





Shock Breakout

Confined-Shell CSM

EAMA11, Niigata

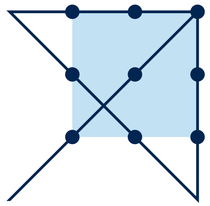
Author: wychen

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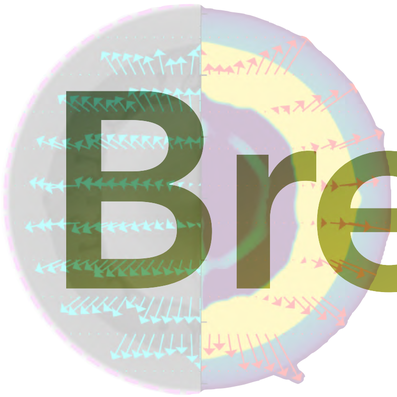
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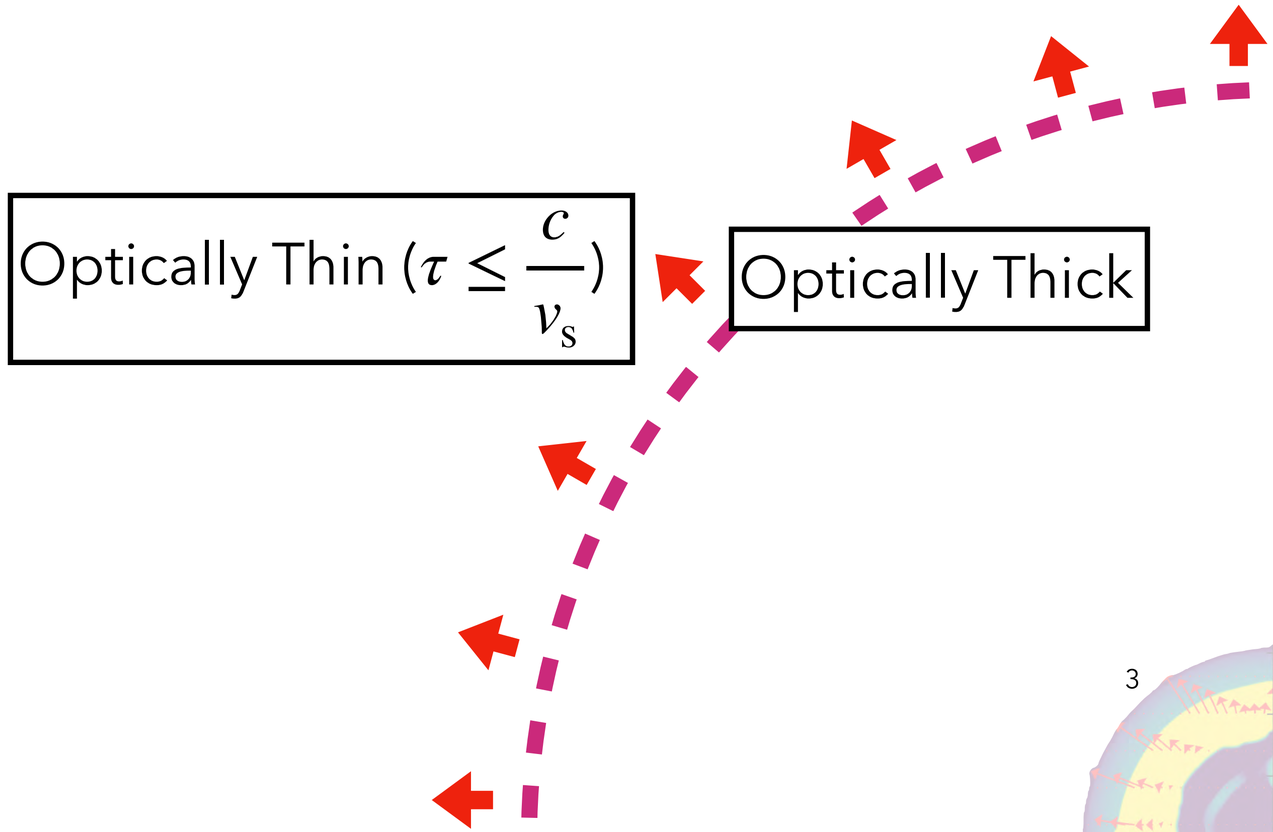
Shock Breakout



The First Light of Supernovae Explosion

Event	Energy	Timescale
Neutrino	100 foe	Seconds
Shock Breakout	1% foe	Seconds/ Hours
SNe	1 foe	Months

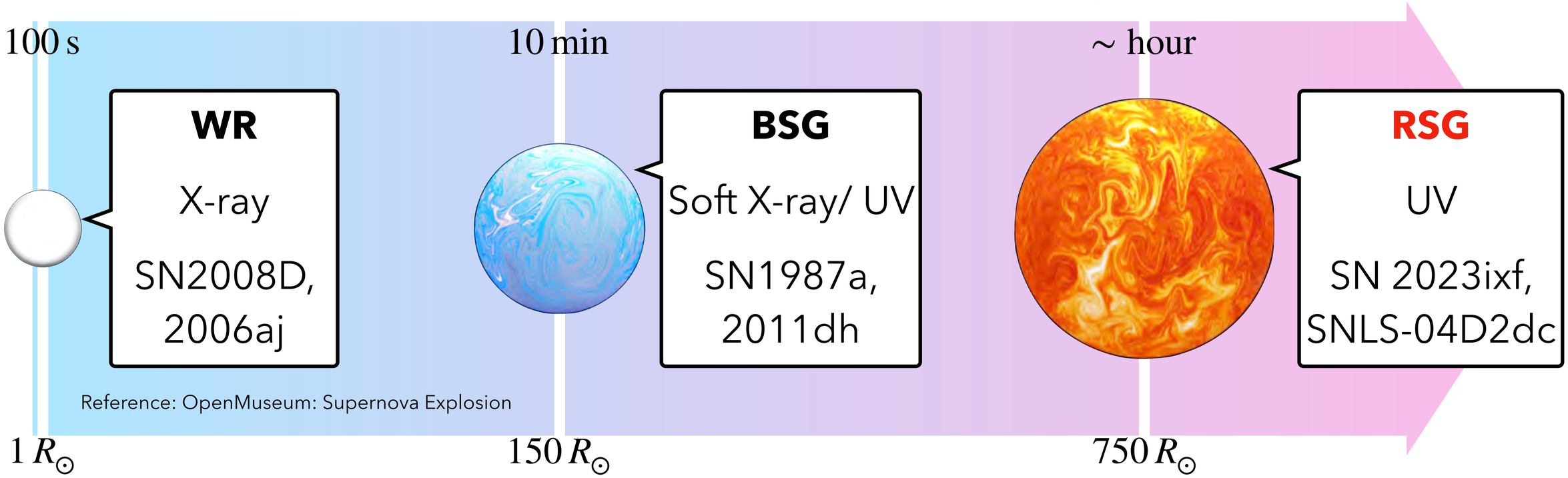
- CCSN Shocks Propagate to **Photosphere**.
- Carry Information through RHD & Shock.



