re:pair - a framework for

# SELF-CONSISTENT ANALYSIS OF SPECTROSCOPIC AND PHOTOMETRIC TIME-SERIES OF DLEB

## A look into mass discrepancy problem

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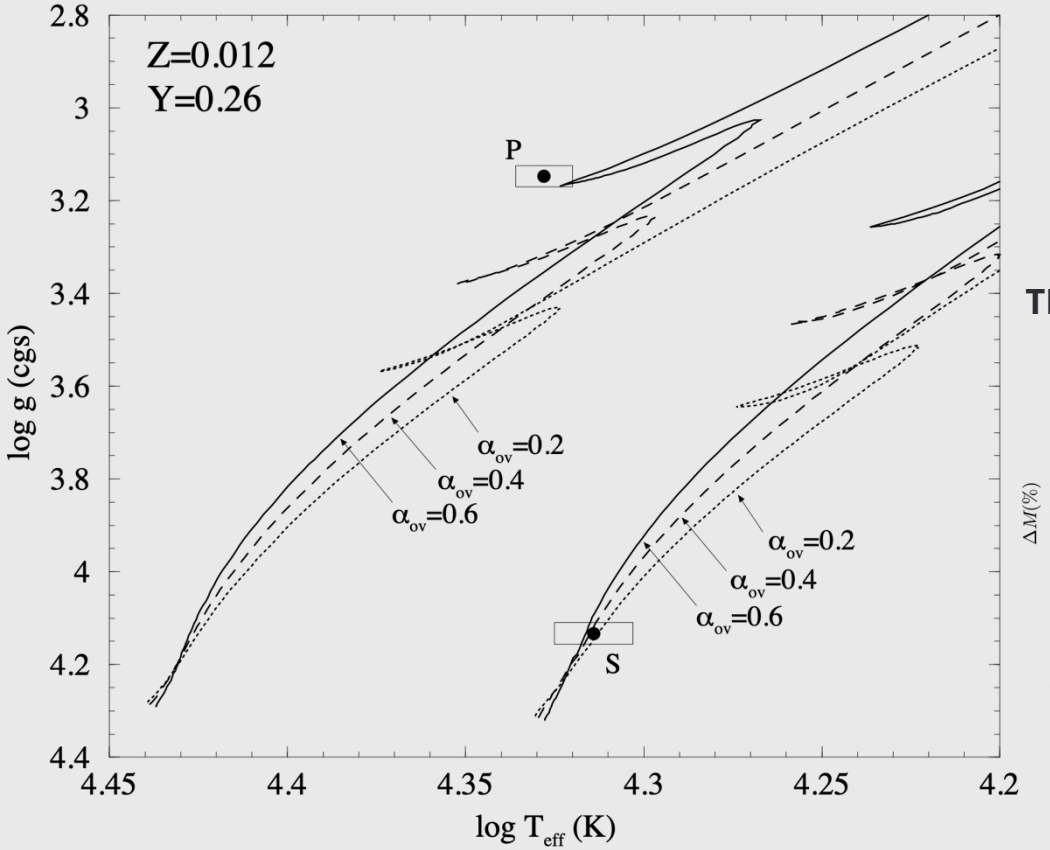
12 Sep 2024

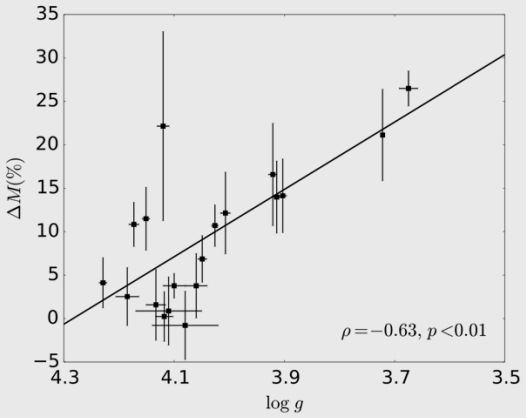
# Eclipsing SB2 (or DLEB) = precise and accurate masses

Mass discrepncy in massive systems – mismatch of dynamic and evolutionary masses

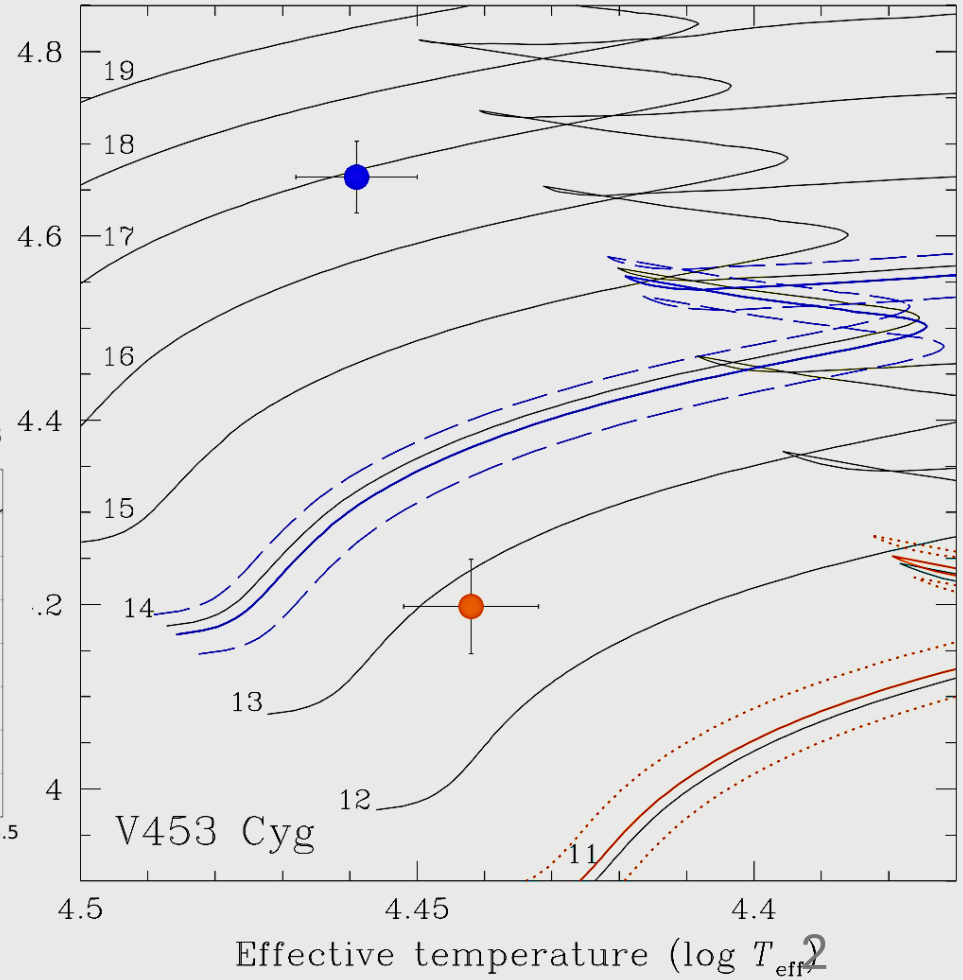
**Guinan et al. 2000: V380 Cyg (11.1 + 6.95 $M_\odot$)**




