SN progenitors from stellar evolution models

Groh+ 13a, A&A, 550, L7

Groh+ 13b, A&A, in press
(arXiv:1308.4601)

Groh+ 13c, A&A, in press
(arXiv:1307.8434)

Jose Groh (Geneva Observatory, Switzerland)

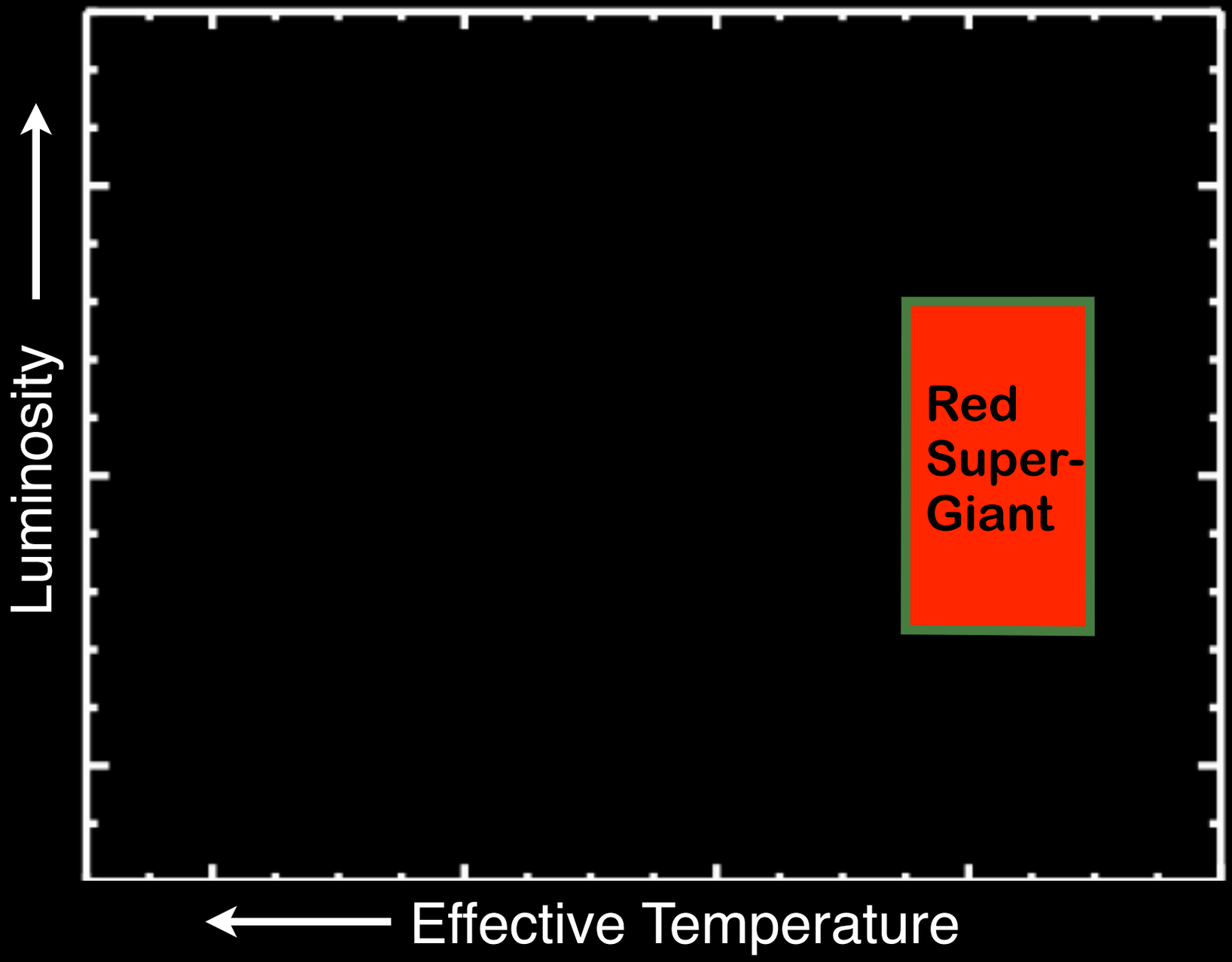
FNSNF
FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

Collaborators

Georges Meynet + Sylvia Ekstrom (Geneva), Cyril Georgy (Keele)

Image credits: NASA/ESA/J. Hester & A. Loll, Arizona State U. (Crab Nebula)

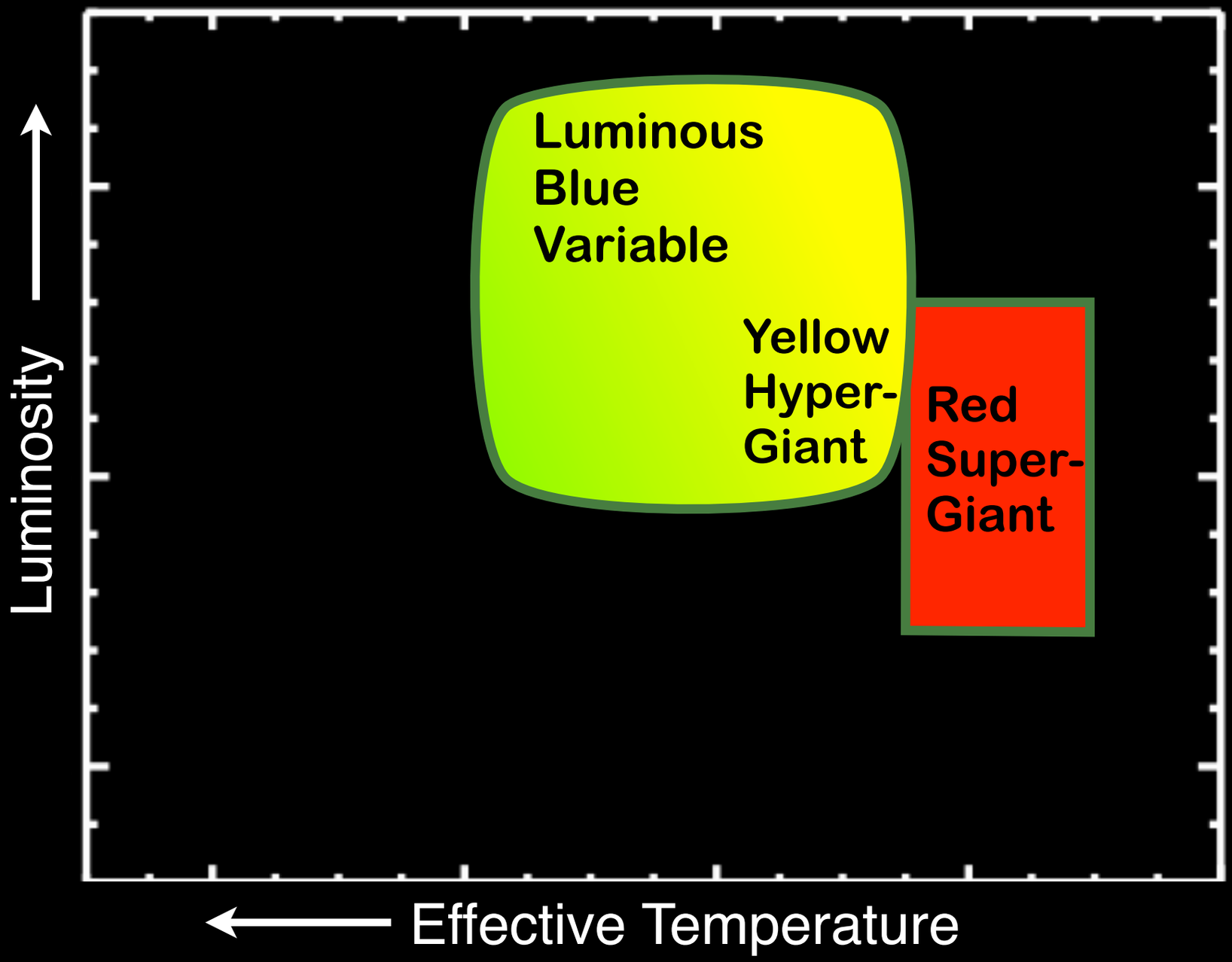
Expected CCSN progenitors at solar metallicity



What we want

- Initial mass range
- SN type
- Progenitor properties
- Single x binary

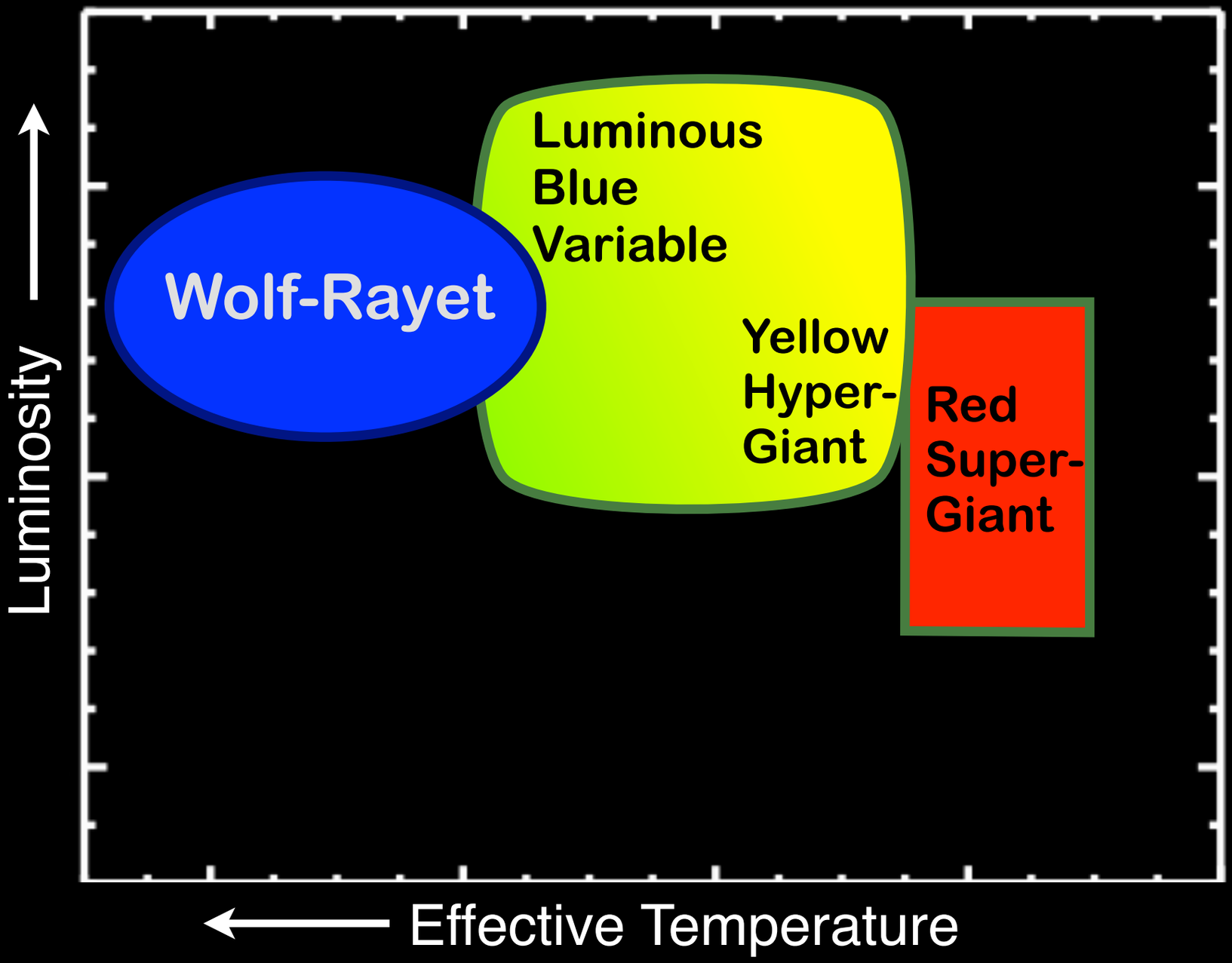
Expected CCSN progenitors at solar metallicity



What we want

- Initial mass range
- SN type
- Progenitor properties
- Single x binary

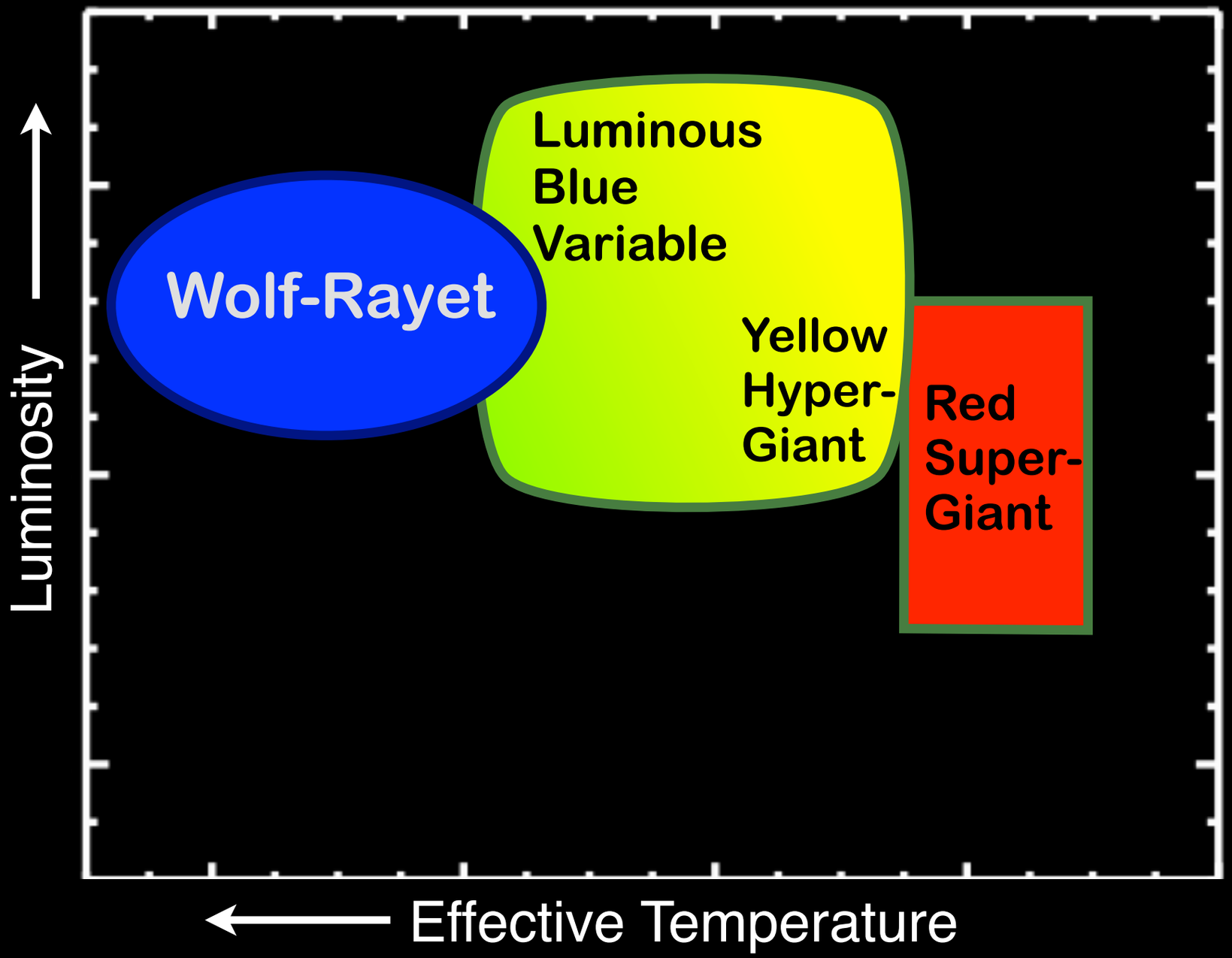
Expected CCSN progenitors at solar metallicity



What we want

- Initial mass range
- SN type
- Progenitor properties
- Single x binary

Expected CCSN progenitors at solar metallicity



What we want

- Initial mass range
- SN type
- Progenitor properties
- Single x binary

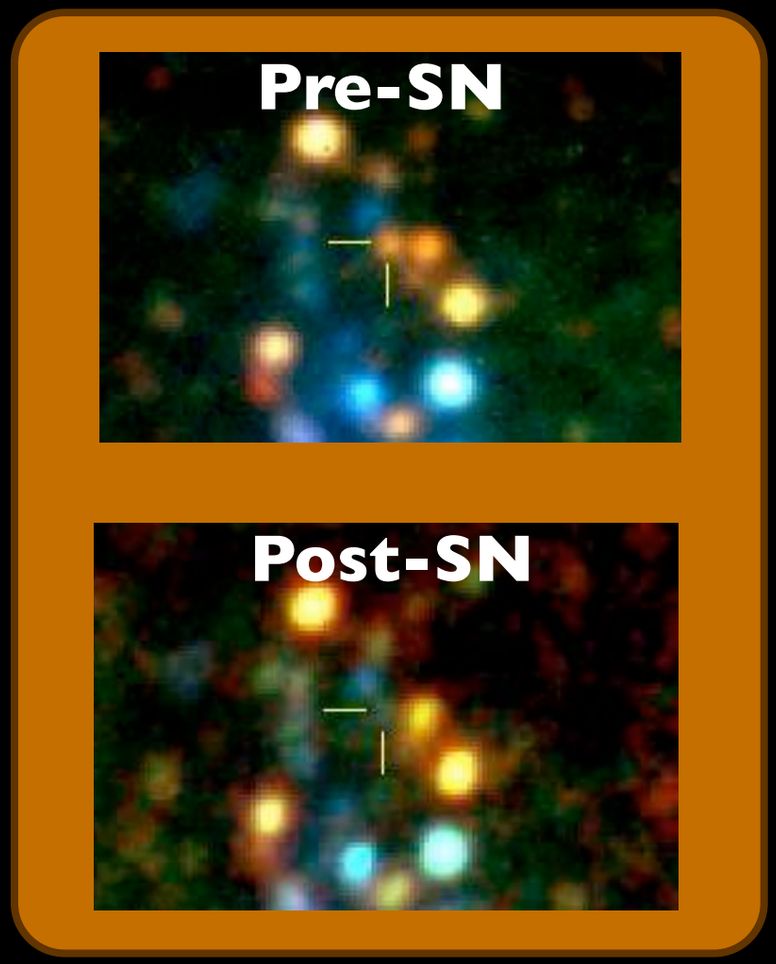
However

- mass loss + rotation
- binarity
- models vs. observations

How to compare observations and stellar evolution models?

Observations

- Photometry: magnitudes + colors
- Spectroscopy: lines (EW + rad. vel)

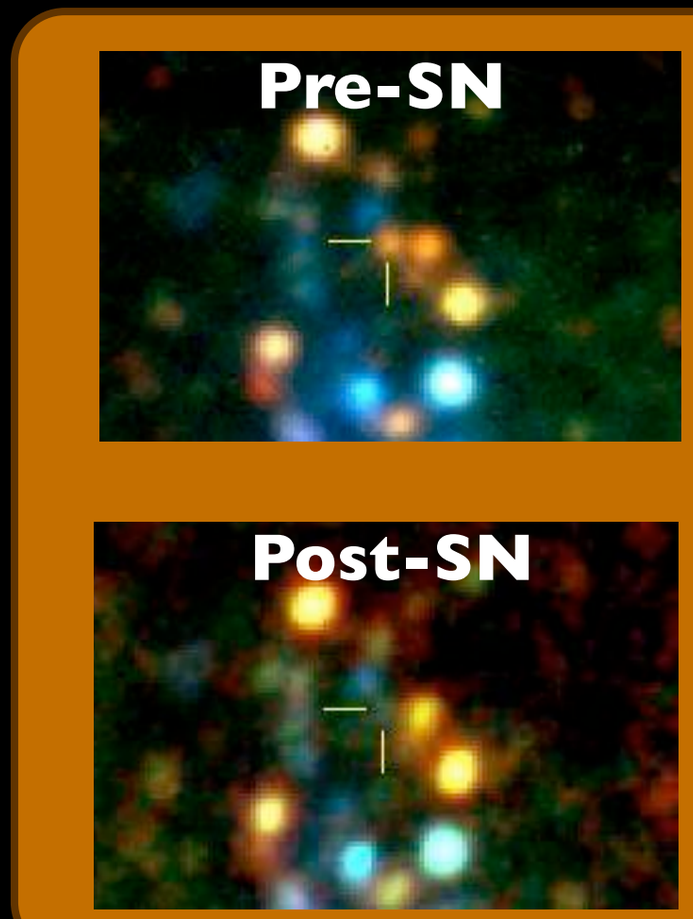


Type IIP SN 2008bk
(Mattila+ 08)

How to compare observations and stellar evolution models?

Observations

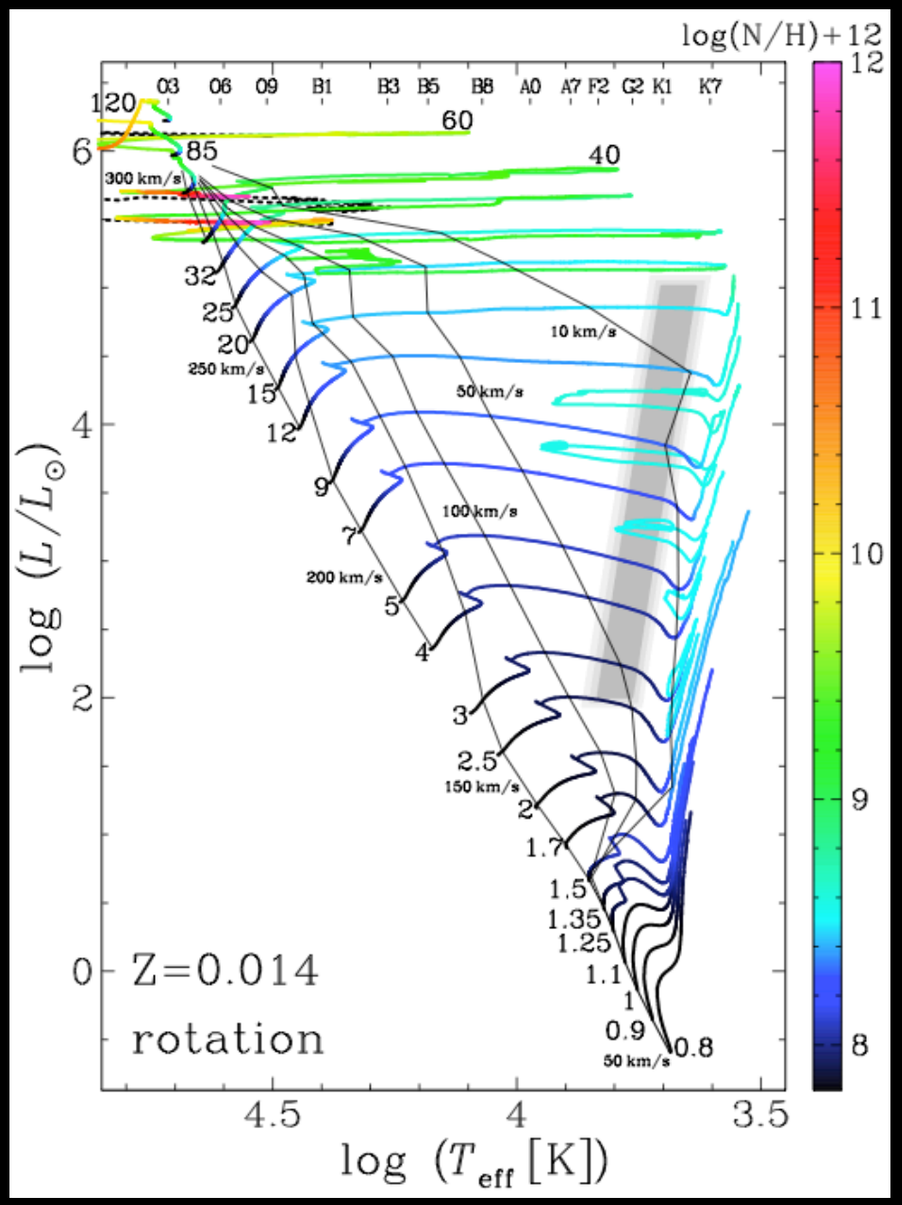
- Photometry: magnitudes + colors
- Spectroscopy: lines (EW + rad. vel)



Type IIP SN 2008bk
(Mattila+ 08)

Stellar evolution models

- Luminosity + temperature
- Abundances

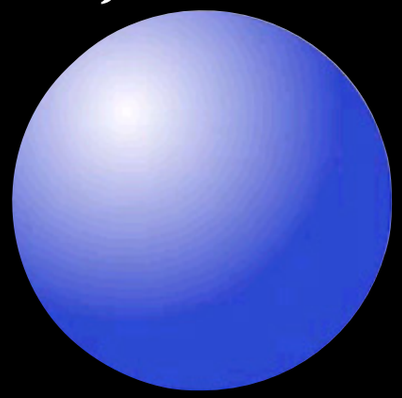


(Ekstrom+ 12)

How SN and GRB progenitors should look

Previously: SN progenitor inferred from L, Teff, and chemical composition
(Maeder & Meynet 00, Heger+03, Eldridge+ 08, Langer+, Yoon & Langer 05, Georgy+ 09, 12)

L, Teff, abundances



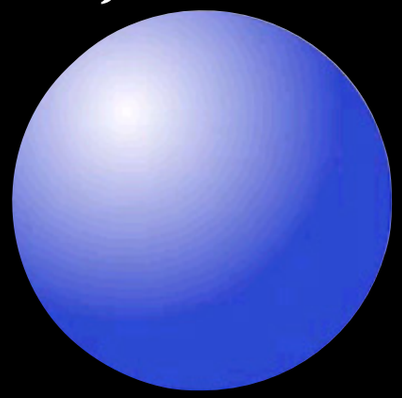
empirical calibration

spectral type
OB
RSG
WN
WC
WO

How SN and GRB progenitors should look

Previously: SN progenitor inferred from L, Teff, and chemical composition
(Maeder & Meynet 00, Heger+03, Eldridge+ 08, Langer+, Yoon & Langer 05, Georgy+ 09, 12)

