THE ASTROPHYSICAL JOURNAL, 328:594–599, 1988 May 15

A CCD SEARCH FOR FAINT VARIABLES IN THE FIELD OF AN ω CENTAURI LOW-LUMINOSITY X-RAY SOURCE, AND IN 47 TUCANAE

MICHAEL M. SHARA,[1] JANUSZ KALUZNY, AND MICHAEL POTTER
Space Telescope Science Institute
AND
ANTHONY F. J. MOFFAT[1]
Université de Montréal
Received 1987 July 31; accepted 1987 November 6

ABSTRACT

We report the results of a CCD search for faint and/or small amplitude variables in the field of a low-luminosity X-ray source in ω Cen, and in a rich field in 47 Tuc. None of the ~ 3750 stars identified by DAOPHOT in the two frames varied by as much as $\sigma = 0.03$–0.08 mag during 3–4 hr of frequently repeated imaging. If the ω Cen X-ray source is variable, it was fainter than $M_B \sim +7.5$ during our observations. Contact binaries (W UMa stars) are at least as rare in the outskirts of these globulars as they are in the solar vicinity.

Subject headings: clusters: globular — stars: binaries — stars: stellar statistics — stars: variables — X-rays: binaries

I. INTRODUCTION

Close binary stars in globular clusters are elusive prey which have been hunted with limited success by astronomers. These stars drive the dynamical evolution of globulars. Thus, understanding the formation, distribution, densities, and destruction (or ejection from clusters) of close binaries is crucial to eventually understanding the evolution of globular clusters.

Positively identified binaries in globulars are four in number: two spectrographically confirmed dwarf novae (Margon, Downes, and Gunn 1981; Margon and Downes 1983); a high-luminosity X-ray source (Auriére, Le Févre, and Terzan 1984); and a white dwarf-neutron star binary with an 11 minute orbital period (Stella, Priedhorsky, and White 1987). An optical candidate for a classical nova has been reported by Shara *et al.* (1986), and three possible W UMa contact binaries have been identified by Irwin and Trimble (1984). None of the low-luminosity X-ray sources ($L_x \lesssim 10^{34.5}$ ergs s^{-1}) described by Hertz and Grindlay (1983) has yet been identified.

If the low-luminosity X-ray sources are cataclysmic-like white dwarf–main-sequence binaries, as suggested by Hertz and Grindlay (1983), then (like cataclysmics) they may flicker in brightness by 10%–20% on time scales as short as 5–10 minutes (due to accretion disk hot-spot variations). Larger amplitude variability over several hours is also possible, due to orbital aspect viewing changes (and occasionally eclipses). Thus a search for variables in the fields of low-luminosity globular X-ray sources seems well justified.

This paper describes just such a sensitive, CCD search for faint and/or small amplitude variables in the field of an ω Centauri low-luminosity X-ray source, and in a field in 47 Tucanae. As an added bonus, any W UMa contact binaries in these fields should also be straightforward to find during several hours of frequent monitoring (Kaluzny and Shara 1987).

In § II we describe our observations and method of reductions. In § III we present and discuss our results, and in § IV we summarize our conclusions.

[1] Visiting Astronomer, Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

II. OBSERVATIONS

a) *The Data*

On the night of 1983 August 14 UT we imaged the 3′ × 5′ field in 47 Tuc shown in Figures 1*a* and 1*b* with the RCA CCD camera at the prime focus of the Cerro Tololo Inter-American Observatory 4 m telescope. Forty-five images were taken in immediate succession through a broad-band *B* filter from 06:43 to 10:01 UT. Each exposure was 4 minutes in duration and required about 20 s to read out. Debiasing and flat-fielding were done with mountain software; the photometry described in § III was carried out with the DAOPHOT package (Stetson 1987) at the Space Telescope Science Institute (ST ScI).

The same telescope, CCD, and *B* filter were used on the night of 1985 May 16 UT to repeatedly image the field of the ω Cen low-luminosity X-ray source labeled "A" by Hertz and Grindlay (1983). The field is shown in Figure 2*a* and its location in ω Cen is shown in Figure 2*b*. The observations, debiasing, and flat-fielding were kindly carried out for us by CTIO staff astronomers as part of that observatory's service observing program. All exposures were 60 s in duration and spread over 3.5 hr. The subsequent analyses reported below were carried out at ST ScI.

b) *Searching for Variables*

Forty-four images of the 47 Tuc field were visually blinked on a deAnza image display against a master frame to look for large amplitude ($\gtrsim 0.3$ mag) variables. None was found.

