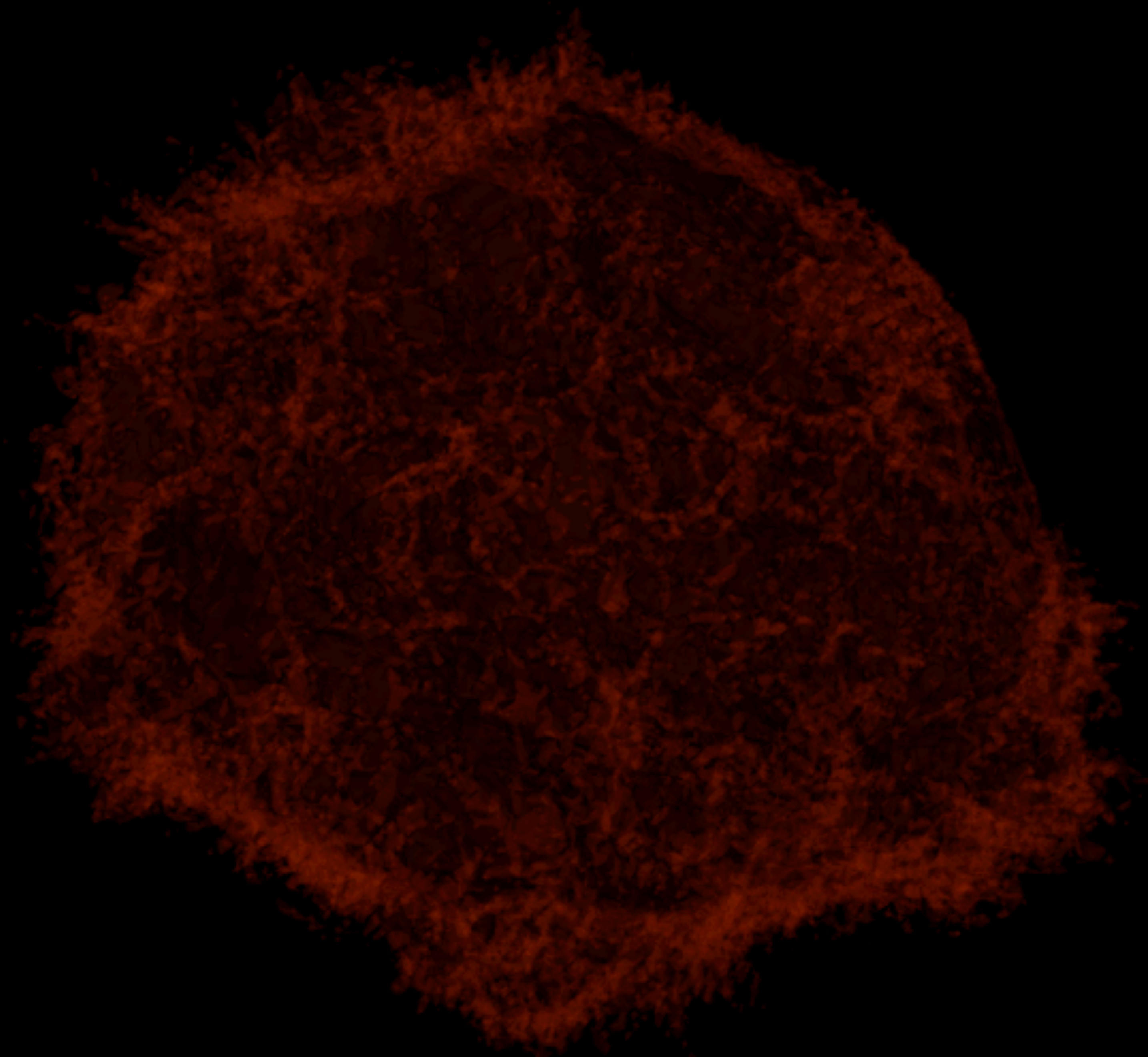
monte carlo transport with the sedona code: improvements and applications

daniel kasen



sedona code

3-D time-dependent multi-wavelength
monte carlo radiation transport

applications

modeling the light curves/spectra of
various supernovae and transients
e.g., type Ia, type II, pair instability, ".Ia" explosions,
neutron star mergers, accretion induced collapse

major assumptions

homologous expansion ($v \propto r$)
no coupling to hydrodynamics
radiative/thermodynamic equilibrium

radiation hydrodynamics techniques and test problems

some monte carlo challenges

- short timescales for radiation/gas coupling
  implicit monte carlo methods
  (e.g., Fleck and Cummings 1971)

$$t \sim \frac{\lambda_p}{c}\frac{nkT}{aT^4}$$

- monte carlo inefficiency at high optical depth
  hybrid discrete diffusion techniques
  (e.g., Gentile 2001, Densmore 2007)
- random noise (esp. in radiation dominated regime)
  smoothing? population control (particle splitting)?
- domain decomposition parallelization
  time step limiter? load balancing? AMR?

coupling to hydrodynamic codes

a monte carlo transport module can be coupled (with little modification) to either lagrangian or eulerian codes using any coordinate systems

1D spherical lagrangian

(artificial viscosity, von neumann-richtmeyer)

1D/2D/3D cartesian eulerian

(split, piecewise linear, HLL solver)

3D state of the art AMR code?

mixed frame transport

particles are propagated in the lab frame, but the opacities/emissivities and scattering/absorption events are calculated in the comoving frame.

$$\nu_0 = \gamma\nu(1 - \mathbf{d}\cdot\mathbf{v}/c)$$

$$\chi = \gamma\chi_0(1 - \mathbf{d}\cdot\mathbf{v}/c)$$

$$\mathbf{d}_0 = \left(\mathbf{d} - \frac{\gamma\mathbf{v}}{c}\left[1 - \frac{\gamma\mathbf{d}\cdot\mathbf{v}/c}{\gamma+1}\right]\right)\left[\gamma(1 - \mathbf{d}\cdot\mathbf{v}/c)\right]^{-1}$$

particle lorentz transformations

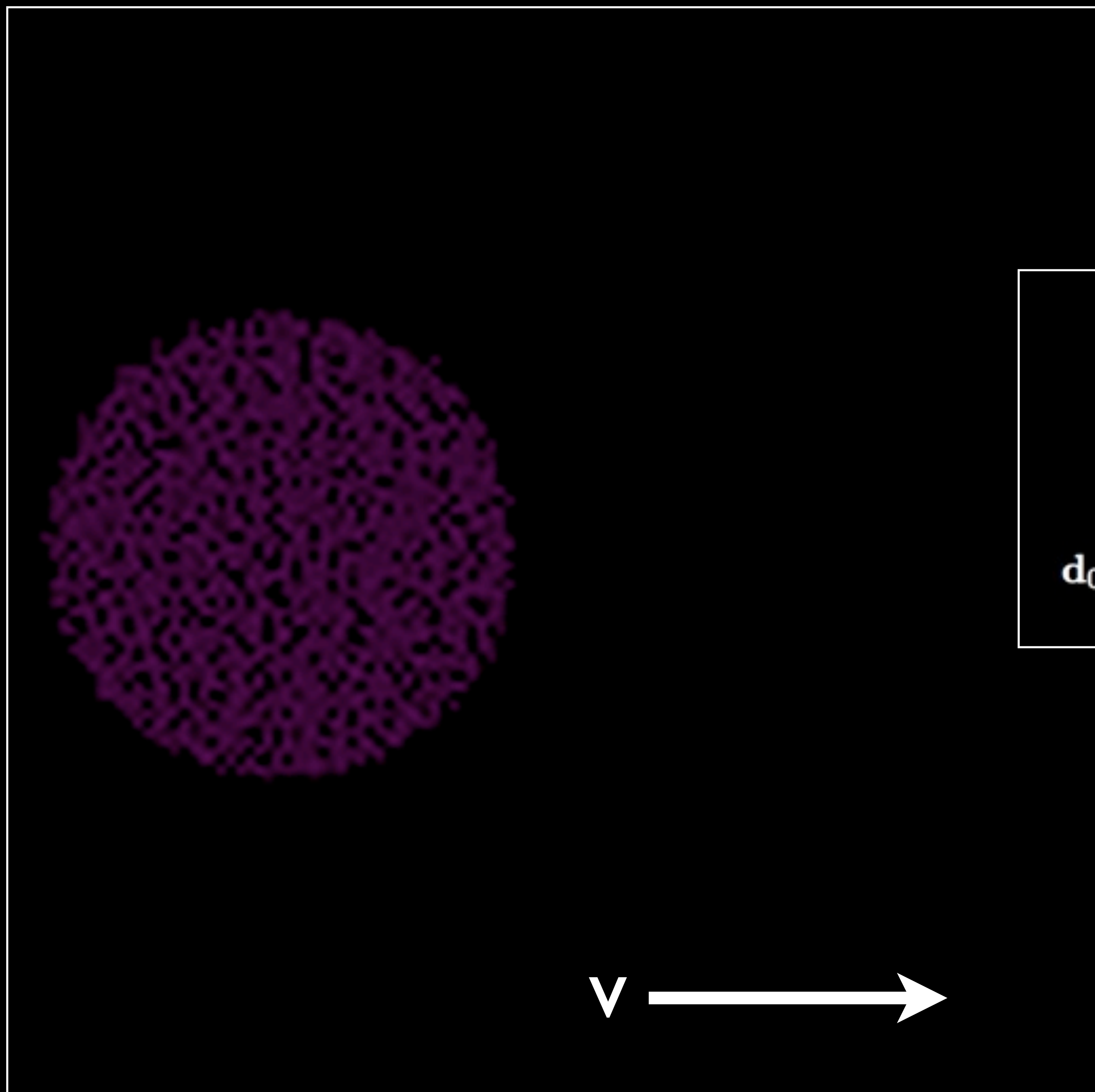
$$G^0_0 = \left[\frac{1}{V\Delta t}\sum_i \epsilon_0 l_i \chi_0(\nu_0)\right] - \chi_0 a T_g^4$$

