Constraining thermohaline mixing in Algol-type systems with the surface carbon to nitrogen abundance ratio

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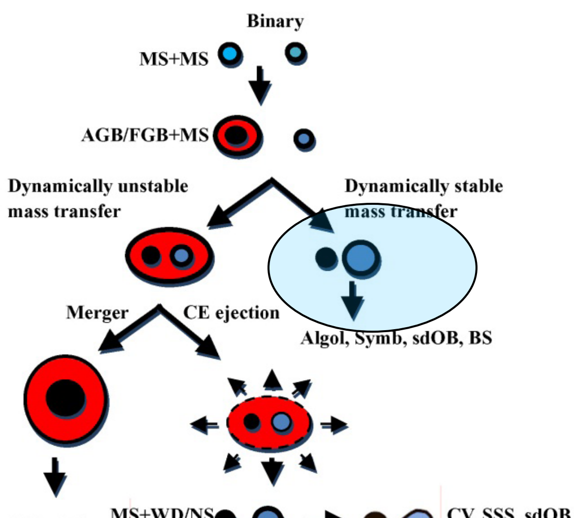
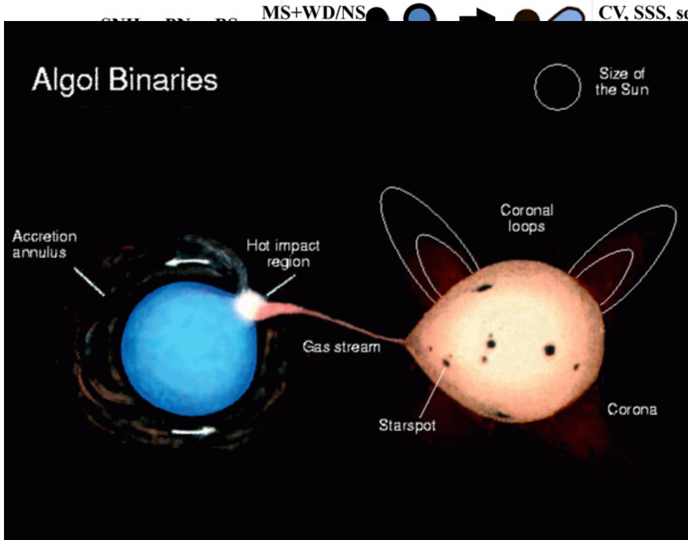
Overview

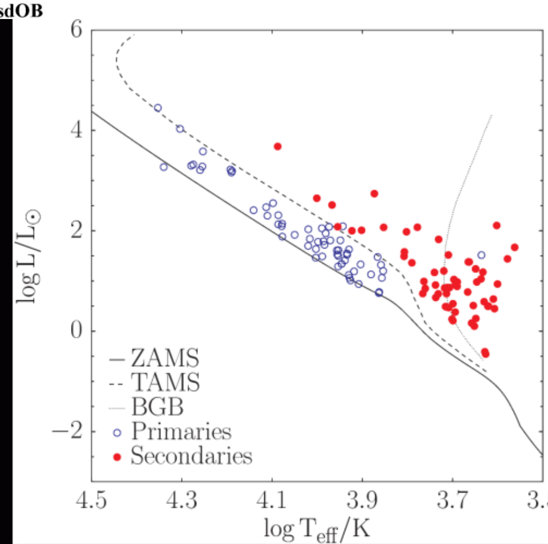
- Introduction
- CNO bi-cycle as a tool
- Classical Algol: δ Lib
  - q^i - β Results
  - Best fitting model & constraining
- Hot Algol: u Her
- Conclusions

Binary Evolution Channels



- So many possibilities.
- We can only model them descriptively, but it is hard to trace back their evolution.
- Every occurrence of mass transfer leads an uncertainties of their initial configuration (M, q, P)
- The optimistic starting point to understand such evolution is Algol systems since there is only one mass transfer process happened.



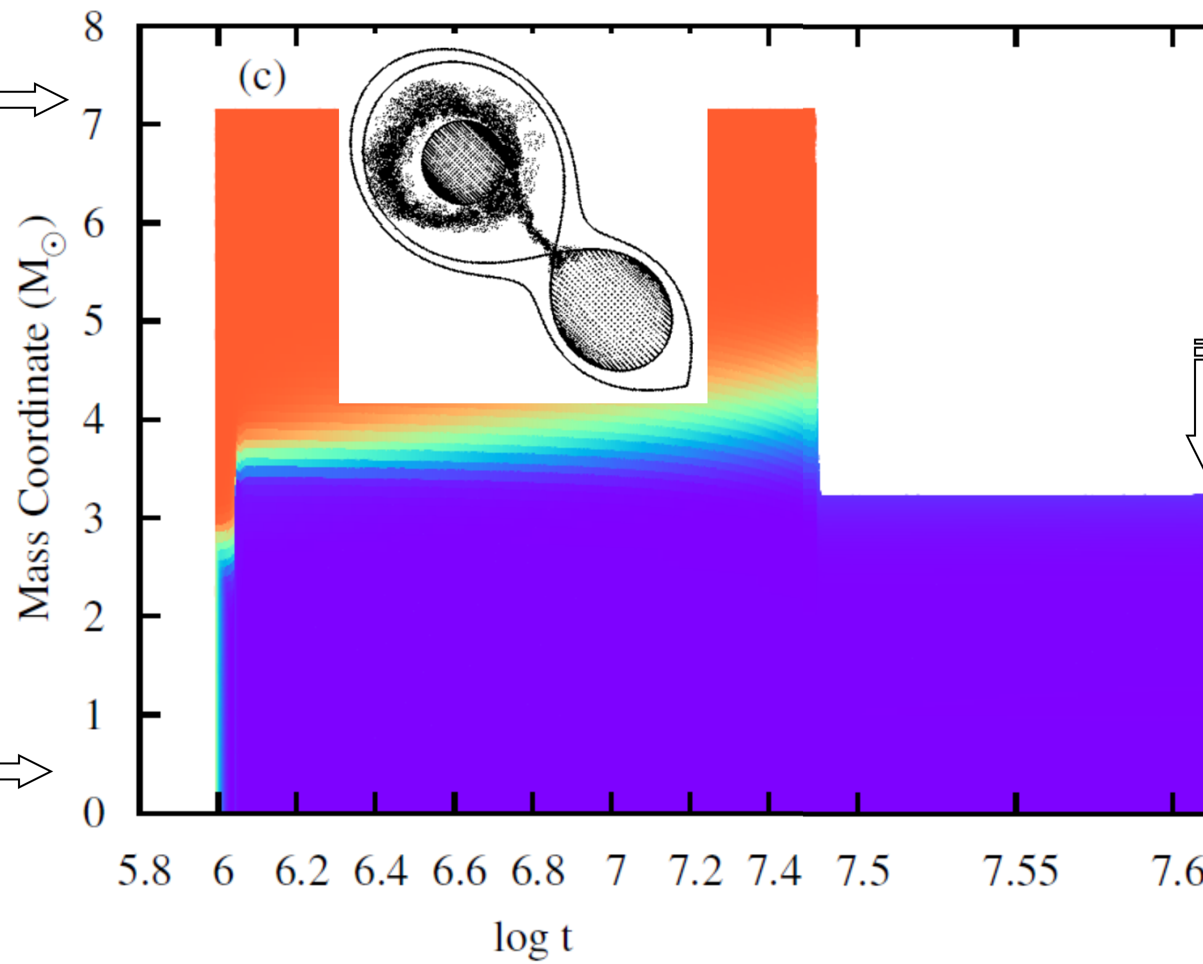


CNO bi-cycle as a tool

Surface

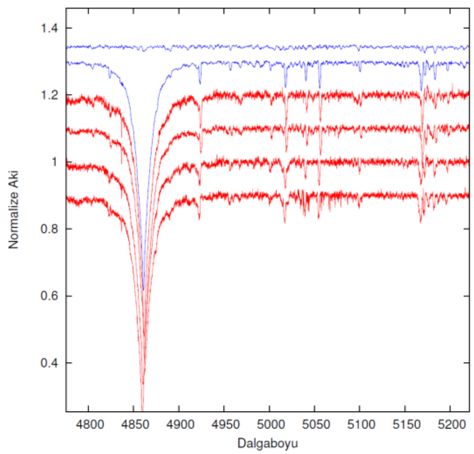
- The net effect of CNO reactions are increased Nitrogen and decreased Carbon (Caughlan & Fowler, 1962)
- The mass fraction ratio changes from C/N~3.5 tc C/N~0.003 (~1000 times!)
- During the mass transfer the star looses up to %8c of it's initial mass (Sarna & De Greve 1996)

Center



C/N profile of 7$M_\odot$ star.

