How should the progenitors of type II-p SNe look like?

Red supergiants in clusters

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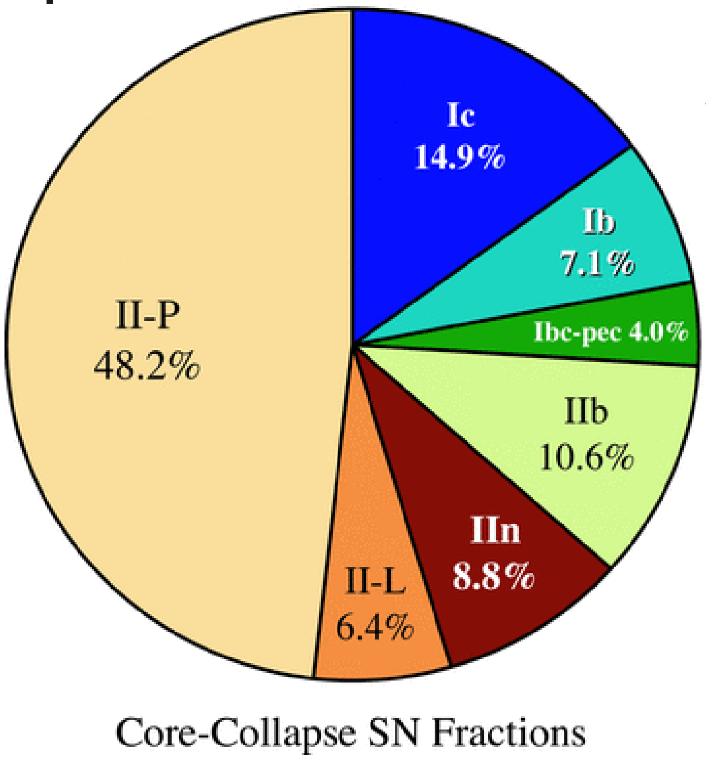
Outline

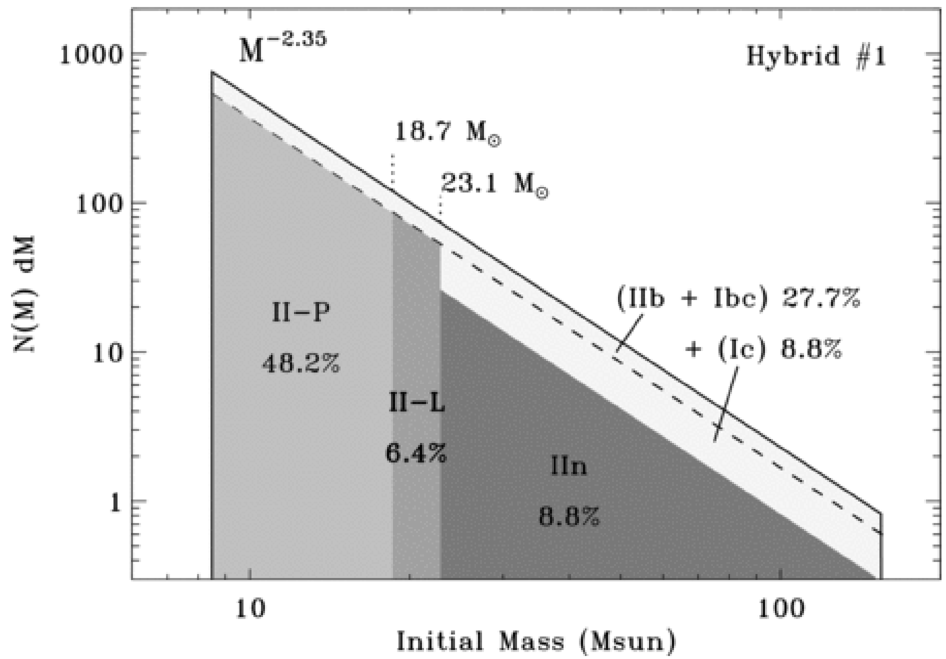
- Red supergiants as SN progenitors
  - Observation vs. theory
- Constraints from clusters
  - Evidence for substantial evolution during the RSG phase
- The AGB boundary
  - Can we tell which stars will explode?

Exploding RSGs



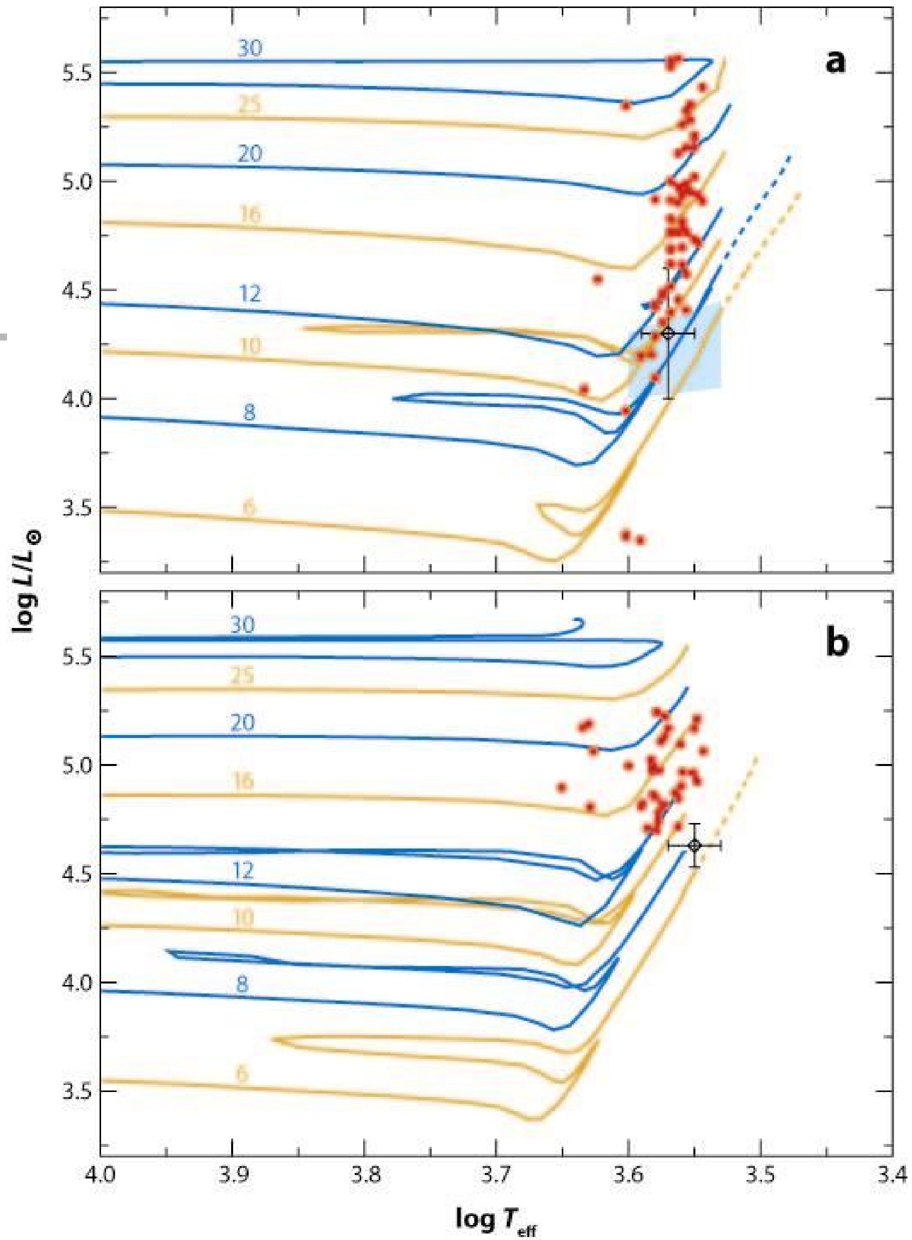
Distribution of supernova types
(Smith et al. 2011, MNRAS 412, 1522)

A possible scenario for supernova progenitors
(Smith et al. 2011, MNRAS 412, 1522)



Lower initial mass for a supernova progenitor

$8.5^{+1}_{-1.5}\ M_{\odot}$

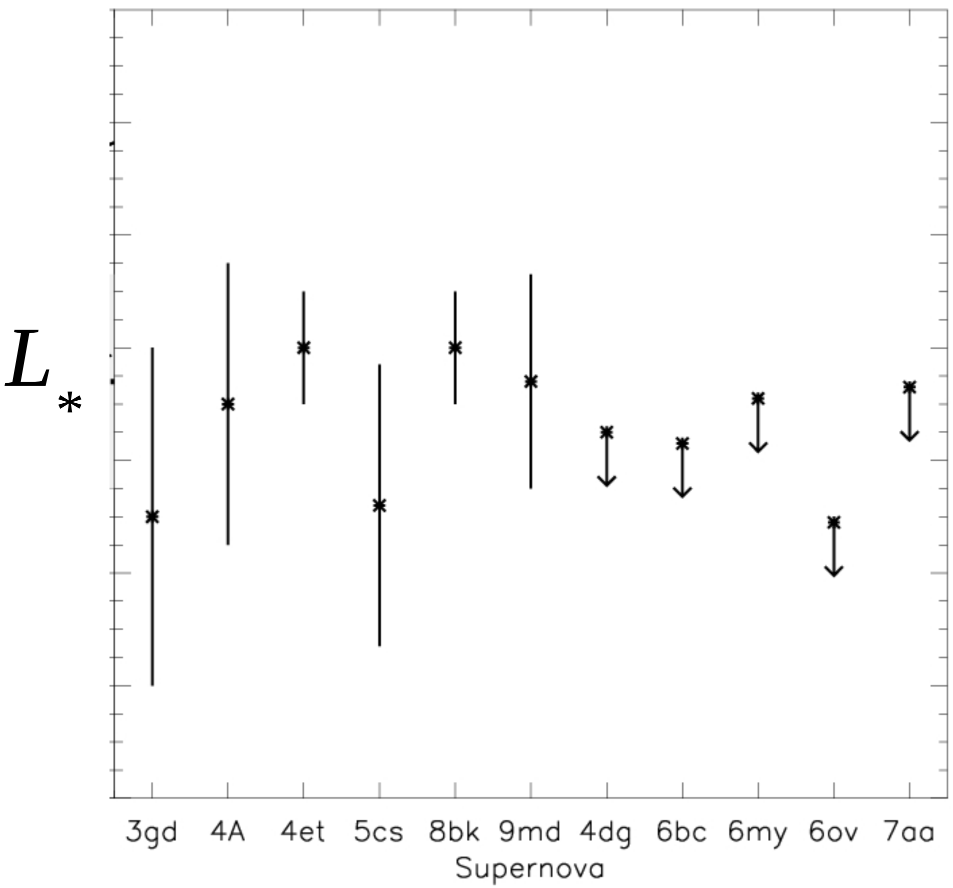


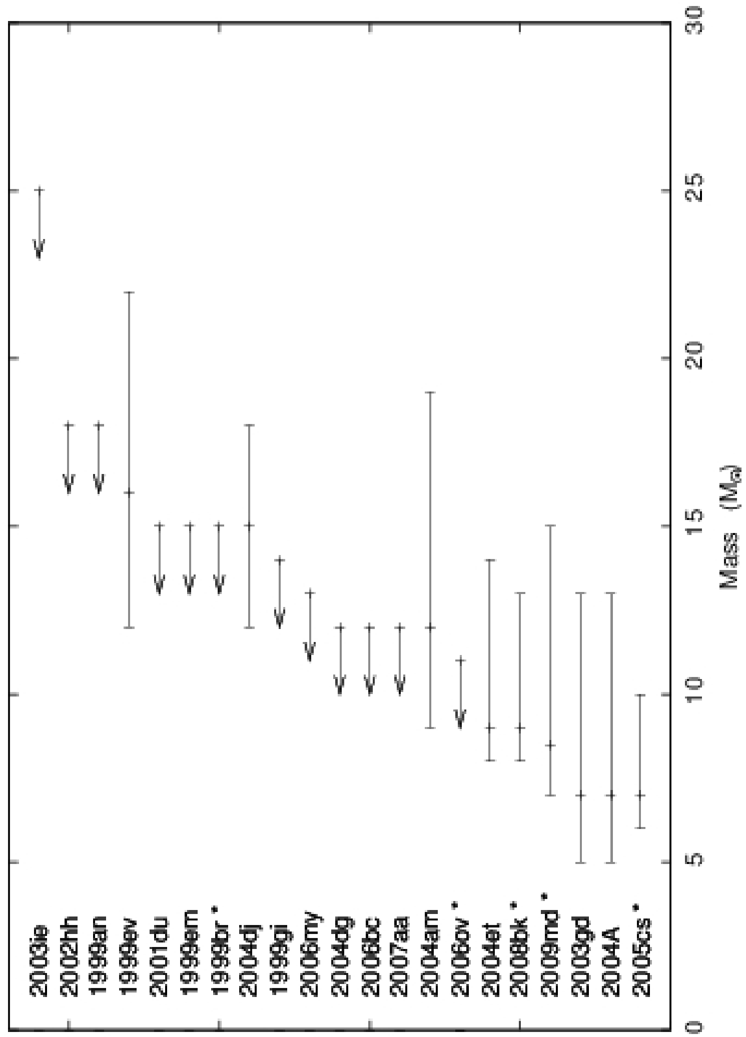
Observed supernova progenitors

(Smartt 2009, ARA&A 47, 63)

Smartt SJ. 2009.
Annu. Rev. Astron. Astrophys. 47:63–106

Very low mass progenitors

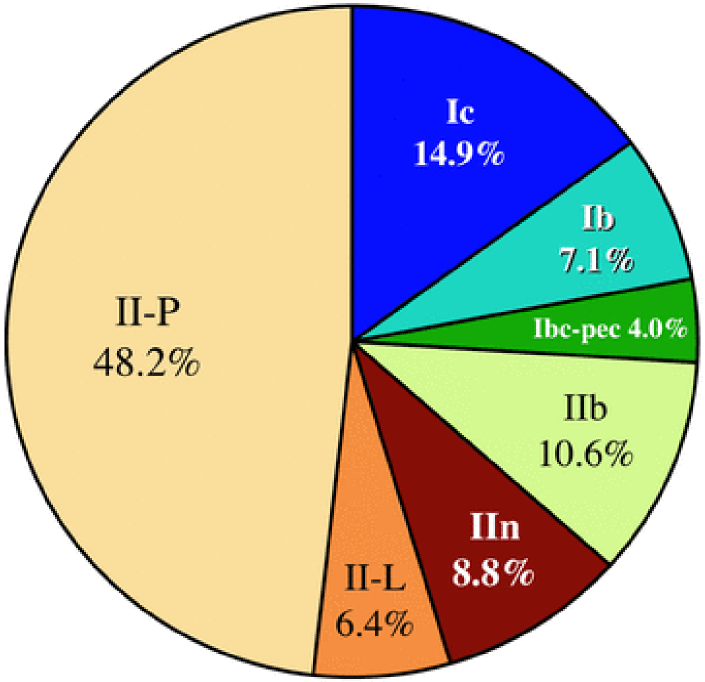




Observed supernova progenitors

(Frasier et al. 2011, MNRAS 417, 1417)

