Chemical composition of stars in high-mass binaries

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Garching, 3-7 July 2017

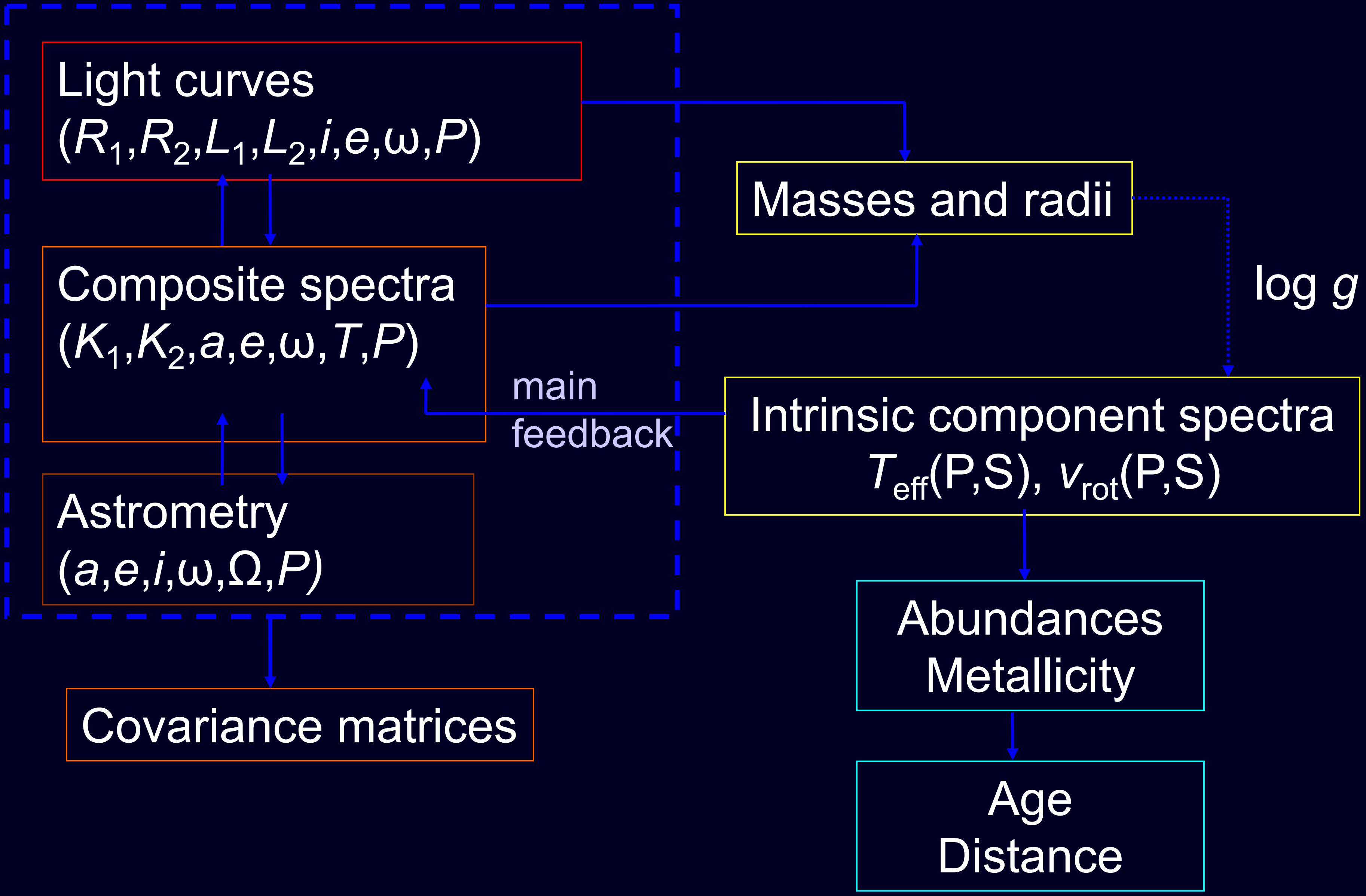
Topics

- Getting accurate fundamental stellar quantities
- Mass discrepancy (matching theoretical evolutionary models)
- Photospheric chemical composition

Legacy of detached binaries

- Detailed analysis of detached binaries provides accurate astrophysical quantities (mass, radius, effective temperature, age, rotation velocity, distance).
- Chemical abundances could be determined from disentangled individual spectra of the components.
- Evolutionary models can be calibrated for the masses, effective temperatures and rotation.

Toward the accurate stellar quantites



Light curves $(R_1,R_2,L_1,L_2,i,e,\omega,P)$

Composite spectra (K_1,K_2,a,e,ω,T,P)

Astrometry (a,e,i,ω,Ω,P)

Covariance matrices

Masses and radii

log g

Intrinsic component spectra $T_{\mathrm{eff}}(\mathrm{P,S})$, $v_{\mathrm{rot}}(\mathrm{P,S})$

main feedback

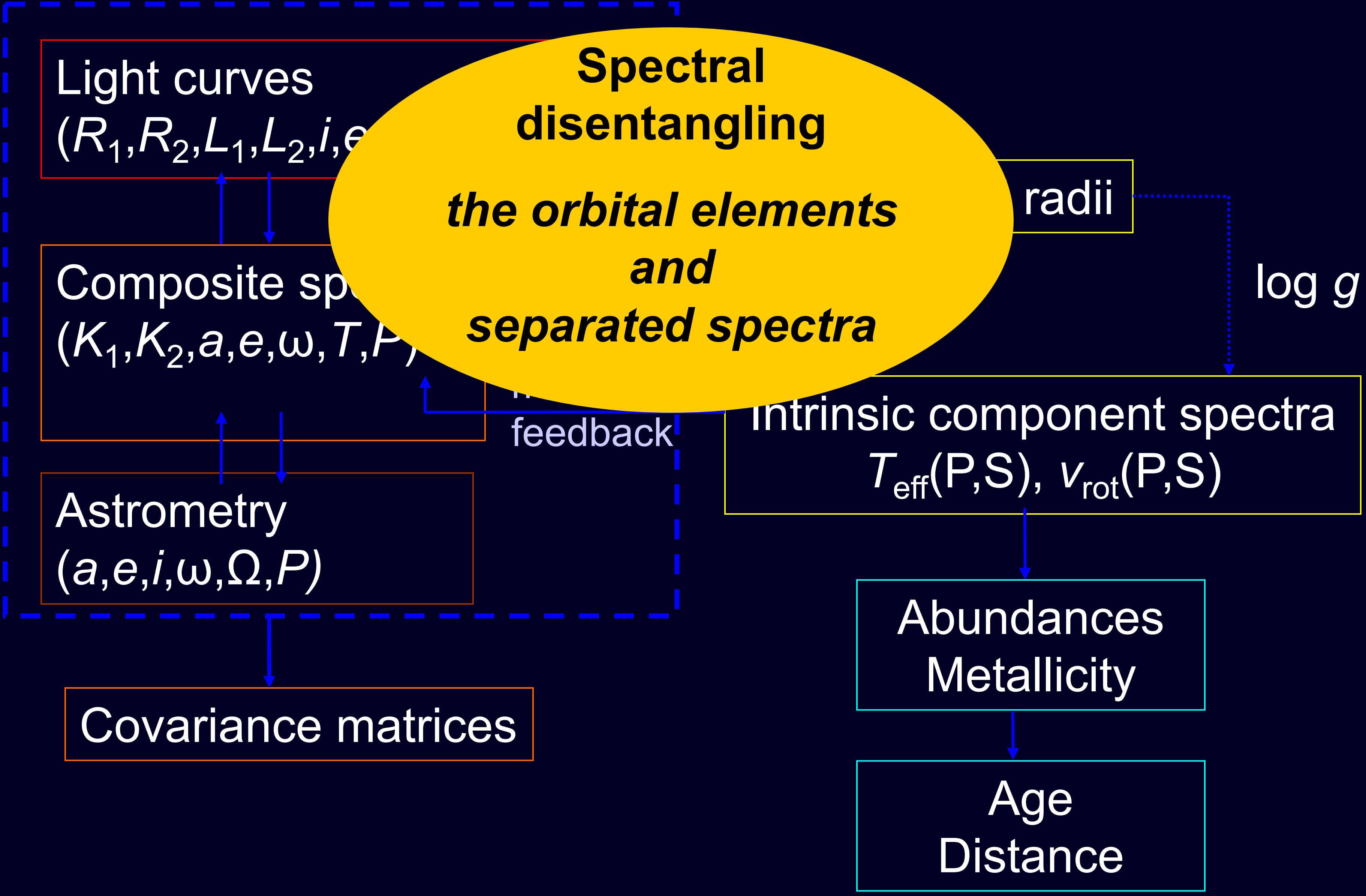
Abundances

Metallicity

Age

Distance

Toward the accurate stellar quantites



Light curves
$(R_1,R_2,L_1,L_2,i,e$

Composite sp
(K_1,K_2,a,e,ω,T,P)

Astrometry
(a,e,i,ω,Ω,P)

Covariance matrices

Spectral disentangling

the orbital elements
and
separated spectra

radii

log g

feedback

Intrinsic component spectra
$T_{\mathrm{eff}}(\mathrm{P,S})$, $v_{\mathrm{rot}}(\mathrm{P,S})$

