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Understanding angular momentum transport in red giants: the case of KIC 7341231

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Abstract

Asteroseimic study of the *Kepler* target red giant KIC 7341231 has produced a first estimation of its rotation profile (Deheuvels et al. 2012). In a previous work (Ceillier et al. 2012) we computed different models of this star with the *Geneva stellar evolution code* (Eggenberger et al. 2008) to compare their rotation profiles with the observed one. The present work quantifies the influence of the modelling parameters on the obtained rotation profiles and constrains angular momentum transport mechanisms in stars during the subgiant evolution.

Introduction

Thanks to the space missions CoRoT (Baglin et al. 2006) and *Kepler* (Borucki et al. 2010), we now have access to high-precision light curves of many red giants. The study of these light curves through asteroseismology has enabled us to probe thousands of red giants' interiors. In particular, analysis of oscillation modes' rotational splittings have allowed to derive strong constraints on the internal rotation profiles of these red giants (Beck et al. 2011).

In parallel, the effects of rotation on stellar structure have been implemented in stellar evolution codes, leading to the computation of the angular momentum transport inside stars during their evolution (Maeder & Meynet 2012).

Observational characteristics of KIC 7341231

Observables	Values	Sources
T_{eff}	5470 ± 30 K 5483 ± 60 K	Casagrande et al. 2010 Ammons et al. 2006
Log *g*	3.55 ± 0.03 4.06 ± 0.29	Deheuvels et al. 2012 Molenda-Zakowicz et al. 2008
[Fe/H]	-2.18 ± 0.06 dex -0.79 ± 0.14 dex	Laird et al. 1998 Ammons et al. 2006
Proper motion	39.18 ± 0.85 mas.yr^{-1} (RA) 255.55 ± 1.24 mas.yr^{-1} (DEC)	van Leeuwen 2007
Radial velocity	-269.16 ± 0.14 km.s^{-1}	Latham et al. 2002

Modeling

- We use the *Geneva stellar evolution code* (Eggenberger et al. 2008) in which the effects of rotation on stellar evolution (Eggenberger et al. 2010) have been implemented.
- All the computed models start at the ZAMS.
- We assume a metallicity [Fe/H] = -1 dex and an initial helium abundance Y_{ini} = 0.26.
- We select a stop point corresponding to when the model's large separation is equal to the observed one. We then compare the model's period spacing with the observed one.
- In order to best reproduce the observed surface rotation, we focussed on models with an initial rotational velocity on the ZAMS v_{ini} = 2 km.s^{-1}.

Observed and modeled properties of KIC 7341231

Quantities	Seismically derived values (Deheuvels et al. 2012)	Values from the model (Ceillier et al. 2012)
$\Delta\nu$	28.9 ± 0.2 μHz	30 ± 4 μHz
$\Delta\Pi_1$	112.8 ± 0.3 s	115 ± 9 s
Ω_c	710 ± 51 nHz	33 ± 6 μHz
Ω_s	< 150 ± 19 nHz	36 ± 10 nHz

First results

- In accordance with Deheuvels et al. (2012), we find that a model with a mass M = 0.84 $M_\odot$ reproduces both the observed large separation and period spacing at the same age T = 13.01 Gyr.
- We find that the obtained rotation profile is much steeper than the observed one, as can be seen in Figure 1. The same problem is found in the Sun for which the rotational profile obtained through heliosismology is almost flat (Mathur et al. 2008) while modeling tends to give a steeper profile (Turck-Chièze et al. 2010).
- For now, it seems that the two best candidates for angular momentum transport from the core to the more external layers are internal gravity waves (Talon & Charbonnel 2008, Mathis & de Brye 2012) and magnetic fields (Eggenberger et al. 2005, Mathis & Zahn 2005, Strugarek et al. 2011). This two processes would tend to flatten the rotation profile and might explain the internal rotation profile of the Sun and red giants.

