

# What Red Supergiants do before they die

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$\log(L/L_{\odot})$

**Evolution to the RSG phase...**

'Humphreys-Davidson Limit'

5.5

Main sequence

30M $\odot$

20M $\odot$

10M $\odot$

Evolutionary tracks....

Red Supergiants

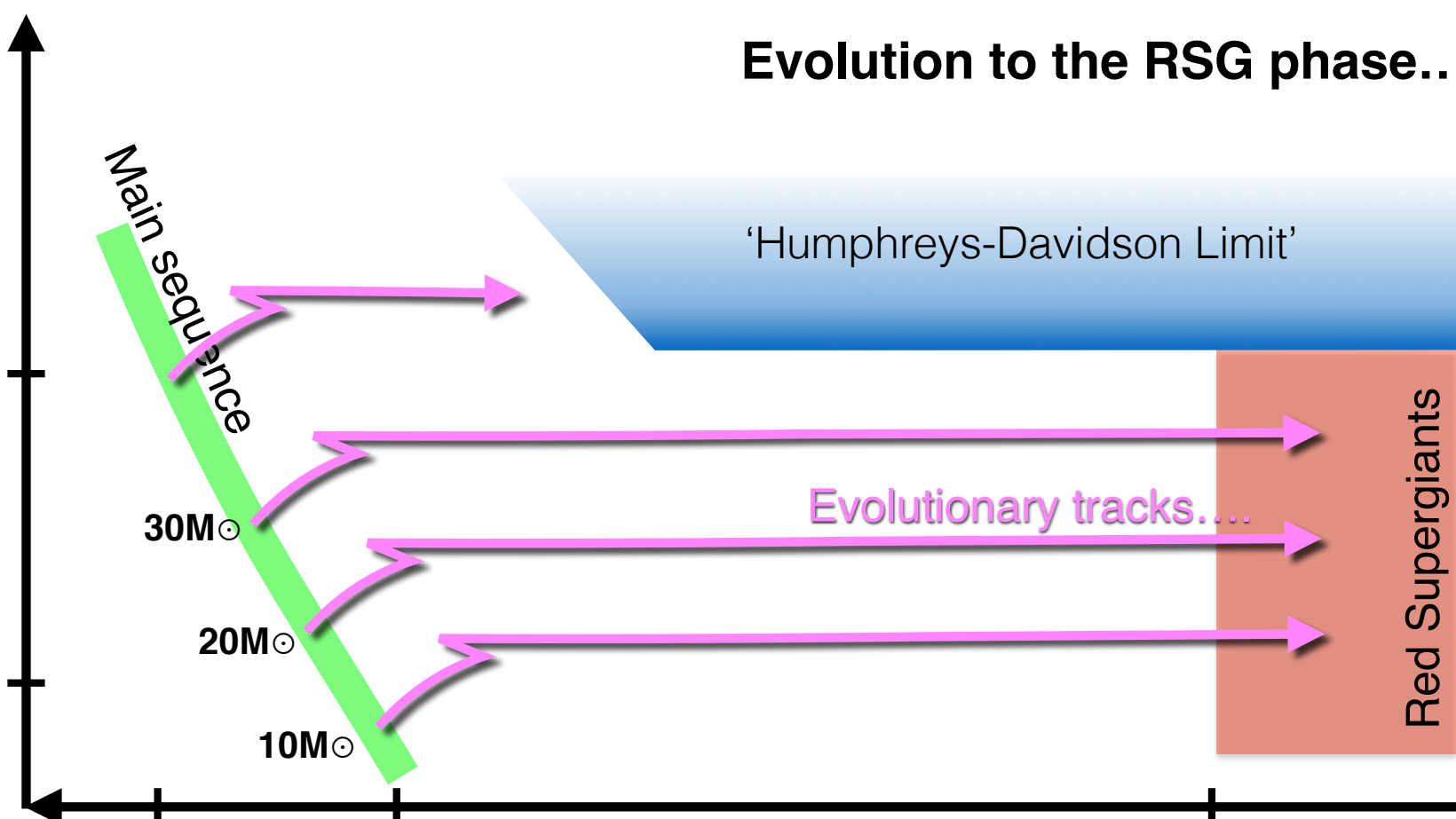
4.5

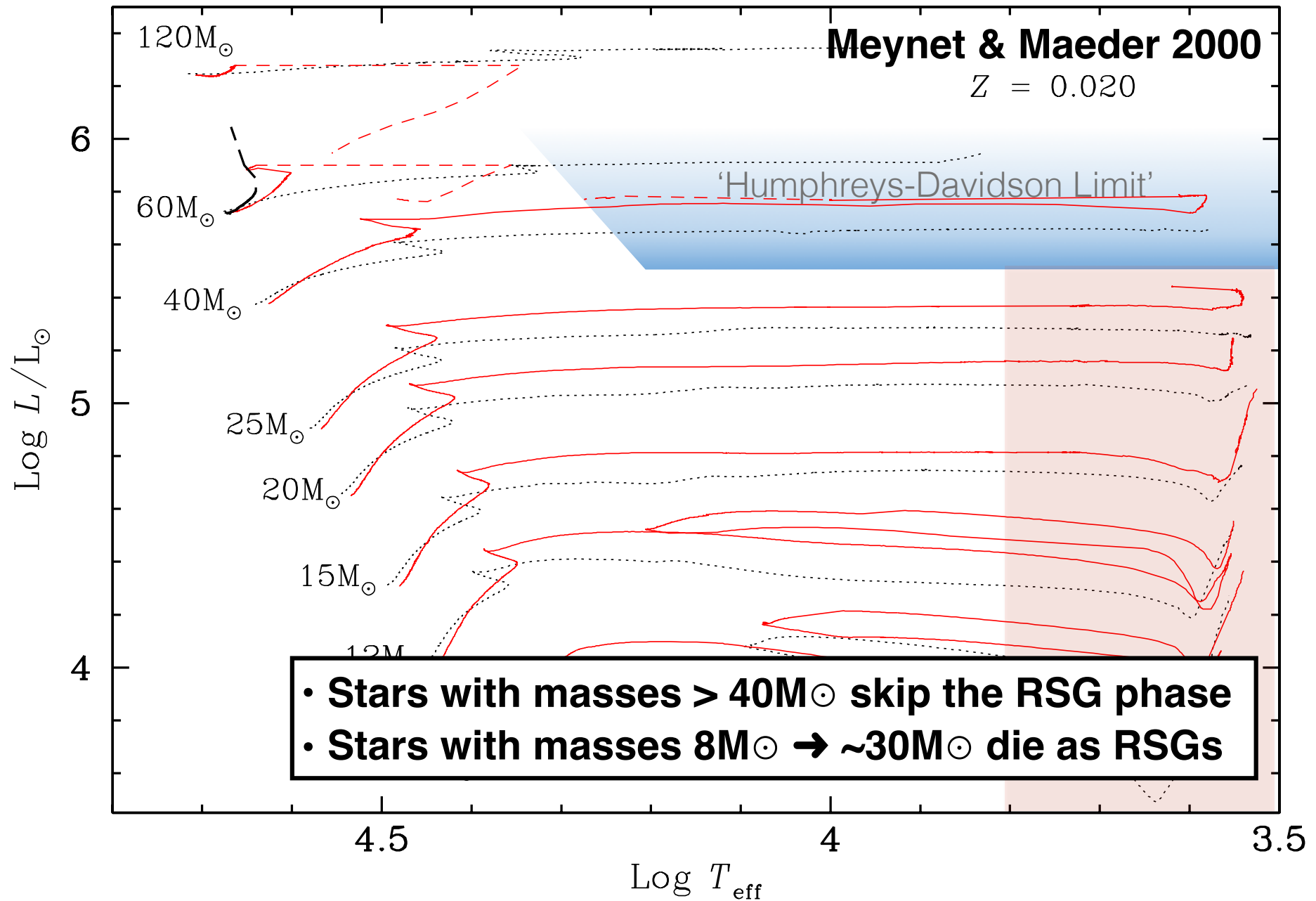
50,000

20,000

4,000

$\log(T/K)$





Evolution predictions can be tested with pre-explosion imaging of SN locations.

