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A Study of the Open Cluster NGC 2374

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Abstract. The results of modified objective grating observations and photoelectric as well as photographic photometry of the open cluster NGC 2374 are presented. The cluster contains at least twenty stars as definite members down to $m_V \approx 15$ mag. There is a uniform extinction of $E(B-V) = 0.175$ mag and the distance is 1.2 ± 0.1 kpc. The most likely age of this cluster is 7.5×10^7 years.

Key words: open clusters—photometry

1. Introduction

The study of young open clusters, especially the estimation of their distances, is very valuable for a better understanding of galactic spiral structure. A search for such young clusters was carried out using the technique of combining the spectral types from the modified objective grating spectra and the transformed V mag from the Palomar Observatory Sky Survey (POSS) Charts (Babu 1983). Out of several clusters observed in the direction of the Monoceros constellation, it was found that NGC 2374 ≡ OCl 585 ≡ C0721 − 131 ($l = 228°.43$; $b = +01°.4$) has the characteristics of a young cluster. It has, therefore, been selected for further photometric work. Its field is given in Fig. 1 along with the identification numbers.

The details of whatever little is known about this cluster are compiled by Alter, Balazs & Ruprecht (1970) and by Lyngå (1980). These are reproduced in Table 1. Ruprecht (1966) has classified the cluster as II 3p in the Trumpler classification system. The meaning of this classification is that it is a detached cluster with little central concentration of stars which is coded as II. The number 3 means that it is composed of both bright and faint stars, while 'p' indicates that it is a sparsely populated cluster with less than fifty stars.

In this paper, the results of modified objective grating observations and photoelectric as well as photographic photometry are presented.

2. Observations and reductions

The modified objective grating spectra for the stars in the region of the cluster have been obtained using the instrument (Babu 1983) which gives a dispersion of 485 Å mm^{-1} in the second order. The exposure time was 2 hours on a Kodak 103a-O plate, from which the spectral types, with an uncertainty of two subclasses on either side

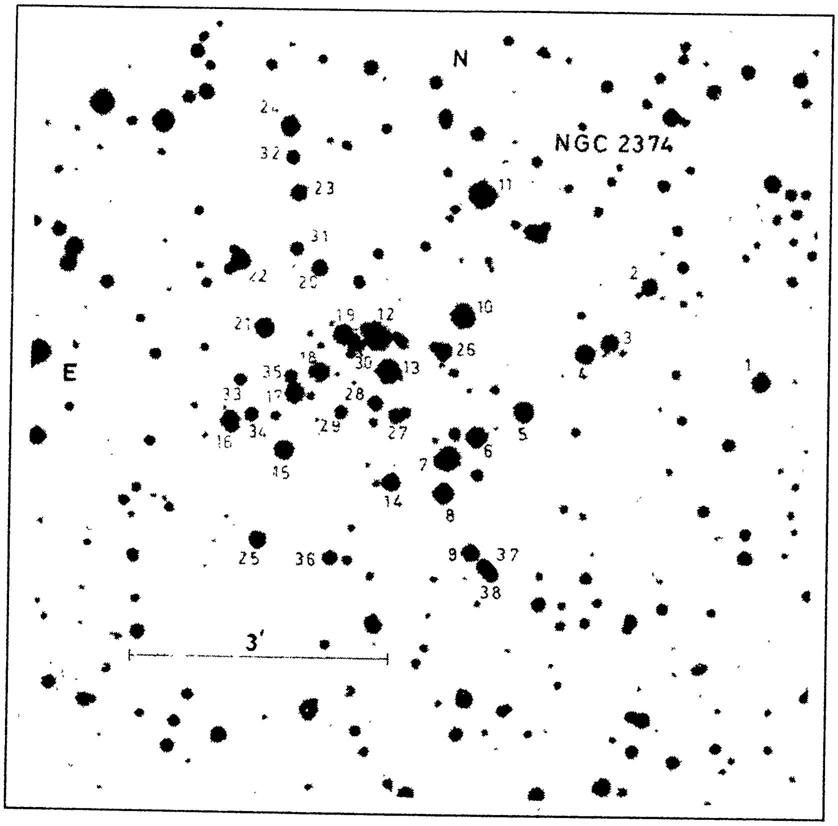

Figure 1. Field of open cluster NGC 2374 reproduced from the Palomar Observatory Sky Survey (POSS) prints. The identification numbers are introduced in the present work.