**Tkachenko et al. 2020: 11 EBs**




**Pavlovski et al. 2018 (13.9 + 11.1 $M_\odot$)**



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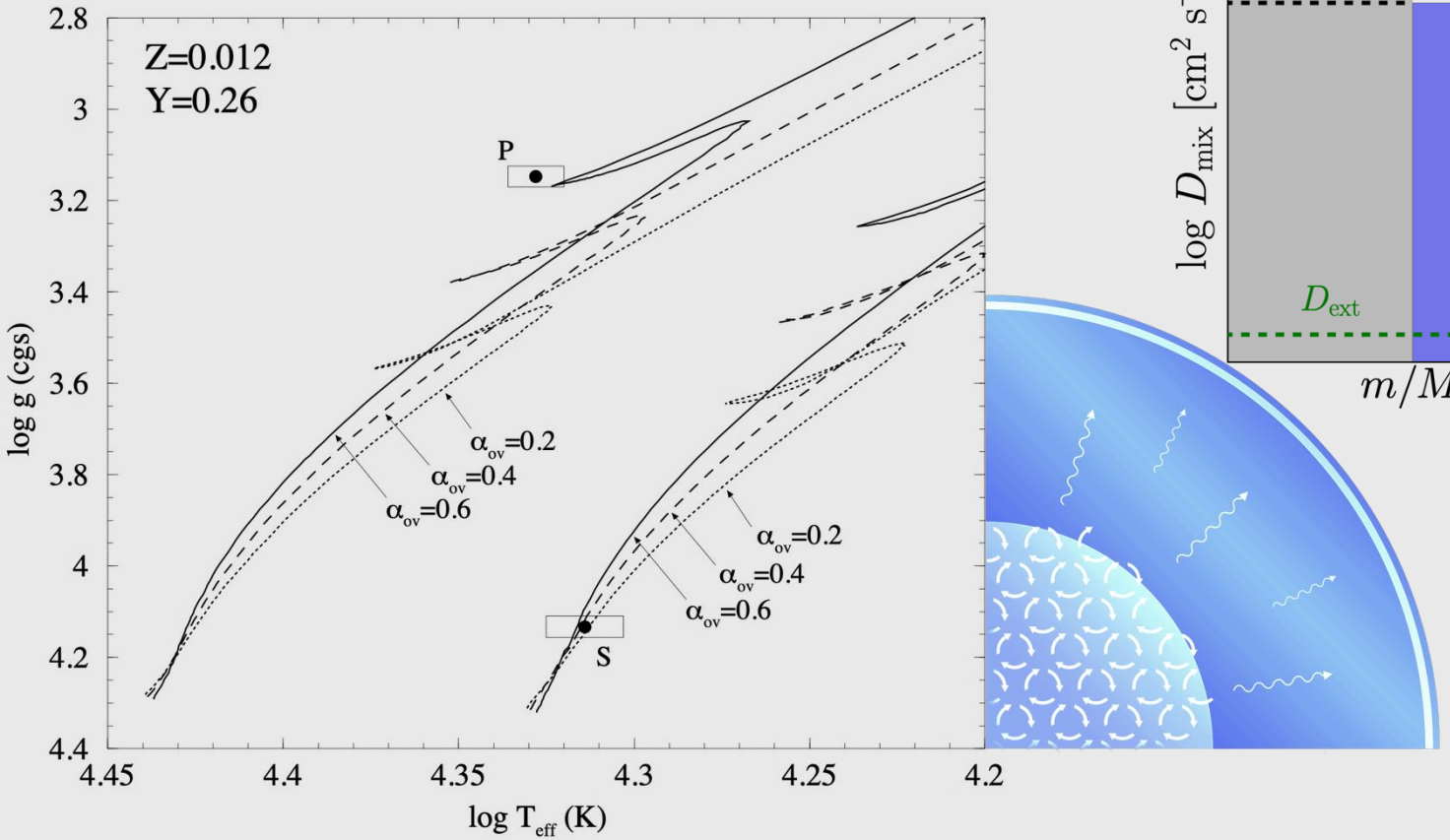
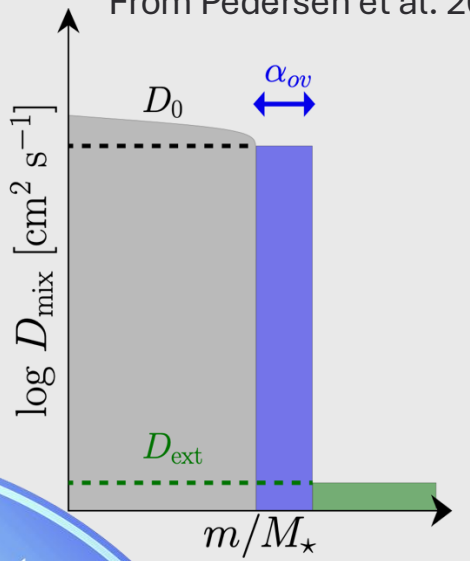
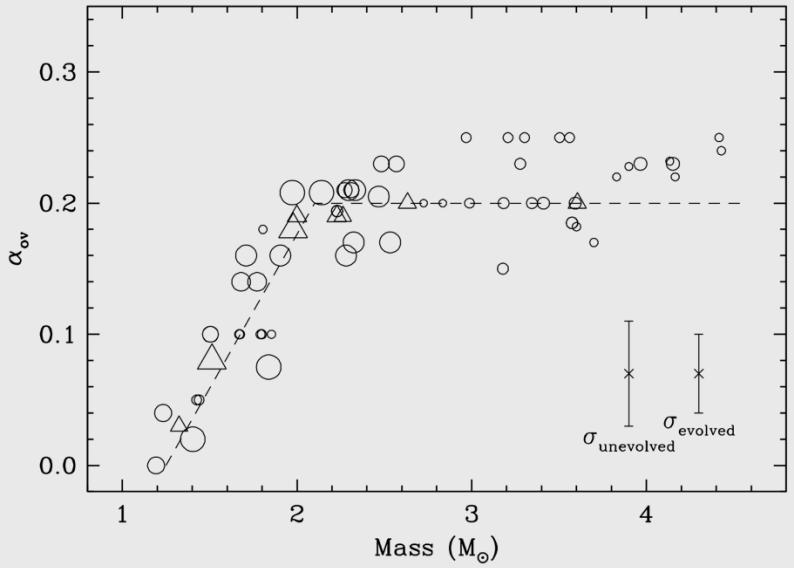



From Pedersen et al. 2018




Guinan et al. 2016-2019
Compillation of 33 binaries

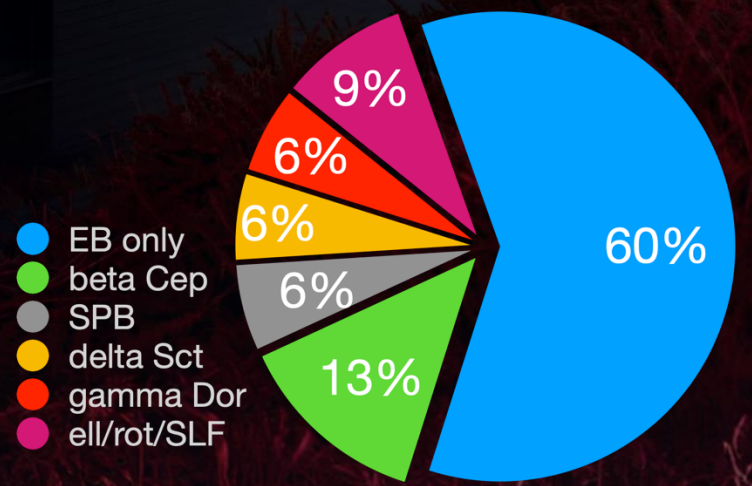


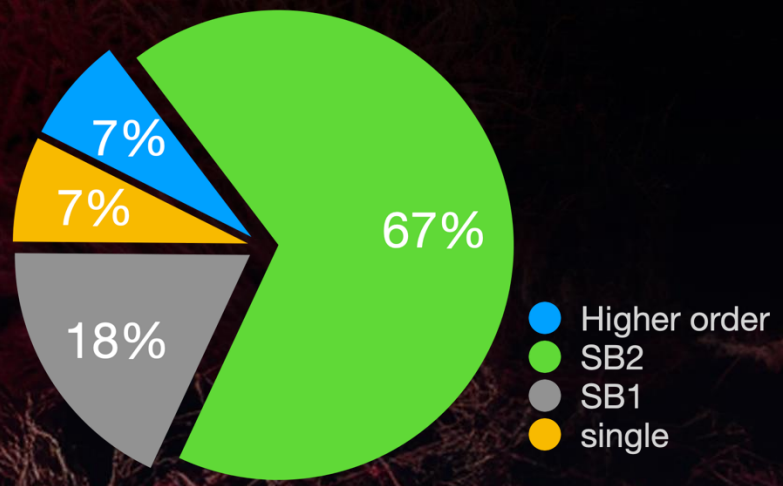
# HERMES follow-up of TESS EB

HERMES: high-resolution spectrograph (R=85000)

EB identification in TESS lightcurves by **Luc IJspeert 2021**

- OBAF
- Periods 0.5d - 30+d
- 8+ spectra per orbit
- 134 started, 91 completed




**Tkachenko et al. 2023 for details**

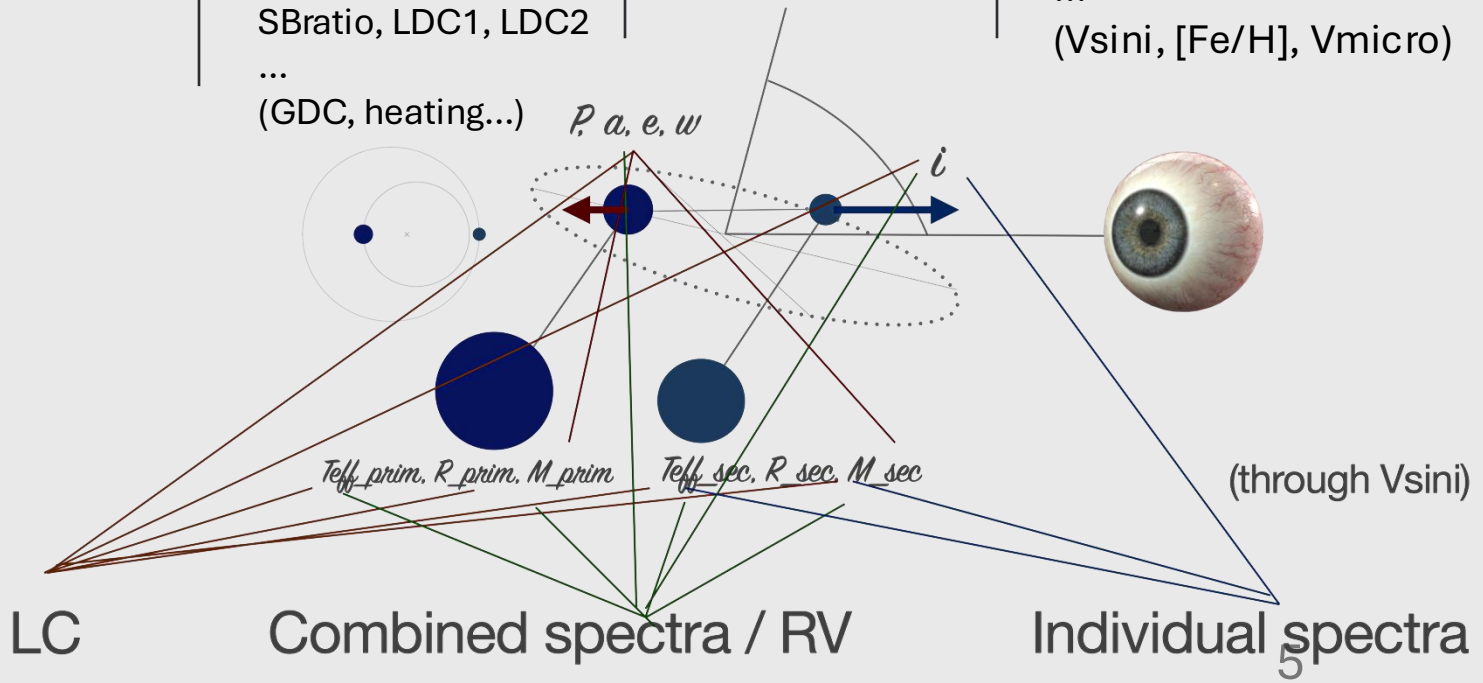
Needed:

**Fast,**
**automated** and
**self-consistent**
framework that handles
time-series of **combined spectra**
and **lightcurves**

Classic:

Iterative fitting of one data type at time

| LC | Combined spectra/RV | Individual spectra |
|---|---|---|
| P, q, R1/a, R2/a, i, f_c, f_s (e, w), SBratio, LDC1, LDC2 … (GDC, heating…) | P, K1, K2, e, w | Teff, logg, … (Vsini, [Fe/H], Vmicro) |



Needed:

**Fast,**
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framework that handles
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and **lightcurves**

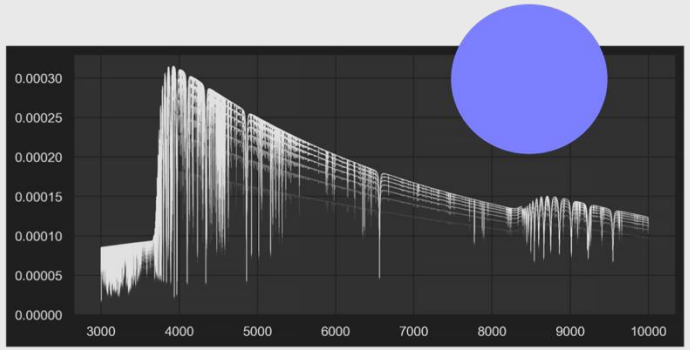
One set of parameters to model all data:

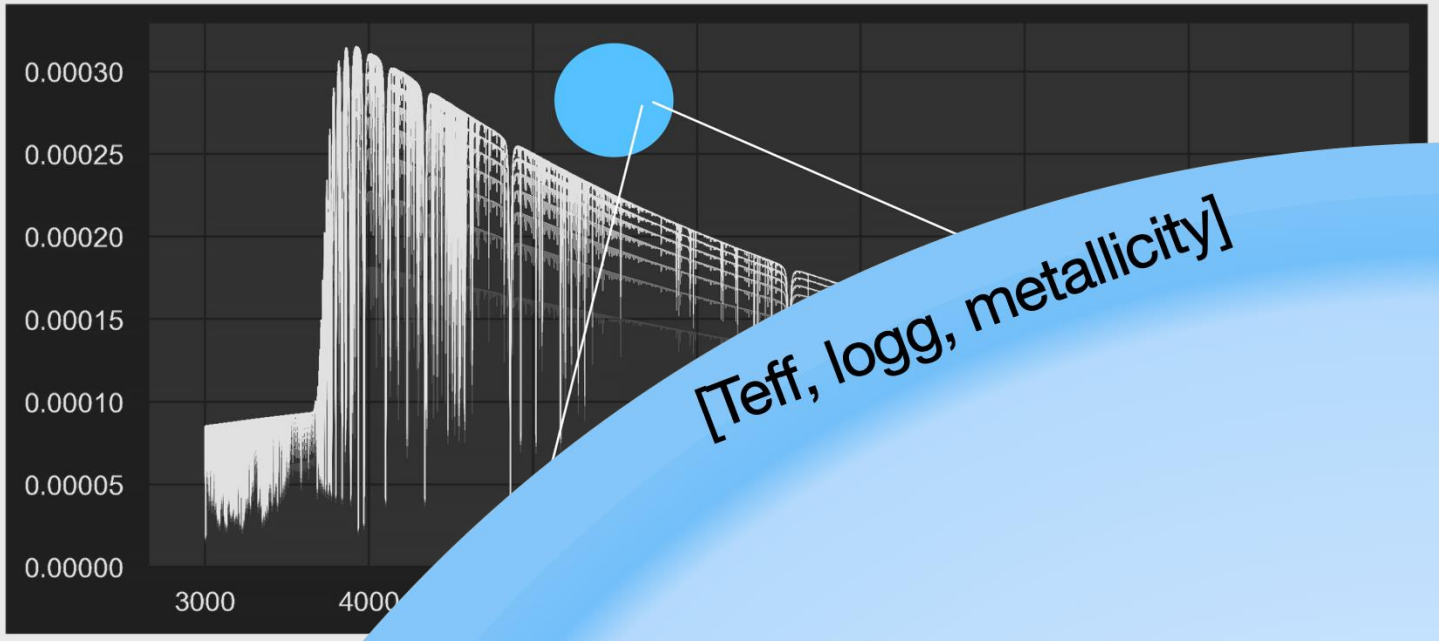
Atmospheric parameters of primary and secondary, orbital parameters, …

Framework around existing codes

| | | |
|---|---|---|
| `ellc` | (Maxted 2016) | - LC modelling |
| `SynthV` | (Tsymbal 1996) | - Spectral synthesis |
| routines from `FDBinary` | (Ilijić 2003) | - Spectra separation |

# Synthetic spectra



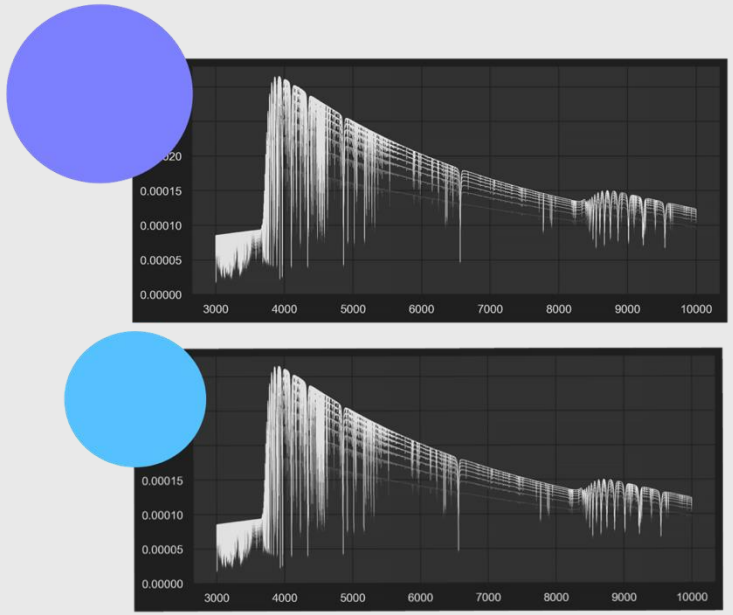




[Teff, logg, metallicity]

Specific intensities I(μ) – limb darkening

Atmosphere models grid: LLmodels
Radiative transfer code: SynthV
(Tsymbal 1996, Tkachenko 2015)
Atomic data: VALD (Pakhomov et al. 2019)

