National Aeronautics and Space Administration

The Great Nebula in Orion

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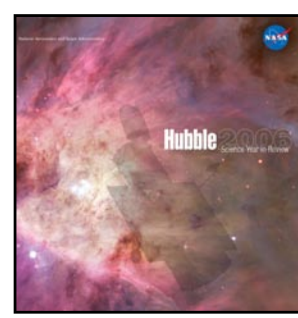

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The Orion Nebula is an opalescent gem in the northern winter sky—an irregular, pale-green swatch encrusted with blue stars shining like diamonds. It is one of the nearest and most observable regions of star formation. Recently, *Hubble* obtained a new portrait of this beautiful object. The largest mosaic *Hubble* image to date, it is truly a work of art, as well as science. Astronomers are studying this image to better understand the formation of stars and planetary systems like the Solar System. Of particular interest are the few very massive stars—blue, hot, and short-lived—that dominate the scene in Orion, shaping the environment and disrupting planet-forming disks around the cooler, longer-lived, and lower-mass, yellow and red stars like the Sun. The Orion Nebula is a special opportunity to observe the general context in which the Solar System formed.

Astronomers have a standard theory that describes how a star like the Sun and its associated planets form. The process starts when a high-density region within a large interstellar cloud of molecular gas collapses under the weight of its own gravity. At the center of the collapsing region, material accumulates and grows into a young star. Around it, a disk of orbiting gas and dust forms, capturing material from the surrounding cloud, and feeding it toward the center. Meanwhile, planets are thought to form by the accretion of material swept up in the disk. Larger planetary bodies develop sufficient gravity to capture gas for atmospheres; smaller ones just form as rocky spheres. Over time, the mother cloud of gas and dust dissipates. Some of the material is incorporated into the central star and forming planets. The remaining fraction is pushed away from the system by the outward pressure of light and by a wind of atoms ejected from the surface of stars. This clearing wind comes from the central star and possibly other stars nearby, which may later move away. A variety of observational evidence supports this standard theory, including protostars deeply embedded in molecular clouds, disks around most or all stars at some period in their youth, and the co-planar alignment of the planetary orbits in the Solar System, which astronomers believe is a fossil of the original disk.

The Orion Nebula is "only" about 1,600 light-years away (9,300 trillion miles!) At that distance, *Hubble* can resolve features as small as the radius of Uranus's orbit or about one five-hundredth of the typical distance between stars in the Nebula.