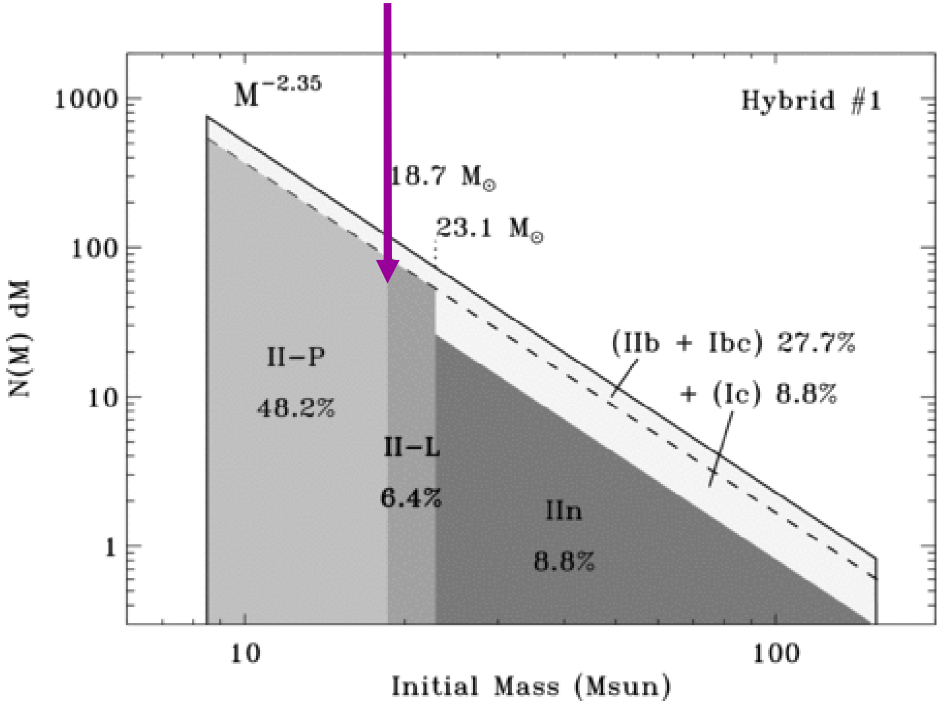
Exploding RSGs



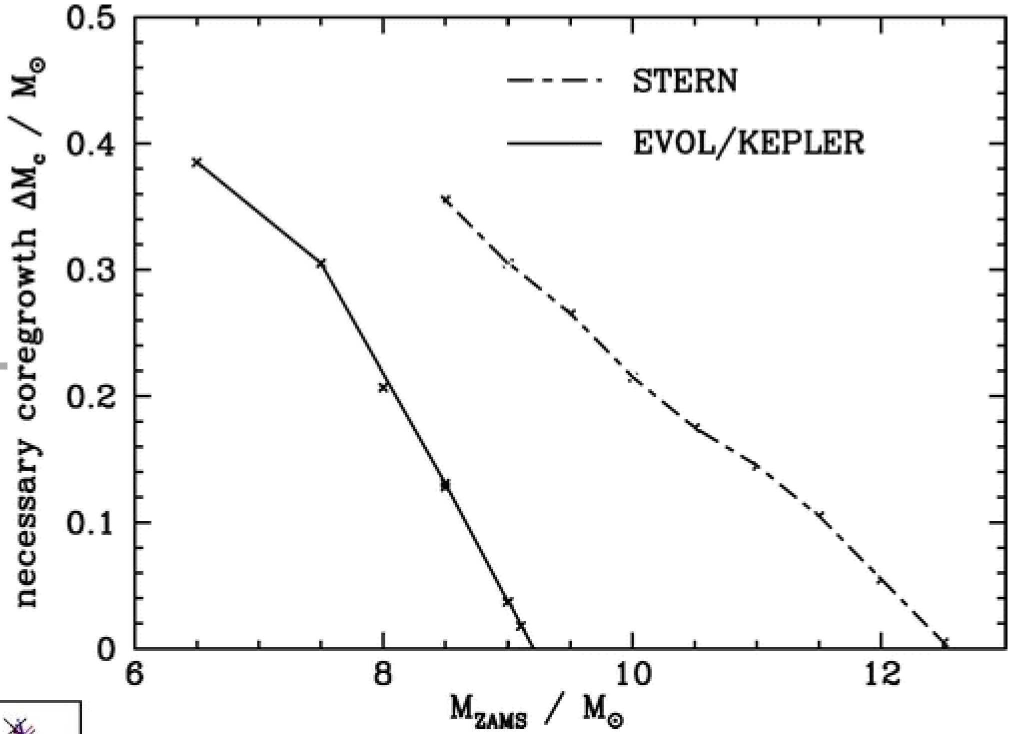
Core-Collapse SN Fractions

Distribution of supernova types
(Smith et al. 2011, MNRAS 412, 1522)

This may shift up a bit because of circumstellar reddening
(Walmswell & Eldridge 2012, MNRAS 419, 2054)

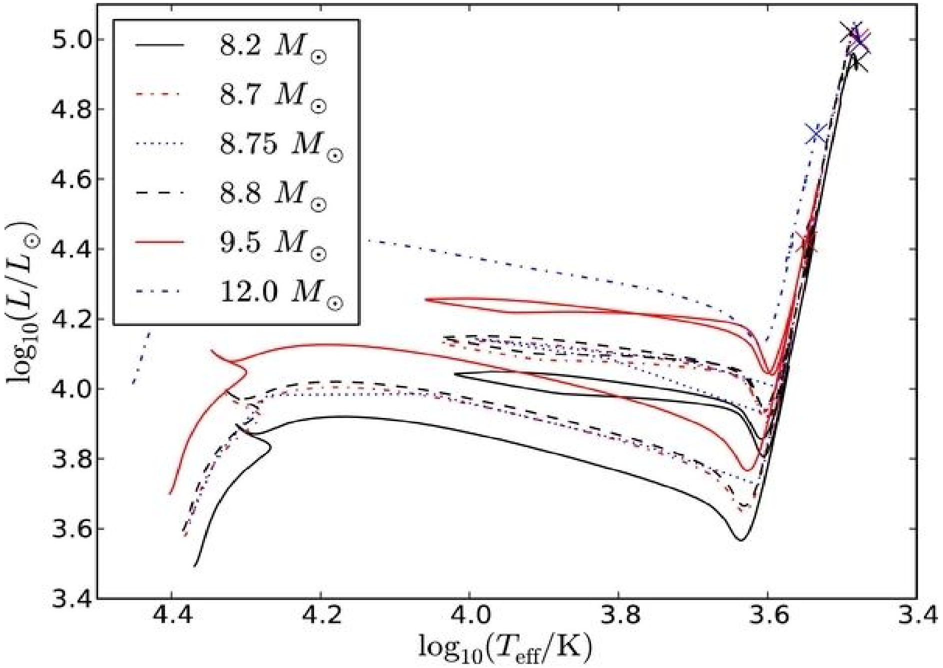


The theory



(Poelarends et al. 2008, ApJ 675, 614)

(Jones et al. 2013, ApJ 772, 150)

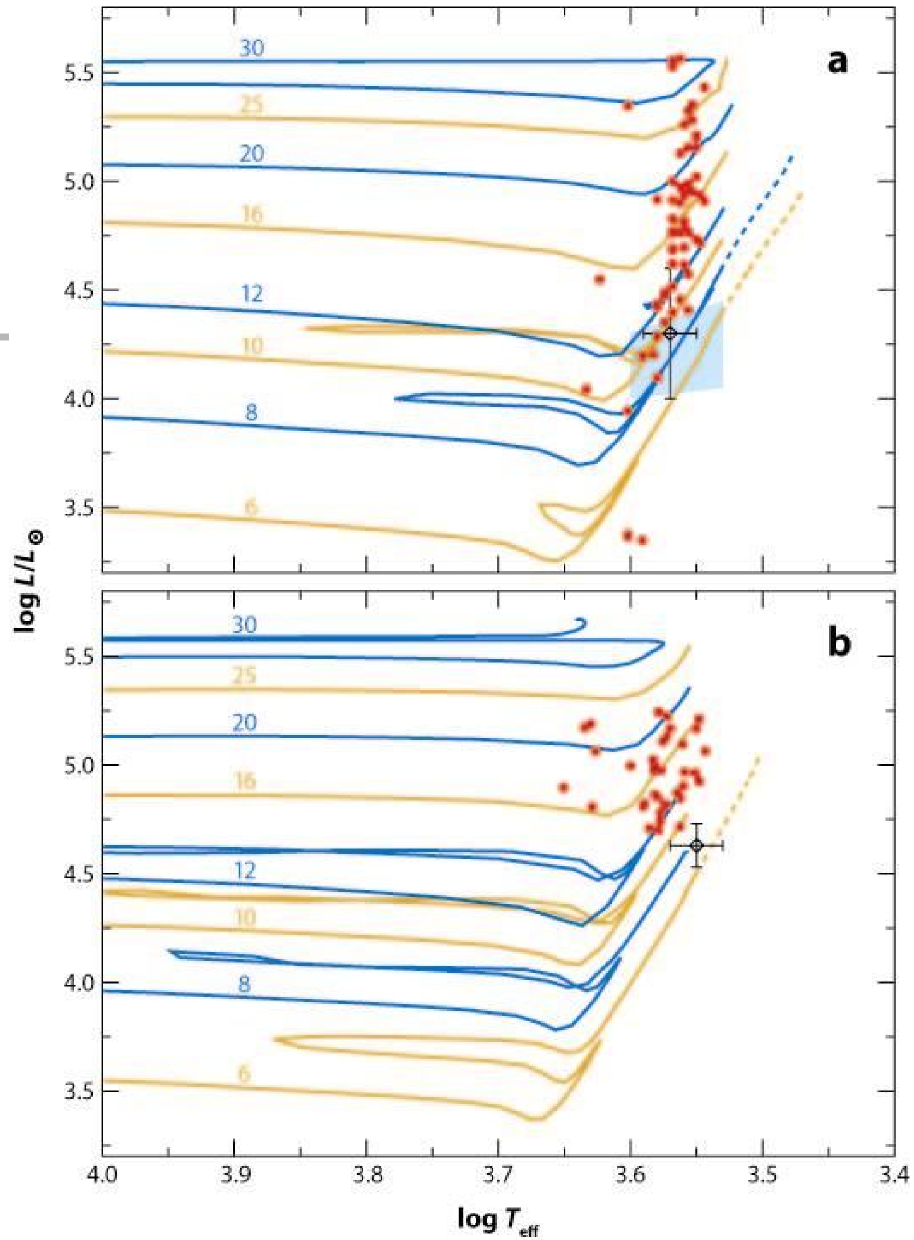


Strong dependence on assumptions but:

- $\sim 9\,M_{\odot}$ for an EC SN
- $\sim 10\,M_{\odot}$ for a CC SN

Lower initial mass for a supernova progenitor

$8.5^{+1}_{-1.5}\ M_{\odot}$

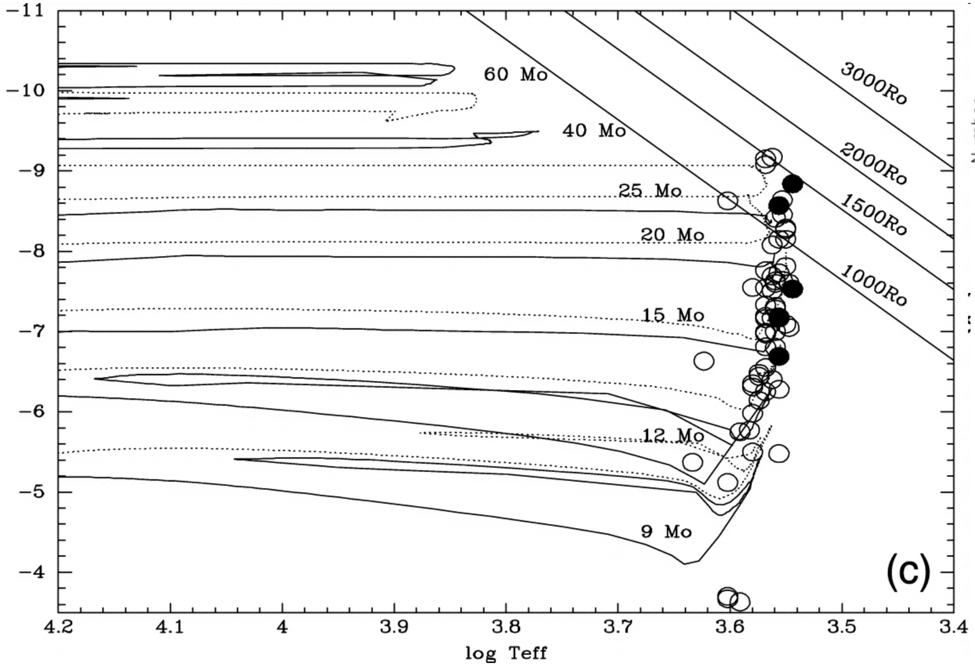


Observed supernova progenitors

(Smartt 2009, ARA&A 47, 63)

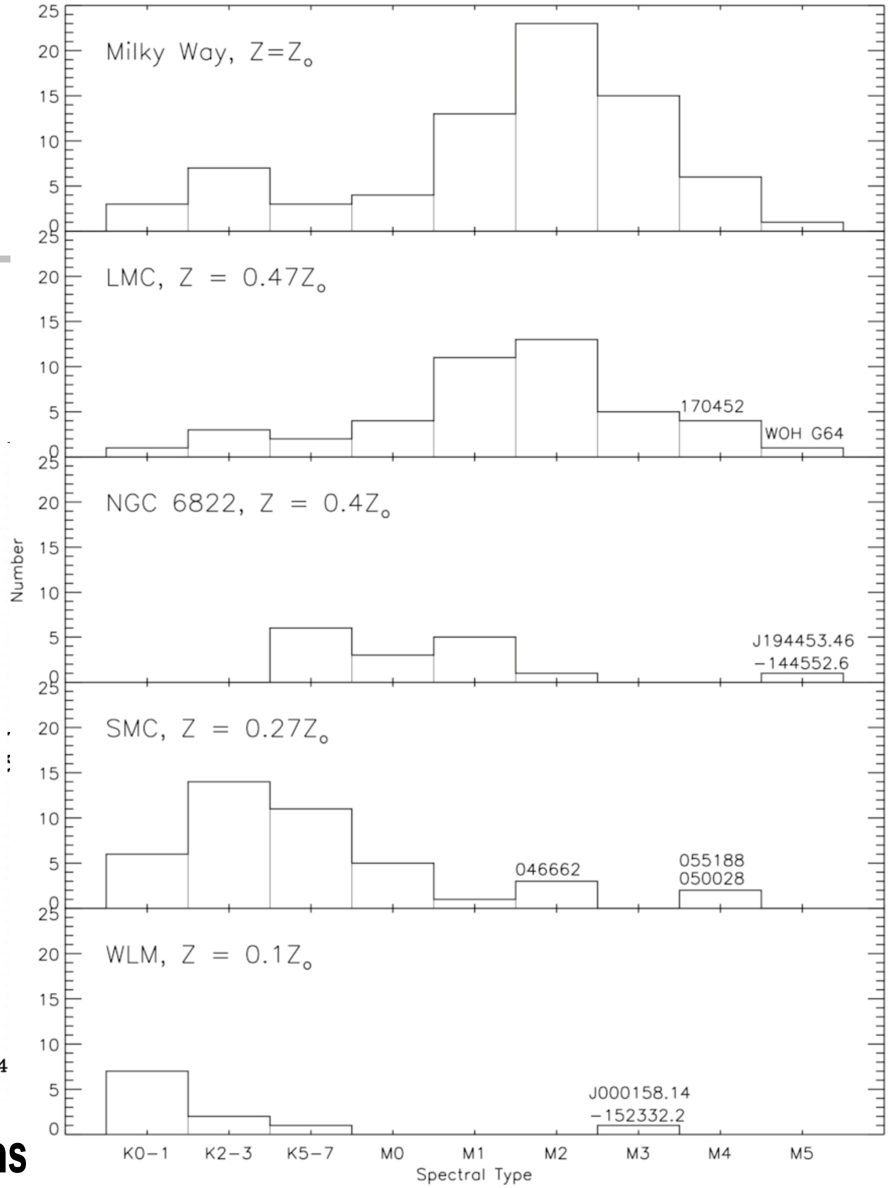
Smartt SJ. 2009.
Annu. Rev. Astron. Astrophys. 47:63–106

RSGs in the Milky Way



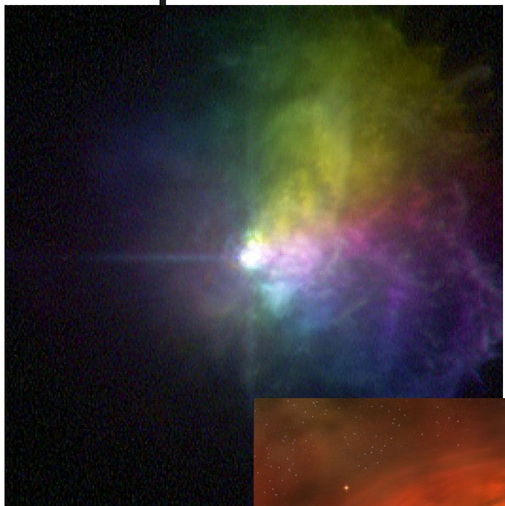
Red supergiants in clusters and associations

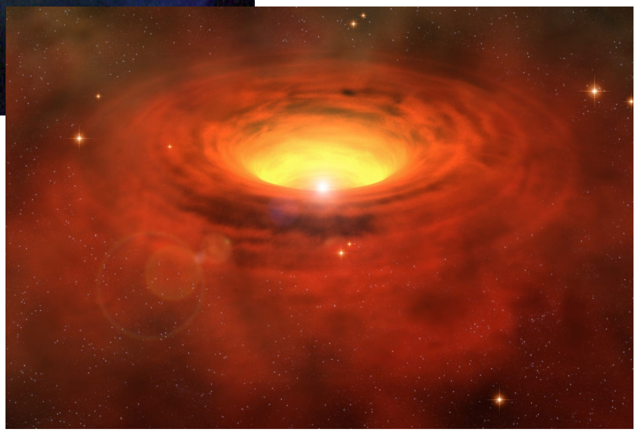
(Levesque et al. 2005, ApJ 628, 973)