Table 1. Physical parameters of NGC 2374 known till date.

	Angular diameter arcmin	Distance kpc	No. of stars	$E(B-V)$	Age yr	Source
Trumpler (1930)	4.5	2.6				Alter, Balazs & Ruprecht (1970)
Collinder (1931)	10.0	1.24	40			Alter, Balazs & Ruprecht (1970)
Ba atova (1950)	15.0	0.93				Alter, Balazs & Ruprecht (1970)
Fenkart *et al.* (1972)		1.26	29	0.0	3.5×10^{8}	Fenkart *et al.* (1972)
Buscombe		1.3		0.0	2×10^{9}	Lyngå (1980)
Babu		1.2 ± 0.1	20	0.175	7.5×10^{7}	Present work

of the mean, could be assigned to a total of twenty-four stars around the cluster centre. The spectral type of star no. 20 could not be estimated because of overlapping. These estimates, listed in Table 2, are plotted in Fig. 2 against the V mag obtained from the POSS Charts, where star nos 1, 2, 3, 4, 5, 6 and 24 do not fit into the general sequence of the other stars. Among the rest of the stars, which are considered as possible members of the cluster, the earliest spectral type is found to be B5 for star no. 11. However, due to the uncertainty inherent in the estimation of the spectral types, this could be anywhere between B3 and B7. Thus, since the clusters containing stars of spectral type B3 or earlier are young enough to be used as spiral arm tracers, NGC 2374 has been selected as a marginally young cluster for further studies.

All the above-mentioned stars were then observed photoelectrically, employing the standard U, B and V filters of the Johnson & Morgan system, with a dry-ice-cooled EMI 9558 B photomultiplier mounted on the Kavalur 102-cm telescope. The data collection was done with the help of an on-line computer (TDC-12). After applying the necessary corrections for atmospheric extinction, the instrumental magnitudes were standardized with the help of photometric sequences taken from Landolt (1973). A minimum of three sets of observations were taken for each star and the average UBV values are given in Table 2.

In order to reach the fainter members of the cluster, photographs of the cluster region were obtained using the following plate + filter combinations:

Kodak 103a-O + Schott UG 2 for U,
Kodak 103a-O + Schott GG 13 for B,
Kodak IIa-D + Schott GG 11 for V.

The magnitudes of thirteen fainter stars have been established from these plates, using the magnitudes of the photoelectrically observed stars for calibration. These are also

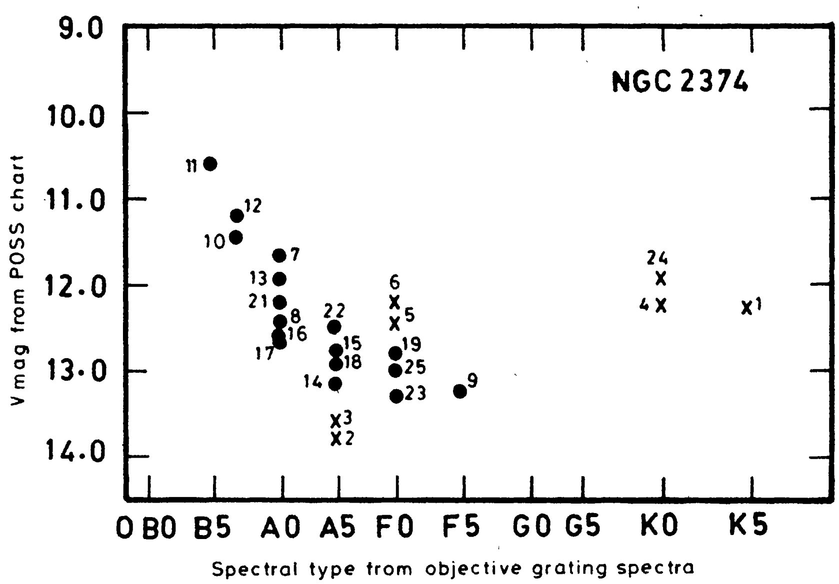

Figure 2. Spectral type obtained from the modified objective grating spectra are plotted against the V magnitudes estimated from the POSS Charts, for the stars in the field of NGC 2374. The filled circles denote the probable members and the crosses indicate the probable non-members.

Table 2. The observational data for individual stars in the open cluster NGC 2374.

