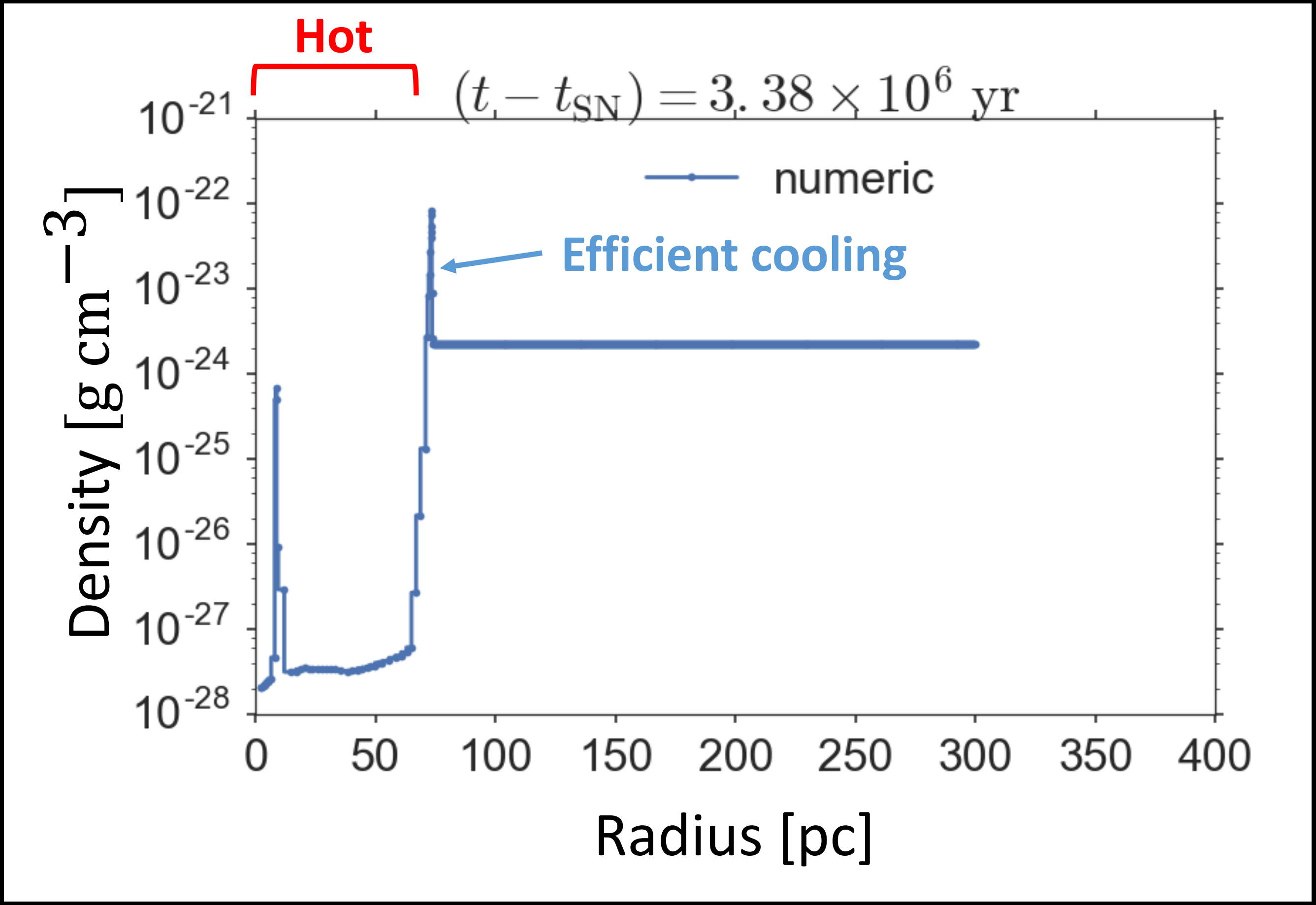
Enhanced Momentum Feedback from Clustered Supernovae

Eric Gentry
with Mark Krumholz, Avishai Dekel, Piero Madau

11 Aug 2016 --- UCSC Galaxy Workshop

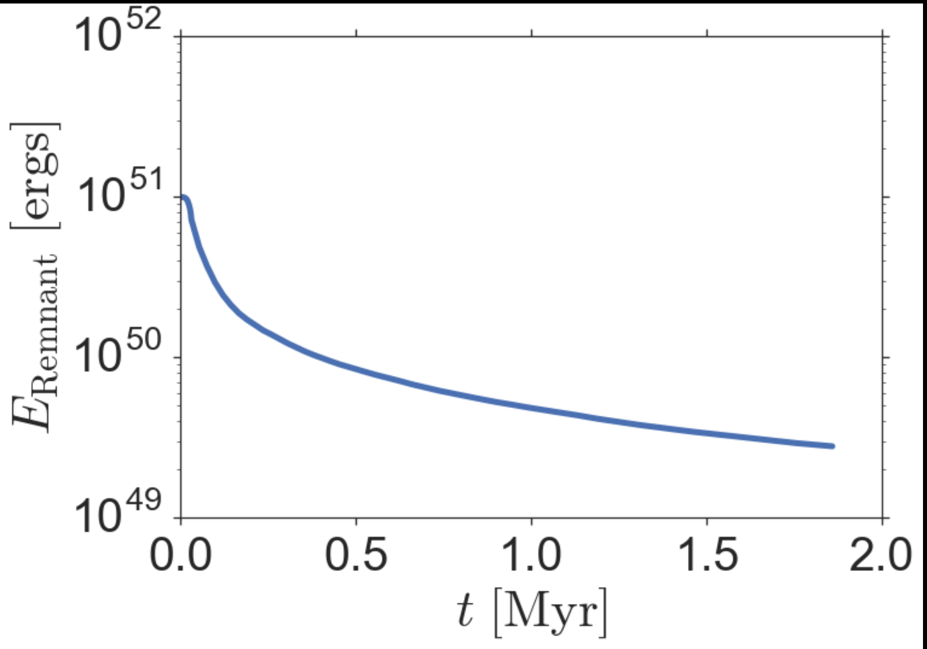
arXiv:1606.01242

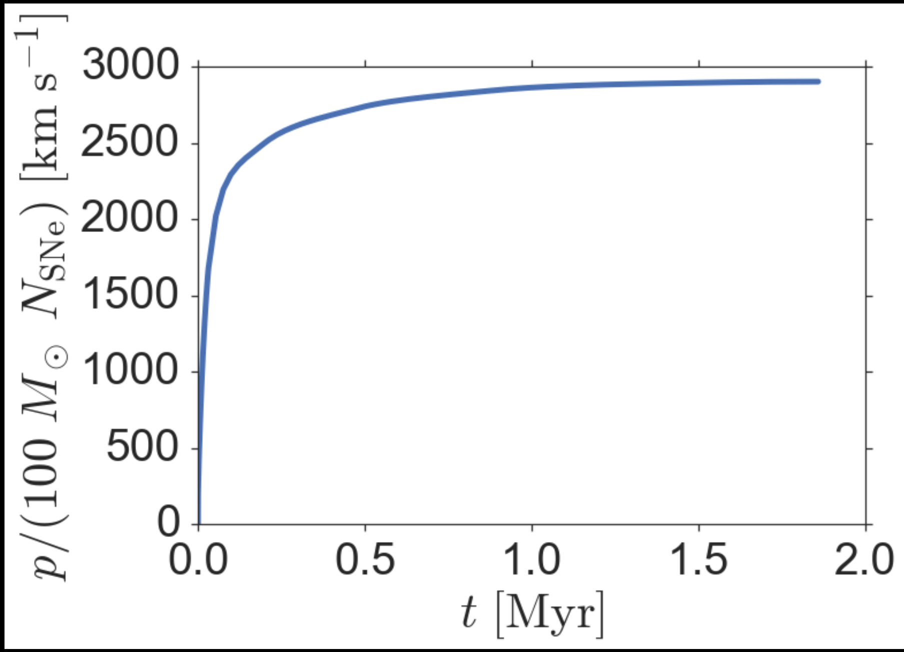
Why SNe feedback models?