*pre-explosion photometry*

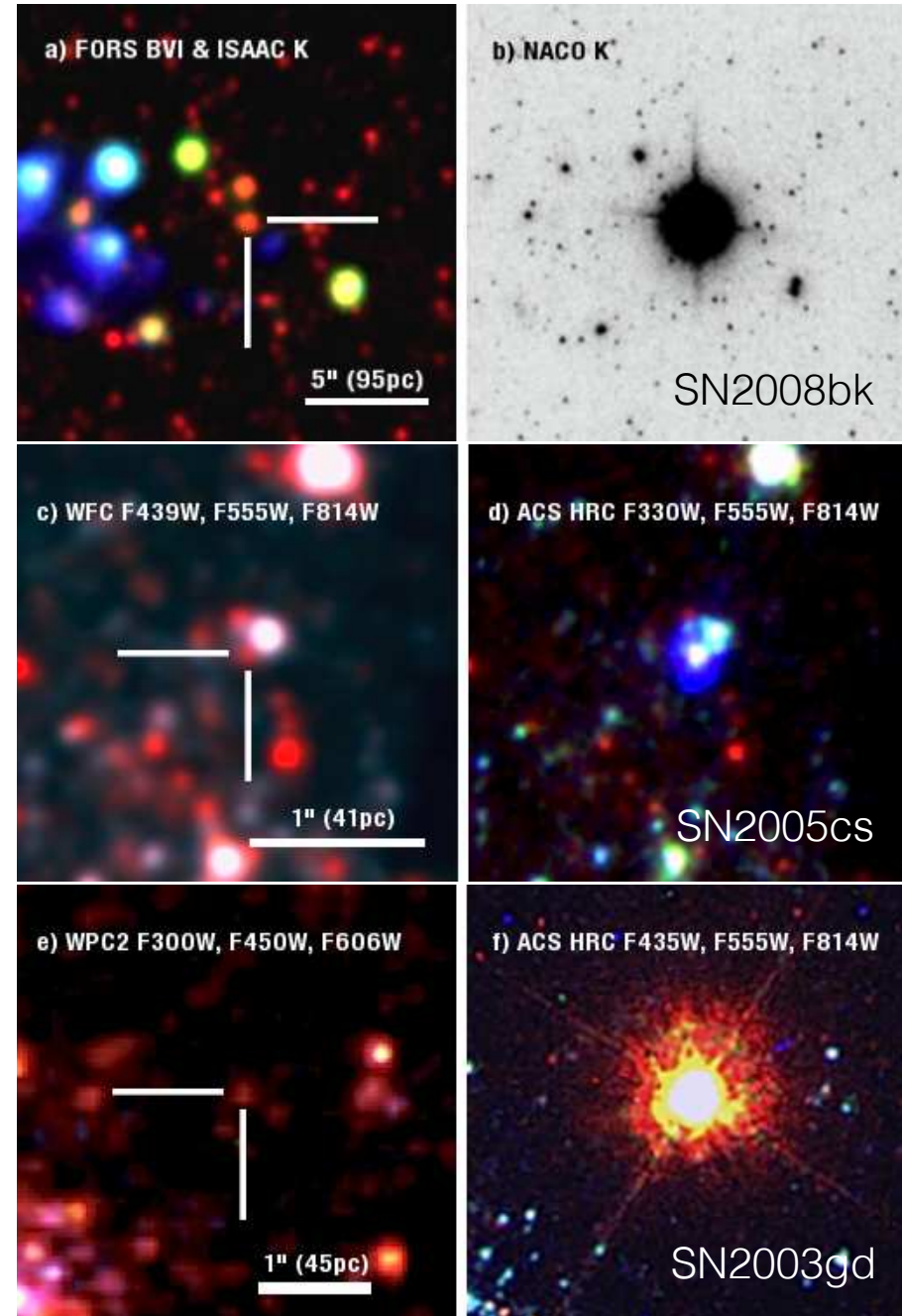


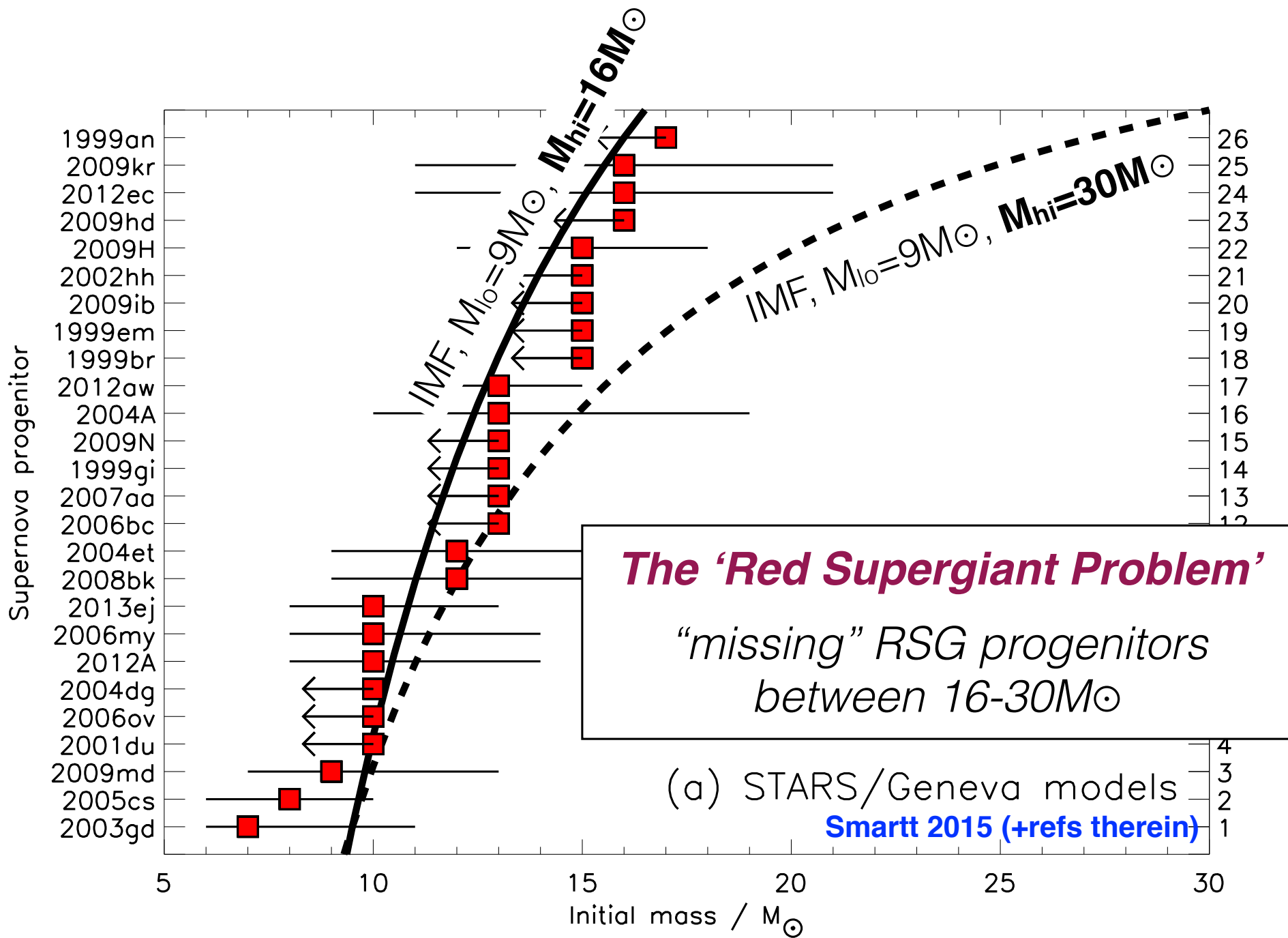
*terminal luminosity*



*initial mass*

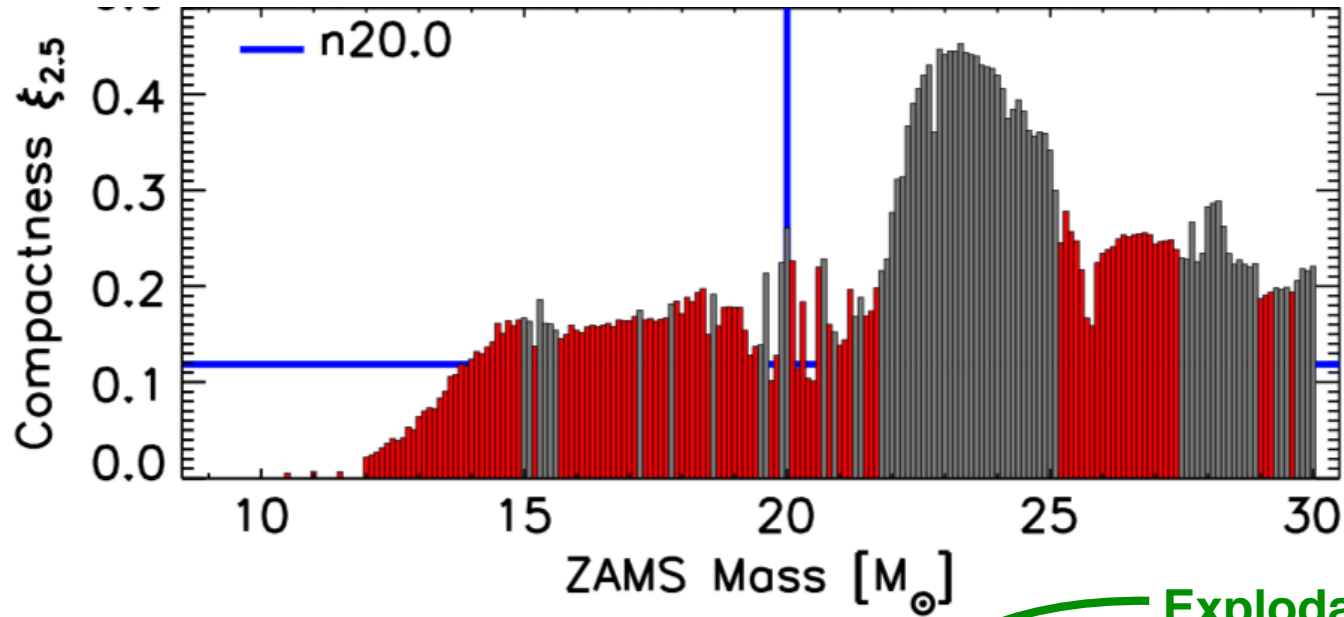
Maud & Smartt (2005)  
Smartt 2009 (+refs therein)





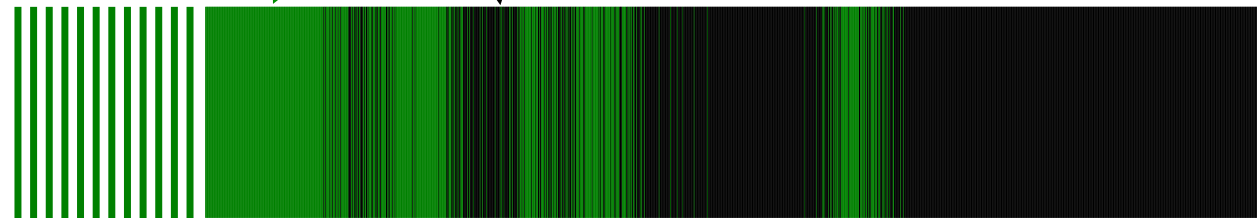
# The 'Red Supergiant Problem'

Evidence of mass threshold for BH formation?



Explodable (NS formation)..?

Not explodable (BH formation)..?



- Sukhbold & Adams (2019)
- Sukhbold+ (2016, 2018)
- Mueller+ (2016)
- Ertl+ (2016)
- Horiuchi+ (2014)
- O'Connor & Ott (2011)

# The 'Red Supergiant' Problem(s)

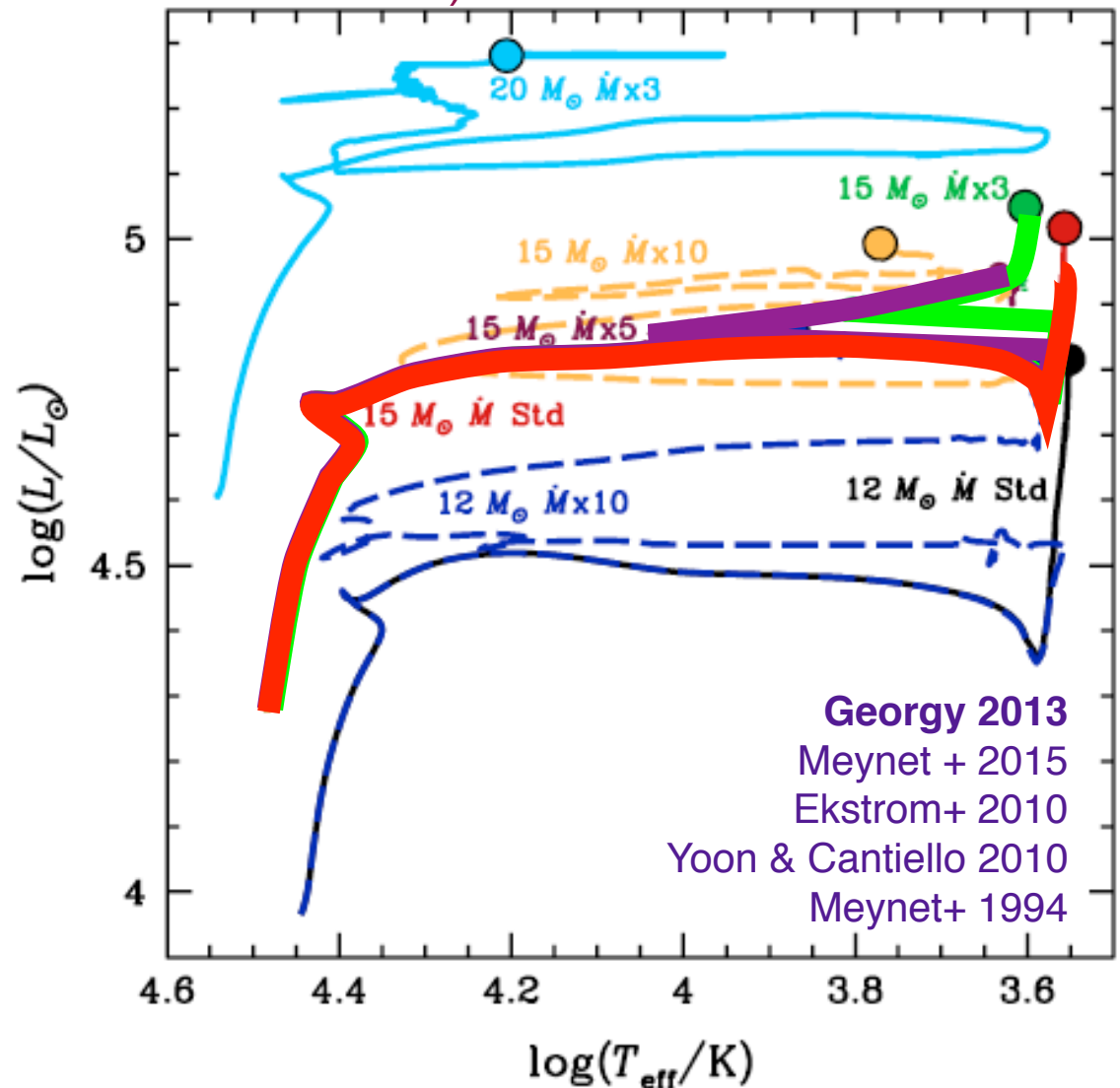
## possible solutions

I: [physics of stellar evolution](#)

