NGC 2660: Gaia DR2, ASteCA and the end of controversies?

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Resumen / NGC 2660, un cúmulo abierto viejo y muy compacto localizado a aproximadamente 3 kpc del Sol en una región de absorción moderada, ha sido objeto de varios estudios fotométricos y espectroscópicos en el pasado. Surgen controversias en cuanto a su distancia, antigüedad y contenido metálico. Las comparaciones llevadas a cabo por investigaciones anteriores con modelos sintéticos de cúmulos no las resolvieron. Decidimos analizar este objeto combinando paralaje de alta precisión, movimientos propios y magnitudes procedentes del Gaia Second Data Release (Gaia DR2) para mejorar los parámetros fundamentales del cúmulo. Para ello seleccionamos los datos de Gaia DR2 en una región de 1 grado de lado centrada en NGC 2660. Para la identificación de miembros utilizamos el código pyUPMASK y completamos el análisis general del cúmulo con el código ASteCA. La secuencia principal del cúmulo muestra un turn-off point bien definido, aunque algunas estrellas se ubican por encima de él, en la posición típica de las estrellas *blue stragglers*. Hay un evidente ensanchamiento de la secuencia principal, que es difícil de atribuir solo a errores fotométricos, siendo más probable que ella se deba a un alto porcentaje de estrellas binarias.

Abstract / NGC 2660, an old and very compact open cluster placed at about 3 kpc from the Sun in a region of moderate absorption, has been subject of several photometric and spectroscopic studies in the past. Controversies arise in terms of its distance, age and metal content. Previous comparisons with cluster synthetic models carried out did not resolve them. We decided to analyze this object combining high precision parallax, proper motions and magnitudes coming from the Gaia Second Data release (Gaia DR2), in order to improve the cluster fundamental parameters. So we collect Gaia DR2 data in a 1 square degree region, centered in NGC 2660. For the membership estimation, we run the pyUPMASK code and completed the overall cluster analysis with the ASteCA code. The cluster main sequence shows a well-defined turn-off point although some stars are placed above it, resembling the typical position of blue straggler stars. There is an evident widening of the main sequence hard to be explained by just photometric errors becoming more probable that it is produced by a high percentage of binary stars.

Keywords / open clusters and associations: individual: NGC 2660

1. Introduction

The open cluster NGC 2660 is placed at $\alpha_{(2000)}$ = 08:42:29.5, $\delta_{(2000)}$ = -47:15:41.05 ($l^\circ = 265.929, b^\circ = -03.010$), in the southwest border of Vela Constellation projected against the Vela SN Remnant. A conflictive issue about this object is its metal content value that has been measured by several authors but with inconsistent results: Hartwick & Hesser (1973) propose a sub-solar metal content for NGC 2660 given the difficulty to fit simultaneously the turn-off and the Red Clump stars, Hesser & Smith (1987) derived [Fe/H]=-0.40, and more recently, Sestito et al. (2006) performed a new estimate using high-resolution spectroscopy founding solar metal content in this cluster, [Fe/H] = +0.04. The age of the cluster is also a controversial point. In literature, it ranges from 0.7 to 1.6 Gyr, probably by-product of the metal content confusion It seems that the only agreement between different authors is for the mean reddening, stated about E(B-V) = 0.4. Other fact that is surely playing a role in the disagreements for age and metal content is the difficulty to produce a trustable estimate of memberships. Cluster members have been been found using the traditional method of veryfing congruent star positions in several photometric diagrams.

But for this cluster, being compact and distant, observers have to deal with the difficulties to get the best and more complete set of faint members. This problem has been partially solved in the very deep, but spatially reduced, analysis undertaken by Sandrelli et al. (1999) down to V= 22 mag. These authors derived the cluster parameters by comparing the observational color-magnitude diagram with several sets of synthetic clusters. In this sense and onto this basis, Sandrelli et al. (1999) found a binary fraction near 30%. Inspection of this value is an important task to be done since photometric errors amongst the faintest members may be large.

Kharchenko et al. (2016) studied NGC 2660 using infrared data and obtained a color excess E(B-V) = 0.468, a distance of 2817 pc and an age of 1.3 Gyr. On the other hand, Jeffery et al. (2016) carried out a Bayesian analysis and obtained an age of 1.64±0.04 Gyr for this cluster.

