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CATACLYSMIC AND CLOSE BINARIES IN STAR CLUSTERS. II. PROBING THE CORE OF NGC 6752 WITH *HUBBLE SPACE TELESCOPE*[1]

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ABSTRACT

The cores of globular clusters have been predicted to be rich in close, interacting binaries. We have used the *Hubble Space Telescope* to test this prediction by monitoring 730 stars in the core of NGC 6752 for rapid variability. Thirty-one Faint Object Camera (FOC) images at 2200 Å, with time resolution of 14 minutes, and spanning 7 hr have been searched for variables.

Artificial star tests demonstrate that we should have found virtually all variables brighter than $m_{2200} = 20$ (i.e., $M_{220} \leq 6.75$) with variability amplitude $\Delta m \geq 0.25$ mag and most variables brighter than $m_{2200} = 22$ (i.e., $M_{2200} \leq 8.75$) with $\Delta m \geq 0.35$ mag. No variables were found; eight were expected based on tidal capture models in the one-fourth of the core that we observed. Our results strongly constrain the number of cataclysmic and contact binaries (with the above variability and luminosity limits) in the core of NGC 6752 to be ≤ 10 in total with 95% probability.

A color-magnitude diagram reveals the presence of four UV-excess stars below the turnoff, all located within 6″ of the cluster center. None show detectable variability ($\sigma \leq 0.1$ mag) during the 7 hr FOC observing sequence. Two of them are detected in archival *HST*/PC *R* and Hα images, but show no Hα excess. The lack of variability, the absence of Hα emission, as well as the fact that none of them appear in outburst in any of four epochs, strongly suggest that they are not cataclysmic variables.

This is the strongest observational test to date of simple tidal capture theory. NGC 6752 appears to have significantly fewer tidal capture binaries than the simple tidal capture theory predicts.

Five blue stragglers are discovered, as well as 14 horizontal-branch stars which completely dominate the cluster light at 2200 Å.

The main-sequence luminosity function of NGC 6752 is remarkably flat at the cluster center. This is in contrast to the rising value found by Da Costa at $10'.1 \leq r < 13'.2$, and Richer et al. at $6' \leq r < 10'$. Mass segregation probably accounts for the difference. The preponderance of low-mass stars in the outer parts of NGC 6752 may be due to enrichment (i.e., depletion of the core and transport outward of these low-mass stars) rather than being primordial. If this is true, then the suggestion that dissolved globular cluster low-mass Population II stars may be an important component of the mass budget of the Galactic halo is further weakened.

Subject headings: binaries: close — globular clusters: individual (NGC 6752) — novae, cataclysmic variables

1. INTRODUCTION

The cores of dense globular clusters are populated by relatively large numbers of exotic stellar species. X-ray binaries (Hertz & Grindlay 1983), millisecond pulsars (Manchester et al. 1991), and blue stragglers (Paresce et al. 1991) are all overabundant by orders of magnitude relative to the Galactic field. Far from being isolated curiosities, these unusual objects emphasize the extreme conditions in the centers of globular clusters.

Stellar densities in globular cores are high enough to give rise to tidal captures (Fabian, Pringle, & Rees 1975), binary disruptions (Hut, McMillan, & Romani 1992b) and stellar collisions (Hills & Day 1976). The energies involved in just a few dozen such events rival the binding energy of an entire globular cluster. Thus an understanding of the dynamical evolution of clusters can only be obtained after the formation, evolution, and destruction of close binaries are understood (see Hut et al. 1992a for a recent, comprehensive review of globular binaries).

A first step in this direction is a thorough census of the stellar inventories (particularly binaries) of several globular clusters, particularly the cores (the region $6r_c \leq r \leq 20r_c$ in M92 has recently been shown by Shara, Bergeron, & Moffat (1994) to be quite devoid of dwarf novae). Such surveys are very difficult to carry out with ground-based telescopes because of severe crowding in the inner few core radii of clusters. The high spatial resolution of the *Hubble Space Telescope* has now made such a survey for binaries in globular cores feasible. We report here on a search for close binaries near the center of the nearby cluster NGC 6752. Grindlay (1994) has recently summarized the *HST* and *ROSAT* surveys of NGC 6397.

Our technique is very similar to that of Shara et al. (1988), who used ground-based images to examine a total of 3754 stars in one 3′ × 5′ field (well outside the core) in both 47 Tuc and ω Cen. The field in 47 Tuc was imaged every 260 s for 3.3 hr; the ω Cen field was imaged (with 60 s exposures) 10 times over 3.5 hr. No variables (with amplitude ≥0.1 mag, and $M_B \leq 7.5$) were found.

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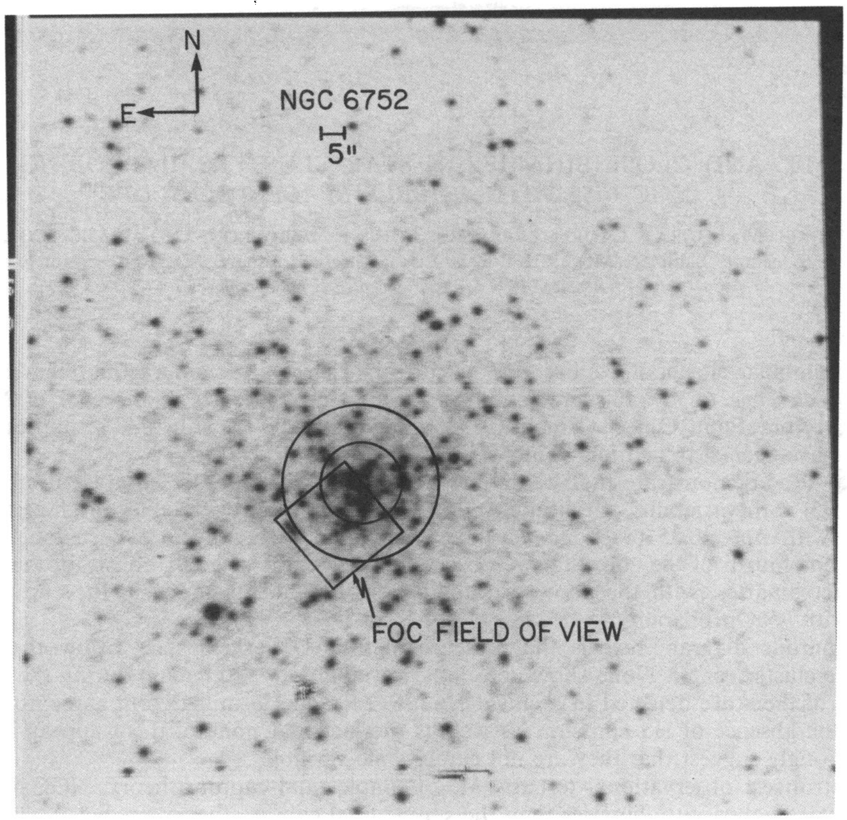