Classical Algol: δ Lib



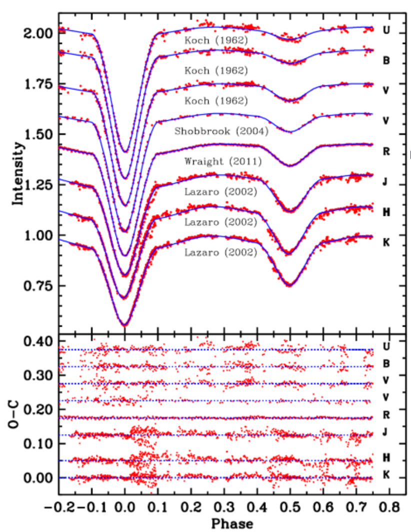
SPD

Parameter	Unit	Star A	Star B
Semimajor axis - a	$R_\odot$	12.32 ± 0.14	
Mass ratio - q		0.38 ± 0.01	
Mass	$M_\odot$	3.35 ± 0.12	1.28 ± 0.06
Radius	$R_\odot$	3.70 ± 0.17	3.65 ± 0.17
$\log g$	$cm\,s^{-2}$	3.84 ± 0.04	3.41 ± 0.03
T_{eff}	K	$10\,650 \pm 100$	$5\,165 \pm 265$
$\log L$	$L_\odot$	2.20 ± 0.04	0.93 ± 0.10
$V_{eq}\ \sin i$	$km\,s^{-1}$	79.6 ± 3.6	80.3 ± 1.9

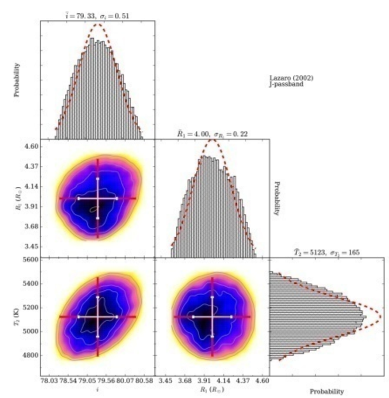
LC Analyses

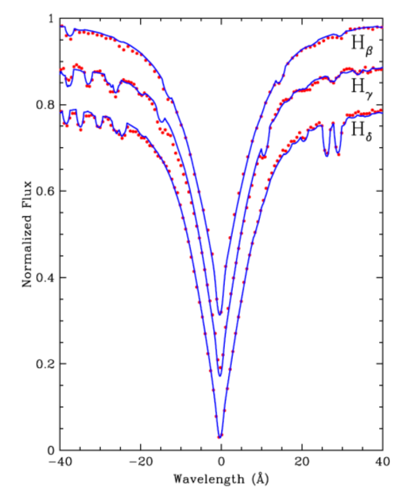
Dervisoglu et al, in preparation, 2017

SPD



LC Analyses





Binary evolution grid: δ Lib

- The degeneracy problem in binary evolution
  - Initial mass ratio (q^i)
  - Systemic mass loss fraction (β)
  - Angular momentum loss
- Assuming loss mass carries out angular momentum of donor star (Hurley, Tout, Pols, 2002), we derive set of equations:

$$\beta = 1 - \left| \frac{\dot{M}_g}{\dot{M}_d} \right| \qquad 0 \leq \beta \leq 1$$

$$M_t^i = M_t^f \frac{(1+q^i)}{(1+q^f)} \frac{[1+q^f(1-\beta)]}{[1+q^i(1-\beta)]}$$

$$P^i = P^f \left(\frac{M_t^f}{M_t^i}\right)^2 \left(\frac{M_g^f}{M_g^i}\right)^3 \left(\frac{M_d^f}{M_d^i}\right)^{3(1-\beta)}$$

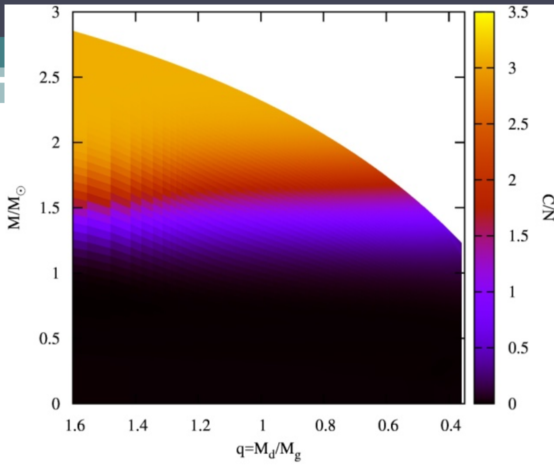
- Cambridge **STARS** (a.k.a **bs**) code (Eggleton (1971, 1972), Stancliffe & Eldridge (2009)
- Python script to automatically calculate and build initial parameters and models with auxiliary files (bg_grid.py)
- Grid size

$$\beta = [0.0 - 0.9] \qquad \delta\beta = 0.05$$

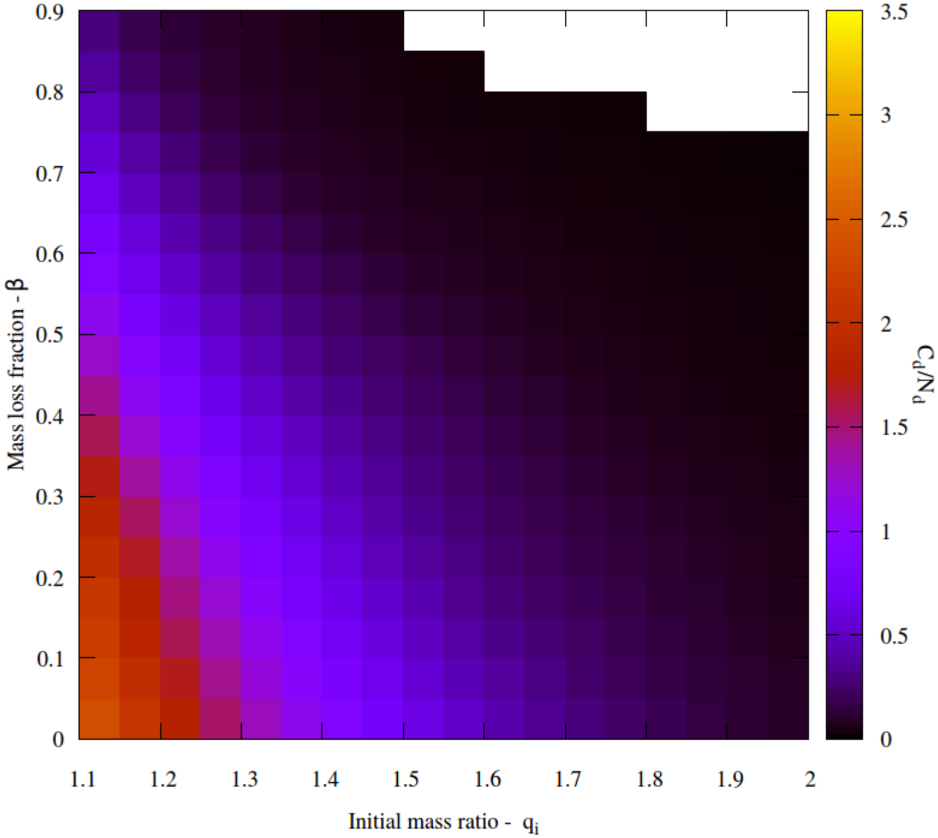
$$q^i = [1.1 - 2.0] \qquad \delta q^i = 0.05$$

