The surprising look of core-collapse SN progenitors

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

Jose Groh (Geneva Observatory, Switzerland)

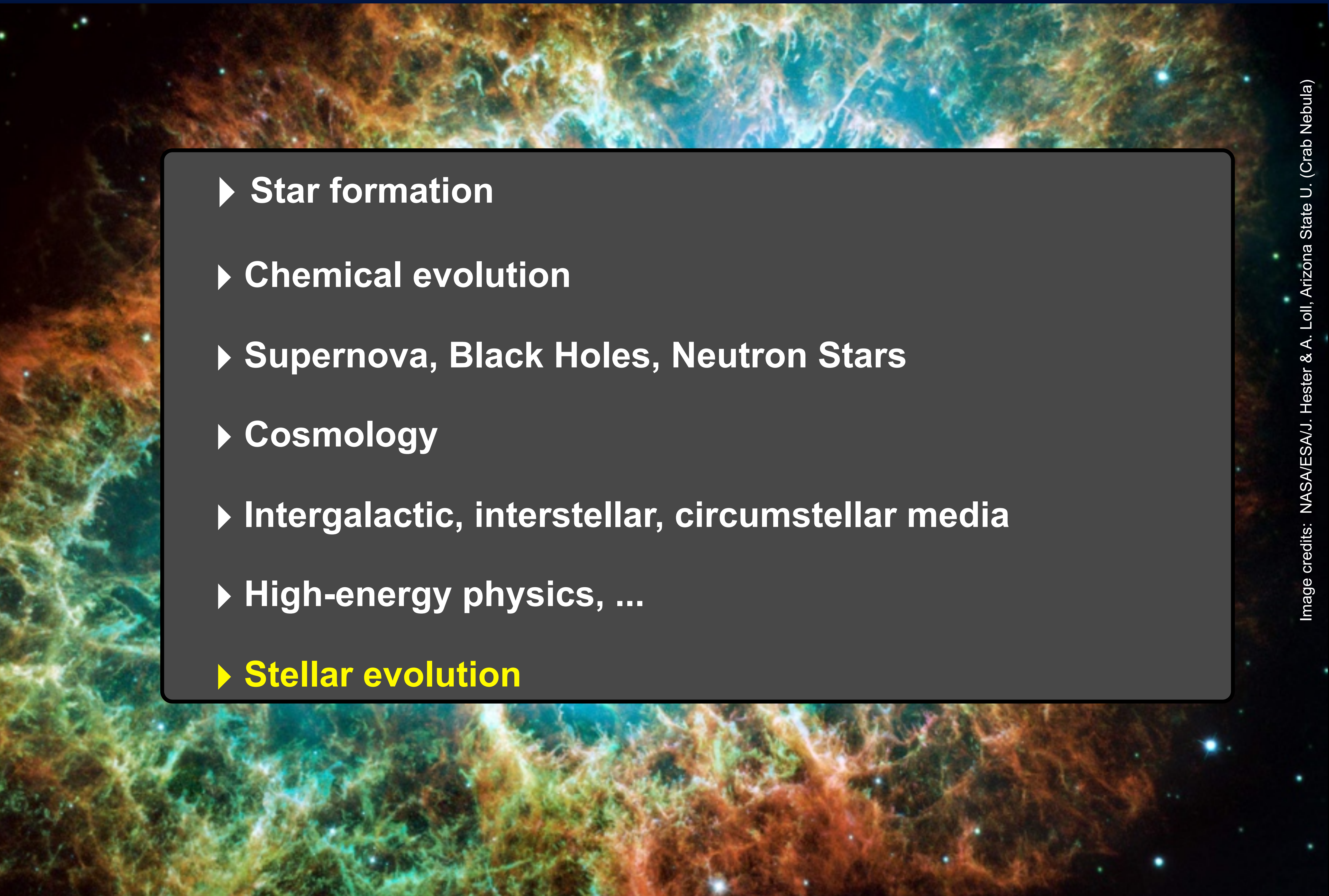
OBSERVATOIRE DE GENÈVE FONDÉ EN 1772

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

Collaborators

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

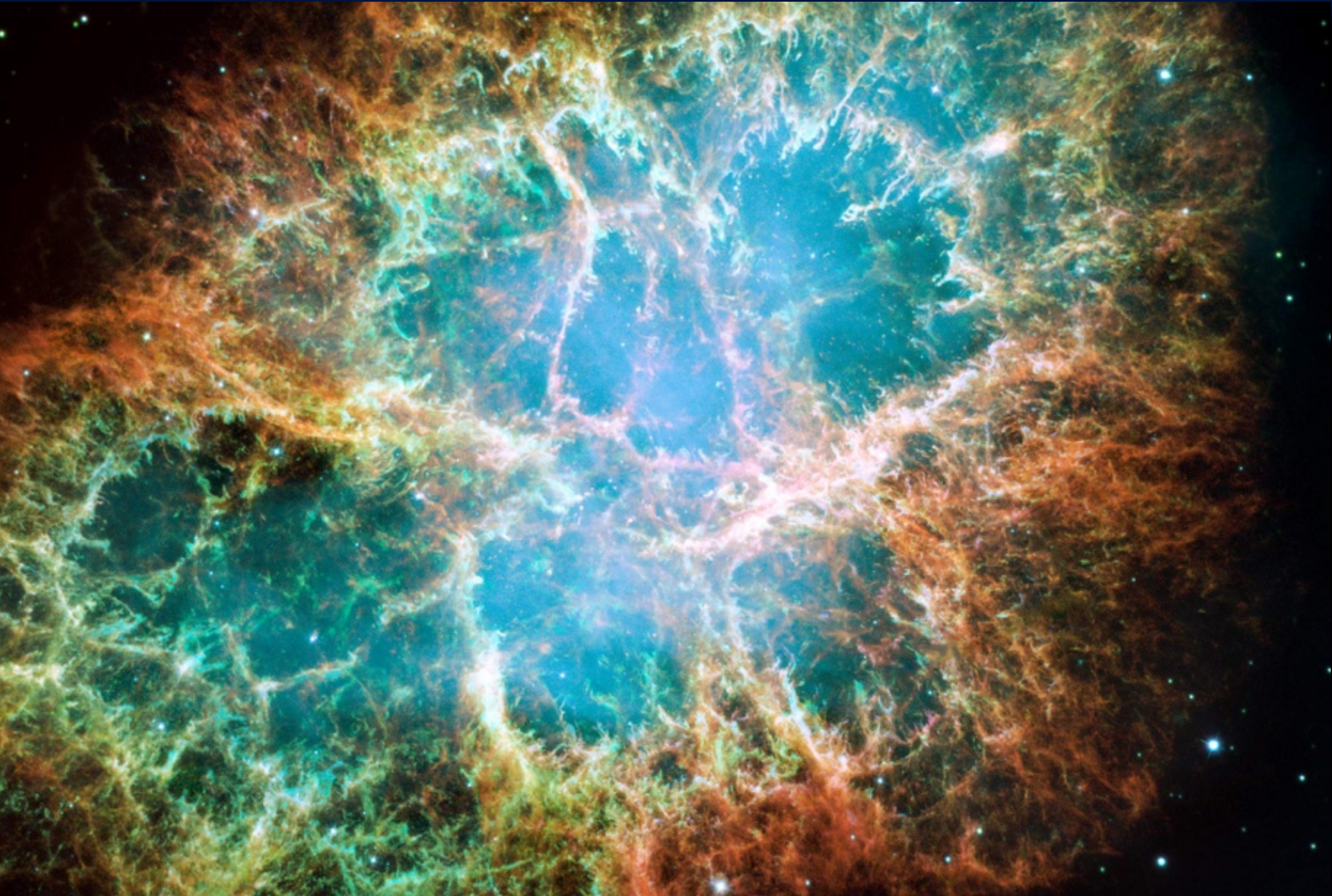
Stellar death bridges many fields of Astrophysics



- Star formation
- Chemical evolution
- Supernova, Black Holes, Neutron Stars
- Cosmology
- Intergalactic, interstellar, circumstellar media
- High-energy physics, ...
- **Stellar evolution**

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

Supernovae: remnant, chemistry, progenitor



Supernovae: remnant, chemistry, progenitor

SN 1054: chinese records

凡十一日沒三年三月乙巳出東南方大中祥符四
年正月丁丑見南斗魁前天禧五年四月丙辰出軒轅
前星西北大如桃速行經軒轅大星入太微垣掩右執
法犯次將歷屏星西北凡七十五日入濁沒明道元
年六月乙巳出東北方近濁有芒彗至丁巳凡十三
日沒至和元年五月己丑出天關東南可數寸歲餘
稍沒熙寧二年六月丙辰出箕度中至七月丁卯犯
箕乃散三年十一月丁未出天囷元祐六年十一月
辛亥出參度中犯掩厠星壬子犯九游星十二月癸
酉入奎至七年三月辛亥乃散紹興八年五月守婁

Image credits: British museum

Types of Supernovae: classification of the spectrum

(after e.g. Fillipenko 1997)

No Hydrogen

Hydrogen

Types of Supernovae: classification of the spectrum

(after e.g. Fillipenko 1997)

No Hydrogen

↓

SN I

Hydrogen

Types of Supernovae: classification of the spectrum

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No Hydrogen → SN I

Hydrogen → SN II

Types of Supernovae: classification of the spectrum

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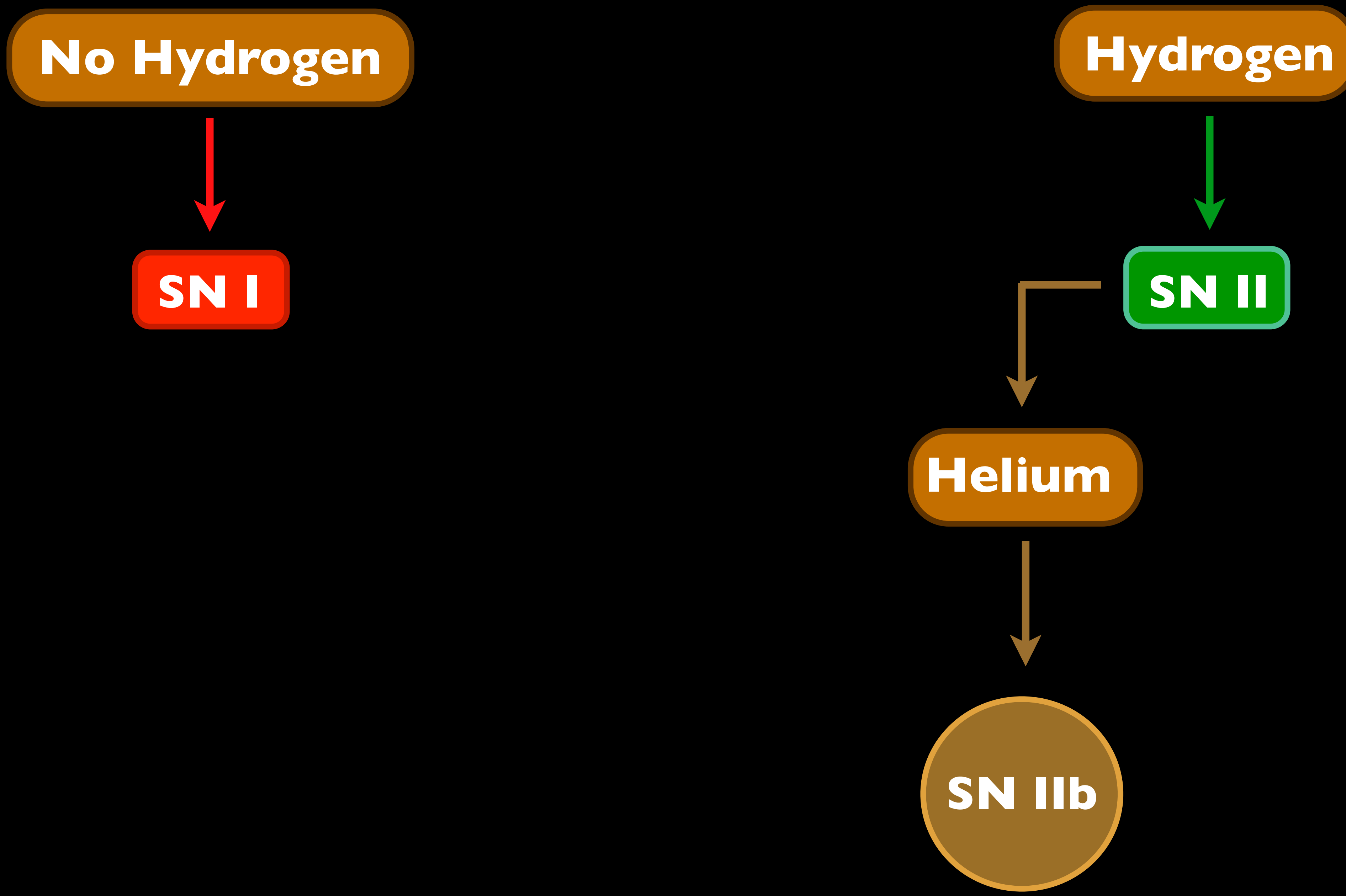

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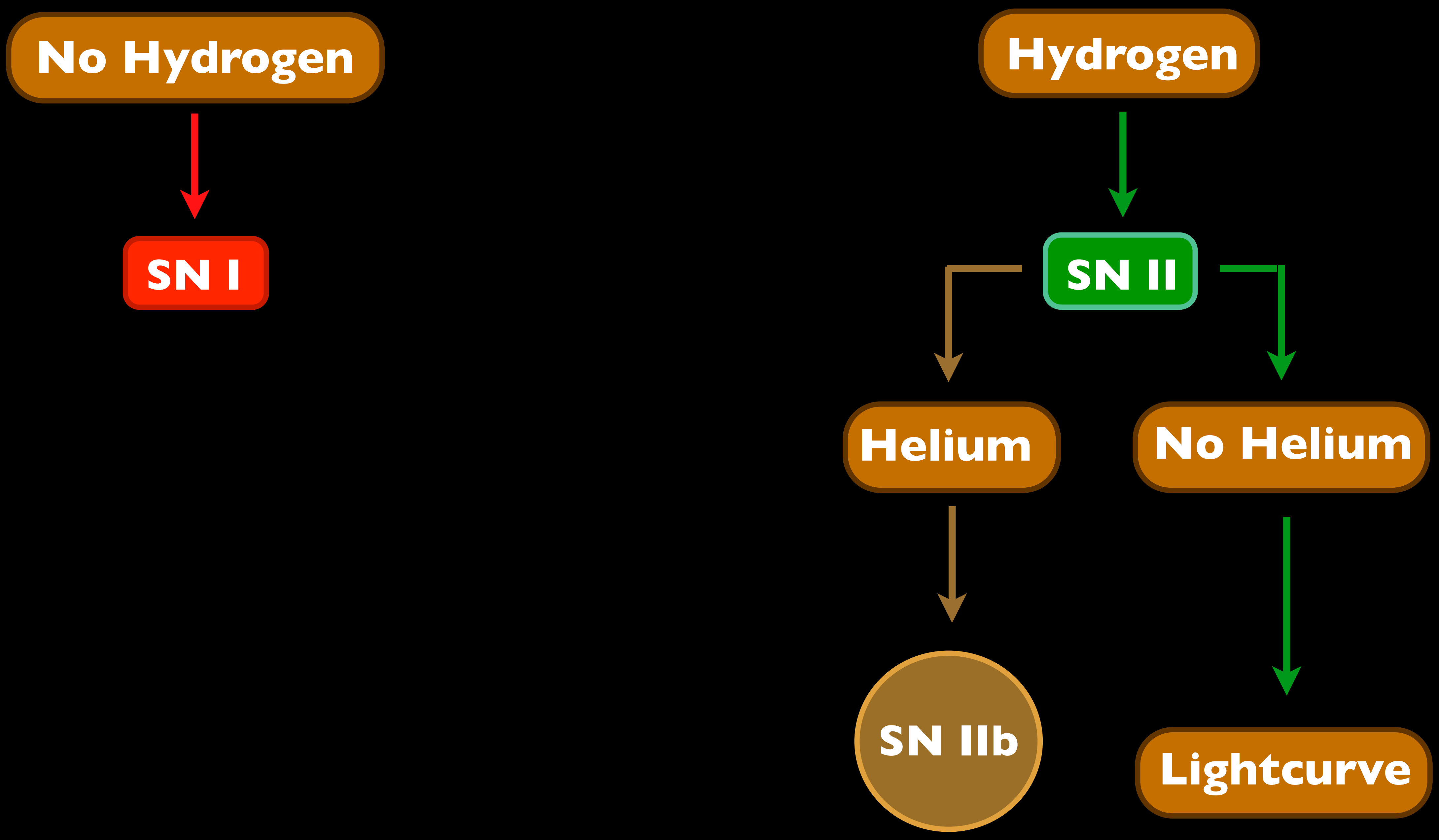

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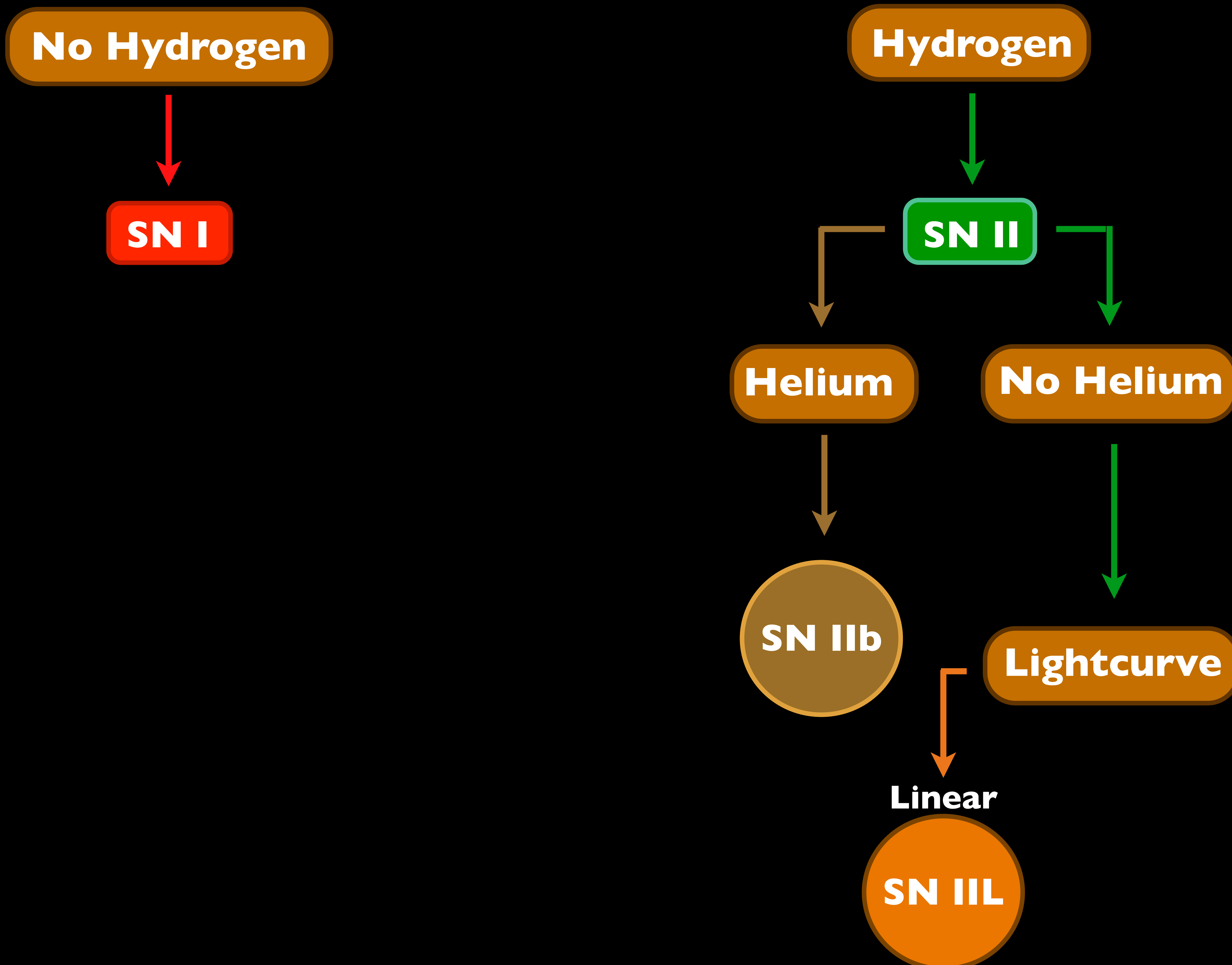

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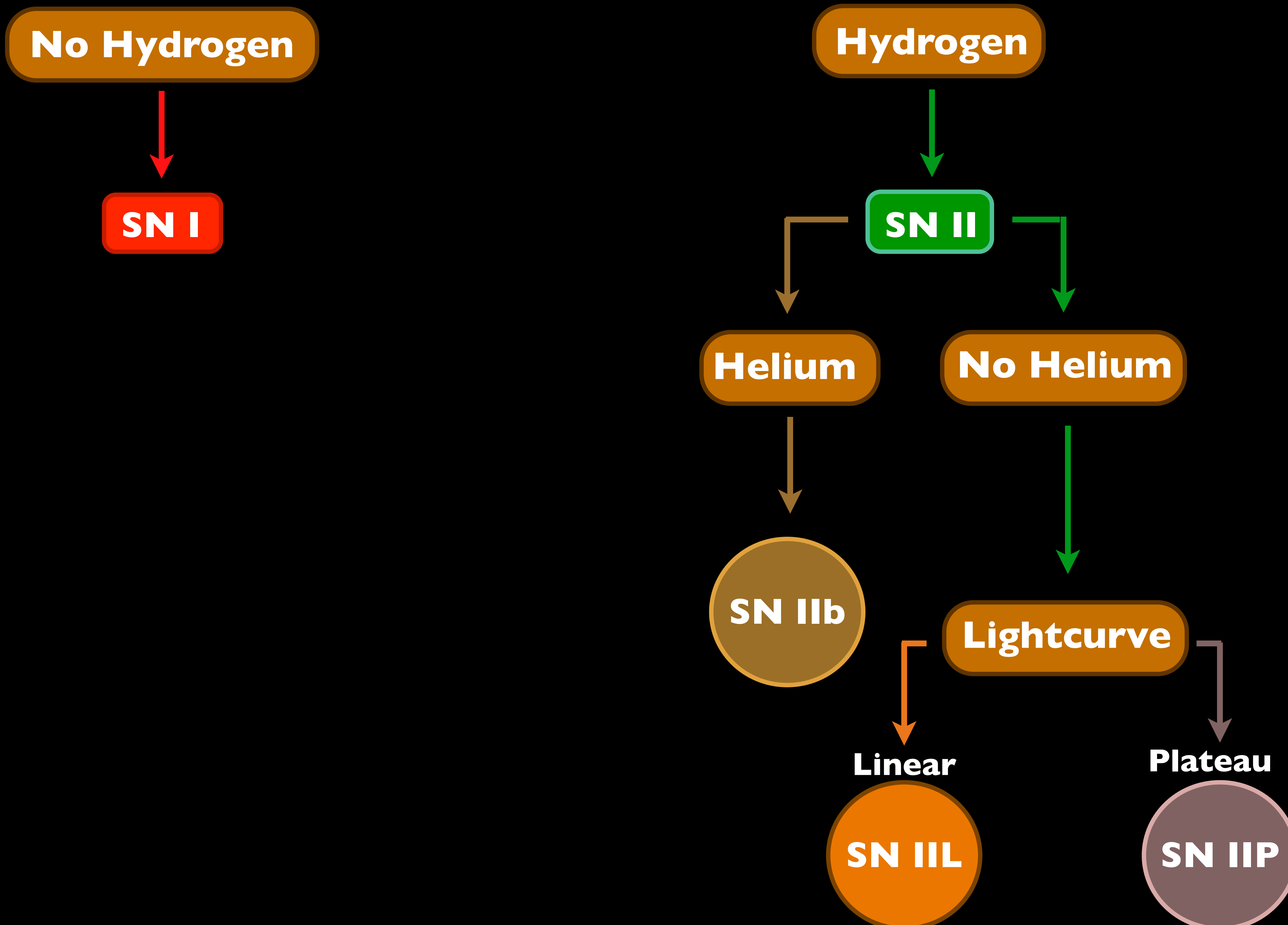

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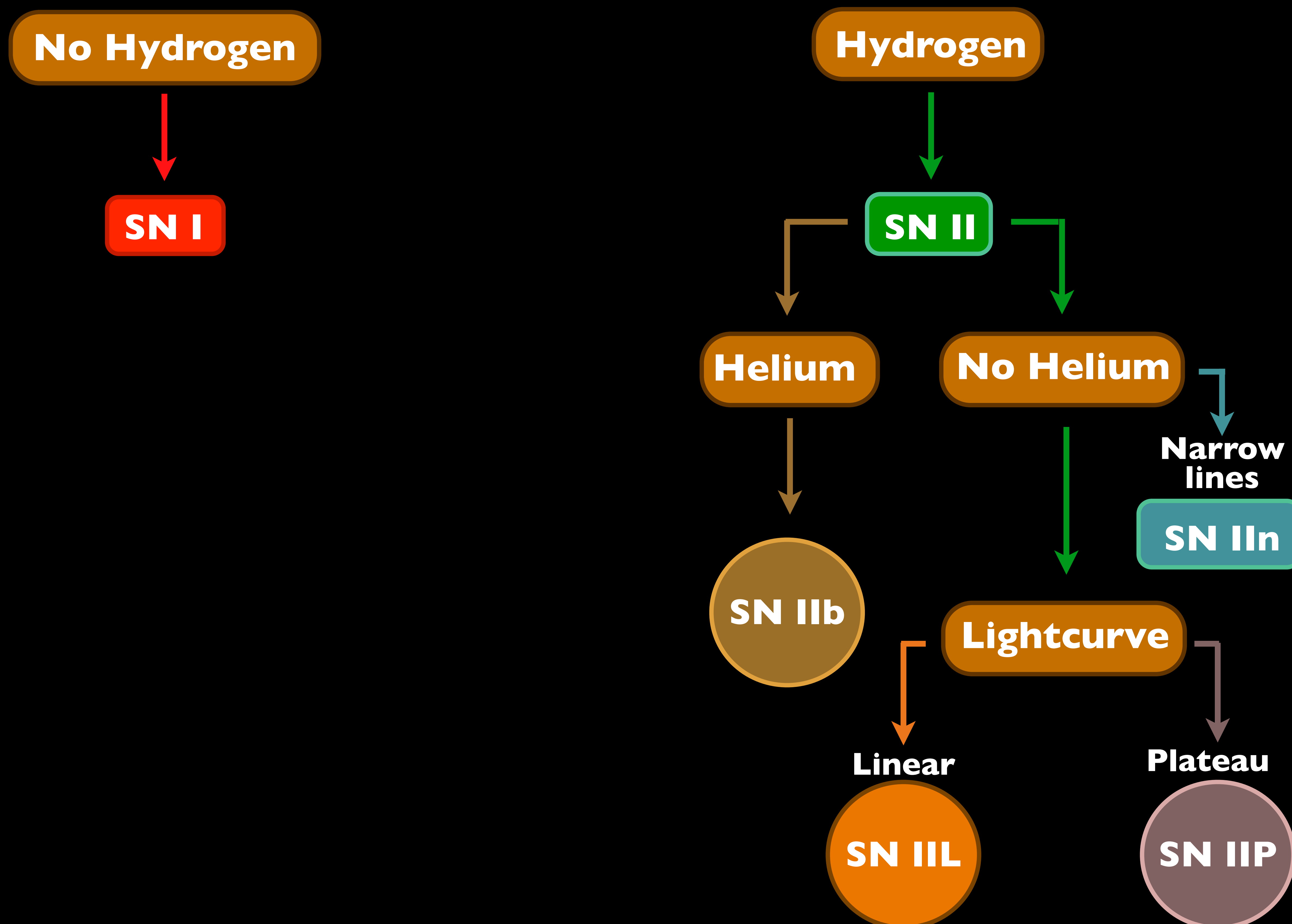

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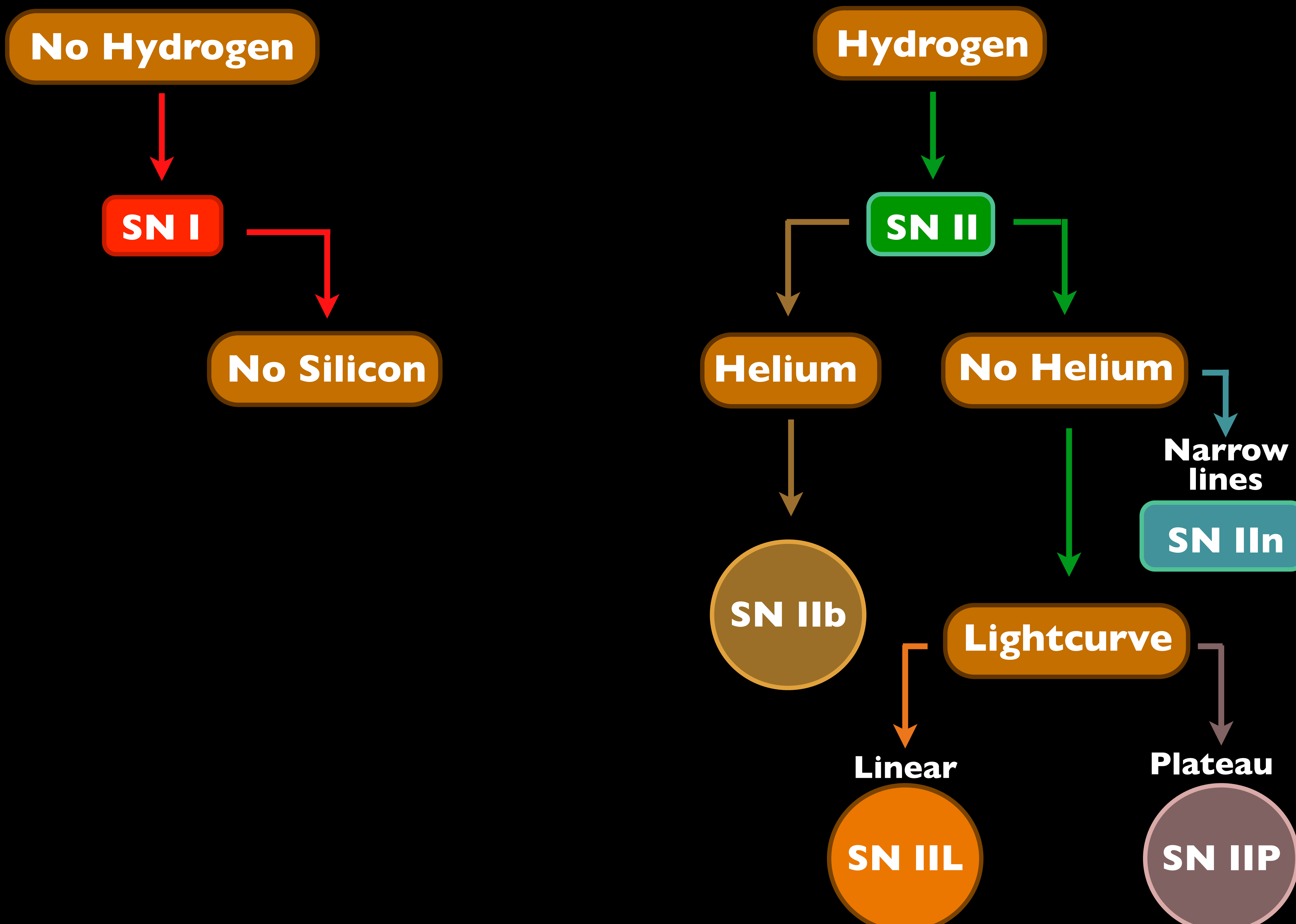

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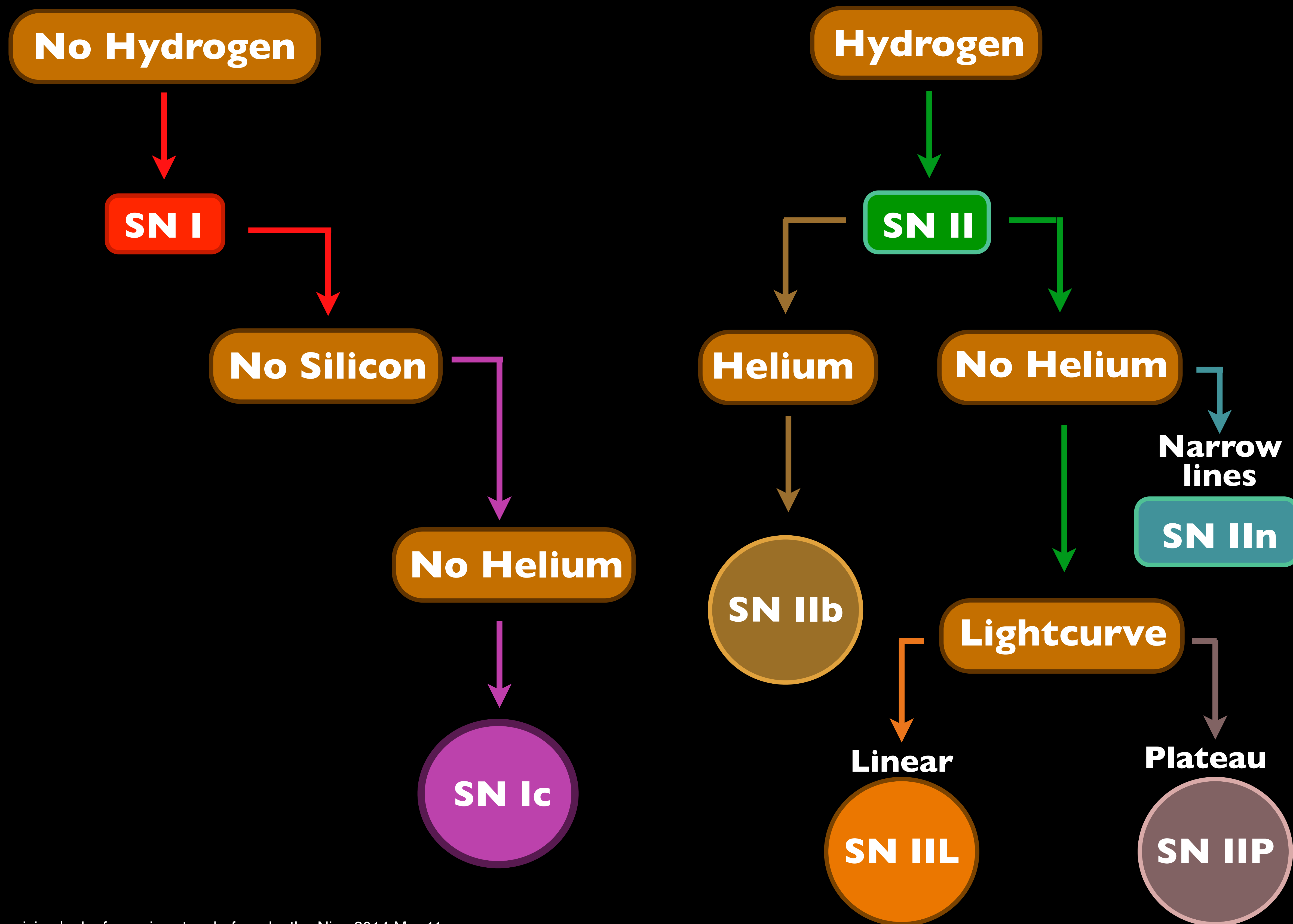

