A Search for the Optical Counterpart of the Luminous X-ray Source in NGC 6652

Eric W. Deutsch, Bruce Margon, and Scott F. Anderson
Department of Astronomy, University of Washington, Box 351580, Seattle, WA 98195-1580
deutsch@astro.washington.edu; margon@astro.washington.edu; anderson@astro.washington.edu

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ABSTRACT

We examine images of the field of X1832-330, the luminous \(L_X \sim 10^{35} \text{ erg s}^{-1}\) X-ray burst source near the center of the globular cluster NGC 6652, in order to identify the optical counterpart for further study. U and B ground-based images allow us to set a limit \(M_B \gtrsim 3.5\) for the counterpart at the time of those observations, provided that the color is \((U - B)_0 \sim -1\), similar to the sources known in other clusters. Archival Hubble Space Telescope observations survey most but not all of the 1\(\sigma\) X-ray error circle, and allow us to set limits \(M_B > 5.9\) and \(M_B > 5.2\) in the WF/PC and WFPC2 regions, respectively.

In the WF/PC images we do weakly detect a faint object with UV-excess, but it is located 11"7 from the ROSAT X-ray position. This considerable (2.3\(\sigma\)) discrepancy in position suggests that this candidate be treated with caution, but it remains the only reasonable one advanced thus far. We measure for this star \(m_{439} = 20.2 \pm 0.2\), \((m_{336} - m_{439}) = -0.5 \pm 0.2\), and estimate \(M_B = 5.5\), \((U - B)_0 = -0.9\), similar to other known optical counterparts. If this candidate is not the identification, our limits imply that the true counterpart, not yet identified, is probably the optically-faintest cluster source yet known, or alternatively that it did not show significant UV excess at the time of these observations. Finally, we assess the outlook for the identification of the remaining luminous globular cluster X-ray sources.

Subject headings: globular clusters: individual (NGC 6652) — stars: neutron — ultraviolet: stars — X-rays: bursts — X-rays: stars

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1. INTRODUCTION

While the X-ray properties of the luminous globular cluster X-ray sources have been studied for over two decades, only in the last five years has there been significant progress in the study of their optical counterparts. During this period the situation has gone from the existence of only one identification of an unusually optically-luminous system in M15, to confirmed or likely optical counterparts in five clusters (Deutsch et al. 1998 and references therein). *Hubble Space Telescope (HST)* has largely been responsible for this advance, principally due to the extreme crowding in these fields, which limits the utility of ground-based programs.

Globular cluster X-ray sources are interesting targets for study for many reasons. It has been known for over two decades that globular cluster X-ray sources are overabundant with respect to those in the field (Katz 1975; Clark 1975); while globular clusters contribute only a tiny fraction to the total number of stars in the Galaxy, 10% of the known low-mass X-ray binaries (LMXBs) are found in globular clusters (van Paradijs 1995). It is still not clear whether these systems are somehow different as a group from those in the field, or instead the globular cluster environment merely enhances their formation probability. Indeed, it has long been suspected that close binaries may dominate the binding energy in globular clusters, and these exotic binaries may hold important clues to binary formation and interaction in these clusters. The number and properties of clusters containing LMXBs have been used to test stellar interaction hypotheses (e.g., Verbunt & Hut 1987, Predehl et al. 1991). In addition, luminosities and intrinsic colors may be determined far more accurately than for field sources, as the distances and redenings to the host clusters can be readily determined. Identification and further study of the optical counterparts of these sources provide many more opportunities to determine system parameters and unravel the nature of these LMXBs than can X-ray observations alone.

Here we present results on a search for the optical counterpart, for which there is as yet no candidate, to X1832-330, the luminous (L_X \sim 10^{36} \text{ erg s}^{-1}) X-ray burst source near the center of the globular cluster NGC 6652. This paper extends the preliminary work presented by Deutsch et al. (1997).

