Distant Screens

External Occultation: Past, Present, and Future?

GSFC Exoplanets Club Presentation

Ian Jordan, CSC/STScI

March 29, 2007

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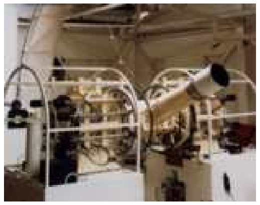
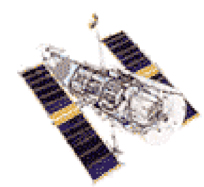


Presenter's Background

- **M.Sc. *Applied Physics*, Johns Hopkins, 2005.**
- **CSC/STScI, HST Project 1997-Present, science planning & operations.**
  - **HST program coordinator, inc. *Hubble* Helix, HST *Deep Impact* observations & planning.**
  - **Built HST long range plans, Cycles 8-12, & 15.**
  - **HST science planning software development & special studies.**
  - **Co-I HST proposals: 9171, 9983.**
- **1999 Spacecraft Design student of the late Charles D. Brown.**
- ***UMBRAS* co-founder, 1998.**
- **PDS/SBN U. Maryland 1996, data archival.**
- **USNO, 1988-1995:**
  - **Washington, 1988-90, observer/data analyst 6" transit circle, 24" B&C.**
  - **Black Birch, New Zealand, 1990-95; robotic 7" transit instrument, RTC FORTRAN maintenance, general operations, Twin-8" astrograph.**
- **AIAA, AA(stronomical)S, AA(stronautical)S, BIS, etc.**
- **B.Sc. *Physics* U. Nevada, 1986.**



I. Some External Occulter History

<1962	Robert Danielson, Princeton	Infinite Half-plane analysis
1962	Lyman Spitzer, Princeton	American Scientist “Beginnings & Future…”
1972	Su-Shu Huang, Northwestern	Resurrected Spitzer’s analysis
1973	-	Skylab solar telescope
1974	Gordon Woodcock, Boeing	Occulter Vehicle Design
1978	Hugh S. Hudson, UCSD, et.al.	Shuttle-borne Pinhole Occulter Facility
1978	James Elliot, Cornell	Lunar occultation for LST, Hill Orbits
1980	Carl Sagan	COSMOS "Backbone of Night" episode
1985	Christian Marchal, ONERA	Hypergaussian starflower screen shapes
1986	Cocks, et.al,	Echo-like ballon w/ HST
1995	Jean Schneider, Obs. de Paris	SCODOTEP
1996	Cocks, Bely, et.al	Occulting spheres & HST
1997	G. Starkman, C. Copi, CWRU	IRIS (opaque occulter)
1998	Copi, Starkman, CWRU	BOSS (apodizing occulter)
1998	A. Schultz, I. Jordan, H. Hart, et.al.	UMBRAS (feasability studies)
1999	D. Spergel, Starkman, TPF Arch. Studies	Spergel petal & BOSS-type occulters.
2000	C. Wu, et.al.	NOME (occulter packages on other s/c)
2001	Starkman, Copi	Binary-apodized occulter.
2001	Starkman, Copi.	SOXS (NIAC X-ray study)
2004	R. Lyon, Schultz, et.al.	ASA+O, (occulter+shaped apertures)
2004	Cash, Simmons	Pinhole Camera
2004	P. Henze, G. Sauter, Jordan, et.al.	WASI-UMBRAS scaled ground demo
2005	Jordan, et.al.	TPF-C+O
2005	M. Kochte, D. Fraquelli, et.al.	Occulter operations studies
2006	W. Cash, J. Arenberg, et.al.	NWD (binary apodized starflower)
2006	Schultz, Lyon, et.al.	Lucifer: Lunar-based occulter
2006	Heap, Cash Arenberg, Kasdin, et.al.	TPF-O
2006	Jordan, Chen, et.al.	Hybrid Lunar-based occulter
2007	Jenson	Distant IRIS-like satellite.