Star No.	Spectral type	*V* (POSS)	*V*	(*B* – *V*)	(*U* – *B*)	Membership
Photoelectric photometry:						
1	K5	12.25	11.750	1.340	0.910	m?
2	A5	13.79	13.710	0.312	0.128	m?
3	A5	13.58	13.721	0.255	0.021	m?
4	K0	12.23	11.840	1.099	0.518	m?
5	F0	12.45	12.334	0.469	−0.155	—
6	F0	12.18	12.308	0.606	−0.074	—
7	A0	11.67	11.866	0.179	0.040	m
8	A0	12.44	12.637	0.292	0.109	m
9	F5	13.23	13.380	0.444	0.104	m
10	B7	11.43	11.664	0.128	−0.069	m
11	B5	10.59	10.653	0.449	−0.125	—
12	B7	11.18	11.540	0.080	−0.170	m
13	A0	11.94	12.027	0.177	−0.018	m
14	A5	13.15	13.762	0.241	0.088	m?
15	A5	12.77	12.996	0.246	0.234	m
16	A0	12.58	12.777	0.190	0.136	m
17	A0	12.67	12.604	0.254	0.228	m
18	A5	12.90	13.261	0.315	0.202	m
19	F0	12.81	13.229	0.398	0.179	m
20	—	13.32	13.793	0.485	0.135	m
21	A0	12.23	12.531	0.219	0.213	m
22	A5	12.48	13.038	0.350	0.123	m
23	F0	13.31	13.875	0.376	0.208	m
24	K0	11.89	12.070	1.014	0.552	m?
25	F0	13.01	13.133	0.399	0.173	m
Photographic photometry:						
26			13.80	0.35	0.20	m
27			15.12	0.21	−0.46	—
28			15.04	0.14	0.02	—
29			14.95	0.63	0.07	m
30			14.79	0.15	0.07	—
31			14.92	0.05	−0.82	—
32			15.14	−0.12	−0.12	—
33			14.69	0.56	0.10	m
34			15.02	0.02	−0.05	—
35			15.49	0.00	−0.36	—
37			13.73	0.36	0.06	m
38			14.95	0.07	−0.32	—

Spectral types are from the objective grating technique and *V* (POSS) are from the image diameters on POSS prints. *V*, (*B* – *V*) and (*U* – *B*) are from photometric observations—photoelectric or photographic. The symbol 'm' in the last column denotes positive membership. Doubtful membership is followed by (?).

included in Table 2. A majority of them appear to be around $V = 15$ mag with an uncertainty of about ± 0.2 mag in B and V, and about ± 0.35 mag in U.

3. Reddening

The $(B-V)$ versus $(U-B)$ diagram of this cluster is shown in Fig. 3. In this figure, most of the stars seem to follow an apparent sequence and show a general shift from the unreddened main sequence taken from Schmidt-Kaler (1965).

According to Burki (1975), the major causes of dispersion in the colour-colour diagram (CCD) of a cluster are stellar evolution, stellar duplicity, stellar rotation, differences in chemical composition, dispersion in ages, dispersion in distances, presence of non-member stars and limited precision of data. In the absence of differential extinction (across the field of the cluster), all these various physical and observational phenomena put together appear to produce only a small spread in the CCD. In order to find the amount of this spread in the CCD of this cluster, following Burki (1975), the unreddened curve is shifted on to the observed sequence parallel to the reddening line (Hiltner & Johnson 1956) so as to determine the minimum and

