2D RAD-HYDRO SIMULATIONS OF SN1987A SHOCK BREAKOUT

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ABSTRACT

We present new multidimensional radiation simulations of Supernova 1987a shock breakout with the CASTRO code. Shock breakout signal can provide progenitors information and pre-explosion environment with its extreme luminosity and short duration. 2D simulation resolve previous 1D thin shell problem and have 5 times longer shock duration of full width 10% maximum to 1.2 hours and 5 times higher peak luminosity to $6 \times 10^{46}\,\mathrm{erg\,s^{-1}}$using detailed opacity from OPAL with Multi-Group Flux-Limited Diffusion. We select radiation from far infrared ray to X-ray and successfully generate lightcurves (LCs) for viewing angles and radiation bands of stellar convection with density perturbation, circumstellar medium with ring-like structures, and binary system with a companion main sequence star. This work bridges the gap between multidimensional supernova explosion simulations and provide spectral energy distribution of shock breakout.

INTRODUCTION

The electromagnetic signals from supernovae (SNe) of massive stars begin when the explosion shock breaks out of the stellar surface*. The so-called shock breakout offer crucial insights into explosion energy, progenitor star radius, and circumstellar environment (CSM) with the observed luminosity light curves (LCs) and shock duration**. Previous models in 1D simulations fell short and create thin shell near the shock front, necessitating the shift to 2D simulations*. Recent 2D rad-hydros simulations* can not evaluate heating and cooling of X-ray and UV emissions with grey opacity. Our research presents the **first results** of multidimensional multi-group rad-hydros simulations. We focus on SN1987a and use abundant previous studies to compare our multi-dimensional supernova shock breakout phenomena**. We employ 2D Multi-Group Flux Limited Diffusion (MGFLD) in **CASTRO*** and incorporating **OPAL** opacity tables*. To evaluate complex environment of shock breakout, we explore **perturbation, ring-like structures,** and a **companion star***. The investigation also includes considerations of CSM profiles calculated from constant mass loss rates across two orders of magnitude.

METHODOLOGY

1. **CASTRO:** After explosion shock reaching stellar surface in **KEPLER***, the 1987a progenitor is transferred to **CASTRO**, a compressible rad-hydros code. Employing 2D cylindrical box with $10^{14}\,\mathrm{cm}$ and 1024 grids each side, reflective and outflow are applied to the lower and upper boundaries, respectively. We use γ law equation of state with poisson gravity.
2. **Rad-Hydro:** MGFLD govern interaction between radiation flux and opacity. We choose 8 radiation groups covering 10^5 to $1\,\mathrm{\AA}$ (infrared ray to X-ray) and calculate opacity from **OPAL** by separating partial degenerate electron scattering*, free-free, and bound-free opacity ($\kappa \propto T^{0.5}\nu^{-3}$). We calculate LCs with different wavelength λ and viewing angles θ by $L_{\lambda,\theta} = 4\pi r^2 F_{\lambda,\theta}$.
3. **Stellar Surface and CSM:** We derived CSM from constant mass loss rate $\alpha\dot{M} \sim 8 \times 10^{-6}\,M_\odot\,\mathrm{yr}^{-1}$* with α covering 2 orders of magnitude. And study density perturbation, ring-like CSM, and a nearby companion star with structures formation and LCs.

RESULTS

1. **Verification:** Resolution is fixed to 1024^2 for optimization of structure evolution and computation resources. (Fig. 1) **Radiation dominate** the fluid during shock breakout and need rad-hydros. (Fig. 3)
2. **LCs:** Calculate LCs across angles to study turbulent that fluctuate the shock front and observe **dimming effect** of ring-like structures. (Fig.2 and Fig. 4)

   Calculate LCs across wavelengths offer spectral energy distribution and show **double peaks** for companion stars. (Fig. 5)
3. **Compare:** Resulting LCs of X-Ray radiation flux in 1D, plain (PL), perturbation (PB), ring-like CSM (R), and companion star (B). (Fig.6) Examine constant mass loss rate CSM that impact on breakout duration and peak luminosity. (Fig.7)

