Impact of rotation and magnetic fields in low mass AGB stars

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Abstract

After core helium burning in stars with an initial mass of 1.5-3 solar masses, starts the AGB phase. In this phase, the s-process takes place, which is believed to be at the origin of half of all elements heavier than iron.
We have calculated stellar evolution models with MESA for stars with an initial mass of 1.5 and 3.0 solar masses, to investigate the effect of the extra mixing. Our models include both rotation and the Taylor-Spruit (TS) dynamo. We will show how the extra mixing contributes to the total diffusion coefficient and how it will effect the transport of angular momentum and the s-process nucleosynthesis.
When comparing the results to observations, we find that the final core spin of the rotating magnetic models is closer to the observed values than that of the rotating non-magnetic models. The preliminary results of the s-process nucleosynthesis suggest the same trend.

AGB stars

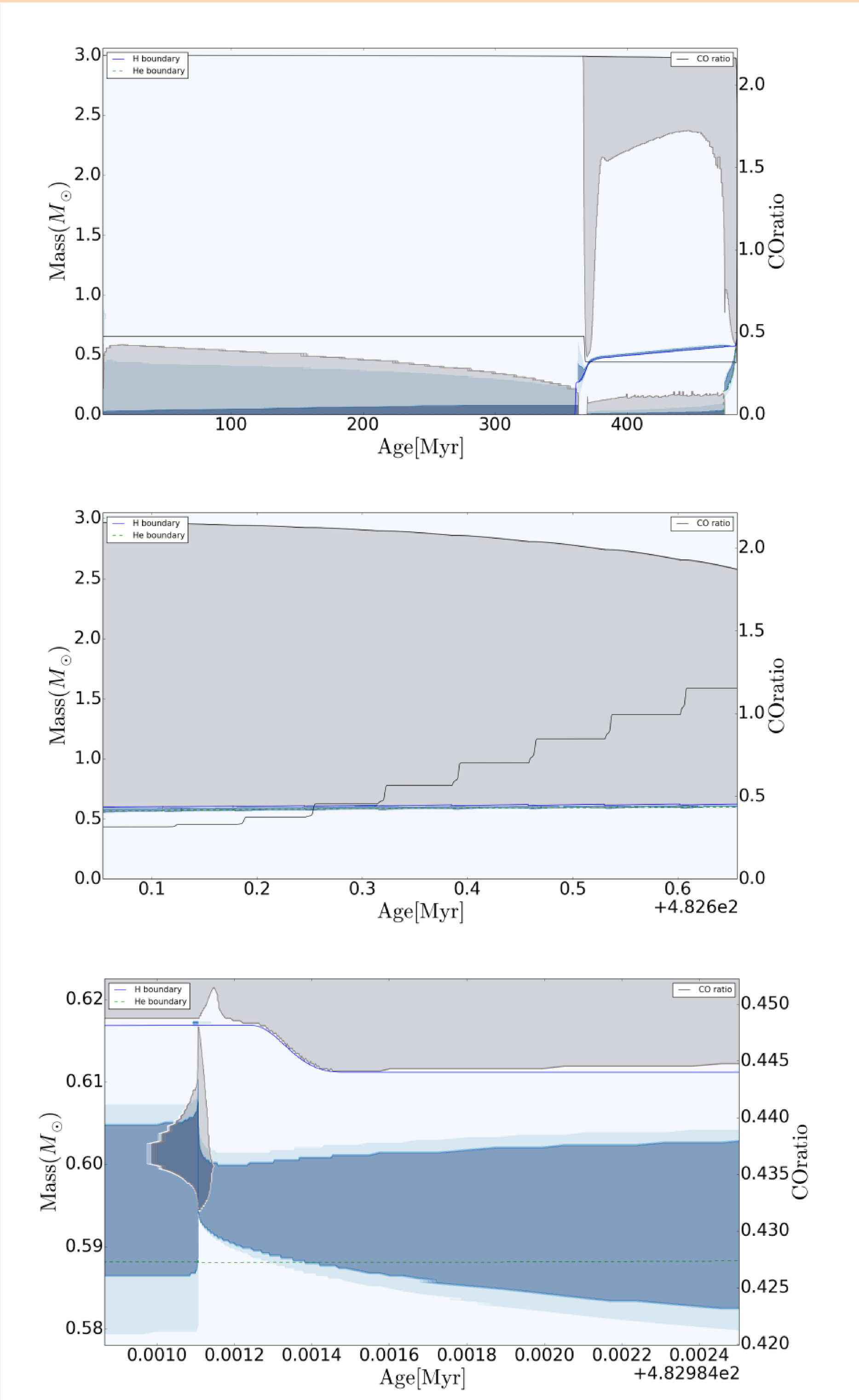

Figure 1: Kippenhahn plots showing the stellar evolution of a 3M$_\odot$ star in one dimension as a function of time. The grey regions represent the convective zones, the white ones the radiative zones. Blue regions indicate energy is produced. From top to bottom: the whole star, a zoom-in of the TP region in the AGB phase where the s-process takes place and finally a zoom-in of a TP. This figure illustrates where to find the AGB phase in both place and time and the need of zooming in to a small area of the whole star.

