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# Photometric and spectroscopic observations of an optical candidate for the X-ray source H 0544 – 665

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**Summary.** We present the results of spectroscopic and *UBV* observations of the brightest star in the error box of the X-ray source H 0544 – 665. This object is a B0–1 V star and a member of the LMC. It shows correlated variations in brightness and colour indices. We suggest that it is a Be-type star observed during a stage of low emission strength. Although a relation between this star and the X-ray source has still to be proven the present data add considerable support to the proposed identification.

## 1 Introduction

The X-ray source H 0544 – 665, located in the direction of the Large Magellanic Cloud, was discovered with the *HEAO – 1* scanning modulation collimator by Johnston, Bradt & Doxsey (1979). The source is rather weak (1.8 $\mu$Jy averaged over the energy interval 1.5–13.5 keV) with a luminosity of $\sim 1.6 \times 10^{37}$ erg s$^{-1}$ at the LMC distance of 52 kpc (see Crampton 1979) and no limits could be placed on its possible X-ray variability. Thorstensen & Charles (1980) found that the brightest star in the error box (star No. 1 in the chart given by Johnston *et al.* 1979) is slightly variable and that its spectrum perhaps shows weak emission in H$\beta$.

## 2 Observations

During 1981 December observations were made (by MvdK) with a two-channel photometer attached to the Danish 1.5-m telescope at ESO (La Silla). With this photometer two areas of

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the sky, separated by 62 arcsec, can be observed simultaneously. One of the channels is set on the star of interest, the other is used to measure the sky brightness. In both channels an EMI 9789 QA photomultiplier is employed as detector. All observations were made through 9 arcsec diaphragms. The relative sensitivity of the two channels was determined by frequent observations of bright stars through both channels.

The optical candidate was observed sequentially through Johnson *UBV* filters. The observed count rates were transformed to *UBV* magnitudes using observations of four stars (Nos 1–19, 1–24, 2–5 and 2–8) from the list of Dachs (1972).

We have reduced the *V* data by making the assumption that the average difference of the *V* magnitude of these four stars with respect to the values given by Dachs, is zero. The rms deviation of the relative *V* magnitudes with respect to the average level observed during one night, is 0.025 mag. It is therefore unlikely that the *V* magnitudes of the H 0544 – 665 candidate, as determined on different nights, are systematically shifted by more than ~ 0.02 mag.

The results of these observations are listed in Table 1. The typical accuracy of these data (including counting statistics, fluctuations in the sensitivity ratio of the two channels) is ~ 0.02 mag in *V* and ~ 0.03 mag in $B-V$ and $U-B$.

During six nights between 1981 December 3 to 18, the star was observed on the 1-m telescope at Siding Spring Observatory. The magnitudes resulting from these observations show a variation with time similar to those obtained in Chile. However, they are fainter by about 0.6 mag, probably due to contamination in the sky aperture. To illustrate the source variability these data have been included in Fig. 1 (as crosses) with a 0.6 mag correction to give the same mean as the ESO observations.

Photoelectric observations of this star were also obtained during two observing runs at CTIO, using the 0.9-m telescope and a single-channel photometer with an RCA 31034 photomultiplier. These measures were transformed to the *UBV* system using observations of standard stars made with a similar tube and filter set. Sky readings were taken in a region

**Table 1.** Results of photometric observations.

| Date | | *V* | $B-V$ | $U-B$ | |
|---|---|---|---|---|---|
| 1979 Dec. | 22.19 | 15.36 | −0.23 | −0.96 | CTIO |
| | 24.13 | 15.47 | −0.23 | −0.96 | CTIO |
| 1981 Jan. | 4.26 | 15.52 | −0.23 | −0.98 | CTIO |
| | 5.24 | 15.46 | −0.22 | −0.98 | CTIO |
| | 6.09 | 15.44 | −0.21 | −1.00 | CTIO |
| 1981 Dec. | 6.26 | 15.60 | −0.22 | −1.03 | ESO |
| | 7.22 | 15.40 | −0.16 | −0.99 | ESO |
| | 8.20 | 15.42 | −0.17 | −0.95 | ESO |
| | 8.33 | 15.46 | −0.21 | −0.97 | ESO |
| | 11.19 | 15.28 | −0.11 | | ESO |
| | 11.20 | 15.25 | −0.11 | −0.87 | ESO |
| | 11.33 | 15.37 | −0.14 | −0.91 | ESO |
| | 12.20 | 15.30 | −0.14 | −0.88 | ESO |
| | 13.06 | 15.44 | −0.18 | −0.94 | ESO |
| | 13.29 | 15.39 | −0.18 | −0.95 | ESO |
| | 14.07 | 15.46 | −0.18 | −0.97 | ESO |
| | 14.24 | 15.43 | −0.18 | −0.95 | ESO |
| | 15.10 | 15.51 | −0.19 | −1.00 | ESO |
| | 15.28 | 15.40 | −0.14 | −0.97 | ESO |
| | 16.07 | 15.53 | −0.17 | −0.97 | ESO |
| | 16.26 | 15.43 | −0.18 | −0.98 | ESO |
| | 18.07 | 15.46 | −0.14 | −0.90 | ESO |

