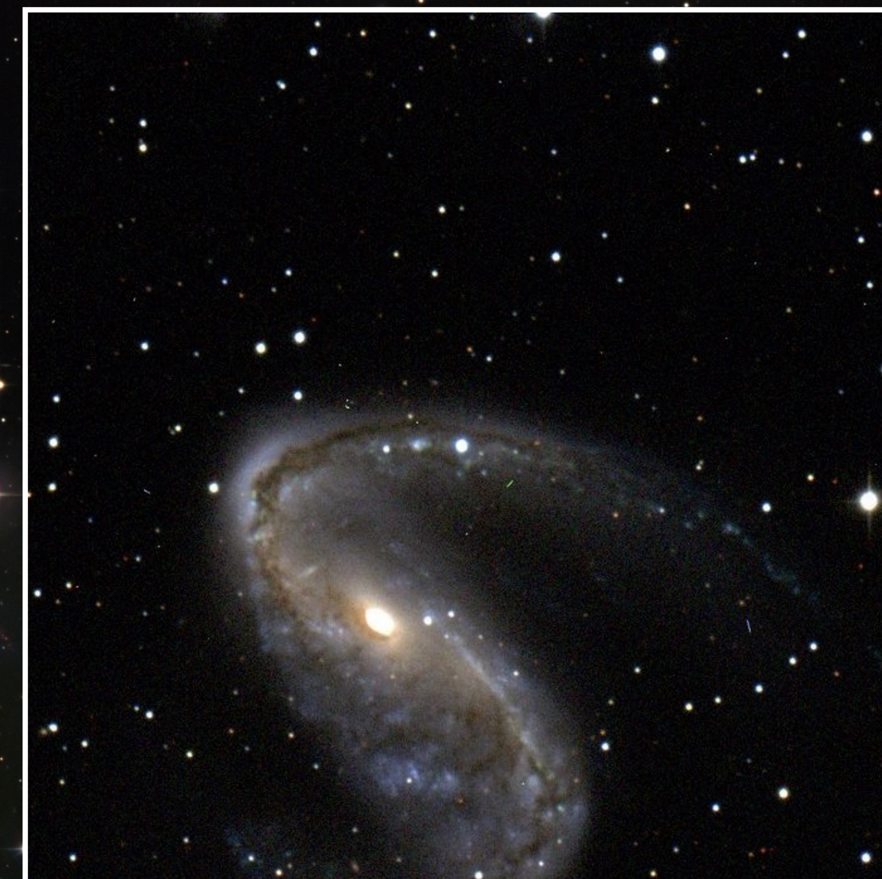


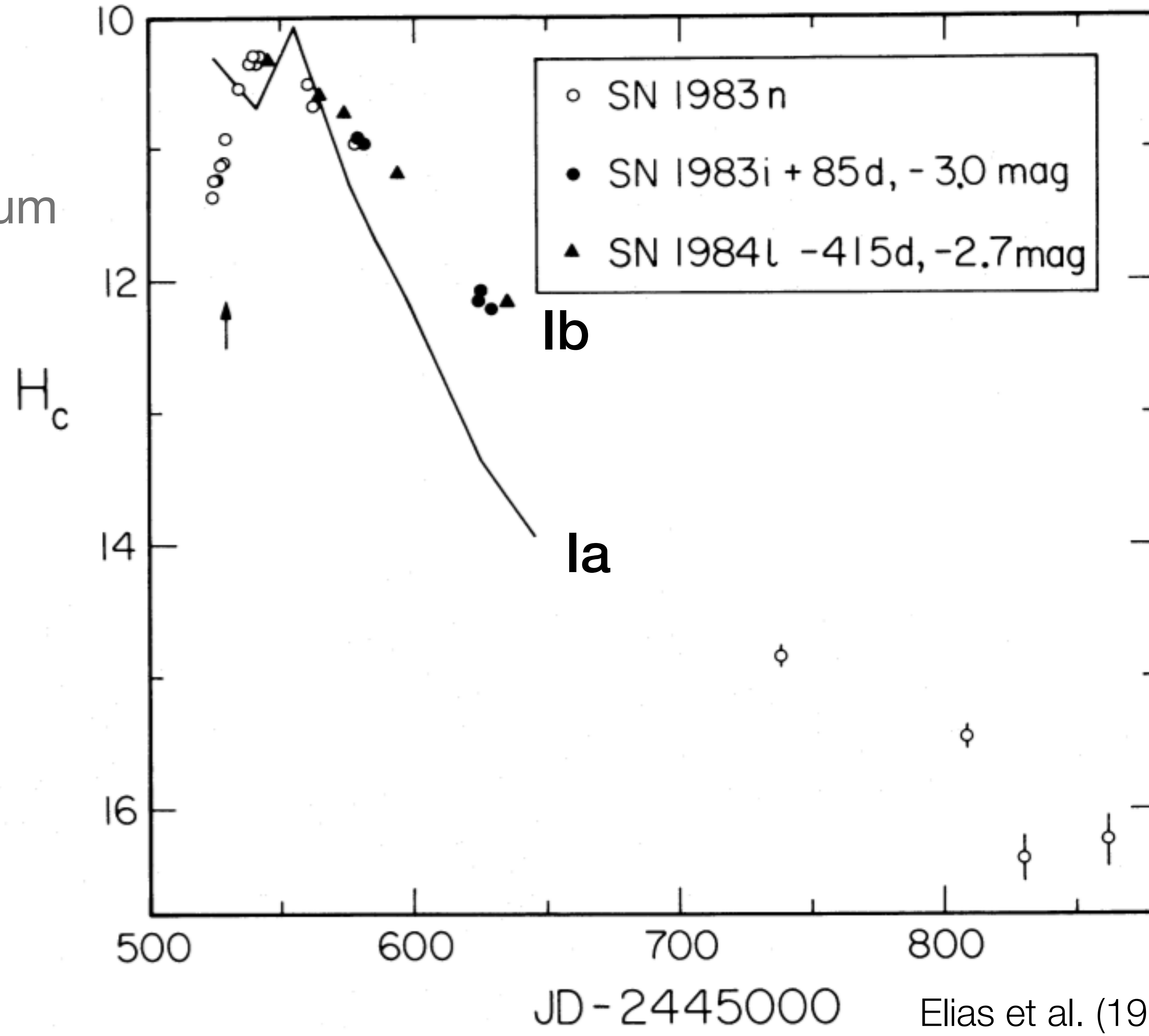
My incomplete take on

Type Ia supernova observational evidence

Eric Hsiao
Florida State University

Type Ia supernova

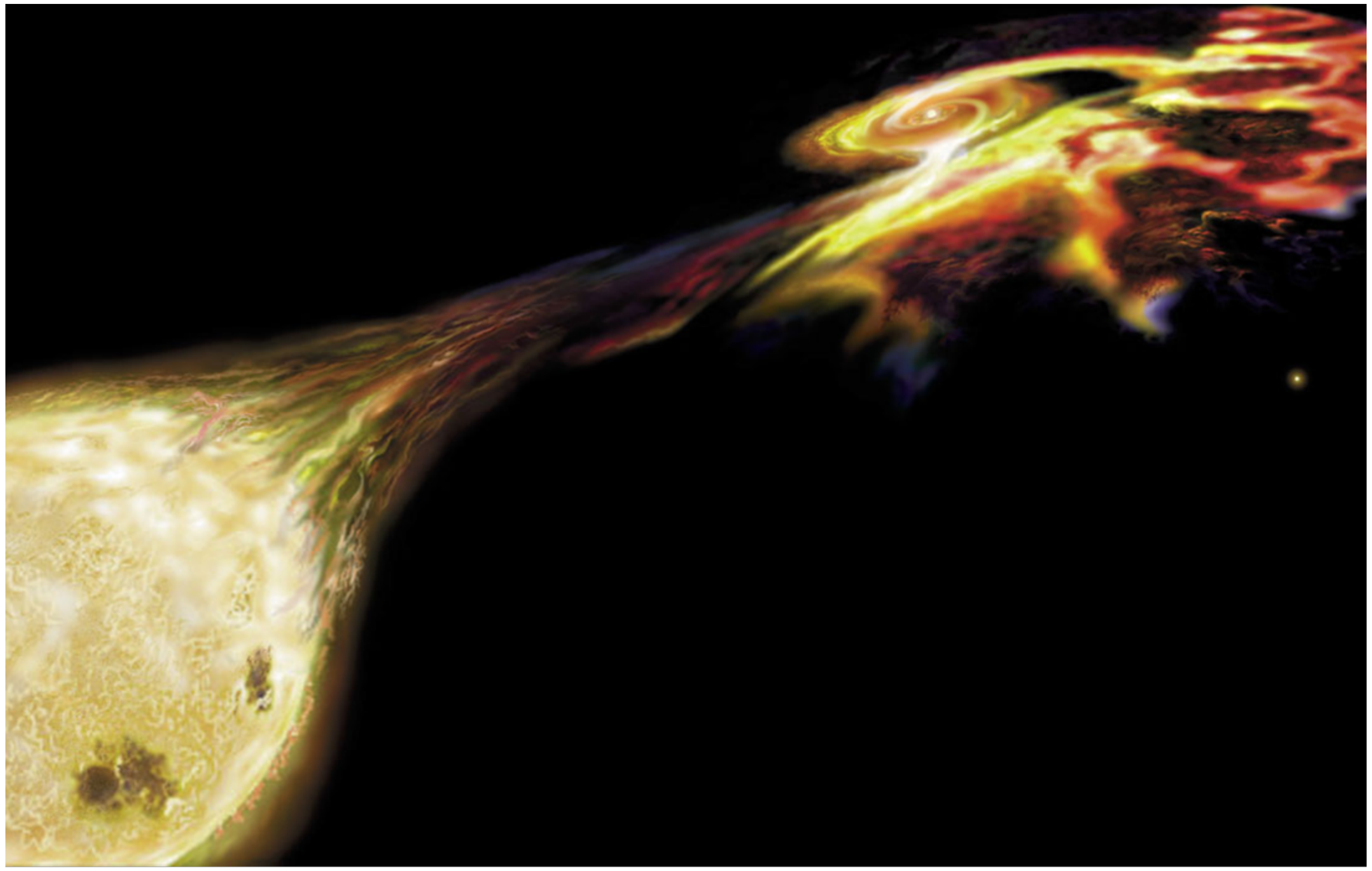
- “Type Ia” first identified by its secondary maximum in the NIR.

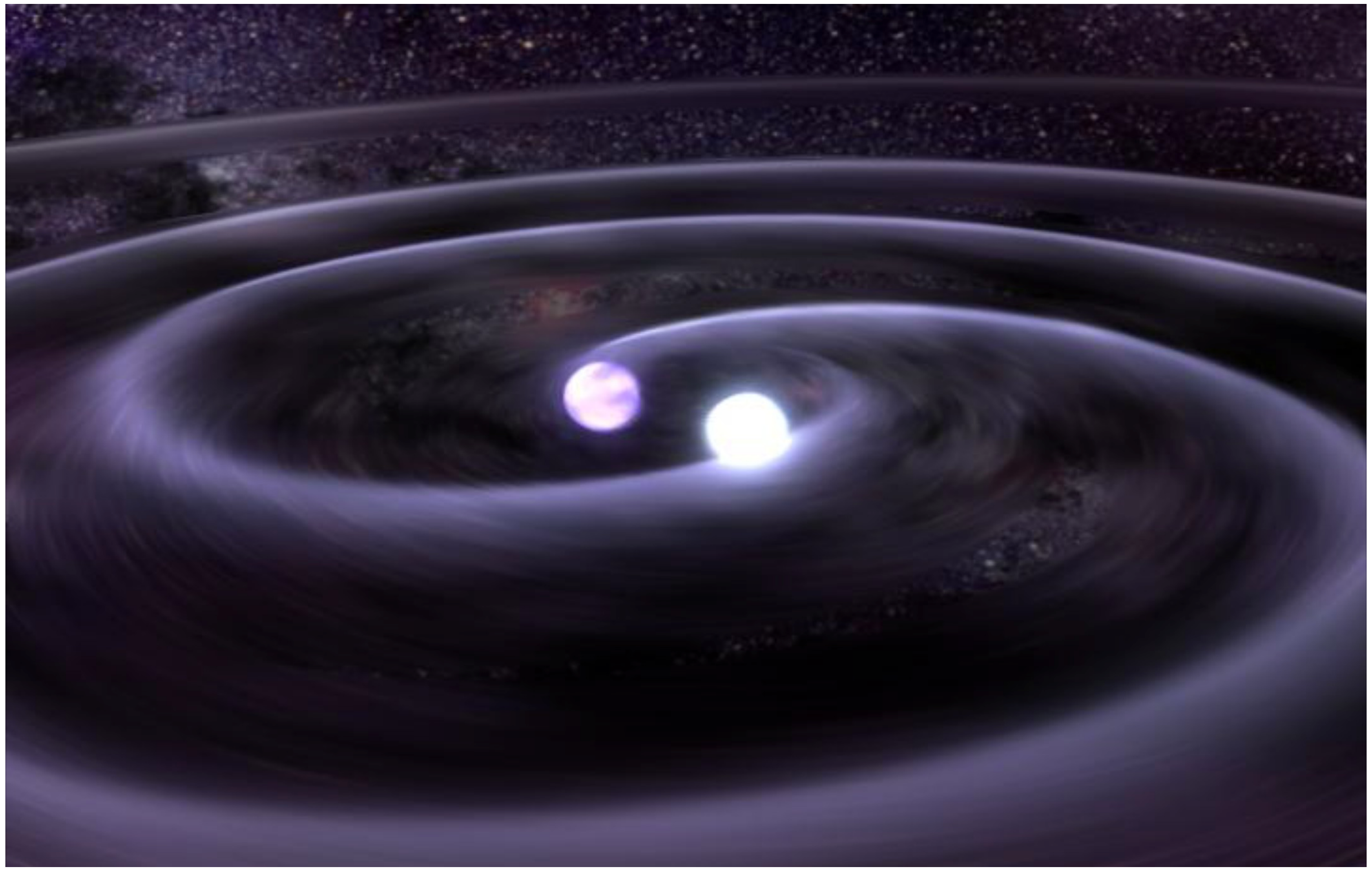


Elias et al. (1985)

Type Ia supernova

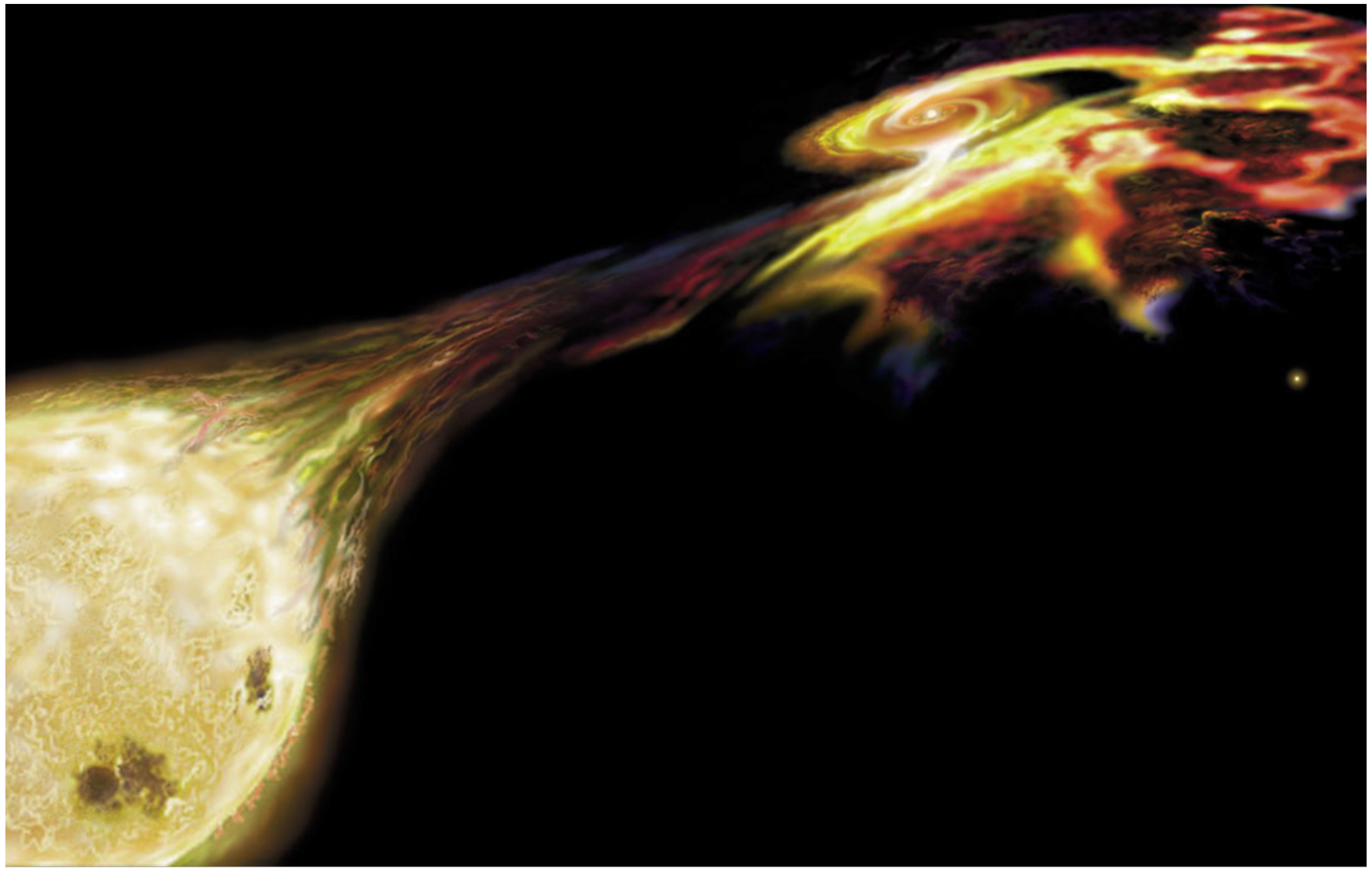
- Consensus explosion of a C/O WD undergoing thermonuclear runaway.

