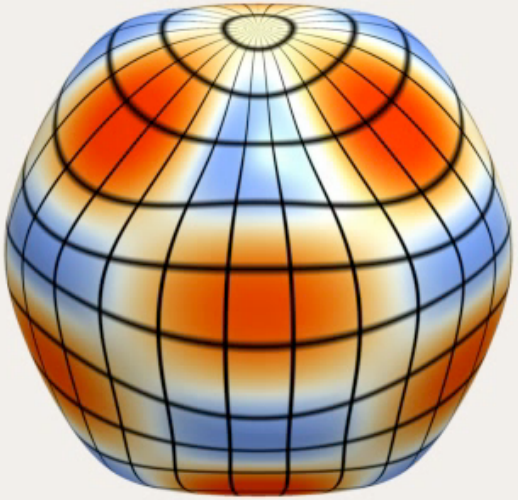
Asteroseismology with MESA - Part II

Rich Townsend

University of Wisconsin-Madison

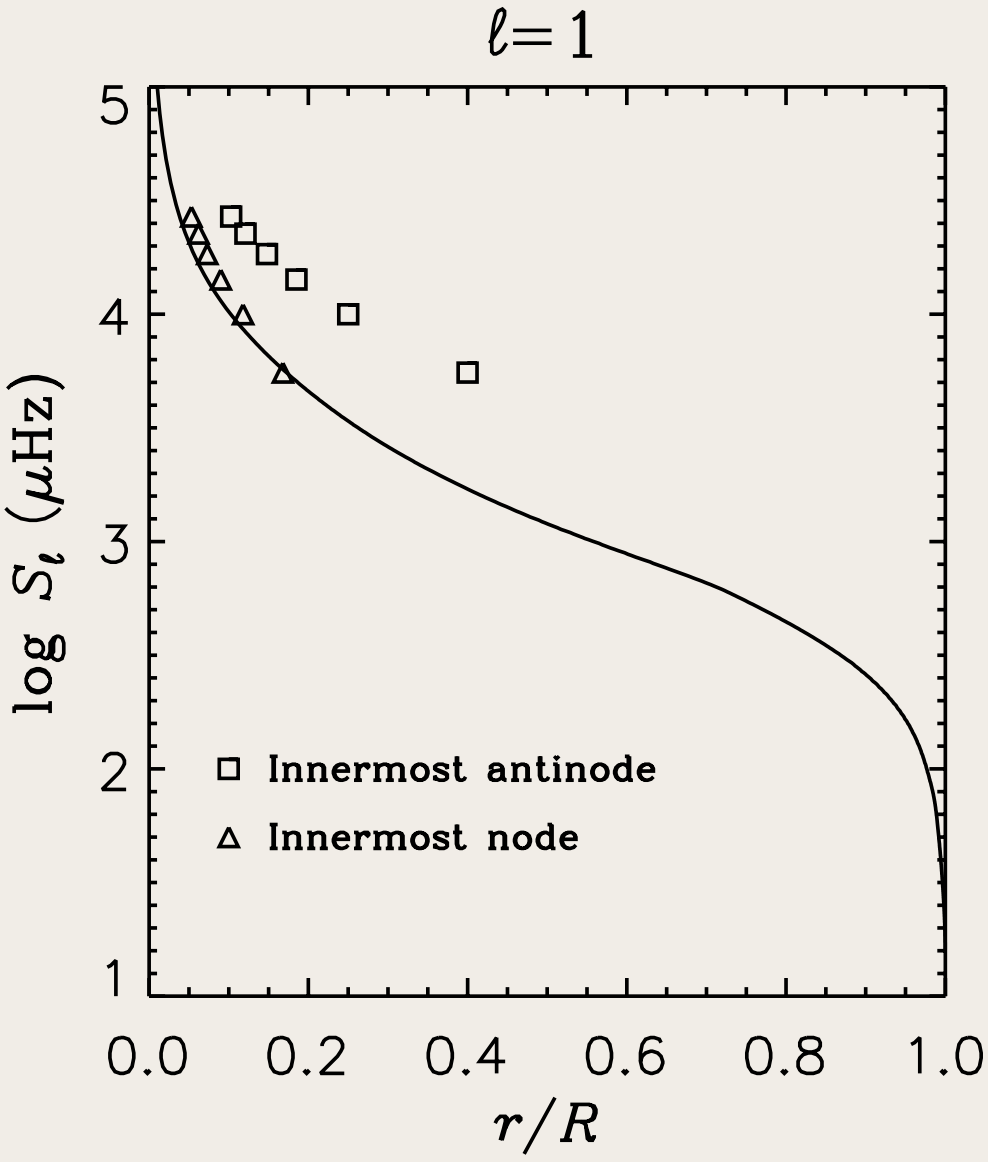


Summarizing Yesterday's 'Progress'