This X-ray source was probably first detected as H1825-331 in the HEAO-1 survey. However, as the 2.7 deg^2 90% confidence error box contained the cluster, but was very close to the Galactic Center, Hertz & Wood (1984) conservatively allowed that the association with NGC 6652 was premature. With the significantly-better spatial resolution of the ROSAT All-Sky Survey (RASS), Predehl et al. (1991) reported a bright X-ray source which was indeed coincident with NGC 6652 to 1'. Using reprocessed RASS data, Verbunt et al. (1995) estimate that the flux was as much as \sim 10 \times higher (depending on spectral assumptions) than during the HEAO-1 detection. Pointed observations with the ROSAT PSPC 1.5 yr after the RASS find the source somewhat brighter still, and show \sim 20% variations on a time scale of a few hours (Johnston et al. 1996). X-ray luminosities inferred from these various observations span the range L_X = 10^{35} - 10^{36} \text{ erg s}^{-1}, all normalized to the 0.5-2.5 keV band and distance adopted below. This luminosity variation prompted Verbunt et al. (1995) to label this source as a transient, although the variability observed thus far seems orders of magnitude less than that of sources indisputably called transients. Most luminous globular cluster X-ray sources are known to be bursters, indicating that the primaries are neutron stars. Just recently X1832-330 joined the ranks of known bursters when two Type I bursts were reported by in 't Zand et al. (1998).
Ortolani et al. (1994) carried out the first color-magnitude study of NGC 6652. They derive \( (m - M)_0 = 14.85 \) \((d = 9.3 \text{ kpc})\), \( E(B - V) = 0.10 \), and estimate \( [\text{Fe}/\text{H}] \approx -0.9 \). These values are similar to previous determinations except for the distance, which is 30% closer. From the compilation of Trager et al. (1993), we adopt a core radius \( r_c = 4''3 \). X1832–330 should be a relatively easy target for a search for an optical counterpart as NGC 6652 is neither heavily reddened nor extremely dense, whereas most of the clusters which harbor luminous X-ray sources do fall into one or both of these two categories. However, as the cluster is near the Galactic center \((l = 1\degree 5, b = -11\degree 4)\) the contamination of the field by bulge stars is of some concern. A brief study of this issue is presented by Ortolani et al. Finally we note that in their color-magnitude diagram, Ortolani et al. indicate a sizable population of blue stragglers.

2. OBSERVATIONS AND DATA REDUCTION

2.1. X-ray Coordinates

While the initially-reported RASS coordinates had only \( 1' \) accuracy, they were refined by Verbunt et al. (1995) to a \( 1\sigma \) uncertainty of \( 20'' \); even the latter would make a search for an optical counterpart difficult. However, a short pointed \textit{ROSAT} HRI observation of NGC 6652 obtained on 1994 March 28 is available in the archive. From these observations, we measure coordinates \( \alpha(2000) = 18^h 35^m 44.0^s, \delta(2000) = -32^\circ 59'29'' \), which agree with the position given as preliminary by Grindlay (1995).

The uncertainty of these coordinates is almost entirely due to the uncertain telescope aspect, as the source is well detected. From a study by Voges (1998) of the correlation between \textit{ROSAT} HRI source positions and stars in the Tycho Catalog (ESA, 1997), we infer based on \( \sim 3500 \) matches that the \( 1\sigma \), 90% confidence, and \( 2\sigma \) uncertainties are \( 5''3 \), \( 8''3 \), and \( 10''2 \), respectively. These values are consistent with the analysis of HRI uncertainties by David et al. (1992).

These coordinates are more uncertain than the \textit{Einstein} HRI positions available for some sources in other clusters. Unfortunately no X-ray sources appear in the \textit{ROSAT} HRI exposure other than the cluster source, so correction of the X-ray aspect via association with other optical identifications, e.g. bright foreground stars, is not possible. However, the coordinates are centered \( 20''5 \) \((4.8 \text{ } r_c)\) from the cluster center where the crowding is not severe by \textit{HST} standards, so the search of a large error circle is still feasible.

