Revealing Core Collapse

Supernova Progenitors

Without Seeing Them

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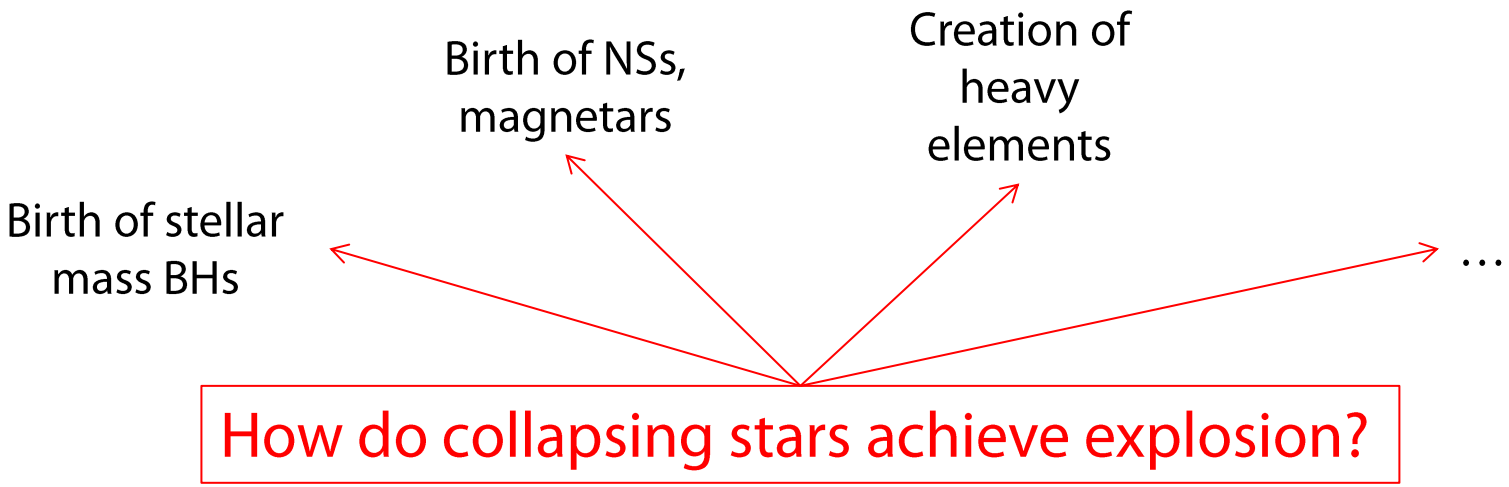
The Big Question: How Do Massive Stars Explode?



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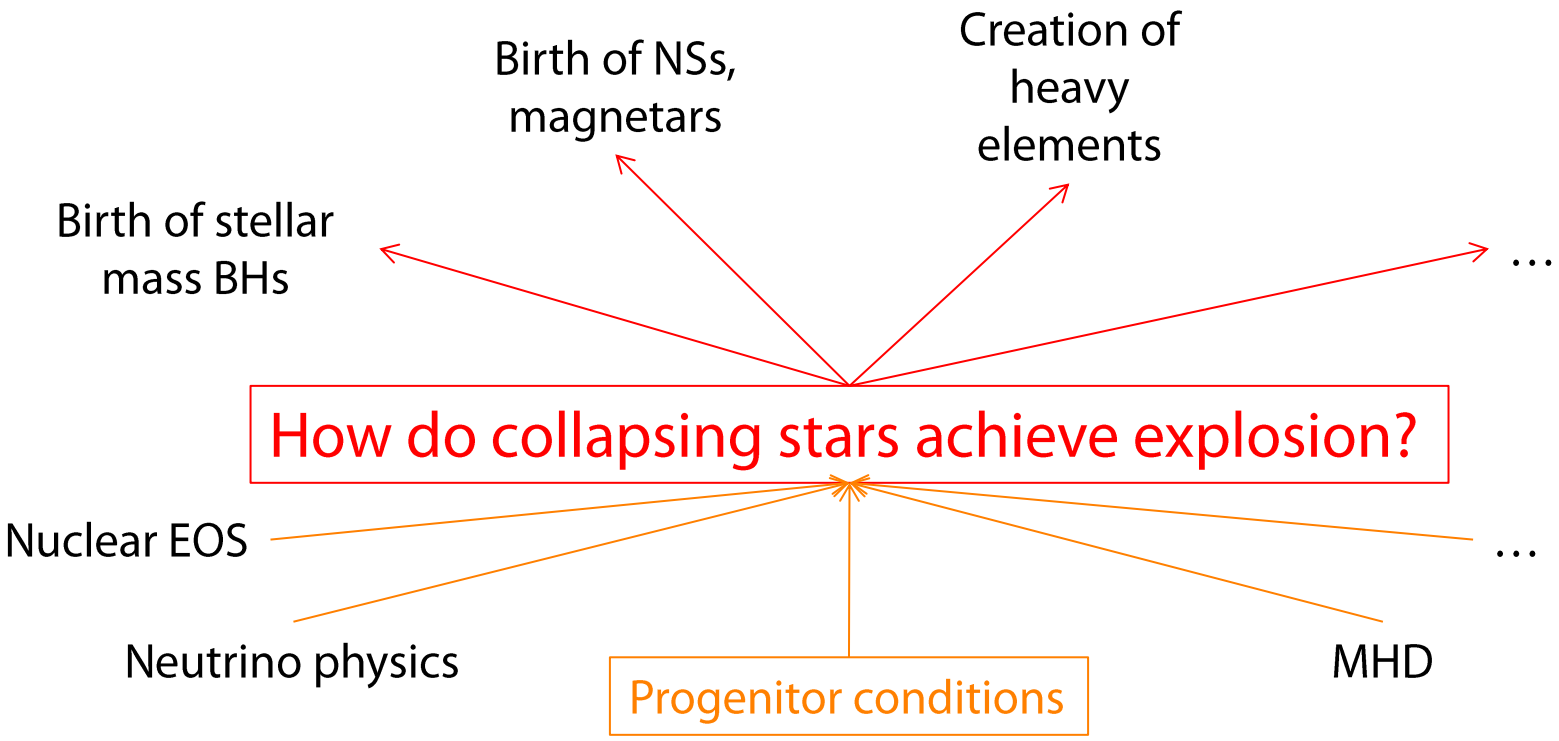
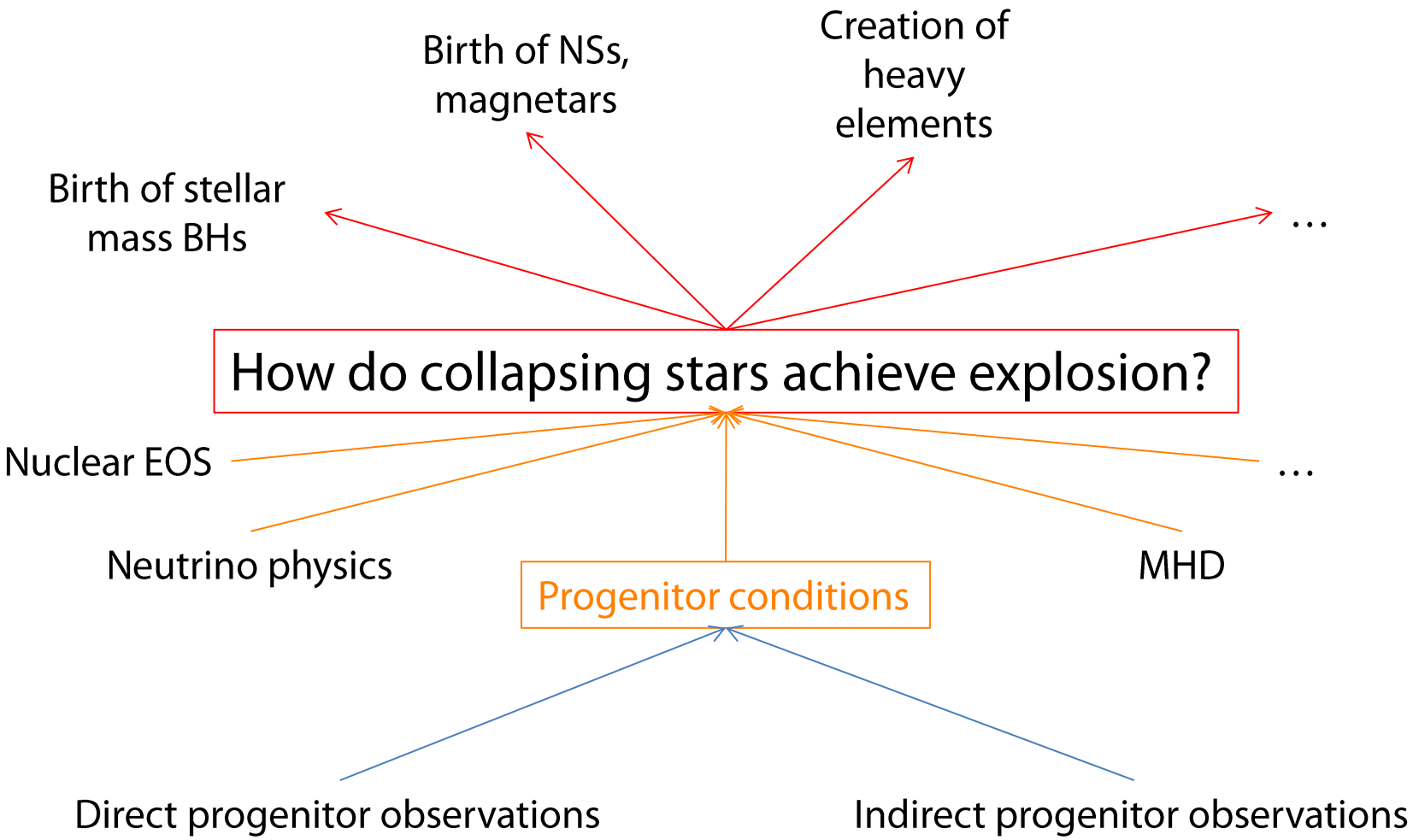


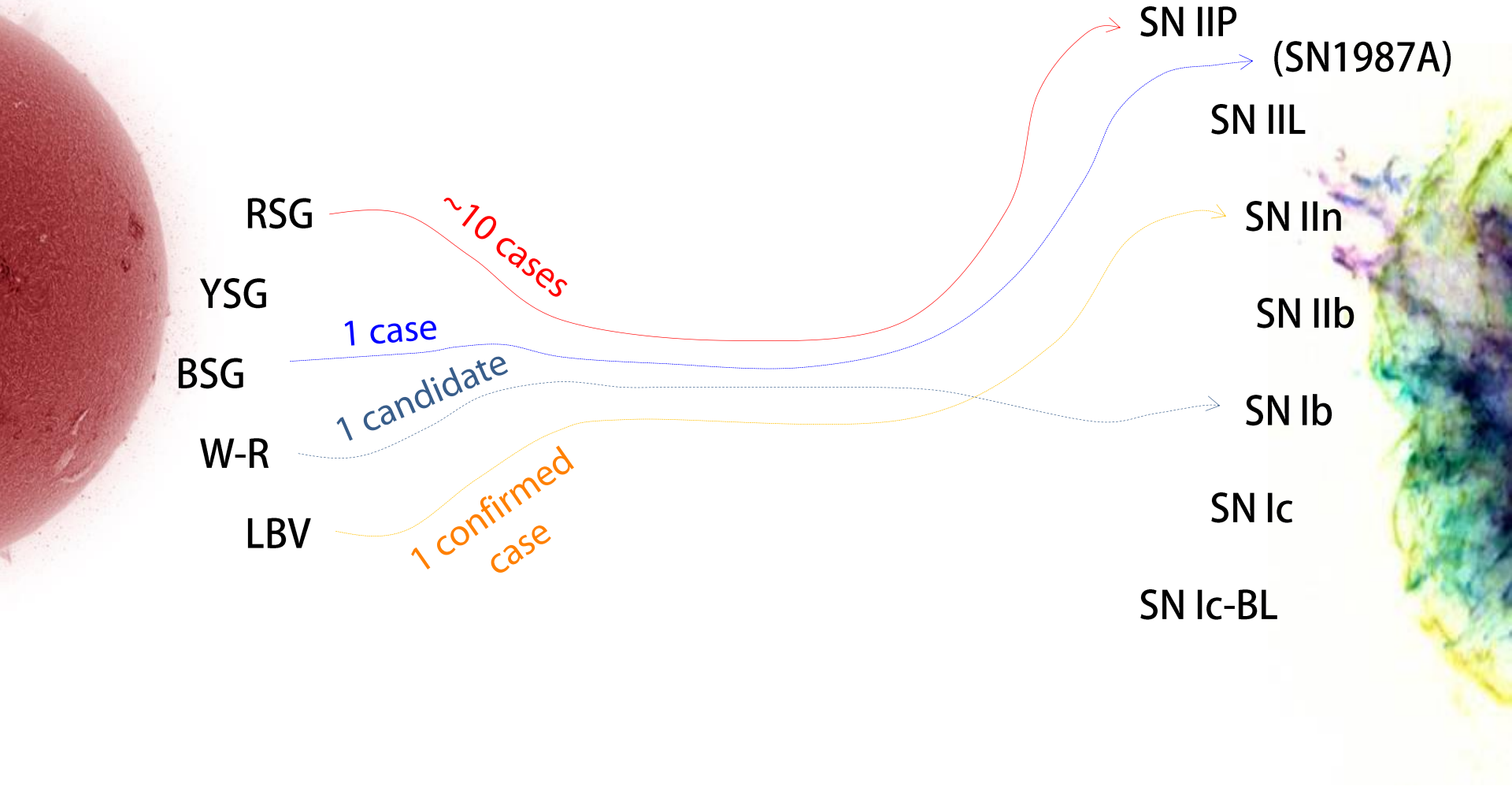
Constraining "initial conditions" for models

How do mass, metallicity, binarity and rotation of massive stars affect the type of explosion they produce?