Angular momentum

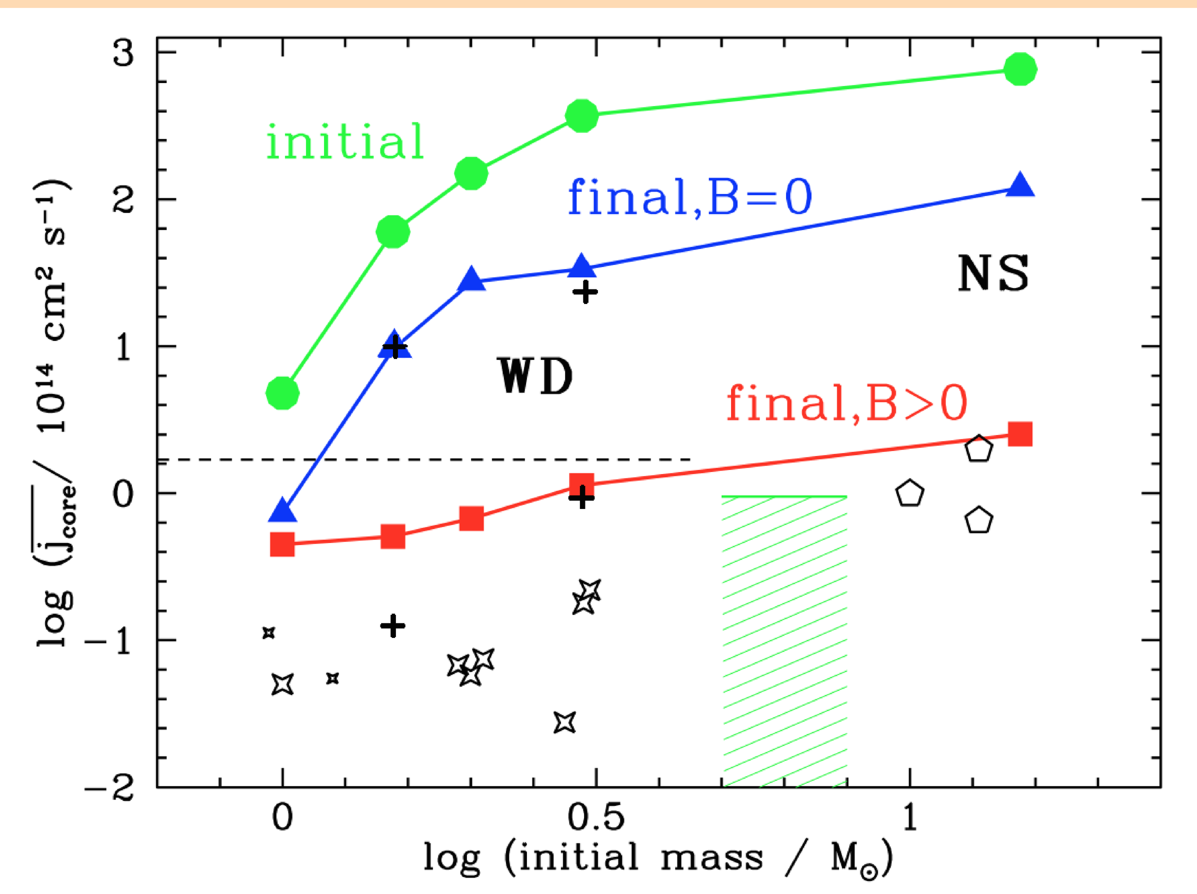

Figure 2: Averaged specific angular momentum of the core, for the initial ZAMS model and the final models of [1]. The two + signs at log(initial mass/M$_\odot$) $\simeq$ 0.5 and $\simeq$0.18, are the values of models 2,3,5 and 6, see table 1. The full drawn lines are the results of [1], the dashed line is the spectroscopic upper limit of DA WDs, the green area is populated by magnetic WDs, the stars are astroseismic measurements of ZZ Ceti stars and the pentagons correspond to neutron stars. Our results are higher than the upper limits of the observations. The inclusion of the TS dynamo results in a improvement of the predicted rotational period of white dwarf (see also [2] and [3]).

