The figure of Orion the Hunter is a familiar sight in the winter sky of the Northern hemisphere. The entire area, which is shown in the large panel of Fig. 5.10, is an extraordinarily active site of star formation and has received intense astronomical scrutiny. Orion hosts many young stellar clusters, superimposed along the line of sight and at different evolutionary stages. Explaining the detailed sequence of events (the so-called star formation history) that caused the formation of such a numerous population is one of the main topics of this thesis.

Almost all the bright blue stars visible in Fig. 5.10 belong to the so-called "Orion OB association". OB associations were first identified as loose groups of young, massive stars. These large structures, whose physical sizes are of order of hundreds of parsecs\(^3\), are the last stage of the massive star formation process and the context in which new stars are born. For example, the current star formation in the Orion Nebula (see Fig. 5.10, bottom) is linked to the earlier generations of massive stars in the adjacent groups of the Orion association.

Similarly, the formation of single OB associations is related to large scale star formation events, occurring on scales of hundreds of parsecs. In the solar neighbourhood (which is the region within 500 pc from the Sun), such events produced numerous associations, that historically were thought to form a ring-like structure which is usually referred to as the Gould Belt. The associations and clusters that compose the Gould Belt are very young compared for example to the Sun, which is around 5 billion years old, and were about to form when dinosaurs became extinct (around 66 Myr ago). The first members of the genus Homo (Homo habilis and Homo erectus) appeared between 4.5 and 2 Myr ago: this is roughly the age of the youngest clusters in the Gould Belt, such as the Orion Nebula Cluster shown in Fig. 5.10, bottom.

Assuming that these archaic humans would look at the stars on a clear night, they would have seen a slightly different sky than what we observe now. Stars indeed move on the sky. They orbit around the centre of our galaxy, the Milky Way, in an orderly fashion, but there are also local velocity patterns that differ from region to region. The members of OB associations were likely born from the same complexes of gas and dust, and thus they not only share the same rotational velocity but also the same local velocity. This property is often used to separate the members of OB associations from other stars.

A fraction of O and B-type stars moves with velocities higher than expected: these are referred to as runaway stars. Runaway stars do not acquire their velocity at birth, but during their life. To explain the origin of such high velocities, two mechanisms have been proposed. The first mechanism predicts that a runaway star might originally have been a member of a binary star system consisting of two massive stars. If one of the stars explodes as a supernova, the other is suddenly released from the gravitational attraction and can be launched away at high speed on a new trajectory. The second mechanism predicts that a runaway might have formed in a very dense young cluster, like the Orion Nebula Cluster. In this environment, two binary star systems

\[3\text{ parsec corresponds to approximately } 3 \times 10^{16} \text{ m}, \text{ or } 3.28 \text{ light years}\]
can pass close to each other, and interact gravitationally. Such interaction can disrupt both systems, and one or more stars can be ejected at high speed.

**Gaia**

Unravelling the structure and star formation history of the young associations requires accurate knowledge of stellar distances, motions, and ages. The data of the ESA Gaia spacecraft are crucial in this respect. The main goal of the Gaia mission is to make the largest, most precise three-dimensional map of our Galaxy by measuring the positions and motions of more than a billion stars in our Galaxy and beyond. A star’s position on the sky changes with time due to its motion relative to the Sun and the motion of the Earth around the Sun. The projection of a star’s space motion relative to the Sun onto the celestial sphere is called proper motion. This is an angular velocity (angle per time). The corresponding velocity is the tangential velocity. When the distance to an object is known, the tangential velocity can be calculated from its angular velocity. If the projection of a star’s velocity on the line of sight (the radial velocity) is also measured, the total velocity can be obtained by adding up the tangential and the radial velocities. The apparent motion of a star due to the rotation of the Earth around the Sun is called parallactic motion, and it is related to the distance of the star. The smaller the parallactic motion is, the larger is the distance to the star with respect to the Sun.

Gaia is not the first mission of this kind. In the 90’s, the Hipparcos satellite produced a catalogue of positions and motions for around one-hundred thousands stars. Hipparcos allowed for an extensive census of the stellar content of nearby OB associations. However, the data were not precise enough to determine the three-dimensional structure of even the nearest association, Scorpius-Centaurus, or to make significant progress in Orion. Gaia significantly improves on Hipparcos for a number of reasons. For example, Gaia measures star positions and motions 200 times more accurately than Hipparcos. As a comparison, Gaia’s precision is so high that it can measure the angle that corresponds to the diameter of a coin on the Moon, while Hipparcos could measure only the height of the astronaut holding it in their hands.