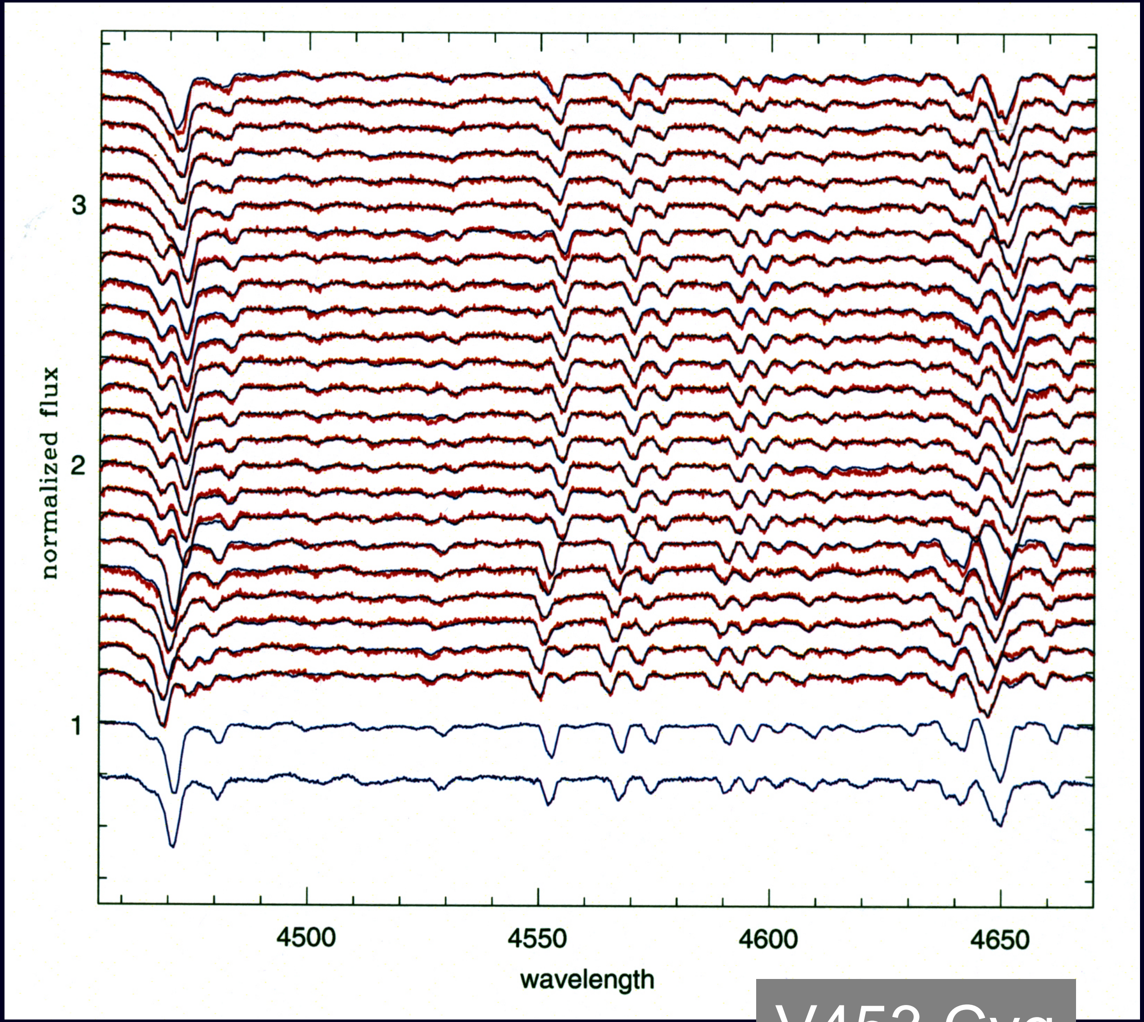
Abundances
Metallicity

Age
Distance

Disentangling: how to do it?

(By courtesy of Doug Gies)

Spectral Disentangling in practice



V453 Cyg

Pavlovski & Southworth, MNRAS, 394, 1519 (2009)

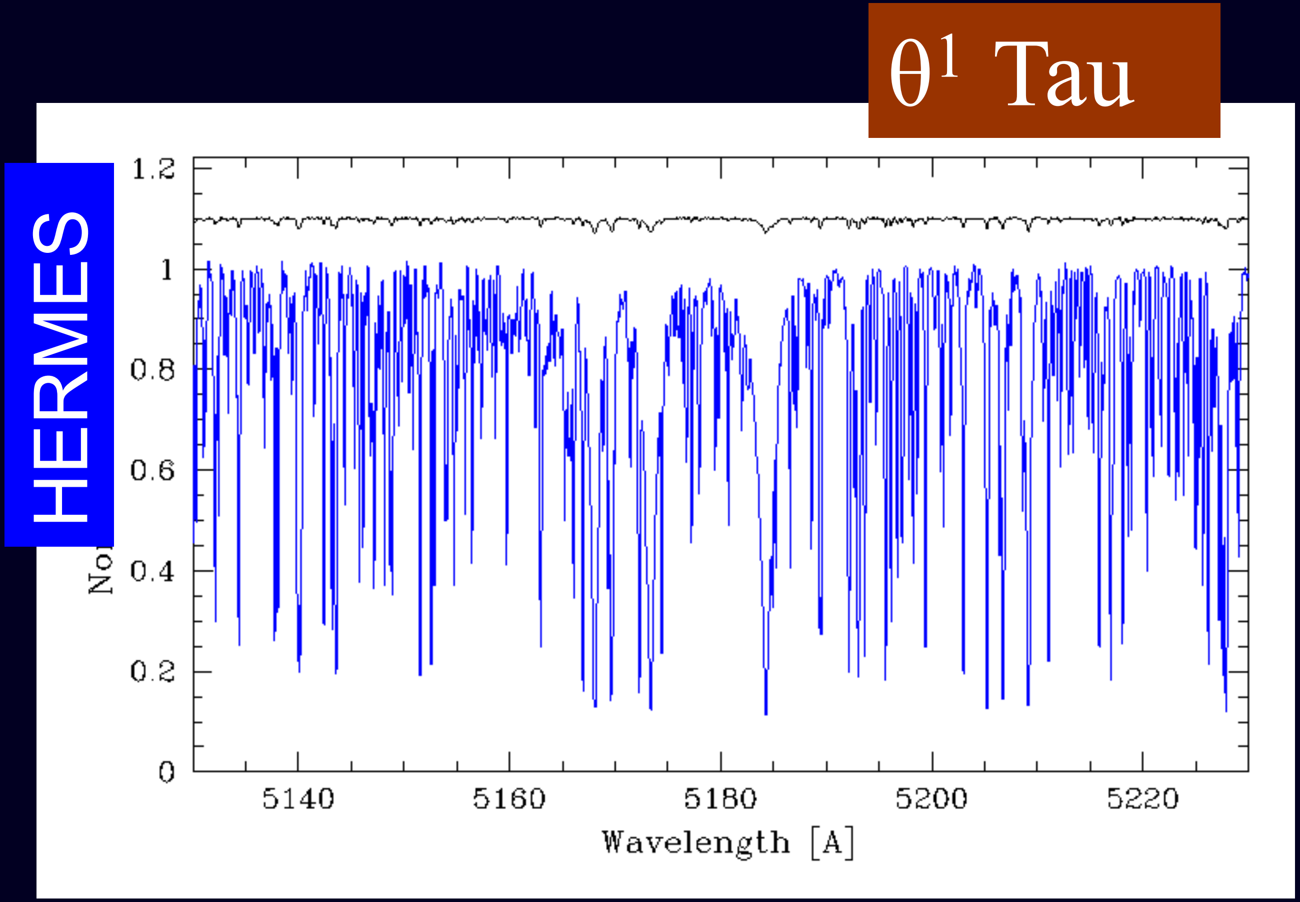
Spectral disentangling provides the orbital elements and separated individual spectra of the components (Simon & Sturm 1994, Hadrava 1995).

Public codes:

KOREL
FDBinary
CRES
TANGLE
SPECTANGULAR
PSOAP

RaveSpan(Poster #64 by Pilecki)

Detecting a faint companion



Beck, Pavlovski, Torres, et al. (2017, in preparation)

$\Delta m \sim 5$ mag

Only SB2 among 4 giants in the Hyades cluster.

δ1 Tau is SB1, ε Tau has a planet, δ Tau uncertain speckle binary

Beck et al. (2015) found solar-like oscillations.

Component spectra: astrophysics

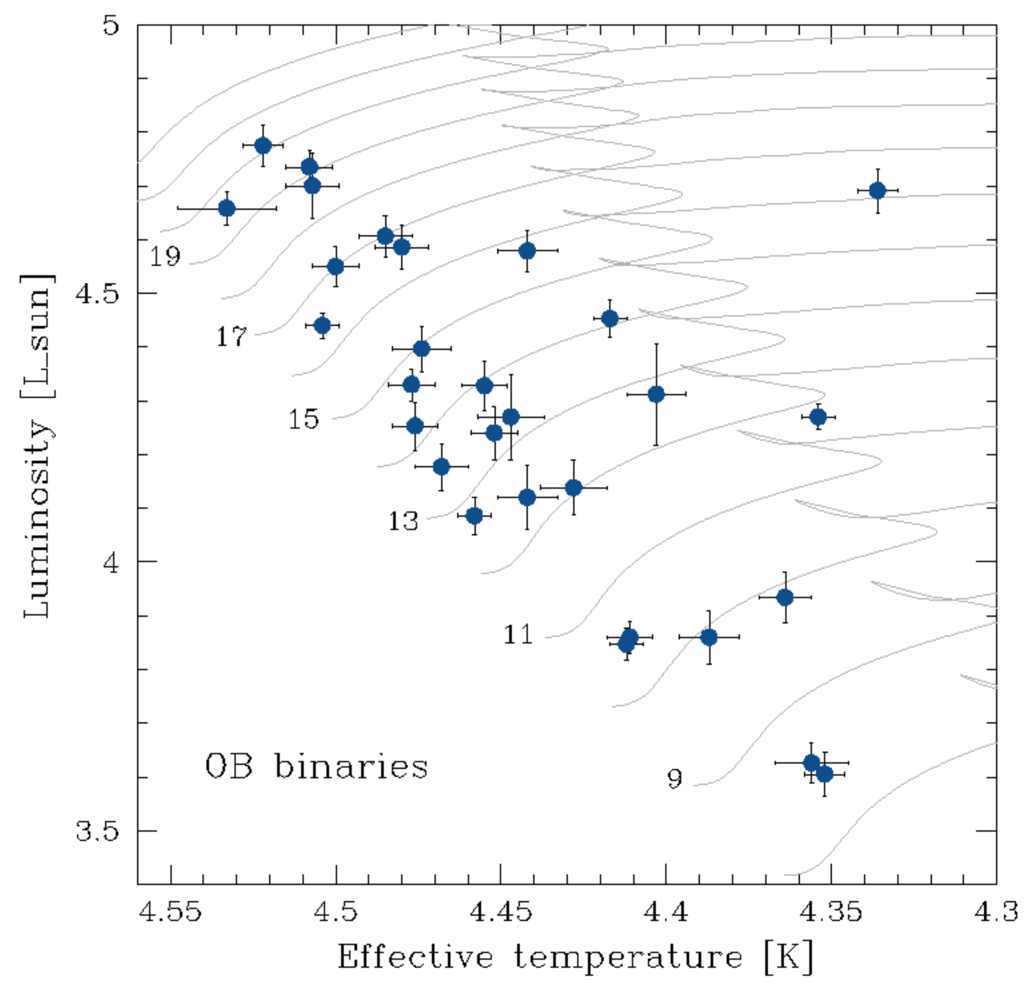
- access to individual components
- atmospheric diagnostics
- detail abundance analysis
- M/L relation in different-metallicity environments
- tests of stellar evolution models
- distance indicators (galactic & extragalactic)
- individuality at same age, and same mass (pulsations, chemical peculiarity, chromospheric activity…)
- spectroscopic detection of eclipses
- spectroscopic light ratio

