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# Binary systems: detection and pre-/post-mass transfer characterisation

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In collaboration with:
1st part → T. Merle, S. Van Eck, A. Jorissen
(see Merle+, submitted)

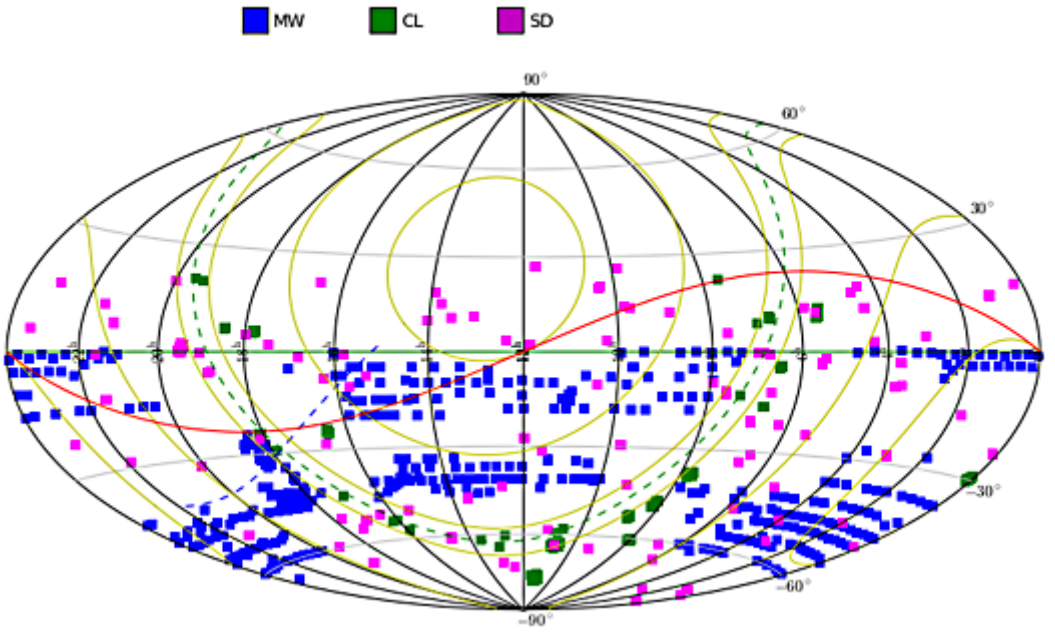
2st part → H. Boffin, A. Jorissen, S. Van Eck
(see Van der Swaelmen+, 2016, arXiv: 1608.04949)

# Part I: detection of spectroscopic binary candidates (SBn, n≥2) within the GES sample

See: The Gaia-ESO Survey: double, triple and quadruple-line spectroscopic binary candidates
Merle et al., submitted

# The Gaia-ESO survey: aim

- ➔ Ground based, mid + high-resolution survey (Gilmore+ 2012, Randich+ 2013)
- ➔ $10^5$ MW stars: bulge, thin and thick discs, halo, open clusters
- ➔ Stars in various evolutionary stages, but mainly MS and RGB stars
- ➔ Aims
  - ⟹ Kinematical and chemical characterisation of stellar populations
  - ⟹ Constrain formation history of the MW


Observed fields (*src*: www.gaia-eso.eu)

# The Gaia-ESO survey: data

➔ GIRAFFE + UVES spectrographs @ VLT

➔ GIRAFFE spectra

⟹ Resolution: from ~16000 (HR21) to 26000 (HR9B)

⟹ S/N ~ 10 (single exposure)

➔ UVES spectra

⟹ Resolution: 47000

⟹ S/N ~ 50 (single exposure)

➔ Spectral coverage: visible and near-infrared (around Ca II triplet)

➔ Faintest targets: V ~ 20

VLT (*src*: www.eso.org)

# Binaries within the GES

➔ Binaries are of great importance

⟹ Direct access to mass, radius, luminosity

⟹ Excellent laboratories to test and constrain stellar evolution, stellar nucleosynthesis, high-energy astrophysics…

➔ Spectroscopic binaries

⟹ binary nature inferred from their spectra

⟹ need to be confirmed (*e.g.* with long term spectroscopic tracking)

➔ Binarity and stellar multiplicity within GES

⟹ extend list of known spectroscopic binaries

⟹ binary nature (SB*n*, $n \geq 2$) has to be taken into account to get reliable stellar parameters and chemical abundances

⟹ preliminary work in the context of the astrometric mission Gaia

# Detection Of Extrema (DOE)

➔ DOE tool implemented by T. Merle
(Merle+, submitted)

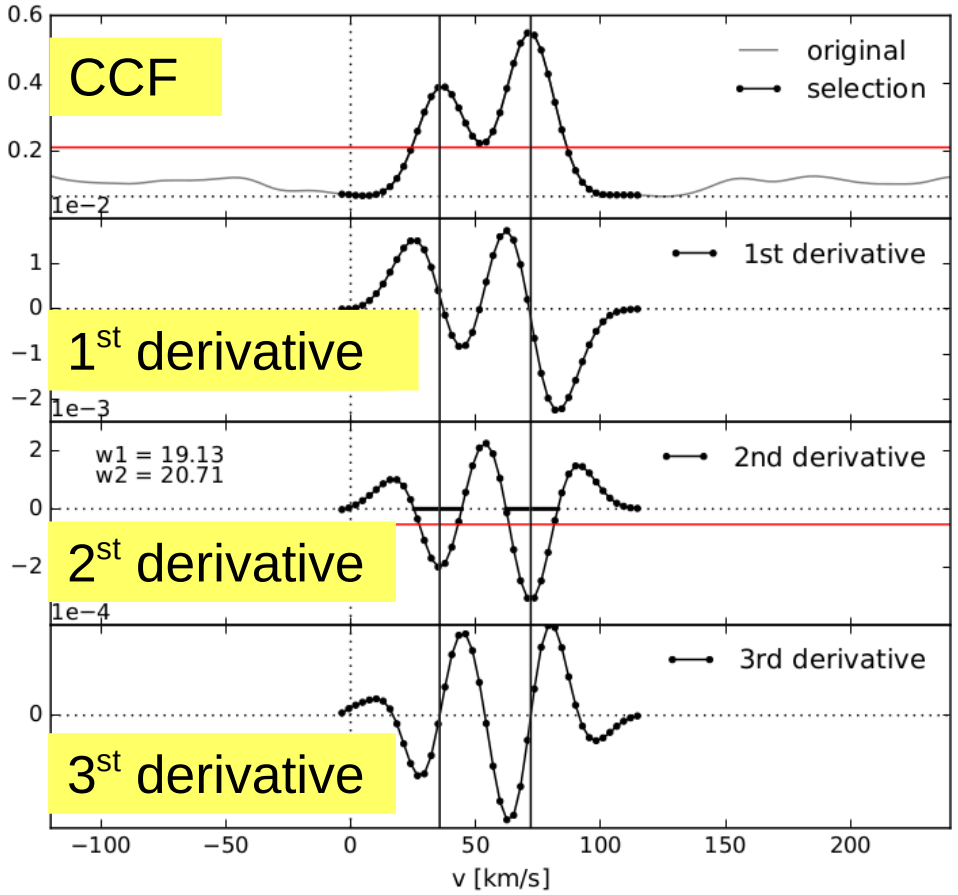
➔ CCF and its successive derivatives used to detect multiple peaks in the CCF

