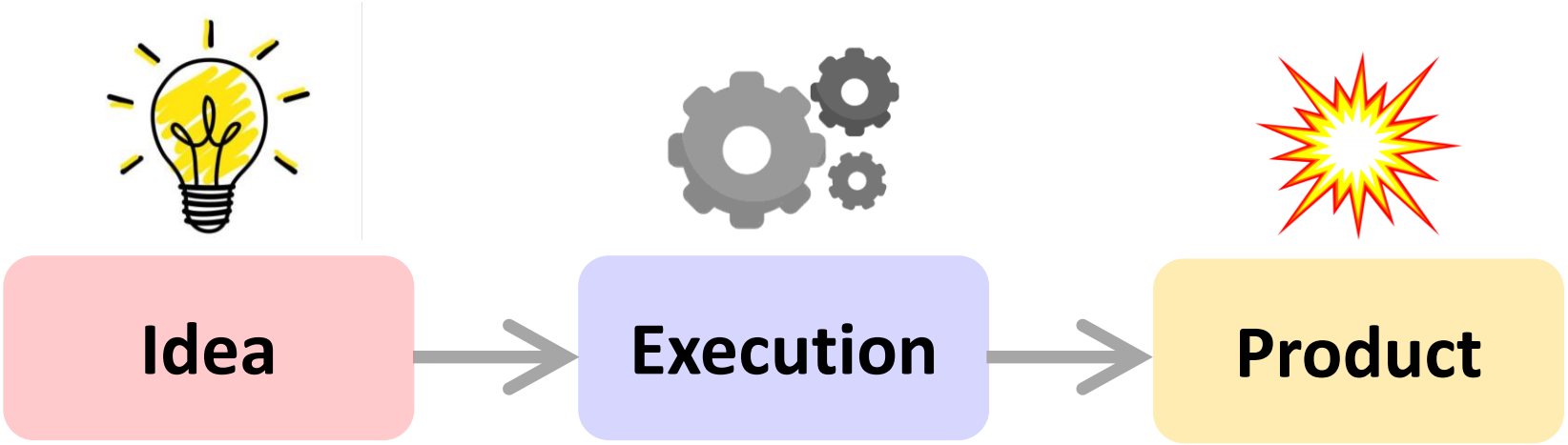
MESA Best Practices



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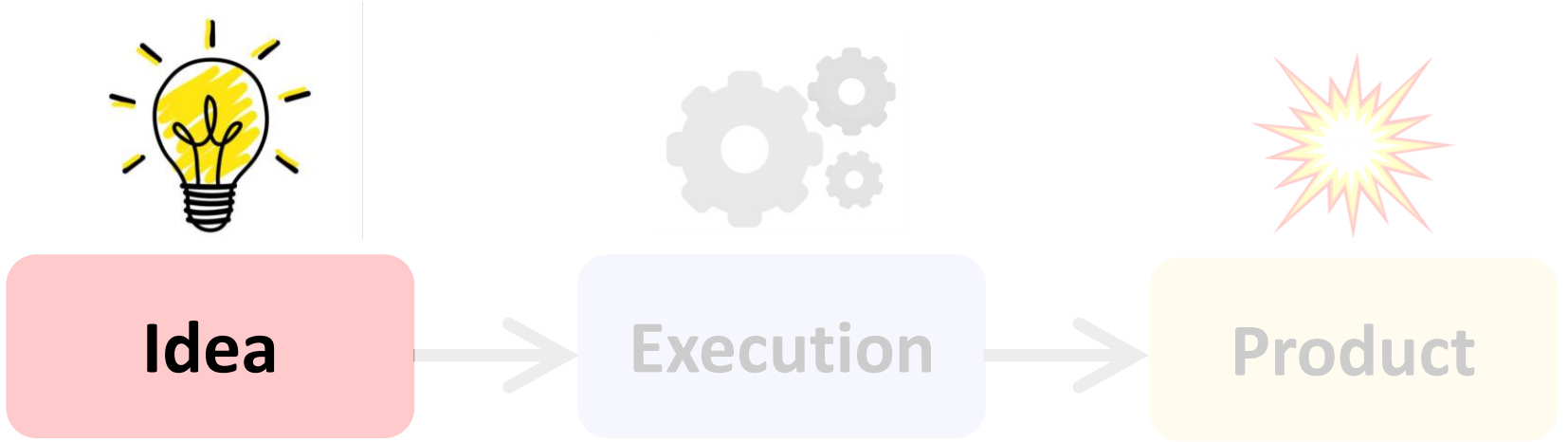
MESA Best Practices



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How to Start a Project with MESA?