Momentum-driven rather than Energy-driven feedback model

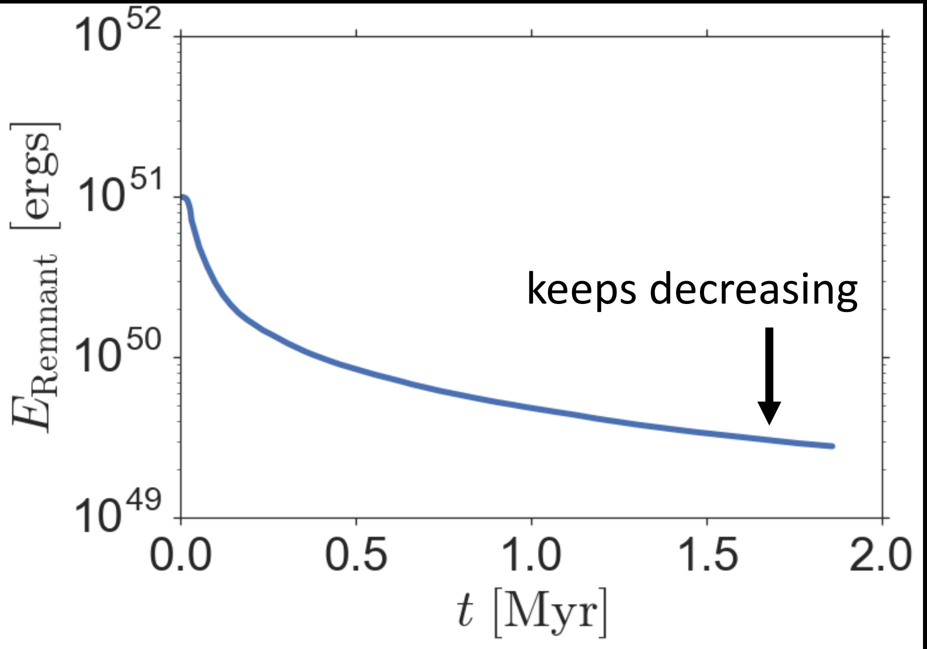
Single SN simulations

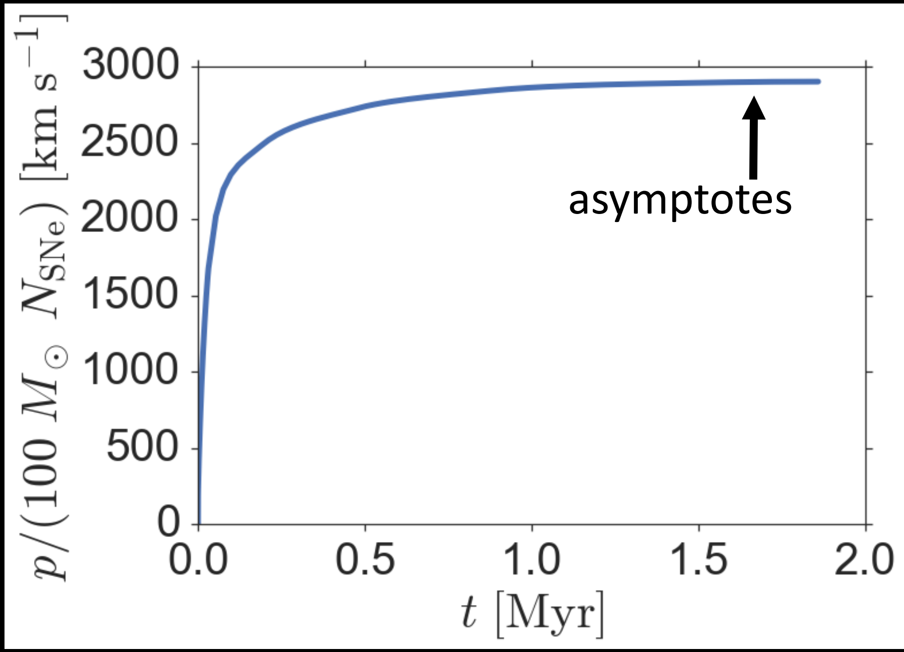




Momentum-driven rather than Energy-driven feedback model

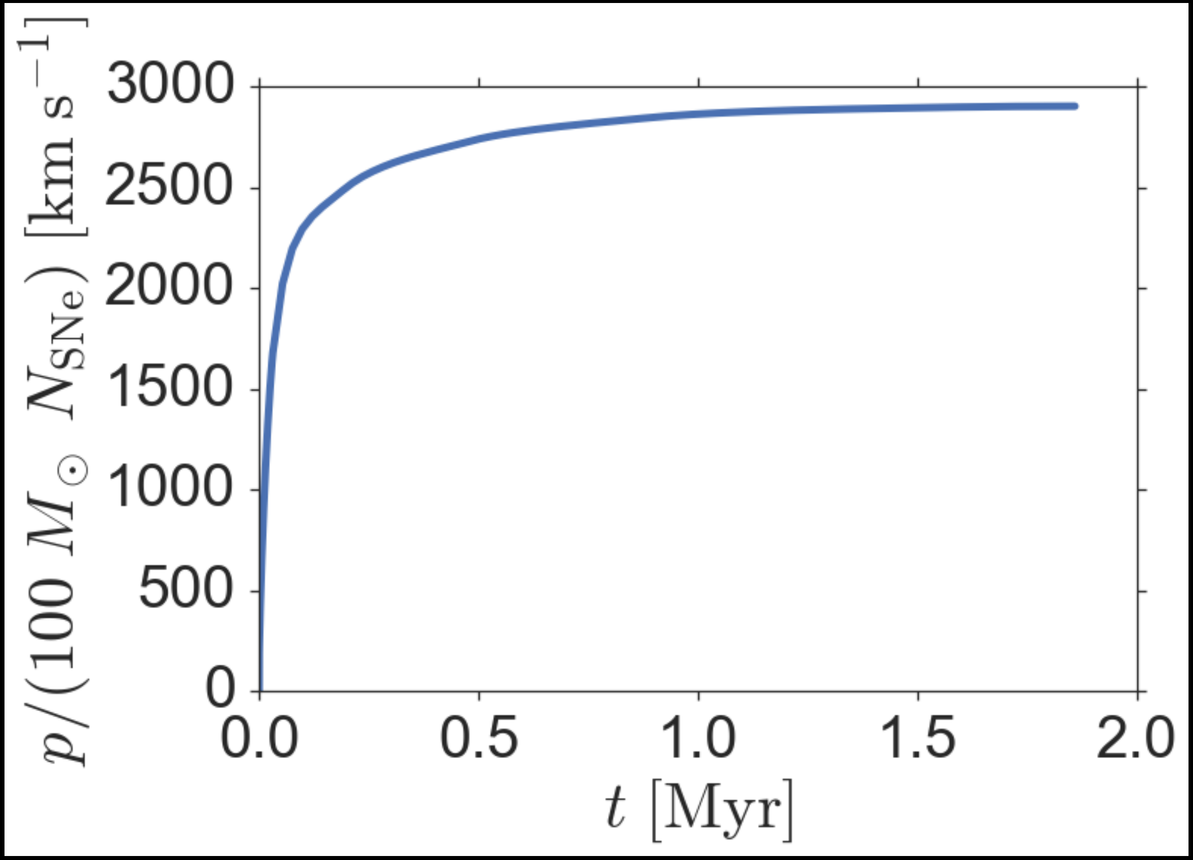
Single SN simulations





Momentum-driven model

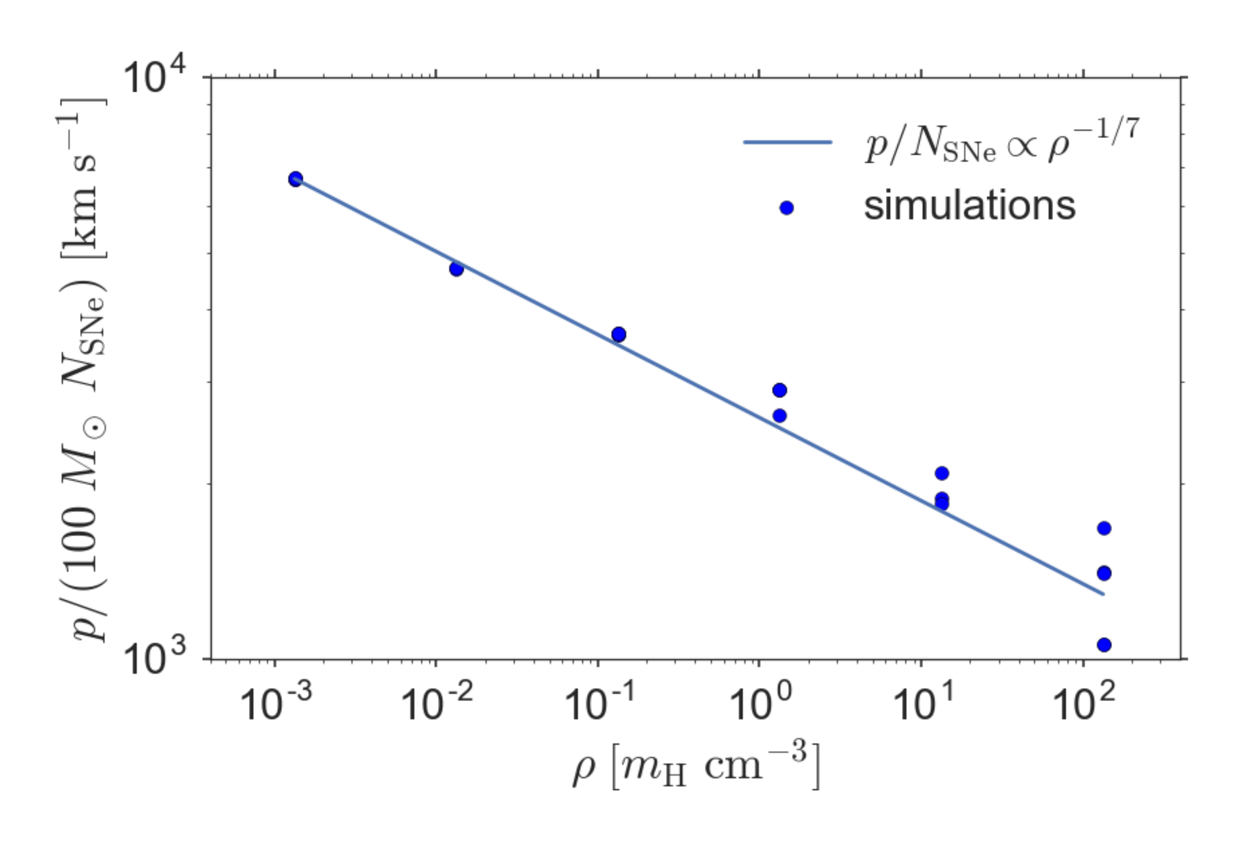
$$p \approx 3000 \quad (100\,M_\odot)\,\mathrm{km\,s^{-1}}$$



Ostriker & Shetty (2011)

Momentum-driven model

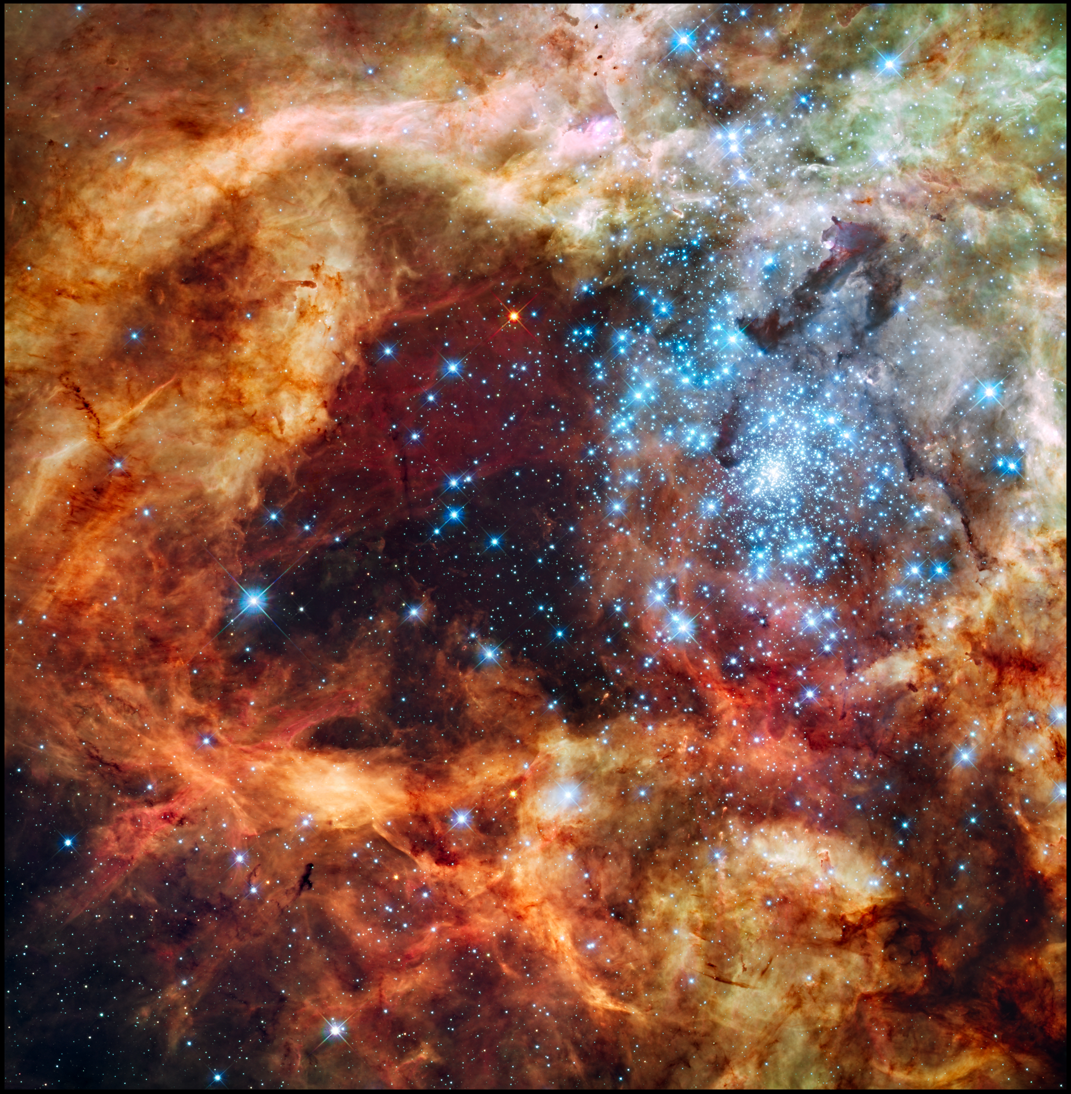
$$p \approx 3000 \left(\frac{n_{\mathrm{H}}}{1\ \mathrm{cm}^{-3}}\right)^{1/7} \left(100\, M_{\odot}\right) \mathrm{km\ s^{-1}}$$



Ostriker & Shetty (2011)

Cioffi+98

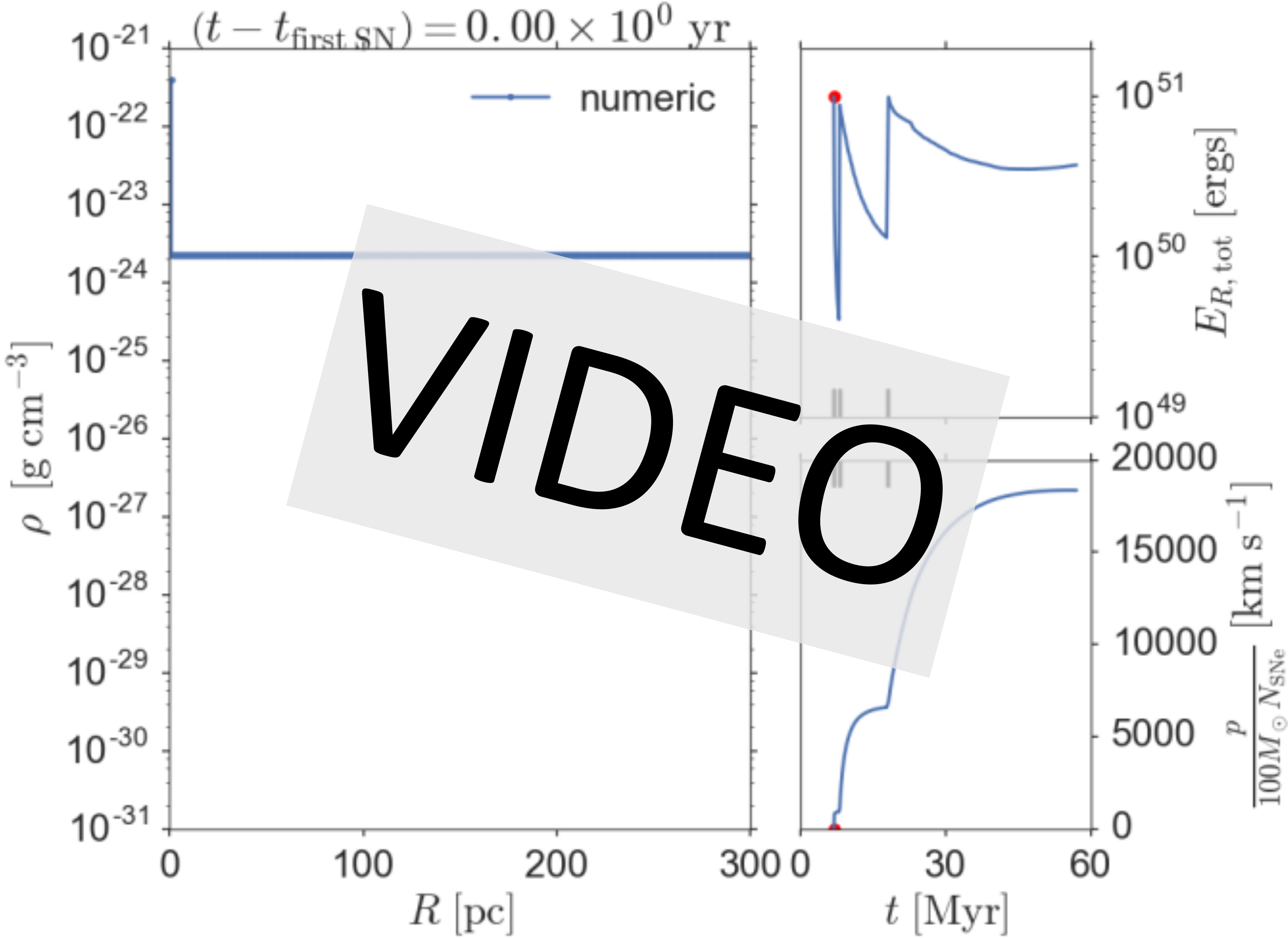
What about non-isolated SNe?