2.2. Ground-Based Imagery

To find the precise optical position of the X-ray coordinates, we create an astrometric solution for a ground-based B-band CCD image (kindly provided by S. Wachter) by using 21 isolated stars in common between the CCD image and the Digitized Sky Survey, which is based on the \textit{HST} Guide Star Catalog (GSC) reference frame. The uncertainty in this transfer is \( 0''04 \). With this transferred coordinate system, we place a cross at our optical position for the X-ray coordinates in Fig. 1. The systematic uncertainty in the GSC frame with respect to other astrometric frames for a typical region is \( \sim 0''5 \) (Russell et al. 1990). Overlaid in Fig. 1 are \( 2''3 \) \((1\sigma)\) and \( 10''2 \) \((2\sigma)\) radius X-ray error circles. From this CCD image, obtained in \( 1''3 \) seeing conditions, it is clear that
the field is quite crowded from the ground. As only one color was obtained, these data are not directly suitable for searching for an optical counterpart.

On 10 June 1997 we obtained brief U (300 s) and B (100 s) exposures of NGC 6652 with the Taurus Tunable Filter (TTF) (Bland-Hawthorn & Jones 1998) in a broadband imaging mode on the Anglo-Australian Telescope (AAT). Despite the 3′5 seeing and cirrus conditions at the time of the exposures, these frames are deep enough to search part of the range of expected luminosities. We subtract the two frames in order to search for some excess UV flux in the error circles, but find none. If we assume that the counterpart has \((U - B)_0 \sim -1\), similar to the other known cluster counterparts, we are able to set a lower limit \(M_{B_0} > 3.5\) within the entire 2σ X-ray uncertainty radius, using artificial star tests. Three of the five currently-known optical counterparts have luminosities brighter than this (Deutsch et al. 1998), and therefore could have been detected with these data, had they been in NGC 6652.

2.3. \textit{HST Imagery}

The recent success in discovering optical counterparts to the globular cluster X-ray sources has largely been due to their considerable UV excess, \((U - B)_0 \sim -1.0\), observed in \textit{HST} images. We therefore take this same approach here, and search for UV-excess objects in a color-magnitude diagram of the cluster. \textit{HST} WF/PC and WFPC2 observations of this cluster, taken as part of unrelated programs, are available in the \textit{HST} data archive, and we have extracted these images for this work. The \textit{HST} fields of view are overlaid on the ground-based CCD frame in Fig. 1. The WF/PC observations were obtained at three different offsets and exposure times for each filter, while the WFPC2 observations were all at the same pointing. It can be seen from the figure that, simply by chance, the X-ray error circles extend somewhat beyond the boundaries of the \textit{HST} frames. While these data are clearly not optimal, there is a reasonably good chance of success in isolating the optical counterpart to X1832–330.

To place the position of the X-ray coordinates on the \textit{HST} images, we transfer the astrometric solution from the CTIO CCD image discussed in \S2.2 to these images. The internal errors in the transfer are negligible compared to the systematic uncertainties in the GSC frame as discussed above.

For the WFPC2 images, measured magnitudes are calibrated to the STMAG system using the photometric zero points from Table 9 (\(Z_{STMAG}\) in Holtzman et al. 1995a). Aperture corrections are taken from Table 2(a) in Holtzman et al. (1995b). There has not been any correction applied for geometric distortions or charge transfer efficiency losses (Holtzman et al. 1995b) as the small errors introduced by these effects are not of concern for our purposes here.

The WFPC2 observations used the F218W (500 s, 900 s), F439W (50 s, 2 × 160 s), and F555W (10 s, 50 s) filters; the latter two closely resemble Johnson B and V filters, respectively. There are no objects detected within 15″ of the X-ray position in the F218W exposures (which do not image the entire error circle), with lower limit \(m_{218} > 19.7\). If we assume that the optical counterpart has \((m_{218} - m_{439})_0 = -1.4\), similar to the optical counterpart in NGC 6441 (Deutsch et al. 1998), we infer a lower limit of \(m_{439} > 20.5\) or \(M_{B_0} > 5.2\) in the region of the error circles subtended by the WFPC2 exposures. This value may be compared with \(M_{B_0} = 5.6\) for the least
luminous globular cluster counterpart, Star A in NGC 1851 (Deutsch et al. 1998).

