Stellar Death and Supernovae

KITP Santa Barbara, August 18, 2009

Outcomes from Deflagration Scenarios

Friedrich Röpke

DFG Emmy Noether Junior Research Group

Max-Planck-Institut für Astrophysik, Garching, Germany

W. Hillebrandt, S. Woosley, D. Kasen, J. Niemeyer, W. Schmidt, P. Mazzali, S. Blinnikov, E. Sorokina, C. Travaglio, S. Sim, D. Sauer, I. Seitenzahl, R. Pakmor, M. Fink, F. Ciaraldi-Schoolmann

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Deflagrations in Thermonuclear Supernovae and Their Implications

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Emmy Noether Research Group

SN Ia

The deflagration phase

hydrodynamics of flame propagation

deflagration
subsonic

flame mediated by thermal conduction of degenerate e^-

detonation
supersonic

flame driven by shock waves

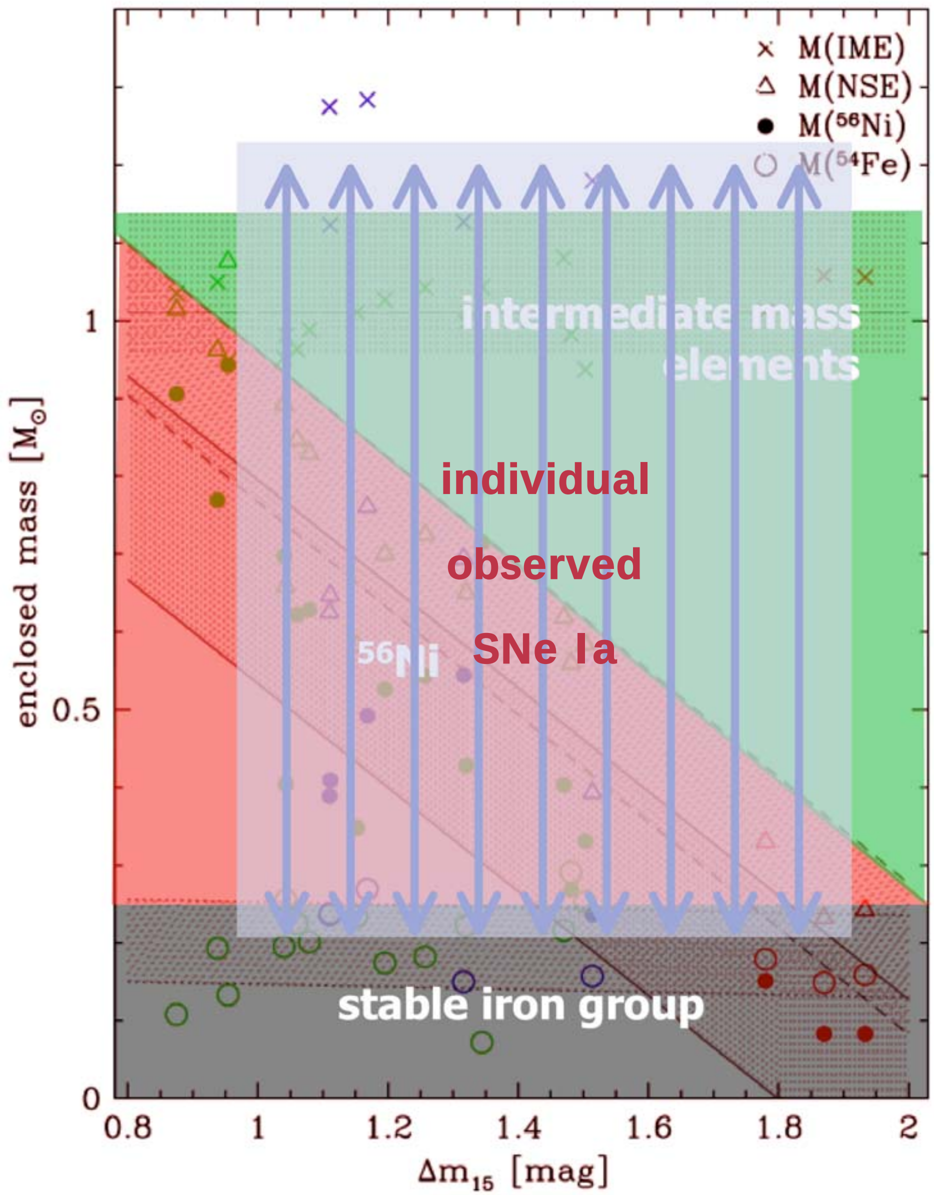
- initial burning mode in all M_{Ch} models of SNe Ia
- flame propagation strongly non-linear (instabilities, turbulence)
  - strongly dependent on ignition shape
  - breaks symmetries easily

! main origin of diversity in models of (normal) SNe Ia

Observed diversity

"Zorro diagram"

(Mazzali et al., 2007)



Speculation on the overall picture

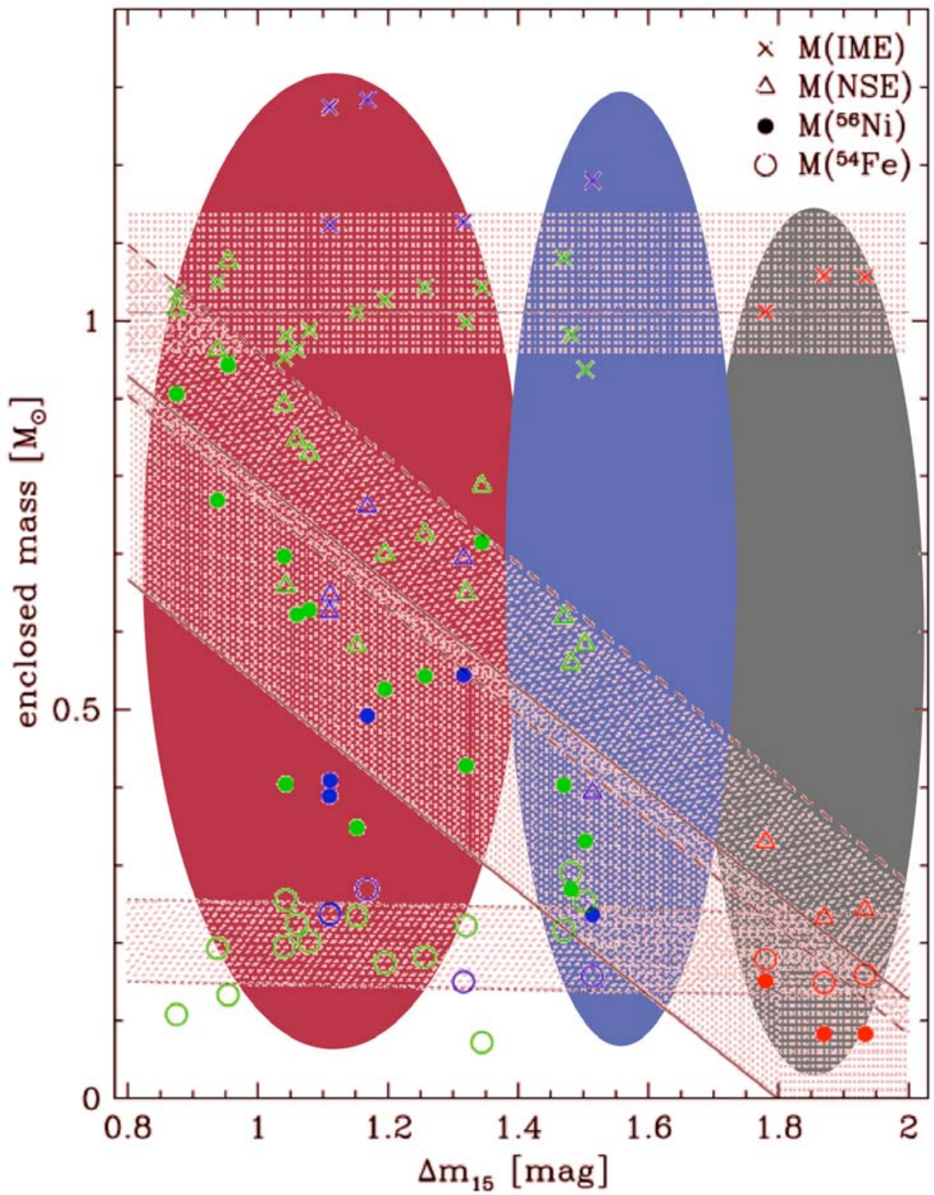
"Zorro diagram"

