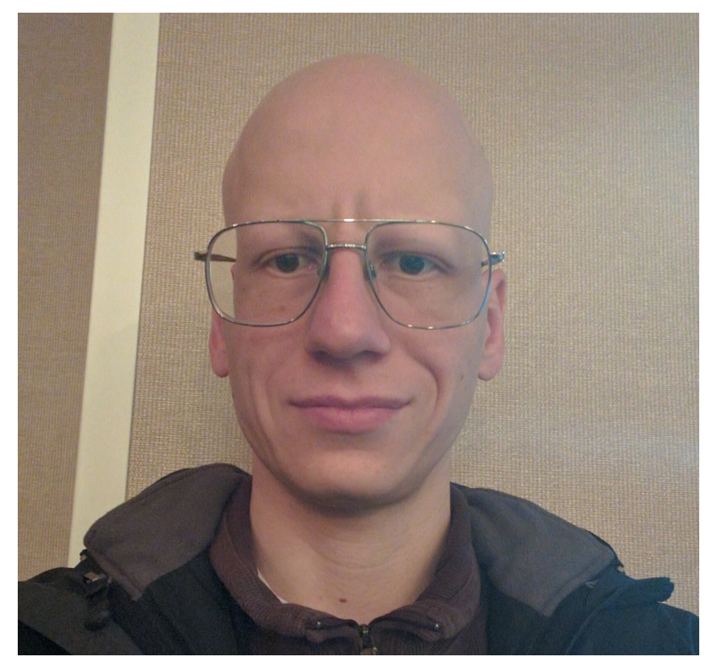
Simulating a Radial Velocity Precursor Survey for Target Yield Optimization for a Future Direct Imaging Mission

Patrick Newman[1], Peter Plavchan[1], Justin Crepp[2], Shannon Dulz[1], Chris Stark[3], Steven Kane[4]
[1]Missouri State University, [2]Notre Dame, [3]Space Telescope Science Institute, [4]San Fransisco State University



Abstract

Future direct imaging mission concepts such as HabEx and LUVOIR aim to directly image 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 direct imaging missions at a fraction of the cost of a blind direct imaging survey. We present a simulation of such a survey. We consider both the WIYN and Large Binocular Telescope, including weather conditions and limitations in telescope time, fitted with spectrometers of varying sensitivities including iLocator and NEID. We recover simulated planets and their orbital parameters, estimating the effectiveness of a pre-cursor radial velocity survey.

Motivation

Space based direct imaging exoplanet surveys proposed for the 2020s and 2030s (e.g.: 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 such ground based surveys are worthwile. At present, this is a proof of concept that a multi-year survey with a large telescope can provide a useful number of observations. Multiple target selection optimization algorithms are considered.

