SN 2008ha and Low-Luminosity Transients

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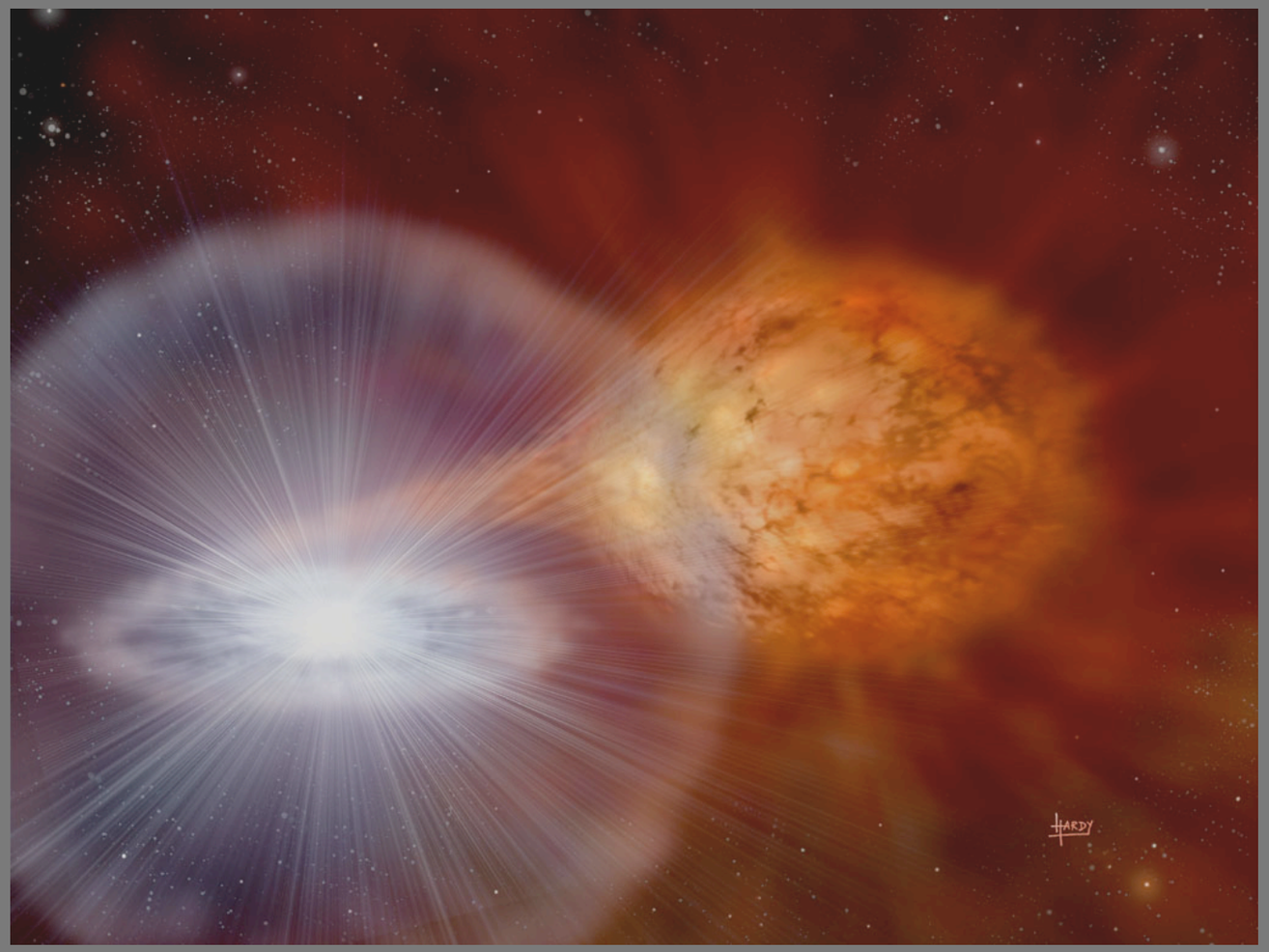
Stellar Death & Supernovae



Collaborators

Kirshner, Challis, Friedman, Rest

Filippenko, Li, Chornock,
Ganeshalingam, Silverman, Steele

Brown

Jha

Wood-Vasey

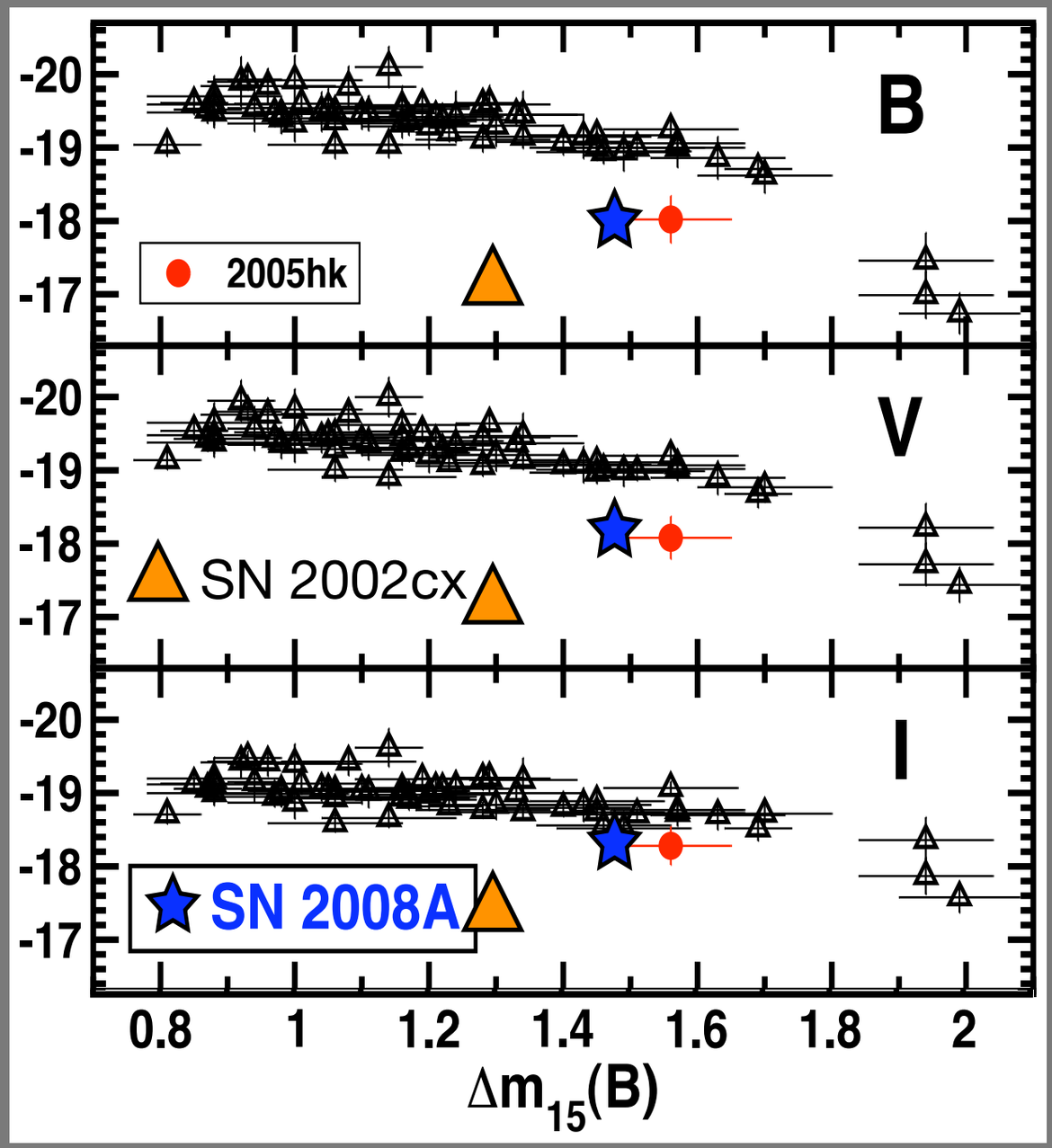
SN 2002cx Had Low Velocities and Low Luminosity