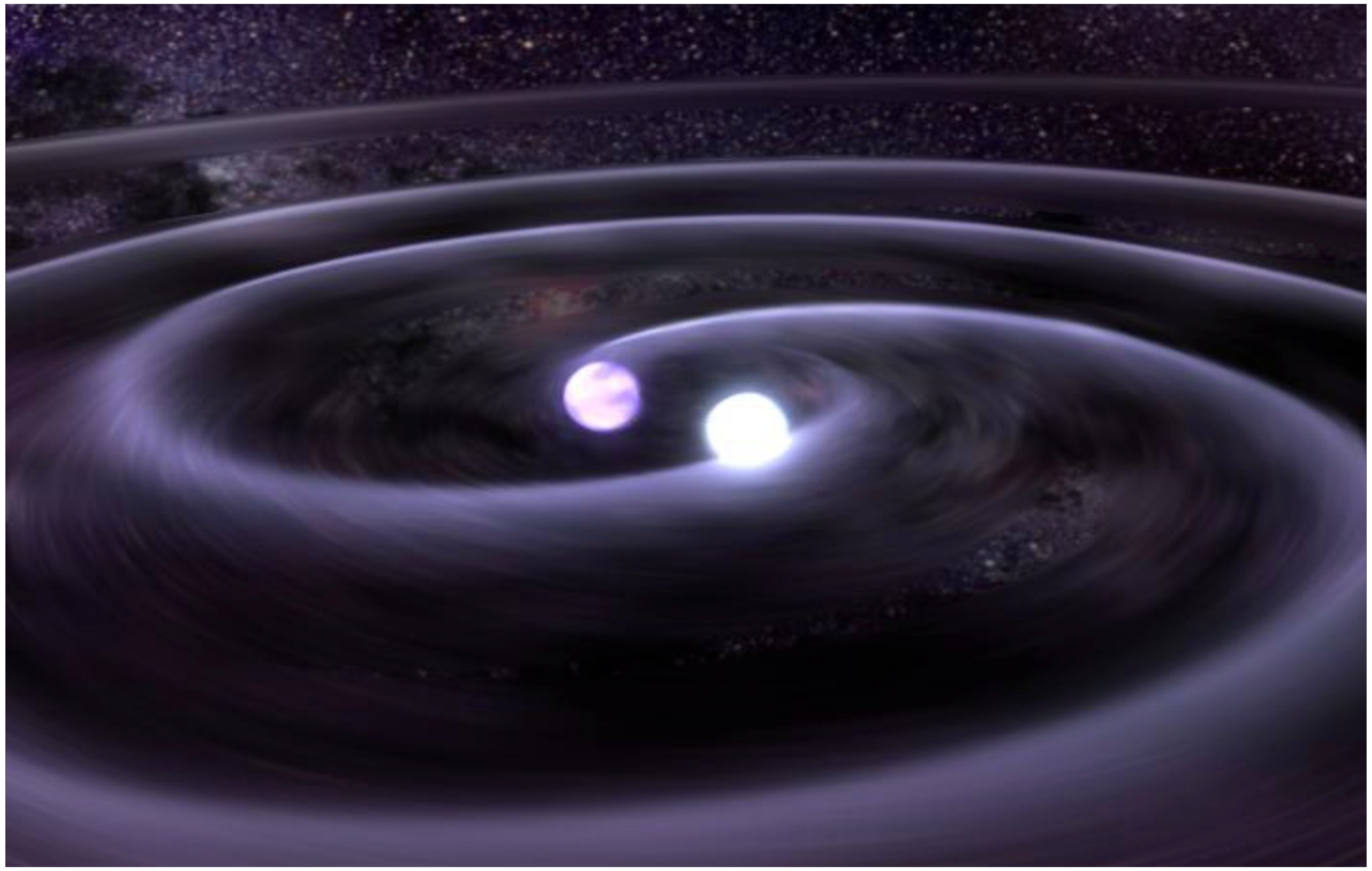




Type Ia supernova

- Consensus explosion of a C/O WD undergoing thermonuclear runaway.
- Progenitor system
  single degenerate
  double degenerate
- Explosion mechanisms
  Chandrasekhar mass, Mch
  He detonation, sub-Mch
  dynamical mergers
  core degenerate
  direct collision





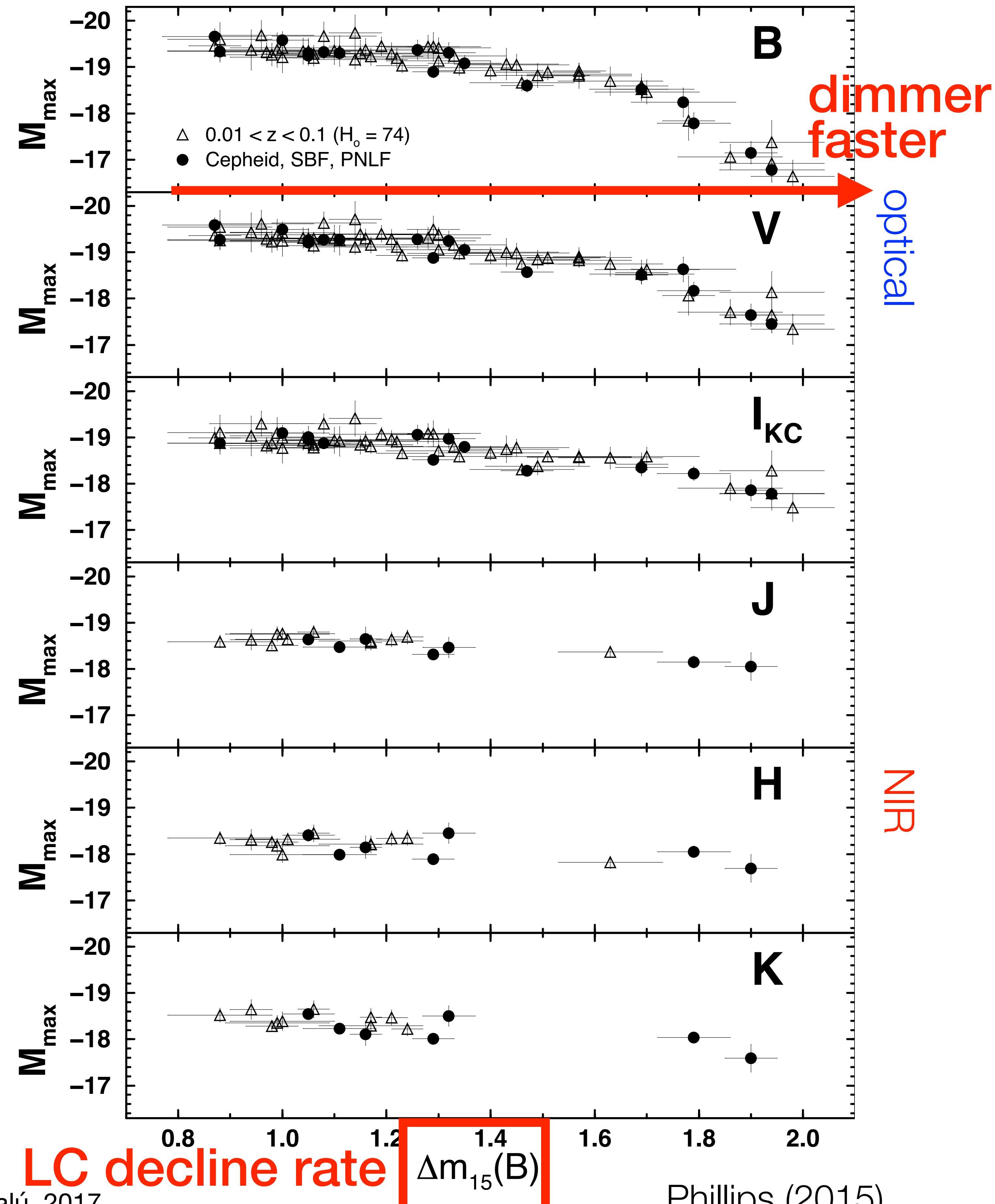
What is the companion star?

What is the explosion mechanism?

What is the origin of the observed homogeneity and diversity?

Diversity

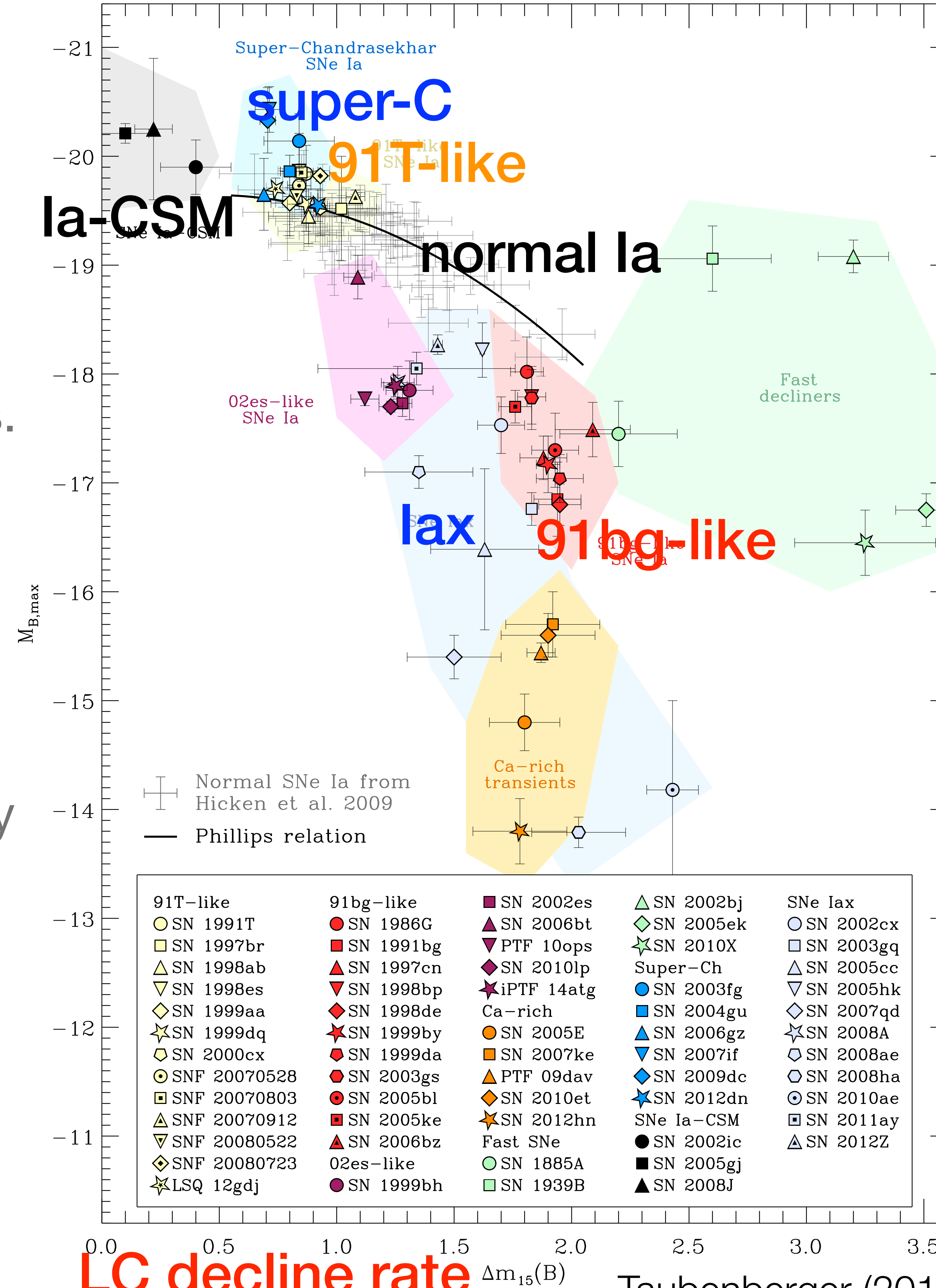
- Width-luminosity relation (dimmer-faster) enables precision cosmology.
- Majority of Ia follow this tight relation.
- Dimmer-faster Ia also redder, conspiring to make true standard candles in NIR.



Phillips (2015)

Diversity

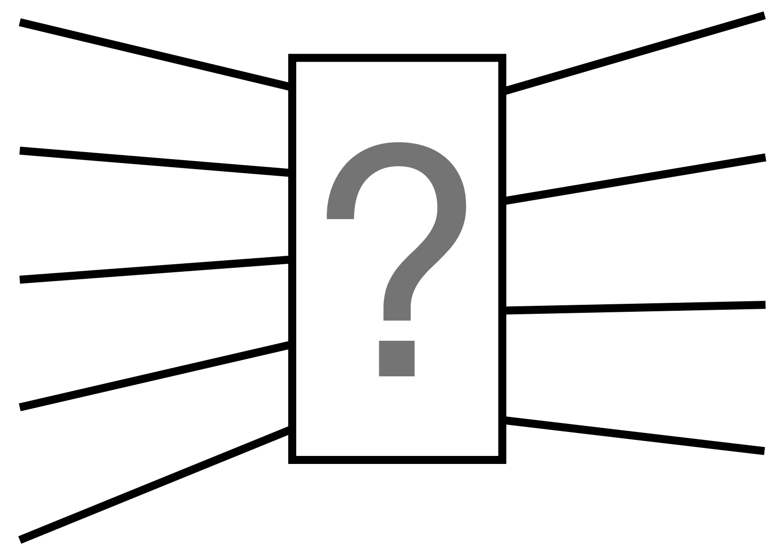
- 91bg and 91T-like are spectroscopically distinct, and also sub- and over-luminous.
- Iax are low-velocity sub-luminous Ia with a wide range of peak mag.
- Super-C Ia are over-luminous, implying ejecta mass significantly higher than Mch.



Taubenberger (2017)

Diversity

- Chandrasekhar mass, Mch
- He detonation, sub-Mch
- dynamical mergers
- core degenerate
- direct collision



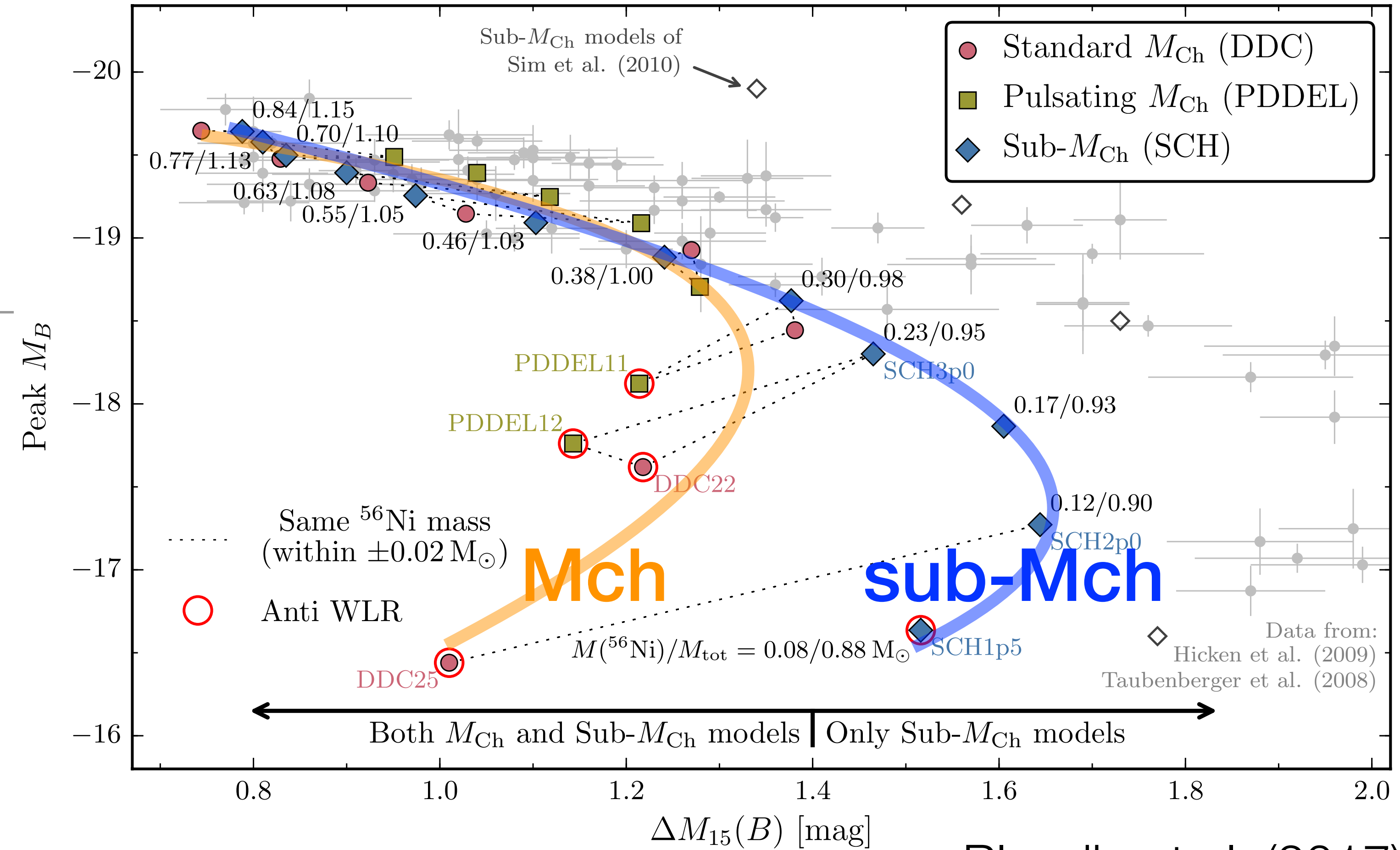
- Normal Ia
- super-Chandrasekhar
- Ia-CSM
- Iax

- It is easier (comparatively) to figure out the mechanisms of peculiar events with their extreme properties. In turn, this helps to determine possible mechanisms for the normal population.