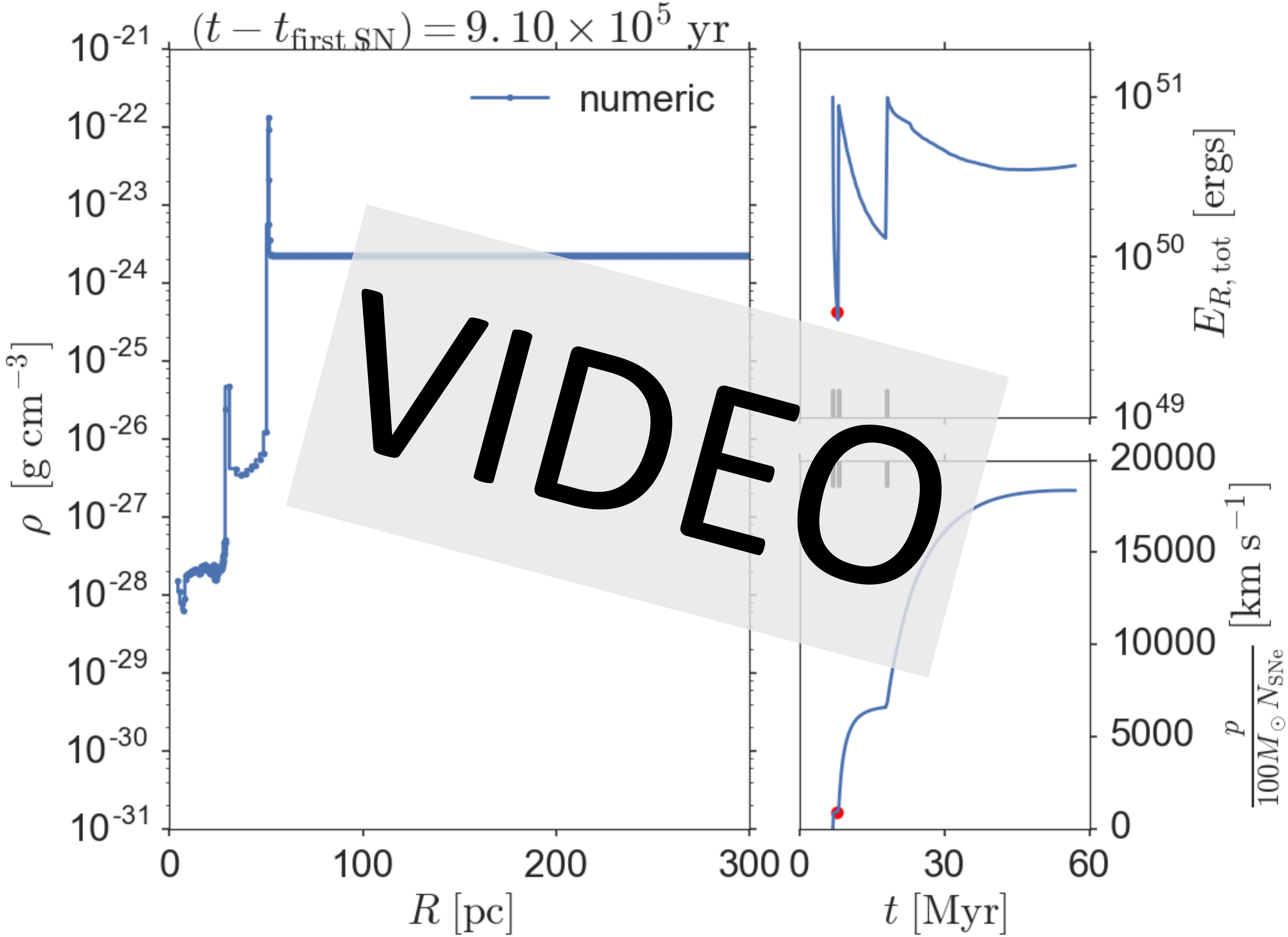
R136 in 30 Dor
50 pc

>70 O stars
Within inner 5pc

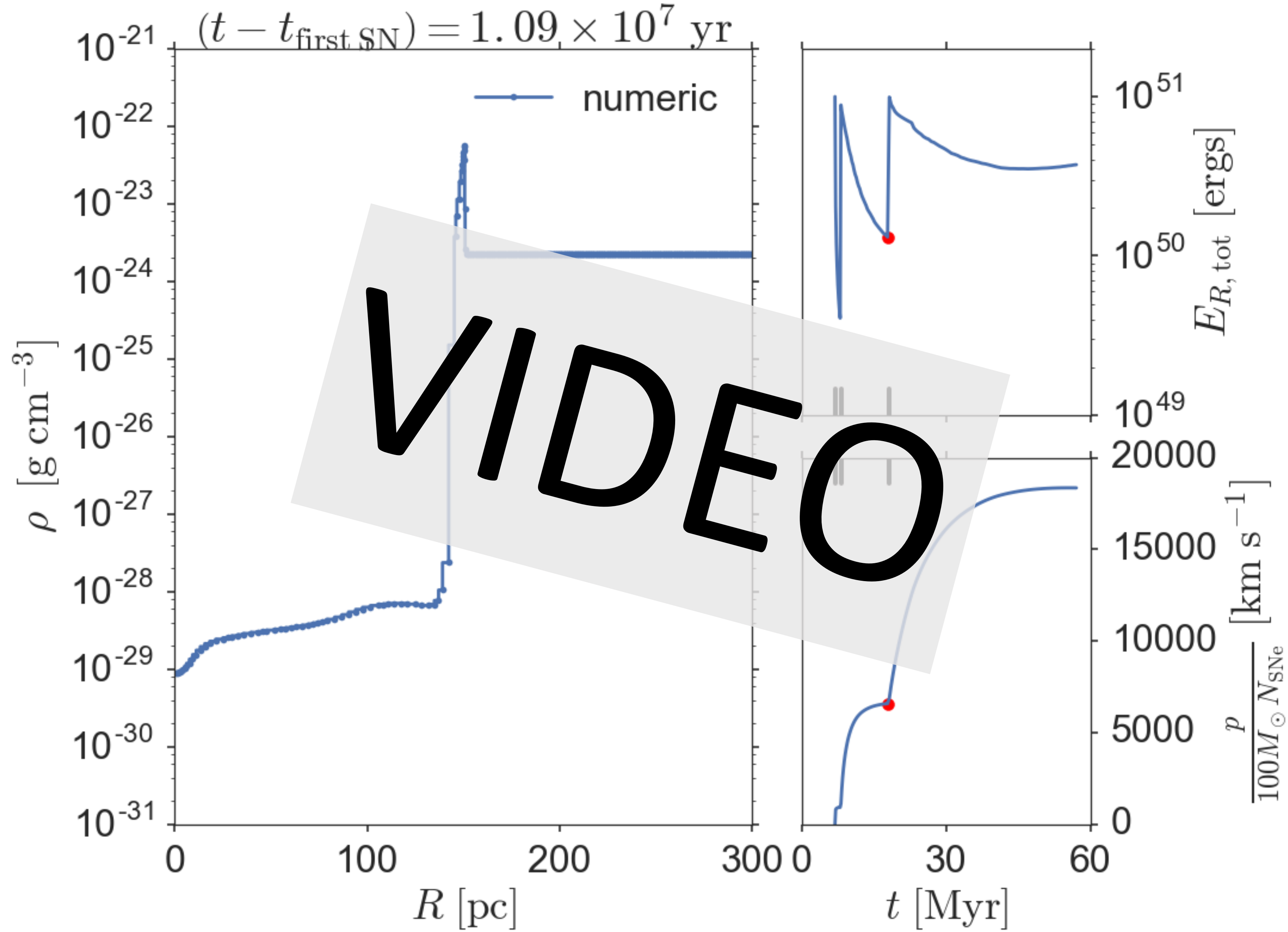
Our simulations



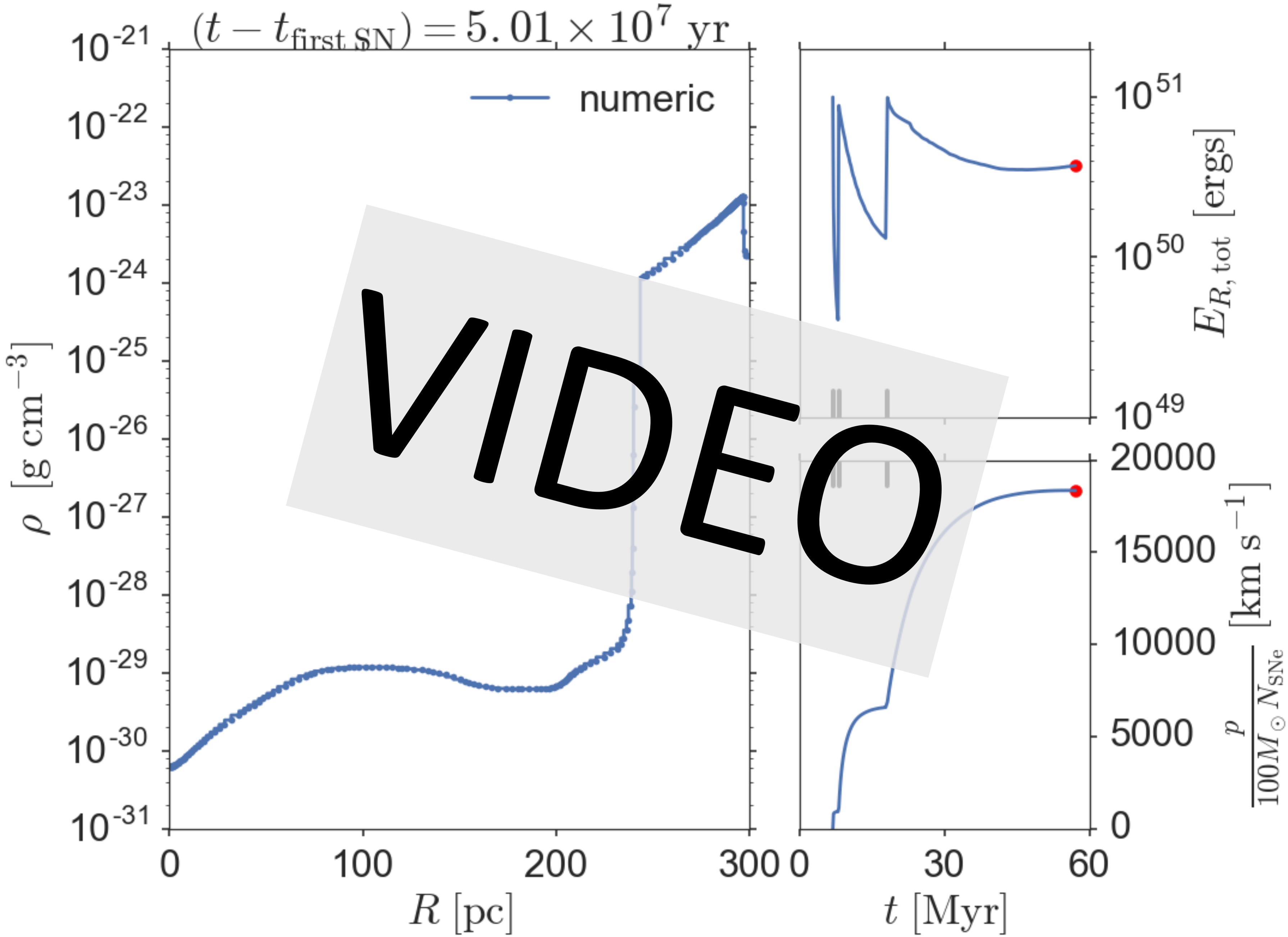
Gentry+16 (in prep.)



Gentry+16 (in prep.)



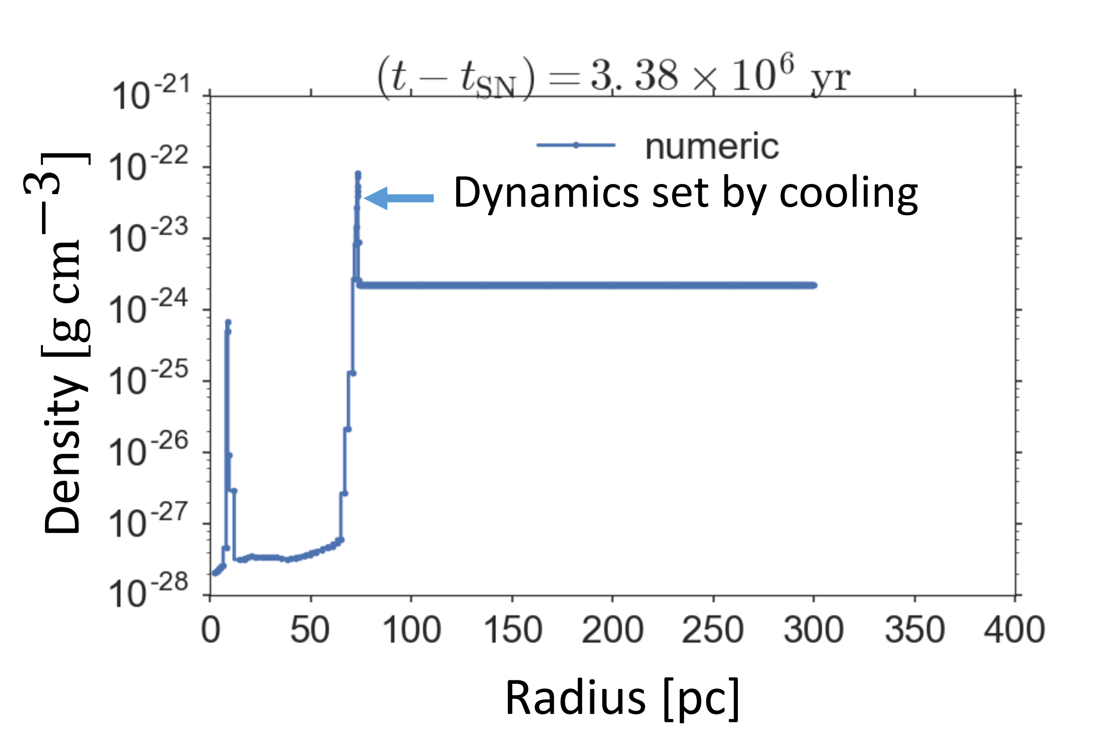
Gentry+16 (in prep.)



Gentry+16 (in prep.)

