Classical Be stars within and beyond the Perseus Arm

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Outline

- **The Perseus Arm: an introduction**
  - Morphology of the area
  - Origin of the database
- Locating classical Be (CBe) stars across the region
  - Reddening determination of Hα emitters → spectroscopic parallax
  - Distance estimate via extinction maps (MEAD)
- Summary

Aims of the project

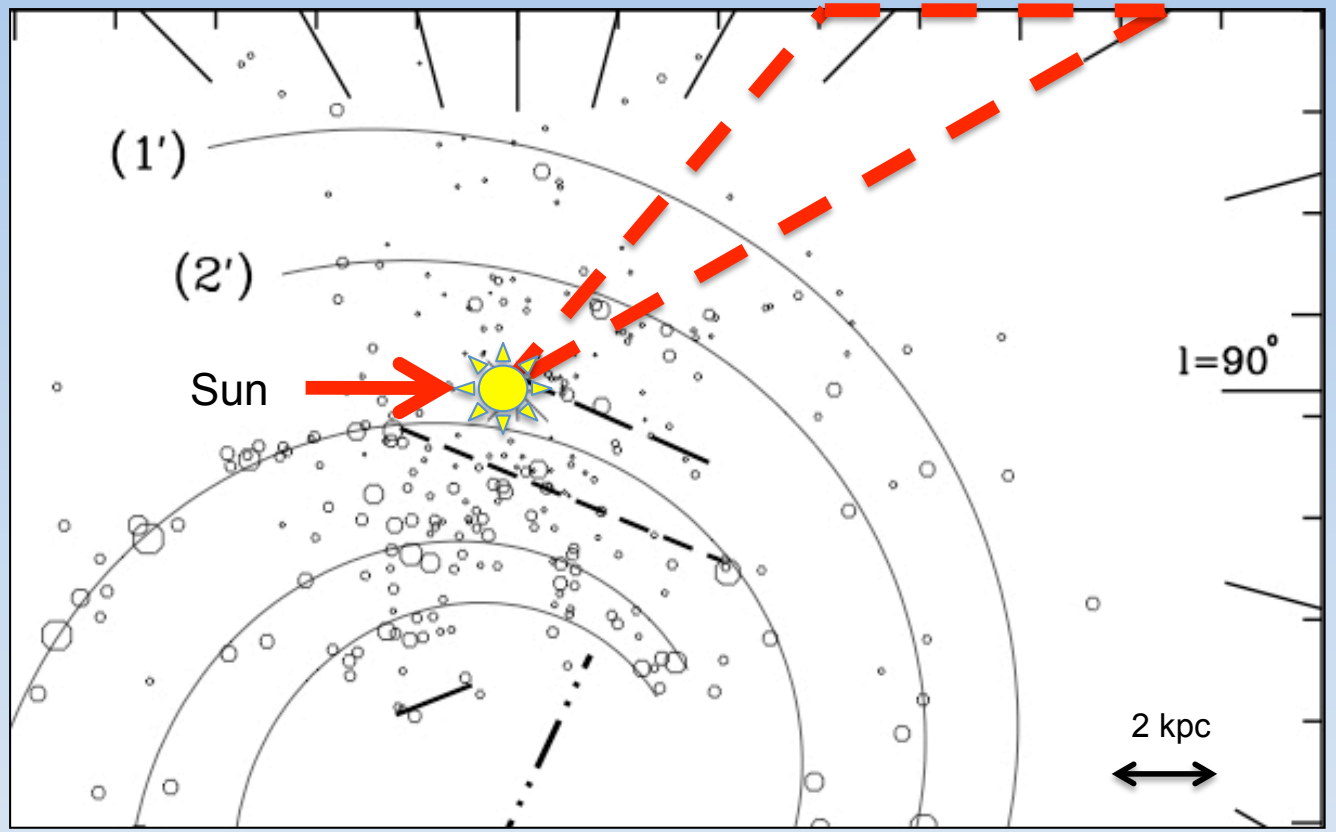
- To study the population of young emission line stars in a section of the second Galactic quadrant

- To gather evidence on the 3-D organisation of the spiral arms in the outer Galaxy without using kinematic distances

The Milky Way structure

$120^o < l < 140^o$

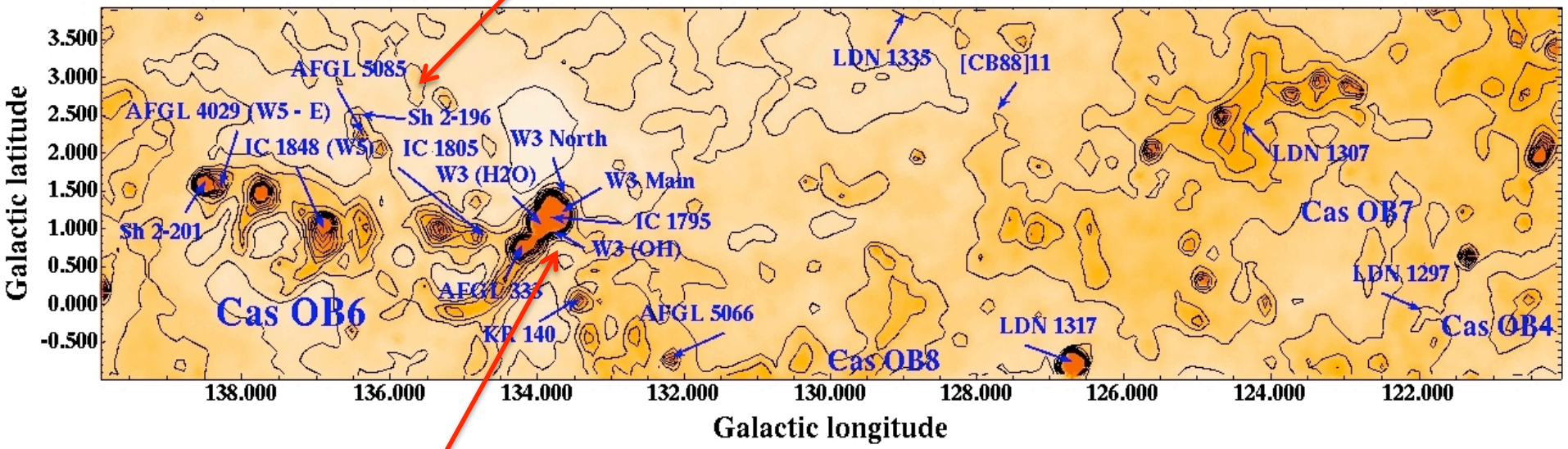
(1') Norma-Cygnus
(2') Perseus

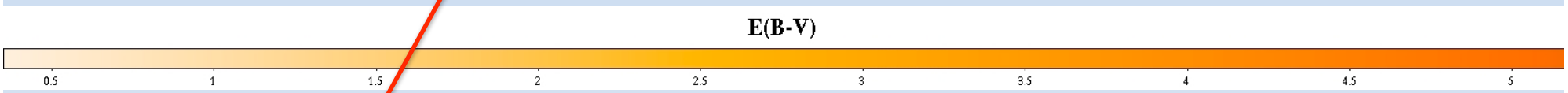


Four arms model - Russeil (2003)

The Perseus Arm between (120°, 140°) and (-1°, 4°)

WB89-437 (d ~ 5.99 kpc)





Dust map - Schlegel et al. 1998

W3(OH) (d ~ 1.95 kpc)

The Outer Arm

Stellar tracers of the Cygnus Arm:
(Negueruela & Marco, 2003)

- 27 stars between 115 $^{o} \leq \ell \leq 150^{o}$
- SpT O7-B2.5, class V-Ia
- Place the Outer Arm at ~5 kpc