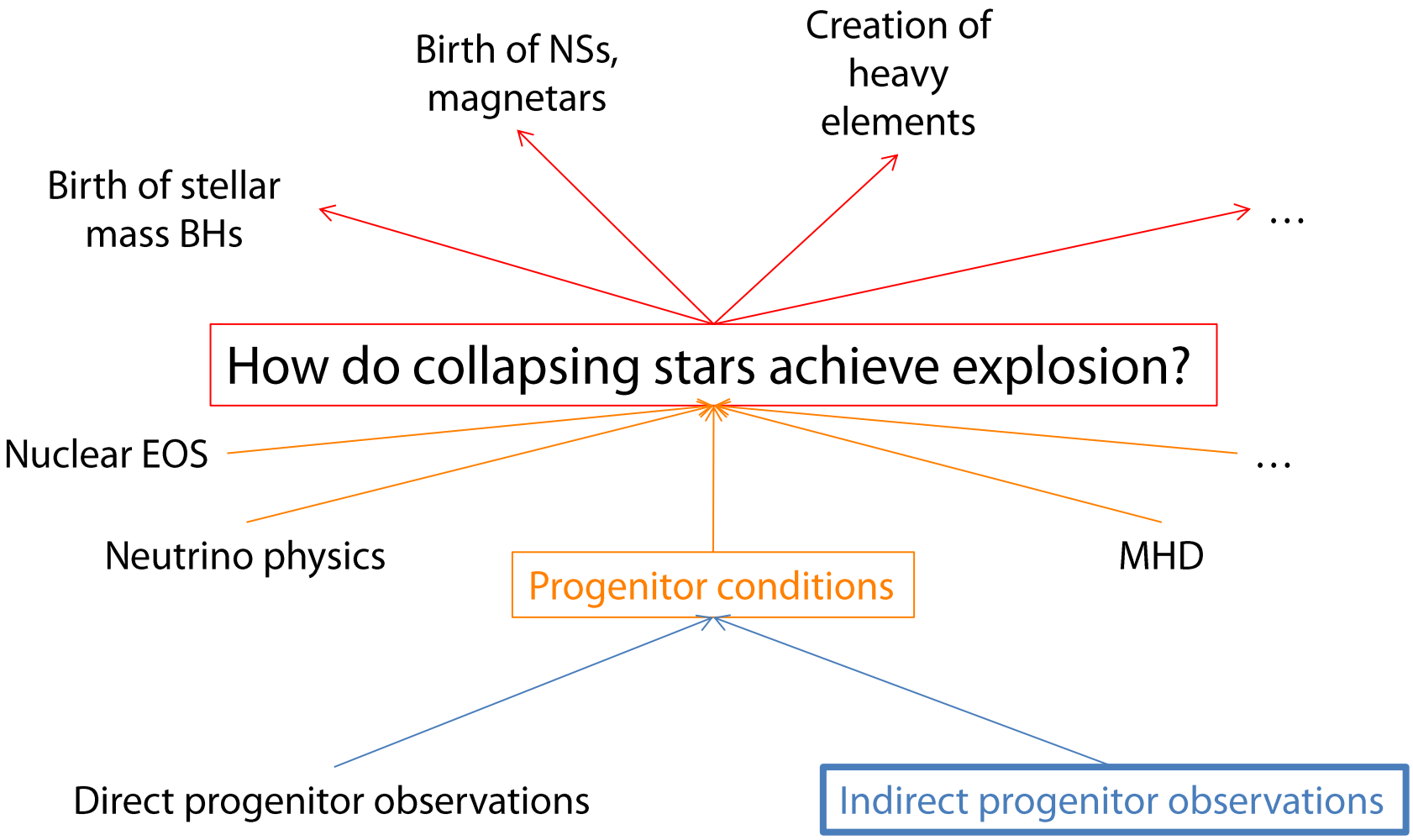
The Big Question: How to Massive Stars Explode?



Direct detections have gotten us so far



Can we constrain the progenitor without seeing it?



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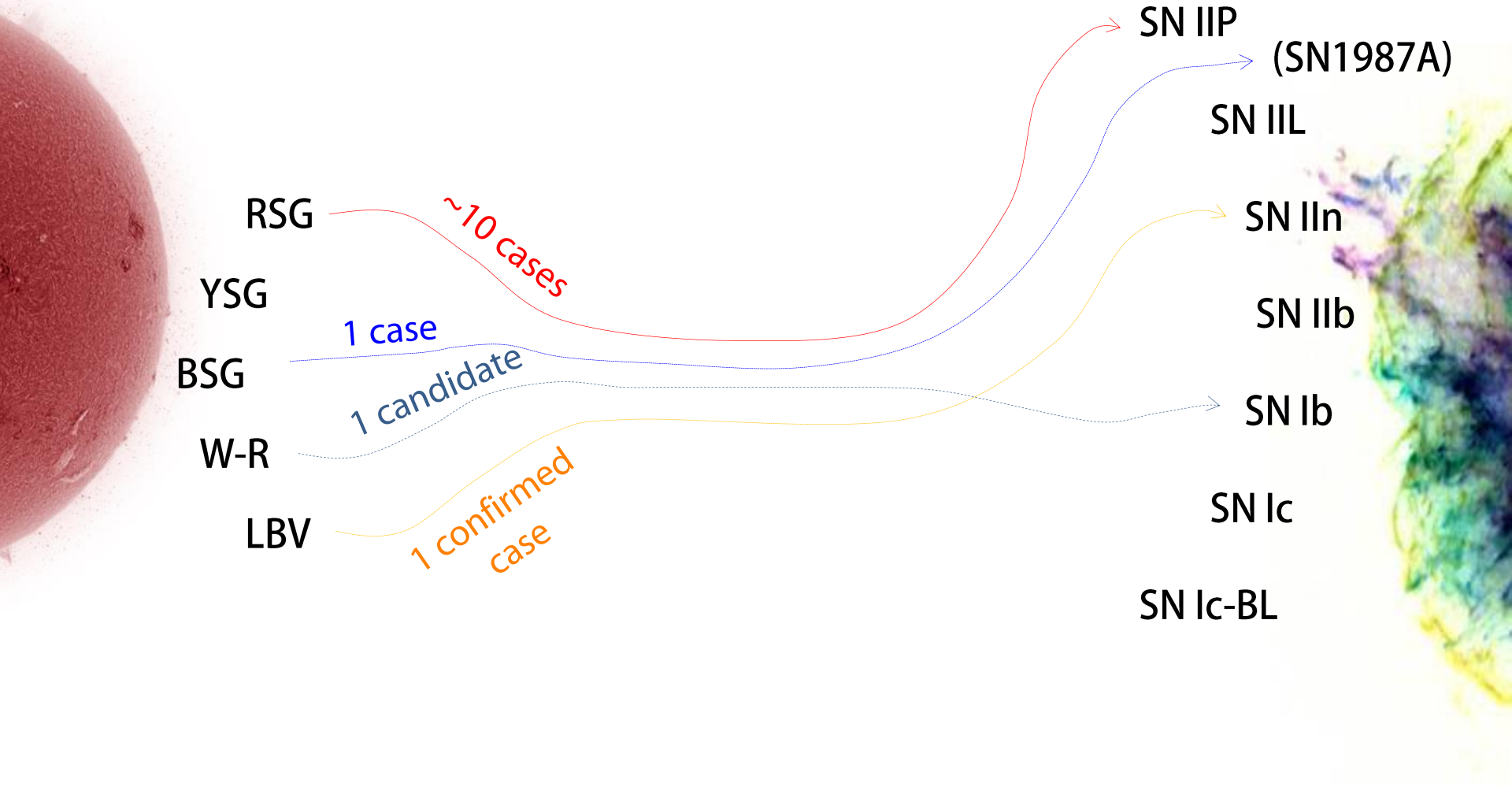
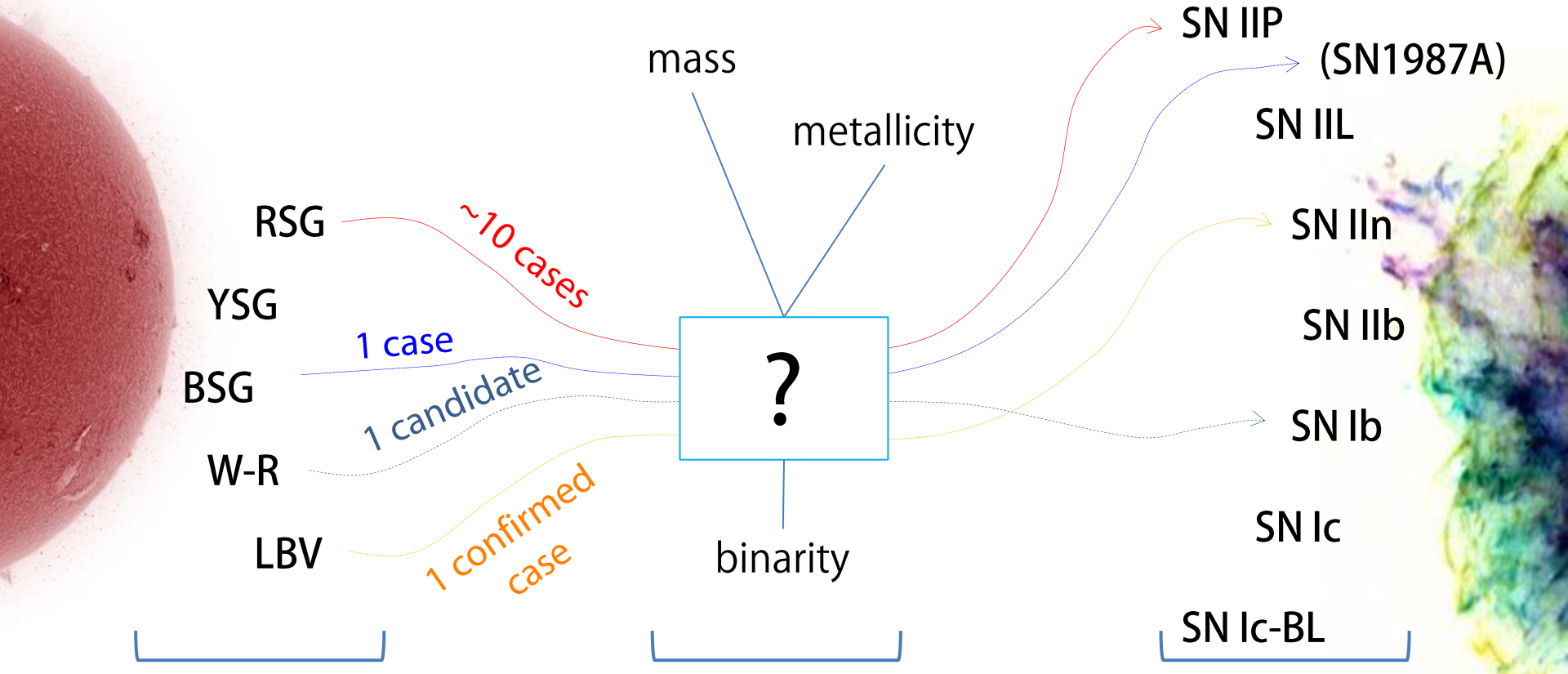


Indirect, more global approach can reveal more



The first hours
progenitor properties from "infant" supernovae

Where do they happen?
study the metallicity of the environment

What do they look like?
what are there "typical" characteristics for each class?

Part I: What do the SNe look like?

Part II: Where do the SNe happen?

Part III: The first hours of a SN

Are core collapse SN types well defined?

SN IIP	H in spectrum, Plateau in light curve
SN IIL	H in spectrum, Linear decline in light curve
SN IIn	H in spectrum, Narrow lines in spectrum
SN IIb	H at early times, He at late times
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SN Ic-BL (hypernovae)	No H nor He in spectrum, high velocities (sometimes come with a long GRB)

Are core collapse SN types well defined?

H-rich → **SN IIP** H in spectrum, Plateau in light curve

H-rich → **SN IIL** H in spectrum, Linear decline in light curve

SN IIn H in spectrum, Narrow lines in spectrum

SN IIb H at early times, He at late times

SN Ib No H in spectrum

Stripped → **SN Ic** No H nor He in spectrum

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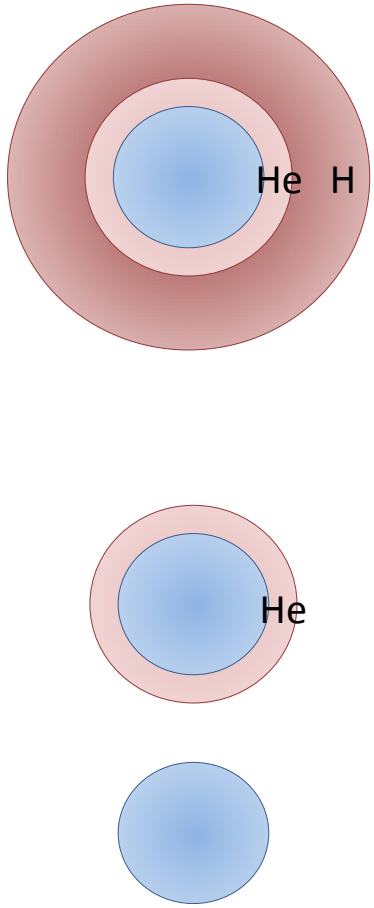
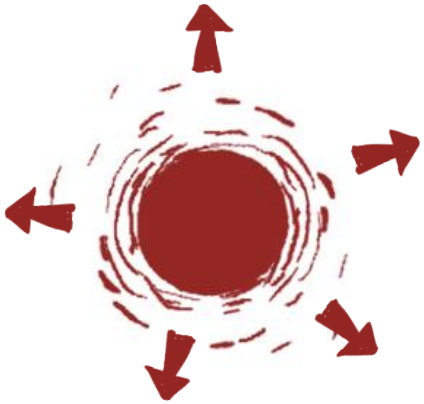
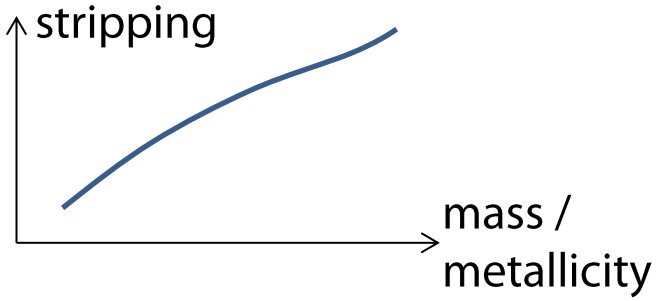


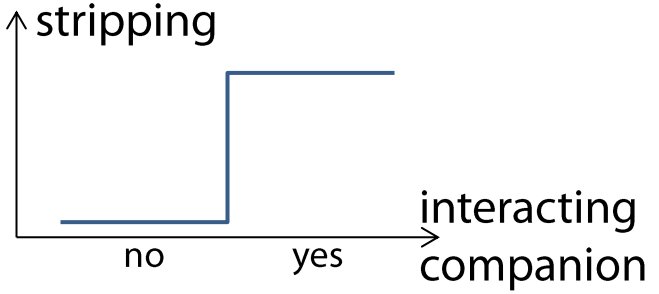
Three Ways for Stars to Lose Their H Envelope

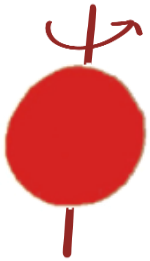


Winds



Interaction with a companion star





Rapid rotation

Are the different core collapse types a continuum?