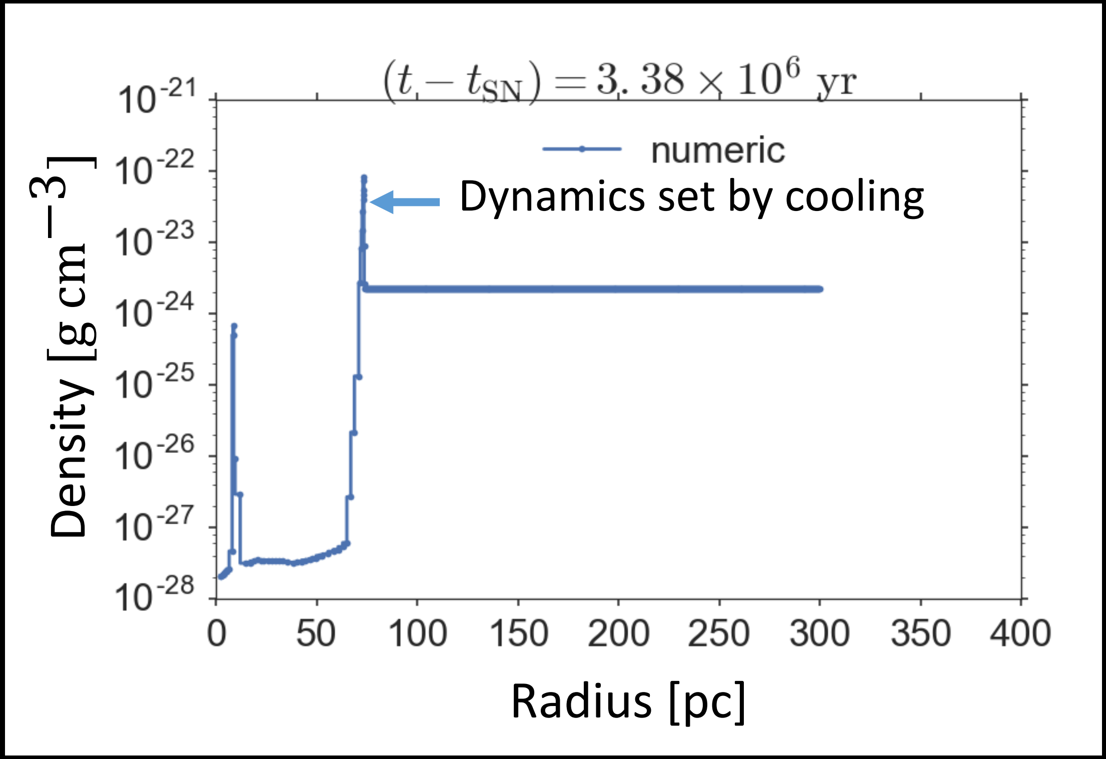
Our simulations

- Hydro: 1D Lagrangian Riemann solver (Duffel+16)



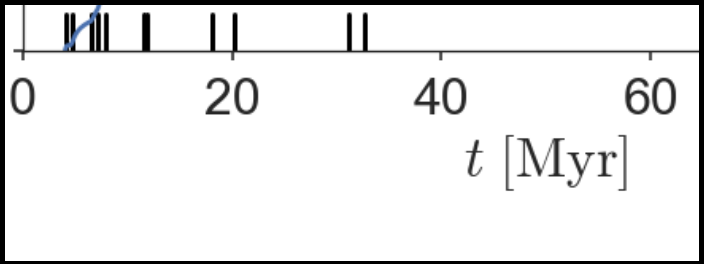
Our simulations

- Hydro: 1D Lagrangian Riemann solver (Duffel+16)
- Cooling: GRACKLE



Our simulations

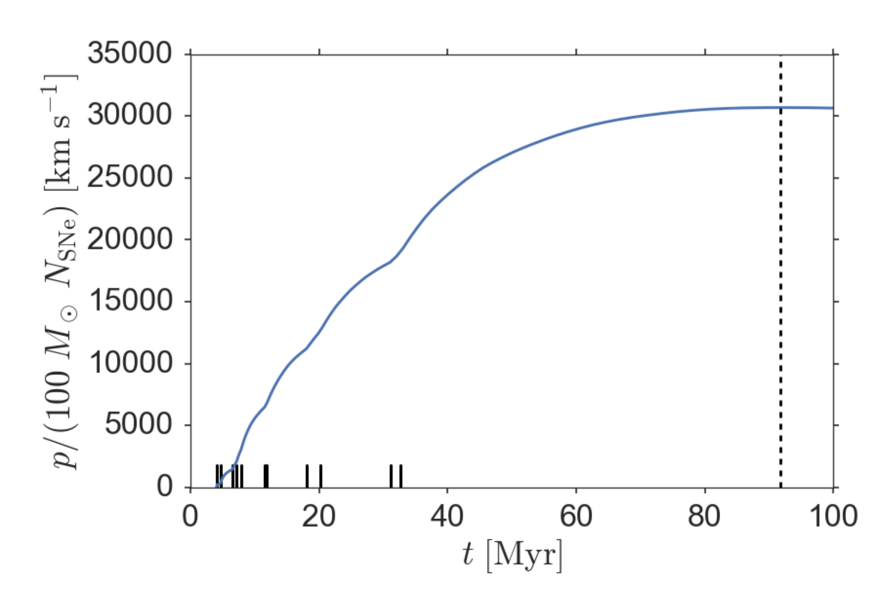
- Hydro: 1D Lagrangian Riemann solver (Duffel+16)
- Cooling: GRACKLE
- Realistic IMF, stellar lifetimes, SN ejecta
  (Kroupa+02, Ekström+12, Woosley&Heger+07)
  - Fixed: $\mathrm{E} / \mathrm{N}_{SN\mathrm{e}} = 10^{51}$ ergs



Our simulations

- Hydro: 1D Lagrangian Riemann solver (Duffel+16)
- Cooling: GRACKLE
- Realistic IMF, stellar lifetimes, SN ejecta
  (Kroupa+02, Ekström+12, Woosley&Heger+07)
  - Fixed: $\mathrm{E} / \mathrm{N}_{SNe} = 10^{51}$ ergs

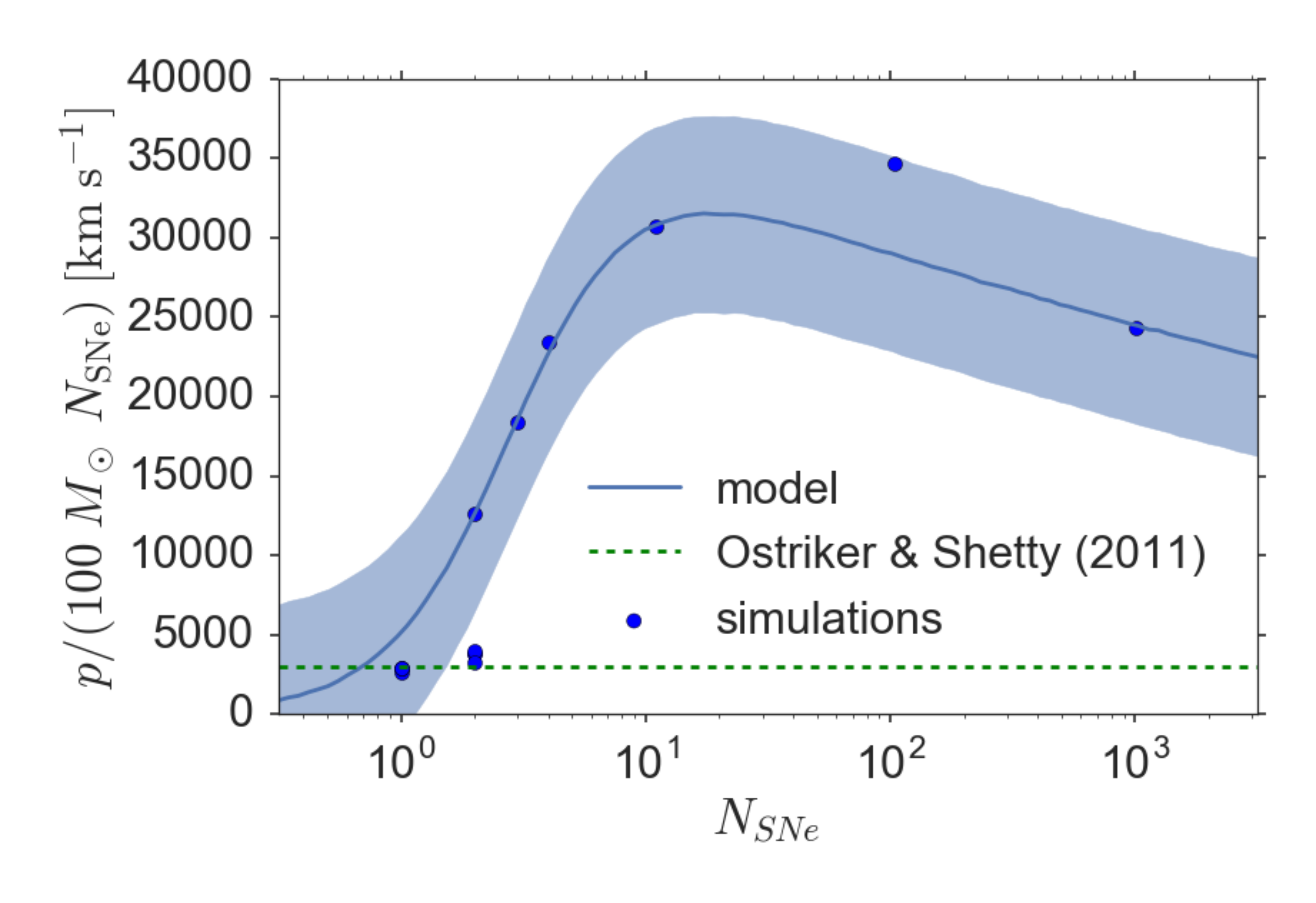
- Evolved until momentum reached a maximum



Results

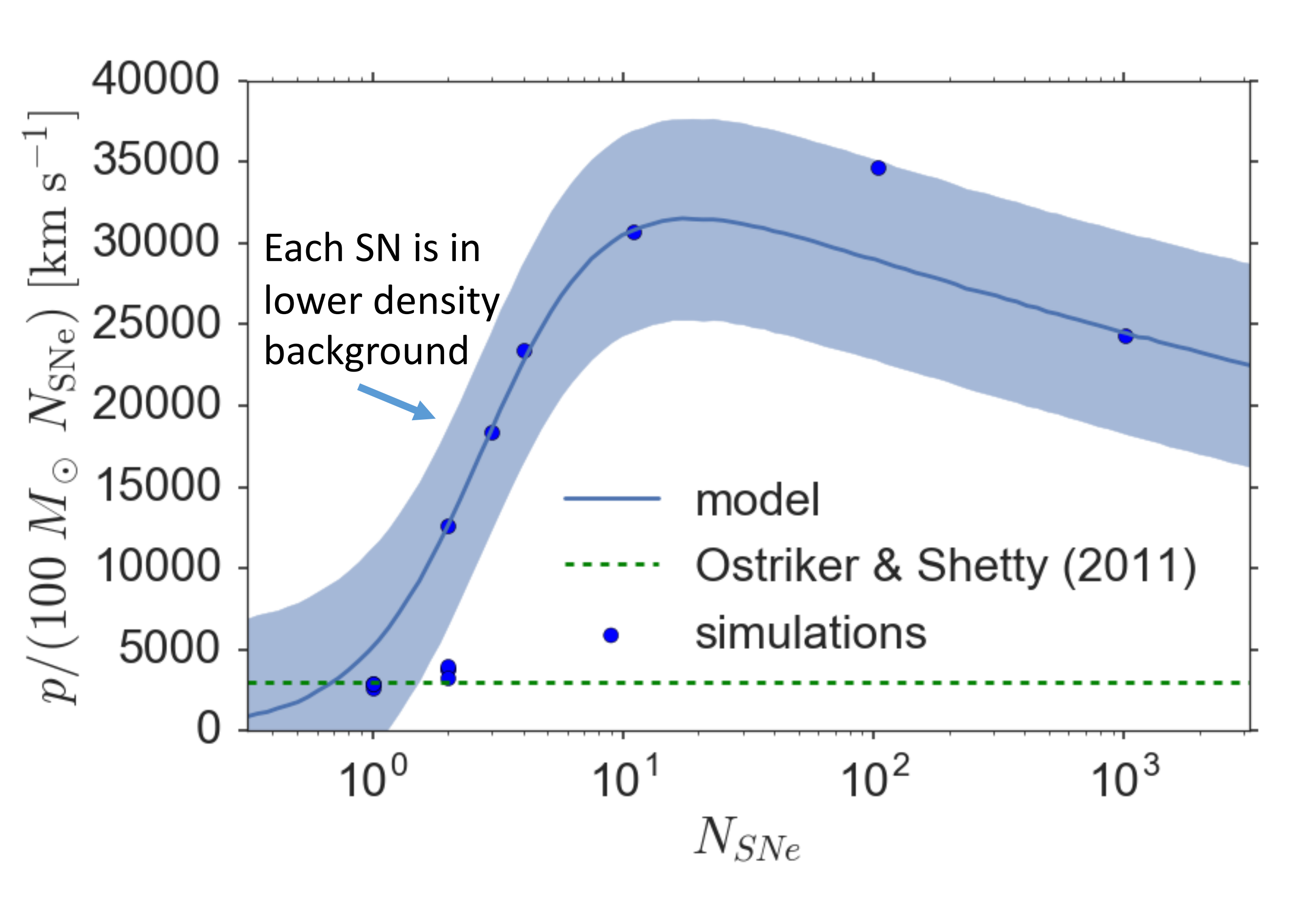
Key results

Only showing simulations with $Z = Z_{\odot},\ \rho = 1.33\ m_H\ \mathrm{cm}^{-3}$



