Exploring variability in B supergiant stars

Pulsation modes and detection of binary systems

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POEMS

Physics of Extreme Massive Stars

Marie-Curie-RISE project funded by the European Union

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Why study pulsations in B supergiant stars?

Uncertainty in their evolutionary state due to the **"blue loop"** (Ekström et al. 2012)

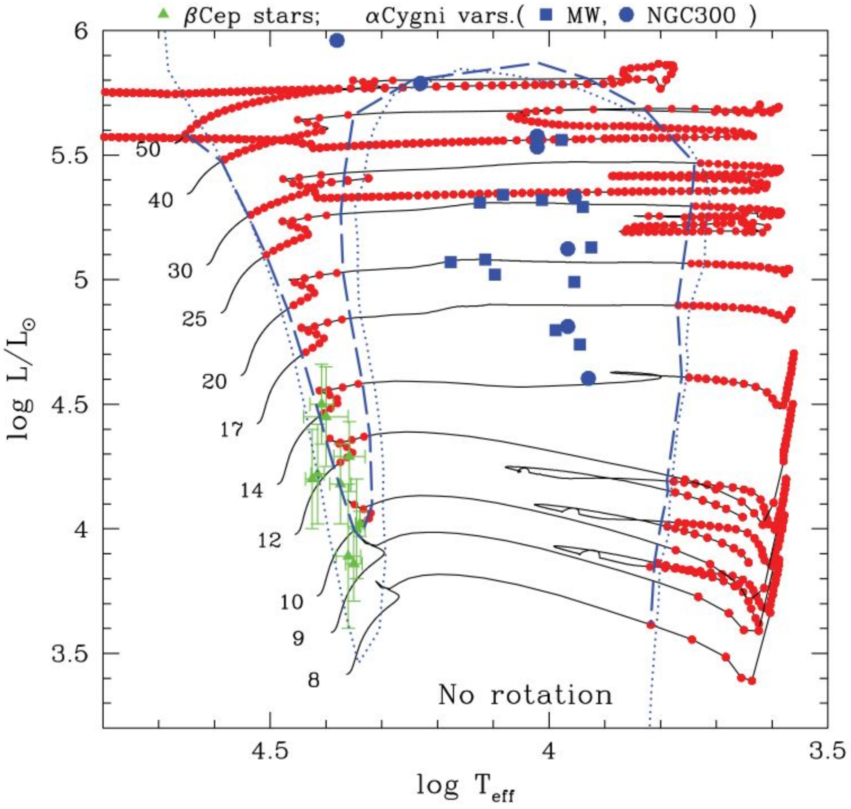
↓

Studying the **pulsation modes**
(Saio et al. 2013)

For stars with Log(L/M) > 4 pulsations excited by **strange modes** could induce variable mass loss phenomena

↓

Modify their evolutionary trajectory
Kraus et al. (2015), Haucke et al. (2018) and Cidale et al. (2023)



(Saio et al. 2013)

Why is it important to search for pulsating stars in binary systems?

Binary systems found for B-SG stars are very rare.

- Natural phenomena (e.g. merger of the binary system (Menon et al. 2024))
- **Observational bias** (pulsations?, observational instruments available?, analysis techniques?)

Mass discrepancy problem:

(Herrero et a. 1992) Spectroscopic mass ≠ Evolutionary mass

(Tkachenko et al. 2014a, 2014b) Dynamical mass ≠ Evolutionary mass

These binary systems are ideal for comparing the **dynamical masses** with those obtained from an **asteroseismological analysis** (model dependent).

Summary

1
Observations

Study 2 stars with Log(L/M) >4
We use light curves obtained by the TESS satellite.

2
Periodicity analysis

Lomb-Scargle periodogram
Weighted Wavelet Z-Transform (WWZ)