L, Teff, abundances

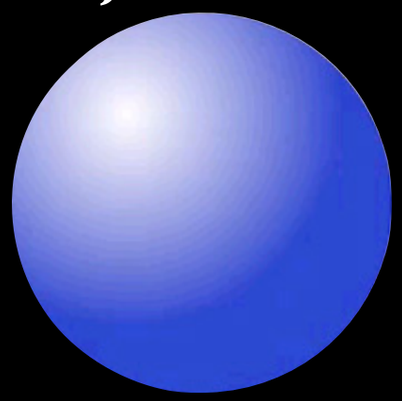


empirical calibration

spectral type
OB
RSG
WN
WC
WO

Now: Evolution (Geneva) + self-consistent atmosph/wind (CMFGEN)
(Groh+ 13a,b,c)

L, Teff, abundances

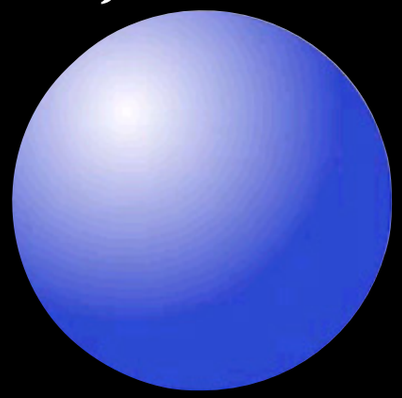


compute spectrum

How SN and GRB progenitors should look

Previously: SN progenitor inferred from L, Teff, and chemical composition
(Maeder & Meynet 00, Heger+03, Eldridge+ 08, Langer+, Yoon & Langer 05, Georgy+ 09, 12)

L, Teff, abundances

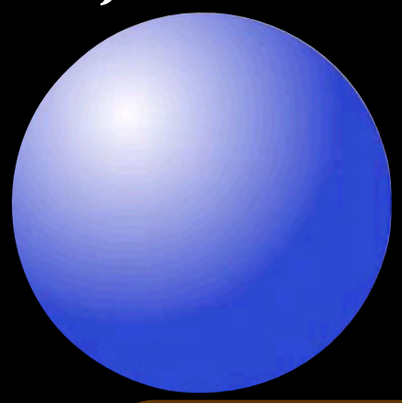


empirical calibration

spectral type
OB
RSG
WN
WC
WO

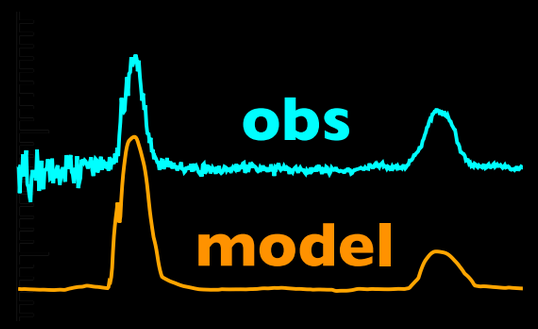
Now: Evolution (Geneva) + self-consistent atmosph/wind (CMFGEN)
(Groh+ 13a,b,c)

L, Teff, abundances



compute spectrum

spectral classification

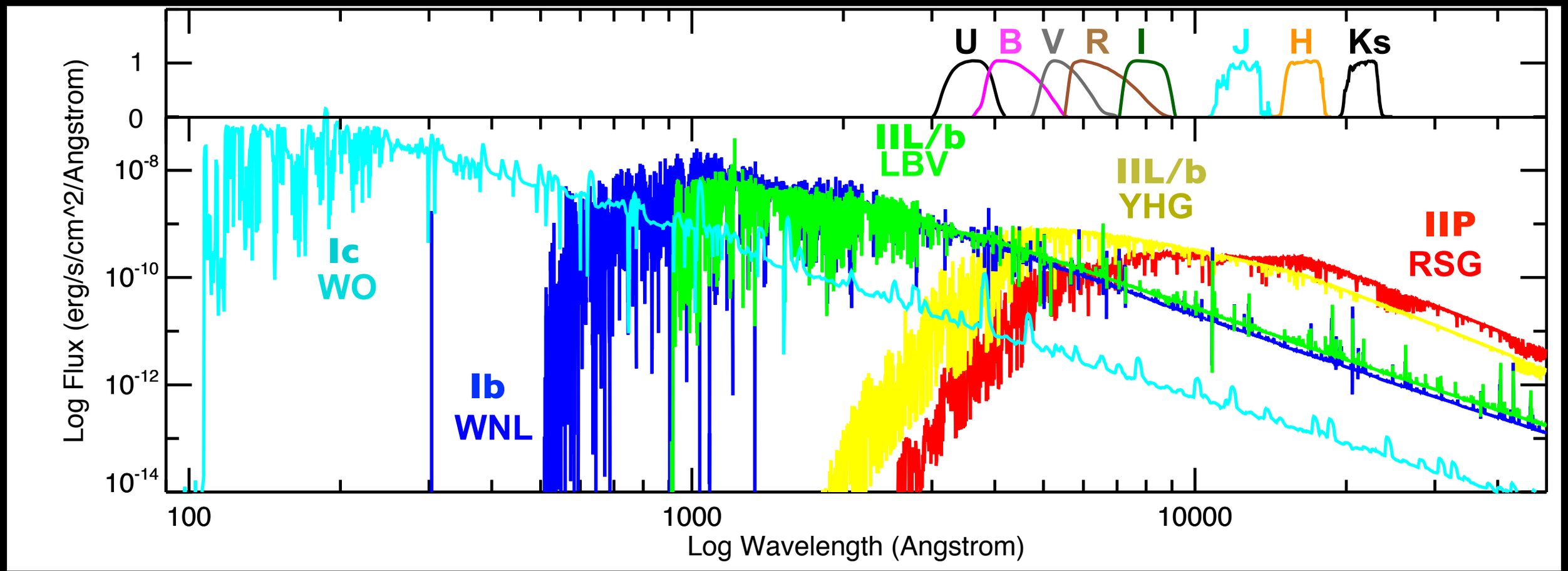


Sp Type
O7 V
M2 I
WN8
WC4
WO3

For the first time, spectrum and abs. mag. of SN progenitors from stellar evolution models

Spectral energy distribution of SN progenitors

From single star evolution at solar metallicity



(Groh+ 13, A&A in press; arXiv 1308.4601)

Predicting the absolute magnitudes of SN progenitors

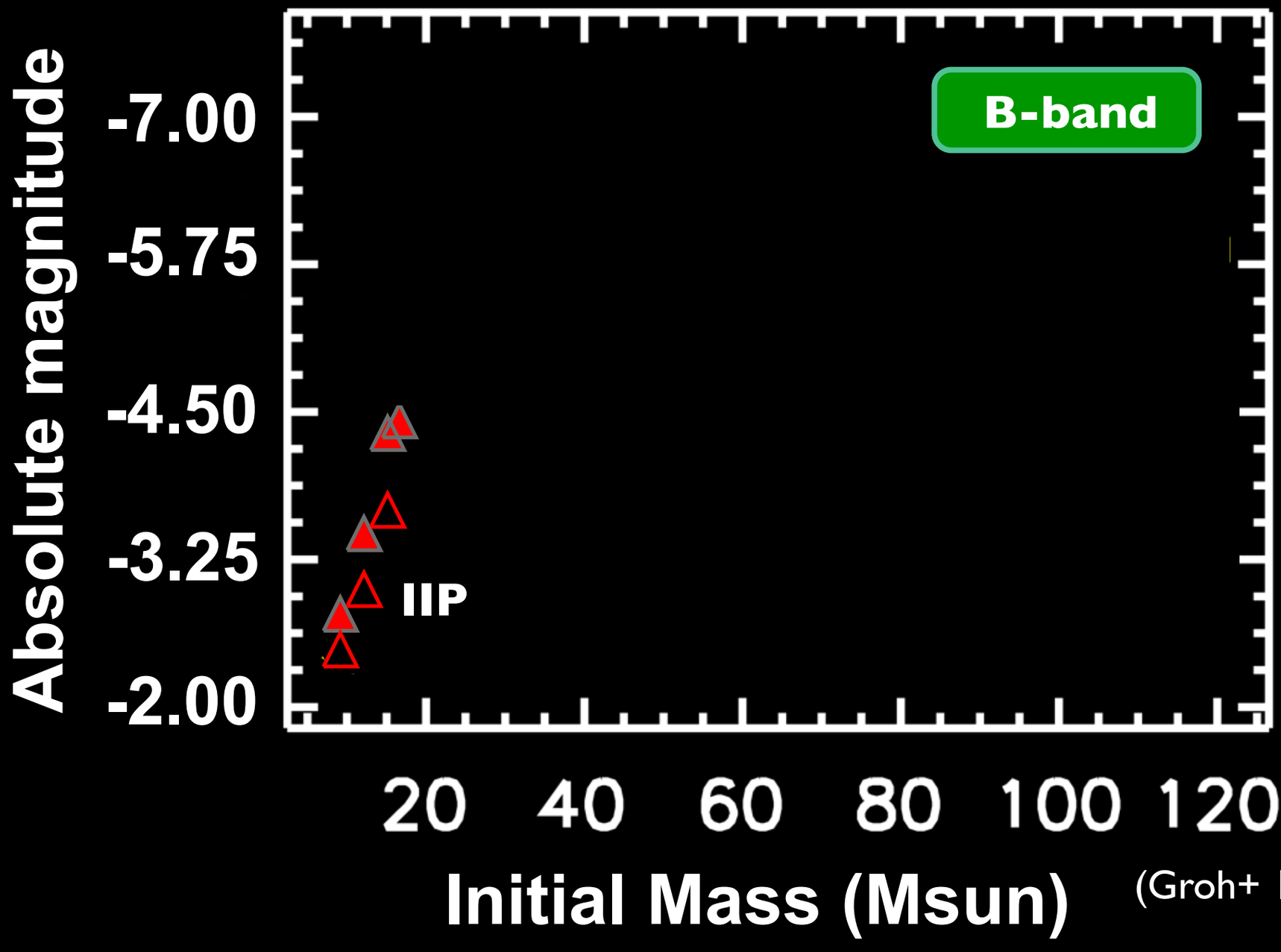
Progenitor Spectral Type

WO
WNL
LBV
YHG
RSG

Supernova Type

Ic
Ib
IIL or IIb
IIP

Open symbols: non-rotating models
Filled symbols: rotating models



(Groh+ 13, A&A in press; arXiv 1308.4601)

Predicting the absolute magnitudes of SN progenitors

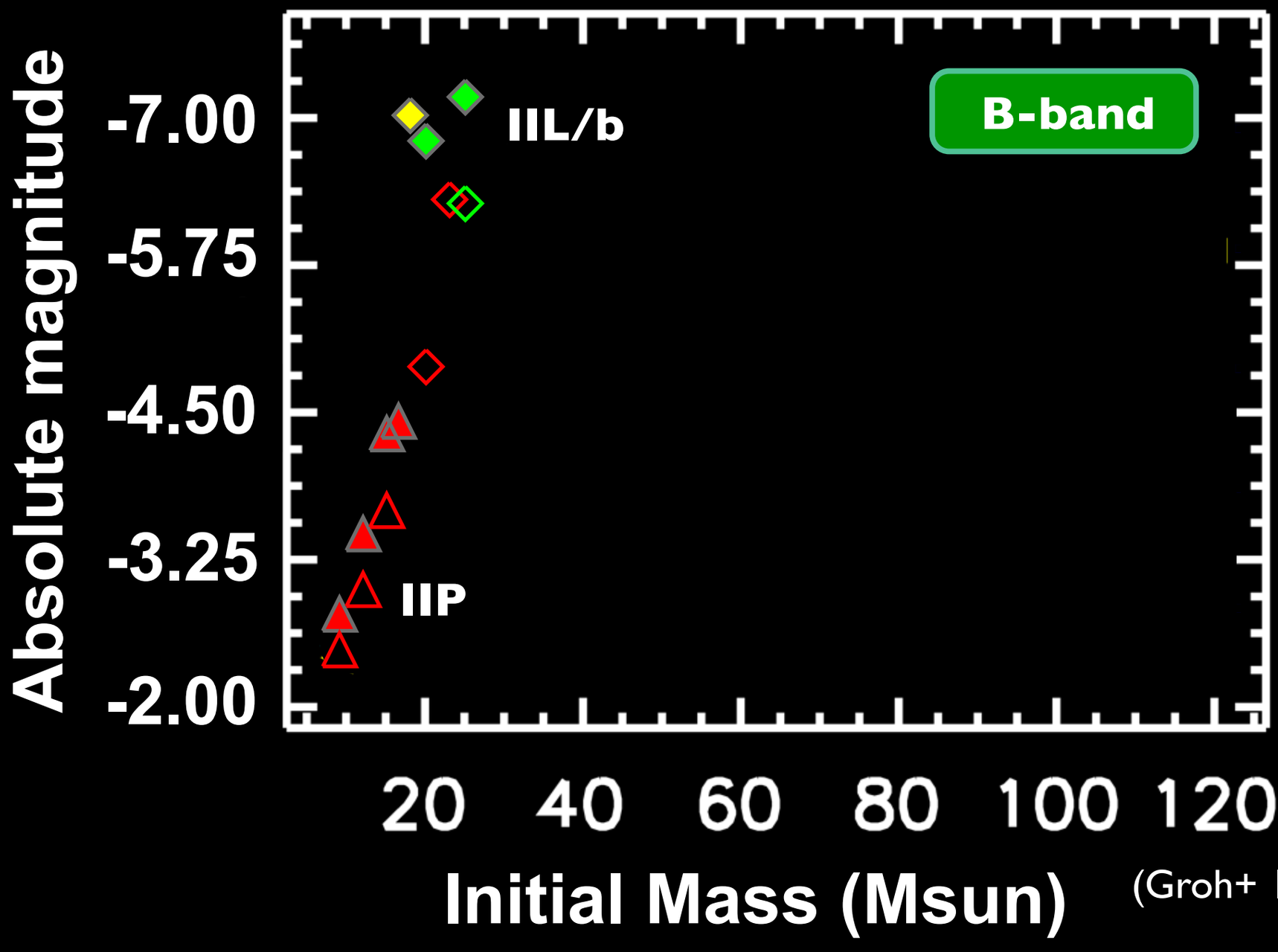
Progenitor Spectral Type

WO
WNL
LBV
YHG
RSG

Supernova Type

Ic
Ib
IIL or IIb
IIP

Open symbols: non-rotating models
Filled symbols: rotating models



(Groh+ 13, A&A in press; arXiv 1308.4601)

Predicting the absolute magnitudes of SN progenitors

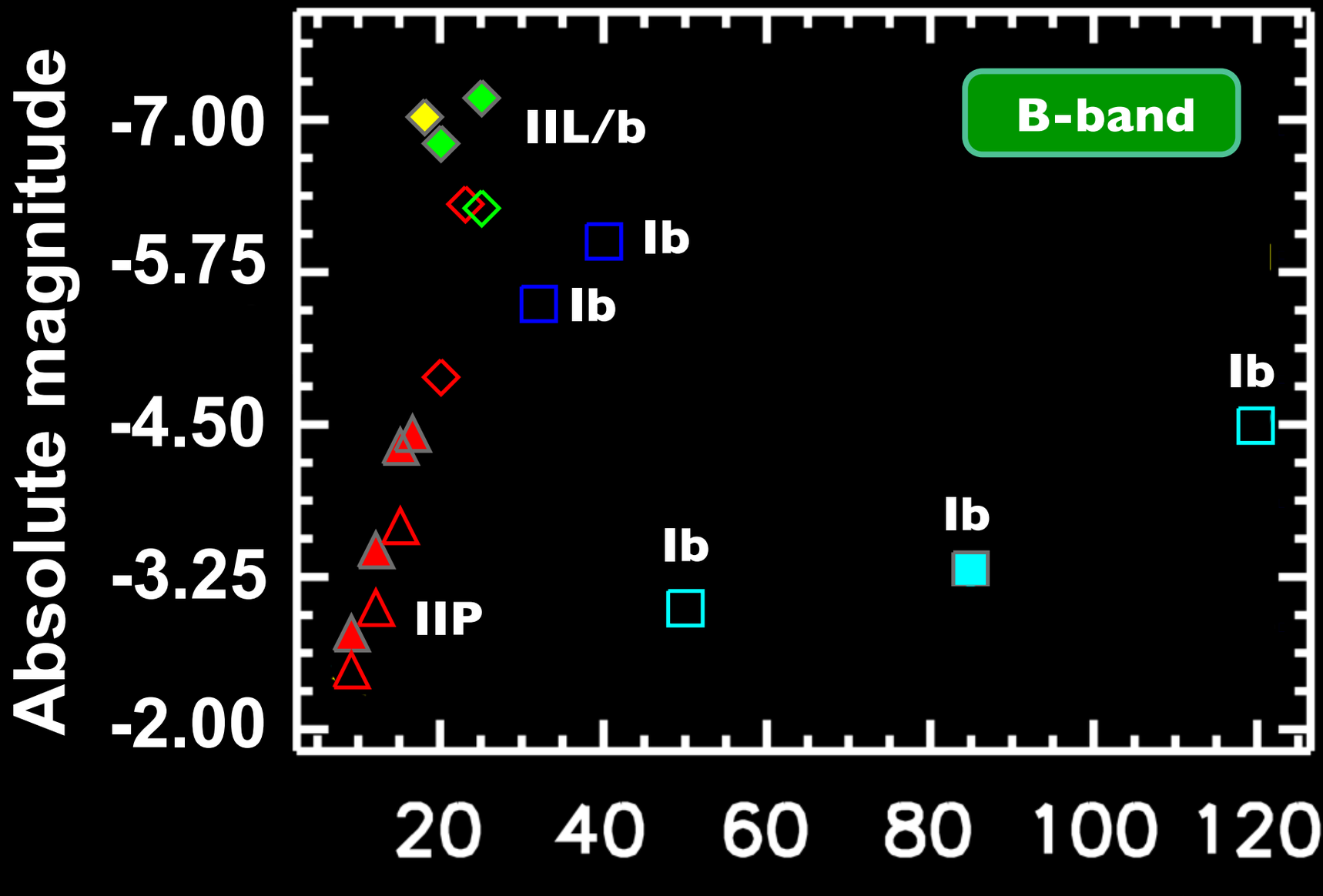
Progenitor Spectral Type

WO
WNL
LBV
YHG
RSG

Supernova Type

Ic
Ib
IIL or IIb
IIP

Open symbols: non-rotating models
Filled symbols: rotating models



(Groh+ 13, A&A in press; arXiv 1308.4601)

Predicting the absolute magnitudes of SN progenitors

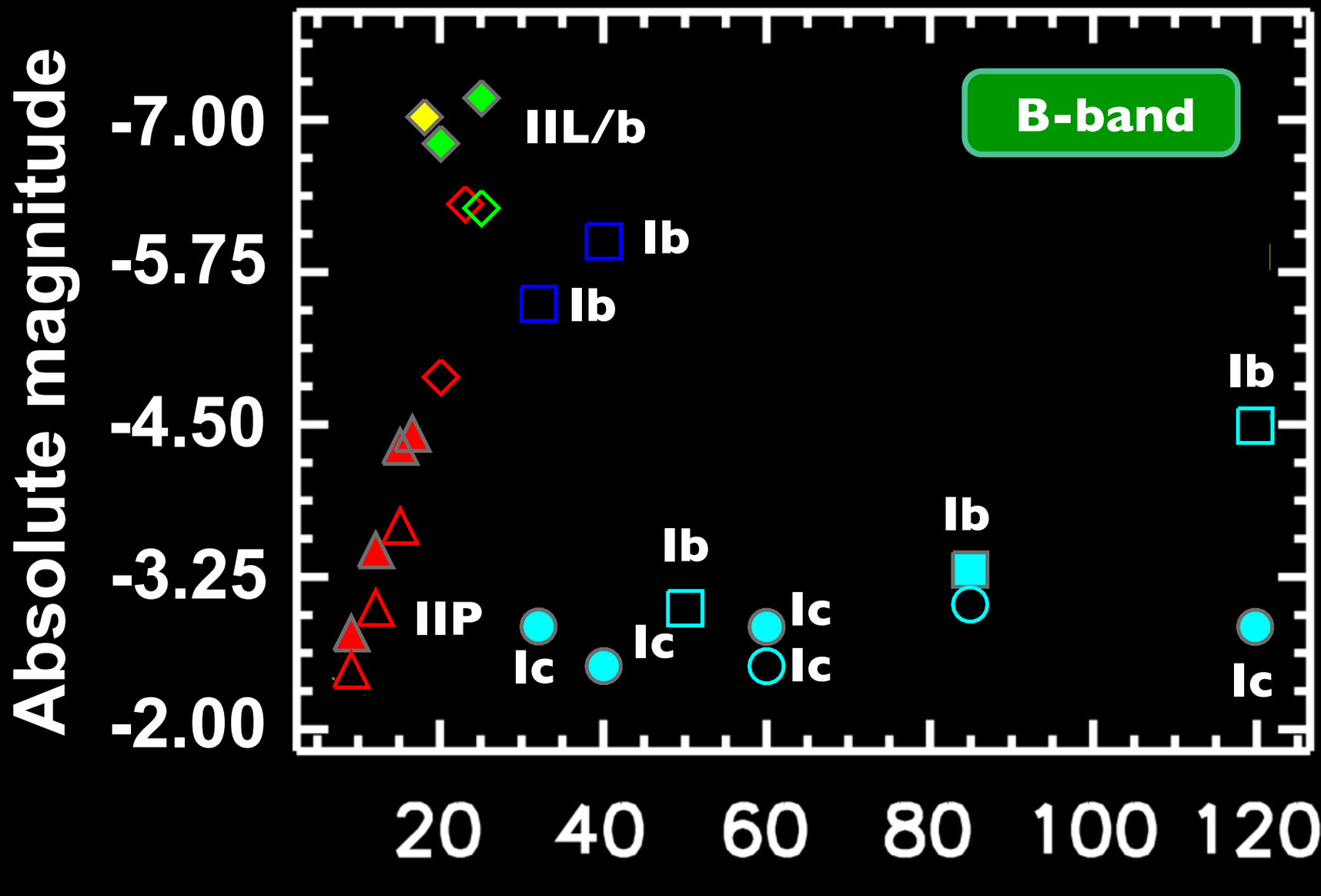
Progenitor Spectral Type

WO
WNL
LBV
YHG
RSG

Supernova Type

Ic
Ib
IIL or IIb
IIP

Open symbols: non-rotating models
Filled symbols: rotating models



(Groh+ 13, A&A in press; arXiv 1308.4601)

