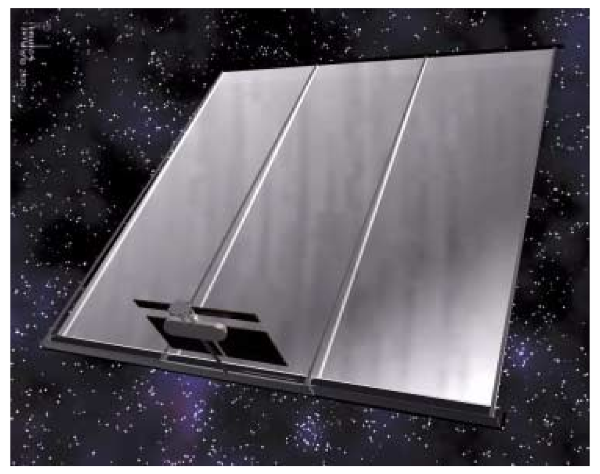
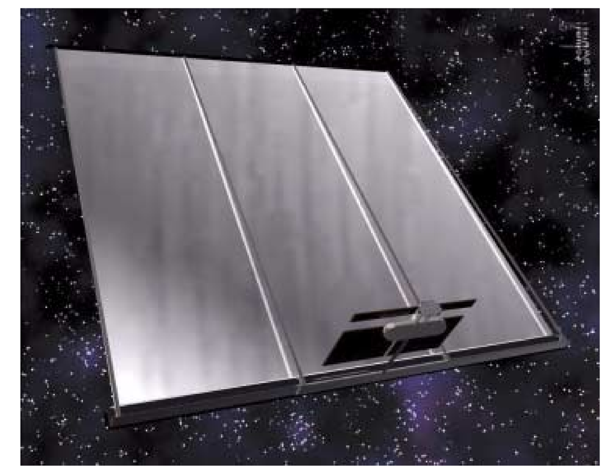


External Occulter Operations Requirements



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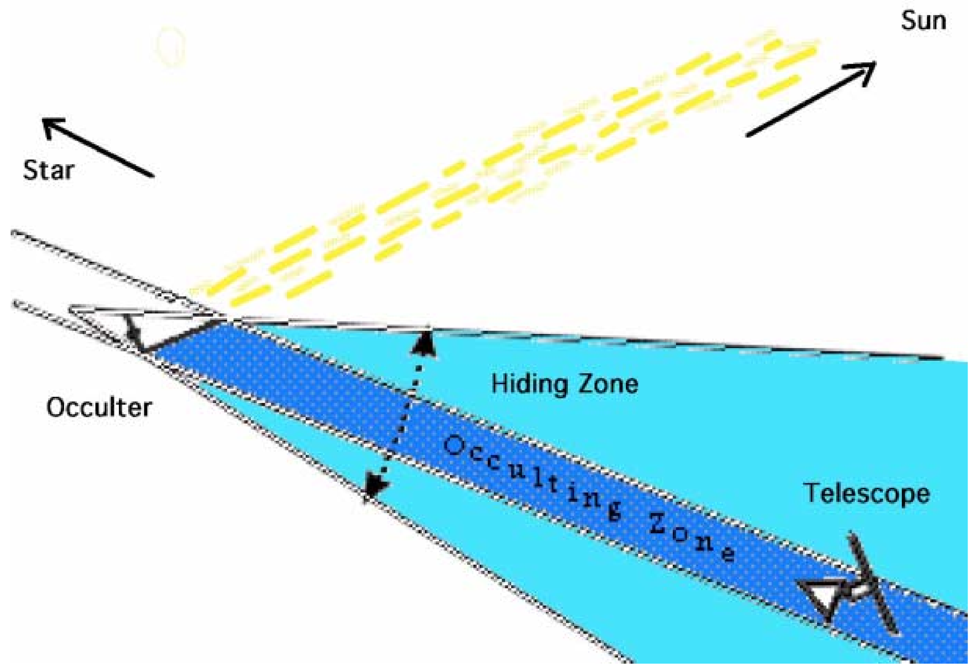
Abstract:

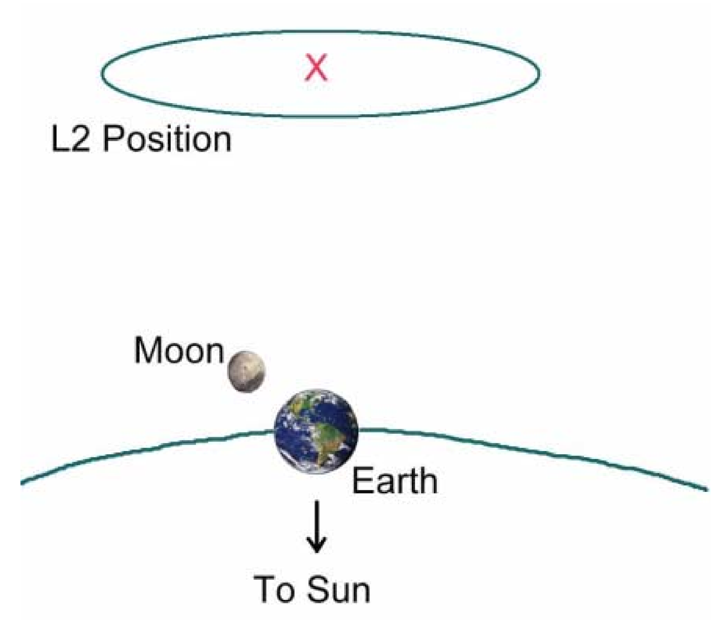
This paper will discuss the system and mission requirements needed for a planet-finding mission consisting of two spacecraft - a space telescope platform and an external occulter vehicle. This two-vehicle configuration may be operated with only modest enhancements to existing space operations systems. These requirements will encompass conventional, new, and unique spacecraft operations domains. Topics this paper will explore include inter-spacecraft operations and science and mission support.



Location, Location, Location!

Telescope & occulter would be best located at the Earth-Sun L2 position. The reasons for this are:

1) The telescope/occulter pair would be somewhat closer to Earth than if they were in an Earth-trailing or Earth-leading orbit.
2) Being closer to Earth enables higher data rate transfers and stronger signals. Assuming ~500 exposures, or 11 Gb of data, per day.
3) The Earth-Moon system would fall into the Solar Avoidance Zone, so there would be no added zones of exclusion for the telescope and occulter to operate in.
4) Differential motion between occulter and telescope along *Telescope-Target-Line-Of-Sight* (TTLOS) is minimized; not near any significant gravitational body.

