Blind Search Single-Visit Exoplanet Direct Imaging Yield for Space Based Telescopes

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Objectives

Modify the WFIRST target list optimization process to detect as many exoplanets as possible on small and large telescopes
1. Optimize coronagraph direct imaging observation times using mixed integer programming and sequential least squares quadratic programming **[2]**
2. Optimally schedule observations
3. Apply process to target starved and target rich telescopes
4. Observe number and distribution of detected exoplanets
5. Answer how much over-optimization effects overall detection yield

Telescope Parameters

	WFIRST	4m Monolith		WFIRST	4m Monolith
Pupil Diam. (m)	2.37	4.0	Contrast mean intensity	1.52e-12	8.24e-15
λ (nm)	565	500	Attenuation fraction	0.509	0.266
IWA (arcsec)	0.15	0.045	Orbit	L2 Halo	L2 Halo
OWA (arcsec)	0.428	2.127	Sun Keepout Angle (deg)	45.0	40.0
Detection SNR	5	7			

Observation Stats

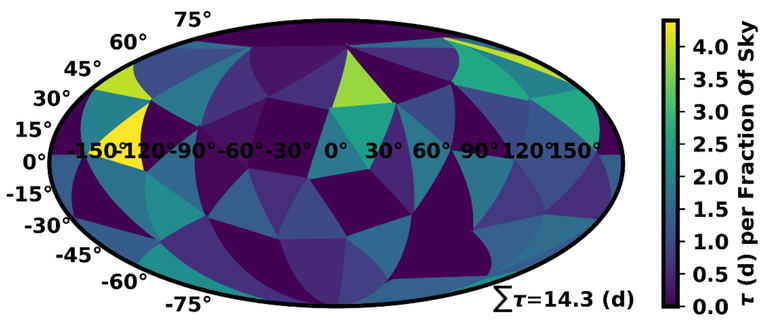
	WFIRST	4m Monolith
Observing Time	3 mo	3.75 yr
$\sum \tau$ (d)	14.307	1167.56
$\sum \tau + t_{OH}$ (d)	91.307	1367.21
Observations	77	1406
Shortest τ (d)	0.019	0.035
Longest τ (d)	0.343	1.344
Mean τ (d)	0.185	0.830
Stars with detections	9*	632*
Around a star:		
Max # Detections	2*	11*
Mean # Detections	1.33*	2.04*
Closest Detection (pc)	3.21*	2.54*
Earthlike Detection:		
Closest (pc)	-*	3.51*
Furthest (pc)	-*	28.31*

*From single simulation

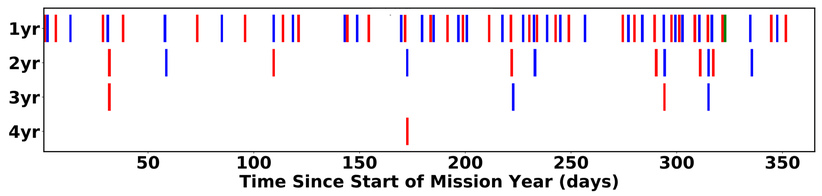
Takeaway: Overhead and settling times significantly effect time observing targets
Takeaway: Integration times vary from minutes to days
Takeaway: For 4m, only ~½ of observations yield detections
Takeaway: Dynamic stability of an 11 planet warrants further investigation
Takeaway: Closest Earth-Like planet detected is 3.51pc

