AY 145: Topics in Astrophysics
Spring, 2005

Midterm Observing Project: RR Lyrae, Rapidly Pulsating Stars

Observations: March 21-24, 2005

Lab Report Due: Friday April 15, 2005

Purpose:
In place of a midterm exam, you will do a midterm observing project. The class will break up into groups of 2-4 and each group will monitor the varying magnitude of an RR Lyrae star, for one night. We will then compile and reduce the data from all groups and then, in combination with other peoples' observations, you will derive properties of the star from your light curves and present your findings in lab report format. Because the weather is so variable, your flexibility/cooperation is greatly appreciated during this project.

Lab Checklist:
During this project, you will complete the following tasks:

- Focus telescope
- Take calibration images (flats, darks, biases)
- Monitor the RR Lyrae's varying brightness
- Compile and analyze observations using IRAF
- Determine physical parameters of the RR Lyrae star

For this project, our star will be RR Gem which has the following celestial coordinates:

RA	07:21:34	(HH:MM:SS)
DEC	30:52:59	(DD:MM:SS)
EPOCH	2000	(J2000)

An Introduction to RR Lyrae Stars
There are many known types of variable stars. A well known group, called cepheid variables, have been studied in great detail. The star that we will study for this project is in a class of stars known as RR Lyrae. Although they share the same mechanism for pulsation, RR Lyrae, once thought to be a sub-group of cepheids, actually form a distinct stellar population.

Parameter	Value
Period	0.2-1.1 days
$<M_v>$	+0.6 ± 0.2 (metal-poor stars)
$<T_e>$	7400 - 6100 K
$<\log g>$	2.5-3.0
$[Fe/H]$	0.0 to -2.5
Mass	$\approx$0.7 $M_\odot$
Radius	$\approx$ 4-6 $R_\odot$

Table 1: List of typical RR Lyrae properties, taken from "RR Lyrae Stars" by Horace A. Smith. The rows are, in order, period of pulsation, time averaged absolute magnitude, time averaged surface temperature, the log of the time averaged surface gravity, the iron to hydrogen abundance ratio, typical mass and typical radius.

Where are RR Lyrae Found?

Cepheids are found only in and near the galactic plane, and typically have small radial velocities. They are believed to be Pop I stars. On the other hand, RR Lyrae are found at all galactic latitudes and have large radial velocities. From this, we infer that RR Lyrae exist in the halo of our galaxy, and are Pop II stars. RR Lyrae have short pulse periods (0.2 - 1.1 days), and are typically low mass, horizontal branch stars that are undergoing core helium burning. See Table 1 for a list of RR Lyrae properties.

Why does the luminosity of a RR Lyra change?

RR Lyrae are pulsating stars. When a star shrinks, it's temperature increases, due to the increased gas pressure. Thus when the RR Lyrae is at its minimum radius, it is also at its hottest and will appear most luminous. When the star is at its maximum size, it will be at its coolest and will be less luminous. This is a highly simplified description of the physics behind stellar pulsation. In your observing report, you will give a more detailed explanation of the physics of pulsation. Guiding questions for you are listed at the end of this document.

Why are RR Lyrae useful objects in astronomy?

There is a correlation between the period and the luminosity of cepheids. Therefore, by measuring the pulse period and the apparent magnitude, one can use the period-luminosity relationship to determine the distance to the star. RR Lyrae stars are a bit more complicated because they all have approximately the same luminosity (check this statement by noting the position of RR Lyrae stars on the HR diagram). Thus, for RR Lyrae stars, other effects, such as the abundance of heavy elements (i.e. their metallicity, or $[Fe/H]$ ratio) can contribute to the variations in pulsation period. RR Lyrae stars, in fact, have a magnitude-metallicity relationship. Nevertheless, the distance to RR Lyrae stars can be determined from period and metallicity measurements to about 10%.

Questions to address in your observing report

Each student should prepare their own observing report. Students are encouraged to work together, but must each prepare a written report separately.

Your report should include a description of RR Lyrae stars including the physics behind their pulsation (see list below for more detailed, guiding questions). In addition, you should include some sample calibrated images from your observation, the light curve from the compilation of the class observations and your estimate of the physical parameters of the RR Lyrae star, including computed error bars on the estimates.

I imagine that your lab report would be 6-10 pages long and will include several CCD images and light curve graphs. This report will serve as a record of how you did the data reduction. You should be able to look back at this years from now and have it jump start a future data reduction project. It could be a very valuable resource for you in the future. Putting effort into the lab report now, while the project is fresh in your memory, is invaluable. Feel free to include as much detail as you like in your report and to ask me questions along the way. You should address the following questions in your lab write-up:

Background physics of RR Lyrae stars

- What kind of stars are RR Lyrae? Include in your discussion properties such as mass, radius, color, luminosity, spatial distribution in our Galaxy, what population (Pop I, II or III) they belong to.