Example Target Stars

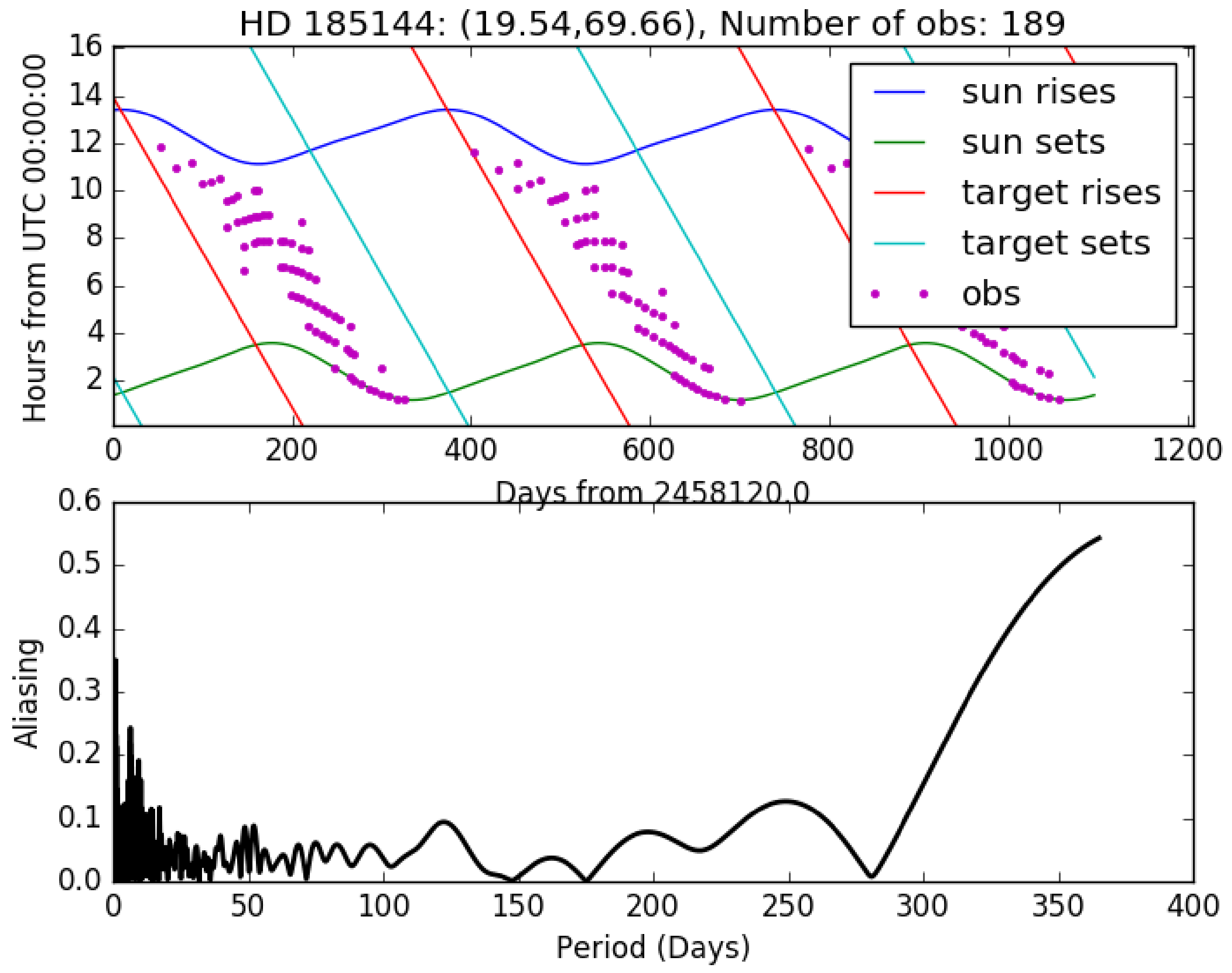


Figure: Observation times for HD 185144 (declination +69°39'40") and sunrise/set times over the course of an example 39 star 3 year run. Also shown is the window function, giving an idea of the orbital periods at which a hypothetical exoplanet could actually be observed in this data. A larger aliasing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

Simulation Code Description

Our code uses the MINVERVA scheduling code 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.

Input:
- Site location (latitude, longitude, altitude)
- Telescope properties (park position, slew speed, minimum altitude)
- Constraints (Minimum moon seperation, maximum sun altitude)
- Survey start/end dates
- Target List (RA, Dec, exposure time)

Output:
- Star rise and set times
- Star observation information
- Sun rise and set times
- Simulation metadata

Constraints:
- Sun is down (typically $\leq$-12°)
- No clouds (probability based on 1999-2006 records)
- Target is above telescope's minimum altitude for duration of observation

Target Priority Weightings:
- Hour angle
- Time since last observation
- Time above a given altitude
- Current altitude
- 3x observations in one night (MINVERVA)

