3D Simulation of SN Ia SNR within the Single-Degenerate Progenitor Scenario

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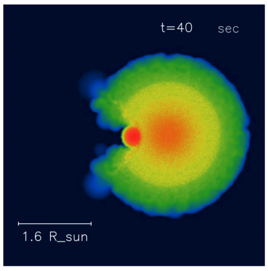
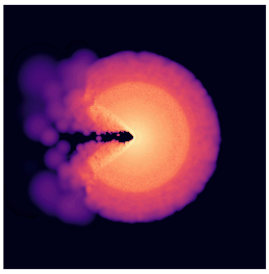
Background

Type Ia supernovae (SNe Ia) serve as one of cosmic standard candles, but their exact progenitor channel is still an open question. There are two popular channels that have been proposed: single degenerate model (SD channel) and double degenerate model (DD channel). In SD channel, the white dwarf accretes material from a non-degenerate companion (e. g., main sequence star or helium star) and explodes when its mass reaches Chandrasekar mass limit. Its supernovae ejecta then **collides and interacts with the companion star**. This leaves an imprint on the ejecta which later may affect the morphology of the SNR. Also, the accretion preceded the SN Ia explosion leaves some **circumstellar material** (CSM) which may also affect the early SNR evolution.
We propose using 3D hydrodynamic simulations to trace the early expansion of SN Ia SNR under the influence of its companion star and progenitor system.

Method

We first used 3D SPH code (GADGET) to simulate the interaction between the SN ejecta and the companion star. We mapped a classic W7 ejecta profile in to 3D and let it impact a close-by companion star:



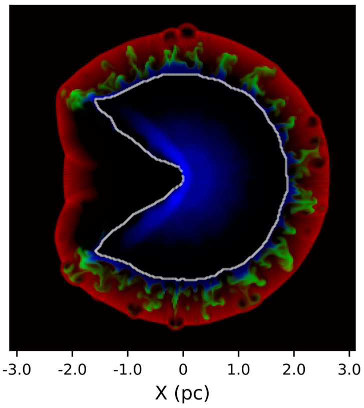


SPH -> Grid (ejecta only)

The companion star survives and later will become a high-velocity runaway star. Here we focused on the SNR so we picked out the ejecta material and mapped it to 3D grid-based code (RAMSES), with a **resolution of 256x256x256**.

In RAMSES, we also filled the rest of simulation space with ISM (or CSM formed from accretion process of the progenitor system). We employed a **comoving reference frame** similar to that of Ferrand et.al. in order to follow the expansion of SNR from less than 0.1pc to a few pc in radius (corresponds to t=1yr after explosion to t=750yr in time).

We traced the evolution of shocks (foward and reverse shock) and contact instability. By back-tracing the original position of SPH particle in the W7 profile, we can also map the **element distribution** in the post-impact ejecta and follow its change into the SNR phase.



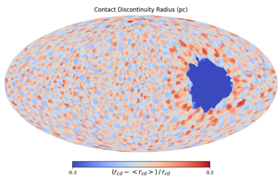
2D-slice of SNR density

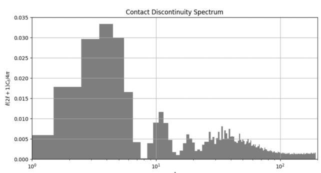
Ejecta: W7 post impact
ISM: $\rho_{ism} = 1.0\, m_H/cm^3$
Age: 200 yrs

Red: Hydrogen and helium
Green: Carbon to silicon
Blue: Everything heavier than Si (incl. iron, nickle, etc...)

White line: locations of reverse shock (material exterior of it is heated and glow in X-ray)

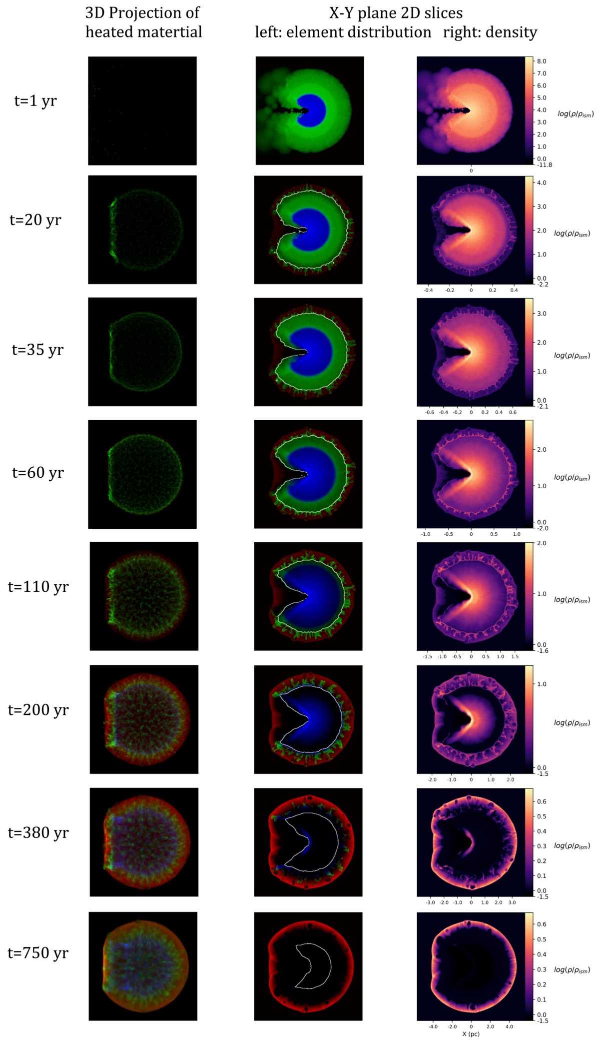
The 3D projection of shock-heated material can be used as a rough proxy for X-ray emission. We plan to implement precise calculation for X-ray emissivity in the near future. Meanwhile, **power spectrum** analyses can be performed and highlight the differences between instability driven small-scale features and interaction driven large-scale features.





Results and time-series

The following is a set of frames of our SNR simulation:



Red: Hydrogen and helium **Green:** Carbon to silicon **Blue:** Everything heavier than Si
White line: locations of reverse shock (material exterior of it glows in X-ray)

Conclusions

I. In the single-degenerate channel, the companion star of the exploding white dwarf alters the morphology of the supernova ejecta.

II. We simulated the hydrodynamic interaction between the companion star and the supernova ejecta, then followed the expansion of the ejecta into a supernova remnant.

III. Our model shows that single-degenerate scenario leaves prominent features on the SNR, which may be detectable at favorable viewing angle. Element distribution in the young SNR may also reflect the interaction between the ejecta and the companion star.

Future works

I. X-ray & radio emissivity calculations

II. Compare 3D-hydro result with real observations

III. Add different CSM (e.g., Optically-thick wind vs. Common-envelope wind)

IV. And more......

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