Binarity among late-type stars: systems with and without white dwarfs

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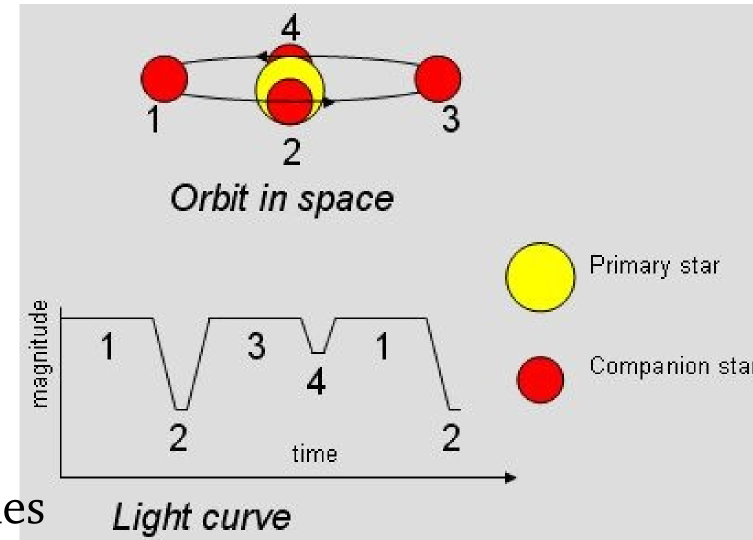
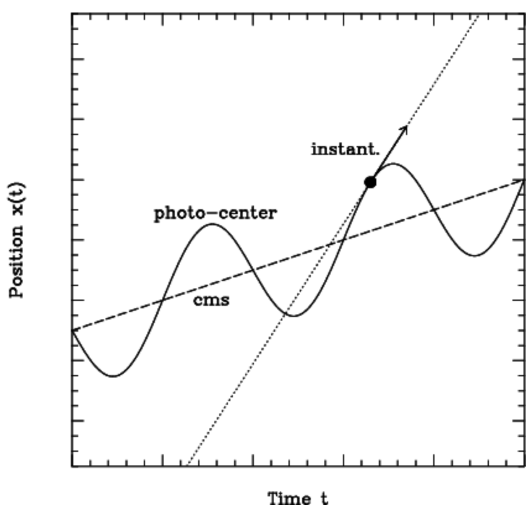
Observatoire de la Côte d'Azur – 24th February 2015

Why studying binary stars?

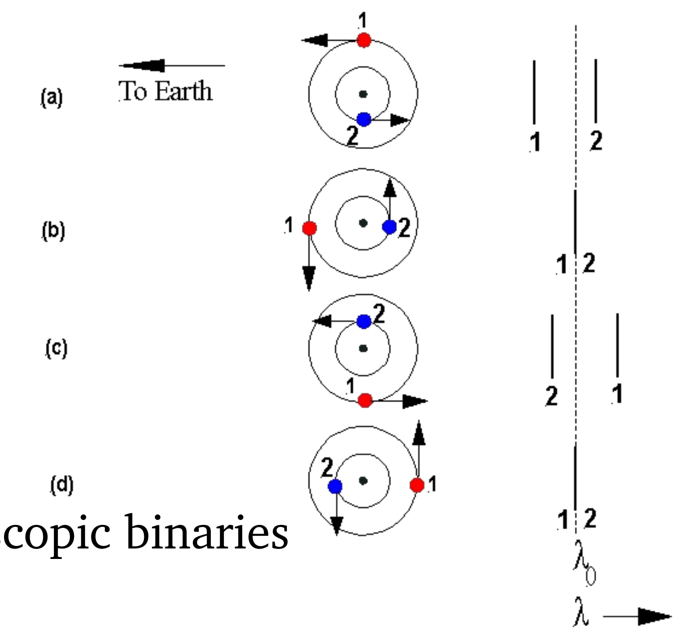
Visual binaries



Eclipsing binaries



Astrometric binaries



Spectroscopic binaries

But also: occultation binaries, LTT, X, ...

Why studying low and intermediate mass binary stars?

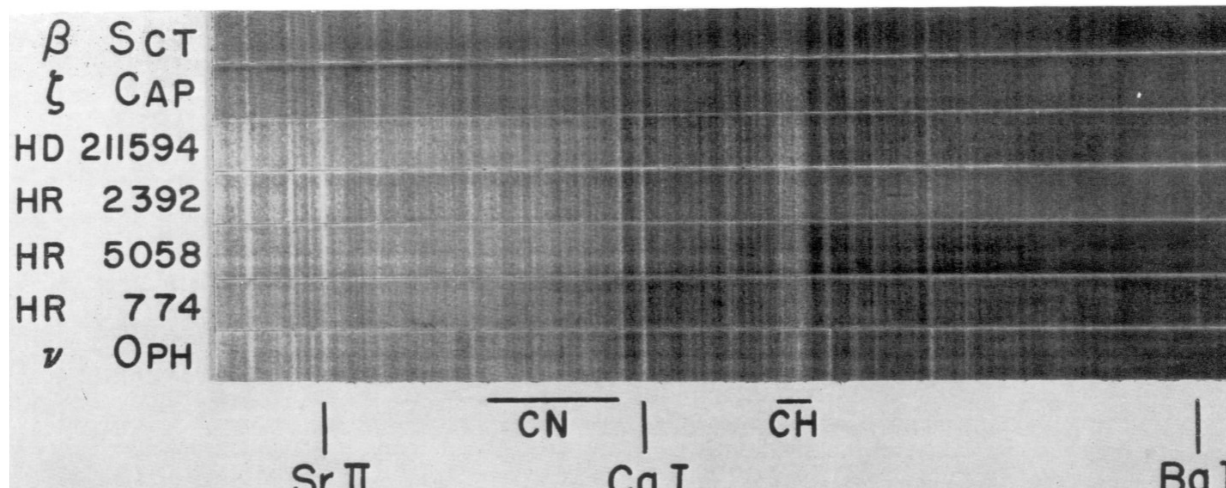
- Stellar physics: direct measurement of physical quantities
  (mass, radius, temperature, luminosity)

- Fundamental for stellar evolution:
  - Constraints on the interaction of the binary components
  - Constraints on possible scenarios of stellar evolution

- Various classes of stars with peculiar abundances
  (Ba stars, CH stars, Tc-poor, S stars, symbiotic stars, etc.)

Binary stars including a white dwarf

Bidelman & Keenan (1951)



G5

K0III

4077 Å 4226 Å 4554 Å

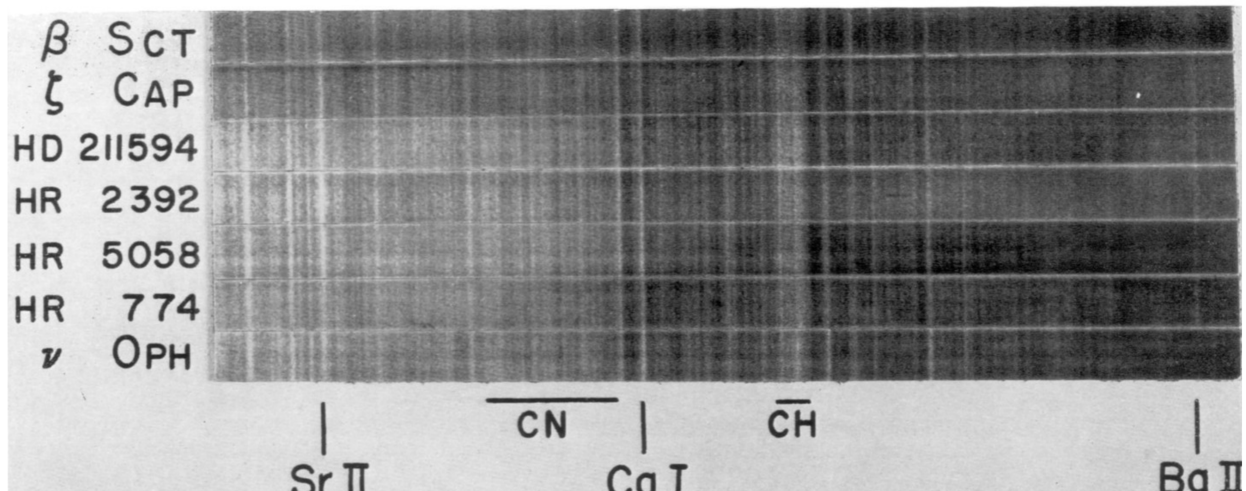
- Barium stars
  - s-process elts
  - C enriched
  - Not on AGB, no Tc

Binary systems (McLure et al. 1980)

Vennes et al. (1995)

Binary stars including a white dwarf

Bidelman & Keenan (1951)



G5

K0III

4077 Å 4226 Å 4554 Å

- Barium stars
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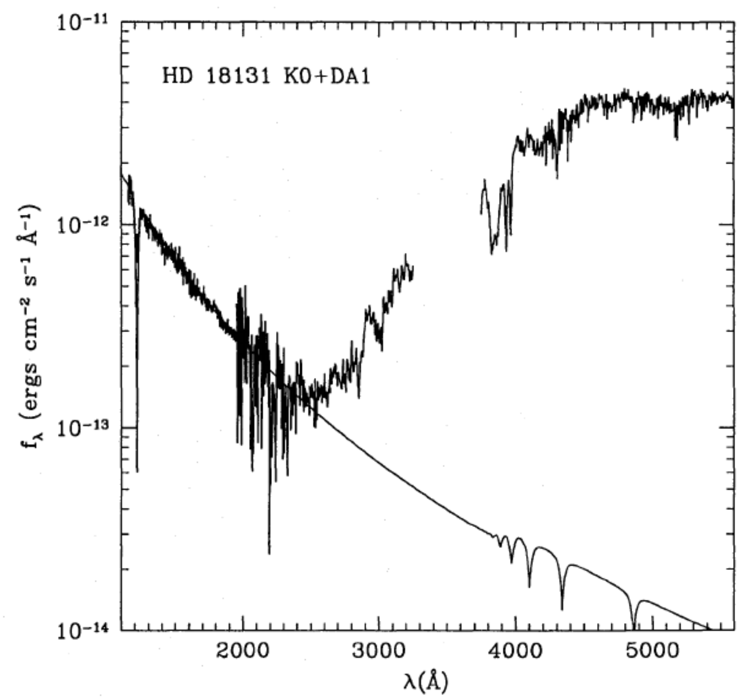
Binary systems (McLure et al. 1980)

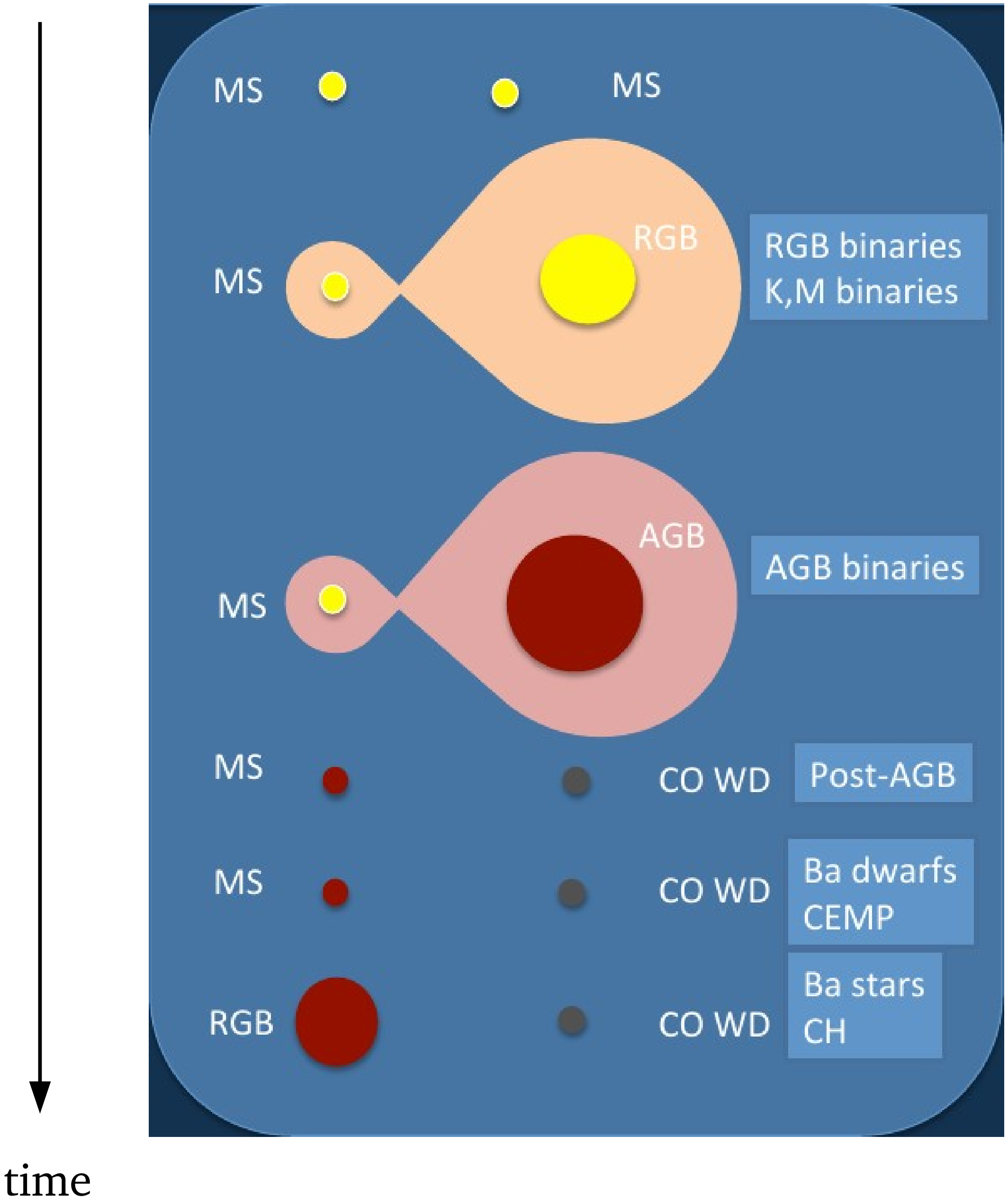
- Far-UV & X-ray, satellites:
  - EUVE, XMM-Newton, ROSAT, GALEX, …

WD companion (Gray et al.2011)



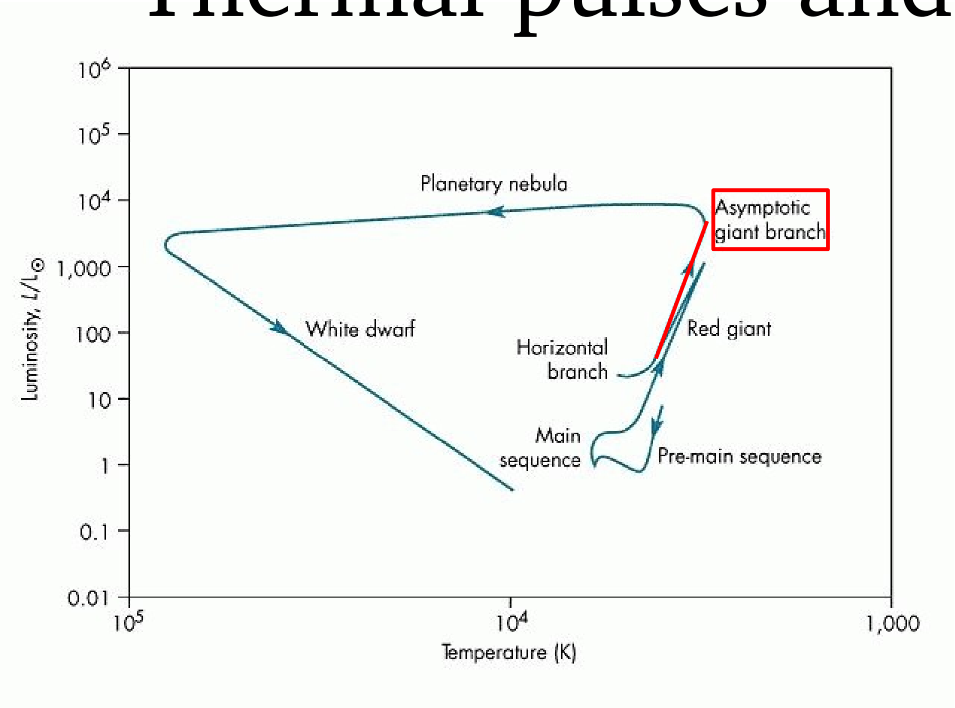
Vennes et al. (1995)

What is the s-process pollution paradigm in binary stars?



The standard scenario (e.g. Jorissen 2003)

Thermal pulses and 3DU on the AGB phase

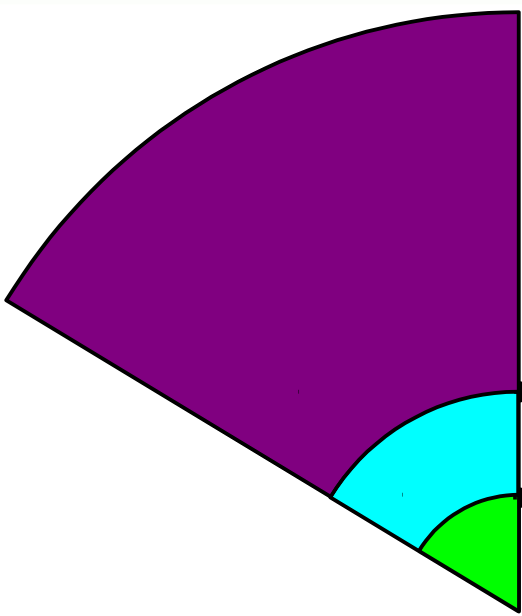


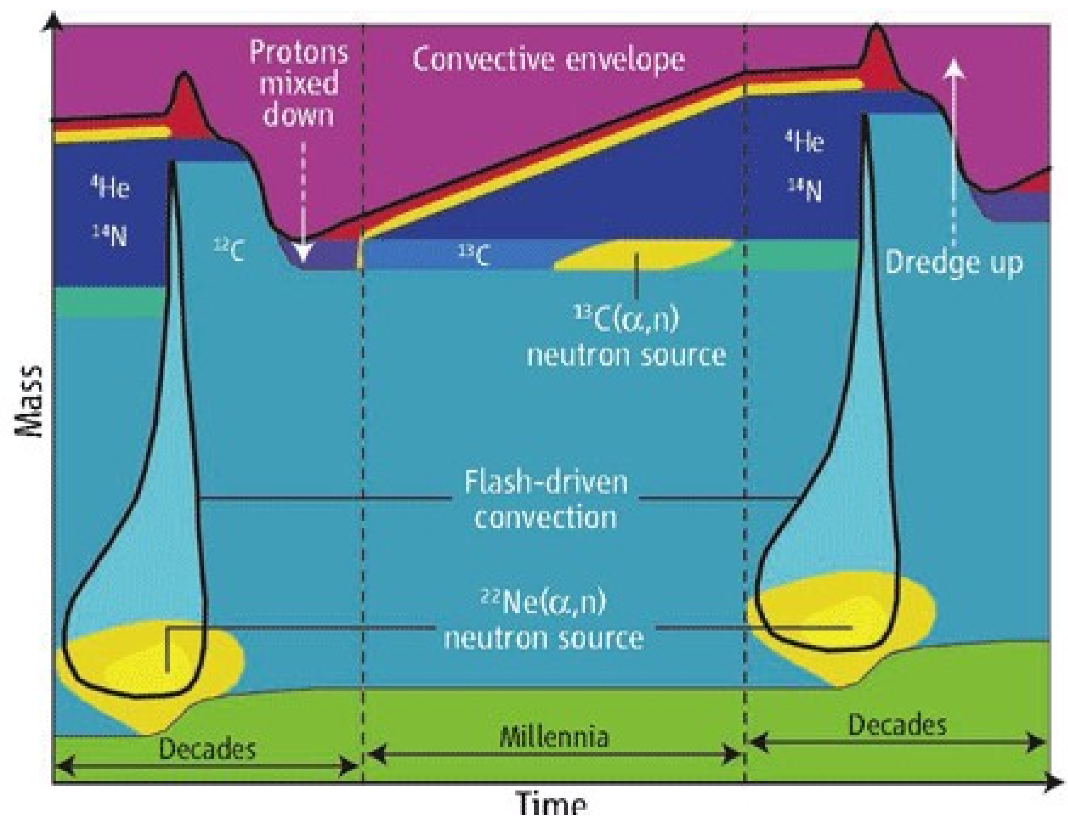
Neutron source :

$^{13}C + {}^{4}He \rightarrow {}^{16}O + n$

$^{22}Ne + {}^{4}He \rightarrow {}^{25}Mg + n$

Neutron capture on Fe seeds provide s-process elements released in the outer convective layer at the next 3DU.





Boothroyd, Science 2006

The HERMES@MERCATOR spectrograph

The HERMES@MERCATOR spectrograph

MERCATOR telescope
(KULeuven)

- Roque de los Muchachos Observatory (La Palma, Spain)
- 1.20 m

HERMES spectrograph
(Raskin et al. 2011)

- Fiber fed echelle
- 380 – 900 nm
- R~85000

- Radial velocity monitoring
- Abundance analysis

IP Eri: a long-period binary system with a He WD

Merle et al. 2014, A&A, 567, A3

- **Binary system:**
  - UV source (ROSAT, EUVE)

    Hot WD DA

    Teff=30000 K, log g =7.5 (Burleigh 1997)

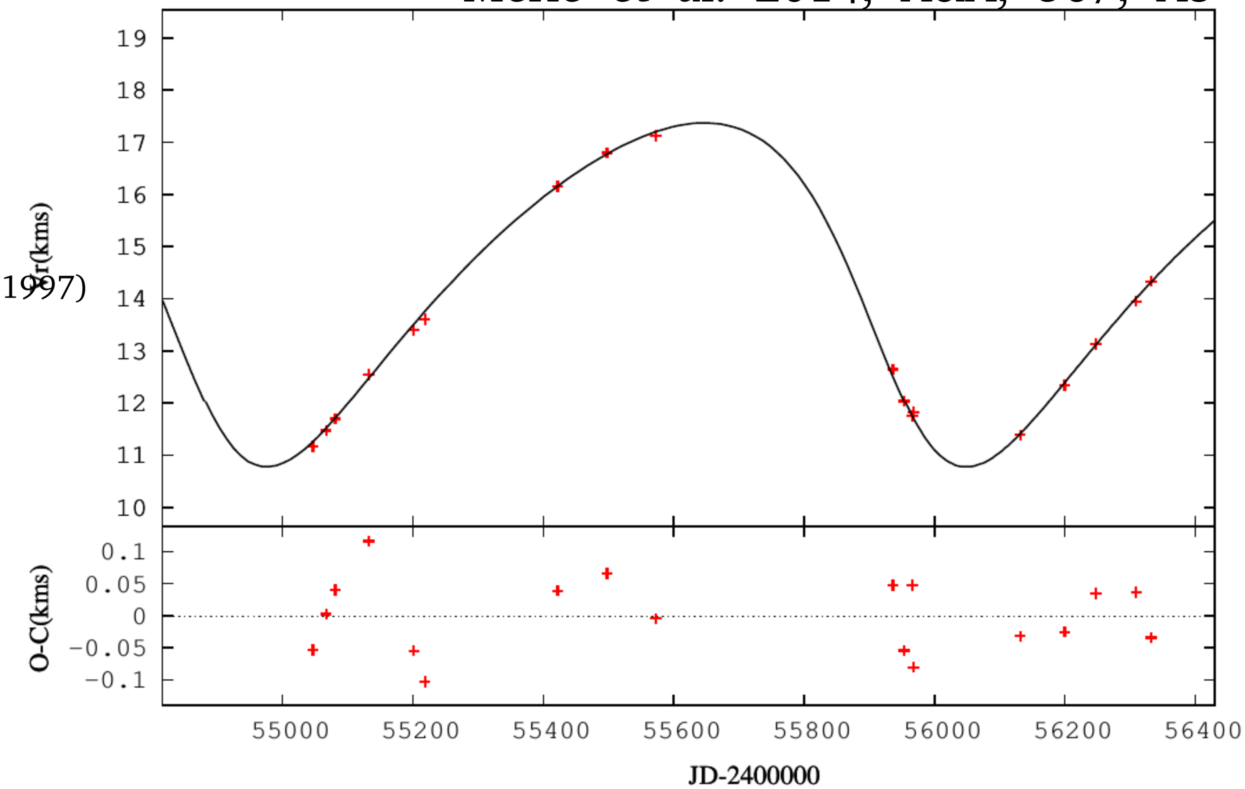
    R= 0.02 $R_\odot$, M=0.4 $M_\odot$ (Wood 1995)
  - K0 sub-giant

    d = 100 pc (Hipparcos)

    M < 4.3 $M_\odot$

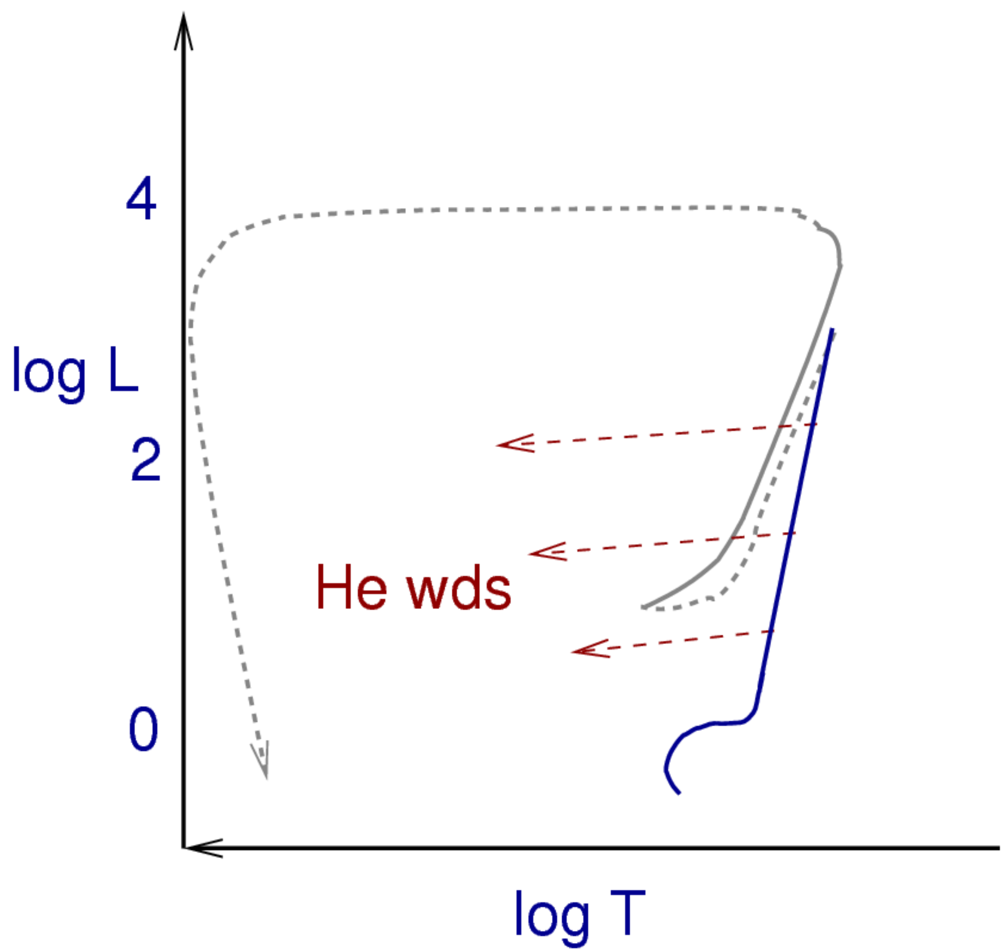
    vsin < 5 km/s (Cutispoto et al. 1995)
- **Observations:**
  - HERMES/Mercator
  - 18 spectra from

    August 2009 to February 2013



- **Orbital parameters:**
  - P = 1071.0±1.8 d
  - e = 0.25±0.01
  - f(M) =(3.6±0.1) 10^{-3} $M_\odot$

But how to form a He WD?