$$G^i_0 = \frac{1}{cV\Delta t}\sum_i \epsilon_0 l_i \chi_0(\nu_0) d^i_0$$

radiation four-force vector

advected radiation pulse

radiation in an optically thick, moving medium



$$\nu_0 = \gamma\nu(1 - \mathbf{d}\cdot\mathbf{v}/c)$$

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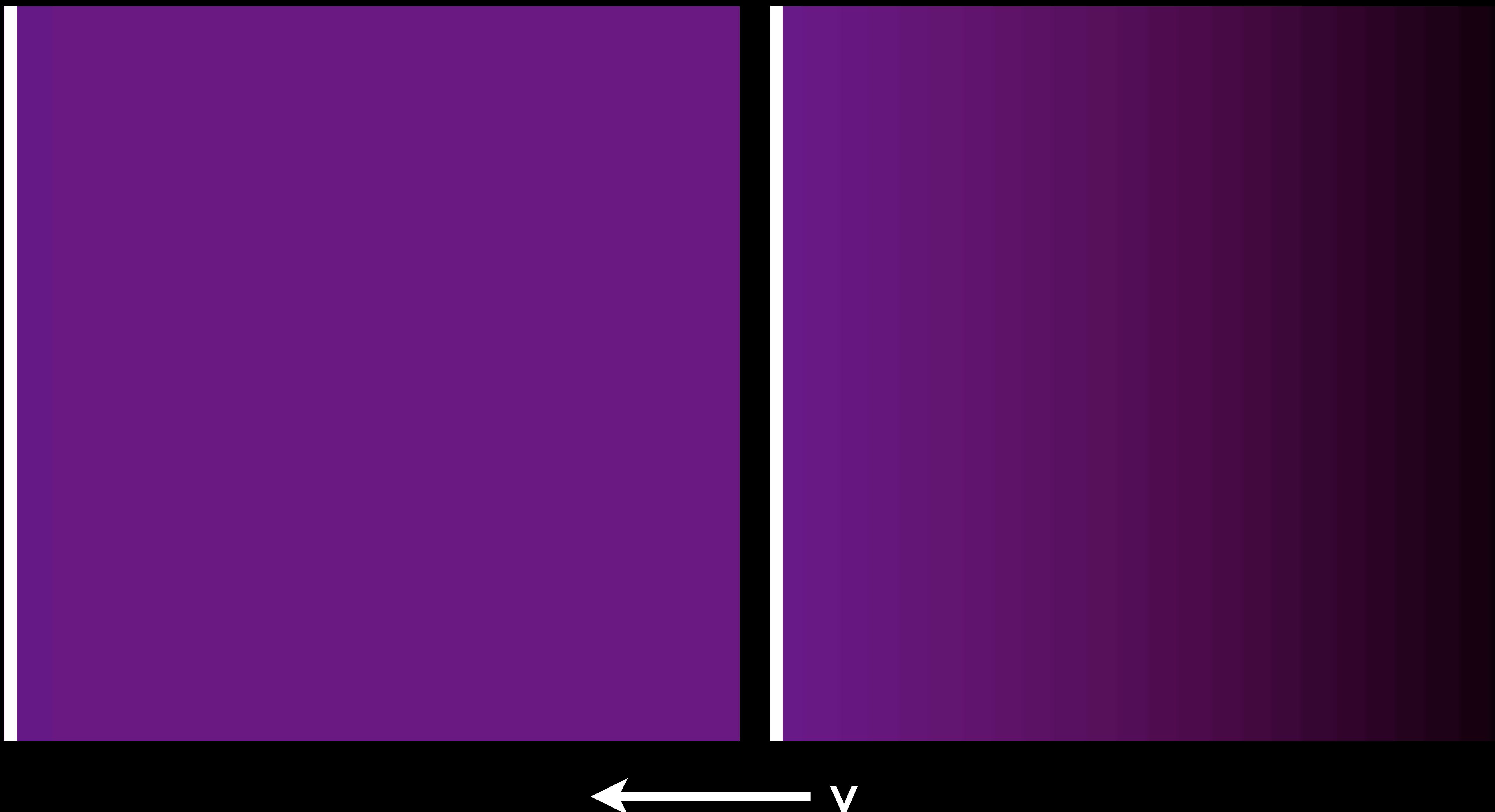
2-D radiative shock problem