FIG. 1a

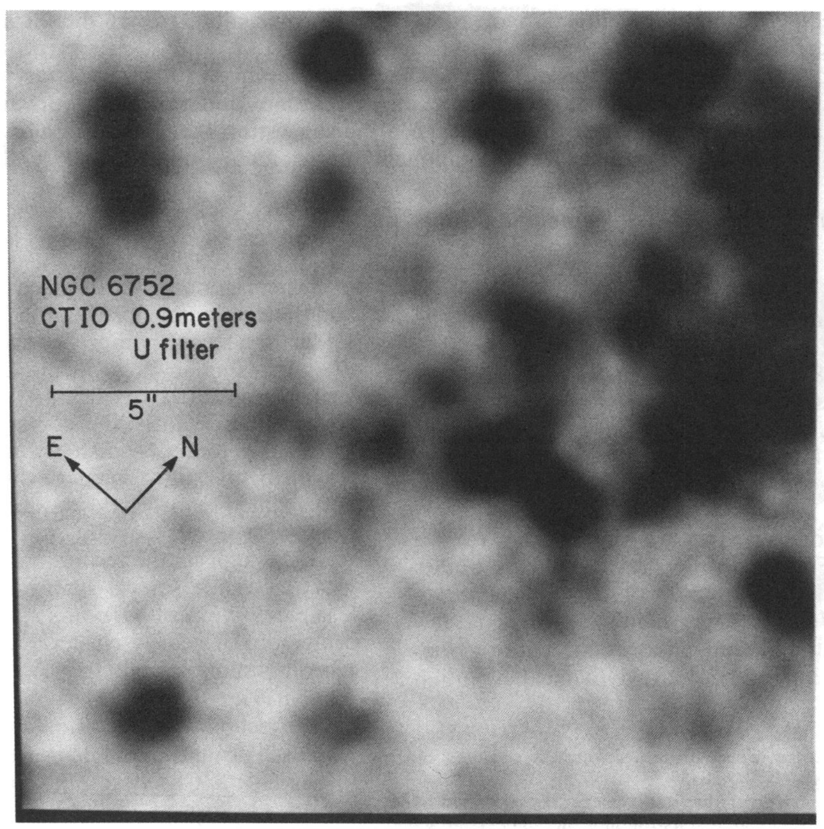

FIG. 1b

FIG. 1.—(a) A U-band image of NGC 6752 taken with the CTIO 0.9 m telescope + TEK 1024 CCD. The *HST* FOC field of view is indicated. The inner circle has a radius of 10".5 (= 1 core radius). The outer circle has a radius of $2r_c$. (b) An enlarged section of (a), covering only the FOC field of view. (c) The median-filtered FOC f/48 image with the F220W filter of much of the core of NGC 6752. The limiting magnitude on this frame is $m_{220} \sim 23.5$.

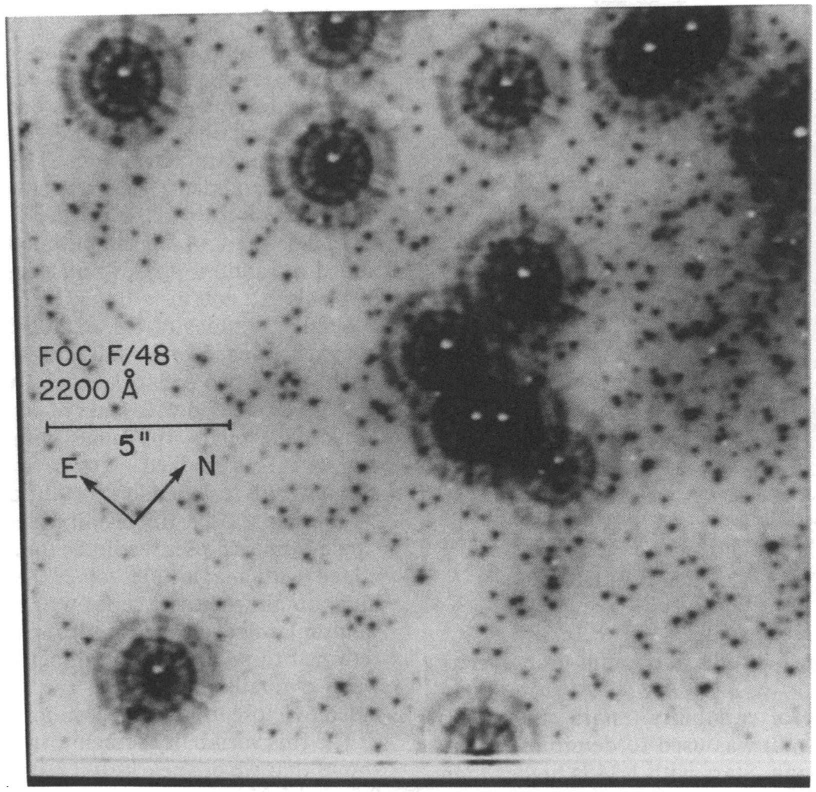

FIG. 1c

The rationale behind the search of Shara et al. (1988) was the following. Virtually all cataclysmic and contact binaries have orbital periods under 12 hr and amplitudes ranging from a few tenths of a magnitude to a full magnitude (or more in the case of cataclysmic eclipses). In addition, most cataclysmics "flicker" with amplitudes of several tenths of a magnitude on timescales of minutes. Such variations are easy to detect on repeated digital frames using PSF fitting and/or aperture photometry techniques.

In § 2 we describe the *HST* observations, and in § 3 we detail the variables search methodology and completeness tests. Searches for faint blue stars are described in § 4. Tidal capture theories' uncertainties and predictions are discussed in § 5. The results and their implications are subjects of § 6. The cluster core luminosity function is presented in § 7, and our results are summarized in § 8.

2. OBSERVATIONS

Thirty-one images of the globular cluster NGC 6752 were taken with the Faint Object Camera (FOC) aboard the *Hubble Space Telescope* on 1991 November 14. Each image is of approximately 600 s duration and the midexposure times are separated by 14 minutes. The FOC was used in the f/48 512 × 512 pixel^2 configuration, giving a field of view of 22″ on a side. The F220W filter ($\lambda_{\rm central}$ = 2250 Å) was used for all the exposures. The images were calibrated through the standard data pipeline at STScI.

The FOC field of view was deliberately centered about 10″ southeast of the cluster core. (This was done to facilitate a check on the radial dependence of the luminosity function; see § 6.) The area of NGC 6752 that was imaged repeatedly is shown in Figures 1*a*–1*c*.

A large number of *HST*/PC images of NGC 6752 are now available in the archives. We have therefore retrieved a series of eight frames (1000 s each) obtained with the F336W filter (∼ Johnson *U*) [w1140403t to w114040at], and five 100 s F555W (∼ Johnson *V*) frames [w11h0101t to w11h0105t], and five 100 s F785LP (∼ Johnson *I*) frames [w11h0106t to w11h010at]. The frames taken with the same filter were then median filtered to remove cosmic rays and produce a deeper image in each of *U*, *V*, and *I* passbands. Although the PC images are 66″ on a side, we analyzed only the area covered by our FOC F220W images (22″ × 22″).

3. THE SEARCHES FOR VARIABLES

3.1. *The Median Frames*

To increase the signal-to-noise ratio, the 31 F220W images were first median-averaged in sets of three. This resulted in a series of 10 median-averaged frames, each separated by 42 minutes in time. DAOPHOT was then used to obtain profile-fitting photometry for each star in each of the 10 frames. To ensure that no stars would be missed on any of the frames, a separate object search was performed on each frame. This produced 10 independent lists of objects which were then matched by coordinates.

Detected objects separated by less than 1.5 pixels on separate frames were considered to be the same object. In this way, a master list was produced and DAOPHOT was run again on all the frames to obtain profile fitting photometry for each object in all 10 frames. The magnitudes were also converted from instrumental to 2200 Å magnitudes.

There were 1942 objects in the master list but only 730 stars. Most nonstars are actually detections of the bright structures

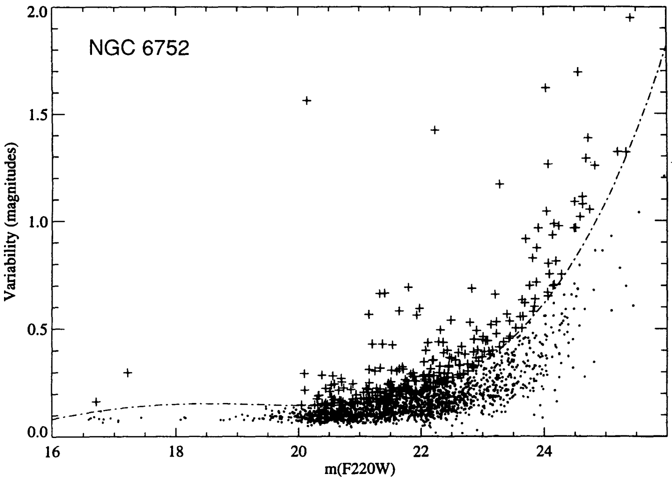

FIG. 2.—The rms magnitude of variability vs. the F220W magnitudes for each star in the 10 median frame set. The dashed line is the 1.5 σ cutoff, above which 297 plus signs are the candidate variables that were examined more closely.

in the PSFs of the 14 extremely bright horizontal-branch stars in the field.