Exceptional SN Ia that did not follow the Phillips relation

Many odd characteristics, including low line velocities

Large group (~16 objects) of similar objects

See Jha's talk for more



Adapted from Phillips et al. 2007

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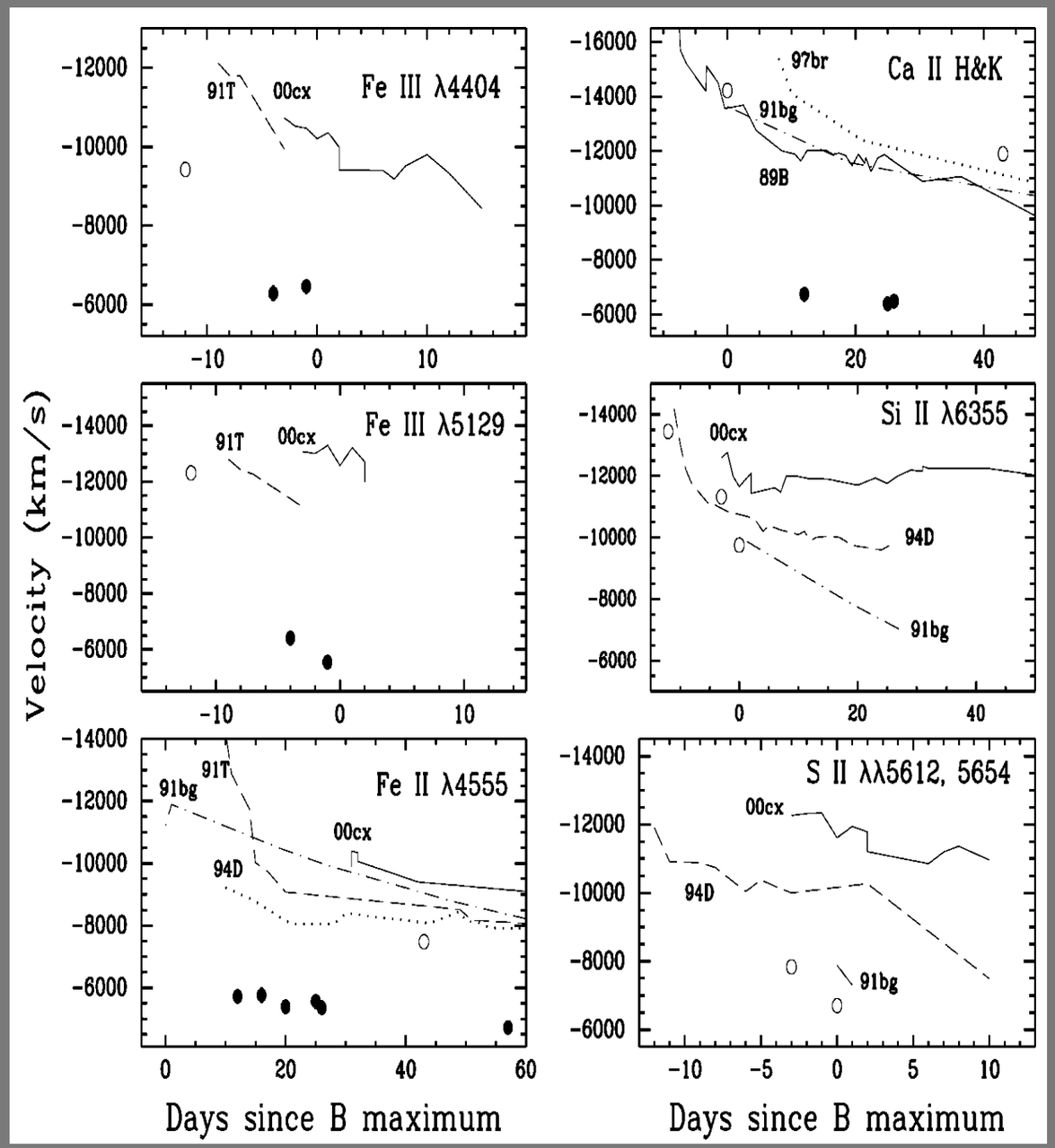
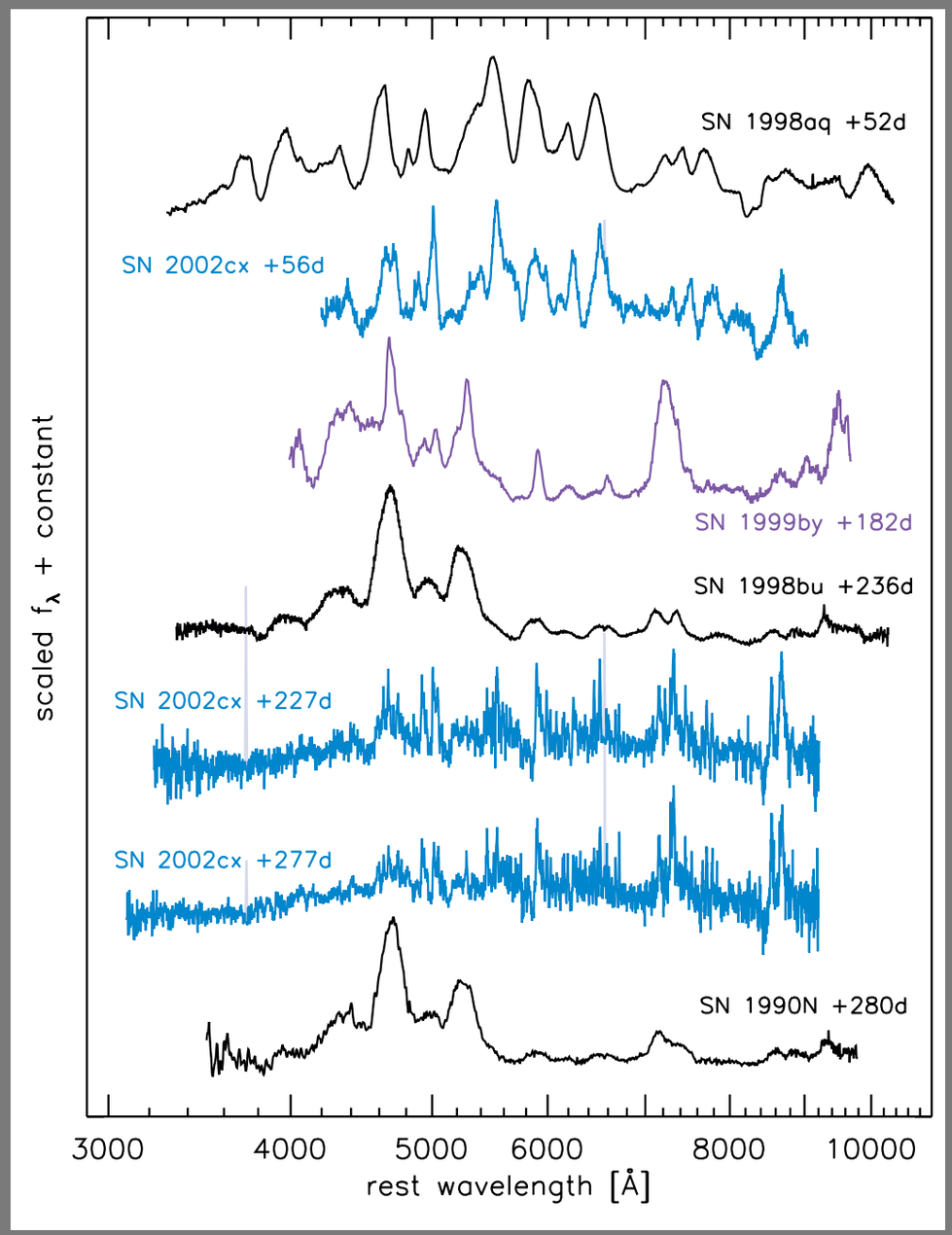


Li et al. 2003

Adapted from Phillips et al. 2007

SN 2002cx-like Objects Form a Distinct Class

- Low ejecta velocity
- Low luminosity
- Hot photosphere (similar to SN 1991T) at early times
- Lacks second NIR maximum
- Late-time spectrum lacks strong forbidden lines



