DETERMINATION OF AGES AND DISTANCES

OF OBSCURED STAR CLUSTERS

by

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INTRODUCTION

Determining Ages of Star Clusters

Defining the age of a star has been an ongoing challenge within astronomy and astrophysics but it holds great importance as it allows us to establish the to study the evolution of the Milky Way galaxy and to understand stellar evolution and star cluster evolution. The only fundamental stellar age we have is that of the Sun, which is derived from radioactive dating of meteorites. There are many available techniques present today that allow for stellar age dating, all of which rely heavily on models or empirical relative calibration. One of the most commonly used methods by astronomers today is the fitting of single stellar age, or isochrones, model fitting. The research presented here is part of an ongoing and larger project to determine fundamental parameters of open clusters including ages, distances, and reddening, defined below, using uniform photometry data for all the open clusters in the sky.

Background

Extinction and Reddening

By definition, extinction is the scattering and absorption of light, by dust and gas between a star and the observer. A similar effect can be seen at dusk, when the Sun is lower in the sky and it appears dimmer and redder. When the Sun is near the horizon, the light must pass through more of the atmosphere, which scatters and absorbs some of the Sun's light, causing the Sun to appear dimmer and redder. This scattering and absorption is wavelength dependent, with shorter wavelengths being much more affected than longer wavelengths. Therefore, during the sunset, the Sun's light looks redder, because much of the blue light has been removed by scattering and absorption. Observed starlight, just like sunlight, is in the same way dimmed and reddened by the time it reaches the surface of the Earth due to dust and gas in interstellar space.

While many astronomers view interstellar dust as a hindrance, it can also be used as a tool. Under the assumption that all the stars in a specific cluster are behind the same amount of matter, the amount of dust between the observer and star can be used to isolate star cluster member stars from non-cluster stars, in a observed field, by using the fact that nearby stars will have less dust in the foreground and more distant stars will have more dust in front of them. The extinction of a star is therefore a measurement of the amount of dust and gas between the observer and the star.

Isochrones

Isochrones, also known as sets of single age evolutionary tracks, are stellar models that represent a variety of stars at different masses with the same age. These isochrones are used as a comparison to observed stars in a color-magnitude diagram, an observed version of the fundamental Hertzsprung-Russell diagram. The basic method of deriving ages from isochrones is fairly straightforward, to compare the set of stellar models to the observed stars in a star cluster. The goal is to use these stellar models to derive estimates of the fundamental parameters of the cluster such as age and distance.

In order to compute the age of a cluster from theoretical isochrones, one must interpolate the stellar evolution tracks and find which age and mass value correspond to the cluster in the observable space. Once interpolated, the theoretical isochrone that best passes through the stellar locus in the color-magnitude is decided normally by visual inspection. Then, the corresponding age is given to that cluster.

Though basic in theory, the process turns out to be more difficult because of the complex shape of isochrones. On the main sequence, the isochrones are very close together, leaving large room for error. Due to this, high accuracy on the observable parameters is needed in order to obtain significant results.

Isochrone fitting is a seemingly straightforward process and the models are based on well-understood stellar physics, especially for solar-type stars. Though it is straightforward and commonly used presenting reliable data, there are many disadvantages to this method. Isochrones are complex and have a non-linear morphology, especially through the main-sequence turn off. Multiple isochrones can also pass through one single point, resulting in large uncertainties in the derived parameters, especially when comparing studies using non-uniform data.

The Clusters

APOGEE/Firstlight Clusters

The clusters used in this analysis are a set of clusters in the constellation of Cygnus, that have also been targeted as part of the Sloan Digital Sky Survey III/ Apache Point Observatory Galactic Evolution Experiment (SDSS-III/APOGEE; Majewski 2012). While this study is focus on the age and distances of the clusters, the APOGEE survey will add velocity and chemistry information, but all of these parameters are needed to fully understand and utilize these clusters.

METHOD

For this analysis, we combine photometry data from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) and *NASA's* Wide-field Infrared Survey Explorer (*WISE*; Wright et al. 2010) to the isolated cluster stars with chemistry information from the SDSS-III/APOGEE survey. The clusters will be fit to isochrones to determine the cluster's age and distance. The following techniques, which use uniform data set for large numbers of clusters, will then be compared to other "single study" results for the same clusters.

