Customizing pgstar for your models

Monique Windju / Frank Timmes/ Emily Leiner

MESA

SI²

SPIDER

Color coded notation used throughout this lecture + lab:

Things you do are in yellow, such as Task.

MESA terms are in orange, such as inlist_pgstar.

General text is in White or Green.

Task: Download the 4.5 MB MESA work directory from

http://mesastar.org/teaching-materials/2015-mesa-summer-school/timmes/mesa_ss_2015_timmes.zip

or

http://cococubed.asu.edu/xfer/mesa_ss_2015_timmes.zip

or

https://www.dropbox.com/s/6r2k1lv41kupoui/mesa_ss_2015_timmes.zip?dl=0

Task: unzip mesa_ss_2014_timmes.zip where you do your MESA stuff. Issue these terminal commands:

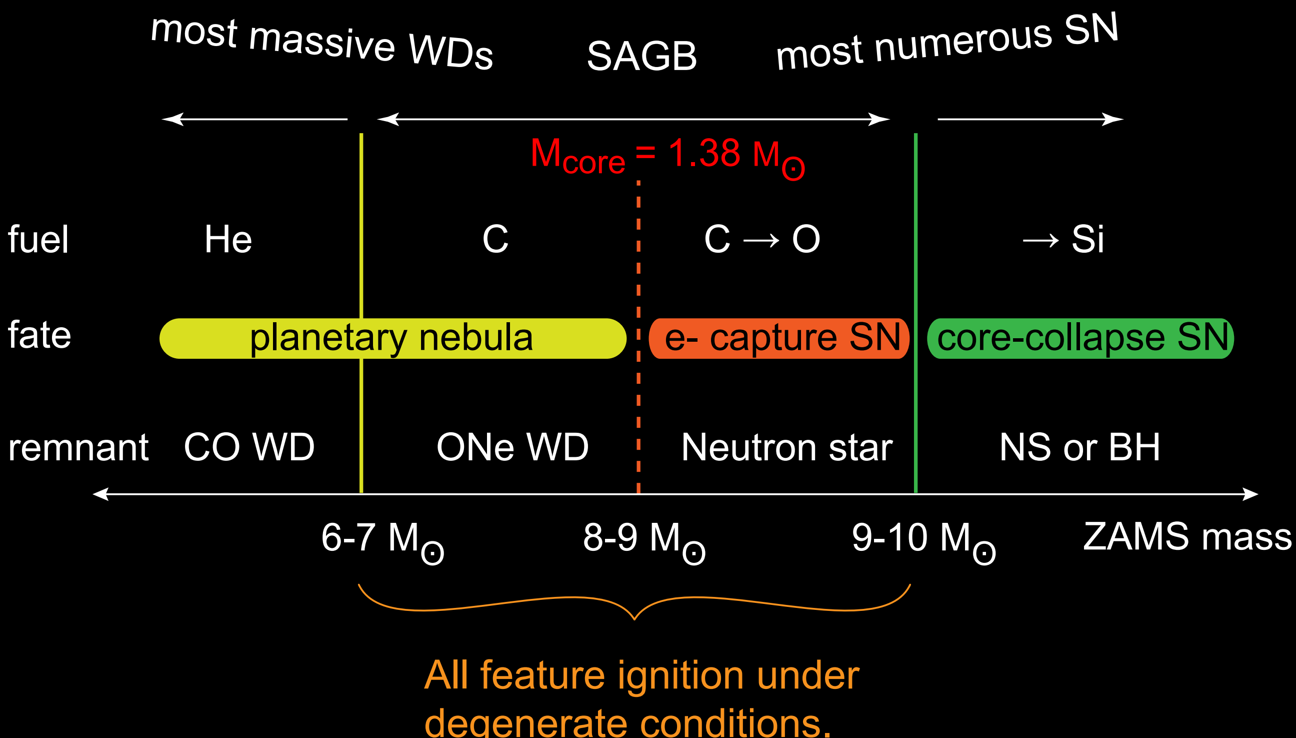
```
% cd mesa_ss_2014_timmes

% ./mk
```

Each group gets a different model file:

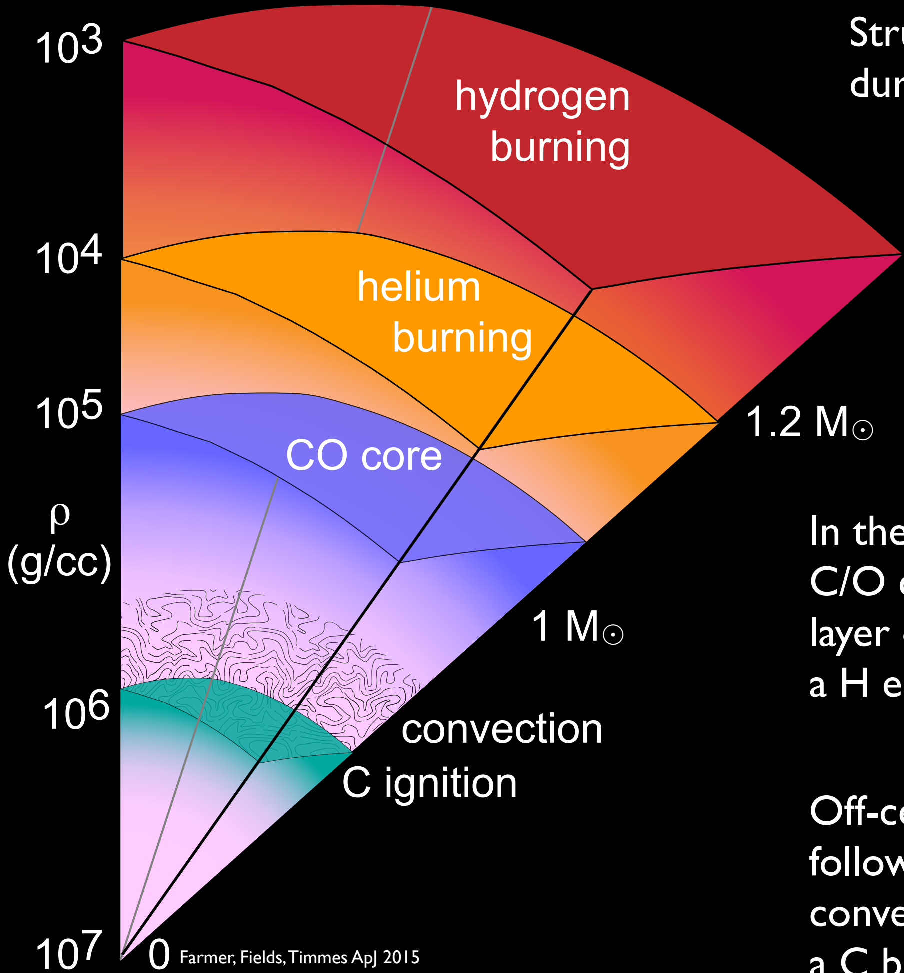
9p5m_0p000_cignition.mod
9p5m_0p001_cignition.mod
9p5m_0p002_cignition.mod
9p5m_0p005_cignition.mod
9p5m_0p010_cignition.mod
9p5m_0p020_cignition.mod
9p5m_0p050_cignition.mod
9p5m_0p100_cignition.mod
9p5m_0p200_cignition.mod
9p5m_0p300_cignition.mod

Task: open inlist_star in your editor. Change the parameter saved_model_name = 'ZZZ.mod' to the model for your group.

A brief background on the astrophysics …



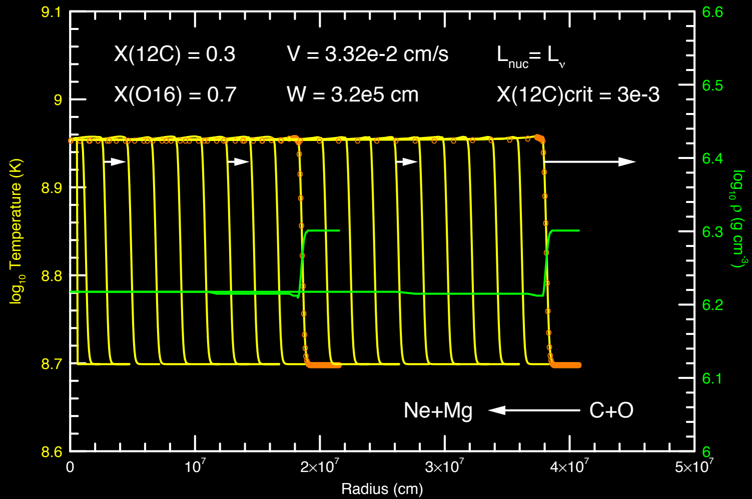
Structure of an SAGB star during carbon burning.



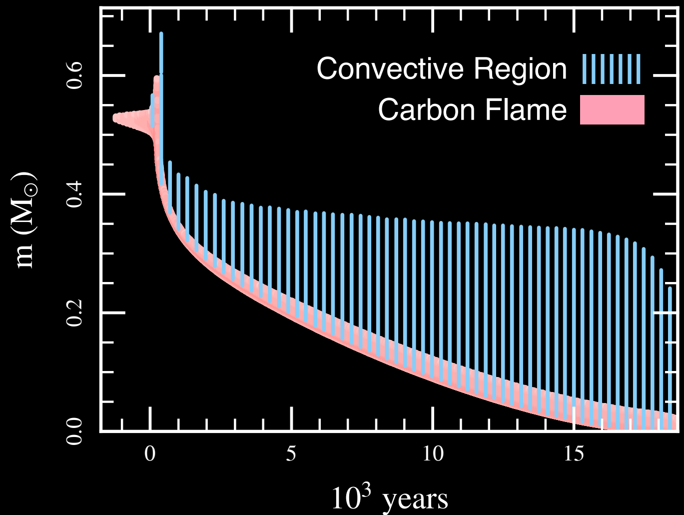
Farmer, Fields, Timmes ApJ 2015

In the center is a degenerate C/O core, surrounded by a layer of He, surrounded by a H envelope.

