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To cite this article: J W den Hartogh *et al* 2018 *J. Phys.: Conf. Ser.* **940** 012038

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Impact of rotation and magnetic fields in low mass AGB stars

J W den Hartogh^{1,8}, R Hirschi^{1,2,8}, C Georgy^{1,3}, P Eggenberger³, F Herwig^{4,5,8}, M Pignatari^{6,8}, U Battino^{7,8}, Jared Keown⁴, C Ritter^{4,5,8}

¹ Astrophysics Group, Lennard Jones Building, Keele University, Staffordshire ST5 5BG, UK

² Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo, Kashiwa, Chiba 277-8583, Japan

³ Observatoire de Genève, Université de Genève, Chemin des Maillettes 51, 1290 Versoix, Switzerland

⁴ Department of Physics and Astronomy, University of Victoria, Victoria, BC V8W 3P6, Canada

⁵ Joint Institute for Nuclear Astrophysics, University of Notre Dame, Notre Dame, IN 46556, USA

⁶ Konkoly Observatory of the Hungarian Academy of Sciences, Konkoly Thege Miklós út 15-17, H-1121 Budapest, Hungary

⁷ Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

⁸ NuGrid collaboration, <http://www.nugridstars.org>

E-mail: j.den.hartogh@keele.ac.uk

Abstract. After core helium burning in low and intermediate-mass stars, 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. The role of rotation and magnetic fields on the AGB phase is still debated and uncertain. We have calculated stellar evolution models with MESA for stars with an initial mass of 1.5 and 3.0 solar masses. Our models include both rotation and the Taylor-Spruit (TS) dynamo. We show how these physical processes contribute to the total diffusion coefficient and how it will effect the transport of angular momentum and the s-process nucleosynthesis.

Our preliminary results confirm previous results that 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. The impact on the s-process nucleosynthesis is underway and will be presented in a forthcoming publication.

1. AGB stars and white dwarfs

After core helium burning is over an unstable phase of hydrogen shell burning and helium shell flash events (thermal pulses or TPs) starts [1]. The TPs are thin-shell instabilities in the helium shell, caused by a lack of energy production in the shell, leading to its contraction and compression. The thin-shell instability will then trigger a thermonuclear runaway or helium-shell flash. This flash leads to the extinction of the hydrogen shell and an expansion of the helium shell, which eventually decreases its temperature. The thermonuclear runaway is now over and helium burning continues in a stable manner. The reduced luminosity leads to a contraction of



the intershell region until the hydrogen layer is hot enough to ignite again. The slow-neutron-capture-process or s process occurs in between the two shells, after enough neutrons have been released by $^{13}\text{C}(\alpha, n)^{16}\text{O}$ [2]. Under these conditions heavier nuclei are synthesized by neutron capture, with iron being the seed. The production of heavy elements can reach Pb.

During the AGB phase the envelope is gradually peeled off by increasing mass loss, caused by pulsation-driven shocks in the atmosphere and dust-driven winds [3]. At the end of the phase a degenerate CO core is left, surrounded by a planetary nebula. The CO core then continues to cool down as a white dwarf.

2. Grid of models

To check the effect of rotation and the TS-dynamo, we ran stellar evolution models with MESA for two different masses ($1.5 M_{\odot}$ and $3.0 M_{\odot}$) and two metallicities ($Z = 0.001$ and $Z = 0.02$). For each combination of mass and metallicity, we ran three models: one without rotation, one with rotation and without the TS-dynamo (R-B) and one with rotation and the TS-dynamo (R+B). We include convective boundary mixing. Rotating models have, on the main-sequence a lower temperature, because of a lower effective gravity, and become more luminous, because rotationally induced mixing brings extra fuel to the core. The core is therefore more massive and the Main-Sequence lifetime is longer in rotating models than in non-rotating models.

3. Results

The size and shape of the ^{13}C pockets is strongly affected by rotation, see Figure 1. Including rotation leads to a stretched out ^{13}C pocket and larger diffusion coefficients. This larger partial mixing zone is the subject of our future analysis. 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.

In Figure 2 the averaged specific angular momentum of the core is plotted, for the initial ZAMS model and the final models of [4]. The rotating model without the TS dynamo have far too high final angular momentum. The inclusion of the TS dynamo results in a improvement of the predicted rotational period of white dwarf (see also [5] and [6]). The impact of the TS dynamo on the s-process nucleosynthesis is underway and will be presented in a forthcoming publication.

Acknowledgements

NuGrid acknowledges significant support from NSF grants PHY 02-16783 and PHY 09-22648 (Joint Institute for Nuclear Astro- physics, JINA). RH acknowledges the support from Eurocore project Eurogenesis and ERC Starting Grant No. 306901. RH acknowledges support from the World Premier International Research Center Initiative (WPI Initiative), MEXT, Japan. FH acknowledges support through an NSERC Discovery Grant (Canada). MP thanks the support from the ‘‘Lendület-2014’’ Programme of the Hungarian Academy of Sciences (Hungary) and from SNF (Switzerland). This work used the DiRAC Complexity system, operated by the University of Leicester IT Services, which forms part of the STFC DiRAC HPC Facility (www.dirac.ac.uk). This equipment is funded by BIS National E-Infrastructure capital grant ST/K000373/1 and STFC DiRAC Operations grant ST/K0003259/1. DiRAC is part of the National E-Infrastructure.

