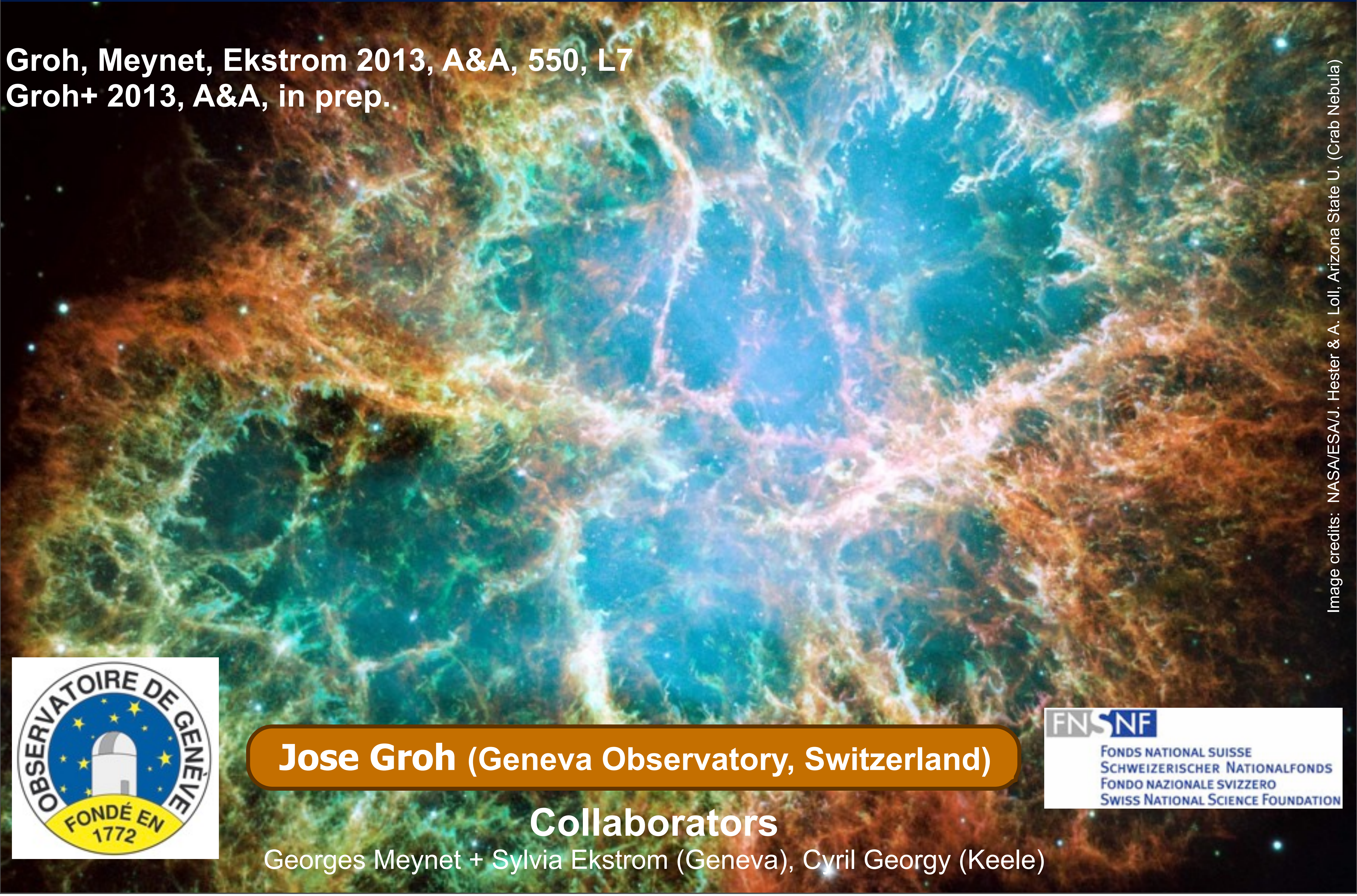
The surprising look of massive stars before death



Groh, Meynet, Ekstrom 2013, A&A, 550, L7
Groh+ 2013, A&A, in prep.

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

Jose Groh (Geneva Observatory, Switzerland)

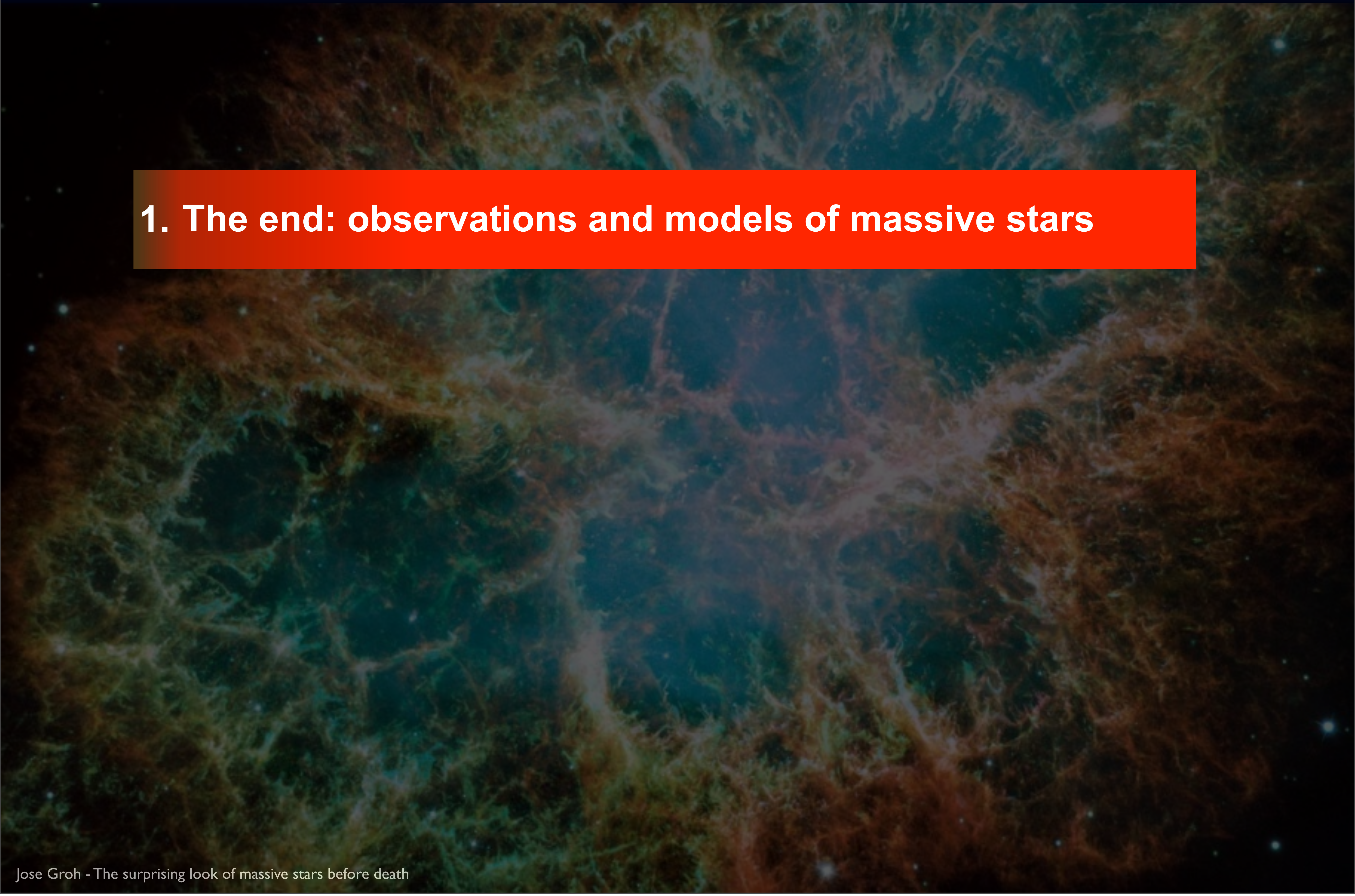
Collaborators

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

OBSERVATOIRE DE GENÈVE FONDÉ EN 1772

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

Outline



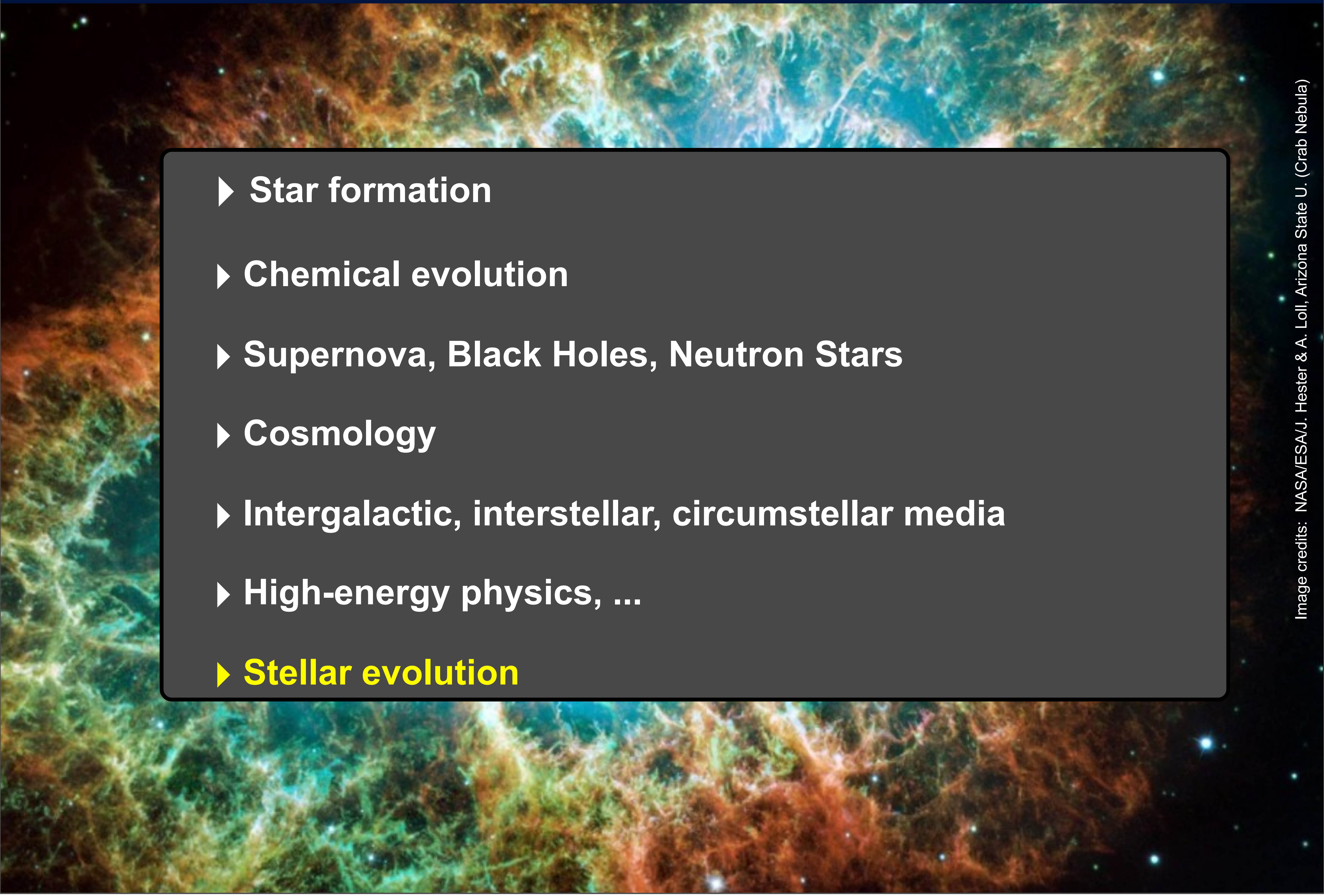
1. **The end: observations and models of massive stars**

Outline

1. The end: observations and models of massive stars

2. Predicting the look of core-collapse SN progenitors

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: progenitor, remnant, chemistry

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

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至十二月癸
酉入奎至七年三月辛亥乃散紹興八年五月丁未

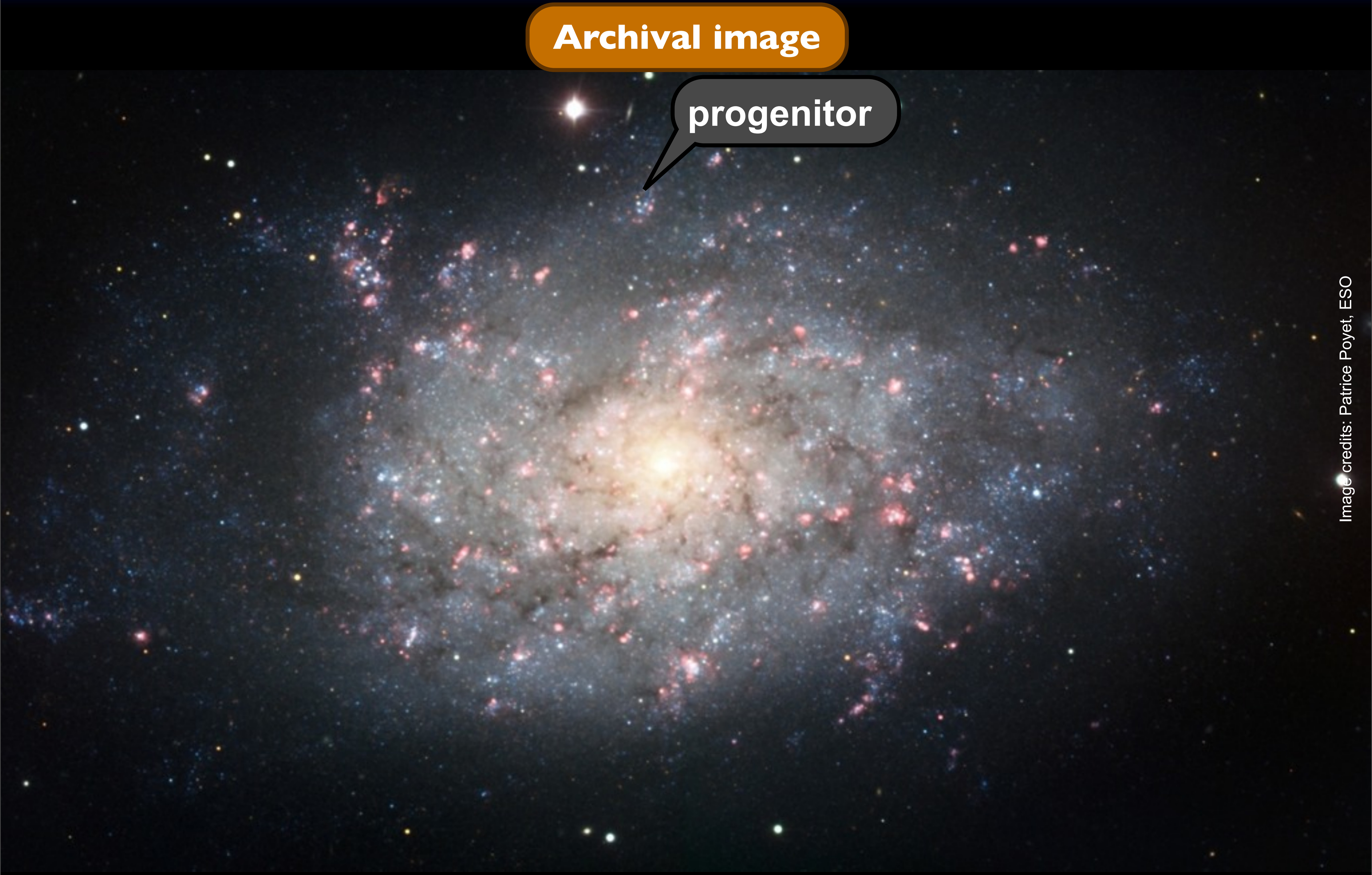
宋史志卷九

Image credits: British museum

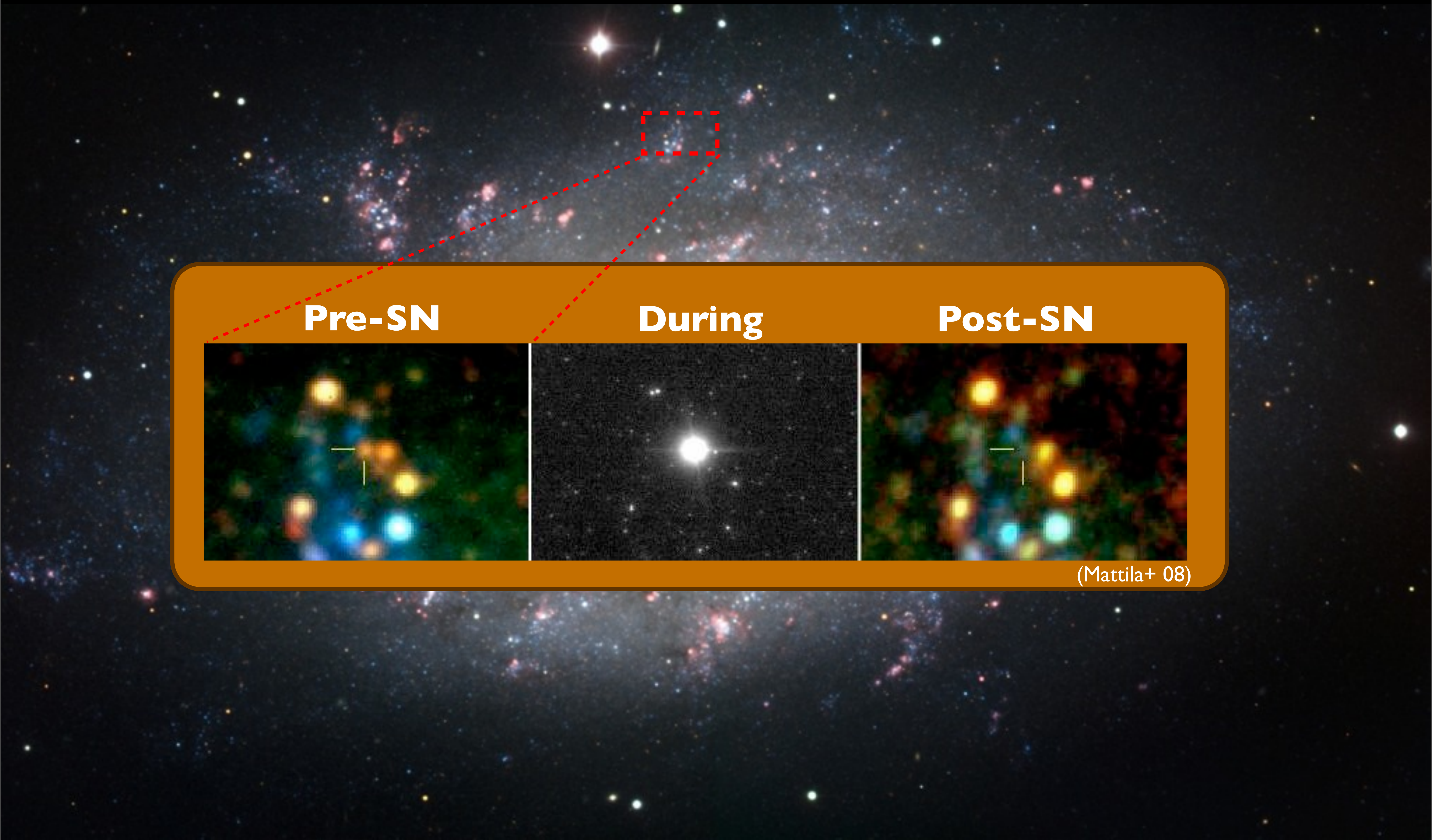
Direct detection of SN progenitors

Image credits: Patrice Poyet, ESO

Direct detection of SN progenitors

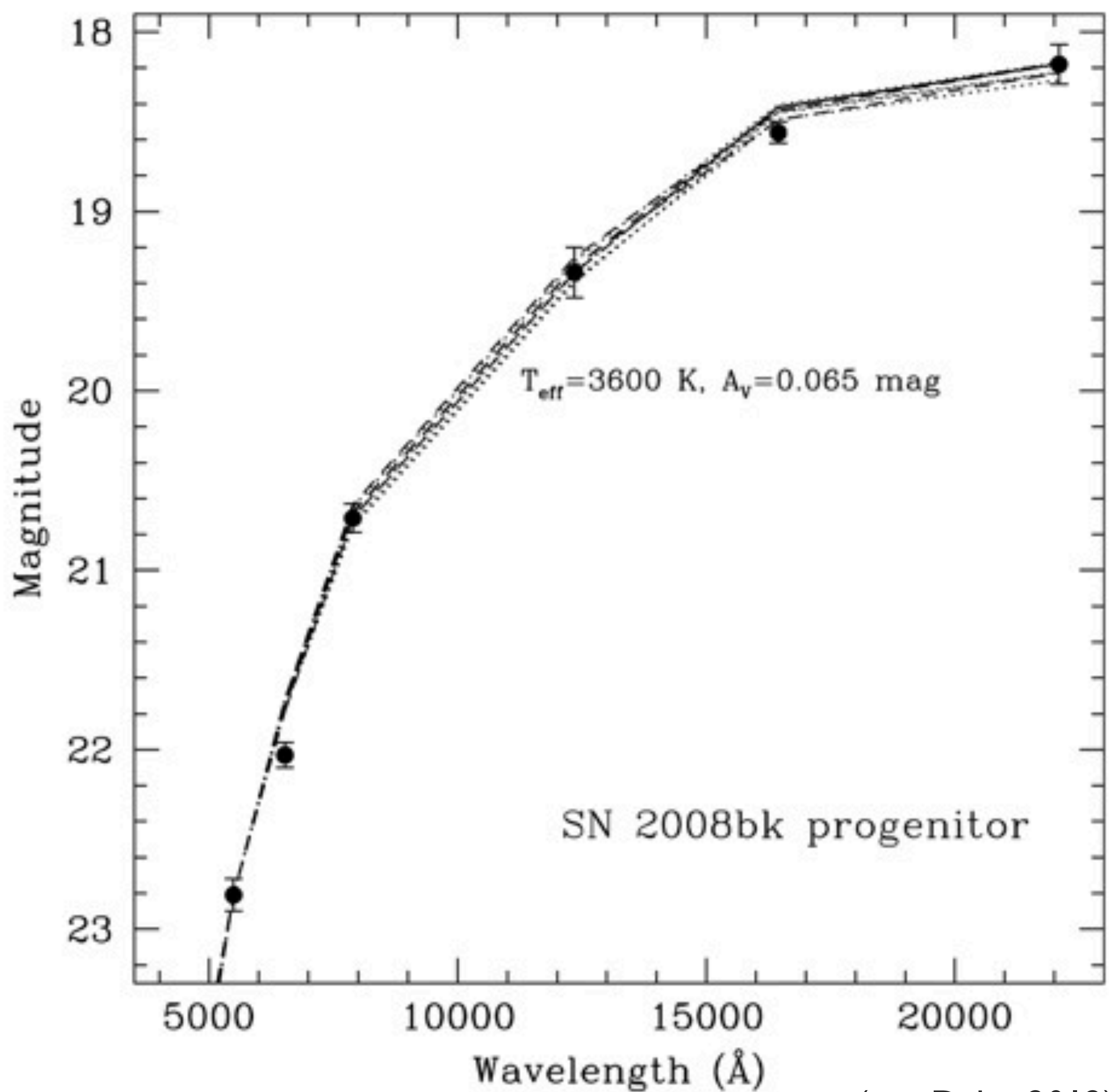


Direct detection of SN progenitors



Direct detection of SN progenitors

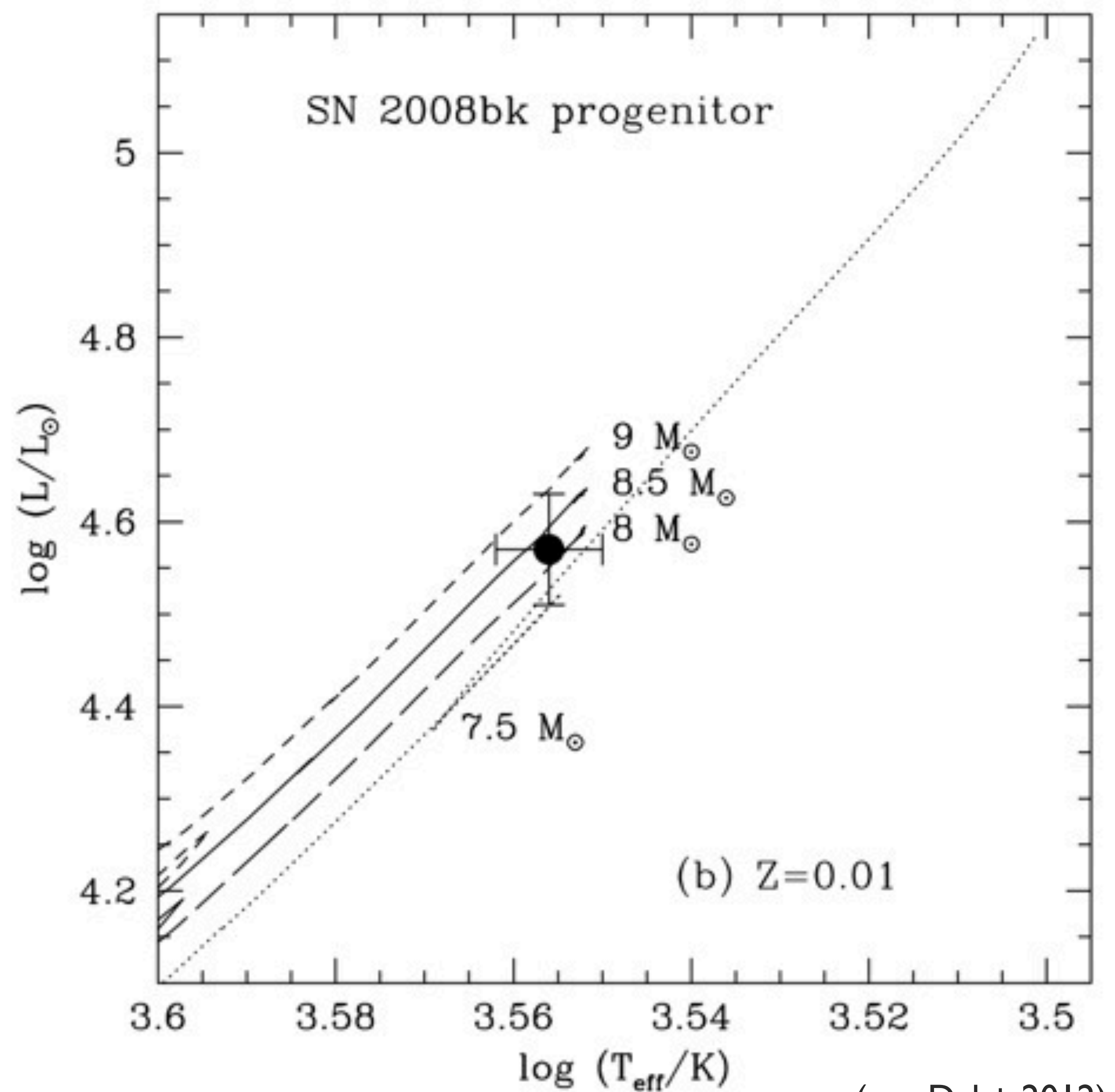
SN progenitor detected in 6 filters (VRIJHK)



