THE MEMBERSHIP AND DISTANCE OF THE OPEN CLUSTER COLLINDER 419

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ABSTRACT

The young open cluster Collinder 419 surrounds the massive O star, HD 193322, that is itself a remarkable multiple star system containing at least four components. Here we present a discussion of the cluster distance based upon new spectral classifications of the brighter members, UBV photometry, and an analysis of astrometric and photometric data from the third U. S. Naval Observatory CCD Astrograph Catalog and Two Micron All Sky Survey Catalog. We determine an average cluster reddening of $(E(B-V)) = 0.37 \pm 0.05$ mag and a cluster distance of $741 \pm 36$ pc. The cluster probably contains some very young stars that may include a reddened M3 III star, IRAS 20161+4035.

Key words: open clusters and associations: individual (Collinder 419) – stars: early-type – stars: individual (HD 193322, IRAS 20161+4035)

1. INTRODUCTION

Collinder 419 is an open cluster in the constellation Cygnus. It was first designated as Barnard 794 (Barnard 1927), but the accepted name comes from the work of Collinder (1931) who classified the cluster as a $\mu$ Normae cluster. This is an intermediate type of grouping between multiple star systems and open clusters. The prototype cluster NGC 6169 contains the bright star $\mu$ Normae = HD 149038 and a host of surrounding fainter stars. In the case of Collinder 419, the bright central star is HD 193322 = HR 7767 = HIP 100069 = WDS 20181+4044. HD 193322 is a multiple star system with a close visual companion STF 2666 AB (separation of 2′′9 and probably orbitally bound) and two more distant companions, STF 2666 AC (34′′0) and TAR 5 AD (49′′6), which, if bound, have very long orbital periods. McAlister et al. (1987) discovered that the A component is a speckle binary, CHR 96 Aa,Ab. An approximately 31 year orbital period for this pair was computed by Hartkopf et al. (1993). In addition, one of the components of the speckle binary is a spectroscopic binary with a $311.03 \pm 0.25$ day period (Fullerton 1990; McKibben et al. 1998). Fullerton (1990) also obtained a spectrum of the B component that suggests that it may also be a spectroscopic binary. Thus, the central AB pair may contain as many as five individual stars.

The primary of the system, Aa1, has a spectral type of O9 V:(n)) (Walborn 1972), with the suffix indicating slightly broadened lines. McKibben et al. (1998) tentatively identify the close spectroscopic companion Aa2 and the B component all as B-type stars. The magnitude difference of the speckle pair Aa,Ab is $\Delta V = 1.2 \pm 0.5$ (Mason et al. 2009) which suggests that Ab is also an early B-type star. Both the Aa2 and Ab companions offer us the means to determine mass for the O star component Aa1 through measurement of the orbital motion. By themselves, neither an orbit of the Aa,Ab pair nor the spectroscopic Aa1, Aa2 pair will yield a mass, but, in conjunction with a distance determination, a mass can be determined. The Hipparcos Catalog (Perryman et al. 1997) has become the standard source for parallaxes, but it may be unreliable for some double stars (Shatskii & Tokovinin 1998) and also for distant O stars (Schröder et al. 2004). Until a new space-based parallax engine is available sometime in the next decade, we are left with classical techniques as the best way to determine O-star distances.

We are currently pursuing efforts to determine the orbits of the central triple through speckle and optical long baseline interferometry (Turner et al. 2008). Here we present a new assessment of the distance to the cluster that we will use in the forthcoming orbit and mass determination. In Section 2 we present spectral classifications for the brighter members, and show fits of their spectral energy distributions (SEDs) that provide estimates of reddening and angular size. We then describe in Section 3 an astrometric and photometric study of cluster membership based upon data in the third U. S. Naval Observatory CCD Astrograph Catalog (UCAC3; Zacharias et al. 2010) and the Two Micron All Sky Survey (2MASS) catalog (Cutri et al. 2003). We also present new $UBV$ photometry of the fainter cluster members in Section 4. Our results are summarized in Section 5.