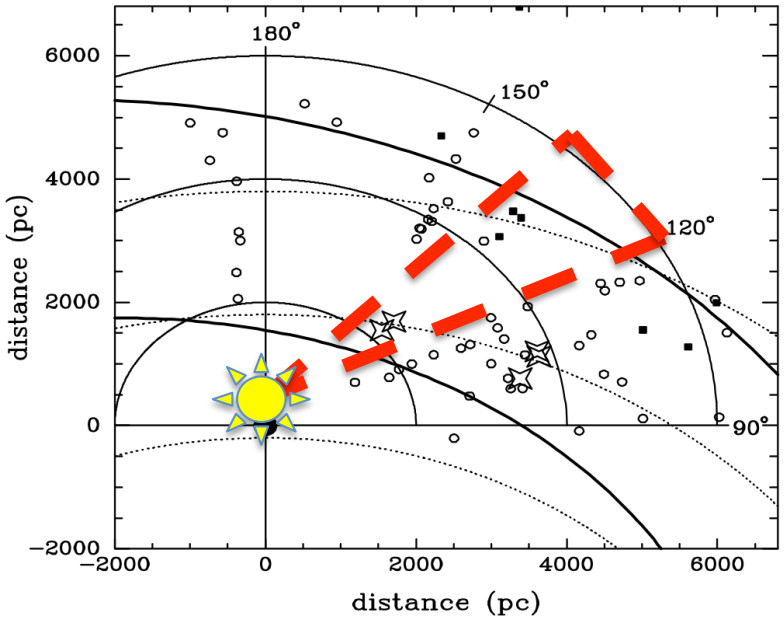
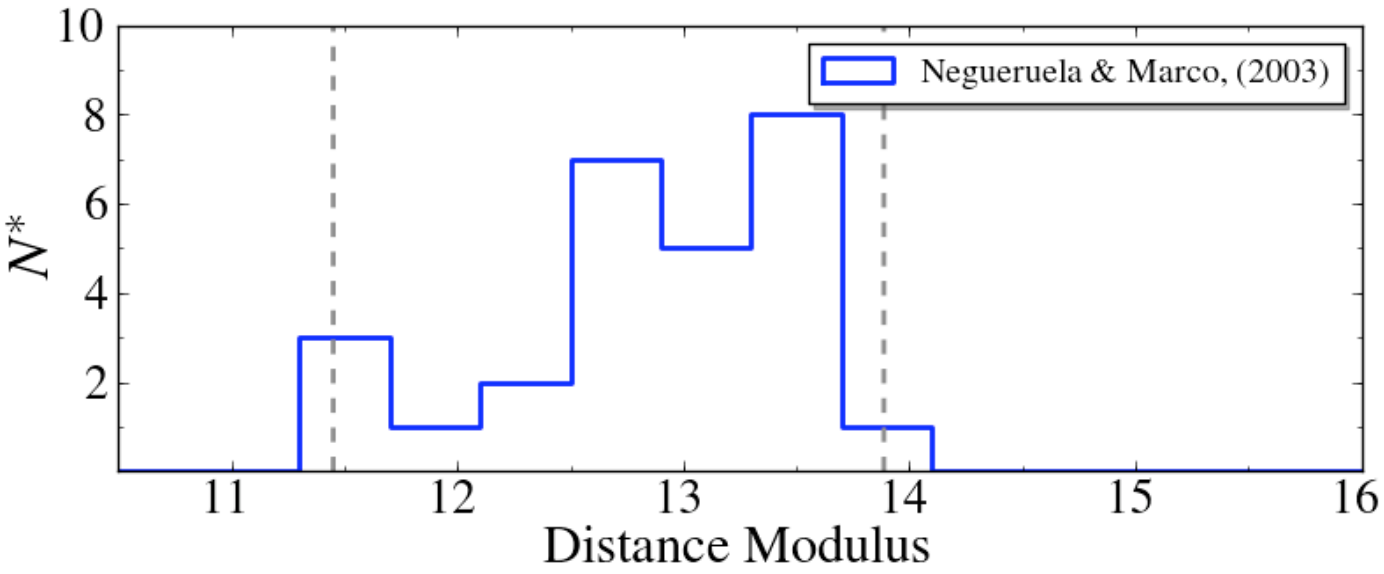


Fig 7, from Negueruela & Marco, 2003



IPHAS photometry applications

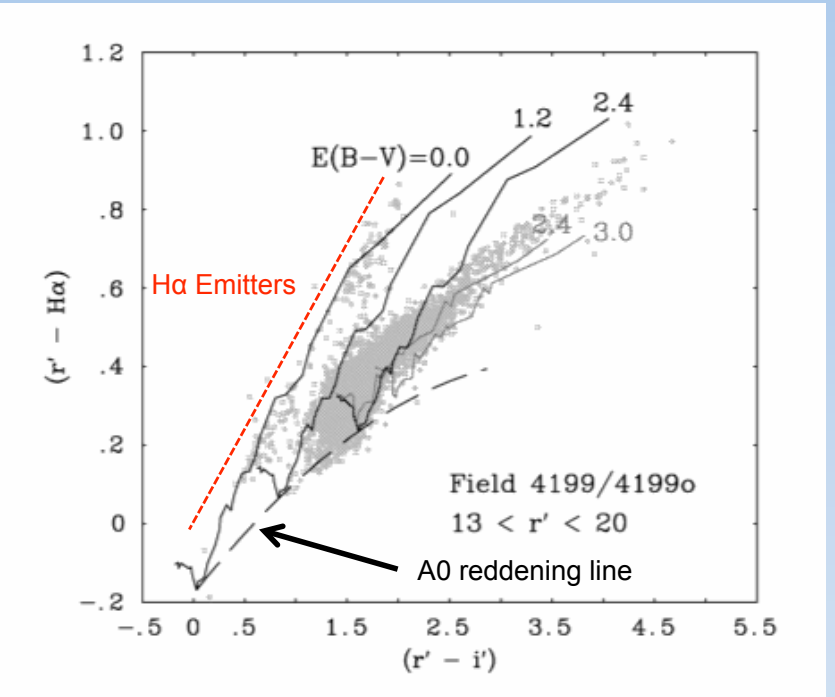
The Isaac Newton Telescope (INT) Photometric Hα Survey of the Northern Galactic Plane (IPHAS) – (Drew et al., 2005):

• Used Hα, r' and i' filters with the Wide Field Camera (WFC) on INT to a depth of r =20 (10σ).

Due to the close dependence of (r' - i') on the interstellar reddening while (r′ − Hα) is an intrinsic colour indicator, the colour-colour plane can be used in a dual way:

1) Emission line point sources - identified efficiently, in the colour-colour plane (r′ − Hα) versus (r′ − i′) (Witham et al. 2008).

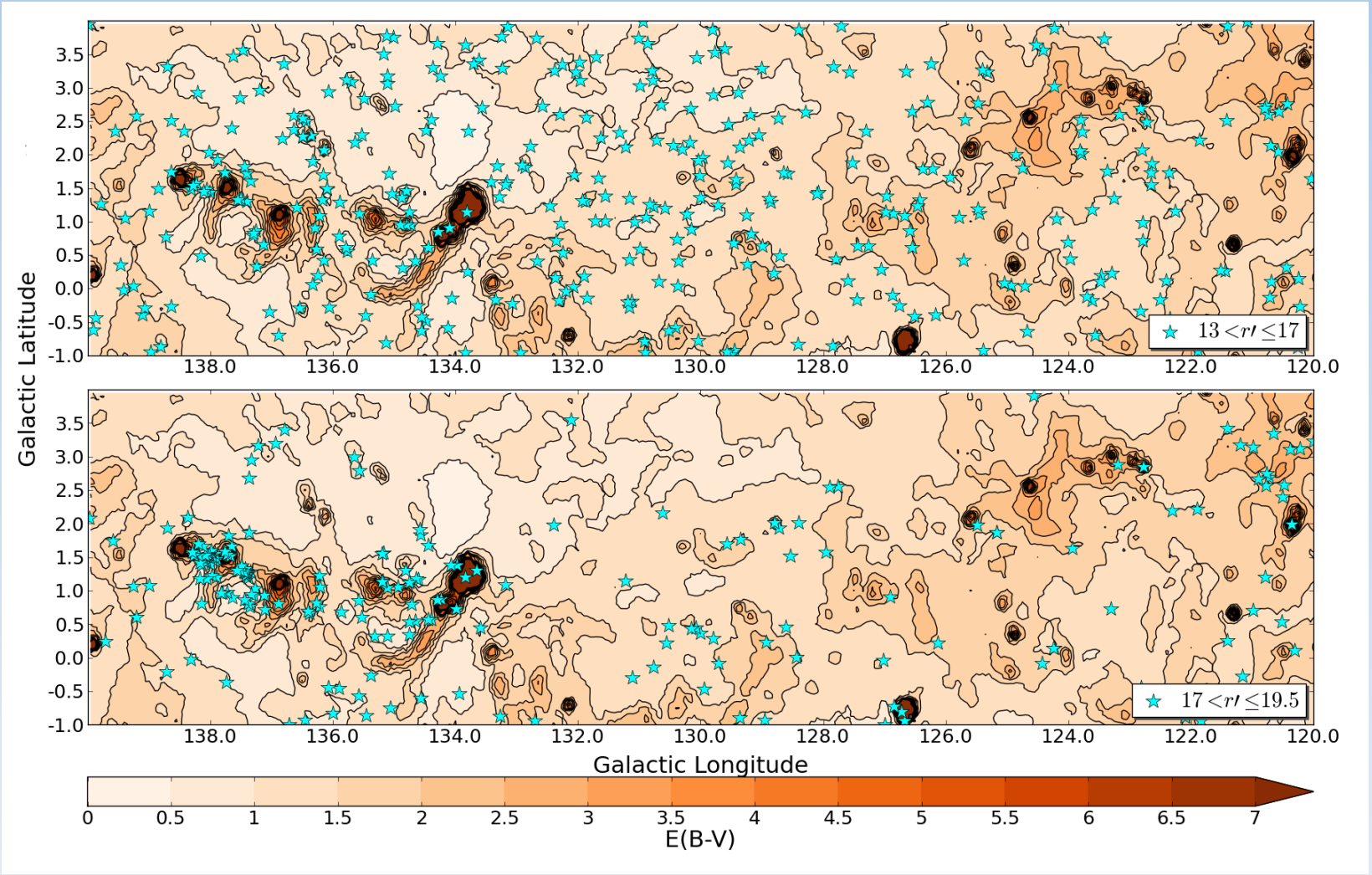
2) Drew et al. (2008), Sale et al. (2009) ➔ possible to determine distance and reddenings for Main Sequence (MS) stars, from the IPHAS photometry.



Colour-Colour diagram example

IPHAS Hα candidate emitters

560 candidates Hα emitters (13 ≤ r' ≤19.5) from Witham et al., (2008).
About 400 have r' ≤17.