(van Dyk+ 2012)

Direct detection of SN progenitors

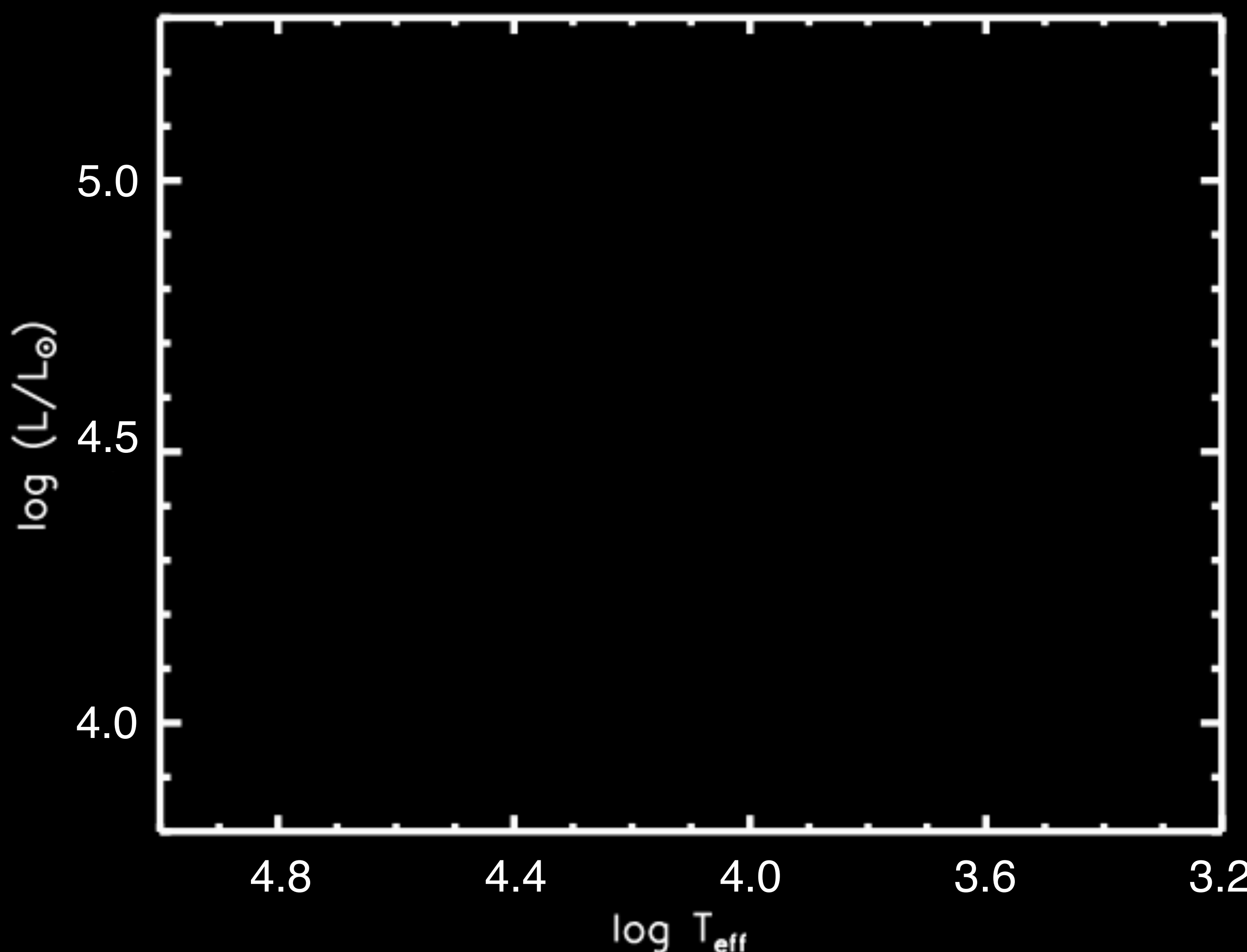
SN progenitor is a RSG with initial mass ~8 $M_\odot$



(van Dyk+ 2012)

Massive star evolution (8 to ~17 $M_\odot$)

(G. Meynet talk)



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

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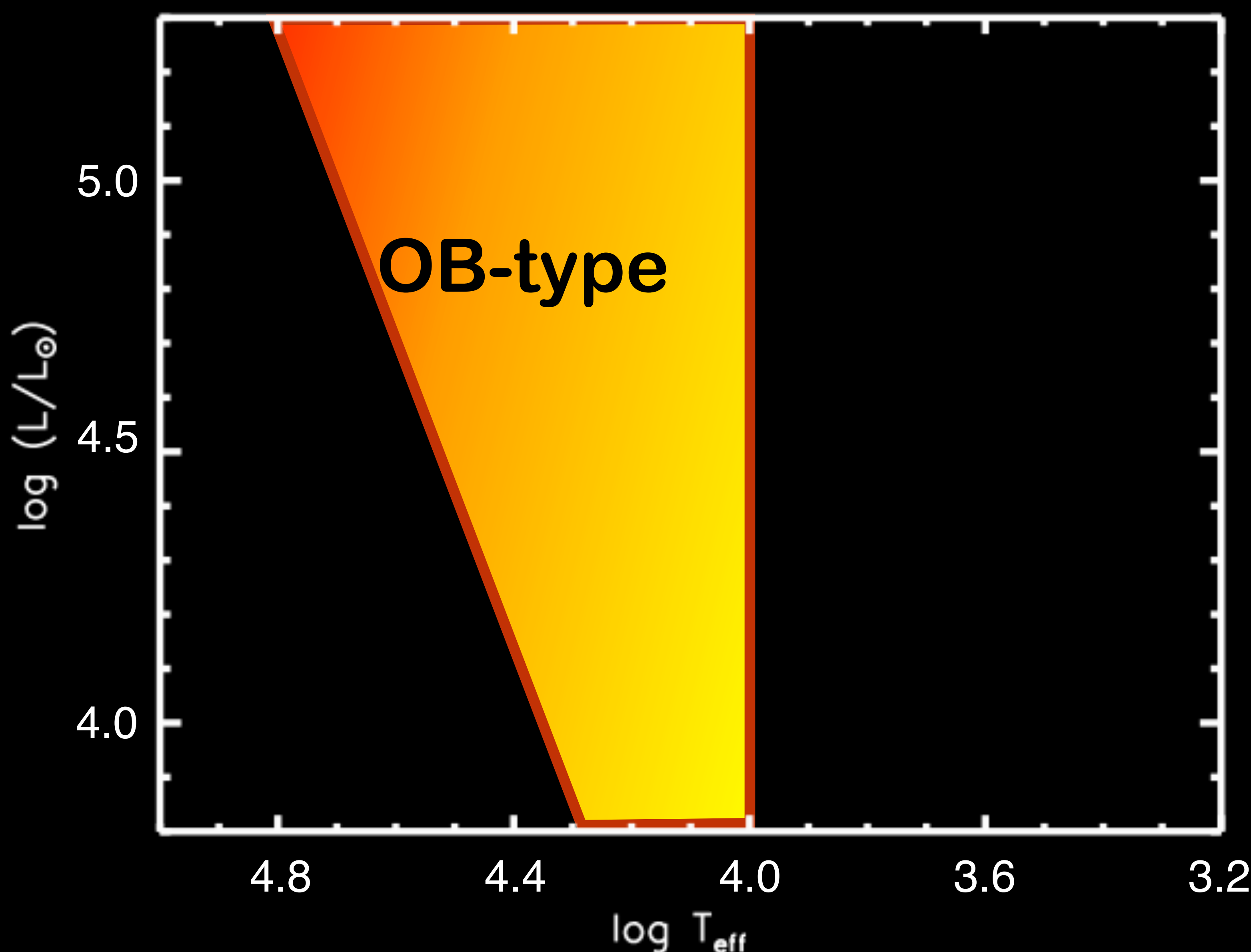

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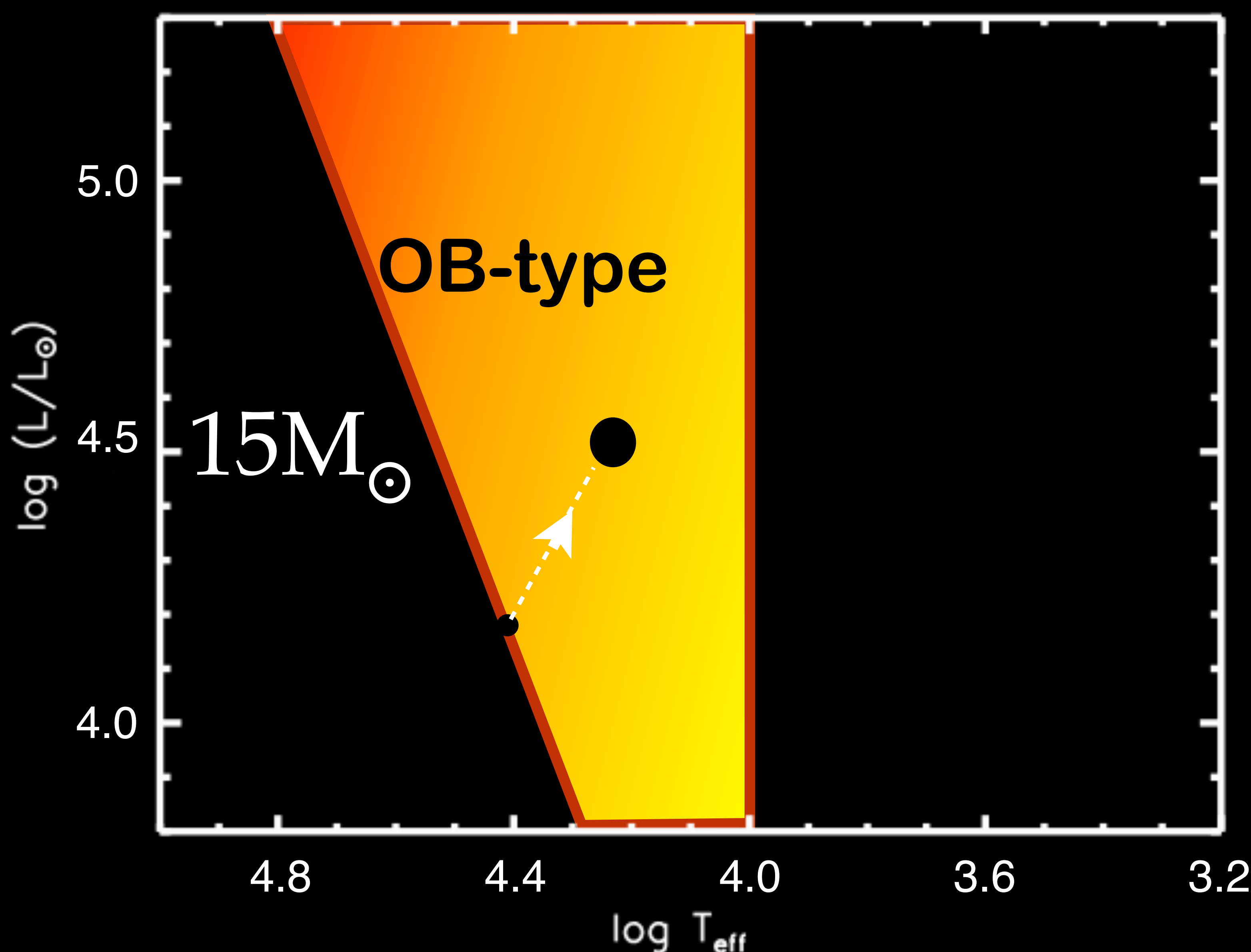

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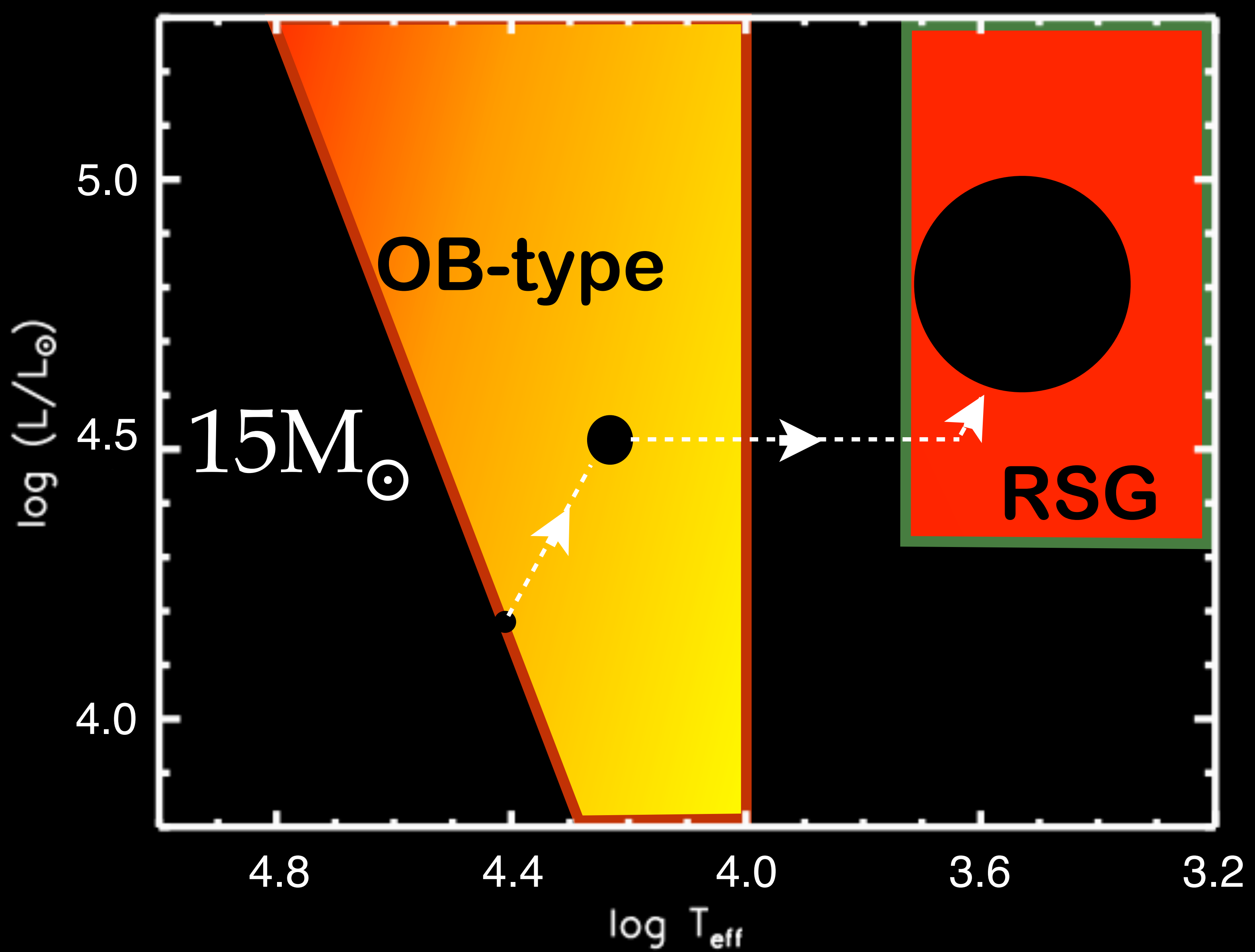

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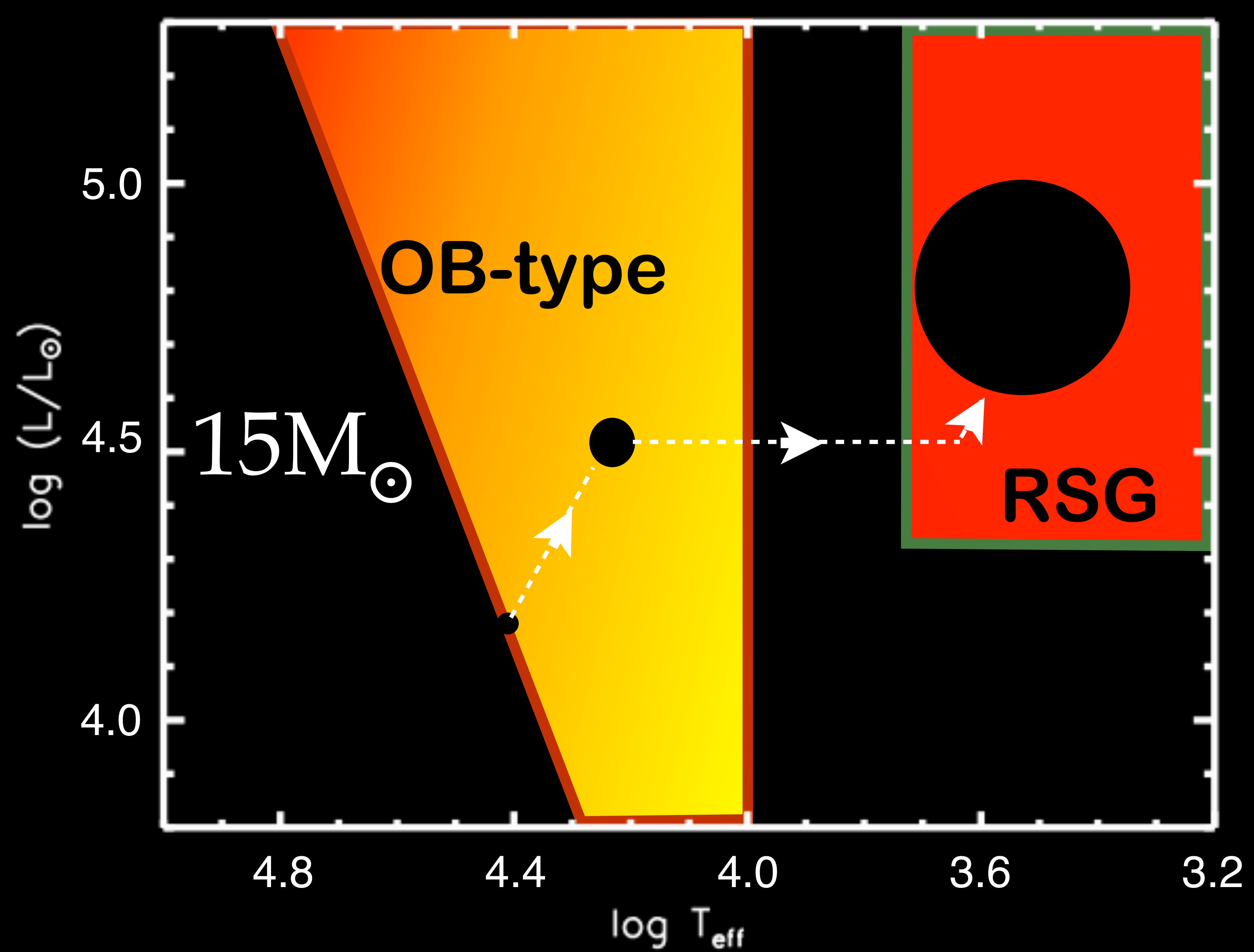
OB-type → RSG → SN II



