RAD-HYDRO SHOCK BREAKOUT : SN1987A & RSG

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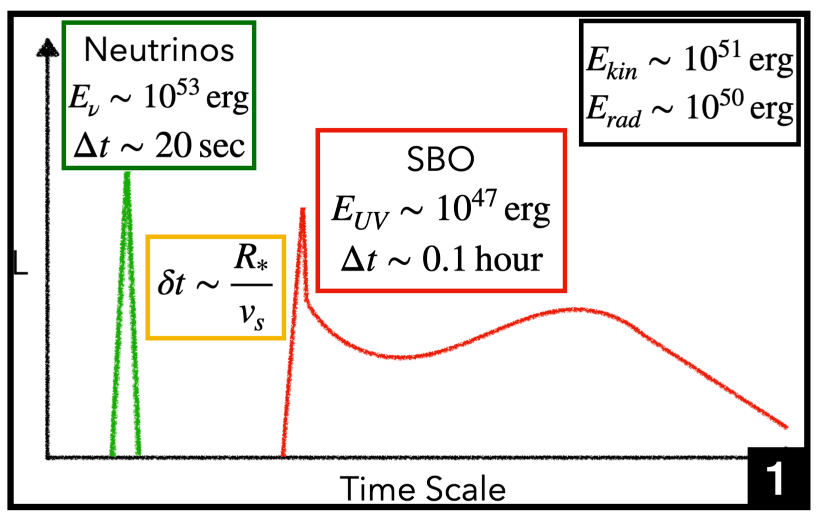
ABSTRACT

We present multi-D rad-hydro simulations of Supernova 1987a shock breakout and RSGs with the CASTRO code. Shock breakout signal can provide progenitors information and pre-explosion environment with its extreme luminosity and short duration. 2D simulation of SN1987a and RSGS resolve previous 1D thin shell problem. With Multi-Group Flux-Limited Diffusion we analyze luminosity variation curves from far infrared ray to X-ray for viewing angles. We discuss the impacts from stellar convection, confined-shell circumstellar medium with different geometry, and binary system. We also present the preliminary results of 3D SN1987a shock breakout. This work aim to bridge the gap between multidimensional supernova explosion simulations and provide spectral energy distribution of shock breakout.

INTRODUCTION

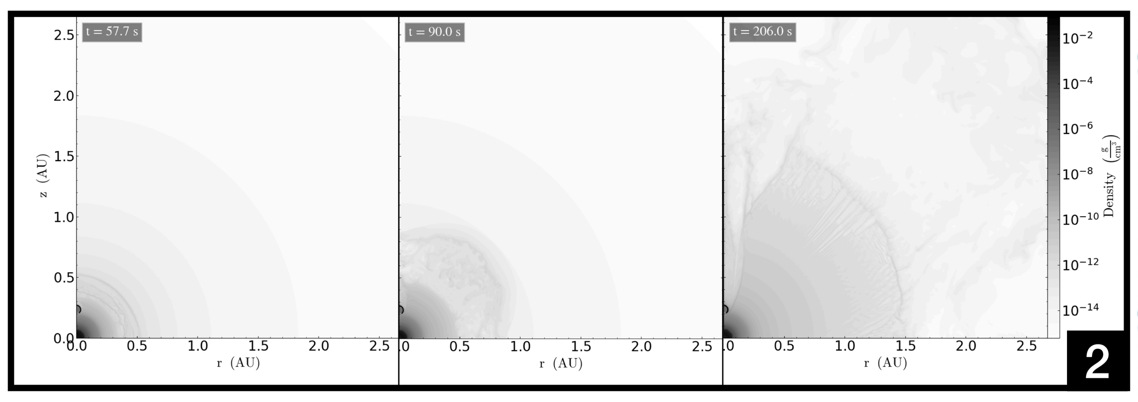
The first EM signals breakouts from SNe when the shock approach stellar surfaces [1]. The observed luminosity variation curves (LCs) and shock duration[2,3] offer insights of explosion energy, progenitor radius, and circumstellar medium (CSM).



