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Evolved Open Clusters in the Gaia era: the case of the Hyades.

Casamiquela, L. [1], Soubiran, C.[1], Olivares, J.[1], Bouy, H.[1], Ikhenache, N.[1], Jofré, P.[2], Blanco-Cuaresma, S.[3], and Heiter, U.[4]

[1] Laboratoire d'Astrophysique de Bordeaux, Univ. Bordeaux, CNRS, France
[2] Núcleo de Astronomía, Facultad de Ingeniería y Ciencias, Universidad Diego Portales, Santiago De Chile, Chile
[3] Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA
[4] Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Abstract

Evolved Open Clusters (OCs) are excellent tracers of the formation and evolution of the galaxy, as well as an ideal laboratory to test theories of star formation and evolution. In particular, nearby OCs are commonly used as benchmark objects to assess the determination of physical properties of field stars. We have designed a project to perform an in-depth study of the physical properties of a sample of benchmark evolved clusters inside a radius of 500 pc around the Sun. We aim to determine shape, radii, extinction, galactic velocity, age and chemical composition, using recent data from Gaia DR2, and complementary ground-based high resolution spectroscopic data. Here we present the first results of this project after the release of Gaia DR2 concerning the Hyades, the most nearby open cluster. We do a membership selection around a large region from the cluster center. And we perform a spectroscopic analysis of the cluster using HARPS spectra of main sequence stars and red giants. We obtain chemical abundances for 11 species with a typical precision of 0.01 dex.

1 Introduction

Open Clusters (OCs) are widely used to trace the history of the Galactic disk. Also, since their stellar populations cover a wide range of masses and evolutionary phases, their HR diagrams represent snapshot in stellar evolution. That is why they are ideal to test theories of stellar evolution. In particular, nearby OCs spanning different ages and chemical compositions are perfect targets to calibrate and validate astrometric, photometric and spectroscopic surveys.

The majority of them dissolve during the first 100 Myr of evolution. Internal interaction between members, encounters with giant molecular clouds and gravitational harrassment by the galactic potential are the processes which contribute to the disruption of an OC. For this reason, OCs which have survived these effects are valuable targets to understand them.

We have designed a project devoted to determine physical properties of the most nearby and evolved OCs in the light of Gaia data and combined with high precision spectroscopy. This will allow to investigate a handful of things: explore the outskirts of the clusters looking for tidal tails and escapees, which provide information about disruption processes, and relate this to the chemical signature; explore how do the kinematical properties correlate with age and environment; among others. We also aim to provide a comprehensive investigation of benchmark OCs to be used to validate and calibrate future studies and large surveys. So far, we are also in process of revisiting the old nearby OC Ruprecht 147 [9]

In the presented context the Hyades play a significant role being the nearest OC to the Sun, and among the best studied stellar groups. Recently, [1] used the *T*ycho-Gaia astrometric solution (TGAS) results from Gaia DR1 ([2]) to build a membership list in a large area up to 30 pc from the center of the cluster. This makes a good opportunity to test with good statistics the typical dispersion of abundances, or whether there are variation of abundances depending on the distance from the center of the cluster. We do a preliminary analysis with a membership selection using cartesian heliocentric velocities calculated from Gaia DR2 results ([3]). We retrieve several spectra of main sequence and giant stars to do a chemical abundance analysis and test the chemical homogeniety of this cluster.

2 Membership selection

After the Gaia DR2 ([3]) we have performed our own membership selection to recover members up to 30 pc from the center. We have queried the catalog 40° around the center of the cluster $(\mathrm{RA}, \mathrm{DEC}) = (67°, 16°)$, restricting to stars having v_r, and parallaxes $\varpi > 10$ mas. We have constrained the sample using stars with low errors in parallax and proper motions: $\delta\varpi < 0.3$ mas, $\delta\mathrm{pm} < 0.3\,\mathrm{mas\,yr^{-1}}$. Because of its large extension in the sky we have changed to cartesian heliocentric coordinates using the package *p*ygaia to avoid the projection effects in proper motions. After all thi, we obtain 8119 stars in the selected region.

We have used the most central stars ($60 < \mathrm{RA} < 75°$, $10 < \mathrm{DEC} < 25°$) to intially pinpoint the motion of the cluster. Then we do a selection of the whole sample of stars cutting at 2σ in the cartesian velocities. Finally we recalculate the center of the cluster with these stars and we restrict the final selection to 30 pc.