Off-center ignition of C is followed by a trailing convective region that drives a C burning front inwards.



X(12C) = 0.3
V = 3.32e-2 cm/s
$L_{nuc} = L_\nu$
X(O16) = 0.7
W = 3.2e5 cm
X(12C)crit = 3e-3
Ne+Mg
C+O
$\log_{10}$ Temperature (K)
$\log_{10} \rho$ (g cm^{-3})
Radius (cm)



Convective Region
Carbon Flame
m ($M_\odot$)
10^3 years

Does the convectively bounded carbon flame reach the center?

The flame reaches the center if all of these conditions are met :

1. there is enough fuel to maintain balanced power.

2. the temperature at the base of the convective region is above the carbon ignition threshold.

3. the temperature at the base of the convective region is maintained longer than the neutrino cooling time scale.

```
% ./rn
```

This job will take ~2-8 hours to complete, but the state of the model is mostly irrelevant for our purposes.

We recommend that you leave the job running as MESA will read the inlist_pgstar file at each step; plot changes can be seen live!

If you make a mistake such that MESA does stop running, do a ./re as tasks at the end of the lab can benefit from having a more advanced evolutionary state.

Task: Open inlist_pgstar in your editor. It will be empty:

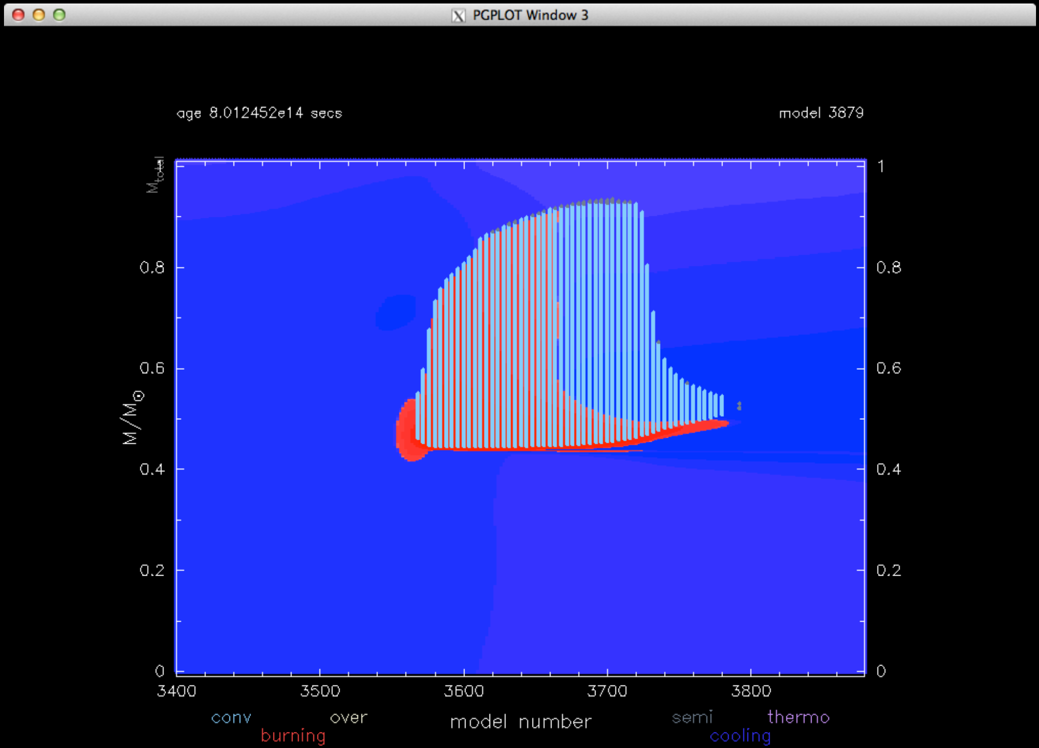
```
&pgstar

/ ! end of pgstar namelist
```

Since we have a convectively bounded carbon flame, visualizing the convective and burning regions seems like a good idea.

Task: Copy these history plot commands from the supplied plot_commands.txt file, paste it into inlist_pgstar, and save inlist_pgstar.

```
pgstar_show_age_in_years = .false.
pgstar_show_age_in_seconds = .true.


! Kippenhahn diagram history plot

Kipp_win_flag = .true.

! window properties
Kipp_win_width = 10
Kipp_win_aspect_ratio = 0.75
Kipp_title = ''

! y axis limits
Kipp_mass_max = 1.0
Kipp_mass_min = 0
Kipp_show_mass_boundaries = .true.
Kipp_show_mixing = .false.

! x axis limits
Kipp_xmax = -101d0            ! maximum step number.  negative means use default.
Kipp_xmin = -101d0            ! minimum step number.  negative means use default.
Kipp_max_width = -1           ! only used if > 0.  causes xmin to move with xmax.

! file output
Kipp_file_flag = .false.
Kipp_file_dir = 'Kipp'
Kipp_file_prefix = 'kipp_'
Kipp_file_cnt = 5             ! output when mod(model_number,Kipp_file_cnt)==0
Kipp_file_width = -1          ! (inches) negative means use same value as for window
Kipp_file_aspect_ratio = -1 ! negative means use same value as for window
file_device = 'png'           ! options 'png' and 'vcps' for png and postscript
file_extension = 'png'        ! common names are 'png' and 'ps'
```

You should see something like this after a while:



Let's change a few of these settings on-the-fly …

```
pgstar_show_age_in_years = .false.
pgstar_show_age_in_seconds = .true.


! Kippenhahn diagram history plot

Kipp_win_flag = .true.

! window properties
Kipp_win_width = 10
Kipp_win_aspect_ratio = 0.75
Kipp_title = ''

! y axis limits
Kipp_mass_max = 1.0
Kipp_mass_min = 0
Kipp_show_mass_boundaries = .true.
Kipp_show_mixing = .false.

! x axis limits
Kipp_xmax = -101d0           ! maximum step number.  negative means use default.
Kipp_xmin = -101d0           ! minimum step number.  negative means use default.
Kipp_max_width = -1          ! only used if > 0.  causes xmin to move with xmax.

! file output
Kipp_file_flag = .false.
Kipp_file_dir = 'Kipp'
Kipp_file_prefix = 'kipp_'
Kipp_file_cnt = 5            ! output when mod(model_number,Kipp_file_cnt)==0
Kipp_file_width = -1         ! (inches) negative means use same value as for window
Kipp_file_aspect_ratio = -1 ! negative means use same value as for window
file_device = 'png'          ! options 'png' and 'vcps' for png and postscript
file_extension = 'png'       ! common names are 'png' and 'ps'
```

History plots show information in your history_columns.list.
The name for a history item must be the same as one of the column headings in your LOGS/history.data.

Profile plots show information about a current model. You can display anything that can be included in a profile_columns.list.
You are not limited to the items in your profile_columns.list.

Single panel plots contain one graph, optionally with a 2nd y-axis. Our Kipp diagram is an example of a single panel plot.

Multiple panel plots stack several graphs using the same x-axis. We will be building a custom multiple panel plot.

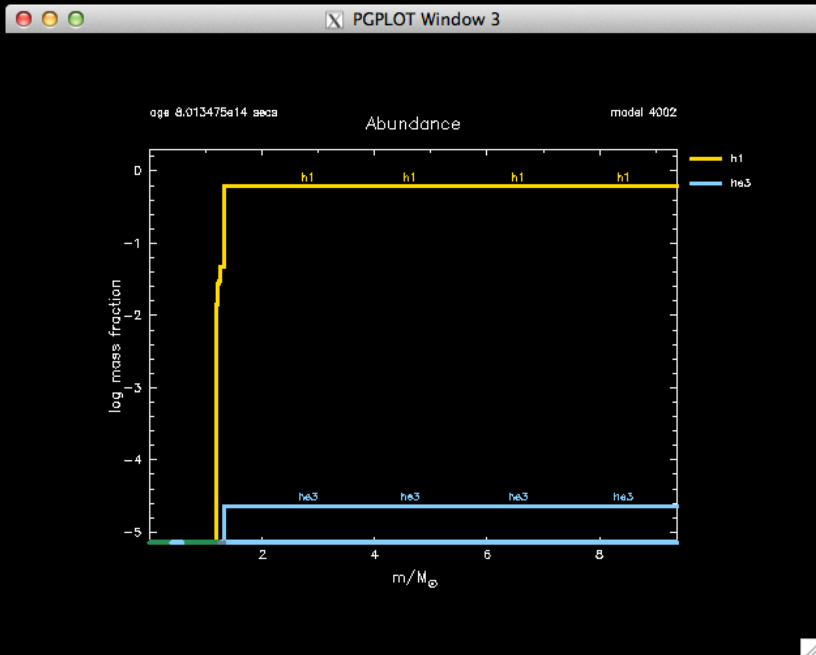
Grid plots combine several plots in a user-specified grid layout. Our goal is to build a custom grid plot relevant for convectively bounded carbon burning flame studies.

Since we are burning carbon, visualizing the abundances is prudent.

