Research Projects for Spring 2013:

Exploring the Physics of the Universe with White Dwarf Stars

Senior personnel: D. E. Winget, M. H. Montgomery

Grad students: Ross Falcon, JJ Hermes, Samuel Harrold, Keaton Bell, Thomas Gomez

Undergrads: Alex, Arina, John, Kevin, Luis, Miquela, Sara, Travis

McDonald Observatory
THE UNIVERSITY OF TEXAS AT AUSTIN

Texas Cosmology Center

FRESHMAN RESEARCH INITIATIVE
THE UNIVERSITY OF TEXAS AT AUSTIN

Information on Summer FRI Fellowships

- http://fri.cns.utexas.edu/student-resources/fellowships
- Deadline for application is March 25th
- List your RE (Mike Montgomery) for your letter of reference
- Students in our group usually have half-time awards, which are $1250 for the Summer
- You don't have to have a fellowship to work with us during the Summer, but this is the way to get paid to do it!

Fellowships

Summer 2013

College of Natural Sciences undergraduate researchers and Freshman Research Initiative students and alumni are eligible for stipend support to allow them to work full or part time in a research group in the summer. Current FRI students (in their first summer at UT Austin) will be funded to work in their FRI Stream. FRI alumni and non-FRI students can be funded to work in another research group on the UT campus. NOTE: Students must be US Citizens or permanent resident aliens to be eligible for this funding.

Full-time fellowships require 35-40 hours per week for at least 8 weeks and come with a stipend of $2500.

Half-time fellowships require either:

1. 18-20 hours per week for the full eight weeks, or
2. 35-40 hours per week for 4 weeks.

Half-time fellowships carry a stipend of $1250.

The type of fellowship and exact dates and hours committed to research each week are stream dependent and will be arranged with your research mentor.

The deadline for 2013 Fellowships is March 25.

Important:

1. If you are a current FRI student, please select your current Research Educator as your reference. There is no need to request an external reference.
2. If you are an FRI alum or non-FRI student you must request an external reference. The CNS scholarship system will allow you to send a request to your listed reference before submission of your complete application. BE SURE TO DO THIS. The 2013 external reference deadline is March 25th, so be sure to give your references plenty of advanced warning. If you wait until the deadline for your portion of the application, your reference will not have any time to complete theirs.

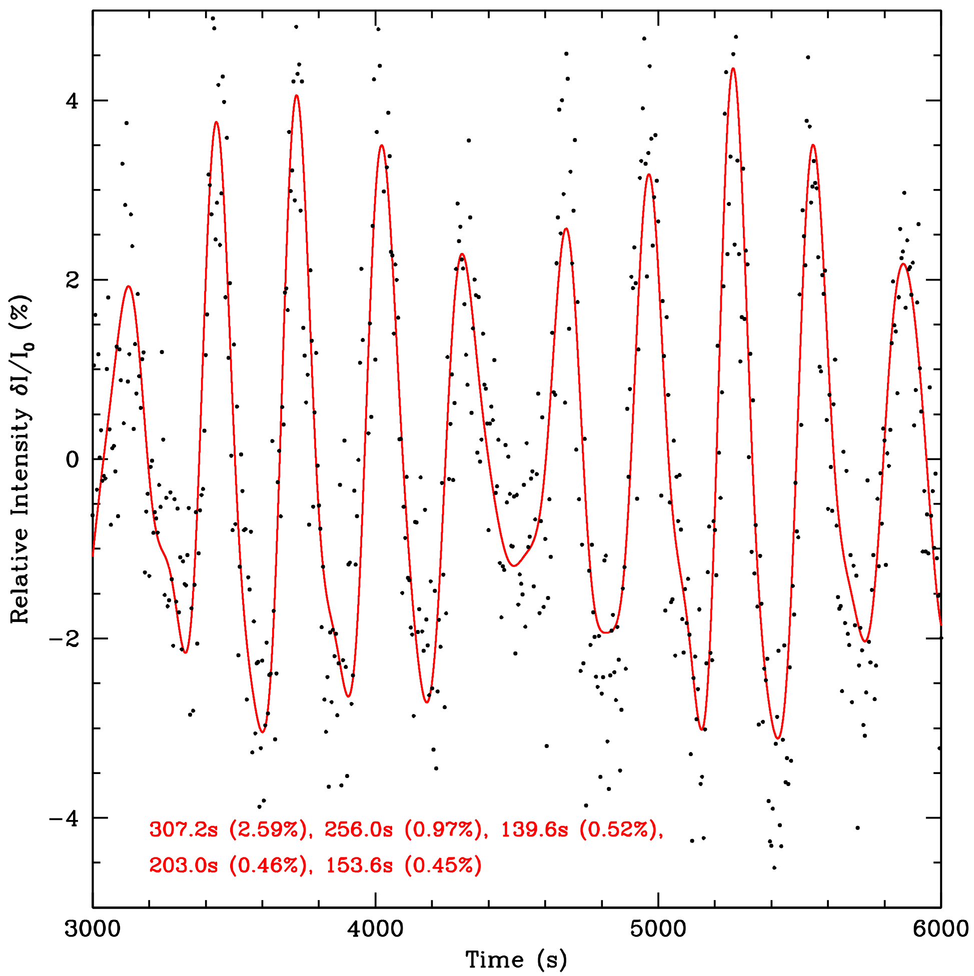
How to apply for projects

- send an email to mikemon@astro.as.utexas.edu
- List your top 3 choices for projects
- List times during the week that you are available to work on projects. The more flexible you are, the easier it is us to place you with other students

The UT/McDonald White Dwarf Planet Search

- Observations since at least 2003
  - Two stars since the 1970s
- Monitor pulse arrival times for about a dozen DAVs (hydrogen-atmosphere WDs)
  - Similar to the pulsar timing method
- > 95% of all stars in our Galaxy (including our Sun) will be DAVs
- Pulsation periods 100-500 s
  - We expect the period change in these pulsations to be very slow ($< 1\ \mu s\ yr^{-1}$)
  - After 9 years we are sensitive to Jupiter-mass planets from 2-10 AU

GD 244, typical DAV in our sample

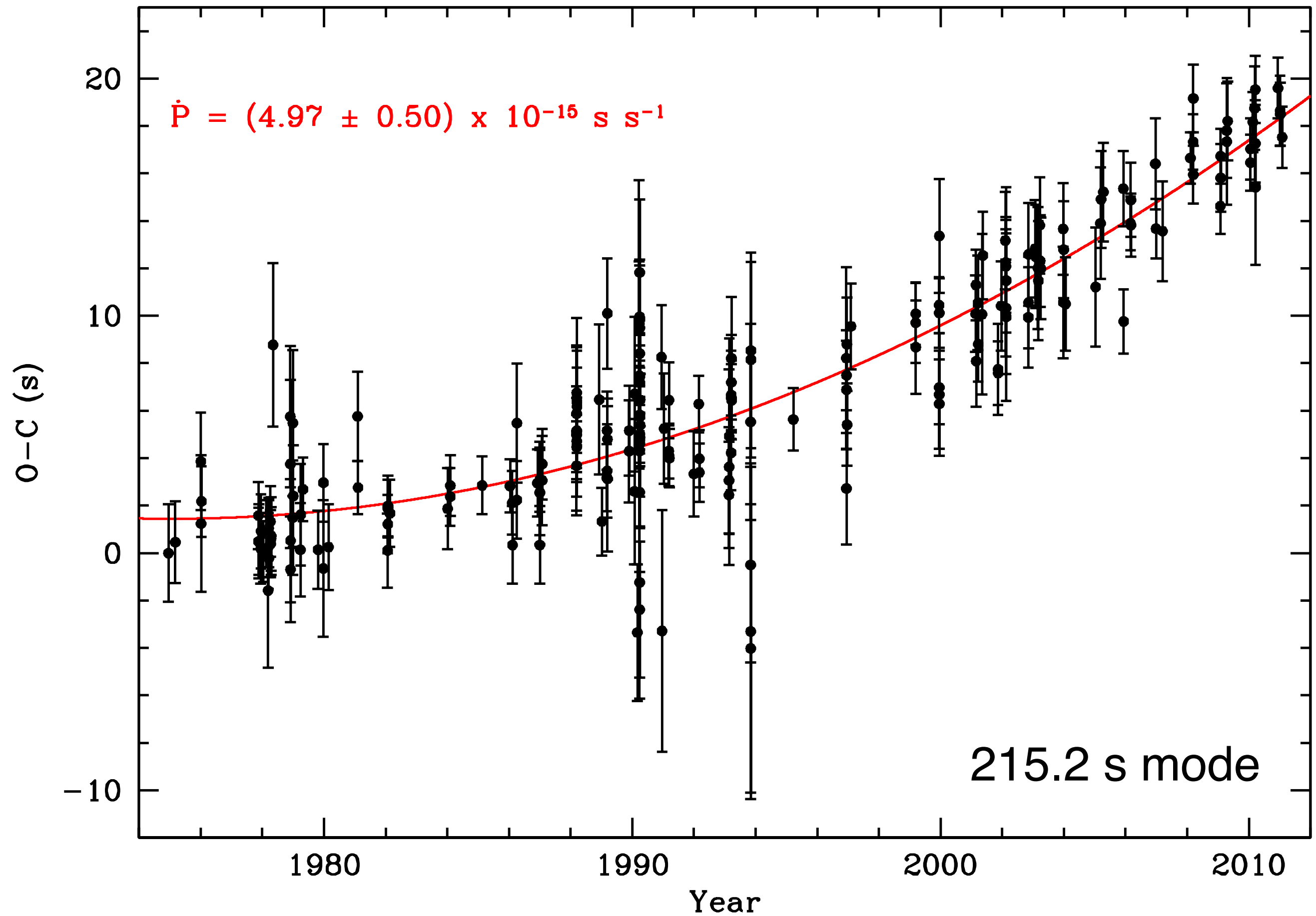


JJ Hermes, UT-Austin, 221st AAS

Mullally et al. 2008, ApJ **676** 573

G117-B15A: An Extremely Stable Optical Clock

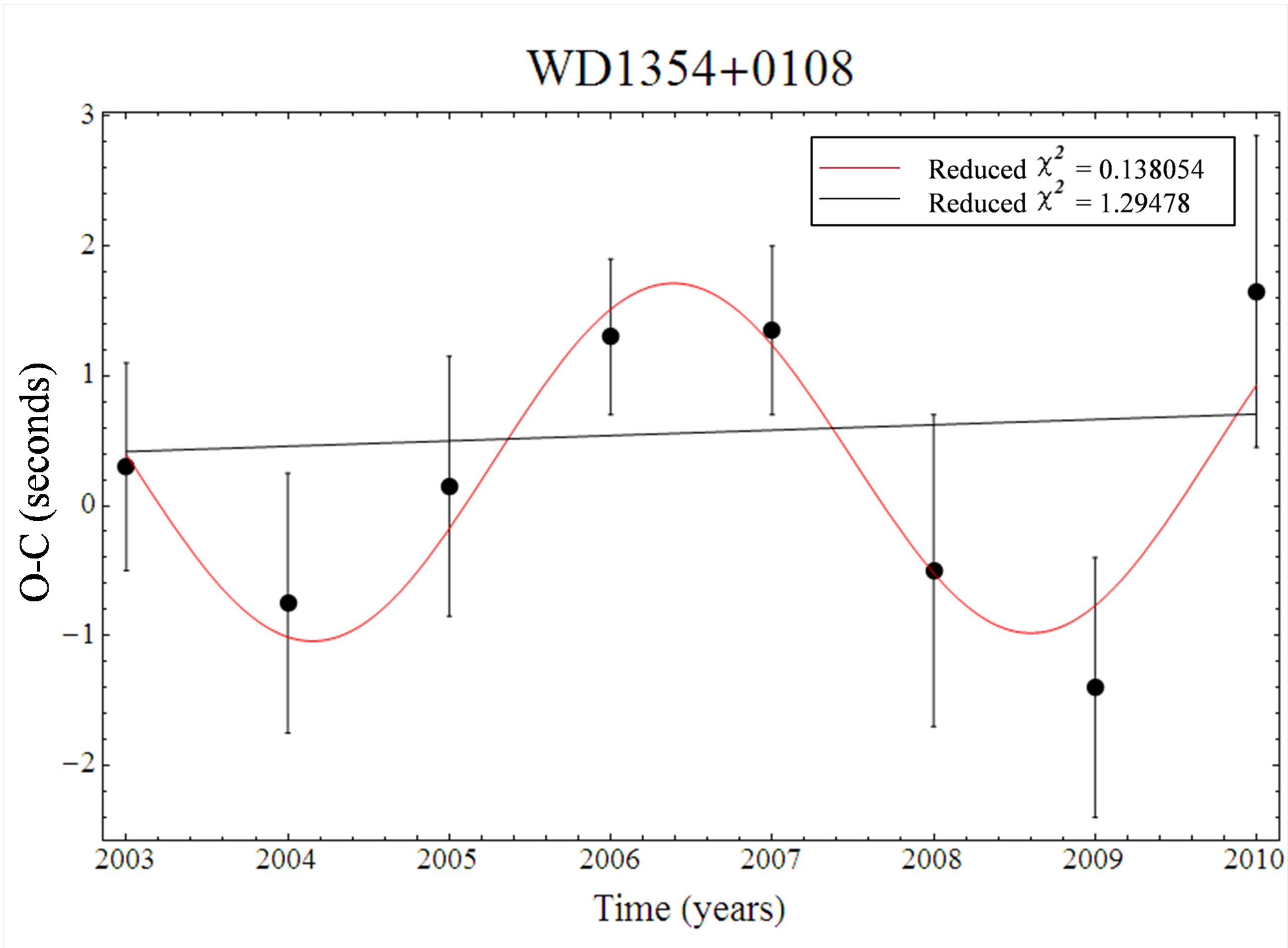
- Some DAVs have been observed for 35+ years, including G117-B15A
- The 215.2 s mode in that star produces an extremely stable rate of change of period with time
- This *dP/dt* is in line with expectations of cooling for this ~12,000 K WD
- The influence of a Jupiter-mass planet at 5 AU would cause an unmistakable 10 s peak-to-peak modulation in the (O-C) diagram



