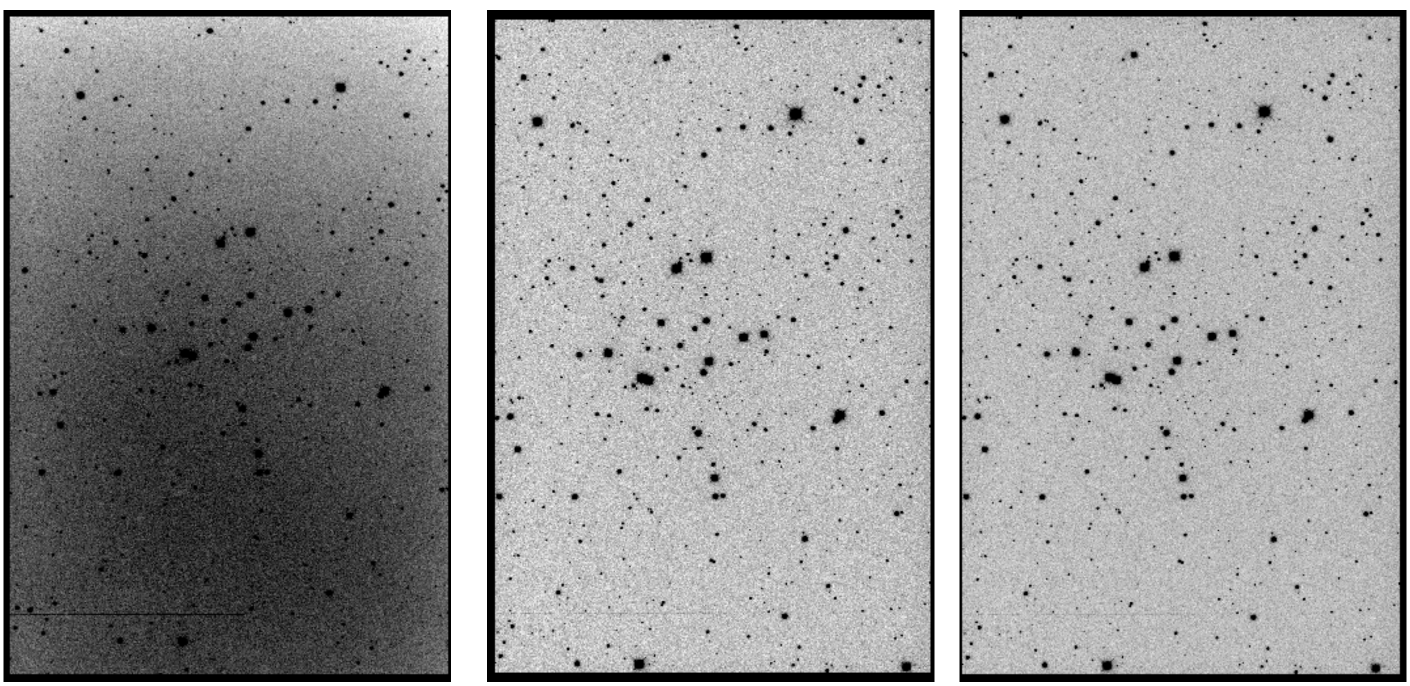
Physics 344 Lab 6 Solutions
Stellar Photometry and the Color-Magnitude Diagram

The purpose of this lab was to measure V- and B-band magnitudes for stars in the field of the open cluster M34. Stars with known standard magnitudes in the field determined the transformation between instrumental and standard magnitudes. Plotting the photometry as a color-magnitude diagram reveals the cluster main sequence. Comparing the main sequence to model isochrones determines the distance and age of the cluster.

I obtained twilight sky flats and cluster images on the evening of 4 November 2011. The class obtained single sets of cluster data on the evenings of 6 November 2011 and 8 November 2011, with twilight sky flats also obtained on the first of these dates. The data taken on the evening of 7 November 2011 turned out not to have the cluster in the field because of some problem with pointing the telescope or setting up the guiding.