- 19x19 initial parameters
- 361 Binary track

q^i - β results

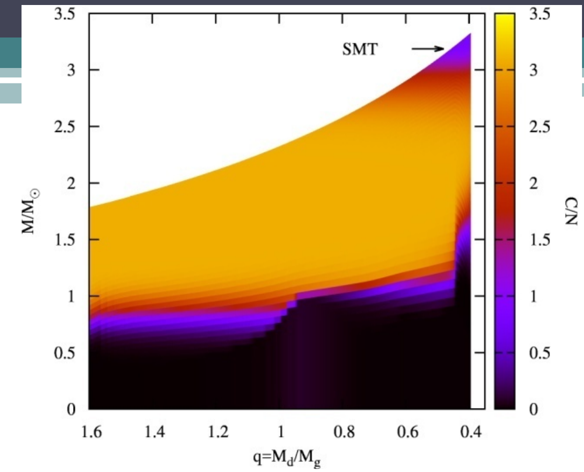


Donor

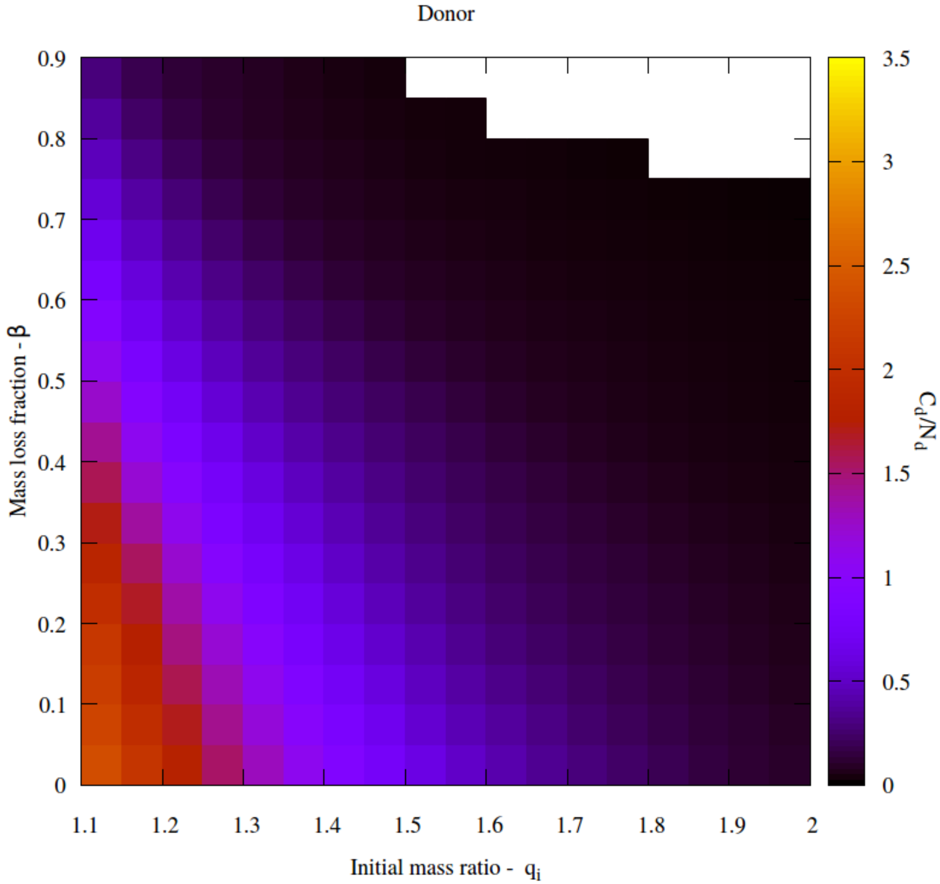


- Mass loss via winds, spin angular momentum evolution and magnetic interactions are neglected.
- Terminated at either second MT or convergence failure.
- Similar method used by Nelson & Eggleton (2001) and de Mink et al. (2007)
- For $q^i > 1.5$ & $\beta > 0.75$ $P^i < P_{lim}$

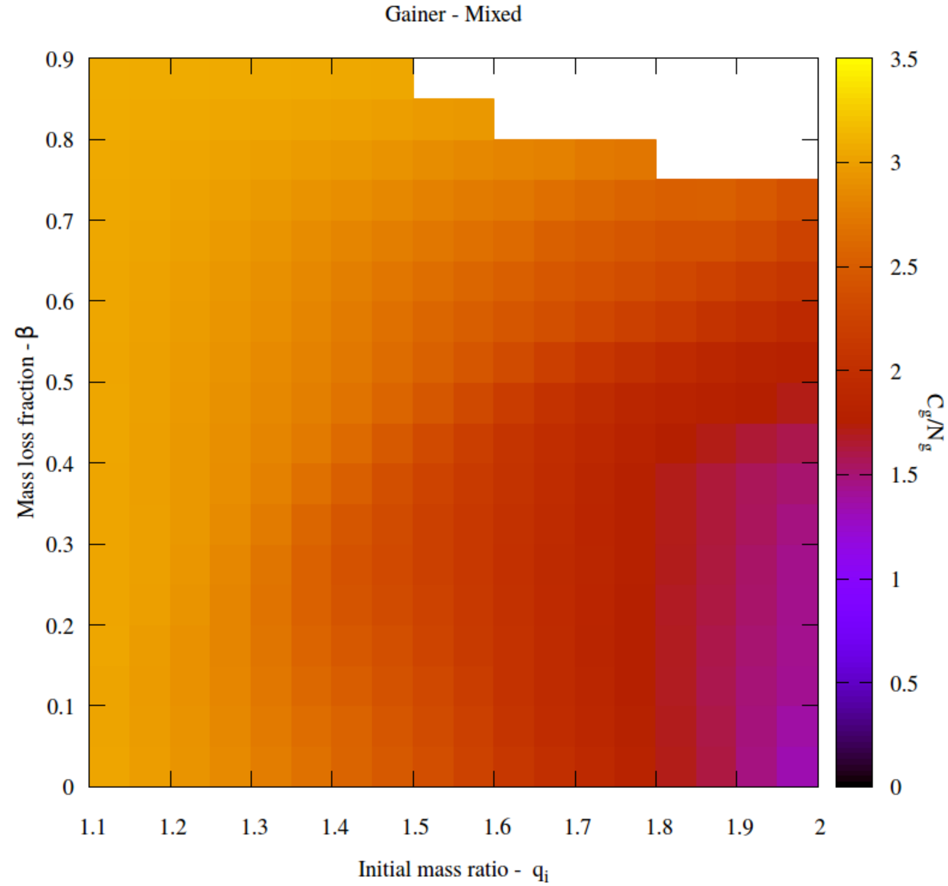
q^i - β Results



SMT
M/M$_\odot$
q=M$_d$/M$_g$
C/N
3.5
3
2.5
2
1.5
1
0.5
0
1.6
1.4
1.2
1
0.8
0.6
0.4



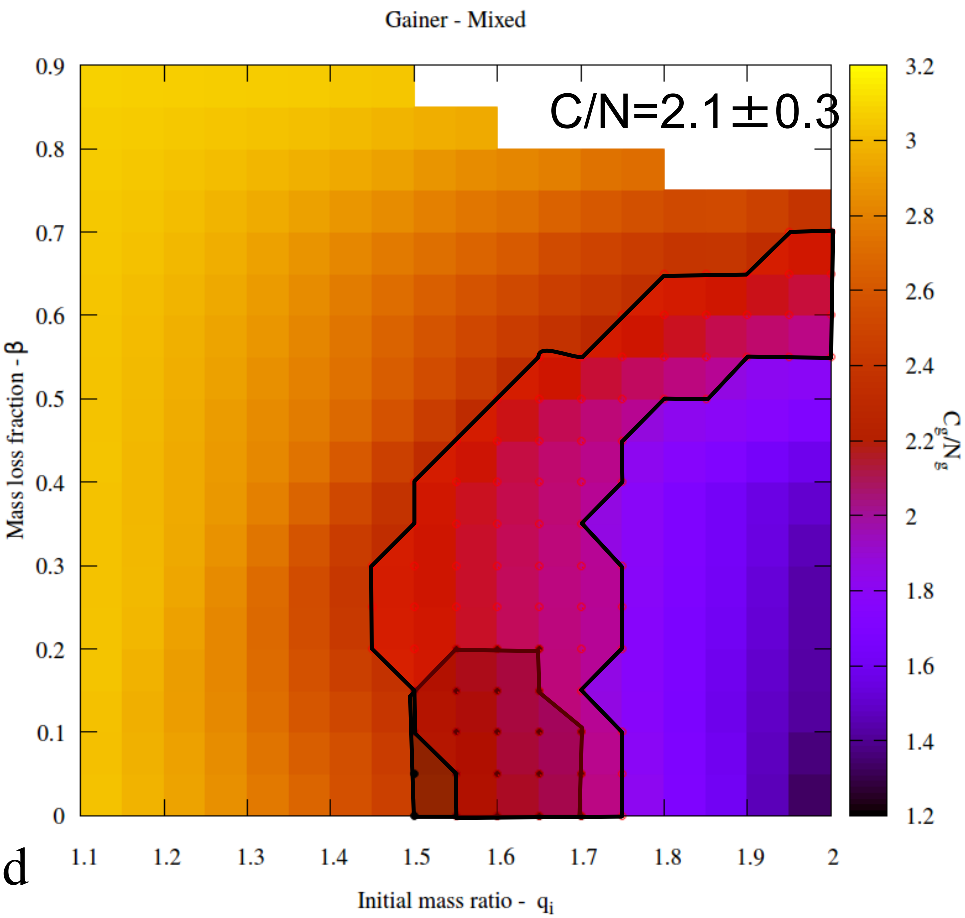
Donor
Mass loss fraction - β
Initial mass ratio - q_i
C_d/N_d
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
3.5
3
2.5
2
1.5
1
0.5
0