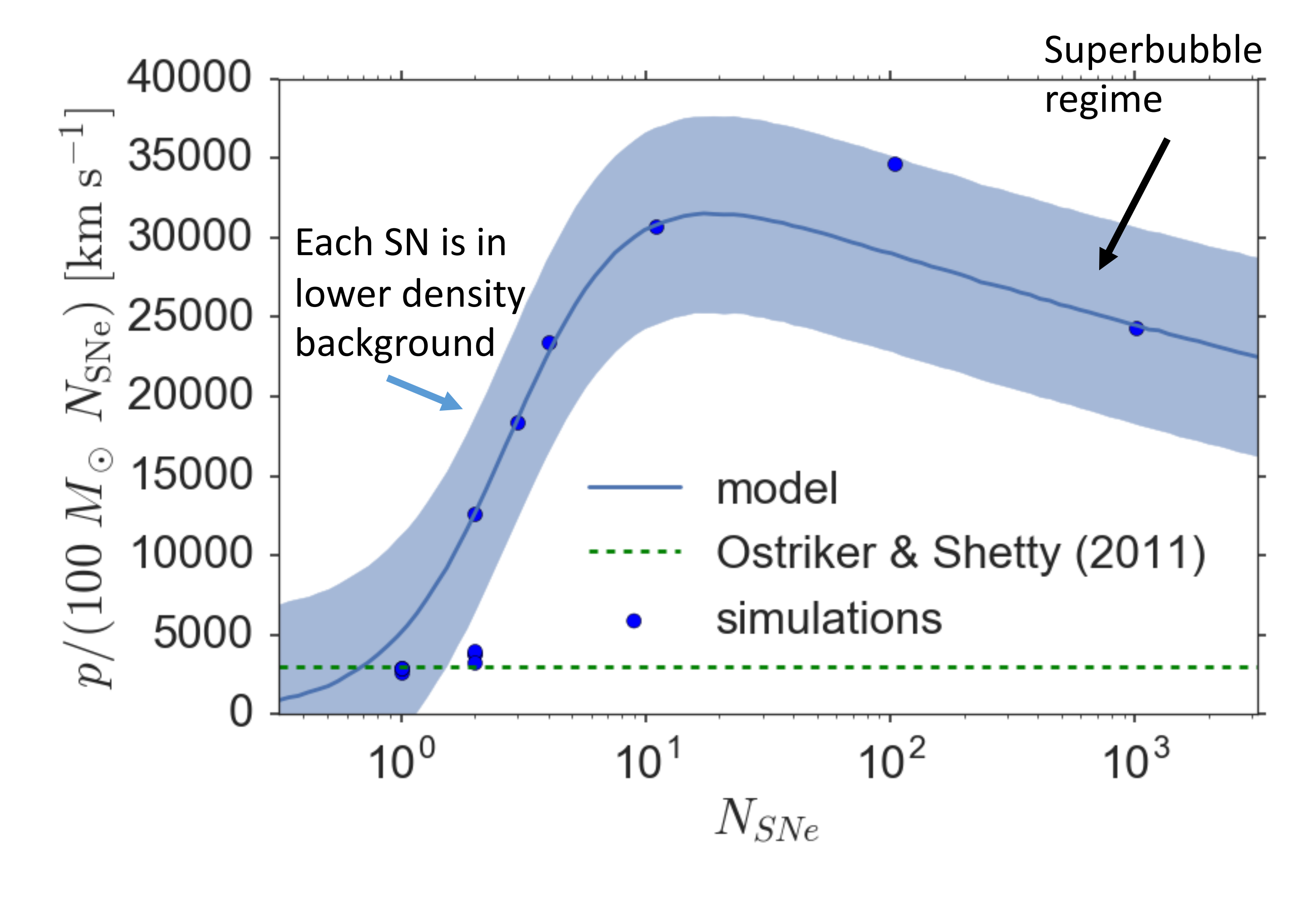
Key results

Only showing simulations with $Z = Z_{\odot},\ \rho = 1.33\ m_H\ \mathrm{cm}^{-3}$



Key results

Only showing simulations with $Z = Z_{\odot},\ \rho = 1.33\ m_H\ \mathrm{cm}^{-3}$



Predicted:

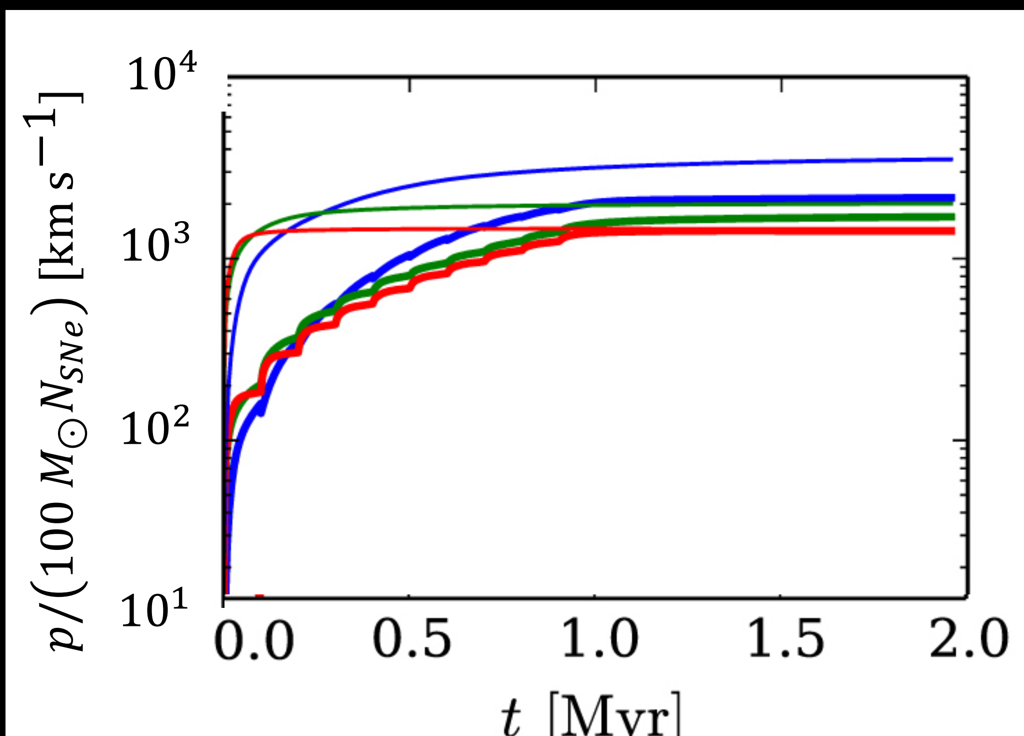
$$\frac{p}{N} \sim N^{-.08}$$

Data:

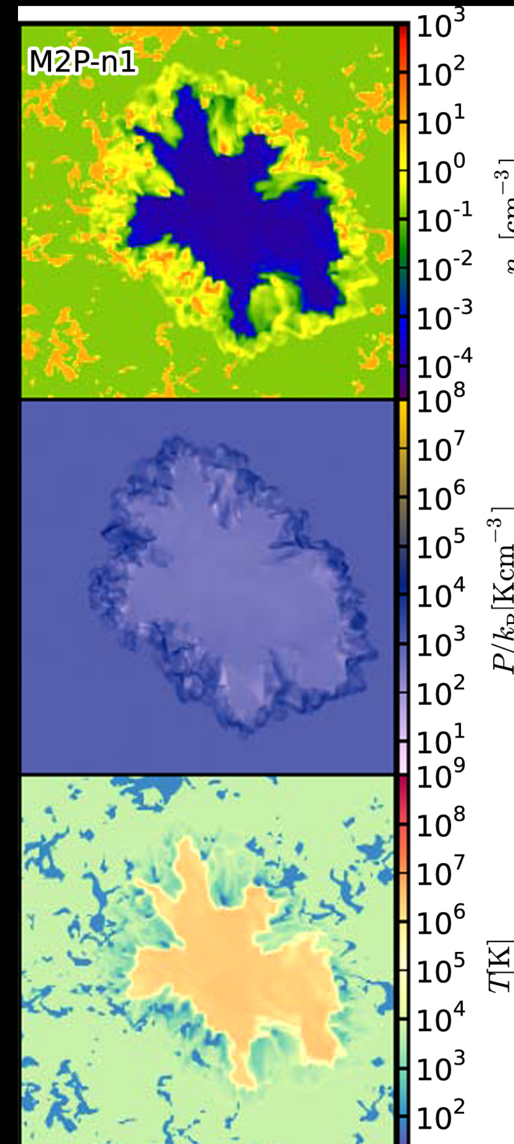
$$\frac{p}{N} \sim N^{-.07\pm.02}$$

Uncertainties

- 2 phase media?
  (CG Kim&Ostriker+15, CG Kim et al. in prep.)

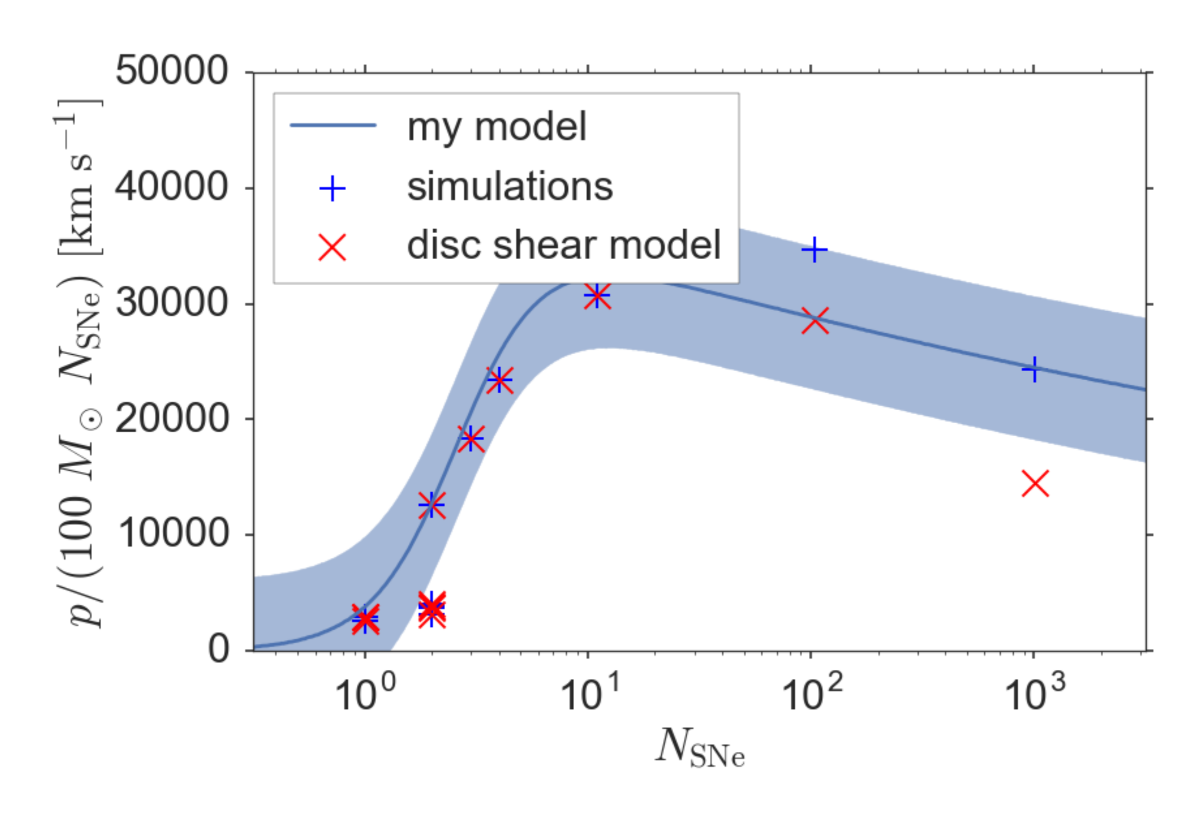


10 SNe simulation



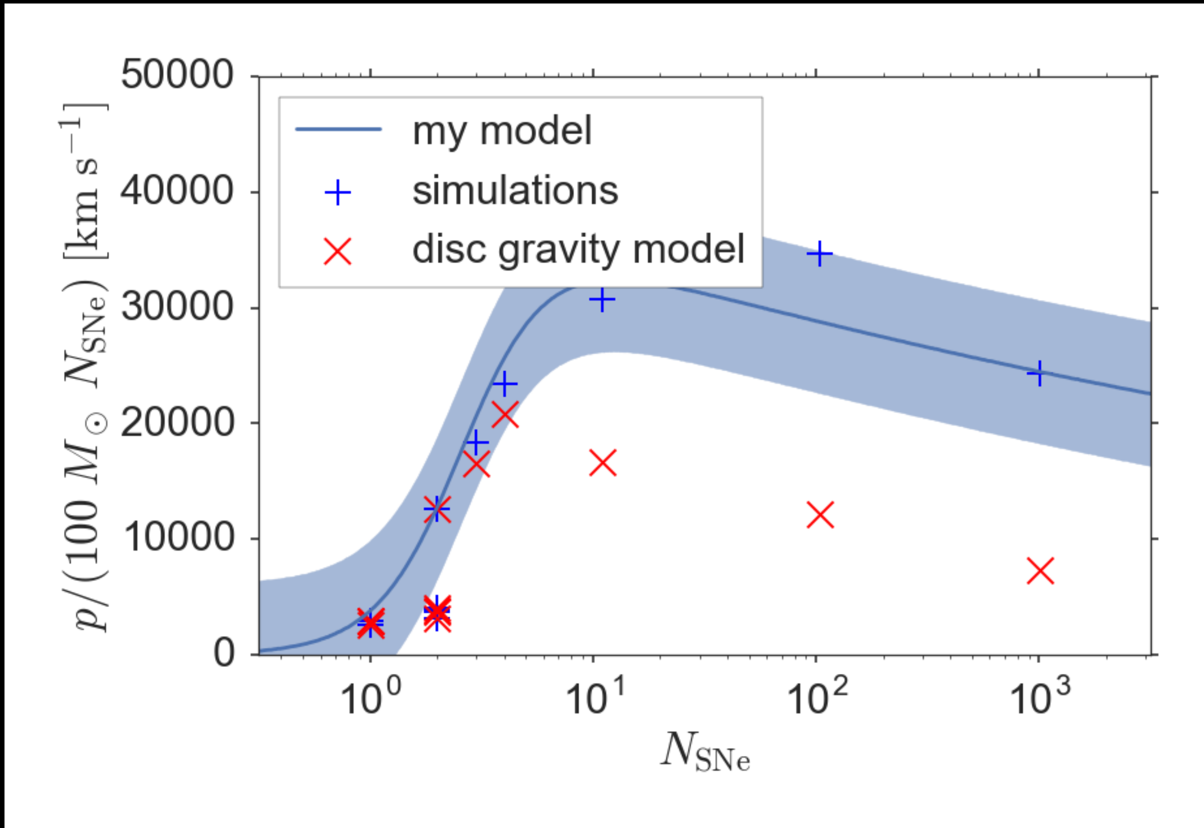
Uncertainties

- 2 phase media? (CG Kim&Ostriker+15, CG Kim et al. in prep.)
- Disk shear?



