The Current LANL Light-curve Modeling Pipeline

- Stars are simulated from pre-shock breakout to up to 1 year with the RAGE radiation hydrodynamics code
  - 1D spherical mesh
  - Eulerian hydrodynamics with adaptive mesh refinement (AMR)
  - Gray diffusion utilizing LANL LTE Oplib opacities

- Ray tracing post-processing radiation package generates a 2D cylindrical mesh to capture edge effects

- Calculates and transports 14,900 photon energy groups per cell
  - Opacities from the LANL Oplib database

- Assumes each zone is in LTE
  - Can break down at late times and extremely low densities

Frey, L., et. al. 2013
Impact of mass removal from a single progenitor ($23 \, M_\odot$)

Impact of mass removal from a single progenitor (23 M☉)

Density, Temperature, and Luminosity for 4 models at peak luminosity

SN Ia with a circumstellar torus

- 1D post-explosion SN Ia profile
- Low density wind
- 1Msun solar mass torus
  - $R=1\times10^{15}\text{cm}$, $r=4.5\times10^{14}\text{cm}$
  - Solar abundance, uniform density

Even, W., unpublished
Future LANL light-curve modeling

- **Cassio**
  - Fully coupled hydrodynamics and radiation transport
    - Multi-group IMC or $S_n$
  - Capture all transport effects
  - Obtain inline light-curves self-consistently
  - Ideal for circumstellar material interactions, but too computationally expensive to run from shock breakout to nebular phase

- **SuperNu**
  - Homologous expansion coupled with IMC transport
  - Can complete 100 day multi-D light-curves in several days
  - We will map from Cassio to SuperNu once the flow is approximately homologous

![Light curves for 3 polar viewing angles for a spiral merger SN Ia simulated with SuperNu, compared to observations of SN 2001ay](image)

van Rossum, D. et al, 2016
Modeling choices

• **Progenitor model**
  – Stellar evolution code
  – Explosion model

• **Hydrodynamics**
  – Homologous vs. shock capturing
  – Lagrangian vs. Eulerian

• **Radiation**
  – Diffusion, Implicit Monte Carlo (IMC), Discrete Ordinates ($S_n$)
  – Gray vs. multi-group
  – In-line vs. post-processing

• **Other physics**
  – Opacity: atomic data, material mixing, LTE vs. nLTE
  – Gamma-ray transport vs. local deposition
Code Comparisons

• Different codes can produce nearly identical light curves, with the correct set of agreements
  – Identical initial model
    • Hydrodynamic structure
    • Elemental composition
  – Mapped post-explosion
  – Common (and simplified) opacity data

• Differences
  – Hydrodynamic scheme
  – Radiation transport scheme
  – Gamma-ray transport

Kozyreva, A., et. al. 2017
Code Comparisons: Opacities are critical

• Same models, but each code using its best multi-group opacities
  – Bolometric – Nearly identical peak values, but but timing shifted by up to 2x
  – Banded Curves – Up to 2 magnitudes in peak and timings shifted by over 2x

Identifying “interesting” SNe

- Will light curves created with multiple sets of modeling decisions be part of the LSST classification pipeline?
- How will these be normalized or otherwise combined?
- If LSST can accurately identify early-phase SNe in real time, other telescopes can follow up

- What cadence is required to identify early-time SNe?
  - Three observations ~0.5 days apart can identify <6 day old Ia SNe
  - Non-homologous flows in core-collapse SNe complicate this phase plot analysis

Phase diagram for Type I SNe, with smoothed observational data from KSN2011b

(Arnett et al 2016, arxiv 1611.08746)
Identifying “interesting” SNe

• How many SNe will LSST discover within ~1 day of explosion?
  – What will the false positive rate be?

• How accurately will SNe be classified?

• What further work needs to be done to determine the cadence required for accurate classification?

Phase diagram for Type I SNe, with smoothed observational data from KSN2011b

(Arnett et al 2016, arxiv 1611.08746)