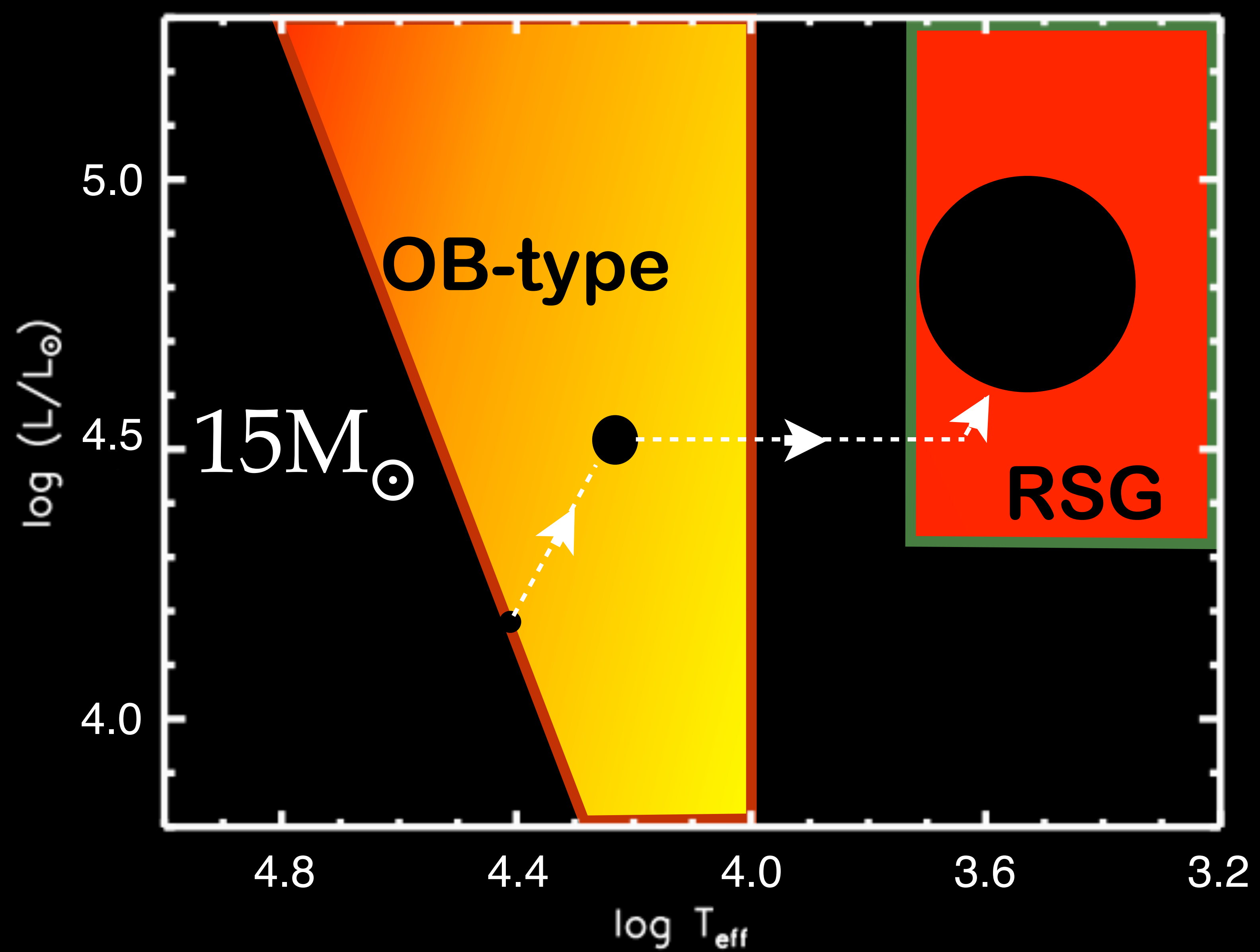
(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)

Massive star evolution (8 to ~17 $M_\odot$)

(G. Meynet talk)

OB-type → RSG → SN II

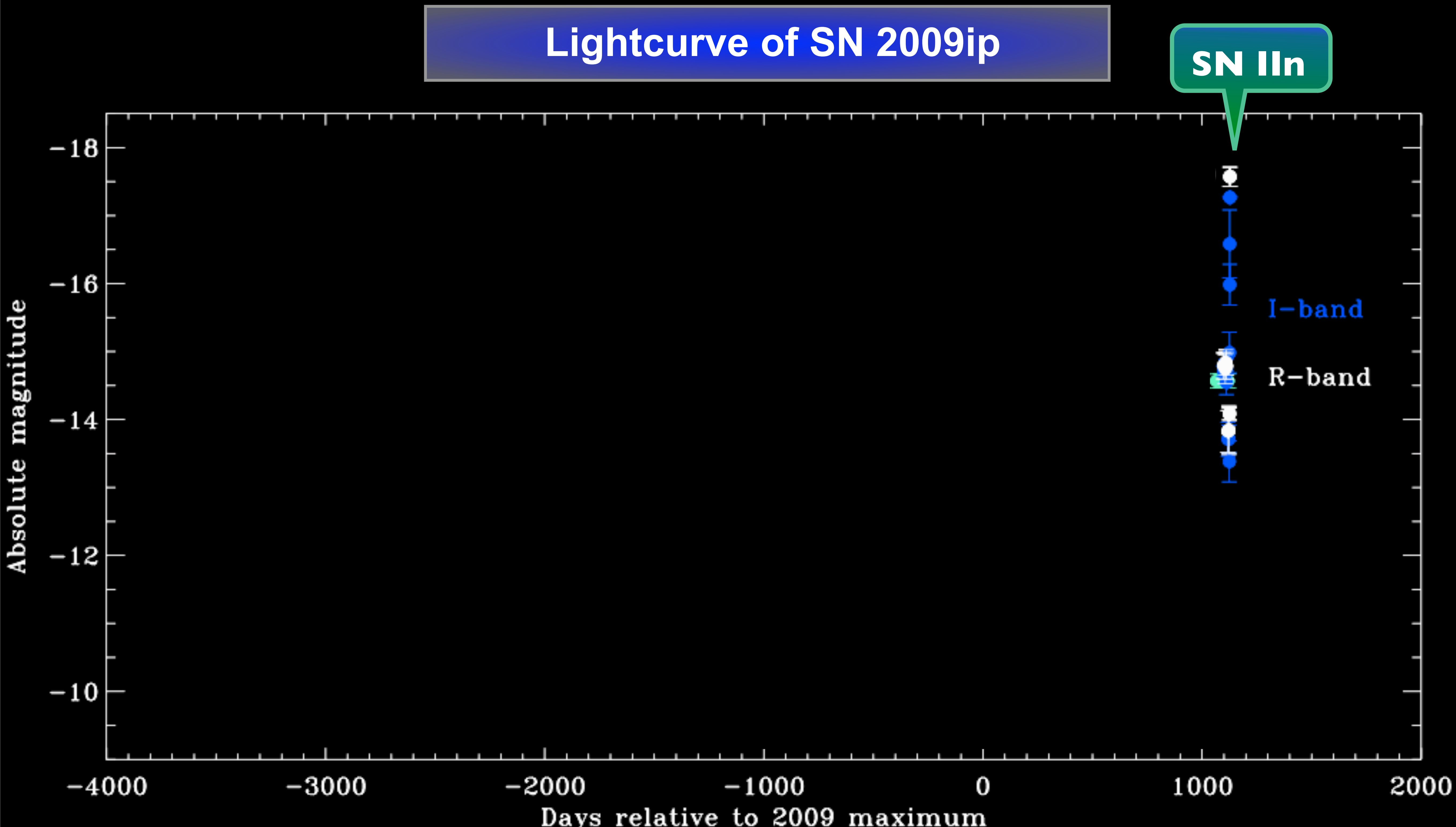
Agrees with observations of SN II progenitors (Smartt 09)



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

SN progenitors from very massive stars

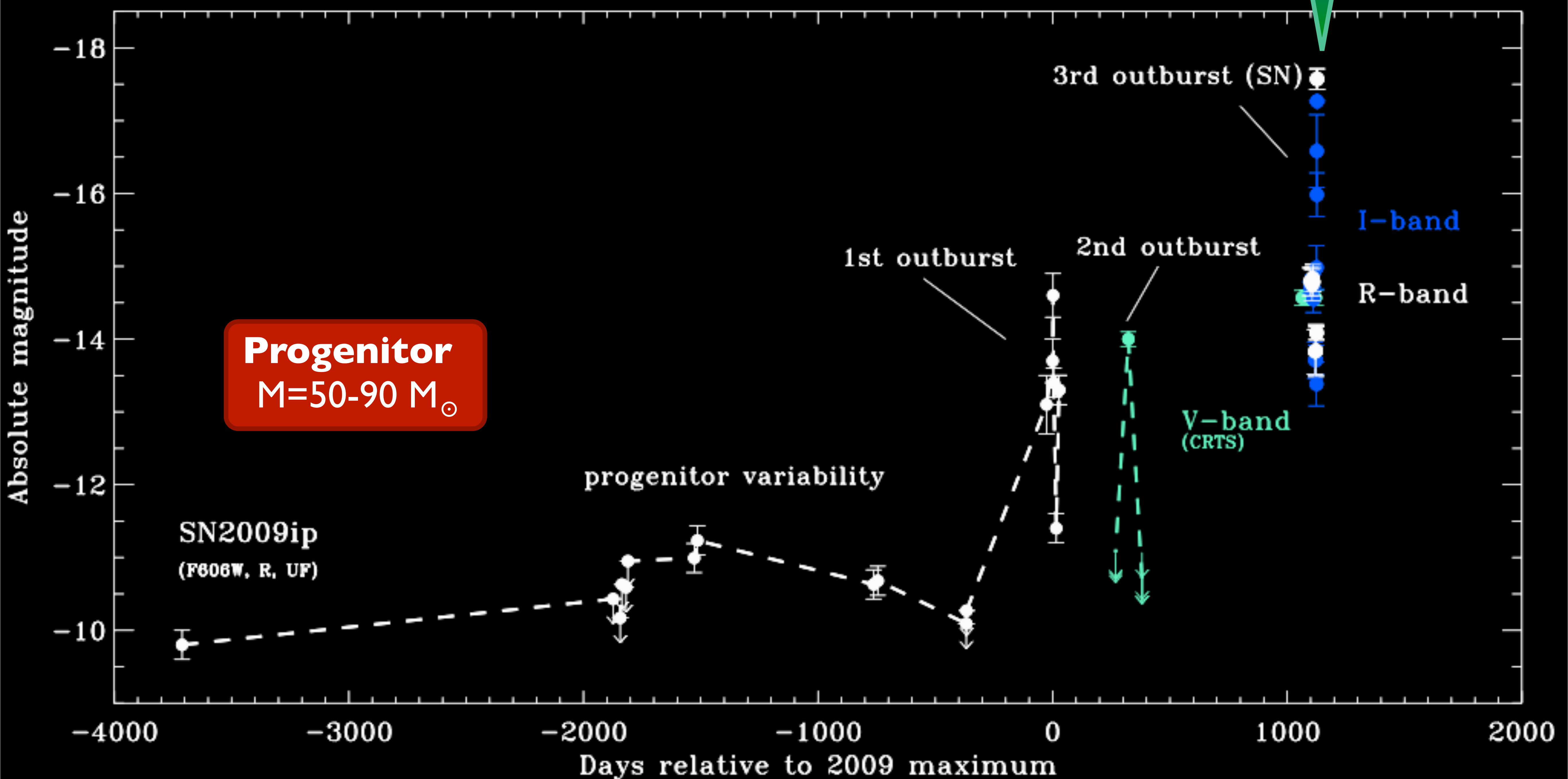
(N. Smith + T. Moryia talks)



(Mauerhan+ 13)

SN progenitors from very massive stars

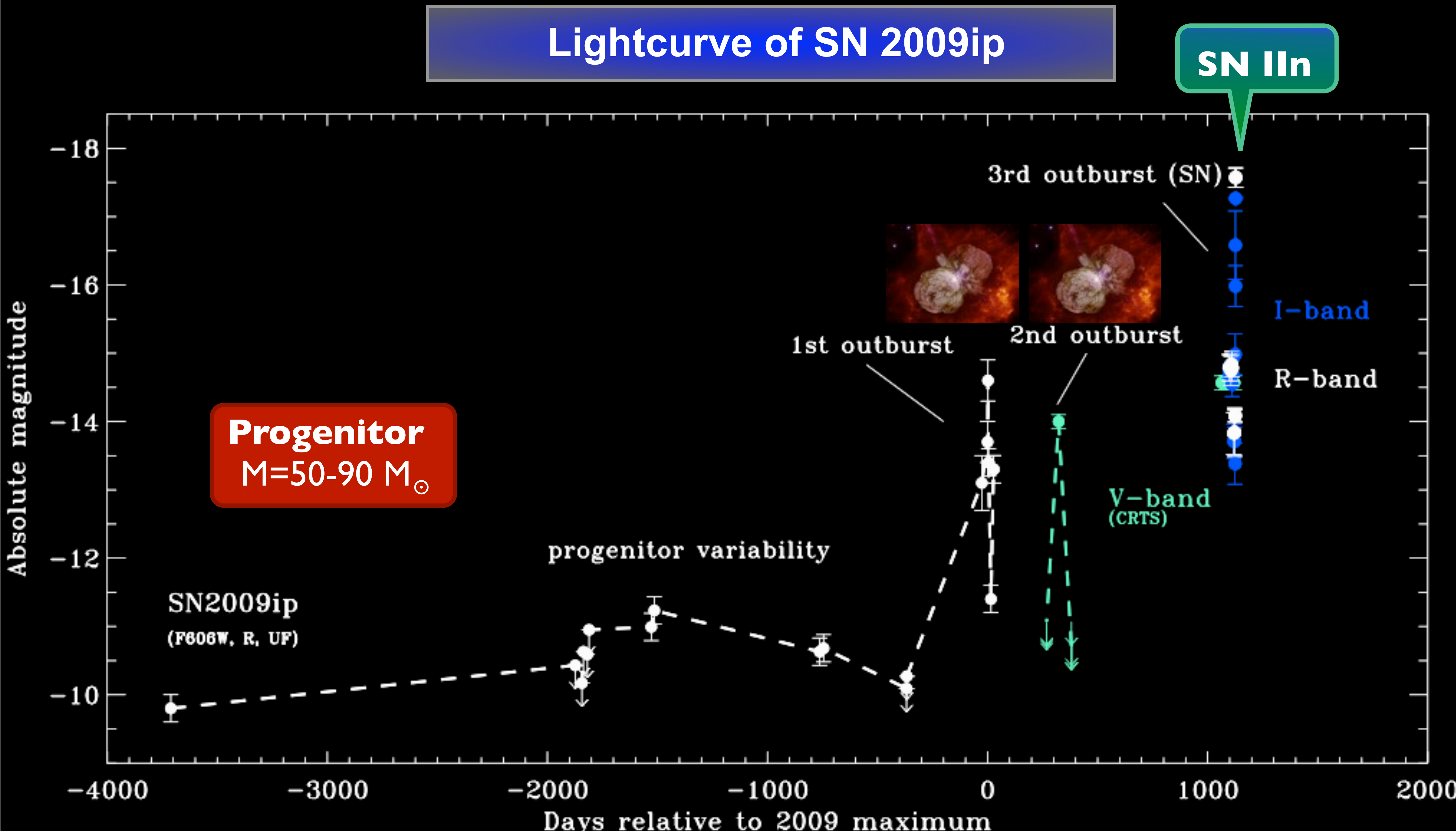
Lightcurve of SN 2009ip



Progenitor
M=50-90 $M_\odot$

(Mauerhan+ 13)

SN progenitors from very massive stars

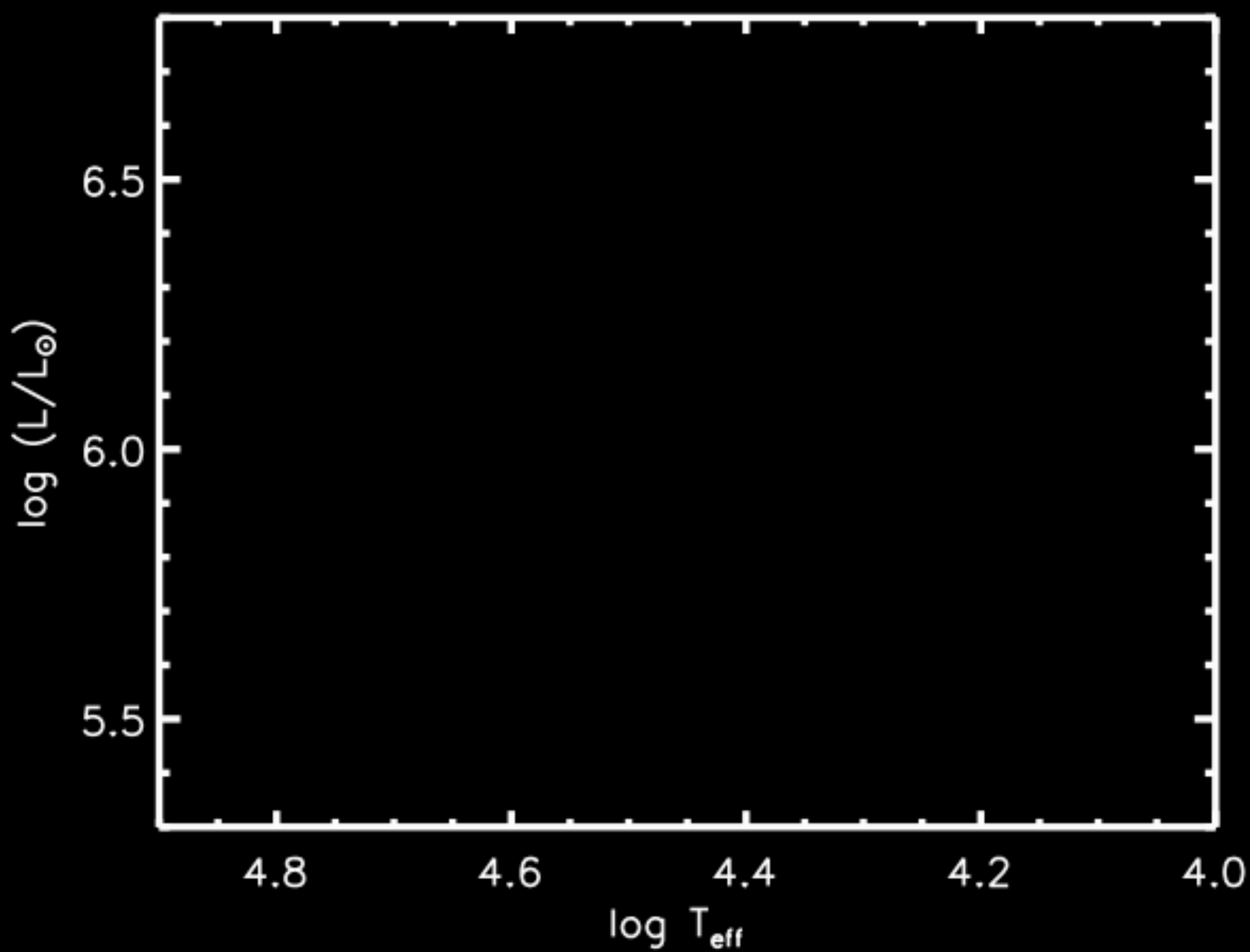


(Mauerhan+ 13)

Massive star evolution (above 40 $M_\odot$)

(G. Meynet talk)

(Eldridge+ 13)



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

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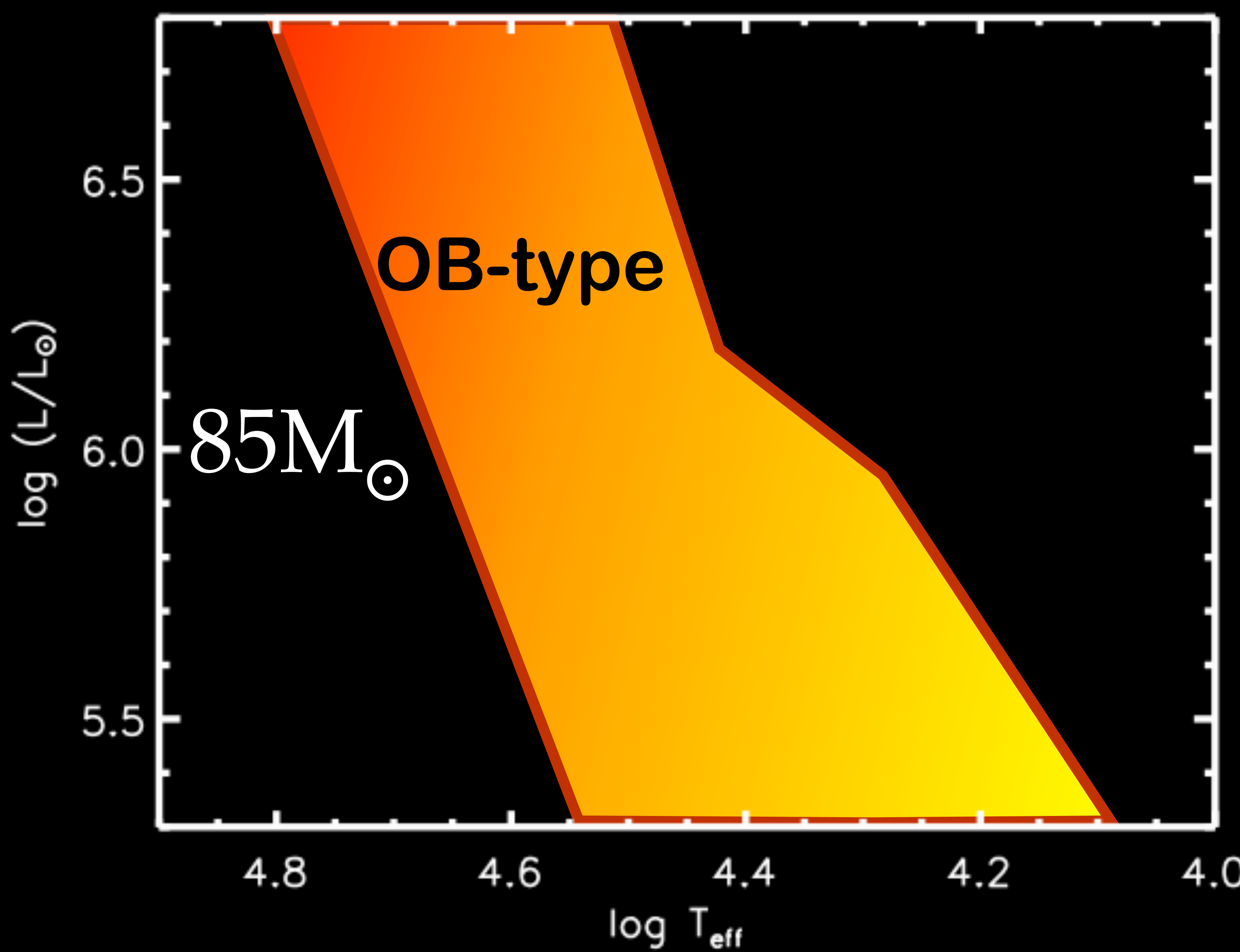

(Eldridge+ 13)

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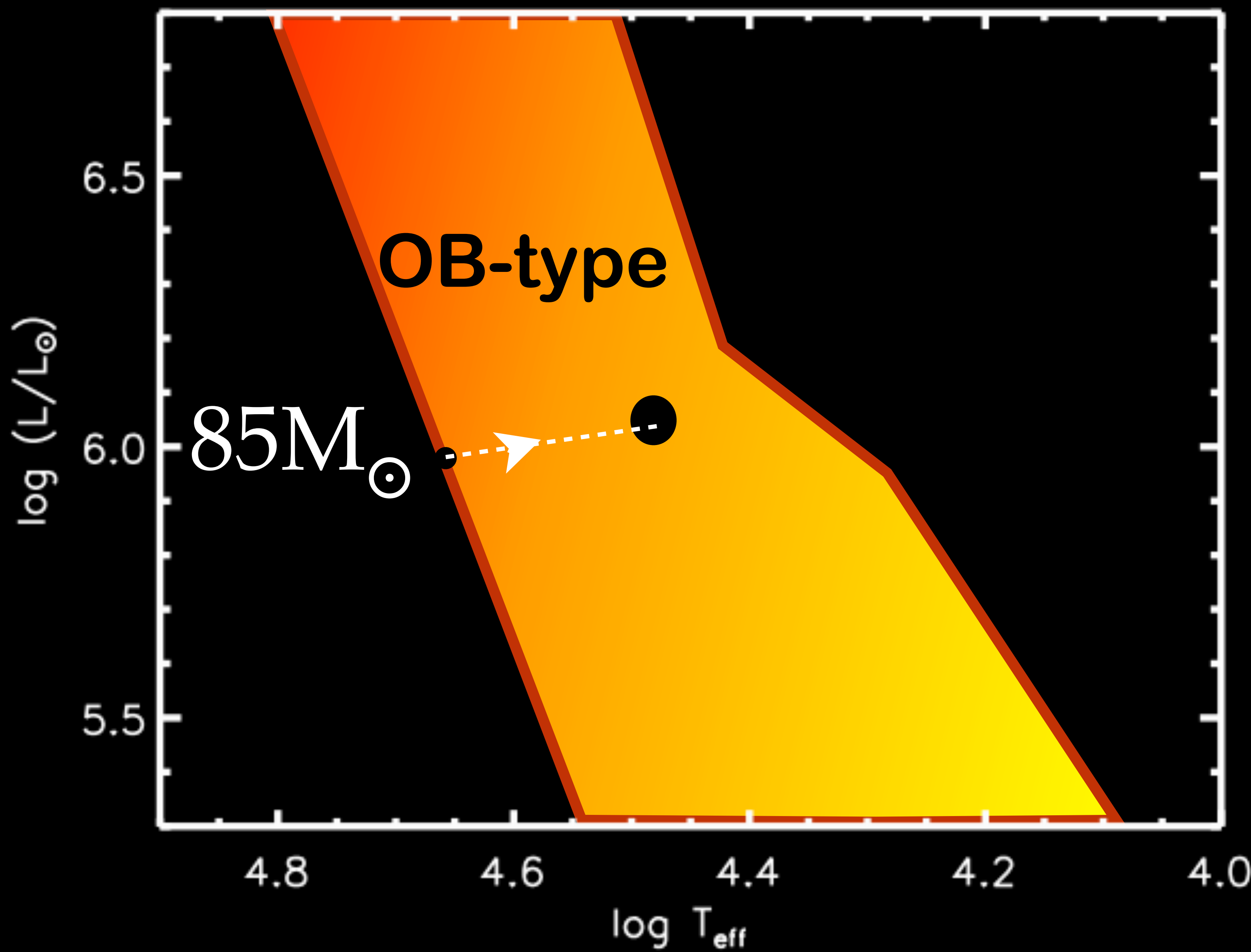