Color Determination

Looking at the spectral energy distribution of stars, the infrared "color" of most stars, which is measured by the calculating the difference of two filters at different wavelengths, is the same across the Rayleigh-Jeans tail regardless of the temperature of stars (Fig 1.a,b). The Rayleigh-Jeans tails from stars are typically covered by the near-infrared bands, JHK_S, and mid-infrared bands, [3.6]-[8.0] micron bands. Majewski, Zasowski, & Nidever (2011) have shown that the color (H-[4.5]) gives color values that are nearly constant and independent of stellar type (Fig 1.c). Majewski *et al* (2011) found that H - [4.5] = 0.08. Therefore, if a star is measured in the Rayleigh-Jeans tail to have H - [4.5] larger than .08, it can be assumed that interstellar dust is causing the color to redden. The difference in color is therefore a determination of how far away the star lies. The redder the star is, the more dust is causing extinction, and therefore the farther away it is. Using this color difference, a cluster can then be isolated from all of the stars we see in a field, by identifying where the maximum amount of stars at a given distance lie, determined by the amount of dust in the foreground of each star.

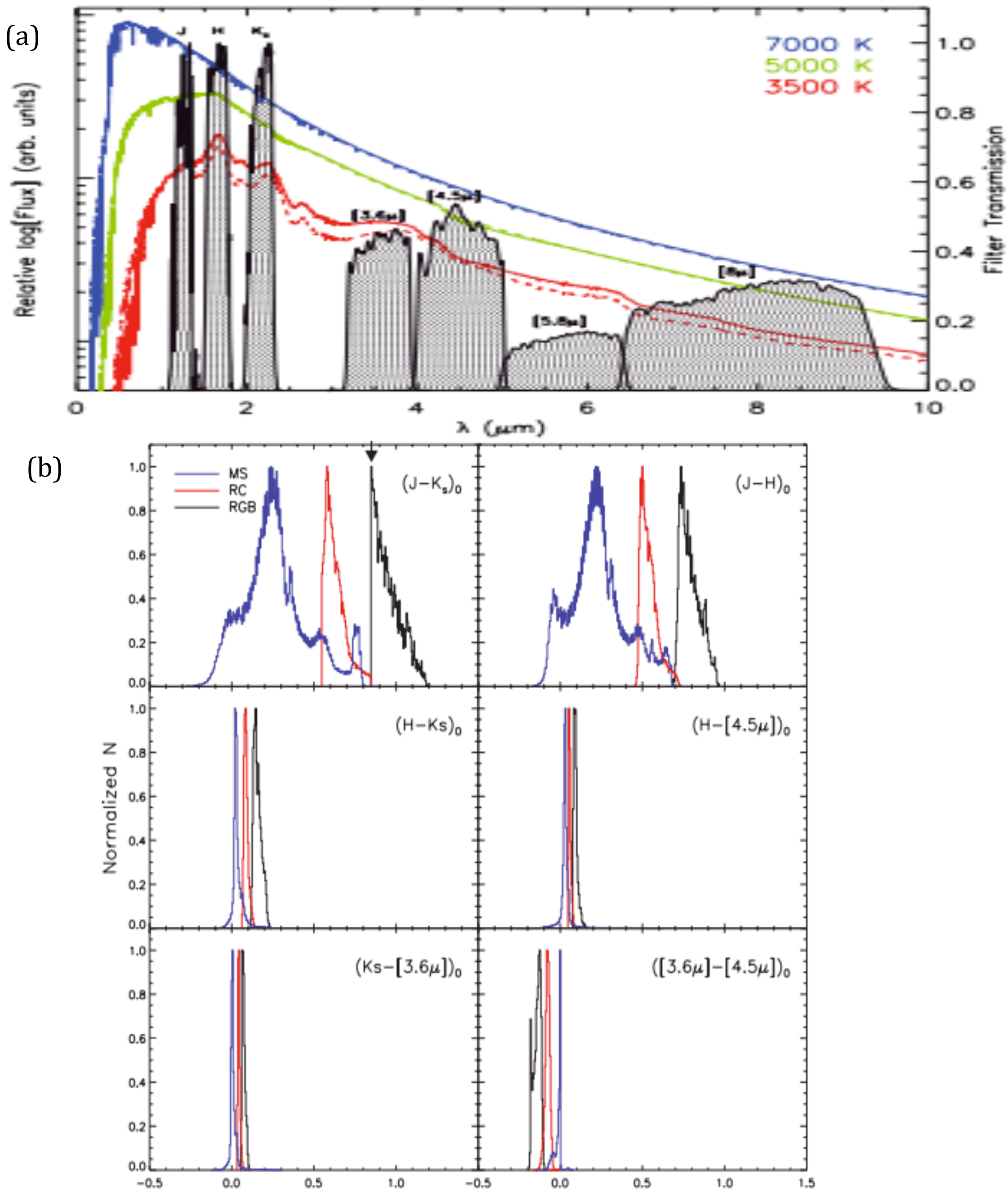

Figure 1
a.) Stellar model spectral energy distributions for three stars of different temperatures against band pass transmission curves. Across the filters in the mid-infrared regions there is a strong uniformity in the slopes of the three SEDs showing again that at the different temperature stars the color of each star should be the same (Figure from Majewski et al 2011 pg. 5)
b.) Histograms which show the color distributions of various color combinations of three different stellar types. The (H-[4.5]) has a very narrow range of color. Therefore, the color (H-[4.5])=0.08 is adopted for stars of all stellar types. (Figure from Majewski et al 2011 pg. 6)