2. SPECTROSCOPY AND REDDENING OF THE BRIGHTER STARS

We obtained spectra for five of the brighter stars in the cluster in order to determine spectral classifications and to estimate the intrinsic colors of the stars. One of us (M.V.M.) obtained spectra of the four blue stars of the central multiple system using the Kitt Peak National Observatory (KPNO) 2.1 m telescope and Cassegrain focus, GoldCam CCD Spectrograph. These spectra were made during 2005 October and November with the No.
Figure 1. Our estimate for the spectral type of HD 193322 B is B1.5 V based on comparisons to stars in Valdes et al. (2004). Walborn & Fitzpatrick (1990) advocate using the Si lines to classify early B stars, and those lines were given the strongest weight. The spectra were normalized and then offset to improve clarity.

Figure 2. We estimate the spectral type of HD 193322 C as B8 V or possibly B9 V. The spectra were normalized and then offset to improve clarity.

Figure 3. We estimate the spectral type of HD 193322 D as B9 V due to the strength of the Ca II K lines. The H Balmer, He, and metal lines are weak. The spectra were normalized and then offset to improve clarity.

Table 1 Reddening Estimates for $R = 3.1$

| Star Name       | Spectral Classification | $E(B-V)$ (mag) | $\beta$ (μas) | $d$ (kpc) |
|-----------------|-------------------------|----------------|---------------|-----------|
| HD 193322Aa1    | O9 V((n))              | 0.31 ± 0.02    | 85 ± 2        | 0.83      |
| HD 193322B      | B1.5 V                 | 0.28 ± 0.03    | 53 ± 2        | 0.73      |
| HD 193322C      | B8 V                   | 0.29 ± 0.02    | 23 ± 1        | 0.79      |
| HD 193322D      | B9 V                   | 0.29 ± 0.03    | 25 ± 1        | 0.70      |
| IRAS 20161+4035 | M3 III                 | 0.74 ± 0.04    | 893 ± 46      | 0.78      |

The very red star IRAS 20161+4035 is the brightest object in the $K_s$ band in this vicinity, and we were curious to determine if indeed it is related to the cluster. One of us (E.D.G.) obtained three spectra of the object with the KPNO 0.9 m Coude Feed Telescope in 2004 October. These spectra cover the range from 6460 to 7140 Å with a resolving power $\lambda/\delta\lambda \sim 9700$. The average spectrum is compared to several other cool star spectra from Valdes et al. (2004) (also made with the KPNO Coude Feed telescope) in Figure 4. We made a digital comparison with all the M2–M5 giants in the Valdes et al. spectral atlas, and the best fit (based mainly on the appearance of the strong TiO bands in this spectral region) was the spectrum of the M3 II star HD 40239 (although there were a number of other M3 III spectra which made an almost equally good fit). Figure 4 shows the good overall match made with the M2 II and M3 III giants compared to the dwarf and supergiant spectra. We also measured the Hα equivalent width in these and similar stars to help establish the luminosity class (Eaton 1995). We found that among stars of similar spectral type the mean equivalent width of Hα ranged from 0.76 ± 0.04 Å for two main-sequence stars, to 1.59 ± 0.08 Å for four giant stars, and up to 1.89 ± 0.04 Å for three supergiant stars. The measured Hα equivalent width of IRAS 20161+4035, 1.38 Å, clearly places the star among those in the giant luminosity class, and we adopted this assignment in Table 1. Note that the spectrum of IRAS 20161+4035 shows the strongest Li i $\lambda 6707$ feature among the spectra illustrated in Figure 4.

