Simulating Radial Velocity Precursor Surveys for Target Yield Optimization in Future Exoplanet Direct Imaging Missions

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Survey, and exposure time/RV precision codes.

Abstract

Future direct imaging missions such as WFIRST, HabEx, and LUVOIR aim to catalog and characterize Earth-analogs around nearby stars. With the scope and expense of these missions, the exoplanet yield is strongly dependent on the frequency of Earth-like planets, and the a priori knowledge of which stars specifically host suitable planetary systems. Ground-based radial velocity surveys can potentially perform the pre-selection of targets and observation times at a fraction of the cost of a blind direct imaging survey. We present the first phases of simulations of such a survey. We consider multiple telescopes, including their locations, weather conditions, observation time limitations, and instrument sensitivities. Multiple target selection optimization algorithms are considered. From this, we generate realistic measurement frequencies, qualities, and RV precision. We will next inject and recover the masses and orbital parameters of real and simulated planets, estimating the effectiveness and optimizing the yield of a precursor radial velocity survey.

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 determine if and to what extent such ground based surveys are worthwhile. At present, this is a proof of concept that a multi-year survey with a large telescope can provide a useful number of observations at useful precision.

Survey Code Description

Our survey code uses the MINERVA scheduler as a starting point, which we have modified for our simulations. It performs a 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 an 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·sin(i), and macroturbulence on RV signal. It does not consider granulation or starspots/faculae.

