Contribution ID: **20**　　Type: **Talk**

Molecules in stripped-envelope supernovae

Friday 22 October 2021 09:35 (10 minutes)

Core collapse supernovae (CC-SNe) are the violent and bright explosions that end the lives of massive stars ($M>8M_\odot$), leaving behind exotic remnants such as black holes and neutron stars. A currently unsolved question in supernova research is the origin of Type Ib and Ic SNe, which lack hydrogen, or hydrogen and helium, spectral signatures respectively, indicating that the outer stellar envelope has been stripped during its evolution. The mechanism for this is not well understood, and two main scenarios have been proposed: that the progenitors of Type Ibc SNe are very massive ($M>25M_\odot$), and lost their outer layers to a strong stellar wind; or that the progenitors are of somewhat lower mass ($M<20M_\odot$) and had their envelopes stripped through interaction with a companion. To disentangle the two scenarios, measurements of nucleosynthesis yields via Type Ibc SNe observations can be used to infer their progenitor masses. However, the interpretation of observations depends on the adopted spectral models. A previously missing ingredient has been the inclusion of molecular effects, which can be significant.

We here present state-of-the-art spectral synthesis models of nebular-phase SNe, for the first time including the coupling between the molecular formation, molecular cooling effects, and radiative transfer. This self-consistent approach is key, as molecules will cool the gas, while in turn, their formation depends on the temperature. We show that in type Ic models ro-vibrational line emission from the most abundant molecules (CO, SiO, SiS) dominate the infra-red (IR) region. Molecules also impart indirect effects on the spectra: material is locked up in molecules, and even a small molecular abundance can effectively cool the surroundings by several thousand degrees; both effects resulting in weaker emission of monatomic species. To accurately determine nucleosynthesis yields from observations it is, therefore, crucial to include molecules in spectral synthesis calculations. Once complemented with observations from the next generation of telescopes, e.g. JWST, these models will help us understand the fates of the most massive stars.

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Session Classification: Kilonovae, Supernovae and SNRs