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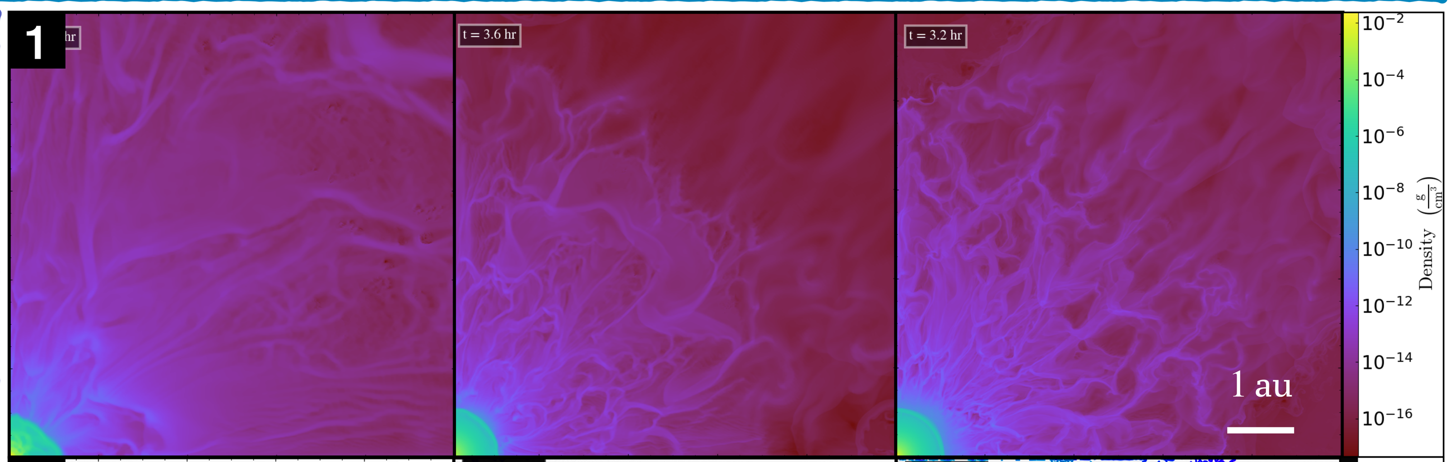

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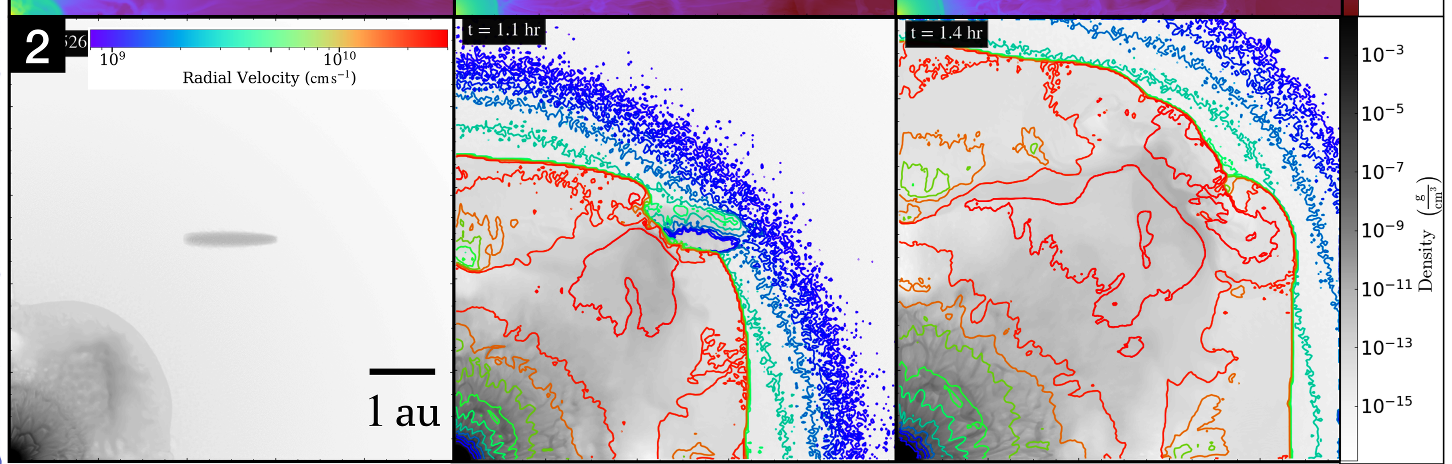