D. Nadyozhin and V. S.imshennik. Physics of supernovae. International Journal of Modern Physics A, 20, 01 2012.

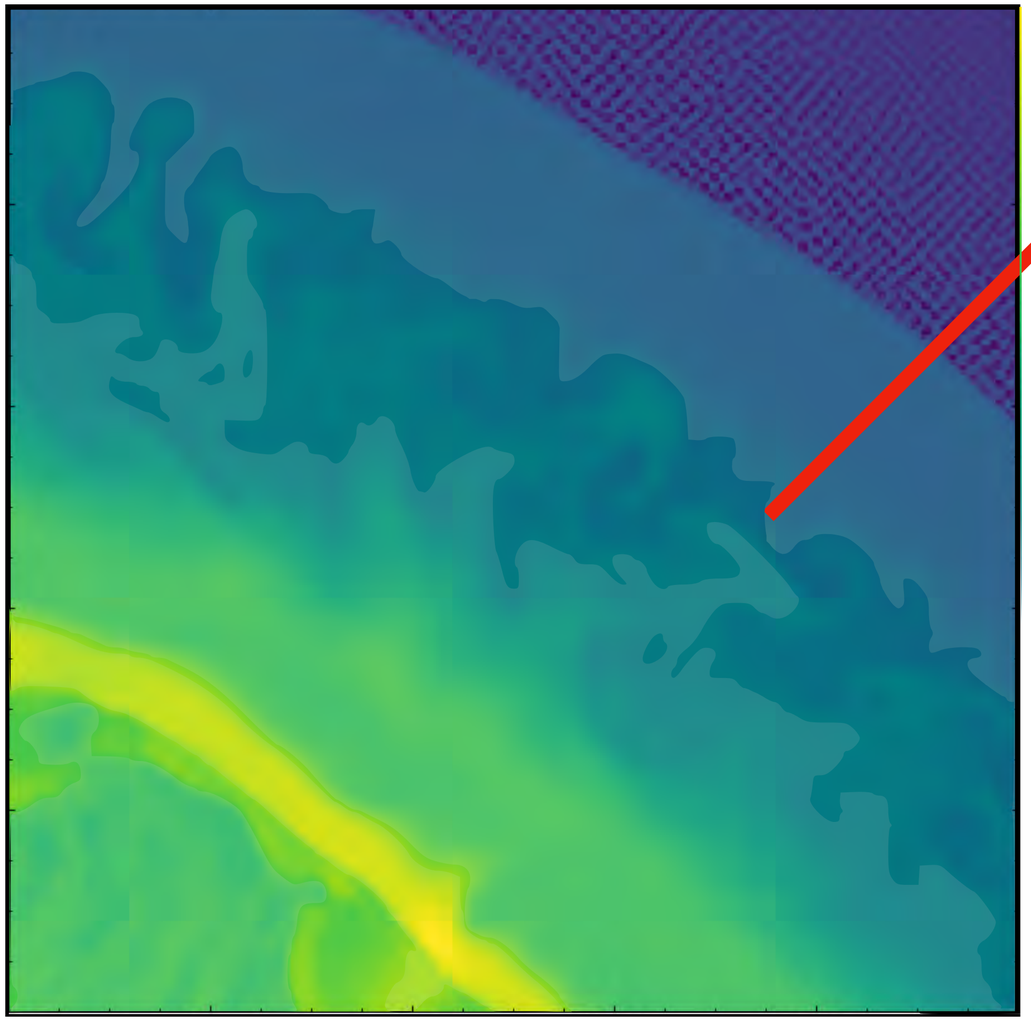
Progenitor Radius Determine Timescale

$$\Delta t_{\text{travel}} \approx \frac{R}{c};\ \Delta t_{\text{cross}} \approx \frac{R}{v} \sim \frac{c}{\kappa \rho v^2}$$



