Stellar Structure and Evolution - Lab

Lecturer:
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Teaching assistant:
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Logistics

- Running MESA (detailed instructions in lab lecture notes)
- Troubleshooting sessions
- Report

1-D stellar evolution codes

- MESA in theory
- MESA in practice

Running MESA (Modules for Experiments in Stellar Astrophysics)

- Copy the following lines (the correct path to the MESA folder etc.) into your `~/.bashrc` file (which can be opened with e.g. `gedit ~/.bashrc`):

```
export MESA_DIR=/vol/software/tools/MESA/MESA
export OMP_NUM_THREADS=3
export MESASDK_ROOT=/vol/software/tools/MESA/MESA/mesasdk
source $MESASDK_ROOT/bin/mesasdk_init.sh
```

MESA installed on /vol/software/<...>

Modules accessible via CIP-pool machines

Running MESA (Modules for Experiments in Stellar Astrophysics)

MESA installed on /vol/software/<...>

Modules accessible via CIP-pool machines

Web interface:
www.guacamole-students.astro.uni-bonn.de

Enter the CIP-pool room

dules for Experiments in Stellar Astrophysics)

Apache Guacamole

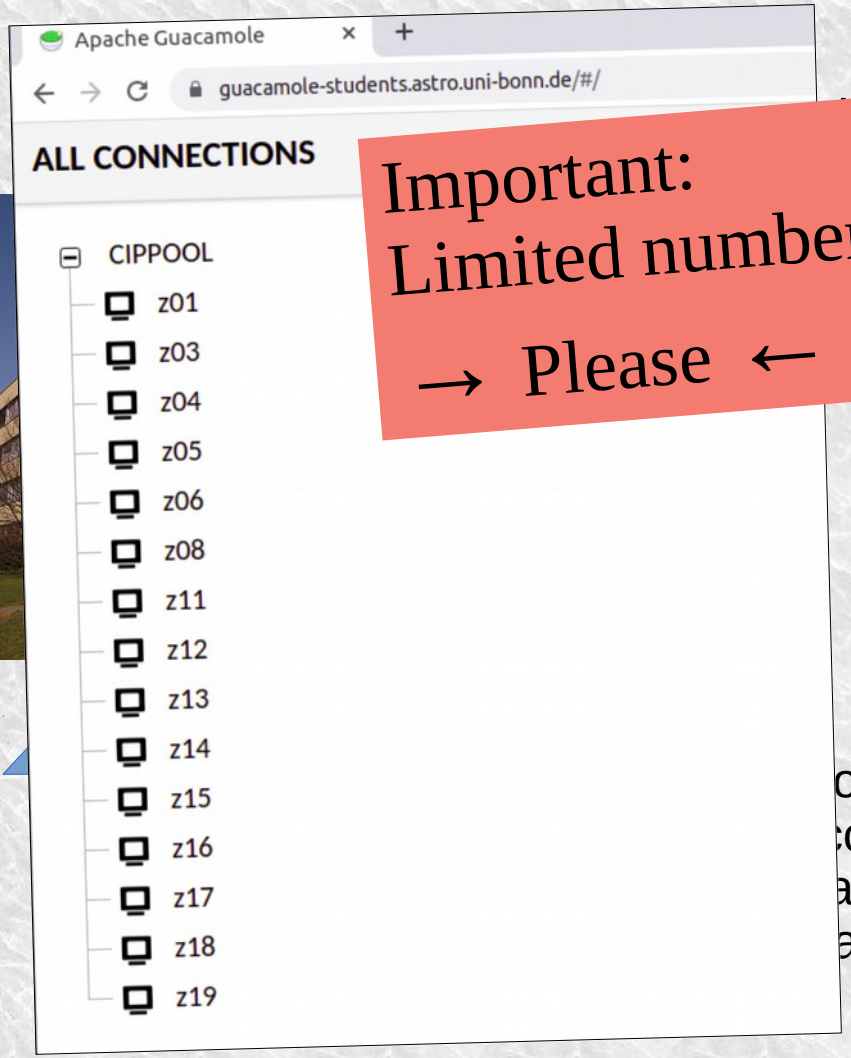
guacamole-students.astro.uni-bonn.de/#/

ALL CONNECTIONS

- CIPPOOL
  - z01
  - z03
  - z04
  - z05
  - z06
  - z08
  - z11
  - z12
  - z13
  - z14
  - z15
  - z16
  - z17
  - z18
  - z19

odules
ccessible
a CIP-pool
achines

Web interface:
www.guacamole-students.astro.uni-bonn.de



Important:
Limited number of machines

→ Please ← log out when you're done

odules
ccessible
a CIP-pool
achines

Web interface:
www.guacamole-students.astro.uni-bonn.de

dules for Experiments in Stellar Astrophysics)

Apache Guacamole

guacamole-students.astro.uni-bonn.de/#/

ALL CONNECTIONS

CIPPOOL

z14
z15
z16
z17
z18
z19

Own laptop?
Sure, but keep in mind:

- MESA needs linux or mac
- We cannot help with installation issues
- The lab is designed for MESA v10000

odules
cessible
a CIP-pool
achines

Web interface:
www.guacamole-students.astro.uni-bonn.de

Classes

- Friday 8:45 to 9:45
- 1 introduction lecture in R0.012
- 4 sessions on the 4 exercises in R0.007 (CIP-pool)
- These are non-obligatory **troubleshooting sessions** (i.e., you work on the exercises *before*)
  - 10.11.2023: introduction lecture
  - 17.11.2023: exercise 1 troubleshooting session
  - 24.11.2023: exercise 2 troubleshooting session
  - 01.12.2023: exercise 3 troubleshooting session
  - 08.12.2023: exercise 4 troubleshooting session

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Questions:
- who has no laptop/desktop with internet?
- who is going to the math tutorial at 10am?