- **From single stars:**

$M<0.9\ M_\odot$ (otherwise: He ignition)

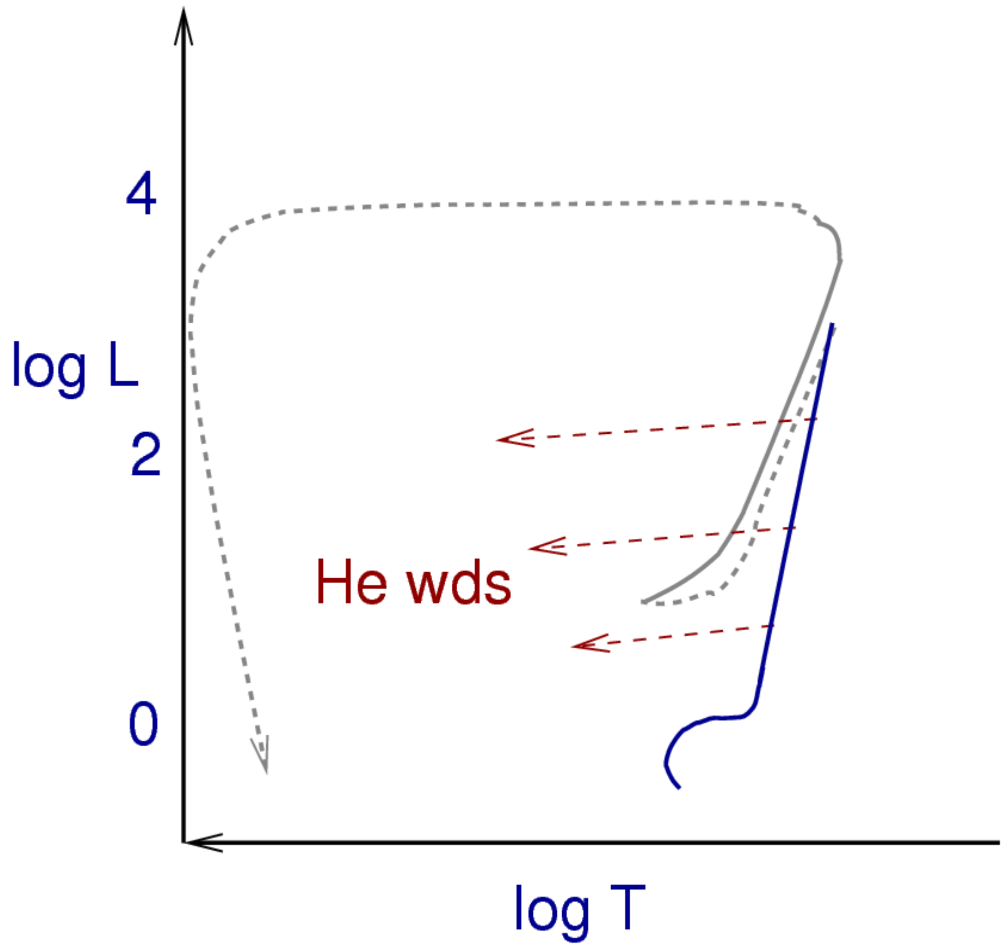
But stars with $M<0.9\ M_\odot$ have main sequence lifetimes > Hubble time

- **From binary stars:**

$M > 0.9\ M_\odot$

The only formation channel is if the H--rich envelope is lost **prior to He ignition**

But how to form a He WD?



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- **From binary stars:**
M > 0.9 $M_\odot$

The only formation channel is if the H-rich envelope is lost **prior to He ignition**

➜ Mass transfer in a binary system

IP Eri: atmospheric parameters

- Based on equivalent widths (EW) of Fe
- Using BACCHUS pipeline

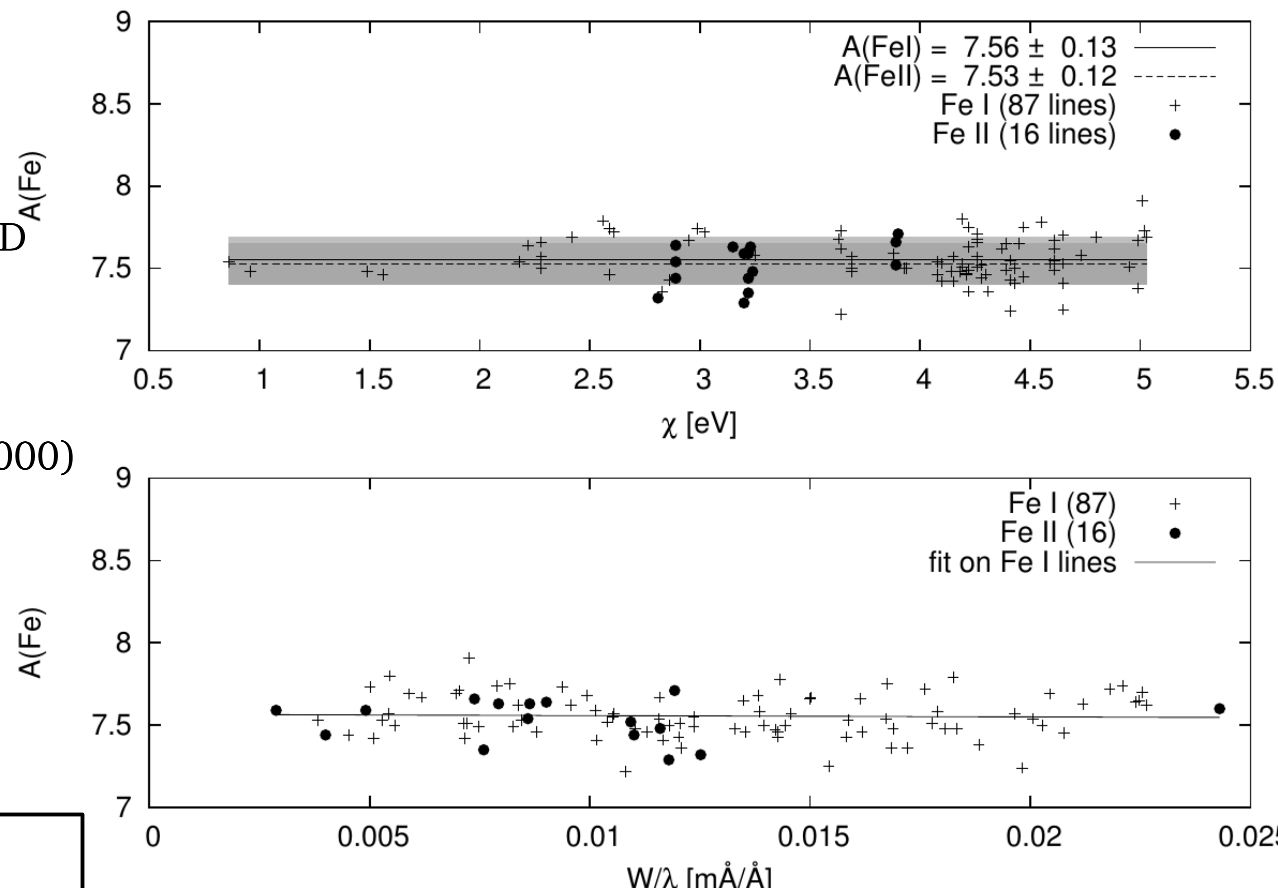
  (T. Masseron):

  overlay on top of Turbospectrum 1D LTE radiative transfer code

  (Plez 2012)
- Linelist from VALD (Kupka et al. 2000)

  and Gaia-ESO-Survey
- Model atmospheres from MARCS

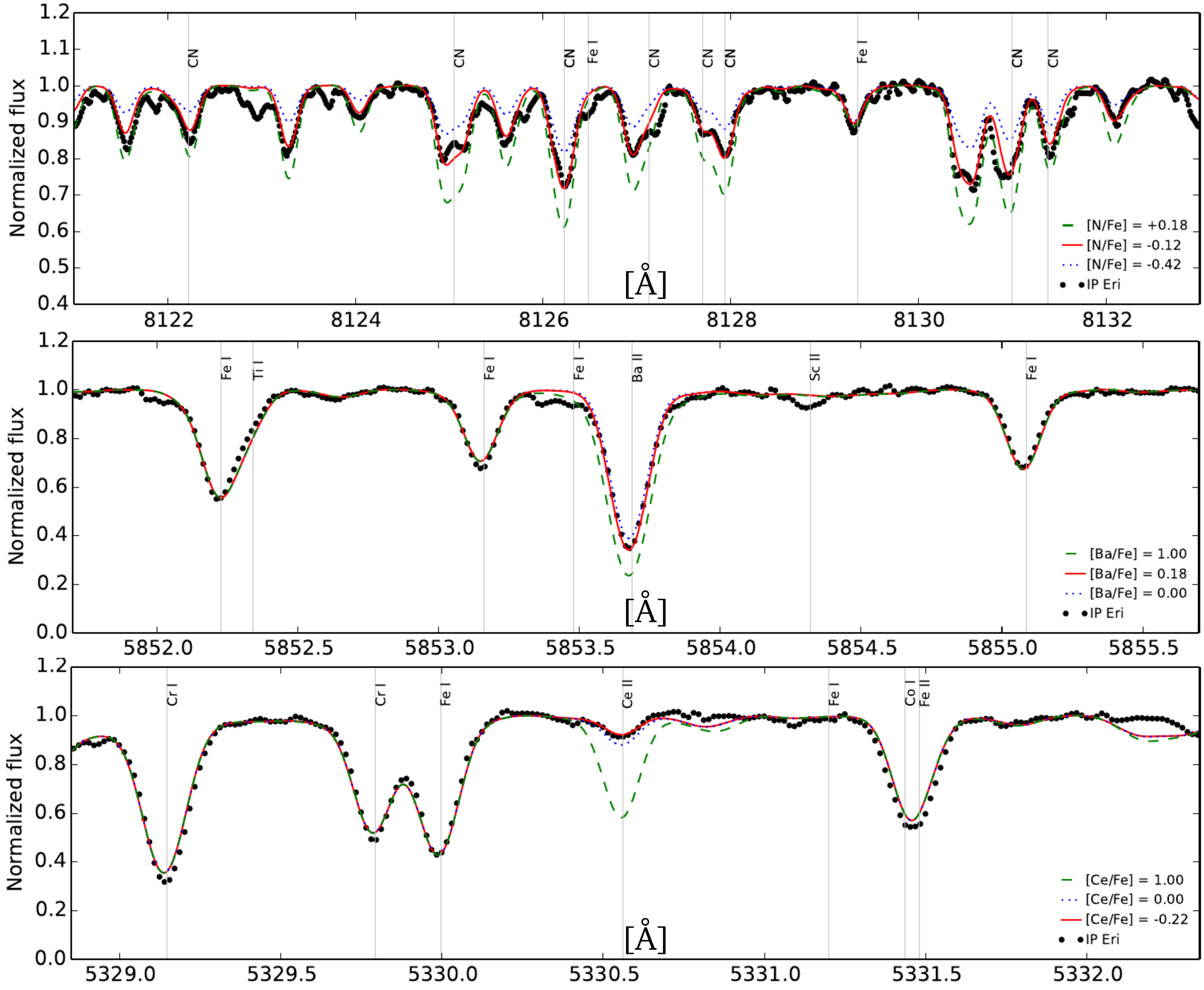
  (Gustafsson et al. 2008)



T_{eff} = 4960±100 K
log g = 3.3±0.3 dex
[Fe/H] = 0.09±0.08 dex
ξ = 1.5±0.1 km/s

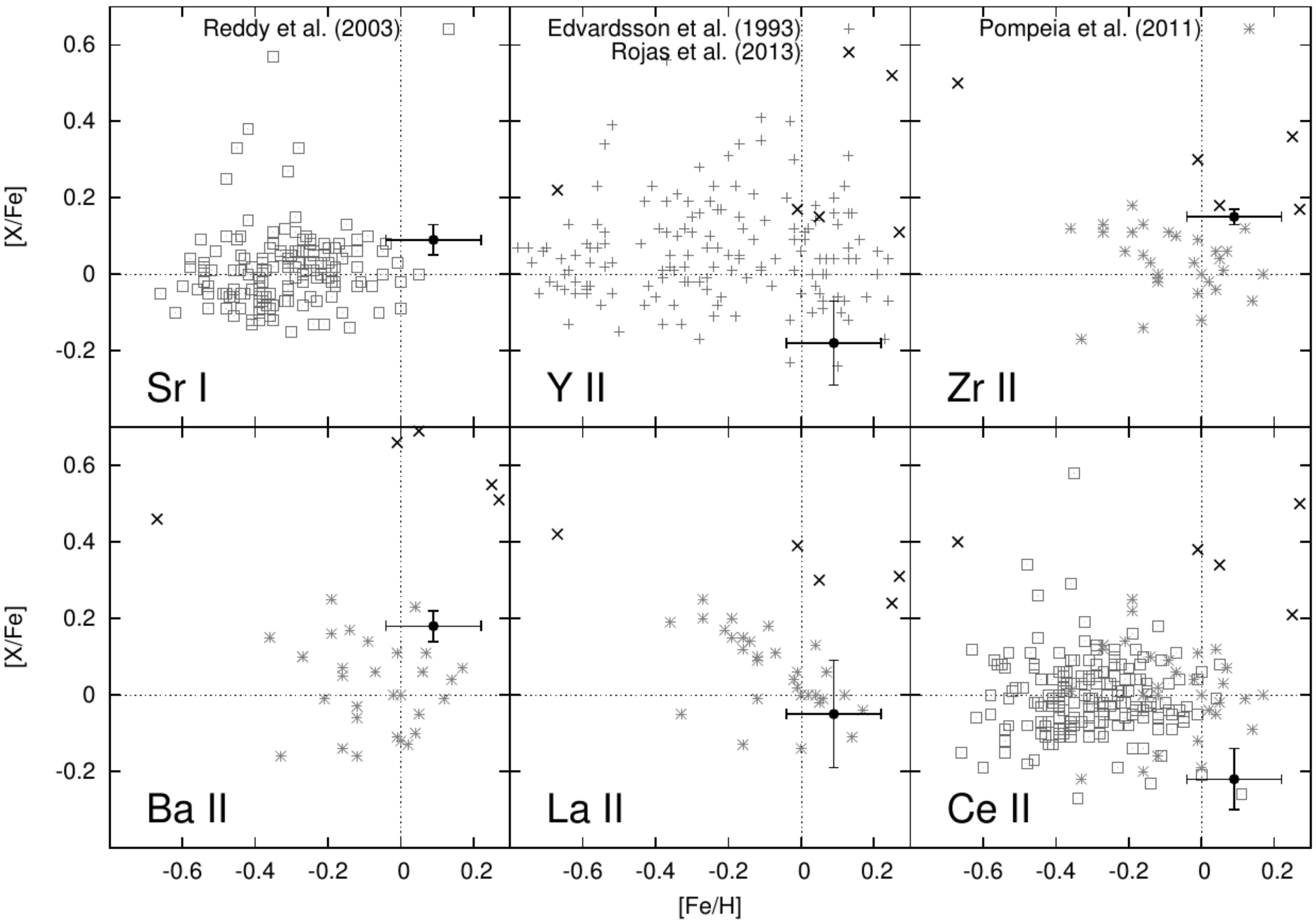
Merle et al. 2014, A&A, 567, A3

IP Eri: abundance analysis



IP Eri: enriched in s-process?

Merle et al. 2014



Reddy et al. (2003) □
Edvardsson et al. (1993) +
Pompeia et al. (2011) ✳

- [Fe/H] = 0.09 ± 0.08
- [C/Fe] = 0.08 ± 0.16

Not C-enriched

12C/13C>20

- s-element abundances typical of disk stars

[Sr/Fe] = 0.09 ± 0.04
[Y/Fe] = -0.18 ± 0.11
[Zr/Fe] = -0.15 ± 0.01

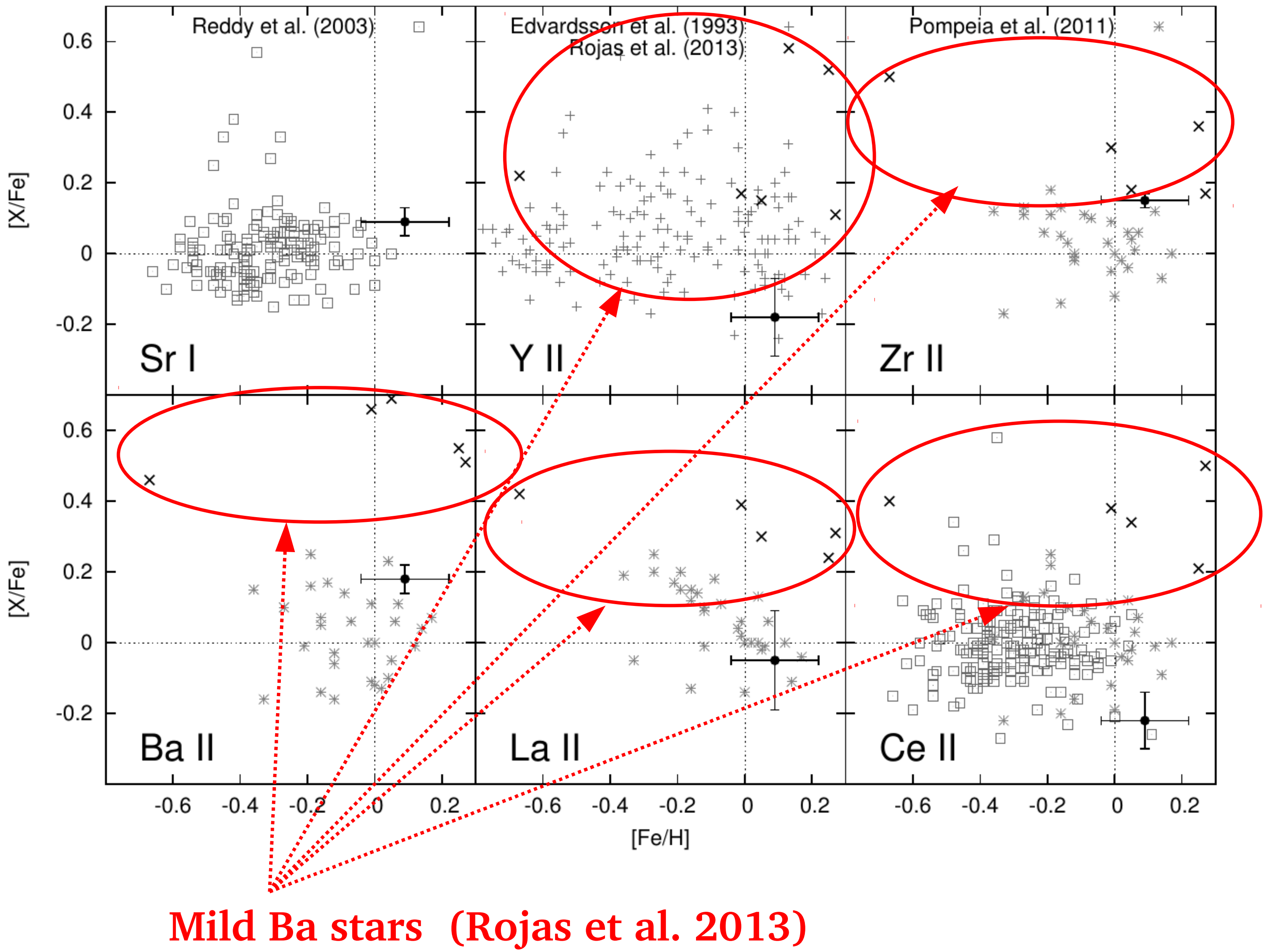
[Ba/Fe] = 0.18 ± 0.04
[La/Fe] = -0.05 ± 0.14
[Ce/Fe] = -0.22 ± 0.08

[ls/Fe] = +0.06 ± 0.04
[hs/Fe] = -0.03± 0.05

Not s-process enriched

IP Eri: enriched in s-process?