➔ Derivatives obtained by convolving the CCF with the derivative of a Gaussian kernel

⟹ technique used in signal processing (e.g., Foster 2013)

⟹ allows to smooth and derive simultaneously

➔ CCF computed by the data reduction node of the GES collaboration



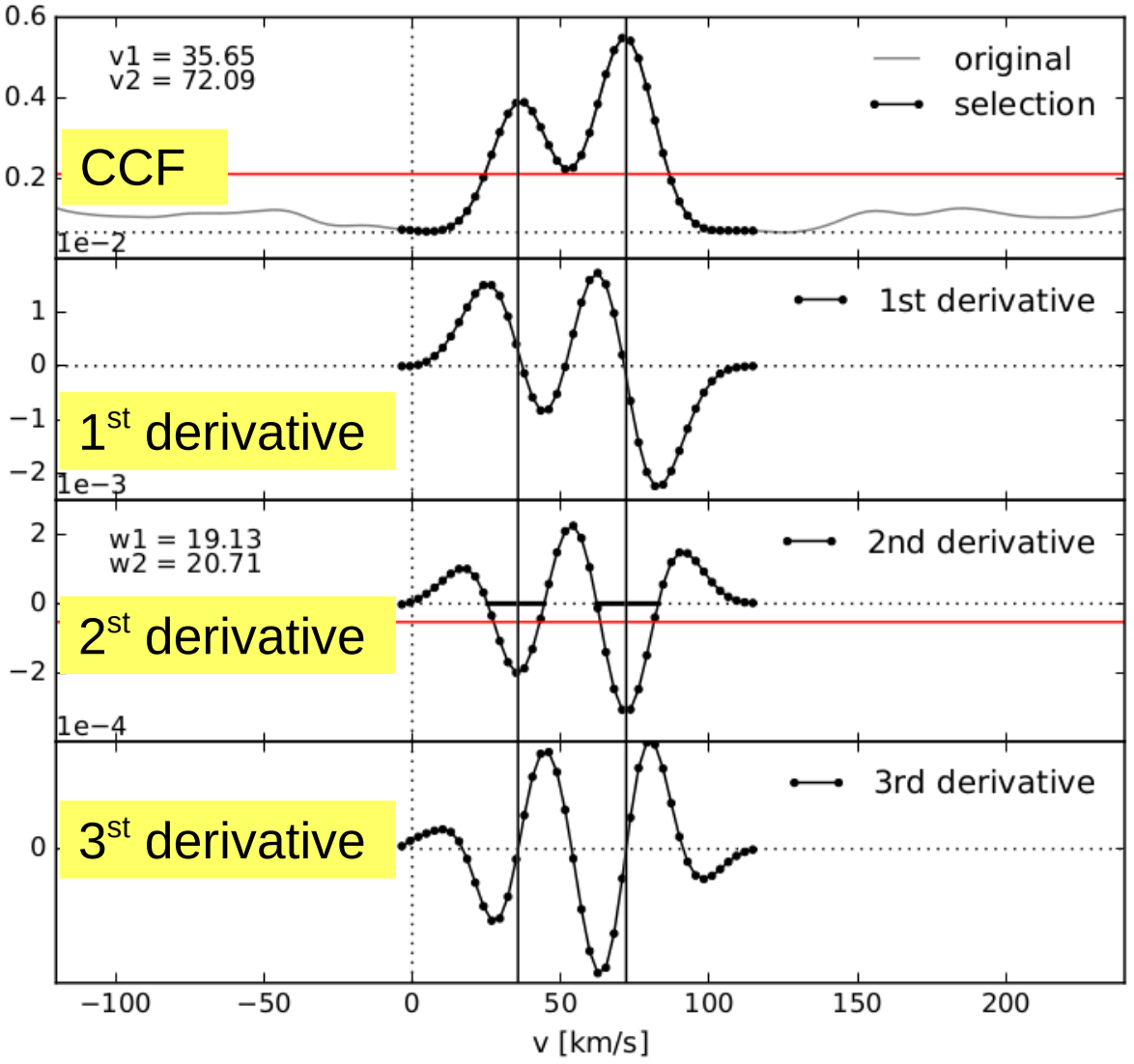

CCF = cross-correlation function

Merle+, subm.

# DOE performances: example 1

➔ Simulated CCF with components at 36 and 72 km/s

➔ DOE returns 35.7 and 72.1 km/s




Merle+, subm.