Progenitor: RSG See AS 18P, Ou

Shock Breakout in Multi-Dimension

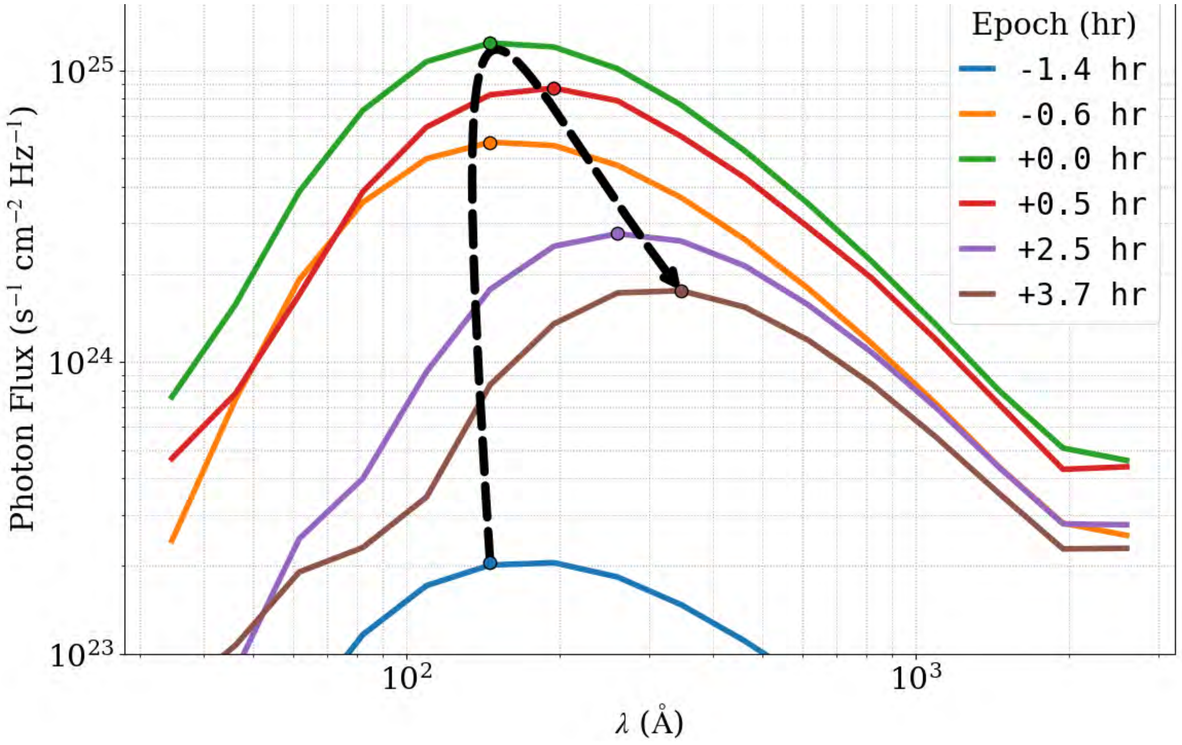


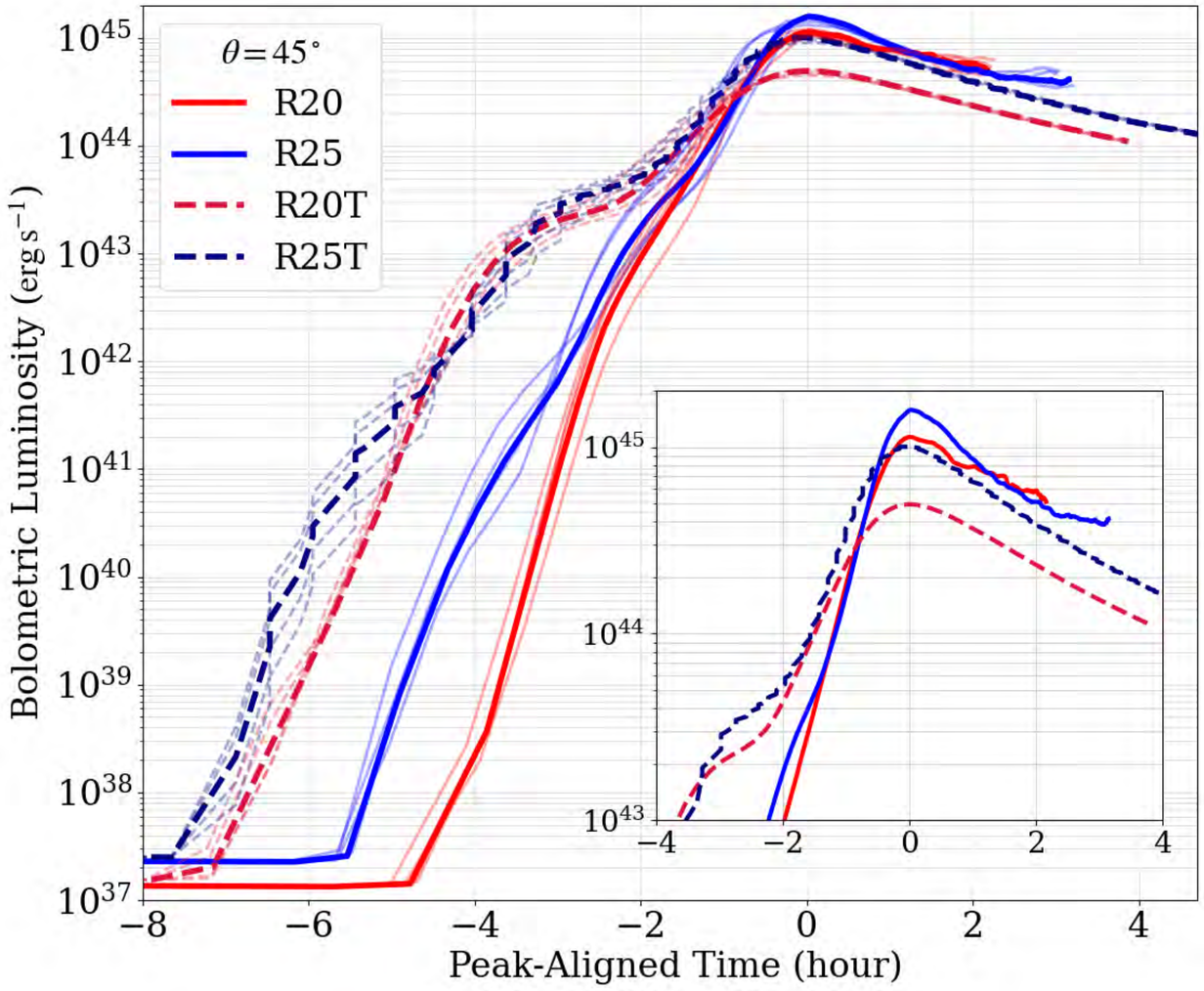
- **Radiation Precursor**
- Chen 2024: 2D MGFLD SN1987a SBO
- Chen 2025 (prep.): RSG
- **This work**: Confined Shell

- Ongoing Investigation:
  - ➡Suzuki 2016: 2D M1 Shock Breakout
  - ➡Goldberg+ 2022: 3D RSG envelope

Shock Breakout in Multi-Wavelength

- Sharply **Blue** and gradually **Red**
- Radiation Precursor indicate CSM density



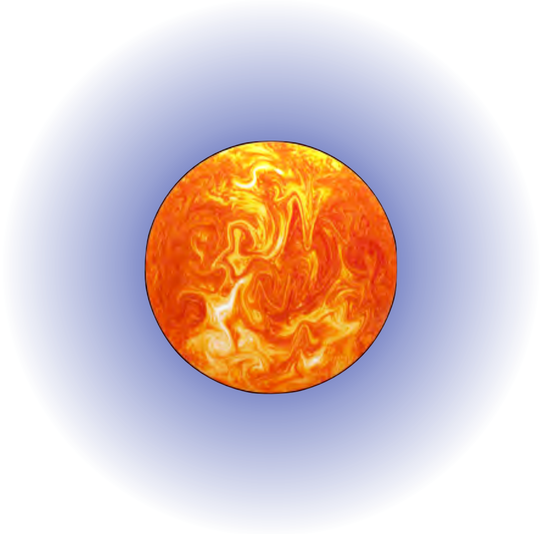


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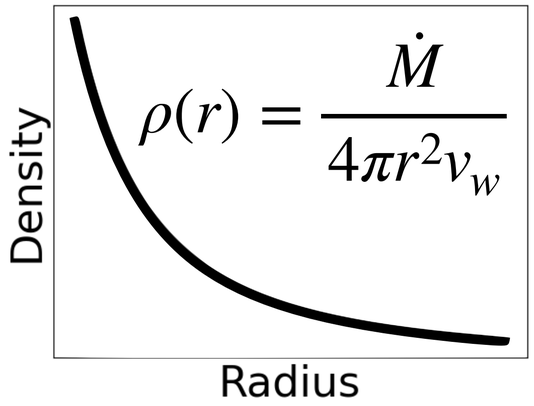
Confined-Shell CSM

Interaction with CSM Prolong SBO

Steady Wind



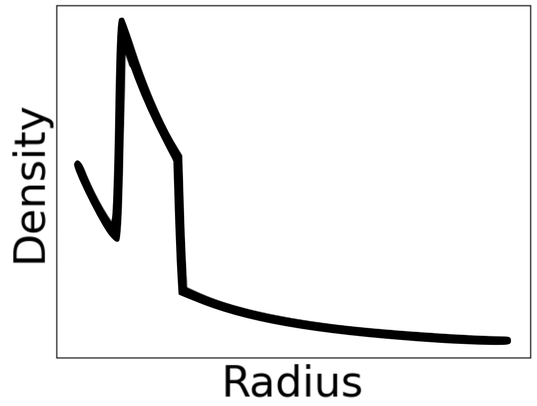
Steady Mass Loss Wind from the progenitor



