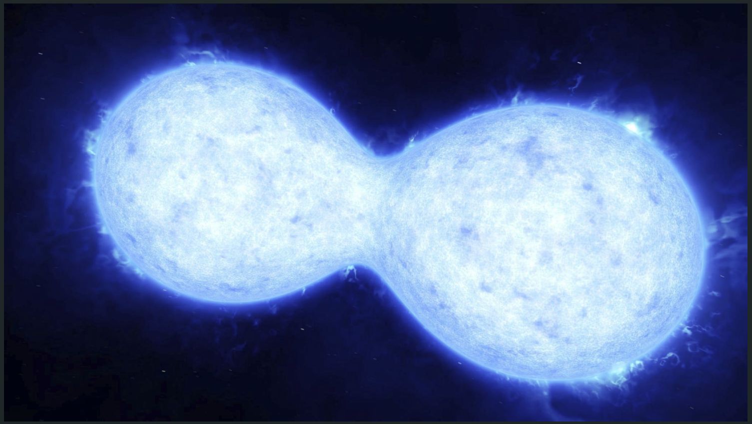


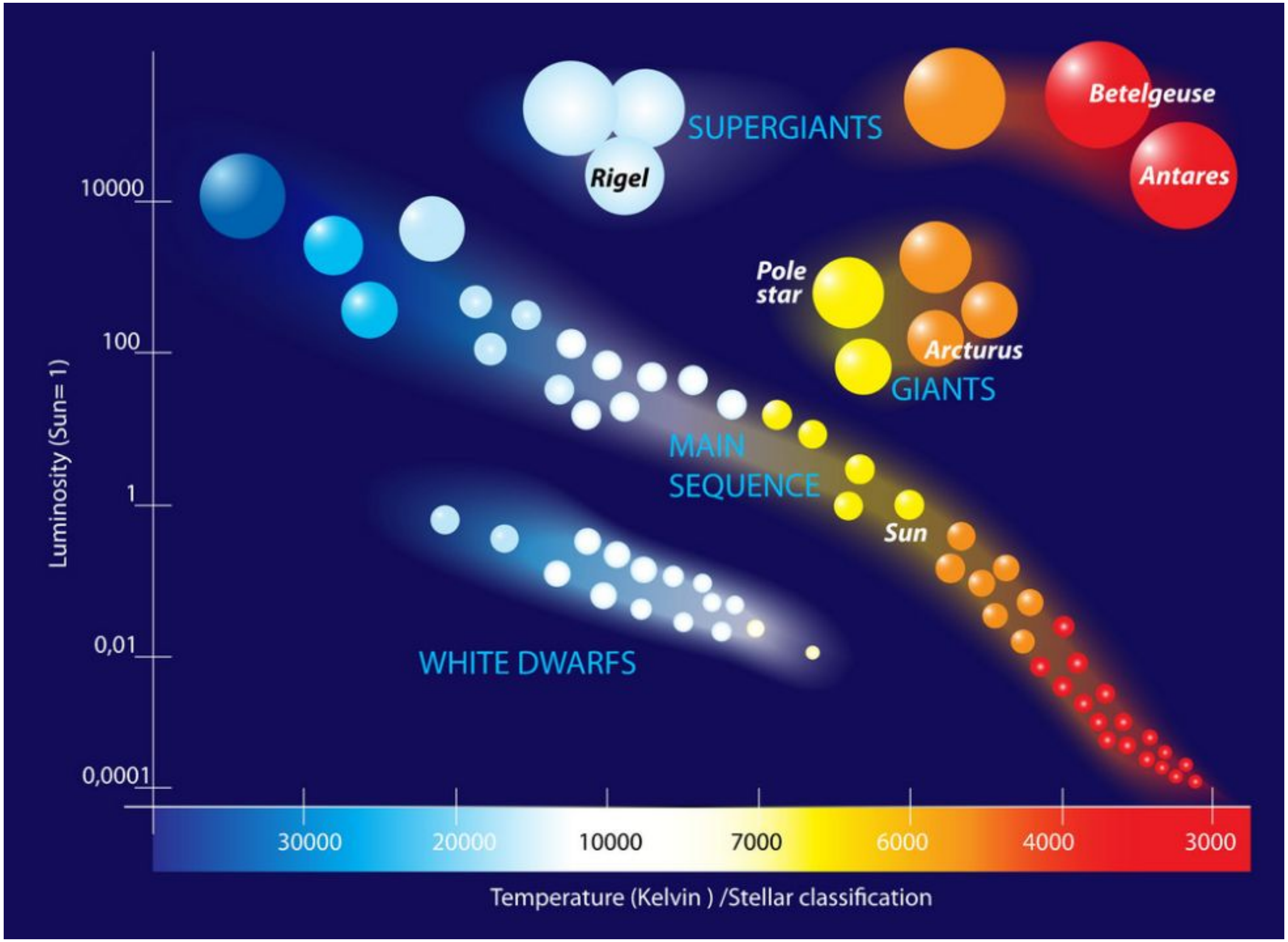
Massive Overcontact Binaries:

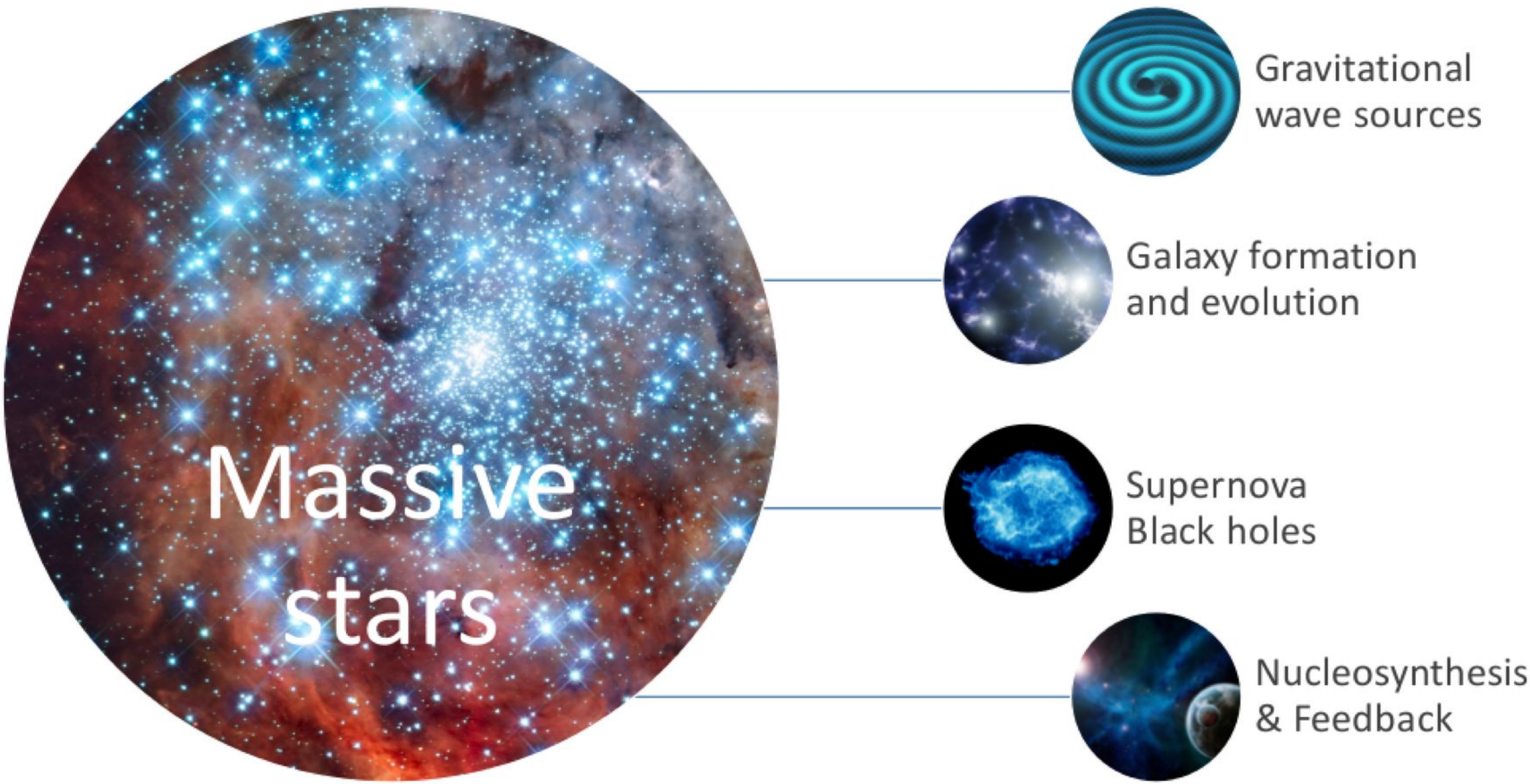
Latest Results and New Spectral Analysis Techniques