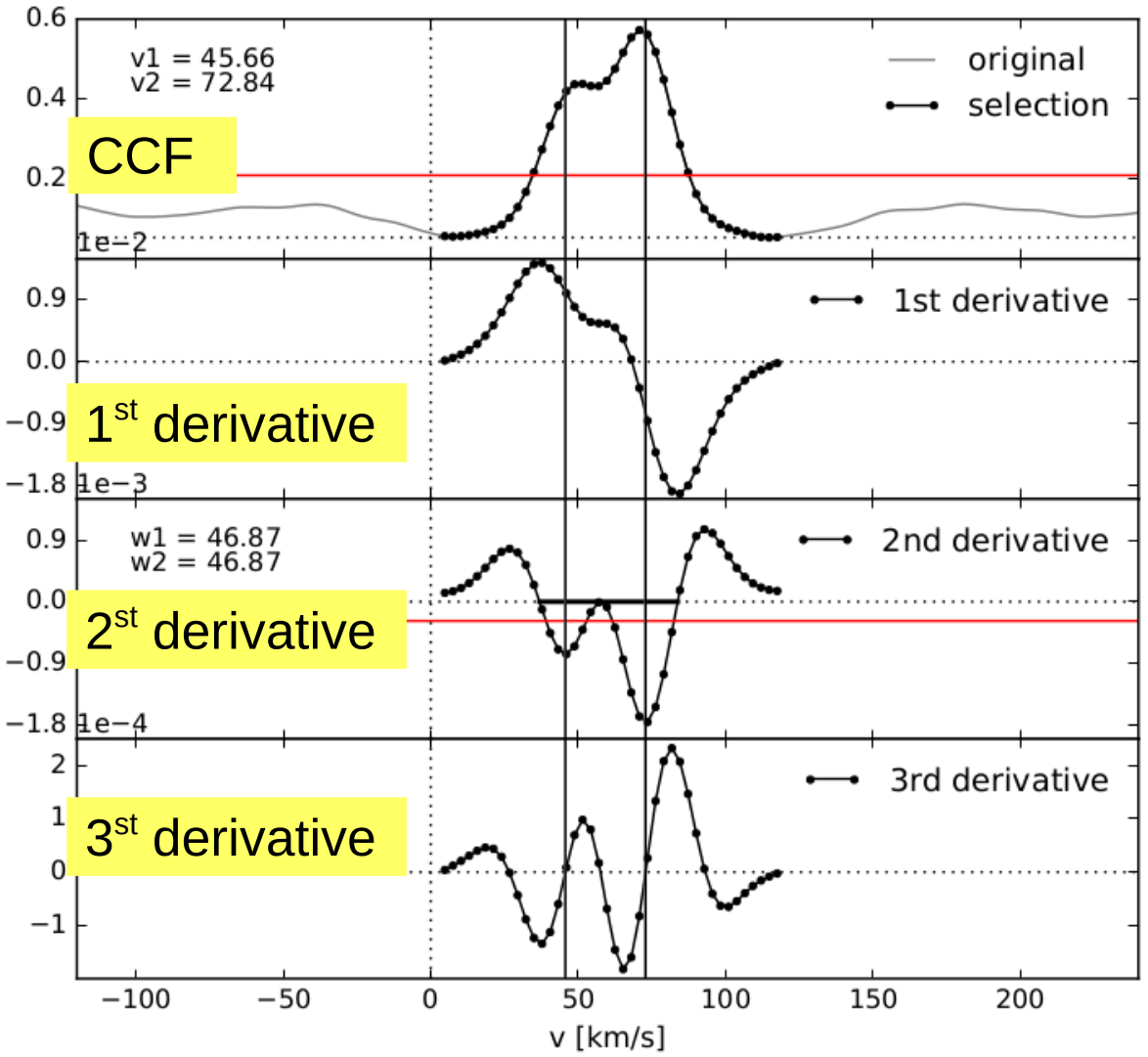
# DOE performances: example 2

➔ Simulated CCF with components at 48 and 72 km/s

➔ DOE returns 45.7 and 72.8 km/s

➔ 1st derivative is not enough to detect the position of the two components

➔ 3rd derivative is mandatory



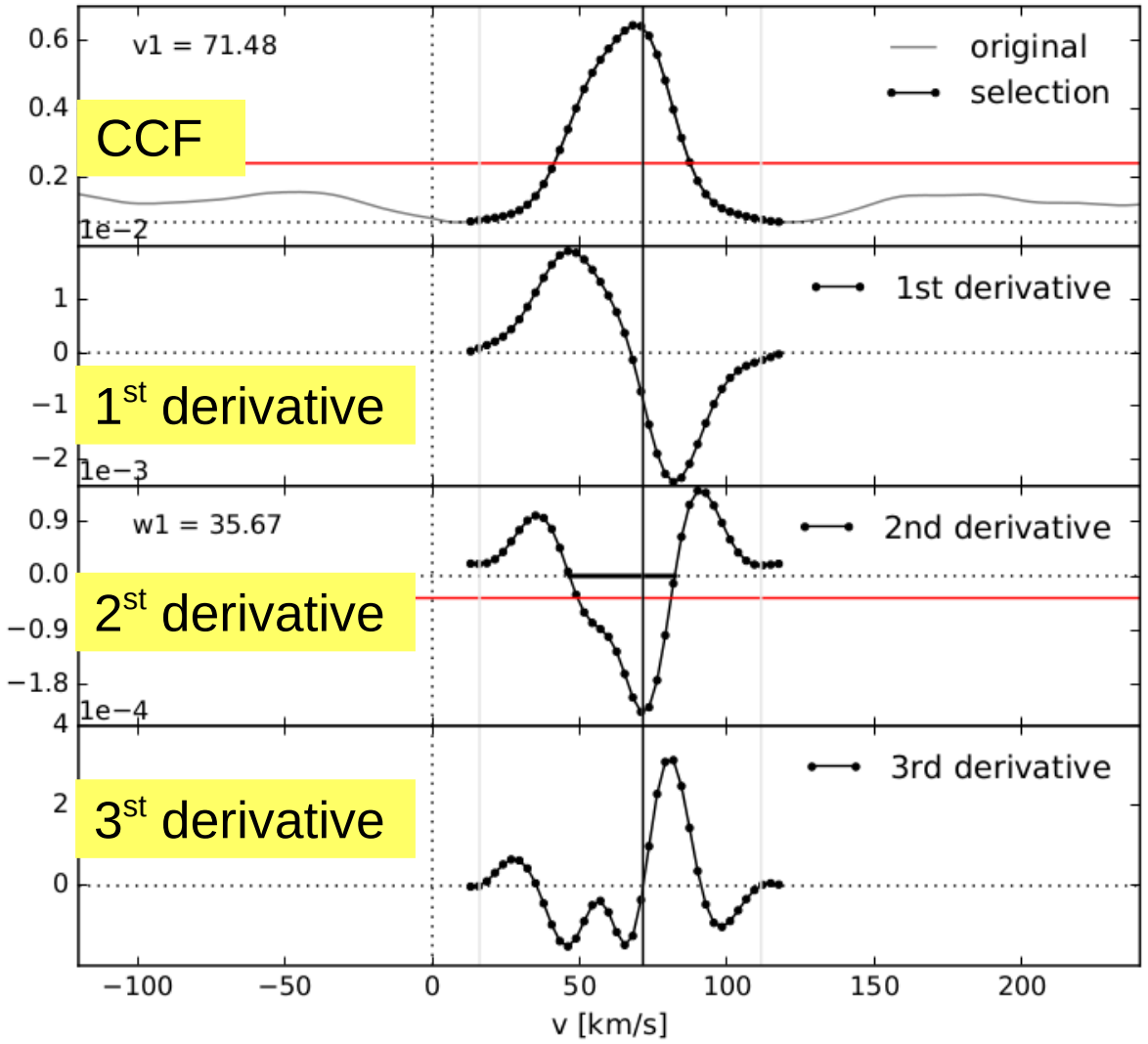

Merle+, subm.

