Research Projects for Spring 2013 of the FRI Stream "Exploring the Physics of the Universe with White Dwarf Stars"

1. Project List

Note: *The highlighted text contains links to introductory and background information relevant to the individual projects.*

1. Observing projects: Students should follow through the observations all the way through reduction and analysis stage. There are four main targets we should hit, all of which could lead to publications and co-authorship. Potential mentors and supervisors: Miquela, Sara, Luis, Alex, Arina, John, Keaton, JJ.

   (a) WD0751-0141 (J2000: 07 51 41.18 -01 41 20.9, V=17.5 mag): This is an ELM WD with high-amplitude ellipsoidal variations (EVs) that hasn't been published yet. It's got a massive unseen companion, and we've used Chandra time to look for an x-ray emitting neutron star (didn't see any x-ray emission). The RV and ellipsoidal variations don't phase well, indicating there might be a third body in the system. We're watching the times of minimum of the EVs to make an O-C diagram, hoping to see evidence of a third body. We should start every night on the 36" with 30s to 2 min exposures of this star.

   (b) G117-B15A (J2000: 09 24 17 +35 16.9, V=15.5 mag): This is a timing fiducial we should observe to check the timings of the new camera and its setup. This will also help for Sam's thesis.

   (c) GD 133 (J2000: 11 19 12.40 +02 20 33.0, V=14.6 mag): This object generated some excitement at the WET workshop in China — Gerard Vauclair has observed this DAV quite a bit, which is also known to have metal lines polluting it (it's a DAZ). It supposedly has short-period, low-amplitude pulsations and spectroscopy says it's hot, so it would be great to see if the ongoing accretion is affecting the pulsations. It'd also be great to start looking at from a planet search standpoint. It's bright, so should look for pulsations. Kepler, the person, couldn't see them in a short SOAR run, and we didn't see them in April 2012 with an 8000 s run, but perhaps there's a closely spaced multiplet at short period, or perhaps we just need a lower noise level, which we can get with more observations.

   (d) WD1354+0108 (J2000: 13 55 00 +01 08 19, V=16.4 mag): This is part of the DAV planet search, and is our best planet-host candidate to date. We need a 2013 point in the O-C. A great target to end the night with in late Spring.

   (e) PJMO monitoring of WASP-12 to confirm/deny possible 3.6 day orbital period from Transit Timing Variations (`http://arxiv.org/abs/1301.5976v1`)

   (f) ELMV candidates: Finally, there are three ELMV candidates that came from a single, low S/N discovery spectra from the 1.5m at Whipple. The uncertainties on the parameters are way too large to dedicate 2.1m time on them, but they could prove to be exciting end-of-night targets:

      i. SDSSJ1250+2908: J2000 12 50 26.852 +29 08 46.37, g=17.0, single, low S/N spectra show $T_{\rm eff}$=9752 K, log g=5.0

ii. SDSSJ1355+1956: J2000 13 55 12.336 +19 56 45.43, g=16.2, single, low S/N spectra show $T_{\rm eff}$=8000 K, log g=6.43

iii. SDSSJ1406+3438: J2000 14 06 30.952 +34 38 41.63, g=17.0, single, low S/N spectra show $T_{\rm eff}$=9473 K, log g=5.0

(g) See Michel Breger's notes for a discussion of O-C techniques.

2. Evaluate the performance of the ProEM camera (2 groups, 3 people per group):

   Rationale: Electron multiplication (EM) CCDs are used in chemical kinetics experiments with $>$ 1000 frames per second in very low-light environments (photon counting). We will apply this technology to astronomical time-series photometry to yield higher frame rates with a comparable photometric signal-to-noise ratio (SNR). With this technique we can do time-series photometry of rapidly variable sources, such as pulsars with periods of $\sim$ 30 ms (YouTube link).

   Goal: Determine the capabilities of the ProEM 1024B EMCCD for time-series photometry.

   Objective: Analyze data from the McDonald 36-inch telescope and take observations from the Meyer 24-inch to determine the optimal settings for the highest frequency spectrum SNR. Analysis will be similar to that of the Agile instrument at Apache Point 3.5m.