Astrophysical value of high-mass stars

- High-mass stars are cosmic engines (a key ingredient in the evolution of galaxies)
- Only 3 high-mass stars per 1000 stars (but they contain about 15% of the stellar mass)
- On short timescales they inject into the interstellar medium great amounts of radiation, mass and mechanical energy
- The most luminous objects, either as stars or in supernova explosions
- Important for the cosmological distance ladder

Recall talks by Norbert Langer and Hugo Sana on Wednesday

The sample



PARAMETER SPACE

Periods: 1.6 – 33 d

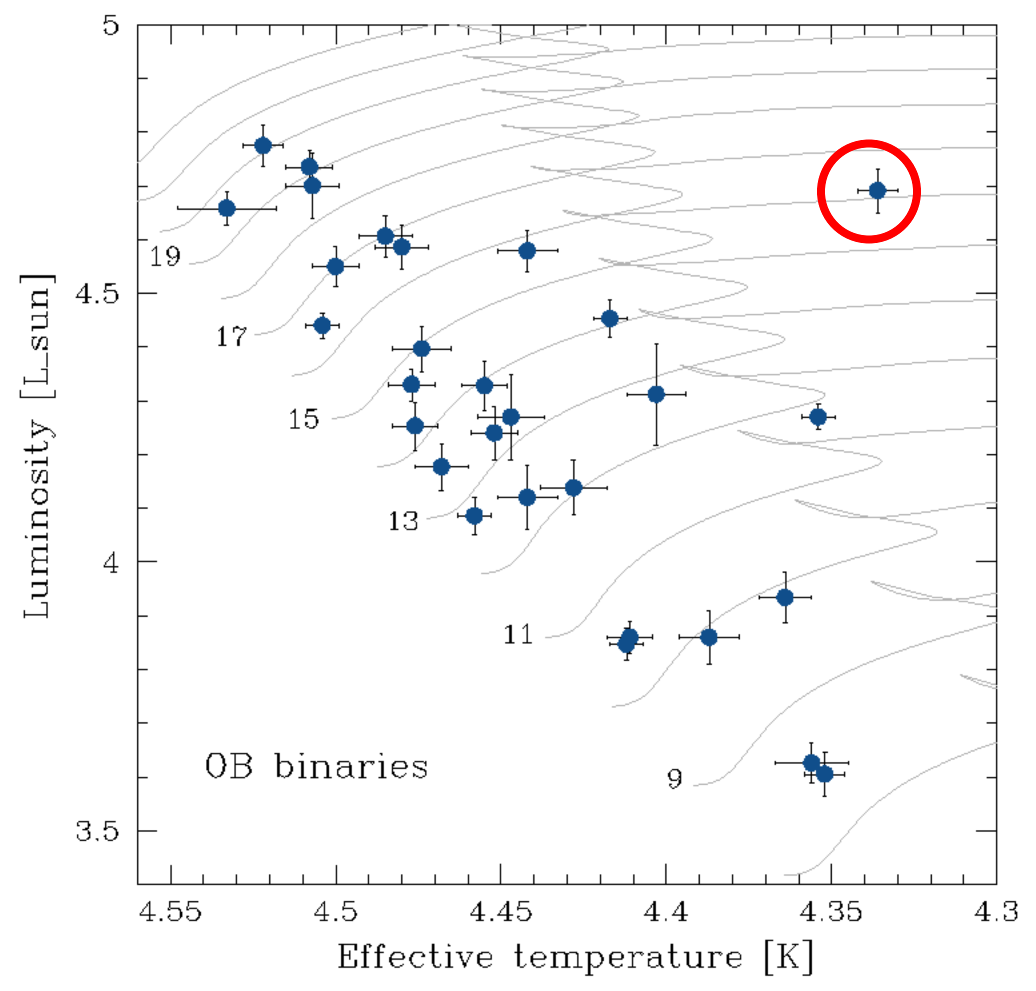
Masses: 8 – 22 $M_\odot$

log *g*: 3.1 – 4.3 [cgs]

v sin *i*: 30 – 240 km/s

Evolutionary models for non-rotating stars after Ekström et al. (2012) and Georgy et al. (2013)

The sample



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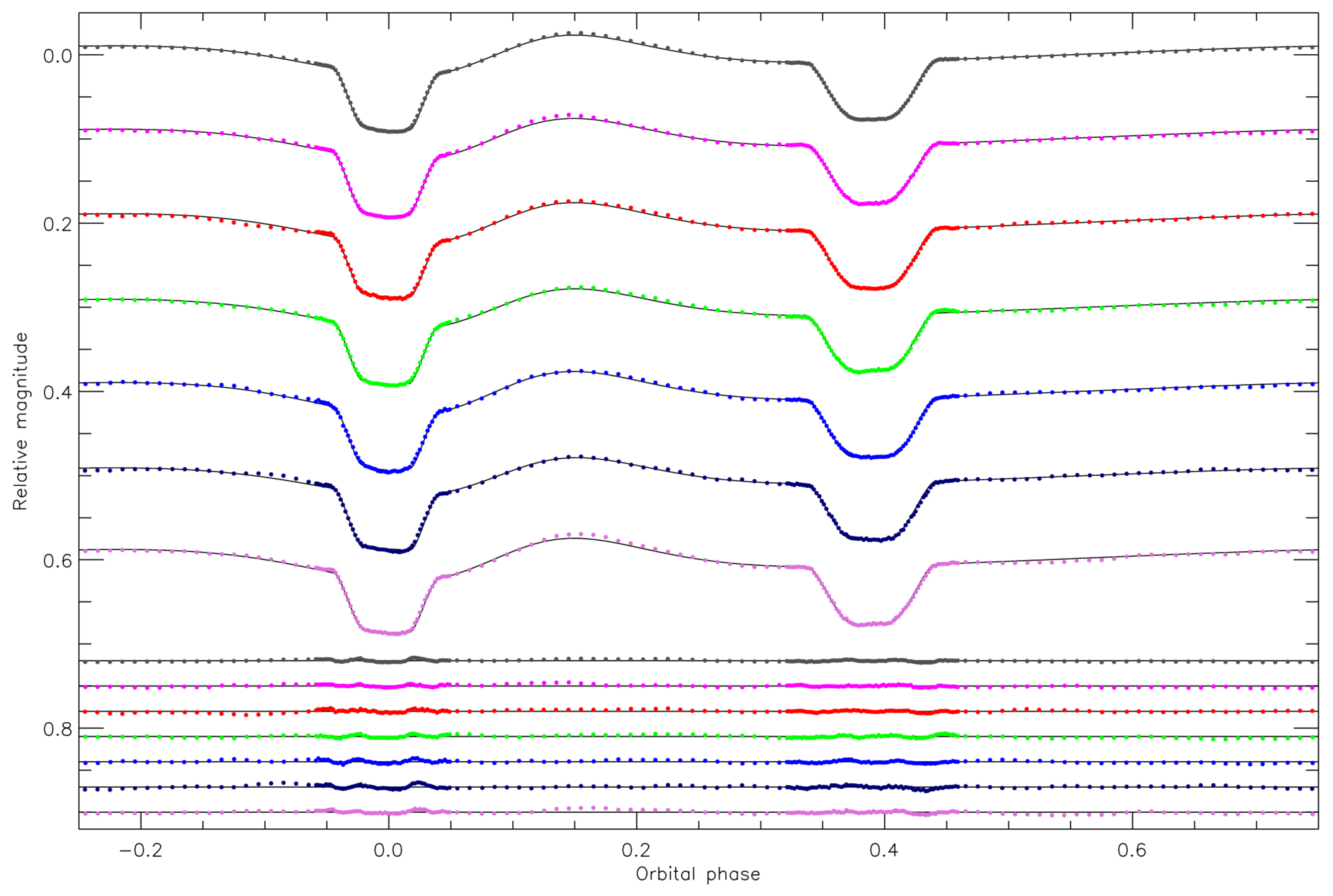
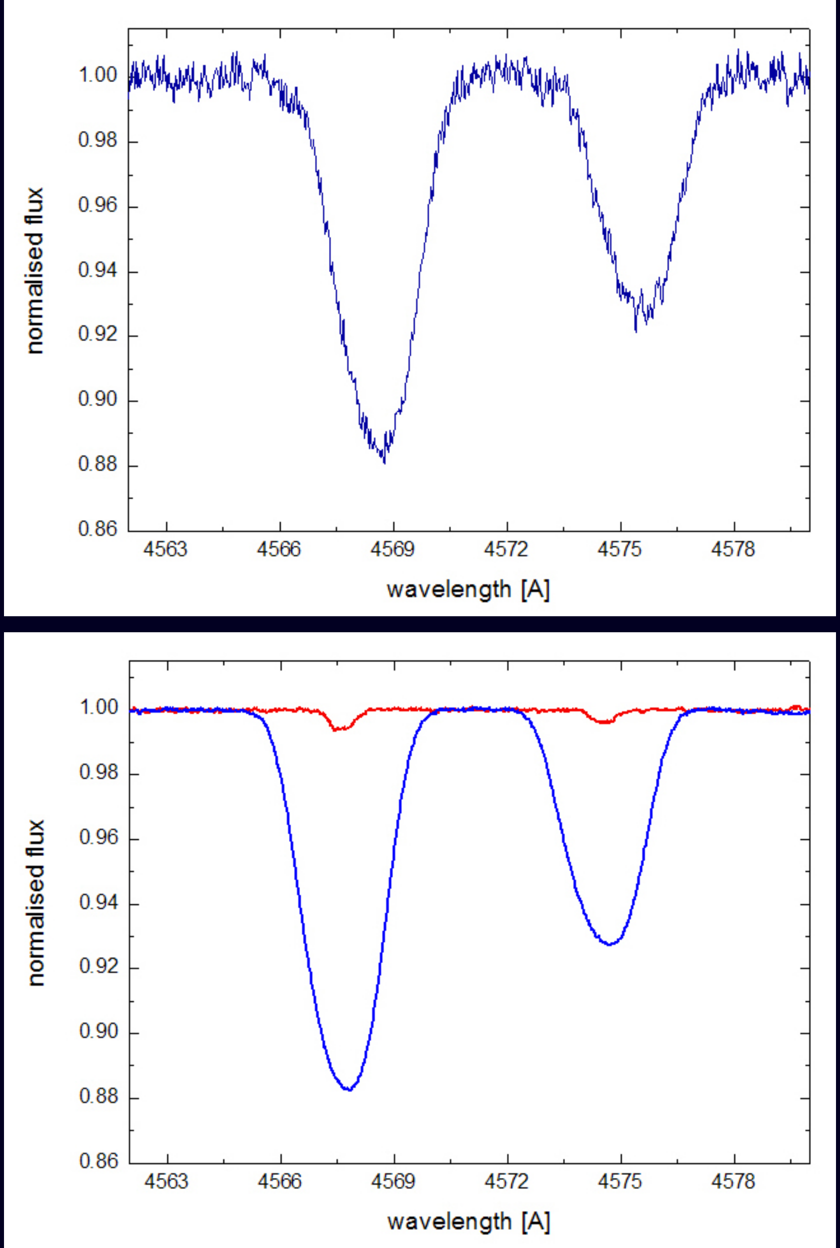
V380 Cyg: Kepler photometry