(Mazzali et al., 2007)

- weak normal SNe Ia
  deflagrations or
  deflagration phase dominant

- bright SNe Ia
  delayed detonations
  for brightes examples:
  detonation phase dominant

- sub-luminous: ???



Deflagrations in SN Ia models

i. pure deflagrations

i. deflagration and subsequent detonation

ii. no deflagration

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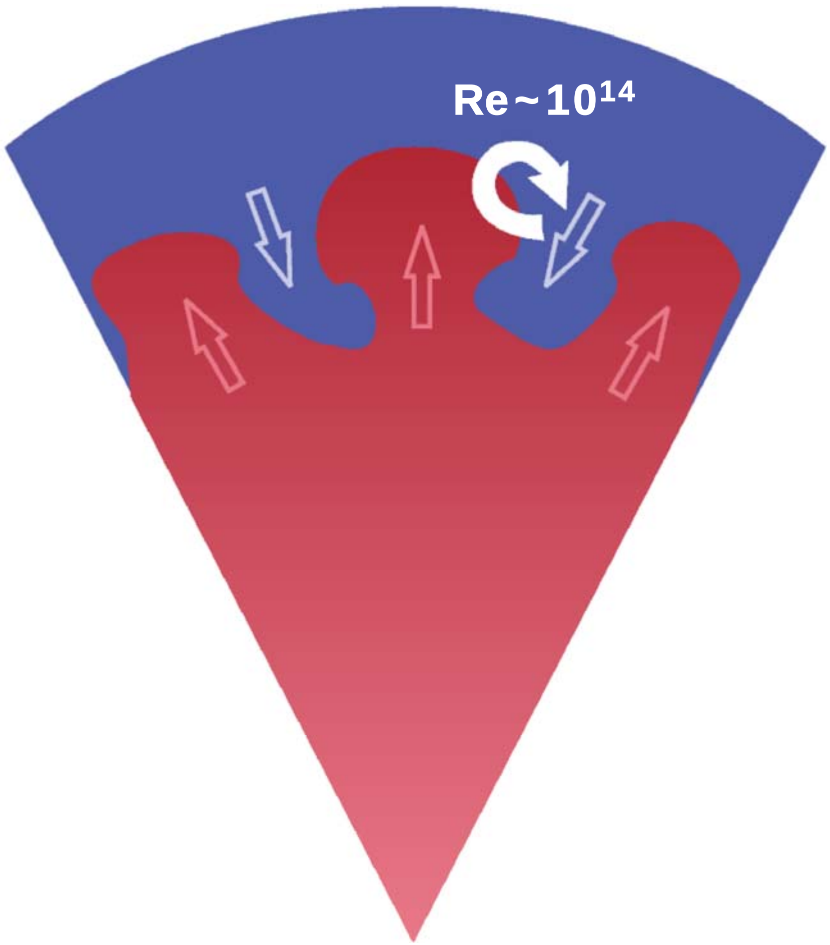
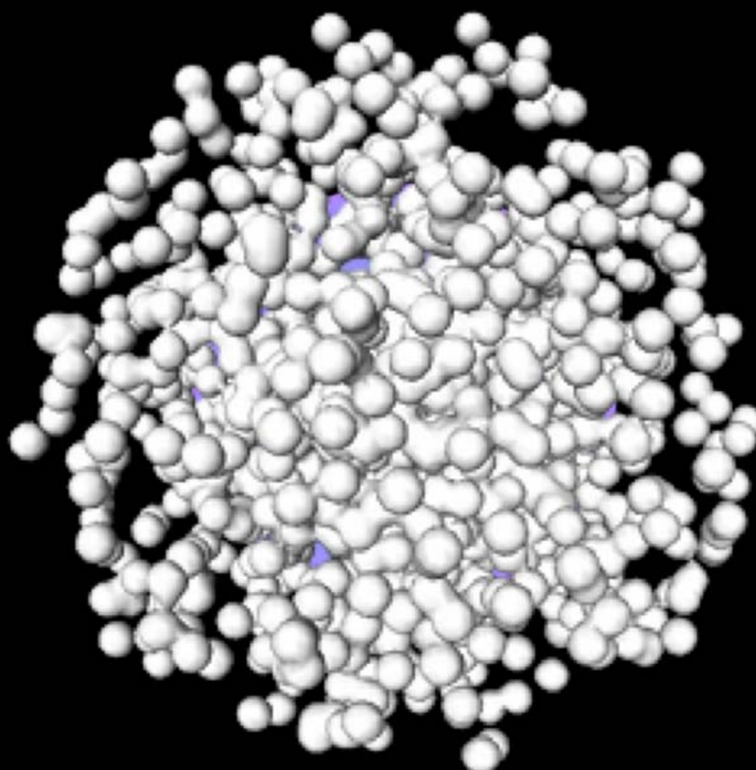
Turbulent combustion in SNe Ia

- Turbulent flame propagation in deflagration mode (consistent treatment)