Merle et al. 2014



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Not C-enriched

$^{12}C/^{13}C > 20$

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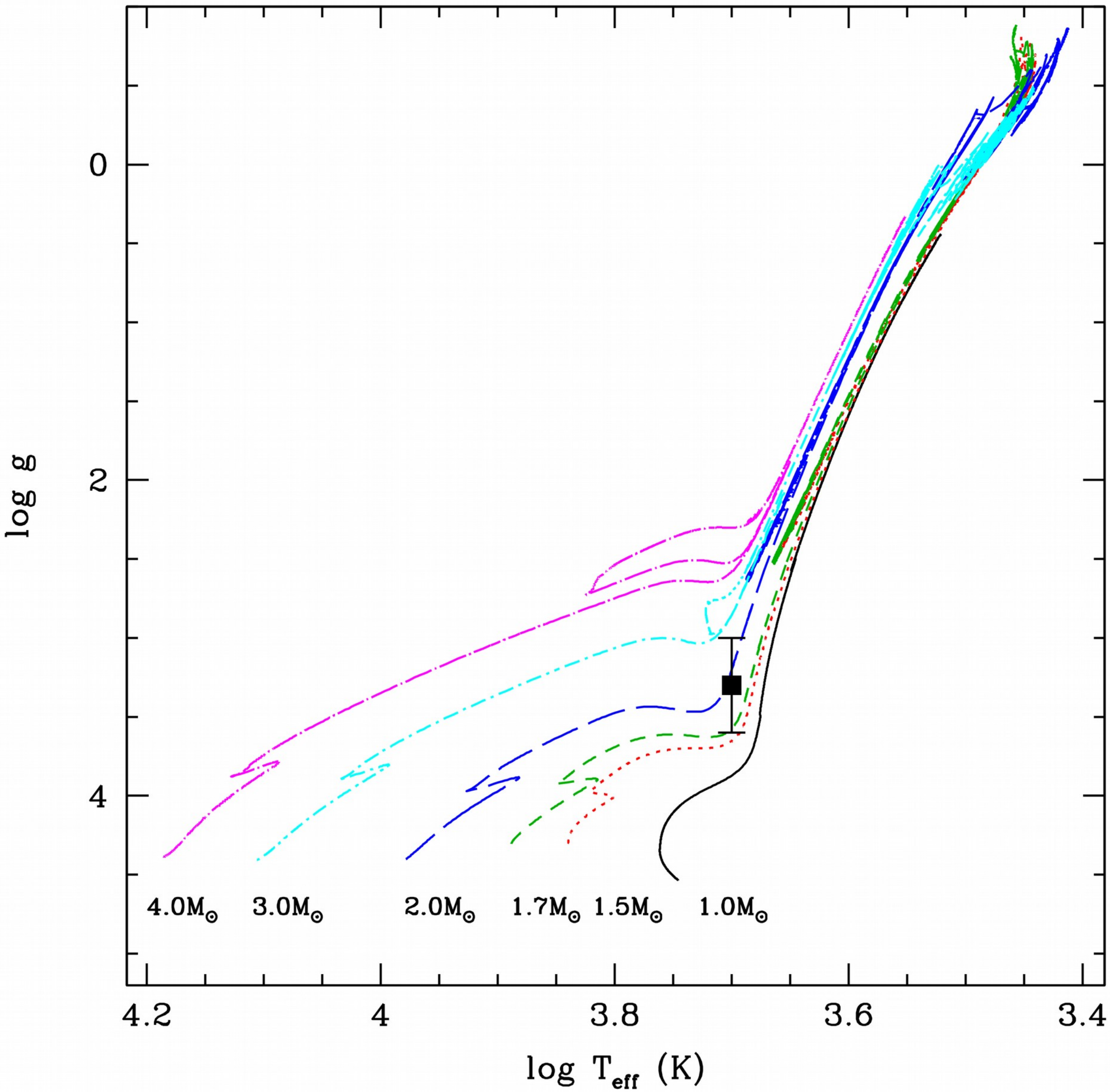
Not s-process enriched

Constraints on the actual mass of the K0 sub-giant

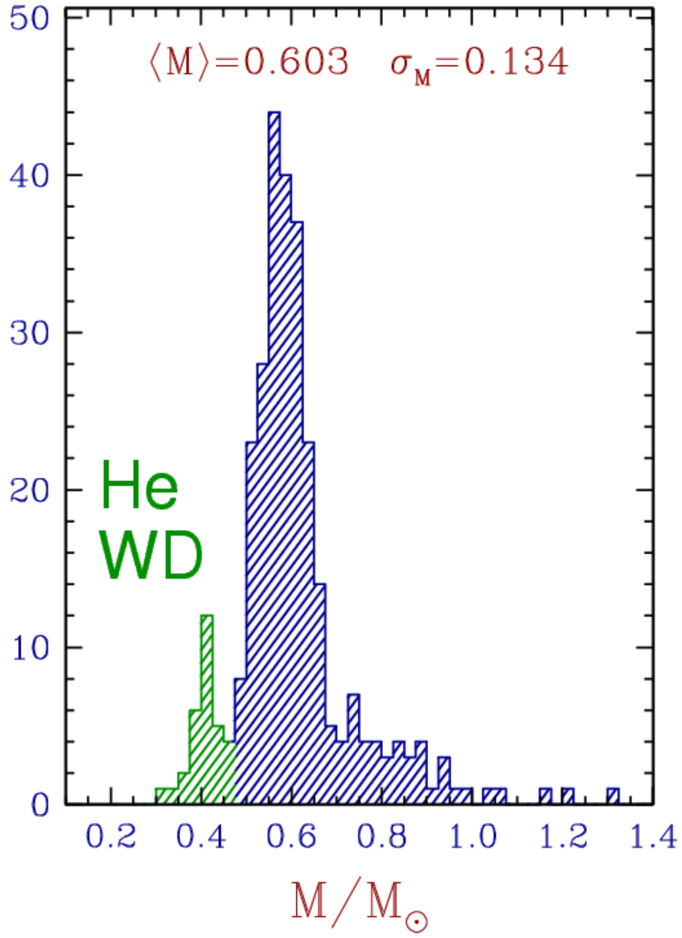


Constraints on the initial mass of the sub-giant:

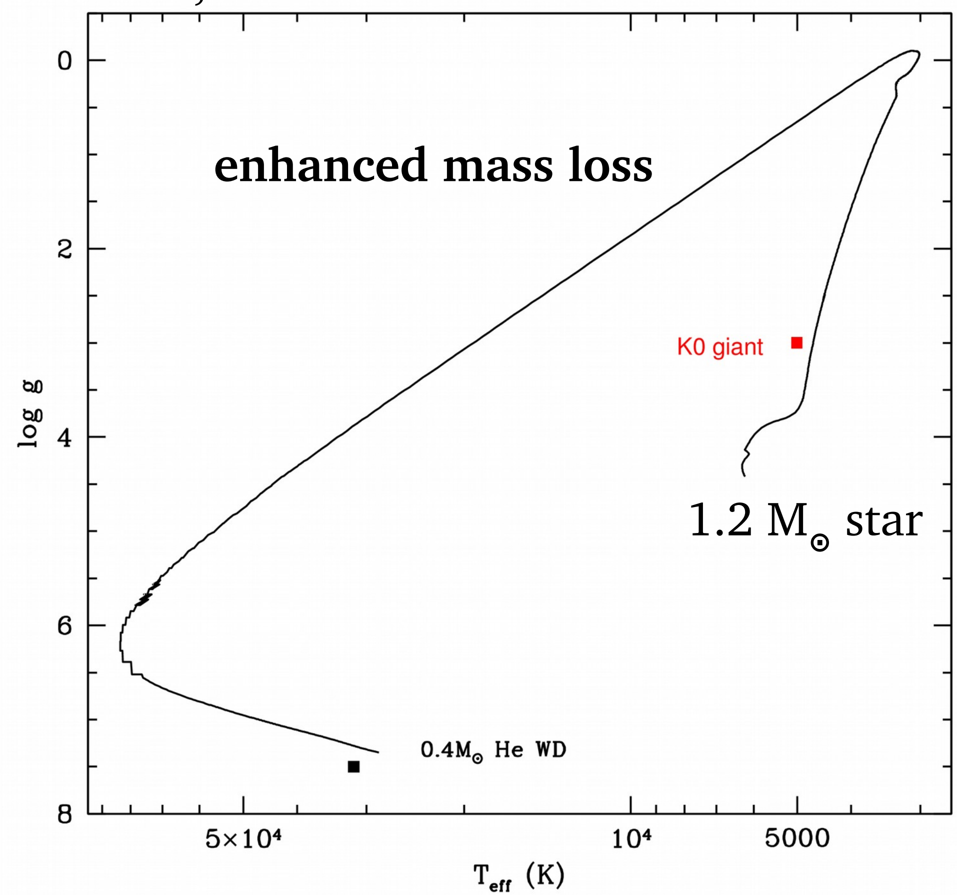
- from the mass function:
  M < 4.26 $M_\odot$
- from the HR diagram:
  1 $M_\odot$ < M < 3-4 $M_\odot$

Constraints on the actual mass of the He WD

Liebert, Bergeron & Holberg 2005

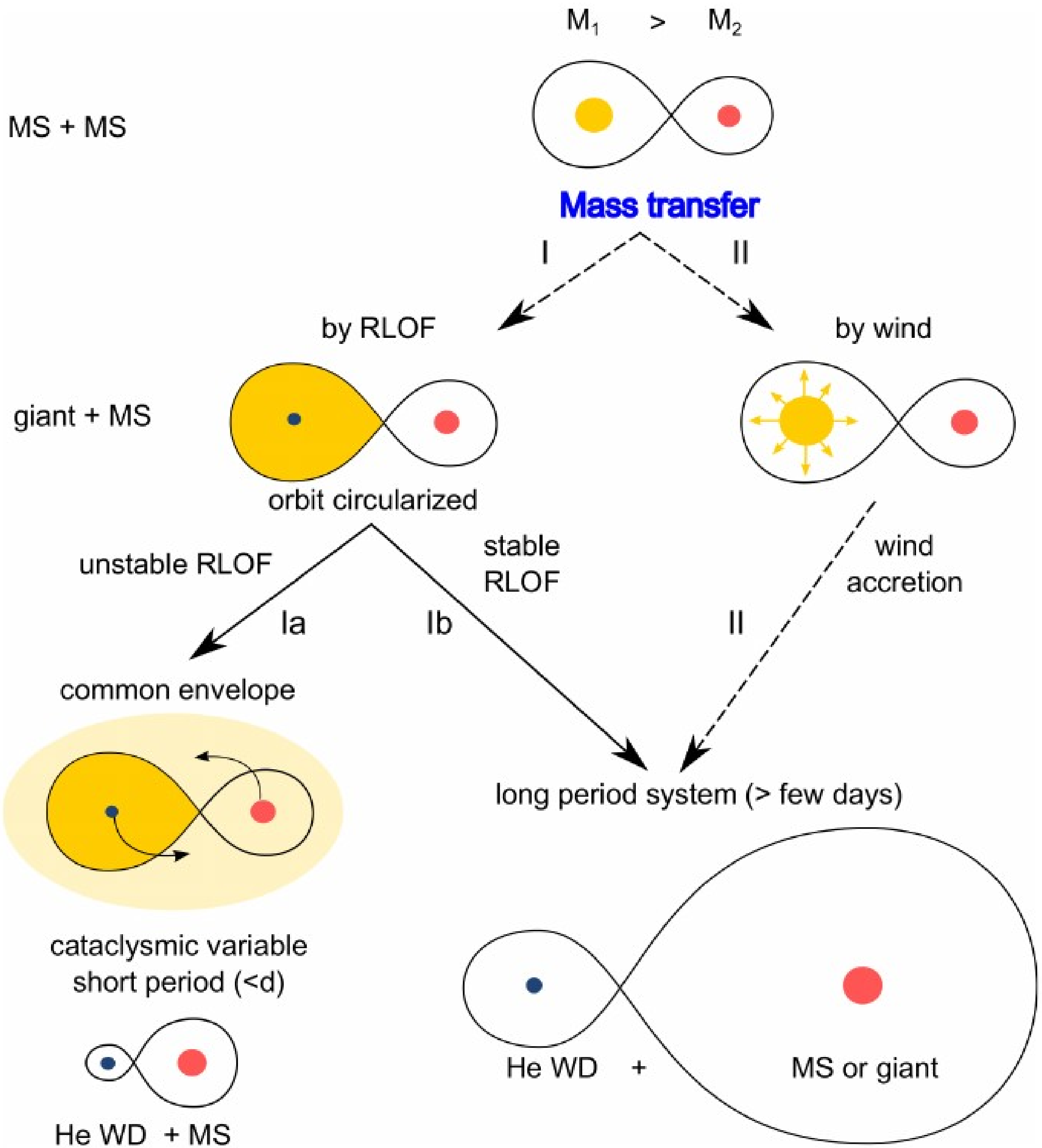


Siess, Davis & Jorissen 2014



mass distribution peaks at ~ **0.43 $M_\odot$ for He WD**

IP Eri: the evolutionary scenario



3 possible scenarios:

- **unstable RLOF**

  Circular orbits

  Short orbital periods

- **stable RLOF**

  long orbital periods

  e=0

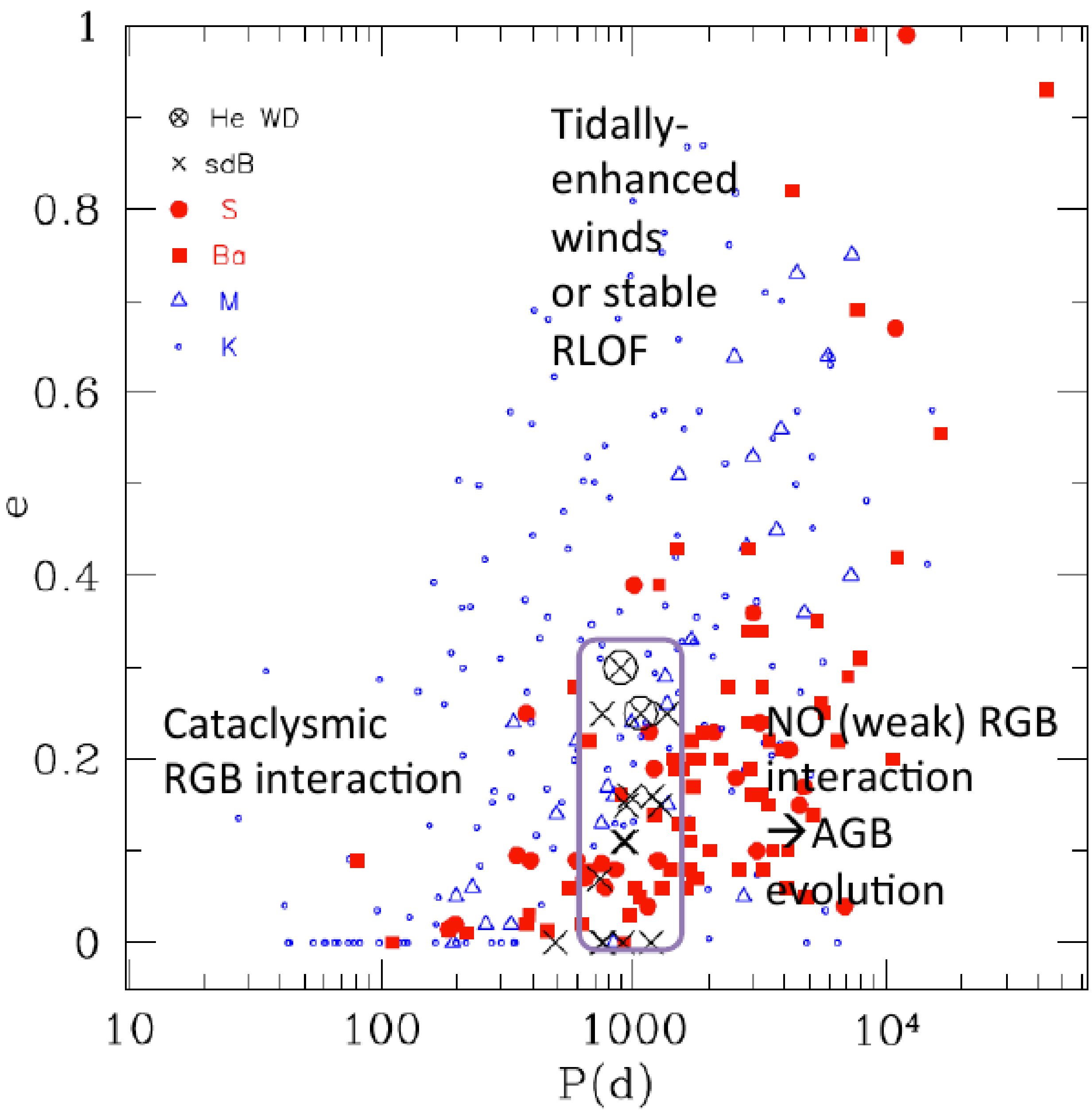
- **mass loss by enhanced wind**

  Companion Re-inforced Attrition Process (Tout&Eggleton 1988)

  Tidally-enhanced mass-loss close to periastron: circularization is avoided (**Siess et al. 2014**)

long and eccentric orbital period!

Location in the excentricity-period diagram



Pre-mass transfer binaries

Post-mass transfer binaries

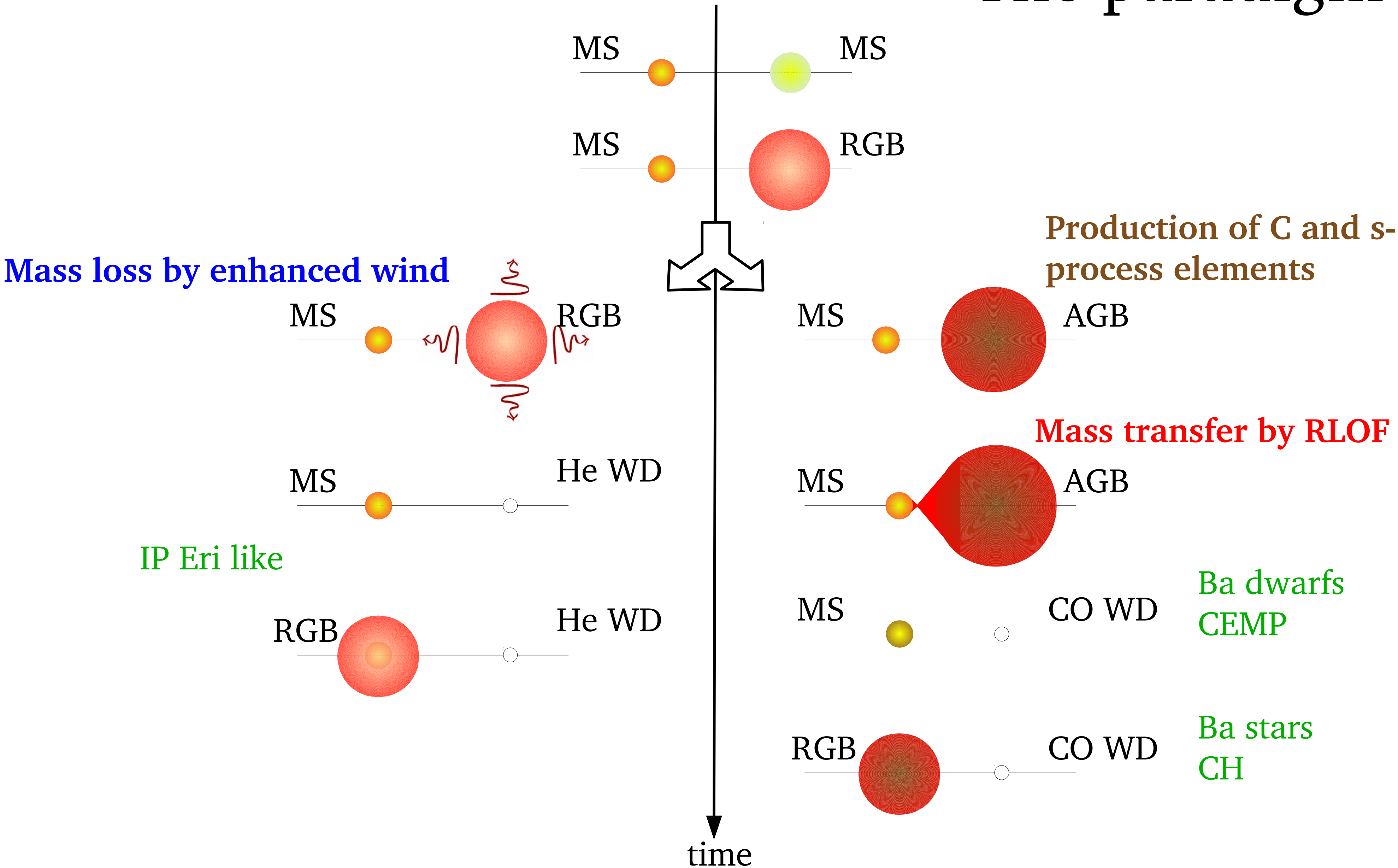
RGB-truncated evolution:

- sdBs
- HR 1608 & IP Eri

P ~1000d (±100d)

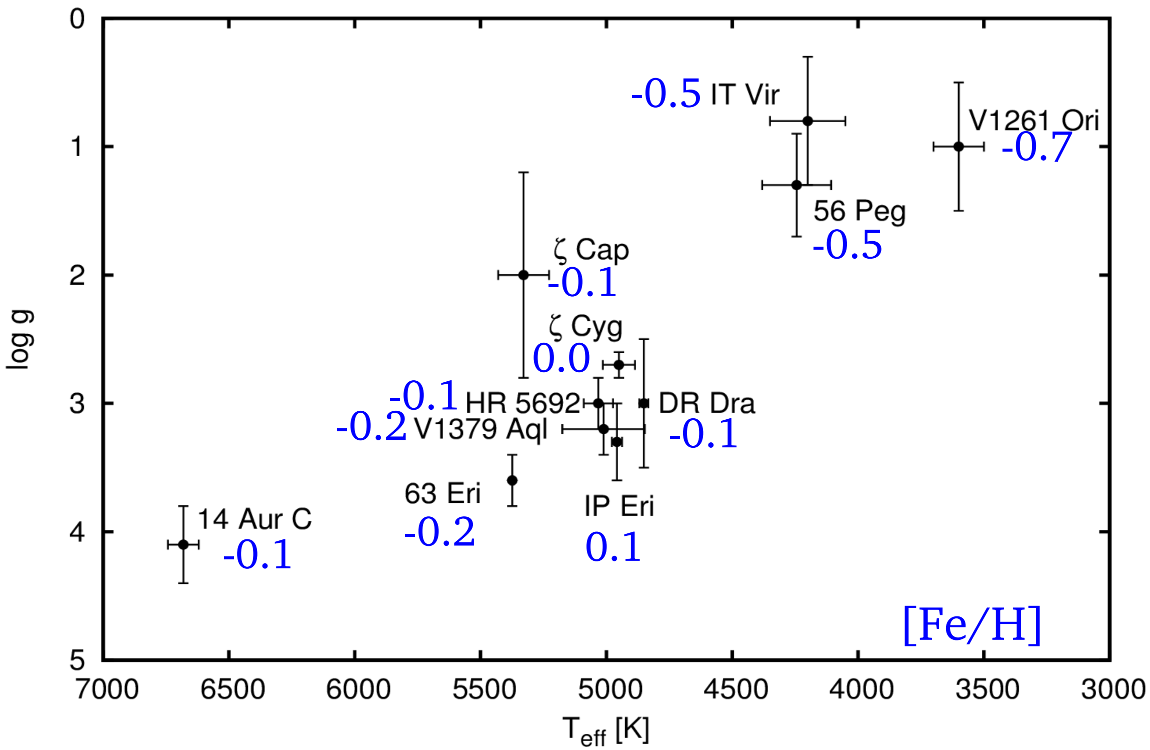
Merle et al. 2014

The paradigm



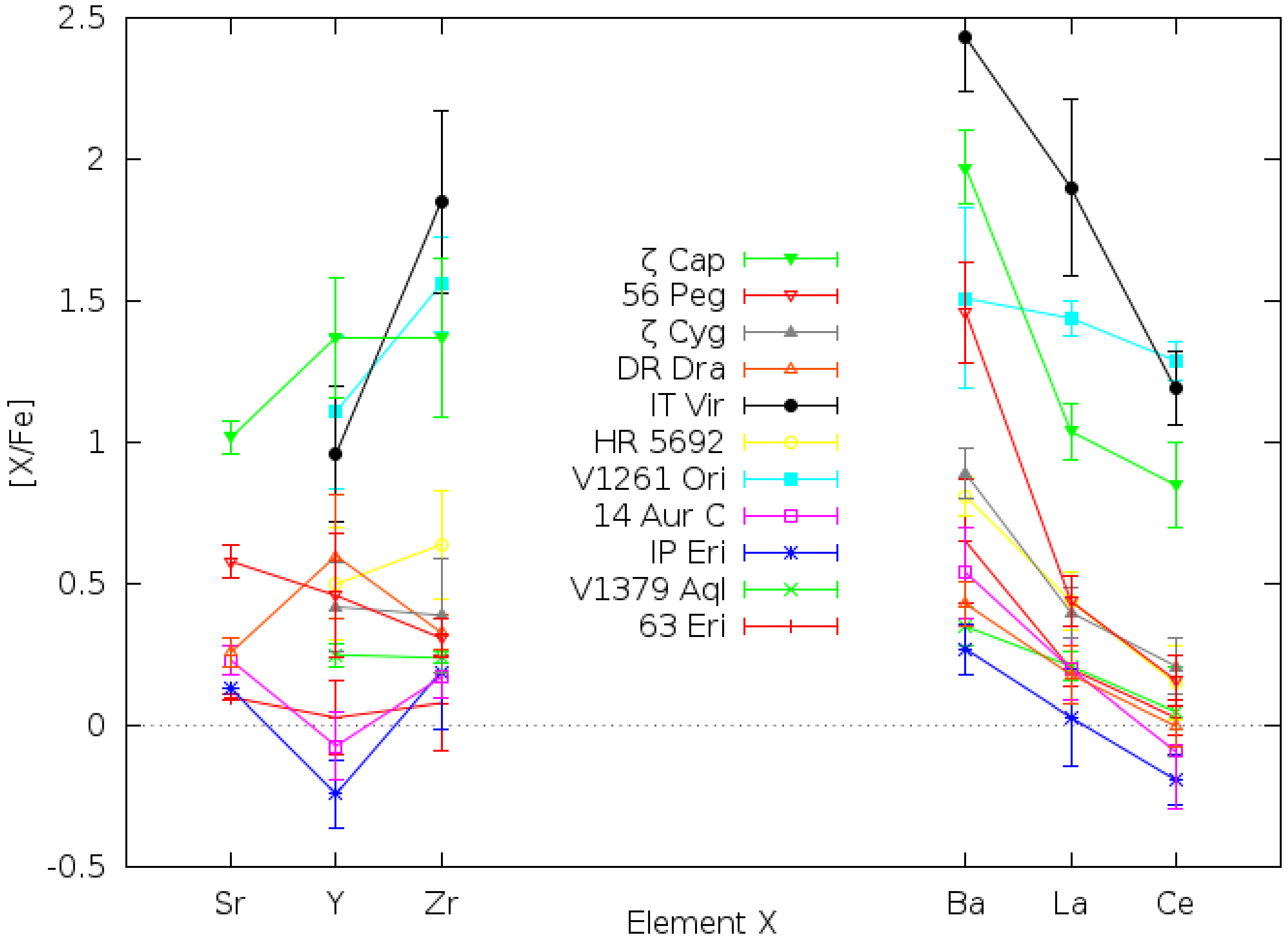
How to distinguish between these 2 evolutions?