Types of Supernovae: classification of the spectrum

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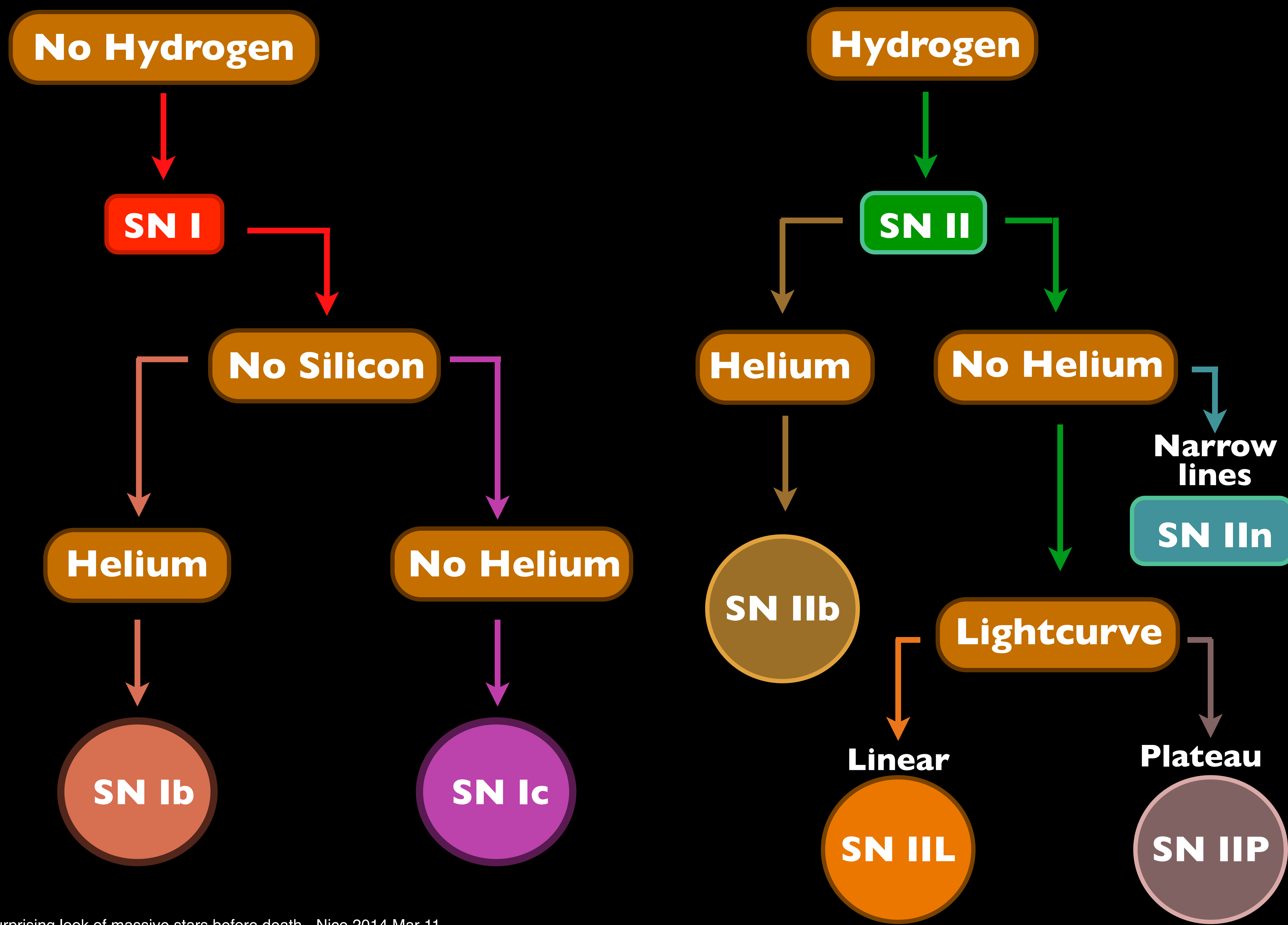

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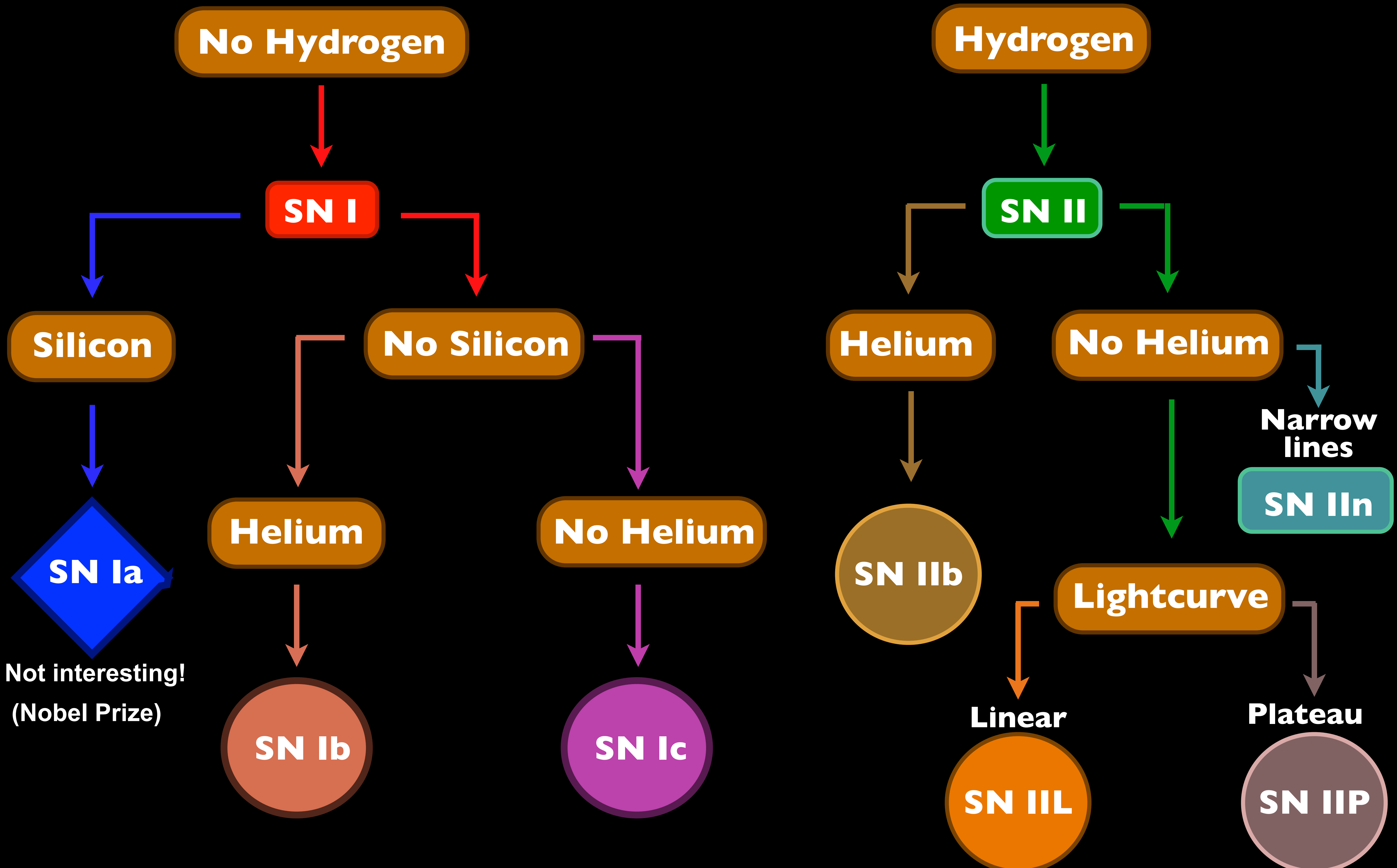

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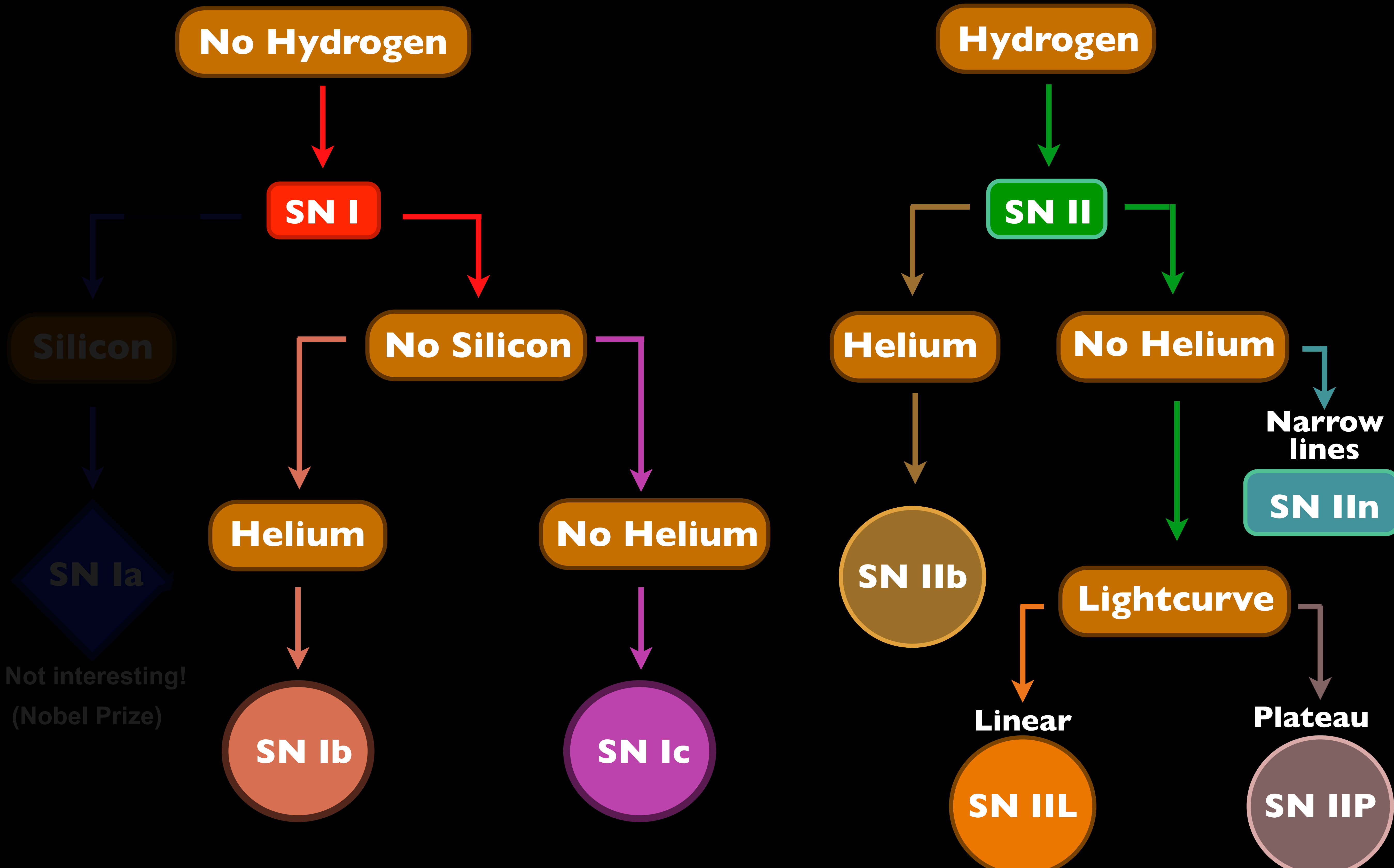
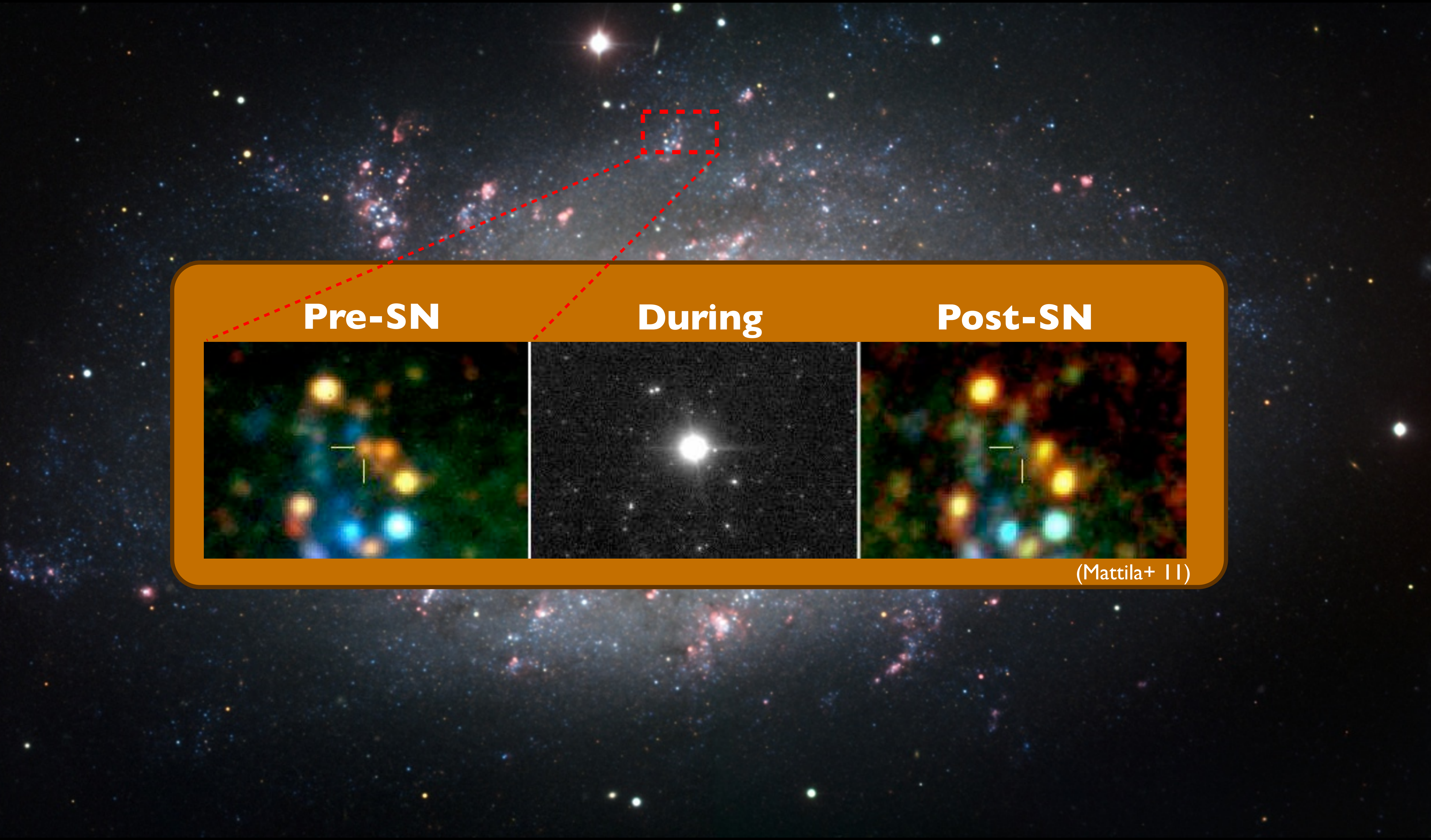


Since last 10 yr: direct detection of SN progenitors

Image credits: Patrice Poyet, ESO

Since last 10 yr: direct detection of SN progenitors

Direct detection of SN progenitors



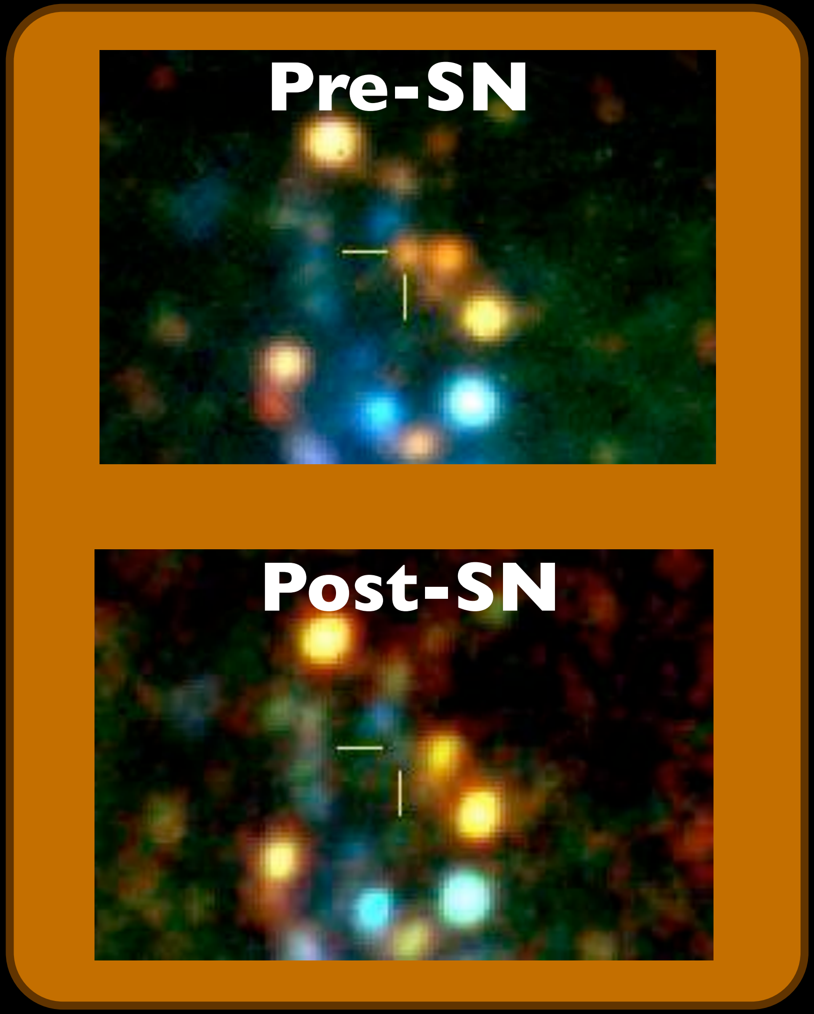
How to compare observations and stellar evolution models?

Observations

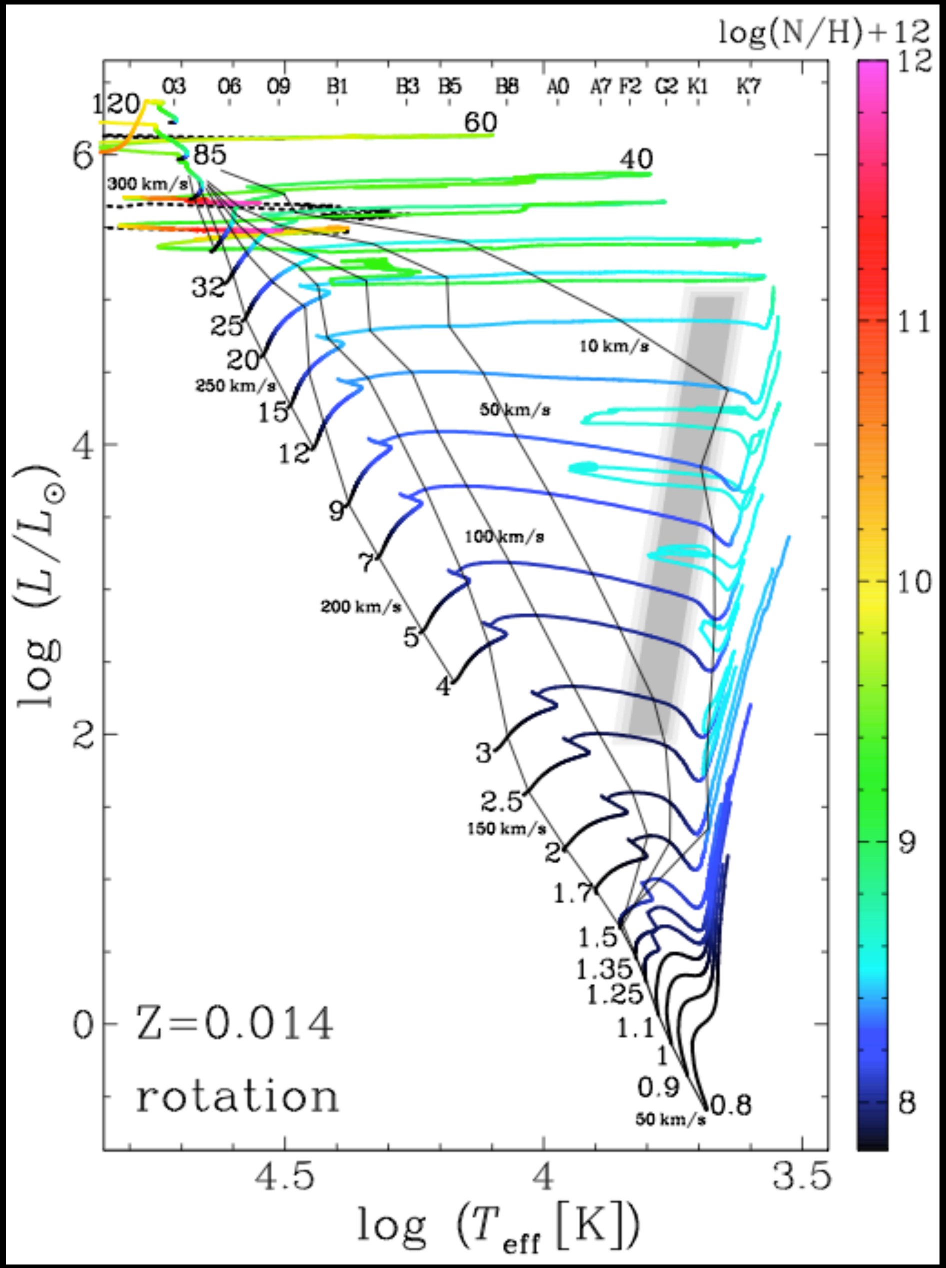
- Photometry: magnitudes + colors
- Spectroscopy: lines (EW + rad. vel)

Stellar evolution models

- Luminosity + temperature
- Abundances



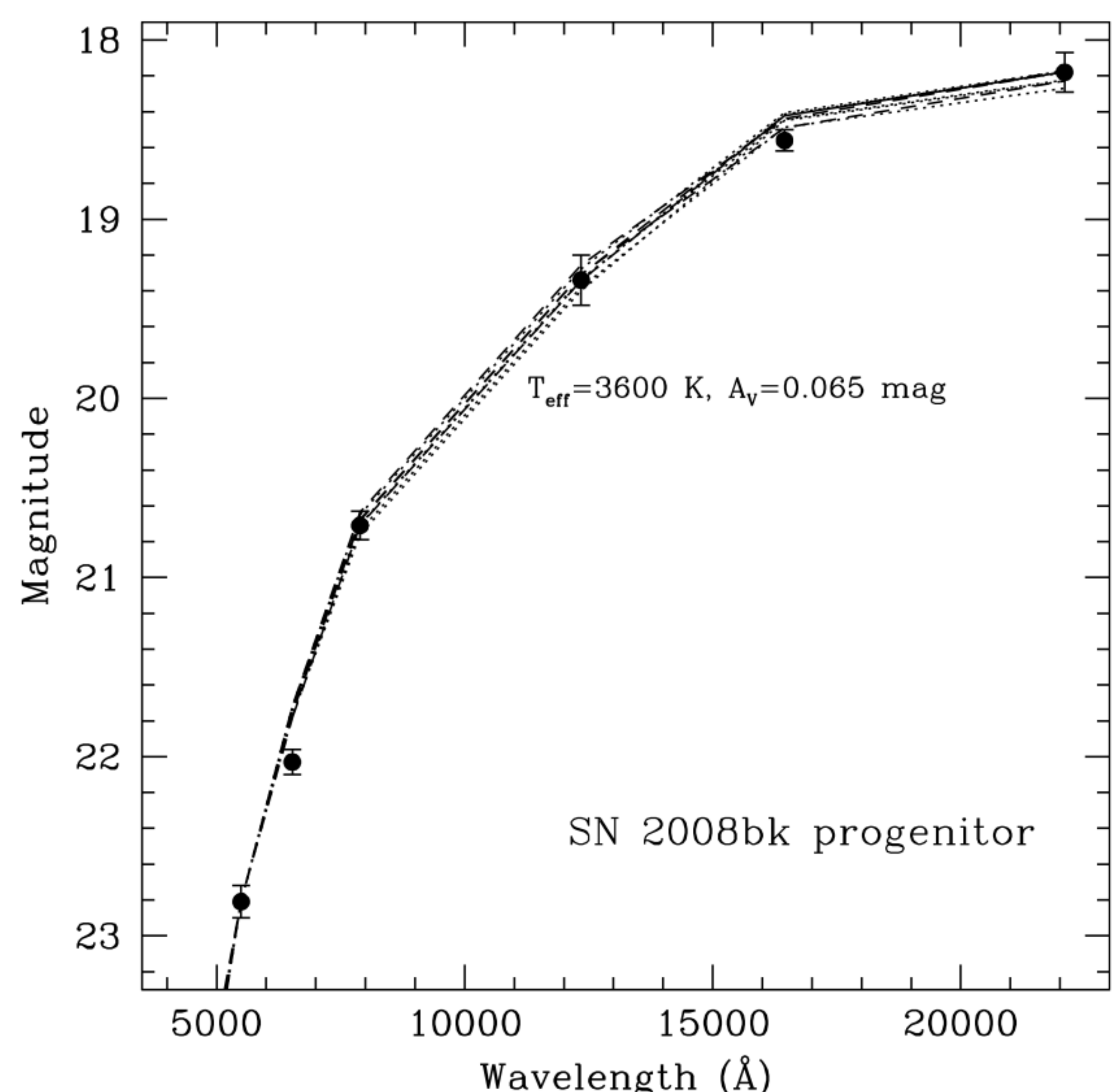
(Mattila+ 08)



(Ekstrom+ 12)

Inverse problem: obtain L and Teff from the observations

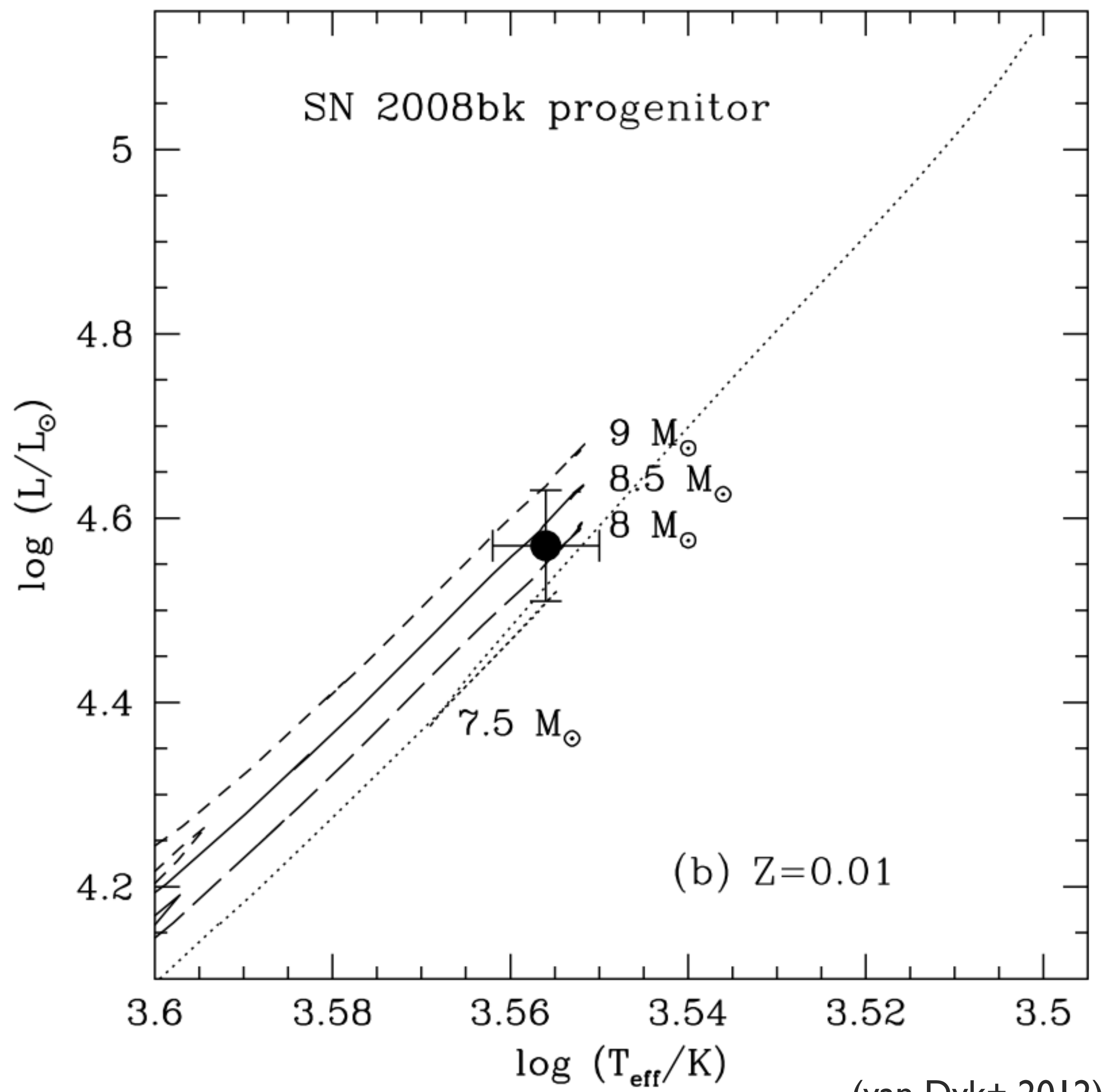
SN progenitor detected in 6 bands (VRIJHK)



(van Dyk+ 2012)

Inverse problem: obtain L and Teff from the observations

SN progenitor is a RSG with initial mass ~8 $M_\odot$



(van Dyk+ 2012)

Observations *vs.* stellar evolution models

Issue: massive stars develop winds that become denser as the star evolves, hiding progressively more and more of the stellar surface.