Sky Distributions

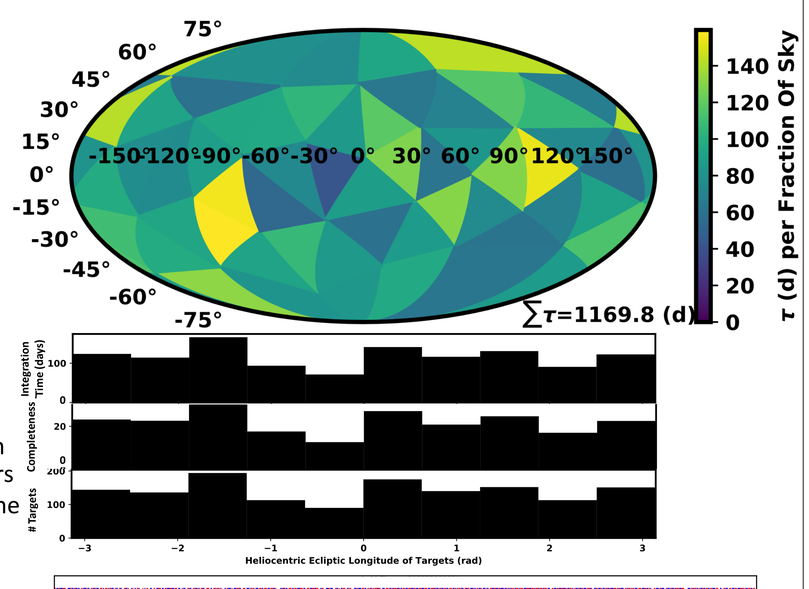
WFIRST



Takeaway: WFIRST targets are non-uniformly distributed
Takeaway: Observations strictly at minimum local zodi would take 3 years for 3mo observing time



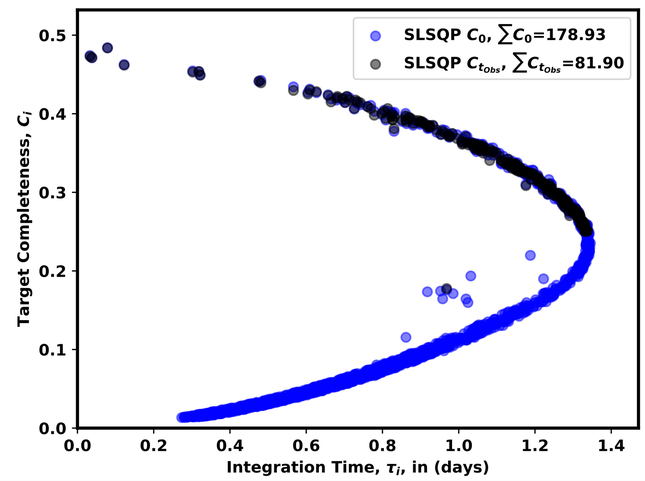
4m Monolith Planet Finder



Takeaway: 4m Telescopes have more uniform target distribution
Takeaway: 3.75 yrs of observation time would take 11 years at optimal observations

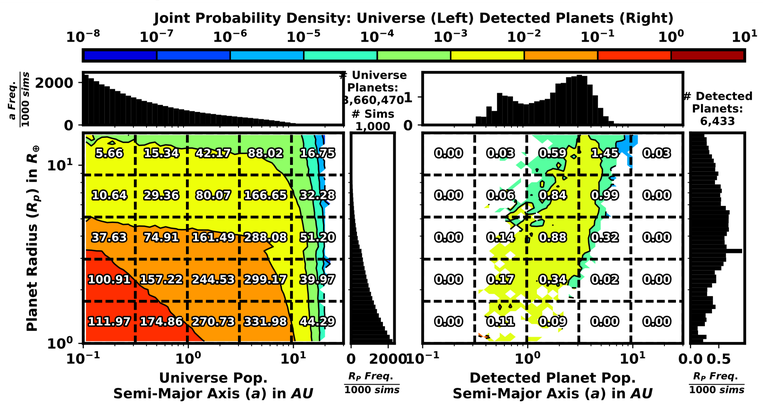
Immediate Characterizations

We make characterizations immediately following detections
- Optimizing τ without accounting for characterization leads to 53% completeness remaining unobserved



