JPL Summer Internship Final Report

Starshade Target Selection and Observation Sequence

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Abstract

The Wide Field Infrared Survey Telescope (WFIRST) is a developing NASA mission to launch an infrared space observatory to explore exoplanets, dark energy, and infrared astronomy. In order to aid WFIRST with its exoplanet imaging objective, an external Starshade (WFIRST-S) may be launched with it. However, there is currently no set observation strategy for WFIRST-S. For this project, the best stars to observe will be determined by calculating the time to disambiguate the target from the background. These stars generally have the highest proper motions, so it will be easier to detect an exoplanet that shares its high proper motion. Stars that take less time are better candidates as this allows more time for needed observation such as spectroscopy or to move onto other stars faster. After this figure of merit is calculated for all the stars in the ExoCat star catalog, it can be used to select a few targets and then create an observation sequence based on the figure and position of each star. This can then be compared to observation sequences produced by prioritizing other parameters such as star magnitude or habitable zone radius and see which stars continue to be good candidates to observe.

Mission Overview

Exoplanet imaging is not an instantaneous process. In order for WFIRST-S (Figure 1) to properly image an exoplanet, it must detect the exoplanet, disambiguate the target from the background to image it, and perform spectroscopy on it. However, all of these processes take different amounts of time to perform on a single target. The best targets will have matching spectroscopy and background disambiguation times. By comparing both values for each potential target, we are able to find which ones are the quickest and easiest to observe which will maximize the number of targets we will be able to observe throughout the mission lifetime and also conserve fuel for the Starshade.

Nature and Scope of Mission

There are currently two observing strategy options for WFIRST-S: either try to discover and observe as many exoplanets as possible or focus on a few targets to discover Earth twins. Regardless, measuring the amount of time it takes to disambigaute the target from the background will help determine good candidates in both cases and help develop an ideal observing sequence. However, there are many more variables that determine a good candidate. Characteristics such as a high magnitude, known exoplanets, and habitable zone also play a role in selecting targets. The observation of stars is also limited by a solar avoidance angle (Figure 2). This makes it so that each target is observable for only certain windows of time. This impacts the observation sequence greatly as we must arrive at a star when it is observable and spend time observing it such that we have enough time to observe the next star.

Motivation

WFIRST-S will continue the search for life outside of our solar system. It will detect and characterize Earth-like planets for traces of compounds essential for life as well as gas giants to learn more about their formation and composition. Prior to WFIRST-S, exoplanets were mainly detected through doppler wobble or transit methods. Exoplanet imaging gives us the ability to physically observe these exoplanets rather than just proving the existence of them. Knowing the time to disambiguate a target from the background is extremely important for stars where an exoplanet is detected. It tells us if we are able to able to visually observe the existence of an exoplanet and remove the noise from background galaxies, making imaging much easier and giving us tangible results of an exoplanet rather than just confirming its existence.

Conclusions

The observing strategy for WFIRST-S is still unknown and depends on various astrophysical and astrometric characteristics of each system, basically all stars within a distance of 30 pc from the Sun. These stars are classified in the ExoCat catalog (Appendix A). 99.15% of stars in ExoCat are observable by WFIRST as well. The best targets can take as little as 3 days to do so while some stars can take up to more than a hundred days. As seen in the histogram of average time to observe 1 PSF of motion (Figure 2), The distribution of times is approximately normal with the median being around 50 days. Taking into account of this new parameter, the generated observing sequence (Figure 4) gets to 33/35 potential targets. The days to disambiguate the target from the background are not so much longer than the time to characterize the star, if both are needed. Even if the disambiguation time is longer, it does not make a significant impact on the observation sequence as for most targets we are able to stay on target for long enough without affecting observation time for the next target. Overall, it is very promising data that the stars we wish to look at have disambiguation times close to their characterization times.