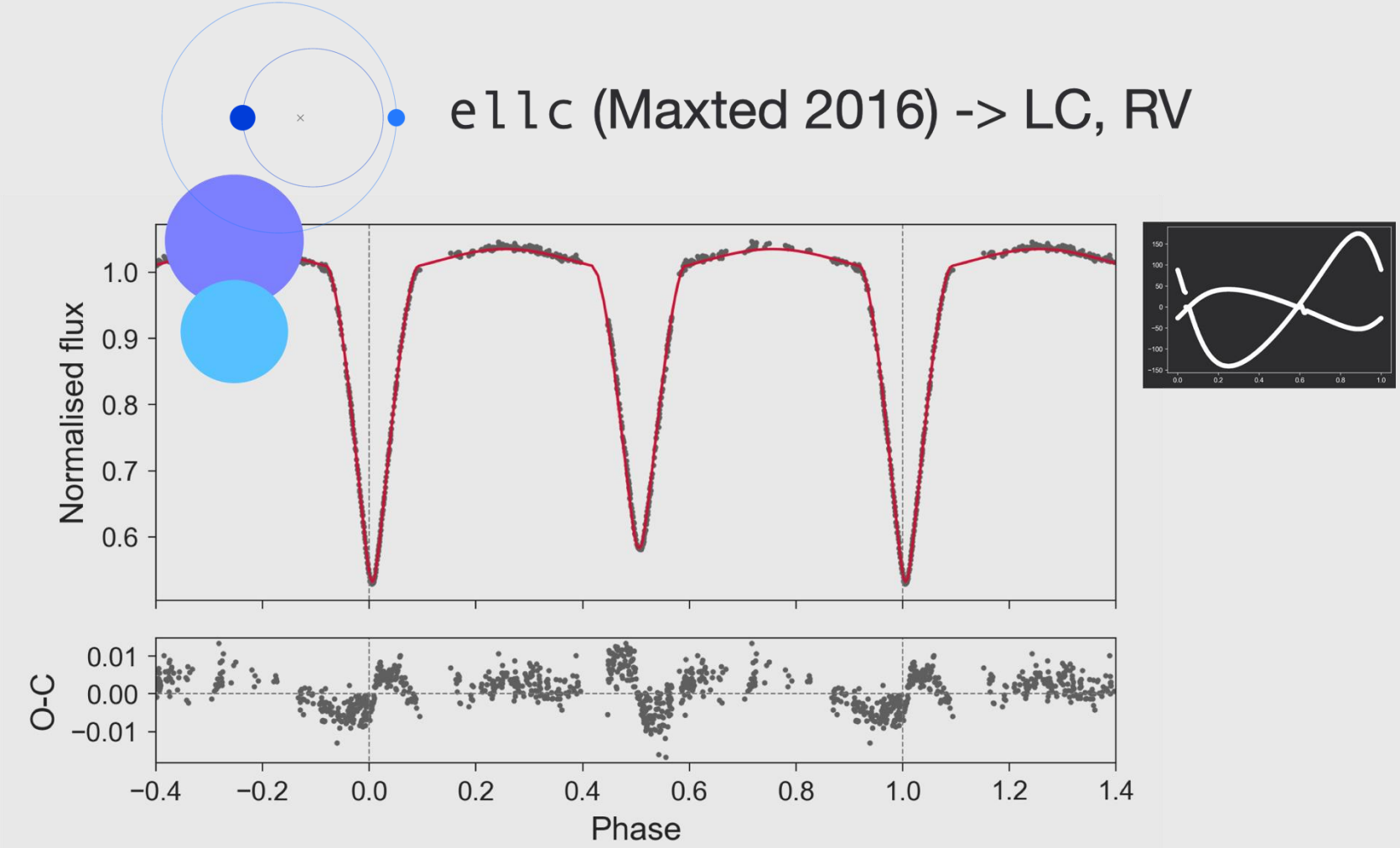
# Model LC and RV





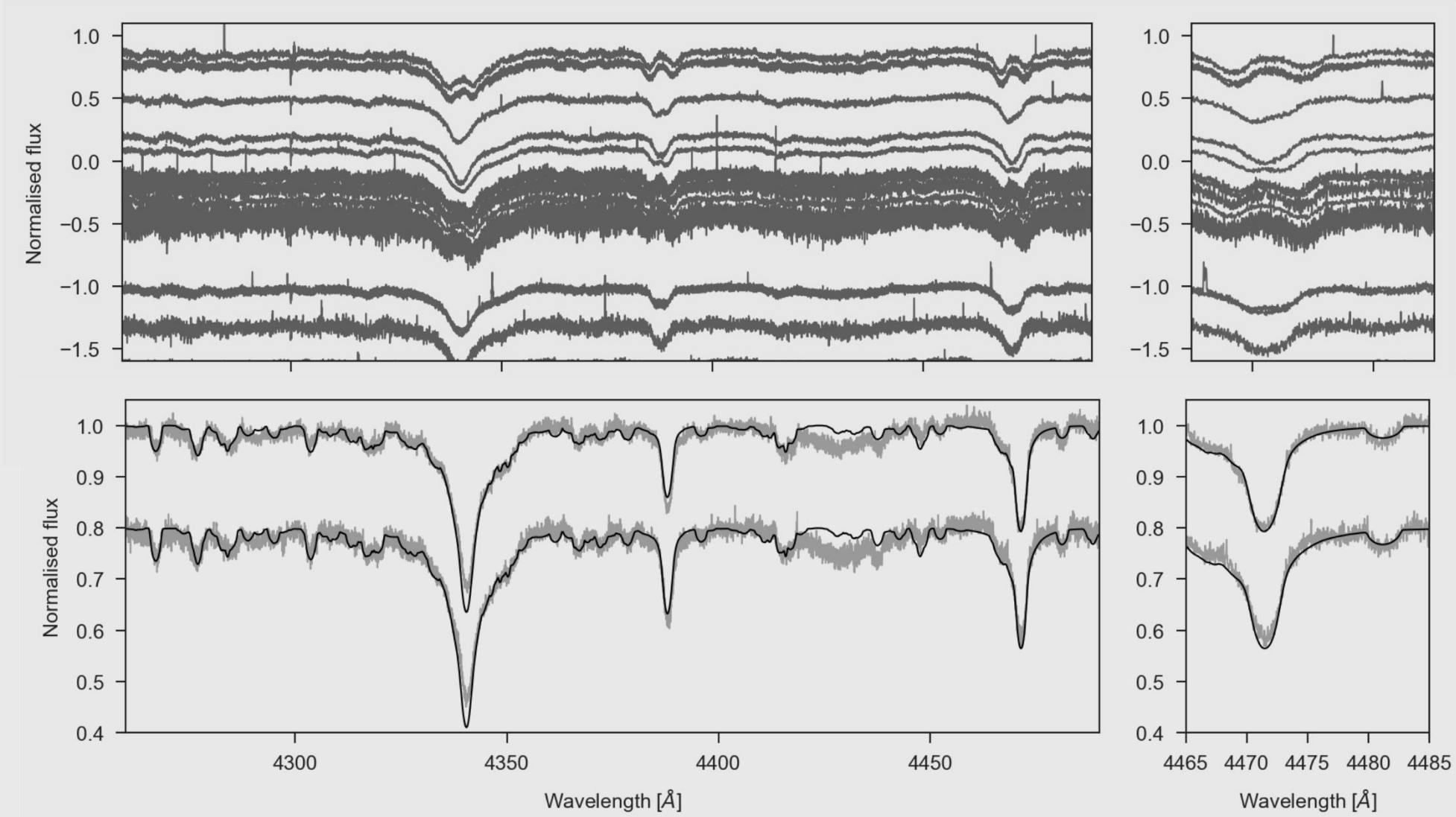


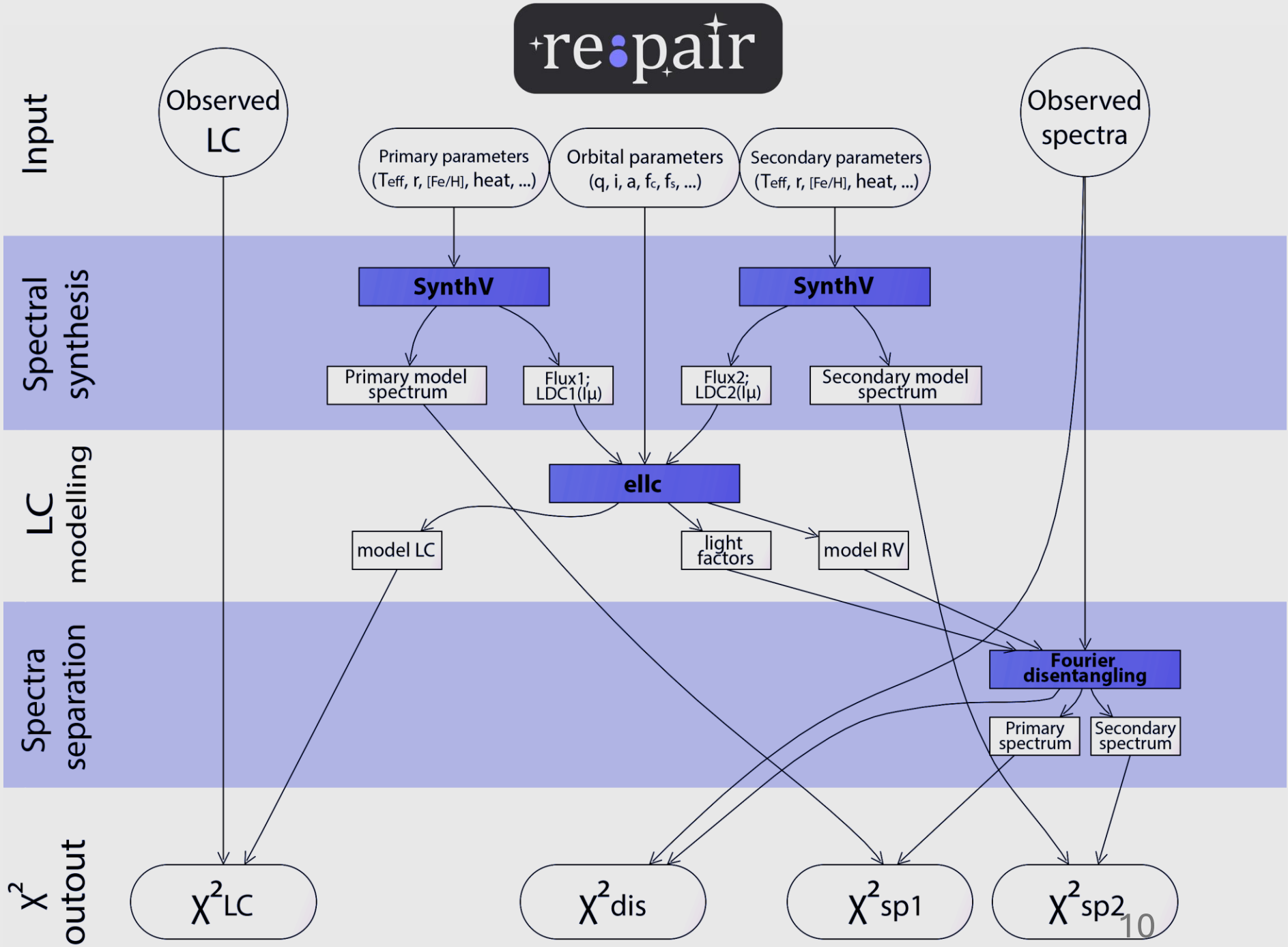
`ellc` (Maxted 2016) -> LC, RV

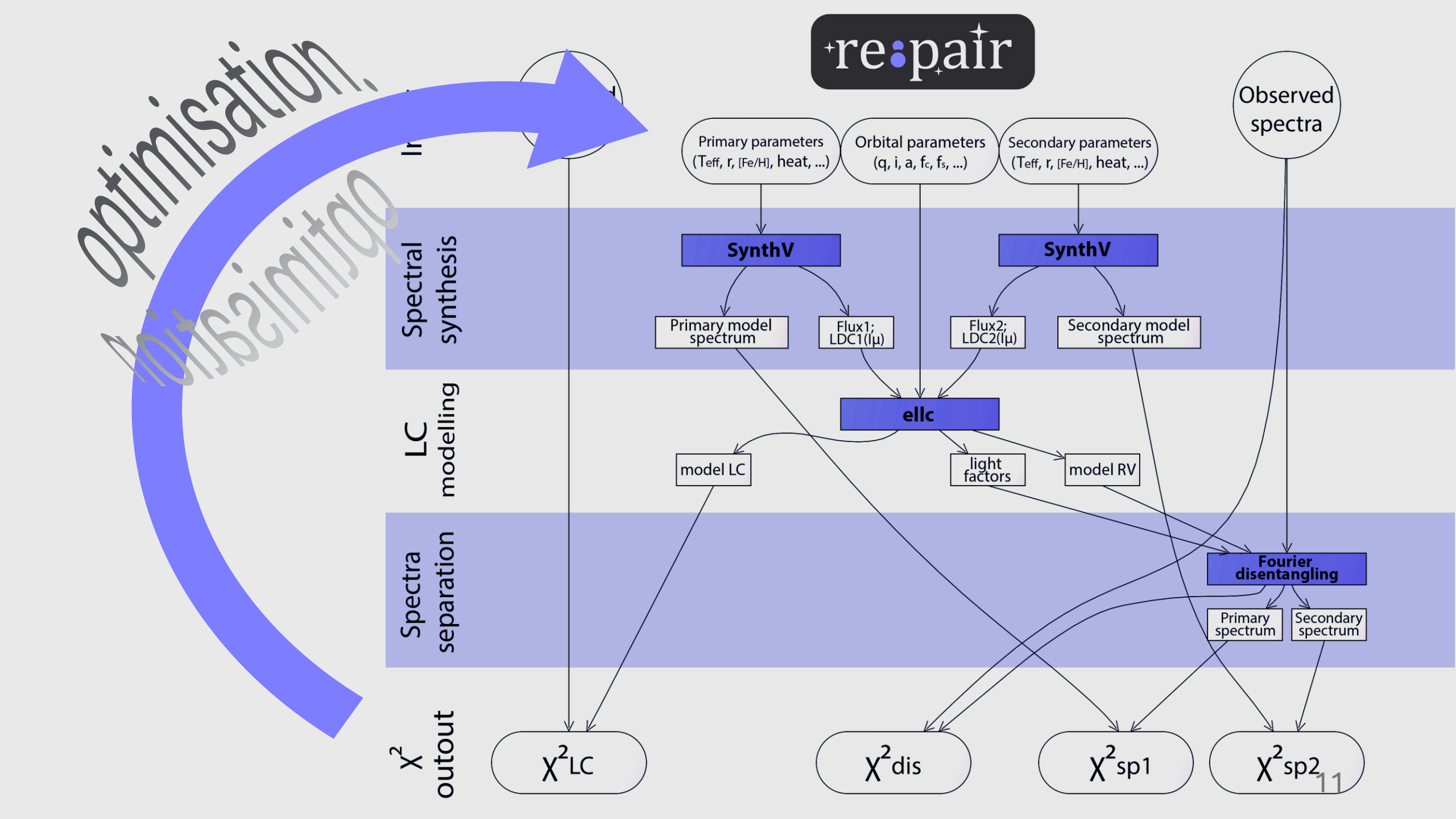


# Spectra separation

`FDBinary` (Ilijić 2003) (Fourier disentangling) - adopted module for spectral separation




re:pair
Input
Observed LC
Primary parameters (Teff, r, [Fe/H], heat, ...)
Orbital parameters (q, i, a, fc, fs, ...)
Secondary parameters (Teff, r, [Fe/H], heat, ...)
Observed spectra
Spectral synthesis
SynthV
SynthV
Primary model spectrum
Flux1; LDC1(lμ)
Flux2; LDC2(lμ)
Secondary model spectrum
LC modelling