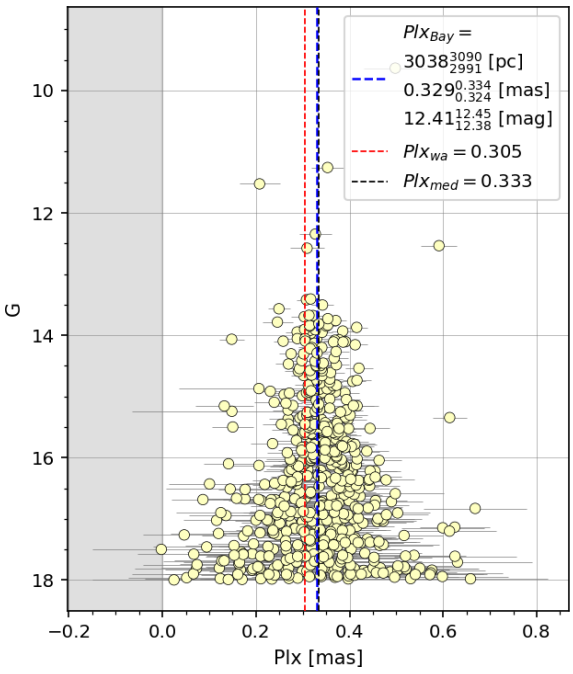

Figure 1: Parallax data analysis for stars with membership probabilities $\geq 95\%$. Plx_{wa} is the parallax weighted average and Plx_{med} is the median.

Cantat-Gaudin et al. (2018) applied the UPMASK code (Krone-Martins & Moitinho (2014)) for unsupervised membership assignment to Gaia DR2 data and identified 425 members of the NGC 2660 cluster. These authors obtained an average proper motion for members $\mu_\alpha cos(\delta)$ = -2.763±0.121 mas/yr and μ_δ =5.165±0.129 mas/yr, estimating 2969.7 pc as the most probable value for their distance. Liu & Pang (2019) recently identified 479 members, and calculated an average proper motion $\mu_\alpha cos(\delta)$ = -2.816±0.29 mas/yr and μ_δ =5.090±0.382 mas/yr. In this work an age of 1.45 Gyr and a metallicity Z=-0.25 are obtained for NGC 2660.

2. Description of the method

We made use of Gaia DR2 data Gaia Collaboration et al. (2018) including positions, parallaxes, proper motions, G magnitudes and BP-RP color indices provided for all the stars in a 1 square degree region centered in NGC 2660. This way we ensure the whole cluster region is under analysis. This area allows a good estimation of the stellar background and reduces the loss of marginal cluster members produced by mass segregation, if present. Finally, to get more reliable results we applied a data cut-off at V = 18 mag.

Membership probabilities were derived from a combination of proper motions and parallaxes processed with pyUPMASK Pera et al. (2021), enhanced version of UPMASK by Krone-Martins & Moitinho (2014). This leaves us with a total of 553 estimated members within a 3′ radius from the cluster center.

The cluster distance was obtained through a Bayesian analysis applied to the parallax data for stars with the largest probabilities ($\geq 95\%$) shown in Figure 1. This subset of 553 stars has been subsequently analyzed with ASteCA code (Perren et al., 2015), in order to derive the fundamental parameters of NGC 2660: metallicity, age, distance (the photometric one), extinction, total mass, and binary fraction (ASteCA uses PARSEC v1.2 isochrones (Bressan et al., 2012)). We draw the attention to the fact that ASteCA derives the cluster parameters via a comparison with synthetic clusters allowing for an extended age range as well as for E(B-V) and metal content. The process is applied in several stages allowing for an initial wide range in metallicity that is gradually reduced.

ASteCA also estimates individual masses for each probable member, as well as its probability of being a binary system (instead of a single star). The individual initial masses are assigned by generating one thousand synthetic clusters, randomly sampling the estimated values for the fitted parameters and their uncertainties. For each sampled synthetic cluster the closest synthetic star for each observed star is found, and its initial mass value is assigned to the observed star. Once all the synthetic clusters have been sampled, each observed star has one thousand initial mass values assigned. The final assigned initial mass for each observed star is then the mean of all these values, and we used them to compute the slope of the IMF of NGC 2660. Before that, we impose a cut in the distribution of binary probabilities in order to match the binary fraction found by ASteCA (38%). We applied the maximum likelihood method described in Khalaj & Baumgardt (2013) to estimate the slope of the IMF. This method works on individual mass estimates, and does not depend on binning the masses. We estimate a IMF slope $\alpha = 2.464$ for the mass range [1, 2] M$\odot$, rather close to the canonical slope of 2.3 in this mass range.

Figure 2 shows the ASteCA output. The mean fit to the observed color magnitude sequence is shown by the red isochrone in the left plot. The rest of the corresponding parameters are included in the accompanying text box at the right side. The right plot shows the best (mean) fit performed by a synthetic cluster. Red stars are binary systems estimated in a 38% to get the best fitting. Notice that the position of the Red Clump stars is essentially composed by binary stars. This is necessary to reproduce the position of real Red Clump stars.

One of the obstacles with this cluster is the large photometric data spread shown in the top left figure. Since binary stars by themselves cannot fully explain the widening, we assume this effect must be a combination of differential reddening data spread and binaries.

The metal content of NGC 2660 has been found to be slightly suprasolar, Z = 0.032±0.002, close to the value found by Sestito et al. (2006) who carried out high resolution spectroscopy, Z = 0.04. Our analysis confirms the age of NGC 2660 is 0.93±0.015 Gyr. The distance of this cluster is then 3060±30 or 3030±40 pc depending on the photometric or the bayesian parallax analysis, respectively.

