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# Mapping young stellar populations towards Orion with *Gaia* DR1

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**Abstract.** OB associations are prime sites for the study of star formation processes and of the interaction between young massive stars with the interstellar medium. 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 interstellar medium, 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 numerous 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.

**Keywords.** Stars: distances - stars: formation - stars: pre-main sequence - stars: early-type

## 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 interstellar medium. The Orion star forming region is the nearest ($d \sim 400\,\mathrm{pc}$) giant molecular cloud complex. All stages of star formation can be found here, from protoclusters, to OB associations (Brown at 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 great detail. Moreover, the Orion region is an excellent nearby example of the effects that young, massive stars have on the surrounding interstellar medium (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 $\sim 30° \times 25°$ (see Fig. 1, left). 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 overall 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* (TGAS, Michalik *et al.* 2015, Lindegren *et al.* 2015), a sub-set of the *Gaia* DR1 catalogue, and on the combination of *Gaia* DR1 and 2MASS photometry. We find evidence for the presence of an extended young (age $<$ 20 Myr) population, loosely clustered around some known groups: 25 Ori, $\epsilon$ Ori and $\sigma$ Ori, and NGC 1980 and the ONC. We derive distances to these sub-groups and (relative) ages. Our

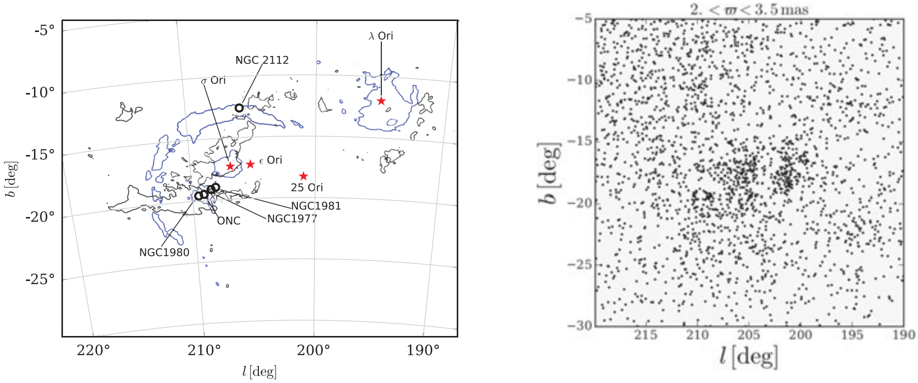


**Figure 1.** Left: Schematic representation of the field. The black contours correspond to the regions where $A_V > 2.5$ mag (Planck Collaboration, 2014), while the blue contours show the $H_\alpha$ structures (Finkbeiner, 2003): Barnard's loop and the $\lambda$ Ori bubble. The positions of some known groups and stars are indicated with black circles and red stars, respectively. Right: Positions in the sky of the TGAS sources selected with Eq. 2.1 with parallax $2 < \varpi < 3.5\,\mathrm{mas}$.

results are the first step to unveil the complex star formation history of Orion towards obtaining a general overview of the episodes and the duration of the star formation processes in the entire region.

## 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:

$$(\mu_{\alpha*} - 0.5)^2 + (\mu_\delta + 1)^2 < 25\,\mathrm{mas}^2\,\mathrm{yr}^{-2}, \tag{2.1}$$

where $\mu_{\alpha*}$ and $\mu_\delta$ are the proper motions in right ascension and declination. Fig. 1 (right) shows the distribution in the sky of the sources with parallax $2 < \varpi < 3.5\,\mathrm{mas}$, which corresponds to a distance $285 < d < 500\,\mathrm{pc}$. 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 three dimensional space. The stars within the density enhancements of Fig. 1 (right) also show a small gradient in the parallax - galactic longitude plane. In particular, the stars associated with 25 Ori have slightly larger parallaxes than those in the direction towards the ONC. We combine *Gaia* and 2MASS photometry to construct color-magnitude diagrams of the sources within the density enhancements. These sources define a sequence at the bright end of the color-magnitude diagram (black big dots in Fig. 2, left). This prompts us to look further at the entire field, and to use the entire *Gaia* DR1 catalogue to find evidence of the faint counterpart of the concentration reported above. Fig. 2 shows a $G$ vs. $G - J$ color magnitude diagram of the central region of the field. A dense, red sequence is visible between $G = 14\,\mathrm{mag}$ and $G = 18\,\mathrm{mag}$. This sequence might indicate the presence of a population of young stars, since it is situated above the main sequence at the distance of Orion. We decided to eliminate the bulk of the field stars by requiring the following conditions to hold (orange line in Fig. 2):

$$G < 2.5\,(G - J) + 10.5 \;\text{ for }\; G > 15\,\mathrm{mag},\;\; G < 2.9\,(G - J) + 9.9 \;\text{ for }\; G < 15\,\mathrm{mag}. \tag{2.2}$$

