

F.O.E. Fifty-One Erg, Raleigh, June 2015

Constraining SN Ia progenitors and diversity using spectroscopic observations

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1. What are the stellar systems that explode as SNe Ia?

Single degenerate



Red giant? Main-sequence star?

Double degenerate



Credit: Howell

Another white dwarf?

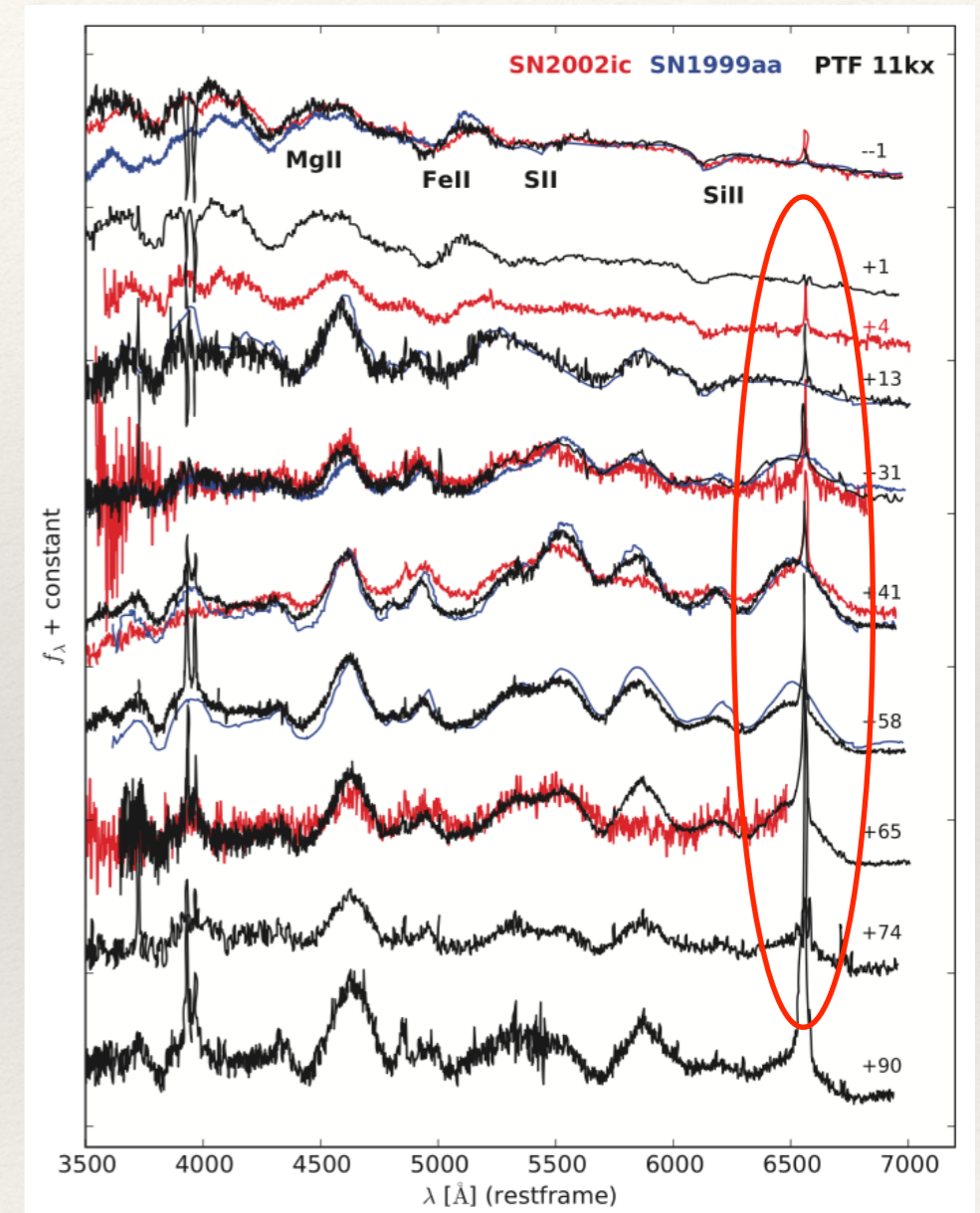
- Aim: Discriminate between progenitor scenarios
- Problem: Normal SNe Ia (generally) look very similar
- Subtle signatures: Circumstellar material? Companion star material?

How to look for circumstellar material

- Number of ways of searching for CSM:
 - Radio / X-ray detections - only mass-loss rate limits for SN 2011fe ($< 6 \times 10^{-10} M_{\odot} \text{ yr}^{-1}$)
 - Narrow emission features in spectra
 - Narrow absorption features of Na I, Ca II, K I

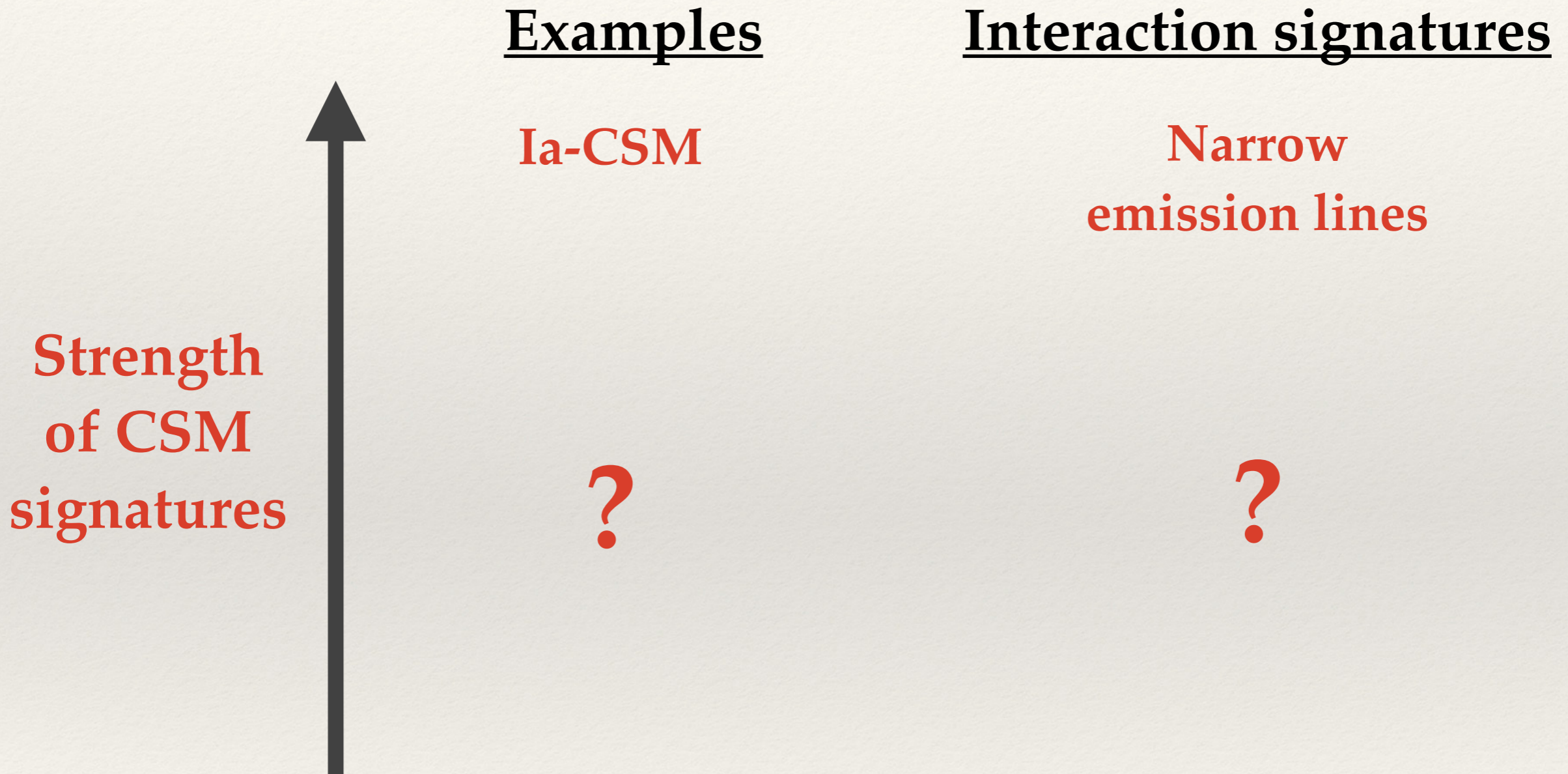
Extreme SNe Ia with CSM

- SN Ia-CSM (see Jeff Silverman's talk later)
- 'Diluted' SN Ia spectrum with narrow H lines
- PTF11kx - 4.3 M_{\odot} of CSM (spherical geometry)



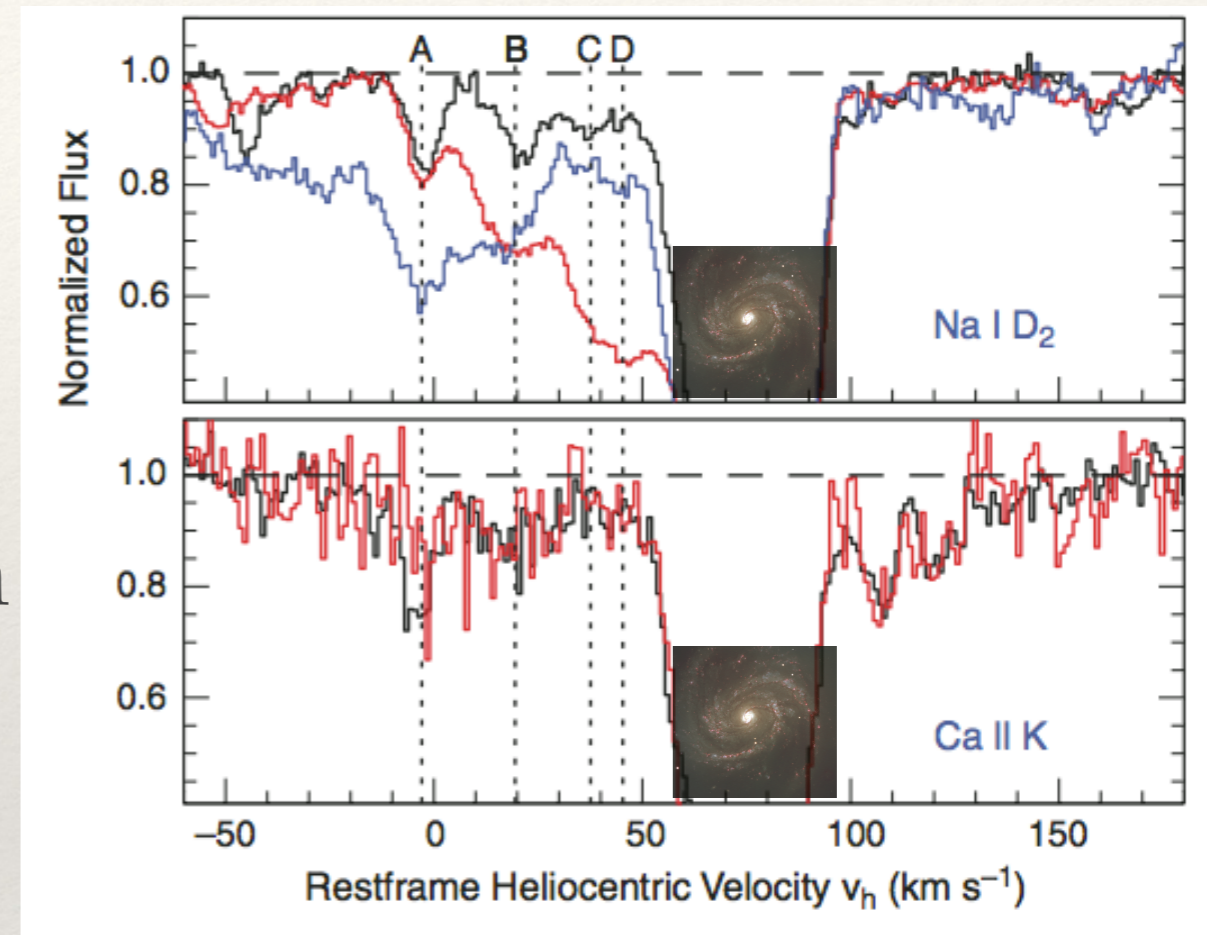
Dilday+ (2012)

