Statistical Methods for Exoplanet Detection

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What is an exoplanet?

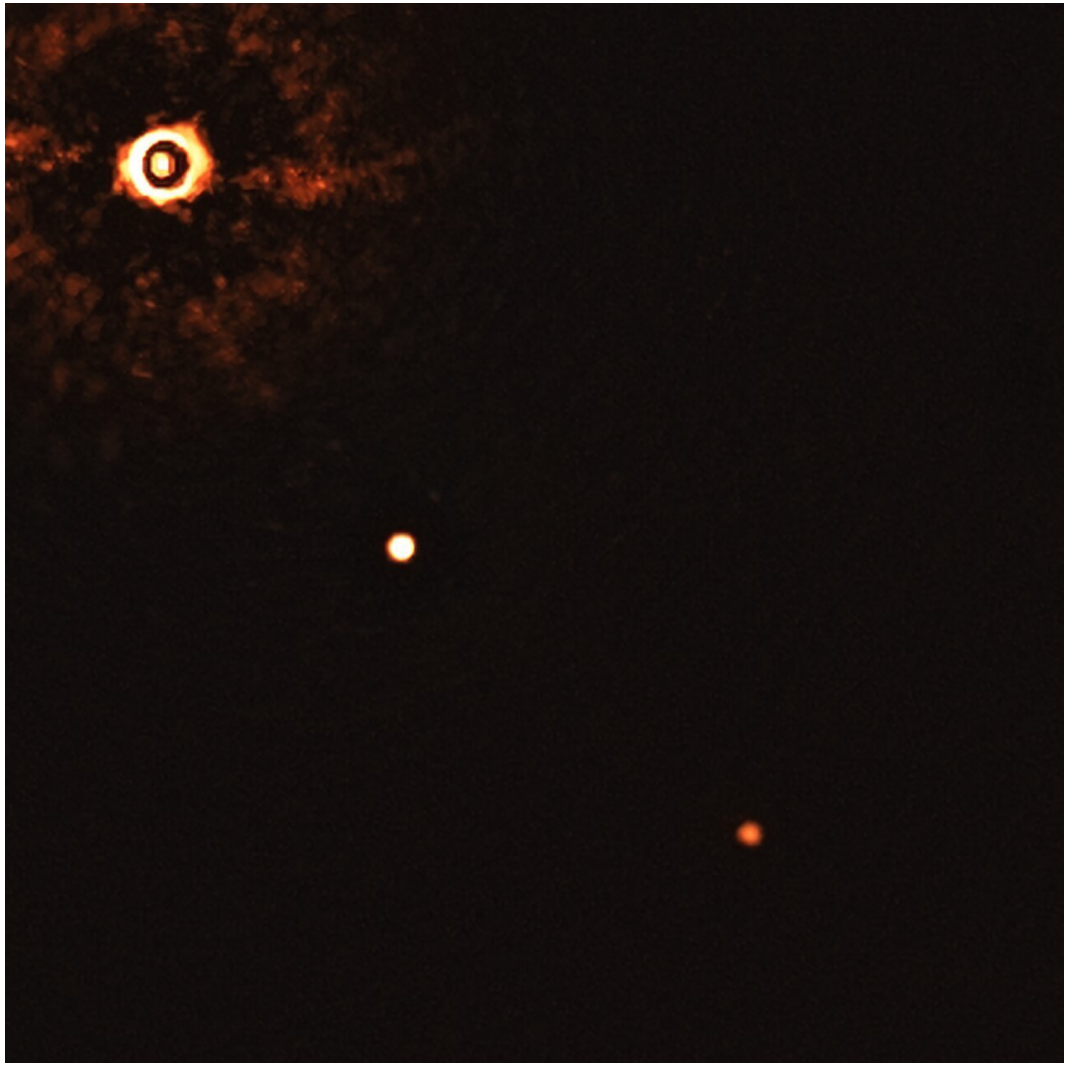