Task: Copy the following abundance profile plot commands from plot_commands.txt, paste it into inlist_pgstar, and save inlist_pgstar.

```
! Abundance profile plot

Abundance_win_flag = .true.


! isotopes to plot
Abundance_num_isos_to_show = 2
Abundance_which_isos_to_show(1) = 'h1'
Abundance_which_isos_to_show(2) = 'he3'
```

You should see something like this:



Let's make this more relevant to the model at hand.

Task: Copy these from plot_commands.txt, and paste it into inlist_pgstar.

As an Experiment, save inlist_pgstar. What happens?

```
! window properties
Abundance_win_width =
Abundance_win_aspect_ratio =

Abundance_xleft =
Abundance_xright =
Abundance_ybot =
Abundance_ytop =
Abundance_txt_scale =
Abundance_title =

! isotopes to plot
Abundance_num_isos_to_show = 8
Abundance_which_isos_to_show(1) = 'h1'
Abundance_which_isos_to_show(2) = 'he3'
Abundance_which_isos_to_show(3) =
Abundance_which_isos_to_show(4) =
Abundance_which_isos_to_show(5) =
Abundance_which_isos_to_show(6) =
Abundance_which_isos_to_show(7) =
Abundance_which_isos_to_show(8) =

! number and size of isotope labels
num_abundance_line_labels =
Abundance_line_txt_scale_factor =

! number and size of isotopes on legend
Abundance_legend_max_cnt =
Abundance_legend_txt_scale_factor =

! xaxis name and orientation
Abundance_xaxis_name =
Abundance_xaxis_reversed =

! xaxis limits
Abundance_xmin =
Abundance_xmax =

! yaxis limits
Abundance_log_mass_frac_min =
Abundance_log_mass_frac_max =
```

Tasks: 1) Add ^{4}He to ^{24}Mg,

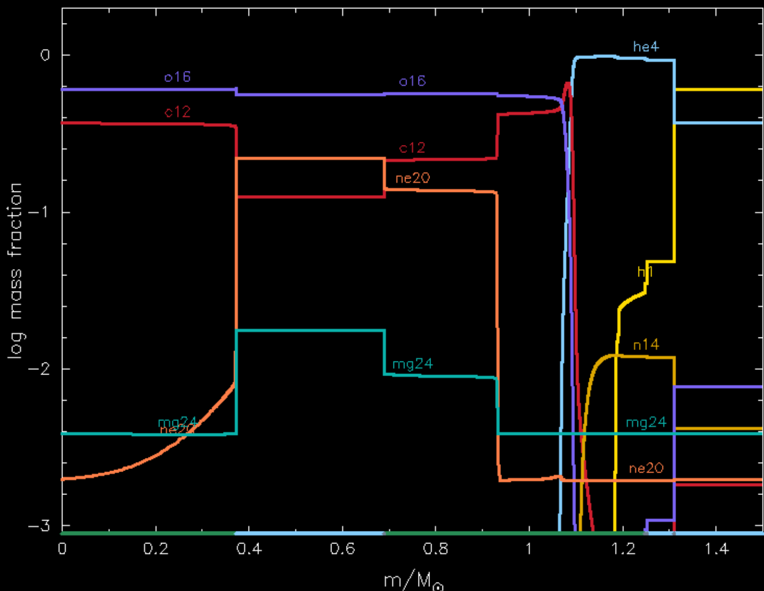
2) only show abundances larger than 10^{-3},

3) limit the mass range from 0 to 1.5 $M_\odot$,

4) no legend on the side of the plot,

5) fill out all the blank keywords,

6) save inlist_pgstar.



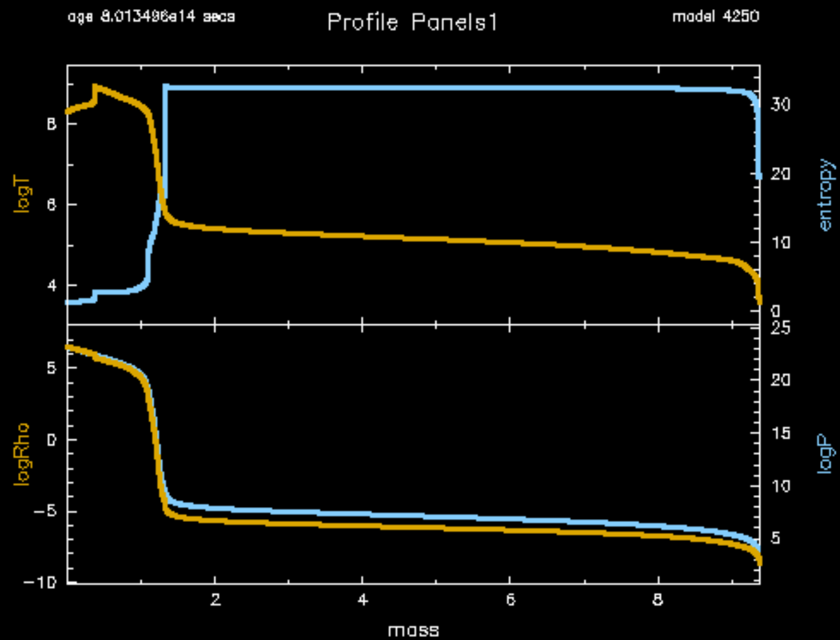
mesa/star/pgstar.defaults is your friend.

A burning front is propagating. Let's look at the thermodynamics.

Task: Activate the Profile_Panel1 plot by a copy & paste from the plot_commands.txt file:

```
! Profile Panel
Profile_Panels1_win_flag = .true.
```

You should see something like this:



Gorgeous as this default beauty is, let's tune it to the study at hand.

Tasks: For the top plot in Profile_Panel1

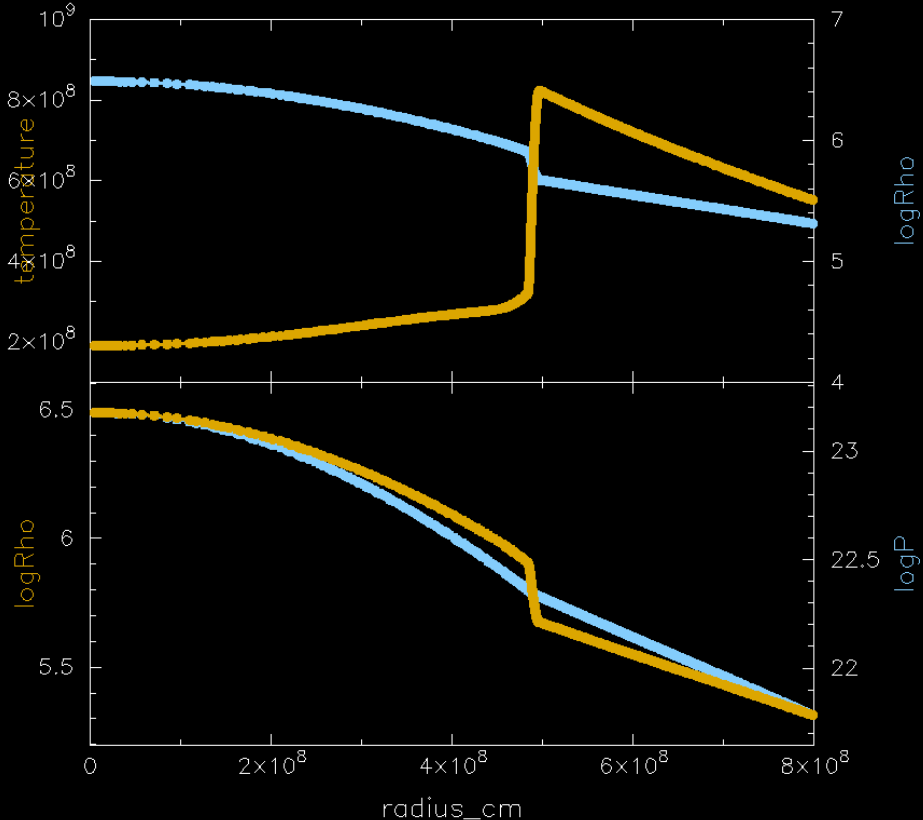
1) Make the x-axis the radius in cm with limits of 0.0 to 4e9.

2) Put the temperature and $\log_{10}$ density on the y-axes with limits of 10^8 to 10^9 for temperature, 4 to 7 for $\log_{10}$ density.