H-rich

continuum?

Stripped

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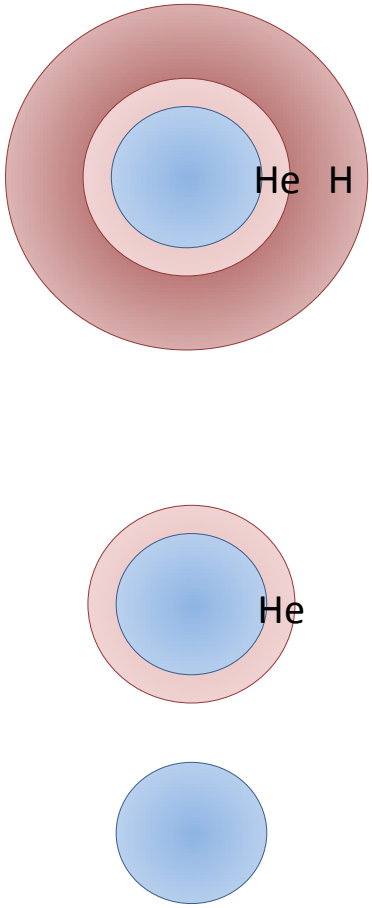
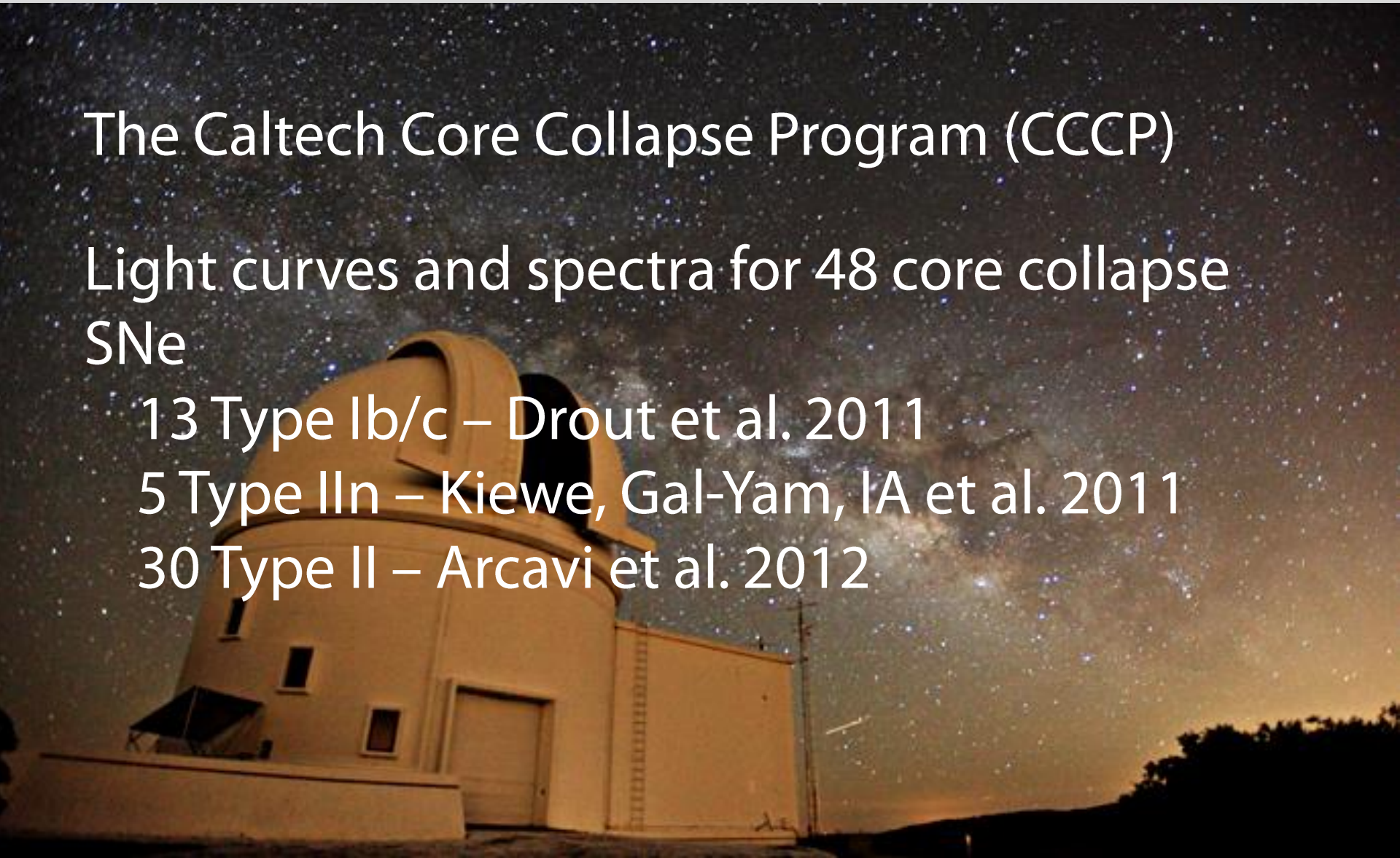


Observe "ordinary" core collapse supernovae

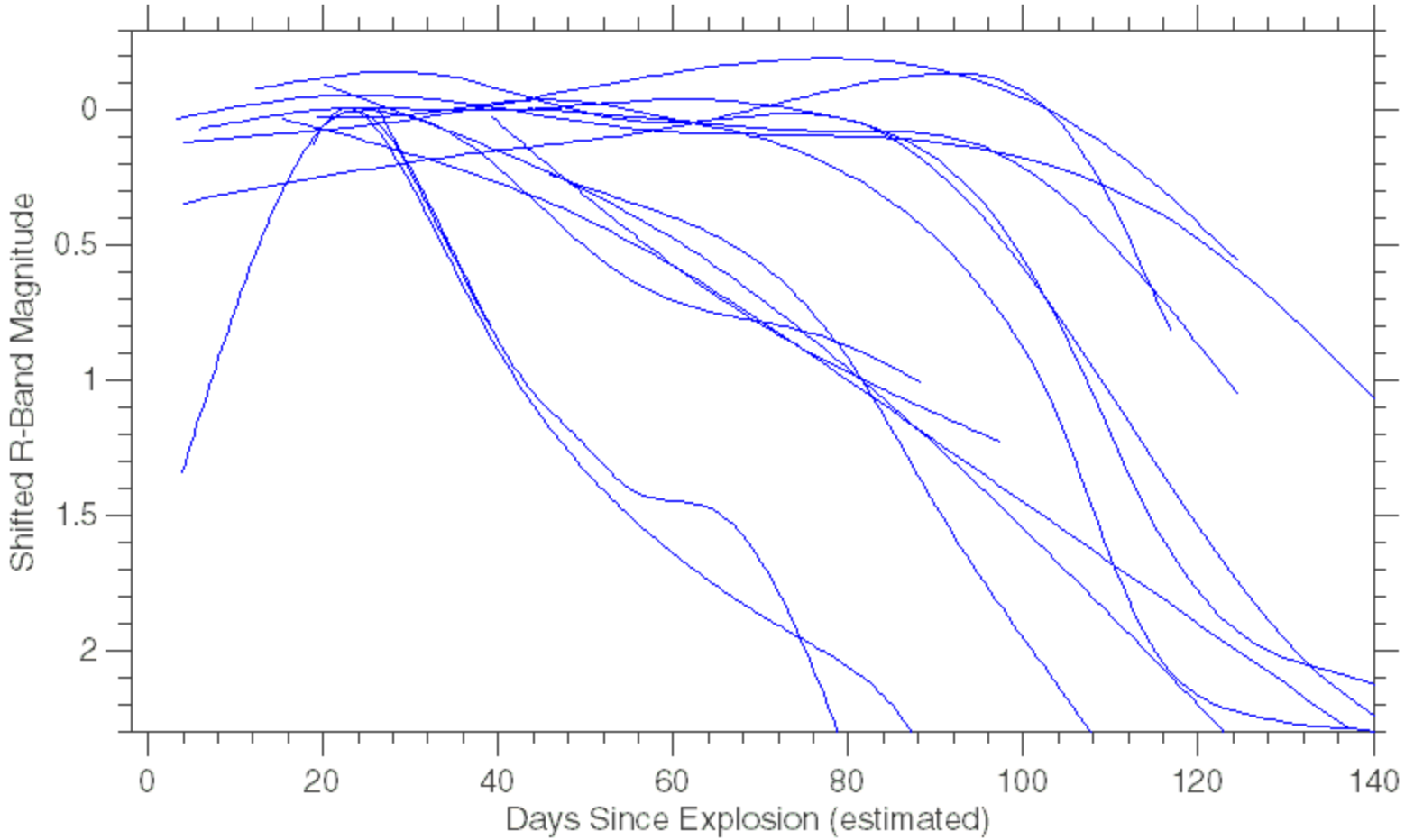


The Caltech Core Collapse Program (CCCP)

Light curves and spectra for 48 core collapse SNe

- 13 Type Ib/c – Drout et al. 2011
- 5 Type IIn – Kiewe, Gal-Yam, IA et al. 2011
- 30 Type II – Arcavi et al. 2012

The light curves (when no interaction) are not a continuum



Arcavi et al. 2012

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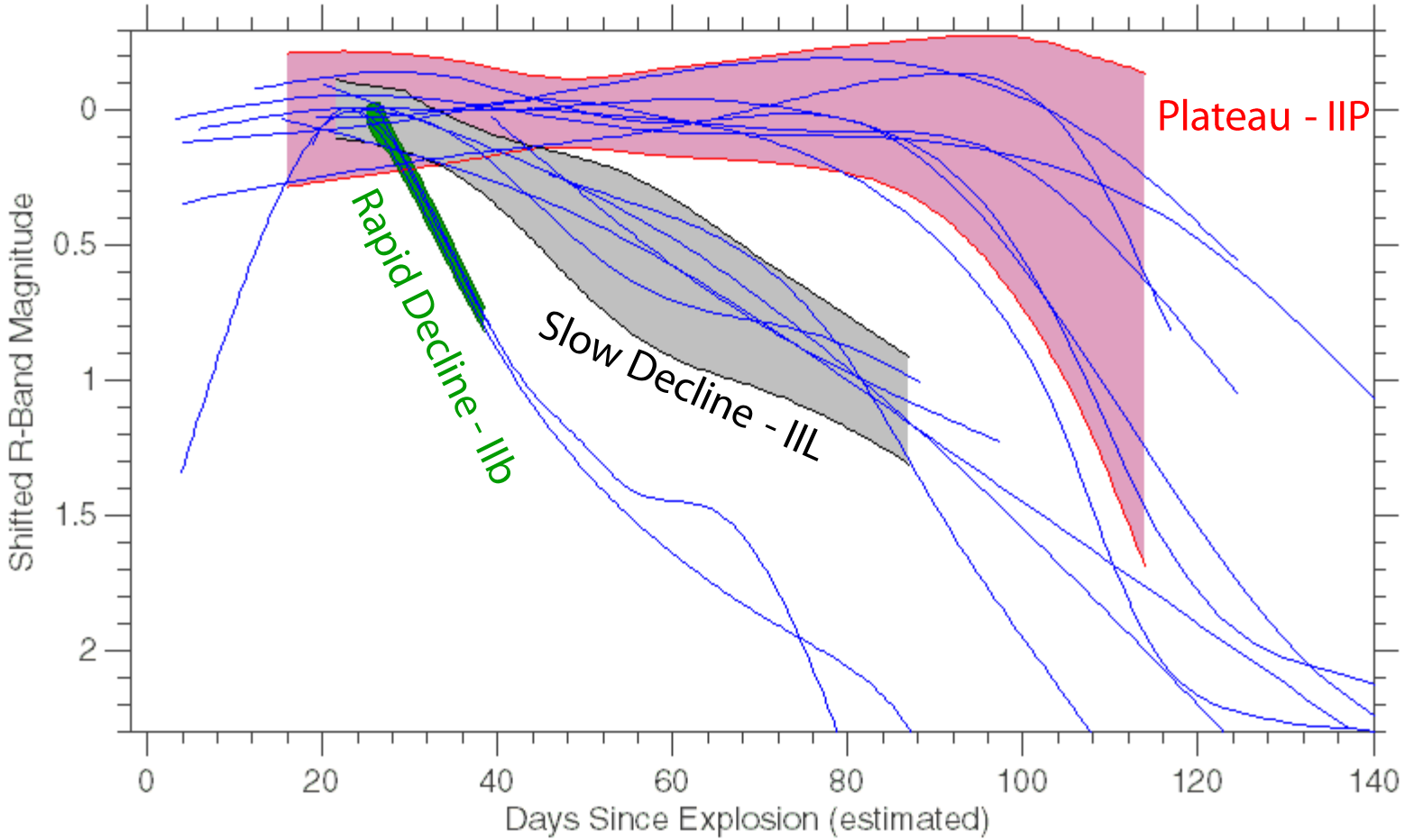