(specifically... turn up the mass-loss rates)

Higher  $\dot{M}$  'wins' over core evolution

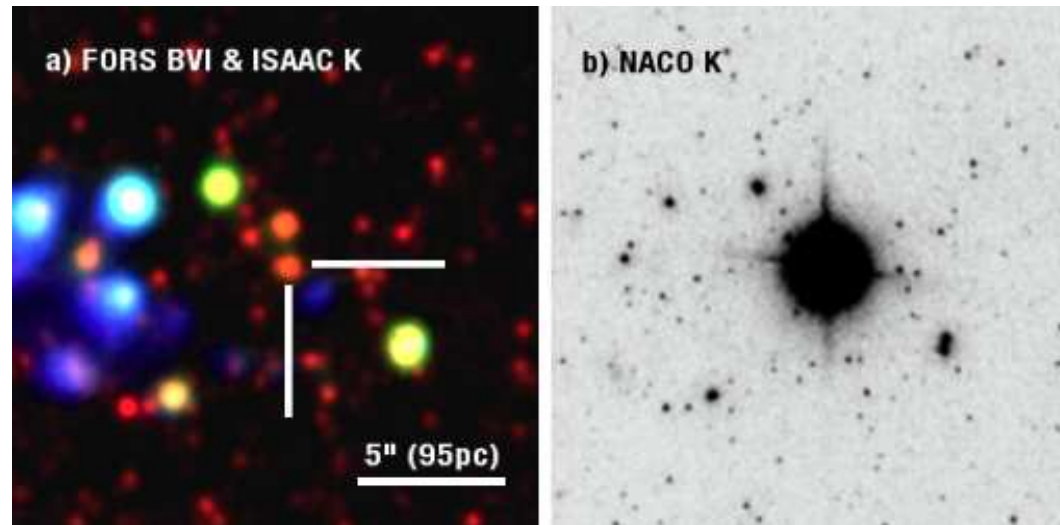
Star evolves back to the blue, explodes in a H-poor SN.