Jha et al. 2006

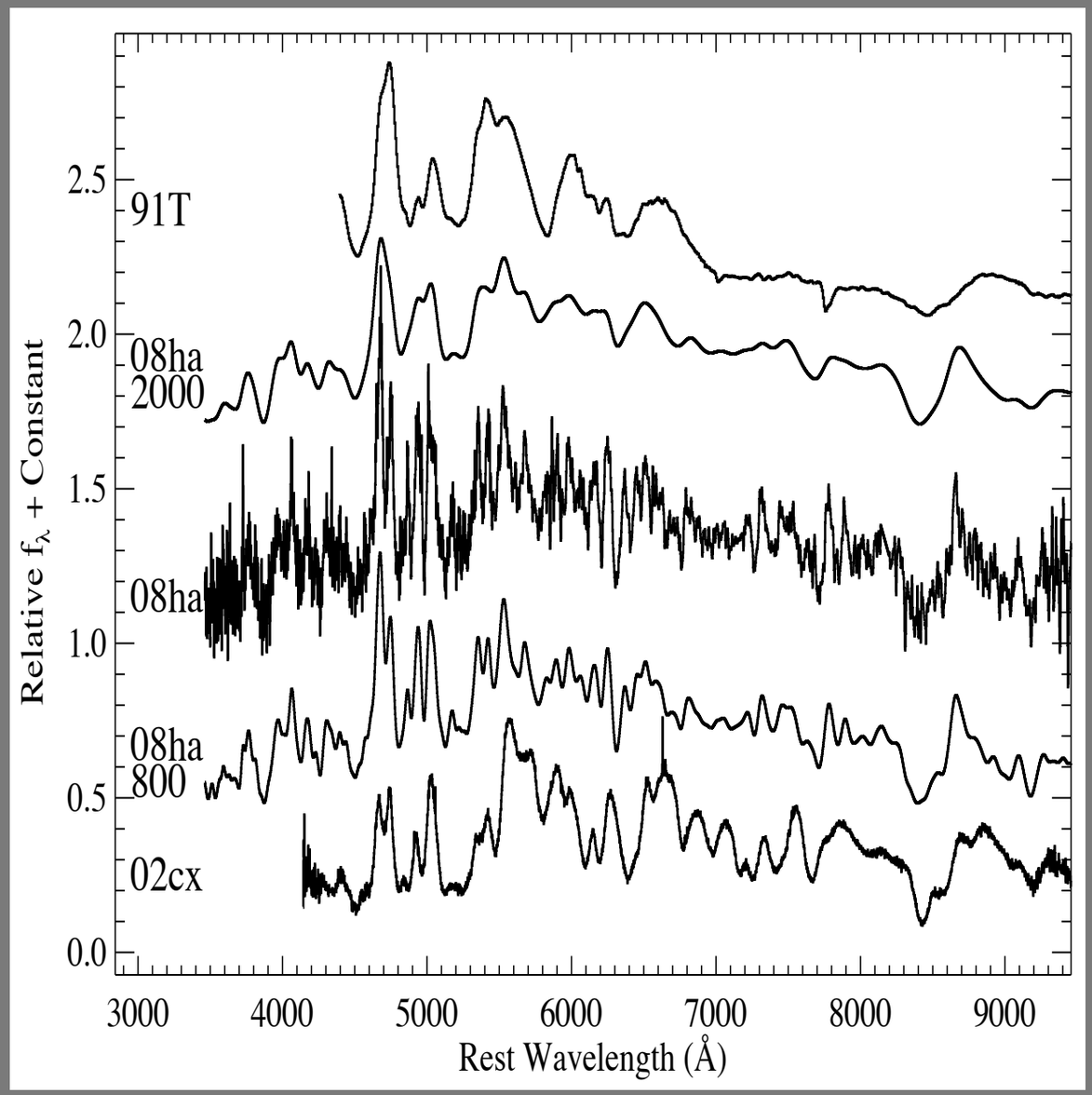
SN 2008ha Had Very Low Ejecta Velocity

At t ≈ 6 days, v_{ej} ≈ 2000 km/s

Very narrow features

Matches SN 2002cx when convolved with a 800 km/s Gaussian

Matches SN 1991T when convolved with a 2000 km/s Gaussian



SN 2008ha Had a Very Fast Light Curve

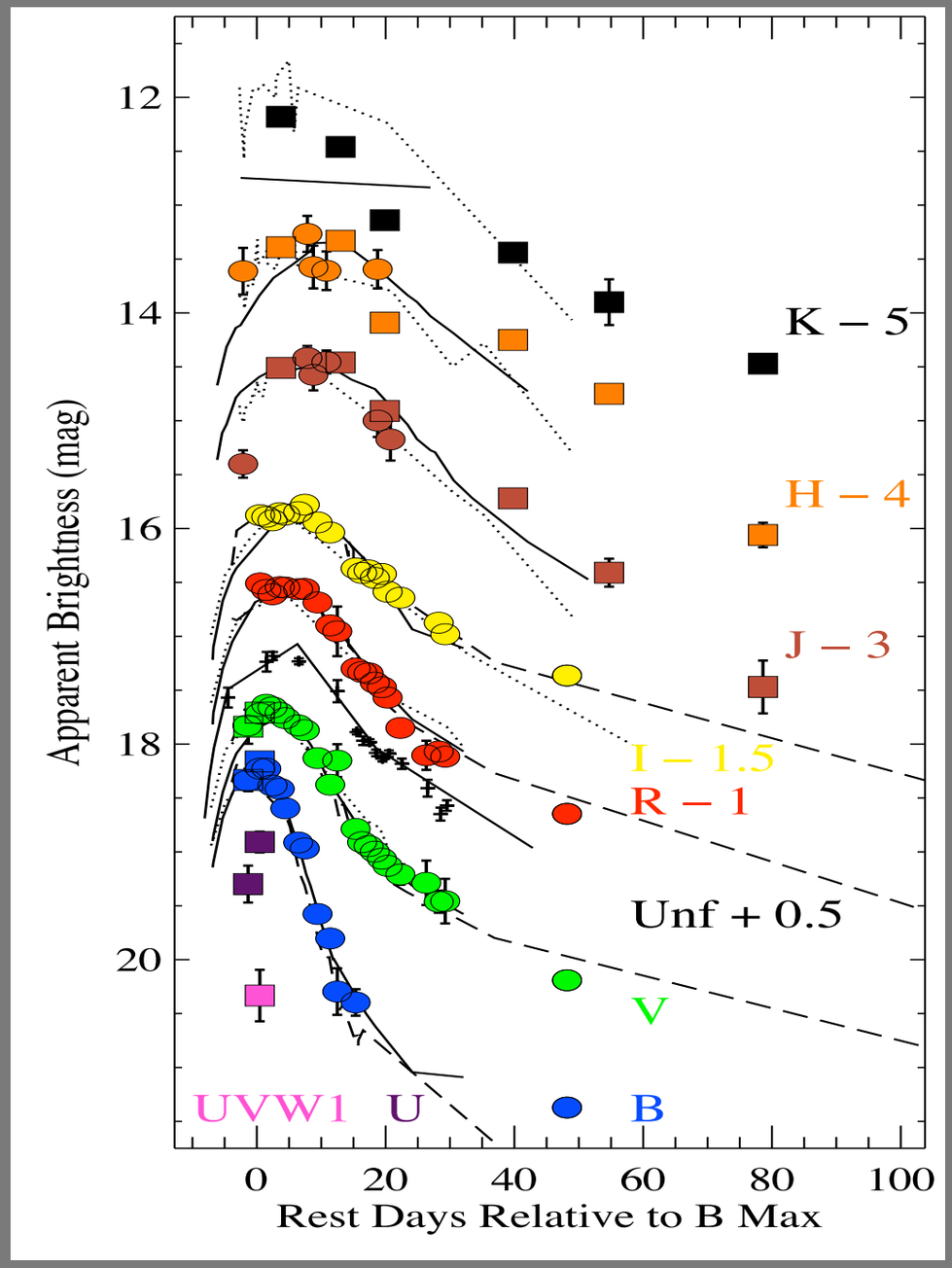
$\Delta m_{15}(B) = 2.17$

Fastest SN ever (by far)

No NIR second maximum

SN 2002cx matches when "stretched" by 0.7.

