Extending the BoOST stellar model grid

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July 23, 2021

Structure

- Theory
  - Stellar Structure Equations
- Motivation
  - BoOST
  - Nucleosynthesis
  - Differences in Evolutionary Behaviour
- Results
  - The Models
  - Mass vs time
  - Hertzsprung Russell Diagramms
  - Surface Helium Mass Fraction

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Stellar Structure Equations[2]

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho} \leftarrow \partial m = 4\pi r^2 \rho \partial r \tag{1}$$

$$\frac{\partial P}{\partial m} = -\frac{Gm}{4\pi r^4} - \frac{1}{4\pi r^2}\frac{\partial^2 r}{\partial t^2} \tag{2}$$

$$\frac{\partial L}{\partial m} = \epsilon - T\frac{\partial S}{\partial t} \tag{3}$$

$$\frac{\partial T}{\partial m} = -\frac{3\kappa L}{64\pi^2 acT^3 r^4} \tag{4}$$

$$\frac{\partial X_i}{\partial t} = \frac{m_i}{\rho}(-\Sigma_{j,k} r_{i,j,k} + \Sigma_{k,l} r_{k,l,i}) \tag{5}$$

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Stellar Structure Equations[2]

$$\frac{\partial T}{\partial m} = -\frac{3\kappa L}{64\pi^2 ac T^3 r^4}$$

$$j = -|D\nabla n| = -|\frac{1}{3} v\, l_p \nabla n| \quad (6)$$

$$|\text{with } v = c,\ l_p = l_{ph} = \frac{1}{\kappa\rho} \text{ and } U = aT^4 \rightarrow \frac{\partial U}{\partial r} = 4aT^3 \frac{\partial T}{\partial r} \quad (7)$$

$$F = -\frac{4acT^3}{3\kappa\rho}\frac{\partial T}{\partial r} = -k_{rad}\nabla T \quad |\text{and with } L = 4\pi r^2 F \quad (8)$$

$$\frac{\partial T}{\partial r} = -\frac{3\kappa\rho L}{16\pi a c r^2 T^3} \quad (9)$$

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BoOST

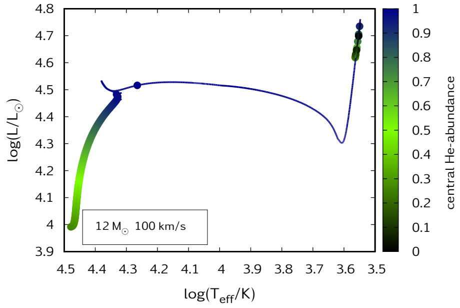

Figure: Unboosted Stellar Track of a 12 M_{sol} model

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BoOST

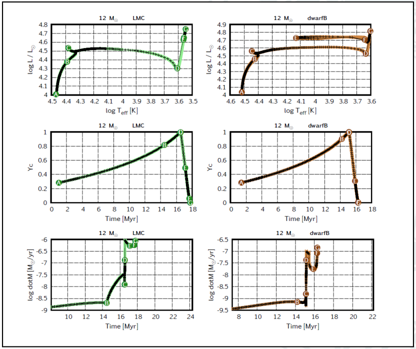

Figure: Position of Equivalent Evolutionary Points (EEPs) during the lifetime of some typical models and amount of datalines for BoOST and non-BoOST [4]

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Nucleosynthesis

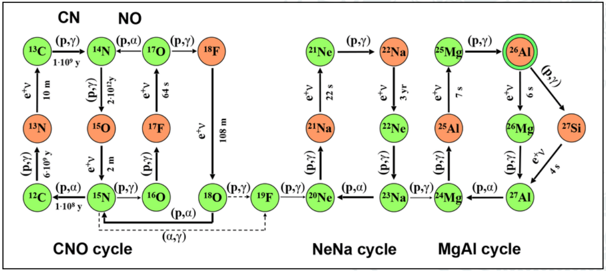

Figure: CNO-, MgAl- and NeNa-cycles[1]