Deflagration SN Ia simulation

t = 0.025 sec

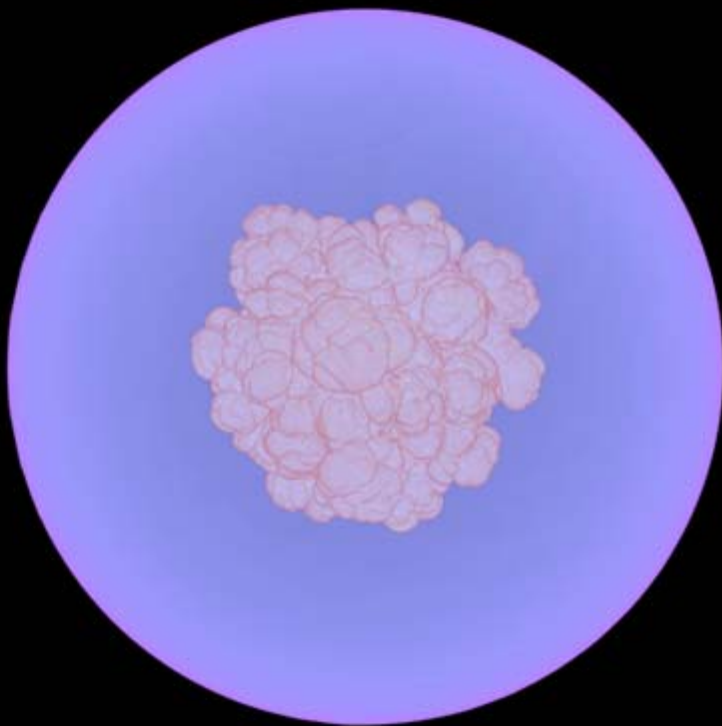


Deflagration SN Ia simulation

t = 0.200 sec

Deflagration SN Ia simulation

t = 0.600 sec

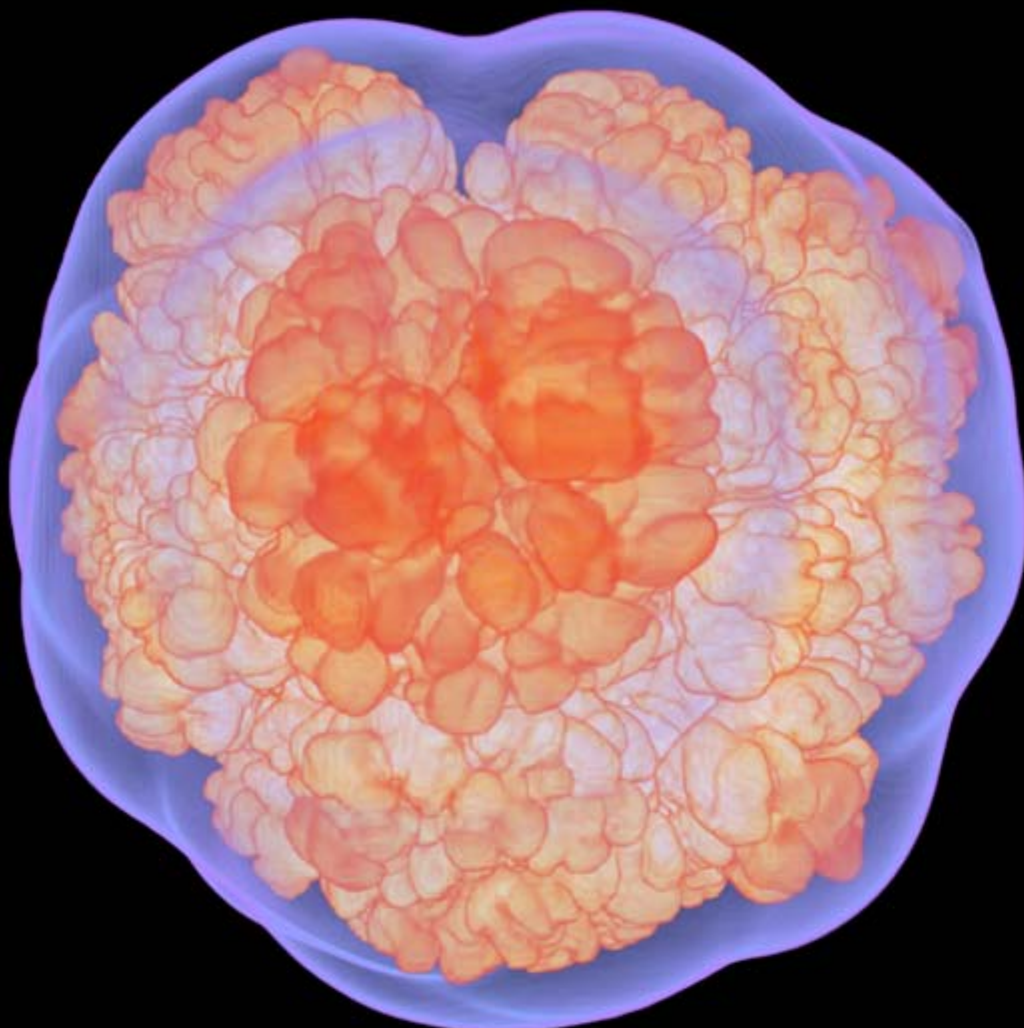


Deflagration SN Ia simulation

t = 1.000 sec

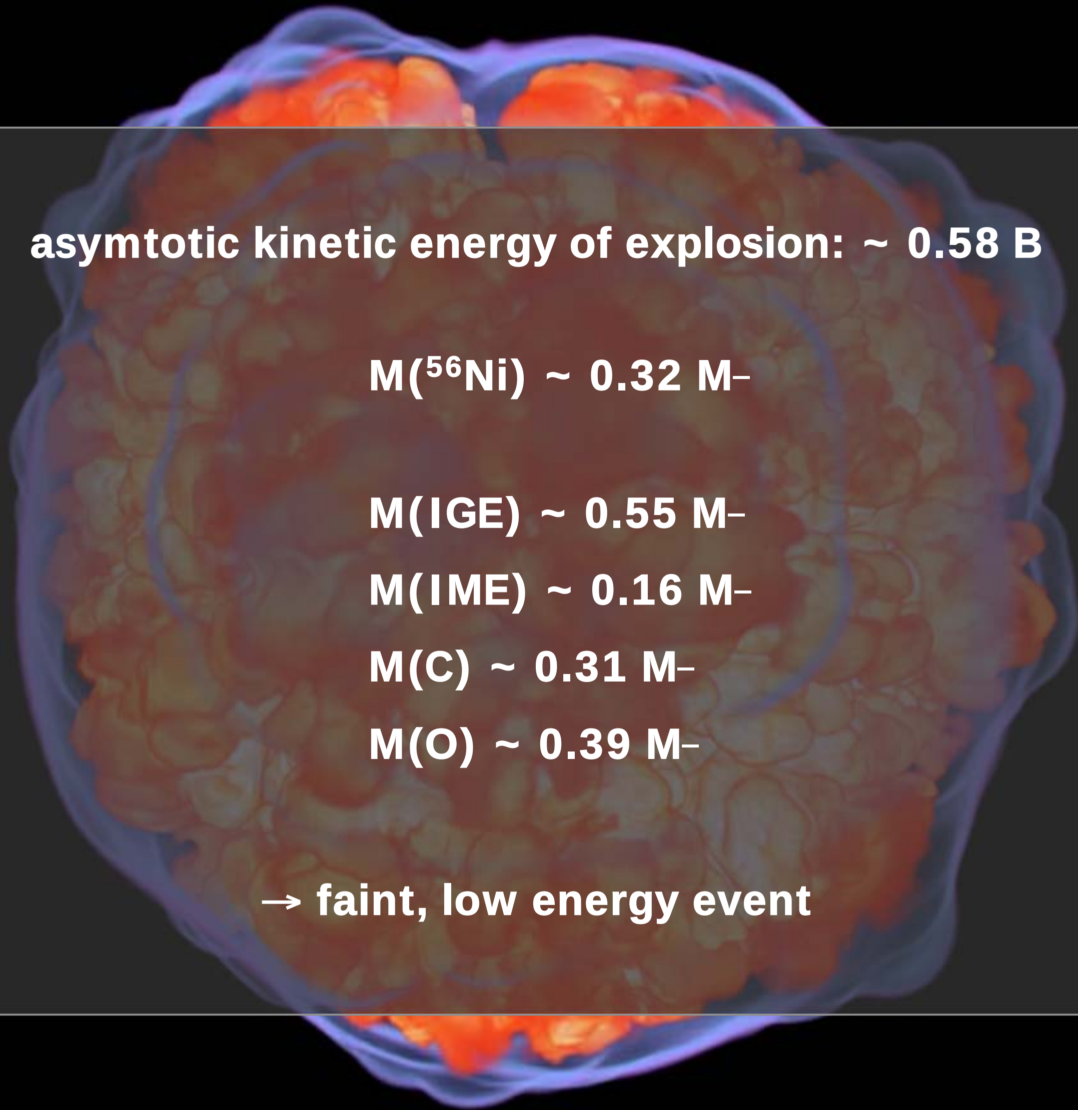
Deflagration SN Ia simulation

t = 1.600 sec



Deflagration SN Ia simulation

t = 3.000 sec



