Exoplanet Target Selection and Scheduling with Greedy Optimization

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WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

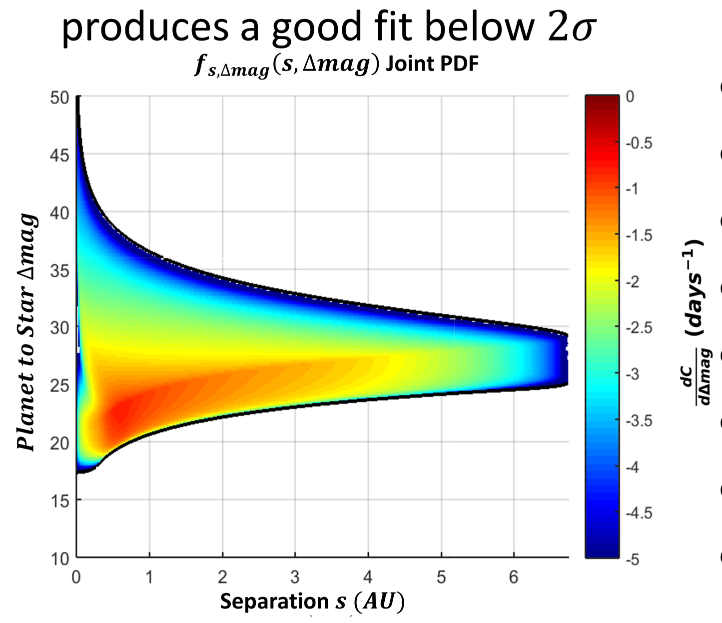
Objectives

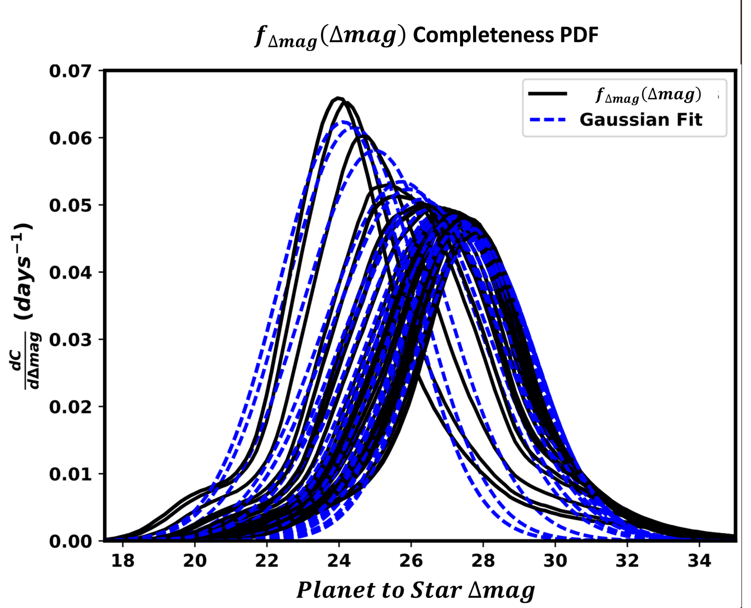
Exoplanet detection yield can be (conditionally) maximized by optimizing 3 parameters: which targets to observe, integration time per target, and when to observe them. Our goal is to inform future imaging missions by:

1. **Creating fast selection and scheduling algorithms**
2. **Quantify assumption sensitivity (Zodiacal Light, Overhead Time)**
3. **Maximizing simulated exoplanet detection yield**