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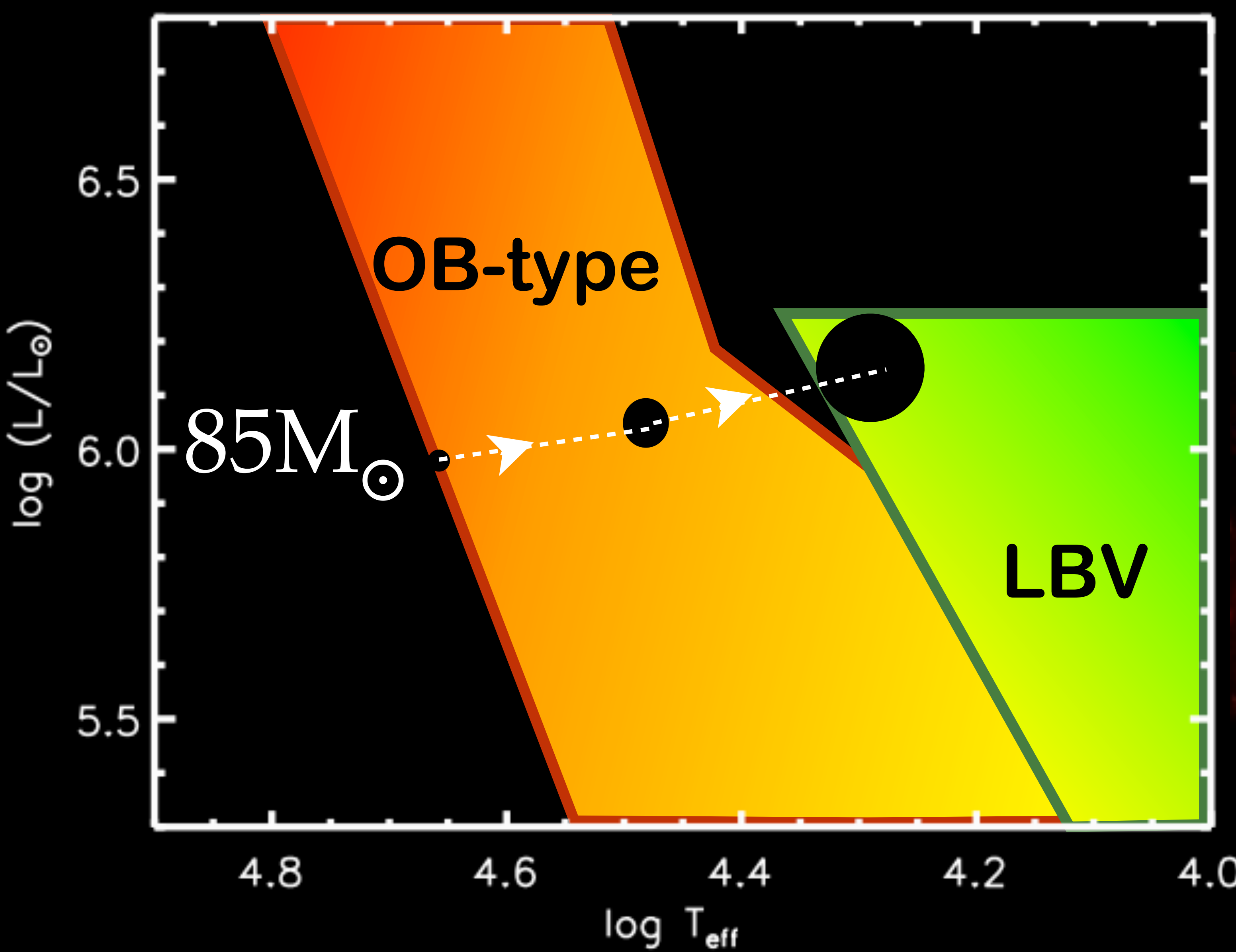

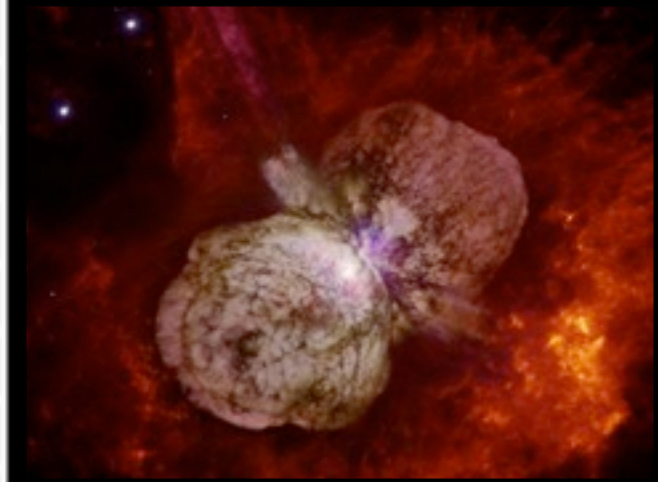

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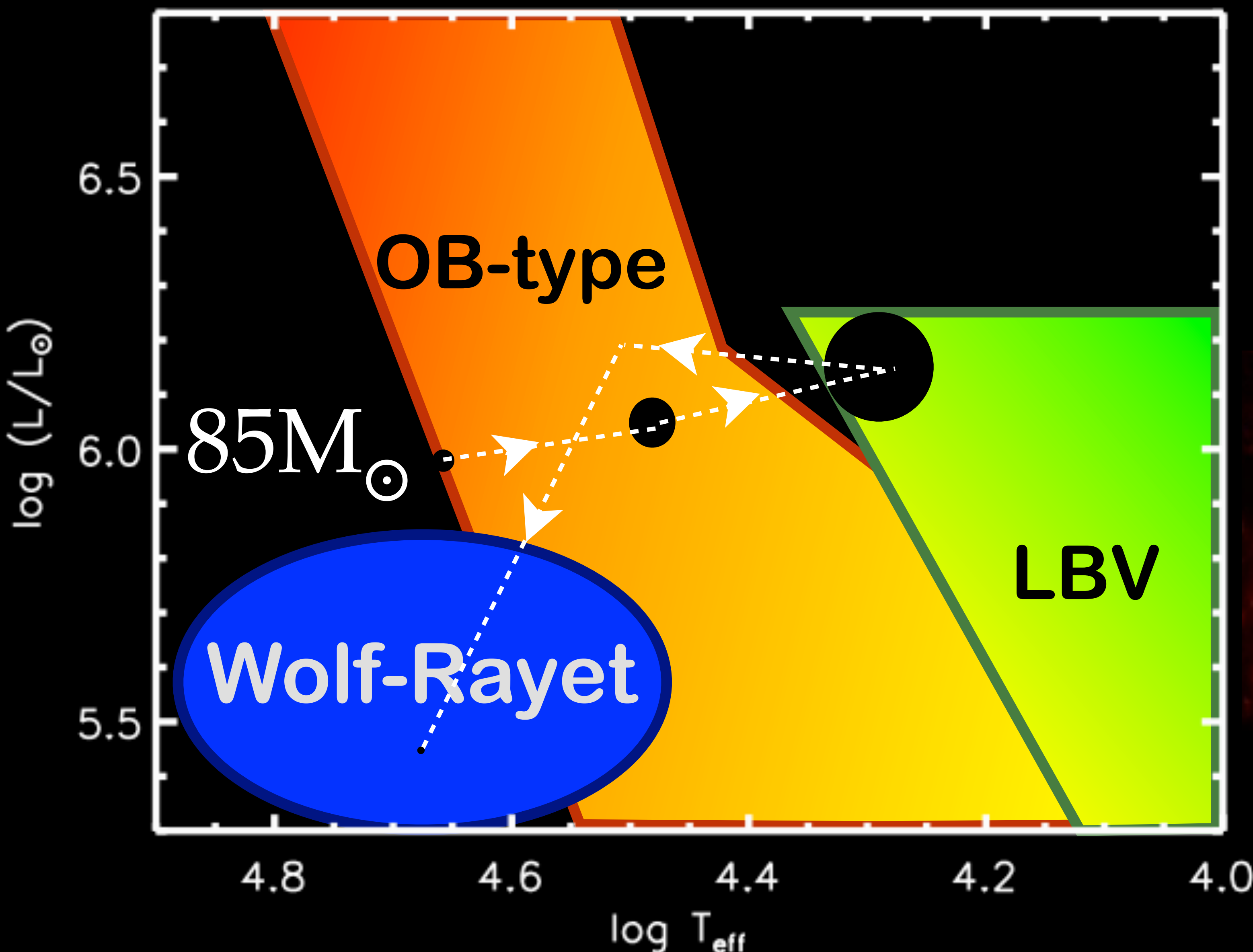

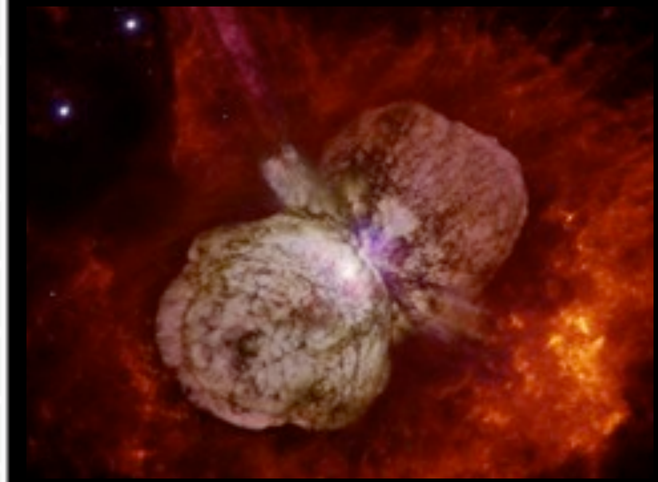

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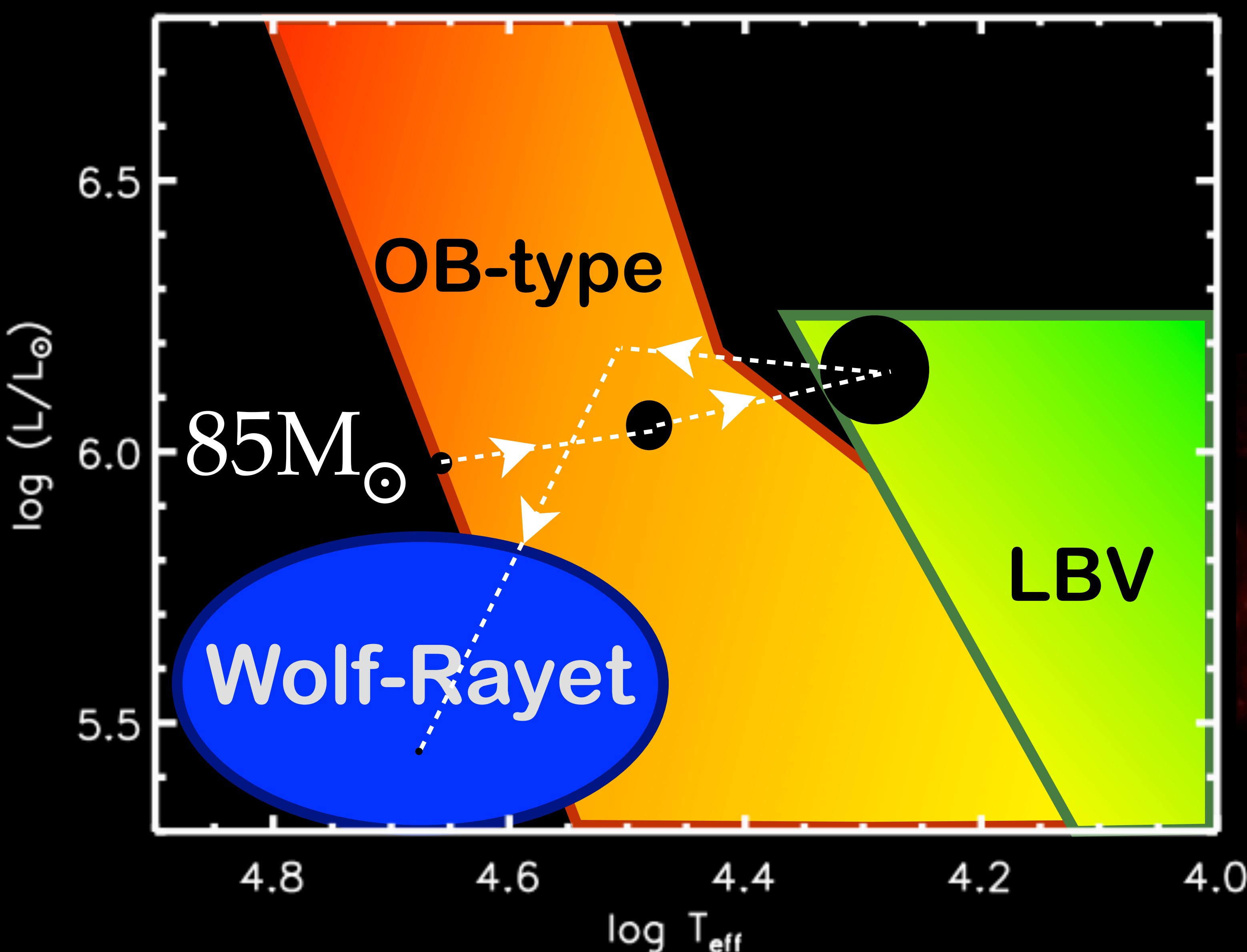
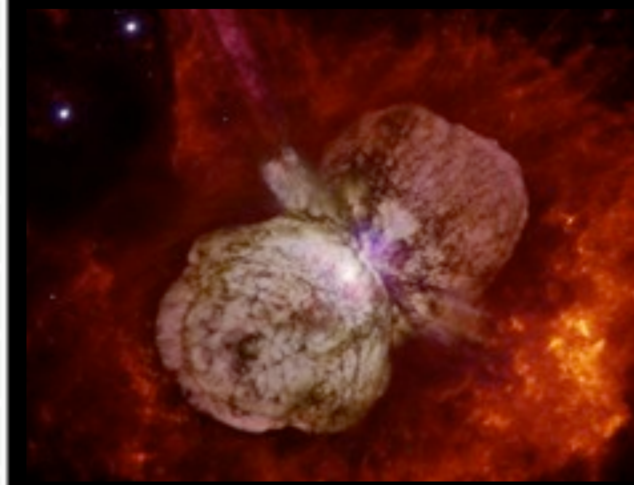
Massive star evolution (above 40 $M_\odot$)

(G. Meynet talk)

OB-type → LBV → WR → SN Ibc

(Eldridge+ 13)





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So far, no observations of WRs as SN progenitors (Smartt 09)

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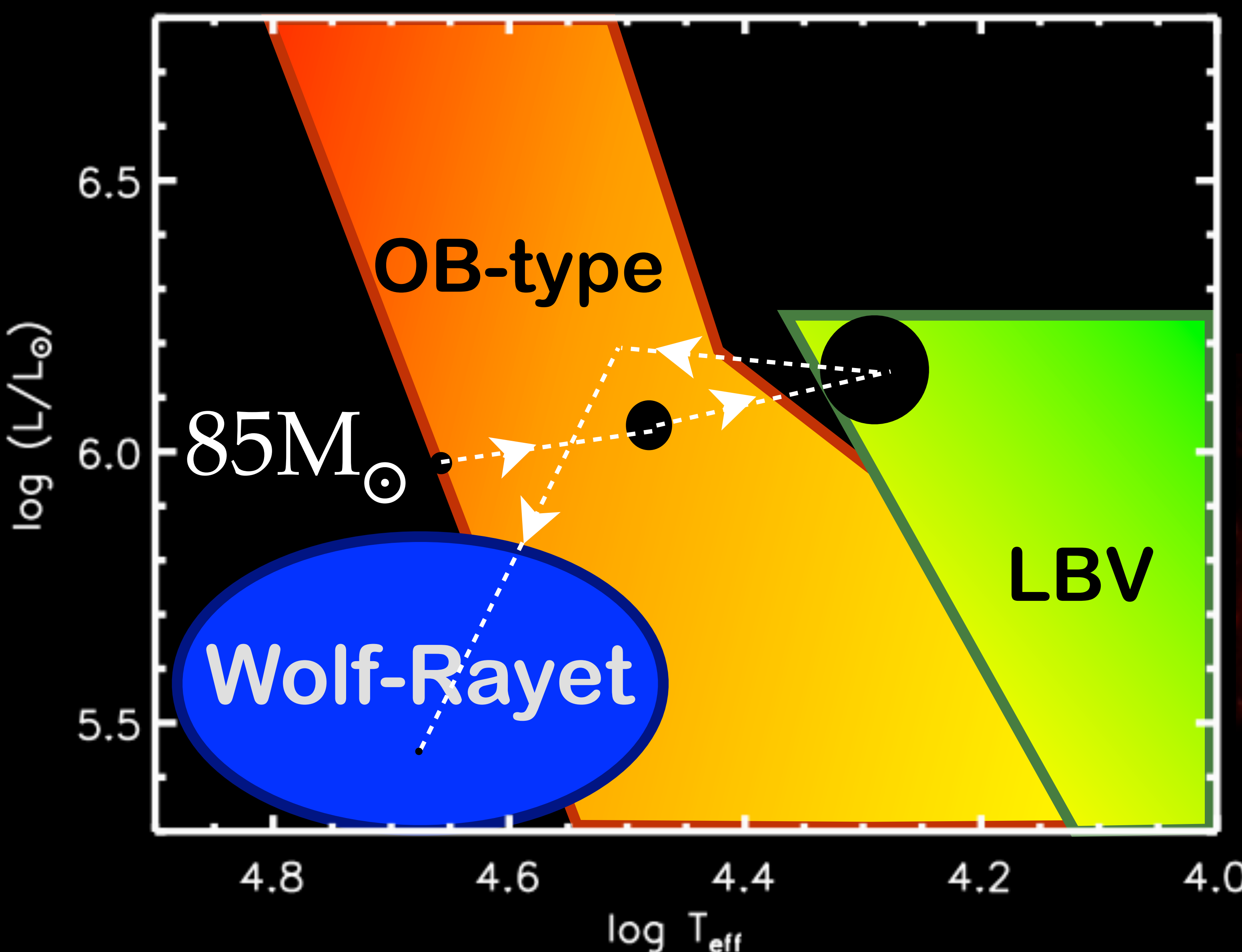

