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UMBRAS: Design of a Free-Flying Occulter for Space Telescopes

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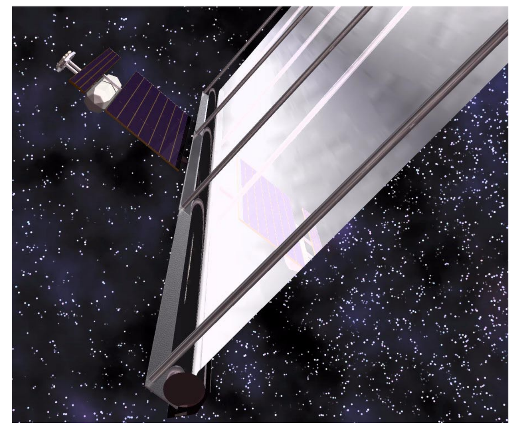
3-D renderings of an N-class UMBRAS Occulter courtesy of Edward Rowles, Multi-Image Productions, http://starships.com/Multi-Image/MIP_Home.HTML

http://www.stsci.edu/~jordan/umbras/

Abstract:

A free-flying occulter used with a space-based telescope can enhance the contrast in the region close to a star, allowing extrasolar planet searches. An occulting spacecraft design, emphasizing configuration, control, propulsion, mass estimates, and power requirements, is presented requiring no extension of existing technology or exotic engineering solutions. The design is scalable for use with telescopes having 1 to 10 metre apertures. Several innovations are employed to block starlight and suppress scattered sunlight. A station keeping control method is possible using various thruster types. Solar electric propulsion enables scientifically useful observation rates and allows the occulting craft to be packaged on existing launchers with no on-orbit assembly.

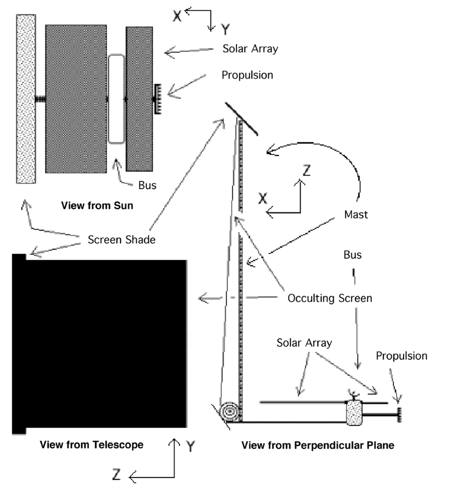


Design

SPIDER =

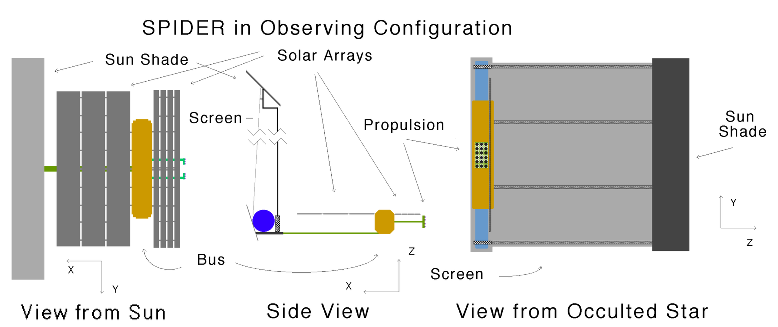
Solar-
Powered
Ion-
Driven
Eclipse
Rover

The artist's rendition above shows the occulter viewed from the target-star side of the screen in its observing configuration. The underside of the bus and solar arrays are visible in the foreground in front of the screen. Astromasts or bistems are shown connecting and supporting the top and bottom of the screen.



Plan views above are of the observing configuration shown from three different perspectives:

- "Above" occulter, looking from the sun.
- From the telescope.
- From the "side"



Major Functional Components:

- Sun Shade
- Occulting Screen
- Pedestal/Cassette & Boom
- Bus
- Solar Arrays
- Propulsion Modules & Boom

Characteristic Solar Array and Bus Sizes for SPIDER in various mission classes.

