Why is the Main Sequence of NGC 2482 So Fat?

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ABSTRACT

We present the results of high resolution spectra of seven stars in the field of NGC 2482, an open star cluster of age 447 Myr. We confirm the previously published values of the radial velocity and metallicity of one giant star. This gives us confidence that another giant star is a bona fide cluster member, and that three stars significantly above the main sequence in a color-magnitude diagram are not members, on the basis of discordant radial velocities. Another star ≈1.7 mag above the main sequence may or may not be a member. Its [Fe/H] value is ~0.1 dex more positive than two giant stars studied, and its radial velocity is 3-4 km s\(^{-1}\) less than that of the two giant stars, which is a significant difference if the velocity dispersion of the cluster is less than \(±1\) km s\(^{-1}\). To a large extent the width of the main sequence seems to be due to the presence of foreground and background stars in the same general direction, stars that masquerade as main sequence stars in the cluster.

Krisciunas, Monteiro, & Dias (2015) give uBVgr\(_i\) PSF photometry of 114 stars in the southern open cluster NGC 2482. Table 2 of our paper gives the celestial coordinates of these stars and the star ID’s we also use in the present paper. From isochrone fits to the PSF photometry we find an age of the cluster of \(\log t = 8.65 ± 0.09\), or \(t = 447^{+103}_{−84}\) Myr. Until now only one star in this cluster has been studied spectroscopically (Reddy, Giridhar, & Lambert 2013). This star, which we will refer to as star 9 of Moffat & Vogt (1975), has a radial velocity of ~39.00 ± 0.2 km s\(^{-1}\) and a metallicity \([\text{Fe/H}] = \log (Z/Z_{\odot}) = -0.07 ± 0.04\), where \(Z\) is the abundance of elements heavier than helium. Presumably, this is the metallicity of the cluster. Analysis based solely on our photometry gives \([\text{Fe/H}] = -0.10 (+0.13, −0.18)\).

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Fig. 1 shows a color-magnitude diagram of NGC 2482 based on a combination of short and long exposures, so as not to saturate the bright stars or to have too low a signal-to-noise ratio for the faint stars. To Fig. 1 we have added star 9 of Moffat & Vogt (1975), using their single channel photoelectric photometry. This star was outside our 8.7 by 8.7 arcmin field of view. In Fig. 1 stars 108 and 206 are at the cluster turnoff point. Star 23 is either a blue straggler or is situated beyond the cluster. Star 166 and Moffat and Vogt’s star 9, presumably asymptotic giants in the cluster, fall on an isochrone that fits the photometry of the upper main sequence stars and those at the turnoff point (Krisciunas, Monteiro, & Dias 2015).

On the right hand side of Fig. 1 the points plotted as magenta triangles clearly correspond to stars not in the cluster. One might wonder: Why is the main sequence so fat? What about the stars considerably above the main sequence? Unresolved binaries in the cluster might be up to 2.5 \( \log_{10}(2) \approx 0.753 \) mag above the main sequence, but not more. Could it be that this cluster’s stars formed over a range of time, possibly with different abundances? That would be noteworthy, as we assume that the stars in an open cluster are coeval and have the same abundances. Two stars in the Pleiades considerably above the main sequence are worthy of the reader’s attention (Oppenheimer et al. 1997), as they have characteristics of stars much younger than the cluster. It is suggested that a cloud that was a member of the “Pleiades Supercluster” recently formed stars, which are now situated between us and the cluster. These two stars could be members of the group. We know that some globular clusters show evidence for multiple main sequences, owing to different helium abundances (Piotto et al. 2007; Milone et al. 2012), but the longer time scale for globular cluster evolution makes this easier.

To investigate the cluster membership of some stars in NGC 2482 we used the McDonald Observatory 2.7-m Harlan J. Smith Telescope and the cross-dispersed Tull coudé spectrograph, which provides a resolving power of 60,000 at 777 nm. Our data were taken on 15 and 16 March 2016 UT. As radial velocity standards we used HD 182572 and HD 42807. Given the declination of the cluster (−24°3’) and the latitude of McDonald Observatory, the cluster was high enough to observe about 5 hours per night.

The spectra were processed with an IRAF\(^4\) script that performed standard bias subtraction, inter-order scattered light subtractions, flat fielding and optimal extraction from 58 echelle orders. We determined stellar parameters using the Kea software (Endl & Cochran 2015).

\(^4\)IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation (NSF).
which matches selected portions of the observed spectrum against a library of model templates. These results are given in Table 1. Star 206, at the turnoff point of the cluster, is too hot and rapidly rotating to show sufficiently deep absorption lines of metals to give accurate values of the radial velocity and metallicity. As a sanity check, our new values of [Fe/H] and the radial velocity of star 9 of Moffat & Vogt (1975) match, within the errors, those previously published (Reddy, Giridhar, & Lambert 2013).

