Mem. S.A.It. Vol. 80, 129

**Memorie** della

# The nearby strongly reddened open cluster Stock2

## A new study based on accurate proper motions and 2MASS photometry

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**Abstract.** The open cluster Stock 2 is situated in the Orion spiral arm and is affected by a strong and patchy interstellar extinction. These characteristics make its investigation rather demanding and a difficult task. We decided to tackle this cluster by means of an integrate use of astrometric and photometric observations. Here we present new results based on accurate proper motions, that we used to identify kinematically the cluster members over an area of 70'x70'. Also, an extinction local map was derived by means of 2MASS photometry and used to produce the unreddered CMD of the cluster. Finally, new, although preliminary, determinations of the cluster distance and age are presented and discussed.

**Key words.** open clusters and associations: individual: Stock 2 – Techniques: astrometric – Techniques: photometric – Surveys

## 1. Introduction

The open cluster Stock 2 is located in the galactic plane ($l$ = 133.5°, $b$ = −1.9°) within the Orion spiral arm almost in front of the double cluster h & $\chi$ Persei. This cluster was discovered by Stock (1956) and, in spite of its close distance ($d$ ∼ 350 pc), its physical properties are still not well defined. The major problem which affects the study of this system is the strong and variable reddening and, secondly, the wide sky region occupied by its members (∼ 3°). The mean reddening, $E_{B-V} \simeq$ 0.38 (Krzemiński & Serkowski 1967), is not extremely high in absolute terms but, due to the close distance, it corresponds to an interstellar extinction of $A_V \simeq 4.0$ mag kpc$^{-1}$ which evidences the presence of dense dust clouds along this line of sight. In addition, the reddening appears highly variable, ranging from $E_{B-V} \simeq 0.1$ to 0.5 mag, making the analysis more complicated.

Photometric distance estimates vary from 302 pc (Martini 1971) to 380 pc (Kharchenko et al. 2005), while Robichon et al. (1999) derived 345 ± 70

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pc from the mean trigonometric parallaxes of 5 members observed by the Hipparcos satellite.

Stock 2 is generally classified as a young cluster with an age of 100 Myr (Krzemiński & Serkowski 1967; Martini 1971; Sanner & Geffert 2001) or 148 Myr (Kharchenko et al. 2005). These values are *not* consistent with the results of Sciortino et al. (2000) who measured the X-ray emission of few Stock 2 dG members and noticed that the X-ray luminosity function is not similar to that of other young clusters (eg. Pleiades) but resembles that of older clusters like the Hyades (600 Myr).

In this study we used accurate proper motions in order to select *bona fide* cluster members and 2MASS NIR photometry which minimize the effects of interstellar reddening.

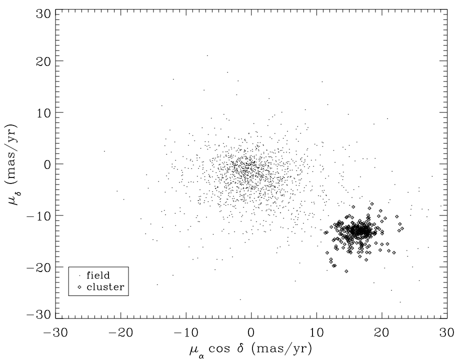


**Fig. 1.** Vector point diagram (VPD).

## 2. Astrometric and photometric data

Accurate proper motions were computed for a $70' \times 70'$ region centered on Stock 2 by means of multi-epoch positions derived from digitized plate material spanning a time-baseline of about 80 years. As first epoch, we acquired old plates realized for the Vatican Zone of the Astrographic Catalog, while the Torino plate archive provided the second epoch plates, based on observations carried out at the Morais and REOSC telescopes. In addition, POSS-I and Quick-V plates from the Schmidt Palomar surveys were used as intermediate epochs. All plates have been digitized at the STScI (Baltimore) with the PDS machines following the procedure described in details by Lattanzi et al. (1991).

Proper motions attain a precision $\sigma_\mu \simeq 1$ mas yr$^{-1}$ per component in the ICRF system, as materialized by Tycho 2 (Høg et al. 2000). The final catalog contains 1782 stars down to $V \simeq$ 15-16 and includes JHK$_s$ photometry derived from the 2MASS catalog.

## 3. Kinematic membership

Stock 2 members have been identified by means of the procedure described by Sanders (1971) and based on Vasilevskis et al. (1958). The frequency distribution of the observed proper motions was modelled as the sum of two populations: an elliptical gaussian frequency distribution for the *field stars*, $\phi_f(\mu_\alpha \cos\delta, \mu_\delta)$, plus a circular gaussian frequency distribution, $\phi_c(\mu_\alpha \cos\delta, \mu_\delta)$, for the *cluster members*, as follows

$$\phi(\mu_\alpha \cos\delta, \mu_\delta; \mathbf{a}) = \phi_c + \phi_f \qquad (1)$$

where **a** is the vector of the parameters, including the moments of the gaussian distributions and the fraction, $n_c/N$, of the cluster members, whose fitted values are reported in Table 1. Because of the low intrinsic proper motion dispersion expected for a typical cluster velocity dispersion ($\sigma_V \simeq$ 1-2 kms), the cluster dispersion, $\sigma_c \simeq 1.55$ mas yr$^{-1}$, provides an upper limit on the proper motion error, thus confirming the high astrometric accuracy of our catalog.