As the optical counterparts in other clusters have been strongly UV excess with unremarkable $B$, $V$ colors, the F439W and F555W images are not suitable for isolating a counterpart based on color alone. However, observed variability can be used to identify a counterpart, as optical/UV variability has been detected for all of the known counterparts for which a suitable study has been performed. Unfortunately, these short consecutive snapshots are unlikely to allow detection of anything but extremely-short timescale, high-amplitude variability. The images have been examined for objects of such variability, but none are found.

Although not as deep at the WFPC2 observations, the (pre-servicing mission) WF/PC images have better areal coverage of the error circle and use two near-optimal filters, F336W (300 s, 900 s, 1200 s) and F439W (100 s, 300 s, 400 s), those also used to identify several other counterparts. We concentrate here on the regions of the WF/PC images which include the X-ray error circles. In Fig. 2 we show a corner section of one of the F439W exposures, with a cross placed at the X-ray coordinates. 5′2 and 10′2 error circles are displayed as in Fig. 1. All images have been cleaned of cosmic-ray hits by an algorithm written by E.W.D. The images were then carefully inspected and any shortcomings of this algorithm were repaired manually; stars which have been clearly hit by a cosmic-ray event were excluded from the color-magnitude diagram.

Initial photometric zero points were taken from the PHOTFLAM keywords in the headers. However, another correction was applied to calibrate the WF/PC $m_{336}$ magnitudes to the WFPC2 $m_{439}$ magnitudes. This correction was calculated using a set of isolated stars in common between images from both cameras, and is primarily an aperture correction, which is difficult to determine for WF/PC images. This same correction was applied to the $m_{336}$ magnitudes.

3. DISCUSSION

3.1. Color-Magnitude Diagram

Figure 3 shows a color-magnitude diagram derived from aperture photometry of the WF/PC F336W and F439W observations. Included are the $\sim$150 objects in PC6 which are detected in the F336W data. Stars within $r < 2′.5$ from the cluster center are excluded as the crowding there causes large errors in the photometry. All objects in this excluded region are $> 18′′$ from the X-ray position, and thus this procedure does not affect the search for the optical counterpart. Magnitudes are in the STMag system, and formal 1σ error bars are provided for each source. Non-negligible flat-fielding imperfections as well as the numerous low-level cosmic-ray hits will cause some sources to be in error by more than the estimated uncertainties.

We overlay an isochrone from Bertelli et al. (1994) for comparison. The 12 Gyr, [Fe/H] = -0.7 isochrone has been converted to the STMag system (conversion factors derived using the STSDAS synphot package), corrected for $(m - M)_0 = 14.85$, and reddened by $E(B - V) = 0.10$. The isochrone does not fit in detail but indicates that the distance, reddening, and metallicity parameters yield an isochrone which follows the observed points reasonably well, particularly given the uncertainties in the filter transformations and absolute calibration. It can be clearly seen, however, that these data do not even reach the main-sequence turnoff adequately. The $M_{R_h}$ scale incorporates the filter correction $(B - m_{336}) = 0.50$, although the true correction should
vary slightly with stellar color; 0.65 is appropriate for stars hotter than type F, and the correction decreases to 0.40 for M0 stars. We also plot open circles for the distance- and reddening-adjusted magnitudes of the five known optical counterparts of luminous globular cluster X-ray sources (Deutsch et al. 1998), if they were relocated to NGC 6652.

