Navigation and Control Performance Utilizing Precision Formation Flying Along a Propellent Optimized Trajectory for the VTXO Mission

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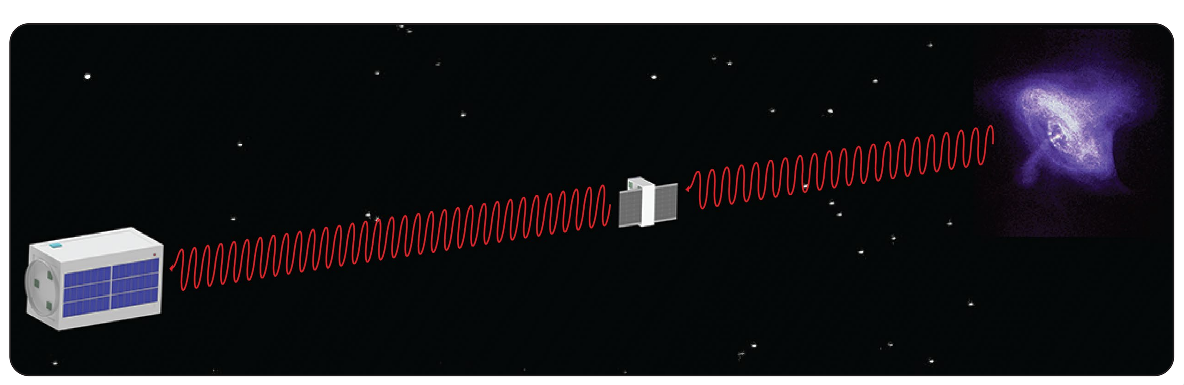
Introduction

The Virtual Telescope for X-Ray Observations (VTXO) is part of a new generation of distributed component, long focal length telescopes which promise to provide orders of magnitude improvement in angular resolution in the X-ray band over the current state of the art. VTXO will include Phased Fresnel Lenses (PFL), which provide nearly diffraction-limited imaging, with around a 1 km focal length carried by the Optics Spacecraft (OSC), which will fly in a precision formation with the Detector Spacecraft (DSC) approximating a rigid telescope body, with the telescope achieving nearly 50 milli-arcsecond angular resolution in the 4.5 – 6.7 keV X-ray band [1]. In order to maintain the precise formation requirements, while pointing the telescope axis at the desired astronomical targets, one or both spacecraft will inherently be traveling on a non-natural orbit trajectory. These families of trajectories require one or both vehicles to maneuver regularly to maintain the desired path.