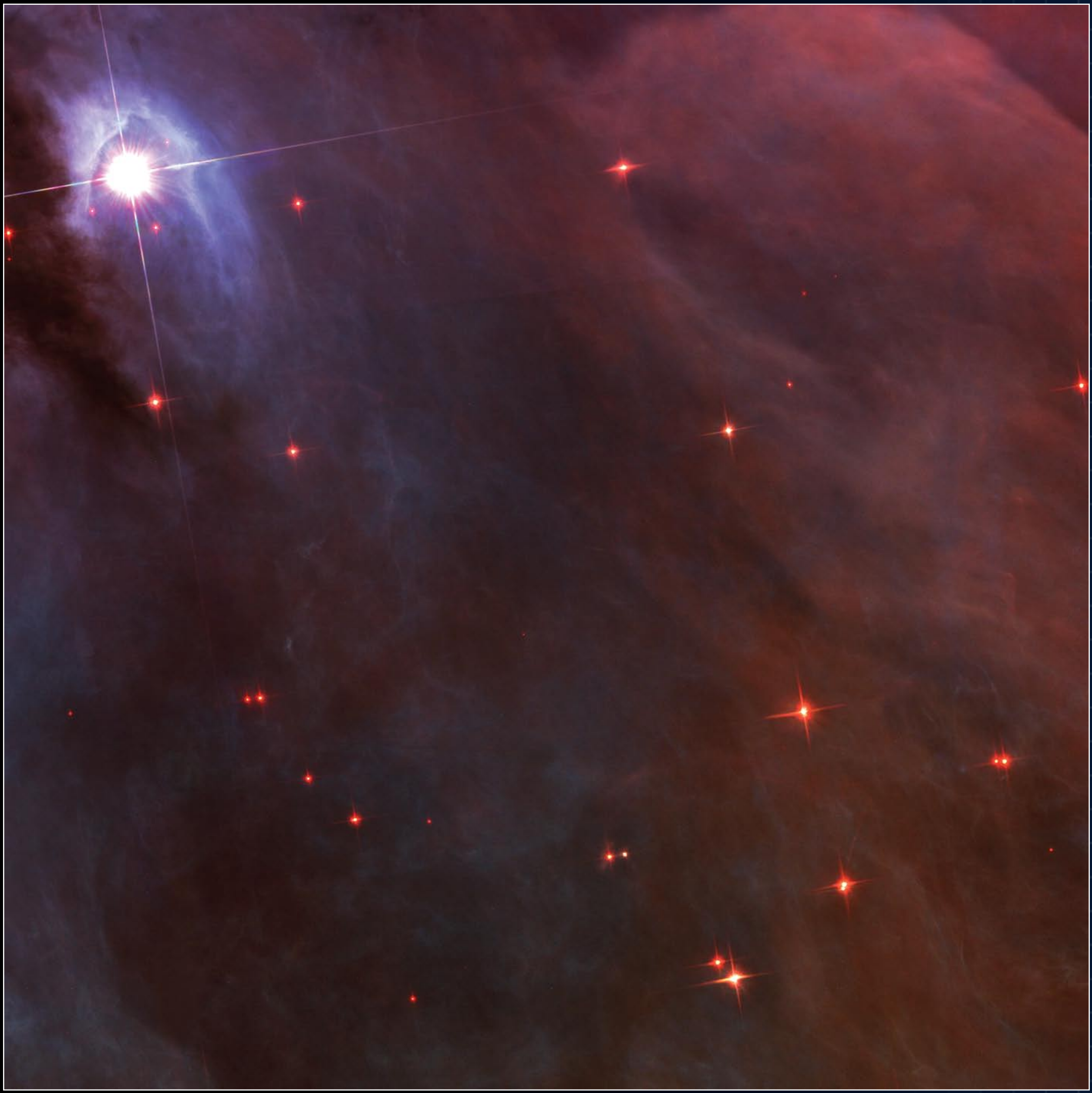
Astronomers have little information about the wider context in which the young Solar System developed. Nevertheless, under the reasonable assumption that the Orion Nebula is a typical star-forming region, it presents astronomers with a valuable laboratory for observing star and planetary system formation in a controlled—or at least understandable—setting. The exact correspondences to the situation of the early Solar System may be uncertain, but the phenomena in Orion are clearly relevant, and therefore, ultimately instructive.

The hot, blue stars in Orion are among the youngest and most massive stars in our galactic neighborhood. Such stars live only a few tens of millions of years. By contrast, stars with the mass of the Sun or less have stable lifetimes ranging upwards of 10 billion years. The hot, blue stars release huge amounts of energy as ultraviolet light and in strong stellar winds—on scales far greater than for young low-mass stars.

The effect of hot, blue stars is devastating *on the whole molecular cloud,* not just locally around the star. Their intense ultraviolet light dissociates molecules into atoms and ions, and accelerates them to high speeds, creating powerful winds. As the temperature and pressure in the ionized gas increases, a hot bubble forms inside the cloud. The bubble grows, and when it reaches the nearest edge of the molecular cloud, the gas flows rapidly away, like champagne from an opened bottle. The Orion Nebula is just such a great cavity in a cold molecular cloud—scoured out, cut open, and exposed to our view.

The Orion Nebula is about 15 light-years wide—about four times the distance from the Sun to the nearest star. Within the open cavity, we can count *thousands* of stars, all formed within about the last million years. These stars include the whole gamut of stellar masses, ranging from many cool, red stars, of typically tenths of a solar mass, to fewer warmer, yellow stars like the Sun, to a very few hot, blue stars, typically of tens of solar masses. We see myriad low-mass stars at various stages of early evolution—some still enshrouded in thinning dust, some with disks, some with jets, and some seemingly free and clear—all situated in the environment created by the hot, blue stars. The goal of the new portrait of Orion is to identify, classify, and characterize the objects, investigate new phenomena, and ultimately draw lessons relevant to the Solar System.

To create the new portrait of the Orion Nebula, we obtained a mosaic of 2,000 exposures, using all *Hubble*'s imaging instruments and nine color filters, which cover wavelengths from the near ultraviolet to the near infrared. We combined images



Brown dwarfs in Orion. The faint red sources in this close-up image of the Orion Nebula are brown dwarfs or “failed” stars.