CSM signatures



Variable Na I D in normal SNe Ia

- High-resolution VLT+UVES spectra of Na I D absorption
- Velocities of 50-200 km/s
- CSM at distance of $\sim 10^{16}$ - 10^{17} cm
- Seen in more SNe Ia (Blondin+ 2009, Simon+ 2009)

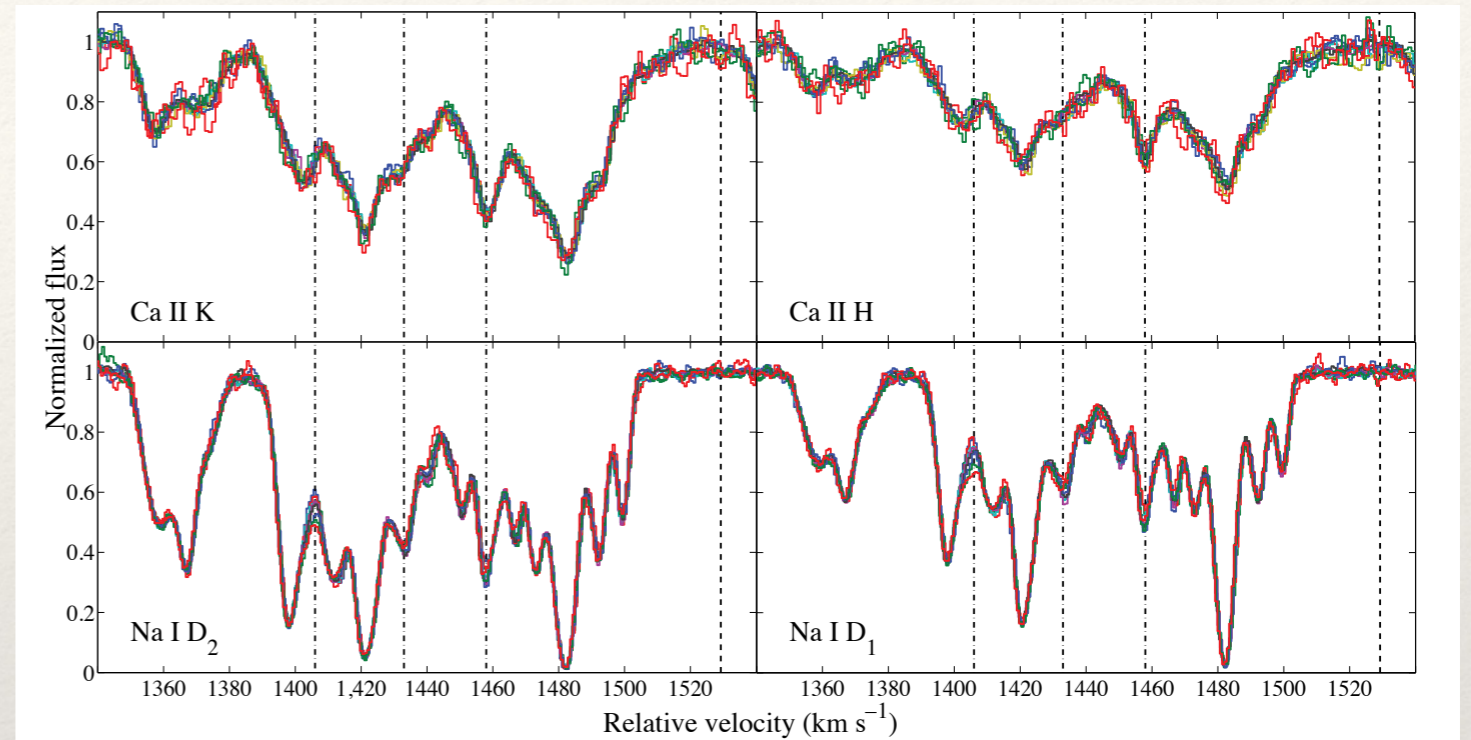


SN 2006X, Patat+ (2007)

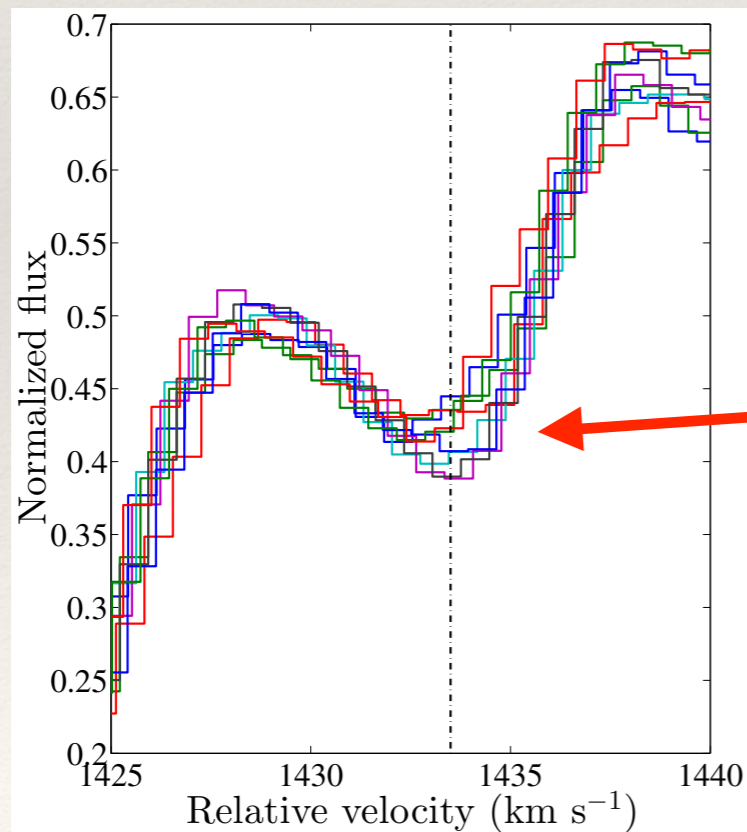
Latest sample of Sternberg+ (2014) -
~18% show time-varying Na I D

Variable Na I D in normal SNe Ia

- New SN Ia with small variations in Na I D (poster by Assaf Sternberg)

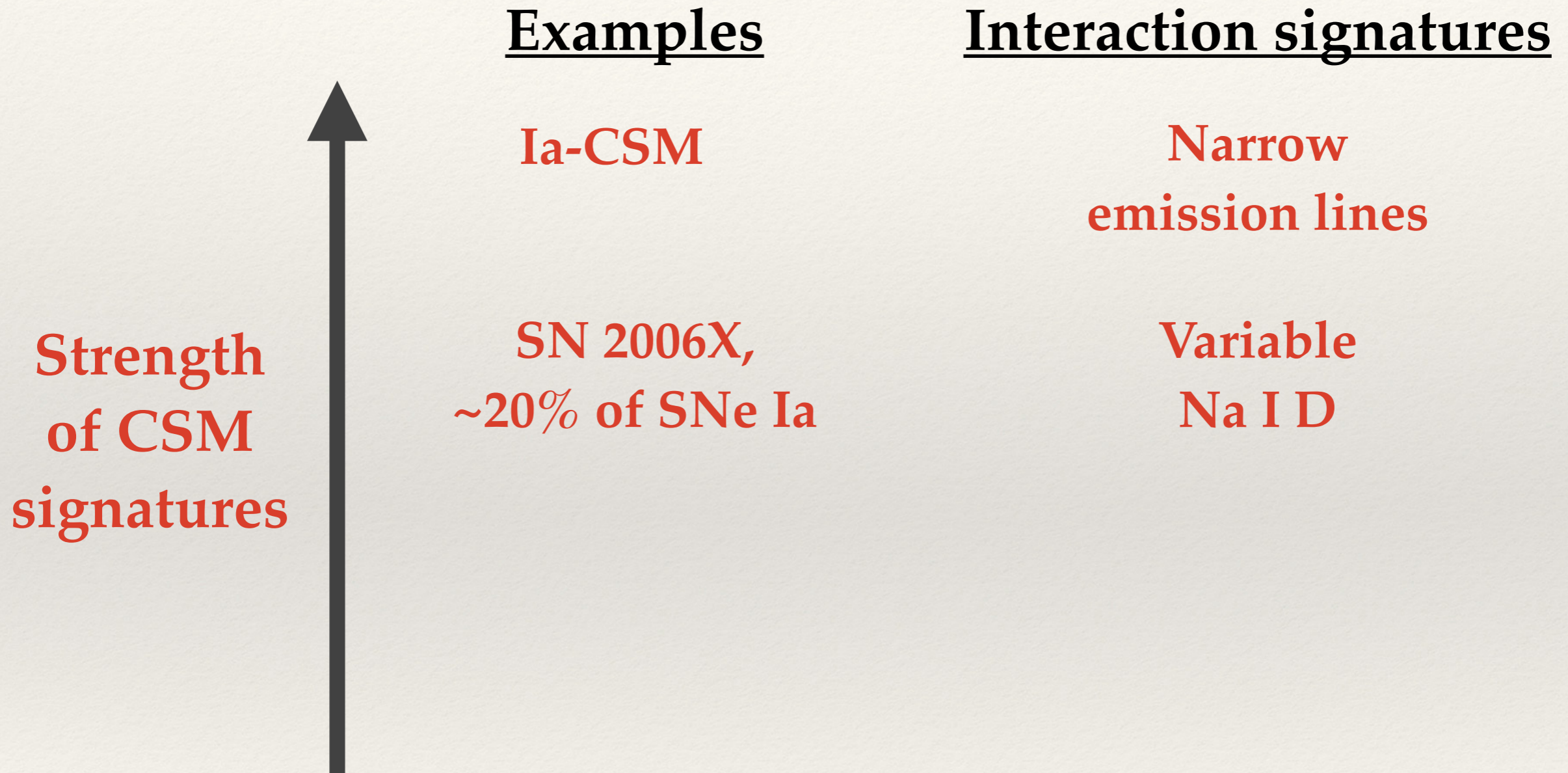


Sternberg+ (in prep.)



