

We investigate the evolution of red supergiant (RSG) progenitors of core-collapse supernovae (SNe) with initial masses between 12 and 20 $M_{\odot}$, focusing on enhanced mass loss driven by pulsation-driven instabilities and shock-induced ejections during advanced nuclear burning stages. Using time-dependent mass loss from detailed MESA stellar evolution models, we construct the circumstellar medium (CSM) before explosion and couple these mass-loss histories with non-equilibrium chemistry to model molecule and dust formation across rates ranging from 10^{-6} to $10^{-2} M_{\odot} \text{ yr}^{-1}$ for both constant and accelerating wind profiles.

Our models produce episodes of enhanced mass loss ($\sim 10^{-4}$ – $10^{-2} M_{\odot} \text{ yr}^{-1}$) in the last centuries to decades before explosion, forming dense CSM ($\gtrsim 10^{-15} \text{ g cm}^{-3}$ at distances $\lesssim 10^{15} \text{ cm}$) consistent with multiwavelength observations of Type II SNe including SN 2023ixf, SN 2020ywx, SN 2005ip, and SN 1998S. These dense circumstellar shells naturally explain observed flash-ionization signatures and X-ray and radio emission. Molecules such as CO, H₂O, SiO, HCN, CS, SO, NH₃, H₂, and O₂ form efficiently within the CSM, with masses spanning 10^{-15} – $10^{-2} M_{\odot}$. O-rich dust—predominantly silicates and alumina—dominates the composition, with total dust masses ranging from 10^{-8} to $3 \times 10^{-3} M_{\odot}$. Accelerating winds promote dust formation closer to the stellar surface and yield greater total dust masses. The resulting spectral energy distributions exhibit strong mid-infrared excesses, with the 9.7 and 18 μm silicate features appearing in emission or absorption depending on CSM optical depth.

Applied to SN 2023ixf, the time-dependent mass-loss history produces a gradual increase in CSM dust mass towards explosion, while a clumpy CSM structure yields substantially better agreement with observed optical and infrared fluxes. Together, these results highlight the critical role of time-dependent mass loss, wind acceleration, and CSM geometry in shaping the observable properties of RSG progenitors and their role as dust contributors to the interstellar medium.