We can use these spectral classifications to estimate the intrinsic colors of the targets, compare these with observed multi-color observations, and find the reddening $E(B-V)$ in each case. However, the available near-infrared 2MASS...
photometry for HD 193322 corresponds to the total flux for the entire Aa1, Aa2, Ab, and B complex. Thus, we need to make some assumptions about the relative flux contributions of each component in each filter band to derive magnitudes and fluxes for the individual stars. The magnitude differences of the AB pair were determined in the Johnson BVRI bands through adaptive optics imaging by ten Brummelaar et al. (2000). Unfortunately, much less is known about the A subcomponents. Mason et al. (2009) found a magnitude difference of $\Delta V = 1.2 \pm 0.5$ mag for the Aa,Ab speckle pair, and McKibben et al. (1998) used a statistical method to estimate the mass ratio and magnitude difference $\Delta V = 1.3$ mag for the Aa1,Aa2 pair in the spectroscopic binary. These magnitude differences (plus $\Delta V$ for the AB pair from ten Brummelaar et al. 2000) lead to $V$-band flux ratios relative to star Aa1 that are given in Table 2. To derive the flux ratios in other bands, we estimated their colors according to their spectral classification and the color calibration from Wegner (1994). We assumed that the Aa2 and Ab stars are main-sequence objects and then estimated their spectral types (B1.5 V and B1 V, respectively) based on their magnitude differences relative to Aa1 (using the absolute magnitude versus spectral type relation for main-sequence stars from Lesh 1979). Table 2 lists the adopted flux ratio estimates for the subcomponents (which agree with those from ten Brummelaar et al. for the Johnson R, I bands, but not for their B-band result for which component B is unusually faint in the B band relative to the other bands). We used these flux ratios to determine the magnitudes of Aa1 and B, the stars with reliable spectral classifications, in the following analysis. Note that the current flux ratio uncertainties probably introduce an error of $\pm 0.2$ mag into the error budget for the magnitudes of these two stars.

We estimated the reddening and angular sizes of the five bright stars listed in Table 1 by comparing their observed fluxes with reddened model SEDs. The optical magnitudes were taken from the work of ten Brummelaar et al. (2000, for components Aa1 and B), Burnichon & Garnier (1976, for components C and D), and Droegel et al. (2006, plus UBV magnitudes given in Section 4 for IRAS 20161+4035), and these were combined with 2MASS magnitudes for the near-IR (Cutri et al. 2003). The magnitudes were transformed to fluxes using calibrations from Colina et al. (1996, Johnson $U, B, V$), Bessell et al. (1998, Cousins $I$), and Cohen et al. (2003, 2MASS $J, H, K_s$). We used Kurucz model atmospheres (assuming log $g = 4.0$, solar abundances, and a microturbulent velocity of 2 km s$^{-1}$) for temperatures from the spectral calibration of Böhm-Vitense (1981, see their Table 1) to create low-resolution versions of the unreddened SEDs. However, for the case of IRAS 20161+4035 (M3 III), we adopted a flux distribution from the MARCS code (Gustafsson et al. 2008) for a model with $T_{\text{eff}} = 3500$ K, log $g = 1.0$, solar abundances, and a microturbulent velocity of 5 km s$^{-1}$. We then fit the observed fluxes with model SEDs reddened according to the formulation from Fitzpatrick (1999). Because the stars have low reddening and limited short-wavelength coverage, it is difficult to obtain an independent estimate of the ratio of total-to-selective extinction $R$, so we adopted the default value $R = 3.1$ throughout. The derived reddening $E(B-V)$ and limb-darkened angular diameter $\theta_{LD}$ are given in Table 1. The blue stars yield a consistent reddening of $E(B-V) = 0.29 \pm 0.01$ mag, which is significantly less than that found for IRAS 20161+4035, $E(B-V) = 0.74 \pm 0.04$ mag. The SED for this red star is shown in Figure 5, and we see that there appears to be an IR flux excess of $48\% \pm 10\%$ near 12 $\mu$m, based upon data from the Midcourse Space Experiment (Egan & Price 1996) and IRAS missions. We argue below (Section 5) that the higher reddening and IR excess may be related to the youth of this star.