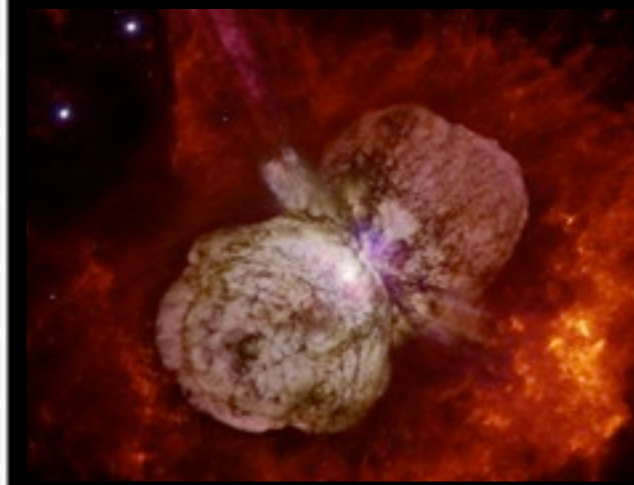

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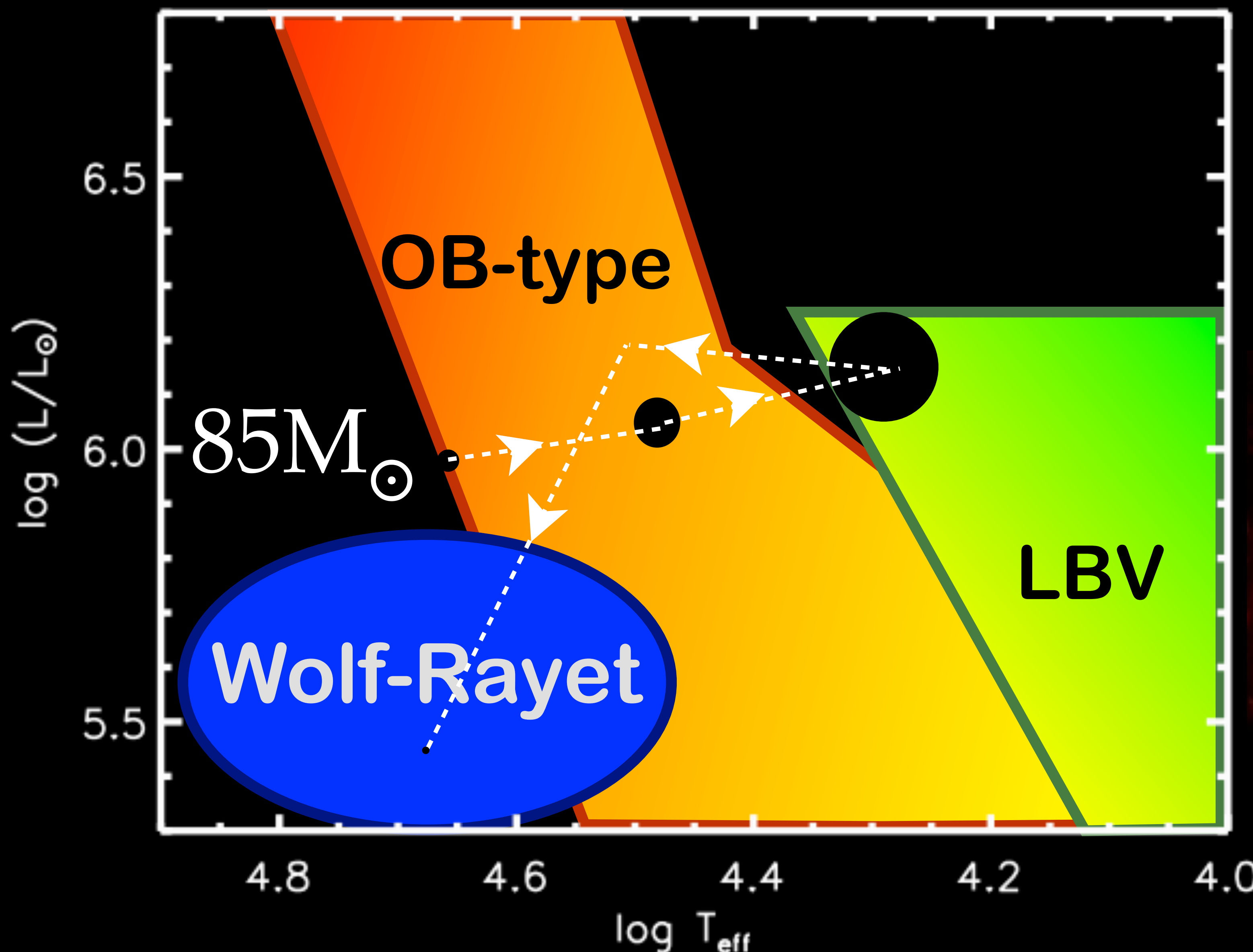
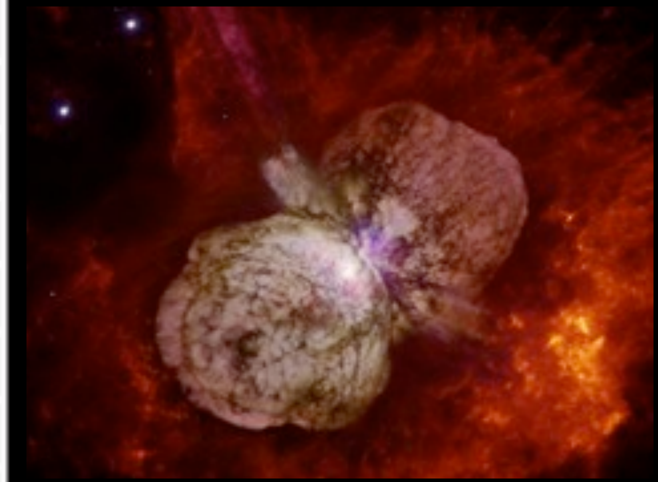
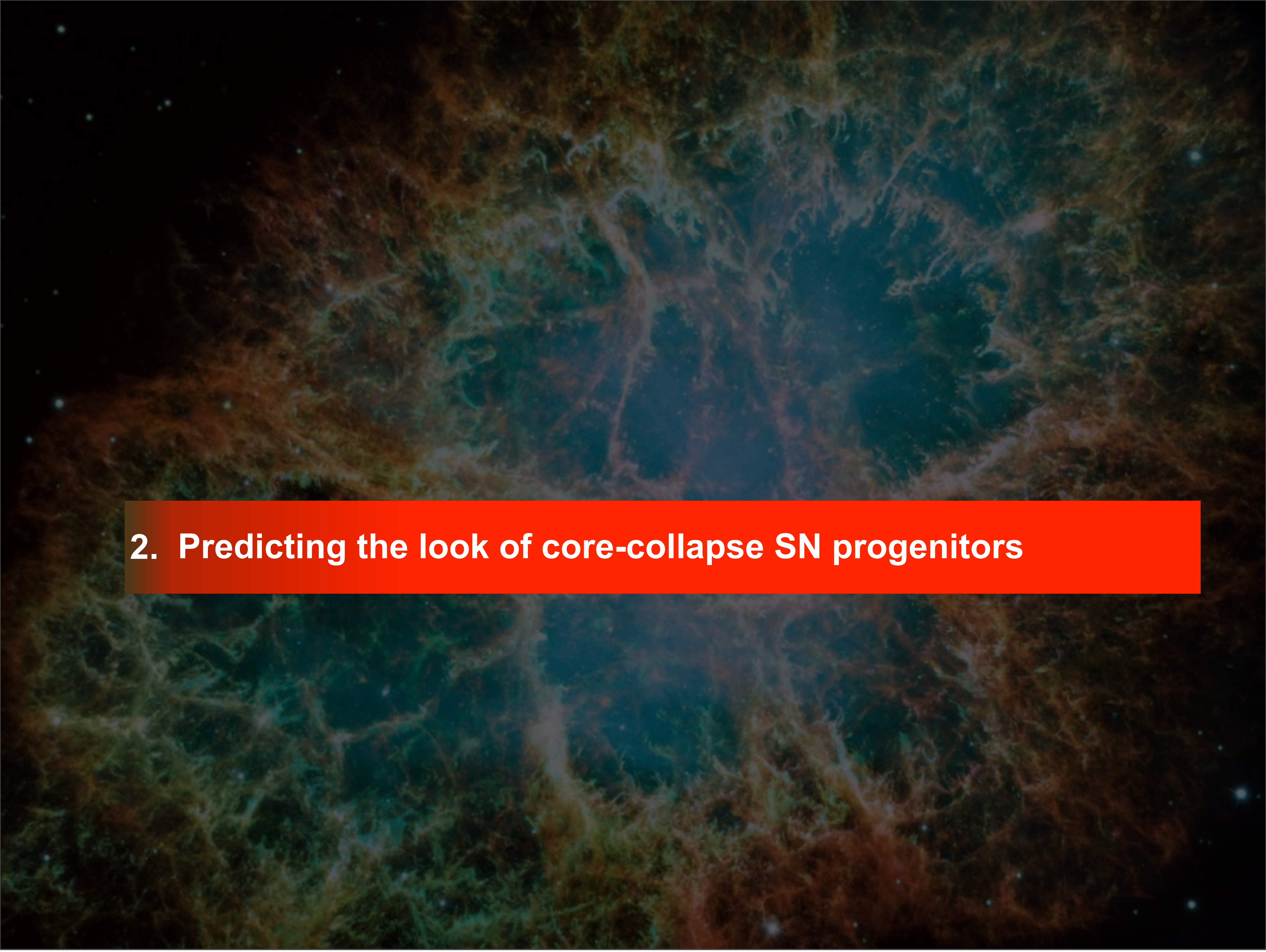




Role of binaries?

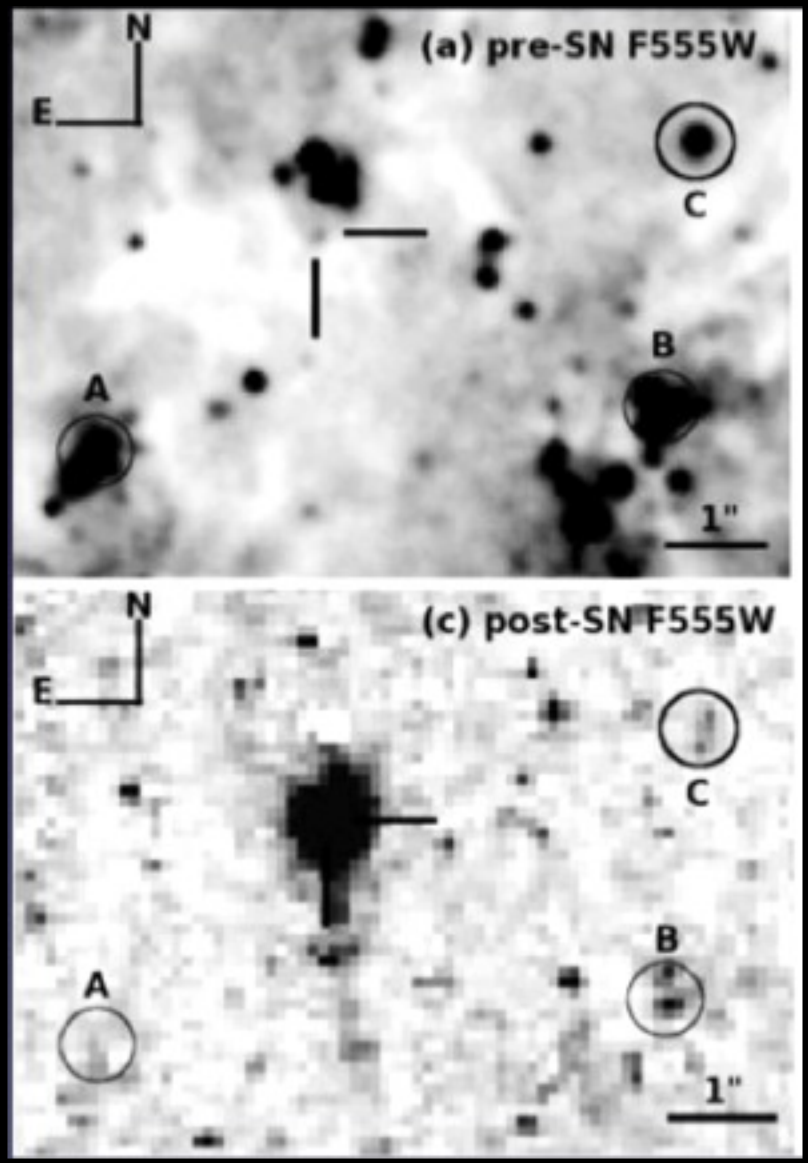
(after evol. tracks from Meynet & Maeder 03, Ekstrom+ 12)



2. Predicting the look of core-collapse SN progenitors

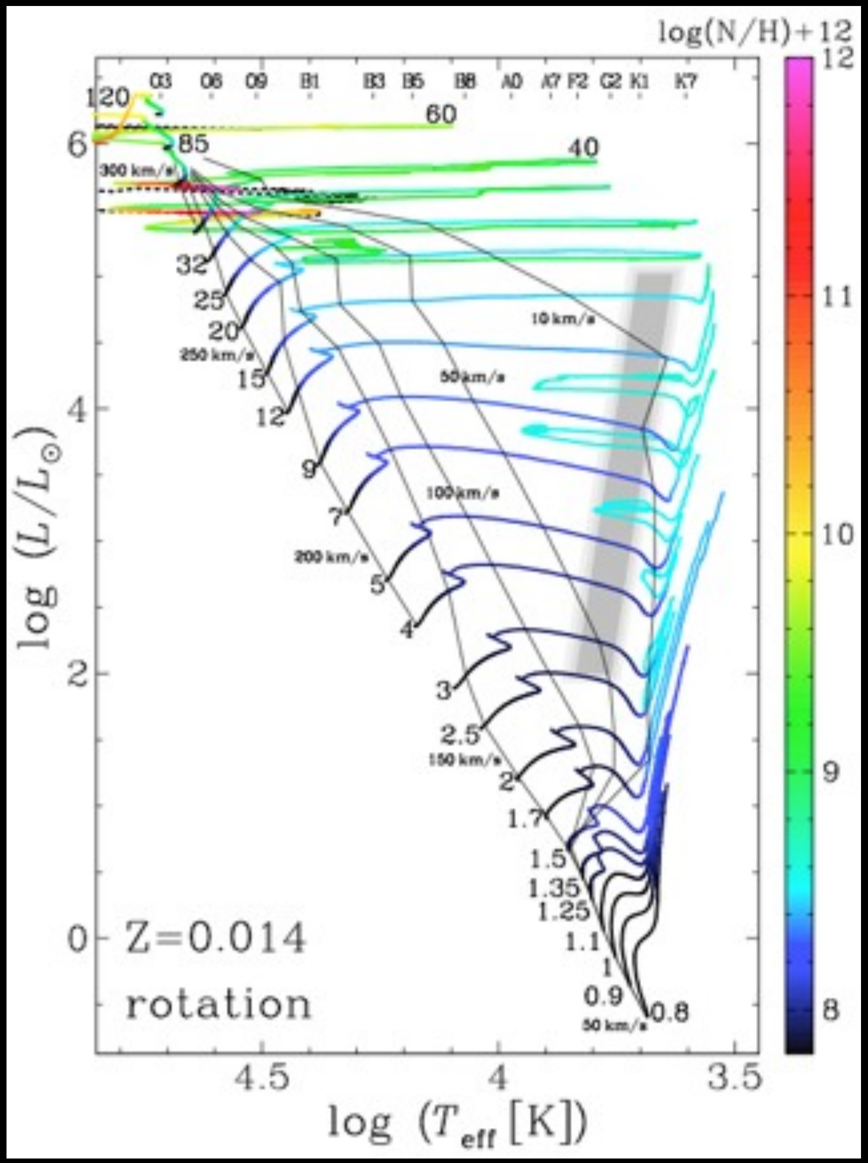
How to compare observations and stellar evolution models?

Observations SN 2008cn (II-P)



(Elias-Rosa+ 09)

Stellar evolution models



(Ekstrom+ 12)

Observations x stellar evolution model

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

Observations x stellar evolution model

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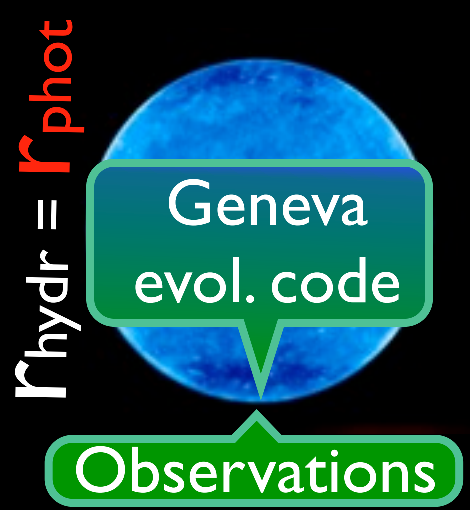
low-mass stars (e.g Sun)



Observations x stellar evolution model

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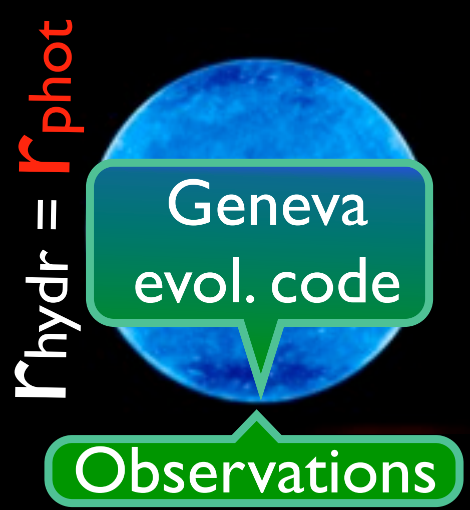
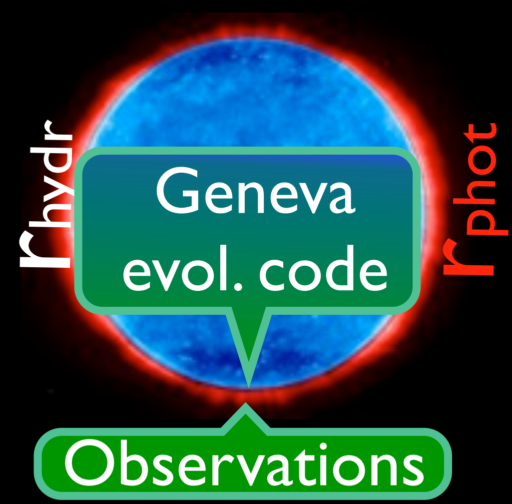
low-mass stars (e.g Sun)

massive stars: beginning of their lives

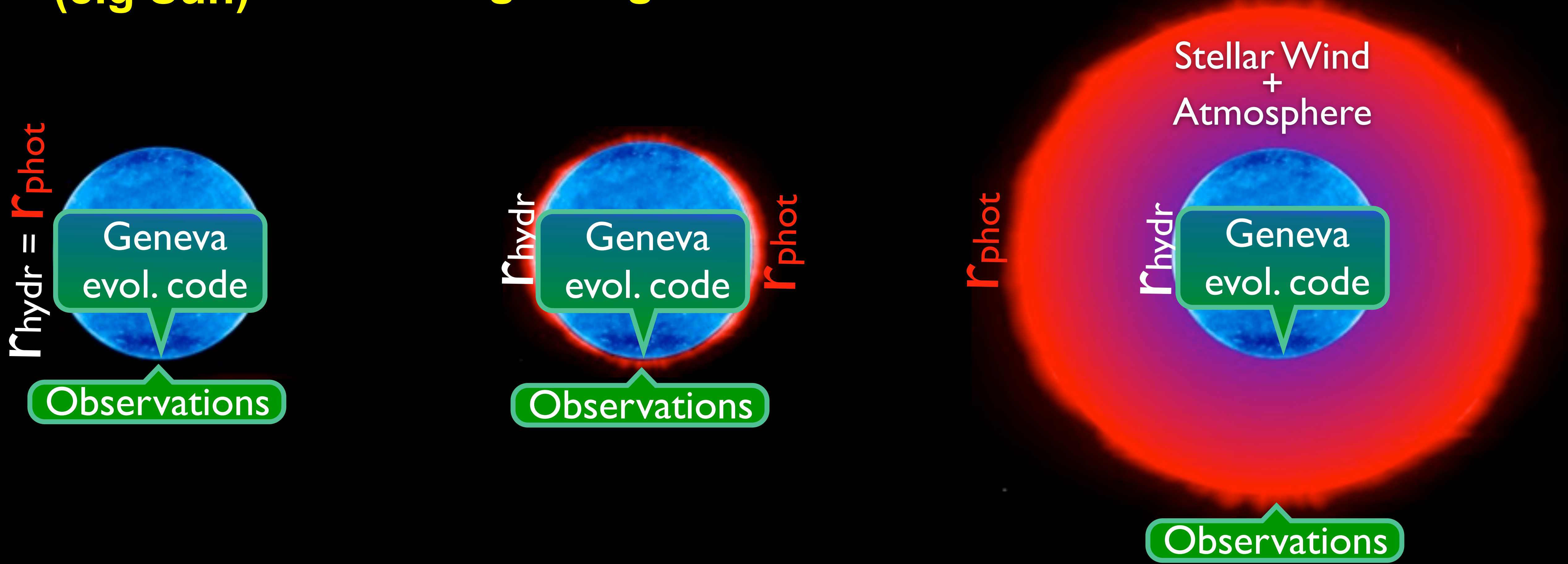




Observations x stellar evolution model

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

low-mass stars (e.g Sun) | massive stars: beginning of their lives | massive stars as they evolve

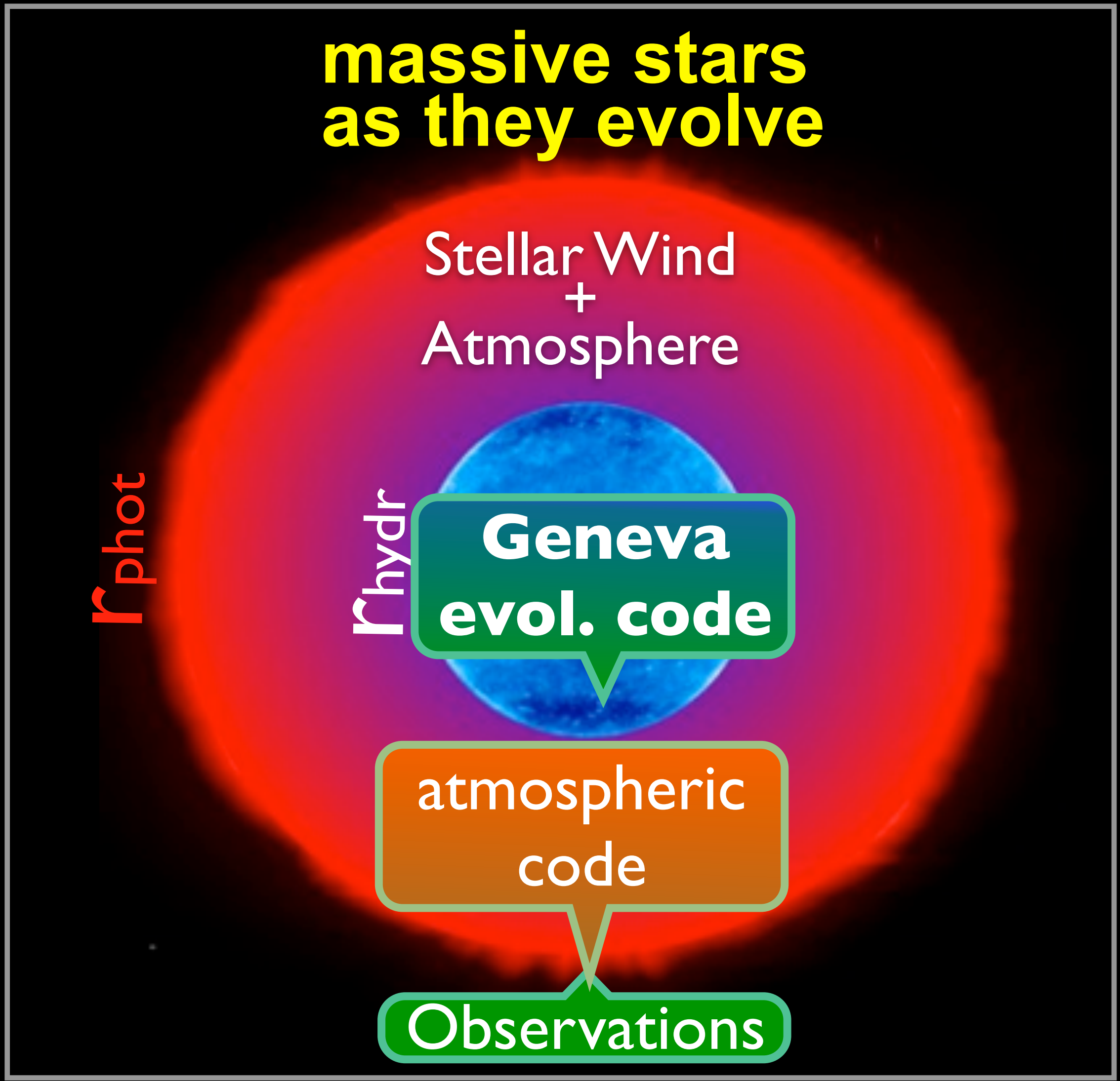


Consequence: predictions from models of the interior of massive stars cannot be directly compared to the observations.

Solution: atmospheric code

Atmospheric code:

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

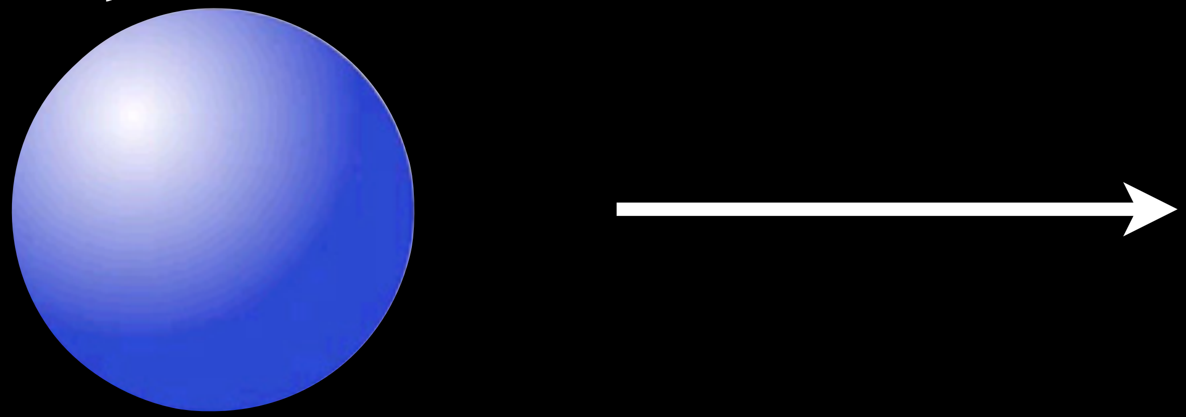


<u>Innovation:</u> couple the Geneva stellar interior/evolution code with the CMFGEN radiative transfer code for the wind and atmosphere.