3
Stability analysis

We obtained the theoretical radial pulsation modes as a function of the mass

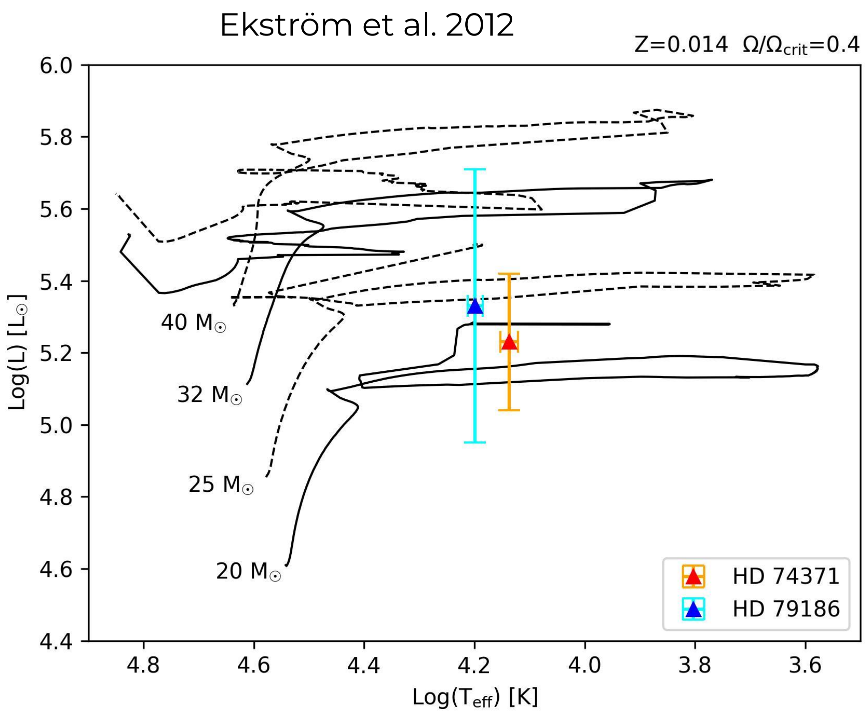
4
Preliminary results

Report independent frequencies
Estimate a value for the mass of the stars
Discuss the possible evolutionary state

Observations

Table 1. Stellar parameters taken from Haucke et al. (2018).

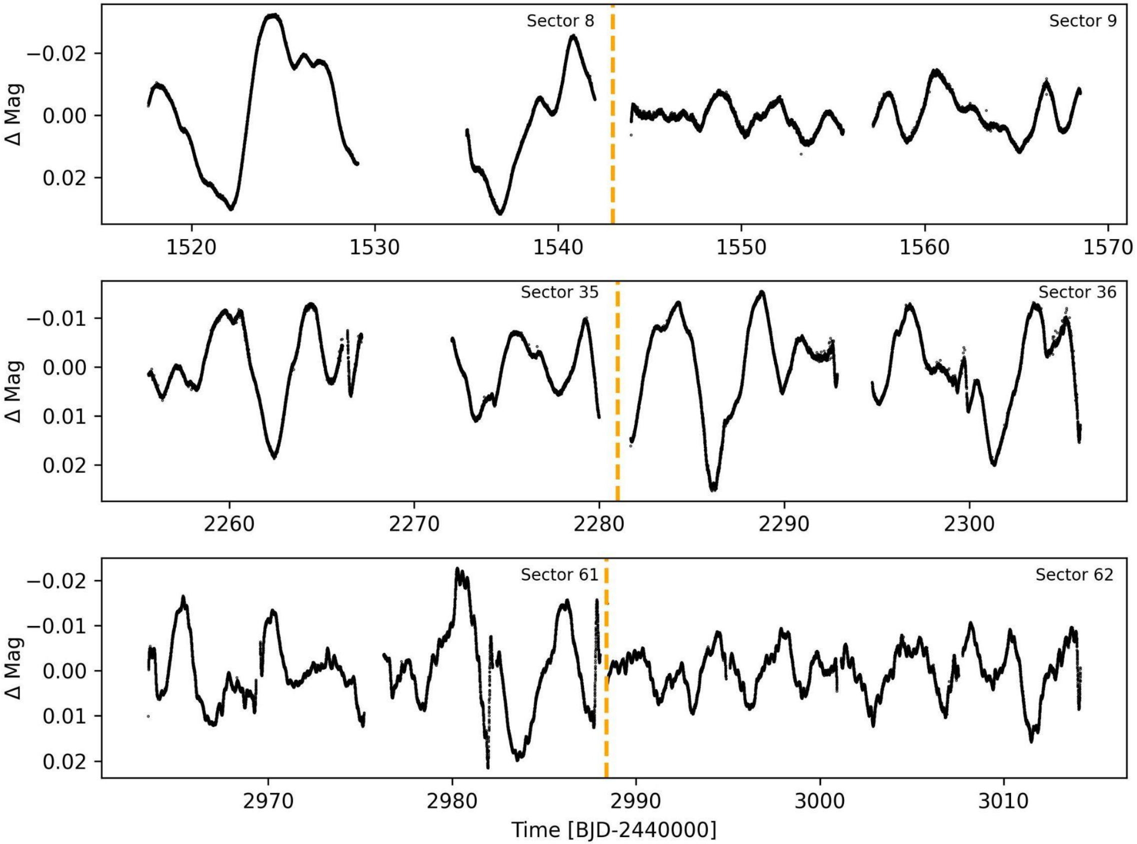
HD Number	HD 74371	HD 79186
S p. type	B6 Iab/b	B5 Ia
T [K]	13700 ± 500	15800 ± 500
$R_\star$ [$R_\odot$]	73	61
$\log(L/L_\odot)$	5.23 ± 0.19	5.33 ± 0.38
$\log(L/M)$	4.17	4.21
$V \sin i$ [km s^{-1}]	40	40

