

A NEW LOOK AT OPEN CLUSTER NGC 6520

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ABSTRACT

We use CCD and photoelectric photometry with Strömgren filters along with medium resolution spectra to investigate NGC 6520, an open cluster very nearly in the direction of the galactic center. We find an age of 60 Myr, a distance of 2 kpc, and an average reddening $E(b - y) = 0.295$, which increases toward the south. The average heliocentric radial velocity of the B stars is -29 km s^{-1} , while the velocity of the nearby Barnard 86 is about 0 (heliocentric; -11 km s^{-1} compared to the LSR). This velocity difference amounts to about 1.8 kpc since the cluster formed, implying that it is extremely doubtful NGC 6520 is related to Barnard 86.

Key words: open clusters and associations: general – open clusters and associations: individual (NGC 6520)

Online-only material: color figures, machine-readable and VO tables, FITS files

1. INTRODUCTION

The young open star cluster NGC 6520 (C1800-279) has been neglected, mostly because it appears in a crowded field only four degrees from the Galactic center. The most recent study of the cluster, by Carraro et al. (2005), derived an age of 150 ± 50 Myr (million years) and distance of 1.90 ± 0.1 kpc. These authors noted that the nearby dark nebula Barnard 86 has a distance consistent with that of the cluster, and that the nebula overlaps the cluster. They made the hypothesis that the two objects are related—that Barnard 86 is perhaps the cluster’s birth cloud, which has become generally accepted. This is puzzling, as it is thought that the mean lifetime of molecular clouds is ≈ 10 Myr (Blitz & Shu 1980).

Hayford (1933), in a study of Galactic rotation, published spectral types (from Trumpler) and radial velocities for three stars in NGC 6520. Mermilliod et al. (2008) superseded that work with velocities for the three late type supergiants.

Zug (1937), in a followup study to Hayford, listed photographic magnitudes and color indices for 50 stars, along with spectral types (also from Trumpler) and color excesses for nine stars. The existence of early B and possibly even an O star in the cluster argued for a very young age. Houck (1957) was analyzing a color–magnitude diagram (CMD) of the cluster, but the results were evidently never published. Houck pointed out that there were three evolved supergiants in the direction of the cluster, which is rather unusual.

Svolopoulos (1966) produced a photographic CMD for NGC 6520, deriving a distance of 1.65 kpc and age of 800 Myr with a reddening estimate for $E(B - V)$ of 0.27. Lindoff (1968) estimated a distance and age of 1.7 kpc and 54 Myr from relative numbers of stars on the upper main sequence, based on Zug’s (1937) data. Santos Jr. & Bica (1993) use integrated spectrophotometry continuum levels and line strengths to estimate reddening of $E(B - V) = 0.56$ and a low age of ≈ 50 Myr.

The first believable photometry for NGC 6520 was done by Kjeldsen & Frandsen (1991) who used a CCD with *UBV* filters; they derive a distance of 1.6 kpc, a mean $E(B - V)$ of 0.43, and they estimate the age to be 190 Myr; they note that the extinction could be variable over the cluster (which we confirm here). Carraro et al. (2005) use this reddening value, as they did not obtain photometry in the *U* filter. These disparate ages motivated the current study, which concludes that the cluster is younger than most previous estimates.

NGC 6520 was featured on the cover of the NOAO/NSO Newsletter 2009 September issue,¹ with a comment that it “...probably formed from gas related to the nearby dust cloud.” We find here that the cluster and the dust cloud were almost certainly not near each other when the cluster formed, even if they might be now.

2. OBSERVATIONS

2.1. Photometry

NGC 6520 never rises above two airmass in Arizona and an inadequate set of standards was observed during the CCD observations discussed below. Therefore, calibration was done with photoelectric photometry (PE) from five nights in 1997 (UT June 29, 30 and July 1) and 1998 (UT July 1 and 2) using the White photometer with Strömgren *uvby* filters on the Lowell Observatory 0.8 m telescope. Over 20 Strömgren standard stars were used each night, and a total of 22 target stars were observed on at least two of the nights. These targets were chosen on the basis of appearing single on preliminary CCD images, and with a range of color.

All five nights were extremely constant, photometric to within about 0.006 mag. The reduction to standard magnitudes was done for each night using the PHOTCAL package of IRAF,² specifically the fitparams and evalfit tasks; color indices were used and a color term was included. These magnitudes were used to further calibrate the CCD images as described next.