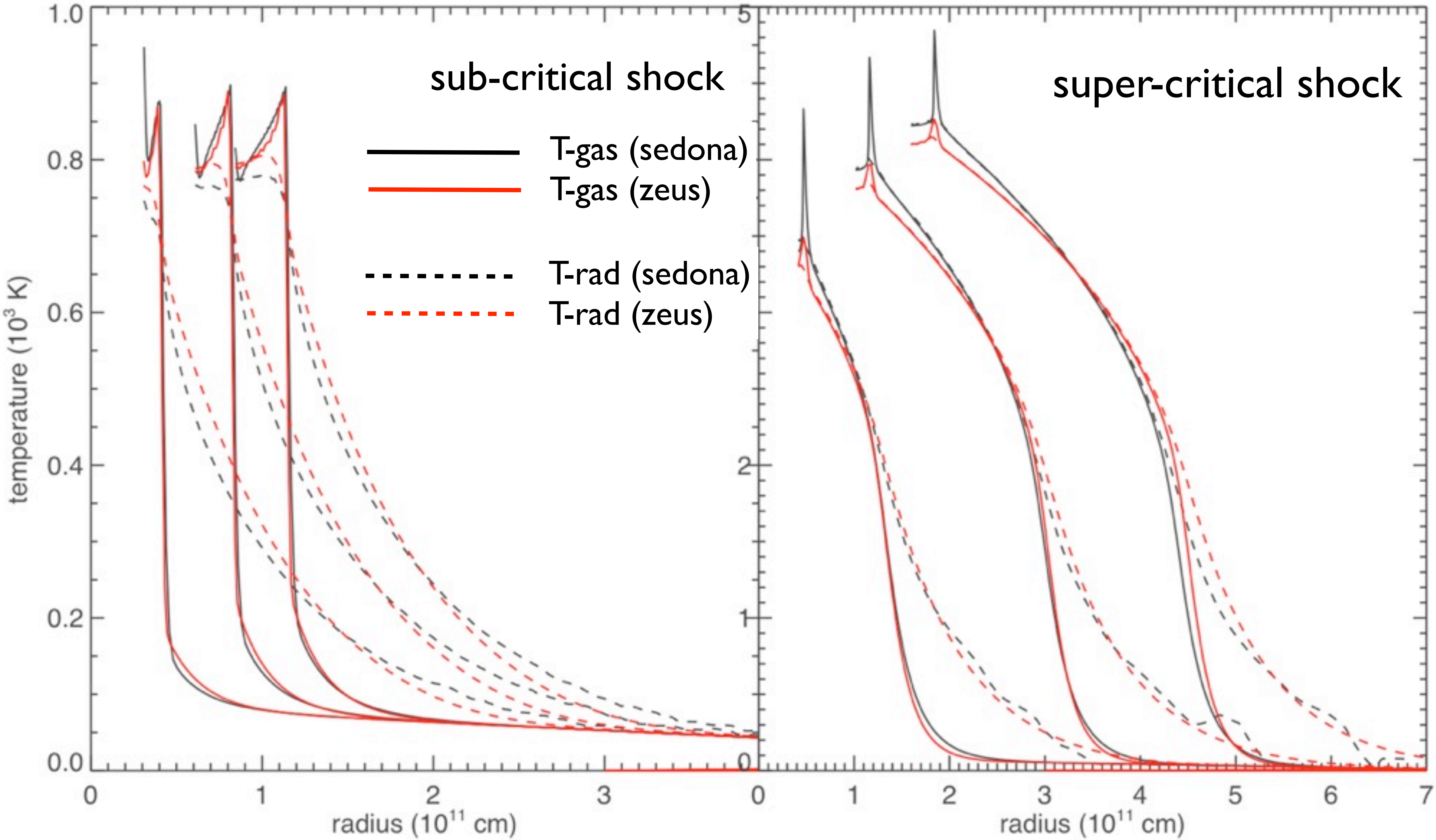
non-equilibirum - following ensman 1994

gas temperature | radiation temperature



1-dimensional radiative shock test

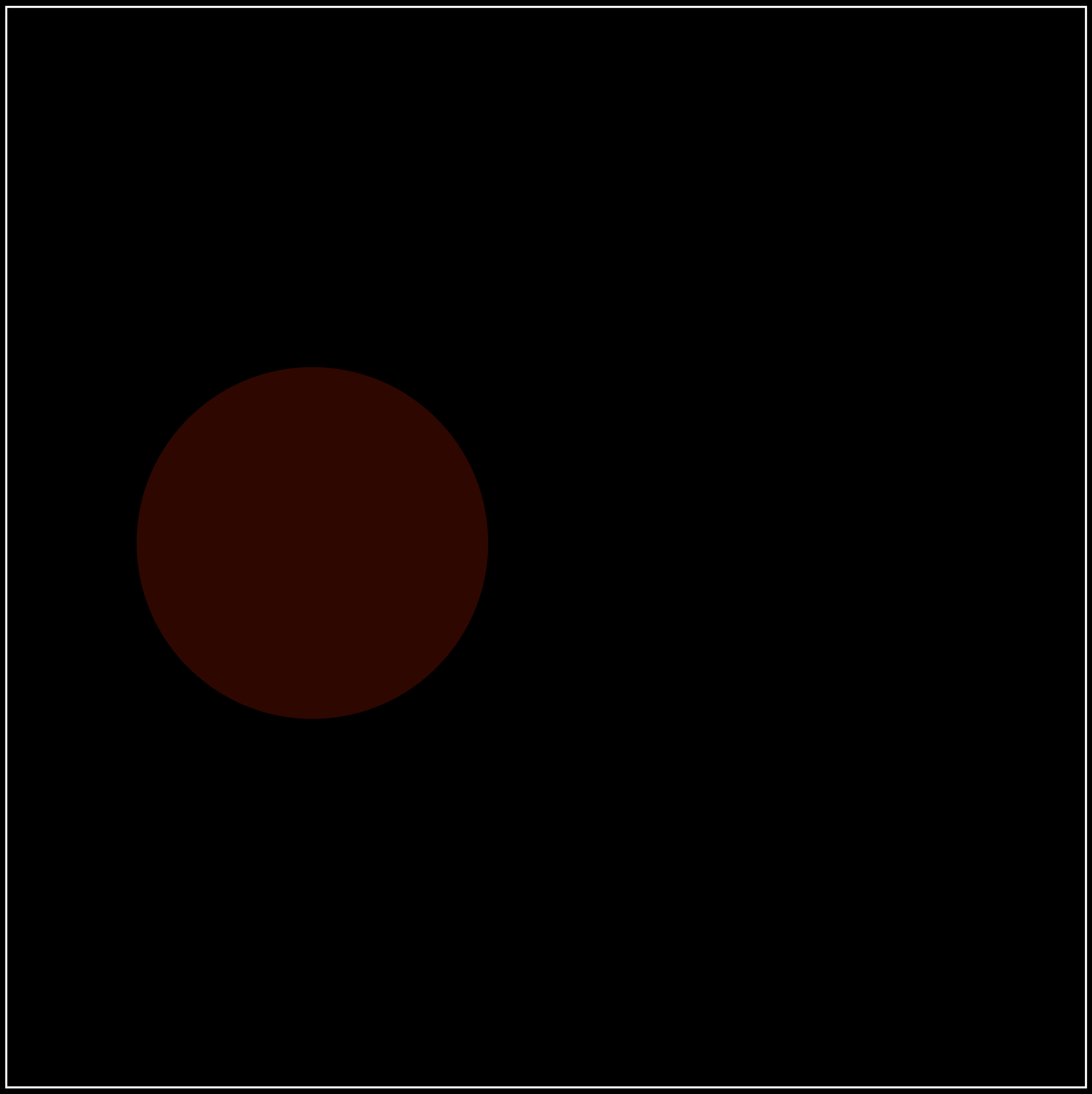
see ensman 1994, hayes & norman 2003



2-D shadow problem - monte carlo

hayes and norman, 2003

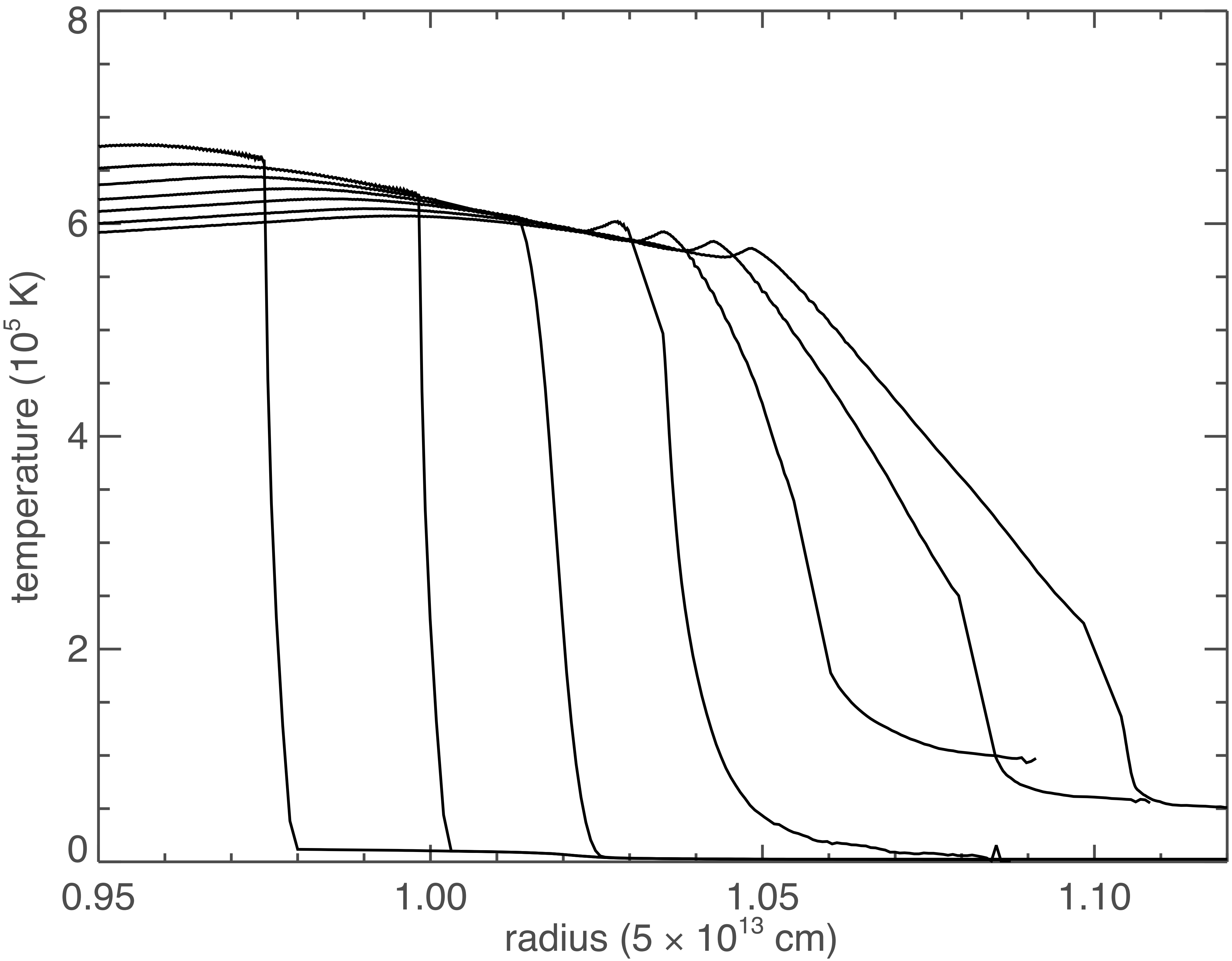
