Fishing for Planets: Analyzing the Fisher Information Content of EPRV Exoplanet Surveys

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Extreme Precision Radial Velocity Exoplanet Surveys

For exoplanet surveys using spectrographs such as NEID (the NEID Earth Twin Survey) and HARPS-3 (the Terra Hunting Experiment), which have the advantage of sub m s^{-1} instrumental precision, the dominant source of noise – and the primary obstacle to detecting low-mass, long-period exoplanets – is expected to be correlated noise from stellar variability. By leveraging our understanding of variability to better inform observing strategy decisions, we can improve our chances of success.

Fisher Information

The Fisher Information (FI; Fisher 1922) content of a dataset tells us the expected uncertainty on a corresponding set of model parameters based on the noise properties of the data. Calculating the FI is an efficient method of predicting the detection sensitivity limits of a radial velocity exoplanet survey.

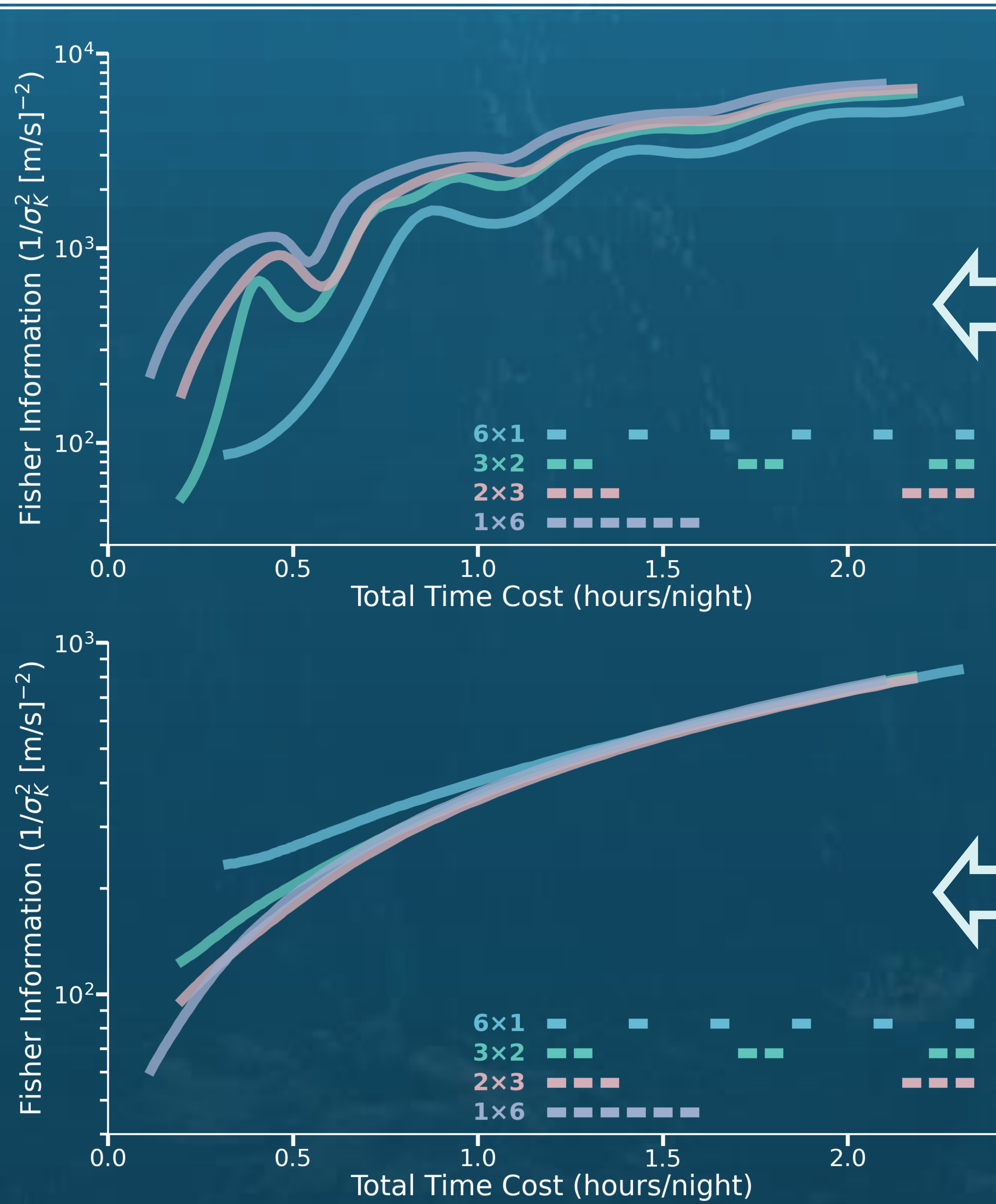


Figure 1a. Based on 100 nights of observations with 6 observations per night. Total time cost accounts for typical overheads. Fisher Information is calculated for an Earth analog.