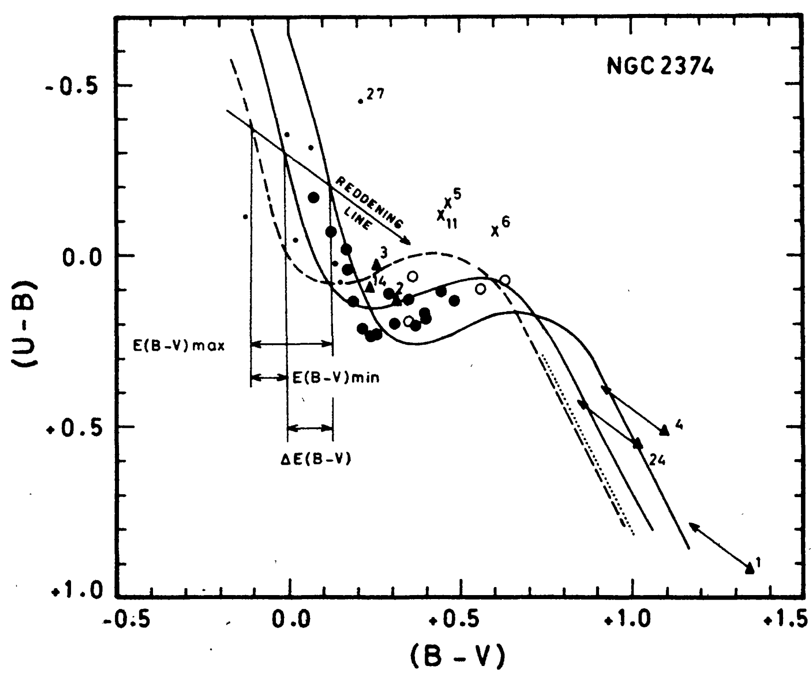

Figure 3. The $(B-V)$ versus $(U-B)$ diagram of the open cluster NGC 2374. The filled circles, crosses and triangles, respectively, denote the members, non-members and doubtful members which are observed photoelectrically. Unfilled circles and small dots indicate the photographically observed members and non-members, respectively. The dashed line is the zero age main sequence (ZAMS) for unreddened stars (Schmidt-Kaler 1965), while the solid lines represent the ZAMS when it is fitted to the observations with maximum and minimum reddening by shifting it parallel to the reddening line (Hiltner & Johnson 1956). The dotted line is the unreddened curve for giants (FitzGerald 1970). The identification numbers of the stars discussed in the text are indicated. Note that the star no. 11 is shown as a non-member and star nos 1, 2, 3, 4 and 14 are indicated as doubtful members (see text).

maximum colour excesses as shown in Fig. 3. The difference Δ between $E(B-V)_{max}$ and $E(B-V)_{min}$ is found to be

$$\Delta E(B-V) = 0.13 \text{ mag}.$$

This value is close to the minimum natural dispersion given by Burki (~ 0.11 mag) and, therefore, indicates an almost non-variable extinction across the field of the cluster. Hence, assuming a uniform extinction, the following mean colour excesses have been adopted.

$$E(B-V) = (B-V)-(B-V)_0$$
$$= \tfrac{1}{2}[E(B-V)_{max} + E(B-V)_{min}] = 0.175 \text{ mag},$$

and

$$E(U-B) = (U-B)-(U-B)_0$$
$$= \tfrac{1}{2}[E(U-B)_{max} + E(U-B)_{min}] = 0.125 \text{ mag}.$$

Earlier, Buscombe (*cf.* Table 1) had given $E(B-V)$ as 0.0 mag.

Using the above-mentioned mean value of $E(B-V)$, the total visual absorption A_v has been calculated as

$$A_v = V - V_0 = 0.569 \pm 0.009 \text{ mag}$$

from the expression $A_v = R \cdot E(B-V)$, where R is the ratio of total-to-selective absorption, taken to be 3.25 ± 0.05 as suggested by Moffat & Schmidt-Kaler (1976).

A few stars, however, are found to show larger deviations than the general spread. For instance, star nos 5, 6, 11 and 27 indicate some excessive reddening. It is rather peculiar for 5 and 6 to show this type of reddening, when the objective grating observations indicate them to be F stars. However, the photographic measurements of these stars by Fenkart *et al.* (1972) match well with our *UBV* measurements. More detailed spectroscopic observations are needed to understand the nature and membership of these stars better. Nos 1, 4 and 24 are at the red end of the curve, away from the rest of the stars.

4. Membership

The observed $(B-V)$ and $(U-B)$ colours are plotted against the corresponding V magnitudes in Figs 4 and 5, respectively. Both figures show fairly well-defined main sequences (MS) formed by a majority of the stars. The respective zero-age main sequence (ZAMS) taken from Schmidt-Kaler (1965) are shifted to match with them. The final cluster membership can now be determined on the basis of these diagrams, since the extinction has been assumed to be uniform. The location of individual stars in the identification chart (Fig. 1) has been used as an additional criterion.

