Modeling Stellar Micro-variability in Multiwavelength Observations: Applications to Exomoon Detection

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Intro: Correlated stellar noise on timescales of minutes to days obscures shallow transit signals. To detect exomoons, we will need to model and remove this micro-variability from light curves. Single-wavelength Gaussian process models suffer from the problem of fitting transits as noise and vice versa. Our work extends Gaussian process based correlated noise models to exploit the wavelength-dependence of stellar variability, which allows us to differentiate transit signals from variability features. This model will be applicable to JWST observations of transiting systems. Detecting exomoons would offer insight into the formation of planetary systems and the habitability of exoplanets.

Motivation

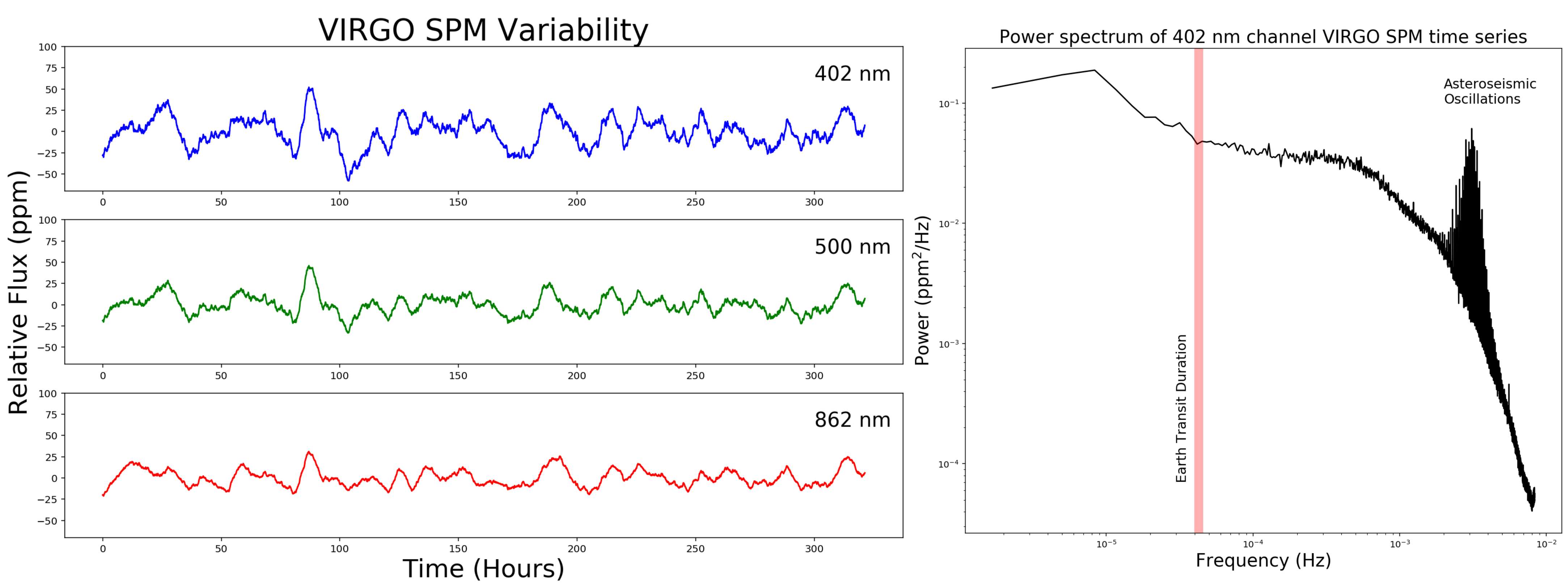


Figure 1. **Left:** Total solar irradiance variability from VIRGO's sunphotometer (SPM) shows correlated variability in three wavelength bands. Variability amplitudes in the 402 nm band are about 1.45 times larger than the 500 nm band, and the amplitude in the 500 nm band is about 1.6 times that in the 862 nm band. **Right:** Power spectrum of VIRGO SPM time series. Significant variability exists on timescales comparable to Earth's transit duration.