   Tools: VNC for remote observing; Princeton Instruments LightField and custom software for camera control; bash and shell scripting for file management; Python for scripting, plotting (matplotlib), and analysis (PyRAF); Period04 for frequency analysis.

   Potential mentors and supervisors: John, Sam

   Tasks:

   - Measure thermal noise. Plot dark current vs exposure time.
   - Measure saturation limit. Plot e^- count variance vs mean e^- count.
   - Measure photometric sensitivity. Plot photometric SNR vs exposure time for:
     - different binning settings
     - different EM gain settings
   - Show empirical relationship between frequency spectrum SNR and photometric SNR. Plot frequency spectrum SNR vs exposure time for multiple short runs on well-known pulsators like G117-B15A (requires stable conditions).
   - Analyze time-series data on Crab pulsar from 36-inch.
   - Predict detection thresholds for April observations on the 82-inch.

   Background information:

   - Handbook of CCD Astronomy
   - Introduction to Astronomical Photometry

3. Projects using the MESA stellar evolution code (see MESA Paper I and Paper II). This code is installable on Linux and OSX (i.e., "Macs"), so you should be able to run it on your laptop or PC. If you run Windows, we can probably create a partition on which to install Ubuntu (Linux), so this should work as well. Potential mentors and supervisors: Arina, Keaton, Mike. Possible projects include:

    - Make a $\gtrsim 1.1\,M_{\odot}$ Oxygen/Neon core WDs that still has a surface hydrogen layer. WDs with $M \lesssim 1.1\,M_{\odot}$ are thought to contain C/O cores, while those with higher masses are thought to have O/Ne (or heavier) cores. Many stellar evolution codes have difficulty producing O/Ne models, so making these models with MESA would improve upon the state-of-the-art. Concerning pulsations, we would like to calculate the average period spacing of O/Ne models as compared to C/O models. All of these models are massive enough that they will be crystallized (see Montgomery & Winget 1999).
    - Accreting systems that undergo outbursts. The WDs in these systems are seen to heat up by a few thousand degrees and then cool back off over the period of a few years. The pulsations of these objects are also seen to evolve over this time period, going from shorter periods when the WD is hotter to longer periods when the WD is cooler (see Mukadam et al. 2011).
    - Making models of the ELM (extremely low mass) WDs. JJ has discovered the first five members of this class, and the only ones known so far, here at McDonald Observatory (see Hermes et al. 2012 and 2013). We would like not only to discover these stars but to model them. These models depend on how the star loses mass to become an ELM WD. We also would like to pulsate these models to see what periods and period spacings they can produce (see Corsico et al. 2012).
    - Work with Craig Wheeler to produce type II supernova progenitor models.
    - Many other projects…
    - Additional background information and example files: Lectures I and II from the first MESA Summer School.

4. Nonlinear light curve fitting of pulsating, moderate-to-high amplitude WDs (see Montgomery 2005 and Montgomery 2010). This technique allows us to measure the depth of a pulsating star's convection zone and also can potentially constrain the ℓ and m indices of the pulsations. This is one of only two ways of empirically measuring the depth of a star's convection zone. Potential mentors and supervisors: Arina, Kevin, Mike. Potential projects:

    - Re-do the nonlinear work in the Yeate's et al (2005) paper that used Argos data on 4 to 8 stars. This would involve re-reducing the light curves of these stars, using the `mode_amps` program for an estimate of the nonlinearities, and using the `lcfit_theta` program for the light curve fits. We could have one student per star.
    - Nonlinear light curve fits for the newly-discovered ELM Vs (variables).
    - Nonlinear light curve fits of radially pulsating Delta Scuti stars. This would involve downloading, extracting, reducing, and fitting KEPLER data on select high amplitude Delta Scuti (HADS) stars. These fits would provide some of the first estimates on the size of the surface convection zones in these objects.

5. Projects with Michel Breger — Kepler-based projects: The Kepler spacecraft measures the light variability of stars with spectacular precision. Most of the these light variations originate from a variety of stellar oscillations. Each of the many oscillations has a definite period, which tells about the astrophysical makeup of individual stars. Potential mentors and supervisors: Alex, Arina, Michel Breger.