The photometry package DAOPHOT (Stetson 1987) was then used to identify and perform photometry on 1550 stars in each of the 45 images of the 47 Tuc field and on 2204 stars in 10 *B* images in the field of the X-ray source ω Cen A.

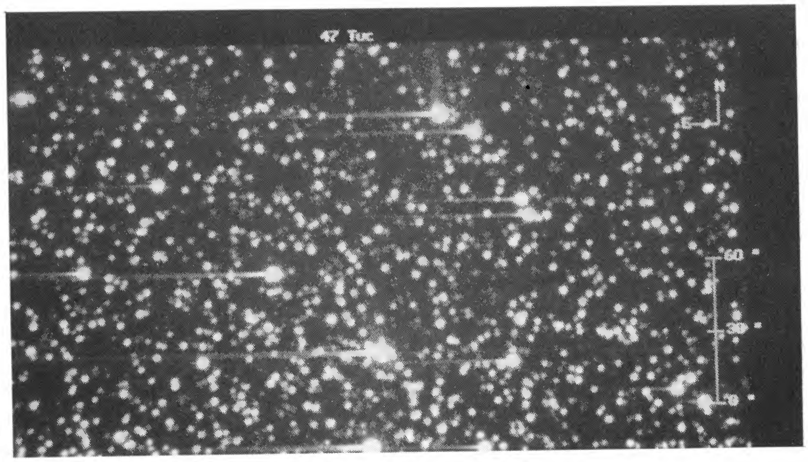

FIG. 1*a*

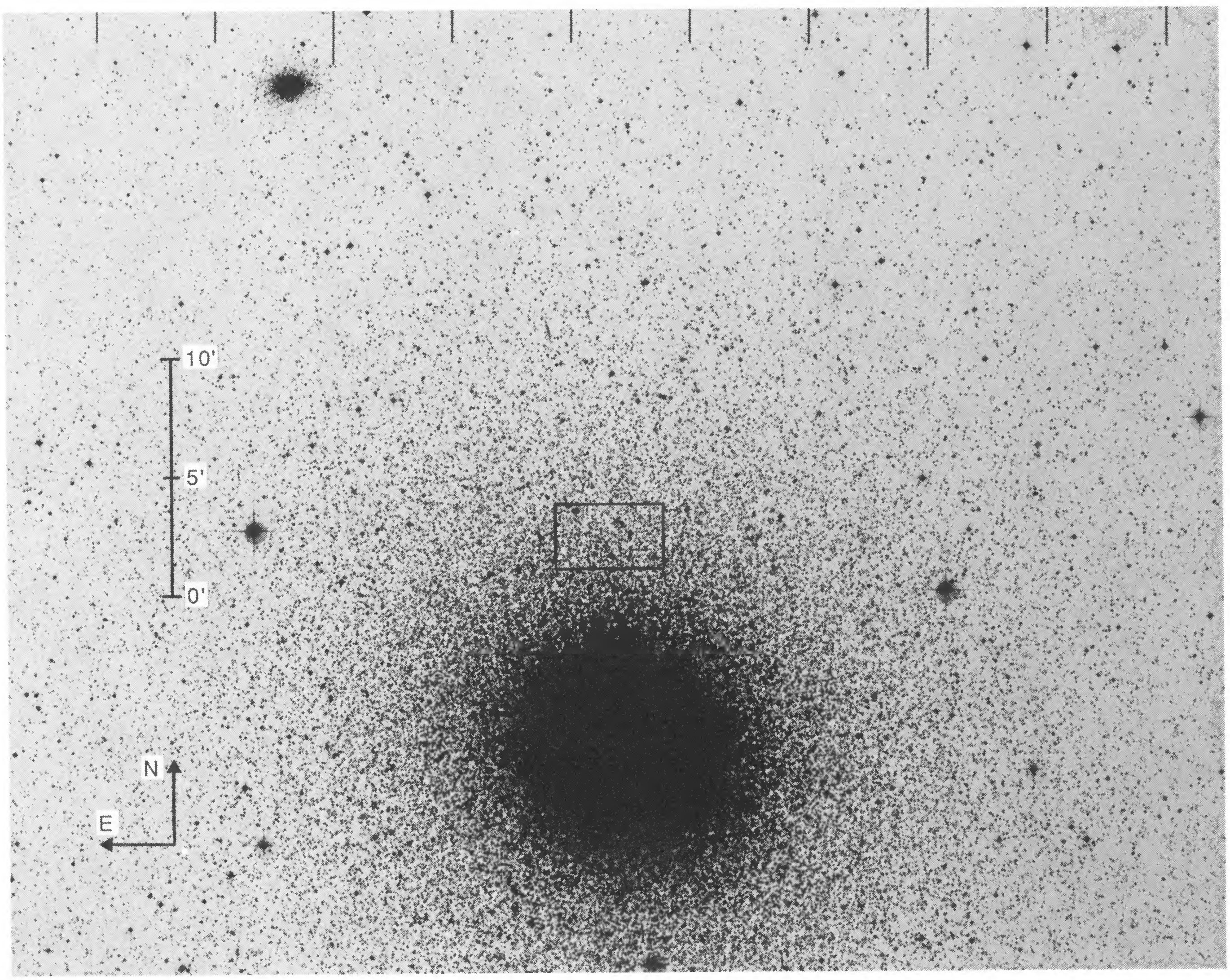

FIG. 1*b*

FIG. 1*a*.—Field in 47 Tucanae imaged with the RCA CCD and *B* filter at the prime focus of the Cerro Tololo Inter-American Observatory 4 m telescope. See text for a description of the search for variables. (*b*) The location of the field in Fig. 1*a* relative to 47 Tucanae.