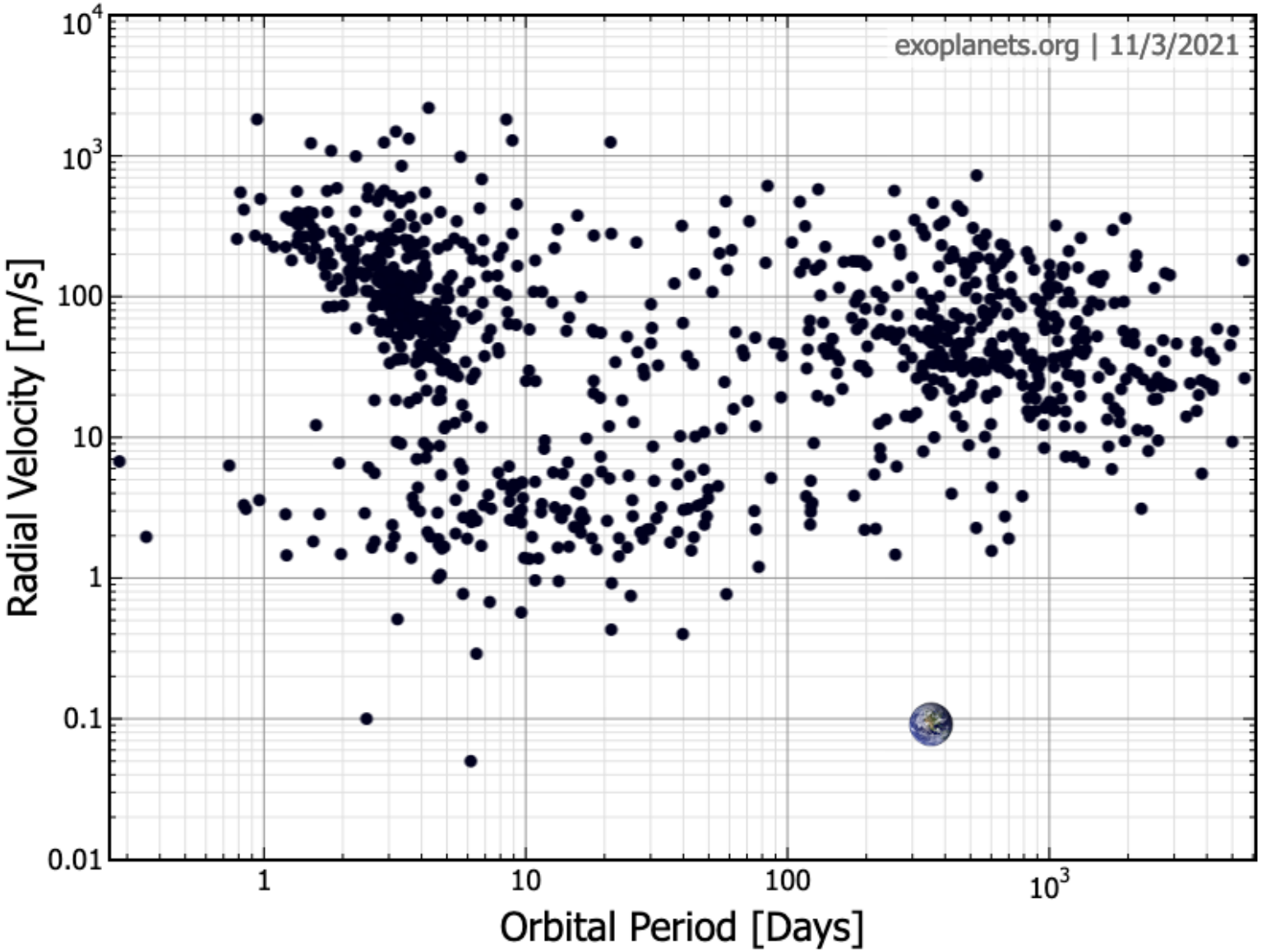
Figure 1: TYC 8998-760-1 b and c

Detected Exoplanets

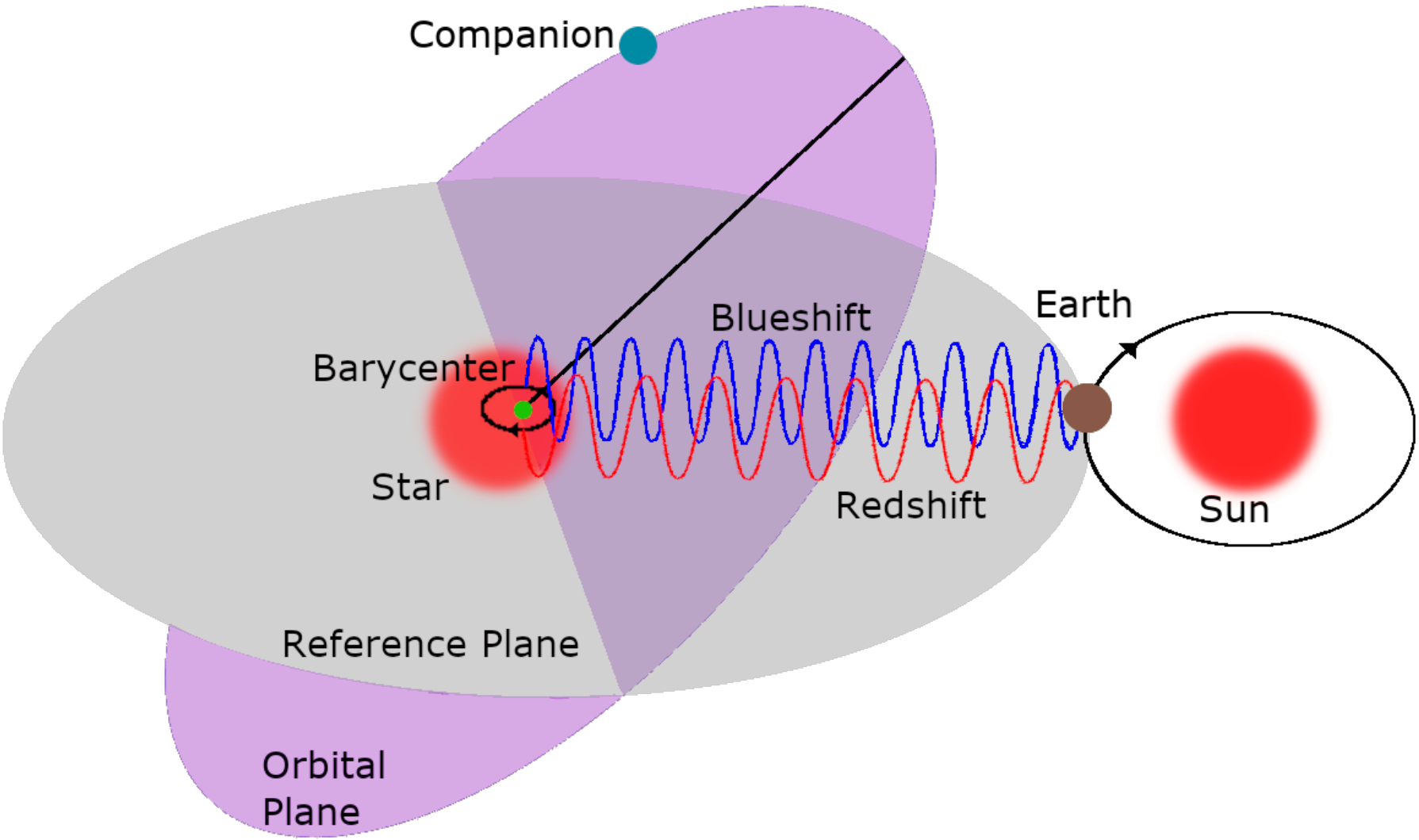
- 51 Pegasi b discovered in 1995 (Mayor and Queloz 1995)

