Constraining Type Ia Supernovae by Synthetic Observables from Explosion Models

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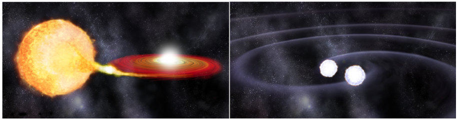
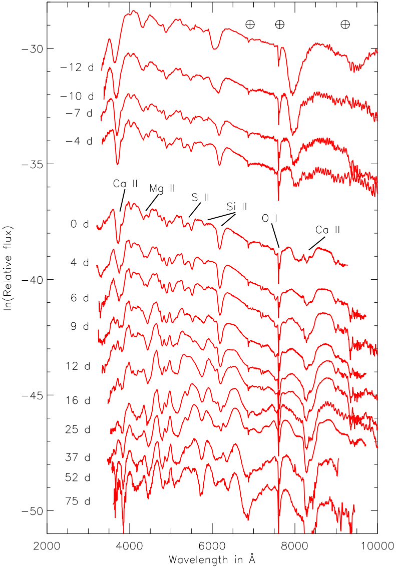
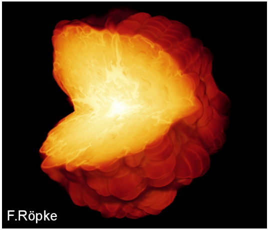
Stockholm, 2.-5.6.2014

Constraining SN Ia progenitors and explosion mechanisms

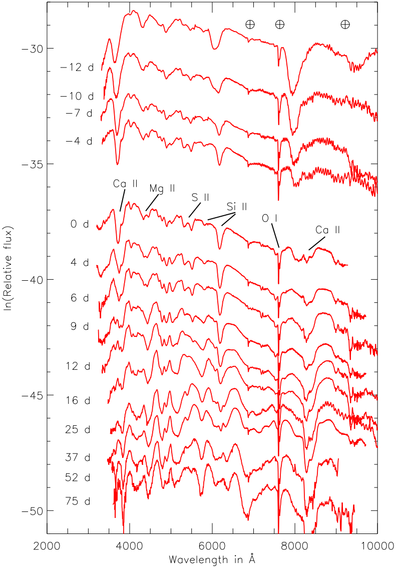




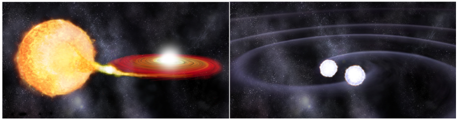
Constraining SN Ia progenitors and explosion mechanisms



Radiative transfer

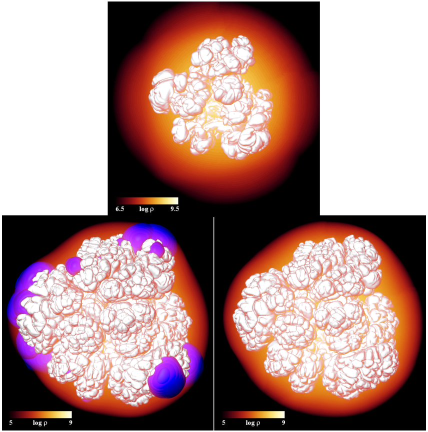


Hydrodynamics coupled to explosive nucleosynthesis

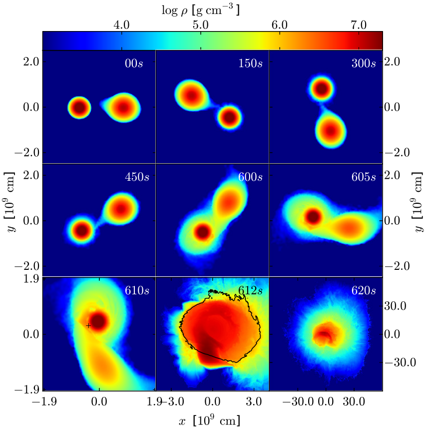


M_{Ch} delayed detonation versus violent merger

N100 (Seitenzahl+ 2013)

