Exocometary Activity around β Pictoris and Nearby Young Stars

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Introduction

β Pictoris is the primary star of interest for exocomet research, after variable, sharp and deep absorption components were discovered in its Ca II H & K lines [7]. At a distance of 19.28 ± 0.19 pc [3] with an age of 18.5 Myr [6], β Pictoris has a useful edge-on orientation enabling the detection of exocomets in its spectrum and light curve [4], [8].

Utilising spectra from the University of Canterbury Mt John Observatory (UCMJO) and light curves from the TESS space telescope, the aim of our project is to monitor exocomet properties over a long time baseline, enabling us to study the changes and evolution in these properties and giving us insights into orbital dynamics and population statistics. The 1.0m McLellan telescope, fibre-fed to the HERCULES spectrograph with a resolution of R∼42,000 captures the spectrum on a single CCD exposure in order to detect evaporating star-grazing exocomets. We will use the 120s cadence TESS observations, reduced with the SPOC pipeline, to detect transiting exocomets.

While β Pictoris is the primary target for investigation, other nearby young stars of a similar stellar type will be included in our study.

Methods

Spectroscopic Method

To begin the spectroscopic method, a reference profile of clean spectra (without exocomets) must be created. Visually clean spectra are selected and averaged (with the circumstellar disk effect removed) for each star to create the reference profile. Each individual spectrum is then normalised by the created reference profile. This enables Gaussian fitting of the normalised spectra to model the circumstellar disk and any blue- or red-shifted exocomets present in the Ca II H & K lines. From the fitted Gaussians, five parameters can be extracted, including: radial velocity; absorption depth in H and K; and Gaussian width in H and K. Following exocomets over time allow the tracking of these properties and their evolution (both nightly and over longer timescales).

Photometric Method

Due to the pulsations in β Pictoris, the TESS SPOC light curve must be prewhitened. This removes the pulsational variations from the light curve and returns the residual clean light curve. Two Fourier-analysis software programmes, FAMIAS and SigSpec, are employed to prewhiten any pulsation frequencies between 30 and 85 cycles per day.

Following the example of Zieba et al. [8], a modified version of the model created by Brogi et al. [2] is processed through Markov-Chain Monte-Carlo (MCMC) to fit exocomet detections to the light curve. From the model, exocomet size, velocity, impact parameter, covering fraction and characteristic tail length can be extracted.

Photometry

TESS Sector 6 photometric data for β Pictoris is shown in Figure 1. Post normalisation and pre-whitening of the same data is displayed for comparison in Figure 2.

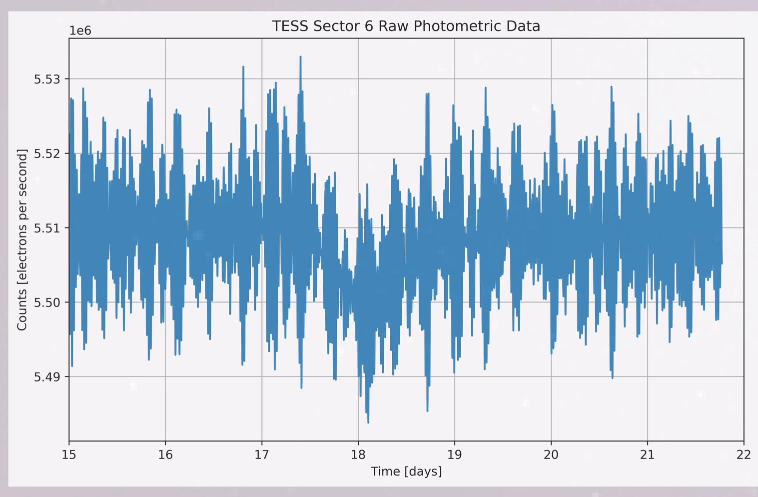

Figure 1. Raw TESS light curve of β Pictoris taken between December 11, 2018, and January 7, 2019