- About 4,500 exoplanets have been confirmed with almost 8,000 more candidate planets

Detected Exoplanets



Detection Methods



Transit Methods

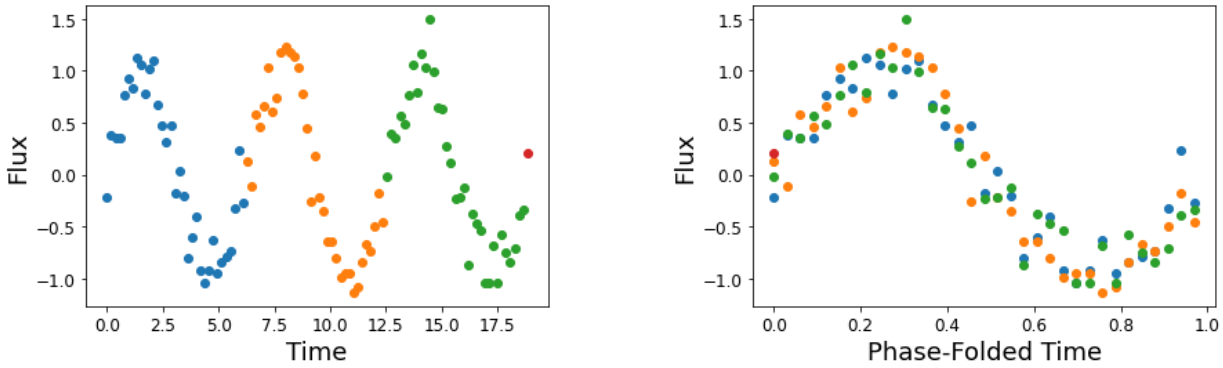


Figure 2: Phase-Folding

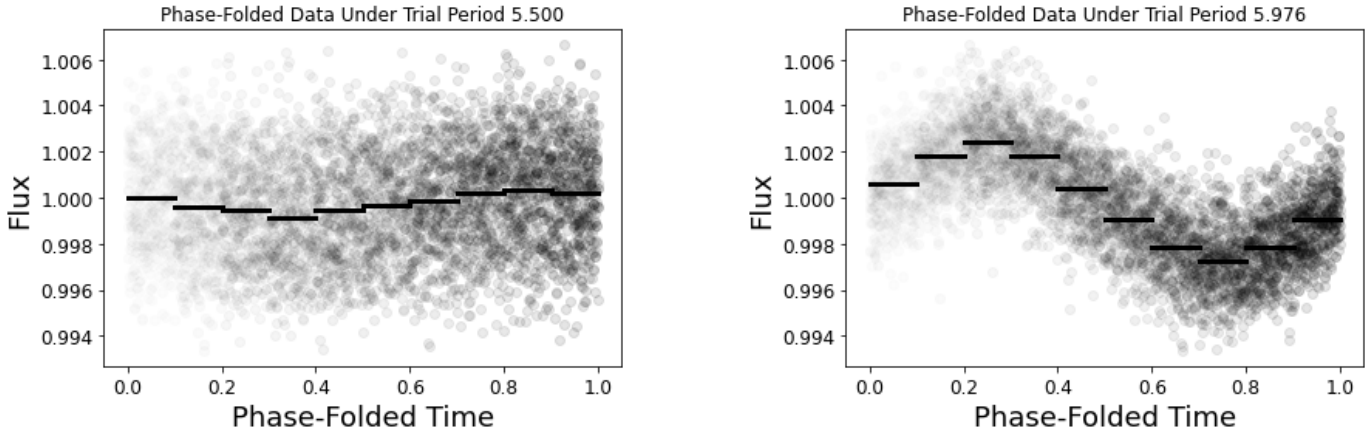


Figure 3: Simulated time-flux pairs which are phase-folded under different trial periods.