A plot of rms magnitude of variability (Shara et al. 1988) versus mean magnitude (Fig. 2) was used to determine if any stars in the cluster was varying. Stars with RMSs higher than 1.5 σ above the mean curve (plus signs in Fig. 2) were considered possible variables and were examined more closely. *No stars in the field were found to be variable over the period of the observations.*

Since a search based strictly on the variability over 10 frames might be somewhat insensitive to objects which erupt or are eclipsed over just a few tens of minutes, a second search was performed. This search involved checking the absolute difference between a star's magnitude in one frame and its magnitude in the next frame. If this difference was larger than 3 σ above the mean of that of all the detected stars (at similar magnitude), then the star was considered a possible variable as before and examined more closely. This "difference search" process was repeated for every pair of frames in the 10 frame set. Again, *no variables were found.*

3.2. *The Individual Frames*

A second search was conducted on the original 31 frames rather than the 10 median-averaged frames, to be sure that nothing had been lost in the medianing process, and to make use of the full time resolution of the data. Aperture photometry was compared directly with the PSF photometry for the 10 median-averaged frames. For very small apertures (about 2 pixels) the aperture results were comparable to (or slightly better than) the PSF results.

A search was therefore conducted with aperture photometry on the 31 frame set using the same master list that was used in the first search. All 83 stars that were above the 2 σ curve in the rms variability plot were examined individually. None were genuine variables. Again, most of the false candidates were spurious detections in the wings of the PSFs of bright stars.

The "difference search" (described at the end of § 3.1) for rapidly eclipsing or erupting stars was also performed on the full set of 31 images. *No variables were found.*

3.3. *Completeness*

To determine the completeness of our search, a number of artificial variable stars were added to the 10 median frame data set in the following manner. (A completeness test on the full 31 frames is described at the end of this section.) In each of two full (and separate) sets of frames, 100 stars with sinusoidal light curves were added. The first set of artificial stars had a faint magnitude limit of 20.0 (in the F220W passband), while the second set had a faint magnitude limit of 22.0. The stars were added at random phases on a regular 10 × 10 grid (i.e., every 50 pixels in *x* and *y*).

Semiamplitudes of 1.0, 0.5, 0.35, 0.25, and 0.175 mag were assigned to each of 20 stars in each set of 100 artificial stars. Each of the two sets of artificial variable stars just described above was created with stars of periods of 2, 4, 8, and 16 hr (i.e., a complete set of 10 frames with 100 stars at each of these periods). This enabled us to determine the period, amplitude, and magnitude dependence of the completeness.

Another set of artificial variables was added to test how well single-frame eclipses would be found. Sets of 20 stars each were added with magnitudes of 22.0—(2.0, 1.0, 0.7, 0.5, and 0.35 mag) on all frames, except on one frame in the set (selected at random) where each star dropped to $m_{220} = 22.0$, and then returned to its original brightness. This simulated stars which were normally well above the detector limit, but suddenly faded to (close to) the detector limit one one frame.

The rms variability search through the sinusoidal set (Fig. 3) shows that we are nearly 100% complete for amplitudes of 1.0, 0.5, and 0.35 mag at periods of 2, 4, and 8 hr for faintest state magnitudes of 20.0 and 22.0 (F220W). Detection completeness falls to ~60% (~40%) at 20.0 (22.0) mag for 0.25 mag amplitudes and is ≤10% for 0.175 mag amplitudes.

The "difference search" through the set of images with artificial single-frame eclipses produced detection completeness virtually identical to those in Figure 3.

A set of artificial stars with "single-frame" eclipses as described above was added to the full set of 31 frames to check if there was any difference in the completeness level between the 10 and 31 frame sets. Virtually all stars eclipsing by 2.0, 1.0, or 0.7 mag, to reach $m_{220} = 22.0$ at minimum are detected. Eclipses 0.5 mag deep are detected with 65% completeness, while 0.35 mag eclipses are found 30% of the time.

4. SEARCH FOR FAINT BLUE STARS

Since the search for variable stars revealed no CV candidates, we decided to look for cataclysmic variables in color-magnitude diagrams obtained from *HST* archival images. CVs are expected to populate a region below the turnoff and significantly bluer than the main sequence.

4.1. *Photometry*

The 25 best F220W frames have been median-filtered to produce a single, very deep image. Since we were looking for very blue objects, we first created a master list of coordinates and magnitudes for stars detected in this deep FOC F220W image, in the following way. Because of the detector's nonlinearity at high count rates, the 15 bright, saturated stars (all of them horizontal-branch stars, as we shall see later) and the fainter, unsaturated stars were treated separately.

As a first step, DAOFIND and PHOT were used to locate most faint stars in the field and to determine their magnitudes. At this stage, the halo around every bright star was masked out

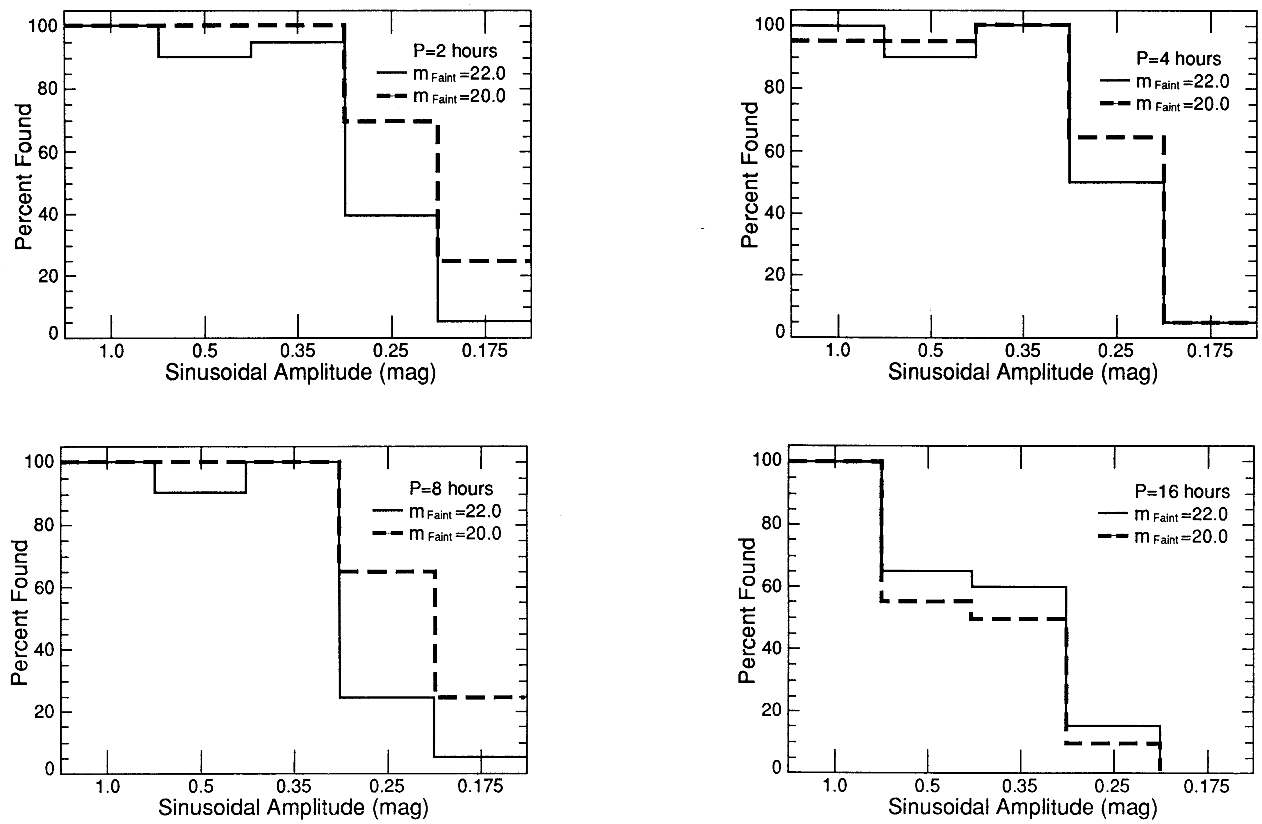

FIG. 3.—The percentage of artificial stars found for the sets of artificial variables (one for each set of periods 2, 4, 8, and 16 hr) with F220W magnitudes of 20.0 and 22.0.

in order to avoid the spurious detection of bright features in the tendrils of the infamous *HST* PSF. An average point-spread function for the faint stars was then determined using seven well-exposed, but unsaturated, isolated stars across the field. We chose to determine this PSF only up to a radius of 7 pixels, since the halo of even the brightest, non–HB star gets lost in the background noise further out. NSTAR was then used to determine PSF-fitting magnitudes for the stars (which is mostly useful to improve the photometric accuracy for crowded stars). These stars were subtracted from the frame, using SUBSTAR. This allowed us to locate faint stars that were overlooked at first. A few iterations of NSTAR and SUBSTAR were performed until all stars visible on the workstation monitor were detected.

