Rapidly Fading Supernovae from Massive Star Explosions

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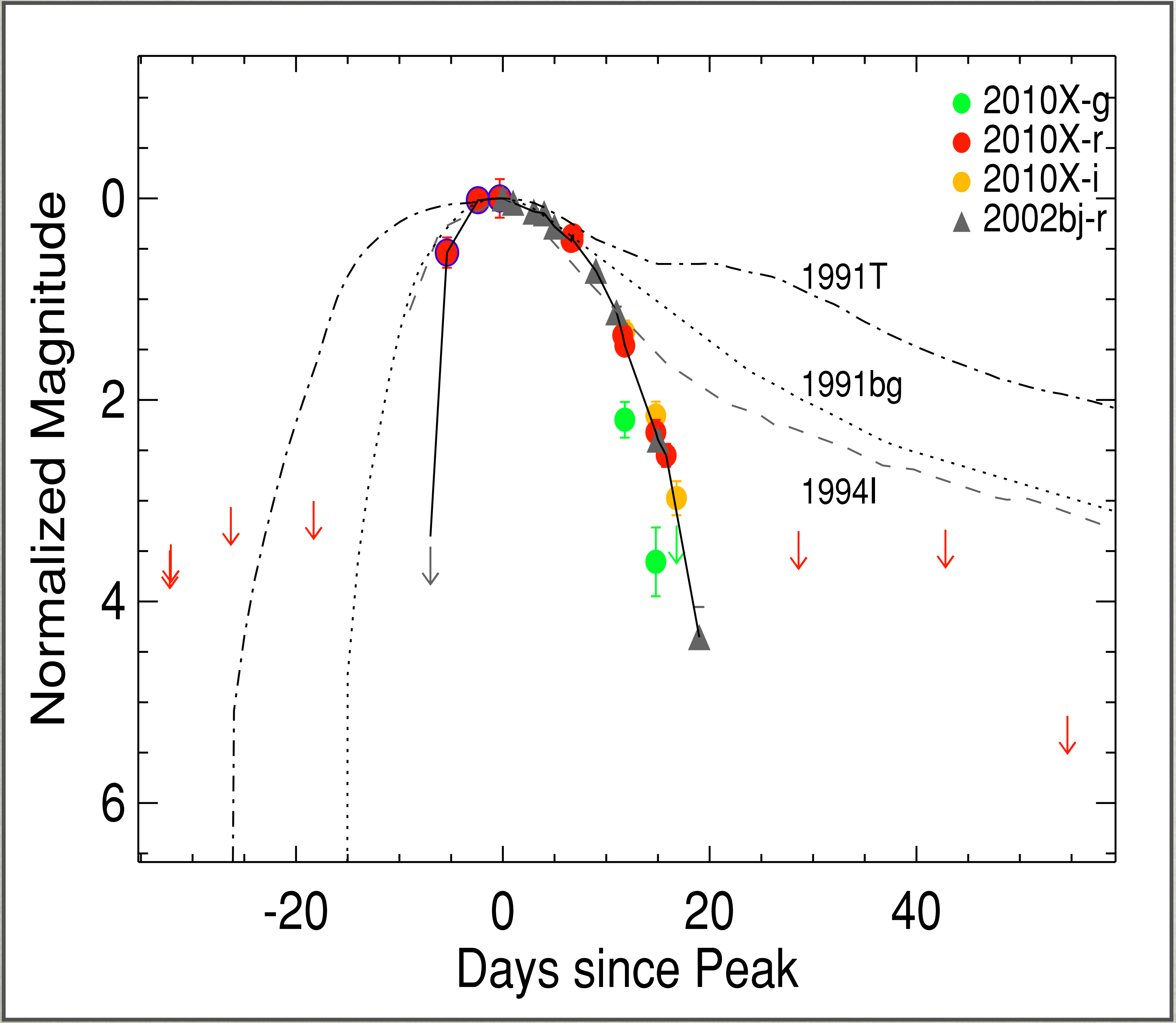
31 October 2013