asymtotic kinetic energy of explosion: ~ 0.58 B

M(^{56}Ni) ~ 0.32 $M_{\odot}$

M(IGE) ~ 0.55 $M_{\odot}$

M(IME) ~ 0.16 $M_{\odot}$

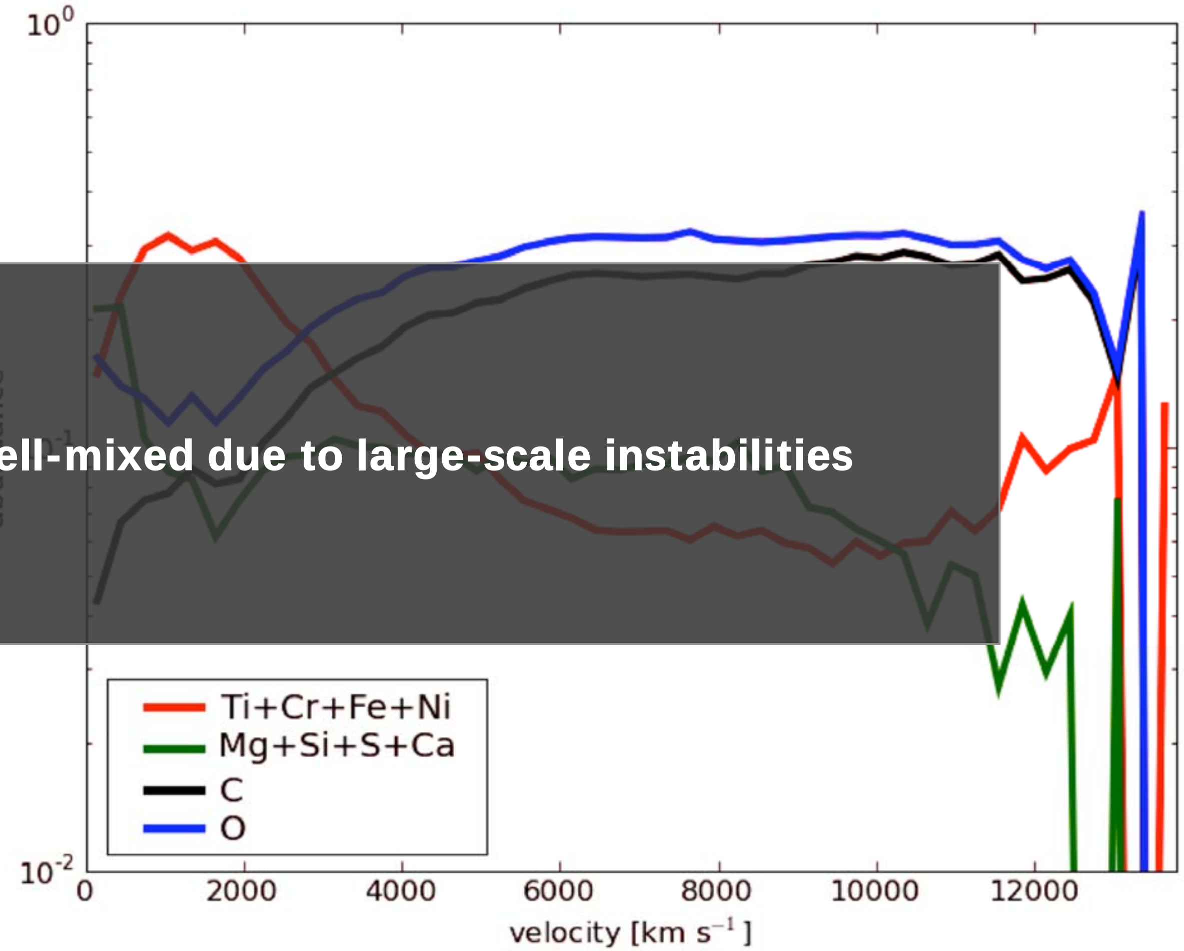
M(C) ~ 0.31 $M_{\odot}$

M(O) ~ 0.39 $M_{\odot}$

→ faint, low energy event

Chemical composition of ejecta

- from nuclear postprocessing:



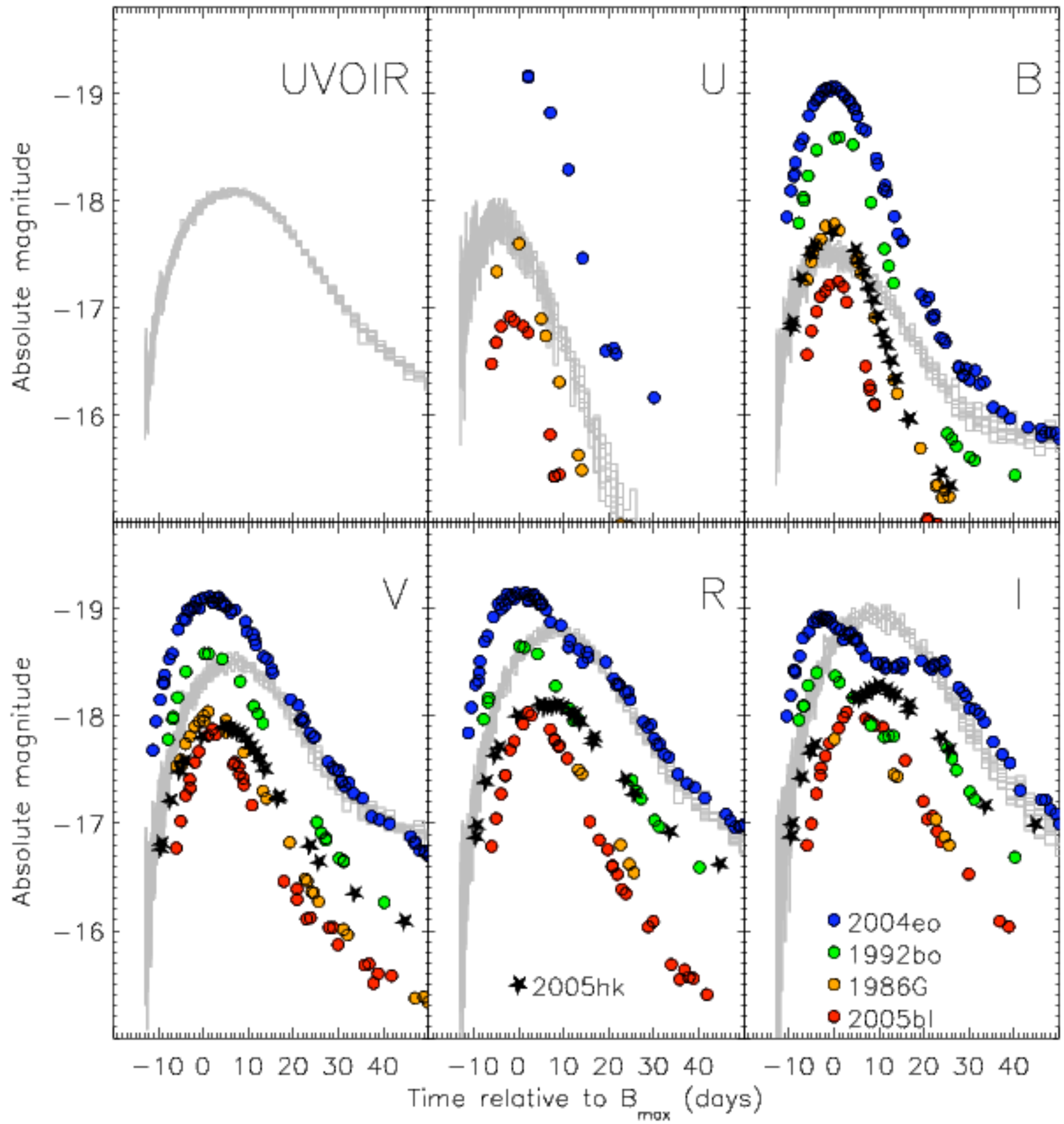
well-mixed due to large-scale instabilities

