Nucleosynthesis in Type Ia Supernovae

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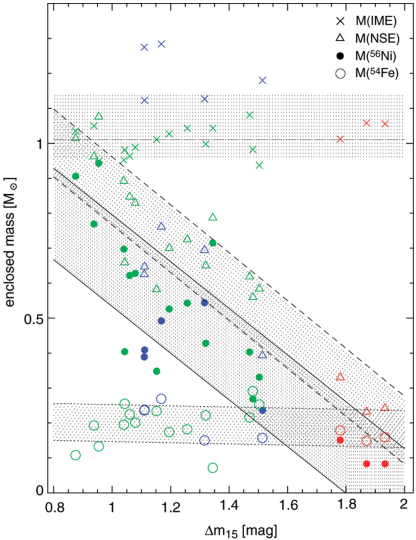
August 21, 2007

Zorro diagram



- Mazzali, Röpke, Benetti, Hillebrandt 2007
- Δm_{15} is the B-magnitude decline over 15 days after maximum brightness.
- Enclosed mass derived from spectra (coverage from pre maximum until nebular phase).
- 23 nearby (< 40 Mpc) Type Ia SNe.
- Fast decliners have less $^{56}\mathrm{Ni}$ and are dimmer.

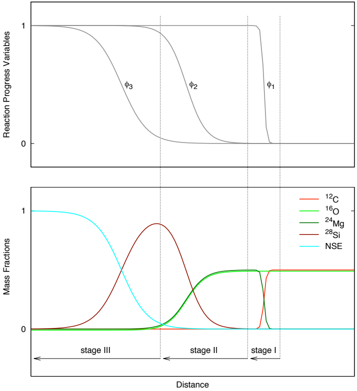
Explosion Models

- Prompt Detonation
  - No expansion, too few intermediate mass elements
  - Very little mixing: Ejecta layered
- Pure Deflagration
  - Weak explosion, not enough Ni, small velocities
- Deflagration-Detonation-Transition (DDT) model
  - Deflagration transitioning into Detonation through turbulence
  - Allows for pre-expansion and intermediate mass element production
- Gravitationally-Confined-Detonation (GCD) model
  - Off center deflagration bubble rising, piercing through surface, sweeping around star and initiating detonation on other side of star
  - Also allows for pre-expansion and intermediate mass element production

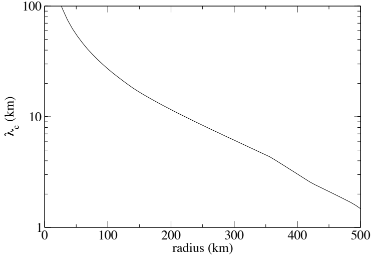
Setup

- M_{Ch} cold C/O WD
- 16km bubble 40km offset, and others
- 4km and 2km resolution
- 2D axissymmetric
- Adaptive Mesh Refinement
- Artificially Thickened Flame model carefully calibrated to give right burning speed and RT instability growth
- Treat NSE as non static and include electron captures and neutrino losses
- See Calder et al. (2007) and Townsley et al. (2007)

Model Flame

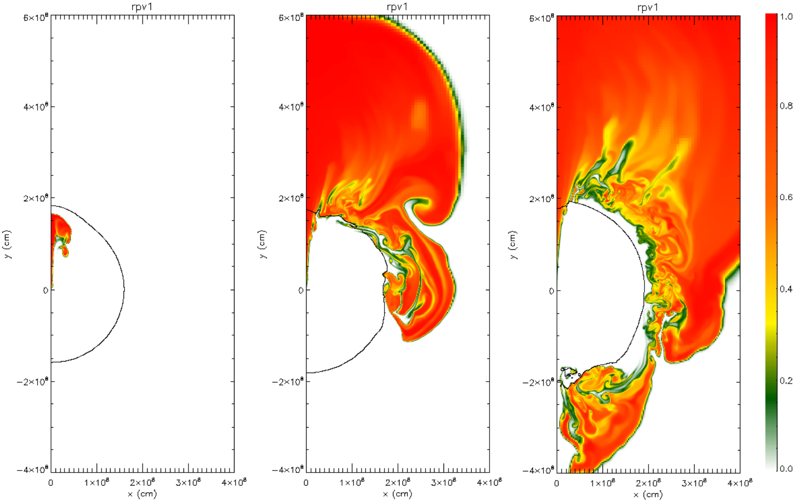


$$\lambda_c = \frac{6\pi s^2}{Ag}$$



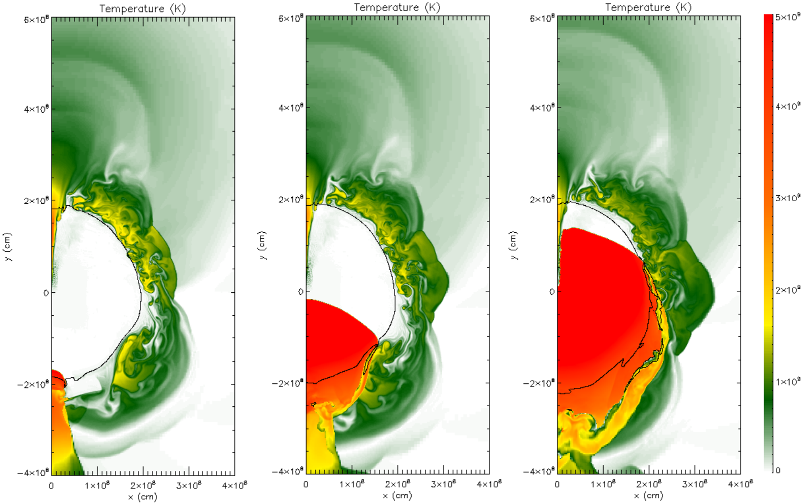
- 3 stage flame model with artificially widened flame calibrated for right energy release and velocity
- Rayleigh-Taylor instability crucial for evolution of bubble