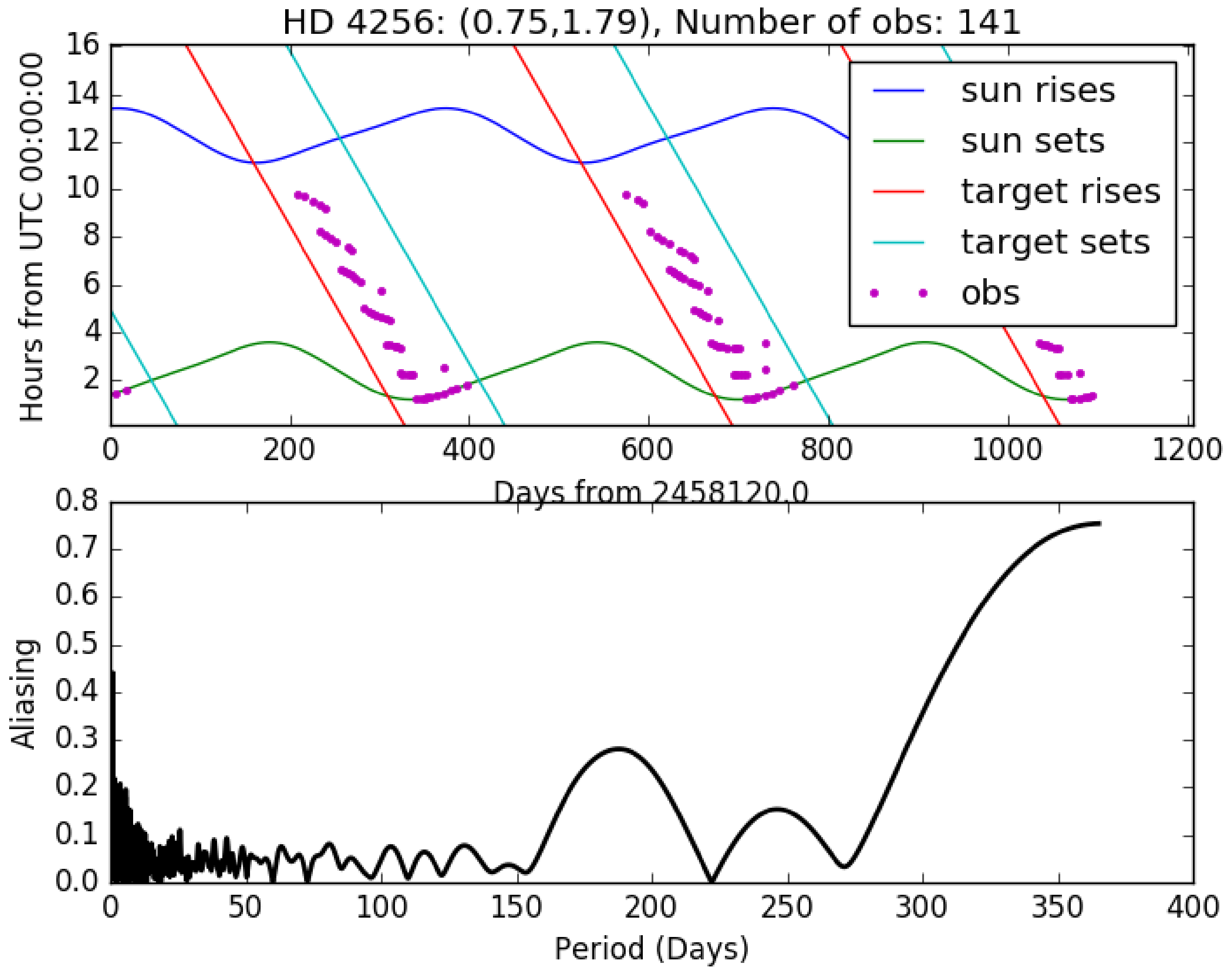


Figure: Observation times for HD 4256 (declination +01°47'07") and sunrise/set times over the course of an example 39 star 3 year run. Also shown is the window function, giving an idea of the orbital periods at which a hypothetical exoplanet could actually be observed in this data. The reduced range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

