Planning and Scheduling External Occulter Space Missions

Ian J. E. Jordan, Computer Sciences Corporation, jordan@stsci.edu
STScI, 3700 San Martin Drive, Baltimore, MD 21218

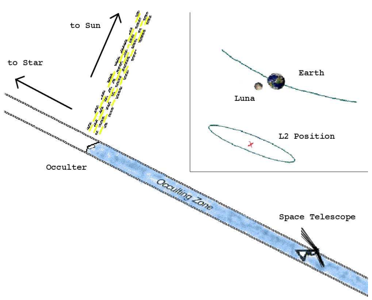
Abstract

This poster summarizes the AAAI paper of the same name presented for the October 2006 *International Workshop on Planning and Scheduling for Space*, at STScI. A class of space science missions employing a telescope and one or more mobile external occulters is introduced, emphasizing the title issues, proposed planning software extensions, advanced mission planning, and science capacity. Significant points are noted.

Introduction

External occulters are a proposed class of space science mission employing a free-flying occulting screen placed far from a space telescope. The screen suppresses a target star's light, primarily for exoplanet studies. The missions are characterized by their constraints outlined in this poster (Earth-Sun L2 configurations emphasized).

Basic Architectures of External Occulter Missions are Constraint and Science Driven

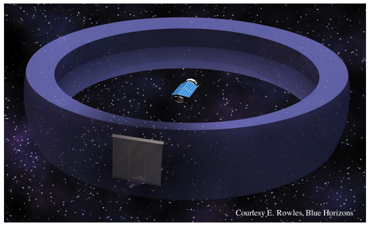


The general layout (not to scale) of an external occulter mission is portrayed above. In the upper-right inset, the oval orbit shows a track relative to the earth-moon upon which the telescope-occulter is likely to lie for near-term missions. The remainder of the cartoon shows a zoomed view on the two spacecraft with the occulter in-line between the target star and telescope (also not to scale). The occulter casts a shadow of the star onto the telescope while remaining oriented to keep scattered sunlight to a minimum.

Occulter Science Mission Phases

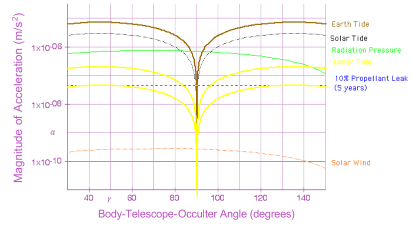
Discovery and *characterization* mission phases will be interleaved in the timeline with discovery likely a major component early in the mission, and characterization likely dominating the late-mission phase.

Science employing the external occulter will not monopolize telescope time (~10-20% per occulter) and can be interleaved with other telescope science.



The *quadrature ring* (QR) of allowable operations is conceptually shown here (not to scale). The tire-shaped ring defines a region where the occulter could be placed to occult target stars for the telescope while obeying sun-angle constraints. The sun is above, in the direction perpendicular to the plane bisecting the QR.

Cross-TTLOS Body-Telescope-Occulter Acceleration Magnitudes

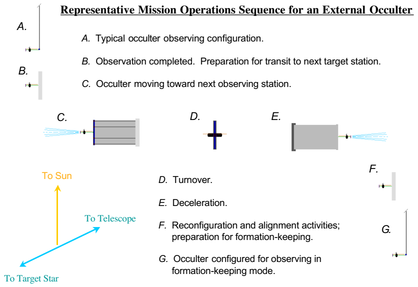


Free-flying spacecraft naturally drift with respect to each other. The cross-TTLOS (*target-telescope line-of-sight*) component is more important for occulter missions. At the Earth-Sun outer-Lagrange point, many of the accelerations are quantifiable (e.g., gravitational tides). Other forces depend upon the spacecraft or environmental characteristics. Above is an acceleration model as a function of occulter-telescope-solar system geometry for a specific occulter mission (important for assessing occulter fuel consumption and operations requirements).

N.B.: This and subsequent simulations presented in this poster use the following assumptions: Telescope-Occulter separation: 50,000 km, occulter screen area: 2000 m^2, screen aspect with respect to telescope/sun: 60-degrees/75-degrees, Telescope/Occulter electromagnetic reflectivities: (0.5/0.1), proton reflectivities (0.1/0.2), Telescope/Occulter masses: 5400 kg/4800 kg, Occulter SEP propellant load 1200 kg.

Target-to-Target Cadence

<u>Representative Mission Operations Sequence for an External Occulter</u>



A representative external occulter operations flow is shown above. An "articulating" design occulter is shown at sequential operational phases as it moves from one target to another. At phases " A " and " G ", the occulter is on-station at two different TTLOSs. Phases in-between illustrate possible reconfigurations and movement between the two TTLOSs.

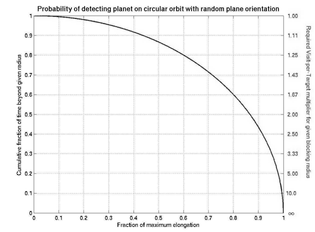
Acknowledgements

Special thanks are extended to Helen Hart, JHU/APL, Mark Kochte, CSC/JHU/FUSE, Wayne Kinzel, Merle Reinhart, and Dorothy Fraquelli, CSC/STScI, Alfred Schultz, Richard G. Lyon, NASA/GSFC, Carey Myers, CSC, Gordon Woodcock, Gray Research, Glenn Starkman, CWRU, Webster Cash, U. Colorado, Christian Marchal, ONERA, Jon Arenberg and Amy Lo, NGST.