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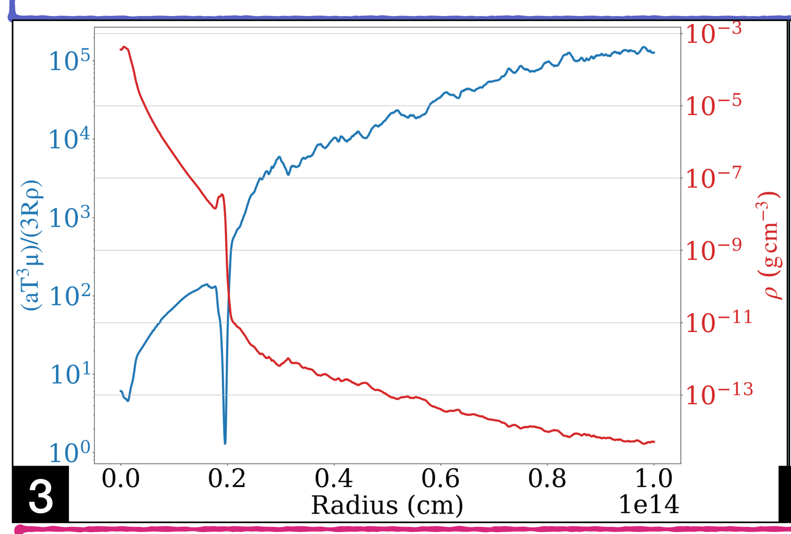

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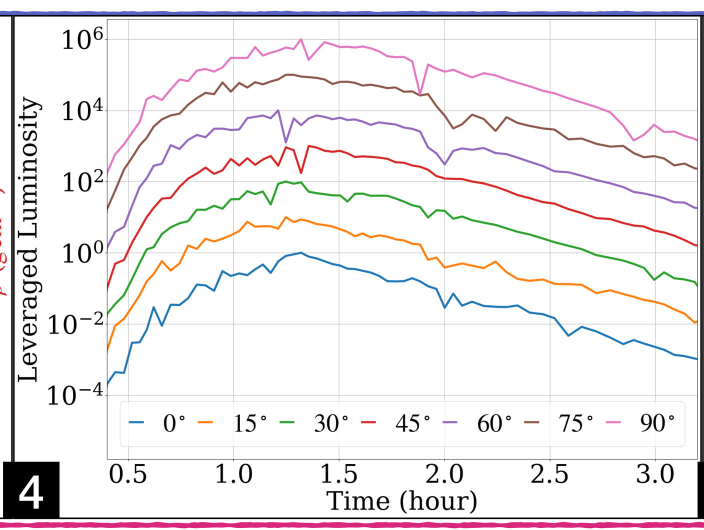

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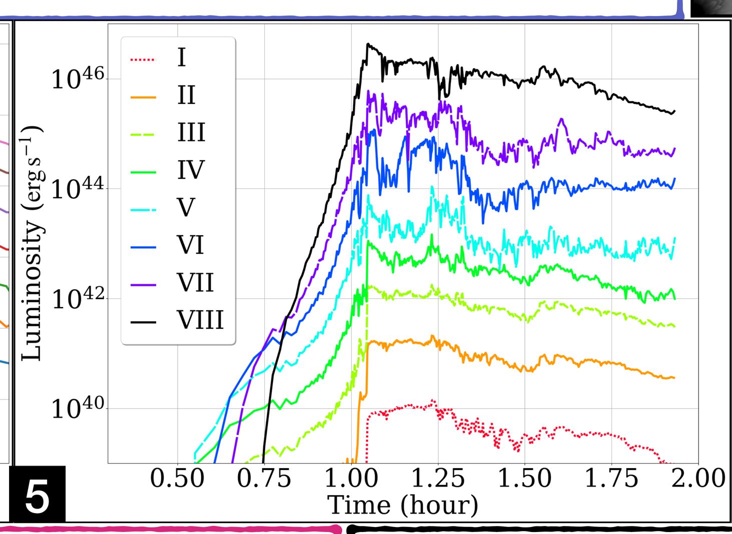