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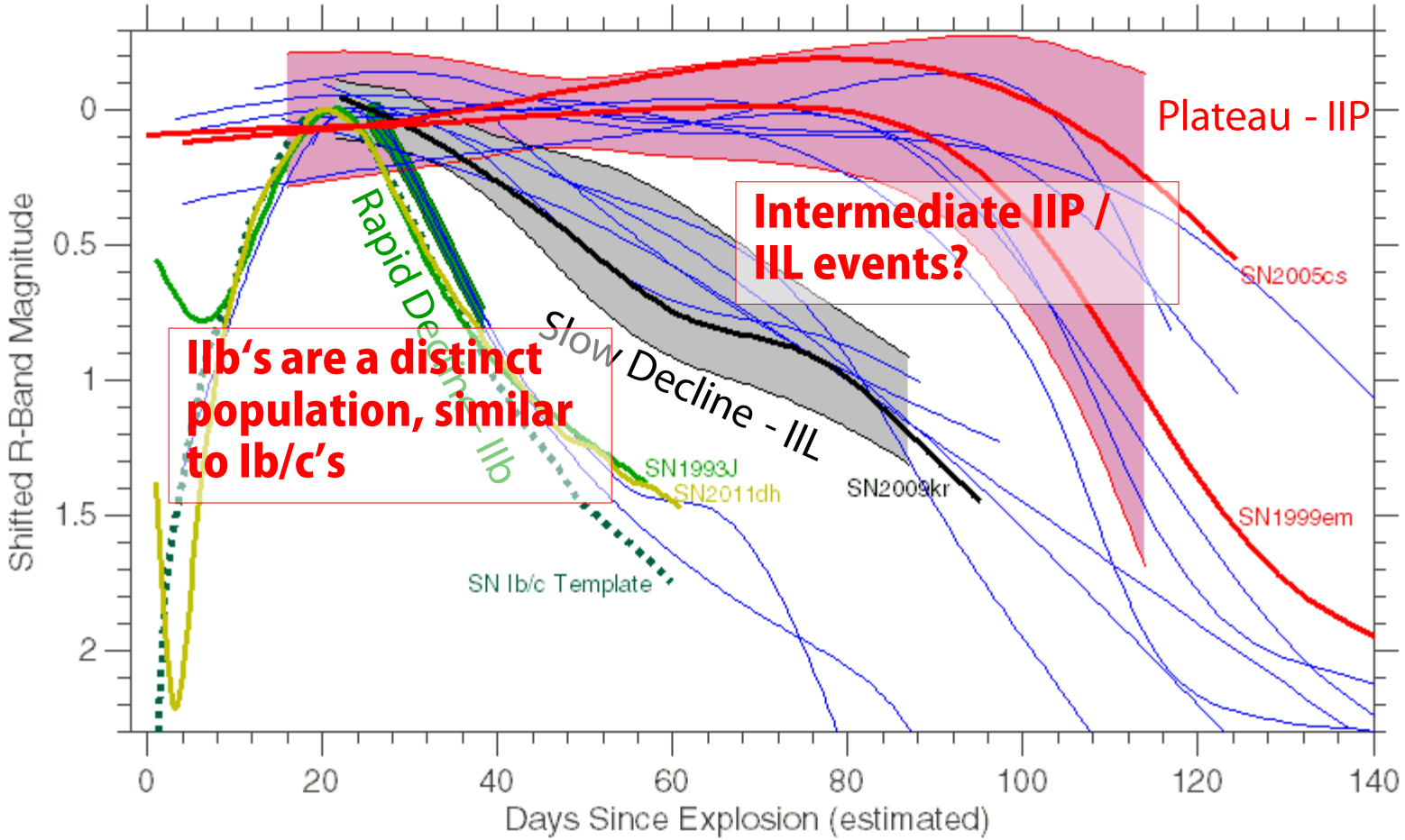

SN1993J – Richmond et al. 1994
SN1999em – Leonard et al. 2002
SN2004fx – Hamuy et al. 2006 (preliminary)
SN2005cs – Pastorello et al. 2009
SN2009kr – Fraser et al. 2010
SN2011dh – Arcavi et al. 2011

Arcavi et al. 2012

Discontinuity in SNe → Discontinuity in Progenitors?

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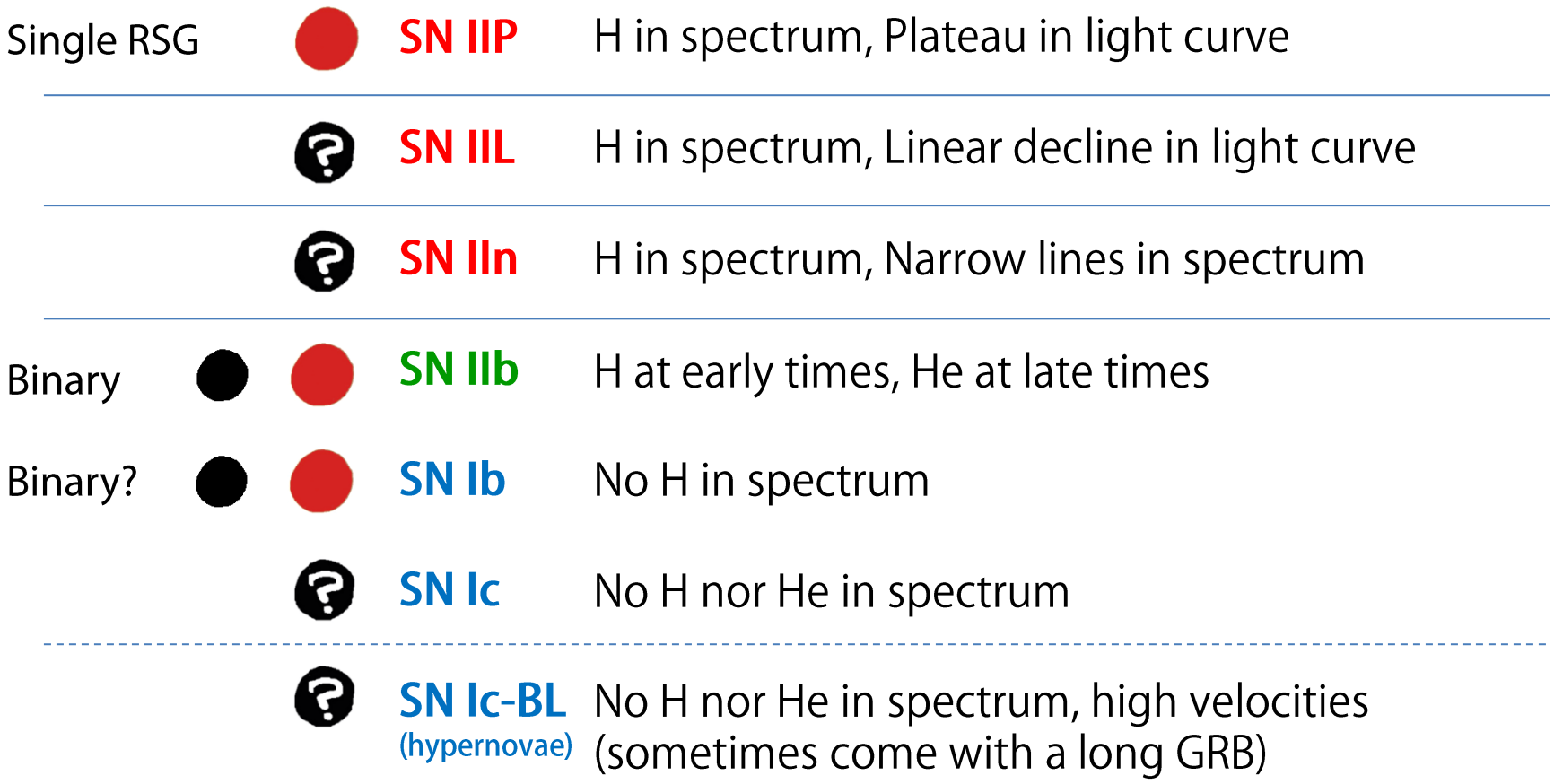

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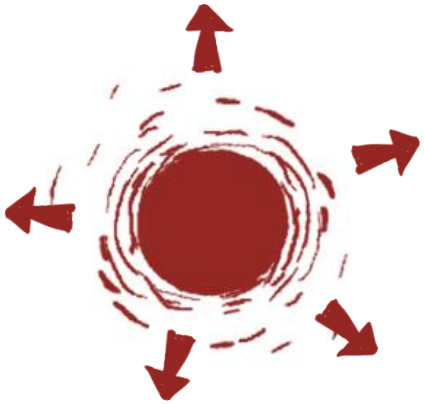
Three ways for stars to lose their H envelope



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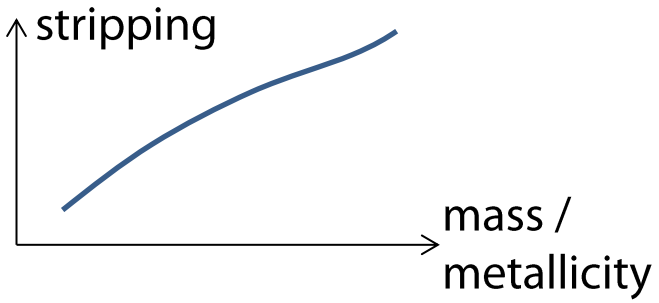

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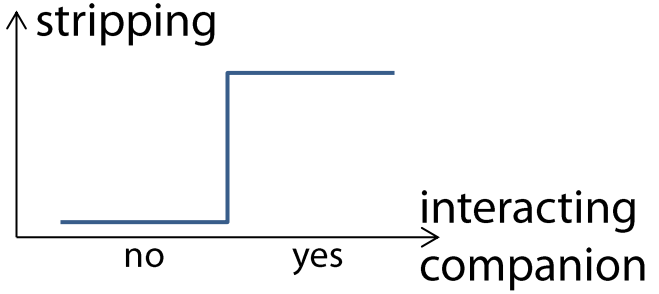
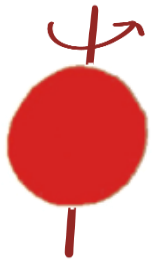
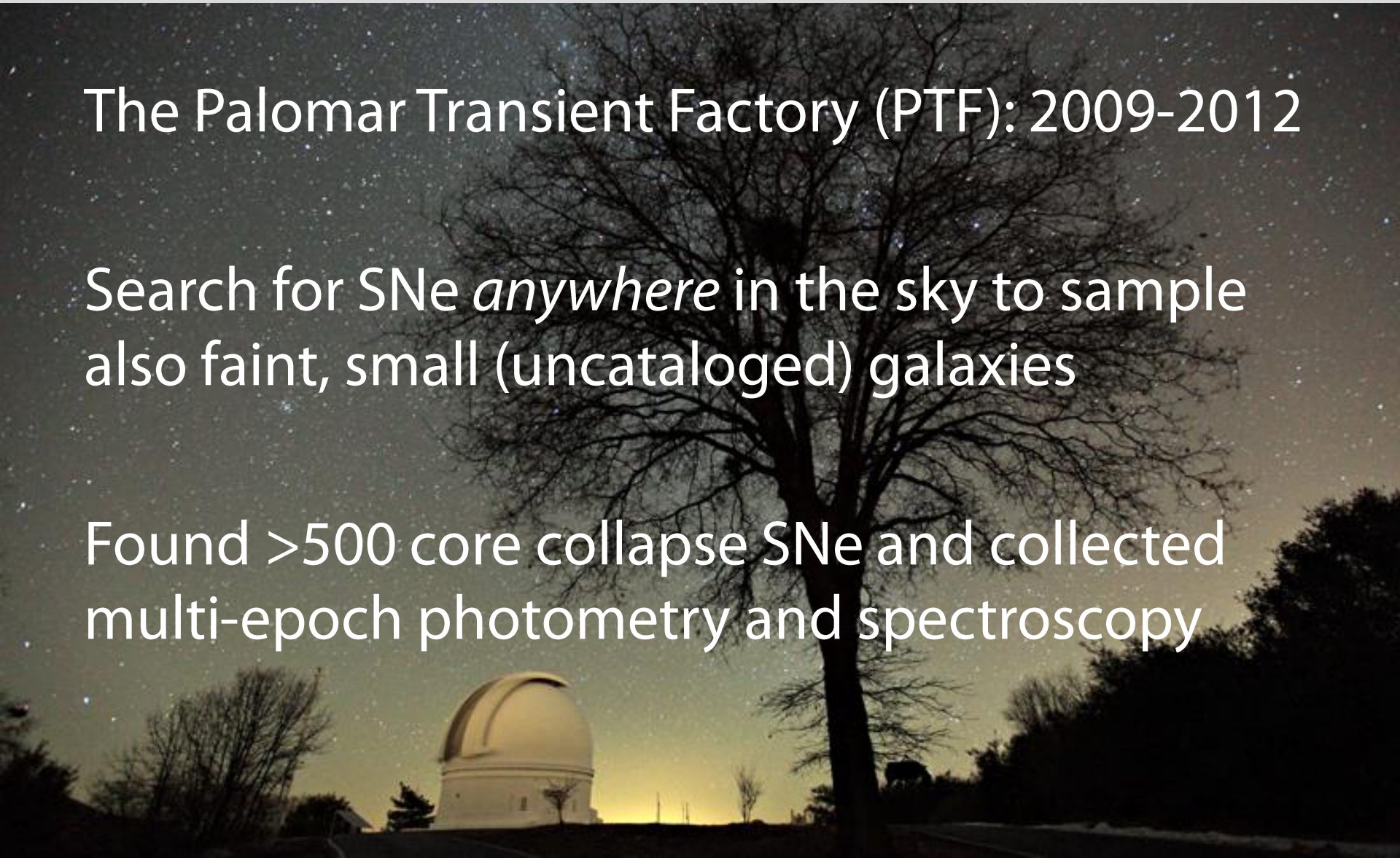