Micro-variability Model

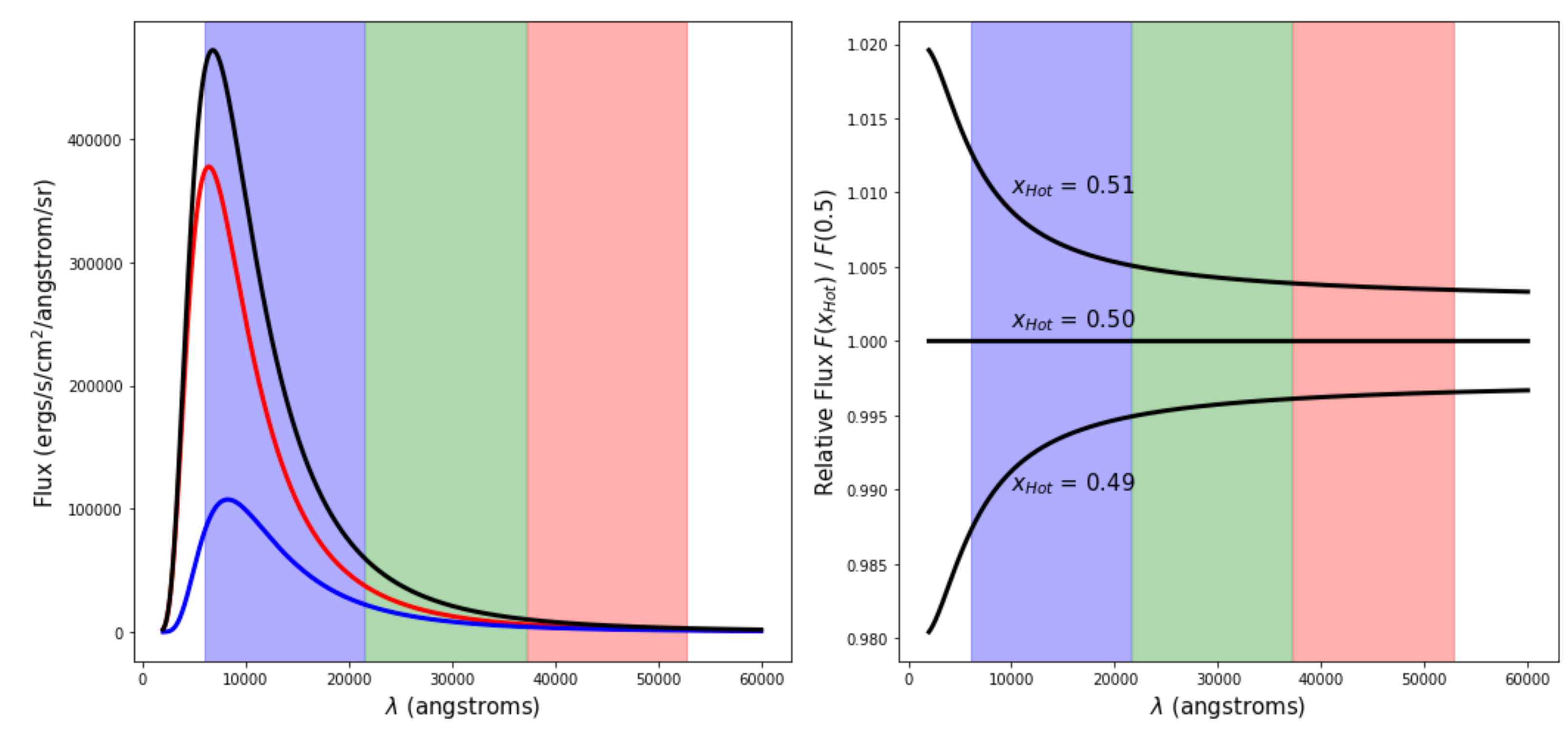
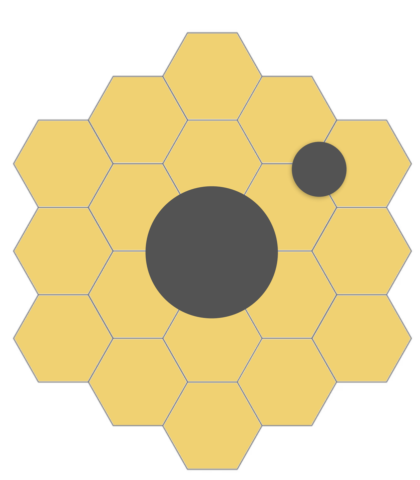


Figure 2. **Left:** Model of a stellar spectrum as the weighted sum of two blackbodies at 4500 and 3500 K, representing contributions from hot and cool components of the stellar disk. **Right:** Variability in the covering fraction of hot and cold components accounts for flux variations in our model. Overlaid colors represent the same wavelength bins as in figure 3.