Gainer - Mixed
Mass loss fraction - β
Initial mass ratio - q_i
C_g/N_g
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
3.5
3
2.5
2
1.5
1
0.5
0

Best fitting model & constraining

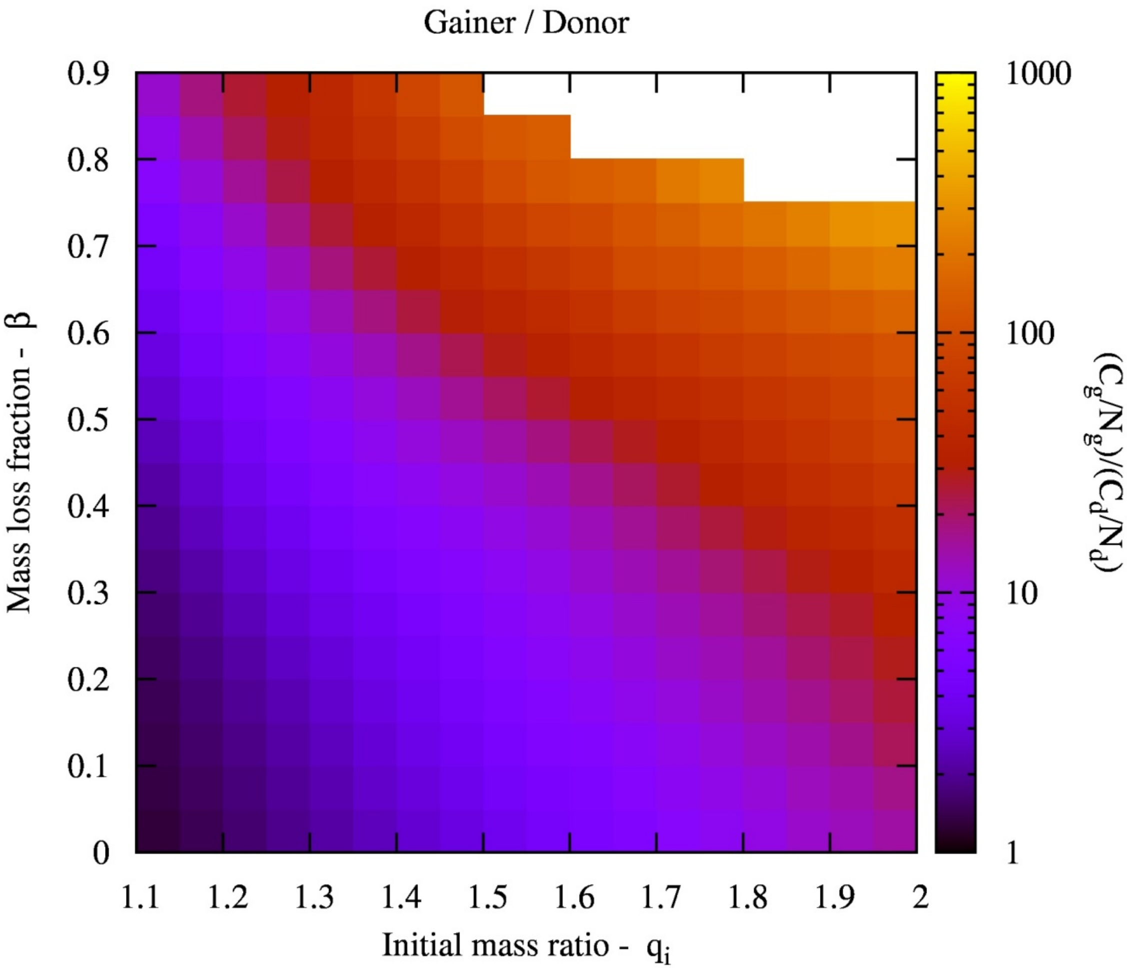
- Followed the similar χ^2 strategy from de Mink et al. (2007).
- Only fitted the independent parameters such as $q, M_1, R_1, T_{1,2}$
- Propagate to all parameter errors to derive confidence interval



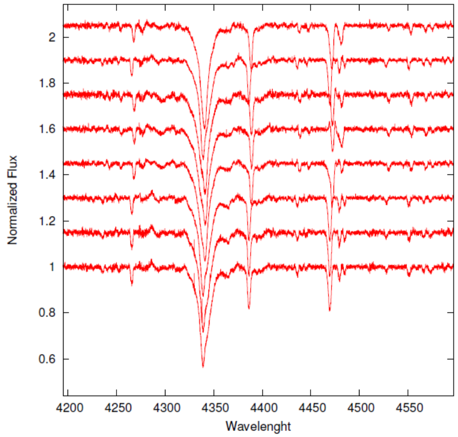
q^i=1.61 ± 0.06 -- β =0.09 ± 0.07

M_d^i=2.95 ± 0.08 $M_\odot$ -- P^i=1.36 ± 0.05 d

For better constraining…



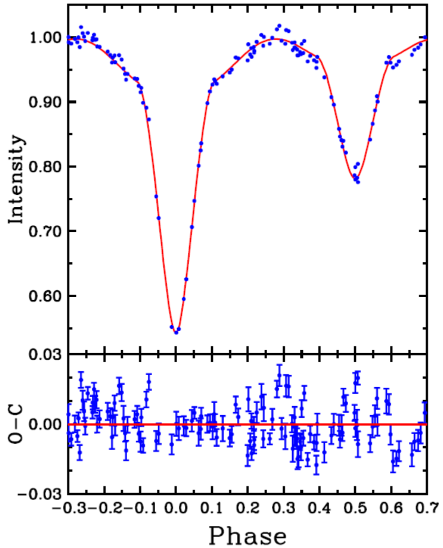
Hot Algol: u Her



SPD

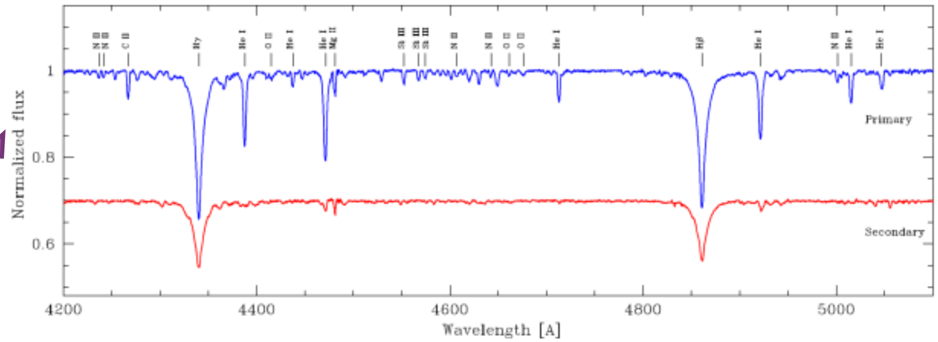
LC Analyses

Parameter	Unit	Star A	Star B
Semimajor axis	$R_\odot$	14.95 ± 0.17	
Mass	$M_\odot$	7.88 ± 0.26	2.79 ± 0.12
Radius	$R_\odot$	4.93 ± 0.15	4.26 ± 0.06
$\log g$	cm s^{-2}	3.948 ± 0.024	3.625 ± 0.013
T_{eff}	K	21 600 ± 220	12 600 ± 550
$\log L$	$L_\odot$	3.68 ± 0.03	2.63 ± 0.08
$V_{eq} \sin i$	km s^{-1}	124.2 ± 1.8	107.0 ± 2.0
V_{synch}	km s^{-1}	121.7 ± 3.5	105.0 ± 1.5