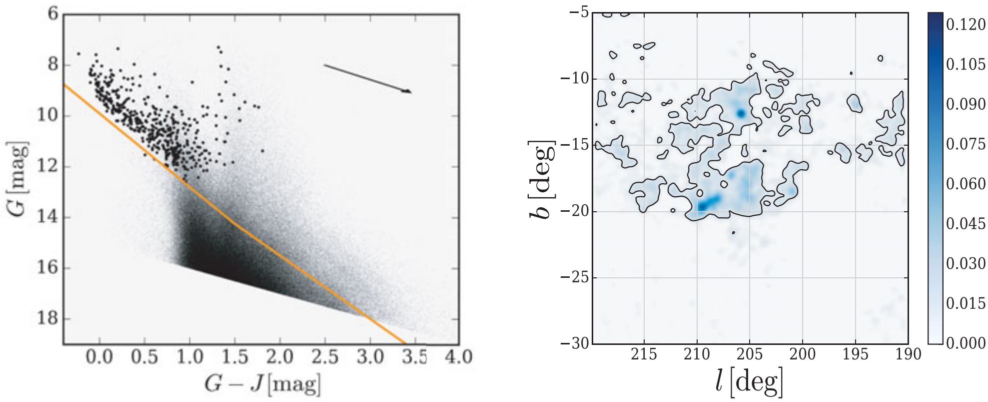


**Figure 2.** Left: Colour magnitude diagram of the *Gaia* DR1 sources cross matched with 2MASS. The sources we focus on are those responsible for the dense, red sequence in the lower part of the diagram. The orange line is defined in Eq. (2.2), and was used to separate the bulk of the field stars from the population we intended to study. The big black points represent the sources within the TGAS density enhancements. The arrow shows the reddening vector corresponding to $A_V = 1$ mag. Right: Background subtracted normalized probability density function of the stars selected with with Eq. (2.2). The density enhancements visible in the centre of the field correspond to the TGAS density enhancements (cf. Fig. 1, right). The peak at $(l, b) \sim (206, -12.5)$ deg corresponds to the open cluster NGC 2112.

We analyse the distribution in the sky of the sources selected with Eq. (2.2) using a multivariate normal kernel, with isotropic bandwidth $= 0.03°$. Fig. 2 (right) shows the background subtracted normalized density function of the source distribution. The groups clearly separate from the field stars. We selected all the sources within the contour levels shown in Fig. 2. To determine the age(s) of the population(s) we identified, we perform a Bayesian isochrone fit using a method similar to the one described in Jorgensen & Lindegren (2005) and Valls-Gabaud (2014). We compare the observed $G$ magnitude and $G - J$ color to those predicted by the PARSEC (PAdova and TRieste Stellar Evolution Code, Bressan *et al.* 2012, Chen *et al.* 2014, Tang *et al.* 2014) library of stellar evolutionary tracks. We applied an extinction correction of $A_V = 0.5$ mag and we fixed the metallicity to $Z = 0.02$, following Brown *et al.* (1994). We applied the fitting procedure to all the stars within the contour levels of Fig. 2 (right), fixing the parallax to $\varpi = 2.65$ mas. Fig. 3 shows the density (Gaussian kernel, with bandwidth $= 0.05°$) 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 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, $\epsilon$ Ori and $\sigma$ 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.

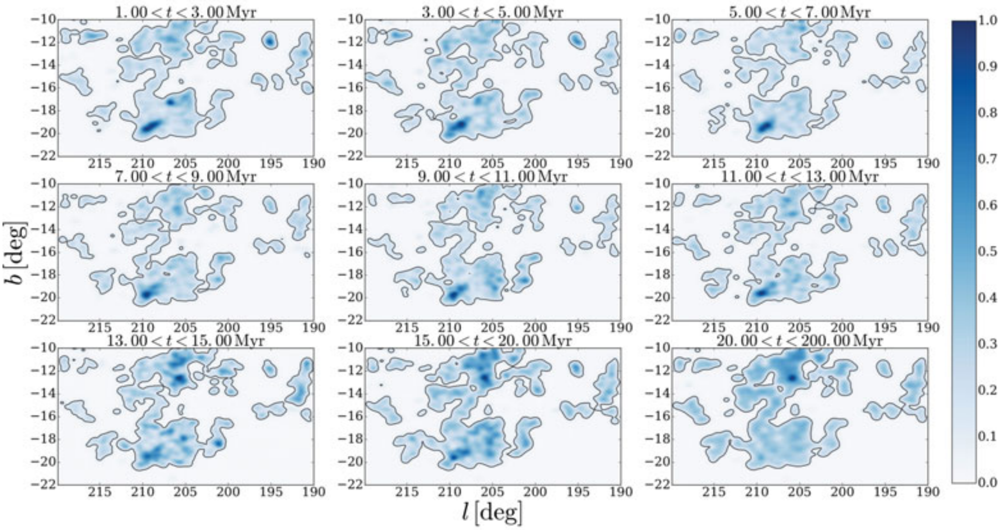


**Figure 3.** Distribution in the sky of the sources in different age intervals. The contours represent the 0.05 density level and are shown only for visualization purposes. The first eight panels show stars with estimated ages < 20 Myr, while the last one shows older sources. The young stars are not coeval, in particular the age distribution shows a gradient, going from 25 Ori and $\epsilon$ Ori towards the ONC and NGC 1980.

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