Starshade Orbital Maneuver Study for WFIRST

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Introduction

The Wide Field Infrared Survey Telescope (WFIRST) will perform exoplanet science via both microlensing surveys and direct imaging. Direct imaging requires starlight suppression, which can be accomplished by an internal coronagraph. Alternatively, an external starshade could be used to achieve required high contrasts with a wavelength-independent inner working angle (IWA) and potentially higher throughput. The work presented here explores the orbital mechanics of the starshade and its fuel usage during flight. Minimum time and Δv trajectories are computed to transfer the starshade from one line of sight (LOS) to another.

Starshade Configuration

- External spacecraft placed in line of sight (LOS) of WFIRST to a target star
- Diffraction effects from target star eliminated through petal design
- Diameter of starshade and fixed separation distance from telescope define inner working angle (IWA) for observing exoplanets

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

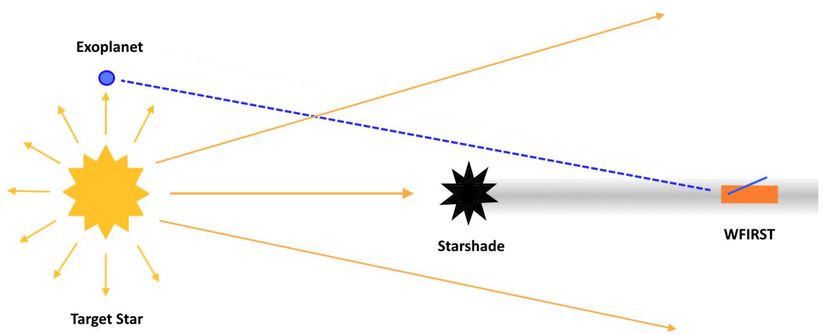


Diagram based on illustration by Kolemen, E., & Kasdin, N. J

Orbital Mechanics and Starshade Alignment

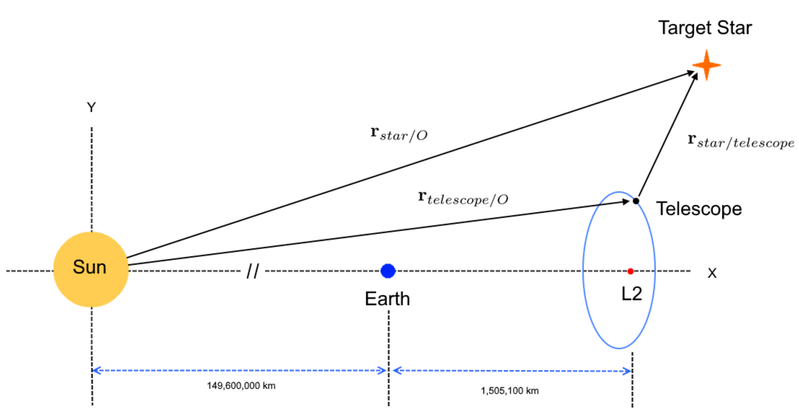
- WFIRST and starshade motion governed by Circular Restricted Three Body Problem equations

$$\ddot{x} = x + 2\dot{y} - \frac{(1-\mu)(\mu+x)}{[(\mu-x)^2+y^2+z^2]^{\frac{3}{2}}} - \frac{\mu(\mu+x-1)}{[(1-\mu-x)^2+y^2+z^2]^{\frac{3}{2}}}$$

$$\ddot{y} = y - 2\dot{x} - \frac{(1-\mu)y}{[(\mu-x)^2+y^2+z^2]^{\frac{3}{2}}} - \frac{\mu y}{[(1-\mu-x)^2+y^2+z^2]^{\frac{3}{2}}}$$

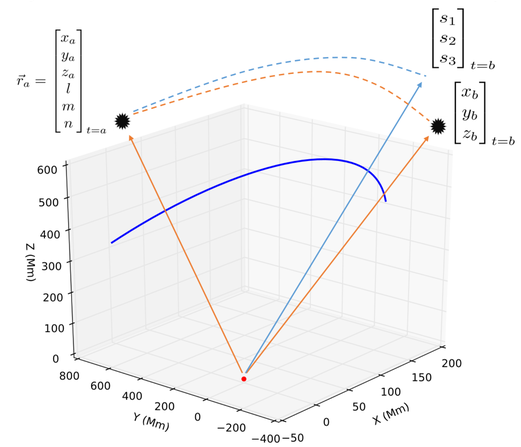
$$\ddot{z} = -\frac{(1-\mu)z}{[(\mu-x)^2+y^2+z^2]^{\frac{3}{2}}} - \frac{\mu z}{[(1-\mu-x)^2+y^2+z^2]^{\frac{3}{2}}}$$

- WFIRST assumed to be on a halo orbit about the Earth-Sun L2 point.
- Dynamics are calculated in the rotating frame of Sun-Earth-Moon system

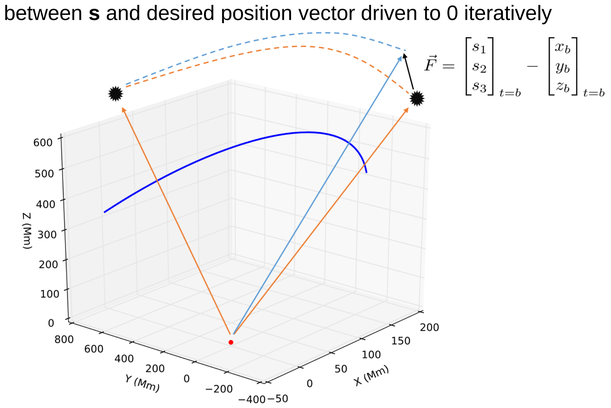


BVP via Single Shooting Method

- Starshade position vectors for two lines of sight calculated at times *a* and *b*
- Need velocity vector at *t* = *a* that will take starshade to desired position at *t* = *b*