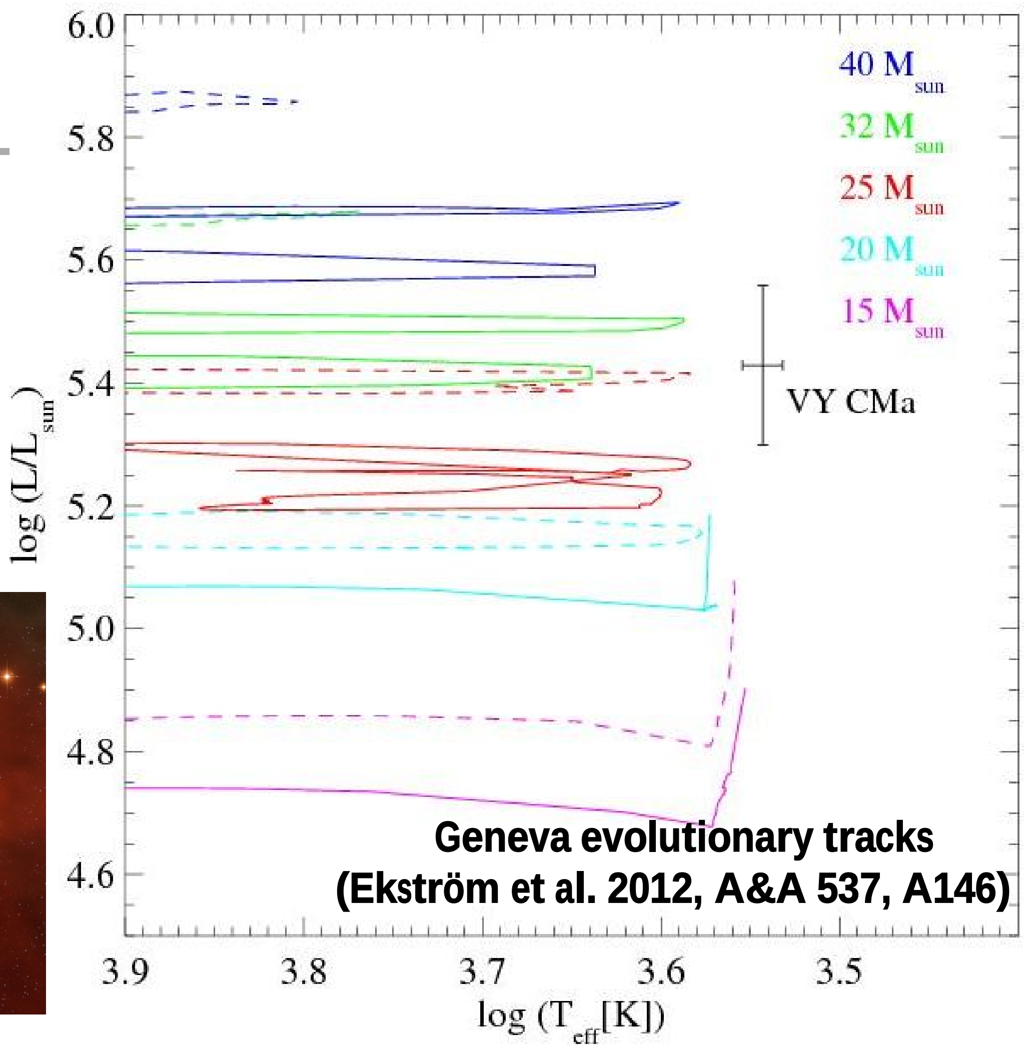
(Levesque et al. 2012, AJ 144, 2)

VY CMa



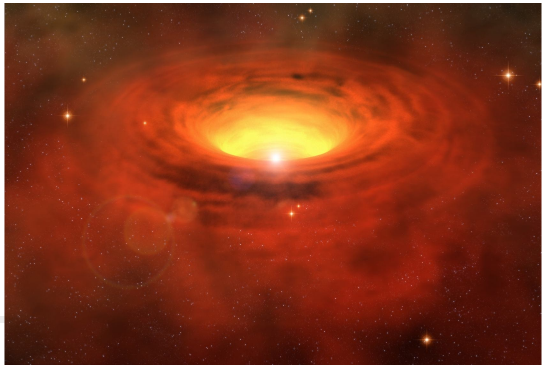


Humphreys et. al. 2007, AJ 133, 2716

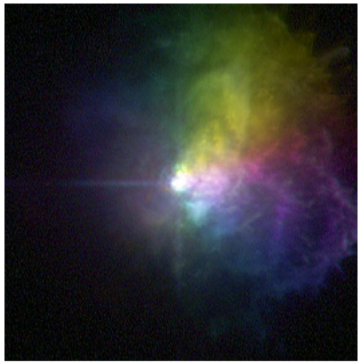


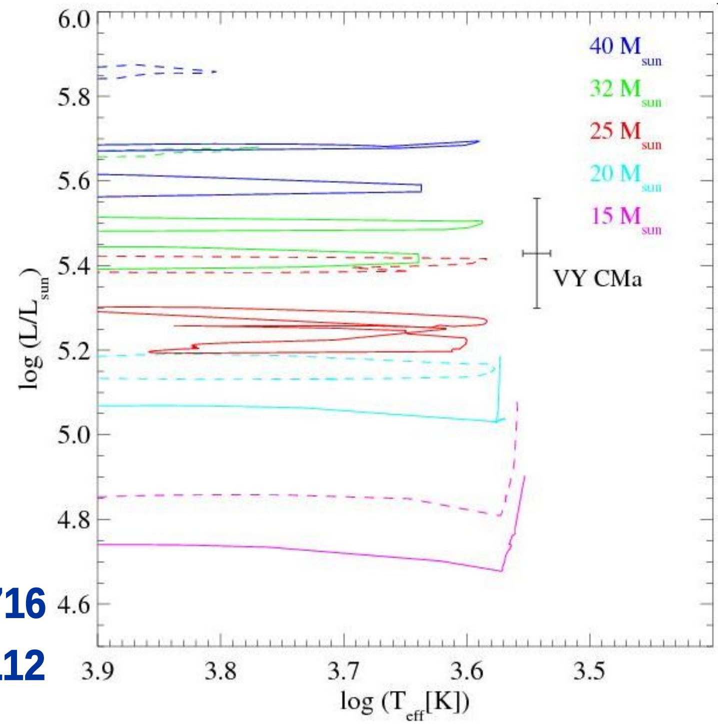
- *Distance from radio parallaxes* **(Zhang et al. 2012, ApJ 744, A23)**
- *Size from VLTI interferometry* **Wittkwoski et al. 2012, A&A 540, L12**

Late M Supergiants

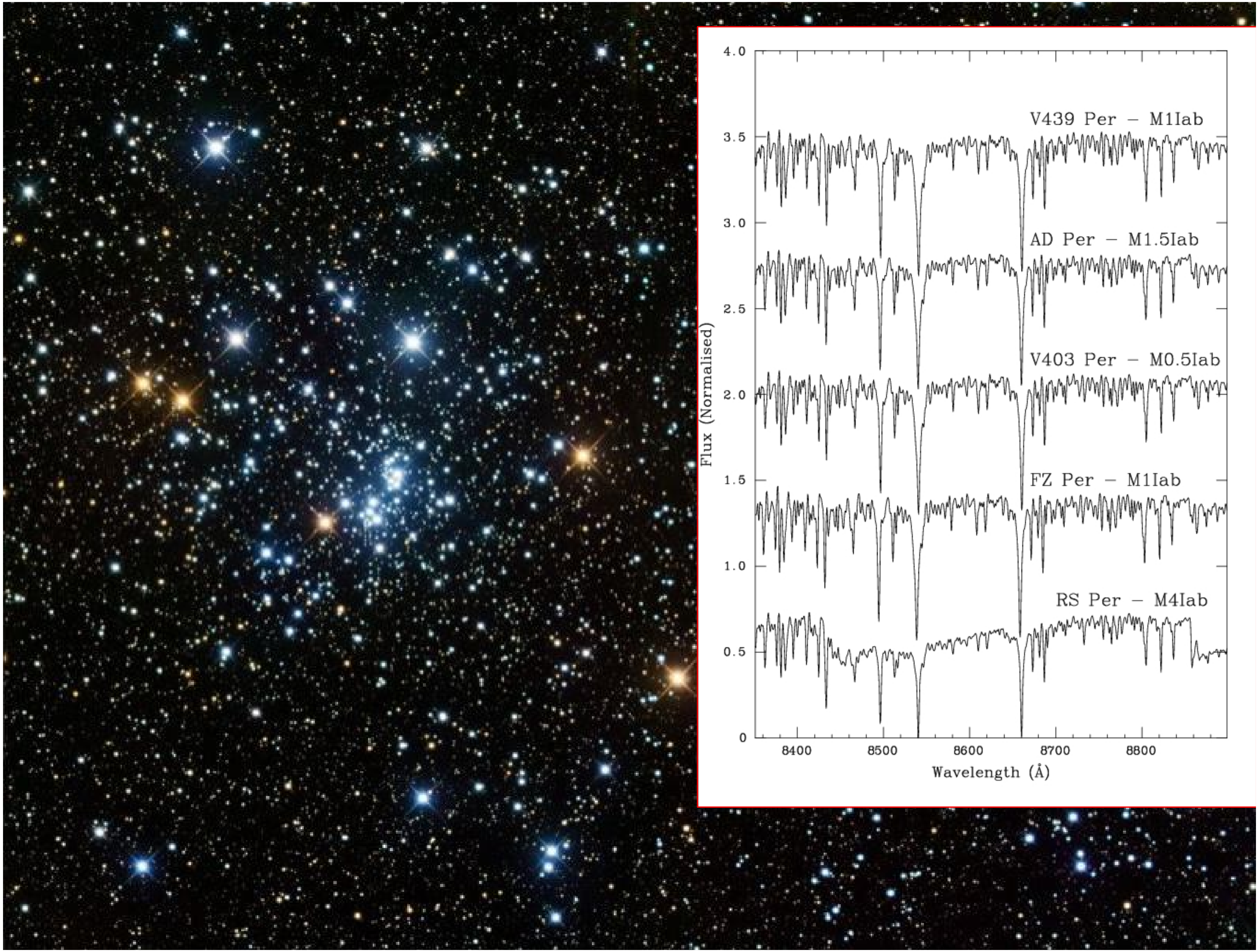


- Evidence for heavy mass loss (**Wing 2009, Verheyen+ 2012**)
  - S Per M4Ia/Iab → M7I (**Humphreys/Fawley**)
  - W Per M3Ia → M5 (**Humphreys/Fawley**)
  - NML Cyg M6Ia?
  - VX Sgr M4Ia → M10Ia
  - VY CMa M4-5Ia
  - AH Sco M5Ia (**Humphreys**)

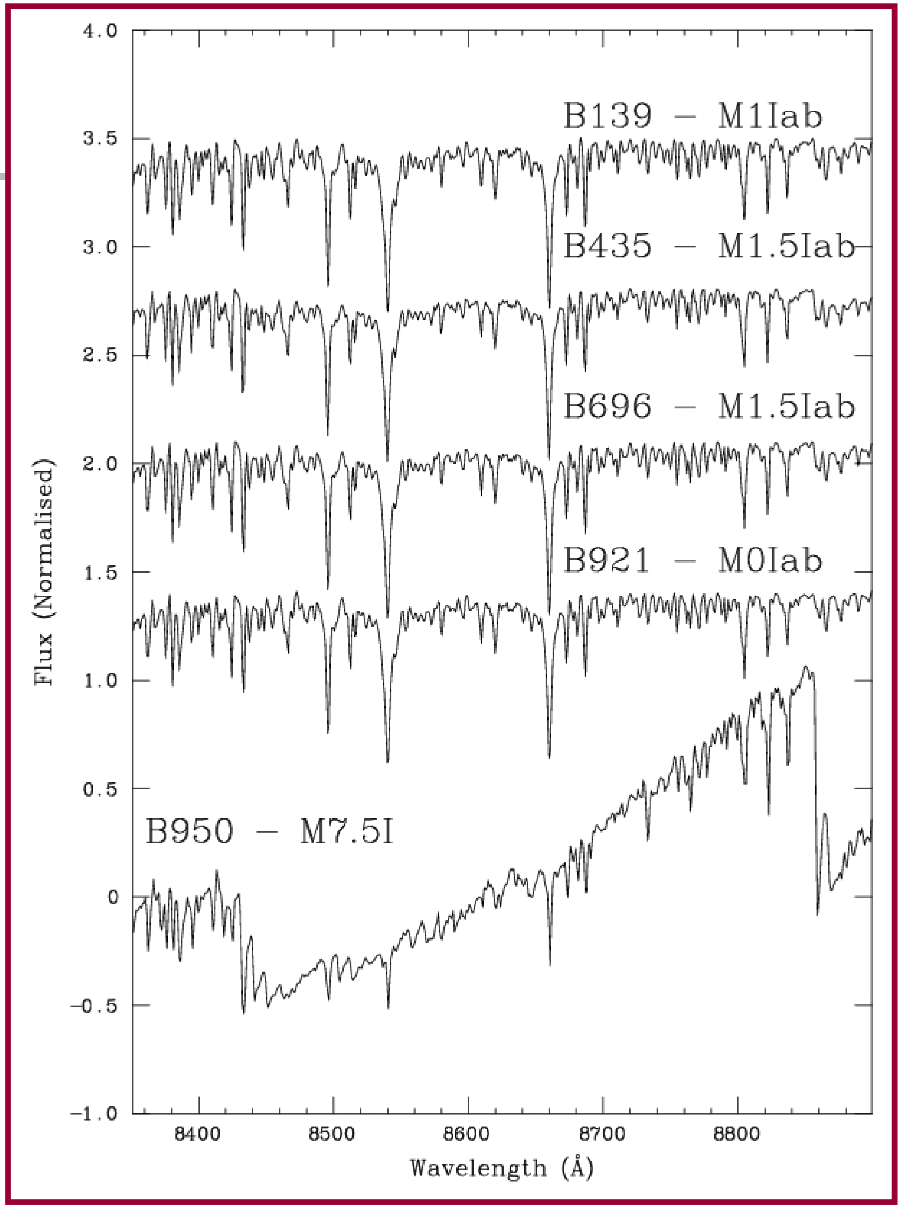




Humphreys et al. 2007, AJ 133, 2716
Wittkwoski et al. 2012, A&A 540, L12

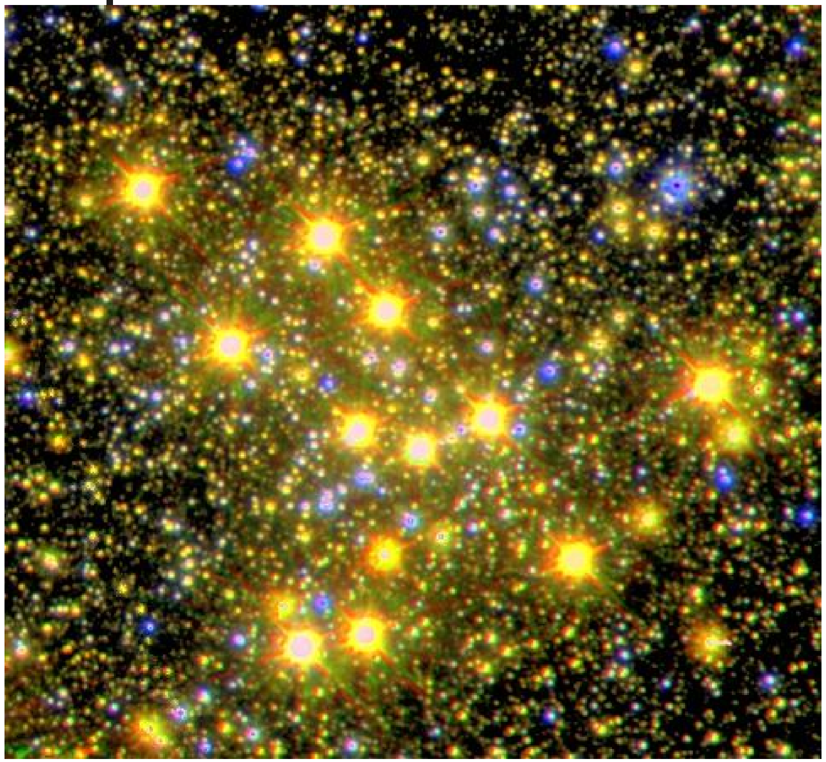

V439 Per – M1Iab
AD Per – M1.5Iab
V403 Per – M0.5Iab
FZ Per – M1Iab
RS Per – M4Iab
Flux (Normalised)
Wavelength (Å)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
8400
8500
8600
8700
8800

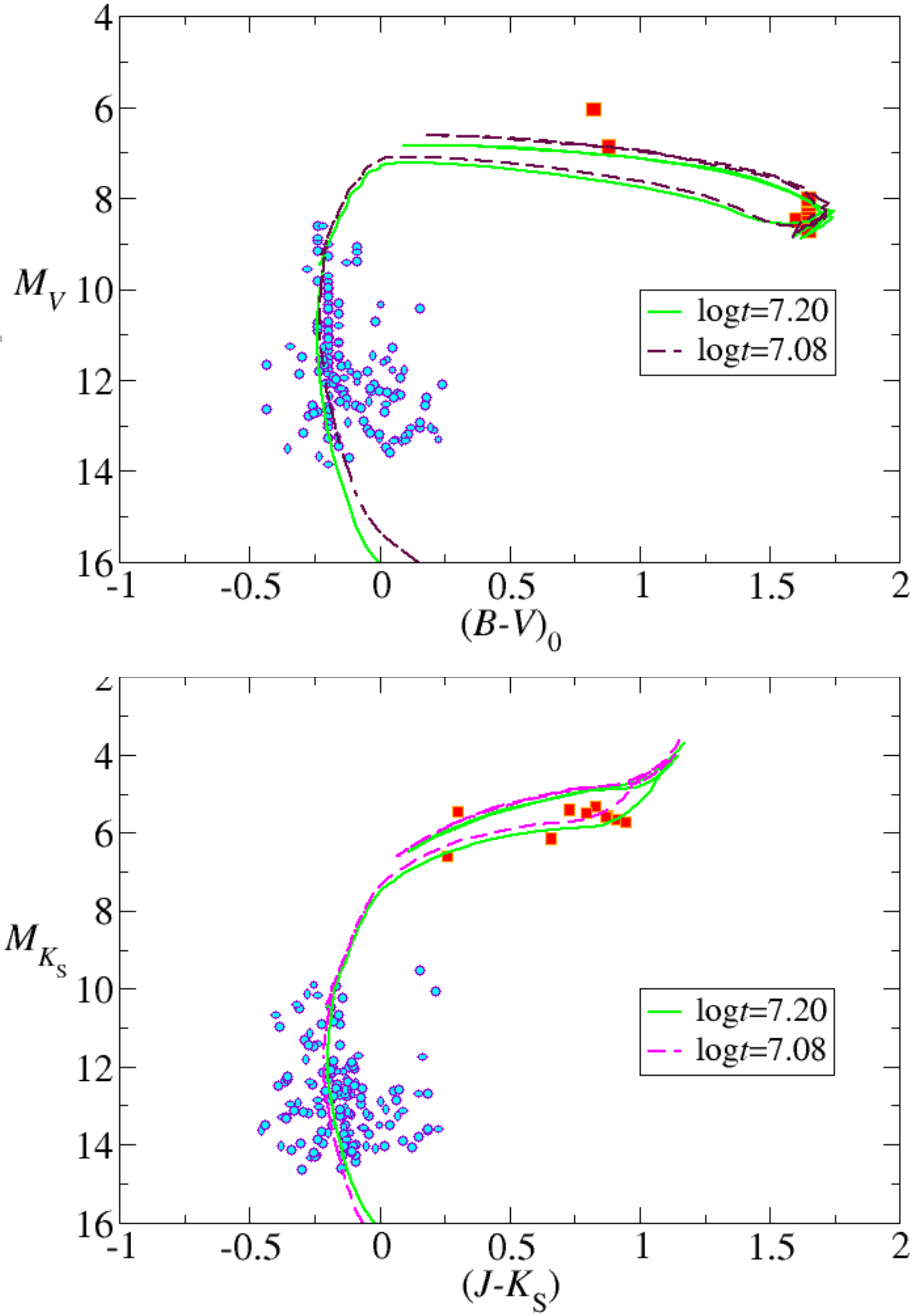
NGC 7419



Marco & Negueruela (2013, A&A 552, A92)