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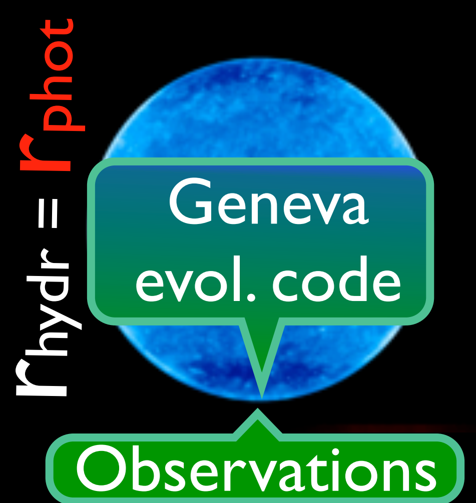
low-mass stars (e.g Sun)



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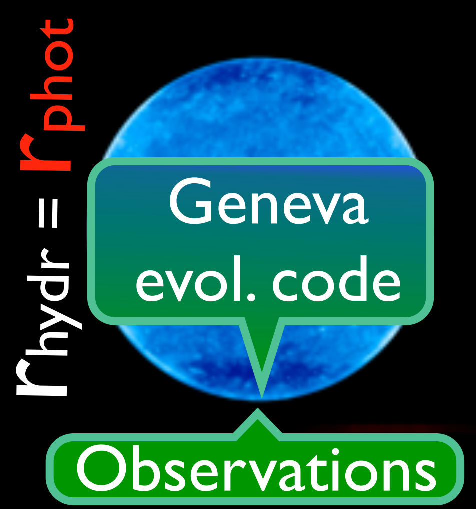
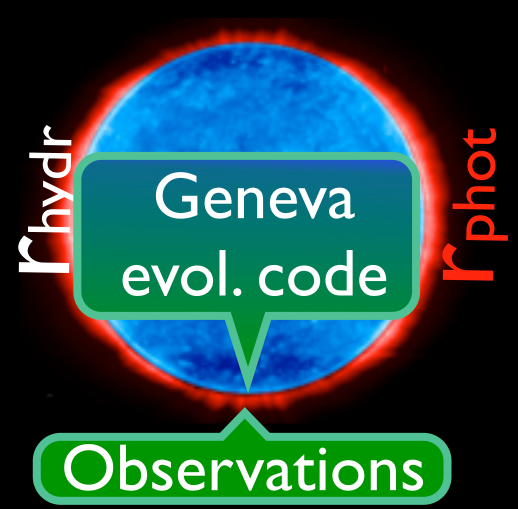


massive stars: beginning of their lives



Observations *vs.* stellar evolution models

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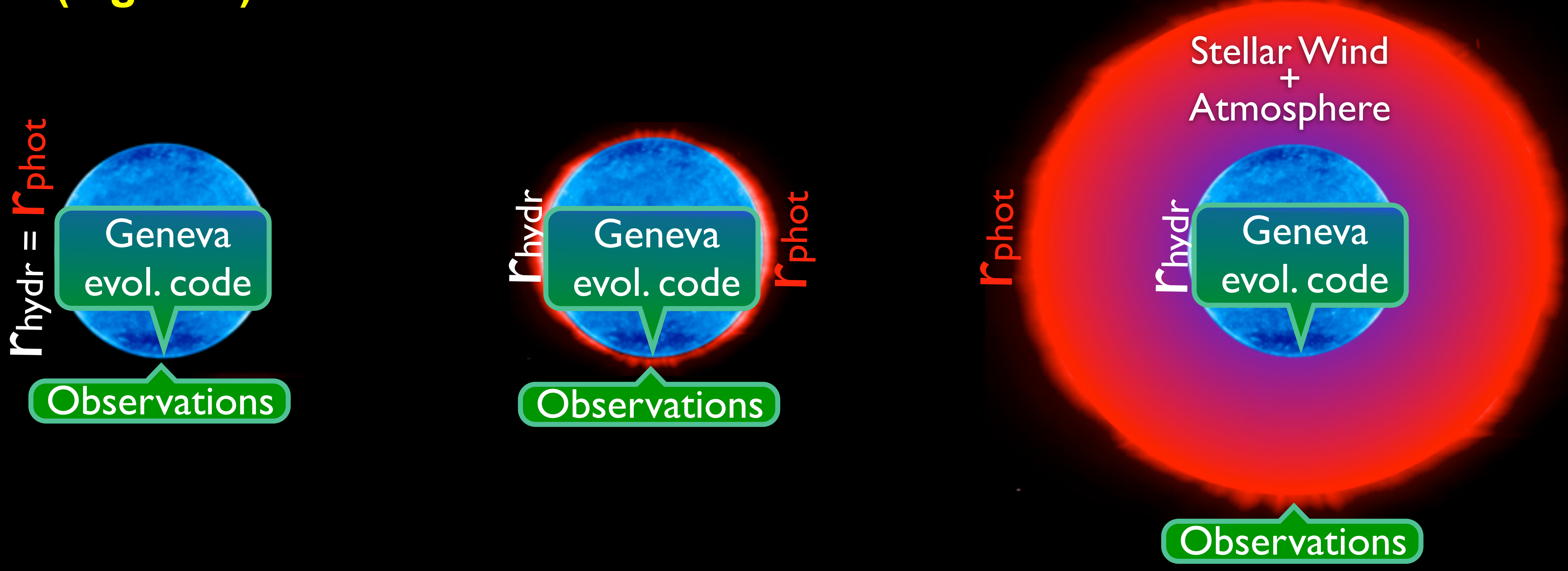
massive stars: beginning of their lives

massive stars as they evolve

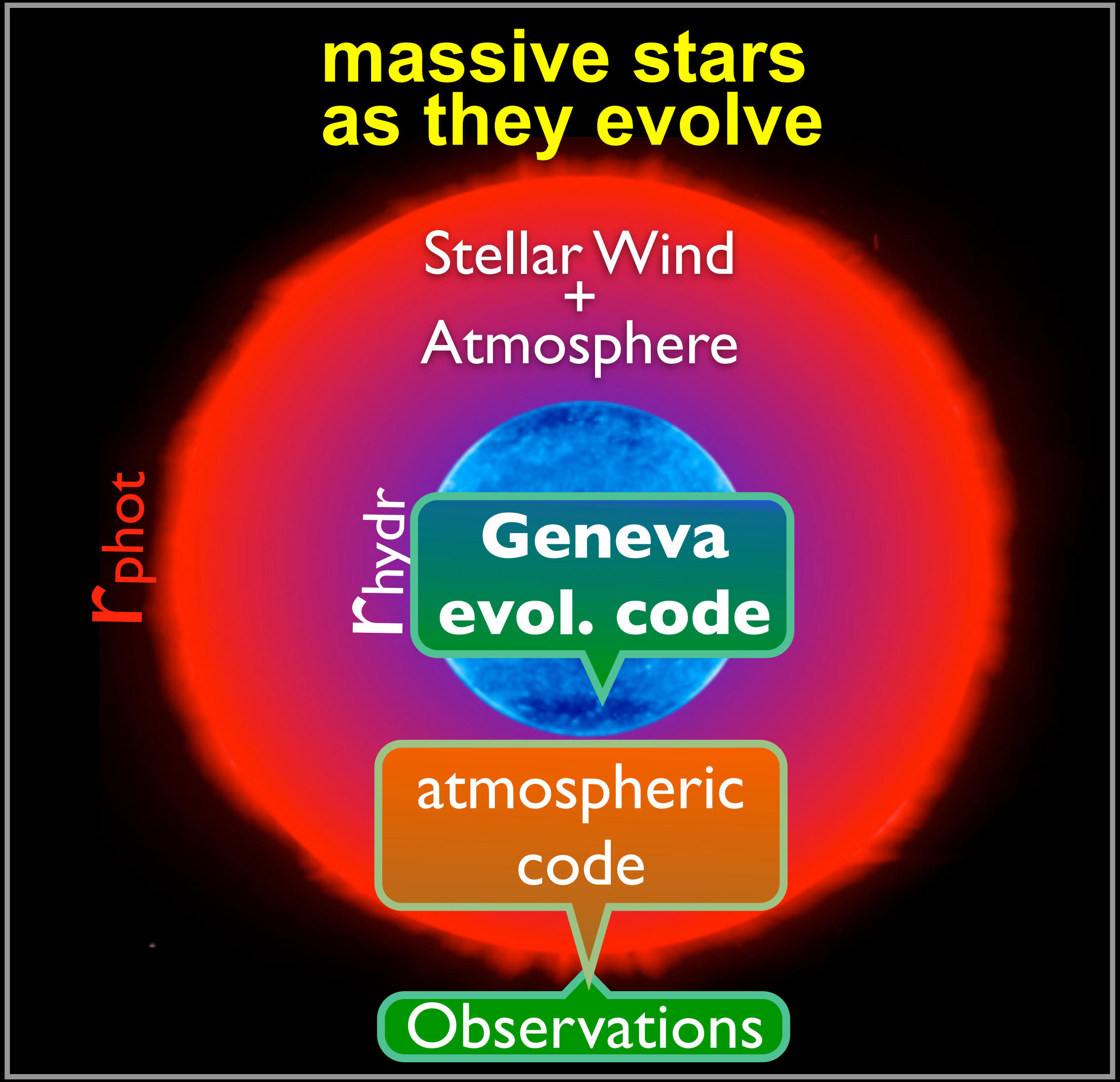


Consequence: predictions from models of the interior of massive stars cannot be directly compared to the observations.

Solution: atmospheric code

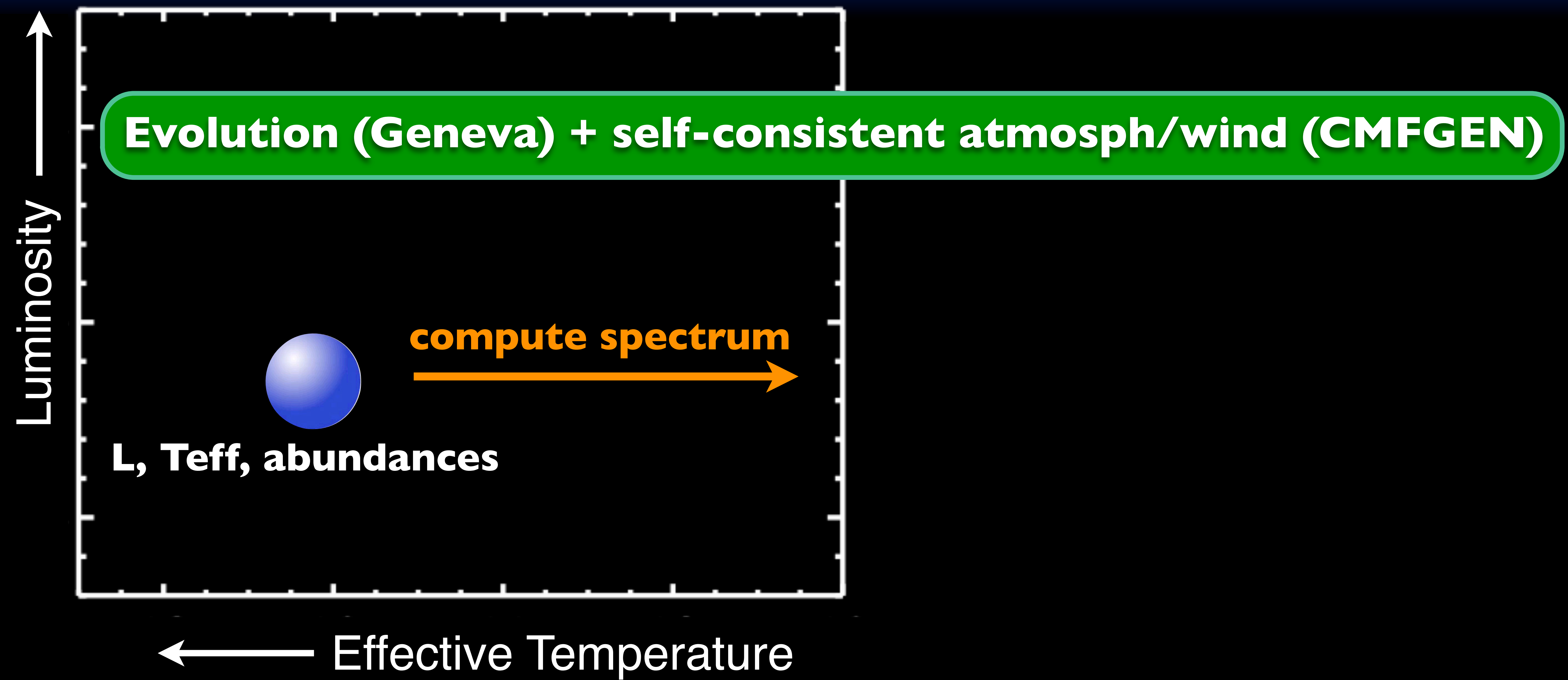
Atmospheric code:

interpreter, translating physical quantities predicted by the interior models to be compared to the observations.

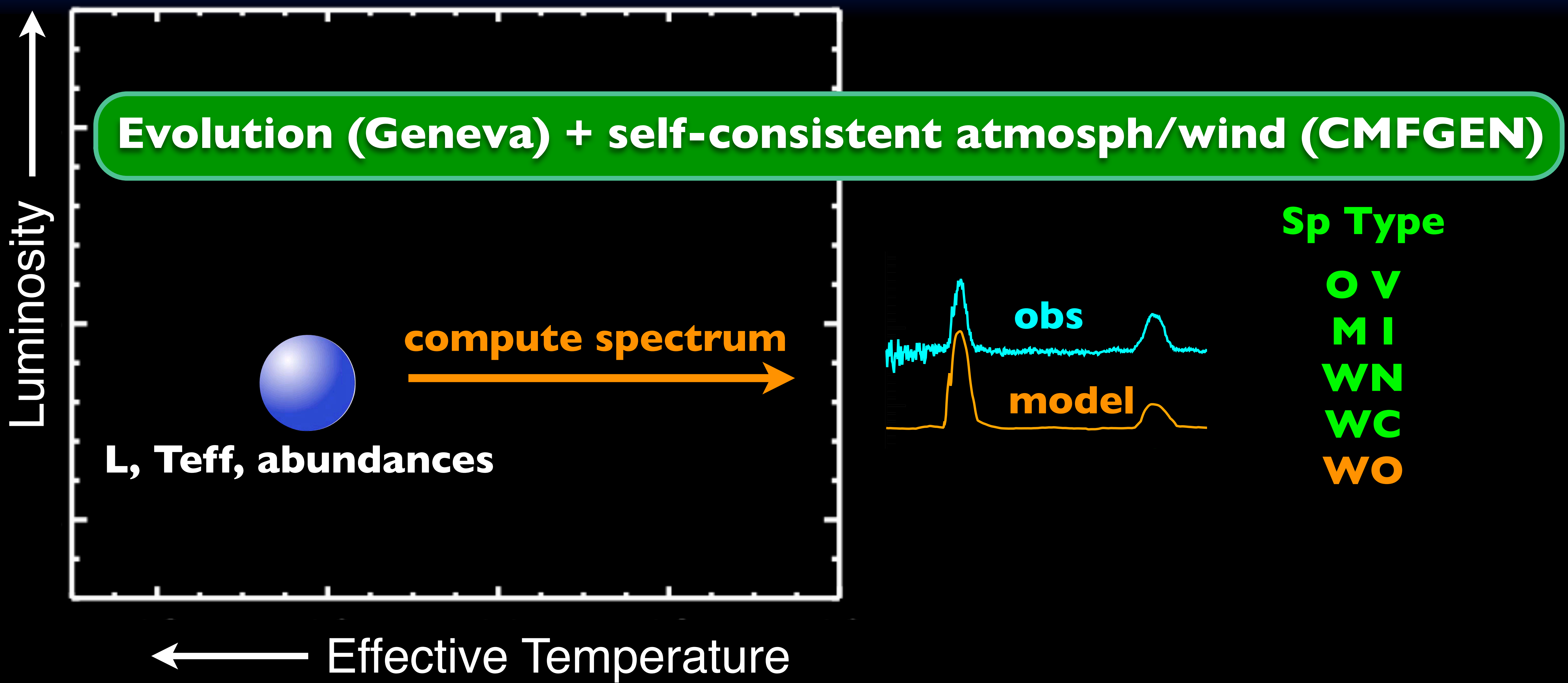


Innovation: couple the Geneva stellar interior/evolution code with the CMFGEN radiative transfer code for the wind and atmosphere.

Predicting the look of massive stars across the cosmic time



Predicting the look of massive stars across the cosmic time



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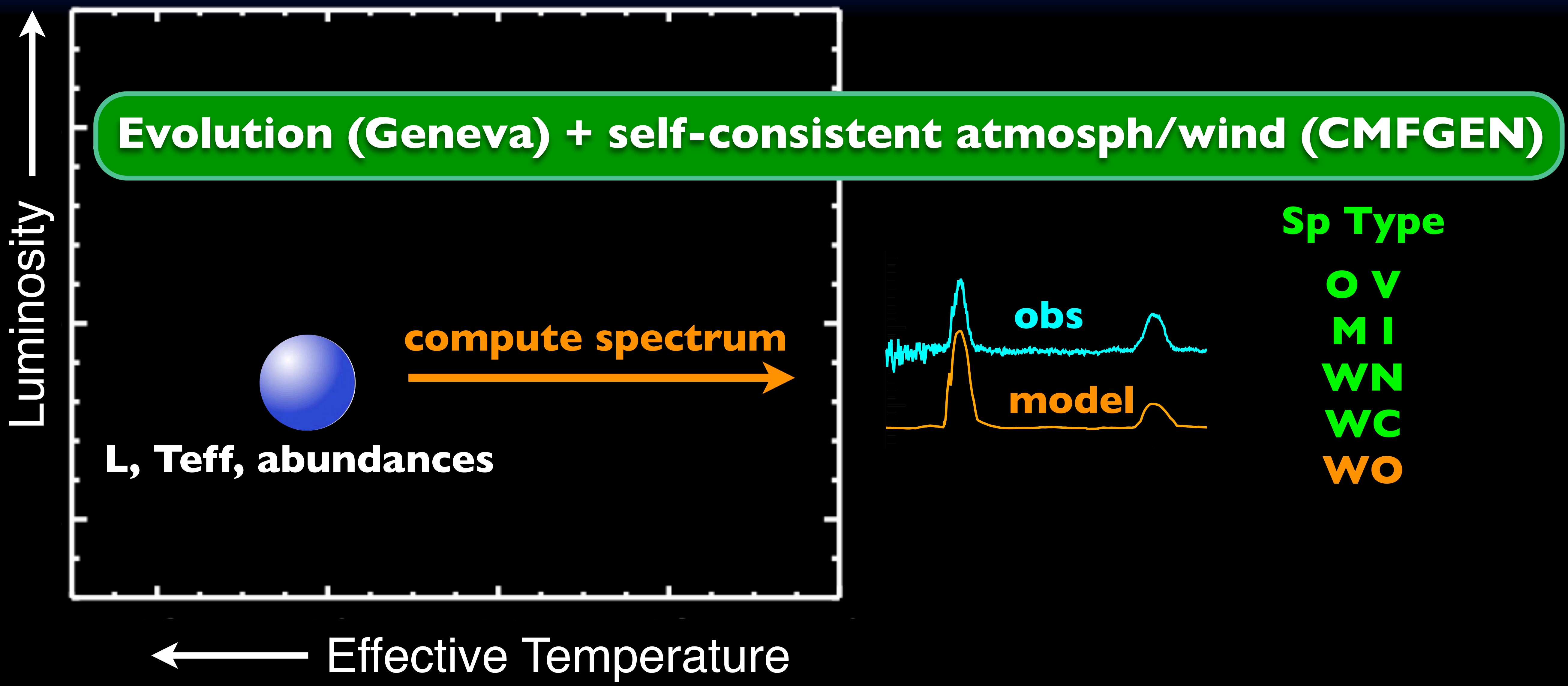

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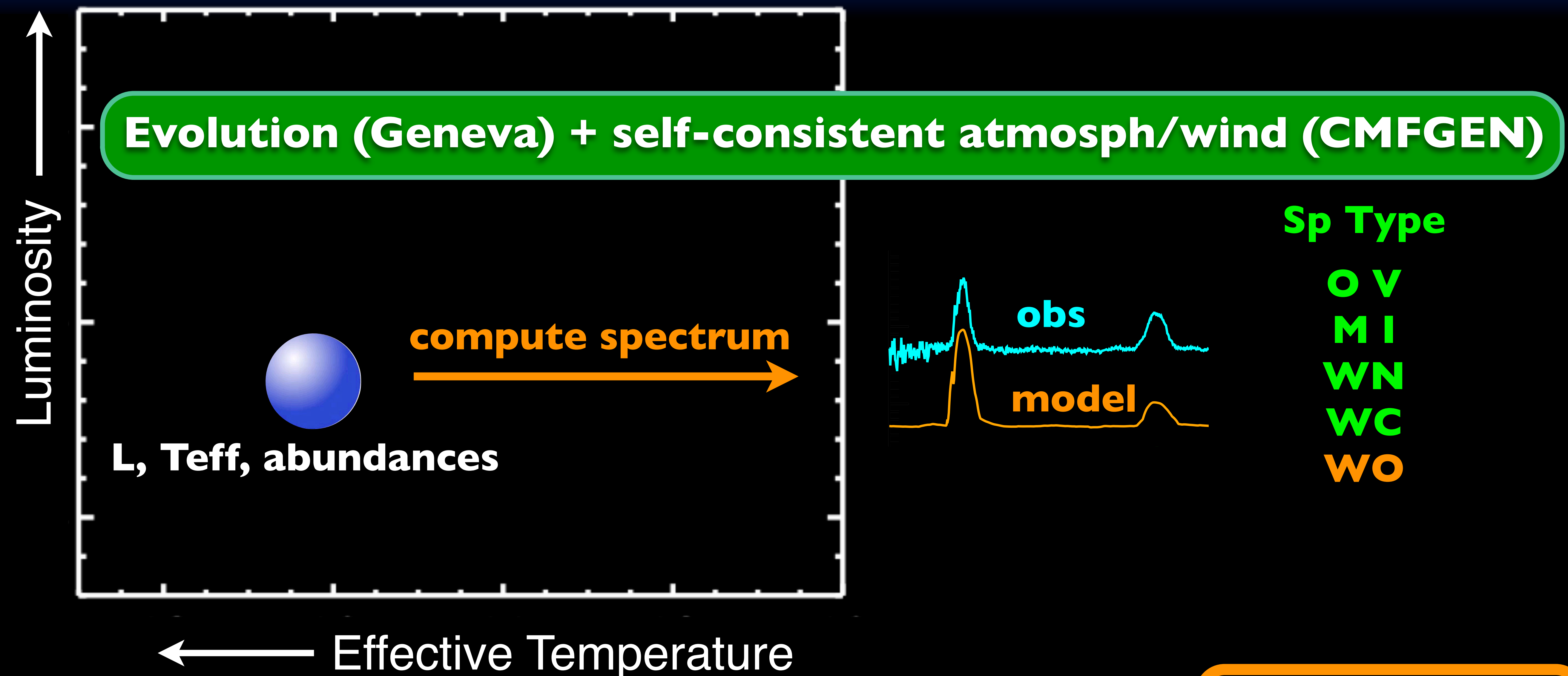
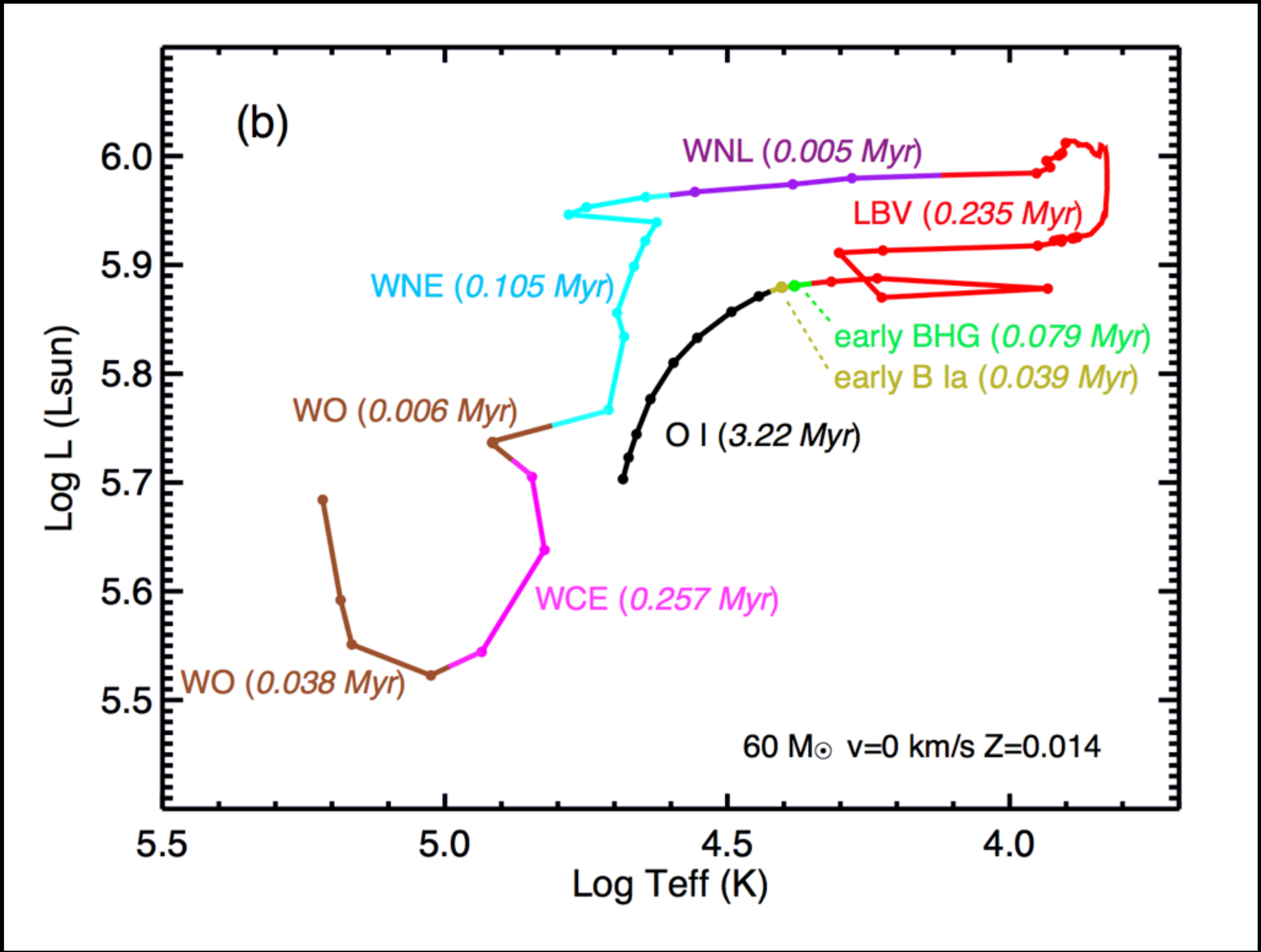


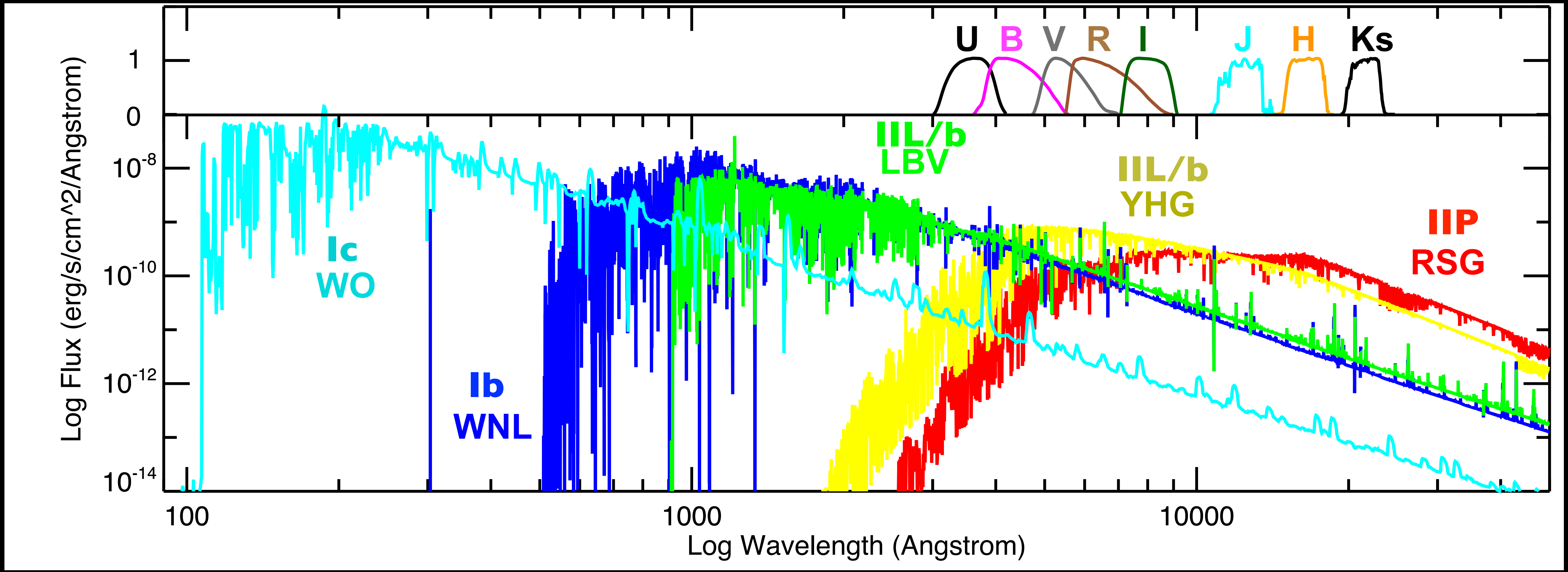
Spectral evolution of massive stars



Groh+ 2014, A&A in press (arXiv 1401.7322)

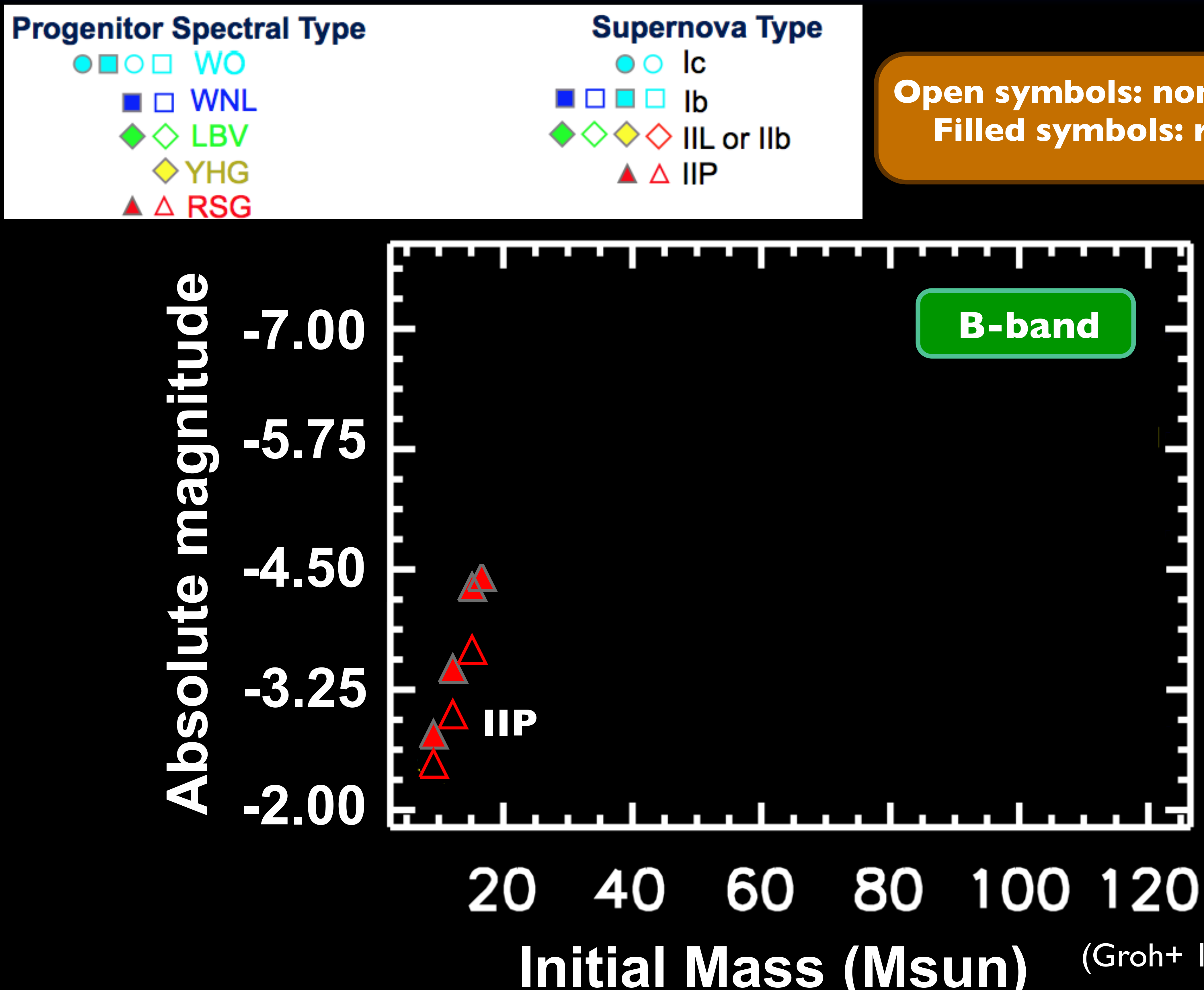
Spectral energy distribution of SN progenitors

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



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

Predicting the absolute magnitudes of SN progenitors



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

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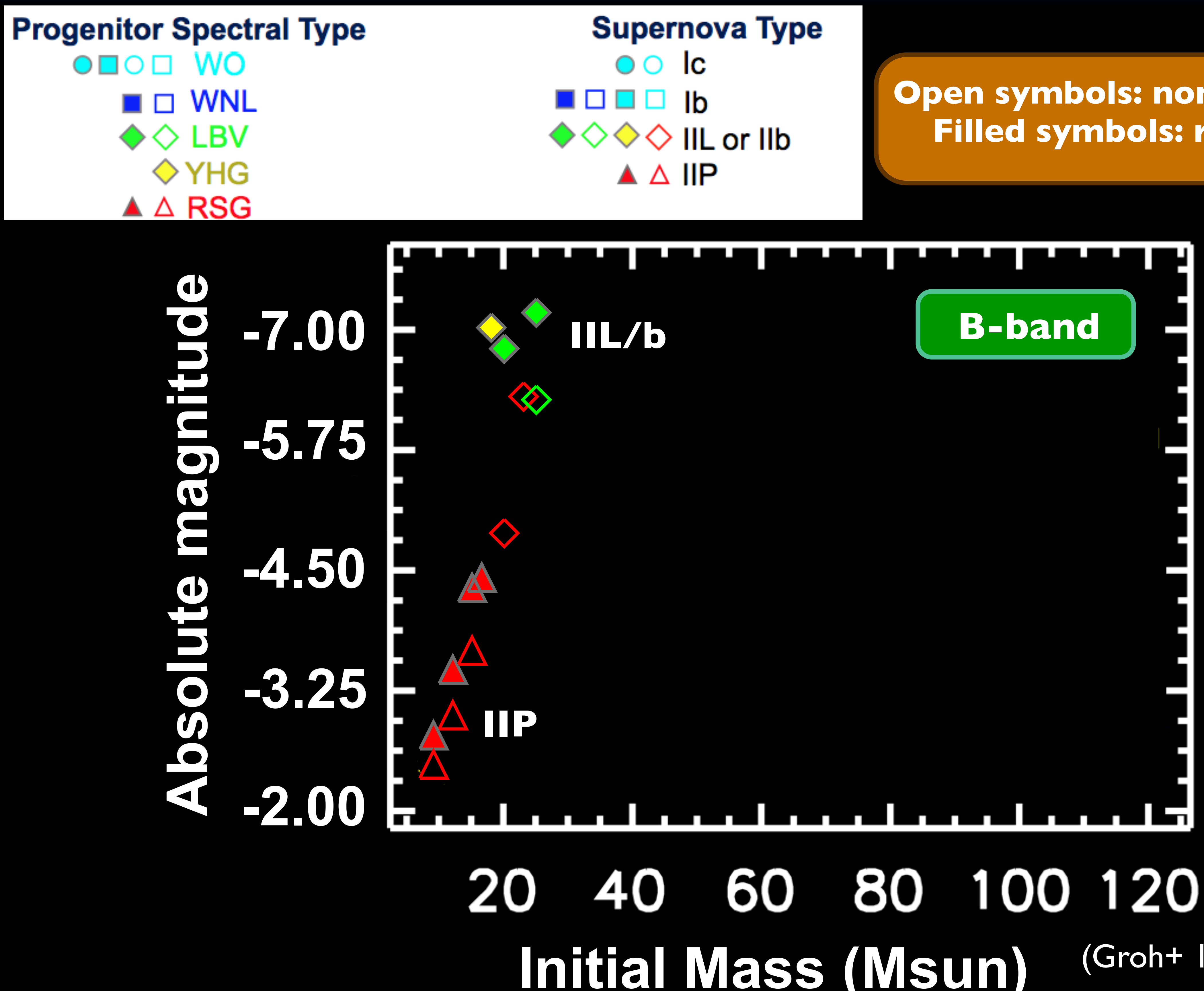

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Predicting the absolute magnitudes of SN progenitors