Multiple CCD images of NGC 6520 were obtained with the Steward Observatory 1.52 m Kuiper telescope on UT 2000 April 3, using Strömgren *uvby* filters with the BigCCD 4K camera (binned 4×4) to give a field $12'$ square and pixel size $0''.7$. The total exposure times were respectively 480, 480, 120, and 50 s in four or more images (to eliminate cosmic rays); twilight flats were used. Eight Strömgren standard stars were observed, which were not adequate for good calibration, so PE as described above was added to the calibration.

The CCD images were reduced in the standard way using IRAF, and the individual frames were combined. Aperture photometry was done with IRAF task PHOT and with the same aperture as for the PE data. This allowed the PE cluster members to be used to derive the transformation to standard Strömgren

¹ <http://www.noao.edu/noao/noaonews/sep09/pics/cover.jpg>.

² IRAF is distributed by NOAO, which is operated by AURA under agreement with the National Science Foundation.

Table 1
NGC 6520 Photometry and Spectroscopy Results

Zug No.	R.A. (18 ^h 03 ^m +))	Decl. (−27 ^o +))	V^a	$(b - y)$	m_1	c_1	$(b - y)_o$	V_o	$E(b - y)^b$	Sp T	RV (km s ^{−1})	Notes ^c
1	12.0	51 45	9.038	0.111	0.044	0.931	−0.028	8.439	0.139	B9 III	−25	
2	22.2	52 55	9.078	0.461	0.118	1.516	0.180	7.869	0.281*	F5 Ib	−29	= Hayford 1
3	30.8	54 44	8.820	0.943	0.771	0.084	0.646	7.544	0.297*	G8 I	−33	
4	24.8	53 27	8.887	0.912	0.682	0.280	0.626	7.658	0.286*	G8 I	−24	
5	27.5	51 21	10.301	0.178	0.050	0.587	−0.064	9.261	0.242	B8 V	−41	
6	31.0	53 27	10.655	0.210	0.057	0.520	−0.071	9.447	0.281	B5 III	−26	= Hayford 4
7	23.0	52 50	10.757	0.245	−0.002	0.597	−0.064	9.428	0.309	B4 IV	−28	= Hayford 6
8	11.3	53 18	10.919	0.215	0.024	0.564	−0.067	9.707	0.282	B5 V	−35	
9	22.2	52 06	10.932	0.236	0.012	0.663	−0.057	9.670	0.293	B7 V	−34	
10	24.8	52 51	11.261	0.203	0.045	0.532	−0.070	10.088	0.273	B5 IV	−34	
11	21.6	53 21	11.366	0.270	0.052	0.630	−0.061	9.941	0.331	B5 III	−22	
12	38.3	52 00	11.367	0.120	0.112	0.370	−0.084	10.490	0.204	B8 V	−25	
13	27.1	53 33	11.532	0.227	0.067	0.599	−0.064	10.283	0.291	
14	15.0	51 27	11.499	0.323	0.175	0.914	0.054	10.343	0.269*	F8 V	−31	N
15	17.2	51 22	11.668	0.200	0.047	0.549	−0.068	10.516	0.268	B6 V	−21	
16	25.0	53 05	11.598	0.414	0.303	0.849	0.133	10.388	0.281*	G8 V	+25	N
17	22.9	53 18	11.865	0.255	0.104	0.661	−0.058	10.519	0.313	B8 V	−51	
18	26.2	52 38	12.034	0.198	0.037	0.649	−0.058	10.933	0.256	
19	27.8	53 00	12.061	0.191	0.098	0.603	−0.062	10.971	0.253	
20	25.2	54 08	11.841	0.274	0.065	0.586	−0.066	10.380	0.340	

Notes.

^a The details of the transformation to standard magnitudes are given in the appendix of arXiv:1310.7227 (<http://arxiv.org/abs/1310.7227>).

^b The * indicates extinction found from a plane fit to B star extinctions. See Section 3.1.

^c N means likely not a cluster member; see Section 3.3.

(This table is available in its entirety in machine-readable and Virtual Observatory (VO) forms in the online journal. A portion is shown here for guidance regarding its form and content.)

magnitudes using the IRAF PHOTCAL tasks FITPARAMS and INVERTFIT.

Final magnitudes were then extracted from each of the four combined images using DAOPHOT in IRAF and corrected to the standard system. The standard colors thus formed are listed in Table 1 Columns 4–7 (V (derived from y), $(b - y)$, m_1 , and c_1). IRAF formal errors are less than 0.04 mag for all colors of the B stars (and usually much smaller), and 0.02 mag in b and y for the A stars. Missing values of m_1 and c_1 are due to large formal errors in the faint, red stars. Dereddening is described in Section 3.