Grid of models

Model	Z_i	M_i ($M_\odot$)	RB?	v_{rot} km/s	τ_H (Myr)	M_c ($M_\odot$)	M_{env}($M_\odot$)	L ($L_\odot$)
1	0.02	1.5	noRB	0	2.35 10^3	0.482	0.848	3.41
2	0.02	1.5	R-B	$\simeq$45	2.36 10^3	0.475	0.861	3.32
3	0.02	1.5	R+B	$\simeq$45	2.40 10^3	0.476	0.859	3.33
4	0.02	3.0	noRB	0	3.60 10^2	0.549	2.428	3.53
5	0.02	3.0	R-B	$\simeq$45	3.61 10^2	0.548	2.428	3.51
6	0.02	3.0	R+B	$\simeq$45	3.73 10^2	0.575	2.395	3.77
7	0.001	1.5	noRB	0	1.33 10^3	0.522	0.868	3.54
8	0.001	1.5	R-B	$\simeq$45	1.34 10^3	0.519	0.873	3.52
9	0.001	1.5	R+B	$\simeq$45	1.41 10^3	0.518	0.874	3.53
10	0.001	3.0	noRB	0	2.47 10^2	0.800	1.944	4.07
11	0.001	3.0	R-B	$\simeq$45	2.48 10^2	0.803	1.927	4.13
12	0.001	3.0	R+B	$\simeq$45	2.55 10^2	0.804	1.921	4.08

Table 1: Initial parameters, main-sequence lifetime and parameters of the first TP of all 12 models.

Mixing and the ^{13}C pocket

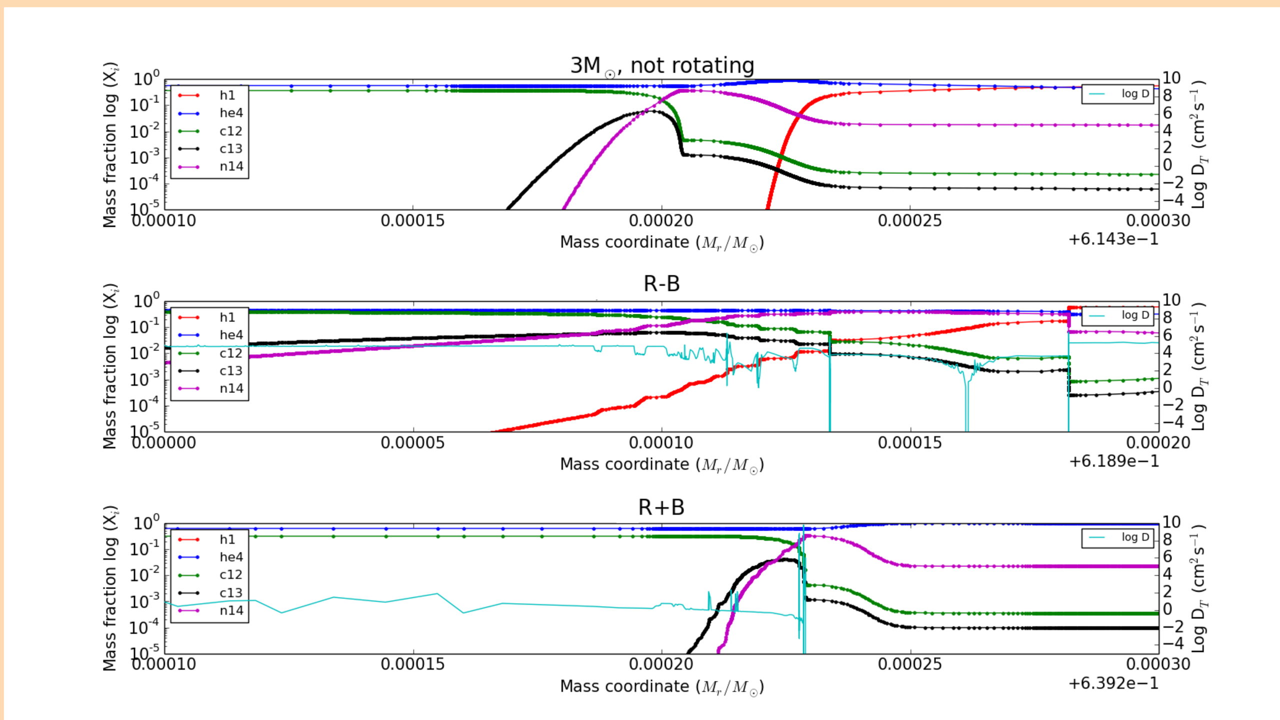

Figure 3: Mass abundances of important chemical elements within the ^{13}C pocket are plotted, as well as the total diffusion coefficient. The size and shape of the ^{13}C pocket differs in all three figures. Including rotation leads to a stretched out ^{13}C pocket and larger total diffusion coefficient, while including the TS dynamo largely cancels out that effect. These figures confirm previous results of [4] and [5] that rotation has important consequences for s-process production in AGB stars.