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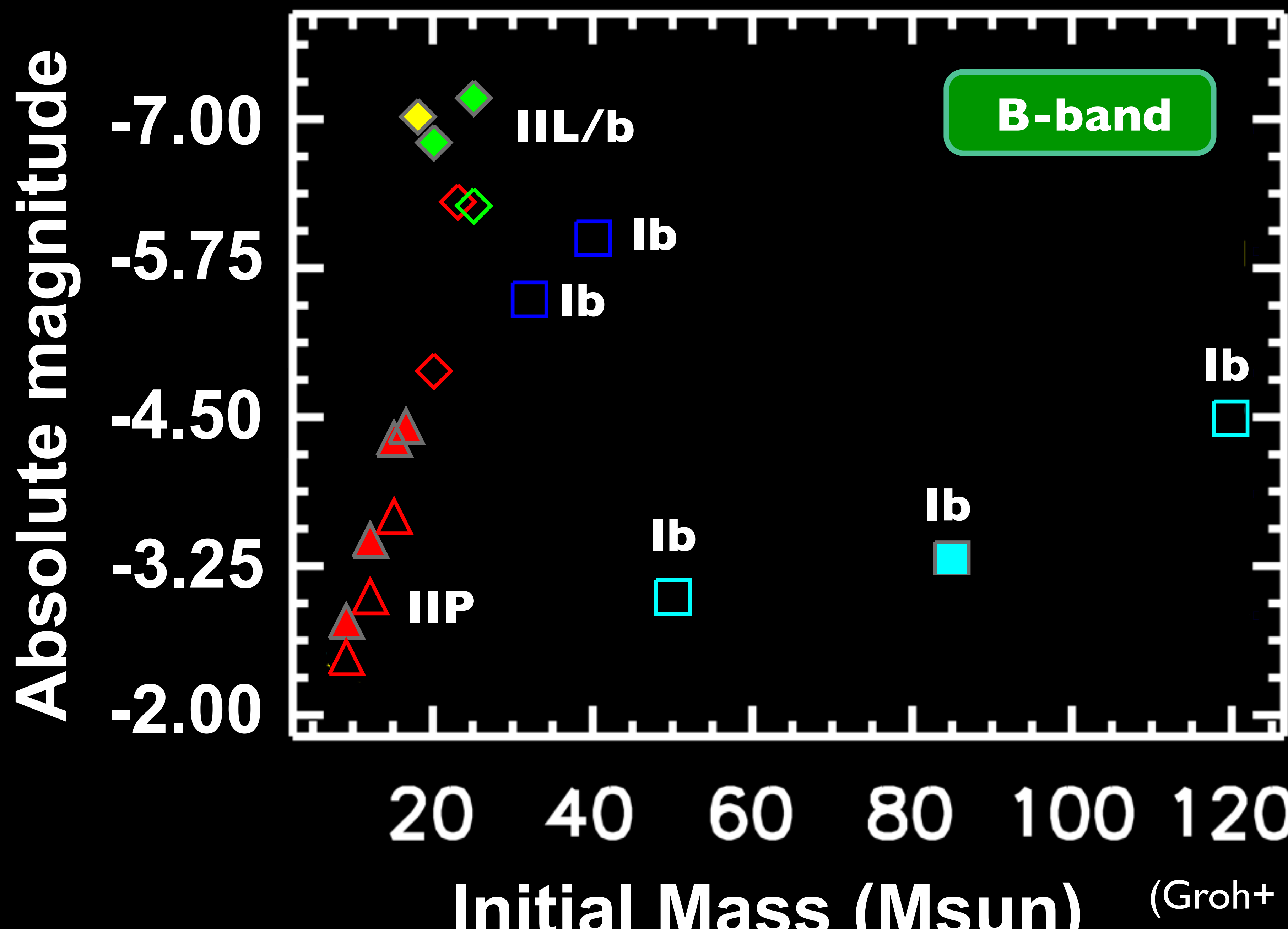

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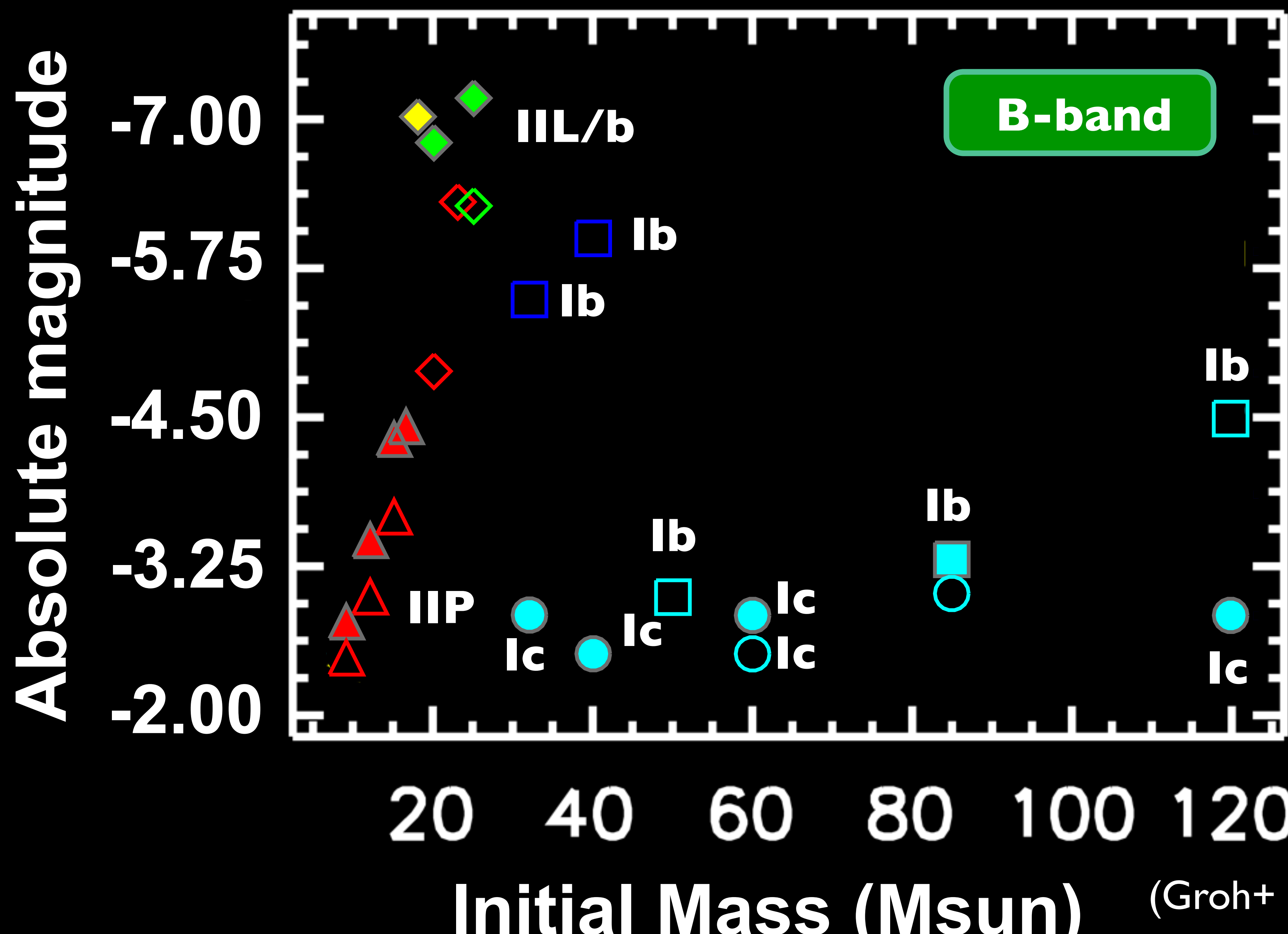

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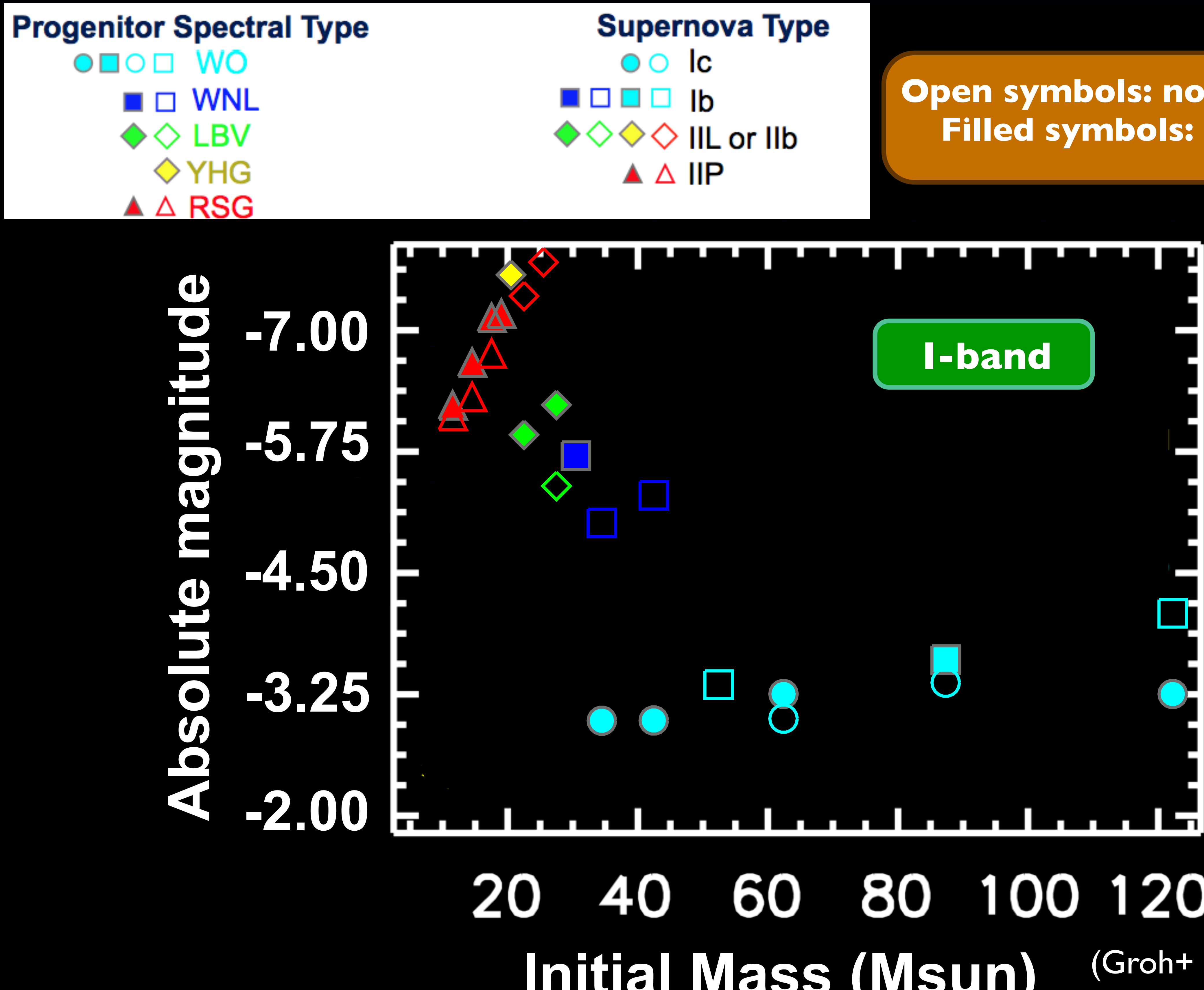

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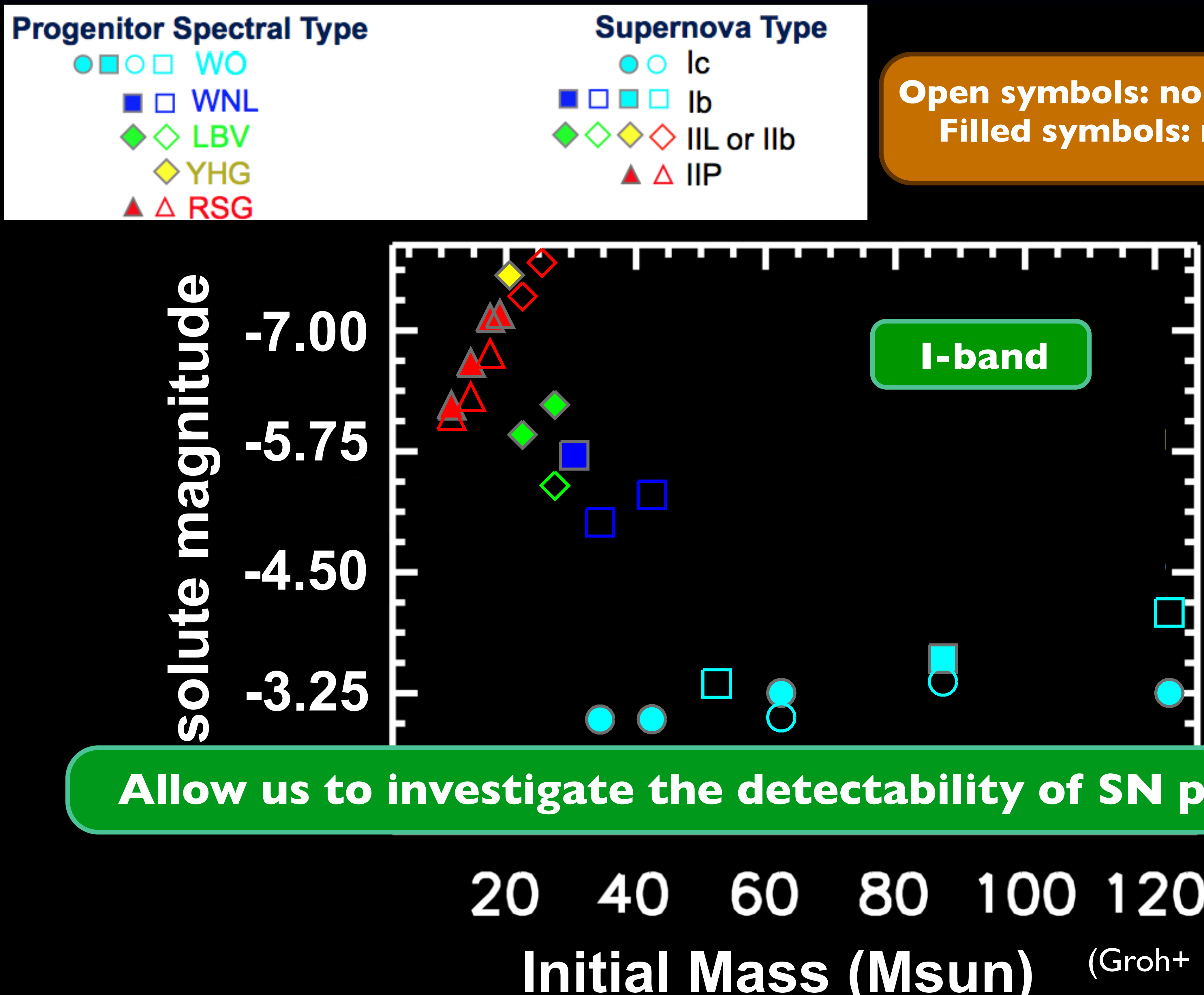

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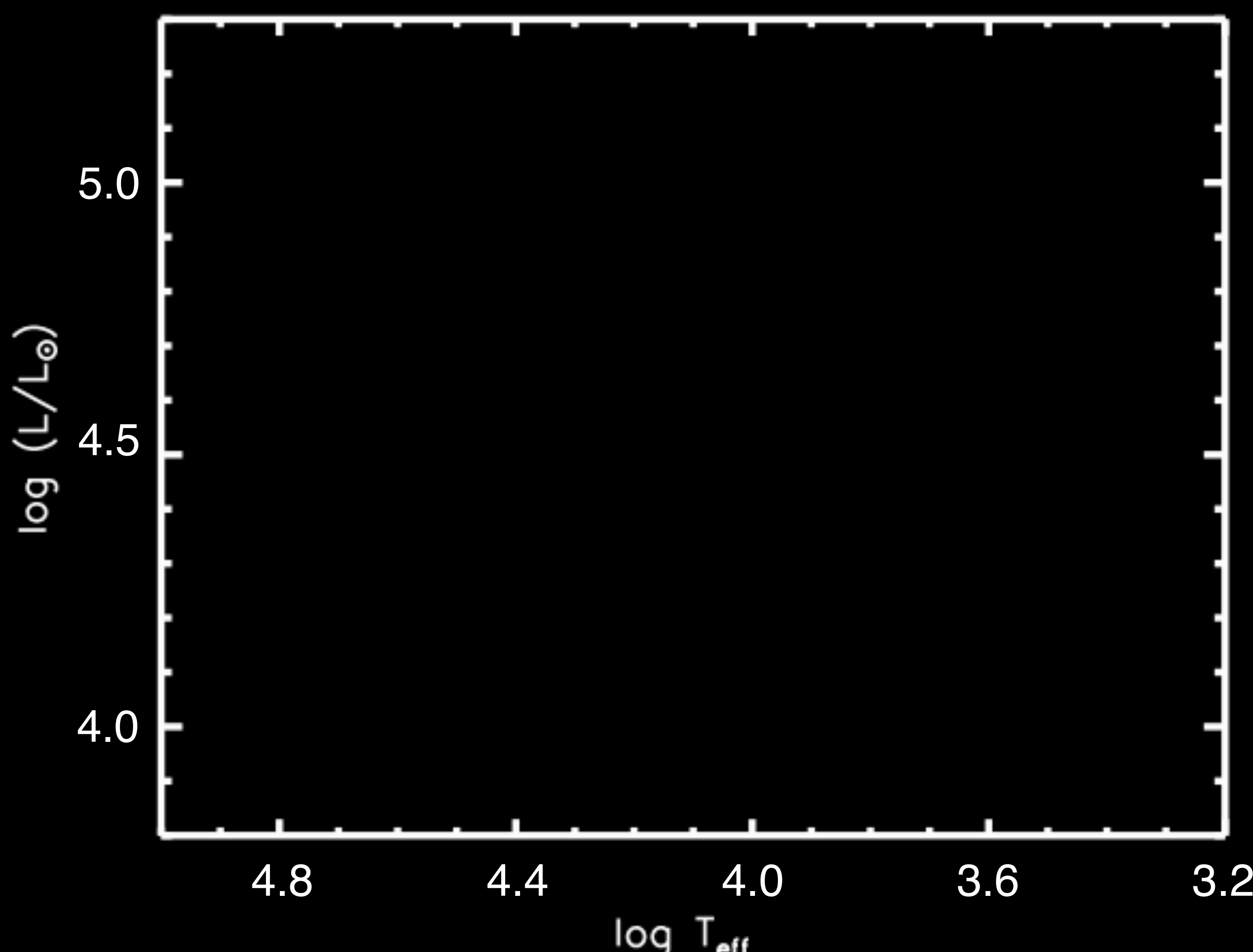
Allow us to investigate the detectability of SN progenitors

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

Single-star evolution at solar Z (8 to ~17 $M_\odot$)



(after evol. tracks from Ekstrom+ 12)

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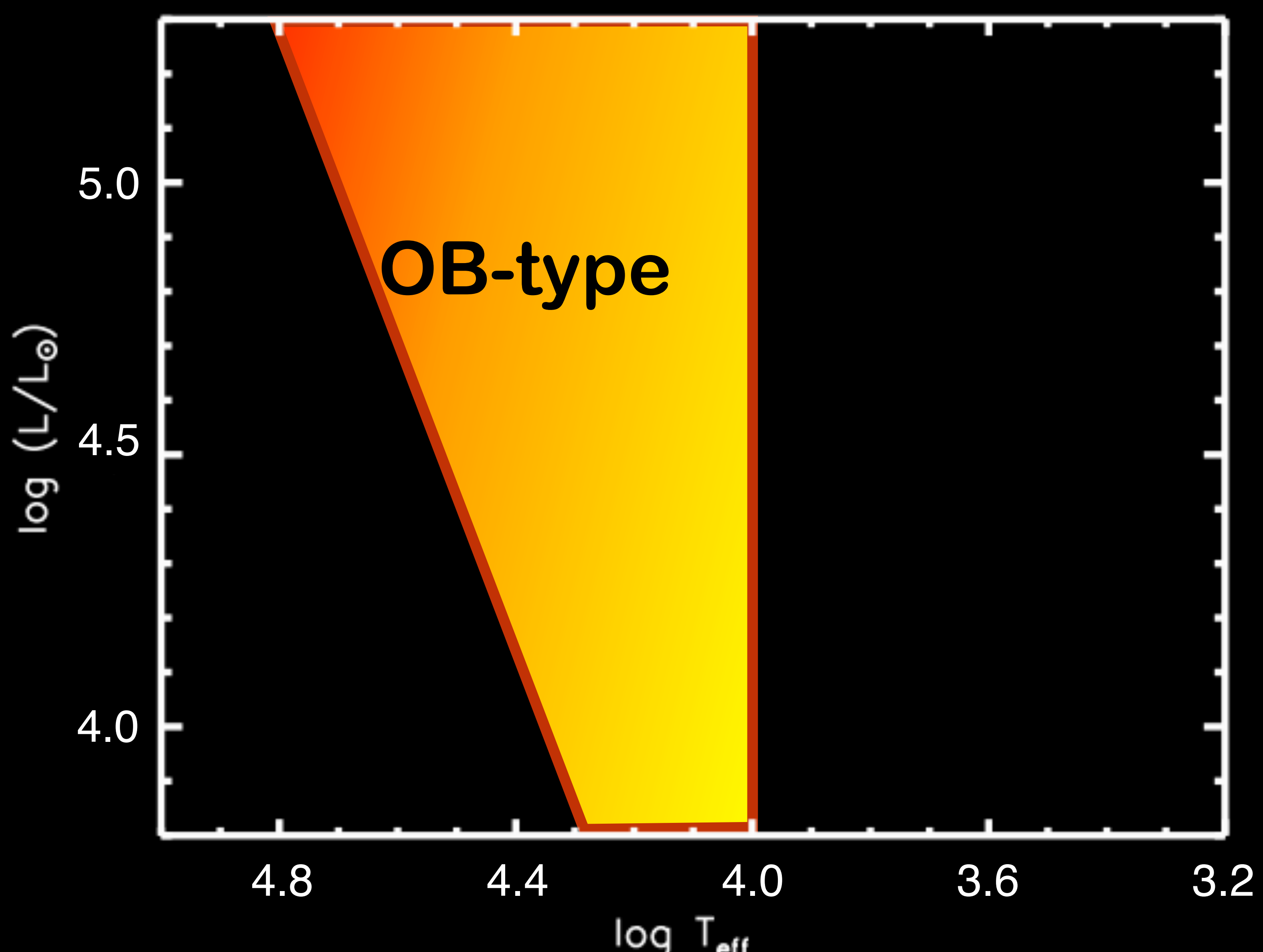

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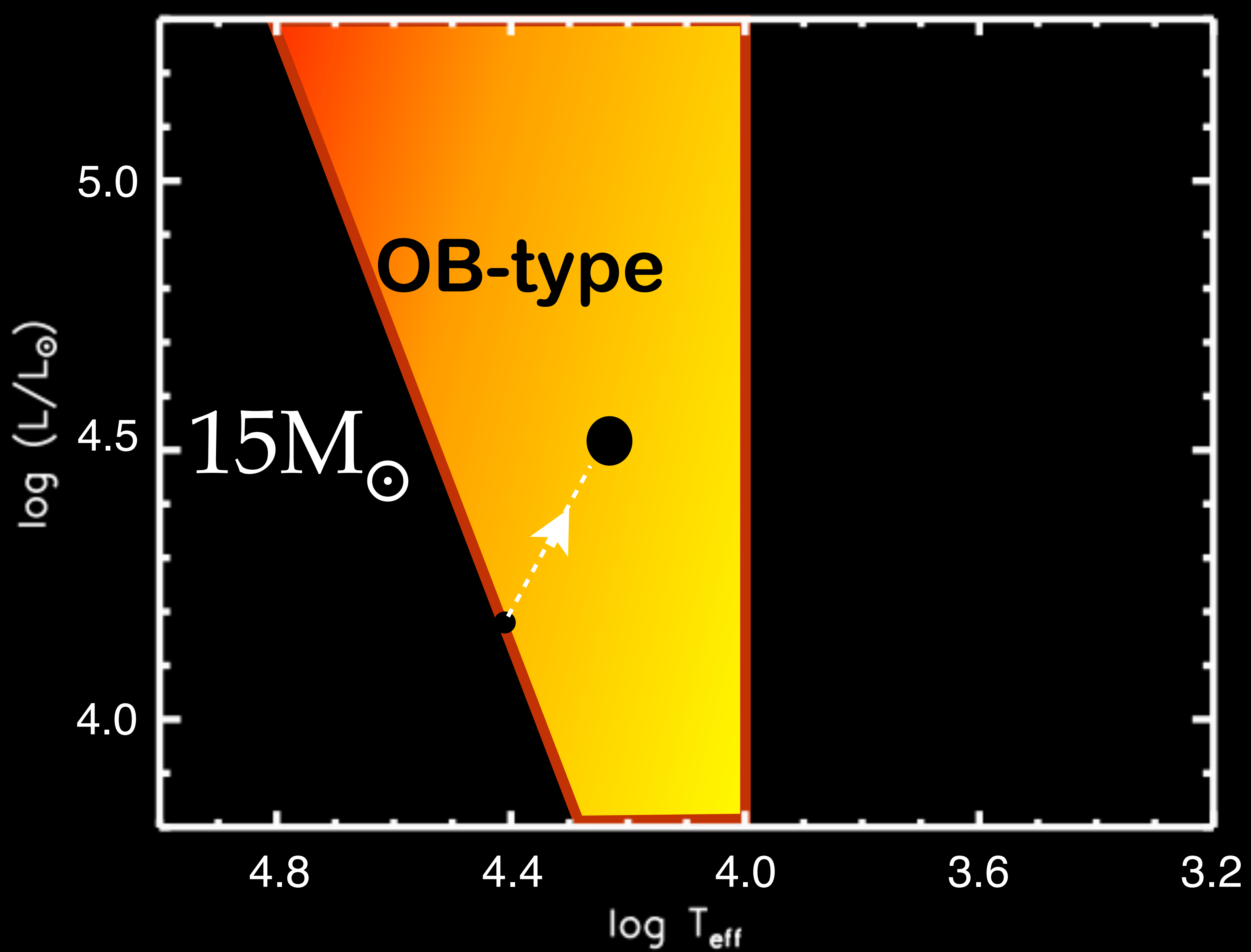

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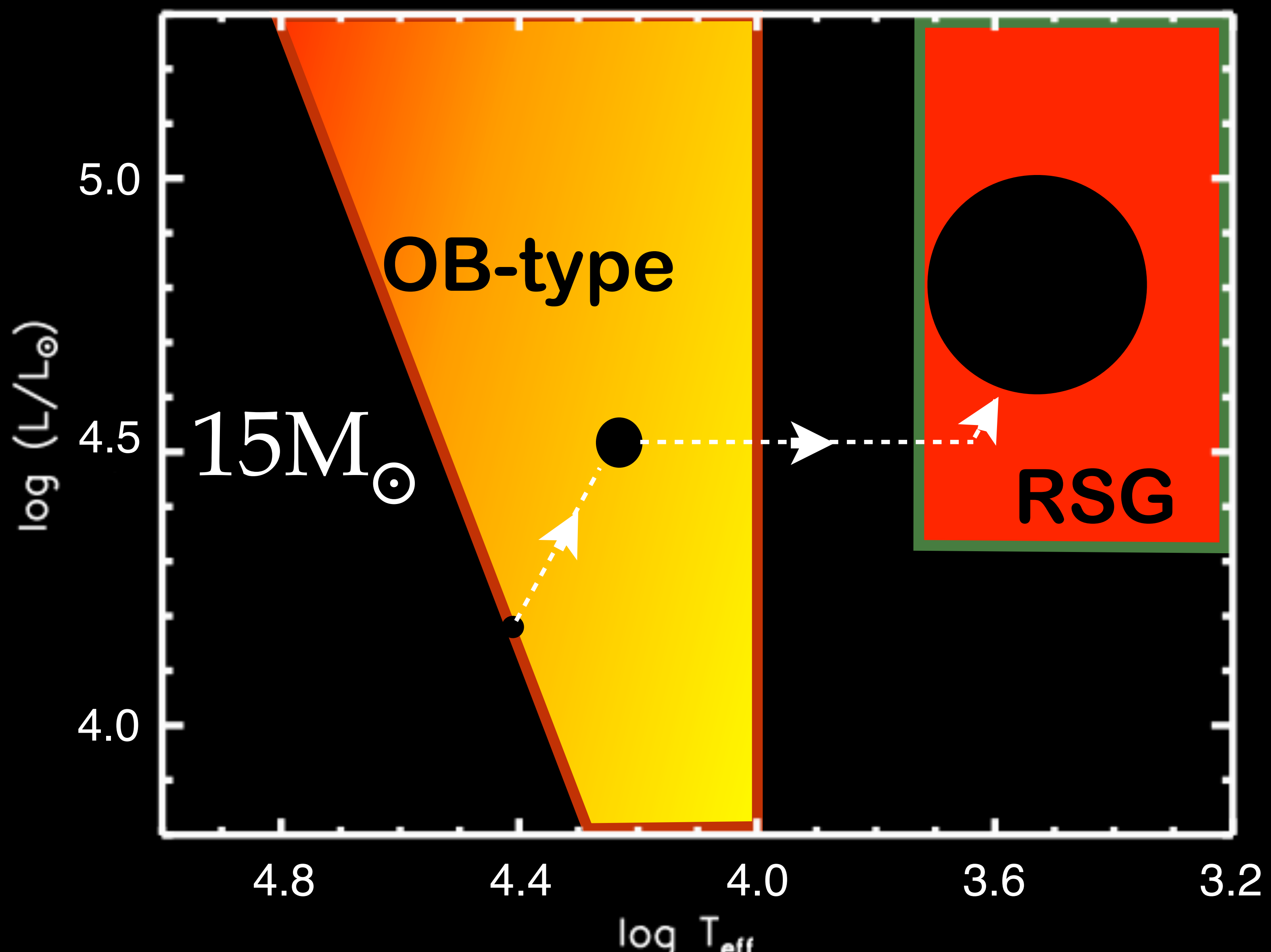

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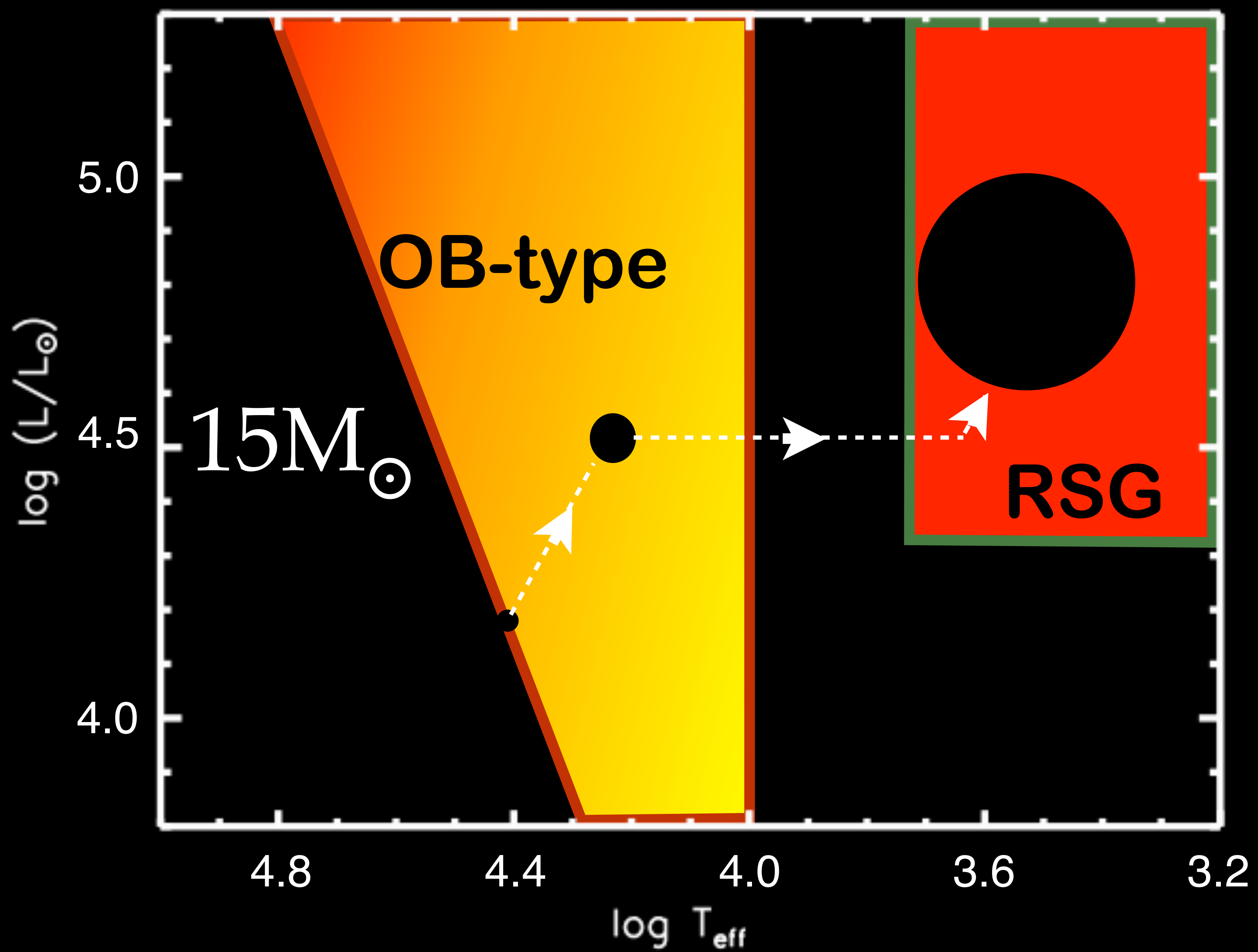
Single-star evolution at solar Z (8 to ~17 $M_\odot$)

OB-type → RSG → SN IIP



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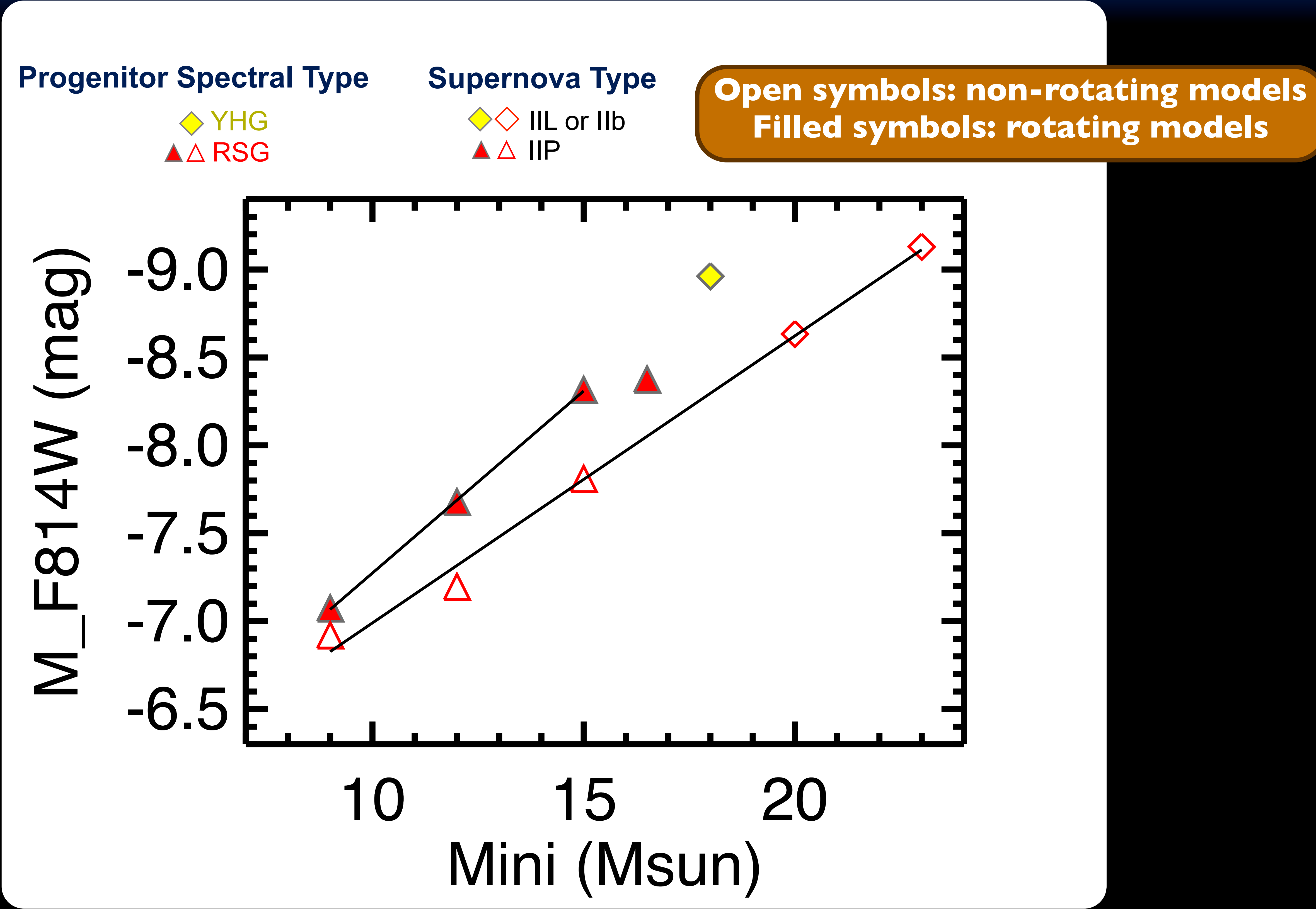
Maximum initial mass of SN IIP progenitors