Predicting the absolute magnitudes of SN progenitors

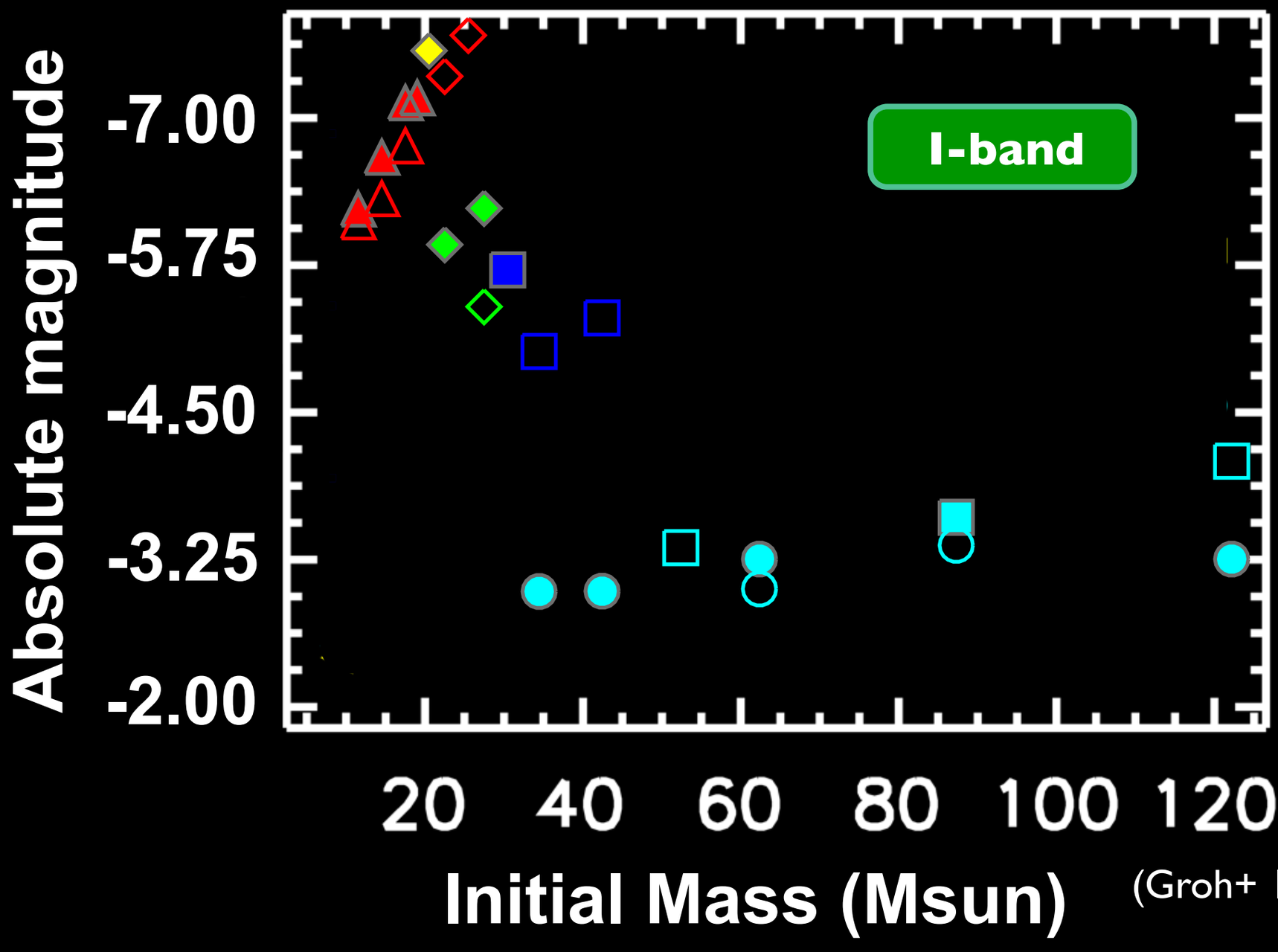
Progenitor Spectral Type

WO
WNL
LBV
YHG
RSG

Supernova Type

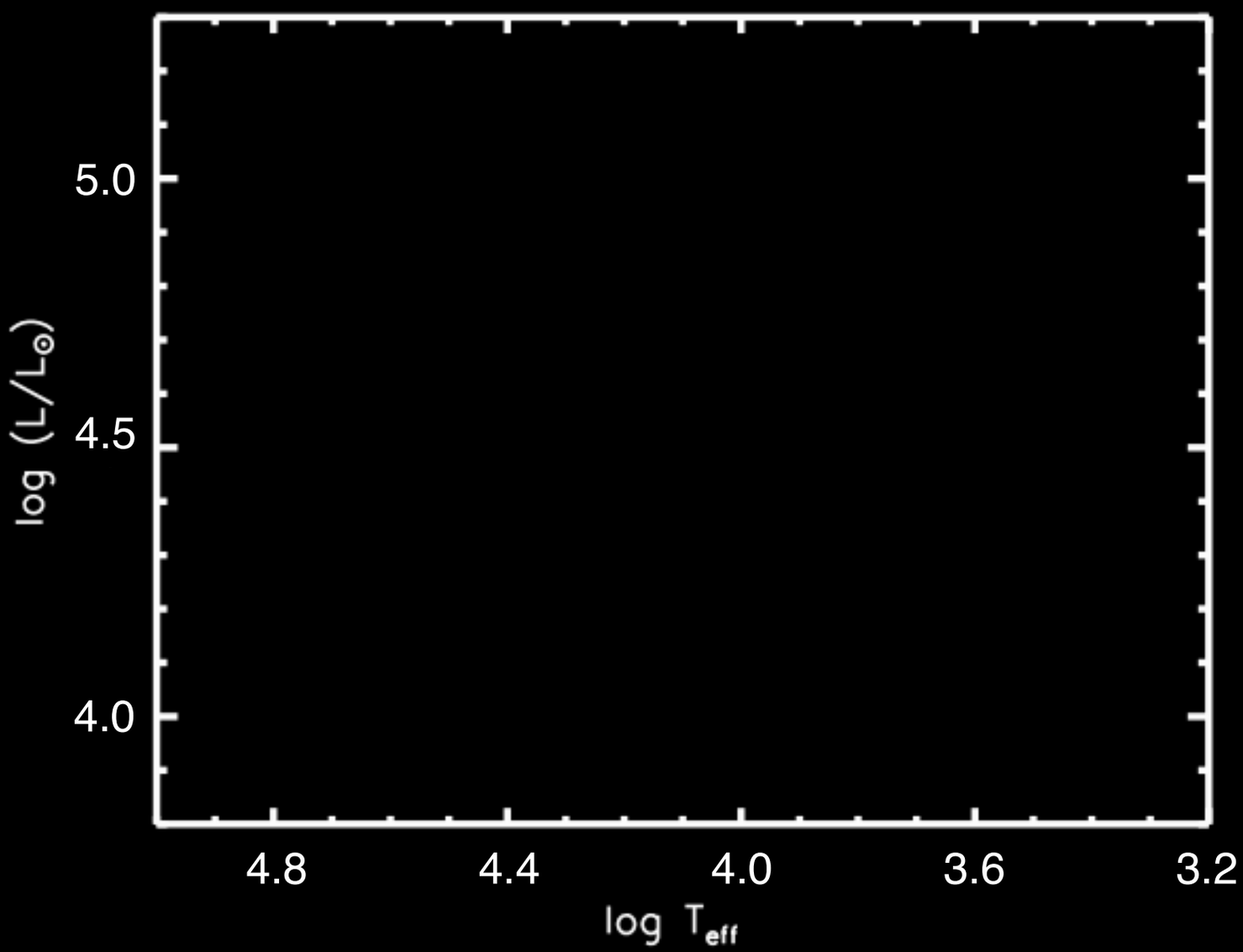
Ic
Ib
IIL or IIb
IIP

Open symbols: non-rotating models
Filled symbols: rotating models



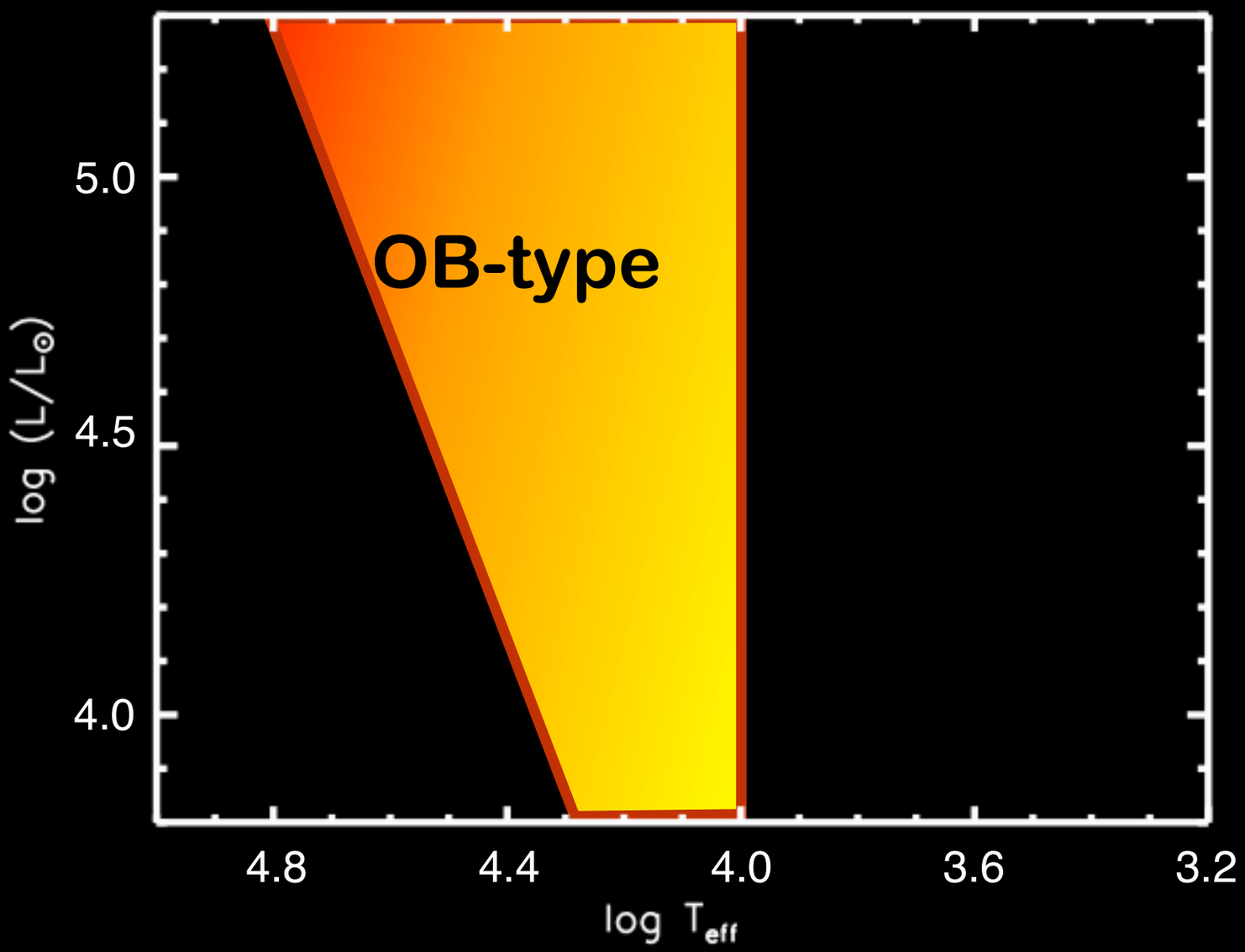
(Groh+ 13, A&A in press; arXiv 1308.4601)

SN IIP progenitors at solar Z



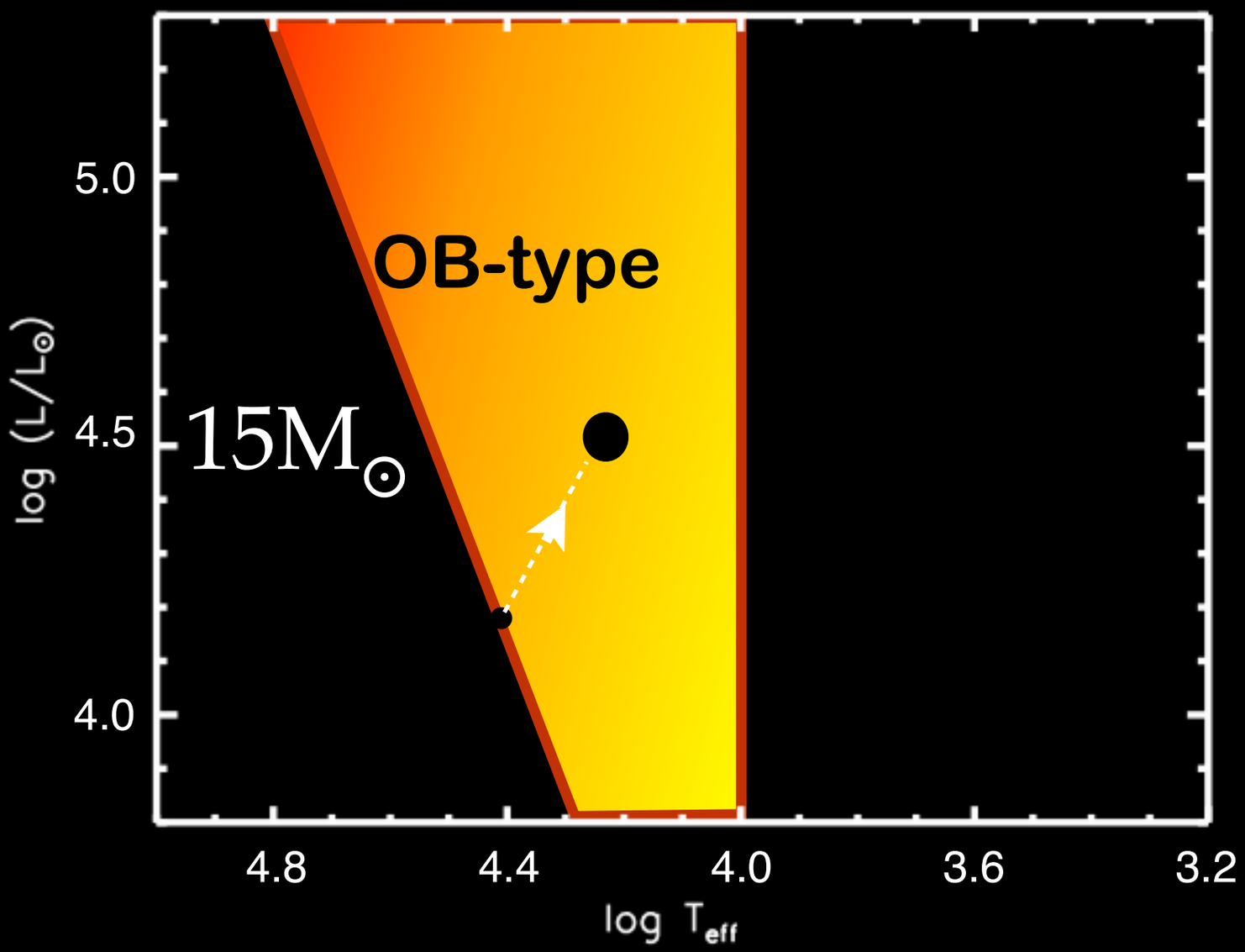
(after evol. tracks from Ekstrom+ 12)

SN IIP progenitors at solar Z



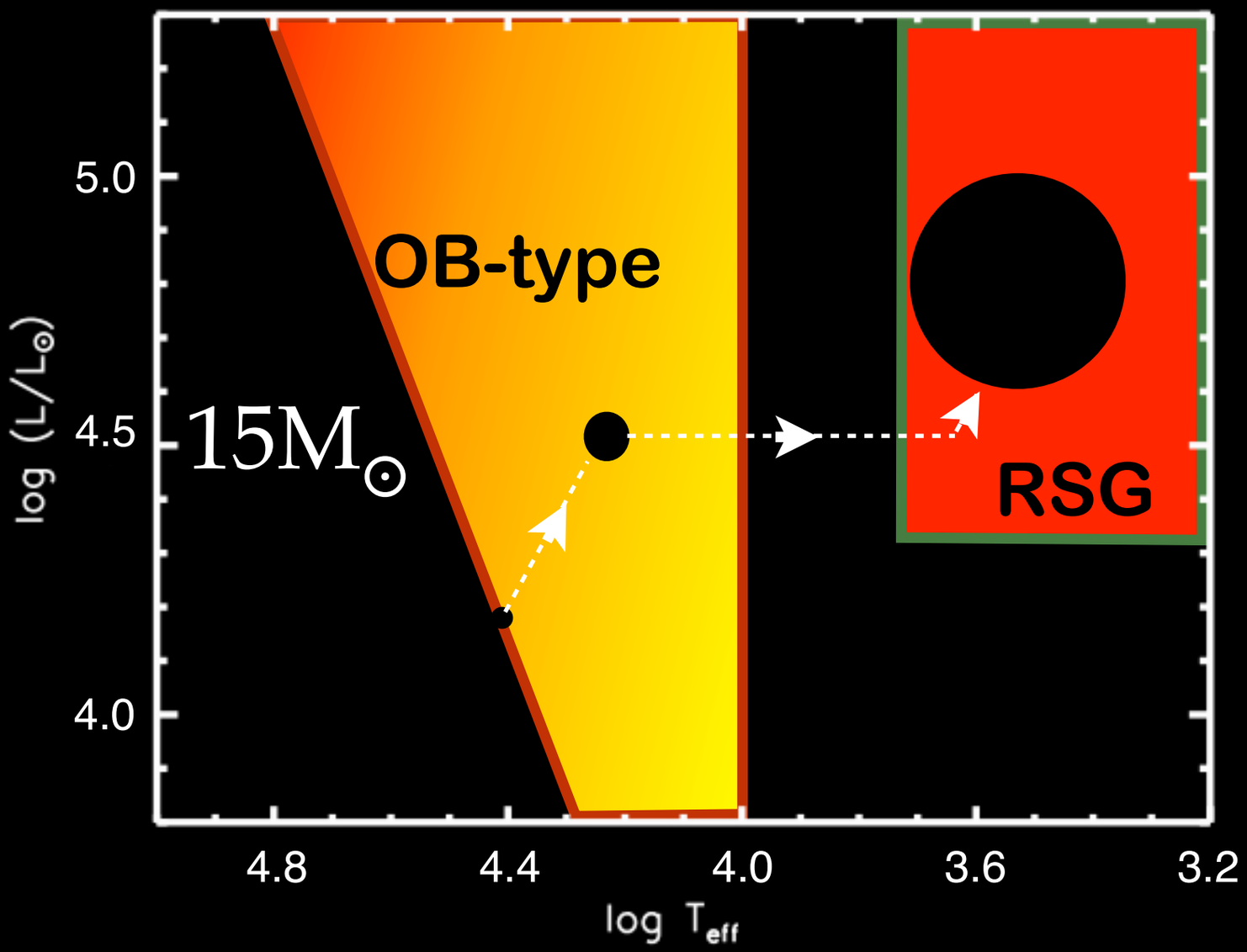
(after evol. tracks from Ekstrom+ 12)

SN IIP progenitors at solar Z



(after evol. tracks from Ekstrom+ 12)

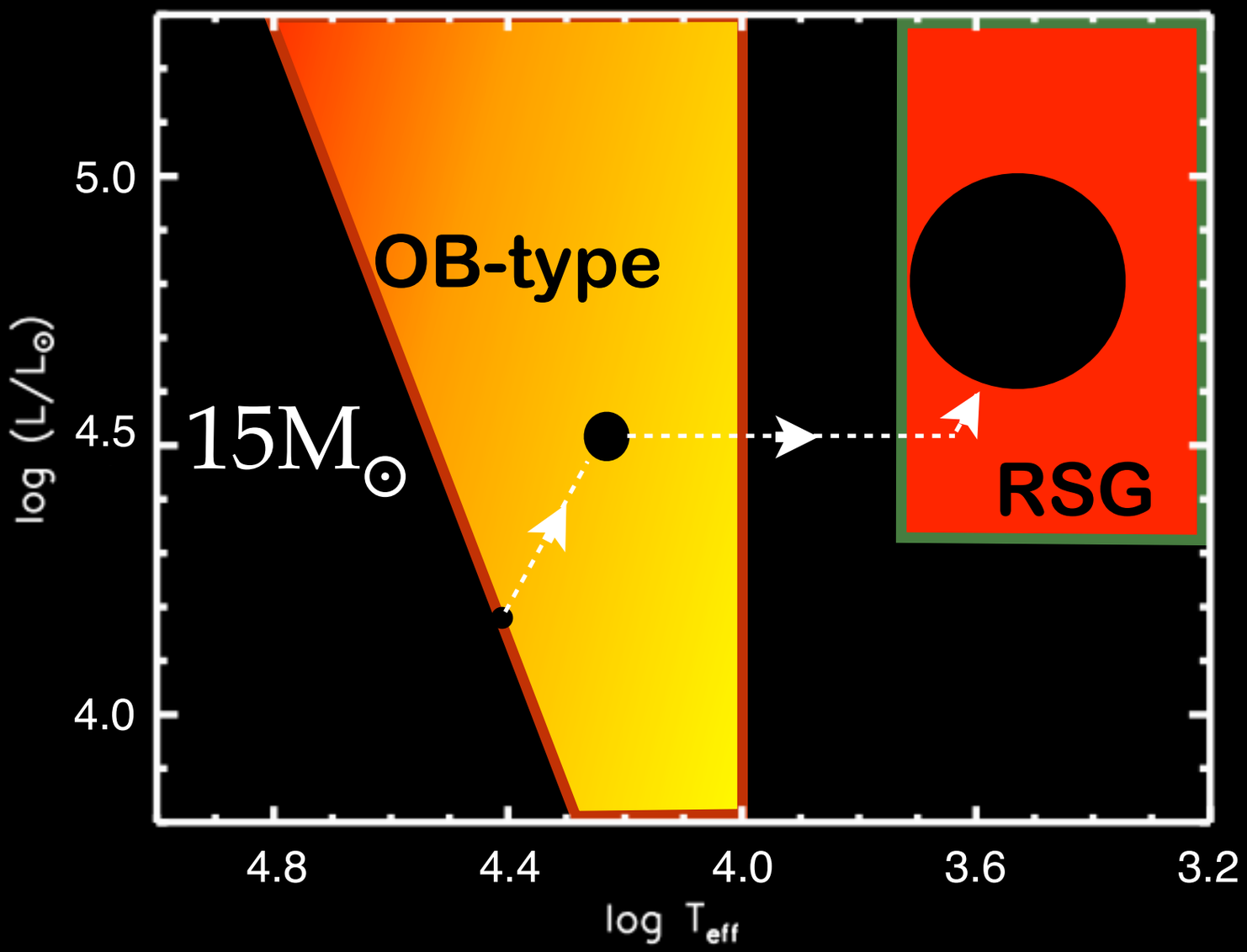
SN IIP progenitors at solar Z



(after evol. tracks from Ekstrom+ 12)

SN IIP progenitors at solar Z

OB-type → RSG → SN IIP



(after evol. tracks from Ekstrom+ 12)

Maximum initial mass of SN IIP progenitors

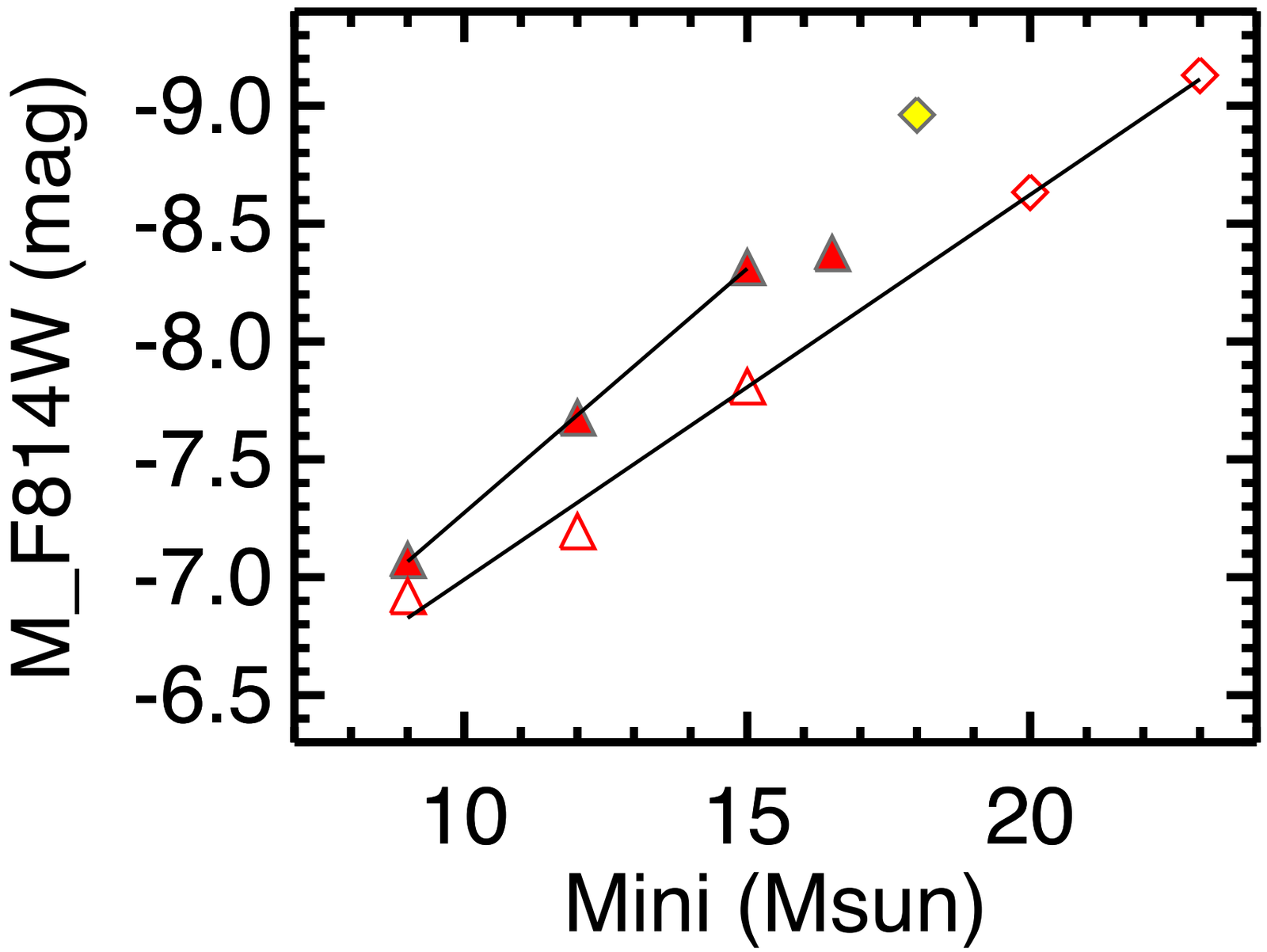
Progenitor Spectral Type

◆ YHG
▲△ RSG

Supernova Type

◆◇ IIL or IIb
▲△ IIP

Open symbols: non-rotating models
Filled symbols: rotating models



(Groh+ 13, A&A in press; arXiv 1308.4601)

Maximum initial mass of SN IIP progenitors

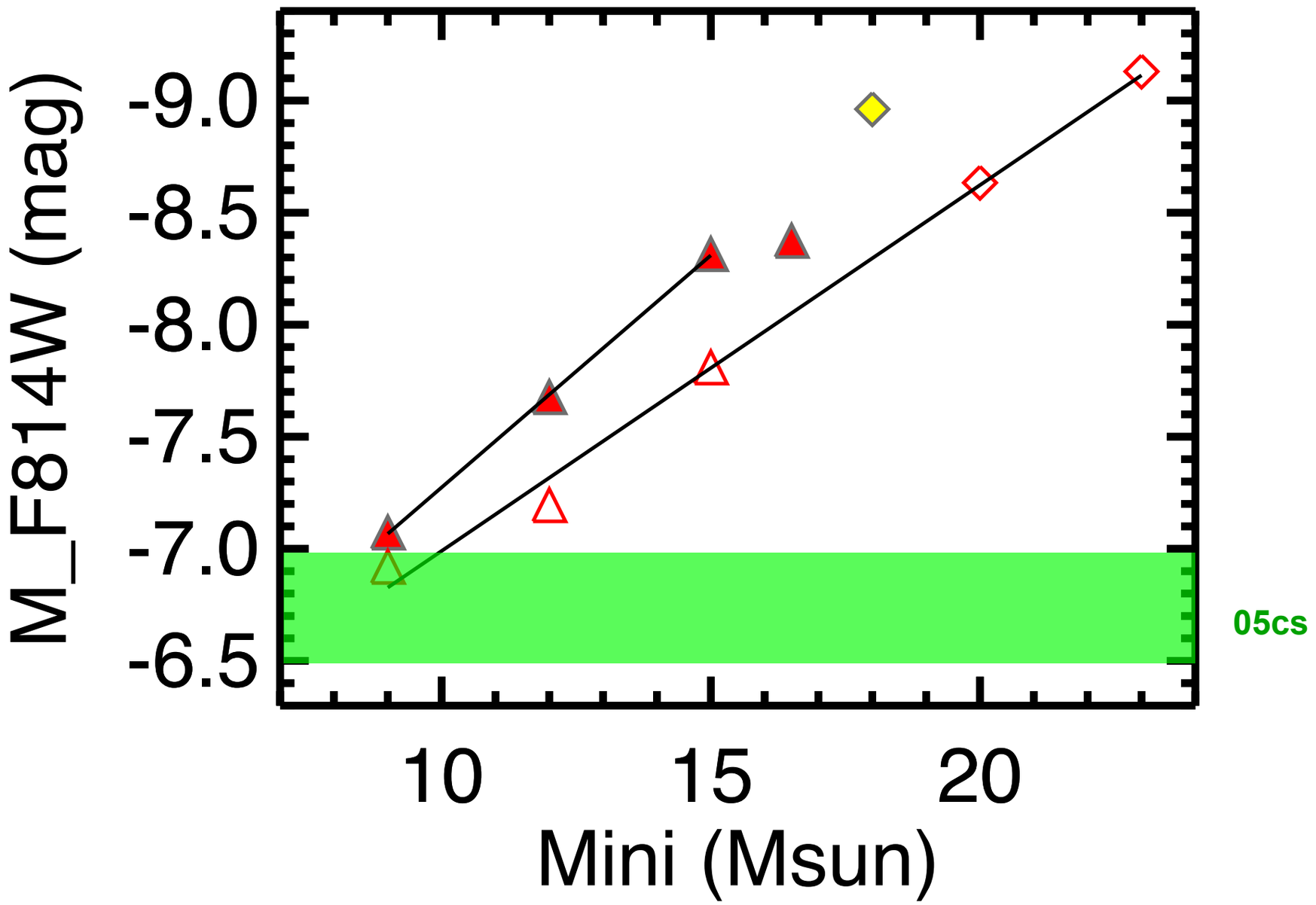
Progenitor Spectral Type

◆ YHG
▲△ RSG

Supernova Type

◆◇ IIL or IIb
▲△ IIP

Open symbols: non-rotating models
Filled symbols: rotating models



(Groh+ 13, A&A in press; arXiv 1308.4601)