SN 2010X Discovery

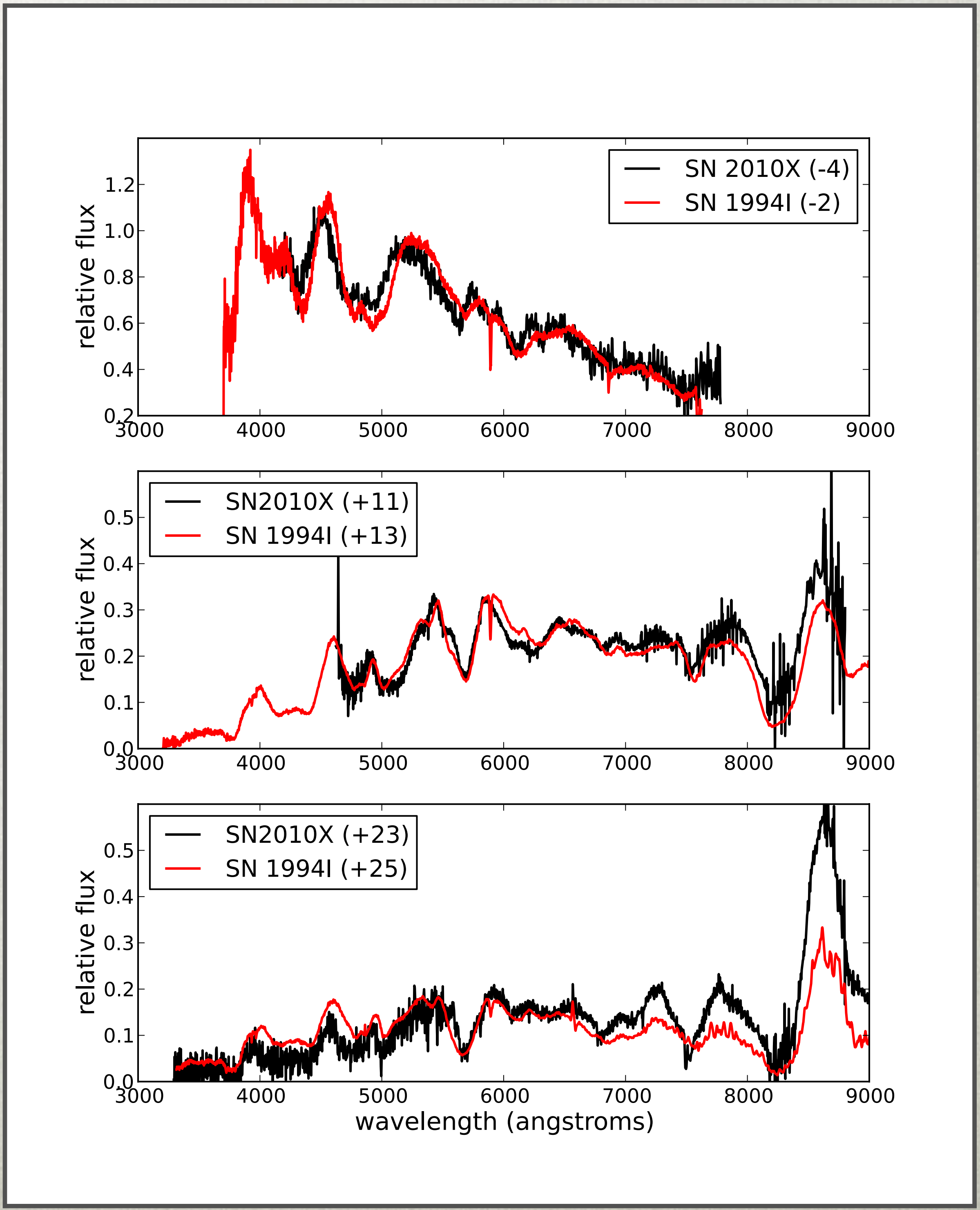


- Extremely rapidly declining light curves
- Similar shape to peculiar SN 2002bj

Kasliwal et al. 2010

Spectroscopic Comparison with SN 1994I

Spectroscopic similarity to other SNe Ic suggests a similar origin, but the light curves decline much more rapidly than normal Ibc SNe

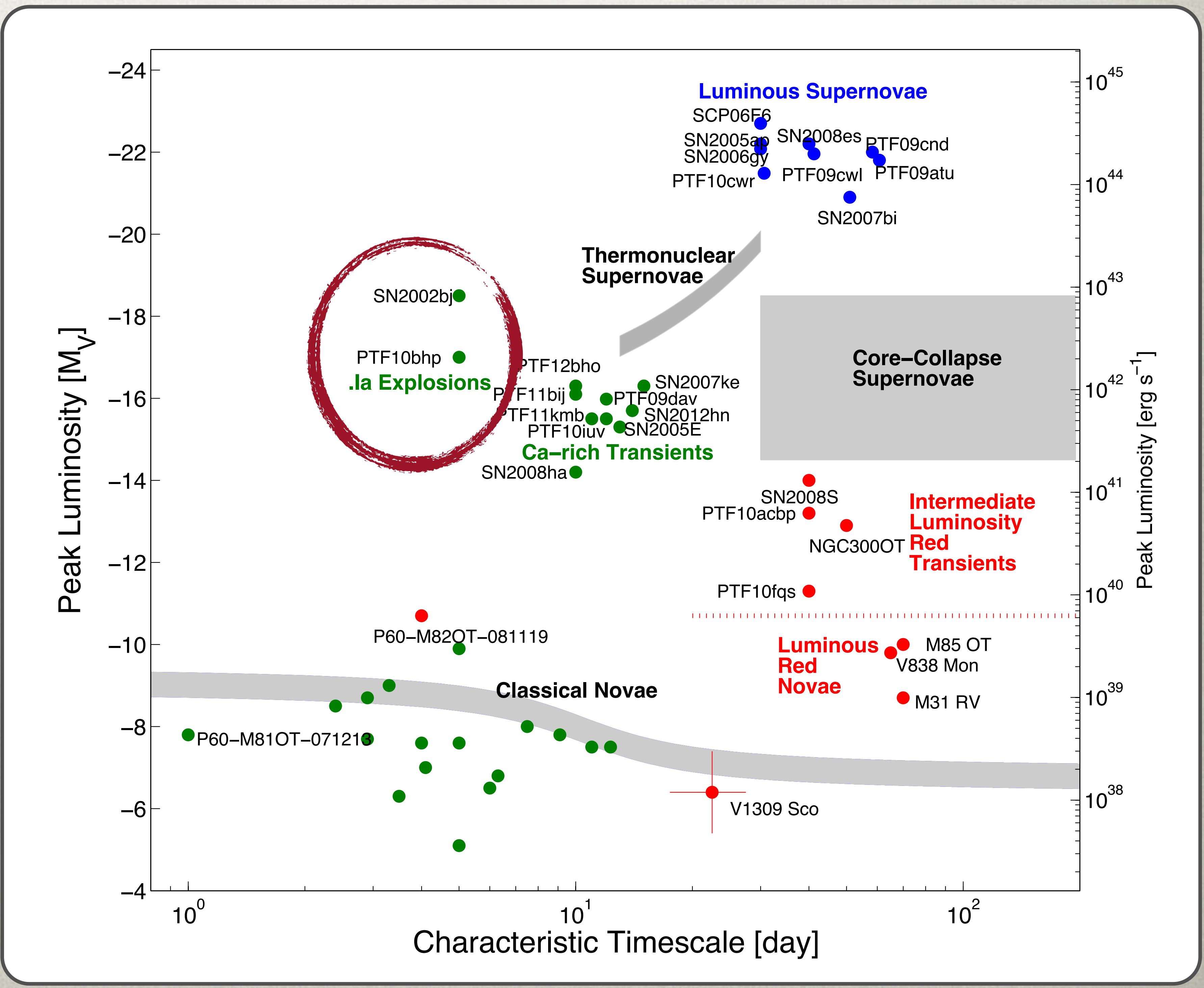


A Small but Growing Class

- Diffusion time (Arnett 1979):

$$t_{\rm sn} \propto M_{\rm ej}^{1/2} \kappa^{1/2} v^{-1/2}$$

- Suggests a small ejected mass ($\sim 0.1\ M_\odot$) as in ".Ia" and similar models



SN 2002bj (Poznanski et al. 2010)

SN 2010X (Kasliwal et al. 2010)

