Optimal Starshade Observation Scheduling

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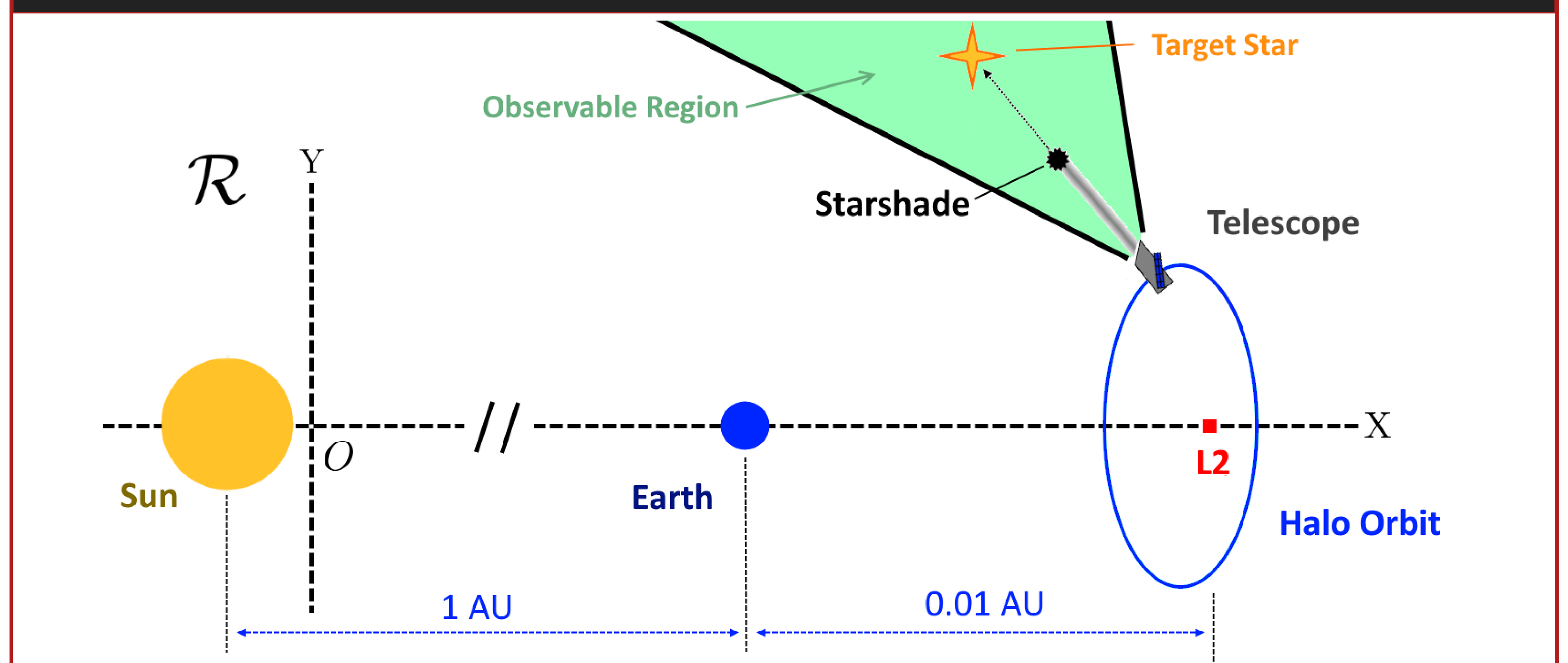
Introduction