Example RV Precision

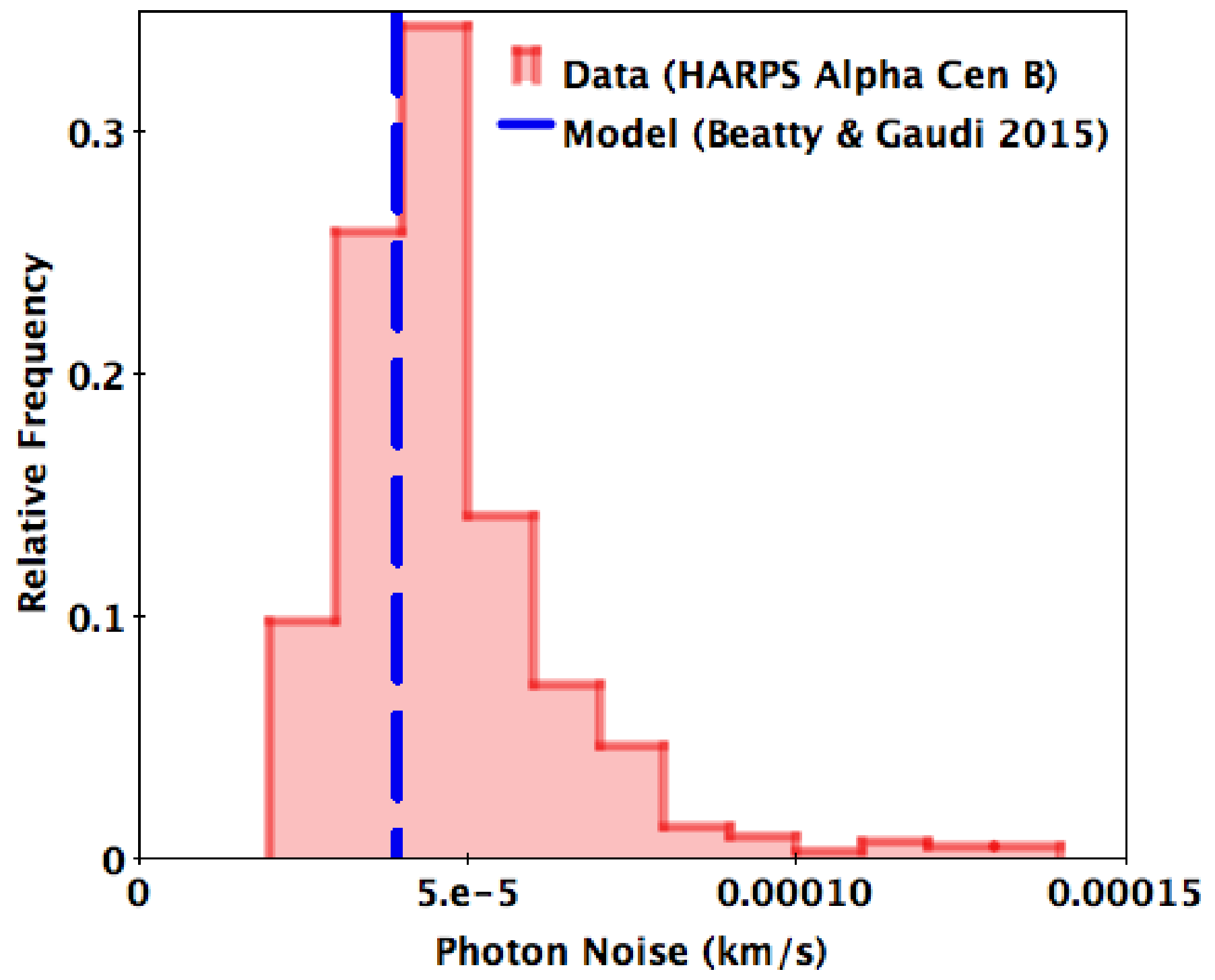

Figure: Simulated single measurement precision (vertical line) for HARPS published parameters on Alpha Cenaturi B. Also included are the precisions of 459 observations (SNR 1575) from the 2008-2011 campaign. Matching up the model required details of equipment performance and imaging technique that are unnecessary in less precise simulations.