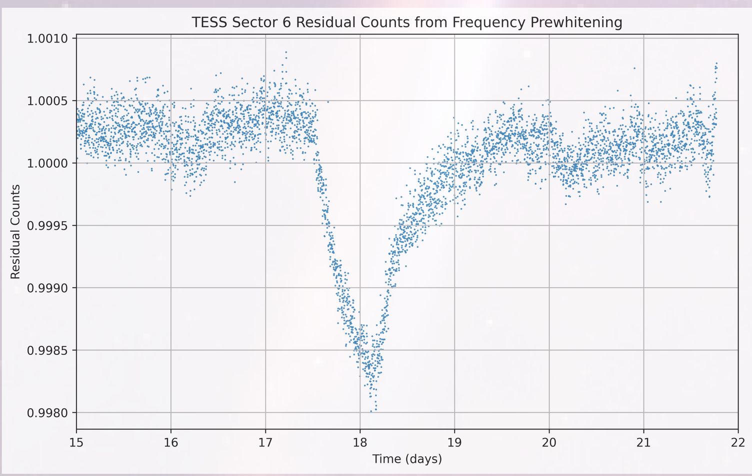

Figure 2. Prewhitened TESS light curve with artefacts and pulsation frequencies removed.

MCMC analysis will determine the best fit model of the prewhitened data, from which the physical and orbital characteristics listed above can be calculated.

Summary

Completing these methods for all available data will provide rich information on the presence and properties of exocomets. Evolution and population statistics of star-grazing exocomet's orbital characteristics, opacity and covering fraction can be determined from the spectroscopic data, while the photometric data will provide statistics about any transiting exocomets size, velocity, impact parameter, covering fraction, and characteristic tail length.

References

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Spectroscopy

The created reference profile for β Pictoris is displayed in Figure 3, where it can be clearly seen that the circumstellar absorption effects have been removed. Figure 4 displays an example of a spectrum that has been normalised by the reference profile.

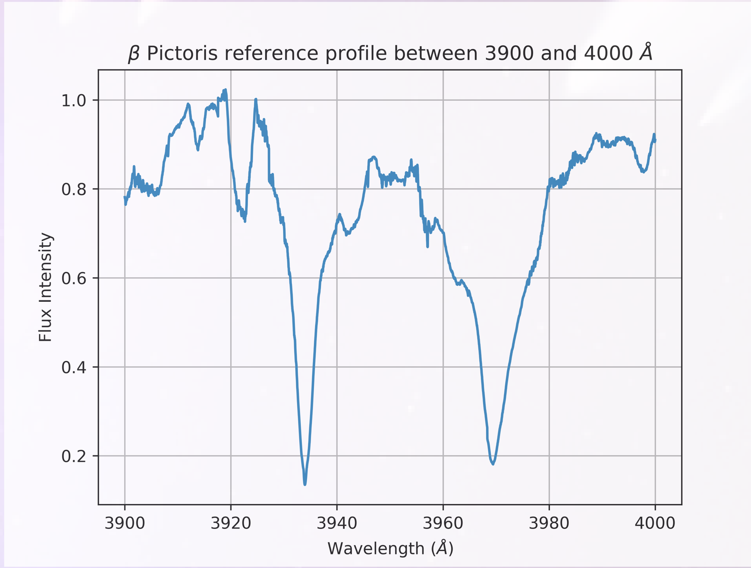

Figure 3. Spectral reference profile for β Pic (between 3900 Å and 4000 Å.)

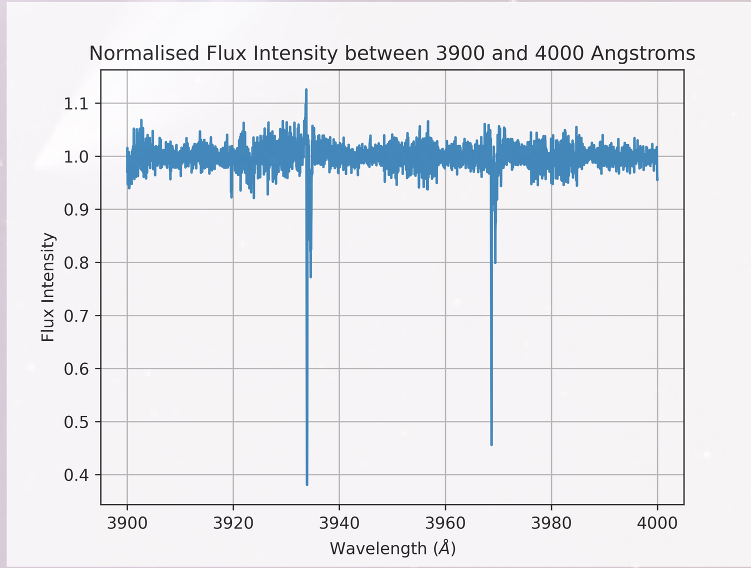

Figure 4. Example of a β Pic spectrum normalised by the reference profile.