Methods

The time to disambiguate the target from the background is defined as the time it takes to observe the target move 1 PSF width of motion where 1 PSF is

$$PSF = FWHM/SNR$$

and FWHM is defined as

$$FWHM = \lambda/Diameter$$

We assume signal to noise ratio of 5 for this mission. Lambda will take values of 730, 760, and 940 nm which are the center wavelengths for each observing band. The PSF for 730 nm and a 2.4m telescope is 62.81 mas. We then calculate the length a target travels during each window it is observed (Figure 5) through a Riemann sum. Dividing the length traveled by the PSF width and then again by the number of days the target observed will give the average velocity of the star for the observing window. The inverse then gives the number of days required to get to 1 PSF width (Figure 6). This calculation is automated through a Matlab program that pull data from the ExoCat star catalog and outputs the values for each star given (Appendix).

Observing Sequence

With this figure of merit, we add this as another parameter to developing an observation sequence for the WFIRST-S mission. There are three times of observation to be considered for each target: exoplanet detection time, characterization time (time to do spectroscopy), and time to disambiguate from the background. There are many considerations to make when constructing an observing sequence including change in velocity when switching targets, fuel, and the observability of each target at a certain date. The beginning parameters for the observing sequence are in the caption of the figure. Fake exoplanets are put among some of the stars to test the sequence. If a star has an exoplanet, it will compare the times for disambiguation and characterization and see if extra time is needed to disambiguate the target, and if that extra time is possible without affecting the observation time of the next target.