Maximum initial mass of SN IIP progenitors

Progenitor Spectral Type

YHG

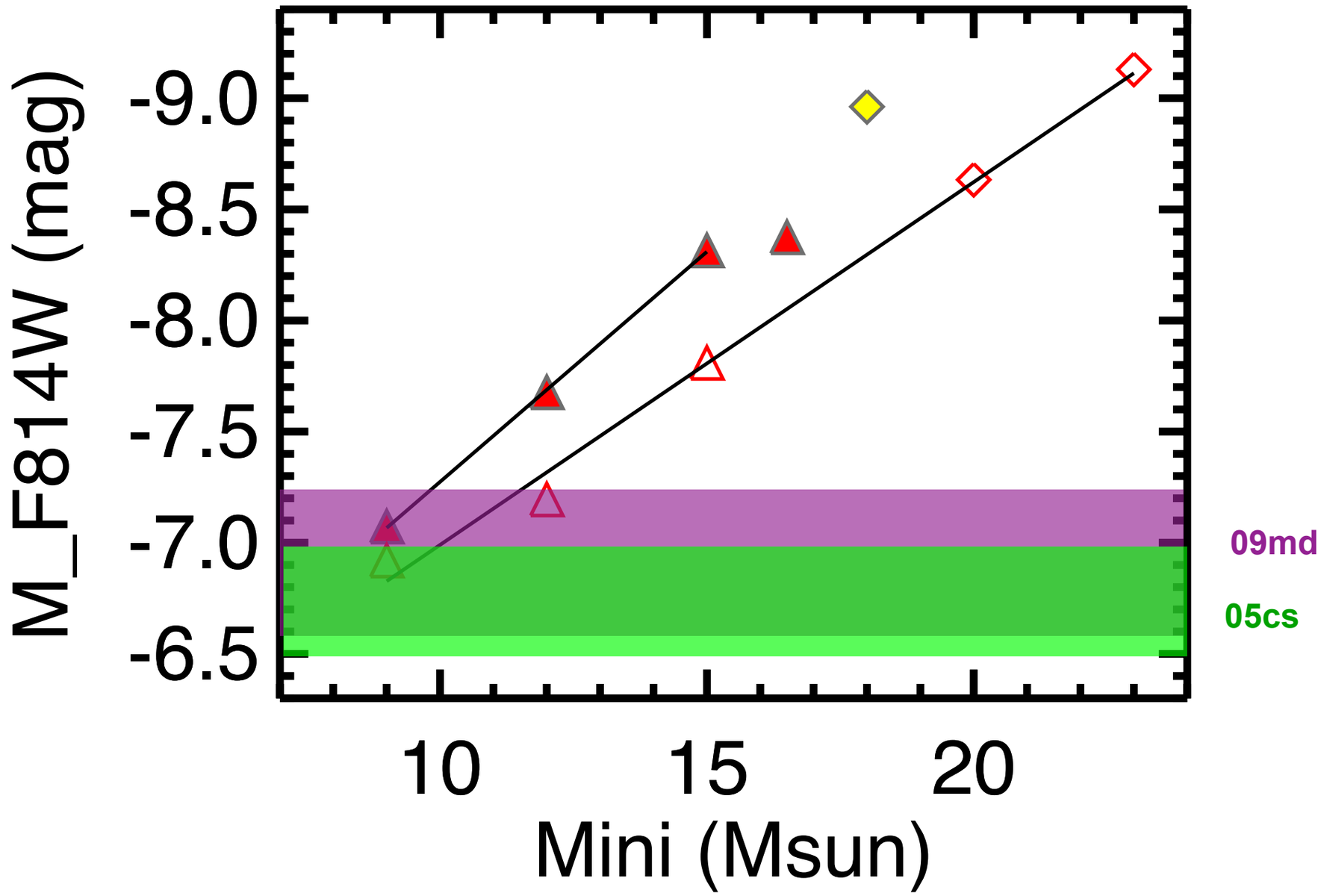
RSG

Supernova Type

IIL or IIb

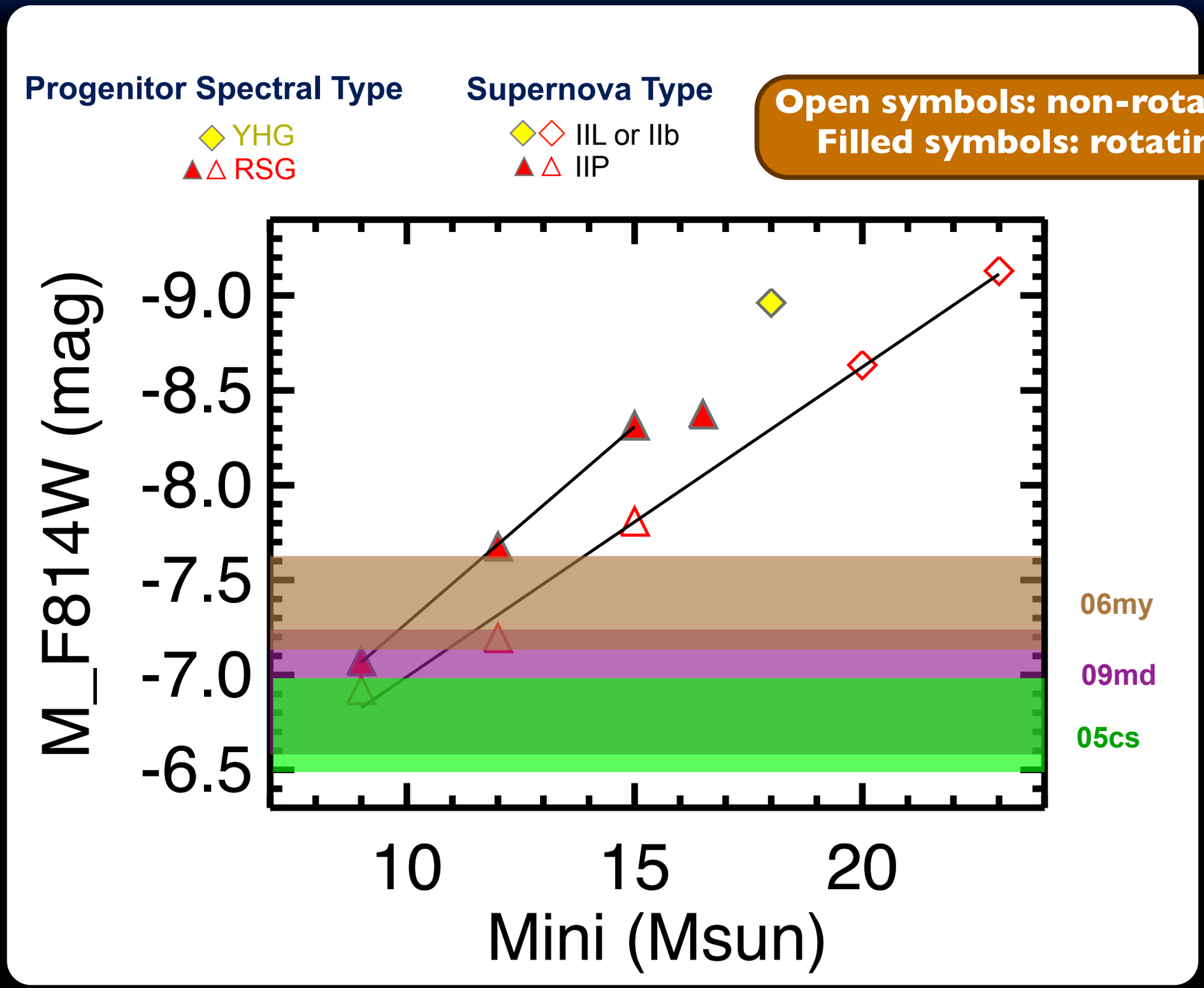
IIP

Open symbols: non-rotating models
Filled symbols: rotating models



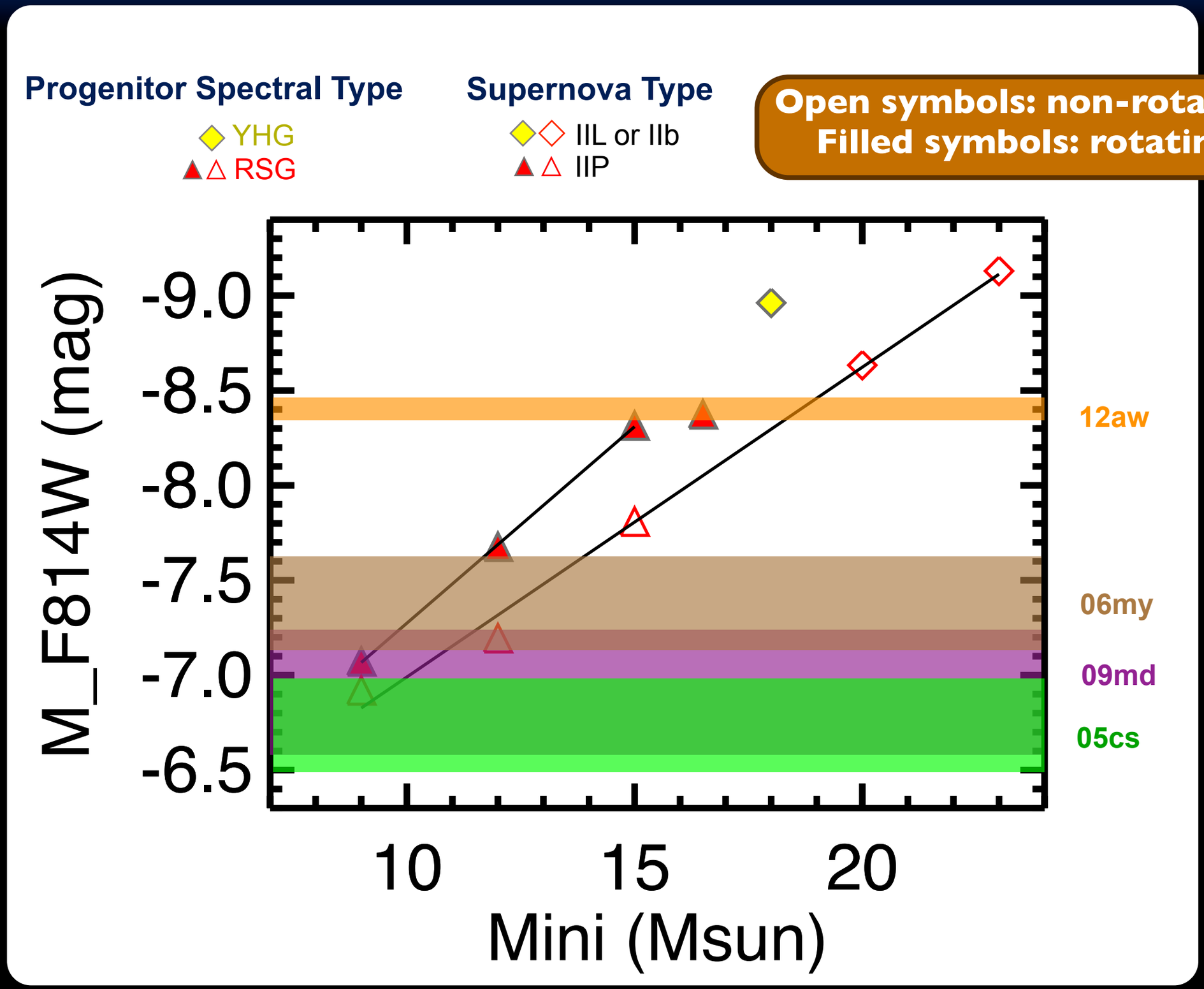
(Groh+ 13, A&A in press; arXiv 1308.4601)

Maximum initial mass of SN IIP progenitors



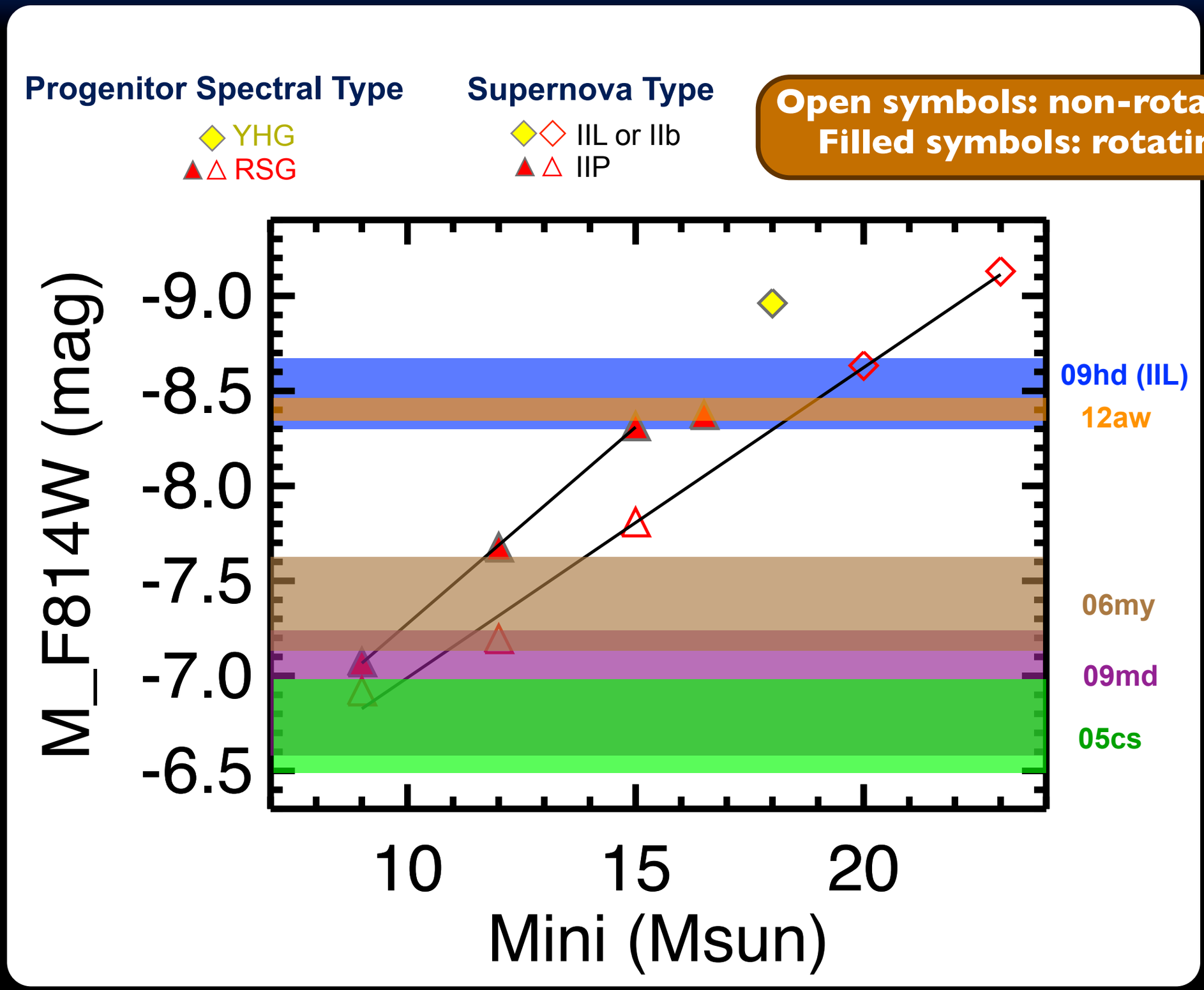
(Groh+ 13, A&A in press; arXiv 1308.4601)

Maximum initial mass of SN IIP progenitors



(Groh+ 13, A&A in press; arXiv 1308.4601)

Maximum initial mass of SN IIP progenitors



(Groh+ 13, A&A in press; arXiv 1308.4601)

Maximum initial mass of SN IIP progenitors

Agrees with observations of SN II progenitors (Smartt 09)

Progenitor Spectral Type

◆ YHG

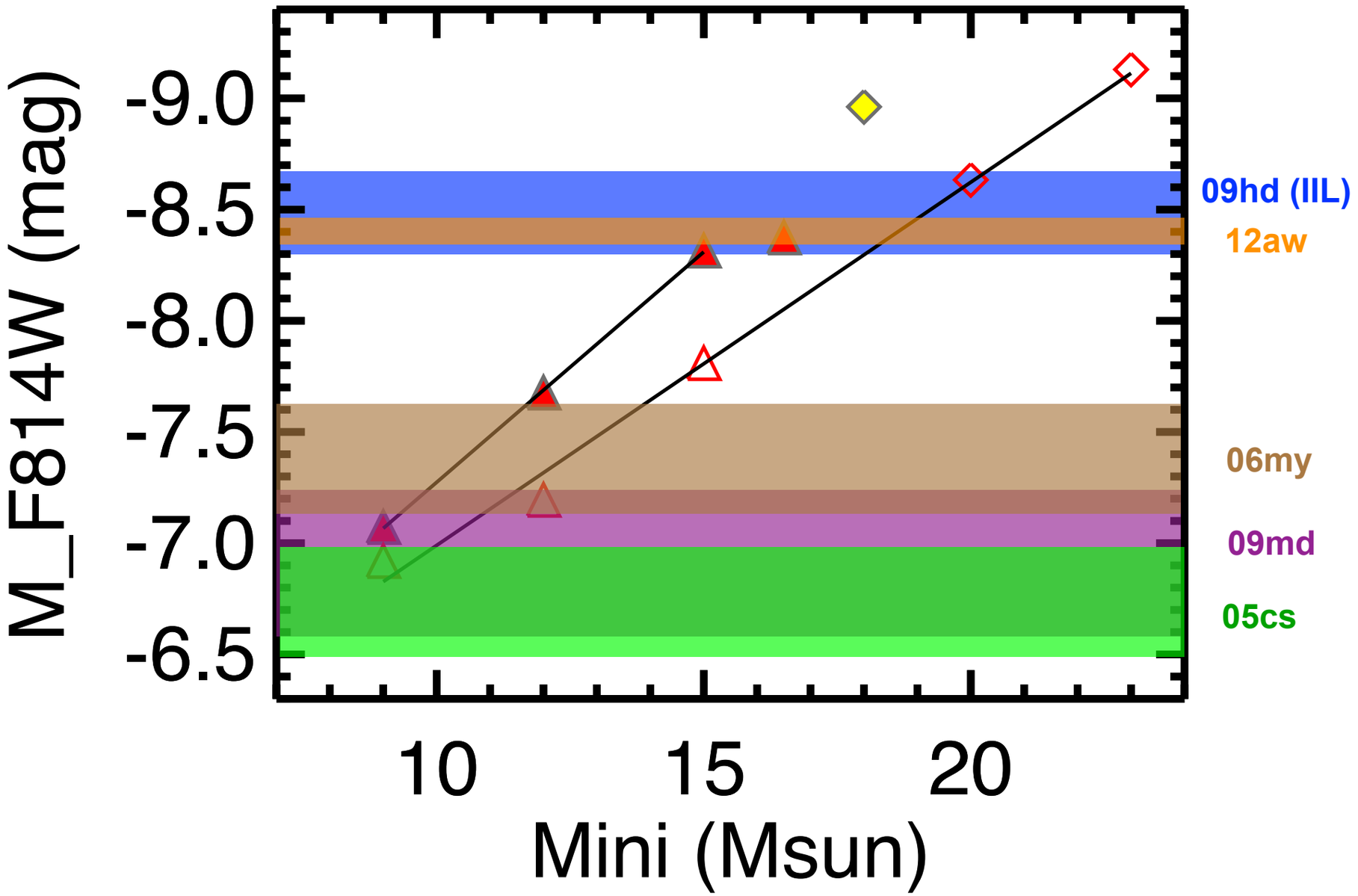
▲△ RSG

Supernova Type

◆◇ IIL or IIb

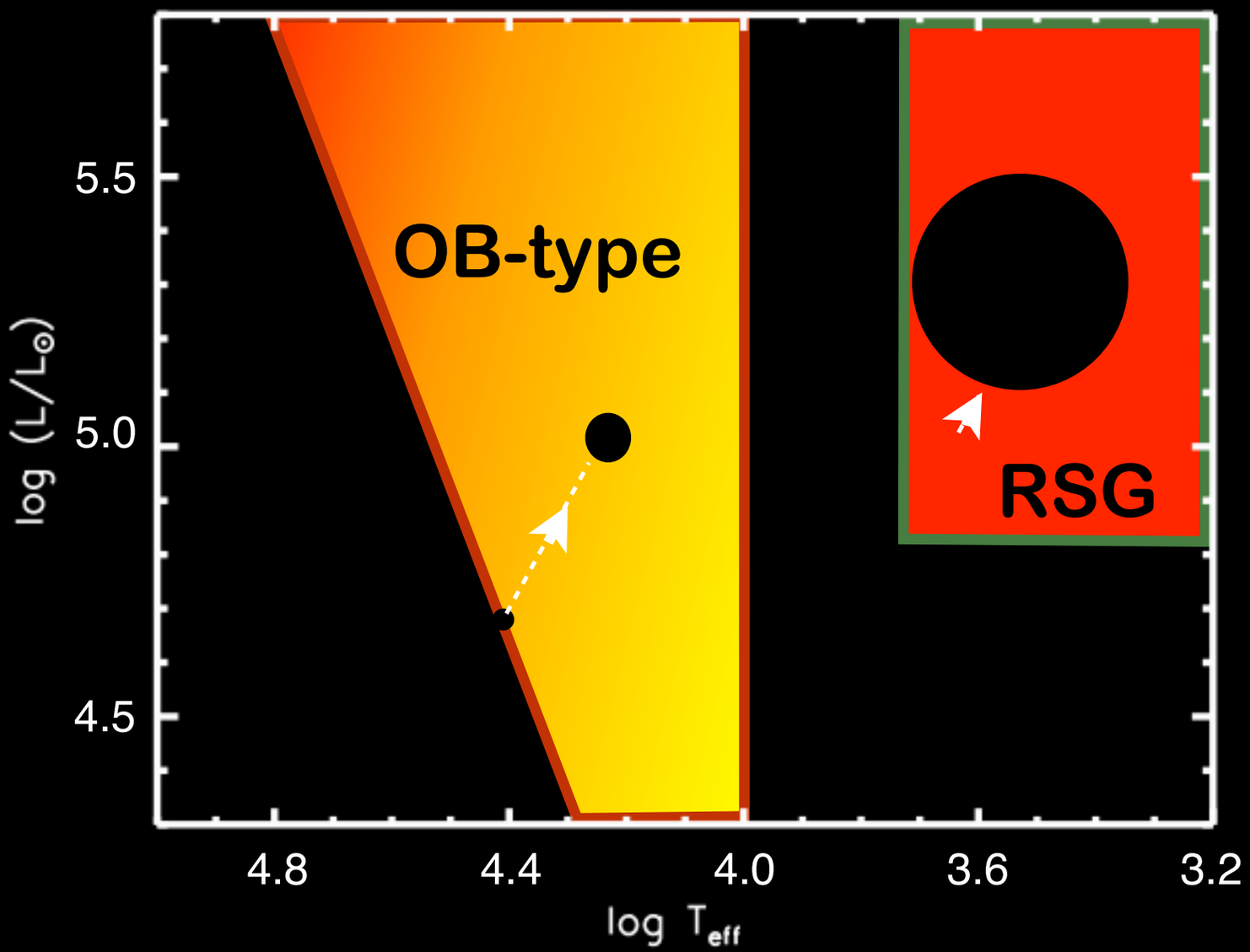
▲△ IIP

Open symbols: non-rotating models
Filled symbols: rotating models



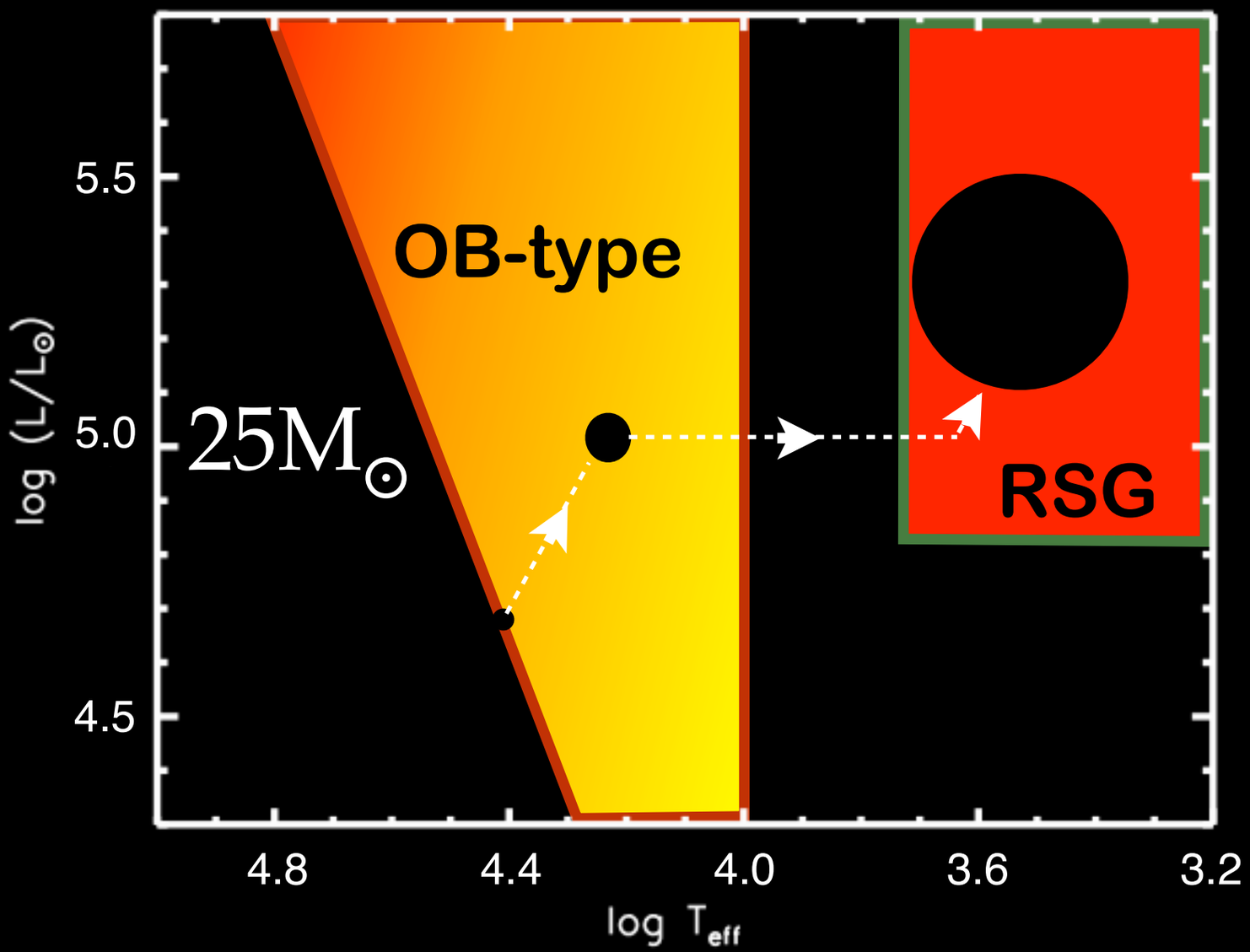
(Groh+ 13, A&A in press; arXiv 1308.4601)