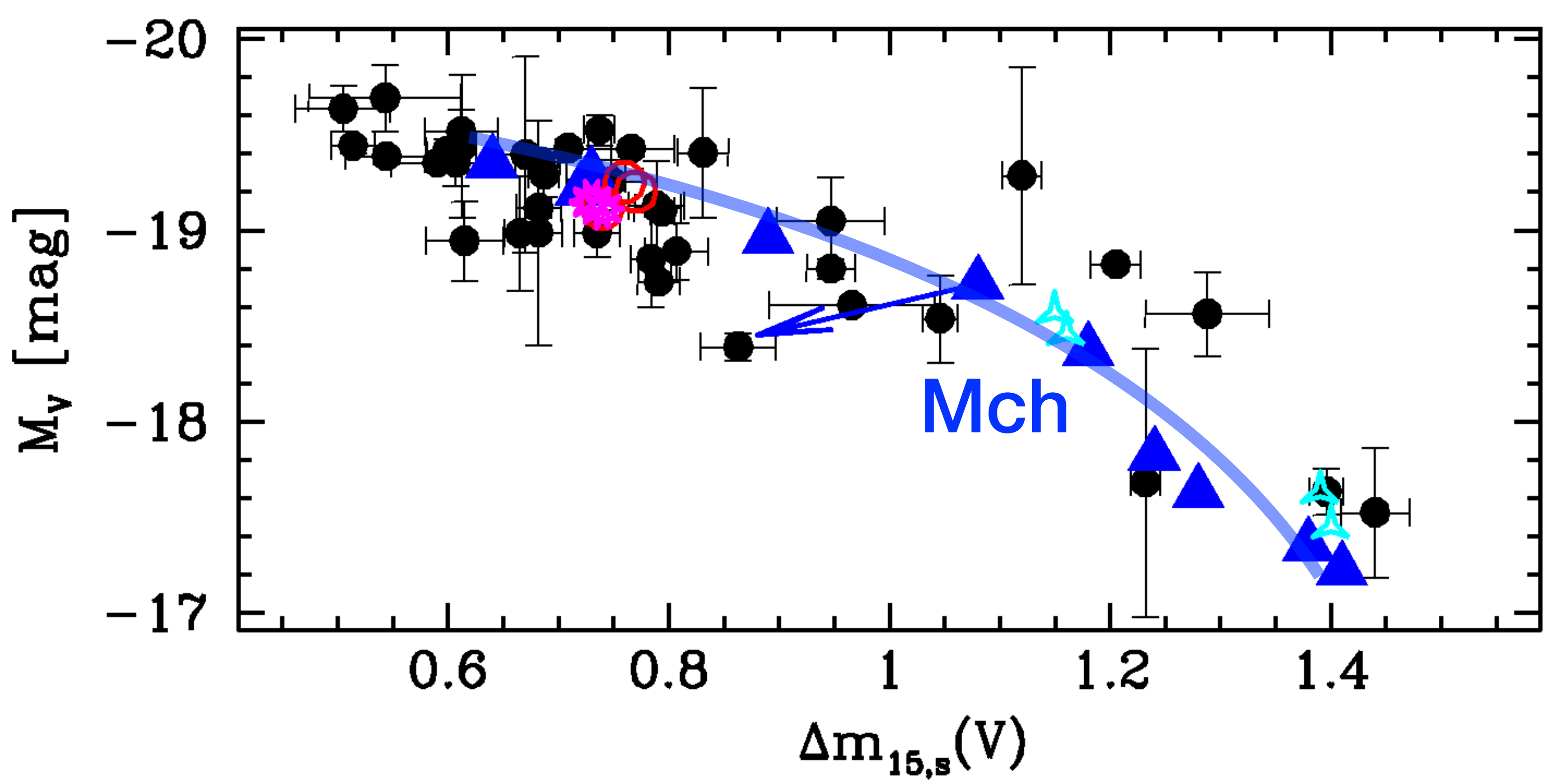
Photometric properties

- Dimmer Ia cannot come from Mch, but should come from sub-Mch channel exclusively.

- One mechanism, Mch.



Blondin et al. (2017)

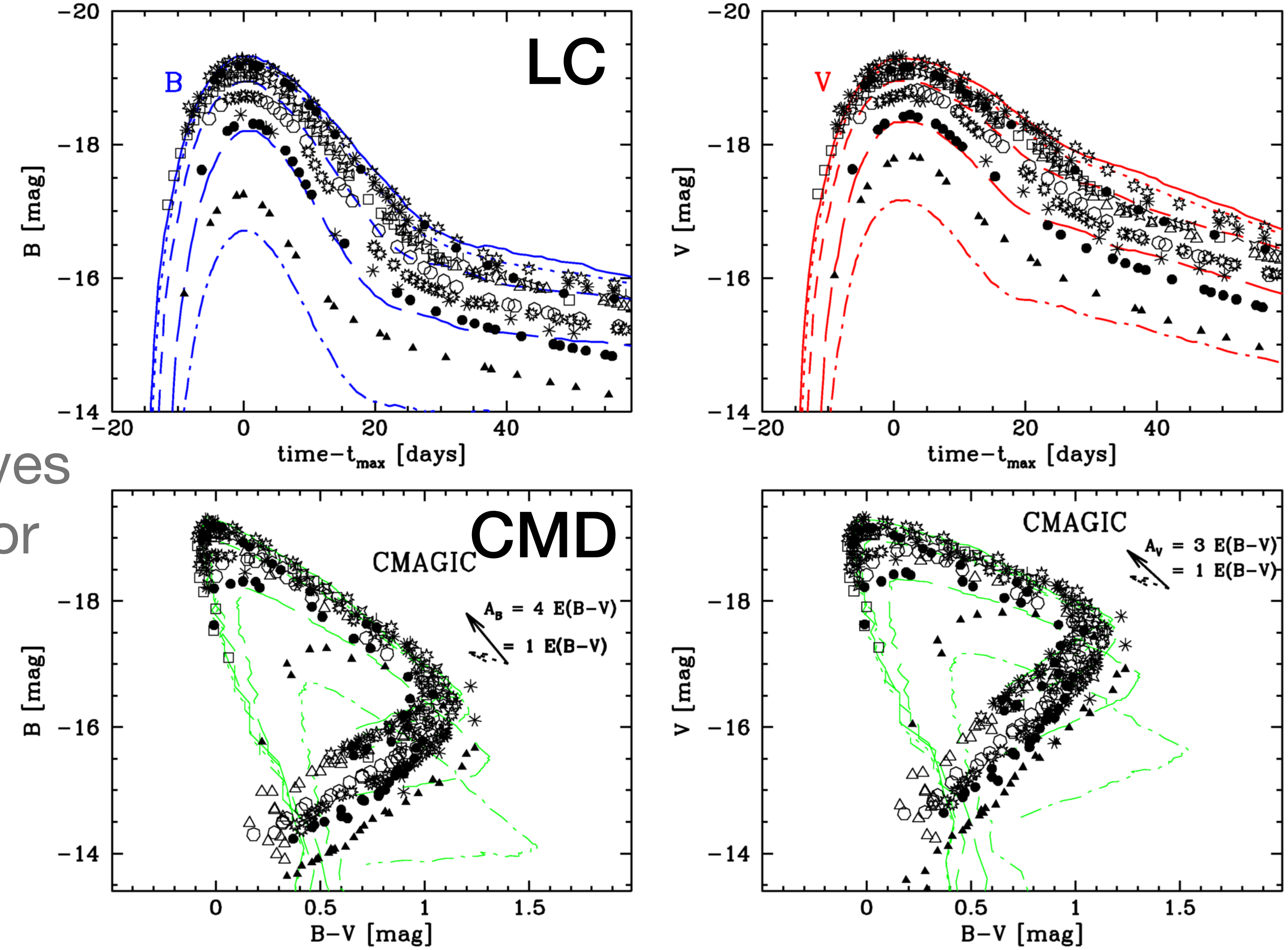


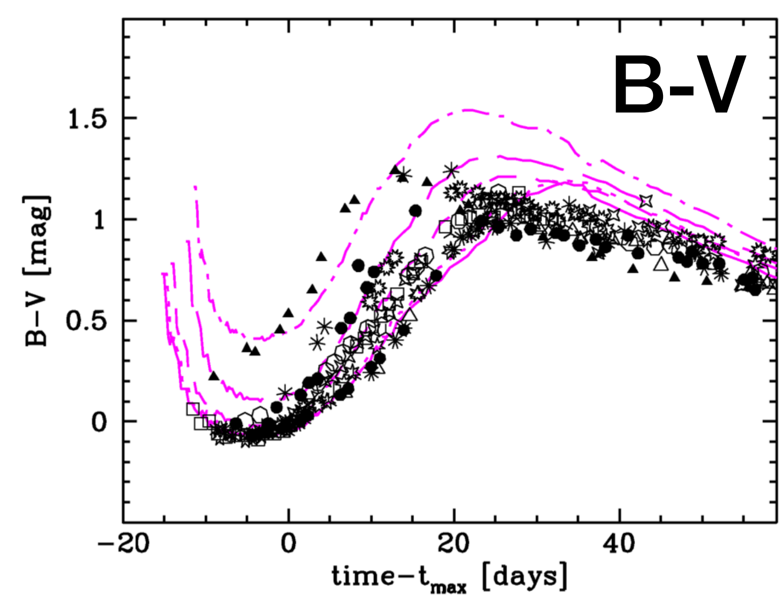
Hoeflich, Hsiao et al. (2017)

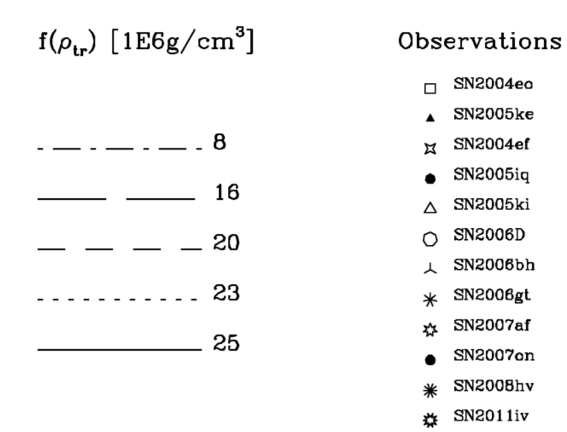
Photometric properties

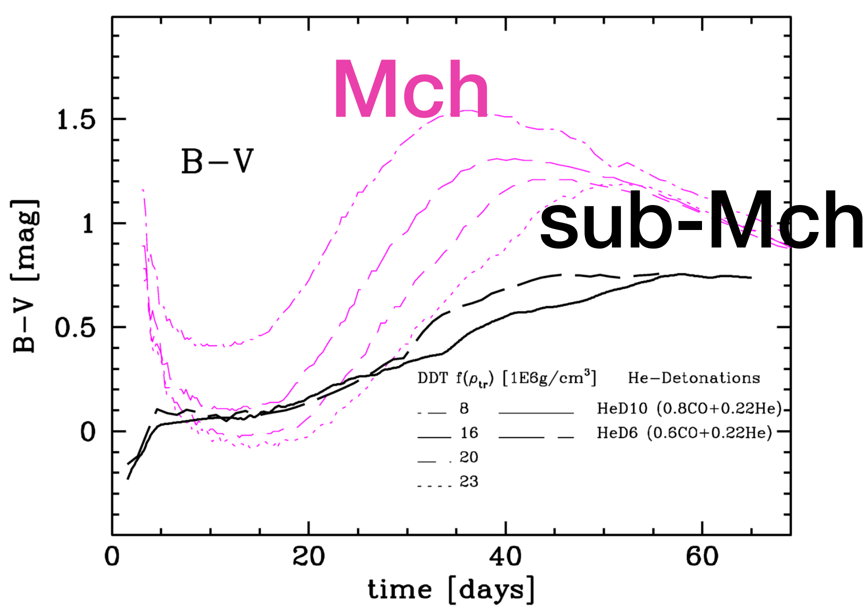
- Mch models provide exceptional match to the observed light + color curves and color-mag diagrams for the full range of normal Ia.

1D Mch models + CSP data





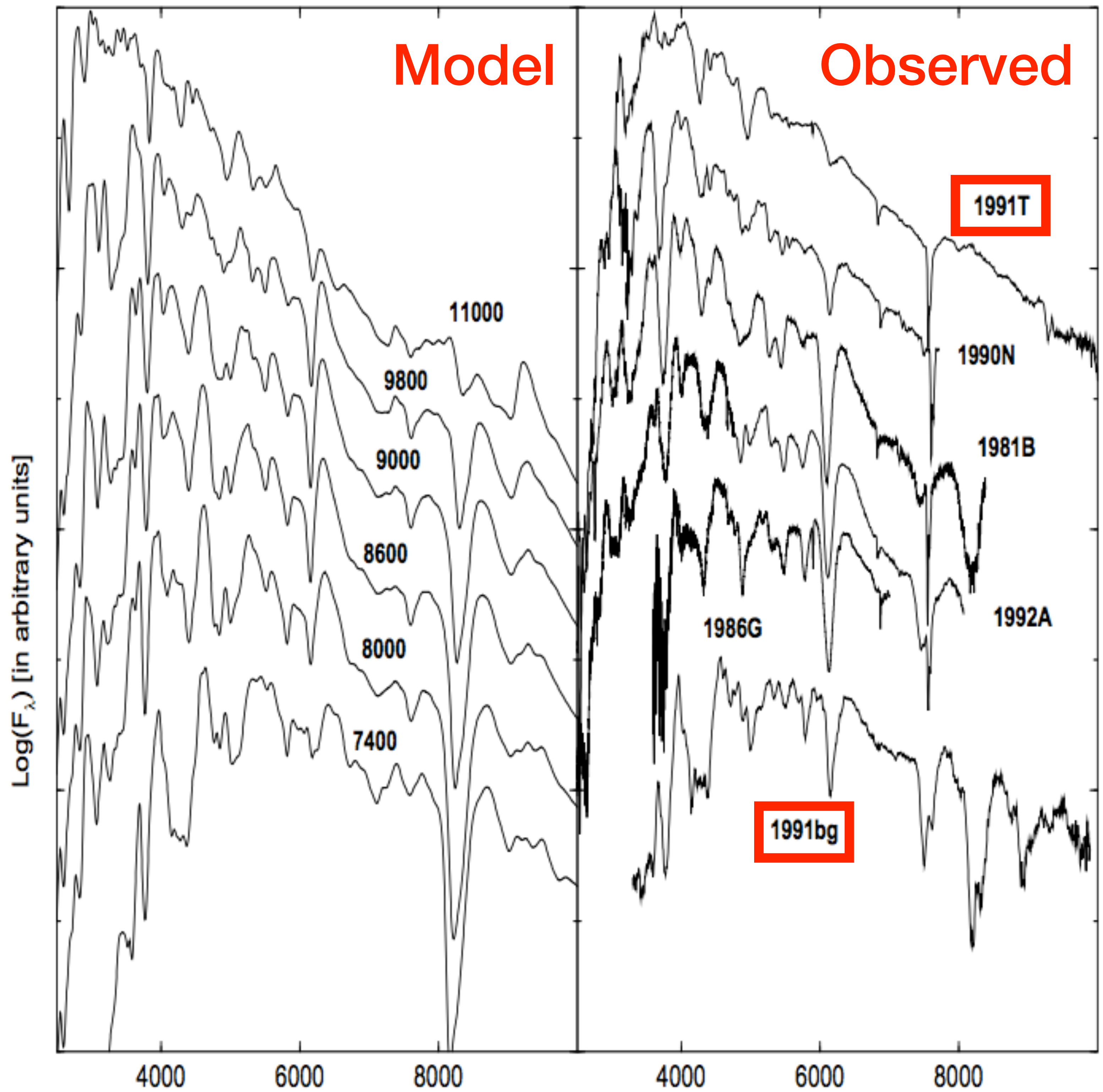




Hoeflich, Hsiao et al. (2017)

Spectroscopic properties

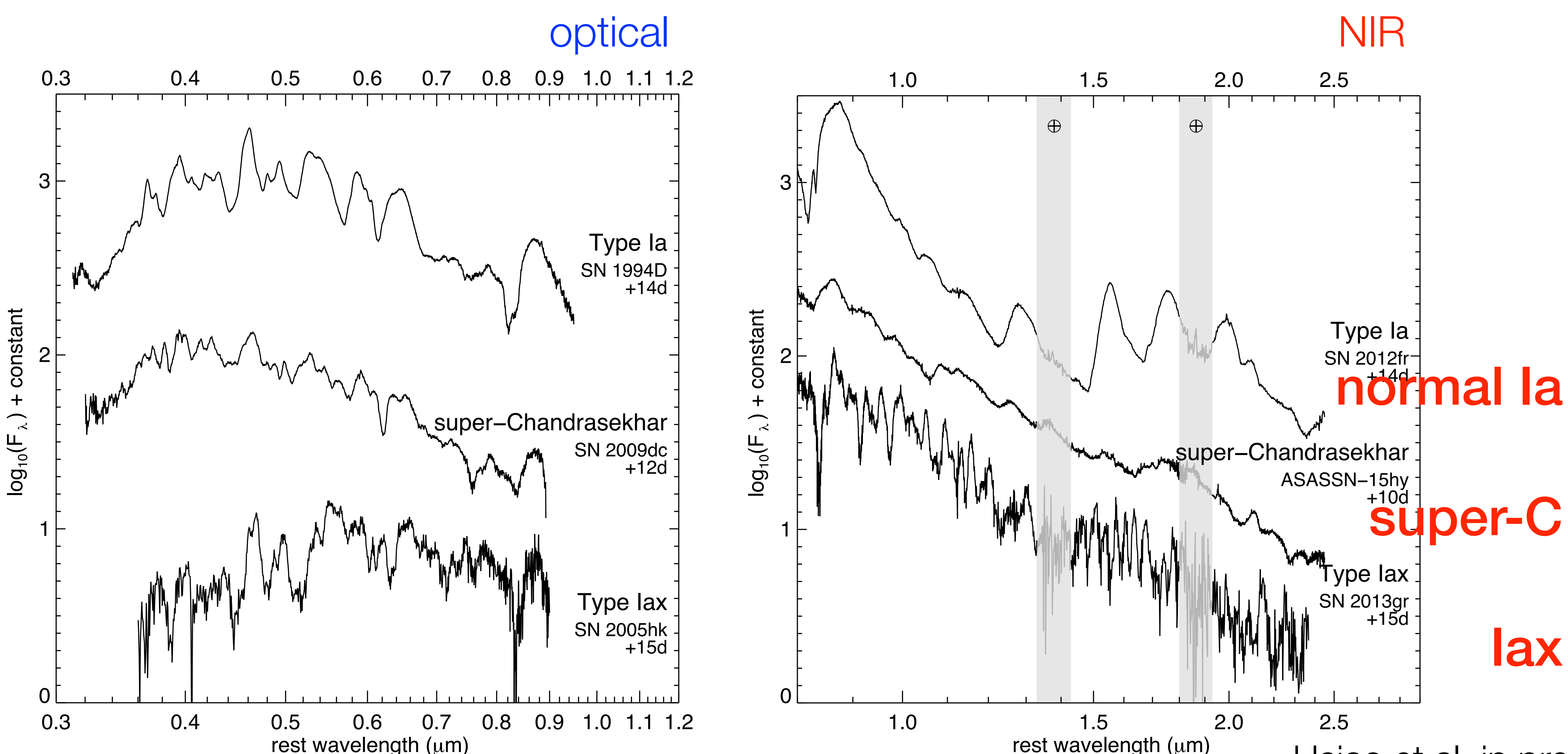
- Dialing the temperature of radiative transport can reproduce the observed spectroscopic diversity, including 91T, normal, 91bg.