The effects of processing the images are illustrated in the following pictures. The frame on the left is a raw 250-second exposure V-band image. The flux gradient over the image is about 15%, and there is a noticeable bright column near the bottom of the image. The center frame is that same image after dark subtraction and flat field division. The large-scale flux gradient is corrected with high precision, and the bright column is mostly removed. The right frame is the combination of three 250-second exposures, shifted to a common center. The improvement here is subtle, but the noise in the sky background is reduced and cosmic ray events have been removed.



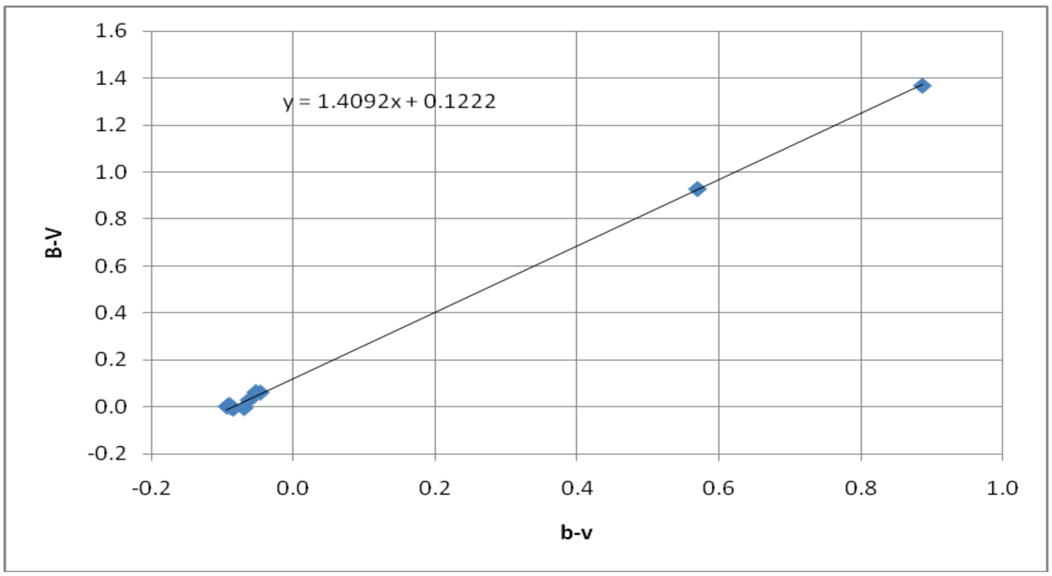
The image quality ranged from 6 to 8 pixels FWHM (3 to 4 arc-seconds. There were some problems with the autoguider producing multiple images – perhaps it was not given sufficient time to stabilize on the guide star before the exposure was started. Shown below is photometry done by Professor Williams in 2010 using images with a 10 pixel FWHM. He chose an aperture radius of 20 pixels and a sky annulus of 25 to 30 pixels for the aperture photometry. His plots for the 10 calibration stars measured in his 5-second B and V images and the fitted calibration equations are included below. These fits yield values for the transformation coefficients of:

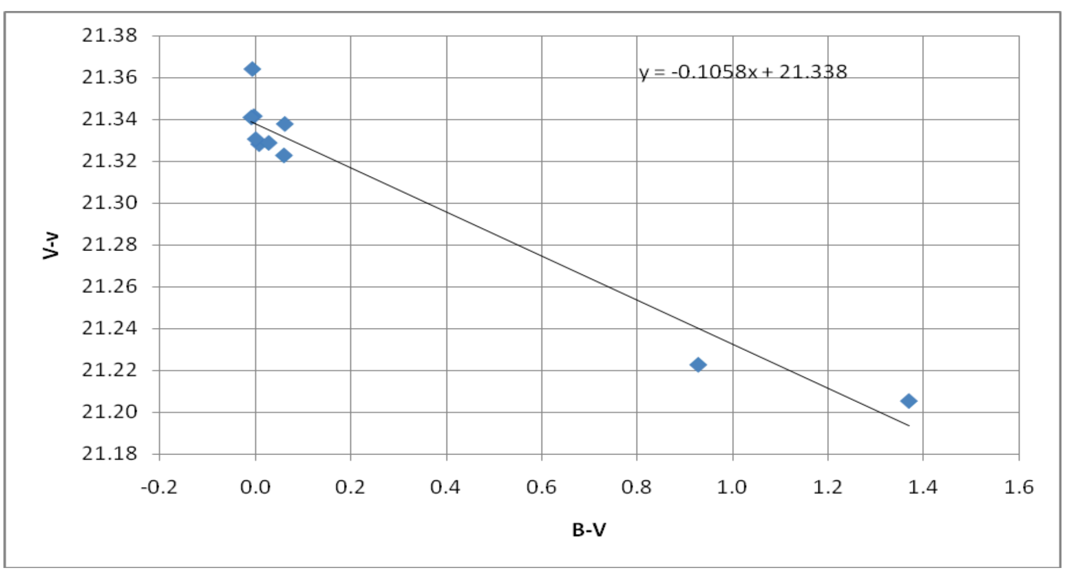
$$\mu_{bv} = 1.4902 \qquad \varepsilon = -0.1058 \text{ (Williams).}$$

