Starshade Orbital Maneuver Study for WFIRST

Gabriel Soto, Dmitry Savransky, Daniel Garrett, Christian Delacroix, Amlan Sinha

Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, NY, United States

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. Only the fuel usage between observations is considered.

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

Starshade Parameters	
Separation	55,000 km
Dry Mass	3400 kg
Total Mass	6000 kg
Isp	400 s
Total Δv	2228.8 m/s

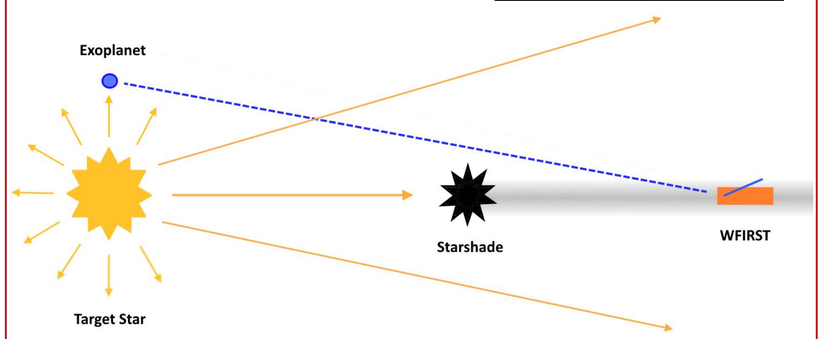
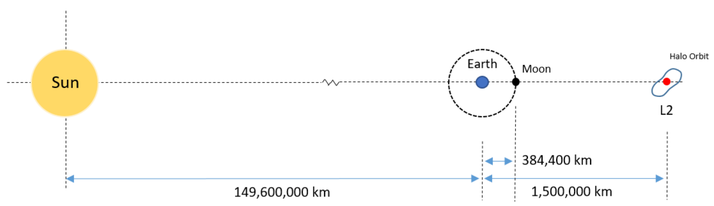


Diagram based on illustration by Kolemen, E., & Kasdin, N. J

Orbital Mechanics

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



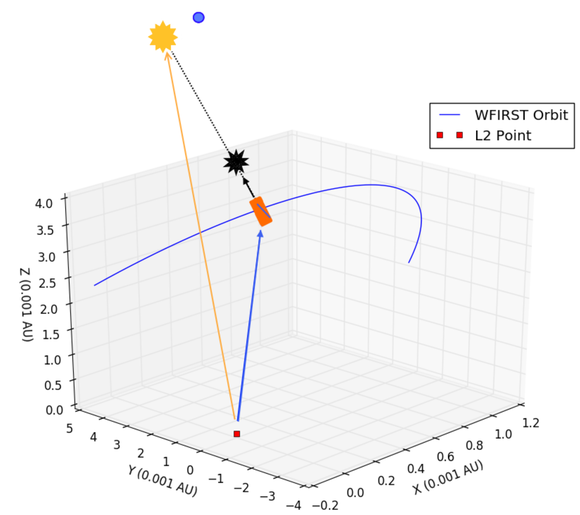
- WFIRST and starshade are governed by Circular Restricted Three Body Problem equations