Transit Methods

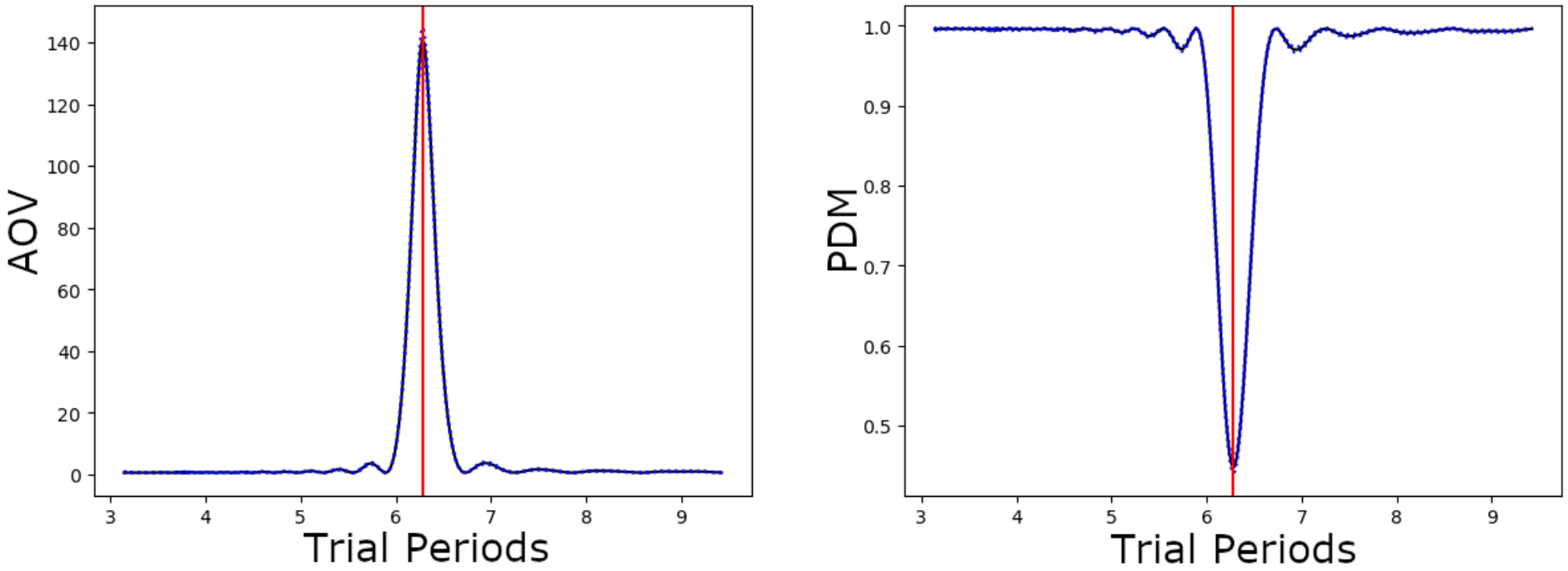


Figure 4: Analysis of Variance and Phase Dispersion Minimization Periodograms

Radial Velocity Methods

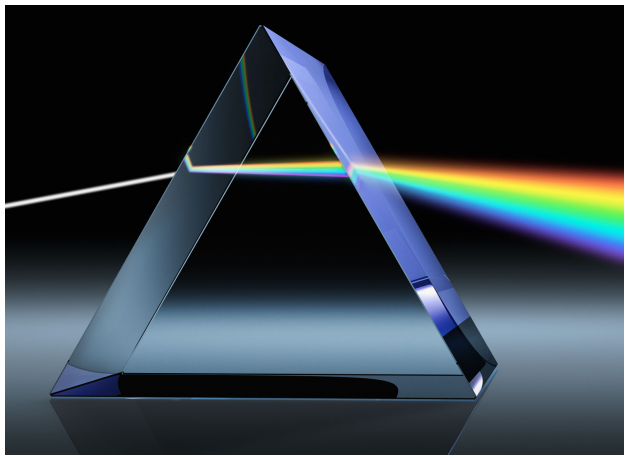


Figure 5: Light being refracted into different wavelengths.

