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Unveiling the Complexity through High Performance Computing: the Link between Massive Stars, Core-Collapse Supernovae, and their Remnants

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Core-collapse supernova remnants (SNRs) exhibit intricate morphologies and a highly non-uniform distribution of stellar debris. In the case of young remnants (less than 5000 years old), their characteristics offer insights into the inner processes of the supernova (SN) engine, including nucleosynthetic yields and large-scale asymmetries originating from the early stages of the explosion. Additional features stem from the progenitor star's internal structure at collapse and the interactions between the remnant and the circumstellar medium (CSM), which is shaped by the mass-loss history of the progenitor.
Hence, investigating the connection between young SNRs, parent SNe, and progenitor massive stars is of paramount importance. Firstly, it allows us to delve into the physics of SN engines by shedding light on the asymmetries that occurred during the explosion. Secondly, it provides an avenue to examine the final stages of massive star evolution and the elusive mechanisms that govern their mass loss.
Presently, our ability to study the progenitor-SN-SNR connection has greatly improved due to advanced 3D MHD models and the availability of adequate high performance computing resources. Now we have the ability to elucidate the long-term evolution from the progenitor star to the SN and subsequently to the SNR. Coupled with high-quality observational data spanning the electromagnetic spectrum, we can effectively constrain these models.
In this talk, I will offer a brief overview of recent advancements in modeling the progenitor-SN-SNR connection. The primary focus will be on investigations aimed at establishing connections between the observed physical and chemical properties of SNRs and their progenitor stars and SN explosions. By doing so, we gain valuable insights into the life and death of massive stars.

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