# The 'Red Supergiant' Problem(s)

## possible solutions

### II: observational biases



*pre-explosion photometry*



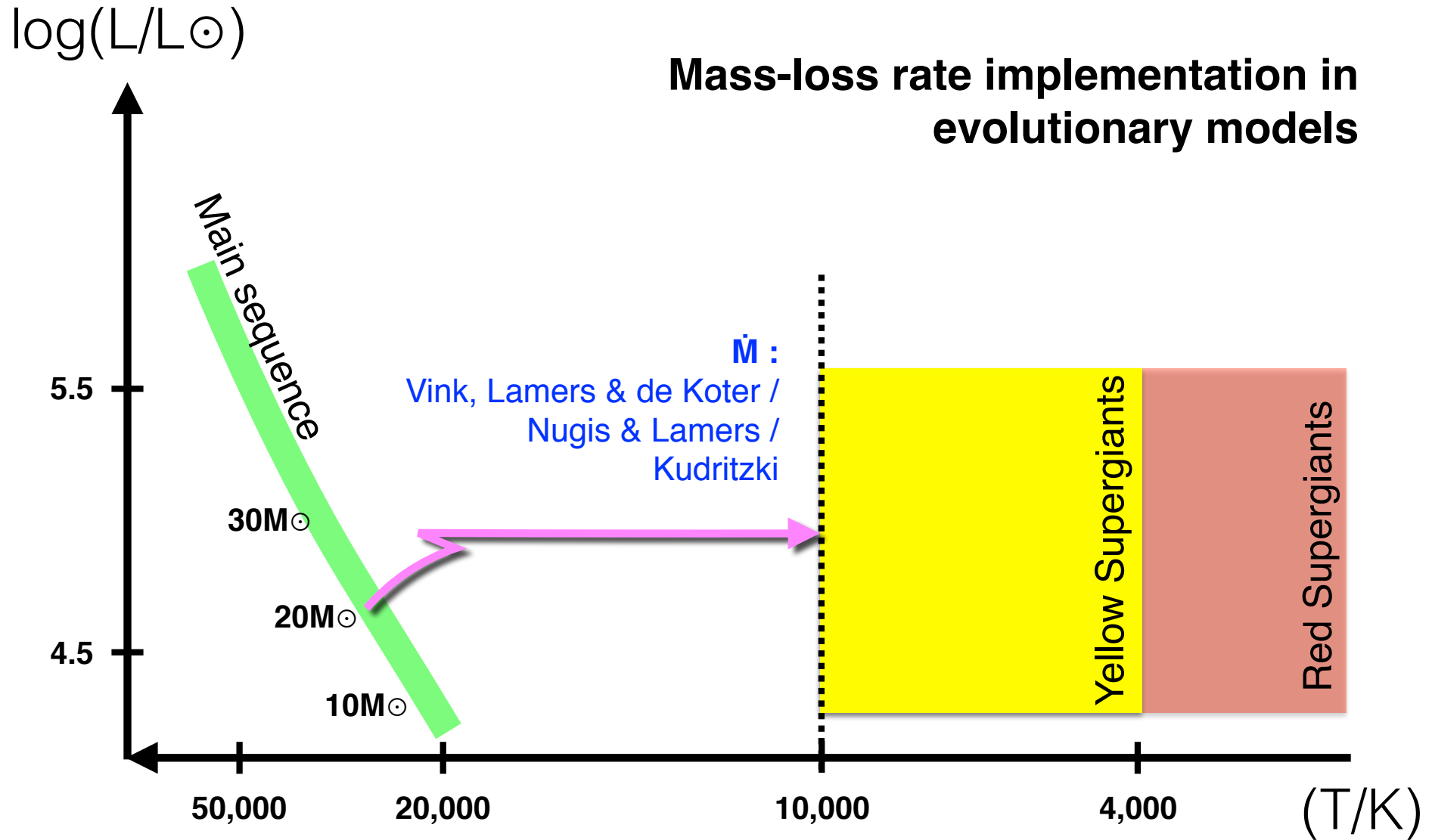
*terminal luminosity*



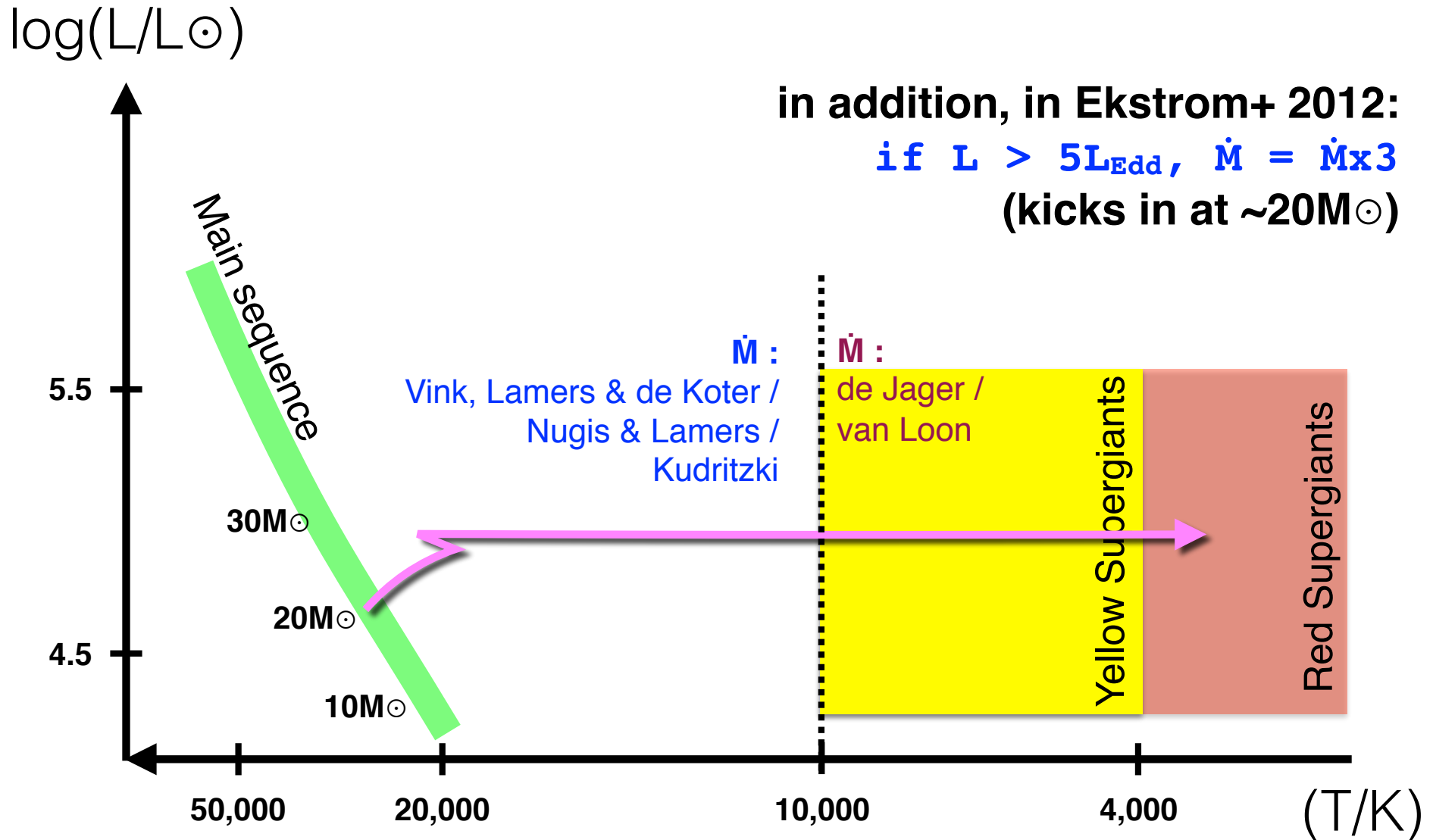
*initial mass*



# I: Can we turn up the mass-loss rates to solve the RSG problem?

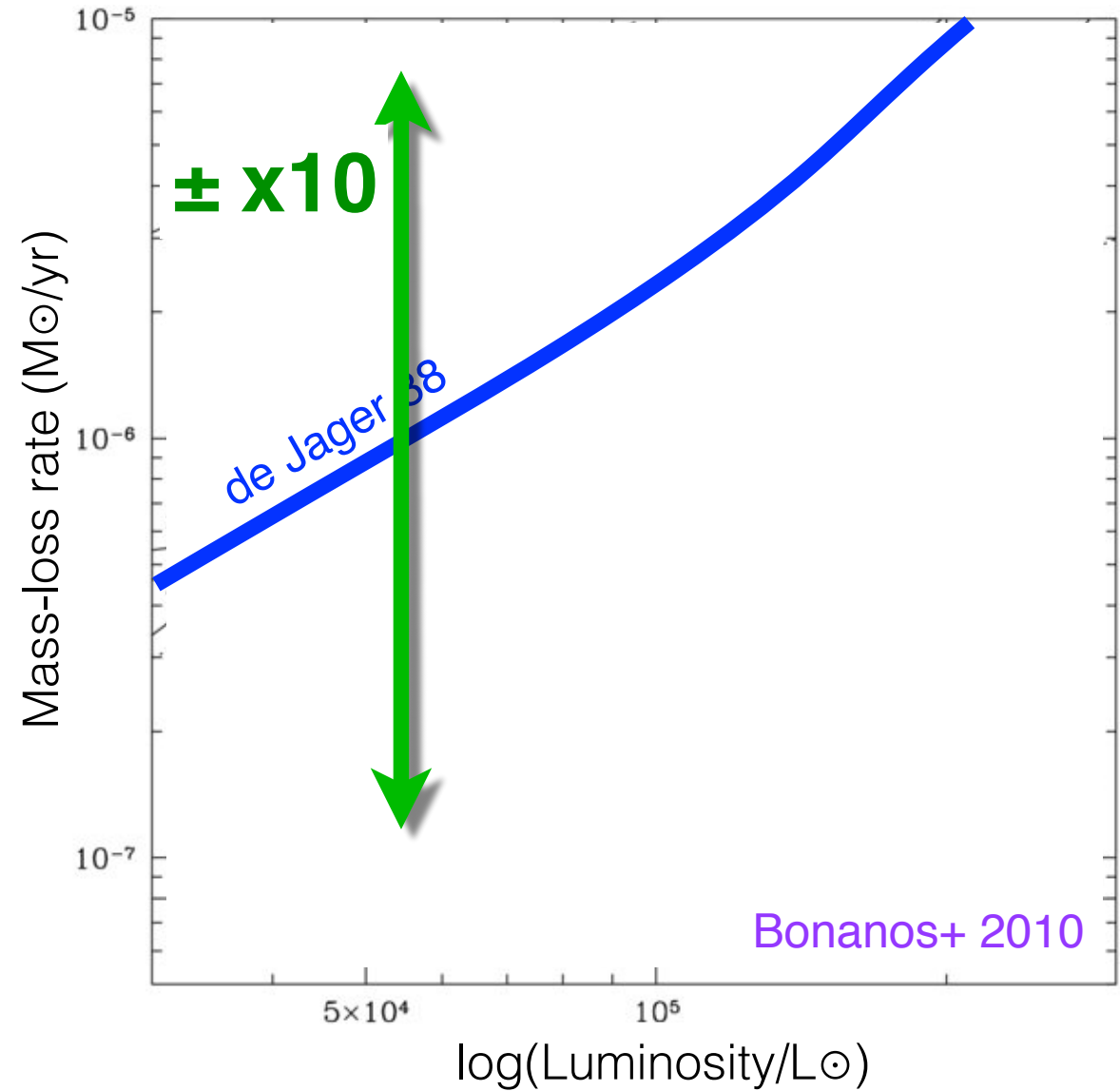


# I: Can we turn up the mass-loss rates to solve the RSG problem?



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*Current implementation  
in models:*



## I: Can we turn up the mass-loss rates to solve the RSG problem?



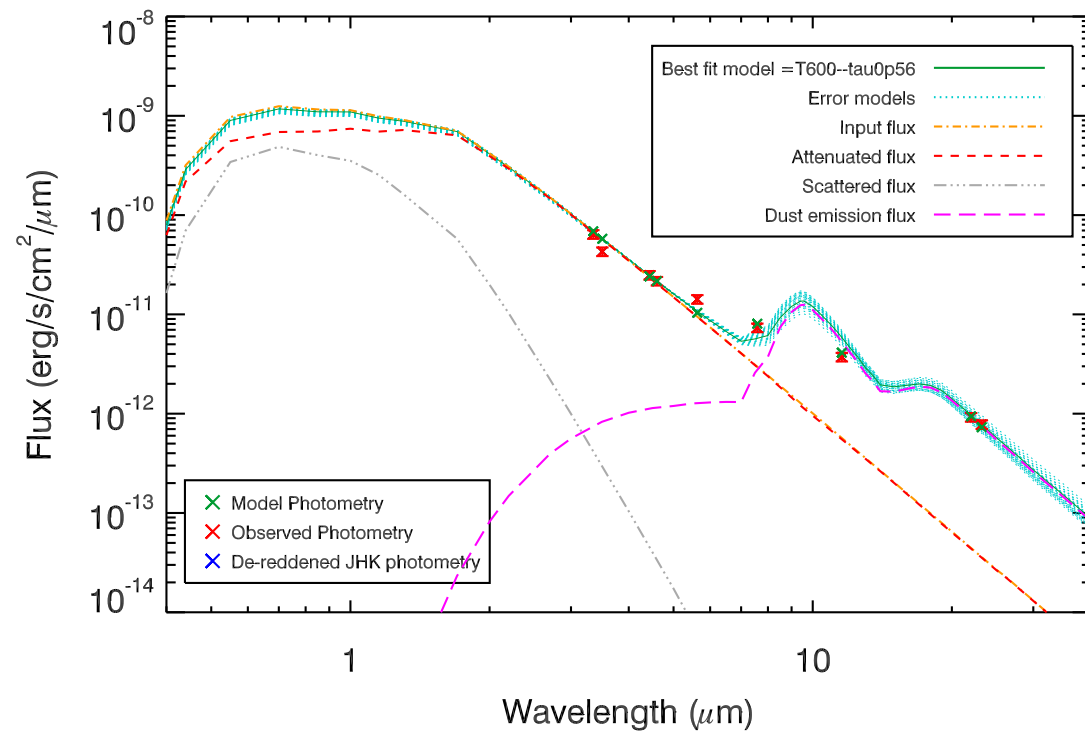
RSG mass-loss rates: let's do it again.