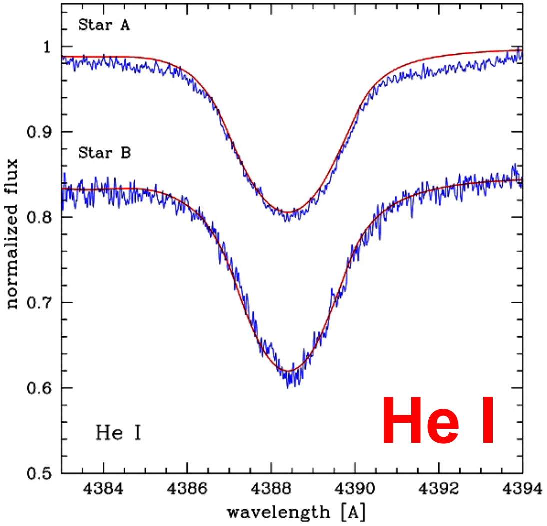
V380 Cyg: HERMES@Mercator



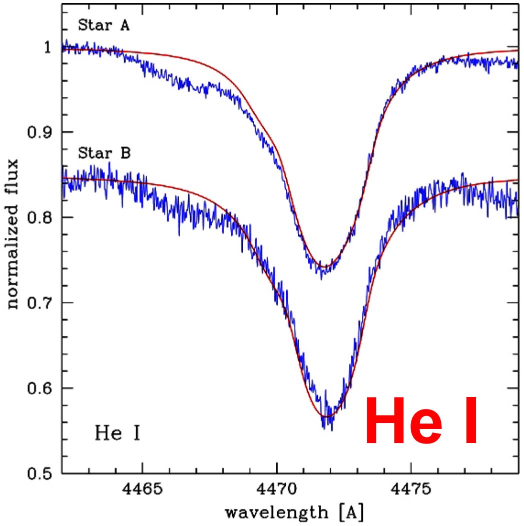
406 echelle spectra secured with HERMES@Mercator

(R = 84 000)

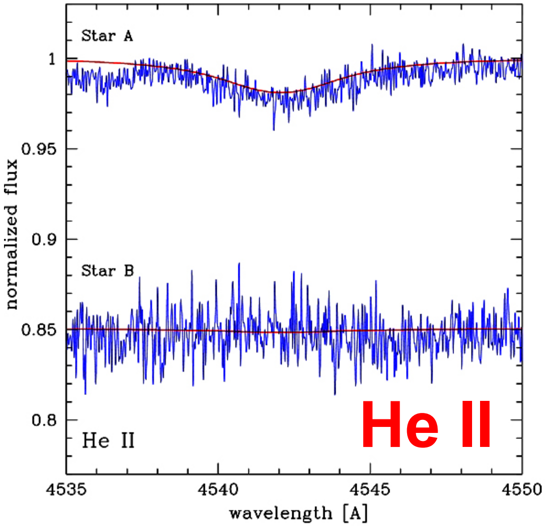
NLTE spectrum synthesis



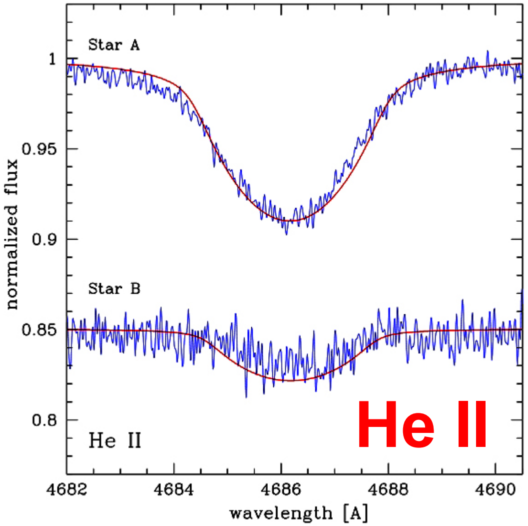
(a) He 4388



(b) He 4471



(c) He 4541



(d) He 4686

NLTE calculations:

ATLAS9 (Kurucz)

DETAIL (Giddings)

SURFACE (Butler)

Model atoms (Butler, Przybilla, Nieva)

Tunning the effective temperature for V578 Mon

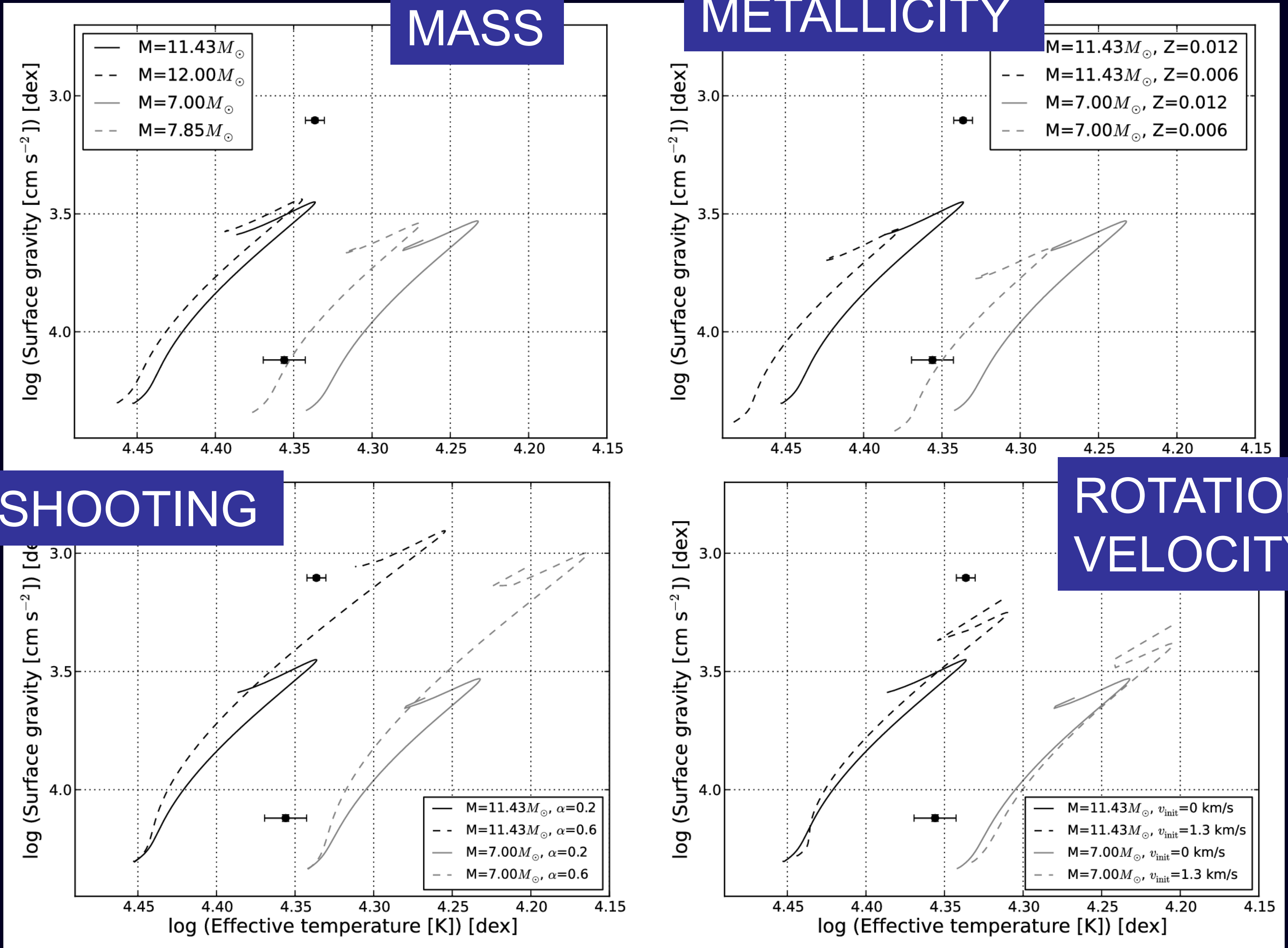
HERMES spectra

Garcia et al. (2015)

Error budget for V380 Cyg

Quantity	Value	p.e.	Uncertainty
M [$M_\odot$]	11.4	0.2	1.7%
R [$R_\odot$]	15.7	0.1	0.6%
log g [cgs]	3.104	0.006	0.006 dex
T_{eff} [K]	21700	300	1.4%
v sin i [km/s]	98	2	2.0%