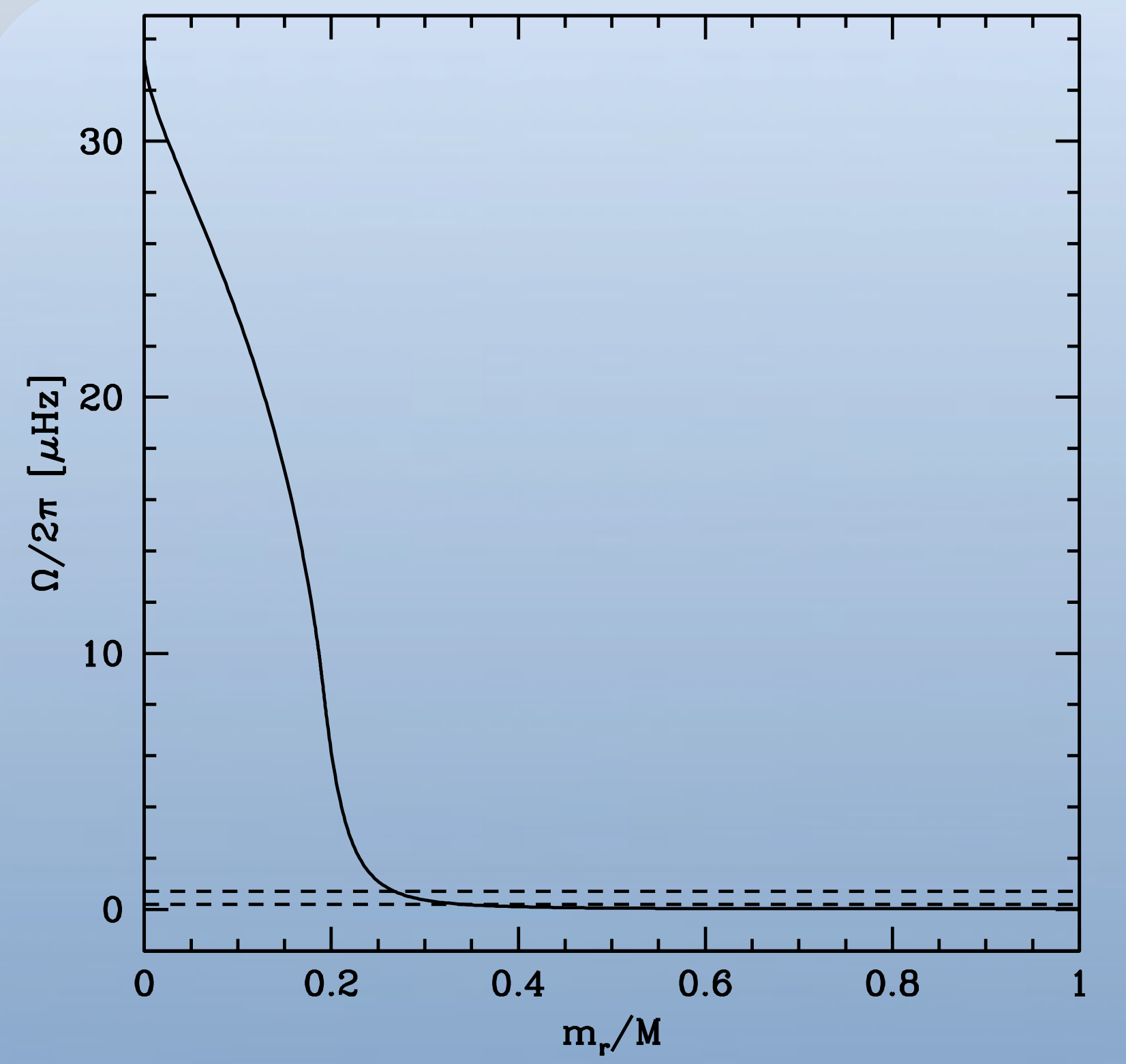

Fig.1: Rotation profile of the model at the end of the evolutionary track (solid line). The two dashed lines correspond to the core rotation and the surface rotation derived by Deheuvels et al.