Example Target Stars

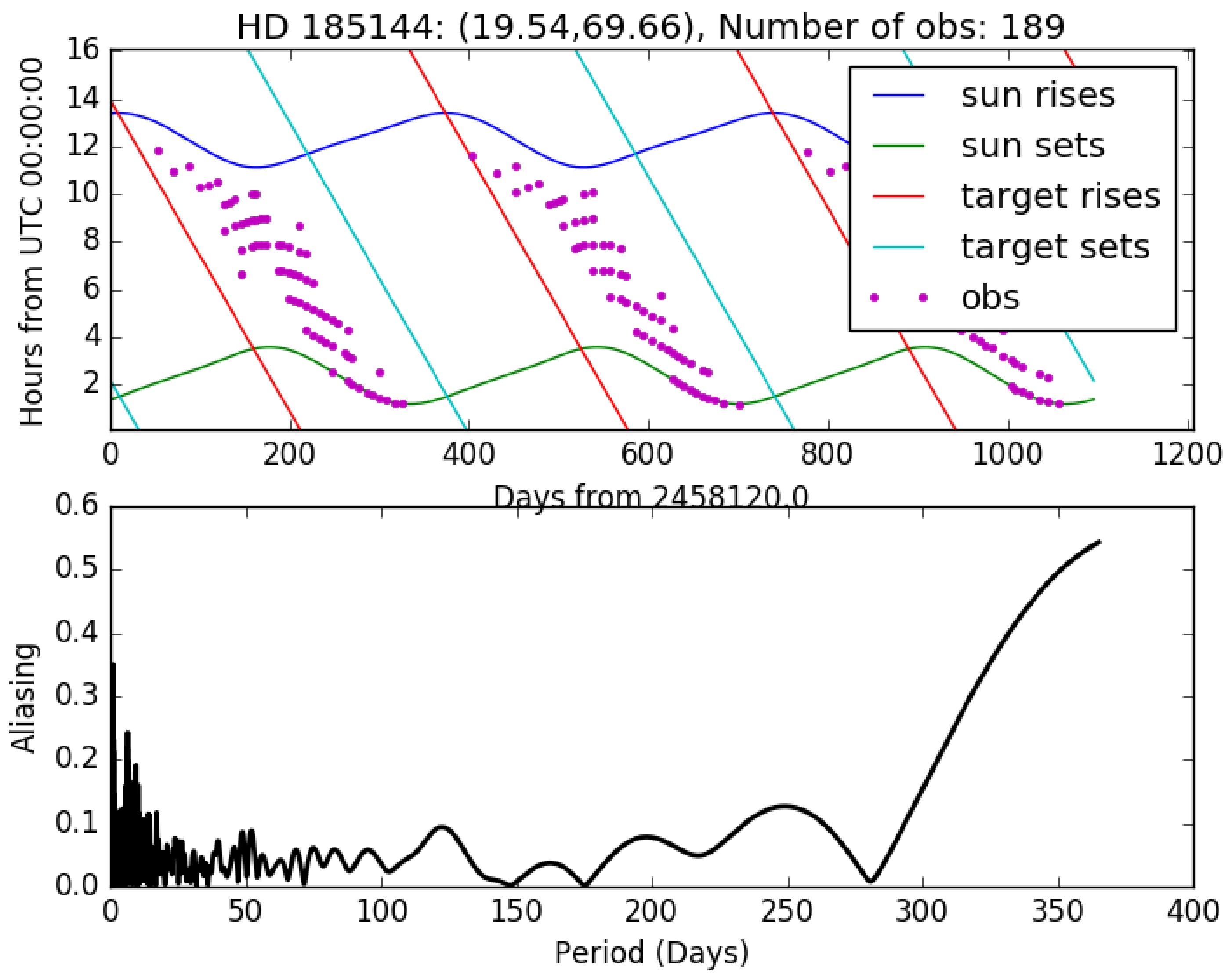

Figure: Observation times for HD 185144 (declination +69°39′40″) and sunrise/set times over the course of an example 39 star 3 year run. Also shown is the window function, giving an idea of the orbital periods at which a hypothetical exoplanet could actually be observed in this data. A larger aliasing value for a given period indicates an increased loss of sensitivity to exoplanet detection at that orbital period.