- Consider using work files from **previous related papers** as your starting point.

- If not applicable, start from the most relevant test case in **$MESA_DIR/star/test_suite.**

Note: test_suites are not science-ready (see Jared's lab)!
If you start from a test case, make sure to include all the relevant physics (can be found in: **$MESA_DIR/star/defaults**)

MESA Best Practices

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Monitoring your MESA Run

- **PGPLOT:** allows you to follow your mesa run live. You could customize your PGPLOT through **your_work_dir/inlist_pgstar.** To save snapshots you can use: **Grid2_file_flag = .true.**

- **Terminal Output:** you can view it live, or save common items to a file by adding **extra_terminal_output_file = ' terminal output.log'** to the **&controls** namelist. To save the errors as well run: **./rn 2>&1 | tee terminal_output.log.**

- **Post Processing Tools: TULIPS** (Eva Laplace), **mesaplot** (Rob Farmer), … See also **MESA Marketplace.**

Debugging – Massive Stars Microlab

- Open the Microlab using this link and follow the instructions within.

- We will run a $15 M_{\odot}$ star from the pre-computed photo x261 until the following **error message** appears

```
retry: max residual jumped -- give up in solver    1266
                          solver rejected trial model
                                  s% model_number        1266
                              s% solver_call_number      1399
                                             nz          1566
                                  s% num_retries          133
                                              dt    1.07377509645114 72D+01
                                       log dt/secyer   -6.46819063972403 98D+00

terminated evolution: hydro_failed
```

Developed by Mathieu Renzo

Debugging – Massive Stars Microlab

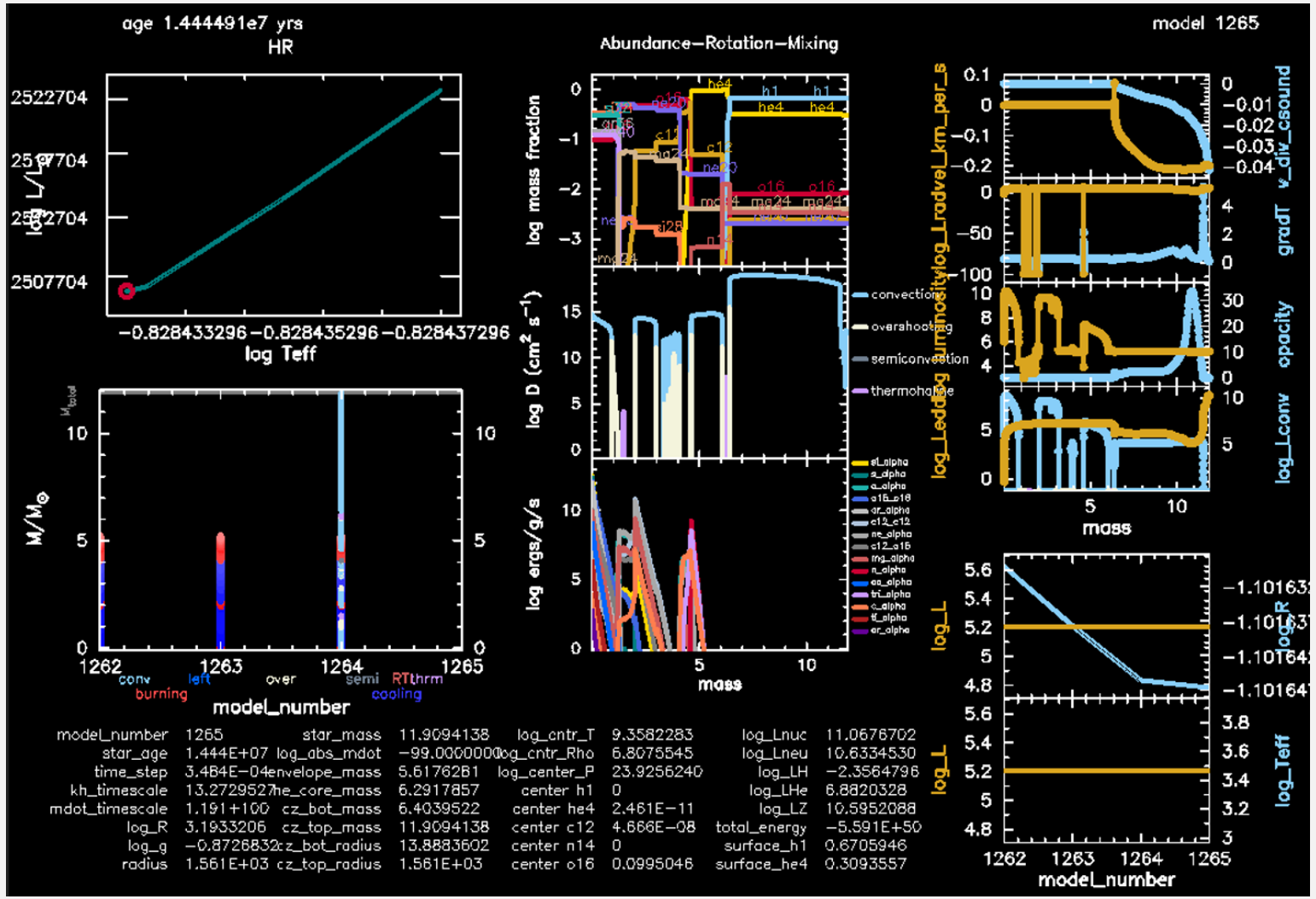
- **Residual:** difference between the RHS and LHS of the differential equations.
- **Retry:** re-solving the differential equations with a smaller timestep.

```
retry: max residual jumped -- give up in solver    1266
                          solver rejected trial model
                                    s% model_number        1266
                                s% solver_call_number      1399
                                                nz         1566
                                    s% num_retries          133
                                                dt    1.07377509645114 72D+01
                                     log dt/secyer   -6.46819063972403 98D+00

terminated evolution: hydro_failed
```