Figures

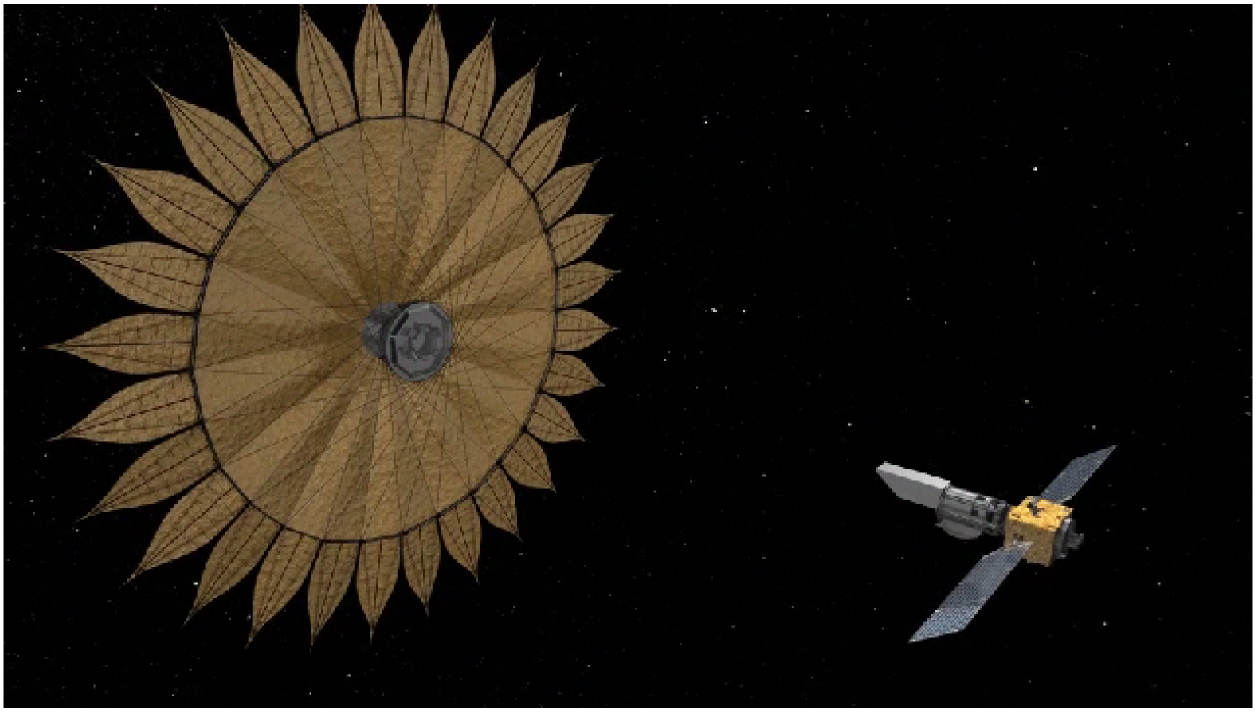

Figure 1. Image of the WFIRST rendezvous mission with Starshade. The Starshade (34m diameter) will block out the star's light before the light reaches the telescope, making it much simpler to image the planets orbiting the star. WFIRST (2.4m diameter mirror) will orbit around the L2 point while Starshade will be between 25,000km to 50,000km.