Synthetic LCs: model for faint SNeIa?

preliminary, low resolution

courtesy of

S. Sim & M. Kromer

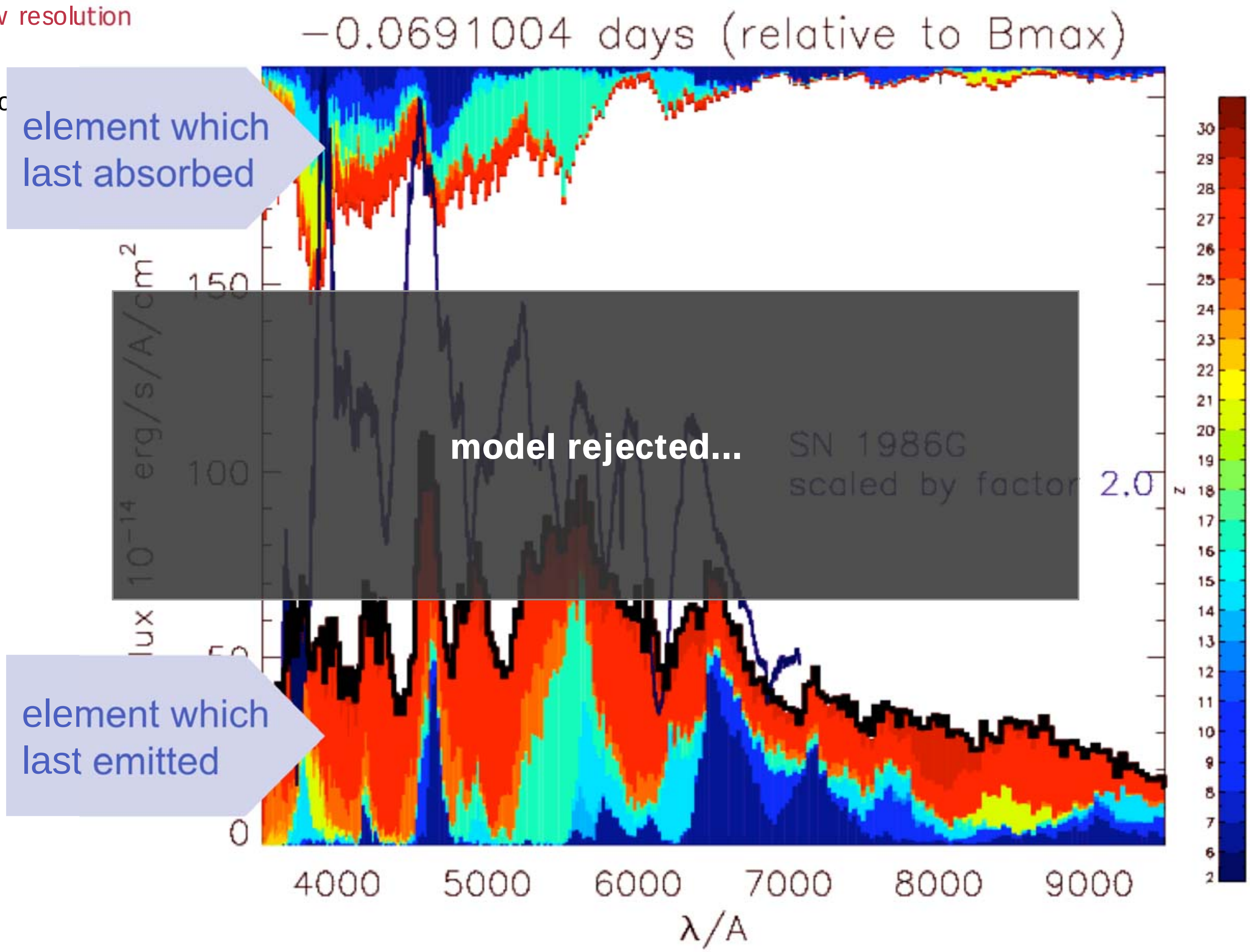


Synthetic spectra: compare SN1986G

preliminary, low resolution

courtesy of

S. Sim & M. Kro

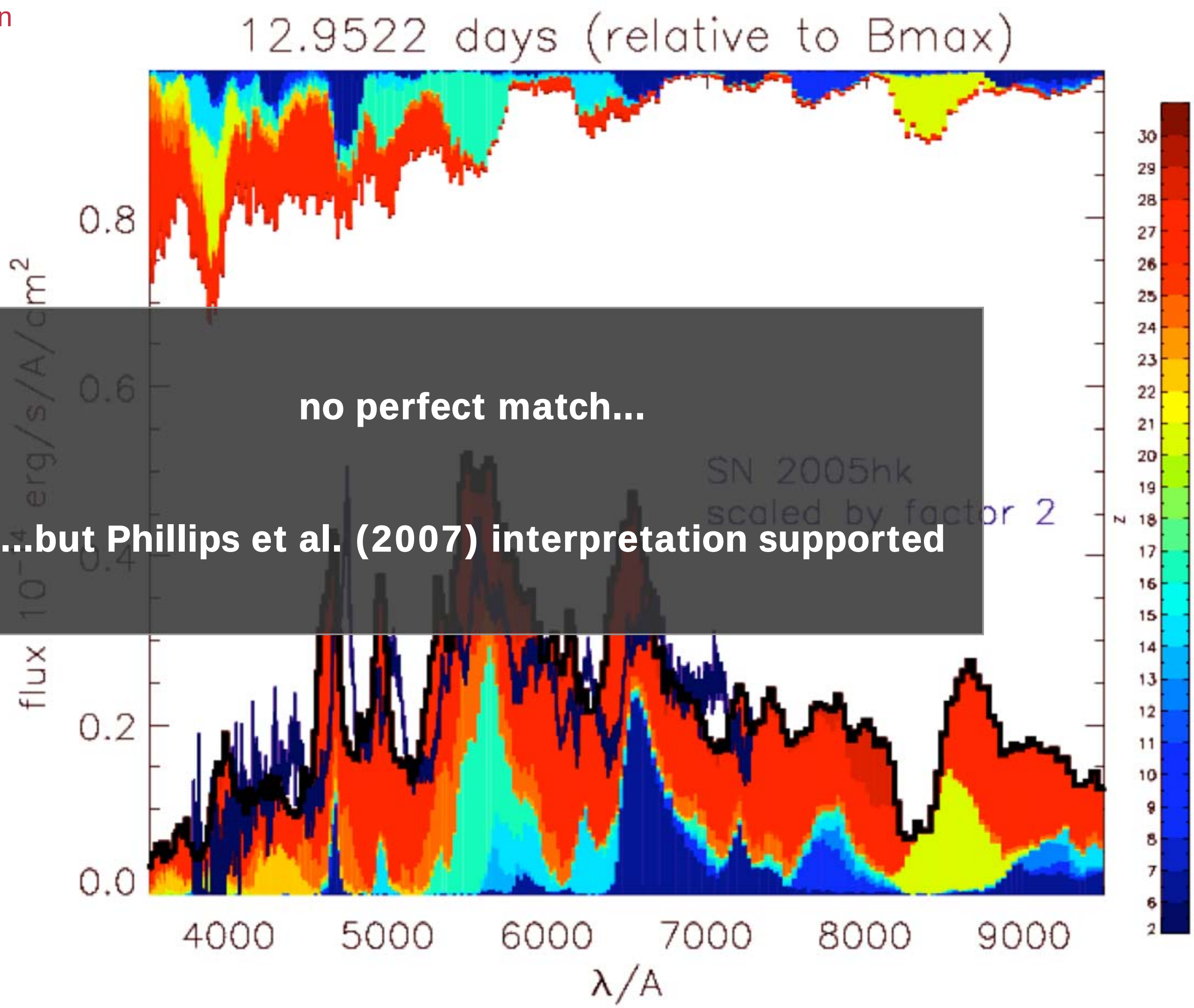


Synthetic spectra: compare SN2005hk

preliminary, low resolution

courtesy of

S. Sim & M. Kromer



no perfect match...