Support for this work includes that provided by Computer Sciences Corporation, Greenbelt, MD, and by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555.

Architecture Influences Science Capacity and Operations.

A few different screen architectures are shown in the corners of this poster. Spacecraft design varies from the 'uni-body' approach of most starflower occulters to the 'articulating screen' design of simpler occulters.



Science capability of external occulters is sensitive to the separation and apparent size of the occulter from the telescope. The fraction of time a planet on a randomly oriented circular orbit would appear beyond the occulter edge is shown above. The x-ordinate represents the ratio of the apparent radius of the occulter to the apparent semimajor axis of the planet. The y-axis on the right gives the multiplying factor by which one would need more than the minimum number of independent observations to determine the orbit of an extra-solar planet assuming that the planet is lost behind the occulter for the corresponding fraction of time.

Mission Operations and Science Optimization Planning Tools

Existing planning tools are not optimized to handle all phases of a telescope+occulter mission. The minimum required functionality of planning and scheduling tools has been broadly outlined (Kochte 2004, and current paper).

Simulation of an optimized science mission in advance is desirable to provide feedback into the occulter architecture and design.

Modest enhancements (e.g., a "target slew constraint") to existing planning tools (such as SPIKE) would allow preliminary planning of occulter science missions.

Availability of advanced planning tools would allow examination of tradeoffs between such aspects as telescope-occulter range, expected overall science capacity, queuing strategies, number of visits to each target, number of targets surveyed, and propulsion capability.

Planning system architecture issues such as integration and separability of occulter- and non-occulter *design reference missions*, and inter-mission operations should be considered for greatest flexibility in science mission planning.

Resource Consumption: Fuel, Time-on-Target, and Transit-Time

On-board fuel is a major constraint on mission duration and number of achievable targets.

Mission planning tools must track critical occulter resources, particularly occulter fuel supply.

Statistical-mechanical analysis of target observation rates and science capacity is possible, but higher-fidelity mission simulations are needed.

Scheduling Issues

Target observations are inherently impacted by cross-TTLOS drift. These accelerations are characterizable. This must be modelled in the flight and scheduling system, and the impact on resource consumption for consumable planning must be accounted for.

Cooperative scheduling between the occulter and telescope is an integral part of operations, however the extent depends upon the degree to which the telescope is an active feedback element in the formation control architecture.

Target Queuing Strategies & Scheduling Efficiency

Mission target sequencing is important for maximizing science efficiency. Many different approaches are possible.

Some strategies inherently introduce biases into a discovery survey that could degrade 'completeness' and must be carefully evaluated for mitigation.

Changes will occur in the planning timeline for an occulter mission due to changing target priorities.

Simple queuing strategies show tens-of-percent fluctuation in their efficiency range.

Mission Science Capacity

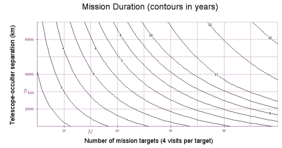
Mission overheads due to architecture and operations constraints are important and must be carefully accounted for.

Changes in the major mission parameters (number of targets, number of visits per target, telescope-occulter range, and propulsion system capability) produce significant changes in science capacity.

Multiple occulters offer a significant boost in mission science capacity.

Scheduling results from a statistical-mechanical model of an occulter science mission are displayed in the two graphs below.

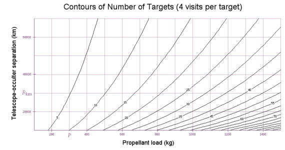
Mission Duration (contours in years)



Above: Contours of mission duration are shown as functions of number of mission targets and telescope-occulter separation. Propellant load is kept fixed at 1200 kilograms, however the average thrust level decreases for the longer duration contours.

Below: Contours of number of targets are shown as functions of propellant load and telescope-occulter separation. Mission duration varies in this plot. Thrust is fixed at the maximum ion thruster rating.

Contours of Number of Targets (4 visits per target)



Select References

Cash, W., 2006, Nature, v.442 pp.51-53, July 6, 2006.

Copi, C. J., Starkman, G. D., 2000, <u>The Astrophysical Journal</u>, vol. 532, pp.581-592, March 2000.

Kochte, M., Hart, H. M., Fraquelli, D., Schultz, et.al., 2004, SpaceOps 2004, AIAA, Montreal, CA, 2004.

Kramer, L., 2000, *2nd IWPSS*, International Conference on Artificial Intelligence Planning and Scheduling, AIPS 2000.

Marchal, C., 1985, <u>Acta Astronautica</u>, vol. 12, no. 3, 195, 1985.

Spitzer, Jr., L., 1962, <u>American Scientist</u>, v. 50, pp. 473-484, 1962.

Woodcock, G. R., 1974, in <u>Future Space Transportation Systems Analysis</u>, Appx to Contract NAS9-14323, December 11, 1974.

http://www.umbras.org