Mission Class	Solar Array Y-width	Solar Array +X-wing	Solar Array -X-wing	Bus
E-class	4 m	4 x 0.8 m	4 x 0.4 m	1.2 x 1.2 x 1.2 m
D-class	4 m	6 x 1.0 m	4 x 0.5 m	1.5 x 1.5 x 4 m
N-class	12 m	5 x 1.0 m	4 x 0.4 m	1.5 x 1.5 x 6-8 m

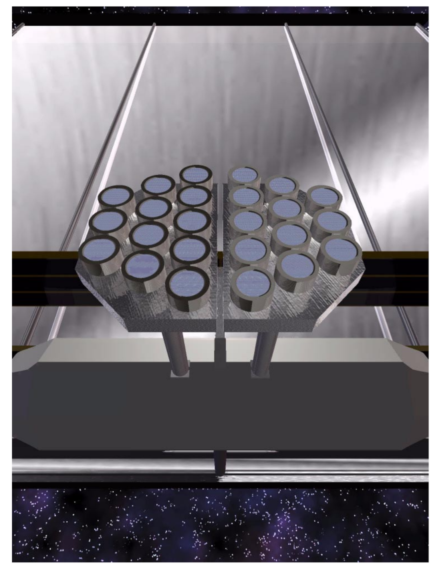
Functionally, the occulting screen is used for two purposes:

- Occulting the Star.
- Hiding other spacecraft structures (e.g., bus, solar array) from the telescope.

MLI screen construction emphasizes:

- optimizing science thermal characteristics for N-class infrared missions.
- preserving science utility by mitigating meteoroid impact damage

The Sun Shade allows minimal scattering of sunlight toward the telescope since it shades the entire side of the screen facing the telescope.



UMBRAS/SPIDER Features:

- Occulting Screen unfurled from 'window shade' cassette on Screen Pedestal.
- Controlled 1-time unfurling of Screen & Propulsion Boom Deployment
- 'Curtain track' to create larger screen from overlapping layers.
- Bistems or coiled Astromasts for shade/screen support.
- Sun Shade shields screen from direct solar exposure during observations.
- Screen/Pedestal articulates for:
  - * transit to provide symmetry for thrust control.
  - * observations to hide bus/array/propulsion from telescope.
- Propulsion Module on boom(s) minimizes contamination & interference.
- Xenon propellant tanks stored in bus.
- Solar Electric Propulsion offers significant observation rates.
- Attitude/Translation Control thrusters mounted on Bus & Propulsion Module.
- 3-axis stabilization for stationkeeping, maneuvering, & transits.

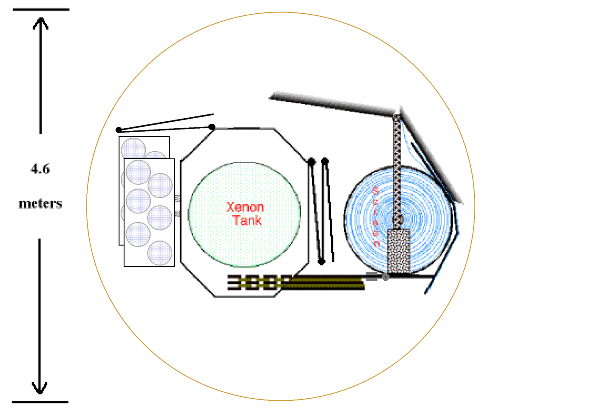
Scalability

UMBRAS (Umbral Missions Blocking Radiating Astronomical Sources) is a class of missions as well as a technique. The general design is scalable for small as well as large occulters. Below is a representative set of missions classes and their general mission design characteristics.