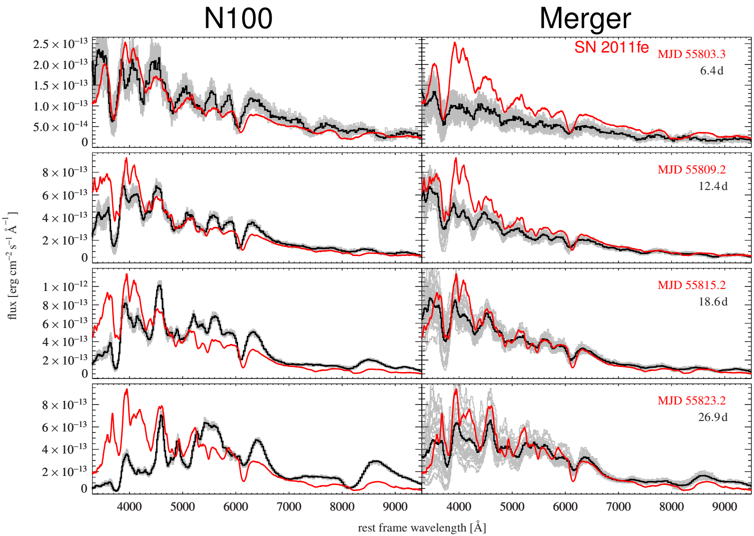


11+09 merger (Pakmor+ 2012)



Both models yield M(^{56}Ni) $\sim 0.6\,M_{\odot}$

Optical spectra (Roepke, MK+ 2012)

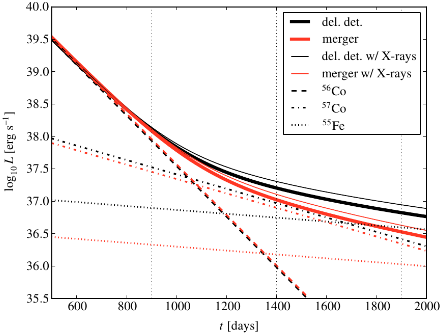


No clear evidence to discriminate the models

Additional constraints required

Predictions have been made for

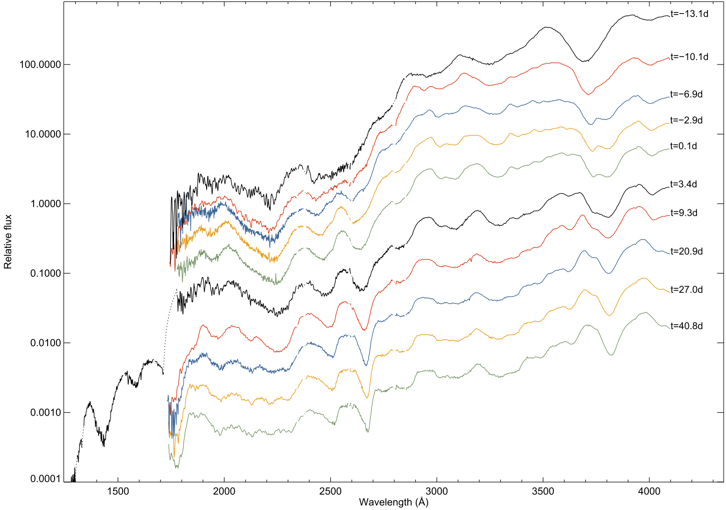
- Gamma rays (Summa+ 2013)
  1st detection of gamma rays from SN Ia for SN 2014J (Churazov+ 2014)
- Late-time bolometric light curves (Roepke+ 2012)
  Interesting epochs will soon be reached for SN 2011fe
- X-rays (Seitenzahl+, subm.)
  Testable at $\sim$ 2000 days past explosion for very nearby SNe



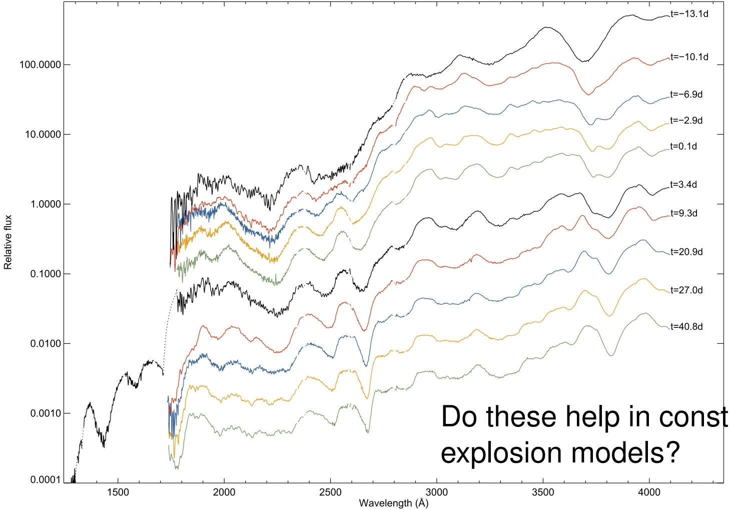
Other promising tools are

- Late-time spectra: differences in the inner ejecta
- Spectropolarimetry: ejecta geometry
- NIR/UV

