

Surveying the massive star formation in the inner Galaxy

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What are red supergiants?

Red supergiants (RSGs) are evolved high-mass stars:

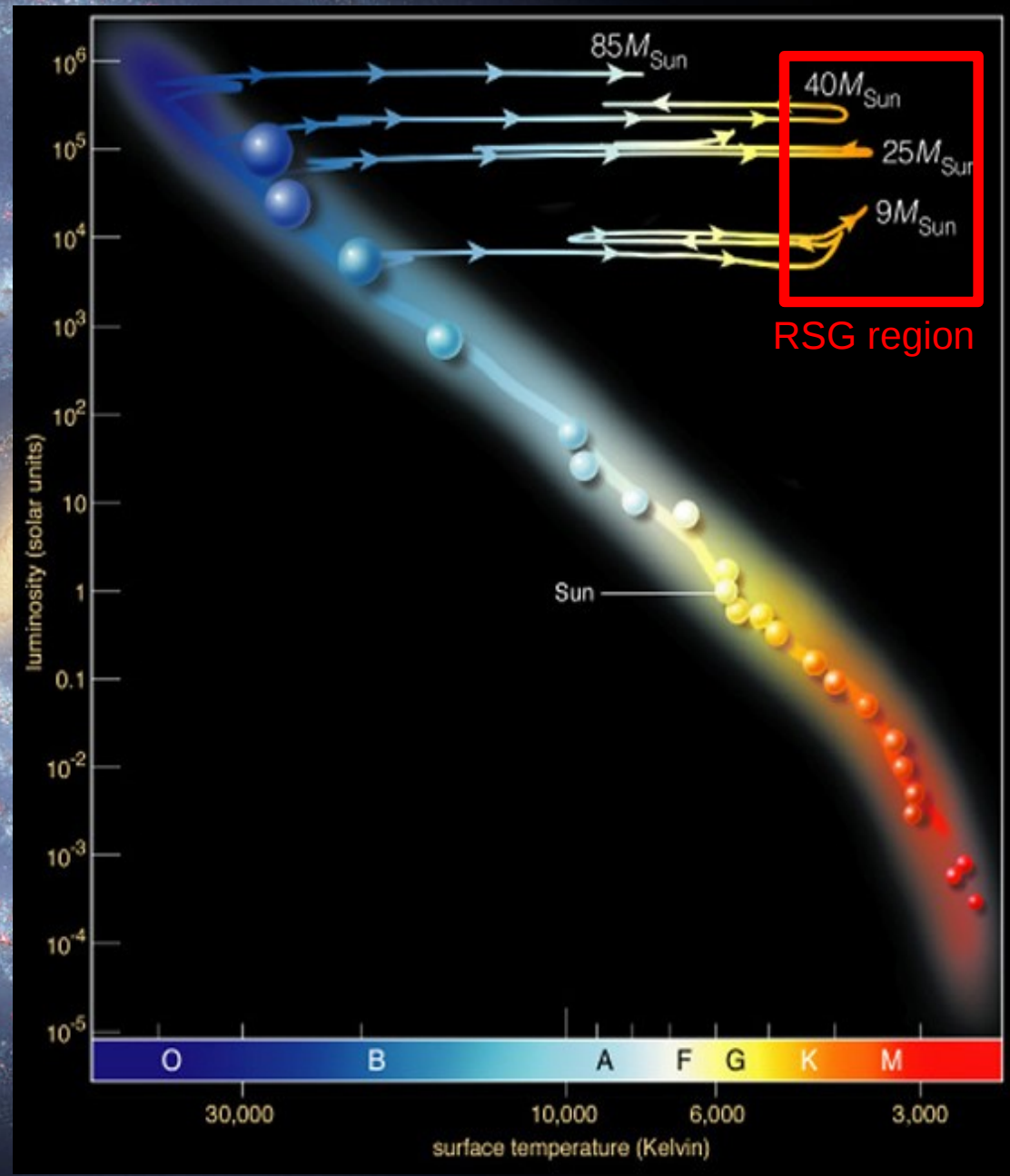
Spectral types: K – M

$M \sim 10 - 30 (40) M_{\odot}$

Age $\sim 8\text{Myr} - 20\text{ Myr}$
(Ekström et al. 2013)

$\log(L/L_{\odot}) \sim 4.5 - 5.8$
(Humphreys & Davidson, 1979)

$R \sim 400 - 1500 R_{\odot}$
(Levesque et al. 2005, 2006)



What are red supergiants telling us?

- Stellar evolution:

About ~80% of high mass stars pass through the RSG phase ~10% of their lifetime.
(Ekström et al. 2013)

- Massive stellar formation:

Associated to massive stellar clusters (e.g. 2 - 4 RSGs → minimum $M_{cl} \sim 10^4 M_{\odot}$)
(Clark et al. 2009b)