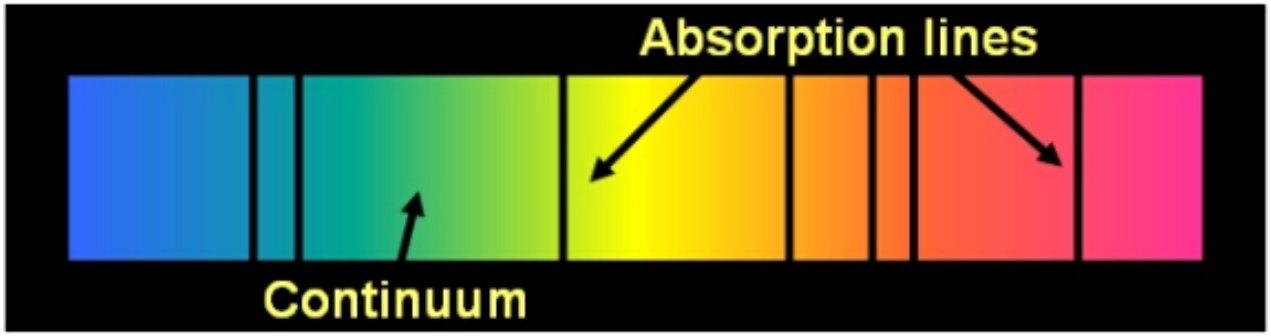


Figure 6: Absorption features present in a spectrum.

Comparison of True Spectra to Red and Blue-Shifted Spectra

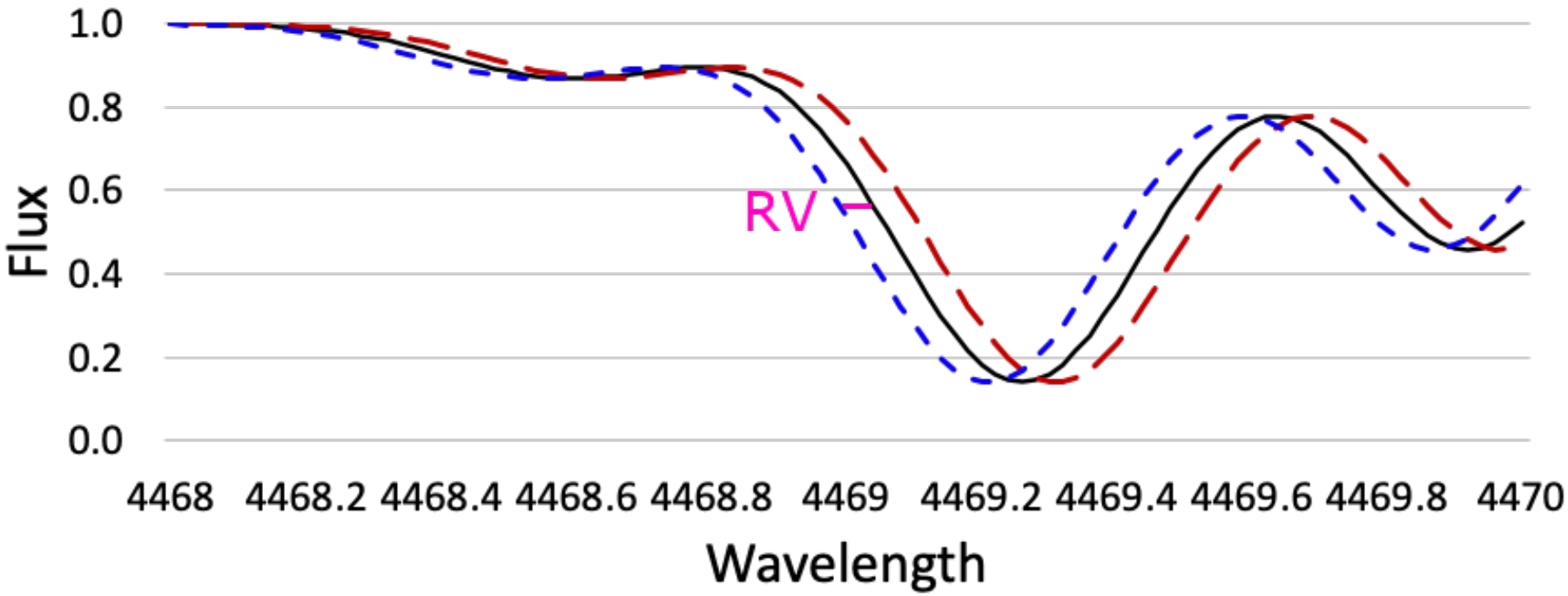


Figure 7: True spectrum of the star (black, solid line) compared to its blue-shifted and red-shifted spectra.