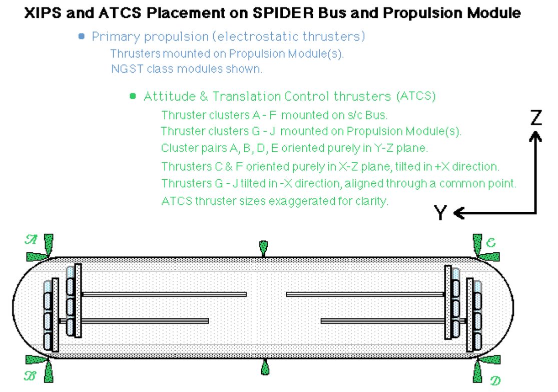
Mission Class	Telescope Aperture	Screen Size	Mission Duration
E-Class (Explorer)	~ 1 m	~5-8 m	~1+ years
D-Class (Discovery)	1-4 m	10-30 m	2+ years
N-Class (NGST)	4-10+ m	~45 m	up to 6 years

Launch Packaging

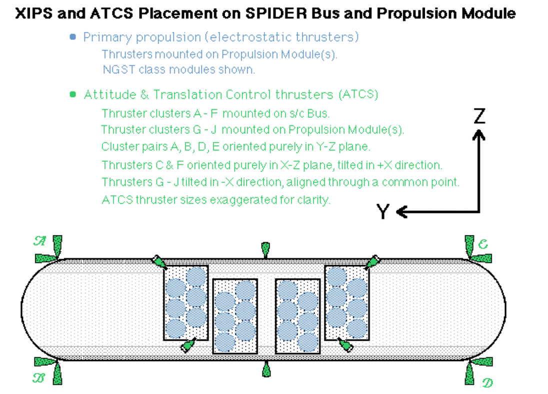
When folded, SPIDER easily fits within the shuttle payload bay.



At left we see a cross-section for packaging a large N-class occulter into a Titan-IV fairing or Shuttle payload bay. The solar arrays fold flat against the bus. The propulsion booms fold longitudinally, and the cassette housing the occulting screen is pulled in next to the bus. The Sun Shade is also folded to fit within the fairing.



At left is a diagram of an N-class occulter bus with the propulsion booms folded to place the modules alongside the spacecraft bus. Folding rigid booms allow the number of flexible propellant line connections to be minimized. Placement of Attitude & Translation Control (ATCS) thrusters on the bus is shown, with nozzle size exaggerated for clarity.



At left is the same diagram as described above, however the propulsion booms have been deployed. Note that the propulsion modules have swung into their operational place. The number of required booms depends upon the number of engines and the packing factor within the launch fairing. Here, we assume 24 required engines. However, fewer may be needed for smaller missions, or for NSTAR engines with longer life carbon-carbon cathodes replacing current molybdenum ones. Placement of ATCS thrusters on the propulsion module is also shown.

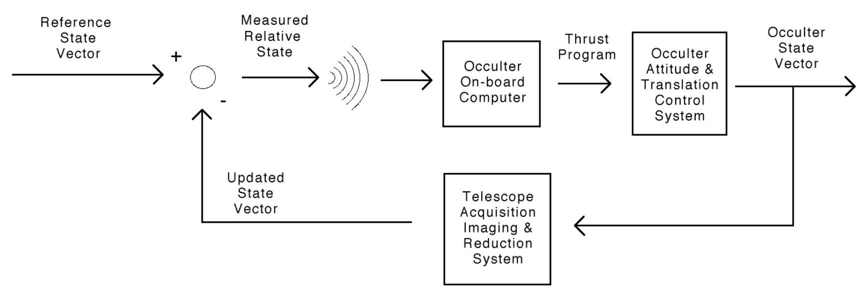
Best guess upper limits on the mass and power budgets for 3 different sized UMBRAS Occulter mission classes.