Example Surveys

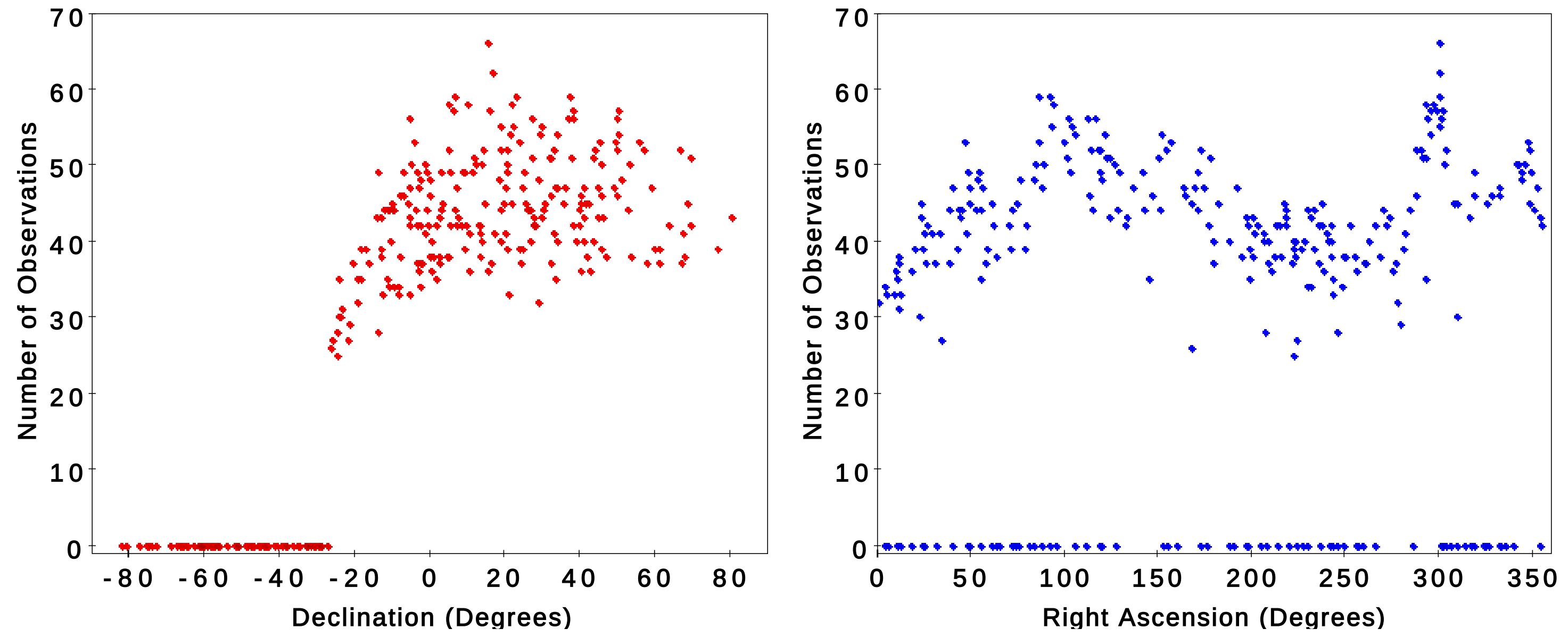


Figure: Distribution of observation counts for 239 stars over a 5 year run verses right ascension (right), and declination (left). The variation in observation count verses right ascension is from a combination of night length and weather conditions.