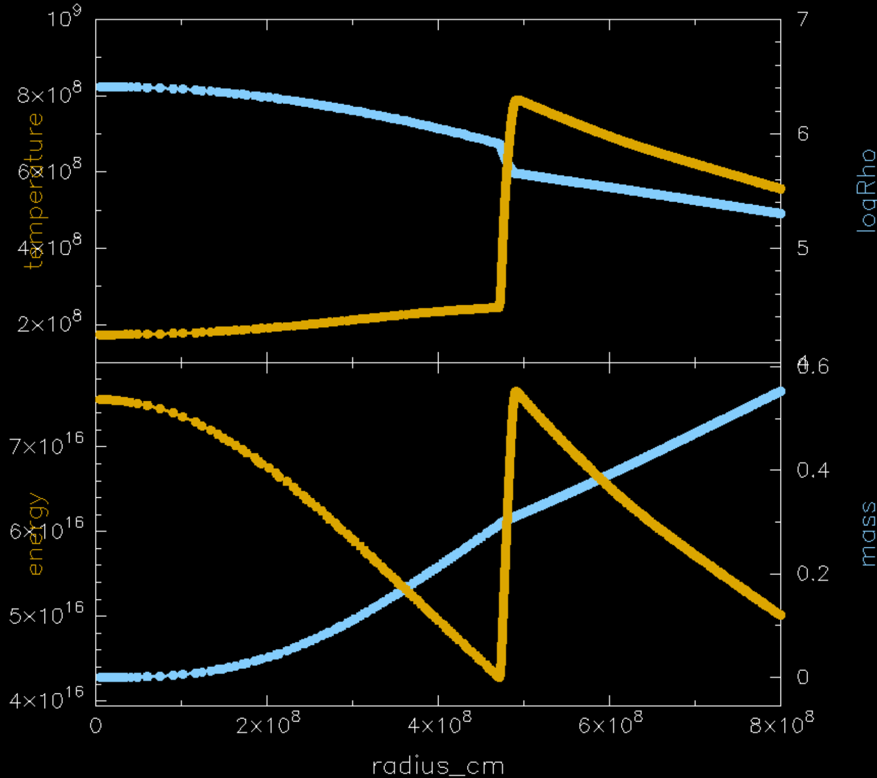
3) Show the underlying mass grid, or more precisely the boundaries between cells in MESA's finite volume scheme.

$MESA_DIR/star/defaults/pgstar.defaults
$MESA_DIR/star/defaults/profile_columns.list
are your friends.

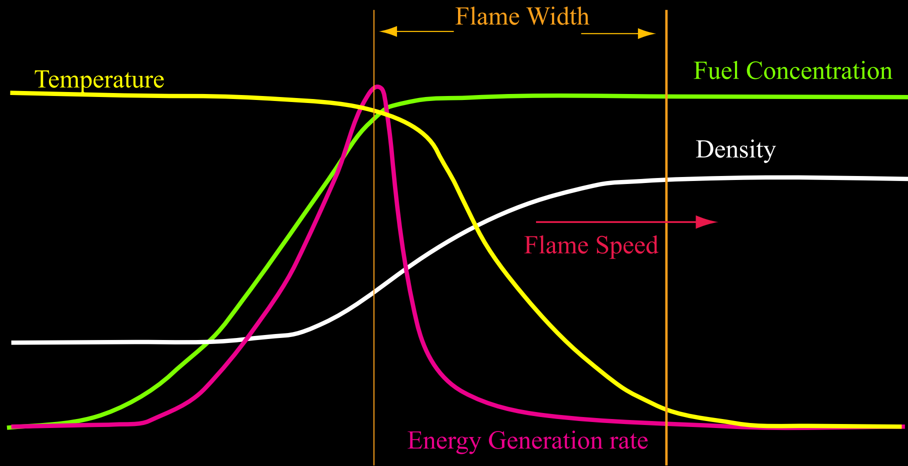
You should now see something like this:



Task: For the 2nd panel, plot the thermal energy and mass. You should now have something like this:



Flame speed analytics



$$\tau_{diff} \sim \frac{\delta^2}{D} \sim \frac{\delta^2}{\lambda c}$$

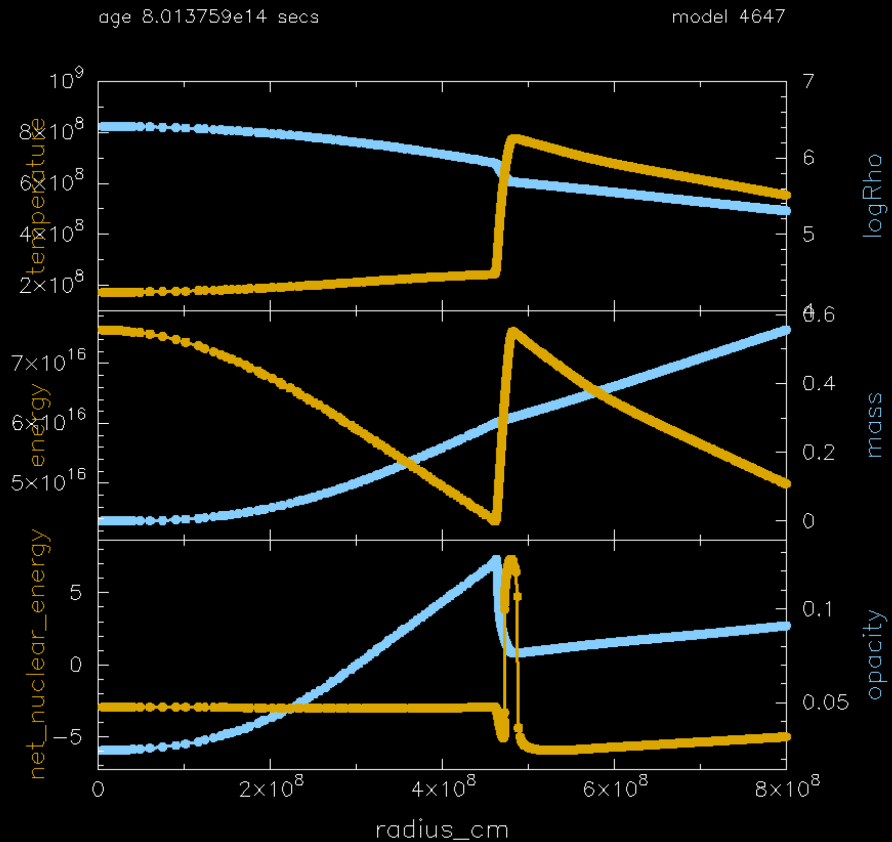
$$\tau_{burn} \sim \frac{E}{\dot{S}}$$

$$\delta \sim \left(\frac{\lambda c E}{\dot{S}} \right)^{1/2}$$

$$v_{cond} \sim \frac{\delta}{\tau_{burn}} \sim \frac{\delta \dot{S}}{E} \sim \left(\frac{\lambda c \dot{S}}{E} \right)^{1/2} \sim \left(\frac{c \dot{S}}{\kappa \rho E} \right)^{1/2}$$

Task: Add a new 3rd panel (Profile_Panels1_num_panels = 3) that visualizes two more variables relevant for the local flame speed.

You should now see something like this:

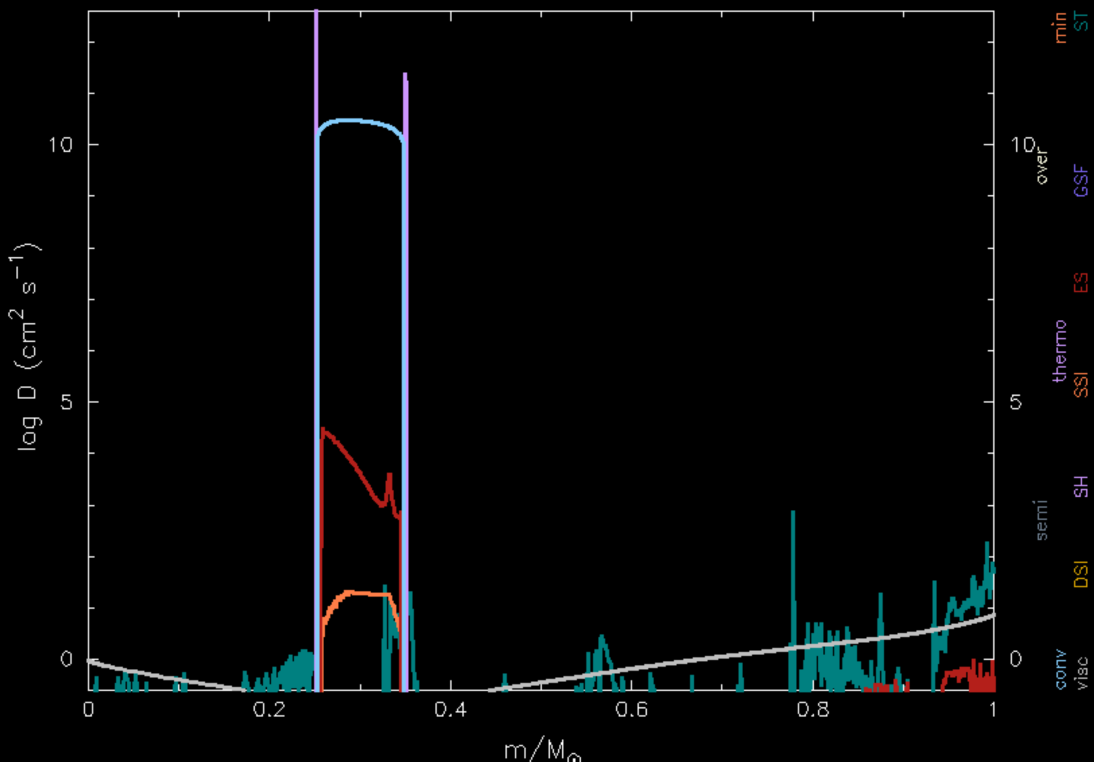


One way to quench the flame is to deplete the precursor of fuel by composition mixing beyond the convective boundaries.
So let's add a mixing profile with mass on the x-axis.