Mass & Power Estimates for UMBRAS Missions

	E-class 5-metre Screen Mass/Power/Dimensions:		D-class 10-metre Screen Mass/Power/Dimensions:		N-class 45-metre Screen Mass/Power/Dimensions:	
Payload:						
extensible screen	13 kg		52 kg		360 kg	
shade	10 kg		20 kg		60 kg	
screen cassette	20 kg		40 kg		90 kg	
bus-screen boom	30 kg		30 kg		70 kg	
metrology (beacons)	10 kg	[50 W]	10 kg	[50 W]	30 kg	[50 W] (inc booms)
pedestal & masts	50 kg		100 kg		130 kg	
Payload subtotal:	*123 kg*		*252 kg*		*710 kg*	
Bus + Array:						
Structure:						
array support	12 kg		20 kg		50 kg	
bus + propulsion boom	75 kg		100 kg		200 kg	
Power Production & Storage:						
Arrays (GaAs @ 18% BOL)	168 kg	{4.2 kW}	280 kg	{7kW}	600 kg	{15 kW}
Power Control & Conversion	175 kg		300 kg		680 kg	
Battery : (450 W-hrs NiH2)	10 kg		10 kg		10 kg	
Propulsion:						
NSTAR @92mN (η_m=.85)	17 kg	(1)	102 kg	(2 op. of 6)	408 kg	(6 op. of 24)
Power Conditioning/Control	30 kg	[~0.3 kW] (*1* units)	120 kg	[~0.6 kW] (4 units)	300 kg	[~1.5 kW] (10 units)
Xe propellant storage tanks	~ 30 kg		~ 130 kg		~1200 kg	
Xe pressure & feed system	50 kg	[100 W]	50 kg	[100 W]	50 kg	[100 W]
Attitude & position determination & control:						
ACS (16 UK-10 @25mN)	-		< 120 kg	(4 x 0.7 kW)	< 120 kg	(4 x 0.7 kW)
ACS aux (16 N2 @5N + pinholes)	40 kg	[100 W]	40 kg	[100 W]	40 kg	[100 W]
N2 tanks + feed system + 25 kg N2	100 kg		100 kg		100 kg	
sun sensors (4 units)	4 kg	[12W]	4 kg	[12W]	4 kg	[12 W]
star trackers/optical navigation cameras	3 kg	[40 W] (2 unit)	6 kg	[80 W] (4 units)	6 kg	[80 W] (4 units)
gyros & reaction wheels	26 kg	[150 W] (4 each)	42 kg	[150 W] (6 each)	142 kg	[500 W] (6 each)
Communications:						
Communications (low gain), 2 units	50 kg	[70 W]	50 kg	[70 W]	150 kg	[170 W]
Command, Control & Data I/O:	50 kg	[50 W]	50 kg	[50 W]	50 kg	[50 W]
Thermal Control:---	10 kg		20 kg		30 kg	
Bus + Array subtotal	*853 kg*		*1527 kg*		*4223 kg*	
Dry mass:	986 kg		1779 kg		4933 kg	
Margin ~ 20% (total dry mass):	197 kg		356 kg		987 kg	
Xenon Propellant	100 kg		440 kg		4000 kg	
Total mass (inc. propellant):	**< 1278 kg**		**< 2700 kg**		**< 9860 kg**	

Different sized missions use different sized launchers. The E- or D-class occulters may be launched from Atlas II AS sized boosters or smaller. The largest conceived N-class occulter might need a shuttle, Titan IV-class vehicle.

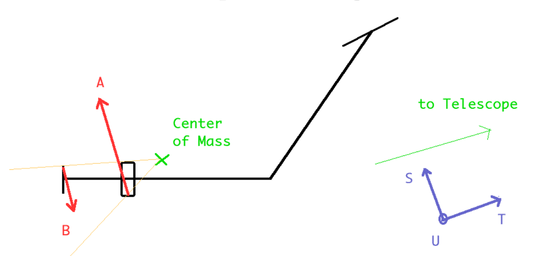
Control



Above is a control block diagram showing a scheme for controlling the relative position of the occulter with respect to the telescope. Imaging of the occulter against the background stars by cameras onboard the telescope allows the occulter to be appropriately positioned.