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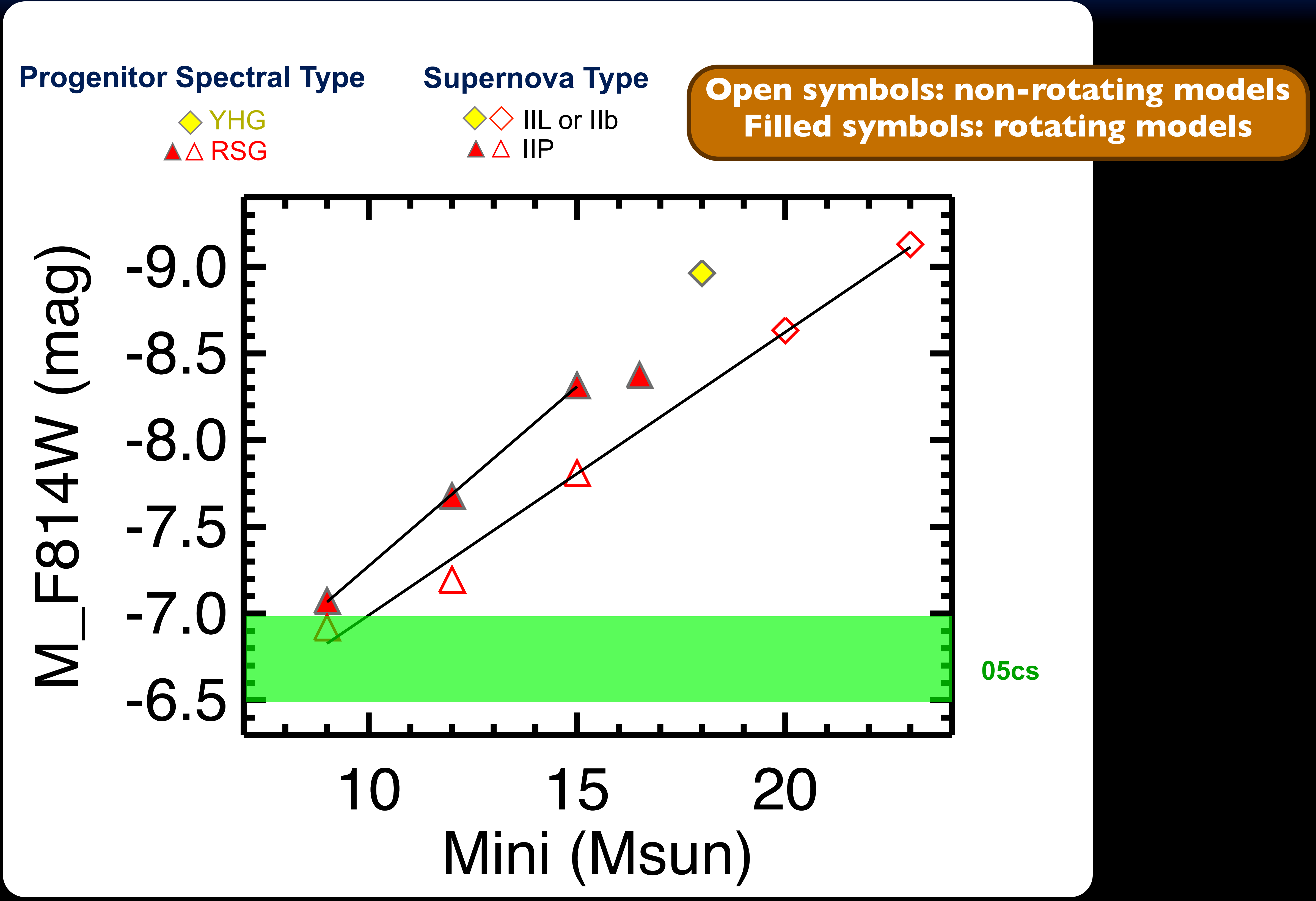

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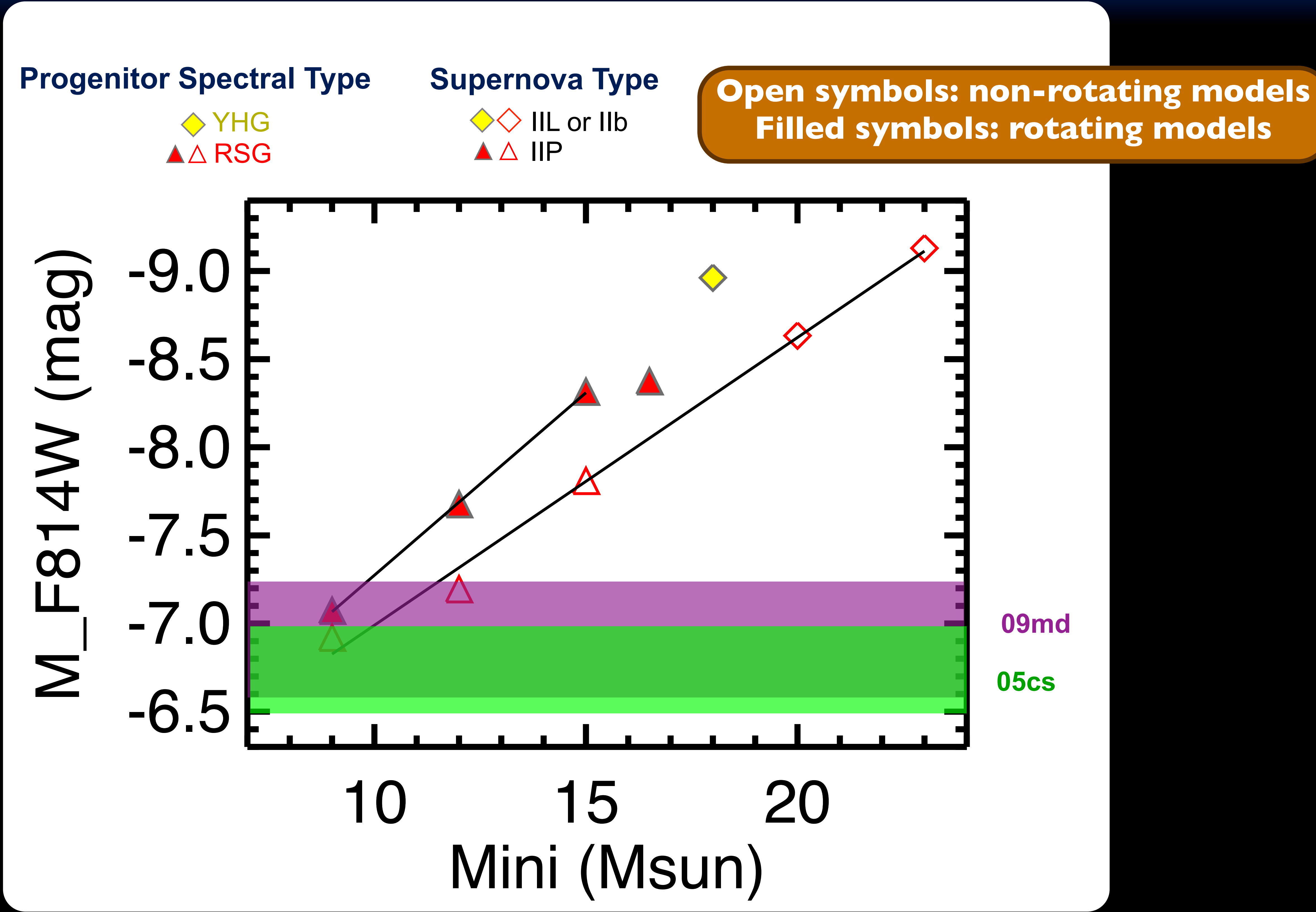

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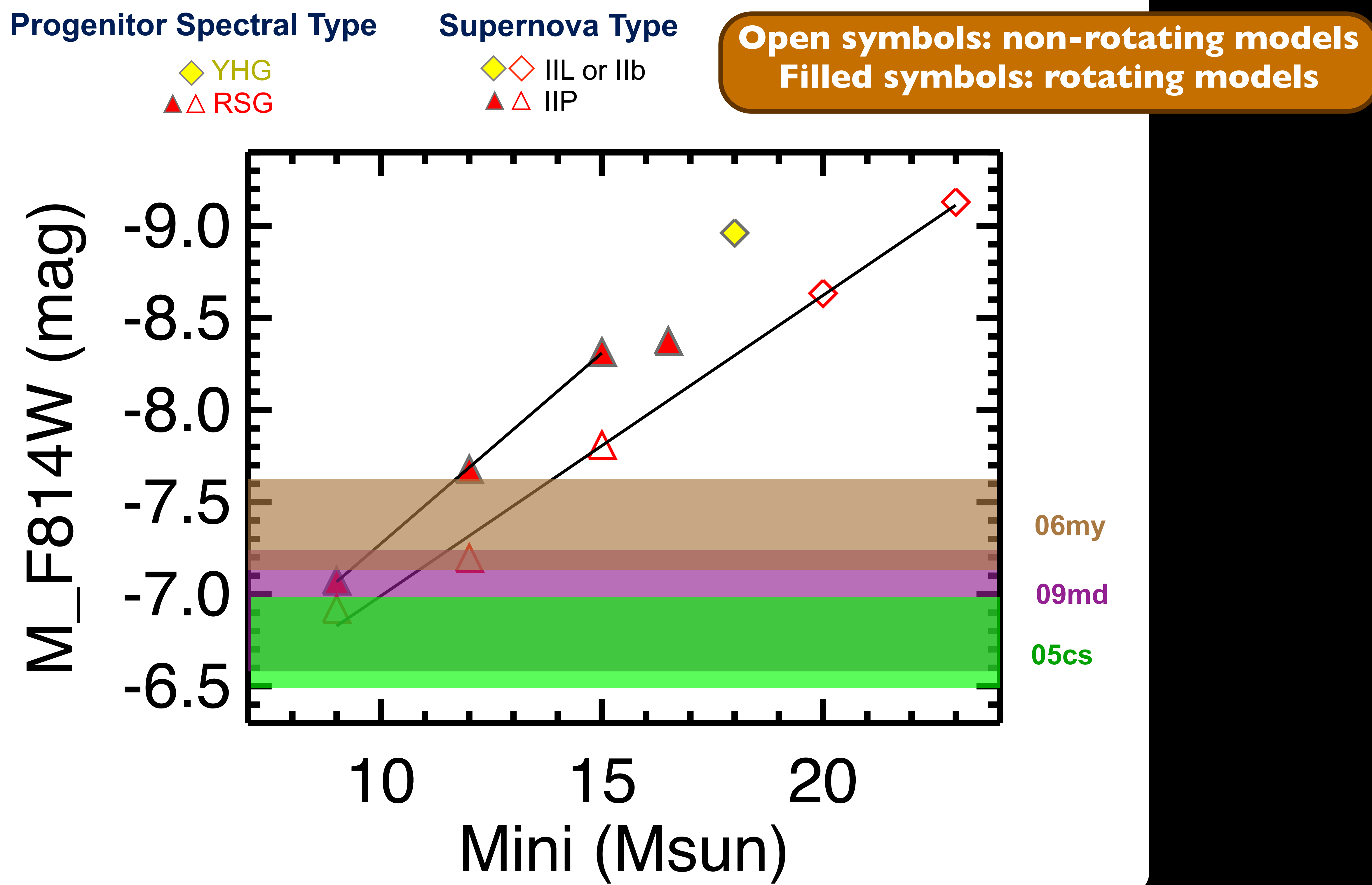

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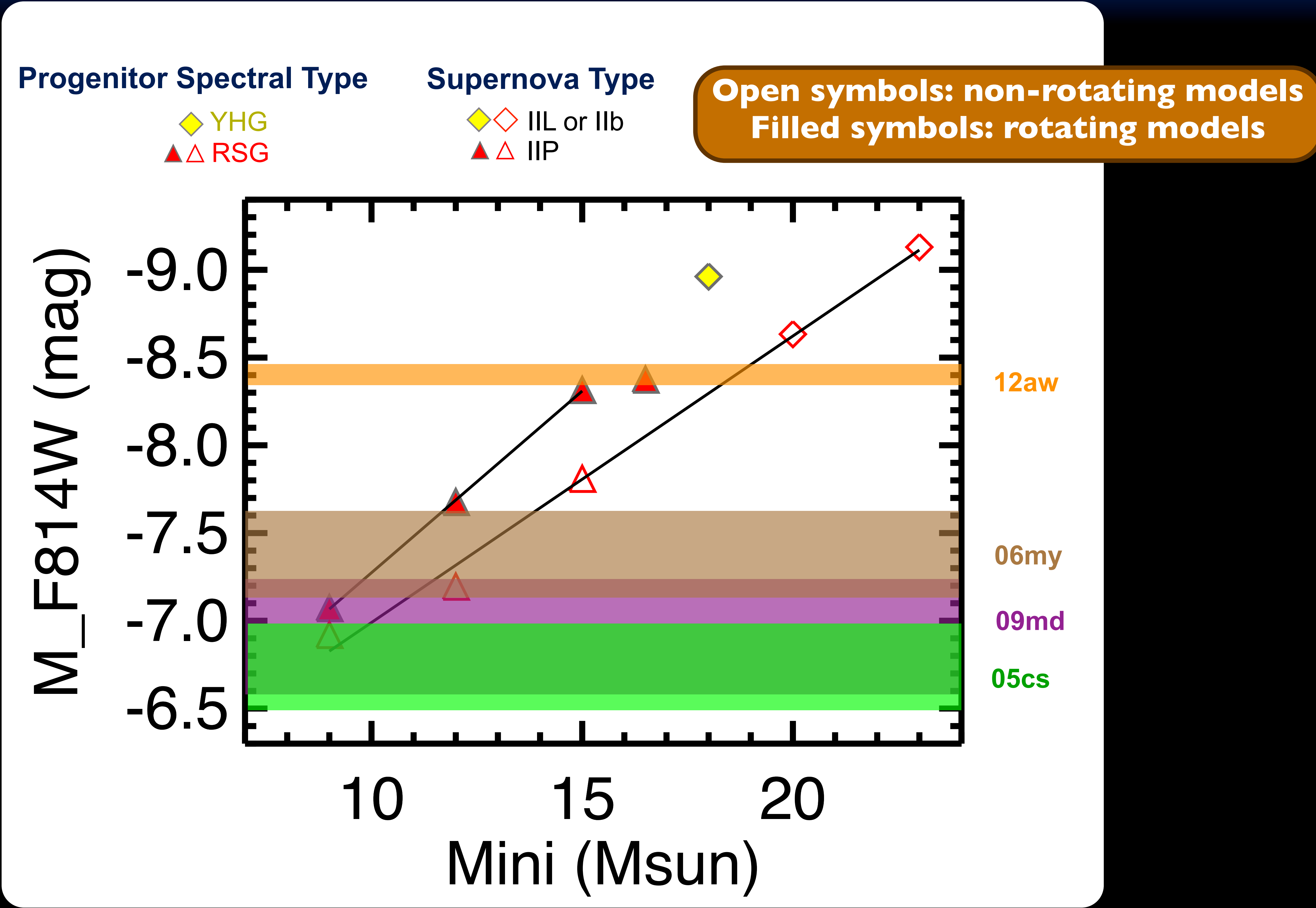

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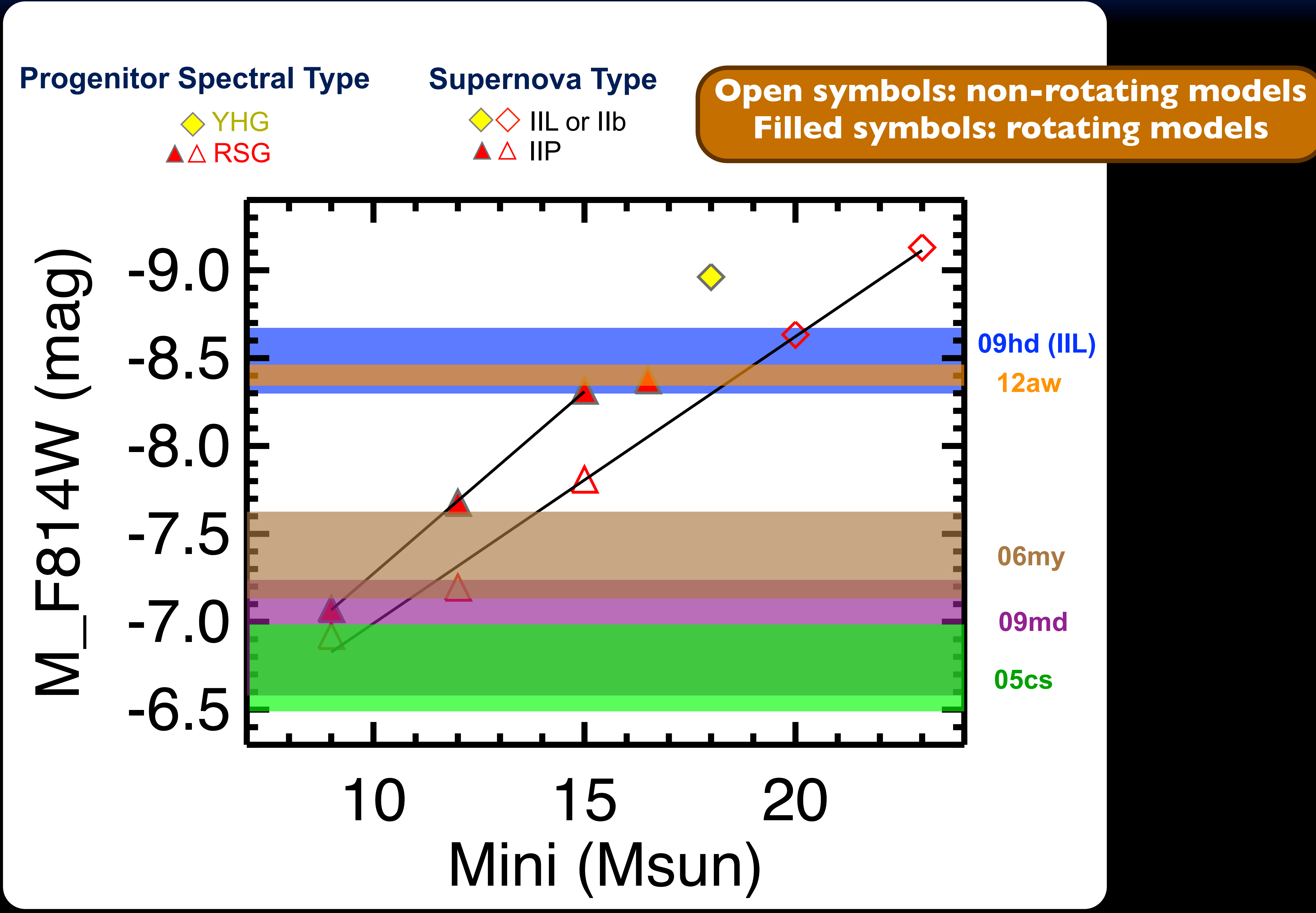
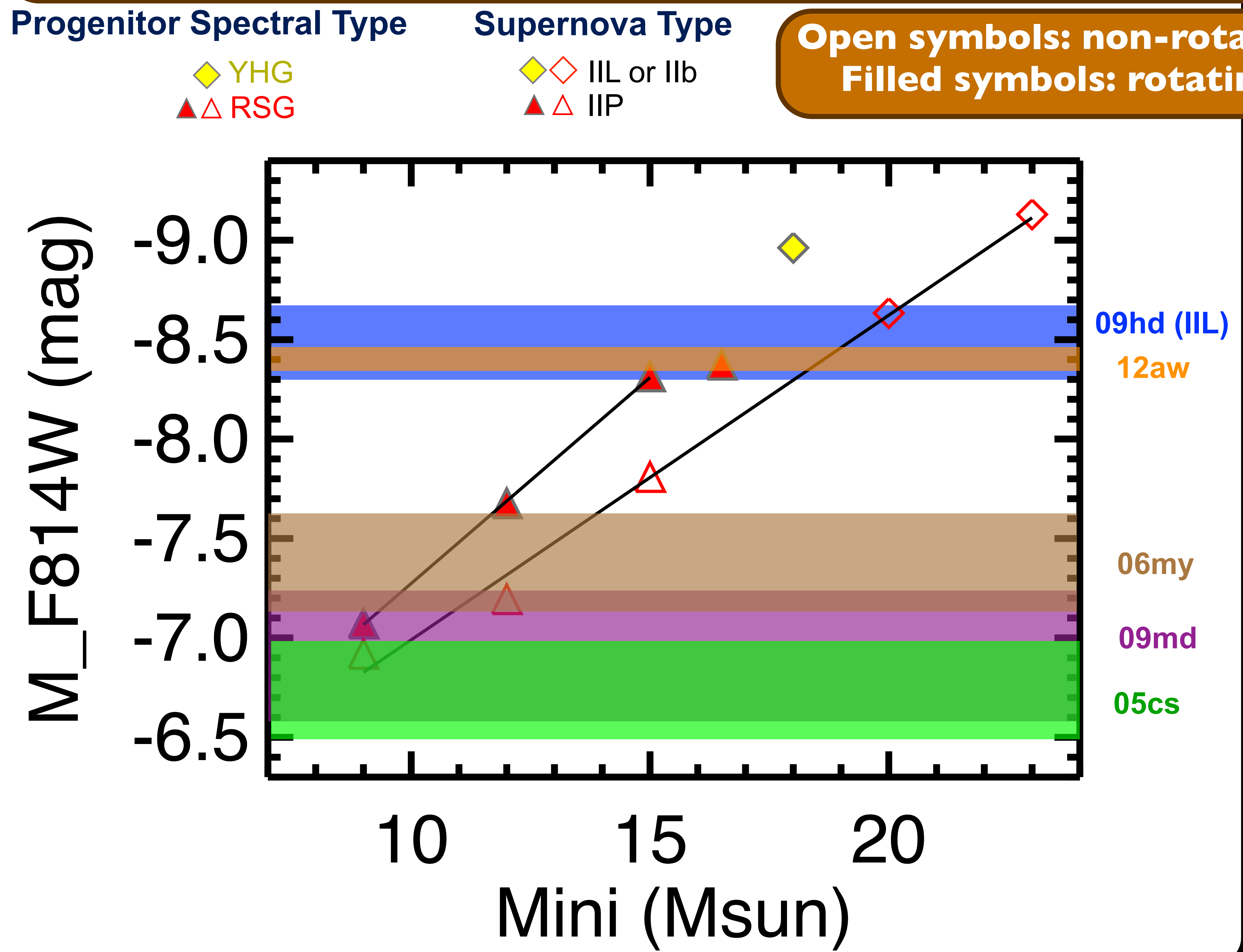


(Groh+ 13a, A&A in press; arXiv 1308.4601)

Maximum initial mass of SN IIP progenitors

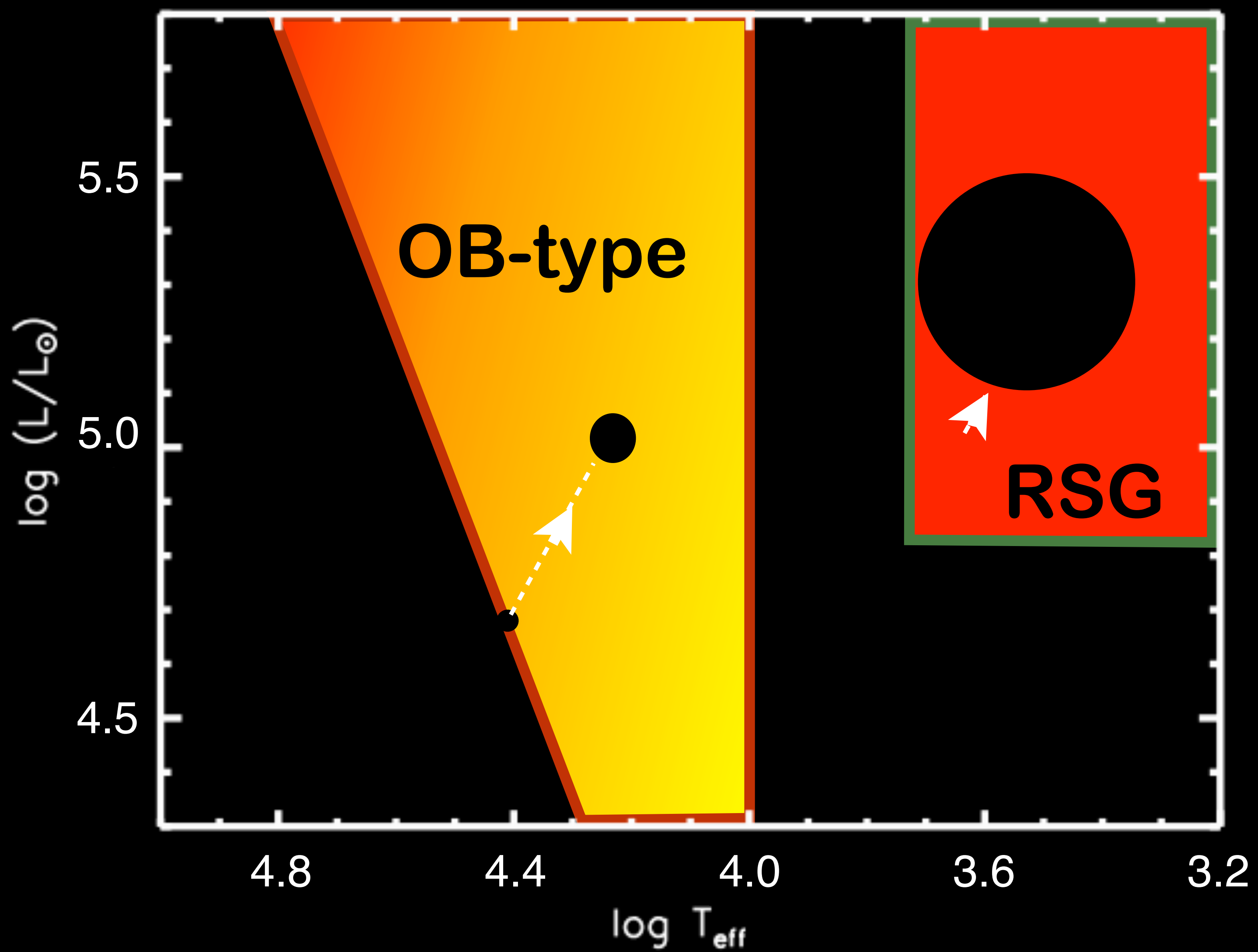
Agrees with observations of SN II progenitors (Smartt 09)

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



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

Single-star evolution at solar Z (18 to 30 $M_\odot$)



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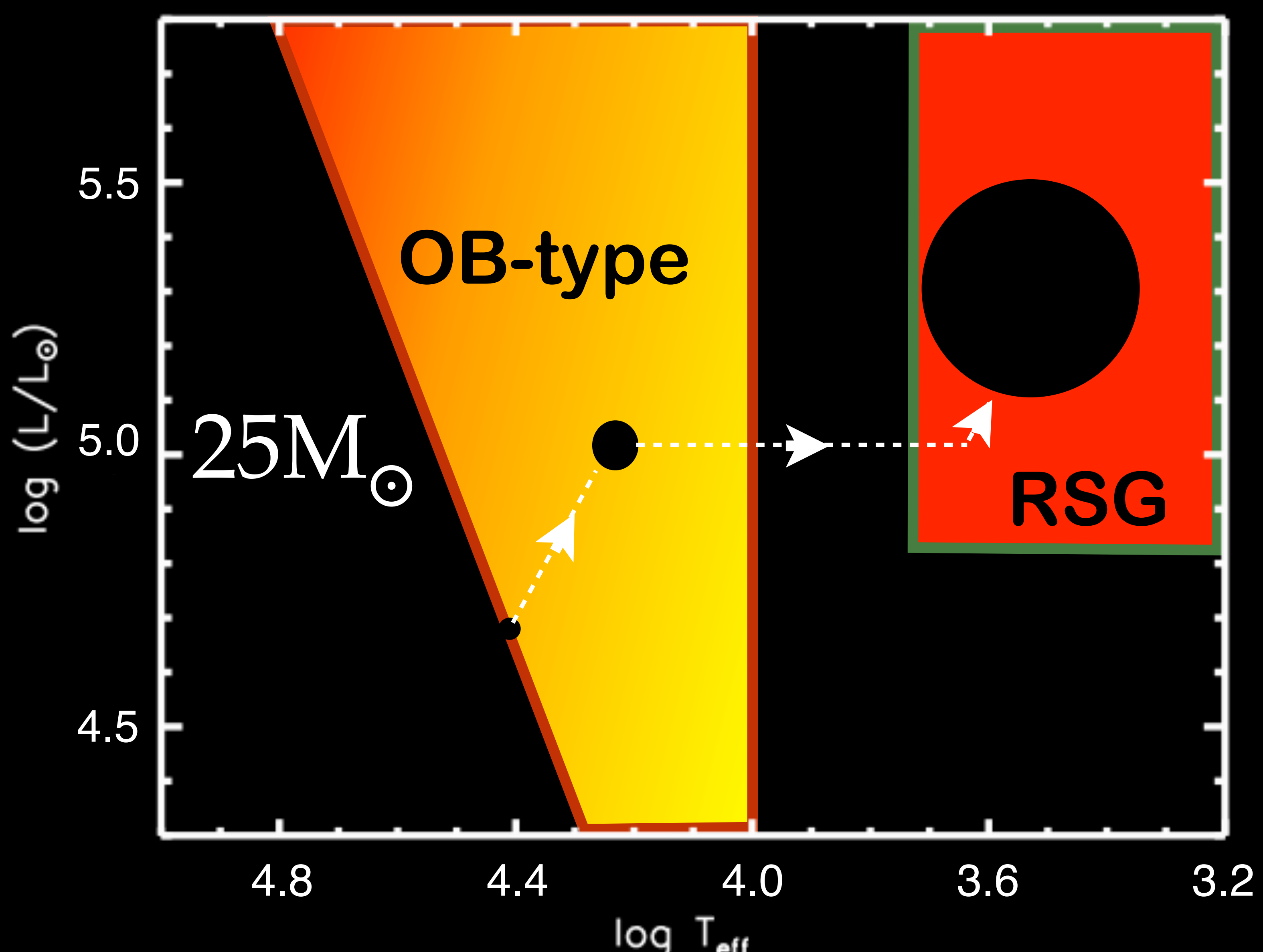

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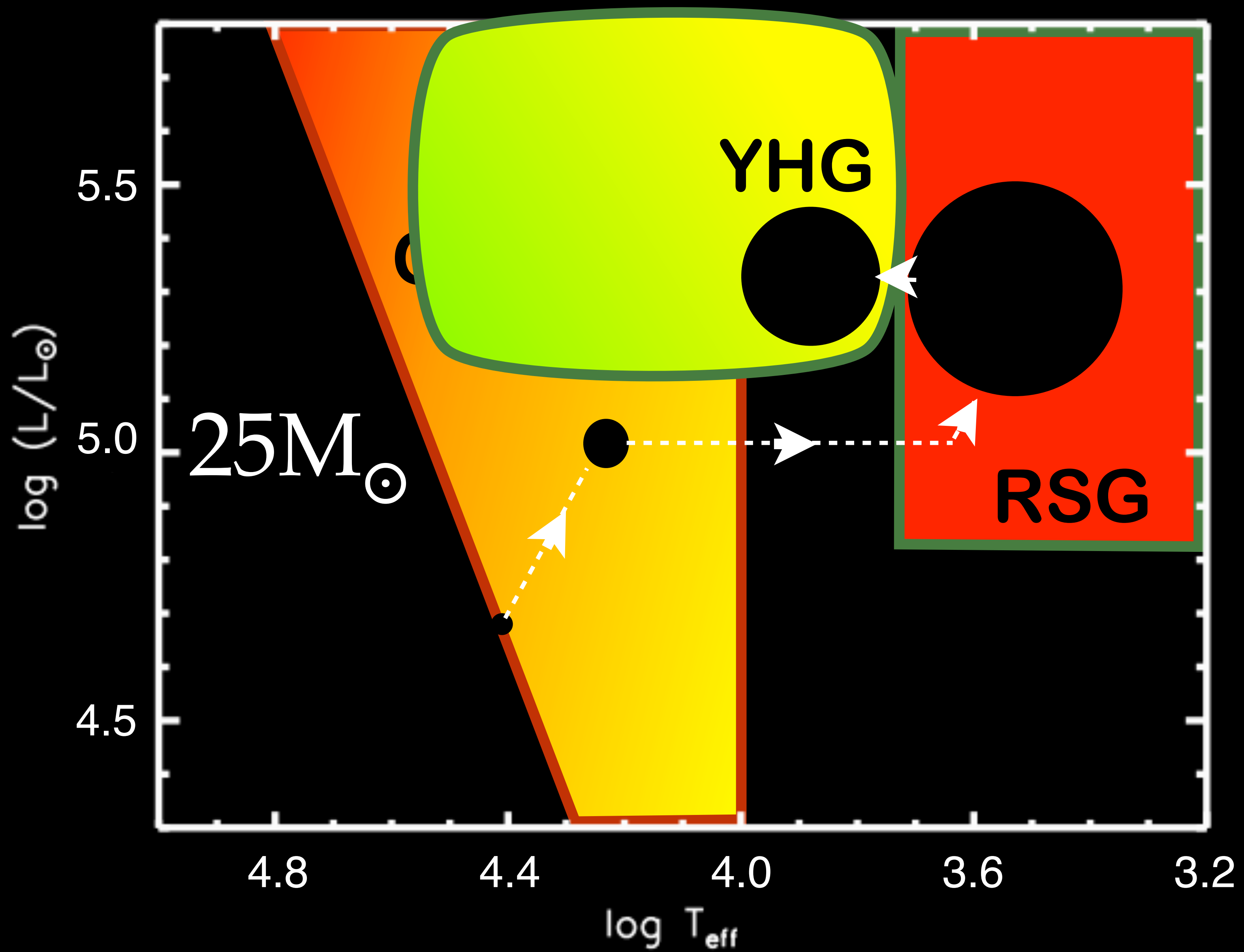