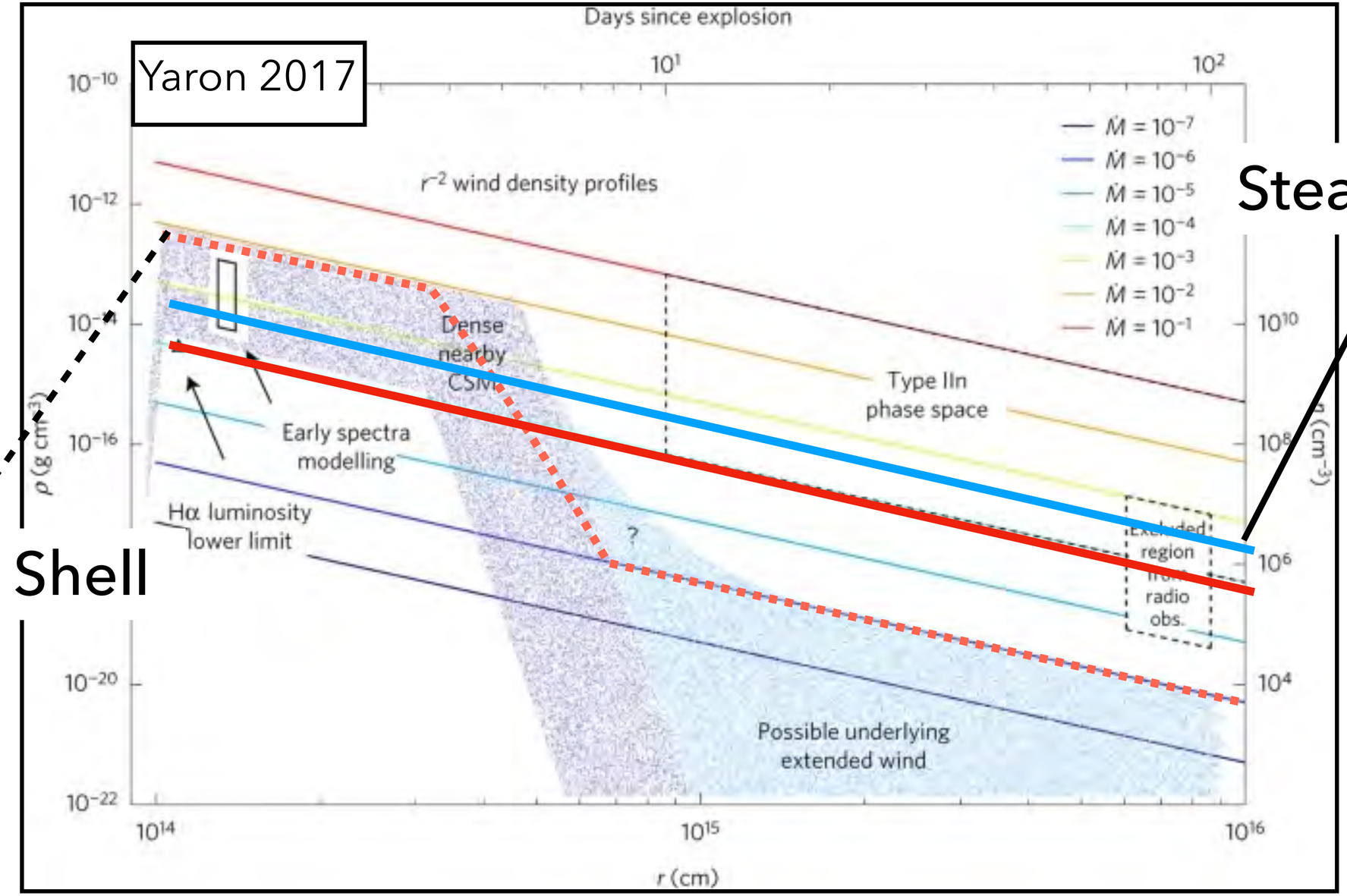
Confined Shell



Eruptive Mass Loss before SNe Explosion



Modeling Observed Prolonged SBO

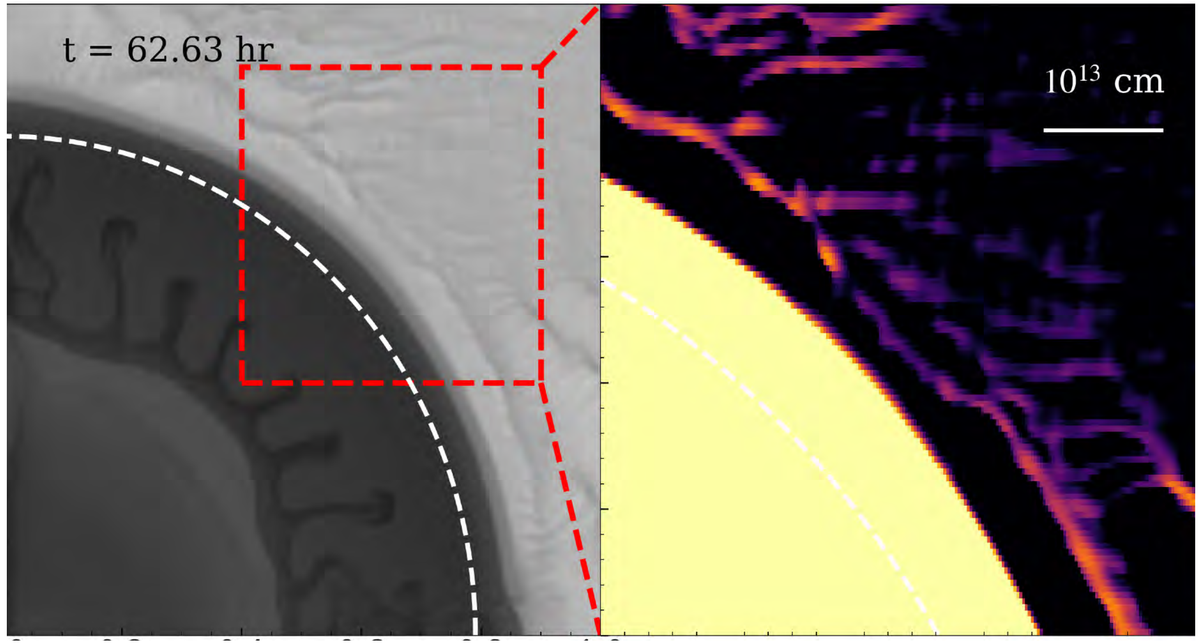


Steady Wind

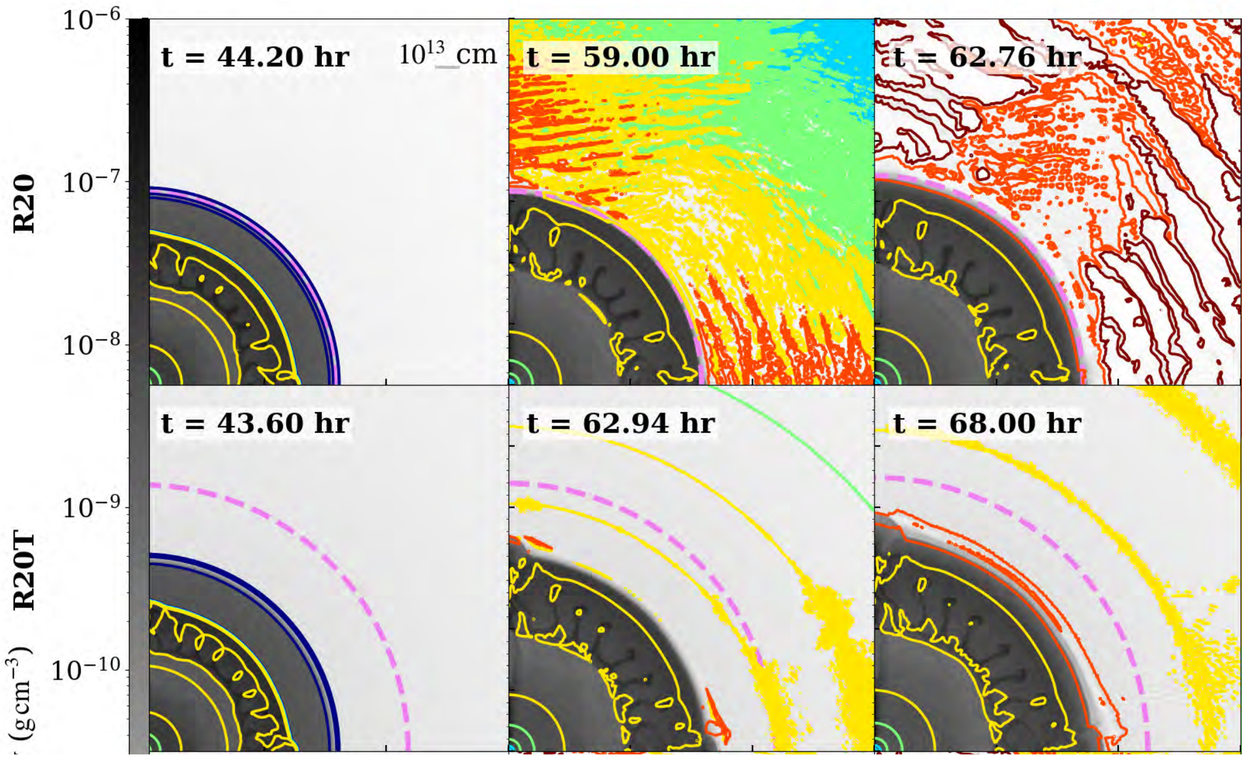
Confined Shell

Radiation Precursor Extend LCs

- Shock Breakout LCs rise with RP.
- RP generate Larger Photosphere.