Selection of targets for spectroscopy

Follow-up optical spectroscopy is needed to distinguish among different classes of emitters:

• YSOs, Be stars, PNe

FLWO/FAST spectra across the region

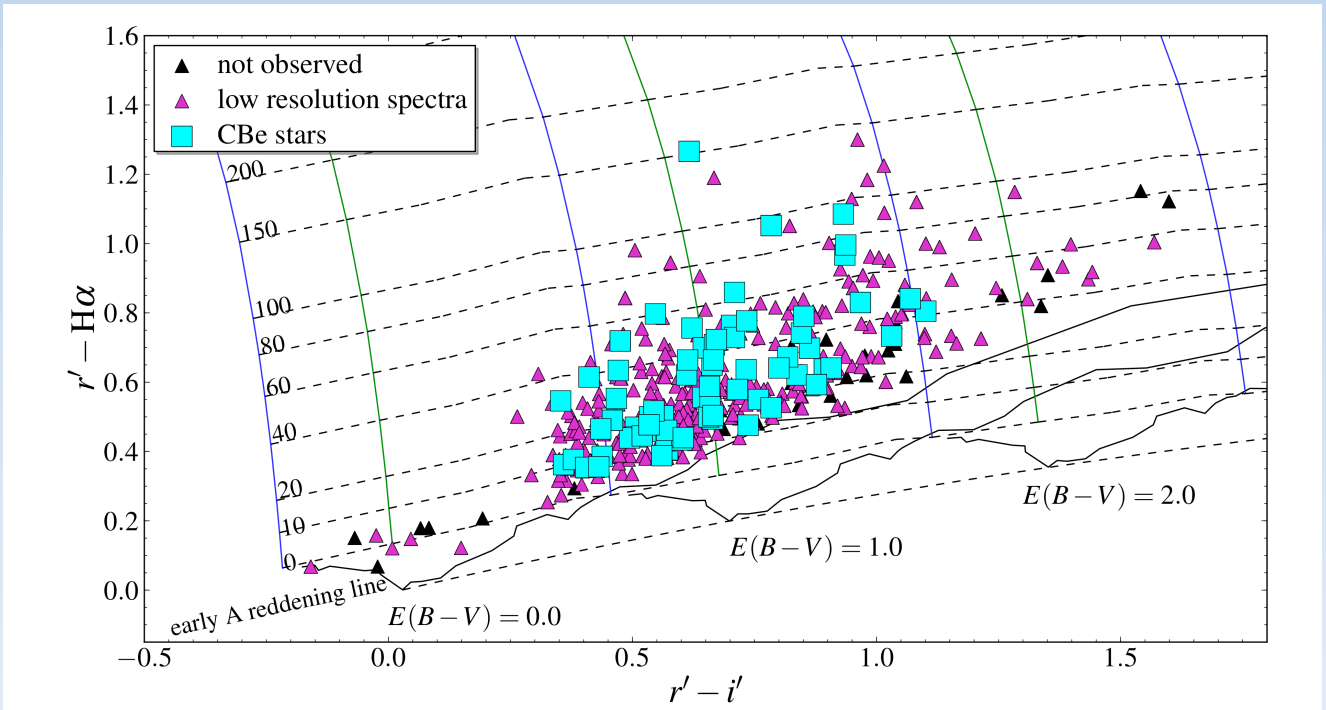
Fundamental for a direct initial appraisal and selection of targets (highly flexible queue)

378 distinct stars in the area acquired between 2005-2011

Spectral interval: 3400Å - 7400Å ca.

Spectral resolution: λ/Δλ≈750 at 4500 Å

Magnitude interval: r'≈12-17



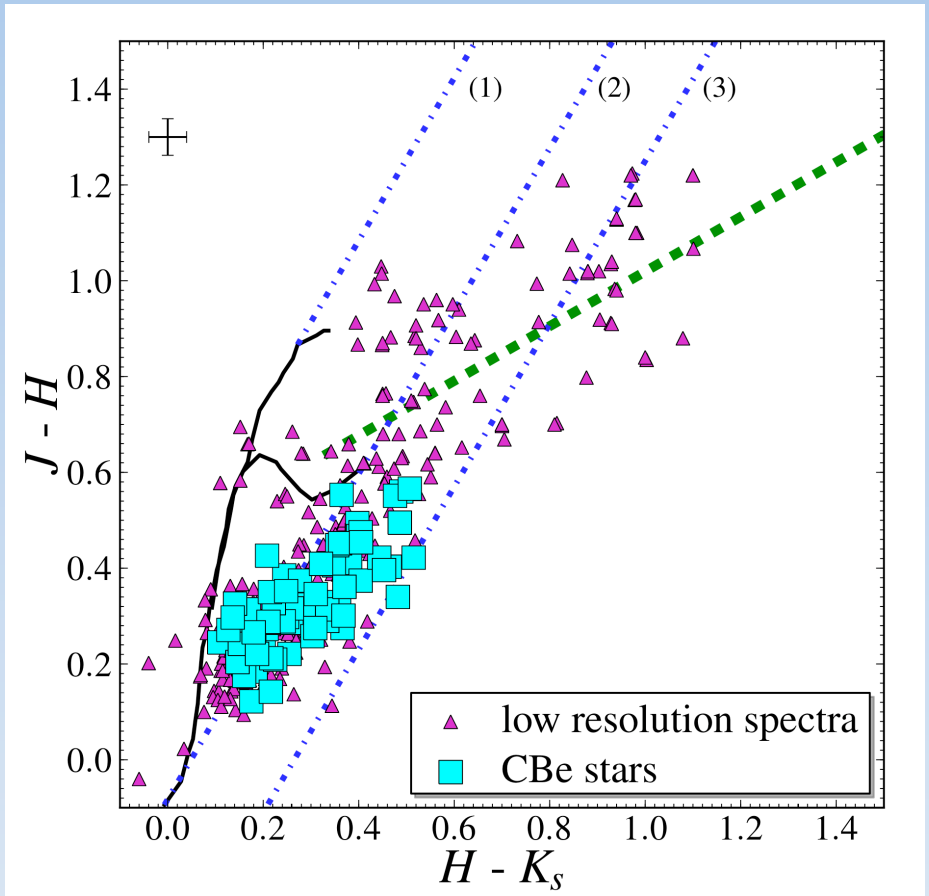
Candidate CBe stars

Classical Be stars are B-type stars close to the MS that exhibit line emission over the photospheric spectrum. (Porter & Rivinius, 2003)

Selection criteria

- B-type spectrum (when FAST data available).
- Not displaying forbidden emission lines
- Moderate infrared excess (2MASS)

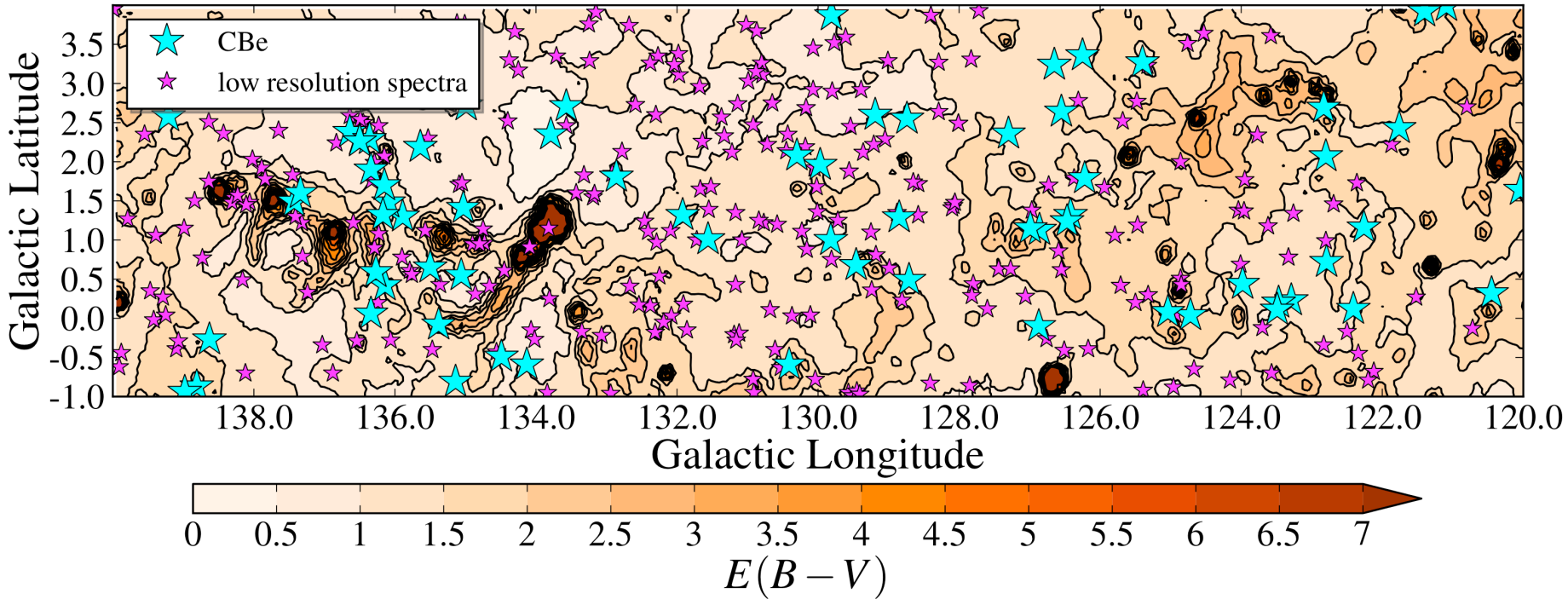
About 140 candidates broadly satisfy these criteria.



Observations and data extraction

69 classification-standard (λ/Δλ≈1000 – 2000) spectra of classical Cbe candidates.