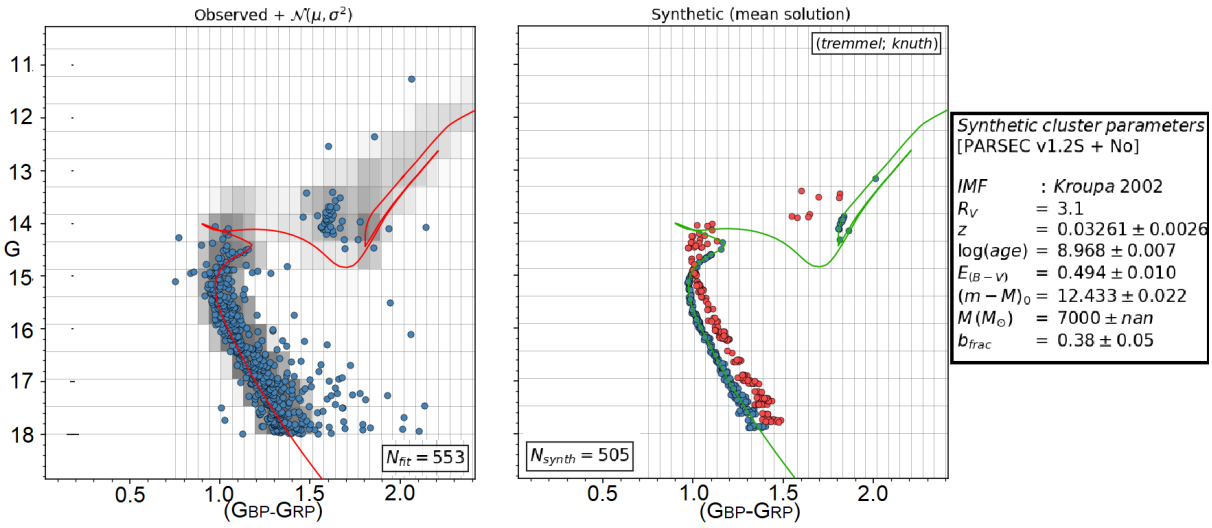

Figure 2: ASteCA output. *Left panel:* The mean fit to the observed color magnitude sequence is shown by the red isochrone. *Center panel:* The best (mean) fit by a synthetic cluster. The red circles represent binary systems and the blue circles single stars. *Right panel:* Parameters fitted by a synthetic cluster. N_{fit} is the number of stars used in the analysis while N_{synth} gives the number of stars of the synthetic cluster with identical properties.

3. Results

The membership analysis allowed us to better determine the fundamental parameters of NGC 2660. The distance to the cluster was calculated by two different methods, by means of a photometric analysis and a Bayesian analysis of the parallaxes. Both methods lead to similar results, placing this cluster at a minimum distance of approximately 3030pc.This value is slightly higher than that found by Kharchenko et al. (2016) (2817 pc) and Cantat-Gaudin et al. (2018) (2969.7 pc). An average proper motion of the member stars was calculated, obtaining $\mu_\alpha cos(\delta)$ = -2.788±0.2 mas/yr and μ_δ =5.162±0.3 mas/yr, values similar to those obtained in previous works. Taking advantage of the fact that all of the cluster members are given an initial mass estimate and a probability of being a binary system by ASteCA, we used them to compute the slope of the IMF of NGC 2660. We estimate a IMF slope α = 2.464±0.217 for the mass range [1, 2] M⊙, rather close to the canonical slope of 2.3 in this mass range. Age is the most controversial parameter for this cluster. The analysis carried out in this work allows us to confirm that this cluster is 0.93±0.015 Gyr old.

4. Conclusions and perspectives

We identify 553 stars as NGC 2660 members, within an area of 3 arcmin radius. A Bayesian analysis in the parallax and coordinates space was also performed. The distance, using Gaia parallaxes and photometric data analyzed by ASteCA, is 3030±30 and 3060±30 pc, respectively, a difference of 0.1%. This value is about 200 pc larger than previous ones from Sestito et al. (2006) and Hartwick & Hesser (1973). The value of 0.49±0.02mag found for E (V-B) is higher than previous estimates. The binary fraction obtained by comparison with synthetic models is 38%, slightly higher than the one found by Sandrelli et al. (1999). Anyway, this fraction must be taken with care until the issue of the high spread along the main sequence is properly addressed. As for the metal content of NGC 2660 we found it is slightly suprasolar, Z = 0.032±0.002. Surprisingly the Red Clump stars are mostly binaries, a condition that allows the coincidence between the synthetic and the true cluster sequences. Our analysis reveals that NGC 2660 is 0.93±0.015 Gyr old. Regarding the IMF, we found a slope α = 2.464±0.217, close to the usual value for most IMFs. Nevertheless we do not ignore that this value corresponds to a very modest mass interval of just 2 solar masses so that things can change with new deep data coming from the future Gaia release.

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