...but Phillips et al. (2007) interpretation supported

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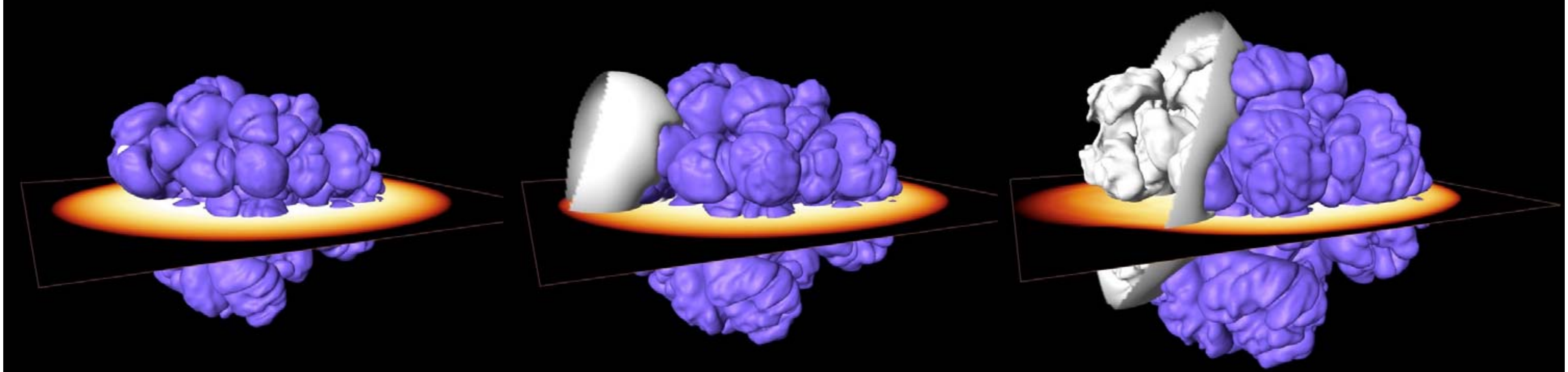
Delayed detonation models



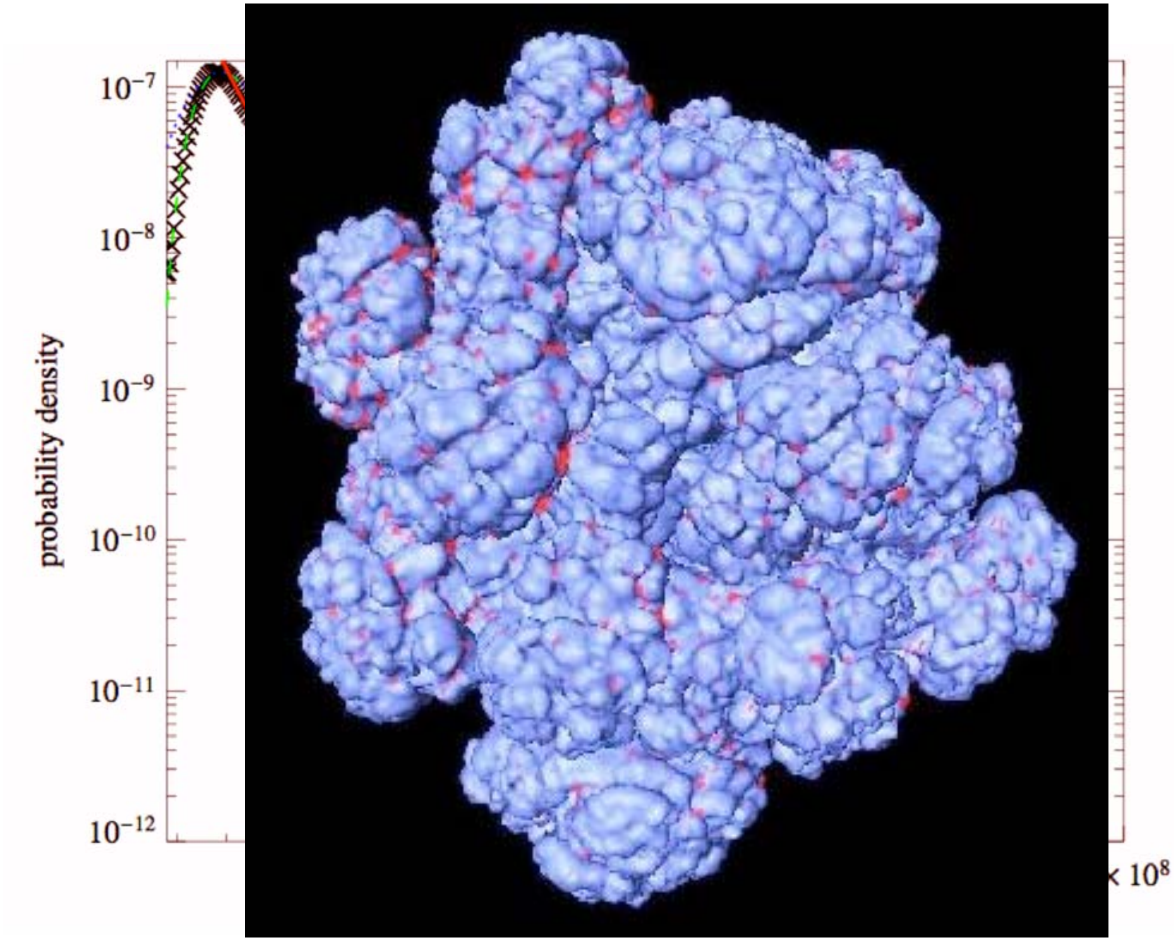
FR & Niemeyer, 2007
Mazzali et al., 2007

preliminary test calculations:

- promising candidate for explaining normal to bright SNe Ia

Deflagration-Detonation Transitions?

- DDT at late stages of the explosion process (onset of distributed burning regime, Niemeyer & Woosley, 1997)?
- high turbulent velocities (~1000 km/s) required (Lisewski et al., 2000; Woosley, 2007, Woosley et al., subm.)
- Analysis of turbulent velocity flucutations in simulations (FR 2007)
- intermittency effects (analytic treatment: Pan et al., 2008 analysis from simulation data: Schmidt et al., subm.)