Run	Telescope/Instrument	Grating	Wavelength interval	Δλ	Observed targets	Apparent magnitude (r')
27-29/08/2006, 08/09/2006	INT/IDS	R300V	3500-7500 Å	∼ 4Å	33	∼ 14.0 – 16.0
04-07/12/2007	NOT/ALFOSC	#16	3500-5000 Å	∼ 2Å	27	∼ 13.5 – 17
27-30/11/2009	INT/IDS	R400V	3500-7500 Å	∼ 3Å	2	∼ 12.0 – 15.5
21-26/10/2010	INT/IDS	R400V	3500-7500 Å	∼ 3Å	7	∼ 13.0 – 16.5



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Spectral typing

By-eye initial classification, by comparison with Indo-US library spectra:

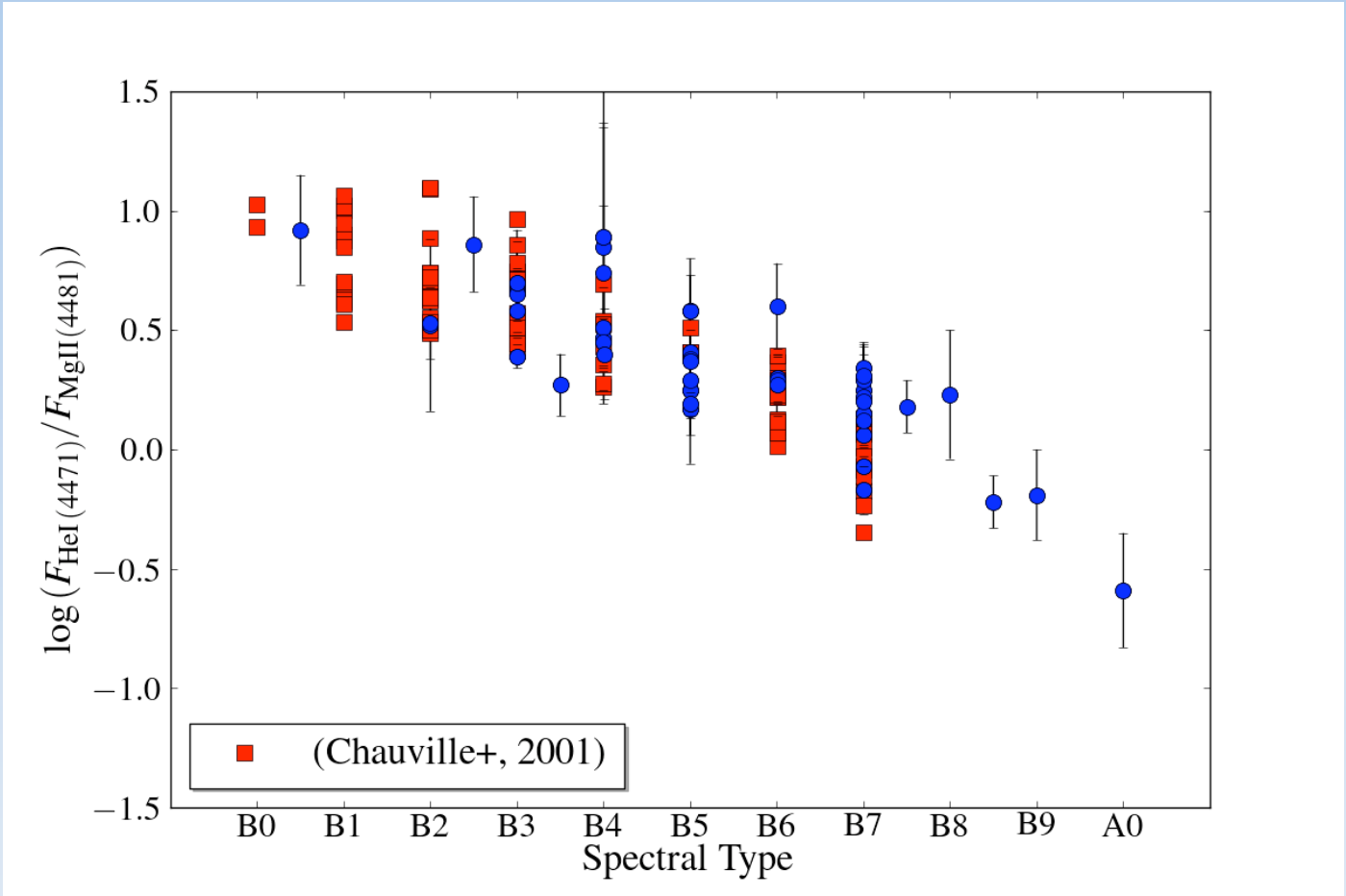
- B-type: He I lines at 4009Å, 4026Å, 4121Å, 4144Å,4387Å and 4471Å compared to the Mg II λ4481Å.
- A-type: Ca I K and Mg II. The absence of He I.

Quantitative typing:

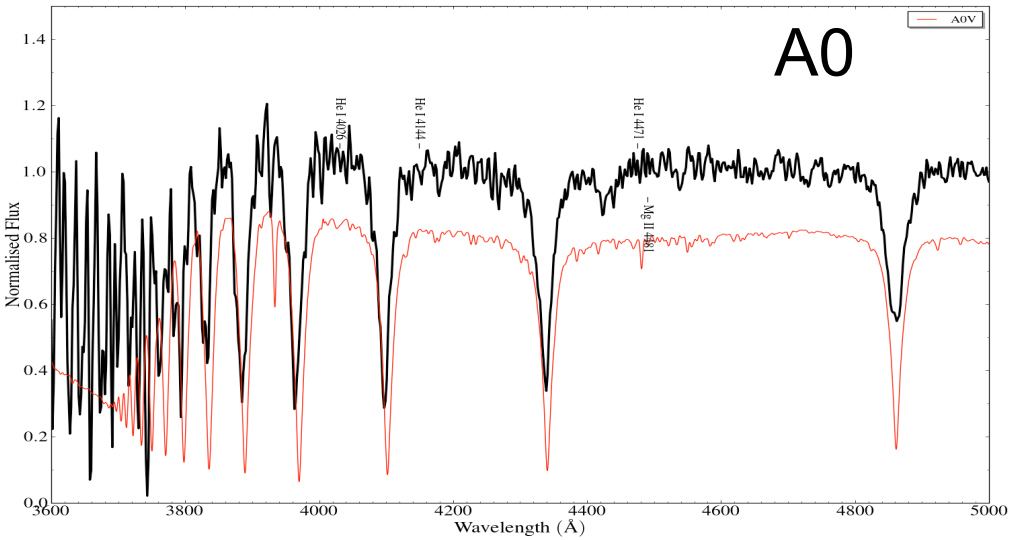
- Line ratio: He I (4471) / Mg II (4481).
- EW measure of He I (4471) and He I (4026).

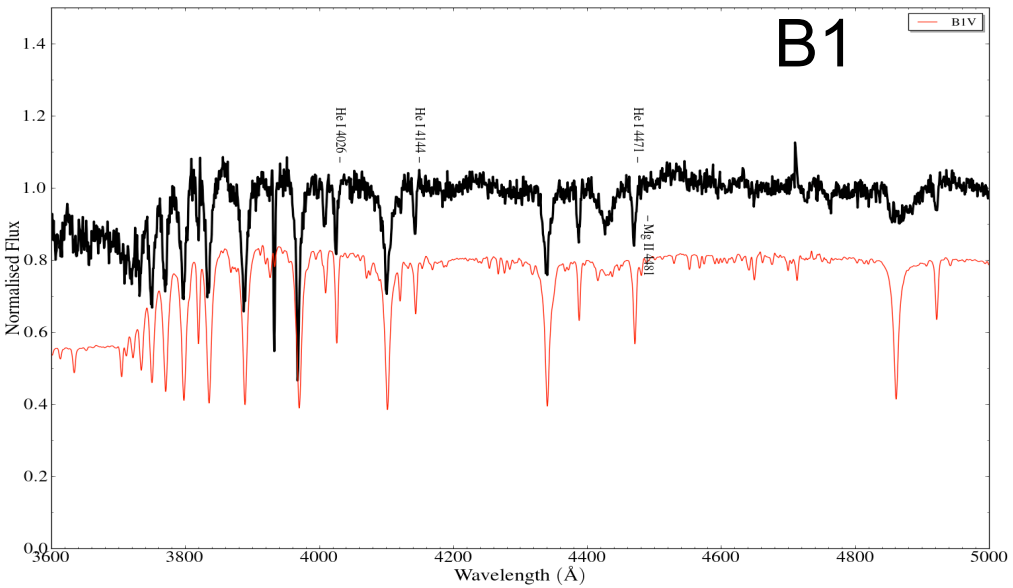
Spectral typing

$\mathrm{Log}_{10}\,(F_{4481}/F_{4471})$ vs. Spectral Type



Spectral typing: a few examples





SpT	N
B0	1
B1	1
B2	6
B3	15
B4	9
B5	14
B6	4
B7	14
B8	2
B9	1
A0	2

Luminosity class?

Typical gravity sensitive features are:

- Balmer lines (wings), especially in later B-types
- Weaker metal lines, i.e. O II, Si II-IV, N II (supergiants).