Task: Cut & paste these pgstar commands and fill in the blanks.

```
! Mixing profile

Mixing_win_flag = .true.

! window properties
Mixing_win_width =
Mixing_win_aspect_ratio =
Mixing_title =

! x-axis
Mixing_xaxis_name =
Mixing_xaxis_reversed =
Mixing_xmin =
Mixing_xmax =

! y-axis
Mixing_ymin =
Mixing_ymax =
Mixing_dymin =

! file output
Mixing_file_flag = .false.
Mixing_file_dir = 'Mixing'
Mixing_file_prefix = 'mixing_'
Mixing_file_cnt = 5            ! output when mod(model_number,Mixing_file_cnt)==0
Mixing_file_width = -1         ! (inches) negative means use same value as for window
Mixing_file_aspect_ratio = -1 ! negative means use same value as for window
file_device = 'png'          ! options 'png' and 'vcps' for png and postscript
file_extension = 'png'       ! common names are 'png' and 'ps'
```

Hopefully you have something like this:

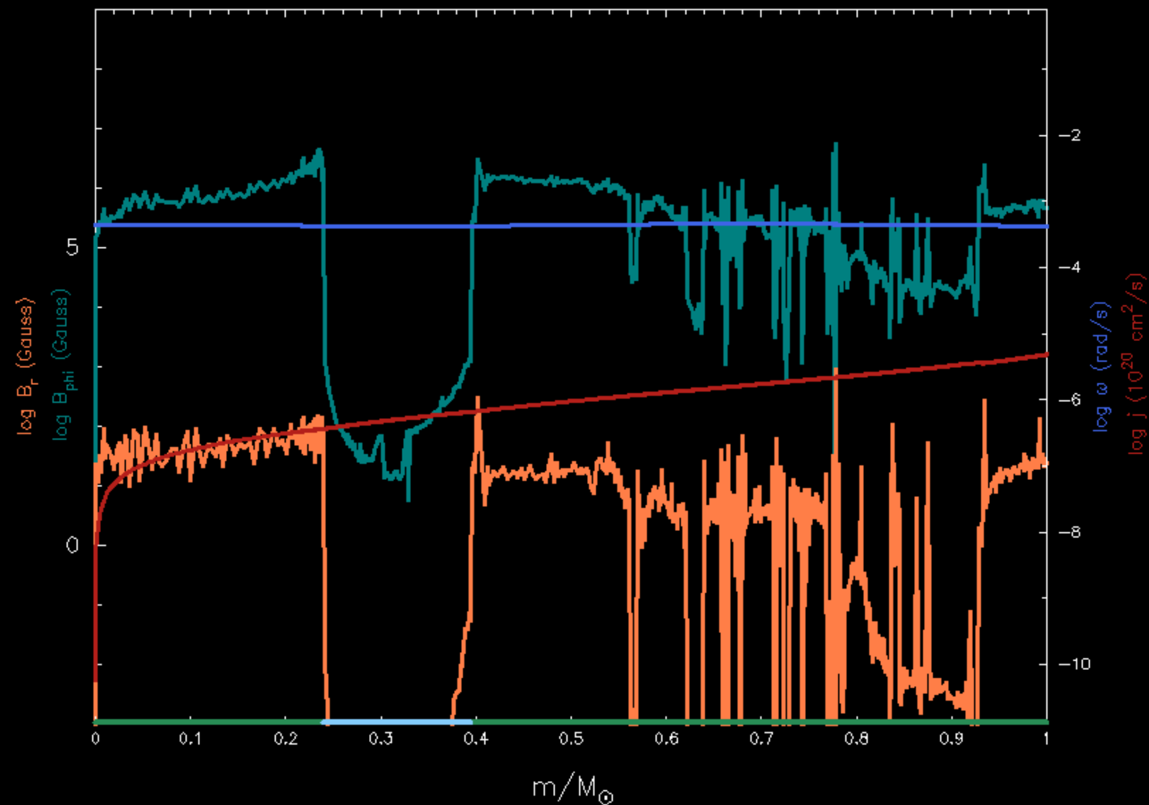


We're exploring if rotation can quench the flame,
so add a dynamo profile plot window.

Task: you are on your own for this one.

mesa/star/pgstar.defaults is your friend.

Hopefully you have something like this:



Let's get some useful text information on the screen.

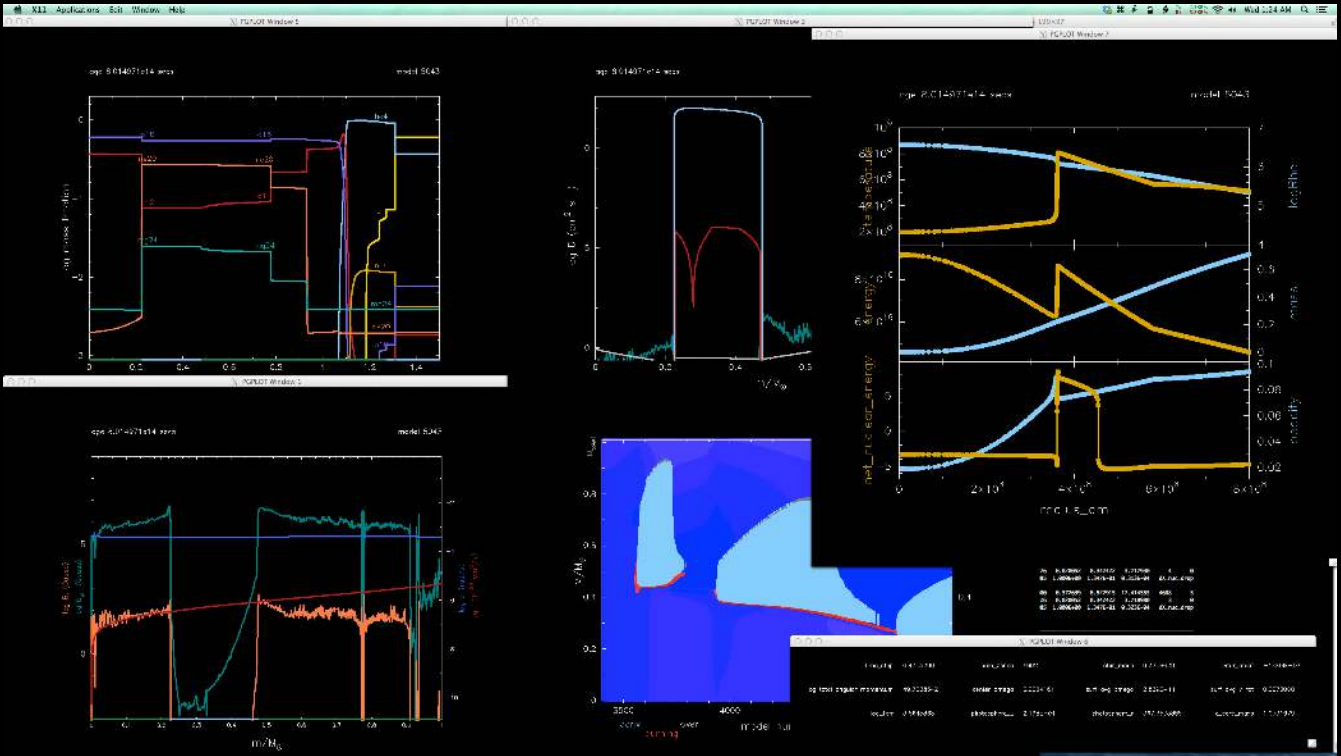
Task: copy & paste these commands into inlist_pgstar.

```
! Text_Summary window

Text_Summary1_win_flag = .true.
Text_Summary1_win_width = 10
Text_Summary1_win_aspect_ratio = 0.15

Text_Summary1_xleft = 0.06
Text_Summary1_xright = 1.02
Text_Summary1_ybot = 0.0
Text_Summary1_ytop = 1.0
Text_Summary1_txt_scale = 4.0
Text_Summary1_title = ''

Text_Summary1_num_rows = 3 ! <= 20
Text_Summary1_num_cols = 4 ! <= 20
Text_Summary1_name(:,:) = ''

Text_Summary1_name(1,1) = 'time_step'
Text_Summary1_name(1,2) = 'num_zones'
Text_Summary1_name(1,3) = 'star_mass'
Text_Summary1_name(1,4) = 'star_mdot'

Text_Summary1_name(2,1) = 'log_total_angular_momentum'
Text_Summary1_name(2,2) = 'center_omega'
Text_Summary1_name(2,3) = 'surf_avg_omega'
Text_Summary1_name(2,4) = 'surf_avg_v_rot'

Text_Summary1_name(3,1) = 'log_Teff'
Text_Summary1_name(3,2) = 'photosphere_L'
Text_Summary1_name(3,3) = 'photosphere_r'
Text_Summary1_name(3,4) = 'c_core_mass'
```

You should see something like this:

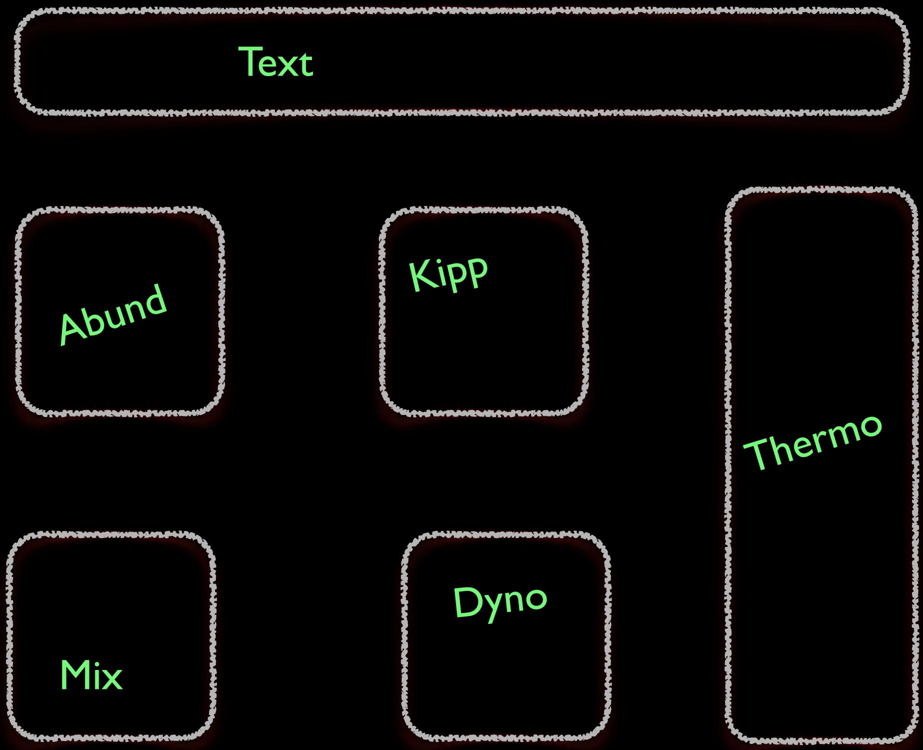
time_step	0.1334458	num_zones	4402	star_mass	9.3769730	star_mdot	−9.459E−07
log_total_angular_momentum	49.7051356	center_omega	0.0006929	surf_avg_omega	2.130E−11	surf_avg_v_rot	0.0062139
log_Teff	3.5559632	photosphere_L	2.672E+04	photosphere_r	421.4794976	c_core_mass	1.0676831

We have 6 plot windows open!



Let's clean up this mess by putting all 6 plots on a Grid Plot.

Sketch the grid plot design you want.



Task: close all the individual windows by setting the plot logicals to false and saving the inlist_pgstar file:

```
Kipp_win_flag = .false.
Abundance_win_flag = .false.
Profile_Panels1_win_flag = .false.
Mixing_win_flag = .false.
Dynamo_win_flag = .false.
Text_Summary1_win_flag = .false
```

PGPLOT will ask you, in the window running the calculation, to hit return to close the X11 windows that were previously open.

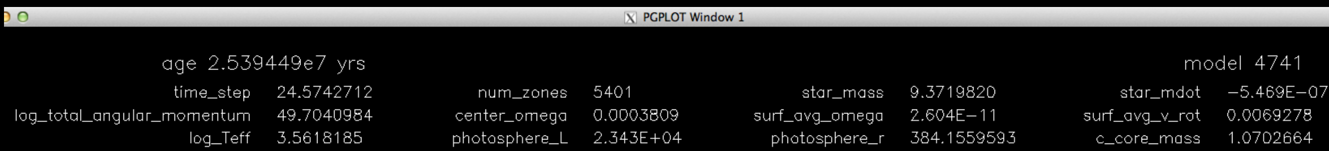
The 2nd step to creating a Grid Plot is to set the window layout.

Task: copy & paste from plot_commands.txt into inlist_pgstar:

```
Grid1_win_flag = .true.
Grid1_win_width = 14
Grid1_win_aspect_ratio = 0.75

! reset the defaults

Grid1_plot_name(:) = ''
Grid1_plot_row(:) = 1            ! number from 1 at top
Grid1_plot_rowspan(:) = 1        ! plot spans this number of rows
Grid1_plot_col(:) =  1           ! number from 1 at left
Grid1_plot_colspan(:) = 1        ! plot spans this number of columns
Grid1_plot_pad_left(:) = 0.0     ! fraction of full window width for padding on left
Grid1_plot_pad_right(:) = 0.0    ! fraction of full window width for padding on right
Grid1_plot_pad_top(:) = 0.0      ! fraction of full window height for padding at top
Grid1_plot_pad_bot(:) = 0.0      ! fraction of full window height for padding at bottom
Grid1_txt_scale_factor(:) = 0.7 ! multiply txt_scale for subplot by this


Grid1_num_cols = 3 ! divide plotting region into this many equal width cols
Grid1_num_rows = 2 ! divide plotting region into this many equal height rows
Grid1_num_plots = 6 ! <= 10
```

Task: put this **Text Summary** roughly in place.

```
Grid1_plot_name(1) = 'Text_Summary1'
Grid1_plot_row(1) = 1           ! number from 1 at top
Grid1_plot_rowspan(1) = 1       ! plot spans this number of rows
Grid1_plot_col(1) =  1          ! number from 1 at left
Grid1_plot_colspan(1) = 3       ! plot spans this number of columns

Grid1_plot_pad_left(1) = -0.05  ! fraction of full window width for padding on left
Grid1_plot_pad_right(1) = -0.04 ! fraction of full window width for padding on right
Grid1_plot_pad_top(1) = -0.04   ! fraction of full window height for padding at top
Grid1_plot_pad_bot(1) = 0.39    ! fraction of full window height for padding at bottom
Grid1_txt_scale_factor(1) = 0.2 ! multiply txt_scale for subplot by this
```



Task: add a title to your grid and set it to the name of your groups input model file:

```
Grid1_title = ‘ZZZ_cignition.mod'
```

age 7.873004e14 secs 9p5m_0p000_cignition.mod model 2394

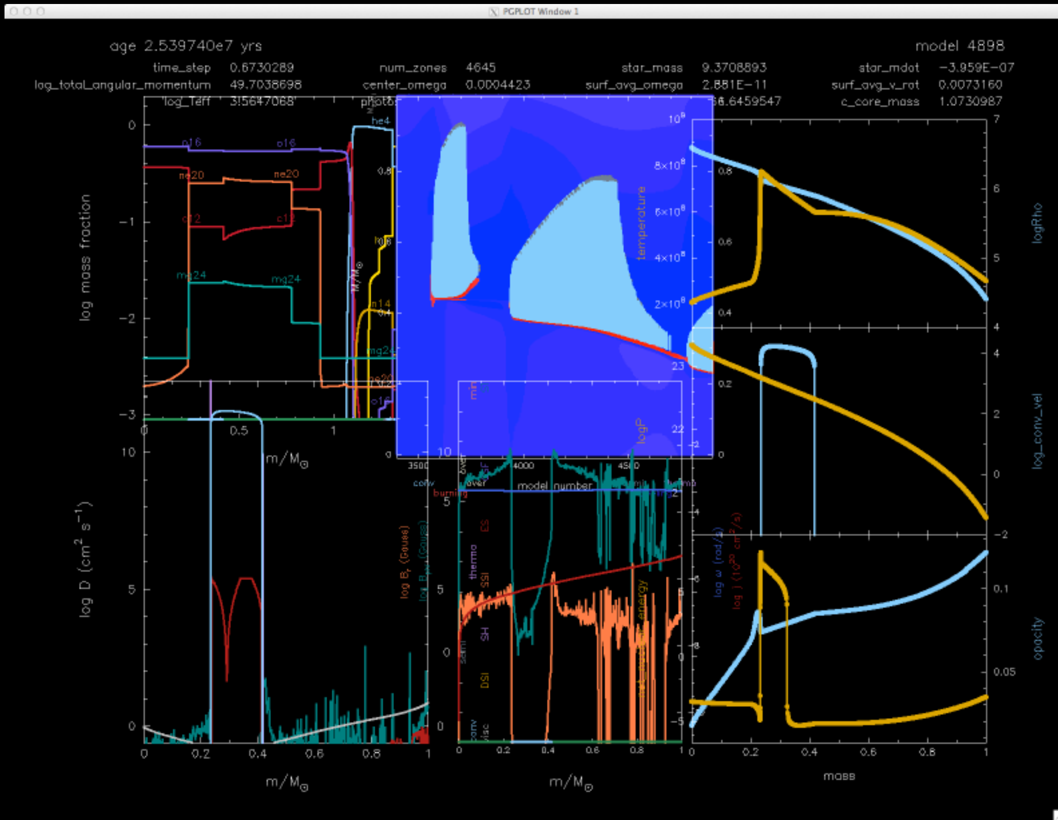
time_step	40.2575988	num_zones	1889	star_mass	9.3770236	star_mdot	−2.114E−07
log_total_angular_momentum	−99.0000000	center_omega	0.0000000	surf_avg_omega	0.0000000	surf_avg_v_rot	0.0000000
log_Teff	3.5654348	photosphere_L	1.895E+04	photosphere_r	339.7926899	c_core_mass	1.0064686

Task: put the Abundance Profile plot roughly in place.

```
Grid1_plot_name(2) = 'Abundance'
Grid1_plot_row(2) = 1           ! number from 1 at top
Grid1_plot_rowspan(2) = 1       ! plot spans this number of rows
Grid1_plot_col(2) =  1          ! number from 1 at left
Grid1_plot_colspan(2) = 1       ! plot spans this number of columns

Grid1_plot_pad_left(2) = -0.06    ! fraction of full window width for padding on left
Grid1_plot_pad_right(2) = 0.05   ! fraction of full window width for padding on right
Grid1_plot_pad_top(2) = 0.03     ! fraction of full window height for padding at top
Grid1_plot_pad_bot(2) = 0.05     ! fraction of full window height for padding at bottom
Grid1_txt_scale_factor(2) = 0.7 ! multiply txt_scale for subplot by this
```

Task: Get the other plots in place according to our design. Don't worry about aesthetically pleasing spaces between the plots just yet, adjust spacings after all the plots are in place.

Your Grid1_plot might look like this after getting all the plots on the grid.