Mazzali+ 2014 published UV spectra for SN 2011fe

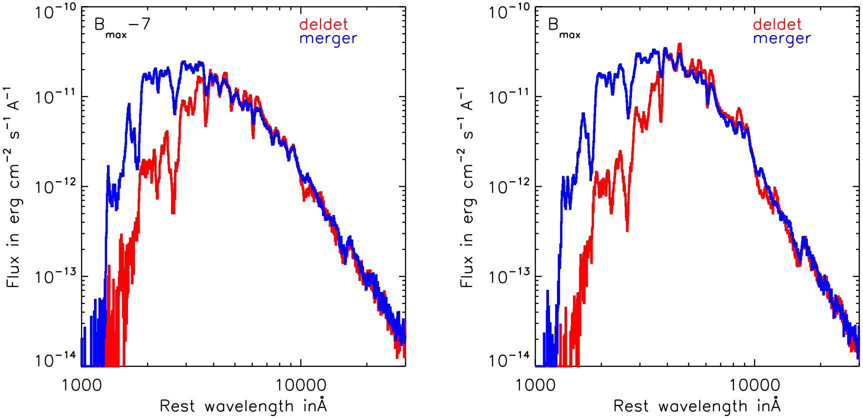


Mazzali+ 2014 published UV spectra for SN 2011fe



Do these help in constraining explosion models?

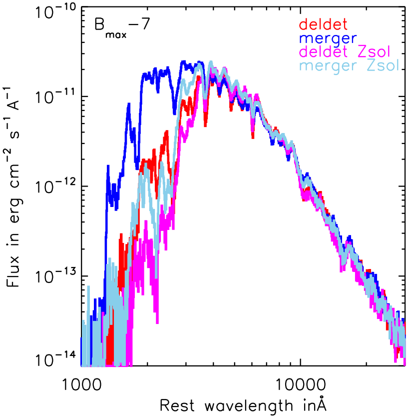
Model spectra from UV to NIR

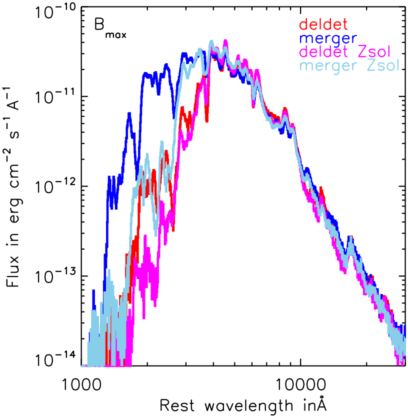


UV seems promising to discriminate between models

No strong sensitivity to different models in optical and NIR

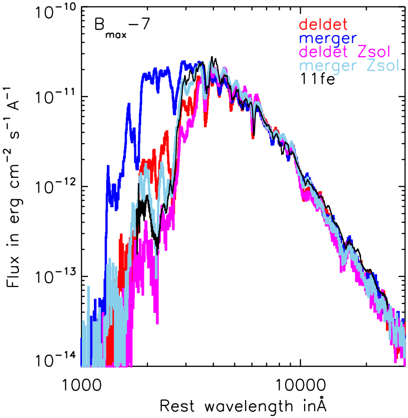
Metallicity introduces UV degeneracy

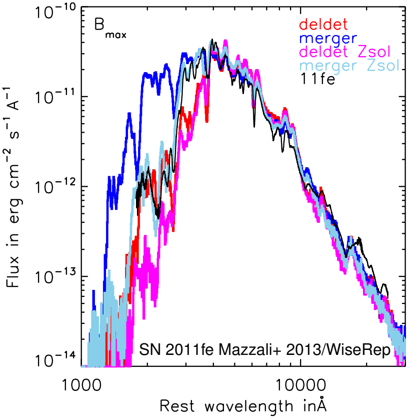




But there is still constraining power in the NUV (2500 . . . 3500 Å)