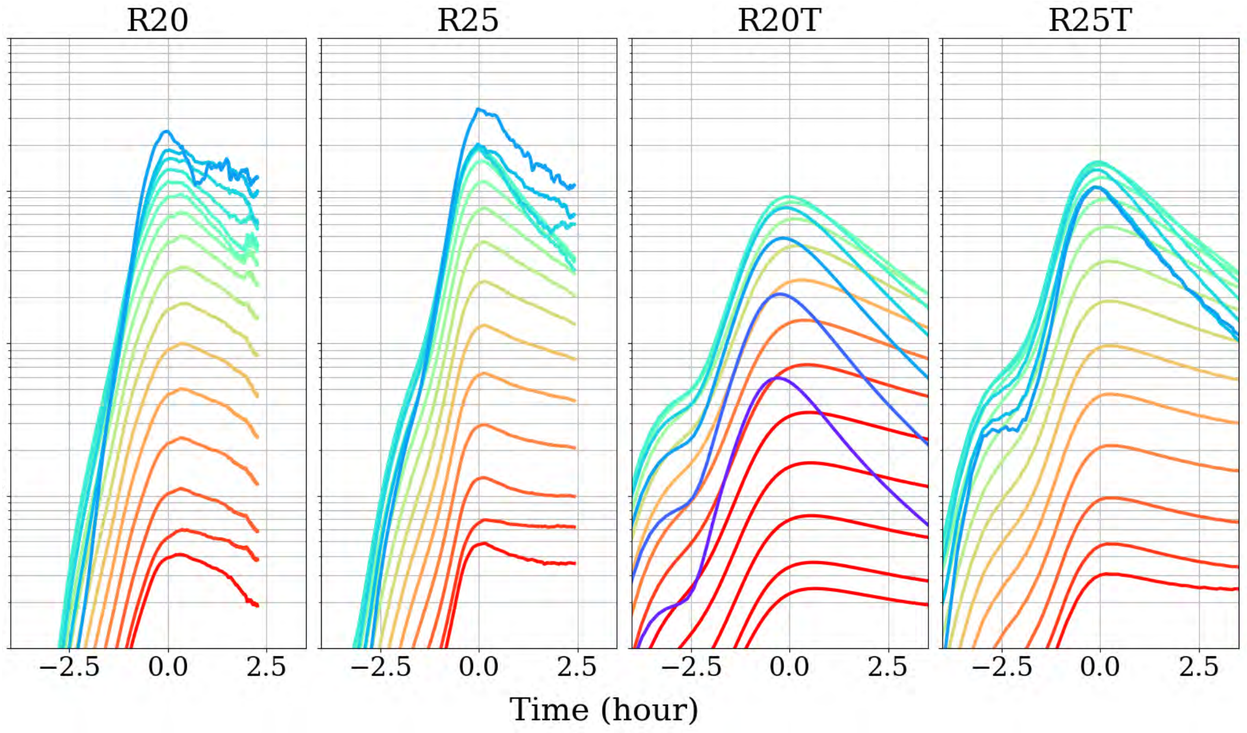


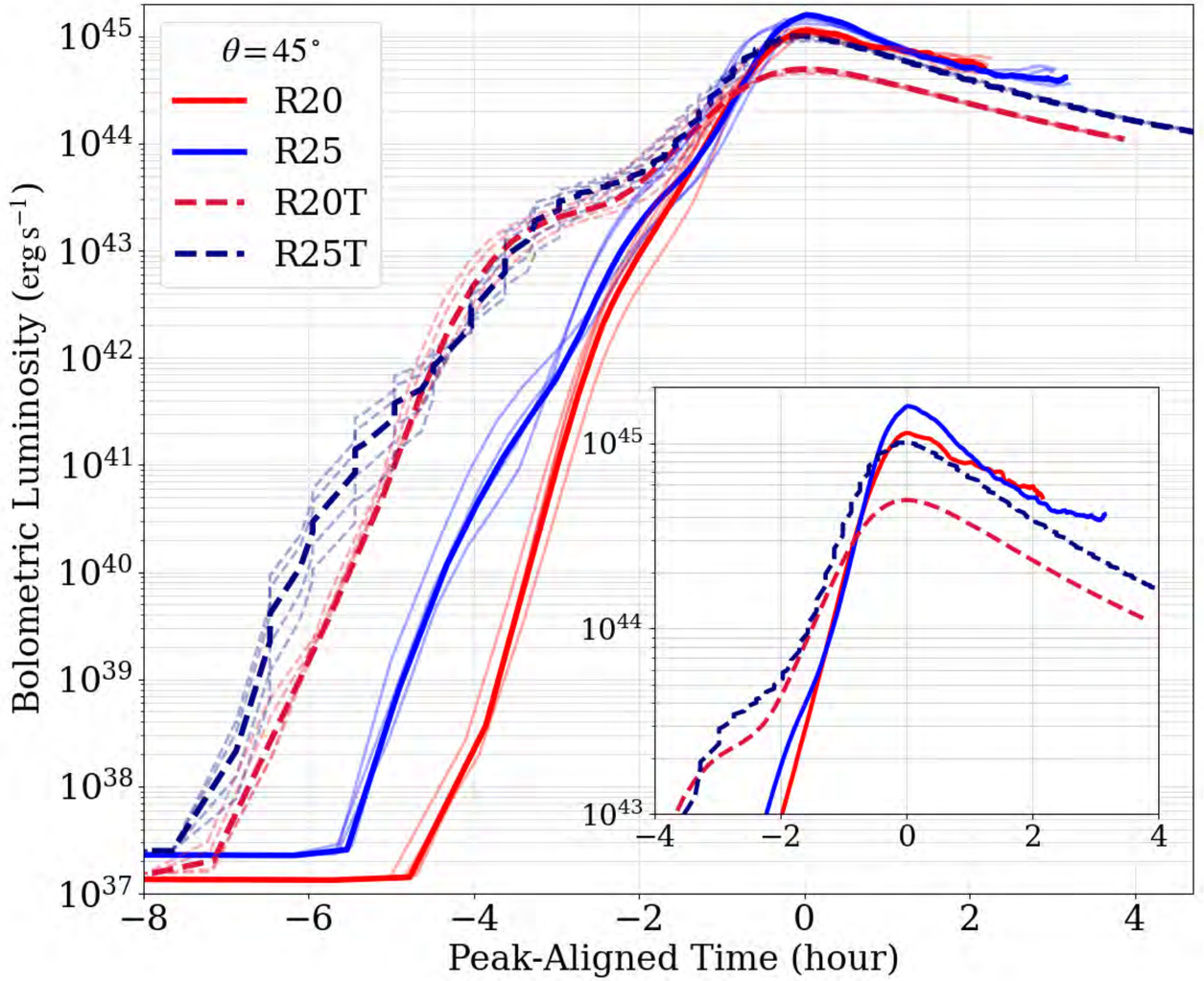
- Larger Photosphere for dense CSM



MGLCs Separate CSM and Radius Effects

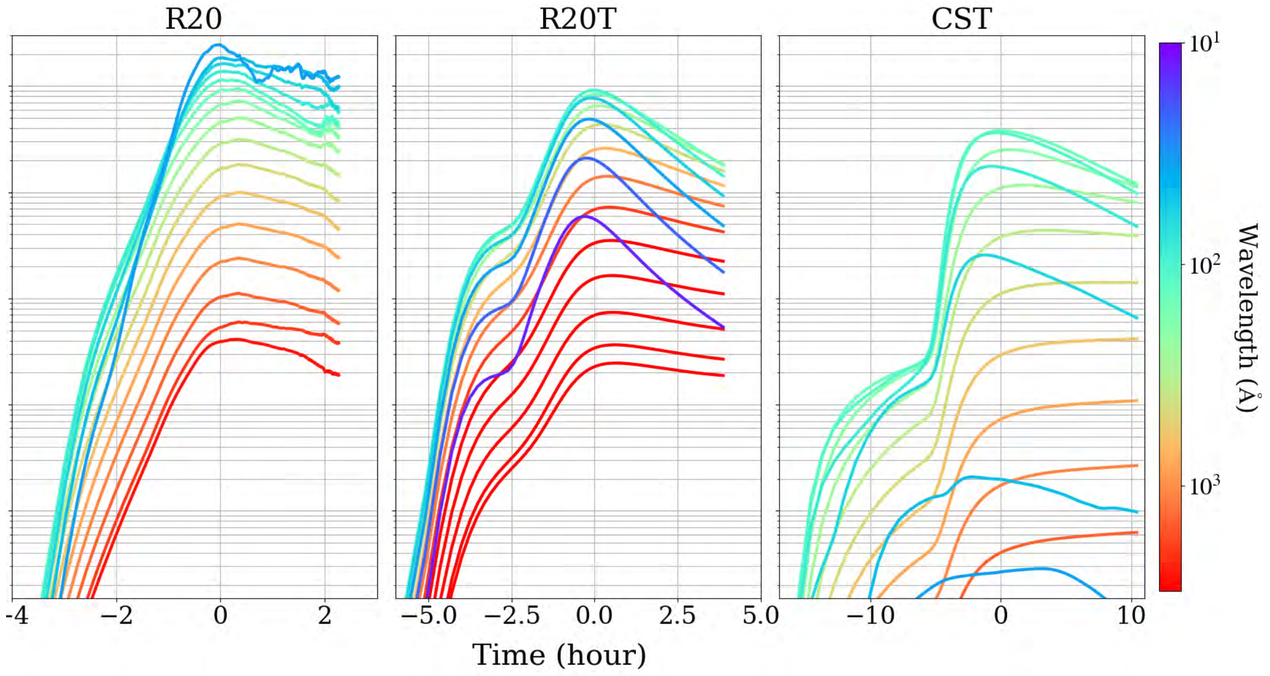
- Shoulder: Dense CSM
- Smooth **Longer-λ**: Larger Radius

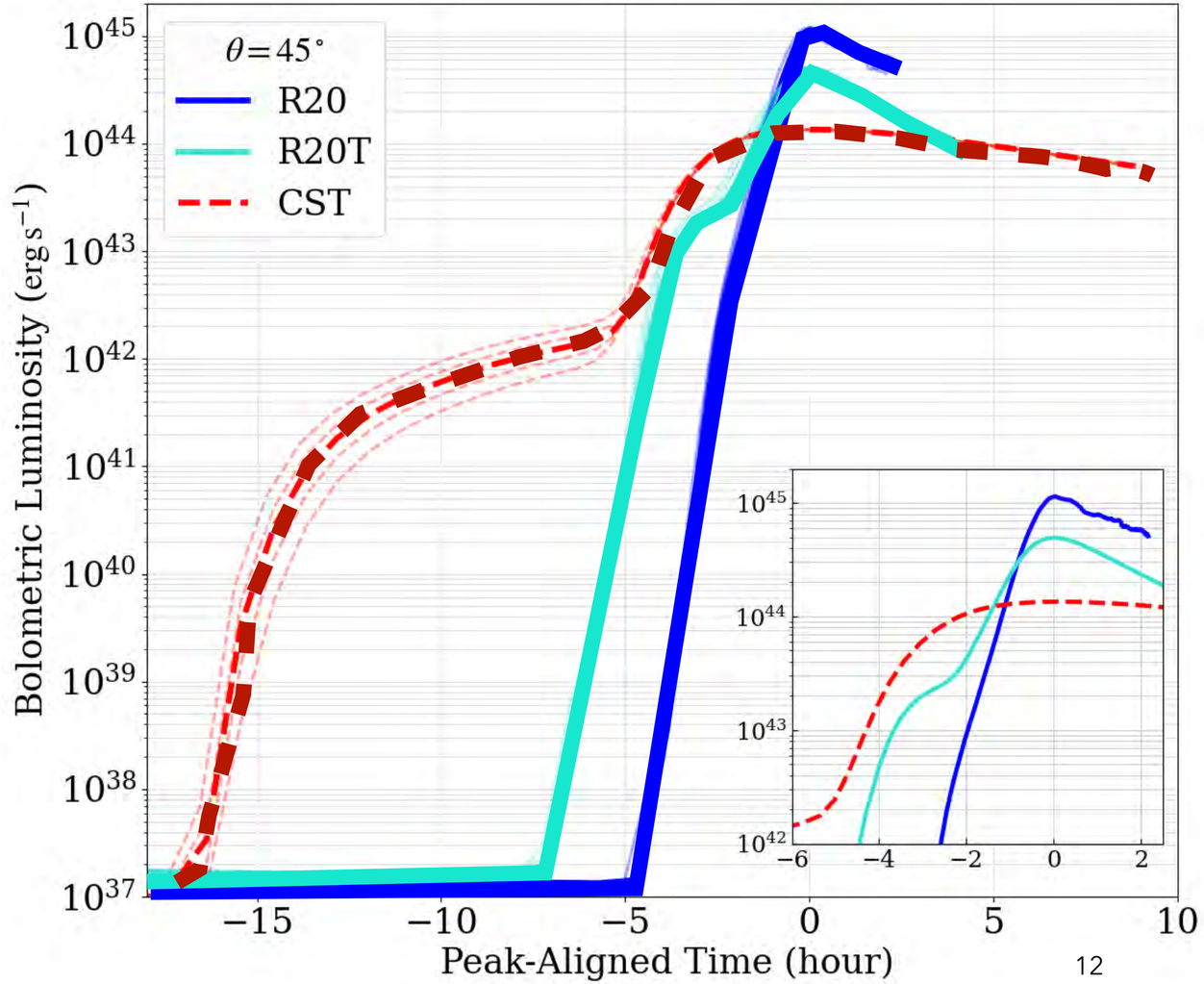




RP Reveals Confined-Shell

- First Rise of **Shorter-λ**: Shell Width
- Second Rise: Shell Density





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However…

Degeneracy of Mass Loss History

- Range of Mass Loss
  - Quiescent: $10^{-5} - 10^{-6}\,M_{\odot}\,\mathrm{yr}^{-1}$
  - Enhanced: $10^{-4} - 10^{-1}\,M_{\odot}\,\mathrm{yr}^{-1}$
- Range of wind Velocity
  - Quiescent: $10 - 25\,\mathrm{km\,s}^{-1}$
  - Outburst: $\sim 100\,\mathrm{km\,s}^{-1}$