Problems

A combination of too low S/N in average (~40) and low-resolution, does not allow precise luminosity class assessment

Satisfactory luminosity class determination has been possible for a more limited number of objects in the sample

Reddening estimates

E(B-V) determined in two ways, both using the spectral types as assessed before

Spectral method (SED fitting):

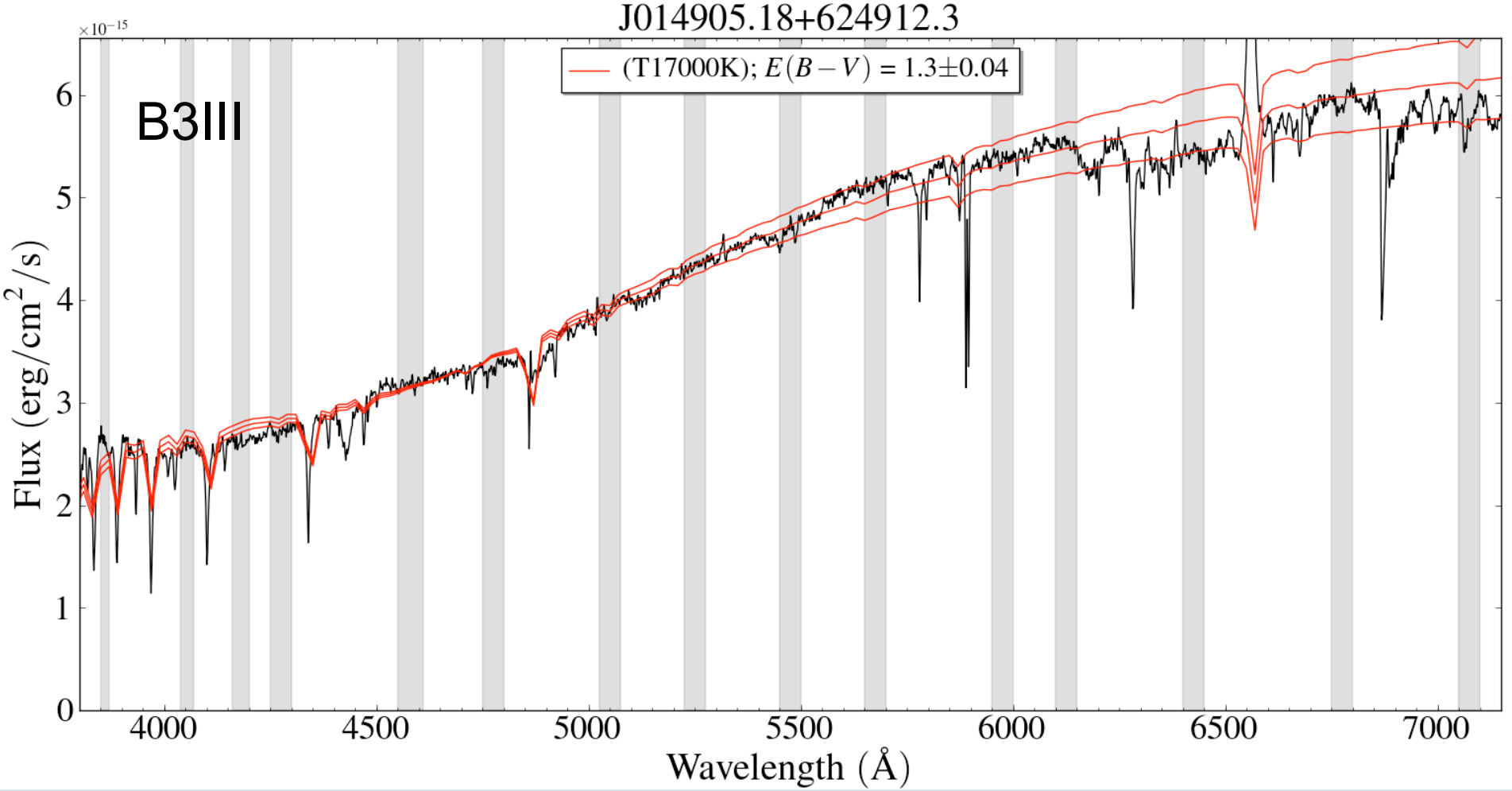
- Spectral Types mapped onto a T_{eff} scale to find an appropriate ATLAS9 model
- Models are progressively reddened onto the observed spectrum, seeking for the χ^2 minimum
- The fit is run in carefully selected lines-free bands, after rebinning the observed spectrum to match the model resolution ($\Delta\lambda$~20Å)

More classical photometric method:

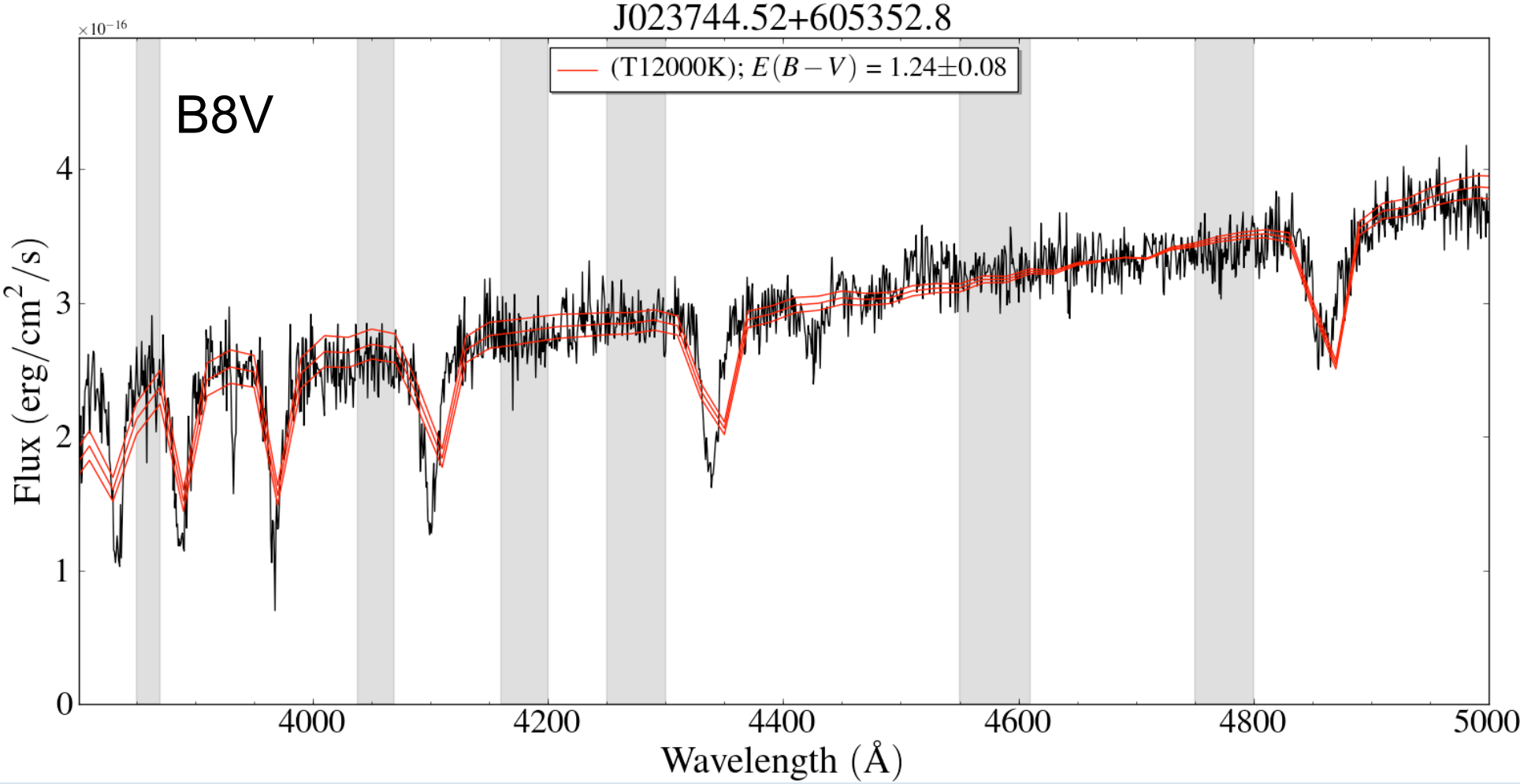
Using IPHAS (r'- i') observed colours and a compilation of intrinsic colours from Sale et al. (2009), Fabregat (pvt. communication), Kenyon & Hartmann (1995), Siess et al. (1997)

The reddening law used in all cases is the mean Rv=3.1 law, presented by Fitzpatrick (1999)

SED fitting → E(B-V)