Detected Populations

SAG13 Input Distribution Detected Distribution

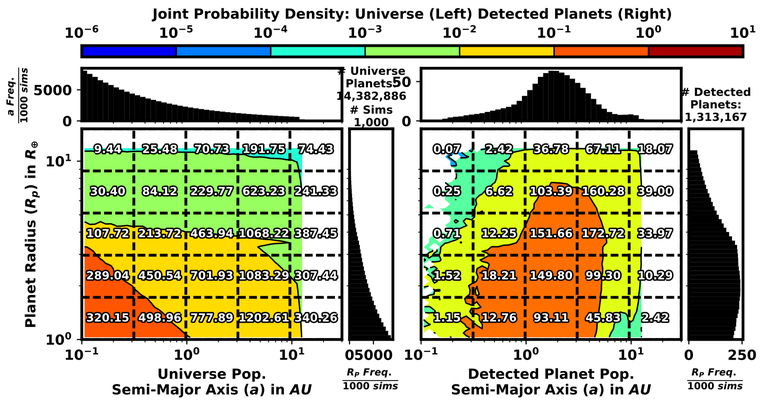


Takeaway: WFIRST observing a SAG13 distribution of planets will detect ~6.5 exoplanet on average

Takeaway: WFIRST will observe no planets with a < 0.4 AU or a > 10 AU
Takeaway: WFIRST is most likely to detect a Jupiter-Like planet and makes no Earth-Like detections

Aside: WFIRST generates less planets than a 4m Monolith because more stars are filtered from the WFIRST target list

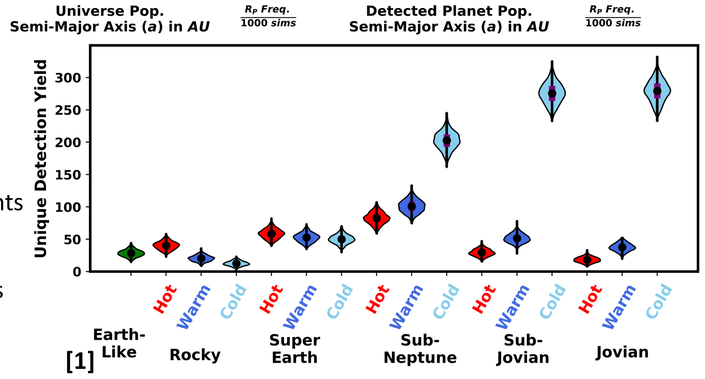
SAG13 Input Distribution Detected Distribution



Takeaway: 4m detects ~1300 exoplanets per simulation

Takeaway: 4m mostly detects large cold gas giants

Takeaway: 4m detects 28.5 Earth-like planets on average detecting as many as 45 and as few as 14 (revisits could improve this)



[1]

Over Optimization

Takeaway: Optimizing τ using Kepler Like 2 (an EXOSIMS planet pop.) conservative planet populations is robust to planet population

WFIRST

For 1000 Simulations

Completeness	Universe Distribution: Kepler Like 2	Universe Distribution: SAG13
Kepler Like 2	$2,048$ *planets* 100%	$6,748$ *planets* 100%
SAG13	$2,002$ *planets* 97.75%	$6,433$ *planets* 95.33%

4m Monolith

For 1000 Simulations

Completeness	Universe Distribution: Kepler Like 2	Universe Distribution: SAG13
Kepler Like 2	$511,299$ *planets* 100%	$1,211,922$ *planets* 95.89%
SAG13	$475,834$ *planets* 93.06%	$1,263,911$ *planets* 100%

References

[1] R. Kopparapu, et al., *Exoplanet Classification and Yield Estimates for Direct Imaging Missions*, ApJ, 2018
[2] D. Savransky, C. Delacroix, D. Garrett, *Multi-Mission Modeling for Space-Based Exoplanet Imagers*, SPIE, 2017
[3] D. Garrett, D. Savransky, *Analytical Formulation of the Single-visit Completeness Joint Probability Density Function*, ApJ, 2016
[4] B. Nemati, *Detector Selection for the WFIRST-AFTA Coronagraph Integral Field Spectrograph*, SPIE 2014

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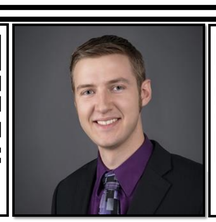

EXOSIMS

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