SN IIL/b progenitors at solar Z



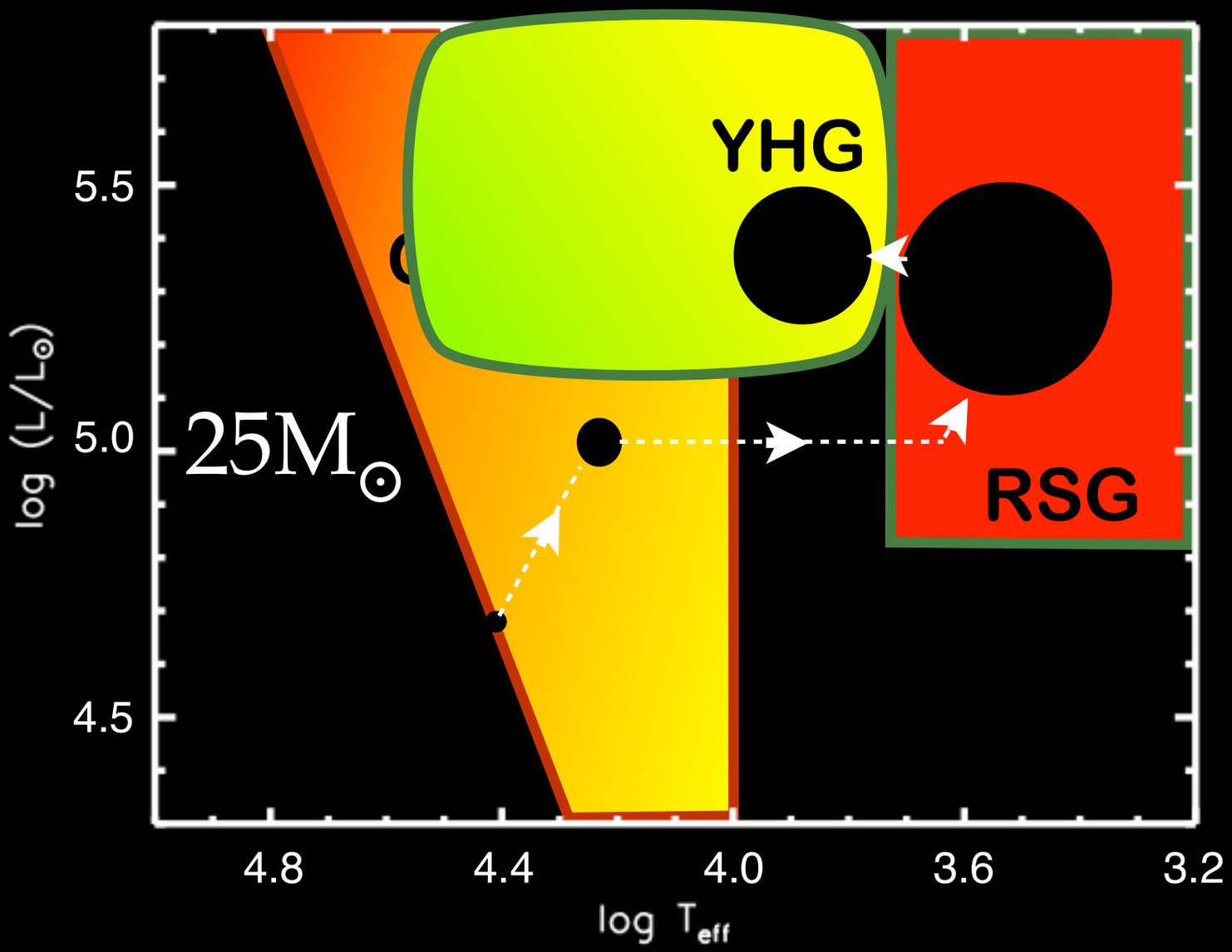
(after Groh+ 13a)

SN IIL/b progenitors at solar Z



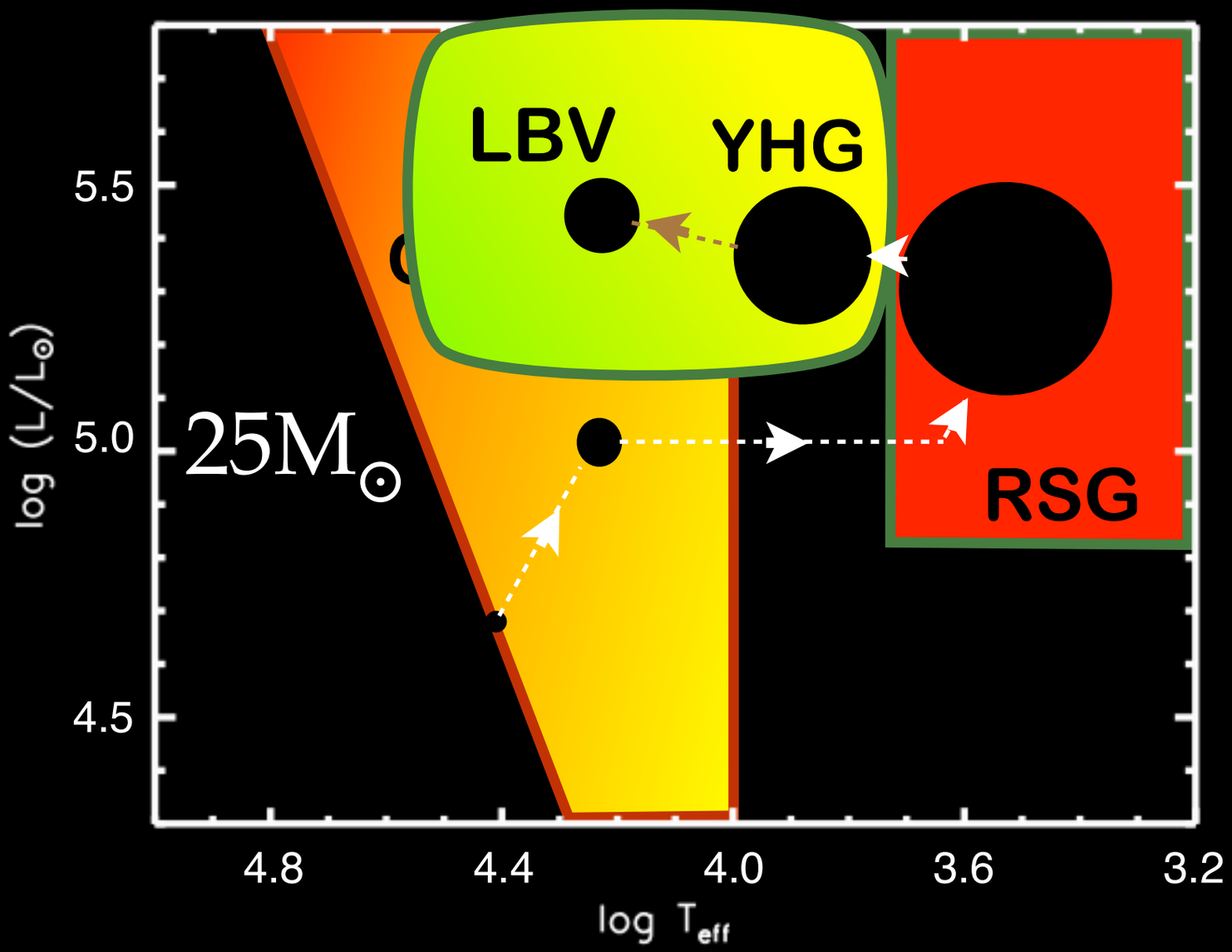
(after Groh+ 13a)

SN IIL/b progenitors at solar Z



(after Groh+ 13a)

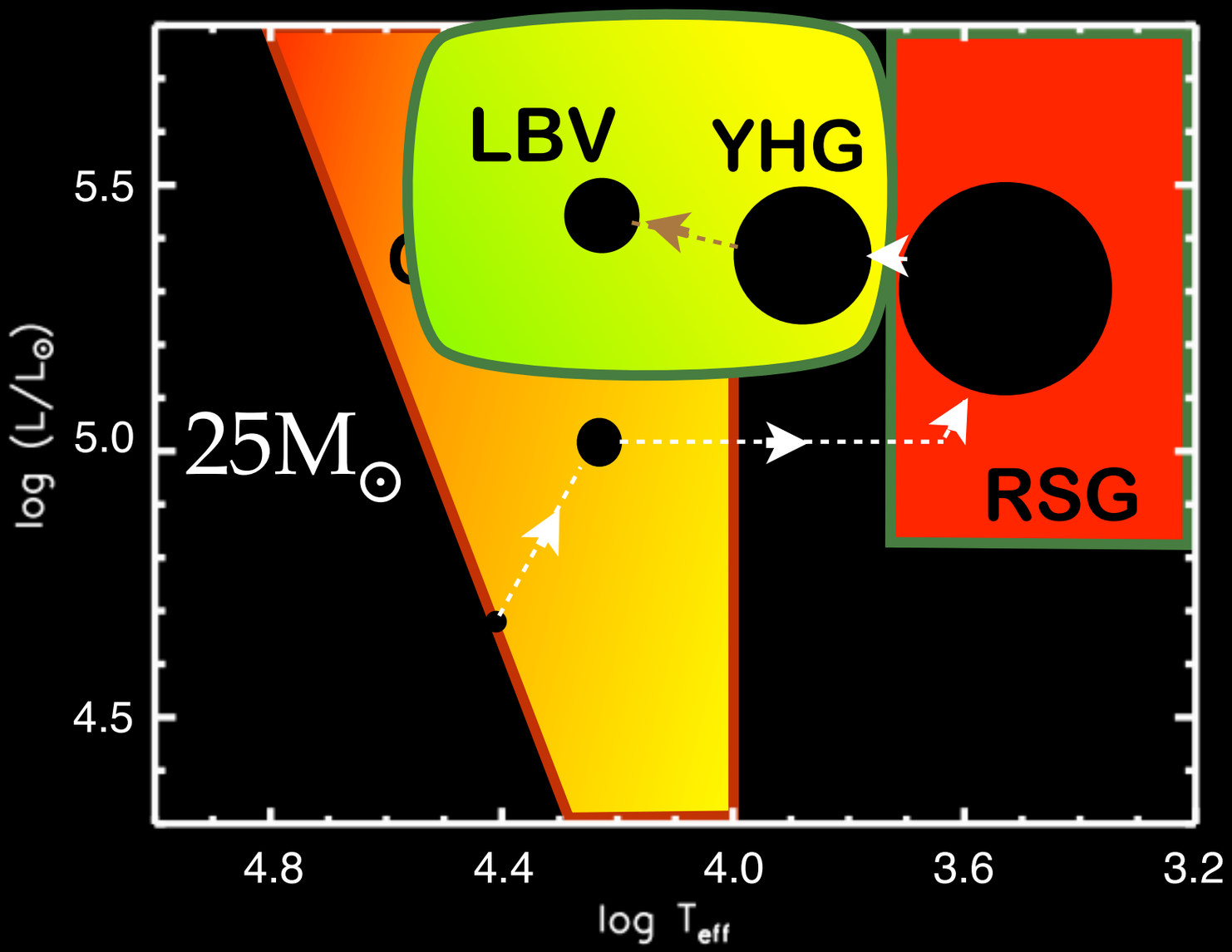
SN IIL/b progenitors at solar Z



(after Groh+ 13a)

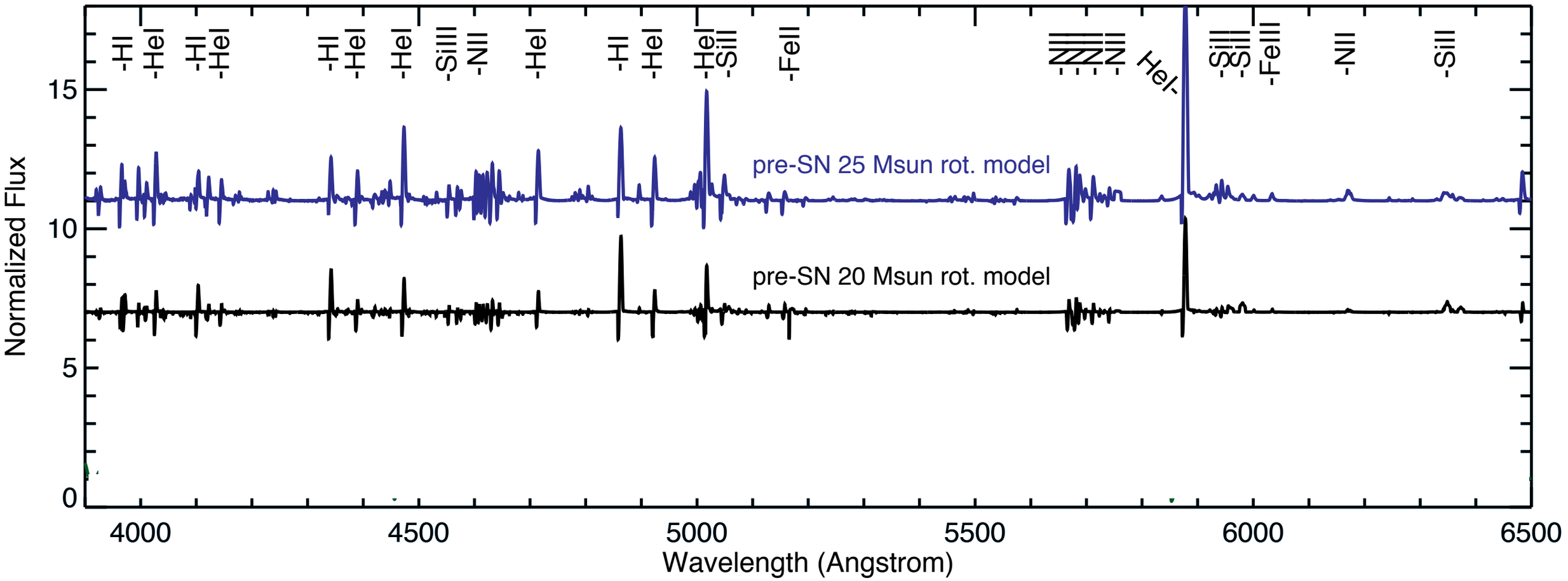
SN IIL/b progenitors at solar Z

OB-type → RSG → YHG/LBV → SN IIL/b



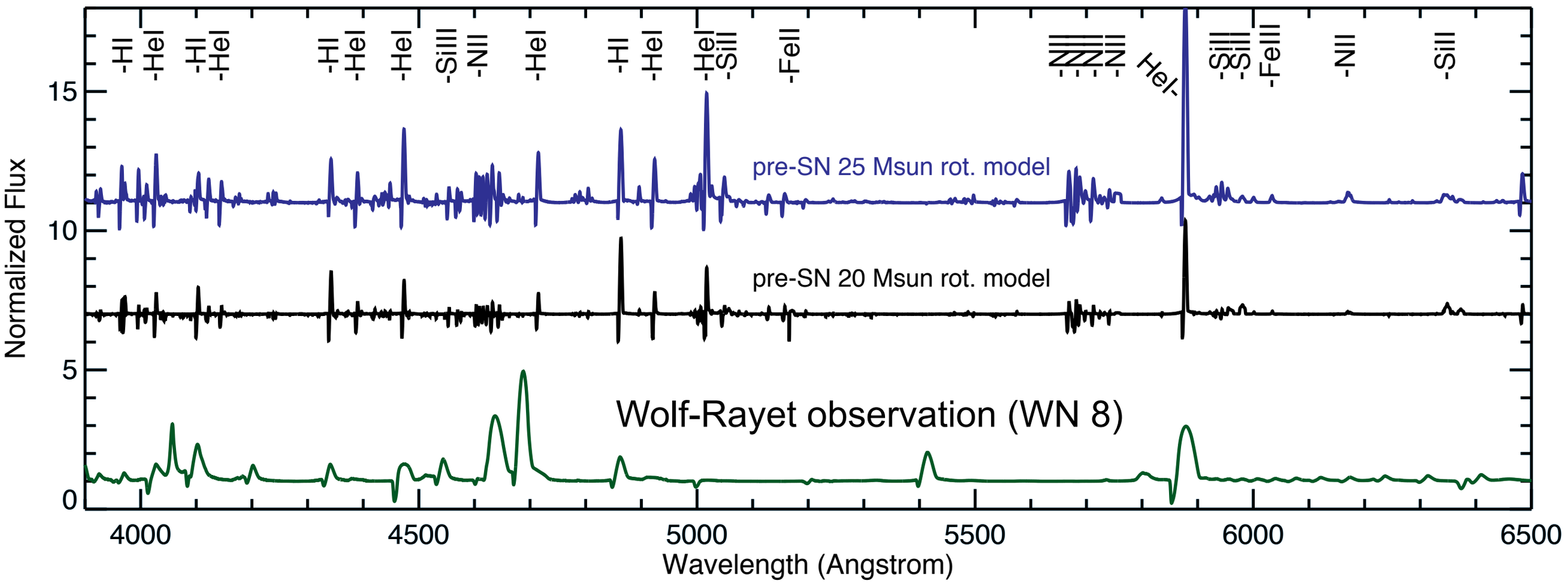
(after Groh+ 13a)

LBVs as progenitors of SNe from 20-25 $M_\odot$ stars



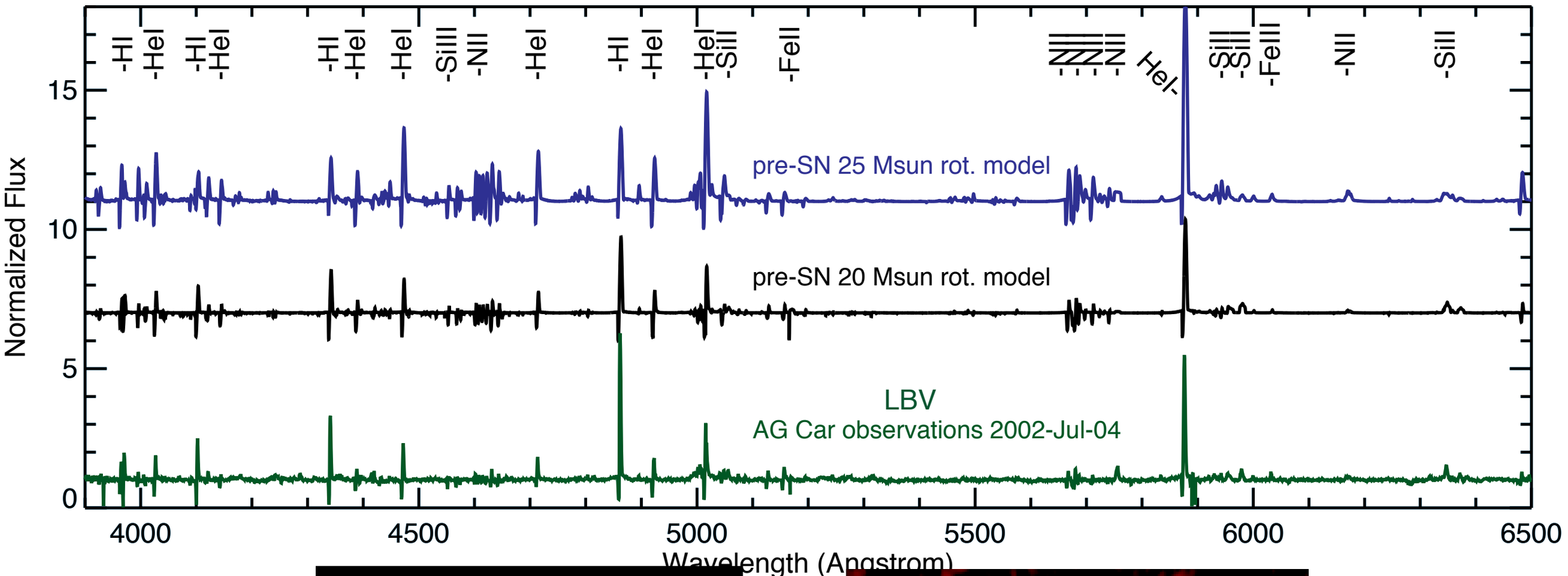
(Groh+ 13, A&A 550, L7)

LBVs as progenitors of SNe from 20-25 $M_\odot$ stars

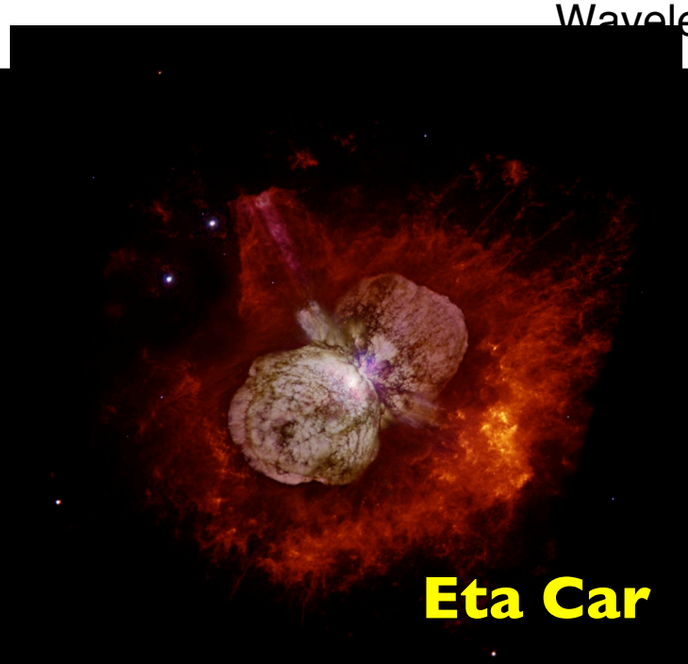


(Groh+ 13, A&A 550, L7)

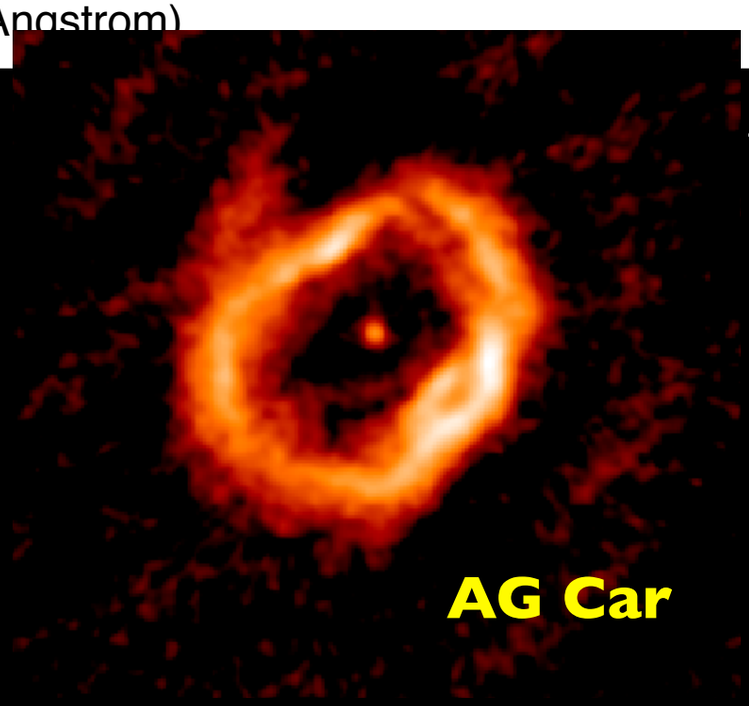
LBVs as progenitors of SNe from 20-25 $M_\odot$ stars



13, A&A 550, L7)