VdBH 222

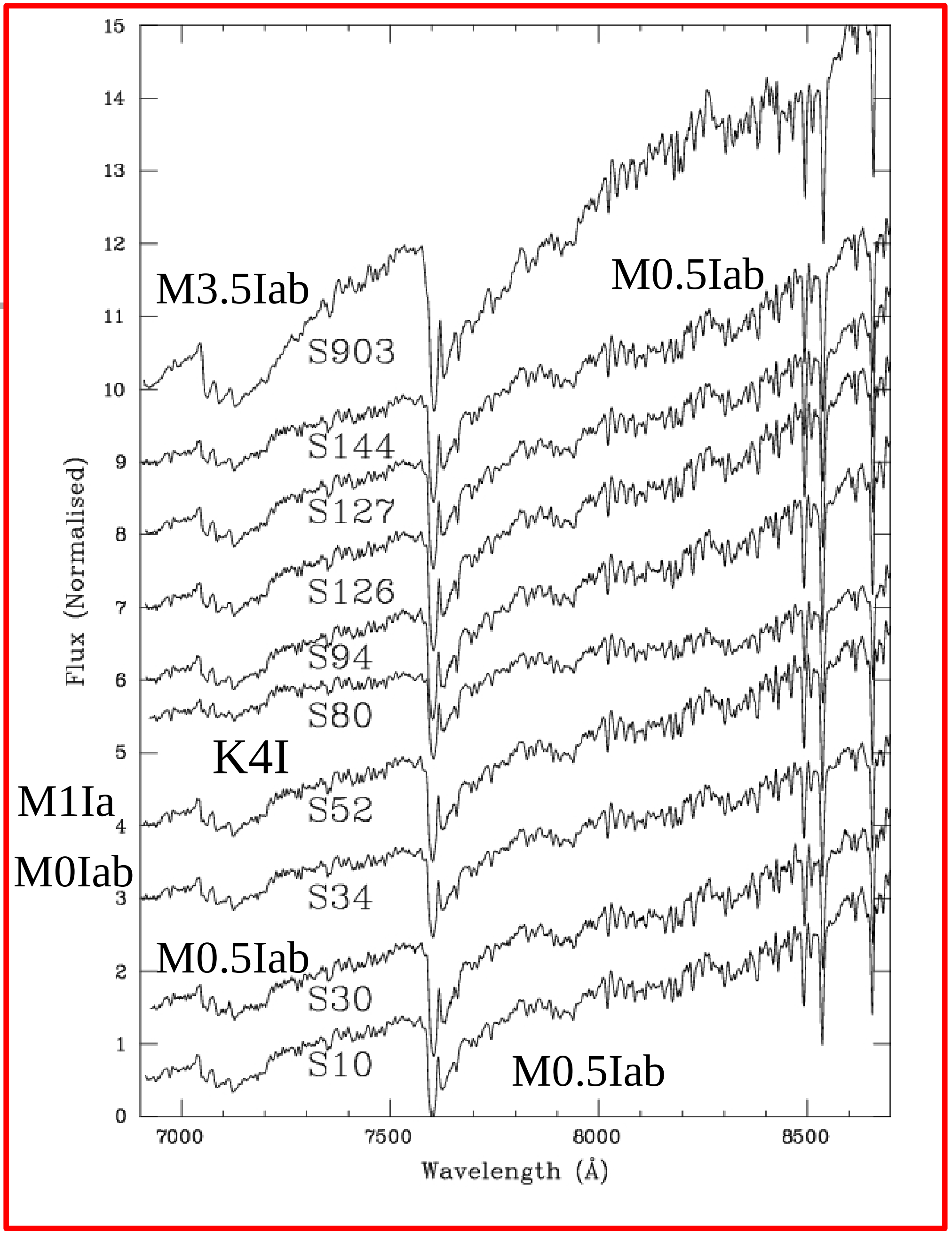




Marco et al., in preparation

VdBH 222

M1.5Iab
M0Iab
M1Iab



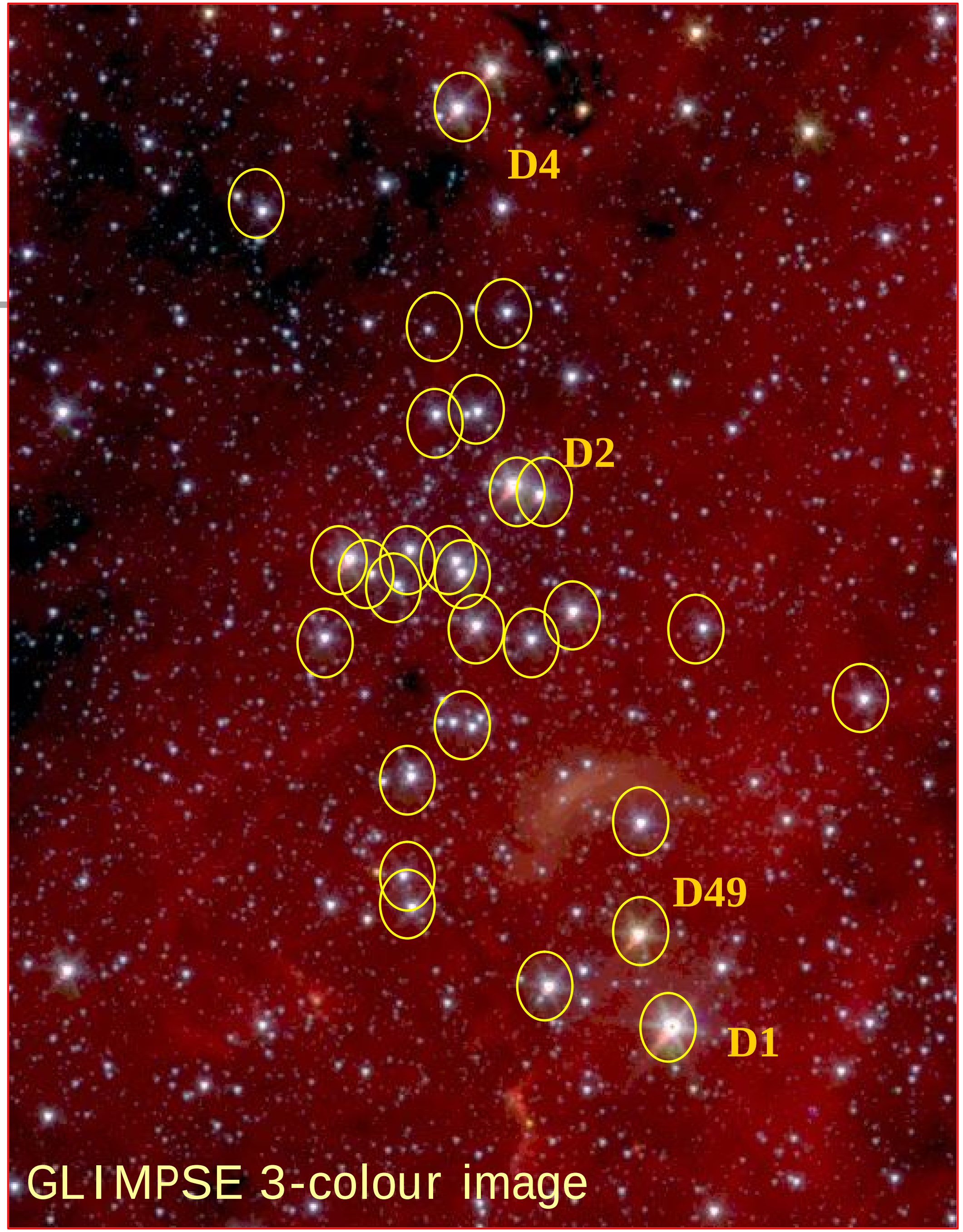
Marco et al., in preparation

Stephenson 2

- Second cluster of red supergiants found towards the base of the Scutum Arm
- Concentration of > 26 RSGs

(**Davies et al. 2007, ApJ 671, 781**)

- Implied mass > $5x10^4\ M_\odot$



Family portrait

D1 M6-7I
D2 M7/7.5I
D3 M5I
D4 M5I
D5 M5I
D6 M3.5Iab
D9 M3.5Iab
D10 M2Iab
D11 M3.5Iab

D13 M2Iab
D14 ~M2.5I
D15 M1.5Iab
D16 M1-1.5Iab
D17 M1.5Iab
D18 M1-1.5Iab
D19 M1Iab
D20 M1.5Iab
D21 ~M1.5I
D23 ?

D26 M2Iab
D27 early MI
D29 ~M0I
D30 ~M1I
D31 M1.5Iab
D49 embedded
D52 ?
D72 ?

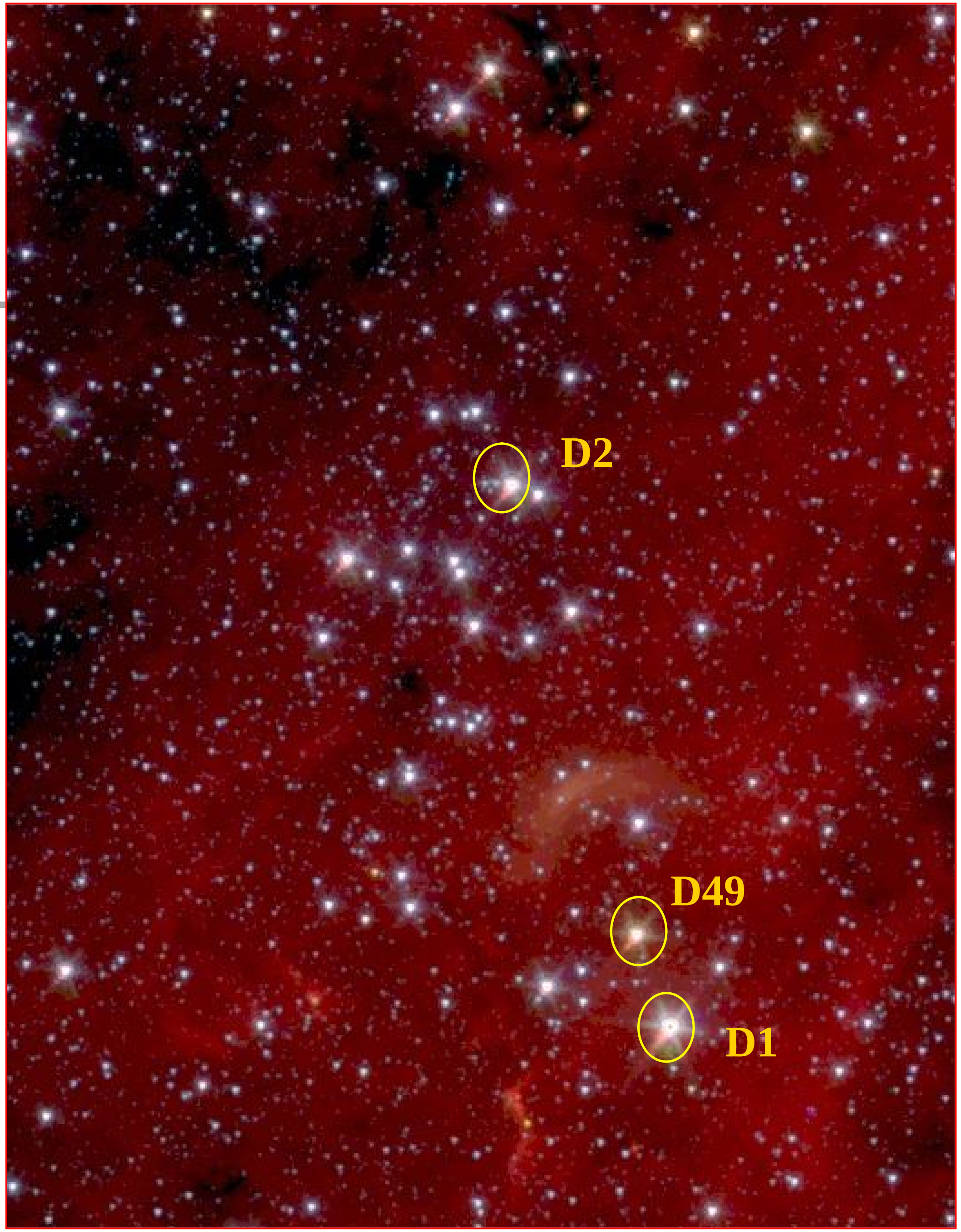
Negueruela et al. 2013, EAS 60, 279

Stephenson 2

- Deguchi et al. (**2010, PASJ 62, 391**) searched for masers associated with the stars. They only detect 3 objects.

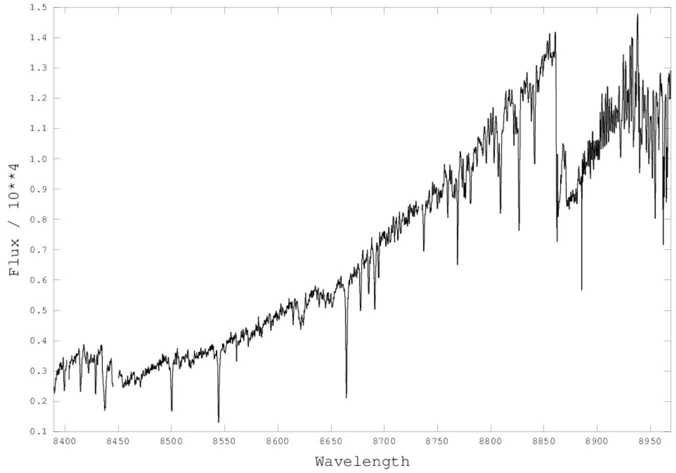
See also Verheyen et al. (2012, A&A 514, A36)