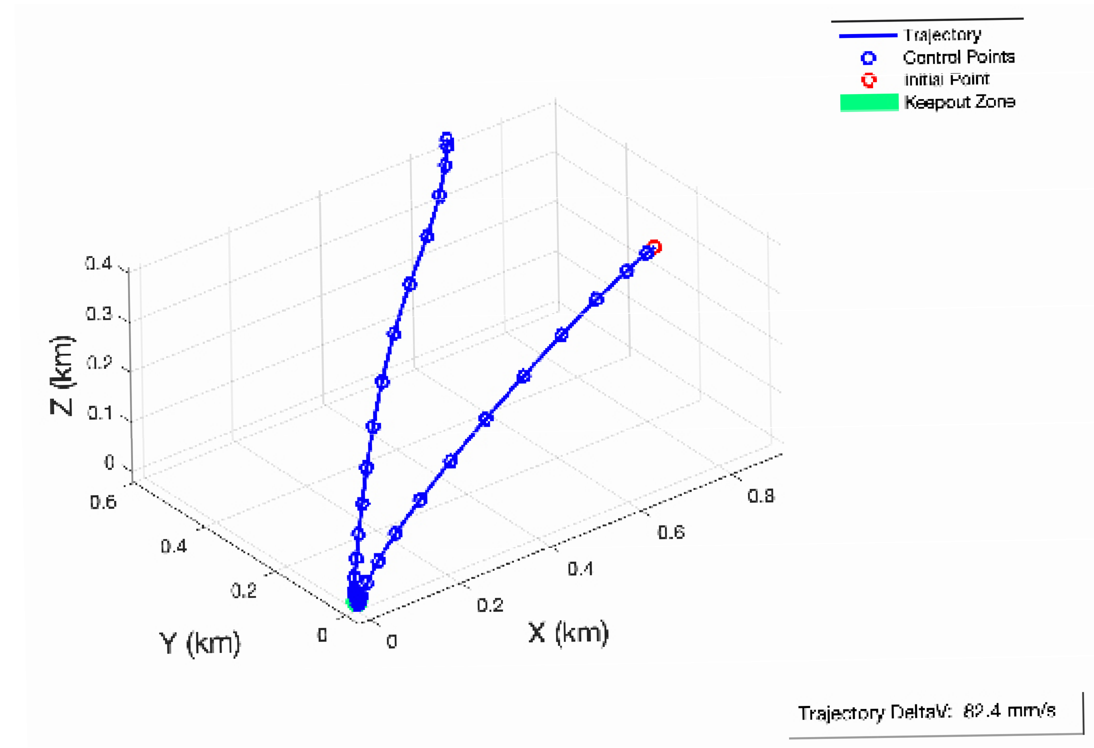
Problem Statement

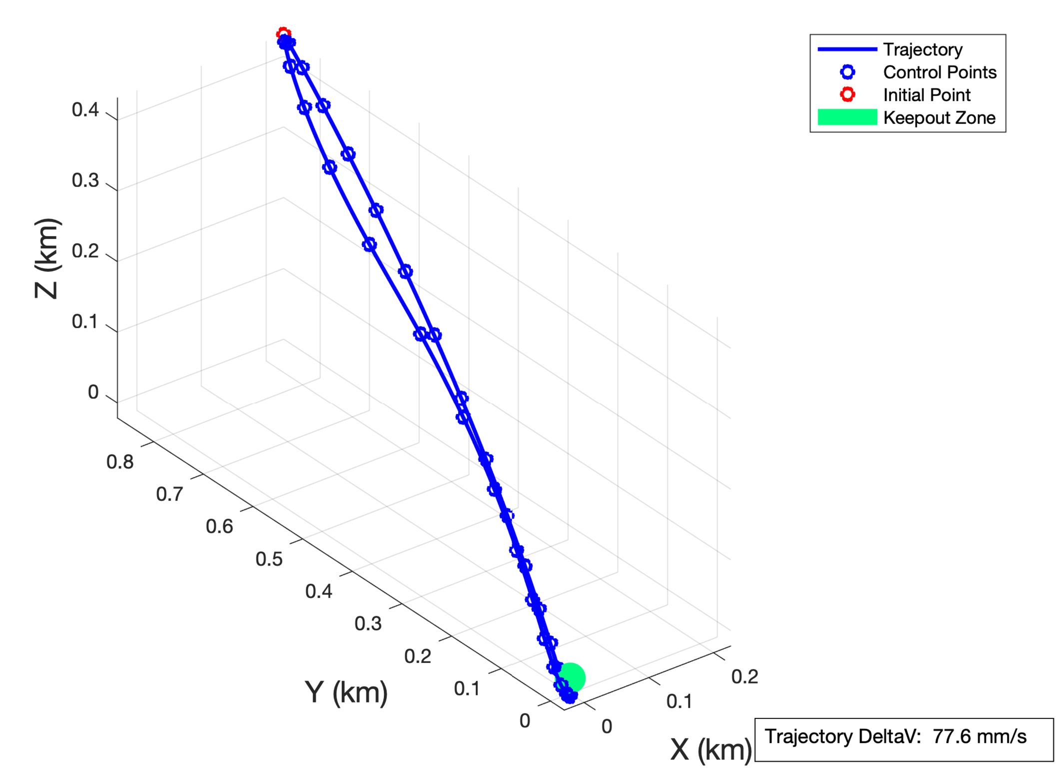
During astronomical observations VTXO's navigation requirements are extremely strict and will be handled by one of a family of currently under development precision optical navigation sensors. However, to use these precision navigation sensors, it becomes necessary to keep the two-spacecraft pointing at each other during the entire orbit [2]. This imposes requirements preventing the formation from being pointed at the Sun, or Earth. These requirements impose significant constraints on the trajectory optimizers which directly impacts mission life, and correspondingly science return. Additionally, these pointing requirements will place limitations on solar panel, antenna, and thruster pointing, all with undesirable impacts on the mission design. As such, it is highly desirable to develop a navigation scheme which permits the flying of the optimized formation trajectories, without the use of the precision optical navigation sensors. A variety of schemes are being assessed such as relative GPS, combining raw GPS data with an IMU based navigation system, the use of an onboard high accuracy clock, and combinations thereof.