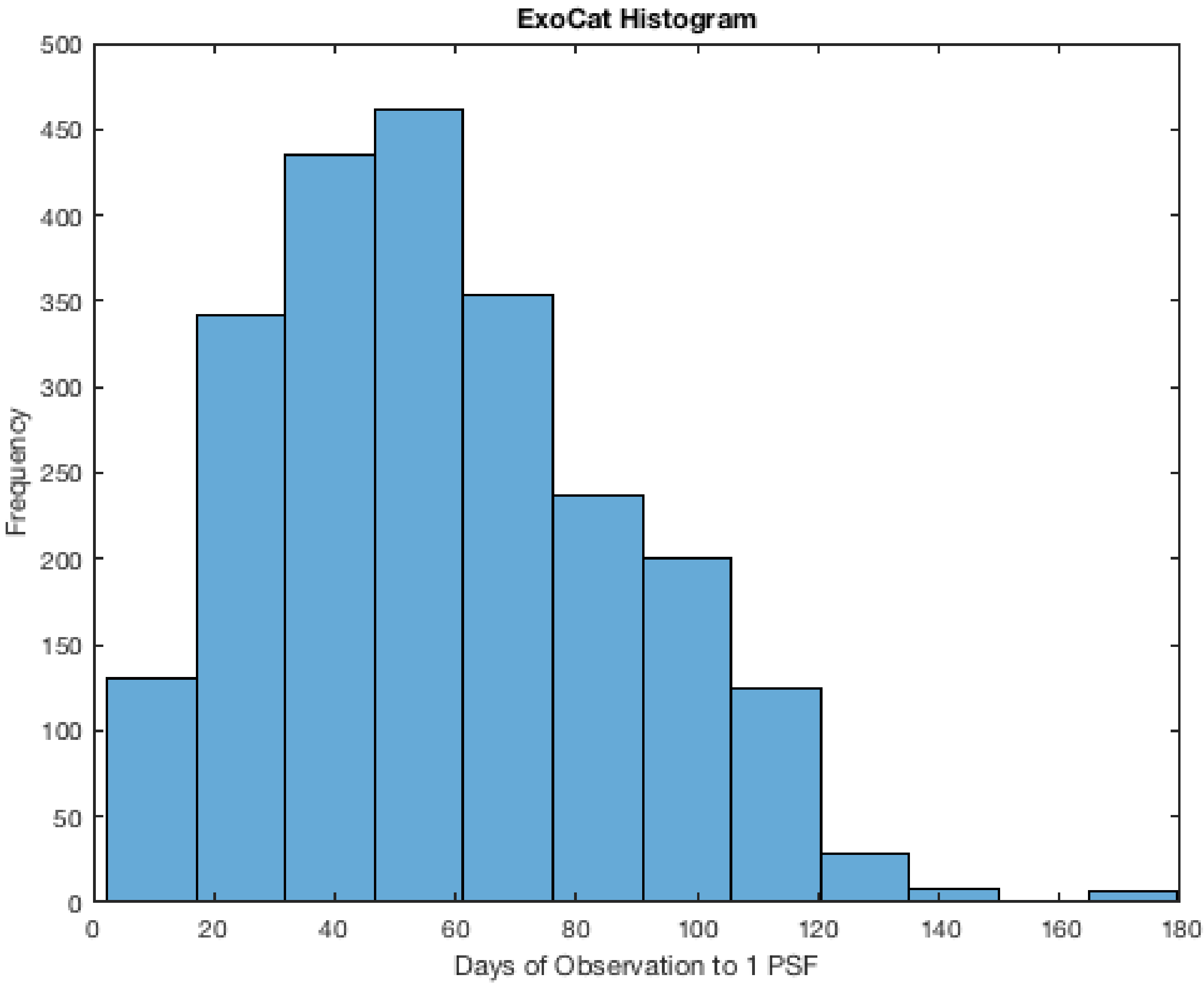

Figure 2. A histogram of the average number of days it takes to get to 1 PSF width for all the targets in ExoCat. The mean value is around 45 days.