GLIMPSE 3-colour image

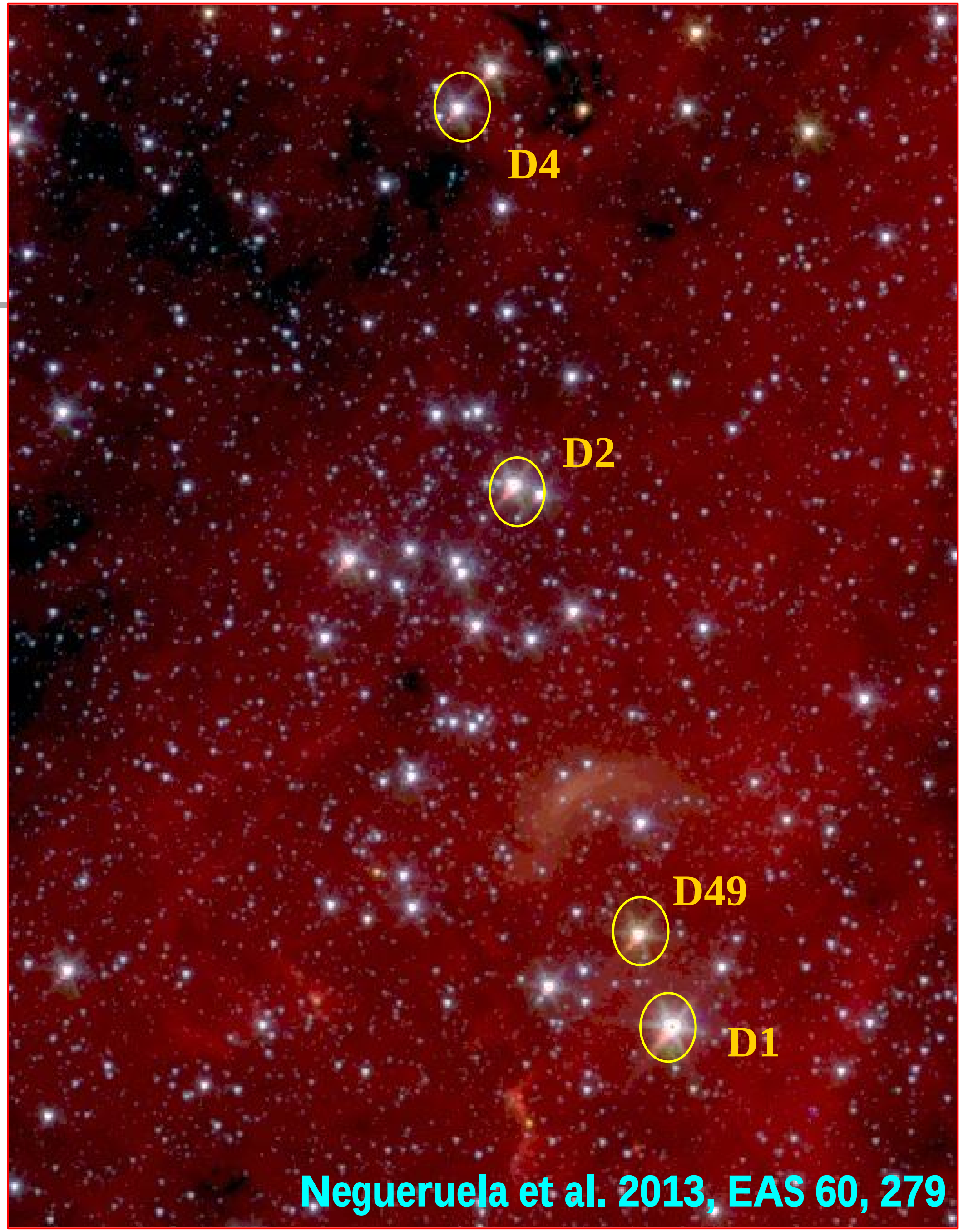


Stephenson 2

- D1 = IRAS 18363-0607
- K =2.9
- M6-7I

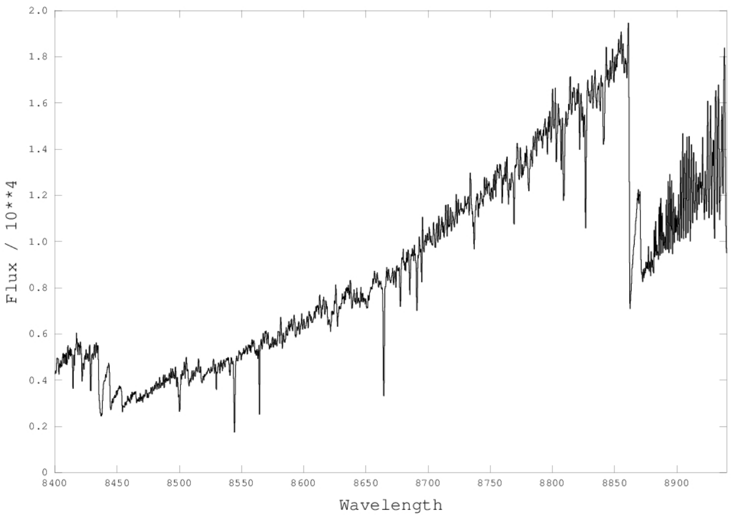


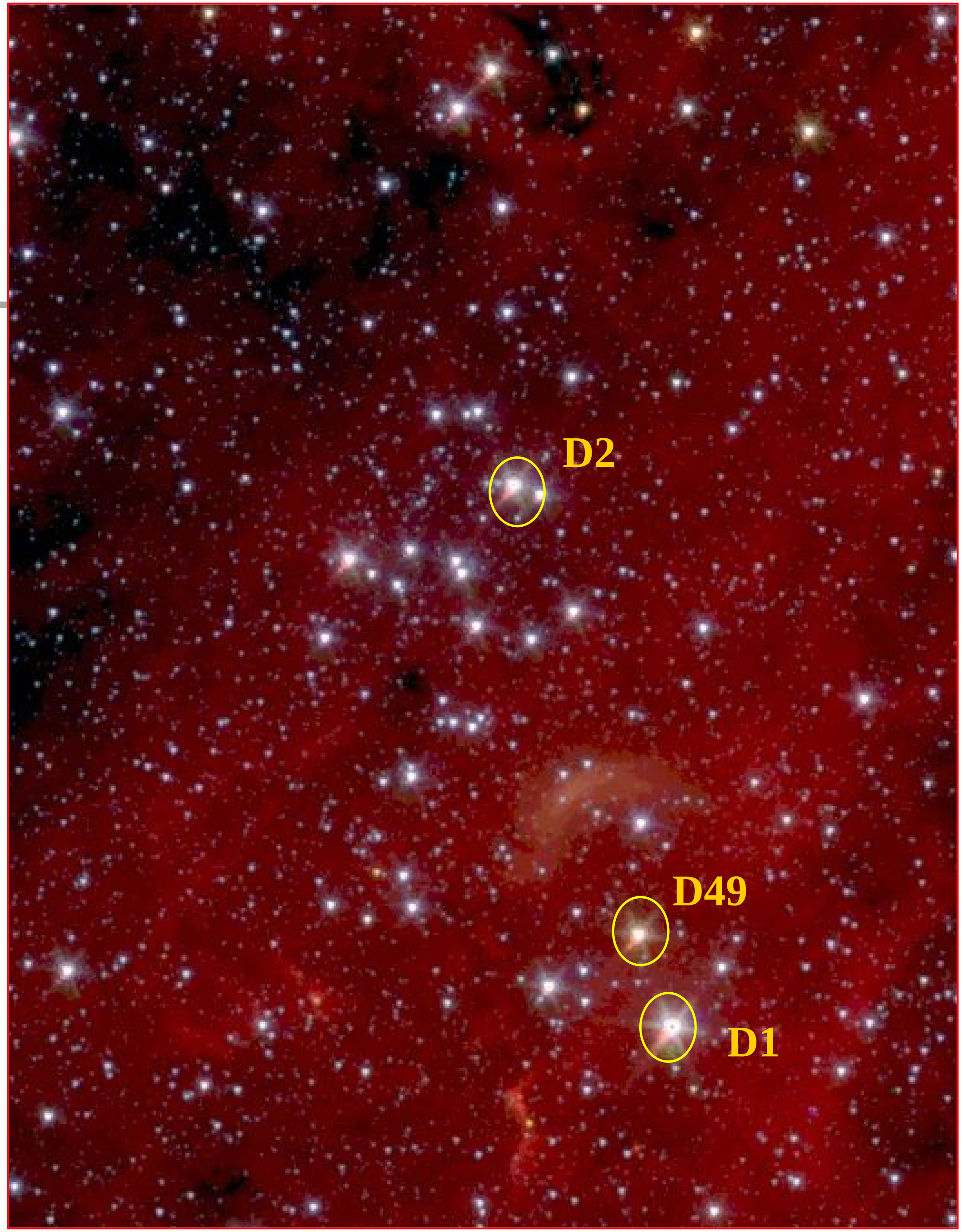
GLIMPSE 3-colour image



Stephenson 2

- D2 = IRC -10 447
- M7I/M7.5I



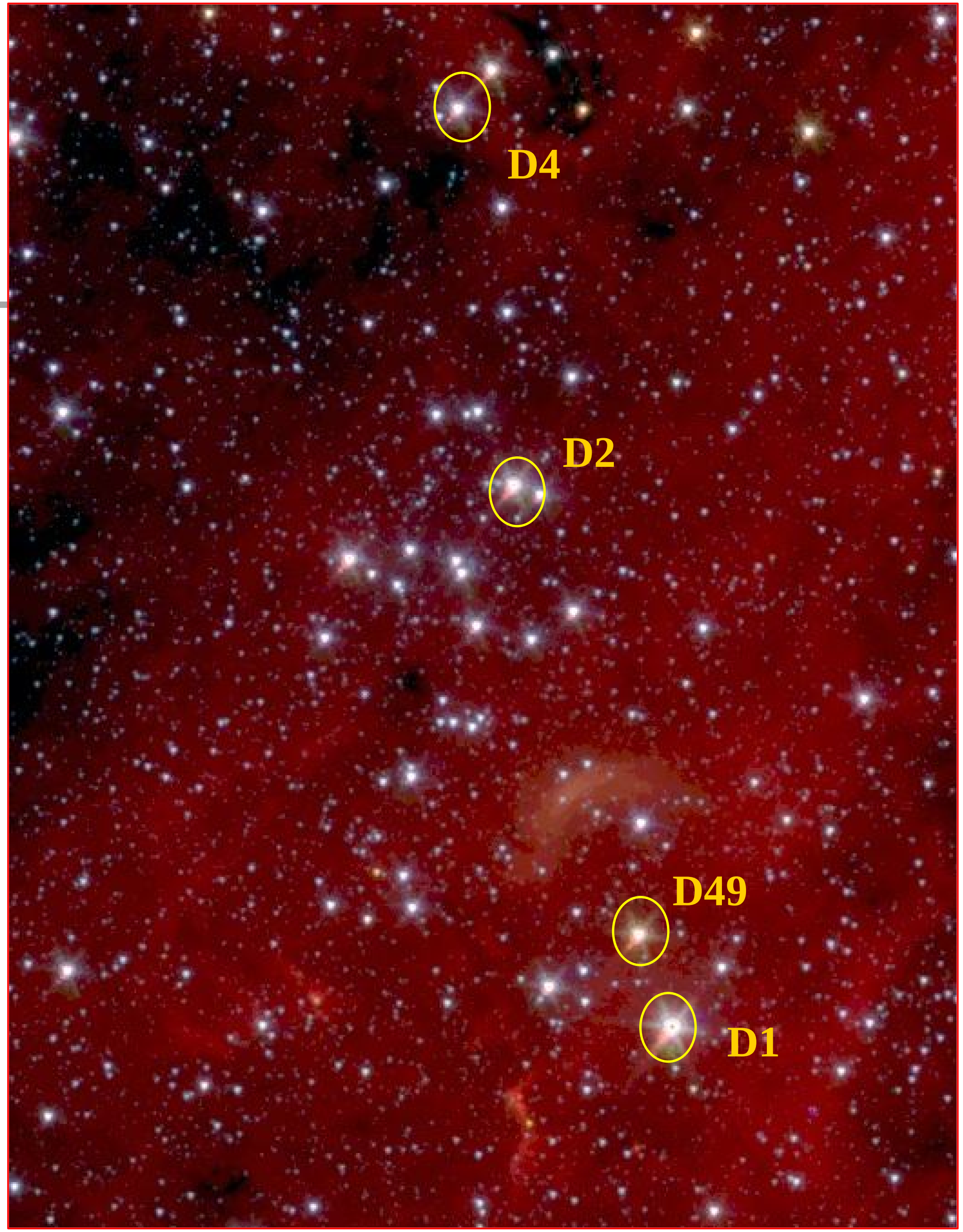


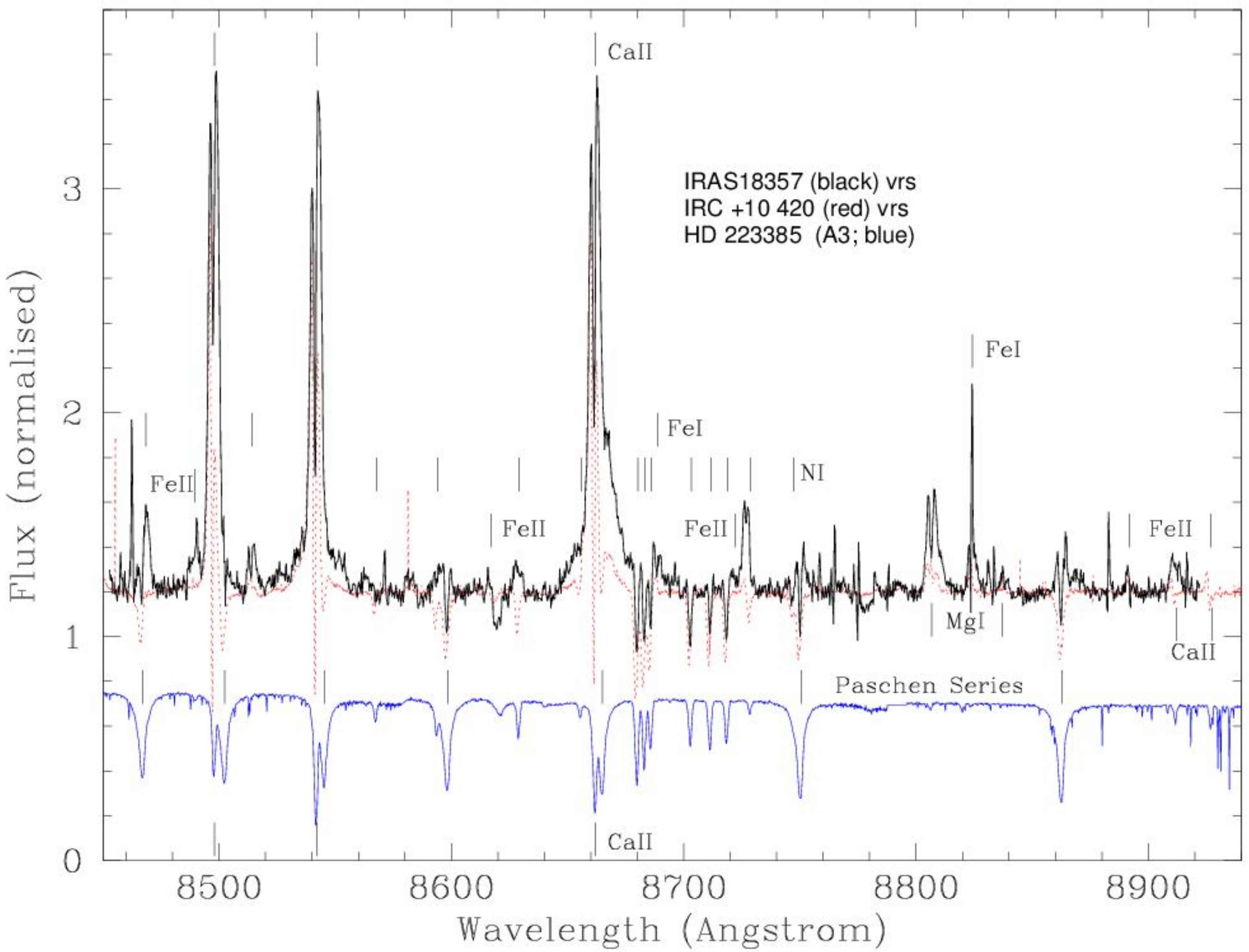
GLIMPSE 3-colour image

Stephenson 2

- D49 is a very embedded source $E(J\text{-}K) \approx 7$, of which around 4 mag are circumstellar, implying
  $A_V \sim 25$ mag