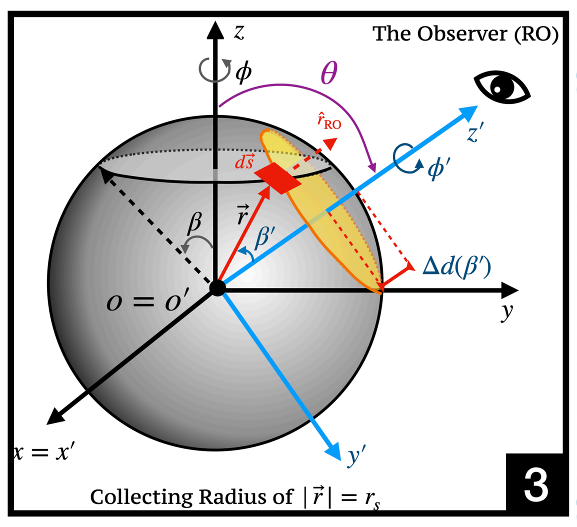
We publish our **first results** of multi-D multi-group rad-hydros simulations last year (Chen W.-Y., Chen K.-J., Ono M., 2024)[4,5,6,7], the RSGs and 3D SN1987a is in preparation. We employ Multi-Group Flux Limited Diffusion (MGFLD) in **CASTRO**[8] with **OPAL** opacity tables[9]. We also explore capabilities of multi-D simulation with **perturbation, confined-shell CSM,** and a **companion star**[10].

METHODOLOGY

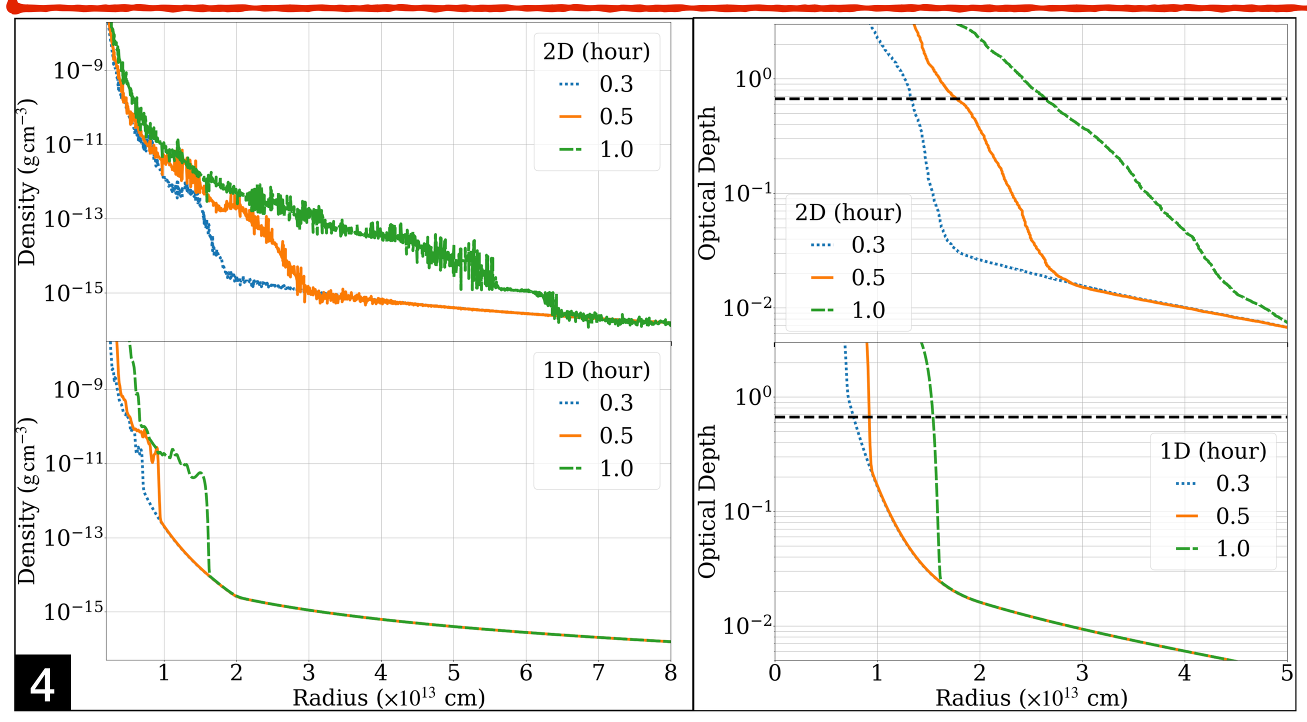
1. **CASTRO:** 1D shock propagates to H/He shell and maps to ×100 **CASTRO** box.