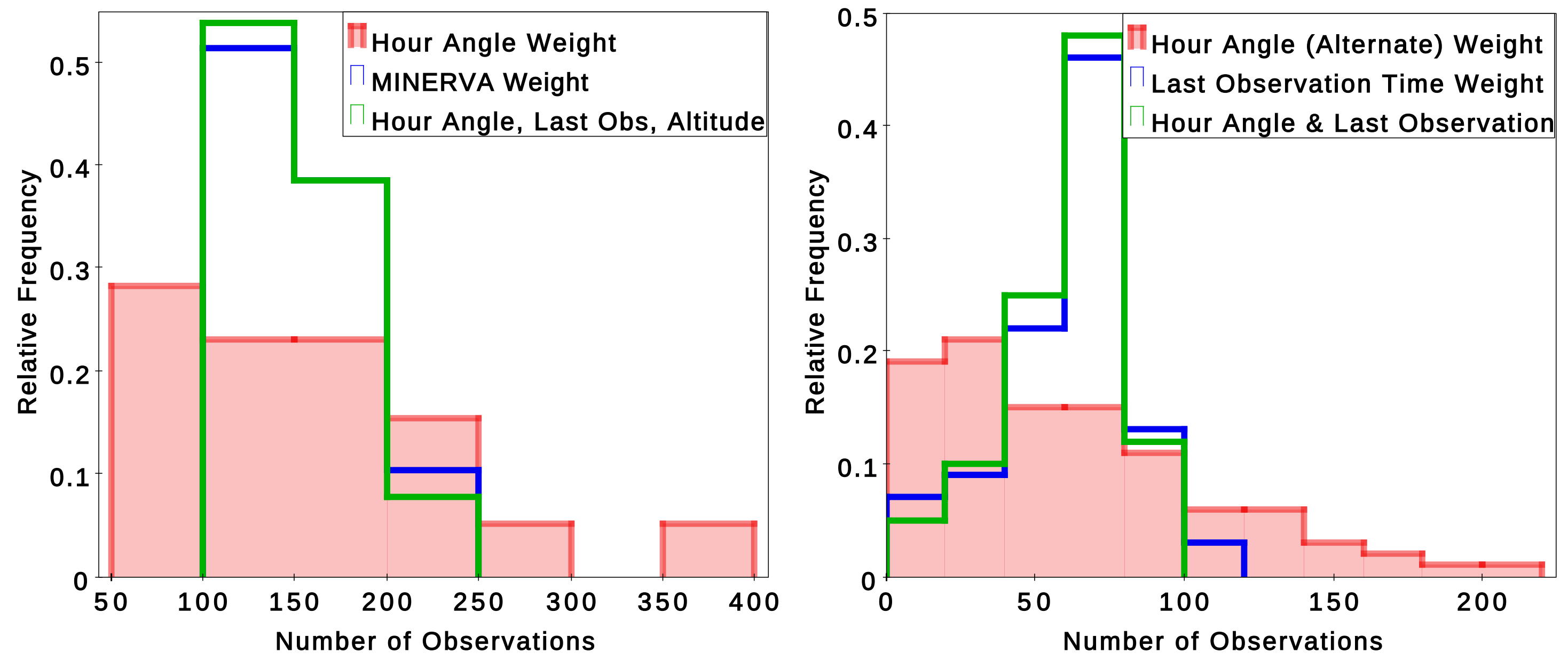


Figure: Distribution of observation counts for 39 stars using multiple parameter weighting functions (left), and 100 stars using separated out/revised weighting functions (right) over a 3 year survey. Narrower distributions are preferred.

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," resulting in some stars recieving few to no observations. This is a greater problem with larger target lists and longer exposure times. Last observation time does not have these exact issues, but there is still significant variance in observation frequency. A combination of the the two provides the best results so far, with about a factor of 2 difference between the most and least observed star in smaller surveys. (Typical of actual surveys.) Additional tweaks (eg: MINERVA's attempt to get 3 observations in a night, our attempts at altitude weighting) have had limited effect. The next step will be to generate radial velocities and realistic measurement uncertainties for the observations times and orbital properties of known and simulated exoplanets. Then we will use those radial velocities to reconstruct the orbits, and determine discovery rate and accuracy.

References

Swift et al. (2015). Miniature Exoplanet Radial Velocity Array (MINERVA) I. Design, Commissioning, and First Science Results. J. Astron. Telesc. Instrum. Syst. 1(2), 027002. dx.doi.org/10.1117/1.JATIS.1.2.027002

Plavchan et al. (2015) Radial Velocity Prospects Current and Future: A White Paper Report prepared by the Study Analysis Group 8 for the Exoplanet Program Analysis Group (ExoPAG). eprint arXiv:1503.01770

Howard, Andrew W. & Fultun, Benjamin J. (2016) Limits on Planetary Companions from Doppler Surveys of Nearby Stars. Publications of the Astronomical Society of the Pacific, 128(969), 114401. dx.doi.org/10.1088/1538-3873/128/969/114401