The PSF of the HB stars was determined as follows. After having located manually the faint stars within the halos of the four isolated HB stars and having removed them with NSTAR, an average PSF was determined for the HB stars. In this case, the PSF was fitted only to the outer, unsaturated part of the profile (in order to avoid nonlinearity effects in the central, saturated part) out to a radius of 50 pixels ($\sim 2''.3$). An approximate position was determined manually for the remaining HB stars (except two of them, for which the center was located outside the detector field). Their precise positions and instrumental magnitudes were then determined by NSTAR.

Finally, the profiles of the HB stars were removed from the original image with SUBSTAR. This allowed us to iteratively locate and measure the faint stars located within the halos of the bright HB stars. A master list of 730 genuine stars resulted from this process. In order to make sure that the positions and magnitudes of all stars were determined accurately, we created an artificial image using the master list and the two PSFs and compared it to the original image. The agreement was excellent.

Using the masterlist, and after having determined the offsets and rotation angles between the FOC and PC images, DAOPHOT's aperture photometry routine PHOT was run on the U, V, and I images. An aperture radius of 2 pixels was used, and the sky was determined in an annulus around the stars with inner and outer radii of 5 and 11 pixels, respectively.

4.2. *Photometric Calibration*

The transformation between instrumental magnitudes determined by DAOPHOT and standard magnitudes was done as follows. In the case of FOC, the *HST* magnitude is defined as

$$M_{\rm FOC} = -21.1 - 2.5 \log \left(\frac{Uc}{\epsilon t}\right),$$

where U is the inverse sensitivity (here, $U_{220\rm W} = 1.74 \times 10^{-17}$), c is the number of counts in the aperture, ϵ is the fraction of energy within the aperture, and t is the exposure time in seconds. To calibrate the nonsaturated stars, we chose five isolated stars and performed aperture photometry using a 5 pixel radius (in which case $\epsilon = 0.294$ for the F220W filter; see Table 8 in Paresce 1992). For the bright HB stars, the count rate of the four isolated HB stars was measured in an annulus with an inner radius of 14 pixels (i.e., farther out, the nonlinearity of the detector becomes negligible) and an outer radius of 50 pixels; the fraction of light included in this annulus, ϵ, is 0.53 (Paresce 1992). The resulting offsets were then applied to all stars in the frame.

For the PC data, the standard magnitude is defined as

$$M_{PC} = Z_{\lambda} - 2.5 \log R ,$$

where Z_{λ} is the system zero point (from Table 12.15 in Hunter et al. 1992, $Z_{336W} = 19.08$, $Z_{555W} = 23.05$, and $Z_{785LP} = 21.543$), and R is the total observed count rate for each star. Aperture corrections determined by Hunter et al. (their Table 12.7) were used to determine the total count rate from the count rate in the small aperture. Moreover, the absolute sensitivity of the CCDs is known to slowly decrease with time after