A single rapidly rotating star

PTF – an untargeted, wide field survey

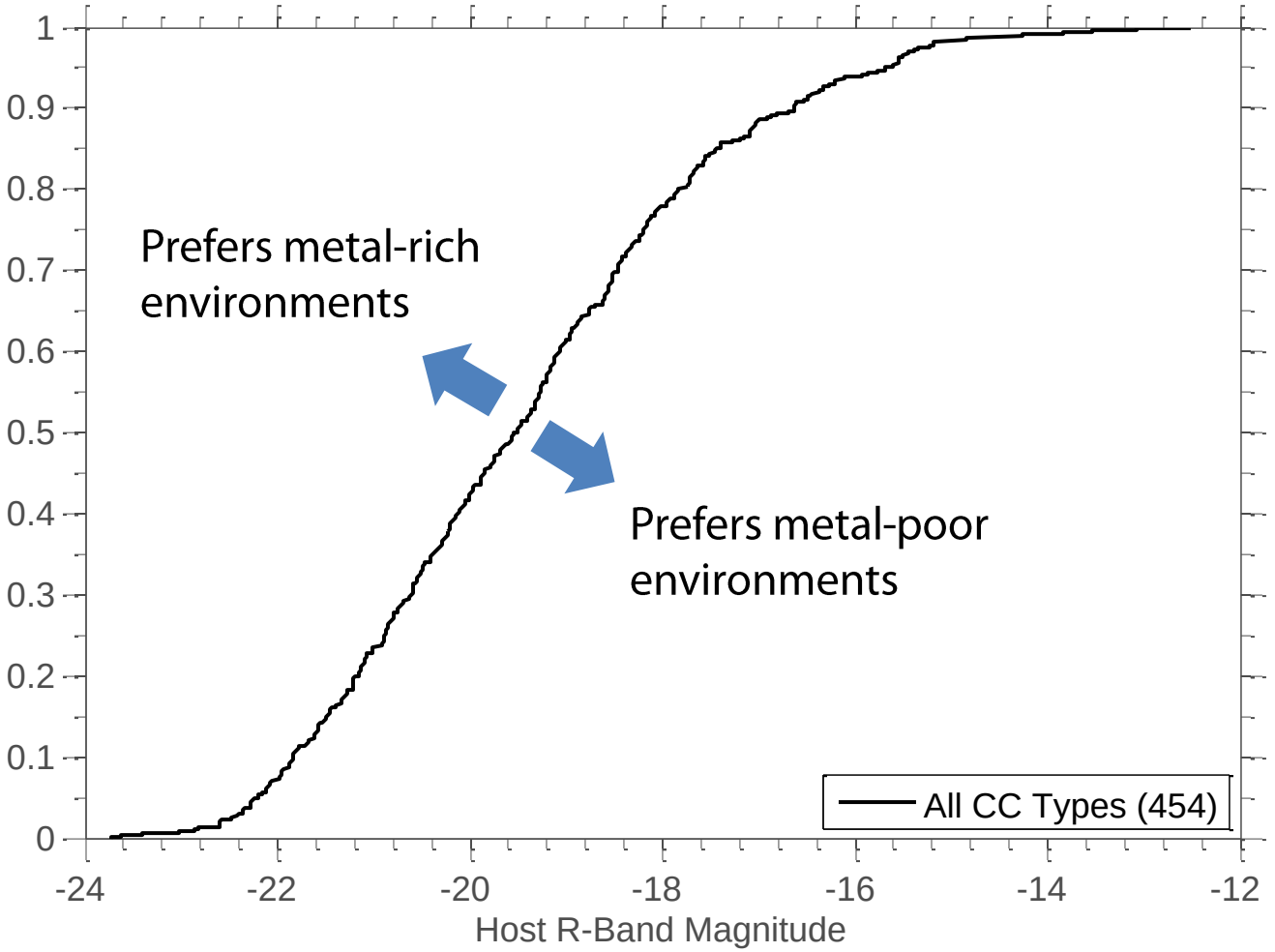


The Palomar Transient Factory (PTF): 2009-2012

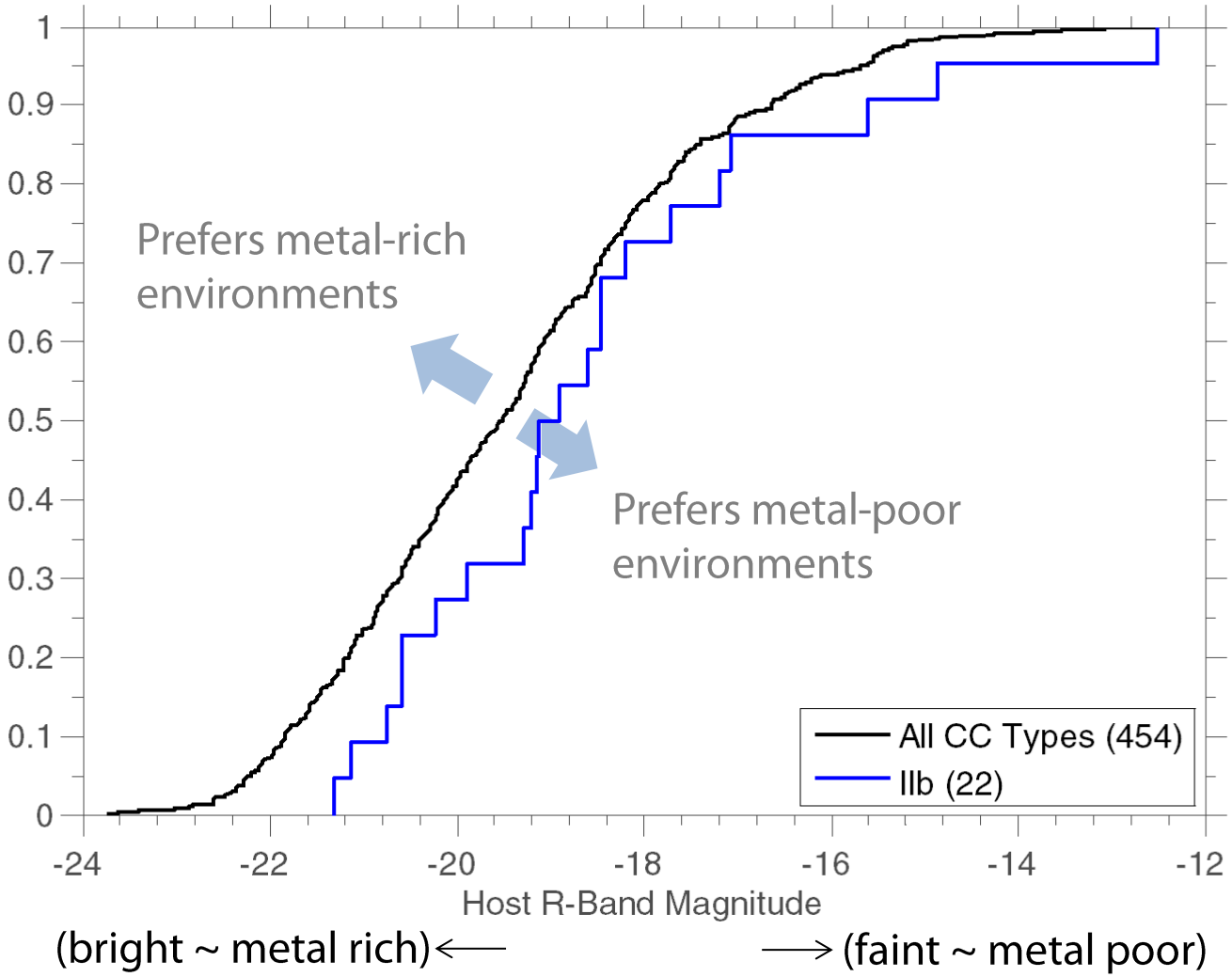
Search for SNe *anywhere* in the sky to sample also faint, small (uncataloged) galaxies

Found >500 core collapse SNe and collected multi-epoch photometry and spectroscopy

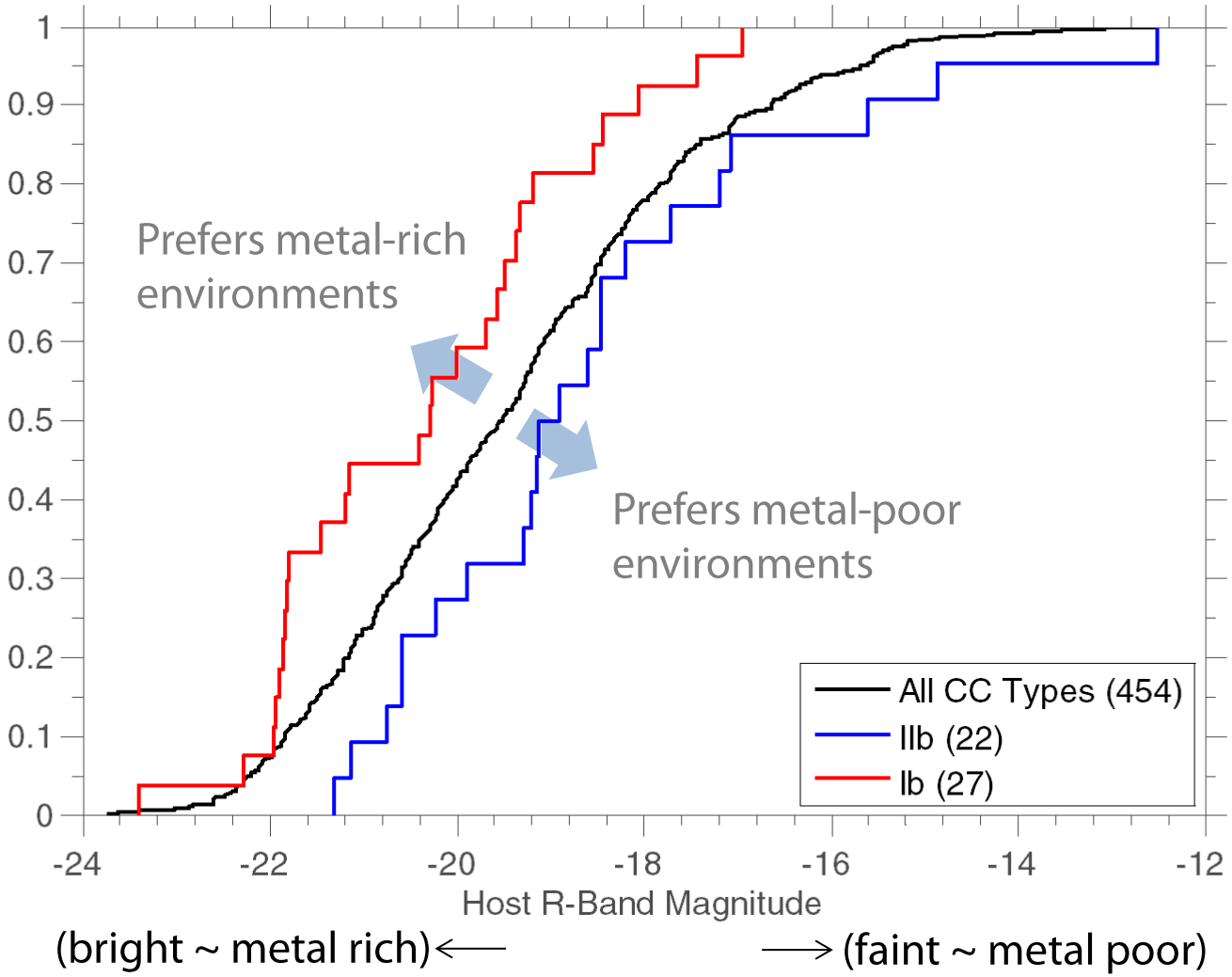
Certain SN types prefer certain environments



SNe IIb prefer faint hosts (low metallicity)



SNe Ib prefer bright hosts (high metallicity)



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Binary?	 	**SN Ib**	No H in spectrum
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Metallicity in addition to binarity?