# DOE performances: example 3

➔ Simulated CCF with components at 54 and 72 km/s

➔ DOE finds one peak

➔ Limiting case in term of radial velocity difference



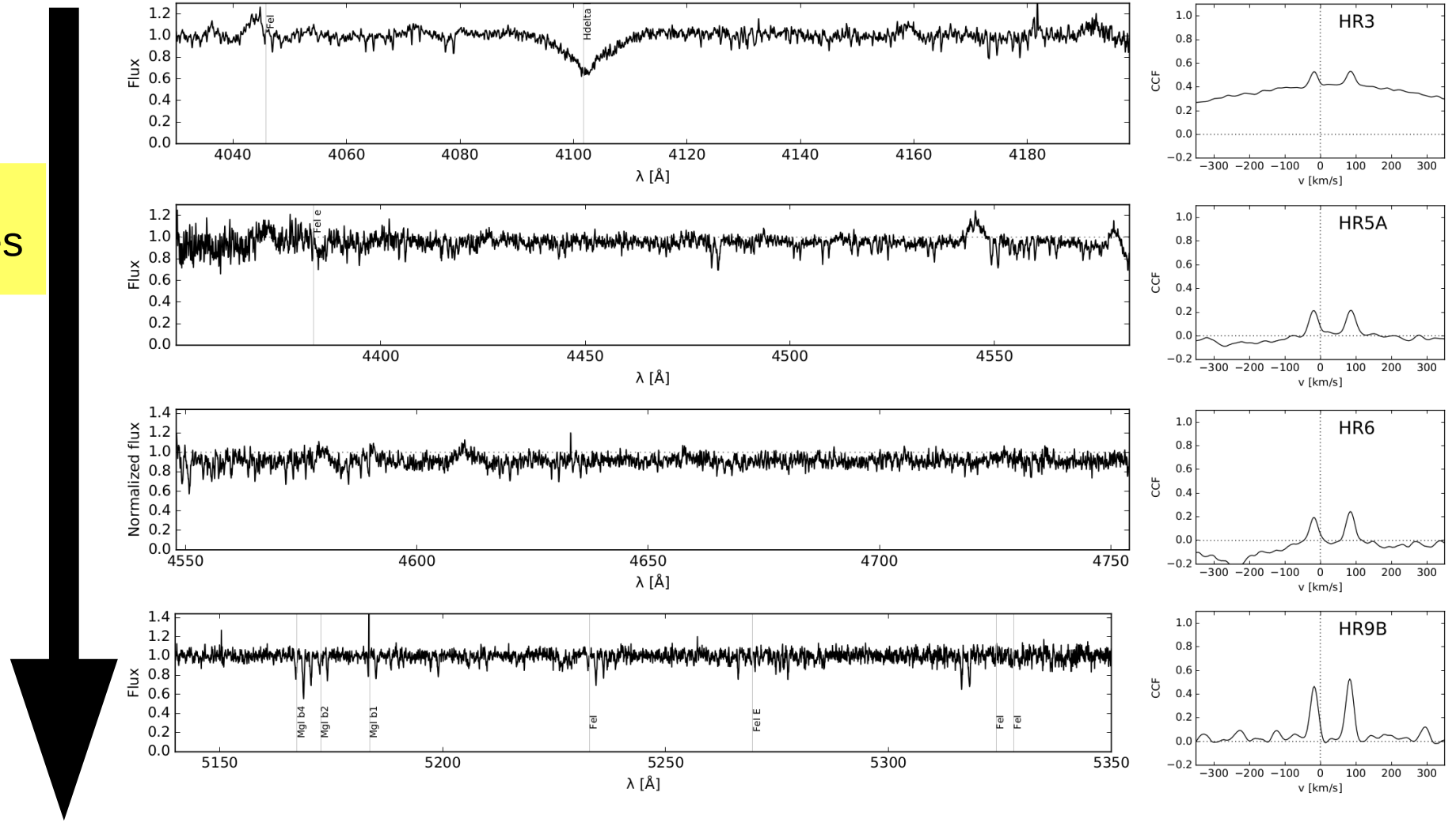

Merle+, subm.

# Same object, different CCF

GIRAFFE spectrum

CCF

Setup changes




CCF = cross-correlation function

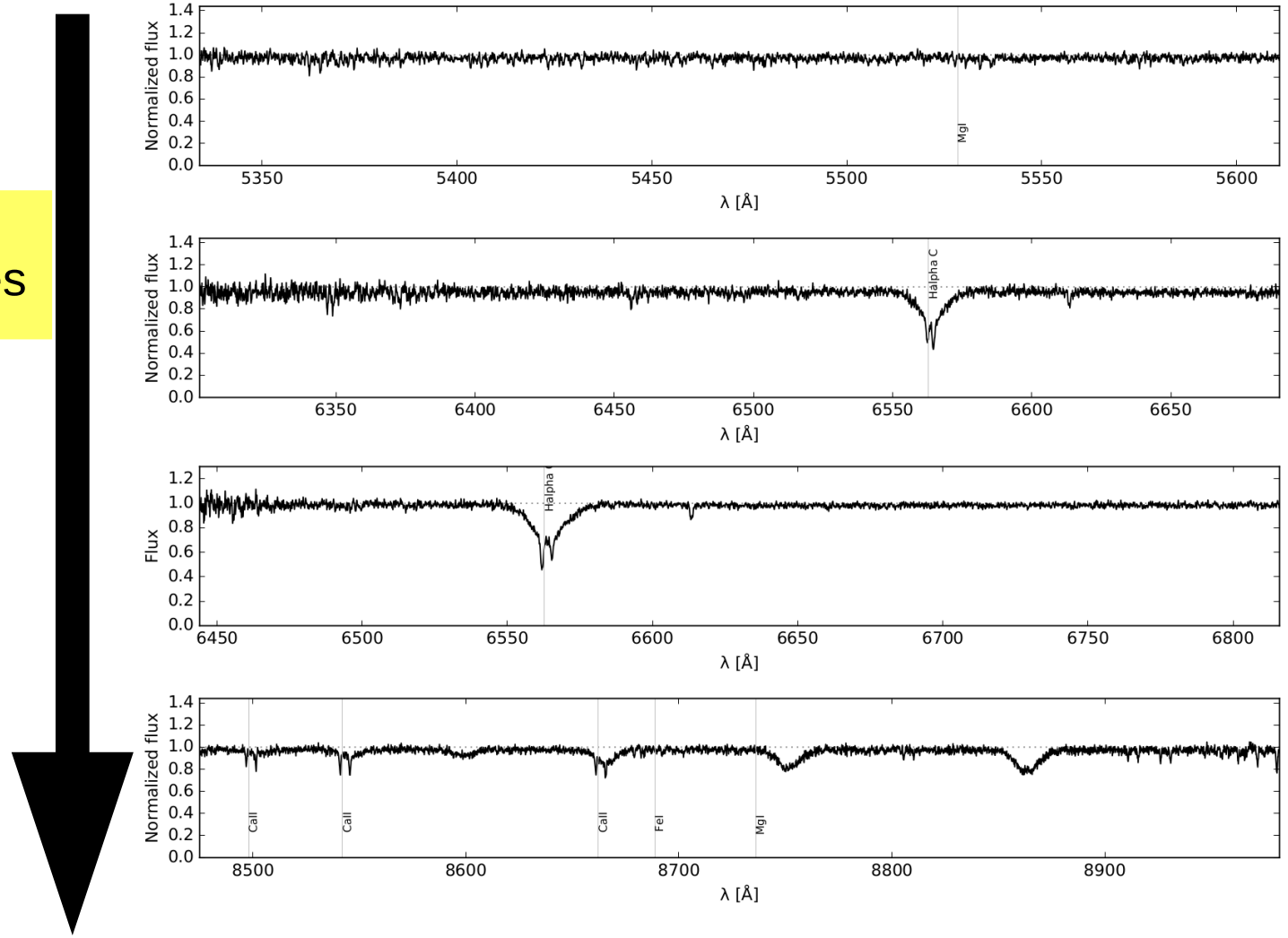
Merle+, subm.