A 2D pilot study

~40 2D models (with D. Kasen, S. Woosley)

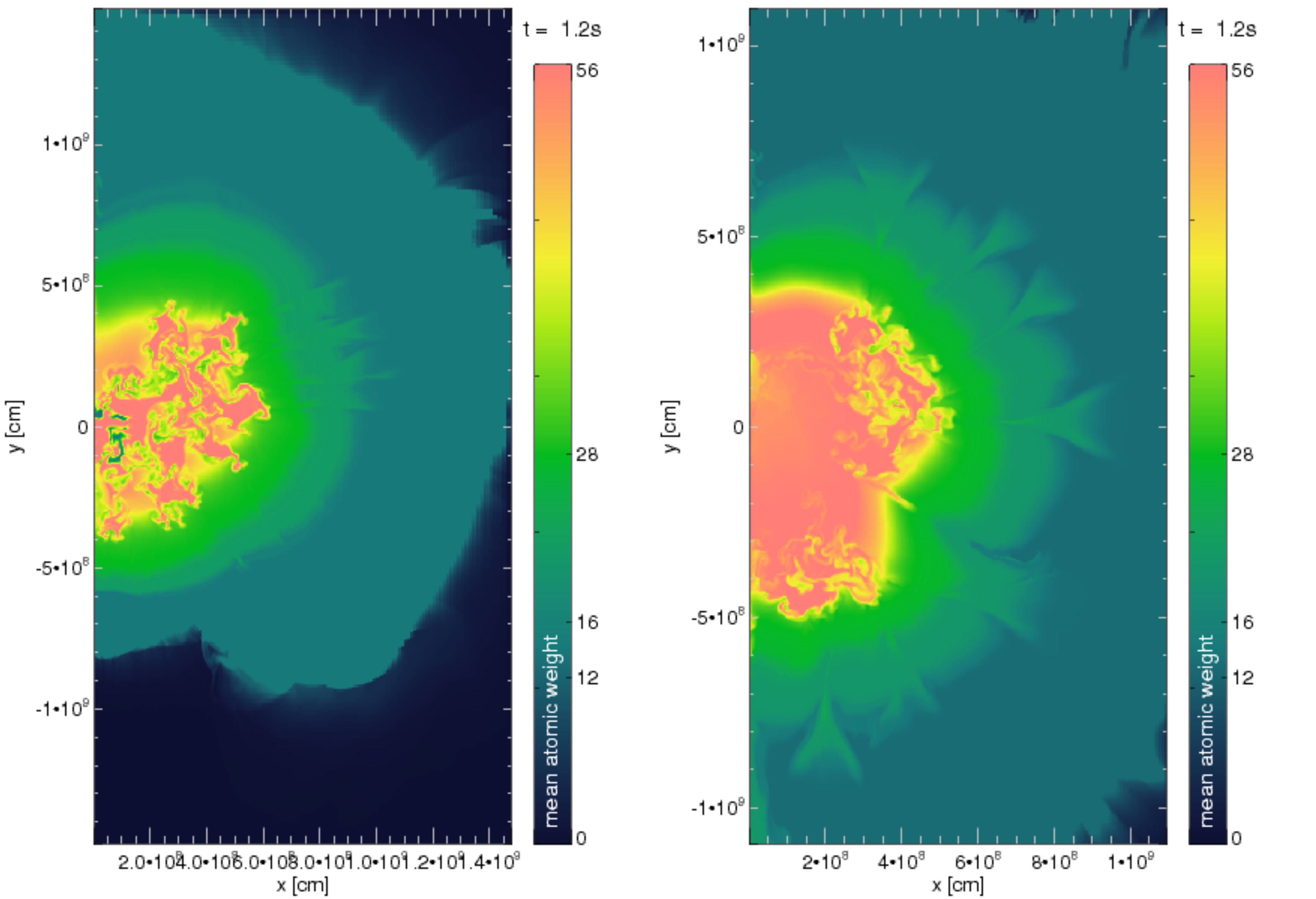
explored parameter space:

- ignition spark distribution
- turbulence criterion for DDT

results:

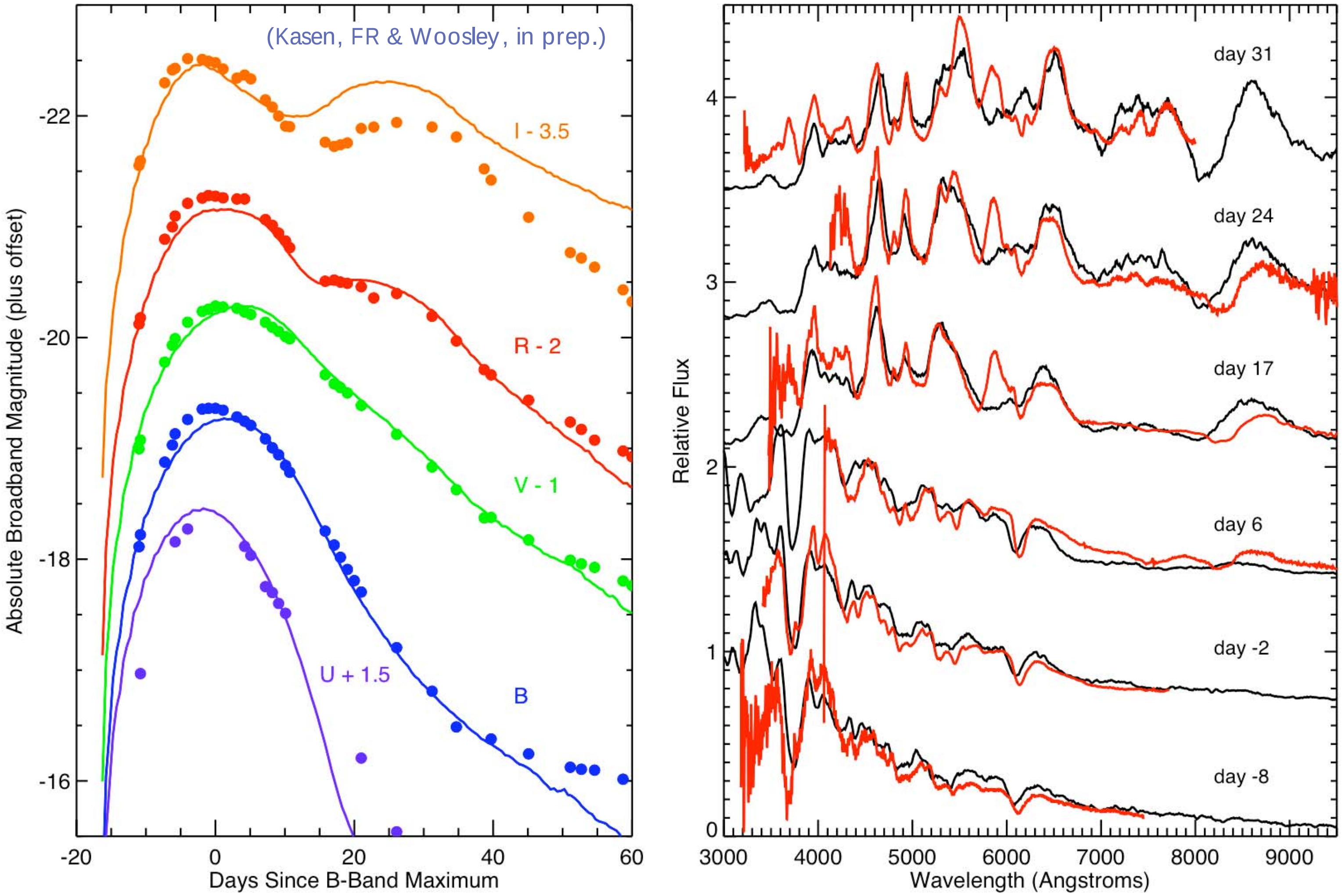
- ^{56}Ni masses: 0.3 to 1.1 $M_\odot$
- kinetic energies: 1.2 to 1.6 B