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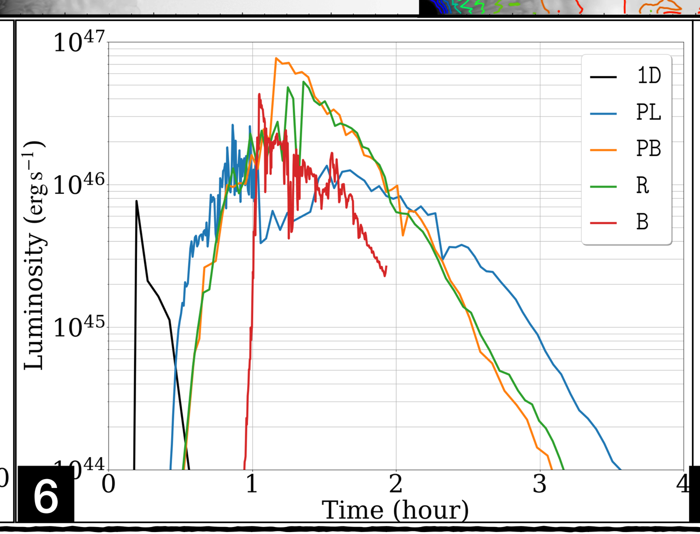

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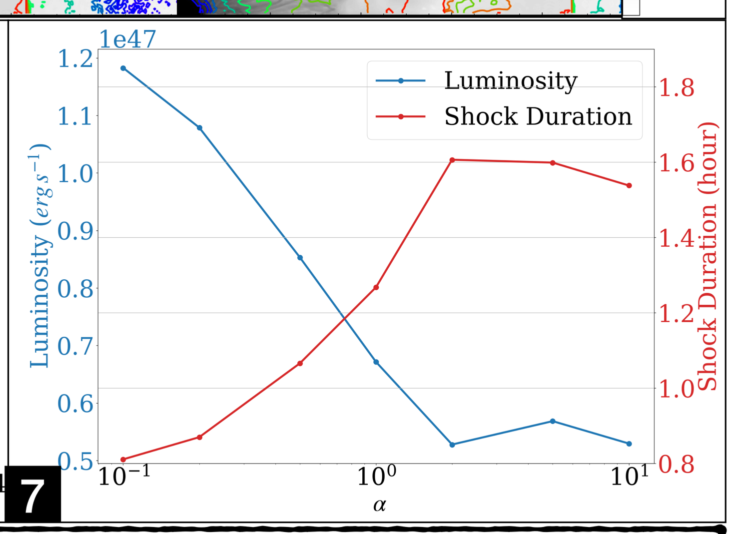

CONCLUSION

1. **2D simulations:** Resolve thin shell problems and have 5 times longer shock duration, which agrees with previous 2D rad-hydro simulations that consider asymmetric explosion. The αcomparison give $\tau \sim 0.443\,log(\alpha)\,\mathrm{hours}$, where 5 times longer shock duration corresponds to 100 times denser CSM*.
2. **Colored Opacity:** Provide spectral energy distribution and cooling process in LCs, we discovered that shock breakout is sensitive to pre-explosion environment and can provide information of motion in stellar envelopes, late-time stellar evolution , and binary systems.
3. **Late-time Evolution:** The cooling and post-breakout luminosity decline rate of $1.5\,\mathrm{mag\,hour^{-1}}$ for UV wavelengths connects well to the detection of SN1987a* shock breakout tail. Our simulations provide connection from shock breakout to supernova remnant formation.

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