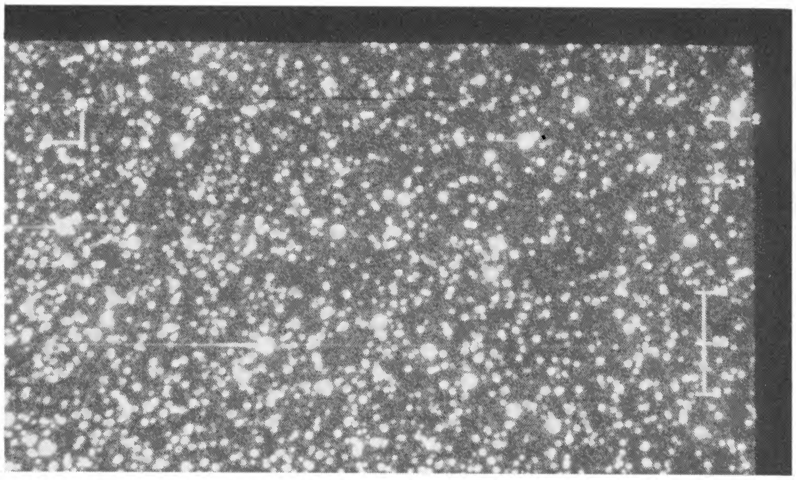

FIG. 2*a*

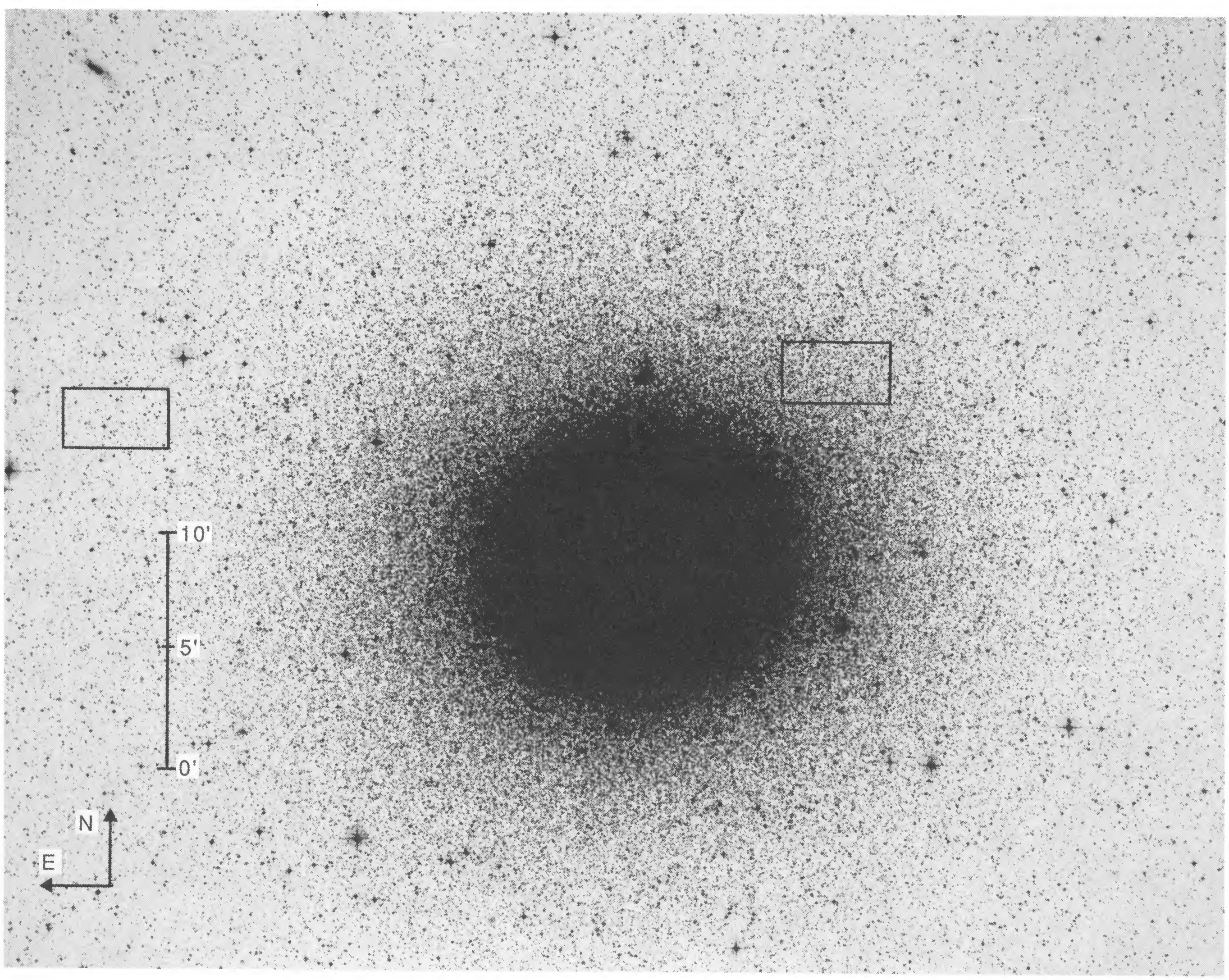

FIG. 2*b*

FIG. 2*a*.—RCA CCD *B* filter image of a field of low-luminosity X-ray source "A" of Hertz and Grindlay (1983) in the globular cluster ω Centauri. (*b*) SRC *J* image showing the location of Fig. 2*a* northwest of ω Cen. Also shown is the field of ω Centauri "E" to the northeast of the cluster.

An index of variability σ_k for the kth star in each field was then constructed as follows.

A master frame M was chosen for each field. The magnitude difference $m_{k,j} - m_{k,M}$ was calculated between the kth star in the jth frame and the same star in the master frame. The mean instrumental magnitude difference between the jth and master frames $\overline{\Delta m}_{jM}$ was then calculated (with appropriate weighting according to magnitude and after deleting stars on bad pixels or columns) and applied to every star in the jth frame. This brought all stars in the jth and master frames onto the same instrumental magnitude system. The same proceduure was followed for all the frames of each field. Finally, the variability index

$$\sigma_k = \left[\frac{\Sigma_{j=1}^{n}(\bar{m}_k - m_{k,j})^2}{n-1}\right]^{1/2}$$

was calculated, where $\bar{m}_k$ is the mean instrumental magnitude of the kth star, and the summation is over all n frames of a field.