3. ASTROMETRIC AND PHOTOMETRIC DATA FROM UCAC3 AND 2MASS

With the recent release of the UCAC3 (Zacharias et al. 2010), we now have access to a large collection of astrometric and photometric data that can be used to search for additional cluster members. We began by selecting all the stars in UCAC3 with complete sets of proper motion and photometric data that are found within a 0.25 radius of HD 193322, the nominal center of Cr 419. In Figure 6, we show the average surface density of star counts within annuli centered on the position of HD 193322. The larger surface density associated with the cluster extends outward to at least 0.10, and we set the outer boundary on cluster membership at 0.16 to avoid including too

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10 http://kurucz.harvard.edu/
11 http://marcs.astro.uu.se/
12 Infrared Astronomical Satellite Catalogs, 1988; The Point Source Catalog, version 2.0, NASA RP-1190.
13 http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/ucac
Table 2
Adopted Flux Ratios for the Components of HD 193322

| Star Name | $T_{\text{eff}}$ (kK) | $F_x/F_{\text{Aa1}}$ | $F_y/F_{\text{Aa1}}$ | $F_z/F_{\text{Aa1}}$ | $R_y$ | $I_y$ | $J_y$ | $H$ | $K_s$ |
|-----------|------------------------|-----------------------|-----------------------|-----------------------|-------|------|------|-----|------|
| HD 193322Aa1 | 33.2                  | 1.00                  | 1.00                  | 1.00                  | 1.00  | 1.00 | 1.00 | 1.00 | 1.00 |
| HD 193322Aa2 | 25.0                  | 0.29                  | 0.30                  | 0.31                  | 0.33  | 0.33 | 0.33 | 0.35 | 0.35 |
| HD 193322Ab  | 25.0                  | 0.41                  | 0.43                  | 0.44                  | 0.46  | 0.47 | 0.47 | 0.48 | 0.48 |
| HD 193322B   | 23.0                  | 0.21                  | 0.21                  | 0.21                  | 0.23  | 0.24 | 0.25 | 0.24 | 0.25 |

Figure 6. Distribution of the stellar number density per unit area in rings of increasing radius centered on HD 193322, the nominal center of Cr 419.

Figure 7. POSS2-IR image centered on HD 193322 with a field of view of 0.25 × 0.25 showing the low stellar density of the cluster. North is up and east is to the left.

Figure 8. Distribution of proper motions in right ascension ($\mu_\alpha \cos \delta$) and declination ($\mu_\delta$) for stars within 0.16 of the cluster center. The position of the circle marks the cluster average proper motion and its circumference represents the boundary for possible cluster membership.
are candidate massive stars \((E(B-V))\) and distance modulus (DM), in order to find values of these parameters that lead to the best fit of the photometry. We adopted model isochrones for the cluster from the evolutionary models of Bertelli et al. (1994) and Marigo et al. (2008).\(^{14}\) We selected an isochrone for solar metallicity and an evolutionary models of Bertelli et al. (1994) and Marigo et al. of these parameters that lead to the best fit of the photometry.

\[^{14}\] http://stev.oapd.inaf.it/cmd

We also applied a faint limit constraint, \(R_\alpha < 15\), to avoid stars with large magnitude errors. Since our initial sample was drawn from UCAC3 stars with complete photometric coverage, the result is that this sample tends toward stars with equal magnitude in all filters at the faint end. This group probably includes foreground A-type stars, so applying the faint limit will help us remove such stars from consideration.

We show two versions of the color–magnitude diagram in Figures 10 and 11. Both of these show evidence of a main-sequence group at the blue end, but both also show a large population of redder stars that lie above the expected main sequence. In order to remove such targets, we restricted the sample to those massive stars with \(Q < 0.116\), the model value for a star of mass \(M = 1.4 M_\odot\). Imposing this limit will mean that we lose fainter, red cluster members, but, on the other hand, we will also remove cool background giants and cooler, low-mass, foreground stars that do not belong to the cluster (for example, stars found near the unreddened isochrone between 0.8 and 1.4 \(M_\odot\)).