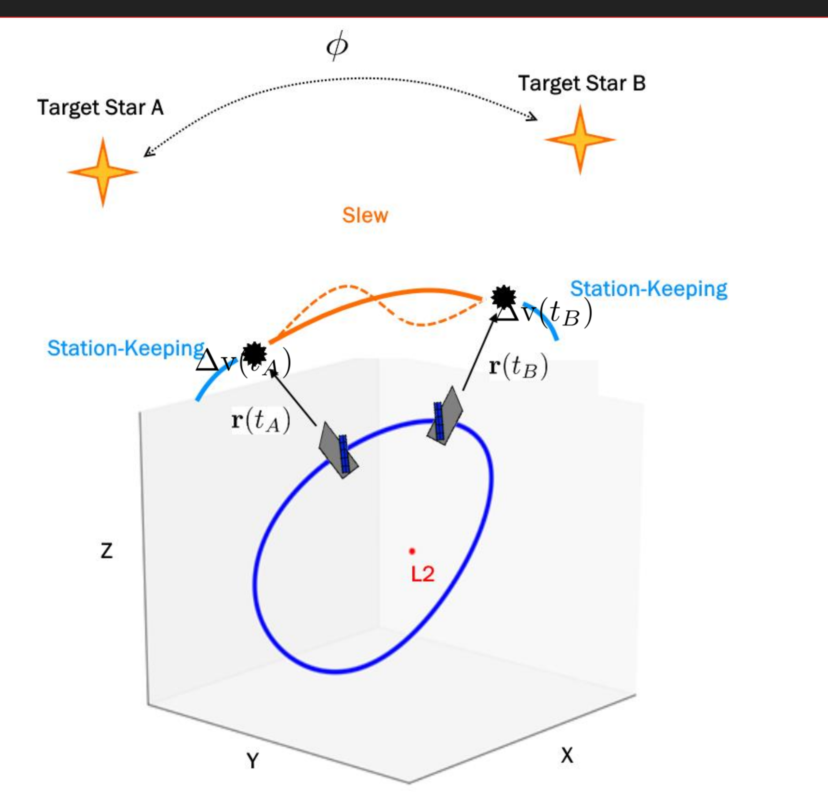
An exoplanet direct imaging mission can employ an external starshade for starlight suppression to achieve higher contrasts and potentially higher throughput than with an internal coronagraph. A starshade class to the survey simulation module of Exoplanet Open-Source Imaging Simulator (EXOSIMS)[1] interpolates fuel costs generated from integrating the full three-body problem equations of motion. Slew times are selected based on when stars are observable due to keepout, integration times, and predefined observing blocks. Stars are chosen for observation based on completeness values[2] and other criteria. We present simulation results for multi-year starshade missions.