2-D shadow problem - discrete diffusion



some applications

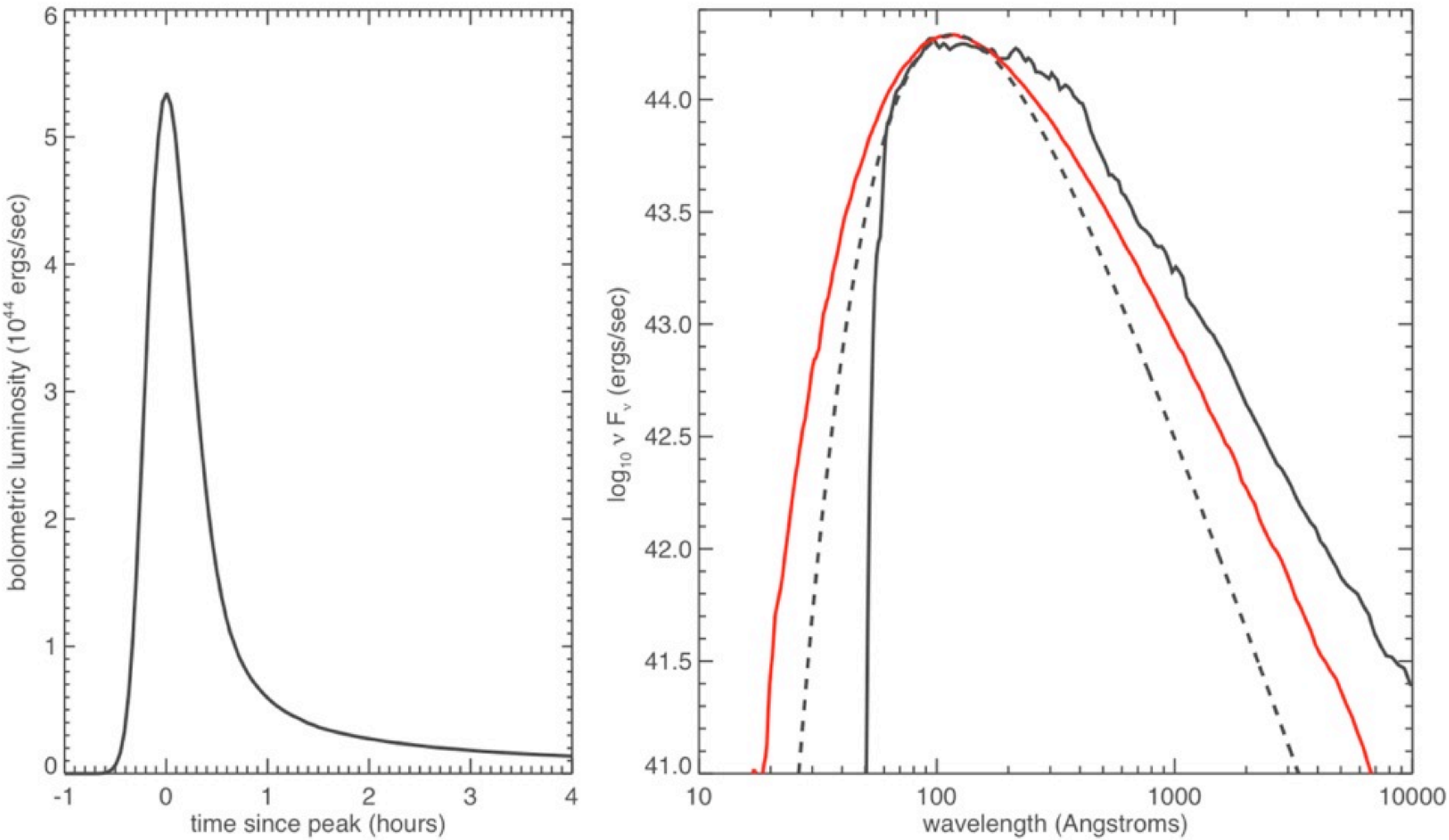
shock breakout in type IIP supernovae

e.g., klein and chevalier 1978, ensman & burrows 1992



shock breakout bursts

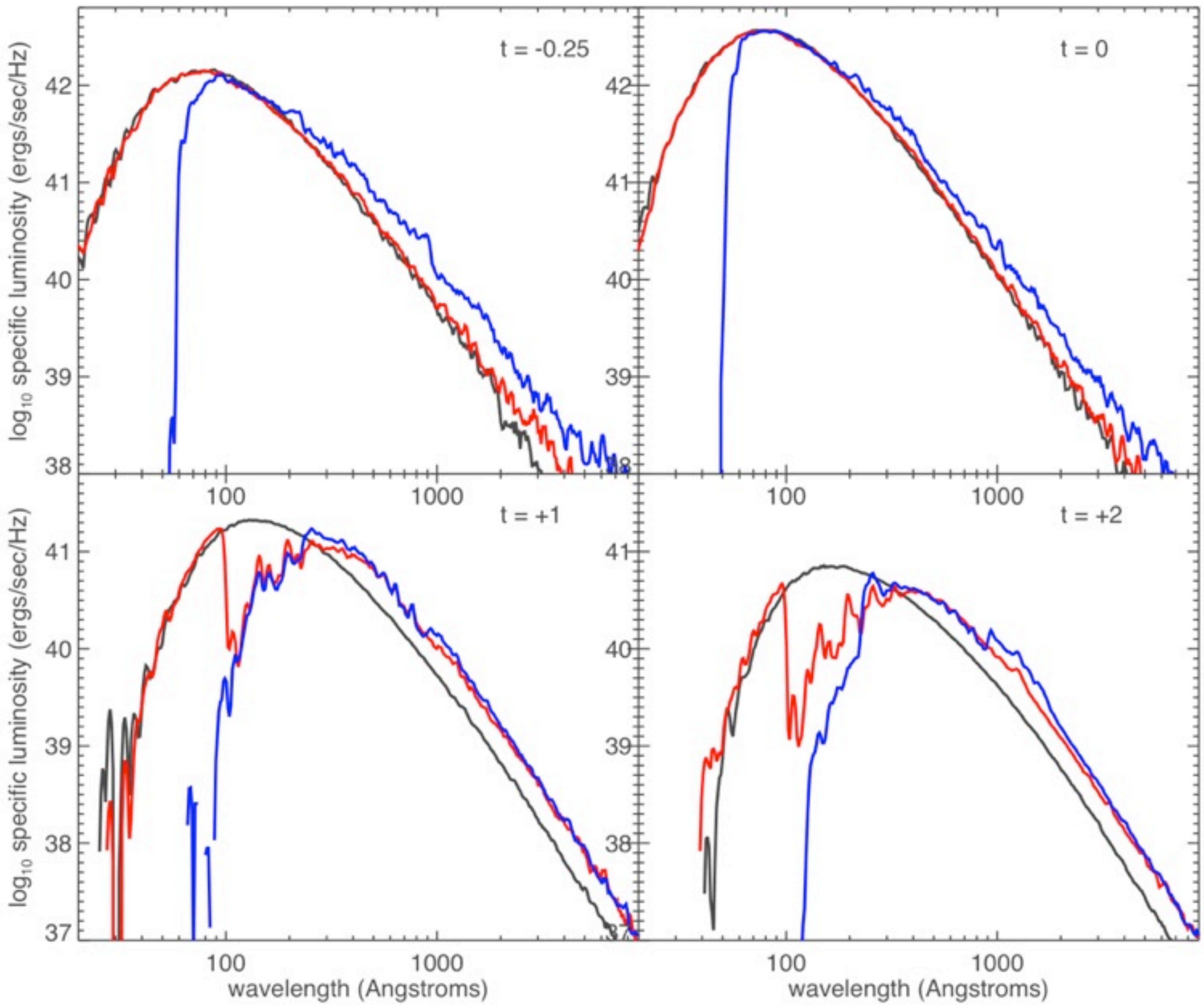
type IIP supernova breakout light curve and peak-averaged spectrum



