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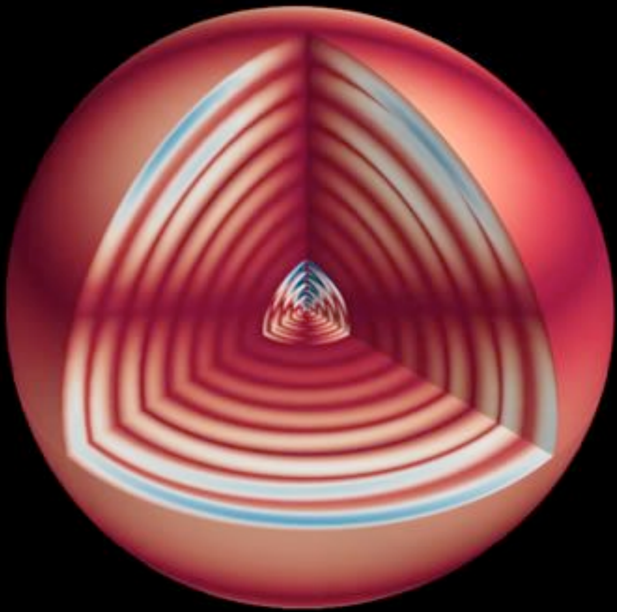
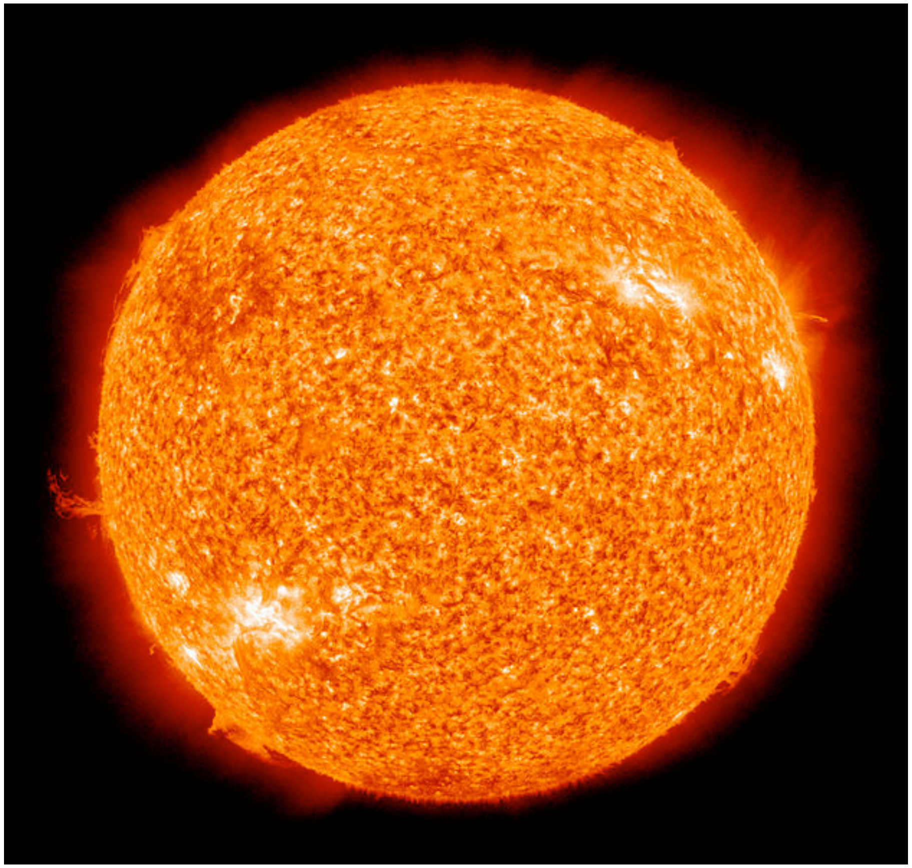


Computational Asteroseismology with MESA

The Basics: What is a Star?

- Gas held together by its own gravity.
- Temperatures and densities high enough to sustain nuclear fusion.
  - H -> He (Main Sequence)
  - Post-Main Sequence
- Radiate energy via convection, radiative diffusion, or conduction.



What Physics Governs a Star?

- Conservation of mass
- Gravity (Poisson's Equation)
- Conservation of energy
- Energy transport
  - Convection, Conduction, Radiation
- Conservation of momentum
  - Hydrostatic Equilibrium

What is Asteroseismology?