Small variation $\sim 8 \text{ m\AA}$

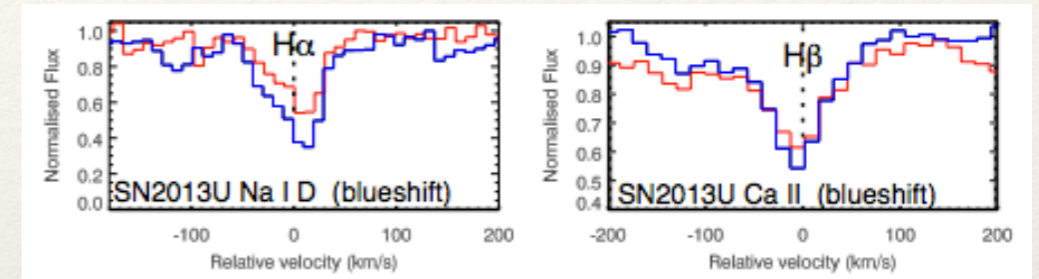
CSM signatures



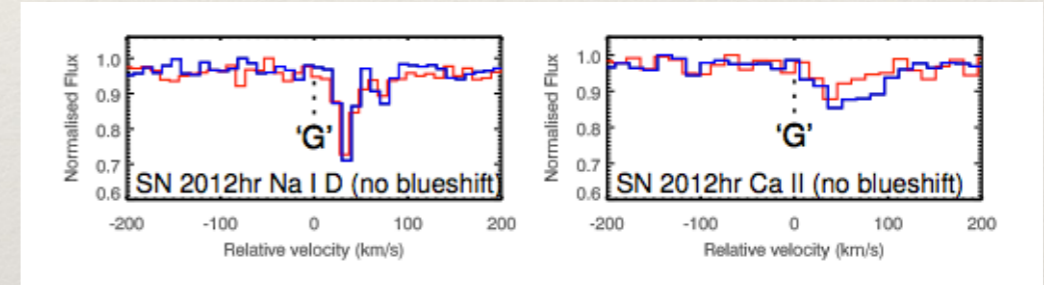
Look for excess of blueshifted Na I D features

- Multi-epoch high-resolution observations are expensive
- Material further out - no interaction expected
- If only galaxy absorption, expect **redshifted** = **blueshifted** Na I D features

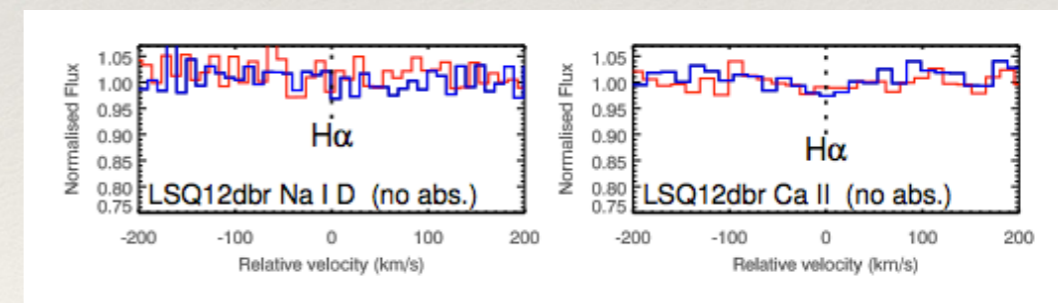
Blueshift



No blueshift

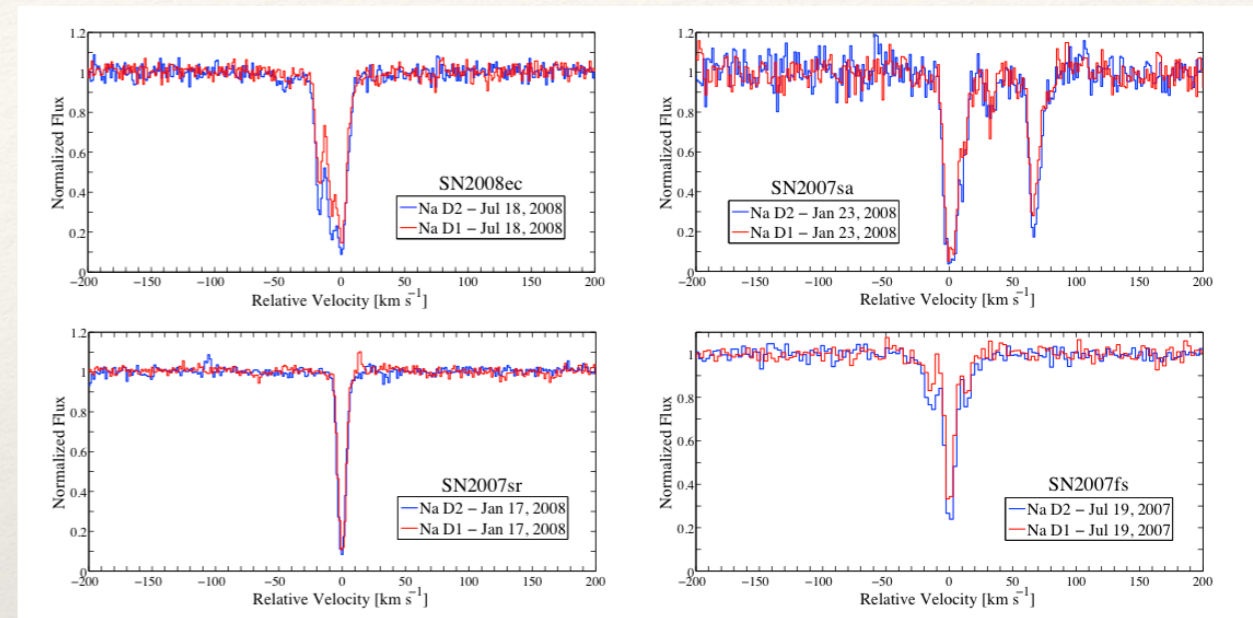


No absorption

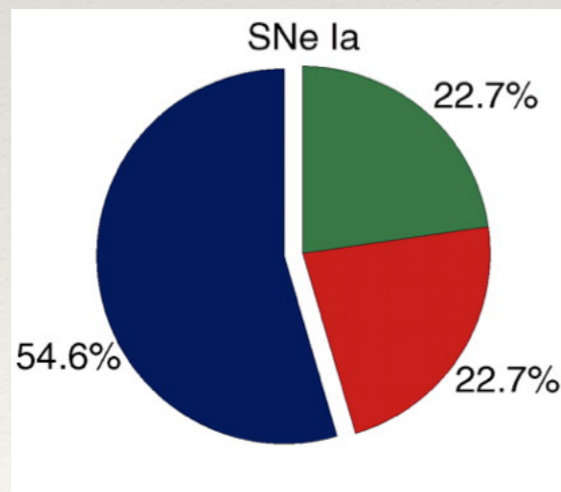


Statistical Na I D samples

- 35 high-resolution Keck+HIRES, Magellan+Mike spectra (Sternberg+ 2011)
- Define shift relative to strongest (interstellar) feature



Sternberg+ (2011)



Sternberg+ (2011)

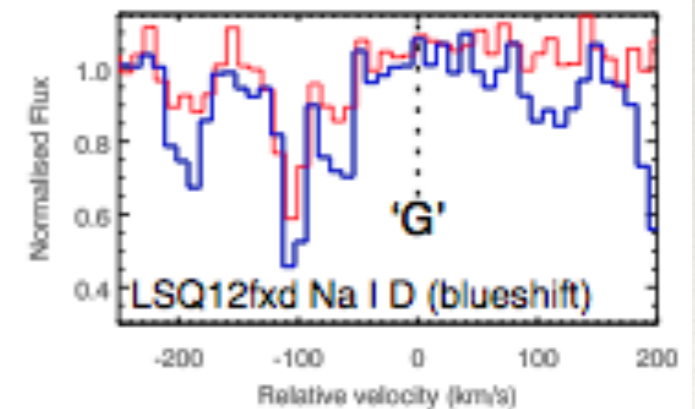
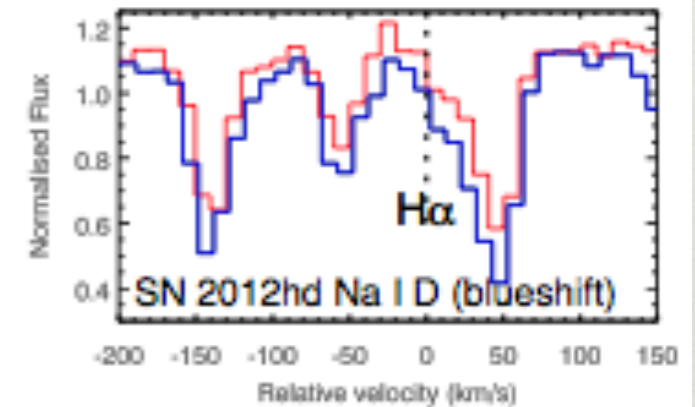
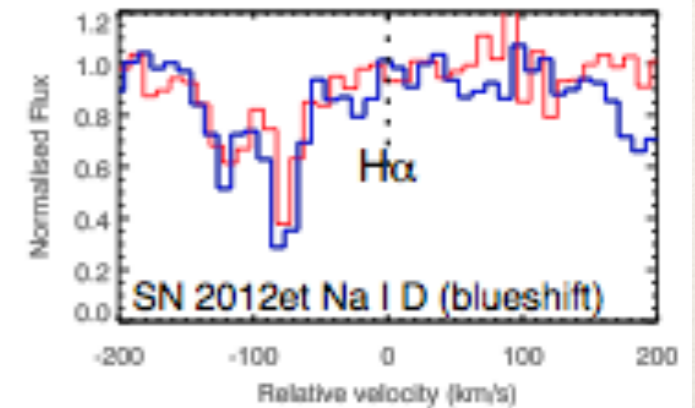
- Preference for blueshifted material in normal SNe Ia in spiral galaxies (~25% excess)

Statistical Na I D samples

- 17 single-epoch spectra at VLT+XShooter
- $R \sim 18000$ - ~ 1 hr exposures
- Extend to more SNe Ia in elliptical galaxies


Credit: ESO/José Francisco Salgado

- Combined sample - $\sim 20\%$ of SNe display blueshifted Na I D absorption features



Maguire+ (2013)

CSM signatures

	<u>Examples</u>	<u>CSM signatures</u>
Strength of CSM signatures 	Ia-CSM	Narrow emission lines
	SN 2006X, ~20% of SNe Ia	Variable Na I D
	~20% of SNe Ia	Excess of blueshifted Na I D
	<80% of SNe Ia	No blueshifted Na I D