Exomoons with JWST



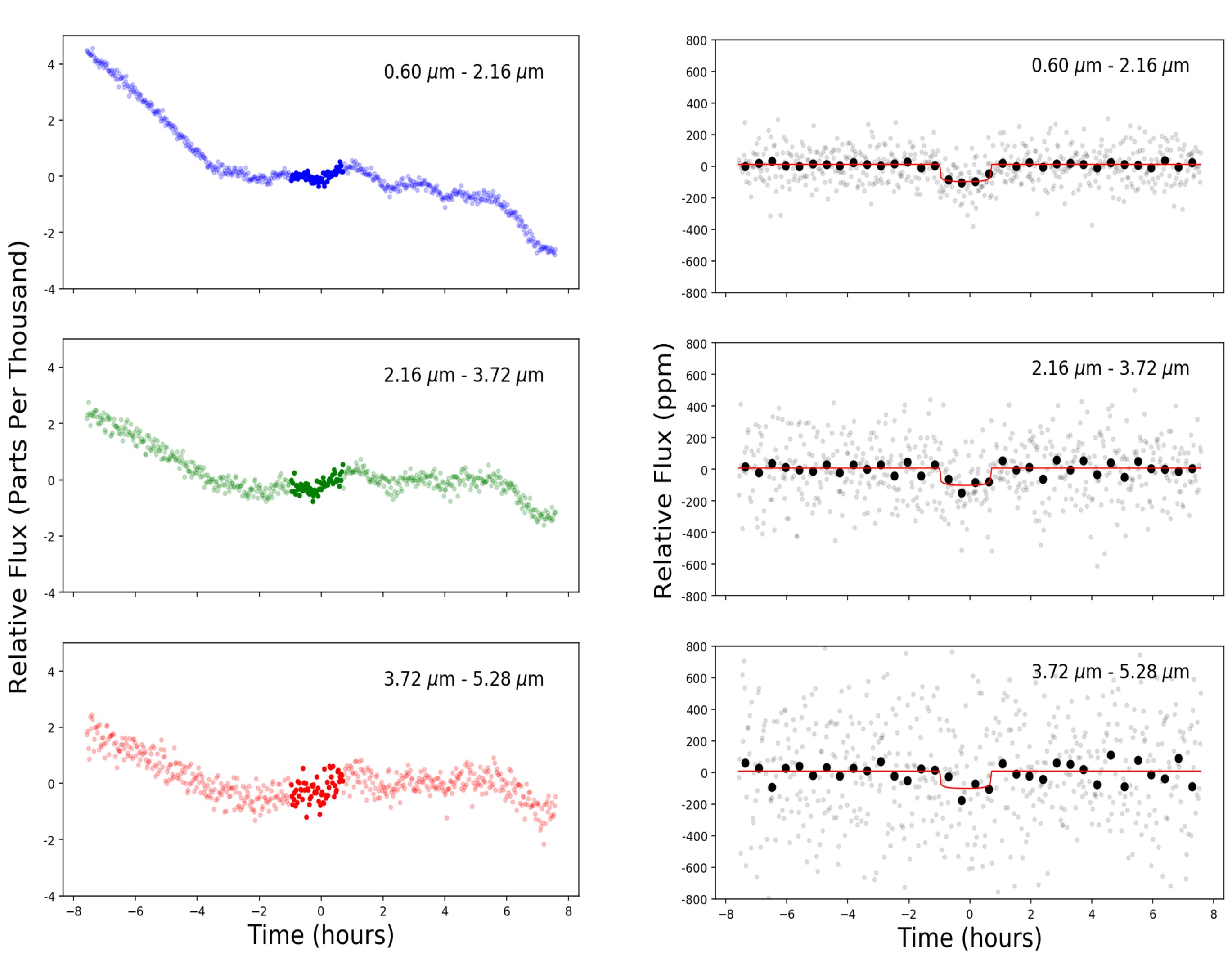


Figure 3. Simulated NIRSpec prism observations of a 190 ppm transit. **Left:** unmodified light curves. **Right:** after filtering with a GP noise model (in this case the transit parameters were known a priori).