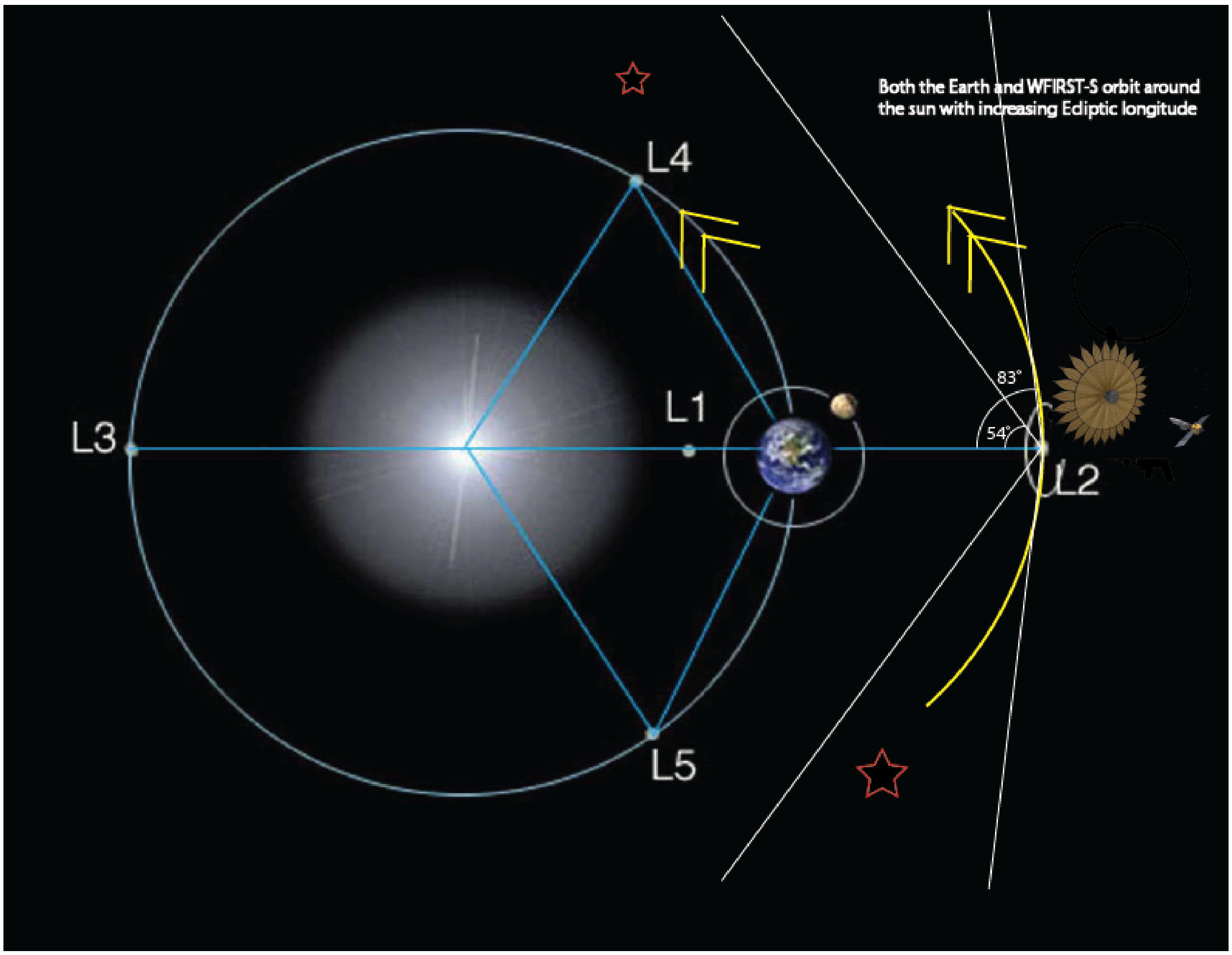

Figure 3. A diagram depicting the observability of stars for WFIRST-S. WFIRST-S orbits around L2 which also orbits in the same direction as the Earth. As stars enter the field of regard (54-83 degrees) they become observable and become unobservable once they exit. The observing sequence is built around when we can observe each star and at what angle relative to WFIRST-S. The assumed mission length is two years so stars generally have 4 or 2 observing windows.