Binary systems with known WDs masses

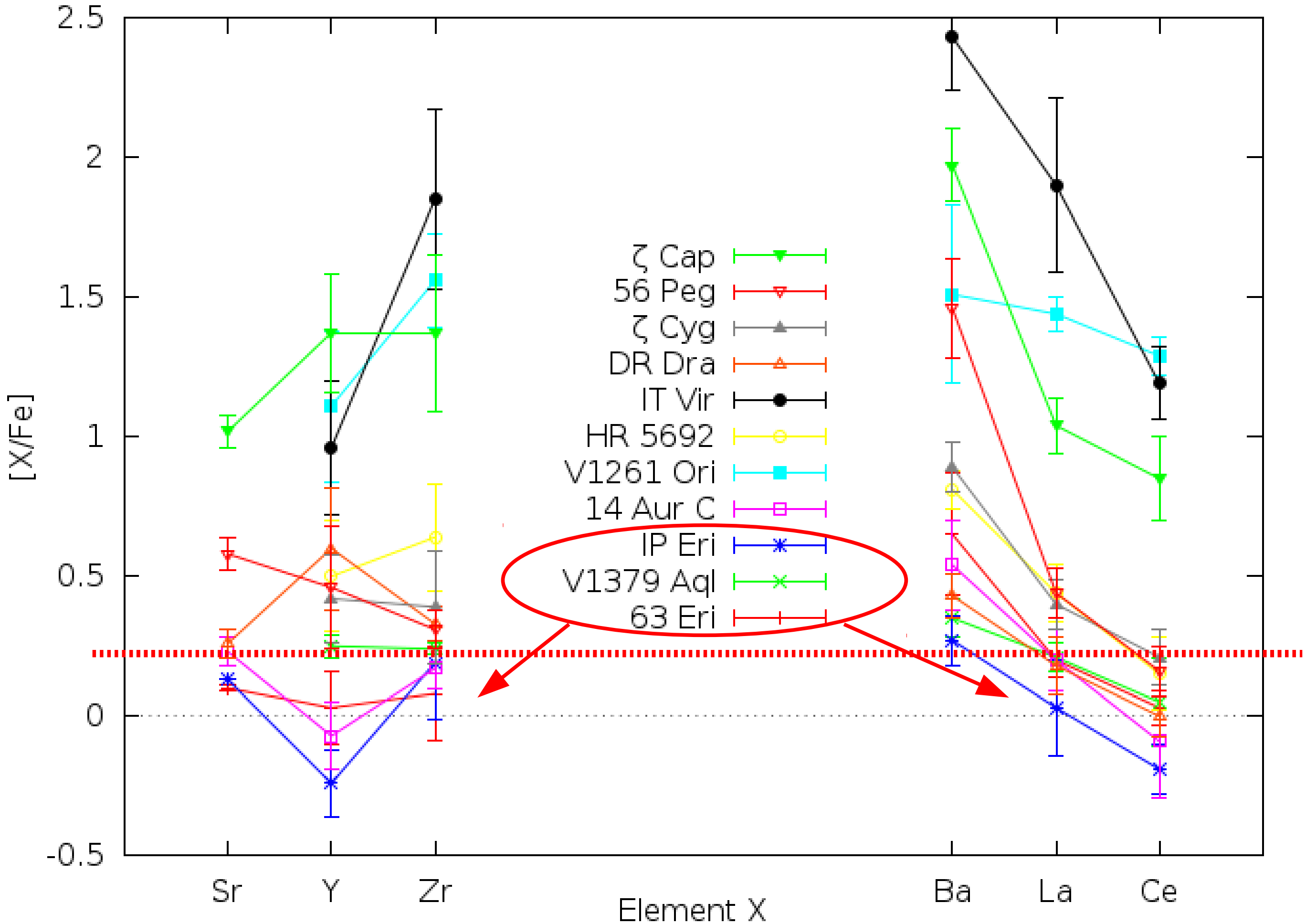


- **Selection**
  post mass transfer binary systems
  known mass of the WD companions
- **Observations**
  HERMES/Mercator
  August 2009 to May 2014
- **Atmospheric parameters**
  MARCS model atmospheres
  atomic and molecular linelists
  BACCHUS pipeline
- **The idea**
  Study the variation of the s-process elements with the mass of the WD

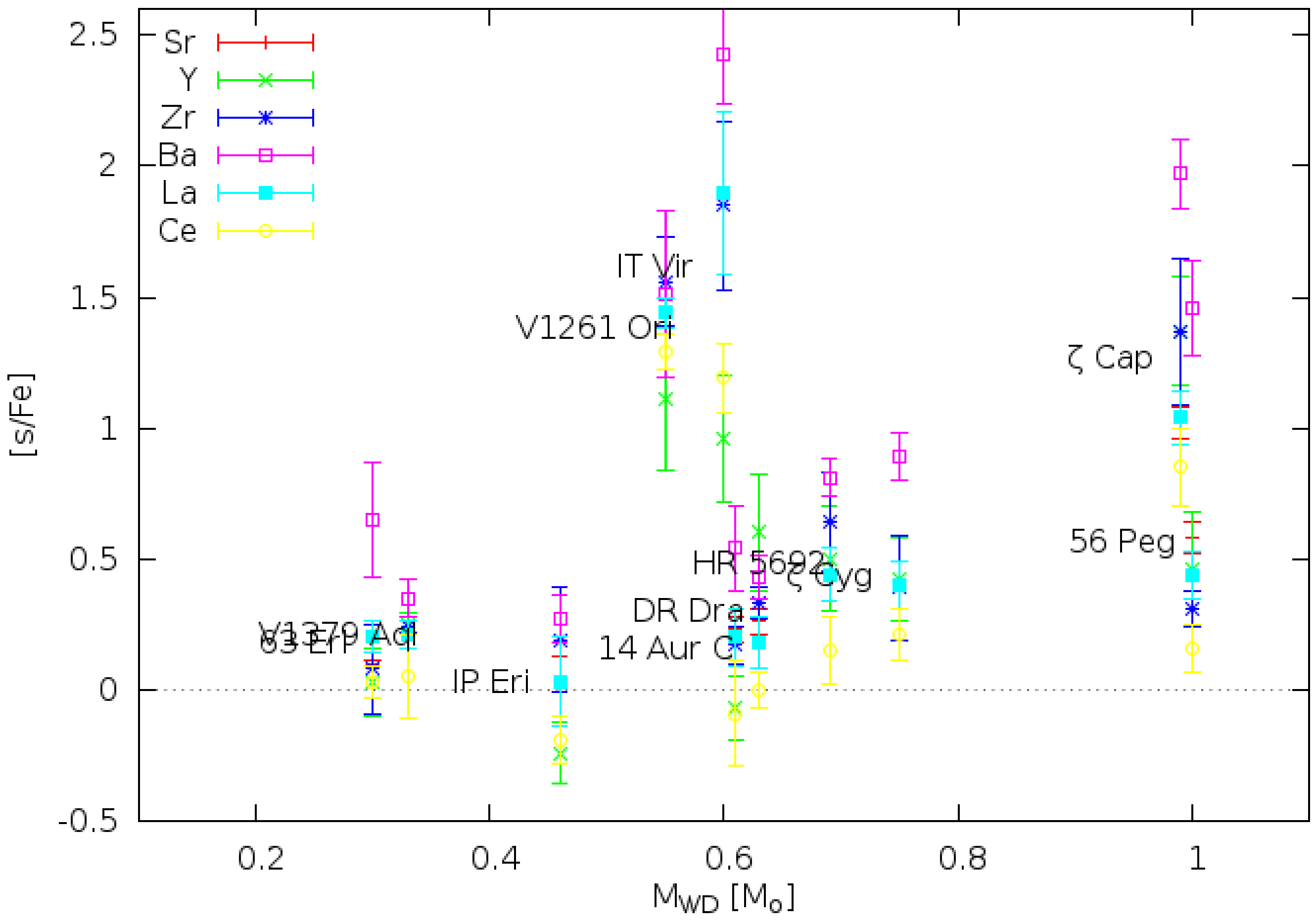
Quantitative analysis of s-process elements



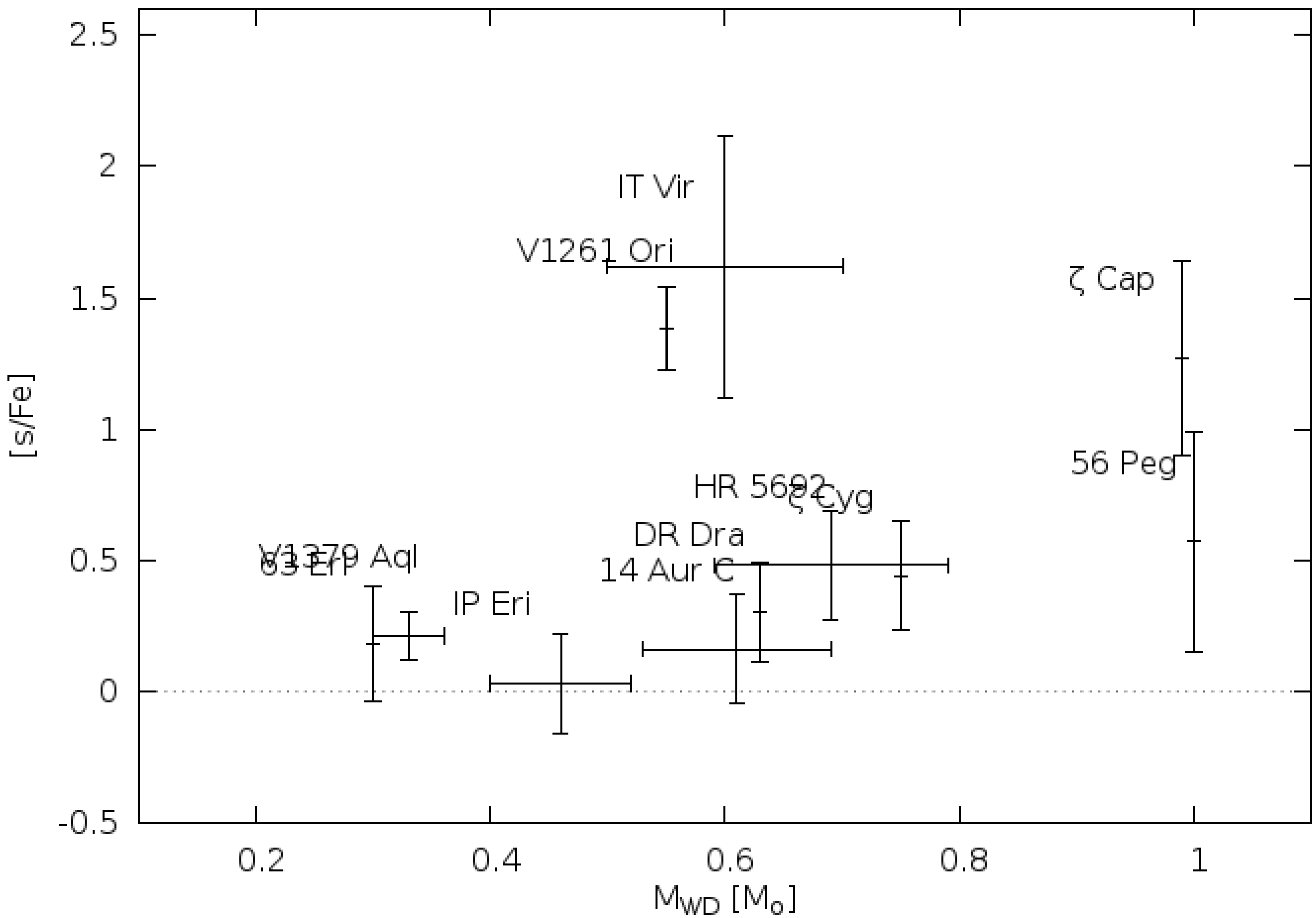
Quantitative analysis of s-process elements



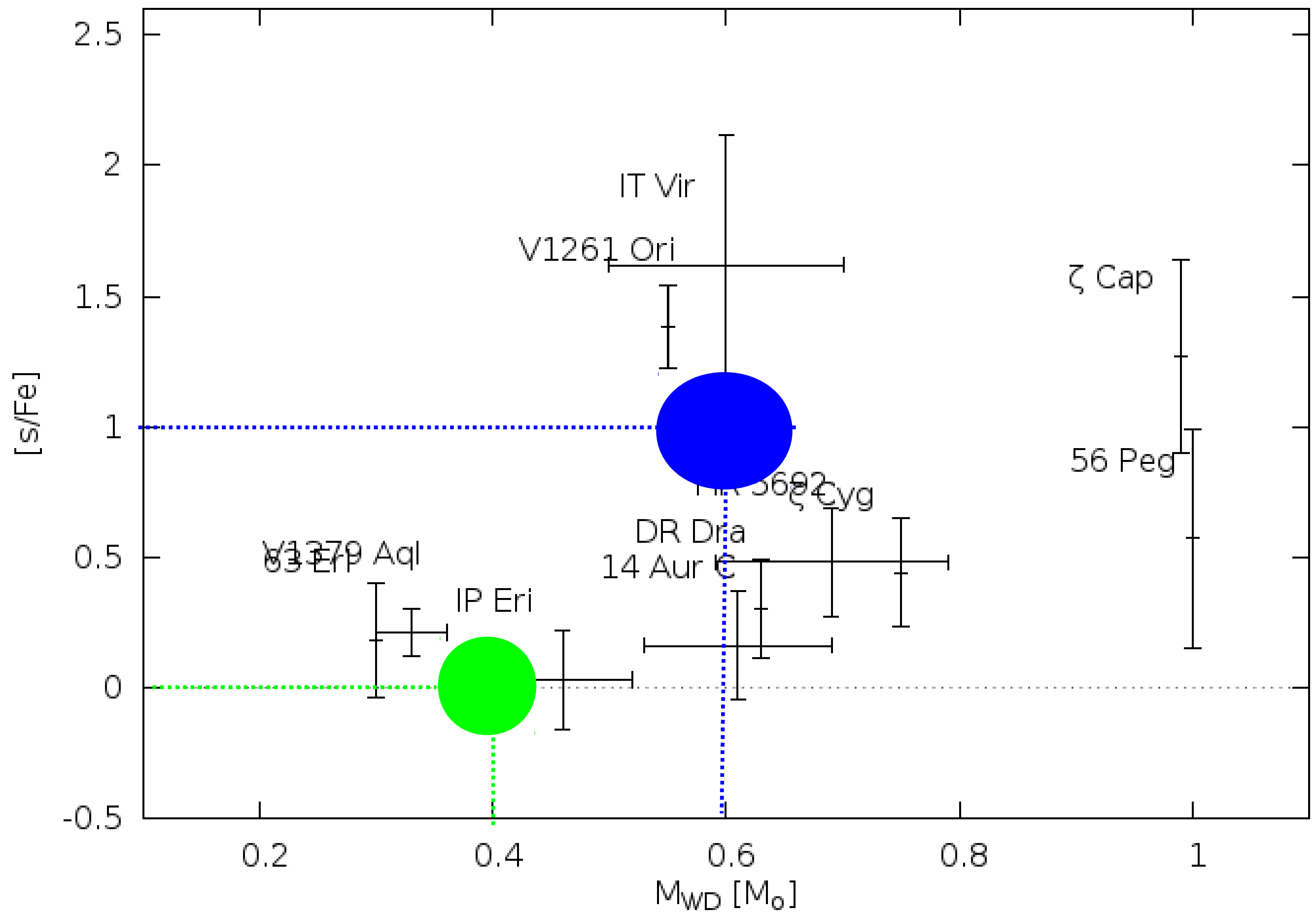
Quantitative analysis of s-process elements



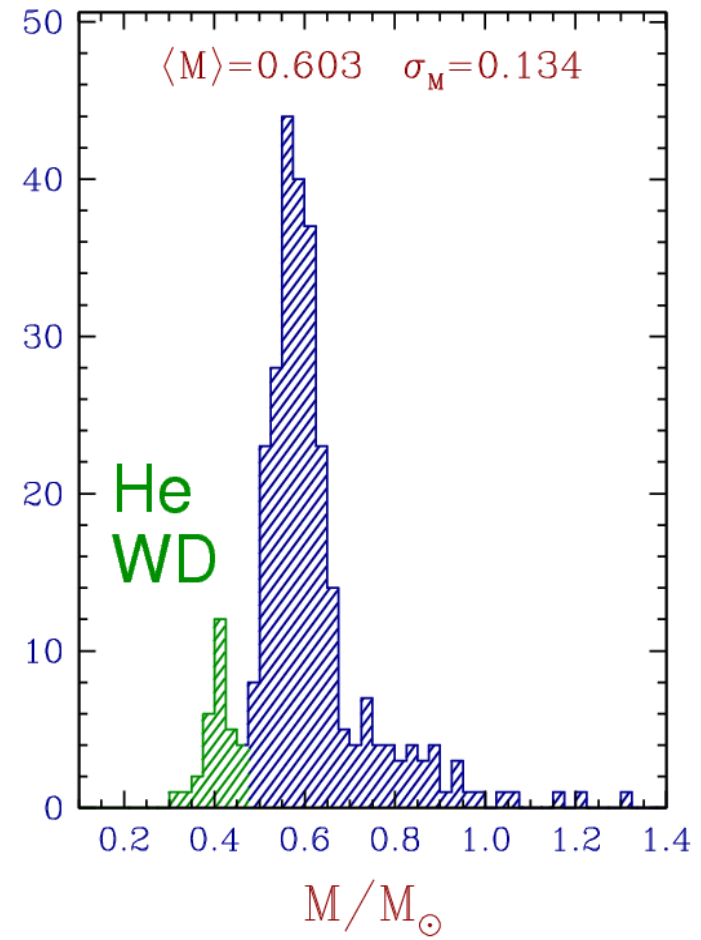
Quantitative analysis of s-process elements



Quantitative analysis of s-process elements



Liebert, Bergeron & Holberg 2005



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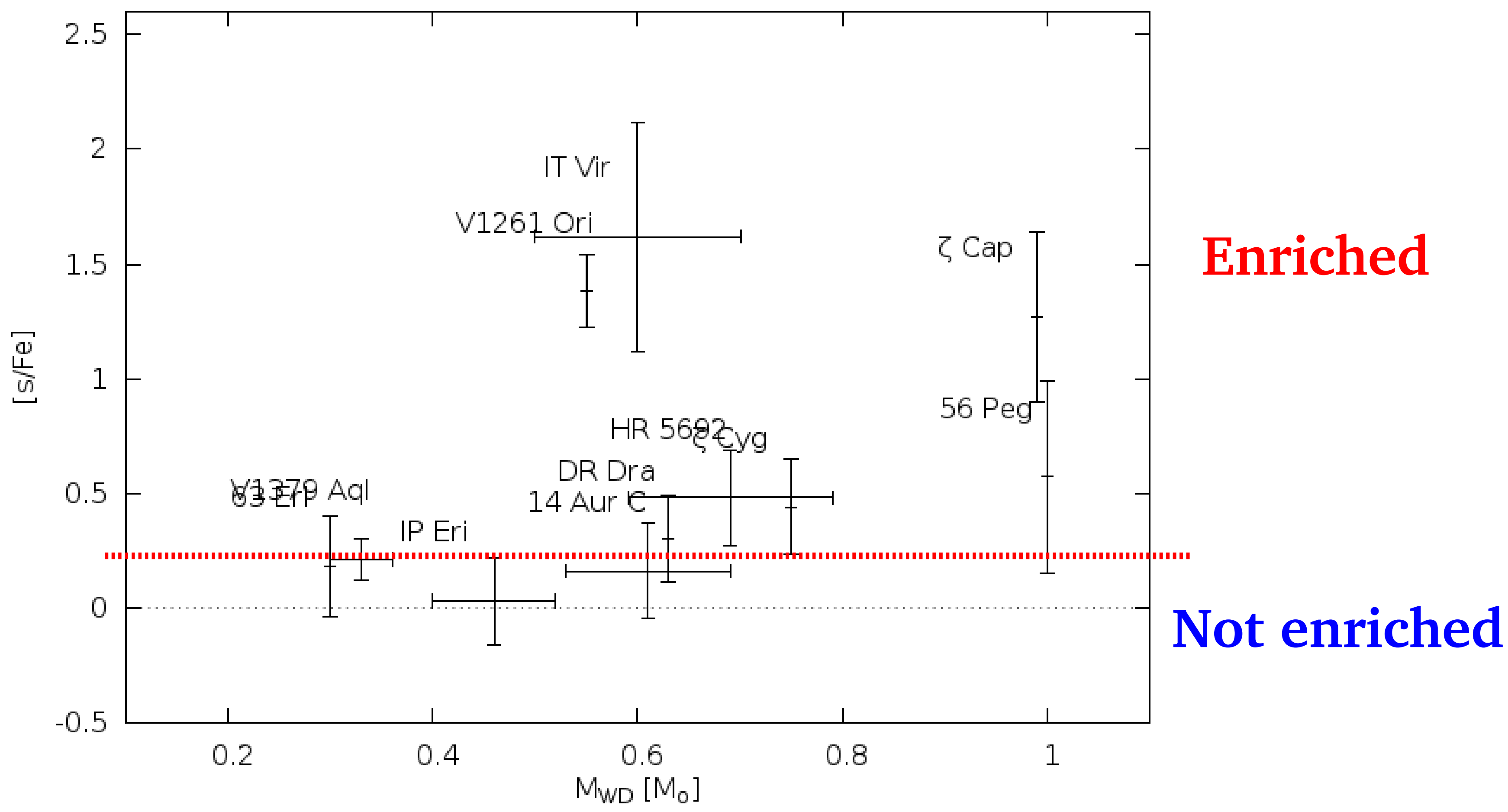
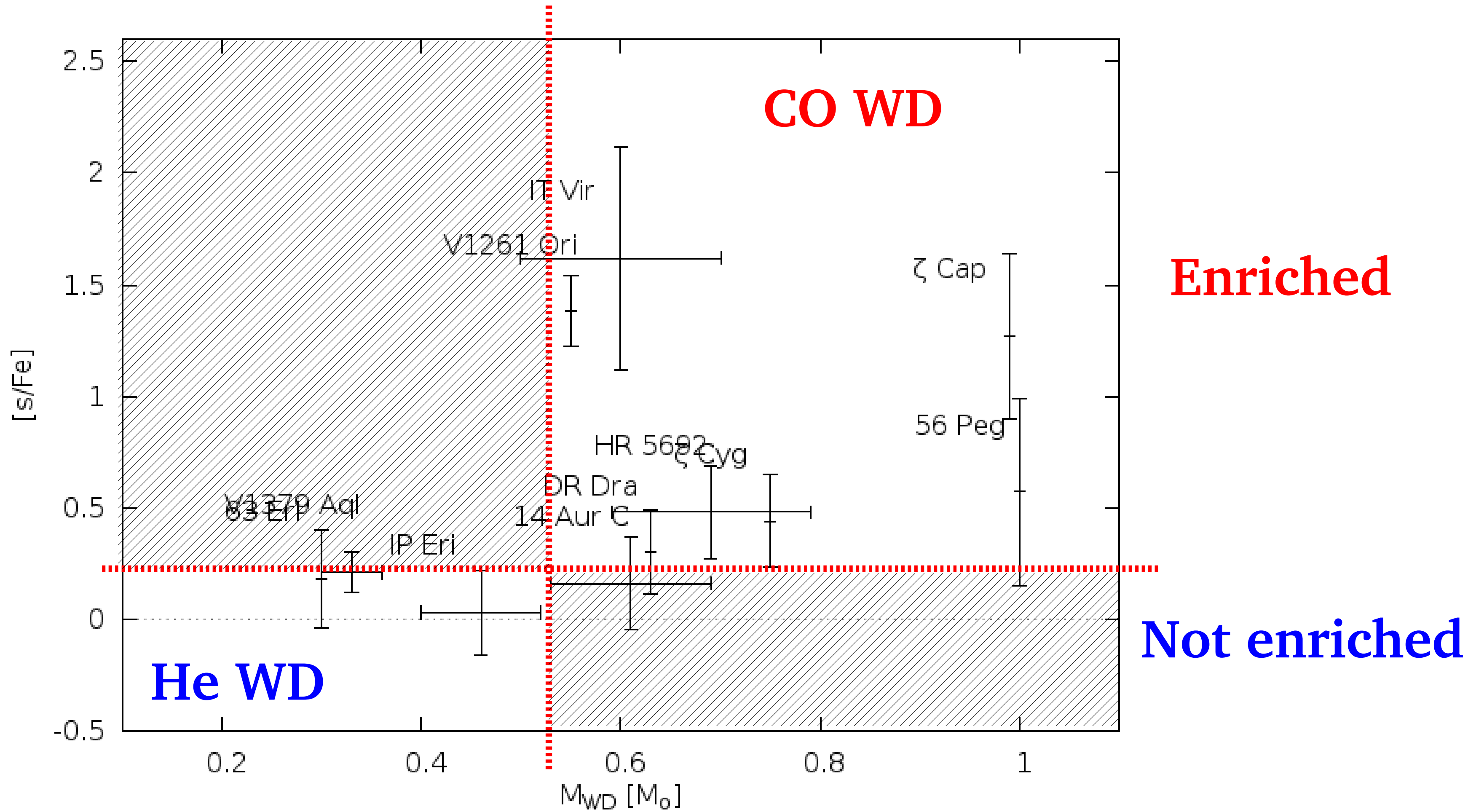


s-process pollution paradigm: toward a homogeneous picture



$M_{WD} \sim 0.55\ M_{\odot}$

How to detect the spectroscopic binaries in the GES?