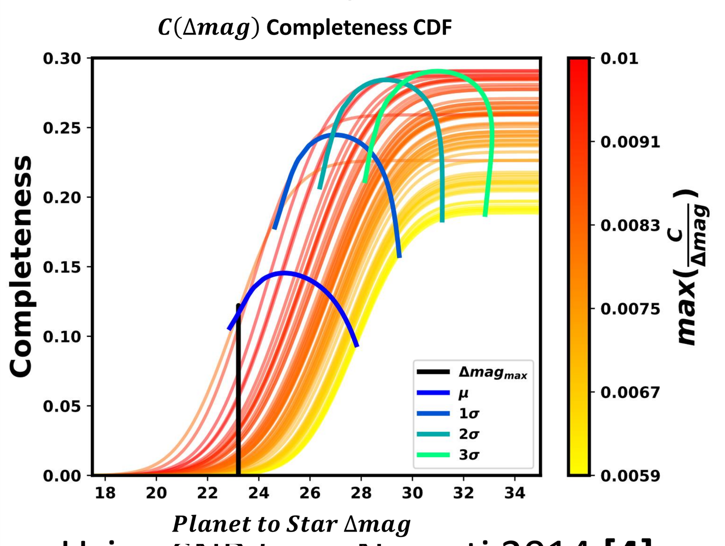
Increasing Optimization Speed

- Using Kepler data derived analytical joint probability distribution of completeness $f_{s,\Delta mag}(s,\Delta mag)$, we marginalize over s to find $f_{\Delta mag}(\Delta mag)$ **[3]**
- Approximating $f_{\Delta mag}(\Delta mag)$ using $Ae^{B(\Delta mag-C)^2} \approx A\sum_{k=0}^{100}\frac{B^k(\Delta mag-C)^{2k}}{k!}$ produces a good fit below 2σ



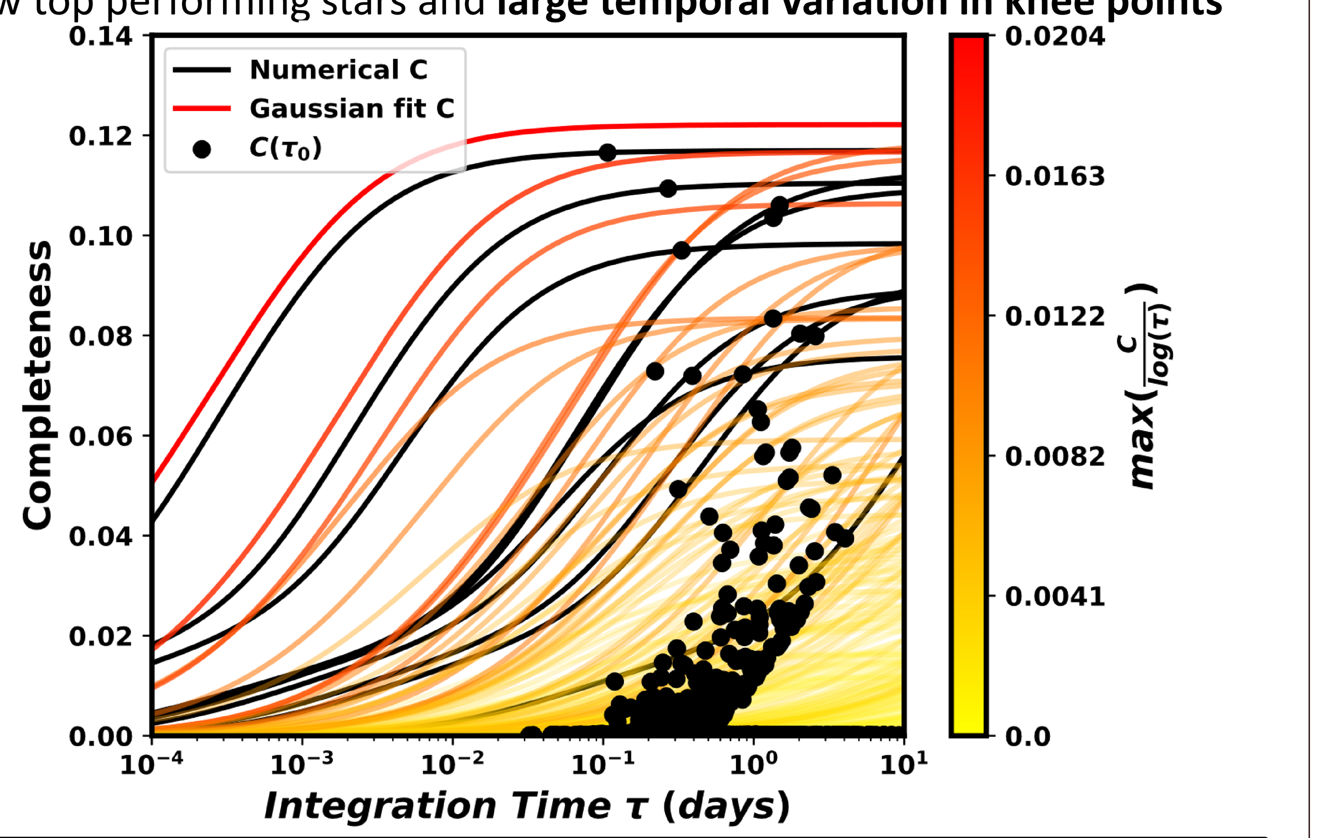


- Integrating $f_{\Delta mag}(\Delta mag)$, we get $C(\Delta mag) = A\sum_{k=0}^{\infty}\frac{B^k}{k!(2k+1)}(\Delta mag - C)^{(2k+1)}$



