Optimization of Automated Planet Finder Observing Strategy

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Abstract

We evaluate radial velocity observing strategies to be considered for future planet-hunting surveys with the Automated Planet Finder, a new 2.4-m telescope at Lick Observatory. Observing strategies can be optimized to mitigate stellar noise, which can mask and imitate the weak Doppler signals of low-mass planets. We estimate and compare sensitivities of 3 different observing strategies to planets around G2-M2 dwarfs, constructing RV noise models for each stellar spectral type, accounting for acoustic, granulation, and magnetic activity modes. The strategies differ in exposure time, nightly and monthly cadence, and number of years. Synthetic RV time-series are produced by injecting a planet signal onto the stellar noise, sampled according to each observing strategy. For each star and each observing strategy, thousands of planet injection recovery trials are conducted to determine the detection efficiency as a function of orbital period, minimum mass, and eccentricity. We find that 4-year observing strategies of 10 nights per month are sensitive to planets ~25-40% lower in mass than the corresponding 1 year strategies of 30 nights per month. Three 5-minute exposures per night provide a 10% gain in sensitivity over the corresponding single 15-minute exposure strategies. All strategies are sensitive to planets of lowest mass around the modeled K7 dwarf. This study indicates that APF surveys with the year strategies should detect Earth-mass planets on <10-day orbits around quiet late-K dwarfs as well as >1.6 Earth-mass planets in their habitable zones.

The Automated Planet Finder (APF)

• 2.4-m robotically controlled telescope operating at Lick observatory
• Currently being commissioned
• Half of observing time dedicated to Geoff Marcy & Andrew Howard
• Levy Spectrometer presently installed: ~1 m/s RV precision expected

• Detection of low-mass planets is limited by stellar noise
• Must optimize observing strategy to mitigate modes of stellar noise and make best use of available time

OBJECTIVE OF THIS STUDY:
Estimate APF planet detection sensitivity as function of observing strategy. Test stars of different spectral types, each with a unique RV noise model.

Methods

Stellar Noise Models

• Created for main sequence stars of 5 spectral types G2-M2

Granulation Phenomena & p-mode Oscillations

• Modeled by correlating velocity power spectra fitting parameters (Dumusque et al. 2011) with log(g) and converting to RV time series.

Magnetic activity

• Modeled as superposition of 3 sinusoids, P = 1, 1/2, 1/3 times stellar rotation period (these modes are known to dominate).

Amplitudes derived from observations (See Fig. 2)
• Quasi-coherent

Results

Detection Sensitivity

Simulated observing strategies

• Eta-Earth Survey observations of M2 dwarf Gl 15A (M2 dwarf) and K dwarf HD 136608 (K7 dwarf) resulting in known planetary orbit periods and minimum mass of the injected planet.

Quantifying detection sensitivity

• Keplerogram peak is above the 1% FAP threshold and detected (i.e., Keplerogram peak is above the 1% FAP threshold and detected (i.e., KEPLEROCOMBI), which is the true detection sensitivity. For bins with all K2 dwarf observations using the 1N1 and 1N4 strategies, a transition from 100% to < 1% FAP is observed (e.g. planetary transit).

Sensitivity of Best (3N4) Strategy

• Sensitivity ultimately limited by stellar magnetic activity at rotation period
• Multi-year time baseline needed to leverage long-term incoherence of magnetic activity
• 4-year strategies of 10 nights/month sensitive to planets ~25-40% lower in mass than corresponding 1 year strategies of 30 nights/month
• 5-min exposures sufficient to mitigate p-modes (minutes-long timescales)
• 2 x 5-min nightly exposures better mitigate granulation modes (hours-long timescales) compared to a single 15-min nightly exposure, improving sensitivity by ~10% (marginal gain possibly negated by increased overhead)

3N4 strategy with APF should be 2-3 x more sensitive than current Eta-Earth survey at Keck and sensitive to HZ planets as small as 1.6 Earth-masses

We now have a useful toolkit to guide future APF observations!

References


Figure 1: Location of HD map of the 5 stars for which RV noise models were created (grove).

Figure 2. Top: RV time-series (black dots) corresponding to ~250-day window of the Eta-Earth Survey observations of M2 dwarf Gl 15A (M2) and K dwarf HD 136608 (K7). Signals of known planets have been removed. The best Keplerogram fit (red line) for Gl 15A has semi-amplitude 1.3 m/s, which is adopted as the magnetic activity noise level for the M2-dwarf model. The best Keplerogram fit for HD 136608 is poor and has semi-amplitude 2.5 m/s, which is adopted as the magnetic activity noise level for the K7-dwarf model. Bottom: Stellar magnetic activity (dark) measured simultaneously with RV measurements (top). The S2 variation for the K3-dwarf is used relative to that of the M2 dwarf (bottom left).

Figure 3. Linear fits to the APF detection sensitivity compared to each observing strategy in the P - M space plane. Data points correspond to a different stellar spectral type as labeled.