JJ Hermes, UT-Austin, 221st AAS

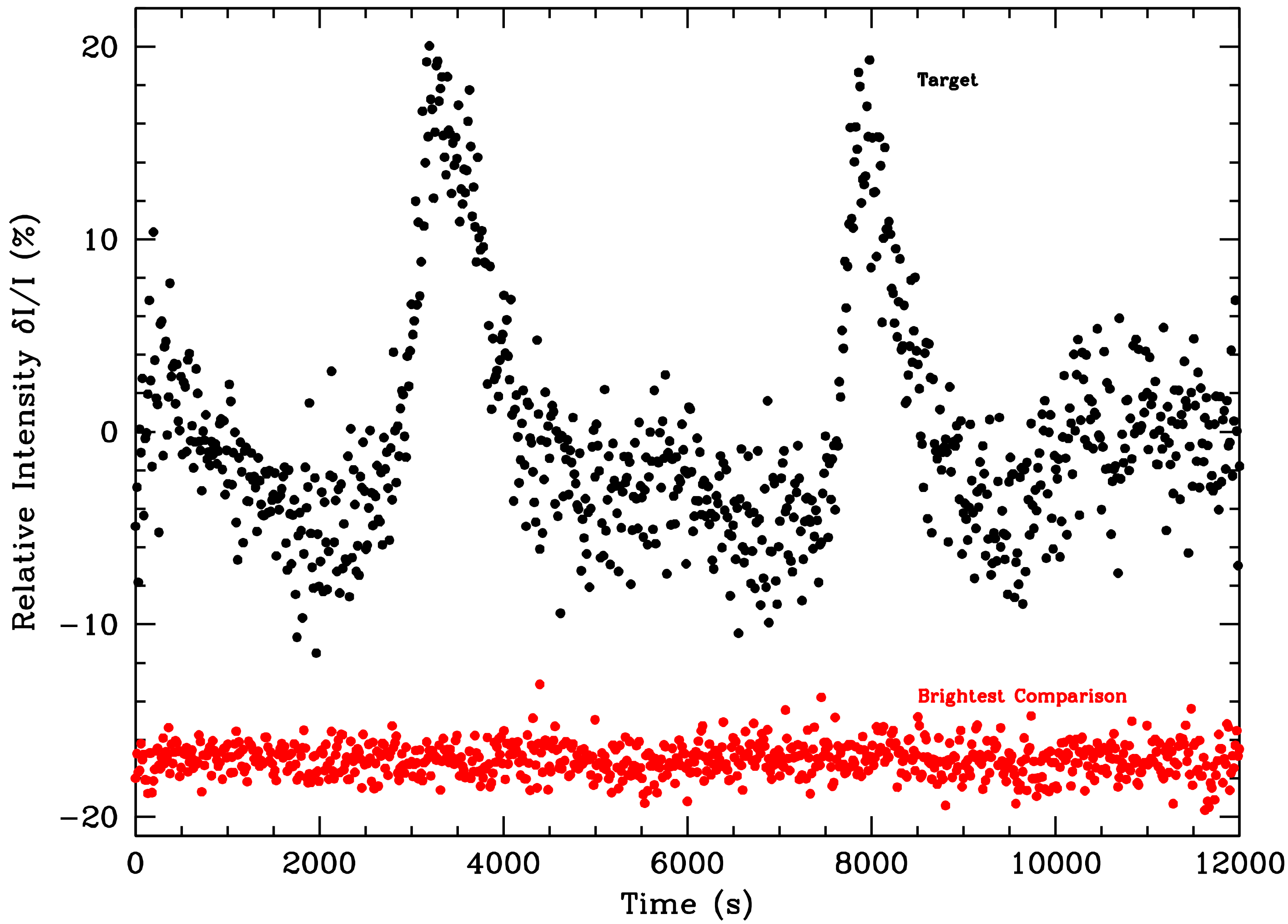
S.O. Kepler 2012, private communication

PG1354+0108: Our Current Best Planet Candidate



The O-C diagram for WD1354+0108, for which there is time series data dating back to 2003, shows preliminary evidence of the presence of a planet with an orbital period of about 5 years. We need a data point for 2013.

On Oct. 24th & 25th, 2011, JJ Hermes at McDonald Observatory found this star:



T_{eff} = 9140 +/- 170 K, log g = 6.16 +/- 0.06, M = 0.17 Msun – the first ELM pulsator!

Period > 4000 sec! Longest known period in a WD pulsator.

We want to find more of these objects!

MESA

Modules for Experiments in Stellar Astrophysics

THE UNIVERSITY OF TEXAS AT AUSTIN

McDonald Observatory
THE UNIVERSITY OF TEXAS AT AUSTIN

What is MESA?

- A description can be found at http://mesa.sourceforge.net
- MESA is an open source software package for doing stellar evolution
- Managed by Bill Paxton, with help from Lars Bildsten and the rest of the MESA users community
- It is designed to do all stages of stellar evolution using state-of-the-art methods and techniques

What is MESA?

- Two papers have come out describing MESA's capabilities:
  - Paper I: Paxton et al. (2011)
    http://adsabs.harvard.edu/abs/2011ApJS..192....3P
  - Paper II: Paxton et al. (2013) (submitted)
    http://adsabs.harvard.edu/abs/2013arXiv1301.0319P

What is MESA?

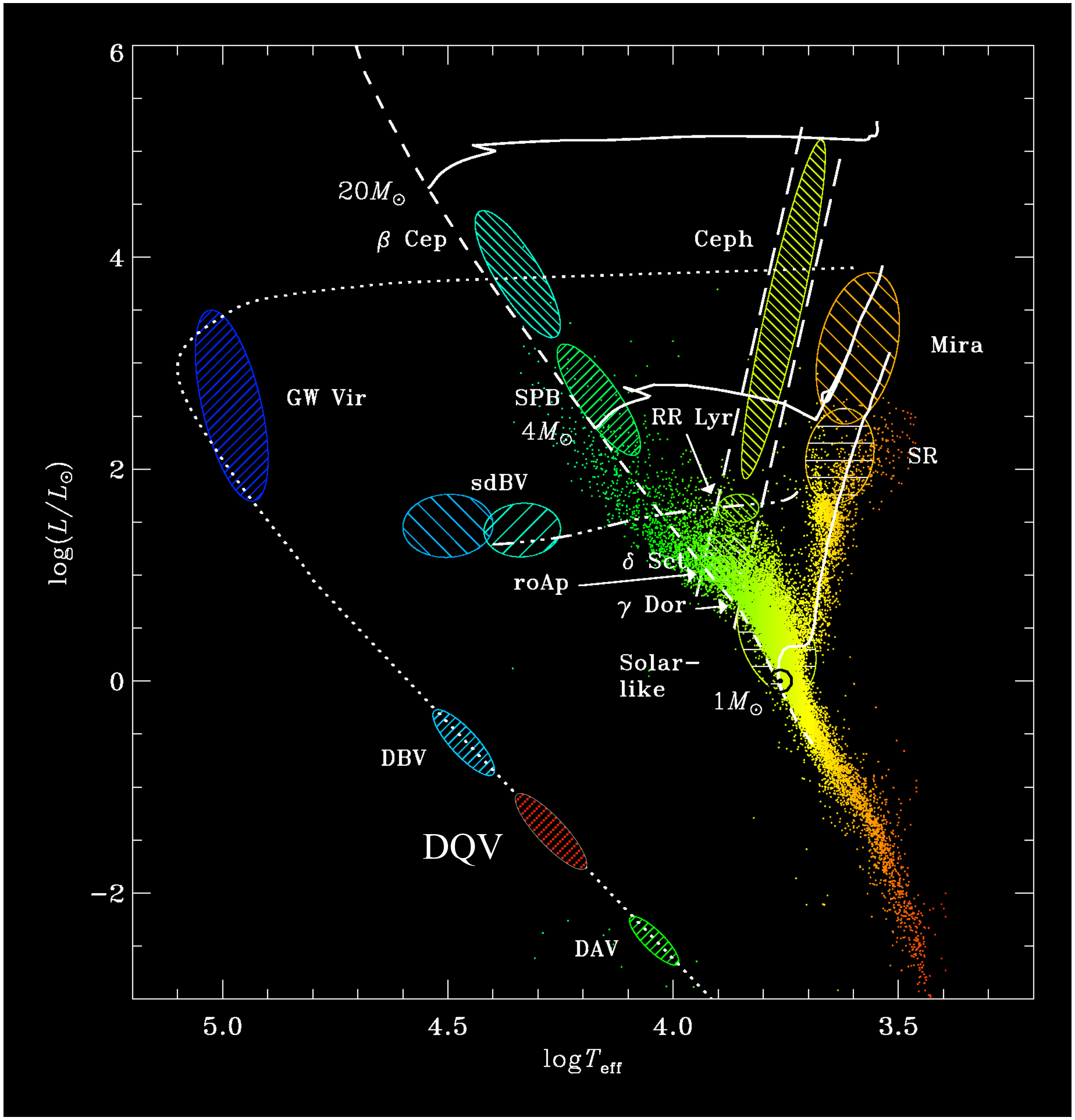
From Paper I:

“MESAstar solves the fully coupled structure and composition equations simultaneously. It uses adaptive mesh refinement and sophisticated timestep controls, and supports shared memory parallelism based on OpenMP. State-of-the-art modules provide equation of state, opacity, nuclear reaction rates, element diffusion data, and atmosphere boundary conditions. Each module is constructed as a separate Fortran 95 library with its own explicitly defined public interface to facilitate independent development.”