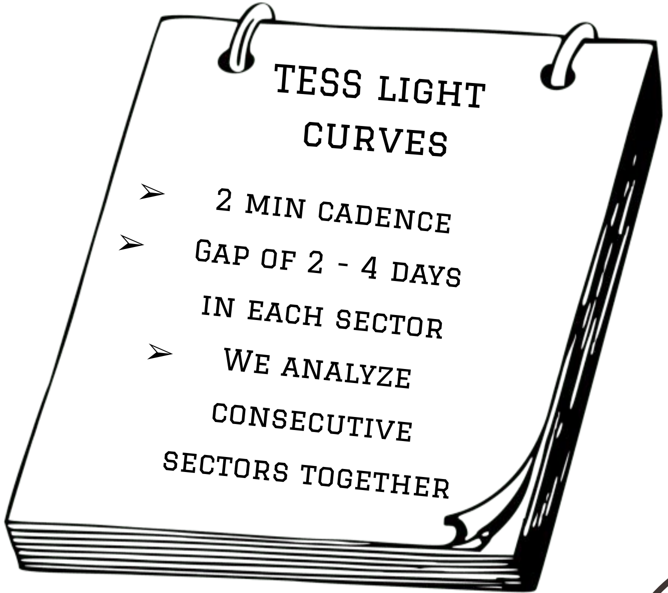


HD 74371

Observations

~50 days in each group

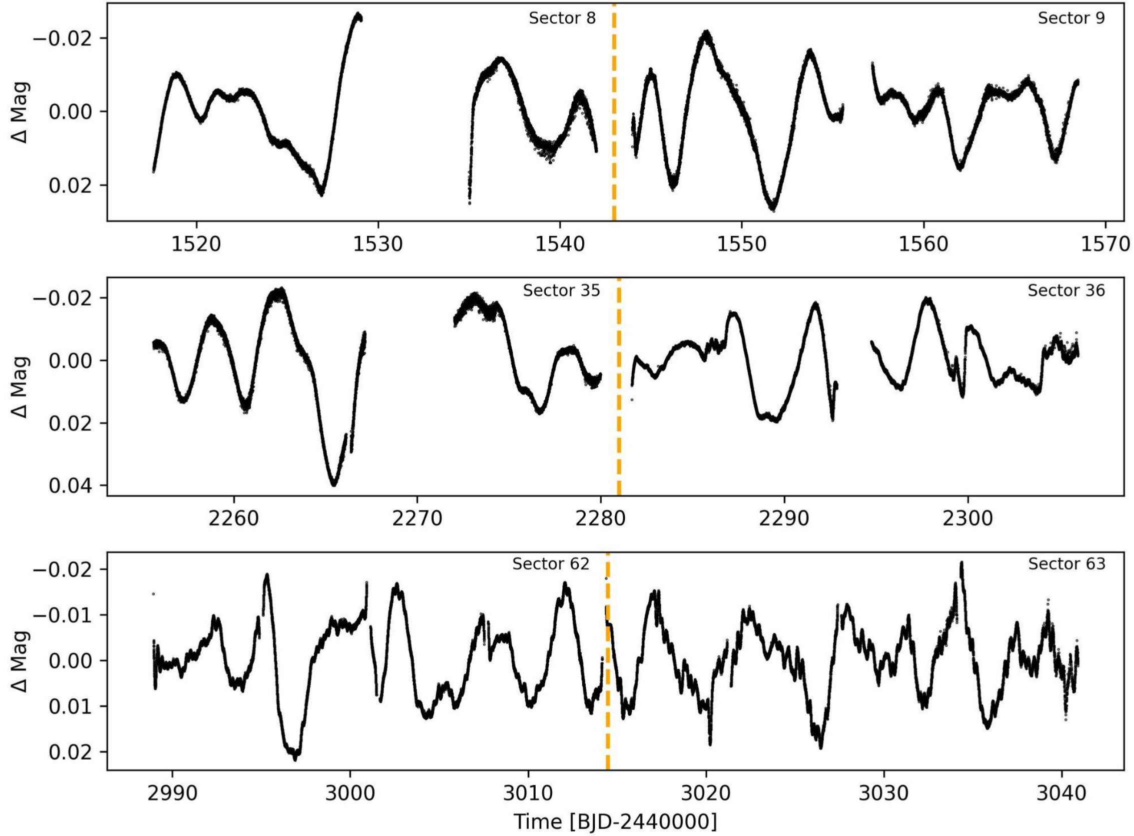


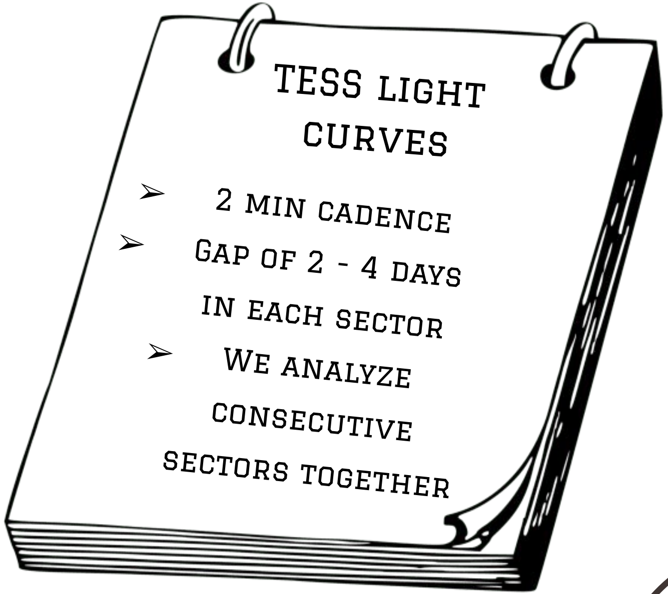


Observations

HD 79186

~50 days in each group

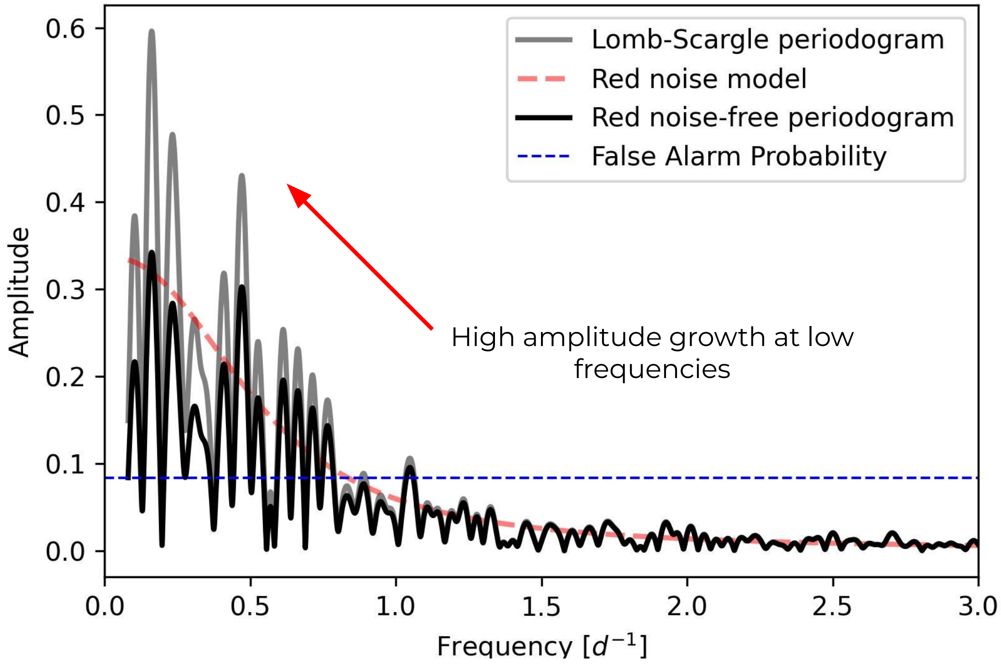