- Mini lab: Running ADIPLS
  - Mostly successful
  - One issue: ADIPLS scripts use `csh`, can be thwarted if `~/.cshrc` resets `PATH` variable
- Main lab: Propagation diagram
  - Big problems running extract_eigfunc on Linux machines
  - Caused by tragic programming errors by RT
  - Fixed version available on Forum; also, `townsend-II` package
  - log3.data file missing; needed to calculate S_ℓ (but inlist provided)
- Main lab: Echelle diagrams
  - No obvious problems
  - But most folks got bogged down on first problem

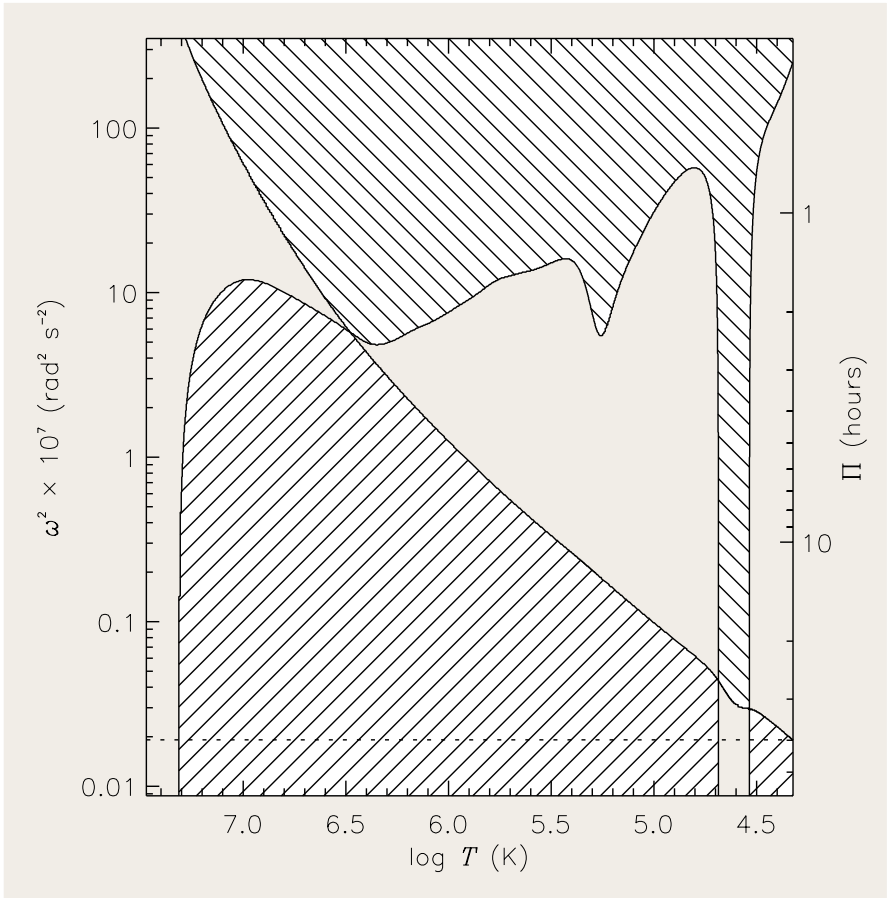
Propagation Diagram

- Reminder:
  - Select six $\ell = 1$ modes
  - Find location of innermost antinode in displacement eigenfunction
  - Plot in propagation diagram; should be close to the inner turning point r_t defined by $\omega = S_\ell$
- Results:
  - Antinode locations correlate with r_t but are somewhat larger
  - In fact, locations of innermost *nodes* agree very well with r_t
  - Success!



More on Propagation Diagrams...