\(^{14}\) http://stev.oapd.inaf.it/cmcd
indicated in Figures 9–11 by plus signs. Note that we make the tacit assumption that the same reddening can be applied to all cluster members, and this can only be true in some average sense. There may be a reddening gradient across this field (Schlegel et al. 1998) and some of the youngest objects may suffer from circumstellar dust reddening. Nevertheless, until spectroscopy is available for many stars and their intrinsic colors found, we must accept this working hypothesis.

We performed a grid search over a range of $E(B - V)$ and DM to find those values that minimized the average $\chi^2$ value for the selected cluster stars. The best fit was made with $E(B - V) = 0.37 \pm 0.05$ mag and DM = 9.35 ± 0.03 mag, yielding an average photometric statistic of $\chi^2 = 4.4$. The isochrones for these parameters are plotted in Figures 9–11, and the corresponding main-sequence masses from the isochrone are listed in the final column of Table 3. Our derived reddening estimate is mainly consistent with earlier estimates for the cluster and star ($E(B - V) = 0.34$, Kharchenko et al. 2005; $E(B - V) = 0.345$, Burnichon 1975; $E(B - V) = 0.38$, Schröder et al. 2004; $E(B - V) = 0.41$, Cardelli et al. 1989). The reddening is slightly larger than that found by SED fitting for the blue stars (Table 1), but we suspect that the differences arise in the variable reddening across the cluster. We also repeated the analysis using an isochrone for a younger cluster (age 3 Myr), but the results were unchanged because the predicted colors and magnitudes were only significantly different for the most massive star HD 193322Aa1 (the predicted colors are marginally closer to the observed ones for the 7 Myr isochrone).

There are many stars that are plotted above the main sequence in Figures 10 and 11. Some of these stars may belong to a massive and more distant population. For example, in the IR color–color diagram (Figure 9), there appears to be a reddened group of OB stars near $H - K_s = 0.2$ and $J - H = 0.4$. An independent analysis of the 2MASS magnitudes of stars in the vicinity of Cr 419 by David Turner (2010, private communication) suggests that these correspond to objects with $E(B - V) = 1.5$ at a distance of 1.6 kpc that may be associated with the nearby cluster Berkeley 87 (Turner & Forbes 1982; Massey et al. 2001). We show how the 7 Myr isochrone would appear for such reddened and distant stars as a dotted line in Figures 10 and 11, and many of the stars appearing above the Cr 419 main sequence are close to the predicted colors and magnitudes of a distant population. Cr 419 is probably young enough that it may host pre-main-sequence stars that would also appear above the main sequence. Dashed lines in Figures 10 and 11 indicate the pre-main-sequence isochrone for an age of 7 Myr from the work of Siess et al. (2000) transformed to the distance and reddening of Cr 419, and indeed we find many examples of stars close to the predicted track. We suspect that redder stars appearing in these color–magnitude diagrams probably include some cluster pre-main-sequence stars and large numbers of distant massive stars and other line-of-sight field stars.

## 4. **UBV PHOTOMETRY**

We also obtained new UBV photometry of the central region of the cluster to explore the optical colors of the fainter stars. One of us (J.R.F.) collected CCD images of Collinder 419 in 2006 October with the Emory University Observatory, DFM 0.6 m Cassegrain telescope.\(^\text{15}\) The detector was an Apogee Ap47 1024 × 1024 pixel CCD camera. In order to concentrate the signal for fainter sources, the camera was set to a 2 × 2 binning

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15 http://www.physics.emory.edu/astronomy/observatory.html

![Figure 11](image-url)  
**Figure 11.** Color–magnitude diagram for 2MASS $J$ and $K_s$ magnitudes (in the same format as Figure 10). The bright, red object (top, right) is IRAS 20161-4035.