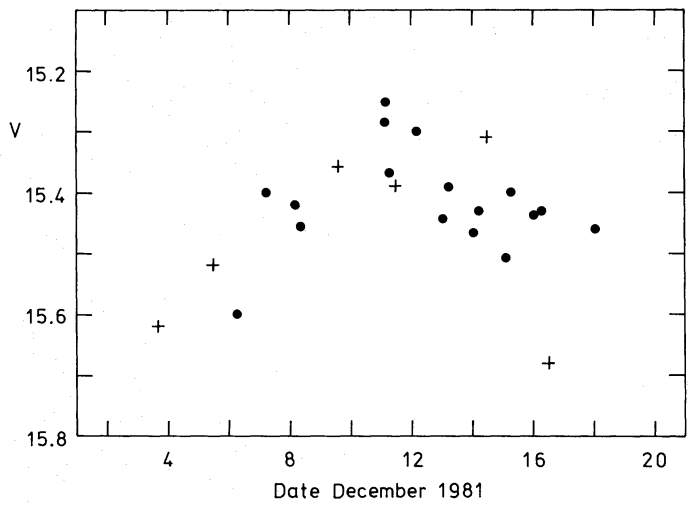


**Figure 1.** Variation of the visual magnitude of the H 0544 – 665 candidate. The dots denote observations made at ESO, the crosses those at SSO (corrected as described in the text).

devoid of comparatively bright stars, as determined from examination of a large-scale image-tube plate of the region. The data are listed in Table 1. The original 1979 observations were first reported by Thorstensen & Charles (1980). The uncertainties are similar to those of the ESO data.

IPCS spectra of the H 0544 – 665 candidate were obtained on 1981 January 12 with the 3.9-m AAT and the RGO spectrograph. The dispersion was 33 Å $mm^{-1}$ and the instrumental resolution was 1.5 Å, as determined from arc calibration spectra.

## 3 Discussion

The only lines clearly visible in the spectrum of the H 0544 – 665 candidate are the Balmer absorption lines. The average radial velocity, as determined from these lines equals + 369 ± 42 km $s^{-1}$, which confirms that the star is a member of the LMC.

From the observations at CTIO and ESO we derive average values for $B-V$ of −0.22 and −0.17, and for $U-B$ of −0.99 and −0.95, respectively. In the standard ($U-B$, $B-V$) diagram these colours correspond to values of the interstellar reddening (using $E(U-B)/E(B-V) = 0.72$) $E(B-V) = 0.07$ and 0.11 magnitudes, respectively. These values are consistent with reddening values given previously for the LMC, which cluster near 0.07 mag (Feast, Thackeray & Wesselink 1960; Sanduleak & Philips 1968; Isserstedt 1975; Crampton 1979).

The H 0544 – 665 candidate definitely has a variable $B-V$ (see below). Assuming that the 'standard' reddening value of 0.07 mag applies, it is often located to the right of the $U-B$, $B-V$ locus of main-sequence stars, indicating a slight $U-B$ excess.

The reddening line crosses the two-colour relation at $B-V = -0.28$, corresponding to a spectral type B0.5. The average, reddening-corrected, visual magnitude $V_0 = 15.1 \pm 0.15$. For a distance modulus to the LMC of 18.6 ± 0.2 mag (Crampton 1979), the absolute visual magnitude $M_V$ equals −3.5 ± 0.3, corresponding to a luminosity class V (using the absolute magnitude calibration of Walborn 1972).

This luminosity classification is supported by the observed equivalent width of Hγ, which equals 4.5 ± 0.4 Å. According to the calibration of the Hγ equivalent width (as a function of spectral type and luminosity class) by Balona & Crampton (1974) this corresponds to luminosity class V.

For a B0.5 V star the expected equivalent widths of He I lines are ~ 1 Å for the triplet lines at λ 4026 and 4471 and ~ 0.5 Å for the singlet lines at λ 4143 and 4387 (Underhill 1966). From a measurement of the equivalent widths of some spurious features we estimate that the equivalent width noise level above which an absorption feature can be trusted to be real is between 0.5 and 1 Å. This explains why the only He I line visible in the spectrum is the λ 4026 triplet line.

Summarizing the above evidence, we conclude that the H 0544 – 665 candidate is a B0–1 V star located in the LMC.

The properties discussed so far do not by themselves make a strong case for the identification of this star as the optical counterpart of H 0544 – 665. We will now turn our attention to its variability and show that this indicates a possible connection with the Be stars, an established class of binary X-ray emitters (Rappaport & Van den Heuvel 1982).