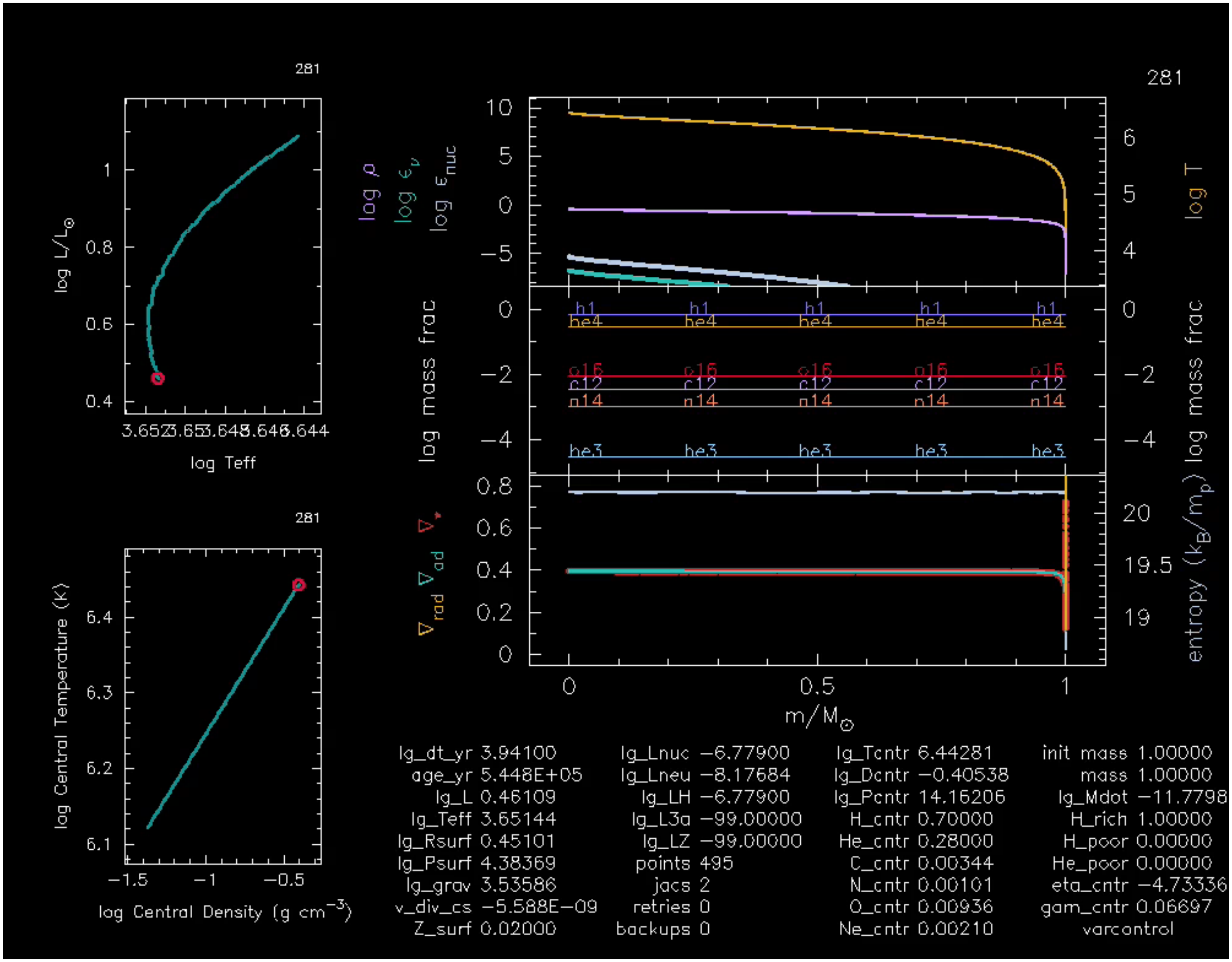
Why are we interested in MESA?

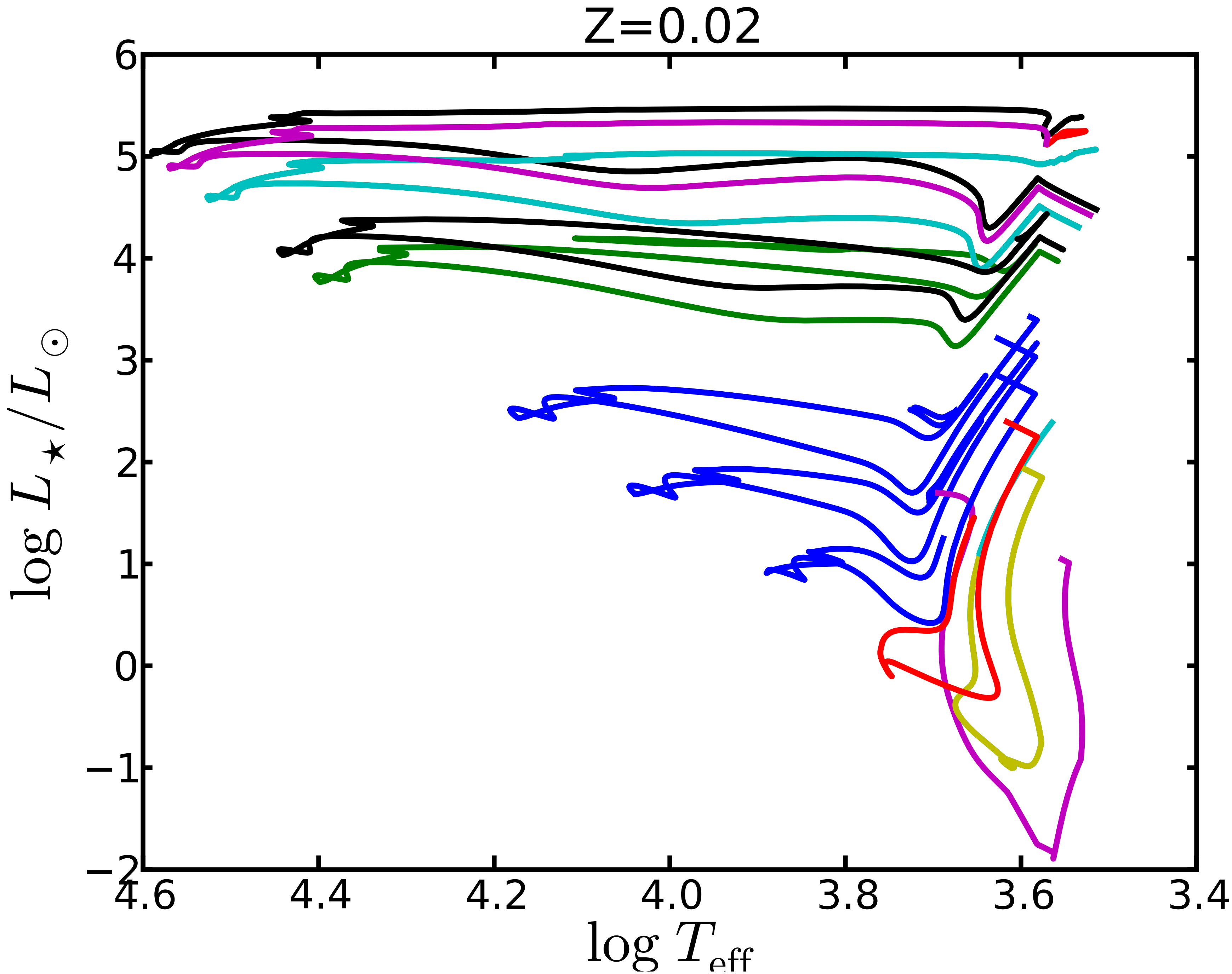
- Can make models prior to WD cooling track
- Time-dependent diffusion
- Non-grey atmospheres as boundary conditions
- Residual nuclear burning
- Complete set of possible chemical species
  - Can make models of ELM WDs
  - Can make models of O/Ne WDs
- Can do 1-D hydrodynamics (dynamical velocity fields)
- Can treat systems with accretion

There are pulsating stars *all over* the HR Diagram!

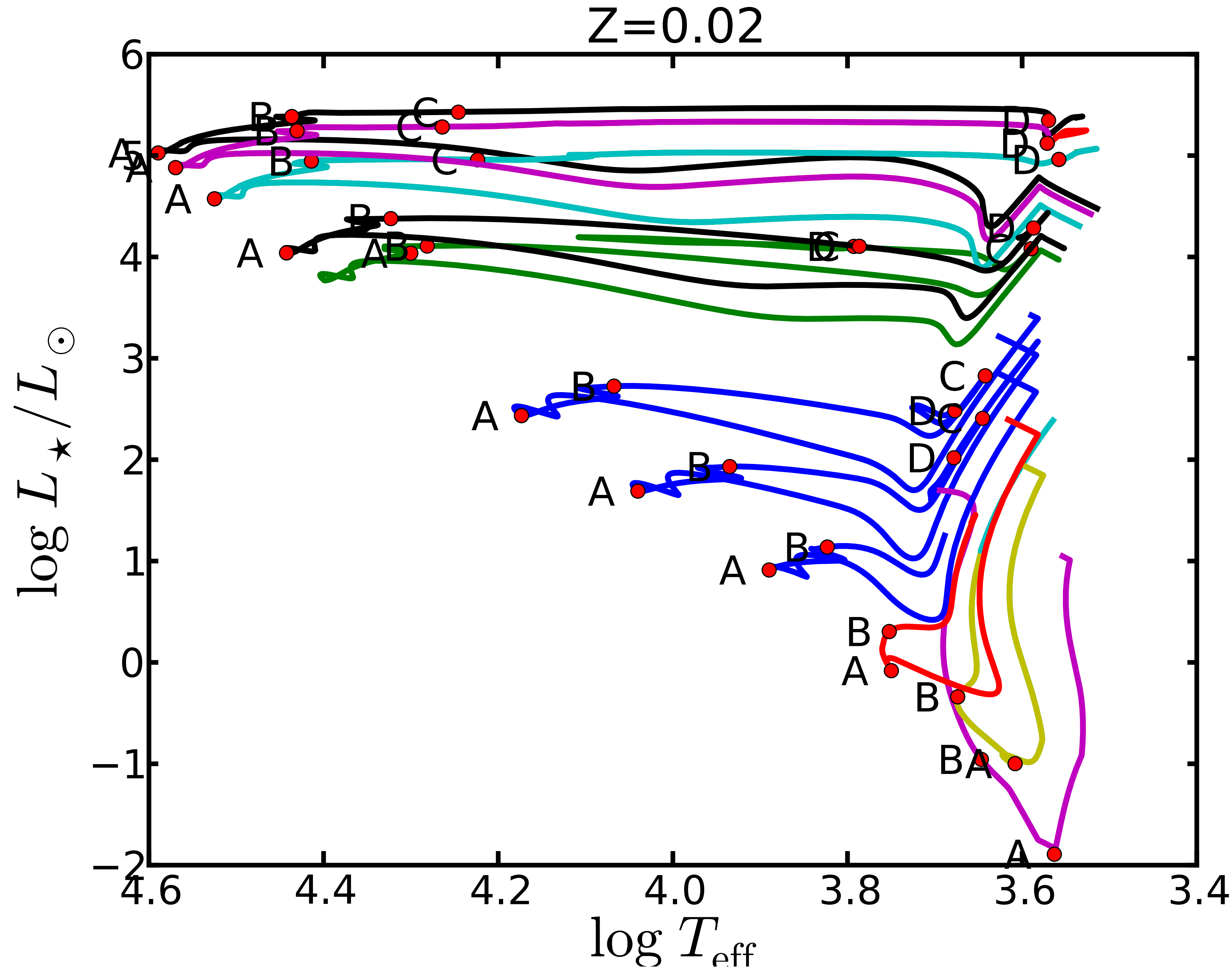


What can you do with MESA?





Z=0.02
6
5
4
3
2
1
0
−1
−2
4.6
4.4
4.2
4.0
3.8
3.6
3.4
$\log L_\star/L_\odot$
$\log T_{\rm eff}$



Z=0.02
log $L_\star/L_\odot$
log $T_{\rm eff}$
6
5
4
3
2
1
0
−1
−2
4.6
4.4
4.2
4.0
3.8
3.6
3.4

MESA Projects

- All WDs with masses $\gtrsim 1.1\ M_\odot$ are believed to have Oxygen/Neon cores instead of Carbon/Oxygen cores. Modern stellar evolution codes have great difficulty getting through the C-burning stage. MESA may be able to do this.
- We have recently discovered $\gtrsim 1.2\ M_\odot$ WD that pulsates, so these models will be directly relevant to it.