We can assert that stars 200, 232, and 256 are not members of the cluster, as their radial velocities are 20 to 35 km s\(^{-1}\) different than Moffat and Vogt’s star 9 and our star 166, and the velocity dispersion of an open cluster is typically less than \(\pm 1\) km s\(^{-1}\) (Geller et al. 2010; Tofflemire et al. 2014). Our star 244 is a possible member of the cluster, as its radial velocity matches those of Moffat and Vogt star 9 and our star 166 within 3-4 km s\(^{-1}\). Given that our star 166 and Moffat and Vogt’s star 9 have almost identical \(BV\) photometry, abundances, radial velocities, and temperatures, and given that they fall on an isochrone that matches the photometry of the cluster, we are very confident that they are both members of the cluster. Stars 206 and 108 (at the turnoff point) fall on the same isochrone.

We would like to have obtained spectra of other stars in NGC 2482 that do not neatly lie on the main sequence, but because of computer problems on the second of our half-nights, we were unable to observe more than a total of seven stars at a signal-to-noise ratio sufficiently high to make the analysis worthwhile. We note that \(V \approx 13.5\) to 14 is about the limit with the 2.7-m telescope and the Tull spectrograph in 1 hr of total exposure time, in order to do abundance analysis and have confidence in cluster membership.

We note that the mean proper motion of NGC 2482 is only 3.3 milliarcseconds per year in both right ascension and declination (see Table 1 of Krisciunas, Monteiro, & Dias 2015). The Gaia project should give us added information on the motions of stars in this cluster.

Still, we have confirmed the radial velocity and metallicity of star 9 of Moffat & Vogt (1975), and we have confirmed that that star and our star 166 are nearly identical regarding measurable parameters. Three stars observed by us to be above the main sequence in a CMD and in the direction of the cluster are clearly not cluster members, based on radial velocities. Another star above the main sequence (star 244) may or may not be a cluster member. Its metallicity [Fe/H] = +0.06 \(\pm\) 0.04, which is \(\sim 0.1\) dex more positive than the two giant stars studied.

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Fig. 1.— Color-magnitude diagram of NGC 2482. Except for star number 9 of Moffat & Vogt (1975), the photometry is from Table 2 of Krisciunas, Monteiro, & Dias (2015); some stars are labelled according to the numbering scheme of this paper. Blue circles correspond to presumed cluster members observed with short (3 second) exposures on 6 January 2012 UT with the Las Campanas Observatory 1-m Swope telescope. Squares correspond to presumed cluster members imaged with 150 second ($B$-band) and 120 second ($V$-band) exposures on 21 December 2012 UT. Magenta triangles represent red stars clearly not in the cluster. The solid black line is the 447 Myr isochrone from Krisciunas, Monteiro, & Dias (2015), which was fit to stars brighter than $V = 15.5$. The red dashed line shows a portion of that isochrone offset by 0.753 mag. That is the upper limit for unresolved close binaries that are *bona fide* members of the cluster.
| Star   | RV (km s$^{-1}$) | $v \sin i$ (km s$^{-1}$) | $T_{\text{eff}}(K)$ | log $g$   | [Fe/H] | Member? |
|--------|-----------------|---------------------------|----------------------|-----------|--------|---------|
| MV star 9 | $+38.7 \pm 0.3$ | $4.6 \pm 0.2$             | $4940 \pm 98$        | $2.38 \pm 0.12$ | $-0.04 \pm 0.03$ | Y       |
| 166    | $+37.4 \pm 0.2$ | $5.1 \pm 0.2$             | $4800 \pm 45$        | $2.25 \pm 0.14$ | $-0.06 \pm 0.03$ | Y       |
| 206    | ...             | $>60$                     | $9162 \pm 143$       | $4.89 \pm 0.07$ | $-0.45 \pm 0.20$ | Y       |
| 244    | $+34.6 \pm 0.2$ | $7.9 \pm 0.2$             | $6320 \pm 86$        | $4.38 \pm 0.07$ | $+0.06 \pm 0.04$ | Maybe   |
| 200    | $+57.4 \pm 0.5$ | $14.2 \pm 0.3$            | $6440 \pm 125$       | $3.62 \pm 0.24$ | $-0.03 \pm 0.05$ | N       |
| 232    | $+63.3 \pm 0.7$ | $8.8 \pm 0.3$             | $6860 \pm 40$        | $3.69 \pm 0.64$ | $-0.40 \pm 0.05$ | N       |
| 256    | $+72.2 \pm 0.4$ | $10.3 \pm 0.2$            | $6320 \pm 169$       | $4.31 \pm 0.16$ | $-0.24 \pm 0.04$ | N       |

For each star we give the heliocentric radial velocity, the projected rotational speed, the effective temperature, log $g$ (where $g = GM/r^2$, and log $g$ in cgs units is $\approx 4.4$ for the Sun), the metallicity, and whether the star is a member of the cluster.