Optimized Trajectories

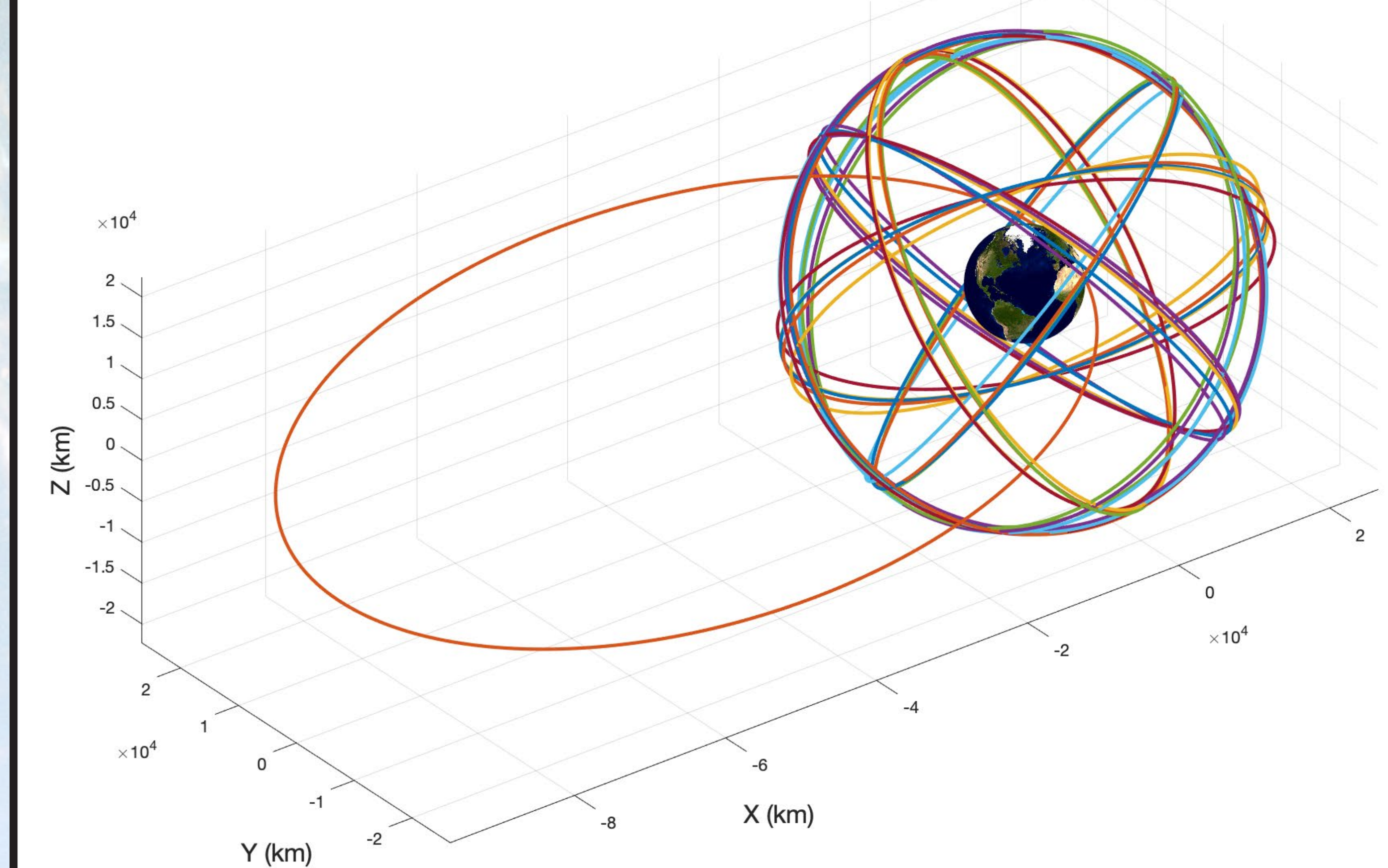
Presented below are two examples of optimized trajectories for the VTXO mission in the relative frame [3]. These trajectories promise to reduce propellent consumption by significantly more than half compared to the mission baseline. However, these benefits will be significantly impacted if Sun and Earth pointing constraints are included.



