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Detecting Binaries Via Cross Correlation Function Subtraction

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Detecting Binaries via Cross Correlation Subtraction: Utilizing the Sloan Digital Sky Survey IV/APOGEE-2 Database

Jessica Reyna, Dr. Kevin Covey & Members of the SDSS-IV/APOGEE-2 Collaborations

Introduction
Spectroscopic binaries provide direct measurements of stellar masses that can be used to test theoretical models of stellar evolution. The SDSS-IV/APOGEE-2 survey has obtained spectra covering the wavelength range of 1.51-1.70 μm for more than 300,000 stars in the Milky Way. This survey primarily focuses on red giants with sub-projects focusing on star forming regions such as the Perseus and Orion molecular clouds. Cross correlation functions (CCFs) measure the similarities of two spectra as a function of their relative velocities. CCFs can be used for measuring the differences in two star’s velocities or it can be used to measure the changes in a single star’s velocity over time. Our program computes the difference of two CCFs measured from distinct observations of a star.

Goal:
We aim to develop a program that reads spectra and categorizes them into two groups, binaries and non-binaries.

Methods

- Detect potential binaries from changes in the residuals of two CCFs.
  - In Figure 1, the blue dashed line (CCF1) is the primary visit and the black dashed line (CCF2) is the secondary visit.
  - The red line is the CCF subtraction result.

- Find all possible CCF combinations. For example, a given source has 7 associated visit spectra so there are 21 possible CCF pairs.

- Calculate all possible unique residuals for CCF pairs in a given source:
  
  \[
  \text{CCF difference} = \text{CCF1} - \text{CCF2}
  \]

- Calculate statistics for describing the residuals of the CCF pairs:
  - Integrate the Residuals
  - Integrate the Squares of the Residuals
  - Root Mean Square Value (RMS) of the Residuals
  - Divide the difference in CCFs for the given spectra by the RMS
  - Divide the square of the difference in CCFs for a given spectra by the RMS

- Visually examine the histograms of each statistic to search for changes in the CCF residuals.

- Refine the statistics used to describe binary system behaviors and non-binary system behaviors. We are primarily interested in finding binary system signatures in the statistics by detecting numerical patterns associated with systems.

Results

- Non-binary candidates tend to demonstrate clean subtractions. (See Figure 1)
- Binary candidates have larger residuals in their subtractions due to changes in their CCFs as the binary members move their orbits. (See Figure 2)
- Potential binaries are tricky. Some demonstrate residuals after subtraction but on a very small scale. (See Figure 3)
- Compare suspected binaries to confirm binaries via histograms (Figure 4 and 5). Distribution differences tell us about how CCFs change over time.

Definitions

A metric is a parameter characterized as an associated statistic (i.e. integrated residuals)
A spectrum is the measurement of a star’s flux as a function of wavelength ($\lambda$)
A cross correlation function measures the agreement between two spectra for various relative velocities of a star
A visit spectrum is one of several spectra obtained for the same source at different times

Future Work

- Create spectra representing artificial binaries by adding Doppler shifted spectra
- Measure the CCF described above and distinguish which features best describe binary behavior
- Measure these metrics for real APOGEE spectra to create a pan-Galactic catalog of spectroscopic binaries
- Identify particularly compelling targets of interest such as low mass and young stars

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Figures

Non-Binary Candidate

![Figure 1: A separate set of CCF pairs for a star. To the left the statistical values associated with the star are given.](image)

Binary Candidate

![Figure 2: A separate set of CCF pairs for a star that demonstrates the desired binary signatures we are looking for in a CCF subtraction curve (in red).](image)

Potential Binary Candidate

![Figure 3: A CCF subtraction for a particular star and to the left there are values associated with the CCF subtraction curve (in red).](image)

Noise or binary signature?

![Figure 4: From the Potential Binary Candidate](image)

![Figure 5: From the Confident Binary Candidate](image)