SN 2005ek (Drout et al. 2013)

Modeling SN 2010X Light Curves & Spectra with SEDONA

Kleiser & Kasen 2013 submitted to MNRAS, arXiv:1309.4088

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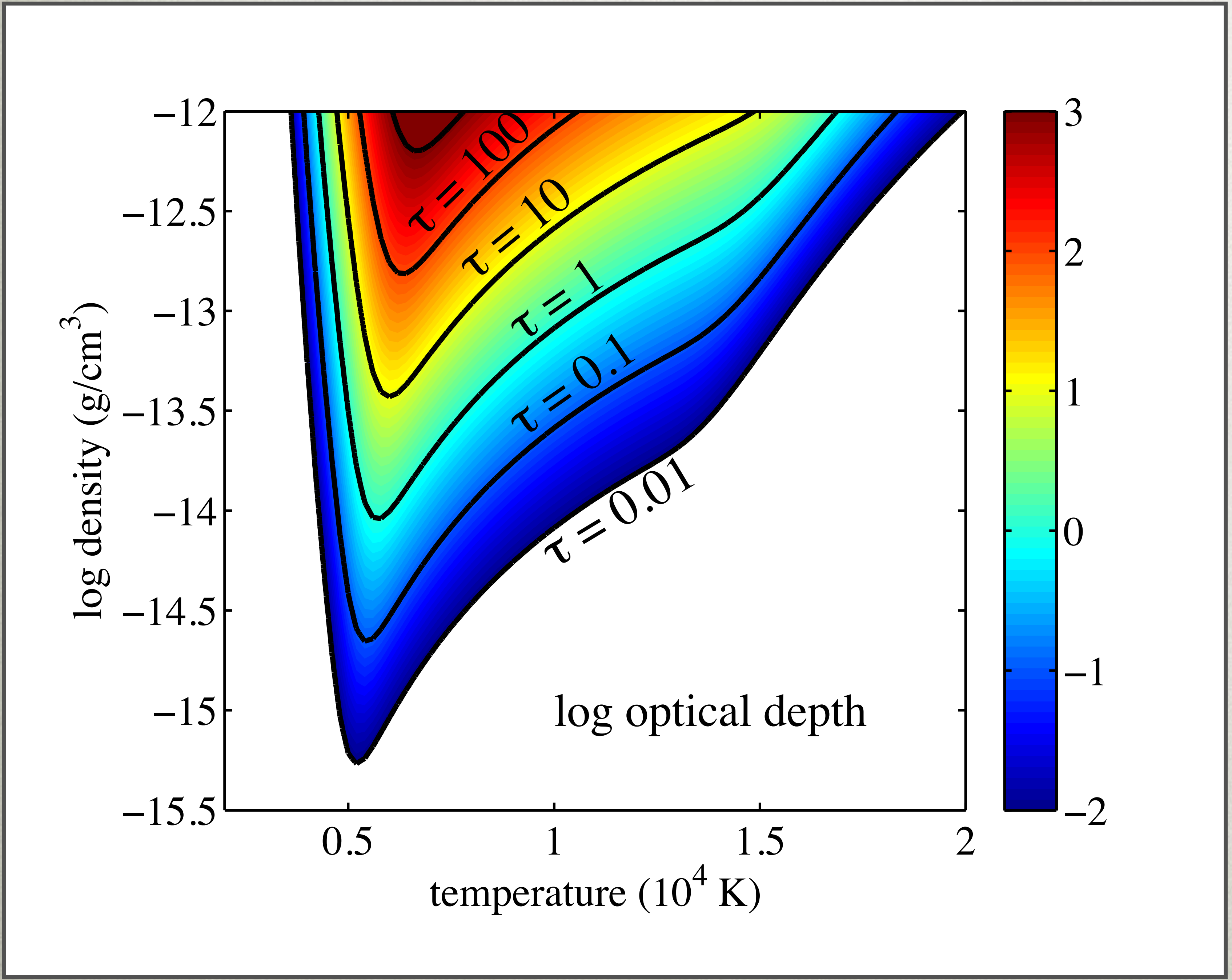
- Parameterized 1D simulations in homologous expansion
- Broken power law density structure
- Uniform composition (two layers: O/Ne-rich and He+solar)