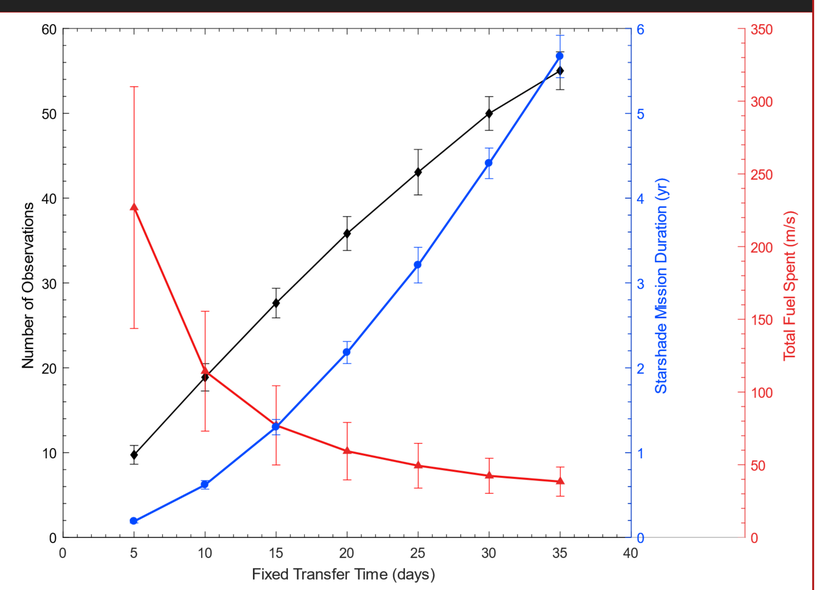


- Dynamics of starshade "shot" forward in time to *t* = *b* to some position vector **s**
- Difference between **s** and desired position vector driven to 0 iteratively



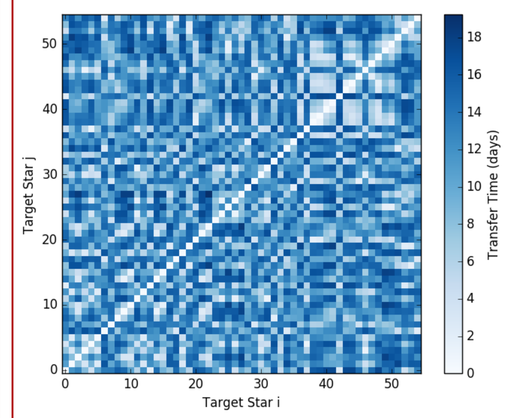
- Δv : velocity differences between BVP trajectory and station-keeping trajectories
- Station-keeping trajectories modelled as BVP with small time steps, assuming discrete thrust control

Starshade Mission Simulations



- Each starshade mission simulation selects random targets for alignment
- Simulation runs sequence of realignments for different fixed transfer times, ends when fuel runs out
- 100 simulations run for each fixed transfer time

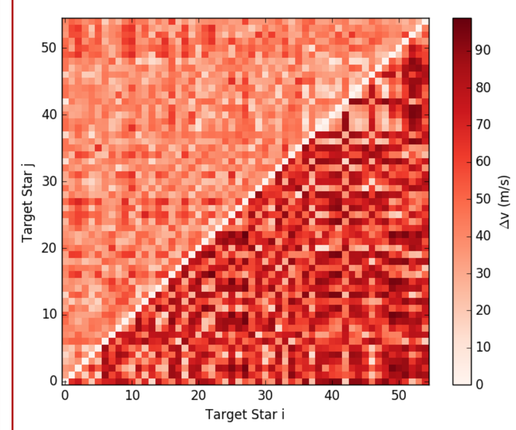
Minimum Transfer Time Optimization



- Transfer time Δt minimized in optimization problem subject to fuel constraint
- Minimum Δt results for transfers between star *i* and star *j* for a 55 star target list
- All transfers are computed relative to the same point on the WFIRST halo orbit
- Transfers cannot use more than 5% of the total fuel on board

	Minimum Δt Results	Fixed Δt Results
Mean Δt	11.38 days	11.38 days
Mean Δv	104.33 m/s	101.01 m/s
# of Observations (6 yrs, No Fuel Budget)	372.00	163.00
Minimum Mission Duration (with Fuel Budget)	0.17 yr	0.74 yr

Minimum Δv Optimization



- Minimum Δv results for transfers between star *i* and star *j* for a 55 star target list
- Lower triangle shows 20 day fixed transfer time Δv results for comparison
- Upper transfer time limit of ¼ of the halo orbit period

	Min. Δv Results		Fixed Δt Results	
Δt Upper Bound	20.0 days	42.0 days	-	-
Mean Δt	19.5 days	38.4 days	20 days	30 days
Mean Δv	62.1 m/s	38.5 m/s	62.3 m/s	45.7 m/s
# of Observations (No Time Limit, w/ Fuel Budget)	122.00	143.00	124.00	136.00
# of Observations (6 yrs, w/ Fuel Budget)	105.00	63.00	107.00	71.00
Minimum Fraction of Total Fuel Used	0.86	0.35	0.84	0.45

Conclusions

- A 30-35 day fixed transfer time per starshade randomly selected realignment achieves 50 observations, achievable within 6 year WFIRST mission lifetime
- Choosing minimum Δt transfers results in reduced starshade mission lifetime
- Minimum Δv results in over 100 observations in a 6 year period

Acknowledgements and References

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