Developed by Mathieu Renzo

Debugging – Massive Stars Microlab



Looking at the PGPLOT snapshot right before the crash, we can't easily see what went wrong ☹

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Debugging – Massive Stars Microlab

- To obtain debugging output, let's set **report_solver_progress = .true.**

```
 1266 10  coeff 0.0400 avg resid  0.218E-01     max resid equL 1221  0.14676E+04 mix type 11111 avg corr  0.422E-03     max corr o16   930  0.21502E+00 mix type 22231  avg+max corr+resid
 1266 11  coeff 0.0400 avg resid  0.184E-02  max resid equ_he4  932  0.86291E+01 mix type 23111 avg corr  0.405E-03     max corr o16   930  0.20642E+00 mix type 22231  avg+max corr+resid
 1266 12  coeff 0.0100 avg resid  0.362E-01     max resid equL 1221  0.14945E+04 mix type 11111 avg corr  0.389E-03     max corr o16   930  0.19817E+00 mix type 22231  avg+max corr+resid
 1266 13  coeff 0.0400 avg resid  0.208E-01     max resid equL 1220  0.14027E+04 mix type 11111 avg corr  0.385E-03     max corr o16   930  0.19619E+00 mix type 22231  avg+max corr+resid
 1266 14  coeff 1.0000 avg resid  0.387E-03     max resid equL  939  0.91399E+01 mix type 11111 avg corr  0.370E-03     max corr o16   930  0.18834E+00 mix type 22231  avg+max resid
 1266 15  coeff 0.0100 avg resid  0.751E-03     max resid equL  939  0.90485E+01 mix type 11111 avg corr  0.851E-06     max corr lnd   934 -0.24859E-02 mix type 11111  avg+max resid
 1266 16  coeff 0.0100 avg resid  0.212E-01     max resid equL 1221  0.15068E+04 mix type 11111 avg corr  0.852E-06     max corr lnd   934 -0.24604E-02 mix type 11111  avg+max resid
 1266 17  coeff 0.2000 avg resid  0.186E-01     max resid equL 1219  0.13331E+04 mix type 11111 avg corr  0.899E-06     max corr lnd   934 -0.24363E-02 mix type 11111  avg+max resid
 1266 18  coeff 0.0400 avg resid  0.179E-01     max resid equL 1219  0.12797E+04 mix type 11111 avg corr  0.699E-06     max corr lnd   934 -0.19568E-02 mix type 11111  avg+max resid
 1266 19  coeff 0.0100 avg resid  0.368E-01     max resid equL 1220  0.14038E+04 mix type 11111 avg corr  0.677E-06     max corr lnd   934 -0.18795E-02 mix type 11111  avg+max resid
 1266 20  coeff 1.0000 avg resid  0.767E-07     max resid equL  937  0.15819E-02 mix type 11111 avg corr  0.680E-06     max corr lnd   934 -0.18610E-02 mix type 11111  avg+max resid
 1266 21  coeff 1.0000 avg resid  0.178E+01     max resid equL 1220  0.18765E+05 mix type 11111 avg corr  0.197E-05     max corr lnd   933  0.23329E-02 mix type 31111  max residual jumped -- give up
                      solver rejected trial model
                                 s% model_number        1266
                           s% solver_call_number        1399
                                            nz        1566
                                 s% num_retries         133
                                            dt    1.0737750964511472D+01
                                  log dt/secyer   -6.4681906397240398D+00

terminated evolution: hydro_failed
```