Nugent et al. (1995)

Spectroscopic properties

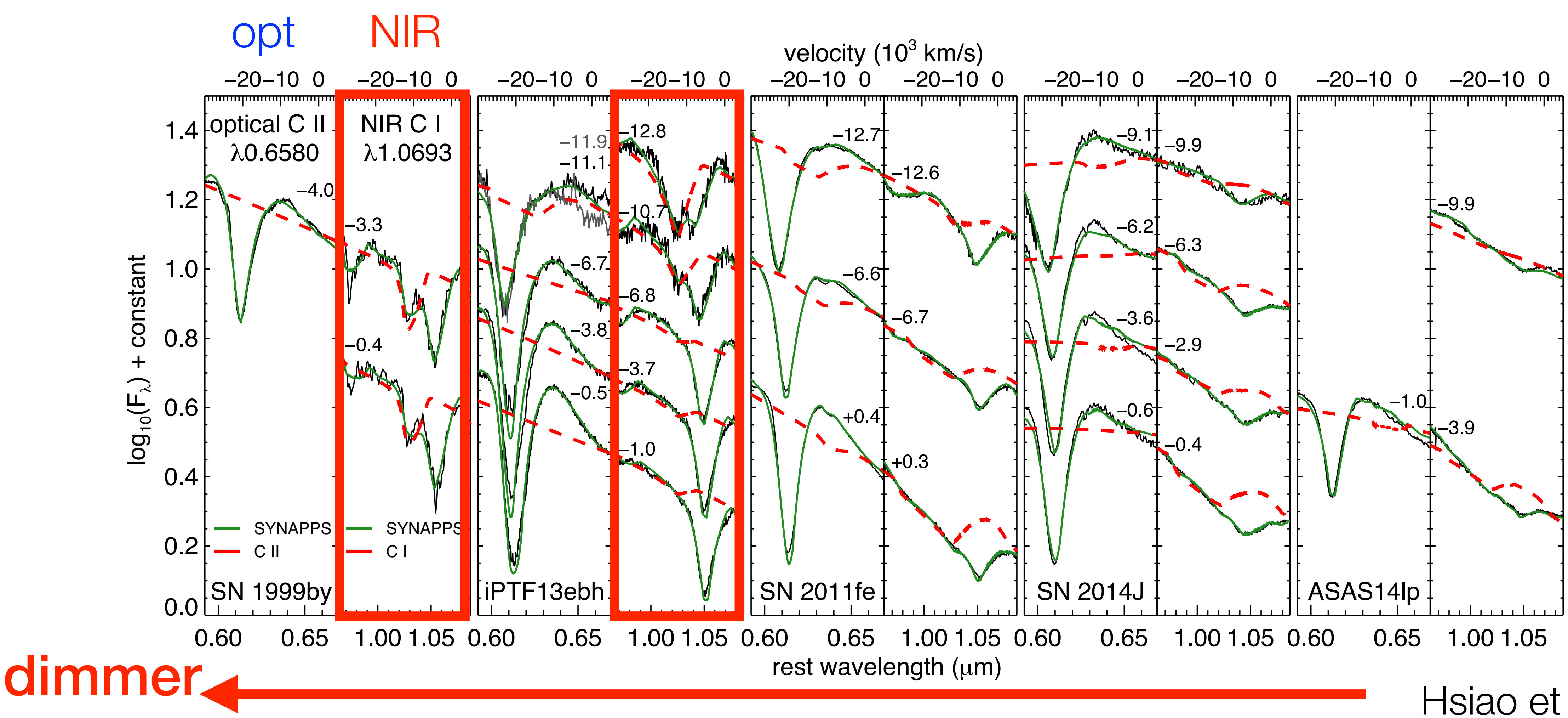
- The differences between normal, Iax and super-C are subtle in the optical.
- However, they are drastic in the NIR, suggesting different mechanisms?



Hsiao et al. in prep

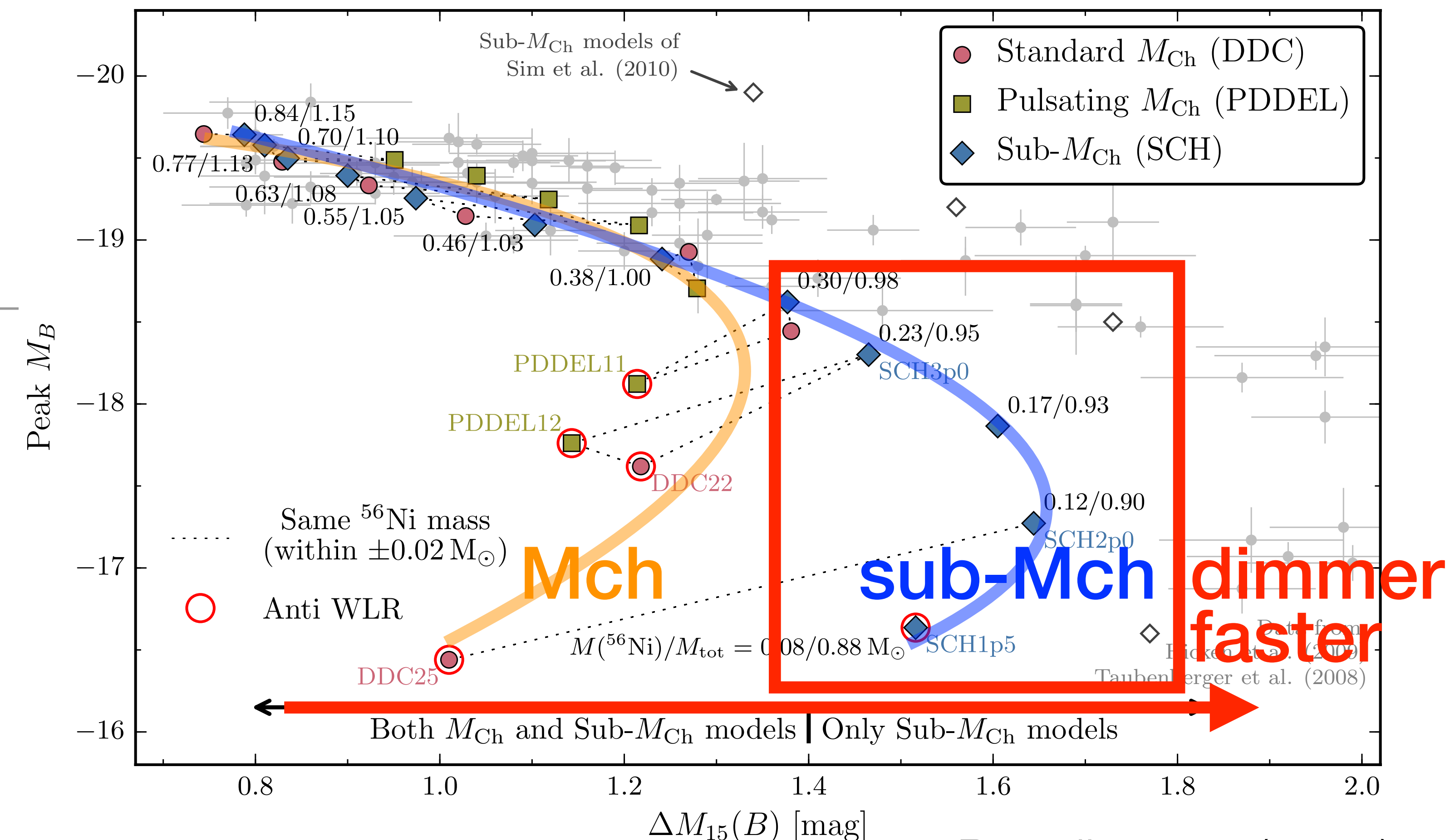
Spectroscopic properties

- Carbon detected in SN spectra is pristine from the progenitor WD, and is observed to be especially strong in dimmer Ia.
- Unburned material is not expected to survive in sub-Mch route due to the surface detonation mechanism.

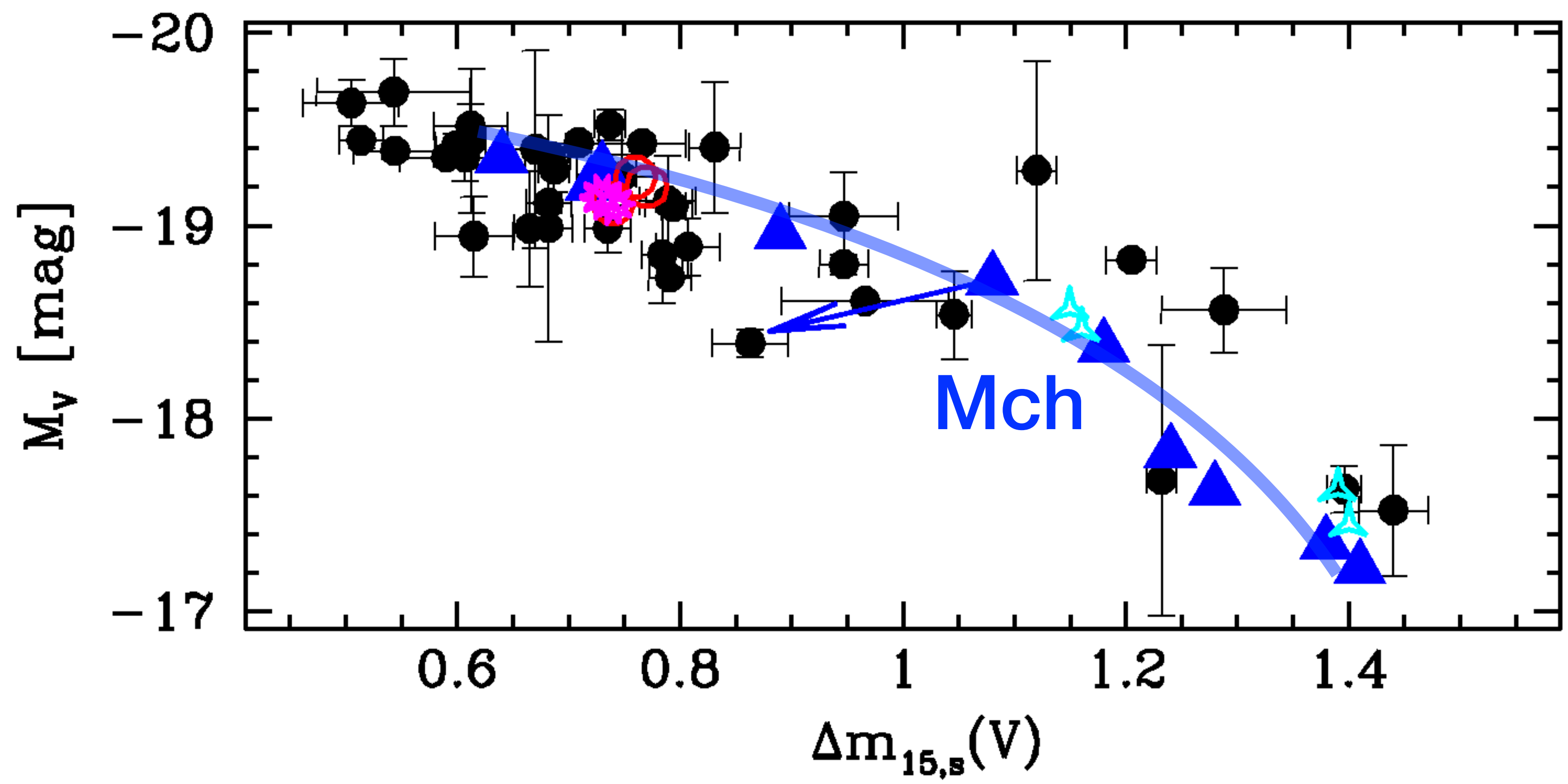


Hsiao et al. (2015)

Spectroscopic properties



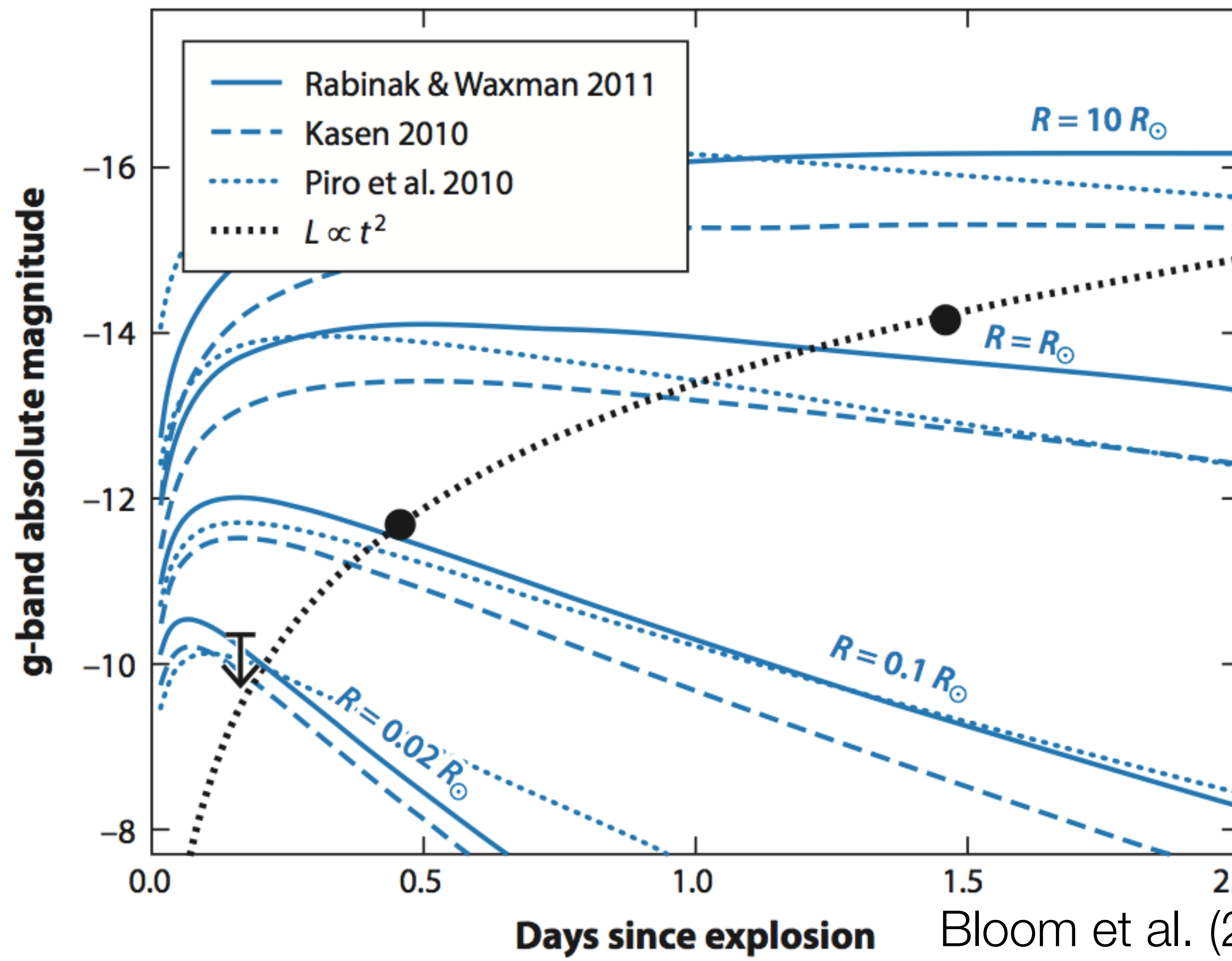
Blondin et al. (2017)



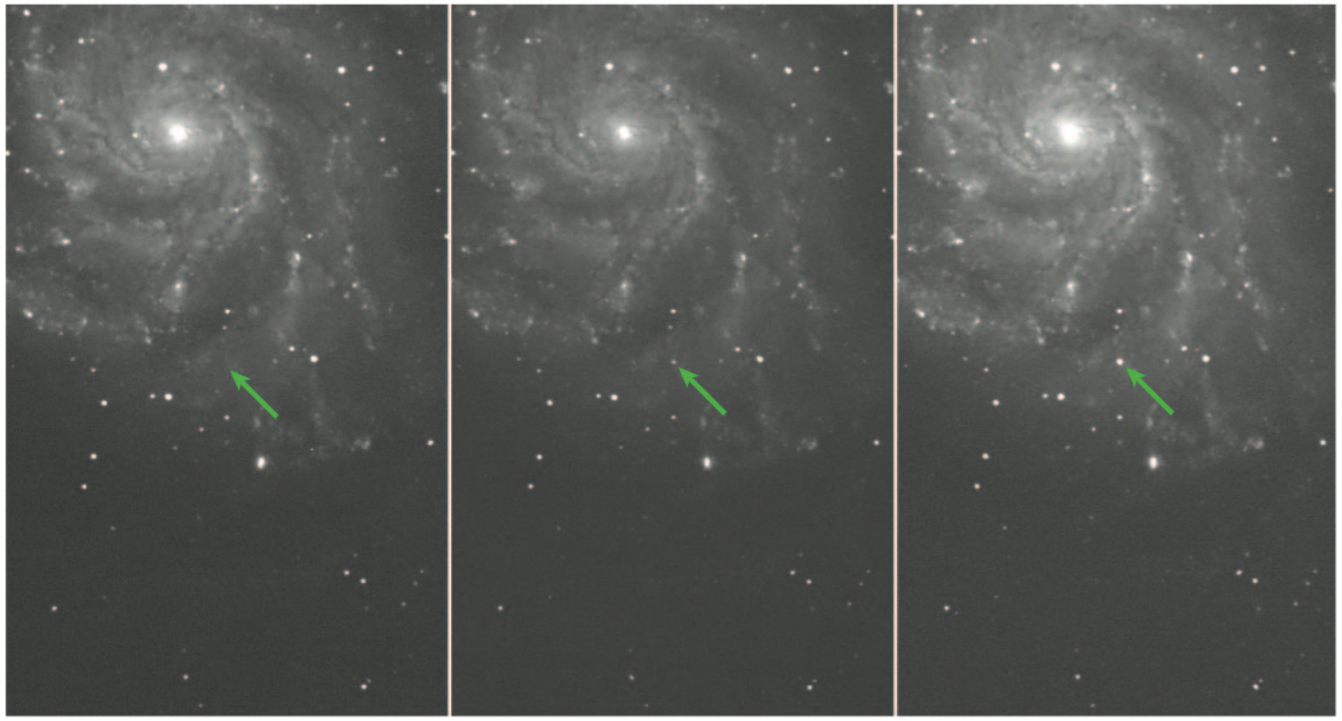
Hoeflich, Hsiao et al. (2017)

Primary star

- SN2011fe, a normal Ia, was discovered hours after its explosion in M101, 6.4 Mpc away.
- Cooling of shock-heated primary or companion depends on radius.
- Only WD and NS are viable as primary star candidates.

