

An Introduction to Modules for Experiments in Stellar Astrophysics



Meredith Joyce
Assistant Professor

Physical Science 109

(307) 766-6150

mjoyce8@uwo.edu

A/Professor Meredith Joyce
Department of Physics and Astronomy
& School of Computing
University of Wyoming, USA
MESA Developers: 2019 – present



What is MESA?

MESA, after astropy, is the most widely used, open-source software project in astronomy and astrophysics

MESA, after **astropy**, is the most widely used, open-source software project in astronomy and astrophysics

MESA and **astropy** were named in the **Astro 2020 Decadal Survey** as critical instruments for the future of astronomy in the next decade

MESA is an incredibly versatile
software instrument

MESA is an incredibly versatile
software instrument

MESA is a team of developers
and thousands of users worldwide

MESA is an incredibly versatile software instrument

MESA is a team of developers and thousands of users worldwide

MESA is a model for open-source and community-driven science

A Brief History of Time(steps)

A Brief History of Time(steps)

Our story
begins
with two
characters...

A Brief History of Time(steps)

Bill Paxton



Our story
begins
with two
characters...

Lars Bildsten





Bill
Paxton

■ Senior Fellow

KITP, Kohn Hall
University of California
Santa Barbara, CA 93106

Bill Paxton

Biographical Sketch



My academic and career background is in Computer Science. While I was in graduate school, I worked with **Doug Engelbart** at **SRI** where he and his group were busy inventing personal computing (check out the 40th Anniversary Celebration of the "**Mother of All Demos**"). As soon as I got my "union card" from Stanford (Ph.D., 1977), I went to work at the Xerox Palo Alto Research Center (**PARC**) where they were creating new technologies like Ethernet, networked personal computers, bitmap displays, graphical user-interfaces, and laser printers. Two of my colleagues at PARC, **Chuck Geschke** and **John Warnock**, eventually left to form **Adobe Systems**. I joined them soon after (1983), in time to help build the original PostScript and later become one of the Adobe recipients of the **ACM's Software System Award** (1989) for PostScript's design and implementation (among other things, I did the Type 1 font algorithms starting from some of John's great ideas).

Thanks to Adobe I've been "retired" since 1990, and now I'm having fun being an unofficial scholar at the University of California, Santa Barbara (**UCSB**). The people at the Kavli Institute for Theoretical Physics (**KITP**), **Lars Bildsten** in particular, have been most welcoming and tolerant of my eccentricities. The stellar evolution program **EZ** was created as part of a project with Lars. I'm now working on **MESA**, an open source set of modules for software experiments in stellar astrophysics.

Since a physicist can do "astro-physics", I imagine a Computer Scientist can do "astro-computing" or perhaps it could be called "computational-astro-physics". That seems to be a good description of what I'm up to these days, and I'm having a great time! But if I do happen to have a bad day, I can always turn to Calvin for inspiration.

A Brief History of Time(steps)

2011 – Instrument paper I Paxton et al.

2013 – Instrument paper II Paxton et al.

2015 – Instrument paper III Paxton et al.

2018 – Instrument paper IV Paxton et al.

2019 – Instrument paper V Paxton et al.

2023 – Instrument paper VI Jermyn et al.



Bill Paxton



Lars Bildsten

ADS library containing
these papers (+errata):

[https://ui.adsabs.harvard.edu/
user/libraries/
vT_uYj92TP6KMn4QWYBcVQ](https://ui.adsabs.harvard.edu/user/libraries/vT_uYj92TP6KMn4QWYBcVQ)



Beatrice M. Tinsley Prize



The Tinsley Prize recognizes an outstanding research contribution to astronomy or astrophysics, of an exceptionally creative or innovative character. The prize is normally awarded every two years.

2021 – Bill Paxton

For his inspired work on providing, maintaining, and supporting the use of open-source stellar-evolution codes that have seeped into the foundation of research and education efforts.

We have **6 instrument papers**, and they should each be cited separately if you use MESA in a paper

Citing MESA

You should cite all of the available MESA instrument papers at the time of the MESA version being used, as MESA is sum of this work. Currently, that is:

```
Modules for Experiments in Stellar Astrophysics  
\citep[MESA][Paxton2011, Paxton2013, Paxton2015, Paxton2018, Paxton2019, Jermyn2023].
```

A bibtex file containing these references is available here:

https://docs.mesastar.org/en/release-r24.03.1/using_mesa/best_practices.html

Also!! cite the works corresponding to significant infrastructure that has been shared with the project

MESA critically rests on the hard work of many researchers who have generated the input microphysics data that underpins the `eos`, `kap`, `net`, and `neu` modules. We therefore encourage users to briefly summarize these, including appropriate citations.

```
The MESA EOS is a blend of the OPAL \citep{Rogers2002}, SCVH  
\citep{Saumon1995}, FreeEOS \citep{Irwin2004}, HELM \citep{Timmes2000},  
PC \citep{Potekhin2010}, and Skye \citep{Jermyn2021} EOSes.
```

```
Radiative opacities are primarily from OPAL \citep{Iglesias1993},  
Iglesias1996}, with low-temperature data from \citet{Ferguson2005}  
and the high-temperature, Compton-scattering dominated regime by  
\citet{Poutanen2017}. Electron conduction opacities are from  
\citet{Cassisi2007} and \citet{Blouin2020}.
```

```
Nuclear reaction rates are from JINA REACLIB \citep{Cyburt2010}, NACRE \citep{Angulo1999} and  
additional tabulated weak reaction rates \citet{Fuller1985}, Oda1994,  
Langanke2000}. Screening is included via the prescription of \citet{Chugunov2007}.  
Thermal neutrino loss rates are from \citet{Itoh1996}.
```

A bibtex file containing these references is available here:
https://docs.mesastar.org/en/release-r24.03.1/using_mesa/best_practices.html



Josiah Schwab



Adam Jermy



Meredith Joyce



Evan Bauer



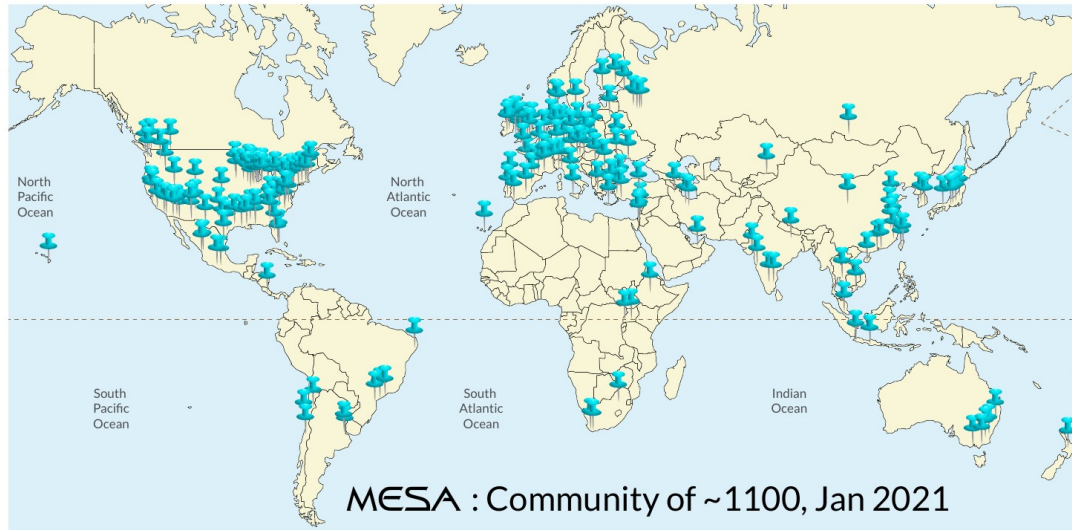
Earl Bellinger



Anne Thoul



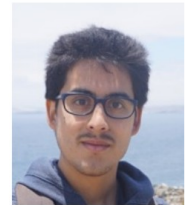
Radek Smolec



Bill Wolf



Rob Farmer



Pablo Marchant



Warrick Ball



Aaron Dotter



Rich Townsend



Frank Timmes



Bill Paxton



Lars Bildsten



Matteo Cantiello



Emeritus

Josiah Schwab

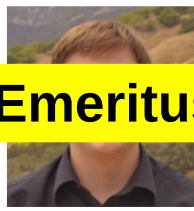


Emeritus

Adam Jermyn



Meridith Joyce

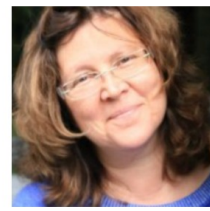


Emeritus

Evan Bauer



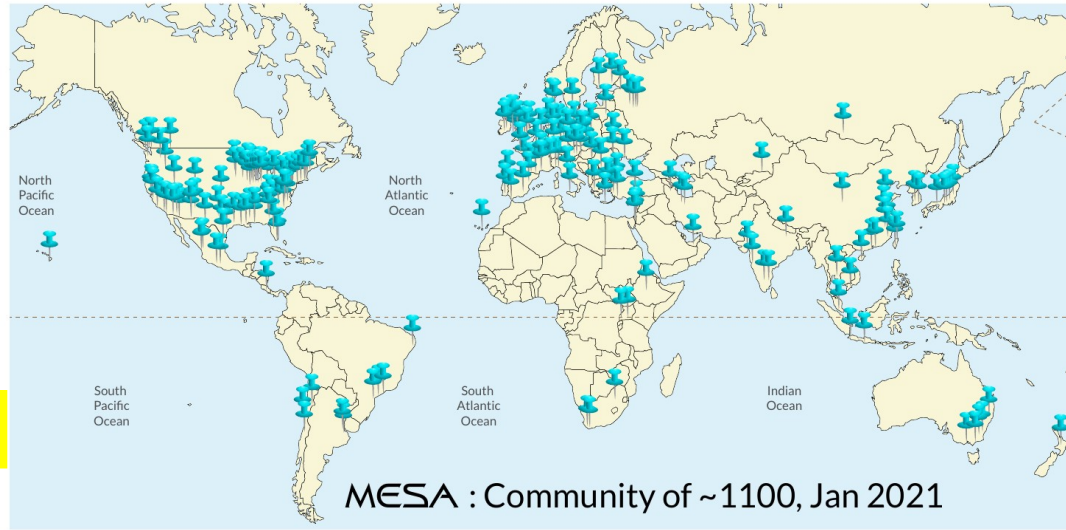
Earl Bellinger



Anne Thoul



Radek Smolec



Bill Wolf



Emeritus

Rob Farmer



Pablo Marchant



Warrick Ball



Emeritus

Aaron Dotter



Rich Townsend



Emeritus

Frank Timmes



Emeritus

Bill Paxton



Emeritus

Lars Bildsten



Matteo Cantiello

Remix!!