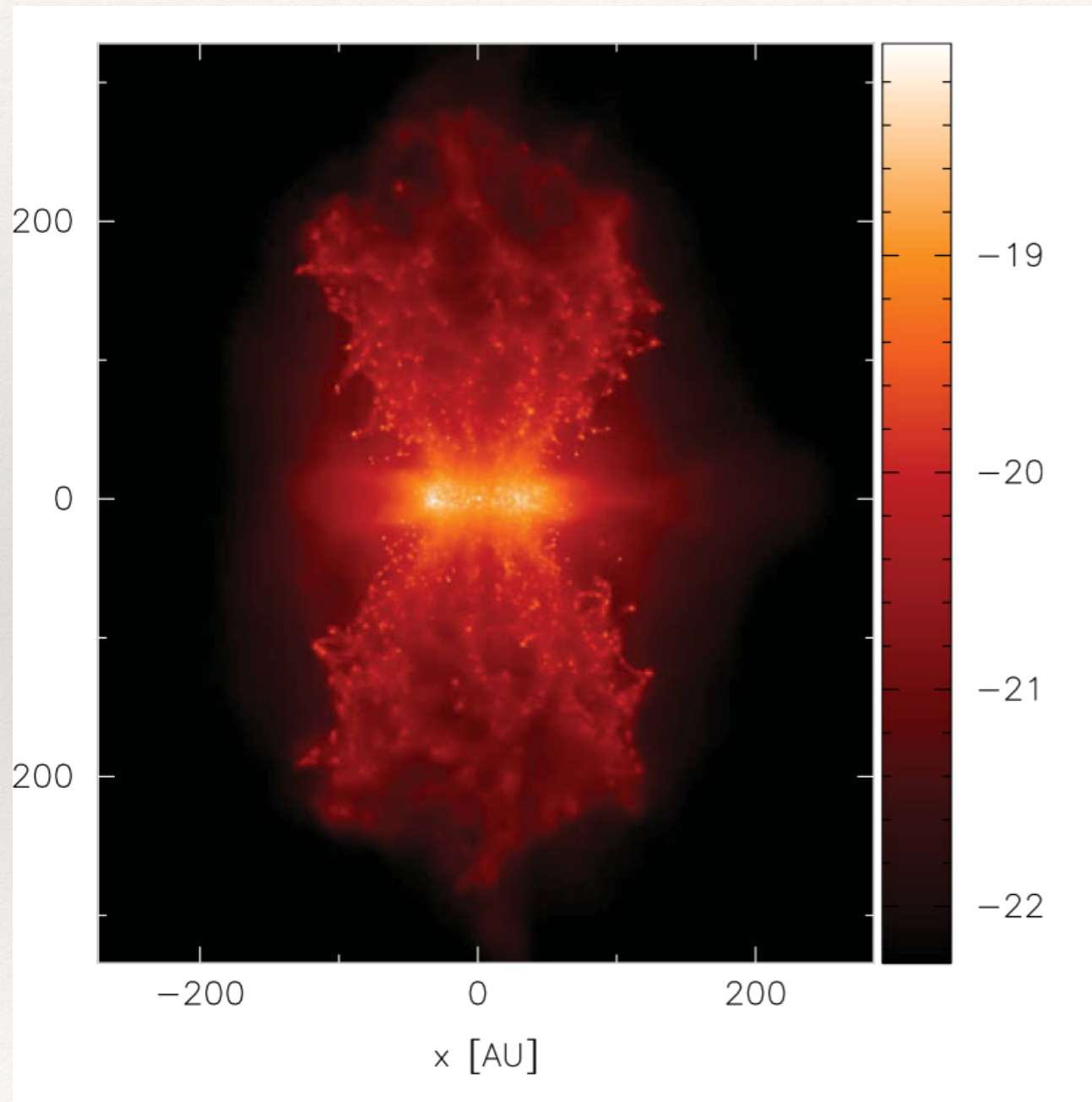
Progenitors signatures

- Some SNe Ia with significant CSM interaction
- 20% of 'normal' SNe Ia show signatures of CSM (both multi-epoch and statistical studies)
- Progenitor scenarios producing CSM?



Na I D and Recurrent Novae?

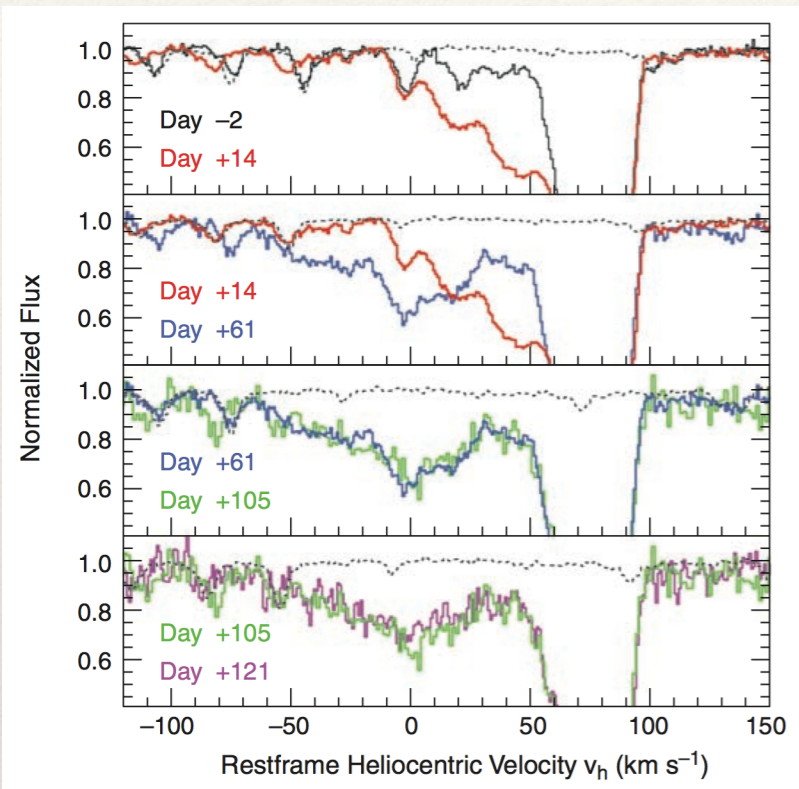
Density structure during nova explosion (Mohamed+, 2013)



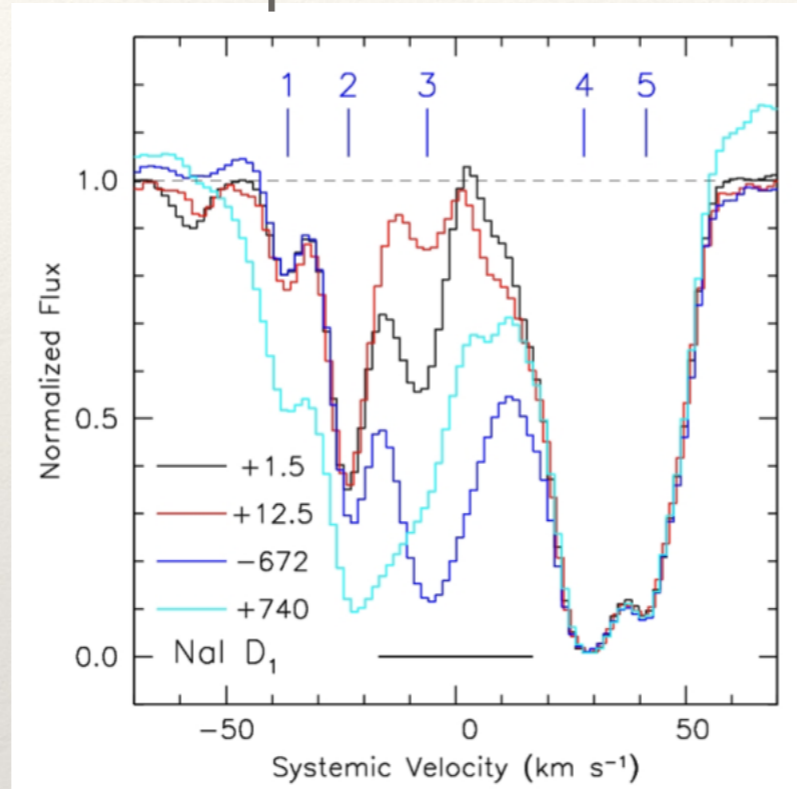
- 3D SPH Gadget 2 code (Springel 2005, Mohamed 2010)

Na I D and Recurrent Novae?

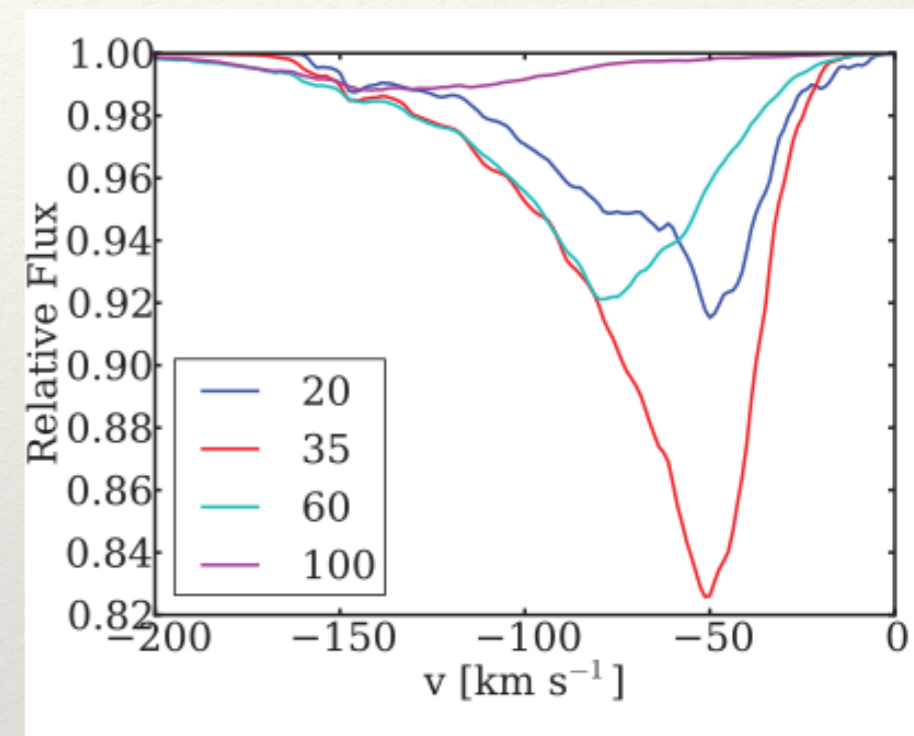
SN observations



RS Oph observations



RS Oph simulations



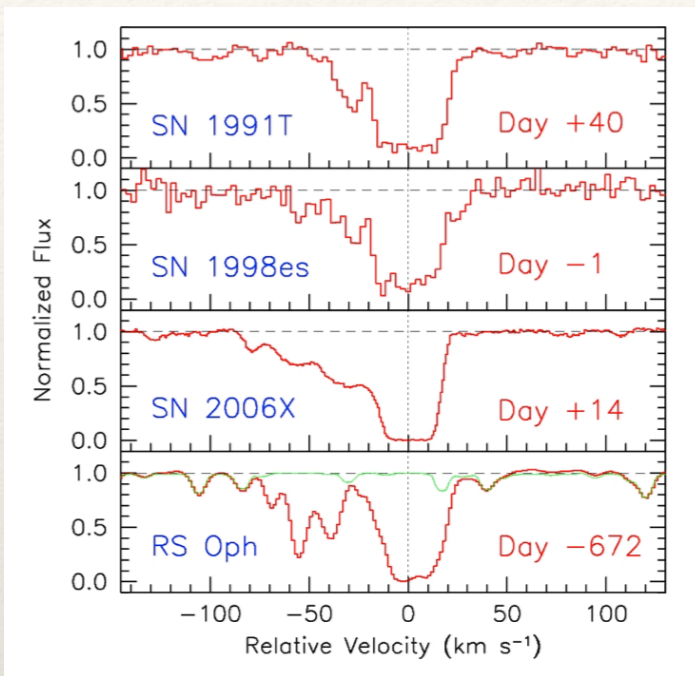
SN 2006X, Patat+ (2007)

RS Oph, Patat+ (2011)

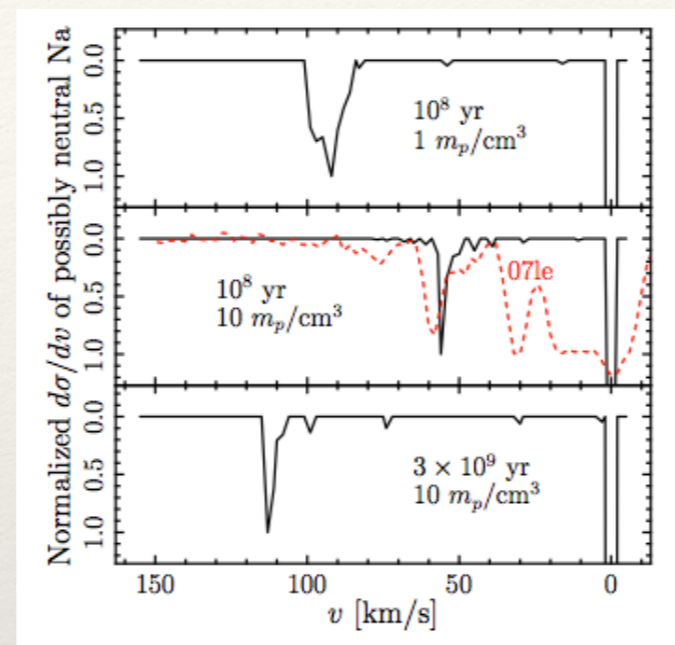
Booth+ (2013)

- Time-varying Na I D features in outburst
- RS Oph - similar velocities / strengths to SN 2006X
- Simulations - densities too low (clumping?)