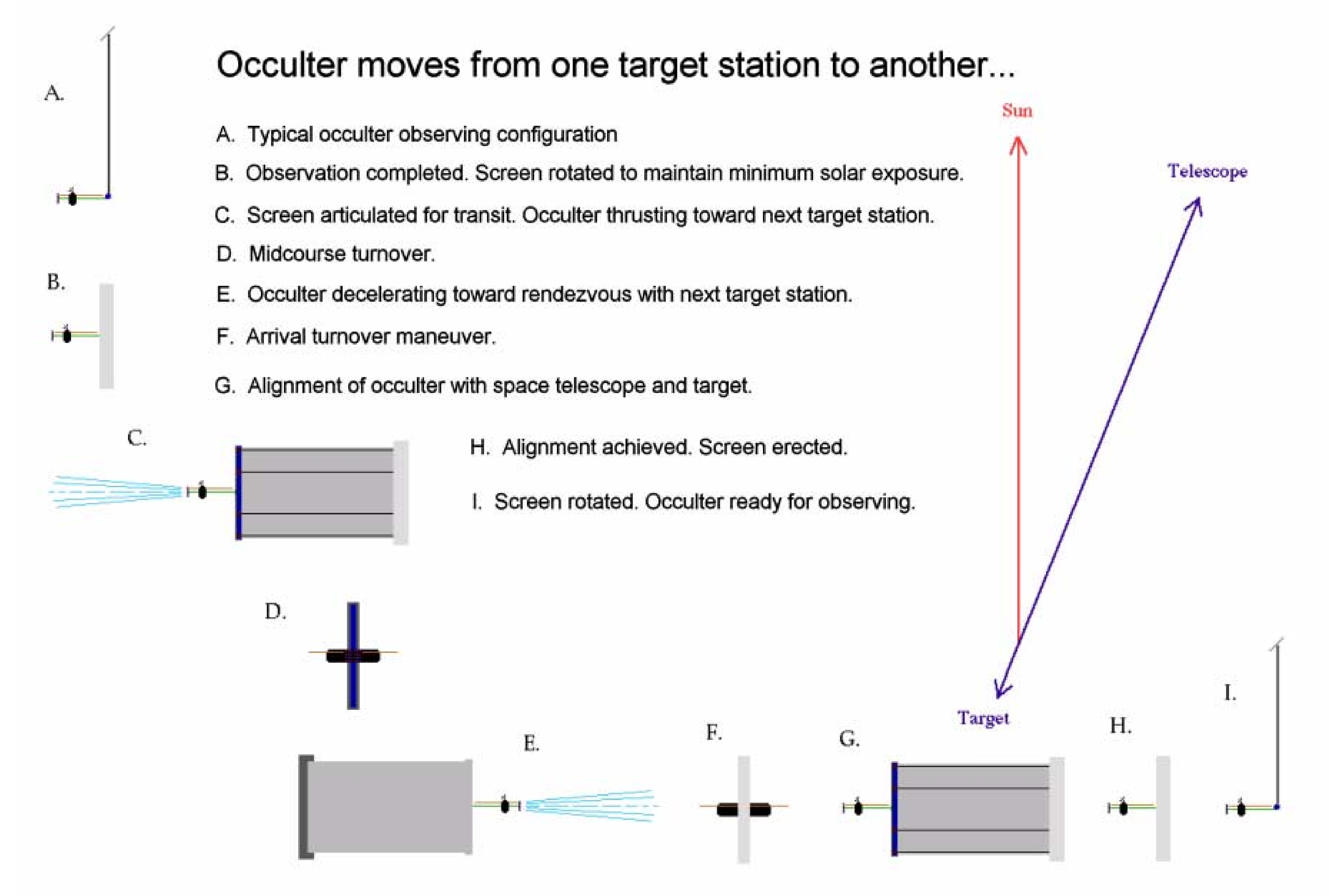


Introduction to External Occulters:

An external, free-flying occulter is a spacecraft designed to fly thousands of kilometers from a space-based observatory. The occulter is interposed between the telescope and a target star in order to block the light from the star, enabling the telescope to image any faint companions in orbit about that star. A 5 year occulter mission would be geared to detect and study extrasolar planets about stars within 15 parsecs of our sun - about 300 targets. Simulations show that an apodized telescope and a free-flying occulter could detect planets about these stars. A 4-meter telescope and 10 meter occulter system could detect terrestrial type planets about these stars.

Spacecraft Operations Domains:

* Occulter operations are partly architecture dependent
* Main components are power (solar), propulsion (occulter only), attitude control, and formation control
* Occulter will use a high-thrust Solar-Electric Propulsion (SEP) engine for movement between target stations. The telescope will have no propulsion engines.
* Several low-thrust SEPs for on-station alignment maneuvering of the occulter.
* Attitude Control will utilize gyros and star trackers.
* Formation flying control will be enabled by beacons on the occulter and sensor systems on the telescope designed to locate the occulter.



Constraints on L2 Operations:

* The occulter will only be able to operate in a 10,000 - 20,000 kilometer diameter spherical ring zone about the space telescope, oriented perpendicular to the direction of the Sun/Anti-Sun line, which is called the *Quadrature Ring* (QR).
* The occulter will be constrained to remain within 40-50 degrees of the plane that bisects the QR lengthwise.
* Operations within the QR will prevent sunlight from entering the telescope aperture or reflecting off the occulter.

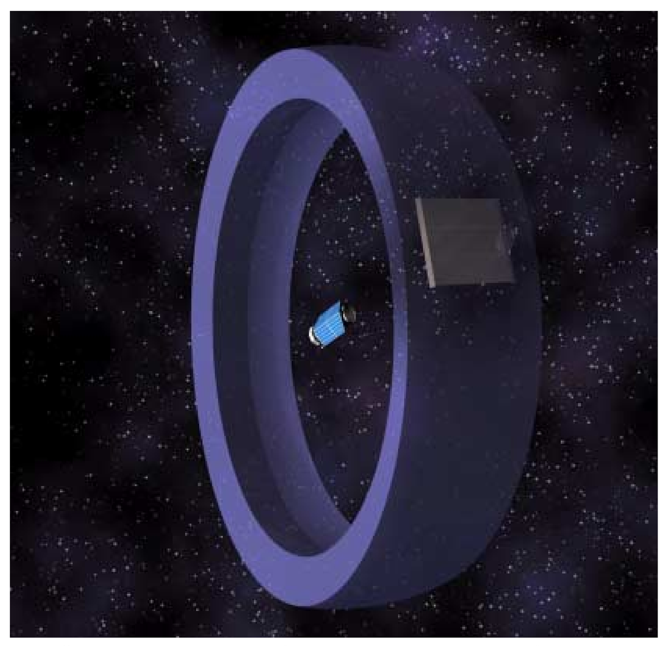
Formation Operations Requirements:

* Knowledge of telescope and occulter relative and absolute positions.
* Communication between telescope and occulter to support alignment on TTLOS.
* Telescope and occulter interact to manage alignment.
* Communication with ground to dump data and receive mission Operations Plans:
  > Uplink ~1 Gb/day (load Operations Plans, observation scripts, flight scripts, etc)
  > Download ~11 Gb/day (science observations, alignment data, telemetry dumps, etc)
  > At 1 Mb/sec from L2, downlink requires about 4 hours/day.

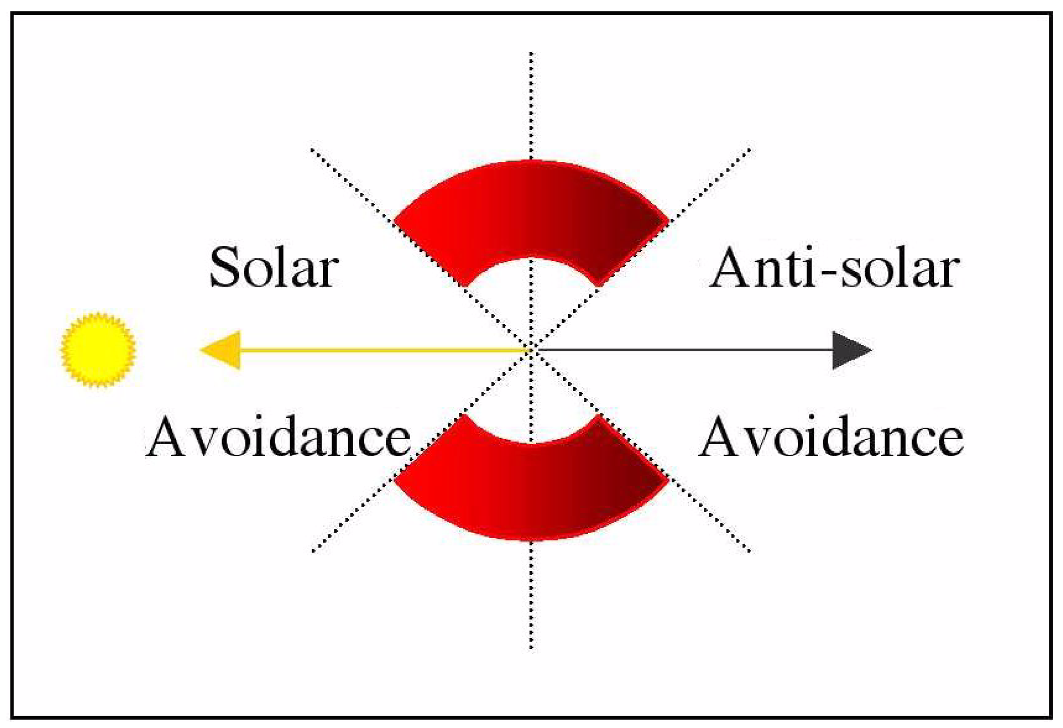
Formation Flying and TTLOS Alignment:

During the time the occulter is moving from one target station to the next, the telescope will be performing non-occulter observations. When the occulter nears its next target station, it begins to interact with the telescope in order to set up for an occulter observation.

