Starshade Observation Scheduling for WFIRST

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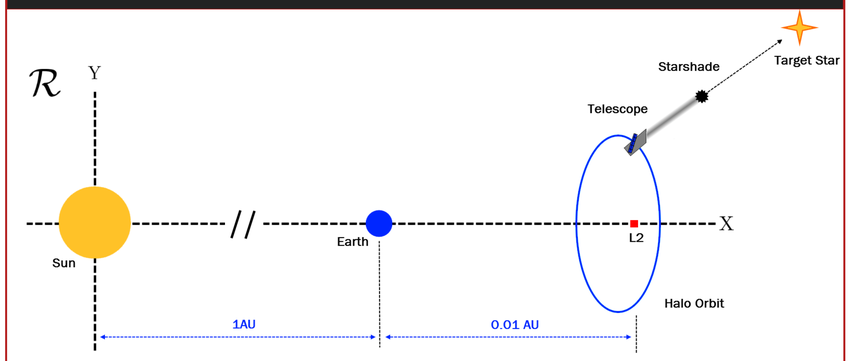
Introduction

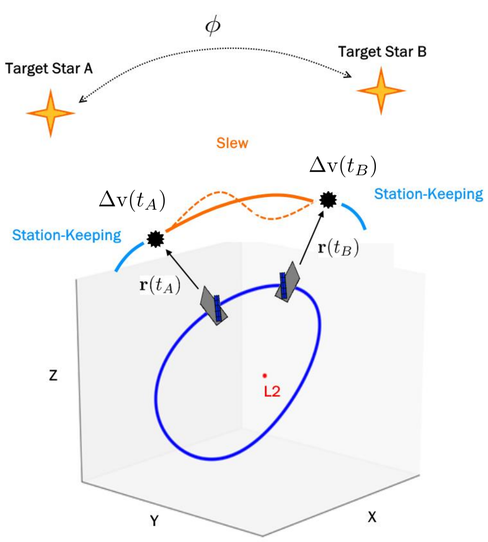
An exoplanet direct imaging mission can employ an external starshade for starlight suppression to achieve higher contrasts and potentially higher throughput than with an internal coronagraph. This study adds a starshade class to the survey simulation module of Exoplanet Open-Source Imaging Simulator (EXOSIMS)[1] which interpolates fuel costs generated from integrating the full three-body problem equations of motion. Time constraints are imposed based on when stars are observable. The star with the highest completeness[2] that meets the constraints of time and fuel cost is selected. This is repeated until the starshade runs out of fuel and an observation schedule is created.

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.

BVP via Collocation



- Starshade motion found through integrating **Circular Restricted Three-Body Problem**[3] equations of motion
- Starshade station-keeps with telescope while star A is observed
- Starshade then retargets to star B while telescope slews / conducts other operations
- Position at t_A and t_B are known
- Solve boundary value problem to find $\mathbf{v}_{slew}(t_A)$
- Collocation algorithm used:
  - Fits cubic polynomial between endpoints
  - Minimizes residual error at mesh points in between

- Velocities known at endpoints of slew trajectory
- Solve two more BVP to find station-keeping velocities[5]

$$\Delta v(t_A) = |\mathbf{v}_{slew}(t_A) - \mathbf{v}_{sk}(t_A)|$$

$$\Delta v(t_B) = |\mathbf{v}_{slew}(t_B) - \mathbf{v}_{sk}(t_B)|$$

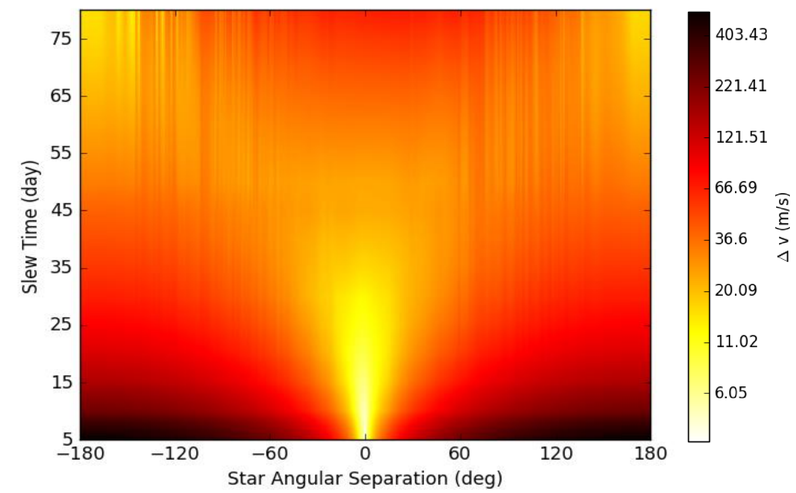
- Total fuel used for one transfer, assuming two-impulse maneuver

