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SPECTRAL MORPHOLOGY AND ROTATION IN THE OPEN CLUSTER NGC 6025

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RESUMEN

Hemos clasificado espectralmente a los probables miembros más brillantes del cúmulo abierto NGC 6025 y hemos calculado sus velocidades de rotación. Encontramos un módulo de distancia de 9.80 ± 0.06 (error probable) y derivamos una edad de 84 millones de años para este cúmulo. La estrella más brillante de NGC 6025, HD 143448 fue clasificada como B1Ve y es una estrella azul desubicada (*blue straggler*) tal como fue propuesto por otros autores (ver Mermilliod 1982). Hemos encontrado tres estrellas peculiares (dos de Si y una de Hg-Mn?) y dos binarias de dos espectros, una de ellas previamente estudiada pero probablemente no miembro del cúmulo. Otra estrella del campo tiene emisión, pero probablemente tampoco es miembro del cúmulo. El promedio de la rotación axial para los miembros de este cúmulo es 73% del promedio de rotación de las estrellas de campo de igual temperatura.

ABSTRACT

We have performed spectral classification and measurements of the axial rotation velocity for the brightest stars in the region of the open cluster NGC 6025. A distance modulus of 9.80 ± 0.06 (pe) and an age of 84 million years were derived. The brightest star of the cluster, HD 143448 was classified as B1Ve and it is a blue straggler as proposed by other authors (see Mermilliod 1982). We found three peculiar stars (two Si and one Hg-Mn?). Another star in the field shows emission but is probably a non-member. We also found two SB2 binaries. The average axial rotation for the cluster members seems to be 73% of the average rotation of the field stars with the same temperature.

Key Words: Hertzsprung-Russell and C-M diagrams — open clusters and associations: individual (NGC 6025) — stars: rotation

1. INTRODUCTION

The galactic cluster NGC 6025 was studied several decades ago in two papers. Feinstein (1971) provided for the first time, UBV photoelectric measurements and derived a distance modulus of 9.4 ± 0.1 and an age of 10^8 years. Four years later Kilambi (1975) published *ubvy* photoelectric and UBV photographic data and obtained 9.7 ± 0.1 for the distance modulus and an age of 9×10^7 years. This author also derived the luminosity function and showed that this cluster has fractionally more bright members than does the Pleiades cluster. There is no spectroscopic study on NGC 6025 even as basic as an MK spectral classification of its members. Paunzen et al. (2001) classified star number 20 in a paper devoted to spectral classification of candidates for λ Bootis stars. There are also some papers in the literature that include NGC 6025 in statistical studies of open clusters (see Kharchenko et al. 2009).

In this paper we classify in the MK system the stars that have been considered to be members in previous papers although we use the new SPM4 Catalogue (van Altena et al. 2010, private communication) to confirm membership. We include other stars in the field of the cluster and we estimate the spectral types of 33 stars and the rotational velocities for 27.

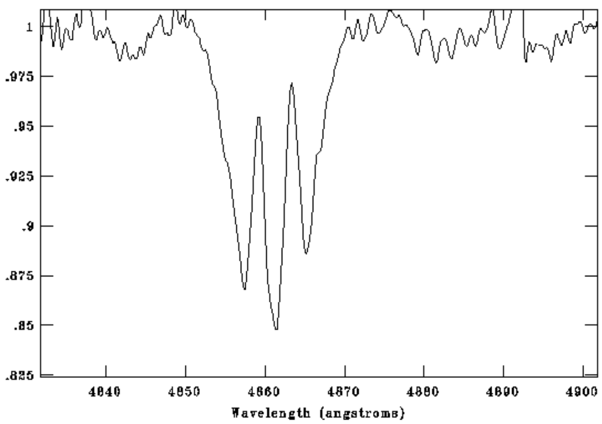

Fig. 1. Hβ profile in the spectrum of HD 143448.

2. OBSERVATIONS AND REDUCTION

The sample contains stars brighter than 11.3 magnitude in the V band. The observations were collected with the Jorge Sahade 2.15 m telescope at Complejo Astronómico El Leoncito, San Juan, Argentina. We used a REOSC spectrograph in simple and cross dispersion mode. The spectra cover the range 3600–6000 Å with a resolution around 3.6 Å/2px for simple dispersion and 0.28 Å/2px and a spectral range between 3700–5700 Å for cross dispersion. The detector was a CCD TEK of 1024 × 1024 pixels, of size 0.024 mm, thinned and back illuminated. Data reduction was carried out using IRAF tasks. The S/N for spectra in cross dispersion was about 100 and 200 for the classification spectra.