Starshade Configuration

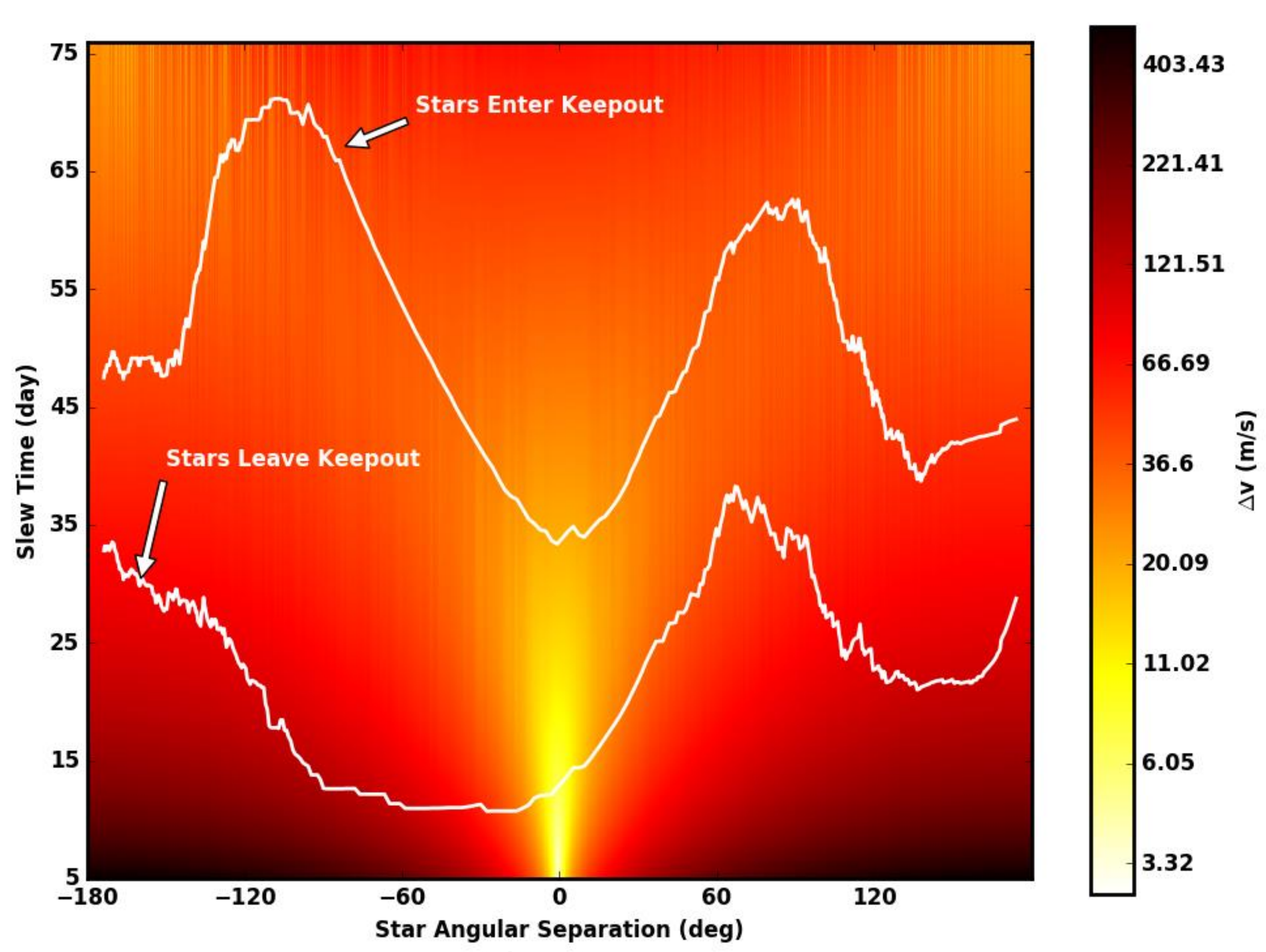


Planar view of the Telescope-Starshade-Target configuration in Sun-Earth rotating frame (not to scale). Starshade aligns with target line of sight (LOS) and suppresses starlight.