2.2. Spectroscopy

To better judge cluster membership, we obtained spectra of 30 stars near the cluster center on UT 2012 July 7, and a second set of spectra for nine of those on July 8 with the B&C spectrograph on the Steward Observatory 2.3 m Bok telescope. The second night was hampered by clouds, and good wavelength calibration was not available, which precludes radial velocities. Spectra were also obtained for spectral standard stars. The spectrograph configuration was such as to produce 1.35 Å (two pixel) resolution, using the 832/mm grating in second order and a slit width of 1".5. Wavelength coverage was about 3865 Å to 4710 Å. The spectra were reduced with IRAF and radial velocities were obtained with the task FXCOR. The IRAF task RVIDLINES was used to derive the velocities of τ Her (−1.0 km s^{−1}) and Zug 2 (−28.6 km s^{−1}), the templates for B stars and later types, respectively. The 57 spectra in FITS format are available in the online journal.

Spectral types and radial velocities are given in Table 1, Columns 11 and 12, respectively. The FXCOR uncertainty in velocity is about 10 km s^{−1} for the B stars, and 4 km s^{−1} for later

types. Binarity is common among B stars; Chini et al. (2012) find about 35% binaries among B4–B6 and 20% among B7–B9 stars. With only one velocity for each case, we cannot identify individual binaries, but undetected companions will have an effect on velocities tabulated here. In Column 13, the letter N indicates the star may not be a cluster member, as discussed in Section 3.3.

Zug 2, 3, and 4 were included in the cluster radial velocity program by Mermilliod et al. (2008), who find −23.13, −24.12, and −23.41 km s^{−1}, respectively. The values found here are −28.6, −32.5, and −23.5 km s^{−1}, in reasonable agreement. Our mean cluster velocity is also consistent with the average velocity of the cluster given by Hayford (1933) of −26 km s^{−1}, which was based on two spectra each of three stars, all having different values for the two spectra (i.e., likely binaries).

3. ANALYSIS

3.1. Extinction

De-reddening was done using the relation for unreddened B stars given in Crawford et al. (1970), $(b - y)_o = -0.116 + 0.097c_1$, by iterating in the following manner. Based on the measured c_1 , a preliminary $(b - y)_o$ was calculated with that equation. That $(b - y)_o$ allowed for a preliminary color excess $E(b - y) = (b - y) - (b - y)_o$ to be found. The extinction to c_1 is $E(c_1) = 0.2E(b - y)$ which allows a better $c_1 = c_1 - E(c_1)$ to be calculated, and is used in the first equation above to get an improved $(b - y)_o$; this is iterated until no further change occurs. The de-reddened $(b - y)_o$ and V_o are given in Table 1, Columns 8 and 9, and the color excess $E(b - y)$ is given in Column 10.

A least-squares plane fit of $E(b - y)$ versus R.A. and decl. shows extinction decreasing eastward at a rate of −0.71 mmag

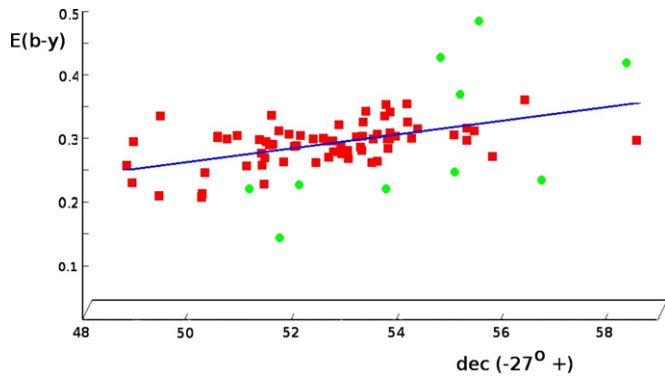


Figure 1. Color excess $E(b - y)$ in magnitudes for NGC 6520 B stars (red squares) and probable non-members (green circles, not used in fit) as a function of declination in arcminutes south from -27° . The (blue) line is the fit of a plane to the members. The third axis of this three-dimensional plot is right ascension looking east into the page, from $18^{\text{h}}03^{\text{m}}00^{\text{s}}$ to $18^{\text{h}}03^{\text{m}}50^{\text{s}}$. The tilt of the R.A. axis has been chosen so that the reader is viewing the plane edge-on; this tilt is so slight that the R.A. values have been omitted from the third axis for lack of space in the figure.