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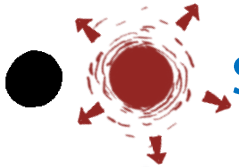
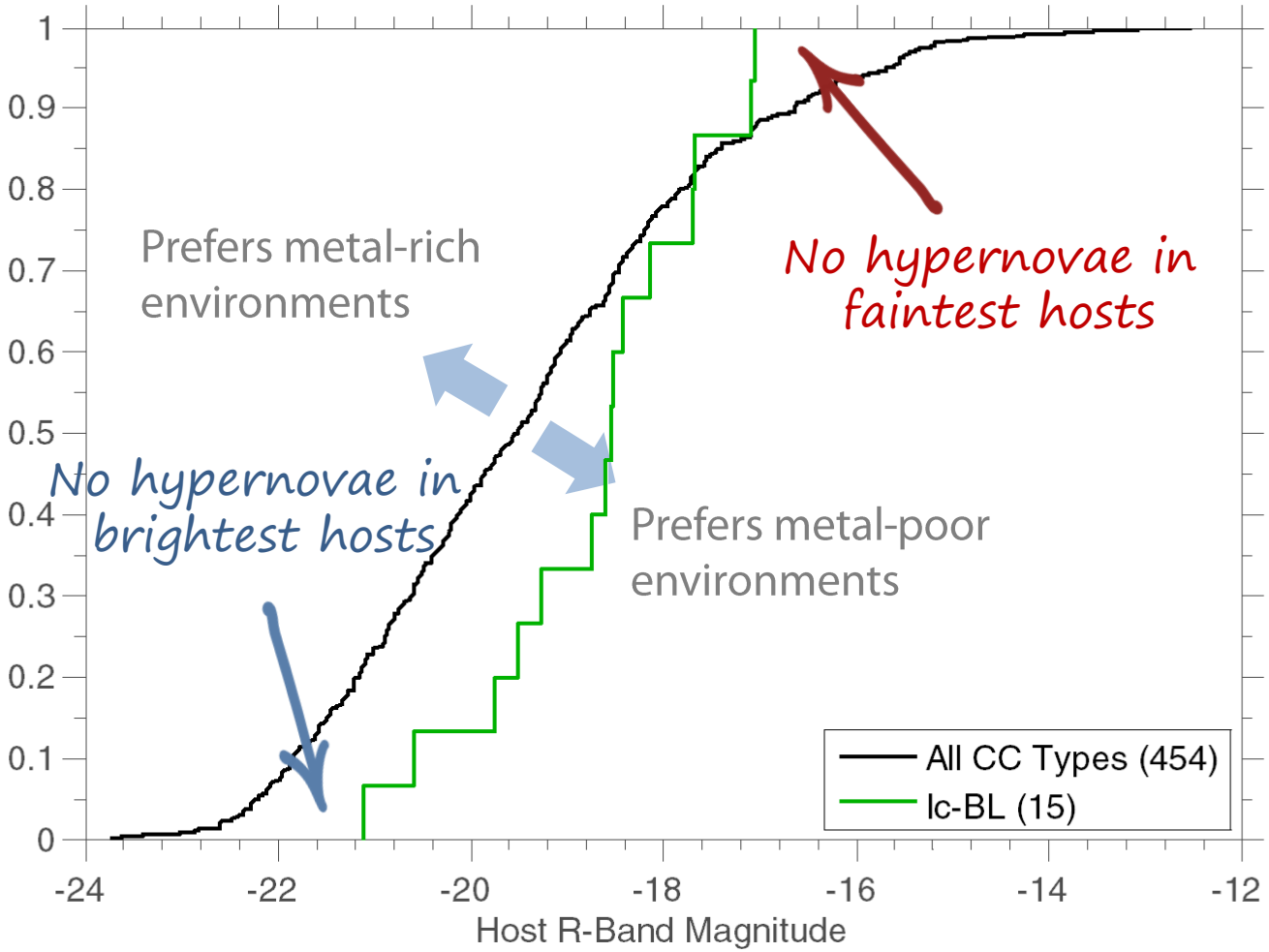
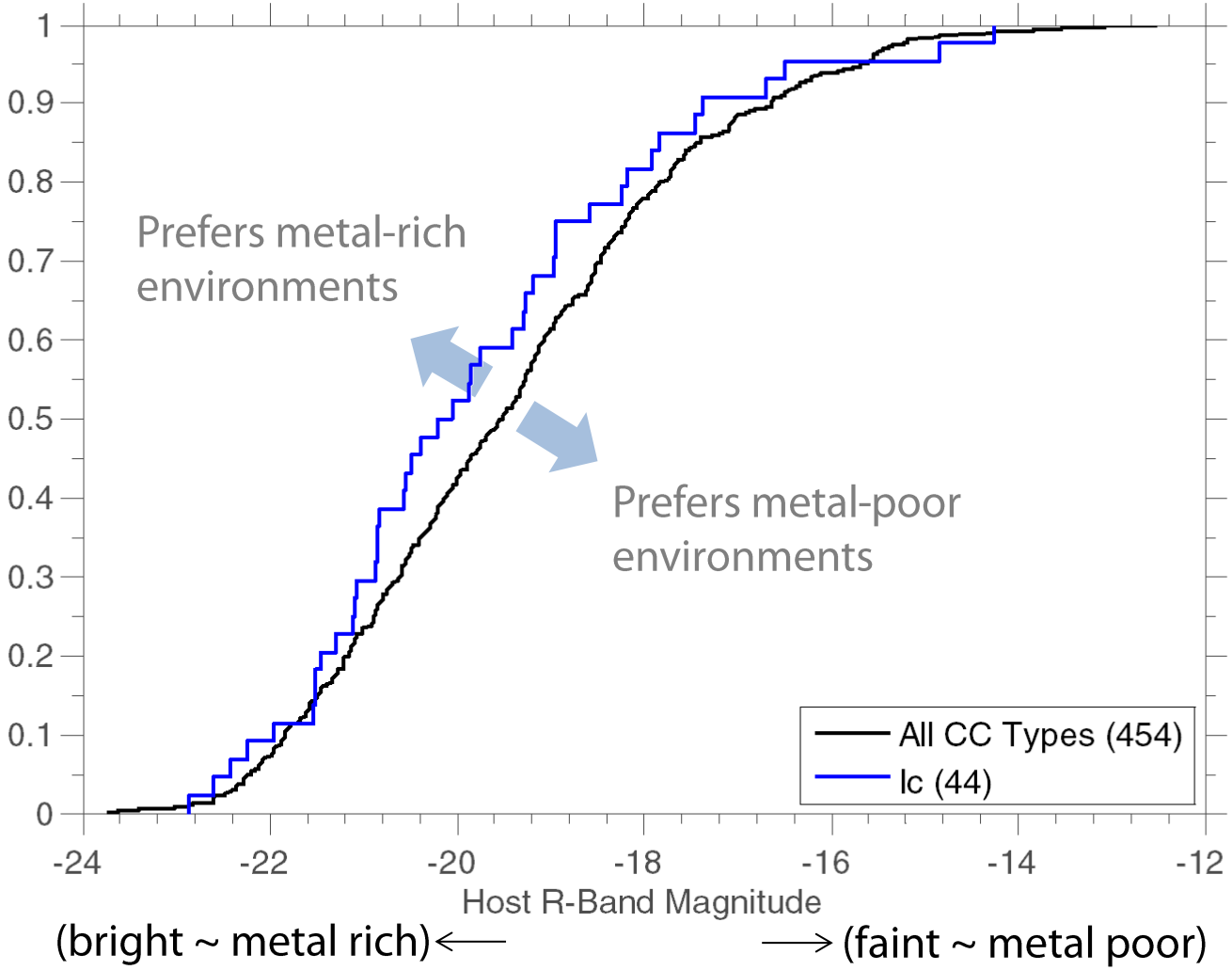
Binary & winds		**SN Ib**	No H in spectrum
		**SN Ic**	No H nor He in spectrum
		**SN Ic-BL**	No H nor He in spectrum, high velocities (sometimes come with a long GRB)

Hypernovae prefer low metallicity but not too low



SNe Ic: a slight preference for metal rich hosts?



Can we probe rotation?

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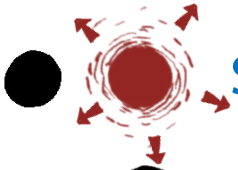
Binary & winds		**SN Ib**	No H in spectrum
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Rotation? Merger?		**SN Ic-BL** (hypernovae)	No H nor He in spectrum, high velocities (sometimes come with a long GRB)

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Part II: Where do the SNe happen?
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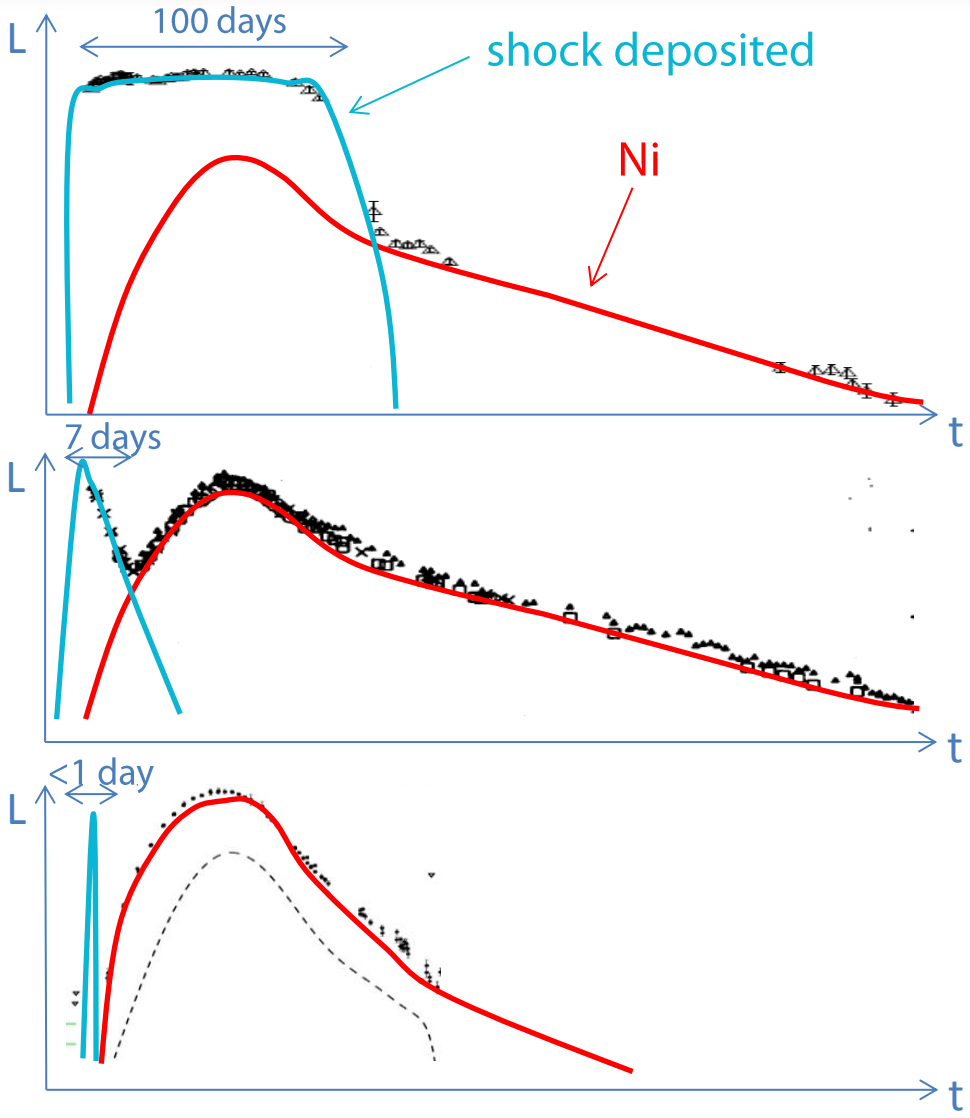
Shock cooling probes radius



SN1999em – IIP

(red super-giant)

[Leonard et al. 2002]

SN1993J – IIb

(partially stripped star)

[Richmond et al. 1994]

PTF10vgv – Ic

(fully stripped star)

[Corsi et al. 2012]

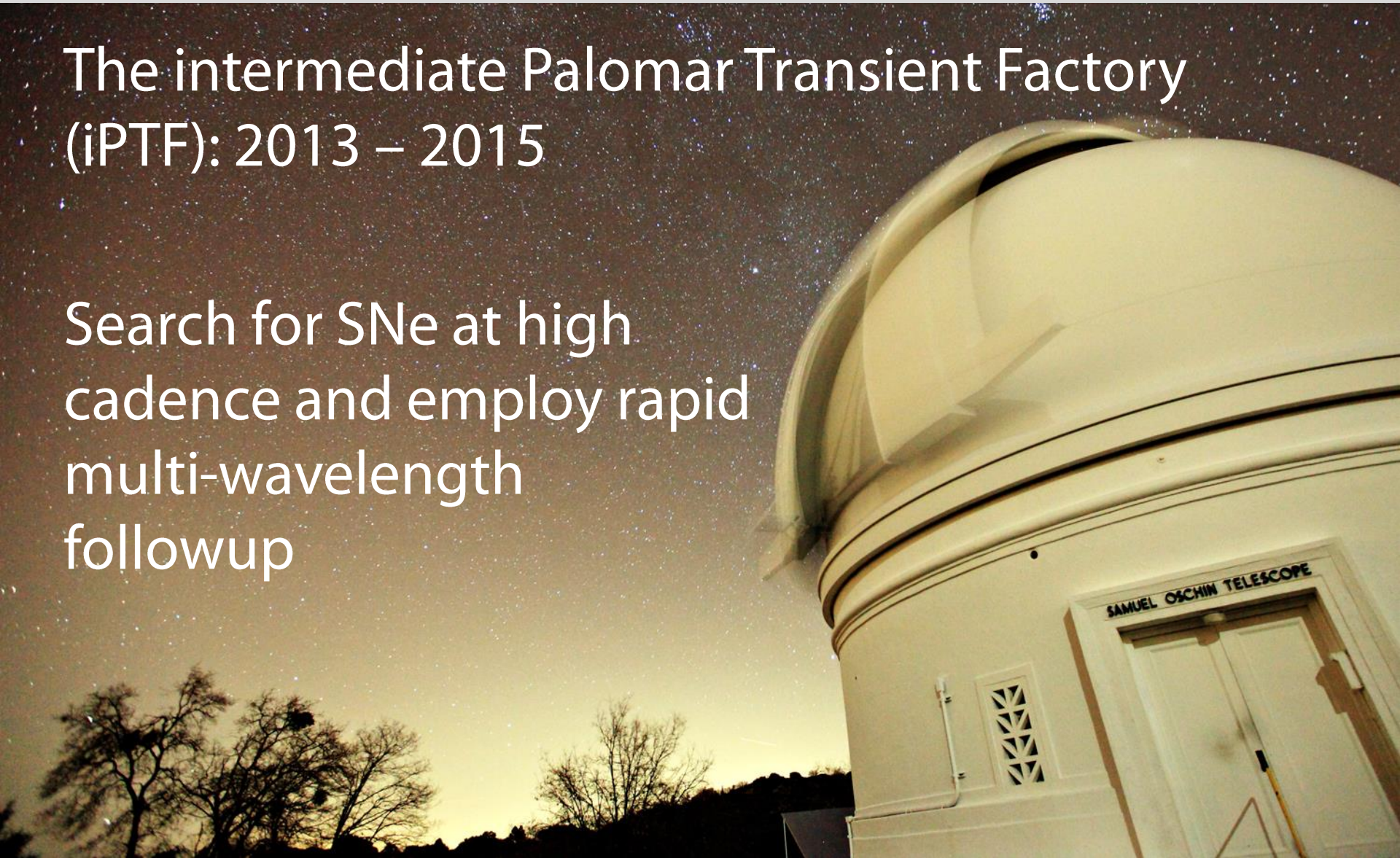
Early SN emission reveals progenitor properties

Shock cooling emission depends on:

- Progenitor radius
- Progenitor surface composition
- Progenitor density profile
- Material around the progenitor
- Explosion physics