Estimating Fuel Cost



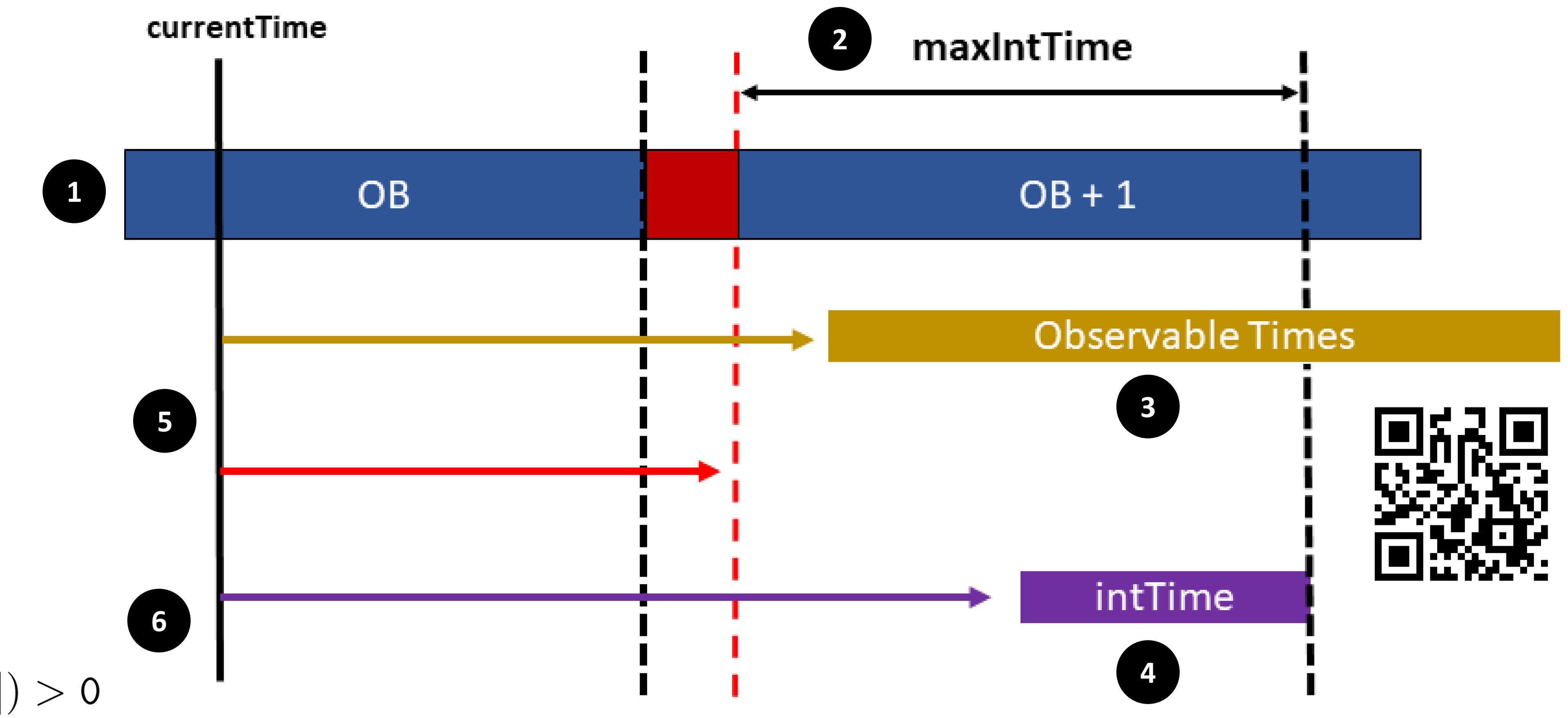
- Starshade motion found through integrating **Circular Restricted Three-Body Problem**[3] equations of motion
- Station-keeps to observe star A, retargets to star B at some future time, then station-keeps with star B
- Fuel costs are the discrete jumps in velocity when transitioning between station-keeping and retargeting[4]



Fuel cost for retargeting maneuvers (slews) between two target stars shown as a function of angular separation of the stars and amount of time needed to transfer. A 2D interpolant is created from this cost matrix to quickly estimate slew fuel costs for any pairs of stars **quickly** within each decision step of a mission simulation[5].