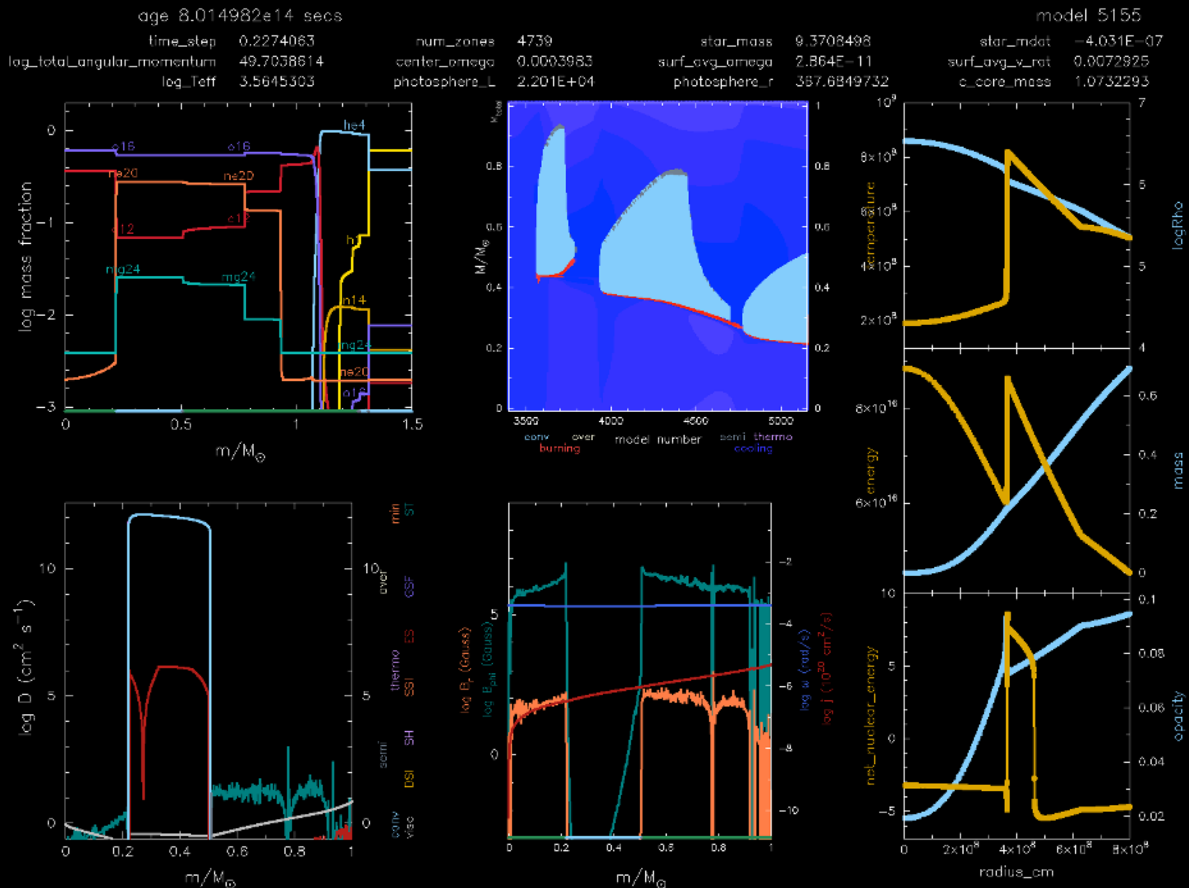


Task: adjust the left, right, top, bottom spacings around each plot (in units of fraction of full window width) until you find something that appeals to your sensibilities.

Tip: you may also want to adjust the global scaling of titles, axes, lines, and labels. Search pgstar.defaults for these control definitions:

```
!### titles
!### grid titles
!### scale for axis labels
!### displacements for axis labels
!### relative scale of axis number
!### line width for data
```

Admire your gorgeous dashboard!



Start saving png files of your dashboard.

```
! file output
Grid1_file_flag = .true.
Grid1_file_dir = 'Grid1'
Grid1_file_prefix = 'grid1_'
Grid1_file_cnt = 5           ! output when mod(model_number,Grid1_file_cnt)==0
Grid1_file_width = -1        ! (inches) negative means use same value as for window
Grid1_file_aspect_ratio = -1 ! negative means use same value as for window

! white_on_black flags -- true means white foreground color on black background
!file_white_on_black_flag = .false.

file_device = 'png'          ! options 'png' and 'vcps' for png and postscript
file_extension = 'png'       ! common names are 'png' and 'ps'
```

Task: copy & paste from plot_commands.txt file to inlist_pgstar.

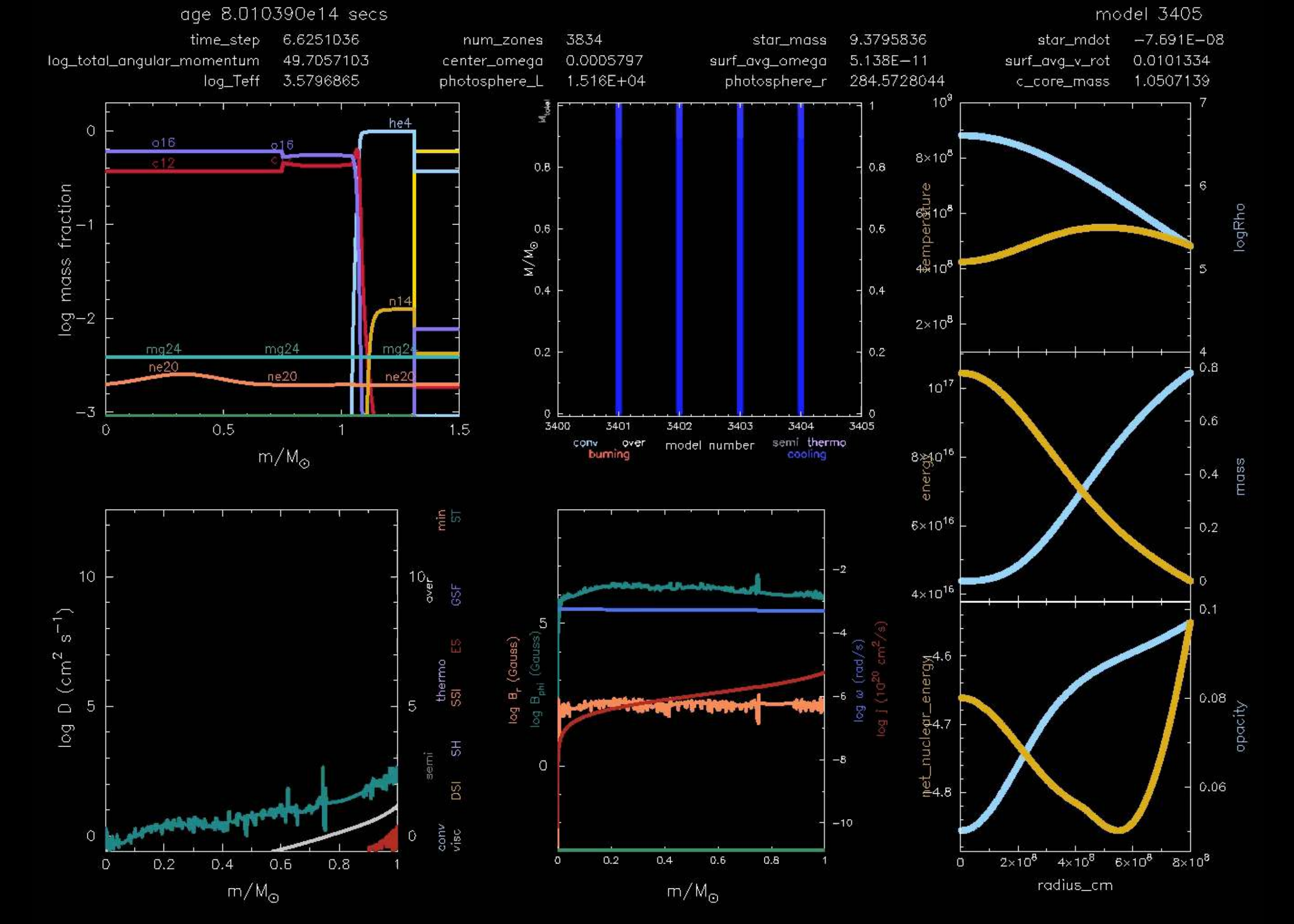
Tip: you may find it useful to do png output without displaying a local pgstar viewport. This is ideal for users with slow graphics, prefer to maintain a clutter-free desktop, run on a cluster, etc. while maintaining the freedom to check the status of your run at any time.