Periodicity analysis

Lomb-Scargle (pre-whitening)

Weighted Wavelet Z-Transform (WWZ)



RED NOISE
Indicates stochastic, chaotic or quasi-periodic effects

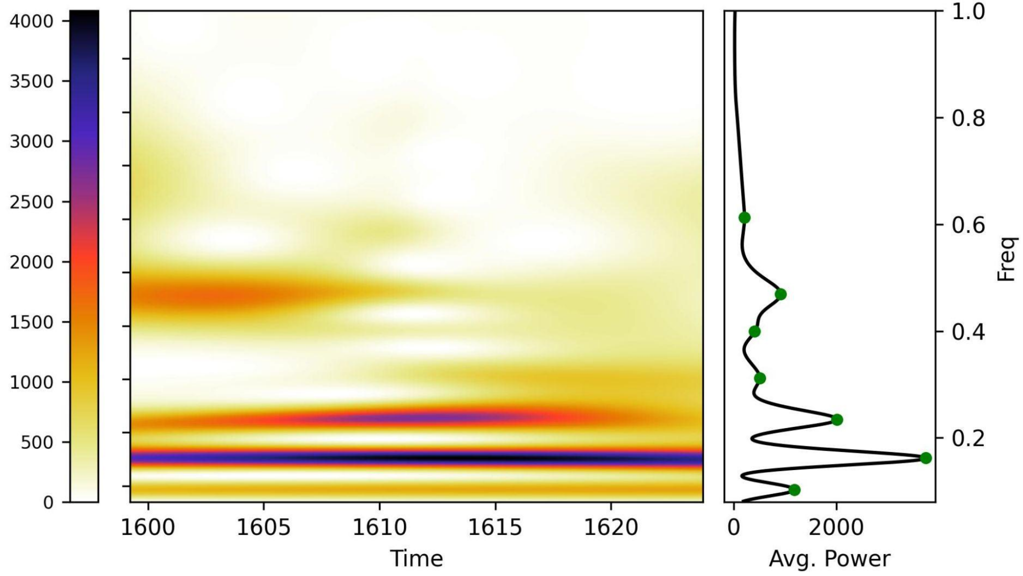
Model and subtract the red noise trend (Blomme et. al 2011)

