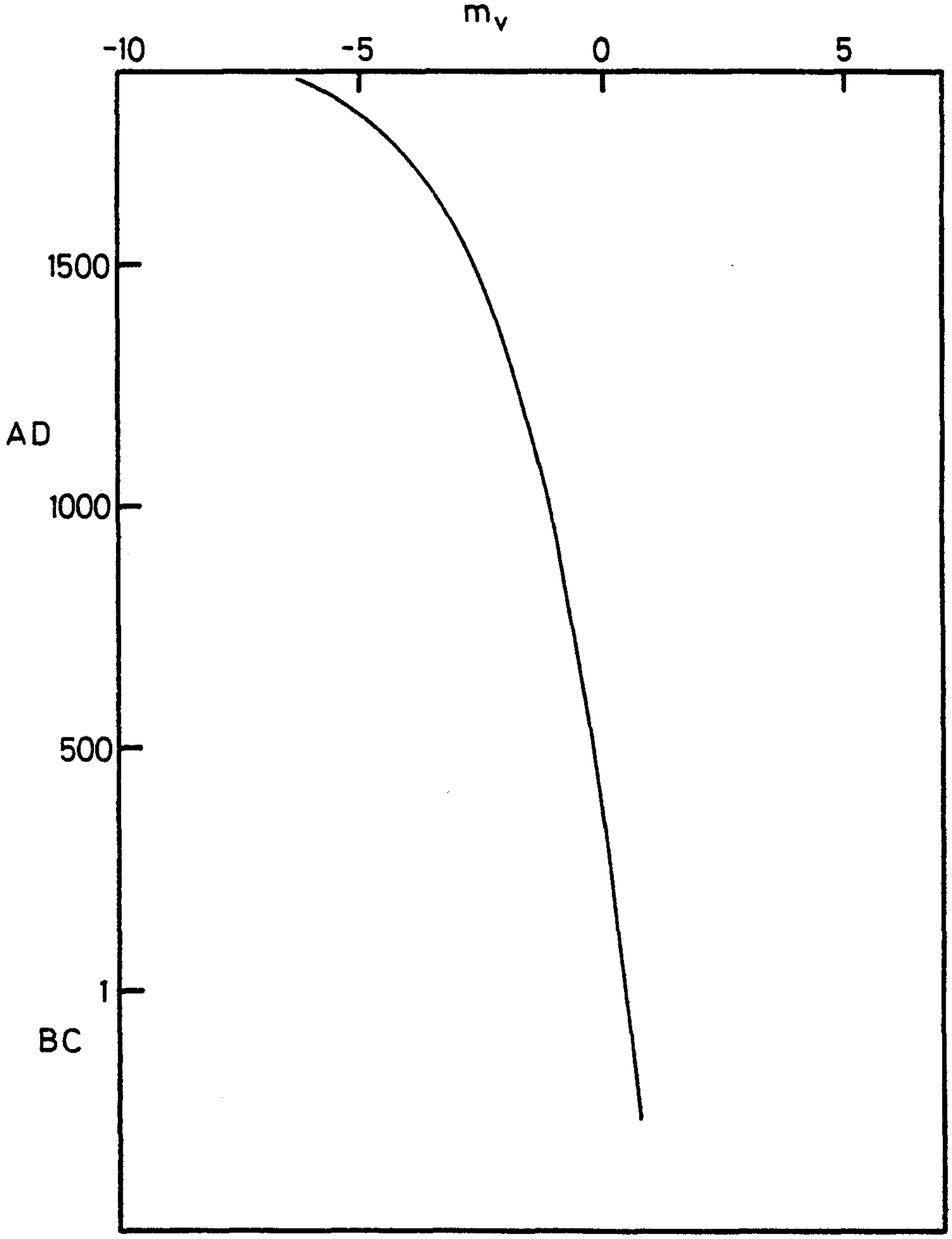


Fig. 3 Relationship between date of outburst and apparent visual magnitude at classical nova maximum for SU UMa. See text for details.

## 6. A POSSIBLE ALTERNATIVE EXPLANATION OF THE HALO

Assuming that, despite its marginal detection the halo was not due to statistical fluctuations (which would not in any case be expected to account for its symmetric disposition about SU UMa) and that it was not a purely instrumental effect (as it did not occur for similar objects at similar exposures (Cordova and Mason, 1981))one other explanation can perhaps be suggested. A localised cloud of small ($\lesssim$0.05 μm) interstellar grains lying between us and SU UMa, with resulting forward scattering of its soft X-ray flux may produce a halo about the object (Martin, 1978; Rolf, 1980). Perhaps the relatively high flux and ring-like nature of the halo are due to such grains scattering the X-ray flux of an outburst or, more plausibly, a superoutburst of the system. The halo would then be expected to expand and dissipate very rapidly. Further soft X-ray observations of SU UMa and related objects after outburst would be extremely useful to explore this possibility.

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