- PIs: Gilmore & Randich
- Spectroscopic survey of 10^5 stars
- Spectros GIRAFFE & UVES
- WG14 : “non-standard object analyses”

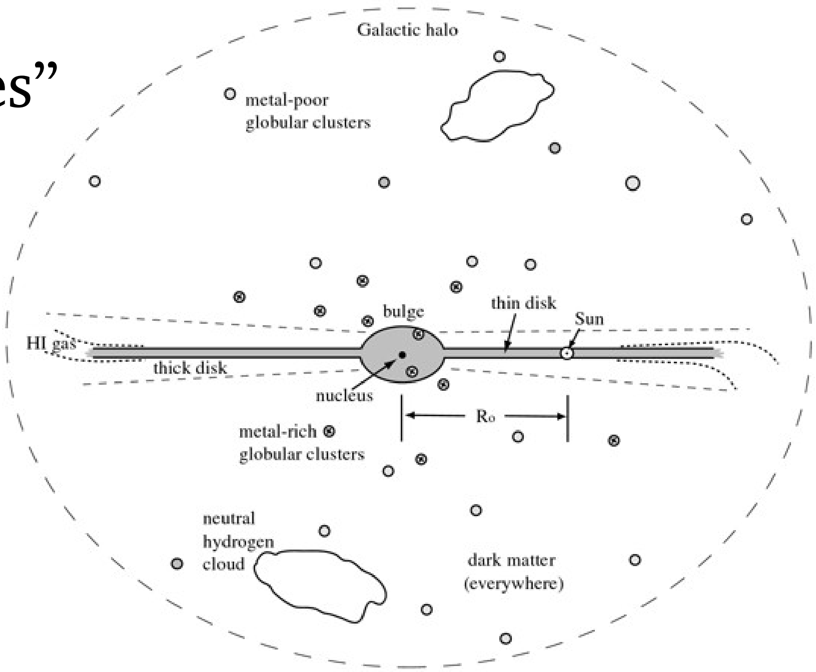


Fig 1.8 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

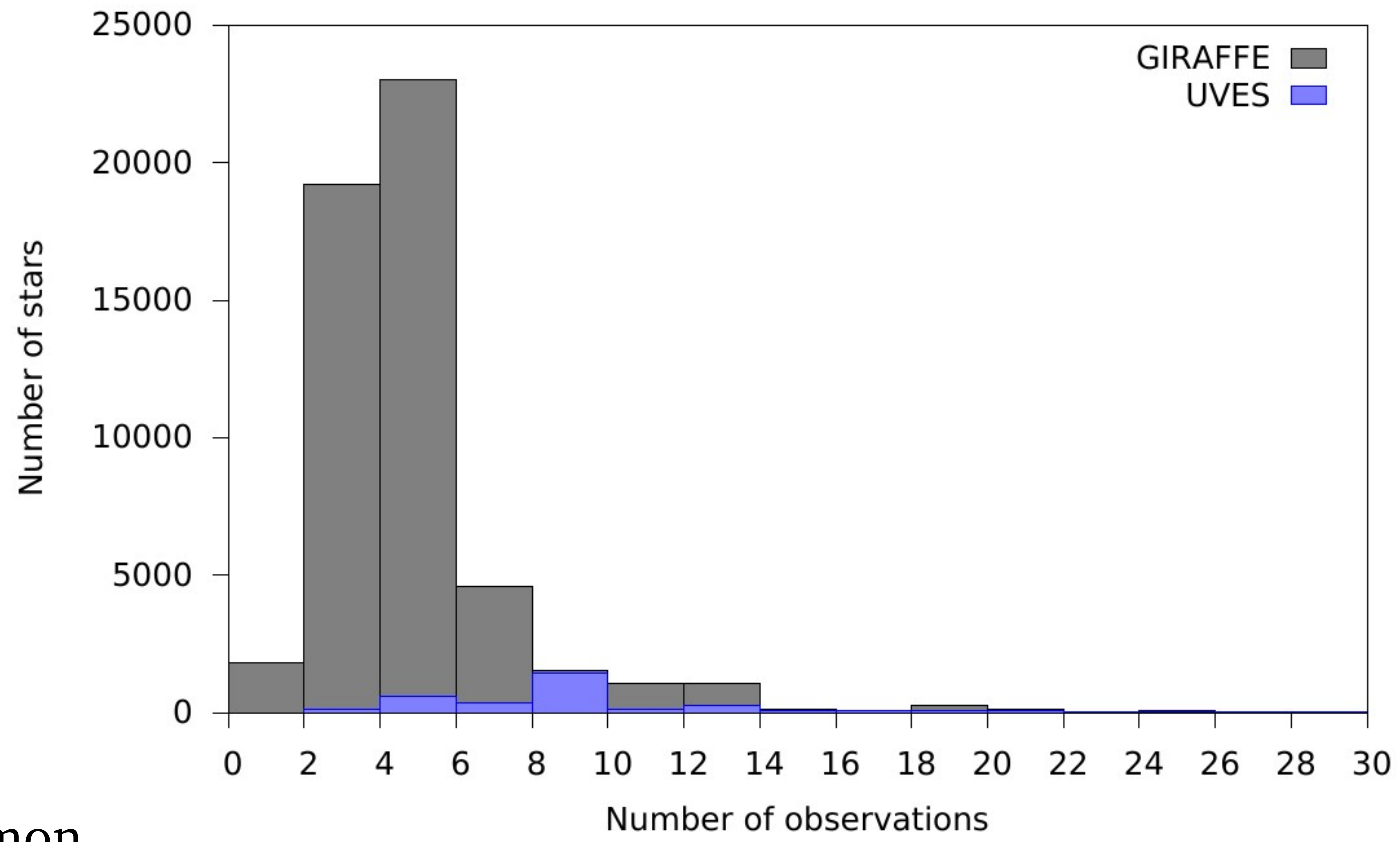
Statistics of iDR4: GIRAFFE and UVES

- iDR4: use of the individual unstacked spectra (GIRAFFE + UVES)
- Selection of spectra with SNR > 3

- GIRAFFE
  - 211081 spectra
  - 53130 stars

- UVES
  - 32031 spectra
  - 3471 stars

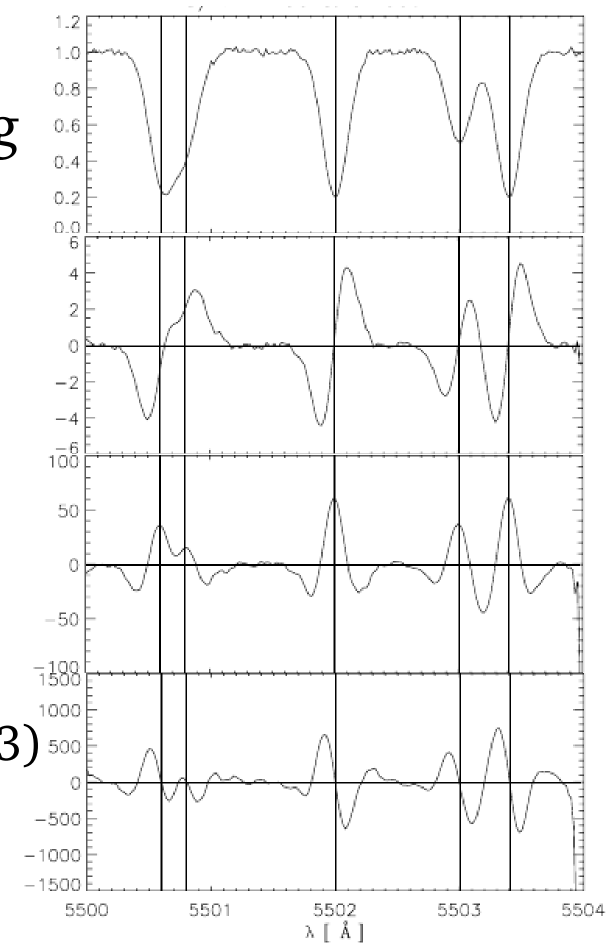
- ~600 stars are in common



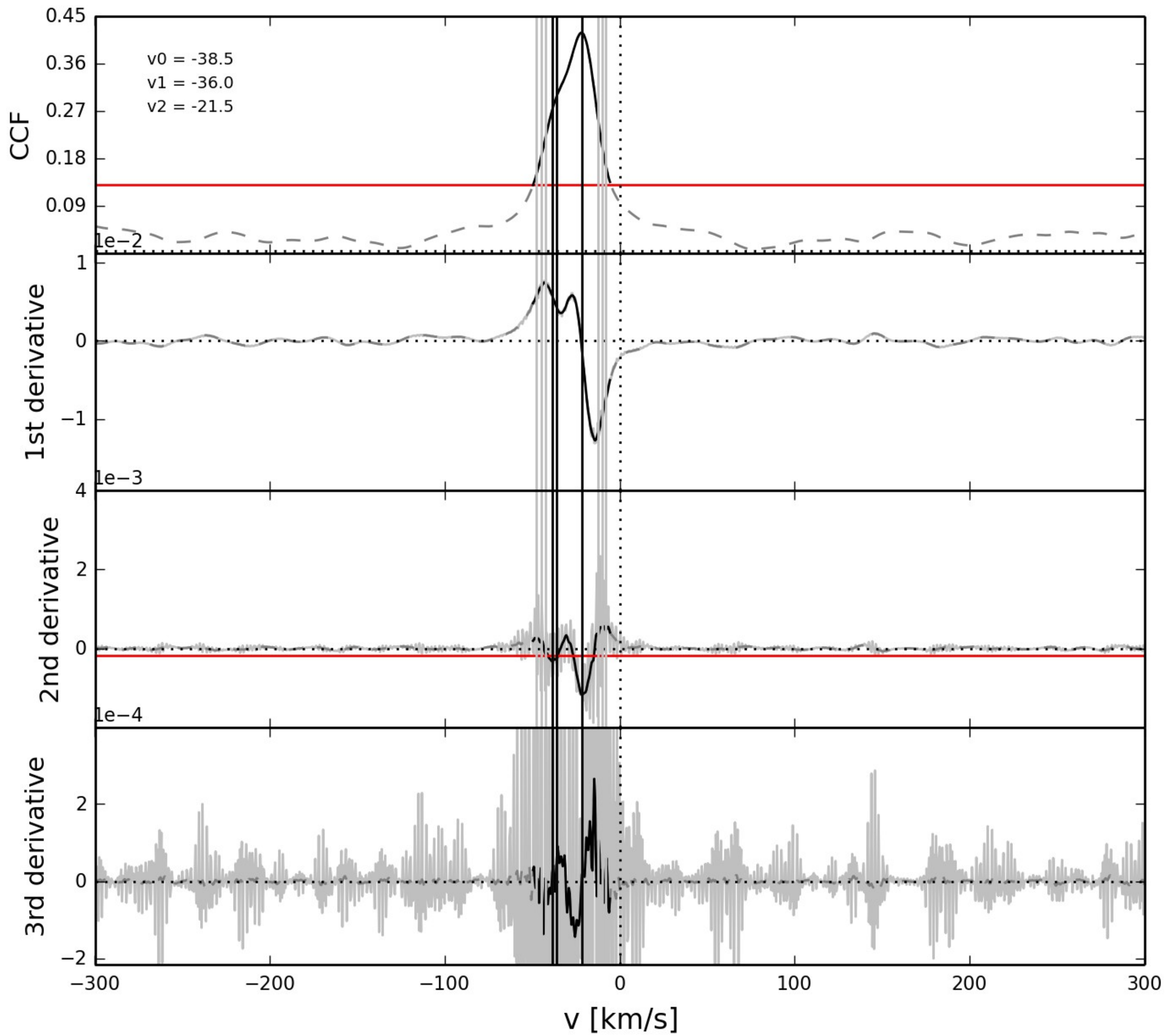
The successive derivatives of the CCFs is used to detect peaks

- CCF = Cross Correlation Function
- For GIRAFFE spectra: CCFs computed by pipelines at CASU (Lewis et al., in prep.) using synthetic spectra templates from U. Munari.
- For UVES spectra: CCFs computed by INAF—Arcetri (Sacco et al., in prep.) using GES synthetic grid from de Laverny et al. 2012.
- Basic idea from the ARES code

(Sousa et al. 2007 A&A 469, 783)



The cut frequency is empirically adjusted

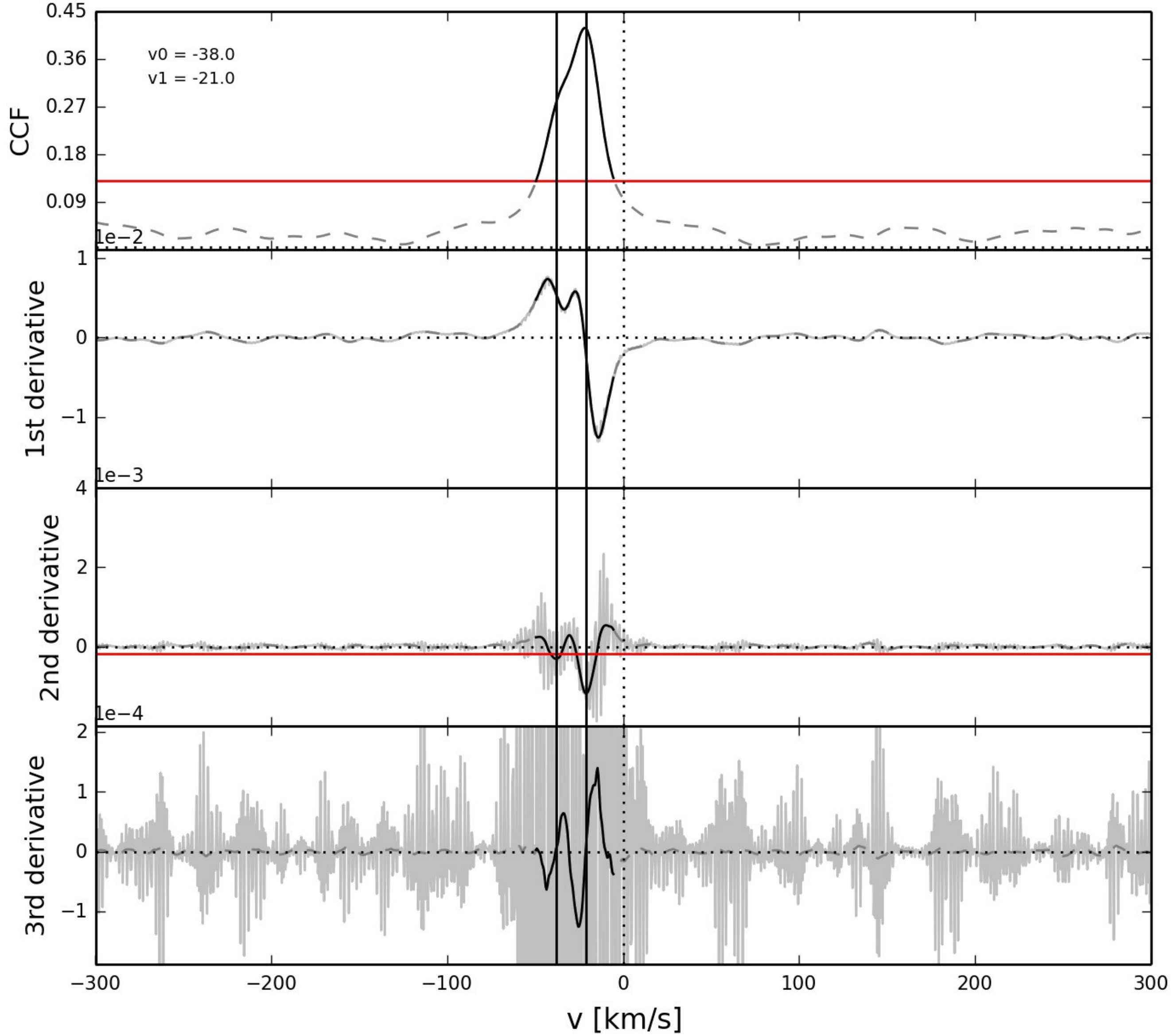


3rd order Butterworth Low-pass filter

First parameter:

Frequency cut of the filter for smoothing the successive derivatives of the CCF

The cut frequency is empirically adjusted



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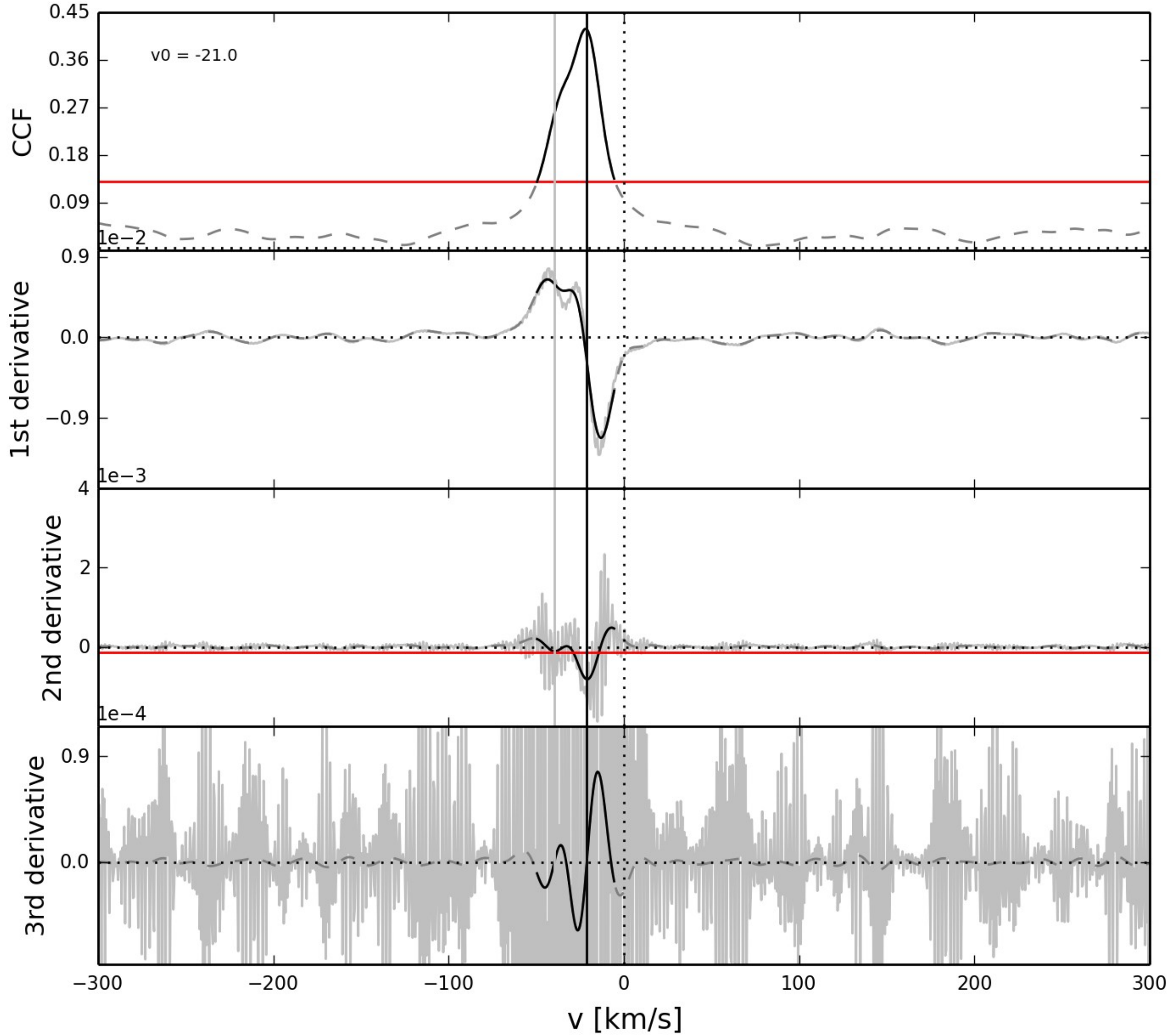

