Mem. S.A.It. Vol. 88, 668

Memorie della

Mapping young stellar populations towards Orion with Gaia DR1

E. Zari and A. G. A. Brown

Leiden Observatory, Niels Bohrweg 2, 2333 CA Leiden, the Netherlands
e-mail: zariem@strw.leidenuniv.nl

Abstract. OB associations are prime sites for the study of star formation processes and of the interaction between young massive stars with the ISM. Furthermore, the kinematics and structure of the nearest OB associations provide detailed insight into the properties and origin of the Gould Belt. In this context, the Orion complex has been extensively studied. However, the spatial distribution of the stellar population is still uncertain: in particular, the distances and ages of the various sub-groups composing the Orion OB association, and their connection to the surrounding ISM, are not well determined. We used the first *Gaia* data release to characterize the stellar population in Orion, with the goal to obtain new distance and age estimates of the stellar groups composing the Orion OB association. We found evidence of the existence of a young and rich population spread over the entire region, loosely clustered around some known groups. This newly discovered population of young stars provides a fresh view of the star formation history of the Orion region.

Key words. Stars: distances – Stars: formation – Stars: pre-main sequence

1. Introduction

OB stars are not distributed randomly in the sky, but cluster in loose, unbound groups, which are usually referred to as OB associations (Blaauw 1964). In the solar vicinity, OB associations are located near star-forming regions (Bally 2008), hence they are prime sites for large scale studies of star formation processes and of the effects of early-type stars on the ISM. The Orion star forming region is the nearest ($d \sim 400$ pc) giant molecular cloud complex. All stages of star formation can be found here, from protoclusters, to OB associations (Brown et al. 1994; Bally 2008; Briceño 2008; Muench et al. 2008; Da Rio et al. 2014). The different modes of star formation occurring here (isolated, distributed, and clustered) allow us to study the effect of the environment on star formation processes in detail. Moreover, the Orion region is an excellent nearby example of the effects that young, massive stars have on the surrounding ISM (Ochsendorf et al. 2015; Schlafly et al. 2015). The Orion OB association (Ori OB1) consists of several groups, with different ages, partially superimposed along our line of sight (Bally 2008) and extending over an area of $\sim 30° \times 25°$. We use the first *Gaia* data release (Gaia Collaboration 2016a,b), hereafter *Gaia* DR1, to explore the three dimensional arrangement and the age ordering of the many stellar groups towards Orion, with the goal to construct a new classification and characterization of the stellar population in the region. Our approach is based on the parallaxes provided in the *Tycho-Gaia Astrometric Solution* (Michalik

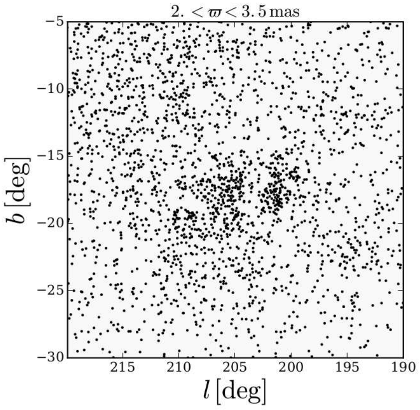

Fig. 1. Positions in the sky of the TGAS sources selected with Eq. (1), and with parallax $2 < \varpi < 3.5$ mas.

et al. 2015; Lindegren et al. 2016, TGAS), a sub-set of the *Gaia* DR1 catalogue, and on the combination of *Gaia* DR1 and 2MASS photometry.

2. Orion in *Gaia* DR1

We first consider all the TGAS sources in the field. Since the motion of Orion OB1 is mostly directed radially away from the Sun, the observed proper motions are small. For this reason, a rough selection of the TGAS sources can be made requiring:

$$(\mu_{\alpha*} - 0.5)^2 + (\mu_\delta + 1)^2 < 25\,\mathrm{mas}^2\,\mathrm{yr}^{-2}, \quad (1)$$

where $\mu_{\alpha*}$ and μ_δ are the proper motions in right ascension and declination. Fig. 1 shows the distribution in the sky of the sources with parallax $2 < \varpi < 3.5$ mas, which corresponds to a distance $285 < d < 500$ pc. Some source over-densities towards the center of the field, $(l, b) \sim (205°, -18°)$, are clearly visible, and they are not due to projection effects but are indicative of real clustering in 3-D space.

We combine *Gaia* and 2MASS photometry to construct color-magnitude diagrams (CMD) of the sources within the density enhancements. Fig. 2 shows the G vs. $G - J$ CMD of the field. The big black points represent the TGAS sources within the density enhancements of Fig. 1, while the small black dots are

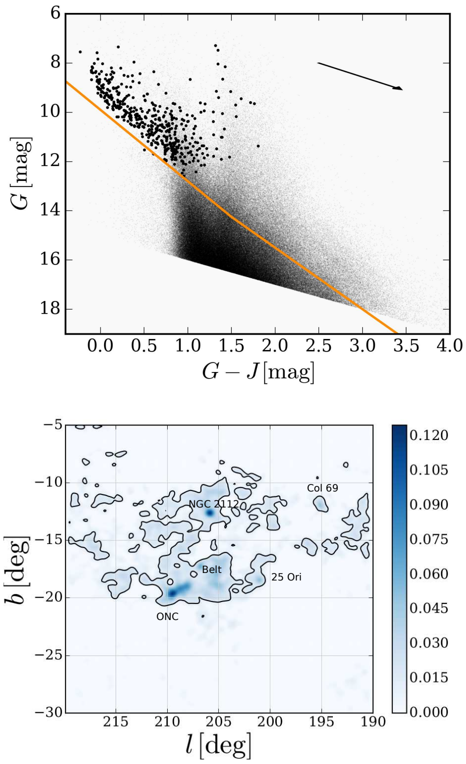

Fig. 2. Top: Colour magnitude diagram of the *Gaia* DR1 sources cross-matched with 2MASS. Bottom: Background subtracted normalized probability density function of the stars selected with with Eq. 2.