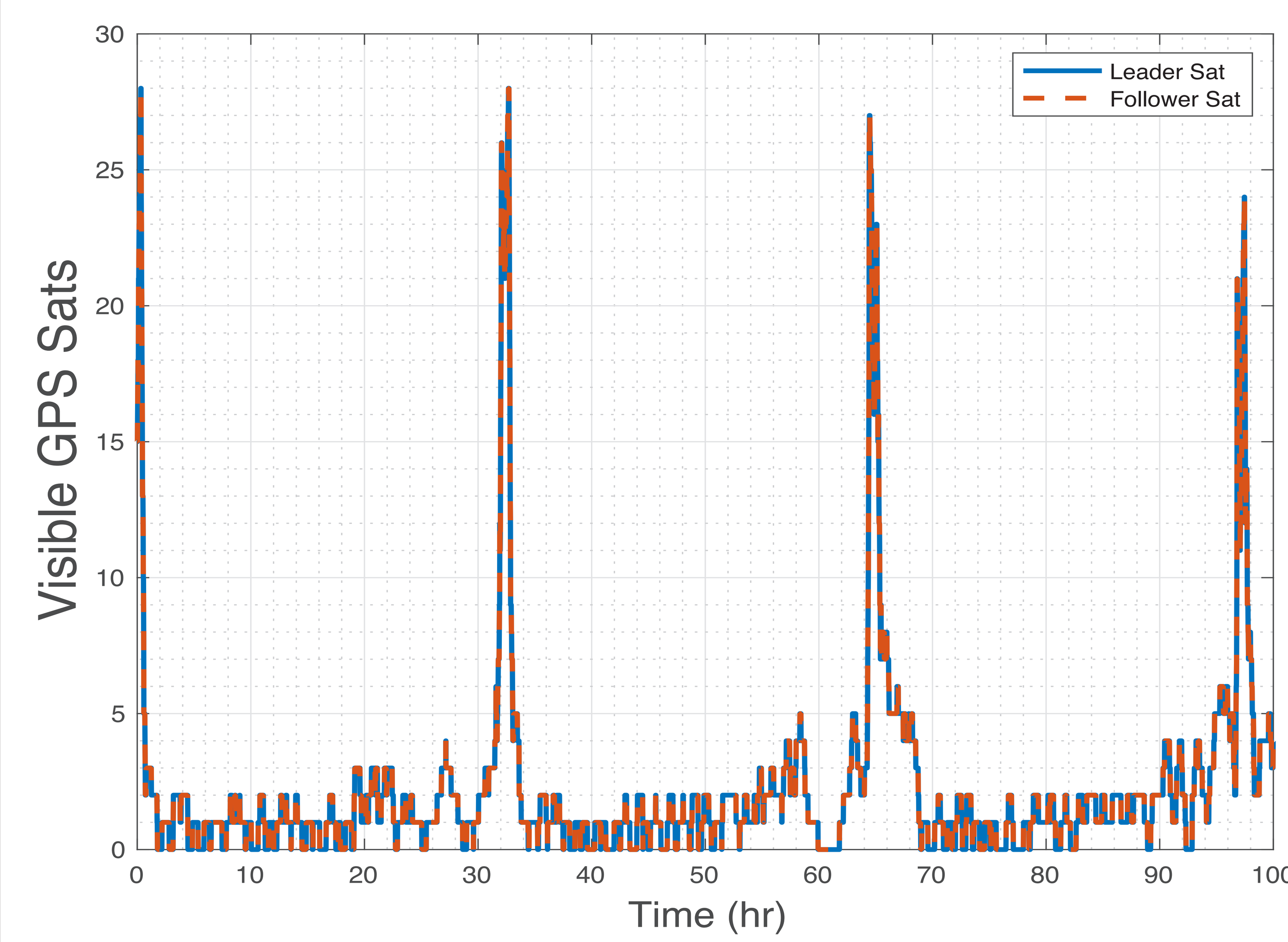


Above the Constellation GPS

VTXO spends a significant portion of its orbit above the GPS constellation. While some GPS signal is available as has been demonstrated by several high earth orbiting satellites such as MMS [4], the reception is limited due to the GPS satellites utilizing directional antennas pointed at the Earth. This results in significant limitations in GPS navigation.