Scheduling extra official sessions is not possible, but a meeting in the CIP-pool room at another time on Friday could be arranged

Classes

- Fri
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- 4 s R0.007 (CIP-pool)
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  - 08.12.2023: exercise 4 troubleshooting session

Please don't use remote access when CIP-pool room is in use:
Wednesday 16:00-18:00
Friday morning

Scheduling extra official sessions is not possible, but a meeting in the CIP-pool room at another time on Friday could be arranged

Writing your report

- Answer Q1.1 etc. point for point
- Be to the point
- Consult SSE lecture notes
- Plotting:
  - basic python script in lab lecture notes
  - other software also ok
  - feel free to ask for help

Exercise 1 — Model resolution and time scales

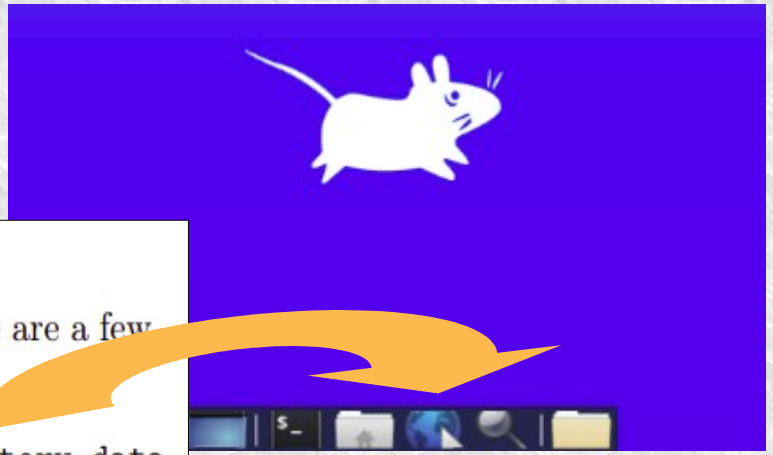
- Compute the evolution of a $1\,M_\odot$ star from the pre-main-sequence (pre-MS) until it has exchausted hydrogen in its core. To get started with the simulation, see 'How to start a run'.
- Enter the value of $1\,M_\odot$ in `inlist_project`.
- There, also set `stop_near_zams` to `.false.` and `xa_central_lower_limit` to `1d-2`
- Start your simulation with `./rn`

Q1.1: What type of information is included in the history file in the `LOGS` folder? Make a plot that shows whether or not the time steps are constant and briefly discuss the reason.

Q:1.2 What type of information is included in the profile files in the `LOGS` folder? Make a plot that shows whether the grid points are spaced evenly or not and briefly discuss the reason.

Writing your report

- 3 options to access data:



Accessing data on CIP-pool machines

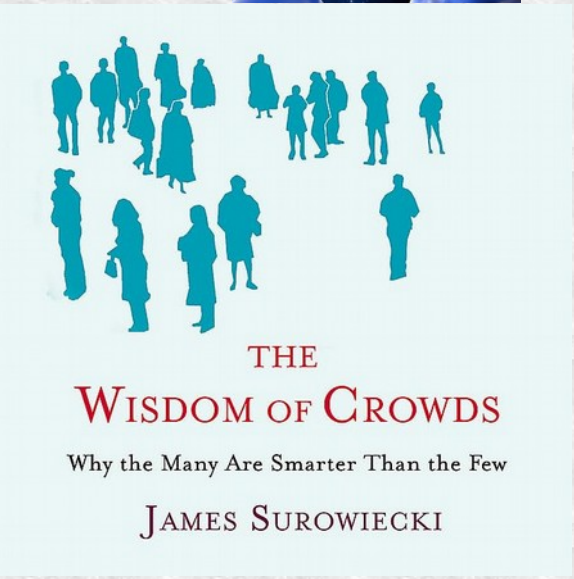
The data from your MESA run will be stored on CIP-pool machines. Then, there are a few ways to work with your data:

- Click on the internet icon when using a CIP-pool machine and upload the `history.data` and `profile<nr>.data` to your Google Drive, Dropbox, or a similar service.
- When physically present in the CIP-pool room, use a USB-stick.
- Access and work with the data whilst logged in at a computer in the CIP-pool.

Writing your report

	A	B	C	D	E
1	Name	mass_in_Msun	q_bottom_tams	q_top_tams	
2	Abel	34.659	0	0.33	
3					

↑ Google sheets



- Everyone simulates random masses
- Group effort: combine results
- You will not be judged by amount of data points in the google sheets file that you use

(but please feel encouraged to follow the exercise schedule)

Writing your report

Download data from Google sheets via
→ file → download → .csv

	A	B	C	D	E
1	Name	mass_in_Msun	q_bottom_tams	q_top_tams	
2	Abel	34.659	0	0.33	
3					

Enter decimal points, not commas

Writing your report

- 10.11.2023: introduction lecture
- 17.11.2023: exercise 1 troubleshooting session
- 24.11.2023: exercise 2 troubleshooting session
- 01.12.2023: exercise 3 troubleshooting session
- 08.12.2023: exercise 4 troubleshooting session

→ Deadline: Sunday 07.01.2024

- Mail your report to **BOTH** aschoot@astro.uni-bonn.de and hjin@astro.uni-bonn.de (write ‘SSE lab report’ in email title)

Writing your report

plagiarism

/ˈpleɪdʒərɪz(ə)m/

noun

the practice of taking someone else's work or ideas and passing them off as one's own.