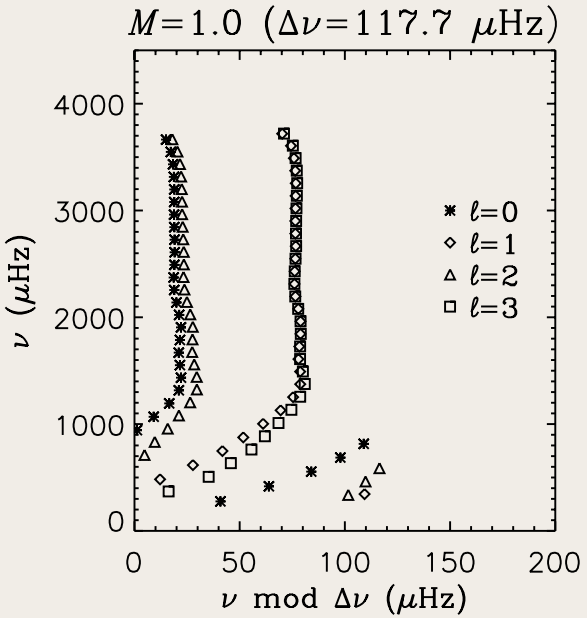
- Full propagation diagram shows $S_\ell{}^2$ and N^2
- More-rigorous dispersion relation (allowing coupling between g and p modes) gives modified propagation requirement ($k_r > 0$):
  - $\omega^2 > S_\ell{}^2, N^2$ (acoustic-wave character)
  - $\omega^2 < S_\ell{}^2, N^2$ (gravity-wave character)
- In evolved stars, mixed modes can arise which have different characters in different parts of the star