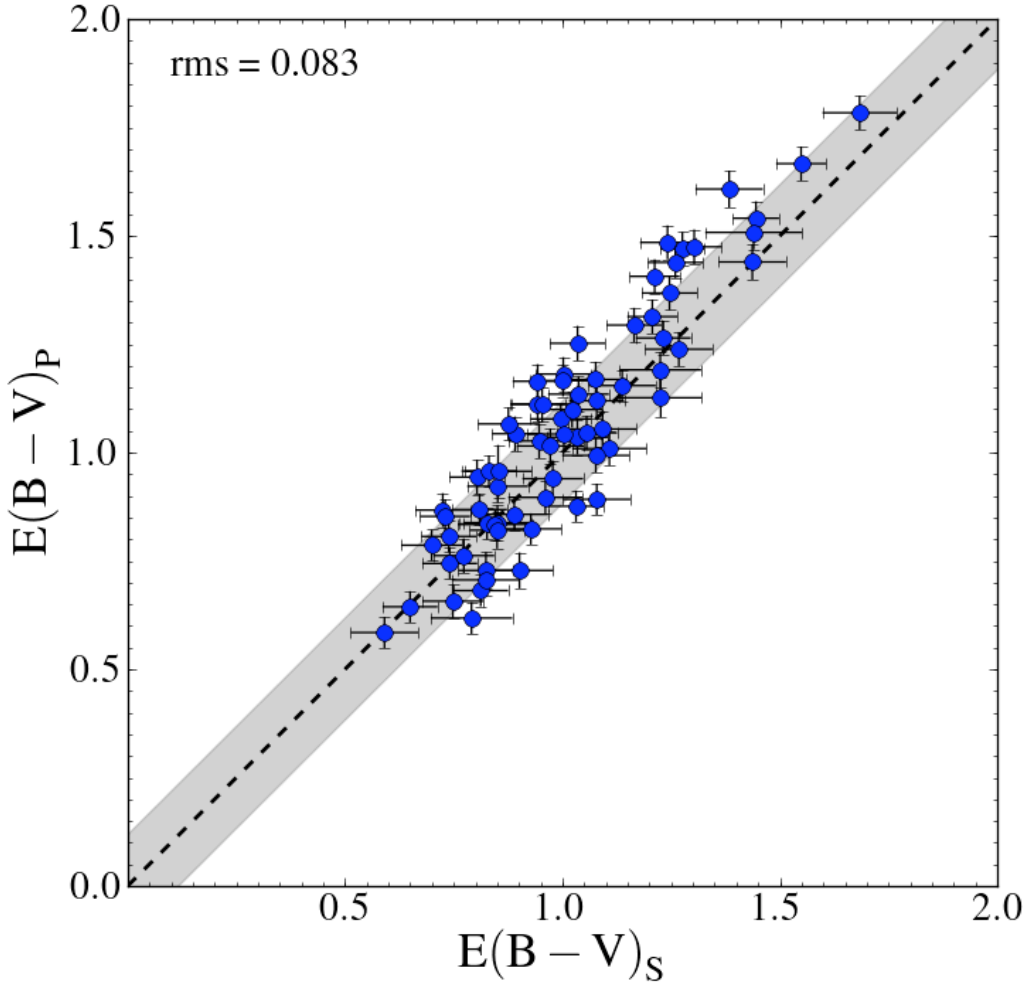
SED fitting → E(B-V)



Reddening determination

Both E(B-V) determinations have been corrected for circumstellar emission, which linearly correlates with Hα

$E^{cs}(B-V)_S = 0.0049 - 0.00185\ EW(H\alpha)$
(Fabregat & Reglero, 1990)



Distance estimates

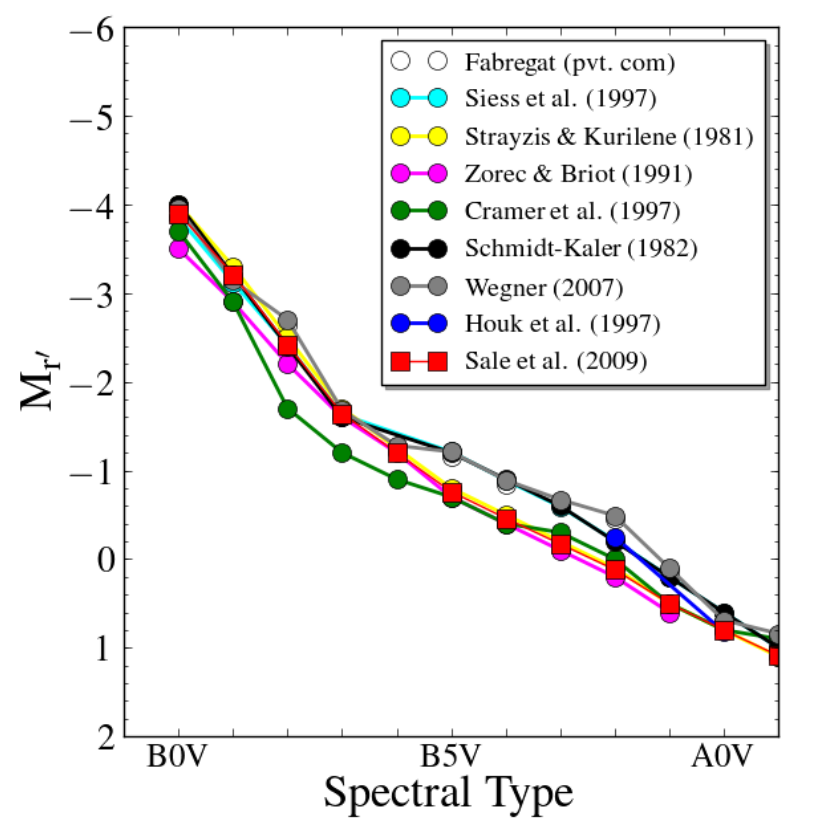
Via the use of MEAD extinction curves (Sale et al., 2009)

- Distances are estimated at the intersection between the measured E(B-V) and line-of-sight reddening curves. These are built-up using IPHAS photometry of the stars within 10’ x 10’ boxes surrounding the target.

Spectroscopic parallaxes

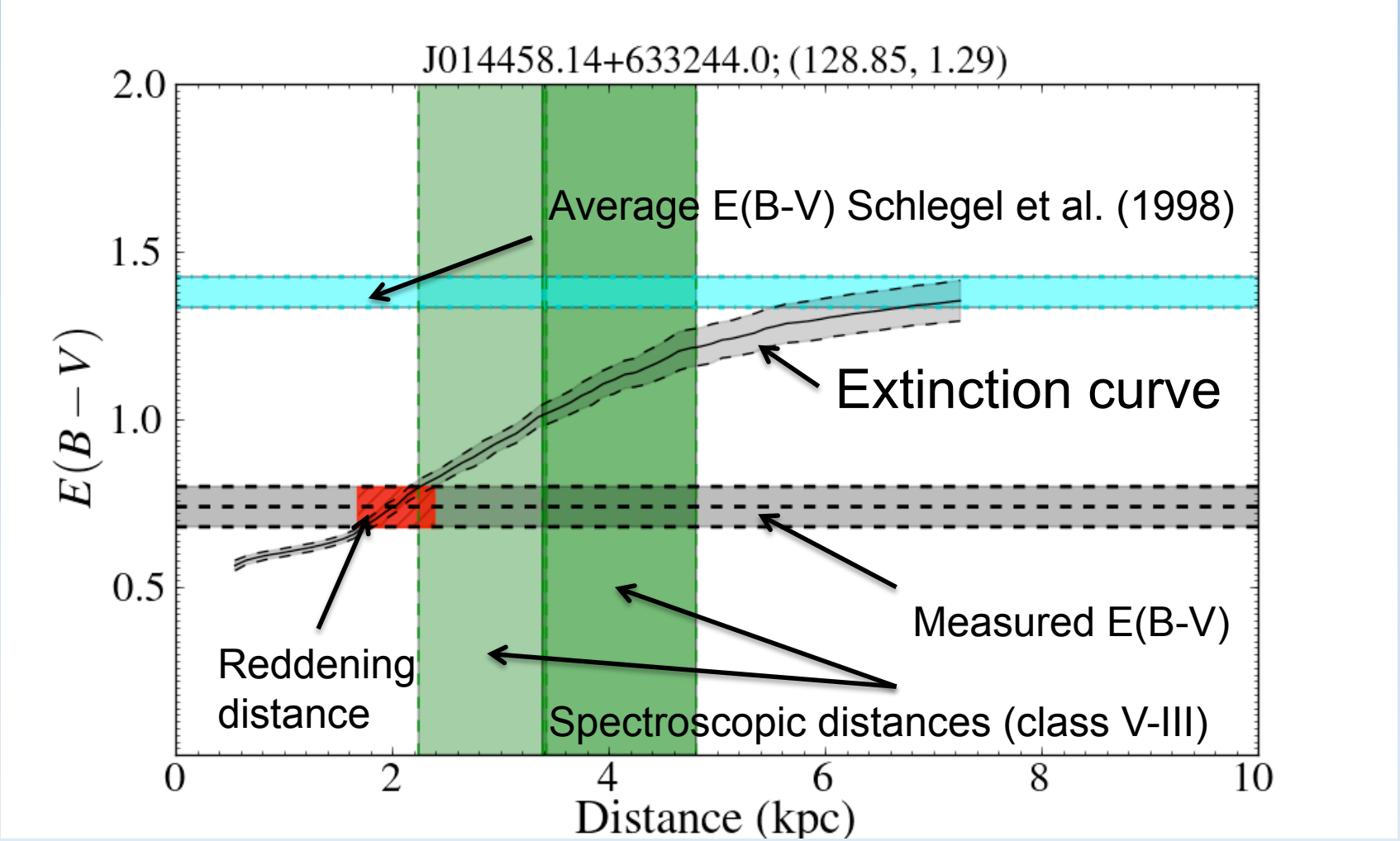
- $D = 10^{(r' - Mr' - Ar' + 5)/5}$

The adopted absolute magnitudes scale is from Sale et al. (2009)