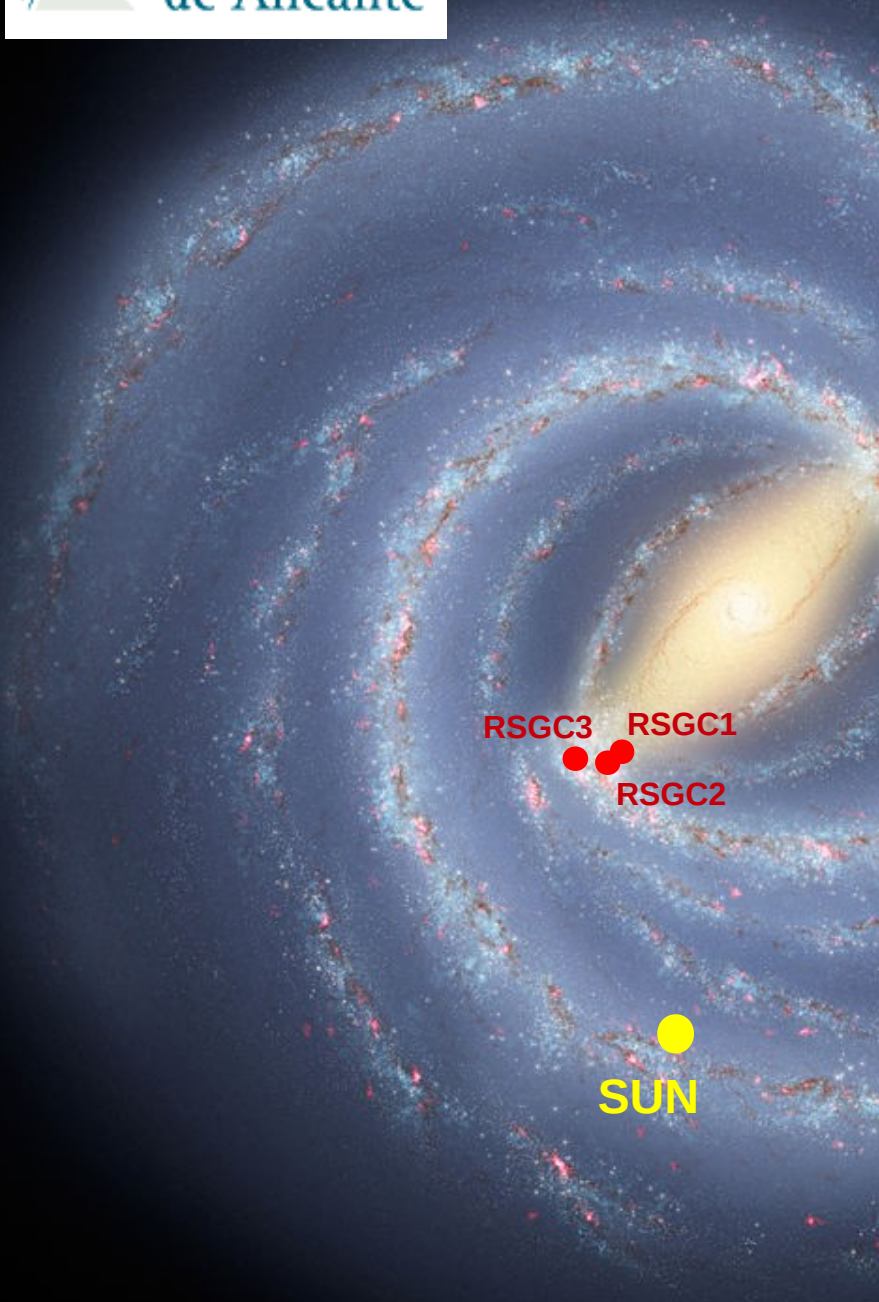
- Galactic structure:

RSGs are visible at large distances, even through very high extinction.
(Clark et al. 2009, Davies et al. 2007, 2008, Figer et al. 2006, Negueruela et al. 2010, 2011, 2012)

- Other galaxies:

RSGs are clearly visible in any near galaxy.
(Humphreys 1979, Massey et al. 2003, Levesque et al. 2006, 2013; Davies et al. 2010, Britavskiy et al. 2014)

Red supergiant Clusters (RSGCs)



RSGC group at Scutum arm base (d~6 kpc):

RSGC1: $l=25.27$ deg, $b=-0.16$ deg, $V_{lsr}\sim 120$ km/s,
RSGs: 15, Age= 12 ± 2 Myr, $M_{init}= 30\pm 10$ kM_{\odot}

$A_k=2.6 \sim A_v=26$

(Figer et al. 2006, Davies et al. 2008)

RSGC2 (Stephenson 2): $l=26.19$ deg, $b=-0.07$ deg,
 $V_{lsr}\sim 110$ km/s, # of RSGs: 26, Age= 17 ± 3 Myr,
 $M_{init}= 40\pm 10$ kM_{\odot}

$A_k=1.1 \sim A_v=11$

(Davies et al. 2007)

RSGC3: $l=29.20$ deg, $b=-0.20$ deg, $V_{lsr}\sim 95$ km/s,
RSGs: 16, Age= 18 ± 2 Myr, $M_{init}= 30\pm 10$ kM_{\odot}

$A_k=1.5 \sim A_v=15$

(Clark et al. 2009a)

Are they part of the same stellar formation
region?

Are there more RSGs?

Looking for new RSGs with a long-slit spectrograph

Observations in the near infrared because of the high extinction ($A_V > 10$): Infrared Calcium Triplet (CaT) spectral region (8400-8900).