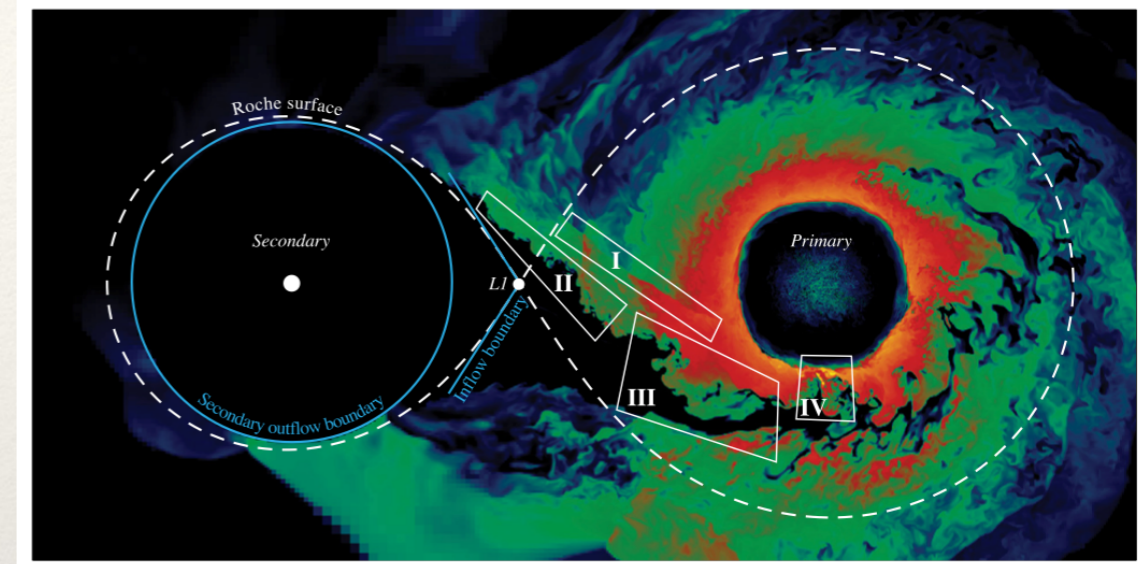
Na I D and double-detonation systems



Patat+ (2011)



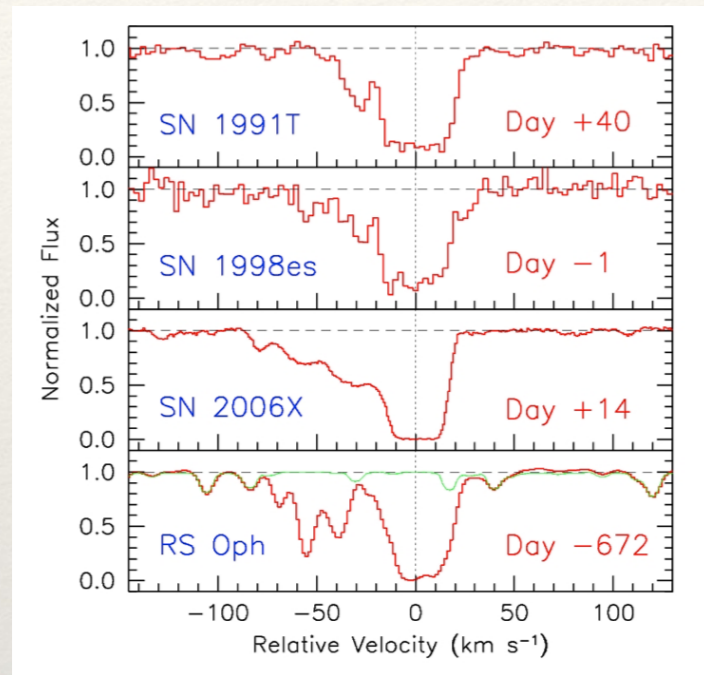
Shen+ (2013)



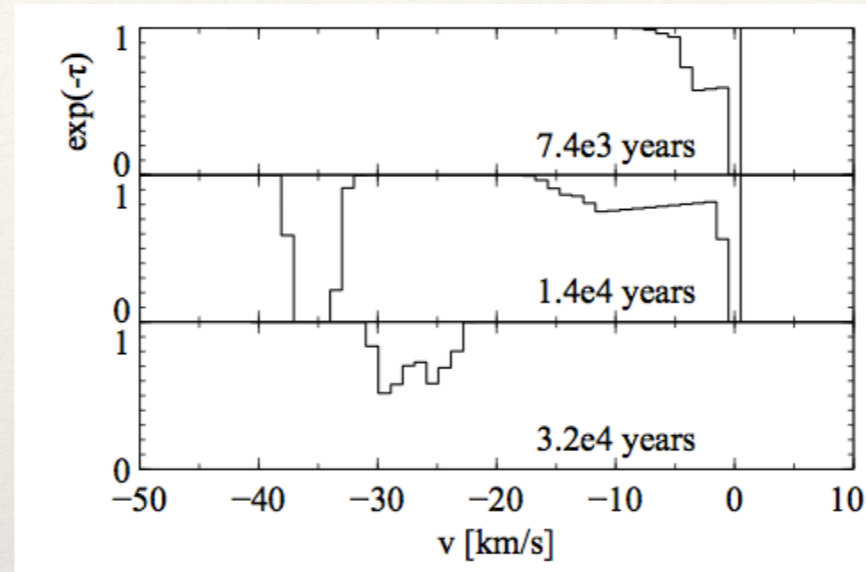
Guillochon+ (2013)

- Ejected material from He+C/O WD system interacts with ISM (Shen+ 2013)
- Good agreement in velocities (50-300 km/s)
- Temp. too high for neutral Na (high ISM density, long time)

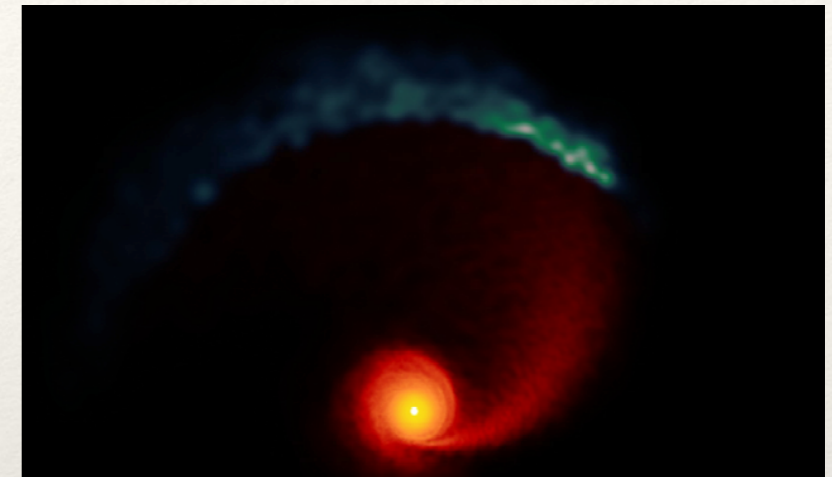
Na I D and mergers



Patat+ (2011)



Raskin & Kasen (2013)



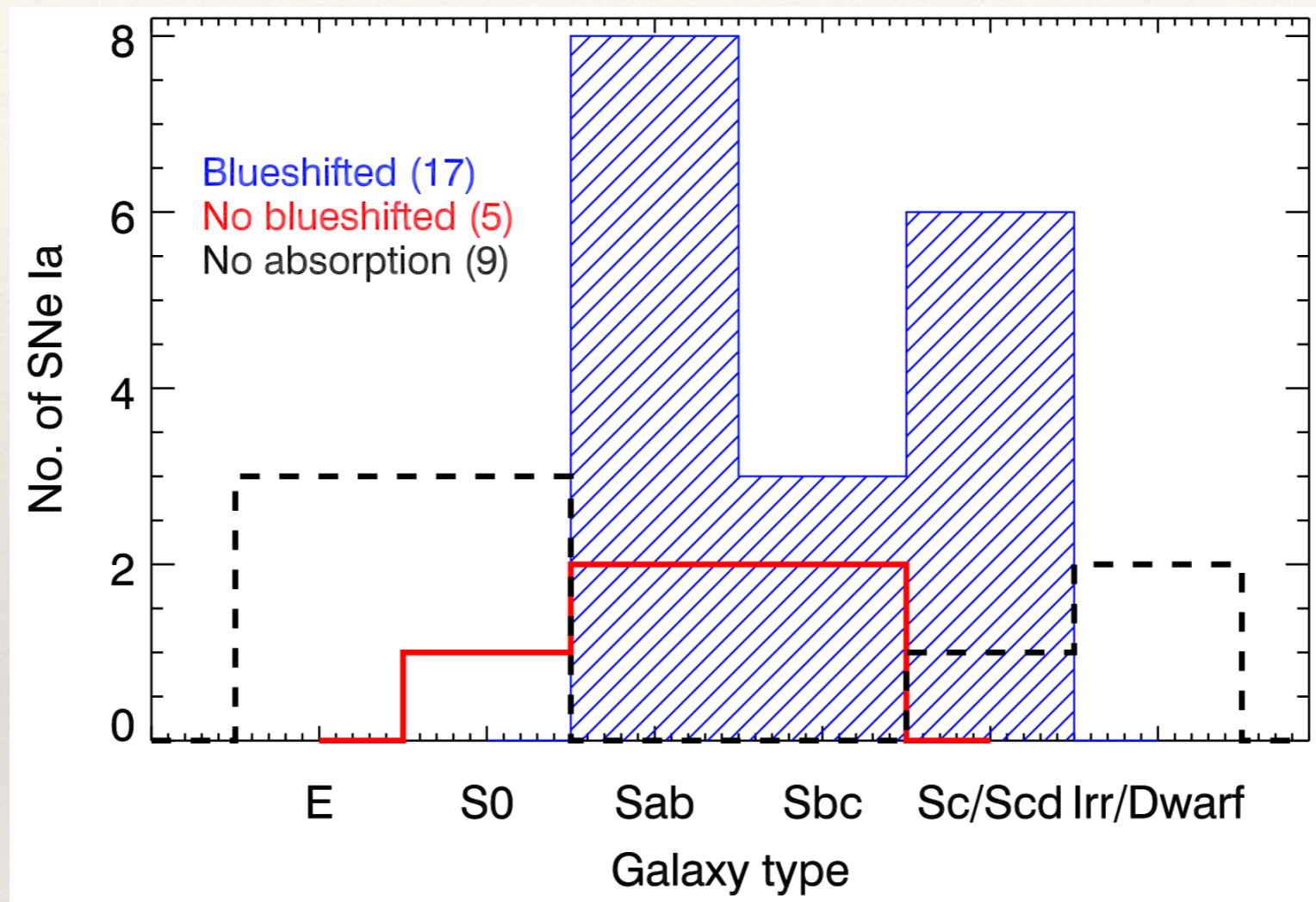
Raskin & Kasen (2013)