kasen & woosley in prep

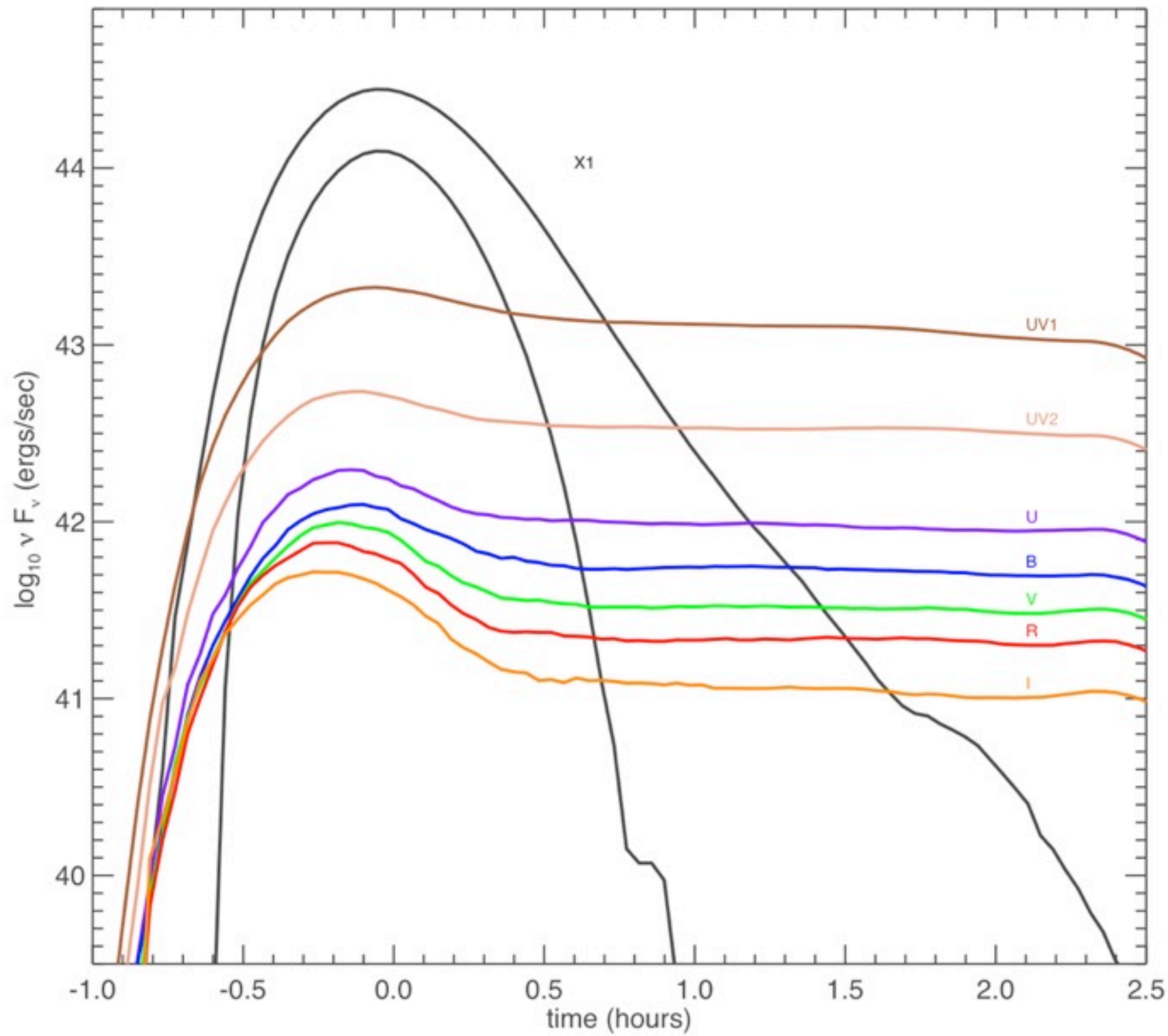
shock breakout spectral evolution

opacity: es, es+lines, es+lines+bound-free

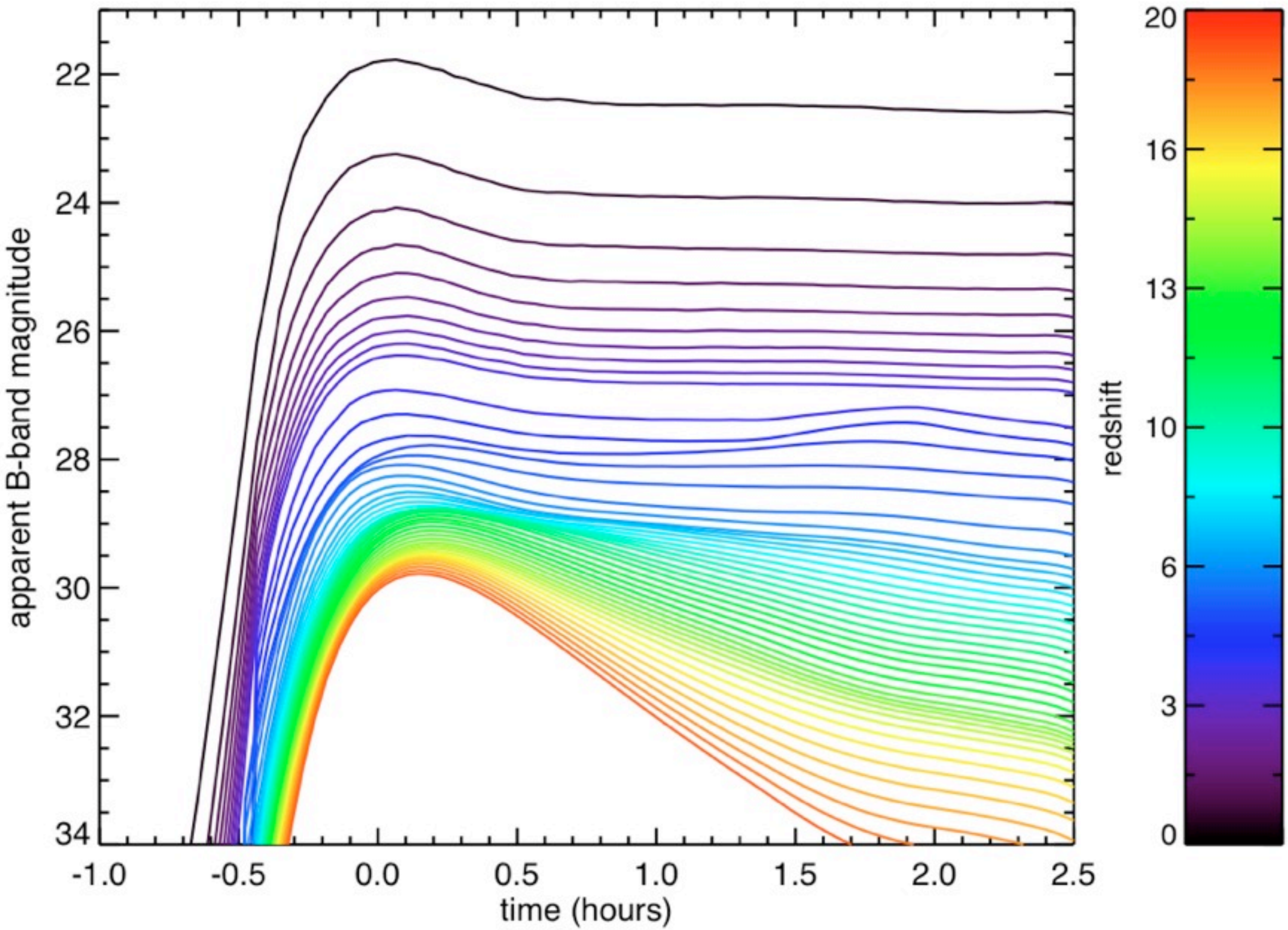


shock breakout - broadband light curves

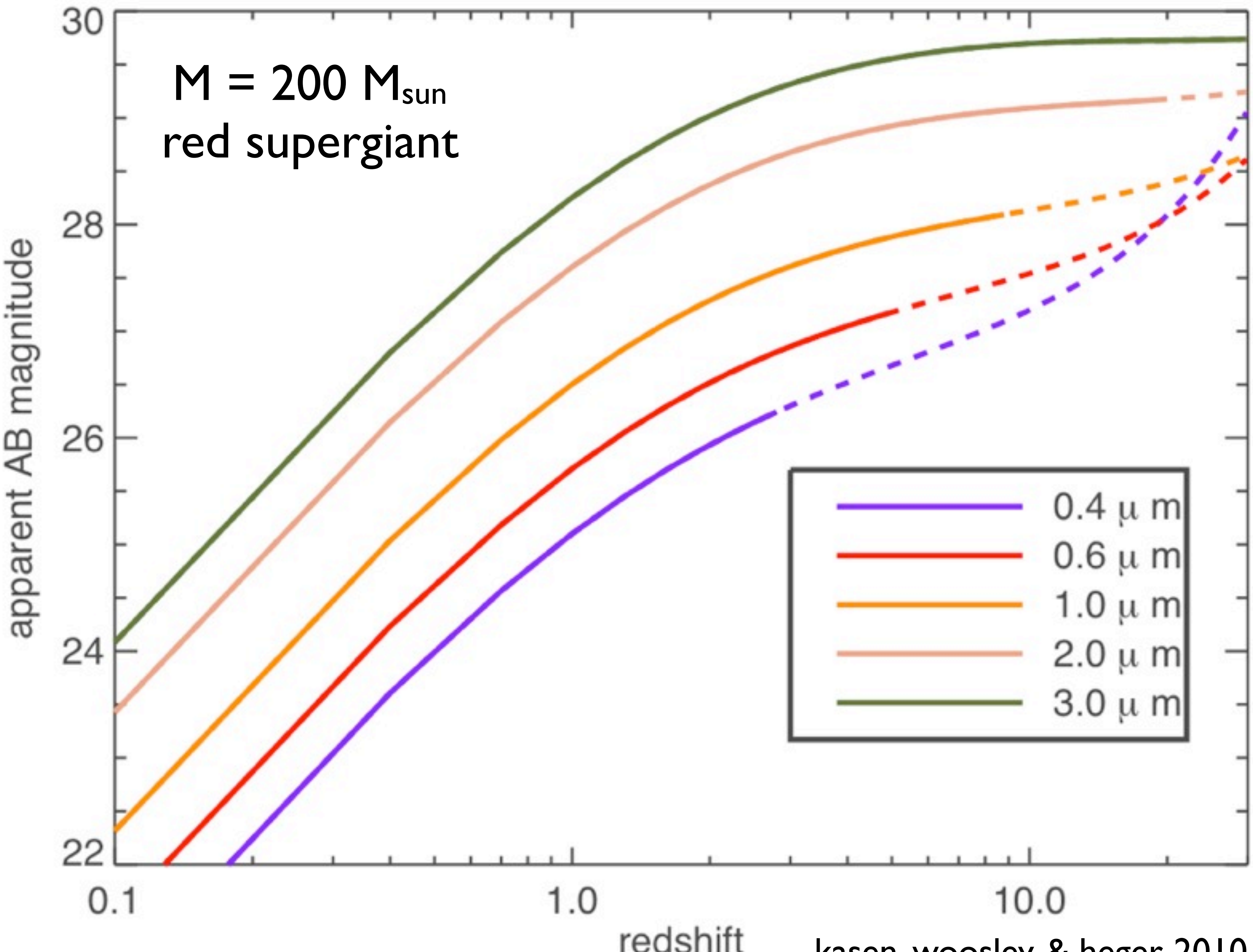
type IIP supernova model



appearance at high redshift

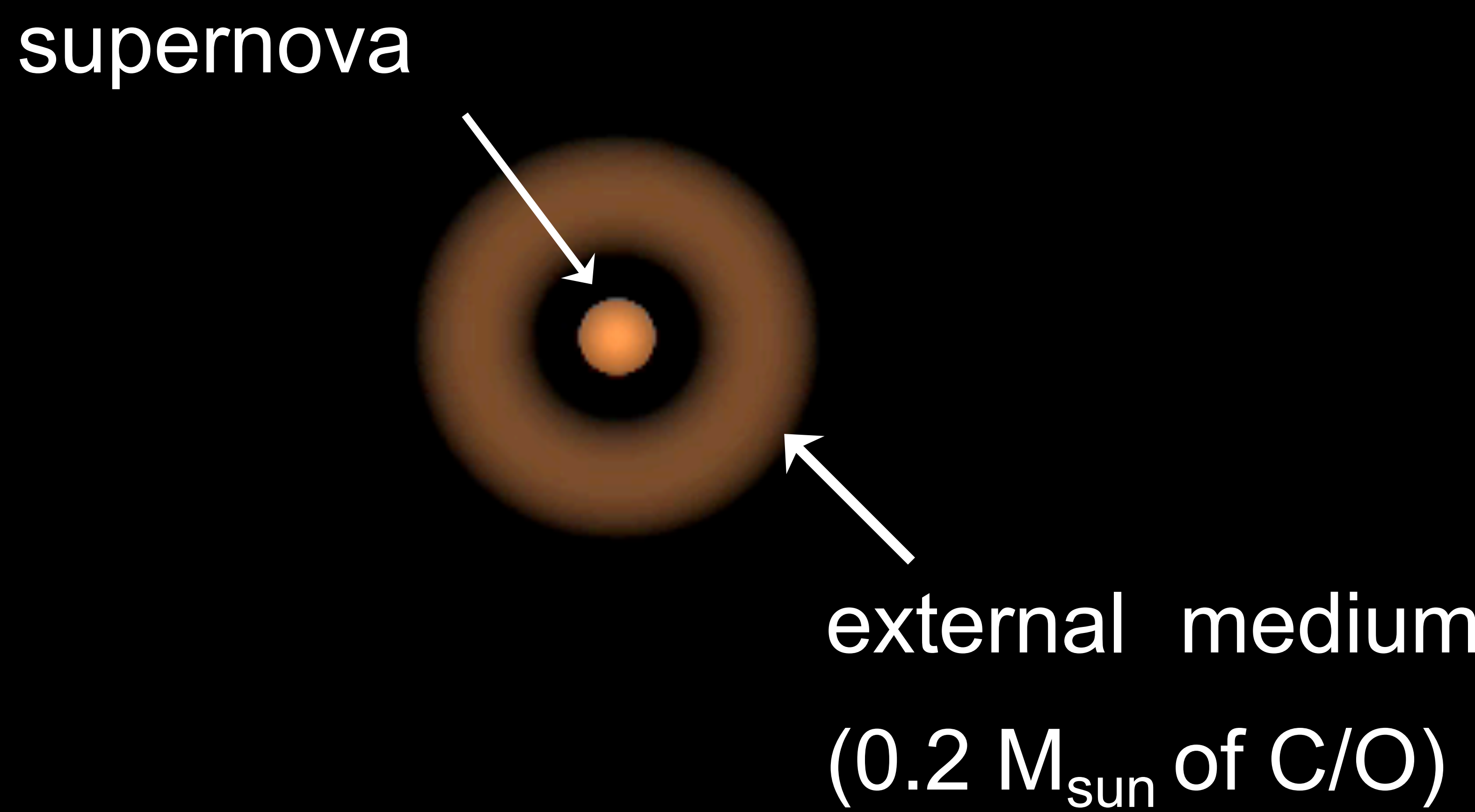


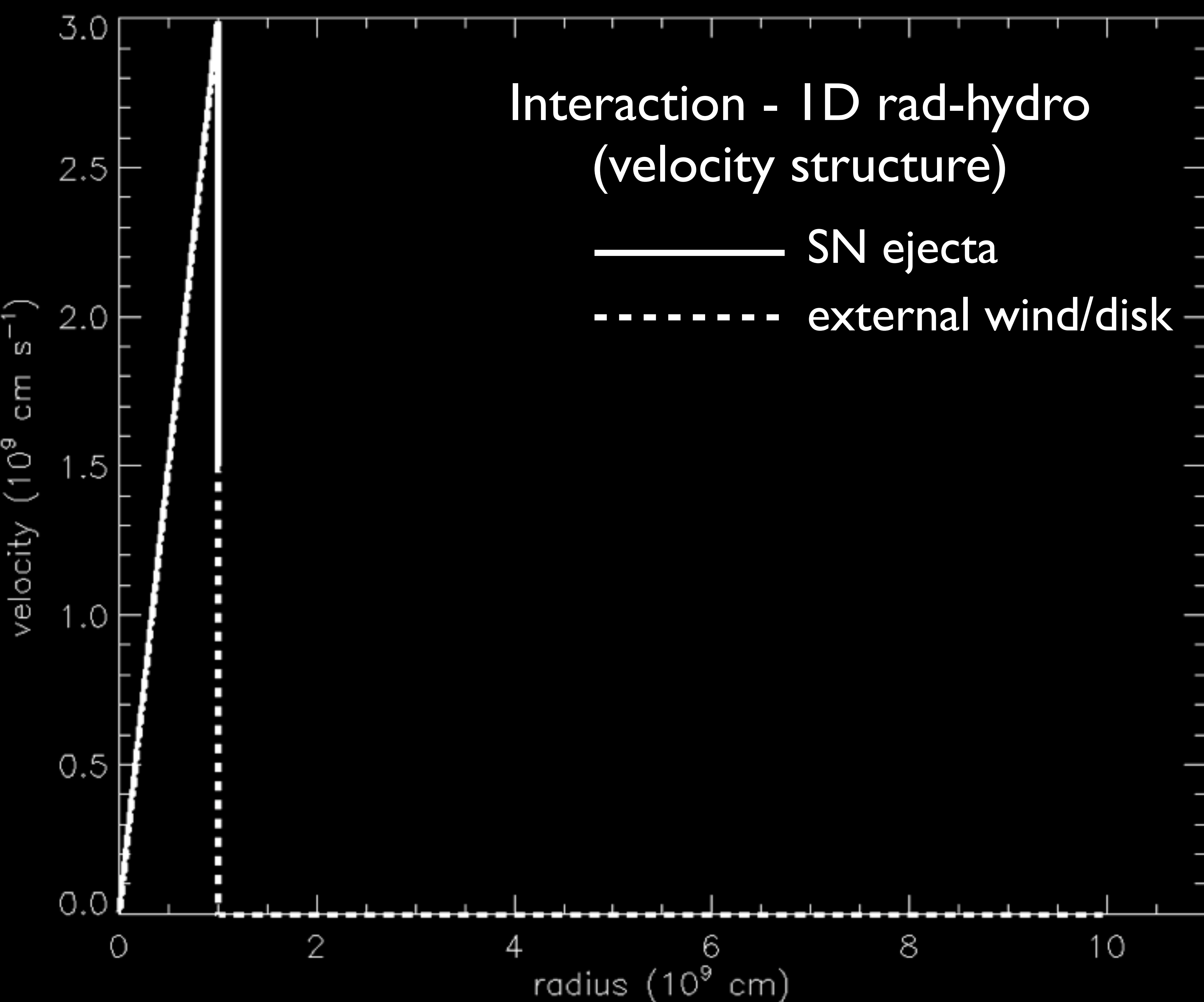