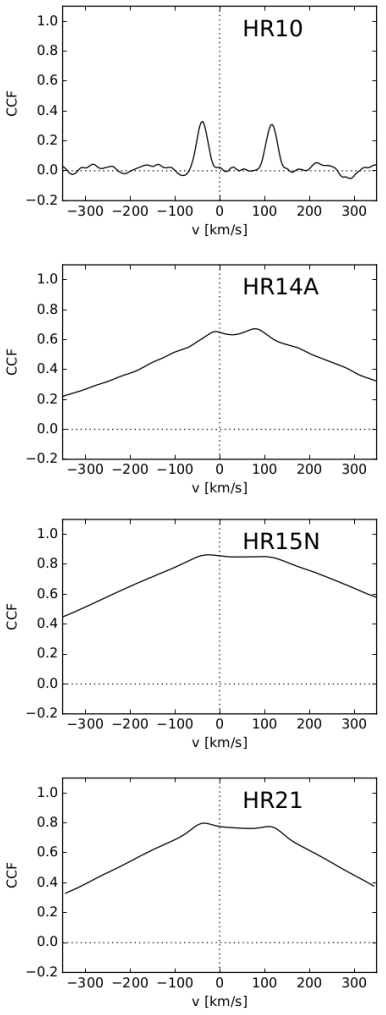
# Same object, different CCF

GIRAFFE spectrum

CCF

Setup changes




Merle+, subm.

# Results: SB2,3,4 among the GES sample

➔ 185 / 27786 = 0.67% detected SB2 in the MW field

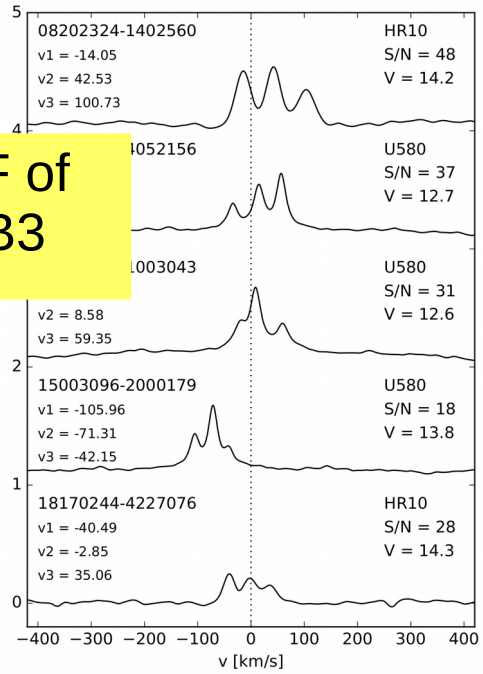
➔ 125 / 16468 = 0.76% detected SB2 in the MW open cluster

➔ Confidence flag indicates the probability of the detection (A > B > C)

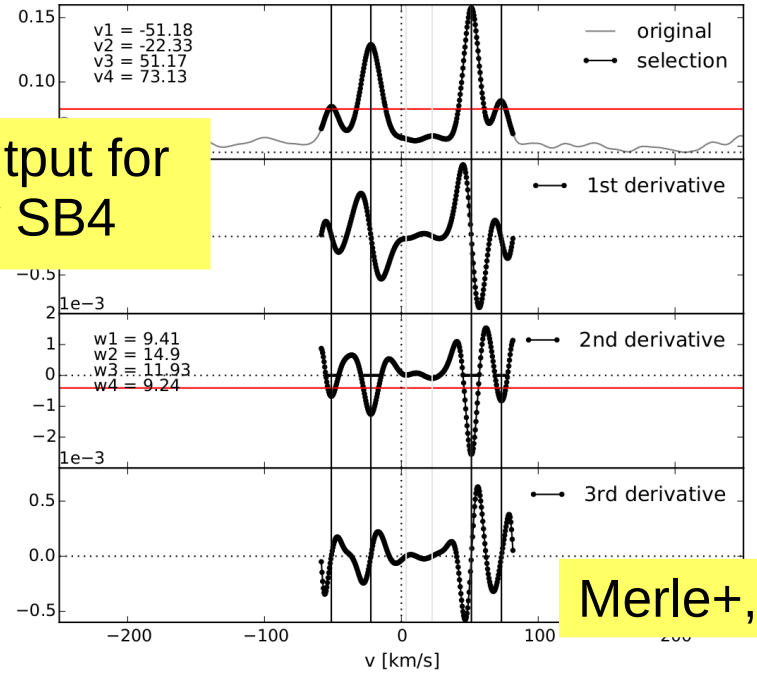
For the whole GES sample (field + cluster)

| Confidence flag | A | B | C | Total |
|---|---|---|---|---|
| SB2 | 127 | 107 | 108 | 342 |
| SB3 | 7 | 1 | 3 | 11 |
| SB4 | 1 | 0 | 0 | 1 |

CCF of 5 SB3




DOE output for the only SB4




Merle+, subm.