Matthias Fabry



Philip Mocz



Joey Mombarg



Ebraheem Farag



Meredith Joyce



Warrick Ball



Rich Townsend



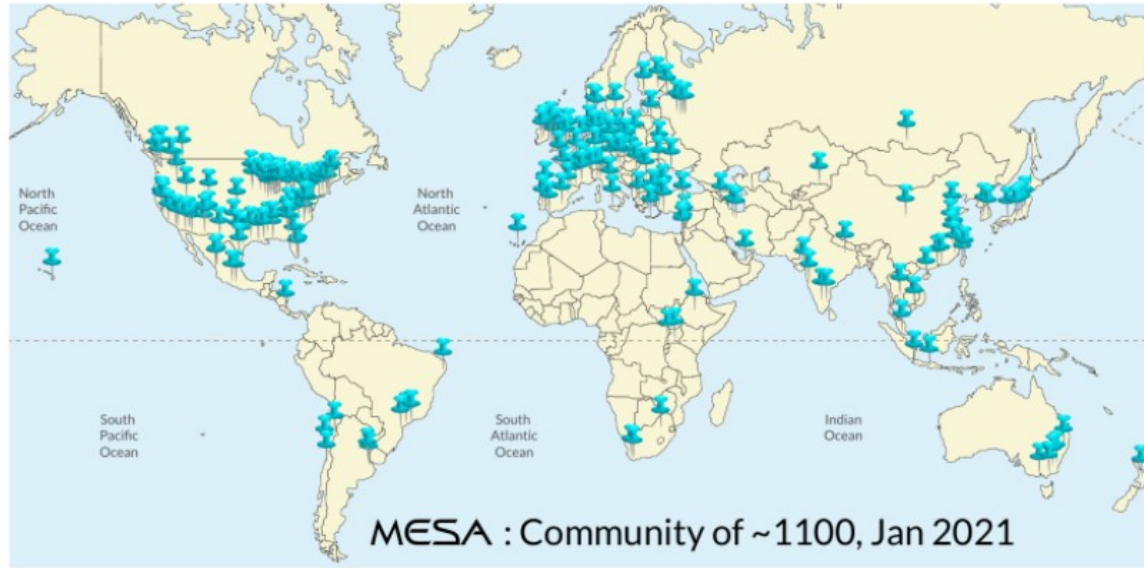
Anne Thoul



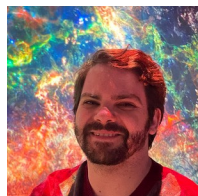
Earl Bellinger



Bill Wolf



Radek Smolec



Jared Goldberg



Mattieu Renzo



Matteo Cantiello

2025!

You can check out the past
and current developers at:

<https://docs.mesastar.org/en/stable/about.html>

MESA's new development home: the Center for Computational Astrophysics (CCA) at the Flatiron Institute, NYC



Fig 1: Philip Mocz, dedicated software engineer

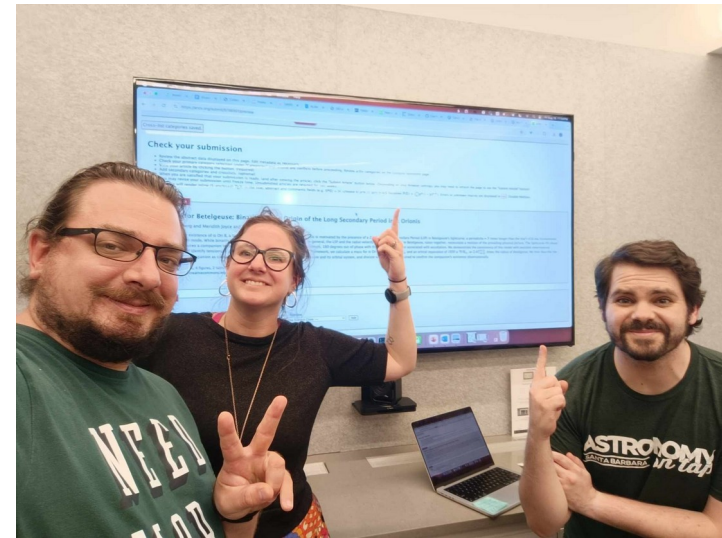


Fig 2: two MESA devs + bonus Hungarian, CCA

MESA Summer Schools

Historically hosted at the University of California,
Santa Barbara (11 years)...

MESA@Konkoly, 2023



**MESA@Konkoly Summer School
Budapest, 2023.08.28-09.01**



MESA Down Under, 2024



THE UNIVERSITY OF
SYDNEY



MESA Summer School, 2015



10-year MESA-versary!!!

MESA Open knowledge philosophy

MESA Open knowledge philosophy

Open Source

The code is freely available, but that's only one piece of the picture. In order for a product to be truly open source, it also has to be usable

MESA Open knowledge philosophy

Open Source

The code is freely available, but that's only one piece of the picture. In order for a product to be truly open source, it also has to be usable

MESA's documentation is thorough, and extensive tutorials and pedagogical materials are freely available along with the software itself. The team is highly responsive to user questions

MESA Open knowledge philosophy

Open Knowledge

MESA Open knowledge philosophy

Open Knowledge

MESA “best practices” encourage the sharing of your parameter control files (inlists) as well as analysis scripts, numerical data, code for making figures, etc. The aspiration is *complete reproducibility* of science that uses MESA.

MESA Open knowledge philosophy

Open Knowledge

MESA “best practices” encourage the sharing of your parameter control files (inlists) as well as analysis scripts, numerical data, code for making figures, etc. The aspiration is *complete reproducibility* of science that uses MESA.

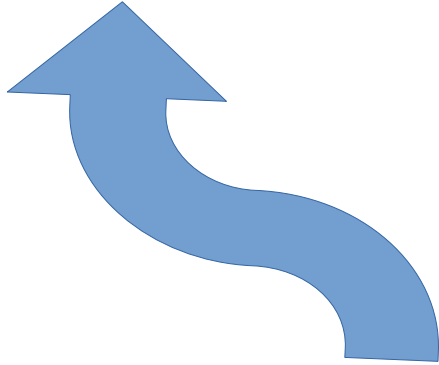
We can't personally enforce this, but we hope the value of this level of scientific accountability is obvious. This is the way the world is heading, and grant agencies are adapting their funding priorities accordingly (e.g., open source/data sharing requirements in the EU)

Zenodo repository:
<https://zenodo.org/records/13353788>

Core Resources

Core Resources

Zenodo repository:
<https://zenodo.org/records/13353788>



This is where you should
download the code from!

Zenodo repository:
<https://zenodo.org/records/13353788>

Core Resources

Stop here!!

TAs: Does everyone at your table have **version 24.08.1** and the **appropriate SDK** installed?

Core Resources

[Communities](#)[My dashboard](#)

MESA Modules for Experiments in Stellar Astrophysics (MESA)

Published August 21, 2024 | Version r24.08.1

Software

Open

Modules for Experiments in Stellar Astrophysics (MESA)

Paxton, Bill¹

Show affiliations

Release versions of Modules for Experiments in Stellar Astrophysics (MESA) in ZIP format.

Files

mesa-24.08.1.zip



mesa-24.08.1.zip



Core Resources

Zenodo repository:

<https://zenodo.org/records/13353788>

Github repository:

<https://github.com/MESAHub/mesa>

Software Development Kit (SDK):

<http://user.astro.wisc.edu/~townsend/static.php?ref=mesasdk>

The code itself:

Mesa-r24.08.1/star/test_suite

Mesa-r24.08.1/star/defaults/*.list ; *.defaults

The web-hosted documentation:

<https://docs.mesastar.org/en/latest/>



MESA

Latest MESA release version

[Get MESA](#)



MESA SDK

MESA Software Development Kit

[Get MESA SDK](#)



Code Repository

Source code hosted on GitHub

[Check out source code](#)



Documentation

How to install and use MESA

[Read the docs](#)



Zenodo Community

Official release versions, SDKs, and MESA project inlists downloads

[Go to Zenodo](#)



MESA Marketplace

Resources for published papers using MESA

[Go to Marketplace](#)



MESA Users Mailing List

Info about new releases, news items, and requests for help/bug reports

[Sign up for mailing list](#)



mesa_reader

Python module to interact and plot MESA data (pip install mesa_reader)

[Get mesa_reader](#)



MESA Summer Schools

Materials from past MESA schools and how to host your own

[Check out MESA summer schools](#)



MESA-web

Web interface to run MESA experiments

[Try MESA-web](#)

What can MESA do?