V380 Cyg: MESA modelling



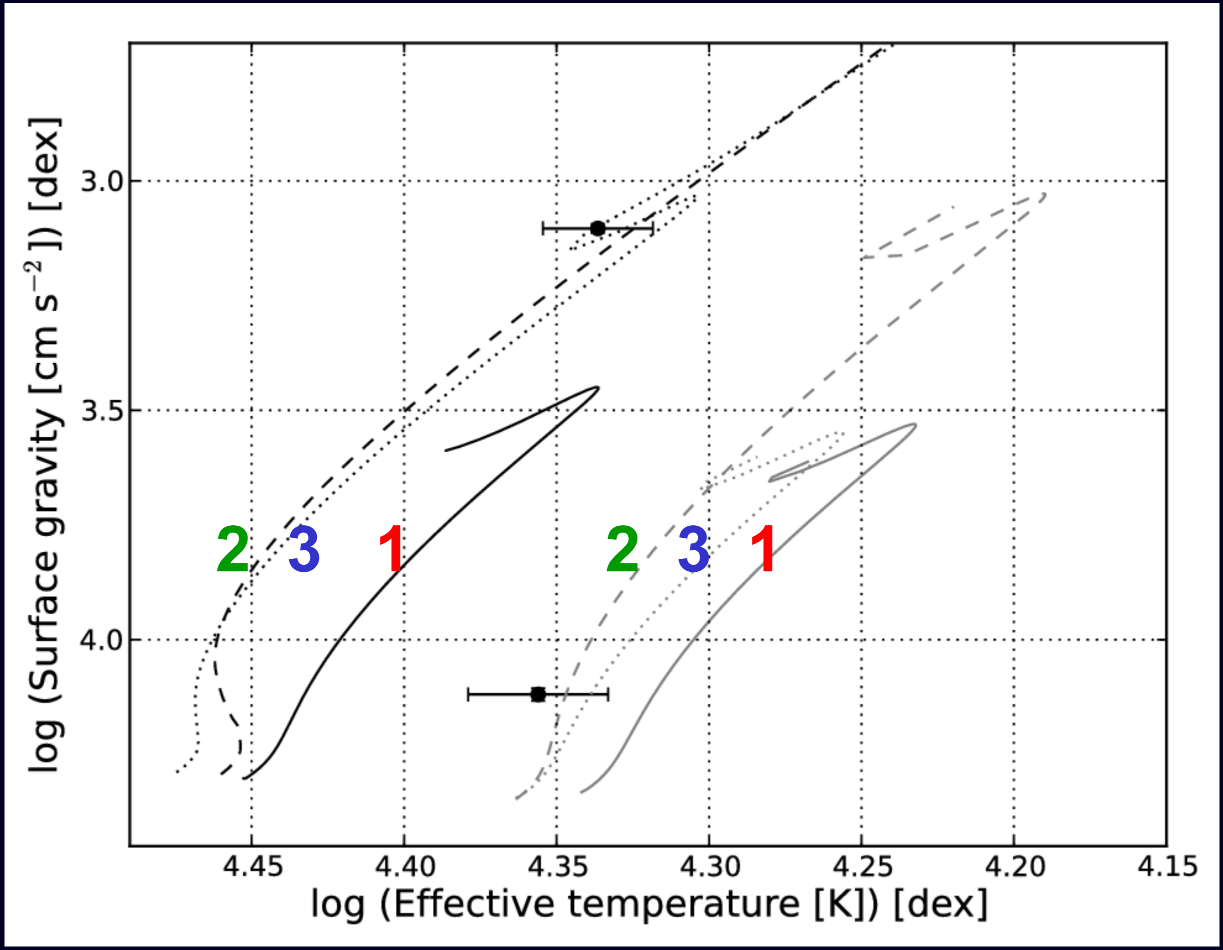
MASS

METALLICITY

OVERSHOOTING

ROTATIONAL VELOCITY

V380 Cyg: MESA modelling



MODELS

1 ————————

11.4/0.2/0

2 - - - - - - - -

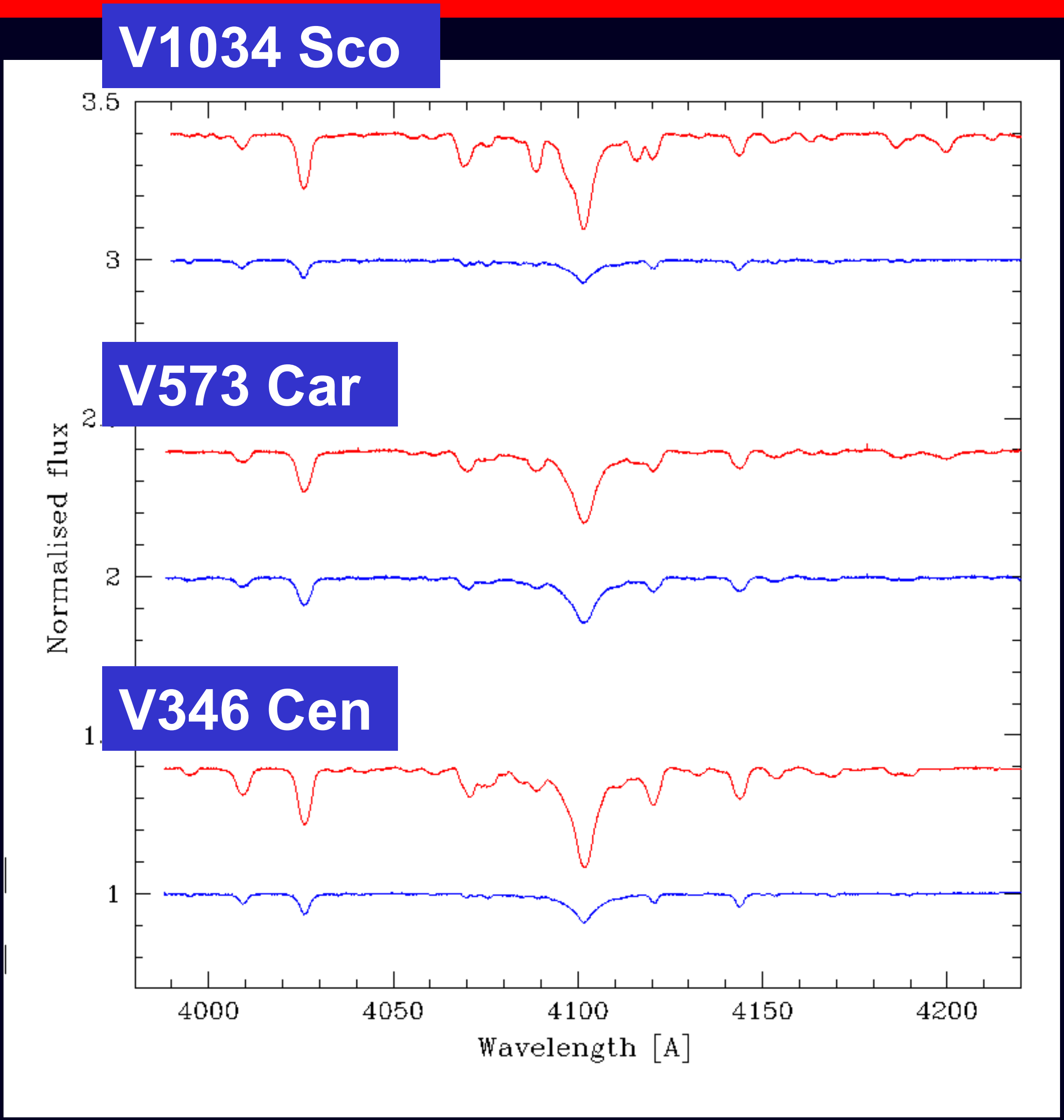
12.0/0.6/241

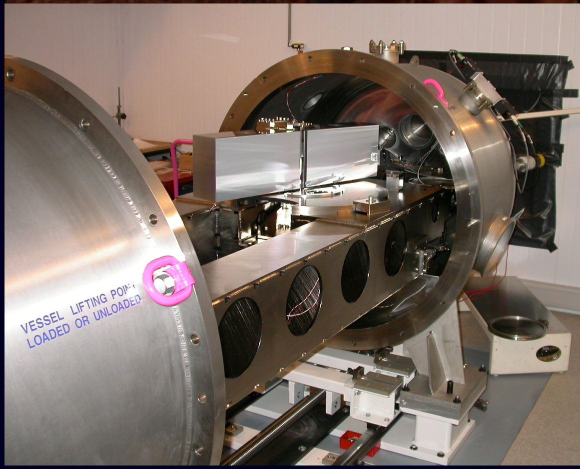
3 ……………………

12.9/0.3/243

The mass discrepancy of ~10% transforms into the age uncertainty of ~50%.

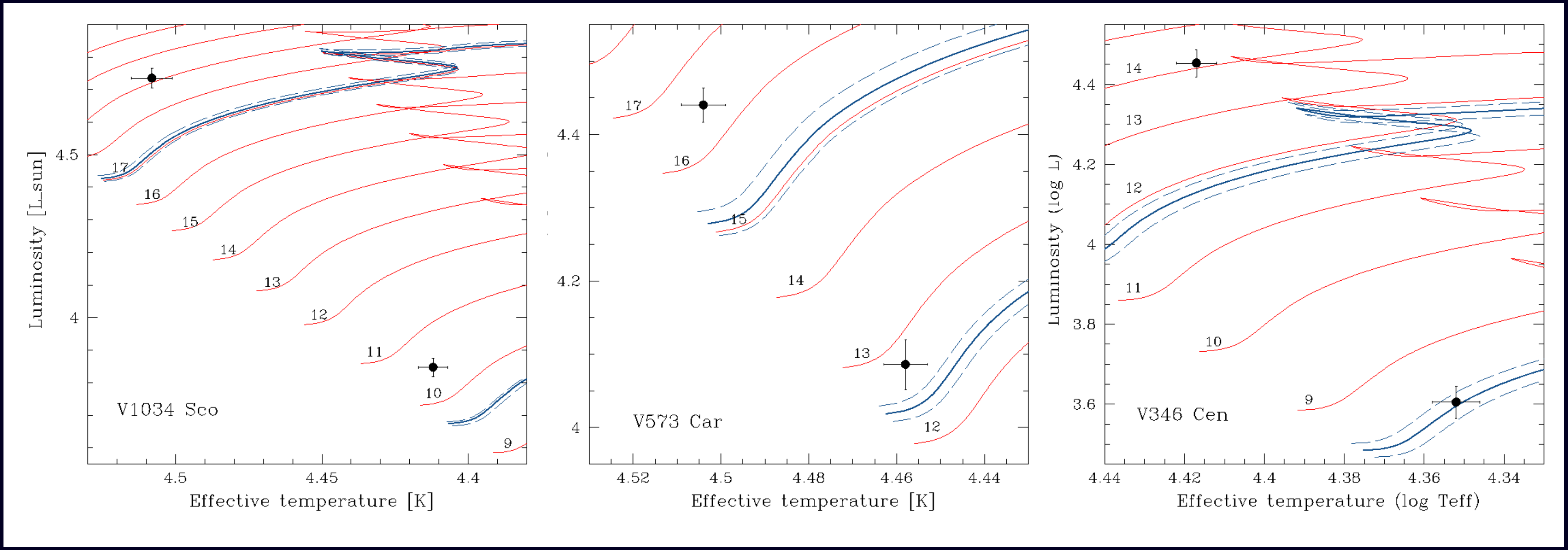
OB binaries with HARPS@ESO





R = 115 000

“Mass discrepancy”