- Tidal tails from WD mergers interacting with ISM (Raskin & Kasen 2013)
- See neutral Na at correct velocities in $\sim 10^4$ year - too distant for time-varying features
- Modelling of time-dependent variations needed

CSM: link to SN observables

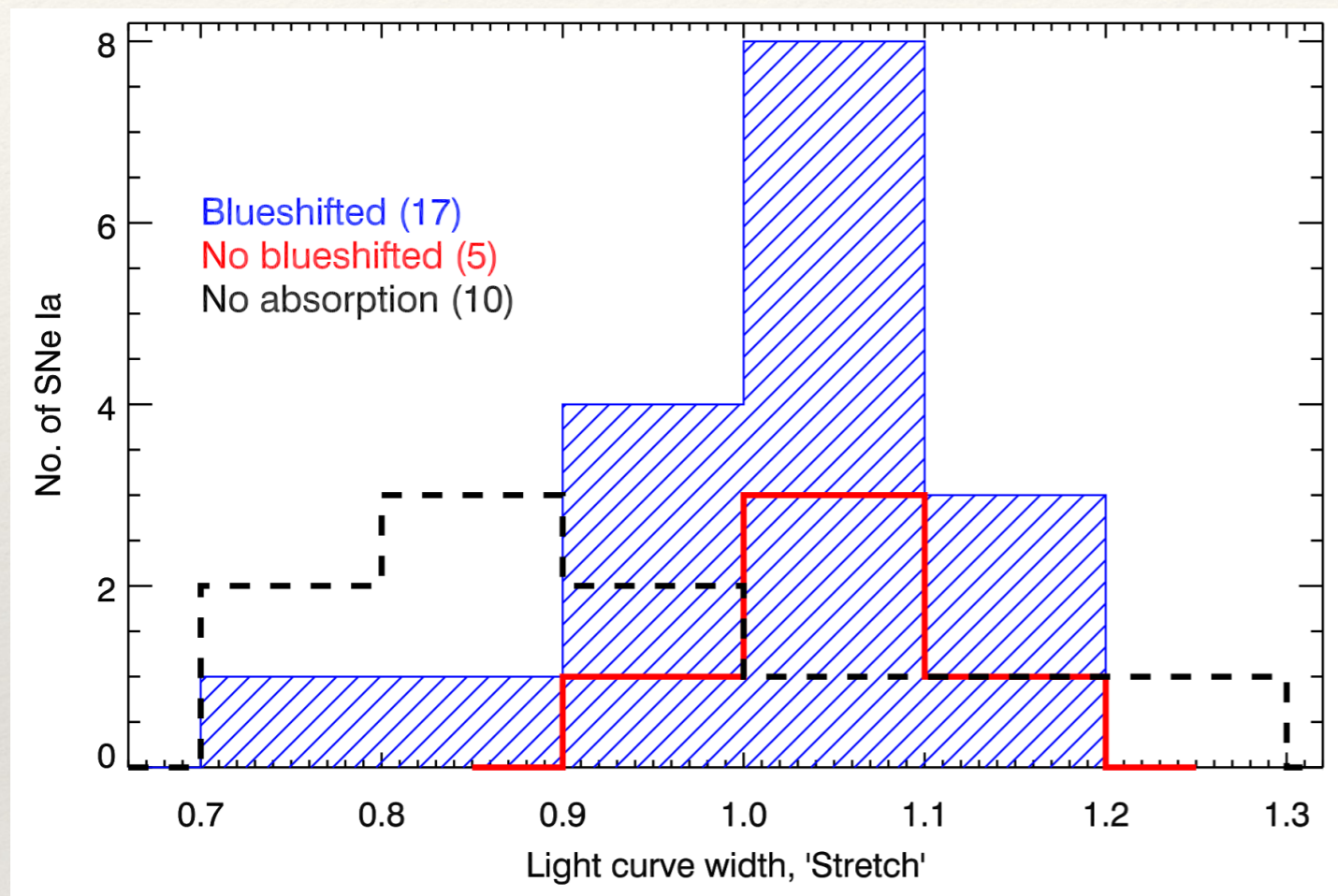
- Number of progenitor models with viable methods of producing CSM
- Unable to distinguish progenitor scenarios from CSM alone
- Can we connect CSM detections to other SN properties?

Link to SN observables: Galaxy type

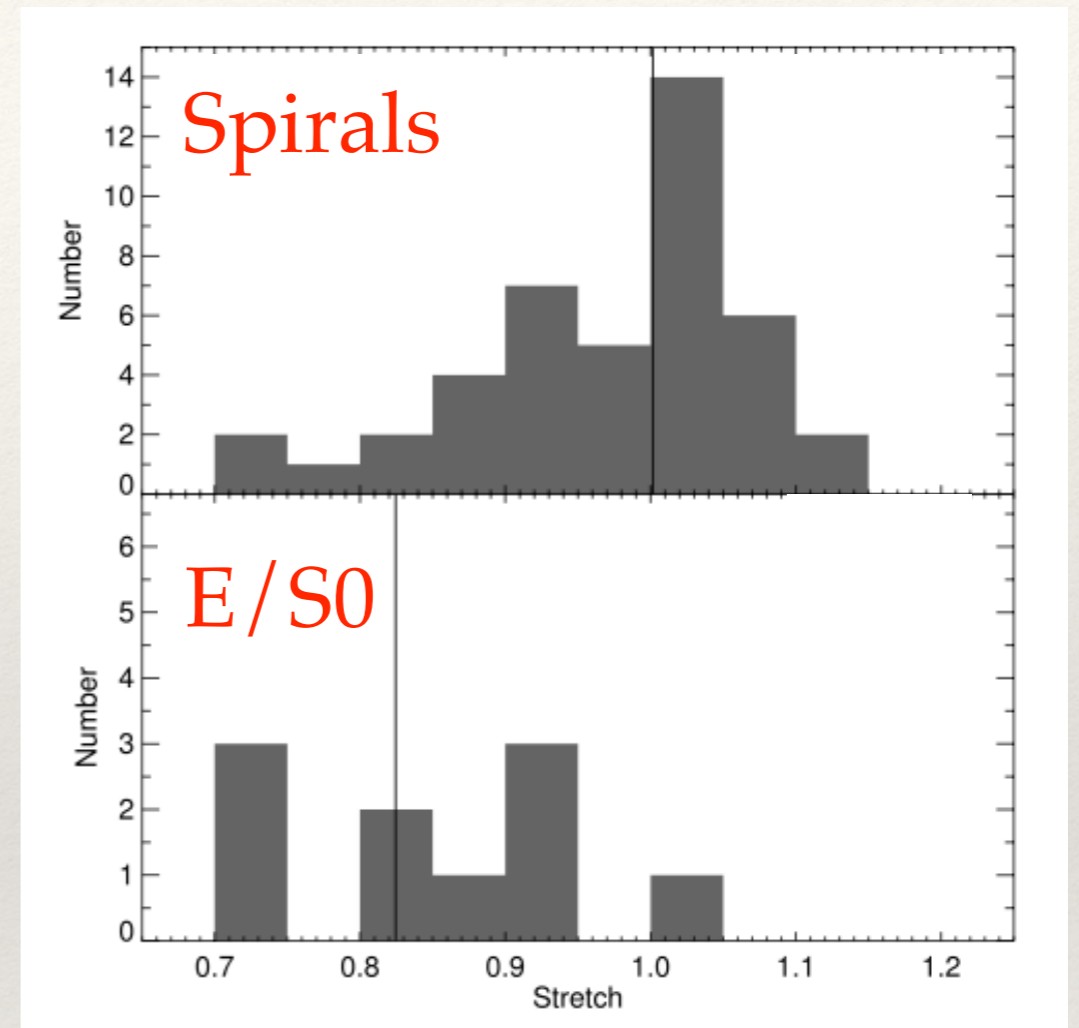


- Na I D features more common in star-forming galaxies
- No blueshifted features in E/S0 galaxies
- Differences not only due to non-spherical CSM

Link to SN observables: Light curve width



Maguire+ (2013) Luminosity \rightarrow

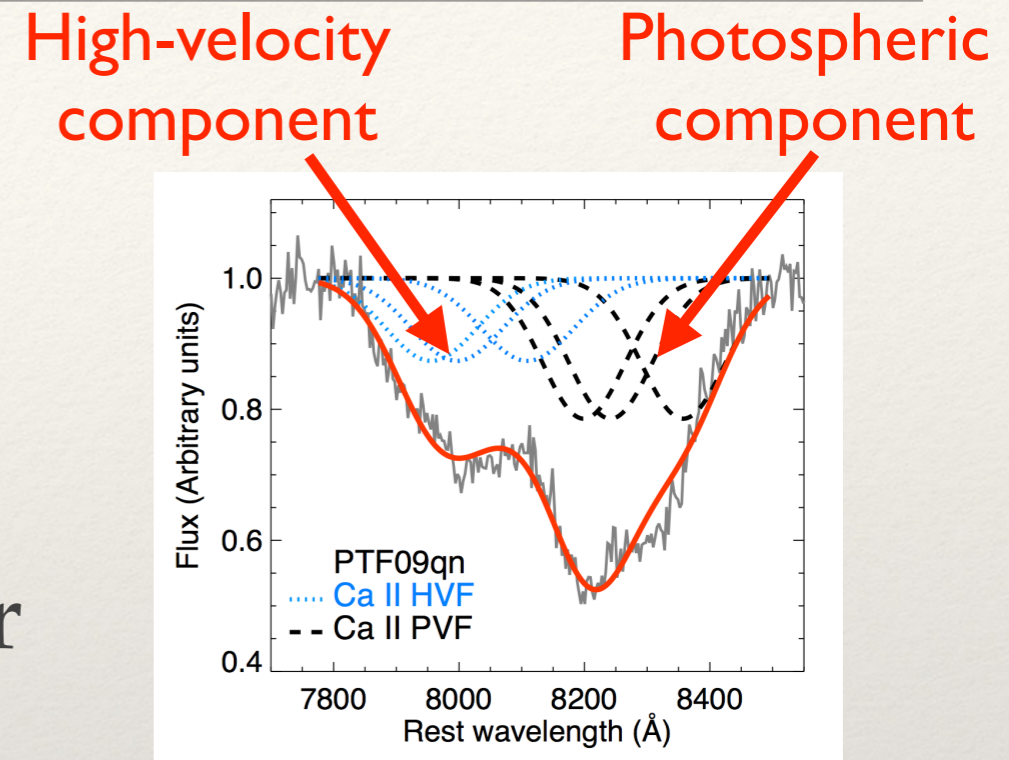


Sullivan+ (2006)

- SNe Ia displaying blueshifted Na I D material have, on average, broader light curves (Foley+ 2012, Maguire+ 2013)
- Driving the galaxy relation?