What can MESA do?

**MESA is BROAD, not
necessarily DEEP**

What can MESA do?

MESA is BROAD, not necessarily DEEP

➔ Depth comes from contributors improving small components of MESA relevant to their expertise

What can MESA do?

A tour of the `test_suite`

After installation, navigate to:
[mesa-r24.08.1/star/test_suite/](https://mesa-robotics.github.io/mesa-r24.08.1/star/test_suite/)

A tour of the test_suite

```
mjoyce@gracehopper:~/MESA/mesa-r24.08.1/star/test_suite$ ls
12M_pre_ms_to_core_collapse  check_redo                gyre_in_mesa_wd           make_zams_low_mass        rsp_Type_II_Cepheid
1.3M_ms_high_Z               conductive_flame           hb_2M                     make_zams_ultra_high_mass semiconvection
1.4M_ms_op_mono              conserve_angular_momentum high_mass                  ns_c                       simplex_solar_calibration
15M_dynamo                   conv_core_cpm             high_rot_darkening        ns_h                       split_burn_big_net
1.5M_with_diffusion          count_tests                high_z                     ns_he                      starspots
16M_conv_premix              custom_colors              hot_cool_wind             other_physics_hooks       test_case_template
16M_predictive_mix           custom_rates               hse_riemann               pisp                       test_memory
1M_pre_ms_to_wd              debugging_stuff_for_inlists irradiated_planet         ppisp                      test_suite_helpers
1M_thermohaline              diffusion_smoothness       list_tests                 radiative_levitation      timing
20M_pre_ms_to_core_collapse do1_rsp_test_source        low_z                      R_CrB_star                T_tau_gradr
20M_z2m2_high_rotation       do1_test_source           magnetic_braking           relax_composition_j_entropy twin_studies
5M_cepheid_blue_loop         each_test_clean            make_brown_dwarf          report                     tzo
7M_premms_to_AGB             each_test_compile         make_co_wd                 rsp_BEP                    wd_acc_small_dm
accreted_material_j          each_test_do              make_env                   rsp_BLAP                   wd_aic
adjust_net                    each_test_run             make_he_wd                 rsp_Cepheid                wd_c_core_ignition
build_and_run                 extended_convective_penetration make_metals                rsp_Cepheid_6M            wd_cool_0.6M
c13_pocket                    gyre_in_mesa_bcep         make_o_ne_wd              rsp_check_2nd_crossing     wd_diffusion
carbon_kh                     gyre_in_mesa_envelope    make_planets              rsp_Delta_Scuti           wd_he_shell_ignition
cburn_inward                  gyre_in_mesa_ms          make_pre_ccsn_13bvn       rsp_gyre                   wd_nova_burst
ccsn_IIP                      gyre_in_mesa_rsg         make_sdb                   rsp_RR_Lyrae              wd_stable_h_burn
check_pulse_atm               gyre_in_mesa_spb         make_zams                  rsp_save_and_load_file    zams_to_cc_80
```

Using MESA

Environment Variables

Environment variables

To run MESA, you must set *environment variables* that point your system to the correct paths for dependent packages

The variables are:

MESA_DIR – the location of your top-level MESA directory

MESASDK_ROOT – the location of the SDK

OMP_NUM_THREADS – the number of threads (= 2x number of cores) you choose to devote to MESA calculations. RECOMMEND: subtract 2 threads for other tasks

*Note that most laptops have between 2 and 8 threads available, or 1 to 4 cores. Setting **OMP_NUM_THREADS** above this will result in overextending the capabilities of your system, causing the calculations to run very slowly or crash*

Environment Variables

The syntax for setting these variables differs between MacOS and Linux and depends on your shell environment (ex. I use Linux and bash shell)

Visit

https://www.youtube.com/watch?v=NmaLHFxpALg&ab_channel=FrankTimmes

for video guides on how to set up these variables for other systems

Other video installation guides also available at my website:

<https://www.meridithjoyce.com/talks.html>

Setting environment variables: the bad way

```
mjoyce@gracehopper: ~/MESA/mesa-r24.08.1
drwxrwxr-x 14 mjoyce mjoyce 4096 Jul 1 07:28 data
drwxrwxr-x 2 mjoyce mjoyce 4096 Jul 1 07:44 lib
drwxrwxr-x 7 mjoyce mjoyce 4096 Jul 1 08:14 gyre
drwxrwxr-x 2 mjoyce mjoyce 12288 Jul 1 08:18 include
-rw-rw-r-- 1 mjoyce mjoyce 172 Jul 1 08:20 testhub.yml
drwxrwxr-x 5 mjoyce mjoyce 4096 Jul 1 08:20 forum
drwxrwxr-x 5 mjoyce mjoyce 4096 Jul 1 08:20 sample
-rw-rw-r-- 1 mjoyce mjoyce 15415 Jul 1 08:21 build.log
-rwxr-xr-x 1 mjoyce mjoyce 13464 Jul 1 08:24 install
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$ export $MESA_DIR=/home/mjoyce/MSEA/mesa-r24.08.1
bash: export: `=/home/mjoyce/MSEA/mesa-r24.08.1': not a valid identifier
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$ export MESA_DIR=/home/mjoyce/MSEA/mesa-r24.08.1
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$ export MESASDK_ROOT=/home/mjoyce/MESA/mesasdk
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$ source $MESASDK_ROOT/bin/mesasdk_init.sh
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$ export OMP_NUM_THREADS=2
mjoyce@gracehopper:~/MESA/mesa-r24.08.1$
```

Setting environment variables the good way: `.bashrc` file

Since `.bashrc` (or equivalent) is read automatically each time you open a new terminal window, assigning environment variables in `.bashrc` (*or the equivalent profile of your local system*) means you do not need to assign them manually

Setting environment variables the good way: `.bashrc` file

```
318  
319 export MESA_DIR=/home/mjoyce/MESA/  
320 export MESASDK_ROOT=/home/mjoyce/MESA/mesasdk  
321 source $MESASDK_ROOT/bin/mesasdk_init.sh  
322 export OMP_NUM_THREADS=16
```

Best way: functions in .bashrc

```
319
320 function mesa-24081 {
321 export MESA_DIR=/home/mjoyce/MESA/mesa-r24.08.1
322 export MESASDK_ROOT=/home/mjoyce/MESA/mesask
323 source $MESASDK_ROOT/bin/mesask_init.sh
324 export OMP_NUM_THREADS=16
325 echo "environment set for version 24.08.1"
326 echo "OMP_NUM_THREADS set to 16"
327 }
```

Because then you can toggle between **MESA** versions, if you ever have reason to do that...

```
320 function mesa-24081 {
321 export MESA_DIR=/home/mjoyce/MESA/mesa-r24.08.1
322 export MESASDK_ROOT=/home/mjoyce/MESA/mesask
323 source $MESASDK_ROOT/bin/mesask_init.sh
324 export OMP_NUM_THREADS=16
325 echo "environment set for version 24.08.1"
326 echo "OMP_NUM_THREADS set to 16"
327 }
328
329 function mesa-colors {
330 export MESA_DIR=/home/mjoyce/MESA/mesa-2025-summer-school-prerelease/
331 export MESASDK_ROOT=/home/mjoyce/MESA/mesask
332 source $MESASDK_ROOT/bin/mesask_init.sh
333 export OMP_NUM_THREADS=16
334 echo "environment set for 2025 Custom Colors pre-release"
335 echo "OMP_NUM_THREADS set to 16"
336 }
```

Now it is straightforward to set up your **MESA** environment:

```
mjoyce@burbridge: ~/MESA/mesa-r24.03.1
-rwxr-xr-x 1 mjoyce mjoyce 461 Mar 5 13:19 each_package_do
xyfile
cs
ta
CONTRIBUTING.rst
drwxrwxr-x 8 mjoyce mjoyce 4096 Mar 5 13:19 const
drwxrwxr-x 7 mjoyce mjoyce 4096 Mar 5 13:19 colors
-rw-rw-r-- 1 mjoyce mjoyce 5195 Mar 5 13:19 CODEOWNERS
-rw-rw-r-- 1 mjoyce mjoyce 1910 Mar 5 13:19 CODE_OF_CONDUCT.rst
-rwxr-xr-x 1 mjoyce mjoyce 356 Mar 5 13:19 clean
-rw-rw-r-- 1 mjoyce mjoyce 21100 Mar 5 13:19 CITATIONS.bib
drwxrwxr-x 8 mjoyce mjoyce 4096 Mar 5 13:19 chem
drwxrwxr-x 11 mjoyce mjoyce 4096 Mar 5 13:19 binary
drwxrwxr-x 8 mjoyce mjoyce 4096 Mar 5 13:19 auto_diff
drwxrwxr-x 8 mjoyce mjoyce 4096 Mar 5 13:19 atm
drwxrwxr-x 9 mjoyce mjoyce 4096 Mar 5 13:19 astero
drwxrwxr-x 6 mjoyce mjoyce 4096 Mar 5 13:19 adipls
mjoyce@burbridge:~/MESA/mesa-r24.03.1$ source ~/.bashrc
mjoyce@burbridge:~/MESA/mesa-r24.03.1$ mesa-24031
environment set for MESA version 24.03.1
SDK version for July 2023 in use
OMP_NUM_THREADS set to 8
mjoyce@burbridge:~/MESA/mesa-r24.03.1$
```

Microlab 0: **Check and set** **environment variables** **(~3 minutes)**

Microlab 0: **Check and set** **environment variables** **(~3 minutes)**

Show of thumbs when complete!