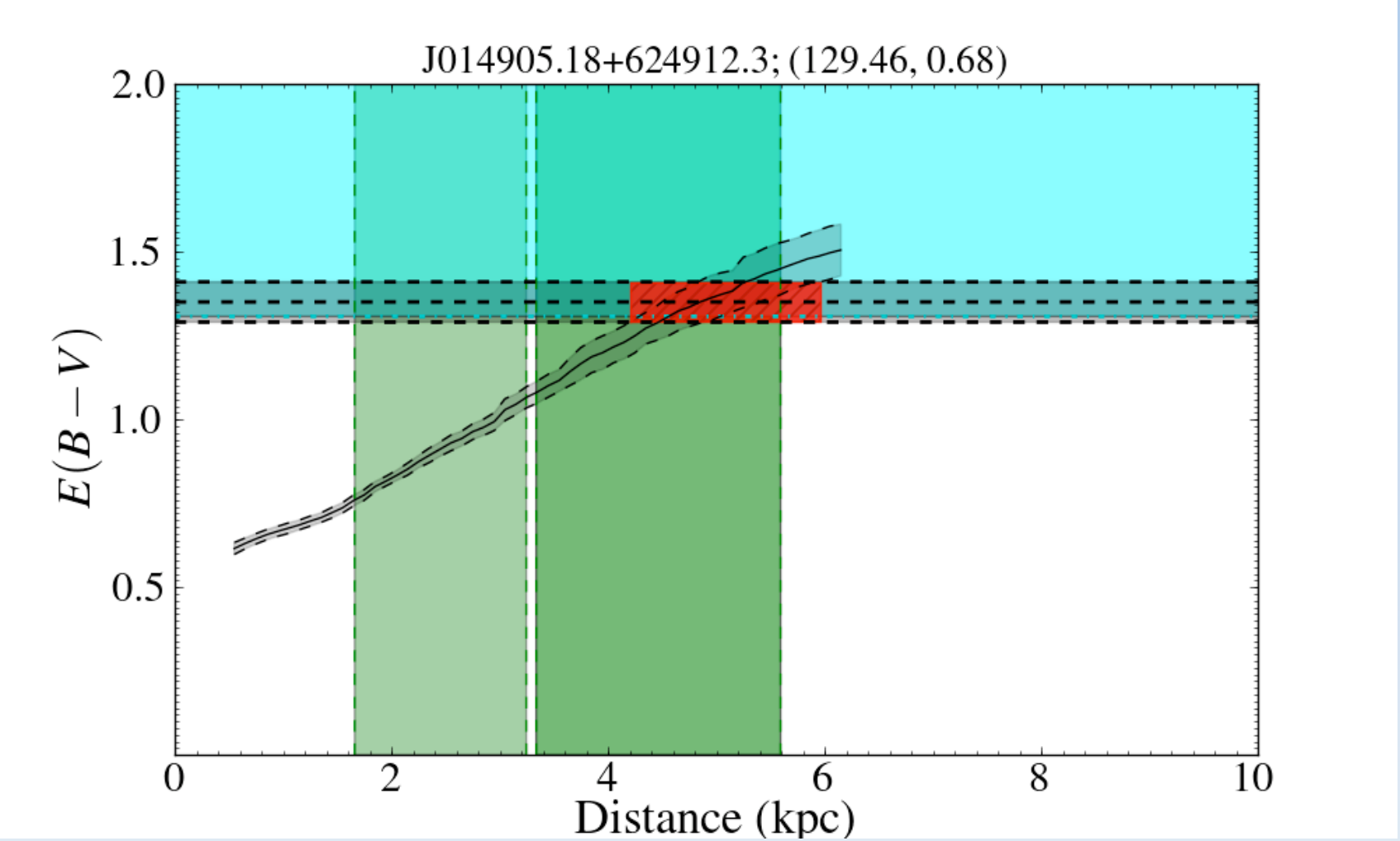
Distance estimates

Perseus object: Mr'=13.96; B7V



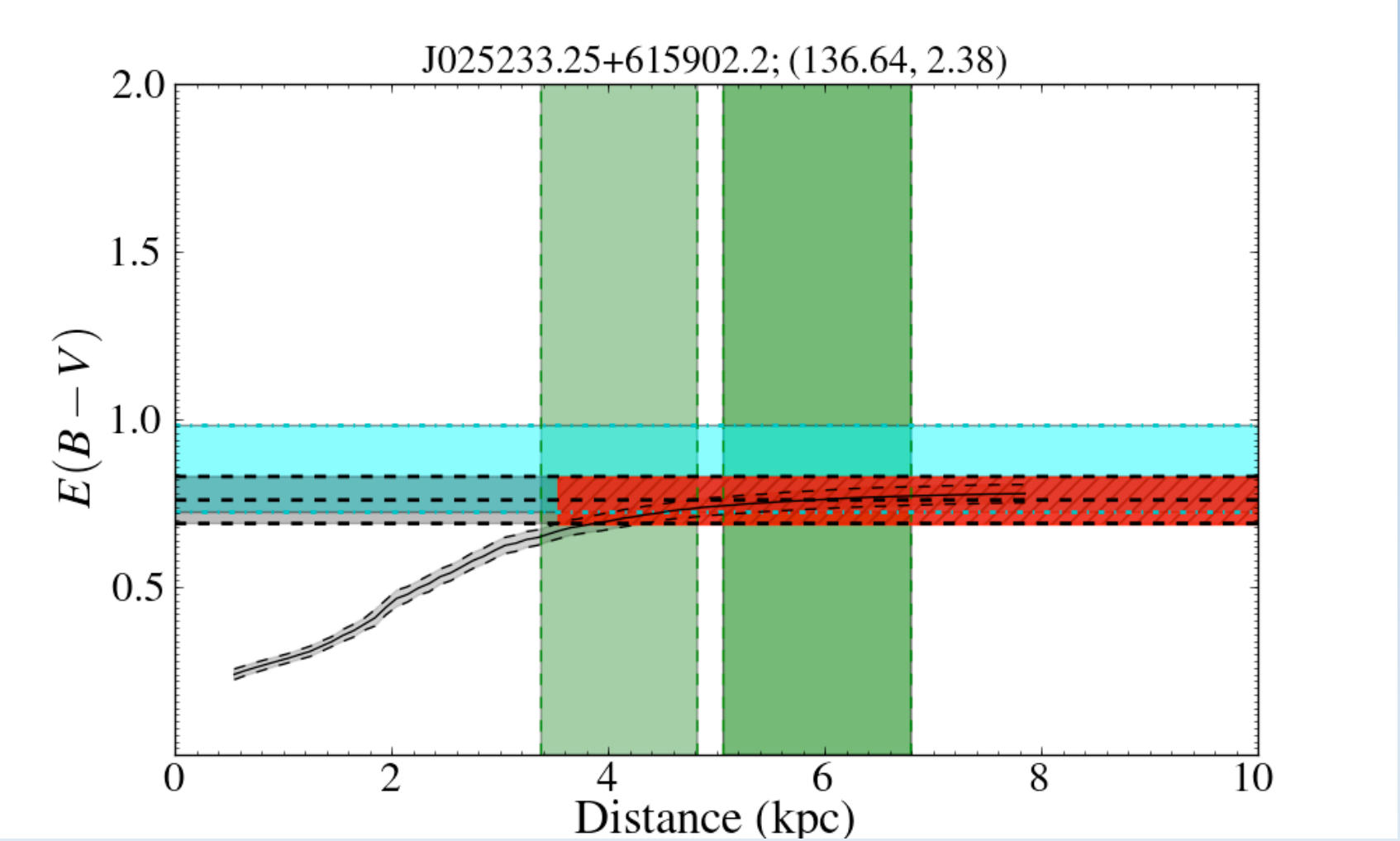
Distance estimates

Outer Arm object: Mr'=13.72; B3III



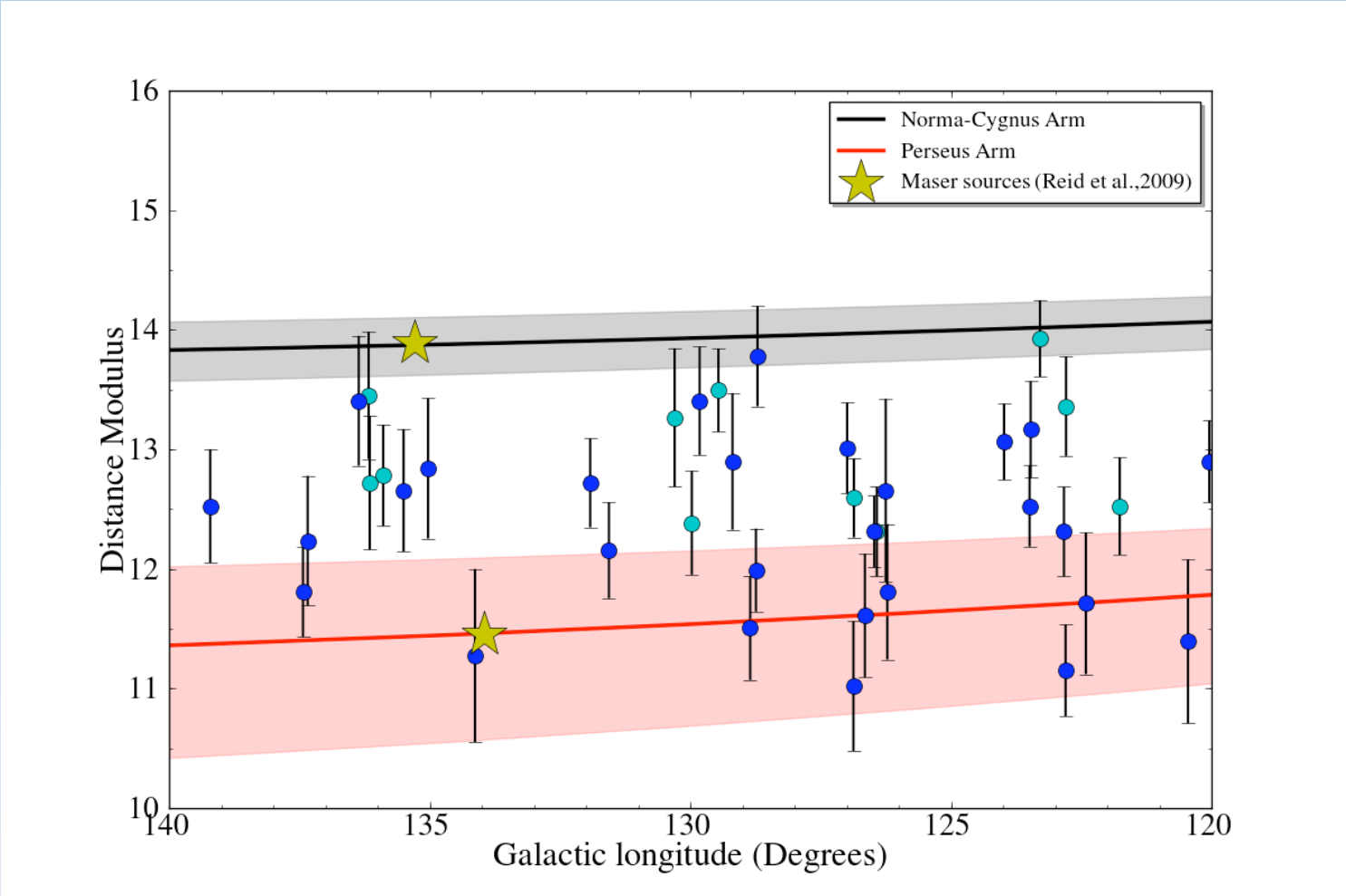
Distance estimates

Lower limit: Mr'=14.82; B7V



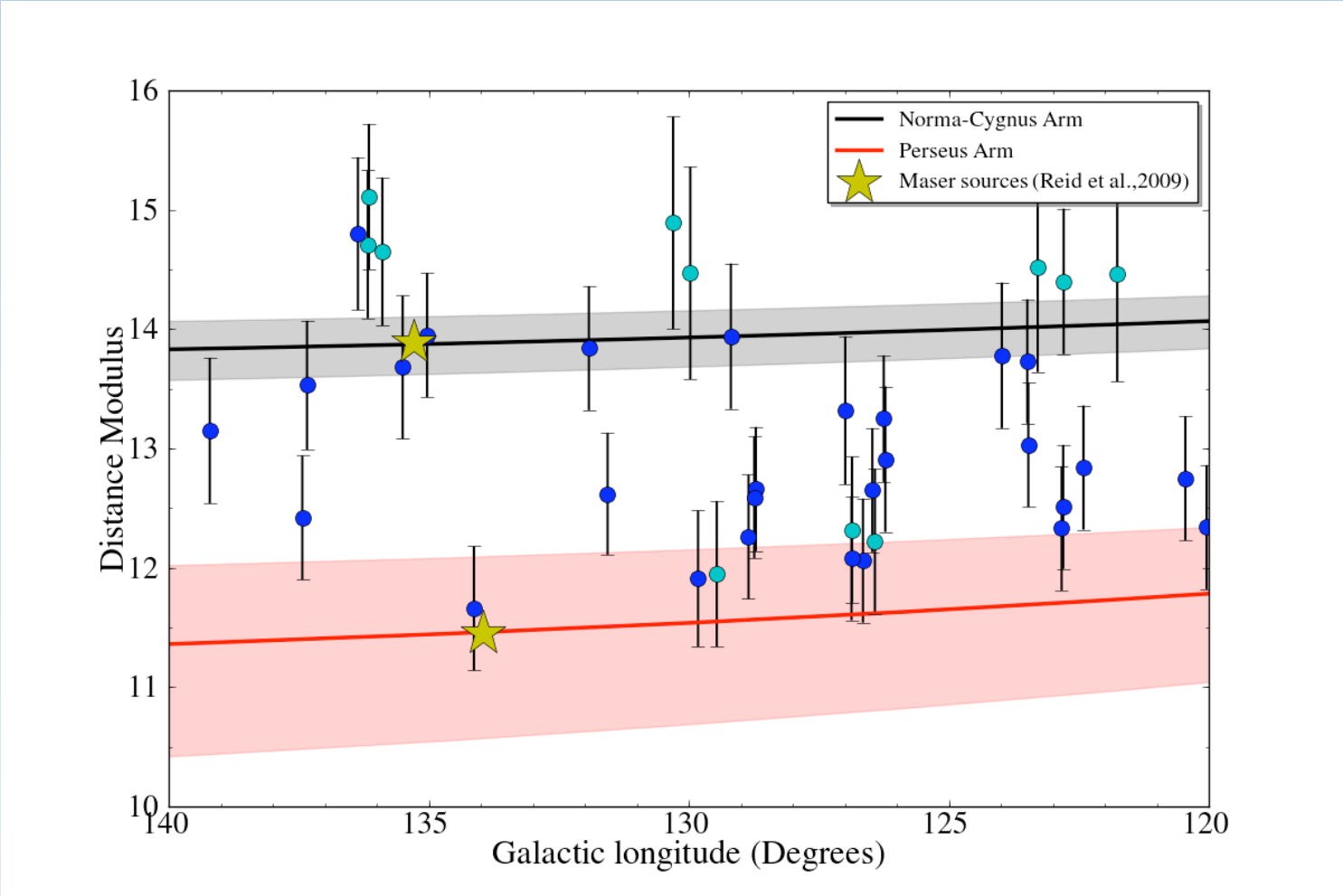
Objects location: extinction distance

39 objects with *measured* extinction distance.
Cyan: Spectral types B0-3; Blue: B4-A0



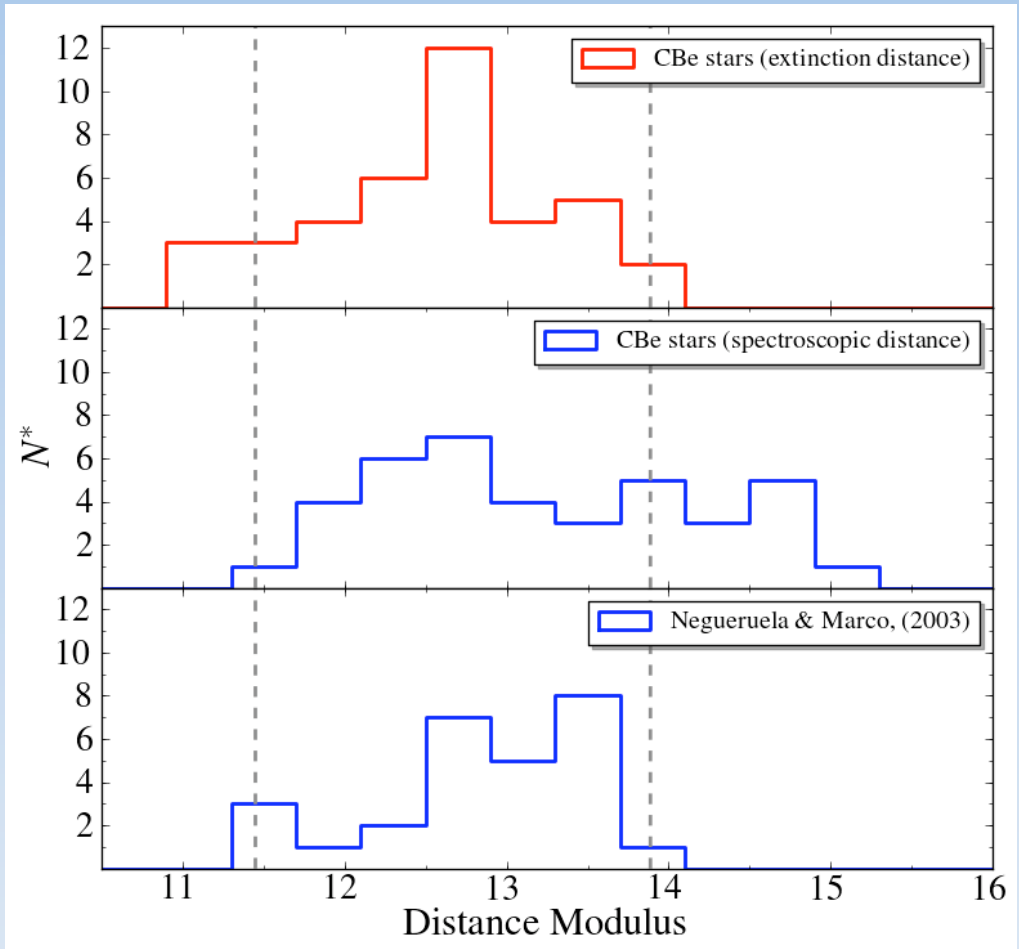
Objects location: spectroscopic distance

Distance modulus as for luminosity class V.
Cyan: Spectral types B0-3; Blue: B4-A0



Objects location: comparison

Mean distance modulus difference between the 2 methods: ~ +0.7 mag



Summary

- IPHAS make possible an easy identification of large number of intrinsically bright and (very) distant CBe stars. Complete identification of the class in the outer Galaxy possible.

- Reddening and spectroscopic parallax distance scales are not yet reconciled

- Possible future developments: to explore the sample for associated clusters