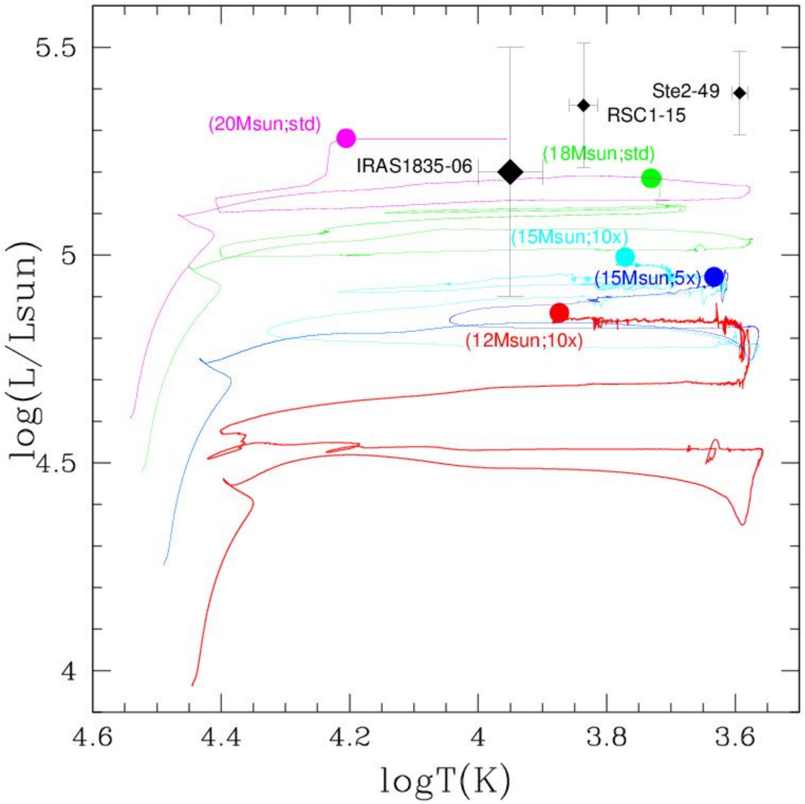
GLIMPSE 3-colour image

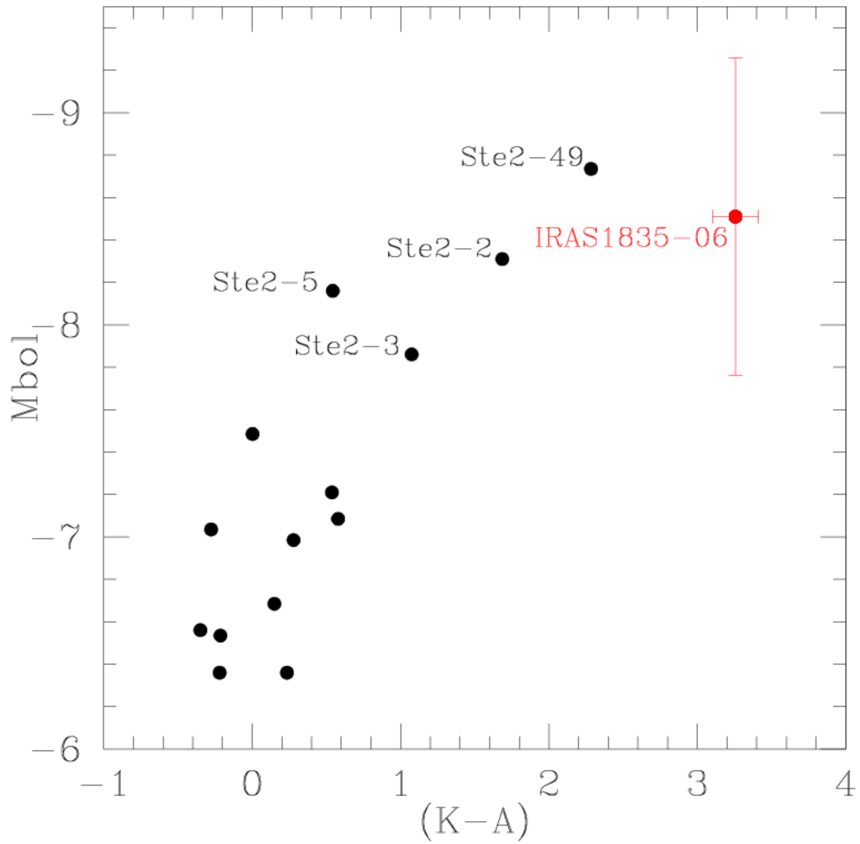




Clark et al., submitted to A&A

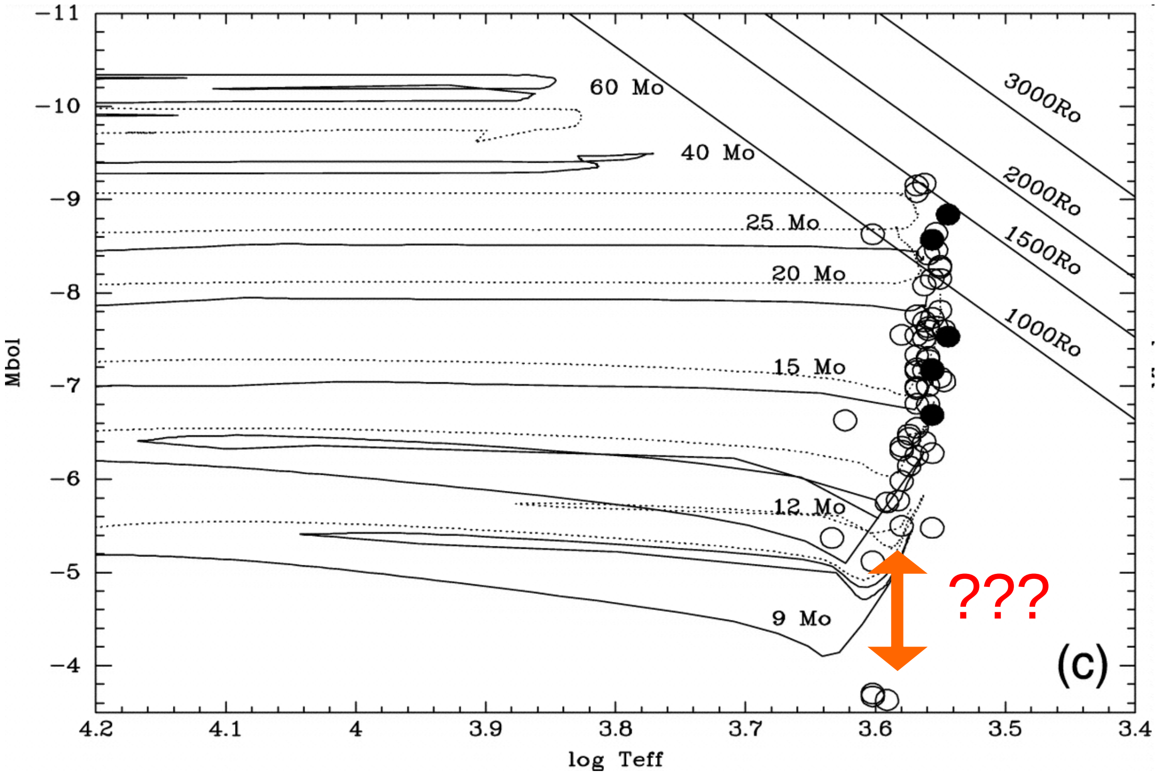
IRAS 18357-0604





Clark et al., submitted to A&A

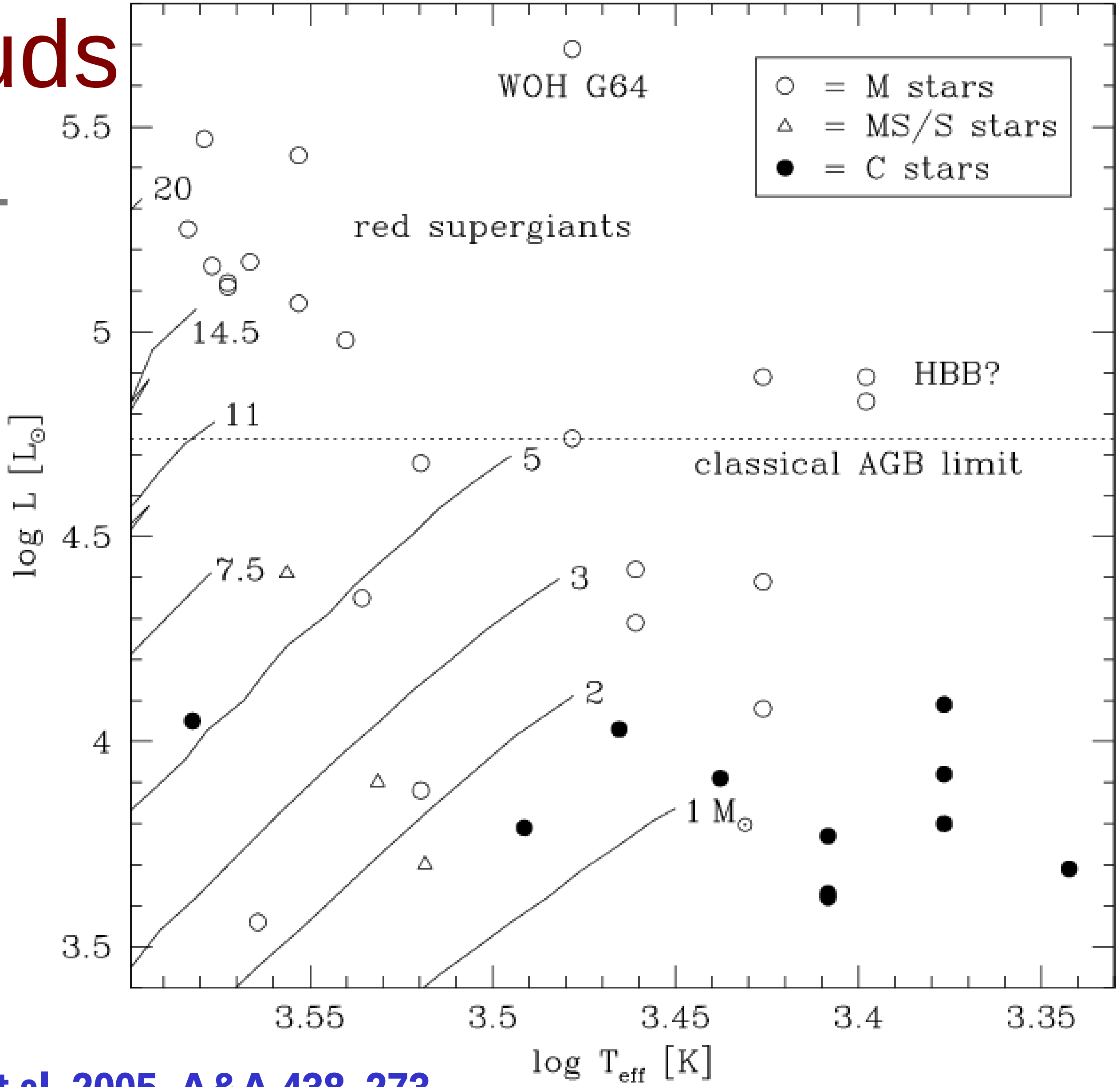
But where are the low-mass RSGs?



Red supergiants in clusters and associations
(Levesque et al. 2005, ApJ 628, 973)

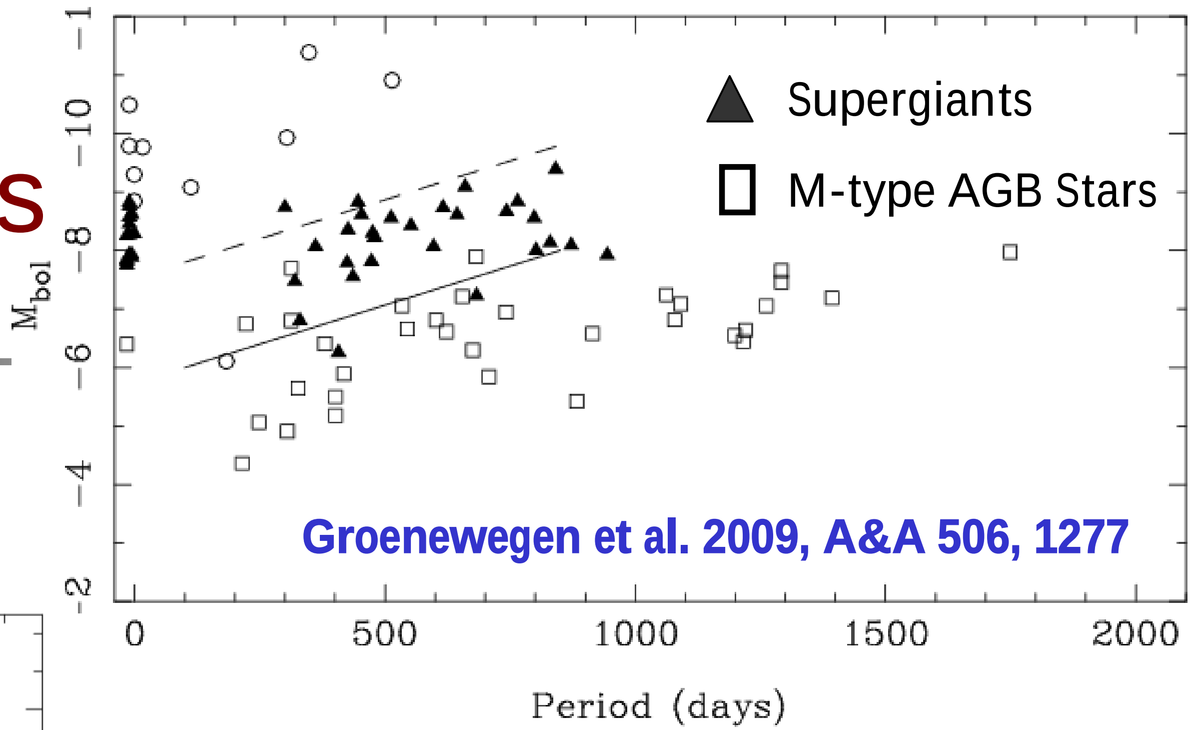
- There must be several observational biases acting here.
- **García-Hernández et al. (2007, A&A 462, 711)** suggest that the most massive Galactic AGB stars are late-M OH/IR stars with Rb overabundance.

The Clouds

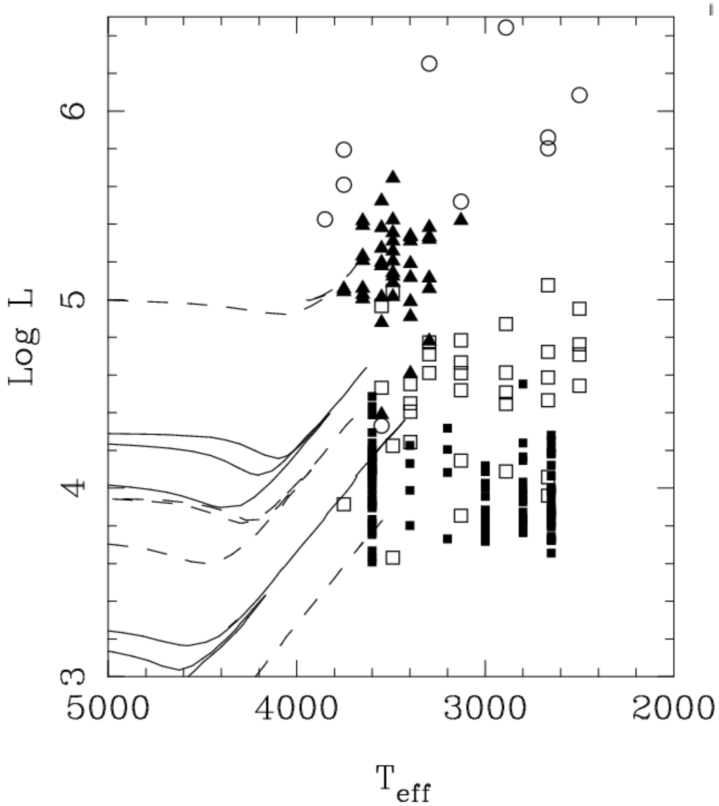


Van Loon et al. 2005, A&A 438, 273

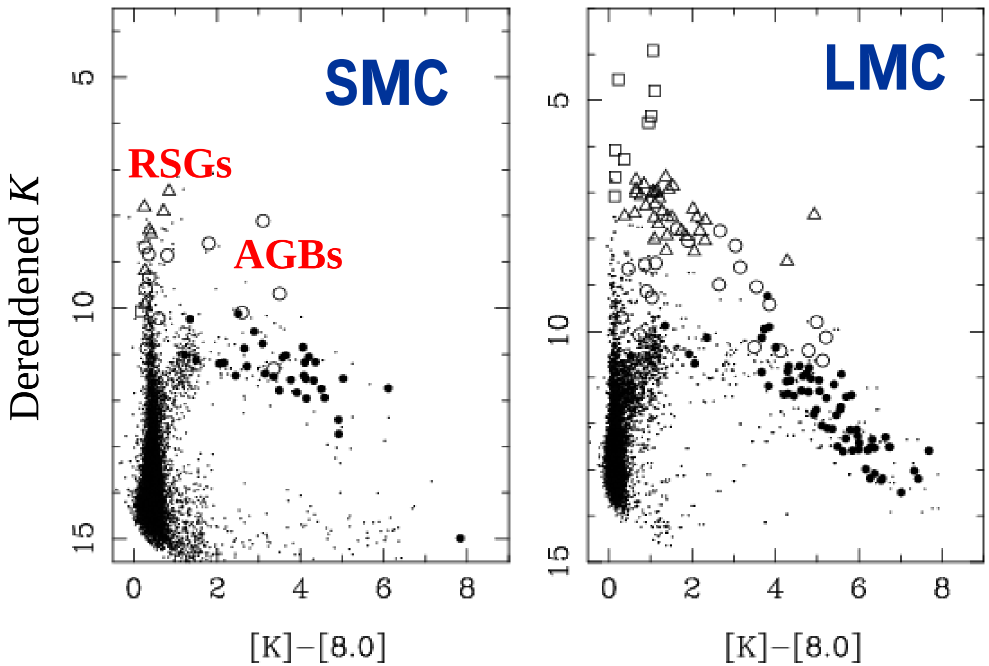
The Clouds



Supergiants
M-type AGB Stars
Groenewegen et al. 2009, A&A 506, 1277
M_{bol}
Period (days)