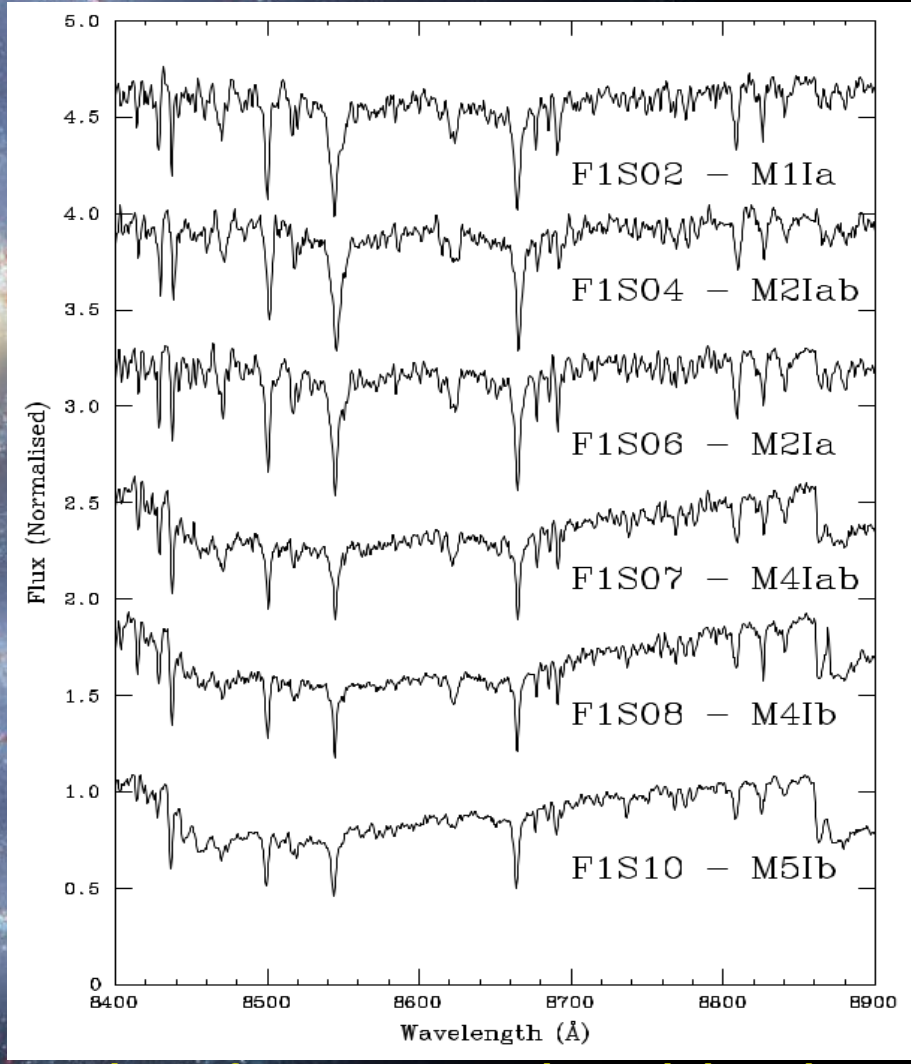
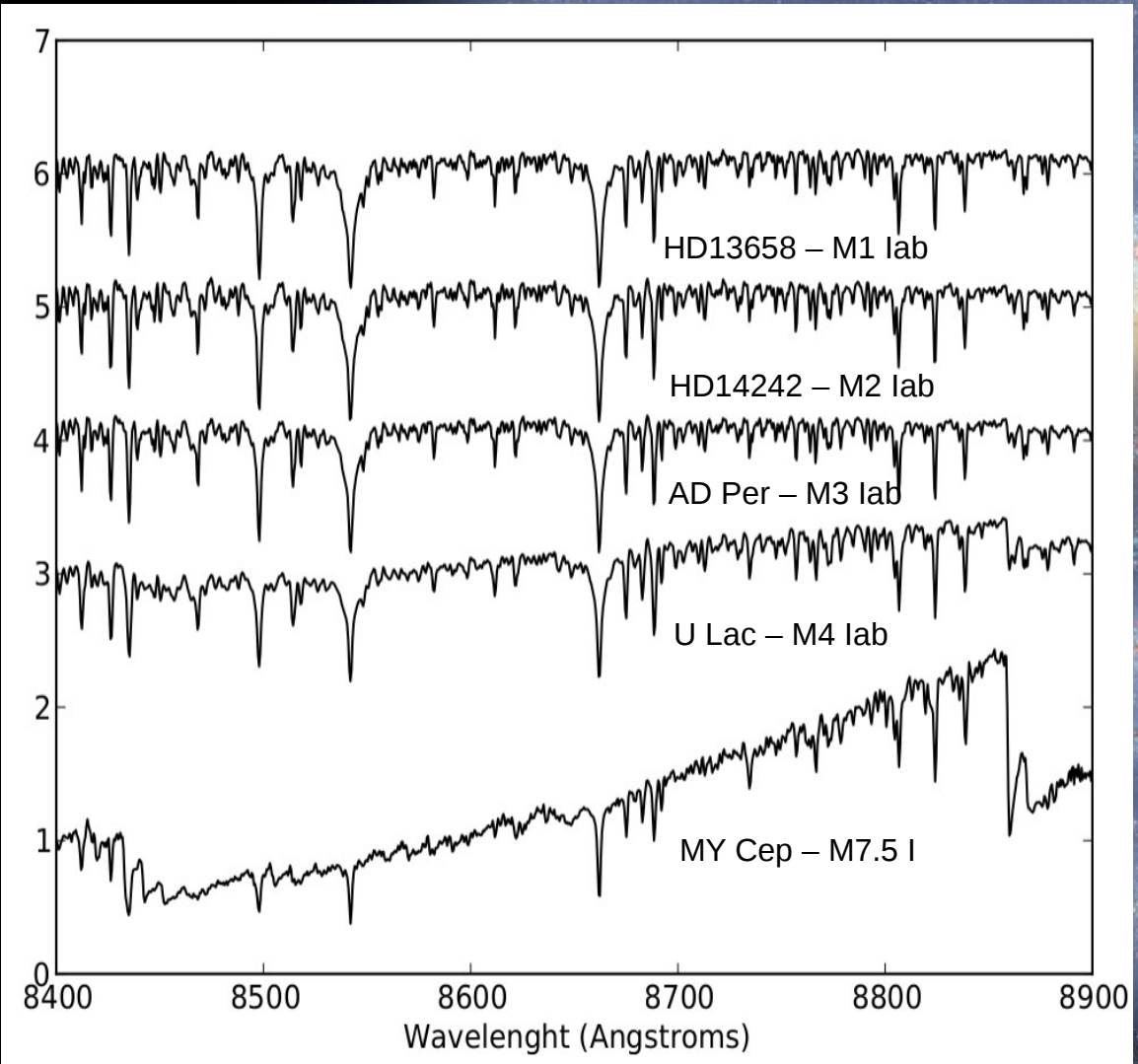
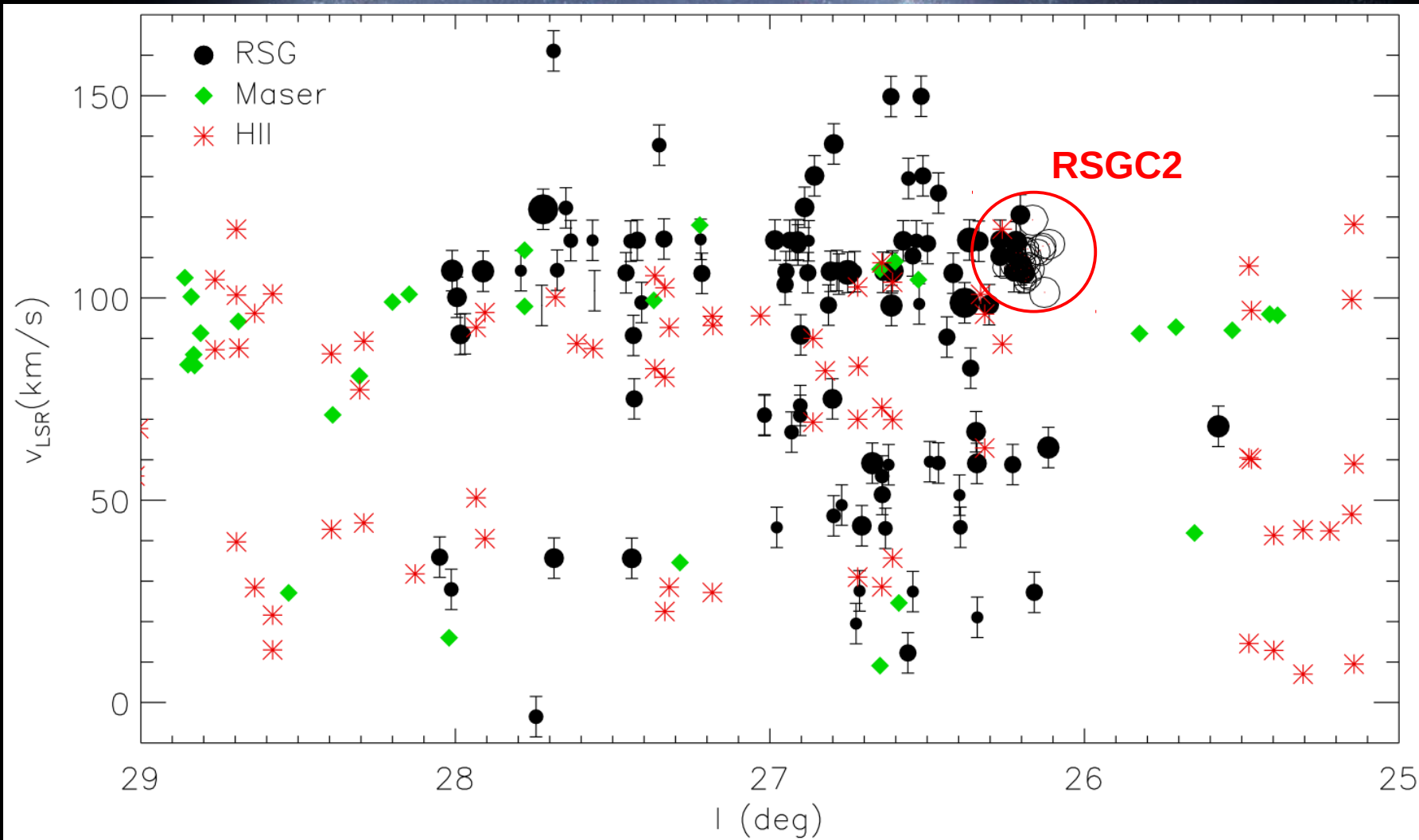