- Asteroseismology is the study of stellar interiors by interpretation of how they pulsate.

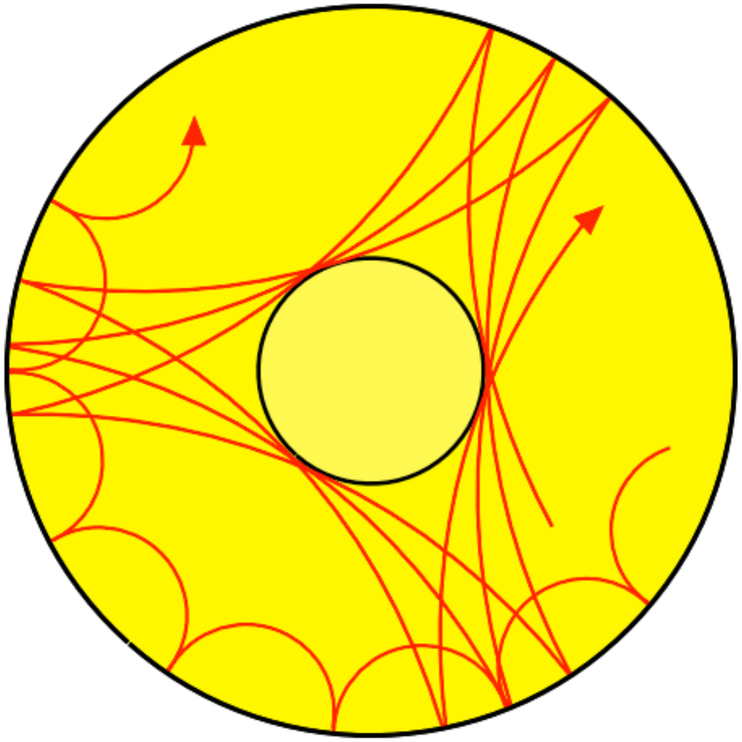
- “P-modes” are acoustic (sound) waves.
  - Pressure is the restoring force.

- “G-modes” are gravity waves