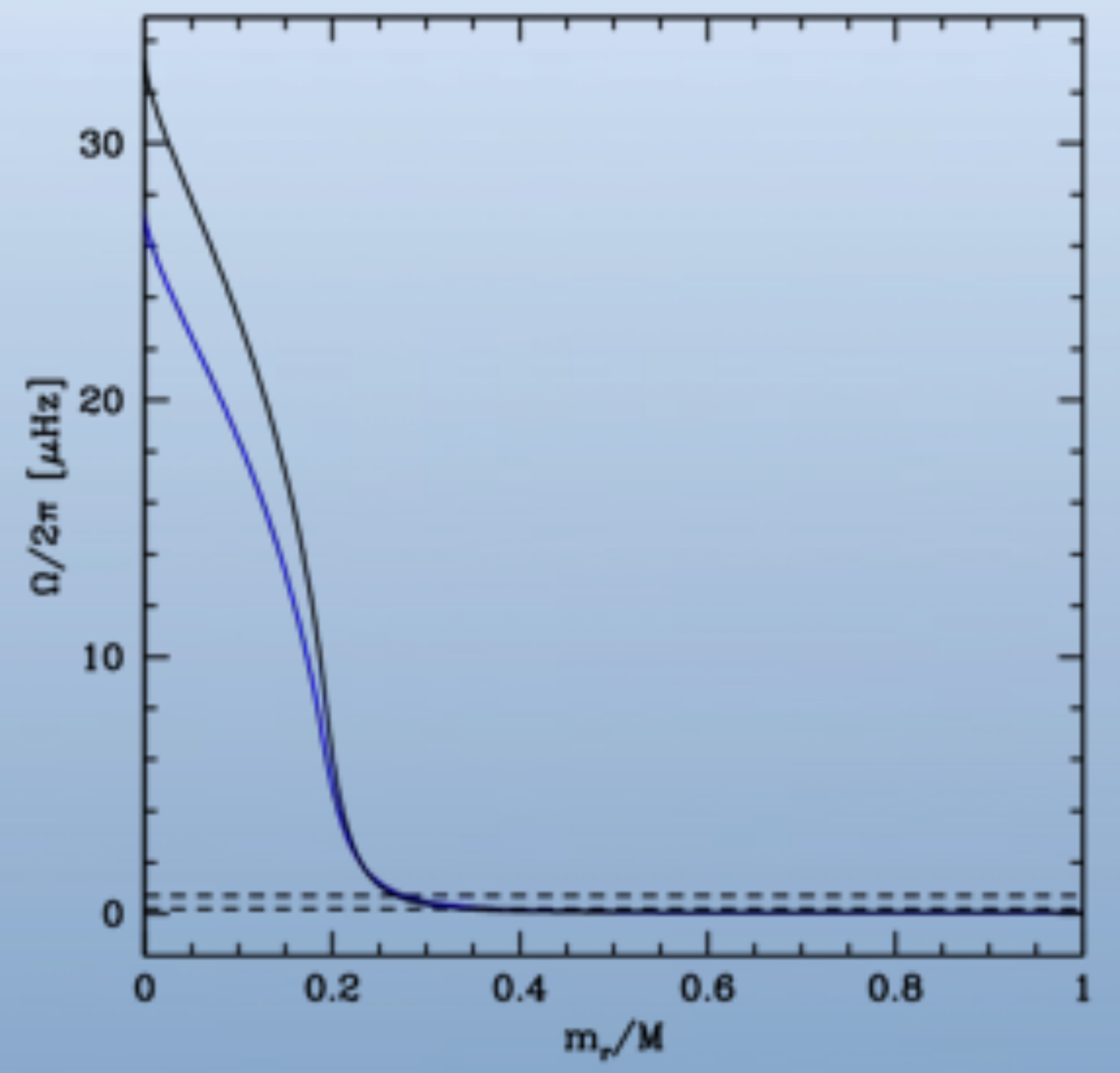

Fig.2: Rotation profiles of the models with Yini = 0.26 (black) and with Yini = 0.3 (blue).

Influence of modelling parameters

- In order to quantify the influence of the modeling parameters on on the rotation profile we computed models with the same global properties (mass, v_{ini},…) but with modified properties. We studied the influence of the magnetic braking during the main sequence, the atomic diffusion, the value of the mixing-length parameter, the value of initial helium abundance and the metallicity.
- We find that the modifications induced by the changes are of small magnitude compared to the discrepancy between the observed and modeled profiles. These changes are summarized in the table below. The most import changes were found for the initial helium abundance Y_{ini} (see Figure 3).

Parameter	Reference model	Modified model	Change for Ω_c	Change for Ω_s
Magnetic braking	OFF	ON	+ 6%	- 14 %
Atomic diffusion	OFF	ON	- 3%	+ 3%
α_{MLT}	1.6	1.7	- 6%	+ 16%
Y_{ini}	0.26	0.3	- 18%	+ 5%
[Fe/H]	- 1	- 0.8	+ 1%	- 0.5%

References

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- van Leeuwen 2007, A&A 474, 653V

Forcing solid body rotation during MS

- In order to simulate an homogenizing process, we forced a solid body rotation of the star during the main sequence, allowing the transport of angular momentum only in the post-main sequence evolution. We have computed two such models : for the first one, the solid body rotation stops when the hydrogen abundance in the core X_c=0.1 while for the second it stops when there is no more hydrogen in the core.
- The resulting rotation profiles (Figure 3) were much less steep than previously, as expected. Nevertheless, the gap is still huge between what we obtain and what is observed, suggesting that whatever the process, it has to be efficient on small time scales such as the subgiant evolution.