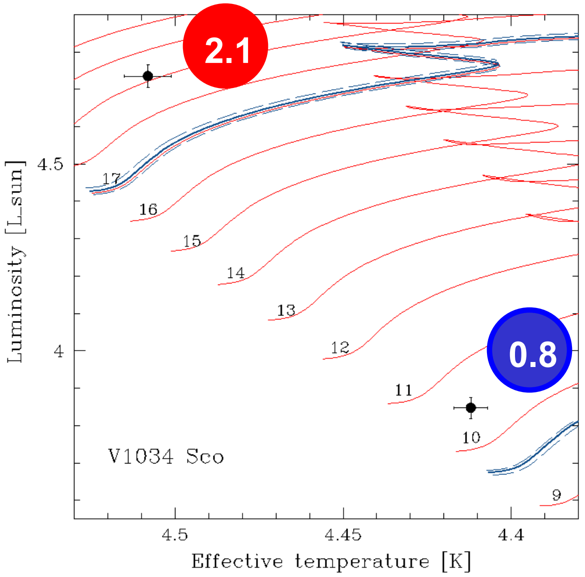
V1034 Sco **V573 Car** **V346 Cen**

Mass discrepancy: disagrement between the spectroscopic and evolutionary masses for a hot, single stars (Herrero et al.1992).

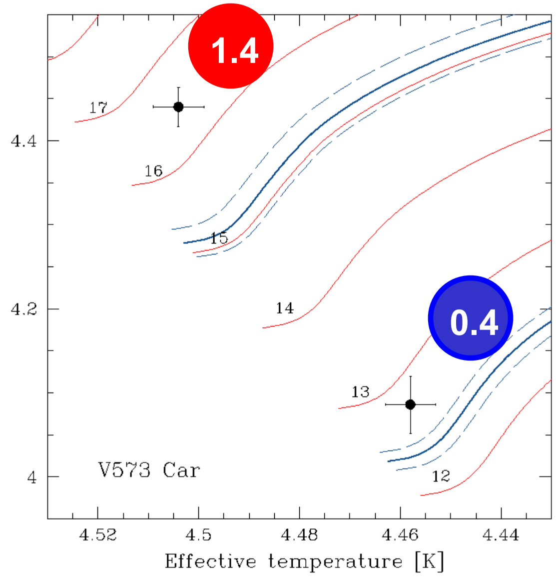
In binary stars the masses are determined from dynamics, and are model indipendent.

“Mass discrepancy”