Rise time is ~10 days

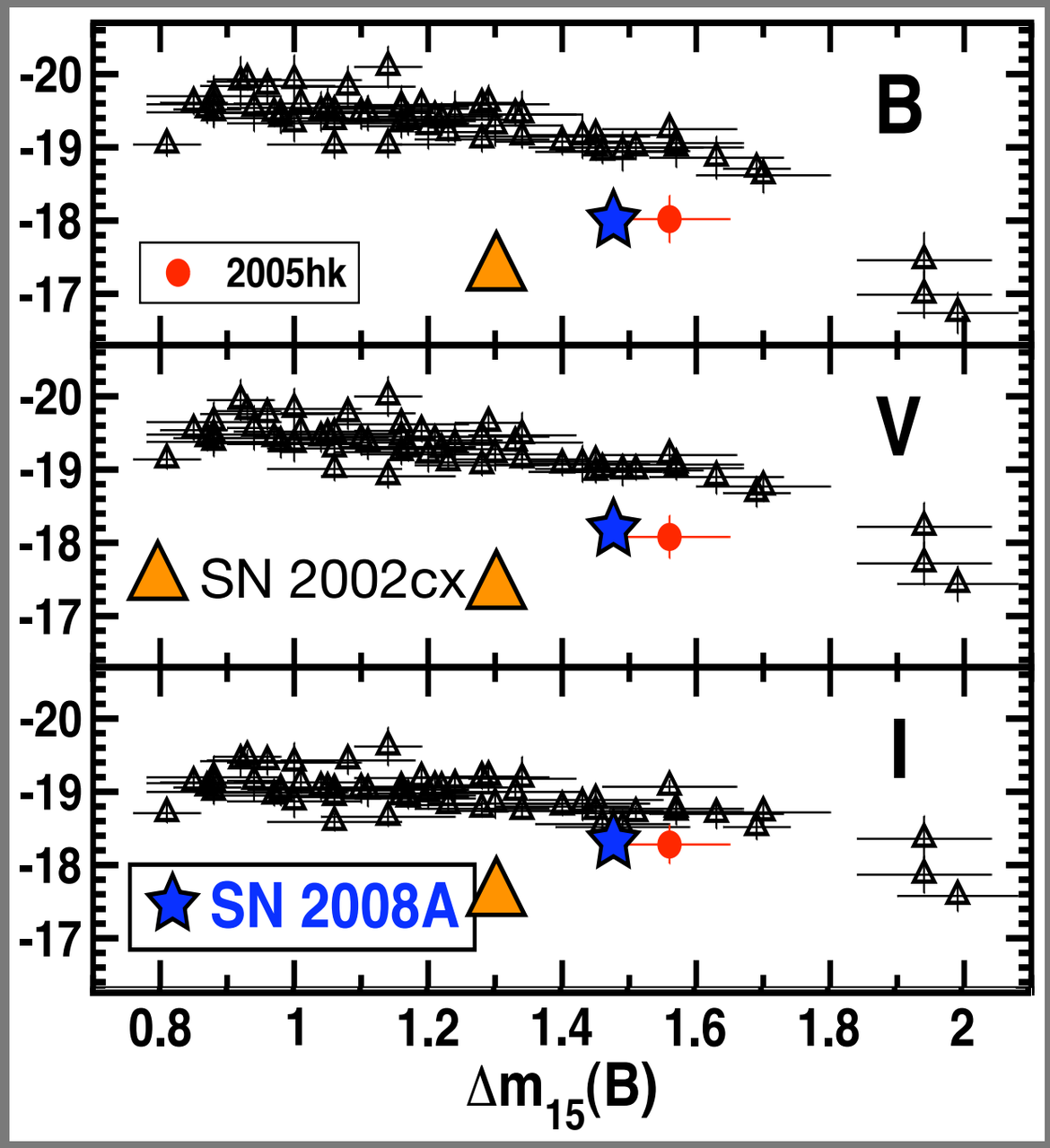


SN 2008ha Had an Extremely Low Luminosity (and ^{56}Ni Mass)

M_B = -13.74 mag
M_V = -14.21 mag

Arnett's Law gives
$M^{56}_{Ni} = 3 \times 10^{-3}\ M_{sun}$

Ejecta mass is ~0.2 M_{sun}
(not 1.4 M_{sun})



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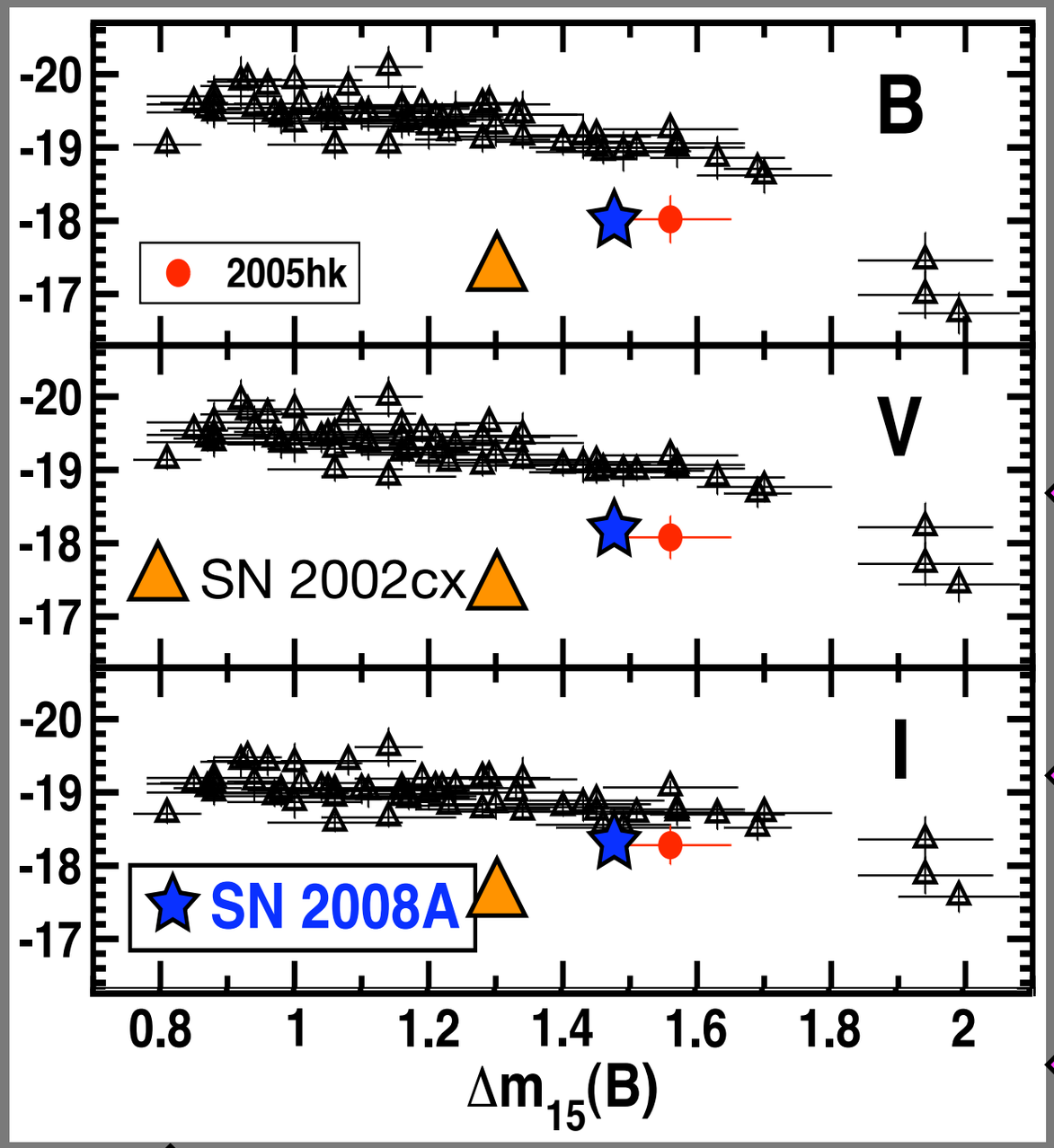


SN 2008ha

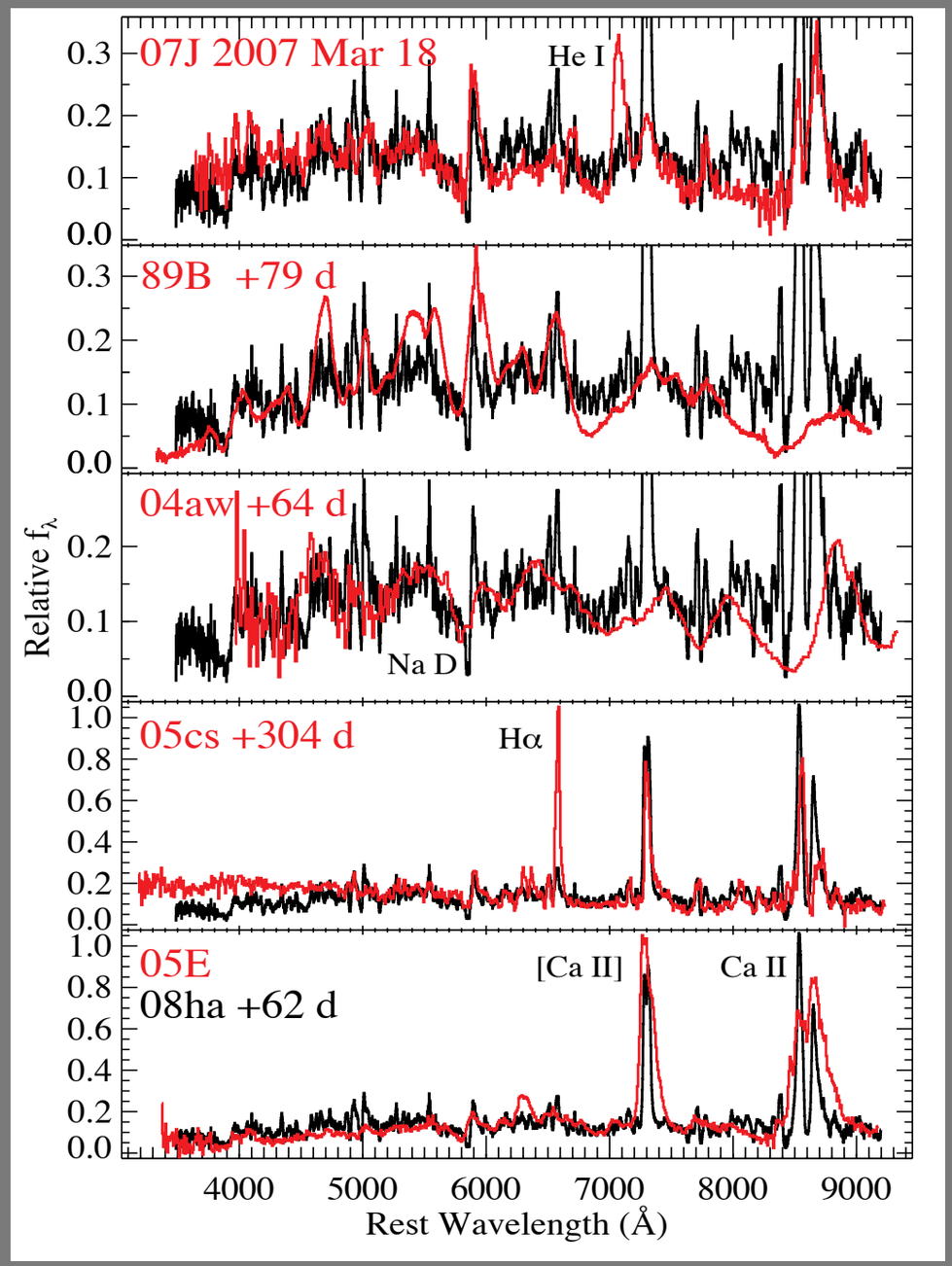
It is Difficult to Determine the Progenitor/Explosion Mechanism

