

Simulating Precursor Radial Velocity Surveys for Future Exoplanet Direct Imaging Missions

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Motivation

Space based direct imaging exoplanet surveys proposed for the 2020s and 2030s (e.g.: WFIRST, HabEx, LUVOIR) are expected to be very expensive for the (high value) data that they will return. Observation time and therefore cost can be reduced by a factor of 2 to 10 if the telescopes can be aimed exclusively at known/imageable exoplanets, but first these planets must be found. Improvements in ground based spectrographs may make such pre-targeting possible with a radial velocity survey in the 2020s. The simulations here are being developed to estimate recovery rates and parameter accuracy.

Code Description

Our survey code uses the MINERVA scheduler as a starting point, which we have modified for our simulations. It performs a physically motivated Monte Carlo simulation of an observing campaign, and includes a visualization script for the results. We take site location (latitude, longitude, altitude, weather), target properties (right ascension, declination, exposure time), survey duration, sun/moon position, and telescope properties (park position, slew speed, integration time, minimum altitude) into consideration. We output sun/rise set times, star rise/set times, star observation logs (altitude, azimuth, conditions), and general survey metadata.

Our radial velocity precision code uses a semi-analytic model of astrophysical sources of uncertainty, given an input SNR and wavelength range (Beatty and Gaudi 2015). This model considers the effects of: Stellar spectrum (BT-Settl), spectrograph resolution, $\log(g)$, T_{eff} , metallicity, $v \cdot \sin(i)$, and macroturbulence on RV signal. It does not consider stellar activity or tellurics as noise sources.

Our planet demographics code draws planets from several preexisting occurrence distributions (SAG 13, Bryan et al. 2016, Cumming et al. 2008, Fernandes et al. 2018), then applies a check based on minimum mutual hill radii for long term stability (Kane et al. 2016). Unstable planets are removed from our initially drawn populations. Later we repeatedly redraw planets (outside a "trusted" region of 0.5 AU) to approximate maximally packed, yet stable, systems.

Where (and what) are the best stars?