Use RSGs in star clusters, where all the stars are  $\sim$  the same mass

# I: Can we turn up the mass-loss rates to solve the RSG problem?

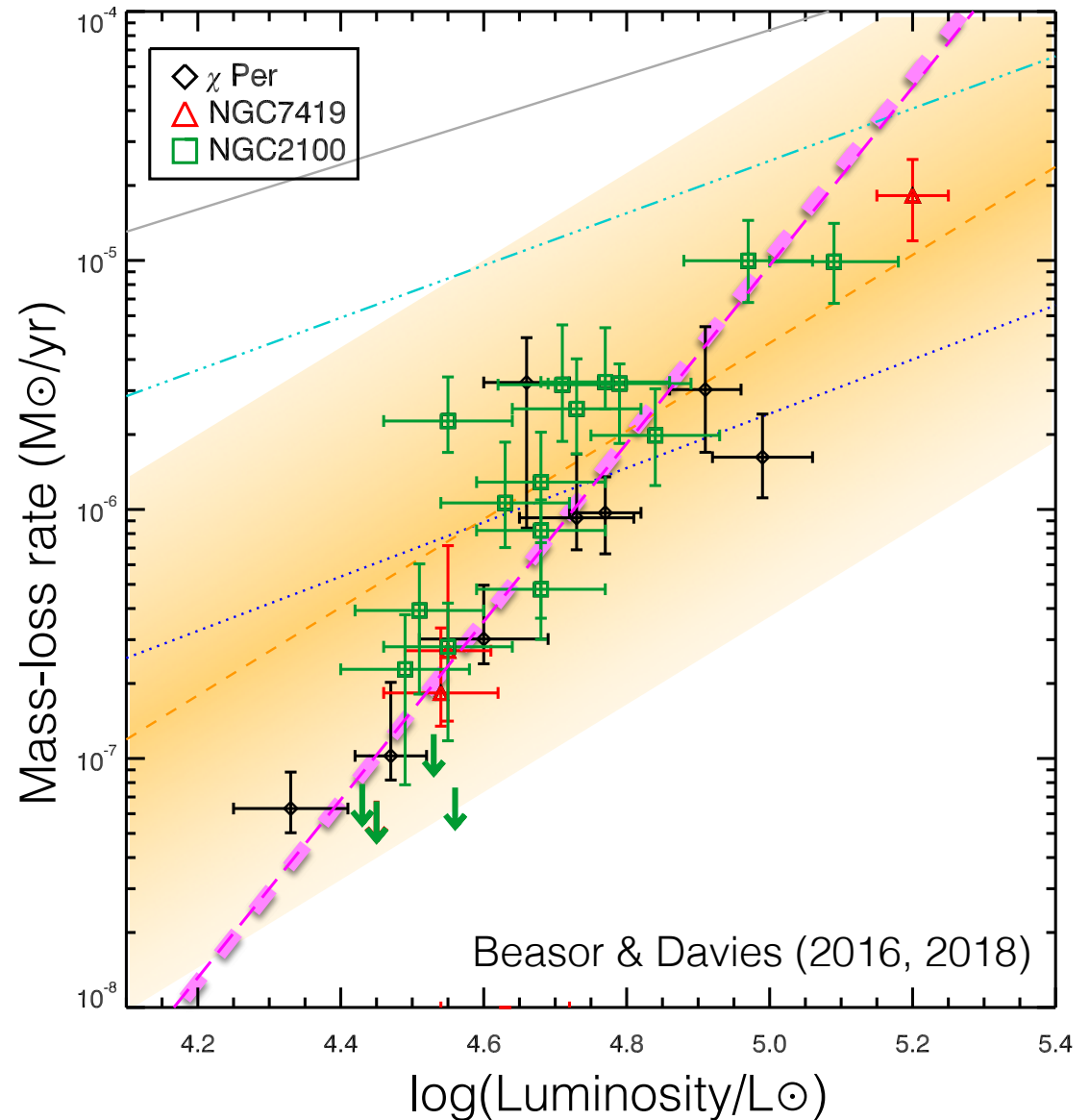


Obtain mass-loss rates by modelling mid-IR excess



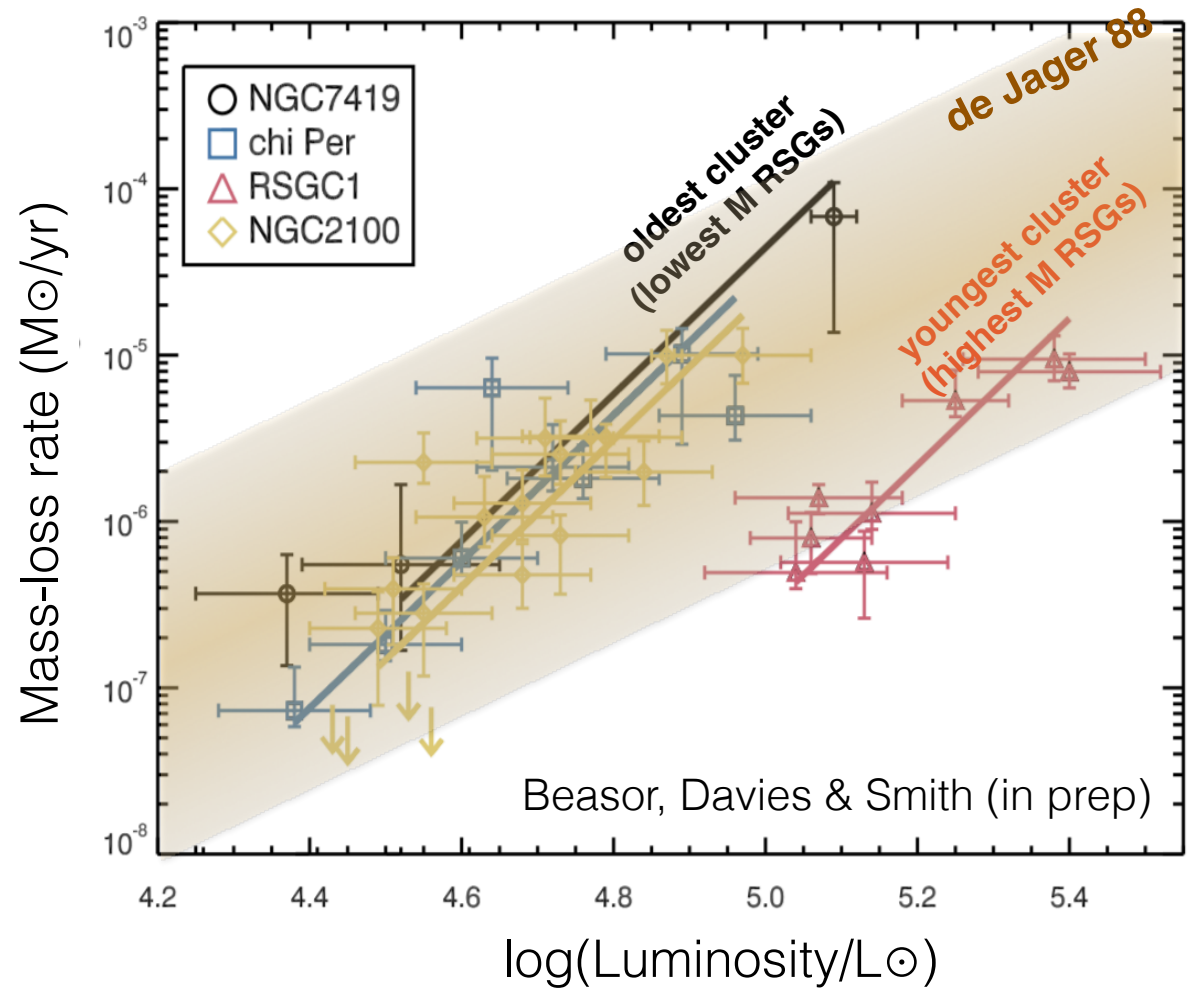
# I: Can we turn up the mass-loss rates to solve the RSG problem?

Controlling for stellar mass reduces the dispersion on the L-M relation



# I: Can we turn up the mass-loss rates to solve the RSG problem?

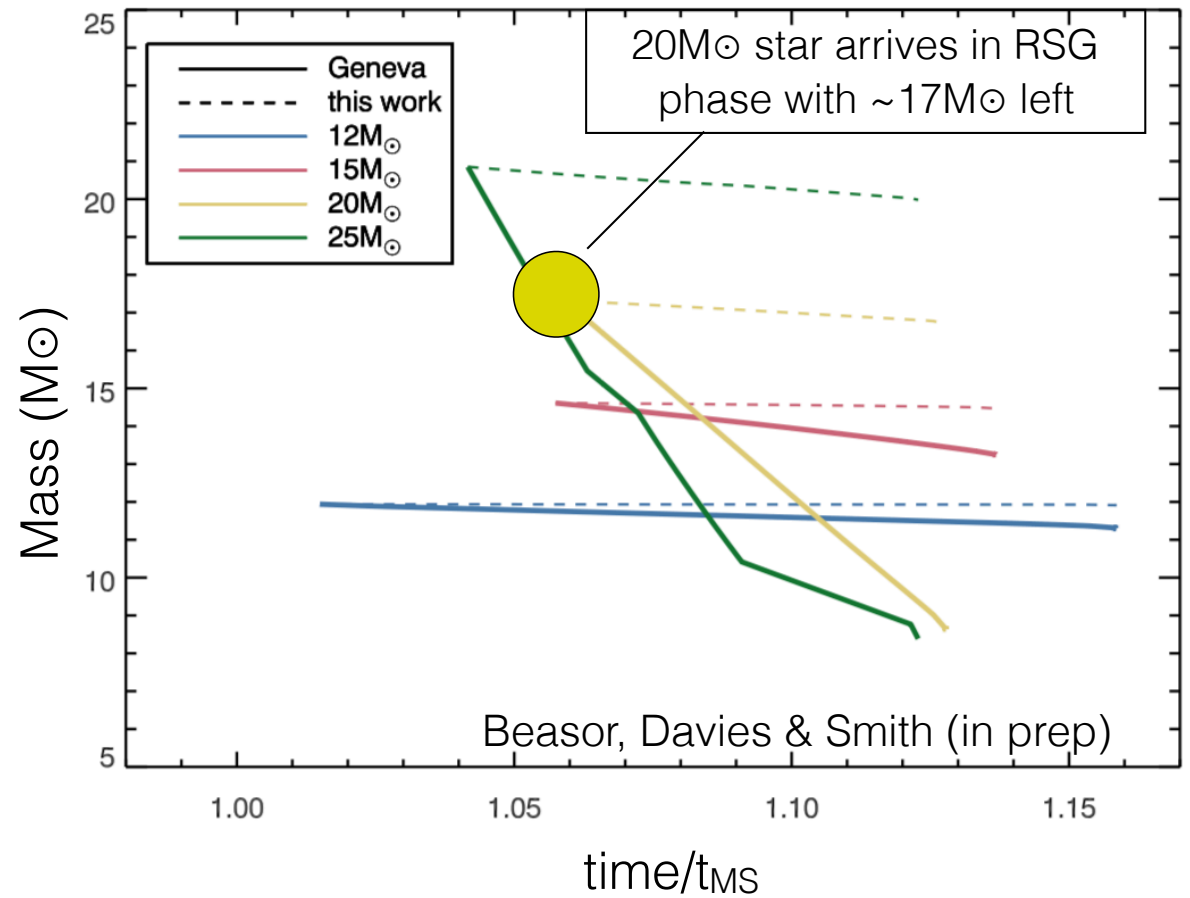
Offset in  $\dot{M}$ -L relation  
is **mass dependent**



# I: Can we turn up the mass-loss rates to solve the RSG problem?

$$\dot{M} = \dot{M}(L, M)$$

folding back into  
evolutionary  
models...