2.1. *MK classification*

The spectral classification in the MK system was derived using the WINMK code version 2.4 developed by Richard Gray at the Appalachian State University, USA[1]. The classification was carried out by comparison with MK standard stars taken with the same equipment and conditions and using the MK technique (Gray & Corbally 2009).

2.2. *Comments about some stars*

Star number 1 is a blue straggler with emission in Hβ and we have classified its spectrum as B1Ve. This star was previously classified by Morris (1961) as B3 IV and by Garrison, Hiltner, & Schild (1977) as B1.5 V. The profile of Hβ is similar in all 5 echelle spectra of star number 1 that we have taken and it is shown in Figure 1.

Star 6 shows emission in Hβ but it is probably a non-member of the cluster according to its absolute proper motion, although its position in the HR diagram fits well (see below). The classification spectrum of Star 11 shows Hg II λ 3984 and probably but less clear Mn II λ 4206. Star 25 is a Bp star of the Silicon type with λ 4200 well seen at the classification dispersion. Star 59 is also a Bp star of the Silicon type but with lower excitation level. Star 10 is an SB2 and eclipsing binary (González & Levato 2010, private communication). Star 26, HD 143511, was extensively studied by González & Levato (2006) and it is an SB2 and also an eclipsing binary with a period of 5.53546 days. It is probably a non-member of the cluster according to its absolute proper motion. Kilambi found stars 4, 6, 10 and 60 to have the Stromgreen m_1 index larger than normal. Additional features for each star are included in the notes to Table 1.

2.3. *Proper motions*

We have included in Table 1 the absolute proper motions in RA and DEC in mas yr^{-1}, taken from the SPM4 (van Altena et al. 2010, private communication) which contains 100 million stars. This catalogue is an excellent tool, among other purposes to decide about membership to open clusters. From the proper motion point diagram shown in Figure 2, it is clear that stars 6, 11, 15, 21 and 26 are probable non-members of the cluster. All of them have proper motions differing by more than 3σ from the average absolute proper motion of the cluster. We have used this criterion to decide about membership from the proper motion data.

3. RESULTS

3.1. *Reddening and distance*

The spectral types and the projected rotational velocities derived in this paper are listed in Table 1. The first column shows Feinstein's identification, the second is the HD number when available, or the CPD number. Columns 3 and 4 list the proper motions taken from van Altena et al. (2010, private communication), Column 5 lists the V magnitude taken from Feinstein (1971), Column 6 the MK types derived in the present paper, and Column 7 the projected axial rotation velocity also derived in this paper (see below). Comments have been included at the end of the table. They include conclusions about membership and the Hipparcos parallaxes available for five stars of the sample. Using the intrinsic $B-V$ for each MK type taken from the calibration published by Allen (2001) and using the observed $B-V$ taken from Feinstein (1971) we derived and interstellar extinction of 0.55 mag. adopting $A_v =$

[1] `www1.appstate.edu/dept/physics/MK/xmk22.htm`.

TABLE 1

RESULTS FOR THE OPEN CLUSTER NGC 6025

N	HD/CPD	μ_α [mas yr^{-1}]	μ_δ [mas yr^1]	V [mag]	ST	$v \sin\ i$ [km s^{-1}]
1[a]	143448	−1.49	−4.53	7.3	B1Ve	195
2[b]	143449	−2.34	−3.93	8.11	B5IV	65
3[c]	143413	−1.59	−7.00	8.42	B7 IV	240
4[d]	−60 6332	−5.46	−8.19	9.73	B8 V	60
5	−60 6316	0.98	0.33	10.23	B9 V	60
6[e]	143288	−0.65	27.21	8.96	B6 Ve	215
7[f]	143340	−2.30	−4.50	8.05	B5 IV	60
8	−60 6325	−6.07	−6.10	8.86	B6 V	200
10[g]	−60 6335	0.89	−3.46	10.8	A2:+A2:	20;20
11[h]	143287	−25.52	−12.15	8.34	B9 IVp(Hg−Mn?)	70
12[j]	143309	5.65	0.26	9.3	B6 V	10
13	−60 6319	−3.30	−4.96	9.62	B8 V	185
14[k]	−60 6322	1.85	0.68	9.85	B8.5 V	15
15[l]	−60 6327	−12.39	−29.72	9.63	F0 V	120
16	−60 6339	2.30	−3.99	9.88	B8 V	270
17[m]	−60 6343	−2.84	−11.15	11.17	B6/B7 V::	70
20	−60 6340	1.35	−7.86	11.25	A1V	···
21[n]	−60 6341	−16.76	−9.01	9.98	F5::	20
22[o]	143388	−1.44	5.89	9.15	B5 V	15
23	−60 6336	−3.66	−3.88	10.59	A0 V	60
24	−59 6562	−0.99	−3.76	10.06	B9 V	···
25	143412	−0.44	−3.56	9.7	B8 IIIpSiλ 4200	···
26[p]	143511	−8.02	−20.66	8.31	A0 V+A0 V:	25;25
29	−60 6313	−8.20	−6.75	10.69	B9 V	125
30	−60 6321	−5.77	−6.17	10.88	B9.5 V	···
34	−60 6362	−6.23	−0.69	10.51	B9 V	···
35	−60 6329	−1.35	4.31	10.97	A0 V	···
37	143220	−1.33	1.54	10.15	A3 III	15
38	−60 6311	−2.09	−4.61	10.68	A0 V	···
39[q]	−60 6342	−5.39	1.39	11.24	F0 V	···
43	143123	0.59	−5.43	9.34	B5 V	10
47	−60 6352	−3.74	−6.30	11.01	A1 V	···
59	143447	−1.67	−6.37	10.69	B9.5 p Si	···
60	−59 6578	−3.27	−3.97	10.48	B9.5 V	85
64	−60 6297	−7.91	−1.94	11.71	···	50
65	−60 6298	−4.98	−8.12	10.86	A0V	80
66	−60 6296	−4.29	−3.33	10.87	B9.5 V	80