- The largest residual that is making our **model crash** is **equL.**

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Debugging – Massive Stars Microlab

- To obtain debugging output, let's set **report_solver_progress = .true.**

```
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                                 s% num_retries         133
                                            dt    1.0737750964511472D+01
                                  log dt/secyer   -6.4681906397240398D+00

terminated evolution: hydro_failed
```

- The **problematic value** is **lnd**, i.e., the density.

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Debugging – Massive Stars Microlab

❖ What is the **equation** for which the residual is equL?

It is defined in **$MESA_DIR/star/private/hydro_temperature.f90**

```
gradT = s% gradT_ad(k)
dlnTdm = dlnPdm*gradT

Tm1 = wrap_T_m1(s,k)
T00 = wrap_T_00(s,k)
dT = Tm1 - T00
alfa = s% dm(k-1)/(s% dm(k-1) + s% dm(k))
Tpoint = alfa*T00 + (1d0 - alfa)*Tm1
lnTdiff = dT/Tpoint ! use this in place of lnT(k-1)-lnT(k)
delm = (s% dm(k) + s% dm(k-1))/2

resid = delm*dlnTdm - lnTdiff
s% equ(i_equL, k) = resid%val
```

Temperature gradient equation!

$$T_{k-1} - T_k = \overline{dm}_k \left[\nabla_{T,k} \left(\frac{dP}{dm} \right)_h \frac{\bar{T}_k}{\bar{P}_k} \right]$$

❖ You can use **grep -IR --include="*.f90" "equL" $MESA_DIR** to search for this.

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Debugging – Massive Stars Microlab

- **Solution:** you can set **convergence_ignore_equL_residuals = .true.** in your **&controls** namelist to ignore the residual.

Why is this ok? There is an **inconsistency** between the **actual temperature gradient** and the temperature gradient predicted **from MLT.**

- Now re-run the model and bypass the problem, and use the methods your learned to solve the **next crash** after the summer school…

Developed by Mathieu Renzo

Debugging – MESA Mailing List

- You can subscribe to the mailing list using this link.
- You can search through the Mailing List Archive using keywords.

Not Optimal

Dear mesa users,

I am trying to run a 20 solar mass model of solar metallicity to the onset of core collapse, and my model won't finish running. I am not sure what went wrong. I'll really appreciate your help.

Best,
Aldana

Much better!

Dear mesa users,

I am trying to run a 20 solar mass model of solar metallicity to the onset of core collapse using the nuclear reaction network mesa_206 on mesa r24.08.1. I define the onset of core collapse with a core infall velocity of 1000 km/s. My model crashes when it reaches the iron core reaches a velocity of 500 km/s with the error message "terminated evolution: hydro_failed". I attach my inlist and run_star_extras.f90 files from this run. I'll really appreciate your help.