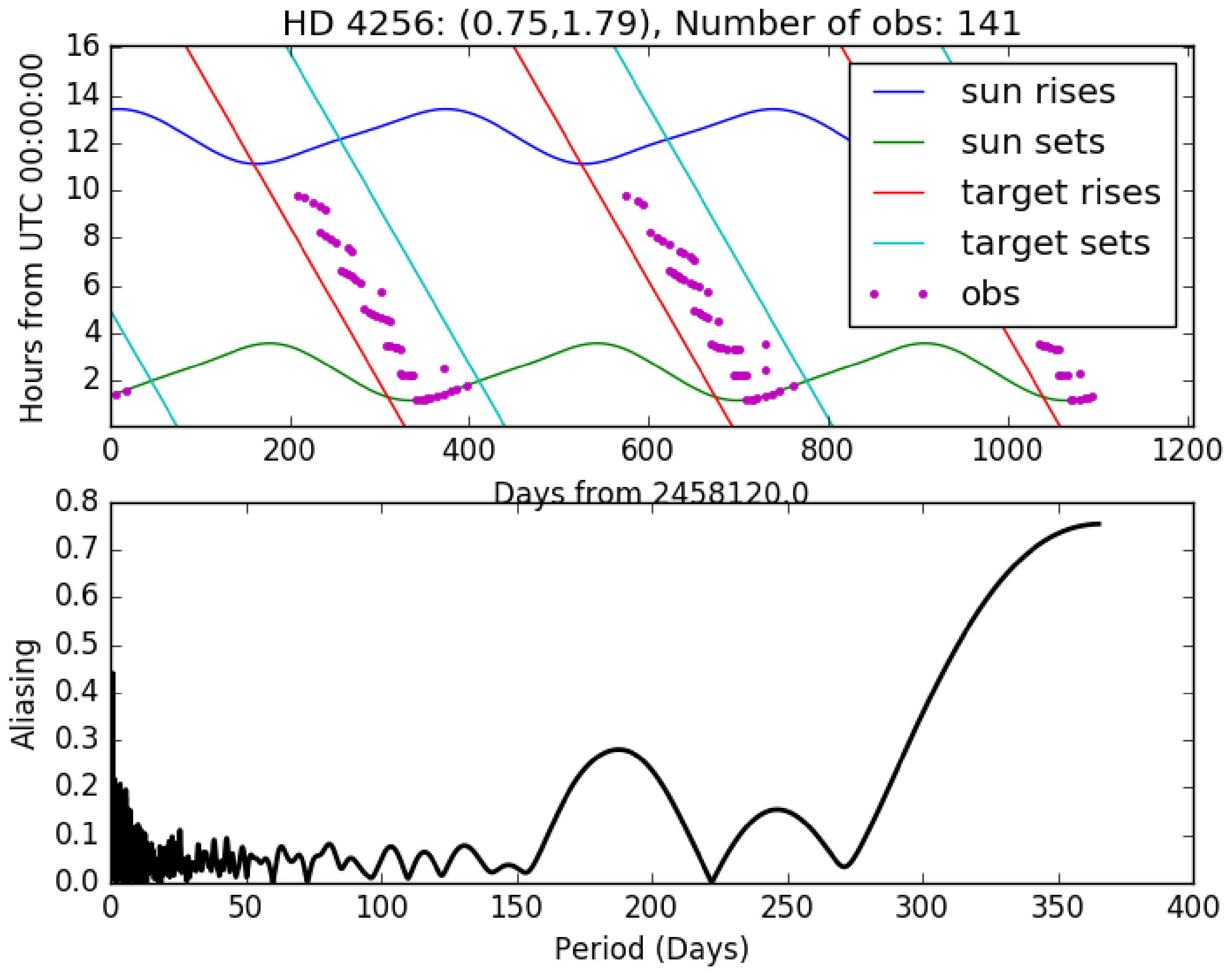

Figure: Observation times for HD 4256 (declination +01°47′07″) and sunrise/set times over the course of an example 39 star 3 year run. Also shown is the window function, giving an idea of the orbital periods at which a hypothetical exoplanet could actually be observed in this data. The reduced range of times where observations are possible visible in the upper graph, results in reduced sensitivity for periods of around 150-220 days.

Example Observation Rates

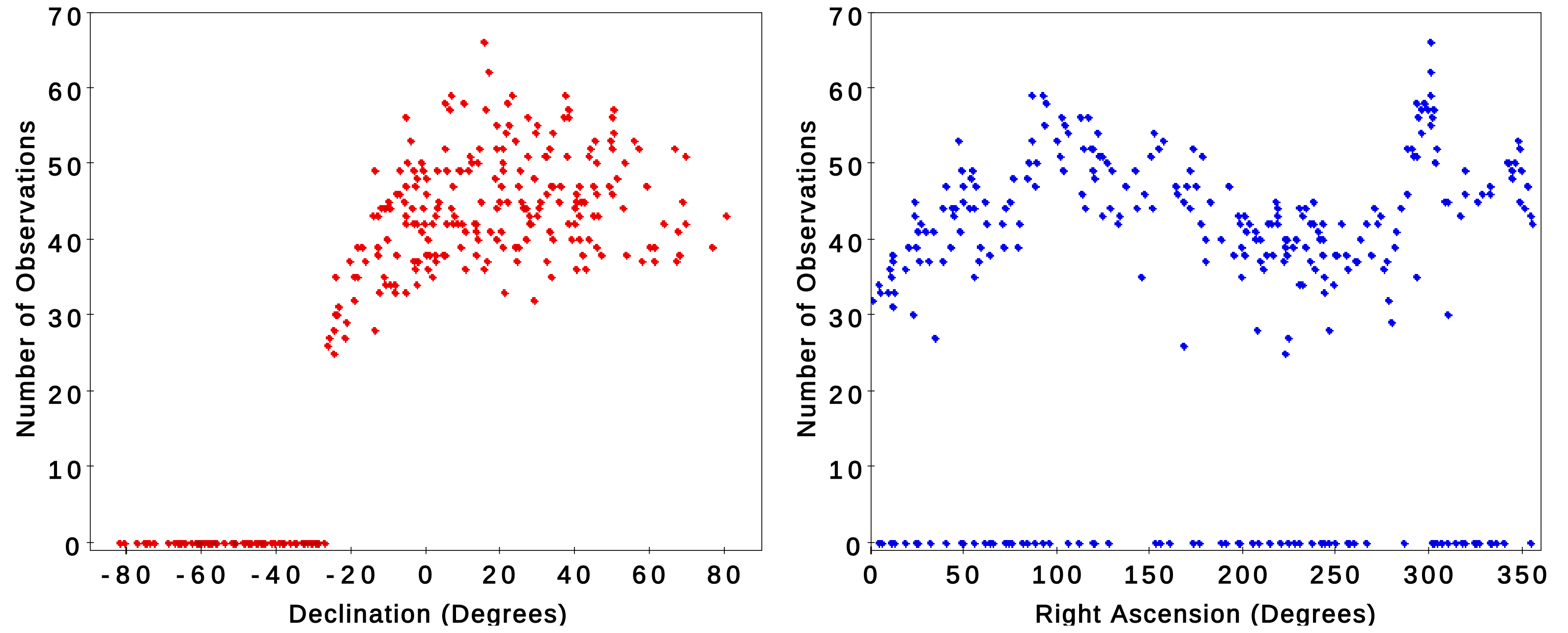

Figure: Distribution of observation counts for 239 stars over a 5 year run verses right ascension (right), and declination (left). The variation in observation count verses right ascension is from a combination of night length and weather conditions.

