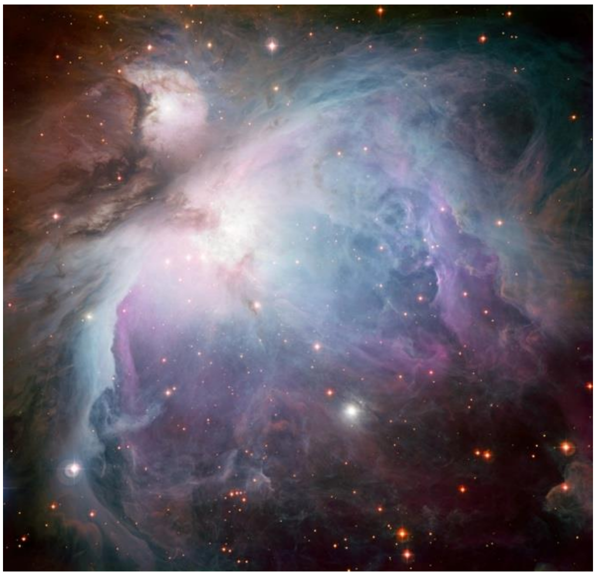
STAR FORMATION IN THE MILKY WAY

If you are in the northern hemisphere and raise your eyes to the sky in an early evening during the winter season you could look for the Orion constellation, easily recognizable by its shape. If you have a binocular and search carefully midway down the sword of Orion, you will notice a bright and extended fog, with a nebular appearance: you are looking at the Orion Nebula, discovered in 1610 by Nicolas-Claude Fabri de Peiresc, and for your information you are peeking in a stellar nursery, a place where new stars are forming. Yes, you read it correctly, there are regions in the universe that are actually forming stars as we speak.

Stars are not immutable as they appear when we look at them during the night, but they are transient objects that constantly form, release energy through nuclear reactions in their interiors and, finally, die, dispersing in the universe a material enriched by the products of these reaction. Such an enriched material become part of large clouds of interstellar gas and dust, which can eventually collapse under the action of gravity and form a new generation of stars, starting the cycle again. This cycle is continuously happening and will only stop when (and if) the expanding universe will be too sparse for gravity to effectively pull material together. Star formation is, therefore, one of the processes involved in the entire evolution of the universe since its beginning.



Left panel: Composite image of the Orion Nebula captured by the Wide Field Camera at MPG/ESO 2.2m telescope at the La Silla Observatory in Chile. The image is composed with observations in different filters at optical wavelengths: ultraviolet emission from massive young stars is colored in purple, while emission from hot hydrogen gas is shown in red. I The dark lane on top left is due to a large abundance of dust able to fully absorb the emission. The stars of the Trapezium star cluster are visible in the centre, slightly offset towards top-left. Credit: ESO/I.Chekalin. *Right panel:* Color composite image of central part of Orion Nebula observed ISAAC on the ESO Very Large Telescope (VLT) at the Paranal Observatory in Chile. The observation is in the infrared revealing about 1000 stars grouped in the Orion Cluster, most of which are invisible in the image on left. These are young stars, with an age of about 1 Myr. Credit: ESO/M.McCaughrean (AIP).