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

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

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

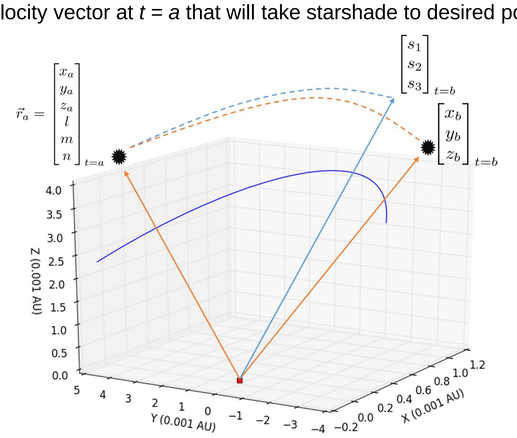
Aligning Starshade with Target LOS



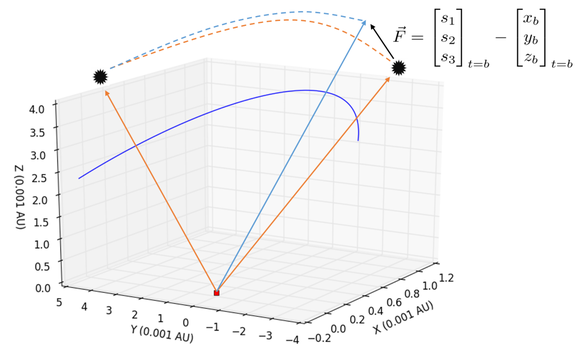
- Target list of stars generated using EXOSIMS with heliocentric position vectors
- Unit vector of target star position with respect to WFIRST is calculated
- Starshade placed a fixed distance along calculated unit vector

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*

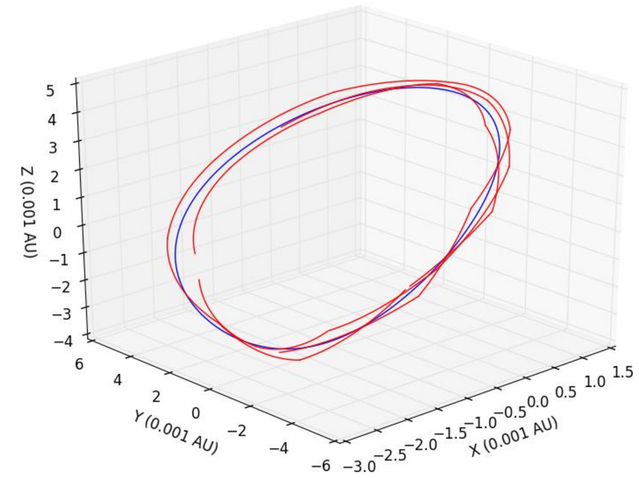


- Dynamics of starshade "shot" forward in time to *t* = *b* to some position vector **s**
- Difference between **s** and desired position vector driven to 0 iteratively

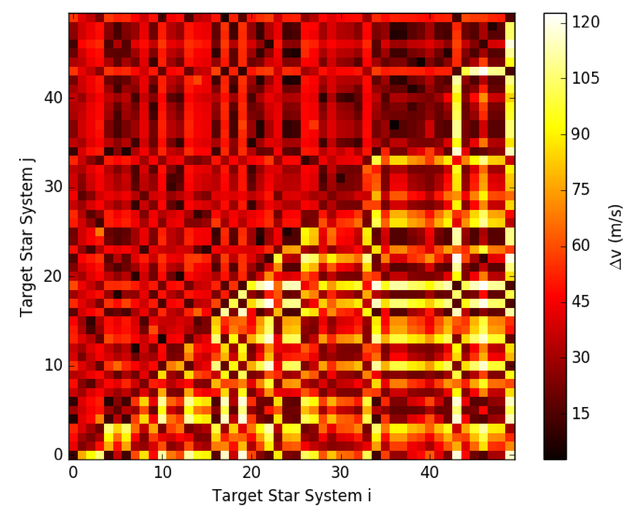


- Δv : velocity differences between BVP trajectory and station-keeping trajectories

Trajectory And Optimization Results



- Starshade trajectory (red) for randomly selected target stars using non-optimized transitions. 22 different observations are possible based on total Δv



- Amount of Δv required to more from one LOS to another shown on bottom diagonal for a 20 day transit time.
- Upper diagonal shows optimized Δv for varying transit time. Transitions along diagonal not optimized.

Conclusions

- Randomly selecting targets and using a time of flight of 20 days for each transfer results in approximately 22 observations for one mission on average
- Minimizing Δv by varying transfer times results in burns of ~20 m/s
- Using these preferable targets results in ~100 observations per mission

Acknowledgements and References

This work is supported by NASA Grant No. NNG16PJ24C (SIT).

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