$$A(\nu) = C + \frac{A_0}{1 + (2\pi\tau\nu)^{\gamma}}$$

Periodicity analysis

Lomb-Scargle (pre-whitening)

Weighted Wavelet Z-Transform (WWZ)



- ➔ We consider all frequencies showing a peak in the average power plot
- ➔ Scalogram to understand the results and find quasi-periodic events

Stability analysis

Construct the hydrostatic stellar models: integrated the stellar structure equations :

- Mass conservation
- Momentum conservation
- Energy conservation
- Energy transport

from the photosphere into the interior of the star up to some conveniently chosen cut- off - temperature

We need input parameters: L, Teff, chemical composition, estimation of the mass (spec. mass) (Haucke et al.(2018))

Log(L/M)> 4 : perform a **linear non-adiabatic stability** with respect to radial perturbations (Gautschy & Glatzel, 1990).

With Pr. W.Glatzel and M. Ruiz Diaz in the Institut für Astrophysik, Göttingen (POEMS proyect)

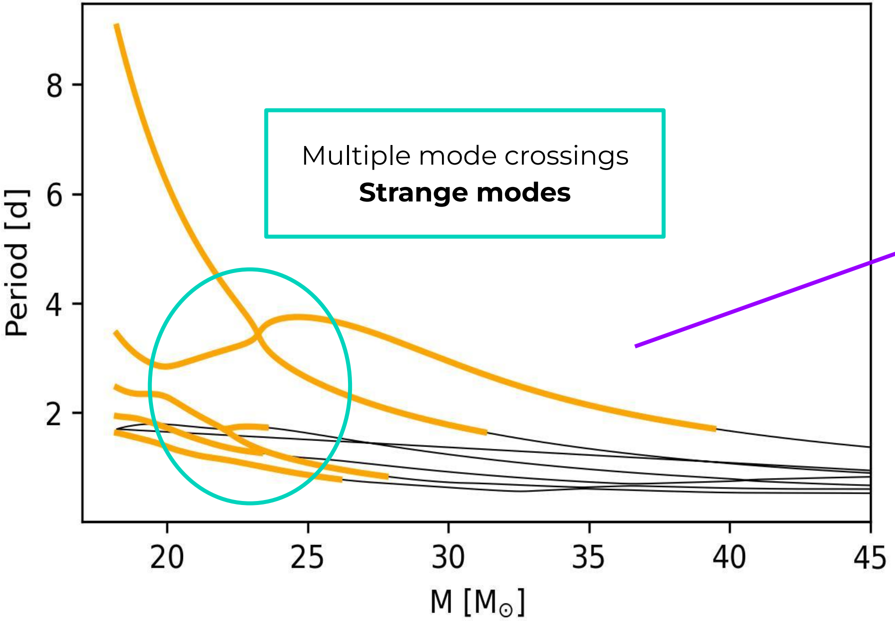
Stability analysis

As a result of the stability analysis, we obtain a set of complex eigenfrequencies:

$$\sigma = \sigma_r + i\sigma_i$$

σ_r: freq. of oscillation

σ_i: (+) **damping** or (-) **excitation** of the modes.



We can estimate the mass by comparing the unstable modes with the observed periods

Instability increases for higher L/M (low masses).