A few V filter frames were also taken of each field. These were used to construct instrumental color-magnitude diagrams for each field, which were in turn compared with published C-M diagrams to derive approximate zero points (to within $\sim$0.1 mag) for the magnitude scales. An example is shown in Figure 3, which refers to field A in ω Cen. The same main sequence width clearly apparent in Walker's (1986) ω Cen data is also seen in Figure 3.

Finally, σ_k versus $\bar{m}_k$ was plotted (in Fig. 4*a* and 4*b*) to locate variables in the two fields.

III. RESULTS AND DISCUSSION

a) *Candidate Variables*

Candidates in Figures 4*a* and 4*b* were taken to be those stars lying above the horizontal lines indicating $\sigma(B) \gtrsim 0.03$–0.08 mag. Every candidate was carefully inspected to find reasons for its observed variations *other* than intrinsic variability. Close bright stars, location very close to the edges of frames, bad columns of pixels, and occasionally resolved faint companions all contributed to stars being flagged as spurious candidates. None of the candidates in any of the frames survived this inspection. We also blinked a CCD image of each field against a digitized scan of the same field on the SRC UK Schmidt J plate (to look for variables on a multiyear time scale). No variables were found. *Our main conclusion is, therefore, that we find no rapid variables with B amplitudes greater than 0.03–0.08 mag in the field of the* ω *Cen low-luminosity X-ray source "A" or in a field of 47 Tuc; or long time scale variables with B amplitudes* >0.5 *mag and* $B \lesssim 21$ *in the above fields.*

Could we have missed variables through some error in our reduction or analysis procedure? We believe not, as two of us (J. K. and M. M. S.) have used the identical procedure to successfully locate both known and new small-amplitude variables in NGC 188 (Kaluzny and Shara 1987). Further, the CTIO data analyzed in this run were of considerably better photometric quality than those used by Kaluzny and Shara (1987).

b) *Interpretation*

Low-luminosity X-ray sources in globular clusters are highly variable in luminosity, or have very soft X-ray spectra, or both (Verbunt *et al.* 1987). Thus it is possible that the X-ray source ω Cen A was in a low (optical) state when we imaged its field in 1985 May.

At the distance moduli of 13.3 (47 Tuc) and 13.5 (ω Cen) (Harris and Racine 1979), our lack of detection of variables to $B = 21$–22 corresponds to $M_B > 7$–8 (after allowing for