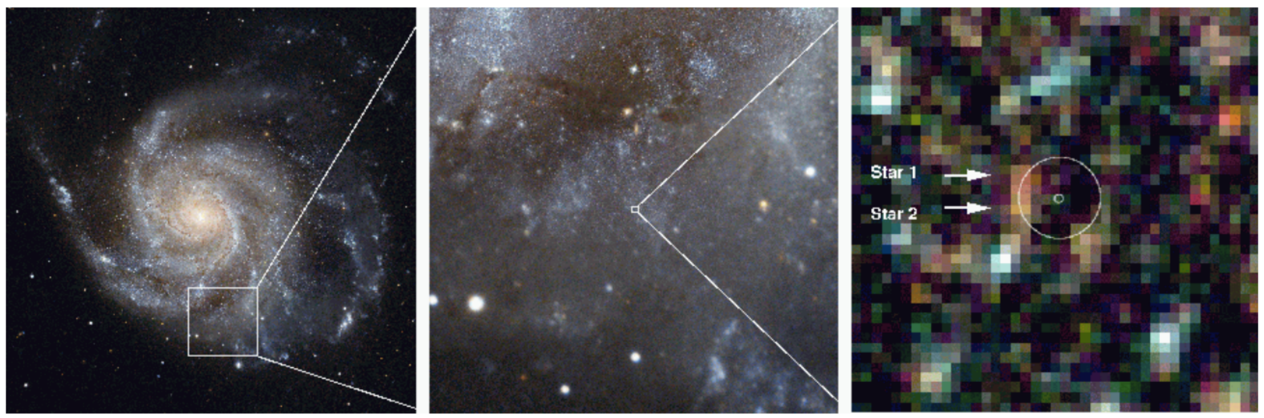


Bloom et al. (2012)

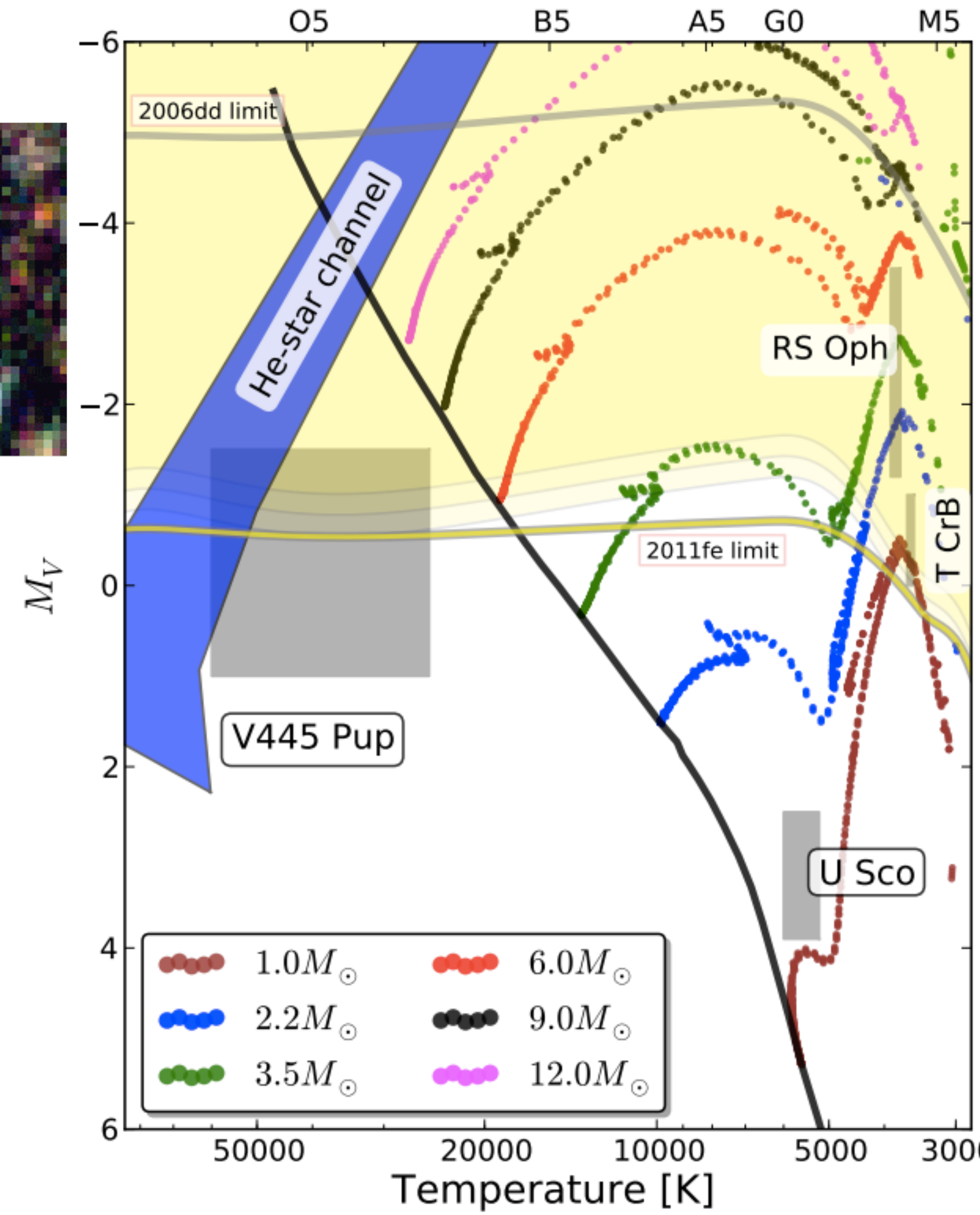


Nugent et al. (2011)

Companion star: shock heating



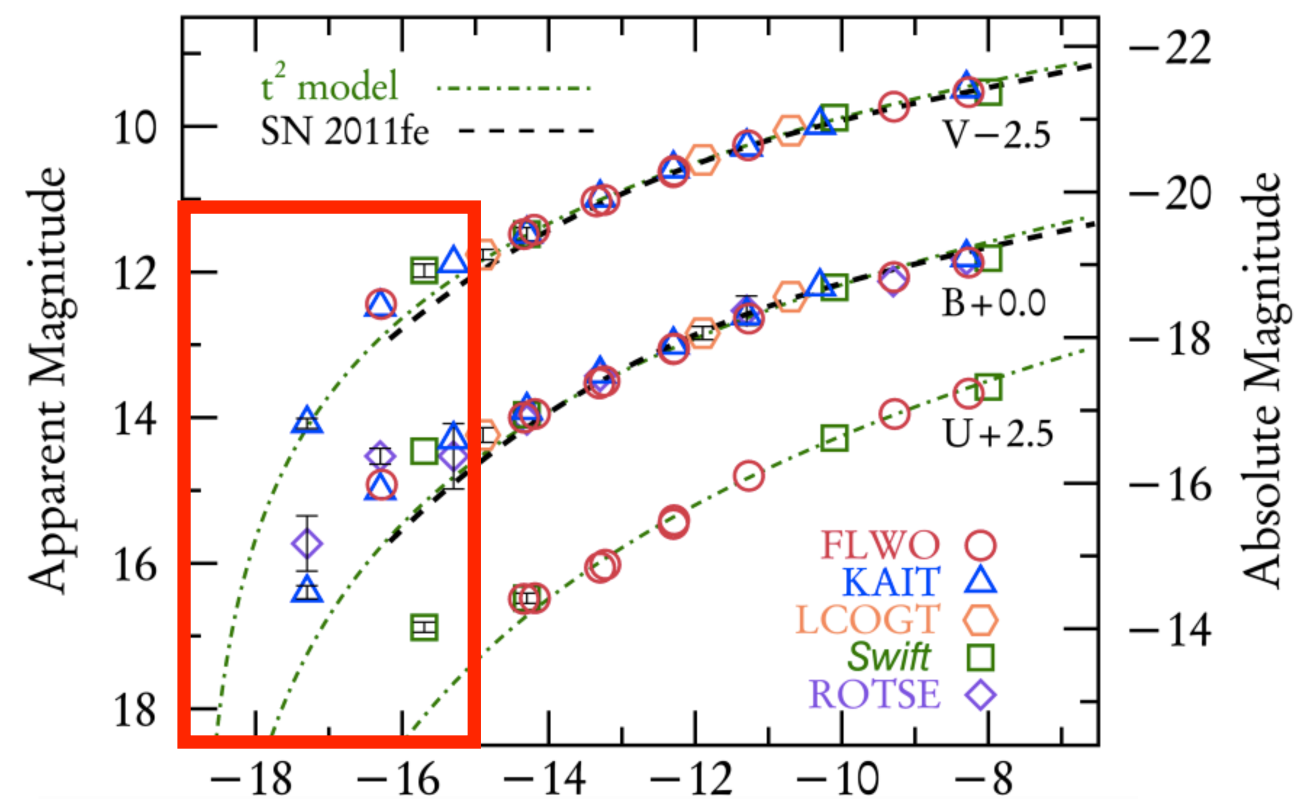
- Can rule out luminous RG and most He-star as companion for SN2011fe.

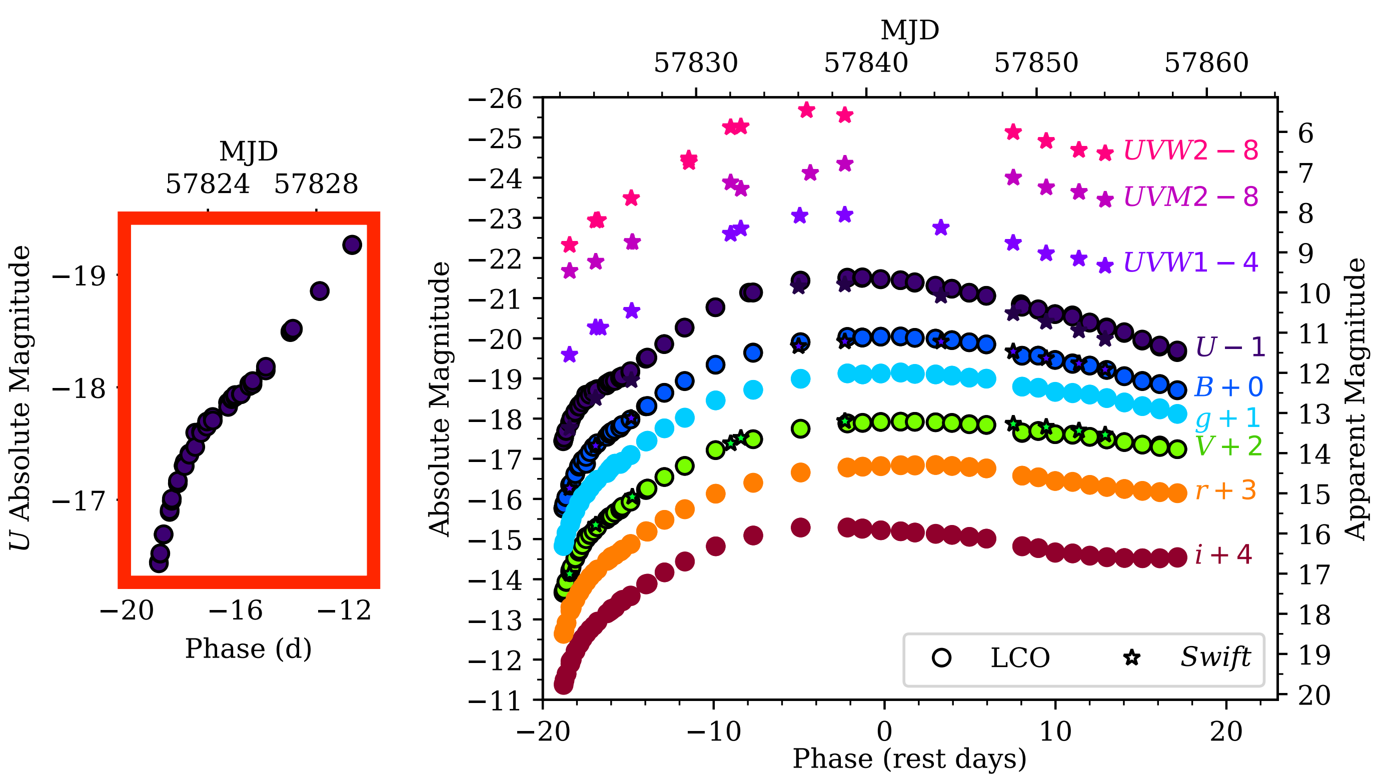


Li et al. (2011)

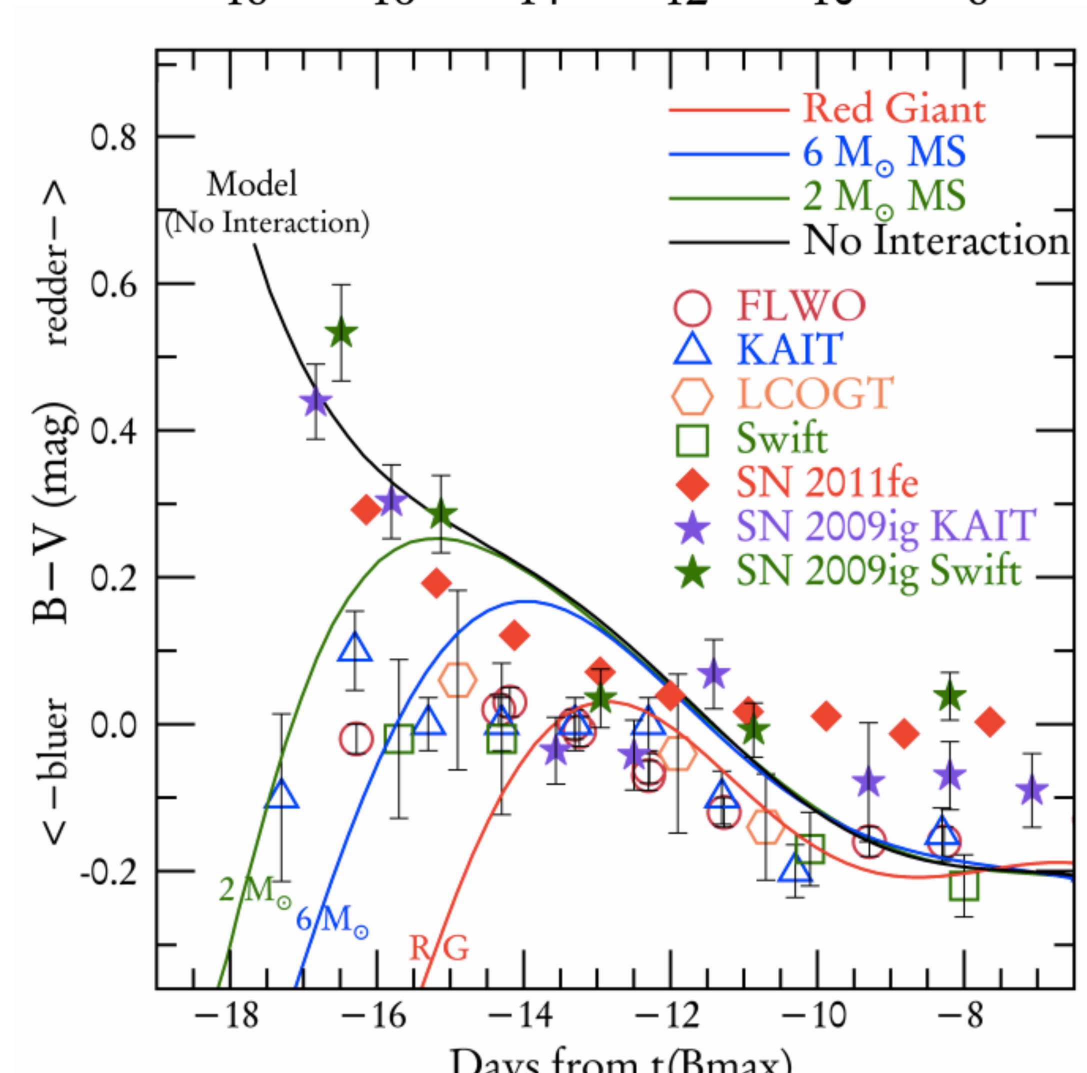
Companion star: shock heating

- There are now 2 examples of normal Ia showing “excess” in their early light curves, interpreted as shock heated companion.





SN2017cbv; Hosseinzadeh et al. (2017)



SN2012cg; Marion et al. (2015)

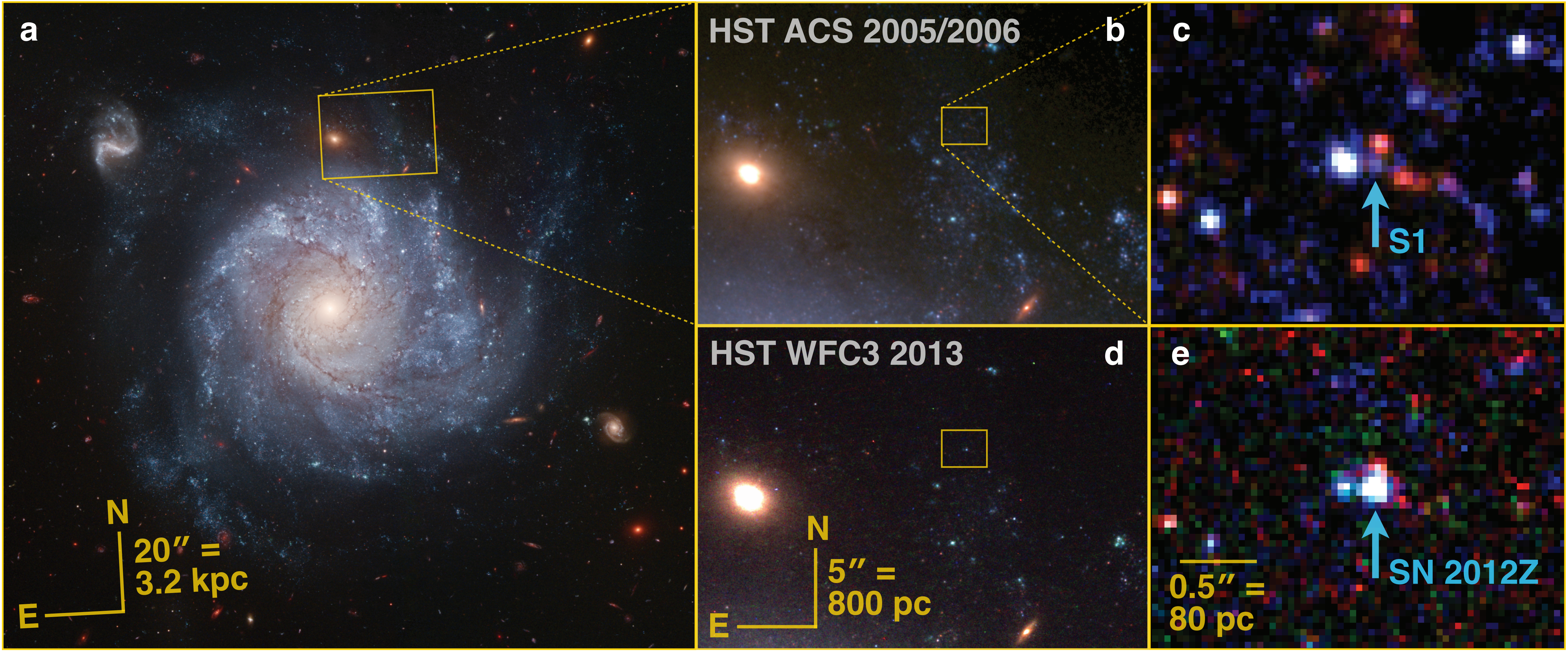
Companion star: shock heating

- These detections are rare.

