How does debris from supernovae make molecules? Scientists may have an answer

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Photo: Seshadri KS

‘We are all made of stardust’ goes the common saying. The phrase is more than just rhetoric; it alludes to the formation of atoms and molecules in the universe. Most atoms and a few molecules around us were mostly formed in the bowels of exploding stars, which then went on to form planets, oceans, living organisms and everything in between. Now, a collaborative study by Raman Research Institute (RRI), Bangalore, Indian Institute of Science (IISc), Bangalore and P. N. Lebedev Physical Institute, Moscow, is studying the processes that may have led to the formation of these molecules from the debris of the exploding stars.

Galaxies contain swirling mass of gases that eventually coalesce under gravity to form stars. “In the most common types of galaxies, like our Milky-Way, the star formation rate is between 0.5 and 1 solar masses per year, resulting in one or two supernova explosions in a century”, explains Dr. Arpita Roy, a former research student at RRI and IISc. Occasionally however, events like close-encounters or collisions with other galaxies can shake things up within a galaxy, causing the rate of star formation to shoot up by 10 or even 100 times. Such galaxies, referred to as starburst galaxies, act as an important window into the birth and evolution of stars and galaxies. “Central regions of starburst galaxies have very high densities and are called starburst nuclei. They are the hubs for very high star formation and hence are, in general, quite violent. They are also the sources of energy, momentum, mass and heavy chemical elements”, adds Dr. Roy.

The current study focused on the processes that lead to the formation of molecules in expanding shock waves caused by supernovae, called superbubbles. “Multiple coherent supernovae in the starburst nuclei create strong shocks or superbubbles. When these strong shocks move through the interstellar medium (ISM), they sweep up ISM materials and store them in dense, thin shells behind the shocks, which further cool and form molecules. These molecular clouds could then again be sites for the formation of second generation of stars”, says Dr. Roy. “It has always been surprising to see how molecules can survive in these extreme violent environments in the central regions of the starburst galaxies. Now, there can be two situations: either these molecules are the old ones, which were originally there in the parent molecular clouds, where the massive stars were initially born, or, these are the new molecules formed in-situ in the dense superbubble shells. Our model tries to understand these issues in detail and describes that molecules in observed outflows in the central regions of the starburst galaxies can be explained by in-situ molecule formation processes" she adds.

The researchers proposed a simplified model in which superbubbles are considered to be roughly spherical in shape. Further, other factors such as the dynamics (velocity), the density and temperature of such a spherical superbubble are calculated. With these values entered in to the model, the researchers ran simulations to predict the processes, which lead to molecule formation. “We performed numerical hydrodynamic simulations with proper numerical descriptions of thermodynamics with all relevant heating (cosmic-ray heating, photo-electric heating, ionising radiation, dust emission etc.) and cooling mechanisms, which then determines the conditions for efficient molecule formation”, explains Prof. Yuri Shchekinov, a Professor at P. N. Lebedev Physical Institute. This model of molecule formation is a collective effort by Prof. Biman Nath at RRI, Prof. Prateek Sharma at IISc along with Dr. Roy and Prof. Yuri Shchekinov

Although a simple model, the simulations matched the observations of molecular outflows in superbubbles with simple spherical morphology. This further confirmed the accuracy of the proposed model and hence the processes which govern molecule formation within a starburst nuclei. The proposed model opens up the prospect of studying other aspects of galaxies and the Universe as a whole. “The detailed information of mass, energy and transport of heavy elements to the interstellar medium (ISM) help us study the overall evolution of the ISM of the host galaxies. These heavy elements may sometimes also enrich the intergalactic medium (IGM) via superbubble evolutions. Therefore, for many astrophysical purposes, such as how stars form and evolve to affect the evolution of the ISM and also the Universe in general, starburst nuclei are the most important experimental sites”, concludes Dr. Roy.