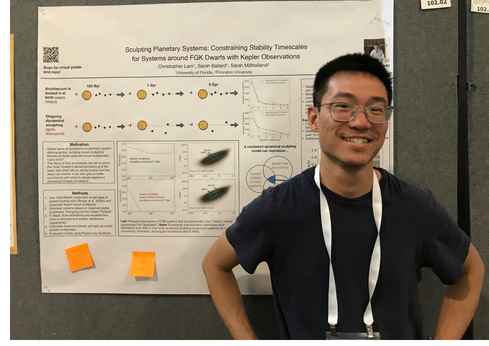
An Information Theoretic Approach to Scheduling Radial Velocity Follow-Up Observations for TESS Systems

Christopher Lam[1,2], Megan Bedell[2], and Lily Zhao[2]

[1]University of Florida, [2]Center for Computational Astrophysics

c.lam@ufl.edu

Scan for virtual poster and repository!



Motivation

- Exoplanet survey missions like *Kepler* and TESS have discovered many more systems than can easily be followed up, since the further study of any one system requires expensive radial velocity (RV) observations.
- RV observations can give us mass constraints on planets, which can be combined with radius constraints from transit surveys to get density — and composition — estimates.
- Previous works have formulated this as an optimization problem to minimize observations and uncertainty and maximize information (Burt et al. 2018; Cloutier et al. 2018).
- We use Fisher Information to quantify the performance of different observing strategies and maximize followup efficiency.

Fisher Information

1. Fisher Information matrix is calculated as:

$$I_{i,j} = \frac{\partial \vec{\mu}}{\partial \vec{\theta}_i}^T \Sigma^{-1} \frac{\partial \vec{\mu}}{\partial \vec{\theta}_j}$$

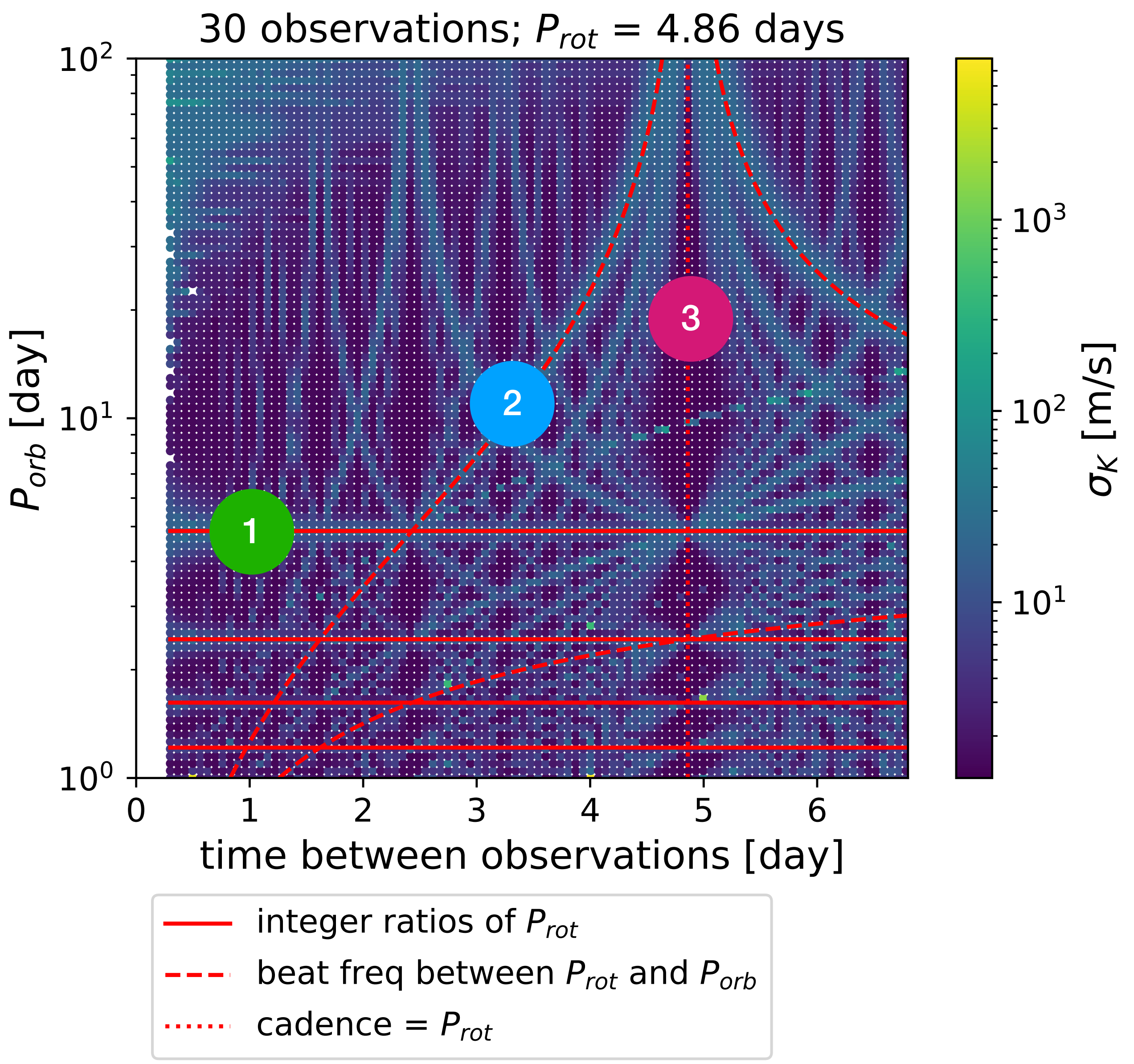
2. For model, $\vec{\mu}$, we assume a circular, single-planet Keplerian orbit
3. For covariance matrix, Σ, the kernel is a quasi-periodic Gaussian Process, which encodes stellar correlated noise:

$$k_{t_a,t_b} = \sigma_{qp}^2 exp[-\frac{(t_a - t_b)^2}{2\tau^2} - \frac{sin^2\frac{(\pi(t_a - t_b))}{P_{rot}}}{2\eta^2}]$$

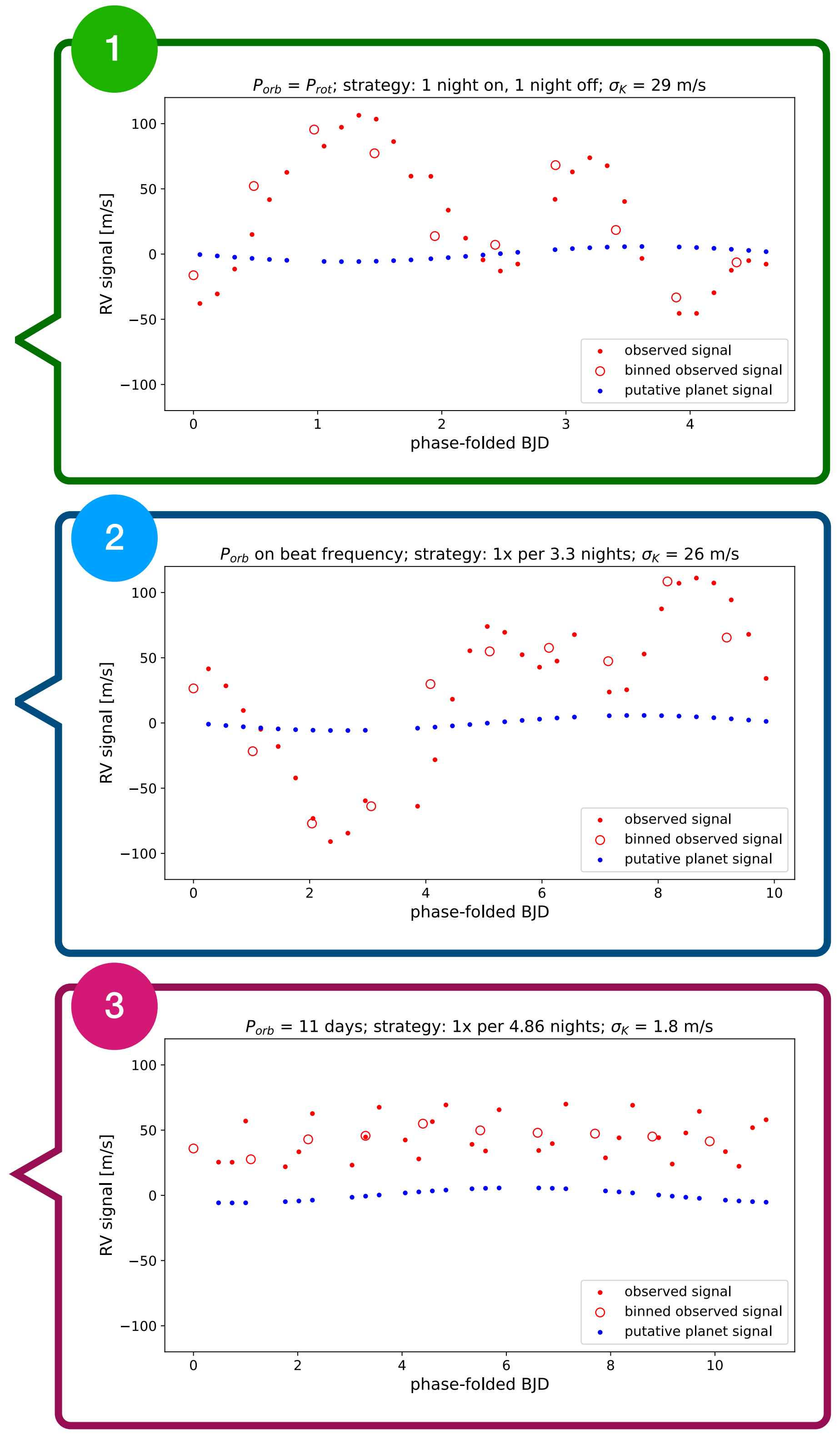
4. We then use the Fisher Information to calculate σ_K

Citations

Burt 2018 AJ 156 25.
Cloutier 2018 AJ 156 82.
Klein 2021 MNRAS 502 188.