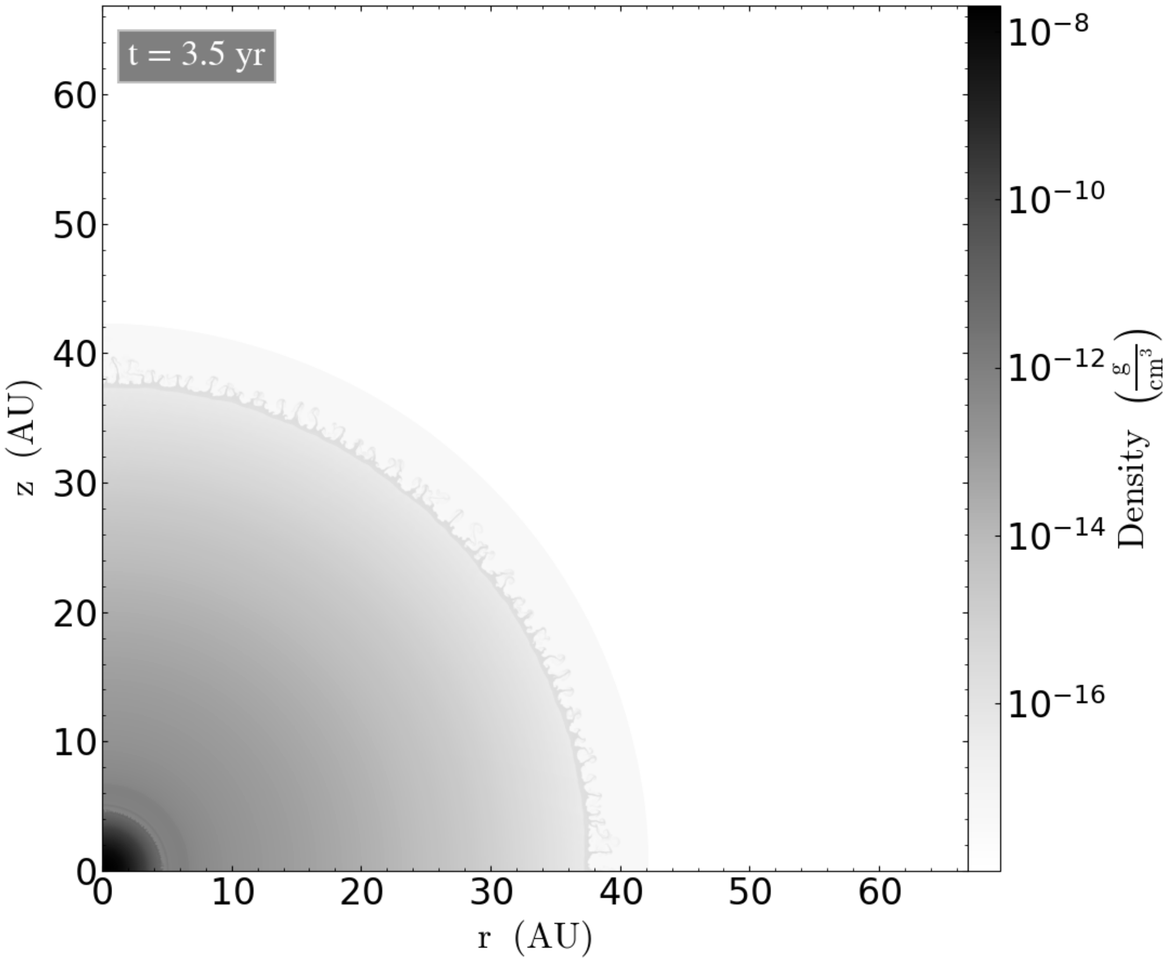
Mass Loss Wind

$$\rho(r) = \frac{1}{4\pi r^2}\frac{\dot{M}}{v_w}$$

Ratio of Wind Velocity and Mass Loss Rate

Stellar Evolution Resolves Degeneracy

- Complicates:
  - Common Envelope Phases
  - Pulsation and Ejection
  - Extended Envelopes
- Inject mass flux from stellar radii
- Evolve 3yr/ 10yr/ 100yr before SN