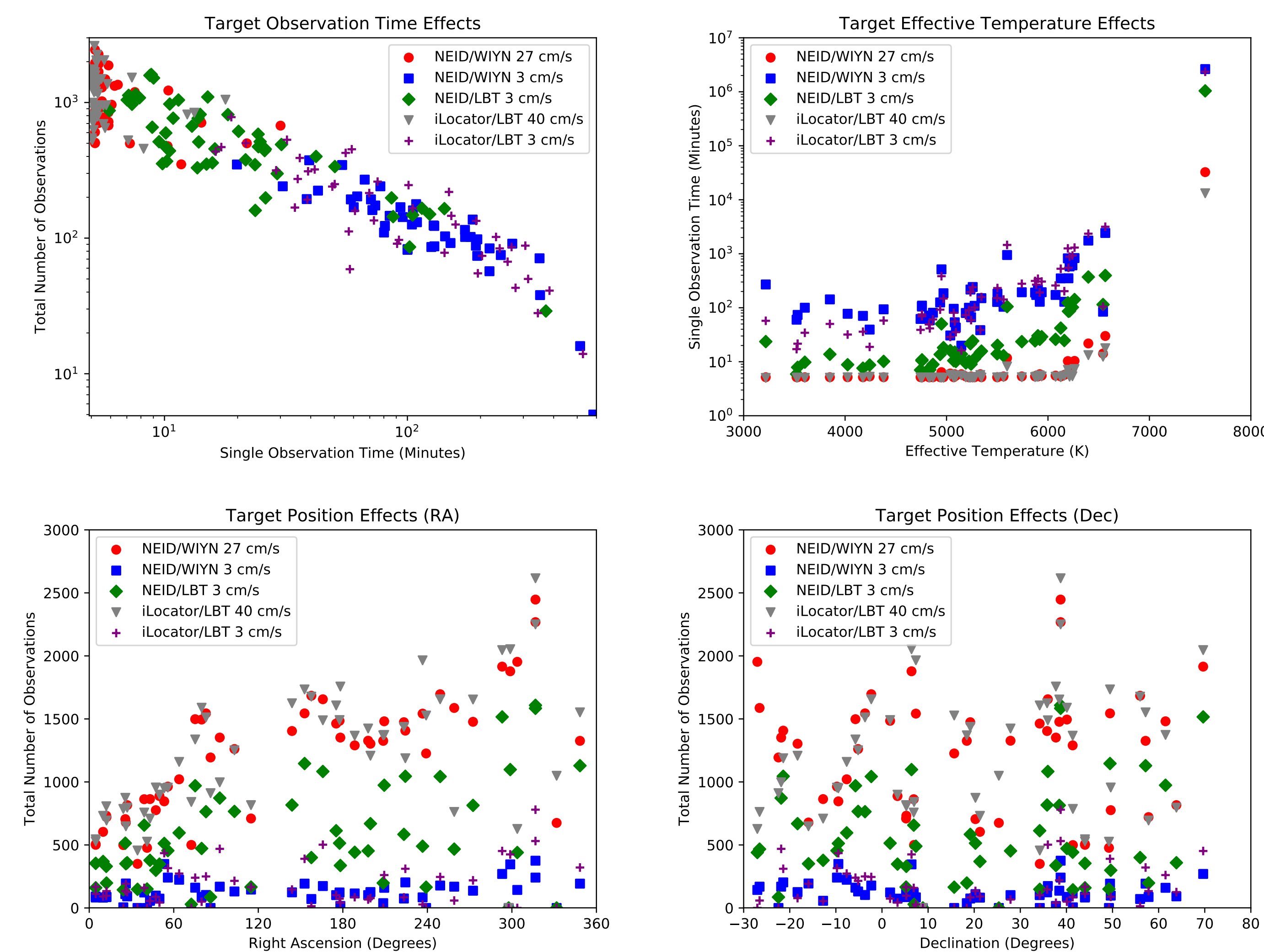