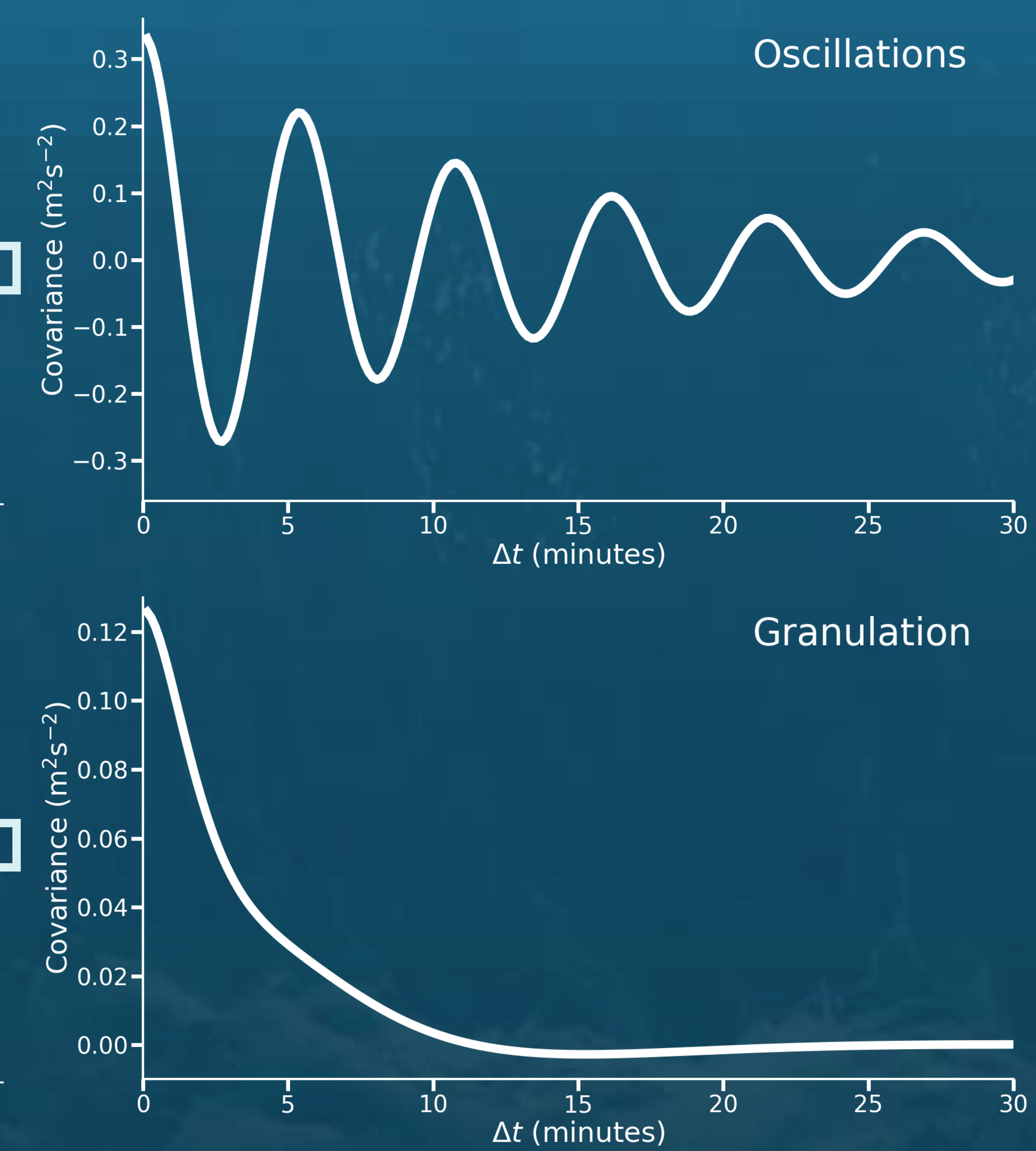


Figure 1b. Oscillation and granulation covariance kernels for a Sun-like star; taken from Luhn et al. (2022) based on work by Guo et al. (2021).

