Minilab 2

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In the second Minilab, we're going to extend our previous input file to include data for individual mode frequencies.

1 Setting up

- Add the data for the individual mode frequencies measured for this star. For convenience, you should be able to copy the data at the end of this document or from `inlist_freq` to the relevant part of `inlist_astero_search_controls`.
- Change `chi2_seismo_fraction` to 0.5 so that MESA knows to include the frequency data in χ^2.
- We also need to tell MESA to make some important choices about what is passed to the evolution code. Change `oscillation_code` to use GYRE instead of ADIPLS. Nearby, turn on `add_atmosphere` and turn off `keep_surface_point`.

Each oscillation code has its own set of controls, most of which are controlled outside of MESA's inlists. For GYRE, this separate input file is another set of Fortran namelists in `gyre.in`.

- From wherever you extracted the materials, copy `gyre.in` to your working directory.
- All the parameters are set except for the frequency range GYRE will search for modes, so change the values of `freq_min`, `freq_max`, `freq_min_units` and `freq_max_units` to something more appropriate. Refer to the GYRE website for help.[1] The inlist `inlist_astero_search_controls` has some tips from Rich for setting these controls.
- Optionally, if in Minilab 1 you found a better solution than your initial guess, change your initial parameter values to those of your previous best.

We finally need to select the parameters that determine when MESA will start comparing the radial mode frequencies and then the non-radial mode frequencies. This *will* require fine-tuning once you start running.

[1] `https://bitbucket.org/rhdtownsend/gyre/wiki/Home`

2 Choosing decision limits

As a reminder, the oscillation calculation is relatively expensive, so MESA avoids it for as long as it can. To do so, it makes a series of decisions about whether the model is close enough to the observed data. The first cut is based on χ^2_{spectro}. When χ^2_{spectro} falls below `chi2_spectroscopic_limit`, it will then compare $\Delta\nu_{\text{as}}$ to `delta_nu`. If $\chi^2_{\Delta\nu}$ is less than `chi2_delta_nu_limit`, then MESA will evaluate the radial mode frequencies and compute their total misfit, χ^2_{radial}. If this χ^2_{radial} is less than `chi2_radial_limit`, if will finally compute the non-radial mode frequencies too and consider those models fully in the optimisation.

All this means you have to choose a bunch of parameters that will have a big effect on how fast or slow your optimisation run will be.

- Choose a value for `chi2_spectroscopic_limit`.[2]
- Estimate values for `delta_nu`, `delta_nu_sigma` and `chi2_delta_nu_limit`. Note that this will be compared to $\Delta\nu_{\text{as}}$, which is different from the actual observed separation. Since we aren't including $\Delta\nu$ in χ^2, just think of this parameter as controlling when the radial modes will be computed. Also, remember that $\Delta\nu_{\text{as}}$ is generally *larger* than the observed spacing between the modes.
- Choose a value for `chi2_radial_limit`. How close to you want the radial mode frequencies to be before you think it's worth computing the non-radial mode frequencies too?

3 Running

Once again, before you try to fit a model, make sure that a single run works as you expect. You should see that MESA is going through the complete logical sequence of evaluating χ^2_{spectro}, $\Delta\nu$, the radial mode frequencies, and then the full set of mode frequencies. You'll probably find that the limits you chose in Section 2 aren't optimal, either because MESA never gets as far as computing all the modes or because it starts too early and spends a long time calculating mode frequencies for models that aren't close to the data. Tweak the various χ^2 limits to make sure your `use_first_values` run works as you expect and reasonably quickly. Once that's going, you can start optimising again.

4 Plotting

Once you've got the run going, we can add an echelle diagram of the observed and modelled frequencies to see how we're doing. Add the end of `inlist_astero_search_controls`, you'll find a second, empty namelist, `&astero_pgstar_controls`. Referring to the defaults, [3] switch on the echelle plot, and tweak the large separation to a reasonable value. Now, when MESA starts computing individual mode frequencies, you should see them appear in the echelle diagram.

[2]This parameter doesn't matter as much as the other χ^2 limits.