SN 2008ha had low luminosity, low kinetic energy, low ejecta mass, a fast light curve, no H/He, spectra similar to SNe Ia and Ic

SN 2002cx-like objects span a range of luminosity/^{56}Ni mass, have mostly late-type hosts

Foley et al. investigated 4 possibilities: fallback, electron capture, .Ia, and deflagration

Valenti et al. preferred a massive star origin (fallback/EC)



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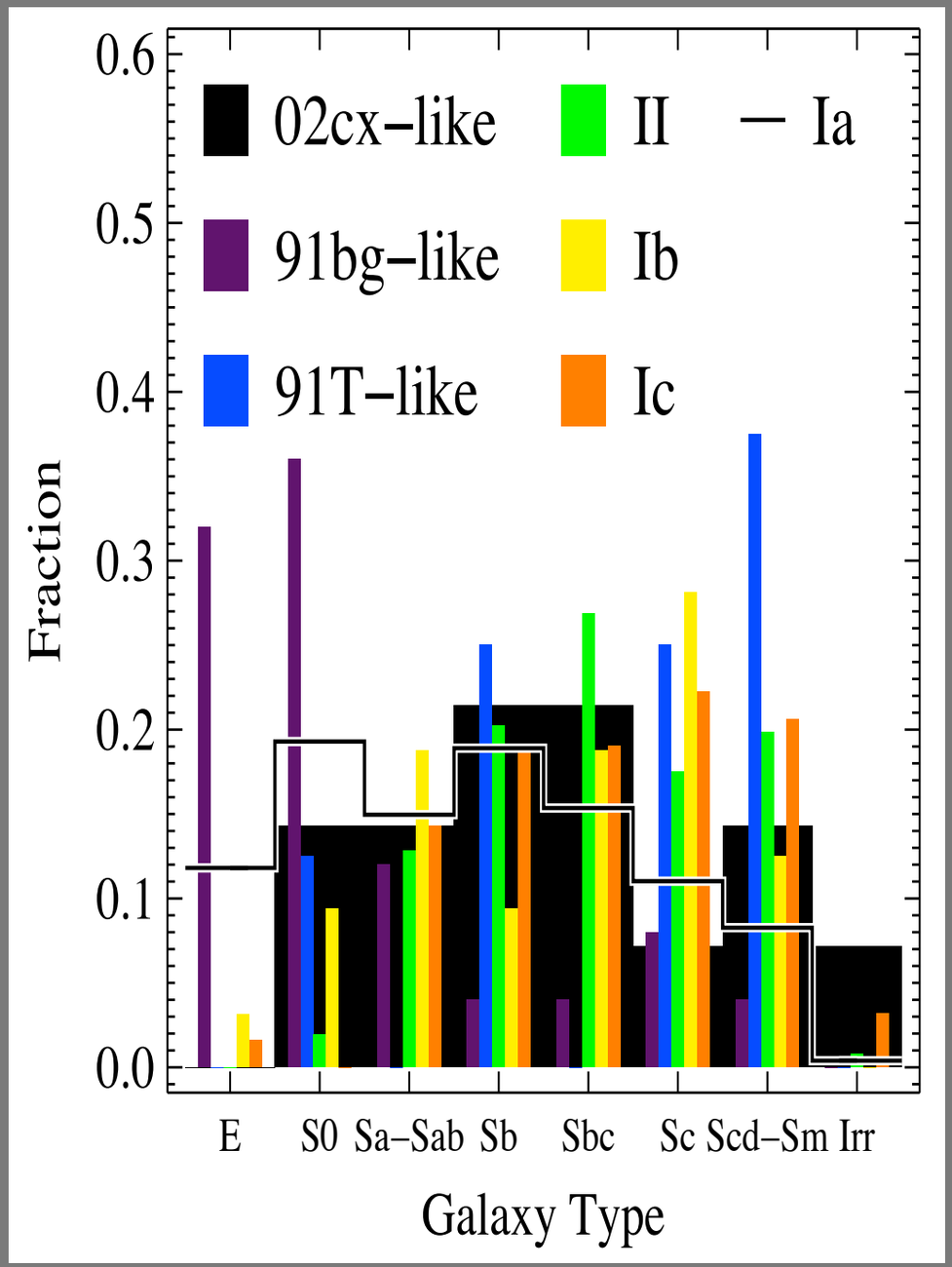


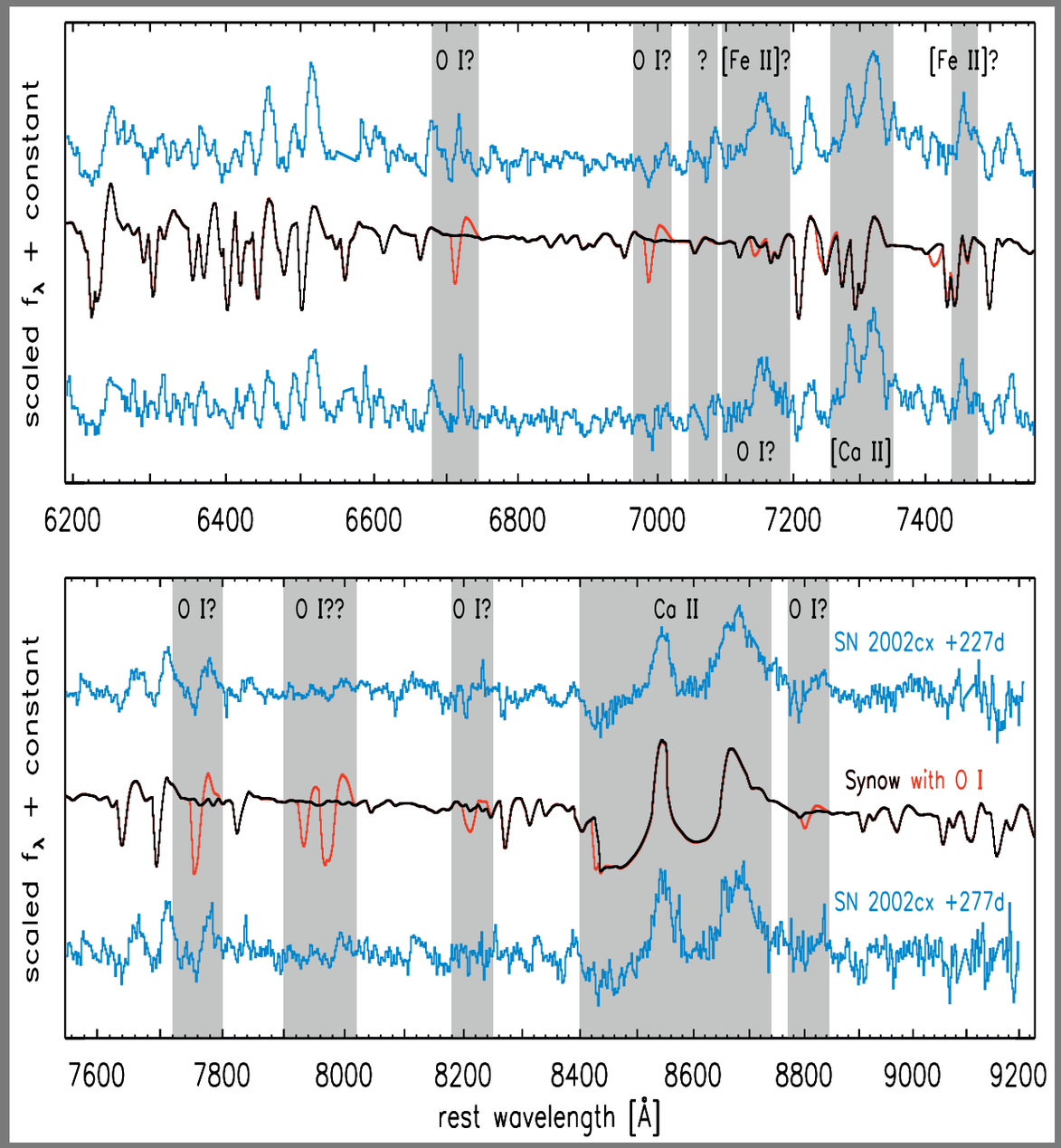
Can Constrain Progenitor with Additional Observations