### Table 3

| UCAC3 Number | Other Name | $R_u$ (mag) | $R_u - J$ (mag) | $J - H$ (mag) | $H - K_s$ (mag) | $K_s$ (mag) | Mass ($\times 10^3$) |
|--------------|------------|-------------|----------------|--------------|----------------|-------------|-------------------|
| 262–202014   | ...        | 12.29       | 1.06           | 0.14         | 0.08           | 11.02       | 2.2               |
| 262–202033   | ...        | 12.90       | 1.20           | 0.23         | 0.12           | 11.35       | 1.7               |
| 262–202070   | HD 228810  | 10.01       | 0.55           | 0.10         | 0.05           | 9.31        | 5.0               |
| 262–202090   | ...        | 12.44       | 0.94           | 0.08         | 0.09           | 11.34       | 1.9               |
| 262–202099   | ...        | 13.66       | 1.33           | 0.26         | 0.09           | 11.98       | 1.4               |
| 262–202103   | ...        | 12.91       | 1.14           | 0.21         | 0.12           | 11.44       | 1.7               |
| 262–202123   | HD 193322C | 11.14       | 0.51           | 0.02         | -0.02          | 10.63       | 2.8               |
| 262–202132   | HD 193322D | 11.26       | 0.58           | 0.03         | 0.08           | 10.57       | 2.8               |
| 262–202133   | HD 193322Aa1 | 6.59     | 0.07           | -0.07        | -0.04          | 6.64        | 14.9              |
| 262–202133   | HD 193322B | 8.29        | 0.17           | -0.03        | 0.01           | 8.14        | 9.0               |
| 262–202155   | ...        | 12.27       | 0.71           | 0.07         | 0.02           | 11.46       | 1.8               |
| 262–202269   | ...        | 12.25       | 0.72           | 0.06         | 0.07           | 11.40       | 1.8               |
| 262–202314   | ...        | 12.83       | 1.09           | 0.23         | 0.06           | 11.45       | 1.7               |
| 262–202350   | ...        | 12.37       | 0.88           | 0.06         | 0.10           | 11.34       | 1.9               |
| 262–202365   | ...        | 11.63       | 0.74           | 0.07         | 0.05           | 10.77       | 2.5               |
| 262–202402   | ...        | 11.67       | 0.78           | 0.11         | 0.02           | 10.76       | 2.5               |
mode with a net pixel scale of 1.1 pixel\(^{-1}\) and a 9.5 \times 9.5 field of view. The images of the brightest stars were saturated in individual frames in order to obtain a stronger signal on the faintest sources. Thirty frames were collected through each Johnson \(UBV\) filter. In addition, standard stars from charts 140, 141, and 148 of Landolt (1992) were observed over a large range in air mass to transform the instrumental magnitudes to the standard system.

All the frames were debiased, dark subtracted, and flat fielded using standard routines in IRAF. The images were combined using IMCENTROID and IMCOMBINE to build a master image in each filter. Photometric measurements of the standard stars were made with aperture photometry routines in IRAF. The transformation coefficients were computed using the IDL procedure trans1.pro, written by Marc W. Buie. This procedure uses the general formula

\[ m_0 = m_i - kX - k''CX + eC + Z, \]

where \(m_0\) is the standard magnitude, \(m_i\) is the instrumental magnitude, \(k\) is the first-order extinction coefficient, \(X\) is the air mass, \(k''\) is the second-order extinction coefficient, \(C\) is a color index, \(e\) is a color coefficient, and \(Z\) is the magnitude zero point. The instrumental magnitudes of the stars in the Collinder 419 frames were measured using point-spread function (PSF) fitting routines in IRAF, and the relation between the PSF and aperture measurements was determined for 10 well-isolated stars in the field. The transformation equations were then used to determine Johnson magnitudes for the cluster stars. The errors in the transformation coefficients were added in quadrature with the instrumental magnitude errors to obtain the net observational errors (approximately 0.04, 0.03, and 0.02 mag in \(UBV\), respectively). The results are listed in Table 4.