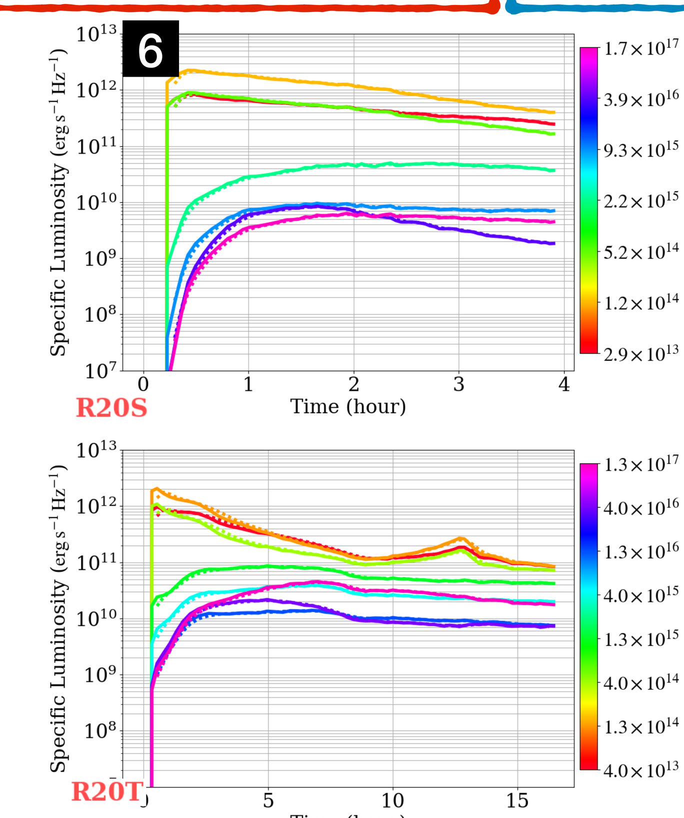
2. **Rad-Hydro:** From infrared ray to X-ray. Combine **OPAL** with electron scattering[11] and Kramer's law ($\kappa \propto T^{0.5}\nu^{-3}$). Calculate LCs for distant observer.



3. **CSM:** Mass loss wind from typical BSGs and RSGs*. Analyze the interaction between **radiation precursors** and CSM.