Task: update these controls (hit 'return' when prompted)

```
Grid1_win_flag = .false.

! file output

Grid1_file_flag = .true.
```

Task: make a movie with the images_to_movie.sh script included in the MESA SDK:

```
% images_to_movie.sh "Grid1/*.png" summary.mp4
```

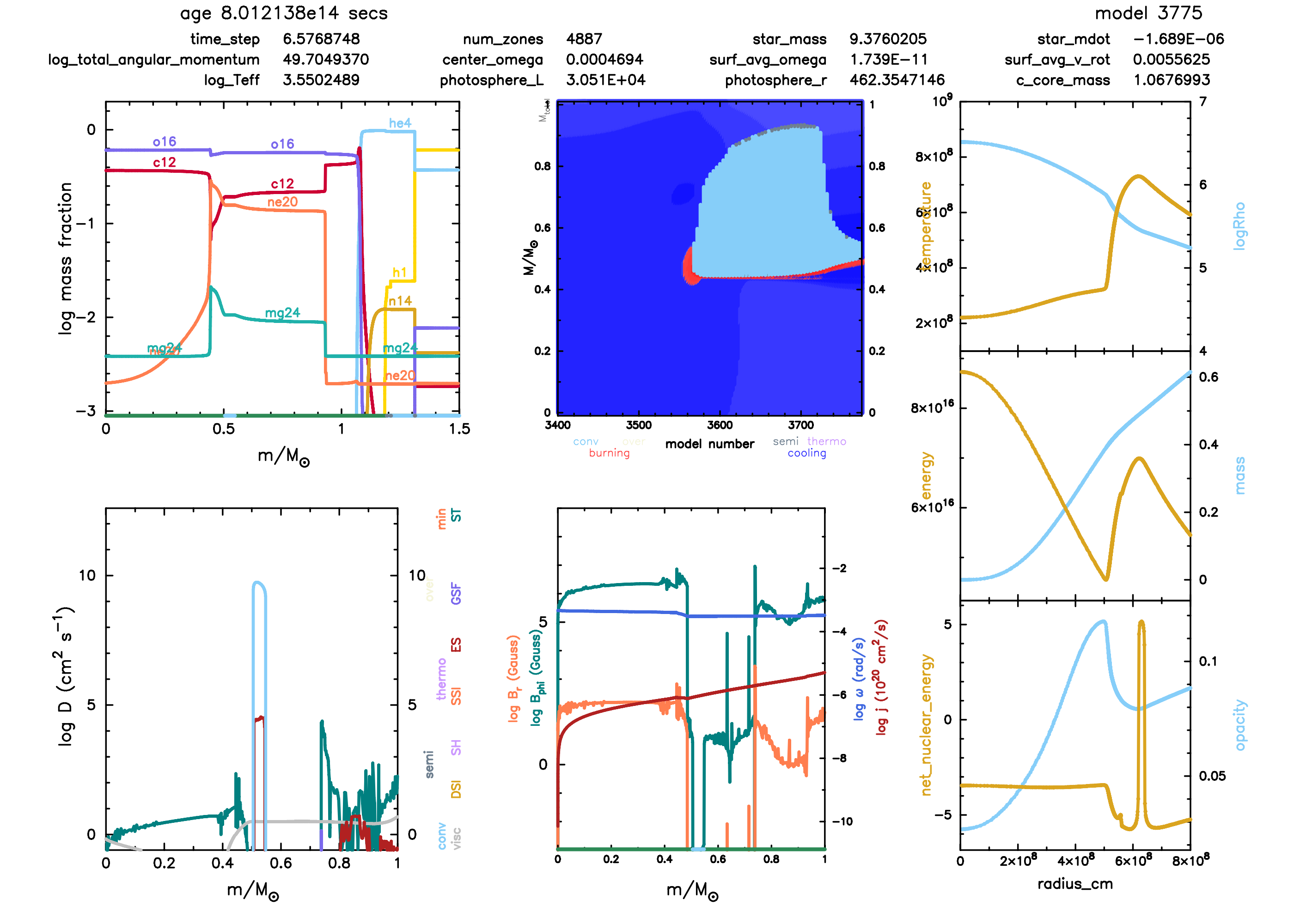


age 8.010390e14 secs
model 3405
time_step 6.6251036
num_zones 3834
star_mass 9.3795836
star_mdot −7.691E−08
log_total_angular_momentum 49.7057103
center_omega 0.0005797
surf_avg_omega 5.138E−11
surf_avg_v_rot 0.0101334
log_Teff 3.5796865
photosphere_L 1.516E+04
photosphere_r 284.5728044
c_core_mass 1.0507139
log mass fraction
he4
o16
c12
n14
mg24
ne20
m/M⊙
M/M⊙
conv
over
burning
model number
semi
thermo
cooling
temperature
logRho
energy
mass
net_nuclear_energy
opacity
radius_cm
log D (cm² s⁻¹)
min
ST
over
GSF
thermo
ES
SSI
semi
SH
DSI
conv
visc
log B_r (Gauss)
log B_phi (Gauss)
log ω (rad/s)
log j (10²⁰ cm²/s)

Devote time watching models evolve.
It's a fun way to learn!

For publication purposes, you want a white background and postscript (vector graphics) file output:

```
! white_on_black flags -- true means white foreground color on black background
file_white_on_black_flag = .false.

file_device = 'vcps'             ! options 'png' and 'vcps' for png and postscript
file_extension = 'ps'            ! common names are 'png' and 'ps'
```


age 8.012138e14 secs
model 3775
time_step 6.5768748
num_zones 4887
star_mass 9.3760205
star_mdot −1.689E−06
log_total_angular_momentum 49.7049370
center_omega 0.0004694
surf_avg_omega 1.739E−11
surf_avg_v_rot 0.0055625
log_Teff 3.5502489
photosphere_L 3.051E+04
photosphere_r 462.3547146
c_core_mass 1.0676993
log mass fraction
m/M⊙
o16
c12
ne20
mg24
he4
h1
n14
M/M⊙
model number
conv
over
burning
semi
thermo
cooling
temperature
logRho
energy
mass
net_nuclear_energy
opacity
radius_cm
log D (cm² s⁻¹)
min
ST
GSF
ES
SSI
SH
DSI
visc
log B_r (Gauss)
log B_phi (Gauss)
log ω (rad/s)
log j (10²⁰ cm²/s)

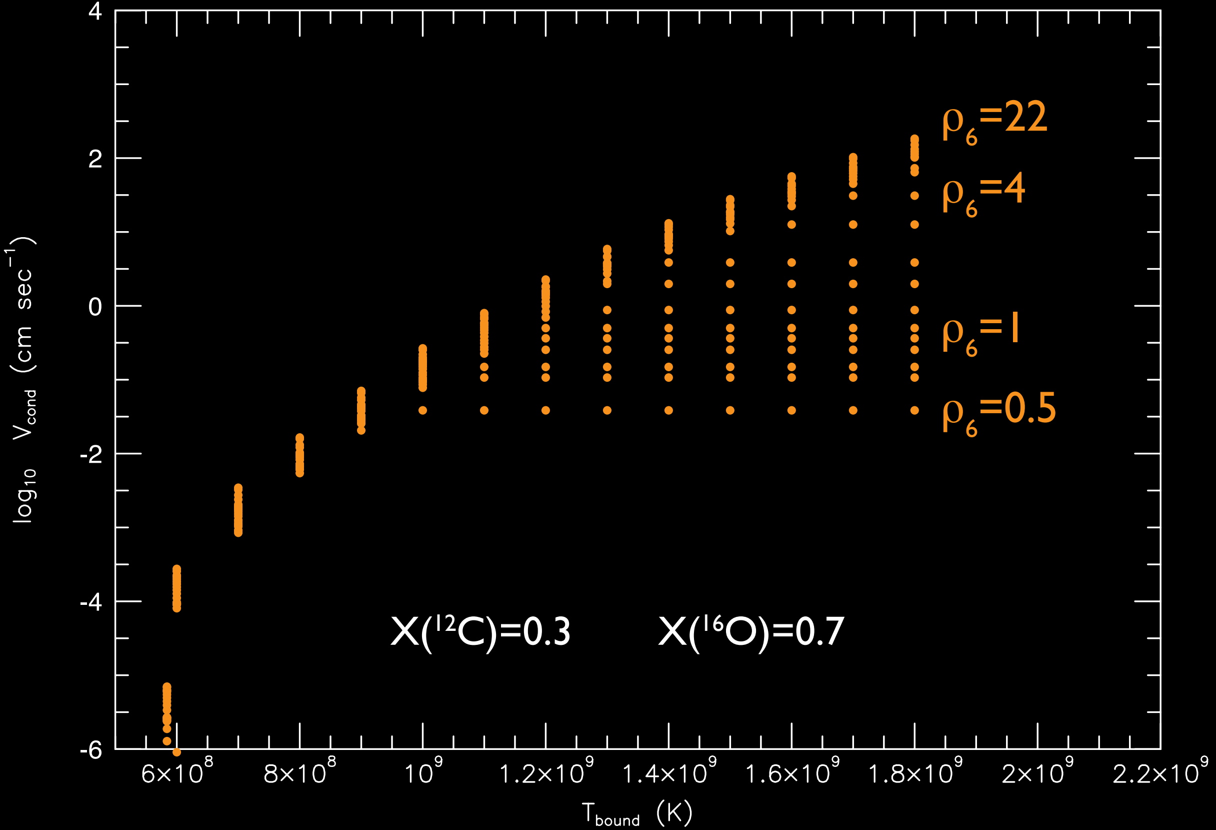
Task: Measure the flame speed Δr/Δt in cm/s from your dashboard. Report the density ahead of the front, the temperature behind the front, and the speed.

Hint - zoom in on the flame front.

Task: Measure the flame speed from our scaling relation

$$v_{cond} \sim \frac{\delta}{\tau_{burn}} \sim \frac{\delta \dot{S}}{E} \sim \left(\frac{\lambda c \dot{S}}{E}\right)^{1/2} \sim \left(\frac{c \dot{S}}{\kappa \rho E}\right)^{1/2}$$

and report your results.



ρ_6=22
ρ_6=4
ρ_6=1
ρ_6=0.5
X(^{12}C)=0.3
X(^{16}O)=0.7
$\log_{10}$ V_{cond} (cm sec^{-1})
T_{bound} (K)
4
2
0
-2
-4
-6
6×10^8
8×10^8
10^9
1.2×10^9
1.4×10^9
1.6×10^9
1.8×10^9
2×10^9
2.2×10^9