Additional comments on individual stars:

[a]Variable (MQ TrA) between 7.2 and 7.3 mag in V. Blue struggler (see Mermilliod 1982). Parallax from Hipparcos (HIP 78682): 0.79 mas.
[b]Parallax from Hipparcos (HIP 78683): 0.64 mas.
[c]Parallax from Hipparcos (HIP 78659): 0.86 mas.
[d]m1 large as measured by Kilambi (1975). SB1.
[e]Probably a non-member due to its p.m. Emmission in Hβ.
[f]HIP 78643. Parallax 2.42 mas in new reduction (van Leeuwen 2007).
[g]SB2 (González & Levato 2010, private communication). $\delta V = 45$ km s^{-1} - m1 large.
[h]HIP 78604. parallax 3.58 mas. non-member according to its pm.
[j]Is it a variable (V350 Nor) between 9.2 and 9.310 V magnitude. It was classified by Houk & Cowley (1975) B9/B9 Ib/II.
[k]Radial velocity variable (González & Levato 2010, private communication).
[l]Probably non-member. Source proper motion.
[m]Spectral type not in the MK system. Only high resolution spectrum available.
[n]Probably non-member due to its proper motion.
[o]Radial velocity variable (González & Levato 2010, private communication).
[p]SB2, eclipsing binary, $P = 5.5354$ days. Probably non-member due to its pm.
[q]Probably non-member due to its spectroscopic parallax.

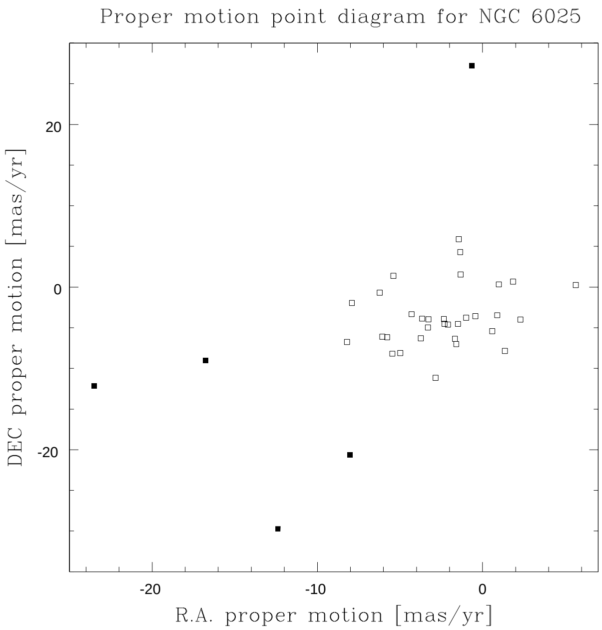

Fig. 2. Proper Motion point diagram for the stars in NGC 6025. Filled squares are non-members according with the 3σ criterium.