Early time data can also probe Ni mixing

iPTF – High Cadence and Rapid Followup

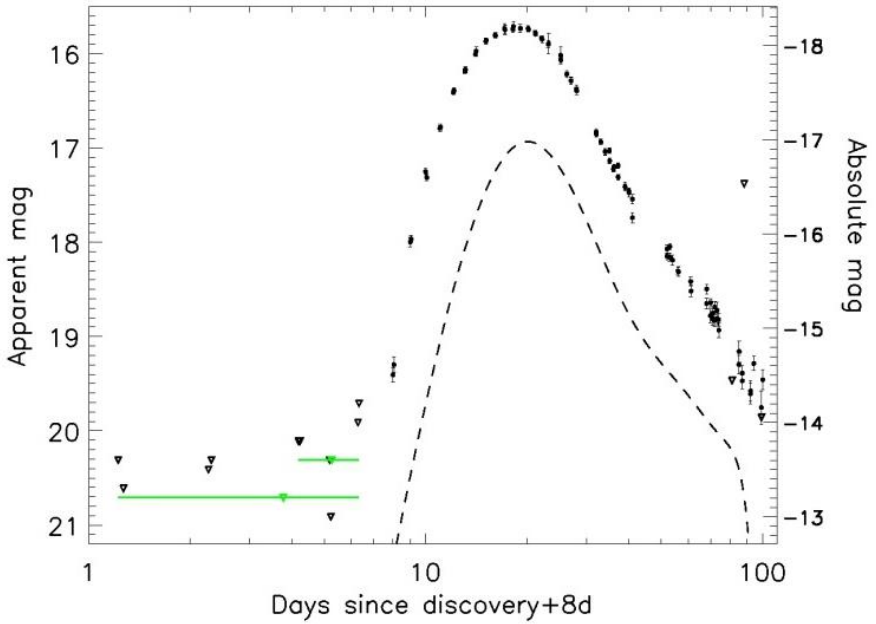


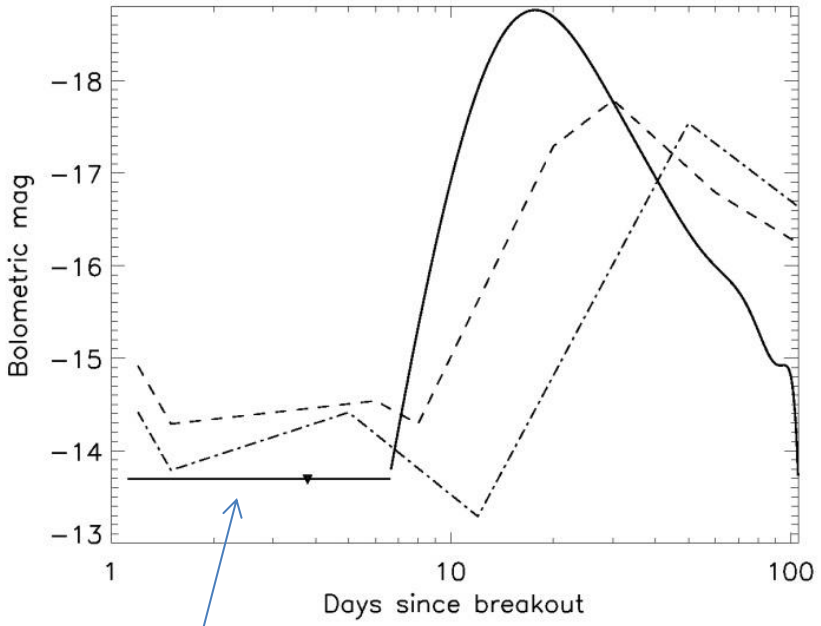
The intermediate Palomar Transient Factory (iPTF): 2013 – 2015

Search for SNe at high cadence and employ rapid multi-wavelength followup

Very quick shock cooling for fully stripped star

(SN Ib)





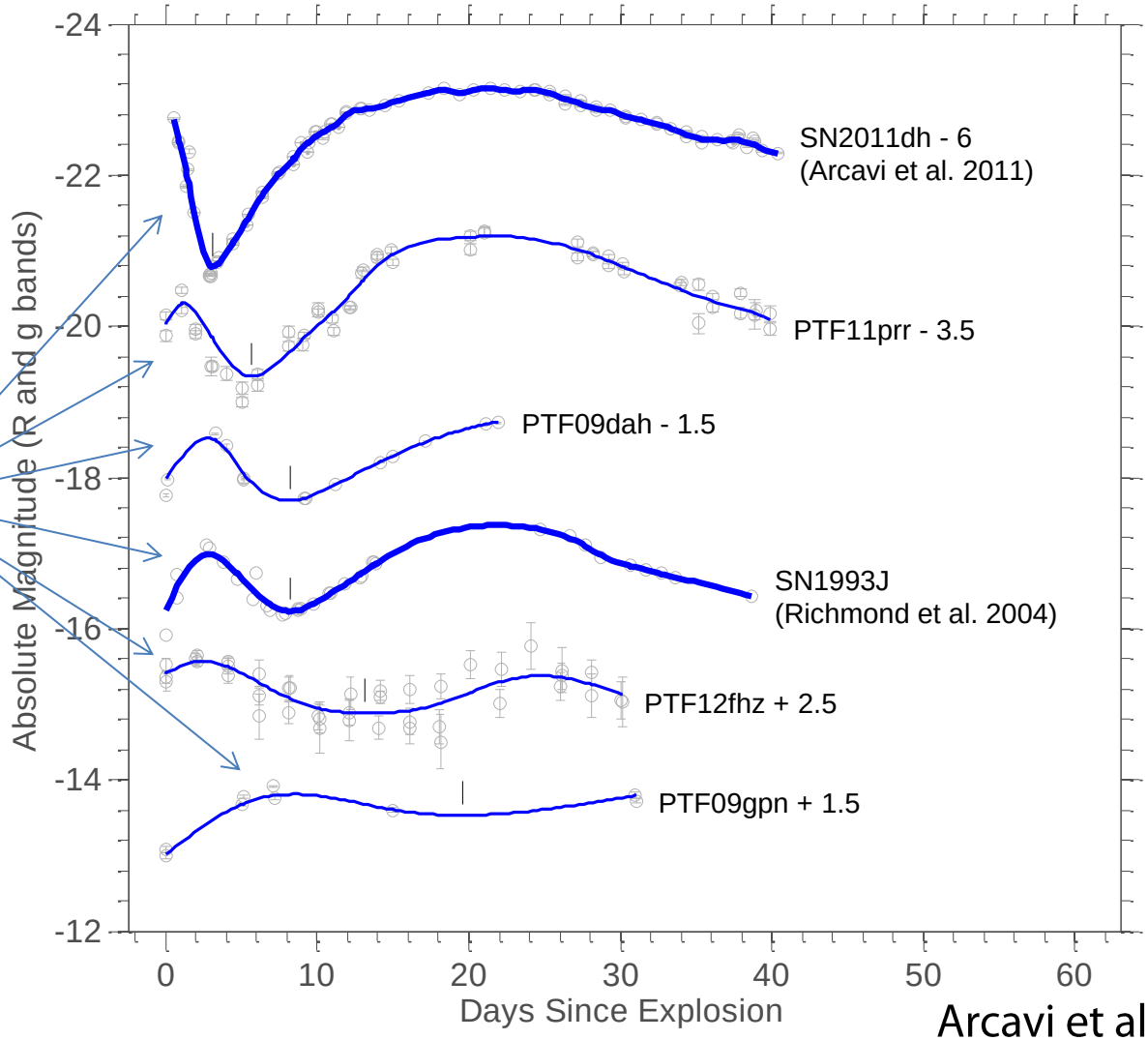
Rule out early plateau

PTF10vgv / Corsi et al. 2012

Variable shock cooling for partially stripped stars

(SNe IIb)

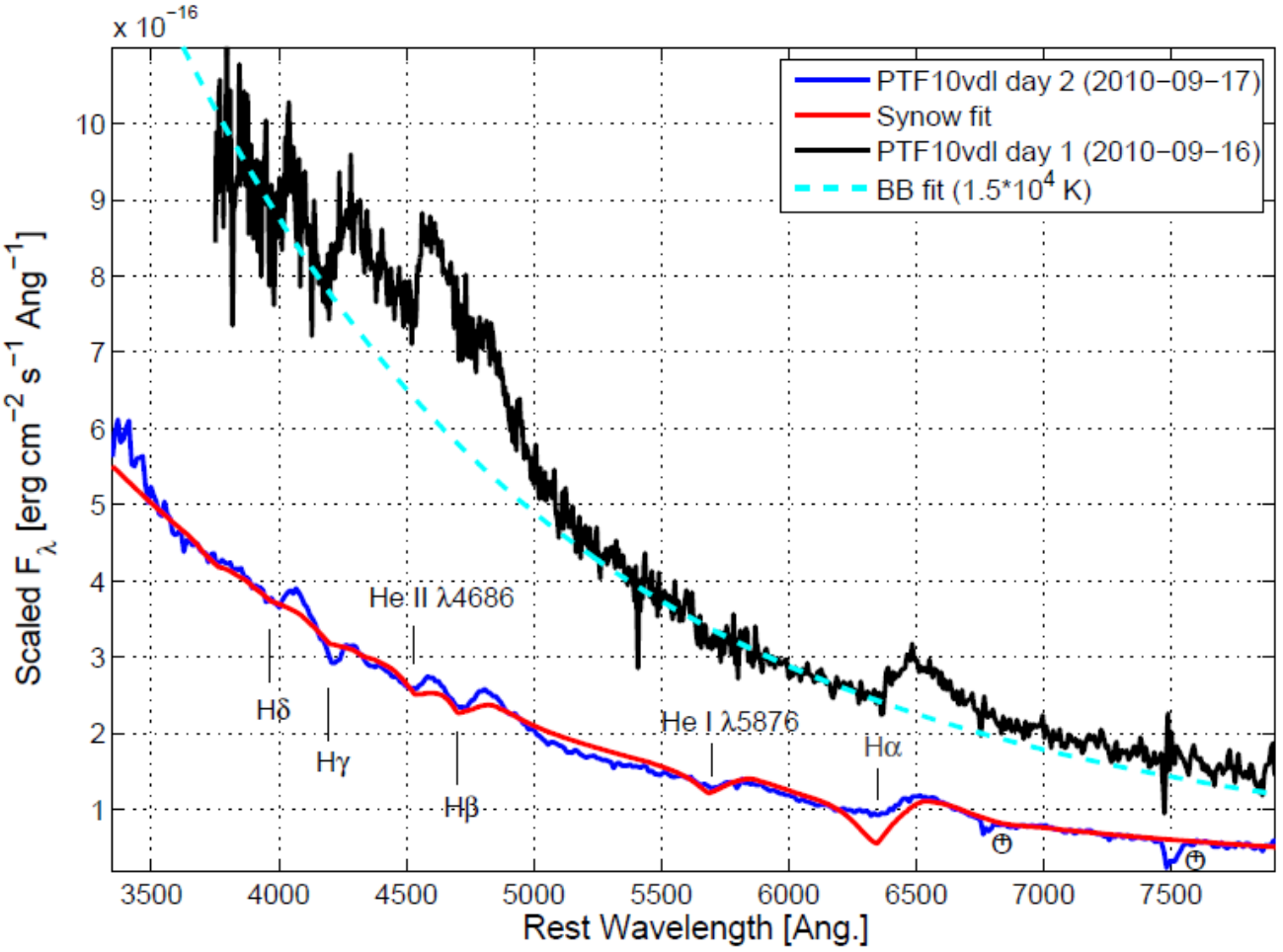
Shock cooling time
?⇔?
radius



Arcavi et al. in prep

Temperature is another constraint on models

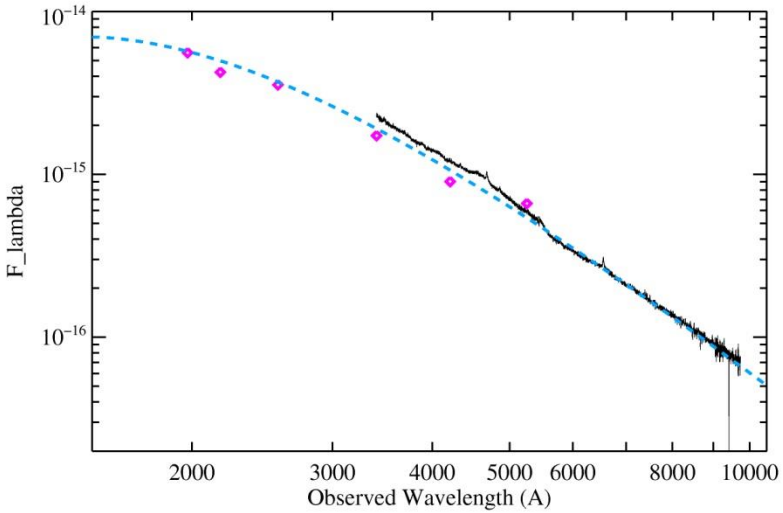
Temperature measurements from first days