Figure from: [Negueruela et al. \(2011\)](#)

([Negueruela et al. 2011](#)) TWIN @3.5m - Calar Alto (8000-9000 Å) -> 8 new RSGs scattered around RSGC3 with similar radial velocities (RVs).

(Negueruela et al. 2012) AF2+Wyffos @WHT – La Palma (7650–8950 Å) → ~35 RSGs scattered in the neighborhood of RSGC2 with compatible RVs (and 40 RSGs with no compatible RVs)



Black Circles: RSGs observed in [Negueruela et al. \(2012\)](#), Open circles: RSGC2 members [Davies et al. \(2007\)](#),
Green Diamonds: Methanol masers [Green et al. \(2011\)](#), Red asterisks: HII regions [Anderson et al. \(2011\)](#)

Surveying the Scutum arm with AAOmega

2dF + AAOmega @ Anglo-Australian Telescope (3.9 m) – Siding Spring Observatory

Features:

- 2 degree diameter field
- 392 science fibres
- Dual-beam

Red grating:

1700D
~8400 to ~8900 Å
R~10000

Observations: 3 campaigns

2010:

- 2* Config. at $l=26.25$ $b=00.00$
- 1 Config. at $l=29.13$ $b=00.02$

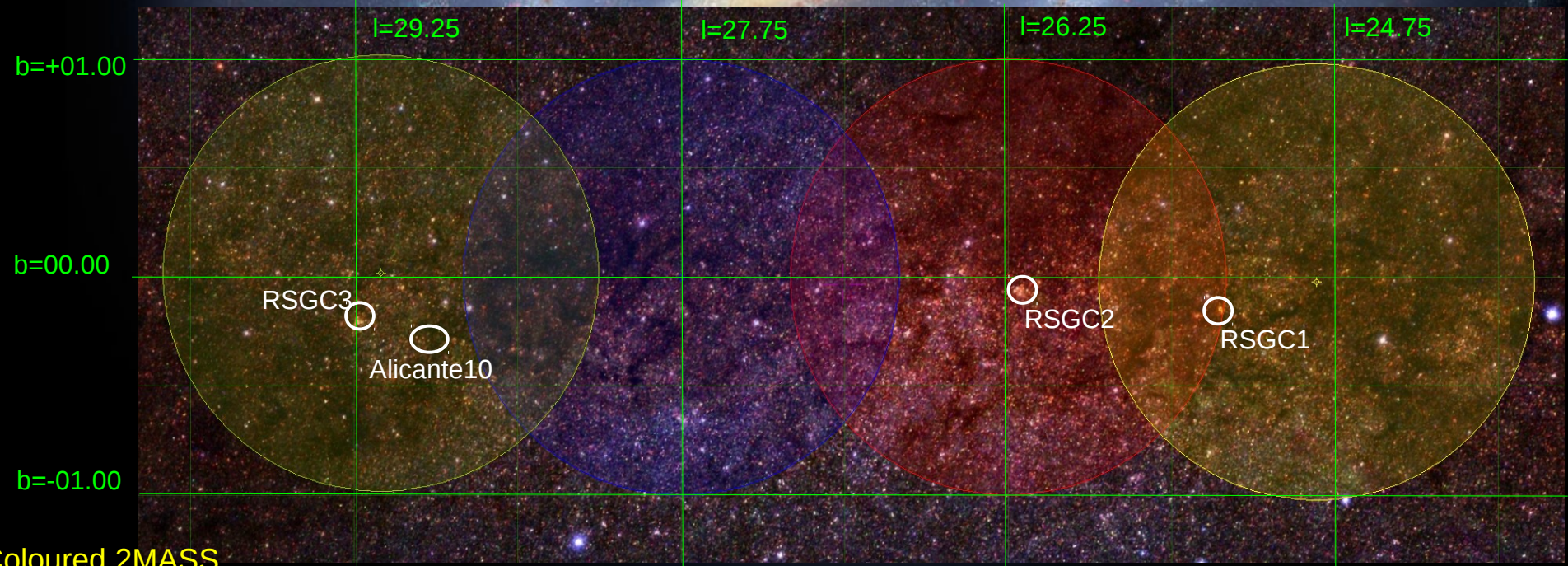
2011:

- 2* Config. at $l=26.25$ $b=00.00$
- 1 Config. at $l=29.13$ $b=00.02$
- 1 Config. at $l=27.75$ $b=00.00$

2012:

- 1 Config. at $l=26.25$ $b=00.00$
- 1 Config. at $l=24.83$ $b=-00.02$
- 1 Config. at $l=20.12$ $b=00.16$
- 1 Config. at $l=15.11$ $b=00.07$

* 1 bright configuration +
1 faint configuration



Candidate selection and observations

Photometric criteria:

Reddened stars: $(J - K_S) > 1.5$

Brightness: $K_S \leq 7$

Reddening-free parameter:

$$Q_{IR} = (J - H) - 1.8(H - K_S) \text{ from } 0.1 \text{ to } 0.4$$

(Negueruela & Schurch, 2007)

Crossed with DENIS and USNO-B1.0:

- Bright configurations: $l < 12.5$
- Faint configurations: $12.5 < l < 15.5$

For more details, see Negueruela's poster

Observed candidates:

2010: 505 observed (Green squares)

2011: 911 observed (White pluses)

2012: (Cyan circles)

in $l=25$ and $l=26$: 527 observed

in $l=20$: 138 observed

in $l=15$: 159 observed

Overlapping:

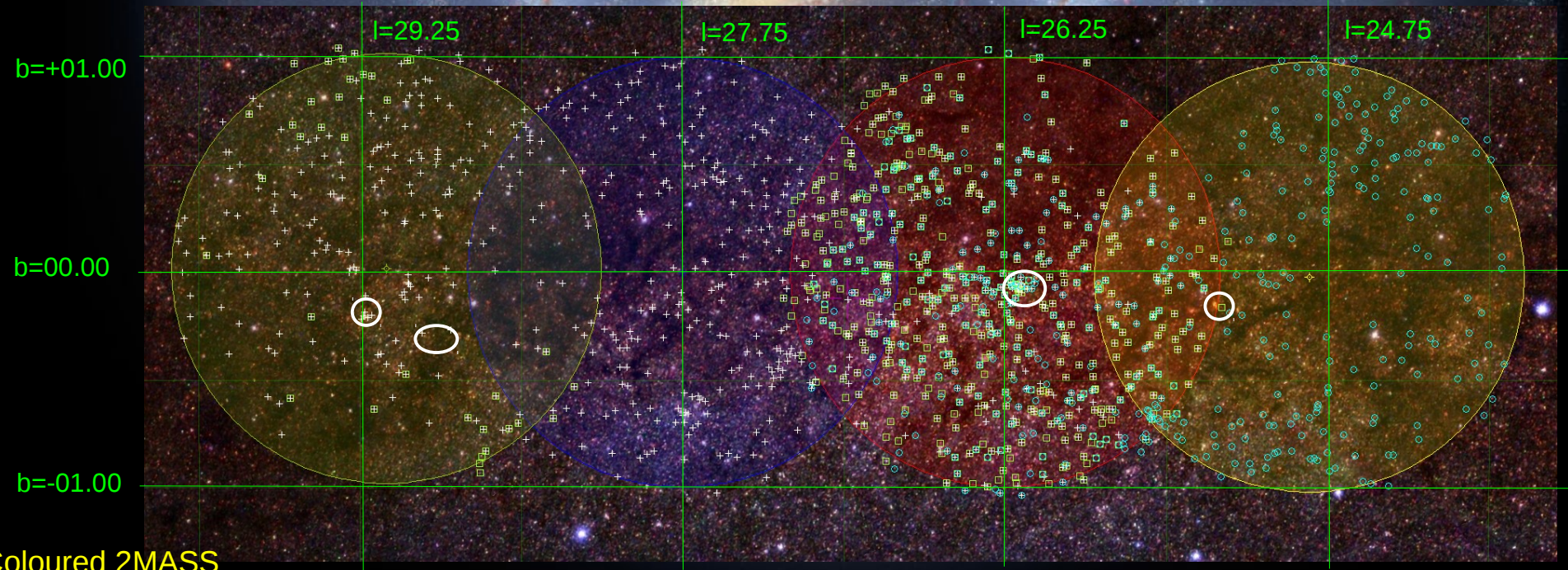
2010 – 2011: 368

2010 – 2012: 144

2011 – 2012: 183

TOTAL:

1655 unique targets



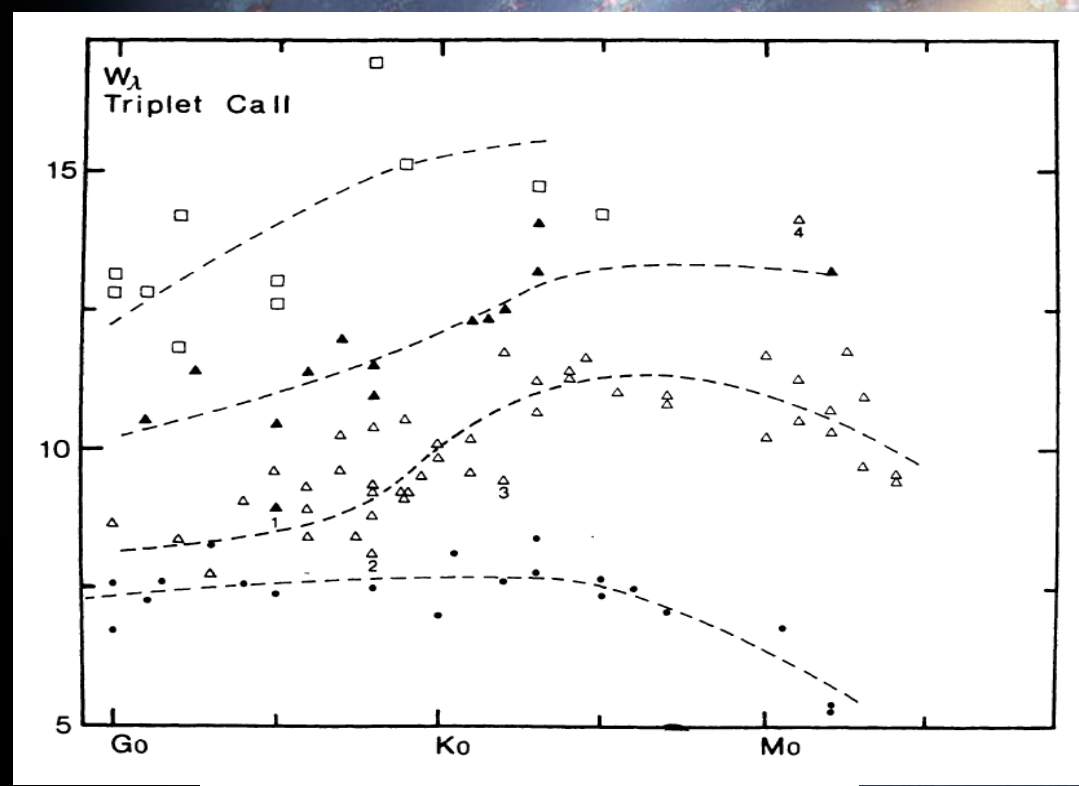
Coloured 2MASS

Automatized classification

>2000 spectra: Automated spectral and luminosity classifications.