- Stellar distance & working angles define $\max(C_i)$ ranging from 0.19 to 0.29
- Coronagraph has a limiting Δmag **of 23.2, limiting $max(C_i)$** to range from 0 to 0.12
- Few targets will see > 50% (μ) of $\max(C_i)$

- Using SNR from Nemati 2014 **[4]**, we analytically solve for $\tau(\Delta mag)$
- With our approximations we numerically solve $\frac{dC}{d\tau}(\tau_0) = const$
- Gaussian fit **approximates** $C(\tau)$ **knee points** but overestimates $max(C_i)$
- Few top performing stars and **large temporal variation in knee points**



- AYO now fast enough to run in dynamic schedule Monte Carlo (calculates τ_0 in **<30 sec** compared to **150 sec** in previous versions)
- New method is **capable of returning sacrificed stars to observation list** without restarting optimization

Altruistic Yield Optimization (AYO)

[1]

Calculate $\tau_{i,0}$ — M = list of stars to observe; N = # stars in M

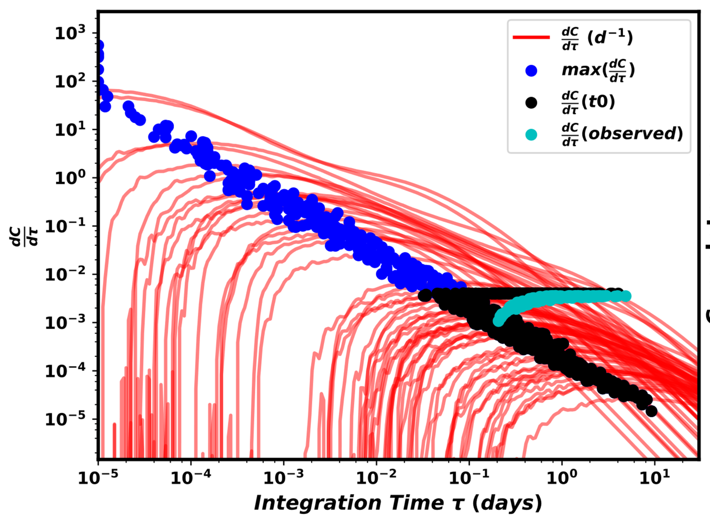
While $\left[N\times(T_{settling}+T_{overhead}) + \sum_i^M \tau_i > T_{mission\ length} \right.$ OR $\left. \sum_i^M C_i(\tau_i) < \text{last iteration} \sum_i^M C_i(\tau_i) \right]$

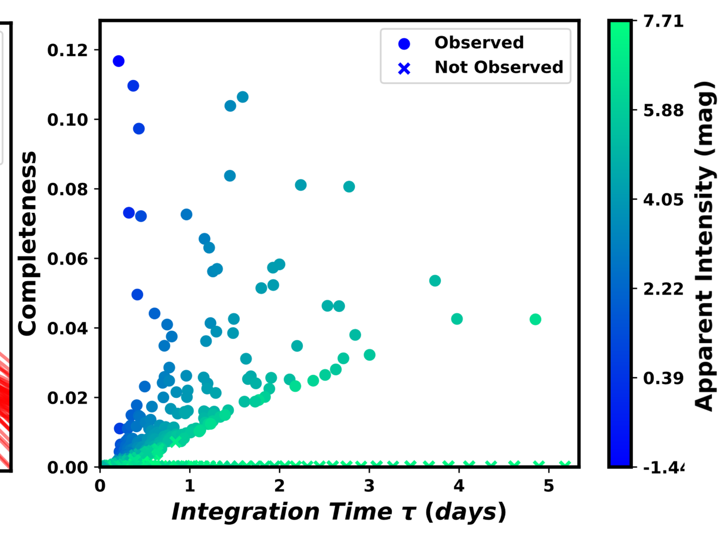
Sacrifice star i where $min\left(\frac{C_i}{\tau_i}\right)$

$\tau_{sacrificed} = \tau_i + T_{settling} + T_{overhead}$

Assign $\tau_{sacrificed}$ in increments of $d\tau$ to $\max\left(\frac{dC_i(\tau_i)}{d\tau_i}\right)$