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Evolutionary Behaviour

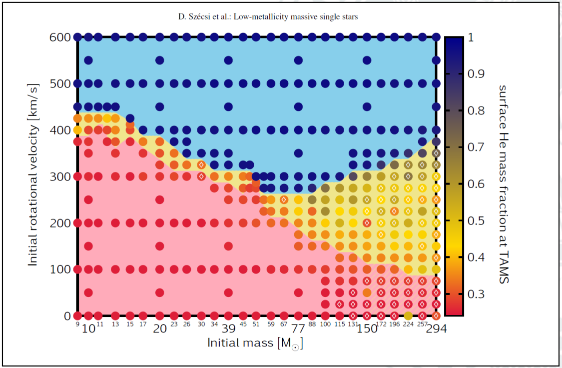

Figure: Surface helium mass fraction at the end of the main sequence for models of 1Zw18[3], a dwarf galaxy with Z=0.02 Z_{mw}

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Evolutionary Behaviour

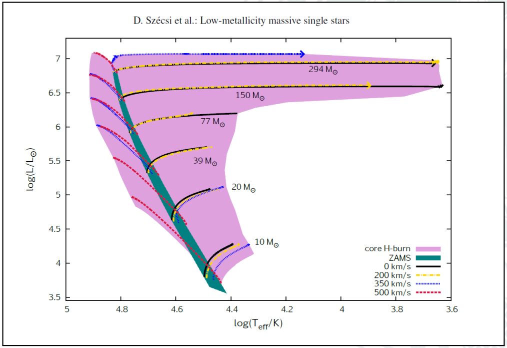

Figure: HRD for models of 1Zw18, picturing both CHE and NE[3]

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Results

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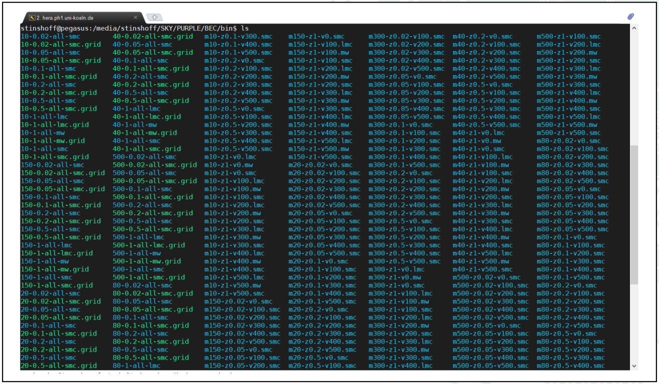
Models done:



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2. hera.ph1.uni-koeln.de
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10-0.02-all-smc.grid   40-0.05-all-smc        m10-z0.1-v400.smc     m150-z1-v100.lmc     m300-z0.02-v200.smc  m40-z0.2-v100.smc     m500-z1-v200.lmc
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150-1-all-mw           500-1-all-mw.grid      m10-z1-v400.mw        m20-z0.1-v0.smc      m300-z0.5-v500.smc   m40-z1-v500.mw        m80-z0.1-v300.smc
150-1-all-mw.grid      500-1-all-smc          m10-z1-v400.smc       m20-z0.1-v100.smc    m300-z1-v0.lmc       m40-z1-v500.smc       m80-z0.1-v400.smc
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```

Figure: 7 masses (10-500 M_{sol}), 8 metallicities (Z_{mw} to 0.02 Z_{smc}) and 6 rot. velocities (0 to 500 km/s), equaling to around 330 models

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Core Helium Mass Fraction

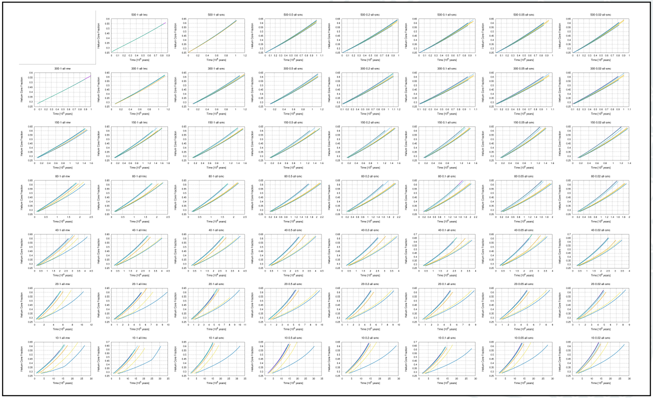

Figure: Core Helium Mass Fraction at the current end of the lifetime of the models