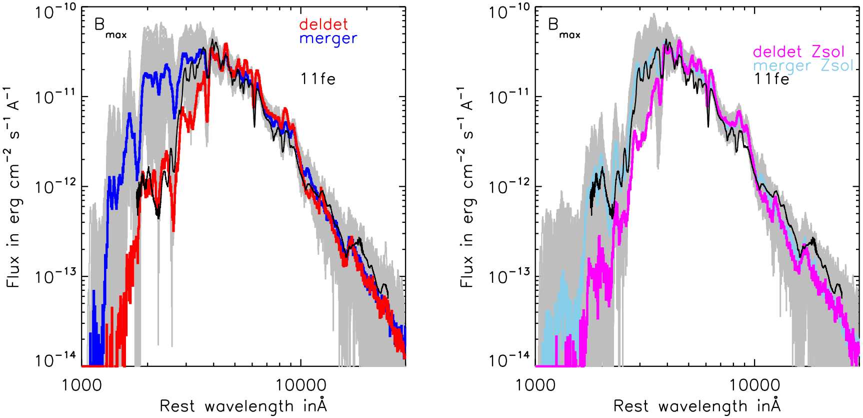
UV observations rule out N100 for SN 2011fe!





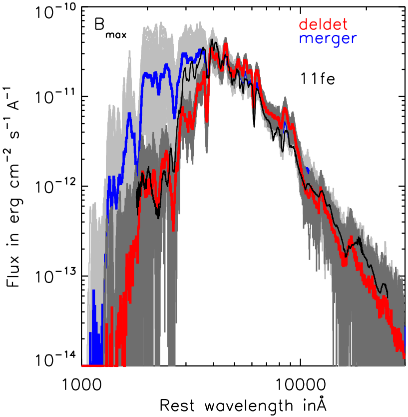
Outward mixing of IGE in N100 suppresses UV flux below the level observed in SN 2011fe

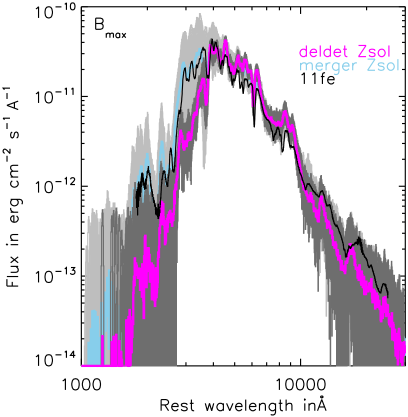
What about different viewing angles?



Introduces some degeneracy

What about different viewing angles?

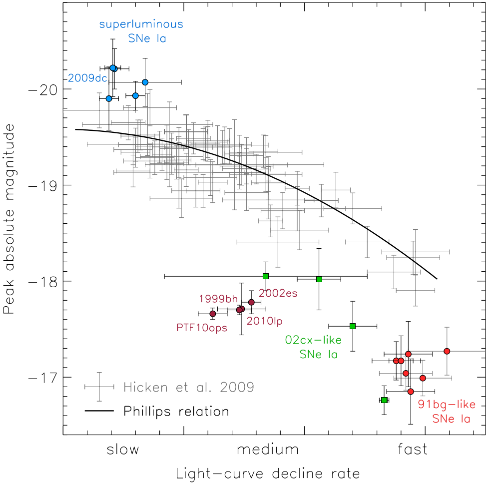




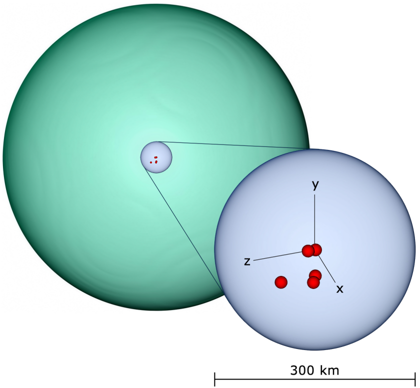
Introduces some degeneracy

But for N100 no viewing angle is compatible with SN 2011fe

Observational diversity of SNe Ia



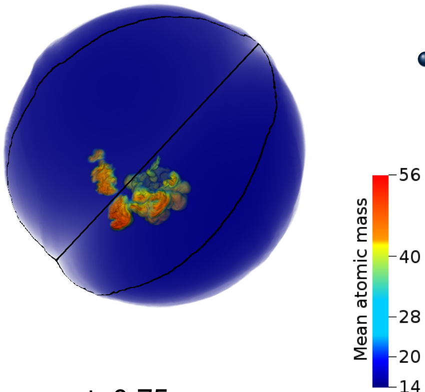
N5def: a deflagration model for 2002cx-like SNe