(A color version of this figure is available in the online journal.)

per R.A. second, or -2.5 mmag per arcminute, and increasing southward by 10.9 mmag per arcminute of decl. This is shown in Figure 1, the derived $E(b - y)$ for B stars as a function of position on the sky (i.e., a three-dimensional plot).

Thus most of the extinction variation is in the north–south direction, even though Barnard 86 is located to the west. This makes it unlikely that much or any of the extinction at the cluster is due to that cloud. In an image of the cluster, it is easy to see patchy clouds of dust in line with its southern border, and thus the scatter in Figure 1 is not unexpected, especially to the right. The figure also shows some outlier stars where the extinction is anomalous and may be indicating these are not cluster members; see Section 3.3.

For stars later than B, the above method will not work to find extinction, so a least-squares fit of a plane was made to the extinction as a function of R.A. and decl. for the B stars. This fit was used to correct for extinction for later type stars in Table 1, and for these stars, the $E(b - y)$ extinction in Column 10 is marked with an asterisk (*). Since the extinction is patchy, we expect this to give rise to substantially more scatter in the dereddened colors for the later type stars.

3.2. Color–Magnitude Diagram

A CMD is an excellent diagnostic tool to determine age and distance for a star cluster. Columns 8 and 9 ($(b - y)_0$ and V_0) of Table 1 are plotted in Figure 2, with different symbols for B stars dereddened individually, and the A stars and supergiants dereddened by a plane fit to the reddening. As expected, the scatter for the B stars is much less than for the A stars.

Also plotted are two isochrones,³ lines of constant age, for stellar evolution models as described by Marigo et al. (2008). The isochrones provide the $uvby$ Strömgren magnitudes for various mass stars at a chosen age and metallicity. There are only a few adjustable parameters needed to fit the observed points, and so the age and distance that best represent the cluster can be determined. The other parameter, metallicity, is chosen to be typical of recent star formation, $Z = 0.019$. Various ages were chosen, and the one that fit reasonably well is 60 Myr. The B stars on the upper main sequence, for which

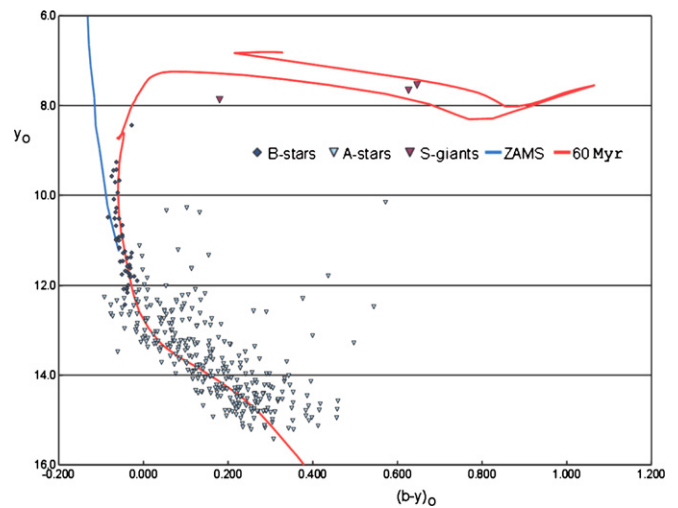


Figure 2. CMD for NGC 6520, showing V_0 vs. $(b - y)_0$. Included are the zero-age main sequence and the 60 Myr isochrones, adjusted to a distance modulus of 11.5.

(A color version of this figure is available in the online journal.)

reddening is well determined, are the prime ones to fit for age. Farther down the main sequence, in the region of the A stars, the isochrone can be adjusted up and down to fit the observed points by converting absolute magnitudes to the measured apparent magnitudes, adding a distance modulus, which is determined to be about 11.5, implying a distance of 2 kpc. The two G supergiants, Zug 3 and 4, are very close to the blue loop in the isochrone.

The primary cause of uncertainty in the age and distance comes from the variable and patchy reddening. However, the spectral types of the B stars indicate that the age of 60 Myr cannot be too far from correct; the earliest type is B4 V, indicating a mass of about $6 M_\odot$, which would have a main sequence lifetime of about this age. It is unlikely that additional observations can improve the CMD analysis.