A population of stars is seen blueward of the red giant branch in the color-magnitude diagram of Fig. 3. Each of these stars was examined individually, and none are obviously due to cosmic-ray hits or other defects in the data. Most of these objects are, without question, stars bluer than the red giant branch, although their nature is not obvious. These stars do fall in the region where one expects blue straggler stars (BSS) based on the extension of the main sequence of the isochrone, and as Ortolani et al. (1994) made a special note concerning the abundance of BSS in this cluster, we entertain the idea that many of these stars might be BSS.

A detailed comparison between the blue stragglers discovered by Ortolani et al. (1994) (obtained in electronic form from CDS) and blue objects isolated here, shows that four of our blue objects correspond directly to four BSS (OBB 772, 857, 858, 865) discovered by Ortolani et al. The other 5 BSS candidates from Ortolani et al. which fall in the PC6 frame do not correspond to remarkable objects in our color-magnitude diagram, and most may be inaccurately photometered blends in the ground-based data. The remaining dozen blue objects in Fig. 3 are crowded by neighboring stars such that they would be very difficult to isolate in ground-based images. In addition, these objects are more numerous near the center of the cluster than in other parts of the frame and many, therefore, are likely to be cluster members.

As the contamination by nonmembers is not negligible, we briefly examine the expected contamination from such stars in the color-magnitude diagram. Although the HST fields are too close to the cluster to study the contamination with these data, we estimate from the contamination investigation in Fig. 5 of Ortolani et al. (1994) that ~10 bulge stars $m_{439} < 20$, and only a few bulge stars $m_{439} < 18$ are expected to appear in PC6. We conclude that a few of the blue stars in our diagram may be nonmembers, but most appear to be cluster members and are likely to be blue stragglers. In any event, none of these blue stars are within the X-ray error circles, and these objects are unlikely to be related to X1832–330.

### 3.2. Optical Counterpart Candidates

Within the partial coverage of the 5\"x3 radius 1\sigma error circle of the ROSAT HRI coordinates, there are no obvious UV-excess candidates with $m_{439} < 20.6$ ($M_R < 5.9$), a limit slightly stronger than the least luminous known globular cluster optical counterpart, Star A in NGC 1851 (Deutsch et al. 1996), when all counterparts are corrected for distance and reddening. However, it is important to stress that the region beyond 4\"", while completely covered by our AAT data, is not completely imaged by these HST frames (Fig. 2): a faint optical counterpart mischievously located > 4\"" due west of the nominal coordinates could not have been seen with existing HST observations.

In the 35\"\"x35\"\" region examined here, only one object stands out as a candidate based on similar color to the other known counterparts. This faint UV-excess object, which we denote Star 49, is the only unusual star in this region, and we therefore offer it as a possible optical
counterpart to the luminous globular cluster X-ray source X1832–330. From Fig. 3 it can be seen that Star 49 has color similar to the other known counterparts, and a luminosity nearly equal to Star A in NGC 1851 (Deutsch et al. 1998). For Star 49 we measure $m_{336} = 19.69 \pm 0.06$, $m_{439} = 20.2 \pm 0.2$, $(m_{336} - m_{439}) = -0.5 \pm 0.2$, and apply approximate filter corrections to estimate $B_0 = 20.4$, $(U - B)_0 = -0.9$, and $M_{B_0} = 5.5$.

However, for Star 49 we measure a position in the GSC frame of $\alpha(2000) = 18^h 35^m 44^s 57$, $\delta(2000) = -32^\circ 59' 38'' 3$, which is 11" away from the X-ray coordinates, at a distance greater even than the estimated 10" 2$\sigma$ uncertainty. About 2% of ROSAT HRI aspect solutions seem to be in error by more than 12", so this object should not be discounted, although it must be treated with caution.

Star 49 itself is near the detection threshold in both filters. The object does, however, appear to be weakly detected in four separate exposures, two F439W frames and two F336W frames (each filter pair at a different spatial offset). It is too faint to be expected to be detected in the other two shorter-exposure HST images, and indeed does not appear. In Fig. 4 we show coadded F336W and F439 frames of Star 49 and the surrounding 8" × 8" region. The existing WFPC2 observations are not helpful for further studying this object, as it falls just outside the WFPC2 field of view.