Hayden et al. (2010)	SDSS-II	No detection
Bianco et al. (2011)	SNLS	No detection
Brown et al. (2012)	Swift nearby	No detection
Zheng et al. (2013)	SN2013dy	No detection
Yamanaka et al. (2014)	SN2012ht	No detection
Firth et al. (2015)	PTF/LSQ	No detection
Olling et al. (2015)	Kepler	No detection
Shappee et al. (2015)	ASASSN-14lp	No detection
Cao et al. (2015)	iPTF14atg	R ~ 20 Rsun
Marion et al. (2015)	SN2012cg	R ~ 10 Rsun
Hosseinzadeh et al. (2017)	SN2017cbv	R ~ 60 Rsun

Companion star: pre-explosion

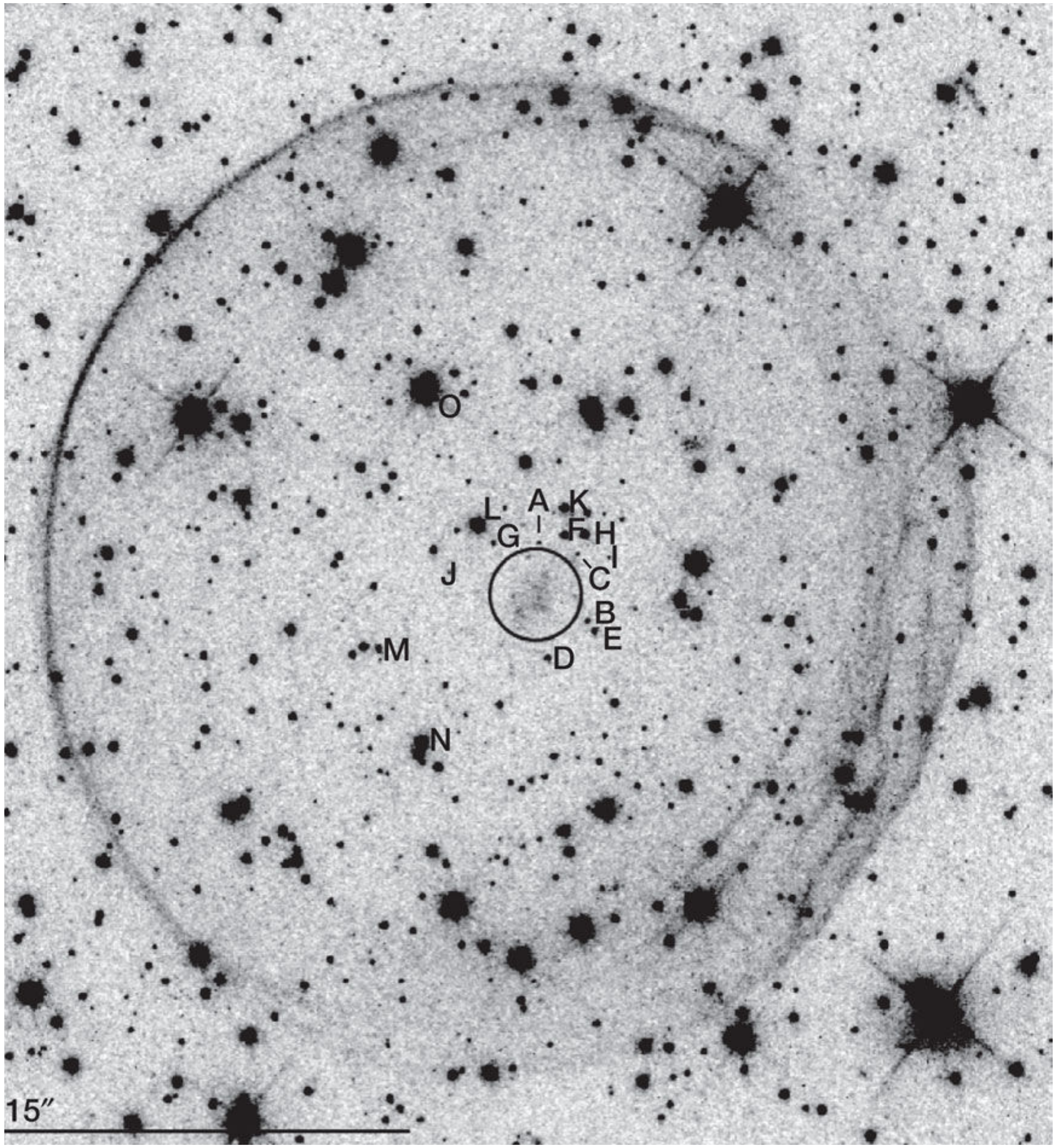
- Pre-explosion images of the site of Iax SN2012Z revealed a luminous blue star, believed to be a He star companion.
- No pre-explosion companion has been found for normal Ia.



McCully et al. (2014)

Companion star: post-explosion

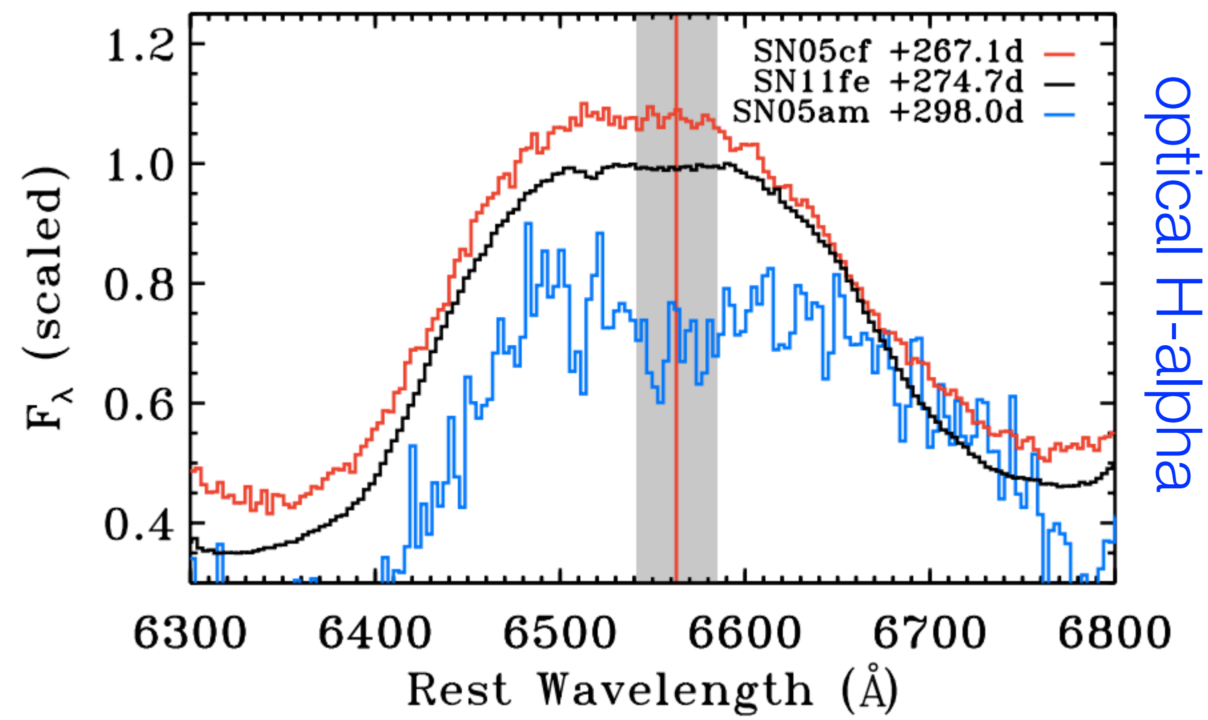
- The searches of companion star remnant in SNR have turned up none, but ever more stringent limit for the companion (Mv > 8 — 9 mag).



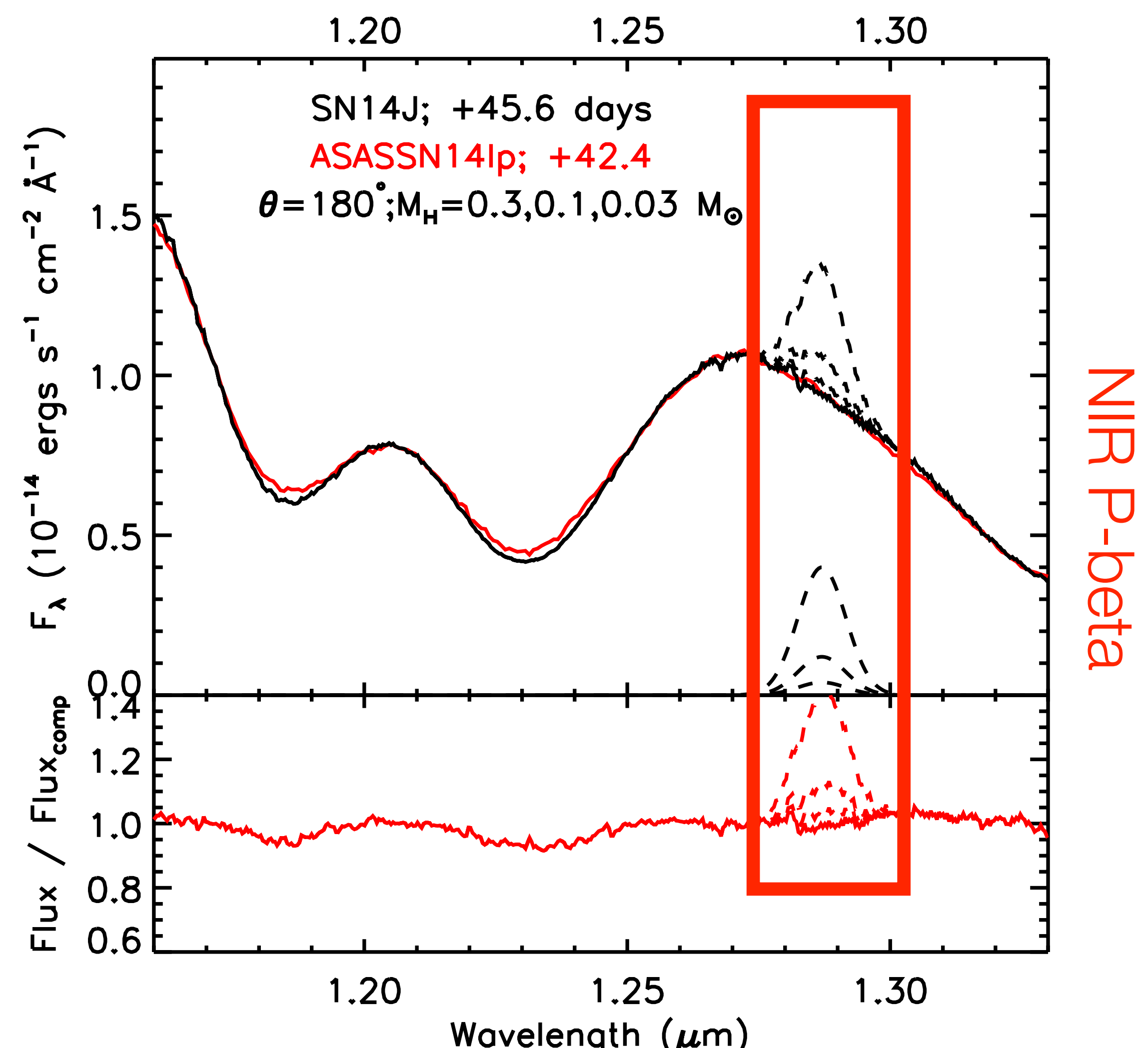
SNR 0509–67.5; Schaefer & Pagnotta (2012)

Companion star: stripped hydrogen

- Hydrogen stripped off non-degenerate companion should be embedded in SN ejecta at low velocity.
- High S/N late time spectra in both optical and NIR have turned up none so far.



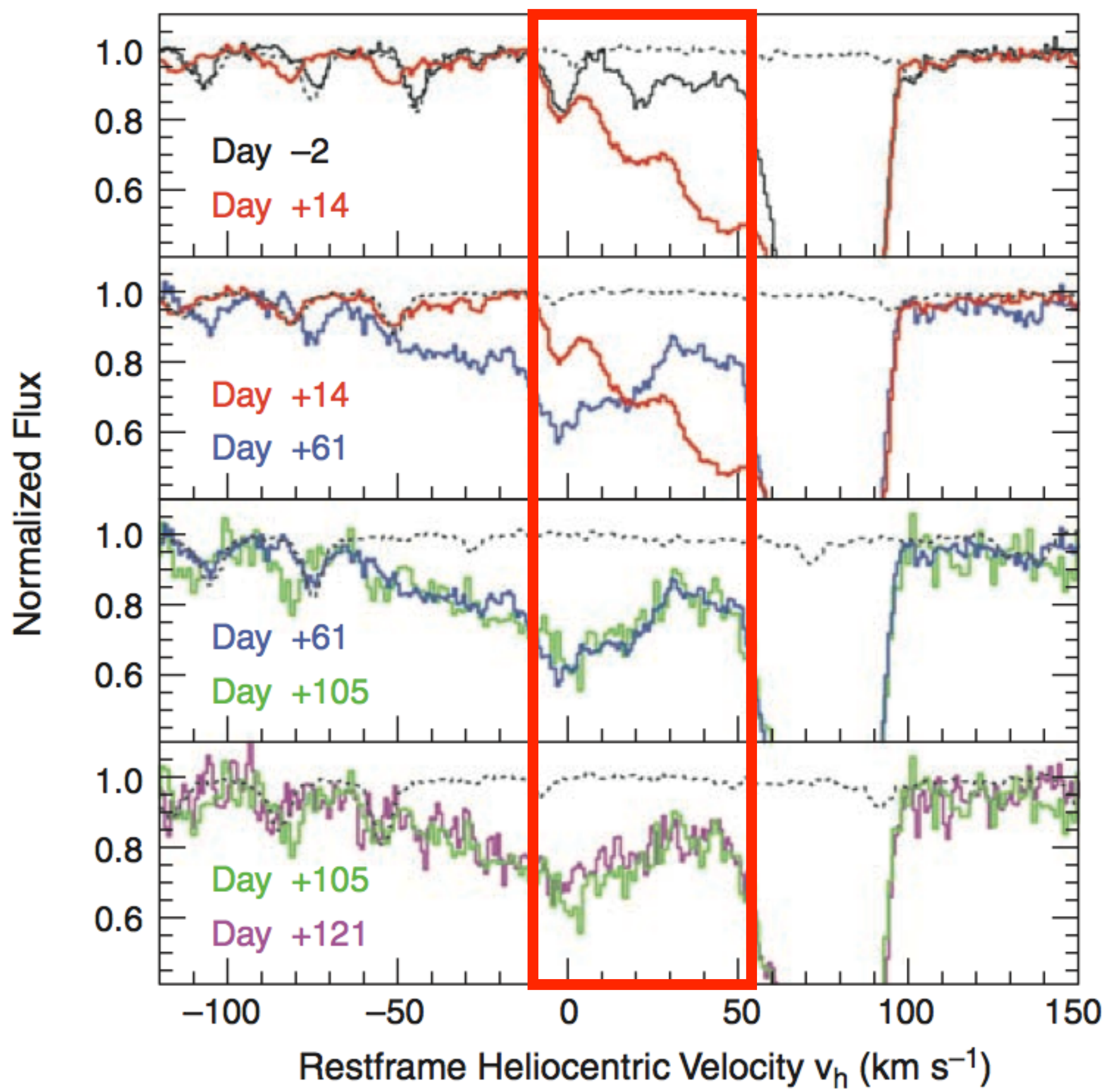
Shappee et al. (2013)



Sand, Hsiao et al. (2016)

Circumstellar material

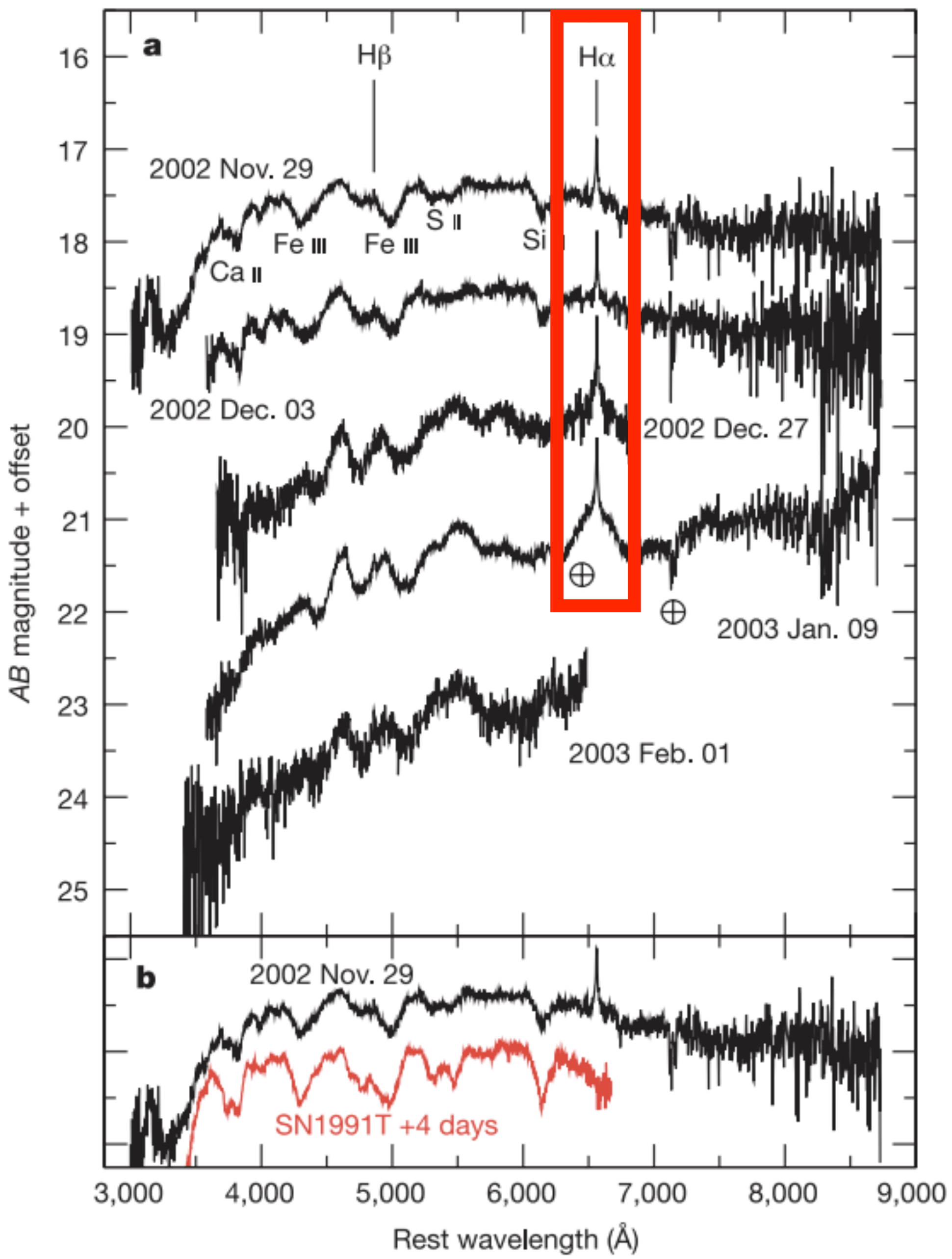
- CSM recombination after photoionization by explosion produces time-varying Na I D.
- There are rare, but definitive examples of time-varying Na I D.