Pre-explosion images
- Most definitive

X-ray/radio detections/limits
- Might expect relativistic ejecta or circumstellar interaction

Nebular spectrum?
- Models have specific predictions, but nothing very satisfying yet

Earlier data?
- Probe outer layers



Jha et al. 2006

Fallback and Deflagration Are Most Promising

Fallback occurs when a massive star undergoes core collapse, creating a neutron star then shortly after the NS collapses to a black hole

Deflagration is a subsonic thermonuclear burning front in a white dwarf (SN 2008ha requires a failed deflagration)

	Fallback	Deflagration
Progenitor	>30 M_{sun}	WD
Metallicity	Low	?
Host	Star forming	All?
KE/^{56}Ni/ Rise time/ Ejecta mass	Requires balancing	Requires failed explosion
Early spectrum	H/He?	Unburned Material
Nebular spectrum	[O I], Ca II, [Ca II], H?	[O I], [Fe II]

Maximum-Light Spectrum Shows IMEs/Carbon

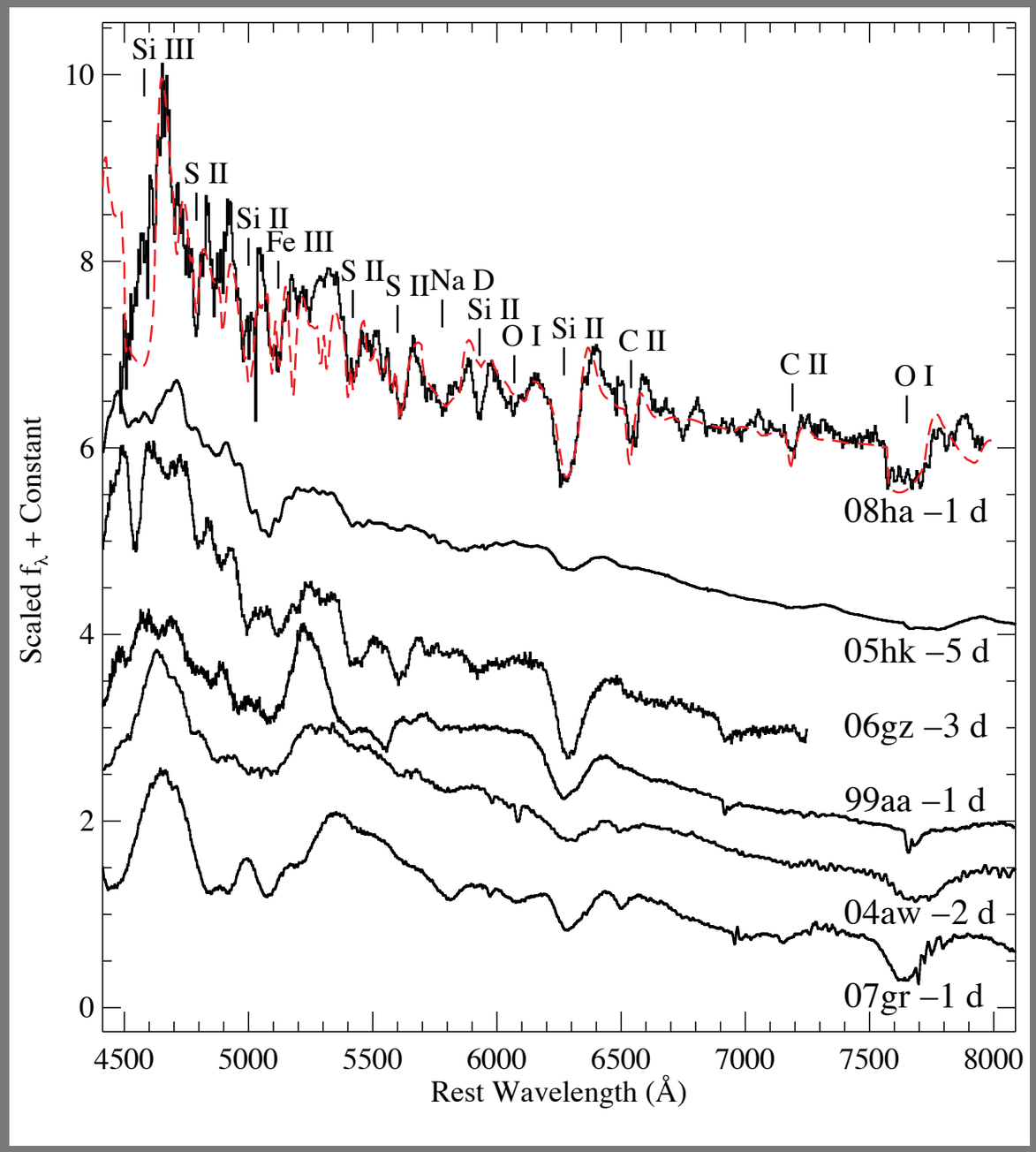
Higher ejecta velocity (~4000 km/s), so larger KE, ejecta mass

Not much Fe (still hot, showing Fe III), as expected

Plenty of IMEs, including sulfur, which is only strong in SNe Ia

Clear detection of carbon, which is rare in SNe Ia ~~and never seen at maximum light~~ (now 09dc!)

“Spectrum is truth” - RPK



Late-Time Data Are Consistent with Most Scenarios

Attempted a late-time (230 days) spectrum with Gemini (~3 hours N&S), but still low S/N

Object on top of an H II region, so could only get limits in imaging

Imaging shows low ^{56}Ni

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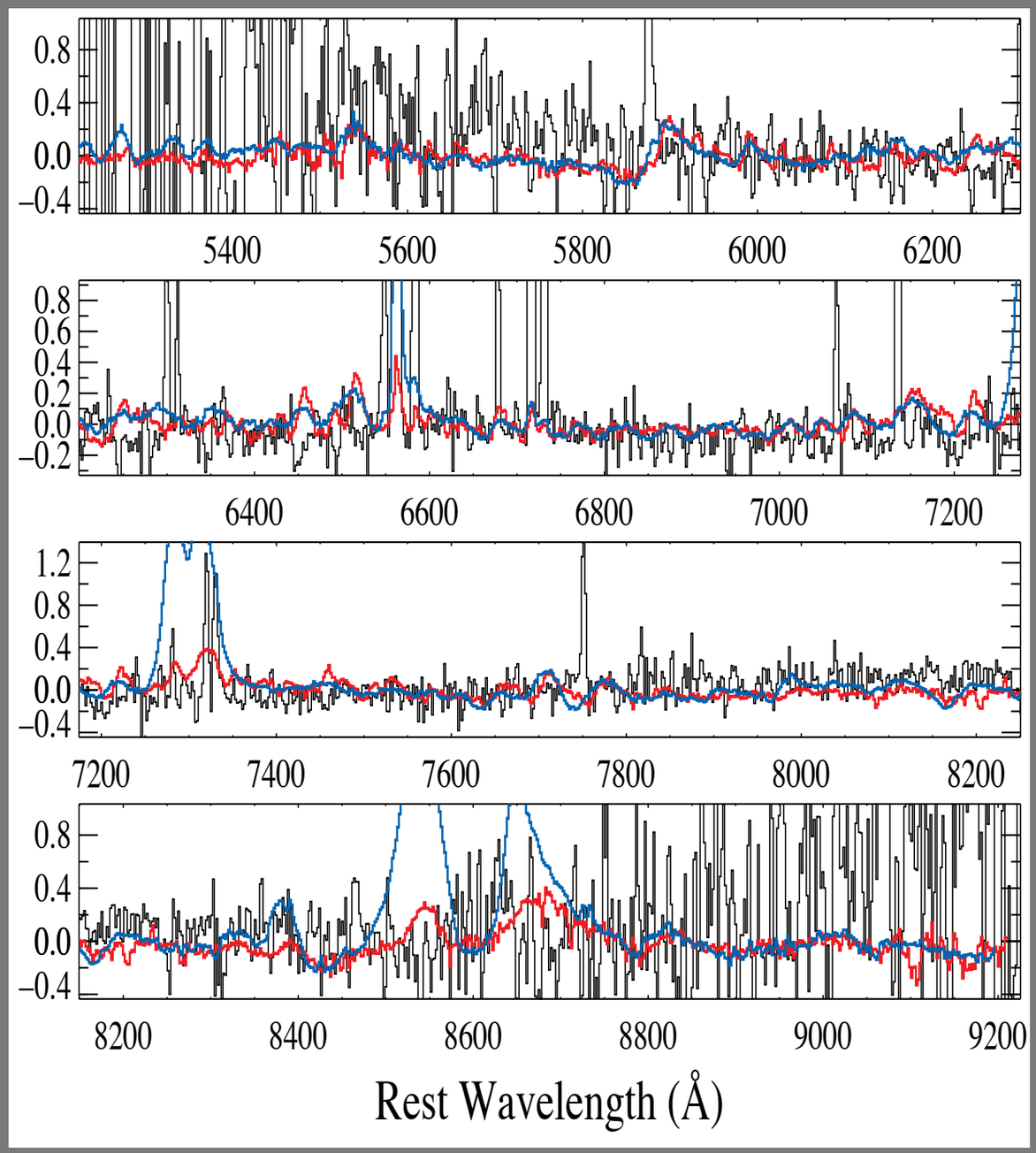