Spectral classification in the infrared Ca II Triplet (CaT) spectral region:

- * Main criteria for spectral types were defined before CCD era. (Solf, 1978 and references there in)
- * RSGs have just been barely covered by the major spectral classification studies in the CCD era. (Kirkpatrick et al., 1991; Ginestet et al., 1994; Carquillat et al., 1997)
- * How does metallicity affect spectral features?



The symbols ● △ △ □ correspond respectively to luminosity Classes V, III, II, and Ib.

Figure from: Ginestet et al. (1994)

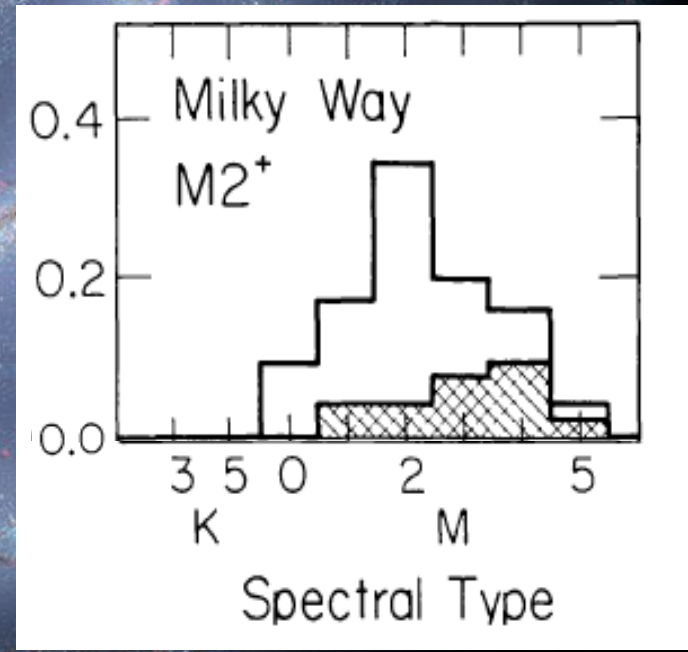


Figure from: Elias et al. (1985)

Statistically significant number of RSGs from Magellanic Clouds (MCs) and galactic standards:

Data from both MCs: observed with AAOmega, in the optical and CaT spectral ranges.

Optical range used for classification.

213 previously known RSGs, 243 new RSGs, 407 no RSGs (LCs II, III and V)

For more details, see [González-Fernández's poster](#) (and [González-Fernández et al. accepted](#)).

Galactic standards: 100 standards (53 RSGs, 47 with LC II and III)

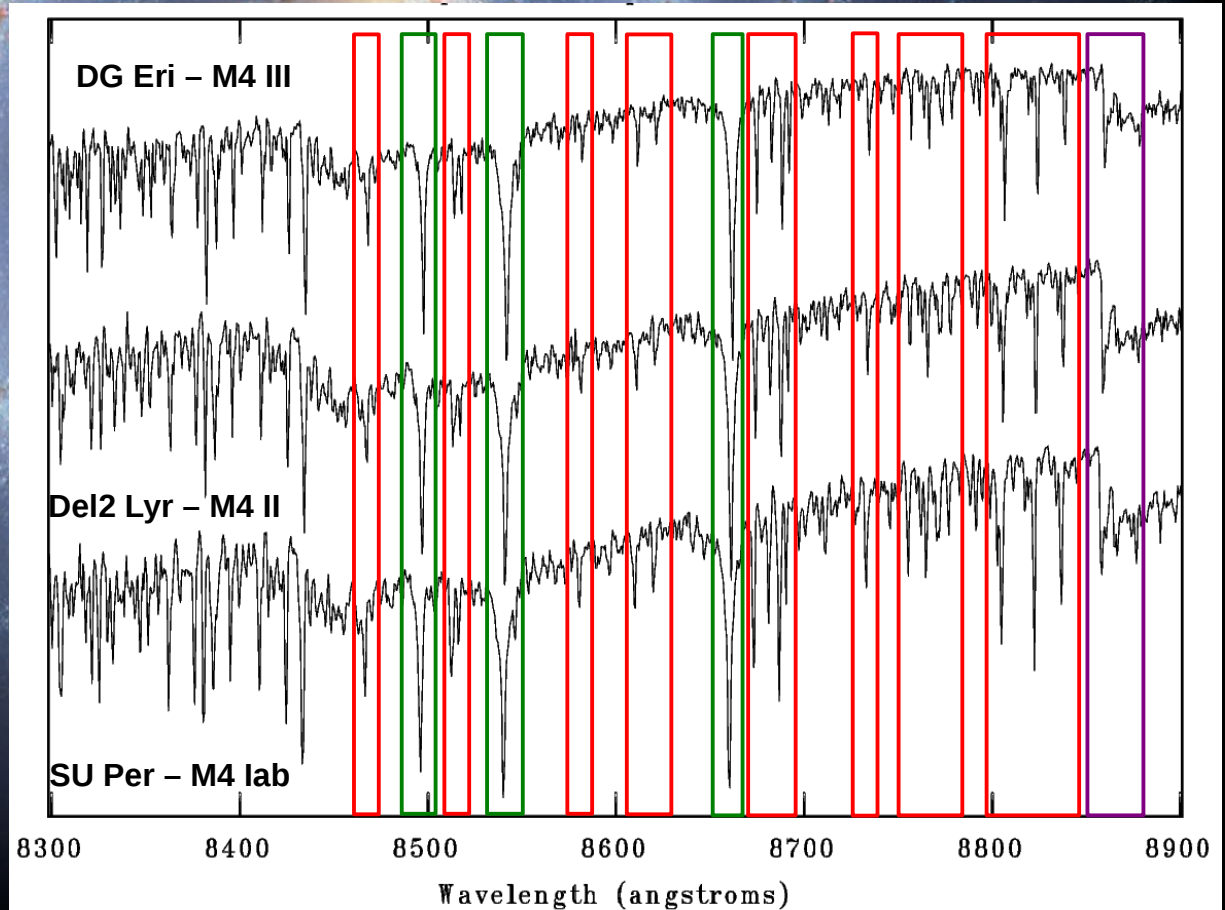
observed with IDS @ INT (La Palma) ([Dorda et al. in prep](#)).