In Figure 12, we show the color–magnitude diagram \((B - V, V)\) for 43 of the 79 stars measured that meet the proper motion limits for cluster membership described above (Section 3). Most of the proposed cluster members (Section 3; Table 3) were too bright and/or outside of the field of view for our \(UBV\) photometric measurements, and we have \(UBV\) photometry for only 5 of the 16 proposed members (indicated by plus signs in Figure 8 and by “Yes” in the final column of Table 4). Figure 12 also shows the main-sequence relation from the models of Bertelli et al. (1994) and Marigo et al.
(2008) for our derived estimates of $E(B - V) = 0.37$ mag and $DM = 9.35$ mag, and this relation appears to be consistent with our optical photometry. There are a number of stars that have magnitudes indicative of lower mass, main-sequence stars, but there are many objects with a position above the main sequence with a distribution similar to that seen in the red and near-IR color–magnitude diagrams (Figures 10 and 11). Figure 13 shows the optical color–color diagram ($B - V$, $U - B$) for the subset with complete $UBV$ measurements and within the proper motion limits for membership. We also show both unreddened and reddened versions of the model colors. Again, there is evidence for some lower main-sequence members (toward the middle and lower sections of the dashed line), but there is also a group of stars with colors near $(B - V, U - B)$ that are characteristic of B stars with a reddening $E(B - V) \approx 1.0$ mag. Most of these stars also have positions in the near-IR color–color diagram associated with reddened, intermediate-mass stars (Figure 9; $(H - K_s, J - H) \approx (0.15, 0.30)$).

5. DISCUSSION

The distance we obtained from the photometric analysis of $d = 741 \pm 11$ pc (formal error) does not account for possible systematic errors in the model isochrone magnitudes. By comparing the $(R_c, J, J)$ color–magnitude diagrams for a 7 Myr cluster from Marigo et al. (2008) with that from Lejeune & Schaerer (2001), we estimate that the model uncertainties amount to $\Delta d \approx 0.10$ mag over the main-sequence range of interest, so we add this error in quadrature with the fitting errors to obtain $d = 741 \pm 36$ pc. We can check this with distances derived from the angular sizes given in Table 1. This distance estimate depends on the ratio of the physical diameter to the angular diameter, and for this comparison, we estimated the stellar radii for HD 193322B, C, and D from the model isochrone values for main-sequence stars with our adopted effective temperatures (Table 2). We could not use this relation for HD 193322A1 because the model isochrone did not extend to stars quite this hot, so we instead adopted a radius of $R = 7.53 R_\odot$ from the spectral calibration for main-sequence stars from Martins et al. (2005). We estimated a radius of $R = 75 R_\odot$ for the M3 III star IRAS 20161+4035 from the calibration for giants by van Belle et al. (1999). The resulting distances are listed in the final column of Table 1, and the average, $d = 766 \pm 51$ pc, agrees with the photometric result. Our results confirm the only previous distance estimate for the cluster from Kharchenko et al. (2005) of 740 pc (no error quoted). The cluster distance also agrees within errors with the Hipparcos distance for HD 193322 of 600$^{+150}_{-110}$ pc (van Leeuwen 2007).

We suspect that some of the red stars that meet the spatial and proper motion constraints of cluster membership but lie above the main sequence are very young objects. A similar population of bright, red objects has been reported for other young star clusters containing O stars (Kumar et al. 2004; Comerón & Pasquali 2005; Carlson et al. 2007; Negueruela et al. 2007; Comerón et al. 2008). These stars may include IR-excess objects with remnant disks like the Herbig Ae/Be stars. Although it is possible that the red object, IRAS 20161+4035, is an old star that is coincidentally passing through the vicinity of Cr 419, we suspect that it may also be a very young member of the cluster, despite its evolved appearance. The star’s large reddening and IR excess both suggest that it is immersed in natal dust, and its strong Li i λ6707 and high luminosity may be indicative of youth. Kumar et al. (2004) identified three other cases of luminous, late-type giants that are found in young clusters. These cool giants may represent another kind of spectroscopic manifestation of young stellar objects.

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![Figure 13. Color–color diagram from optical photometry in a format similar to Figure 9. The solid and dashed lines show the model unreddened and reddened colors, respectively.](image-url)
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