DISK INSTABILITIES IN HUBBLE-SANDAGE VARIABLES?

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The brightest individual objects in extragalactic nebulae are the Hubble-Sandage variables. They were first investigated by Hubble and Sandage (1953). Observations by Tamman and Sandage (1968) and Rosino and Bianchini (1973) followed. The main characteristics are high luminosity ($L/L_\odot \approx 10^5$), blue color indices, F type spectra and irregular variability.

Bath (1979) has suggested that the Hubble-Sandage variables contain an accreting main-sequence star with a Roche Lobe filling companion in a wide binary system. Based on this model we derive theoretical color indices for disks and determine the mass in the disk for different mass accretion rates. Further we discuss an instability of the disk which could explain the change in the color index observed for Var A in M33.

a) COLOR INDICES

The color index of a disk is determined by radiation from regions of different effective temperature. We derived the (absolute) visual luminosity for each ring of thickness Δs in the disk at a distance s from the centre

$$L_V(s) = 4\pi s\ F(s)\Delta s\ 10^{0.4\ B.C.}$$

where F(s) is the energy flux density

$$F(s) = \frac{3}{8\pi}\ \frac{GM_{m.s.}\dot{M}}{s^3}\ ,$$

$M_{m.s.}$ mass of main-sequence star, $\dot{M}$ mass accretion rate, B.C. bolometric corrections (Allen, 1973 p. 205). From the corresponding visual magnitude M_V and the color index (Allen, 1973, p.206; because of the low surface gravity the data for supergiants were used) the blue magnitude M_B can be derived for each ring.

$$M_B = M_V + (B - V)$$

and an energy flux L_B in the blue spectral region can be defined

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$$\log L_B = \log L_V - 0.4(B - V).$$

The difference of the energy fluxes gives the theoretical quantity for a comparison with the color index of the whole disk

$$(B - V)_d = 2.5(\log \sum_s L_V(s) - \log \sum_s L_B(s))$$

As an example we give in Fig. 1 the bolometric and the visual luminosity from disk rings of thickness Δs ($\Delta \log s = 0.25$, $M_{m.s.} = 15\ M_\odot$). To study the effect we have chosen a lower and a high mass accretion rate (already above the critical rate for the innermost disk region).

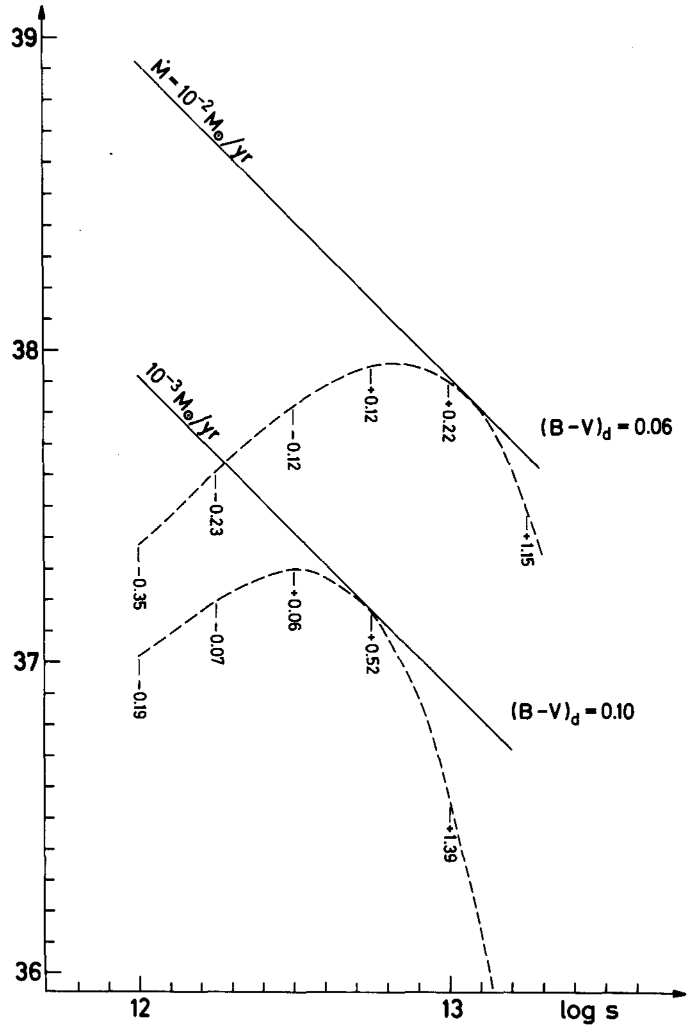

Fig. 1: Luminosity from disk regions of thickness Δs,
——— bolometric luminosity $\log L(s) = \log 4\pi sF(s)\Delta s$,
-------- visual luminosity $\log L_V(s)$ (see text). Color indices are added.