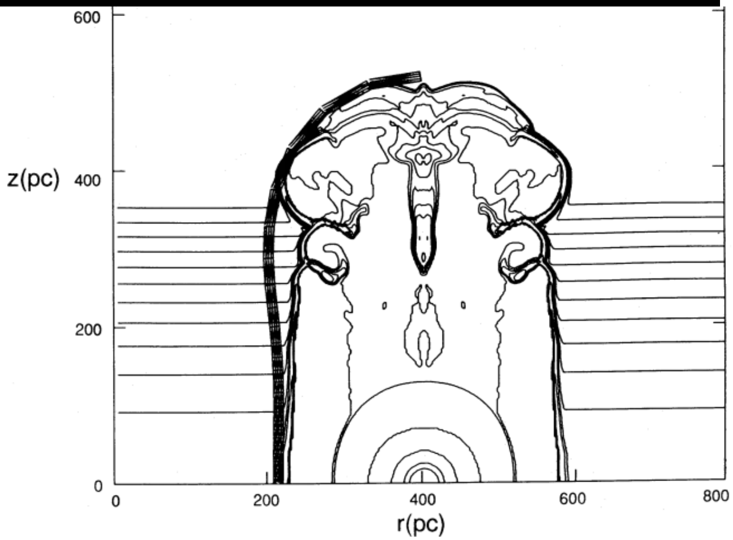
Uncertainties

- 2 phase media? (CG Kim&Ostriker+15, CG Kim et al. in prep.)
- Disk shear?
- Galactic gravity?

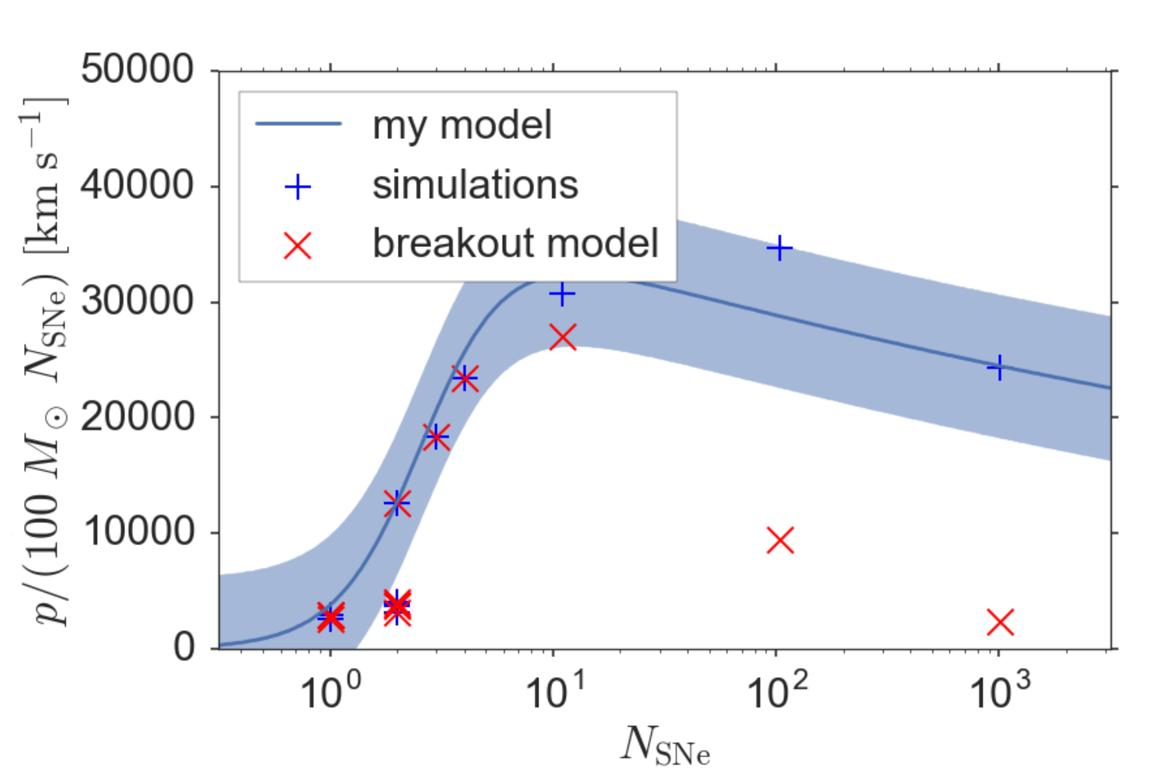


Uncertainties

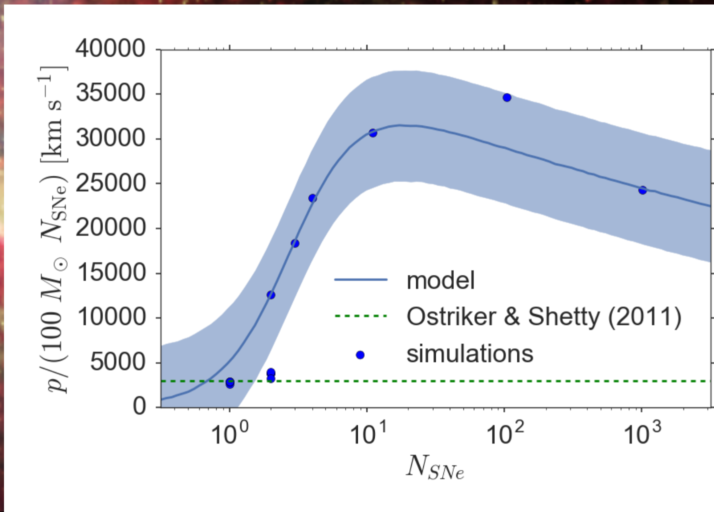
- 2 phase media? (CG Kim&Ostriker+15, CG Kim et al. in prep.)
- Disk shear?
- Galactic gravity?
- Disk breakout?