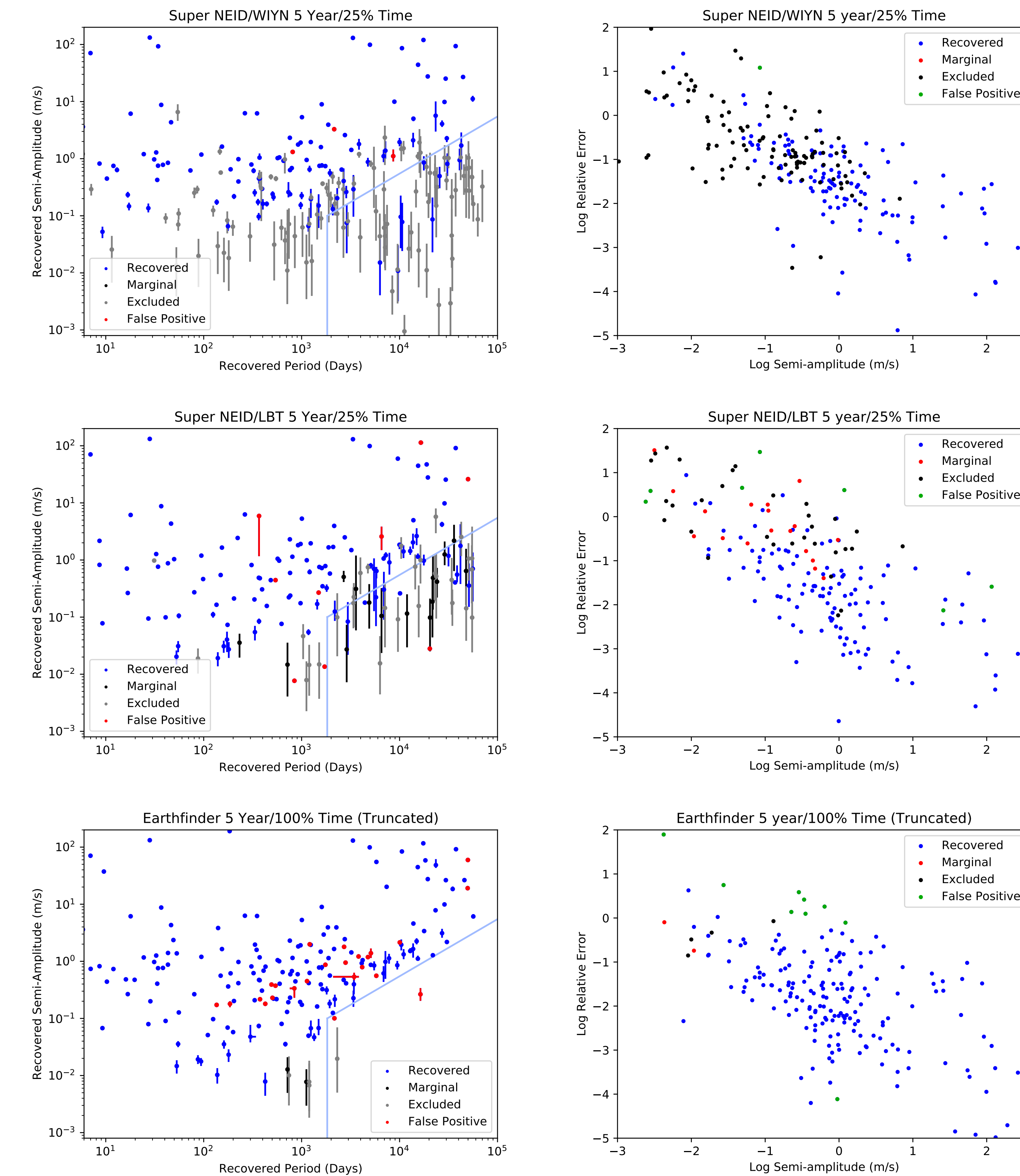