We obtain 167 members with median values of: (X, Y, Z)= $(-43\pm8, 1\pm7, -17\pm4)$ pc, (U, V, W)= $(-42.3\pm0.6, -19.2\pm0.3, -1.2\pm0.4)$ $\mathrm{km\,s^{-1}}$. Their distribution in the 6D space, and the resulting color-magnitude diagram (CMD) are shown in Figure 1. The resulting sample is incomplete because only the brighter stars with a RV in Gaia DR2 have been considered. This selection is well adapted for our study of chemical composition of the cluster but not to derive its physical parameters.We obtain a very consistent HR diagram, which ensures us that the recovered stars are true members. There are four known K giants in the cluster which we do not recover for being out of the bright limit of Gaia DR2.

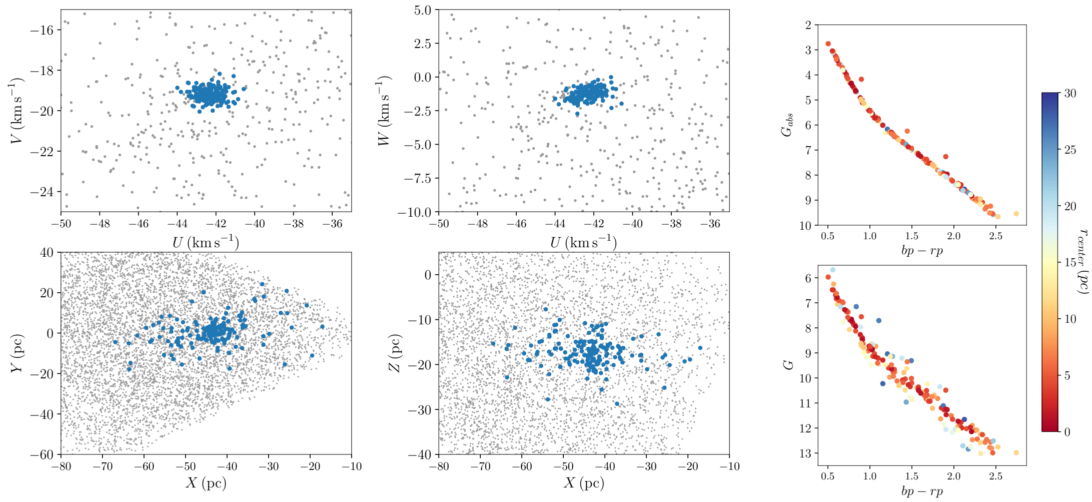

Figure 1: *L*eft: Distribution in velocity (top panels) and physical (bottom panels) space of the selected stars as members of the Hyades (blue), and the whole analyzed sample (grey). *R*ight: CMD diagram in apparent and absolute magnitudes from Gaia DR2 of the selected stars, they are colour-coded according to the distance to the center of the cluster.

3 Spectroscopic analysis

With this selection we have queried the HARPS (R=115,000) archive looking for high-resolution and high SNR (> 100) spectra. We have retrieved spectra for 21 main sequence (MS) stars and of the 2 giants[1] with 7 and 12 spectra each.

We have used iSpec [4] to derive atmospheric parameters and abundances from spectral synthesis fitting using a grid of precomputed synthetic spectra available in the new version of iSpec (Blanco-Cuaresma et al., in prep). The derived $T_{\rm eff} - \log g$ diagram is shown in Figure 2. In general, stars with $T_{\rm eff} > 6500$ K show wider correlation peak in the cross-correlation function. This has an impact in the derived abundances adding more line-by-line dispersion. So, for our purpose, we have focused in the range 6300-5300 K, which are solar-type stars, colored in blue in the left panel of Figure 2. This effect has direct consequences in the expected precision of Galactic archaeology surveys which usually tag giants or turnoff stars because of their brightness.

3.1 Chemical abundances

Chemical abundances are obtained from spectral synthesis fitting using iSpec. In brief, it compares regions of the observed spectrum with synthetic ones generated on-the-fly. The line selection was done based on the automatic detection of absorption lines in a solar spectrum from the Gaia Benchmark Stars library ([5]). Each line was cross-matched with the atomic

[1] In fact, we found spectra for 3 giants. However, one of them gave inconsistent results of abundances, probably because it is an spectroscopic binary. Therefore, we have not included its analysis.