4. CONCLUSION

We have presented a search of the optical counterpart for X1832–330, the luminous globular cluster X-ray source in NGC 6652. Using the GSC reference frame, we determine the optical position of the ROSAT X-ray coordinates on a CCD image. U and B ground-based images from the AAT allow us to set a limit $M_{B_0} < 3.5$ for the counterpart at the time of those observations, provided the color is $(U - B)_0 = -1$. Archival HST WFPC2 exposures which subtend most but not all of the error circle allow us to infer $M_{B_0} > 5.2$ for the counterpart if in that region, again provided at the time of observation the source is UV-excess $(m_{218} - m_{336}) = -1.4$, like the counterpart in NGC 6441. Archival WF/PC observations allow a more sensitive search: within the 1$\sigma$ error circle about the X-ray coordinates contained in the WF/PC images, we detect no objects at $m_{439} < 20.6$ ($M_{B_0} < 5.9$) with colors compatible with the other known optical counterparts in globular clusters. The region outside radius 4" is not completely imaged by these data, and therefore a faint UV-excess counterpart could have been missed with these HST observations.

We do weakly detect a faint UV-excess object 11" from the ROSAT coordinates. This is a 2.3$\sigma$ deviation from the X-ray coordinates, and thus this object certainly should not be completely ruled out based on its position. If it is indeed the correct identification, this object provides another example of the extremely underluminous optical counterpart seen in NGC 1851. We measure for Star 49 $m_{439} = 20.2 \pm 0.2$, $(m_{336} - m_{439}) = -0.5 \pm 0.2$, and estimate $B_0 = 20.4$, $(U - B)_0 = -0.9$, and $M_{B_0} = 5.5$.

Should the X-ray coordinates prove to be accurate to better than 4", the likely conclusion is that the true optical counterpart, not yet identified, is the intrinsically faintest cluster source yet known, at least at the time of these observations, and Star 49 may be yet another example of a faint UV-excess cluster object of unknown nature (see, e.g., Deutsch et al. 1996, 1998). Another
possibility is that the optical light from the system was not dominated by the hot accretion disk at the time of these observations, but rather by the secondary, thereby rendering the object's color unremarkable in our color-magnitude diagram; however, such behavior has not been observed for the other identified cluster sources. Clearly, deep F336W, F439W WFPC2 observations placing the X-ray coordinates in the center of the PC chip are desirable to search this field more thoroughly, and a more accurate X-ray position would reduce the number of objects which must be considered as possible candidates.

Identification of optical counterparts in the remaining clusters with luminous X-ray sources will be difficult using current techniques, as is seen in Fig. 5. Here we have plotted the $m_{336}$ apparent magnitudes, either observed or predicted, of the optical counterparts of luminous X-ray sources in the cores of globular clusters. The objects are ordered by right ascension, so the units on the abscissa are of no significance. Clusters with boxed names are those with optical counterparts already identified (or tentatively suggested in this work); all but one required *HST* observations. The dashed vertical lines denote the 5 mag range of the luminosity dispersion implied by the current complement of identifications, adjusted for the distance and reddening of each cluster (cluster parameters principally from the compilation of Djorgovski 1993). The filled squares are the observed $m_{336}$ magnitudes derived from our HST photometry (Deutsch et al. 1998); the positions of the squares within the dashed lines indicate the luminosities compared with the luminosity range of all the known sources (e.g., the object in NGC 1851 appears at the bottom of the dashed line as it is the least luminous one). For the six sources with no current identification, the six open diamonds indicate where each of the known identifications would fall if relocated to the target cluster, again with appropriate distance modulus and reddening. The horizontal line at $m_{336} = 23$ denotes the approximate flux reached by a typical short WFPC2 program, i.e., 10% photometric precision in a two-orbit multicolor exposure series in a moderately crowded field.