Problems with the ".Ia" Model

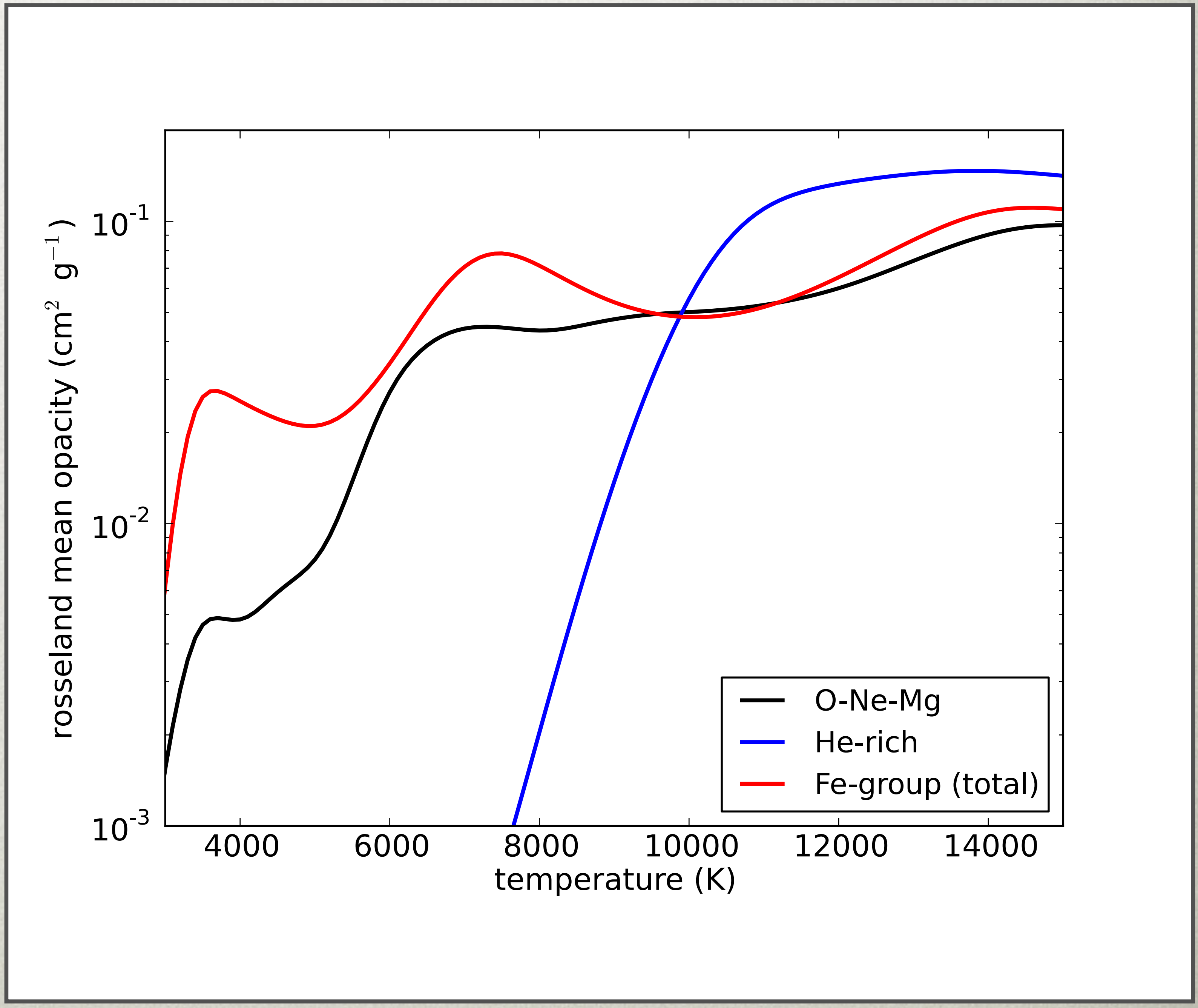


- No radioactive tail seen (could be below limits; could be little γ-ray trapping)
- Deep oxygen features require a large O mass ($\sim 0.3\ M_\odot$), larger than the total ".Ia" ejected mass of $\sim 0.1\ M_\odot$

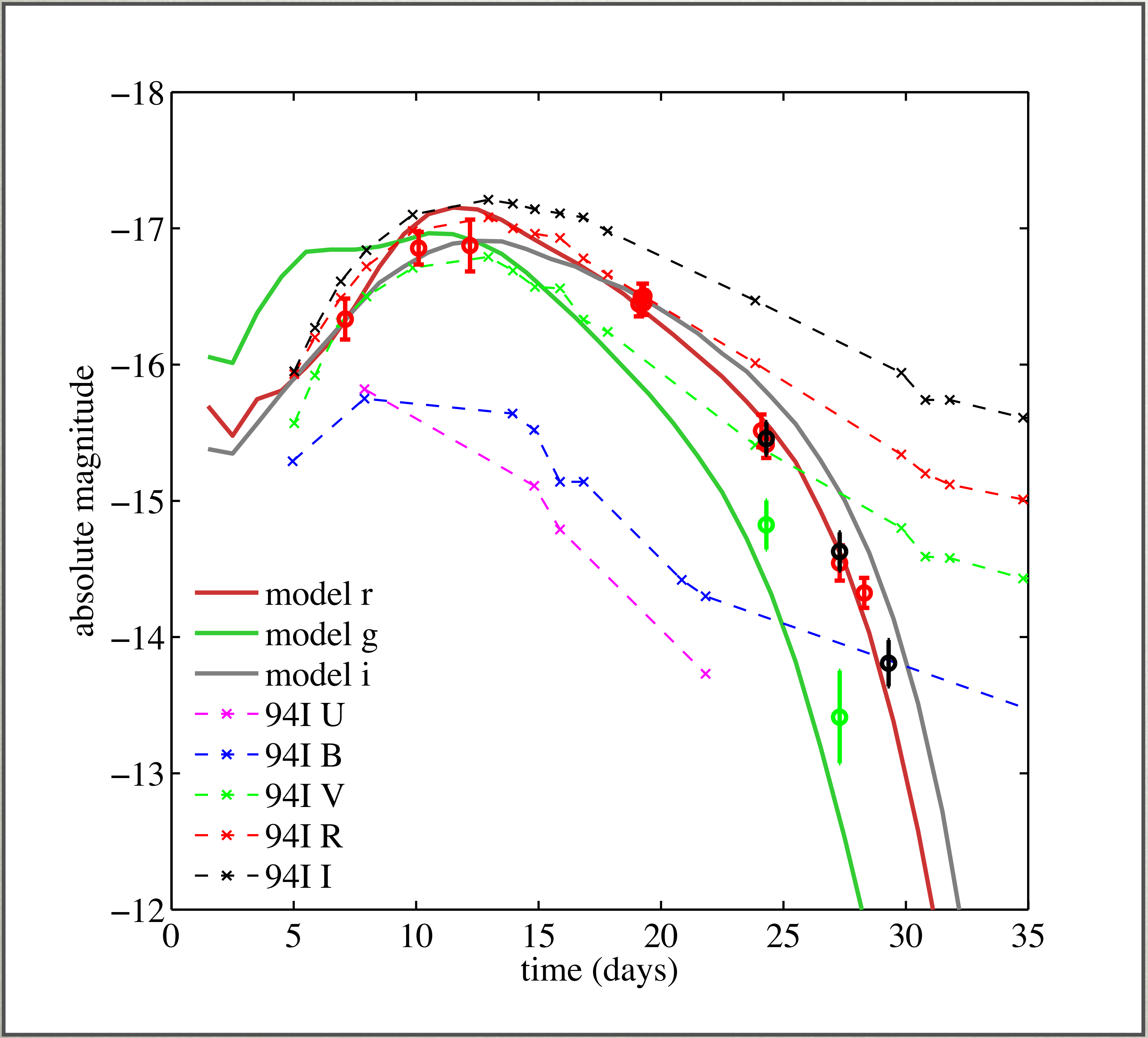
Different Approach: Core-Collapse Model with Recombination

- If little or no nickel is present, the luminosity could be due to the diffusion of thermal energy deposited in the explosion shock
- O recombination allows radiation to be released more rapidly
- This is analogous to a Type II "plateau"