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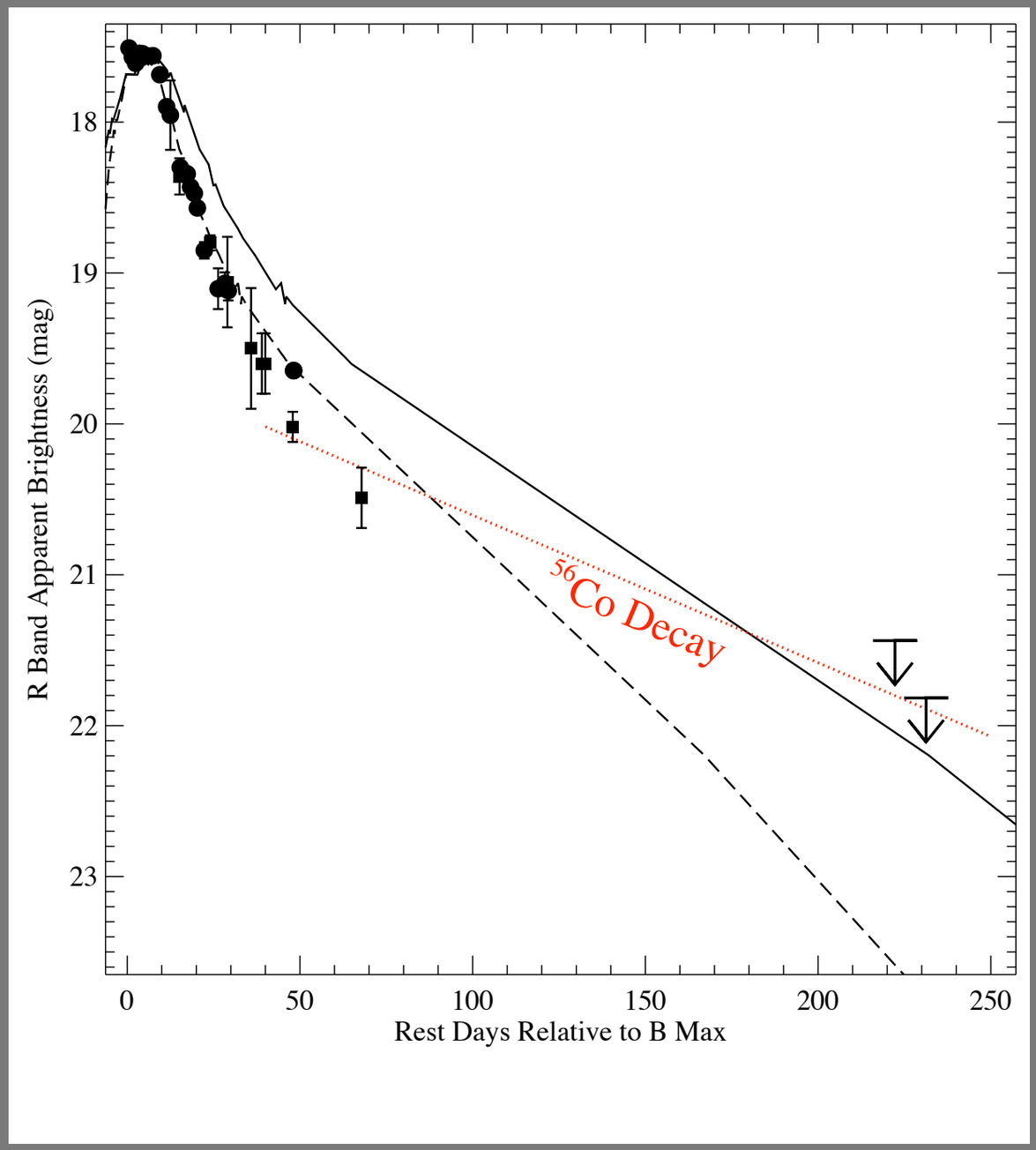
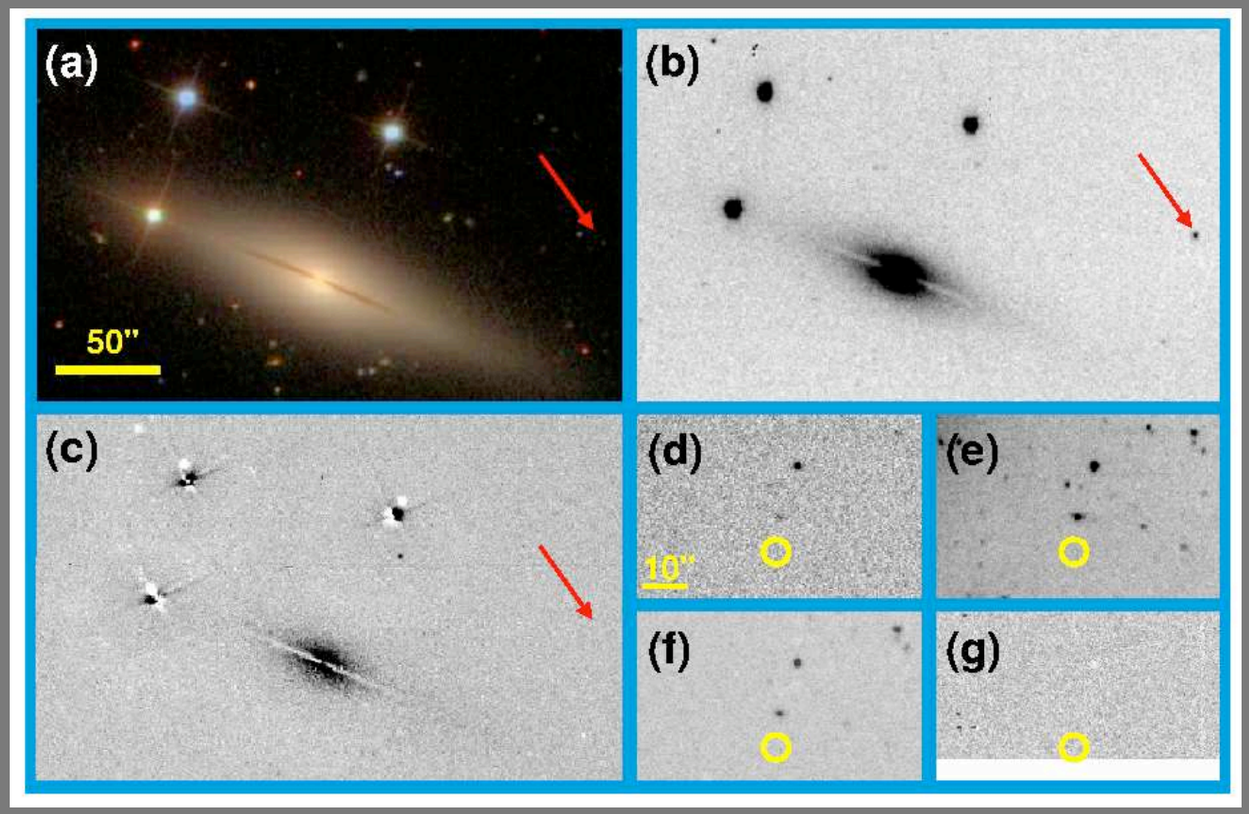


Are SNe 2008ha and 2005E Related?