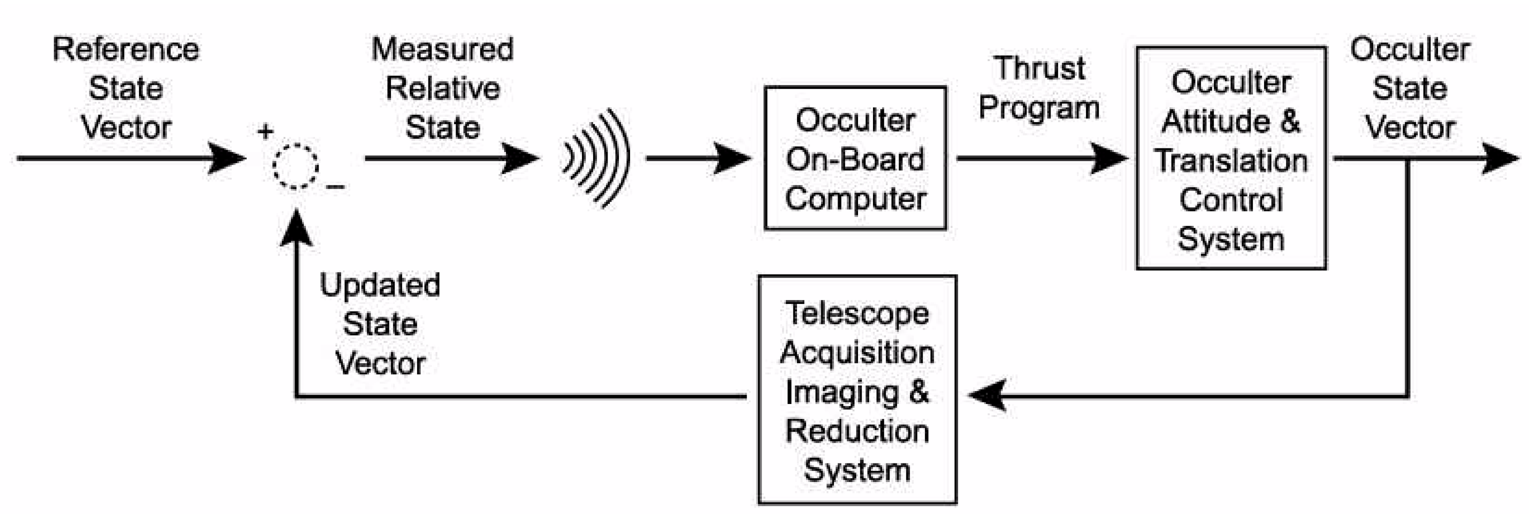
1) Occulter transits toward new target station, not yet having reached the field
2) Occulter signals the telescope, triggering an interrupt flag
3) Telescope takes reference images of the field
4) Occulter arrives near TTLOS (initial alignment)
5) Occulter articulates into observing configuration
6) While occulter is still off TTLOS:
  a) Telescope beacon sensor is used to measure occulter location and velocity
  b) Telescope alignment imager used to measure sun-glint
  c) Relative position uplinked to occulter
7) Occulter translates into alignment along TTLOS
8) Telescope alignment imager images occulter/star
9) Alignment determined, compute state vector
10) If velocity cannot be satisfactorily computed for, return to Step 6a
11) Uplink computed and desired occulter state vector from telescope to occulter
12) Occulter computer determines and executes alignment maneuver sequence
13) Telescope images target field to verify alignment
14) If alignment does not pass check, return to Step 6a
15) Proceed with science, re-checking alignment after each observation is taken



Quadrature Ring Representation
(not to scale)



Quadrature Ring Cross-Section



Control Block Diagram of TTLOS alignment

Ground Team Functions:

* Two primary shifts of personnel: Operations Teams to operate at night, while in communication with the telescope/occulter spacecraft, and Commanding Team to operate the hours prior to and/or after the Ops Team.
* Ops Team: download science & engineering data from the telescope and occulter, upload new Observation Plans, ability to 'joystick' telescope and occulter when absolutely necessary, process and archive science & engineering data.
* Commanding Team: generate command loads and Observation Plans, respond to events and problems reported by the Operations Team, perform data analysis.

Commanding Team Planning Software:

The Commanding Team will need a toolkit for creating the Observation Plans. This would include:
* *Visibility Predictor:* will provide target visibility for any given date.
* *Accessibility Predictor:* will provide fuel estimates and transit times on a per target basis.
* *Sequence Planner:* will determine if the occulter can stay longer on the current target and how that may affect a subsequent target. Will also be able to generate, rank, and display different target sequencing scenarios.