Please don’t plagiarize:
- we have to take this very seriously
- we are able to find out

↓Source: Oxford languages

Writing your report

plagiarism

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the practice of taking someone else's work or ideas and passing them off as one's own.

Please don’t plagiarize:
- we have to take this very seriously
- we are able to find out

Ergo, it is not allowed to:
- use someone else’s simulation
- copy text
- include a figure you didn’t make

But it is allowed to:
- discuss exercises together
- work on problems together

Main takeaways from ‘logistics’

- Next 4 Friday 08:45-09:45 sessions are troubleshooting sessions in R0.007 (CIP-pool room)
- Lab report deadline 07.01.2024
- Most of this info is discussed in lab lecture notes
- Log out when not using remote access
  AND when CIP-pool room is used:

Wednesday	16:00-18:00
Friday	morning

MESA in theory

- Very frequently used in astrophysical research to test our understanding of stellar physics

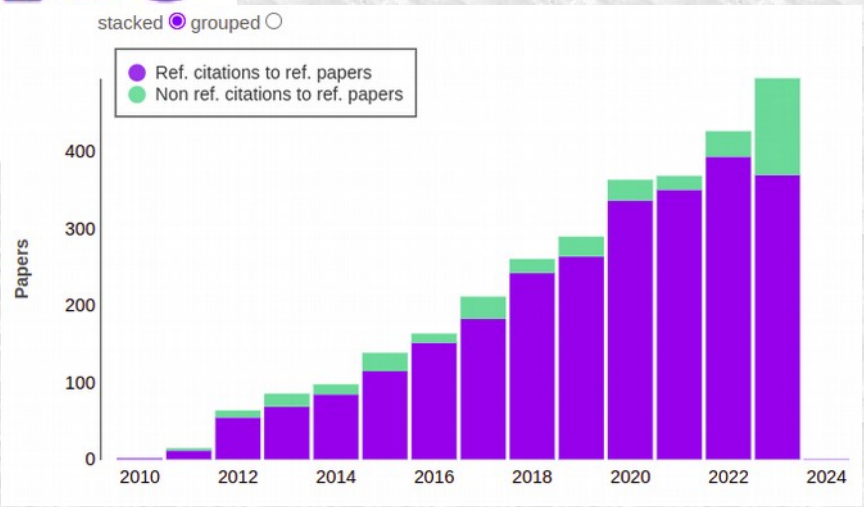
  (see https://ui.adsabs.harvard.edu/ ↓)

2011ApJS..192....3P 2011/01 cited: 2988

Modules for Experiments in Stellar Astrophysics (MESA)

Paxton, Bill; Bildsten, Lars; Dotter, Aaron *and 3 more*

MESA



MESA in theory

- Assuming spherical symmetry saves *a lot* of computation time (compared to 3-D)
- Stars are modeled in Lagrangian coordinates, i.e., in the co-moving frame

MESA in theory

MESA solves differential equations (Lecture notes, Chapter 6)
throughout the star, at one point in time → stellar model

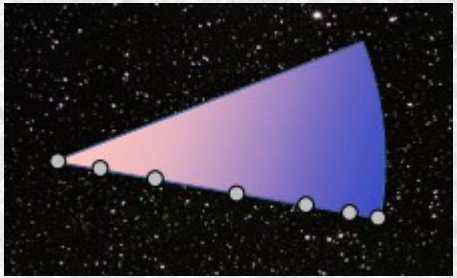
$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho} \tag{6.1}$$

$$\frac{\partial P}{\partial m} = -\frac{Gm}{4\pi r^4} - \frac{1}{4\pi r^2}\frac{\partial^2 r}{\partial t} \tag{6.2}$$

$$\frac{\partial l}{\partial m} = \epsilon_{\rm nuc} - \epsilon_\nu - T\frac{\partial s}{\partial t} \tag{6.3}$$

$$\frac{\partial T}{\partial m} = -\frac{Gm}{4\pi r^4}\frac{T}{P}\nabla \quad \text{with} \quad \nabla = \begin{cases} \nabla_{\rm rad} = \dfrac{3\kappa}{16\pi acG}\dfrac{lP}{mT^4} & \text{if } \nabla_{\rm rad} \le \nabla_{\rm ad} \\ \nabla_{\rm ad} + \Delta\nabla & \text{if } \nabla_{\rm rad} > \nabla_{\rm ad} \end{cases} \tag{6.4}$$

$$\frac{\partial X_i}{\partial t} = \frac{A_i m_u}{\rho}\left(-\sum_{j,k} r_{ij,k} + \sum_{k,l} r_{kl,i}\right) \quad [+ \text{ mixing terms}] \qquad i = 1 \ldots N \tag{6.5}$$



MESA in theory

4+N equations, ~11+N variables

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho} \tag{6.1}$$

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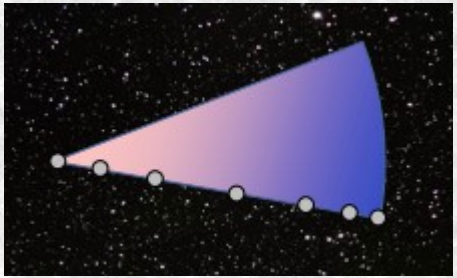
variables:
P, s, ∇_{ad} , $\Delta\nabla$, κ, ε_{nuc},ε_{ν}, $r_{i\,j,k}$,
ρ,T,r,l