Lagrange-Henri et al. [5] and Beust et al. [1] use Gaussian profiles to model exocomets in spectra. We currently employ two methods in the fitting process: automatic fitting using LMfit; and a manual fit with a created python pipeline. The automatic method can work well, and has detected multiple exocomets present in spectra. However it is fallible and does miss some detections. Figure 5 exhibits a good detection from the automatic pipeline. The manual pipeline provides results presented in Figure 6, and, while it guarantees a result, it relies on its visual acceptability and a chi-squared value to determine its suitability. Furthermore, it is much more time-intensive than the automatic method.

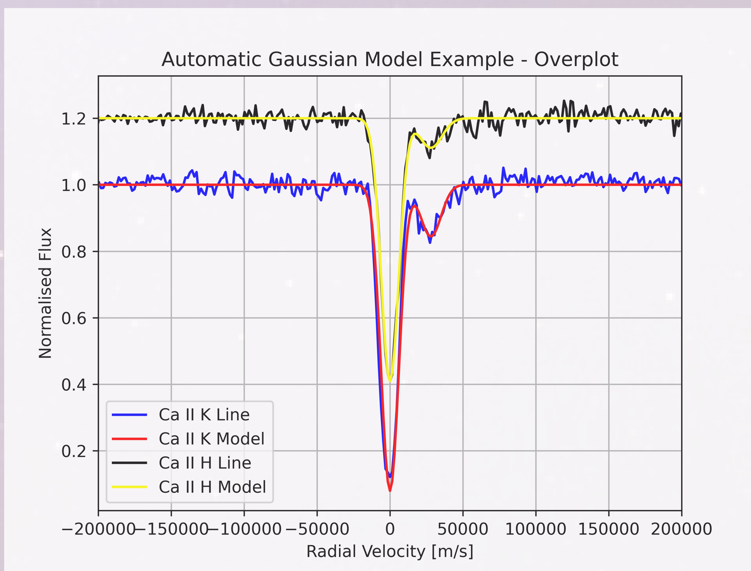

Figure 5. Complete detection of an exocomet in the spectra of β Pictoris by the automatic pipeline.

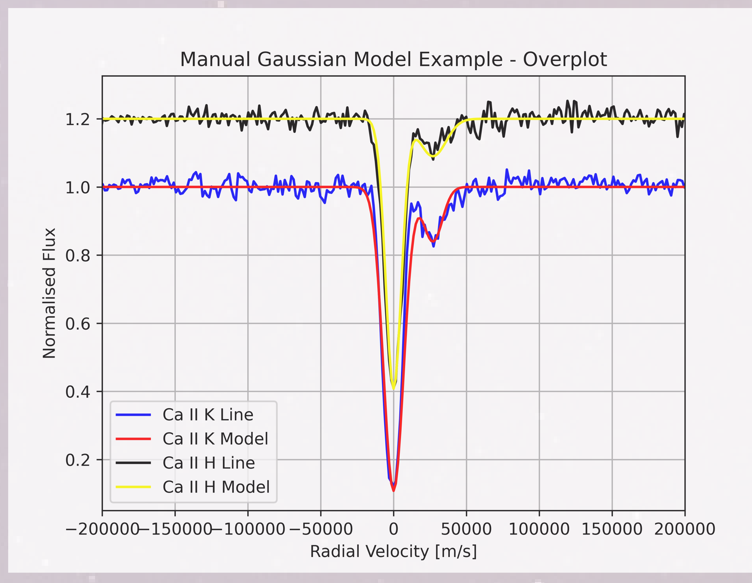

Figure 6. Manual Gaussian model fit to the same observation as the automatic pipeline.