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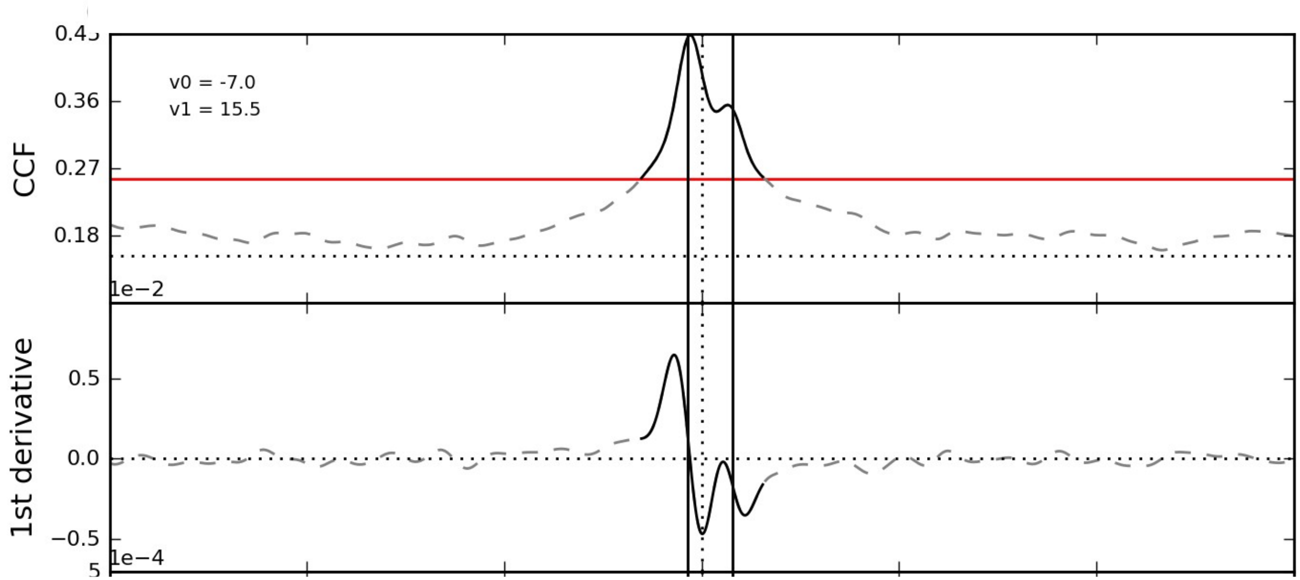
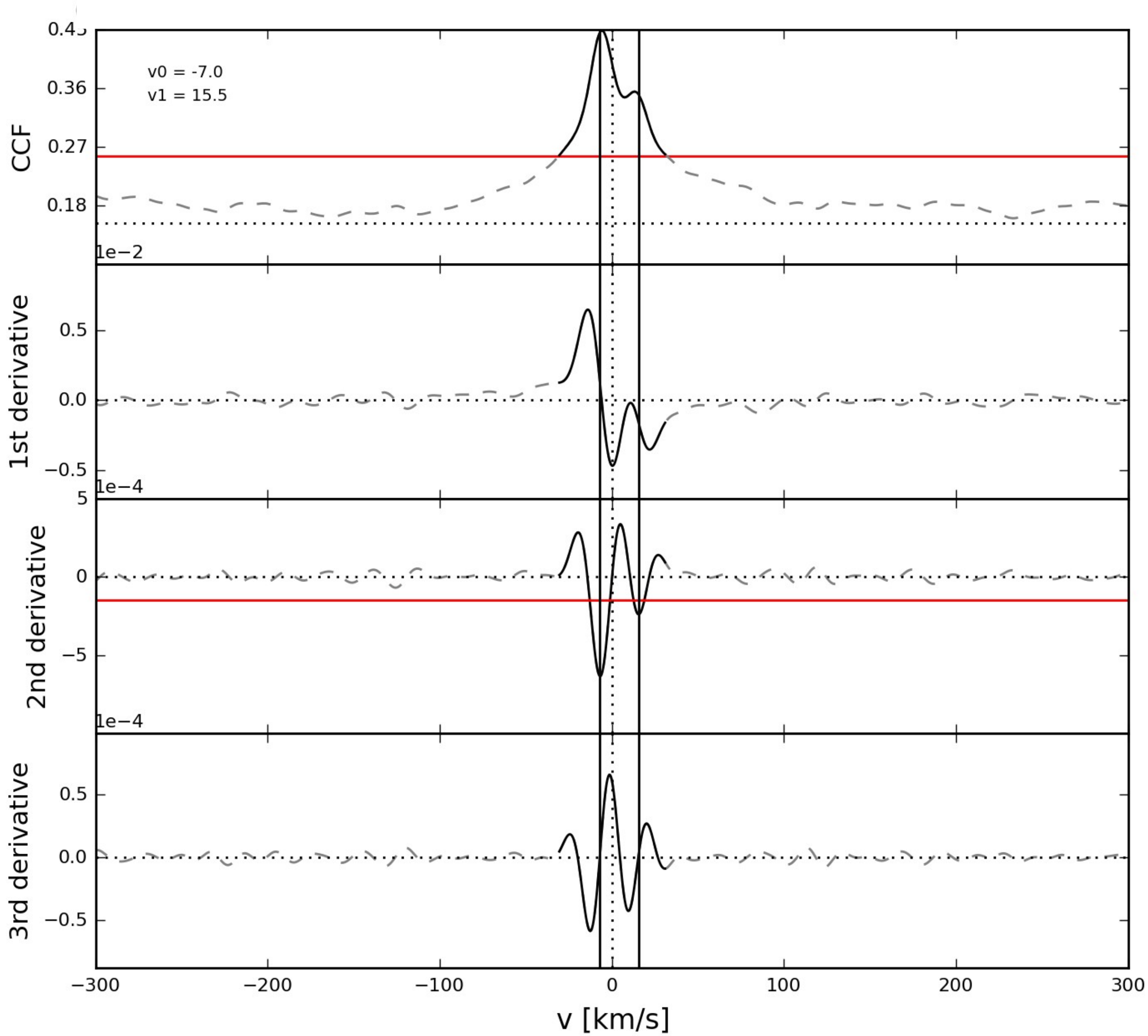
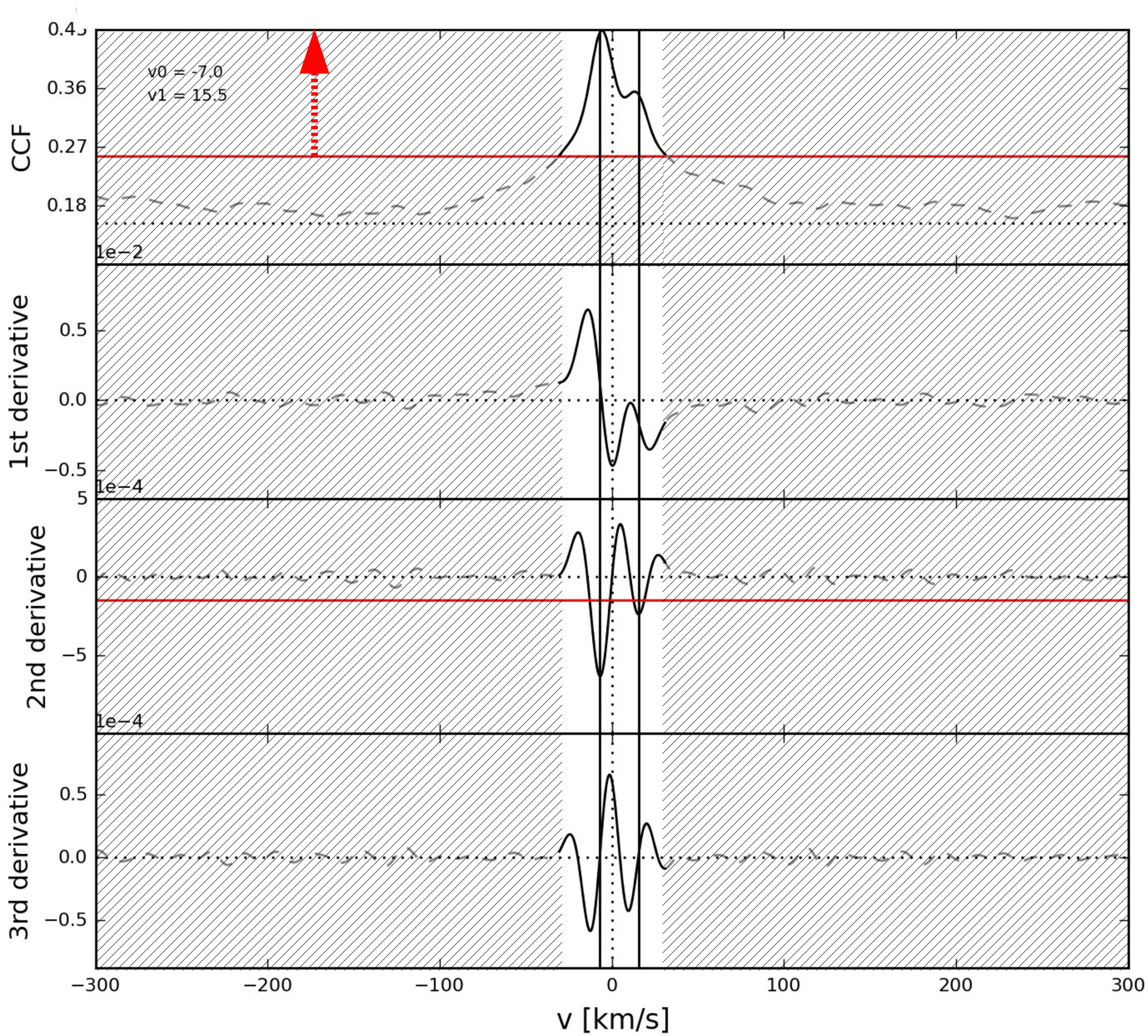
Second CCF derivatives give the positions of the close double peaks



Second CCF derivatives give the positions of the close double peaks



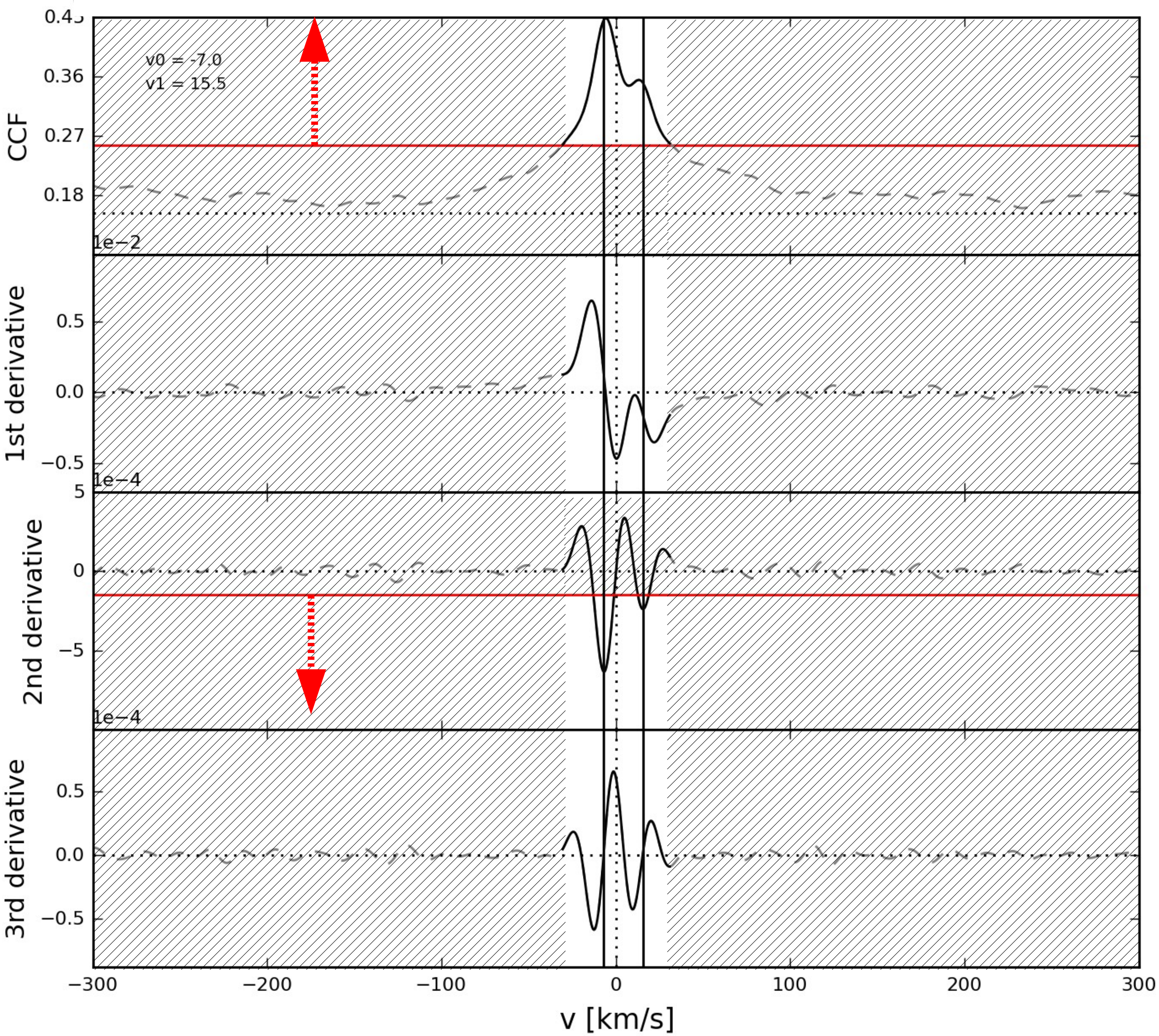
Second CCF derivatives give the positions of the close double peaks



2nd parameter:

Threshold on the CCF

Second CCF derivatives give the positions of the close double peaks



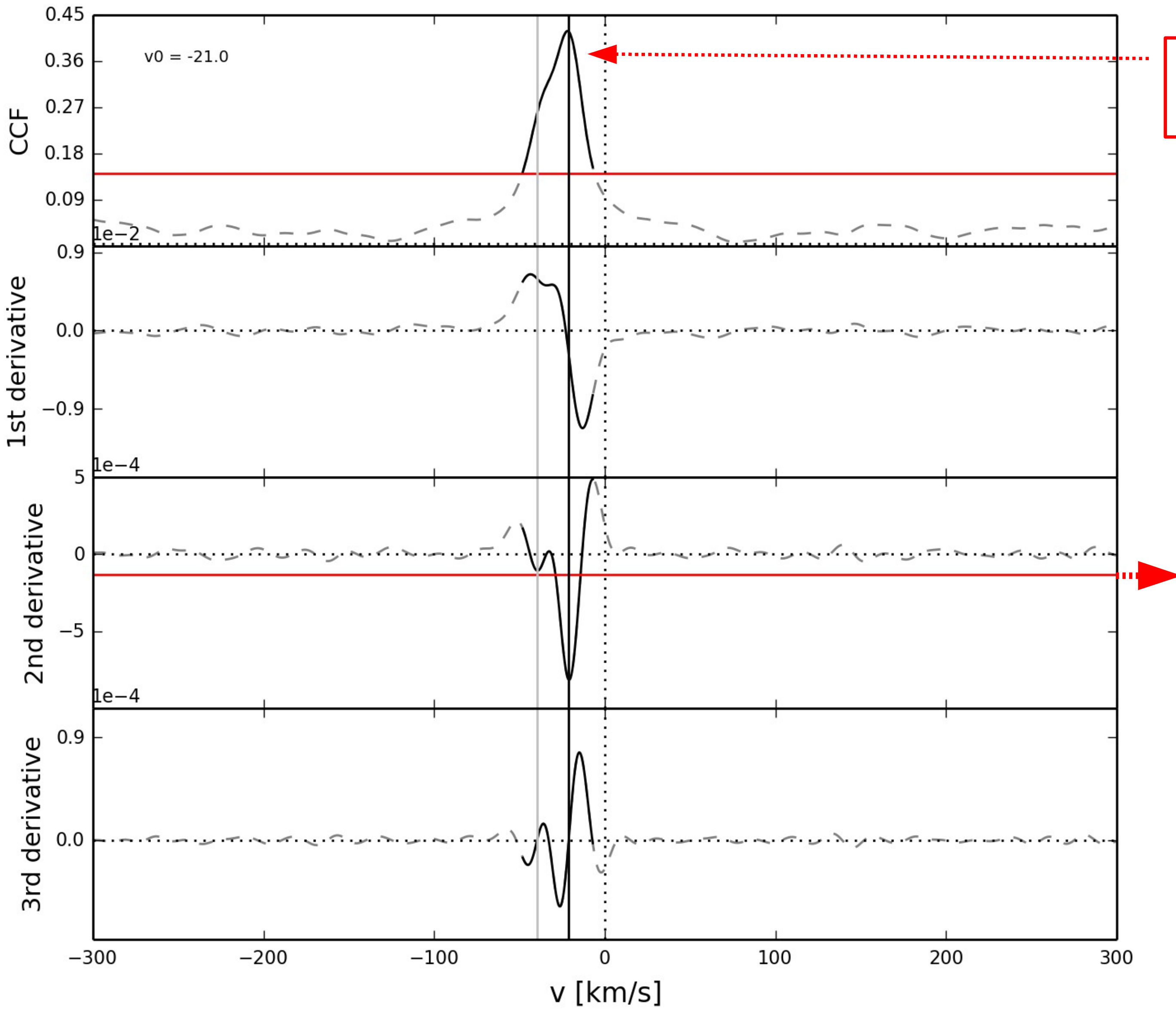
2nd parameter:

Threshold on the CCF

3rd parameter:

Threshold on the 2nd derivative

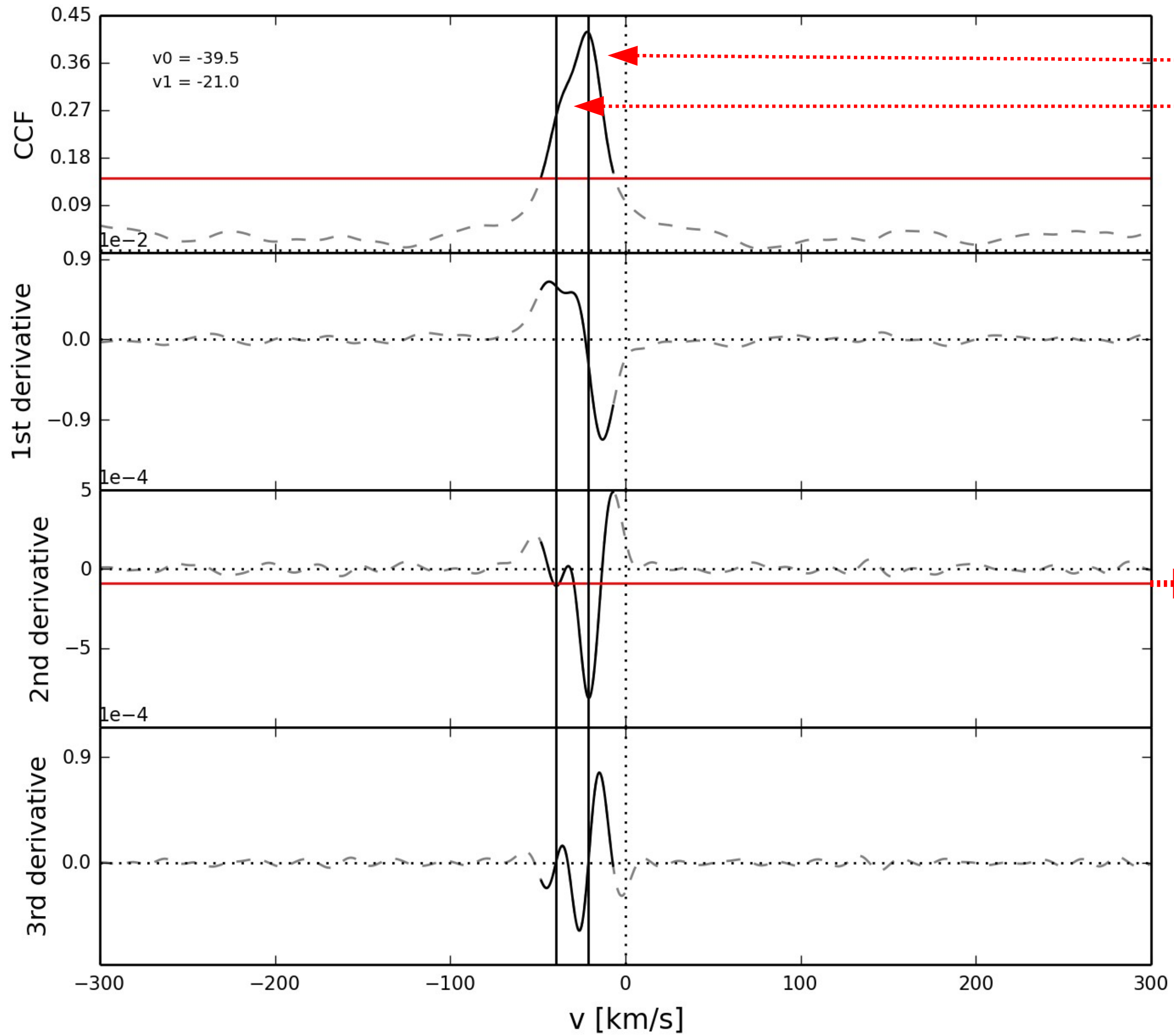
Close double peaks are easily detected



1 peak detected

Threshold on the 2nd derivative = 10 % of the full amplitude

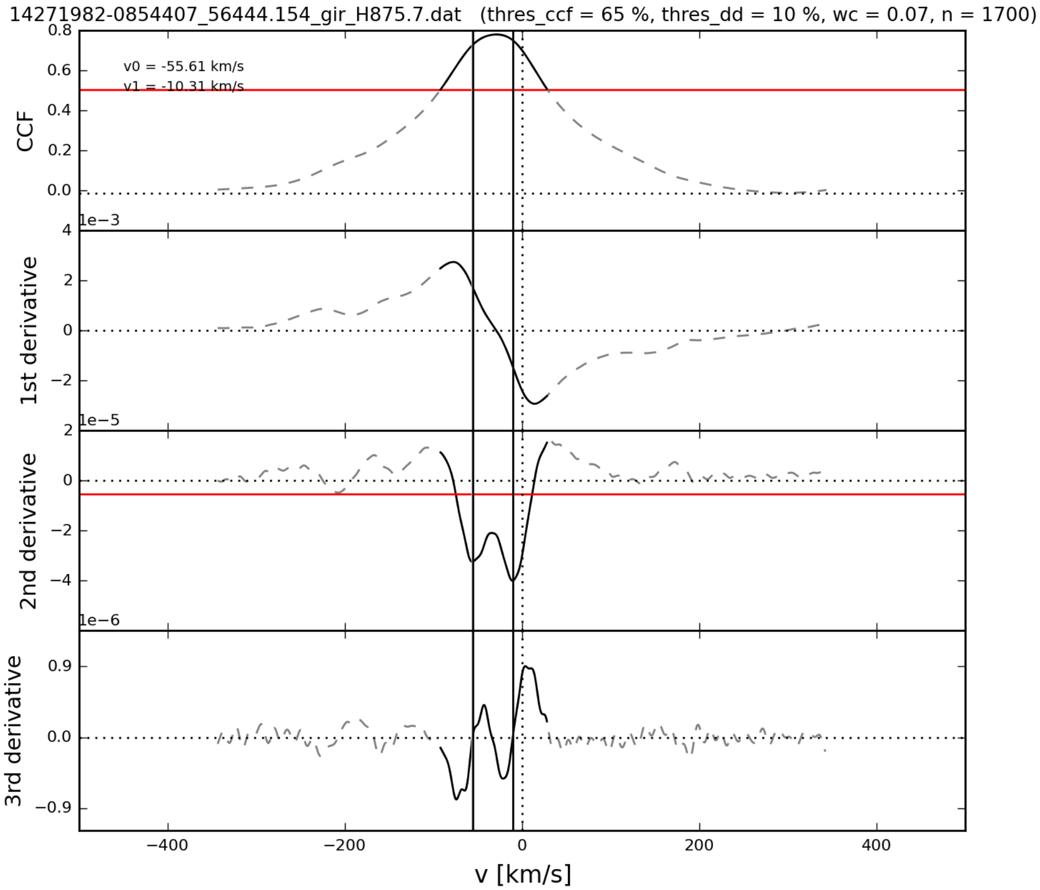
Close double peaks are easily detected



2 peaks detected

Threshold on the 2^{nd} derivative = 7 % of the full amplitude

Fitting the code parameters



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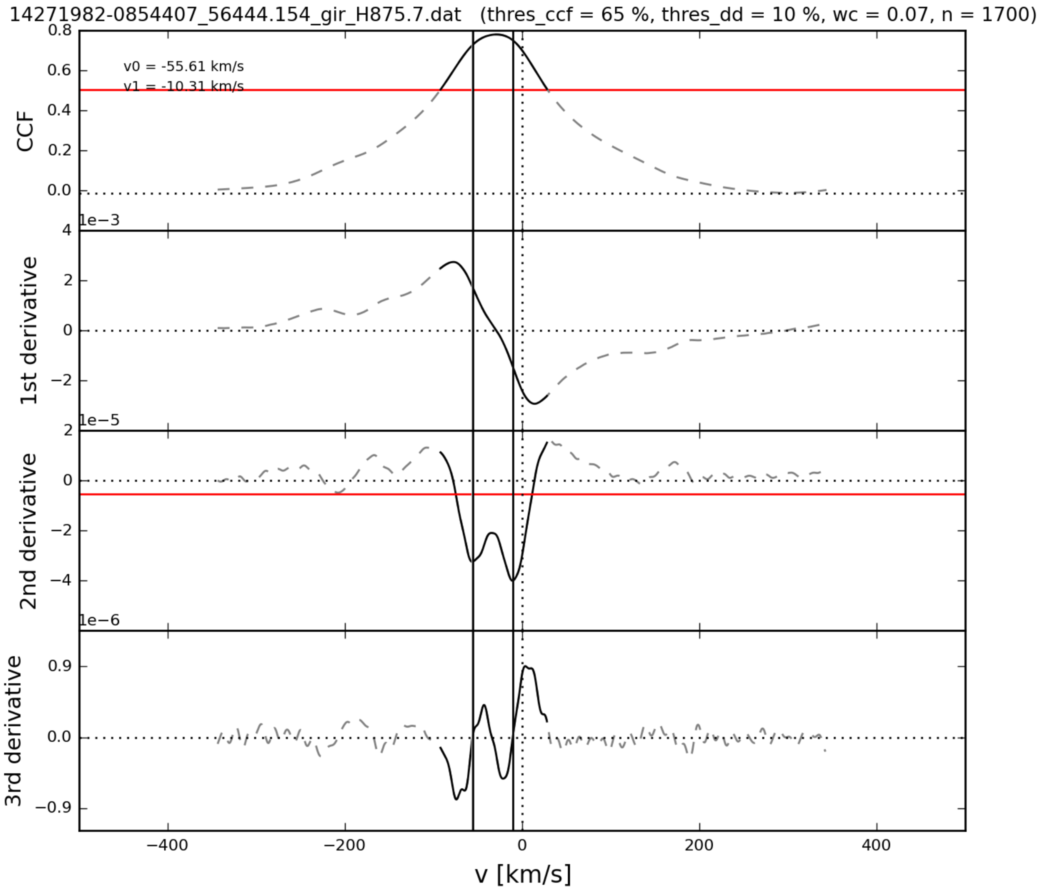
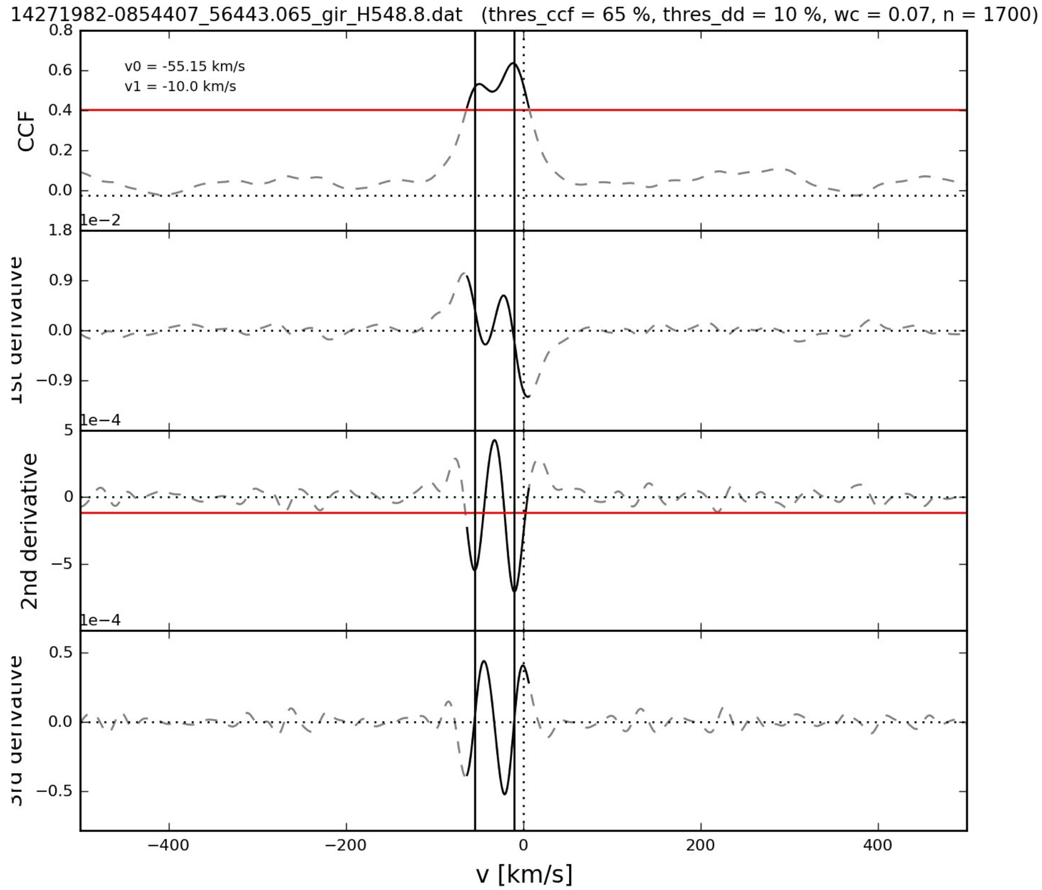
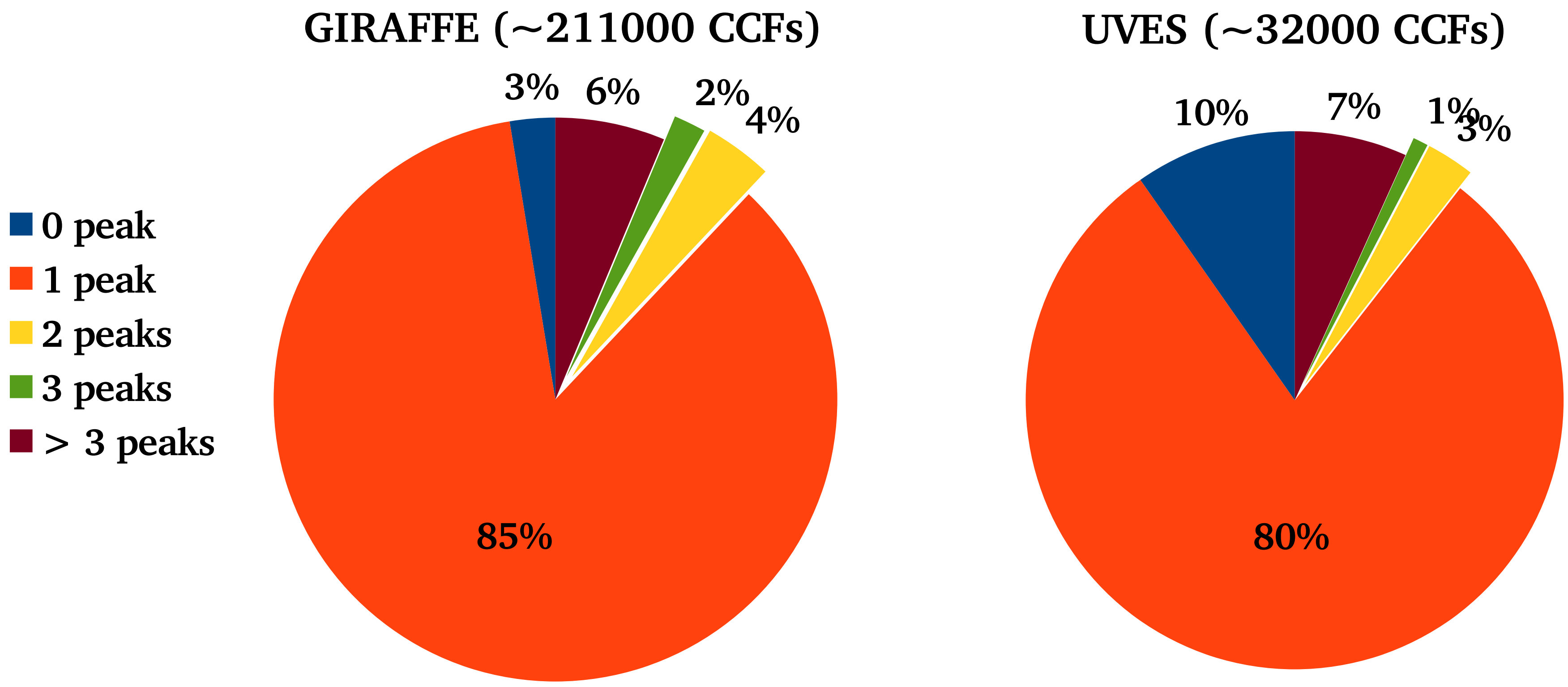




iDR4 raw results of the automatic peaks detection



Automatic SB2/3 classification in iDR4: GIRAFFE and UVES

The strongest criterium:
Same number of peaks for all observations in all setups

Stars	GIRAFFE	%	UVES	%
SB2 candidates	522	1.0	46	1.3
SB3 candidates	0	0.0	3	0.1
Total stars	53130	100	3471	100

The weakest criterium:
At least one N-peaked CCF per star (with N = 2 or 3)

Stars	GIRAFFE	%	UVES	%
SB2 candidates	4952	9.3	281	8.1
SB3 candidates	2641	5.0	156	4.5
Total stars	53130	100	3471	100

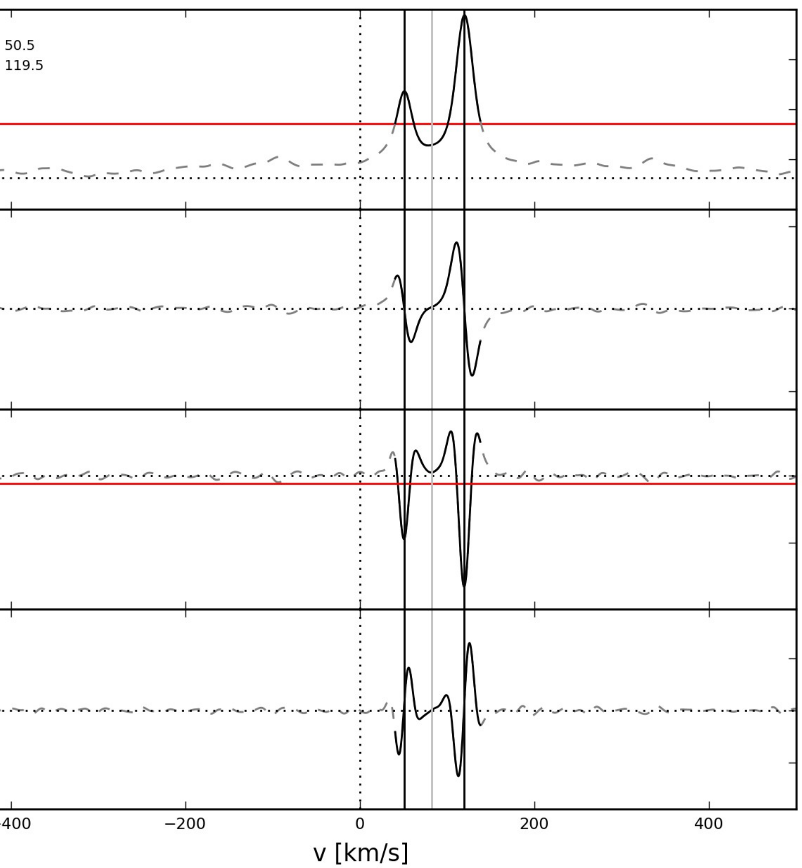
iDR4 first-pass analysis

- SNR > 10
- Setups selection:
  - UVES U520 and U580: 28528 spectra (3374 stars)
  - GIRAFFE HR10 and HR21: 107324 spectra (31369 stars)
- Automatic peak detections
- For a given setup, we combine all CCFs corresponding to a given star an apply the following criterium:
  - A SB2/SB3 candidate must have 75 % or more of CCFs with 2 or 3 detected peaks

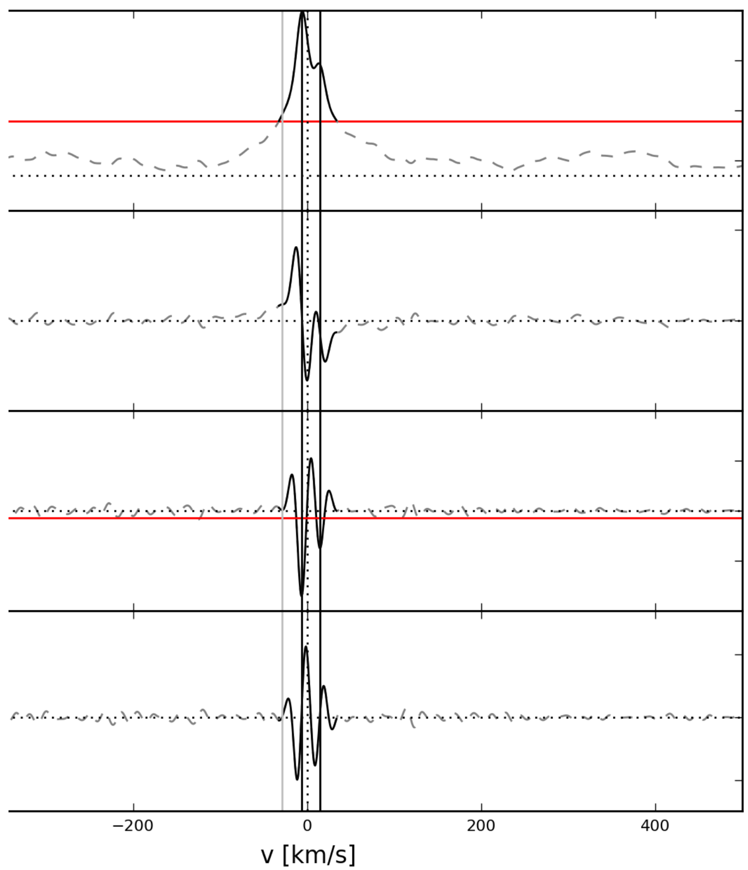
UVES SB2 candidates: visual inspection

67 SB2 candidates / 137 spectra

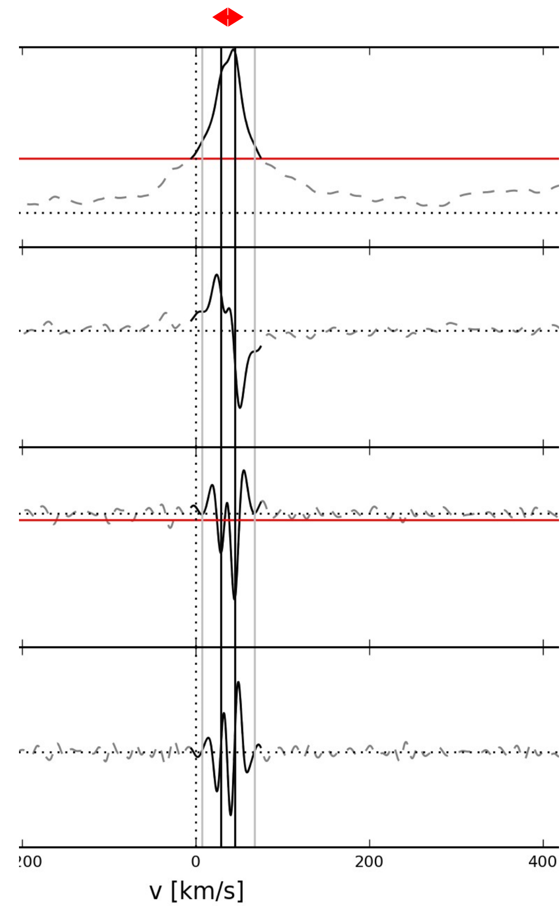
Min $\Delta v_{rad} \sim$ 15 km/s



38
Probable detection
Confidence flag A



18
Possible detection
Confidence flag B

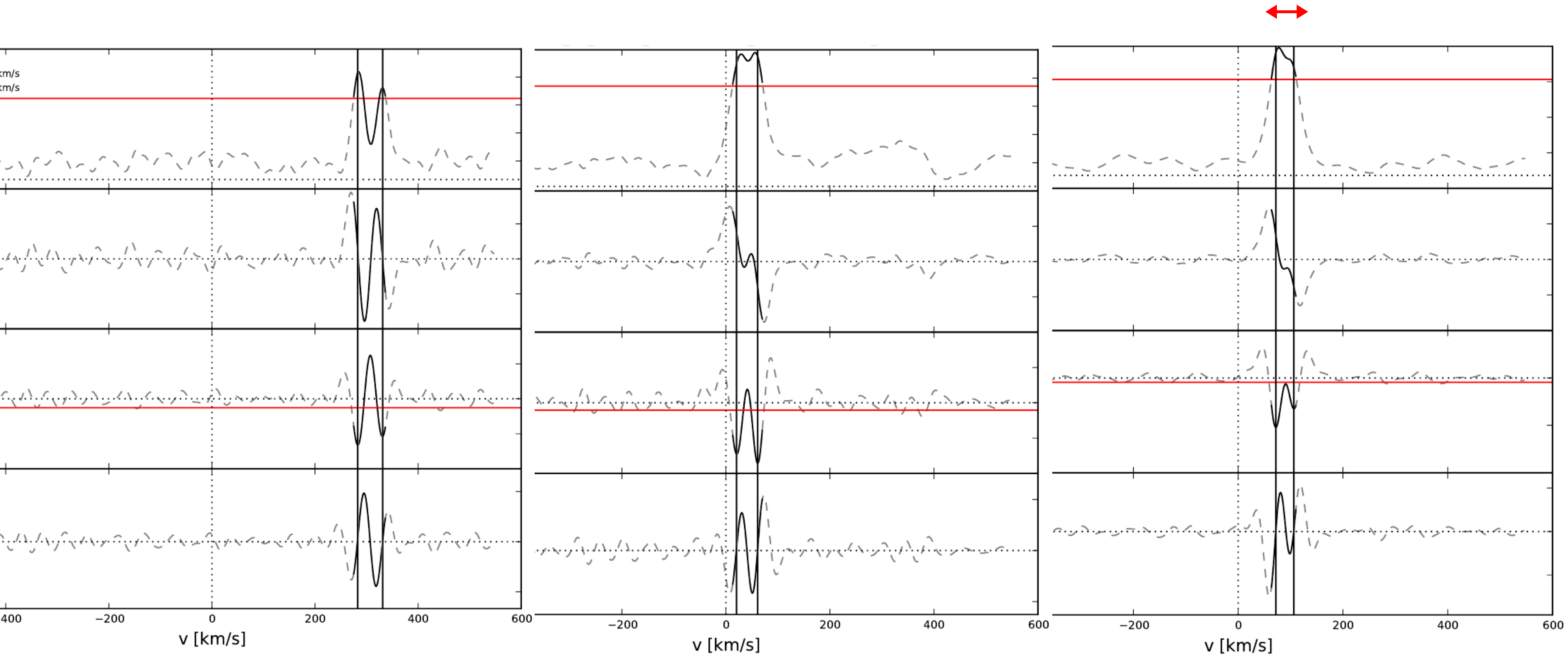


10
Tentative detection
Confidence flag C

GIRAFFE SB2 candidates: visual inspection

174 SB2 candidates / 474 spectra

Min $\Delta v_{rad} \sim$ 30 km/s

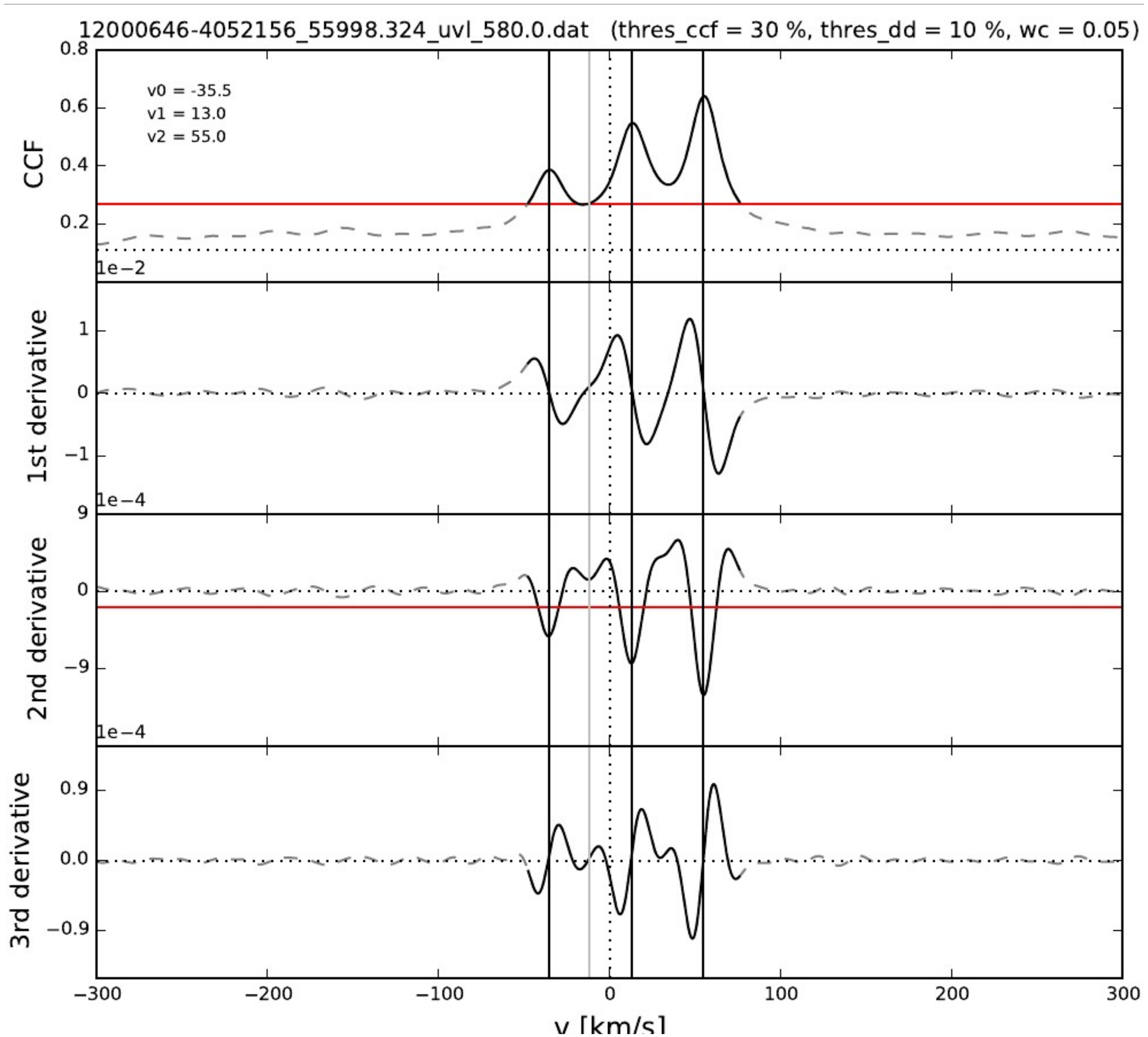


62
Probable detection
Confidence flag A

35
Possible detection
Confidence flag B

77
Tentative detection
Confidence flag C

1 example of UVES SB3 candidate



8 CCFs with 3 peaks detections
(but the same night)

Not in Simbad
(within a radius of 2 arcmin)

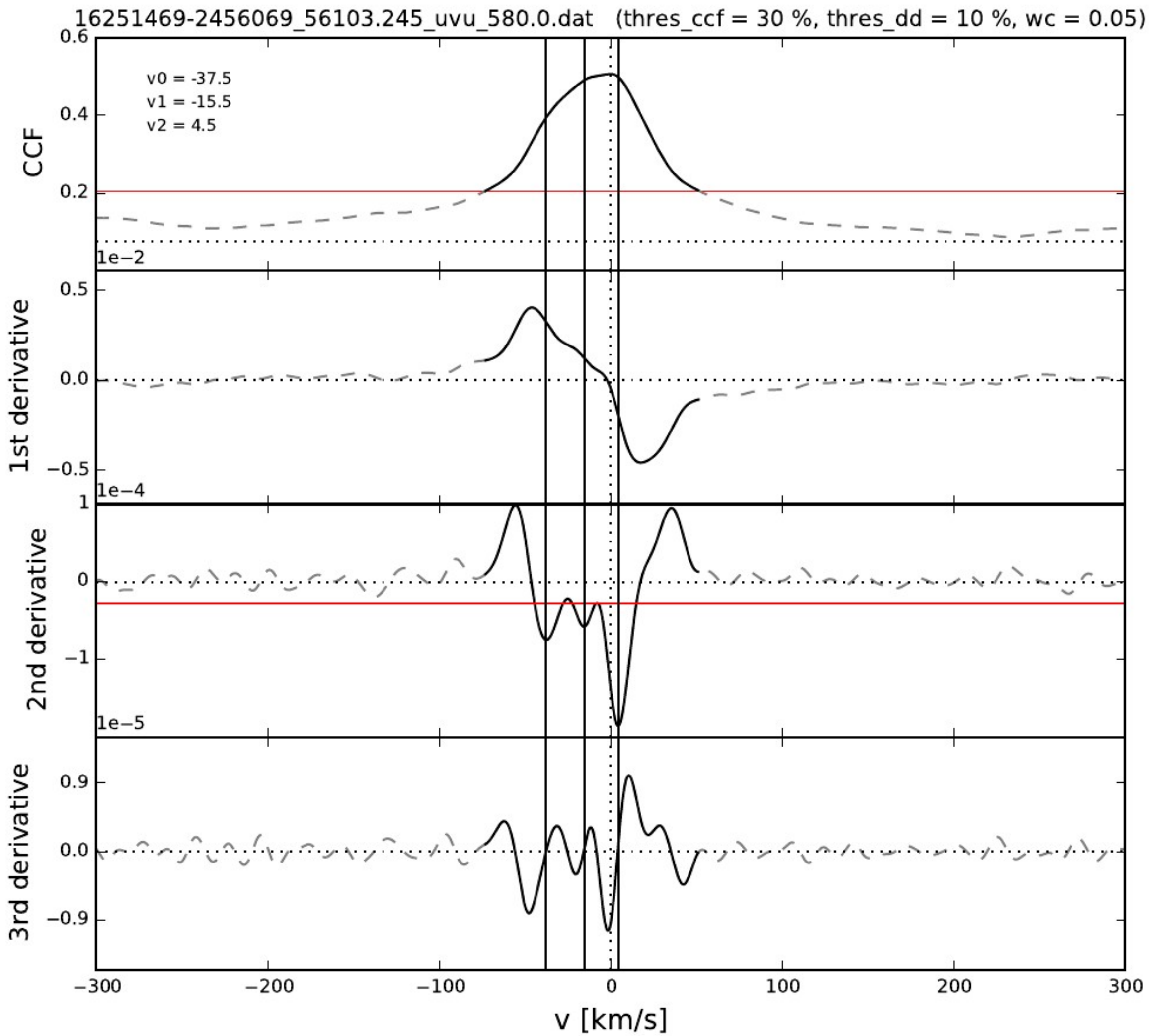
GES_MW
APASS photometry
V = 14.31 ± 0.06
From Fibinfo extension
RV = 12.5 ± 0.6 km/s