MESA in theory

4+N equations, ~11+N variables

→ We need to get closed system of eqs

$$\frac{\partial r}{\partial m} = \frac{1}{4\pi r^2 \rho} \tag{6.1}$$

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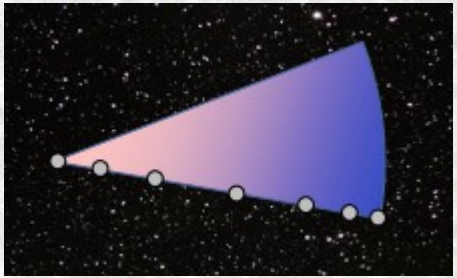
Fortunately:
P, s, ∇_{ad} , $\Delta\nabla$, κ, ε_{nuc},ε_{ν}, $r_{i\,j,k}$
Can be obtained with ρ,T,r,l



MESA in theory

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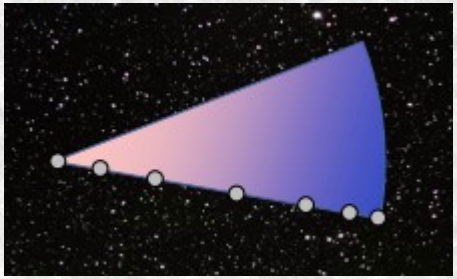
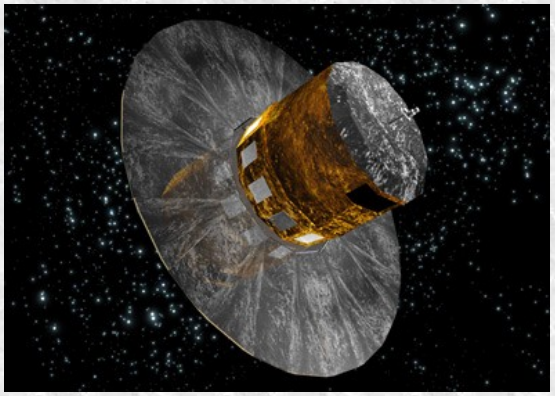


This is the task of some of the MESA Fortran modules (eos, kap, rates, …)

… Then MESA can start to solve iteratively

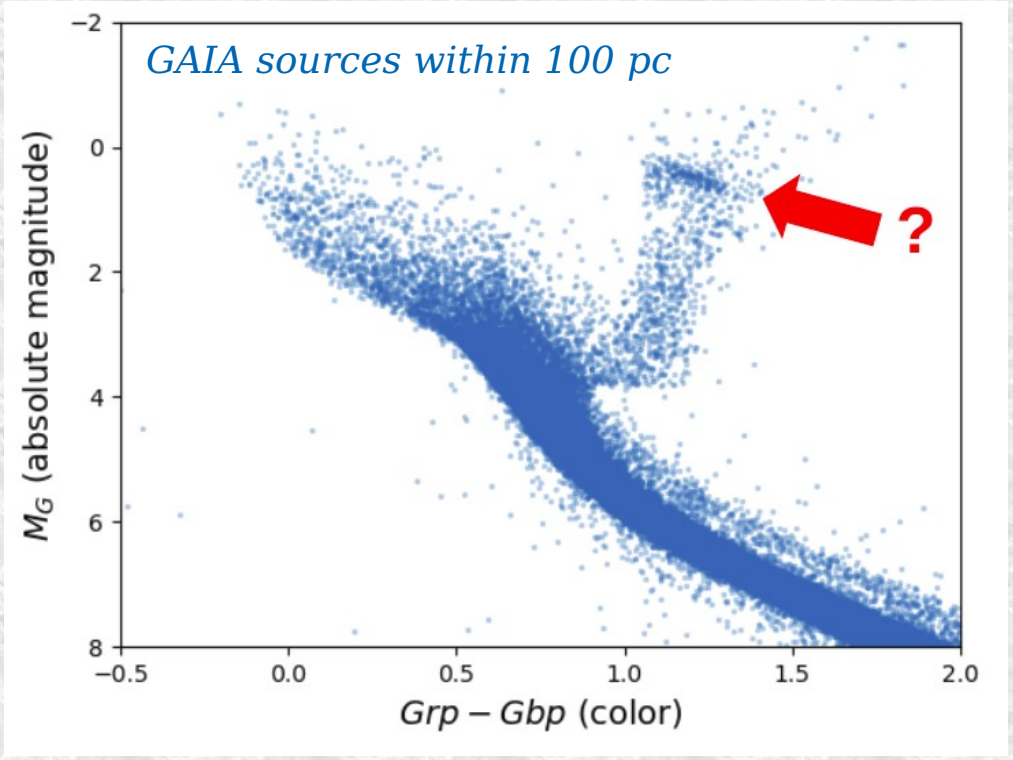
MESA in theory

Cool story, but does that work in practice?



Data from GAIA observations →

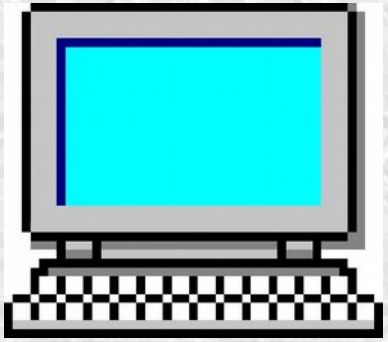
Downloaded from
https://gea.esac.esa.int/archive/



MESA in practice

MESA installed on /vol/software/<...>

(Or MESA installed on laptop/desktop)



With MESA directory set…

- Copy the following lines (the correct path to the MESA folder etc.) into your ~/.bashrc file (which can be opened with e.g. gedit ~/.bashrc):

```
export MESA_DIR=/vol/software/tools/MESA/MESA
export OMP_NUM_THREADS=3
export MESASDK_ROOT=/vol/software/tools/MESA/MESA/mesasdk
source $MESASDK_ROOT/bin/mesasdk_init.sh
```