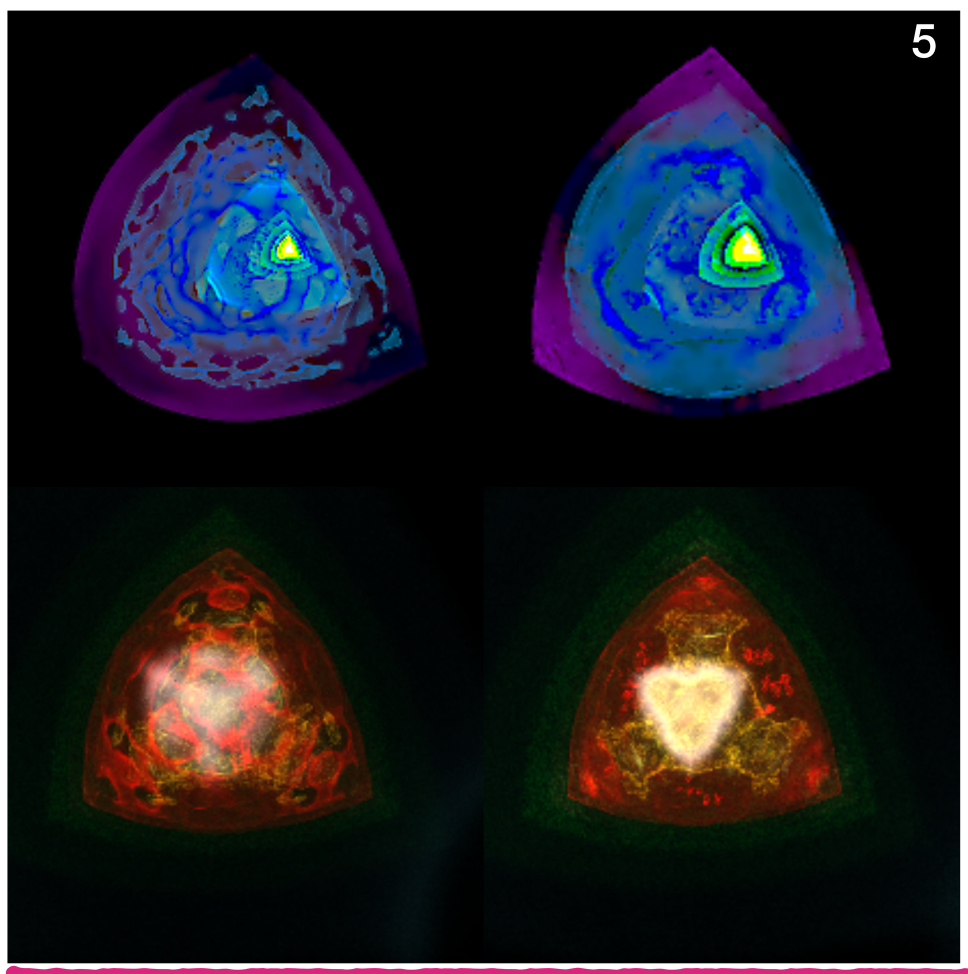


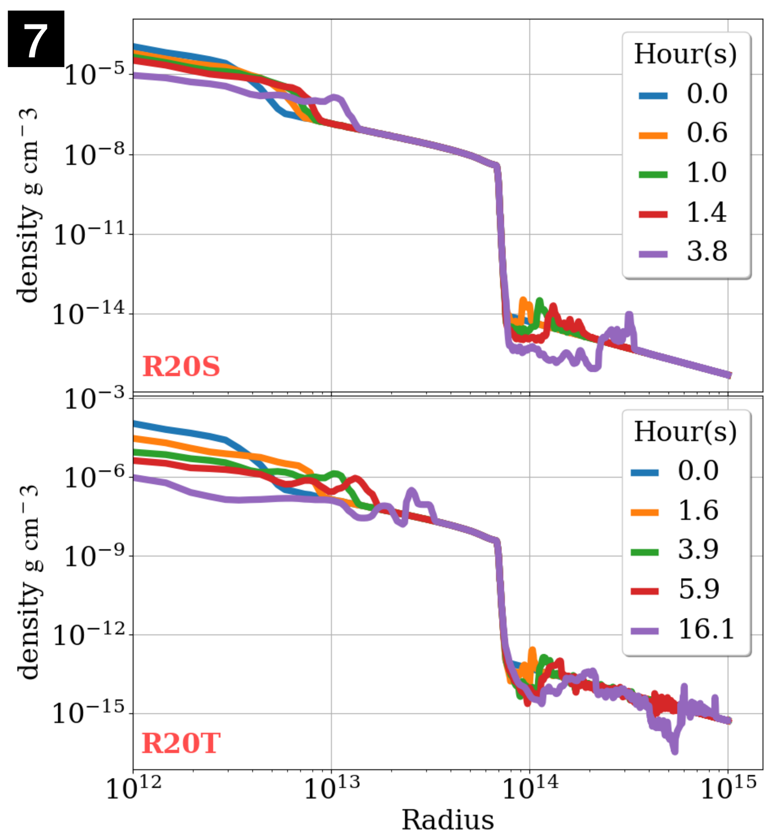
1D vs 2D radial density. The **radiation precursors** drive pre-shock structures in 2D and change the optical depth.