(see Ensman & Woosley 1988, Dessart et al. 2011)



Model Light Curves



SN 2010X data; representative model fit; Type Ic SN 1994I for comparison

Model parameters:

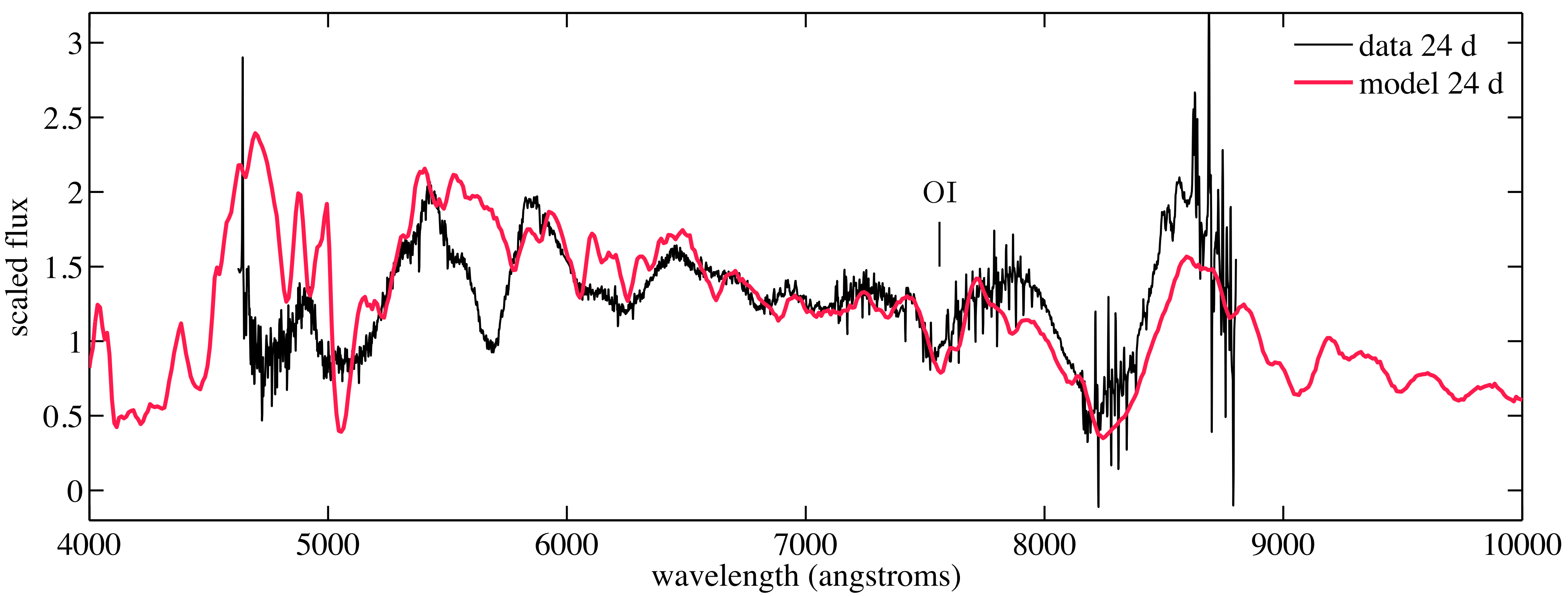
$M = 3.5\ M_\odot$