Unstable modes must be followed in non-linear regime

HD 74371

Preliminary results

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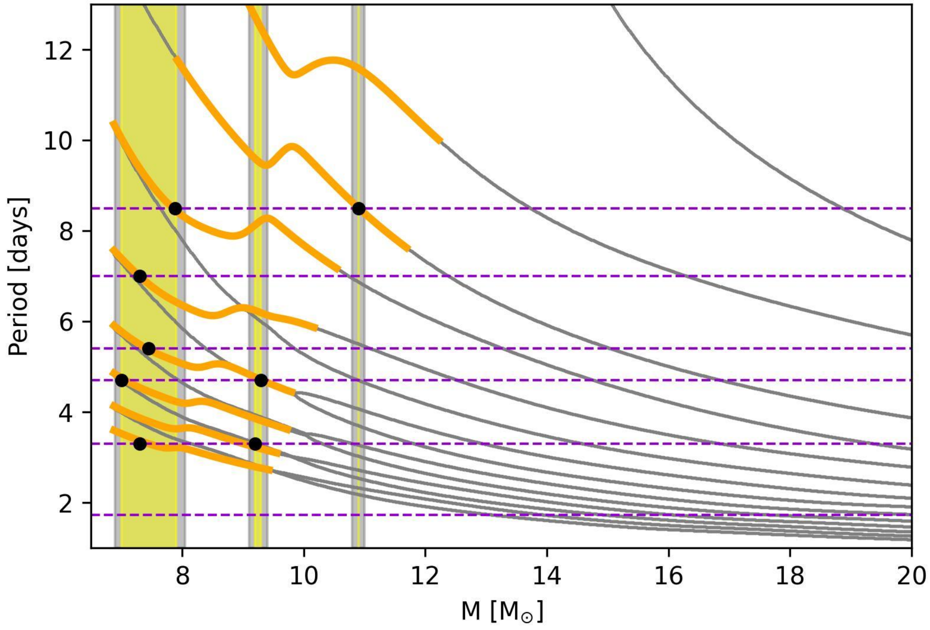
Unstable modes M < ~ 13



P [day] *Lit.*	P [day] *This work*	P_{rot} [days] $i = 30°$	$i = 45°$	$i = 52°$	$i = 90°$
[5 - 20]	8.53 ± 0.16	46.20	65.34	72.82	92.41
8.29	7.1 ± 0.2				
	5.34 ± 0.05				
	4.77 ± 0.1				
	3.3 ± 0.2				
	1.73 ± 0.19 [*]				

→ 1 sector : **Stochastic variation?**

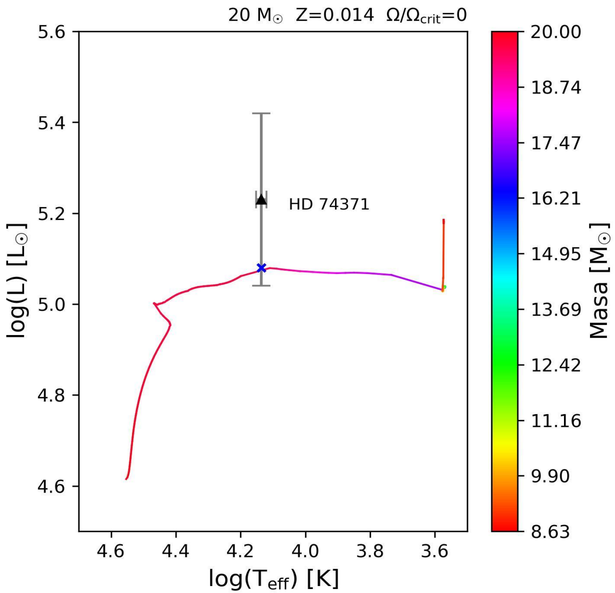
M [$M_\odot$] (Pul. modes)
7.5 ± 0.5
9.25 ± 0.15
10.9 ± 0.1

This range could explain 5 of 6 periods

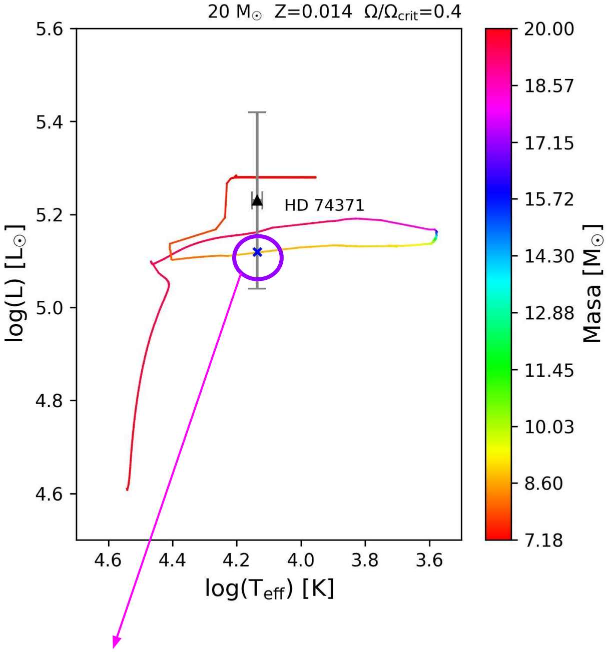
Post RSG?