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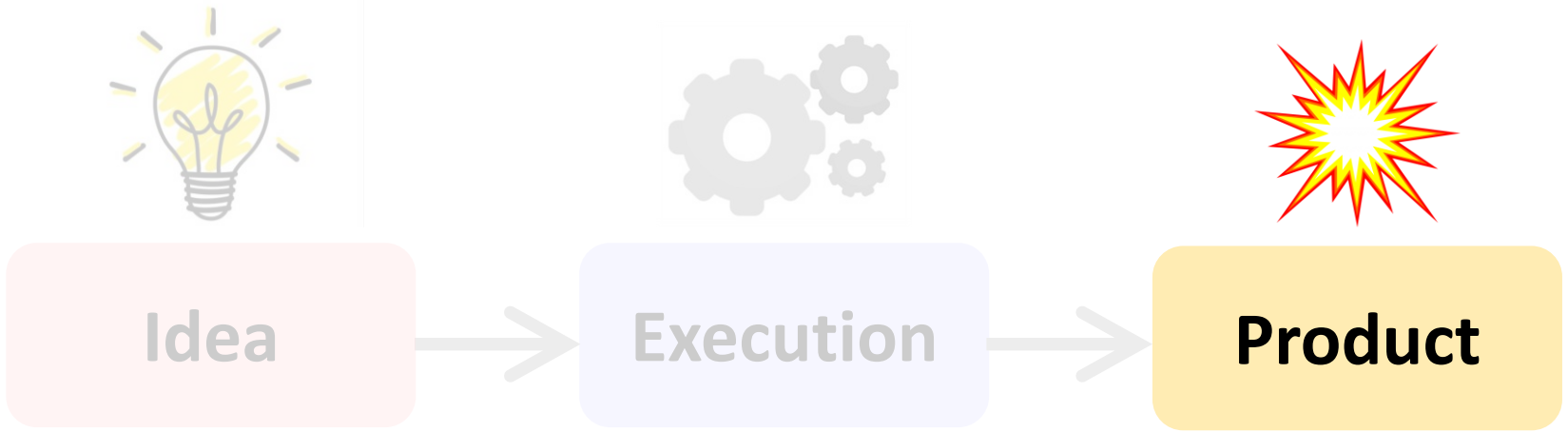

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Relevant Citations

- Cite all the published **mesa method papers**: Paxton et al. (2011, 2013, 2015, 2018, 2019); Jermyn et al. (2023)

- Make sure to include citations to **relevant microphysics** (e.g., nuclear reaction rates, opacities, equations of state, …) and **relevant included tools** (e.g., GYRE, STELLA, …).

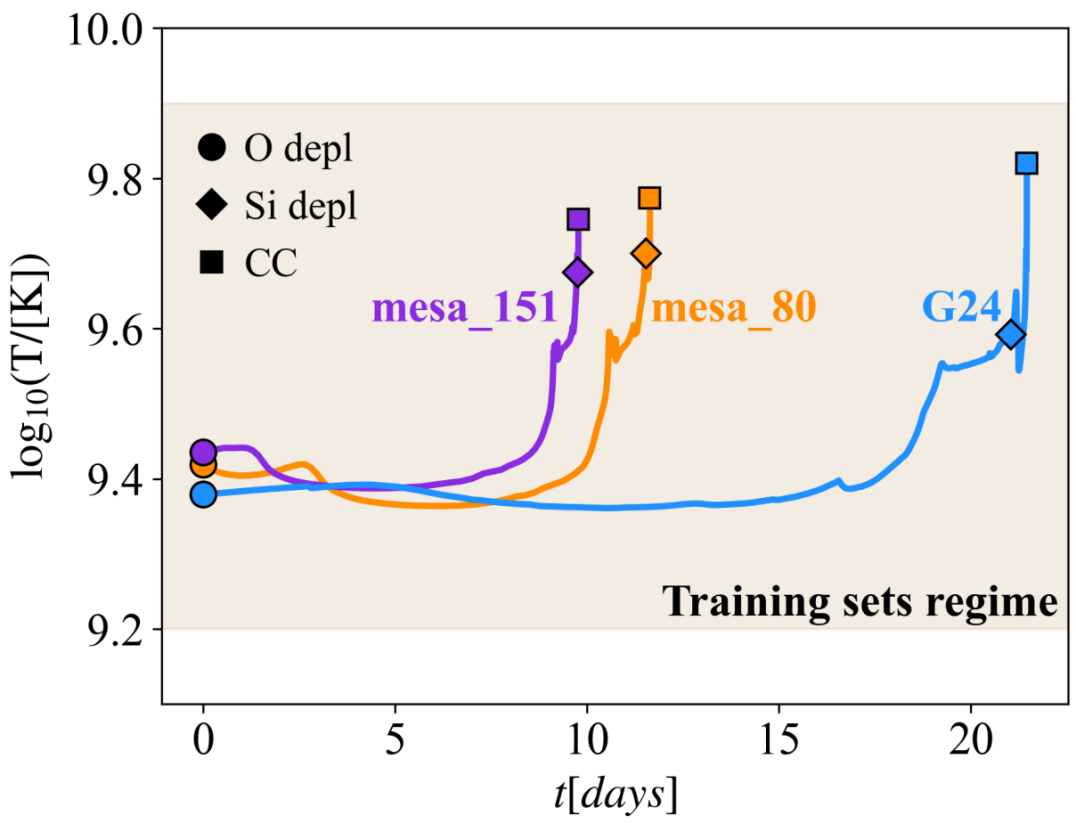
- If you have any doubts/want to know more, check out the **MESA manifesto**.