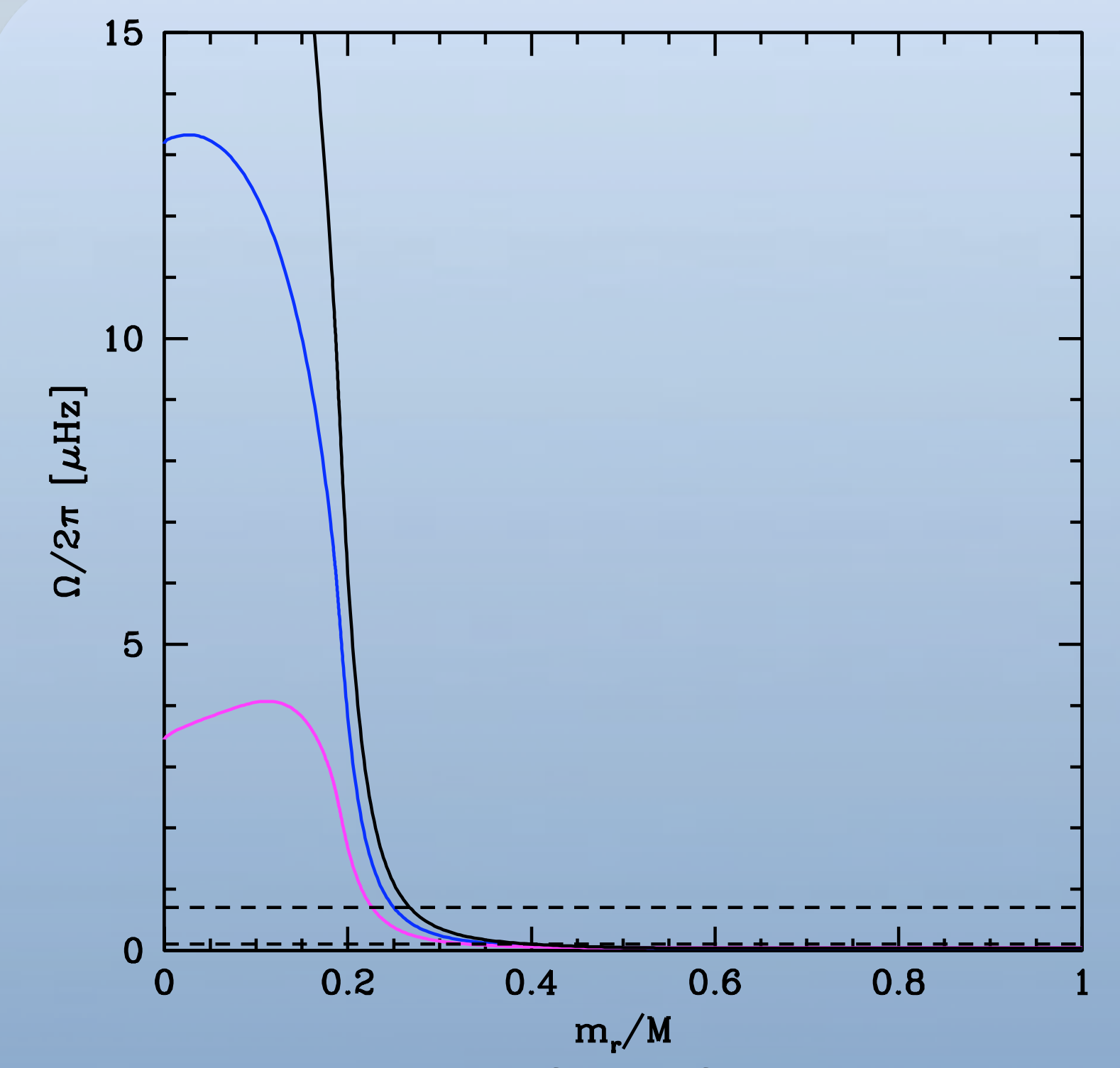

Fig.3: Rotational profiles of the models with and without solid body rotation. Black: same as Fig.1. Blue: model with solid body rotation until X_c=0.1. Magenta: model with SBR until X_c=0.