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The total visual luminosity from the whole disk is $10^{38.5}$ ($\dot{M} = 10^{-2} M_\odot$/yr) and $10^{37.8}$ ($\dot{M} = 10^{-3} M_\odot$/yr). The color indices $(B-V)_d$ for the whole disk show very little dependence on M. We therefore conclude that the variation of color indices is related to the size of the disk; the smaller the disk the bluer the color index.

The color index 0.3 of Var A in M33 cannot be explained from our results. It could possibly come about by a contribution of a bright red giant companion (for example an 18 - 20 $M_\odot$ star) or by reddening from a dust cloud around the system.

b) MASS CONTAINED IN THE DISK

The vertical structure of an accretion disk around a 15 $M_\odot$ main-sequence star was computed with a code (α-model, non-self-gravitating) which includes radiative and convective energy transport (Meyer and Meyer-Hofmeister, 1981). The computations show, as given in Fig. 2, that the mass in the disk rings, and also the total mass in the disk, do not vary essentially with $\dot{M}$, but depend very much on the size of the disk. Then non-monotonic increase of mass with the increase of M is due to a changeover from convective to radiative structure.

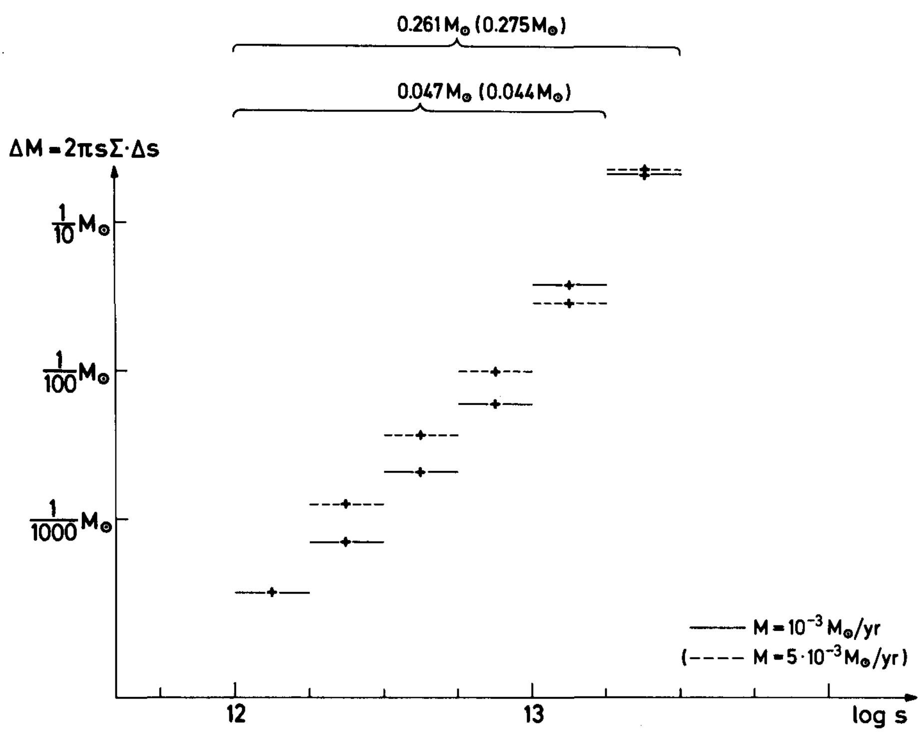

Fig. 2: Mass in regions Δs and total mass in the disk for disk radius log r = 13.25 and 13.50 (values in paranthesis correspond to higher rate M). Σ surface density.

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c) INSTABILITY OF THE DISK

In the innermost disk region the radiation pressure becomes important and it is possible that (maybe due to a fluctuation in $\dot{M}$) the mass, originally in the disk, forms a sphere around the main sequence star. From the disk structure computations we know the distribution of mass and entropy in the disk. We find that mass with lower entropy is then above mass with higher entropy, and there should be convective mixing in this innermost sphere. We assume that the restructuring into a sphere and the convective mixing are fast processes and that the total energy is approximately conserved. In this simplified model we will have an isentropic gas sphere around the main sequence star. If we now determine the radius of this sphere we find it to be larger than that of the disk region from which it formed. Thus this process can spread to the next disk region until all mass originally contained in the disk is transformed into an extended envelope. For a given disk radius s_d we give, in the table, the radius R_{is} of the corresponding isentropic gas sphere, and the settling time $\tau (= E/L_{Edd})$ after which the energy E (mostly gravitational) is used up by the radiative losses with about Eddington luminosity L_{Edd}. The values given are determined for $M_{m.s.} = 15M_\odot$ and $\dot{M} = 5 \times 10^{-3} M_\odot/yr$.

TABLE

log s_d	log R_{is}	log τ
12.75	13.34	6.99
13.00	13.65	7.67
13.45	13.67	8.17
13.50	14.12	8.90

The radius of the envelope is so large, that we might even expect the formation of a common envelope. Additional luminosity generated by friction may prevent the mass in the envelope from settling down to a disk again.

We suggest that such a process could have happened in Var A in M 33 for which the color index changed from 0.3 to 1.51 (Hubble and Sandage, 1953).

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