Michael Abdul-Masih

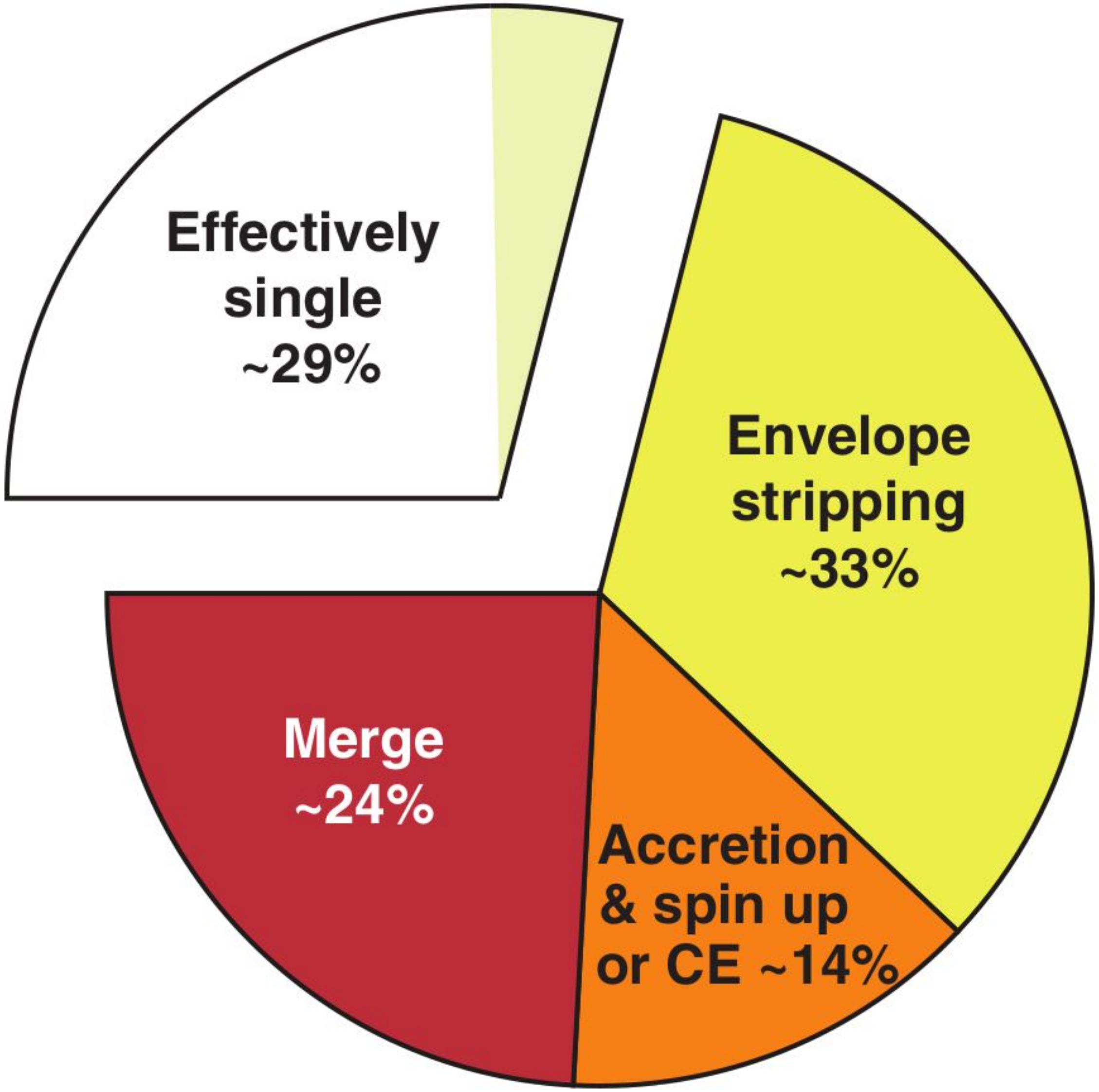
+ Hugues Sana, Jon Sundqvist, Alex De Koter, Selma de Mink, Jo Puls, Frank Tramper, Norbert Langer, Laurent Mahy, Tomer Shenar, Athira Menon, Stephen Justham, Leonardo Almeida, Andrej Prsa, Kyle Conroy

Massive Overcontact Binaries



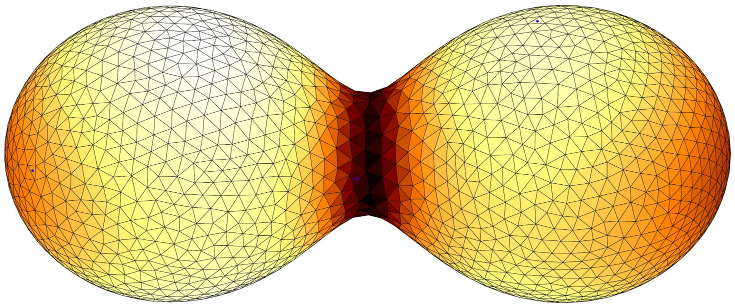

Massive stars
Gravitational wave sources
Galaxy formation and evolution
Supernova Black holes
Nucleosynthesis & Feedback

Massive Overcontact **Binaries**



Massive Overcontact Binaries

Motivation



- Roughly peanut shaped
- ~25% of all massive stars are expected to go through a contact phase
- Not much known about this phase
- Potential Gravitational Wave progenitor

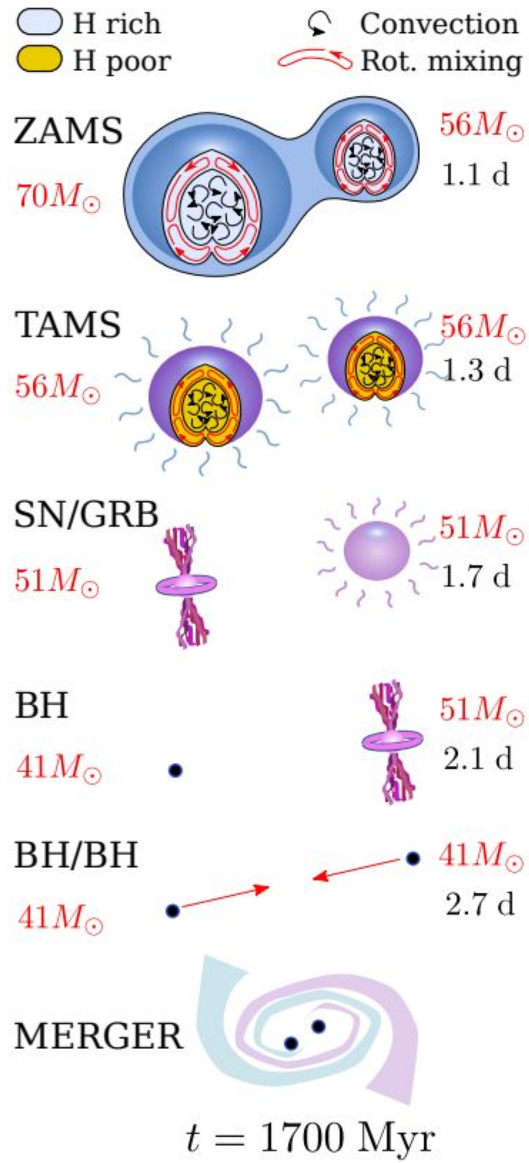
(Sana et al. 2012)

Motivation: Chemically Homogeneous Evolution (CHE)

- First proposed for single stars
- High rotation rates cause mixing
- Stars shrink instead of expand as they evolve