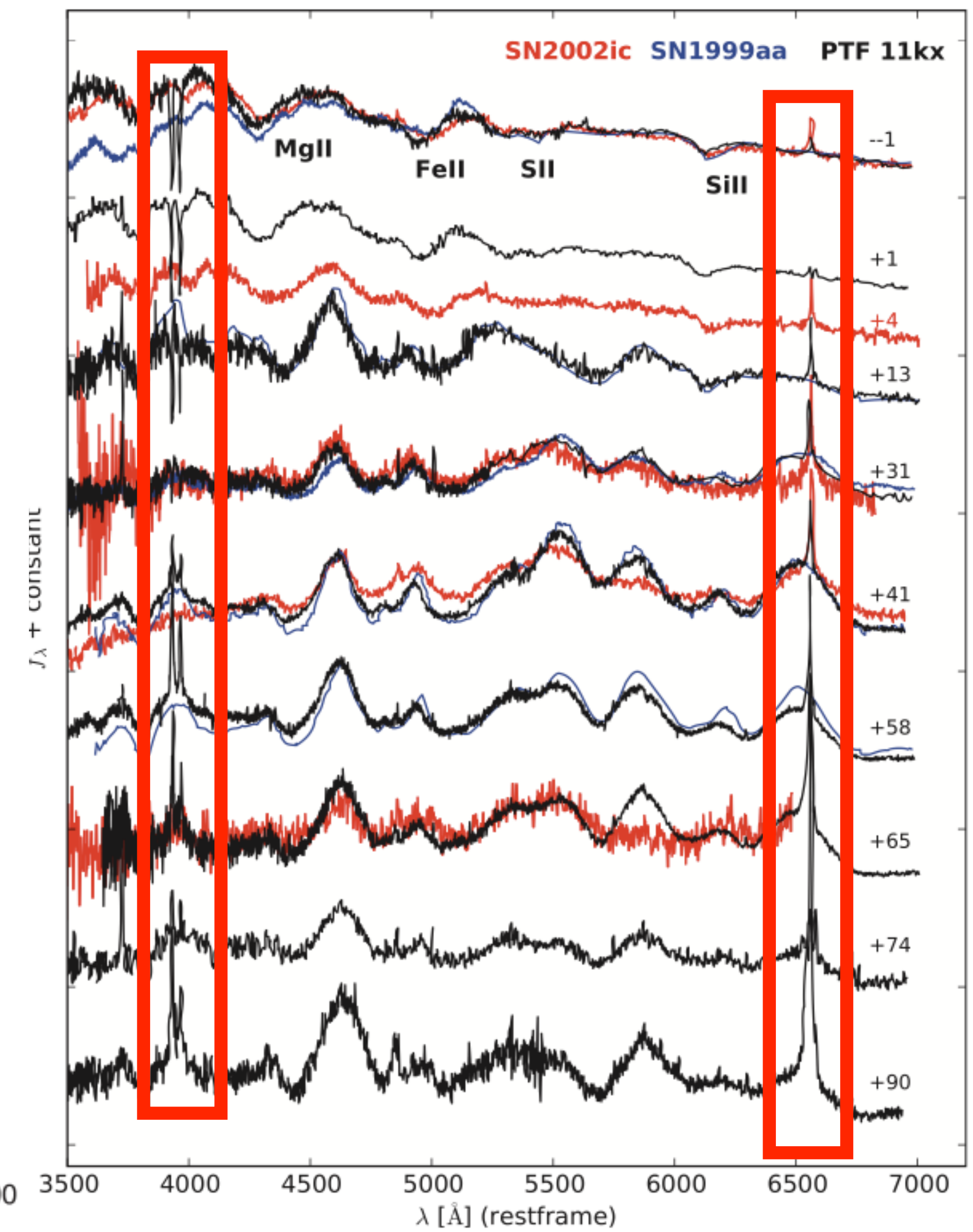
SN2006X; Patat et al. (2007)

Circumstellar material

- There are rare, but definitive examples of Ia-CSM interaction.



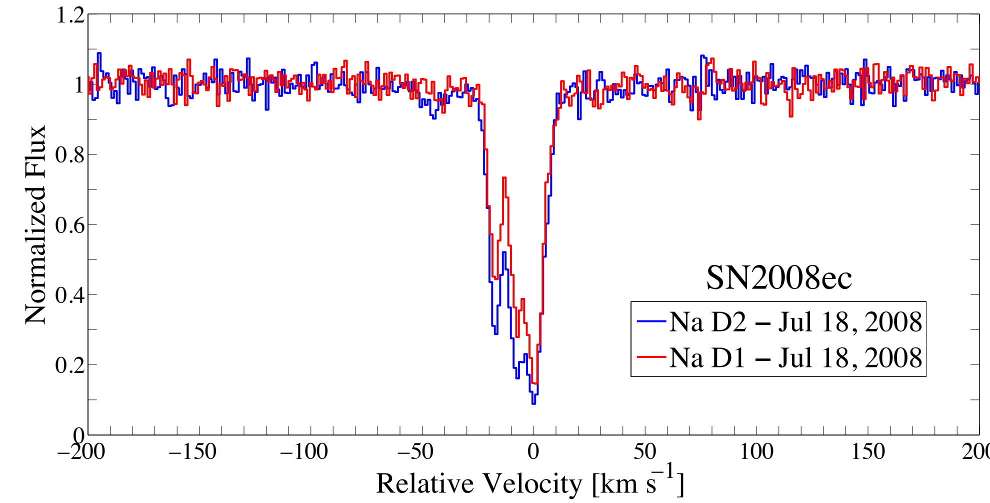
SN2002ic; Hamuy et al. (2003)



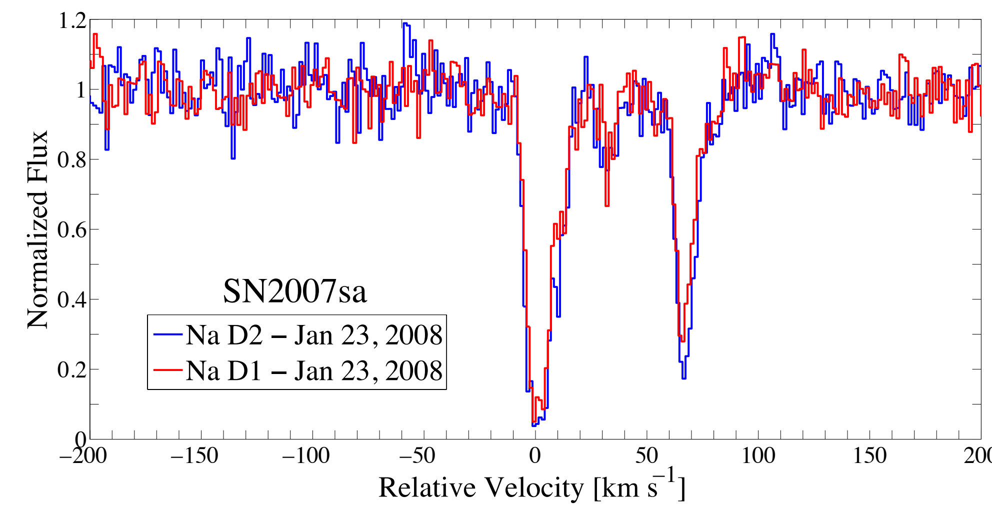
PTF11kx; Dilday et al. (2012)

Circumstellar material

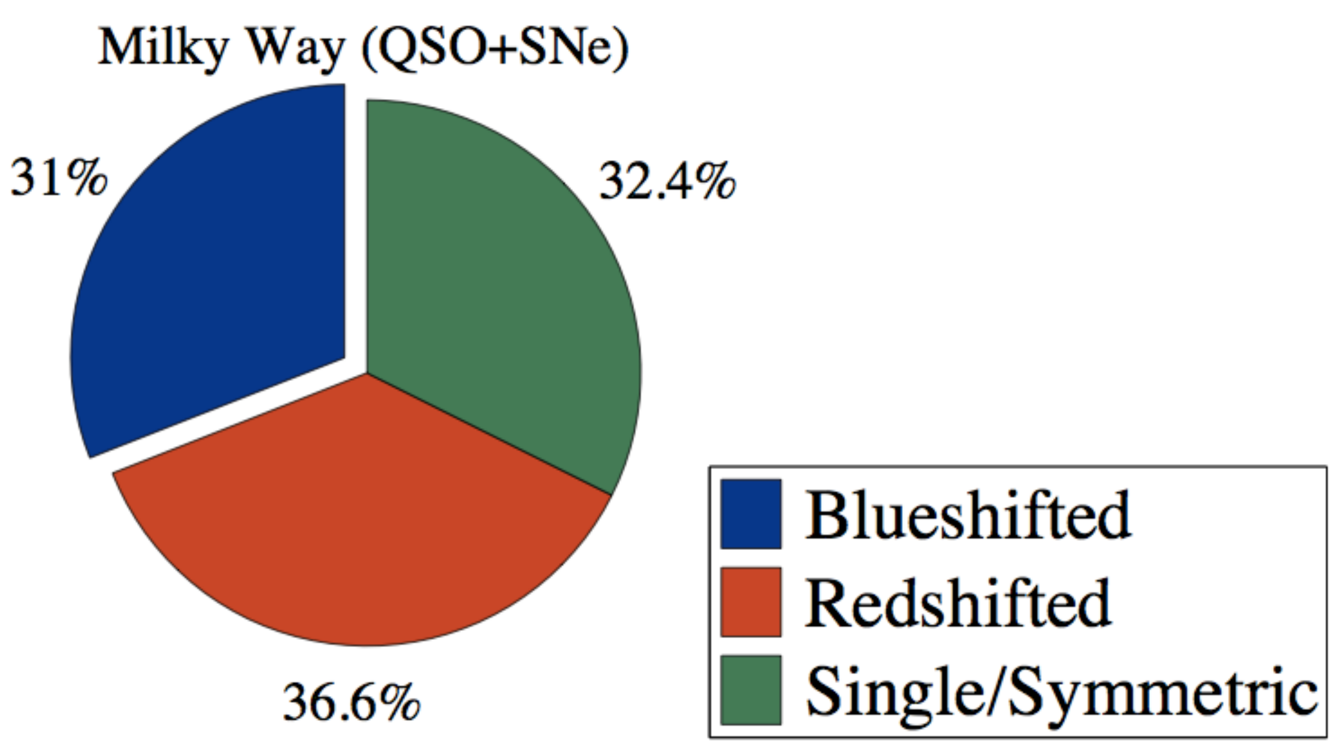
- Ia show strong preference for blueshifted Na I D structures, indicating gas outflows and CSM.

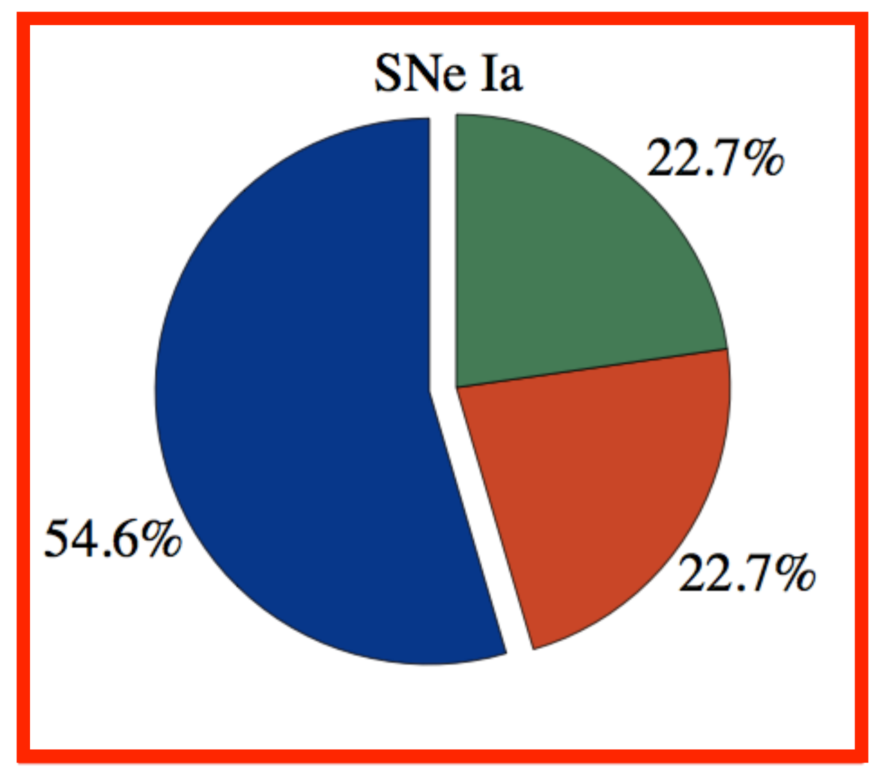


blueshifted



redshifted

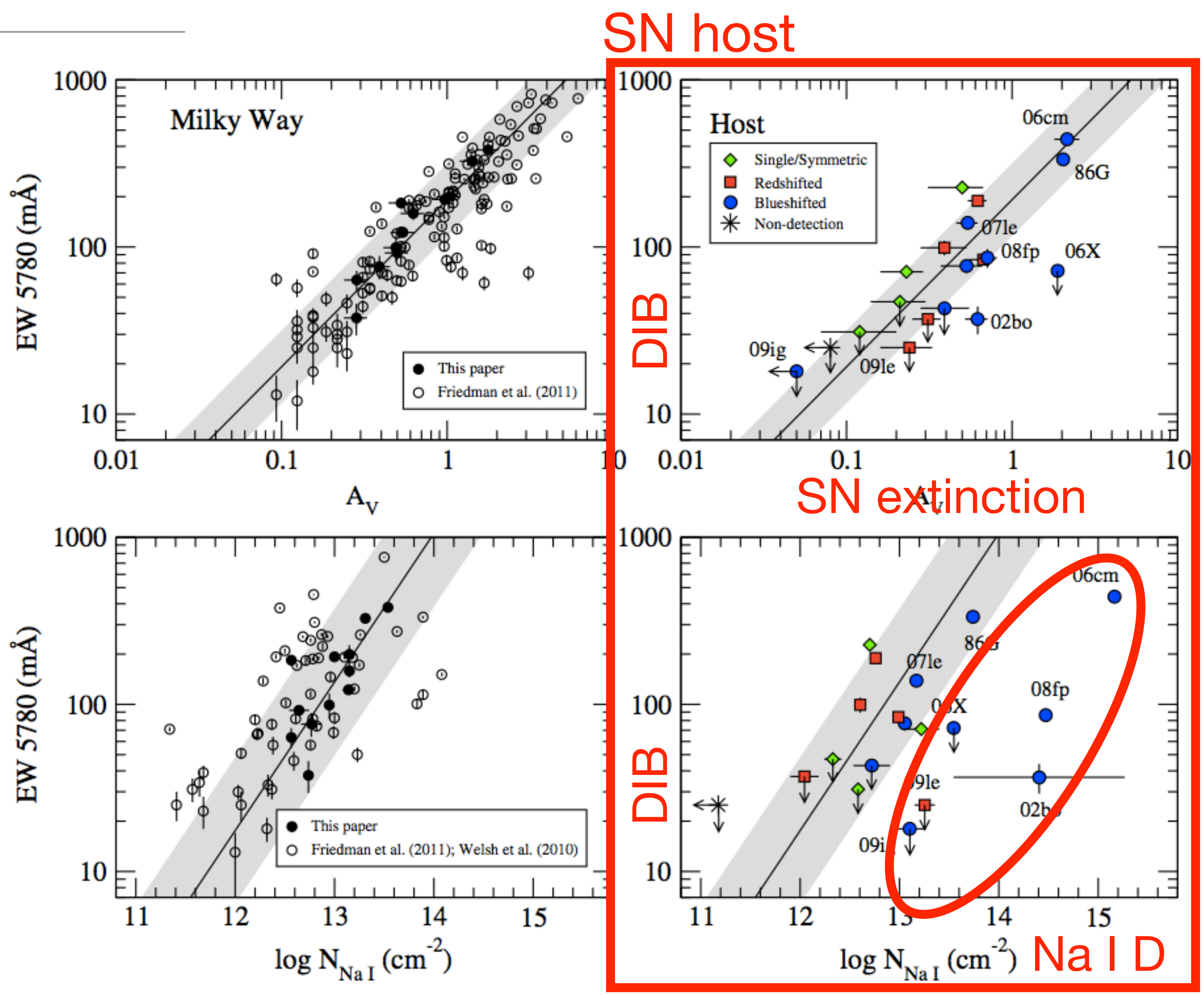




Sternberg et al. (2011)

Circumstellar material

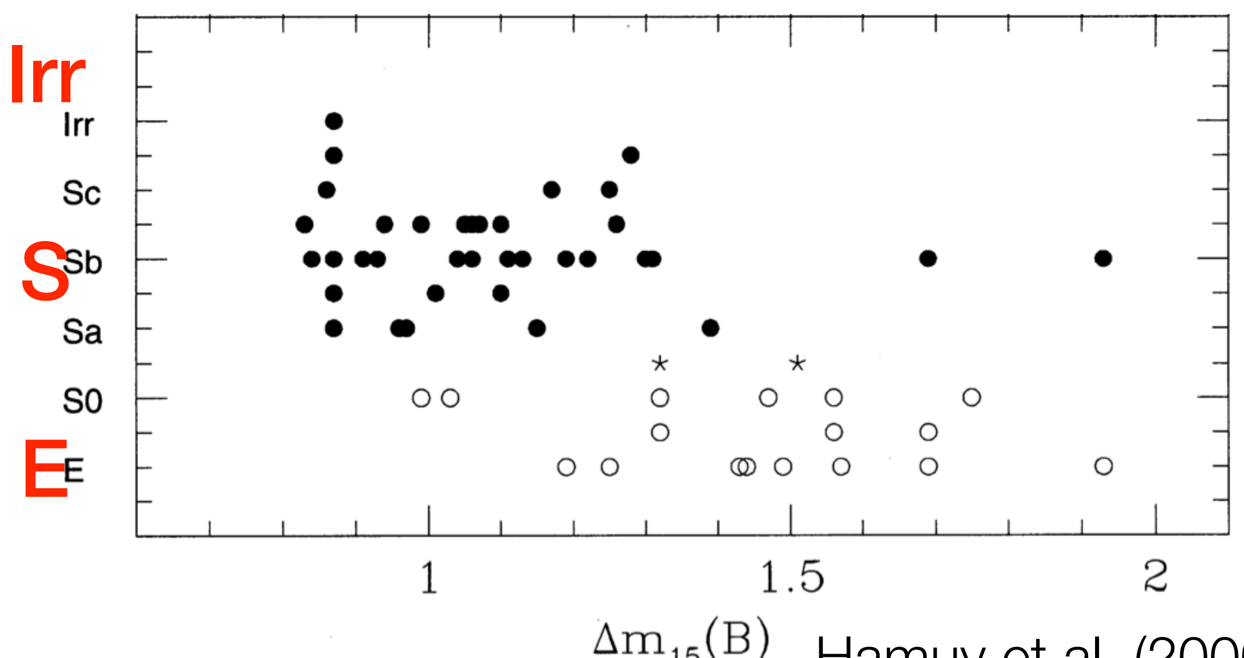
- However, strong correlation between strength of DIB 5780 and Ia extinction suggests that the main source of dust extinction come from ISM.
- Excess Na I D gas associated with “blueshifted” objects