detectability of pair instability supernova shock breakout at high Z



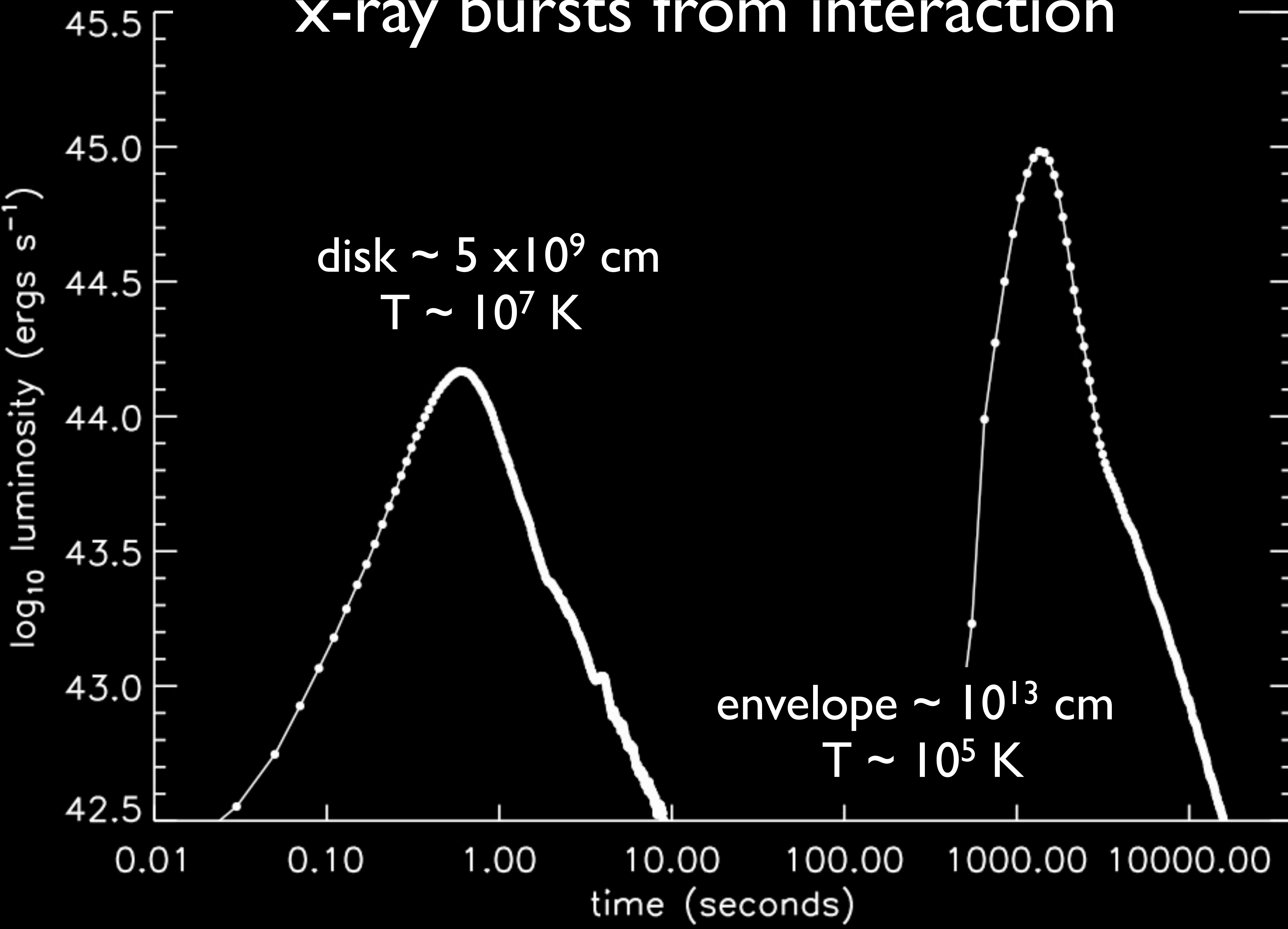
kasen, woosley, & heger, 2010 submitted

interaction with surrounding medium (wind, disk, envelope, debris etc...)



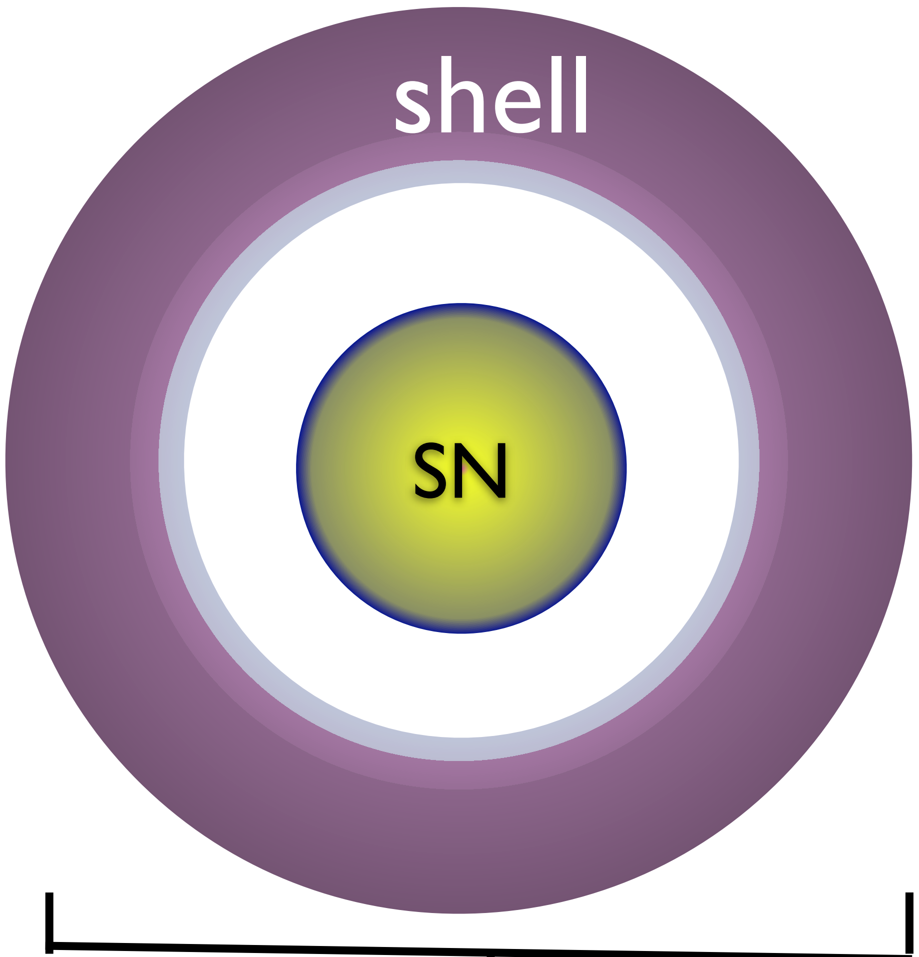

Interaction - 1D rad-hydro
(velocity structure)
SN ejecta
external wind/disk
velocity (10^9 cm s^{-1})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
radius (10^9 cm)