# Results: comparison with catalogues

**➔ GES sample brings new spectroscopic binary candidates, fainter than previous catalogues**

**➔ Intersection with already published catalogues show that most of GES SB2 are new spectroscopic binary candidates**

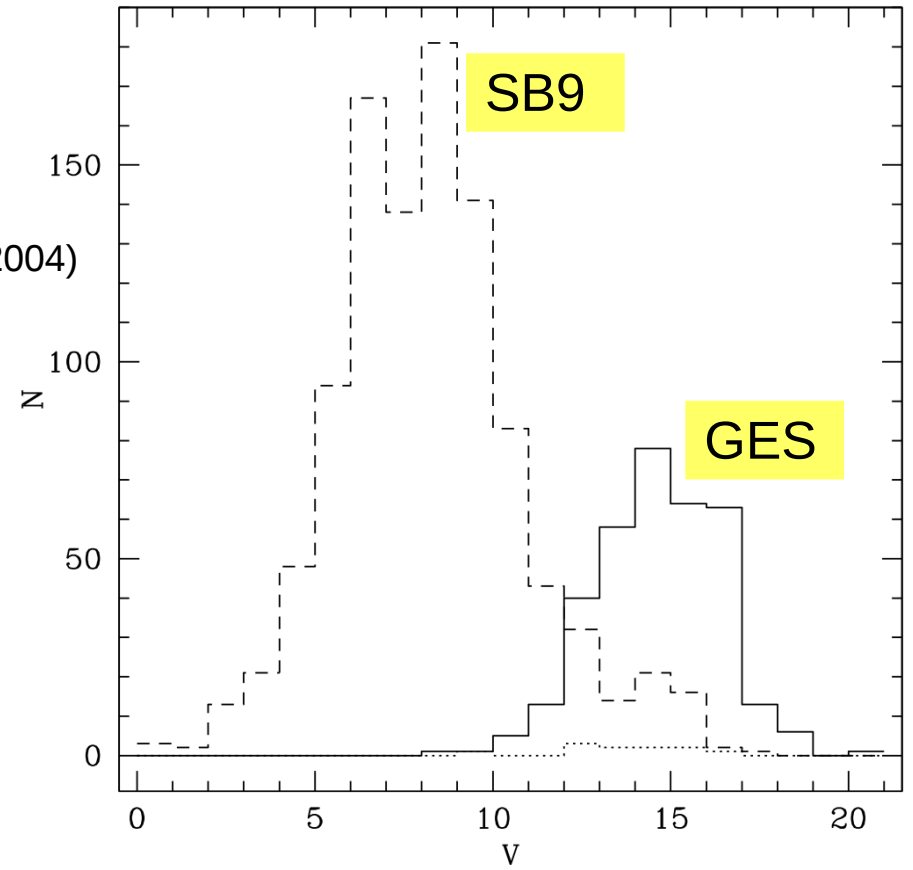
⟹ GES vs Simbad: 6 known binaries

⟹ GES vs SB9: 3 known SB2 (Pourbaix+2004)

⟹ GES vs GSC: empty (Homberg+2009)

⟹ GES vs RAVE: empty (Matijevic+2010)

⟹ GES vs Malaroda+2006: empty




Merle+, subm.

# Conclusion

- ➔ DOE can efficiently detect SB2,3,4 among GES spectra
- ➔ We increase the list of sectroscopic binary (SB2) candidates belonging to a magnitude range not well covered by published catalogues
- ➔ Need a spectroscopy tracking to confirm the binary nature
- ➔ Preliminary work; Gaia astrometric orbit will give access to individual masses

# Part II: characterisation of pre- and post-mass transfer systems

See: The mass-ratio and eccentricity distributions of barium and S stars, and red giants in open clusters
Van der Swaelmen et al., 2016

# What is a Barium star?

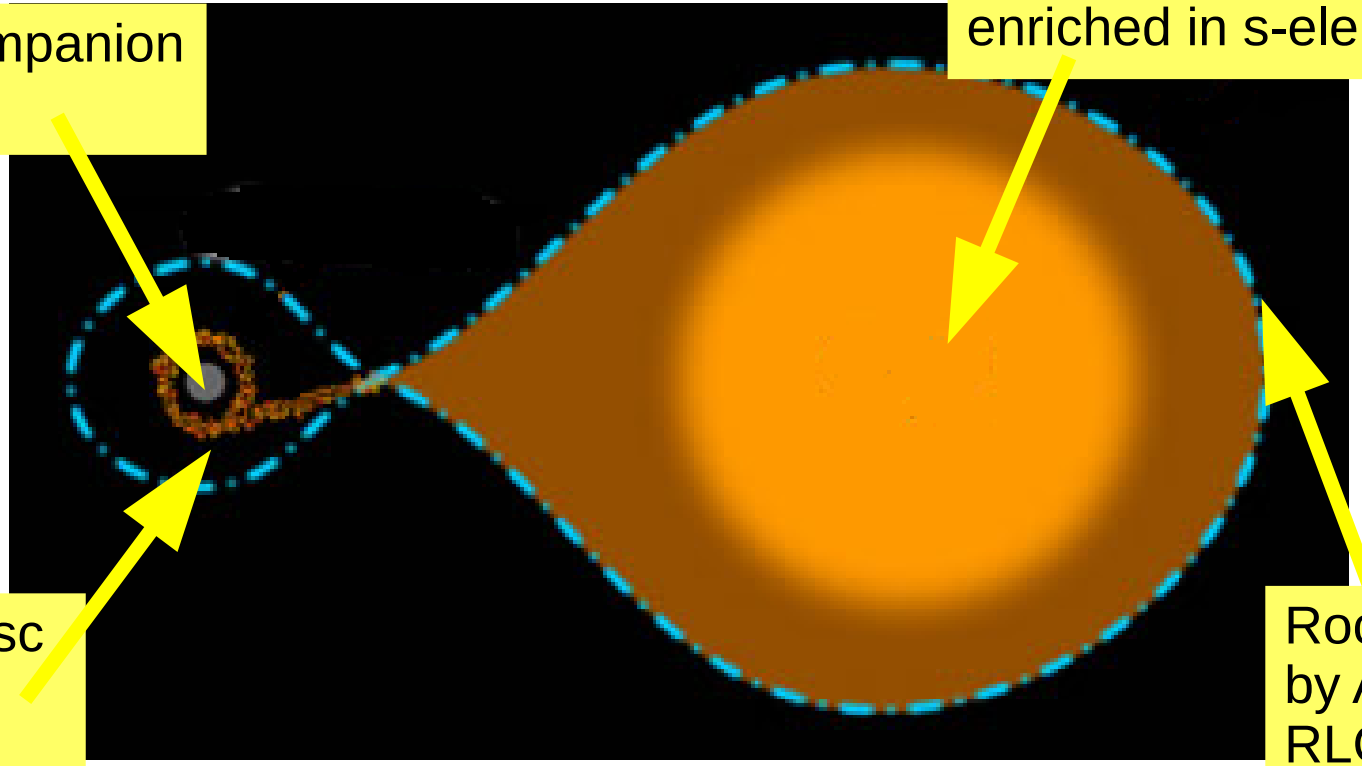
➔ Barium stars = prototype of post-mass transfer systems (field star)