MESA Projects

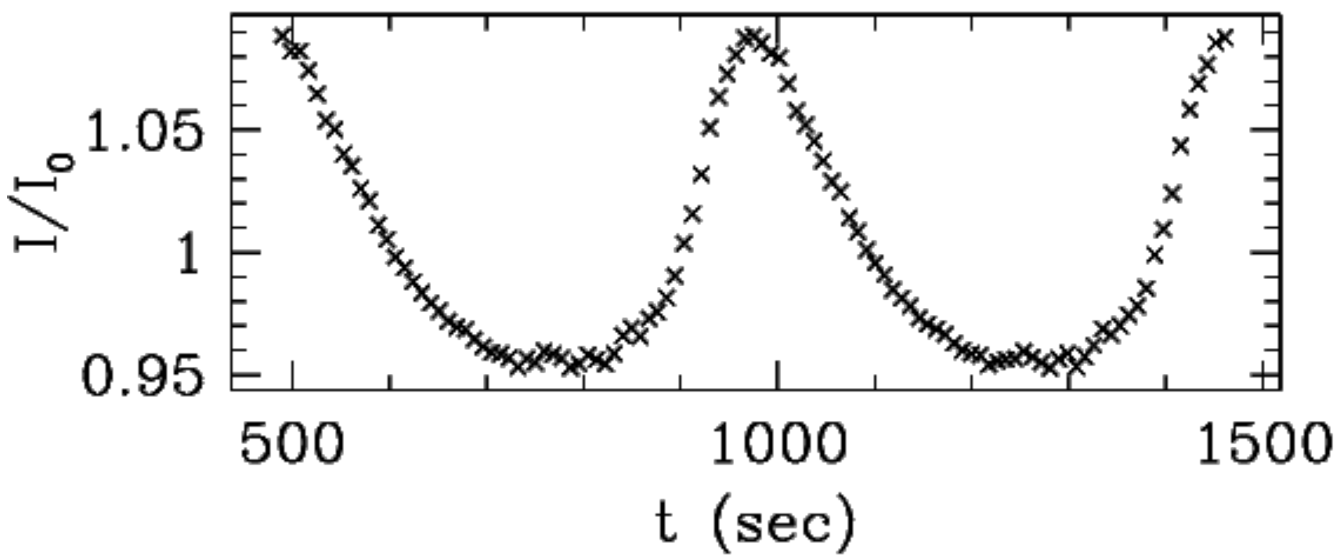
- JJ has discovered all 5 of the extremely low mass (ELM) WDs that pulsate. We would like to make models of these stars to better understand their possible evolutionary histories.
- Some WD pulsators are in accreting systems, and we would like to use MESA to study what happens to the pulsations as the WD heats up during an outburst and then cools over the next few years.

Stellar Convection/Nonlinear Light Curves

Convection is one of the largest sources of uncertainty in modeling of stars, yet it is common throughout the H-R diagram:

- cores of Main Sequence stars more massive than the Sun
- Stellar envelopes of MS stars < 2 $M_{\odot}$
- Red giant envelopes

Can we use the lightcurve shape itself to learn about these stars?

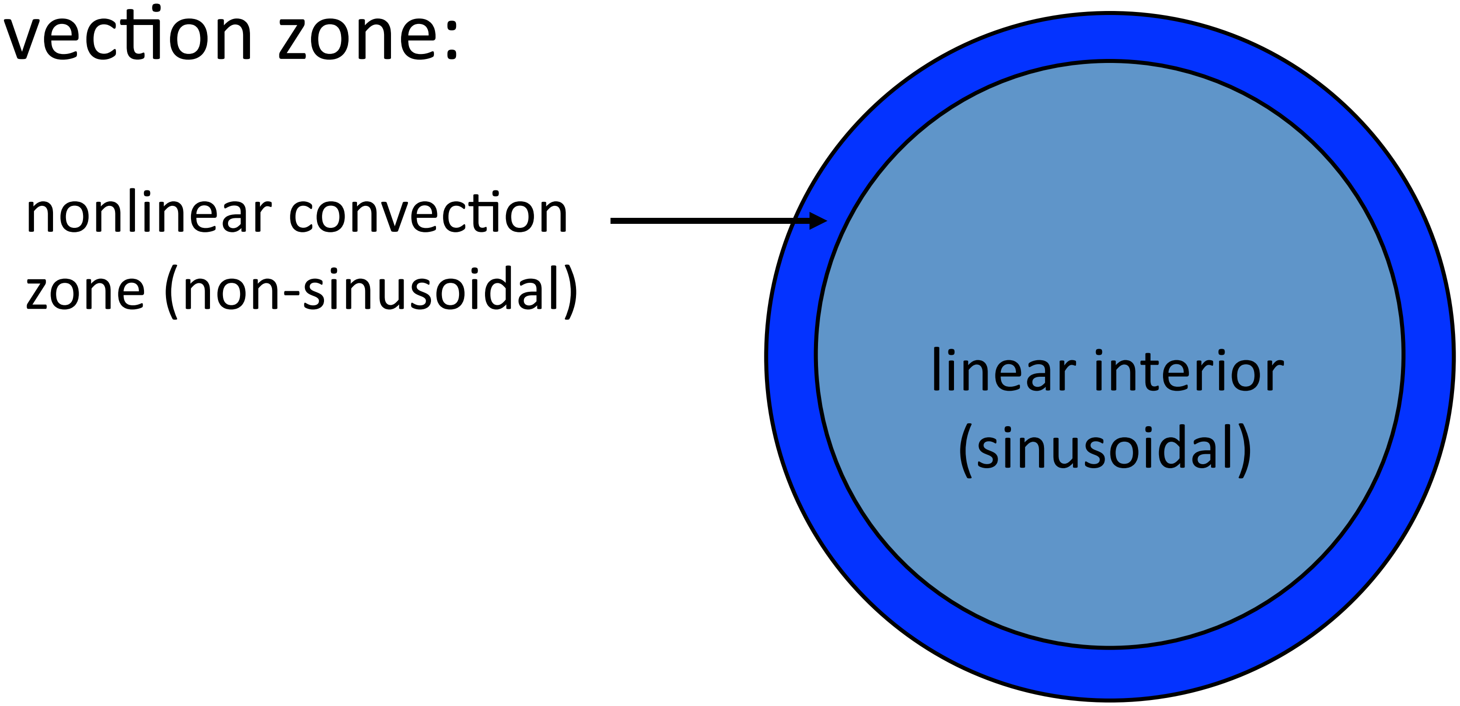


- Need a mechanism for producing non-linearities
  - convection zone is most likely candidate
  - can change thickness by $\sim$ 10 during pulsations

Hybrid Approach

(Montgomery 2005, ApJ, 633, 1142), based on work of Brickhill (1992), Wu & Goldreich (1998), and Ising & Koester (2001)

$\Rightarrow$ Assumes all the nonlinearity is caused by the convection zone:

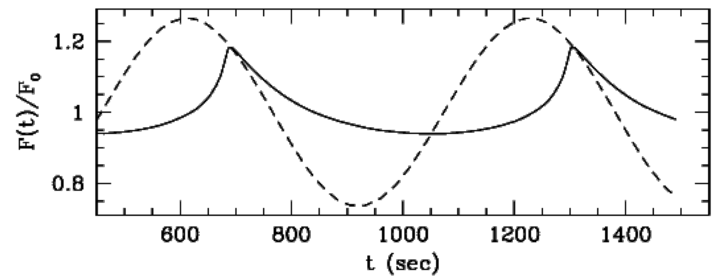


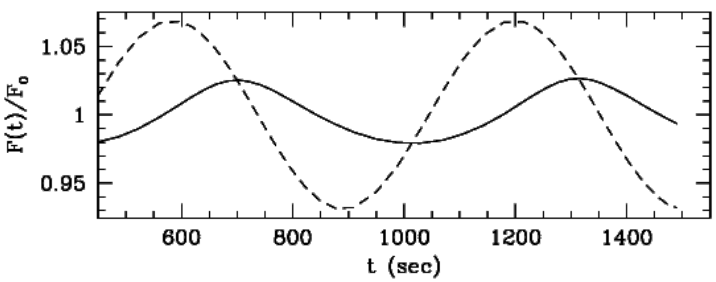
Non-radial Modes

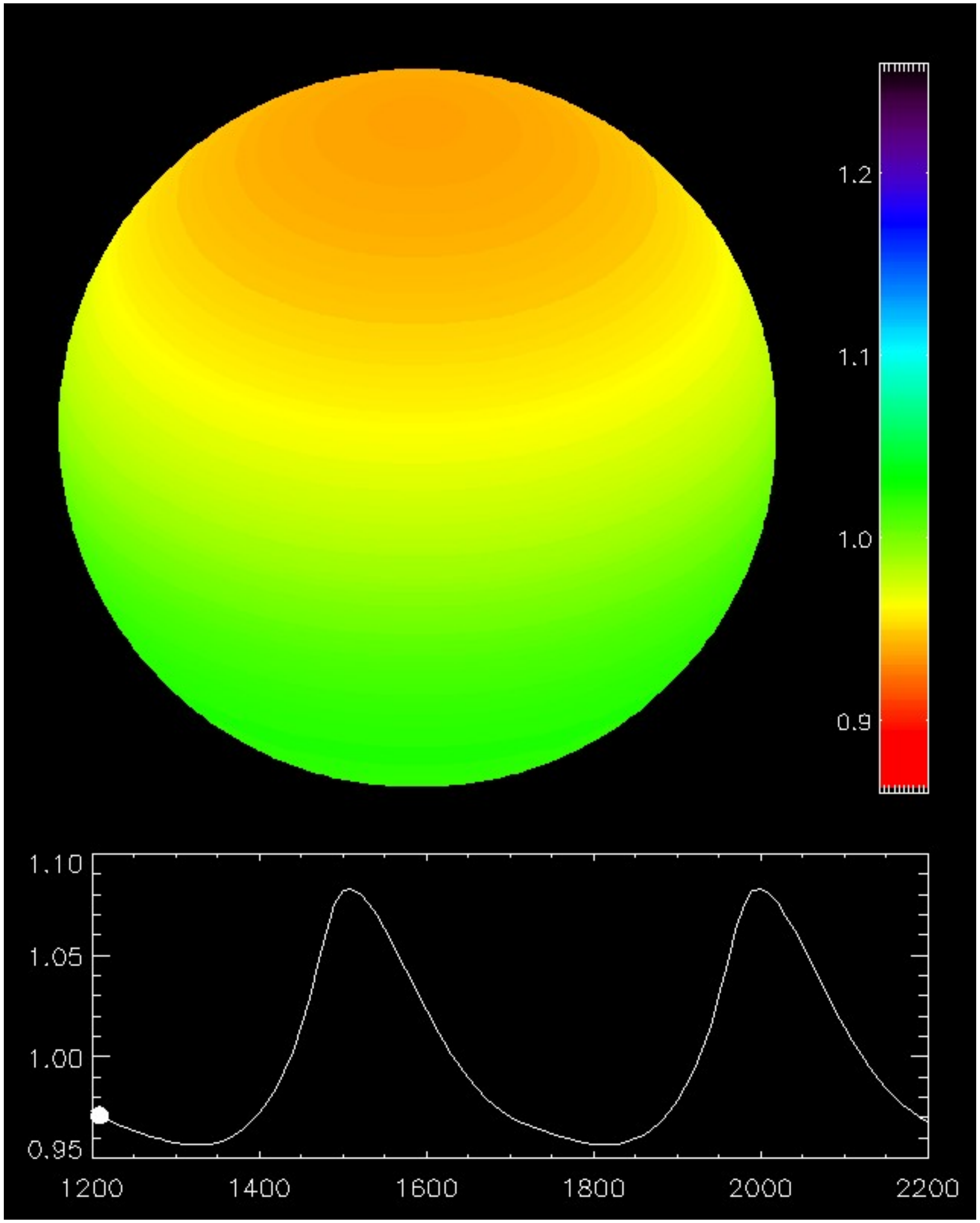
l=1,*m*=0

(traveling wave)