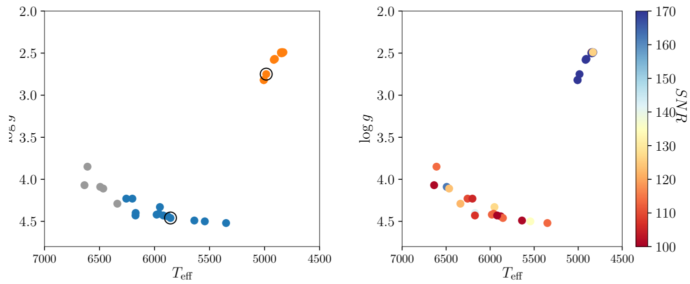

Figure 2: $T_{\rm eff} - \log g$ diagram of the stars in the Hyades observed with HARPS. In the right panel the stars are coloured SNR of the spectrum, and in the left panel we show the two groups of stars made to derive the differential abundances (orange-red giants, and blue-solar type) and the reference star chosen.

line list and we derived solar line-by-line chemical abundances using the reference atmospheric parameters for the Sun. Good lines lead to abundances similar to the solar ones ([7]), thus we selected all lines with an abundance that falls in the range ±0.05 dex. Atomic data is taken from the v5 of the Gaia-ESO survey master line list ([8]).

We have used a strictly line-by-line differential abundance strategy to obtain abundances of 11 different species including Fe-peak and α elements. This technique consists in using a reference star within the cluster which is in the same evolutionary state as the other stars. This allows to reach a very high precision in abundances (~ 0.01 dex) because it erases the differences that arise from slightly wrong atomic parameters in the lines and other effects. The purpose is to show how different are the stars among them. We have made this in two groups: solar type stars using as reference HIP19793, and giants with reference HIP20885. References are indicated in Figure 2. Typical errors in the obtained abundances are of the order of 0.01 dex. This can be checked using the different spectra that we have for HIP20889, which are analysed as if they were different stars. As shown in Figure 3, indeed the 12 spectra of the star give dispersions of the order of 0.01 dex.

We have not found any significant trend of the derived abundances with $T_{\rm eff}$ or $\log g$. However, if we plot the abundance of each element with respect to all the others, very significant correlations show up (see Figure 4). Also, almost all elements show an amplitude in abundance of 0.1 dex, one order of magnitude larger than the typical error. It is improbable that these trends are caused by random errors. Furthermore, most of the stars are physically very similar and doing a differential analysis, the difference in abundance could not be explained by difference in diffusion. This leads to think that in the cluster some of the stars have different abundances, as already reported [6].

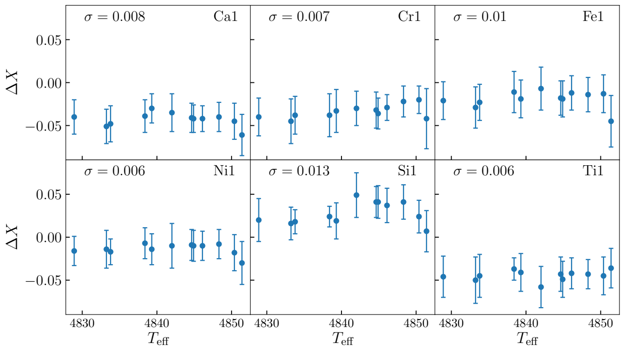

Figure 3: Differential abundances (based on lines of neutral Ca, Cr, Fe, Ni, Si, Ti) for the 12 spectra of the giant star HIP20889 as a function of the derived effective temperature. Abundance dispersion is indicated in each panel

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References

[1] Reino, S. et al. 2018, MNRAS, 477, 3197

[2] Gaia Collaboration et al. 2016, A&A, 595, A2

[3] Gaia Collaboration et al. 2018, A&A, 616, A1

[4] Blanco-Cuaresma, S. et al. 2014, A&A, 569, A111

[5] Blanco-Cuaresma, S. et al. 2014b, A&A, 566, A98

[6] Liu, F. et al. 2016, MNRAS, 457, 3934

[7] Grevesse, N. et al. 2007, SSRv, 130, 105

[8] Heiter, U. et al. 2015, Physica Scripta., 90, 054010

[9] Casamiquela, L. et al. 2018, "The 20th Cambridge Workshop of Cool Stars, Stellar Systems and the Sun (CS20)", Boston, MA, `https://doi.org/10.5281/zenodo.1452285`

Figure 4: Differential abundances of all elements with respect to all others. Solar-type stars plot in blue, giants in orange.