Mitigating stellar noise by mapping RV activity signals to physical processes within host stars

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The discovery and characterization of extrasolar planets using radial velocity (RV) measurements is limited by noise sources from the surfaces of host stars. Current techniques to suppress stellar magnetic activity often rely on decorrelation using an activity indicator (e.g., strength of the Ca II lines, width of the cross-correlation function). However, flexible activity detrending models—such as Gaussian process regression—are potentially degenerate with Keplerian signals, while physically motivated models—such as FF'—require high cadence observations or simultaneous photometry. Here, we leverage line-by-line and pixel-by-pixel RV measurements to detrend stellar noise, by connecting activity signals to physical processes within host stars. Using HARPS, EXPRES, and NEID observations of standard star HD 26965, we map the convective and photometric components of stellar activity to different ranges of formation-temperature within the host star, through comparison of pixel-by-pixel RV measurements with traditional FF' modeling. Motivated by these trends, we introduce derivative-free FF' modeling, where the difference between RV measurements from distinct formation-temperatures informs a physically motivated spot model. Derivative-free FF' modeling lowers the amplitude of magnetic activity in the HD 26965 RV measurements from over 2.4 m/s to 1 m/s for each instrument, even though the observing cadence of the HARPS data is ten-times lower than the NEID data. Derivative-free FF' modeling is not unique to HD 26965 and offers physically motivated activity detrending over a wide range of observing cadences. Probing sources of stellar activity with line-by-line and pixel-by-pixel RV measurements represents a powerful tool in the future mitigation of stellar activity.