Filtering the Target List

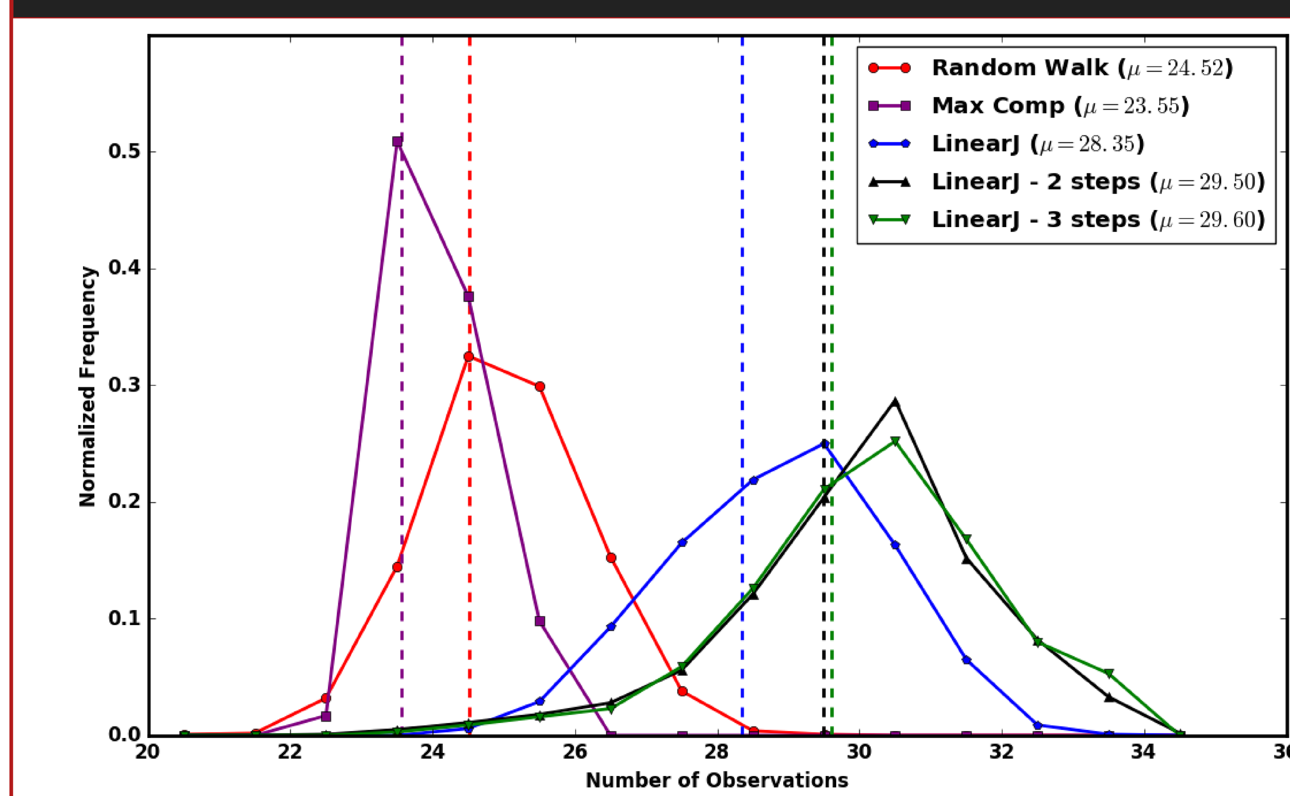
1. **Observing Blocks**
   Calculate start and end of observing blocks for current time and future times
2. **Max Integration Times**
   $$\min(\Delta t_{\mathtt{OB}}, \Delta t_{\mathtt{MissionEnd}}, \Delta t_{\mathtt{Imaging}})$$
3. **Observable Times**
   Times when a particular star leaves keepout (becomes observable) and enters keepout again
4. **Integration Times**
   Calculated starting at every possible observable time
5. **Min Allowed Slew Time**
   $$\max(\min(\mathtt{ObservableTimes}), \mathtt{OBstartTime}[\mathtt{OB}+1]) > 0$$
6. **Max Allowed Slew Time**
   $$\mathtt{OBstartTime}[\mathtt{OB}+1] + \mathtt{maxIntTime} - \mathtt{IntTimes} > 0$$