HD 74371

Preliminary results



M [$M_\odot$] (Pul. modes)	M [$M_\odot$] (Evol. tracks) $\omega/\omega_{\rm crit} = 0$	$\omega/\omega_{\rm crit} = 0.4$
7.5 ± 0.5	19.57 ± 0.001	19.47 ± 0.04
9.25 ± 0.15		8.57 ± 0.02
10.9 ± 0.1		7.18 ± 0.001



Significant difference in the possible evolutionary states, modifying only the rotational velocity.

According to the predictions of the excited radial modes of Saio et al. (2013).

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HD 74371

Preliminary results

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What about abundances CNO?

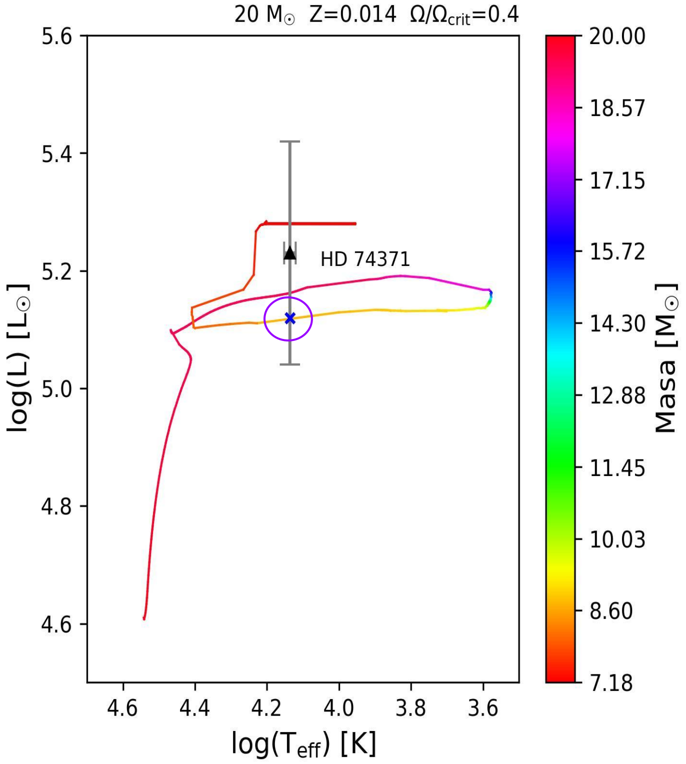
- Haucke et al. (2018): High EWs in C II
  (not enough for a post-RSG)

Discrepancy between asteroseismological models with CNO abundances.

(Saio et al. 2013) Julieta Sánchez (talk)

M [$M_\odot$] (Pul. modes)	M [$M_\odot$] (Evol. tracks) $\omega/\omega_{crit}=0$	M [$M_\odot$] (Evol. tracks) $\omega/\omega_{crit}=0.4$	M [$M_\odot$] Haucke et al. (2018)
7.5 ± 0.5	19.57 ± 0.001	19.47 ± 0.04	12.56 ± 2.54
9.25 ± 0.15		8.57 ± 0.02	
10.9 ± 0.1		7.18 ± 0.001	

Mass discrepancy problem



HD 79186

Preliminary results

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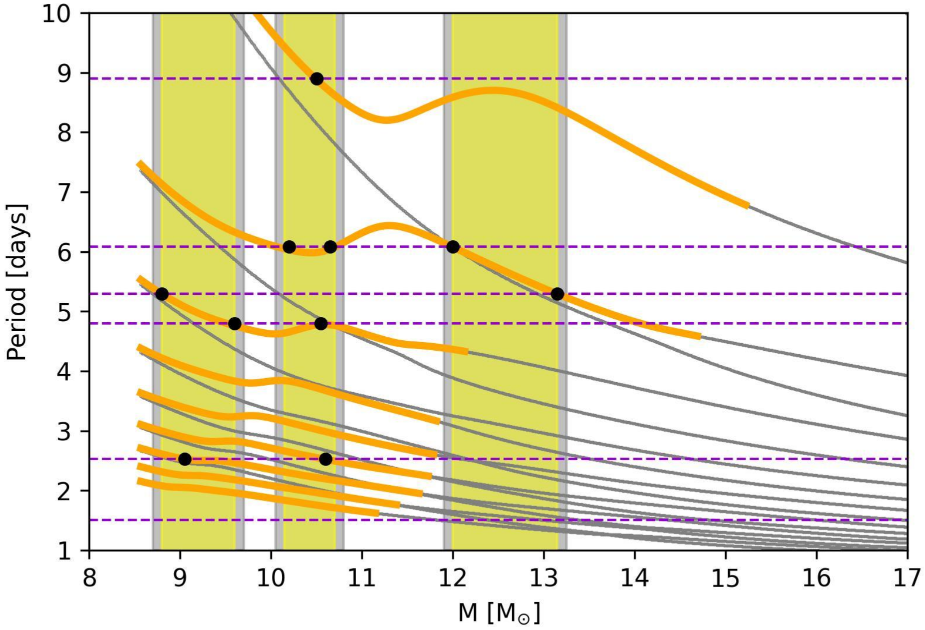
Unstable modes M < ~ 15