- Ignition

Kromer+ 2013

N5def: a deflagration model for 2002cx-like SNe

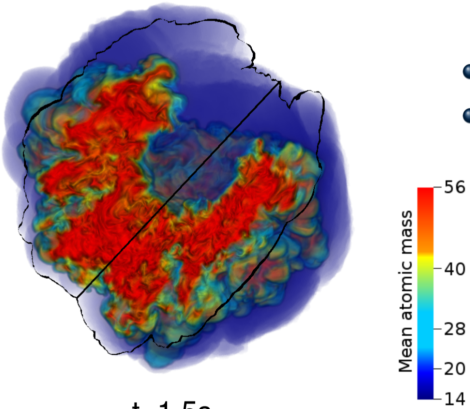


t=0.75s

Kromer+ 2013

- Deflagration plumes rise to the surface
- Rayleigh-Taylor instabilities form

N5def: a deflagration model for 2002cx-like SNe

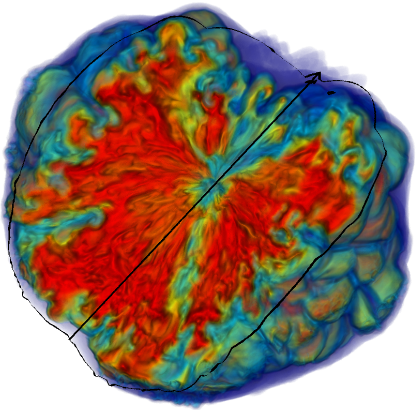


t=1.5s

Kromer+ 2013

- Plumes fail to burn all high density material of the core
- Burning quenches
- Burned material wraps around the core

N5def: a deflagration model for 2002cx-like SNe



t=100s

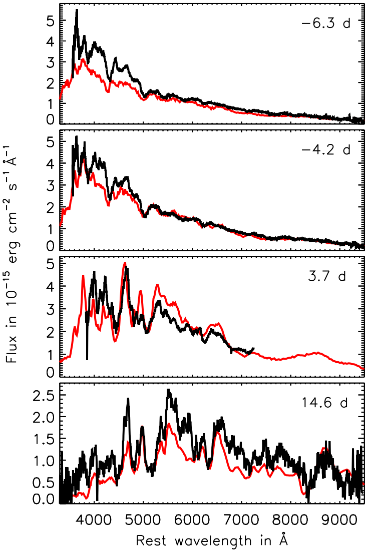
Kromer+ 2013

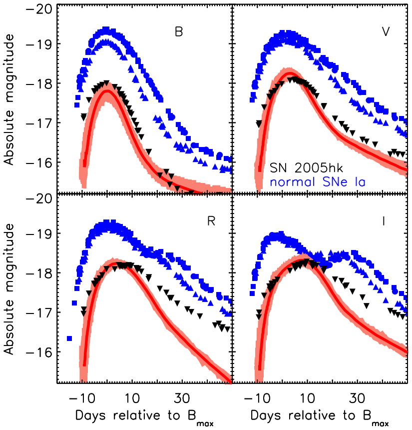
Fails to unbind the WD

See also Jordan et al. 2012

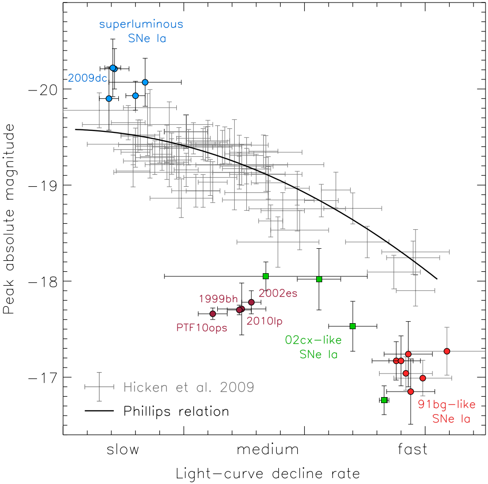
$$E_{\text{kin}} = 0.14 \times 10^{51}\,\text{erg}$$
$$M_{\text{ejecta}} = 0.37\,M_\odot$$
$$M(^{56}\text{Ni}) = 0.16\,M_\odot$$
$$M(\text{IGE}) = 0.22\,M_\odot$$
$$M(\text{IME}) = 0.05\,M_\odot$$
$$M(\text{O}) = 0.06\,M_\odot$$
$$M(\text{C}) = 0.04\,M_\odot$$