Setup and output

Inlists – Fortran namelists that contain **value** definitions for all of the **parameters** of your run
ex) **history_filename = 'history_my_run.data'**

Parameter libraries- *all of the possible values for your parameters can be found in the module defaults files*

Mesa-r24.08.1/star/defaults/ contains

controls.defaults
star_job.defaults
pgstar.defaults
history_columns.list
profile_columns.list

Opacity defaults can be found in
mesa-r24.08.1/kap/defaults/kap.defaults

EOS defaults in
mesa-r24.08.1/eos/defaults/eos.defaults

Setup and output

Executable

star or **binary**; this is the program that is built by the compiler and runs your simulation

Scripts

clean, mk, rn, re – these are shell scripts that build and manipulate your program

Setup and output

By default, MESA keeps track of the full stellar structure of your model across evolutionary time

Output is stored in the **LOGS/** directory

history.data traces evolutionary quantities

profileX.data gives you the structural model at some time step dt .
you can adjust the frequency of these outputs in the inlists

profiles.index provides a mapping between the integer in the profile output names and the model number from the evolutionary run (in cases where a profile is not generated at every time step)

You can also store binary snapshots of the models: **photos**

Setup and output

History output should look something like this:

```
~/MESA/mesa-r15140/star/work/LOGS/history.data - Sublime Text (UNREGISTERED)
File Edit Selection Find View Goto Tools Project Preferences Help
inlist_start_header x inlist_start x bashrc x history.data x
1 | 1 2 3
2 | 4 5 6
3 | 7 8 9
4 | version number compiler build
5 | MESA_SDK version math backend date
6 | burn_min1 burn_min2 "10.2.0" "20211101"
7 | "15140" "gfortran"
8 | "x86_64-linux-20.12.1" "CRMATH"
9 | 5.000000000000000000E+001 1.000000000000000000E+003
10 | 1 2 3
11 | 4 5 6
12 | 7 8 9
13 | 10 11 12
14 | 13 14 15
15 | 16 17 18
16 | 19 20 21
17 | 22 23 24
18 | 25 26 27
19 | 28 29 30
20 | 31 32 33
21 | 34 35 36
22 | 37 38 39
23 | 40 41 42
24 | 43 44 45
25 | 46 47 48
26 | 49 50 51
27 | 52 53 54
28 | 55 56 57
29 | 58
30 | model_number num_zones star_age
31 | log_dt star_mass log_xmstar log_abs_mdot
32 | mass_conv_core conv_mx1_top conv_mx1_bot
33 | conv_mx2_top conv_mx2_bot mx1_top
34 | mx1_bot mx2_top mx2_bot log_LZ
35 | log_LH pp cno
36 | log_Lnuc epsnuc_M_1 epsnuc_M_2
37 | tri_alfa epsnuc_M_4 epsnuc_M_5
38 | epsnuc_M_3 epsnuc_M_6 epsnuc_M_7 epsnuc_M_8
39 | he_core_mass c_core_mass o_core_mass
40 | si_core_mass fe_core_mass neutron_rich_core_mass
41 | log_Teff log_L log_R log_g
42 | v_div_csound_surf log_cntr_P log_cntr_Rho
43 | log_cntr_T center_mu center_ye center_ye
44 | center_abar center_h1 center_he4
45 | center_c12 center_o16 surface_c12
46 | surface_o16 total_mass_h1 total_mass_he4
47 | num_retries num_iters
48 | 1 492 1.000000000000000001E-005 -4.99999999999999991E+000
49 | 1.500000000000000002E+001 3.4474597169416349E+001 -9.89999999999999986E+001
50 | 0.000000000000000000E+000 9.9998828386135030E-001 3.0124054712287992E-003
51 | 0.000000000000000000E+000 0.000000000000000000E+000 0.000000000000000000E+000
52 | 3.0124054712287992E-003 0.000000000000000000E+000 9.9998828386135030E-001
53 | -1.7113671445755475E+001 -9.89999999999999986E+001 -9.89999999999999986E+001
54 | -1.7113671445755475E+001 -1.7113671445755475E+001 -9.89999999999999986E+001
55 | -9.89999999999999986E+001 -2.000000000000000000E+001 -2.000000000000000000E+001
56 |
57 |
58 |
59 |
60 |
61 |
62 |
63 |
64 |
65 |
66 |
67 |
68 |
69 |
70 |
71 |
72 |
73 |
74 |
75 |
76 |
77 |
78 |
79 |
80 |
81 |
82 |
83 |
84 |
85 |
86 |
87 |
88 |
89 |
90 |
91 |
92 |
93 |
94 |
95 |
96 |
97 |
98 |
99 |
100 |
101 |
102 |
103 |
104 |
105 |
106 |
107 |
108 |
109 |
110 |
111 |
112 |
113 |
114 |
115 |
116 |
117 |
118 |
119 |
120 |
121 |
122 |
123 |
124 |
125 |
126 |
127 |
128 |
129 |
130 |
131 |
132 |
133 |
134 |
135 |
136 |
137 |
138 |
139 |
140 |
141 |
142 |
143 |
144 |
145 |
146 |
147 |
148 |
149 |
150 |
151 |
152 |
153 |
154 |
155 |
156 |
157 |
158 |
159 |
160 |
161 |
162 |
163 |
164 |
165 |
166 |
167 |
168 |
169 |
170 |
171 |
172 |
173 |
174 |
175 |
176 |
177 |
178 |
179 |
180 |
181 |
182 |
183 |
184 |
185 |
186 |
187 |
188 |
189 |
190 |
191 |
192 |
193 |
194 |
195 |
196 |
197 |
198 |
199 |
200 |
201 |
202 |
203 |
204 |
205 |
206 |
207 |
208 |
209 |
210 |
211 |
212 |
213 |
214 |
215 |
216 |
217 |
218 |
219 |
220 |
221 |
222 |
223 |
224 |
225 |
226 |
227 |
228 |
229 |
230 |
231 |
232 |
233 |
234 |
235 |
236 |
237 |
238 |
239 |
240 |
241 |
242 |
243 |
244 |
245 |
246 |
247 |
248 |
249 |
250 |
251 |
252 |
253 |
254 |
255 |
256 |
257 |
258 |
259 |
260 |
261 |
262 |
263 |
264 |
265 |
266 |
267 |
268 |
269 |
270 |
271 |
272 |
273 |
274 |
275 |
276 |
277 |
278 |
279 |
280 |
281 |
282 |
283 |
284 |
285 |
286 |
287 |
288 |
289 |
290 |
291 |
292 |
293 |
294 |
295 |
296 |
297 |
298 |
299 |
300 |
301 |
302 |
303 |
304 |
305 |
306 |
307 |
308 |
309 |
310 |
311 |
312 |
313 |
314 |
315 |
316 |
317 |
318 |
319 |
320 |
321 |
322 |
323 |
324 |
325 |
326 |
327 |
328 |
329 |
330 |
331 |
332 |
333 |
334 |
335 |
336 |
337 |
338 |
339 |
340 |
341 |
342 |
343 |
344 |
345 |
346 |
347 |
348 |
349 |
350 |
351 |
352 |
353 |
354 |
355 |
356 |
357 |
358 |
359 |
360 |
361 |
362 |
363 |
364 |
365 |
366 |
367 |
368 |
369 |
370 |
371 |
372 |
373 |
374 |
375 |
376 |
377 |
378 |
379 |
380 |
381 |
382 |
383 |
384 |
385 |
386 |
387 |
388 |
389 |
390 |
391 |
392 |
393 |
394 |
395 |
396 |
397 |
398 |
399 |
400 |
401 |
402 |
403 |
404 |
405 |
406 |
407 |
408 |
409 |
410 |
411 |
412 |
413 |
414 |
415 |
416 |
417 |
418 |
419 |
420 |
421 |
422 |
423 |
424 |
425 |
426 |
427 |
428 |
429 |
430 |
431 |
432 |
433 |
434 |
435 |
436 |
437 |
438 |
439 |
440 |
441 |
442 |
443 |
444 |
445 |
446 |
447 |
448 |
449 |
450 |
451 |
452 |
453 |
454 |
455 |
456 |
457 |
458 |
459 |
460 |
461 |
462 |
463 |
464 |
465 |
466 |
467 |
468 |
469 |
470 |
471 |
472 |
473 |
474 |
475 |
476 |
477 |
478 |
479 |
480 |
481 |
482 |
483 |
484 |
485 |
486 |
487 |
488 |
489 |
490 |
491 |
492 |
493 |
494 |
495 |
496 |
497 |
498 |
499 |
500 |
501 |
502 |
503 |
504 |
505 |
506 |
507 |
508 |
509 |
510 |
511 |
512 |
513 |
514 |
515 |
516 |
517 |
518 |
519 |
520 |
521 |
522 |
523 |
524 |
525 |
526 |
527 |
528 |
529 |
530 |
531 |
532 |
533 |
534 |
535 |
536 |
537 |
538 |
539 |
540 |
541 |
542 |
543 |
544 |
545 |
546 |
547 |
548 |
549 |
550 |
551 |
552 |
553 |
554 |
555 |
556 |
557 |
558 |
559 |
560 |
561 |
562 |
563 |
564 |
565 |
566 |
567 |
568 |
569 |
570 |
571 |
572 |
573 |
574 |
575 |
576 |
577 |
578 |
579 |
580 |
581 |
582 |
583 |
584 |
585 |
586 |
587 |
588 |
589 |
590 |
591 |
592 |
593 |
594 |
595 |
596 |
597 |
598 |
599 |
600 |
601 |
602 |
603 |
604 |
605 |
606 |
607 |
608 |
609 |
610 |
611 |
612 |
613 |
614 |
615 |
616 |
617 |
618 |
619 |
620 |
621 |
622 |
623 |
624 |
625 |
626 |
627 |
628 |
629 |
630 |
631 |
632 |
633 |
634 |
635 |
636 |
637 |
638 |
639 |
640 |
641 |
642 |
643 |
644 |
645 |
646 |
647 |
648 |
649 |
650 |
651 |
652 |
653 |
654 |
655 |
656 |
657 |
658 |
659 |
660 |
661 |
662 |
663 |
664 |
665 |
666 |
667 |
668 |
669 |
670 |
671 |
672 |
673 |
674 |
675 |
676 |
677 |
678 |
679 |
680 |
681 |
682 |
683 |
684 |
685 |
686 |
687 |
688 |
689 |
690 |
691 |
692 |
693 |
694 |
695 |
696 |
697 |
698 |
699 |
700 |
701 |
702 |
703 |
704 |
705 |
706 |
707 |
708 |
709 |
710 |
711 |
712 |
713 |
714 |
715 |
716 |
717 |
718 |
719 |
720 |
721 |
722 |
723 |
724 |
725 |
726 |
727 |
728 |
729 |
730 |
731 |
732 |
733 |
734 |
735 |
736 |
737 |
738 |
739 |
740 |
741 |
742 |
743 |
744 |
745 |
746 |
747 |
748 |
749 |
750 |
751 |
752 |
753 |
754 |
755 |
756 |
757 |
758 |
759 |
760 |
761 |
762 |
763 |
764 |
765 |
766 |
767 |
768 |
769 |
770 |
771 |
772 |
773 |
774 |
775 |
776 |
777 |
778 |
779 |
780 |
781 |
782 |
783 |
784 |
785 |
786 |
787 |
788 |
789 |
790 |
791 |
792 |
793 |
794 |
795 |
796 |
797 |
798 |
799 |
800 |
801 |
802 |
803 |
804 |
805 |
806 |
807 |
808 |
809 |
810 |
811 |
812 |
813 |
814 |
815 |
816 |
817 |
818 |
819 |
820 |
821 |
822 |
823 |
824 |
825 |
826 |
827 |
828 |
829 |
830 |
831 |
832 |
833 |
834 |
835 |
836 |
837 |
838 |
839 |
840 |
841 |
842 |
843 |
844 |
845 |