ellc
model LC
light factors
model RV
Spectra separation
Fourier disentangling
Primary spectrum
Secondary spectrum
χ2 outout
χ2LC
χ2dis
χ2sp1
χ2sp2


optimisation
re:pair
Observed spectra
Primary parameters (Teff, r, [Fe/H], heat, ...)
Orbital parameters (q, i, a, fc, fs, ...)
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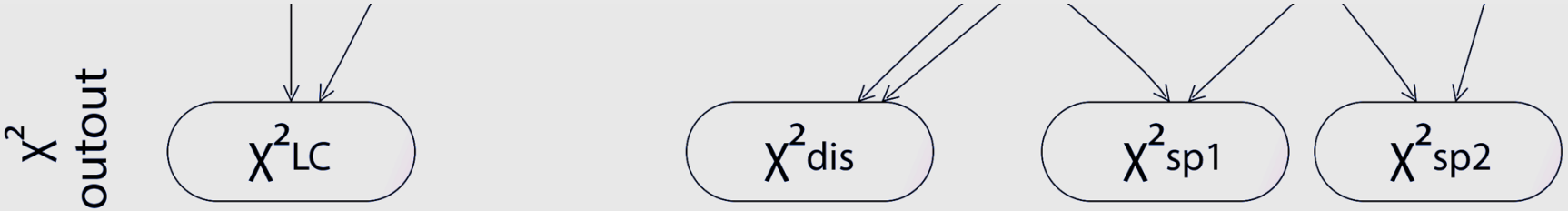
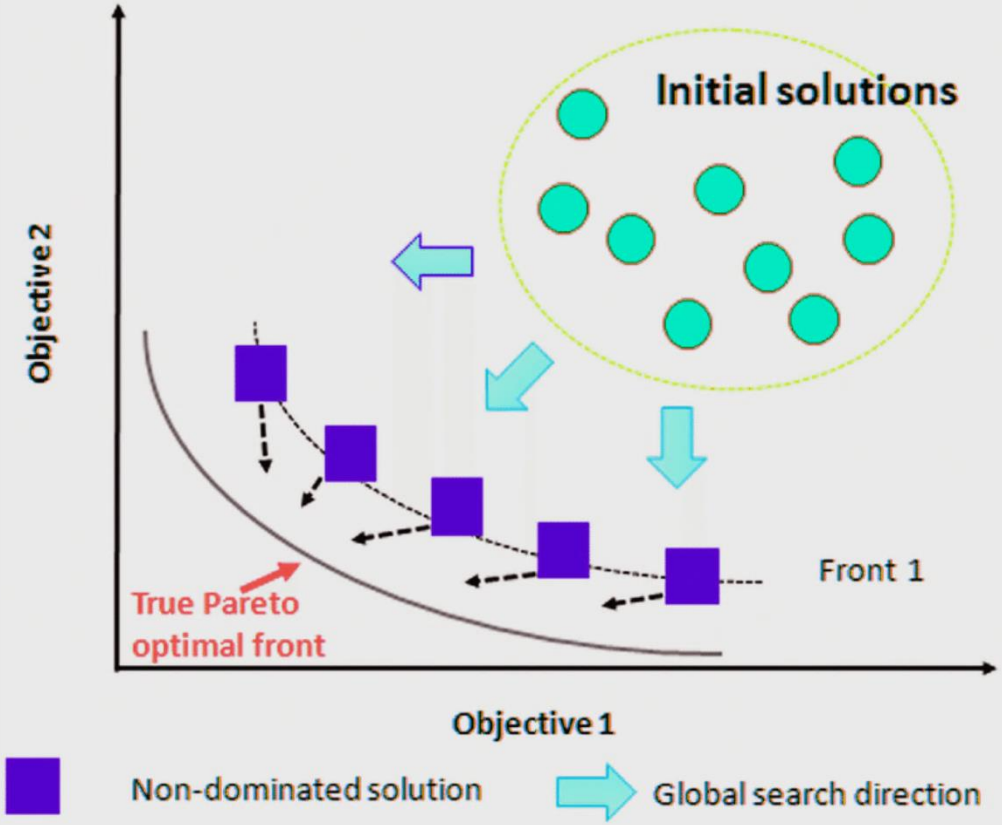
# Multi-objective optimisation




2D illustration
(we need to deal with 4D objectives space!)

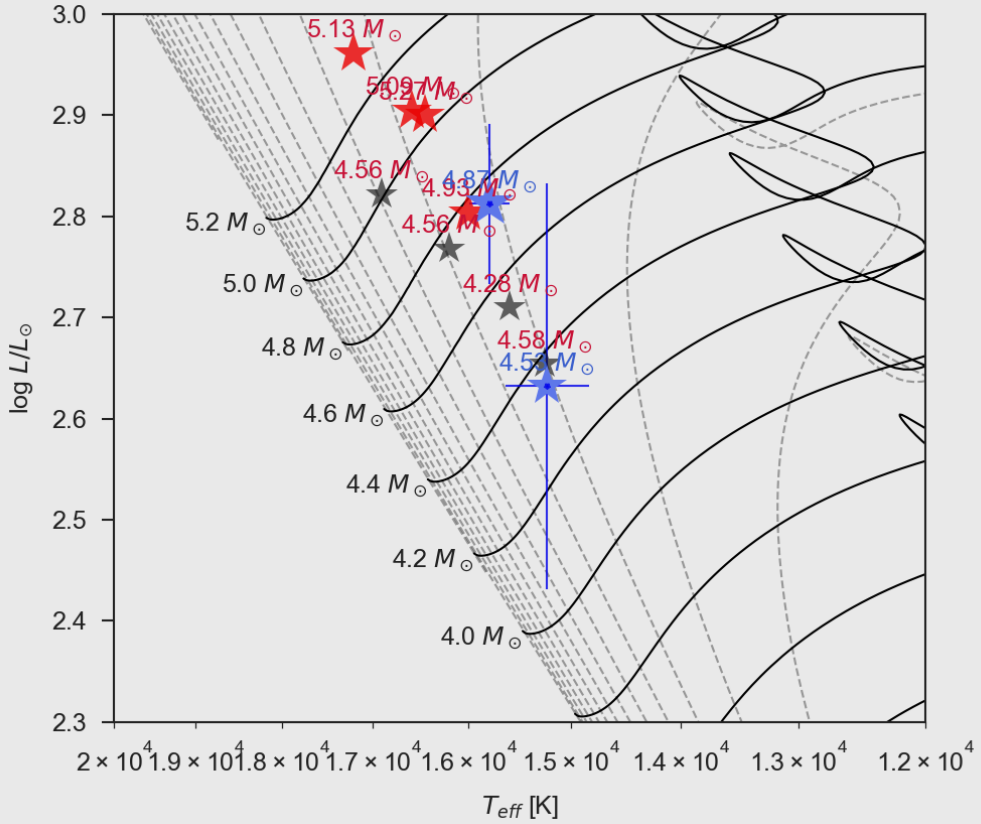
DEAP python library implementation
NSGA-II
Non-dominated Sorting **Genetic** Algorithm