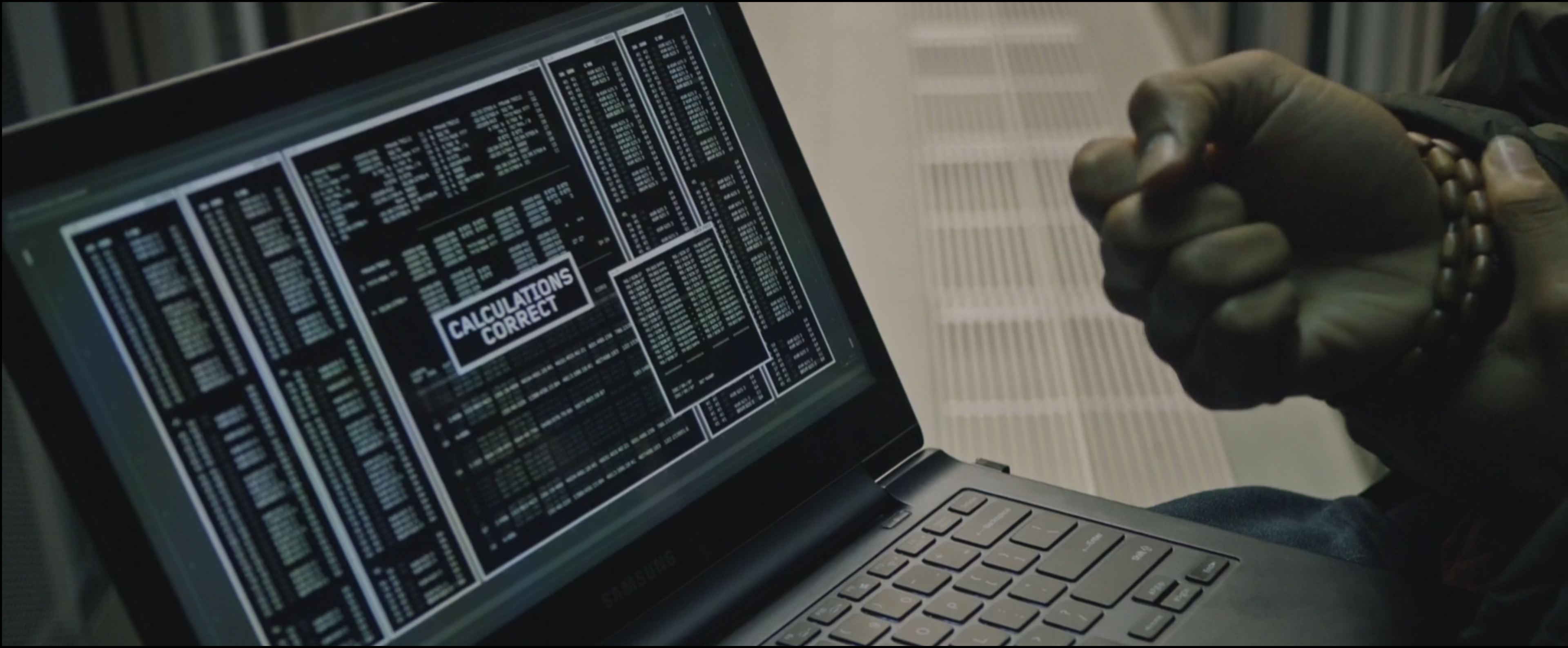
Mac Low+89



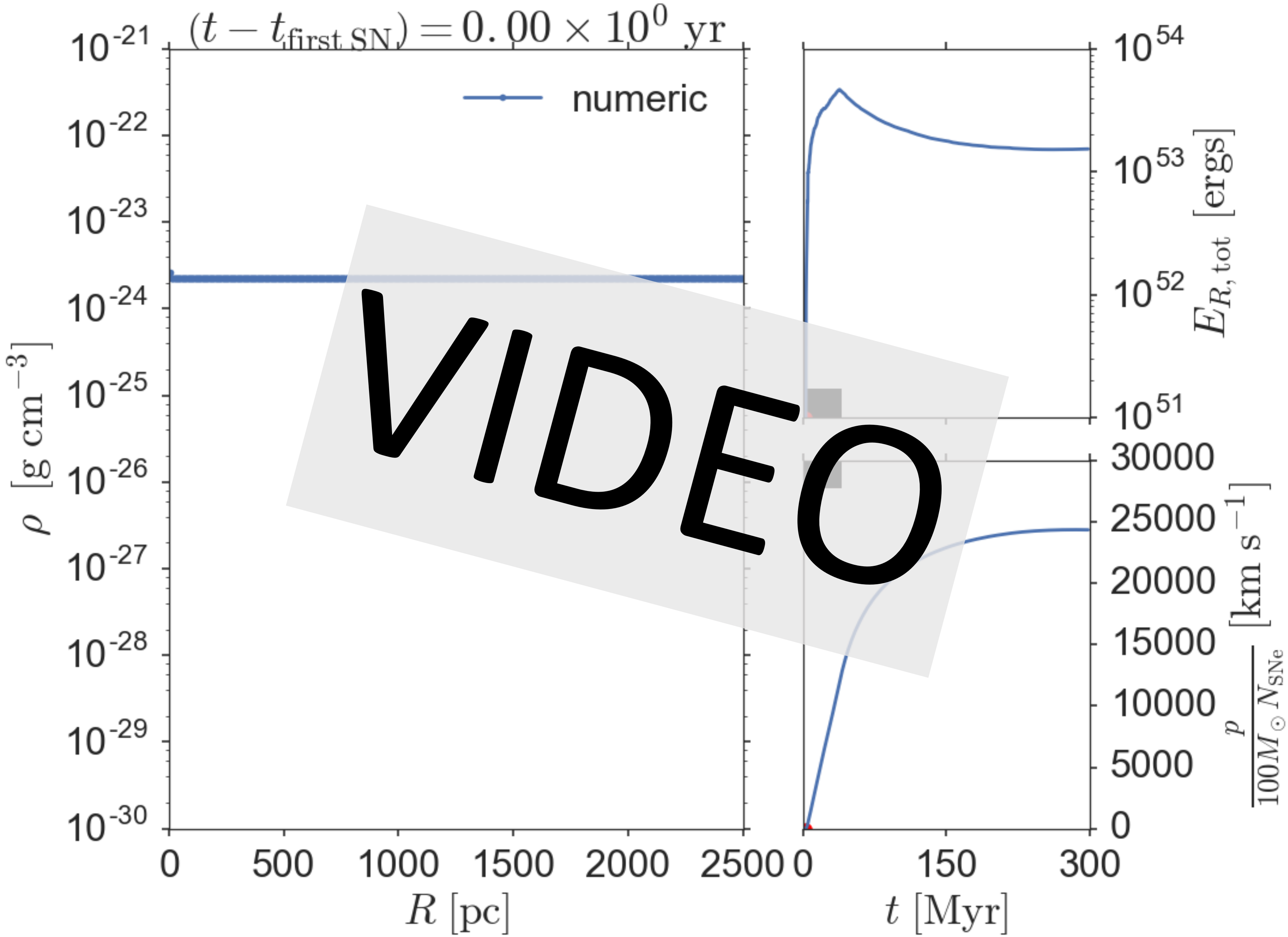
Summary & Case Study



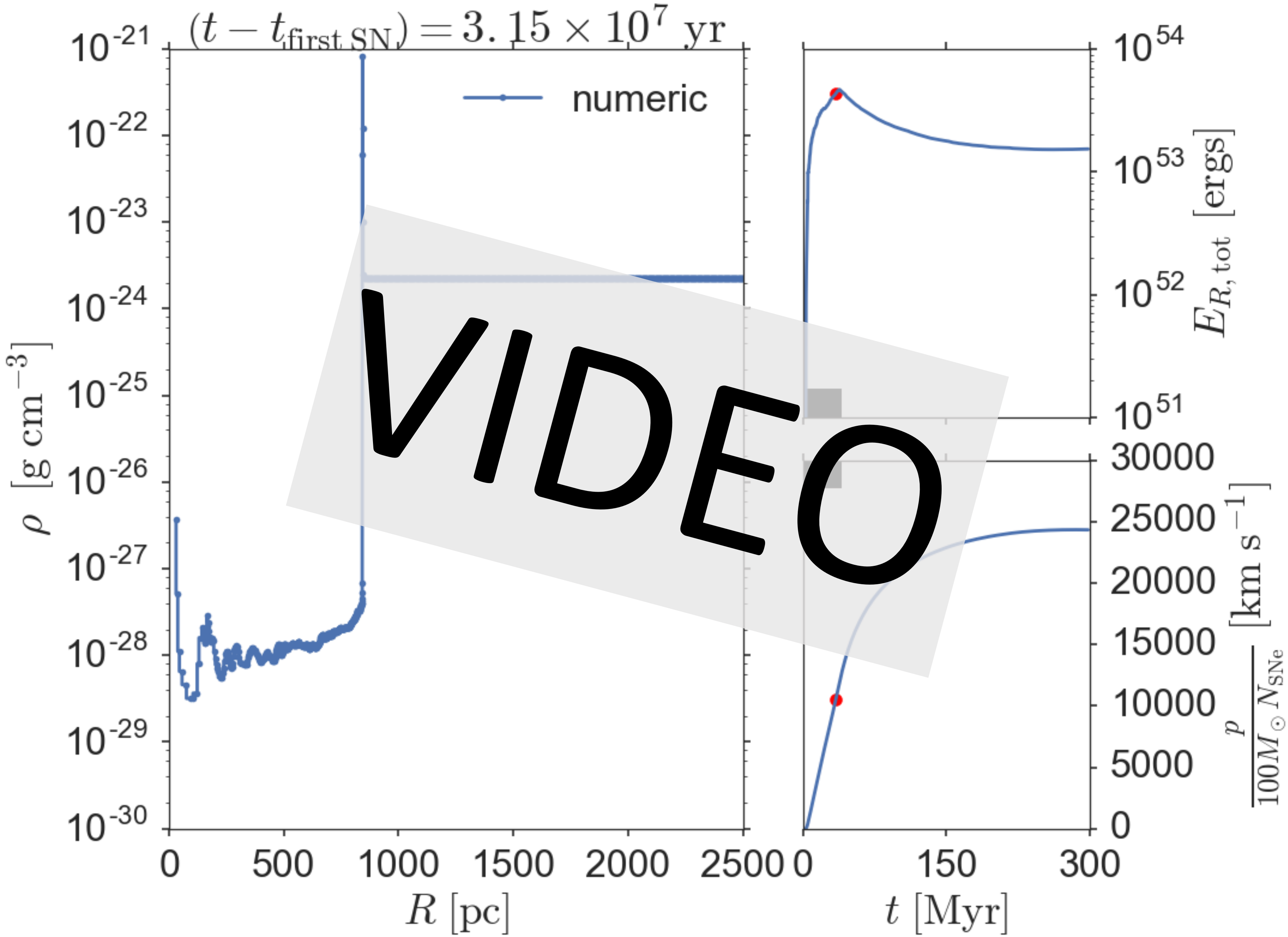
- Clustered SNe in R136 could increase momentum budget by 10x
- Bubble would grow to 1 kpc over 150 Myr
  - LMC size: 4 kpc
  - Bubble evolution not easily separable from galactic evolution
- SNe momentum budget remains quite uncertain



Additional Slides

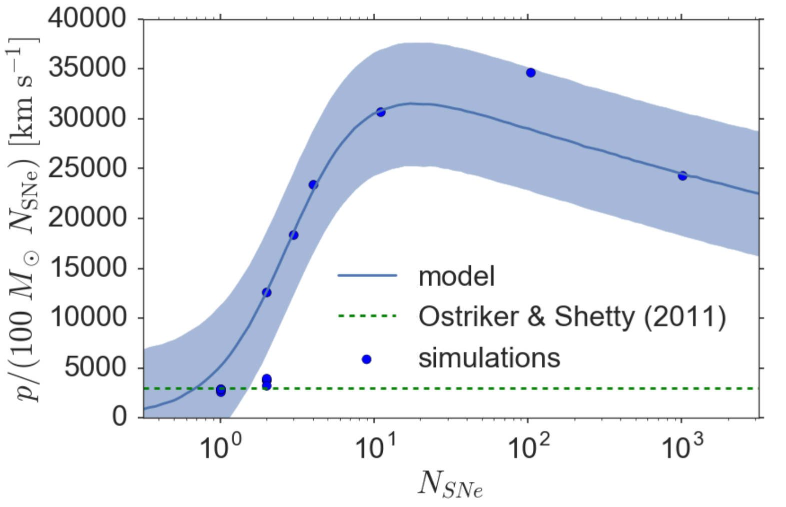


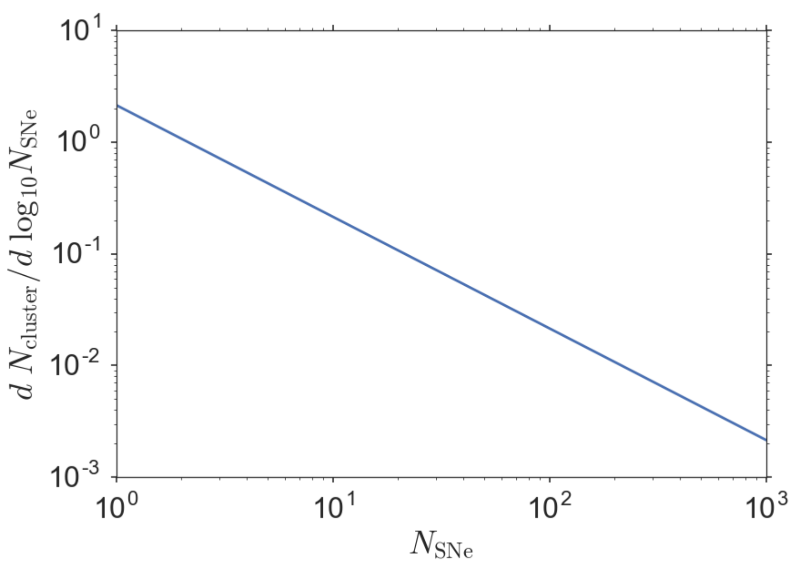
Gentry+16 (in prep.)



Gentry+16 (in prep.)

More momentum than expected!





Peak:
30,000

Expected:
3,000

$$\frac{dN_{\text{cluster}}}{dM_{\text{cluster}}} \propto M^{-2}$$

$$\frac{dN_{\text{cluster}}}{dN_{\text{SNe}}} \propto N_{\text{SNe}}^{-2}$$

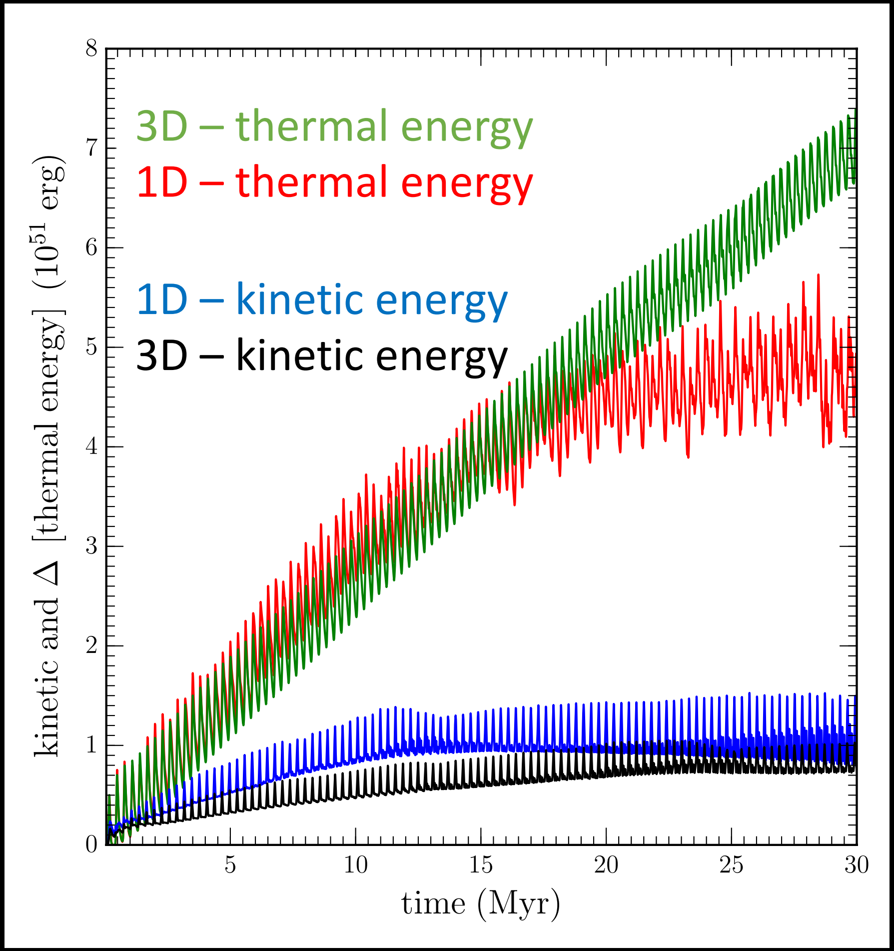
$$\frac{dN_{\text{cluster}}}{d\log N_{\text{SNe}}} \propto N_{\text{SNe}}^{-1}$$

$$\left(\langle N_{\text{SNe}}\rangle = 6\right)$$

$$\frac{\langle \frac{p}{N_{\text{SNe}}} N_{\text{SNe}}\rangle}{\langle N_{\text{SNe}}\rangle} = 25{,}000 \pm 1{,}000\ \frac{100 M_\odot\ \text{km}}{s}$$

Effects of 3D vs. 1D?

Low Res. (2.5 pc)

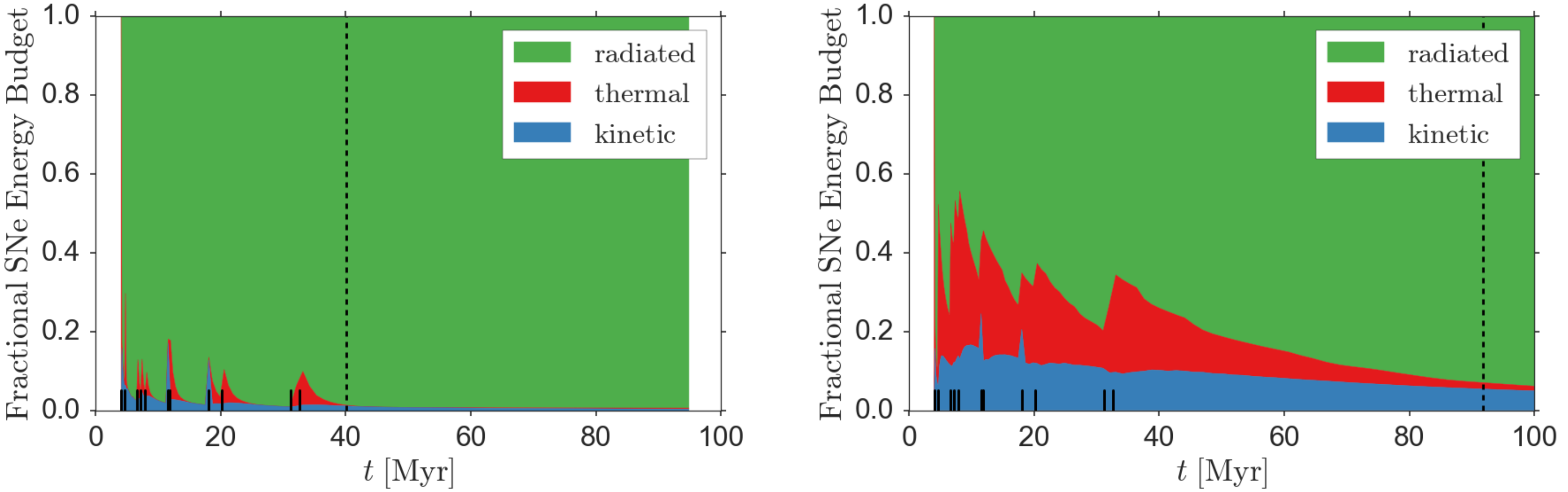


Yadav+16 (submitted)