The probability to be a cluster member is then simply, $\mathrm{Pr} = \frac{\phi_c}{\phi_c+\phi_f}$. In Figure 1 we show the proper motion VPD where the cluster members, selected with Pr≥ 90% and limited to $5\sigma_c$ from the cluster mean motion, are evidenced with different symbols. In total, we identified 275 cluster members, 265 of them having a cluster membership probability above 99%.

**Table 1.** VPD fitted parameters. Proper motion units are mas yr$^{-1}$.

| Cluster | Field |
|---|---|
| $\mu_{\alpha,c} = 16.27 \pm 0.09$ | $\mu_{\alpha,f} = 0.03 \pm 0.10$ |
| $\mu_{\delta,c} = -13.33 \pm 0.07$ | $\mu_{\delta,f} = -2.28 \pm 0.08$ |
| $\sigma_c = 1.55 \pm 0.05$ | $\sigma_{\alpha,f} = 4.17 \pm 0.08$ |
| $n_c = 288 \pm 13$ | $\sigma_{\delta,f} = 3.59 \pm 0.07$ |
| | $\rho_f = -0.09 \pm 0.03$ |
| $\chi^2/\nu = 1.758$ | |

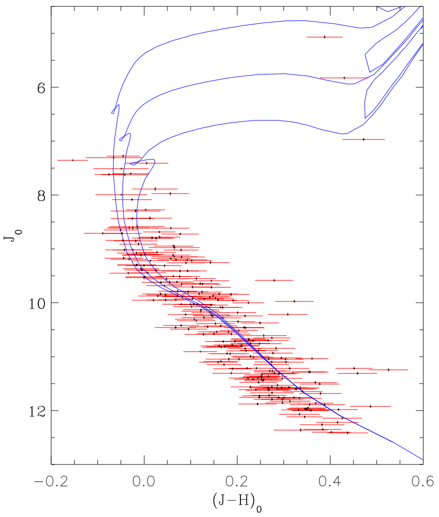


**Fig. 2.** Color-magnitude diagram (CMD) compared with 178, 300, and 500 Myr isochrones (Z=0.019) for a cluster distance $d = 350$ pc. Error bars represent the 2MASS photometric errors.

## 4. Reddening correction

The issue of the reddening correction has been tackled by means of the method proposed by Knude & Fabricius (2003) and based on the the $J-H$ vs. $H-K_s$ diagram that we used to estimate individual reddening of main sequence stars with $0.1 \leq J-H \leq 0.5$. We adopted the 178 Myr isochrone from the Padova model (Bertelli et al. 2008) and the reddening ratios ($A_J/A_V = 0.2956$, $A_H/A_V = 0.1891$, and $A_{Ks}/A_V = 0.1216$) computed through the extinction law model of Cardelli et al. (1989) and assuming $R_V = A_V/E_{B-V} = 3.5$, as estimated by Martini (1971) for the Stock 2 field. The resulting individual $E_{J-H}$ were averaged to produce an extinction map of the area with a resolution of $11.7'' \times 11.7''$ that we applied to correct all the cluster members. The map shows a factor two extinction variability, with a mean extinction of $\langle A_J \rangle = 0.31$ and $\langle E_{J-H} \rangle = 0.11$, which corresponds to $\langle E_{B-V} \rangle = 0.30$ that is quite consistent with the previous direct estimations in those visual bands.

## 5. Discussion

Figure 2 shows the intrinsic color-magnitude diagram and the Padova isochrones (178, 300, and 500 Myr) for solar metallicity stars (Z=0.019). Thanks to the $\mu$-selected cluster members, a clear main sequence down to late dG stars is apparent, plus three giants. A large dispersion is still present; this depends on the 2MASS photometric errors and, possibly, to uncorrected residual extinction. The distance spread and the presence of unresolved binaries also contribute to the observed CMD dispersion.

The Stock 2 *age* cannot be well constrained by our data, which show a turn-off consistent with a large interval, 200-500 Myr. These preliminary results seem to indicate that Stock 2 is significantly older than the 100 Myr, as suggested also by Sciortino et al. (2000), and contrary to what found by the previous studies in the visual wavelengths. This indication is also supported by the three giants. In this case the large magnitude spread, which would imply a significant time interval, cannot be explained simply in term of residual extinction and photometric errors. The age issue in Stock 2 appears intriguing and it will be subject of further studies.

Finally, Stock 2 distance has been estimated by fitting the distance modulus of unevolved main sequence stars with $0.05 \leq J-H \leq 0.40$. For Z=0.019 isochrones, we found $\langle m-M \rangle = 7.72 \pm 0.03$ ($d = 350$ pc), while for a slightly metal deficient model (Z=0.013) which takes into account the abundance uncertainty (Claria et al. 1996), we got $\langle m - M \rangle = 7.59 \pm 0.04$ ($d = 329$ pc).

*Acknowledgements.* We are pleased to thank G. Coyne and S. Maffeo of the Vatican Observatory who kindly lent us the first epoch plates. We acknowlegde B. Lasker and B. McLean of the STScI for supporting the digitation of all the plate material. Partial financial support to this study comes from INAF through the PRIN 2007 grant n. CRA 1.06.10.04.

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