… you can copy the MESA work folder anywhere and start working

Terminal -

File Edit View Terminal Tabs Help

```
aschoot@z07:~/Desktop/mesa_work$ cp -R $MESA_DIR/star/work example
aschoot@z07:~/Desktop/mesa_work$ cd example
aschoot@z07:~/Desktop/mesa_work/example$ ls
clean   inlist_pgstar   LOGS  mk       re              rn
inlist  inlist_project  make  photos   README_first    src
```

MESA in practice

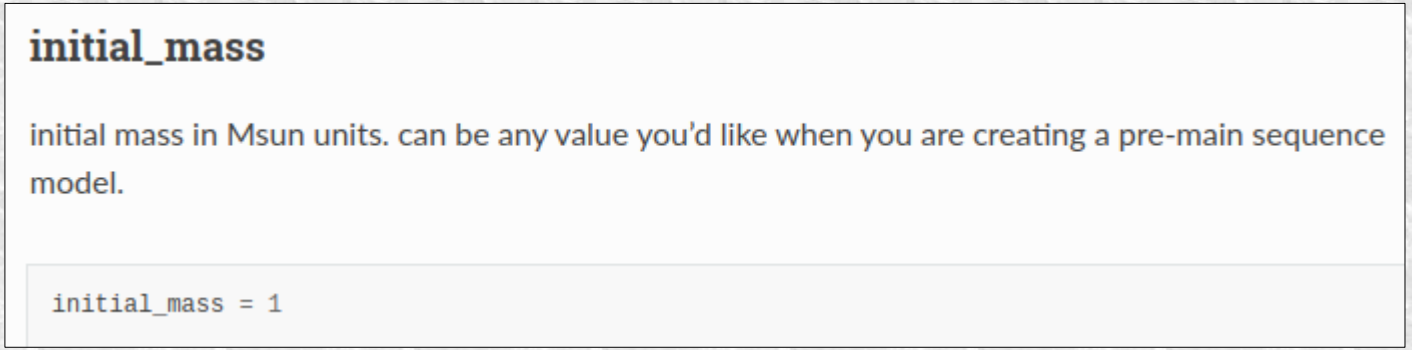
Copied work folder:

```
aschoot@z07:~/Desktop/mesa_work$ cp -R $MESA_DIR/star/work example
aschoot@z07:~/Desktop/mesa_work$ cd example
aschoot@z07:~/Desktop/mesa_work/example$ ls
clean    inlist_pgstar    LOGS  mk       re             rn
inlist   inlist_project   make  photos   README_first   src
```

- Mk, rn, re (& clean) are executables for running MESA
- LOGS: stores history.data & profile<nr>.data
- photos: saves models that can be restarted with ./re
- inlist_*: overwrites MESA default settings

MESA in practice

https://docs.mesastar.org/en/latest/reference/controls.html



initial_mass

initial mass in Msun units. can be any value you'd like when you are creating a pre-main sequence model.