Oscillations & Granulation

On timescales of a single night, p-mode oscillations and granulation have significant correlated noise contributions. We explore four intra-night observing strategies: 6 uniformly spaced observations, 3 pairs of 2, 2 sets of 3, and a sequence of 6 back-to-back. When a granulation term is included, the first strategy maximizes the FI, but when oscillations are included, the last strategy performs best

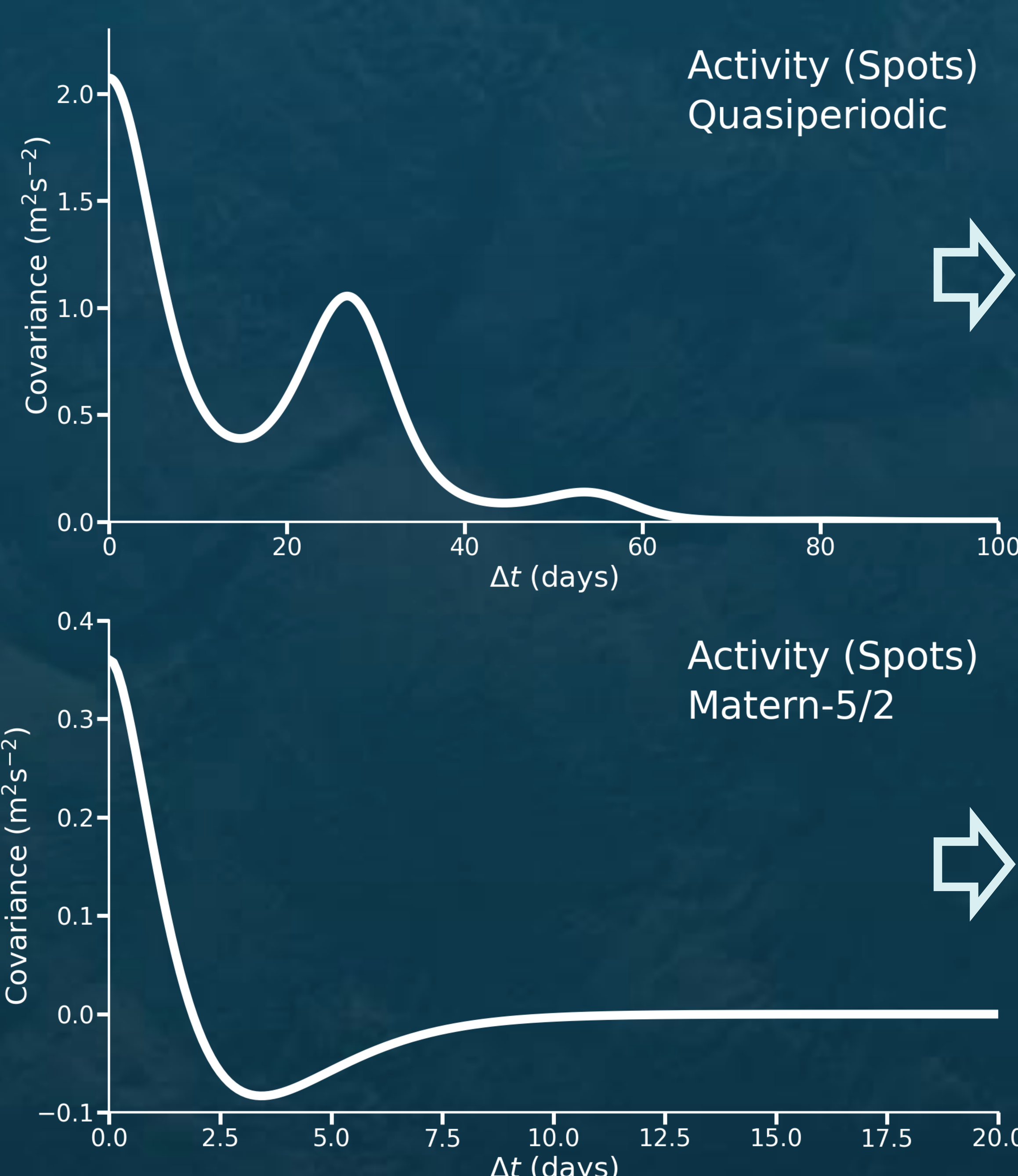


Figure 2a. Spot covariance kernels for a Sun-like star; Matern kernel taken from Luhn et al. (2022) based on work by Gilbertson et al. (2020), and Quasiperiodic kernel taken from Langellier et al. (2021).