How SN and GRB progenitors should look

Previously: SN progenitor inferred from L, Teff, and chemical composition

L, Teff, abundances



spectral type
OB
RSG
WN
WC
WO

How SN and GRB progenitors should look

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spectral type
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Now: Apply unified models to the pre-SN stage of stellar evolution

L, Teff, abundances

compute spectrum

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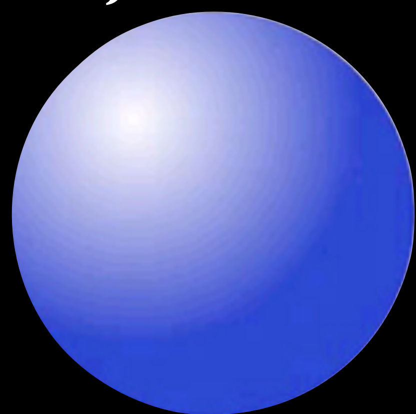

spectral type
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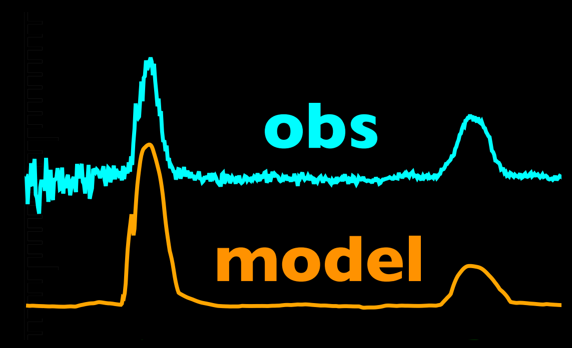
RSG
WN
WC
WO

Now: Apply unified models to the pre-SN stage of stellar evolution

L, Teff, abundances

compute spectrum

spectral classification

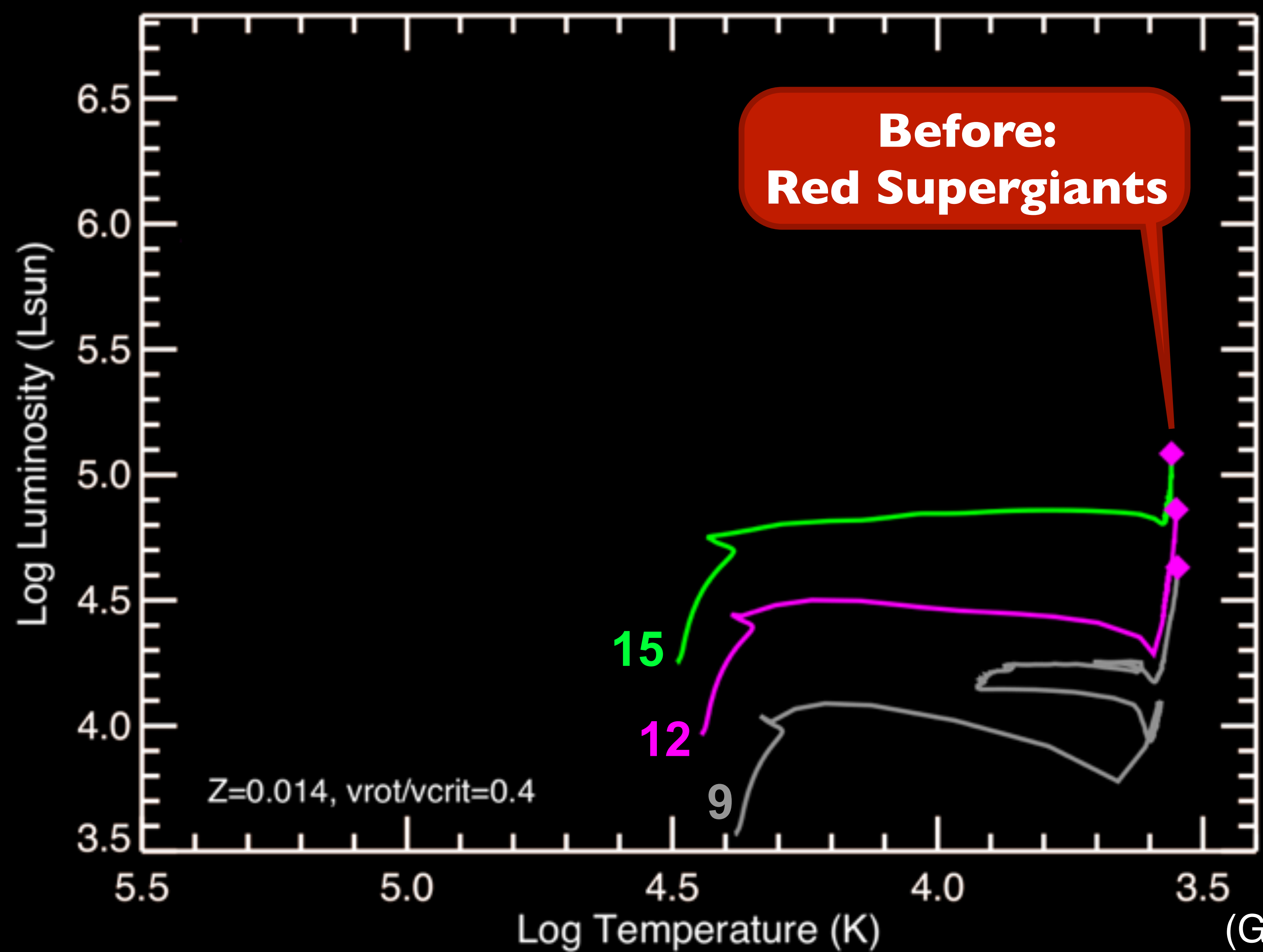


Sp Type
O7 V
M2 I
WN8
WC4
WO3

For the 1st time, spectroscopic classification of SN progenitors from stellar evolution models

Progenitors of core-collapse Supernova

Between 9-17 $M_{\odot}$:



(Groh+ 13, in prep.)

Progenitors of core-collapse Supernova

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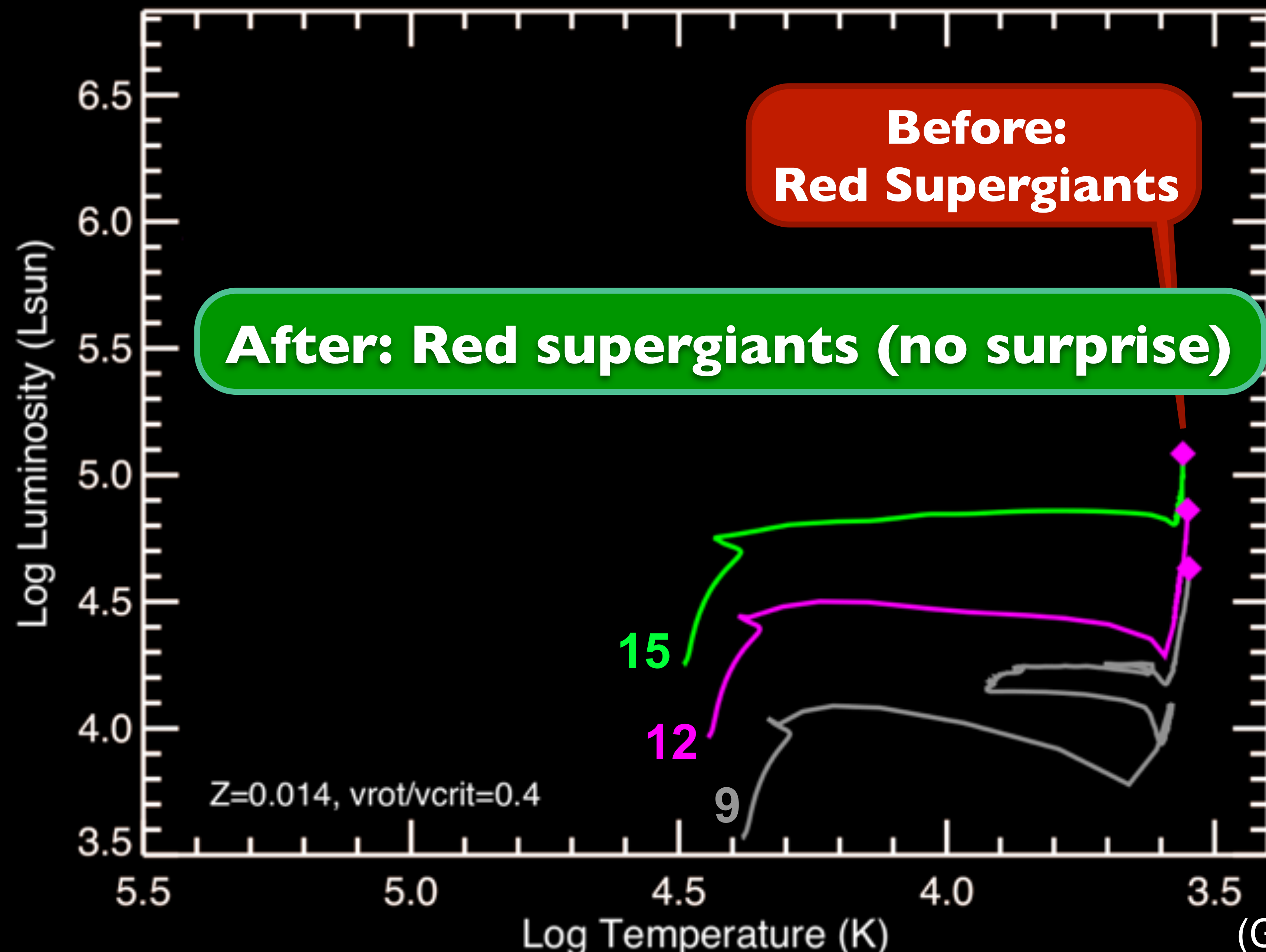
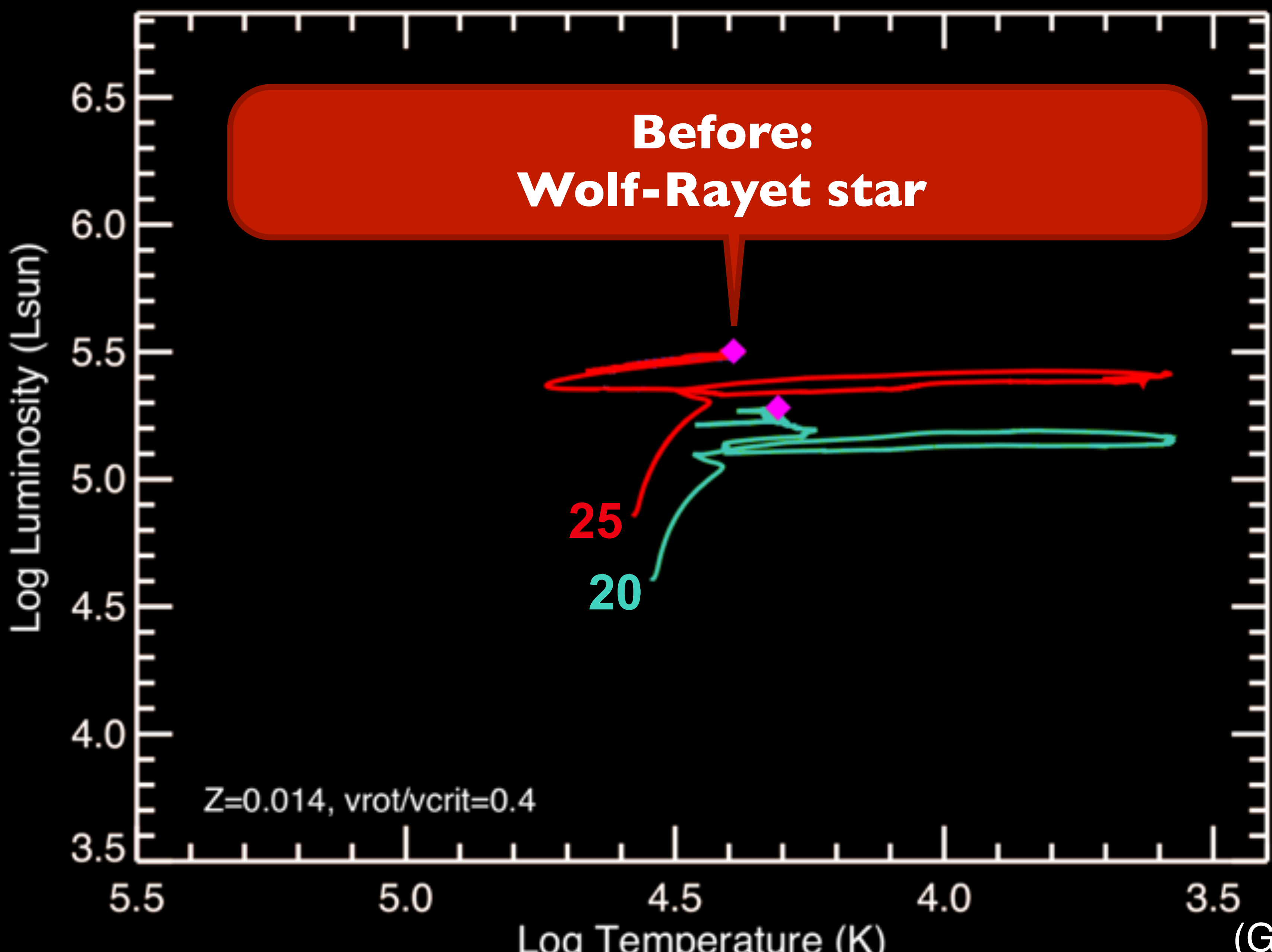


(Groh+ 13, in prep.)

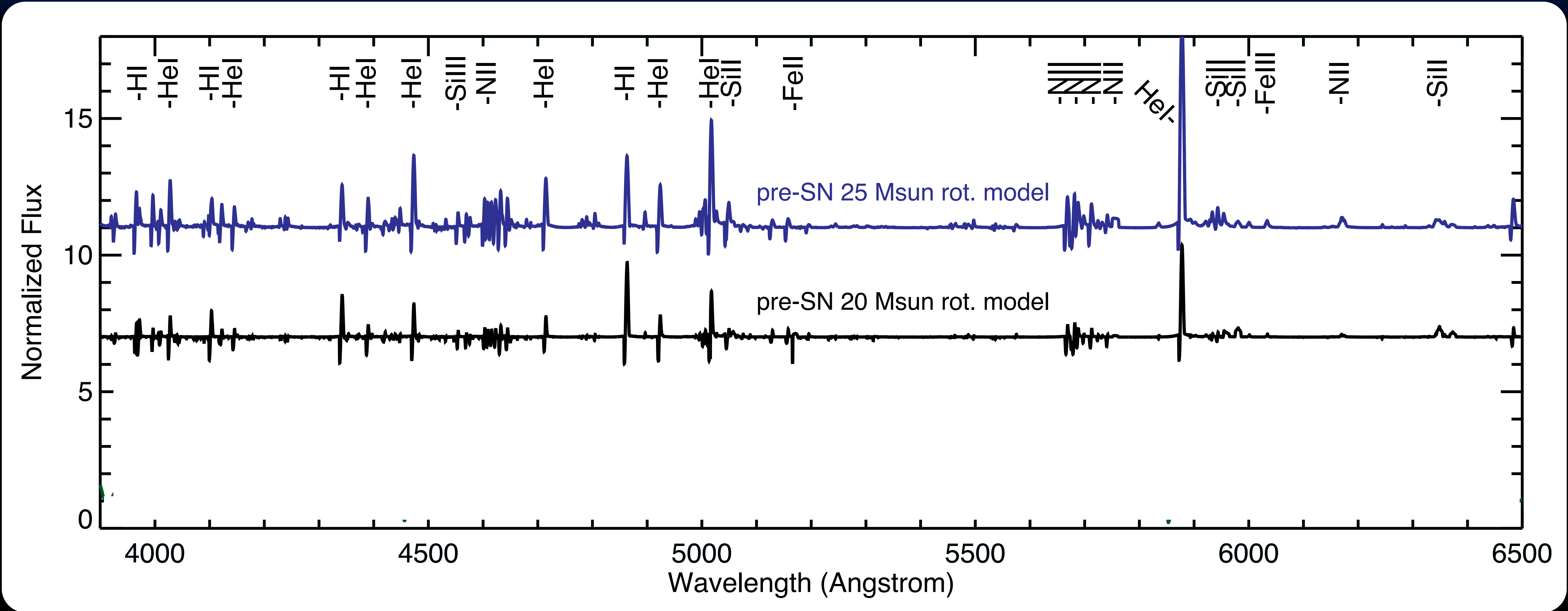
Progenitors of core-collapse Supernova

Between 20-25 $M_{\odot}$:



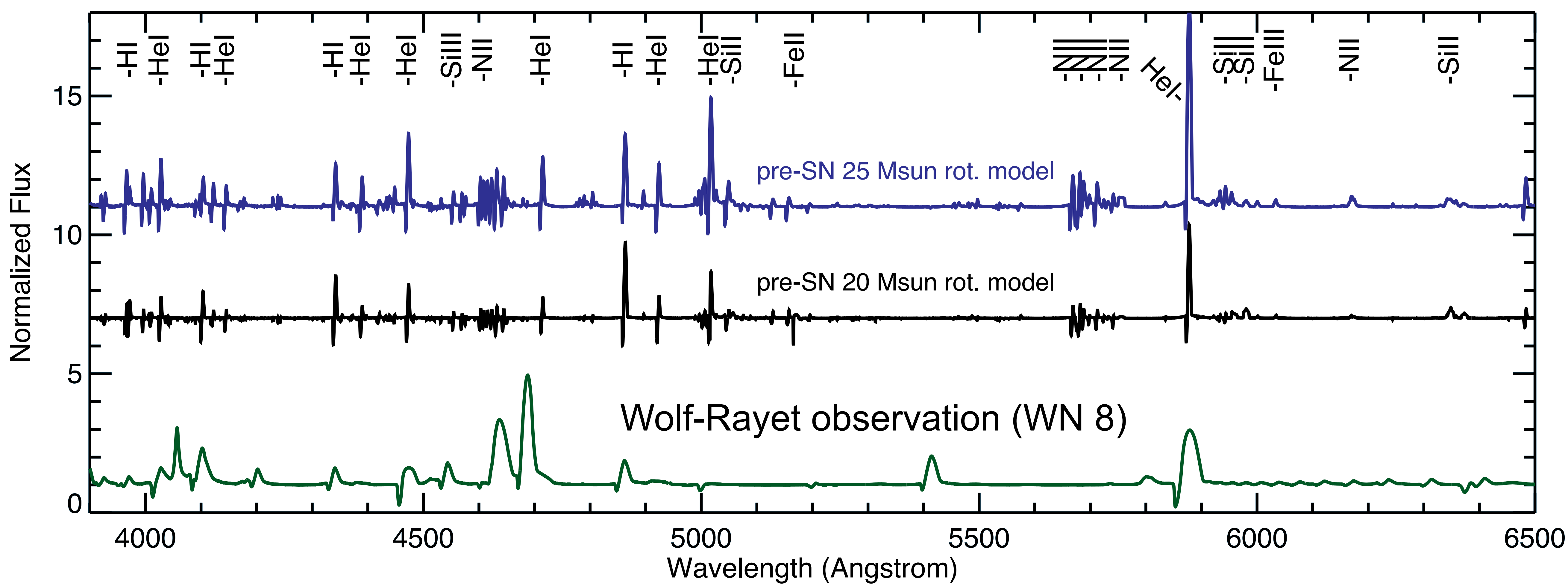
(Groh+ 13, in prep.)

Progenitors of SNe from 20-25 $M_{\odot}$ stars



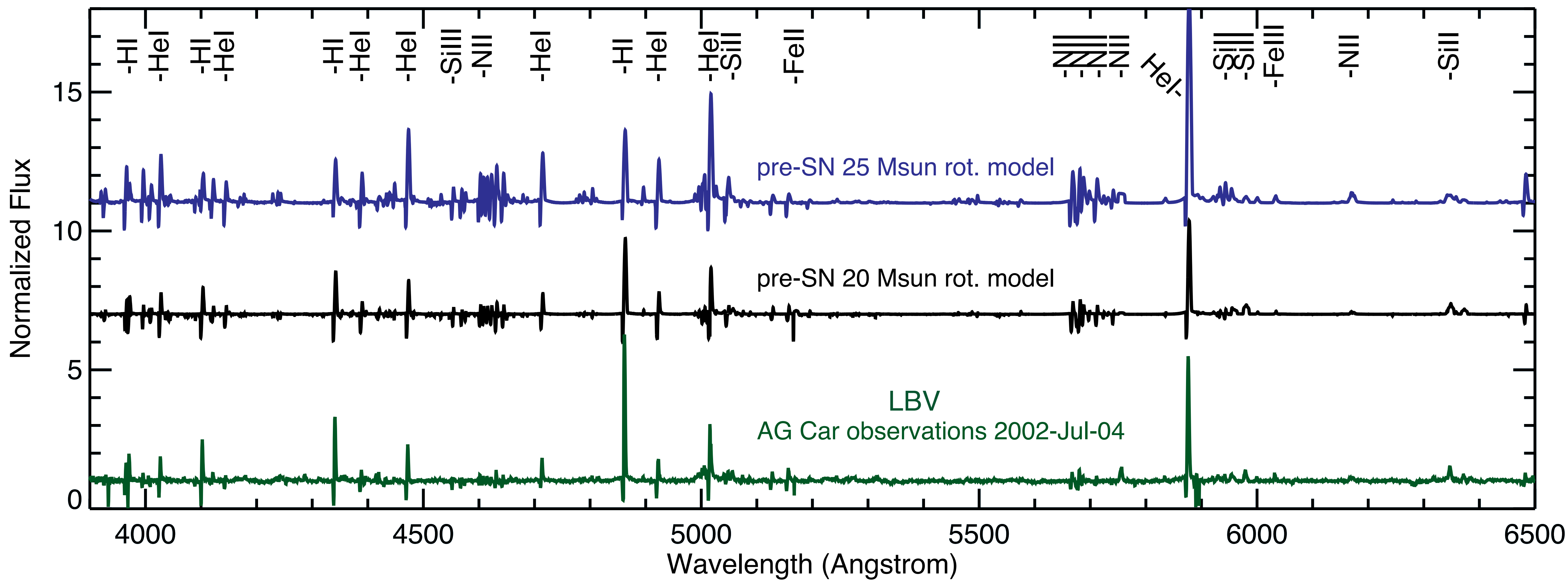
(Groh+ 13, A&A 550, L7)

Progenitors of SNe from 20-25 $M_\odot$ stars



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

Progenitors of SNe from 20-25 $M_\odot$ stars



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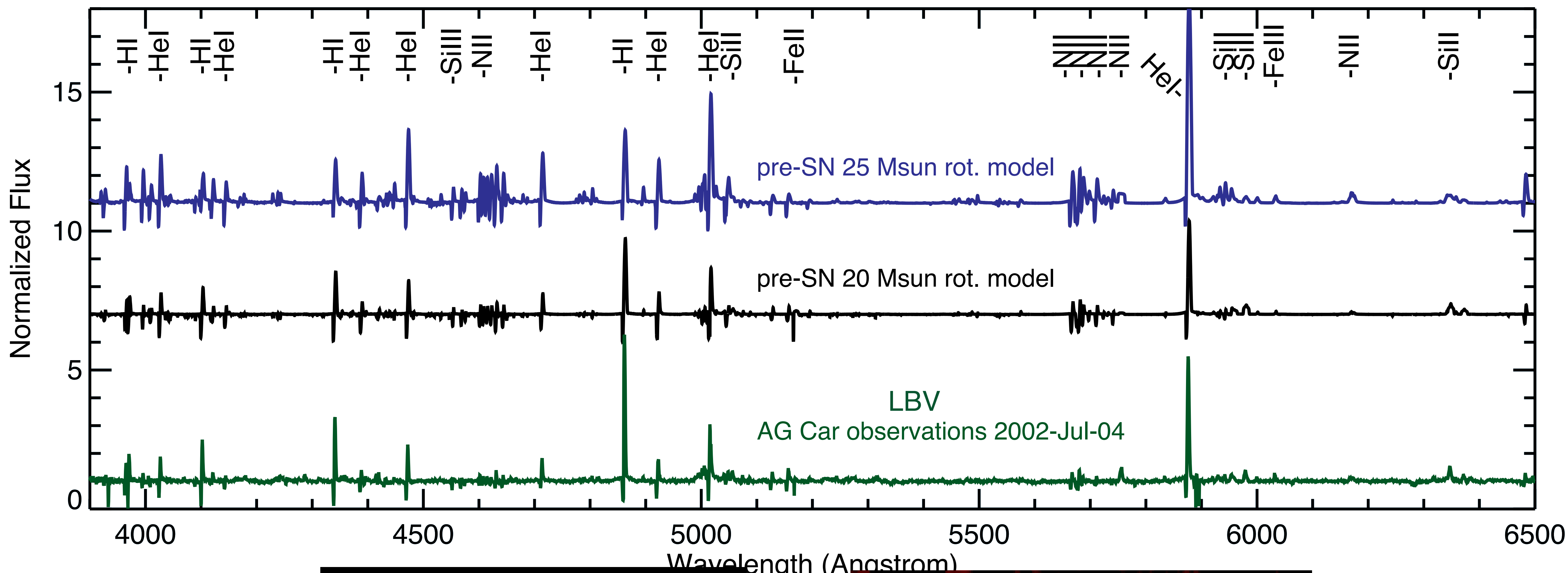
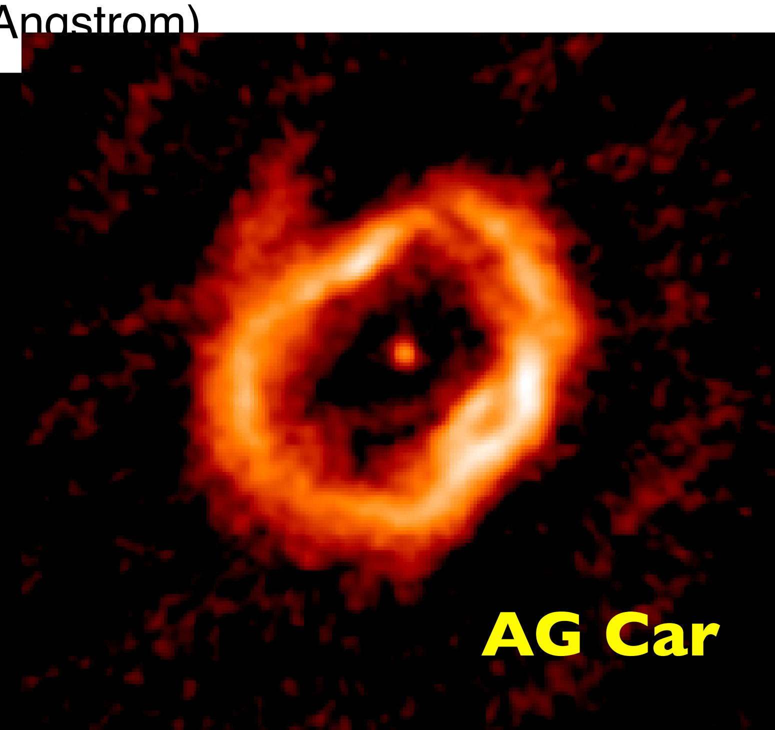