Star Cluster Isolation

Using data from Two Micron All Sky Survey (2MASS) (Skrutskie et al 2006), and Wide-Field Infrared Survey Explorer (WISE) (Wright et al 2010) a process is used in which the color excess, E(*H*-[4.5]), or extinction A(K_S), is determined using the IR extinction law:

$$A(K_S)= 0.918 * (H - [4.5] - .08)$$

The extinction, A_K, is then compared to the number of stars inside and outside the assumed cluster radius. In general, due to the expanding cone of observation, when one looks out into the sky there is a natural growth in density with distance until the density drops off due to the photometric limits of the survey. Looking at the number density against extinction, one can define a cluster as an enhancement of stars at a certain distance, which is displayed as a bump off of the natural curve. In order to find this bump, a narrow window of A_K is defined, and in this window the ratio of the number of stars inside of our cluster radius to the average of those in the field is measured. The A_K window is swept through extinction space from no extinction to the largest measured extinction in steps of 0.01 E(H-[4.5]). At each step, the number of stars in the cluster radius is compared to the average of the stars in the field, looking for the maximum stellar enhancement, which denotes the cluster. The maximum over-density is flagged as the cluster and all of the other stars are thrown out. The cluster at the found A_K is then plotted in a color magnitude diagram (CMD) and matched to a set of stellar models, or isochrones.

Isochrone Fitting Process

For isochrone fitting, the isochrones were fit by eye. Once the isochrone is fit, the 4-parameter space of age, distance, reddening, and chemistry can be determined.

RESULTS

The above technique was used with a step size of 0.01 and an extinction window width of 0.3. The cluster members were determined and the clusters can be seen in Figure 2 below. Due to limitations of the data at this point, we chose to study in detail only four of the clusters (Table 1) to fully determine parameters and compare to previous work. The fitted isochrones parameters for age, distance, and reddening (assuming a solar chemical composition as expected for nearby clusters) are presented in Table 1, with the isochrones fits shown in Figure 3.