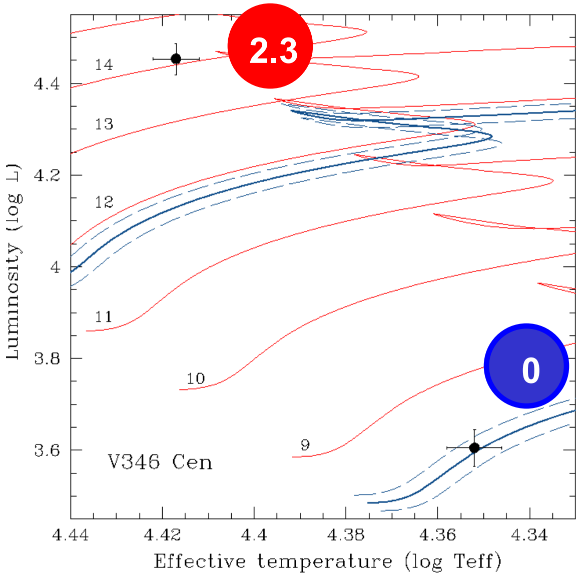
V1034 Sco



V573 Car

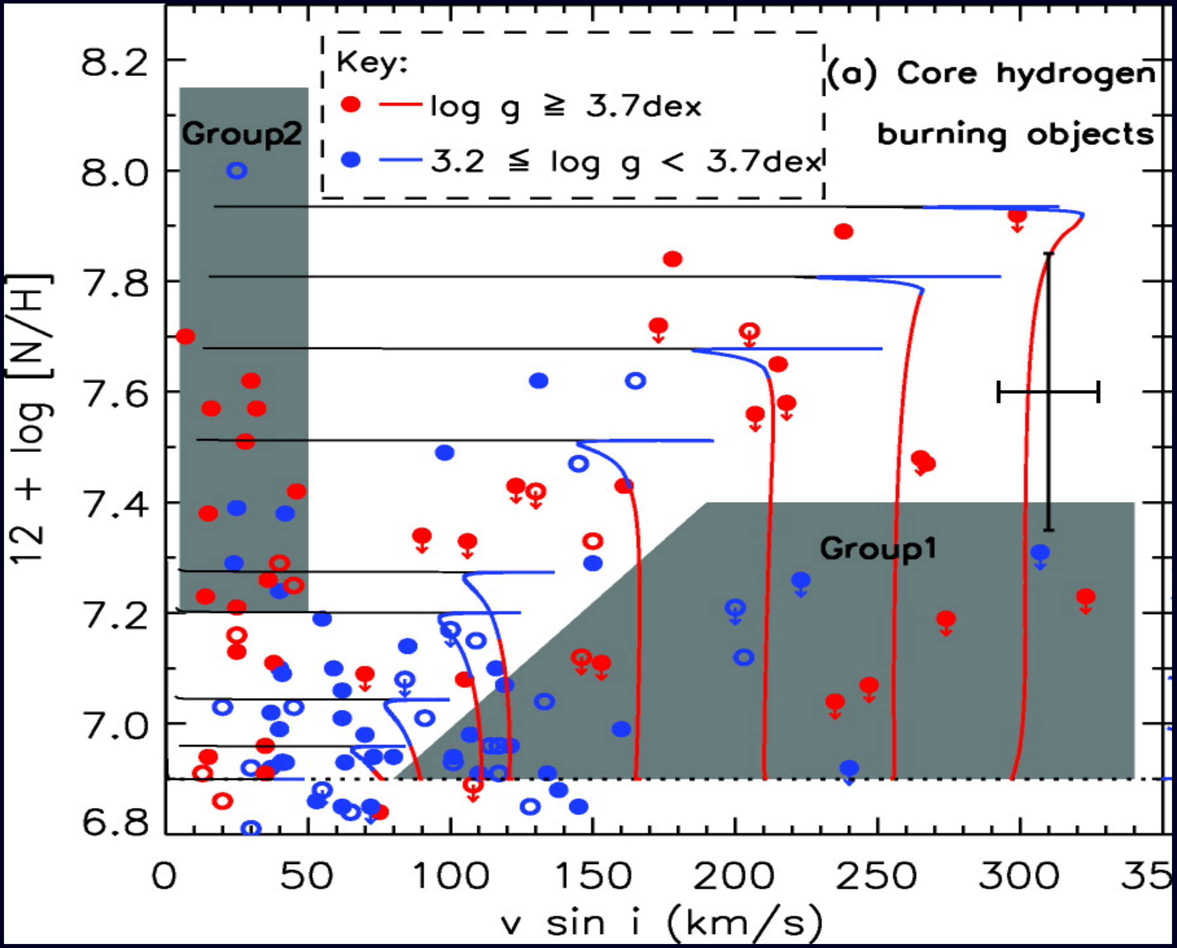


V346 Cen



VLT/FLAMES survey

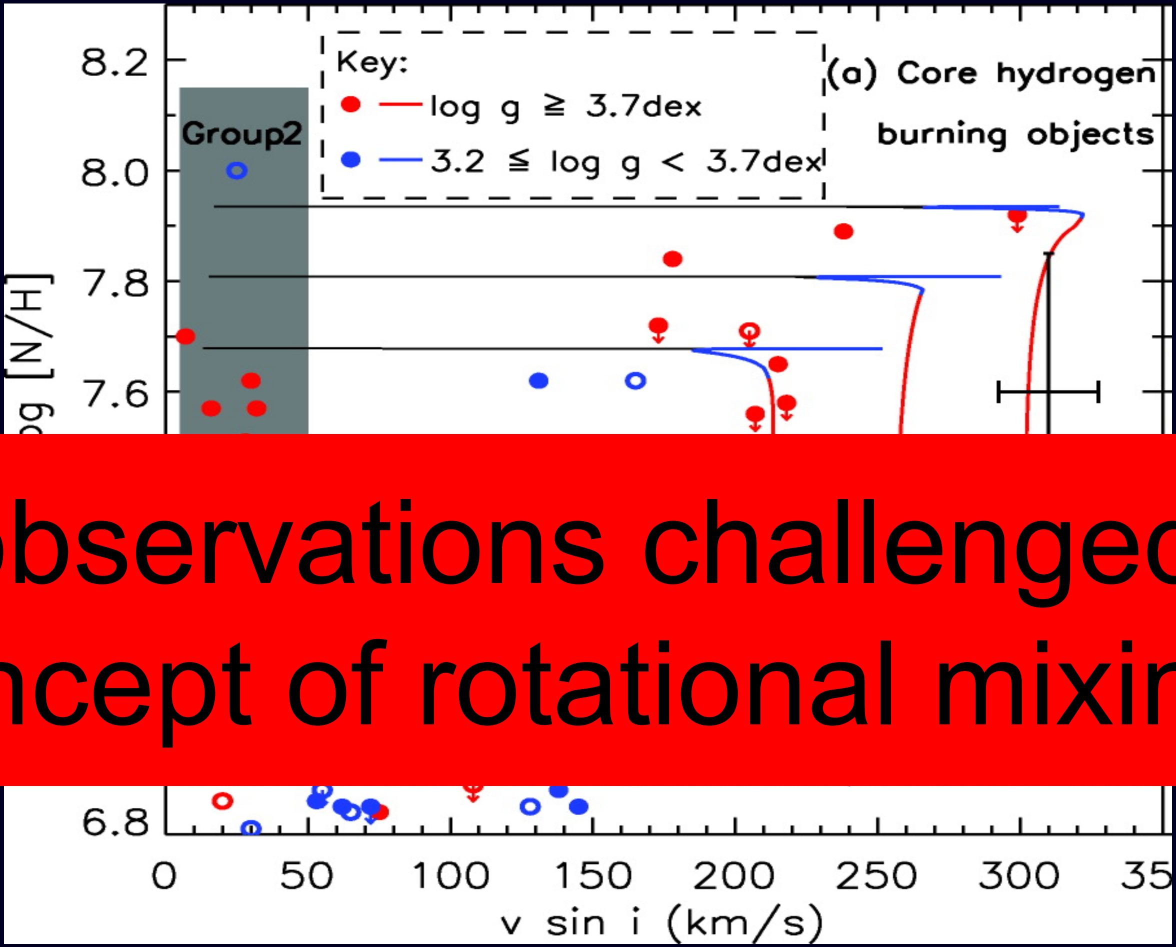
20%



15%

Surface evolution of nitrogen
VLT/FLAMES diagram (Hunter et al. 2009)

VLT/FLAMES survey



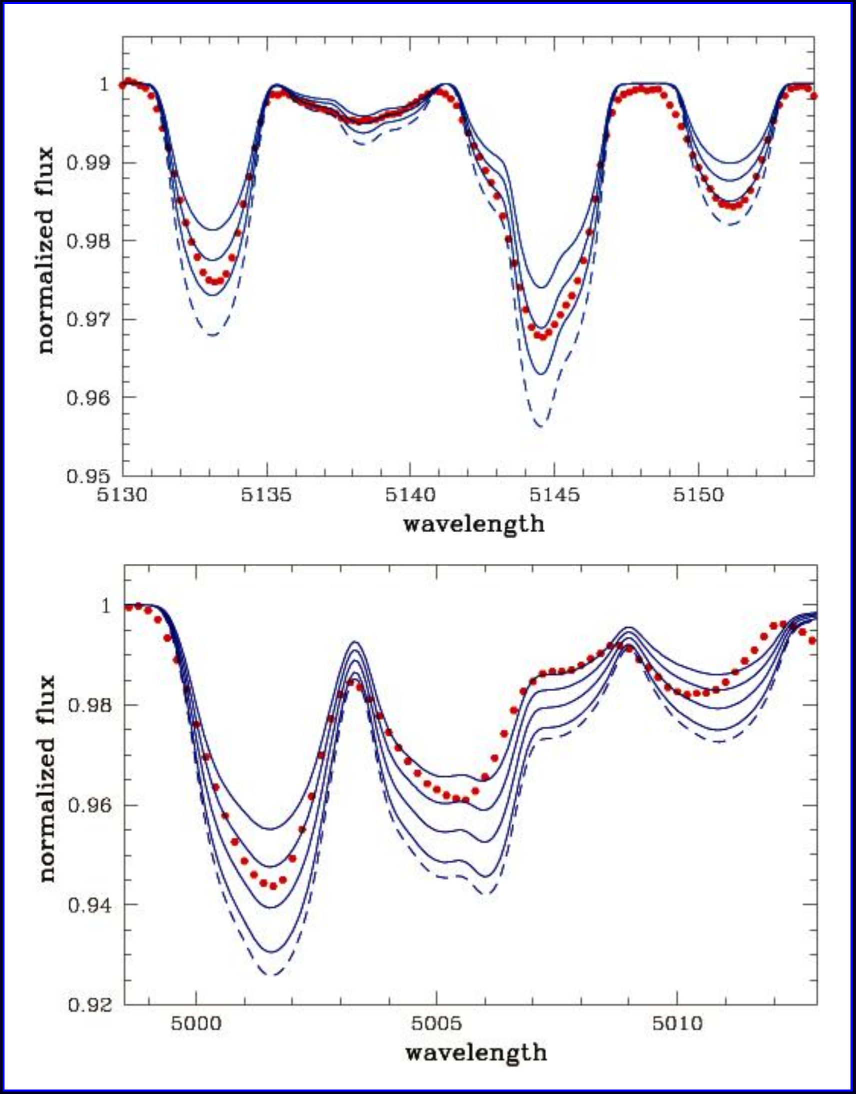
The observations challenged the concept of rotational mixing

Surface evolution of nitrogen
VLT/FLAMES diagram (Hunter et al. 2009)

CNO for V380 Cyg

NITROGEN

CARBON



log(N/C) = -0.65 ± 0.05

log(N/O) = -1.09 ± 0.09

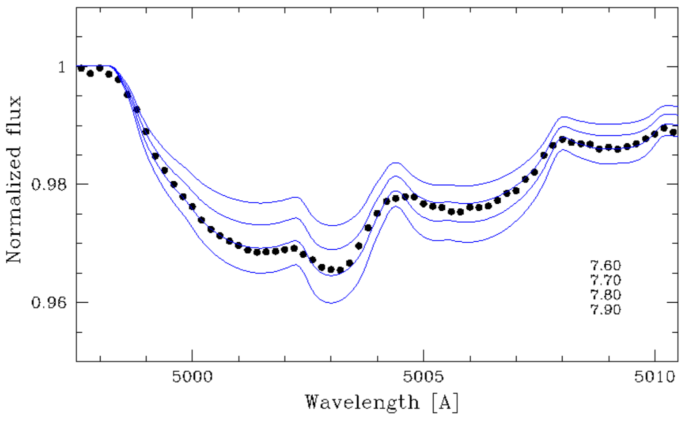
Tkachenko et al., MNRAS, 438, 3093 (2014)