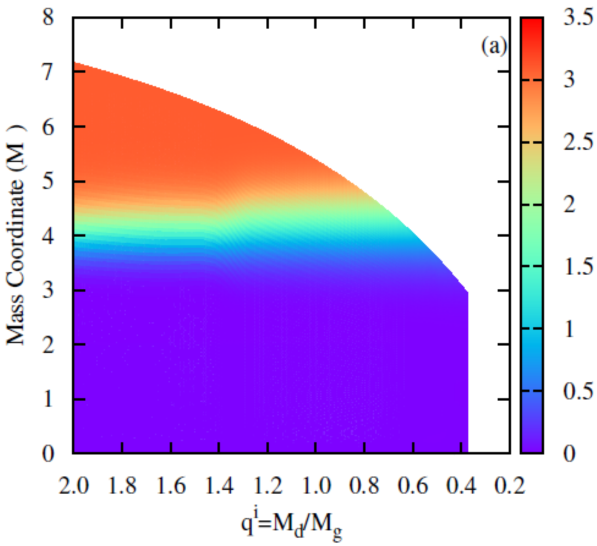
SPD

LC Analyses



Kolbas et al, 2014

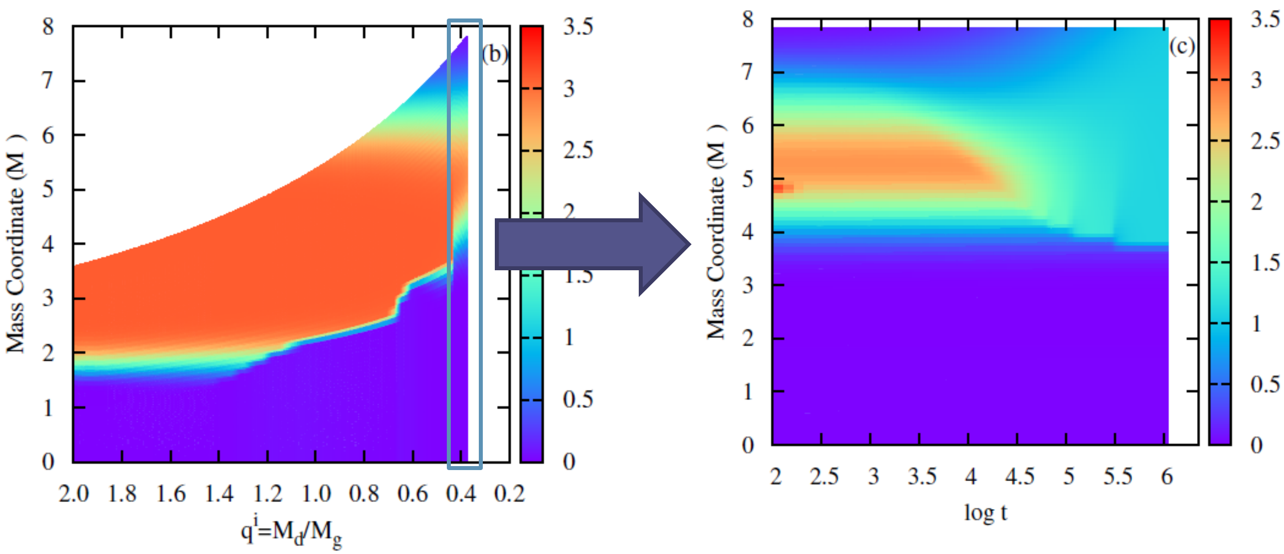
Evolutionary Status



- The most likely initial systemic parameters are:

$q^i \approx 2.00 \pm 0.25$, $M^i_d = 7.16 \pm 0.4\ M_\odot$ and $P^i = 1.35 \pm 0.1$ d

- The observed C/N~0.9± 0.2 ratio is corroborating with calculations.



Conclusions

- Spectral disentangling of Algol-type systems combined with photometry is giving us opportunity to derive abundances precisely.
- So far we are limited for short period systems

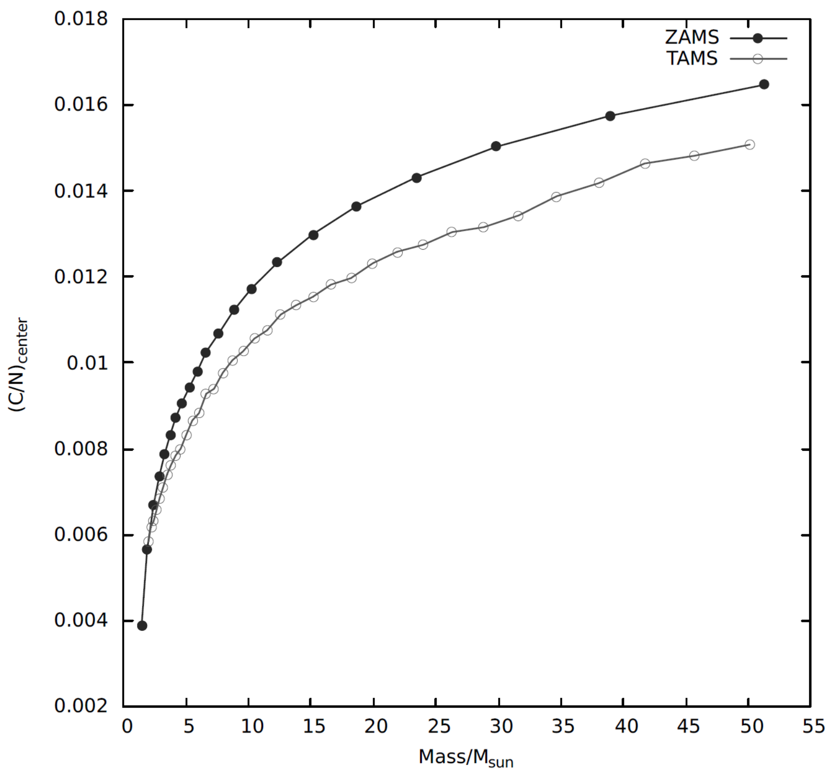
u Her: P=2.05 days	q=0.35	Mt=10.67 $M_\odot$
δ Lib : P=2.33 days	q=0.38	Mt= 4.63 $M_\odot$

- The results for δ Lib and u Her are promising and motivating for future studies.
- Securing and analyzing of donor spectra seems with a help of constraining results with thermohaline mixing may open new window towards to understating of post-mass transferred systems.
- Our list of binary and the number of spectra is increasing.

Thank you for your attention.