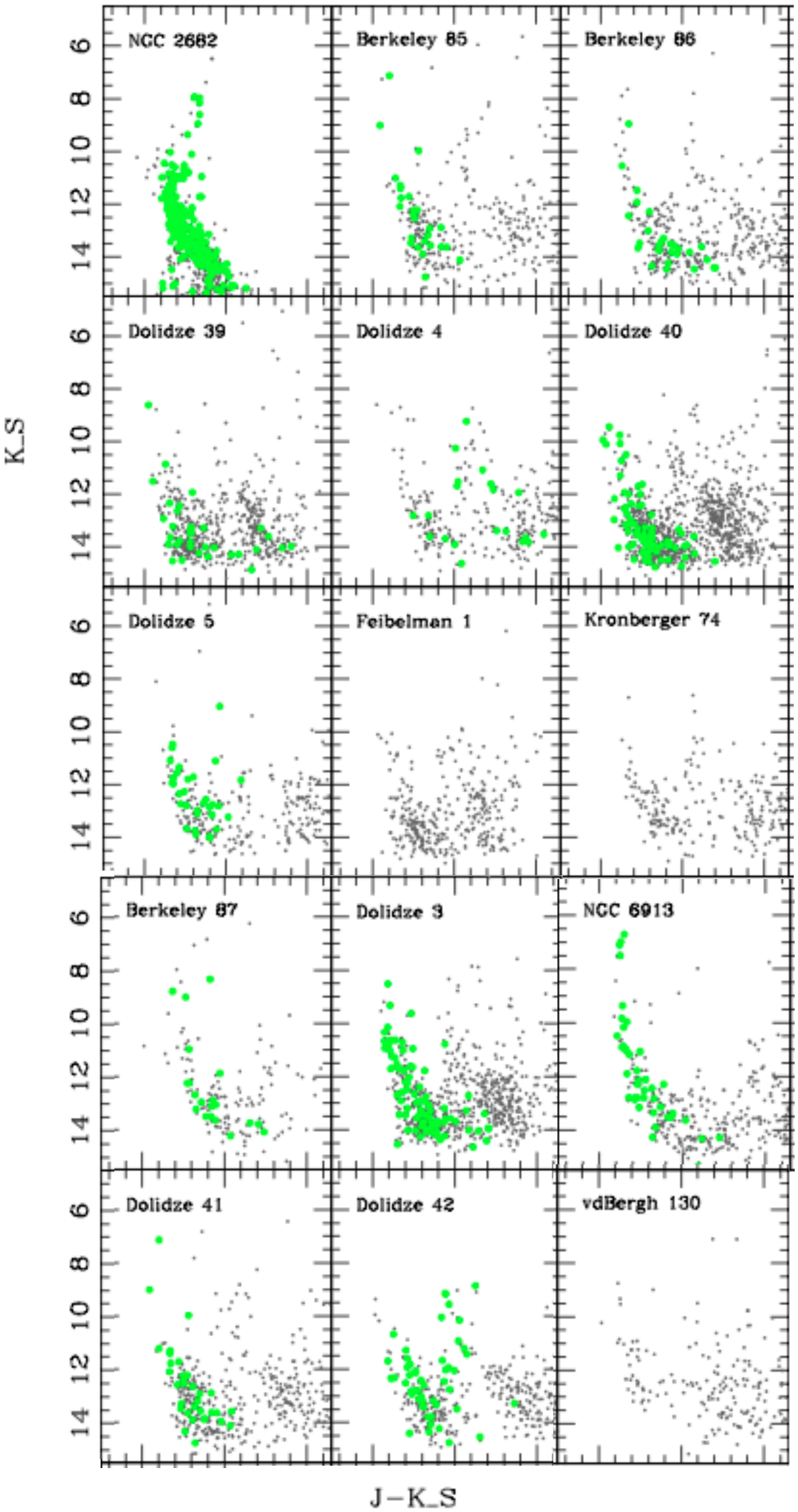

Figure 2: Selected cluster members are shown in green while nonmembers are grey.

Table 1: parameters for clusters

Cluster Parameters

Cluster	[Fe/H]	Log(age)	(m-M)	E(J-K)
Berkeley_86	0.000	7.37	10.23	0.90
Berkeley_87	0.000	7.35	9.61	0.93
Dolidze_42	0.000	7.19	9.54	0.58
NGC_6913	0.000	7.61	9.80	0.70

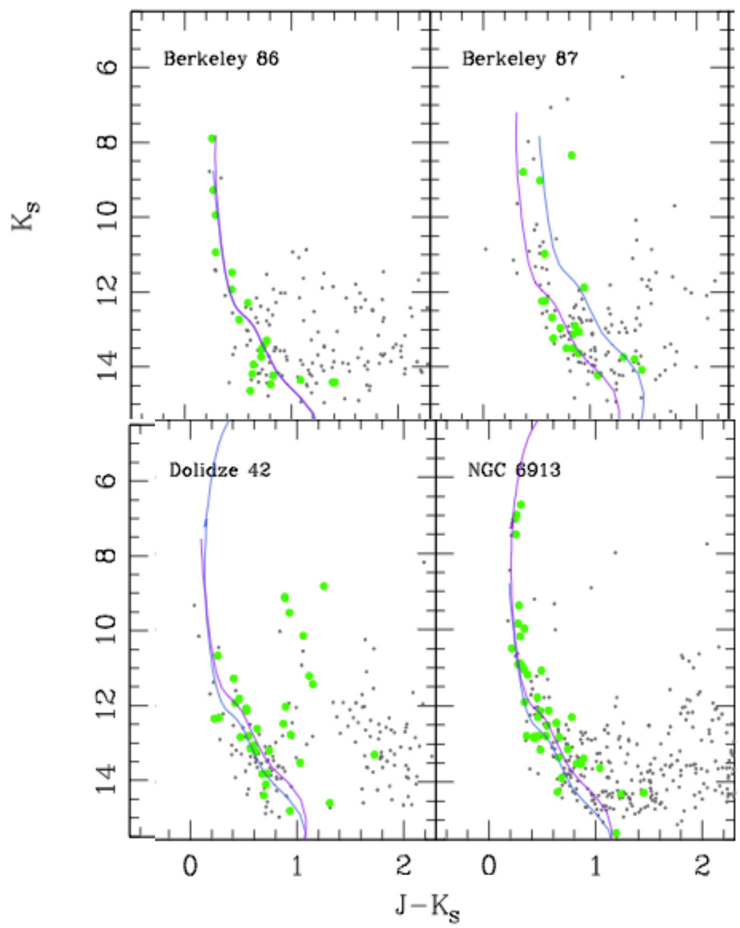

Figure 3: Isochrones fitted for a subset of clusters

DISCUSSION

The ages and distances of the clusters in the First Light field were determined through isochrone fitting. The parameters of age and distance which was obtained for clusters NGC 6913, Dolidze 42, Berkeley 85, Berkeley 87, Berkeley 86, are compared to previous values for these clusters in order to determine the accuracy of this research. Table 2 gives current values for age and distance of the clusters.