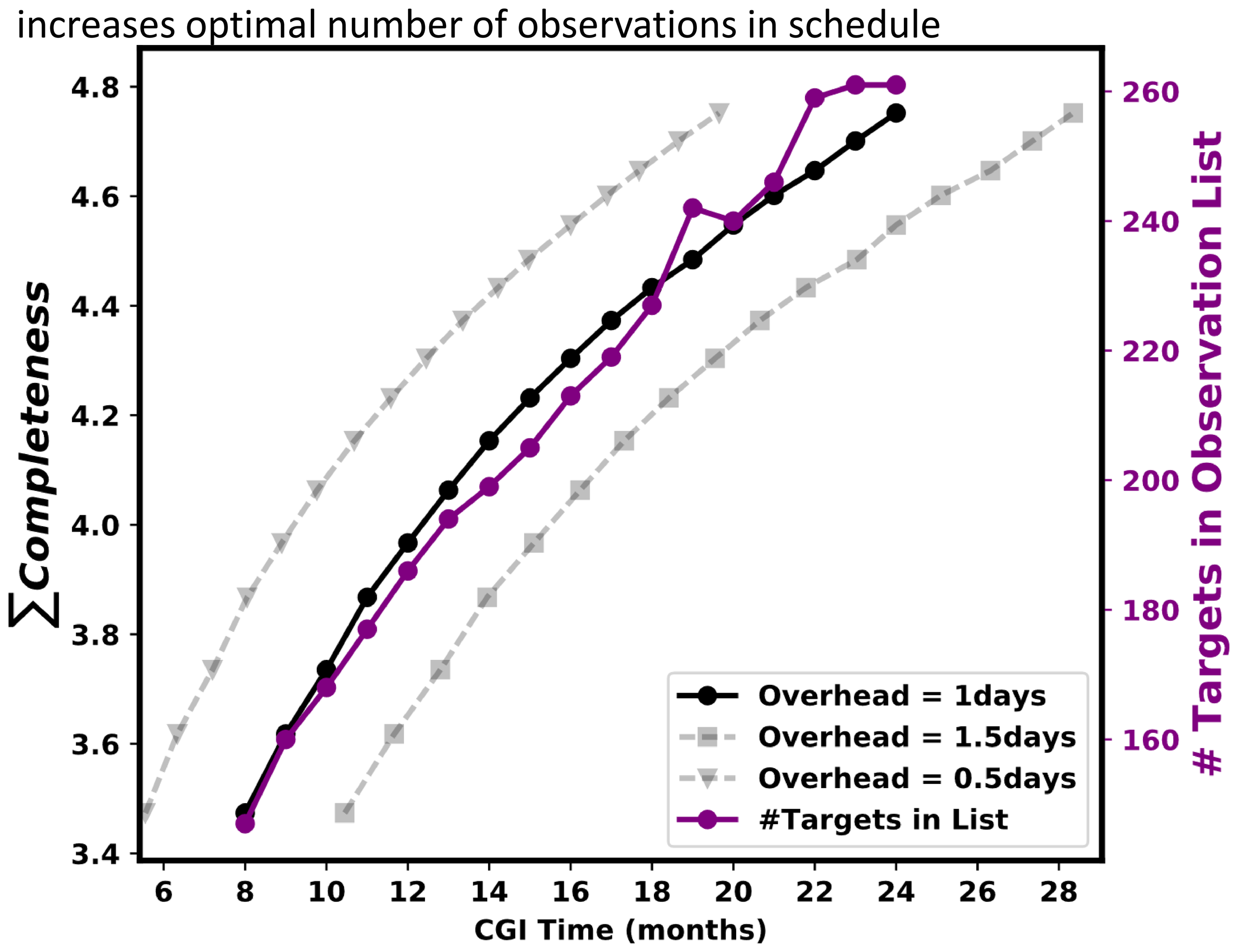
- AYO $\frac{dC}{d\tau}$ reward mechanism produces a horizontal line in the $\frac{dC}{d\tau}$ vs τ
- Many targets have **max** $\left(\frac{dC}{d\tau}\right) < \frac{dC}{d\tau}(observed)$
- Sacrifice of min $\left(\frac{C}{\tau}\right)$ seen in constant $\frac{C}{\tau}$ slope of observed targets
- **Higher** $\frac{C}{\tau}$ **performance of a star ∝ Lower apparent star magnitude**