$E = 1\ B$

$R = 2 \times 10^{12}$ cm

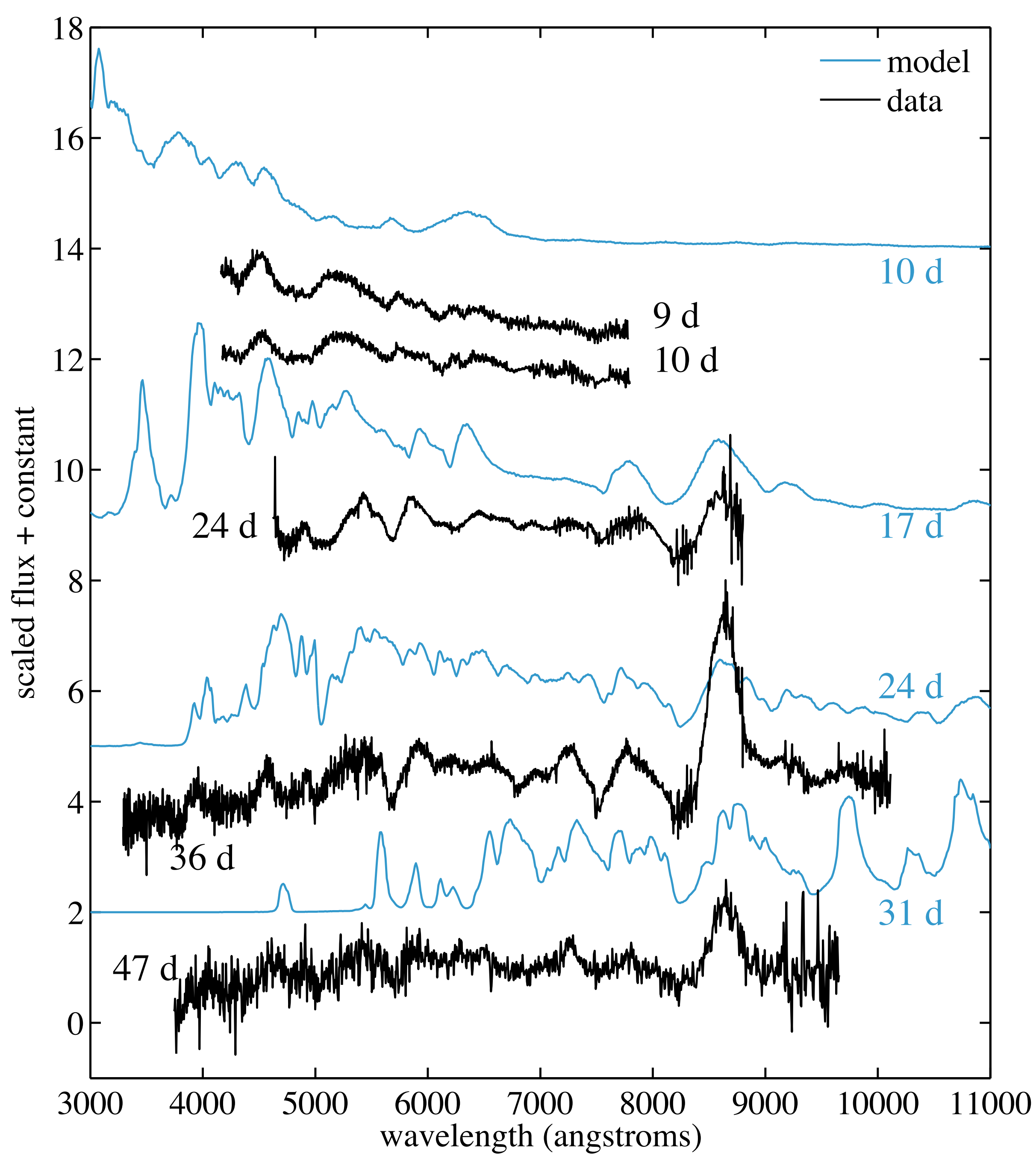
Dominantly O, Ne, Mg in composition

Model Spectrum



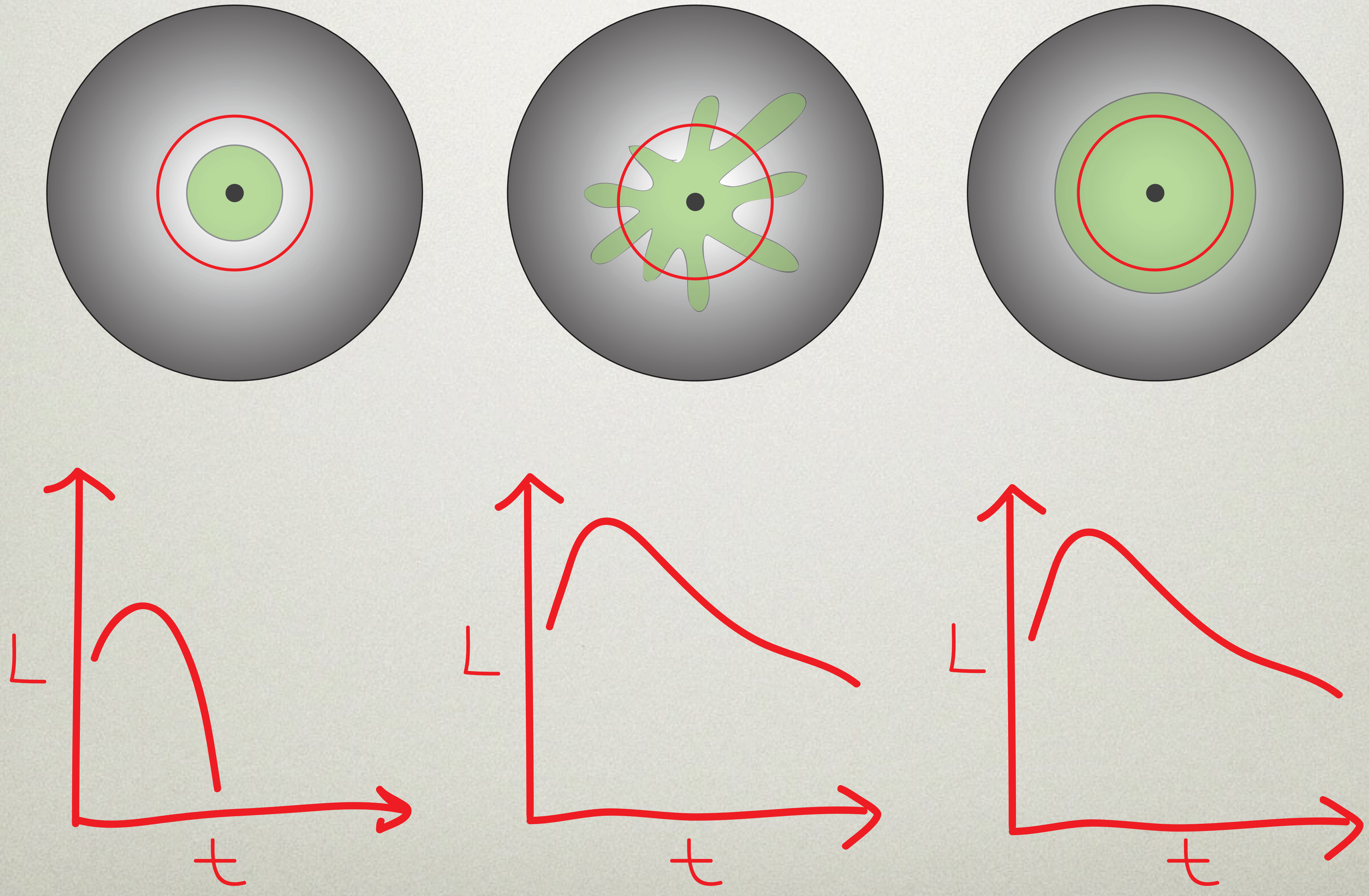
O/Ne/Mg-rich ejecta + thin He/solar outer layer