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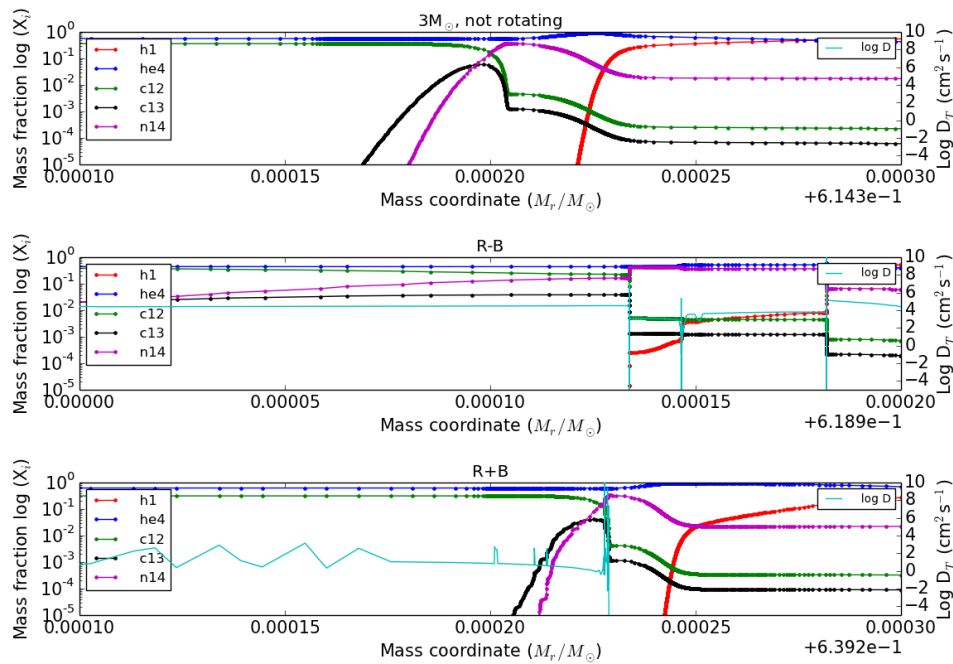


Figure 1: Abundances of important chemical elements within the ^{13}C pocket are plotted with the total diffusion coefficient, for the $3M_{\odot}$, $Z = 0.02$ models. These figures confirm previous results of [1] and [7] that rotation has important consequences for s-process production in AGB stars.

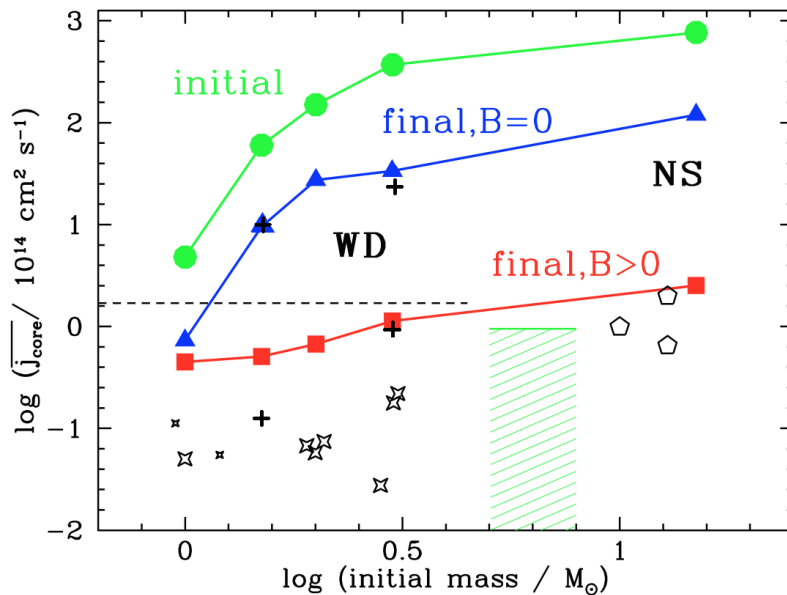


Figure 2: The two + signs at $\log(\text{initial mass}/M_{\odot}) \simeq 0.5$ and $\simeq 0.18$ are the final values of our rotating models with $Z = 0.02$ and the full drawn lines are the results of [4]. The dashed line is the spectroscopic upper limit of DA WDs, the green area is populated by magnetic WDs, the stars are asteroseismic measurements of ZZ Ceti stars and the pentagons correspond to neutron stars. See [4] for the details on these observations. Adapted from Figure 5 of [4].