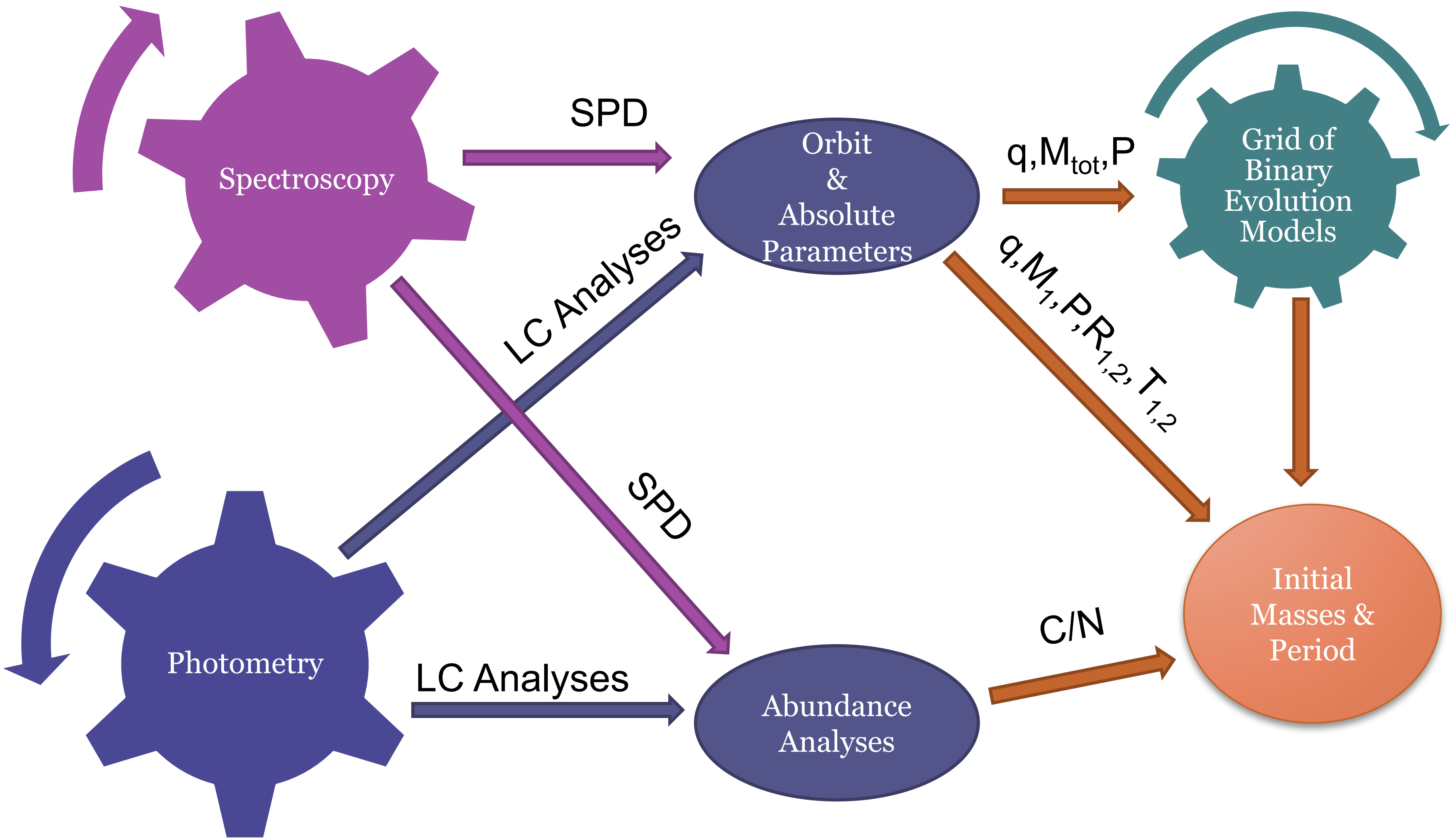
A.D and K.P acknowledge the support from Croatian MZOS HRZZ-IP-2014-09- 8656 and TUBITAK 113F067.

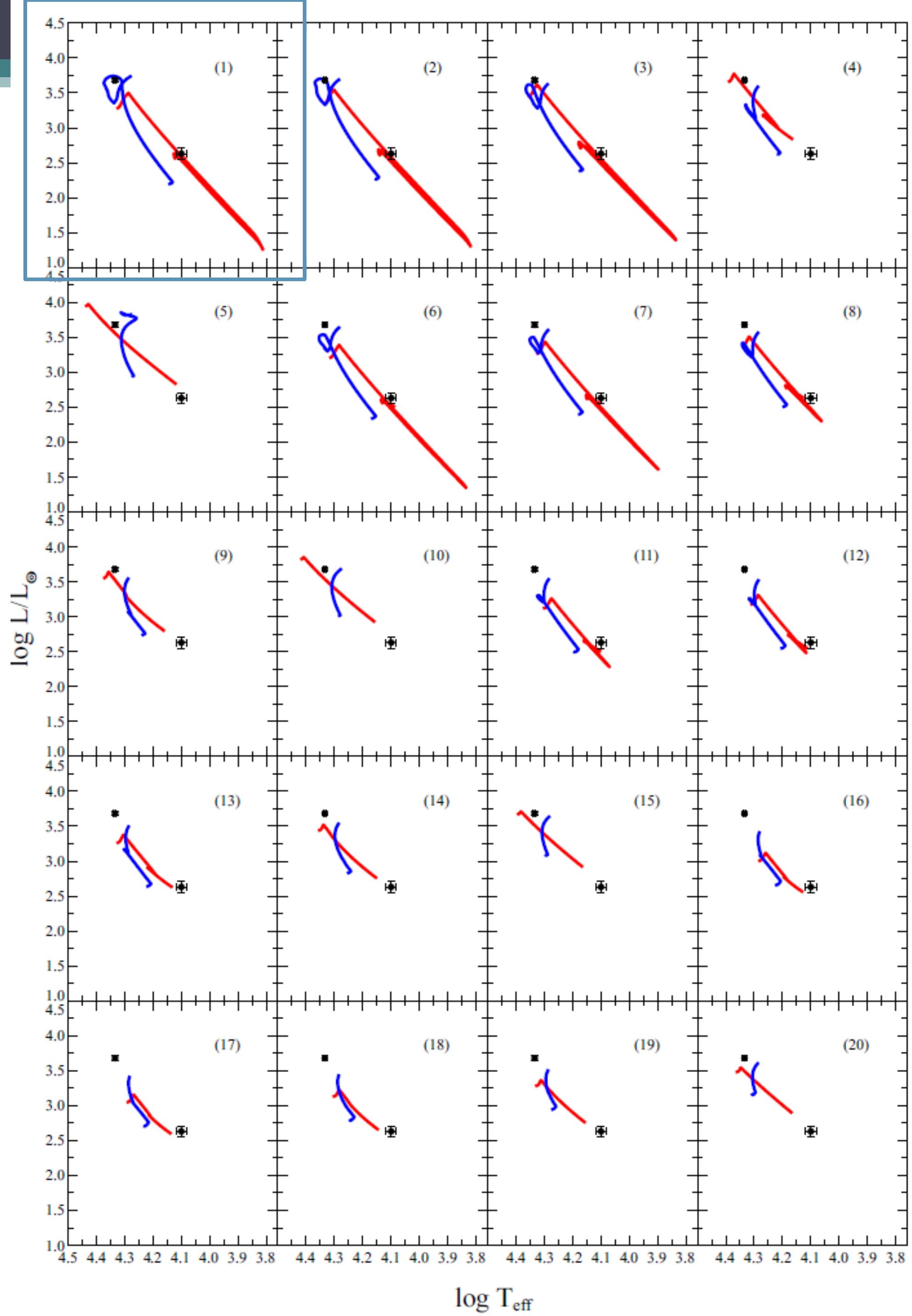
Current Algols



- Initial massive star (a.k.a mass donor) is now faint and low mass stars. It’s surface is CNO occurred regions. Contributes only ~%10 of total light. Good opportunity to test our nucleosynthesis theories.
- Current primary component (a.k.a mass gainer) is now B-type star and has CNO contaminated material on it’s surface. Again, good opportunity to test our nucleosynthesis theories and mixing mechanisms of massive stars.