Cross-Correlation Function

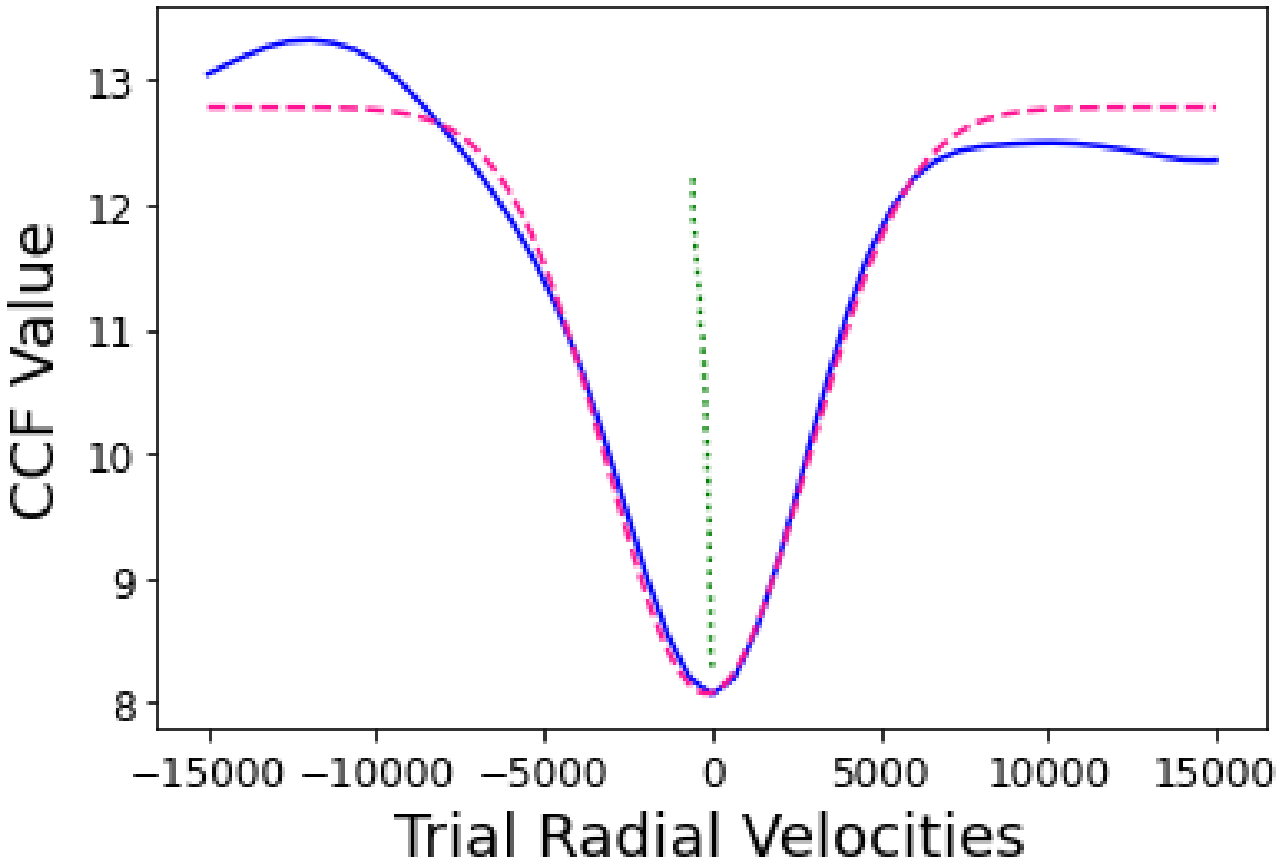


Figure 8: The solid, blue line is the CCF profile.