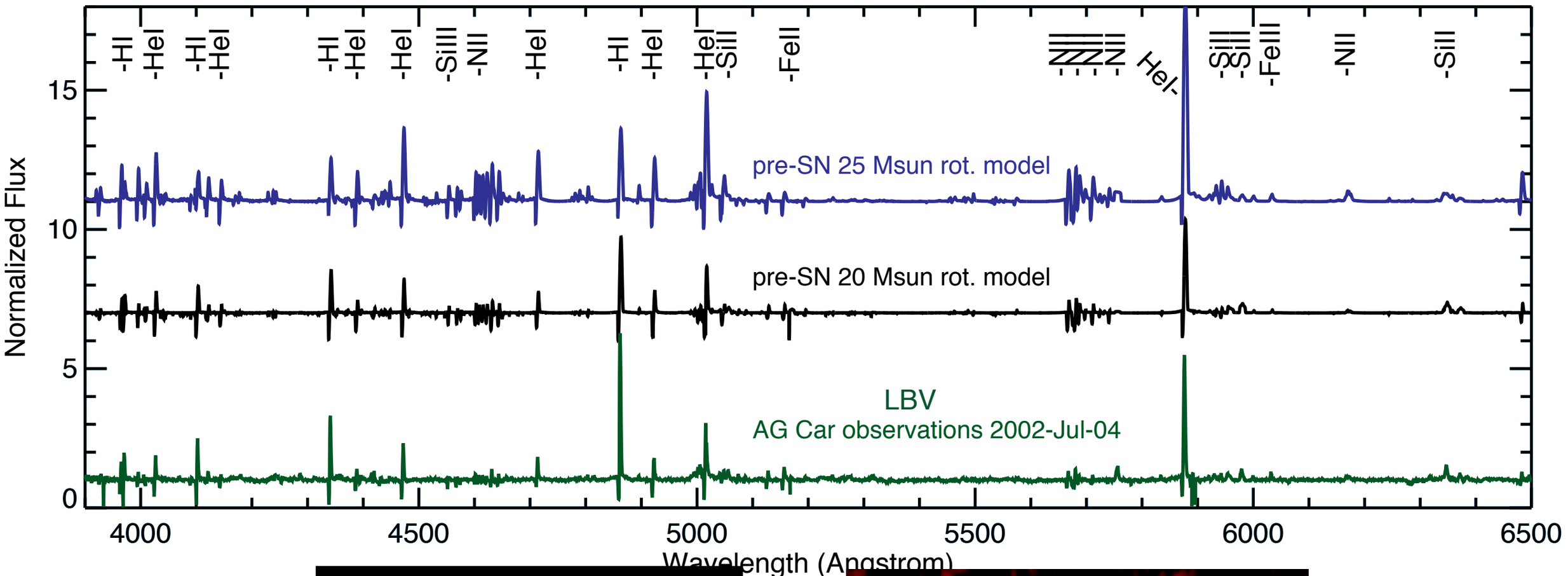


(Credit: N. Smith, J. Morse, NASA/ESA)



(Credit: S. White)

LBVs as progenitors of SNe from 20-25 $M_\odot$ stars



13, A&A 550, L7)

Now: LBVs are progenitors of SNe from 20-25 $M_\odot$ rotating stars (similar spectrum to Eta Car and AG Car , but lower luminosity)

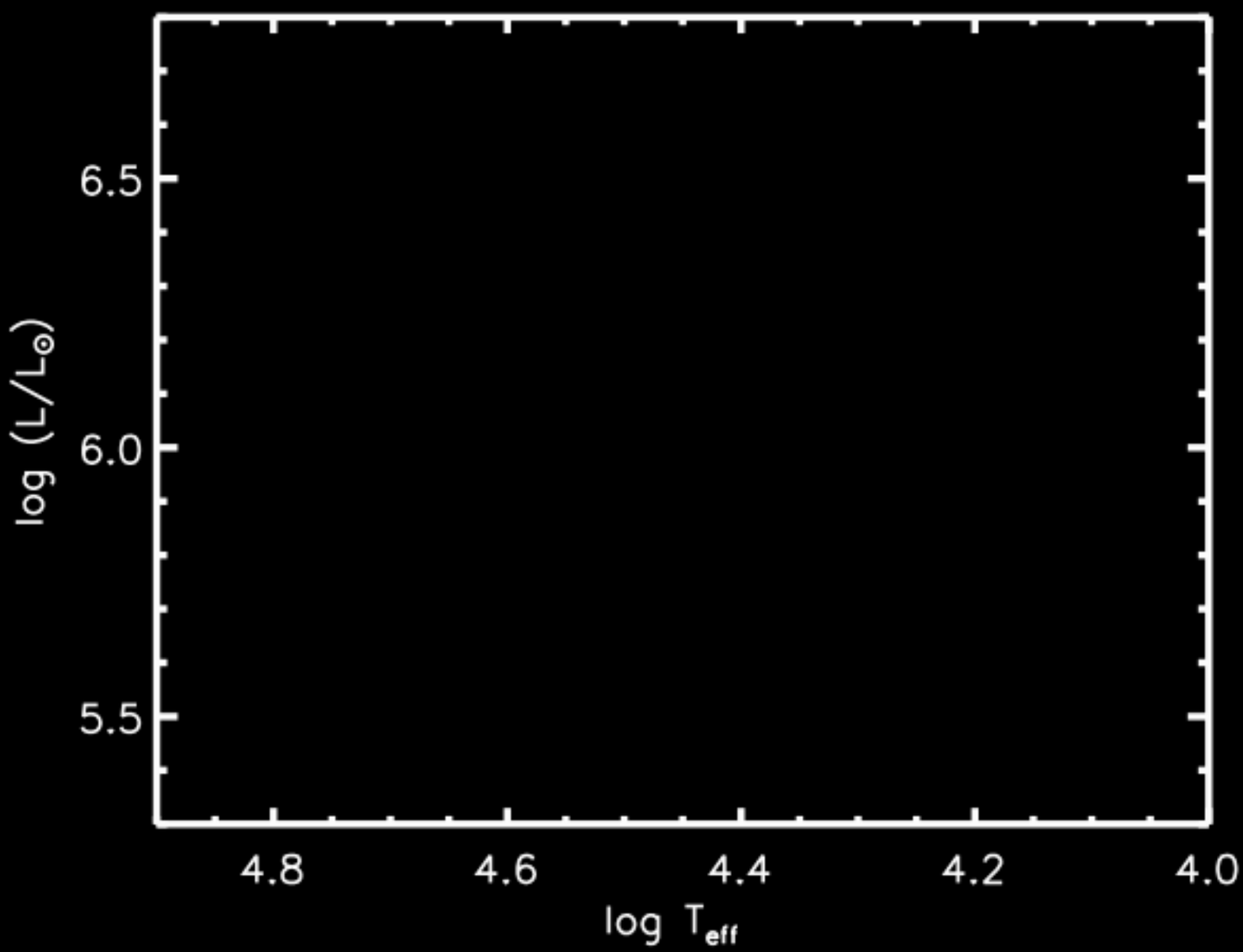
Eta Car

(Credit: N. Smith, J. Morse, NASA/ESA)

AG Car

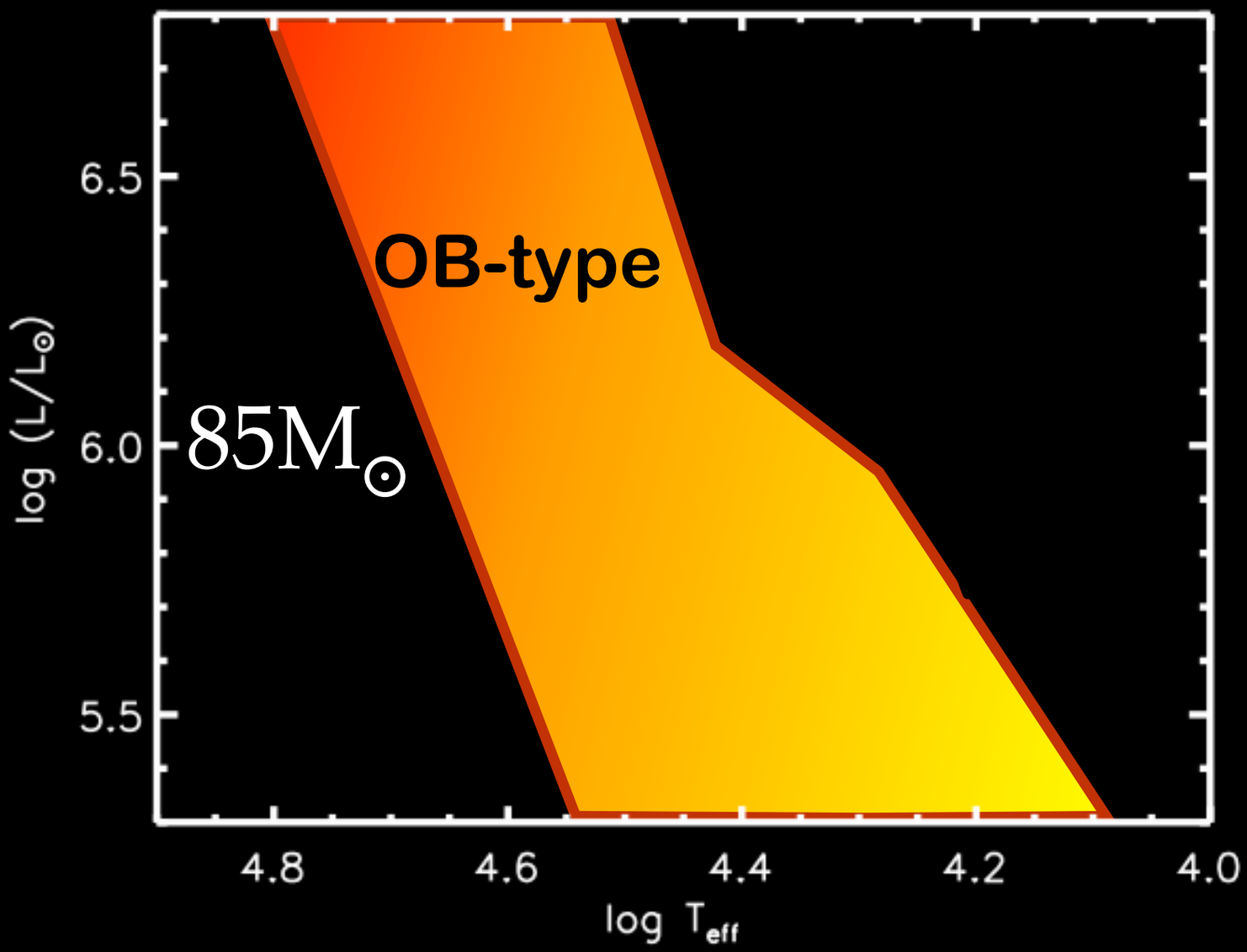
(Credit: S. White)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)



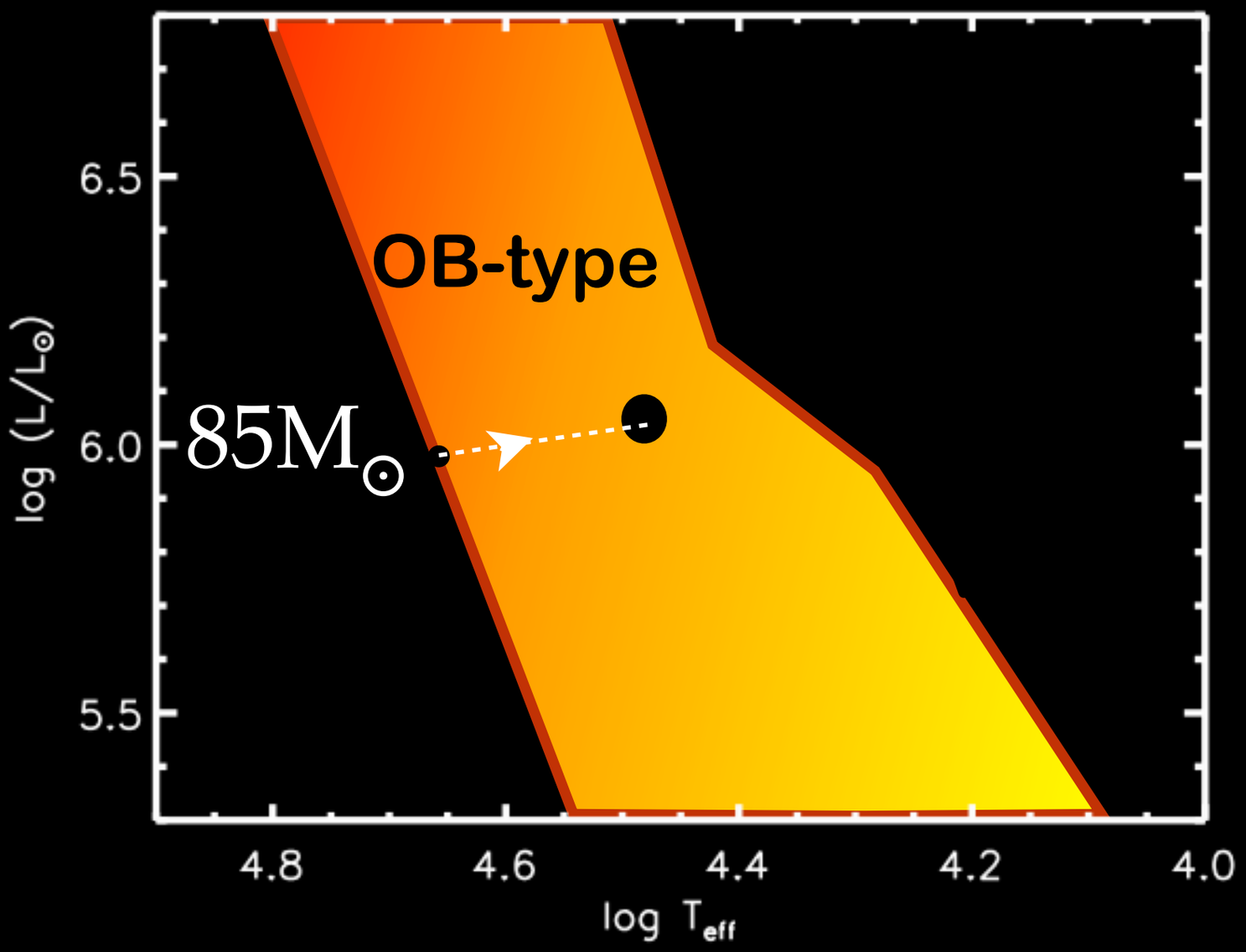
(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)



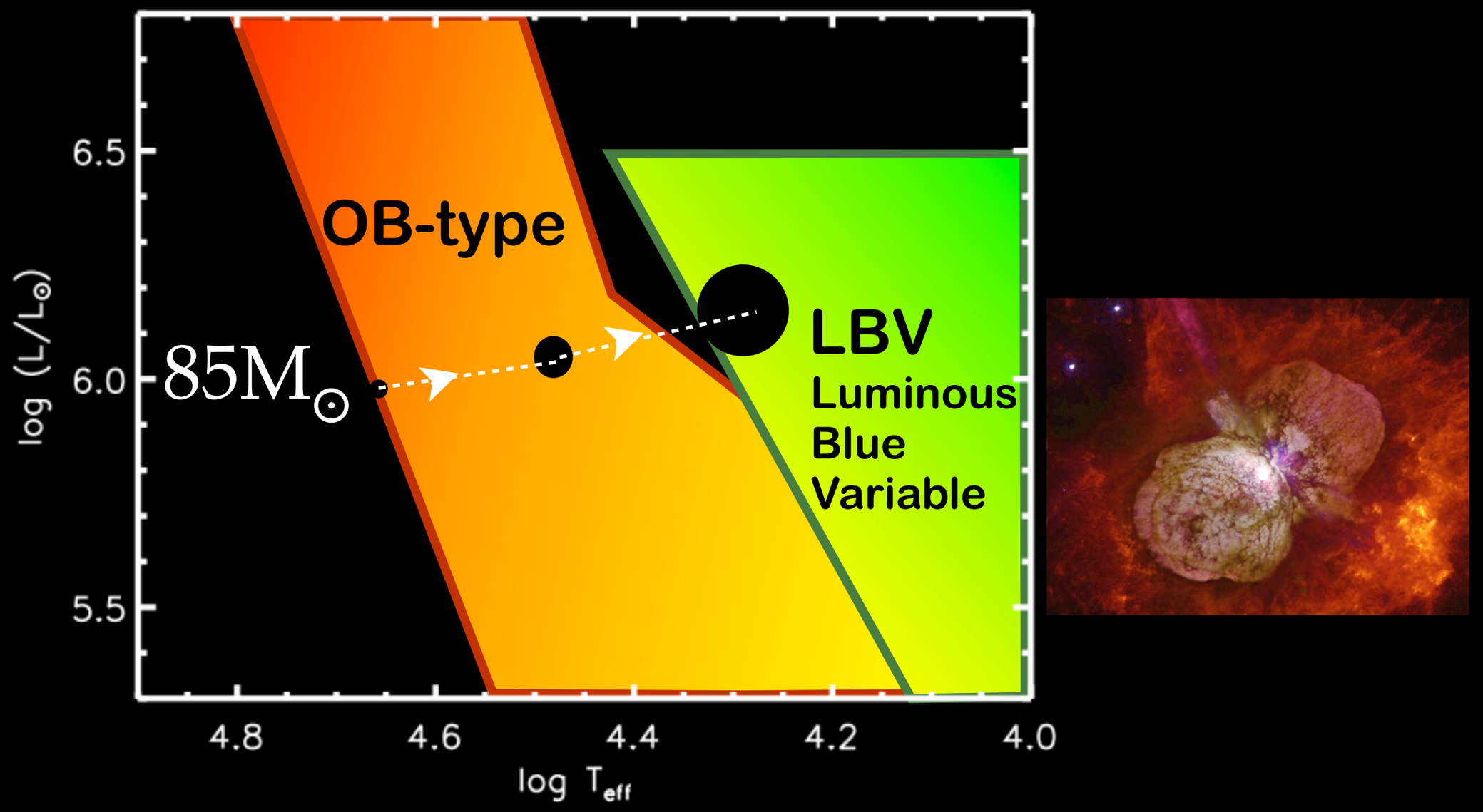
(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)



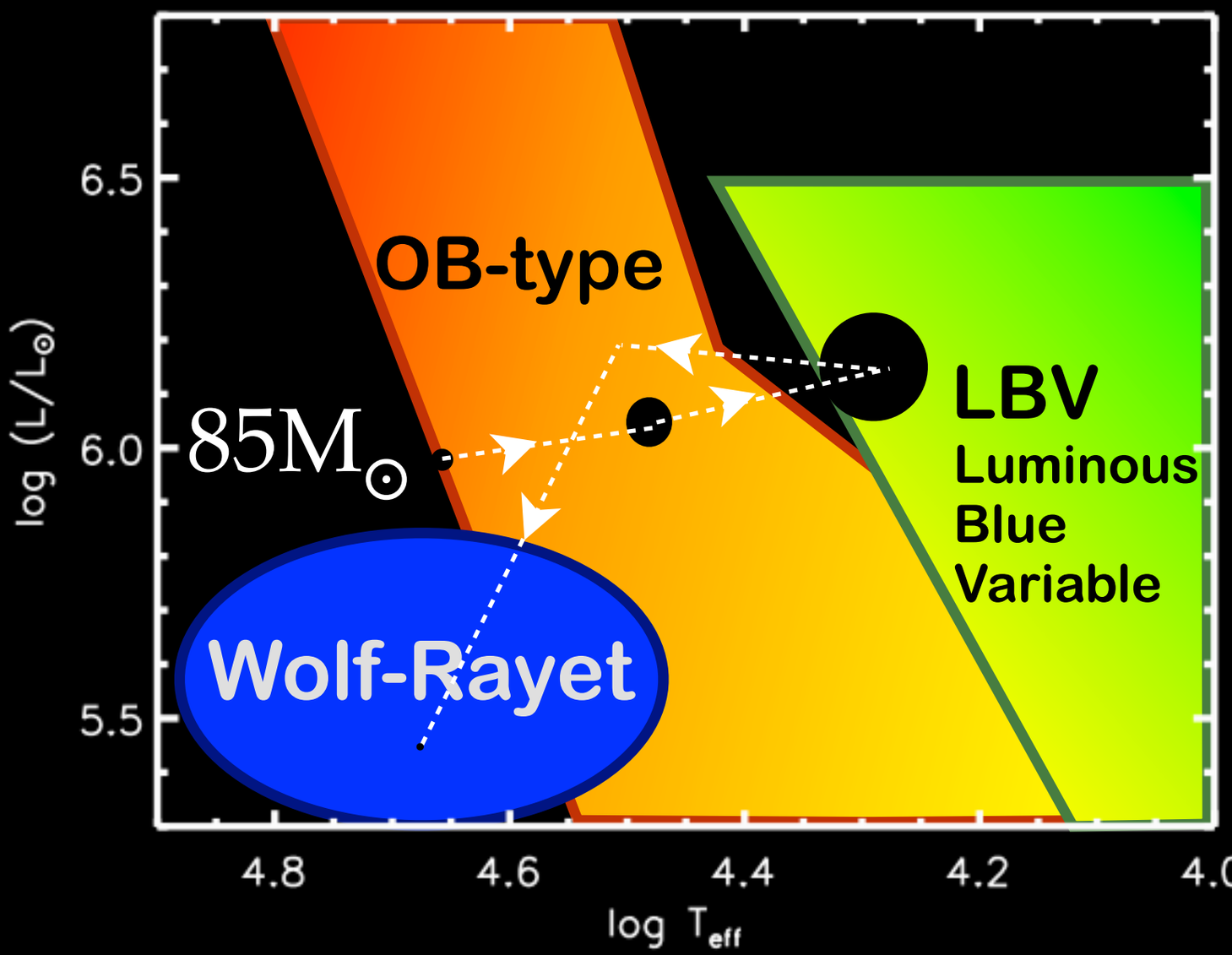
(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)



(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

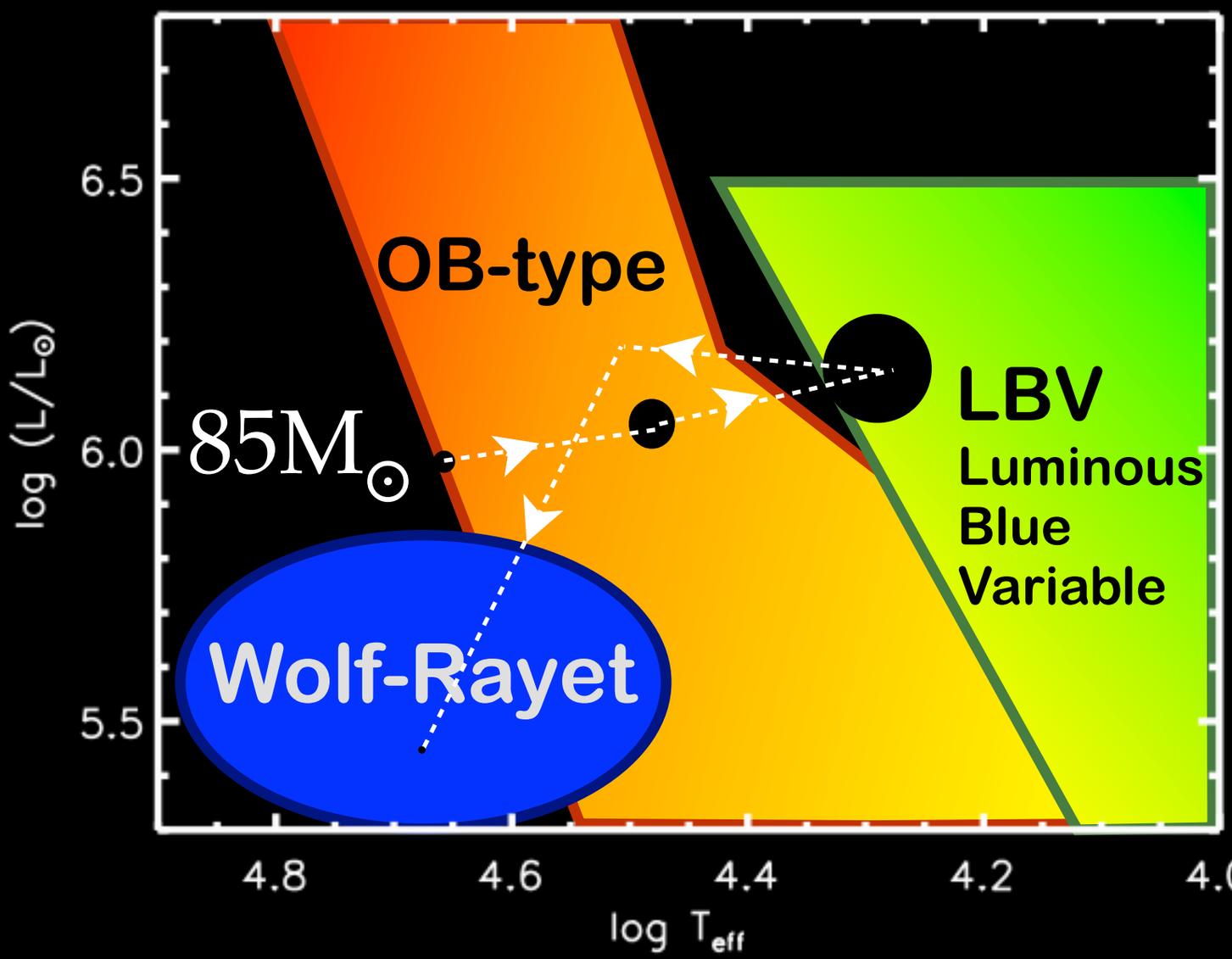
SN Ibc progenitors at solar Z (above 30 $M_\odot$)



(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)