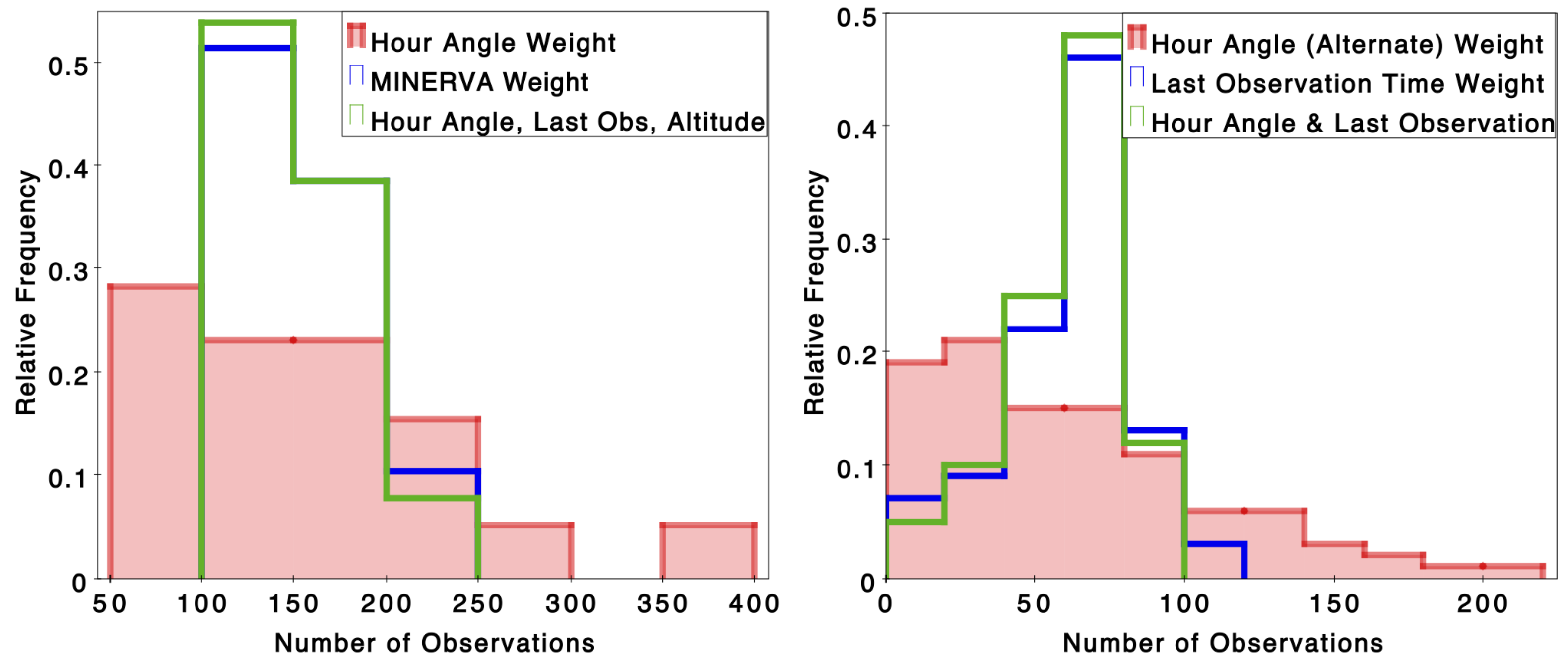

Figure: Distribution of observation counts for 39 stars using multiple parameter weighting functions (left), and 100 stars using separated out/revised weighting functions (right) over a 3 year survey. Narrower distributions are preferred.

Conclusions and Future Work

Both hour angle and last observation time provide useable observations distributions, with caveats. Pure hour angle weighting can cause "RA shadowing," with some stars recieving few to no observations. This is a greater problem with larger target lists and longer exposure times. Last observation time avoids these, but still shows significant variance in observation frequency. A combination of the two provides the best results, with about a factor of 2 difference between the most and least observed stars in smaller (more typical) surveys. Additional tweaks (eg: MINERVA's 3 observations in a night, our attempts at altitude weighting) had limited effect. Simulated radial velocities are roughly consistent with actual photon noise, though some detector parameters are poorly documented as to be nearly free. Next, we will use these observation times and uncertainties to attempt to recover real/simulated planets, and predict survey yield and precision.

References

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