Dust Survival after Shock Processing in Bipolar Circumstellar Environments

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Dust formed in stellar ejecta is a major contributor to the cosmic dust budget, yet its long-term survival remains uncertain. Massive stars can produce important amounts of dust during eruptive mass-loss events, such as those that formed the bipolar nebula around η Carinae, which contains an estimated 0.25–0.4 $M_\odot$ of dust. However, the intense radiation and mechanical feedback from the star itself, especially a potential subsequent supernova (SN), could efficiently destroy this dust. Understanding the balance between dust formation and destruction is critical for determining the net contribution of massive stars to cosmic dust.

We present 3D hydrodynamical simulations, performed with the FLASH code and the CINDER dust module, to study dust survival in the ejecta of bipolar stellar remnants. Our models follow the interaction of stellar winds, eruptive outflows, and supernova feedback for both spherical and bipolar geometries. The simulations include on-the-fly dust physics, including grain growth, sputtering, and gas–dust cooling.

Our results show that dense, asymmetric circumstellar environments created by pre-supernova eruptions promote efficient radiative cooling, which weakens the impact of the SN shock and allows a significant fraction of dust to survive. For short time delays between eruption and explosion, up to 75% of the dust mass can persist. Conversely, longer delays allow the circumstellar medium to expand. This decreases the circumstellar gas density, and thus reduces dust survival to $\lesssim$ 10%. These findings show the importance of large eruptive mass loss events in shielding dust from SN feedback and suggest that massive stars, under the right conditions, can be significant net contributors to the cosmic dust budget.