846 |
847 |
848 |
849 |
850 |
851 |
852 |
853 |
854 |
855 |
856 |
857 |
858 |
859 |
860 |
861 |
862 |
863 |
864 |
865 |
866 |
867 |
868 |
869 |
870 |
871 |
872 |
873 |
874 |
875 |
876 |
877 |
878 |
879 |
880 |
881 |
882 |
883 |
884 |
885 |
886 |
887 |
888 |
889 |
890 |
891 |
892 |
893 |
894 |
895 |
896 |
897 |
898 |
899 |
900 |
901 |
902 |
903 |
904 |
905 |
906 |
907 |
908 |
909 |
910 |
911 |
912 |
913 |
914 |
915 |
916 |
917 |
918 |
919 |
920 |
921 |
922 |
923 |
924 |
925 |
926 |
927 |
928 |
929 |
930 |
931 |
932 |
933 |
934 |
935 |
936 |
937 |
938 |
939 |
940 |
941 |
942 |
943 |
944 |
945 |
946 |
947 |
948 |
949 |
950 |
951 |
952 |
953 |
954 |
955 |
956 |
957 |
958 |
959 |
960 |
961 |
962 |
963 |
964 |
965 |
966 |
967 |
968 |
969 |
970 |
971 |
972 |
973 |
974 |
975 |
976 |
977 |
978 |
979 |
980 |
981 |
982 |
983 |
984 |
985 |
986 |
987 |
988 |
989 |
990 |
991 |
992 |
993 |
994 |
995 |
996 |
997 |
998 |
999 |
1000 |
1001 |
1002 |
1003 |
1004 |
1005 |
1006 |
1007 |
1008 |
1009 |
1010 |
1011 |
1012 |
1013 |
1014 |
1015 |
1016 |
1017 |
1018 |
1019 |
1020 |
1021 |
1022 |
1023 |
1024 |
1025 |
1026 |
1027 |
1028 |
1029 |
1030 |
1031 |
1032 |
1033 |
1034 |
1035 |
1036 |
1037 |
1038 |
1039 |
1040 |
1041 |
1042 |
1043 |
1044 |
1045 |
1046 |
1047 |
1048 |
1049 |
1050 |
1051 |
1052 |
1053 |
1054 |
1055 |
1056 |
1057 |
1058 |
1059 |
1060 |
1061 |
1062 |
1063 |
1064 |
1065 |
1066 |
1067 |
1068 |
1069 |
1070 |
1071 |
1072 |
1073 |
1074 |
1075 |
1076 |
1077 |
1078 |
1079 |
1080 |
1081 |
1082 |
1083 |
1084 |
1085 |
1086 |
1087 |
1088 |
1089 |
1090 |
1091 |
1092 |
1093 |
1094 |
1095 |
1096 |
1097 |
1098 |
1099 |
1100 |
1101 |
1102 |
1103 |
1104 |
1105 |
1106 |
1107 |
1108 |
1109 |
1110 |
1111 |
1112 |
1113 |
1114 |
1115 |
1116 |
1117 |
1118 |
1119 |
1120 |
1121 |
1122 |
1123 |
1124 |
1125 |
1126 |
1127 |
1128 |
1129 |
1130 |
1131 |
1132 |
1133 |
1134 |
1135 |
1136 |
1137 |
1138 |
1139 |
1140 |
1141 |
1142 |
1143 |
1144 |
1145 |
1146 |
1147 |
1148 |
1149 |
1150 |
1151 |
1152 |
1153 |
1154 |
1155 |
1156 |
1157 |
1158 |
1159 |
1160 |
1161 |
1162 |
1163 |
1164 |
1165 |
1166 |
1167 |
1168 |
1169 |
1170 |
1171 |
1172 |
1173 |
1174 |
1175 |
1176 |
1177 |
1178 |
1179 |
1180 |
1181 |
1182 |
1183 |
1184 |
1185 |
1186 |
1187 |
1188 |
1189 |
1190 |
1191 |
1192 |
1193 |
1194 |
1195 |
1196 |
1197 |
1198 |
1199 |
1200 |
1201 |
1202 |
1203 |
1204 |
1205 |
1206 |
1207 |
1208 |
1209 |
1210 |
1211 |
1212 |
1213 |
1214 |
1215 |
1216 |
1217 |
1218 |
1219 |
1220 |
1221 |
1222 |
1223 |
1224 |
1225 |
1226 |
1227 |
1228 |
1229 |
1230 |
1231 |
1232 |
1233 |
1234 |
1235 |
1236 |
1237 |
1238 |
1239 |
1240 |
1241 |
1242 |
1243 |
1244 |
1245 |
1246 |
1247 |
1248 |
1249 |
1250 |
1251 |
1252 |
1253 |
1254 |
1255 |
1256 |
1257 |
1258 |
1259 |
1260 |
1261 |
1262 |
1263 |
1264 |
1265 |
1266 |
1267 |
1268 |
1269 |
1270 |
1271 |
1272 |
1273 |
1274 |
1275 |
1276 |
1277 |
1278 |
1279 |
1280 |
1281 |
1282 |
1283 |
1284 |
1285 |
1286 |
1287 |
1288 |
1289 |
1290 |
1291 |
1292 |
1293 |
1294 |
1295 |
1296 |
1297 |
1298 |
1299 |
1300 |
1301 |
1302 |
1303 |
1304 |
1305 |
1306 |
1307 |
1308 |
1309 |
1310 |
1311 |
1312 |
1313 |
1314 |
1315 |
1316 |
1317 |
1318 |
1319 |
1320 |
1321 |
1322 |
1323 |
1324 |
1325 |
1326 |
1327 |
1328 |
1329 |
1330 |
1331 |
1332 |
1333 |
1334 |
1335 |
1336 |
1337 |
1338 |
1339 |
1340 |
1341 |
1342 |
1343 |
1344 |
1345 |
1346 |
1347 |
1348 |
1349 |
1350 |
1351 |
1352 |
1353 |
1354 |
1355 |
1356 |
1357 |
1358 |
1359 |
1360 |
1361 |
1362 |
1363 |
1364 |
1365 |
1366 |
1367 |
1368 |
1369 |
1370 |
1371 |
1372 |
1373 |
1374 |
1375 |
1376 |
1377 |
1378 |
1379 |
1380 |
1381 |
1382 |
1383 |
1384 |
1385 |
1386 |
1387 |
1388 |
1389 |
1390 |
1391 |
1392 |
1393 |
1394 |
1395 |
1396 |
1397 |
1398 |
1399 |
1400 |
1401 |
1402 |
1403 |
1404 |
1405 |
1406 |
1407 |
1408 |
1409 |
1410 |
1411 |
1412 |
1413 |
1414 |
1415 |
1416 |
1417 |
1418 |
1419 |
1420 |
1421 |
1422 |
1423 |
1424 |
1425 |
1426 |
1427 |
1428 |
1429 |
1430 |
1431 |
1432 |
1433 |
1434 |
1435 |
1436 |
1437 |
1438 |
1439 |
1440 |
1441 |
1442 |
1443 |
1444 |
1445 |
1446 |
1447 |
1448 |
1449 |
1450 |
1451 |
1452 |
1453 |
1454 |
1455 |
1456 |
1457 |
1458 |
1459 |
1460 |
1461 |
1462 |
1463 |
1464 |
1465 |
1466 |
1467 |
1468 |
1469 |
1470 |
1471 |
1472 |
1473 |
1474 |
1475 |
1476 |
1477 |
1478 |
1479 |
1480 |
1481 |
1482 |
1483 |
1484 |
1485 |
1486 |
1487 |
1488 |
1489 |
1490 |
1491 |
1492 |
1493 |
1494 |
1495 |
1496 |
1497 |
1498 |
1499 |
1500 |
1501 |
1502 |
1503 |
1504 |
1505 |
1506 |
1507 |
1508 |
1509 |
1510 |
1511 |
1512 |
1513 |
1514 |
1515 |
1516 |
1517 |
1518 |
1519 |
1520 |
1521 |
1522 |
1523 |
1524 |
1525 |
1526 |
1527 |
1528 |
1529 |
1530 |
1531 |
1532 |
1533 |
1534 |
1535 |
1536 |
1537 |
1538 |
1539 |
1540 |
1541 |
1542 |
1543 |
1544 |
1545 |
1546 |
1547 |
1548 |
1549 |
1550 |
1551 |
1552 |
1553 |
1554 |
1555 |
1556 |
1557 |
1558 |
1559 |
1560 |
1561 |
1562 |
1563 |
1564 |
1565 |
1566 |
1567 |
1568 |
1569 |
1570 |
1571 |
1572 |
1573 |
1574 |
1575 |
1576 |
1577 |
1578 |
1579 |
1580 |
1581 |
1582 |
1583 |
1584 |
1585 |
1586 |
1587 |
1588 |
1589 |
1590 |
1591 |
1592 |
1593 |
1594 |
1595 |
1596 |
1597 |
1598 |
1599 |
1600 |
1601 |
1602 |
1603 |
1604 |
1605 |
1606 |
1607 |
1608 |
1609 |
1610 |
1611 |
1612 |
1613 |
1614 |
1615 |
1616 |
1617 |
1618 |
1619 |
1620 |
1621 |
1622 |
1623 |
1624 |
1625 |
1626 |
1627 |
1628 |
1629 |
1630 |
1631 |
1632 |
1633 |
1634 |
1635 |
1636 |
1637 |
1638 |
1639 |
1640 |
1641 |
1642 |
1643 |
1644 |
1645 |
1646 |
1647 |
1648 |
1649 |
1650 |
1651 |
1652 |
1653 |
1654 |
1655 |
1656 |
1657 |
1658 |
1659 |
1660 |
1661 |
1662 |
1663 |
1664 |
1665 |
1666 |
1667 |
1668 |
1669 |
1670 |
1671 |
1672 |
1673 |
1674 |
1675 |
1676 |
1677 |
1678 |
1679 |
1680 |
1681 |
1682 |
1683 |
1684 |
1685 |
1686 |
1687 |
1688 |
1689 |
1690 |
1691 |
1692 |
1693 |
1694 |
1695 |
1696 |
1697 |
1698 |
1699 |
1700 |
1701 |
1702 |
1703 |
1704 |
1705 |
1706 |
1707 |
1708 |
1709 |
1710 |
1711 |
1712 |
1713 |
1714 |
1715 |
1716 |
1717 |
1718 |
1719 |
1720 |
1721 |
1722 |
1723 |
1724 |
1725 |
1726 |
1727 |
1728 |
1729 |
1730 |
1731 |
1732 |
1733 |
1734 |
1735 |
1736 |
1737 |
1738 |
1739 |
1740 |
1741 |
1742 |
1743 |
1744 |
1745 |
1746 |
1747 |
1748 |
1749 |
1750 |
1751 |
1752 |
1753 |
1754 |
1755 |
1756 |
1757 |
1758 |
1759 |
1760 |
1761 |
1762 |
1763 |
1764 |
1765 |
1766 |
1767 |
1768 |
1769 |
1770 |
1771 |
1772 |
1773 |
1774 |
1775 |
1776 |
1777 |
1778 |
1779 |
1780 |
1781 |
1782 |
1783 |
1784 |
1785 |
1786 |
1787 |
1788 |
1789 |
1790 |
1791 |
1792 |
1793 |
1794 |
1795 |
1796 |
1797 |
1798 |
1799 |
1800 |
1801 |
1802 |
1803 |
1804 |
1805 |
1806 |
1807 |
1808 |
1809 |
1810 |
1811 |
1812 |
1813 |
1814 |
1815 |
1816 |
1817 |
1818 |
1819 |
1820 |
1821 |
1822 |
1823 |
1824 |
1825 |
1826 |
1827 |
1828 |
1829 |
1830 |
1831 |
1832 |
1833 |
1834 |
1835 |
1836 |
1837 |
1838 |
1839 |
1840 |
1841 |
1842 |
1843 |
1844 |
1845 |
1846 |
1847 |
1848 |
1849 |
1850 |
1851 |
1852 |
1853 |
1854 |
1855 |
1856 |
1857 |
1858 |
1859 |
1860 |
1861 |
1862 |
1863 |
1864 |
1865 |
1866 |
1867 |
1868 |
1869 |
1870 |
1871 |
1872 |
1873 |
1874 |
1875 |
1876 |
1877 |
1878 |
1879 |
1880 |
1881 |
1882 |
1883 |
1884 |
1885 |
1886 |
1887 |
1888 |
1889 |
1890 |
1891 |
1892 |
1893 |
1894 |
1895 |
1896 |
1897 |
1898 |
1899 |
1900 |
1901 |
1902 |
1903 |
1904 |
1905 |
1906 |
1907 |
1908 |
1909 |
1910 |
1911 |
1912 |
1913 |
1914 |
1915 |
1916 |
1917 |
1918 |
1919 |
1920 |
1921 |
1922 |
1923 |
1924 |
1925 |
1926 |
1927 |
1928 |
1929 |
1930 |
1931 |
1932 |
1933 |
1934 |
1935 |
1936 |
1937 |
1938 |
1939 |
1940 |
1941 |
1942 |
1943 |
1944 |
1945 |
1946 |
1947 |
1948 |
1949 |
1950 |
1951 |
1952 |
1953 |
1954 |
1955 |
1956 |
1957 |
1958 |
1959 |
1960 |
1961 |
1962 |
1963 |
1964 |
1965 |
1966 |
1967 |
1968 |
1969 |
1970 |
1971 |
1972 |
1973 |
1974 |
1975 |
1976 |
1977 |
1978 |
1979 |
1980 |
1981 |
1982 |
1983 |
1984 |
1985 |
1986 |
1987 |
1988 |
1989 |
1990 |
1991 |
1992 |
1993 |
1994 |
1995 |
1996 |
1997 |
1998 |
1999 |
2000 |
2001 |
2002 |
2003 |
2004 |
2005 |
2006 |
2007 |
2008 |
2009 |
2010 |
2011 |
2012 |
2013 |
2014 |
2015 |
2016 |
2017 |
2018 |
2019 |
2020 |
2021 |
2022 |
2023 |
2024 |
2025 |
2026 |
2027 |
2028 |
2029 |
2030 |
2031 |
2032 |
2033 |
2034 |
2035 |
2036 |
2037 |
2038 |
2039
```