(Mandel et al. 2016)

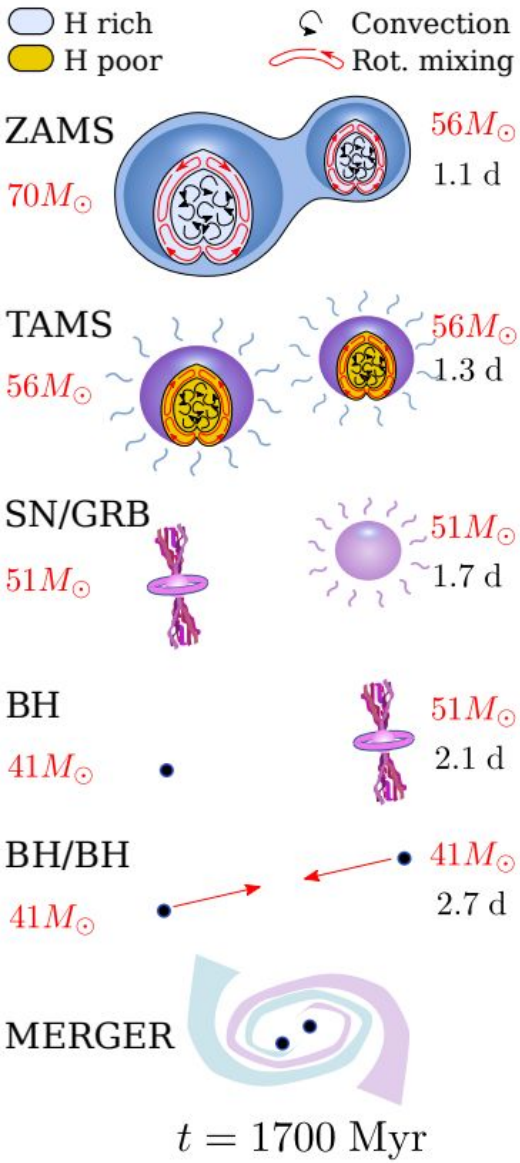
- First proposed for single stars
- High rotation rates cause mixing
- Stars shrink instead of expand as they evolve



(Mandel et al. 2016)

How do we look for CHE?

- Temperature increases
- Abundance changes
  (i.e. enhancement of He, N
  and depletion of C, O)



(Mandel et al. 2016)

VFTS 352

- One of the most massive overcontact binaries known ($28.6 + 28.6\ M_\odot$, $p = 1.124$ days)
- Located in the LMC

Goal: Test CHE in VFTS 352

- Obtain T_{eff}
- Obtain abundances (He, C, N, O)

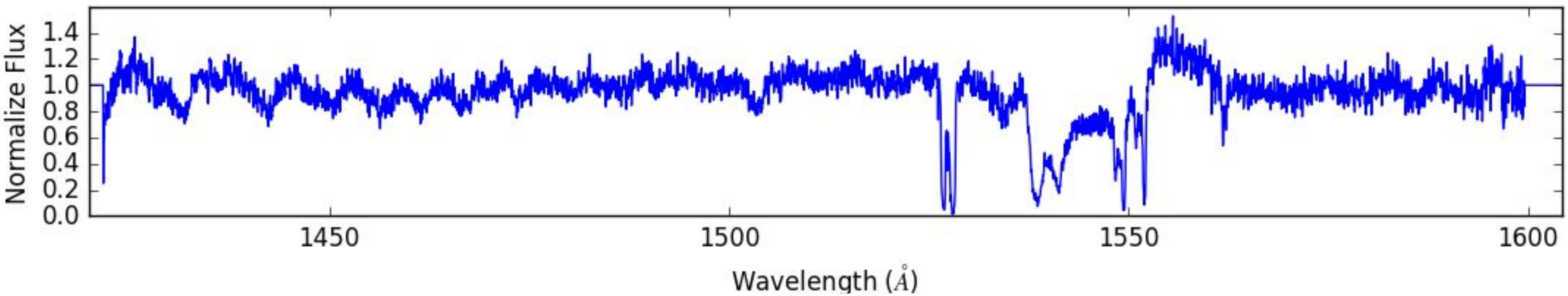
Method:

- Fit synthetic spectra (from FASTWIND) to observed spectra

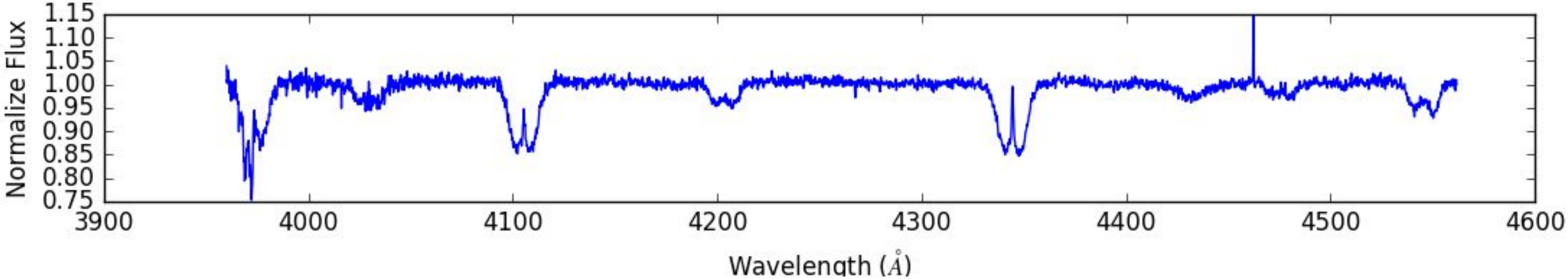
(Puls et al. 2005; Ilijic et al. 2004)