High-velocity Ca II features

- Ca II HV features in >80-90% SNe Ia (Childress+ 2014, Maguire+ 2014, Silverman+ 2015)
- High-velocity features due to CSM or intrinsic to the SN?
- Density / abundance enhancement (Gerardy+ 2004, Mazzali+ 2005, Tanaka+ 2008)
- Different polarisation for HV feature (Wang+ 2003)

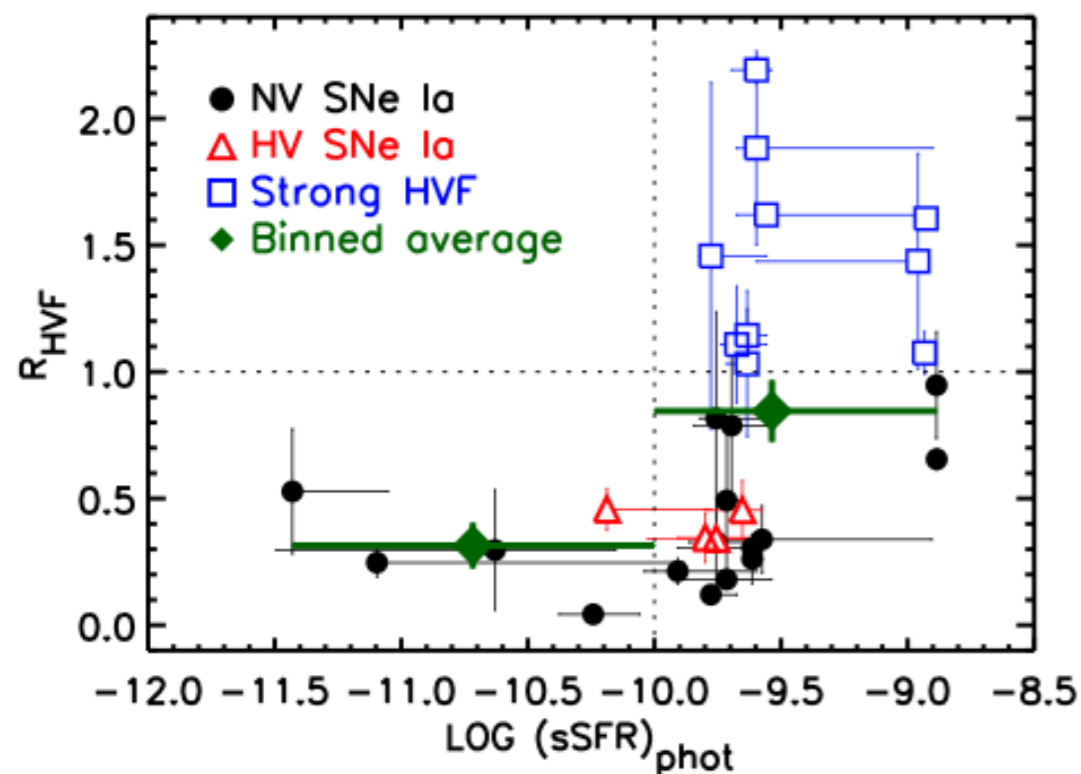


Maguire+ (2014)

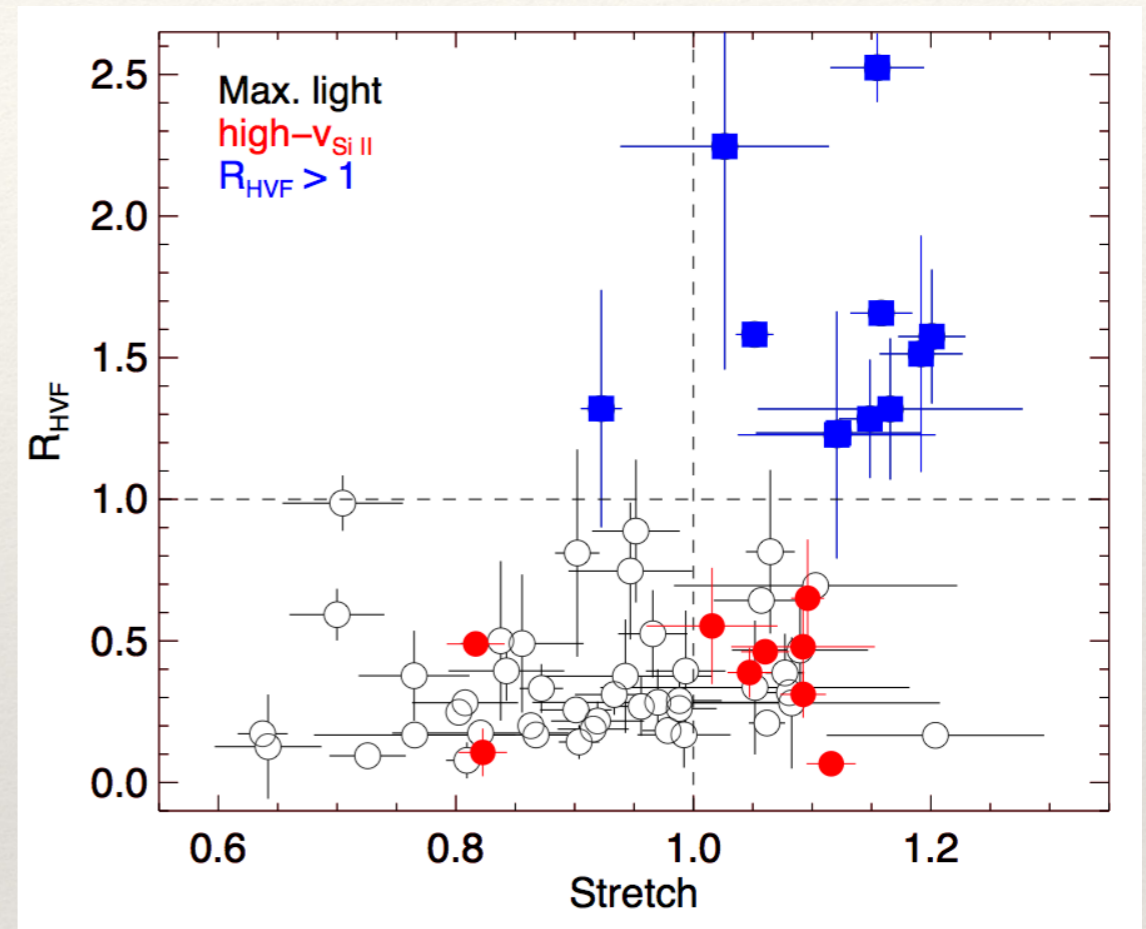
High-velocity Ca II features

Maguire+ (2014)

- SNe Ia with stronger Ca II ratio have broader light curves (Childress+ 2013)



Pan+ (2014)



Luminosity \rightarrow

- Found in strongly star-forming galaxies - younger population? (Pan+ 2014)

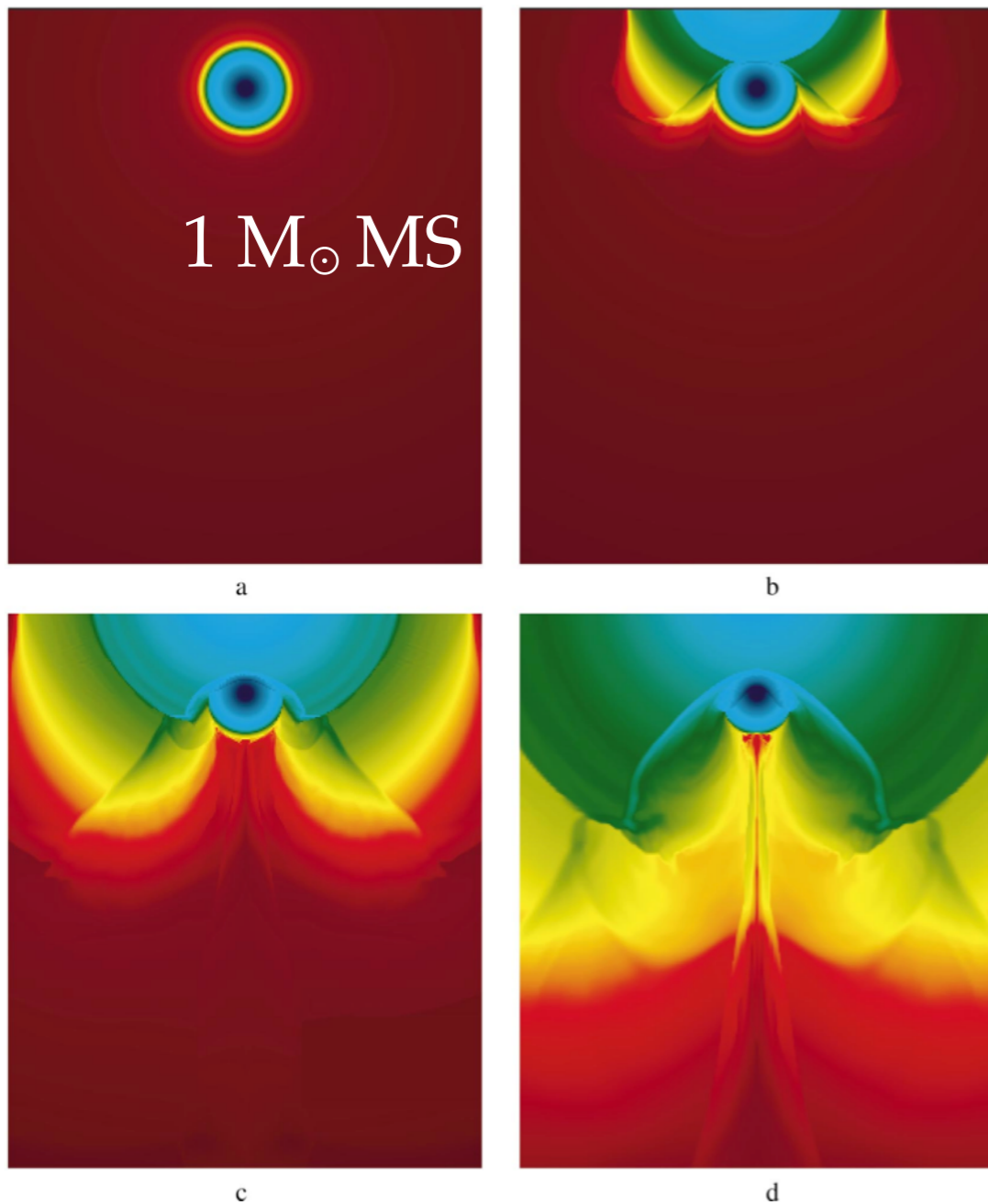
CSM + observables

- CSM features are more common in more luminous SNe Ia
- CSM features - more common in SNe Ia in late-type galaxies
 - Younger population?
 - Need ISM for interaction?
- Connection to high-velocity SN features
- What explosion models can explain high-velocity features?

Are there other spectral features that
can distinguish progenitor scenarios?