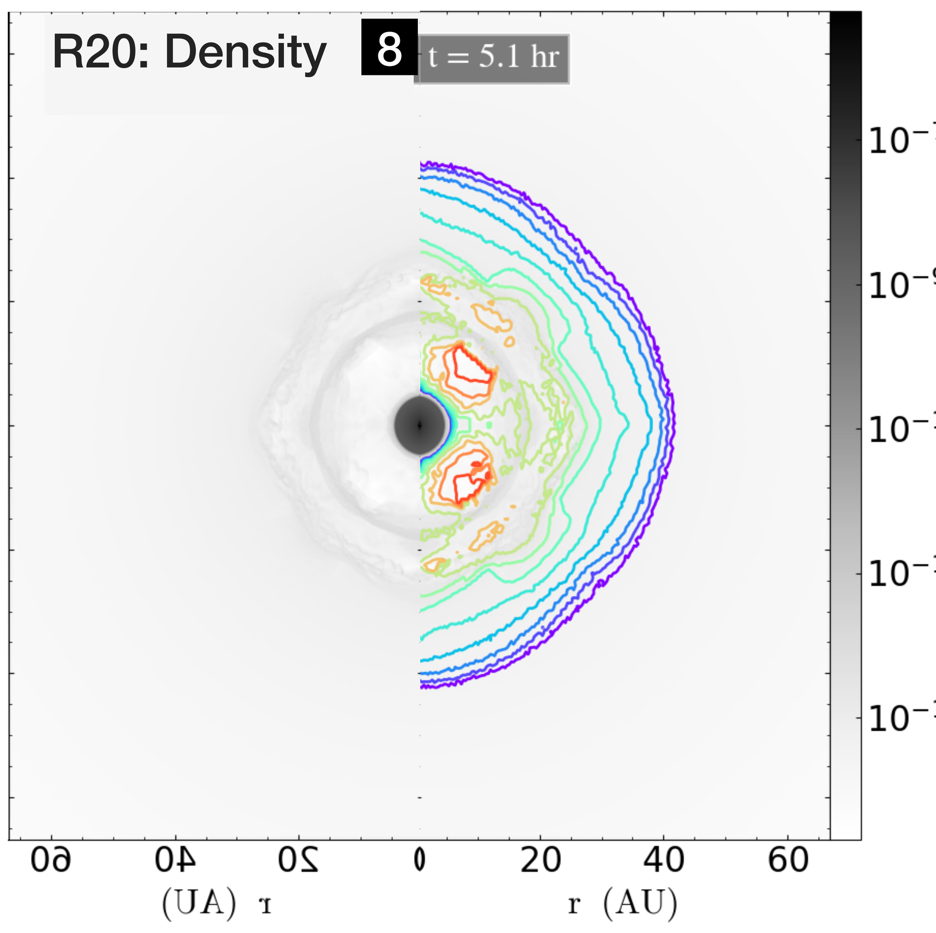
RESULTS

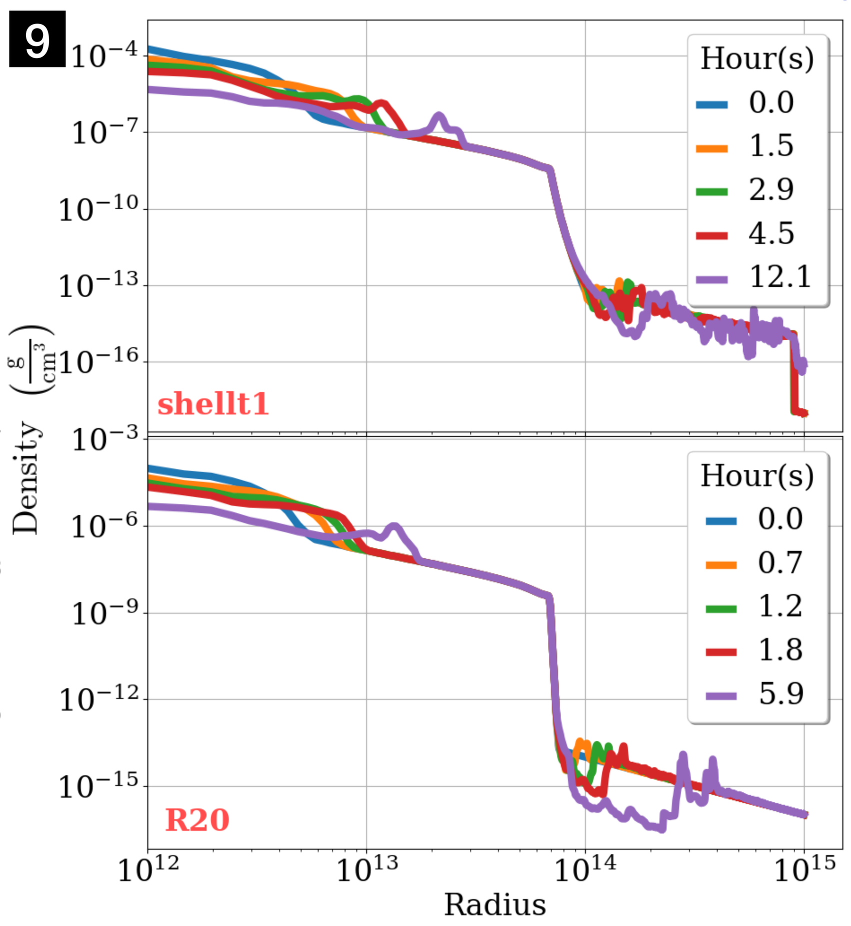
1. **SN 1987a** 1D/2D LCs and Shock duration difference due to radiation precursors that drive the non-linear structures in CSM (Fig. 2-4). 3D simulation have bubble-like structures and have smoother LCs and forward shocks (Fig. 5).
2. **RSGs** shock breakout are longer in time and more dilute in specific luminosity due to extend stellar surfaces and thicker CSM (Fig. 6-8). While radiation precursors energy budget is the same, different CSM, including Confined shell CSM (Yaron 2017), drive different structures (Fig. 9).





RSGs Radial density. Dense CSM delay shock breakout.





CONCLUSION

1. **Multi-D simulations:** Resolve thin shell problems, LCs agree with 2D/3D rad-hydro simulations that consider asymmetric explosion. Previous 1D simulation overestimate the CSM[12] for delayed shock breakout. Our current model begins with 1D progenitors, however, future development of multi-D progenitors is promising with AMReX structures in **CASTRO**.
2. **MGFLD:** Provide spectral energy distribution and cooling process in LCs[13]. Shock breakout is sensitive to CSM and radiation precursors, which can provide information of late-time stellar evolution. This requires different emitting regions with rad-hydro structures formation during shock heating.
3. **Confined-Shell CSM:** The shock breakout signals colliding with shell-like CSM may create layers of structures which also contribute to LCs.

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