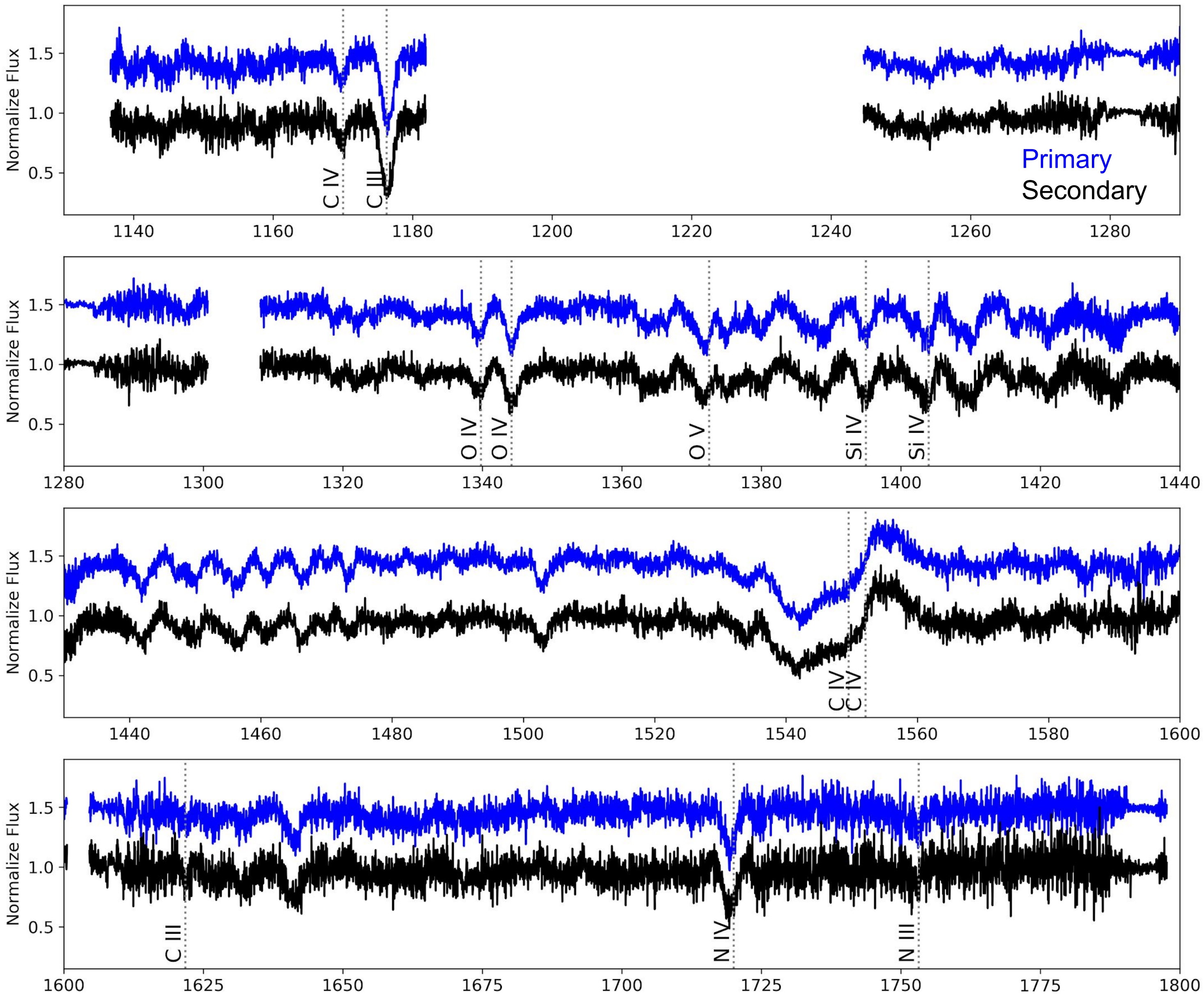
Our Dataset

- 8 epochs of Hubble COS Far-UV spectra (G130M and G160M)

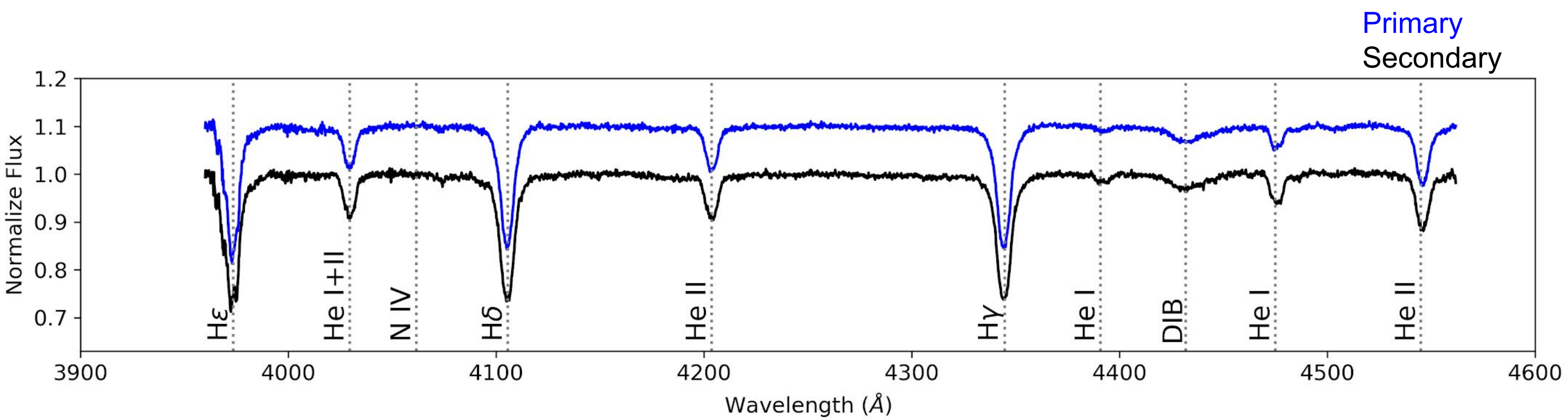


- 32 epochs of FLAMES visual spectra




Normalize Flux
C IV
C III
Primary
Secondary
O IV
O IV
O V
Si IV
Si IV
C IV
C IV
C III
N IV
N III

Optical Disentangled Spectra

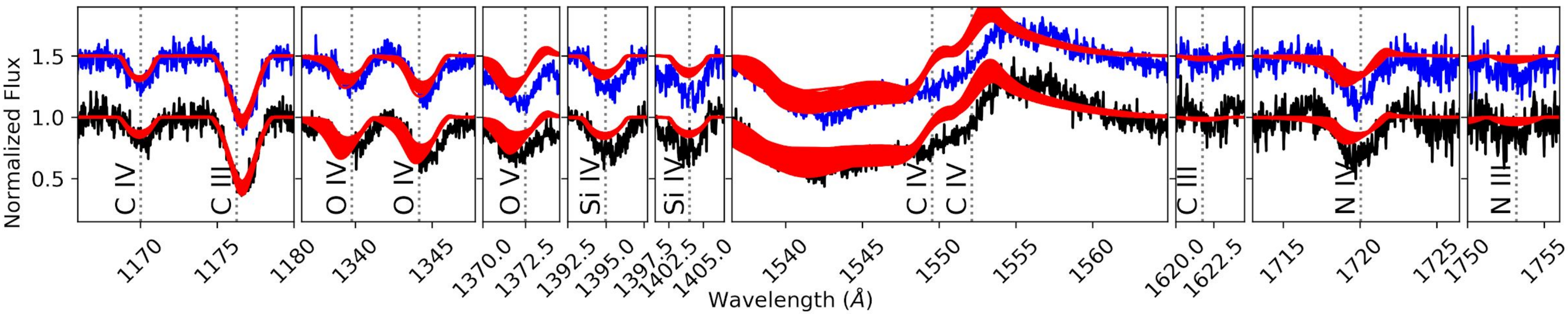


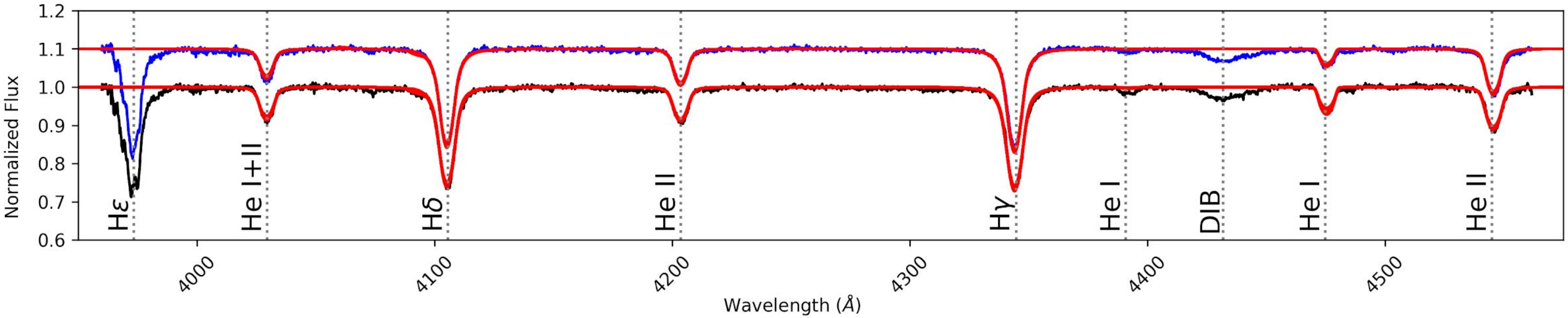
11 Parameter fit

- Teff
- log g
- v sin i
- (Microturbulence)
- Mass loss rate
- Beta
- V_{inf}
- Abundances: He, C, N, O, Si (P)