We note here that the difference between our age and that of Carraro et al. (2005) arises from their exclusion of B stars farther than $30''$ from the cluster center. Our radial velocities show these stars to almost certainly be cluster members; they are the brightest, bluest stars in the cluster. Further, dereddening individual B stars substantially decreases the scatter in our B star measurements.

3.3. Cluster Membership

There are several potential indicators in the data described here that could indicate cluster membership, such as radial velocity, extinction, strength of the Ca II K line (for the B stars), position in the CMD, and/or distance from the cluster center (here taken to be $18^{\text{h}}03^{\text{m}}25^{\text{s}}$, $-27^\circ53'40''$). The stars that are most interesting in this regard are as follows.

Zug 1 (=HD164621) is classified as a B9 III. It is rather far from the cluster center, about $4'$ west. Its extinction is the lowest of any B star in the cluster, $E(b - y) \approx 0.14$, where the average is about 0.27 mag at its decl. The Ca II line has an equivalent width of about 0.6 \AA , whereas the typical B star in the cluster is more like 0.3 \AA . The radial velocity is about -25 km s^{-1} , similar to the average of the other B stars in the cluster of -29 km s^{-1} . This being the brightest star in the cluster, it would be valuable as an age indicator, but not essential; it lies about a half-magnitude

³ Available at <http://stev.oapd.inaf.it/cmd>

below the 60 Myr isochrone. Taken together, all of this indicates that the star may not be a cluster member.

Zug 2 (=HD164654, Hayford 1) is an F4 or F5 Ib star located about an arcminute from the cluster center. The extinction and Ca II line cannot indicate anything about cluster membership. Its radial velocity is -28.6 km s^{-1} , near the cluster average. This star's position in the CMD is also about a half magnitude below the first crossing to the red with a hydrogen burning shell. This crossing is quite fast, so it would be unlikely to catch a star in this phase, but not impossible.

Zug 3 (=HD164684) and Zug 4 (=CD-27 12315) are both G8 I spectral type, the former about 2 arcmin southeast of the cluster center, the latter within a few arcseconds. Their radial velocities are -33 and -24 km s^{-1} , both close to the average. They both lie on the blue loop of the CMD, indicating they are in the core helium burning phase.

There are several other, less important stars that are probably not cluster members, based on radial velocity and extinction; they are indicated in Column 10 of Table 1.

4. CONCLUSIONS

We find NGC 6520 to be quite a bit younger than most previous estimates, i.e., about 60 ± 10 Myr, consistent with stars of spectral type B4 and B5 in the cluster (Negueruela & Marco 2012). Its distance of about 2 ± 0.2 kpc (putting it on the outer edge of the Scutum-Centaurus spiral arm; Churchwell et al. 2009) has been reasonably estimated, but the distance to Barnard 86 has never been measured. Under the assumption that Barnard 86 is at the same distance as the cluster, Carraro et al. (2005) found its properties to be reasonable, but this is hardly proof.

They also measured a radial velocity of $+11 \text{ km s}^{-1}$ compared to the local standard of rest, which is consistent with that estimated by Clemens & Barvainis (1988). This translates into roughly 0.0 km s^{-1} heliocentric velocity. Table 1 Column 12 lists the heliocentric radial velocities of stars for which we obtained spectra; the typical velocity is about -30 km s^{-1} .

The main conclusion here is that the cluster and cloud have different heliocentric radial velocities by about 30 km s^{-1} . This, in the 60 Myr the cluster has been in existence, amounts to about

1.8 kpc relative motion, and would be greater if the cluster were older. So, if the two objects are at the same distance today, they were not at the time the cluster formed, and thus almost certainly have nothing to do with each other. Other problems with this idea include no known mechanism for ejecting an entire cluster from its birth cloud at that speed, and an ejection radially outward through the galaxy, but with essentially no tangential velocity. We conclude that NGC 6520 was not formed in Barnard 86.

It is possible that very long baseline interferometry radio observations could establish a heliocentric parallax for Barnard 86, which would be interesting to determine its location and pin down some of its characteristics.

I thank Steward and Lowell Observatories for allocating telescope time for this project. I appreciate many useful discussions with Brian Skiff, and correspondence with Daniel Majaess and Giovanni Carraro, as well as many useful comments from an anonymous referee. This work made use of the SIMBAD database, operated at CDS, Strasbourg, France.

I would like to dedicate this paper to the memory of Dr. Theodore E. Houck, who taught me to be careful in everything I do.

Facilities: SO:Kuiper (BigCCD), Bok (B&C Spectrograph), LO:0.8m (White photometer)

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