   (a) The first project is concerned with finding the stellar variations in the reduced spacecraft data and to understand them in terms of our present knowledge of stellar pulsations using mainly simple, straightforward concepts.

   (b) The second project is concerned with examining these detected oscillations in detail using the technique of Fourier transforms and the so-called Running Fourier Method. This enables the viewer to see and understand the complex variations.

6. Additional projects involving the KEPLER satellite. Potential mentors and supervisors: Miquela, Sara, Luis, Alex, Arina, John, Keaton, JJ.

   (a) Observations of mid-eclipse times of Kepler eclipsing binaries to look for possible transit-timing variations (TTV) that would uncover third bodies or planets (see Rappoport et al. 2013).

   (b) "Own" one or a few of the eclipsing binaries found through planethunters.org (`http://www.planethunters.org/candidates#`) for the TTVs mentioned above. It would also be nice to get a list of variable stars from planethunters, if that's available, and try to classify the variable stars, either with the pulsation periods or by using the Kepler-INT survey (a U, g, r, i photometric survey of the Kepler field).

   (c) "Own" one of the pulsating stars in the Kepler field.

7. Sandia-related projects. Potential mentors and supervisors: Travis, Thomas.

   - Learn the data reduction process for the Sandia data. We will be re-examining our data to look for other signatures besides atomic hydrogen, including molecular hydrogen. The goal is to have the highest quality data possible for examining spectral line shapes.
   - Get involved in some theoretical calculations involving line broadening theory and plasma physics. Thomas Gomez has developed a code to make line shapes. There is also a suite of codes available to calculate spectra of different plasmas which will allow us to examine inhomogeneities in plasmas and do radiative transfer with Thomas' new line shapes.

2. Glossary

2.1. ELM(V) – Extremely Low Mass (variable)

These white dwarfs are unusual because they cannot be the product of single-star evolution; a main sequence star with a low enough mass to produce these ELMs would have a lifetime $\gtrsim$ 100 Gyr, so no such stars have yet produced white dwarfs. We believe these ELM WDs must be produced in binary systems in which the companion causes increased mass loss, leading to a low mass WD. We also believe these stars have not burned any elements beyond hydrogen, so we expect their cores to be composed of helium, unlike normal mass WDs which are thought to have carbon/oxygen coes.

2.2. EV – Ellipsoidal Variations

This phenomenon happens in binary targets who are close and/or massive enough to distort each others shape. These object look more like footballs then perfect spheres. When the long side faces us, we see more star, and so get more light than when the short side faces us. This results in a sinusoidal change in brightness as the two stars orbit each other.

2.3. Radial Velocities (RV)

Radial here is referring to distance from us to the star. Velocity in this direction can be measured by shifts in the wavelength of light. When objects come toward us the light is blue-shifted. Conversely, an object traveling away from us has its light red-shifted. By measuring the apparent wavelength of a known spectral line we can see the amount of red or blue shifting that has occurred and thus the radial velocity of the object we are observing. When an object is orbiting another object its wavelength, and therefore its velocity, varies sinusoidally.

2.4. O-C, "Observed minus Calculated"

This technique involves simply plotting what your model (the "calculated") predicts and subtracting that from the "observed". Then you see what's left and try to figure out what it is you are missing (see Michel Breger's notes for more discussion). In our case, we are plotting the actual time a star peaks in brightness and subtracting the expected time of the peak. If the result is sinusoidal, it indicates that there is a planet orbiting the star, modulating the light-travel-time (see this link).

2.5. DAZ

A DA white Dwarf is one that has a surface of pure hydrogen. The addition of the letter Z means that metals are also seen in its atmosphere. In most WDs these metals should have long ago sunk out of sight, so their presence indicates that the WD must be actively accreting metals, probably from a thin dust disk.

2.6. Limb Darkening

When we look at the disk of a star the surface does not appear uniformly bright; the brightness decreases toward the edges, and this is termed "limb darkening". The reason for this is that in the center of the disk we are looking straight into the star, to regions that are hotter and therefore brighter. At the limb of the star, we are looking almost perpendicular to the radial direction, so the layers we see are not as deep or bright.