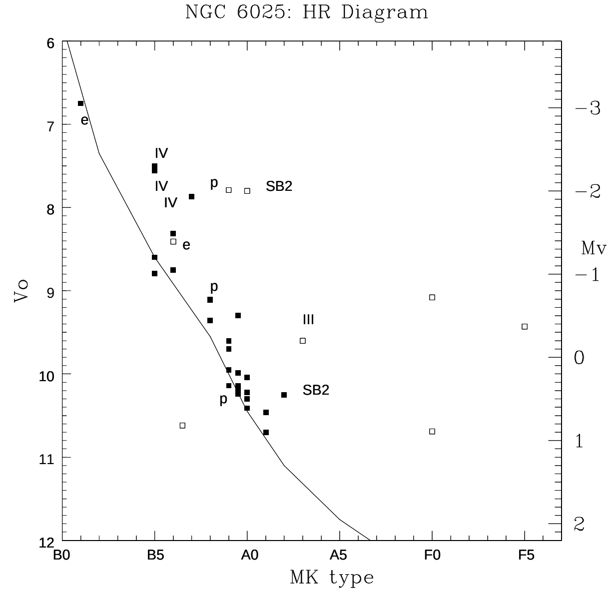

Fig. 3. Observed HR diagram for NGC 6025. Filled squares are probable members while open squares are non-members.

$3.3E(B-V)+0.28(B-V)E(B-V)+0.04E(B-V)^2$ from Allen (2001). Using the calibration between M_v and MK spectral types published by Allen (2001) we derived a true distance modulus for each star and obtained an average true distance modulus for the cluster $(m_v - M_v) = 9.80 \pm 0.06$ (pe of the mean which corresponds to 912 pc) using only the probable members as indicated in Table 1. We have not included neither CP, Be, giants nor binaries in the calculation. It is interesting to note the uncertainties in the Hipparcos parallaxes for stars 1, 2, and 3 that imply distances larger than 1 kpc. The errors in their parallaxes quoted in the Hipparcos catalogue are as large as the parallaxes themselves. We also want to point out a significant difference in the absolute visual magnitude vs MK type calibration between Allen (2001) and Gray & Corbally (2009) for the range B8-A2, which is an important range in this cluster. The visual absolute magnitude difference for the A0 V reaches 0.75 magnitudes, but it is 0.6 magnitudes for A2 V, in the sense that Allen's calibration is brighter than Gray & Corbally's. For late A stars the calibrations agree. To choose one or the other calibration to derive the spectroscopic distance of NGC 6025 is important, because the distance may increase or decrease by almost 50%. We have used Allen (2001) in order to keep consistency with our previous results on open cluster classification. The HR diagram for NGC 6025 is presented in Figure 3 where the absolute magnitude scale was drawn for a distance modulus of 9.8 mag. The main sequence has been taken from Allen (2001). Emission line stars, evolved stars, binaries and Bp-Ap stars were labeled. Probable non-members as indicated in Table 1 were plotted as open squares in Figure 3.

3.2. *Age*

We checked the age, taking into account that the earliest type on the main sequence of the cluster is B6 V. This implies a mass of 5.2 solar masses according to the calibration by Allen (2001). In such a case, the maximum age of the cluster should be 88 million years old using Schaller et al.'s (1992) results. This agrees quite well with the old determination by Kilambi (1975) (90 million years). We also checked the age using the isochrone grids calculated by Girardi et al. (2000). We plotted isochrones for solar composition on a $B-V$ vs Mv HR diagram and the best fit corresponds to log(age) = 7.9 (80 million years). So we have adopted 84 ± 4 million years as the most probable age determined in this paper (log(age) = 7.92).

3.3. *Axial Rotational velocities*

For the determination of the projected rotation velocities we have used as standards those from the Slettebak's system (Slettebak 1975). Calibration curves were constructed between the *fwhm* of the lines λ 4471 of HeI and λ 4481 of MgII against the $v \sin i$ for the selected standards. Linear regression lines were obtained for the spectral ranges B2–B5, B5–B7, B8–A2, A2–A5, A7–F2 for λ 4471 for the first two ranges and λ 4481 for all ranges except the first one. We have calculated the mean percentage of projected rotation velocities for the members of NGC 6025 with respect to field stars of the same types. These mean values were adopted from Abt & Morrell (1995) and Abt, Levato, & Grosso (2002). The extreme values of $v \sin\ i$ observed for cluster members are 10 km s^{-1} and 270 km s^{-1} for the minimum and maximum respectively. The cluster members seem to rotate with $73\% \pm 9\%$ of the rotation of field stars of same temperatures.

4. CONCLUSIONS

We have derived a distance of 912 pc for NGC 6025, somewhat larger than previous determinations. We have found two peculiar stars of the silicon type among its members. We found a Hg-Mn? peculiar object in the region but it is probably a non-member. We found that the average axial rotation of the main sequence cluster members of NGC 6025 is less than 75% of that of the field stars of the same temperatures. This may be due to the presence of spectroscopic binaries in a larger proportion than among field stars (see Abt 2009). A thorough spectroscopic study to determine the spectroscopic binaries among the upper main sequence of NGC 6025 is under way.

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