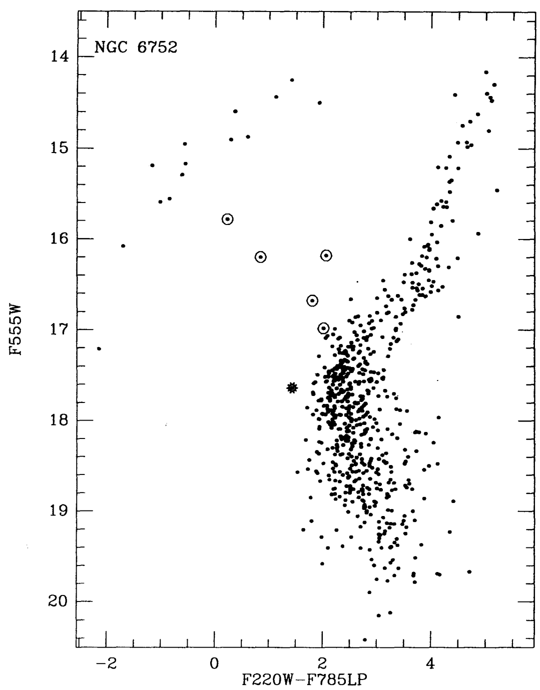

FIG. 4*a*

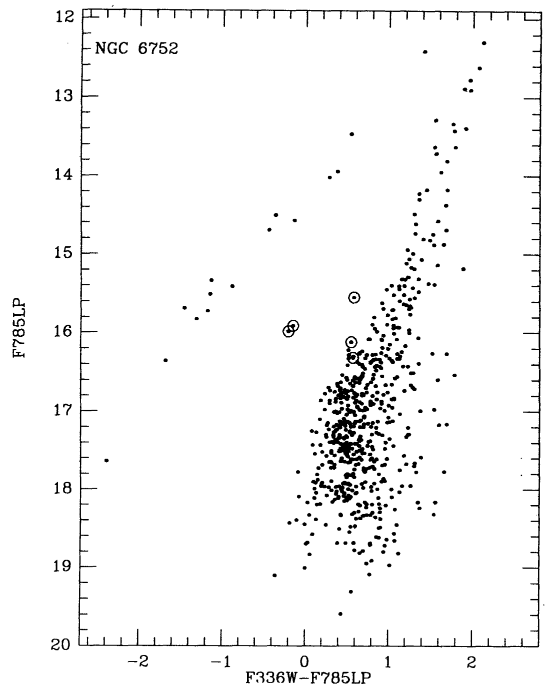

FIG. 4*b*

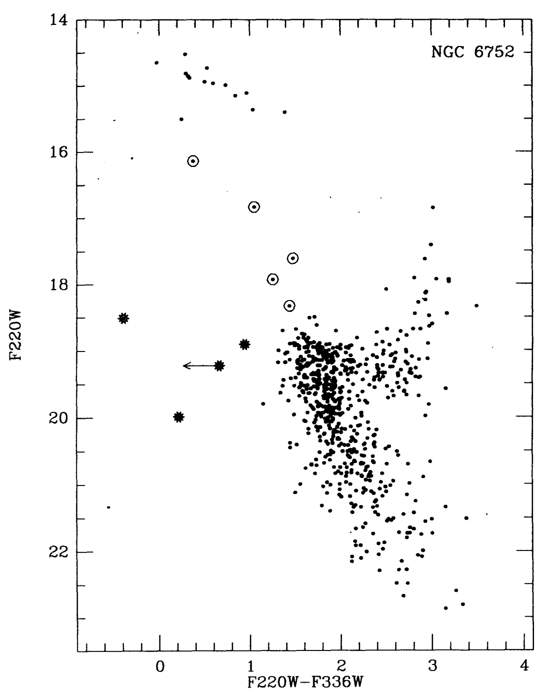

FIG. 4*c*

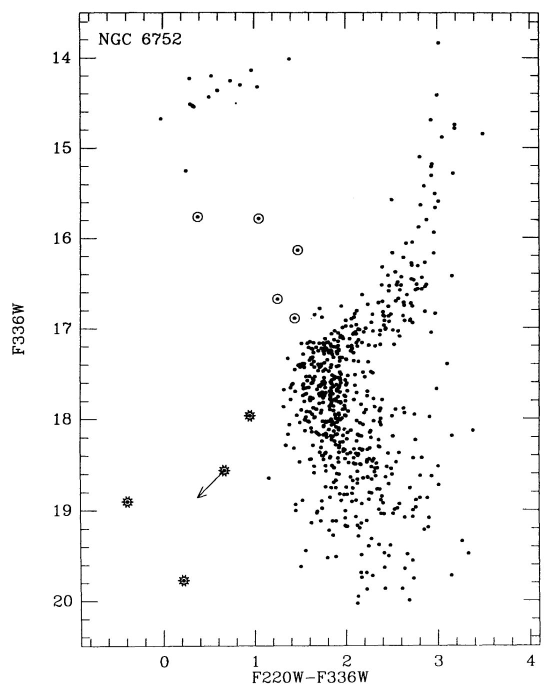

FIG. 4*d*

FIG. 4.—Color-magnitude diagrams of the inner 22″ of NGC 6752. Larger filled circles indicate blue straggler stars, and starred points indicate the four faint UV-excess stars.

each decontamination event (Ritchie & MacKenty 1993). This effect was taken into account.

4.3. *The Color-Magnitude Diagrams*

Color-magnitude diagrams of NGC 6752 obtained as described above are shown in Figures 4*a*–4*d*. They can be compared with ground-based CMDs of the cluster's outer regions (Gascoigne & Ogson 1963; Cannon 1981; Buonanno et al. 1986a, b; Penny & Dickens 1986). The main sequence is clearly seen in all diagrams, down to $\sim$3 mag below the turnoff. The subgiant and red giant branches are also well defined. As noted previously from ground-based CMDs, very few, if any, horizontal-branch stars are seen on the red side of the RR Lyrae gap (itself devoid of any variable star). This HB morphology is expected for an old, low-metallicity cluster such as NGC 6752 ([Fe/H] $= -1.5$; Buonanno et al. 1986b).

All ground-based CMDs of NGC 6752 show a dichotomy in the distribution of the blue HB stars: the bulk of HB stars have $13.5 \leq V \leq 15.5$, and a second, less populated group (the extended horizontal branch; EHB), lies at $16.5 \leq V \leq 18.0$. The "gap" between these two regions is very scarcely populated. Spectroscopy of a few BHB stars in NGC 6752 (Caloi et al. 1986) showed that these stars may represent the cluster counterpart of the field B subdwarfs (see Saffer et al. 1994). Figure 4 shows that *only one EHB star is present in the cluster core.*

Buonanno et al. (1986a) previously noticed that the ratio of the number of EHB stars to the number of their bright counterparts decreases towards the inner regions of NGC 6752 (and, to a lesser extent, in M15), down to $r = 1\farcm5$ (i.e., the limit of ground-based observations). This ratio, N(EHB)/N(HB), was measured by Buonanno et al. (1986a) and is seen to drop from 1.1 (45/41) at $r \geq 4\farcm5$, to 0.4 (37/87) at $1\farcm5 \leq r \leq 4\farcm5$. Our measurement at $r \leq 0\farcm35$ yields N(EHB)/N(HB) = 0.08 (1/13); see Fig. 5. Our data therefore strongly confirm this trend and demonstrate that EHB stars shun the core of NGC 6752.

Also, in contrast with the outer regions of the cluster, where no blue straggler population is seen (Cannon 1981; Buonanno et al. 1986b), the core of NGC 6752 (i.e., the region covered by the FOC data) is seen to contain five blue stragglers.

4.4. *The Four Faint Blue Stars*

Four faint stars show a clear UV excess in Figures 4*c*–4*d*; *they are among the bluest stars in the cluster, and are all located within 6″* (i.e., 0.6 $r_{\rm core}$) *of the cluster's geometrical center.* Although easily detectable in the F220W image (between 3 and 4.5 mag above the detection limit), three of them are barely visible in the F336W (Fig. 6). Only star 603 is also detected at longer wavelengths, and its colors longward of 2200 Å are comparable to those of main-sequence stars. The location of these four stars in the F220W versus F220W–F336W CMD is very similar to that of the four faint blue stars recently discovered by De Marchi & Paresce (1994, hereafter DP; see their Fig. 2) in the core of NGC 6397. Because of their magnitudes and colors, possible variability of three of the four blue stars over a 5 hr interval and position within the error circle of *ROSAT* HRI X-ray sources, DP suggested that the four blue stars in NGC 6397 are cataclysmic variables. The three blue stars in NGC 6397 that DP tentatively identified as variable (DP1, DP2, and DP4) were located in FOC focus-test frames before the successful *HST* refurbishment mission. DP3 could not be tested for variability because it lay in the wings of the PSF of a bright, nearby star.

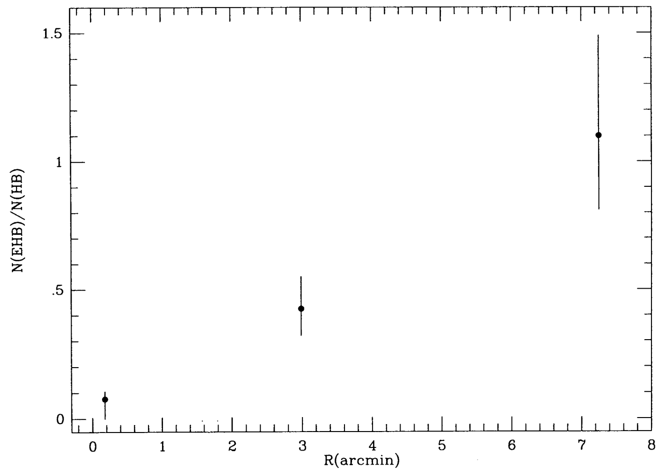

FIG. 5.—The ratio of number of extended horizontal-branch stars (EHB) vs. horizontal-branch stars (HB) as a function of the distance from the center of NGC 6752. The outer two points are due to Buonanno et al. (1986a), while the inner point is from the present work.

We have now been able to examine five postrefurbishment images of the core of NGC 6397 taken with the FOC through the F253M filter over the space of 3 hr on 1994 March 4. Further instrumental details will be published in Paresce & De Marchi (1994). During the 3 hr of observation, DP1, DP2, and DP4 did *not* show any variability above the instrumental threshold. The rms variability of these three stars is $\leq$0.1 over the period of the observations. While we have not observed the three blue stars often enough, or over an interval long enough to rule out variability beyond any doubt, we can say with confidence that they were remarkably constant during our observations. PSF variability during the focus test observations of DP might be responsible for some or all of the variability of DP1, DP2, and DP4 reported by these authors.

The fourth star, DP3, is clearly variable; its light curve is shown in Paresce & De Marchi (1994b). The star's amplitude is 0.4 mag over the five observations, with similar brightness stars showing variations $\leq$0.05 mag.

Although it is tempting to suggest that the four UV-excess stars in NGC 6752 are CVs (and, since they occupy the same region in the CMD as the blue stars in NGC 6397, that these are also CVs), their nature is far from clear for several reasons. First, they do not show variability even remotely approaching that of most cataclysmics, above the instrumental threshold during the 7 hr FOC observations. *The σ values for all four stars range from 0.05 to 0.1 mag, i.e., comparable to the variability level of surrounding stars of similar magnitude* (Fig. 7). Moreover, none of them show any sign of being in eruption in any of the archival *HST* images, obtained at four different epochs. Finally, *HST*/PC archival *R* and Hα images were examined to detect possible Hα enhancements. Only two of the four faint blue stars were detected in these images, and they do not show any significant Hα excess. These arguments cast serious doubts on the suggestion of a CV nature of these four stars (but do not completely rule it out, either.) The remarkably blue colors and strong central concentration of these stars clearly warrant further study.