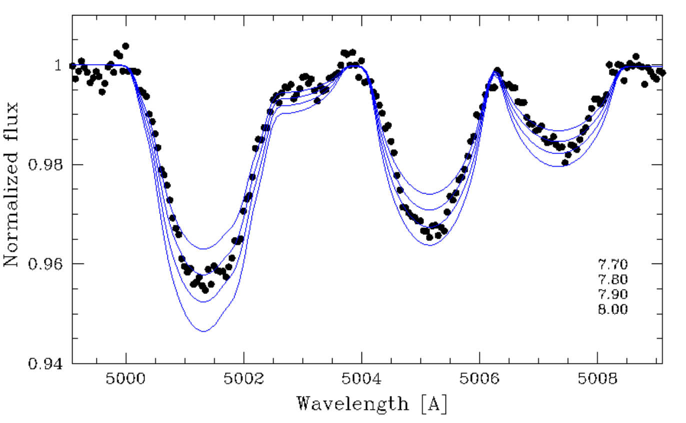
CNO for Spica

PRIMARY
165 km/s

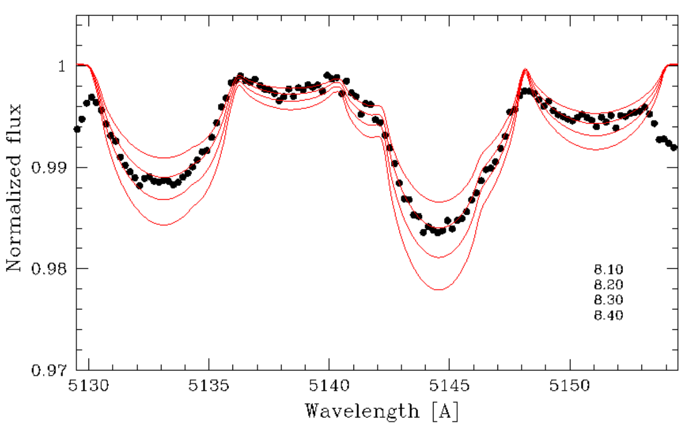
SECONDARY
60 km/s

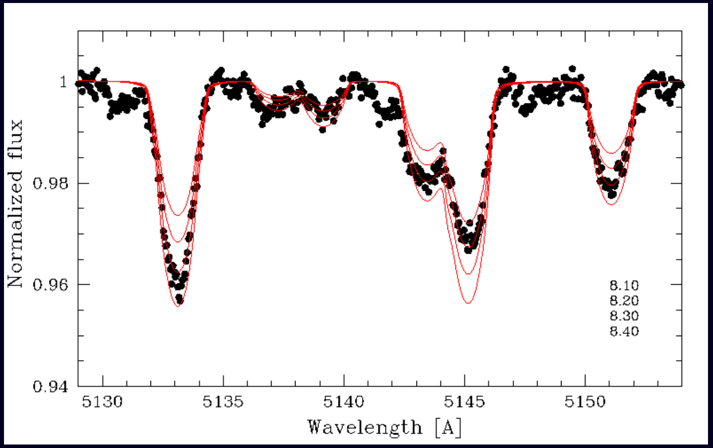
NITROGEN





CARBON





log(N/C) = -0.43 ± 0.06

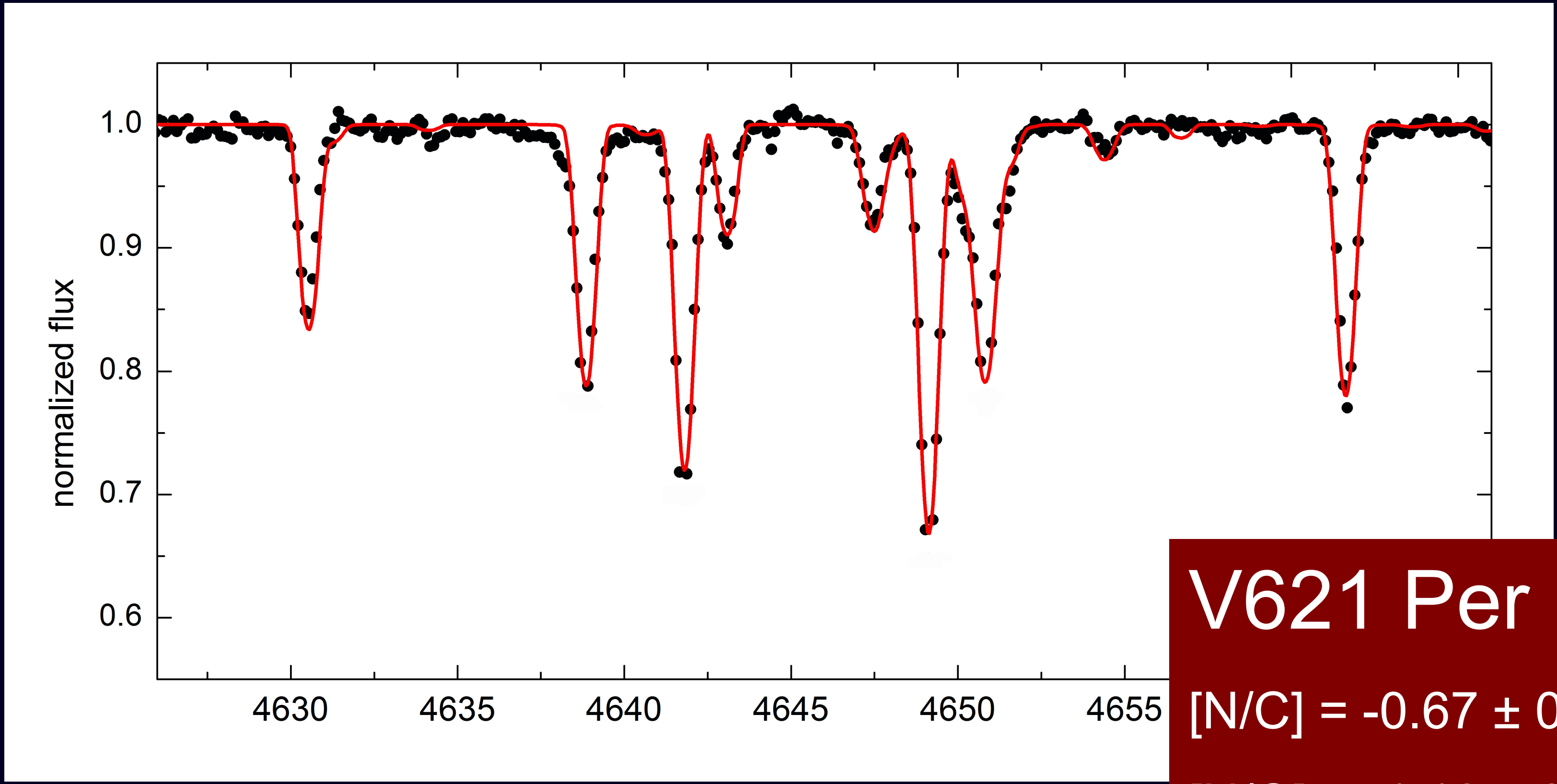
log(N/O) = -0.96 ± 0.09

log(N/C) = -0.45 ± 0.21

log(N/O) = -1.01 ± 0.29

Tkachenko et al. MNRAS (2016)

CNO V621 Per in χ Per



V621 Per

[N/C] = -0.67 ± 0.09

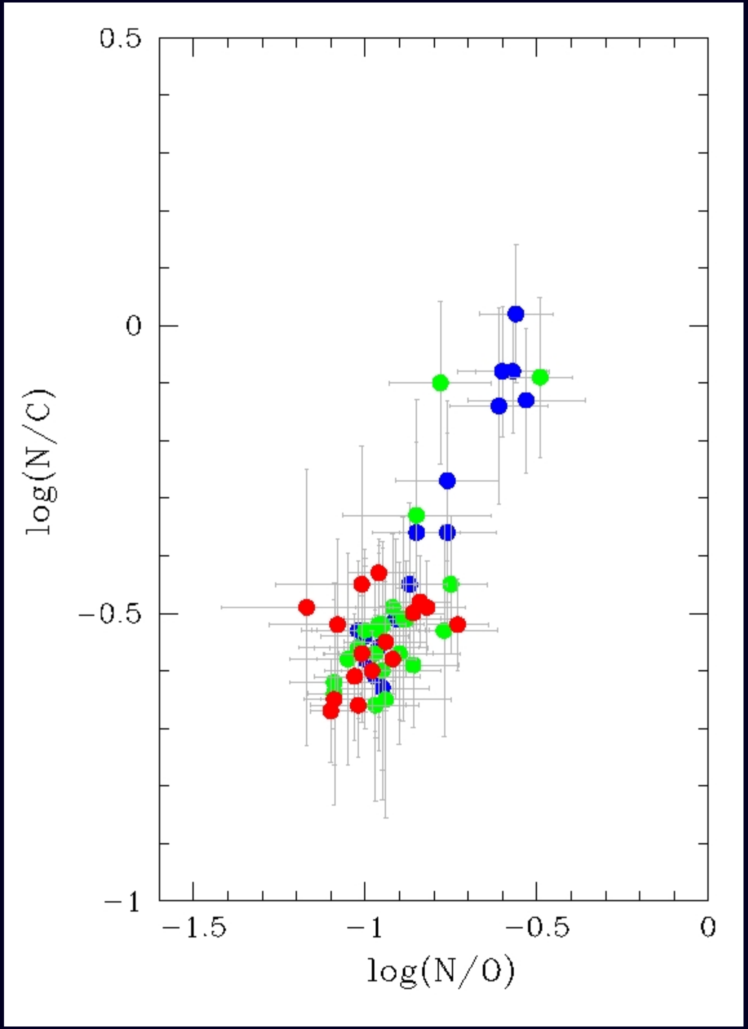
[N/O] = -1.10 ± 0.06

log *g* = 3.51 ± 0.01

v sini *i* = 32 ± 0.5 km/s

Southworth et al., 2017, in prep.

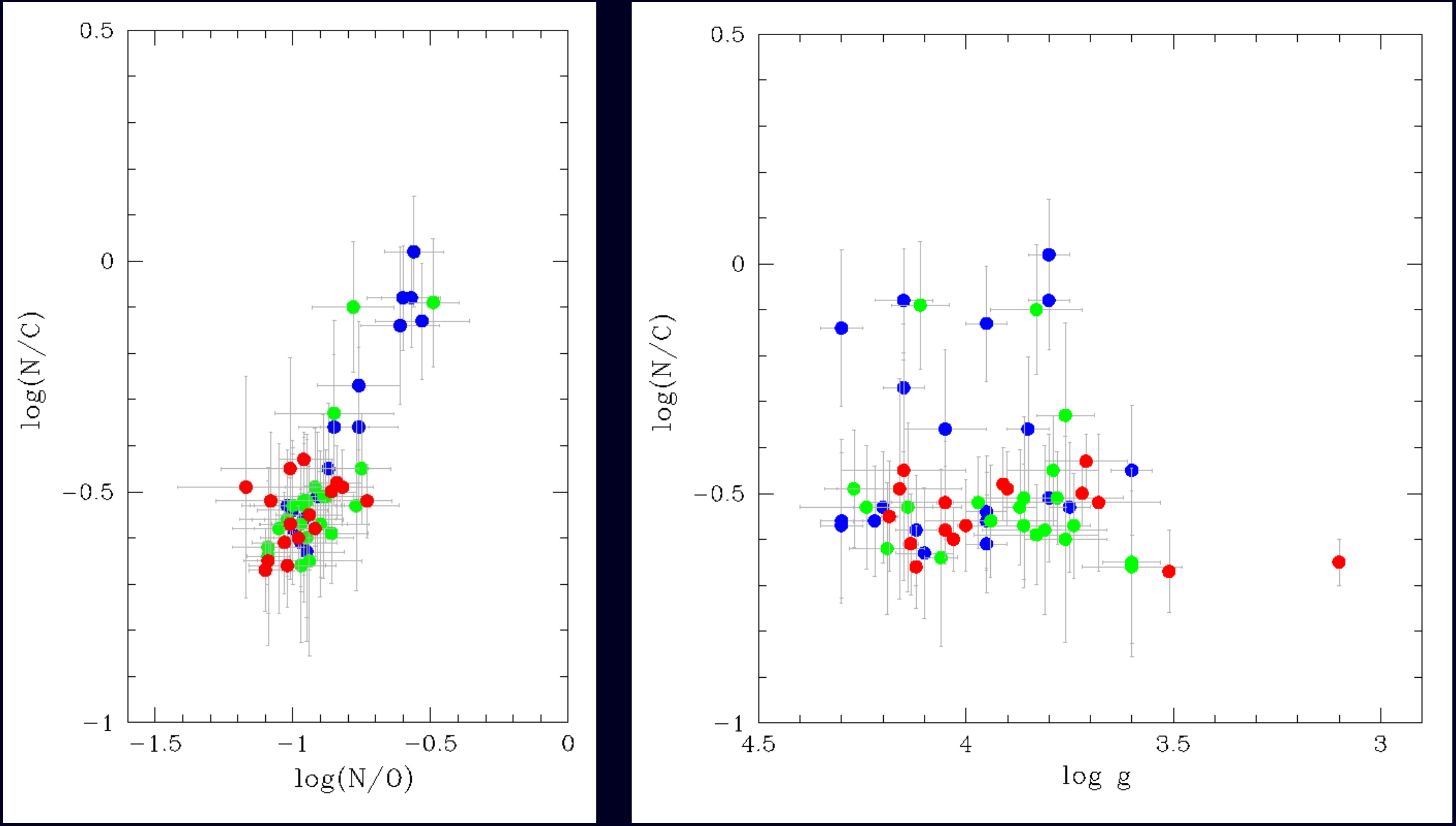
Single stars vs Binary components



Symbols:

- ● Nieva & Przybilla (2015)
- ● Lyubimkov et al. (2016)
- ● OB binaries (this work)

Single stars vs Binary components



Summary

- Discrepancy between dynamical and evolutionary mass is present for high-mass stars, the components of binary systems (binary components are overluminous for their mass).
- No pronounced changes in the surface CNO abundances are found, so far, for the high mass stars in binaries in a range of $M = 8 – 22\ M_{\odot}$, contrary to single stars.
- What is suppressing internal mixing and transport of CNO products to the surface layers in binary components?