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Mass vs time

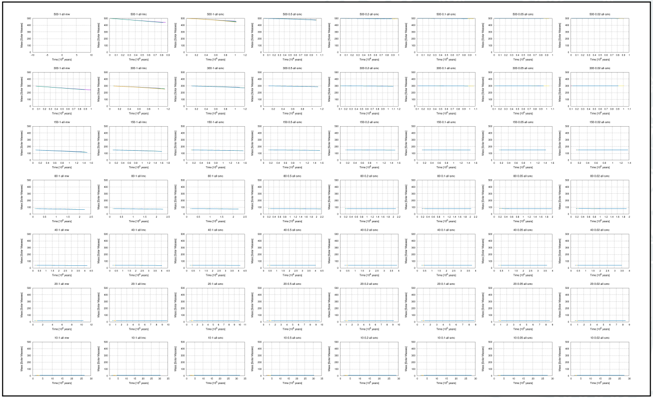

Figure: Mass in M_{sol} vs time in 10^6 years of the models

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Mass vs time

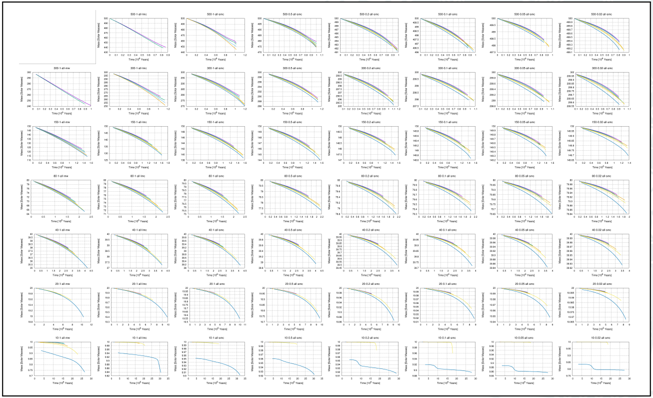

Figure: Mass in M_{sol} vs time in 10^6 years of the models

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HRD

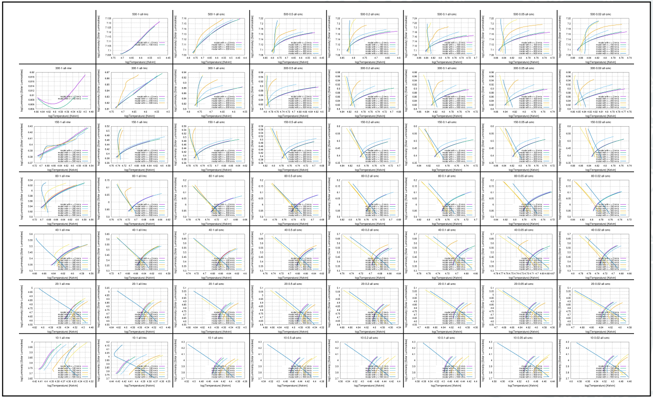

Figure: Hertzsprung Russell Diagramms of the models

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4D Plot of the surface helium mass fraction

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Y_S

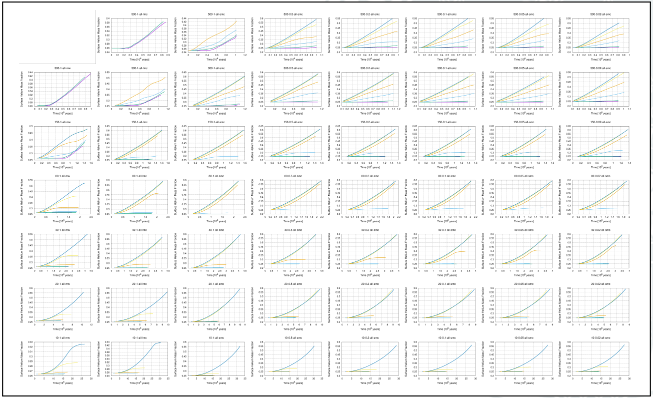

Figure: Y_S vs time of the models

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Summary of the Results

- Big grid of models (330 models)
- Displays properties like expected
- Evolutionary behaviour shown
  - (CHE/TE/NE)