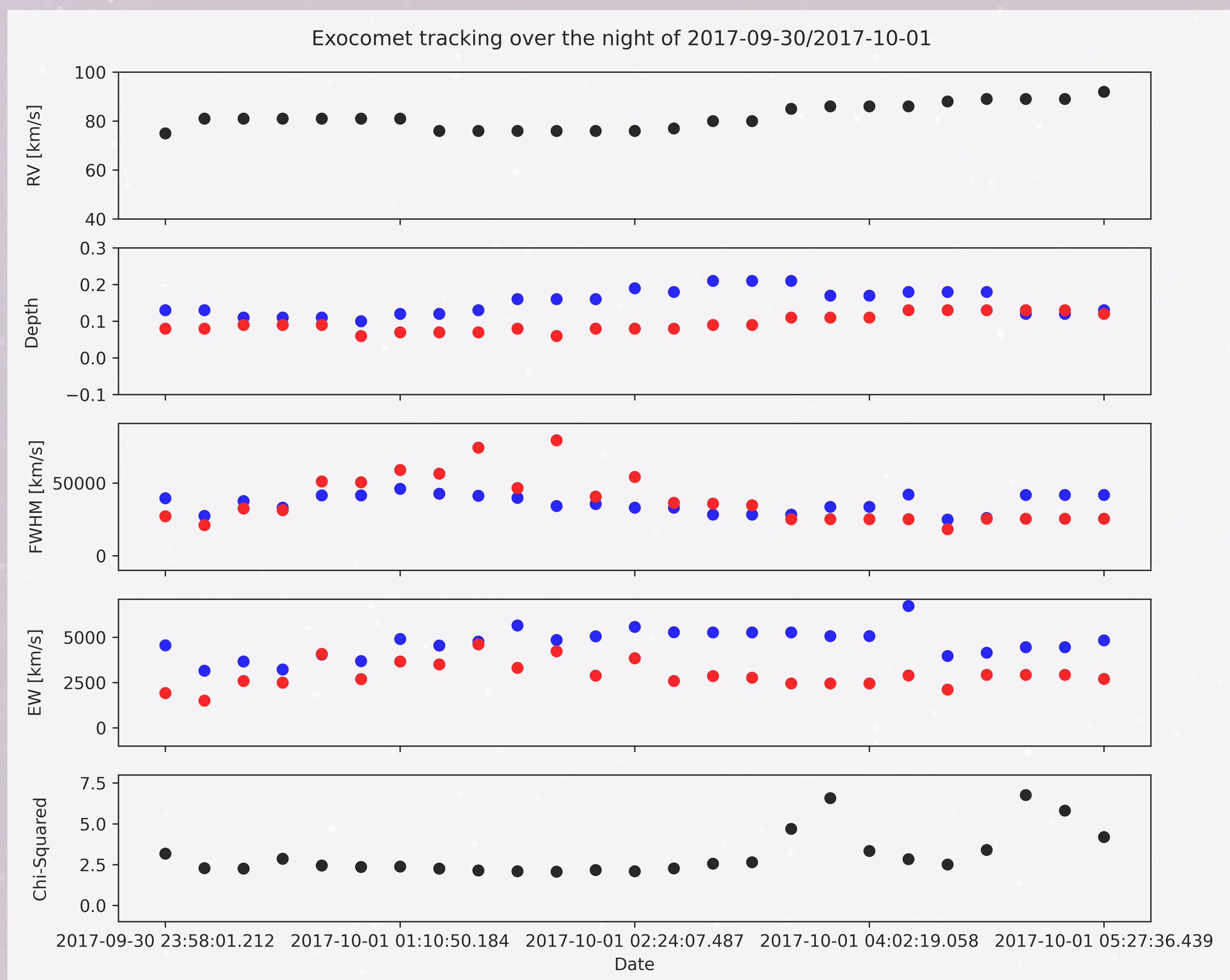

Figure 7. Results from tracking the primary exocomet over a night's observations of β Pictoris. Blue and red values correspond to the Ca II K and H lines respectively.

Figure 7 displays the evolution of an exocomet over a night. The exocomet's radial velocity is gradually increasing, inferring its accelerated in-fall onto β Pictoris.