⟹ Observed star = Ba enriched RGB

⟹ All Ba stars are in binary systems

⟹ Ba = s-element produced in envelope of AGB stars

⟹ Most massive star evolves faster, transfers enriched material and is now WD



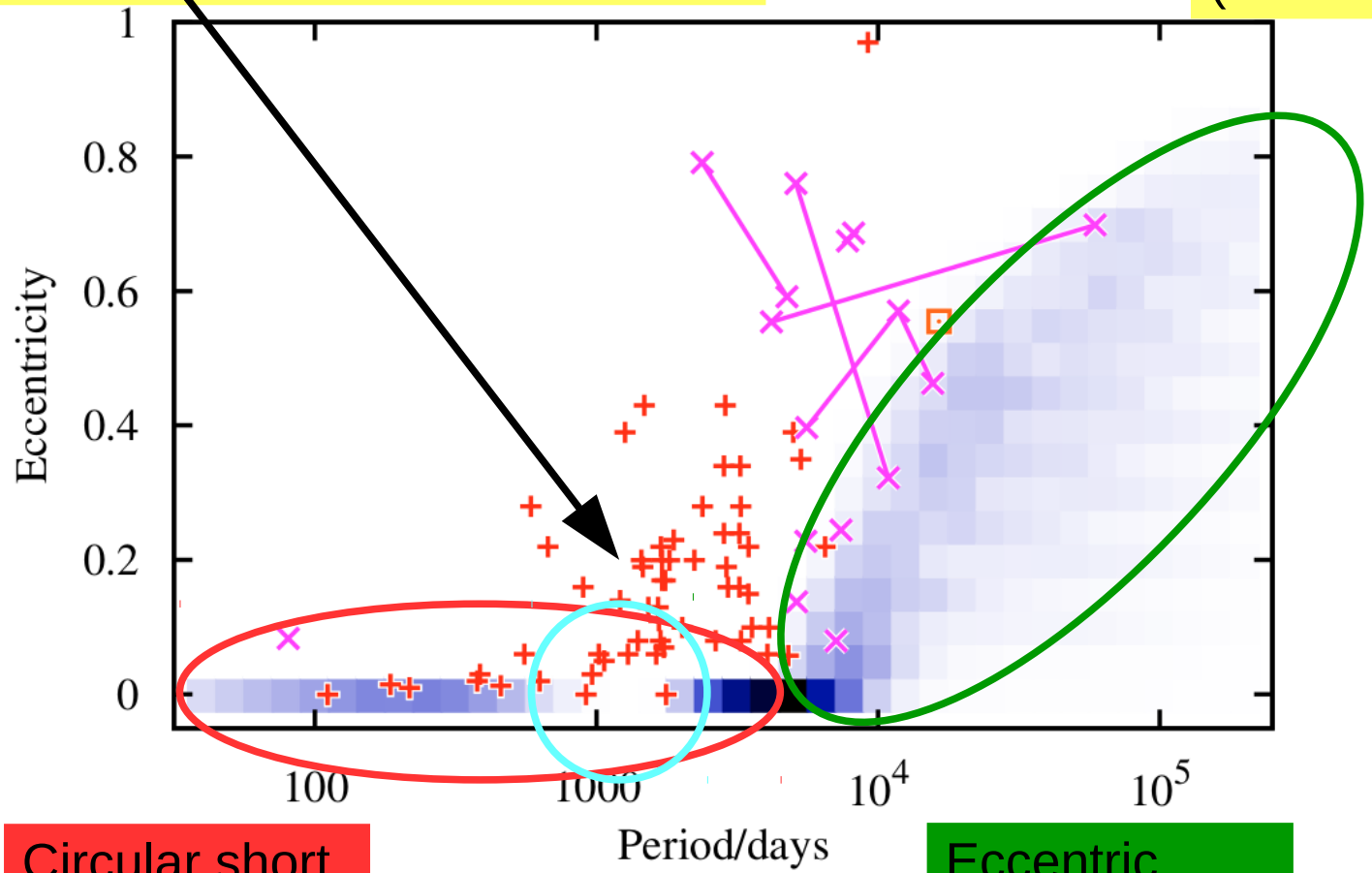

*src*: adapted from astronomy.swin.edu.au/cosmos/R/Roche-lobe

# Period – eccentricity properties of post-mass transfer binary systems

➔ Models for Ba stars do not predict observed properties

Observed location of Ba stars (Jorissen+1998, Dermine+, Griffin2008)

Predicted location of Ba stars (Izzard+2010)




Circular short period due to RLOF

Gap at P~1000 d

Eccentric long-period (avoid RLOF)

Izzard+, 2010

# Pre- vs post-mass transfer systems

➔ How to characterise post-mass transfer system from their properties?
(period, eccentricity, mass ratio, chemistry)

➔ Properties of post-mass transfer systems in open cluster vs. field Ba stars?

➔ Comparison of two samples to answer

⟹ Mermillod+ 2007 (M07, hereafter)
* red giant binaries in open clusters
* expected to include pre- and post-mass transfer systems

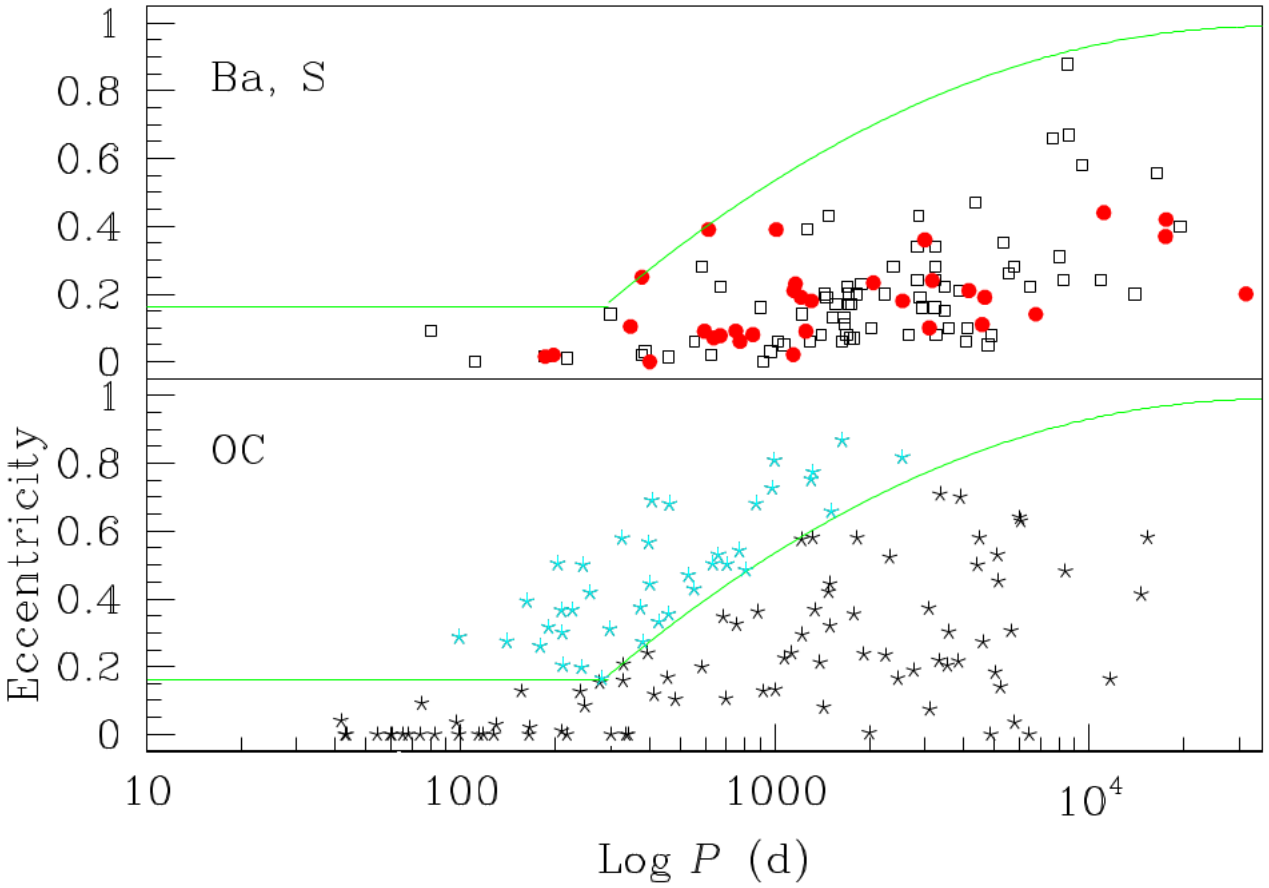
⟹ Jorissen+ 2016 (J16, hereafter)
* Field Ba and S stars, monitored with HERMES @ Mercator
* Longest period = 50 y
* 72 spectroscopic binaries with orbital elements
* Only post-mass transfer systems