N5def: synthetic observables



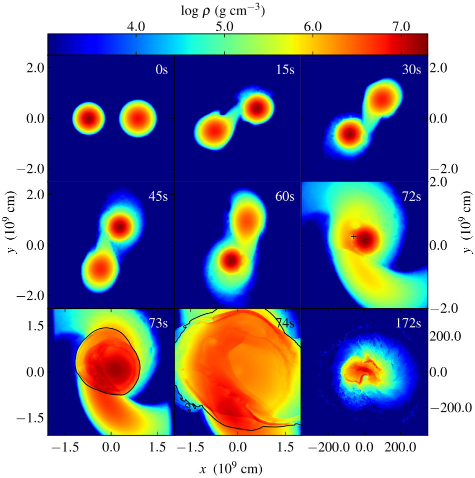


Observational diversity of SNe Ia

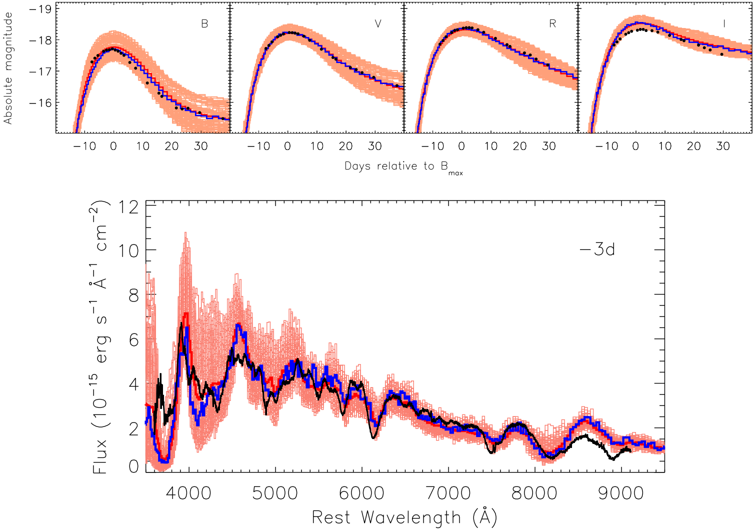


A merger model for SN 2010lp (Kromer+ 2013)

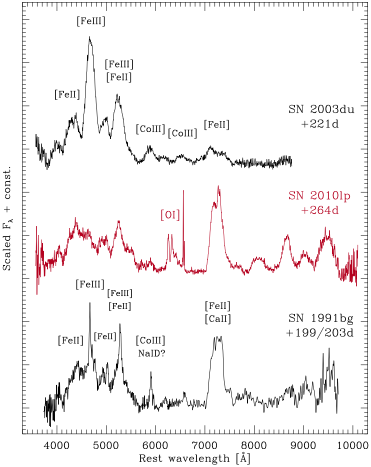
- Progenitor system: 0.9+0.76 $M_{\odot}$ CO WDs
- SPH simulation to model coalescence of WDs
- Trigger detonation
- Follow explosion with grid code
- Energy release unbinds the object
- Nucleosynthesis postprocessing yields $0.1 M_{\odot}$ ^{56}Ni