$$F_{\mathrm{b}} \propto \mathrm{Re}\{e^{i\omega t} Y_{11}\}$$





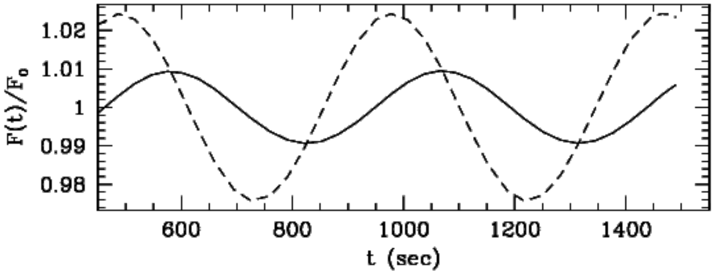


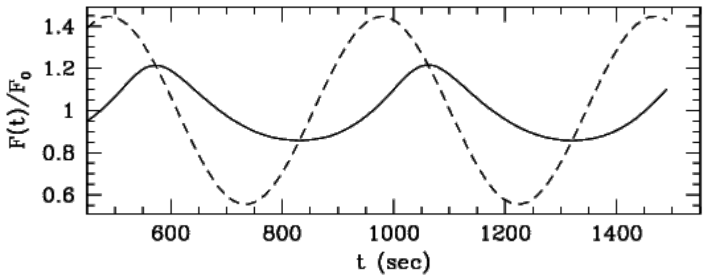
Non-radial Modes

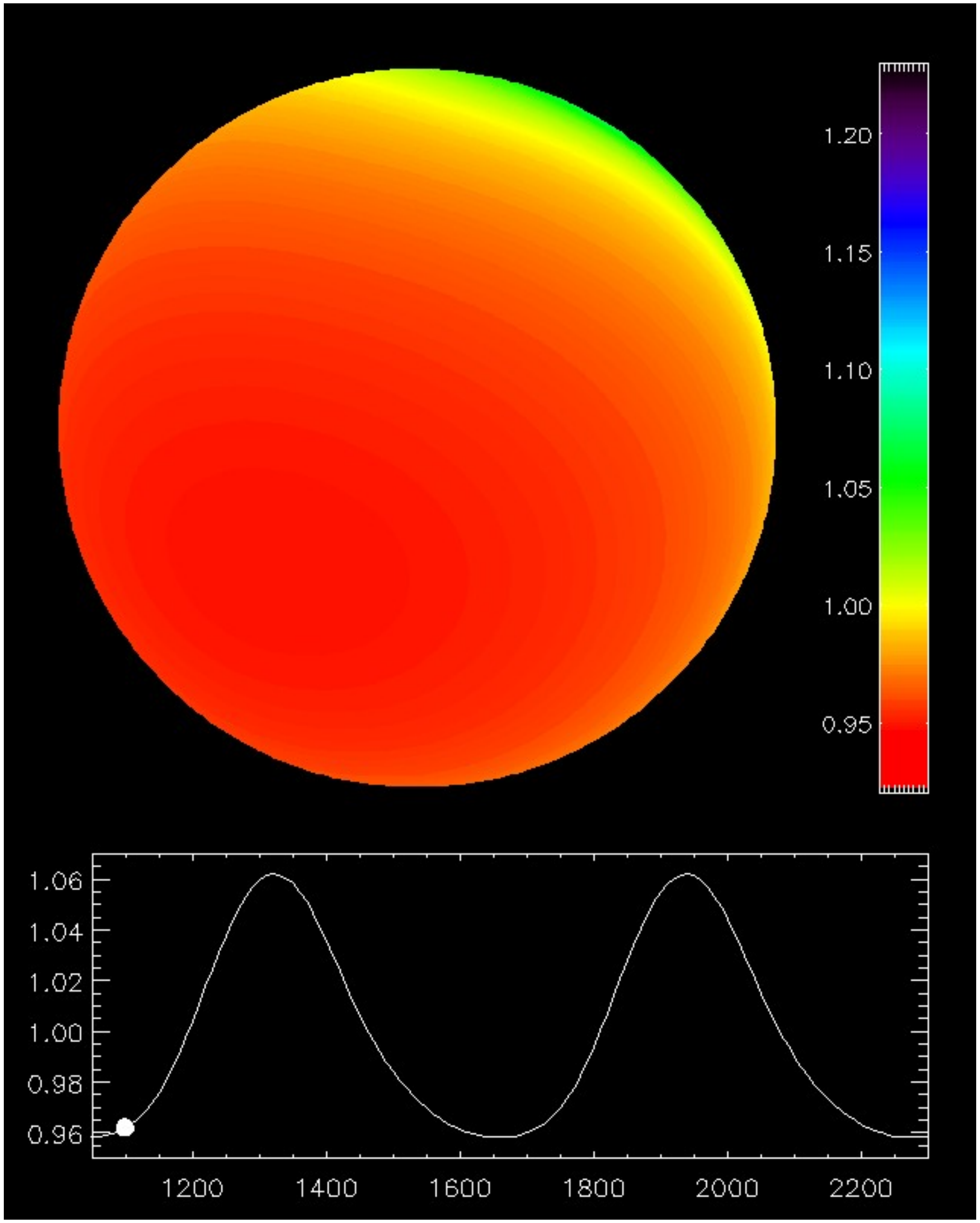
l=1,m=1

(standing wave)

$$F_{\mathrm{b}} \propto \mathrm{Re}\{e^{i\omega t}Y_{10}\}$$

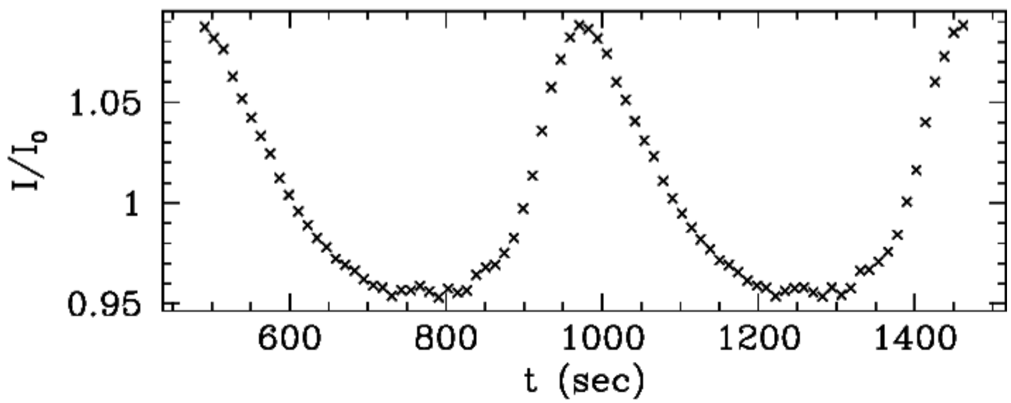




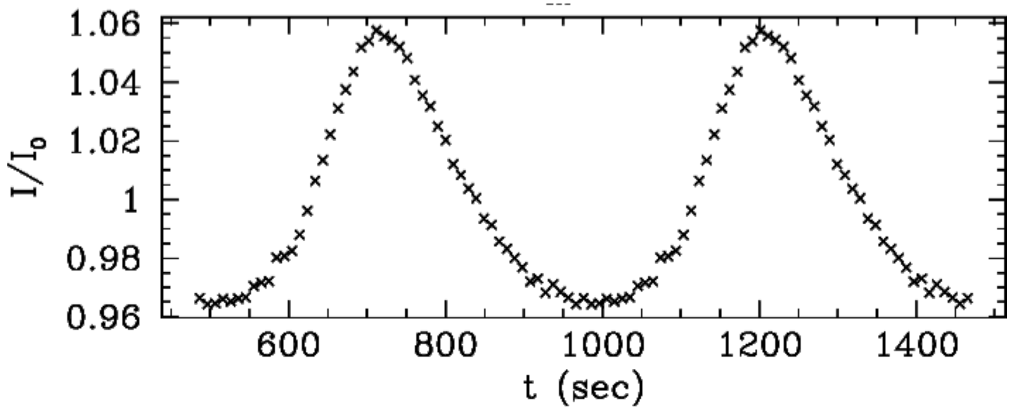


PG 1351+489 (DBV)

Whole Earth Telescope (WET) – 1995



Single site data – May 2004



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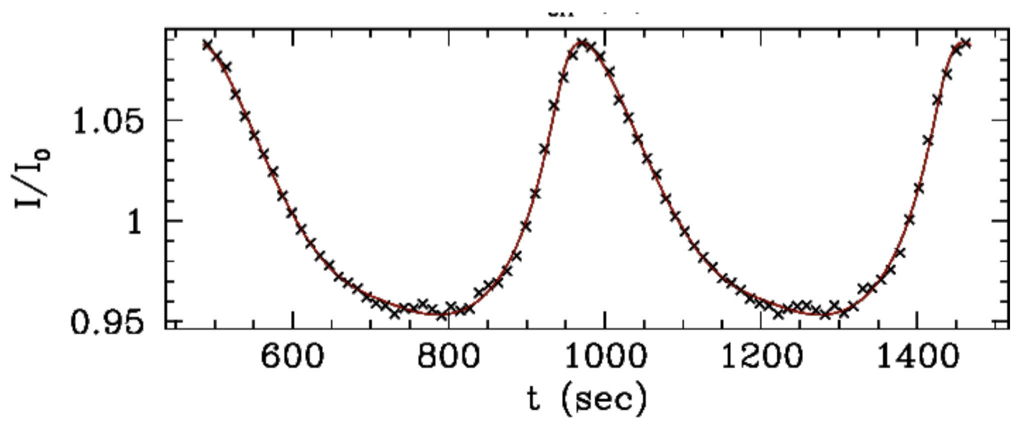
Whole Earth Telescope (WET) – 1995



τ_C= 86.7 sec

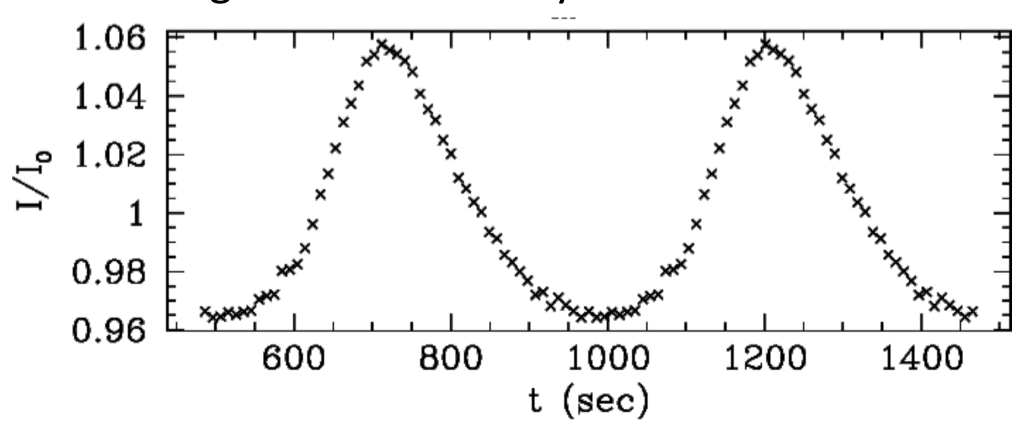
N=22.7

θ_i=57.8 deg

l=1,m=0

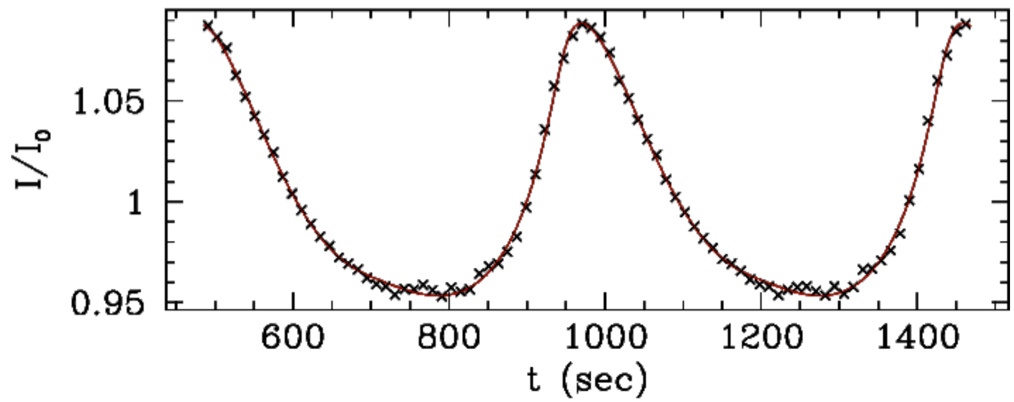
Amp=0.328

Single site data – May 2004



PG 1351+489 (DBV)