Figure: Number of observations vs right ascension, declination, and measurement time for a 53 star 5 year 100% time survey on several instruments and measurement precisions. Also shown is measurement time as a function of effective temperature. Variations in exposure time tend to wash out previous effects seen in stellar location.

Recovering Planets

Planet recovery is performed via inputting the observations and "guess" orbital parameters into radvel (Fulton et al 2018). Radvel runs an MCMC analysis to give probability distributions of the planet parameters, and the likelihood of different system configurations. At present, the initial guesses are the actual parameters (the best case scenario). For the purposes of these graphs, recovery is defined by a planet being in the most likely system architecture. Marginal planets appear in systems with a close log likelihood. False positives deviate from their actual (known because these are simulated systems) period or semi-amplitude by more than 10 percent and 3 sigma.



References

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Example Systems

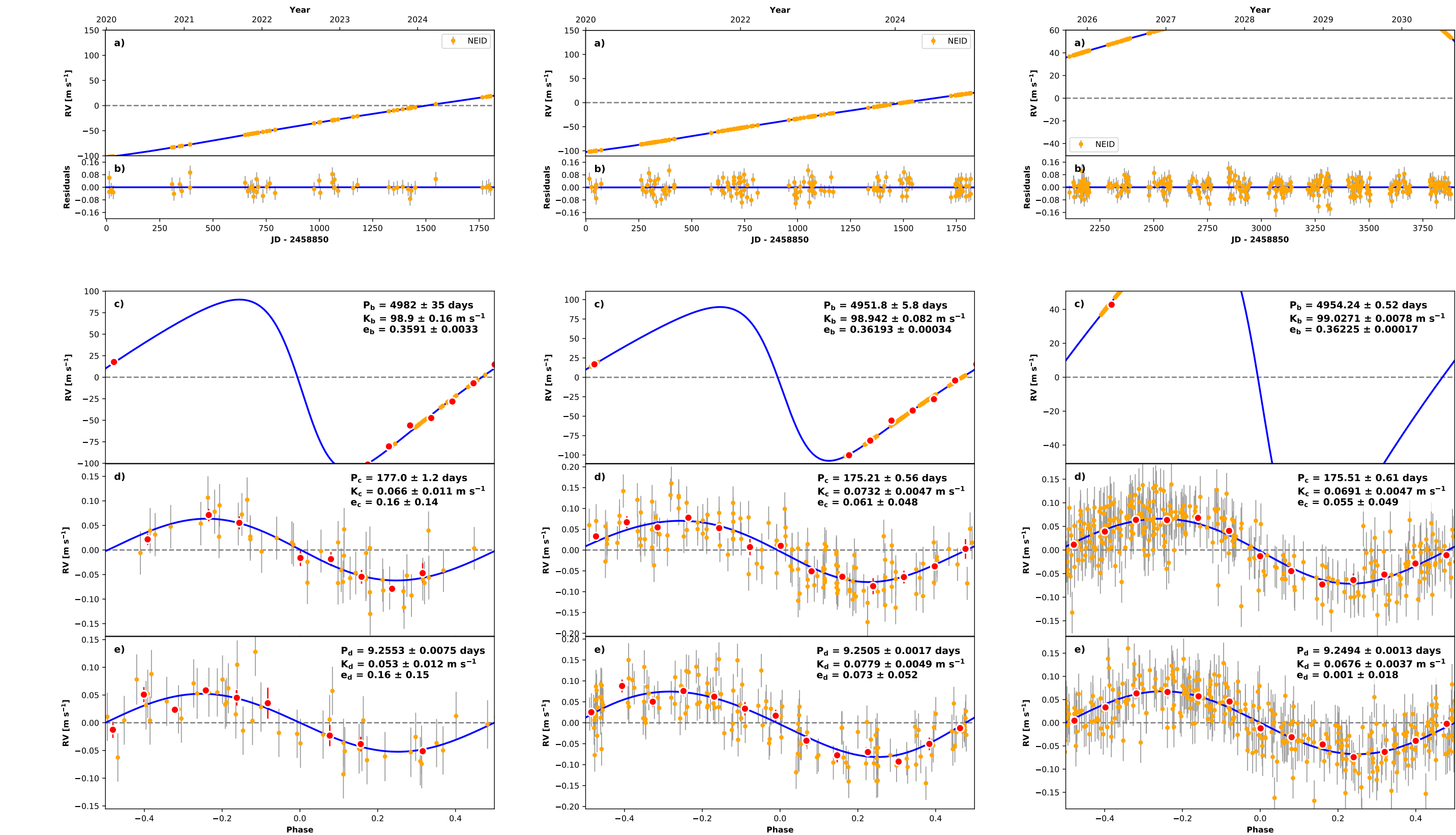
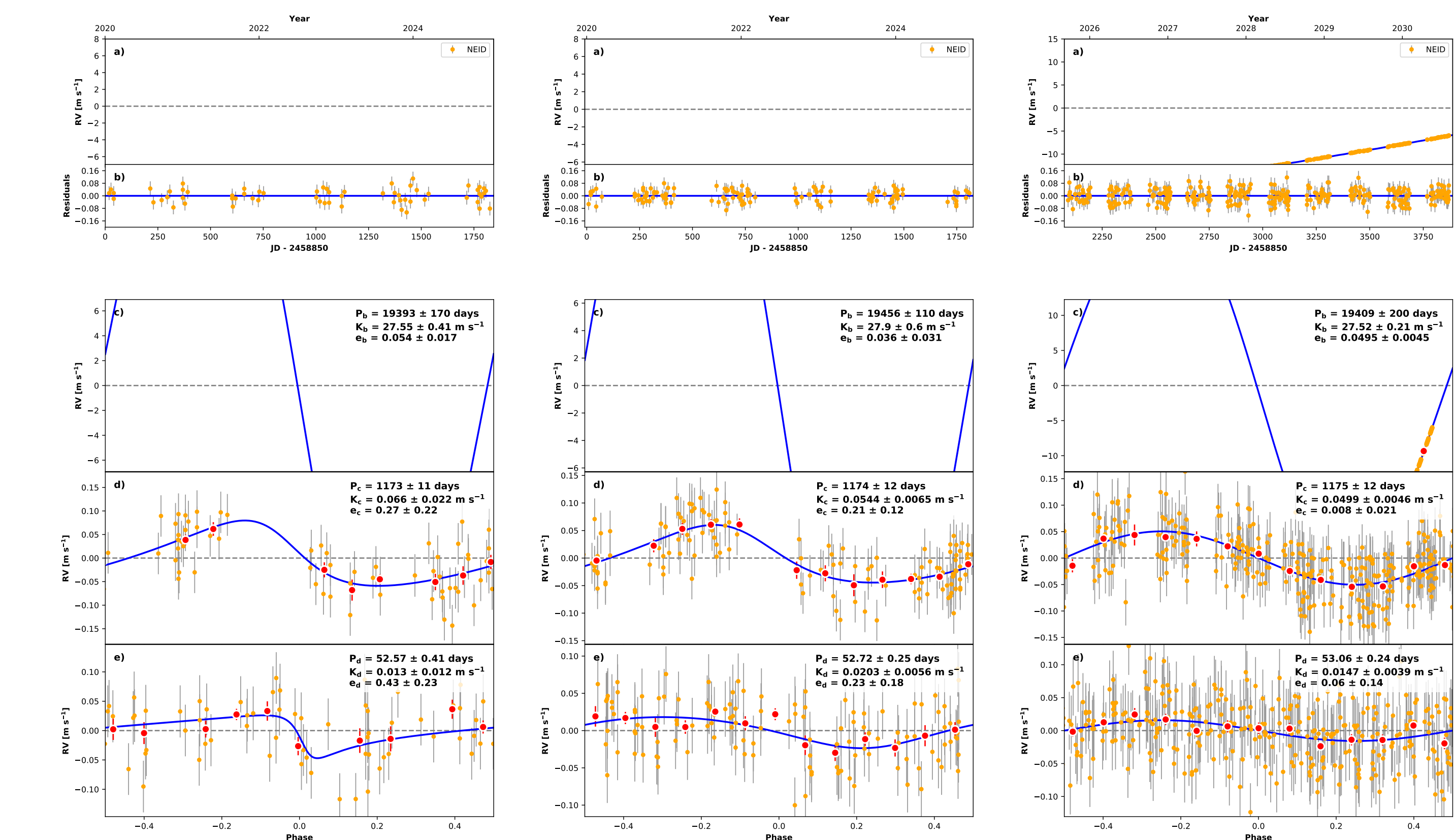


Figure: HIP 19849 (above) and HIP 17378 (below) with simulated 3 planet systems, as observed by a 3 cm/s Super NEID instrument. Telescopes considered are the ground-based on the WIYN (left), LBT (center), and space-based Earthfinder (right).



Conclusions and future work

Both stellar effective temperature and telescope aperture are important to high precision radial velocities. Bright F stars present impractical observation times compared with nearby K dwarfs. Even for these stars, exposure times can become unphysically long without eight meter class instruments. Previously seen effects in right ascension and declination are largely washed out by the heterogeneous (and sometimes short) nature of actual exposure times. If single measurement precisions of 3 cm/s can be obtained, then an extended campaign may be able to find earth analogs. Direct analogs around sunlike stars are in a marginal region, but super-earths and cooler stars are distinctly practical. We are currently looking into to what extent stellar activity degrades these signals, and how much it can be corrected.

Acknowledgements

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