Methodology

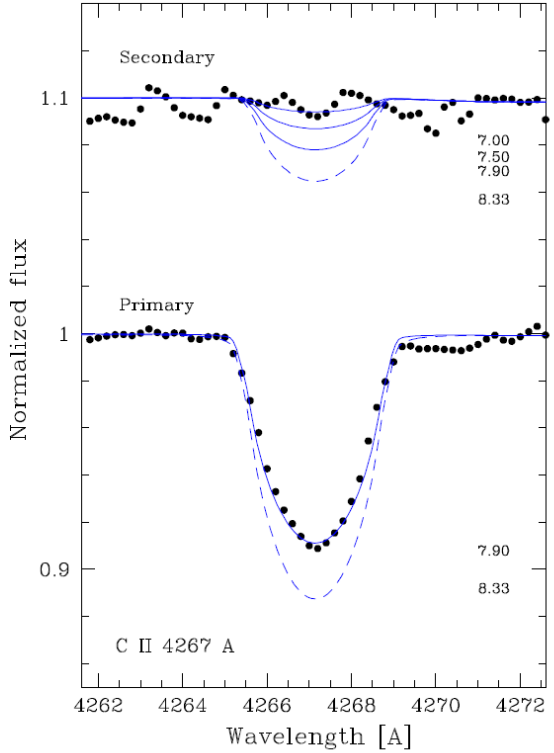


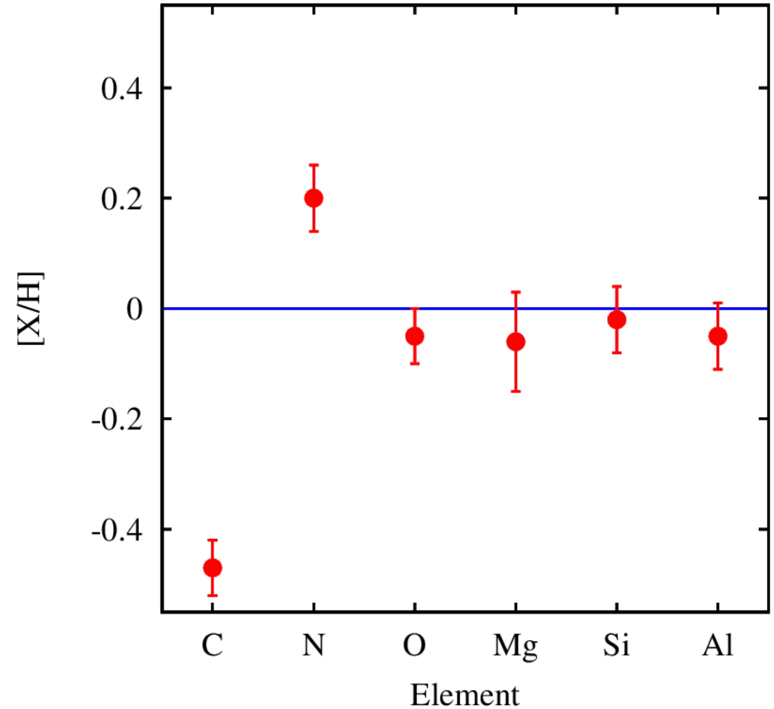


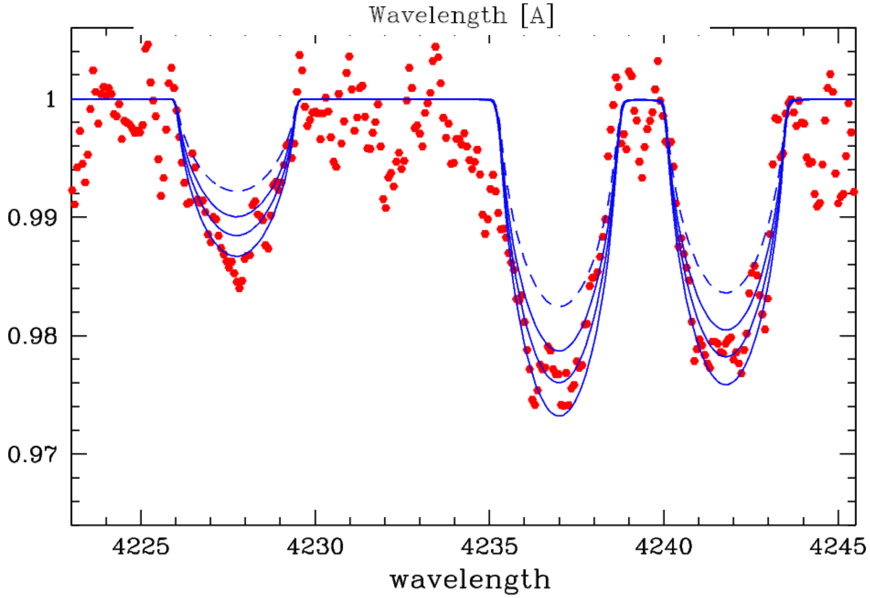
$$q^i = [1.25, 1.50, 1.75, 2.00]$$

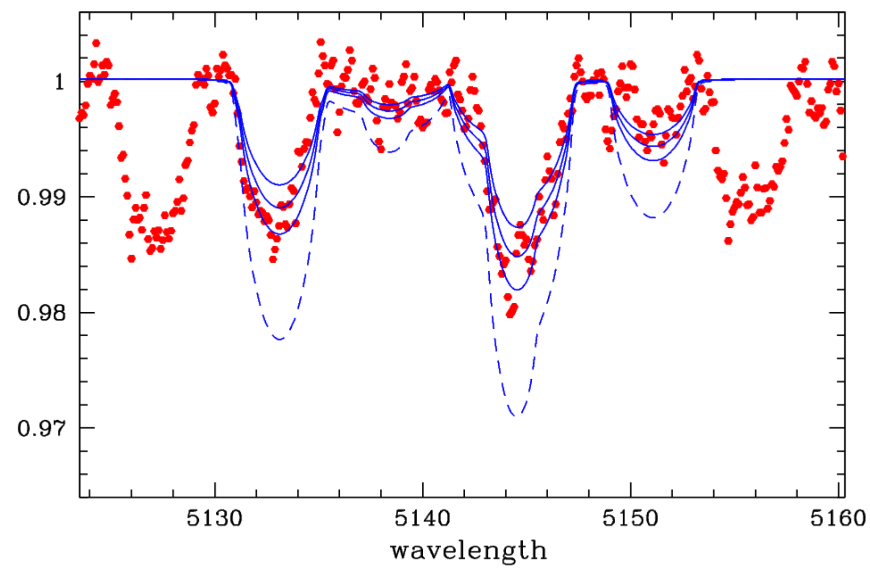
$$\beta = [0.0, 0.10, 0.25, 0.50, 0.75]$$

f ⊙	P^f d	$\log L_d$ $L_\odot$	$\log T_d$ K	$\log R_d$ $R_\odot$	$\log L_g$ $L_\odot$	$\log T_g$ K	$\log R_g$ $R_\odot$
4	1.93	2.56	4.09	0.63	3.73	4.28	0.83
1	1.77	2.60	4.11	0.62	3.69	4.28	0.80
1	1.59	2.68	4.13	0.60	3.62	4.29	0.76
1	1.54	2.85	4.17	0.61	3.58	4.29	0.74
3	2.34	2.84	4.12	0.70	3.83	4.28	0.88
8	1.65	2.51	4.09	0.60	3.64	4.28	0.77
8	1.55	2.56	4.11	0.59	3.60	4.29	0.75
7	1.48	2.64	4.13	0.59	3.56	4.29	0.73
4	1.45	2.81	4.16	0.60	3.54	4.29	0.72
7	1.89	2.94	4.16	0.67	3.68	4.28	0.81
8	1.42	2.51	4.10	0.57	3.53	4.29	0.72
5	1.39	2.56	4.12	0.57	3.52	4.29	0.71
9	1.35	2.64	4.14	0.57	3.49	4.29	0.70
2	1.44	2.77	4.15	0.60	3.53	4.29	0.72
0	1.71	2.93	4.17	0.65	3.63	4.28	0.77
2	1.22	2.57	4.13	0.54	3.41	4.28	0.66
2	1.22	2.61	4.14	0.55	3.41	4.28	0.66
0	1.25	2.66	4.15	0.56	3.43	4.29	0.67
4	1.36	2.77	4.16	0.59	3.50	4.29	0.70
6	1.58	2.91	4.17	0.64	3.60	4.29	0.75

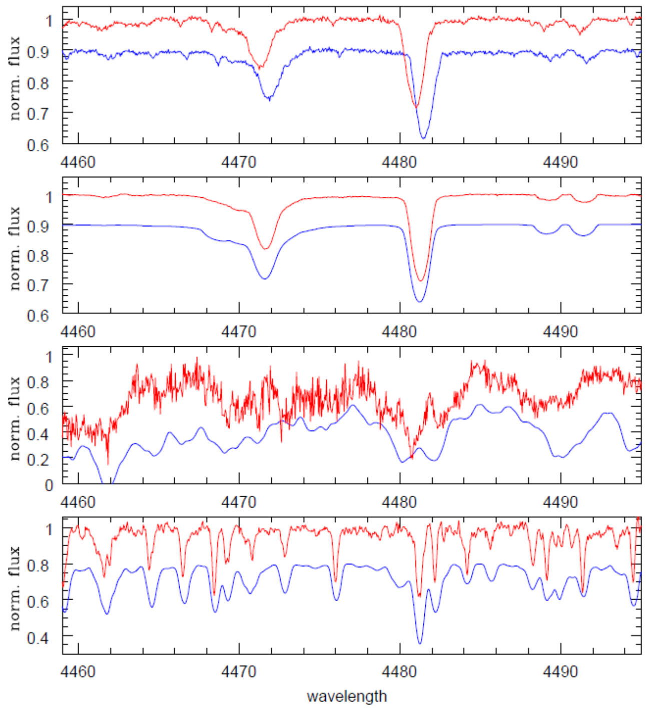

Secondary
7.00
7.50
7.90
8.33
Primary
7.90
8.33
C II 4267 A
Normalized flux
1.1
1
0.9
4262
4264
4266
4268
4270
4272
Wavelength [A]