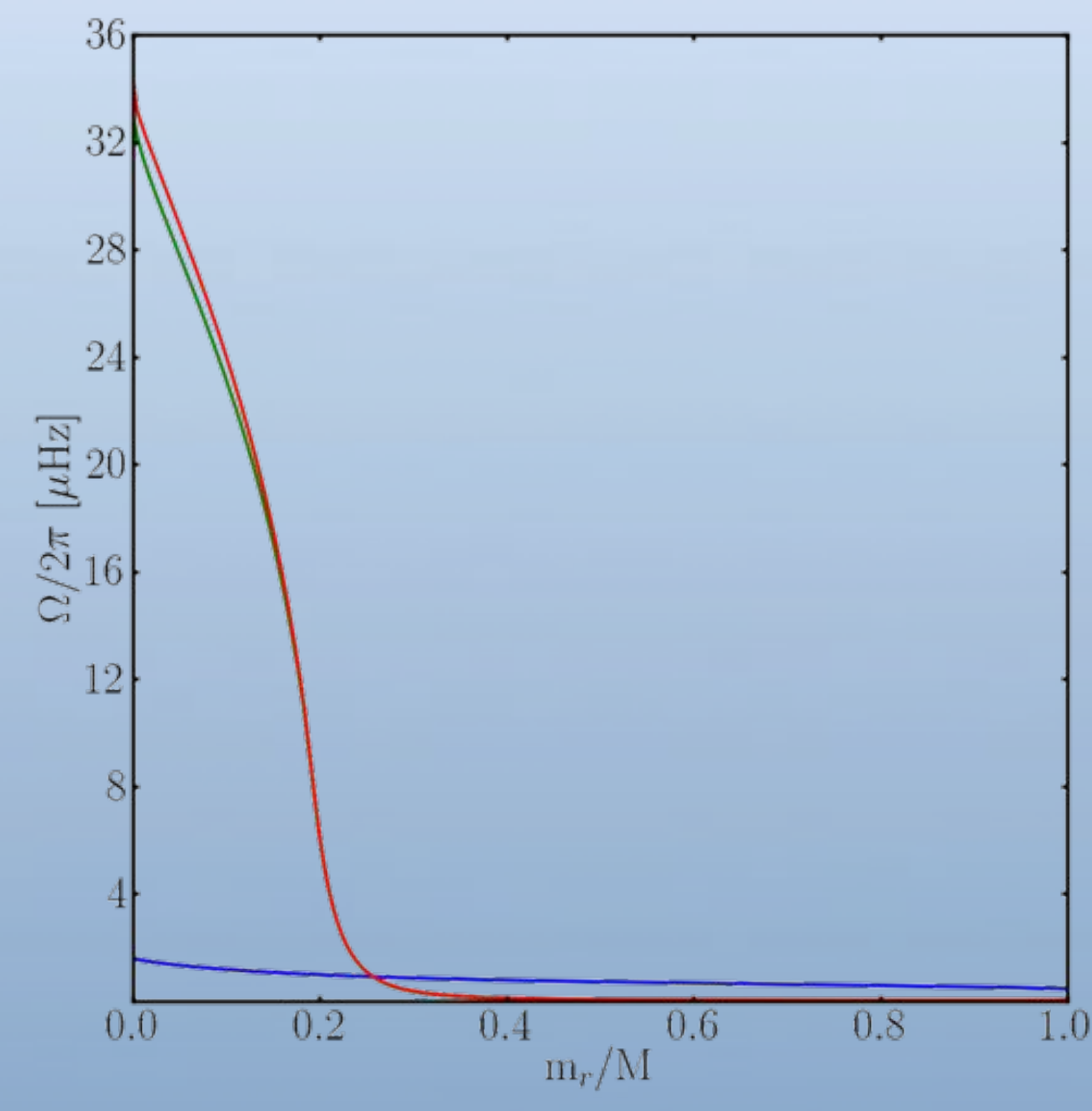

Fig.4: Rotational profiles at different evolution times. Blue: end of MS. Green: end of subgiant phase (all angular momentum transport mechanisms). Red: end of subgiant phase (only conservation of angular momentum).

Subgiant evolution and angular momentum transport

- To estimate the efficiency of the implemented angular momentum transport mechanisms during the rapid subgiant phase, we computed models for which we consider only the conservation of angular momentum during this phase and compared the obtained profile with the reference model's one.
- The resulting rotation profile (Figure 4) is very similar to the previous one. The evolution of the star's rotation profile during the subgiant phase is therefore completely dominated by the conservation of angular momentum due to the profound changes in the star's structure. This emphasizes that any additional angular momentum transport phenomenon has to be strong enough to counterbalance angular momentum conservation on small timescales.

Conclusion

Taking KIC 7341231 as an example, we showed that there is a discrepancy between observed rotational profiles and the profiles we can obtain through the computation of stellar models including shellular rotation. We also showed that this gap cannot be bridged by merely modifying the modeling parameters. It is thus necessary to develop new processes, such as internal gravity waves or magnetic fields, as is progressively done

We demonstrated that the rotational behaviour during the Main Sequence can have a strong impact on the future rotational profile of the star. The rapid and violent evolution of the star during the subgiant phase is a key point of this rotational profile. Consequently, the new angular momentum transport mechanisms will have to be efficient on such timescales.