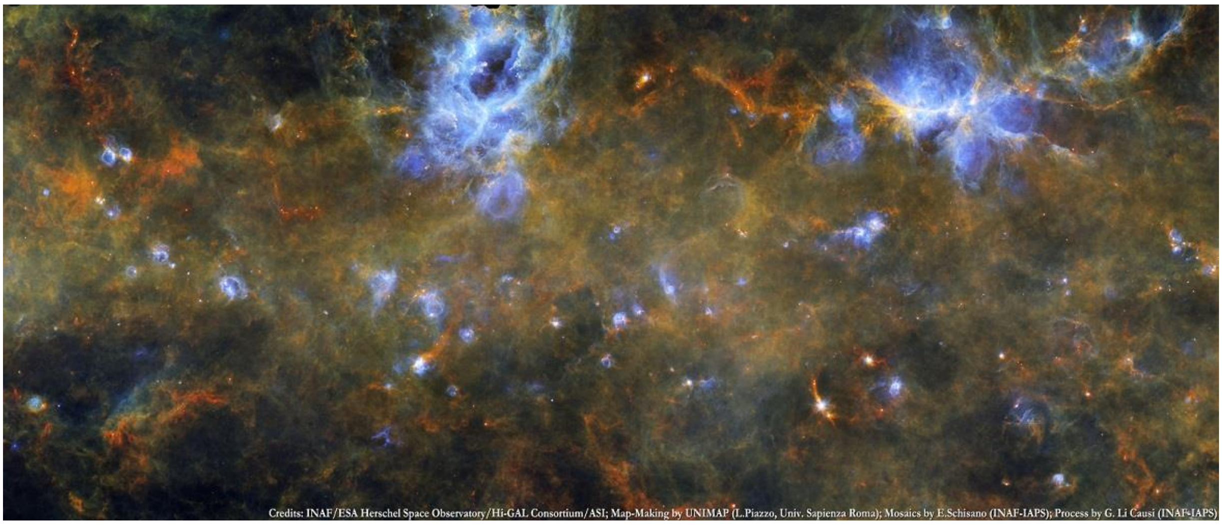
On average, every year in the Milky Way, two solar masses of interstellar matter are converted in stars. It is a rather small number when compared to the billions of stars in our Galaxy, but it is still an exciting thought, especially if you consider that, when the universe was younger, galaxies were much wilder, with millions of stars forming per year following the same physical processes we observe nowadays. Despite the fact that star formation is happening in all galaxies, astrophysicists mainly study it in the Milky Way, where we are able to observe such a process in a much greater detail that in more distant galaxies.

Stars form on timescales much longer than human lifetime, from hundreds of thousands up to millions years, so it is unreasonable to simply look at one single star forming region, like Orion Nebula, and study the process as it unfolds. Luckily, the Orion Nebula is just one of many sites in the Milky Way where star formation is happening, so it is possible to study the entire process by observing all these regions, sort them on the basis of their evolution, and build an evolutionary sequence. To clarify such an approach, imagine that in few days you want to study the characteristics of the entire human life span. You cannot hope to observe the entire life cycle in such a short time, but you can look at snapshots of crowded places where you could find people representative of all the ages. What you are doing is a sampling of the life span from instantaneous snapshots, inferring information on all the phases that a single human being would experience during his/her life. This is exactly what astronomers do to study physical processes in the universe, and it is also applied to star formation: we observe as many sites as possible where we know star formation is happening and we figure out how the entire process proceeds.

Nevertheless, for years astronomers were severely limited by a strong observational constrain: the star formation sites are inaccessible to observations with optical telescopes. The reason behind this is that stars form in regions where there is a large accumulation of material due to gravity. Interstellar material is composed not only by gas, but it includes a fraction of about ~1% of dust, whose grains absorb visible light very efficiently. Only when astronomers started observing in spectral windows where dust absorption is less efficient, such as at infrared and millimeter wavelengths, they were able to directly observe the sites of star formation and shed light on the details of the physical process.

Studies carried out at the end of the past century, mainly focused on nearby star forming regions, allowed researchers to give a first answer to one of the major problems of modern astrophysical research: how does a star form? Nowadays we understand and model reasonably well the formation and early evolution of stars, especially for isolated ones with masses similar to our Sun. Broadly speaking, stars form in cold and dense portions of a molecular cloud, usually referred as "clumps". Within these regions, matter piles up to a sufficiently high density that it becomes unable to remain stable against the pull of its own gravity, and so it starts collapsing. These regions are usually referred as "dense cores", that will typically form one or few stars. The outcome of the initial collapse of a core is a stable structure, usually referred as a protostar, that however is not hot enough to ignite stable thermonuclear burnings. The protostar is generally surrounded by a circumstellar disc, where a planetary system may eventually form. Protostars continue to slowly contract, warming up during such a process, while still accreting material from their surroundings and releasing large amounts of energy in the process in the form of radiation. This radiation travels in the protostar natal cocoon of gas and dust, being continuously absorbed and re-emitted at progressively longer wavelength. As a result, a protostar mostly emits in the far infrared/millimeter during its earliest stages, shifting to mid and near infrared when the protostar is formed. As rule of thumb, the more a given star-forming object evolves, the shorter is the wavelength at which it becomes observable.