Of the ‘easy’ clusters, i.e. those for which the optical counterpart can be expected to be detected in one or two *HST* orbits, NGC6652 is the last for which a candidate has been put forth. Due to the considerable foreground extinction, the remaining unidentified luminous cluster X-ray sources will be difficult to identify with current techniques at the UV and blue wavelengths where these sources have in the past been studied. A possible exception is NGC 6440, which could be adequately studied in a few orbits. For the remaining clusters, the amount of time required to detect a low-luminosity counterpart in an F336W frame with the WFPC2 becomes prohibitive, although detection of counterparts at the high end of the luminosity range is feasible. Variability searches in the infrared may afford a way to identify and study the remaining, heavily-reddened sources. Future searches will also be facilitated when arcsecond-accuracy X-ray coordinates become available via AXAF observations, thereby drastically reducing the number of optical objects which must be considered. Nonetheless, there still remains much to be learned from the current crop of optical counterparts, just discovered in the last few years.

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Fig. 1.— 50′′ × 50′′ ground-based B-band CCD image centered (cross) on the ROSAT HRI coordinates for the luminous globular cluster X-ray source X1832-330. North is up and East is left. Overlaid are 5′′ 3 1σ and 10′′ 2 2σ radius X-ray error circles. The image was obtained in 1″ 3 seeing conditions, and shows that the field is quite crowded from the ground. Also overlaid are the multiple archival HST exposure fields of view. The WF/PC observations were obtained at three different offsets and exposure times for each filter, while the WFPC2 observations were all at the same pointing. Unfortunately, the X-ray error circles extend beyond the boundaries of the HST frames.
Fig. 2.— 22′′ × 29′′ corner section of the 300 s F439W (B) WF/PC image, which has been cleaned of cosmic-ray hits. Our optical position for the X-ray coordinates is marked with a cross. 5′′3 1σ and 10′′2 2σ error circles are displayed as in Fig. 1. The field is not severely crowded by HST standards, although there are still ~40 objects within the 1σ error circle. A faint object, discussed in the text as a possible counterpart, is marked with an arrow.
Fig. 3.—Color-magnitude diagram derived from the WF/PC F336W and F439W observations for the ~150 objects in PC6 which are detected in both passbands. Magnitudes are in the STMag system, and formal 1σ error bars are provided for each object, although a few objects will have greater error due to low-level cosmic-ray hits which could not be identified and flagged. Solid line: a 12 Gyr, [Fe/H] = −0.7 isochrone from Bertelli et al. (1994), added for comparison. Dashed line: approximate detection threshold for these data. The distance- and reddening-adjusted locations for the five known optical counterparts of luminous globular cluster X-ray sources (Deutsch et al. 1998) are plotted as open circles. Only one object near the X-ray source, which we denote Star 49, has color and magnitude similar to other known optical counterparts.
Fig. 4.— $8'' \times 8''$ sections of the F336W ($U$) and F439W ($B$) images of the region near Star 49, which we select as a possible optical counterpart due to significant UV excess, similar to other known cluster optical counterparts. These *HST* WF/PC data were obtained on 1992 October 10. Each frame is the sum of the two longest images for each filter.
Fig. 5.— Apparent $m_{336}$ magnitudes for the six confirmed or suggested optical counterparts to luminous globular cluster X-ray sources (filled squares), full range of optical luminosities of the ensemble of the current candidates (dashed vertical lines), and predicted magnitudes for each of the known identifications if relocated to other target clusters with appropriate distance modulus and reddening (open diamonds). The horizontal line at $m_{336} = 23$ denotes an estimate of the S/N=10 limit in a sequence of $4 \times 700$ s WFPC2 F336W exposures in moderate crowding conditions, i.e. part of a typical short WFPC2 program. Of the “easy” clusters, i.e. those for which the luminosity range is almost entirely above the short HST program detection limit, NGC 6652 is the last for which a candidate has been suggested.