Deflagration bubble rise, breakout and flow

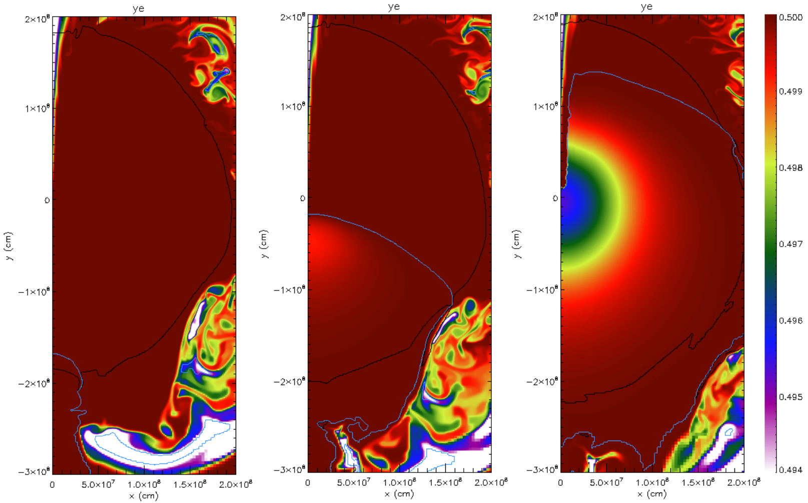


Calculations by **Casey Meakin**

Detonation sweeping across star



Electron capture hole

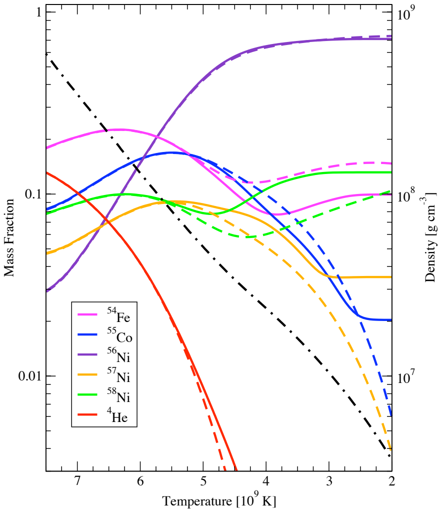


SN 2003du (Höflich et al. 2004) ; SN 2003hv and SN 2005df (Gerardy et al. 2007)

Tracer Particles vs. NSE

- Simulations include massless tracer particles that flow passively across the grid
- Tracer particles record thermodynamic trajectories, which are essentially temperature and density as a function of time along the path of the tracer
- Trajectories can be post processed afterwards by integrating a nuclear reaction network along the trajectory
- By averaging over an appropriately distributed family of tracer particles one obtains the final abundance distribution of the supernova
- Estimating yields based on NSE has the advantage of being computationally much less demanding at the cost of introducing abundance errors due to non equilibrium reactions during freeze out.

Mass fractions behind detonation front



- Final $Y_e = 0.4954$.
- Slightly different freeze out temperature and density for each nuclear species.
- Temperature at which network falls out of NSE different from freeze out temperature.
- Assuming that all ^{4}He nuclei at $T_9 \sim 4.5$ capture on ^{54}Fe to make ^{58}Ni accounts remarkably well for deviation from NSE at freeze out.

We can make bright SNe

Δx (km)	R_{bub} (km)	R_{off} (km)	t_{det} (s)	R_{det} (km)	M[DEF] (10^{-2} $M_\odot$)	M[IME] ($M_\odot$)	M[NSE] ($M_\odot$)	M[^{56}Ni] ($M_\odot$)
4	16	20	fail	fail	...	...	...	...
4	16	25	2.45	2.19	3.88	0.16	1.21	1.16
4	16	30	2.32	2.05	2.96	0.13	1.24	1.16
4	16	40	2.24	2.04	2.75	0.09	1.28	1.16
4	16	60	1.99	1.84	1.84	0.07	1.30	1.14
4	16	80	1.98	1.83	1.70	0.07	1.30	1.13
4	16	100	1.89	1.79	1.38	0.05	1.32	1.12
2	16	30	2.52	2.79	6.97	0.28	1.09	1.04
2	16	40	2.16	2.26	4.81	0.16	1.21	1.14
2	16	60	2.22	2.30	3.60	0.12	1.25	1.16

What's next?

- Calculate improved NSE based freeze out yields for suite of 2D models
- Prepare for post processing of large number of trajectories
- Watch out for paper with Casey Meakin (near future)
- New QRPA electron capture rates [**Reyes**, **Gupta**, **Schatz**, **Kratz** and Möller] are larger for important Fe-peak nuclides than the ones we are currently using and could lead to significant increase in neutronization (intermediate future)

I appreciate the generous support and altruistic help of ...

... my collaborators:

E. Brown, A. Calder, C. Graziani, G. Jordan, D. Lamb,
C. Meakin, B. Messer, F. Peng,
D.Townsley, J. Truran, N. Vladimirova & more

... and the funding agencies:

This work is supported in part at the University of Chicago by the U.S. Department of Energy, under Grant B523820 to the ASCI Alliances Center for Astrophysical Flashes and in part by the NSF under Grant PHY 02-16783 for the Frontier Center Joint Institute for Nuclear Astrophysics JINA.

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