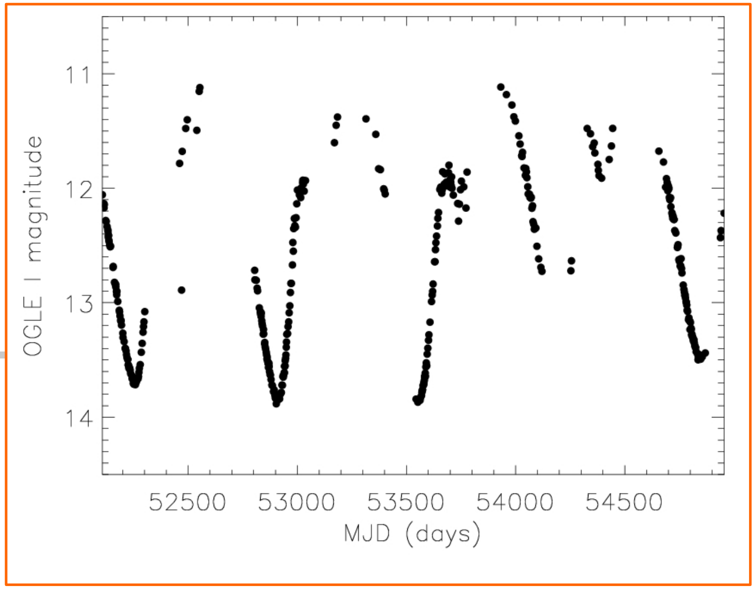
Log L
T_{eff}

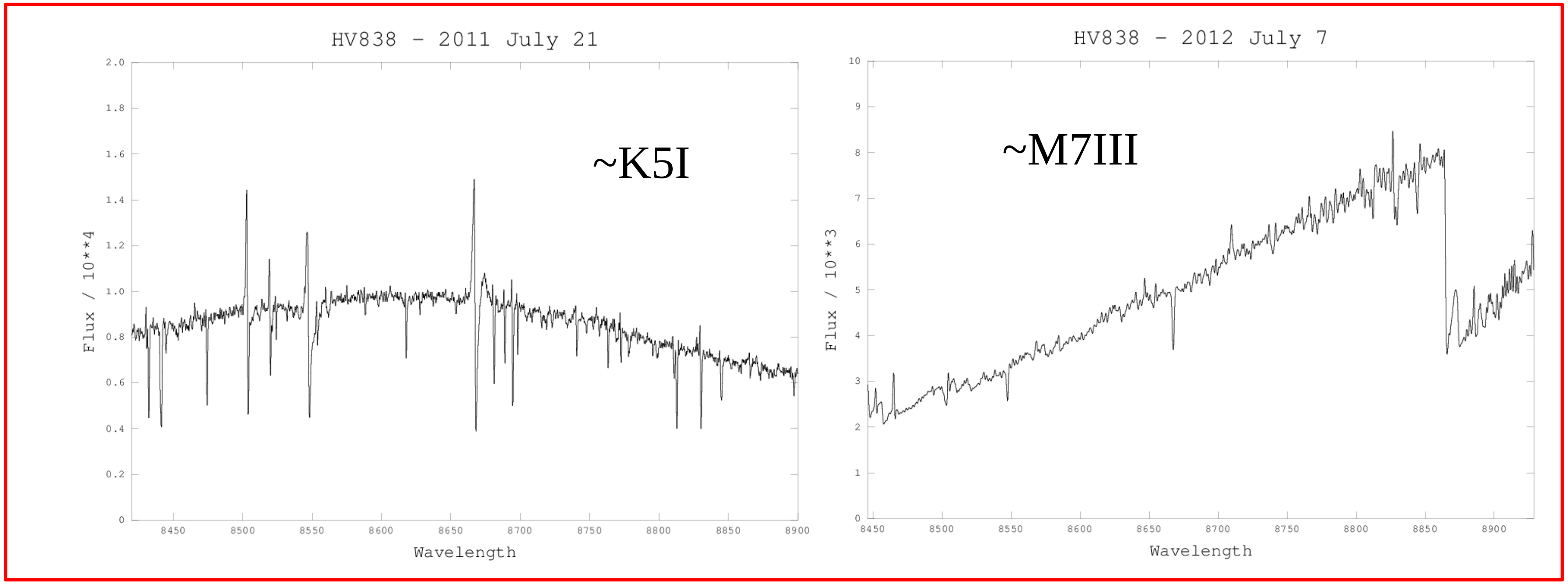


SMC
LMC
RSGs
AGBs
Dereddened K
[K]−[8.0]
[K]−[8.0]

HV 838

$M_K \approx -9.5$

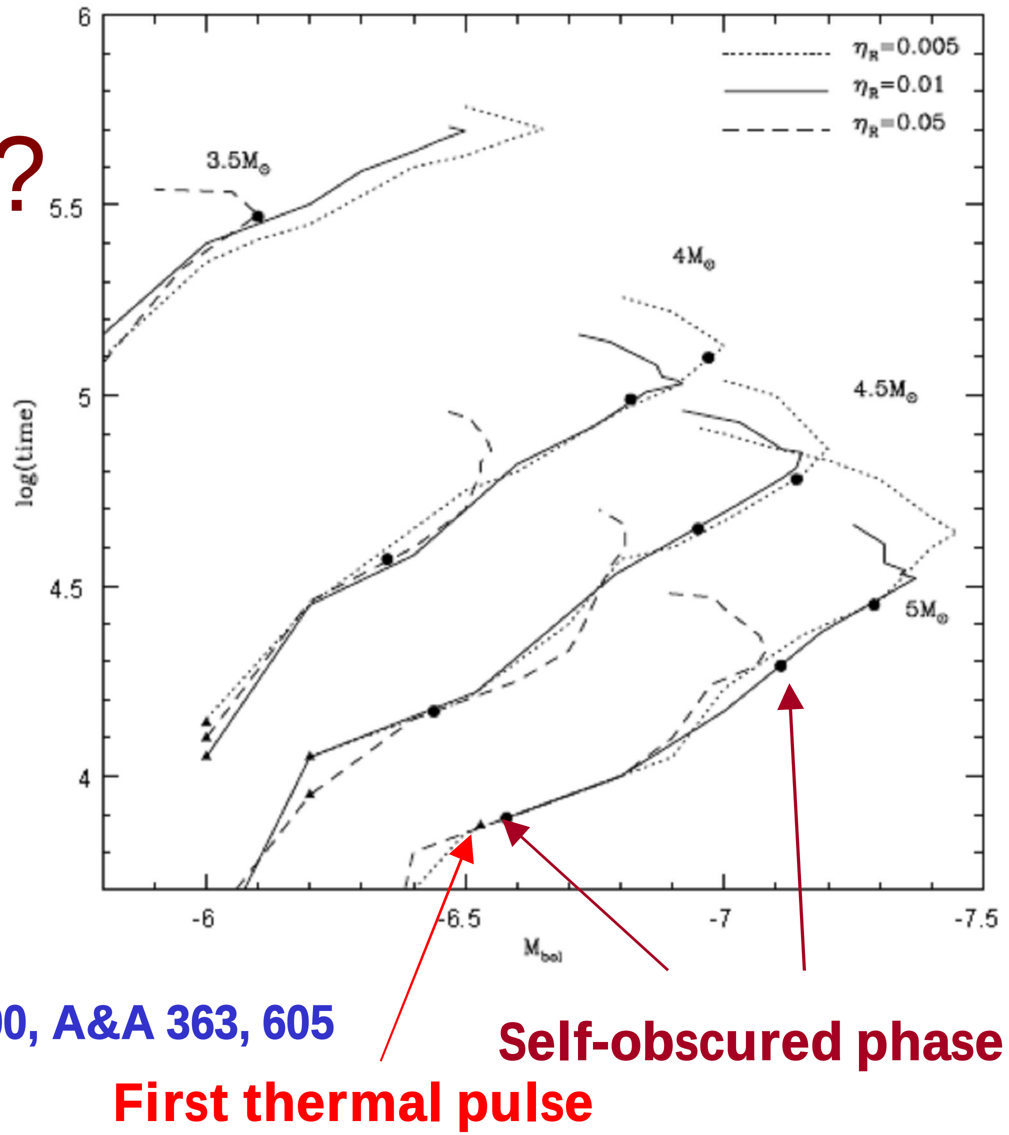




Dorda et al., in preparation

What are these things?

- Theoretical models for LMC sources suggest these are ~6 $M_{\odot}$ stars just before the first thermal pulse.
- Later, they become more luminous, but obscured by dust.

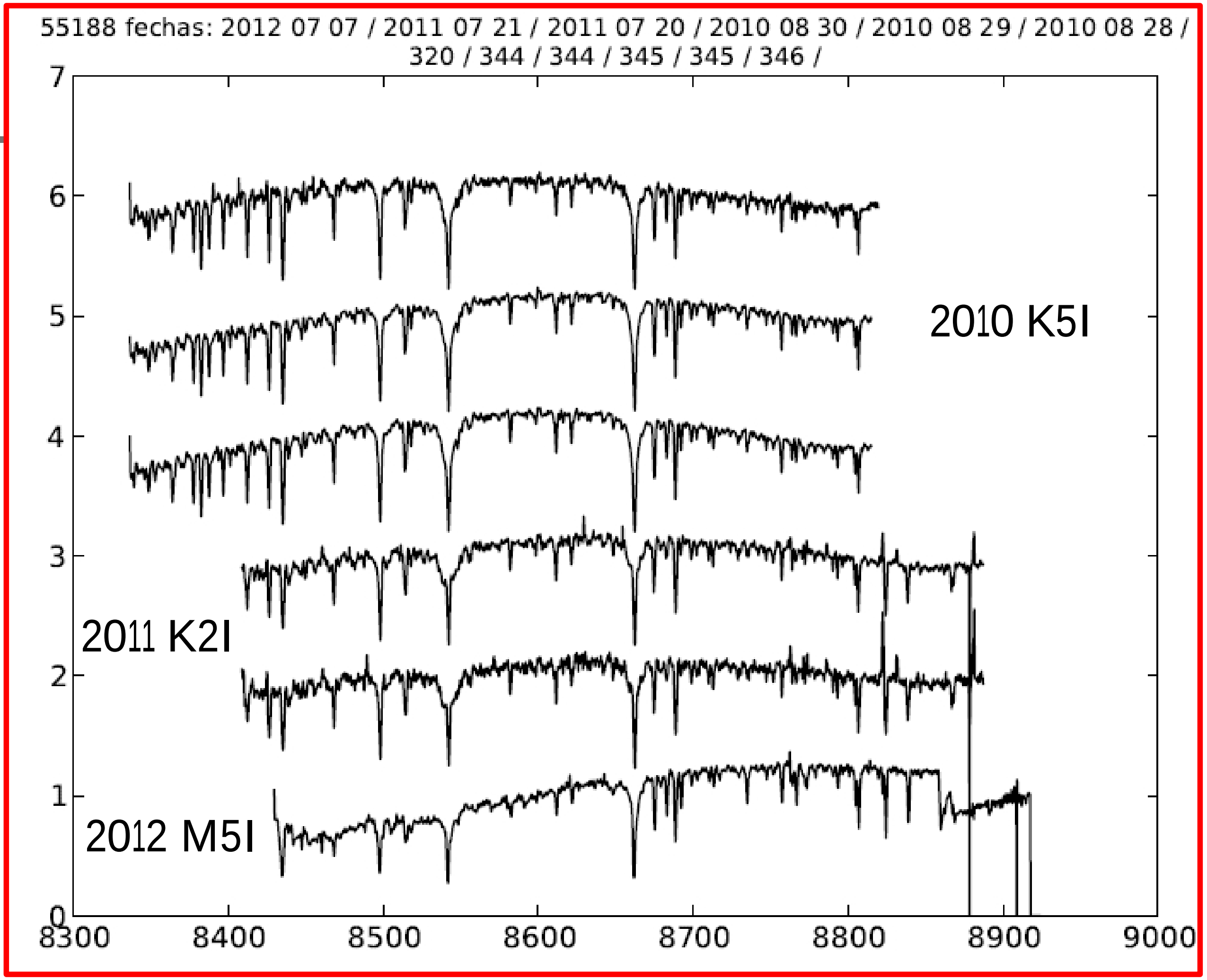


Ventura et al. 2000, A&A 363, 605

- Based on this, **García-Hernández et al. (2013, A&A 555, L3)** suggest that the Milky-Way equivalents are super-Li-rich late-M giants.

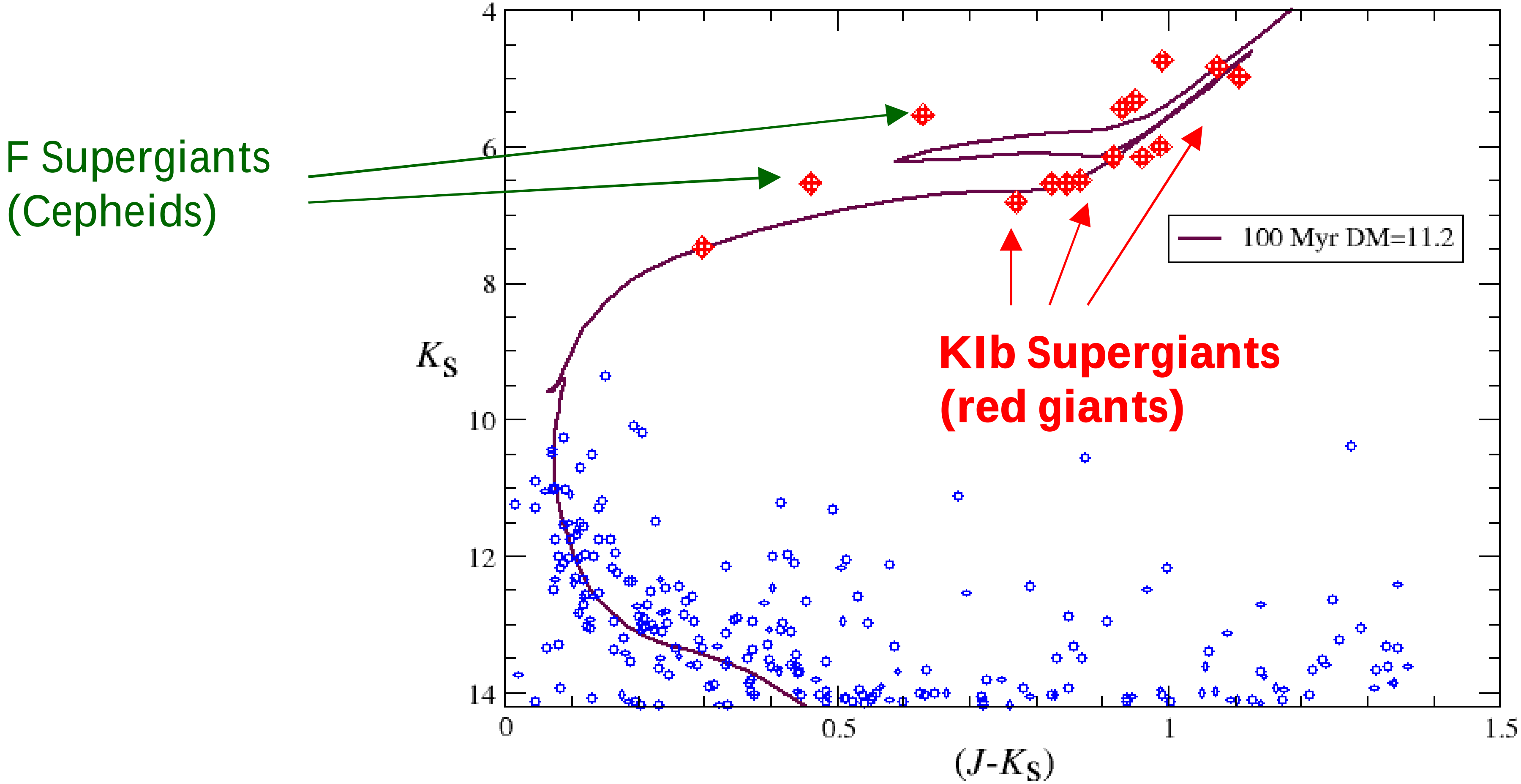
55188

$M_K \approx -10.3$



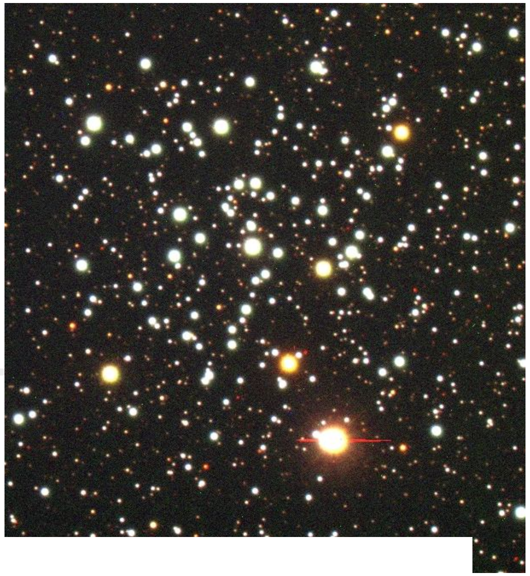
Dorda et al., in preparation

NGC 6067



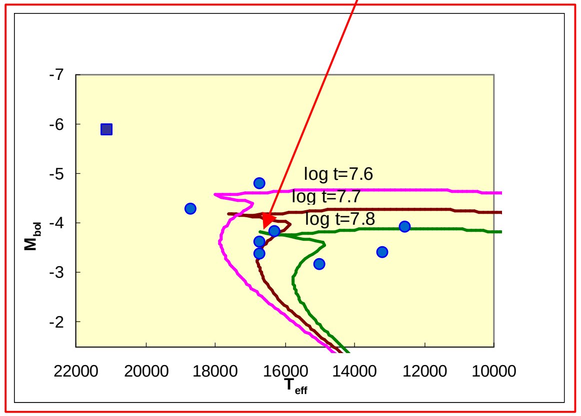
F Supergiants
(Cepheids)
KIb Supergiants
(red giants)
100 Myr DM=11.2
K_S
$(J-K_S)$
4
6
8
10
12
14
0
0.5
1
1.5