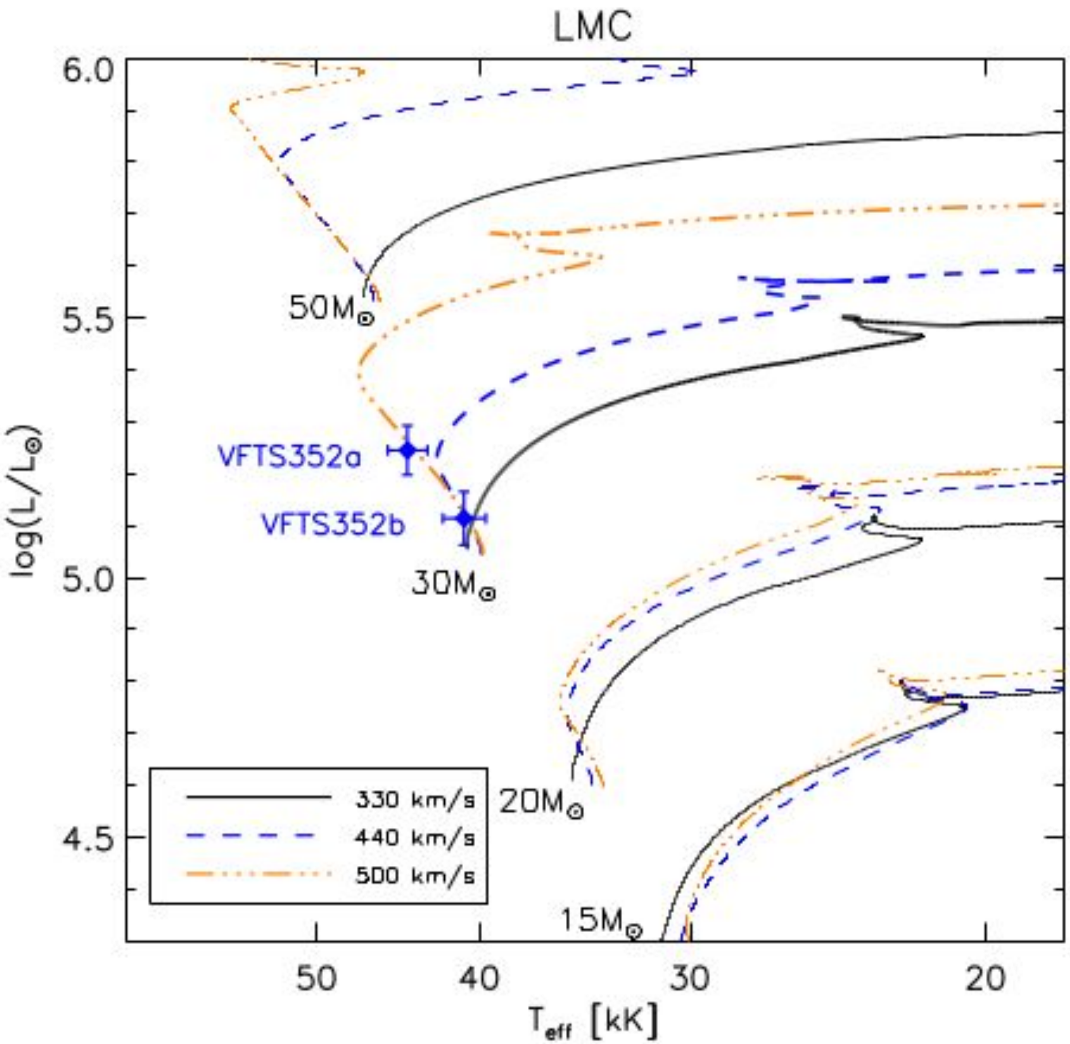
Best fit models

Primary
Secondary
Family of Solutions



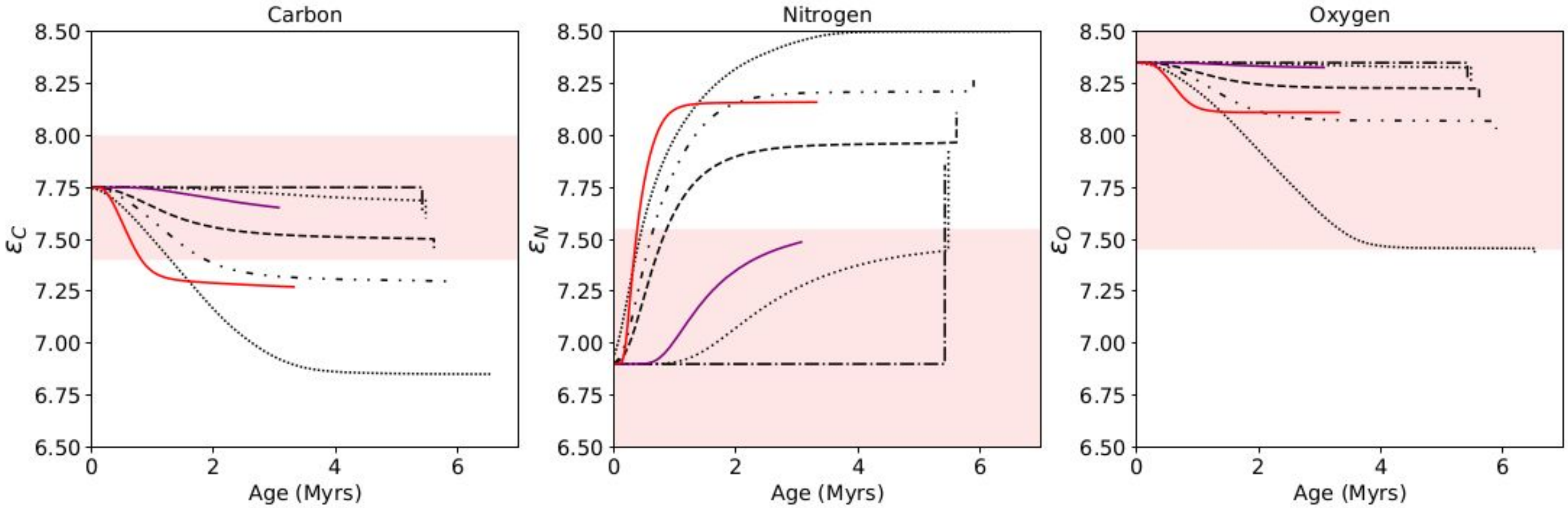


Comparison with Evolutionary Tracks on HRD

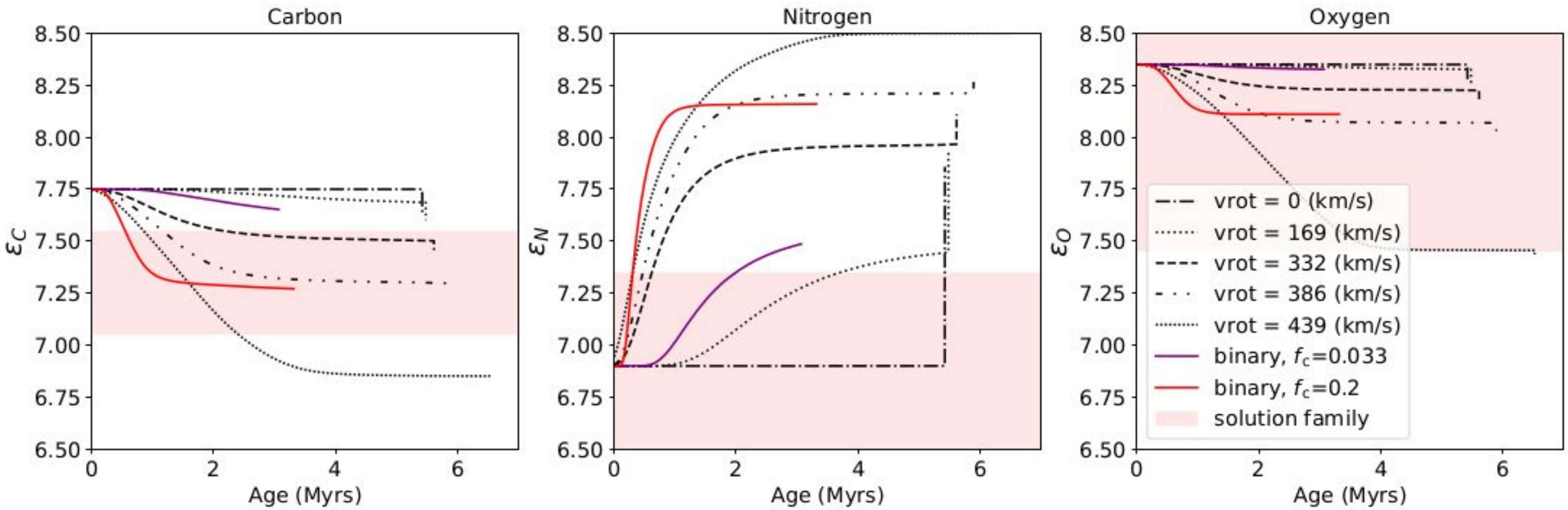


(Evolutionary Models from Brott et al. 2011)