- What and where is the instability strip on the HR diagram? In what region of this strip to RR Lyrae exist? Answer the same question for cepheid variables. What distinguishes cepheids and RR Lyrae as two distinct classes of stars? Do RR Lyrae fall onto the cepheids' period-luminosity relationship?

- Stellar pulsations are caused by the propagation of sound waves in the star's interior. Starting with the the speed of sound ($v_s = \sqrt{\gamma P/\rho}$) and assuming a constant density star in hydrostatic equilibrium, derive the relationship between the density, ρ, of the star and its pulsation period, Π.

- Using the period-density relationship you derived above, show that for an RR Lyrae ($M \sim 0.7 M_\odot$, $R \sim 5 R_\odot$), the pulsation period is roughly 1 day.

- Explain the physical mechanism that drives radial pulsations in variable stars. Then using the functional form of the Kramer's Opacity (see Carroll & Ostlie, Equations 9.19 and 9.20 (p.274))

  $$\kappa \propto \frac{\rho}{T^{3.5}} \tag{1}$$

  explain why pulsations are not seen in all stars.

- What physical processes determine the hot (left) and hot (right) boundaries to the instability strip in the HR diagram?

Data reduction and analysis

- An image taken with a telescope contains both your desired signal (the RR Lyrae star in this case) and unwanted noise. Define and describe the origin of the sources of noise (overscan, bias and dark frames). What is the overscan region in an image from a telescope and what information does it contain? How do we correct for overscan, bias and dark noise during the data analysis? Also describe the need for flat field correction to account for the response of our telescope and CCD, and how we construct our flat field correction image. Which of the above changes from image to image and which can be considered constant over the course of a night?

  Your answers to this question would be greatly aided by the inclusion of an example of a bias, dark, flat, raw image, cleaned image and image with overscan region.

- Complete the following table with bias, dark, flat, sky (each can be used more than once):

Correct the	?	images for overscan
Correct the	?	images for bias
Correct the	?	images for dark
Correct the	?	images for flat

- If the measured image is I_m and the desired (cleaned) image is I, write out schematically the operations you need to do on I_m to arrive at I. You have at your disposal *overscan, bias, dark, flat*.

- Describe what Julian Date (JD) is and why it is useful in the analysis of time series data over long time baselines. What is the current value of JD (hint, IDL has a built in routine to give you the current JD)? What does heliocentric julian date (HJD) mean and why did we convert to HJD in our analysis? What parameters were required by the IRAF routine *setjd* in order to compute the HJD for each image? What is the magnitude of the timing error if the HJD correction is ignored?

- Attach a printout of the data reduction script that you used to reduce the variable star data in IRAF.

The derived physical properties of the RR Lyrae star

- Show 4 graphs of the light curve of RR Gem. One graph for each of the three nights of observations and a fourth graph containing all three nights on a single set of axes. The x axis should be HJD and the y axis should be magnitude. Do you see periodicity in the RR Lyra star?

- Describe how the star's radius and temperature relate to it's brightness. In other words, at maximum light is the star at maximum radius or minimum radius or somewhere in between? Describe the phase relationship between luminosity, temperature and radius. Note: you should be much more accurate than in my brief description in the beginning of this document.

- If you are able to find a pulsation period (remember, RR Lyrae periods are typically 0.2-1 days), see if you can make a phase-magnitude diagram from our data.

- What physical parameters of RR Gem can be derived from a well measured light curve?
- What are your estimates of these parameters given the three nights of data that we collected?
- What are appropriate error bars on your measurement?
- Pick a parameter, such as the mass of RR Gem. How does an error in the measured magnitude of RR Gem translate into an error in the estimate of the mass of RR Gem?

References for observing project

RR Lyrae Stars

There is a book on reserve at the Cabot Science Library called *RR Lyrae Stars* by Horace Smith. It is a useful resource for this project. You will also find it helpful to read current literature about RR Lyrae stars as much progress has been made since Smith's book was published. You should cite at least two articles in your observing report. These articles are readily available at the ADS astronomy abstract repository (also linked to off of the AY145 homepage):

http://adsabs.harvard.edu.ezp2.harvard.edu/abstract_service.html

Hint: Searching for articles with "RR Lyrae" in the title, and Fernley in the author will pull up many relevant articles.

CCD Data Reduction

There are many good references describing how to reduce CCD images. The Handbook of CCD Astronomy, by Steve Howell is a complete reference and quite readable as well. Many other resources can be found online. For example:

http://www.astro.utoronto.ca/~bridge/handouts/ccd.pdf