Whole Earth Telescope (WET) – 1995



τ_C= 86.7 sec
N=22.7
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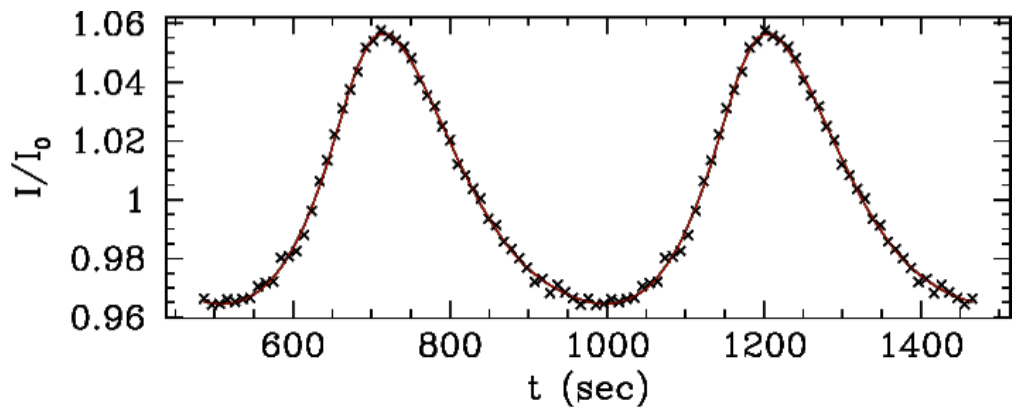
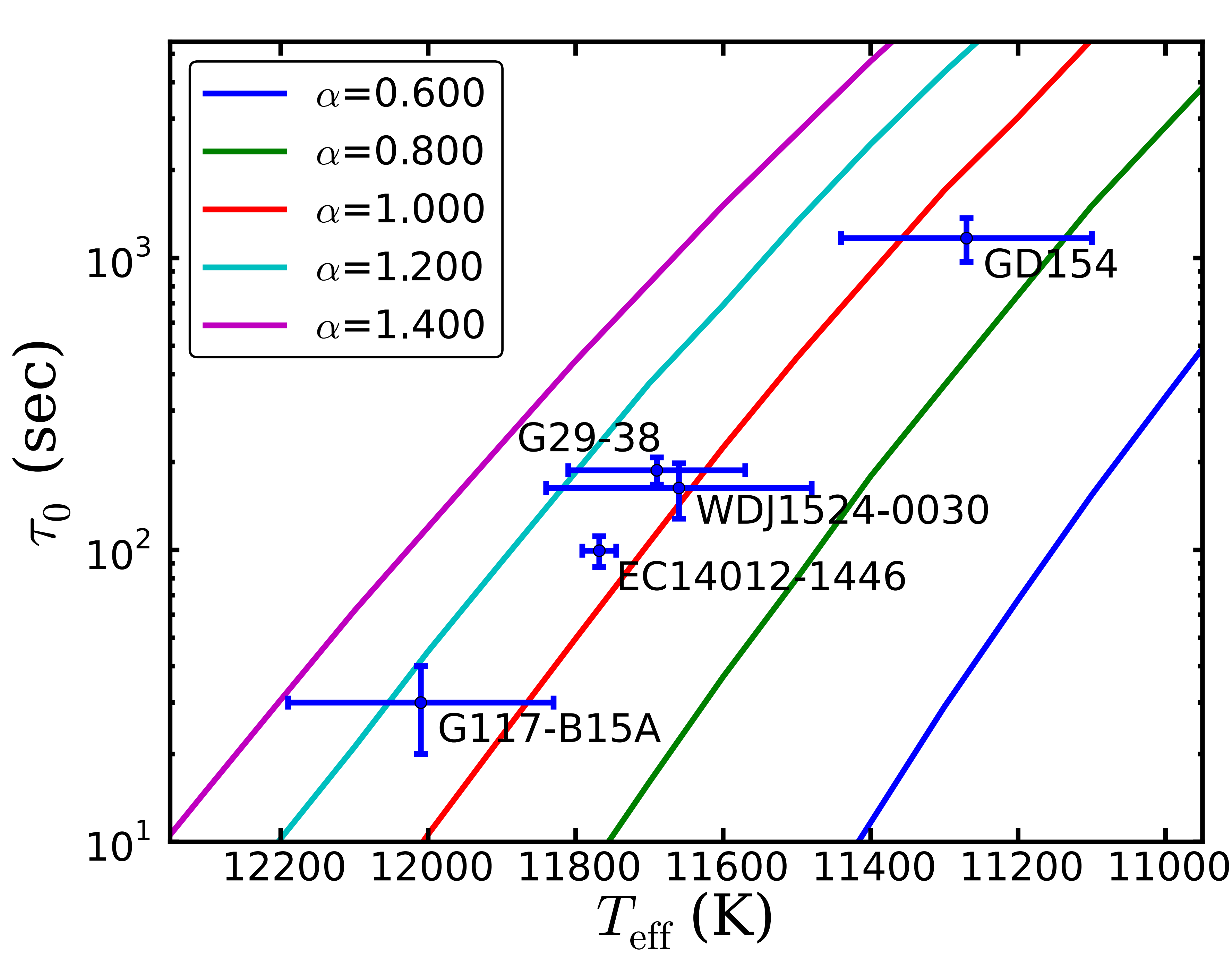
l=1,m=0
Amp=0.328

Single site data – May 2004



τ_C= 89.9 sec
N=19.2
θ_i=58.9 deg
l=1,m=0
Amp=0.257



α=0.600
α=0.800
α=1.000
α=1.200
α=1.400
GD154
G29-38
WDJ1524-0030
EC14012-1446
G117-B15A
10^3
10^2
10^1
12200
12000
11800
11600
11400
11200
11000
τ_0 (sec)
T_eff (K)

MODE IDENTIFICATION FROM COMBINATION FREQUENCY AMPLITUDES IN ZZ CETI STARS

CELESTE M. YEATES,[1] J. CHRISTOPHER CLEMENS,[1] S. E. THOMPSON,[2] AND F. MULLALLY[3,4]

Received 2005 June 17; accepted 2005 August 31

ABSTRACT

The light curves of variable DA stars are usually multiperiodic and nonsinusoidal, so that their Fourier transforms show peaks at eigenfrequencies of the pulsation modes and at sums and differences of these frequencies. These combination frequencies provide extra information about the pulsations, both physical and geometrical, that is lost unless they are analyzed. Several theories provide a context for this analysis by predicting combination frequency amplitudes. In these theories, the combination frequencies arise from nonlinear mixing of oscillation modes in the outer layers of the white dwarf, so their analysis cannot yield direct information on the global structure of the star as eigenmodes provide. However, their sensitivity to mode geometry does make them a useful tool for identifying the spherical degree of the modes that mix to produce them. In this paper we analyze data from eight hot, low-amplitude DAV white dwarfs and measure the amplitudes of combination frequencies present. By comparing these amplitudes to the predictions of the theory of Goldreich & Wu, we have verified that the theory is crudely consistent with the measurements. We have also investigated to what extent the combination frequencies can be used to measure the spherical degree (ℓ) of the modes that produce them. We find that modes with $\ell > 2$ are easily identifiable as high ℓ based on their combination frequencies alone. Distinguishing between $\ell = 1$ and 2 is also possible using harmonics. These results will be useful for conducting seismological analysis of large ensembles of ZZ Ceti stars, such as those being discovered using the Sloan Digital Sky Survey. Because this method relies only on photometry at optical wavelengths, it can be applied to faint stars using 4 m class telescopes.

Subject headings: stars: individual (GD 66, GD 244, G117-B15A, G185-32, L19-2, GD 165, R548, G226-29) — stars: oscillations — stars: variables: other — white dwarfs

We can apply these techniques to the stars and data in this sample of objects…which is based on Argos data!

FRI Spring 2013: Evaluating the ProEM Camera

Mentor: Samuel Harrold

About the new camera

Tasks

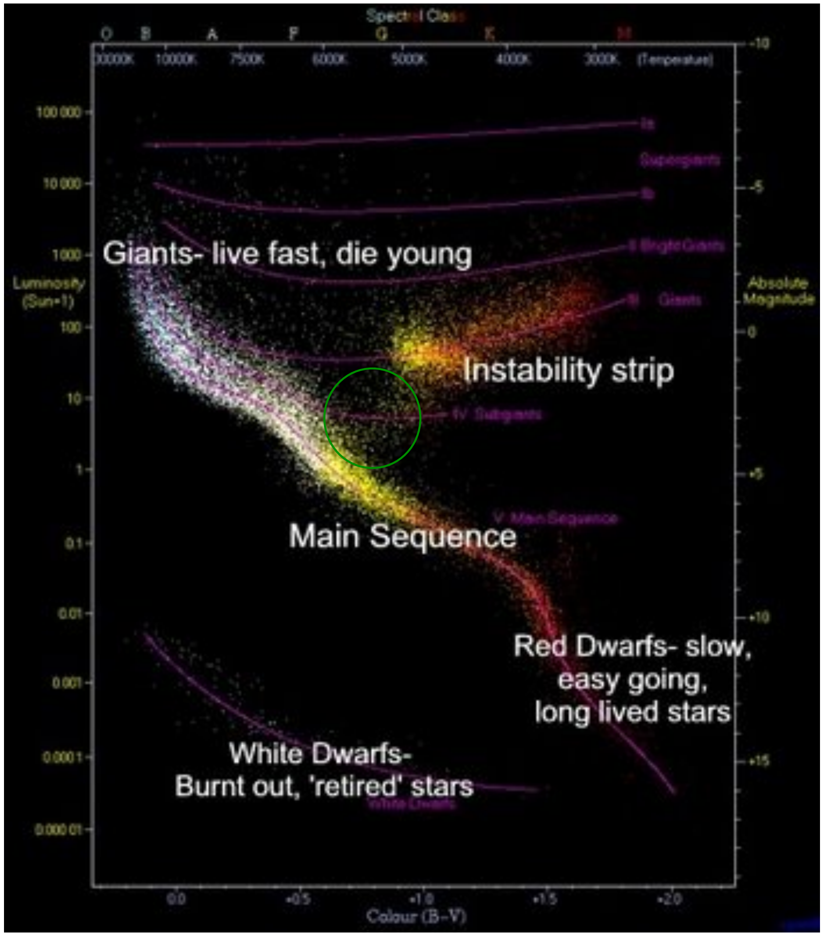
- Determine whether or not we can detect an object using this camera on a telescope.
    - What magnitude?
    - What amplitudes?
    - What frequencies?
    - Similar analysis: http://www.apo.nmsu.edu/arc35m/Instruments/AGILE/#3p3
- Can we detect a pulsar from the 82-inch? http://www.youtube.com/watch?v=_grWV6c_3_o

Research with Michel Breger:

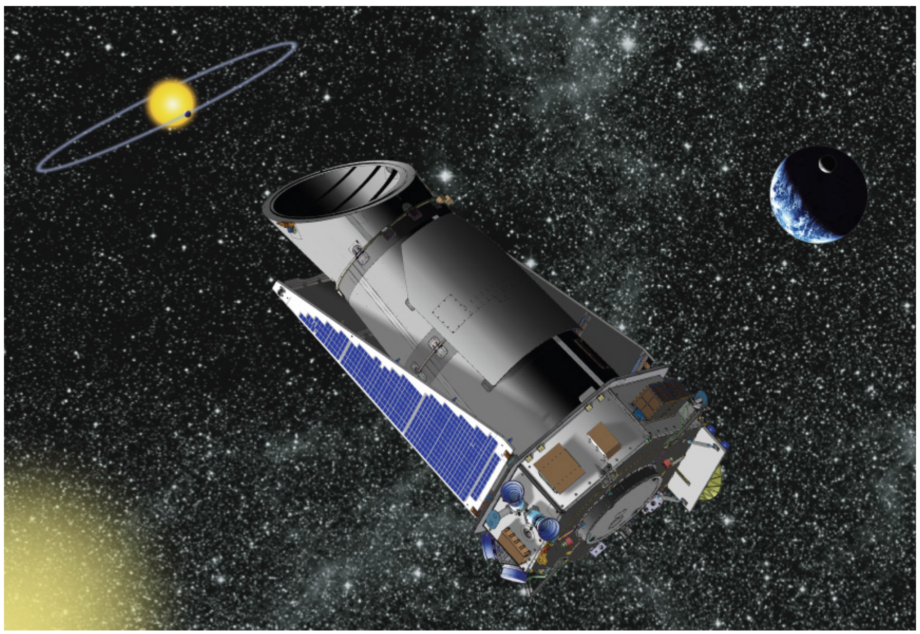
Studying Modes of Pulsation in Delta Scuti Variable Stars