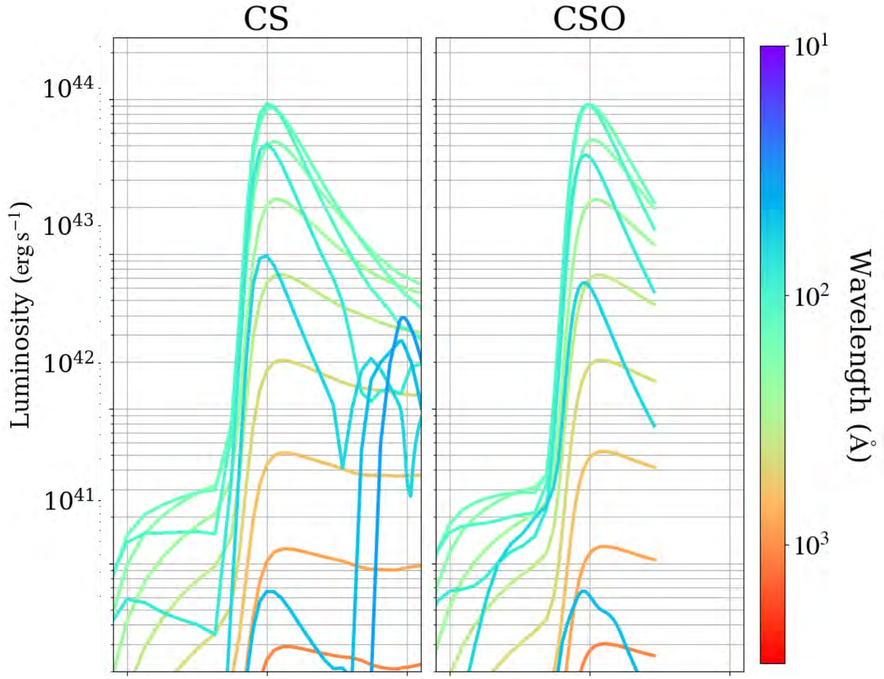
Progenitor: Binary See AS 10P, Tsai

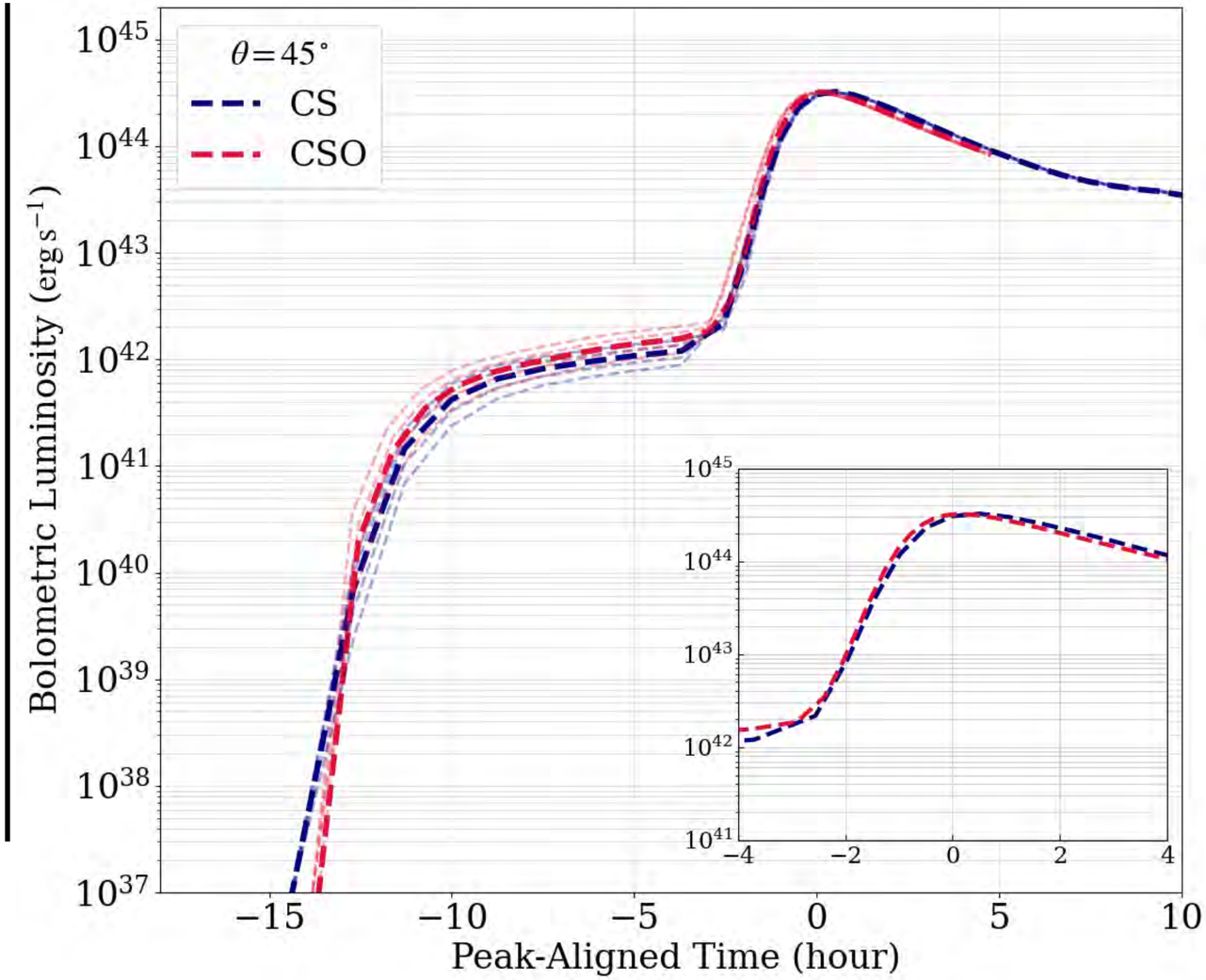
Detailed Opacity Prolongs SBO

➡Electron Scattering

➡OPLIB from MESA: z=0.02

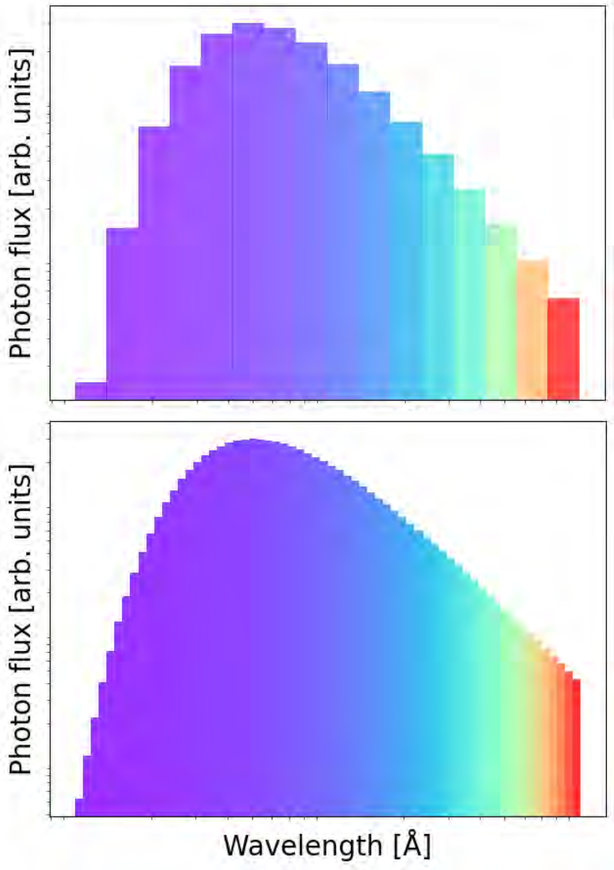
- Longer duration, Redder, Dimmer





Future Work of our SBO

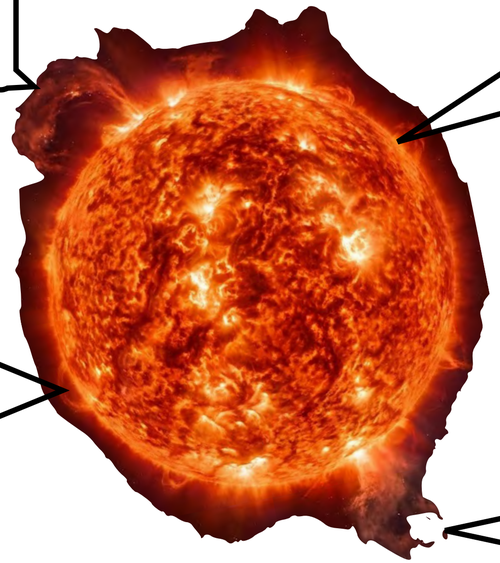
More MGs



Multi-D CSM

Pulsation Driven Shell

Convective Surface



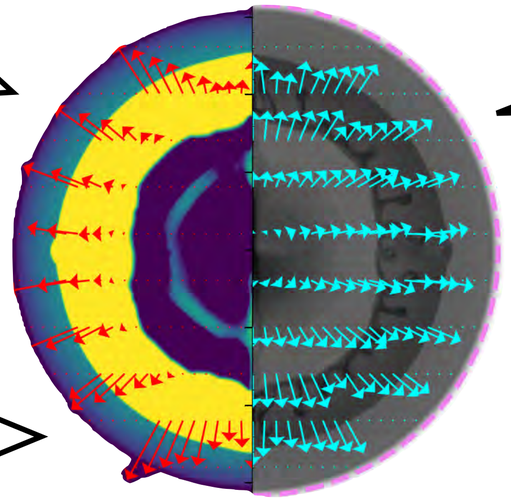
Long-Term High-Density Region. (2025 Ma)

Clumpy, Inhomogeneous CSM

Take Home Message

Multi-D Improves Radiation Precursor.

Multi-Wavelengths Resolve Degeneracy of CSM and Radius



Confined Shell - Dense CSM degeneracy.

Need Stellar Evolution Model to Explain Mass Loss.