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Outlook

Hanno Stinshoff's Master Thesis Plans. ***Updated: 6/7/21*** **Supervisor: Dorottya Szécsi**

Task \ Time (Semester/Month)	*I/1*	*I/2*	*I/3*	*I/4*	*I/5*	*II/1*	*II/2*	*II/3*	*II/4*	*II/5*
Preparationary Projects										
Reading and learning the relevant literature	√									
Learning R programming language	√									
Writing own script to plot data files of stellar models		√								
Installing the Bonn Code via the "BEC Interface" on the external hard drive			√							
Learning to run stellar models with the Bonn Code ("BEC Interface")			√							
Comparing result to published result using R			√							
Research project part I. – Grid in a 3D parameter space (M, v, Z) on the early Main Sequence, *Setting Up*										
Designing the 3D parameter space				√						
7 masses, 6 velocities and 8 metallicities = ~336 models				√						
Writing the scripts to loop over the parameters					√					
Research project part II. – Grid in a 3D parameter space (M, v, Z) on the early Main Sequence, *Optimizing & Computing*										
Experimentally establishing the right number of structure models to be stored per sequence				√	√					
Finding a way to stop the computation at before of EEP point 'B' of the BoOST format (Yc~0.6)					√	√				
Computation of the models, checking for completeness						√				
Research project part III. – Creating tools to analyse the models										
Plotting the time evolution of the models' physical quantities						√				
Creating "bunch diagrams" out of plots						√				
Visualizing the grids in a 3D diagram							√			
Research project part IV. – Analysing the models										
Analysing the physical predictions of the models (M, Mdot, central & surface abundances etc.)						√	√			
Understanding the problematic cases (Eddington limit proximity, breakup velocity etc.)							...			
Describing the occurrence of Chemically homogeneous evolution								...		
Giving Research Seminar & Writing the Thesis										
Getting experience with scientific writing in English				√		√				
Giving a research seminar (slides, learning presentation tool "*impress!ve*", trials, giving the talk)							...			
Designing the thesis, researching & writing the Introduction							√	...		
Writing down thesis results and the scientific conclusions										
Incorporating all scripts into the 'beci' interface for future convenience										

Figure: Current Progress Plan of the thesis

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Outlook

- Grid can and will be expanded (timewise and finer resolution in critical areas)
- BoOST format can and will be implemented for those models, once they're at the end of their development
- More investigations on various parameters possible and planned (e.g. isotope abundances)

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The end

Thanks for your attention!

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Faculty of Mathematics and Natural Sciences

University of Cologne

- Axel Boeltzig, C. Bruno, Francesca Cavanna, Sergio Cristallo, T. Davinson, R. Depalo, Richard Deboer, A. Leva, Federico Ferraro, Gianluca Imbriani, P. Marigo, Filippo Terrasi, and Michael Wiescher.
Shell and explosive hydrogen burning.
The European Physical Journal A, 52, 04 2016.

- Rudolf Kippenhahn, Alfred Weigert, and Achim Weiss.
Stellar Structure and Evolution.
Springer, 2nd edition, 2012.

- Dorottya Szécsi, Norbert Langer, Sung-Chul Yoon, Debashis Sanyal, Selma de Mink, Christopher J. Evans, and Tyl Dermine.
Low-metallicity massive single stars with rotation - evolutionary models applicable to i zwicky 18.

A&A, 581:A15, 2015.

Dorottya Szécsi, Richard Wünsch, Poojan Agrawal, and Norbert Langer.
'bonn' optimized stellar tracks (boost). simulated populations of massive and very massive stars for astrophysical applications, 2020.