The light curve of a variable star:

AN EXAMPLE UPPER-DIVISION CODING PROJECT ACCESSIBLE TO STUDENTS WITH NO PRIOR PROGRAMMING EXPERIENCE

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Abstract

Observations of the brightness of a variable star are almost always unevenly spaced in time, and the periodicity is not readily apparent. Students in an Observational Astronomy course with no prior programming experience were successful at coding a Lomb-Scargle periodogram to find the period of a variable star, and then “folding” the data to create a light curve (a graph relating the brightness to the phase of the period). Possible factors contributing to that success and implications for designing other computational projects when no programming experience can be assumed will be discussed.
The Situation

- Mount Union
- Small department
- No computational course or plan
The old dog

- AAPT recommendations
- PICUP Workshop
The Course

- PHY 220 – Observational Astronomy
- Elective taught every other year
- Prerequisites do not include any computational courses
Resources

• Meeting space with Macs (student access outside of class also)

• BYOD Initiative

• Virtual meeting space/screen sharing
Why code at all?
Delta Cephei

Periodic variable star

Archival data readily available
Student goals:

Find the period

“Fold” the data to find light curve
Delta Cephei

Students could also observe it themselves

Analyze image(s) with (free) computational package
  ◦ Aperture Photometry Tool
  ◦ AstrolImageJ
The generalised Lomb-Scargle periodogram

A new formalism for the floating-mean and Keplerian periodograms

M. Lombardo and M. Rizzi

Astronomy

The generalised Lomb-Scargle periodogram...
Lomb-Scargle periodogram

• Based on 7 sums

$$\tan 2\omega = \frac{\sum_i \sin 2\omega t_i}{\sum_i \cos 2\omega t_i}.$$  

$$\hat{p}(\omega) = \frac{1}{YY} \left[ \frac{Y \hat{C}_\tau^2 + \hat{Y} \hat{S}_\tau^2}{\hat{C}_\tau^2 + \hat{S}_\tau^2} \right]$$

$$= \frac{1}{\sum_i y_i^2} \left\{ \frac{[\sum_i y_i \cos \omega(t_i - \hat{\tau})]^2}{\sum_i \cos^2 \omega(t_i - \hat{\tau})} + \frac{[\sum_i y_i \sin \omega(t_i - \hat{\tau})]^2}{\sum_i \sin^2 \omega(t_i - \hat{\tau})} \right\}$$
Introduction to Python/Jupyter notebooks

• One page handout of basic commands & examples

• Scaffolding exercises:
  • Very simple calculations
  • Output
    • Print
    • Plot
  • Loops

```python
In [1]:
from numpy import *
from pylab import *
from math import *
import matplotlib

In [2]:
x = 3.0
y = 0.1415926
z = x + y
print(z)
```

3.1415926
Lomb-Scargle periodogram

• Based on 7 sums

$$\tan 2\omega \hat{\Phi} = \frac{\sum_i \sin 2\omega t_i}{\sum_i \cos 2\omega t_i}.$$ 

$$\hat{p}(\omega) = \frac{1}{YY} \left[ \frac{Y C_{\hat{\Phi}}^2}{C_{\hat{\Phi}}^2} + \frac{Y S_{\hat{\Phi}}^2}{S_{\hat{\Phi}}^2} \right]$$

$$= \frac{1}{\sum_i y_i^2} \left\{ \frac{[\sum_i y_i \cos \omega(t_i - \hat{\tau})]^2}{\sum_i \cos^2 \omega(t_i - \hat{\tau})} + \frac{[\sum_i y_i \sin \omega(t_i - \hat{\tau})]^2}{\sum_i \sin^2 \omega(t_i - \hat{\tau})} \right\}$$
What makes coding difficult?

- Debugging, debugging, debugging!
- F2F – lab with computers
- Online – Microsoft Teams – screen sharing
Period = 5.3658 days
Light curve:

\[ \text{# of periods since epoch} = \text{int}\left(\frac{t_i - \text{epoch}}{P}\right) \]

\[ \phi_i = \frac{(t_i - \text{epoch})}{P} - \text{# of periods since epoch} \]
Future work

- Homework questions with typical bugs
- Peer teams (2 – 3 students)
- Move this to earlier in semester and add more projects throughout semester to reinforce concepts