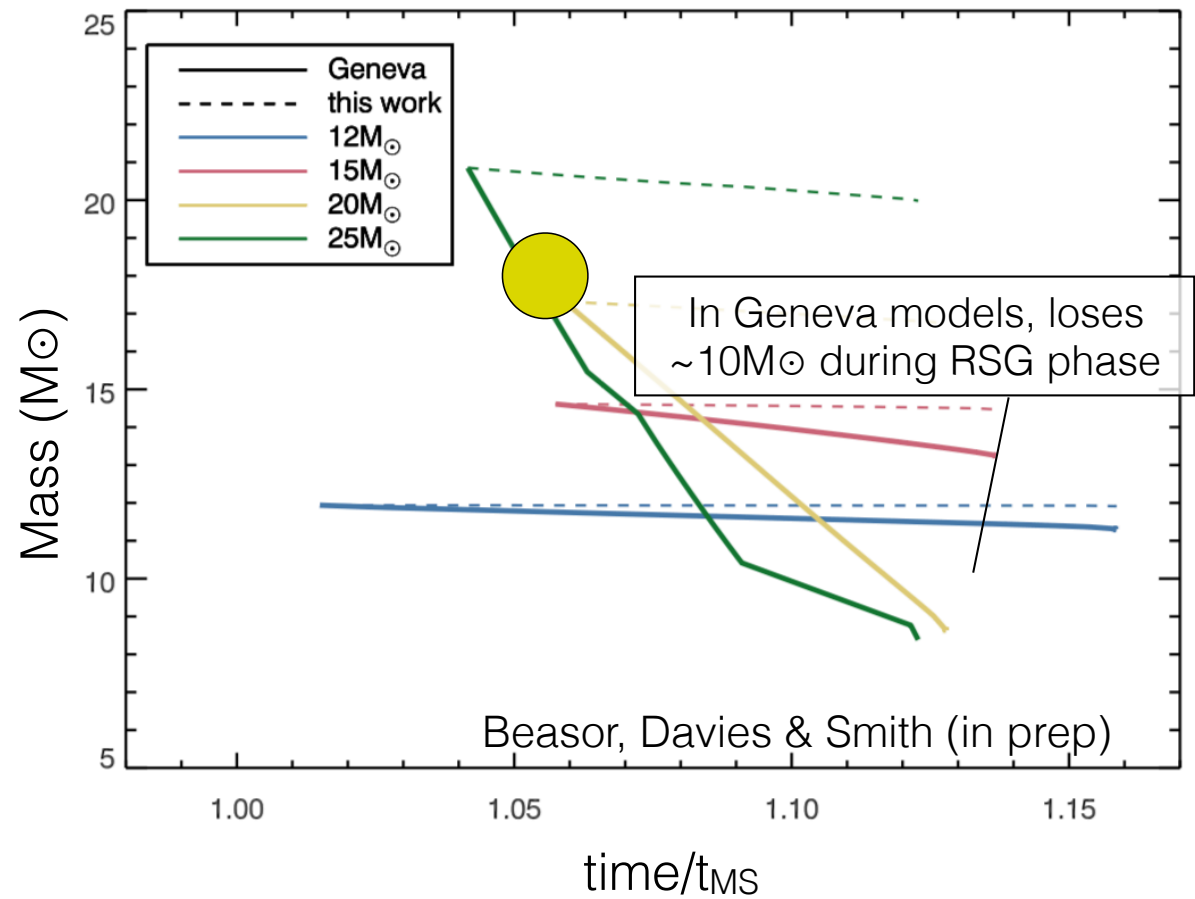




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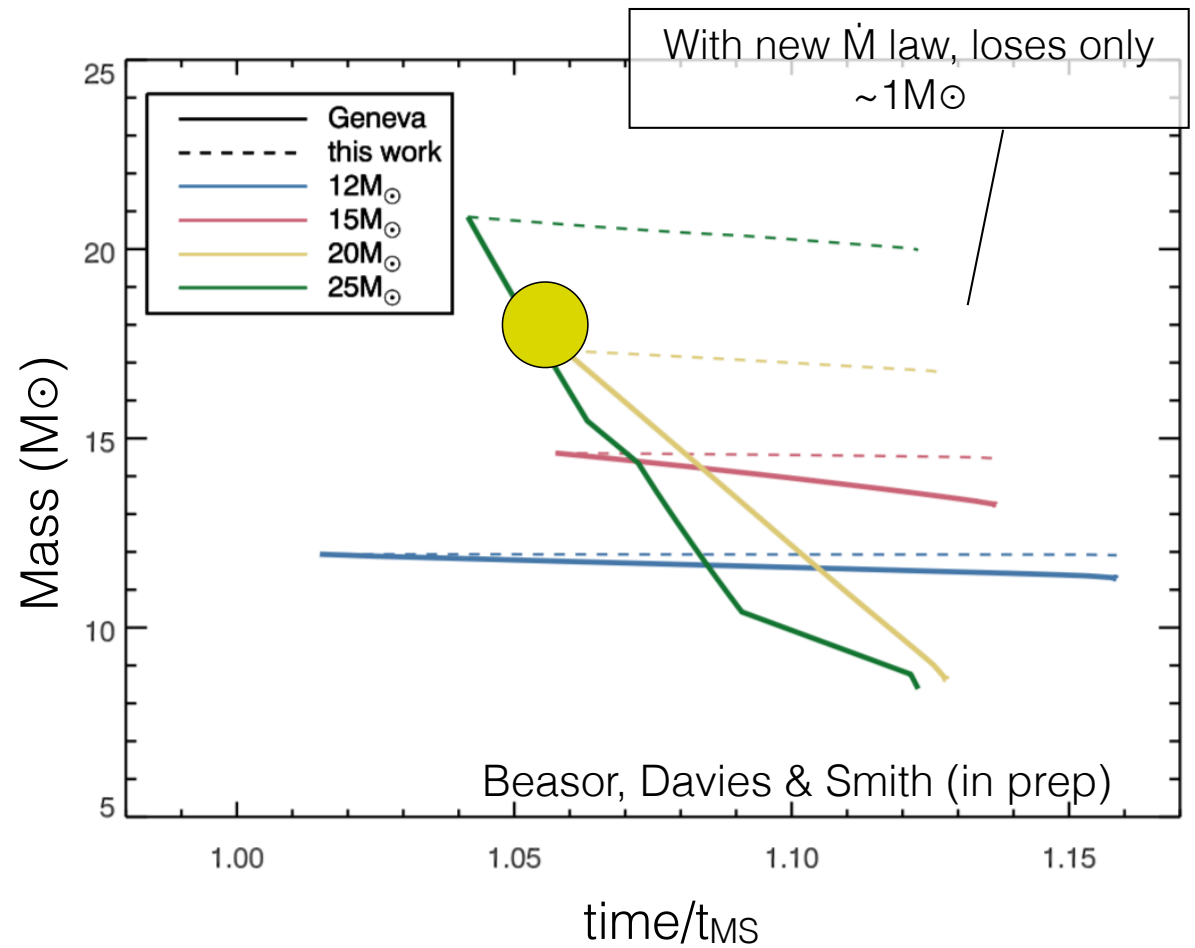
folding back into  
evolutionary  
models...



# I: Can we turn up the mass-loss rates to solve the RSG problem?

$$\dot{M} = \dot{M}(L, M)$$

folding back into  
evolutionary  
models...



**I: Can we turn up the mass-loss rates to solve the RSG problem?**

**Answer: no.**

**In fact, we need to turn them down. By a lot.**

**(Opposite of what's required!)**

# I: Can we turn up the mass-loss rates to solve the RSG problem?

## Also:

RSG wind *cannot* strip the envelope

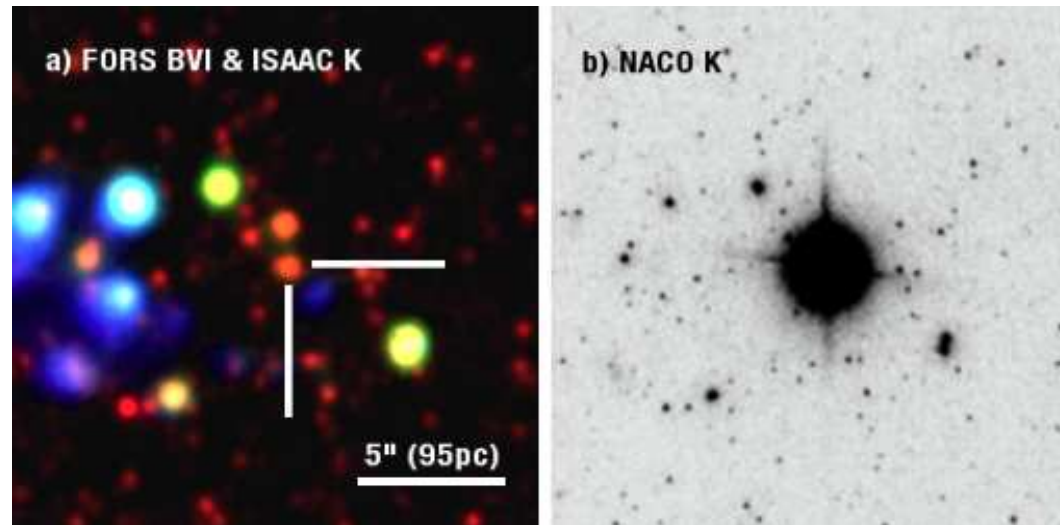
→ no single-star channel for SN-Ibc below  $\sim 60M_{\odot}$

→ H-D limit much too high in models

# The 'RSG (SN progenitors) Problem'

## possible solutions

### II: observational biases



### *pre-explosion photometry*

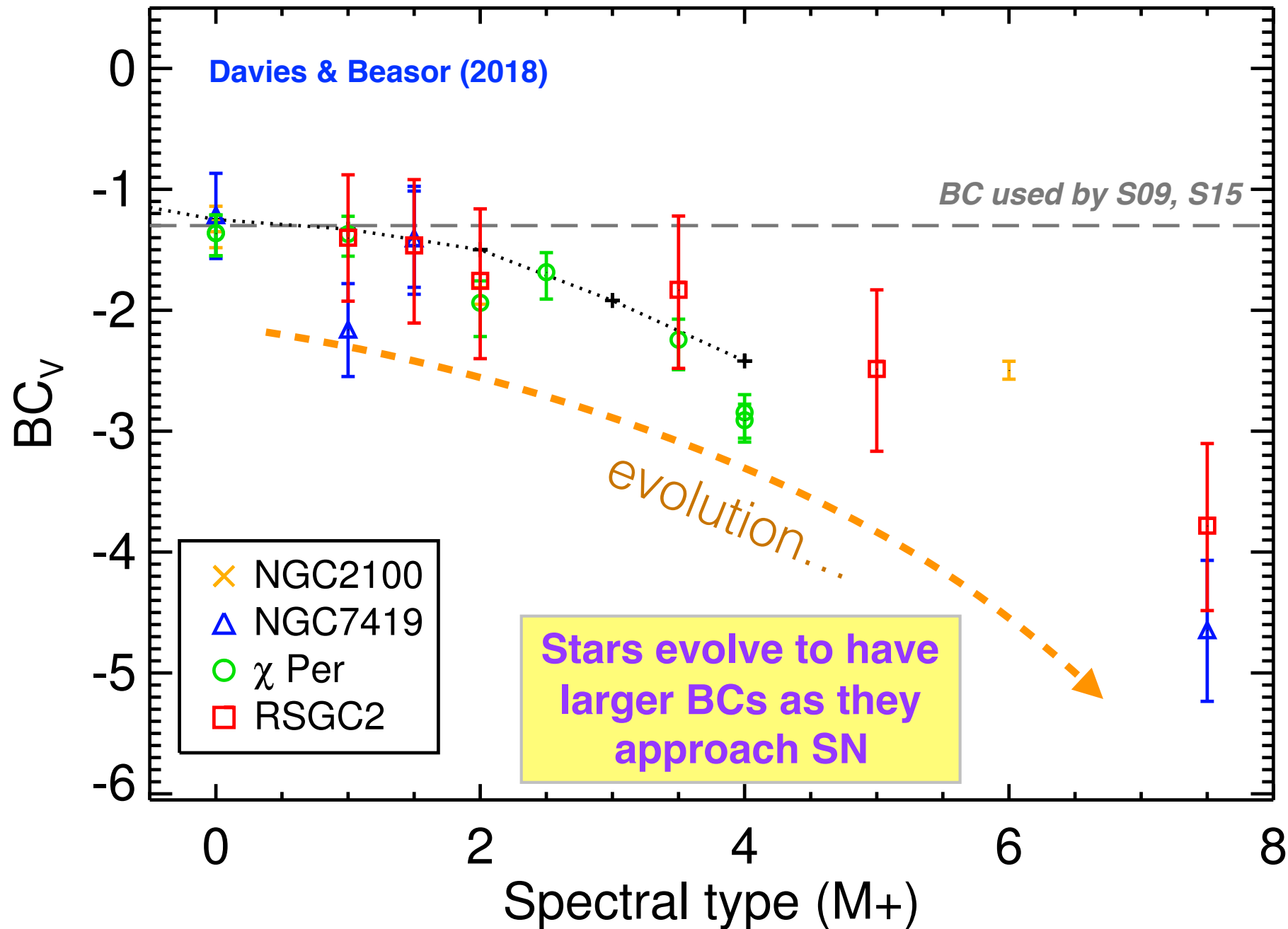
→ Assumptions about:  $T_{\text{eff}}$ ,  $BC_V$ , extinction...