According to the criteria given by Vogt & Moffat (1972), star nos 5 and 6 are considered as foreground stars, because they appear to be above the MS in one CMD and below it in the other. The same is found by Fenkart *et al.* (1972) for these stars. Star nos 4 and 24, being above the MS in both the CMDs, are possible giant members of the cluster, especially because their brightnesses also appear to be compatible with those of the brightest stars on the MS. A further indication about their likely membership as giants is that when these two stars are dereddened by the amounts of colour excesses obtained for the MS stars, they get much closer to FitzGerald's (1970) unreddened curve for giants, as shown in Fig. 3 by arrows. In this connection, since star no. 1 is seen

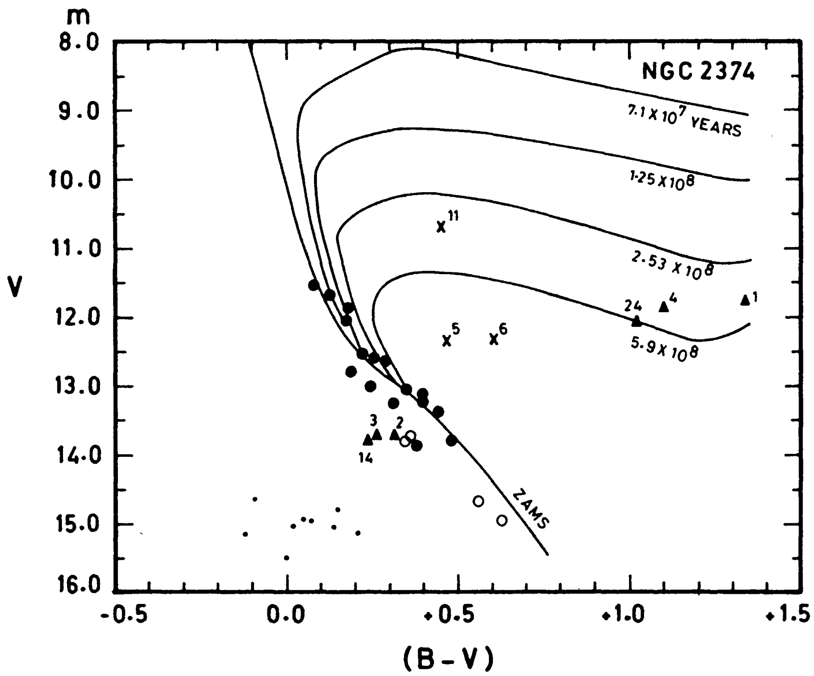

Figure 4. The $(B-V)$ versus V diagram of the open cluster NGC 2374. The symbols are the same as in Fig. 3. The solid line is the ZAMS taken from Schmidt-Kaler (1965), but is shifted to match with the observations. The theoretical isochrones are from Barbaro *et al.* (1969). The identification numbers of the stars discussed in the text are indicated.

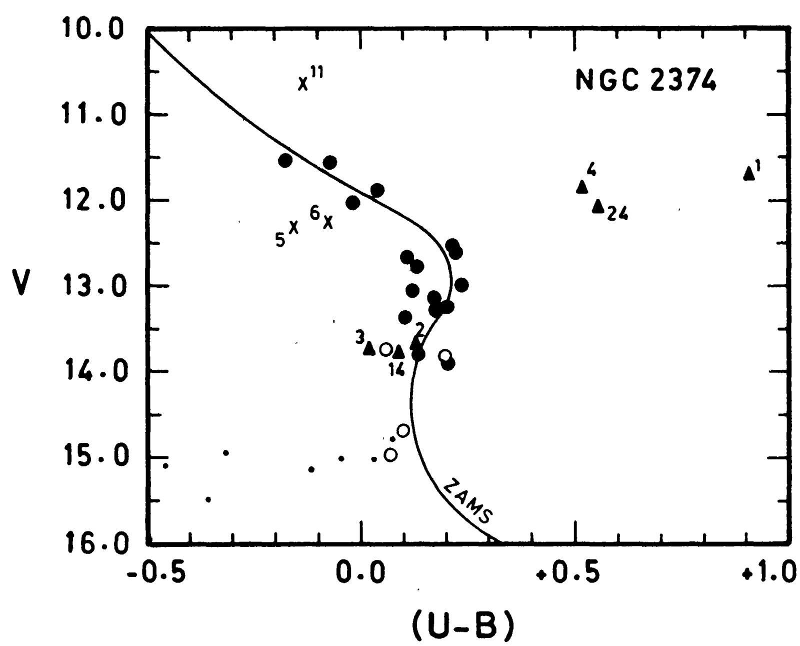

Figure 5. The $(U-B)$ versus V diagram of the open cluster NGC 2374. The symbols are the same as in Fig. 3. The solid line is the ZAMS taken from Schmidt-Kaler (1965), shifted to match the observations. The identification numbers of stars discussed in the text are indicated.

closer to star nos 4 and 24 in all the diagrams, it may also be a probable giant member, even though its location is relatively far off from the centre of the cluster (*cf.* Fig. 1).