OB-type → LBV → WR → SN Ibc

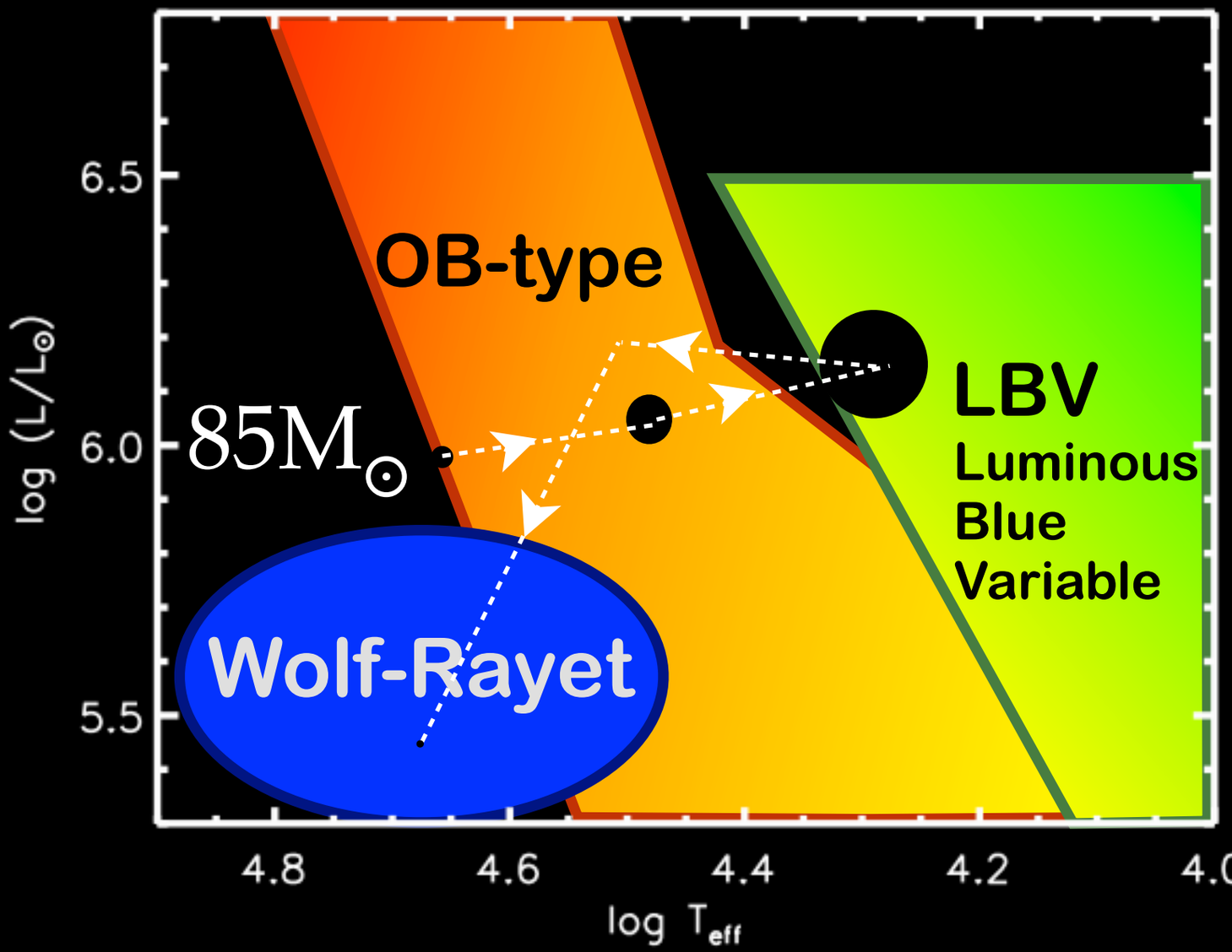


(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)

OB-type → LBV → WR → SN Ibc

LBVs detected as SN progenitors (Kotak & Vink 06; Smith+ 07, 10, 11; Pastorello+ 07; Gal-Yam & Leonard 07, 09; Mauerhan+ 12; Fraser+ 13)



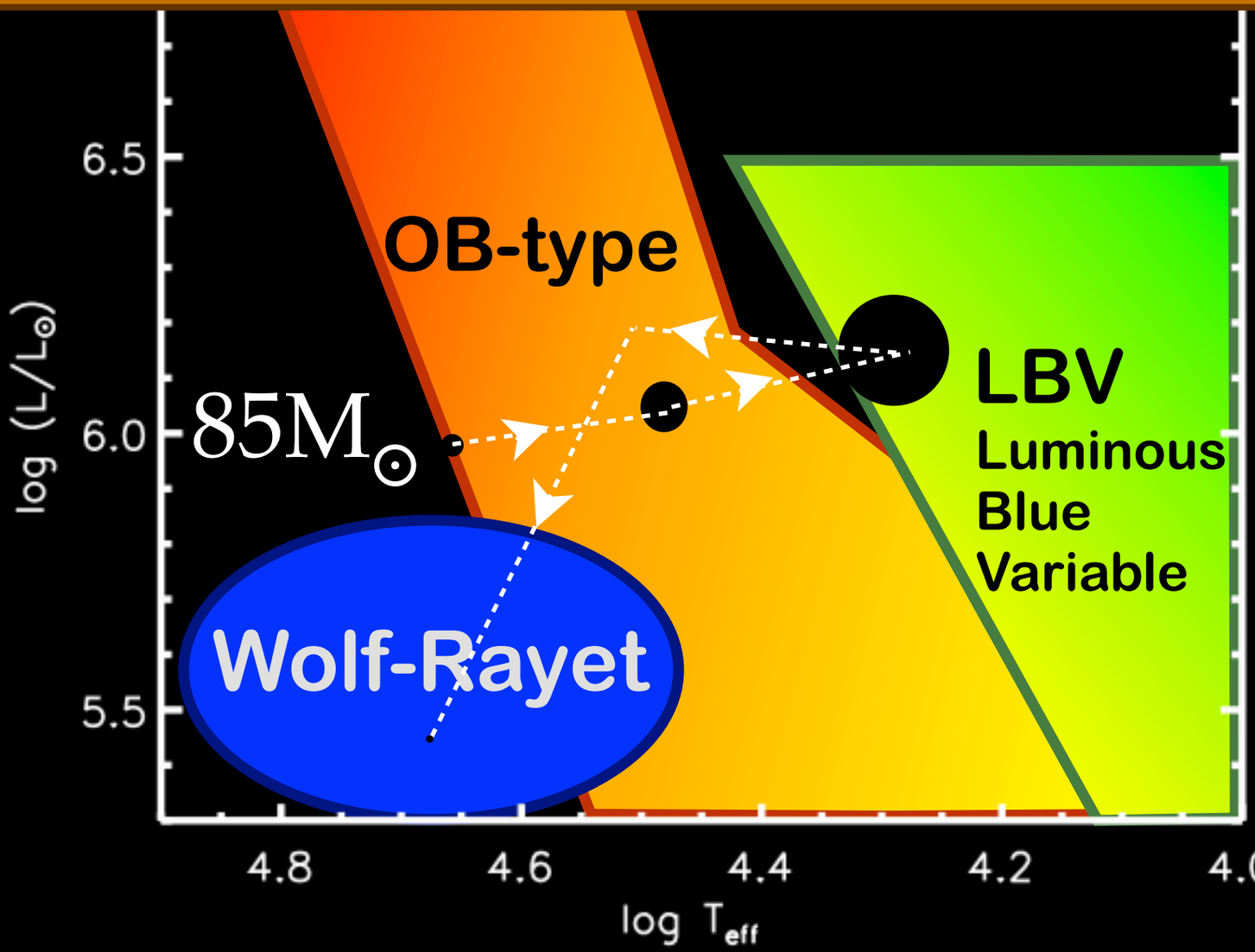
(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)

OB-type → LBV → WR → SN Ibc

LBVs detected as SN progenitors (Kotak & Vink 06; Smith+ 07, 10, 11; Pastorello+ 07; Gal-Yam & Leonard 07, 09; Mauerhan+ 12; Fraser+ 13)

No detections of WRs as SN progenitors (Maund & Smartt 05; Maund+ 05; Crockett+ 07; Smartt09; Eldridge+ 13; Elias-Rosa+ 13)



But see Cao+ 13; Groh +13b

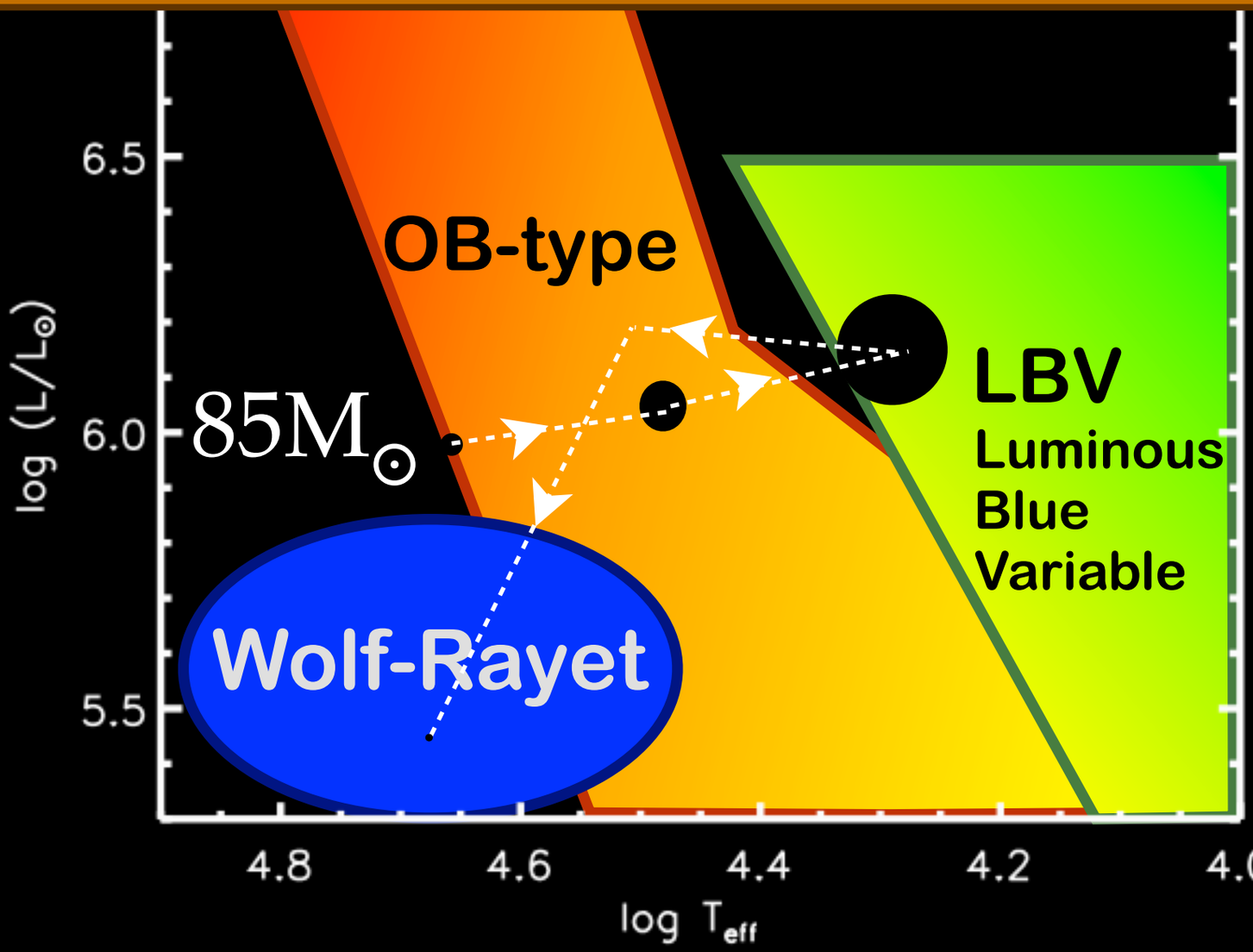
(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

SN Ibc progenitors at solar Z (above 30 $M_\odot$)

OB-type → LBV → WR → SN Ibc

LBVs detected as SN progenitors (Kotak & Vink 06; Smith+ 07, 10, 11; Pastorello+ 07; Gal-Yam & Leonard 07, 09; Mauerhan+ 12; Fraser+ 13)

No detections of WRs as SN progenitors (Maund & Smartt 05; Maund+ 05; Crockett+ 07; Smartt09; Eldridge+ 13; Elias-Rosa+ 13)



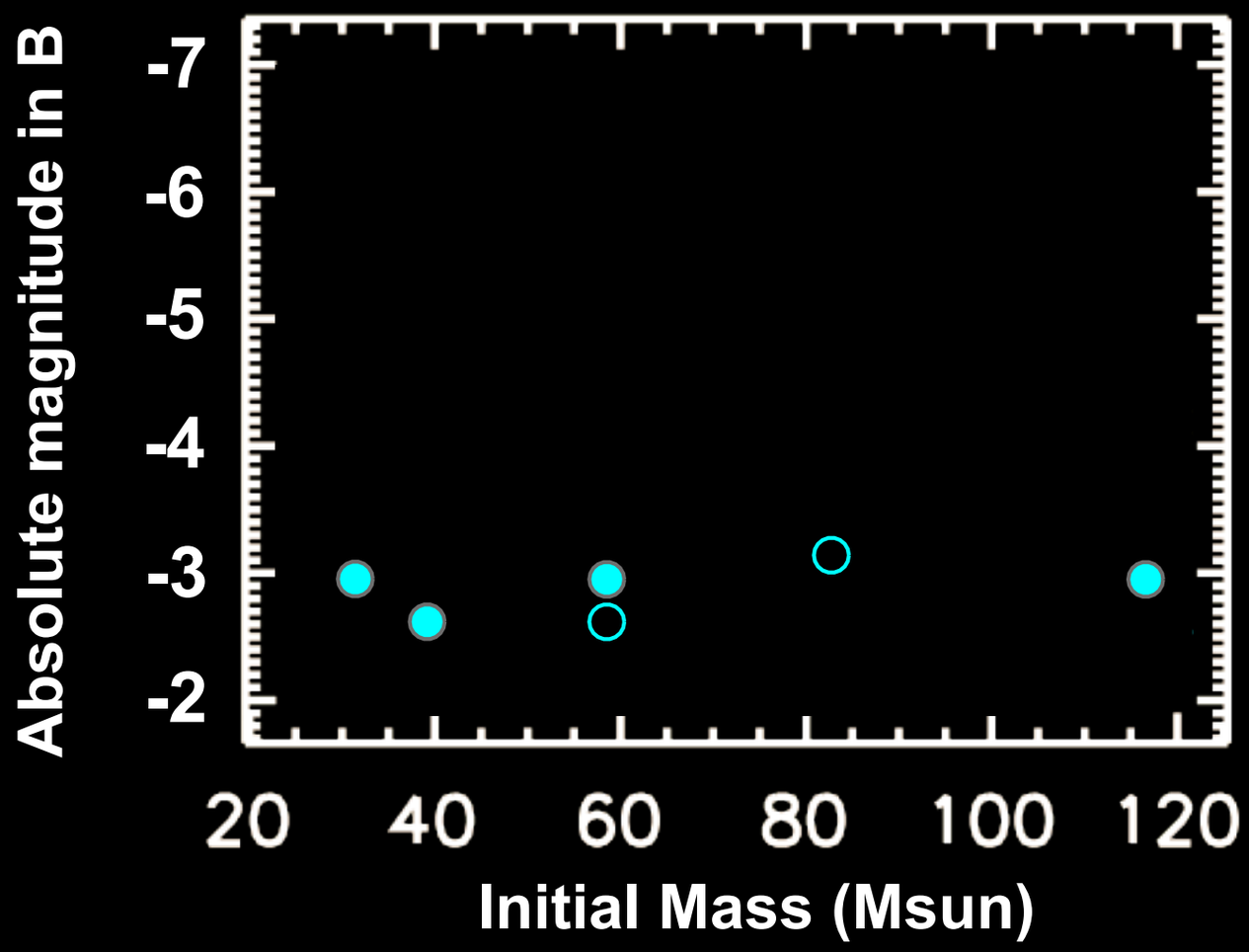
But see Cao+ 13; Groh +13b

Role of binaries? What is the most frequent evolutionary scenario?

(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

Detectability of SN Ic progenitors

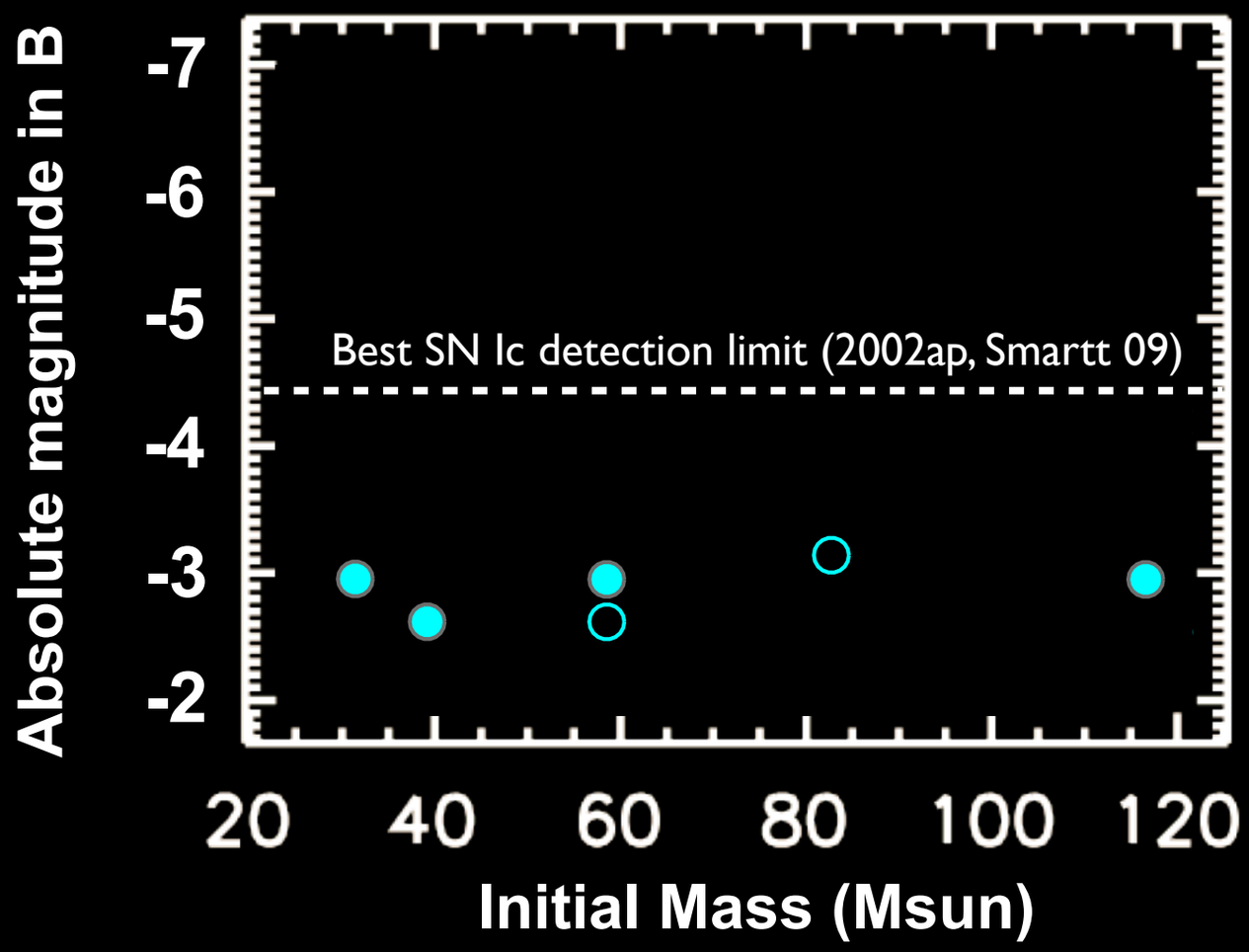
WR stars have not yet been observed as SN Ic progenitors
(Smartt 09; Eldridge+ 13)



(Groh+ 13, A&A in press; arXiv 1308.4601;
see also Yoon+ 12)

Detectability of SN Ic progenitors

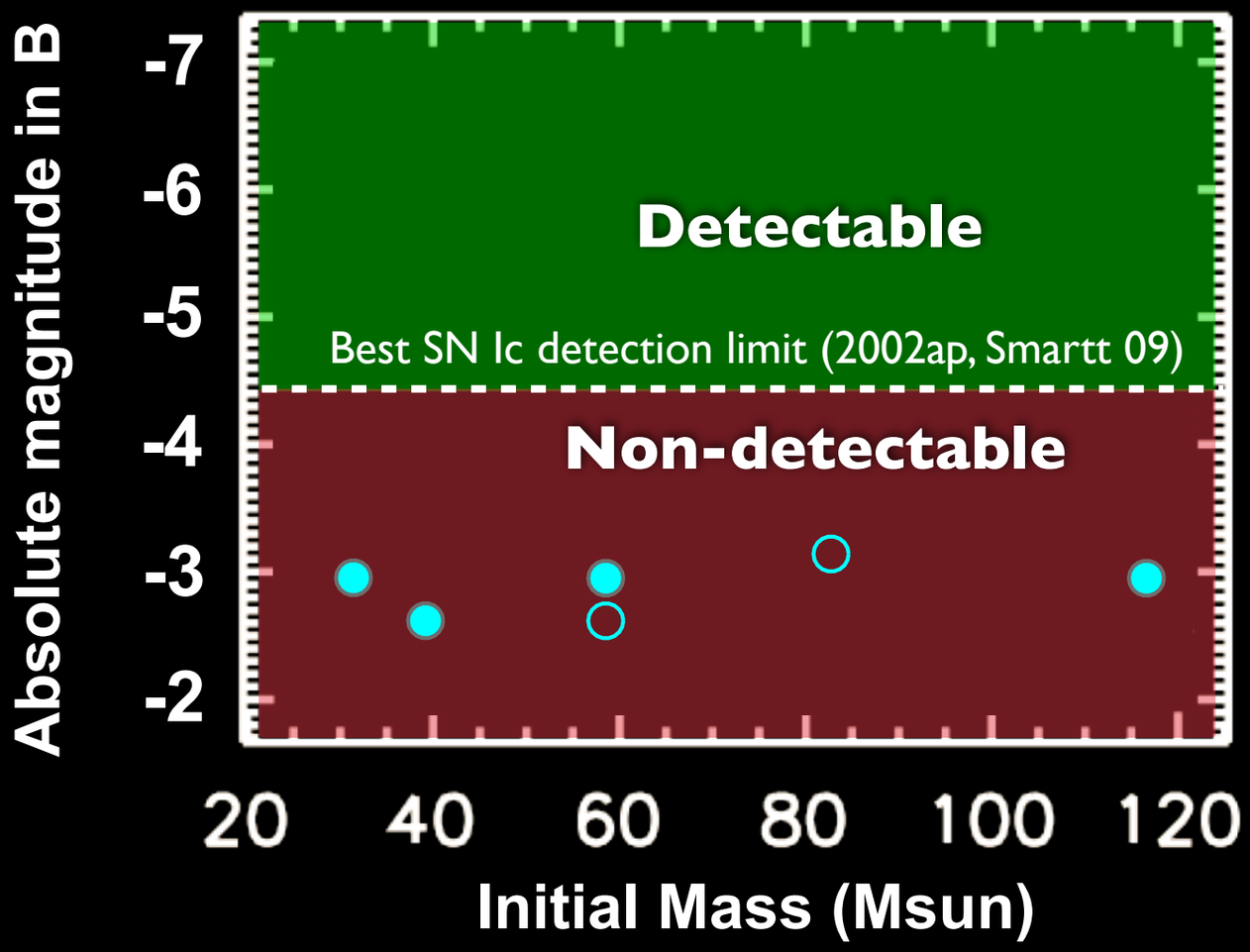
WR stars have not yet been observed as SN Ic progenitors
(Smartt 09; Eldridge+ 13)



(Groh+ 13, A&A in press; arXiv 1308.4601;
see also Yoon+ 12)

Detectability of SN Ic progenitors

WR stars have not yet been observed as SN Ic progenitors
(Smartt 09; Eldridge+ 13)

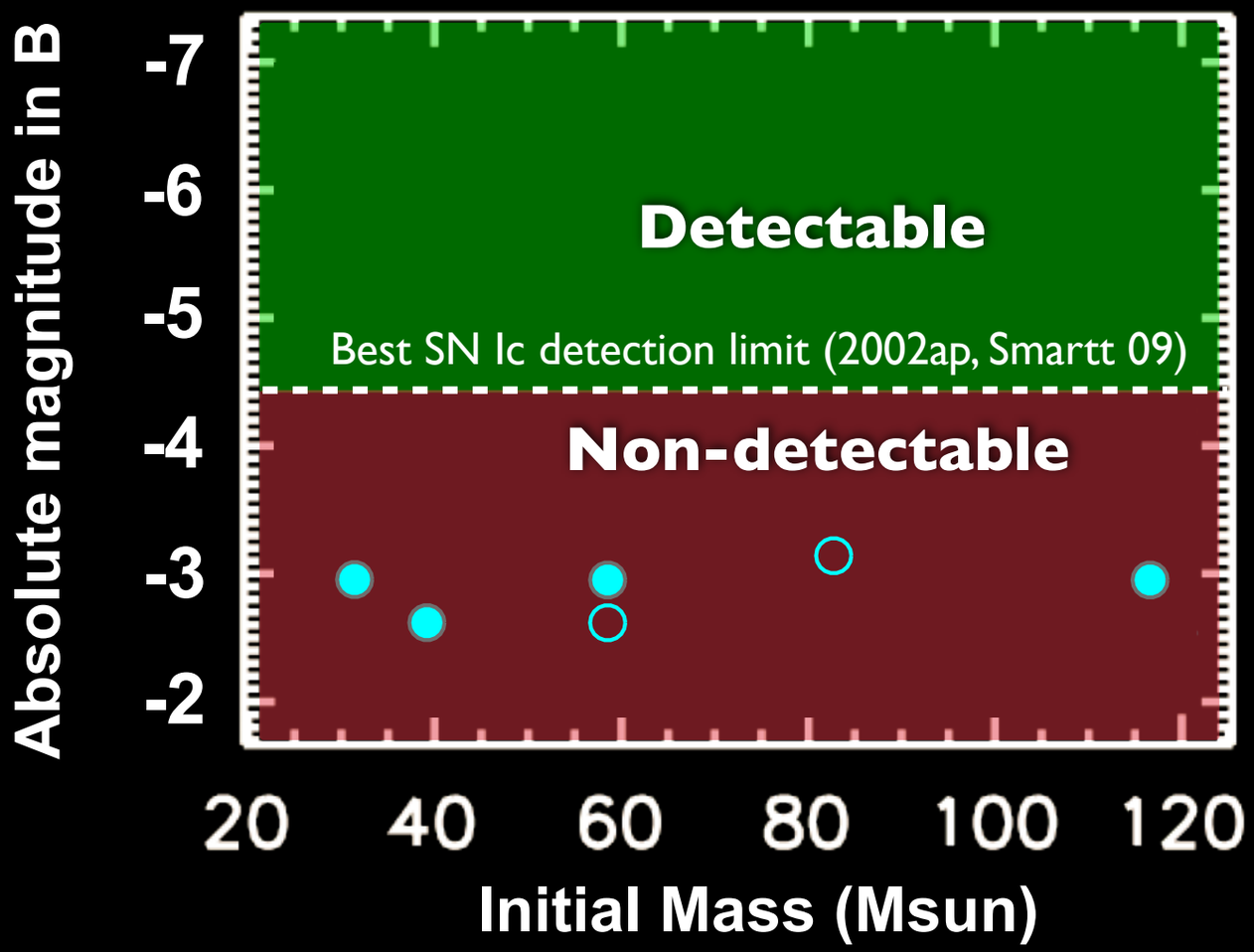


(Groh+ 13, A&A in press; arXiv 1308.4601;
see also Yoon+ 12)

Current non-detection of WRs as SN Ic progenitors is OK with single stellar evolution models!