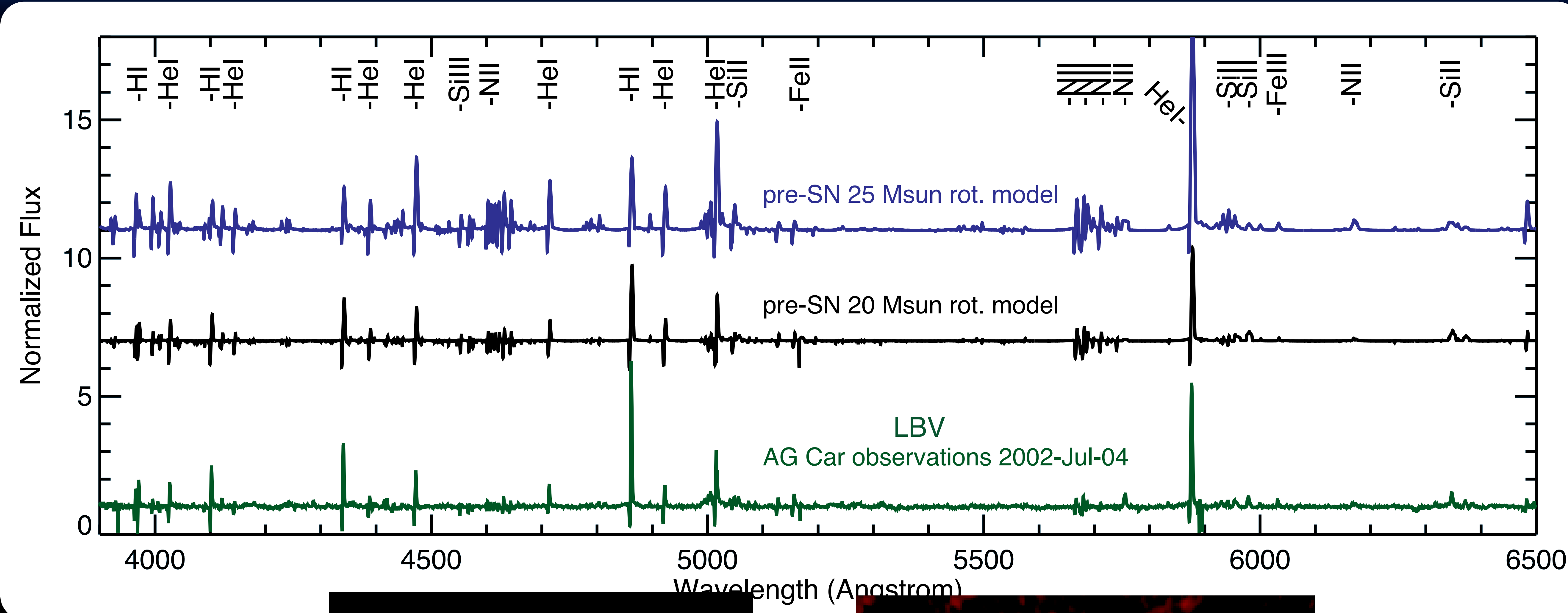
(Credit: N. Smith, J. Morse, NASA/ESA)



(Credit: S. White)

13, A&A 550, L7)

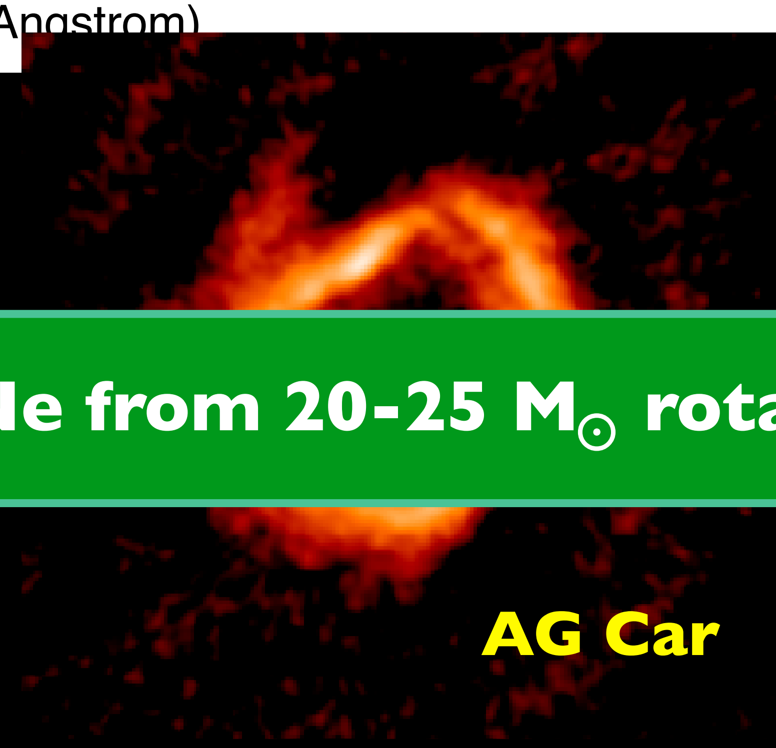
Progenitors of SNe from 20-25 $M_{\odot}$ stars



13, A&A 550, L7)

Eta Car

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

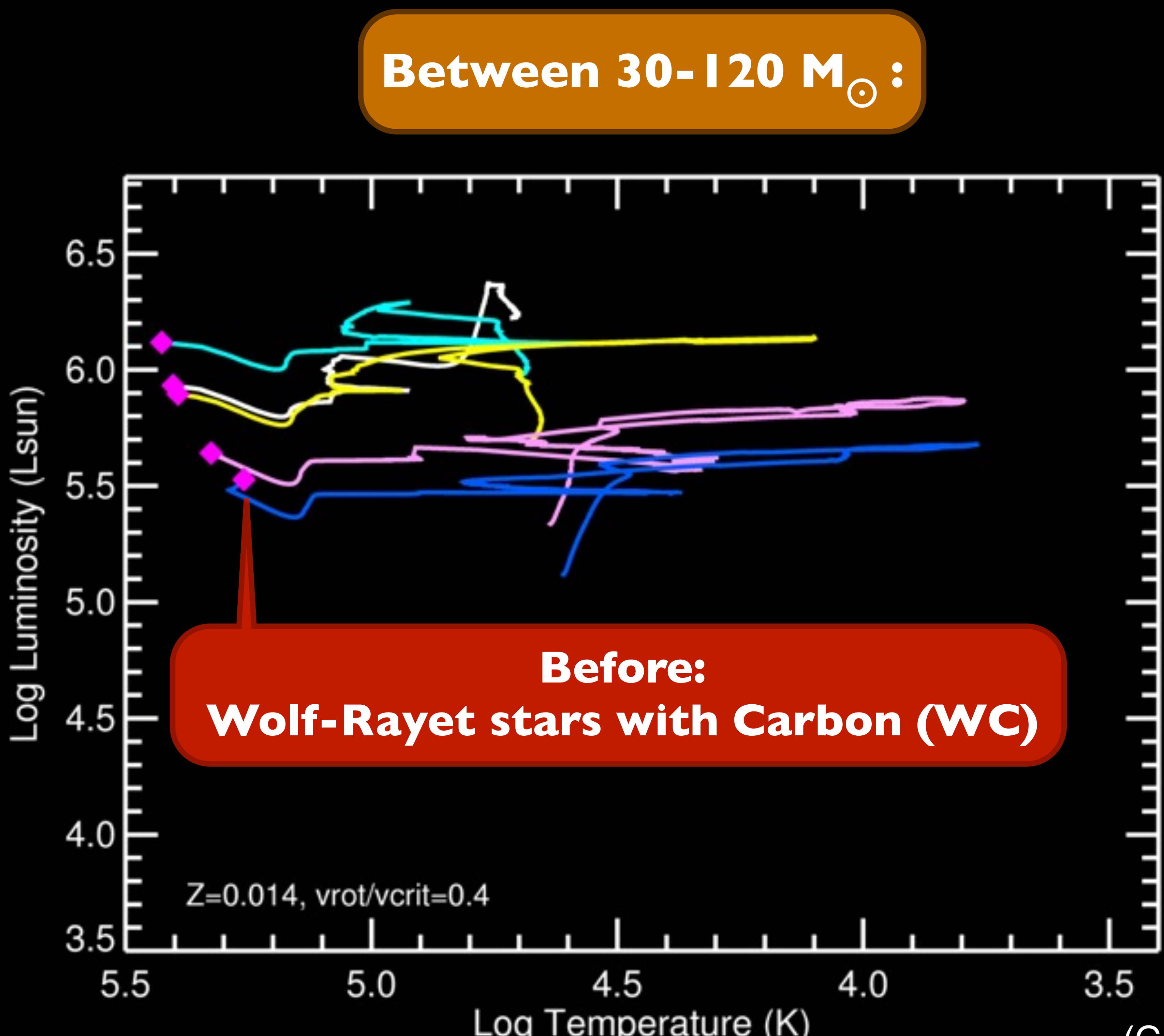


AG Car

(Credit: S. White)

After: LBVs are progenitors of SNe from 20-25 $M_{\odot}$ rotating stars

Progenitors of SNe from 30-120 $M_\odot$ stars

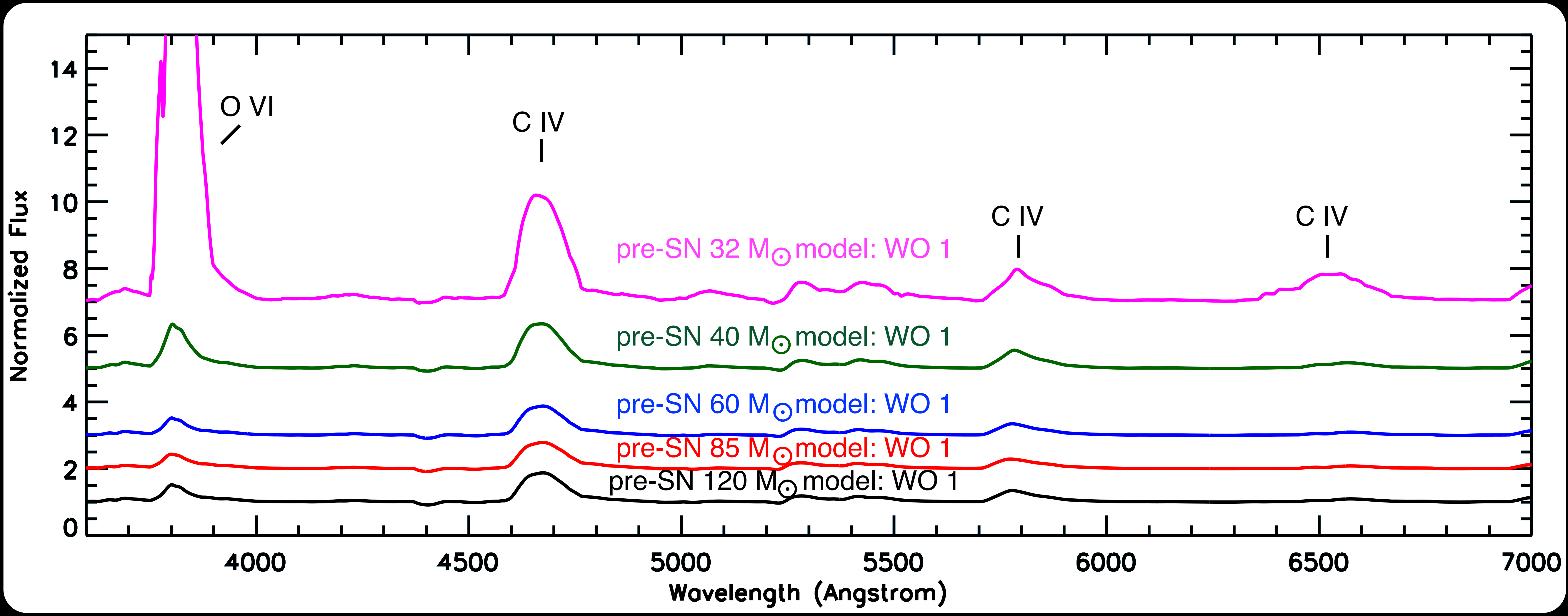


(Groh+ 13, in prep.)

Progenitors of SNe from 30-120 $M_\odot$ stars

Between 30-120 $M_\odot$:

After: WO stars are progenitors of SNe from 20-25 $M_\odot$ rotating stars

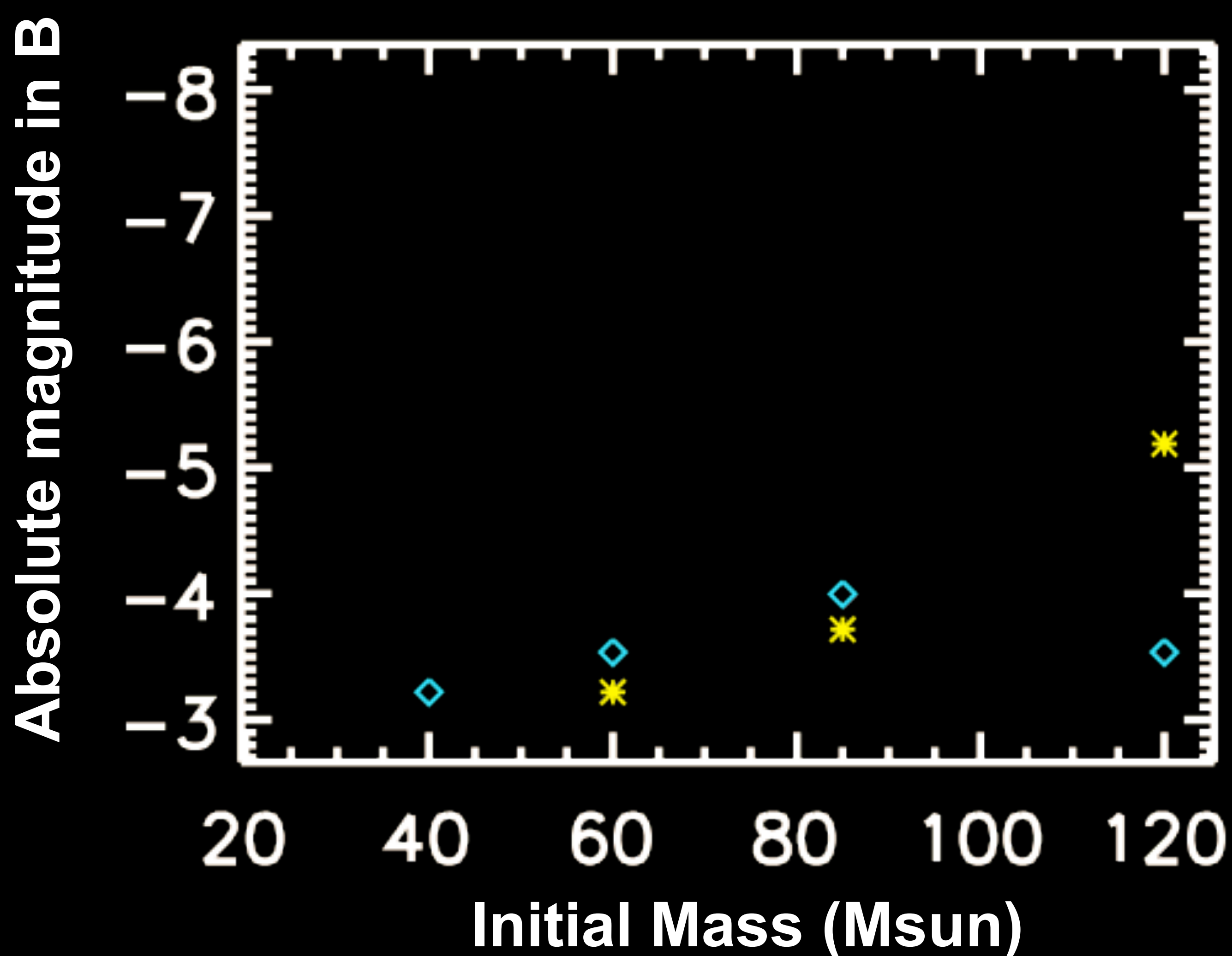


(Groh+ 13, in prep.)

Detectability of SN Ibc progenitors

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

Yellow: non-rotating models
Cyan: rotating models



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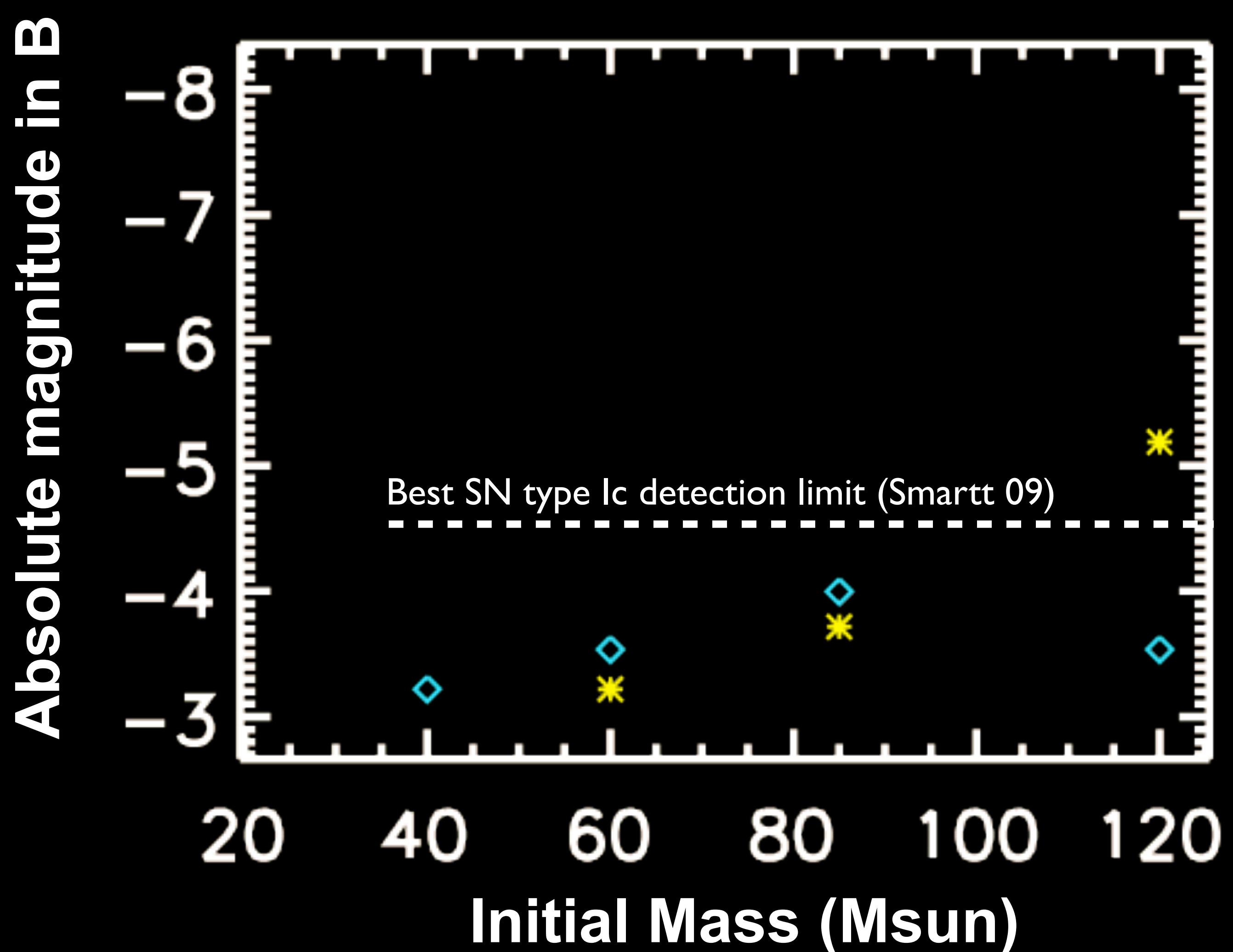

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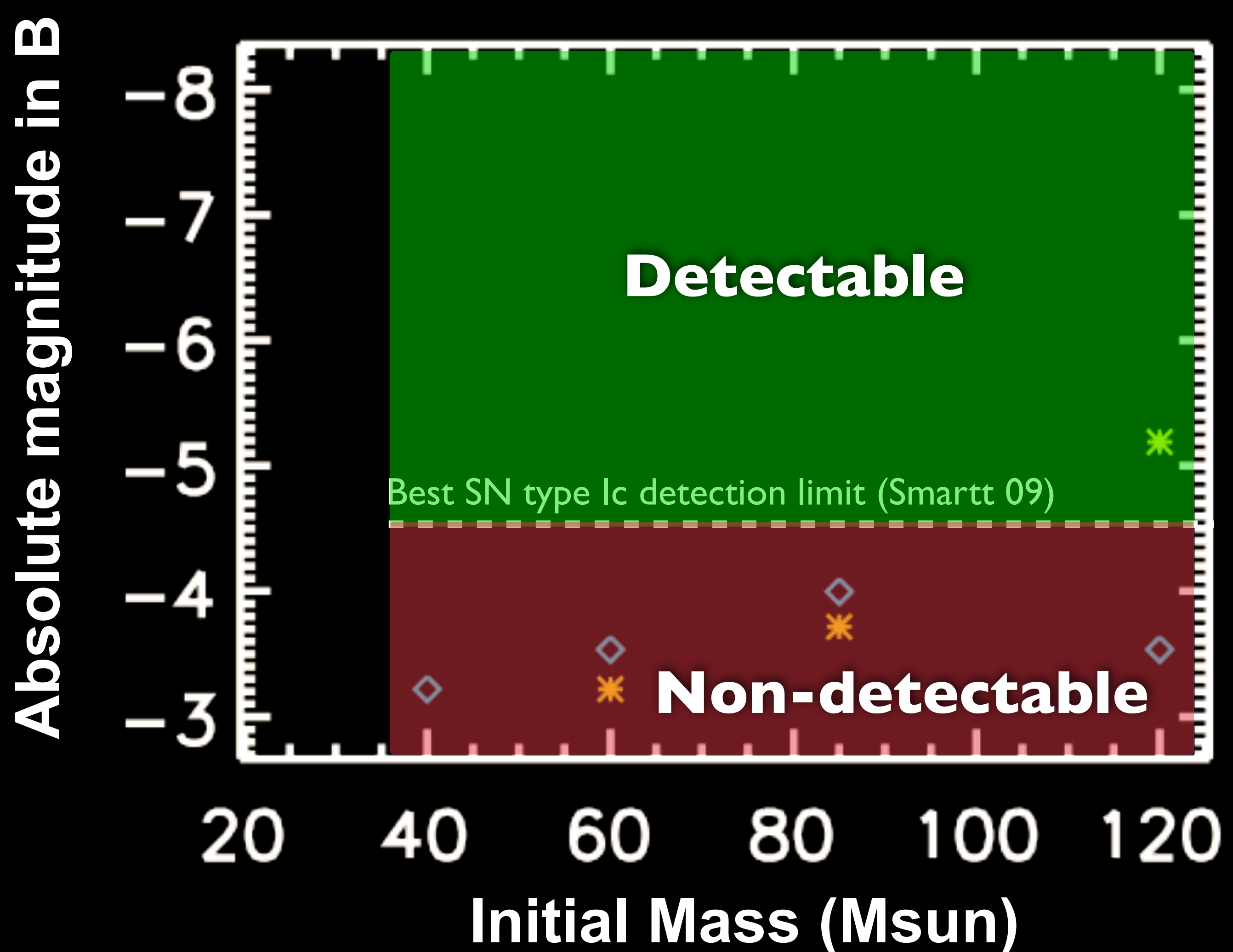