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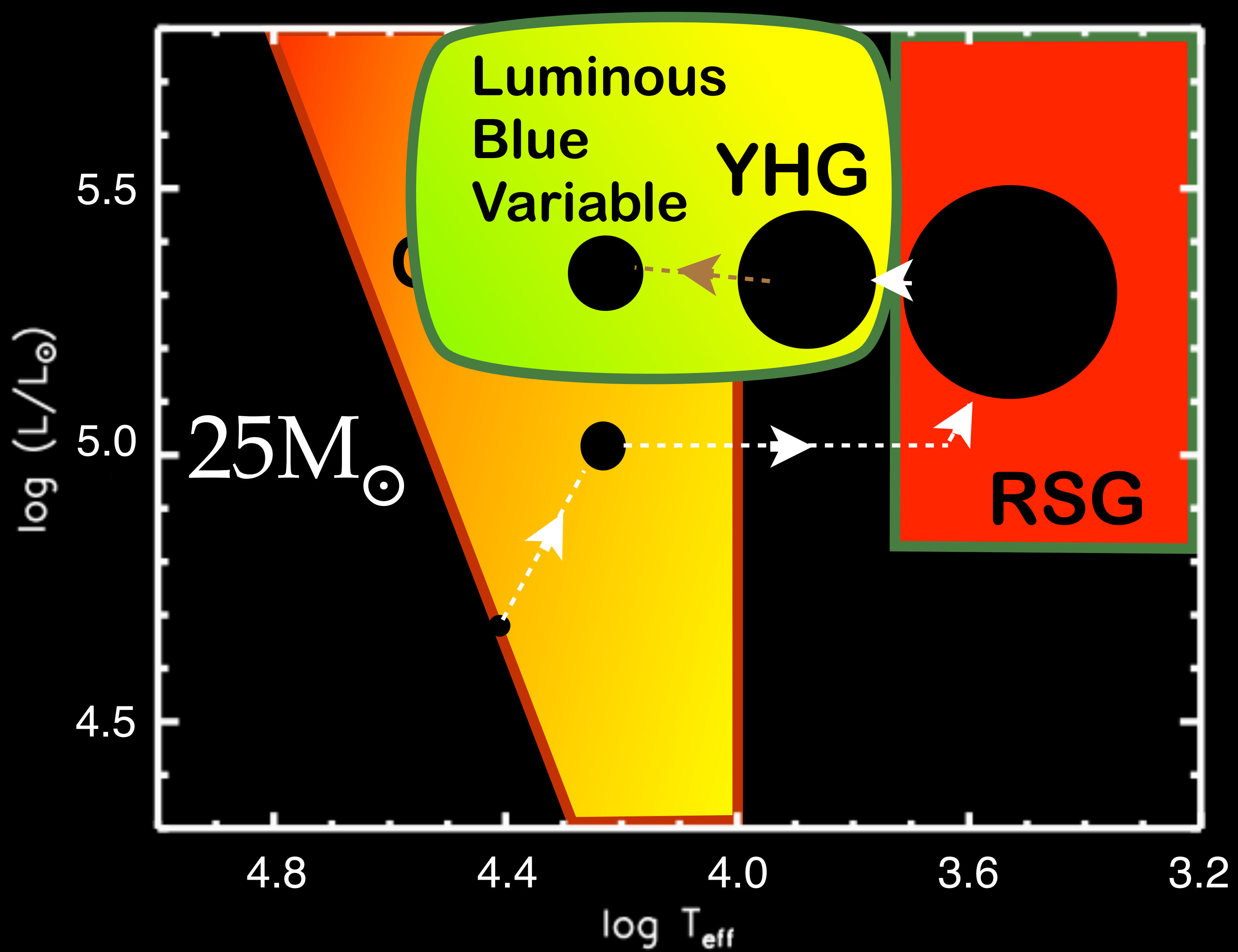
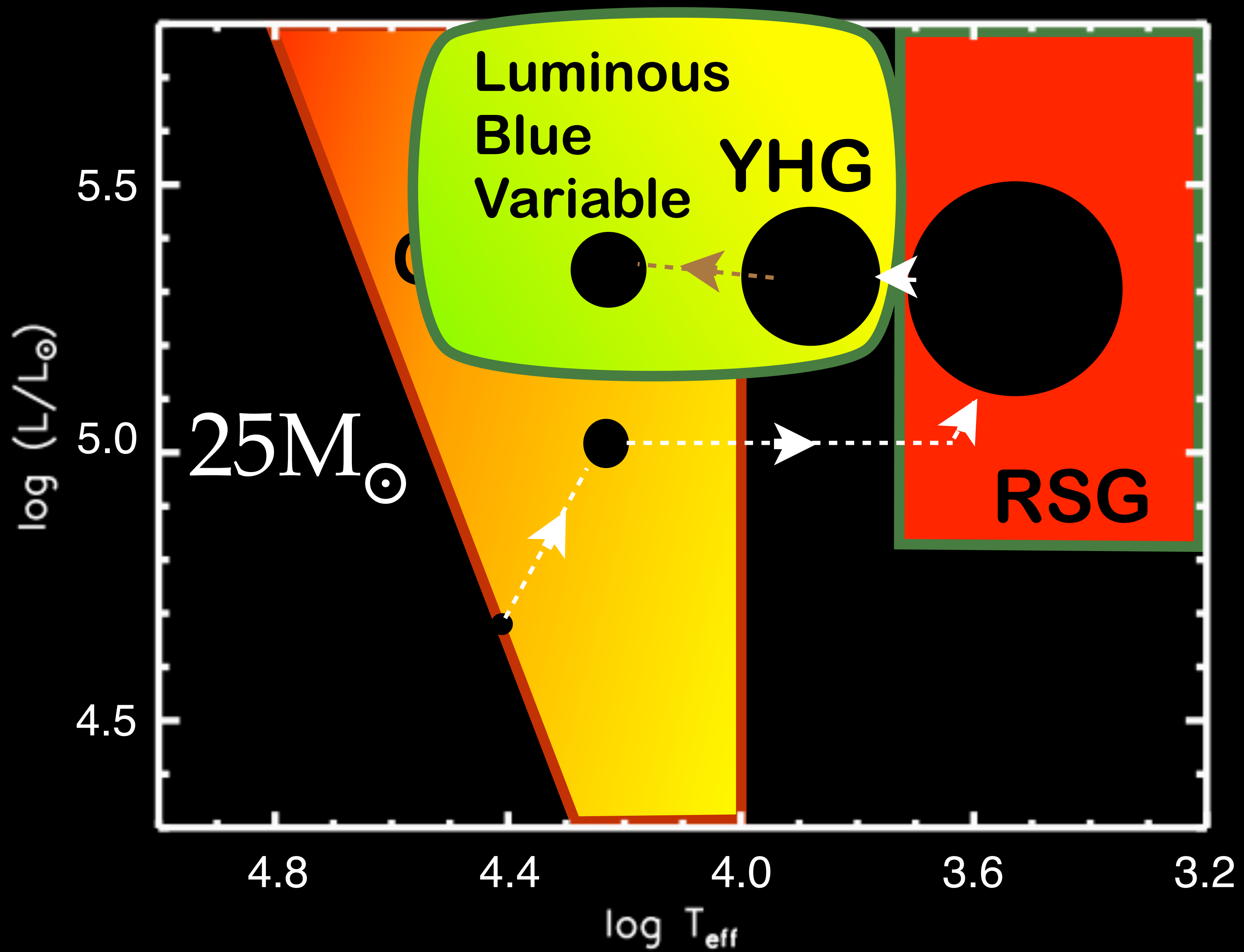


(after Groh+ 13a)

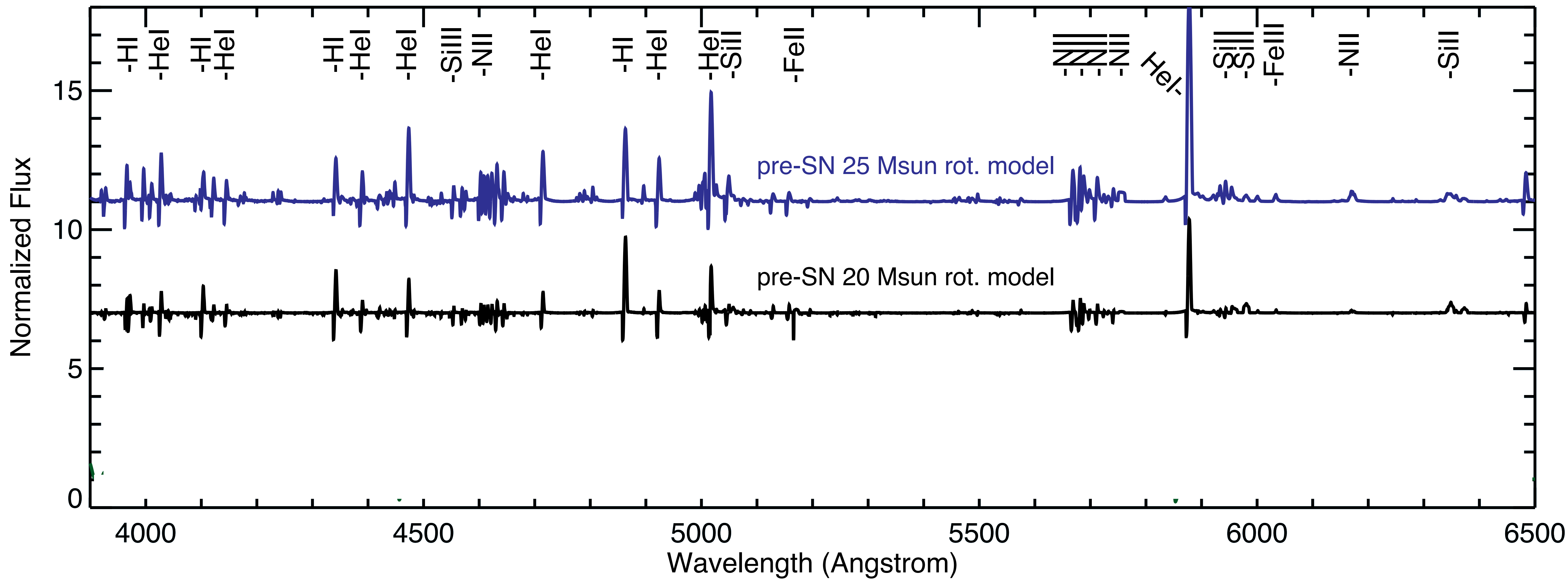
Single-star evolution at solar Z (18 to 30 $M_\odot$)

OB-type ➡ RSG ➡ YHG/LBV ▶ SN IIL/b



(after Groh+ 13a)

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



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

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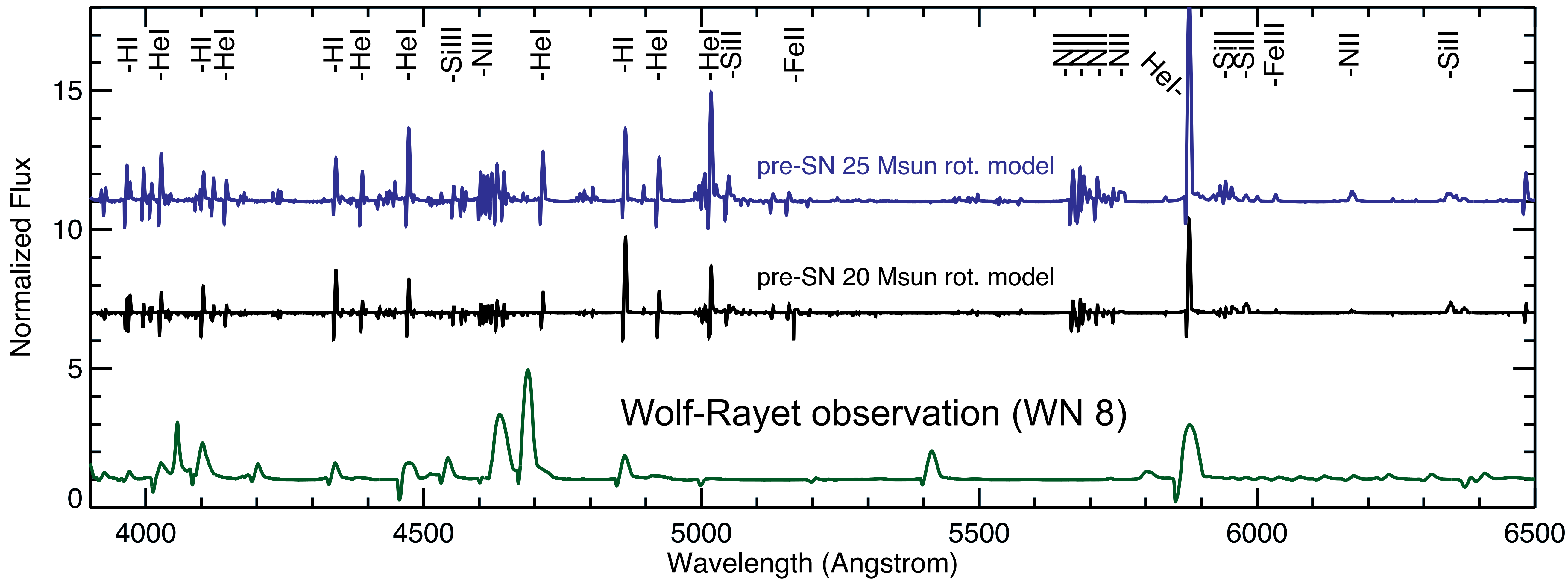
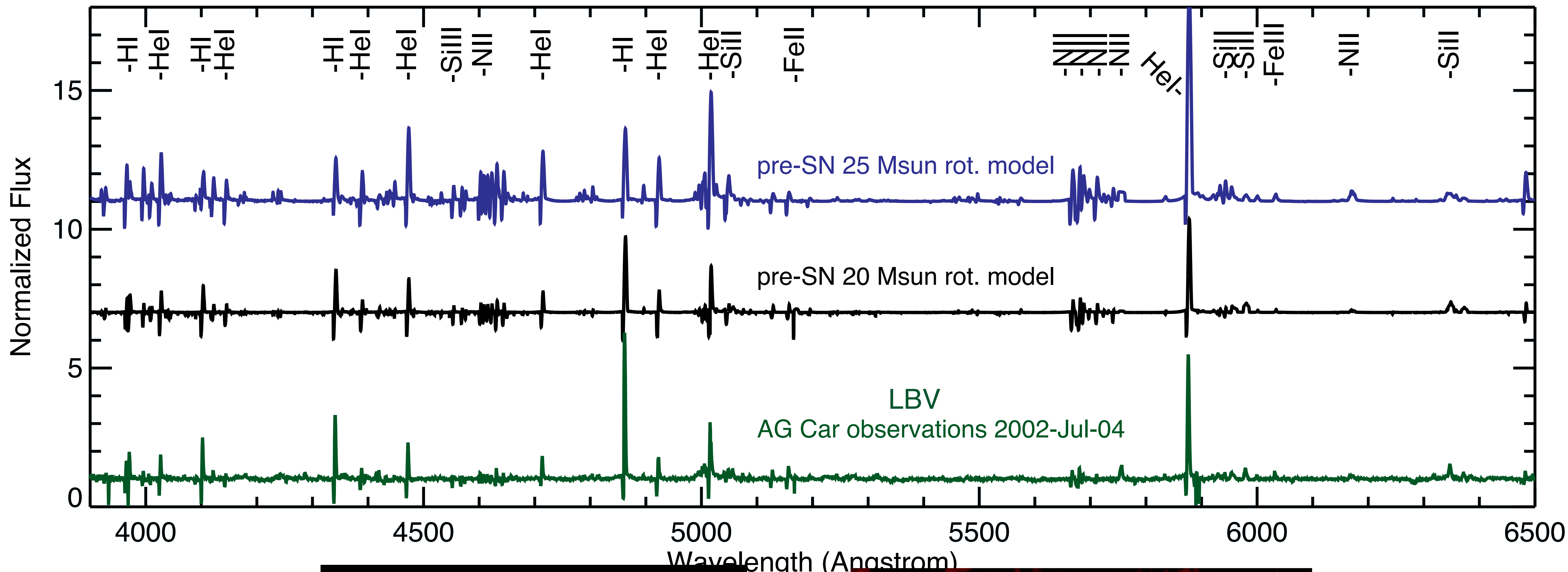


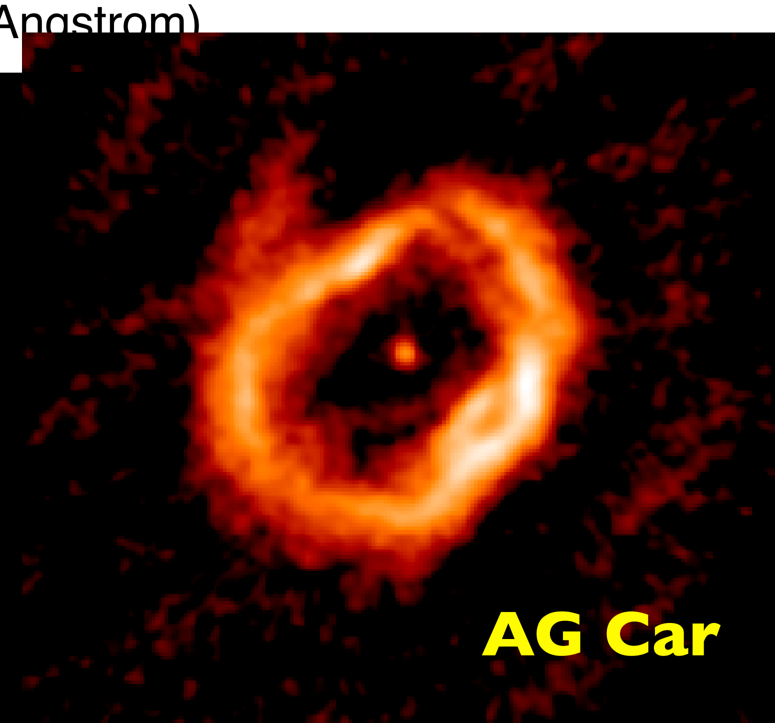
(Groh+ 13b, A&A 550, L7)

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



13b, A&A 550, L7)

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



(Credit: S. White)

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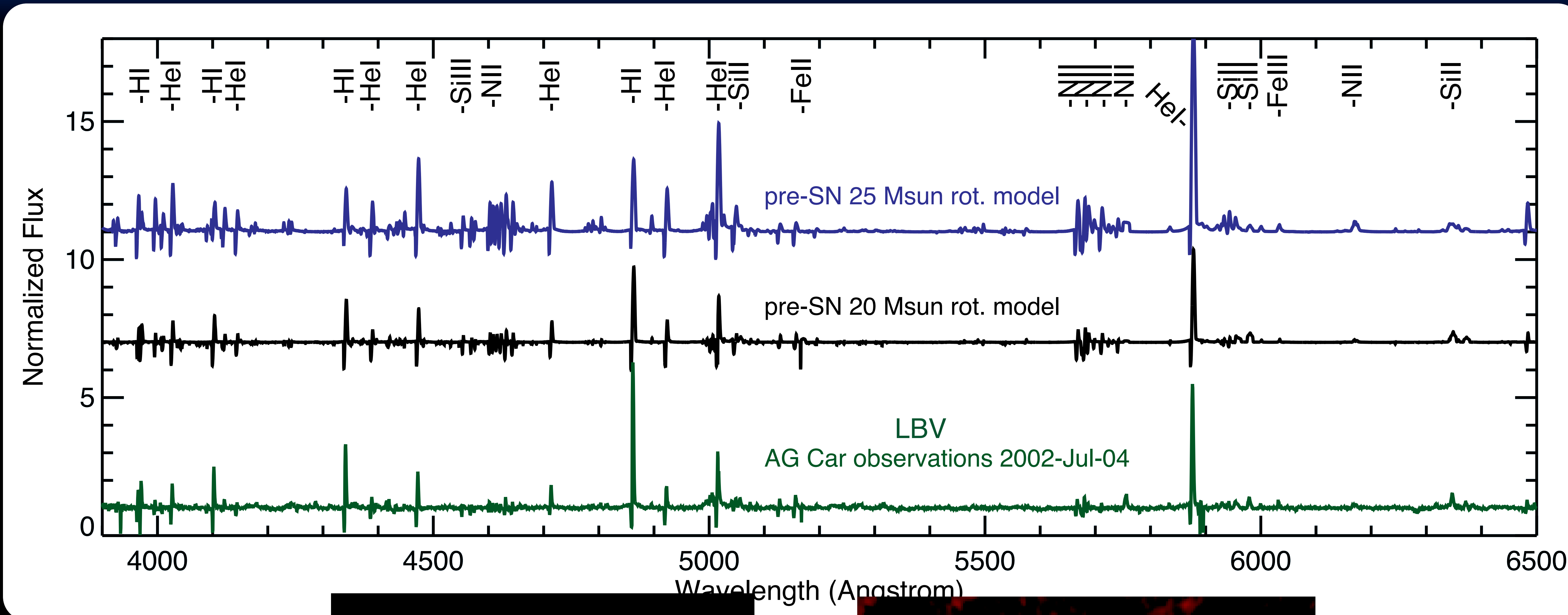

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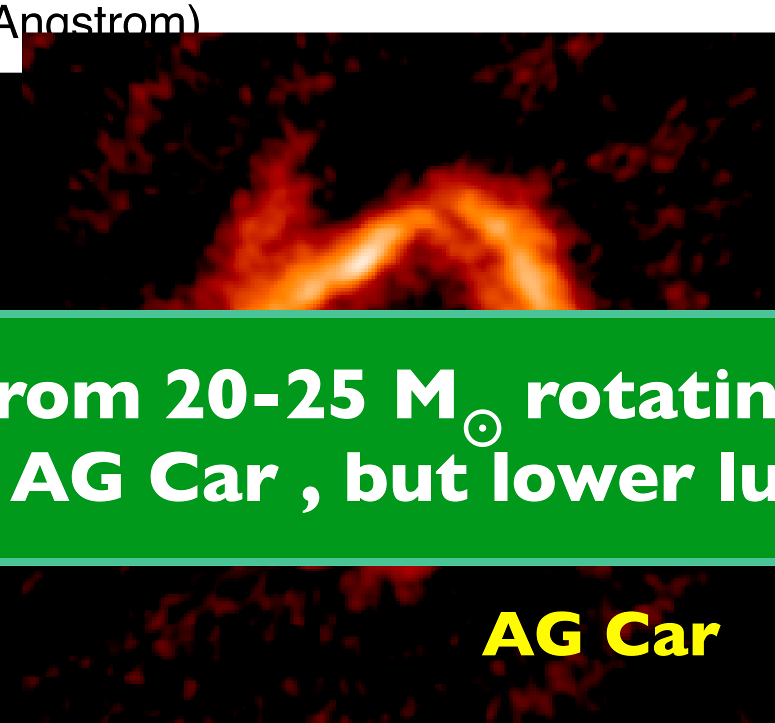


LBVs are progenitors of SNe from 20-25 $M_\odot$ rotating stars (similar spectrum to Eta Car and AG Car , but lower luminosity)

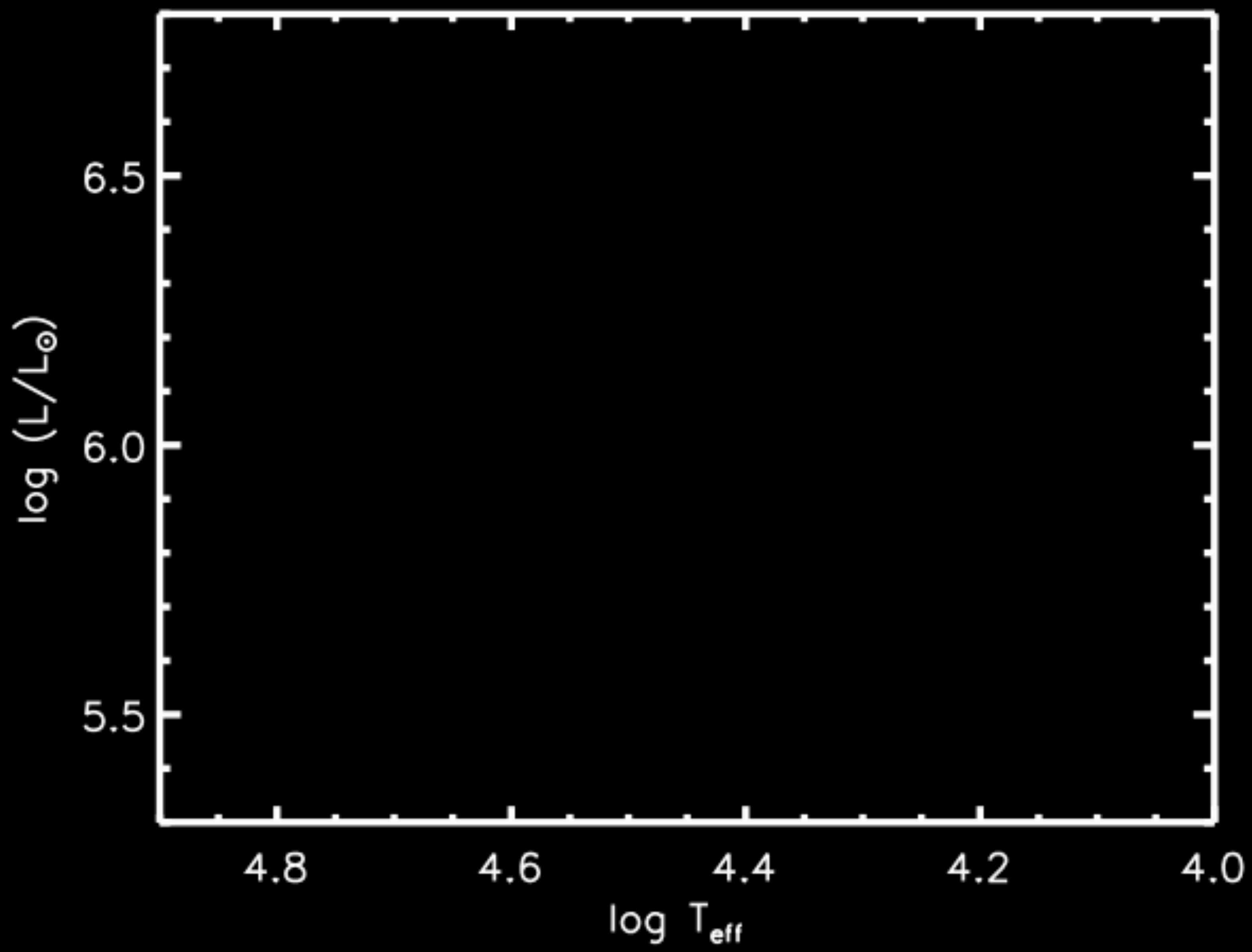
Eta Car

AG Car

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

(Credit: S. White)

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



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

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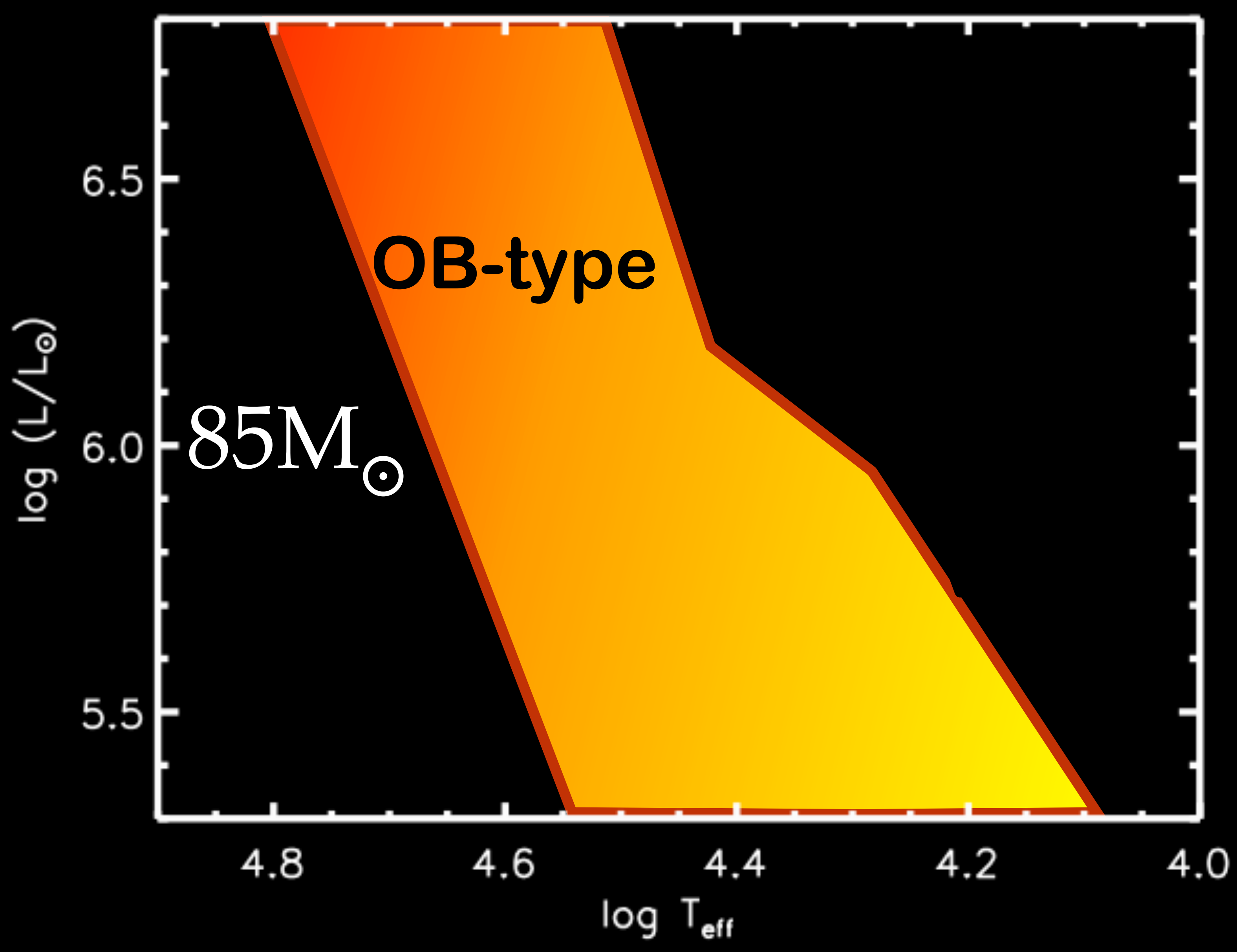

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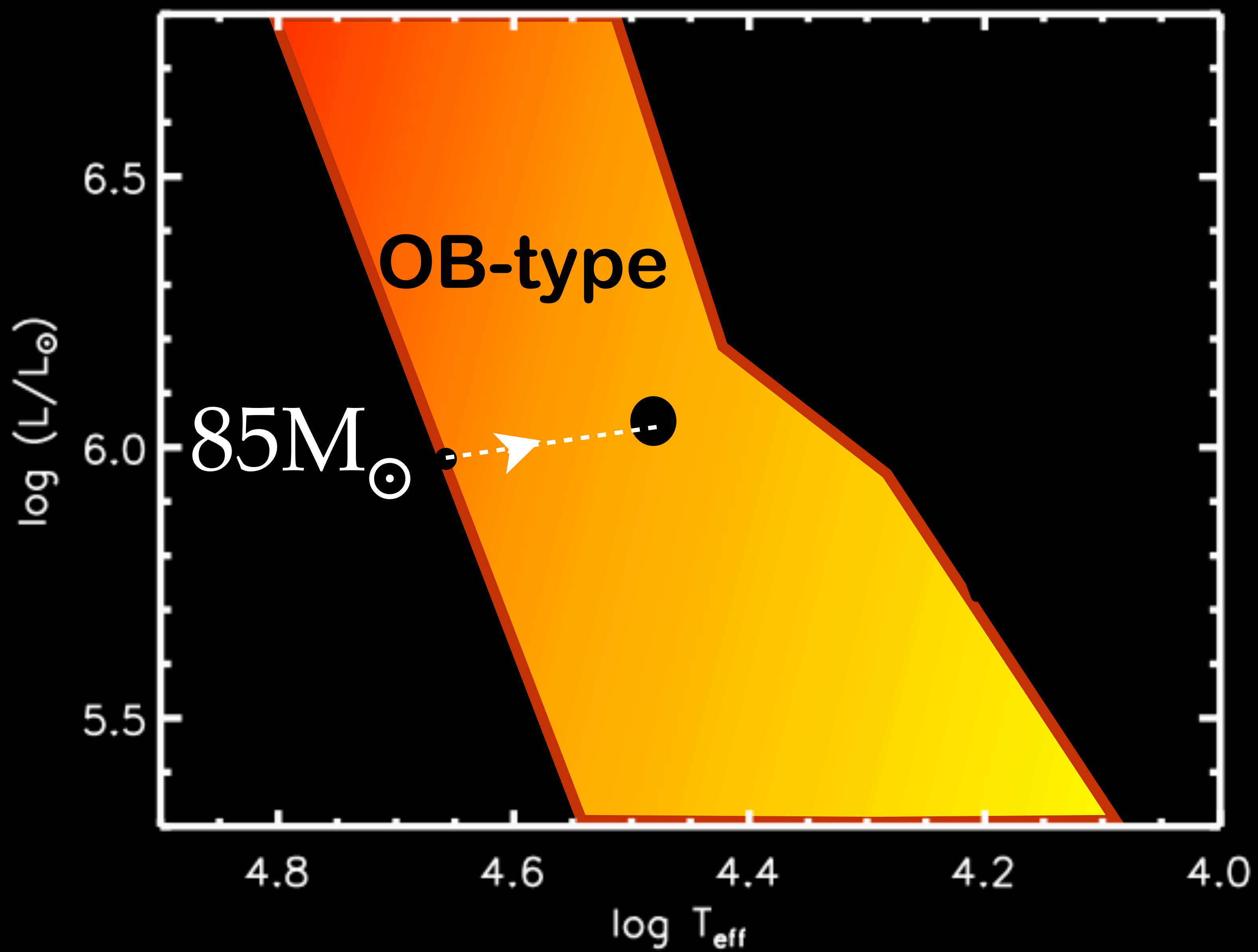