**This thesis**

This thesis makes use of the first Gaia data releases (Gaia DR1 and DR2) to obtain a detailed census of the young stellar populations in the solar neighbourhood, exploring the distribution and the properties of both high-mass, early-type stars and low-mass, pre-main sequence stars. Figure 5.11 shows where high-mass stars and pre-main sequence stars are located in a colour-magnitude diagram of the Orion region. A colour-magnitude diagram is a tool used to classify stars according to their luminosity, temperature, mass, and evolutionary stage. When a star starts the nuclear fusion of hydrogen in its central regions, it enters the main sequence (dashed line in Fig. 5.11). The position of a star on the main sequence depends on its mass: the upper main sequence (grey box in the upper left corner of the plot) is where massive, early type stars are located. Just before stars enter the main sequence, they are located on the pre-main sequence (grey ellipse): in this stage, stars are contracting and their temperature is rising, but hydrogen fusion has yet to start. New born stars enter the pre-main sequence after they have acquired almost all their mass and blown away their envelope of gas and dust. The pre-main sequence stage lasts from a few million years to a few tens of million years depending on the star’s mass: this is very short
Figure 5.10: Top: stars and gas in the Orion region. The bright red circular filament arcing down from the middle is Barnard’s loop (Rogelio Bernal Andreo, DeepSkyColors.com). Bottom right: the Orion Nebula, where star formation is currently taking place (ESO/G. Beccari). Bottom left: central part of the Orion Nebula Cluster (K.L. Luhman (Harvard-Smithsonian Center for Astrophysics, Cambridge, Mass.); and G. Schneider, E. Young, G. Rieke, A. Cotera, H. Chen, M. Rieke, R. Thompson (Steward Observatory, University of Arizona, Tucson, Ariz.) and NASA/ESA).
Figure 5.11: Colour-magnitude diagram of the stars in the Orion region. The dashed grey line indicates the main sequence; the grey box is a rough boundary for the upper main sequence; the grey ellipse highlights the pre-main sequence.
compared to the average time stars spend on the main sequence.

The goal of this thesis is to understand how OB associations form and disperse, what are the characteristics of the stellar populations within single associations, what are the properties of the ensemble of OB associations in terms of their disposition in space, and how this compares with what is observed in other galaxies. These topics are addressed by using the Orion OB association as a benchmark to study the mechanisms leading to the formation of an OB association, by studying the disposition of OB associations and star forming regions within 500 pc from the Sun, and finally by analysing the kinematic properties of O and B stars within 1 kpc from the Sun. In particular, the focus is on answering the following questions:

- What are the stellar populations in the Orion OB association?
- What is the star formation history of the Orion OB association?
- What is the structure of the solar neighbourhood as traced by young stars?
- How many runaway stars are there in the solar neighbourhood?

The study presented in Chapter 2 represents the first step to unravel the complexity of the star formation history of Orion, in terms of the various star formation episodes, their duration, and their effects on the surrounding interstellar medium. The Gaia DR1 data provided evidence for the presence of a young stellar population loosely distributed around known clusters. The estimated ages of the members of this population suggested the presence of an age sequence in the association.

These conclusions are partially revisited in Chapter 3. The better accuracy of Gaia DR2 compared with Gaia DR1 and the larger number of sources for which it was possible to determine distances and tangential velocities allow for a thorough study of the three dimensional configuration of the stellar groups composing the Orion OB associations and of their motions and ages. The main finding of this chapter is that the star formation events in Orion follow a complex history, which caused kinematic and physical sub-structure.

The focus of Chapter 4 is the entire solar neighbourhood. Three-dimensional maps of the spatial distribution of pre-main sequence (PMS) and upper main sequence stars show three prominent structures, Scorpius-Centaurus, Orion, and Vela (see Fig. 5.12). The distribution of the PMS stars as a function of their age shows that younger stars cluster in dense, compact clumps, and are surrounded by older sources, whose distribution is instead more diffuse. Strikingly, the maps do now provide any evidence for the existence of the ring-like structure which is usually referred to as the Gould Belt.

Chapter 5 presents a search for runaway stars within 1 kpc from the Sun. Candidate runaway stars are selected among upper main sequence stars, and classified as such by using their tangential velocity, and, when possible, their total velocity. In particular, candidate runaway stars are defined as sources that have tangential velocities significantly different from the rest of the population or total velocities higher than 30 km s\(^{-1}\). The analysis is focused on the runaway star candidates in the Orion and Scorpius-Centaurus (Sco-Cen) regions. In Orion, six new runaway star candidates are added to the sample of previously known runaway stars. In Sco-Cen, two runaway star candidates that likely share the same origin are identified.
Figure 5.12: Density distribution of pre-main sequence sources younger than 20 Myr in the galactic plane. The Sun is at the centre, in $(X, Y) = (0, 0)$, the x-axis is directed towards the galactic centre (whose direction is indicated by the arrow), and the y-axis towards the direction of the galactic rotation.
Conclusions

The main conclusion of this thesis is that large scale star formation events that lead to the formation of OB associations are complex, and not well understood. There is not a general star formation theory that completely explains the sub-structure (in space, kinematics, and ages) observed in Orion and in other OB associations in the solar neighbourhood. The origin of OB associations remains somewhat mysterious. The structure of the solar neighbourhood is undeniably different than what was thought in the pre-Gaia era. These findings call for a revision of the theories of propagation and triggering of star formation. Data from the future releases of the Gaia satellite and from upcoming spectroscopic surveys will contribute in exploring in more detail the kinematic and physical sub-structure of large star-forming complexes.