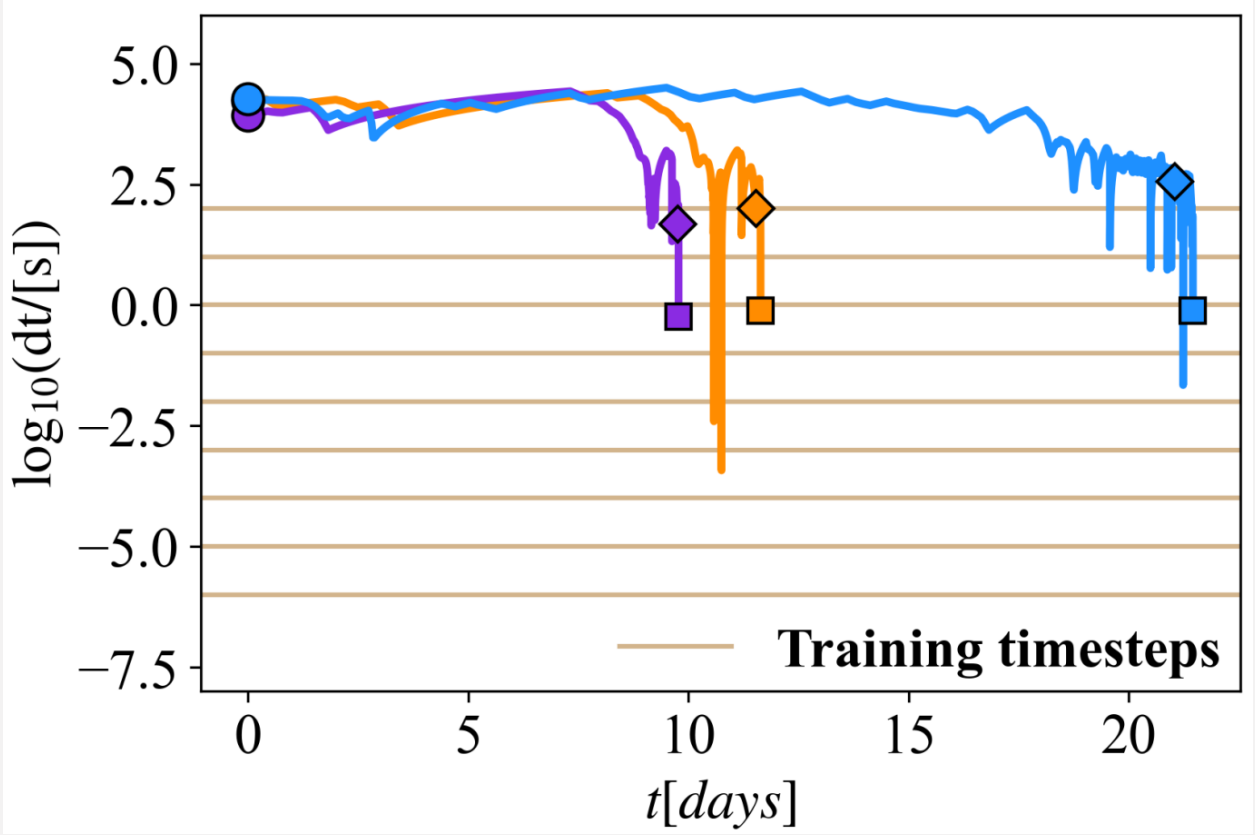
Reproducibility and Beyond

- Upload all the work files (e.g., **inlists**, **run_star_extra.f90**) needed to reproduce your results to Zenodo. Adding the relevant **history.data** and **profile.data** is strongly encouraged.

- Consider uploading the files you used to analyze your data, and preparing a **README.txt**/guide that walks the reader through the paper.

Reproducibility and Beyond





Grichener+2025; used data from Renzo+2020; Gottlieb+2024; Wang+2024.

Contributing to MESA

- Reporting **bugs/issues**, or making **PRs** in the mesa GitHub page.
- **Answering questions** in the mailing list – you don't have to be a mesa developer!
- Adding your own routines to MESA Contrib.