23 spectral features measured:

Calcium II Triplet

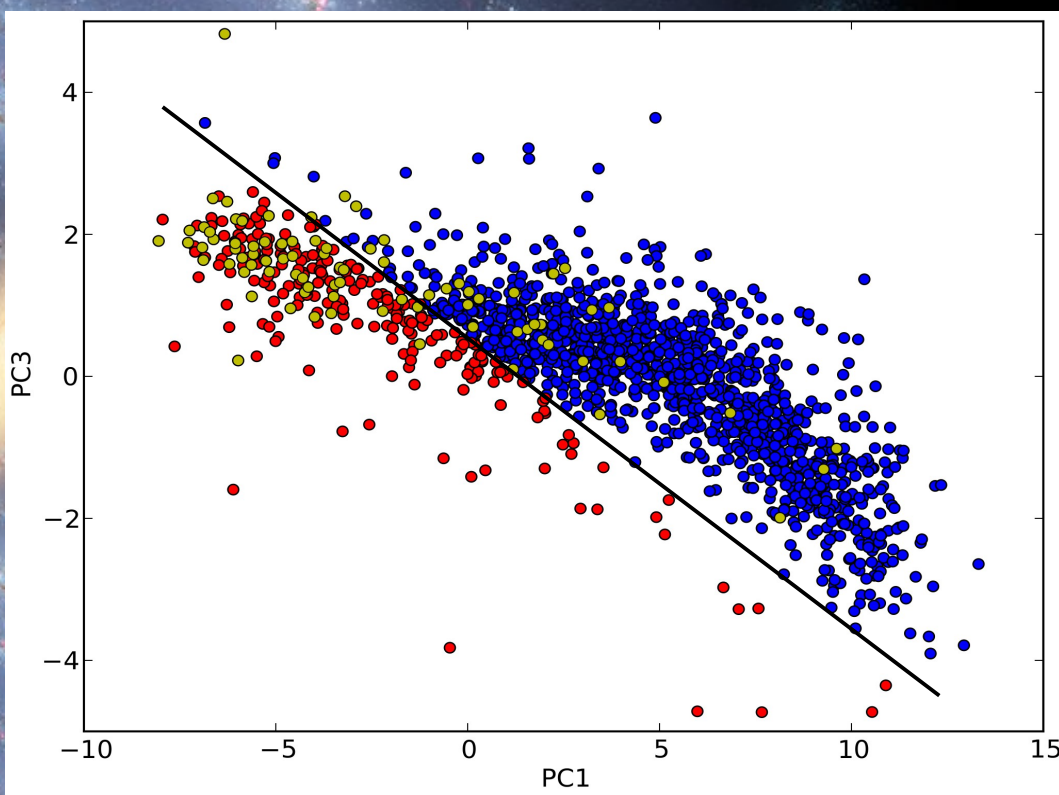
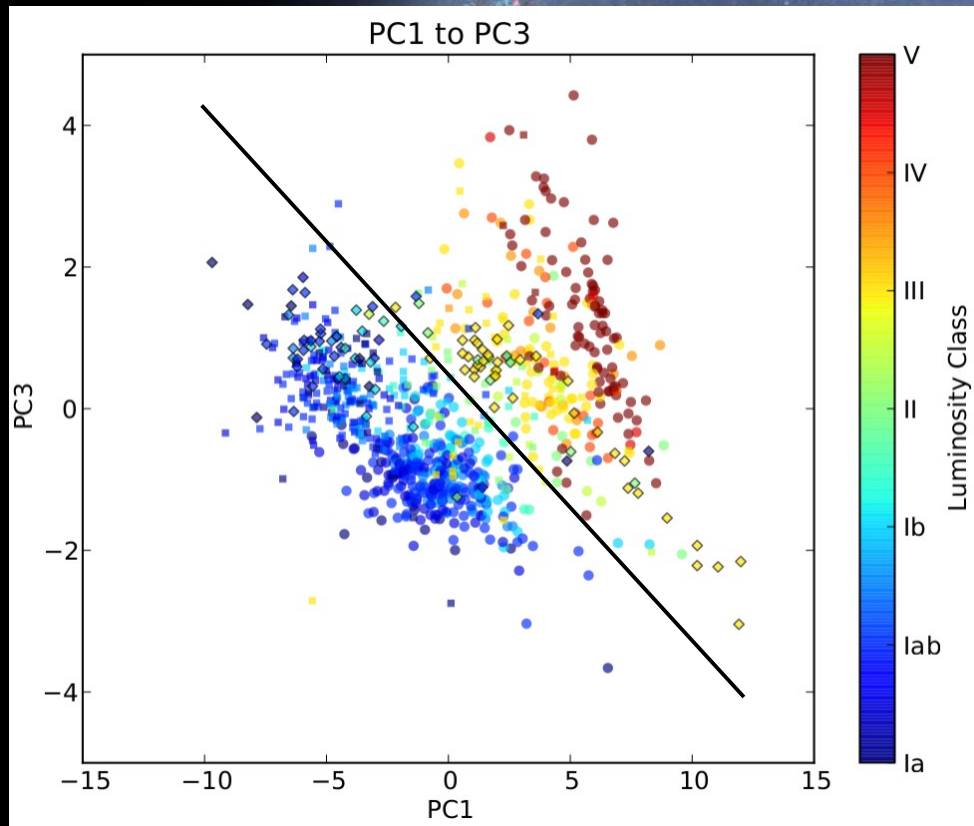
Ti I and Fe I

TiO bandhead at 8860 Å



Principal Component Analysis (PCA)

PCA performed with the EWs measured:
 LC and SpT criteria obtained, independent on metallicity.
 Principal Components (PCs) are lineal combinations of the input spectral data.