The results listed in Table 1 show that the candidate star is definitely variable on a timescale of weeks, with a total observed variation of ~ 0.3 mag in $V$. The light curve, as observed during 1981 December, is shown in Fig. 1. In Fig. 2 we have plotted $V$ as a function of $B-V$ (ESO observations only). Clearly, there is a colour–magnitude correlation, in the sense that when the star brightens it becomes redder. A linear fit to the ESO data (these span the largest range in colour and magnitude) gives a slope $\Delta V/\Delta(B-V) = -2.5$. Similarly, there is a correlation between $U-B$ and $B-V$ (see Fig. 3), which vary according to $\Delta(U-B)/\Delta(B-V) = 1.7$.

Long-term variability, with amplitudes up to ~ 0.5 mag and correlated changes in $V$, $B-V$ and $U-B$ are a well-known property of many Be stars (see, e.g. Dachs 1982; Hirata 1982 and references therein). According to Hirata (1982) the slopes $\alpha = \Delta V/\Delta(B-V)$ and $\beta = \Delta(U-B)/\Delta(B-V)$, as observed for many Be stars, are related. The values of $\alpha$ and $\beta$ we find here are consistent with that relation. Another interesting result found by Hirata (1982) is the connection between $\alpha$ and the projected rotational velocity $V_{\rm rot}$ sin $i$. The value of $V_{\rm rot}$ sin $i$ expected according to his results for Be stars is ~ 300 km s$^{-1}$. The average FWHM of the Balmer absorption lines in the spectrum of the H 0544 – 665 candidate (corrected for instrumental broadening through a Gaussian subtraction of the FWHM of the narrowest emission lines in the comparison spectrum) indicates a rotational broadening of 300 ± 50 km s$^{-1}$. Although this can be considered only a rough estimate of $V_{\rm rot}$ sin $i$, this result does serve

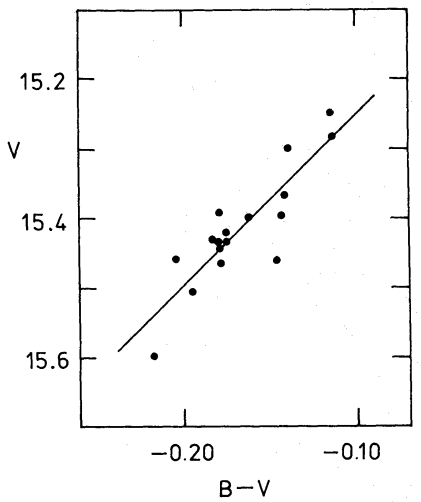


**Figure 2.** Correlation between $V$ and $B-V$ of the H 0544 – 665 candidate (ESO data only). The straight line through the data corresponds to $\Delta V/\Delta(B-V) = -2.5$.

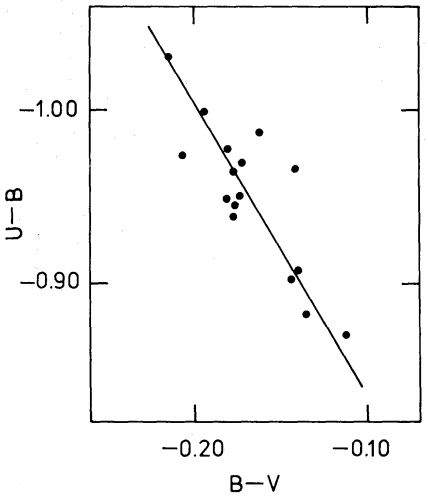


**Figure 3.** Correlation between $U-B$ and $B-V$ of the H 0544 – 665 candidate (ESO data only). The straight line through the data corresponds to $\Delta(U-B)/\Delta(B-V) = 1.7$.

to show that the photometric behaviour of the candidate star is similar to that observed for many Be stars.

In order to find a possible indication for the presence of line emission we have measured the equivalent widths $W$ of the Hβ and Hγ absorption lines. The ratio $W(\mathrm{H}\beta)/W(\mathrm{H}\gamma)$ equals $0.65 \pm 0.15$. This is somewhat smaller than the values for normal early-type main-sequence stars (*cf.* Williams 1936; Mihalas 1966), suggesting that perhaps the Hβ line is partially filled in by weak emission.

The lack of obvious Be spectral characteristics of the H 0544 – 665 candidate may simply mean that it was observed during a state of low activity. Disappearance and reappearance of line emission has been observed in many Be stars (*cf.* Slettebak 1979, 1982).

A definitive connection between star 1 and the X-ray source H 0544 – 665 cannot yet, in our opinion, be made. However, the evidence presented here for a connection between this star and the Be stars (which form a major class of massive X-ray binaries) indicates that it is an attractive candidate for such an identification.

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