Searching for companion material

SN



- Stripping of material from companion
- Stripped masses of $0.05-0.3 M_{\odot}$ (Pan+ 2010,2012; Liu+ 2013)
- $WD+He < WD+MS < WD+RG$



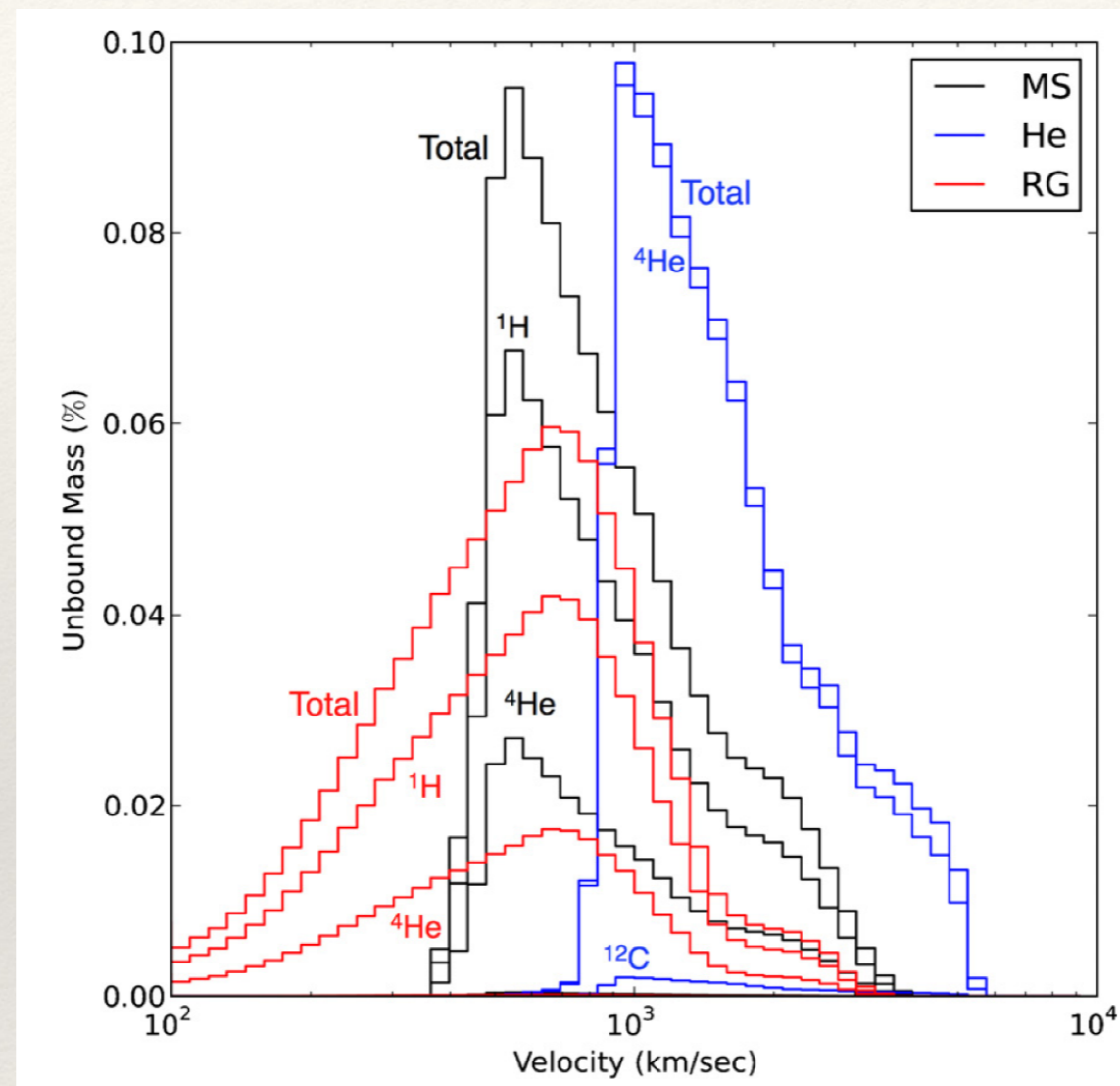
Little mass lost



Nearly all envelope mass lost

Marietta+ (2000)

Velocity distributions of material

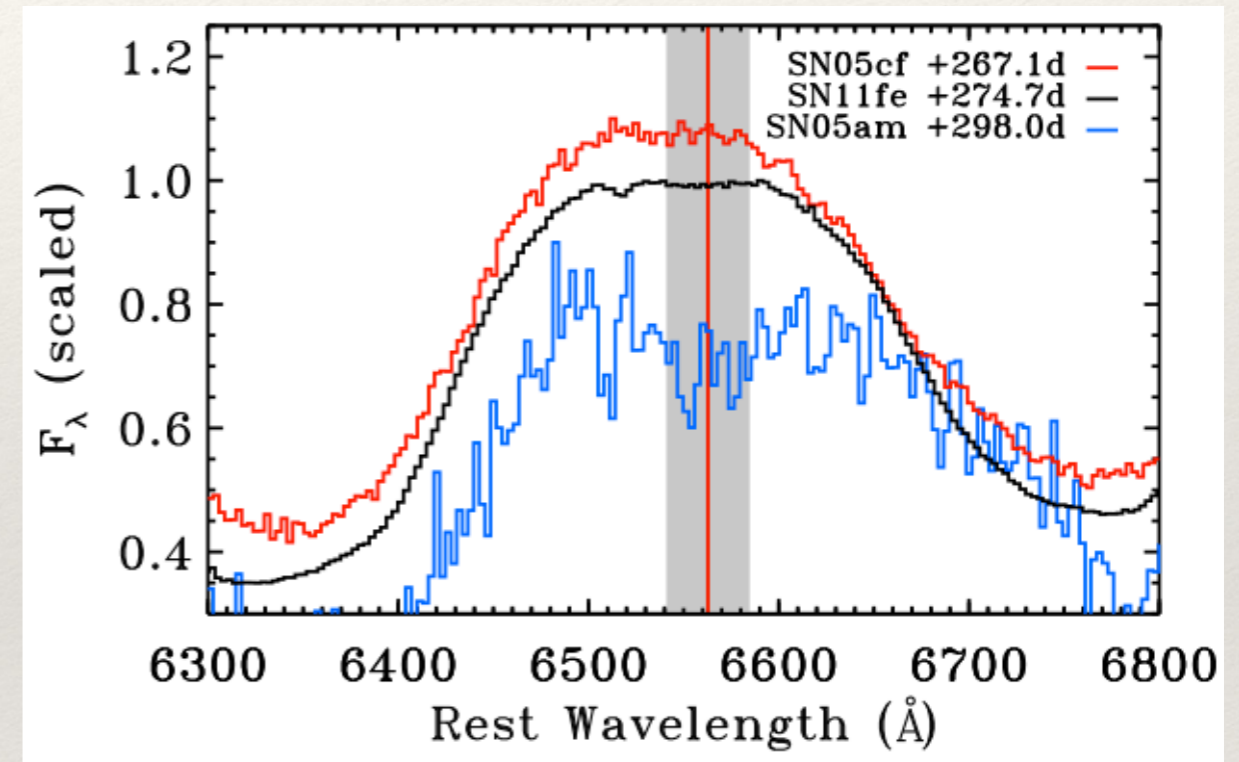


Pan+ (2012)

- Present at low velocities (~ 500 - 1000 km/s) \rightarrow wait for late times and look for narrow features

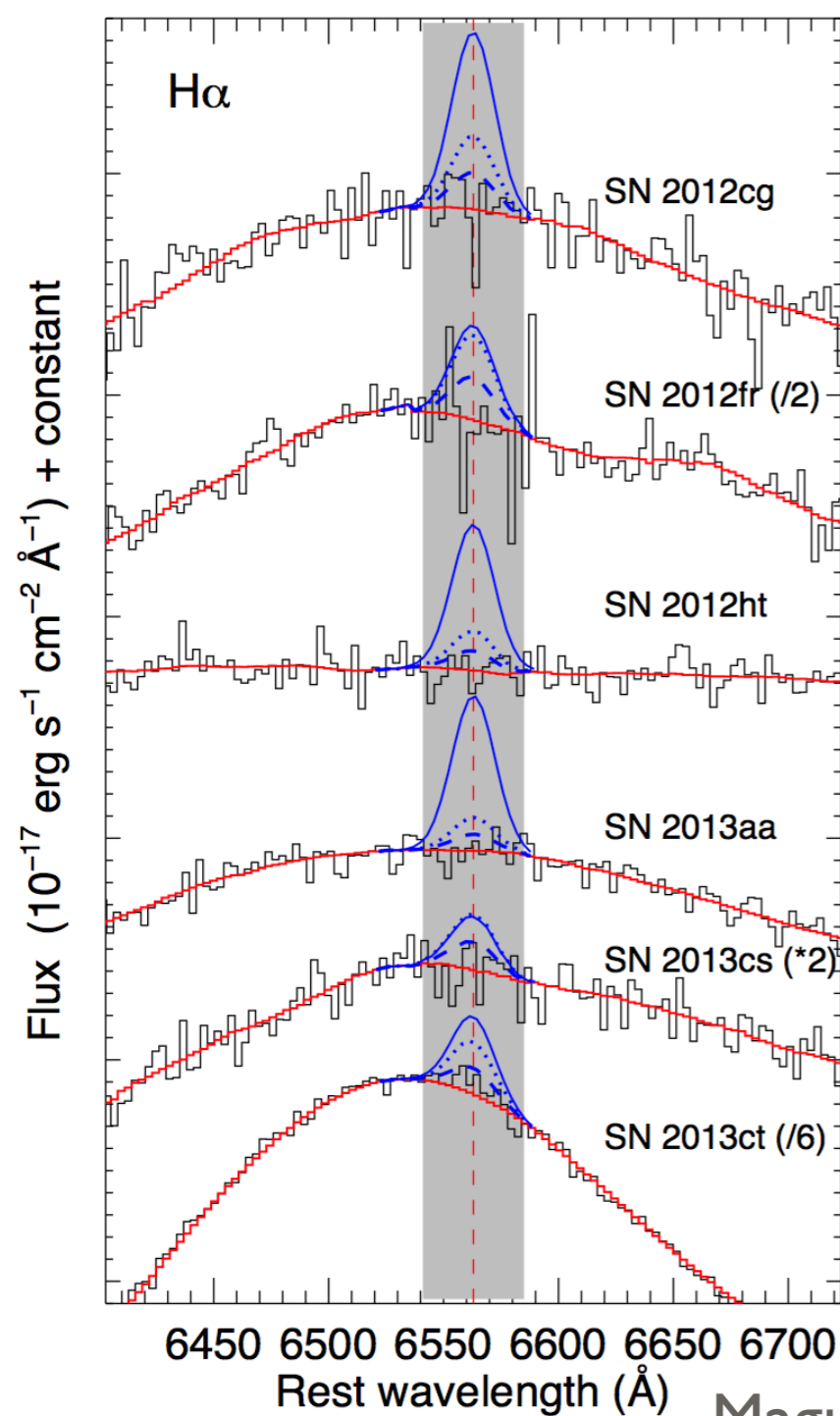
Previous searches for Hydrogen

- Intermediate resolution - features are ~ 1000 km/s wide
- No detections for 7 normal SNe Ia (Mattila+ 2005, Leonard 2007, Shappee+ 2012, Lundqvist+ 2013)
- Combined VLT+XShooter and VLT+FORS2 sample



Shappee+ (2012)

Searching for Hydrogen in late-time spectra



Maguire+ (in prep.)

- New sample of 11 SNe Ia with nebular phase (3 Å binning)
- <0.001 - $0.03 M_{\odot}$ H-rich material (Mattila+ 2005)
- No detection of H in 10 SNe Ia
- Tentative detection in one event

Summary

- Evidence of CSM in 'normal' SNe Ia (~20 %)
- Some have no Na I D absorption
- SNe Ia with blueshifted Na I D have higher stretches & occur more frequently in late-type hosts (and higher Ca II ratios)
- Further modelling of CSM in the different scenarios - able to explain these properties
- Two progenitor scenarios?
- Search for H at late times - tentative H detection in one SN (out of sample of 17)