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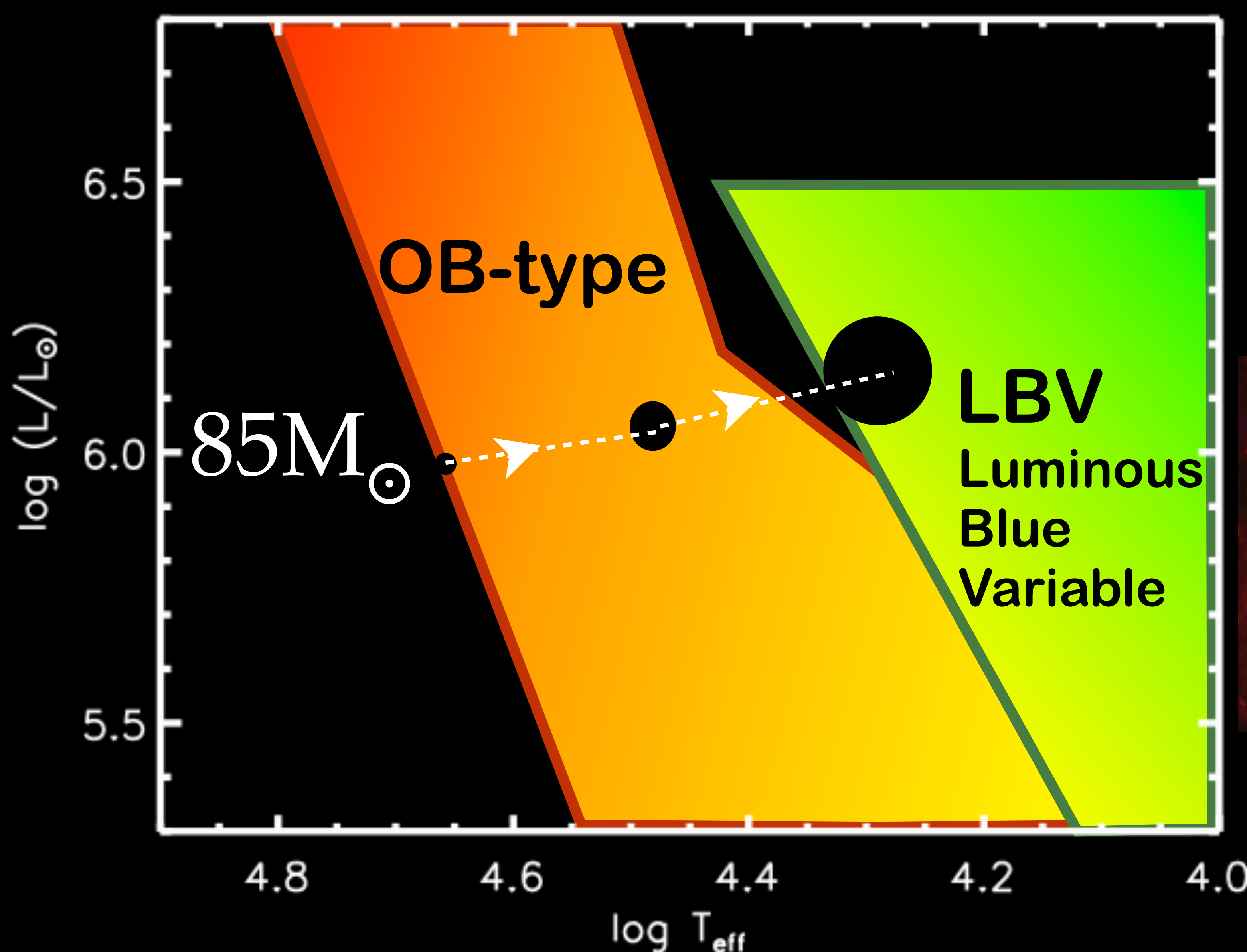

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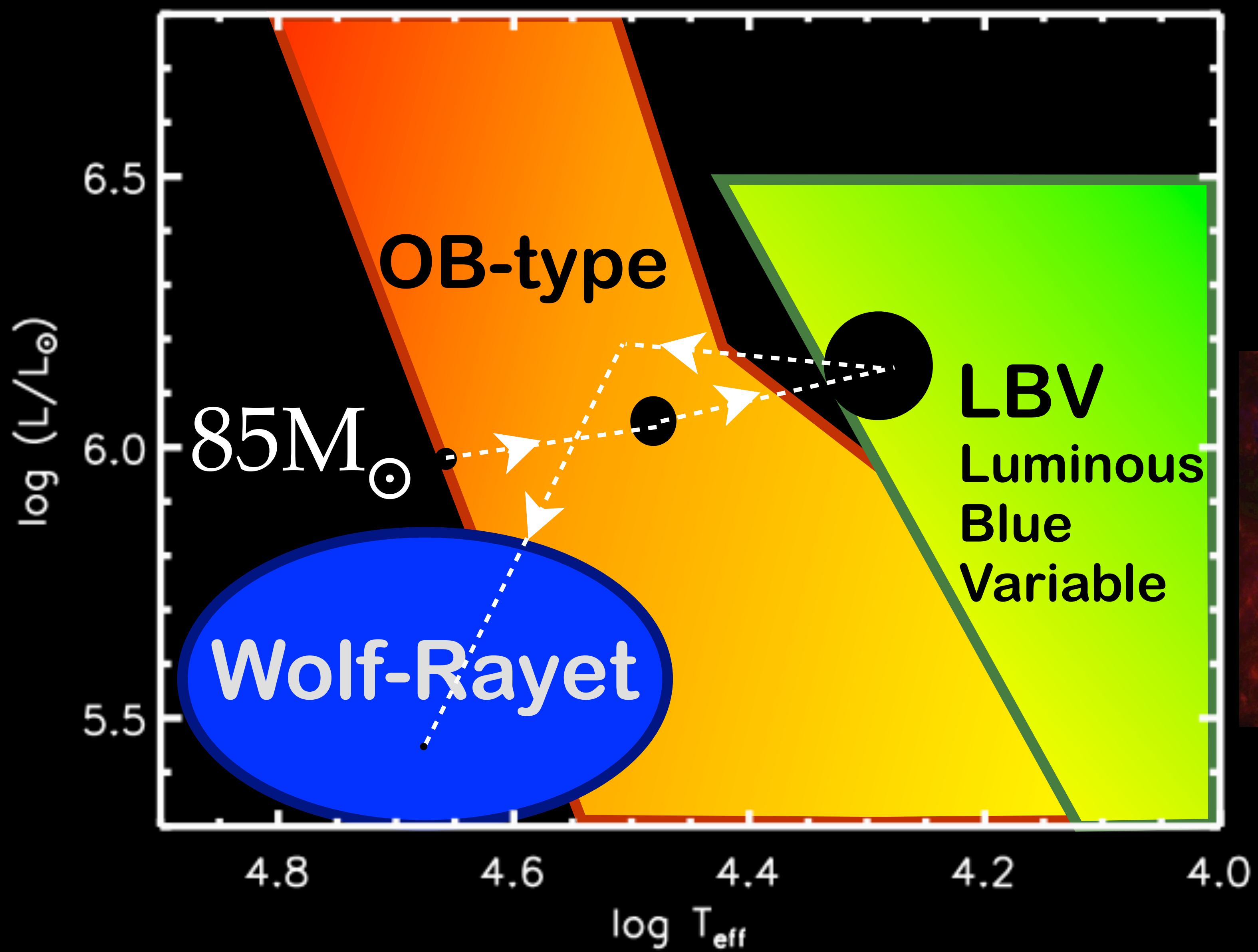

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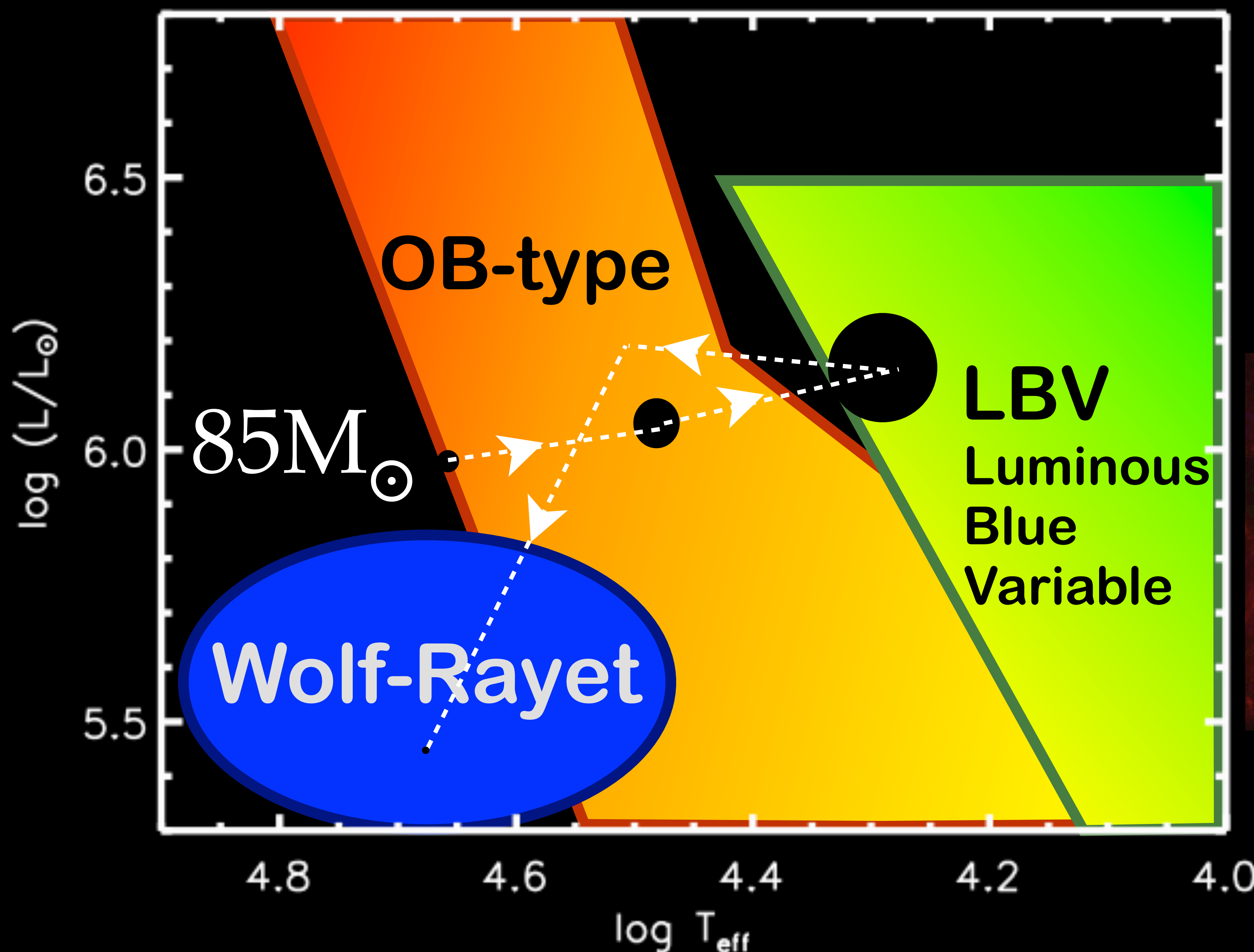
OB-type → LBV → WR → SN Ibc



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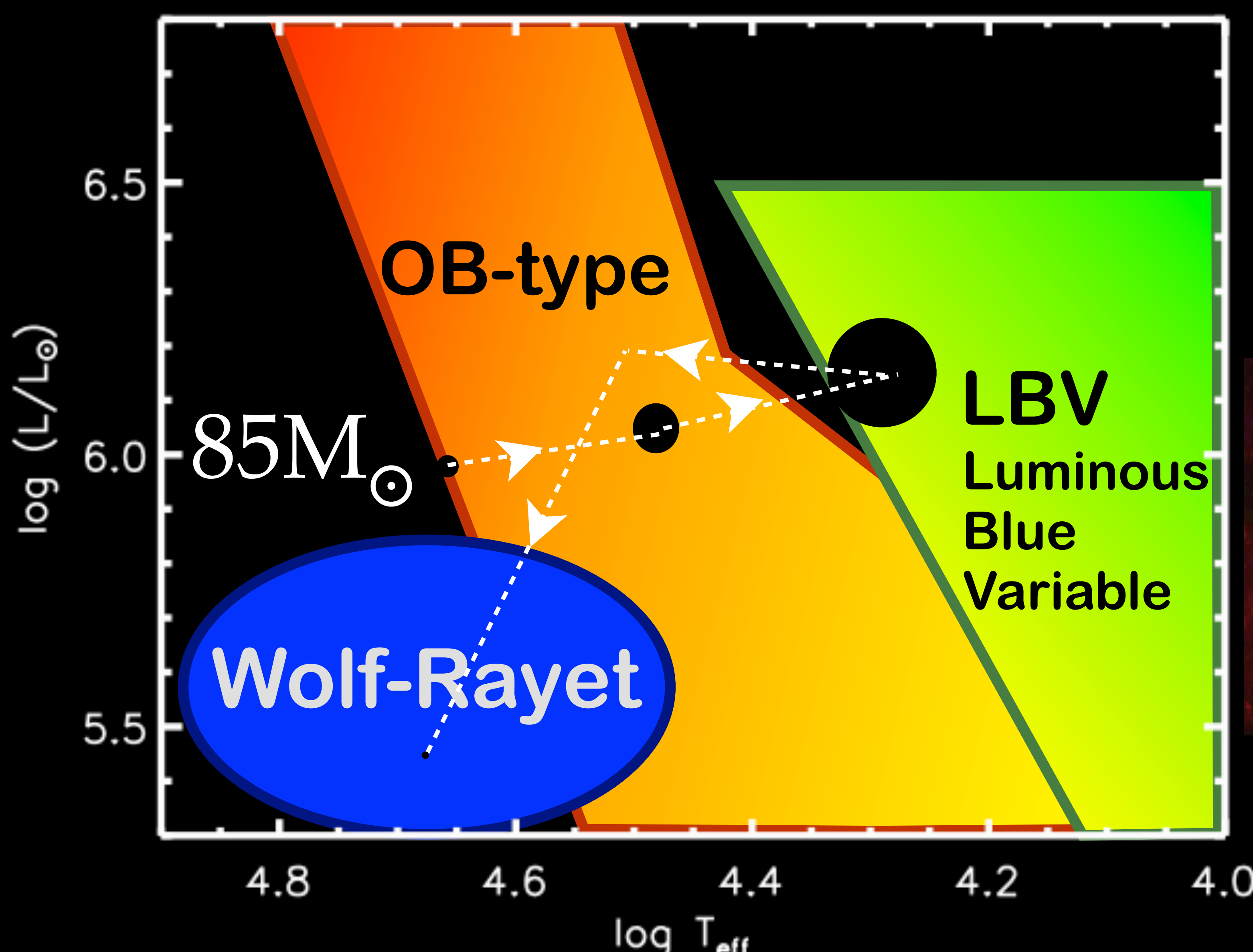

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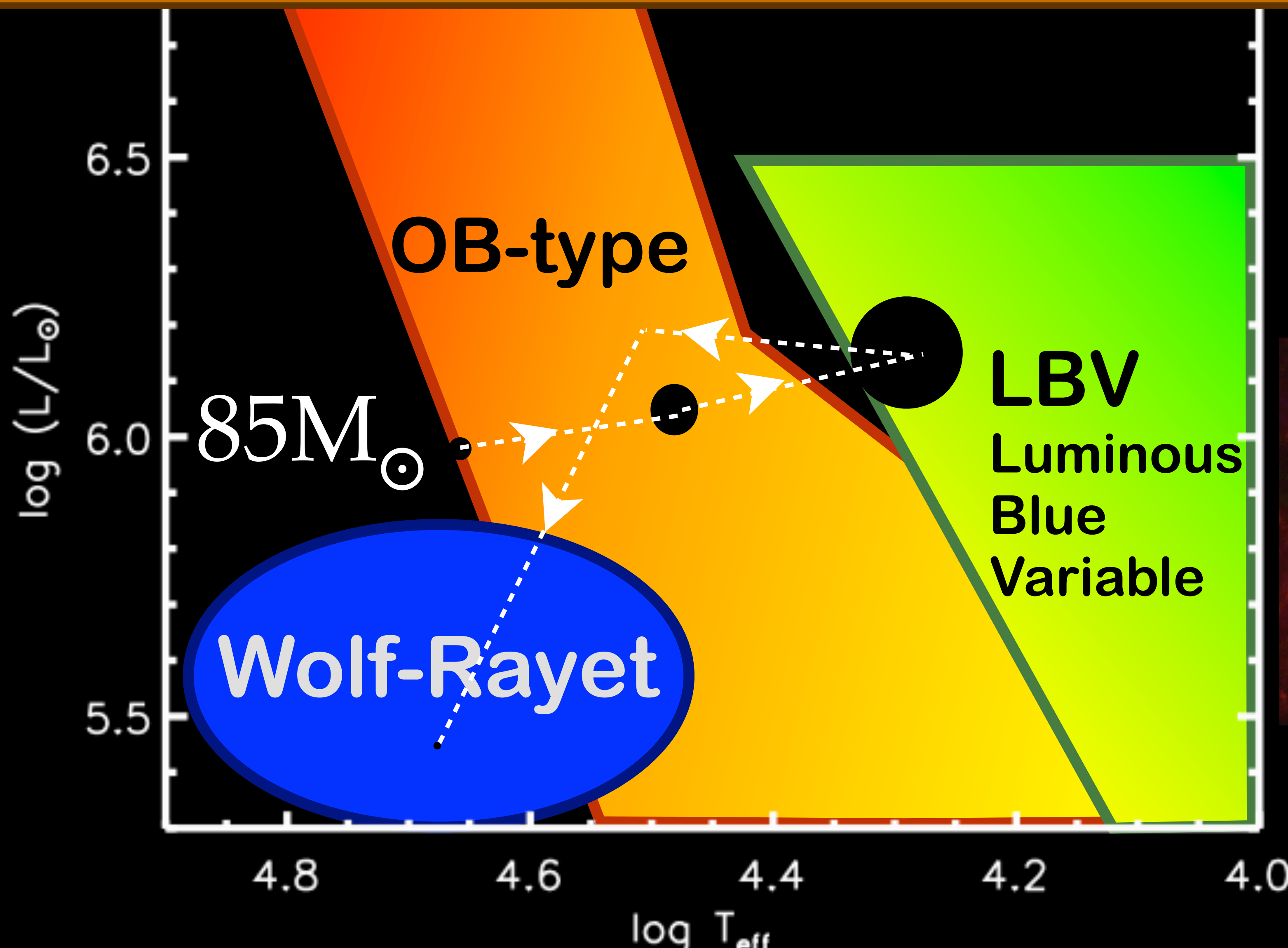

But see Cao+ 13; Groh +13b

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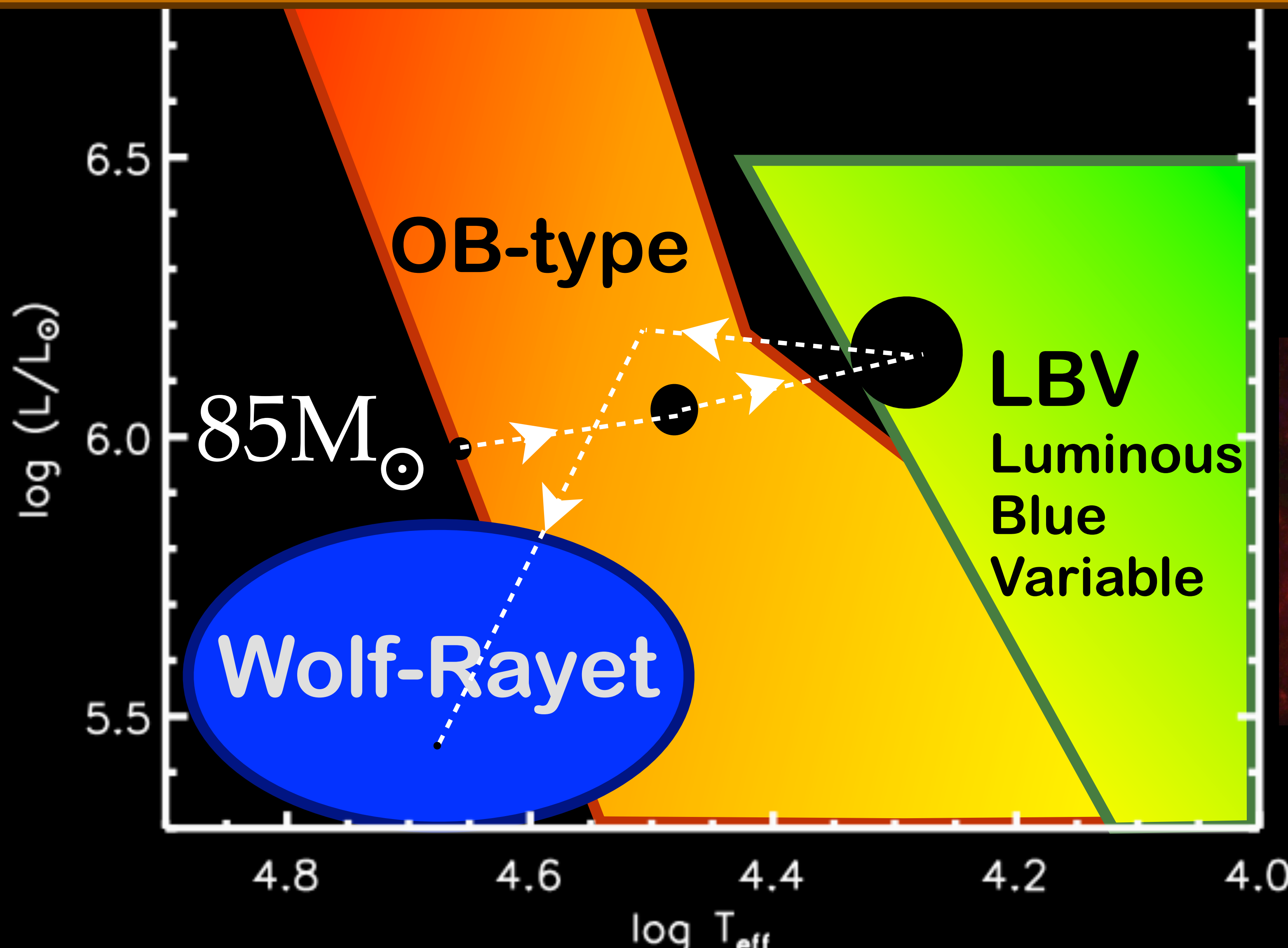


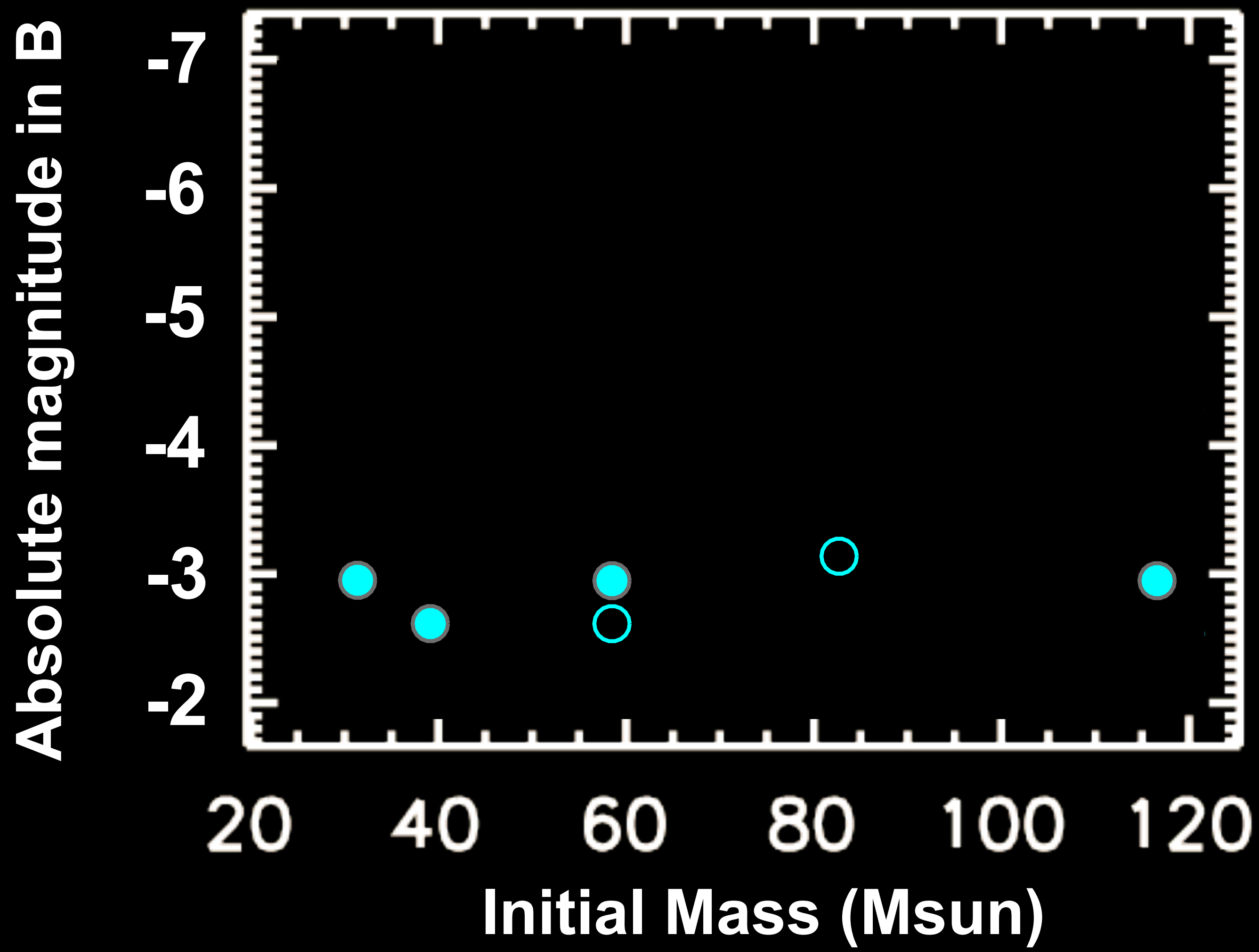
But see Cao+ 13; Groh +13b

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

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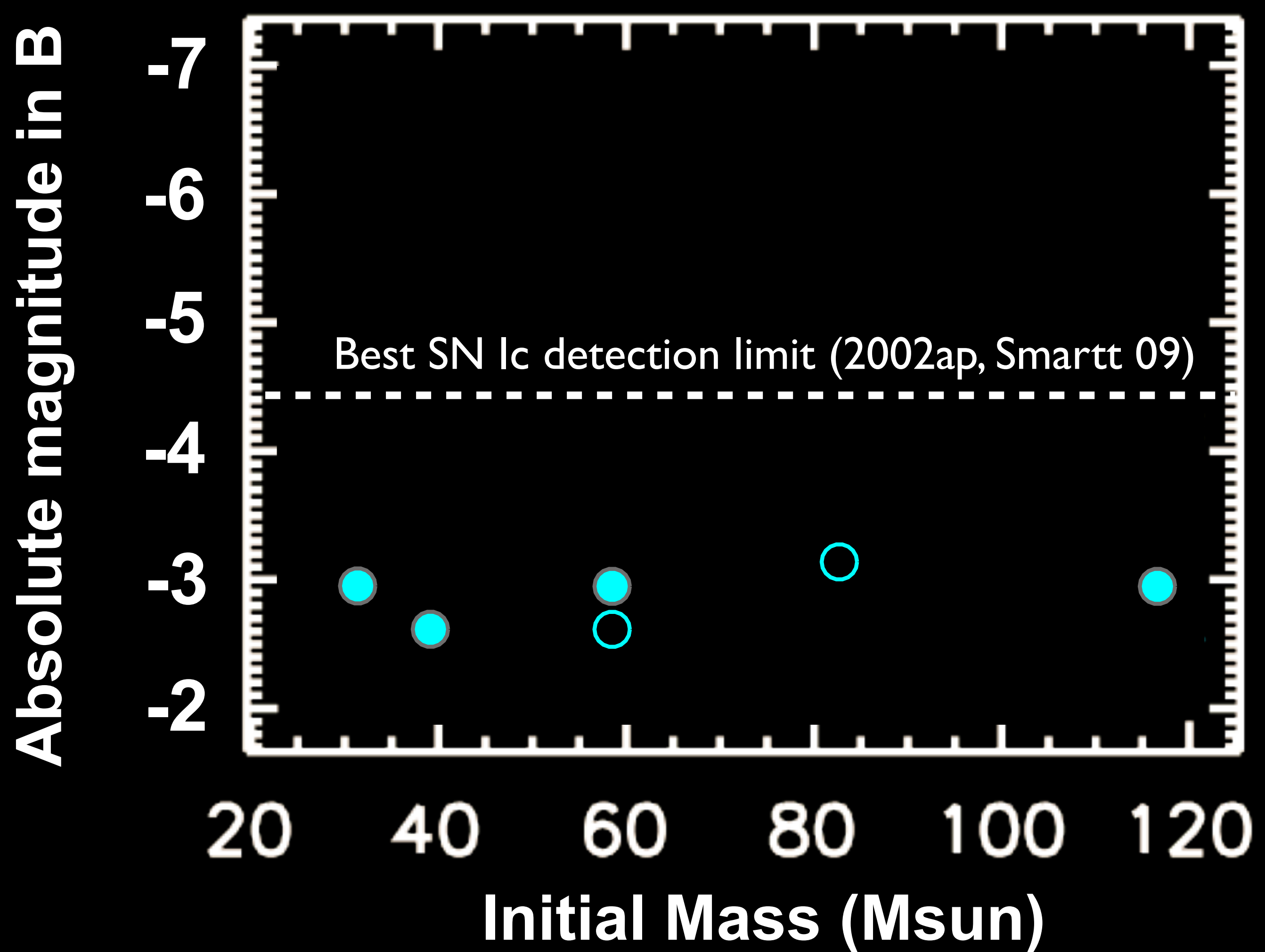

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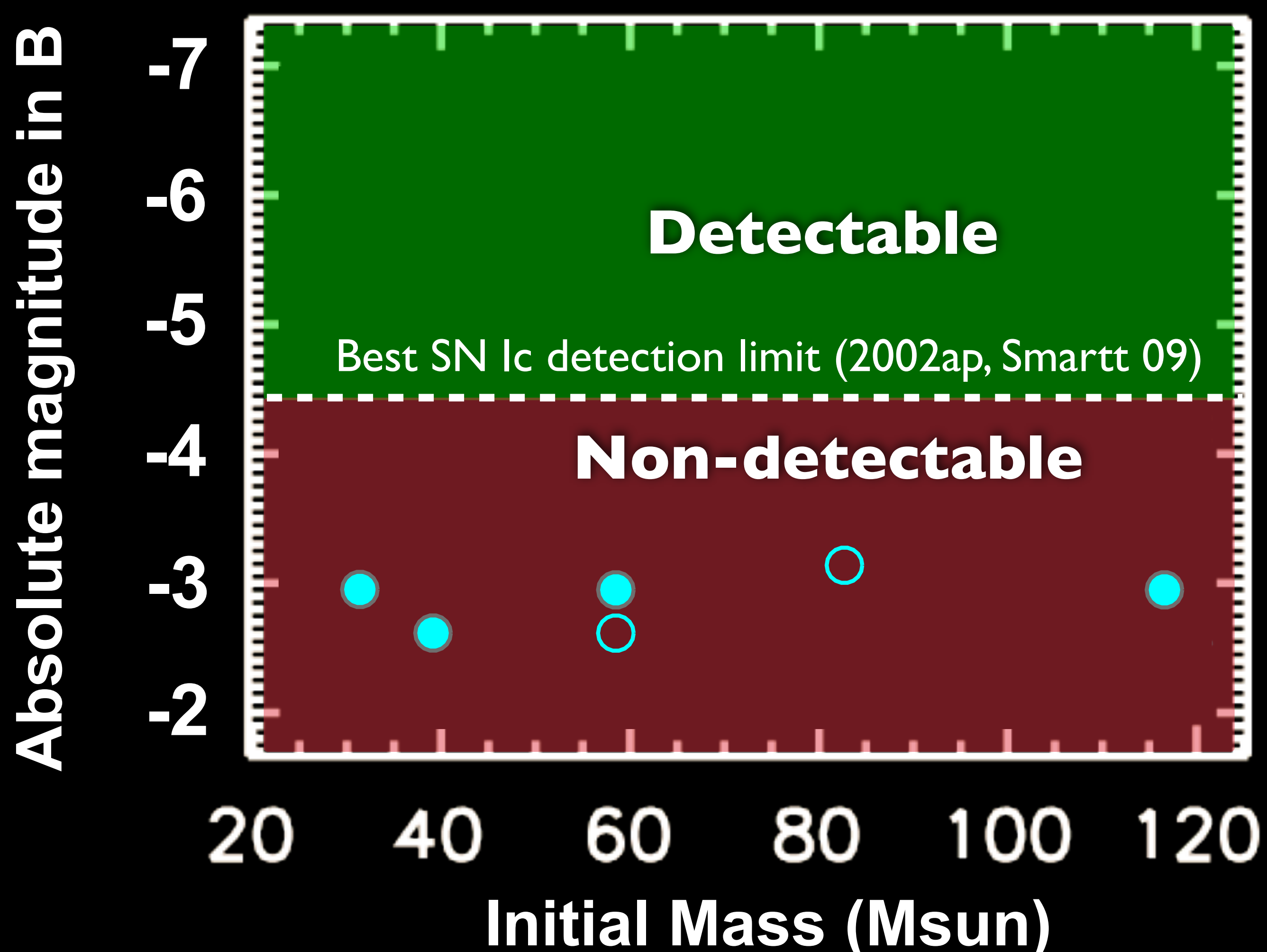

Current non-detection of WRs as SN Ic progenitors is OK with single stellar evolution models!