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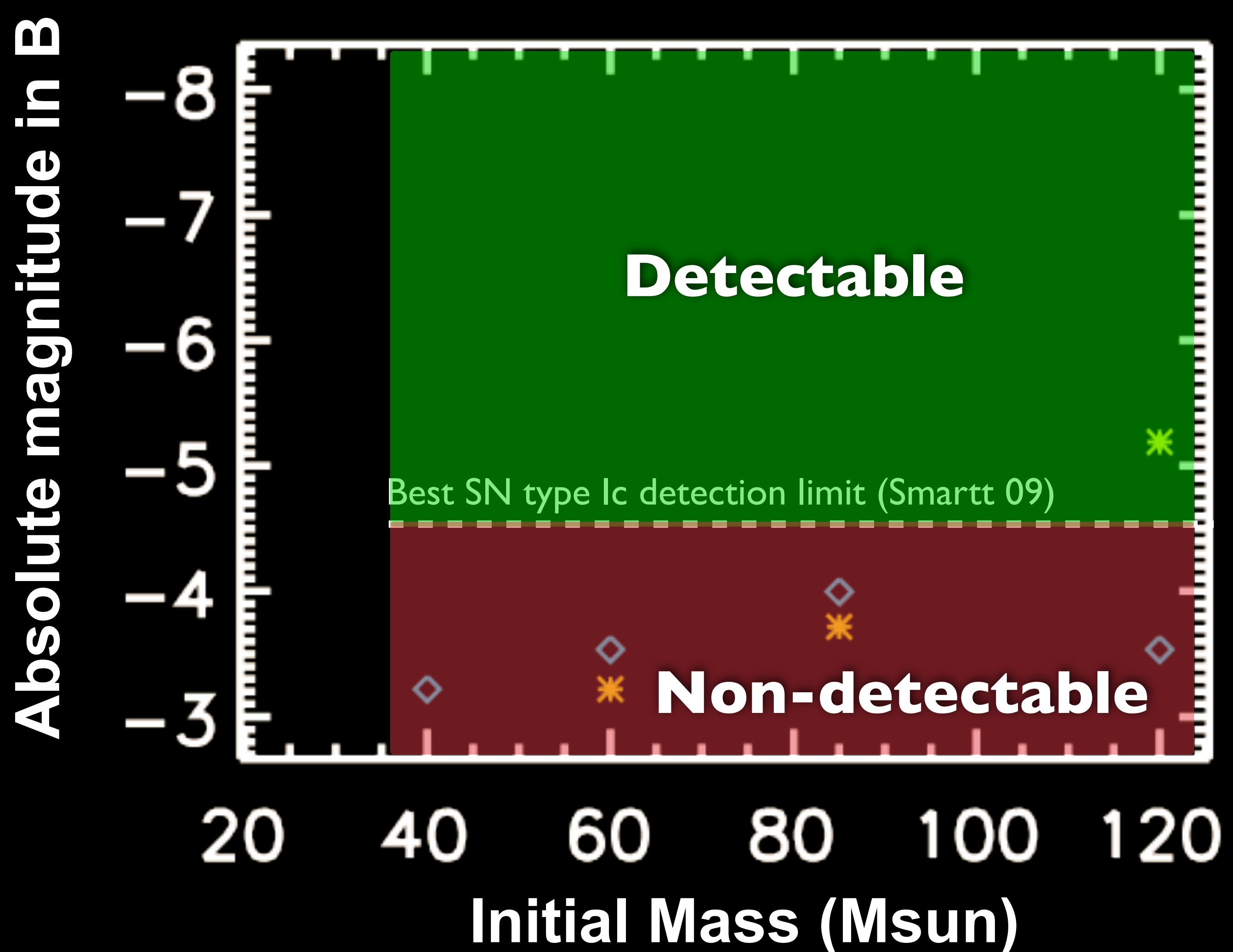

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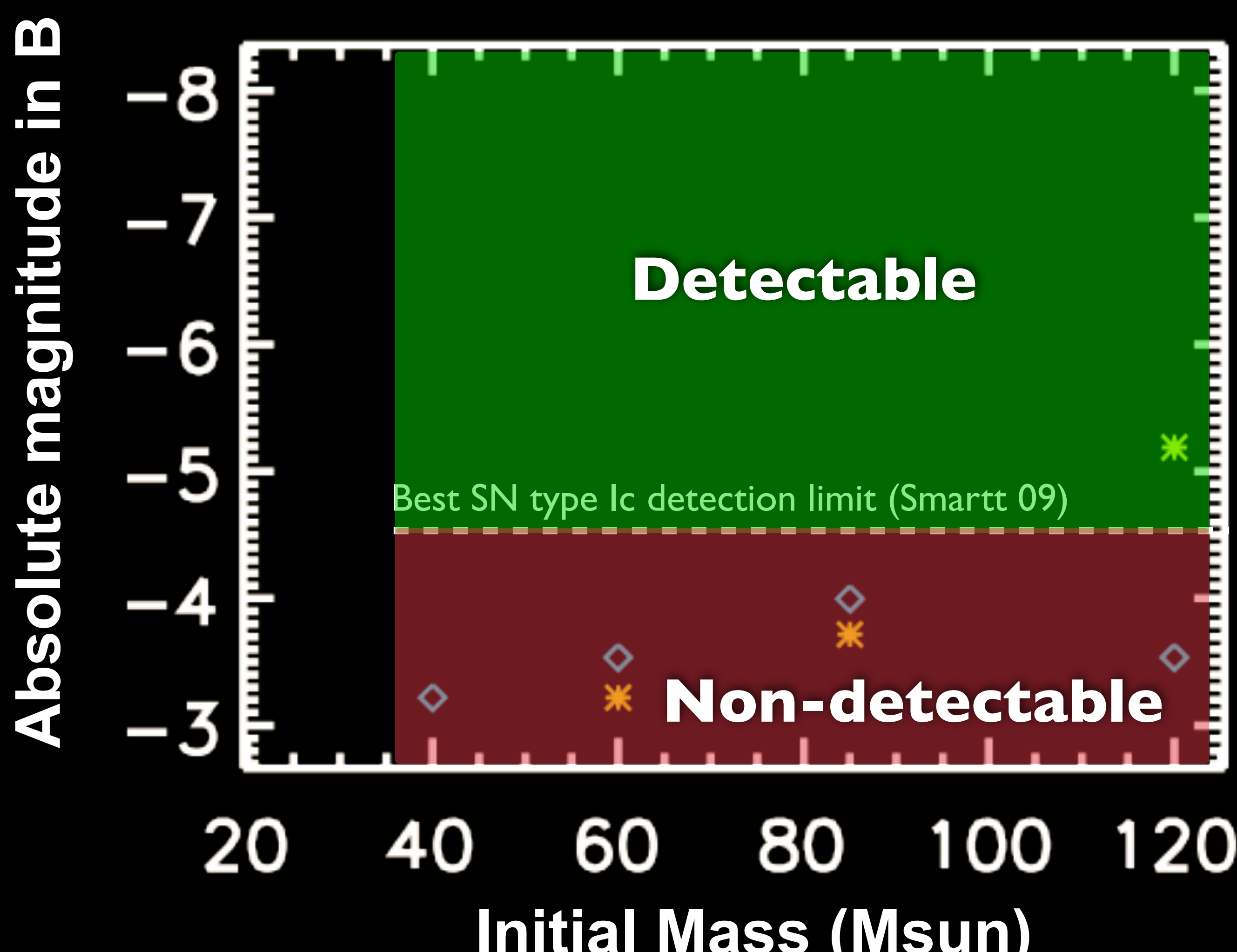
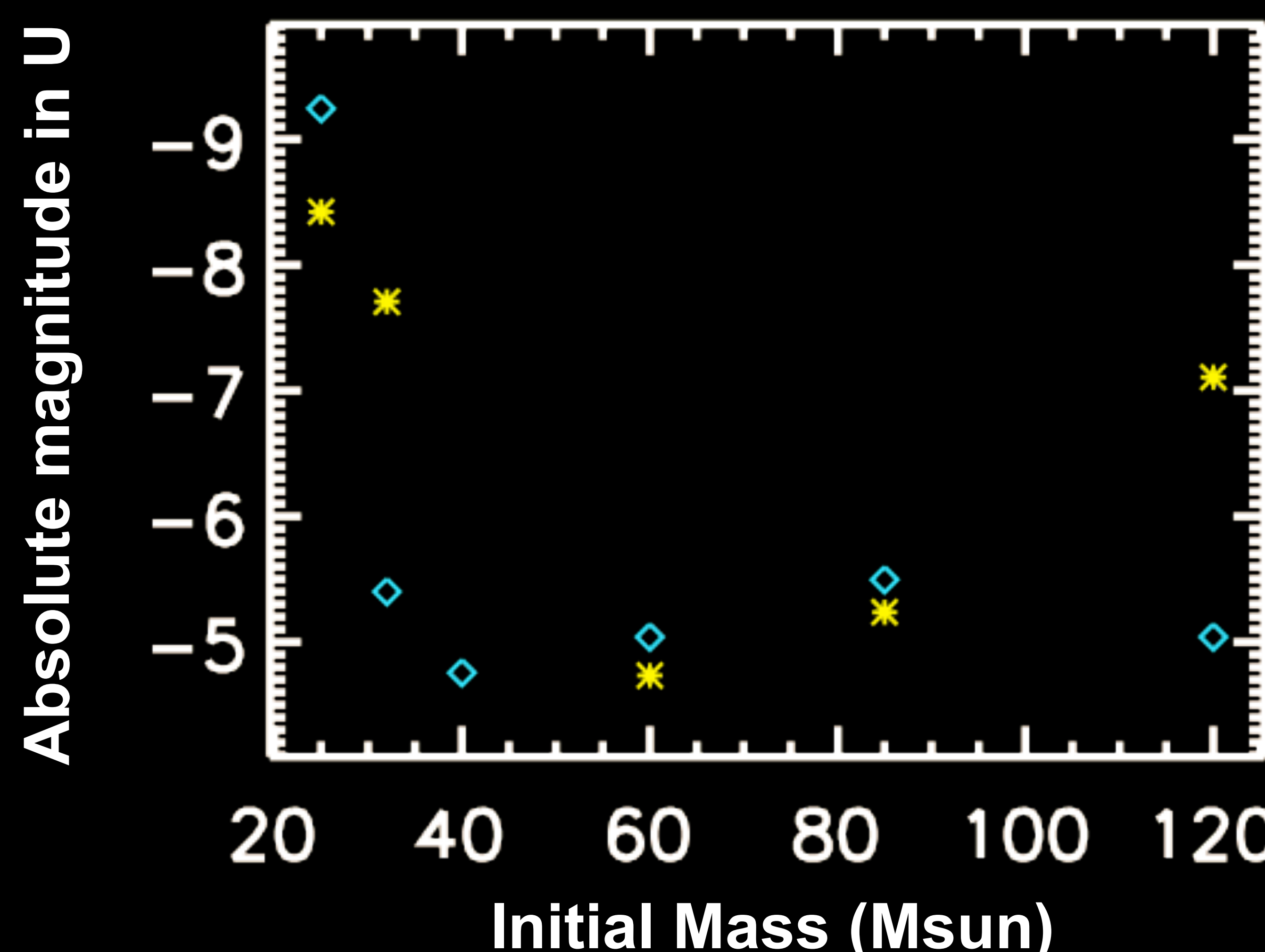
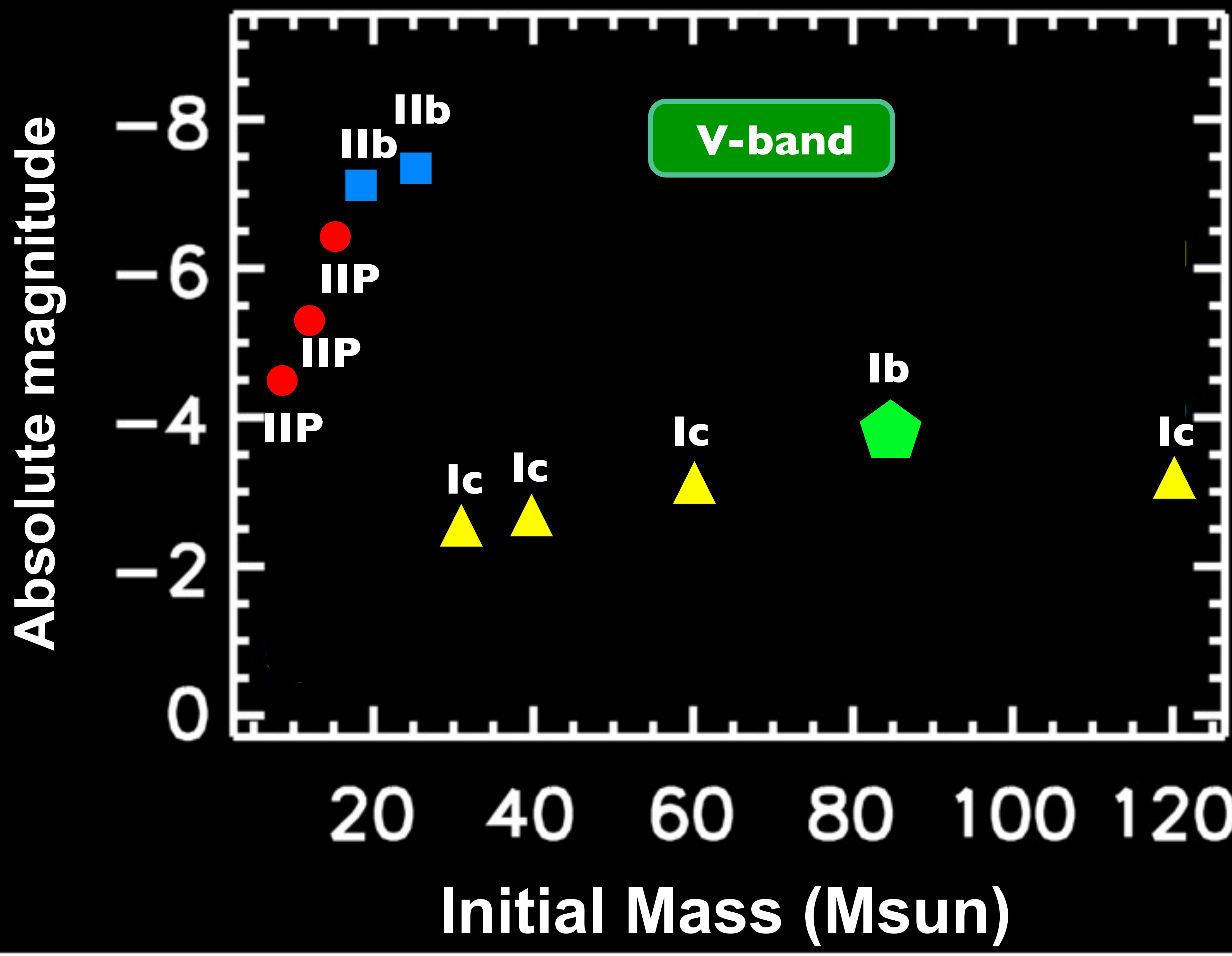




(Groh+ in prep)

Detectability of SN progenitors in general

We are now able to predict magnitudes and colors in all bands



(Groh+ in prep)

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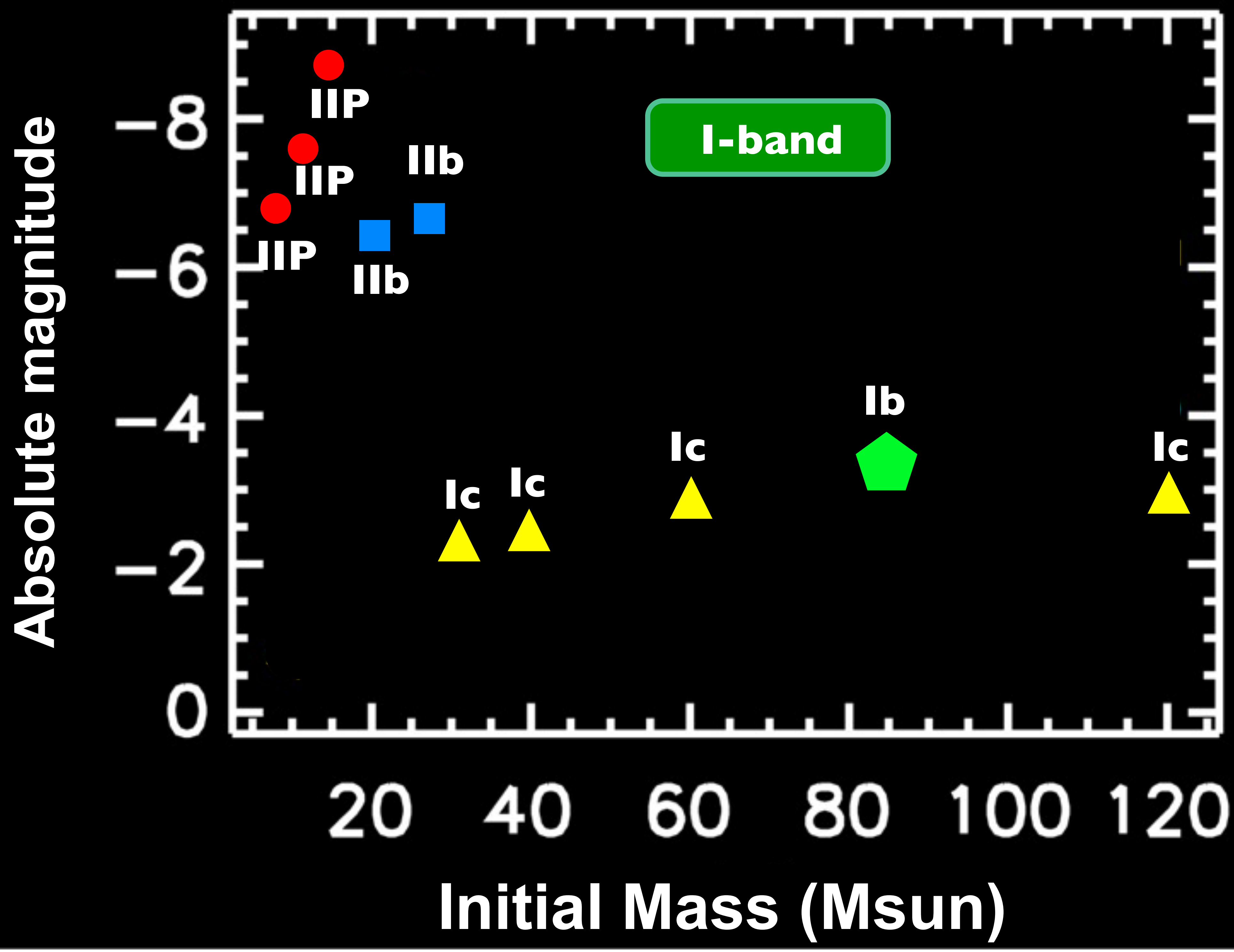

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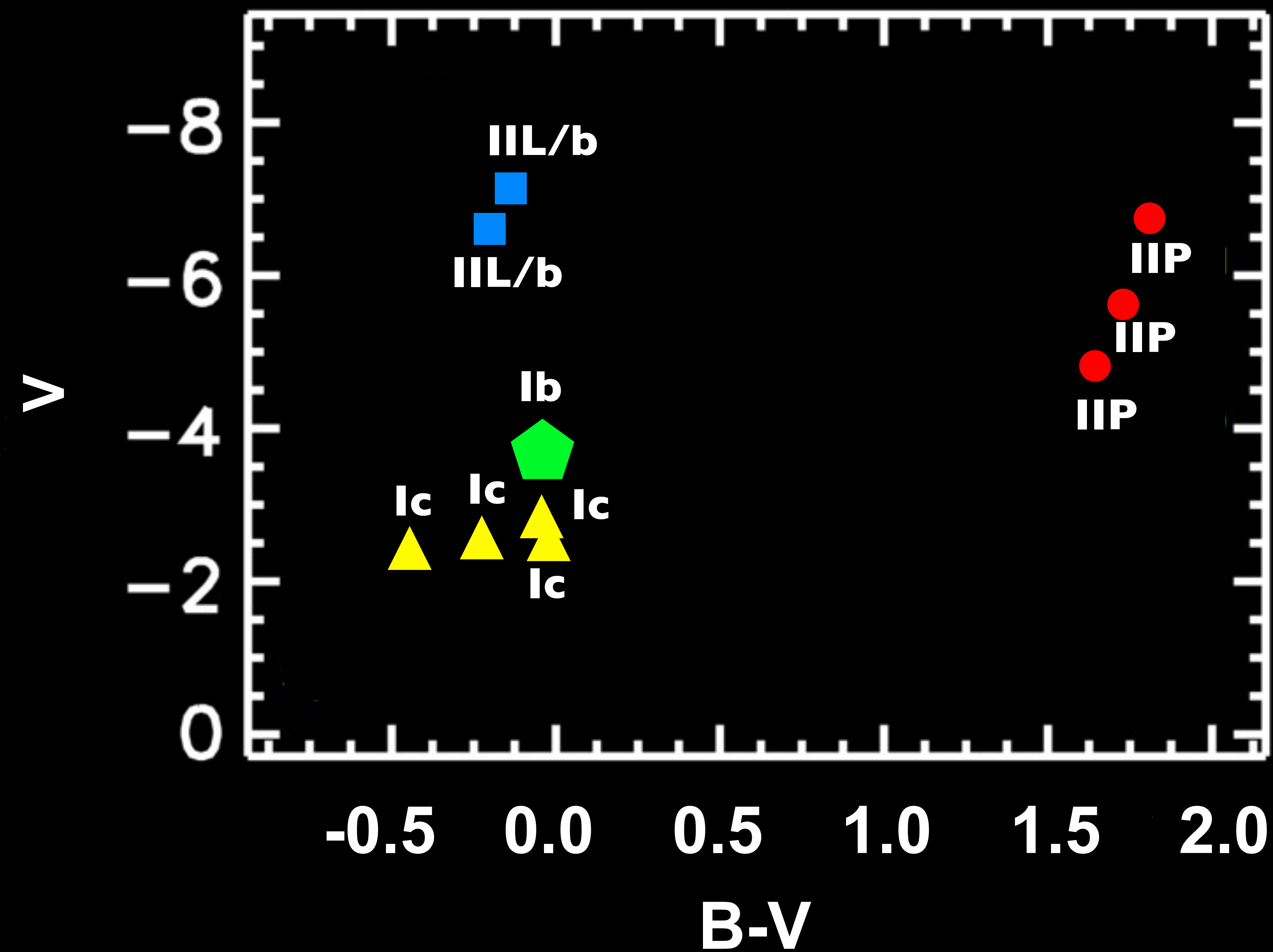

(Groh+ in prep)

Summary

Previously, SN progenitors from stellar evolution models were inferred from L, Teff, and chemical composition: RSGs and WR stars rich in Nitrogen or Carbon.

Now, we produce synthetic spectra out of stellar evolution models: SN progenitors are RSGs, LBVs, and WRs with Oxygen lines