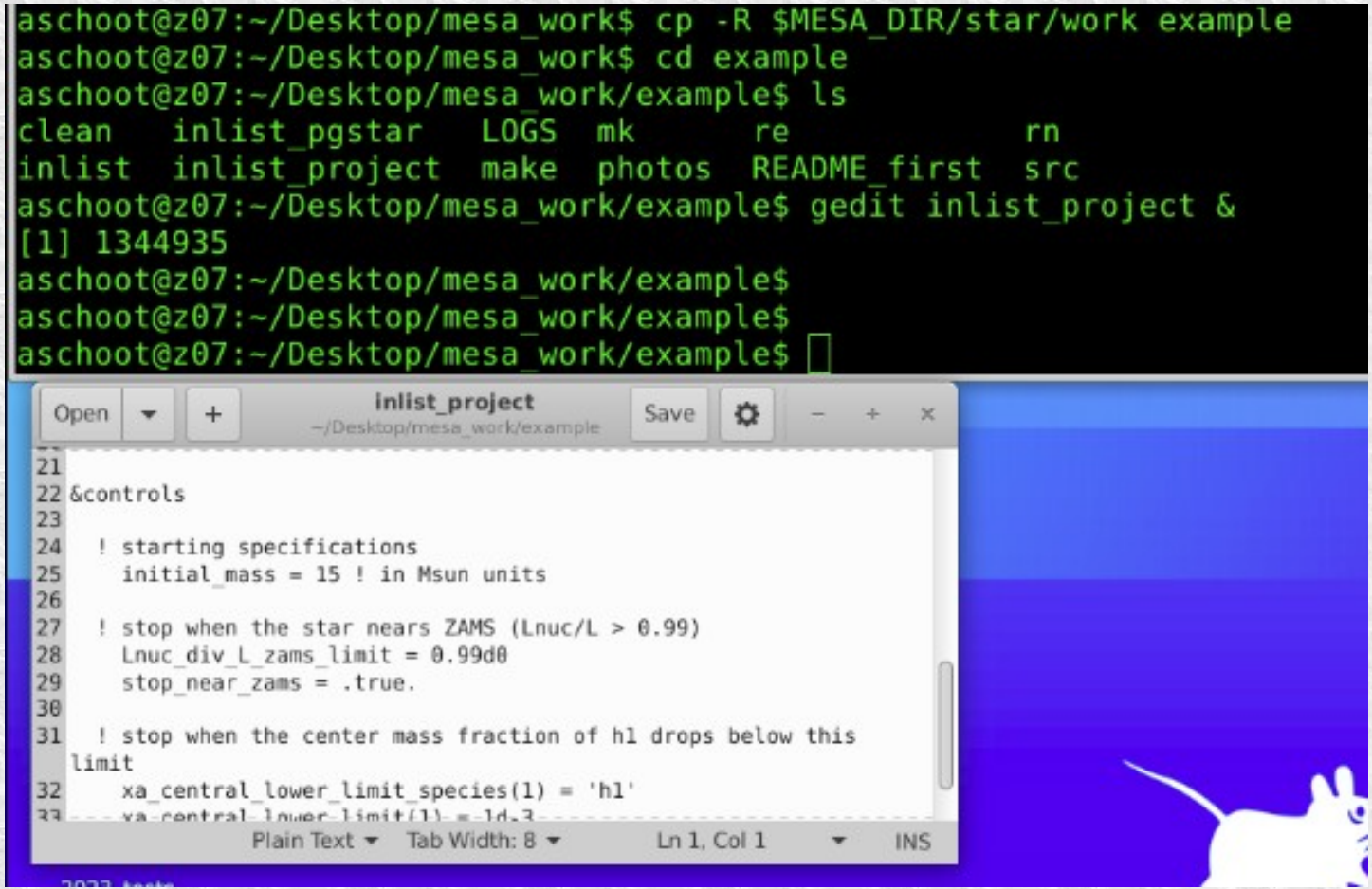
```
initial_mass = 1
```

Also stop conditions, physics assumptions (wind, convection criterion, ……), numerics, …

MESA in practice