Primary Component



Secondary Component



Results and Conclusions

- There is some evidence for mixing
    - Stars are hotter than expected
    - Carbon and Oxygen show possible depletion
    - HOWEVER, no Nitrogen enrichment

- **Most likely a result of binary interactions, not of internal mixing.**

Clues on the Origin and Evolution of Massive Contact Binaries: Atmosphere Analysis of VFTS 352

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Submitted to ApJ

ABSTRACT

The massive O4.5 V + O5.5 V binary VFTS 352 in the Tarantula nebula is one of the shortest-period and most massive overcontact binaries known. Recent theoretical studies indicate that some of these systems could ultimately lead to the formation of gravitational waves via black hole binary mergers through the chemically homogeneous evolution pathway. By analyzing ultraviolet-optical phase-resolved spectroscopic data, we aim to constrain atmospheric and wind properties that could be later used to confront theoretical predictions from binary evolution. In particular, surface abundances are powerful diagnostics of the evolutionary status, mass transfer and the internal mixing processes. From a set of 32 VLT/FLAMES visual and 8 HST/COS ultraviolet spectra, we used spectral disentangling to separate the primary and secondary components. Using a genetic algorithm wrapped around the NLTE model atmosphere and spectral synthesis code FASTWIND, we perform an 11-parameter optimization to derive the atmospheric and wind parameters of both components, including the surface abundances of He, C, N, O and Si. We find that both components are hotter than expected compared to single-star evolutionary models indicating that additional mixing processes may be at play. However the derived chemical abundances do not show significant indications of mixing when adopting baseline values typical for the system environment.

Results and Conclusions

- There is some evidence for mixing
  - Stars are hotter than expected
  - Carbon and Oxygen show possible depletion
  - HOWEVER, no Nitrogen enrichment

- **Most likely a result of binary interactions, not of internal mixing.**

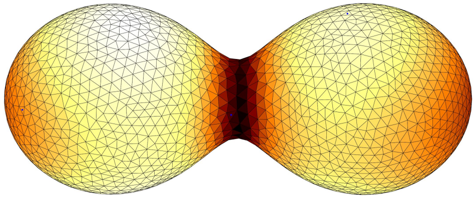
- The non-spherical nature of the system can also cause uncertainties
  - 2-D Surface Patch Model could help this

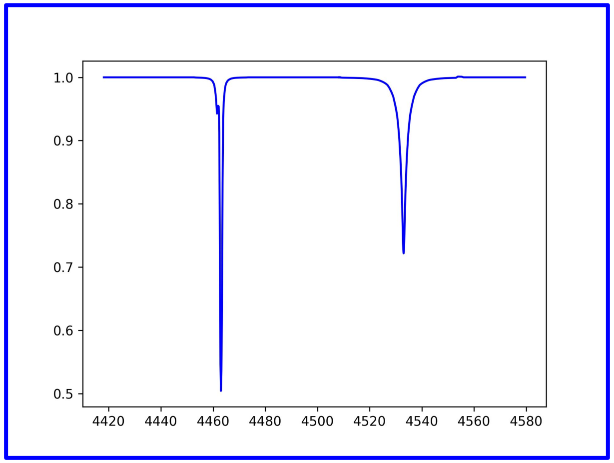
How can we solve this?

PHOEBE + FASTWIND

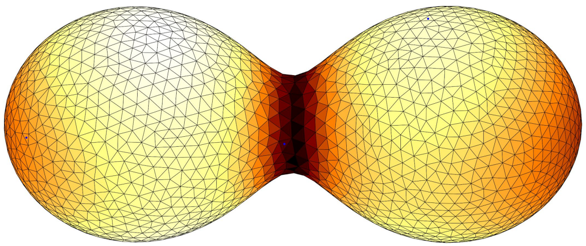
How can we solve this?

PHOEBE + FASTWIND





Phoebe 2

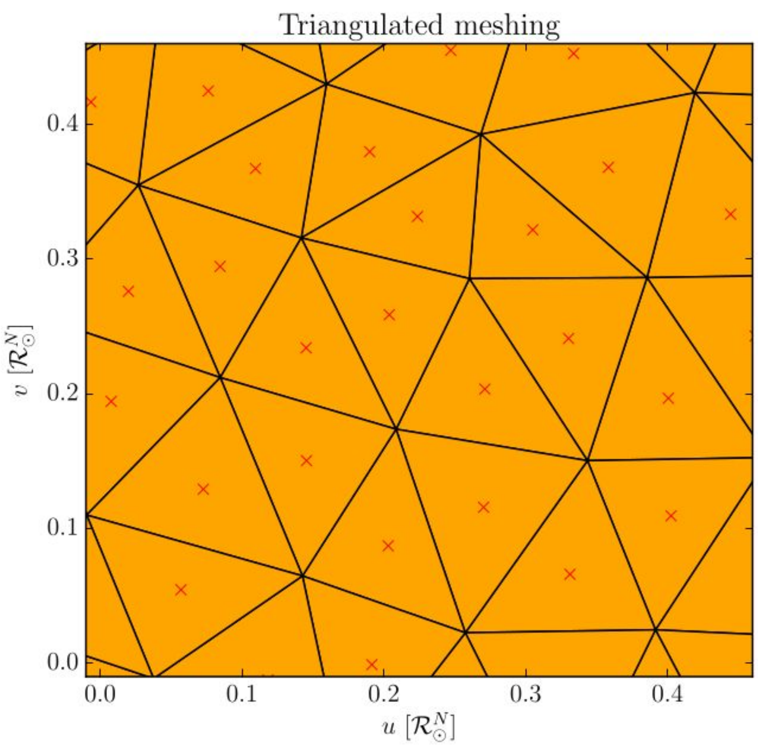


- Wilson-Devinney-like code used to model eclipsing binary light curves and radial velocity curves
- From the binary solution, a 3D mesh model is constructed
- Using the 3D mesh, a light curve (or RV curve) is constructed

(Prša et al. 2016)

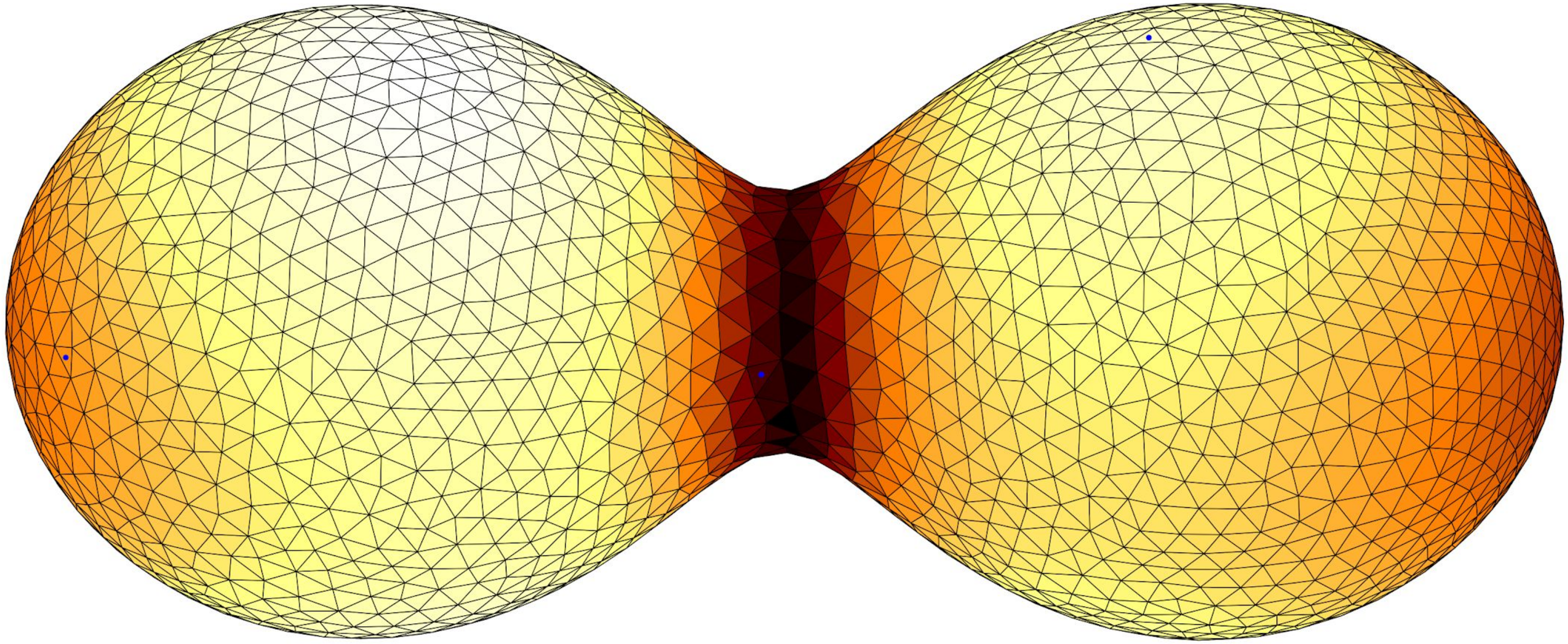
Physics already included in Phoebe:

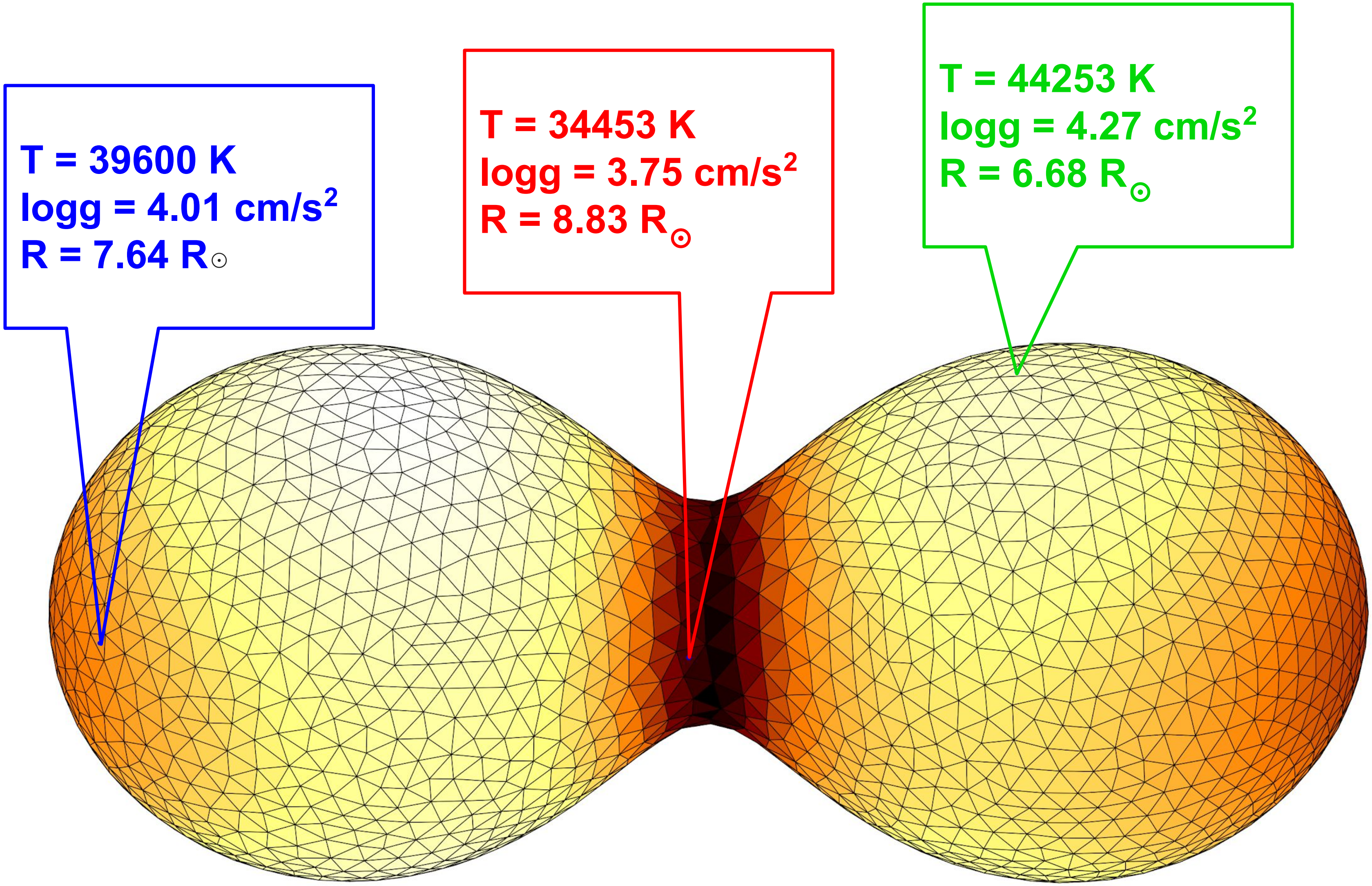
- Surface deformation
- Surface meshing
- Limb darkening
- Gravity brightening
- Reflection effect
- Radial velocity across the surface
- Volume conservation for eccentric orbits

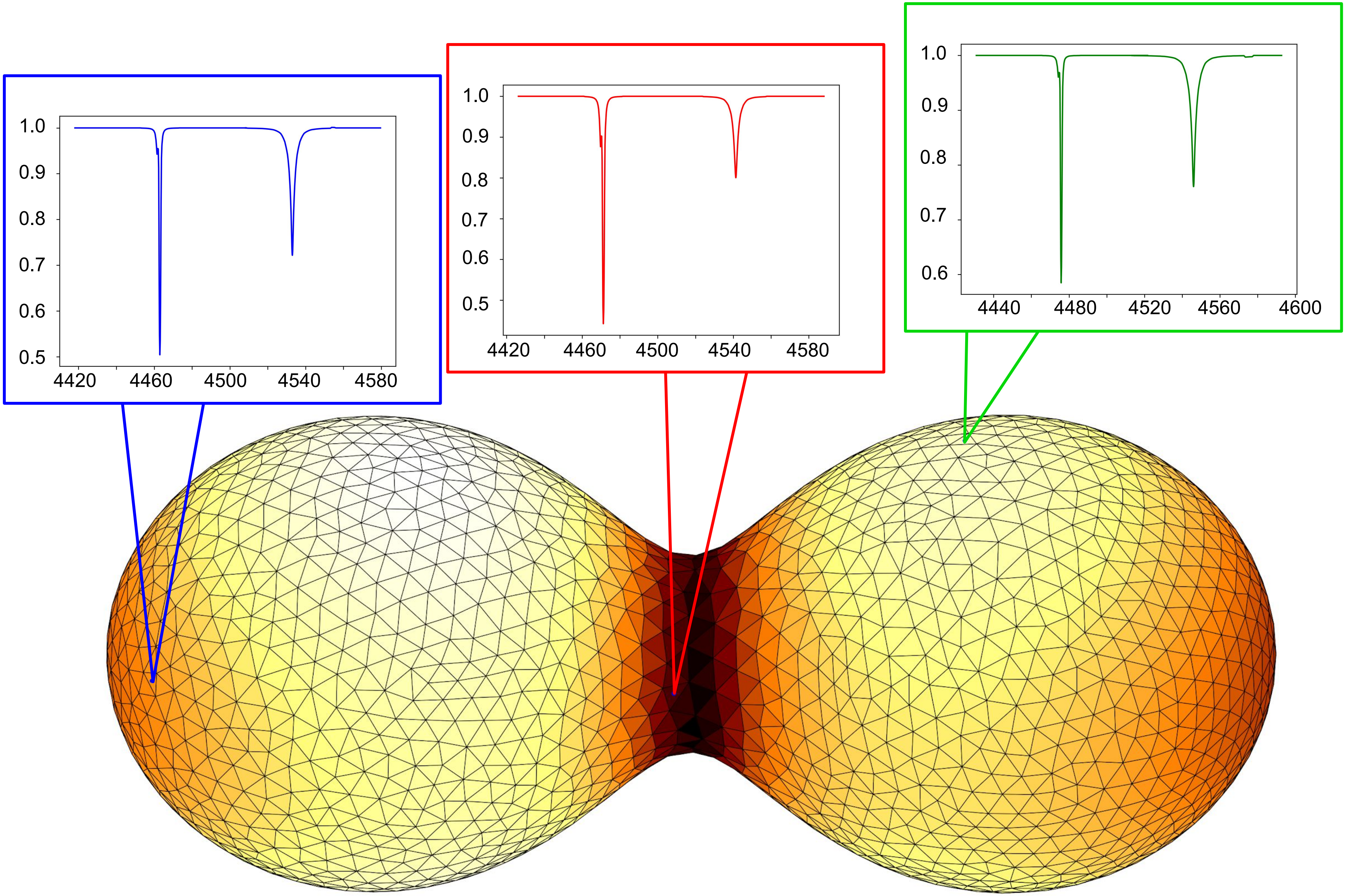


(Prša et al. 2016)