Excellent agreement with SN 2010lp

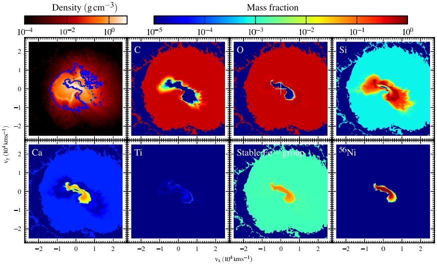


10lp shows narrow [OI] in nebular spectra



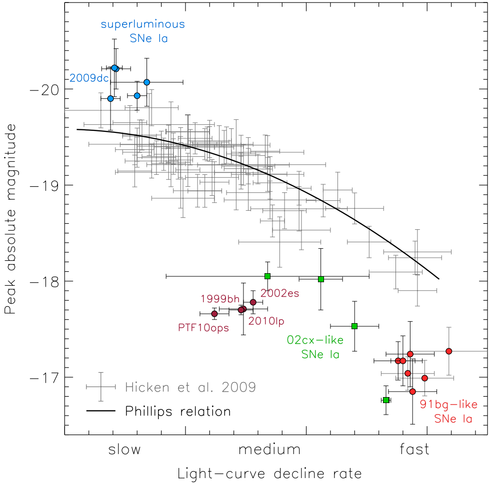
Taubenberger, MK+ 2013

May be possible to achieve within our model



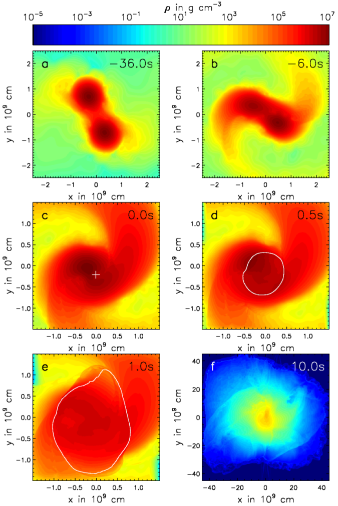
- Requires detailed nebular modelling
- Other objects?

Observational diversity of SNe Ia

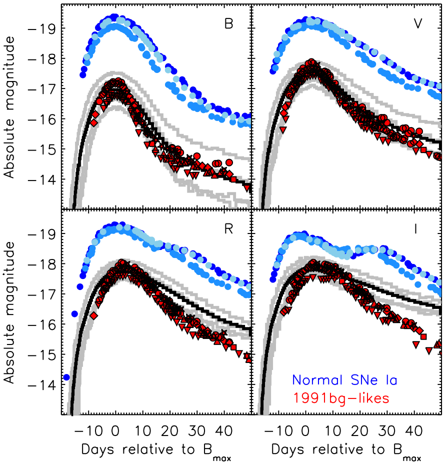


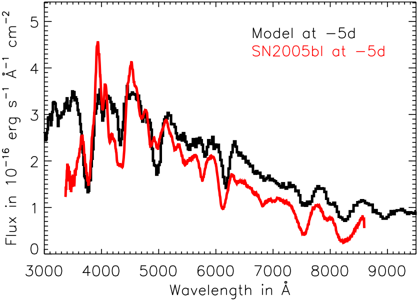
Merging two 0.9 $M_\odot$ WDs (Pakmor, MK+ 2010)

- SPH simulation to model coalescence of WDs
- Trigger detonation
- Follow explosion with grid code
- Energy release unbinds the object
- Nucleosynthesis postprocessing yields $0.1 M_\odot$ ^{56}Ni
- Similar evolution for $0.93 < q < 1$



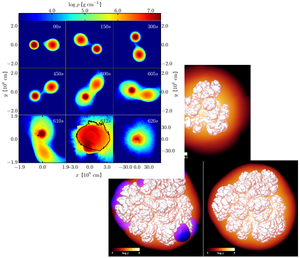
Synthetic observables

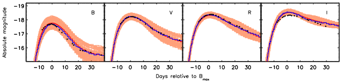




Summary

- Difficult to constrain models for normal SNe Ia from optical spectra
- UV promising to discriminate different models
  - NUV sensitive to model differences
  - FUV dominated by progenitor metallicity
- Application to SN 2011fe
  - Delayed detonation N100 (Seitenzahl+ 2013) ruled out
  - Violent merger (Pakmor+ 2012) possible





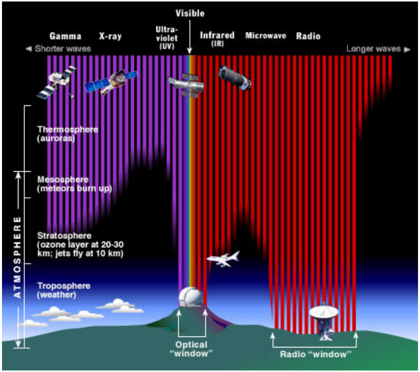
- Succesful models for peculiar SNe
  - SN 2002cx
  - SN 2010lp

Conclusion

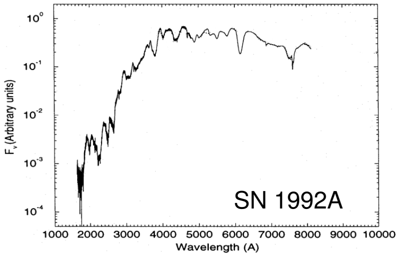
- First principle SN Ia models from explosion to emission
- Typically, to expensive to “fit” individual SN Ia observations
- Happy to contribute when connection to models is required