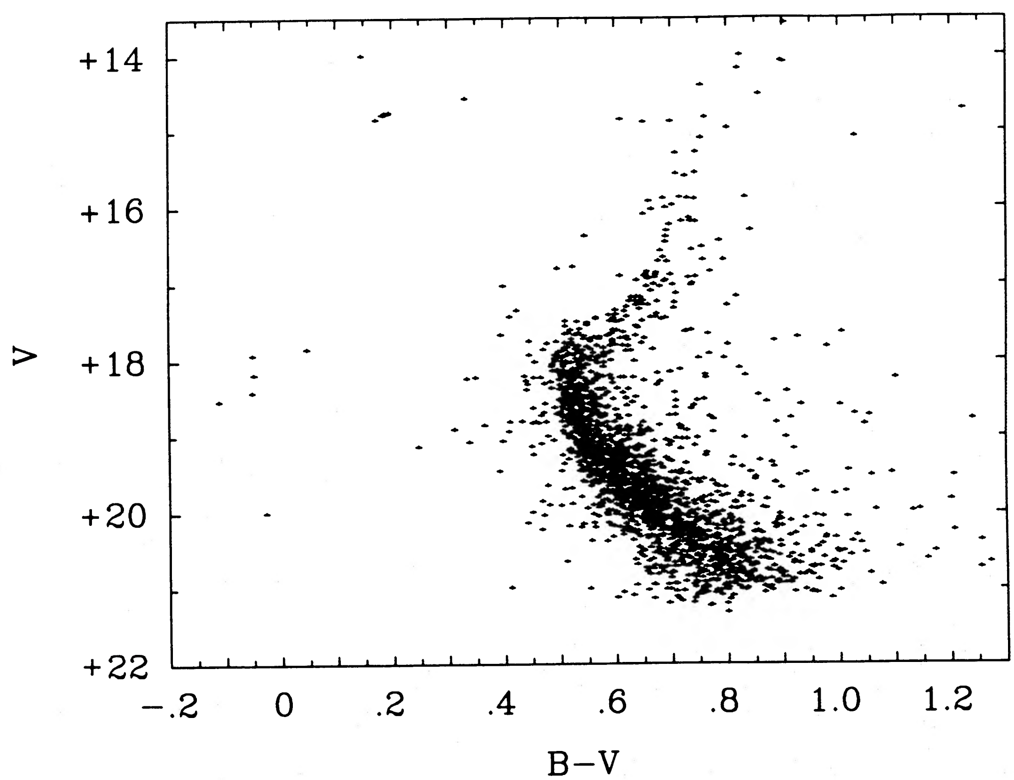

FIG. 3.—A color-magnitude diagram of the field of the low-luminosity X-ray source "A" in ω Cen. See text for details.

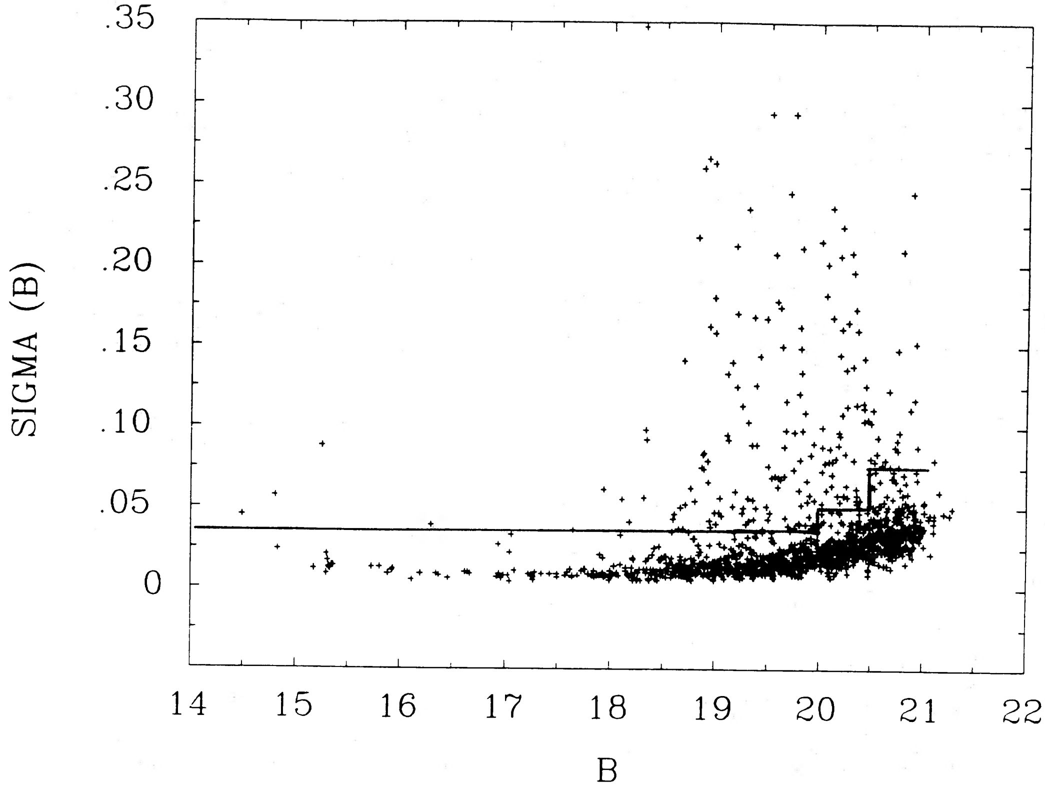

FIG. 4*a*

FIG. 4*a*.—Measure of variability $\sigma(B)$ of each DAOPHOT-identified star in the field of low-luminosity X-ray source "A" in ω Cen vs. apparent *B* magnitude. All stars above the horizontal lines were considered candidate variables. See text for details. (*b*) Same as Fig. 4*a*, but for the 47 Tuc field shown in Fig. 1*a*.