Low resolution leads to overcooling

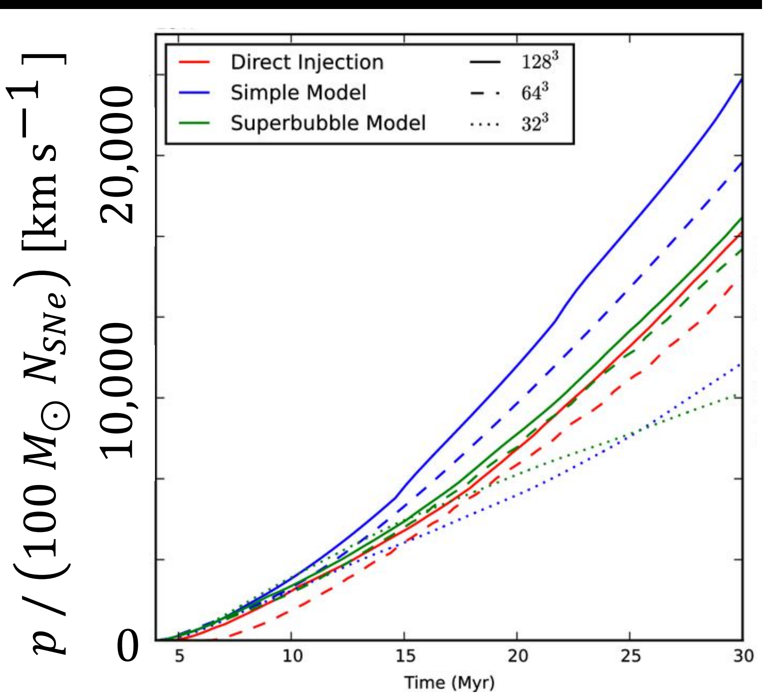
Eulerian (2.5 pc)

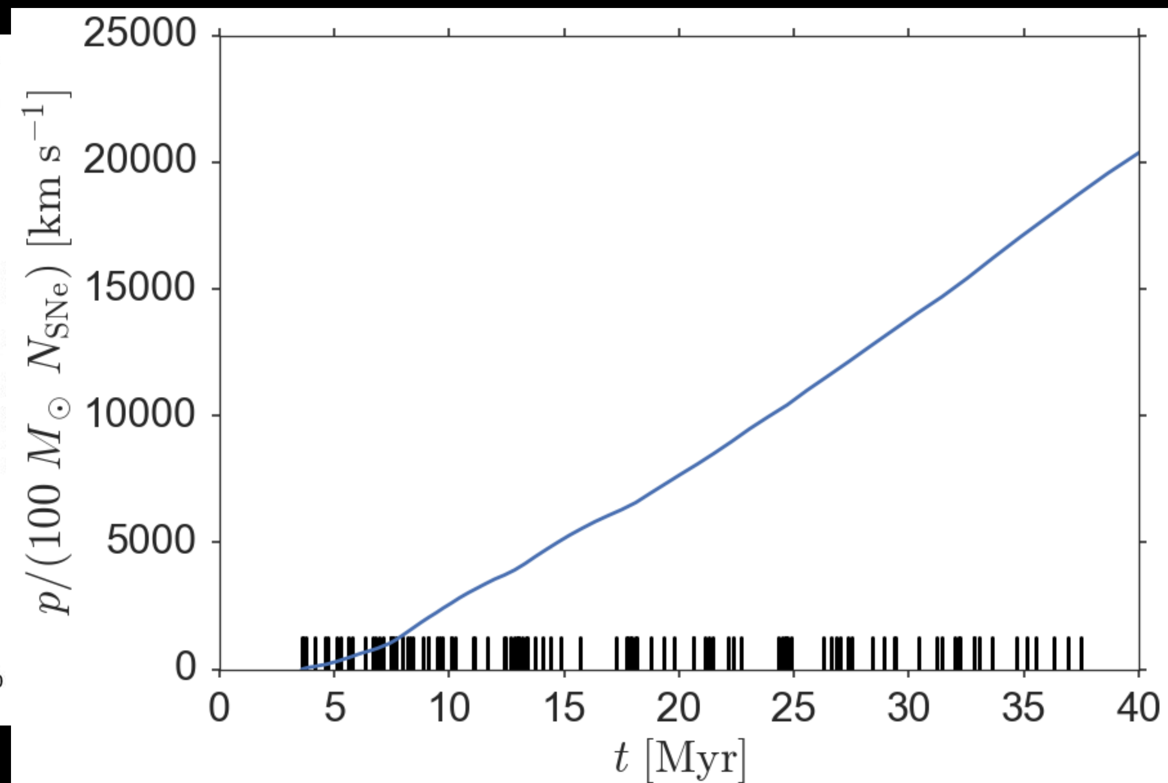
Lagrangian (0.06 pc)



Gentry+16

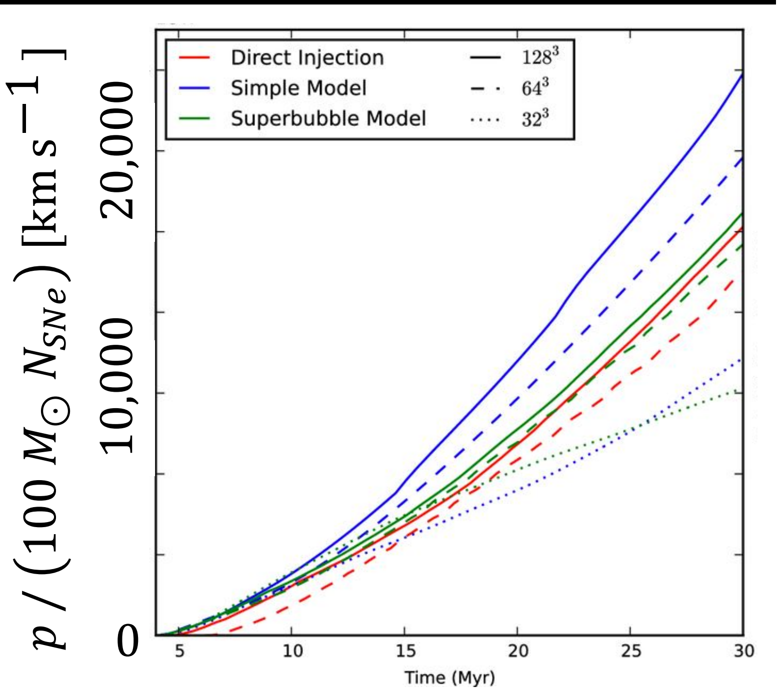
Comparison to Keller+14



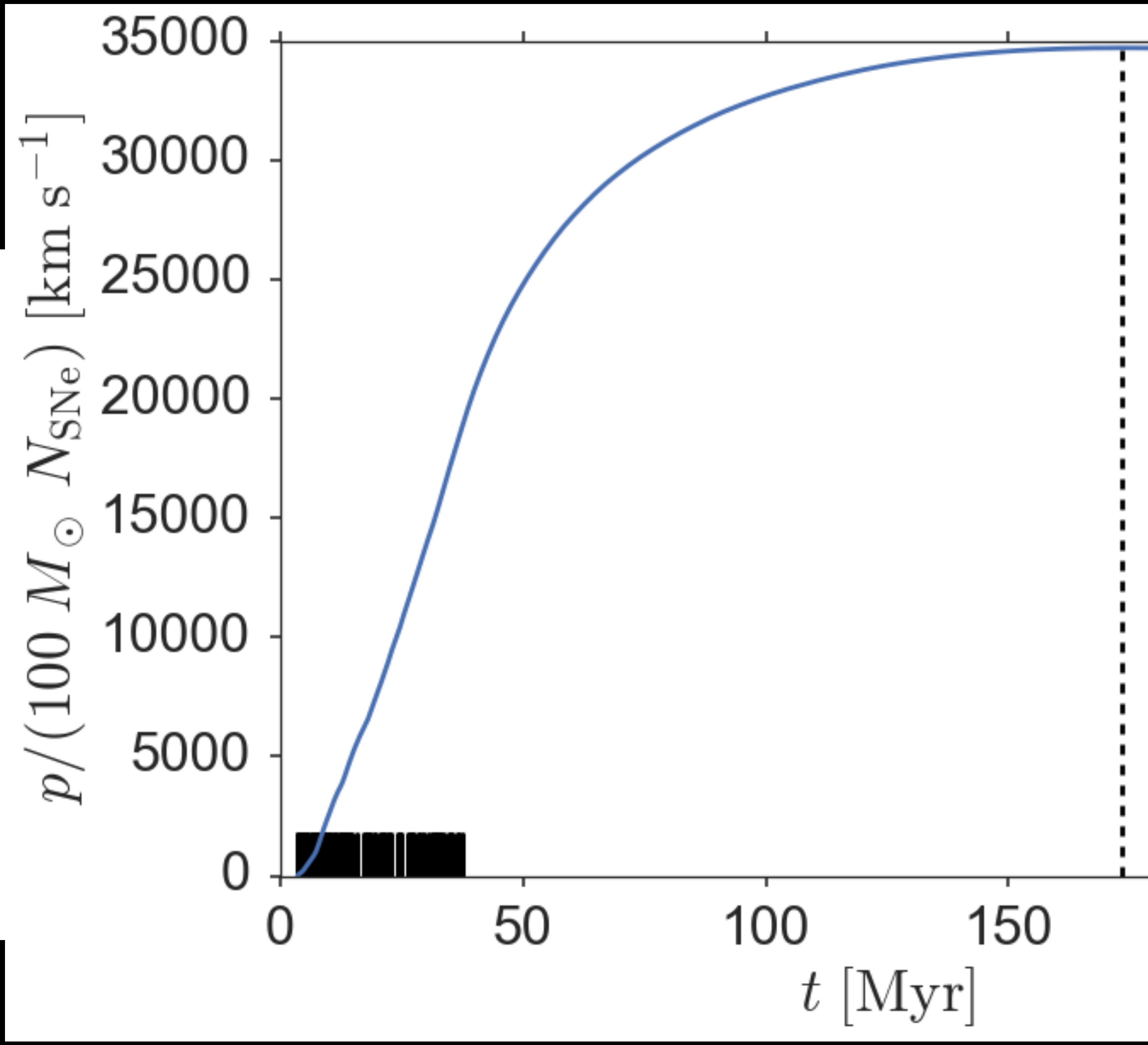


Keller+14

Comparison to Keller+14



Keller+14



Other stellar feedback: Pre-SN HII Regions

Ionizing radiation from massive stars creates HII regions

HII regions expand, adding momentum and decreasing the gas density

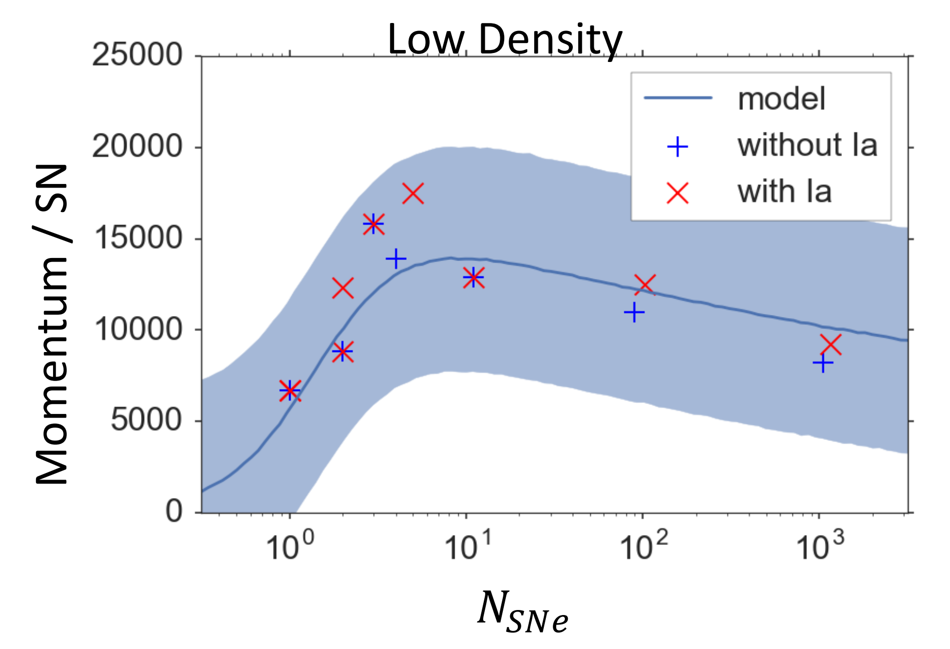
This directly adds momentum

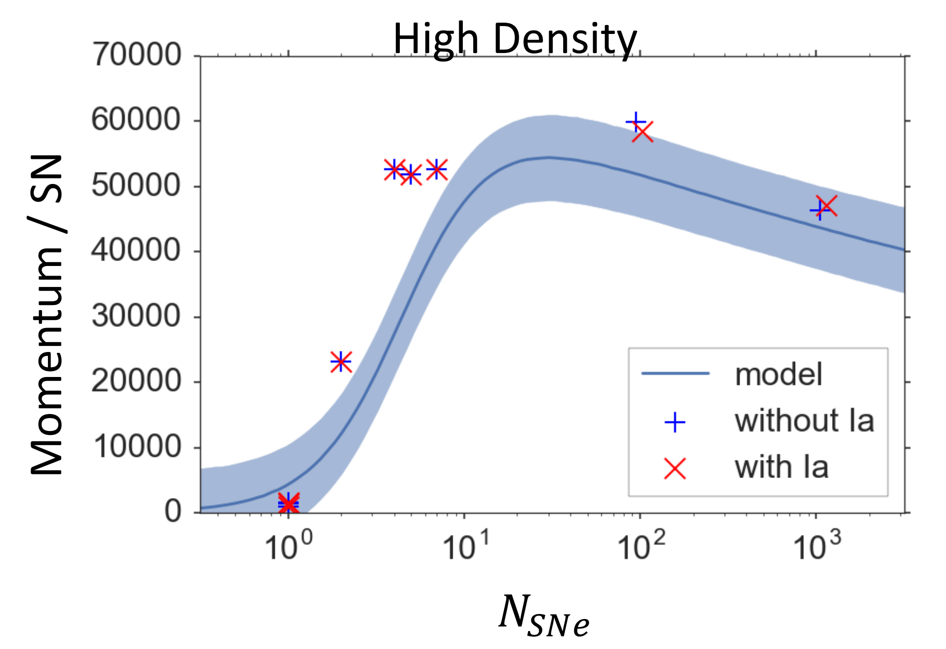
- $p_{HII} \lesssim 50\% \, p_{SNe}$

This changes effective density

- Changes momentum by a few percent

Other stellar feedback: Type Ia SNe





Type Ia SNe can have an impact,
But that impact is smaller than the model's uncertainties