Delta Scuti Variable Stars

- What is a Delta Scuti Variable Star?
  - Exists where the instability strip and main sequence cross
  - Low Amplitude, Short Period (.03 - .3 days)
  - About 1.5 – 2.5 Solar Masses

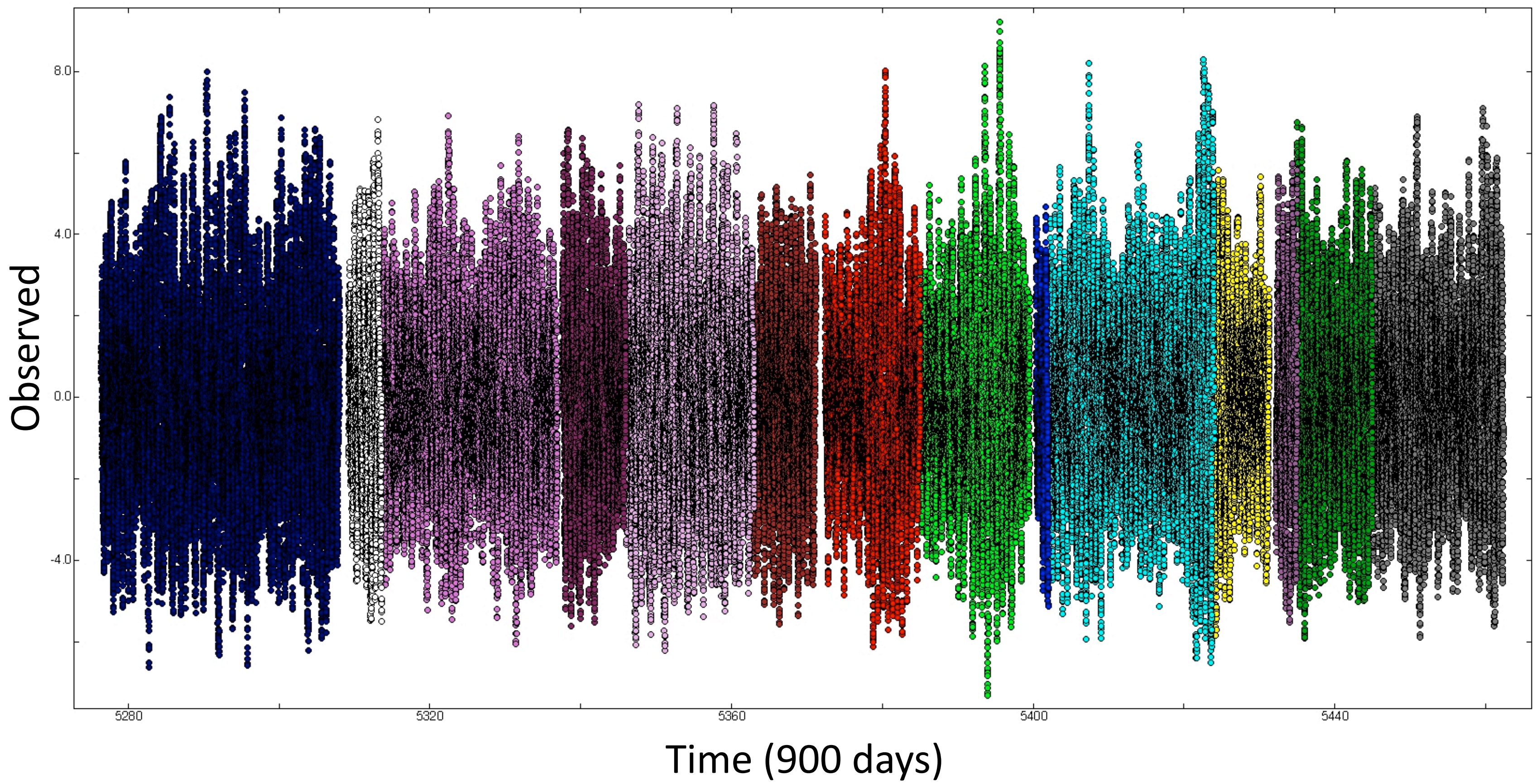


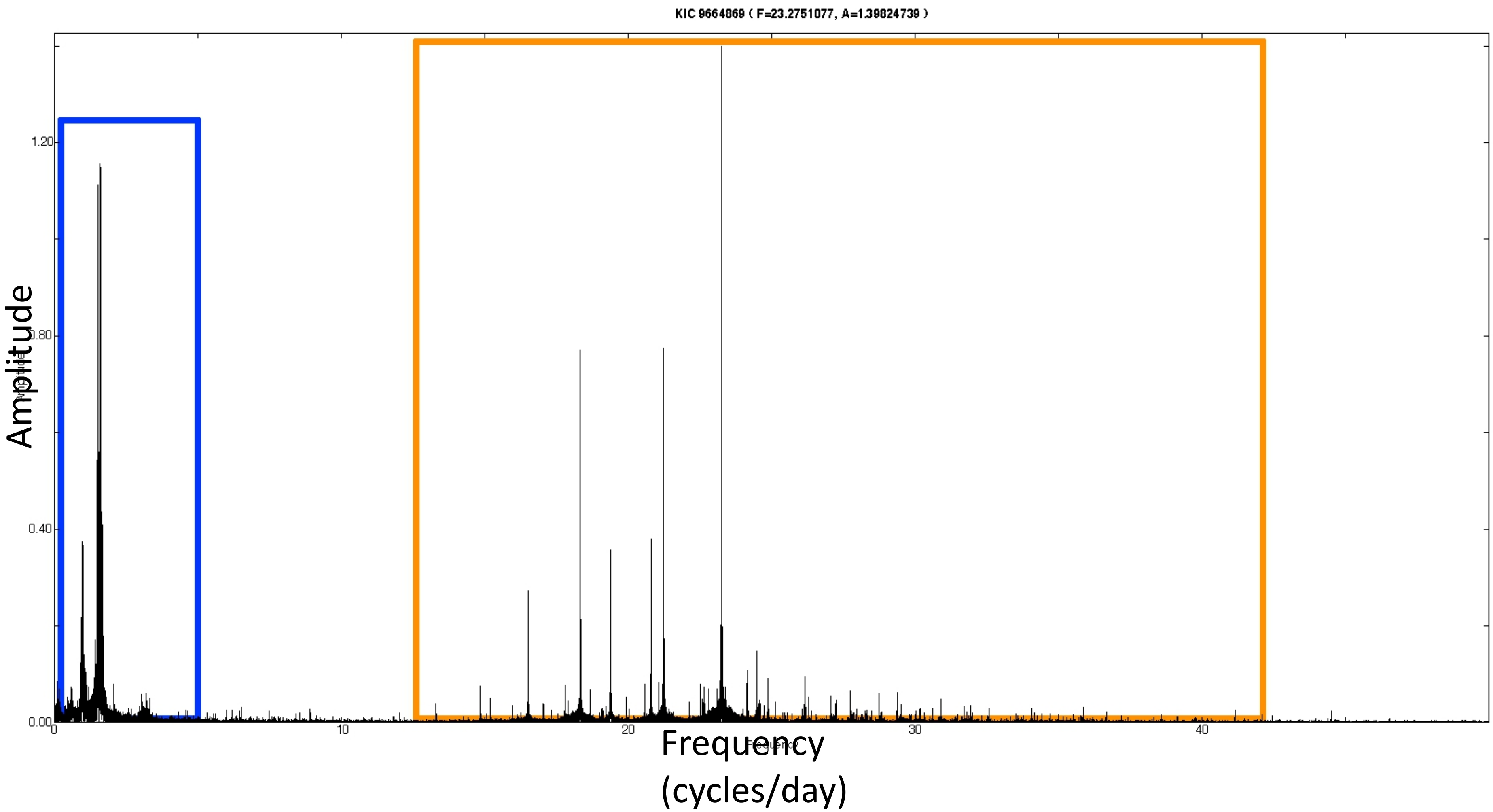
Kepler Spacecraft



- Designed to discover Earth-like planets orbiting other stars
- We reduce the raw data sent from the Kepler spacecraft to a form workable for asteroseismology
- We use Short Cadence data (30 second intervals) and Long Cadence data (30 minute intervals) – Extremely accurate!

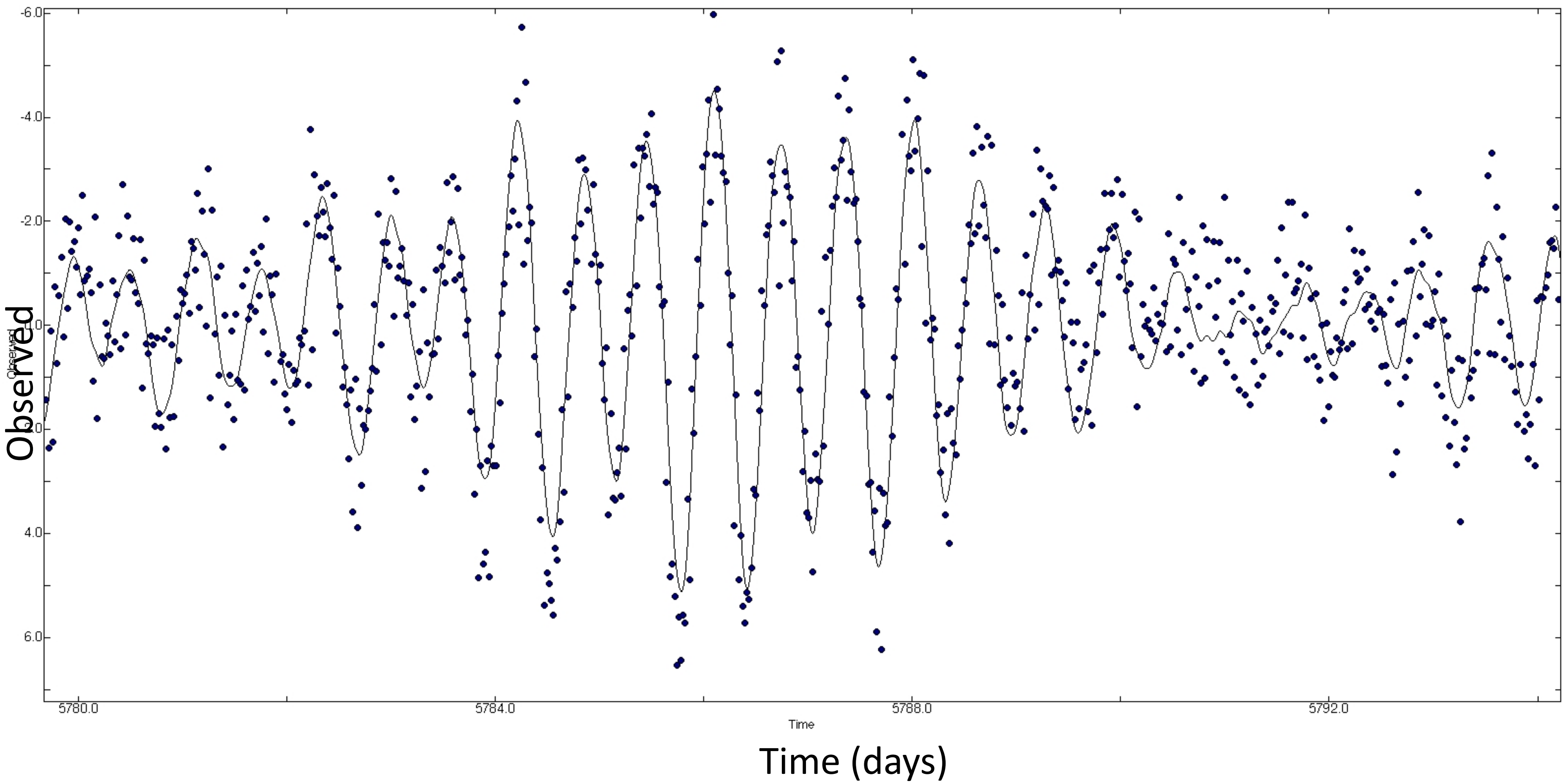
KIC 9664869




KIC 9664869 (F=23.2751077, A=1.39824739)
Amplitude
1.20
0.80
0.40
0.00
0
10
20
30
40
Frequency
(cycles/day)