### *terminal luminosity*

→ Need  $M$ - $L$  relation from models

### *initial mass*

## II: can observational biases explain the RSG problem?



# The 'Red Supergiant' Problem

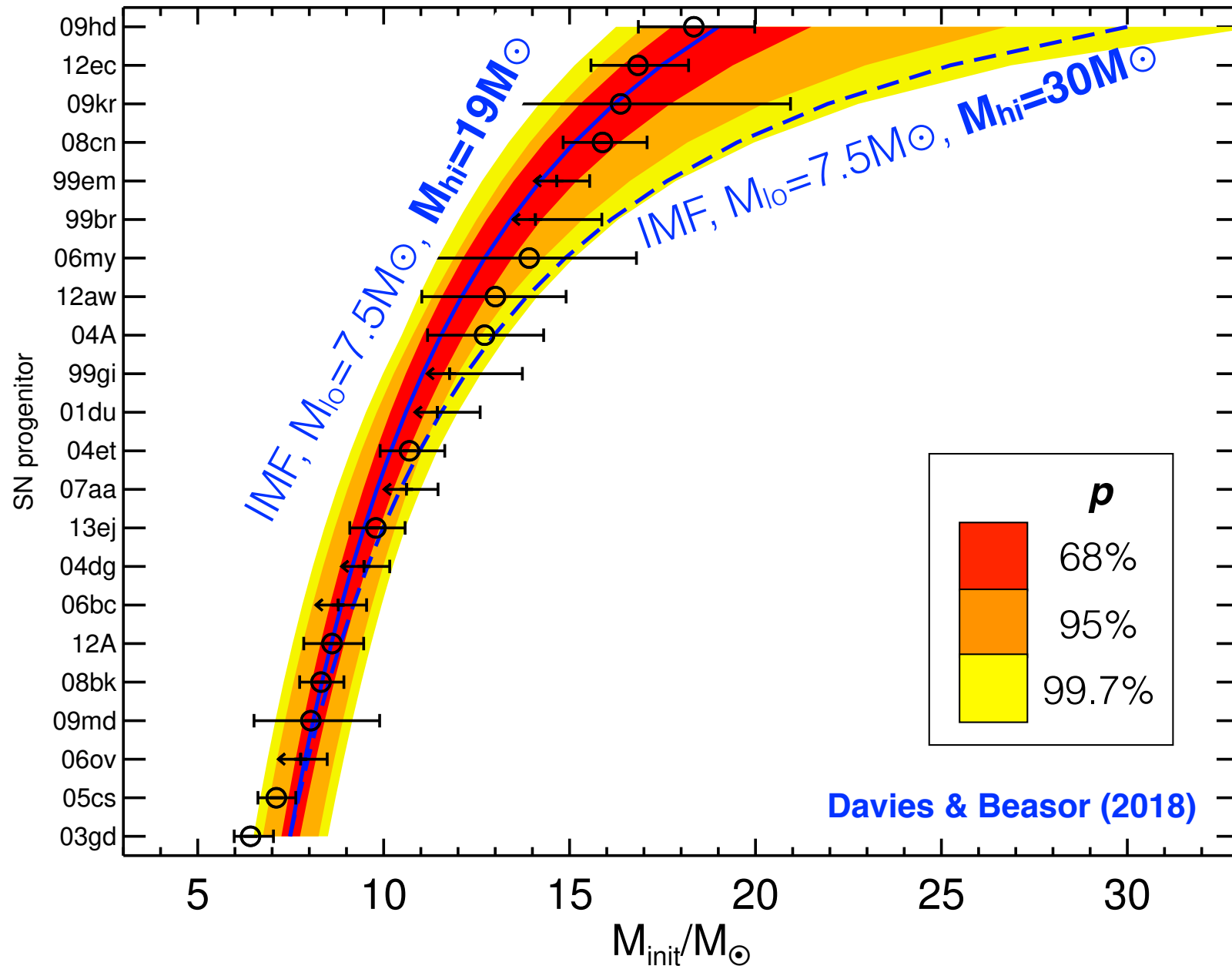
A reappraisal of the mass spectrum of II-P progenitors

Davies & Beasor (2018):

- ★ 'redder' bolometric corrections
- ★ better foreground extinction estimates (Maund 2017)

# The 'Red Supergiant' Problem

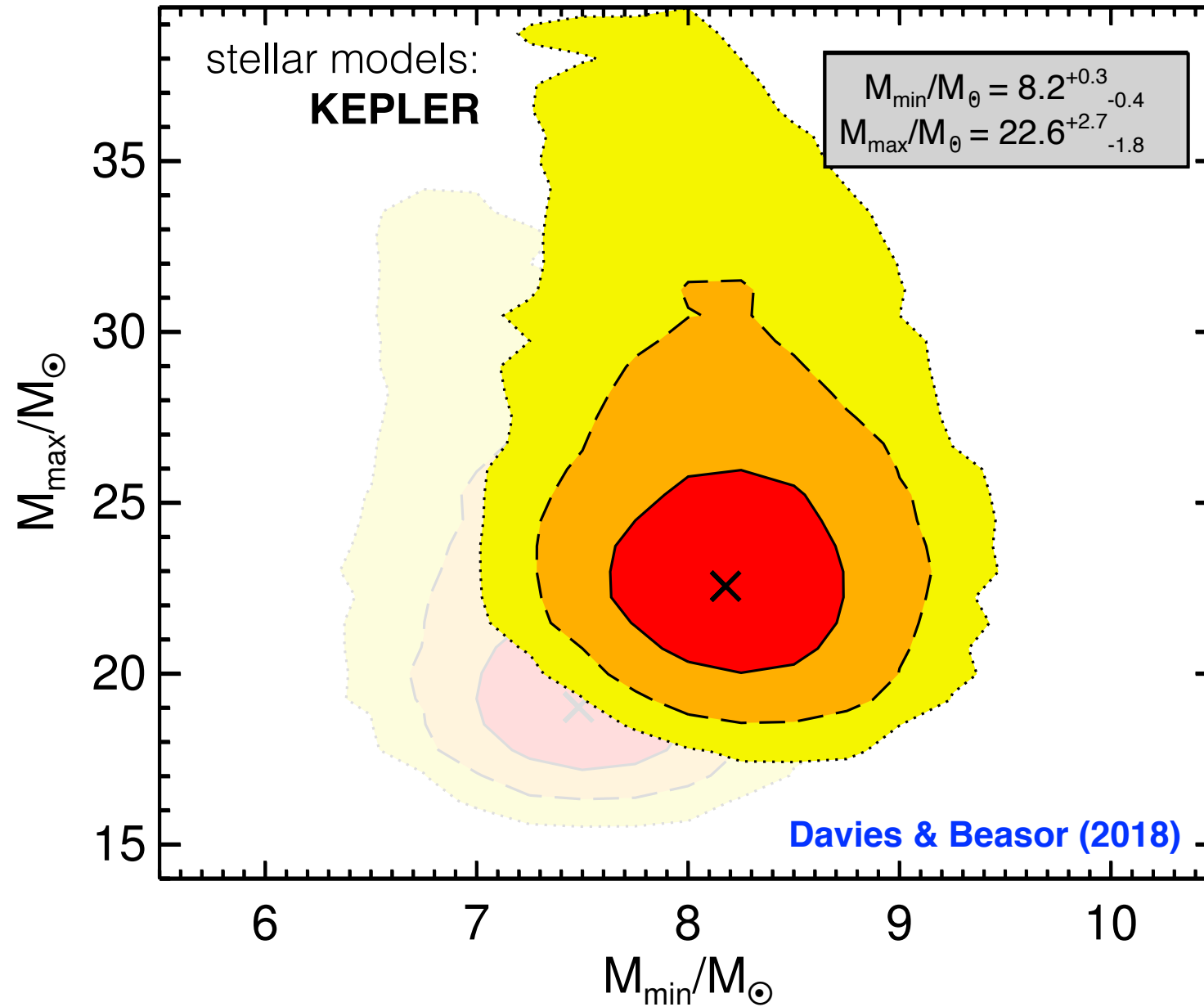
## A reappraisal of the mass spectrum of II-P progenitors





# The 'Red Supergiant' Problem

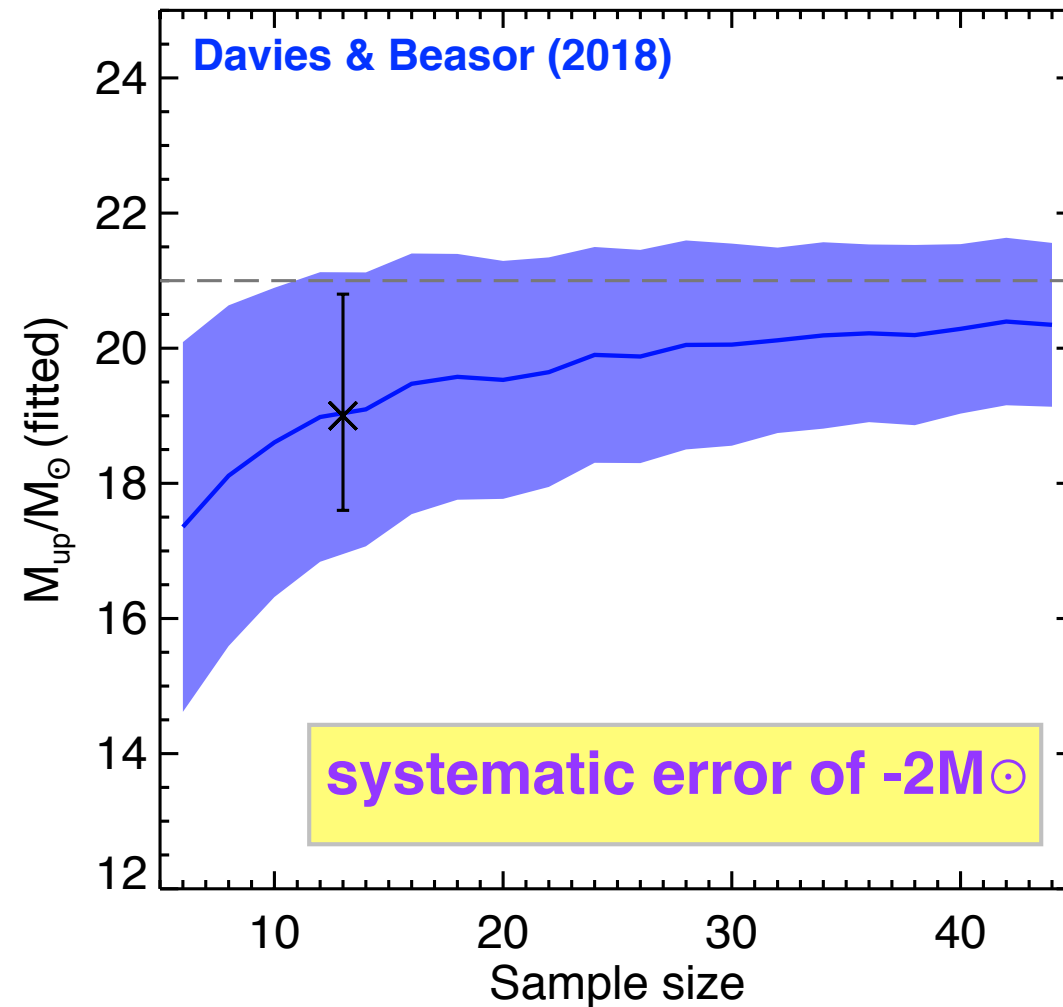
## A reappraisal of the mass spectrum of II-P progenitors