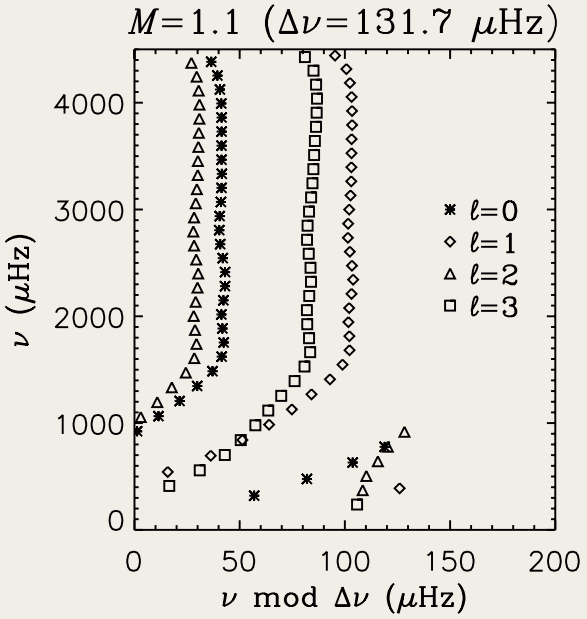


Echelle Diagrams

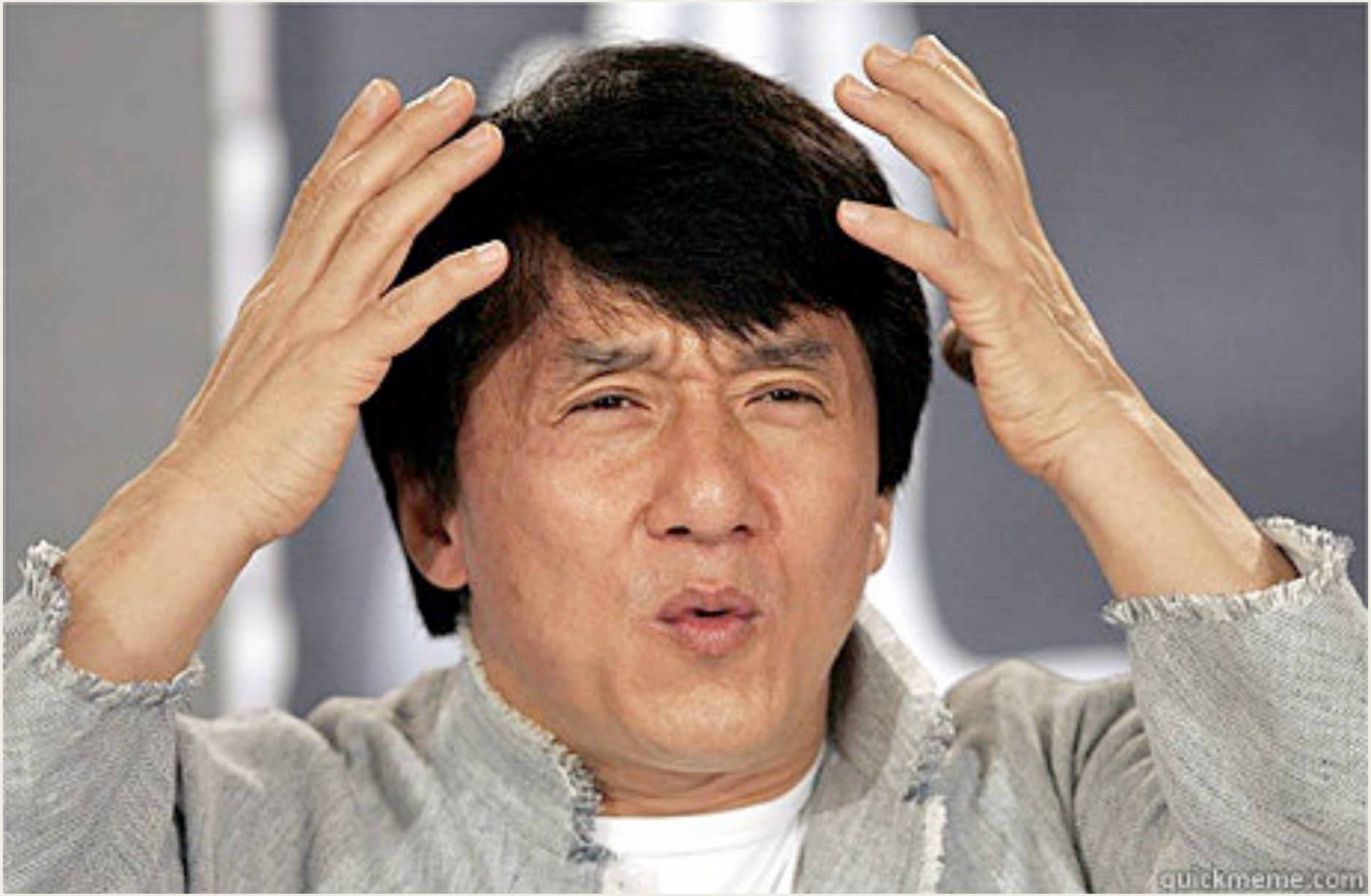
- Reminder:
  - Calculate frequencies for
    - near-TAMS 1.0$M_\odot$ model
    - near-ZAMS 1.1$M_\odot$ model
  - Plot echelle diagrams
  - Inspect large and small separations
  - Say something about stellar structure

- Results:
  - Echelle diagrams show similar-ish large separations (trade-off between mass and radius)
  - But small separations are very different; much smaller in 1.0$M_\odot$ (evolved) model
  - This comes from the positive sound-speed gradient in the 1.0$M_\odot$ core





15 Minutes with ADIPLS...



The ASTERO Module to the Rescue!

ASTERO: ADIPLS from within MESA

- Two levels of functionality

- ADIPLS callable from within usual star routines...
  - ...at end of evolution run
  - ...after each timestep of evolution run
  - Trivial!
  - Worked example in mini-lab

- ADIPLS callable from highly-automated optimization infrastructure
  - Define search region ($T_{\rm eff}$, log g, etc.)
  - Define observed frequency sets
  - Code optimizes parameters (M, $l_{\rm over}$, F/H, etc.) which lead to minimum χ^2
  - Worked example in main lab

Calling ADIPLS from within MESA

Initialization

```
call run_adipls(NULL(), .TRUE., .TRUE., ierr)
```

Find modes in frequency interval

```
call adipls_get_one_el_info(                &
     s, l, nu_1, nu_2, n_nu, R, G, M, &      ⟵ Inputs
     .TRUE., .FALSE., 0, '',          &      ⟵ Flags
     num, l_freq, l_inertia, l_order, ierr)  ⟵ Outputs
```