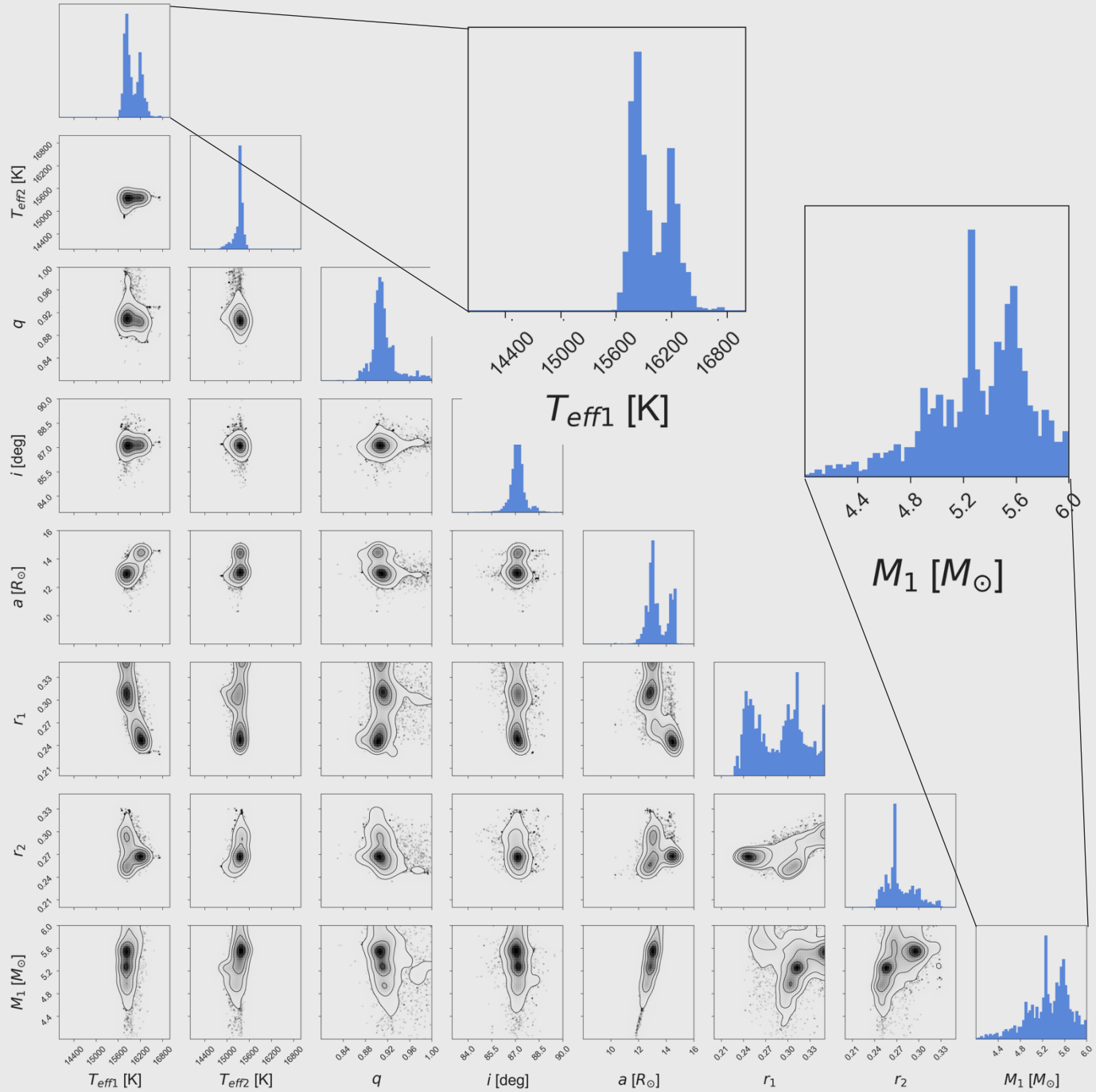



re:pair
[ **R**evising **E**clipsing binaries analysis : **P**hotometry **A**nd spectroscopy **I**nfused **R**ecipe ]

# U Oph – 5 $M_\odot$

| Holmgren et al. (1991) | Vaz et al. (2007) |
|---|---|
| 4.93 ± 0.05 | 5.273 ± 0.091 |
| 4.56 ± 0.04 | 4.783 ± 0.072 |
| **Budding et al. (2009)** | **Johnston et al. (2021)** |
| 5.13 ± 0.08 | $5.09^{+0.06}_{-0.05}$ |
| 4.56 ± 0.07 | $4.58^{+0.05}_{-0.05}$ |



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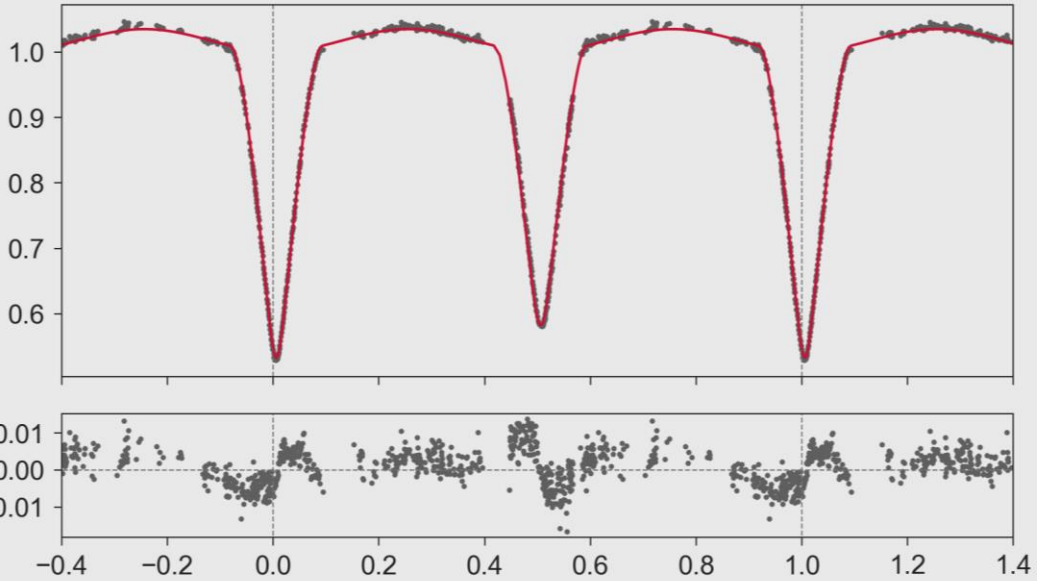
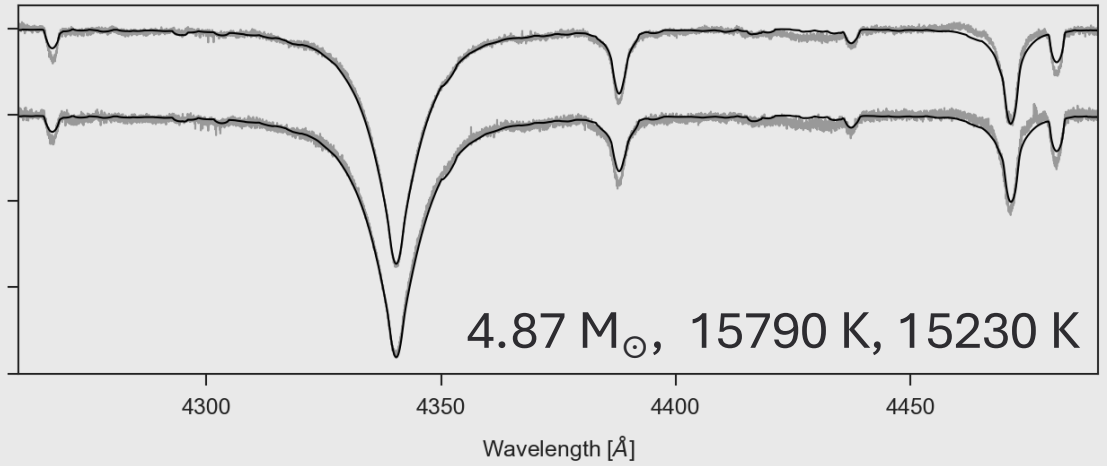
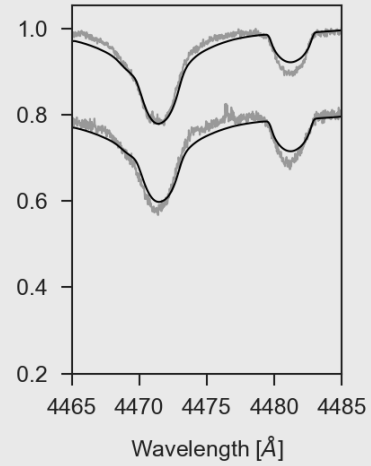
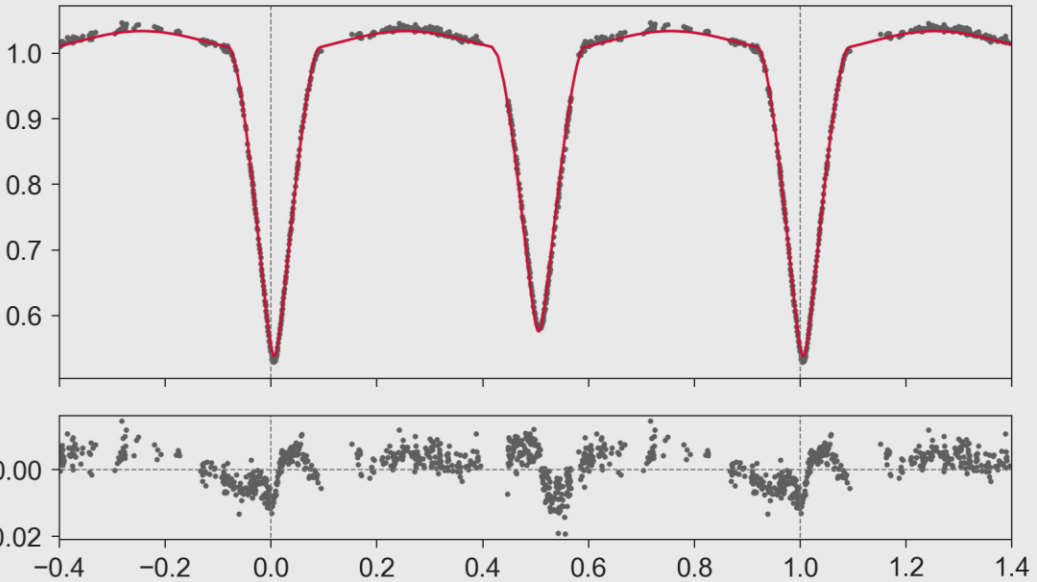
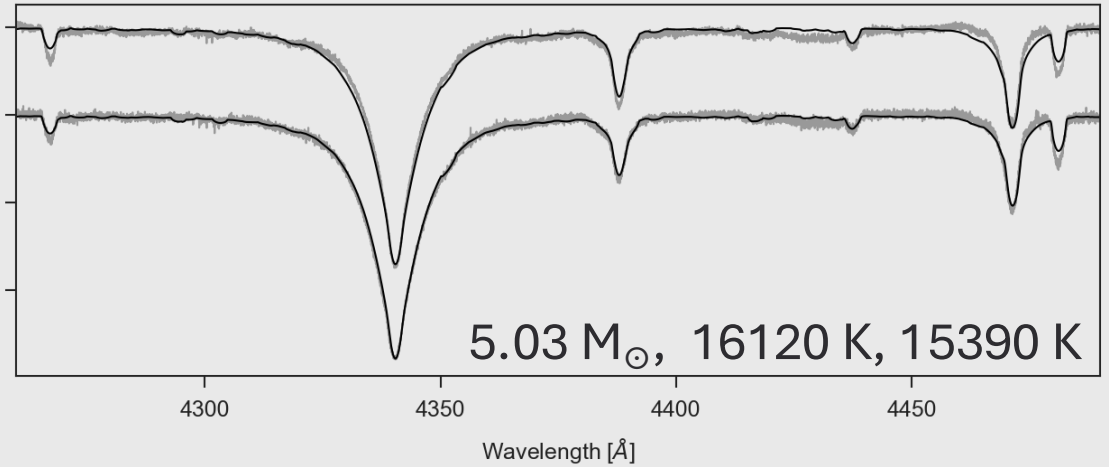