  - Gravity/buoyancy is the restoring force.

Asteroseismology

- Different acoustic modes penetrate to different depths of a star.

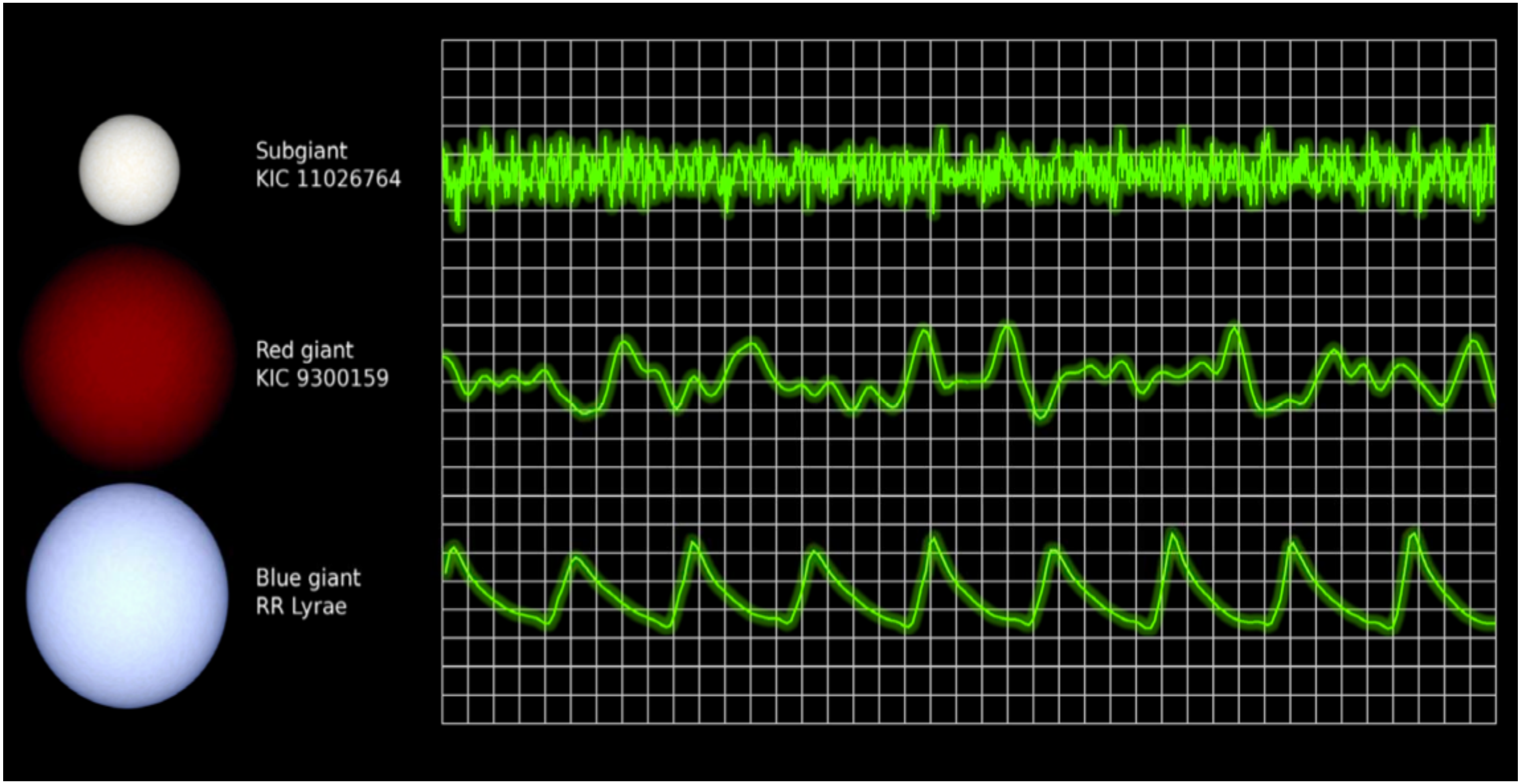
- This tells about the sound speed which tells about the composition and temperature!