The interplay between stellar rotation period, planet orbital period, and observing cadence lead to so-called "beat frequencies", shown as contours of high uncertainty on K (or low information content).



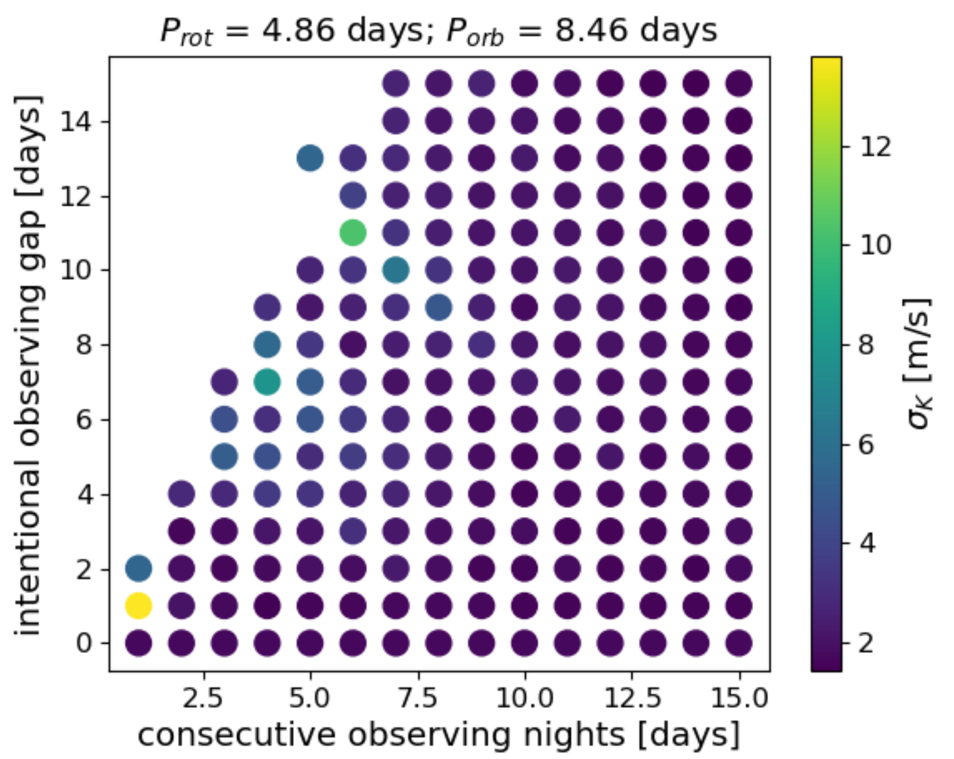
Observing Strategy Considerations/Beat Frequencies

1. Planets with orbital period equal to the stellar rotation period (or its integer ratios) will be difficult to disentangle from the stellar signal.
2. Similarly, beat frequencies between the planet orbital and stellar rotation periods produce circus tent-shaped features of low Fisher Information content that vary based on the choice of observing cadence. These contours represent strategies that result in sampling times when the stellar signal is entangled with the planet signal.
3. An example of a high-information-content strategy, away from any beat frequencies. The phase curve shows that the sampled planet signal is not entangled in the stellar signal.

Strategy Optimization with `gaspery`

Example use case:

- Let's say I want to follow up AU Mic b with the NEID spectrograph on Kitt Peak and have 30 observations to spend. My choice of target, observing budget, and location informs the white noise and time available to observe.
- I first feed in fitted GP model parameters from sources like Klein+ 2021. This informs the covariance matrix.
- I then feed in transit parameters from TESS (central crossing time and orbital period) and an expected K.
- Now I can try different strategies and build a map showing where the best and worst of them are.



Dots are not drawn if a strategy leads to an observing baseline that takes us past the end of the observing season. A strategy of {5, 2} would be 5 nights observing, 2 nights off, and so on until 30 observations are made. Most strategies in this case perform comparably, although there are some near the edge of the observing baseline that are poor.

Acknowledgments

Material is based on work done during the CCA Pre-Doctoral Fellowship and is also supported in part by the National Science Foundation GRFP under Grant No. 1842473.