Text editors:

- e.g. gedit



MESA in practice

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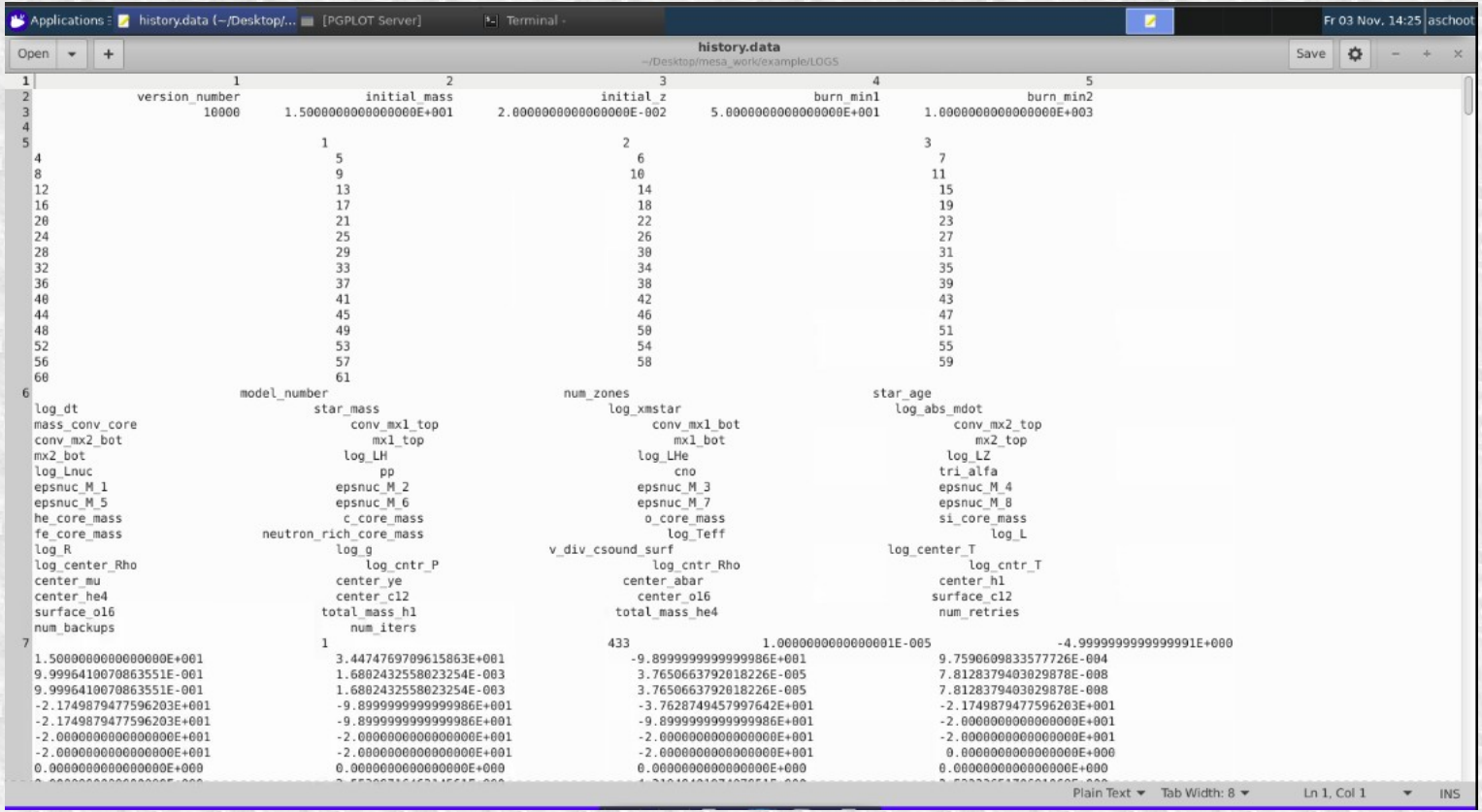
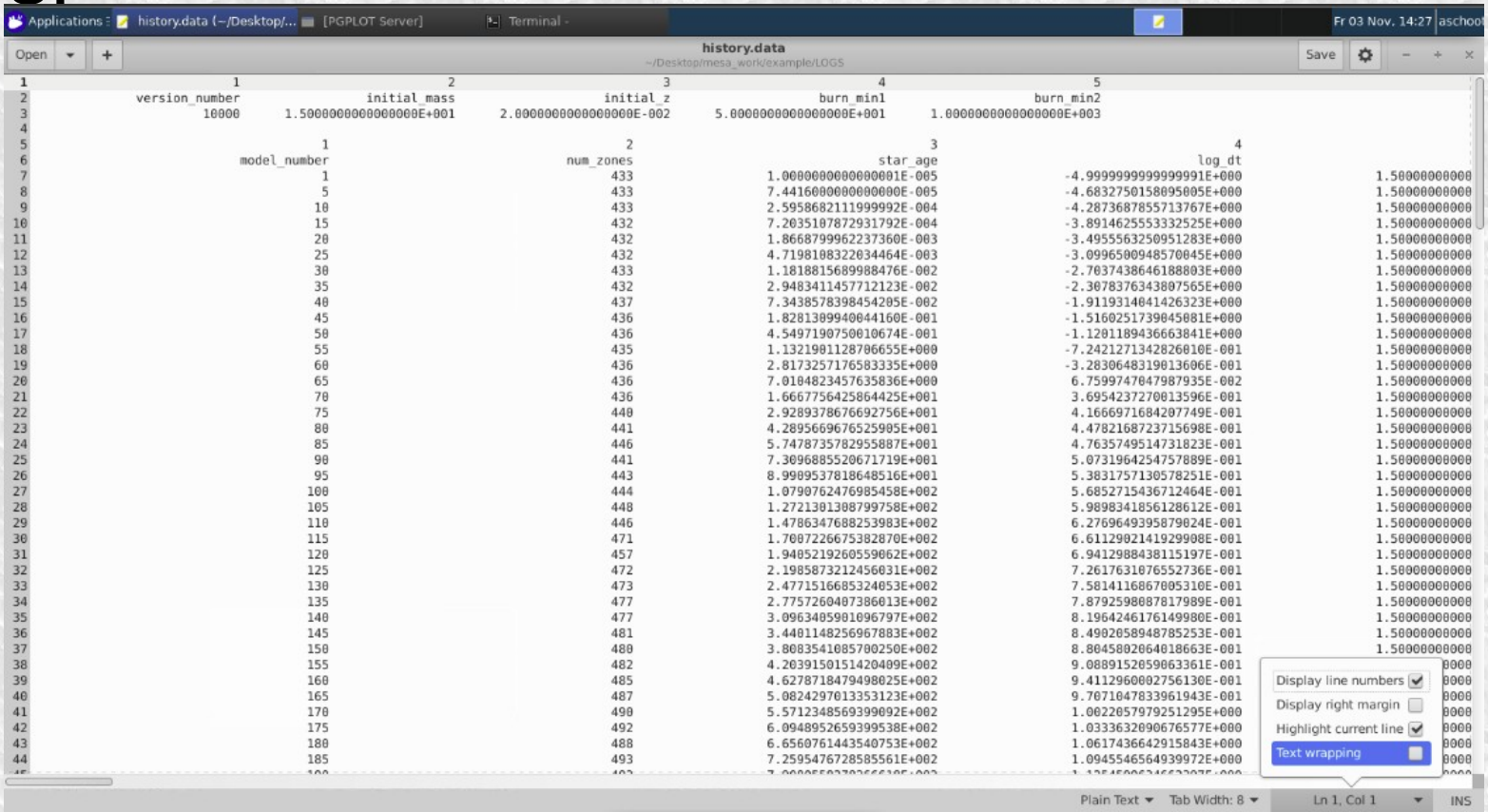