Microlab 1:

- 1) Explore your inlists
- 2) Run MESA out-of-the-box

(~10 minutes)

Microlab 1: Exploring MESA & inlists (10 min)

- (1) What is the initial mass of the model that runs when you launch a simulation in `mesa-r24.08.1/star/work/` ?
- (2) What causes this model to stop?
- (3) Does MESA create a starting model for this simulation, or does it load an existing model?
- (4) Try to run this model using **`./clean; ./mk; ./rn`**
Ask a TA for help if you cannot! What do these scripts do?
- (5) How hot is the star at step number 35 of this run?

Using `run_star_extras.f90`

Using `run_star_extras.f90`, we can introduce our own

-project-specific physics, or

-additional functionality

without compromising the entire **MESA** source code base

```
1 ! *****
2 !
3 ! Copyright (C) 2010-2019 Bill Paxton & The MESA Team
4 !
5 ! this file is part of mesa.
6 !
7 ! mesa is free software;
8 ! it under the terms of the
9 ! GNU General Public License
10 ! (at your option) any later
11 ! version.
12 !
13 ! mesa is distributed in the
14 ! hope that it will be useful,
15 ! but without any warranty,
16 ! without even the implied warranty of
17 ! merchantability or fitness for a particular purpose. see the
18 ! GNU General Public License for more details.
19 ! you should have received a copy of the GNU General Public License
20 ! along with this software; if not, write to the Free Software
21 ! Foundation, Inc., 59 Temple Place, Suite 330, Boston, MA 02111-1307 USA
22 ! *****
23 module run_star_extras
24
25 use star_lib
26 use star_def
27 use const_def
28 use math_lib
29
30 implicit none
31
32 ! these routines are called by the standard run_star check_model
33 contains
34
35 include 'standard_run_star_extras.inc'
36
37 end module run_star_extras
38
39
```