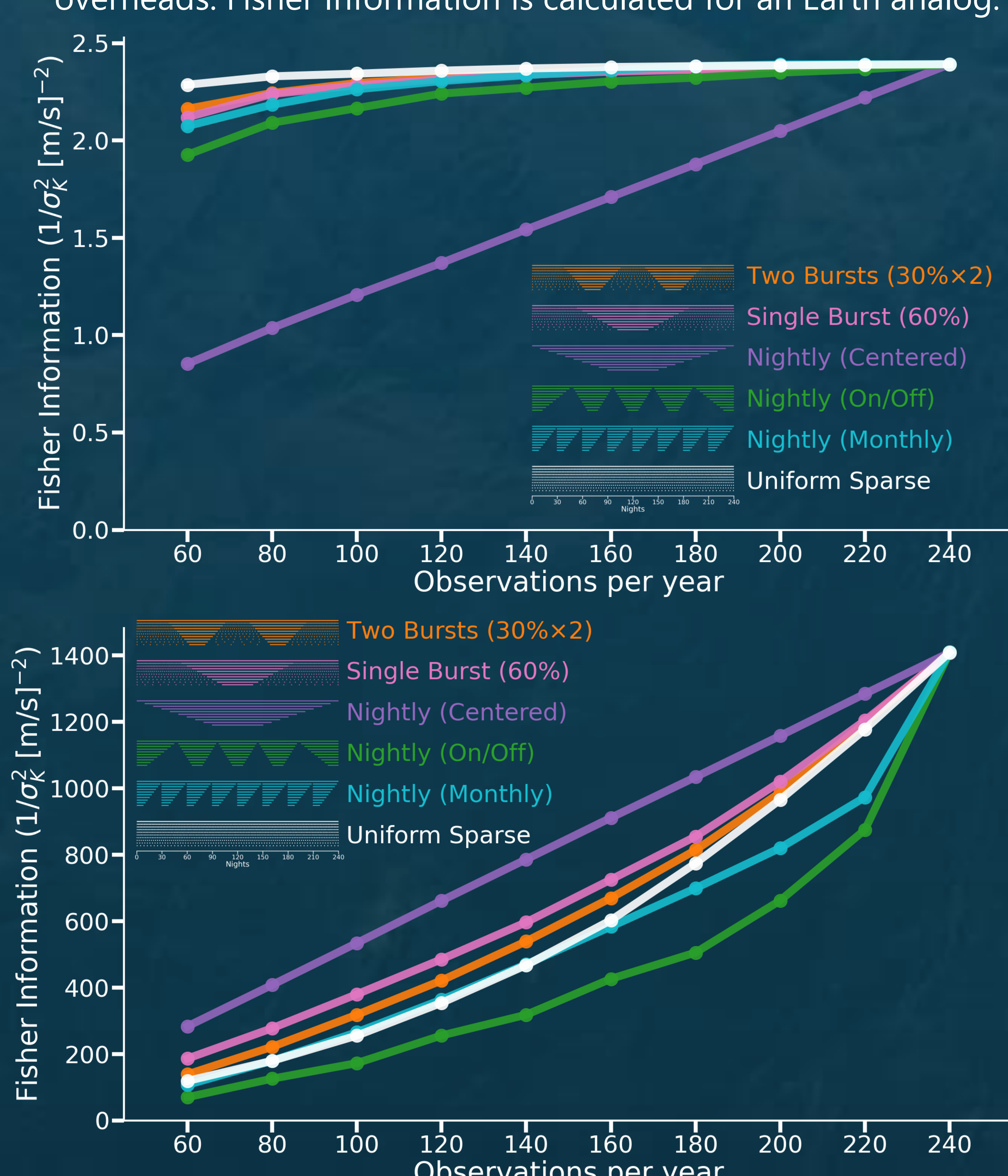


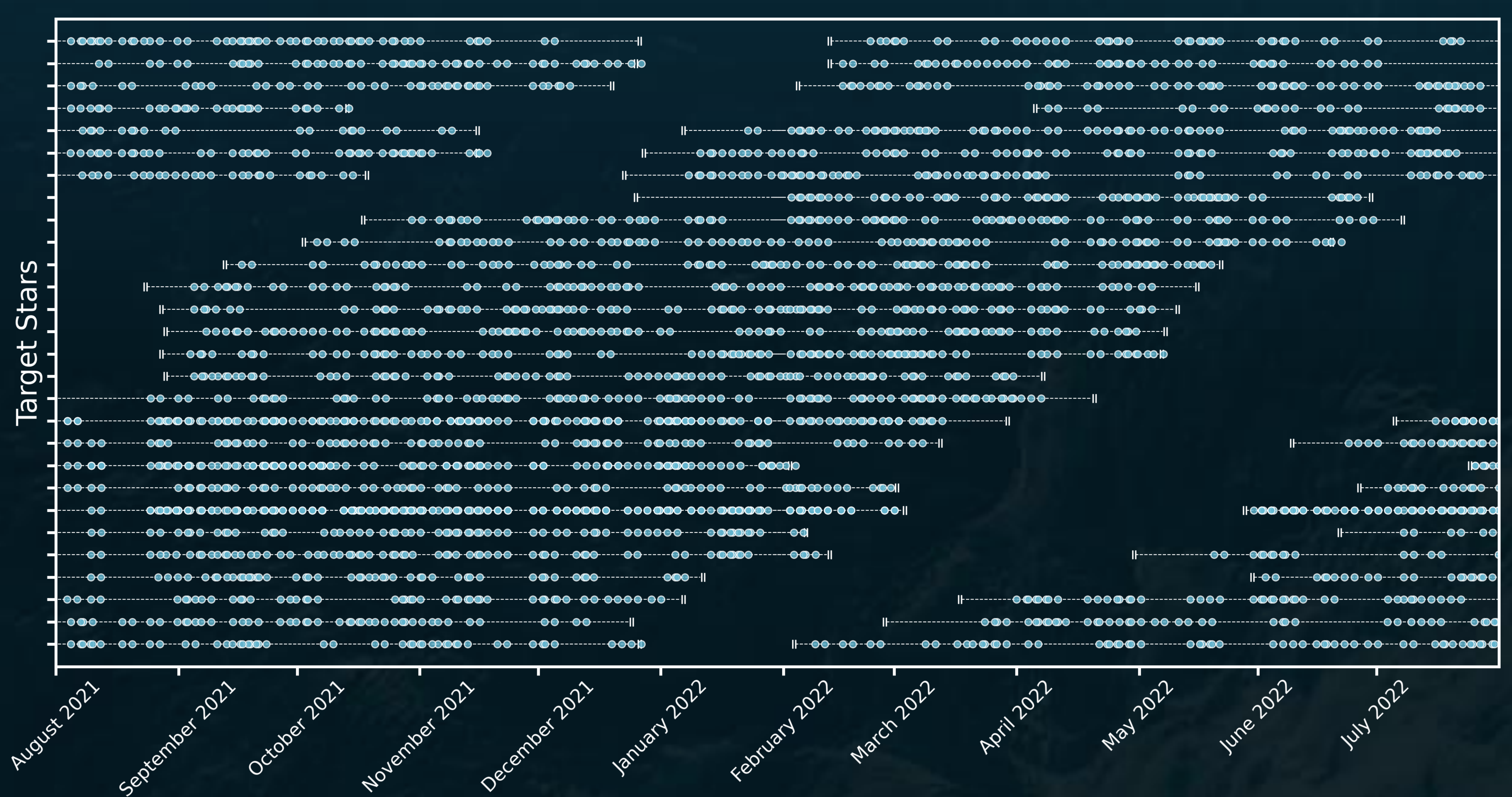
Figure 2b. Based on 10 years of simulated observations. FI is calculated for $K = 10\ \mathrm{cm\ s^{-1}}$, $P = 300$ d rather than $P = 365$ d to avoid phase sampling limitations.

Activity-induced Variability

Across many nights, stellar activity is the most important source of correlated noise. We consider several strategies for distributing observations across an 8-month observing season for two different activity kernels. While some strategies clearly deliver higher radial velocity precision, we note that the preferred strategy is strongly model dependent.

Simulating a Survey with Realistic Constraints

While the above tests rely on an idealized observing schedule, we have also built a survey simulation tool that accounts for real world constraints such as weather losses, intra-survey competition for telescope time, and each star's individual observing season.