Overhead & Settling Time

- $T_{overhead} + T_{settling}$ variation of $\pm 0.5 days$ $\propto \sum C$ variation of ∓ 0.4
- Overhead variation of $\pm 0.5 days$ varies static schedule observation times by $\pm 2mo$, demonstrating he importance of flexible scheduling
- 12mo mission schedules have 186 targets, increasing mission length increases optimal number of observations in schedule

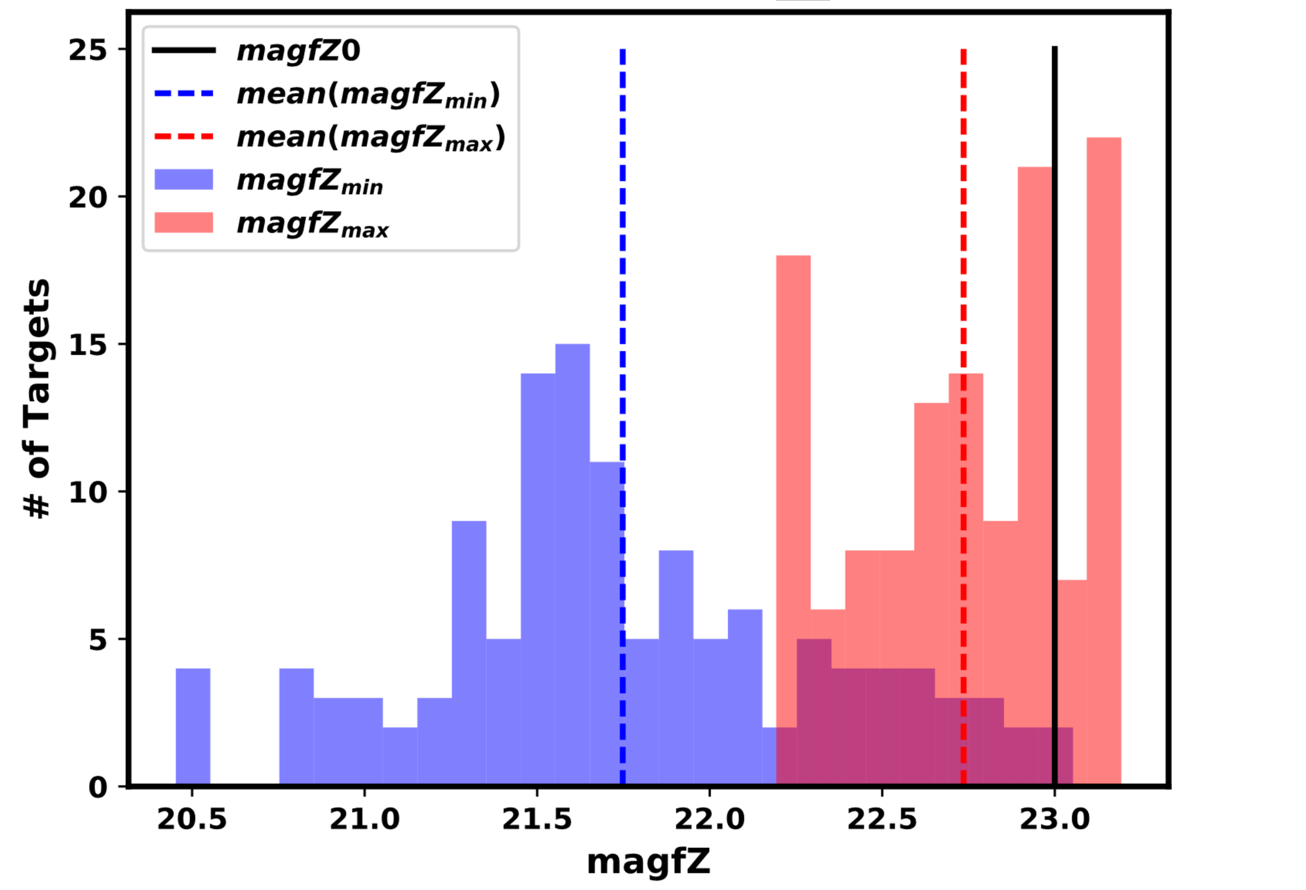


Zodiacal Light

- Observing stars at solely $magfZ_{min}$ or $magfZ_{max}$ varies $\sum C$ by 10%