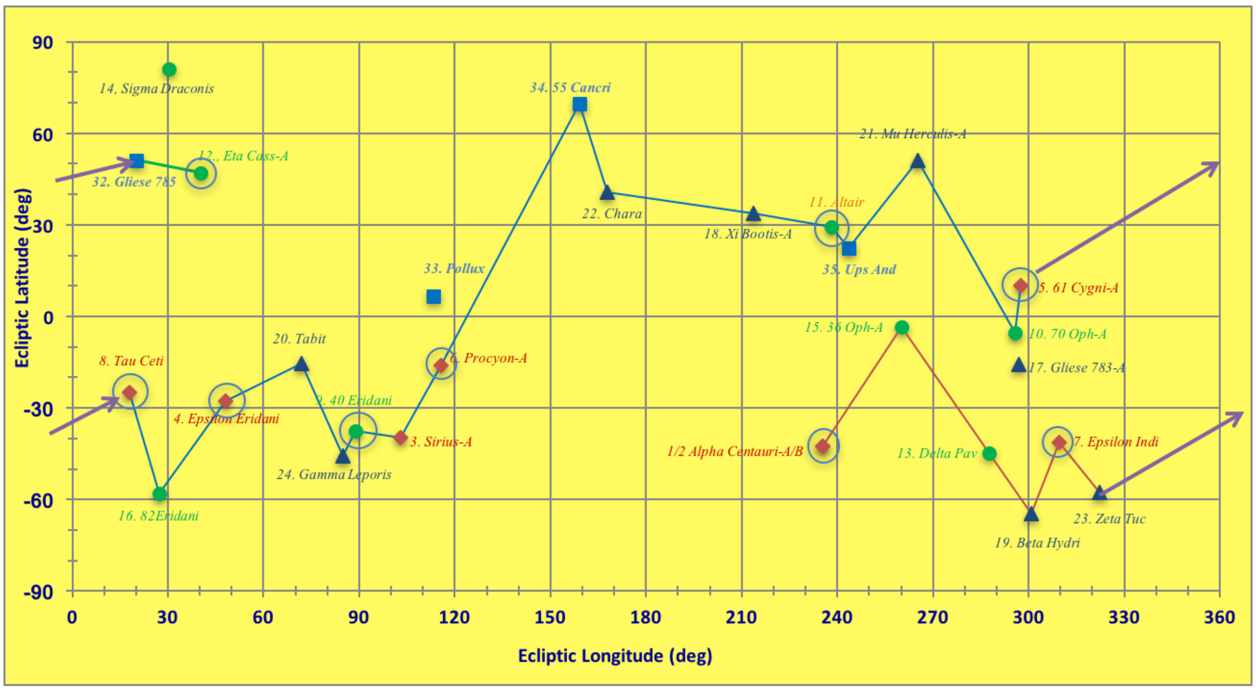

Figure 4. The final observation sequence developed. It assumes a start date of January 1st 2028 0:00 with the first target being Alpha Centauri A. Stars with circles around them denote that they have a planted exoplanet there. 33/35 targets are able to be observed by this sequence (they are not important enough to observe without sacrificing fuel or observation time for another target).

