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Complex study of the open cluster NGC 2281

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Abstract. We present the complex study of the open cluster NGC 2281 where both traditional and newly developed methods for study of open clusters have been used. Morphological and dynamical parameters of the cluster were obtained from the accepted astrometric data. The new method "Superposition of Gaussian surfaces" along with proper motion of stars was used to determine membership probabilities which were helpful in selection of stars for further analysis. Metallicity and radial velocity of the cluster were obtained from spectroscopic measurements. Age, colour excess, and distance of the cluster were determined using absolute CCD photometry combined with previous results. The results were compared with those of previous studies.

Keywords. complex study, NGC 2281, membership probability

1. Membership probability

A new method "Superposition of Gaussian surfaces" (SGS) was developed for determination of membership probability p_μ of field stars of the cluster. The SGS method generates three-dimensional proper motion diagram of field stars of the cluster. For each point in diagram the surface density is given by equation:

$$f_s(\mu'_\alpha, \mu_\delta) = \sum_i^n R + \frac{K}{m_i^2} \exp\left[- \left(\frac{(\mu'_\alpha - \mu'_{\alpha i})^2}{2\sigma'^2_{\mu_\alpha i}} \frac{(\mu_\delta - \mu_{\delta i})^2}{2\sigma^2_{\mu_\delta i}} \right) \right], \tag{1.1}$$

where R and K are constants, m_i is brightness of i-th star in the V filter, $\mu_{\alpha i}$, $\mu_{\delta i}$, $\sigma_{\mu_\alpha i}$, and $\sigma_{\mu_\delta i}$ are proper motions of i-th star and their uncertainties. Both $\mu'_{\alpha i}$ and $\sigma'_{\alpha i}$ are equal to $\cos\delta_i \mu_{\alpha i}$ and $\cos\delta_i \sigma_{\alpha i}$ respectively to reduce a spherical projection.

Proper motions data from the PPMXL (Roeser *et al.*, 2010, reference positions), NOMAD (Zacharias *et al.*, 2004), UCAC4 (Zacharias *et al.*, 2012), IGSL (Smart *et al.*, 2013), URAT1 (Zacharias *et al.*, 2015), and TYCHO (Hog *et al.*, 2000) catalogues were averaged for each star up to 15th magnitudethe in the V filter inside a radius of half degree with the centre in cluster's catalogue coordinates. The averaged data were used for generate of the diagram by SGS method. A superposition of two Gaussian surfaces was used as a model for description of the resulting diagram, where the first surface is for background stars and the second surface for stars of the cluster. Membership probabilities of field stars were derived from a single Gaussian surface with determined parameters of the cluster.

2. Spectroscopy

Spectra of two stars were acquired in October 2014 with the Echelle spectrograph ($R = 18\,000$) on the 2.4m telescope (Ritchey-Chretien) at Doi Inthanon in Thailand. The SYNSPEC software (E1) with ATLAS9 grid models (Castelli *et al.*, 2003) and ROTIN3 software (E1) for rotational convolution were used for modelling of synthetic spectra.

The first star with $p_\mu = 59$ % has metallicity [Fe/H] = 0.13 ± 0.03 dex and the second star with $p_\mu = 58$ % has [Fe/H] = 1.30 ± 0.05 dex which is typical of chemically peculiar stars. Therefore, metallicity of the first star was accepted as metallicity of the cluster. Both stars have almost the same radial velocity (-17.7 and -17.1 km/s) and their average value is $v_r = -17 \pm 1$ km/s.

3. Photometry

Photometric CCD data were acquired in October 2013 and January 2014 using the 600mm reflector at the Suhora Observatory in Poland. Landolt's field (PG1633+099, Landolt *et al.*, 1992) as a season's primary standards and chosen stars from NGC 2281 and NGC 7142 as a night's secondary standards were used for transformation of the cluster stars into the standard photometric system.

Measured photometric data with $p_\mu > 10$ % were plotted into the colour–magnitude diagram where a well-defined evolving trace is created. Points were fitted by the PARSEC isochrone (Bressan *et al.*, 2012) with the known metallicity and colour excess. The distance modulus $m_V - M_V = 8.81$ mag and the logarithm of age $\log t = 8.70$ of the cluster were obtained from a vertical shift and a change of the shape of the isochrone towards points. A red isochrone for binary stars with the -0.75 mag shift in the y axis was added.

Final membership of field stars to the cluster was determined as intersection of stars with high membership probability and those which are close to isochrones. Photometric data from the 2MASS catalogue were used to cover the whole one degree diameter. Stars with $p_\mu > 50$ % and distance less then 0.07 mag from the isochrones were considered as real members of the cluster. Stars with $50\ \% \geqslant p_\mu > 10$ % and distance less then 0.05 mag were considered as candidates of membership to the cluster. There were found 69 real members and 42 candidates of membership of the cluster.

4. Results and discussions

Derived morphological and dynamical parameters of the cluster are almost the same as the current catalogue values. Measured radial velocity of the cluster is opposite to the current catalogue value +13.3 ± 4.1 km/s (Kharchenko *et al.*, 2013). The value -17 ± 1 km/s should be adopted as a radial velocity of the cluster because of good agreement of radial velocities of both chosen stars. The found distance $d = 550$ pc and age $t = 500{\times}10^6$ yr of the cluster are slightly different from the catalogue values (Kharchenko *et al.*, 2013) because stars with high probability of membership were used in our method. The found metallicity (Z = +0.019) is the same as in the catalogue (Kharchenko *et al.*, 2013). The cluster should be classified as I3m instead I3p in Trumpler's system because of the amount of true star members of the cluster.

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