Findings

- Three equidistant frequency triplets are found in the star, each with different separations
  - Not sure which one results from rotation
- We have managed to calculate almost exact frequency compared to the data, but the amplitude is misaligned.
  - This is caused by more than two years worth of super-accurate data still being insufficient in length to sample the multitude of excited frequencies of similar values – a resolution error



-6.0
-4.0
-2.0
4.0
6.0
5780.0
5784.0
5788.0
5792.0
Time
Observed
Observed
Time (days)

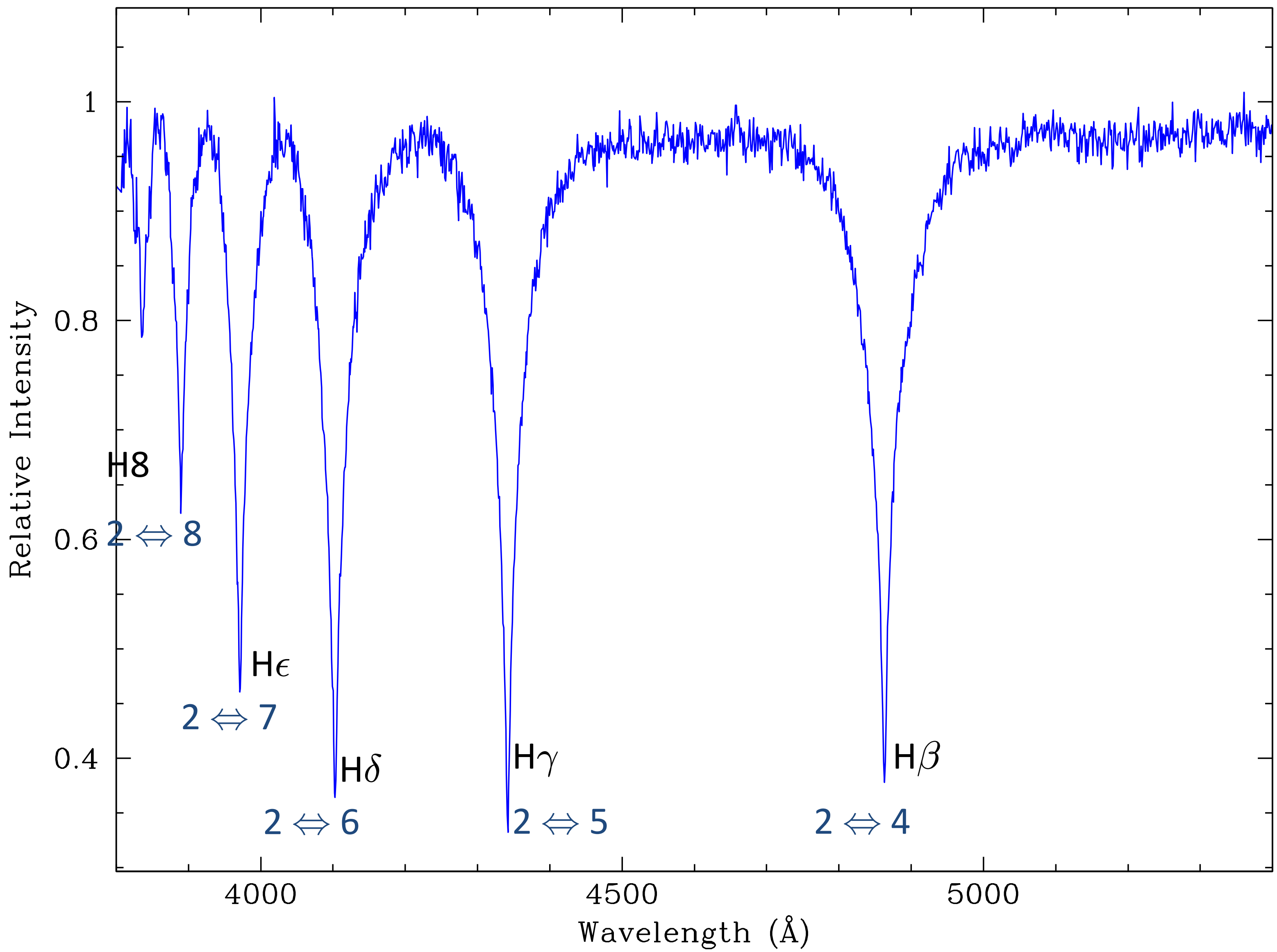
Further Work

- Create a better fit for the light curve as more data is released
- Determine whether the gravity modes or pressure modes are the dominant cause of variability
- Analyze the triplets in more detail to better understand the star
- We have analyzed a little under 400 frequencies, but there are still many more to be detected.

White Dwarf Project at Sandia

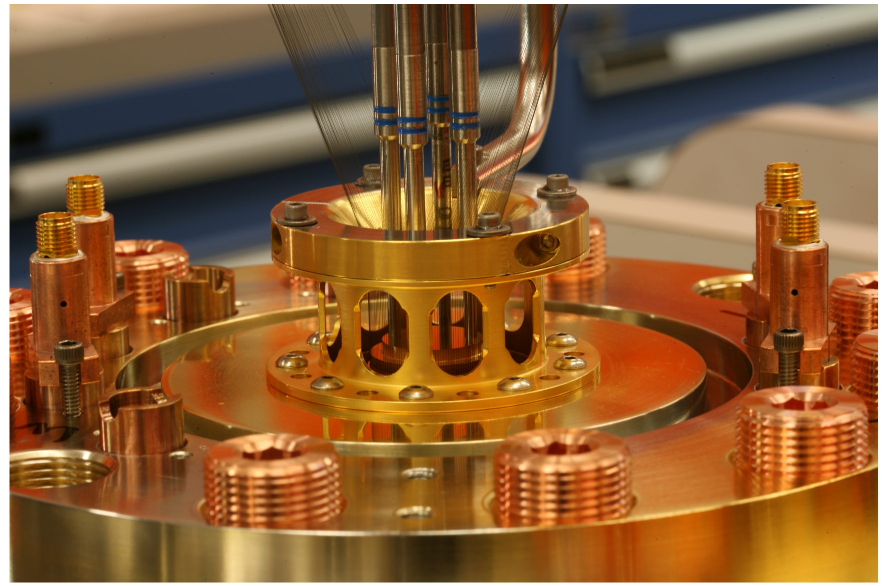
Don Winget, Mike Montgomery, Jim Bailey, Greg Rochau, Ross Falcon, Thomas Gomez, Travis Pille, Sean Moorhead

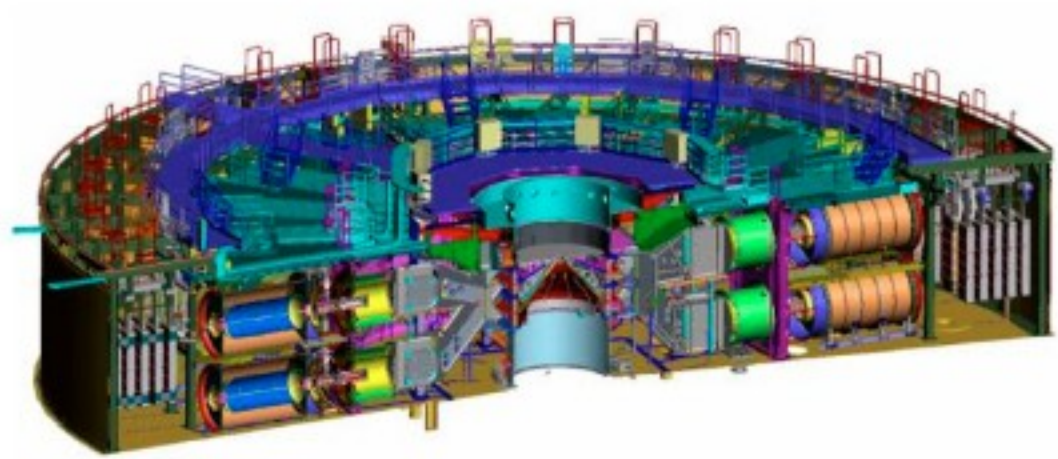
“Typical” WD Spectrum: the Balmer Series



The Z Machine: Pulsed Power

- The Z machine is capable of converting 26 million amps into a peak X-ray emission of 350 terawatts, allowing us to create extreme conditions in a laboratory setting
- **"Z Machine Produces Six Times the World's Energy to Create White Dwarf Star"**
  - http://techland.time.com/2012/08/10/z-machine-produces-six-times-the-worlds-energy-to-create-white-dwarf-star/
- More information can be found at www.sandia.gov/z-machine/

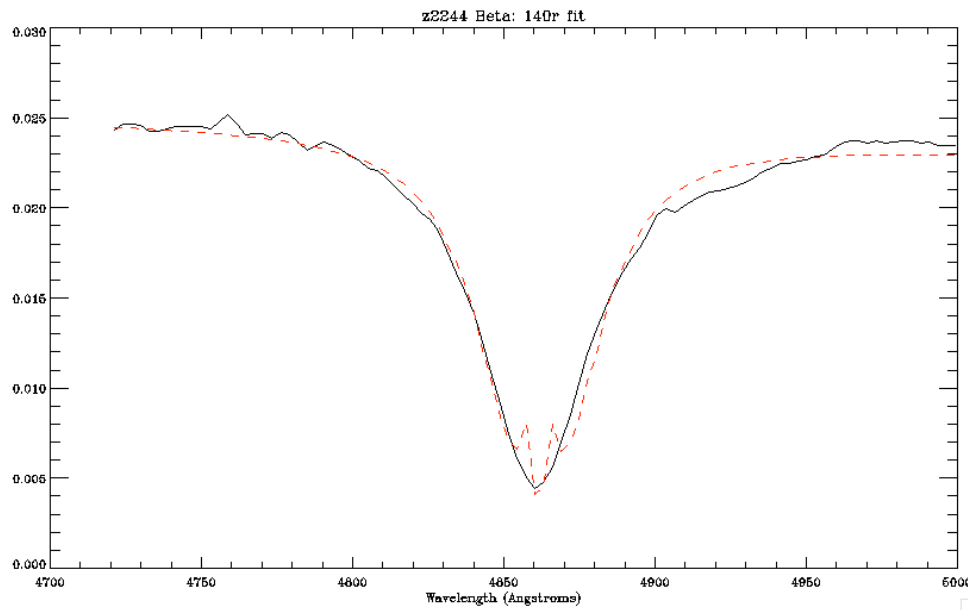




Cross section of the refurbished Z Machine at Sandia National Laboratories

The Experiment

- We use these extreme conditions to ionize a confined hydrogen gas, recreating a white dwarf photosphere.
- We then are able to observe the time evolution of the gas' spectrum (Balmer series) using fiber optic cables and a streak camera.
- Thanks to Ross Falcon's ACE configuration, we are now able to measure absorption and emission spectra as well as the background continuum simultaneously!



Why is this important, we can just observe actual white dwarf spectra right?

- Ross Falcon, a grad student working with our group, found that the masses of white dwarfs as determined through gravitational redshifting were much larger than those determined spectroscopically. (Ask for paper)
- Because of this, we have set out to create our own data set at known conditions in order to test and constrain current spectral line theories.

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