0.4
0.2
0
-0.2
-0.4
[X/H]
C
N
O
Mg
Si
Al
Element

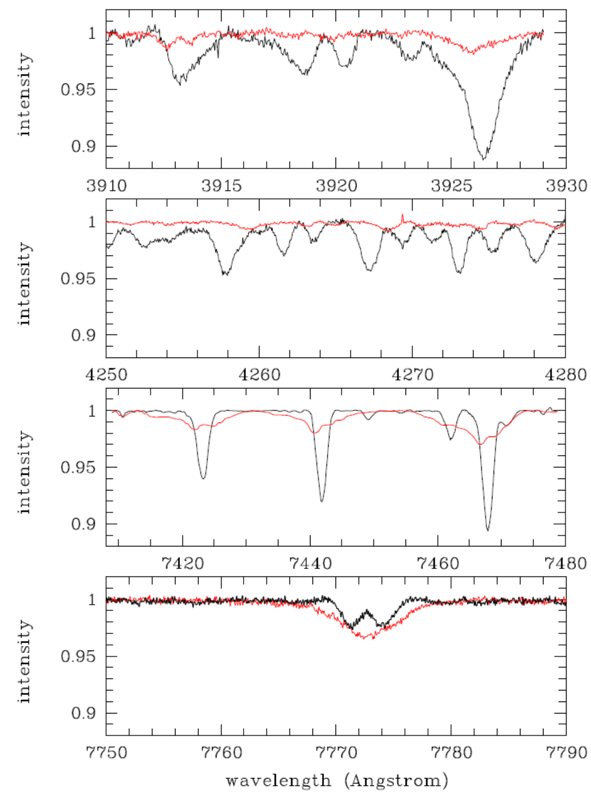

1
0.99
0.98
0.97
4225
4230
4235
4240
4245
wavelength


1
0.99
0.98
0.97
5130
5140
5150
5160
wavelength

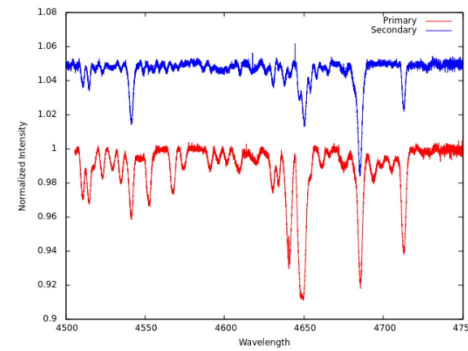
Ongoing Projects



β Per (Algol) C/N=2.0±0.4



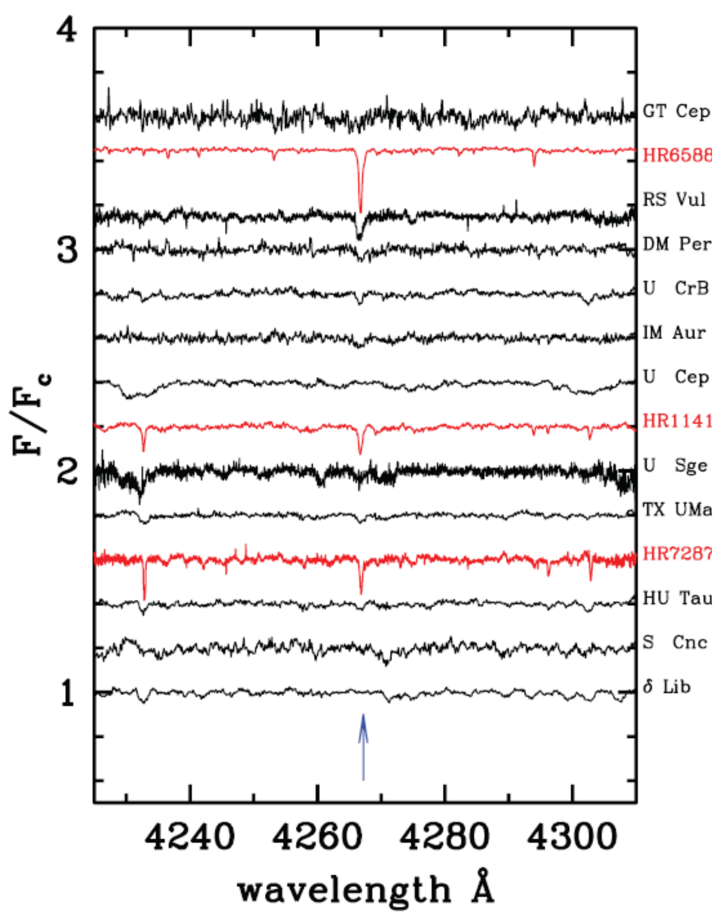
β Lyr - Disentangled

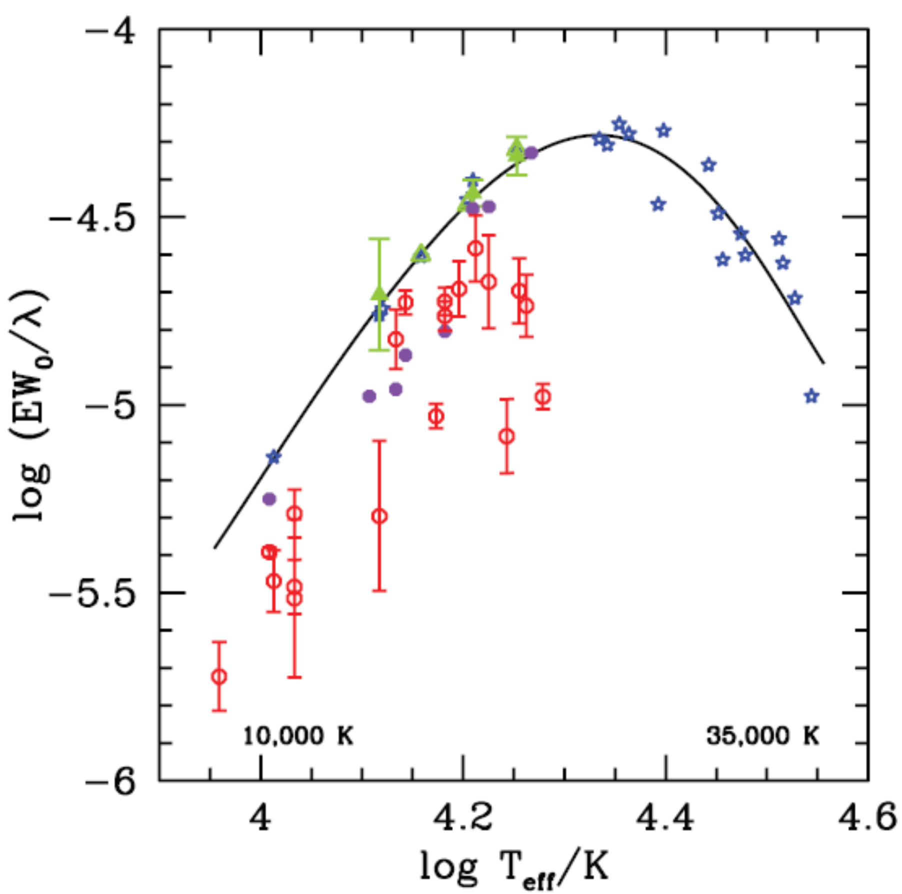


AO Cas- Disentangled

Secured Spectra
- U CrB
- U Sge
- λ Tau
- RS Vul

Carbon underabundances confirmed!





Ibanoglu, Dervisoglu, Cakirli, Sipahi, 2012 >> 18 Algol primaries
But only one line and only relative abundance.