Kepler

- Space telescope launched 3/7/2009 with the objective of finding earth-like planets within the habitable zone of their stars.
- Yielding light-curves (brightness vs. time) unprecedented in precision.
- Provides great tool for asteroseismology!

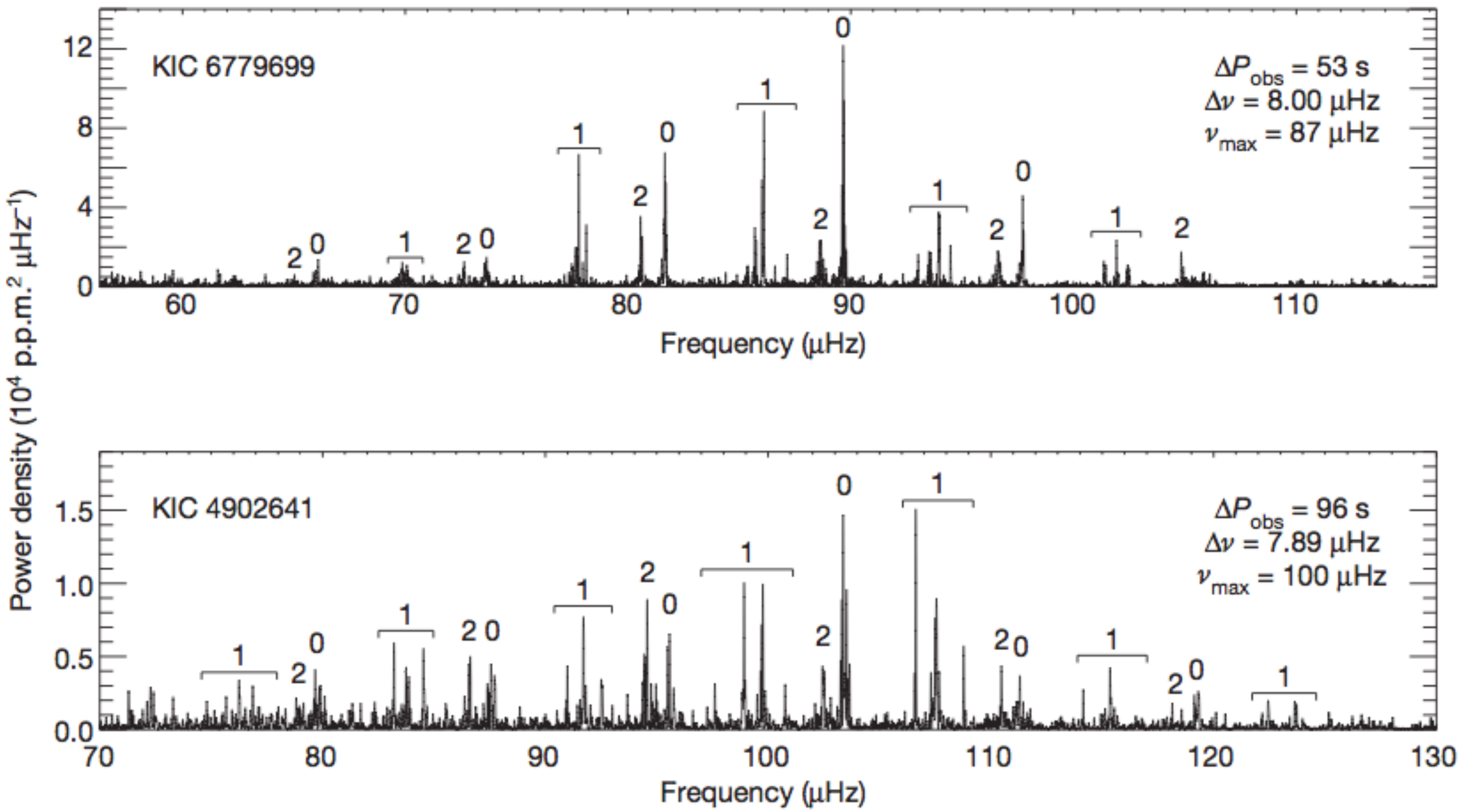
Typical Light-curves of Pulsating Stars



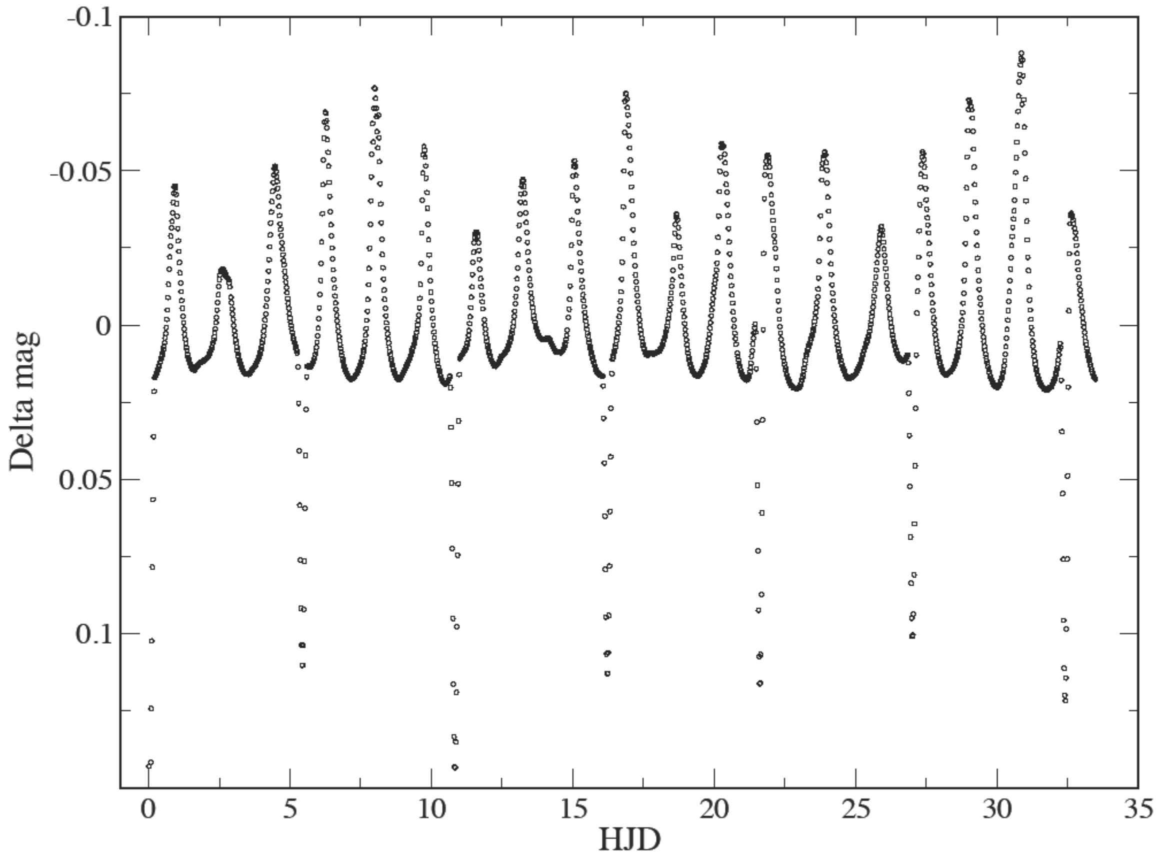
Recent Results

- Recent observations done with Kepler were able to distinguish a helium burning vs. hydrogen-shell burning red giant!
- This was done by analyzing the frequencies of their g-modes (gravity waves).

Recent Results (Cont.)



Recent Results (Cont.)



Sample data from the first 34 days of Kepler data collection. This is the slowly pulsating B-star, KIC-11285625, which shows both multiple period pulsations, as well as primary and secondary eclipses (Gilliland et al., 2010)