Star nos 2, 3 and 14 show slight deviations from the ZAMS in Fig. 4 while no. 3 shows it in Fig. 5 as well. However, they show similar colour excesses as those of the MS stars (*cf.* Fig. 3). But, while star no. 14 is well inside the physical group of the cluster, star nos 2 and 3 are at the periphery. Therefore, they are considered only as doubtful members and along with star nos 1, 4 and 24, are denoted by 'm?' in Table 2. Radial velocities and proper motion measurements are required to confirm their membership.

All the stars whose magnitudes are determined by photographic photometry, except star nos 26, 29, 33 and 37 are considered to be non-members. The reason for this is that seven of them lie below the ZAMS in both CMDs, while the remaining two lie above the ZAMS in one CMD and below it in the other. Thus, they turn out to be background and foreground stars, respectively (*cf.* Vogt & Moffat 1972).

Finally, star no. 11, being the brightest in the physical group, needs special mention. Fig. 2 shows it as a B5 star and its position in that diagram occurs on the extension of the apparent main sequence. However, its position in the CCD shows that it needs a much larger reddening correction (~ 0.60 mag) in $(B-V)$ to bring it back into the vicinity of the unreddened curve. Also, its position in Fig. 4 is above the MS, while it is closer to the MS in Fig. 5. Its location is nearer to the periphery than to the centre of the cluster. Thus, all these points make it look more like a reddened, background early-type star than a member of the cluster with some anomalous reddening. Fenkart *et al.* (1972) also have not considered this star as a member.

This brings the total of non-members and doubtful members to eighteen, leaving the other twenty as probable members of the cluster.

5. Distance

The cluster main sequences, composed of the probable members in both the CMDs, are shifted to match with the respective ZAMS. This resulted in a mean true distance modulus of 10.3 ± 0.2 mag, corresponding to a distance to the cluster

$$d = 1.2 \pm 0.1 \text{ kpc}.$$

This is in good agreement with the values of distance obtained by Collinder (1931), Fenkart *et al.* (1972) and Buscombe (Lyngå 1980)—*cf.* Table 1.

6. Age

Since no well-evolved stars are seen among the probable members, except for the three doubtful giants, it is not possible to locate the turn-off point on the cluster main sequence in the CMD of Fig. 4. Therefore, the theoretical isochrones given by Barbaro, Dallaporta & Fabris (1969) were superimposed on this figure so as to identify the most likely age of the cluster or at least the upper limit of the age. It is found that the brighter MS stars extend upto the isochrone of 7.1×10^7 yr. That is, the age of the cluster could be 7.1×10^7 yr or perhaps somewhat younger. It has also been estimated from $(B-V)_0$ and the spectral type of the brightest star on the MS as 6×10^7 yr and 1×10^8 yr respectively by using the relationships given by Allen (1981) and Hoerner

(1957). This gives a mean value of 8×10^7 yr, which agrees fairly well with the isochrone age of the MS stars. Fenkart *et al.* (1972) estimated the age of this cluster to be 3.5×10^8 yr from the earliest spectral type using Hoerner's (1957) method.

If the three giants are considered as likely members of the cluster, then their apparent fitting to the isochrone of 5.9×10^8 yr might indicate the non-coeval nature of this cluster, as has been shown to be the case in several other open clusters by many previous workers (McNamara 1976; Piskunov 1977; Sagar & Joshi 1979). But the corresponding non-coeval spread by the stars at the turn-off area of the giant-branch isochrone is not found in this diagram.

7. Conclusions

The open cluster NGC 2374 is found to contain at least twenty stars as definite members down to $m_V \simeq 14$ mag. Three of the six doubtful members would be red giants, if they were members. There is a uniform extinction of $E(B-V) = 0.175$ mag due to interstellar matter intervening between the cluster and the observer. The distance of this cluster is found to be 1.2 ± 0.1 kpc which places it at the outer edge of the Orion–Cygnus arm in the direction of the Monoceros constellation. The most likely age of this cluster is 7.5×10^7 yr.

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