Spectral Time Series

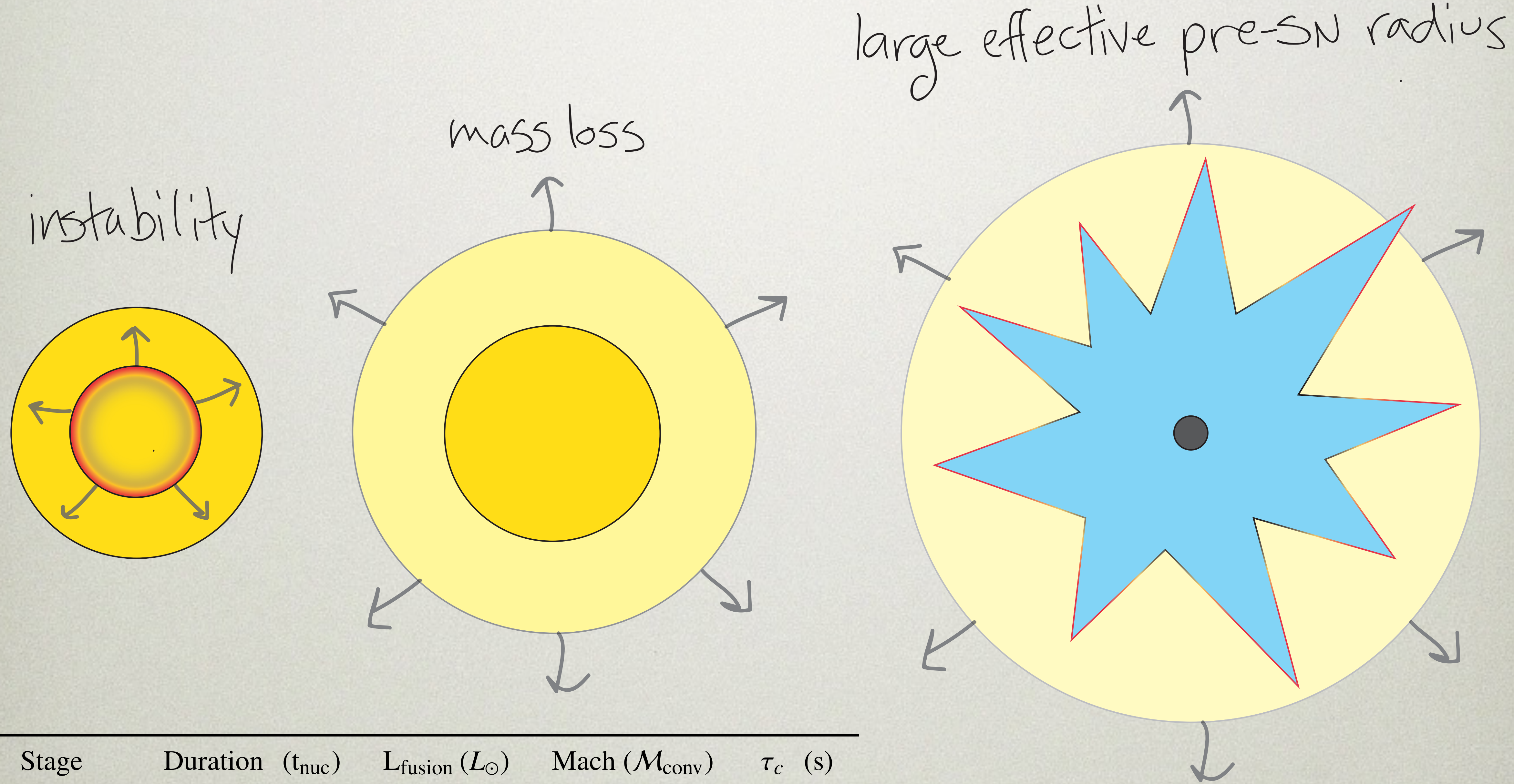


- Color evolution is faster in model spectra than in data, but most major features are reproduced
- Discrepancies may be due to simplicity of the 1D uniform-composition model and potentially could be reduced with finer tuning

Hiding Radioactive Nickel



Large Presupernova Radii



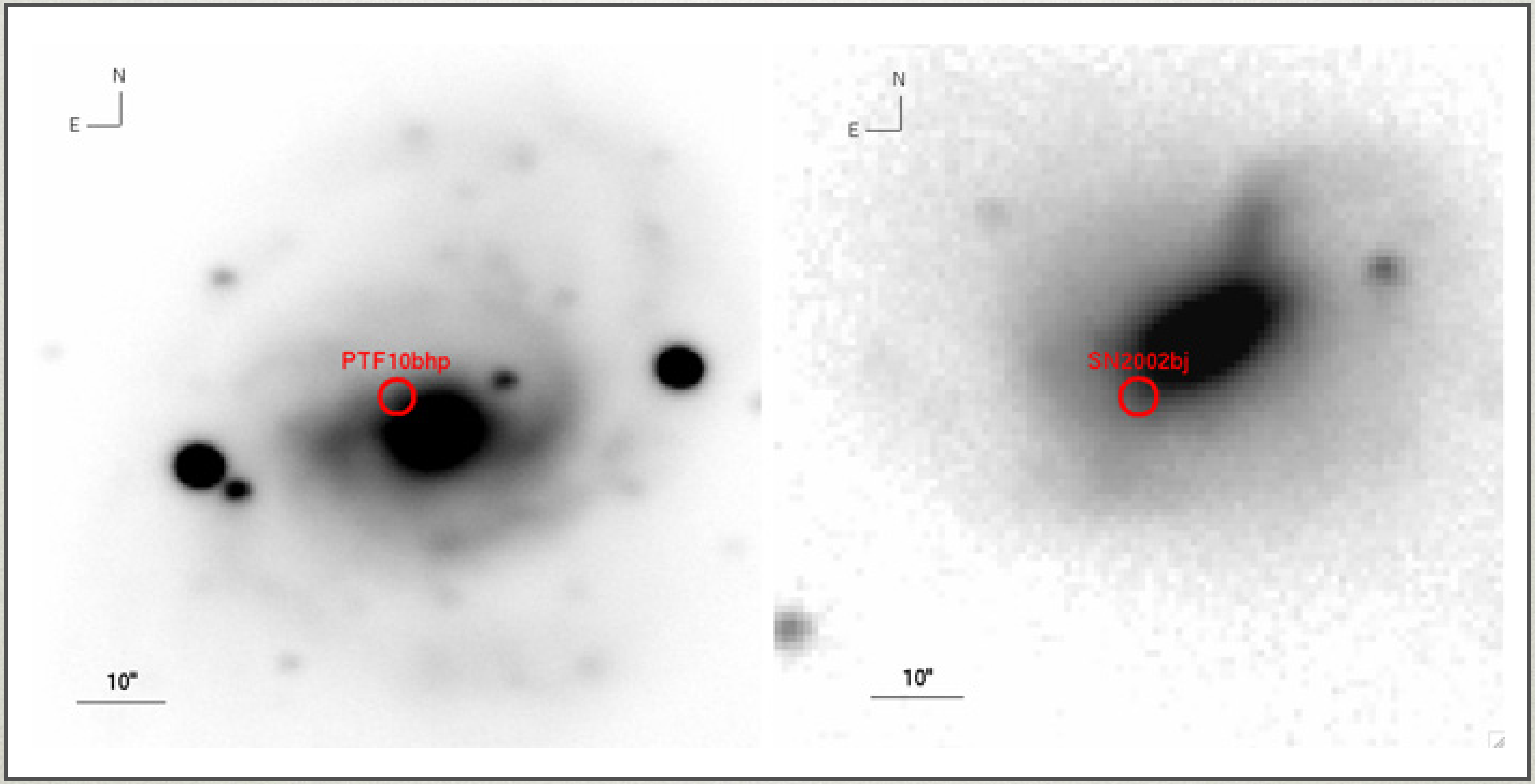
Stage	Duration (t_{nuc})	L_{fusion} ($L_\odot$)	Mach ($\mathcal{M}_{conv}$)	τ_c (s)
Carbon	~ 10^3 yr	~ 10^6	~ 0.003	~ $10^{4.5}$
Neon	~ 1 yr	~ 10^9	~ 0.01	~ 10^3
Oxygen	~ 1 yr	~ 10^{10}	~ 0.02	~ 10^3
Silicon	~ 1 day	~ 10^{12}	~ 0.05	~ 10^2