the *Gaia* DR1 sources. The TGAS sources define a sequence at the bright end of the CMD, whose faint counterpart is visible between $G = 14$ mag and $G = 18$ mag. The latter might indicate the presence of a population of young stars, since it is situated above the main sequence at the distance of Orion. To clean our sample, we first excluded the bulk of the field stars by requiring (orange line in Fig. 2): $G < 2.5(G-J) + 10.5$ for $G > 15$ mag, $G < 2.9\,(G-J) + 9.9$ for $G < 15$ mag. Then we analyse the distribution in the sky of the remaining sources using a multivariate normal kernel, with isotropic bandwidth = 0.3°. Fig. 2 (bottom) shows the background subtracted normalized density function of the source distribution. The groups clearly separate from the field stars.

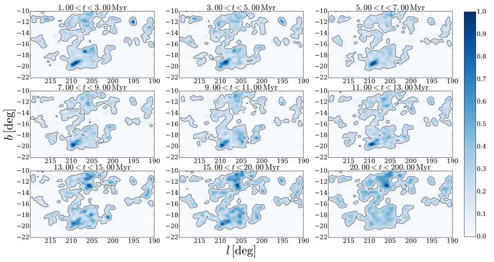

Fig. 3. Distribution in the sky of the sources in different age intervals.

We further select all the sources within the contour levels shown in Fig. 2, and we determine their ages with a Bayesian isochrone fitting procedure (Jørgensen & Lindegren 2005) and (Valls-Gabaud 2014), fixing the parallax to $\varpi = 2.65$ mas. This value corresponds to the mean parallax for the TGAS sources within the density enhancements shown in Fig. 1. Fig. 2 (bottom) shows the density (Gaussian kernel, with bandwidth = 0.5°) of the source sky distribution as a function of their age, t. The coordinates of the density enhancements change with time. This means that the groups we identified have different relative ages. The last panel shows the stars with estimated ages > 20 Myr. These are field stars: their distribution is almost uniform, and their density increases towards the Galactic plane.

3. Conclusions

We studied the stellar population towards Orion and we found evidence for the presence of a young stellar population, at parallax $\varpi \sim 2.65$ mas, loosely distributed around some known clusters: 25 Ori, ϵ Ori and σ Ori, and NGC 1980 and the ONC. We also found hints of the presence of a parallax gradient going from 25 Ori to the ONC. We estimated the ages of the populations, and we found an age gradient corresponding to the parallax gradient. In particular, the closest stars to the Sun are also the oldest ones.

Acknowledgements. This project was developed in part at the 2016 NYC Gaia Sprint, hosted by the Center for Computational Astrophysics at the Simons Foundation in New York City. This work has made use of data from the European Space Agency (ESA) mission *Gaia* (`https://www.cosmos.esa.int/gaia`), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, `https://www.cosmos.esa.int/web/gaia/dpac/consortium`). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

References

Blaauw, A. 1964, ARA&A, 2, 213

Bally, J. 2008, Handbook of Star Forming Regions, Vol. I: The Northern Sky, ed. B. Reipurth (San Francisco, ASP), 459

Bressan, A., Marigo, P., Girardi, L., et al. 2012, MNRAS, 427, 127

Briceño, C. 2008, Handbook of Star Forming Regions, Vol. I: The Northern Sky, ed. B. Reipurth (San Francisco, ASP), 838

Brown, A.G.A., de Geus E.J. & de Zeeuw P.T. 1994, A & A, 289, 101

Chen, Y., Girardi L. & Bressan, A. 2014, MNRAS, 444, 2525

Da Rio N., Tan J. C. & Jaehnig, K. 2014, ApJ, 795, 55

Finkbeiner, D. P. 2003, ApJS, 146, 407

Gaia Collaboration, Brown, A.G.A., Vallenari A., et al. 2016a, A & A, 595, A2

Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al. 2016b, A & A, 595, A1

Jørgensen, B.R. & Lindegren, L. 2005, A&A, 436, 127

Lindegren L., Lammers, U., Bastian U. et al. 2016, A&A, 595, A4

Michalik, D., Lindegren L., & Hobbs, D. 2015, A&A, 574, A115

Muench, A., Getman K., Hillenbrand L. & Preibisch, T. 2008, Handbook of Star Forming Regions, Vol. I: The Northern Sky, ed. B. Reipurth (San Francisco, ASP), 483

Ochsendorf,B. B., Brown A. G. A., Bally J. & Tielens, A. G. G. M. 2015, ApJ, 808, 111

Planck Collaboration, Abergel, A., Ade, P.A.R, et al. 2014, A & A, 571, A11

Schlafly, E. F., Green G., Finkbeiner D. P. 2015, ApJ, 799, 116

Tang, J., Bressan A., Rosenfield P. et al. 2014, MNRAS, 445, 4287

Valls-Gabaud, D. 2014, EAS Publication Series, 65, 225