5. TIDAL CAPTURE THEORIES: UNCERTAINTIES AND PREDICTIONS

The simple tidal capture theory of Fabian, Pringle, & Rees (1975, hereafter FPR) was formulated to explain the remark-

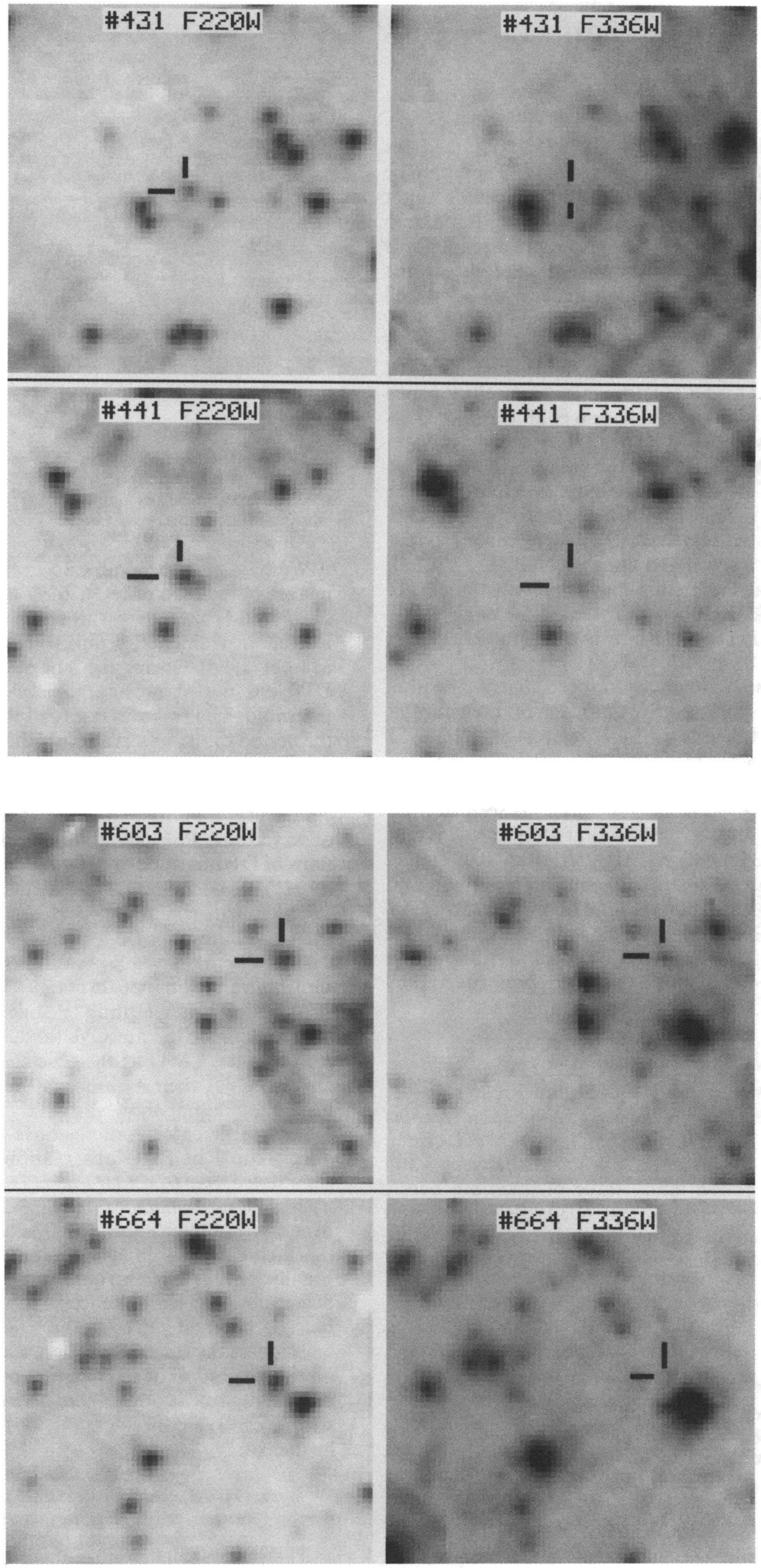

FIG. 6.—Finding charts for the four faint UV-excess stars in NGC 6752. Each chart is 3″ on a side, and the orientation is the same as in Fig. 1*c*.