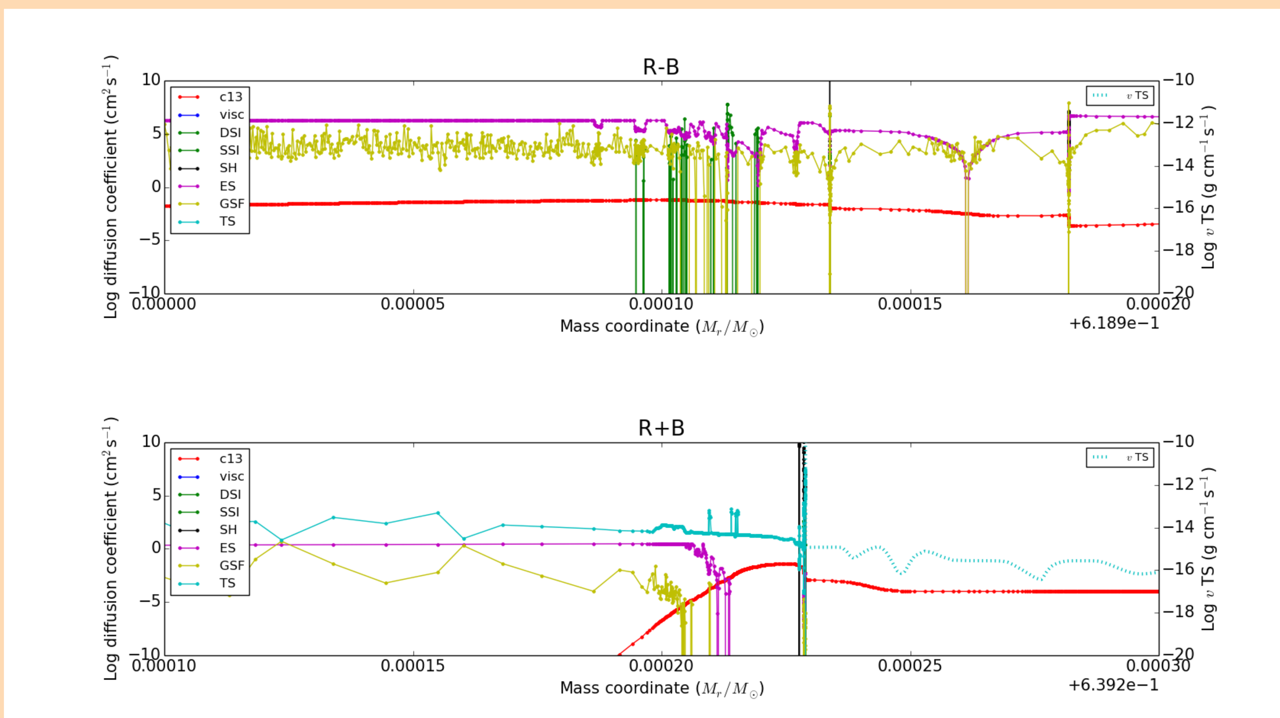

Figure 4: Rotationally induced diffusion coefficients of the R-B and R+B models of figure 3. The figures are made at the same location and moment in the evolution. The ^{13}C-profile has been added as reference point between figure 3 and 4. ν TS stands for the effective viscosity caused by the TS dynamo, a variable indicating transport of angular momentum. Including the TS dynamo decreases the rotationally induced diffusion coefficients, because those depend on the angular velocity as: D$\propto$ $\Omega\frac{d\Omega}{dr}$. The TS dynamo decreases both terms by increasing the coupling between core and envelope.

References

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Conclusions

- S-process takes place in an evolutionary stage both small in timespan as in space
- Inclusion of rotation and the TS dynamo, compared to inclusion of rotation alone, results in an improvement of the predicted rotational period of white dwarfs
- Inclusion of the TS dynamo reduces the rotationally induced mixing. At the moment, we are investigating what this effectively means for the s-process production.