Using a slightly different set of standard magnitudes for 12 stars, which I think is better than that given in the lab, I found transformation coefficients of:

$$\mu_{bv} = 1.3594 \qquad \varepsilon = -0.0975 \text{ (Pryor).}$$

The relatively large correction for colors indicates that our system differs significantly from the standard system – this is mostly due to the sensitivity variation with wavelength of our CCD.





Measuring the two standard stars for the 35-second and 250-second exposures, Professor Williams calculated the zero points for those exposures, using the above values for the transformation coefficients. His results are summarized in the table below and are similar to those found by the class using this year's data.

Exposure	ϕ_{bv}	ϕ_{v}
5-sec	0.1222	21.338
35-sec	0.03851	21.339
250-sec	0.09661	21.787

Additionally correcting for interstellar extinction produced the following color-magnitude

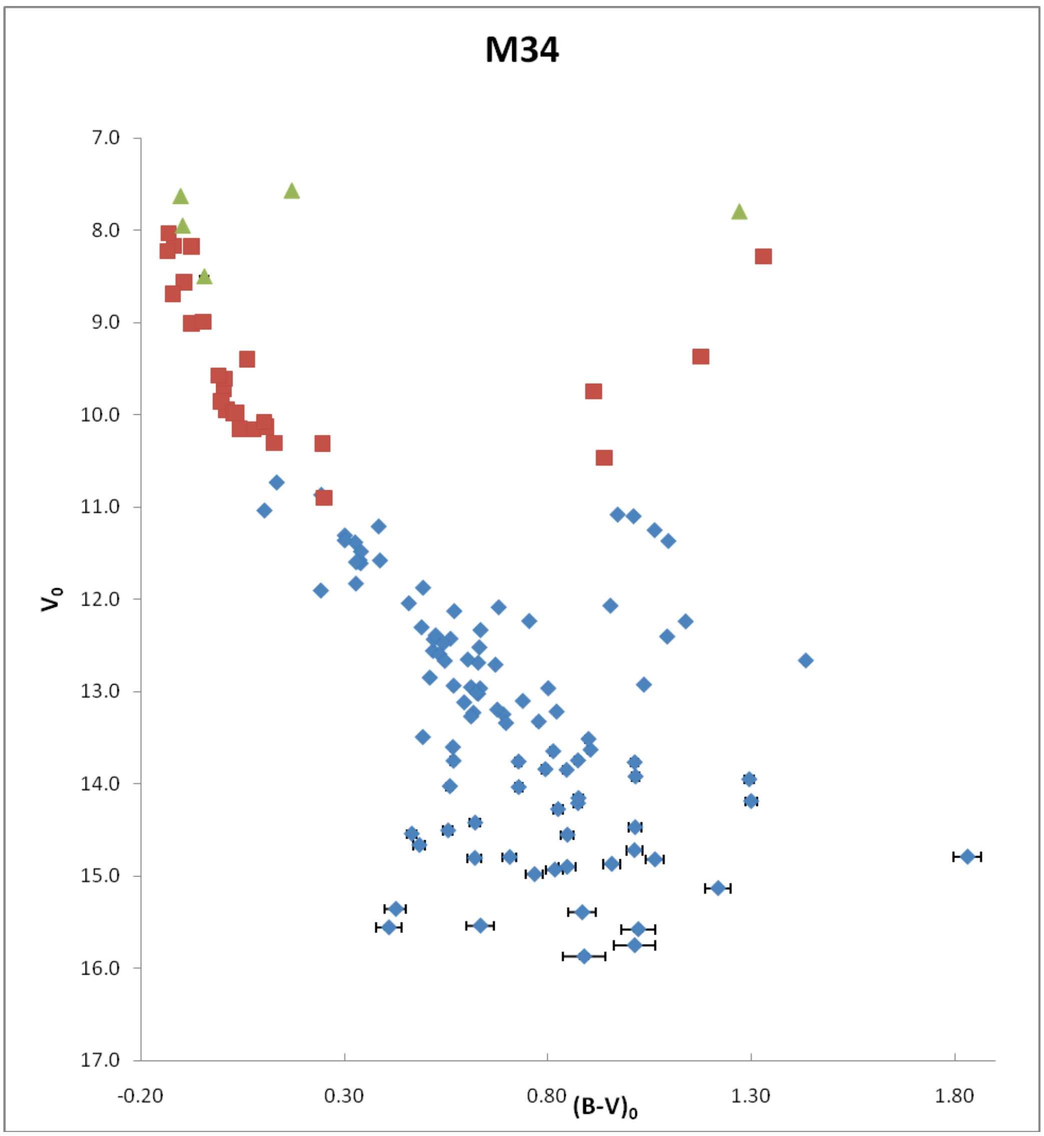
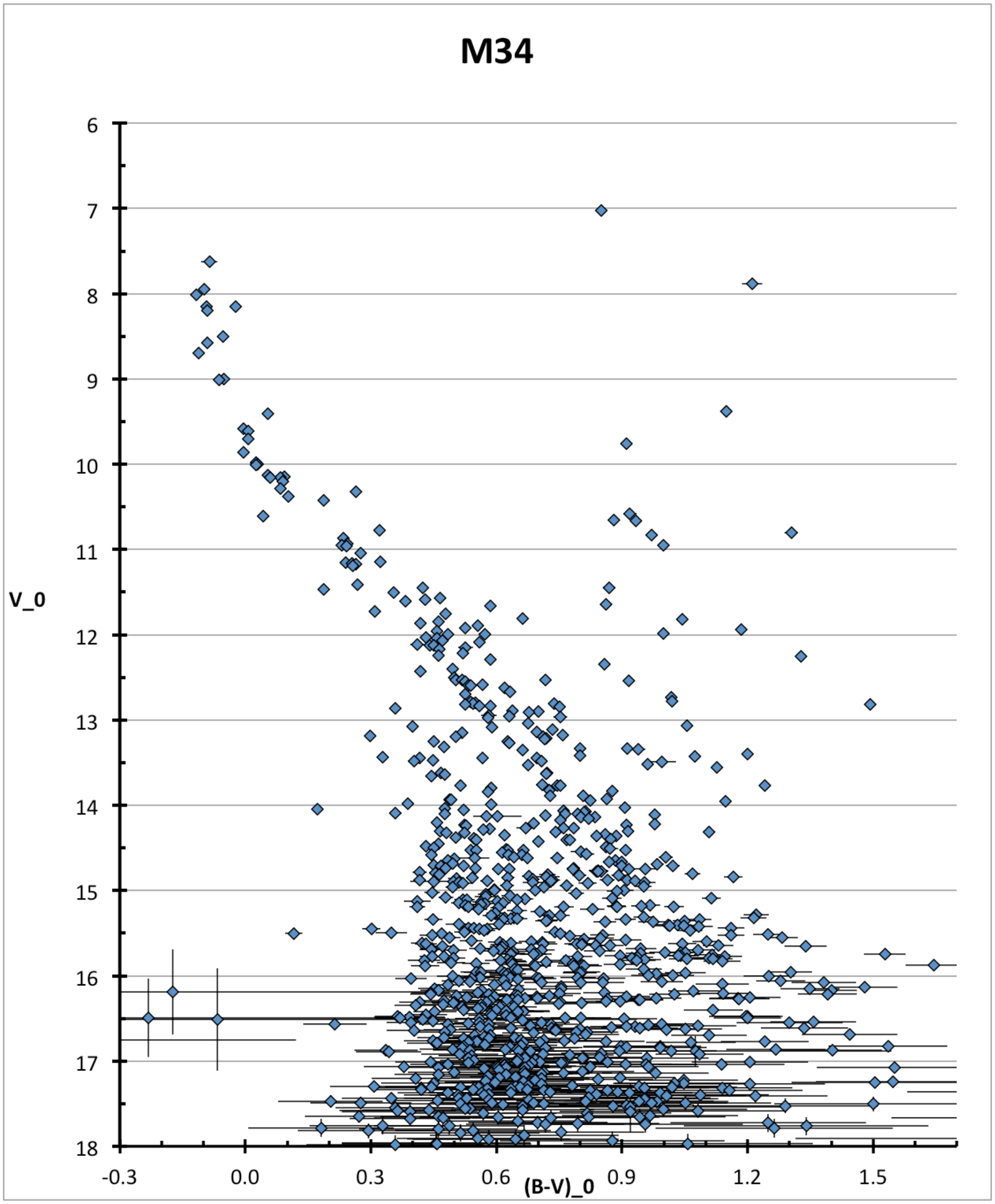