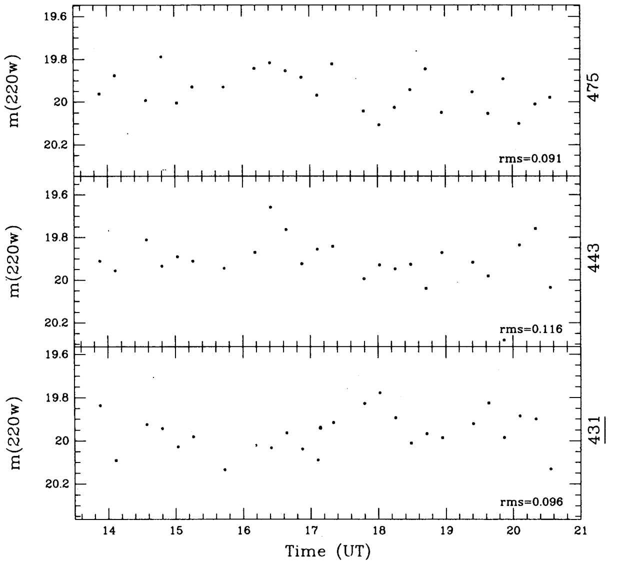

FIG. 7*a*

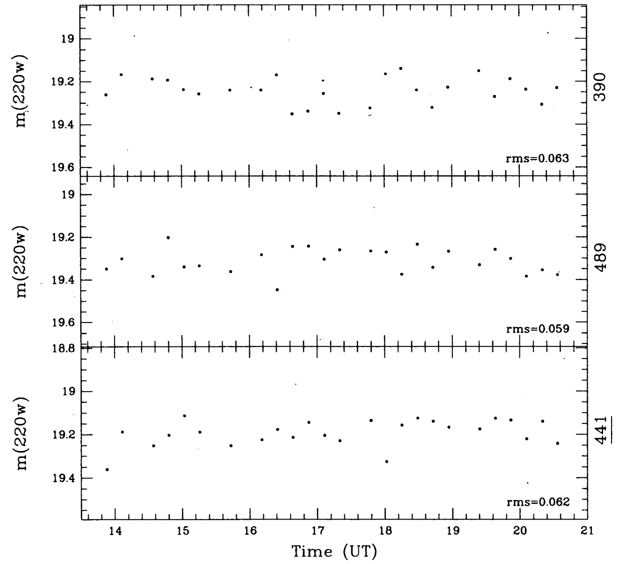

FIG. 7*b*

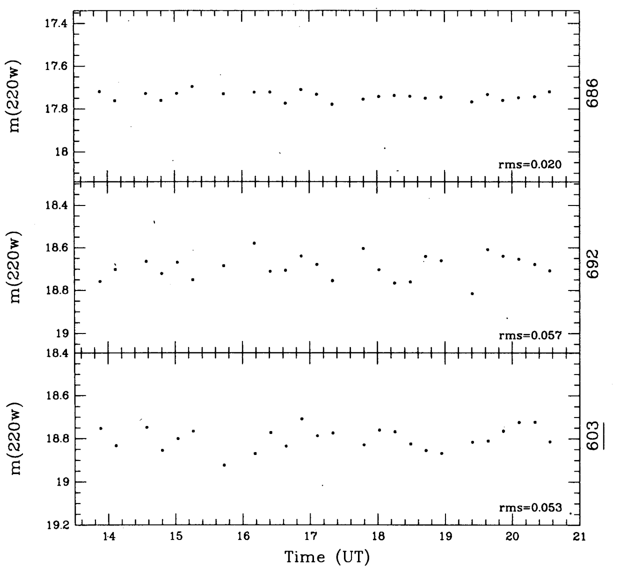

FIG. 7*c*

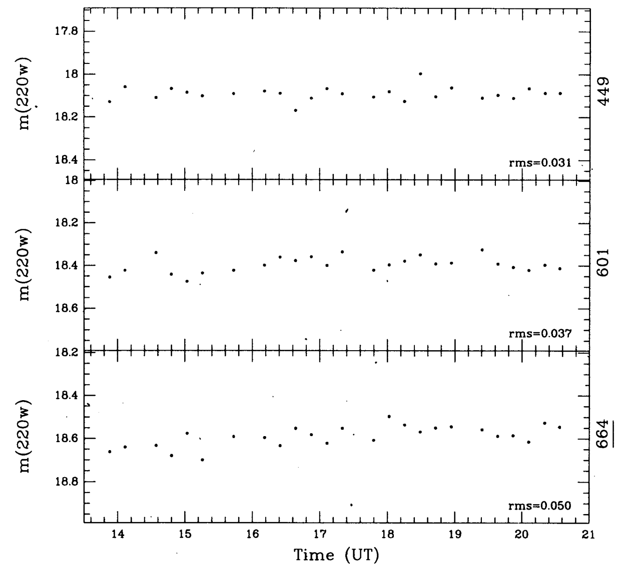

FIG. 7*d*

FIG. 7.—Light curves of the four faint UV-excess stars (*underlined*) and comparison stars

ably large population of X-ray sources (Katz 1975) in globular cluster cores. A compact object passing within roughly 3 stellar radii of a nondegenerate star was shown by FPR to deposit enough tidal energy (at the expense of orbital energy) in the nondegenerate star to change the orbit of the two stars from hyperbolic to elliptical. When the compact object is a neutron star, an X-ray source will form after orbit circularization. In the case of a white dwarf capturing a main-sequence star, a cataclysmic variable will form. The same process, at least in principle, should also work toward forming very close binary main-sequence stars.

This simple theory, coupled with an estimate of the stellar population, density, and velocity dispersion in a globular cluster can be used to predict the formation rate of close binaries. Coupled with a stellar evolution code (to model the development of the tidal capture binaries) the FPR theory can be used to predict the numbers, types, and luminosities of globular cluster core close binaries.

The focus of this paper is to test the above simple model. Anticipating that we will find a significant discrepancy between the model's predictions and our observations, we now review the main caveats and possible modifications to the baseline FPR theory. Principal among these is uncertainty about the fate of energy deposited in the nondegenerate star or stars during tidal capture.

McMillan, McDermott, & Taam (1987), Ray, Kembhavi, & Antia (1987), and others have suggested that rapid mergers are likely to result from most tidal captures. This is because the timescale to dissipate the deposited tidal energy (the envelope thermal timescale) can be long when compared with the timescale for envelope heating due to repeated periastron passages. Such mergers should lead to blue stragglers and a dearth of close binaries.

A contrary view is taken by Kochanek (1992) and Mardling (1994). These authors demonstrate that tidal energy can be fed back into a binary's orbit, dramatically slowing or reversing the rate of tidally induced envelope expansion. Mardling (1994) maintains that 10^8 yr is the circulation time for many tidal capture binaries, and that fairly elliptical orbits should be commonplace during the long circularization process. We now review our observational results and use them to place constraints on the theories described above.

6. CONSTRAINTS ON TIDAL CAPTURE THEORY FROM LIMITS ON CATACLYSMIC BINARIES AND CONTACT BINARIES

Our search of NGC 6752, from the cluster center to about 2 core radii ($r_c = 10\farcs5$; cf. Trager, Djorgovski, & King 1993) yielded zero variables with $m_{220} \leq 22$, periods ≤ 16 hr, and semiamplitudes ≥ 0.25 mag. Our field-of-view center was deliberately offset from the cluster center, so that we covered about 40% of the inner core radius, and 25% of the volume between $r_c \leq r \leq 2r_c$ (see Fig. 1*a*). This corresponds to about 30% of the core mass, and about 80% × 0.3 ~ 1/4 of the cluster massive binaries (Verbunt & Meylan 1988).

Di Stefano & Rappaport (1994, hereafter DR) have estimated the tidal capture formation rate and subsequent evolution of cataclysmic binaries in the core of 47 Tuc. They estimate that ~100 CVs should now be active in that globular cluster, with ~45 having luminosities L over 10^{33} ergs s^{-1}. (Our variability detection limits of $M_{2200} \leq +8.5$ and $M_{2200} \leq +6.5$ correspond [roughly] to 10^{32} ergs s^{-1} and 10^{33} ergs s^{-1}, respectively. We will use only the conservative 10^{33} ergs s^{-1} detection limit in the probabilistic arguments given below.)

Scaling from their 47 Tuc simulations, DR find ~100 CVs in NGC 6752, but only ~15 should have accretion luminosities above 10^{33} ergs s^{-1}. A similar number of contact binaries CBs (assuming CVs and CBs form via tidal capture) should also exist in NGC 6752. Our areal and binary fraction coverage of the core of NGC 6752 then suggests that we should have detected 1/4 × 15 ~ four CBs and four CVs.

The absence of any variables with periods of hours, and brightnesses and colors comparable to typical cataclysmic variables or contact binaries is striking. The further paucity of Hα emission stars (Grindlay 1994 reports the discovery of two marginal detections down to $M_V \sim +6$) or dwarf nova–like eruptions during four independent epochs of observation further weighs against a significant population of cataclysmics.

A simple probabilistic limit on the number of CVs or contact binaries present in the core of NGC 6752 can now be derived. We assume that N CVs and N CBs inhabit the core of this globular. Then the probability that N CVs or N CBs are located in the 75% of the core we did not observe, while 0 close binaries are located in the 25% of the core that we did observe is $(0.75)^N$. Thus, for example, the probability of there being 15 bright cataclysmic variables in NGC 6752 but 0 in the one-fourth of the core that we observed is $(0.75)^{15} = 0.013$. A similar probability exists for CBs. Similarly, the probability of there being 10 CBs and CVs in total in the core of NGC 6752 (DR predict 30) is $(0.75)^{10} = 0.056$.

These probabilities are, of course, based on small number samples. They certainly demonstate (together with our observations) that simple tidal capture theory is not *underestimating* the number of globular core CVs or CBs. The present results suggest that the core of NGC 6752 is remarkably deficient in CVs and CBs (with respect to the prediction of simple tidal capture theory), but fainter coverage of the entire cluster core will be needed to make the argument airtight. Nevertheless, the simultaneous presence of blue stragglers and absence of close binaries strongly suggests that blue stragglers are the products of direct stellar collisions or tidal capture–induced mergers, rather than merger after close binary evolution. The lack of close binaries also argues against the Kochanek (1992) and Mardling (1994) scenarios of extended orbital circularization times, though longer continuous time coverage (larger than the 7 hr reported here) of several globular cores is needed before this argument can be considered certain.

Finally, we note that binary-single and binary-binary collisions have been proposed as the sources of at least some blue stragglers (Leonard & Fahlman 1991; Leonard & Linnell 1992). The lack of detected short-period binaries ($P < 16$ hr) in the core of NGC 6752 certainly suggests that such binaries do not play a role in blue straggler formation.

7. LUMINOSITY FUNCTION

The UV luminosity function for the inner region of NGC 6752 was determined from the master list of stars detected in the deep, median-filtered FOC F220W image. To determine the completeness level of our star detections, we have performed a series of artificial star recovery tests as follows. For each magnitude interval (of 1 mag, from $m_{220} =$ 19.0 to 23.0), 25 artificial stars were inserted randomly in the median-filtered frame with the routine ADDSTAR; the same detection techniques as described in § 4.1 were then used to recover them. This procedure was performed 3 times per magnitude interval in order to improve the statistics. The success rate was consistently lower in the (most crowded) upper left part of the image.

The luminosity function at 2200 Å is graphed in Figure 8*a* (where Φ is the number of stars between $m - 0.25$ mag and $m + 0.25$ mag). Two corrections were applied to the observed data points (shown as filled circles in Fig. 8*a*). First, as one can see in Figure 4*c*, the subgiant stars have the same m_{220} magnitude as the upper part of the main sequence; this creates a "bump" in the LF between $m_{220} = 18.75$ and 19.75. Therefore, the values of Φ after the subgiant stars were removed are shown as open circles. Second, incompleteness factors become nonnegligible for stars fainter than $m_{220} = 19.75$. The corrected values are also shown as open circles.