Computational Asteroseismology: Why?

- Kepler is providing accuracy greater than agreement between current stellar modeling codes (< 0.1%)!
- A broad goal of asteroseismology is to be able to reverse engineer a star based on its observed oscillation frequencies
  - Need a large number of accurate stellar models to compare observed frequency spectrum to

What is MESA?

- One dimensional stellar evolution code.

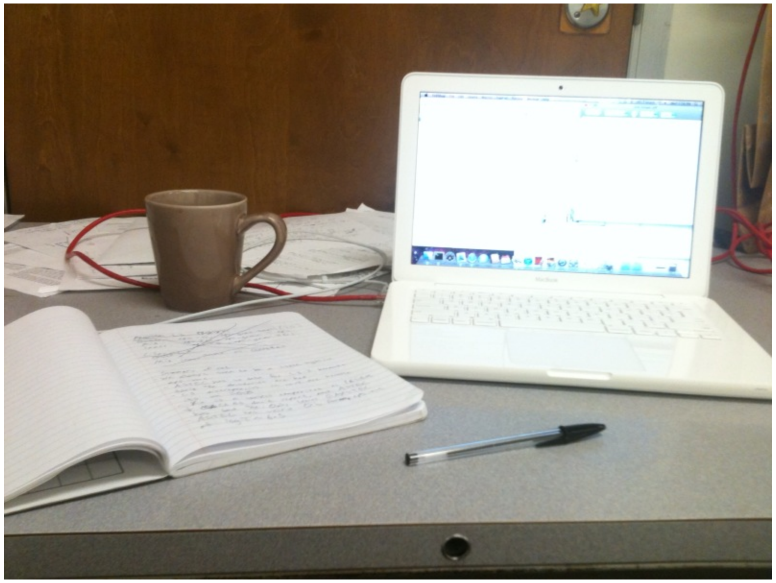
- Contains independent modules for different physical processes.
  - Equation of state, opacities, nuclear reaction rates, etc.

- Can simulate the evolution of a wide variety of stars.
  - Running a model takes 3 minutes to several hours, depending on evolutionary stage.

What I Did

- Compare output of stellar evolution codes to see if MESA agrees.
  - Run models, compare internal modules independently, etc.