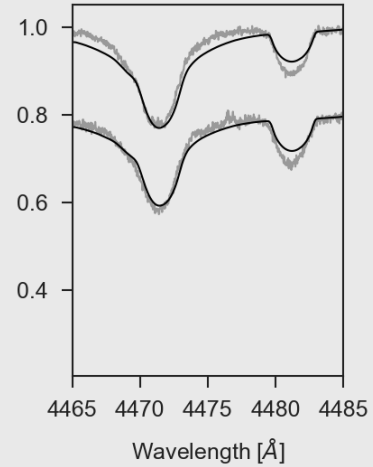




$X^2$LC = 0.022, $X^2$DIS = 26.108, $X^2$SP = 0.725, $X^2$SS = 1.212

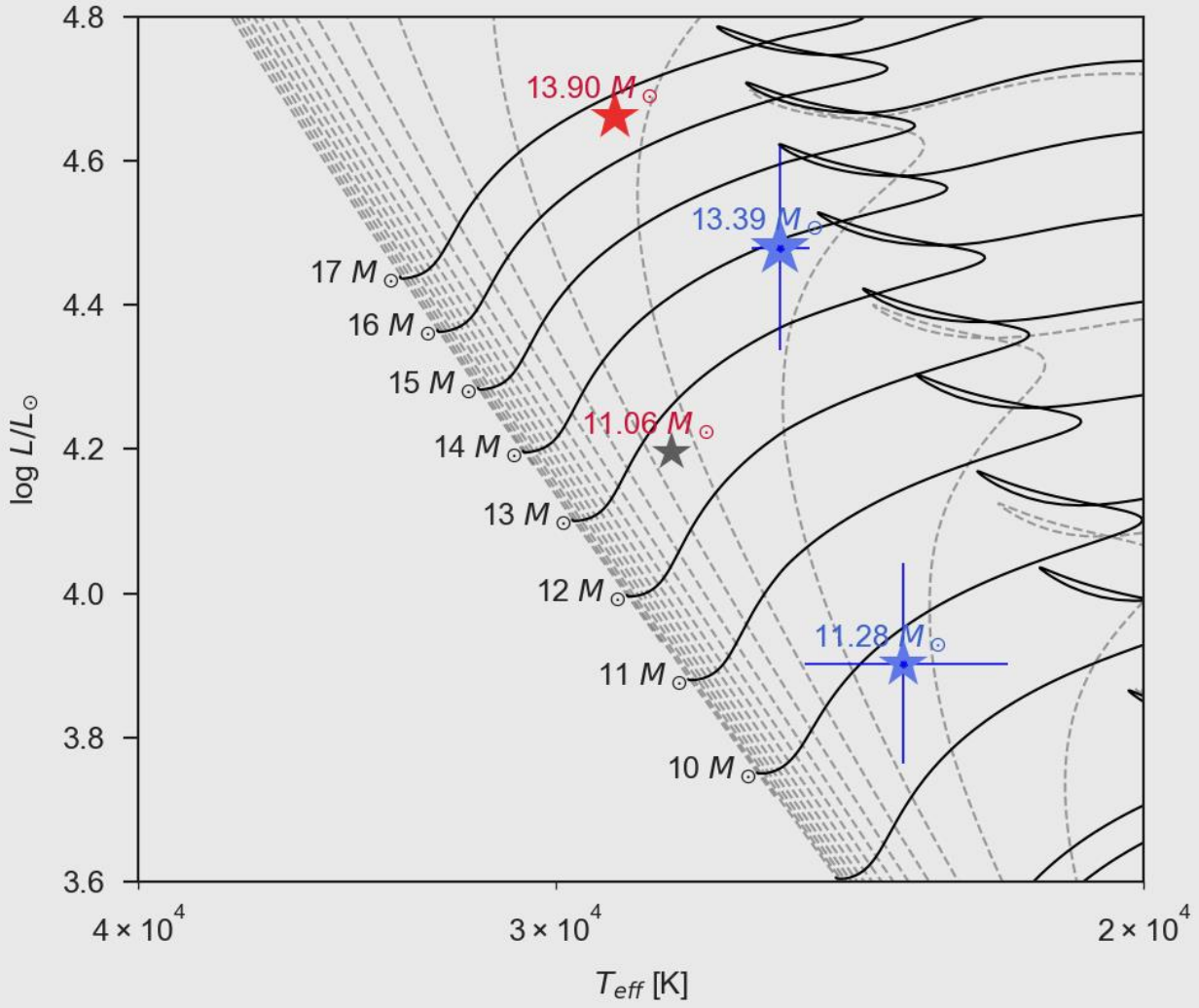


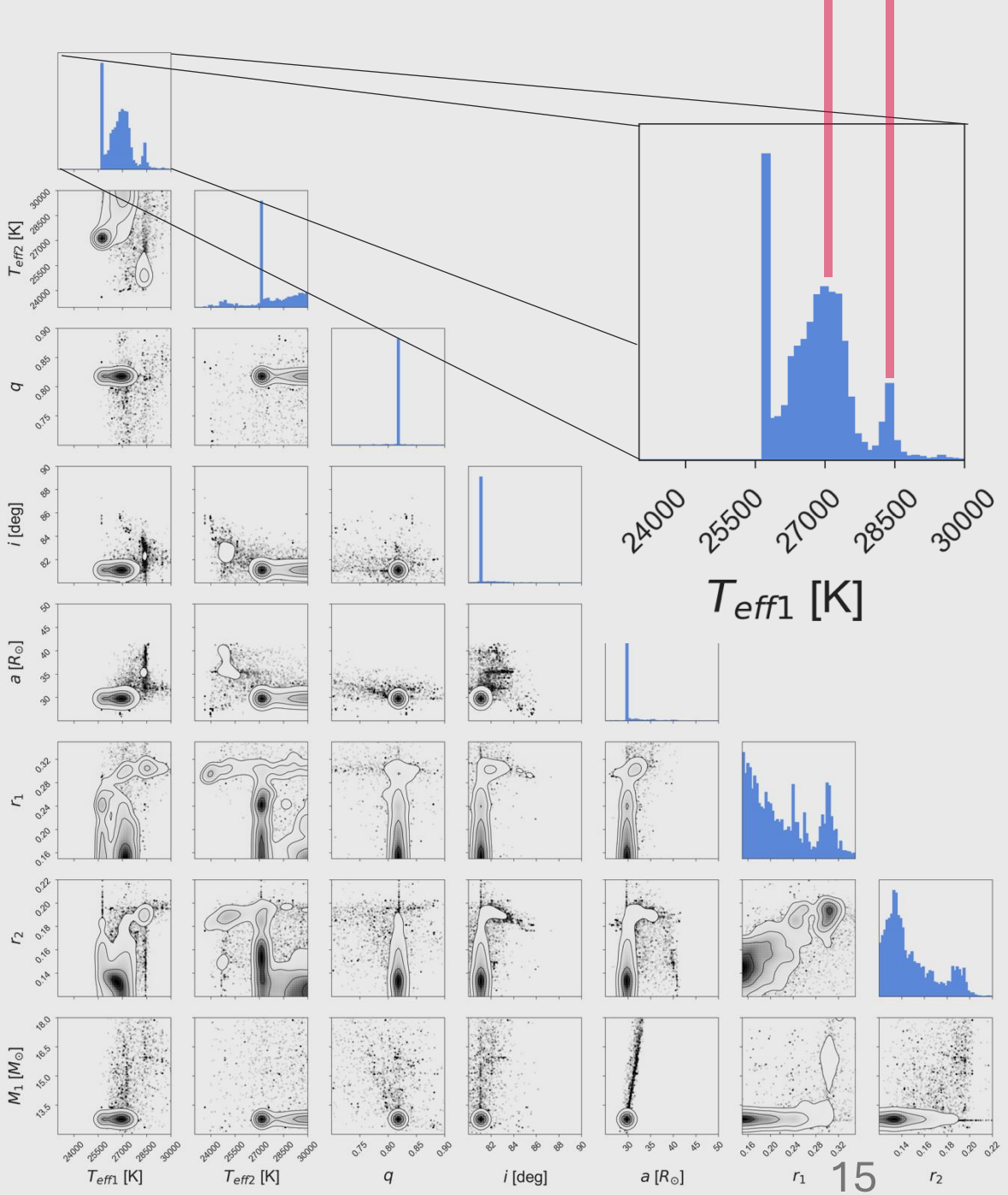




$X^2$LC = 0.026, $X^2$DIS = 37.098, $X^2$SP = 1.414, $X^2$SS = 0.711

# V453 Cyg – 14 $M_\odot$



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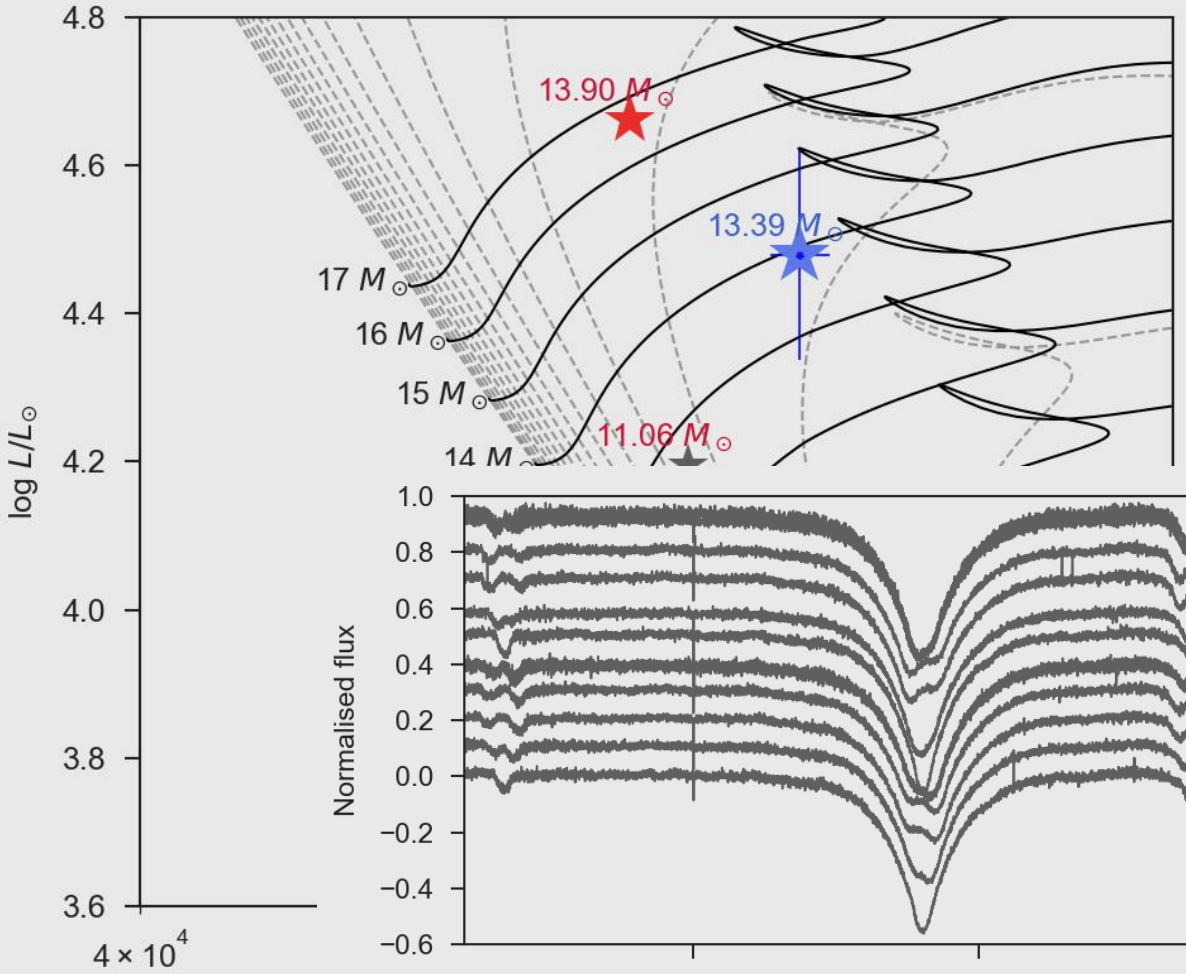


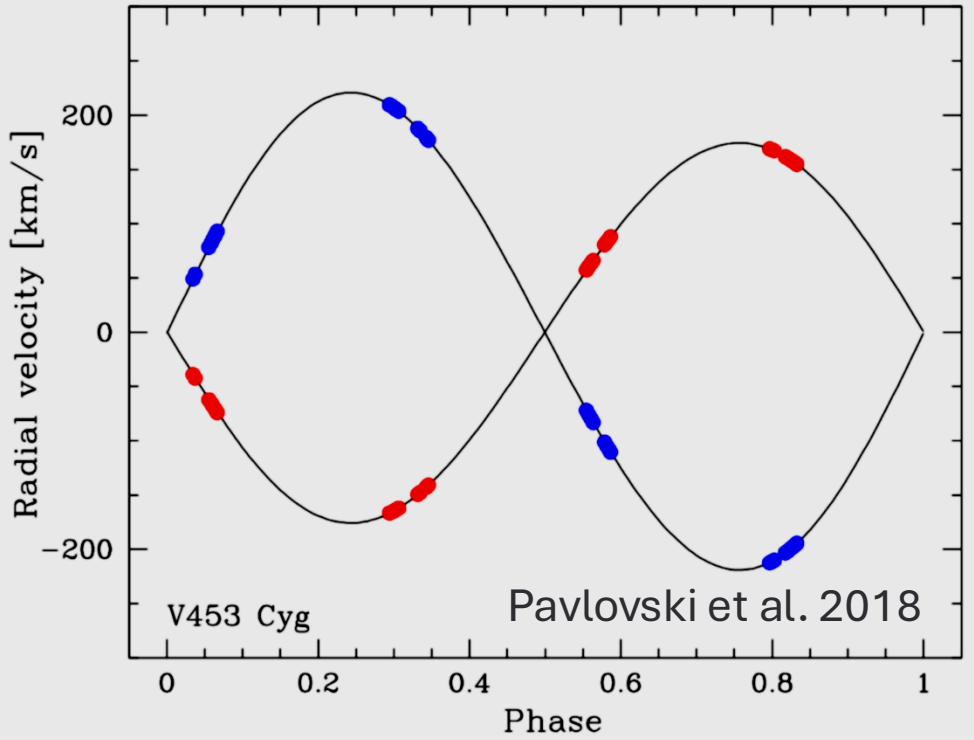


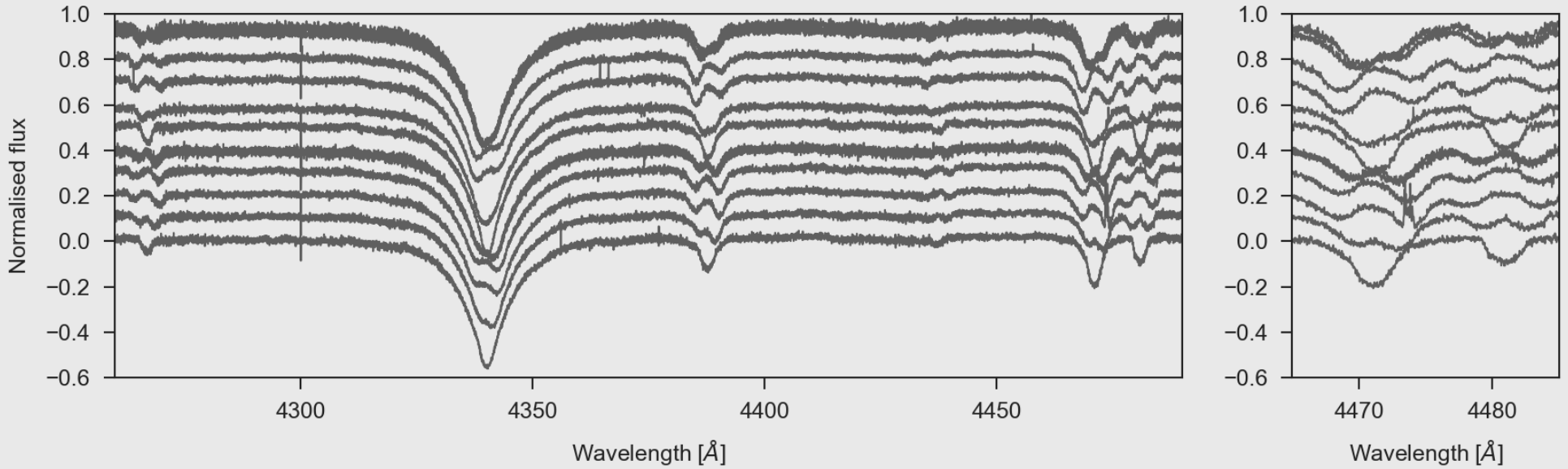

# Conclusions

- Multi-objective optimisation:

  **Pros**: allows parameter space exploration without discrimination of non-dominated solutions
  **Cons**: allows parameter space exploration without discrimination of non-dominated solutions

- Mass discrepancy:

  When evolutionary models are the culprit and when are we?
  Homogeneous analysis of a large sample of eclipsing SB2 needed (we are working on it!)

- re:pair - release soon!

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**Acknowledgements**

**This work is possible due to open source codes `ellc` (P. Maxted), `SynthV` (V. Tsymbal), and `FDBinary/fd3` (S. Ilijić), that are all extremely efficient, well-tested, and flexible**

Special thanks to **Kresimir Pavlovski** for extensive masterclass on spectral disentangling