This schematic model roughly describes the processes of formation and early evolution of stars. However, the scenario is far from being fully understood. How are molecular clouds formed? what triggers the initial collapse of the gas within a clump? Why is star formation so inefficient since less than one-third of the material involved in its process is assembled in the final star? How the collapse and accretion phases proceed? What is the influence of the central protostar on its surrounding circumstellar disk? Those are just few examples of the questions that are being investigated by astrophysicists. More importantly, most stars are born in clusters dominated by relatively high-mass stars (with masses greater than 8 times the solar one), and the understanding of these processes are still pivotal problems in this research field.



Portion of the Galactic Plane observed with Herschel Space Telescope in the framework of Hi-GAL project. The region is part of the Scorpius constellation and includes two star forming regions, NGC 6357 (named War and Peace Nebula on top left) and NGC 6334 (also known as Cat's Paw Nebula on top right). Massive young stars, roughly 10 times as massive as the Sun, are found in these two regions. The image is produced by combining observations in far infrared at 70 (blue), 160 um (green), and 250 um (red). The blue color representing regions where material is warmed up to temperature of several hundreds of K by embedded young protostars, while in red represent the distribution of the cold, 10-20 K, material from which stars form. A large variety of filamentary and wispy features are visible in the image as result of the turbulent environment of the Galaxy. Arc-like structures are produced by the interaction of the strong radiation field and winds produced by newborn massive stars with the natal cloud. Credit image: INAF/ESA – Observation of Hi-GAL, post-processing in Via Lactea Project.

Understanding the formation process of massive stars is fundamental because, despite their rarity, they play a fundamental role in shaping the structure, the energetic and the enrichment of the interstellar medium. Indeed, massive star ionize the surrounding material and provide large quantities of energy and momentum from their strong winds. These, and eventually their explosion as supernovae, sculpt their surrounding environment, triggering subsequential generations of star formation, and influence the entire galactic evolution.

Astronomers design surveys to map large portions of the Milky Way with high sensitivity and high spatial resolution, such as the one carried by Spitzer, Herschel, and WISE space telescopes in the last two decades. These data are showing us new details on how star formation proceed in our Galaxy. The near/mid infrared data from Spitzer allowed to identify and characterize the entire galactic population of young stars, opening the path to the study of young clusters. On the other hand, Herschel data shed light on the earlier phases, studying the young cores both before and after the formation of protostar, defining the early evolutionary sequences. Moreover, Herschel images revealed the morphology of the interstellar medium with a highly filamentary pattern, possibly due to the turbulent motions of the gas. The denser regions appear as an intricate network of filamentary features, and cores and clumps from which newborn stars form are connected to this complex web.

All these surveys have an extraordinary legacy value with a strong potential of serendipitous science that is still being exploited nowadays. At the same time, new generations of instruments and surveys are being developed and planned to observe, with higher detail, objects that are fainter and are located farther away from us.

Astrophysicists are being flooded with information about thousands of stars forming regions and new approaches are required to handle these data with respect to the works of the previous century where the analysis was performed mostly "by hand". The services integrated and offered to the scientific community by the NEANIAS project will certainly help to face this problem. These are directly derived from the innovative tools and methodologies developed in the modern astrophysical research, but whose application remains often limited to the specific problem they were called to solve. The availability and easy accessibility of these services to all the community have the potential for a more homogeneous and systematic analysis of the data from galactic plane surveys.

Statistical studies and automatic processing are a must to extract the information contained in these surveys, starting from the position of the compact and extended sources. Novel visualization methods are a key to identify objects at different degree of evolution thanks to the comparison of images at different wavelength. Furthermore, scientists usually search for indicators, given by physical quantities or combination of them, that give strong constrains on the evolutionary stage of a star-forming object. The idea is to look for relations between physical parameters and their variation, and the modern tools of machine and deep learning seem to be promising to discovery unexpected connections able to point towards which physical processes are active during formation and early evolution of stars.

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