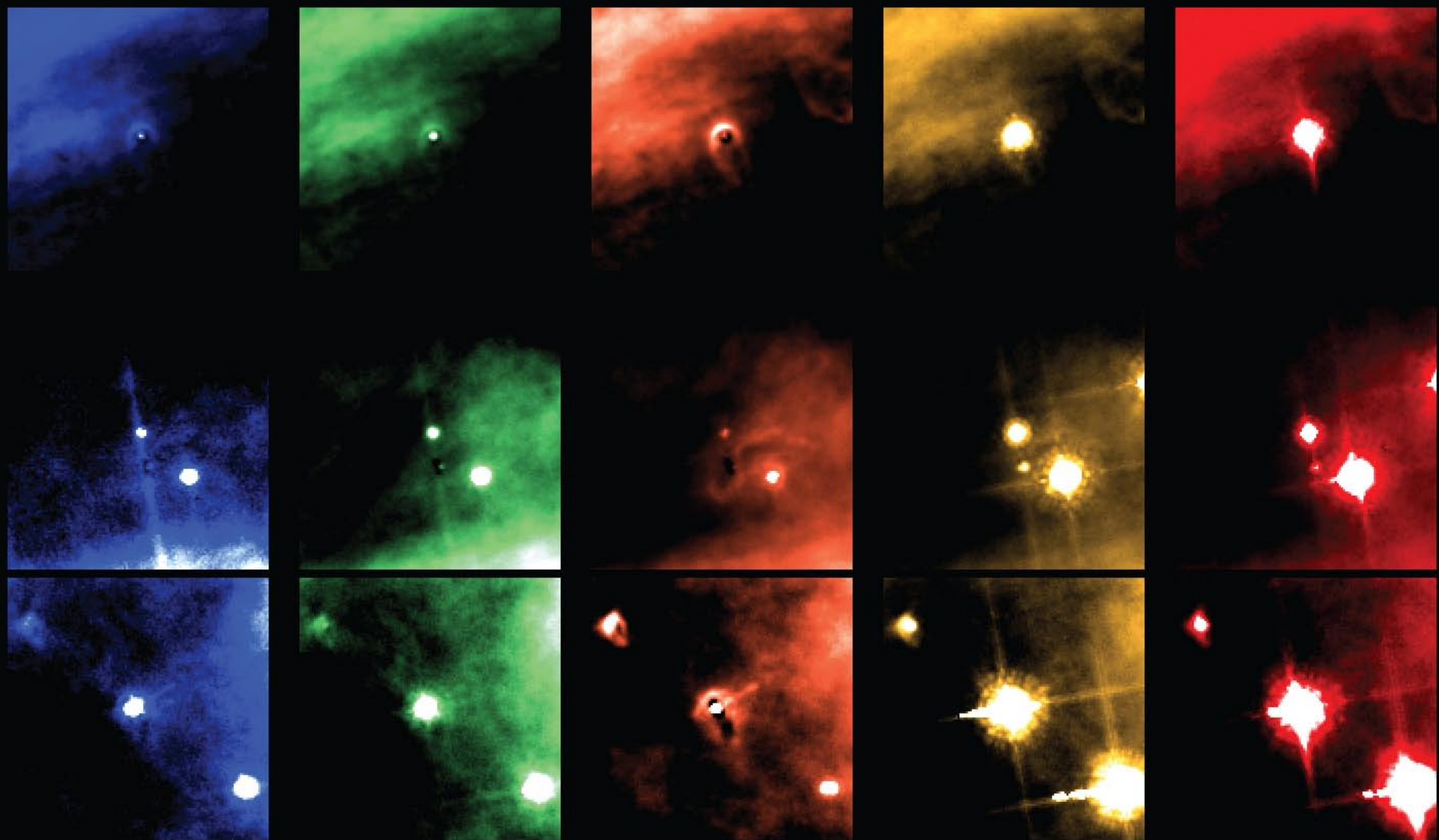
from the Advanced Camera for Surveys into a single image with 33,000 by 36,000 picture elements. These exposures are the deepest look ever taken into the Orion Nebula—or any star-forming region; they pierce through the veil of nebular light to reveal galaxies in the distant background.