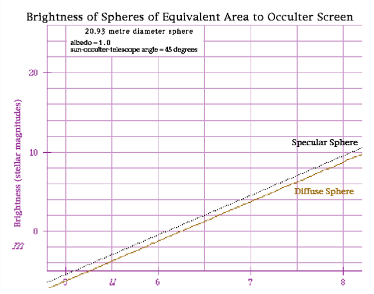
Solar Electric Propulsion for primary propulsion is sufficient to achieve science goals. NASA/Hughes NSTAR engines are baselined for this mission. XIPS or cold-gas thrusters may be used for the ATCS (Attitude & Translation Control Sub-

SPIDER Stationkeeping with respect to Telescope Line of Sight



Shown above is the general scheme of coplanar force-couples, with the center of mass in the plane of the couple, enabling attitude and translational control amidst science observations. Thruster plume impingement on the screen is avoided. Attitude control thrusters are located on the propulsion module (B) and the spacecraft bus (A) and allow some T-axis translational motion with little impact on the observation.

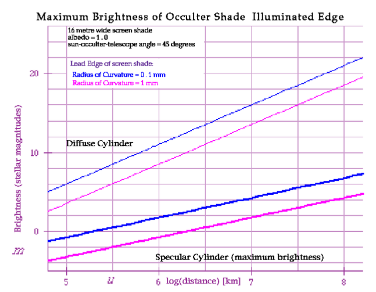
Sun Shade

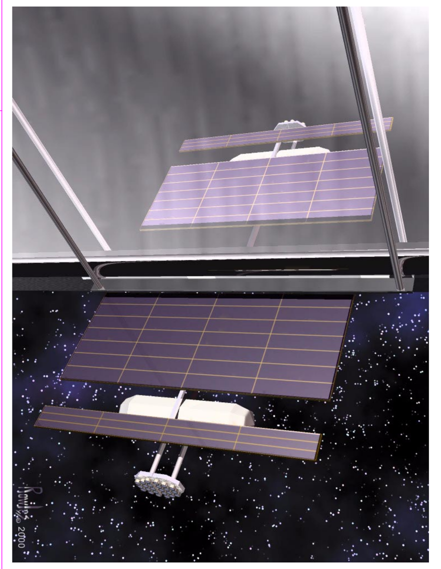


The occulter would appear bright to a telescope if it were not shaded from the sun (*a problem for most previous free-flying occulter ideas*). The plot at left shows the equivalent brightness (in astronomical magnitudes) of a sphere with the same projected area as a 45-metre N-class occulter at various distances (log of separation in metres). An unshaded structure, is quite bright.

UMBRAS employs a sun shade to shield the screen from sunlight. The Shade's razor-like edge is designed to minimize sunlight scattering from the edge into the telescope.

At right is shown the brightness of diffuse and specular edges illuminated by the sun, for two different edge sharpnesses. Note that the edge is much less bright than the spheres shown above. The specular curves are for an orientation with the brightness at a maximum (viewer perpendicular to the edge). Properly oriented, the shade reflects most of this away from the telescope. Vapor deposition of a micro-beading material on the edge could strike a balance minimizing overall light scattered into the telescope.





At left is a close-up of the spacecraft along with its reflection off of the occulting screen. Bistem or astromast supports for the screen-and-shade (shade not within field of view) are visible both directly and in reflection rising from the cassette-pedestal structure.

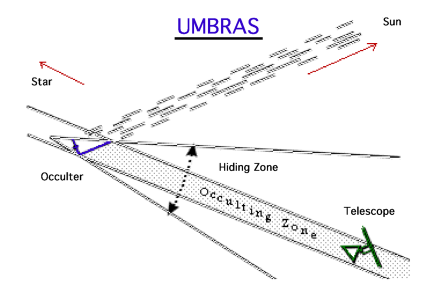
CORVET is a proposed demonstration mission that could validate the external free-flying occulter technique.