# The 'Red Supergiant' Problem

## A reappraisal of the mass spectrum of II-P progenitors

### Finite sample size effects:



# The 'Red Supergiant' Problem

## A reappraisal of the mass spectrum of II-P progenitors

$$M_{\text{upper}} = (19+2+2) = \mathbf{23M_{\odot}}$$

$$95\% \text{ confidence limit} = 33M_{\odot}$$

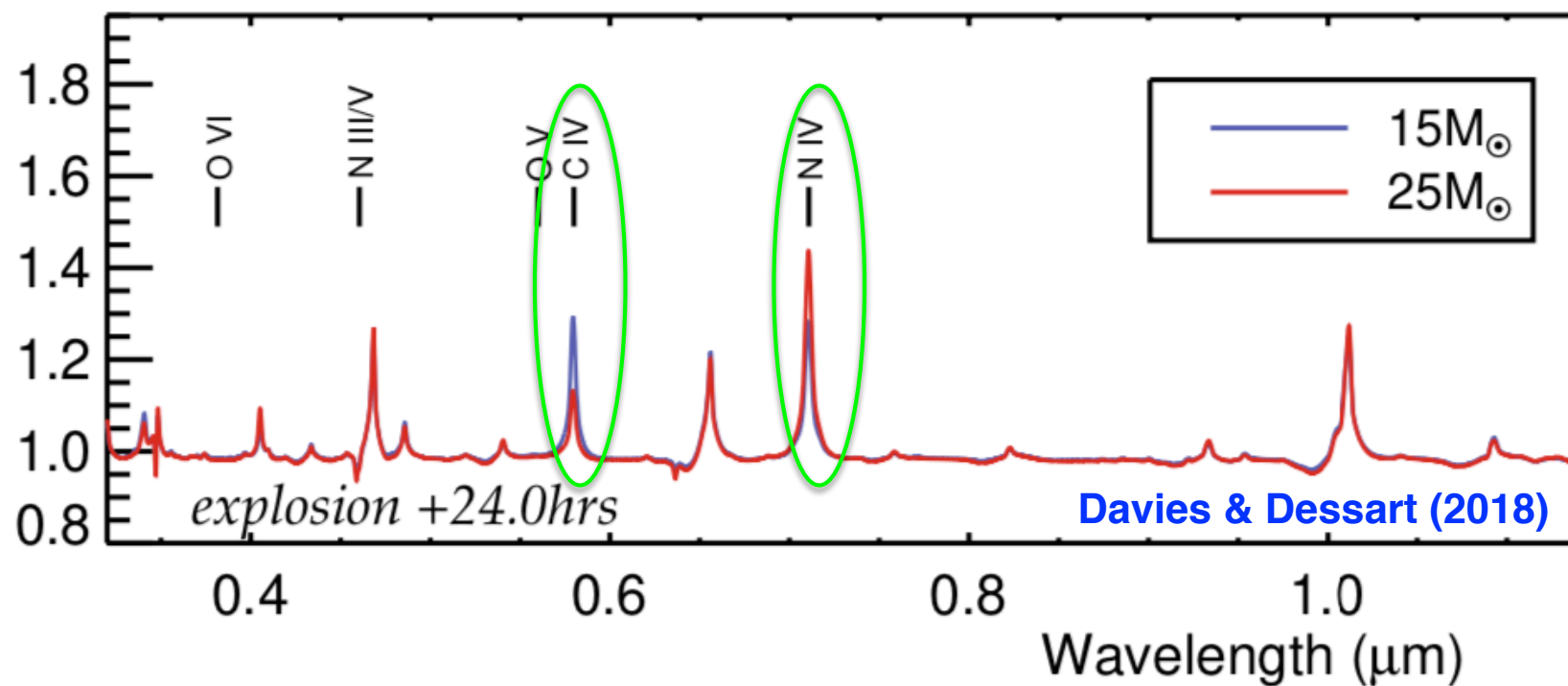
(expectation: 25-30M $\odot$ )

### Conclusion:

No strong evidence for 'missing progenitors'.

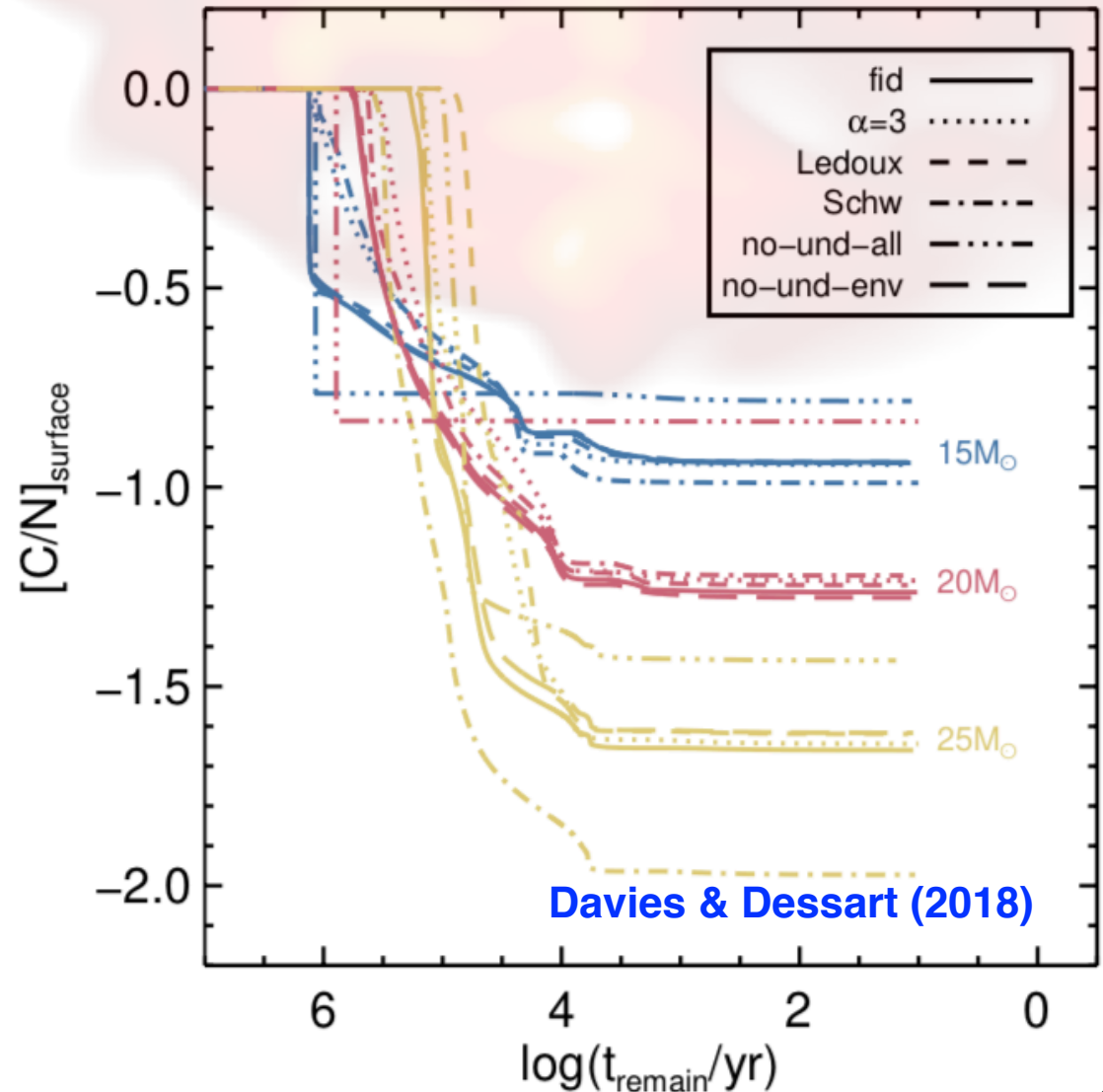
## SN diagnostics of the progenitor

- ★ Progenitor's surface C/N can be measured from flash spectroscopy (see talk by Gal-Yam)



## SN diagnostics of the progenitor

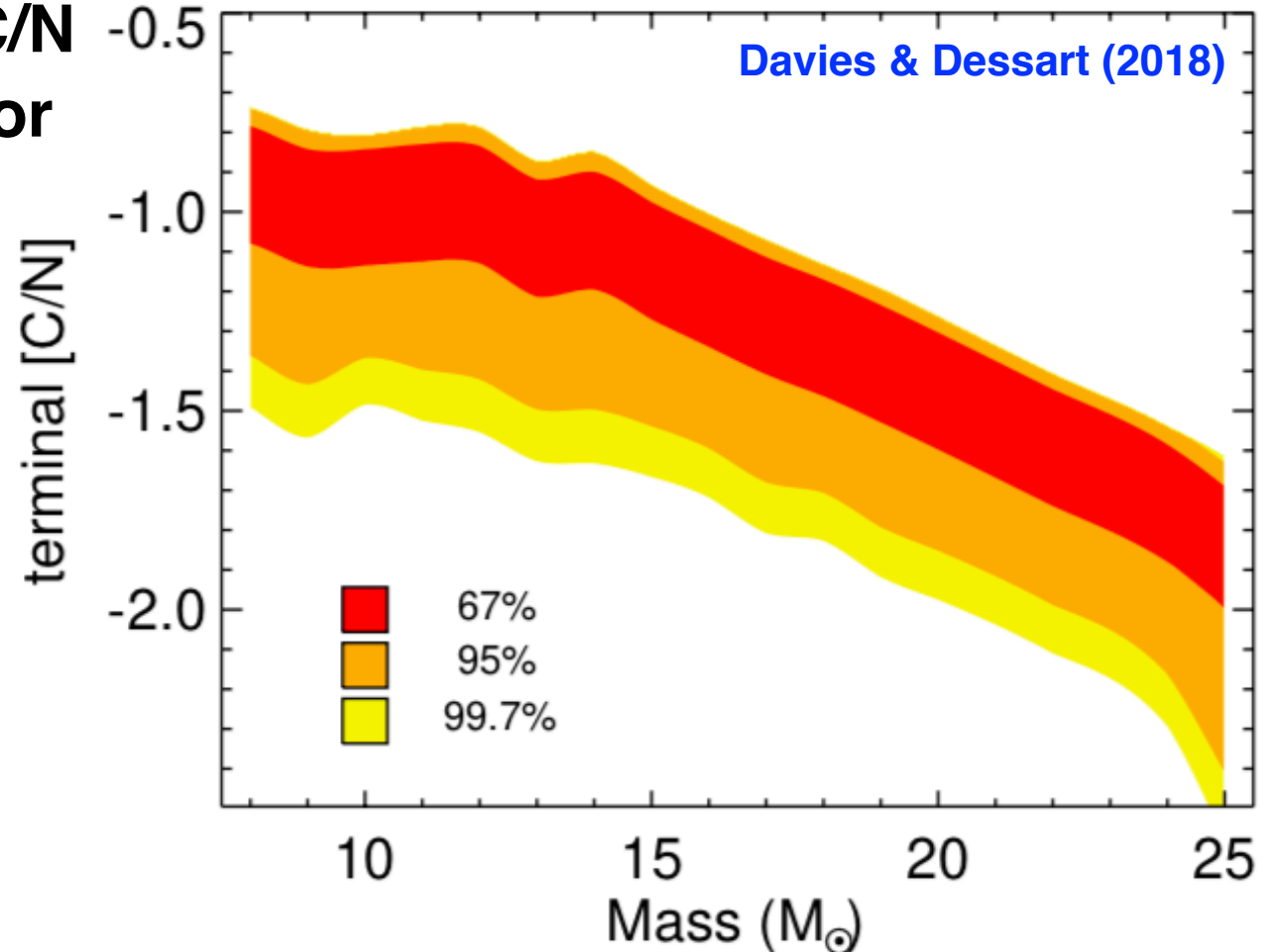
- ★ Progenitor's surface C/N can be measured from flash spectroscopy (see talk by Gal-Yam)
- ★ **terminal surface C/N linked to progenitor mass**



## SN diagnostics of the progenitor

★ Progenitor's surface C/N can be measured from flash spectroscopy (see talk by Gal-Yam)

★ **terminal surface C/N linked to progenitor mass**



# Summary

## Mass-loss during the RSG phase

- ★ up to x10 weaker than previously thought
- ★ Not enough to make a ‘stripped’ (Ibc) SN out of a single star

## The ‘Red Supergiant’ Problem

- ★ No evidence for ‘missing’ SNe from high-mass stars
- ★ Doesn’t mean that higher mass RSGs aren’t making BHs...

## Flash spectroscopy of II-PS

- ★ Can we get the progenitor mass from C/N..?