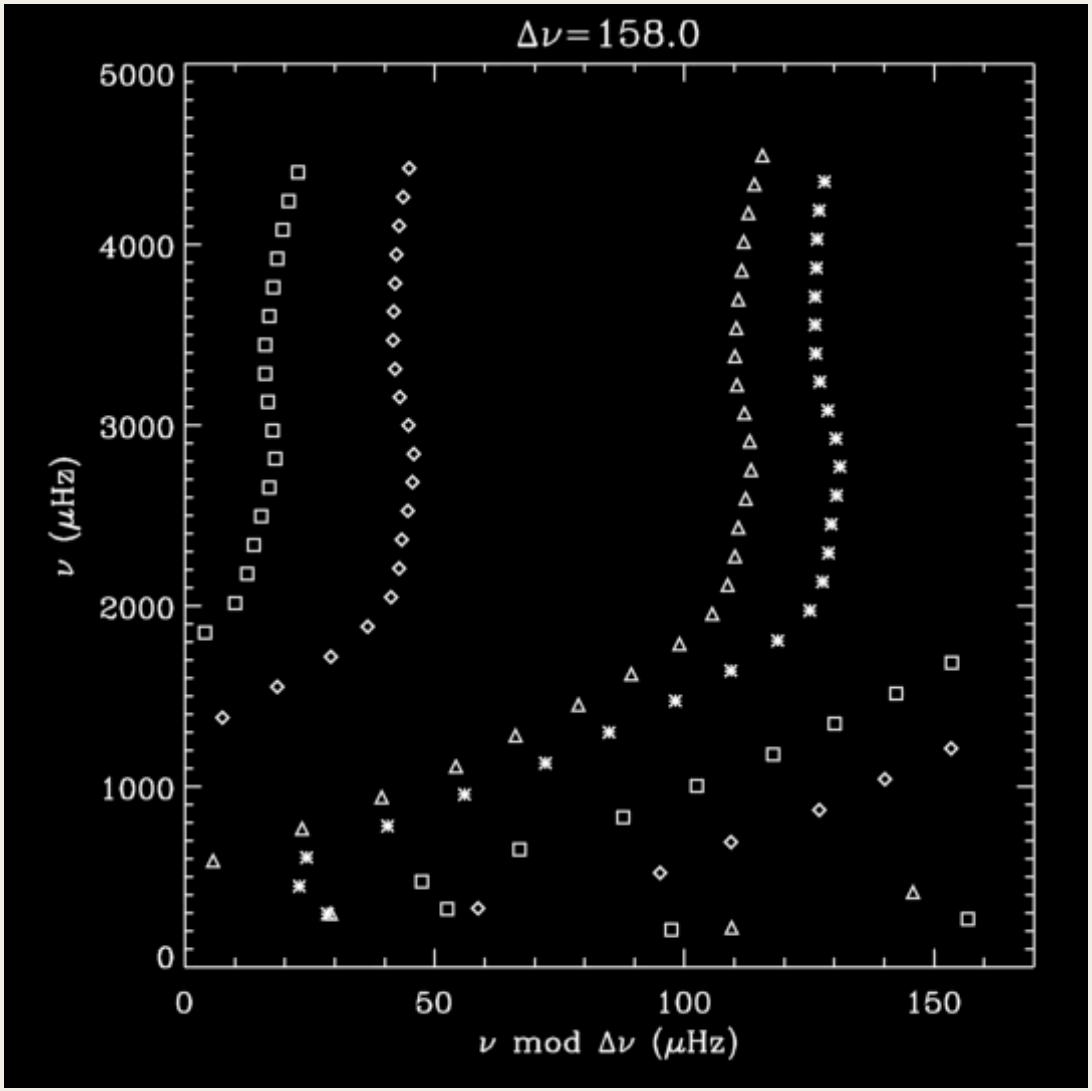
Mini-Lab: Calculate freqs. using ASTERO

- Do a partial update to the 4329 release of the ASTERO module:

```
cd $MESA_DIR
mv astero astero.old
svn update -r 4329 astero
```

- Download & unpack `townsend-II.zip` from the MESA Forum
  - Home › FAQ & tutorials › MESA summer school activities › Asteroseismology › Zipped Version of Townsend II
- Change into `solar-pulse` subdirectory
- Build using `./mk` (note how stuff from `mesa/astero/...` is pulled in)
- Run using `./rn`
- Frequency data written to screen and to files `freq-l0.dat`, `freq-l1.dat`, ...
- Have a look at the `inlist_pulse_controls` and `src/run_star_extras.f` to see how it all works

Here's One I Made Earlier...