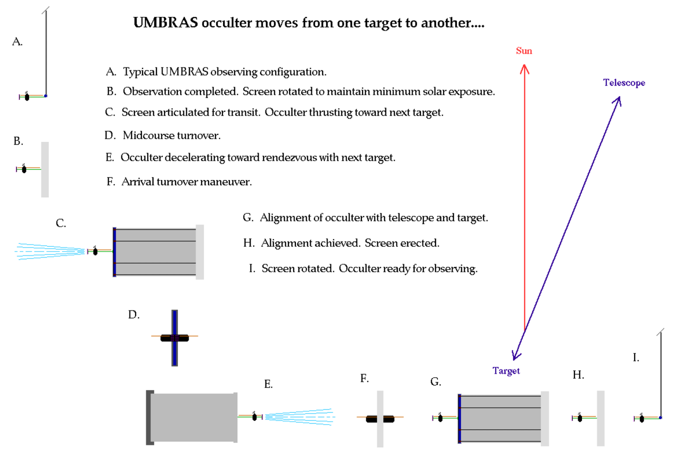
Coronagraph &
Occulting
Rover,
Visible
Exoplanet
Telescope

- Single launch (both craft) onboard Atlas II AS
- Near-Earth Solar-orbit or L2
- ~ 1-metre space telescope (~1000 kg)
  - o Unoccluded, off-axis primary mirror
  - o Focal plane coronagraphic imager
- Occulter (<1300 kg) w/
  - o 5- to 8-metre occulting screen
  - o 1 NSTAR XIPS engine
  - o Fuel for 1-2 year mission
  - o 50 bright targets, 2 visits each
  - o Jovian search 0.25" - 4" at λ = 0.5 µ

Operations

Occulter and telescope must operate far from Earth to minimize the effects of differential gravitation on stationkeeping. At right (not to scale), the sun, telescope, and occulter lie in a plane. The occulter is positioned such that the telescope is in the star-shadow cast by the occulter. The occulter spacecraft bus is hidden from the telescope by the screen.

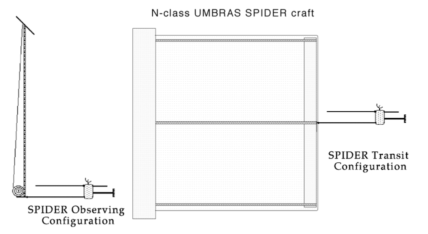




SPIDER operation requires articulating the occulting screen into a symmetric configuration for movement between targets. At left is a conceptual diagram showing snapshots of an N-class occulter's configuration at different times as viewed from above the telescope-occulter-target plane. Phases (A) and (I) represent successive stations on different Target-Telescope Lines-of-Sight (different science targets). The phases in between show snapshots of the occulter at representative moments during the journey between targets.

Distinct phases of target-to-target transit operations:

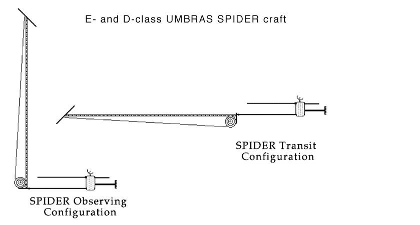
- Articulate the screen into transit position.
- Orient occulter toward next Target-Telescope Line-of-Sight.
- Acceleration toward next Target-Telescope Line-of-Sight.
- Mid-course turnover
- Decelerate to a halt.
- Alignment of Occulter along Target-Telescope Line-of-Sight.
- Articulate screen into observing configuration.



At left, the N-class occulter transits with the sun in the plane of the occulting screen to minimize solar heating of the screen. This helps the screen reach a lower temperature, enabling utility at longer wavelengths than if the screen had to dissipate heat absorbed by more direct solar exposure during transits.

The transit configuration allows simpler control of the spacecraft. The diagrams above and below show the observing and transit configurations of UMBRAS' occulter for two different mission classes.

Below, the E- and D-class occulters do not need the extra twist placing the sun in the plane of the screen that the N-class do since smaller telescopes are not likely to be efficient planet hunters at wavelengths where thermal emission by the screen would compromise science objectives.



At right, is a view from the sunward side of the bus/array. SPIDER is configured for observing.