Detectability of SN Ic progenitors

WR stars have not yet been observed as SN Ic progenitors
(Smartt 09; Eldridge+ 13)



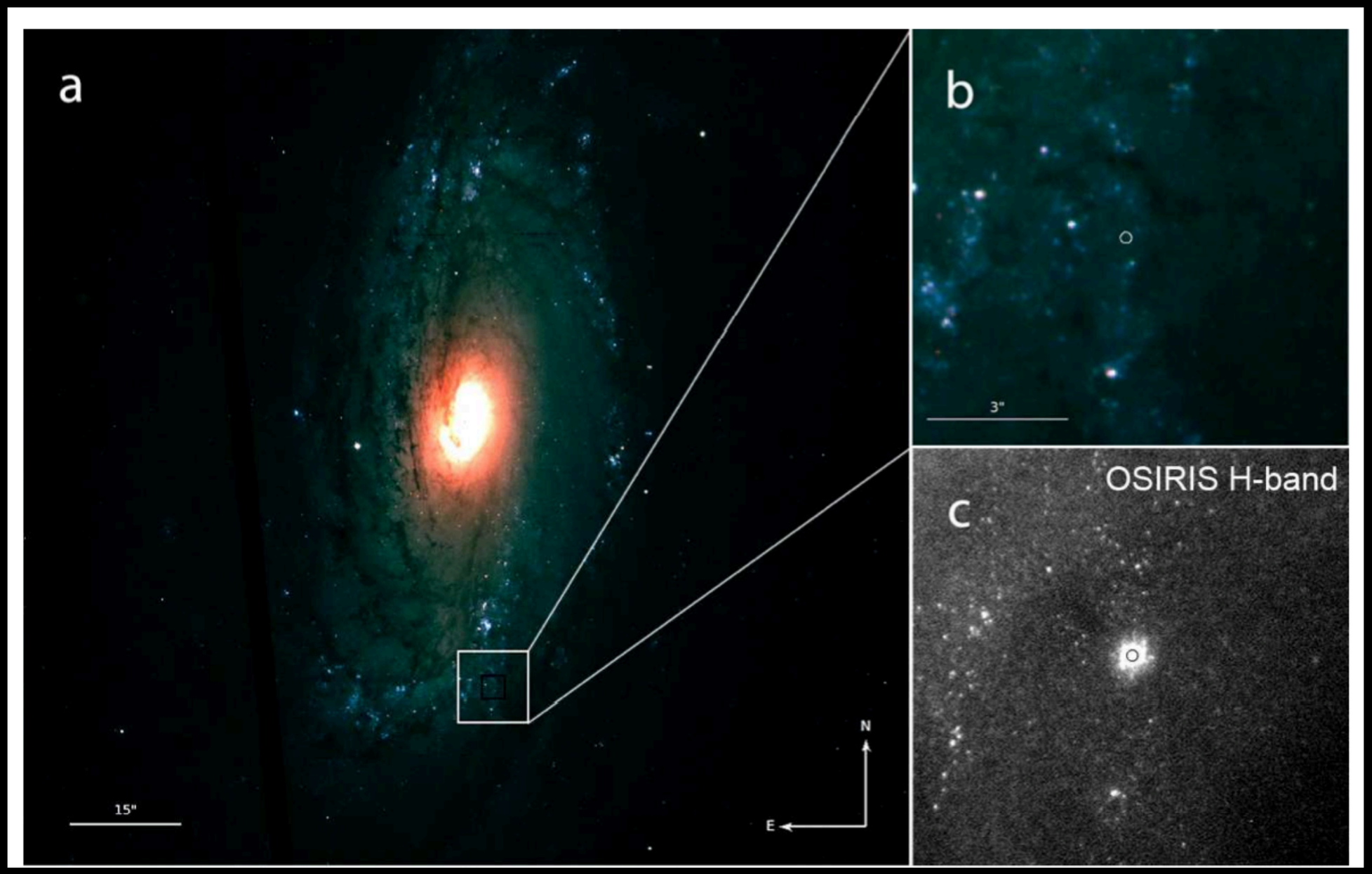
(Groh+ 13, A&A in press; arXiv 1308.4601;
see also Yoon+ 12)

Current non-detection of WRs as SN Ic progenitors is OK with single stellar evolution models!

Ic progenitor detectable up to 2.7 Mpc (m=24.5mag), 5.5 Mpc (m=26.0 mag).

Detectability of SN Ib progenitors

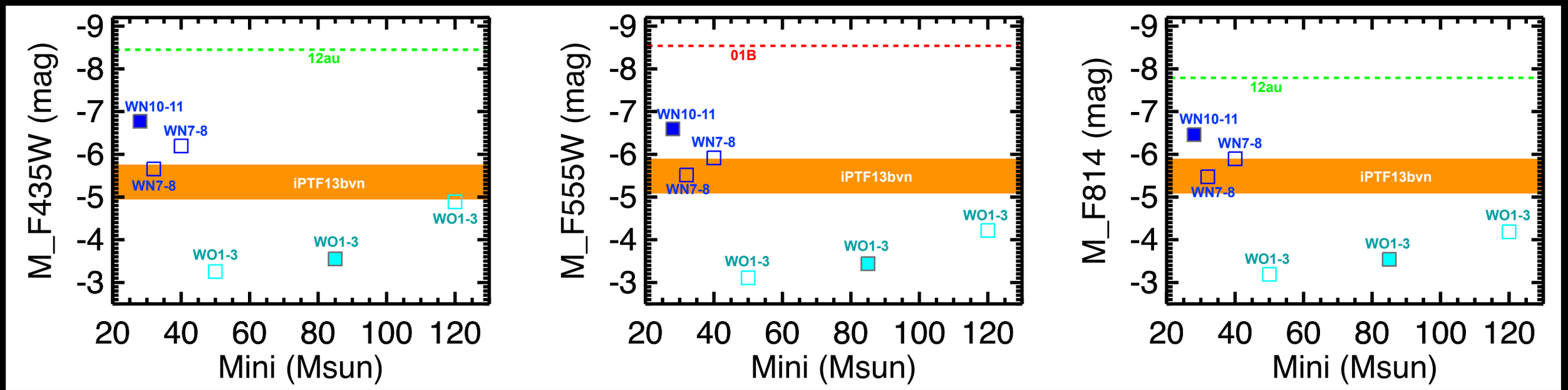
Possible detection of progenitor of SN Ib iPTF13bvn.
(Cao+ 13)



(Cao+ 13)

The candidate progenitor of iPTF13bvn

Absolute magnitude vs. initial mass for SN Ib progenitors

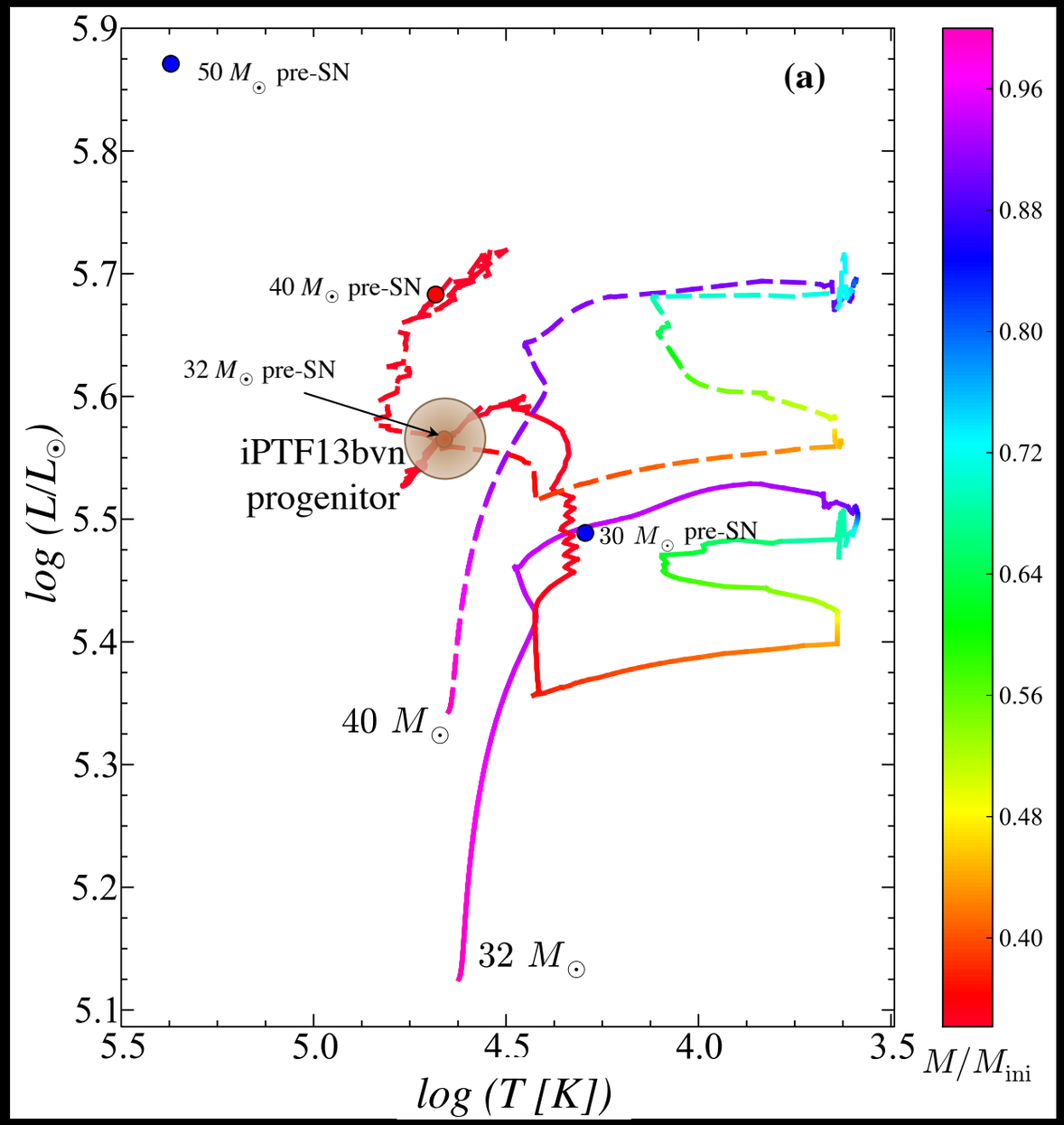


A slowly-rotating WN star with initial mass 31-35 M⊙

(Groh+ 13, A&A in press; arXiv 1307.8434)

The candidate progenitor of iPTF13bvn

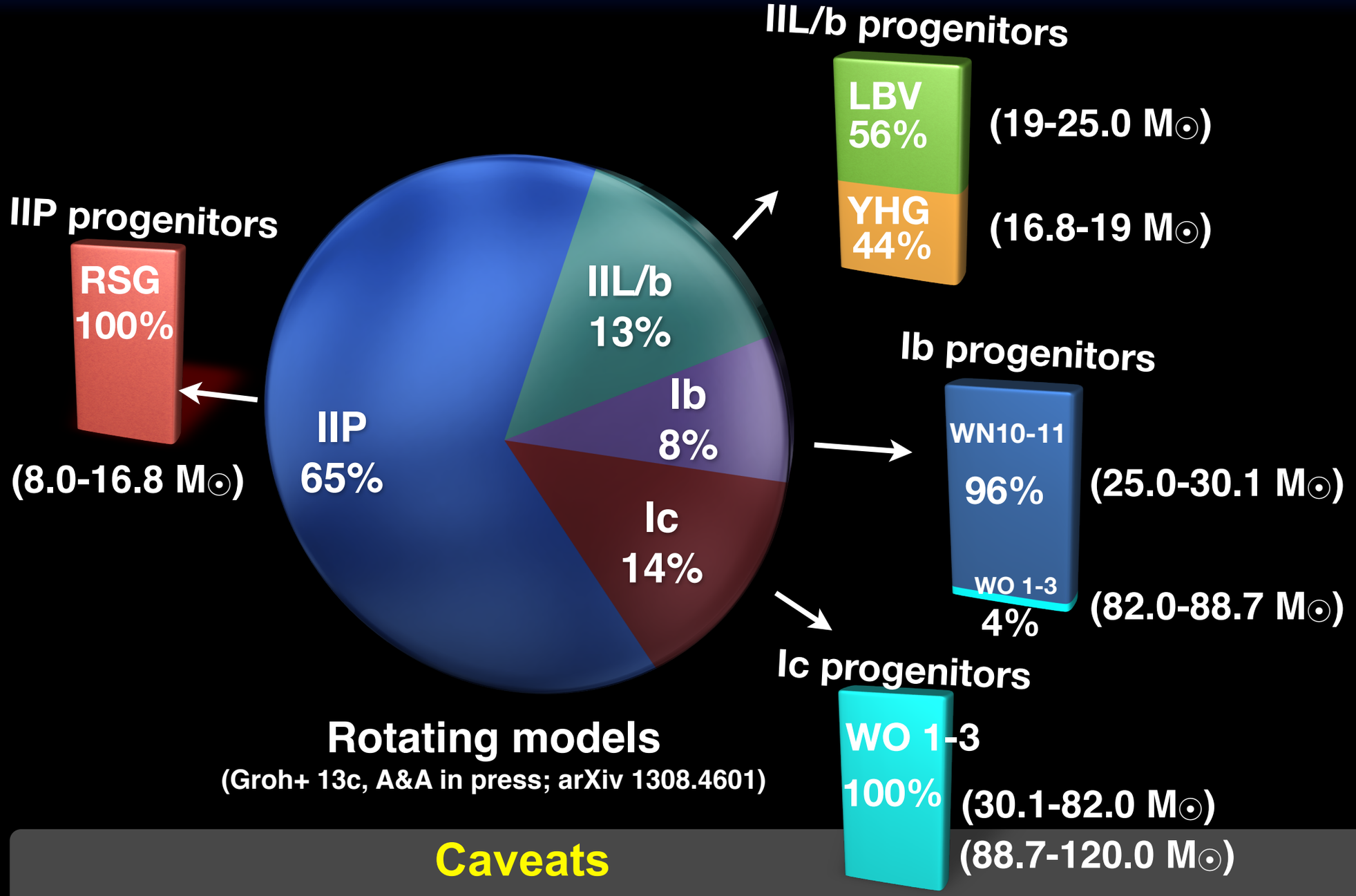
Location in the HR diagram



A slowly-rotating WN star with initial mass 31-35 M⊙

(Groh+ 13, A&A in press; arXiv 1307.8434)

Predicted nature of CCSN progenitors from single stars



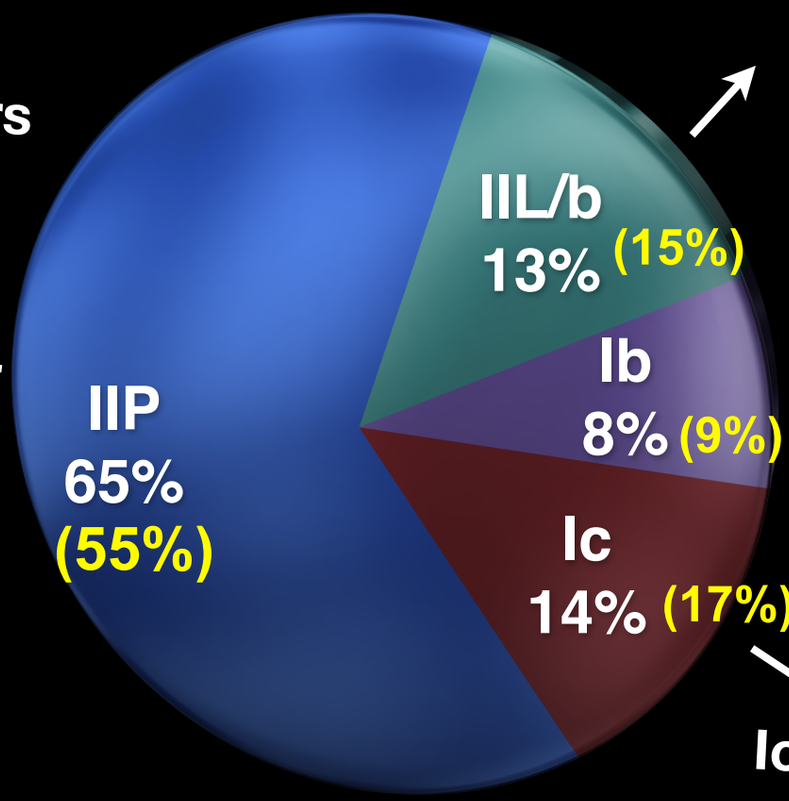
Rotating models
(Groh+ 13c, A&A in press; arXiv 1308.4601)

Caveats

- Binarity + not all stars rotate at 40% of critical speed; see e.g. Sana+12,13
- Assumes all stars with 8-120 $M_\odot$ give rise to SNe; but see e.g Fryer 06; Ugliano+ 12
- SN type based on H and He abundance in the ejecta.; see e.g. Dessart+12

Predicted nature of CCSN progenitors from single stars

Observed rates in yellow
(Eldridge+ 13)



IIP progenitors

RSG 100%

(8.0-16.8 M⊙)

IIL/b progenitors

LBV 56% (19-25.0 M⊙)

YHG 44% (16.8-19 M⊙)

Ib progenitors

WN10-11 96% (25.0-30.1 M⊙)

WO 1-3 4% (82.0-88.7 M⊙)

Ic progenitors

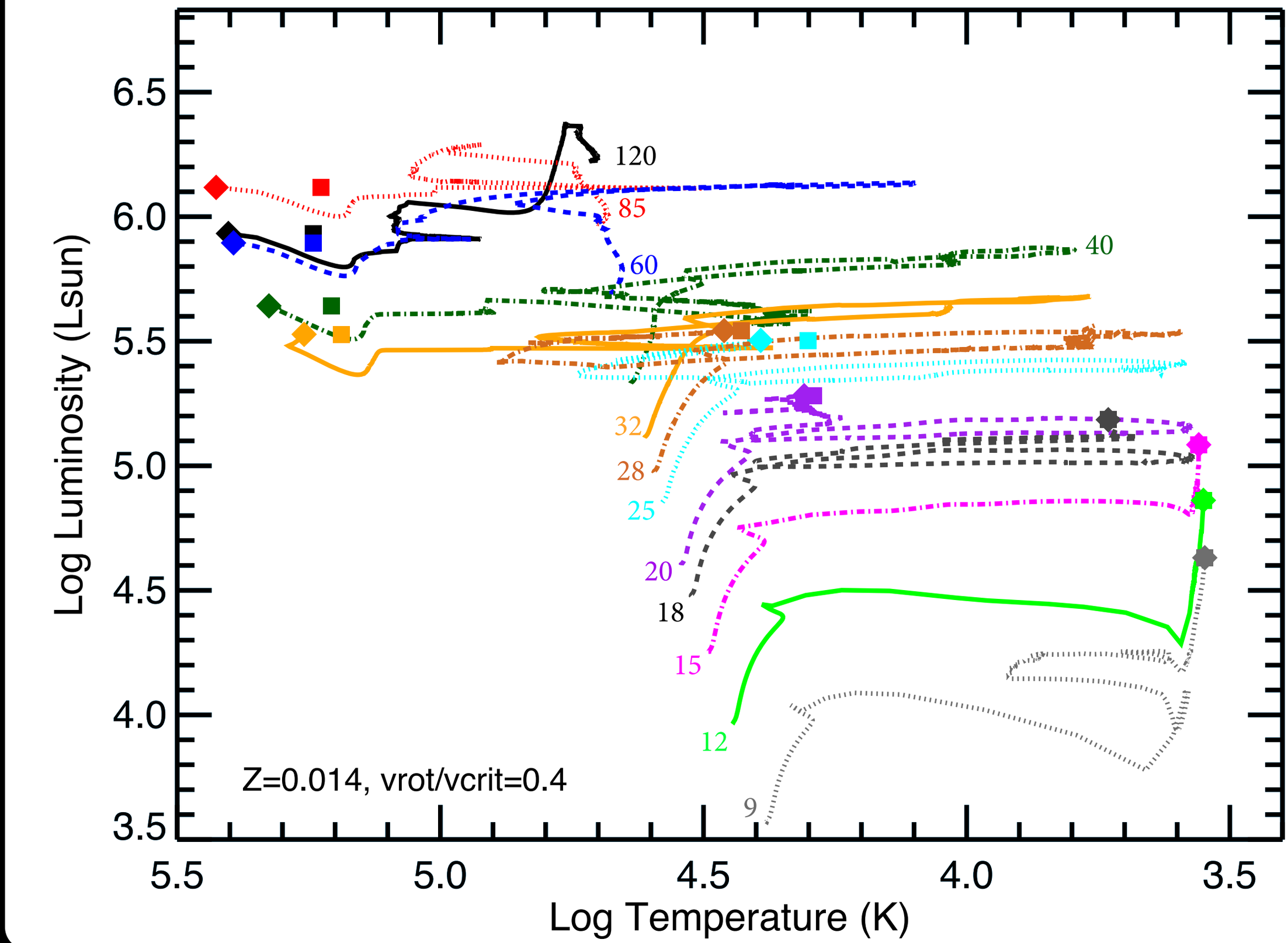
WO 1-3 100% (30.1-82.0 M⊙) (88.7-120.0 M⊙)

Rotating models
(Groh+ 13c, A&A in press; arXiv 1308.4601)

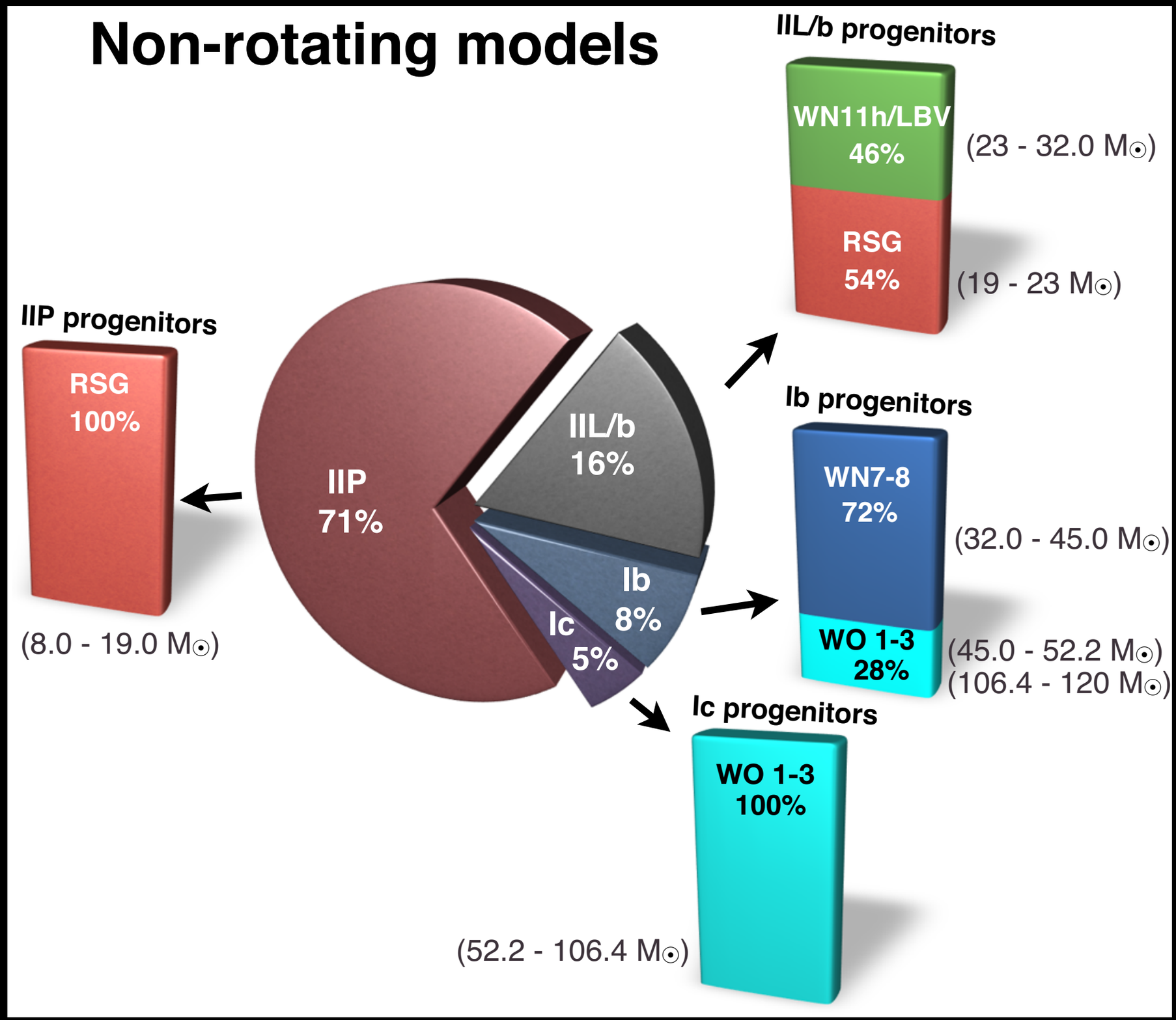
Caveats

- Binarity + not all stars rotate at 40% of critical speed; see e.g. Sana+12,13
- Assumes all stars with 8-120 $M_\odot$ give rise to SNe; but see e.g Fryer 06; Ugliano+ 12
- SN type based on H and He abundance in the ejecta.; see e.g. Dessart+12

Location of SN progenitors in the HR diagram



Predicted nature of CCSN progenitors at solar Z



Outline

1. Predicting the look of core-collapse SN progenitors

2. Comparison with observations of SN IIP, IIb and Ibc progenitors

2. Comparison with observations of SN IIP, IIb and Ibc progenitors