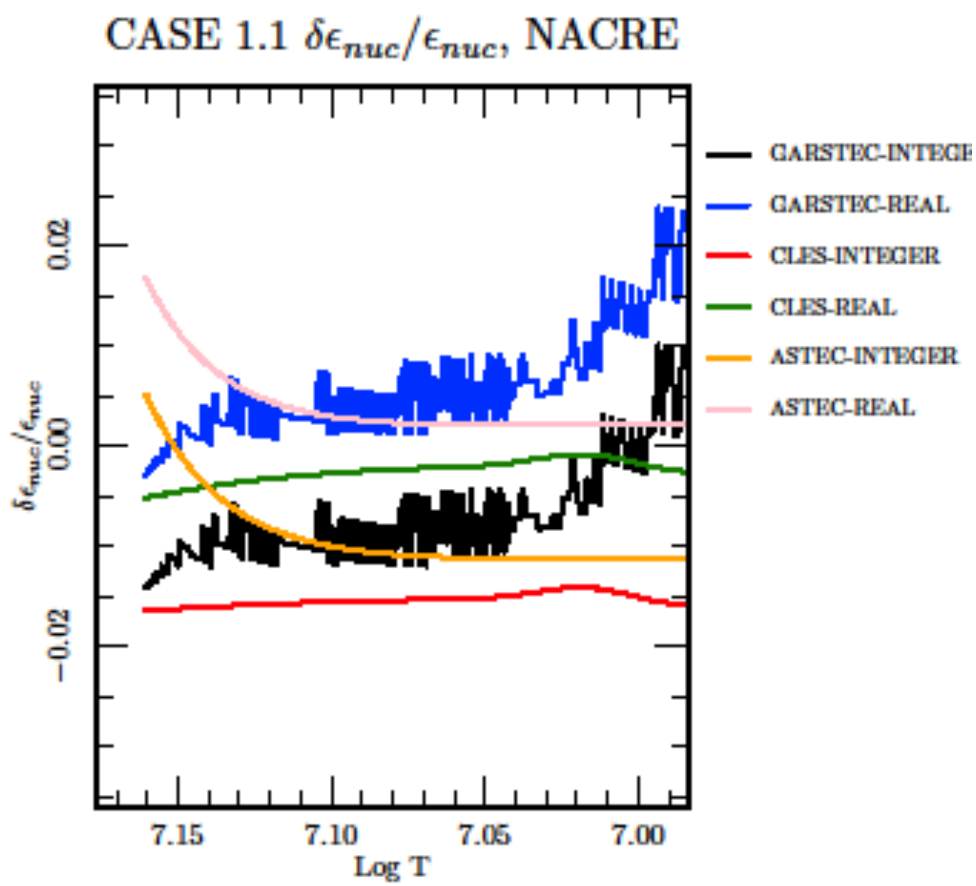
- Compare oscillation frequencies of different codes vs. MESA's pulse Module (in progress!)



"The Lab"

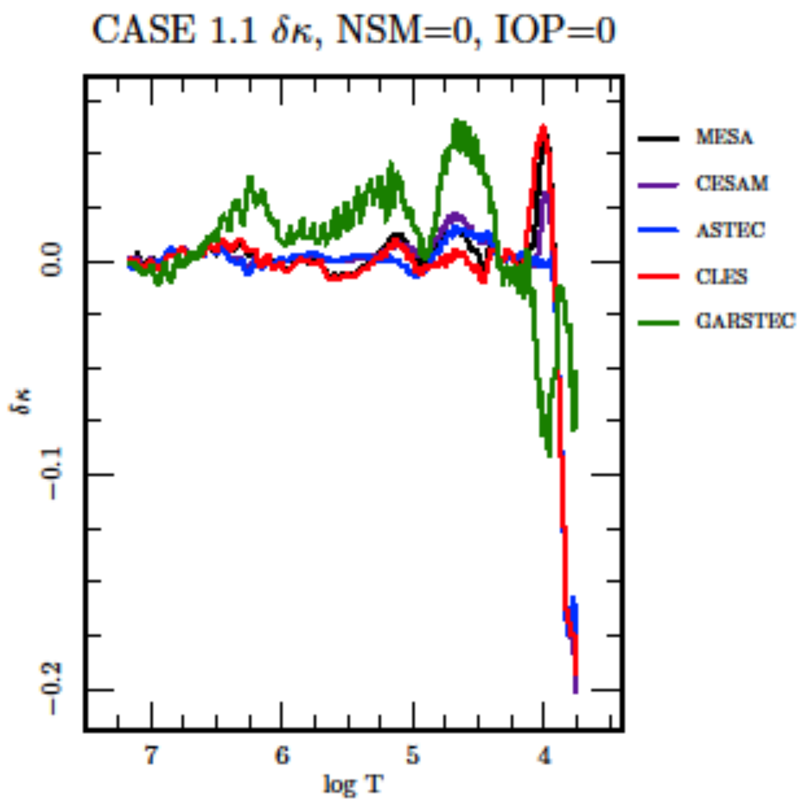
Improvements to MESA: Nuclear Reaction Rates

We found that using real atomic weights instead of integer values for atomic weights results in a difference of ~1% for nuclear energy generation rates.



Improvements to MESA: Opacity tables

We have found that increasing the resolution of pre-computed opacity tables greatly improves ~1% differences in global properties such as luminosity and temperature.



Future Work

- See how differences in MESA output manifest as differences in stellar oscillation frequencies.