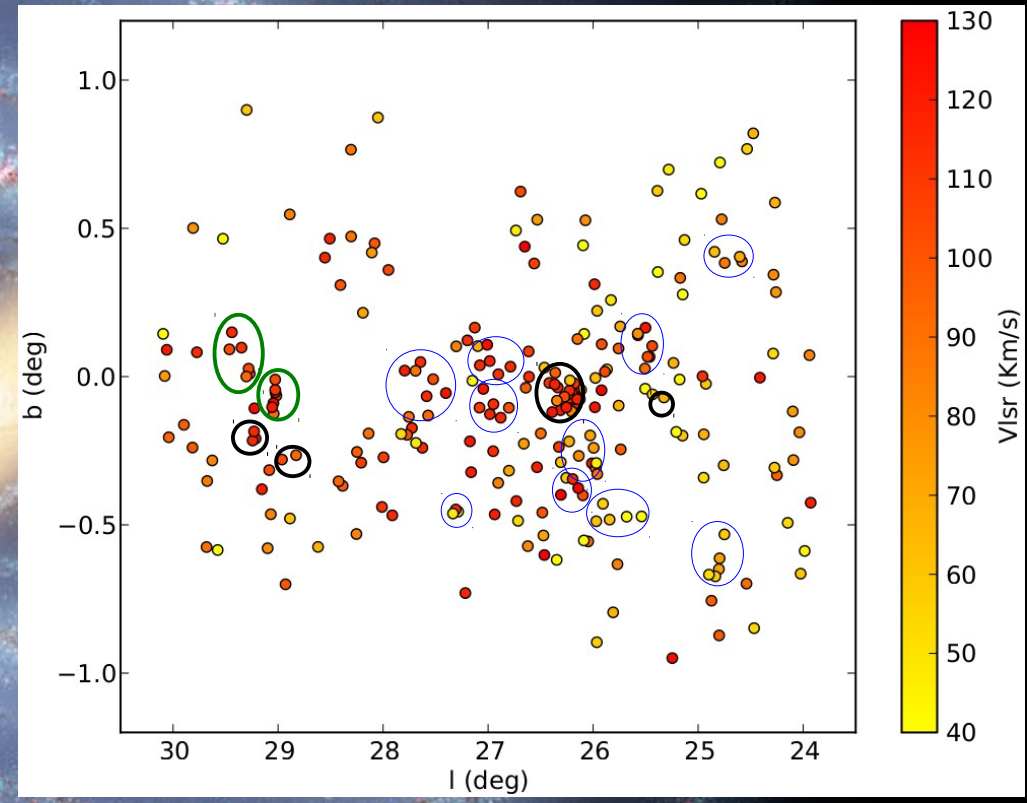
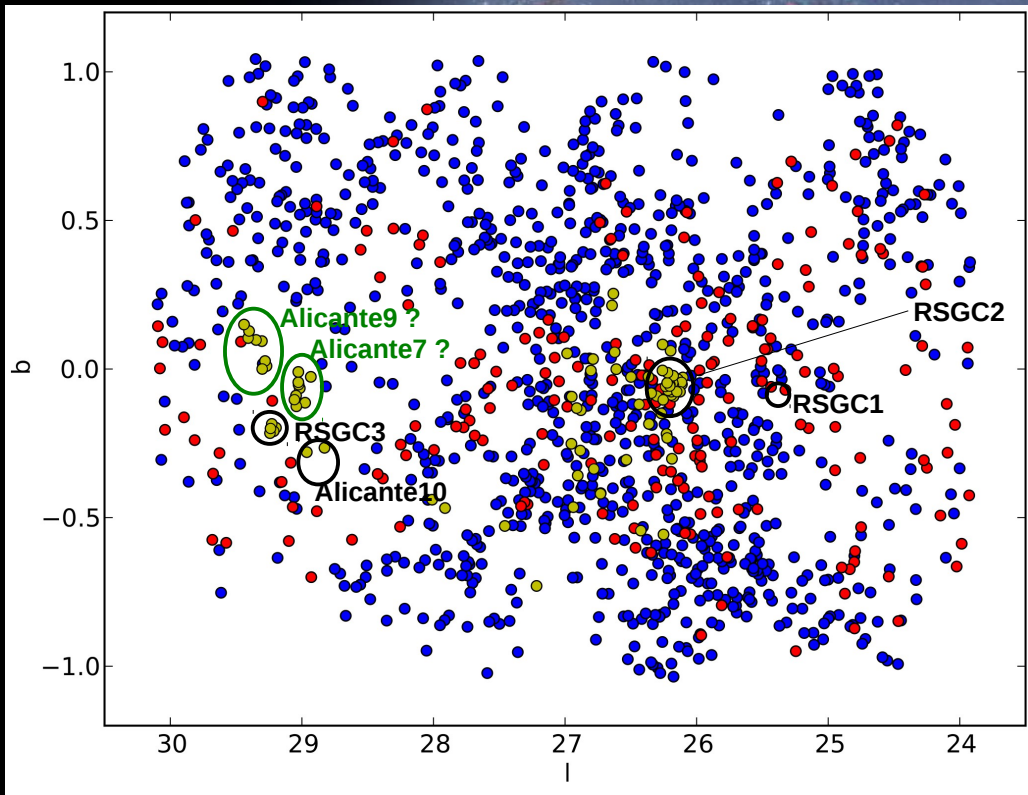
Calibration stars:
 Squares: LMC survey.
 Circles: SMC survey.
 Diamonds: Galactic standards.

Scutum surveys (2011 and 2012):
Red: very likely supergiants (245, 192 of them are new)
Blue: probably not supergiants
Yellow: RSGs previously known in the region.

Preliminary results!
 This criterion only has good results for SG earlier than M3. Its just a part of the final method.

Results

Preliminary classification for 2011 and 2012 (l=27 to 24 deg):
 245 very likely RSGs, 192 of them previously unknown.



Scutum surveys (2011 and 2012):
Red: very likely supergiants.
Blue: probably not supergiants.
Yellow: RSGs previously known in the region.

Very likely supergiants from 2011 and 2012: 245 stars.
Black circles: Known RSGCs.
Green circles: Candidates to RSGCs previously considered.
Blue circles: promising groups with similar RVs.

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Results:

- 1655 candidates observed.
- (at least) 192 new RSGs.
- Automated method for measurements and classification.
- New RSG clusters candidates found.

Future work:

- Publishing the final catalog, with spectral types, luminosity classes and radial velocities.
- Studying the structure and stellar formation at base of Scutum arm: is this the largest stellar formation region known?
- Studying spectral variability.

**** And finding a postdoc ****

**Thank you very much
Muchas Gracias**