[3]`$MESA_DIR/star/astero/defaults/astero_pgstar.defaults`

Frequency data

```
nl0 = 15
l0_obs(1) = 2203.674d0
l0_obs(2) = 2354.521d0
l0_obs(3) = 2508.436d0
l0_obs(4) = 2660.843d0
l0_obs(5) = 2811.986d0
l0_obs(6) = 2962.637d0
l0_obs(7) = 3113.66d0
l0_obs(8) = 3265.644d0
l0_obs(9) = 3418.235d0
l0_obs(10) = 3571.021d0
l0_obs(11) = 3723.93d0
l0_obs(12) = 3876.94d0
l0_obs(13) = 4030.414d0
l0_obs(14) = 4184.206d0
l0_obs(15) = 4338.698d0
l0_obs_sigma(1) = 0.693d0
l0_obs_sigma(2) = 0.366d0
l0_obs_sigma(3) = 0.212d0
l0_obs_sigma(4) = 0.135d0
l0_obs_sigma(5) = 0.0947d0
l0_obs_sigma(6) = 0.0729d0
l0_obs_sigma(7) = 0.0615d0
l0_obs_sigma(8) = 0.0569d0
l0_obs_sigma(9) = 0.0578d0
l0_obs_sigma(10) = 0.0646d0
l0_obs_sigma(11) = 0.0793d0
l0_obs_sigma(12) = 0.107d0
l0_obs_sigma(13) = 0.159d0
l0_obs_sigma(14) = 0.26d0
l0_obs_sigma(15) = 0.468d0
```

```
nl1 = 15
l1_obs(1) = 2274.242d0
l1_obs(2) = 2426.458d0
l1_obs(3) = 2579.111d0
l1_obs(4) = 2731.679d0
l1_obs(5) = 2882.368d0
l1_obs(6) = 3033.247d0
l1_obs(7) = 3184.96d0
l1_obs(8) = 3337.322d0
l1_obs(9) = 3490.221d0
l1_obs(10) = 3643.27d0
l1_obs(11) = 3796.157d0
l1_obs(12) = 3949.575d0
l1_obs(13) = 4103.204d0
l1_obs(14) = 4257.812d0
l1_obs(15) = 4412.375d0
l1_obs_sigma(1) = 0.62d0
l1_obs_sigma(2) = 0.326d0
l1_obs_sigma(3) = 0.189d0
l1_obs_sigma(4) = 0.121d0
l1_obs_sigma(5) = 0.0858d0
l1_obs_sigma(6) = 0.0668d0
l1_obs_sigma(7) = 0.0571d0
l1_obs_sigma(8) = 0.0538d0
l1_obs_sigma(9) = 0.0559d0
l1_obs_sigma(10) = 0.064d0
l1_obs_sigma(11) = 0.0808d0
l1_obs_sigma(12) = 0.113d0
l1_obs_sigma(13) = 0.173d0
l1_obs_sigma(14) = 0.295d0
l1_obs_sigma(15) = 0.555d0
```

```
nl2 = 12
l2_obs(1) = 2492.878d0
l2_obs(2) = 2645.072d0
l2_obs(3) = 2797.192d0
l2_obs(4) = 2948.31d0
l2_obs(5) = 3099.615d0
l2_obs(6) = 3252.244d0
l2_obs(7) = 3405.212d0
l2_obs(8) = 3557.893d0
l2_obs(9) = 3711.1d0
l2_obs(10) = 3864.686d0
l2_obs(11) = 4018.158d0
l2_obs(12) = 4172.249d0
l2_obs_sigma(1) = 0.596d0
l2_obs_sigma(2) = 0.357d0
l2_obs_sigma(3) = 0.237d0
l2_obs_sigma(4) = 0.173d0
l2_obs_sigma(5) = 0.139d0
l2_obs_sigma(6) = 0.123d0
l2_obs_sigma(7) = 0.12d0
l2_obs_sigma(8) = 0.129d0
l2_obs_sigma(9) = 0.153d0
l2_obs_sigma(10) = 0.2d0
l2_obs_sigma(11) = 0.289d0
l2_obs_sigma(12) = 0.462d0
```