Table 2

Literature Values

Cluster	log(age)	Distance (pc)	Source
NGC 6913	5.47-6.24	-----	1
	7.00	-----	2
	6.699	-----	3
	7.17	-----	4
	7.111	1148	9
Dolidze 42	6.00	930	5
	7.542	972	9
Berkeley 87	6.00	-----	6
	6.00-6.30	950	7
	6.00-6.30	996	8
	7.152	633	9
Berkeley 86	7.116	1112	9

Sources: 1.) Joshi, *et al*, 1983 2.) Lynga, 1987 3.) Boesche, *et al* 2003 4.) Malysheva 1997 5.) Zakirov ,1989 6.) Eigenbrot, Zernow, 2009 7.) Skinner, 2008 8.) Turner, *et al,* 1982 9.) Dias, *et al,* 2002

NGC 6913

It has been determined that the log(age) of NGC 6913 is 7.61, giving an age of 40 Myr. It has also been found that the distance of the cluster is at a distance of (m-M) of 9.8 corresponding to 921 pc. The age is somewhat higher than previous literature values for this cluster, but the three evolved stars fit better with our isochrones match. The distance we have found is in good correspondence with the value found by Dias *et al.* (2002).

Dolidze 42

With a log(age) of 7.91, corresponding to 81.6 Myr, which is again significantly higher than the previous values for age of this cluster of 1 Myr (Zakirov, 1989) and 34.8 Myr (Dias *et al,* 2002). For this fitting we were limited by lack of bright stars that show all of the variation for young clusters ages, which results in a very high uncertainty in our measured age. The derived distance of (m-M) is 9.54, or 809.1 pc. This distance is in good correspondence with previously literature values.

Berkeley 87

The age for Berkeley 87 was determined to be log(age) of 7.35, or 22.4 Myr. This is significantly higher than the previously recorded age values which all ranged around 1 Myr. However, as can be seen in Figure 3, the previous literature values provide a poor fit to the data and again the lack of bright stars limits our ability to derive a reliable age. A distance (m-M) was determined to be 9.61, corresponding to 835 pc. This is also in good relation to the current literature values.

Berkeley 86

This research has derived a log(age) of 7.37, or 23.4 Myr for Berkeley 86. Again this is a high value for this cluster when looking at the current literature values given by Dias *et al.* (2002). A distance of (m-M) 10.23, corresponding to an distance of 1112 pc was found, which matches the value found by Dias *et al* (2002) of 1112 pc.

Future Research

After finding the cluster members, there are hopes to use the TCU Astrophysics Group's new method for systematically fitting isochrones by computer matching. This process will hopefully diminish the bias and uncertainty that can arise when fitting isochrones by eye. Using this method, each star in the cluster, the distance between the star's color and magnitude and that of the isochrone is computed for a given set of parameters: age, distance, reddening, and chemistry (defined as the abundance of elements that are not hydrogen or helium in a star). The best-fit isochrone is considered to be the one with the mean-minimum distance to the isochrone. Once the isochrone is picked, the 4-parameter space of age, distance, reddening, and chemistry can be determined. This method should allow for better and more accurate fits to the clusters. Also, the group hopes to supplement with additional bright star data to better constrain the ages for these very young clusters.

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ABSTRACT

Defining the age of a star has been an ongoing challenge within astronomy and astrophysics but holds a great importance within these fields because it allows us to understand stellar evolution and cluster evolution and to understand the history and evolution of the galaxies, including our own Milky Way galaxy. Isochrones, also known as stellar evolutionary tracks, are models of the H-R Diagram which represent a variety of stars at different masses with the same age, and are a common method used to determine the ages of star clusters. This research shows work that determines new and improved values for age and distance of star clusters using new measurements for the chemical composition of star cluster stars. It also employs a new technique that uses interstellar dust as a tool to isolate member stars in the star clusters from random stars in the Galaxy.   Using this uniform dataset, an isochrone fitting method is applied to those members in order to determine new values for the fundamental parameters (age and distance) for obscured star clusters with chemistry measured using the APOGEE survey.