run_star_extras.f90: default

Locate:

```
$MESA_DIR/include/standard_run_star_extras.inc
```

And replace the line

```
include 'standard_run_star_extras.inc'
```

in **run_star_extras.f90** with the contents of this file

```
22
23 module run_star_extras
24
25 use star_lib
26 use star_def
27 use const_def
28 use math_lib
29
30 implicit none
31
32 ! these routines are called by the standard run_star check_model
33 contains
34
35 subroutine extras_controls(id, ierr)
36   integer, intent(in) :: id
37   integer, intent(out) :: ierr
38   type (star_info), pointer :: s
39   ierr = 0
40   call star_ptr(id, s, ierr)
41   if (ierr /= 0) return
42
43   ! this is the place to set any procedure pointers you want to change
44   ! e.g., other_wind, other_mixing, other_energy (see star_data.inc)
45
46
47   ! the extras functions in this file will not be called
48   ! unless you set their function pointers as done below.
49   ! otherwise we use a null_version which does nothing (except warn).
50
51   s% extras_startup => extras_startup
52   s% extras_start_step => extras_start_step
53   s% extras_check_model => extras_check_model
54   s% extras_finish_step => extras_finish_step
55   s% extras_after_evolve => extras_after_evolve
56   s% how_many_extra_history_columns => how_many_extra_history_columns
57   s% data_for_extra_history_columns => data_for_extra_history_columns
58   s% how_many_extra_profile_columns => how_many_extra_profile_columns
59   s% data_for_extra_profile_columns => data_for_extra_profile_columns
60
61   s% how_many_extra_history_header_items => how_many_extra_history_header_items
62   s% data_for_extra_history_header_items => data_for_extra_history_header_items
63   s% how_many_extra_profile_header_items => how_many_extra_profile_header_items
64   s% data_for_extra_profile_header_items => data_for_extra_profile_header_items
```

run_star_extras.f90: include

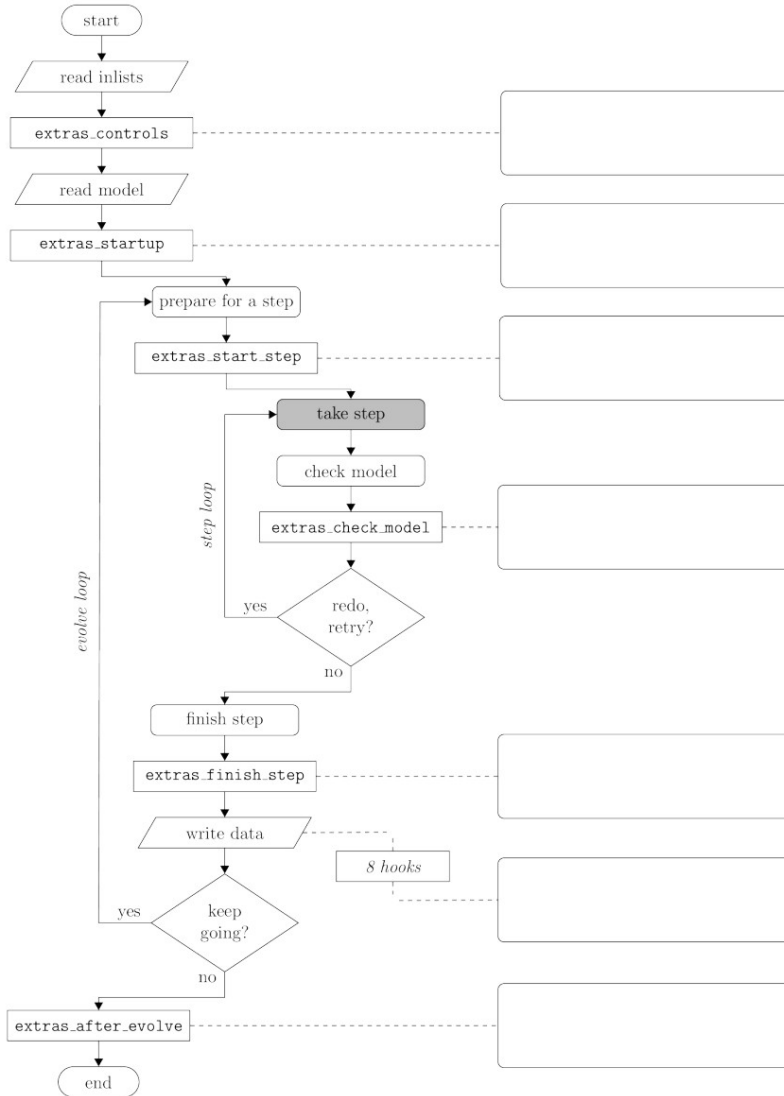
Using run_star_extras.f90

Every time you modify `run_star_extras`, you must

```
mjoyce@marsha: ~/MESA/mesa-r22051/star/work
drwx----- 2 mjoyce mjoyce    4096 Jul 25 10:26 LOGS
drwx----- 2 mjoyce mjoyce    4096 Jul 25 10:26 photos
mjoyce@marsha:~/MESA/mesa-r22051/star/work$ mesa-22051
environment set for MESA version 22.05.1
mjoyce@marsha:~/MESA/mesa-r22051/star/work$ ./clean; ./mk
gfortran -Wno-uninitialized -fno-range-check -fmax-errors=7 -fprotect-parens -fno-sign-zero -fbacktrace -ggdb -finit-real=snan -fopenmp -fbounds-check -Wuninitialized -Warray-bounds -ggdb -ffree-form -ffree-line-length-none -x f95-cpp-input -I/home/mjoyce/MESA/mesa-r22051/include -I../src -c ../src/run_star_extras.f90
gfortran -Wno-uninitialized -fno-range-check -fmax-errors=7 -fprotect-parens -fno-sign-zero -fbacktrace -ggdb -finit-real=snan -fopenmp -fbounds-check -Wuninitialized -Warray-bounds -ggdb -ffree-form -ffree-line-length-none -x f95-cpp-input -I/home/mjoyce/MESA/mesa-r22051/include -I../src -c /home/mjoyce/MESA/mesa-r22051/star/job/run_star.f90
gfortran -Wno-uninitialized -fno-range-check -fmax-errors=7 -fprotect-parens -fno-sign-zero -fbacktrace -ggdb -finit-real=snan -fopenmp -fbounds-check -Wuninitialized -Warray-bounds -ggdb -ffree-form -ffree-line-length-none -x f95-cpp-input -I/home/mjoyce/MESA/mesa-r22051/include -I../src -c ../src/run.f90
gfortran -fopenmp -o ../star run_star_extras.o run_star.o run.o -L/home/mjoyce/MESA/mesa-r22051/lib -lstar -lgyre -latm -lcolors -lturb -lstar_data -lnet -leos -lkap -lrates -lneu -lchem -linterp_2d -linterp_1d -lnum -lauto_diff -lhdf5io -lmtx -lconst -lmath -lutils `mesasdk_crm_ath_link` `mesasdk_lapack95_link` `mesasdk_lapack_link` `mesasdk_blas_link` `mesasdk_hdf5_link` `mesasdk_pgplot_link` -lz
mjoyce@marsha:~/MESA/mesa-r22051/star/work$
```

recompile the executable!!

Code Organization



Go to Sunny Wong's Lab 3 from last year for a high-resolution version of this chart!

https://courtcraw.github.io/mesadu_wdbinaries/lab3.html

Code Organization

There are some actions you will want to compute *once per evolutionary time step* (**evolve loop**)

there are others you may want to compute *once per Newton solver iteration* (**step loop**)

where one evolve step contains several solver iterations

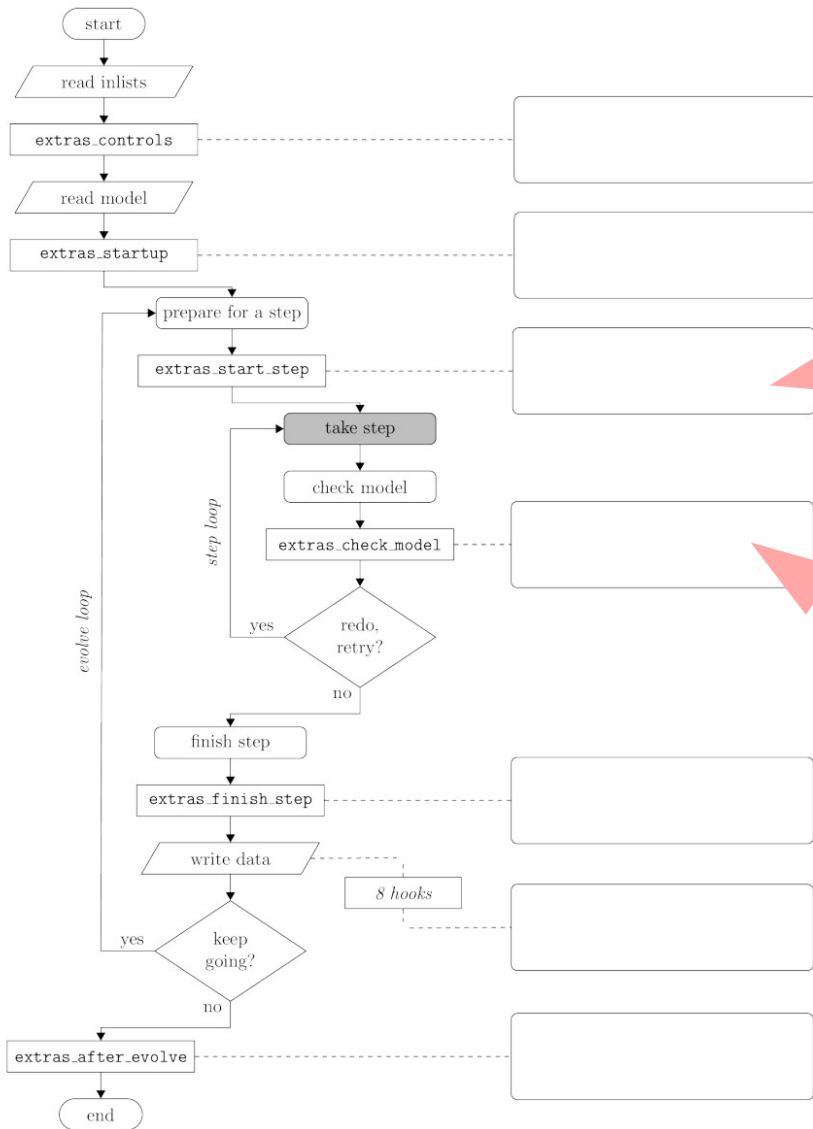
Code Organization

There are some actions you will want to compute *once per evolutionary time step* (**evolve loop**)