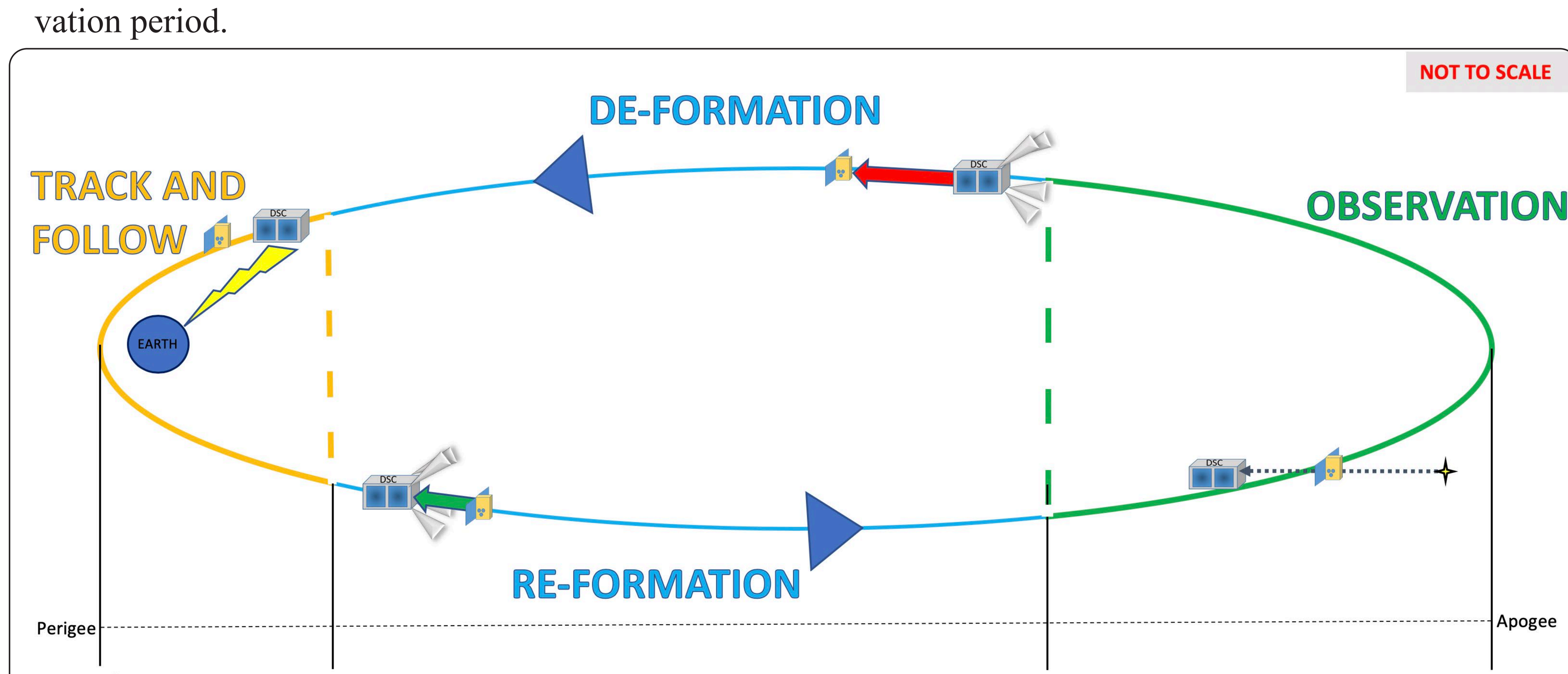
Depiction of the GPS satellites orbits along with that of VTXO, showing that the VTXO mission travels well above the constellation, including for the critical portions of the mission where observations are occurring, and along with the period where the spacecraft are establishing that formation.



Plot showing the number of GPS satellites that can be seen by VTXO over 3 orbits. This model assumes the satellites can contact each other if VTXO is within the 23.5° main lobe of the GPS antenna [5], and is not masked by the Earth. Note that four GPS satellites are needed for a traditional solution method.

ConOps

- Mission performs observations near apogee where gravity gradient is minimized.
- Mission performs observations for about 10h.
- Mission observation formation is broken at end of observation window.
- Mission flies a propellent optimal trajectory which is followed through perigee until beginning of next observation period.



Future Work

Future work includes developing navigation filters to evaluate various navigation schemes, including evaluating the potential of relative GPS solutions to improve the relative solution. Additionally, introduction of an onboard high-performance clock, and a relative dynamics model has significant potential to improve the relative navigation performance of the VTXO mission.

Citations

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