- Observables for “exotic” transients $\rightarrow$ S. Rosswog

UV difficult to observe

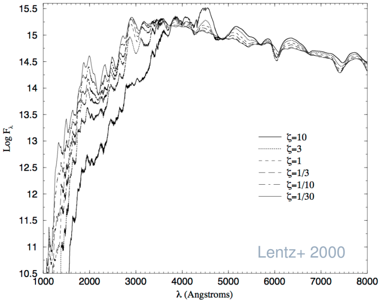


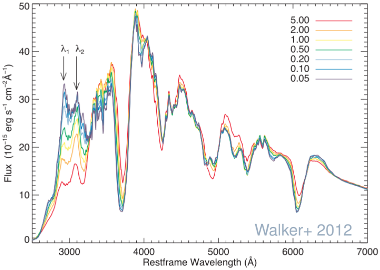
Requires space based detectors

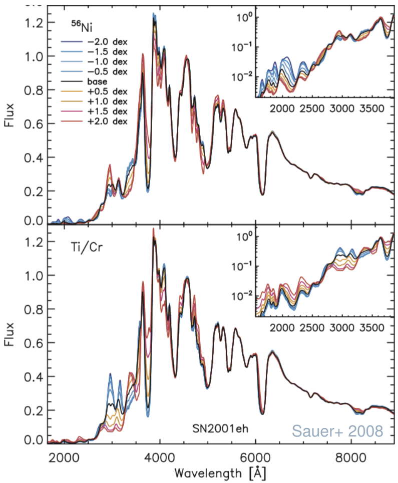


Relatively low flux due to severe line blocking

UV very sensitive to metallicity and mixing





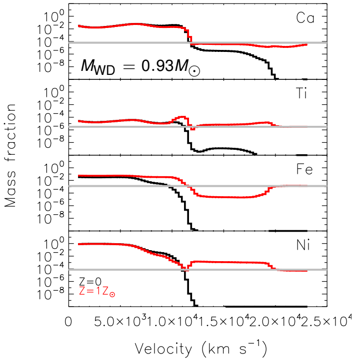


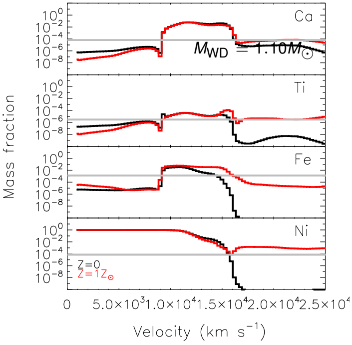
Details not well understood

A self-consistent approach to study metallicity effects

Set of sub-Chandrasekhar mass detonations: $M_{\mathrm{WD}} \Rightarrow M(^{56}\mathrm{Ni})$

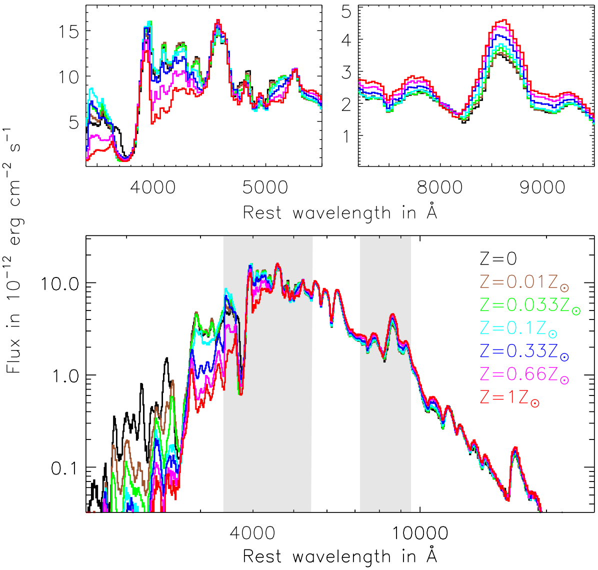
- Pollute progenitor WD with metals
- Simulate hydrodynamic explosion (LEAFS)
- Nucleosynthesis post-processing
- Radiative transfer simulation (ARTIS)





Higher progenitor metallicity leads to lower UV flux

$M_{\mathrm{WD}} = 0.93 M_\odot$



UV sensitivity depends on ^{56}Ni mass

$M_{\mathrm{WD}} = 1.10 M_\odot$