See e.g. Quataert & Shiode 2012

Summary

- SN 2010X and similar SNe (SN 2002bj, SN 2005ek, others upcoming) are generally thought to be small-mass explosions, perhaps related to the ".Ia" model
- **Lack of a visible radioactive tail** is difficult but not impossible to accommodate in these models
- Particularly, **prominent oxygen features suggest** that a **large ejected mass** is needed
- We explore **core-collapse models** in which **little or no radioactive material** is present in the ejecta—recombination allows for higher masses (O plateau)
- Parameterized radiative transfer calculations agree with the data, but more detailed modeling is required to understand the progenitors
- How can we avoid ejecting radioactive nickel?
- How can we expand progenitor radii enough to achieve observed luminosities?

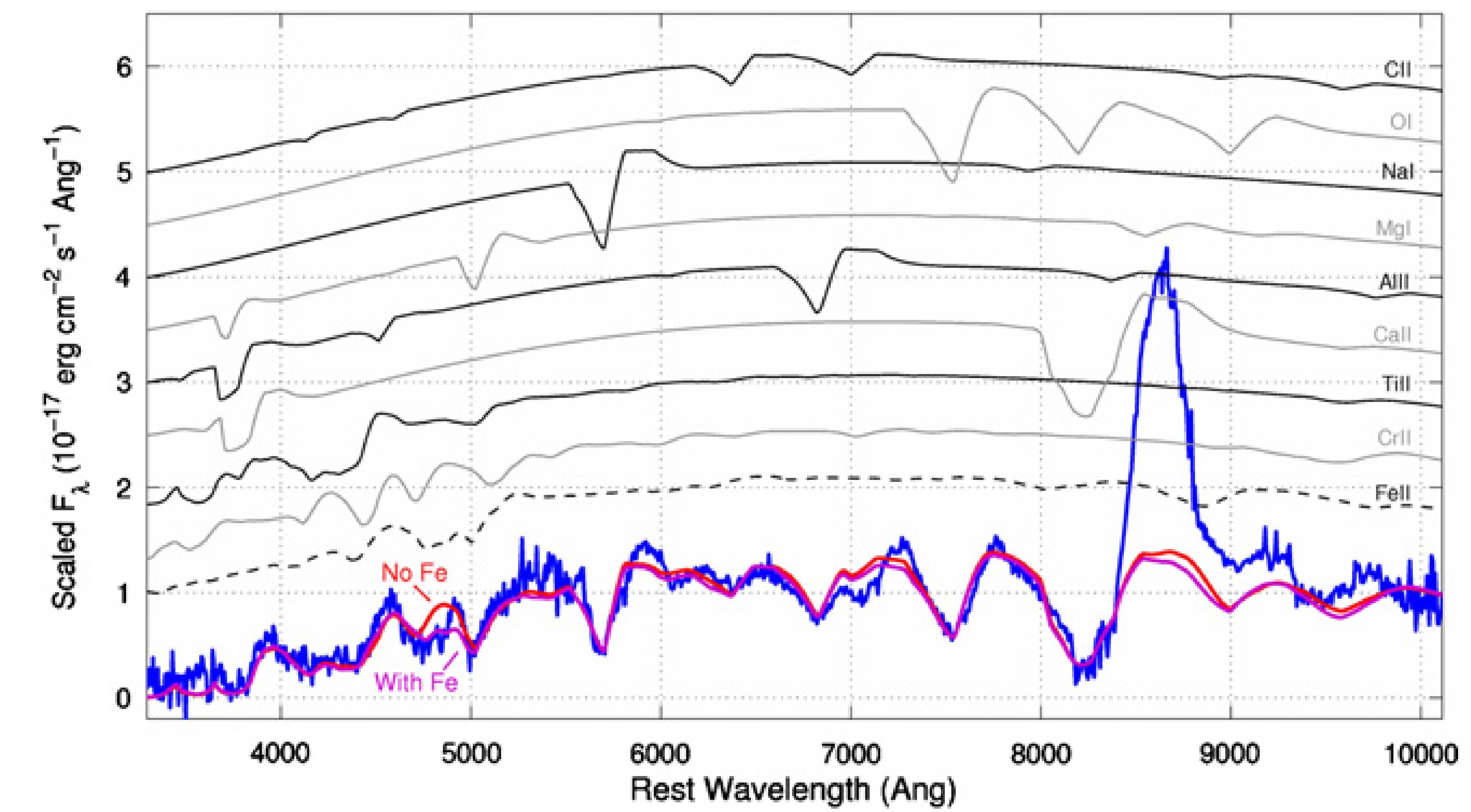
Host Galaxies



Hosts of SN 2010X (left) and SN 2002bj (right) are both star-forming galaxies and do not constrain the progenitors

Kasliwal et al. 2010

SN 2010X Spectrum SYNOW Fit



Type Ic light curve showing strong features of C, O, Ca

Kasliwal et al. 2010

Degeneracy in the Model

- These three parameters can be adjusted to fit a wide range of Ni-free light curves
- SN 2010X can also be fit with other combinations of values (lower right panel)