Hubble's high resolution enables us to separate the light of the closely packed stars in Orion. Its high stability and light-measuring accuracy overcome the challenge of the non-uniform brightness of nebula. In the *Hubble* images, we can precisely compare the stellar signals through many filters. We can use these accurate comparisons to measure the stellar temperature and luminosity. From these measurements, we can determine the radius, mass, age, and even the mass accretion rate of each star. This catalog of stellar properties will be the largest uniform survey of young stars ever achieved.

The *Hubble* images reveal dozens of candidates for brown dwarf, or "failed," stars—including isolated singles, companions of more massive "real" stars, and even some binary brown dwarfs. Brown dwarfs are stars with a mass less than 8% of the solar mass. The temperature at the centers of these objects is not sufficient to start the nuclear reactions that cause larger stars to shine. At a young age, they may burn deuterium—a heavy isotope of hydrogen—but this phase is short-lived, and after it is over, brown dwarfs radiate only the energy released from their slow gravitational contraction. Old brown dwarfs cool and fade from view, and unseen brown dwarfs represent an unknown fraction of the mass of the universe. In Orion, we can estimate the fraction of brown dwarfs in the general star-formation process, which can be used to constrain their total mass in the universe.

We also see many circumstellar disks in Orion, and we presume that planets may be growing in some or all of them. Some disks have developed cometary features due to heating by ultraviolet light and stellar winds. Clearly, these disks are being disrupted and dissipated—and perhaps interrupted in the process of building planets. If Earth formed in an environment like Orion, its early days were not an easy ride.

The final products of the Orion portrait project will be catalogs of the brightness and location of stars, an atlas of diffuse objects, and multi-epoch images of the region in nine filters. With these data, astronomers can address fundamental questions about the Orion Nebula, such as whether all stars formed at the same time or in different episodes, whether the massive



Images through various filters (denoted by false colors) reveal aspects of three circumstellar structures in Orion. The stars are generally brighter in redder filters because of dust, which absorbs bluer light more strongly than redder light. A star at the center of each image appears to be surrounded by a circumstellar disk, evidenced by dark silhouettes in the non-red filters. The hydrogen/nitrogen filters show arcs of emission from those elements, excited by the intense ultraviolet light from the massive stars in the Nebula. In the bottom row, the hydrogen/nitrogen filter reveals a jet protruding from the central star, perpendicular to disk plane, which is seen edge-on.

The Orion Nebula through History

The four "Trapezium" stars, seen at the center of this image, are the four brightest and most massive stars in the Orion Nebula. Before the invention of the telescope, the Orion Nebula was never recognized as an extended object. Makers of star charts from Ptolemy in the second century, to Johann Bayer in 1603, recorded it as a single fifth-magnitude star.

As a celestial object, the Orion Nebula is huge—larger than the full Moon—with many faint stars and rich nebulosity. Interestingly, Galileo missed the nebulosity when he observed the Trapezium region using the first astronomical telescope in 1610. He left it to a French lawyer, Nicholas-Claude Fabri de Peiresc, to announce the discovery of the nebulosity the next year. Charles Messier added Orion to his famous catalog of nebulae in 1769, as M42 and M43, thinking the two major features were unrelated objects.

The first to articulate the scientific significance of the Orion Nebula was Sir William Herschel (1738–1822), who presciently called it "an unformed fiery mist, the chaotic material of future suns." Today, astronomers study the Orion Nebula to better understand the processes that formed the Sun and planets in the Solar System.

stars are latest to appear, and the reason they are clustered at the center. We can also learn the initial distribution of stellar masses—a fundamental astrophysical principle—including the fraction of brown dwarfs. In these ways, the Orion project will be a long-lasting contribution by *Hubble* to our understanding of how stars and planets form, providing insights to the origin of the Solar System, Earth, and the life it bears.

Massimo Robberto received his Ph.D. in Astronomy at the University of Turin in Italy. He worked for 10 years at the Turin Observatory, before moving to the Max Planck Institute für Astronomie in Heidelberg, and then to the Space Telescope Science Institute. His technical interest is infrared astronomical cameras. His main scientific interest is star formation, particularly in the Orion Nebula. Massimo leads the *Hubble* Treasury program on the Orion Nebula. His free time is devoted to his wife Giuliana, four-year-old daughter Gloria, and their friends. His hobbies include playing the baroque flute and piano, climbing, playing chess on the Internet, studying harmony and counterpoint, and of course, stargazing.