NGC 6649



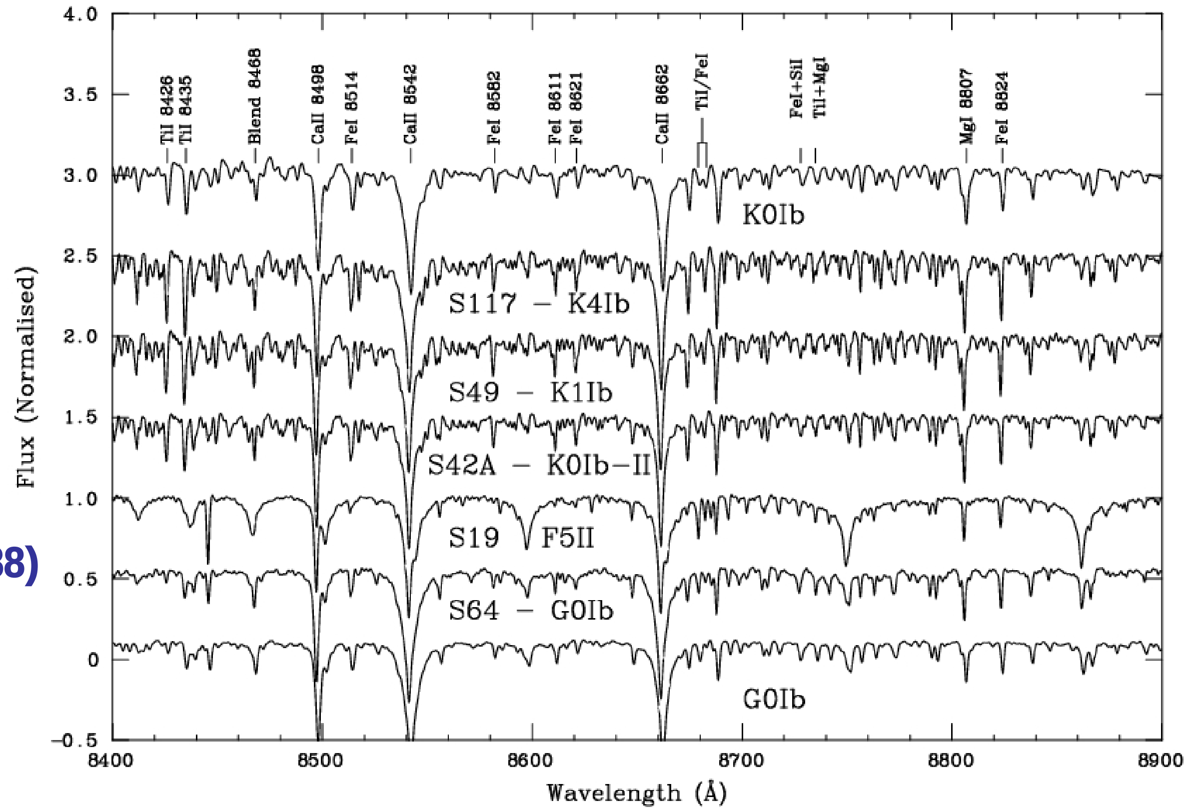
Age ~70 Myr

B4 V



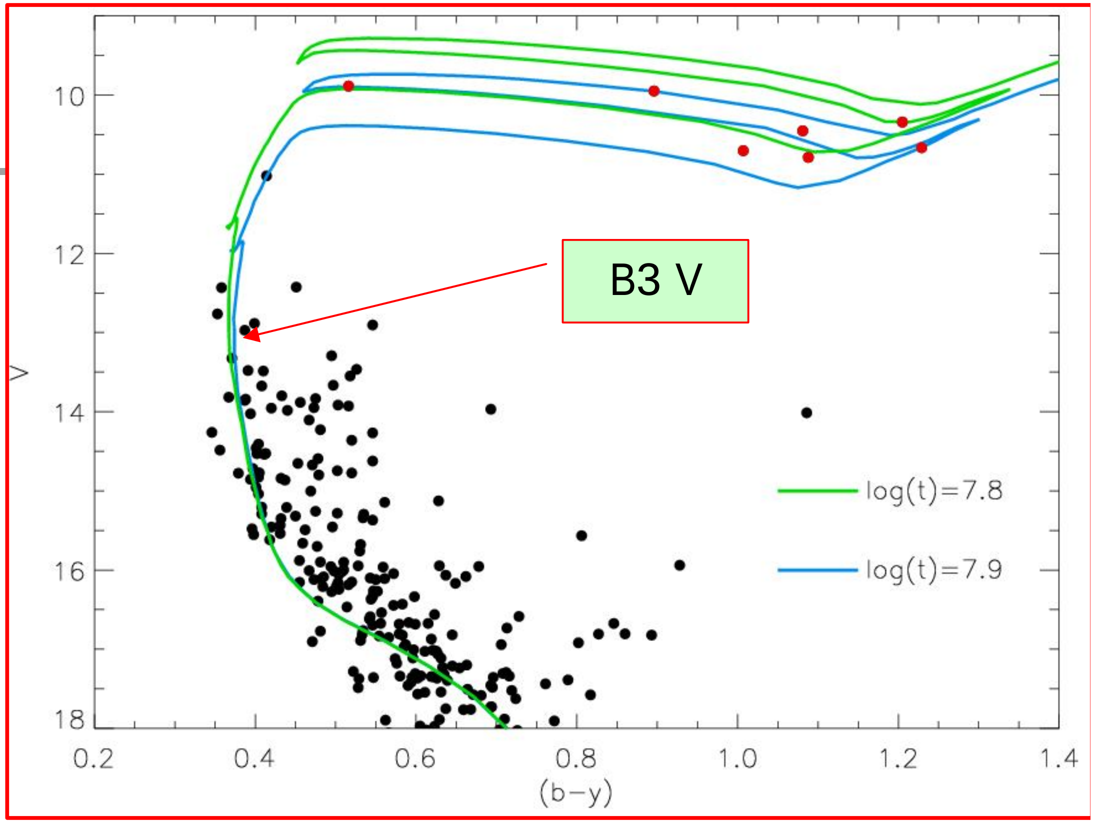
HR diagram of NGC 6649

(Marco et al. 2007, ASPC 361, 388)



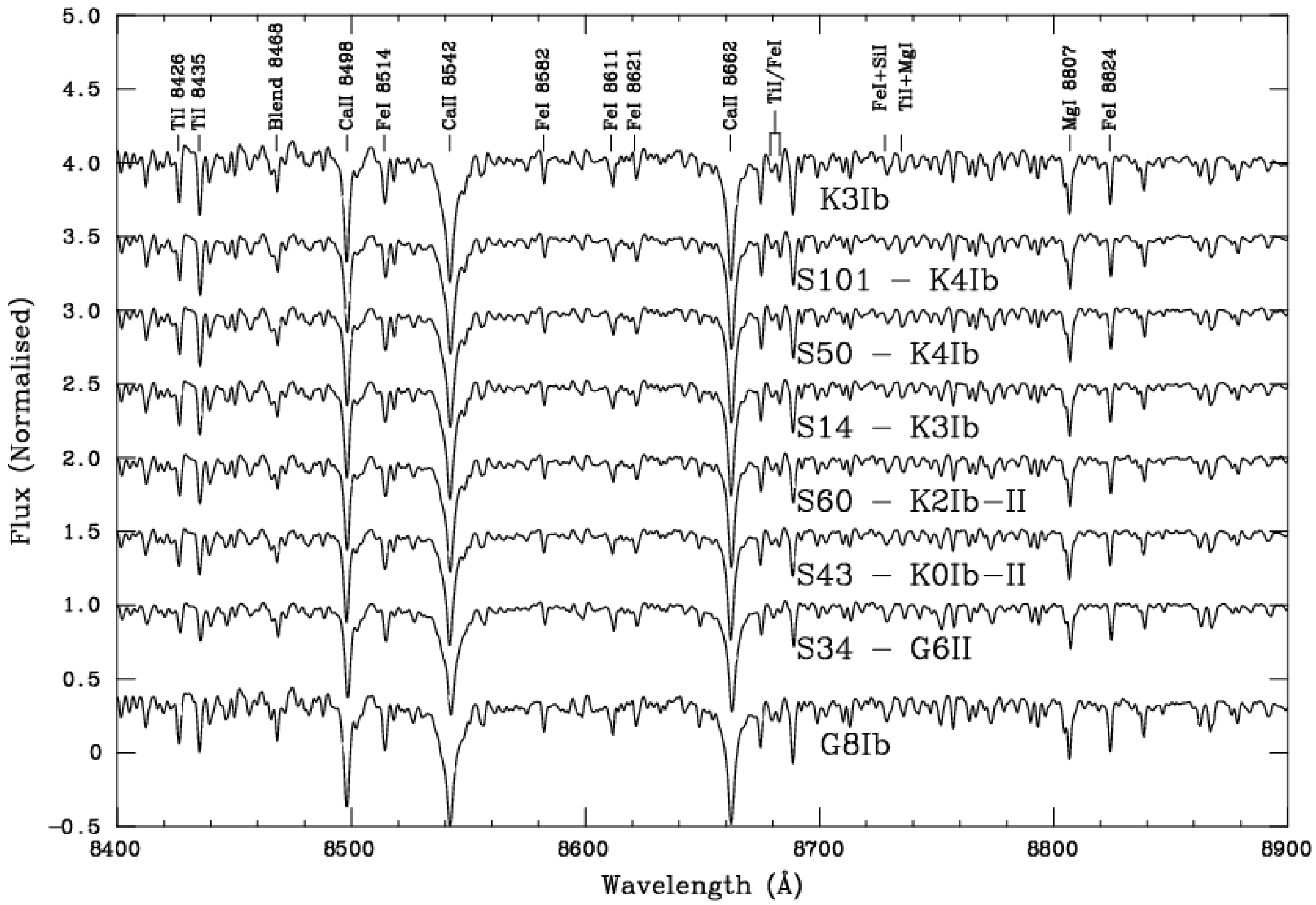
NGC 2345

Age ≈60 Myr



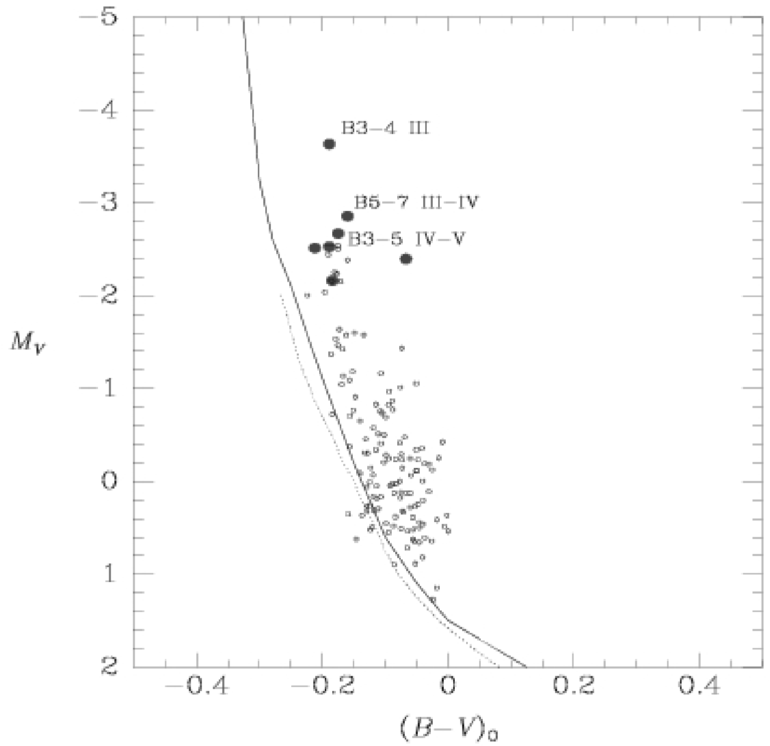
$M \sim 7\,M_\odot$

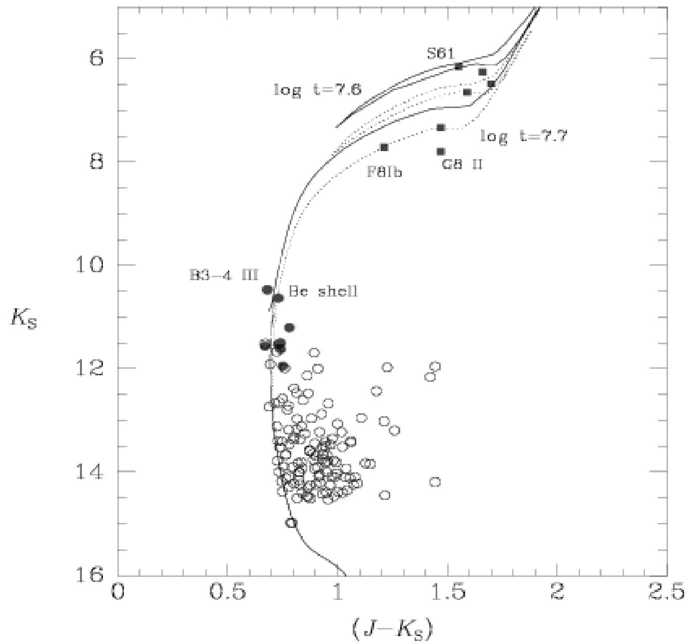
NGC 2345



TiI 8426
TiI 8435
Blend 8468
CaII 8498
FeI 8514
CaII 8542
FeI 8582
FeI 8611
FeI 8621
CaII 8662
TiI/FeI
FeI+SiI
TiI+MgI
MgI 8807
FeI 8824
K3Ib
S101 – K4Ib
S50 – K4Ib
S14 – K3Ib
S60 – K2Ib–II
S43 – K0Ib–II
S34 – G6II
G8Ib
Flux (Normalised)
Wavelength (Å)

Be 55



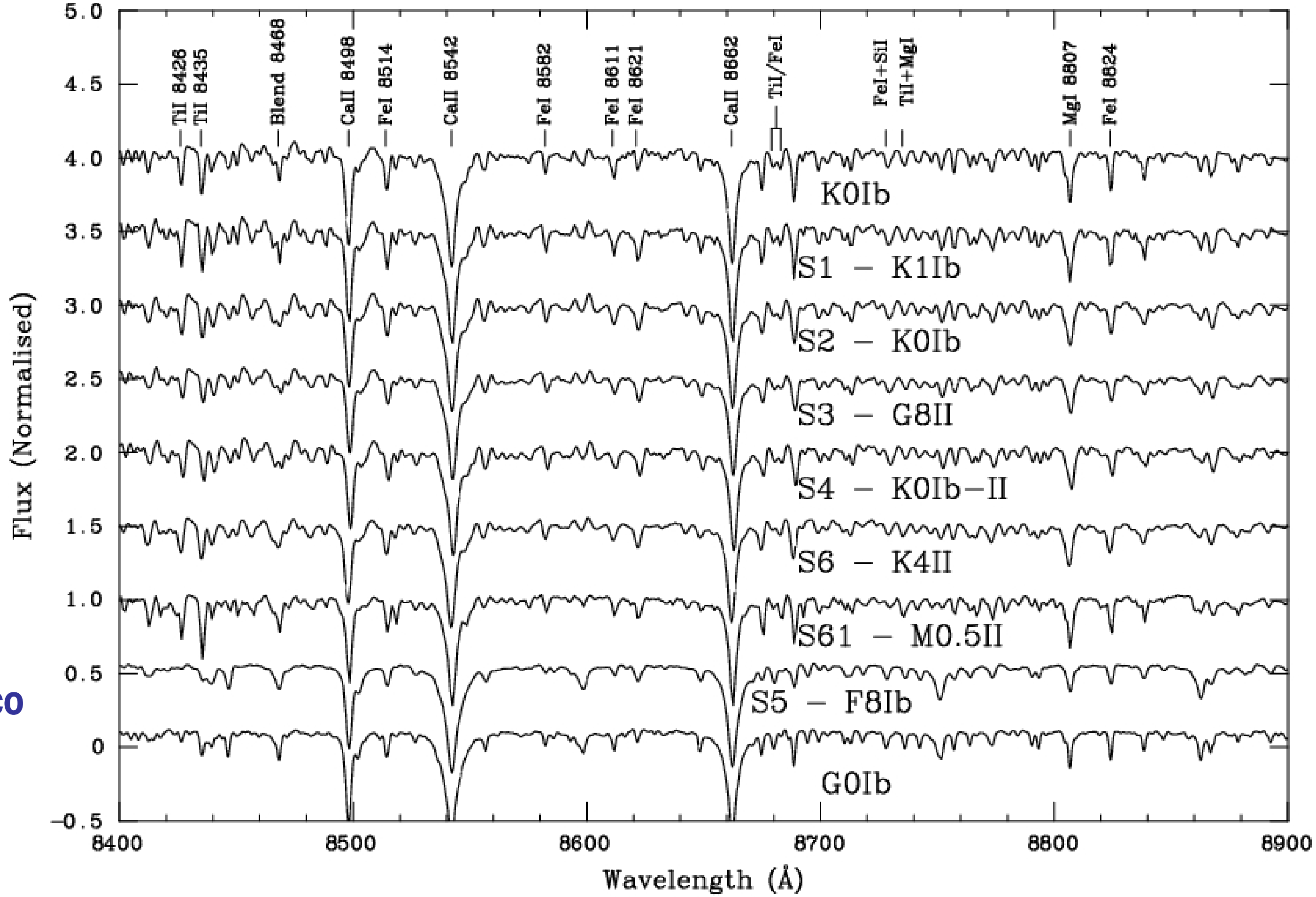


HR diagram of Be 55

(Negueruela & Marco 2012, AJ 143, 46)

Be 55

$M \sim 7.3\,M_\odot$



Age 50±10 Myr
(Negueruela & Marco 2012, AJ 143, 46)

Summary

- The detected SN progenitors suggest that objects with masses as low as $7M_\odot$ can explode.
- The separation of RSGs from AGB stars is very difficult.
- Evidence from clusters very strongly hints at a bimodal distribution in RSG spectral types, with a majority of the population in the M0-2 range and a few objects at later types.
- Late-M RSGs show evidence of heavy mass loss, and there are indications that these are the most evolved objects.
- Do stars explode as RSGs or do they loop bluewards?
- No young open cluster contains the kind of object observationally identified as a very massive AGB star.


How should the progenitors of type II-p SNe look like?
Red supergiants in clusters
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Cabo de Gata
September 2013