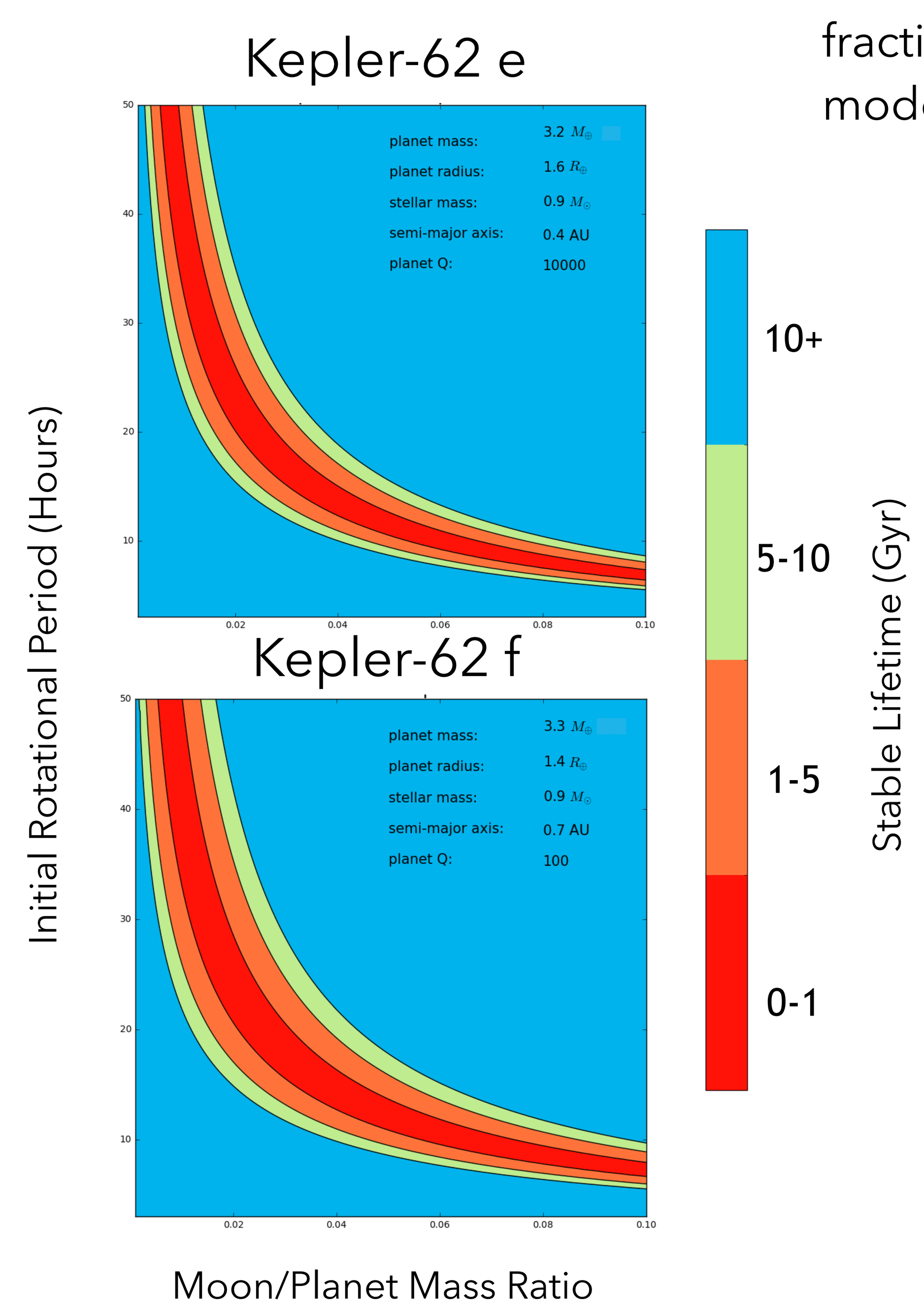


Figure 4. Stability of Exomoons in the Kepler-62 System, one candidate system for hosting habitable zone exomoons.

Next Steps

- Implement this noise model in the Celerite framework (github.com/dfm/celerite) to speed computation.
- Apply to VIRGO data with injected planet + moon transits.
    - Does our two-component noise model explain solar variability, or do we need a more complex model?
- Apply this model to existing multi-wavelength transit datasets (e.g. HST transit spectroscopy).
- JWST Proposal (NIRSpec prism to obtain time-series spectroscopy of transiting systems)

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