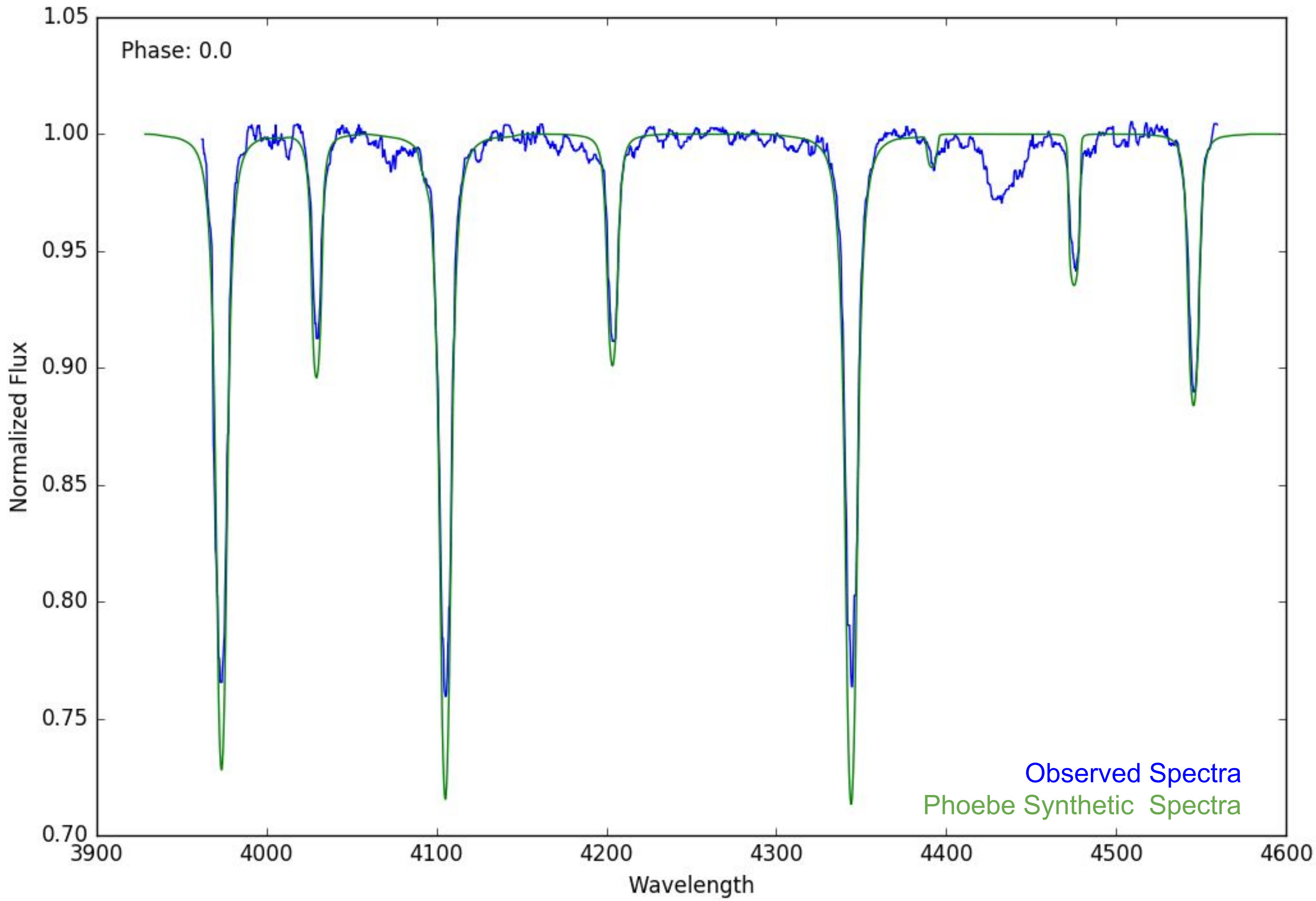
PHOEBE 2 Model of VFTS 352




T = 39600 K
logg = 4.01 cm/s^2
R = 7.64 R$_\odot$
T = 34453 K
logg = 3.75 cm/s^2
R = 8.83 R$_\odot$
T = 44253 K
logg = 4.27 cm/s^2
R = 6.68 R$_\odot$

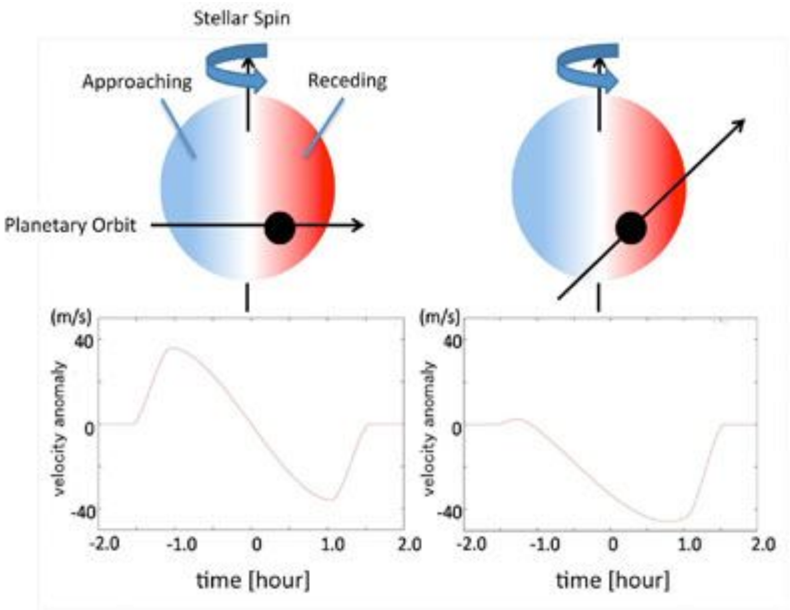

1.0
0.9
0.8
0.7
0.6
0.5
4420
4460
4500
4540
4580
1.0
0.9
0.8
0.7
0.6
0.5
4420
4460
4500
4540
4580
1.0
0.9
0.8
0.7
0.6
4440
4480
4520
4560
4600

Phoebe Spectra by Phase



Other Applications of this technique

- Rapidly-rotating systems
- Heartbeat stars
- Semi-detached binaries
- Binaries
    - Struve Sahade effect
    - Rossiter-McLaughlin effect
- Triples
- Anything that Phoebe can model!



Benefits and Drawbacks

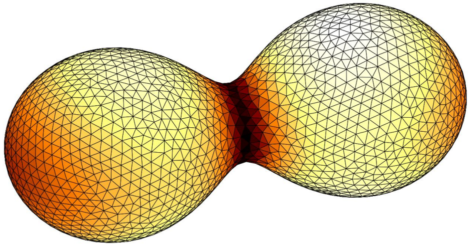
Pros:

+ All of the physics included in Phoebe comes for free
+ 3D shape of systems are accounted for
+ Both components can be fit simultaneously (No disentangling needed!!!)

Cons:

- Wind treatment needs improvement
- Constrained by the pre-computed FASTWIND grid (however a new grid can be provided by the user if they wish)

Summary



Spectroscopic Analysis of VFTS 352

- Temperatures suggest CHE, however abundances do not
- Likely a result of **binary interactions**

Phoebe Spectral Modeling

- **3D** treatment of massive overcontact binaries with more physics than any previous method
- Can be applied to a variety of spherical and **non-spherical** objects
- All components fit simultaneously