# Where are post-mass transfer systems?

➔ Our statistical analysis predicts 22% of post-mass transfer in M07

➔ Are we able to identify such systems in M07?

Ba stars all located in a specific region of log P – e diag.



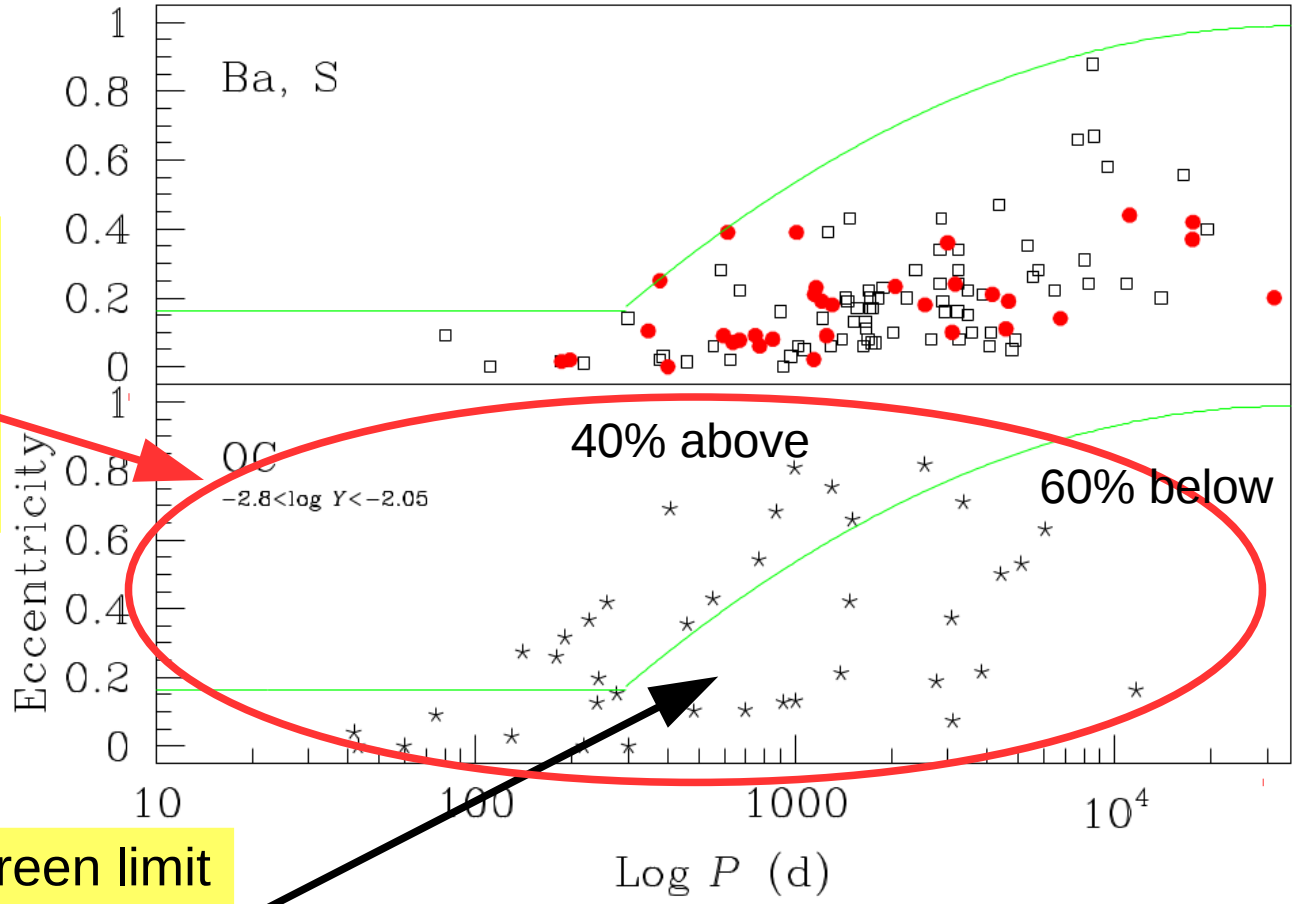

➔ M07 stars lie above and below the envelope of Ba stars
➔ Both subsets show an excess of systems with WD companion

**➔ log P – e diag. is not enough to disentangle pre- and post-mass transfer systems**

Van der Swaelmen+, 2016

# Where are post-mass transfer systems?

➔ Are M07 OC stars located in the Ba region of the log P – e diag. s-enriched?




➔ Subset of M07 with the highest fraction (57%) of RGB+WD systems spreads also above and below the envelope of Ba stars

➔ 12 OC stars below the green limit with HERMES @ Mercator for chemical analysis

**➔ 4 out of 12 = 1/3 are enriched in s-elements**

**➔ Non-barium stars exist in the locus of Ba stars in the log P – e diag.**

**➔ Might be pre-mass transfer system (MS + RGB) or post-mass transfer system (RGB + WD) involving matter not s-enriched**

Van der Swaelmen+, 2016

# Conclusion

➔ Mermillod+07 sample of open cluster red giant binaries contain 22% of systems with a WD companion

➔ Among the OC RGB binaries:

⟹ Post-mass transfer systems are expected above and below the limit of Ba stars in the log P – e diagram

⟹ Pre- and post-mass transfer systems are expected in the locus of Ba stars

⟹ Depending on the efficiency of s-process (correlated with the metallicity), post-mass transfer systems do not always exhibit s-element enrichment

➔ Ongoing chemical analysis of OC stars with a mass function compatible with a WD companion AND located above the limit of Ba stars