RV_SB2 = 1

TMPL_TEFF = 5000 K
TMPL_LOGG = 4
TMPL_FEH = -1

Recommended parameters
T_{eff} = 6058 ± 250 K
Log g = 4.54 ± 0.53
[Fe/H] = -0.40 ± 0.33

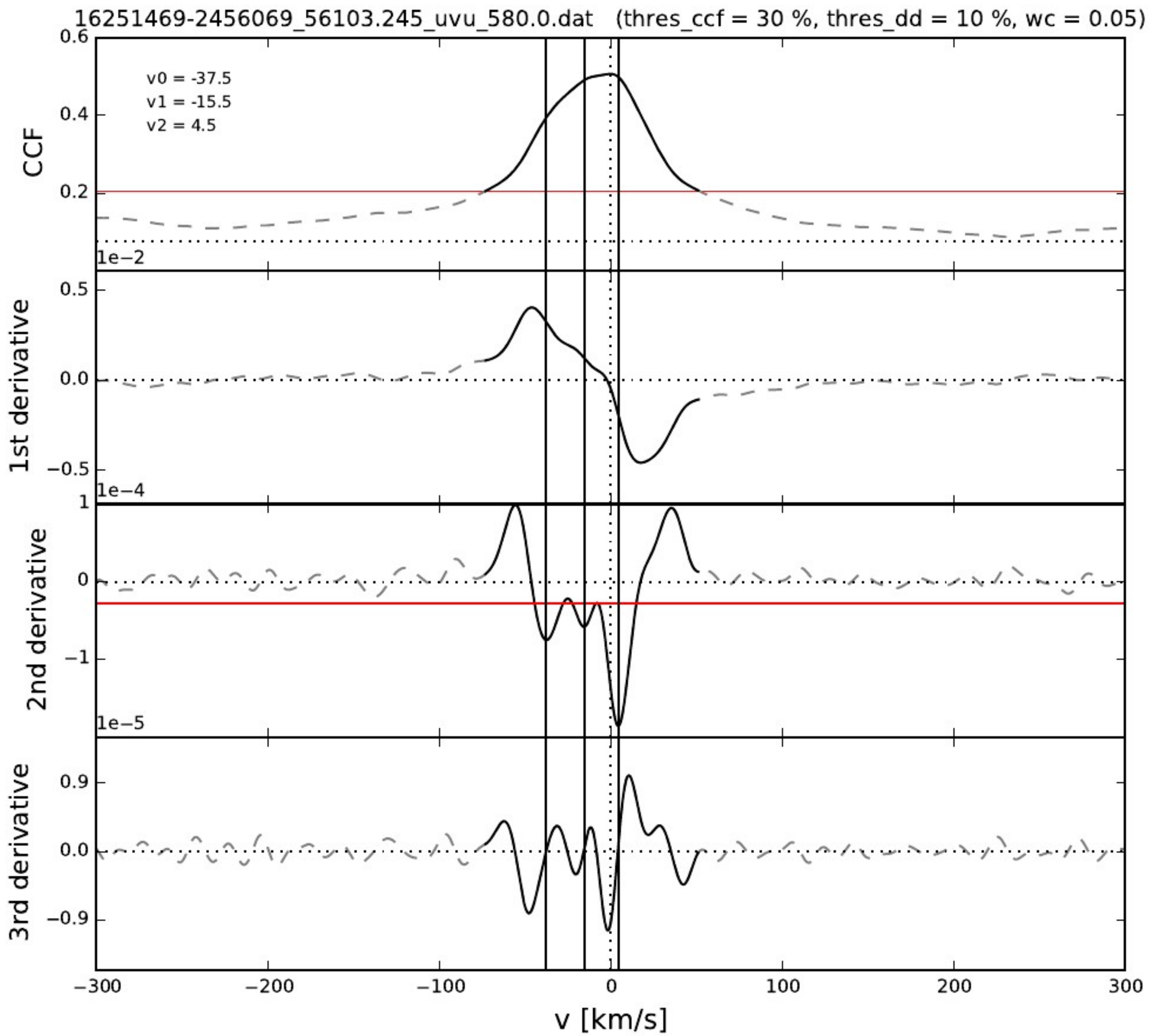
Fake UVES SB3



4 CCFs with 3 peaks detection
(but the same night)

V ~12.9
Object: TARGET_38
RV=-3.34 ± 0.60 km/s

Fake UVES SB3



4 CCFs with 3 peaks detection (but the same night)

V ~12.9
Object: TARGET_38
RV=-3.34 ± 0.60 km/s

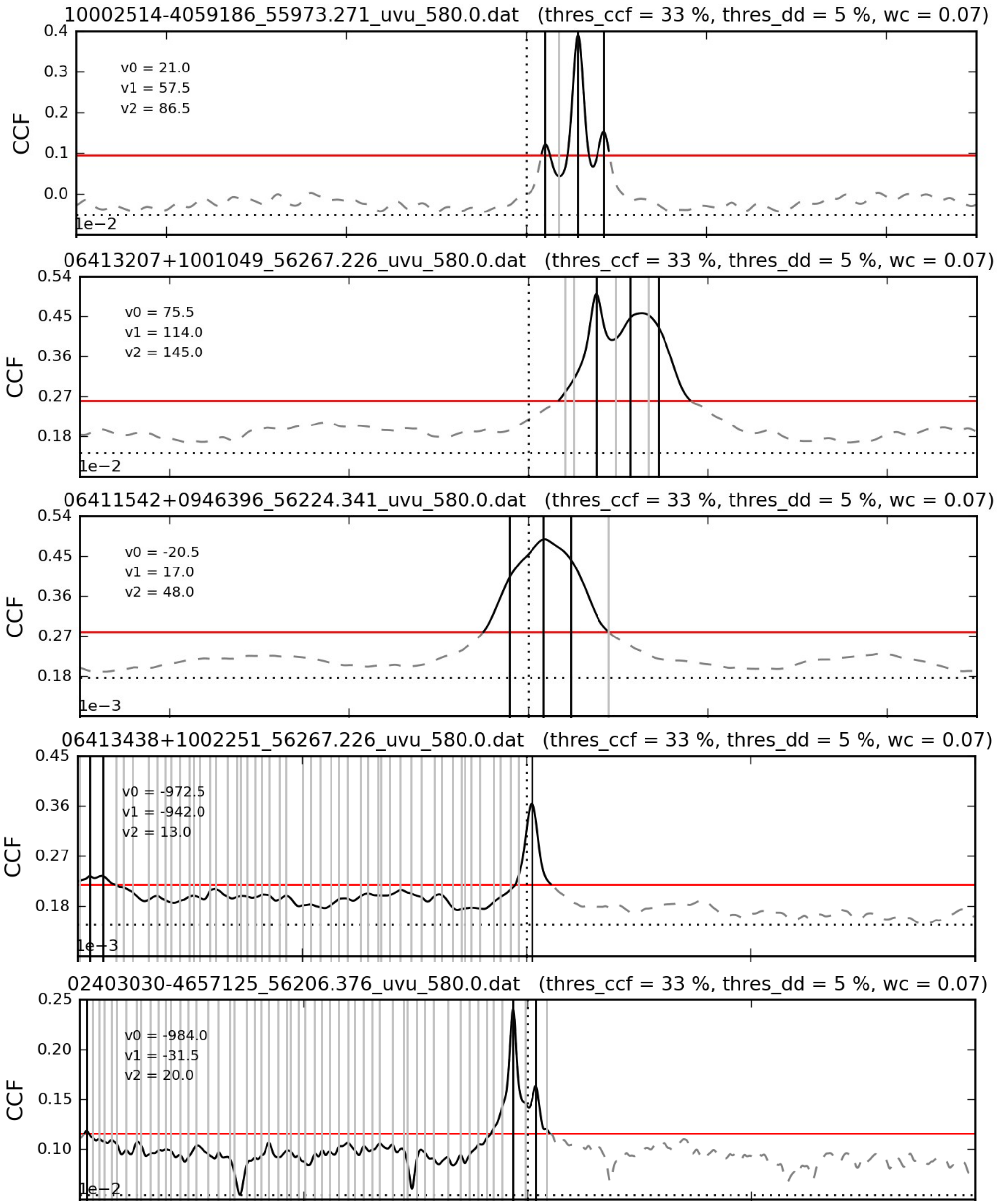
Simbad identification:
d = 6.24"

2MASS J16251469-2456069

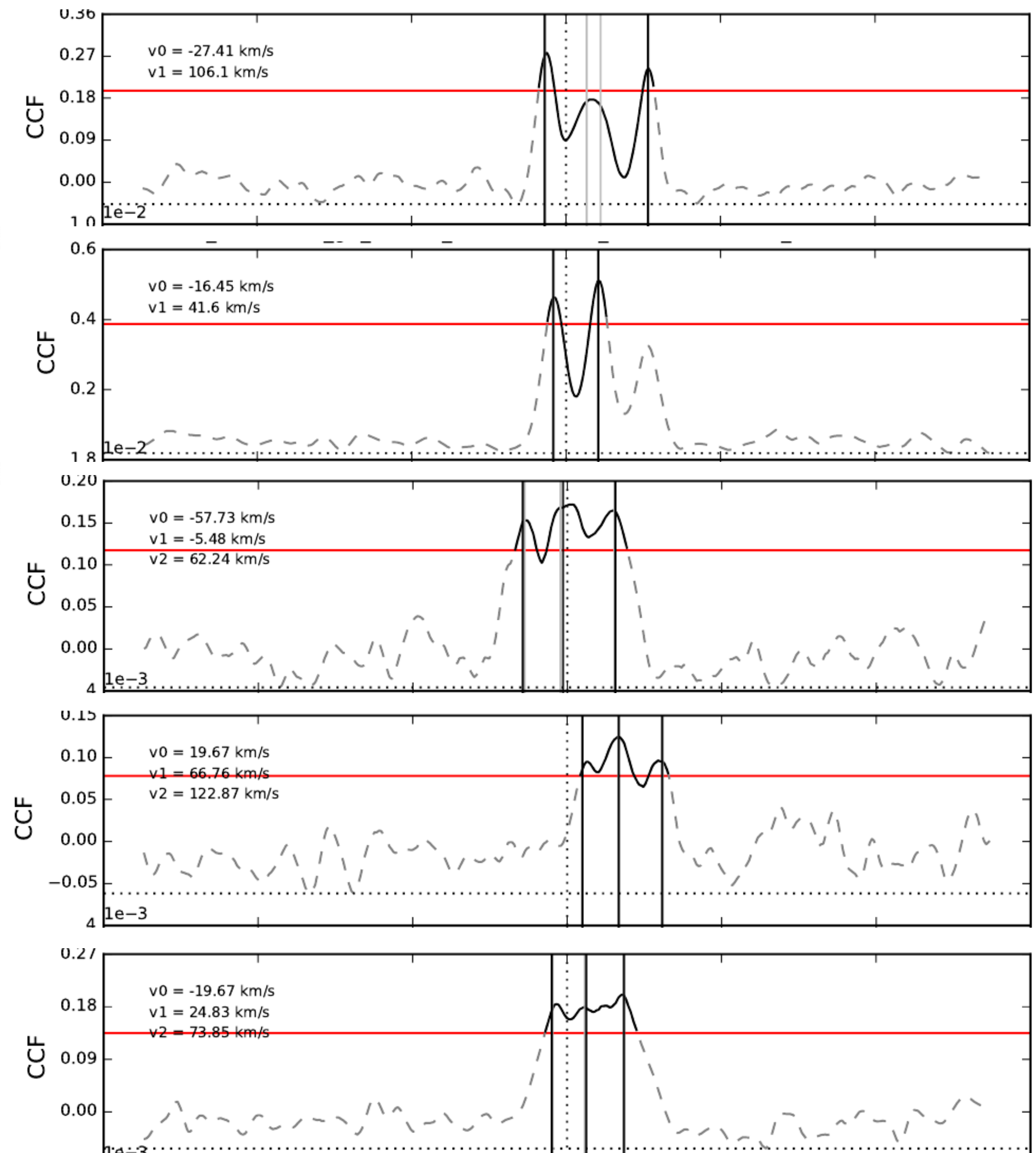
Known as T Tau-type Star

SB3 candidates: visual inspection

UVES

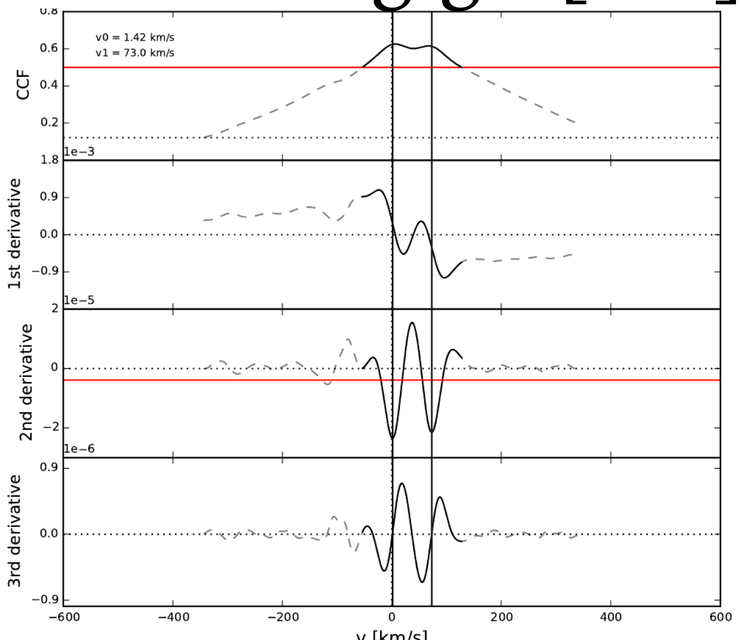


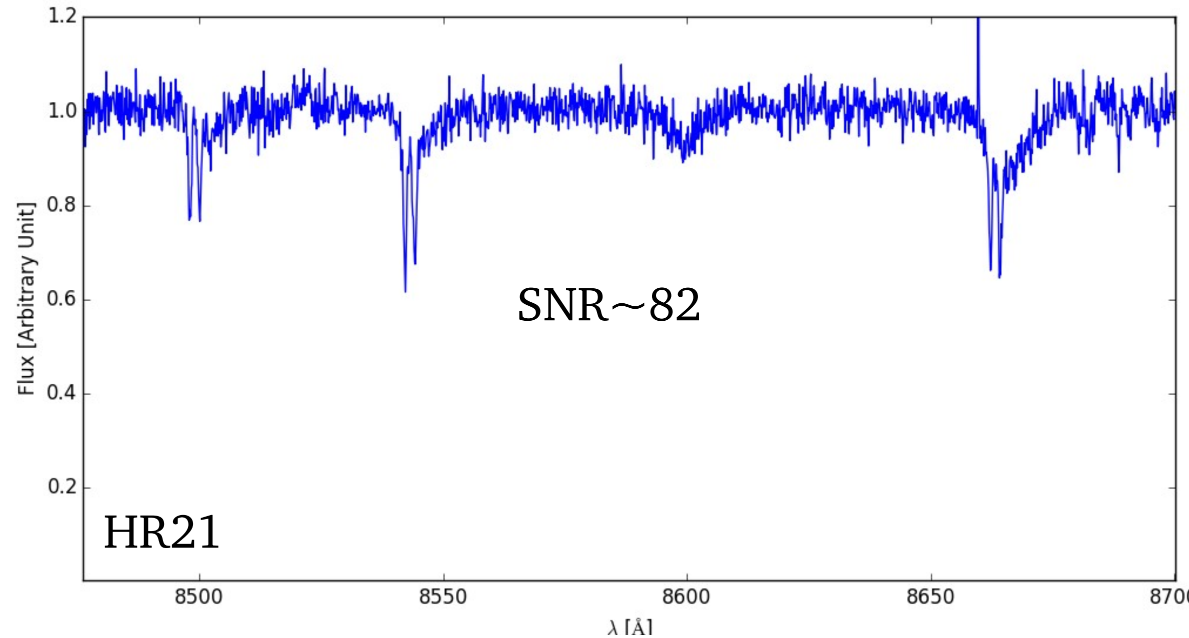
GIRAFFE

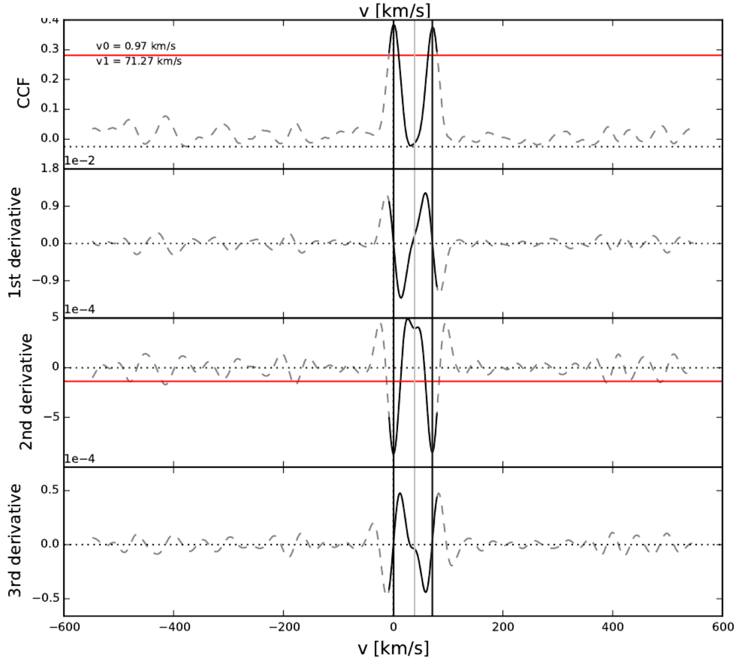


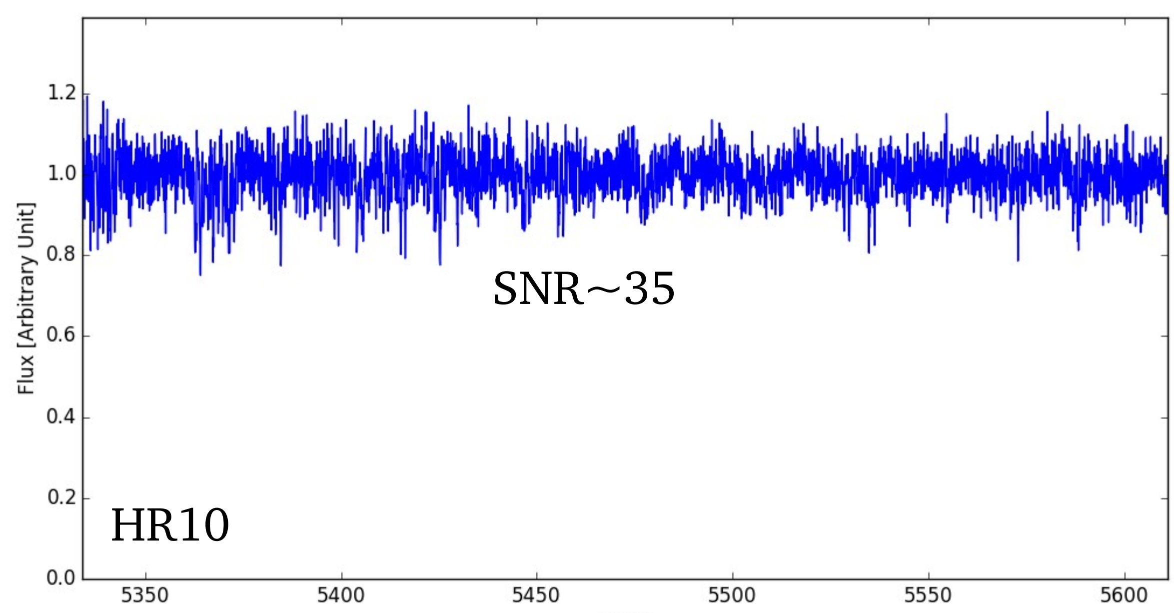
18511134-0616106

GIRAFFE example: V~14, Teff=[6000~8000] K, log g=[1-4], [Fe/H]=[-2.5,-0.5], NGC6705

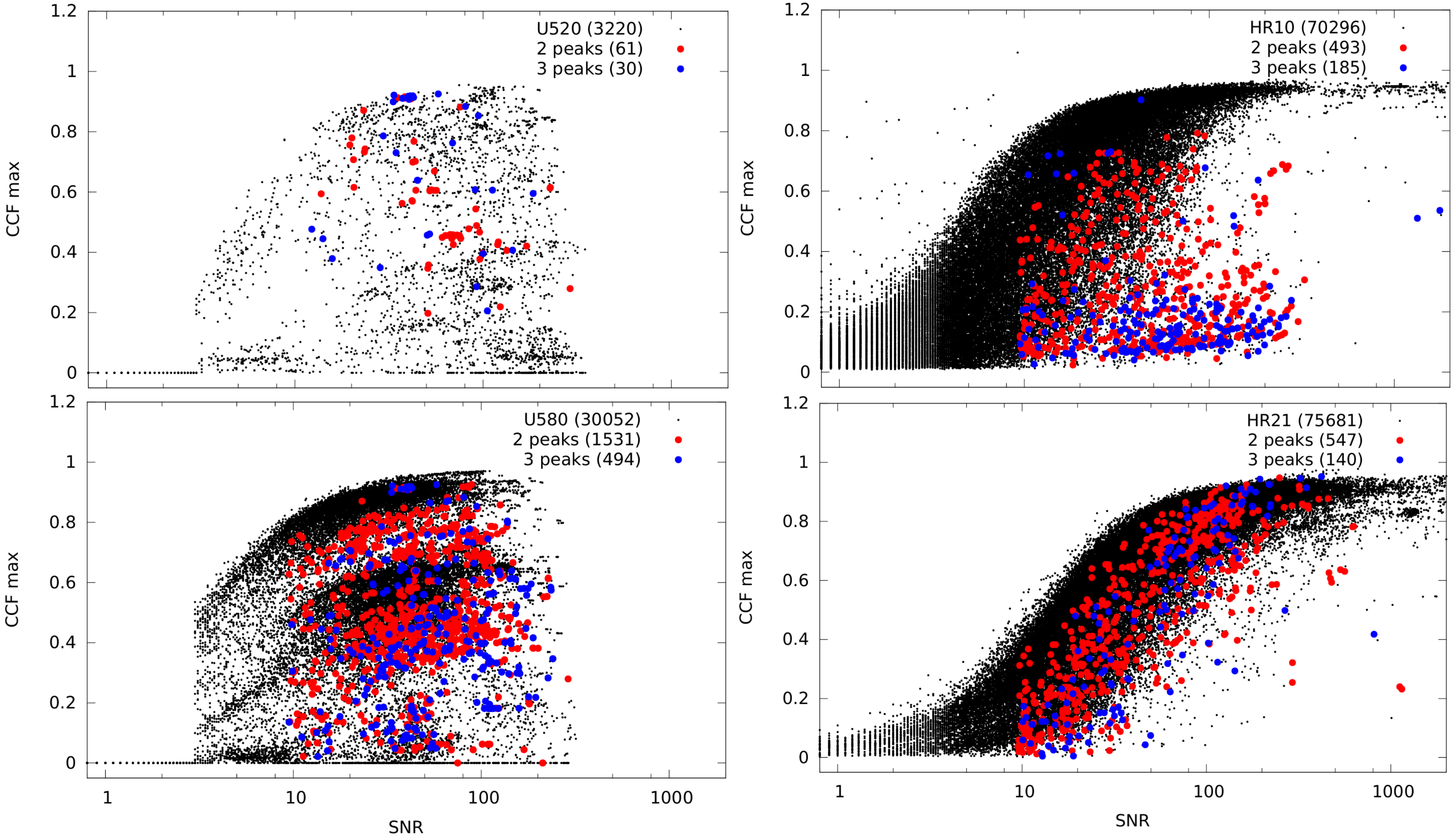








Selection criteria



Conclusions

- **Part I: SB in HERMES consortium: binary stars with WD**
  - IP Eri as a 2nd system including He WD with large period and high eccentricity
  - New evolution scenario to explain that the WD loss its envelope before He ignition
  - Sample homogeneously analyzed which show that the s-process enrichment probably depends on the mass of the WD companion
  - Need to increase the statistic to confirm this conclusion
- **Part II: SB in GES**
  - The successive derivatives of the CCFs are used to automatically detect peaks and asymmetries in the CCFs of the GES spectra
  - UVES: **67 SB2, 7 SB3** candidates (among 3374 stars)
  - GIRAFFE: **174 SB2**, **15 SB3** candidates for the moment (among 31369 stars)
  - SB1: work in progress (preliminary results: several candidates in UVES CCFs)
  - **Future improvements:**
    - Measurement of the peak widths
    - Code parameters fine tuning **(cut frequency, threshold on CCF and 2nd derivative)** according to setups
    - Detection efficiency based on Monte-Carlo simulations