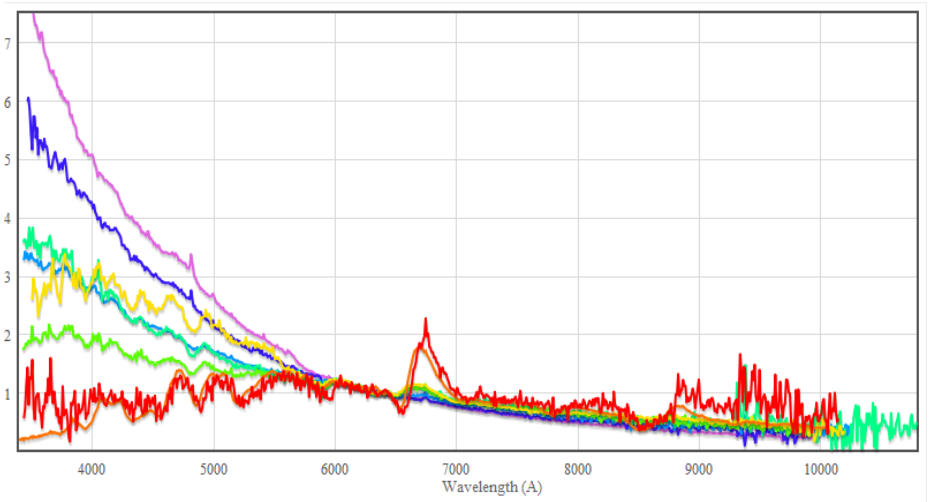


Gal-Yam, Kasliwal, IA et al. 2011

Temperature is another constraint on models

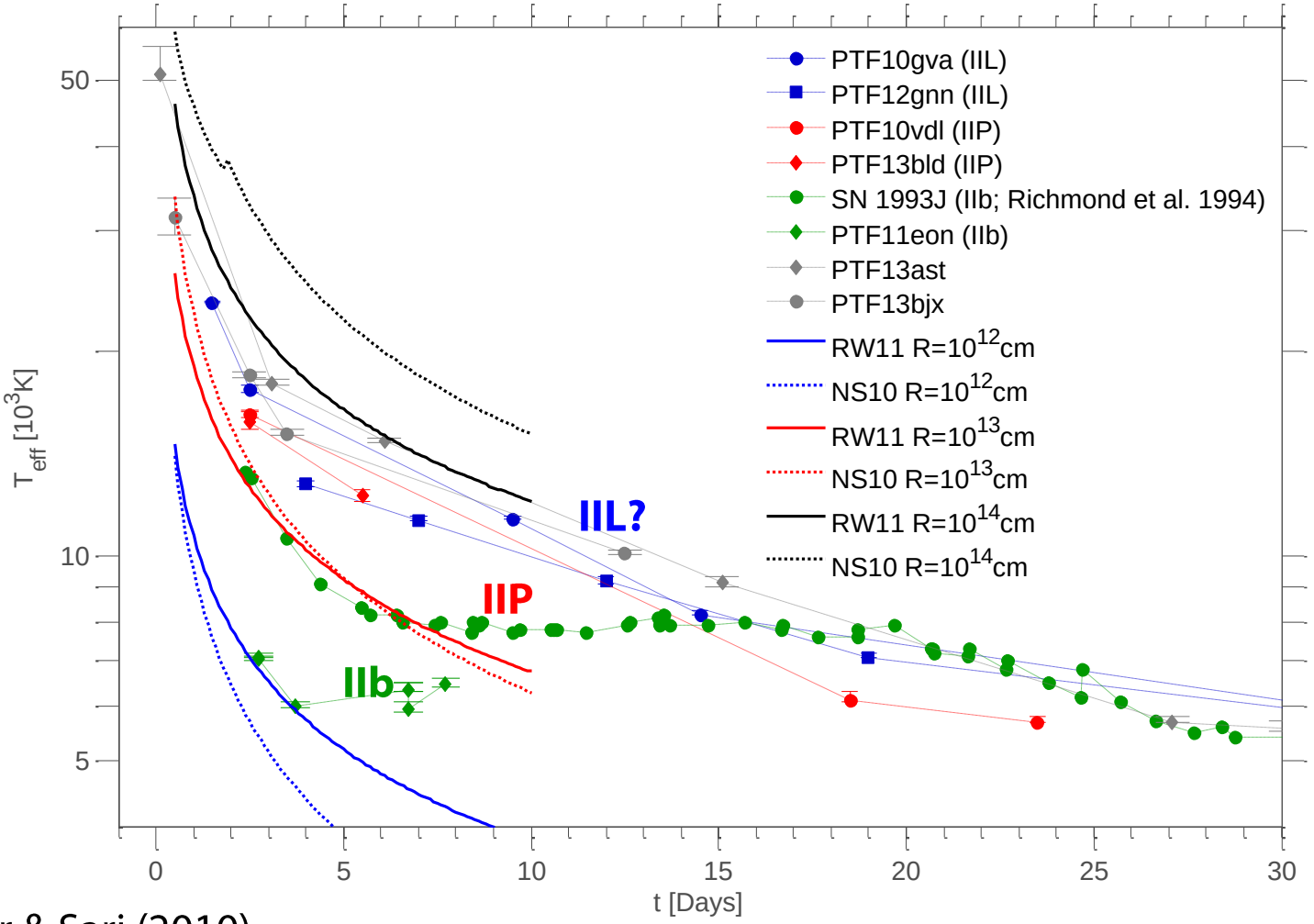
Early temperatures so high that require UV data to constrain blackbody





PTF10gva / Cenko et al., in prep.

Differences in Temp Evolution During First Days

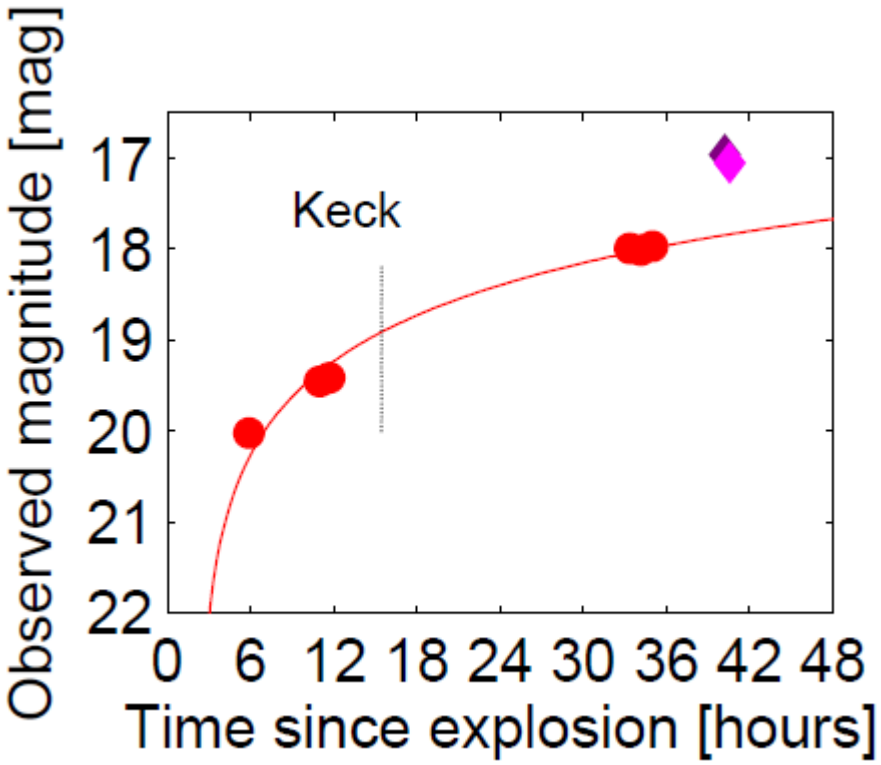


NS = Nakar & Sari (2010)

RW = Rabinak & Waxman (2011)

Preliminary

Latest result: the youngest SN spectrum ever taken

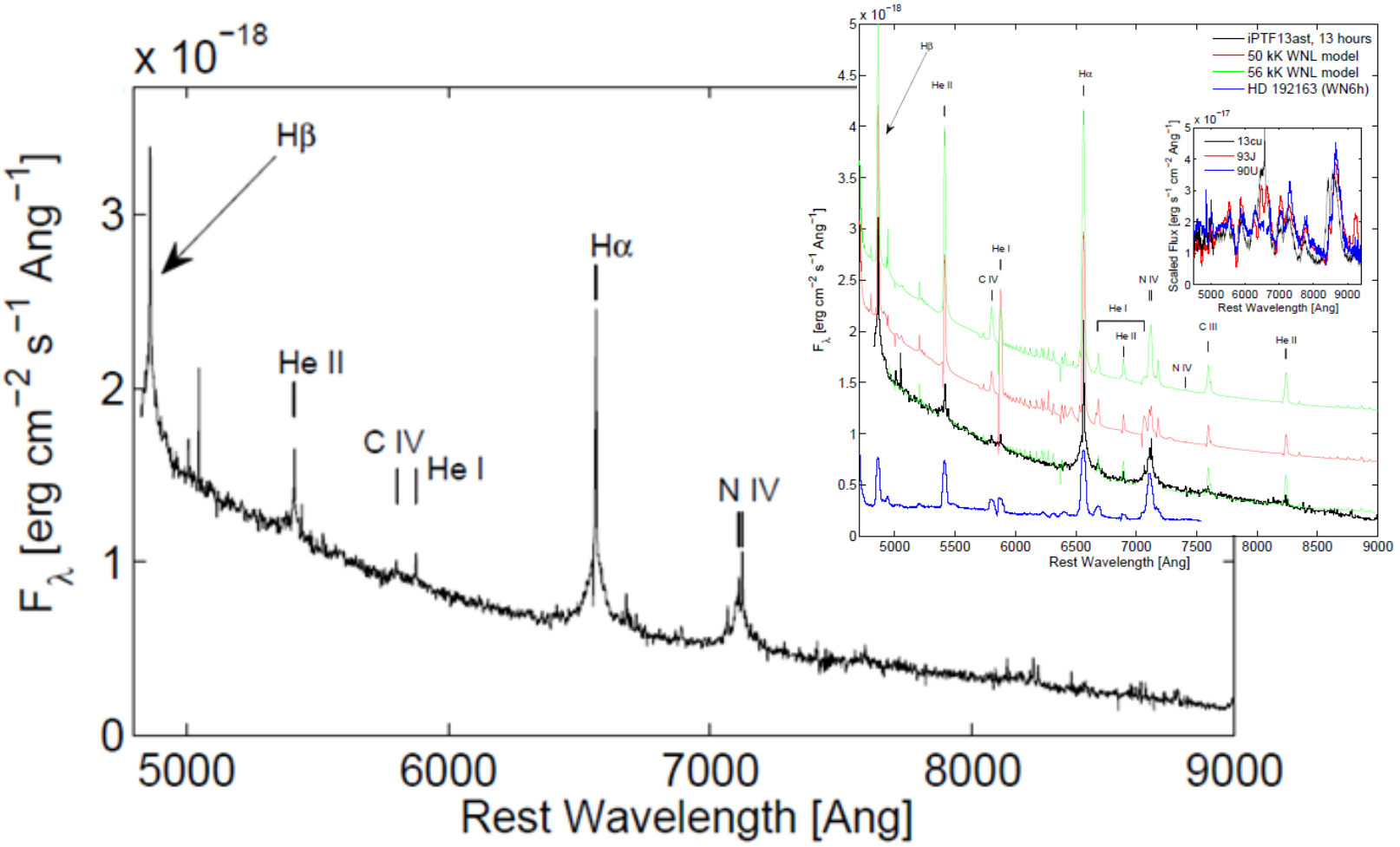


Spectrum obtained before the ejecta reached ~10^{13}cm

Outer layers of the progenitor still intact!

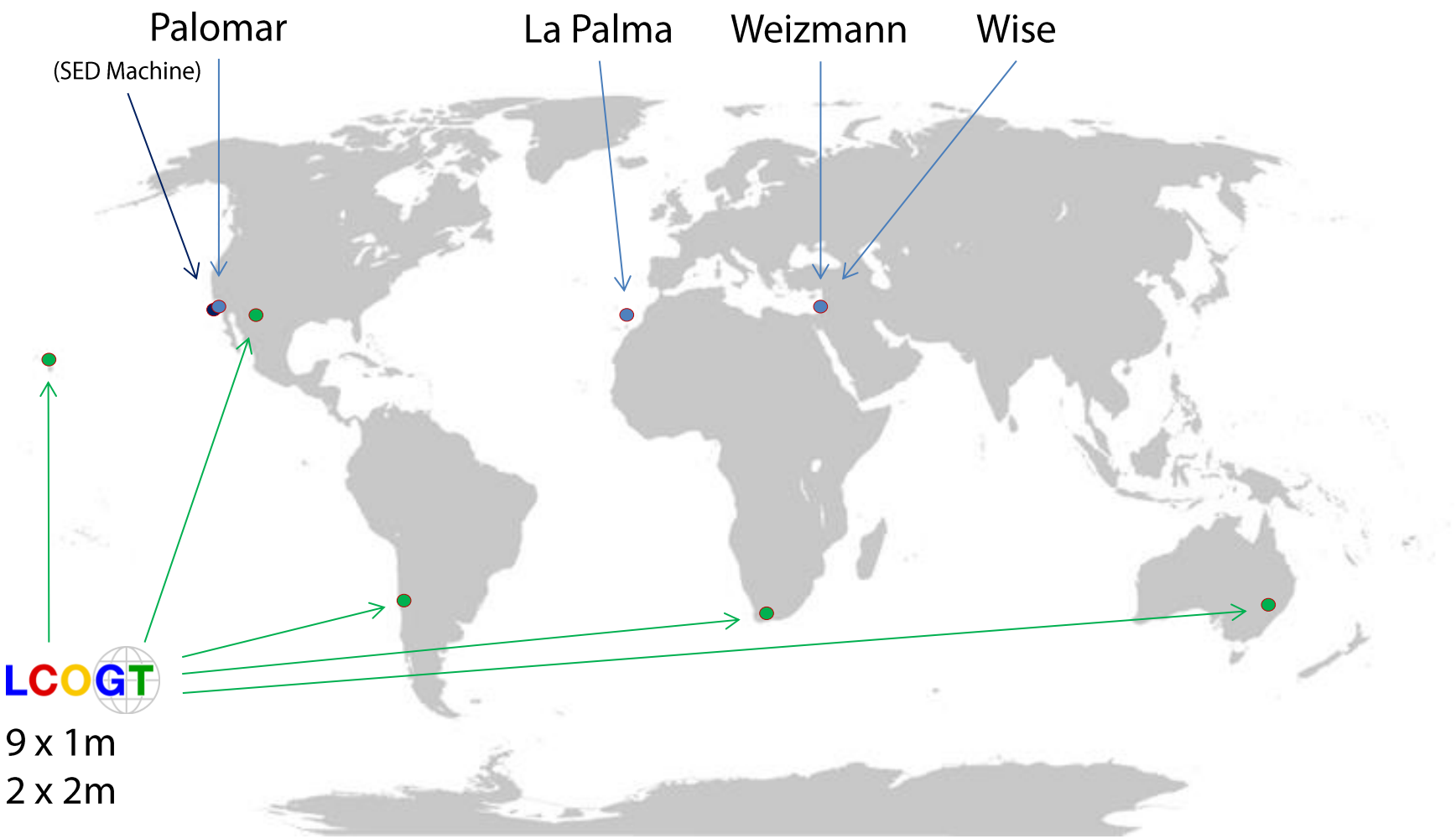
Gal-Yam, IA et al., in prep.

Spectrum shows outer layers of the star still intact



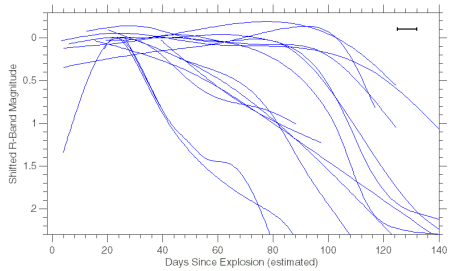
Gal-Yam, IA et al., in prep.

Worldwide effort to catch the early emission



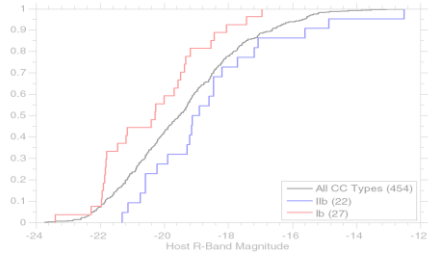
Summary

Can we constrain the properties of pre-explosion massive stars without seeing them? Yes



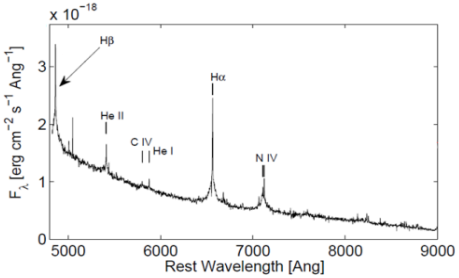
Distinct light curve classes hint at **single / binary** progenitors

Repeating analysis with 300 SNe from PTF



Host galaxy statistics elucidate the role of **metallicity**

Complementing with direct metallicity measurements



Early observations reveal **direct progenitor properties**

Infrastructure and techniques in place, first results, more to come