$E_{B-V} = 0.04$ to 47 Tuc and $E_{B-V} = 0.11$ to ω Cen). $M_B = 7.5$ is typical of the luminosities of quiescent dwarf novae (Warner 1976), but intrinsically fainter minima are not uncommon (Patterson 1984). Thus ω Cen A could be as optically variable as cataclysmics, but below our detection limit. However a recent paper by Margon and Bolte (1987) reports no evidence, on the basis of photometric colors, of cataclysmic-like candidates to $M = 10.6$ in the fields of three ω Cen low-luminosity X-ray sources.

The main sequence of 47 Tuc is at most a few hundredths of a magnitude wide (Hesser *et al.* 1987); binaries of any kind are therefore not expected and were not found photometrically by Hesser *et al.* (1987) or by ourselves.

Omega Cen has a remarkably broad main sequence (cf. Fig. 3) which suggests (at first glance) that a hunt for contact binaries would be rewarded. Ours is the first CCD survey for low-amplitude variables in ω Cen of which we are aware; we consider our complete lack of detections somewhat surprising. Metallicity variations in ω Cen may be the cause of the broad main sequence.

We found seven W UMas among 500 stars searched in the 10^{10} year-old NGC 188 (Kaluzny and Shara 1987), though the density of easily photometrically detectable (amplitude $\gtrsim 0.3$ mag) contact binaries in the solar neighborhood is probably one star in 10^3 (Duerbeck 1984). The density of contact binaries with amplitudes greater than 0.1 mag should be twice as great, i.e., 1 in 500. Using the latter value we find that the observed density (0 out of almost 4000) of contact binaries in our observed fields in ω Cen and 47 Tuc is at least as low, and possibly 8 times lower than that expected (8 out of 4000) in the solar neighborhood.

IV. CONCLUSIONS

We can briefly summarize our conclusions as follows.

1. No variables with *B* amplitudes greater than $\sigma_B =$ 0.03–0.08 mag were found among ~ 2200 stars with $M_B \lesssim +7.5$ in the field of a low-luminosity X-ray source in the globular cluster ω Cen or among 1550 stars with similar luminosity in 47 Tuc.
2. The ω Cen X-ray source most likely avoided detection by being very faint—either in a temporary or permanent low state. Alternatively, it may not be variable.
3. The space density of W UMa contact binaries is at least as low, and possibly 8 times lower in the outer parts of ω Cen and 47 Tuc than in the solar neighborhood.

We are pleased to thank the staff of CTIO for obtaining the ω Cen images for us, as part of their service observing program. M. M. S. and A. F. J. M. thank Pat Seitzer and Mauricio Navarette for support at the telescope. A. F. J. M. is grateful for financial support from the Natural Sciences and Engineering Research Council of Canada.