MESA in practice

Text editors:

- e.g. gedit
- You can turn off text wrapping:

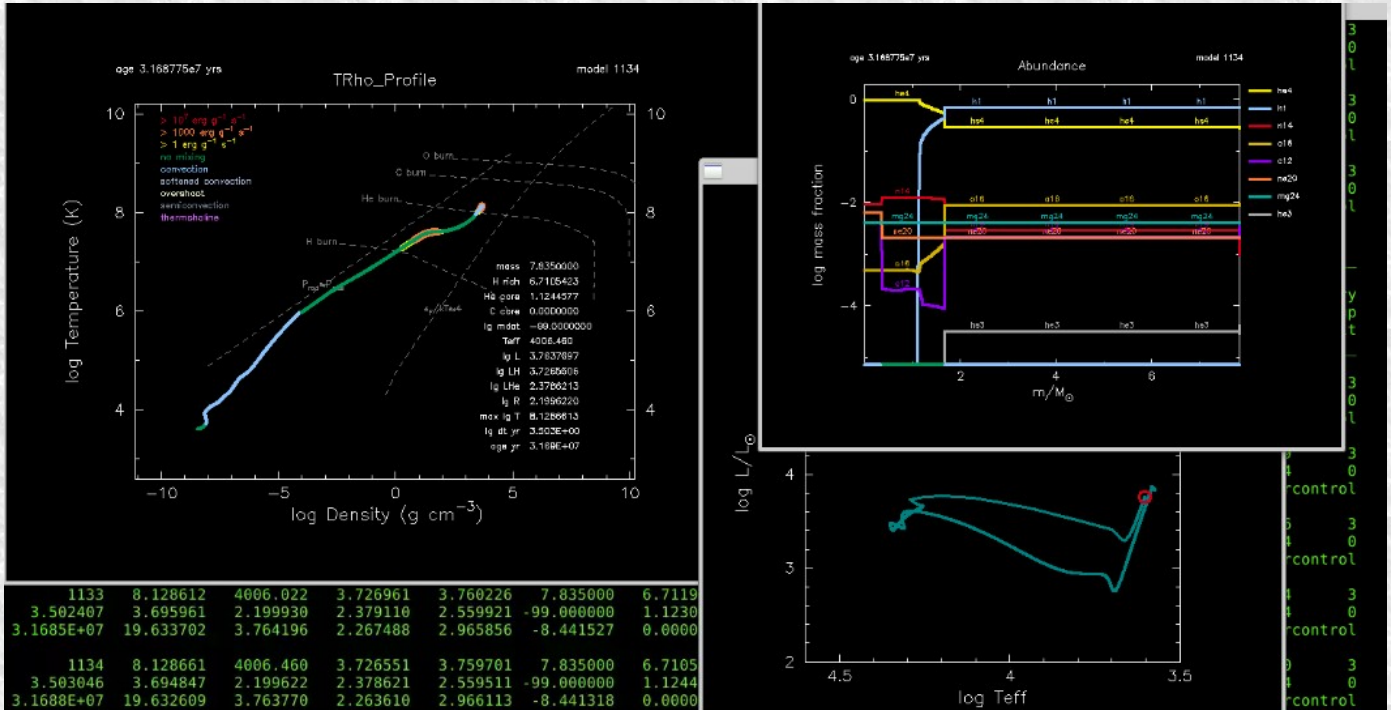


1	2	3	4	5
version_number	initial_mass	initial_z	burn_min1	burn_min2
10000	1.5000000000000000E+001	2.0000000000000000E-002	5.0000000000000000E+001	1.0000000000000000E+003

1	2	3	4
model_number	num_zones	star_age	log_dt
1	433	1.0000000000000001E-005	-4.9999999999999991E+000	1.5000000000
5	433	7.4416000000000000E-005	-4.6832750158095005E+000	1.5000000000
10	433	2.5958682111999992E-004	-4.2873687855713767E+000	1.5000000000
15	432	7.2035107872931792E-004	-3.8914625553332525E+000	1.5000000000
20	432	1.8668799962237360E-003	-3.4955563250951283E+000	1.5000000000
25	432	4.7198108322034464E-003	-3.0996500948570045E+000	1.5000000000
30	433	1.1818815689988476E-002	-2.7037438646188803E+000	1.5000000000
35	432	2.9483411457712123E-002	-2.3078376343807565E+000	1.5000000000
40	437	7.3435783984542050E-002	-1.9119314041426323E+000	1.5000000000
45	436	1.8281309940044160E-001	-1.5160251739045081E+000	1.5000000000
50	436	4.5497190750010674E-001	-1.1201189436663841E+000	1.5000000000
55	435	1.1321901128706655E+000	-7.2421271342826010E-001	1.5000000000
60	436	2.8173257176583335E+000	-3.2830648319013606E-001	1.5000000000
65	436	7.0104823457635836E+000	6.7599747047987935E-002	1.5000000000
70	436	1.6667756425864425E+001	3.6954237270013596E-001	1.5000000000
75	440	2.9289378676692756E+001	4.1666971684207749E-001	1.5000000000
80	441	4.2895669676525905E+001	4.4782168723715698E-001	1.5000000000
85	446	5.7478735782955887E+001	4.7635749514731823E-001	1.5000000000
90	441	7.3096885520671719E+001	5.0731964254757889E-001	1.5000000000
95	443	8.9909537818648516E+001	5.3831757130578251E-001	1.5000000000
100	444	1.0790762476985458E+002	5.6852715436712464E-001	1.5000000000
105	448	1.2721301308799758E+002	5.9898341856128612E-001	1.5000000000
110	446	1.4786347688253983E+002	6.2769649395879024E-001	1.5000000000
115	471	1.7007226675382870E+002	6.6112902141929908E-001	1.5000000000
120	457	1.9405219260559062E+002	6.9412988438115197E-001	1.5000000000
125	472	2.1985873212456031E+002	7.2617631876552736E-001	1.5000000000
130	473	2.4771516685324053E+002	7.5814116867005310E-001	1.5000000000
135	477	2.7757260407386013E+002	7.8792598687817989E-001	1.5000000000
140	477	3.0963405901096797E+002	8.1964246176149980E-001	1.5000000000
145	481	3.4401148256967883E+002	8.4902058948785253E-001	1.5000000000
150	480	3.8083541085700250E+002	8.8045802064018663E-001	1.5000000000
155	482	4.2039150151420409E+002	9.0889152059063361E-001	1.5000000000
160	485	4.6278718479498025E+002	9.4112960002756130E-001	1.5000000000
165	487	5.0824297013353123E+002	9.7071047833961943E-001	1.5000000000
170	490	5.5712348569399092E+002	1.0022057979251295E+000	1.5000000000
175	492	6.0948952659399538E+002	1.0333632090676577E+000	1.5000000000
180	488	6.6560761443540753E+002	1.0617436642915843E+000	1.5000000000
185	493	7.2595476728585561E+002	1.0945546564939972E+000	1.5000000000

MESA in practice

inlist_pgstar: changes MESA default settings for on-the-fly plotting. Add, remove, adapt plots



1133	8.128612	4006.022	3.726961	3.760226	7.835000	6.7119
3.502407	3.695961	2.199930	2.379110	2.559921	-99.000000	1.1230
3.1685E+07	19.633702	3.764196	2.267488	2.965856	-8.441527	0.0000
1134	8.128661	4006.460	3.726551	3.759701	7.835000	6.7105
3.503046	3.694847	2.199622	2.378621	2.559511	-99.000000	1.1244
3.1688E+07	19.632609	3.763770	2.263610	2.966113	-8.441318	0.0000

MESA in practice

inlist_pgstar: changes MESA default settings for on-the-fly plotting. Add, remove, adapt plots