The most remarkable feature of the LF is the rather flat main sequence. This is in sharp contrast to the NGC 6752 V luminosity function of Da Costa (1982) (see also Penny & Dickens 1986). The latter continues to rise monotonically toward fainter magnitudes (all the way to $M_V = +9$). Although the completeness factors in the five faintest bins are difficult to evaluate, and may be inaccurate, it should be mentioned that stars with $m_{220} \leq 21.5$ were very easily detectable and that incompleteness factors cannot be responsible for the apparent lack of stars in this magnitude range.

Since we are using a very different passband from Da Costa's V, could the discrepancy between the two LFs be caused by a color effect? We tested this by determining the LF in archival *HST*/PC F555W images (only the area in common with the F220W frame was analyzed). The results are shown in Figure 8*b*. We see again here that, in contrast with Da Costa's result, the luminosity function of the main sequence does not increase

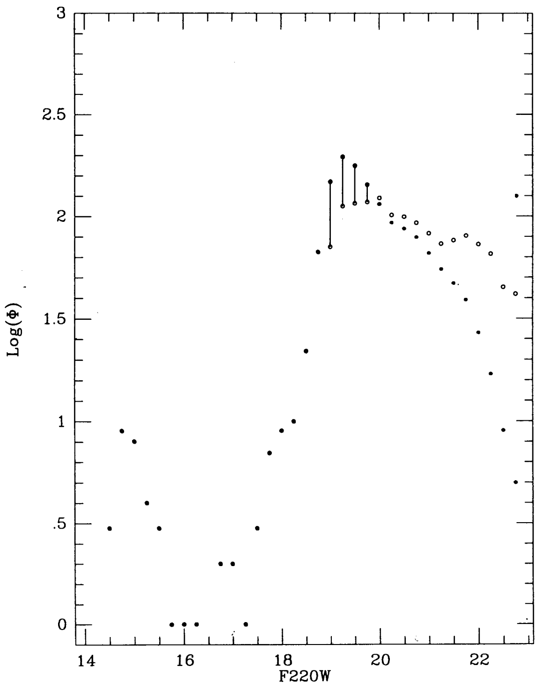

FIG. 8*a*

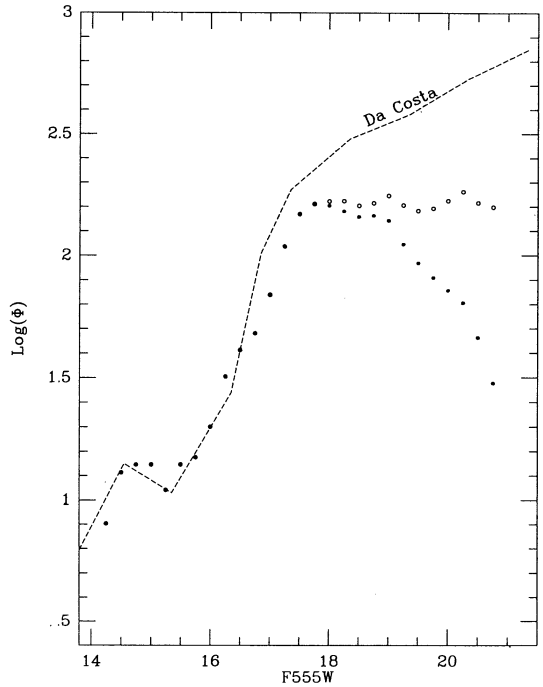

FIG. 8*b*

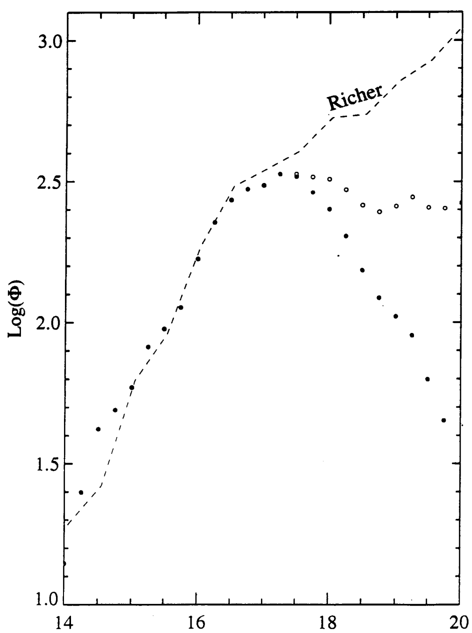

FIG. 8*c*

FIG. 8.—The differential luminosity function of the central region of NGC 6752 shown in Fig. 1*c*. Φ is defined as the number of stars between $M - 0.25$ mag and $M + 0.25$ mag. (*a*) F220W filter. For stars between $m_{220} =$ 19 and 20, two values are shown: the lower one (*open circles*) indicate the values of Φ after subgiant stars have been removed. For stars fainter than 20, the upper value (*open circles*) indicate the data corrected for incompleteness. (*b*) F555W filter. The original data are shown as filled circles, and open circles are the data corrected for incompleteness. The dashed line is taken from Da Costa (1982), after proper scaling (see text). (*c*) Same as (*b*), but for F785LP filter. The dashed line is from Richer et al. (1991).

with increasing magnitude. In this figure, Da Costa's LF (scaled so that it fits our data for the giant stars) is shown as a dashed line.

Another comparison was done between the *I*-band *HST* photometry and that reported by Richer et al. (1991). The results are shown in Figure 8*c*. Again, the core luminosity function in *I* from the *HST* data is flat, while that found by Richer et al. (1991) rises monotonically toward fainter magnitudes.

Da Costa's (1982) differential luminosity function was determined between 10'.1 and 13'.2 from the core of NGC 6752. The luminosity function of Richer et al. (1991) was generated between 3' and 5' (6–10 core radii) from the cluster core. Our area of coverage stretches from the core center to less than 0'.5. We therefore suggest that we are seeing mass segregation (i.e., progressively fewer low-mass stars) at the cluster core.

The strongly rising luminosity functions in the peripheries of six well-studied globular clusters were presented by Richer et al. (1991). These authors noted that if much of the Galactic halo is composed of dissolved globular clusters, then low-mass stars may contain most of the Galactic dark matter.

Our demonstration of a flat luminosity function in the core of NGC 6752 points to another possibility. Dynamical relaxation and mass segregation may have enhanced the population of low-mass stars in the peripheries of at least some globular clusters. The overall, integrated luminosity function of entire clusters could be quite flat (as much of the mass is in the inner few core radii). The suggestion that the Galactic halo is dominated by low-mass stars from disrupted globulars loses its basis in this scenario. Very recent near-infrared observations (Hu et al. 1994) demonstrate conclusively that little of the dark mass can be in hydrogen burning stars with masses $>0.1\ M_\odot$ even if these objects are of zero metallicity.

8. CONCLUSIONS

We can briefly summarize our results as follows.

1. A 7 hr time series of FOC images of part of the core of NGC 6752 (with 14 minute resolution) reveals no variables with amplitudes $\Delta m > 0.25$ mag ($M_{220} < +6.75$); or $\Delta m > 0.35$ mag ($M_{220} < +8.75$). At least four CVs and four CBs were expected on the basis of simple tidal capture theory. The observations do not rule out the theory but are in conflict with it.

2. Four UV-excess stars are located within 6″ of the cluster core. None shows variability. Neither of two of these UV-excess stars, seen in an Hα frame, shows an Hα excess. None of the four stars varies in brightness over four well-separated epochs of observation. These stars are unlikely to be cataclysmics.

3. Five blue stragglers are discovered in the cluster core.

4. Extreme horizontal-branch stars shun the cluster core.

5. The main-sequence luminosity function is very flat at the cluster center, in marked contrast to the rising function further out. This is probably due to mass segregation.

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