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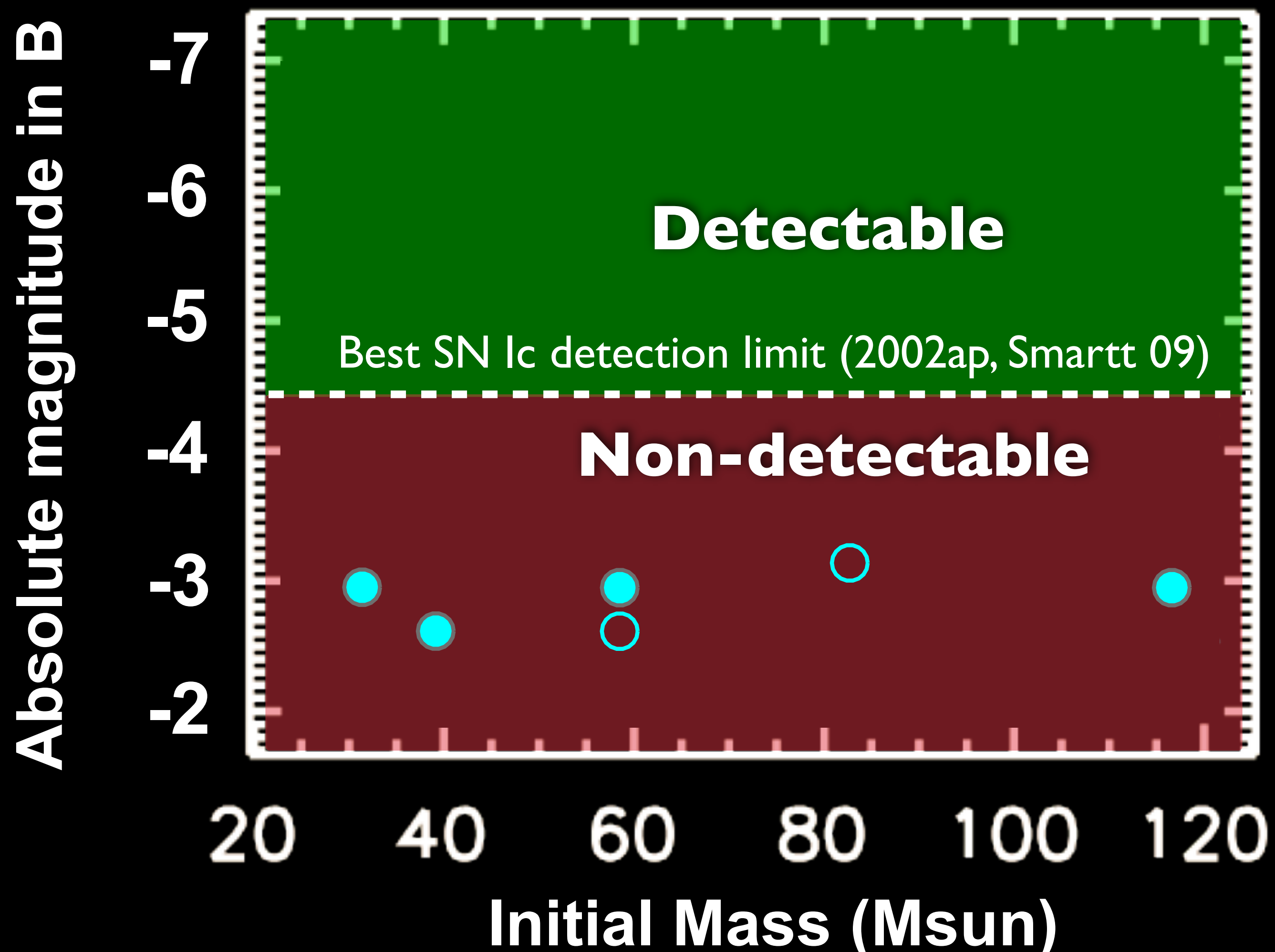


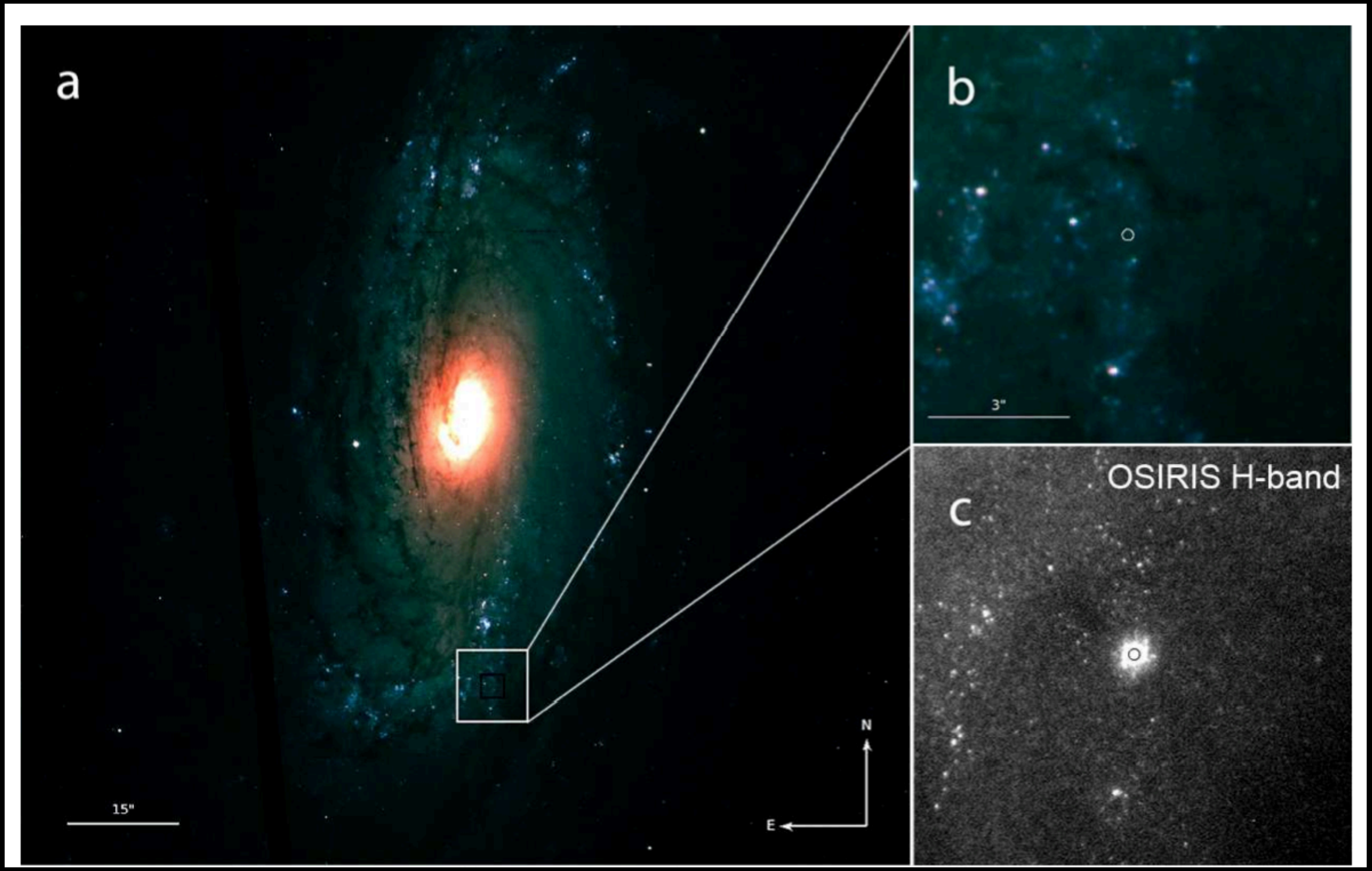
(Groh+ 13a, A&A in press; arXiv 1308.4601; see also Yoon+ 12)

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

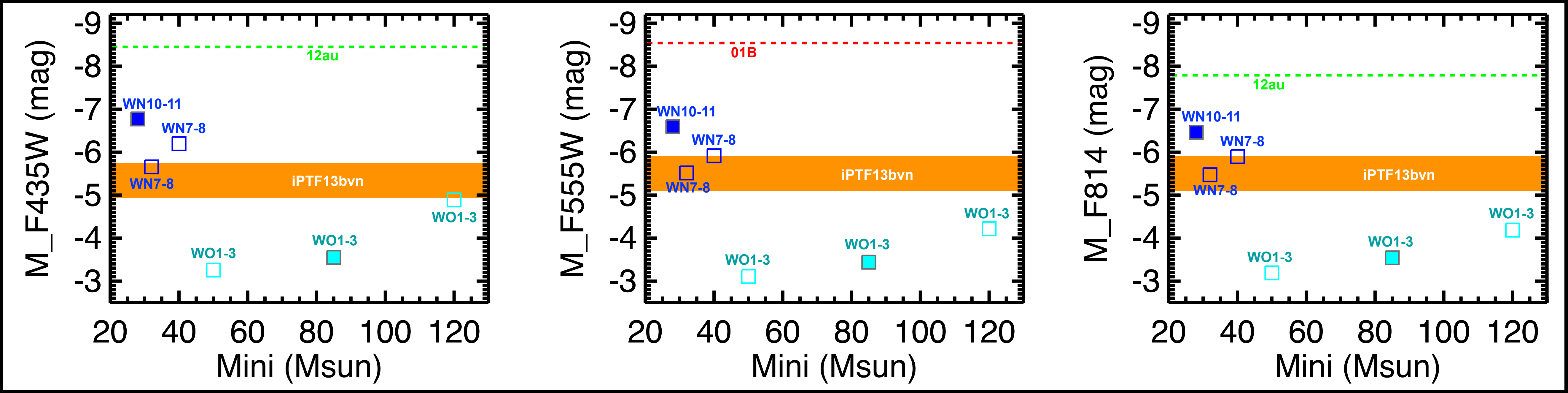
Possible first detection of a SN Ib progenitor (iPTF13bvn)
(Cao+ 13)



(Cao+ 13)

The candidate progenitor of iPTF13bvn

Absolute magnitude vs. initial mass for SN Ib progenitors

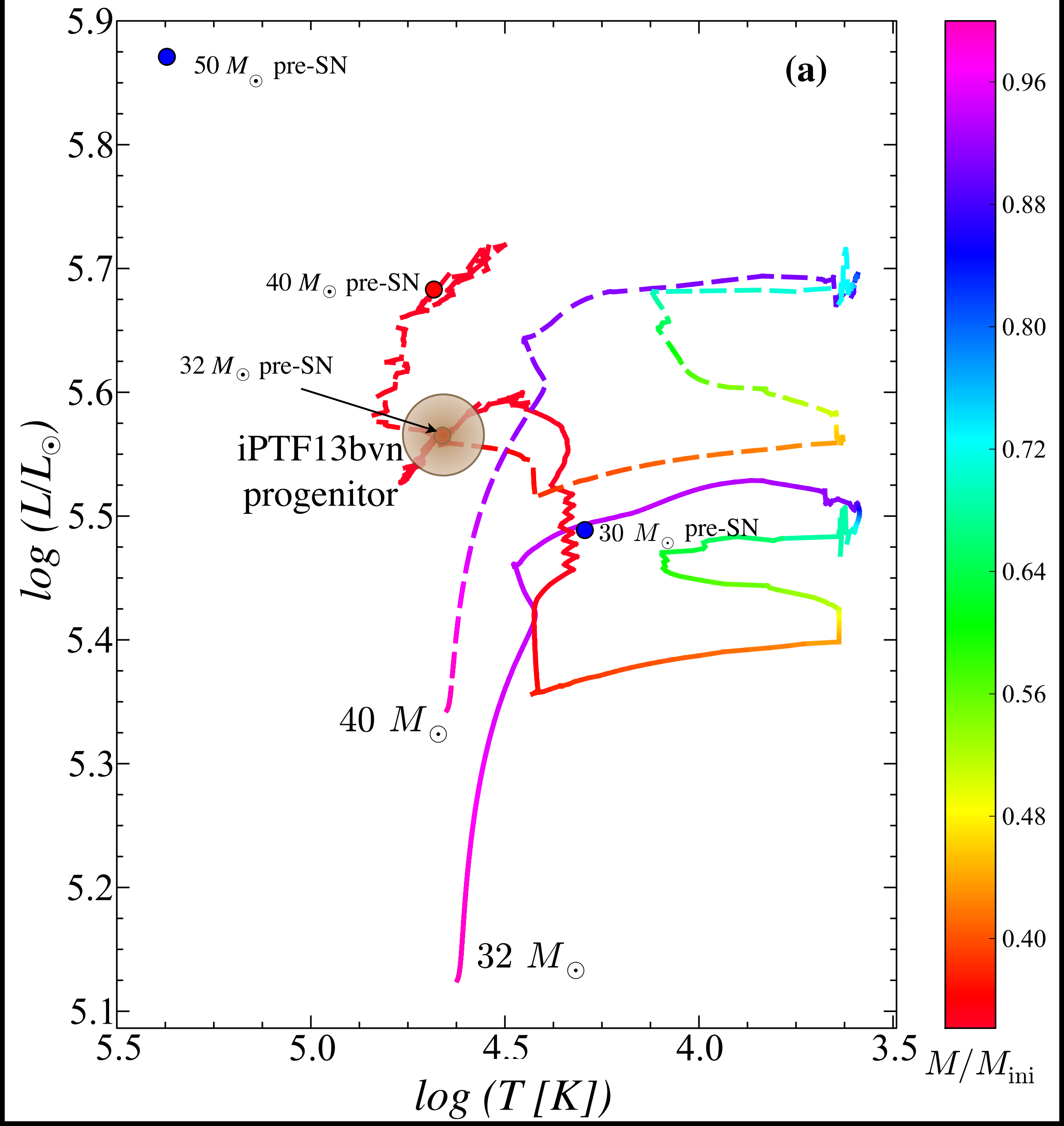


A slowly-rotating WN star with initial mass 31-35 $M_{\odot}$

(Groh+ 13c, A&A 558, 1)

The candidate progenitor of iPTF13bvn

Location in the HR diagram



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Predicted nature of CCSN progenitors from single stars

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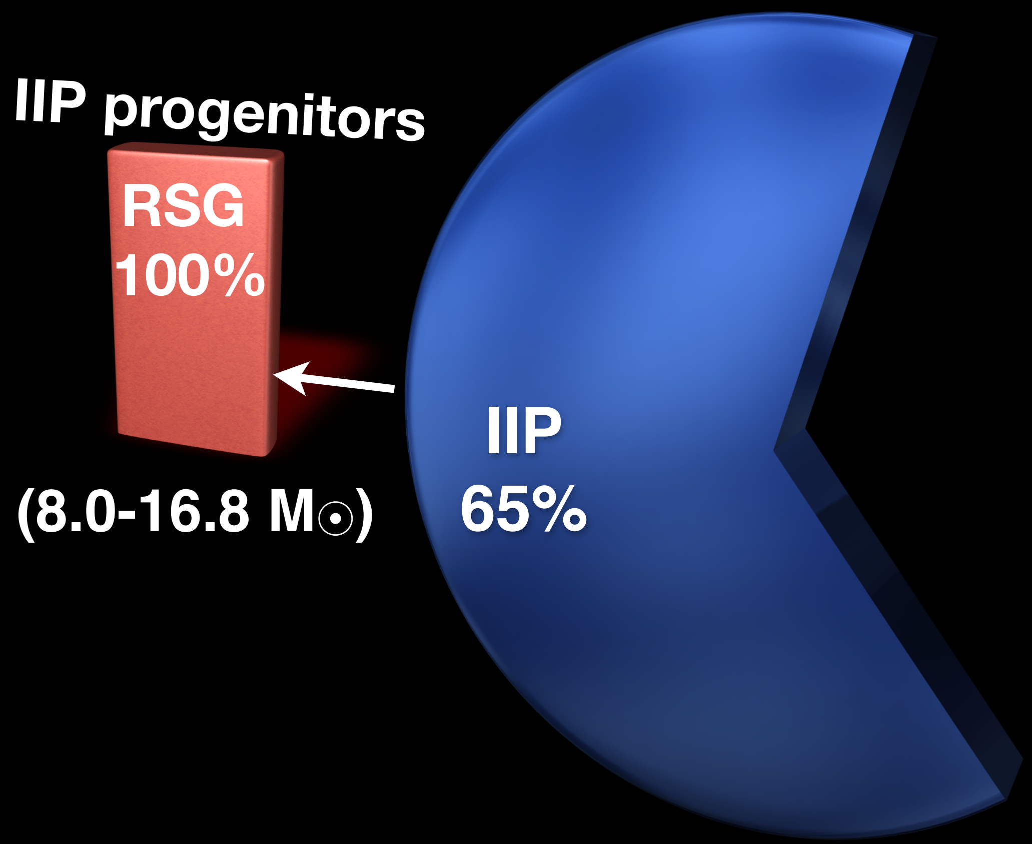
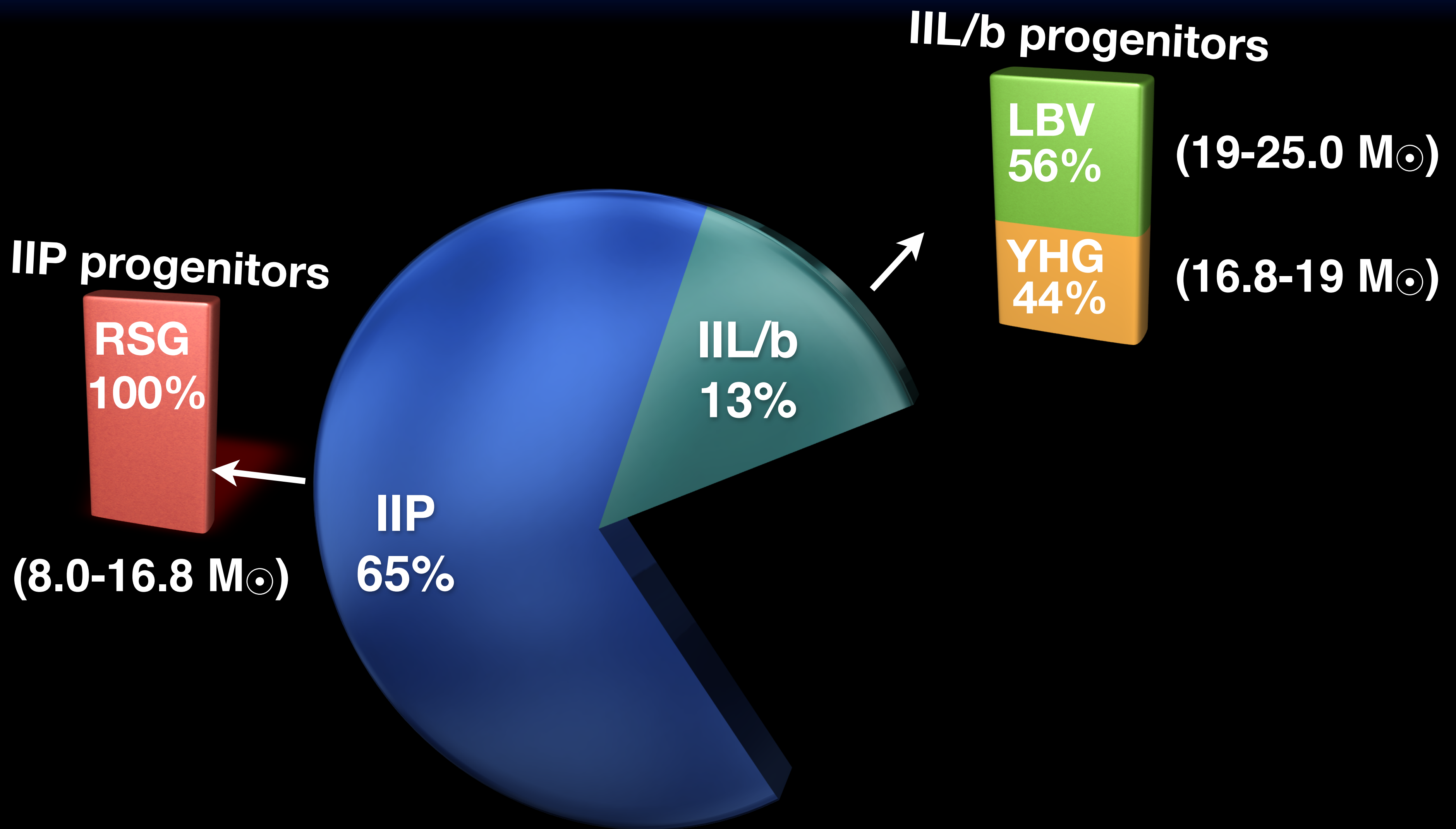


Rotating models
(Groh+ 13c, A&A in press; arXiv 1308.4601)

Predicted nature of CCSN progenitors from single stars



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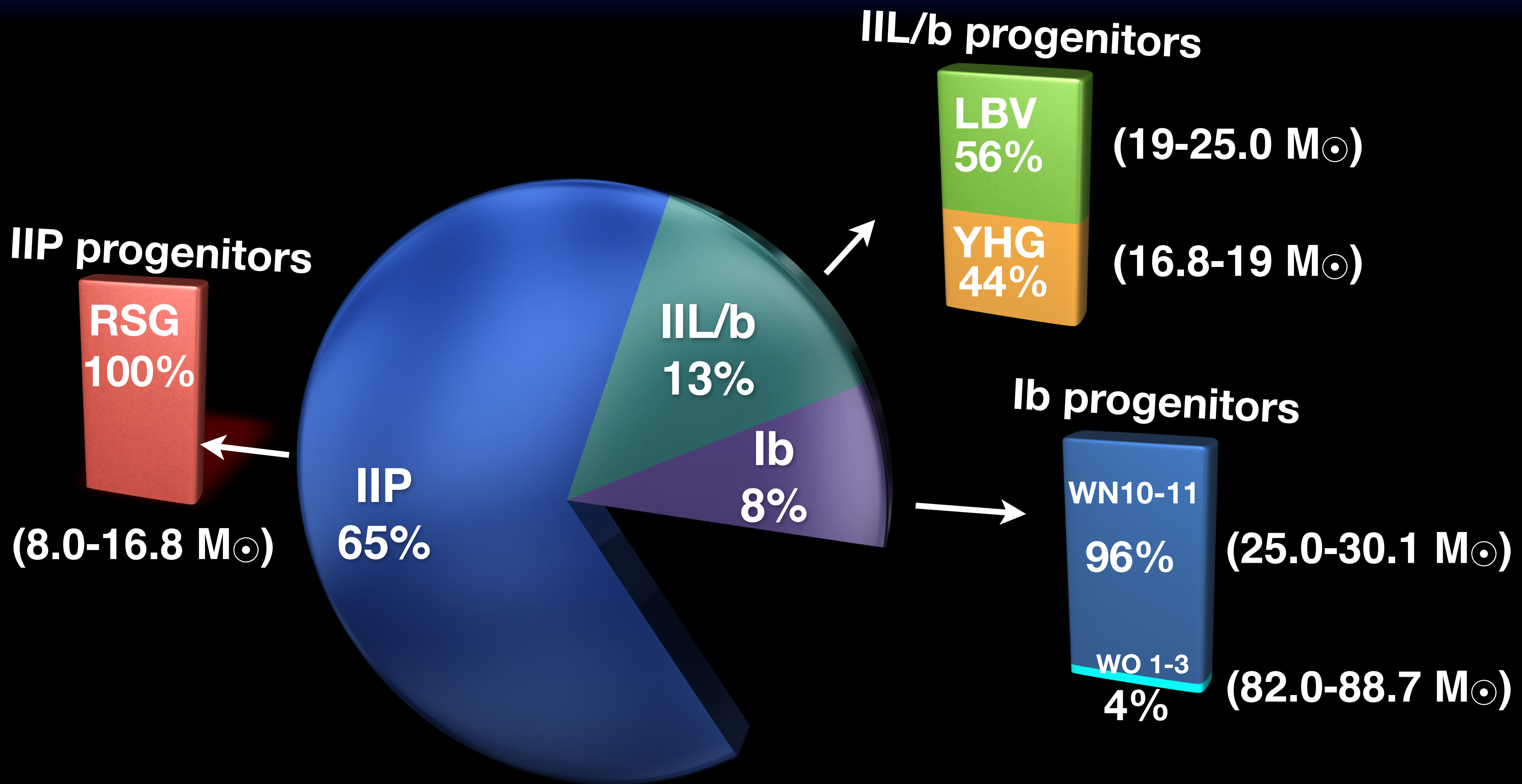

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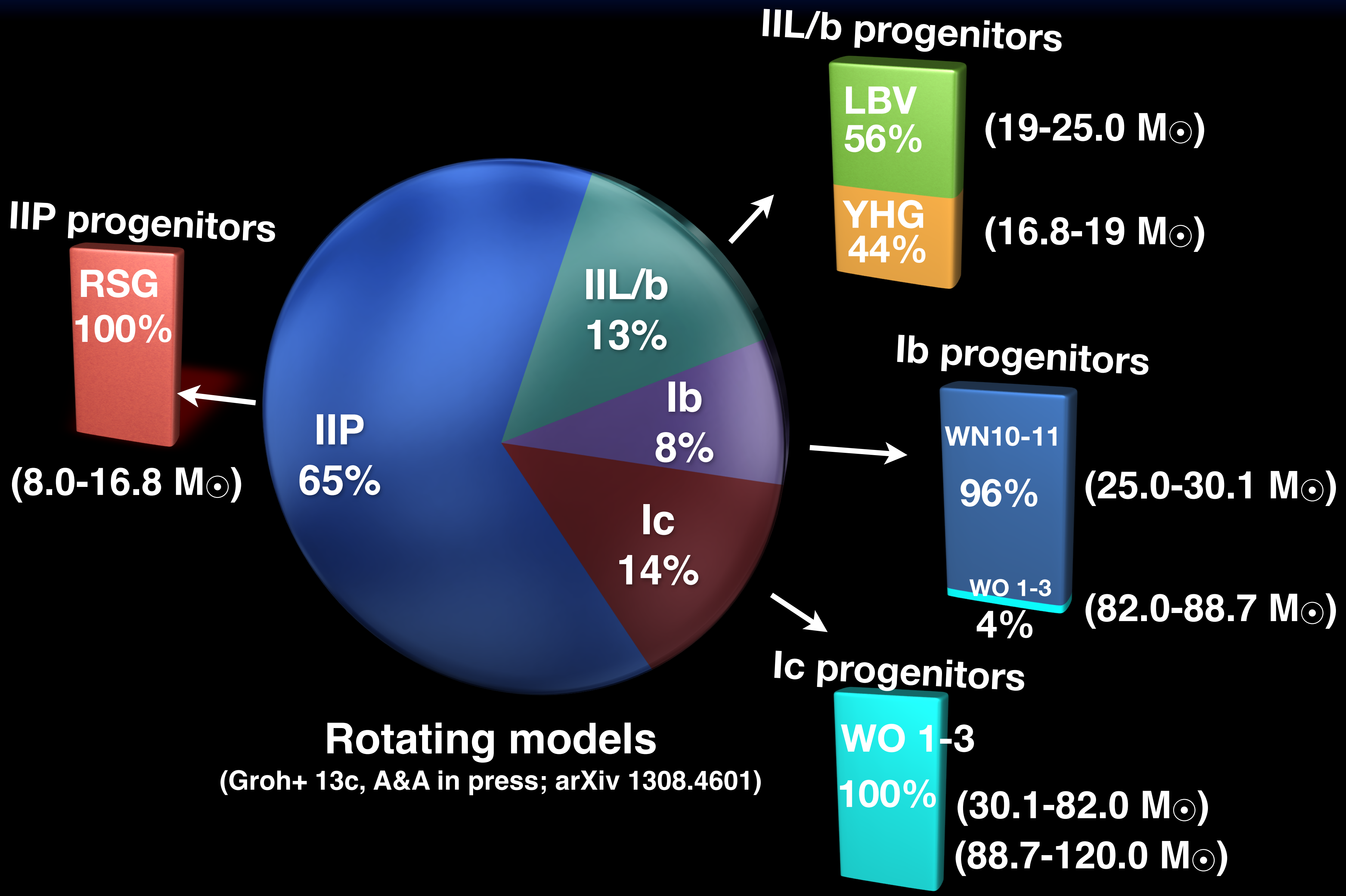

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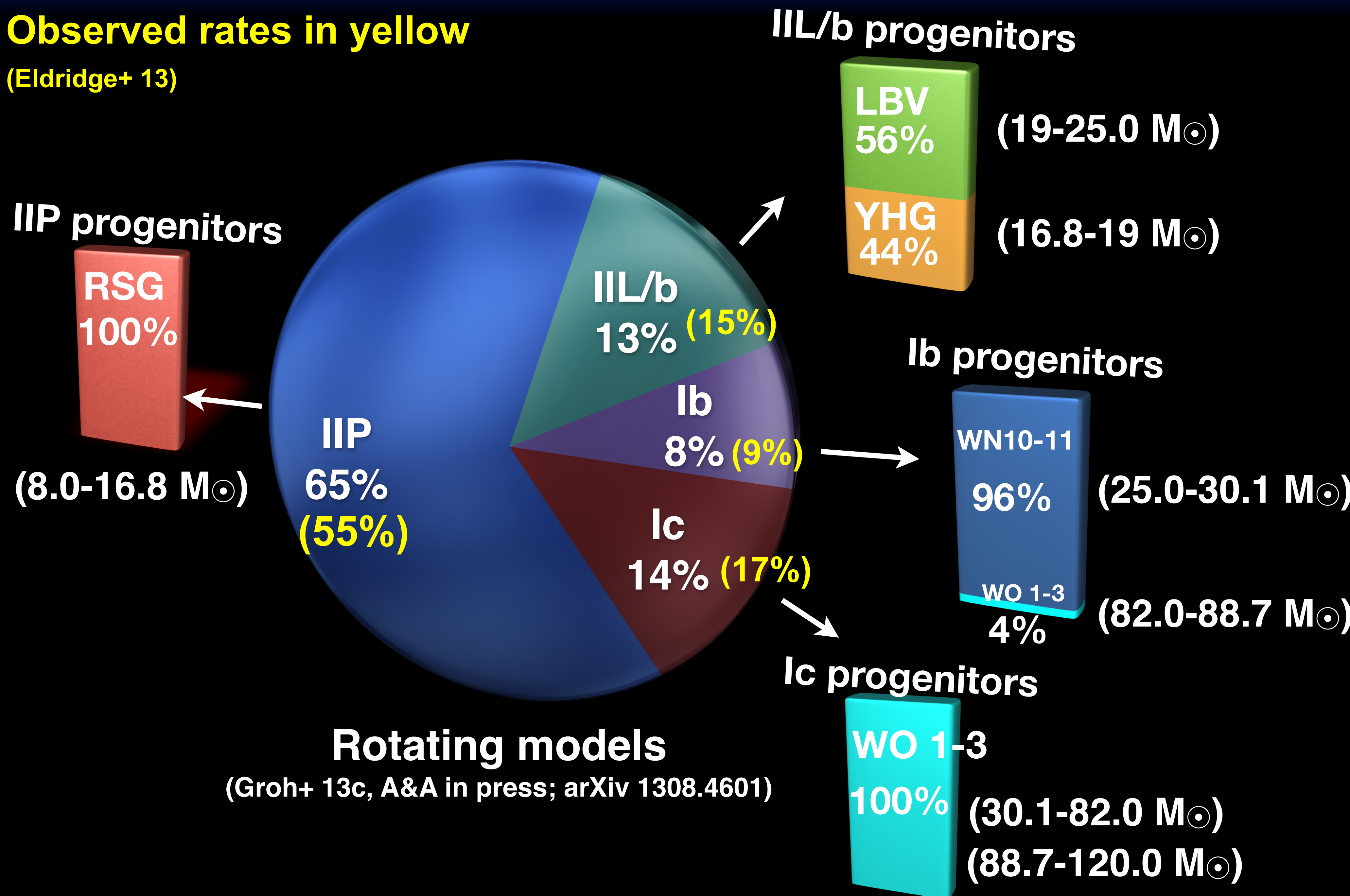

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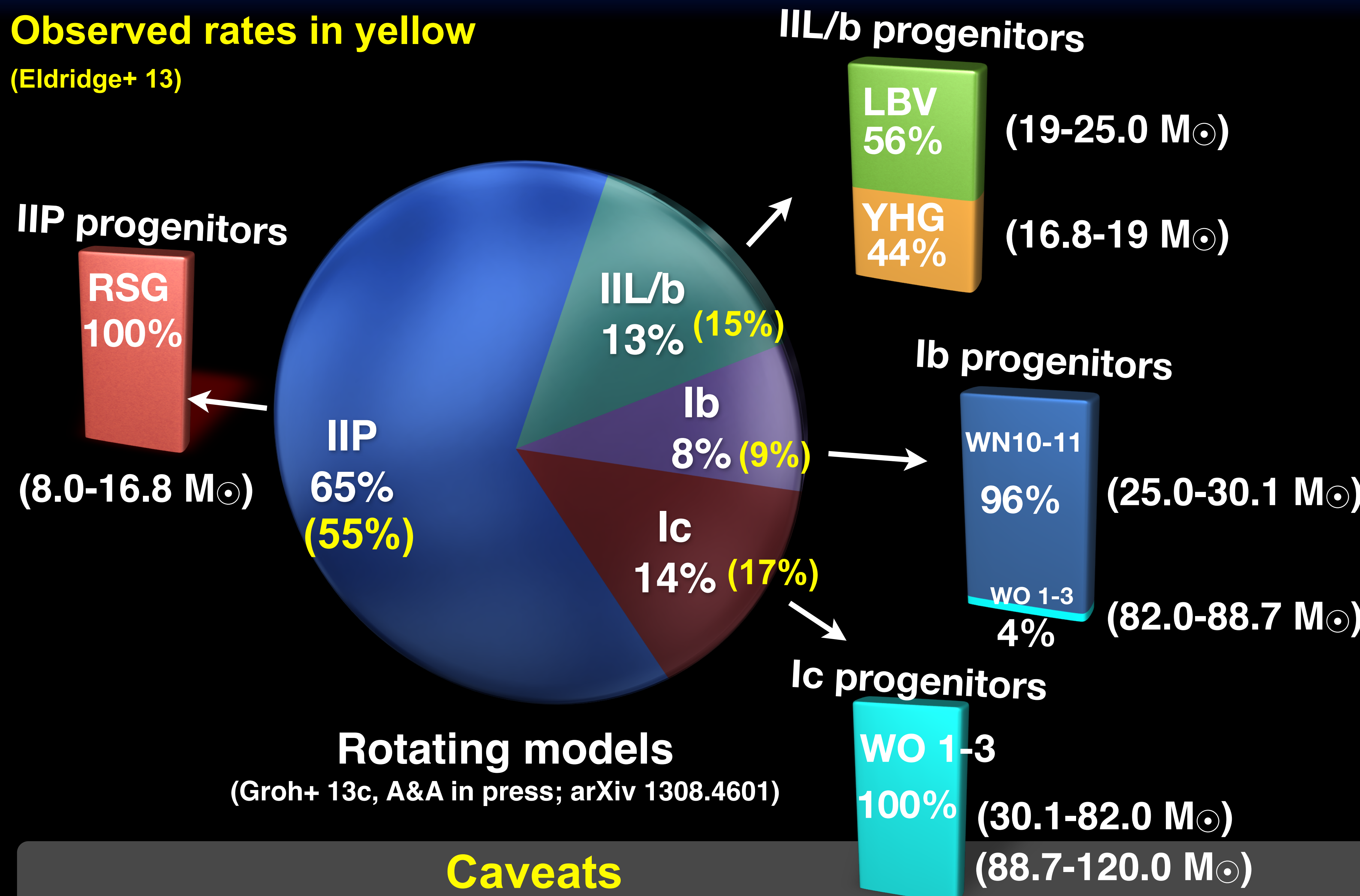

Rotating models
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Caveats

- 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

Take-home messages

1. We are able to predict the look of massive stars across their evolution and at the pre-SN stage, in the near and far Universe.

2. Predictions compare well with observations of SN IIP, IIb and Ibc progenitors.