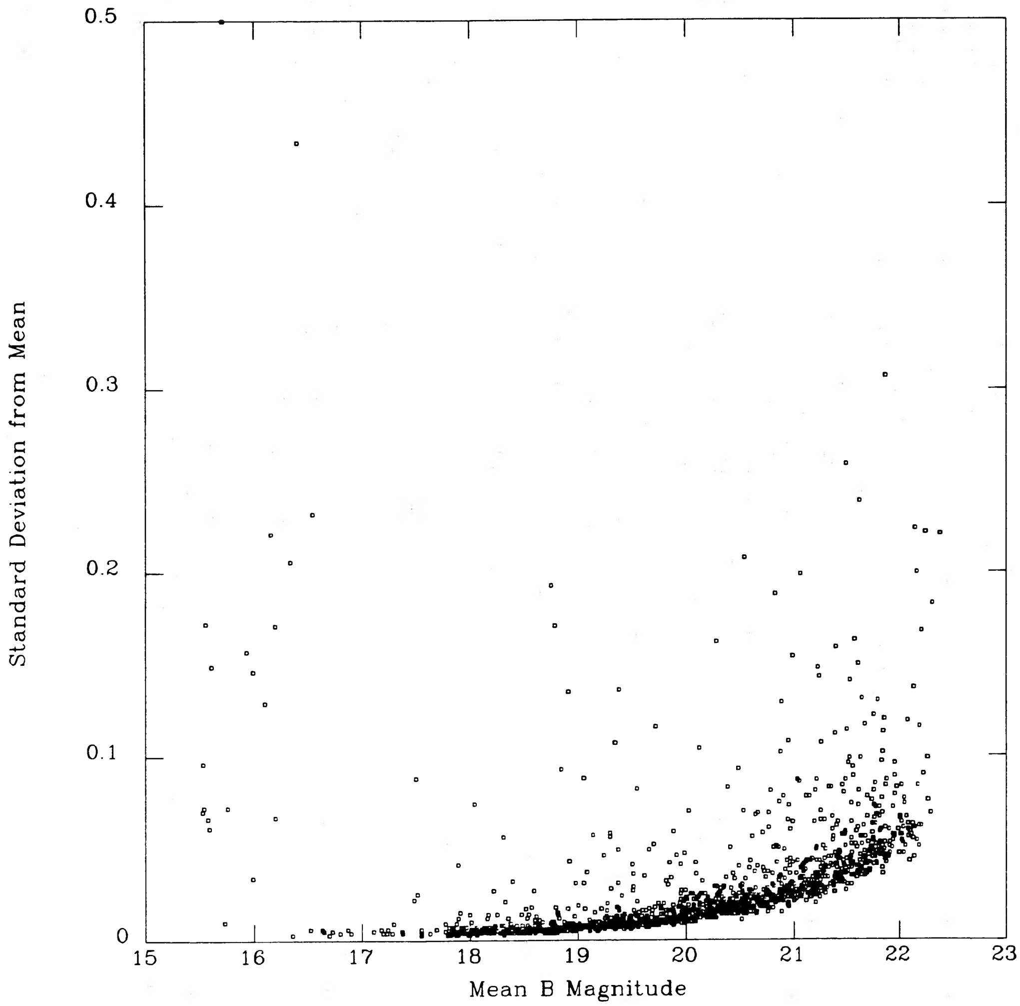

FIG. 4*b*

REFERENCES

Aurière, M., Le Fèvre, O., and Terzan, A. 1984, *Astr. Ap.*, **138**, 415.
Duerbeck, H. W. 1984, *Ap. Space Sci.*, **99**, 363.
Harris, W. E., and Racine, R. 1979, *Ann. Rev. Astr. Ap.*, **17**, 241.
Hertz, P., and Grindlay, J. E. 1983, *Ap. J.*, **275**, 105.
Hesser, J. E., Harris, W. E., VandenBerg, D. A., Allwright, J. W. B., Shott, P., and Stetson, P. 1987, preprint.
Irwin, M. J., and Trimble, V. 1984, *A.J.*, **89**, 83.
Kaluzny, J., and Shara, M. M. 1987, *Ap. J.*, **314**, 585.
Margon, B., and Bolte, M. 1987, *Ap. J.* (*Letters*), **321**, L61.
Margon, B., and Downes, R. A. 1983, *Ap. J.* (*Letters*), **274**, L31.
Margon, B., Downes, R. A., and Gunn, J. E. 1981, *Ap. J.* (*Letters*), **247**, L89.
Patterson, J. 1984, *Ap. J. Suppl.*, **54**, 443.
Shara, M. M., Moffat, A. F. J., Potter, M., Hogg, H. S., and Wehlau, A. 1986, *Ap. J.*, **311**, 796.
Stella, L., Priedhorsky, W., and White, N. 1987, *Ap. J.* (*Letters*), **312**, L17.
Stetson, P. 1987, *Pub. A.S.P.*, **99**, 191.
Verbunt, F., Shafer, R. A., Jonsen, F., Arnaud, K. A., and van Paradijs, J. 1987, preprint.
Walker, A. R. 1986, in *IAU Symposium 118, Instrumentation and Research Programmes for Small Telescopes*, ed. J. B. Hearnshaw, and P. L. Cottrell (Dordrecht: Reidel).
Warner, B. 1976, in *IAU Symposium 73, Structure and Evolution of Close Binary Systems*, ed. P. Eggleton, S. Mitton, and J. Whelan (Dordrecht: Reidel), p. 85.

JANUSZ KALUZNY, MICHAEL POTTER, and MICHAEL M. SHARA: Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

ANTHONY F. J. MOFFAT: Département de Physique, Université de Montréal, C.P. 6128, Succ. A, Montréal, P. Q. H3C 3J7 Canada