x-ray bursts from interaction



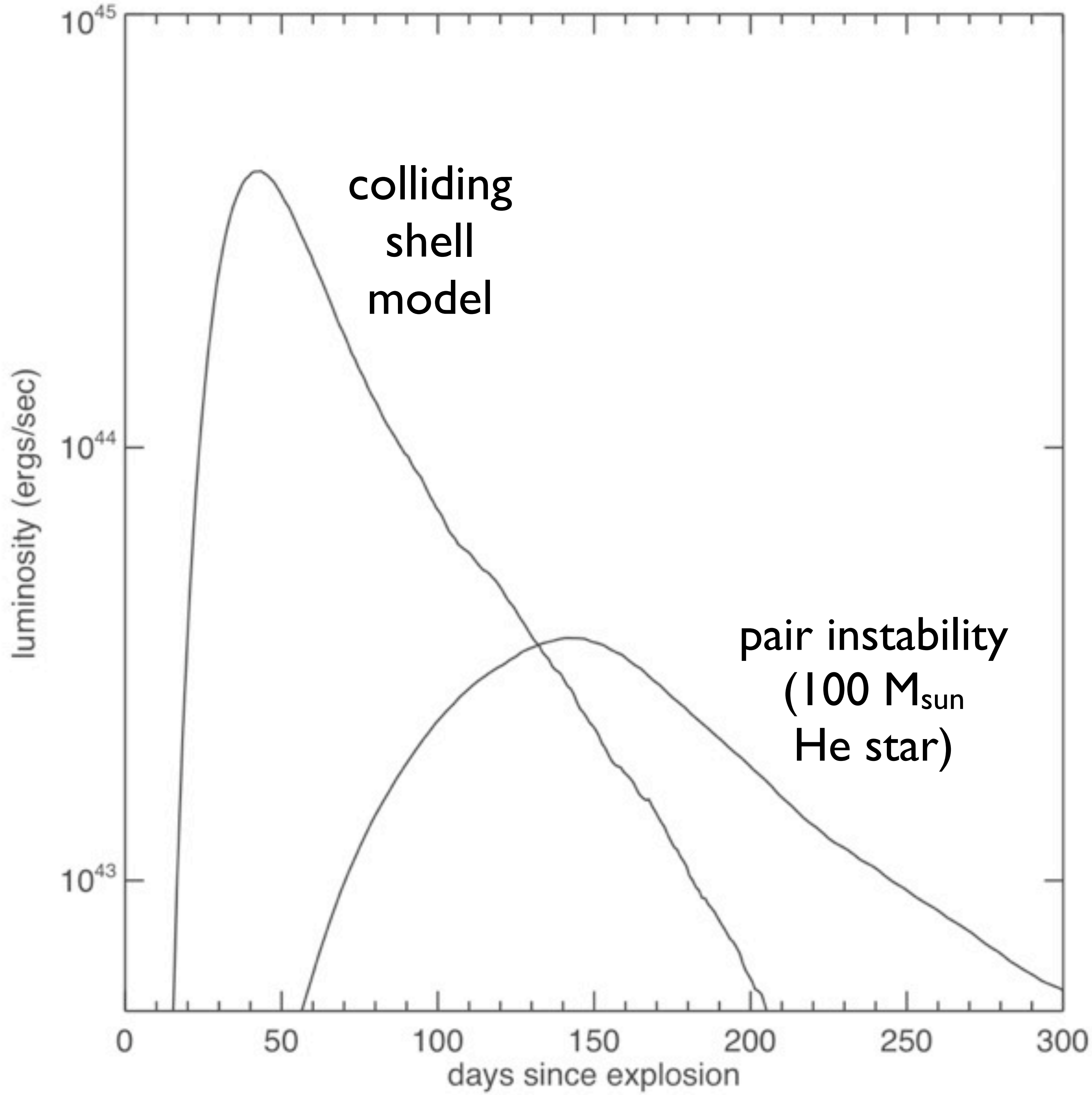
colliding shell supernovae

pulsational pair ($M < 150\ M_{sun}$) or eta car-like LBV's



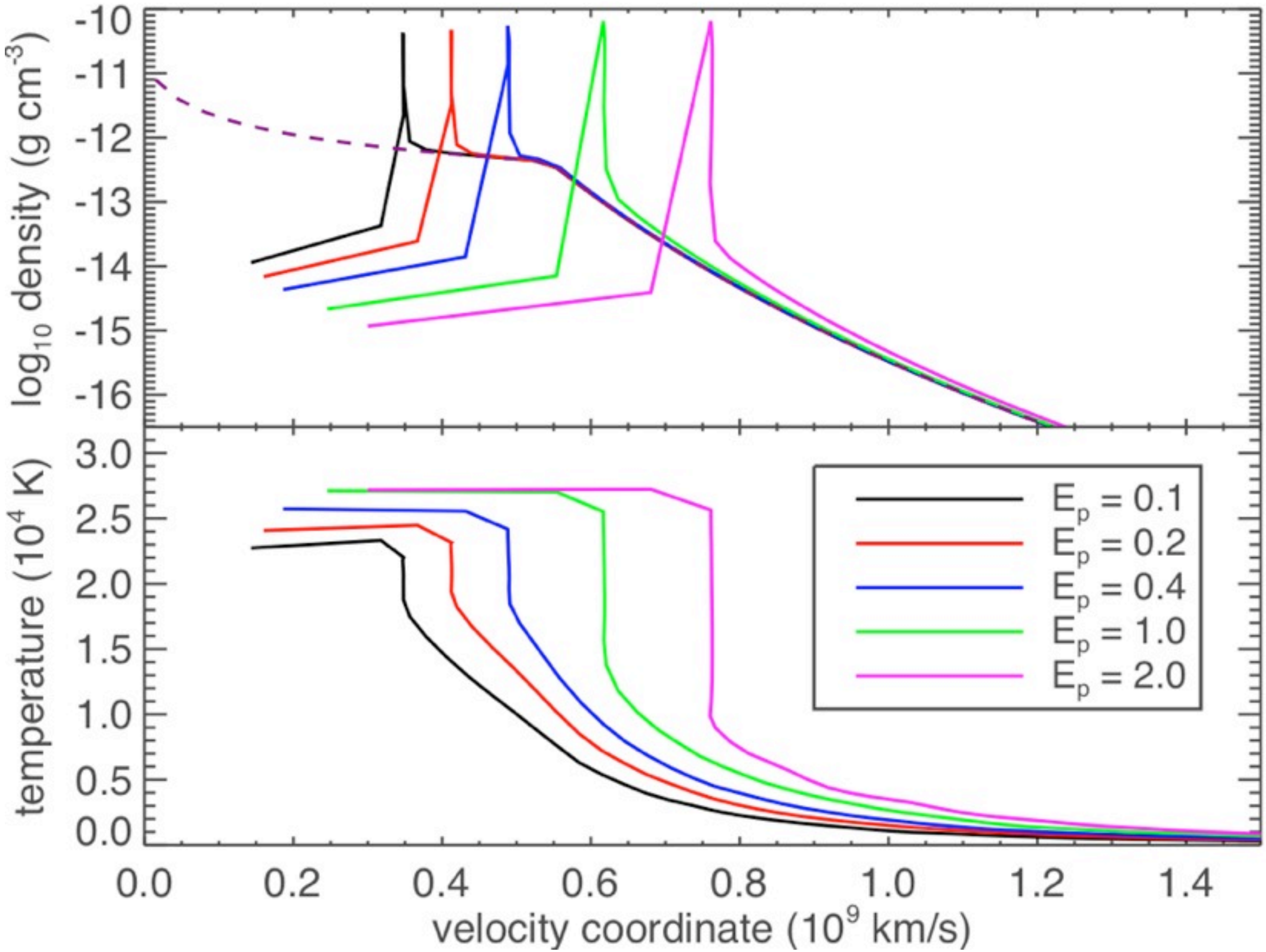
$R_{shell} \sim 10^{15}$ cm

interaction of
a supernova with
a previous ejected shell
produces bright emission
(e.g., woosley et al., 2007)