$$\mathtt{IntTimes} < \max(\mathtt{ObservableTimes}) - \mathtt{minSlewTime}$$

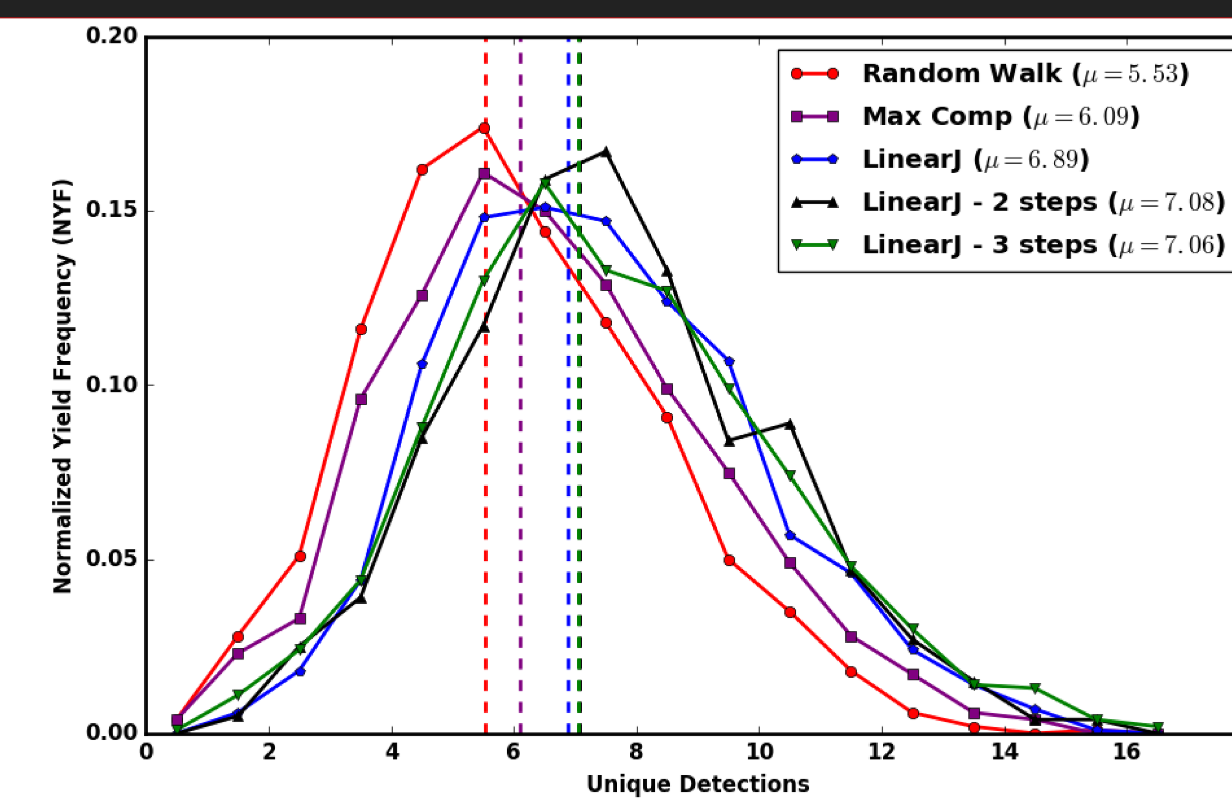
$$\mathtt{maxAllowedSlewTime} > \mathtt{minAllowedSlewTime}$$

Mission Simulations



1000 mission simulations were conducted using 5 different mission selection schemes:

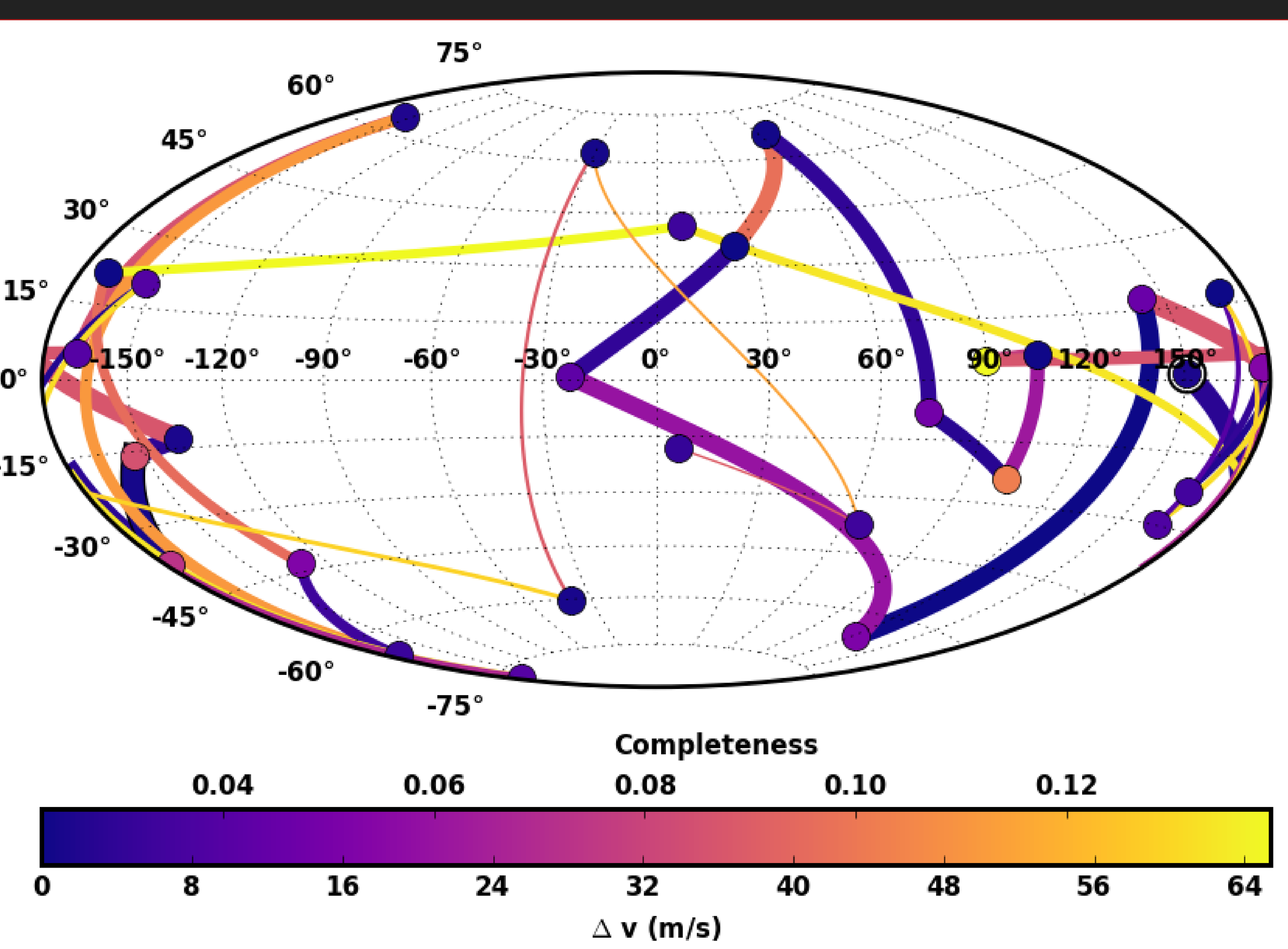
1. Random walk
2. Maximizing star completeness
3. Linear cost function
4. Two time steps of the linear cost function
5. Three time steps of the linear cost function



Linear cost function allows the mission to perform more observations due to more convenient slew times on stars with higher completeness values.

Unique exoplanet detections shown for all 5000 mission simulations. Looking two steps in the future produces optimal results using the linear cost function.

Observation Schedule



A mission timeline is shown below for the 3 year mission. The starshade slews to the next target for observation within specified observing blocks. There were 7 detections and 2 characterizations in this mission.

Linear Cost Function

$$\mathbf{c} = c_1 \Delta v_{min} + c_2(1 - C_O) - c_3 f_{unv} + c_4 f_{rev}$$

$$f_{unv}(j) = \begin{cases} 0 & N(j) > 0 \\ \left(\frac{t}{t_F}\right)^2 & N(j) = 0 \end{cases} \qquad f_{rev}(j) = \begin{cases} 0 & j \notin \mathbb{E} \\ 1 & j \in \mathbb{E} \end{cases}$$

Linear cost function[5,6] prioritizes slews with low fuel usage towards stars with high completeness values. Unvisited stars and stars selected for revisits are also included.

Size $1 \times j$ for stars $j \in \mathbb{T}$

Target List $\mathbb{T} \subset \mathbb{Z}$

Number of Observations $N(j)$

Revisit List $\mathbb{E} \subset \mathbb{T}$

Acknowledgements and References

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