Supernova Bullets impinging upon Molecular Clouds

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Observations have shown that supernova ejecta is anisotropic and clumpy. Recent simulations [1] have demonstrated that Rayleigh-Taylor instabilities are responsible for the formation of clumps and predict that they reach a size of about 10^{11} cm and a density of 10^{-4} g/cm^3 six hours after the explosion. Such clumps, also known as bullets, will expand over time. Knots of N, O, and S [2] have been catalogued in the supernova remnant Cas A, and their spatial velocity and size measured.

Our purpose is to study the contamination of molecular clouds by supernova bullets. We intend to investigate the depth at which bullet material is deposited inside the cloud, the mixing with molecular cloud components due to Kevin-Helmholtz instabilities and compare our results with previous studies.

We have carried out a three dimensional simulation with sample bullets denser than the molecular cloud by one to four orders of magnitude, a size ranging from 100 AU to 2000 AU, and a velocity of a few thousands of km/s. We are using the FLASH code to solve the hydrodynamic equations and accurately capture strong shocks. FLASH is a parallel, adaptive-mesh simulation code for studying multidimensional compressible reactive flows. It uses a customized version of the PARAMESH library to manage a block-structured adaptive grid, adding resolution elements in areas of complex flow such as strong shocks. The primary hydrodynamical module of FLASH uses the Piecewise-Parabolic Method on the Euler equations for compressible gas dynamics.

We are making two hypothesis. The first one is inspired by direct observations [2] and assumes that the bullet is made of a single element. We have selected carbon, a key bioessential elements, for our preliminary study. FLASH can track the evolution over time of different species. The second one is related to the environment. Before exploding as a supernova a high mass star carves a wide HII region. We assume that the ejecta bullet is coming from the HII region and entering the molecular cloud and that both regions are in pressure equilibrium.

The computational domain covers a volume of 233 AU x 233 AU x 9500 AU. The velocities chosen are 500 km/s, 2000 km/s, 6000 km/s and 8000 km/s. The temperature of the HII region is set to 10^4 K and the temperature of the molecular cloud to 10 K. The densities are such that the density ratio between the molecular cloud and the HII region is 100, and the density ratio R between the bullet and the molecular cloud is 10 (Figure 1).

When the bullet enters the molecular cloud, it drives a bow shock into the gas. A reverse shock is driven back into the bullet, which is in turn highly compressed. The material inside the bullet then expands laterally, is entrained by Kelvin-Helmholtz instabilities and taken in the turbulence behind the bullet. This is what Figure 1 shows.

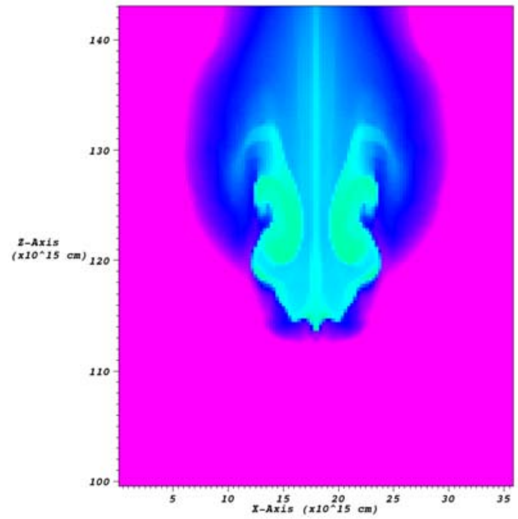

Figure 1: Mass distribution of ^{12}Carbon, 12 years after entering the molecular cloud at a velocity of 8000 km/s.

The two main parameters are the velocity of the bullets and the density ratio R defined above. A high velocity implies a faster evolution and a stronger shock. The density ratio R has an impact on the maximum depth reached by the bullet: the denser the bullet, the farther it penetrates into the molecular cloud, the more material it leaves behind.

References

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