there are others you may want to compute *once per Newton solver iteration* (**step loop**)

where one evolve step contains several solver iterations

Example: Checking whether your model has satisfied some global physical property (i.e., reaching a certain radius) can take place once per evolutionary step



```

integer function extras_start_step(id)
integer, intent(in) :: id
integer :: ierr
type (star_info), pointer :: s
ierr = 0
call star_ptr(id, s, ierr)
if (ierr /= 0) return
extras_start_step = 0
end function extras_start_step
  
```

```

! returns either keep_going, retry, or terminate.
integer function extras_check_model(id)
integer, intent(in) :: id
integer :: ierr
type (star_info), pointer :: s
ierr = 0
call star_ptr(id, s, ierr)
if (ierr /= 0) return
extras_check_model = keep_going
if (.false. .and. s% star_mass_h1 < 0.35d0) then
! stop when star hydrogen mass drops to specified level
extras_check_model = terminate
write(*, *) 'have reached desired hydrogen mass'
return
end if

if (extras_check_model == terminate) s% termination_code = t_extras_check_model
end function extras_check_model
  
```

Suppose we want MESA to stop when the star reaches a certain luminosity

-When during the **step** should this condition be checked?

-How often should this condition be checked?

-In which **subroutine** should we check this condition?

How to start, and restart, a run

- .mod (model) files – human-readable
- profiles and profile indexing
- photos (binary snapshots)

Best practice: always run your project outside of the main MESA tree!

Best practice: always run your project outside of the main MESA tree!

Best practice: move your control files into your local working directory so you have a parameter reference

Microlab 2:

1. `cp -r $MESA/star/work/` to a location outside of your main MESA directory tree. Rename the project (e.g. `work_intro_day1`)
2. Locate your `controls.defaults`, `star_job.defaults`, `profile_columns.list`, `history_columns.list` files. Copy these files into your renamed work directory
3. Within these files, locate the controls that dictate how many profiles and photos are generated per run

(show of thumbs when complete)

Open Session tonight!

New Feature Highlight

MESA Custom Colors

You can now **compute synthetic photometry directly from MESA** for any filter system in the Spanish Virtual Observatory (SVO) database



Niall Miller
Postdoc, U Wyo

MESA Custom Colors:

Constructing an SED on the fly with MESA:

- MESA evolves the star and outputs – *Teff*, *log(g)*, and *metallicity (Z)*
- Precomputed stellar atmosphere lookup tables are queried using these parameters
- Multiple nearby SEDs are interpolated to create a synthetic SED matching the exact stellar properties
- SEDs are convolved with user-defined filter transmission curves
- Synthetic magnitudes are calculated with Vega zero-point calibration



Niall Miller
Postdoc, U Wyo



To participate in tonight's open session, you must download & build a second version of MESA!



The screenshot shows the Zenodo interface for a software record. At the top left is the Zenodo logo. Below it, the record title "MESA Modules for Experiments in Stellar Astrophysics (MESA)" is displayed. The publication date "Published July 18, 2025" and version "Version 5d9f195f" are shown on the left. On the right, there are two buttons: "Software" and "Open". The main title of the record is "Modules for Experiments in Stellar Astrophysics (MESA) 2025 Summer School Pre-Release Custom Colors Feature Demo". At the bottom, the authors are listed as "The MESA Team", "Miller, Niall", "Joyce, Meridith¹", and "Mocz, Philip²".

zenodo

MESA Modules for Experiments in Stellar Astrophysics (MESA)

Published July 18, 2025 | Version 5d9f195f

Software Open

Modules for Experiments in Stellar Astrophysics (MESA)
2025 Summer School Pre-Release Custom Colors
Feature Demo

The MESA Team; Miller, Niall; Joyce, Meridith¹; Mocz, Philip²

<https://zenodo.org/records/16092864>

To participate in tonight's open session, you must download & build a second version of MESA!

<https://zenodo.org/records/16092864>

- one of the most common feature requests is now available
- example of the type of contribution that will get you noticed by the team
- this version is NOT a long-term stable release – *oooh spooky*
- downloading a new MESA version can take up to an hour – please download this BEFORE the session – you can do this safely while you are doing the regular MESA labs
- Try to build this on your own (we will help if you encounter problems!!)

To participate in tonight's open session, you must download & build a second version of MESA!

<https://zenodo.org/records/16092864>

HINT: Make a new bash function

```
329 function mesa-colors {  
330 export MESA_DIR=/home/mjoyce/MESA/mesa-2025-summer-school-prerelease/  
331 export MESASDK_ROOT=/home/mjoyce/MESA/mesasdk  
332 source $MESASDK_ROOT/bin/mesasdk_init.sh  
333 export OMP_NUM_THREADS=16  
334 echo "environment set for 2025 Custom Colors pre-release"  
335 echo "OMP_NUM_THREADS set to 16"  
336 }
```

Detailed setup instructions at:

https://niallmiller.github.io/custom-colors_mesa-school-labs/

Getting involved in
the MESA project

Future of MESA Summer Schools

Funding for the 2027 through 2029 summer schools has been applied for within the team, but results are not known yet

There is currently **no confirmed host for 2026**

The MESA team will be using a **proposal and bid system** (as is used for, e.g., TASC) for 2026 – formal rules for proposing will be published to the MESA users list in roughly three weeks

Getting involved in
the MESA project

Getting involved in the MESA project

users-list engagement: asking and answering questions

Feature requests

Feature development and sharing your code

Large contributions

Becoming a **MESA developer**

“MESA doesn’t work!”

“MESA sucks at X!”

“I want MESA to do something it does not currently do!”

Raise an issue on github!

Raise an issue on github!

<https://github.com/MESAHub/mesa/issues>

[Website]

Becoming a MESA developer

- ➔ Membership to the MESA developers team is done by nomination
- ➔ Any MESA developer can nominate a new member. The existing members of the team have two weeks to approve the nomination or not
- ➔ Typically, nomination is discussed with a candidate before the formal nomination process

Becoming a MESA developer

The MESA Team

The missions of the MESA Team are:

- **Stewardship:** supporting contributors, maintaining the access and updates, seeking enabling funding, supporting MESA Summer Schools that allow for continued engagement, documenting MESA development in the refereed literature, and sustaining advanced development.
- **Interface with the User Community:** answering questions from users, developing or accepting new code in an integrated fashion, supporting MESA workshops and events, maintaining a user registry, and identifying new MESA Team members from those most active and engaged in the intelligent use of MESA.
- **Enable Scientific Research and Education:** promoting MESA and its goals, e.g., through scientific contributions at relevant conferences, identifying science opportunities that match MESA capabilities, facilitating and encouraging appropriate scientific collaborative

Becoming a **MESA** developer

Supporting the **MESA** project is voluntary service work, but it is a prestigious project that opens a lot of opportunities

Writing code—whether developing MESA directly, its support tools, or programs that integrate with it—is a core component of MESA development

But it is not the only way to contribute!

Becoming a MESA developer

As developers inevitably move on (or advance to professor, at which point they no longer have time to do anything), it is important to bring outstanding young astrophysicists into the team to keep MESA relevant and ensure that it continues to serve the needs of the research community

Becoming a MESA developer

As developers inevitably move on (or advance to professor, at which point they no longer have time to do anything), it is important to bring outstanding young astrophysicists into the team to keep MESA relevant and ensure that it continues to serve the needs of the research community

We are especially interested in **recruiting women** and people from other **underrepresented** groups. If you would like to know more about what it means to be a **MESA developer**, please talk to me at this workshop!



SCHOOL OF COMPUTING



UW Homepage

School of Computing

People

Faculty

Meridith Joyce

UNIVERSITY OF WYOMING | SCHOOL OF COMPUTING

MENU

RESEARCH SCIENTISTS

ELLEN AIKENS | ASSISTANT

PROFESSOR

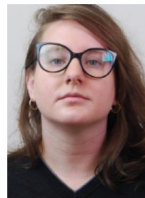
MARGO BERENDSEN | GIS ANALYST

SEAN FIELD | ASSISTANT

PROFESSOR

MERIDITH JOYCE | ASSISTANT

PROFESSOR



Meridith Joyce

Assistant Professor | Physics | Astronomy | Mathematics | Statistics | School of Computing

Room 4083, Engineering

Laramie, WY

Phone: 307-766-5299

Talk to me about PhD openings at **Wyo** or how to apply to postdocs and fellowships in the **United States and Europe!**

We are hiring a tenure-track astronomer

The most important part of this program is networking with the next generation of stellar astrophysicists

Tuesday's open session:
introductions & networking games