Comparison of True Spectra to Red and Blue-Shifted Spectra

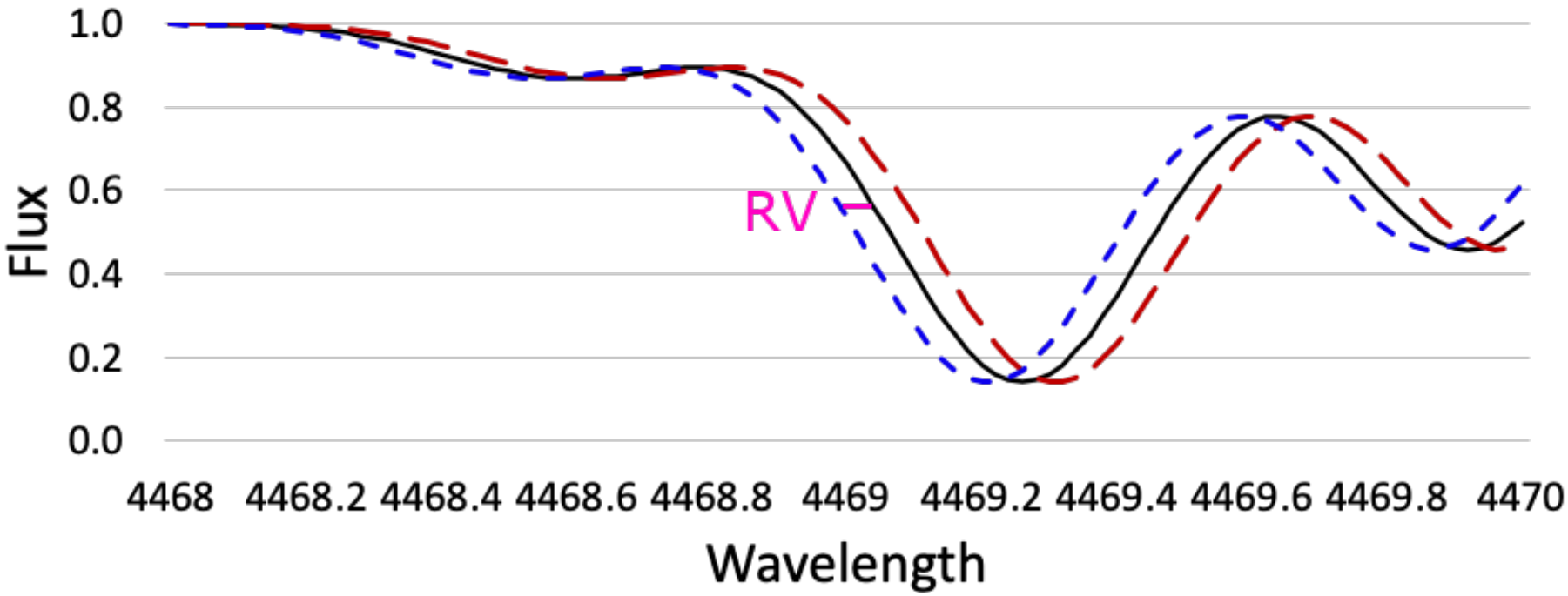


Figure 9: True spectrum of the star (black, solid line) compared to its blue-shifted and red-shifted spectra.

Hermite-Gaussian Radial Velocity Method

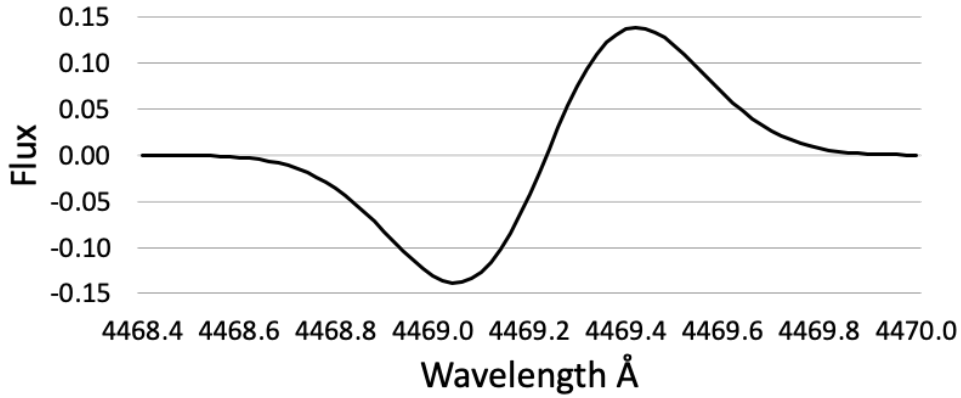


Figure 10: Difference Flux

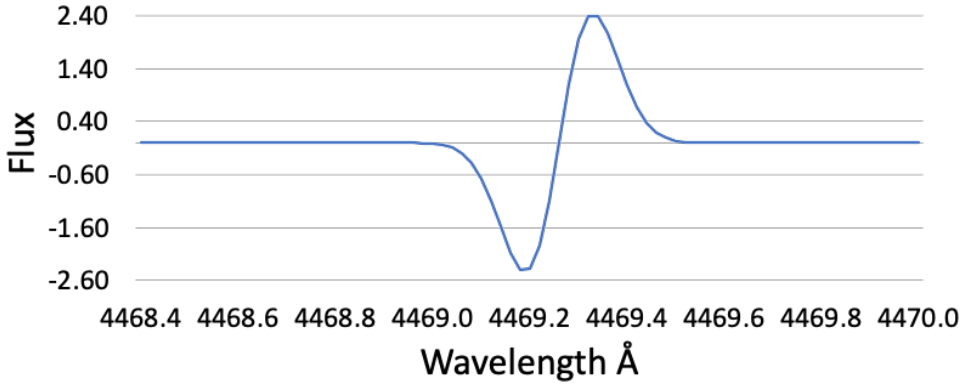


Figure 11: Physicist's first order Hermite Gaussian function.

Statistical Challenges:

- Uneven Observation Times
- Stellar Activity
- False Alarm Probability

Unevenly Spaced Observation Times

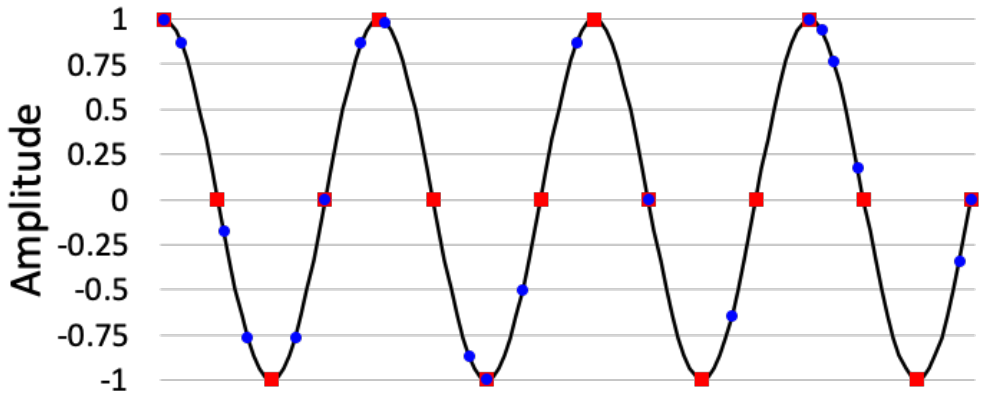


Figure 12: Uneven Versus Even Observation Times

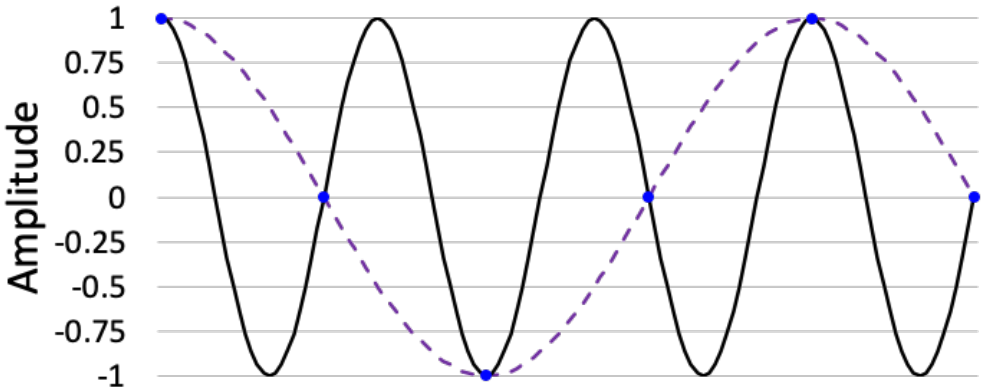


Figure 13: Aliasing

Stellar Activity

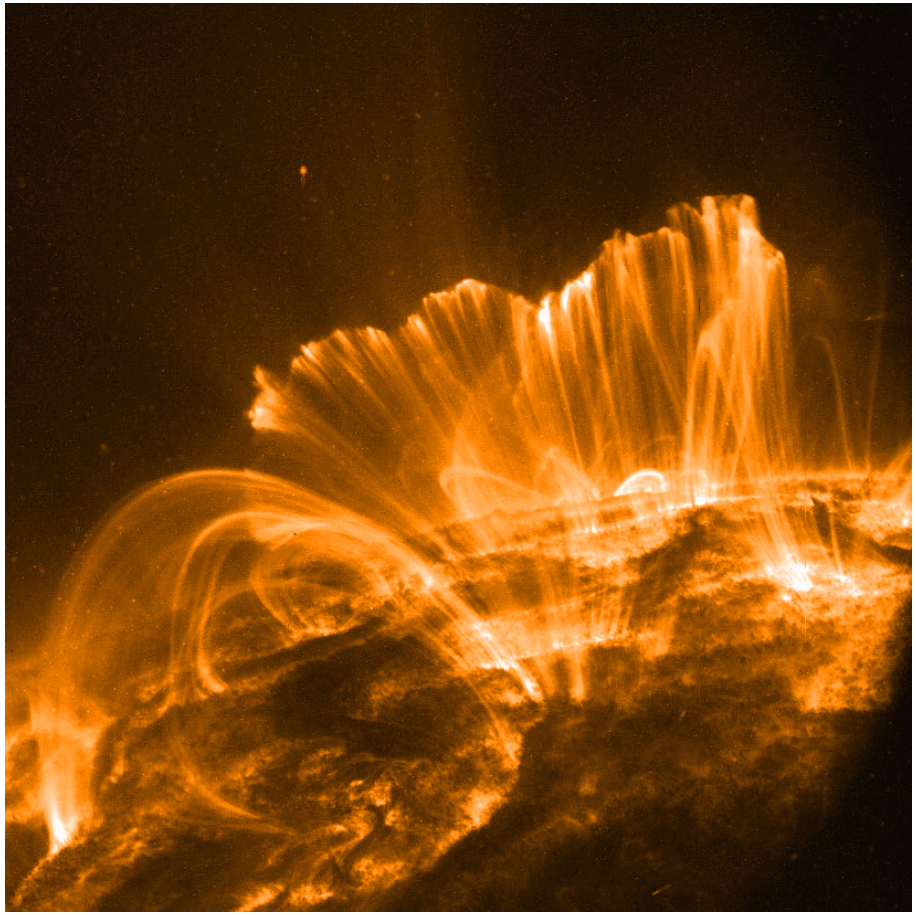


Figure 14: Solar Flare

False Alarm Probability (FAP)

Is this really a planet?

- Transit Methods: FAP is difficult to determine theoretically
- Radial Velocity Methods: FAP can be determined theoretically for some methods but not all

What Statisticians Offer

- Statistical issues caused by uneven sampling in the transit methods have not been examined by statisticians despite their prevalent use in astronomical papers over four decades (Feigelson 2021)
- Determine or approximate the FAP
- Develop methods to disentangle stellar activity noise from radial velocity signal
- Billion-dollar Rubin Observatory Legacy Survey of Space and Time project to start in 2022-23
- Urgent need for specialized methodology for the expected 37-billion sparse, irregular, multivariate time series