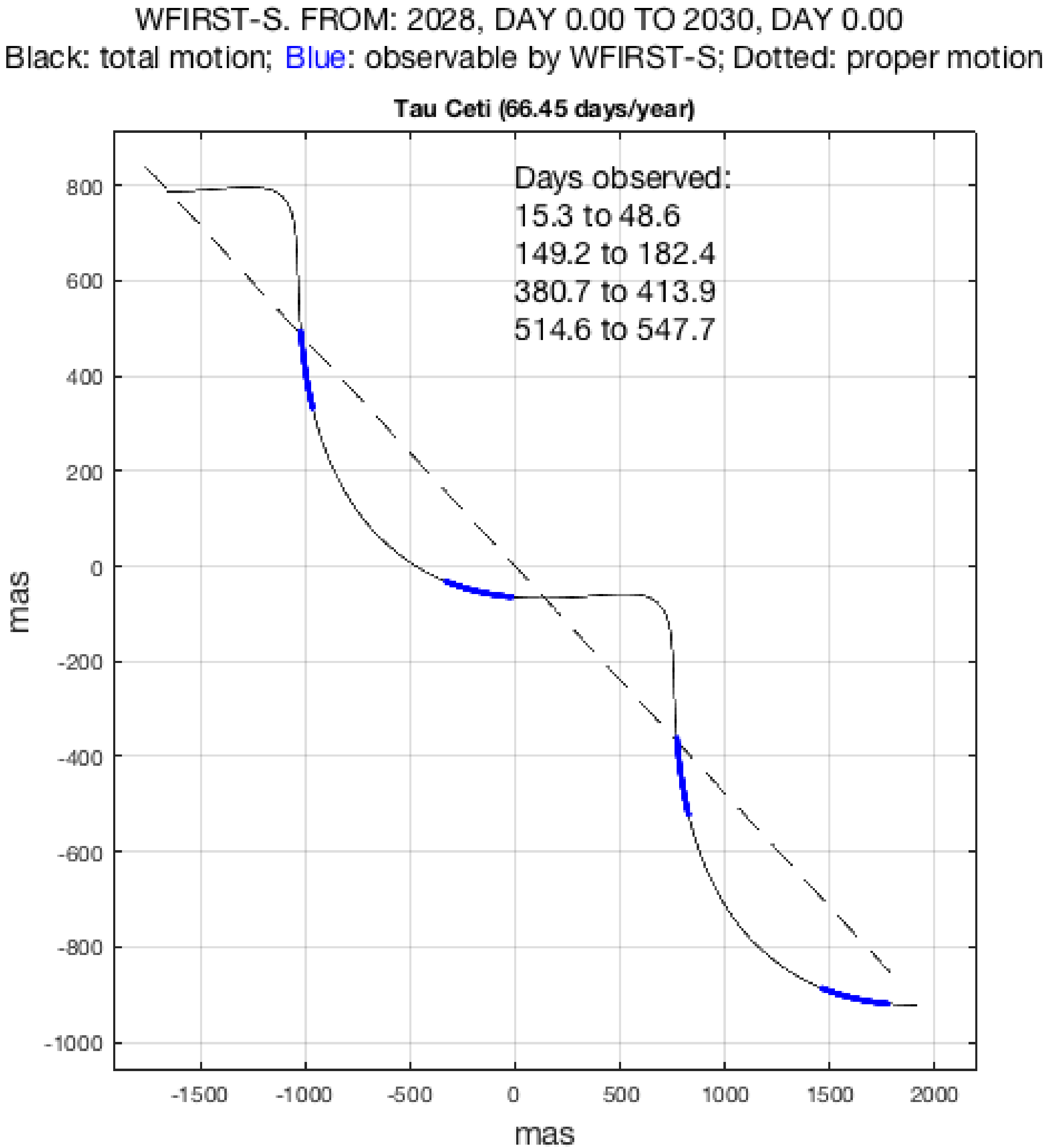

Figure 5. A motion plot generated by the code. It plots the total motion, which is a combination of proper motion and parallax, and gives the observable windows of the star. The observability is when the star is inside the field of regard from Figure 2. The blue interval is where the calculation for the days it takes the target to travel 1 PSF width.

				730nm	62.81mas			
#	Name	HIPID	first day	Days to get to 1 PSF per observing window				
1	Alpha Cen-A	71683	-4.47	21.44235873	2.992059239	19.63669098	2.991841029	14.36242919
	Day of window beginning			'01-Jan-2028 00:00:00'	'30-Aug-2028 02:24:00'	'26-Dec-2028 21:36:00'	'30-Aug-2029 09:36:00'	'27-Dec-2029 07:12:00'
2	Alpha Cen-B	71681	-4.47	15.97610672	2.938735696	14.8830228	2.938536771	11.86486627
				'01-Jan-2028 00:00:00'	'30-Aug-2028 02:24:00'	'26-Dec-2028 21:36:00'	'30-Aug-2029 09:36:00'	'27-Dec-2029 07:12:00'
3	Sirius-A	32349	104.2	8.536169068	16.38835202	8.56166498	16.43422244	Inf
				'14-Apr-2028 04:48:00'	'15-Aug-2028 00:00:00'	'14-Apr-2029 14:24:00'	'15-Aug-2029 09:36:00'	
4	Epsilon Eridar	16537	46.3	8.258679575	22.5512268	8.284365591	22.62358712	Inf
				'16-Feb-2028 07:12:00'	'27-Jun-2028 16:48:00'	'15-Feb-2029 16:48:00'	'28-Jun-2029 00:00:00'	
5	61 Cygni-A	104214	-22.4	5.965169811	3.730096143	6.159643873	3.729722155	6.867906887
				'01-Jan-2028 00:00:00'	'14-Mar-2028 12:00:00'	'09-Dec-2028 00:00:00'	'14-Mar-2029 21:36:00'	'09-Dec-2029 09:36:00'
6	Procyon-A	37279	114.3	9.507534523	18.07289829	9.541826876	18.14751169	Inf
				'24-Apr-2028 07:12:00'	'08-Sep-2028 07:12:00'	'24-Apr-2029 16:48:00'	'08-Sep-2029 14:24:00'	
7	Epsilon Indi	108870	68.2	4.745163712	6.234538865	4.755953589	6.247147609	Inf
				'09-Mar-2028 04:48:00'	'09-Nov-2028 04:48:00'	'09-Mar-2029 14:24:00	'09-Nov-2029 12:00:00'	
8	Tau Ceti	8102	15.3	7.079761736	12.6016895	7.101898044	12.63812147	Inf
				'16-Jan-2028 07:12:00'	'29-May-2028 04:48:00'	'15-Jan-2029 16:48:00'	'29-May-2029 14:24:00'	

Figure 6. The resulting data from the code. The sheet shows the days to observe 1 PSF of motion for each observing window of a star and at a certain wavelength. Each observing window also has the starting date in order to help line up with the observing sequence. This data is repeated for all the other targets and for wavelengths of 760nm and 960nm.

Acknowledgements

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Appendix

Github: https://github.com/hsergi/WFIRST-S-Observations/tree/master/wfirst_s_observations

ExoCat: https://github.com/hsergi/WFIRST-S-Observations/tree/master/wfirst_s_observations/in