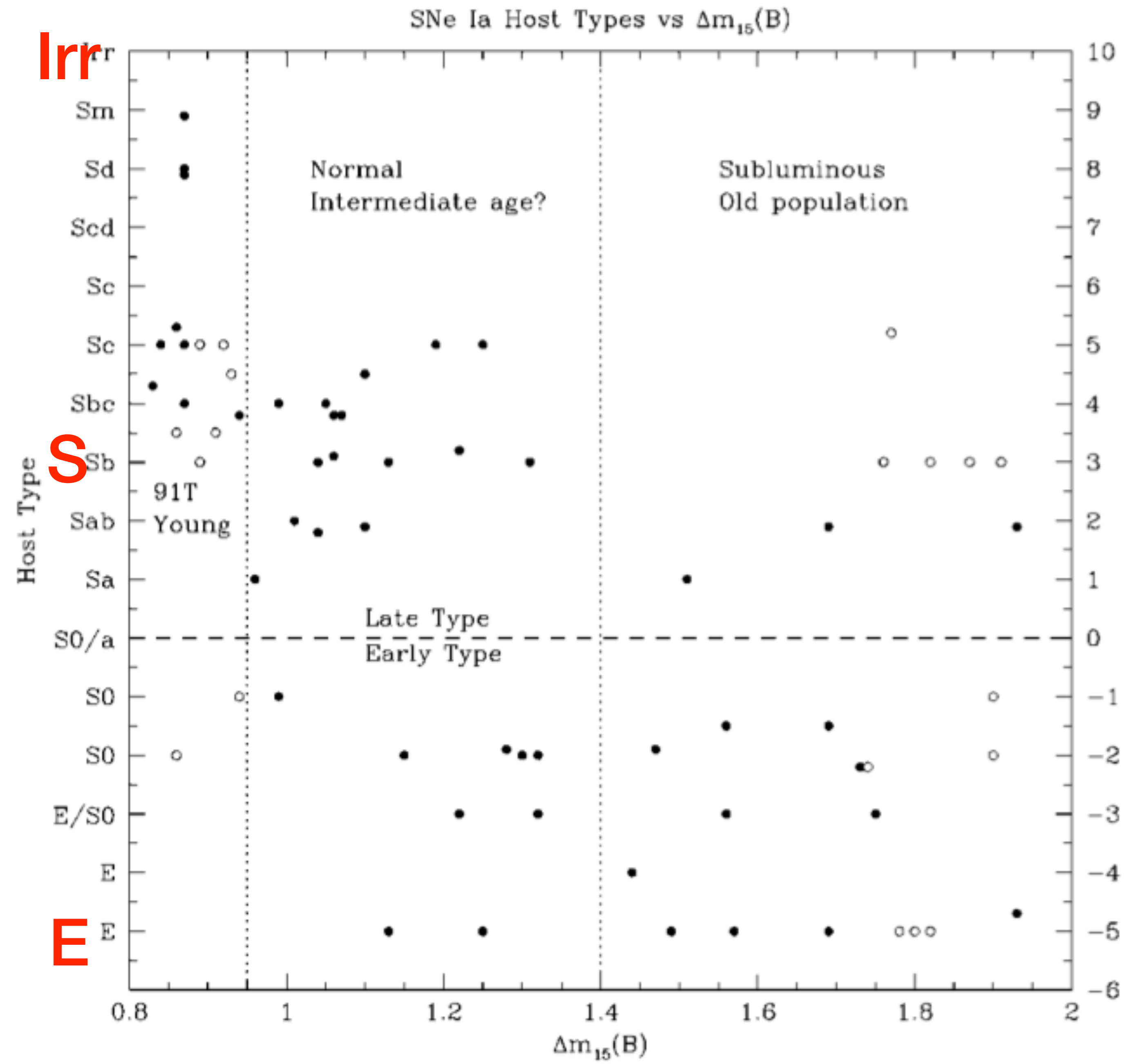
Phillips et al. (2013)

Host environment

- SN Ia luminosity depends on host environment.
- Does not post a problem for cosmology if the width-luminosity relation does not evolve with redshift.



Hamuy et al. (2000)

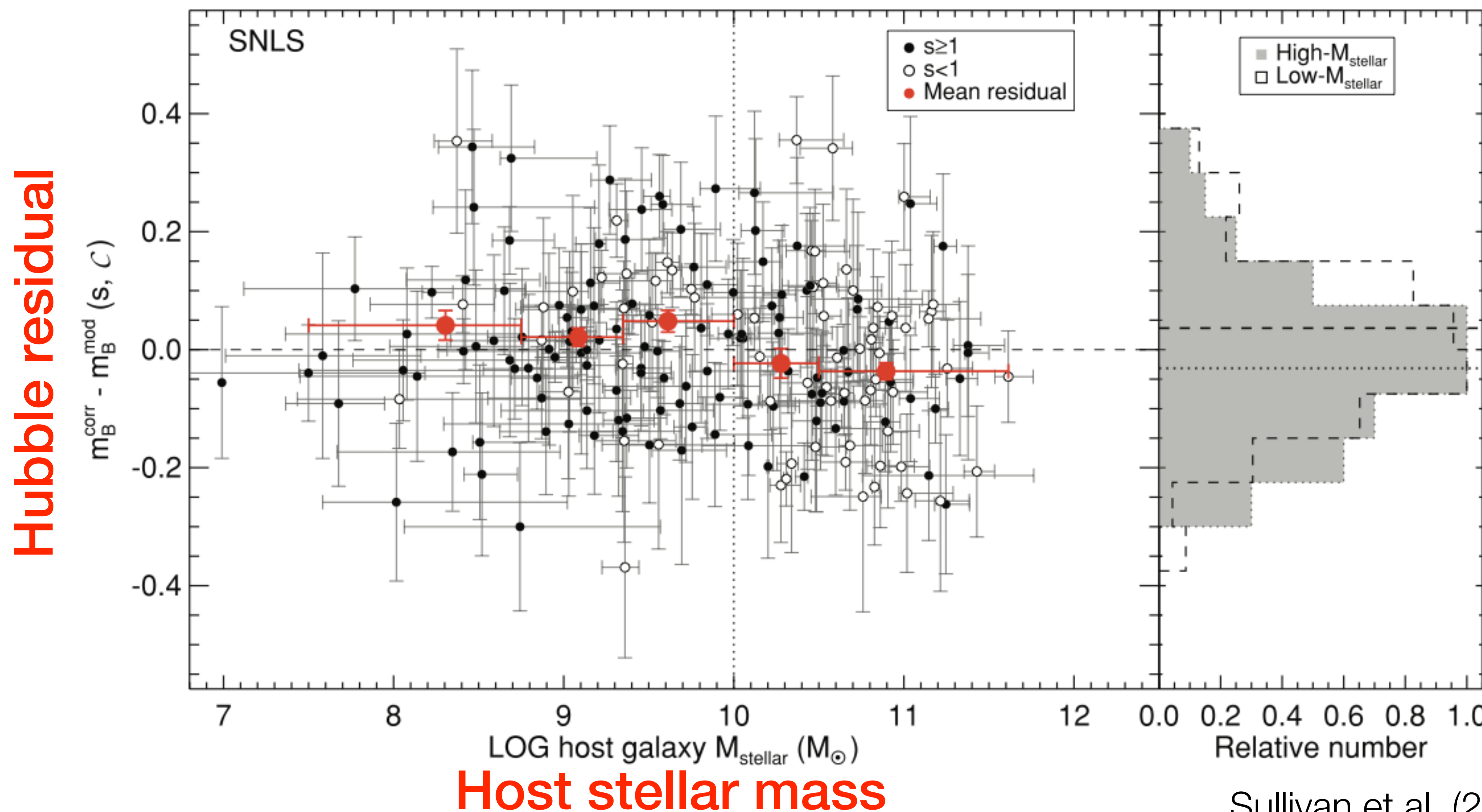


LC decline rate

Howell et al. (2001)

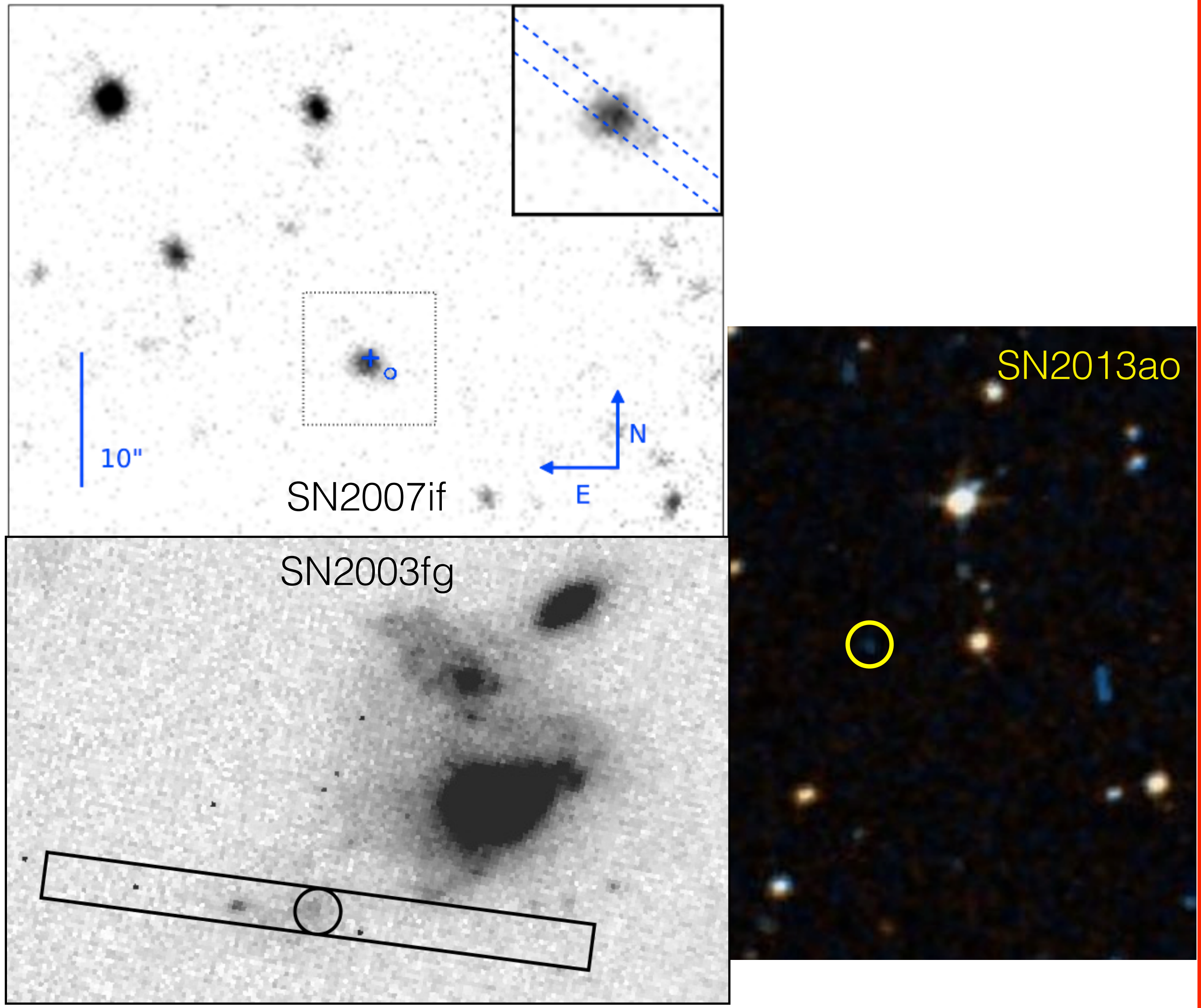
Host environment

- After light-curve width and color corrections, normal Ia are 0.08 mag brighter in massive host galaxies.

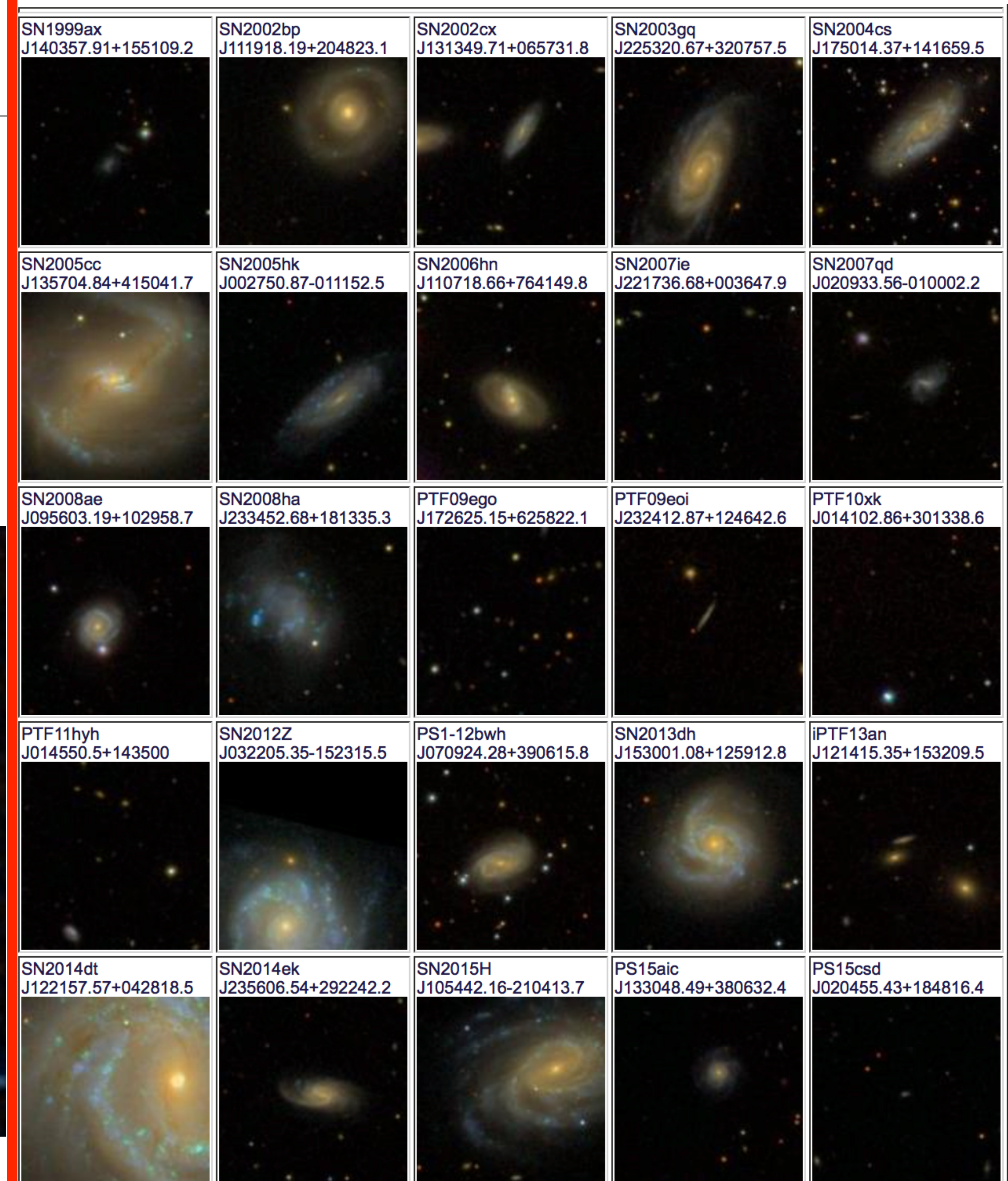


Sullivan et al. (2010)

Host environment



super-Chandrasekhar

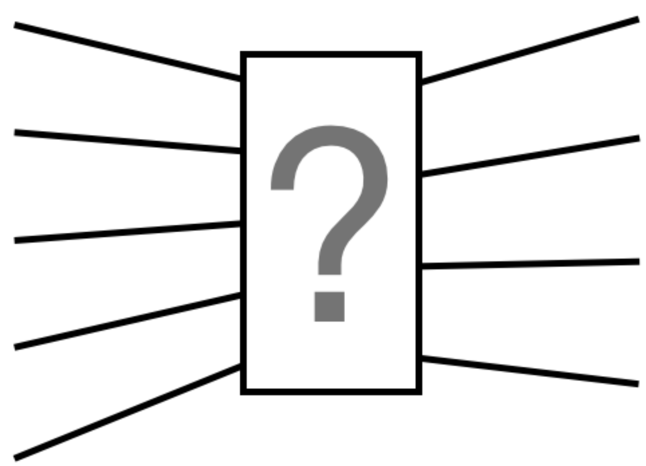


Iax

Summary

- Normal Ia have observational properties well described by Chandrasekhar-mass models, but it's 1D and evidence for non-degenerate companion of normal Ia is rare.
- Iax have 1 confirmed non-degenerate companion, and are most likely pure deflagration.
- Super-Chandrasekhar may achieve observed Ni^{56} produced through core degenerate route. (Peter Hoeflich's talk)

- Chandrasekhar mass, Mch
- He detonation, sub-Mch
- dynamical mergers
- core degenerate
- direct collision



- Normal Ia
- super-Chandrasekhar
- Ia-CSM
- Iax

Summary

- Normal Ia have observational properties well described by Chandrasekhar-mass models, but it's 1D and evidence for non-degenerate companion of normal Ia is rare.
- Iax have 1 confirmed non-degenerate companion, and are most likely pure deflagration.
- Super-Chandrasekhar may achieve observed Ni^{56} produced through core degenerate route. (Peter Hoeflich's talk)

- "Clean" surrounding =? sub-Mch =? double degenerate
  e.g., Shen et al. (2013): H-rich material can be ejected prior to He WD and C/O WD merger.
- "Dirty" surrounding =? Mch =? single degenerate
  e.g., Dragulin et al. (2016): wind from accretion disk produces a low-density void several light years across.