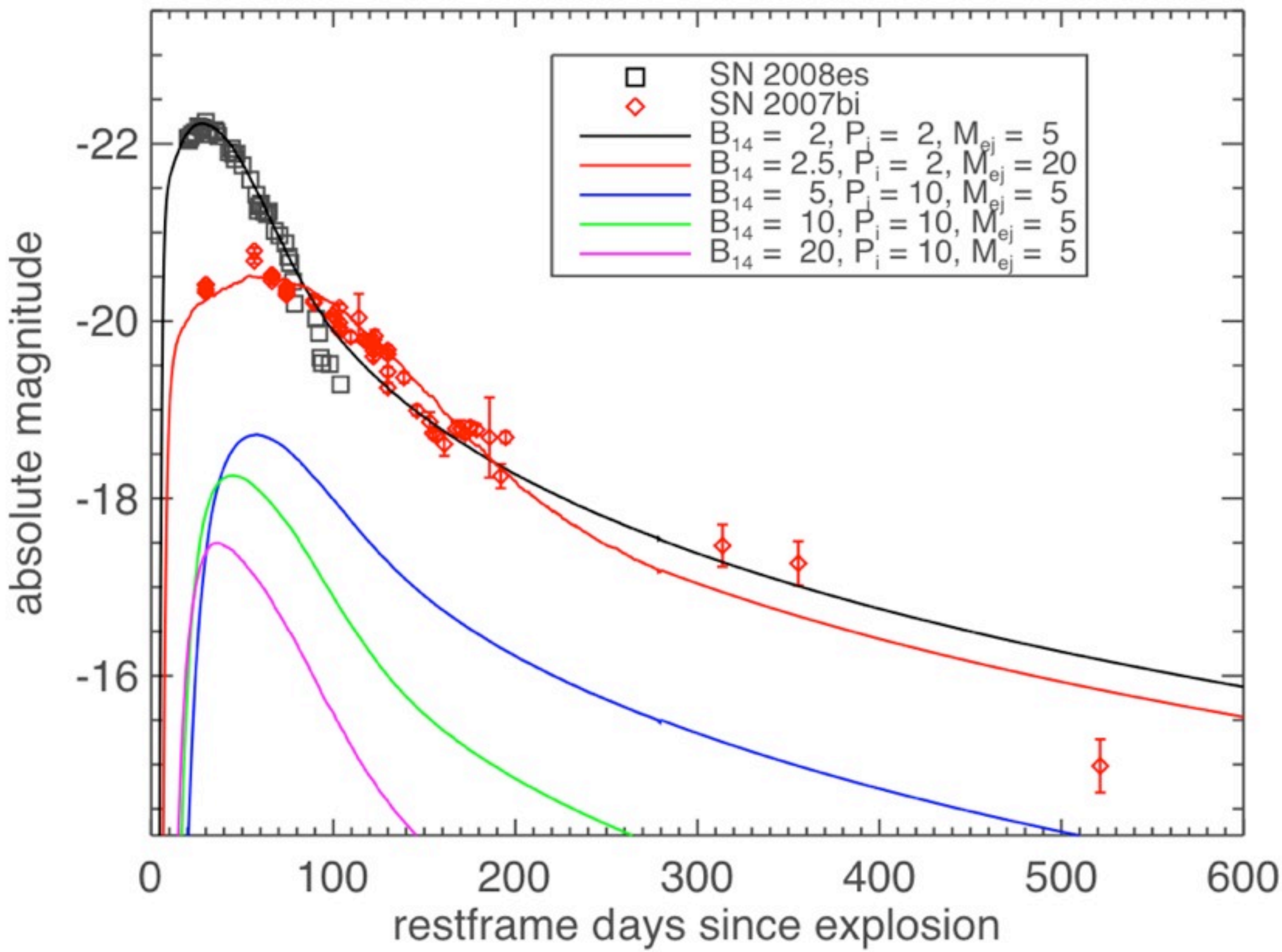
magnetar powered supernovae

kasen & bildsten 2009, woosley 2009



magnetar powered supernovae

kasen & bildsten 2009, woosley 2009



future directions

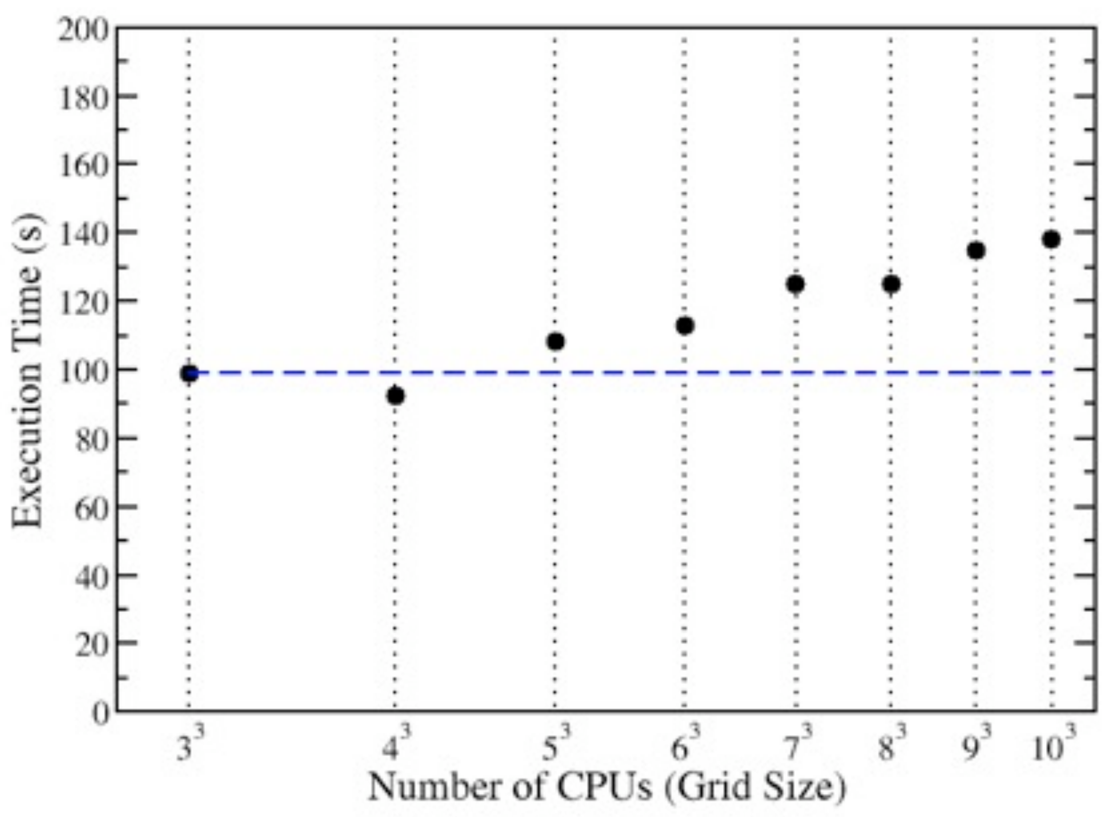
- multi-D applications to supernovae and other astrophysical phenomena
- neutrino physics?
- coupling monte carlo transport to AMR codes?
- domain decomposition parallelism and load balancing

Domain Decomposed Monte Carlo

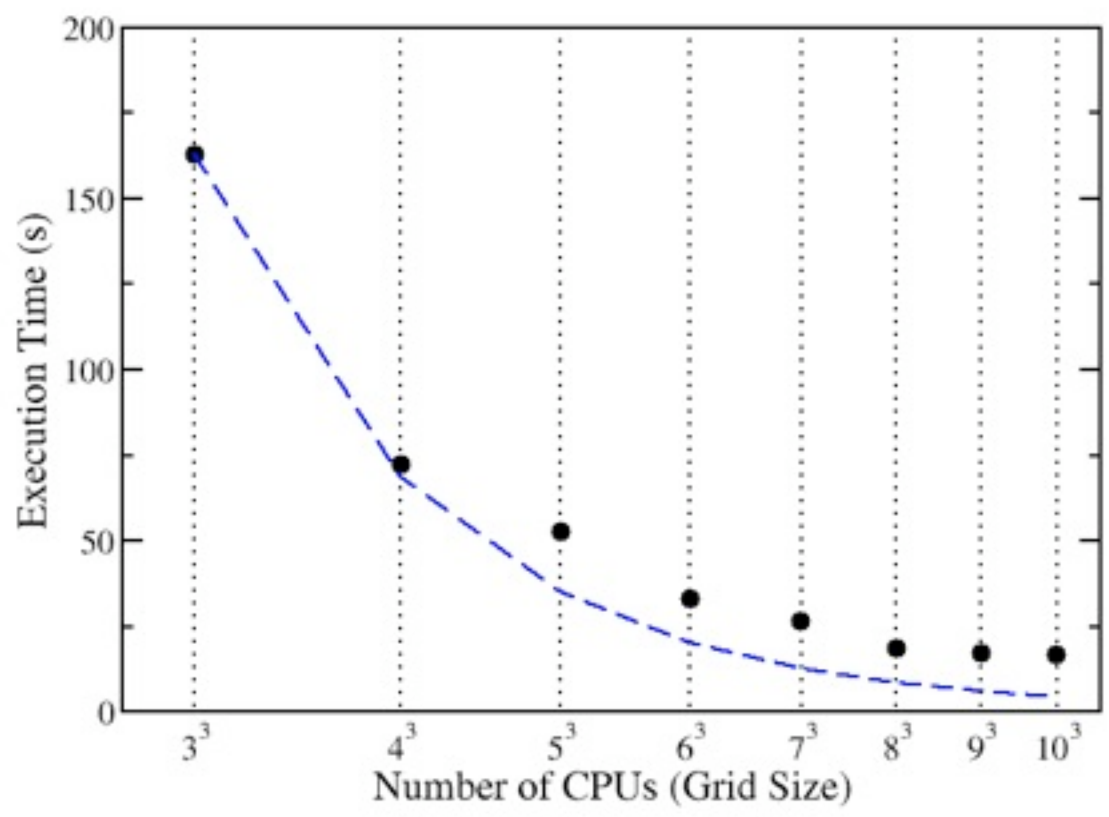
Test problem scaling out to 1000 CPUs

Franklin Cray XT4, NERSC - Rollin Thomas, LBNL

weak scaling



strong scaling



Scaling extended to 10,000 CPUs using full replication