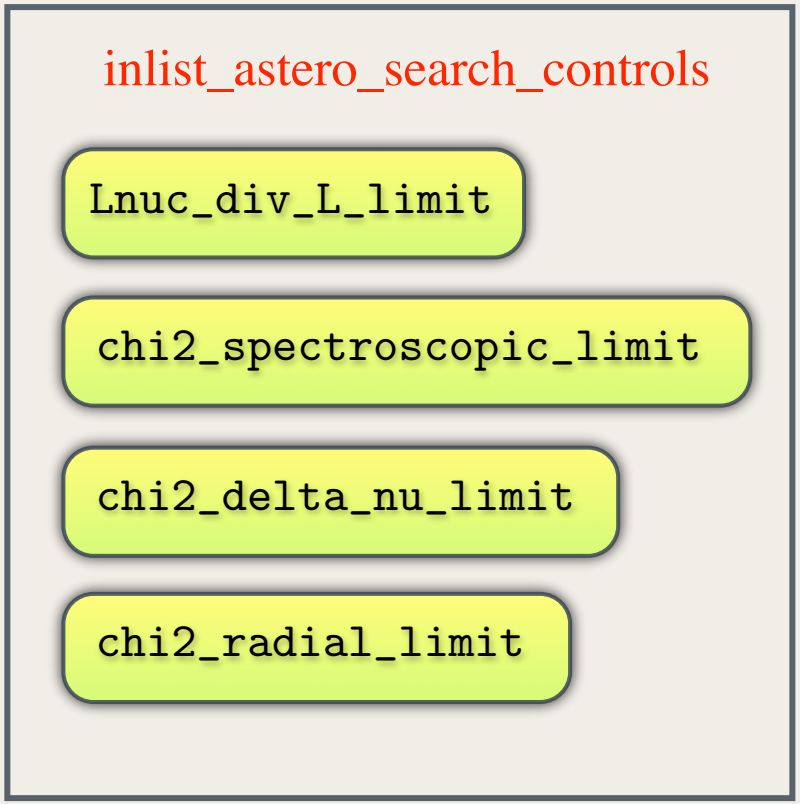


Optimization using ASTERO

- Inputs
  - Spectroscopic search region (Teff, logg, etc, plus errors)
  - Observed frequencies for $\ell = 0...3$ modes
- Outputs
  - Stellar parameters $(M, f_{\rm over}$, etc.) which minimize $\chi^2 = \chi^2_{\rm seismic} + \chi^2_{\rm spectral}$
- Search strategies
  - `use_first_values`
    - use fixed stellar parameters
    - evolve to minimize χ^2
  - `scan_grid`
    - scan over grid of parameter combinations
    - for each combination, evolve to minimize χ^2
    - determine combination with smallest χ^2
  - `hooke`, `bobyqa`
    - adaptively search for best parameter combination
- ADIPLS execution filters give big efficiency boost

Filters

- Very expensive to run ADIPLS at every timestep
- Filtering strategy used to decide whether to invoke ADIPLS
- Decision tree:
  - Has the star reached the main sequence?
  - Is χ^2_{spectro} small enough?
  - Is $\Delta\nu$ close enough to $\Delta\nu_{\text{obs}}$?
  - Is χ^2_{radial} small enough?



Lab Parameter Choices

first_mass

first_f_ov	1.2909	1.3009	1.3109	1.3209	1.3309
0.013	214.0 Cantiello	209.1 209.2	198.8 198.9	36.8 26.9	244.7 (segfault) 250.0 (259.3)
0.014	238.7 238.7	225.6 225.3 (224.8)	198.5 (197.5) 198.4	30.4 (50.3) 79.4 (71.2)	261.7 (236.0) 244.3 (242.9)
0.015	225.7 198.2, 225.7 (272.6)	Sukhbold 4.22 222.7	6.30 (8.89) 6.44	250.1 (250.7)	*failed* 219.1
0.016	182 183.4	160.9 (100.2) 103.7 (131.6, 54.6)	219.6 (221.2) 218.1 (219.2)	258.7 (240.4) 300.1	273.2 Pan(failed) 225.2
0.017	219.1 130.7 (malloc err, 210.5)	Luan 85.1	235 233.3	226.1 (232.4) 226.1	235.6

New Plan: run with original first_mass and first_f_ov (as in zip file) and OMP_NUM_THREADS of your choice

What Bill Said

- Run with original parameters
- Re-run with:
  - mesh_delta_coeff = 0.375 (inlist_3)
  - max_yrs_dt_when_cold = .75D7 (inlist_astero_search_controls)
  - max_yrs_dt_when_warm = .75D6 (inlist_astero_search_controls)
  - max_yrs_dt_when_hot = .75D5 (inlist_astero_search_controls)
- Write down your results somewhere
- Post results to a new thread in the forum that Max has started. Note computer type, OMP_NUM_THREADS, SDK/not SDK.