$$\Delta v_{total} = \Delta v(t_A) + \Delta v(t_B)$$

Diameter	26 m
IWA	72 mas
Separation Distance	37,242.26 km
Dry Mass	1250 kg
Total Mass	3500 kg
I_{sp}	308 s
Total Δv	2094.33 m/s

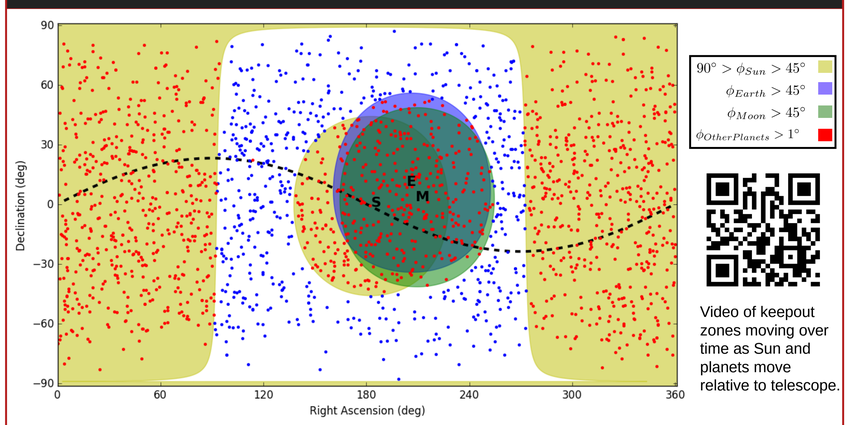
Starshade parameters[4] used for simulations in this study. The starshade is assumed to have a bi-prop propulsion system given the impulsive maneuver assumptions inherent in the BVP solutions.

Estimating Fuel Cost – Any Star, Any Time



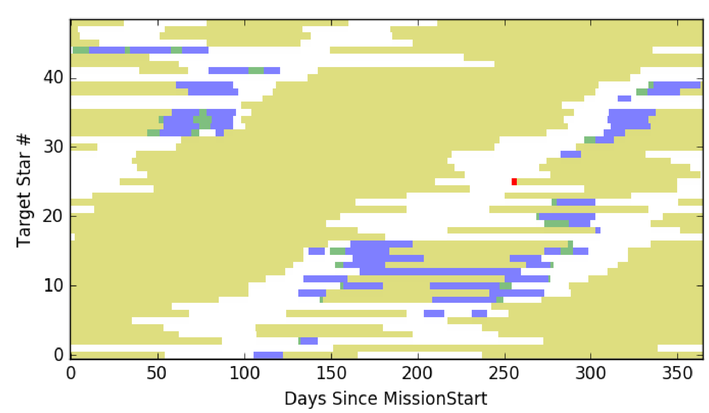
- Need fast way of calculating cost of getting from one star to all others in a target list
- Solving every BVP takes approximately 12 minutes with a dual core 2.50 GHz CPU
- Arranging target stars by angular separation ϕ from previous observed star reveals structure in a Δv vs. ϕ plot (asymmetric about the 0° line)
- Can add second dependency for slew time $\Delta t = t_B - t_A$
- Interpolant generated to calculate $\Delta v = f(\phi, \Delta t)$ within a fraction of a second