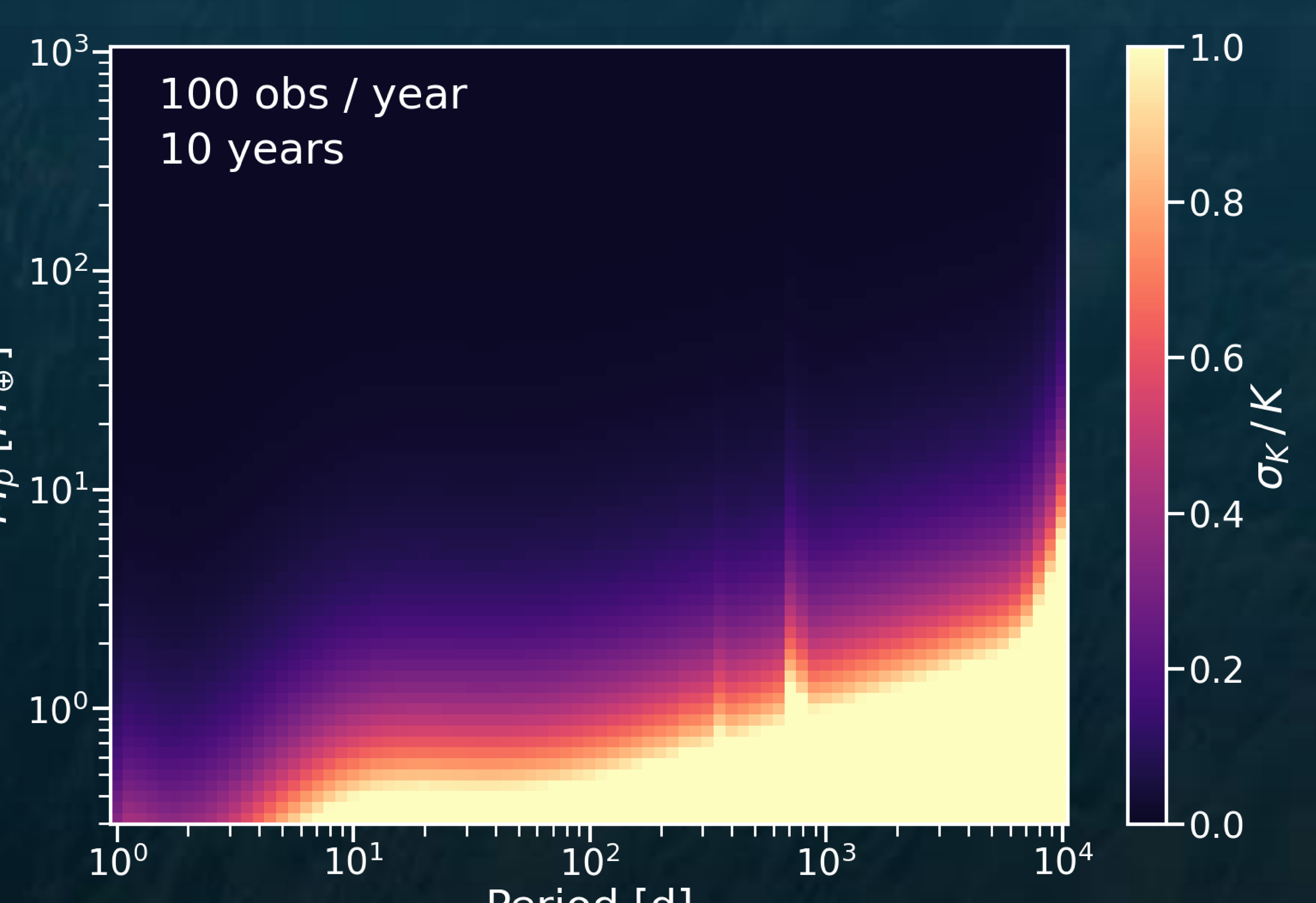


Figure 3. Detection sensitivity for simulated observations of a Sun-like star. Our model assumes zero eccentricity.

Detection Sensitivity Limits

When we simulate a survey accounting for realistic observing constraints and all sources of noise, we can calculate the FI of the resulting observations and determine the sensitivity limits for each star.

References:
[1] Fisher, R. A. 1922, Philosophical Transactions of the Royal Society of London Series A, 222, 309 **[2]** Guo, Z., Ford, E. B., Stello, D., et al. 2022, arXiv e-prints, arXiv:2202.06094 **[3]** Gilbertson, C., Ford, E. B., Jones, D. E., & Stenning, D. C. 2020, ApJ, 905, 155 **[4]** Langellier, N., Milbourne, T. W., Phillips, D. F., et al. 2021, AJ, 161, 287 **[5]** Luhn, J. K., Ford, E. B., Guo, Z., et al. 2022, arXiv e-prints, arXiv:2204.12512