Strong vs. weak deflagration phase



Synthetic observables

- model with emphasis on detonation phase compared with SN 2003du



Synthetic spectra: compare SN1986G

preliminary, low resolution

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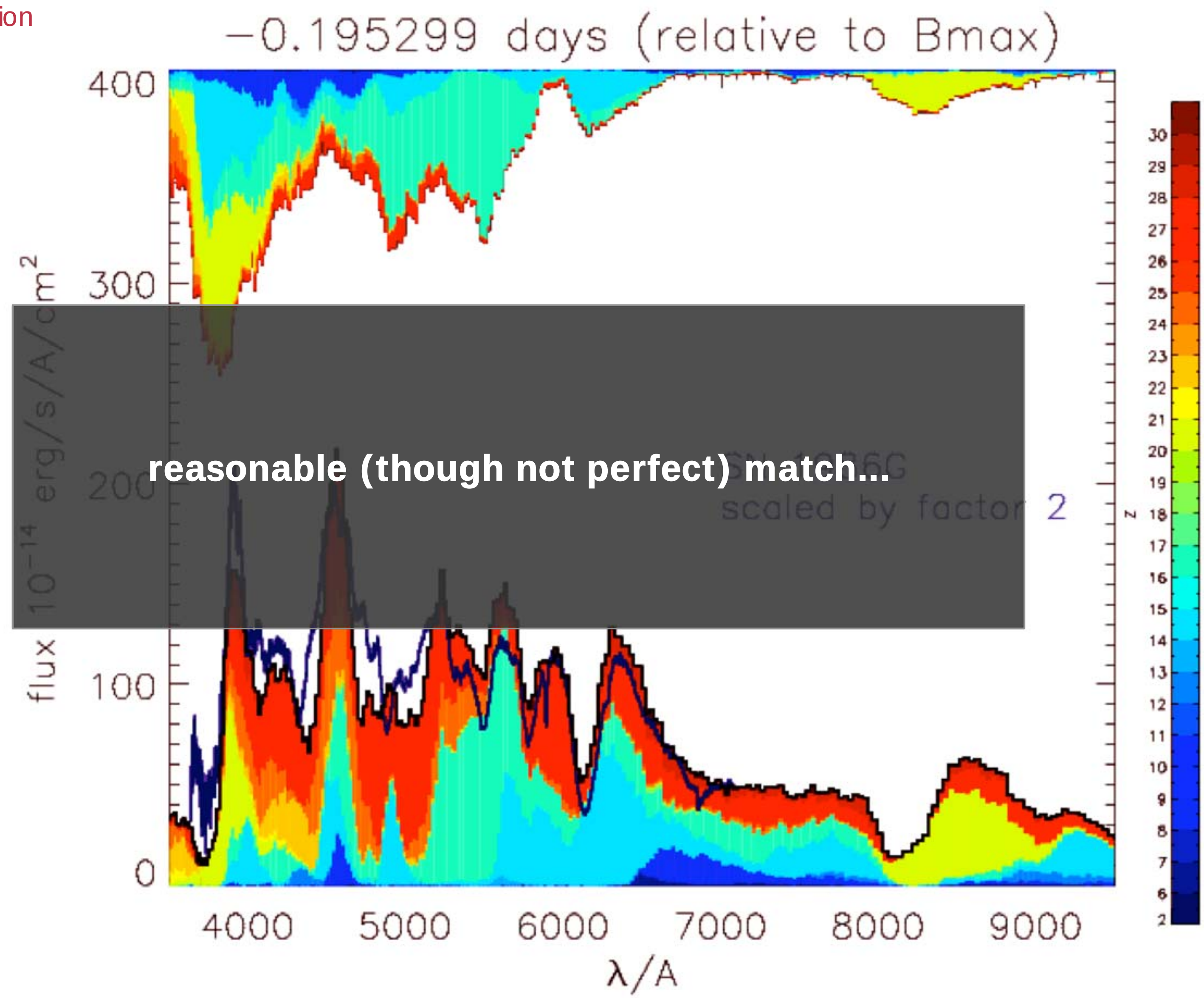

reasonable (though not perfect) match...

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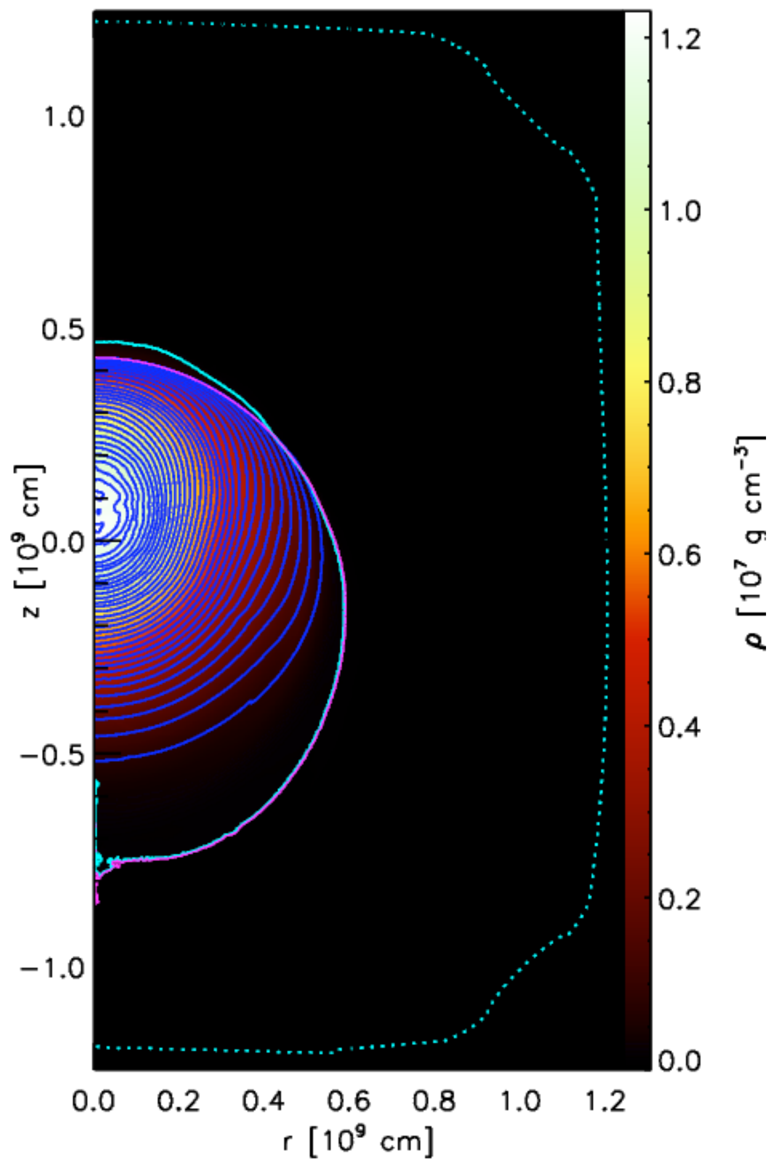
Pure detonations

- detonations in very rapidly rotating WDs (Steinmetz et al., 1992)
- sub-M_{Ch} explosions (Fink et al., 2008)



Summary

- deflagration stages play crucial role in most SN Ia models
  $\rightarrow$ need to be modeled accurately

- pure deflagration models perhaps account for sub-class of faint SNe Ia

- deflagration stage sets initial condition for detonation in delayed detonation models
  $\rightarrow$ gives rise to diversity in models for normal/bright SNe Ia