Moving Keepout Zones as Time Constraints



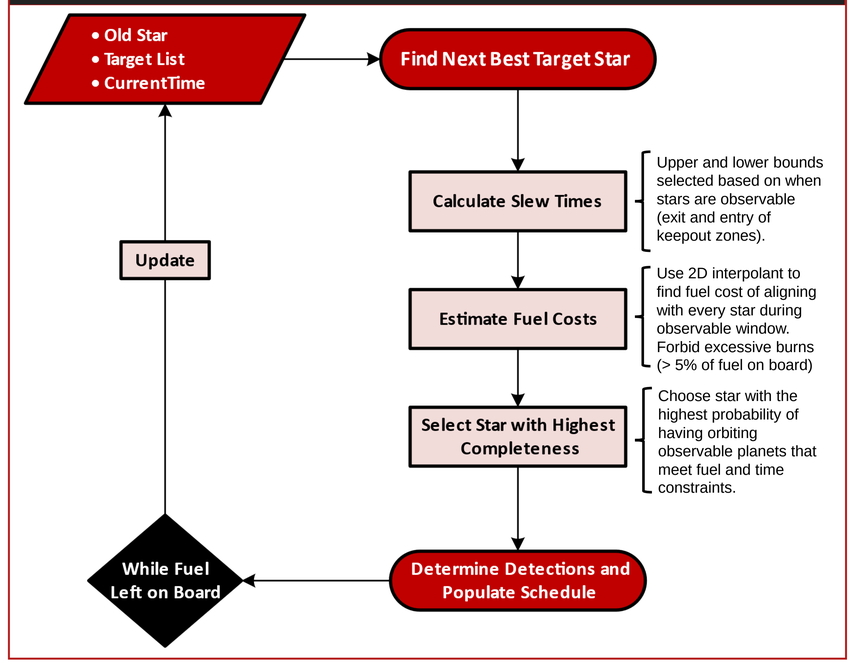
Video of keepout zones moving over time as Sun and planets move relative to telescope.

- **Keepout Zone**: stars are unobservable due to sun or planet light directly entering (or being reflected by starshade) into telescope
- Need to point telescope away from bright sources, imposes angular constraints[6]

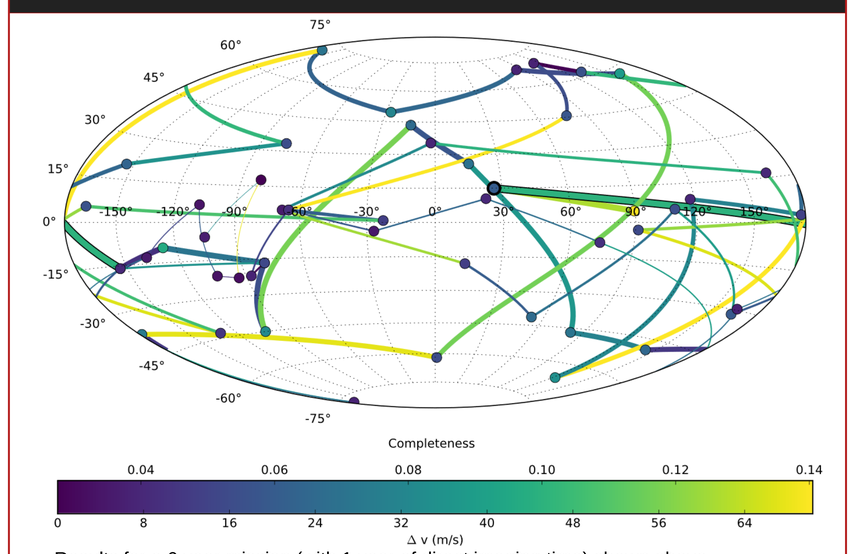


- Stars enter and exit keepout zones as the telescope orbits the L2 point
- Plot above shows times since the start of the mission during which a particular target star is in a keepout zone (colors indicate which bright source is the culprit)
- Times when star **exits** and **re-enters** keepout zone used as bounds for slew times

Choosing the Next Best Star to Observe



Starshade Observation Schedule



- Results for a 6 year mission (with 1 year of direct imaging time) shown above
- Color scaling on each point indicates completeness value of that particular target star
- Color scaling for each line indicates Δv value for each transfer (thickness indicates order of observation with first star highlighted in bold)
- 51 observations were made with 10 detections overall in 149s
- Future work on this scheduler will include comparisons with other schedulers and more aggressive slew times early in the mission before instrument deterioration

Acknowledgements and References

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