Both have low luminosity, strong [Ca II], low ejecta/^{56}Ni mass

SN 2005E was far from its S0/Sa host, so probably not core collapse

Helium at early times, no sulfur, and $M_{ej} < M_{sun}$, so Perets et al. says it is likely a He detonation



Perets et al. 2009

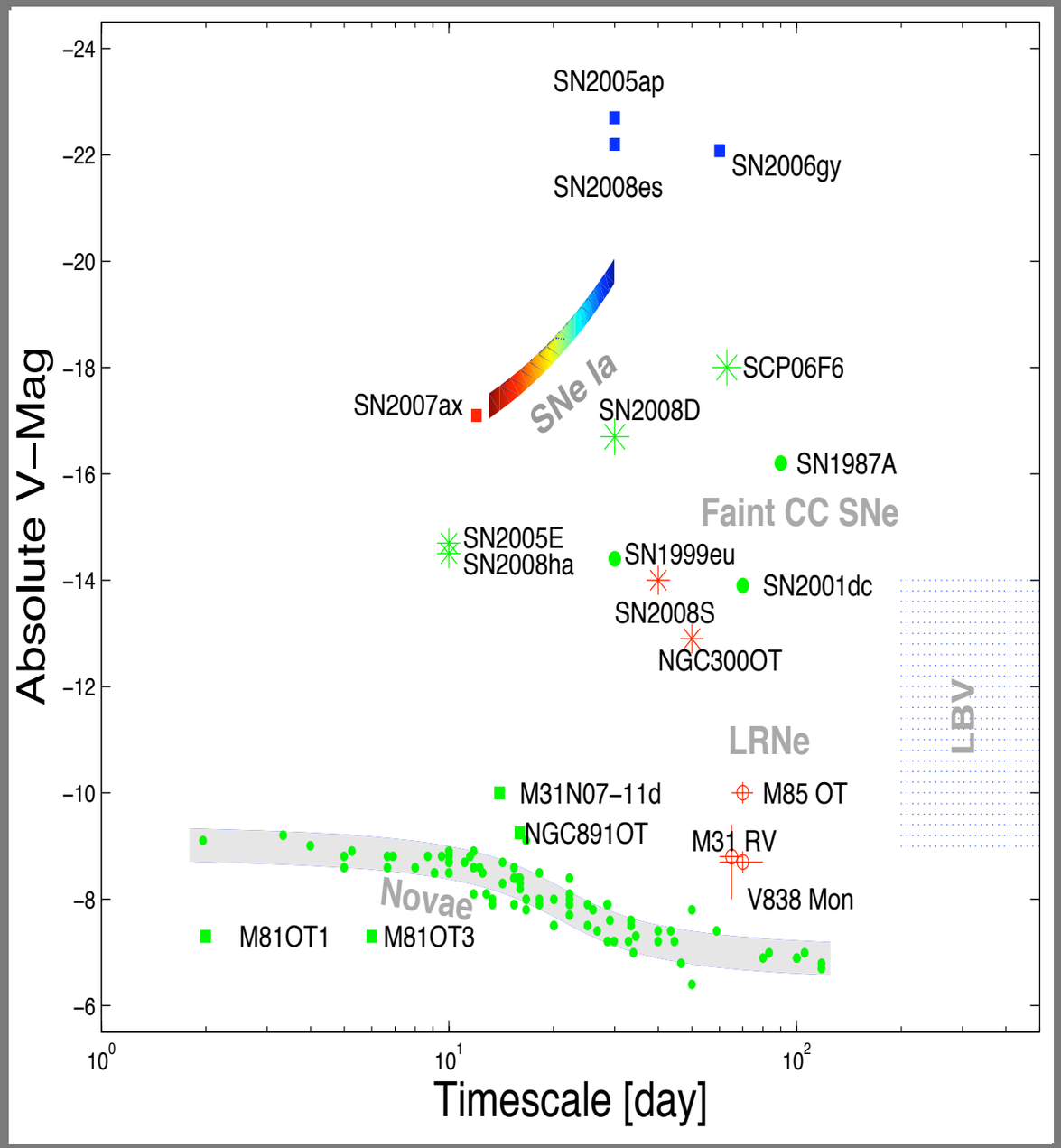
There Are Few Known Low-Luminosity Transients

There are only a few objects with $-11 > M_V > -14$ and $2 < t < 100$

Included are SN 2008ha, SN 2005E, luminous red novae, very faint SNe II, and “SN imposters”

Volume probed is tiny ($\mu \approx 30$-33 mag); SNe Ia detected in 10^5 times the volume

PS1, PTF, Sky Mapper will improve things dramatically, but still requires follow up



Kulkarni & Kasliwal 2009

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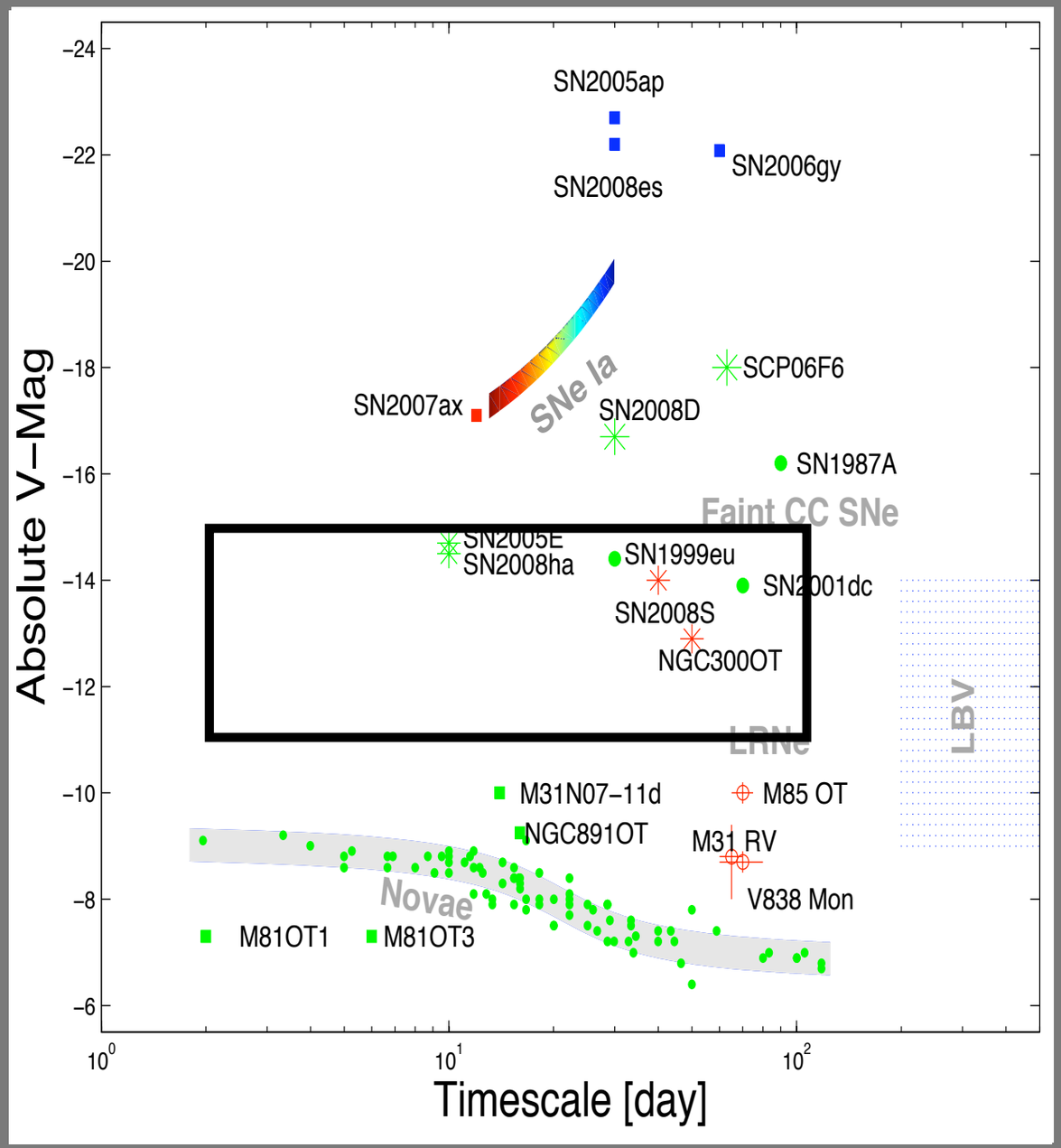

Kulkarni & Kasliwal 2009

Concluding Remarks

- SN 2008ha is an extreme member of the SN 2002cx class
- SN 2008ha had very low luminosity, ejecta mass, kinetic energy
- Maximum-light spectrum suggests thermonuclear explosion
- All observations can be explained by a failed deflagration
- Links to Ca-rich (SN 2005E-like) SNe (varying C/O:He ratio?)
- Within a few years, there should be many more examples
- There will also be plenty of new weird things

Many Related Talks/Posters

Roepke: Outcomes from Deflagration Scenarios

Howell: Puzzles Presented by Superluminous and Subluminous Events

Jha: Power of Nebular Spectroscopy and SN 2002cx, 2005hk

Chamulak: The Nucleosynthetic Signature of Surface Detonation in Type Ia Supernovae

Gonzalez: The Rise-Time of Underluminous SNe Ia

McCully: HST and Ground-Based Observations of SN 2008A: A Peculiar 2002cx-like Type Ia Supernova

Moriya: Faint Supernovae with Fallback

Pastorello: Subluminous Core-Collapse Supernovae

Timmes: On Type Ia Supernovae From The Collisions of Two White Dwarfs

Timmes: Trends in 44 Ti and 56 Ni from Core-Collapse Supernovae

Valenti: A Low Energy Core-Collapse Supernova without a Hydrogen Envelope