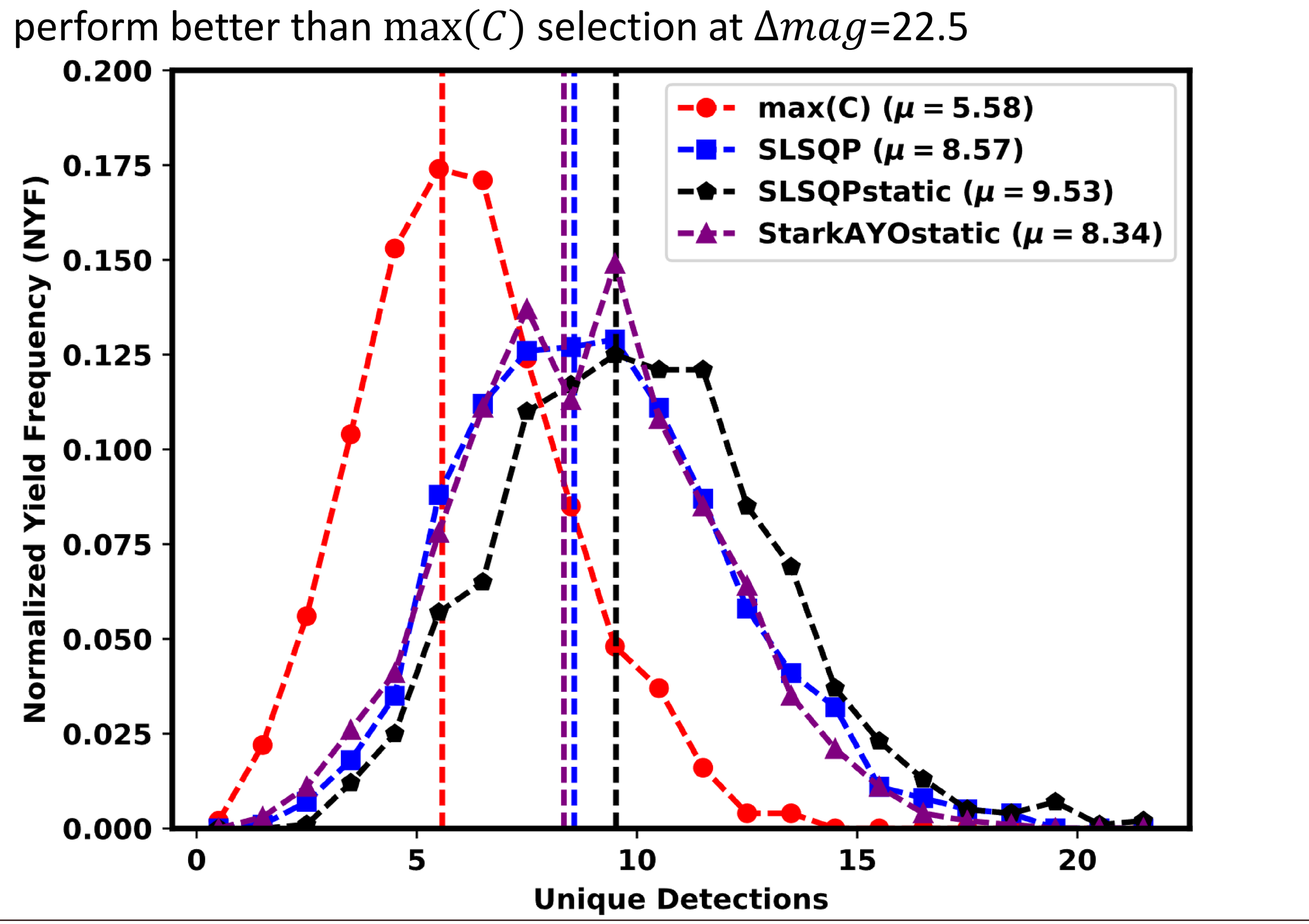
$\sum C(magfZ_{min}) = 3.96$

$\sum C(magfZ_{max}) = 3.64$



Monte Carlo Results

- WFIRST Coronagraphic Instrument should detect **9.5 exoplanets** with sequential least squares quadratic programming (SLSQP static), dependent on a contiguous year long mission with Kepler planet populations (will be different for SAG13)
- SLSQP static out performs dynamic scheduling methods by ~10% without considering Zodiacal Light **[2]**
- SLSQP and StarkAYO (similar methods) produce similar total yields
- **Any optimization** is better than **no optimization** since all schedulers perform better than $\max(C)$ selection at Δmag=22.5



Acknowledgements & References

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[1] C. Stark, A. Roberge, A. Mandell, T. Robinson, *Maximizing the ExoEarth Candidate Yield from a Future Direct Imaging Mission*, ApJ, 2014

[2] D. Savransky, C. Delacrois, 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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