P [day] Lit.	P [day] This work	P_{rot} [days] $i = 30°$	$i = 45°$	$i = 52°$	$i = 90°$
78.9	8.90 ± 0.01 [*]	38.61	54.60	60.85	77.22
-	6.08 ± 0.03				
-	5.30 ± 0.16				
-	4.8 ± 0.45				
-	2.53 ± 0.1				
-	1.50 ± 0.03 [*]				

1 sector

M [$M_\odot$] (Pul. modes)
10.42 ± 0.38
9.2 ± 0.4
12.57 ± 0.58

This range could explain 4 of 6 periods

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HD 79186

Preliminary results

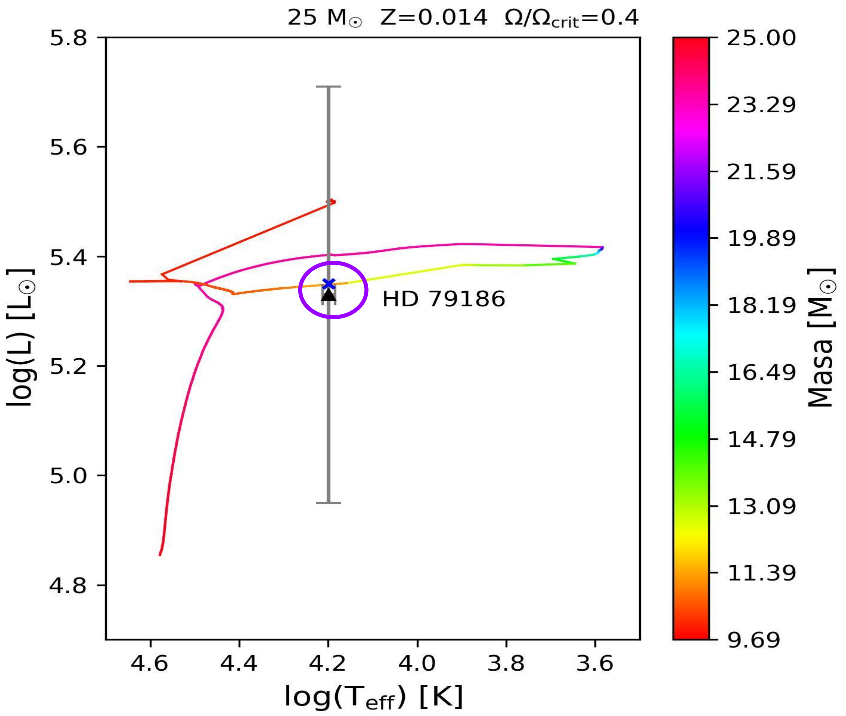
In agreement with the number of excited modes found

What about abundances ?

- Haucke et al. (2018): Very high EWs in C II an N II (MP)

Could be in the post-RSG

M [$M_\odot$] (Pul. modes)	M [$M_\odot$] (Evol. tracks) $\omega/\omega_{crit} = 0$	M [$M_\odot$] (Evol. tracks) $\omega/\omega_{crit} = 0.4$	M [$M_\odot$] Haucke et al. (2018)
10.42 ± 0.38	24.163 ± 0.003	23.585 ± 0.01	14.22 ± 2.86
9.2 ± 0.4	8.293 ± 0.005	11.116 ± 0.002	
12.57 ± 0.58		9.70± 0.01	



Conclusions and future work...

- ➔ We identify multiple oscillation frequencies probably related to a unstable radial modes.
- ➔ We estimate their masses with an asteroseismological model **(first approximation!)**
- ➔ We find a discrepancy between asteroseismological models with CNO abundances.
- ➔ We find some periods no related to radial unstable modes. Origin of these ones should be study.
- ➔ We find evidence of the mass discrepancy problem.
- ➔ No evidence of binarity was found (has to be confirmed by spectroscopic analysis).

Conclusions *and future work...*

- ➔ We will follow unstable modes until the non-linear regime and recalculate the masses.
- ➔ We will perform a stability analysis for non radial pulsations.
- ➔ We will calculate new evolutionary tracks (changing the rotational speed, initial mass, ...) and test different evolutionary models.
- ➔ We need to measure new abundances for these stars.

Thanks :)