diagram. The different symbols indicate stars measured on the different length exposures. In general, the estimated measurement uncertainties are smaller than the plotted symbols for all but the faintest stars. I used a program that derived and fit a point-spread function (PSF) to stars in the images taken this year. A weighted average of the magnitudes measured in the three different length exposures produced the color-magnitude diagram below. The two diagrams are very similar, with the few differences resulting from a slightly different centering of the images or a few cases where the point-spread function fit resolved two closely-separated stars.



The PSF-fitting photometry is more accurate than the aperture photometry, as indicated by the sharper lower boundary of the main sequence for $V_0 > 13$. The upper boundary of the main sequence is expected to be more diffuse than the lower because of unresolved binary stars. Because of the increasing uncertainties, stars fainter than $V_0 = 16$ contain little information about the cluster main sequence.

The red ($(B-V)_0 > 0.8$) stars above the main sequence in the diagram and the scatter of stars at faint magnitudes are foreground and background stars, respectively, that are not members of the cluster. There have been several recent studies that use proper motions to assess which stars are likely to be cluster members.

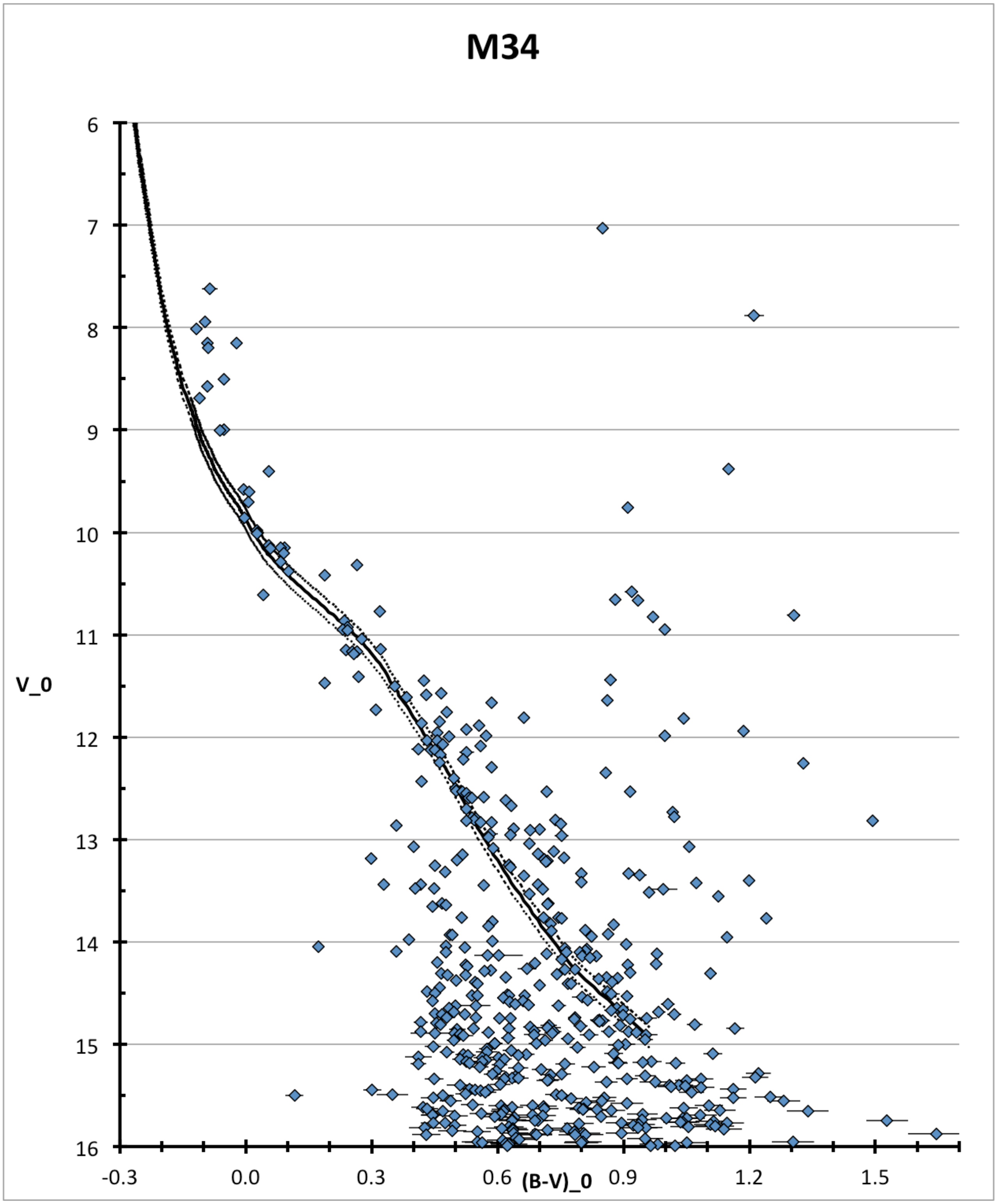
Adding the 10^3 year isochrone (essentially the zero-age main sequence) to the color-magnitude diagram and shifting it vertically to align with the observed main-sequence stars gives the following plot. The amount of the shift needed is called the distance modulus and is the difference between the apparent magnitude of the cluster stars and their absolute magnitude. The shift for the solid line in the plot is 8.30 magnitudes, and the dotted curves are ±0.10 magnitudes about this best fit, indicating the approximate precision of the measurement. The distance to the cluster is then given by:

$$(m - M)_0 = 5 \log (d/10 \text{ pc})$$

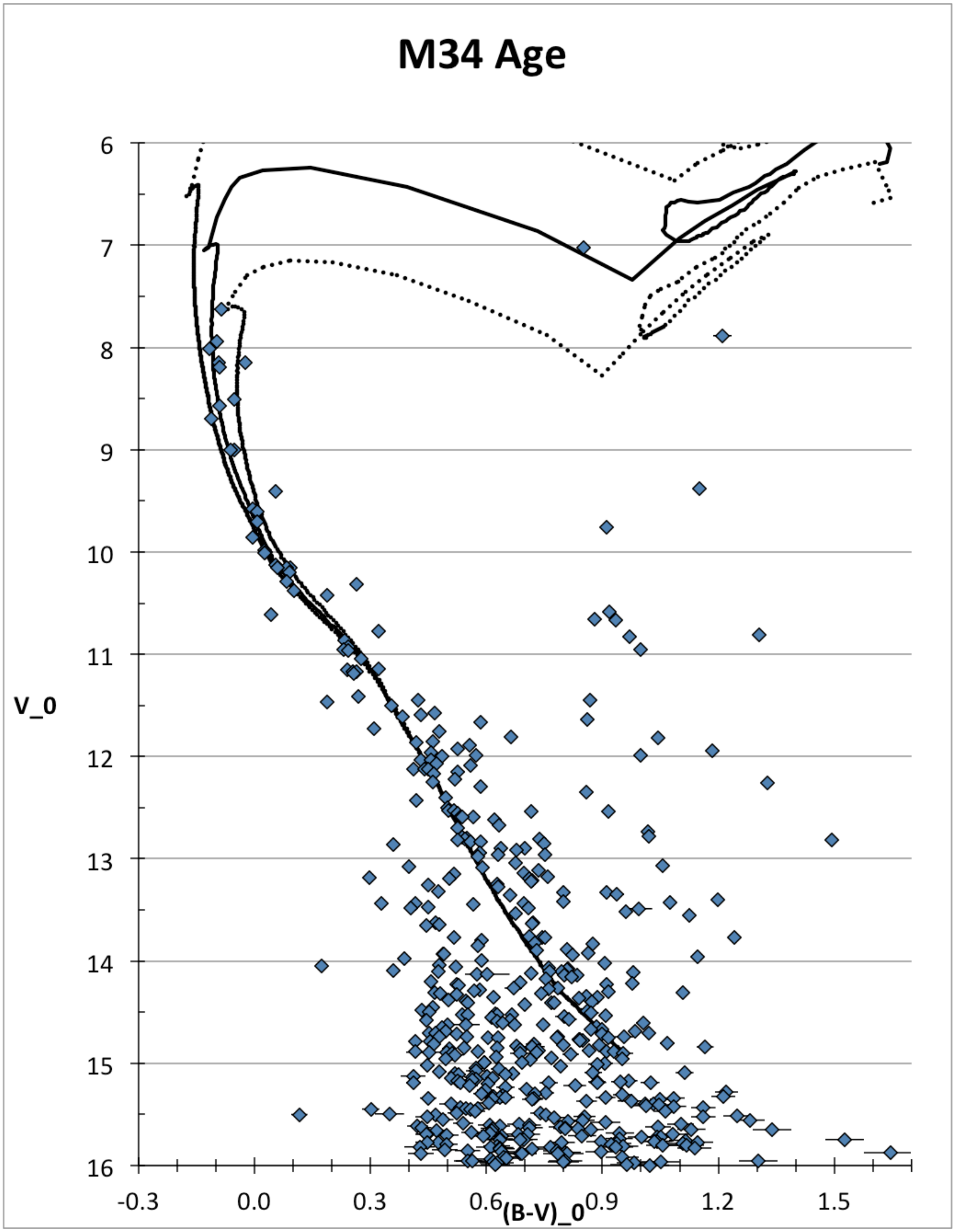
$$d = 460 \pm 20 \text{ pc}$$

The uncertainty in the reddening probably contributes an additional uncertainty of ±10 pc. The effect of changing the metallicity of the fitted isochrones throught he allowed range is probably similar. Jones & Prosser (1996, Astronomical Journal, 127,991) find a distance modulus for M 34 $(m\text{-}M)_0 = 8.29$, after adjusting their value to $E(B-V) = 0.10$. Thus, our results are in good agreement with those from professional telescopes.

The stars at the top of the main sequence in M34 are beginning to depart from the 10^3 year isochrone; this indicates that these stars are exhausting the hydrogen in their cores and are beginning to evolve into red giants. Even more massive stars further up the main sequence that were presumably in the cluster at earlier times have now completed their lives and become white dwarfs or exploded as supernovae. The last figure below shows the M34 CMD plotted with three isochrones, of ages $10^{8.00}$, $10^{8.25}$, and $10^{8.50}$ years, all using a distance modulus of 8.30 magnitudes. The solid curve, representing the $10^{8.25}$ year isochrone, fits the data well. Few stars are on the red giant branch of these isochrones because the stars evolve rapidly through these phases, making it unlikely that we will catch many giants at any particular time. The younger and older curves (both dotted lines in the plot) clearly do not fit the data, and a reasonable estimate of the age uncertainty might be ± 0.15 in the log or ±35% in the age. Our measurement of the cluster's age is then 180 ± 60 Myr. Standard values for the age are 200 to 250 Myr. These slightly older values may have been estimated using a smaller value for the reddening than we adopted (a redder turnoff equates to an older age). Still, our agreement with the standard values is quite respectable.



M34
V_0
(B-V)_0
6
7
8
9
10
11
12
13
14
15
16
-0.3
0.0
0.3
0.6
0.9
1.2
1.5


M34 Age
V_0
(B-V)_0
6
7
8
9
10
11
12
13
14
15
16
-0.3
0.0
0.3
0.6
0.9
1.2
1.5