Some Known Contributors to External Occulter Studies

Alfred B. Schultz (CSC/STScI/GSFC)
Richard G. Lyon (GSFC)
Dan Schroeder (Beloit College)
Helen M. Hart (CSC/JHU/APL)
Dorothy Fraquelli (CSC/STScI)
Chi-Chao Wu (CSC/STScI)
Kenneth Carpenter (GSFC)
Robert Woodruff (LMMSC)
Scott Starin (GSFC)
Mark Kochte (CSC/STScI/JHU/APL)
Edward Rowles (Blue Horizons)
Fred Bruehweiler (IACS/CUA)
Dennis Skelton (Orbital)
Glenn Starkman (CWRU)
Craig Copi (CWRU)
Riley Duren (JPL)
Charley Noecker (Ball)
Christian Lindensmith (JPL)
George Sauter (WASI)
Paul Henze (WASI)
Brian Eney (WASI)
Peter Chen (GSFC)
Zolt, Levay (AURA)
Jesse Leitner (GSFC)
Forrest Hamilton (CSC/STScI)
Melodi Rodrigue (UNR)
Ian J.E. Jordan (CSC/STScI)

Robert J. Danielson (Princeton)
Lyman Spitzer (Princeton)
Gordon Woodcock (Boeing, Gray Research)
Christian Marchal (ONERA)
Carl Sagan (Cornell)
Richard Burns (GSFC)
Webster Cash (U. Colo)
Jonathan W. Arenberg (NGST)
Amy Lo (NGST)
Charles Lillie (NGST)
Ronald S. Polidan (NGST)
Jeremy Kasdin (Princeton)
Willard Simmons (U. Colo. & MIT)
Eric Schindhelm (U. Colo)
Michael Wenher (TRW)
Sara Seager (DTM/MIT)
Sally Heap (GSFC)
David Spergel (Princeton)
Robert J. Vanderbei (Princeton)
Tiffany Glassman (NGST)
Marc Kuchner (GSFC)
Don Lindler (Sigma Space Corp.)
Eric Wilkinson (Ball)
Naomi Chow (Princeton)
Erica Gralla (Princeton)
Johanna Kleingeld (Princeton)
Sarah Hunyadi (JPL)

John Mather (GSFC)
Barry Madore (JPL/IPAC)
Larry Krauss (CWRU)
Douglas Campbell (GSFC)
Lee Peterson (U. Colo)
William Oegerle (GSFC)
Steven Kilston (Ball)
Michael Klenlen (NASA)
Keith Gendreau (GSFC)
Steve Oleson (GRC)
Tom Bank (Ball)
Chuck Garner (JPL)
Art Chmielewski (JPL)
Geoff Marcy (SFSU/Berkeley)
B. Matisack ( )
Sidney Drell (SLAC)
Scott Tremain (Toronto)
Richard Helms (JPL)
Leo Lichodziejewski (L'Garde)
F. Kostas (Lockheed)
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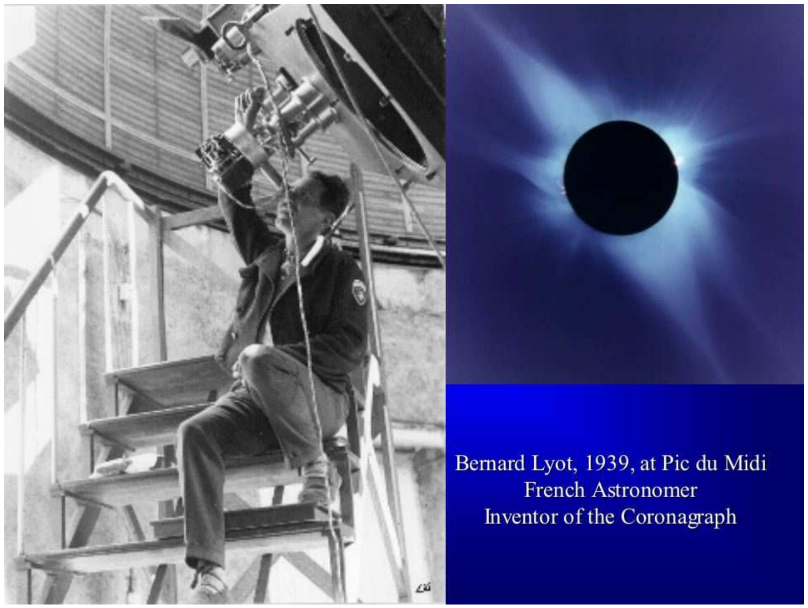
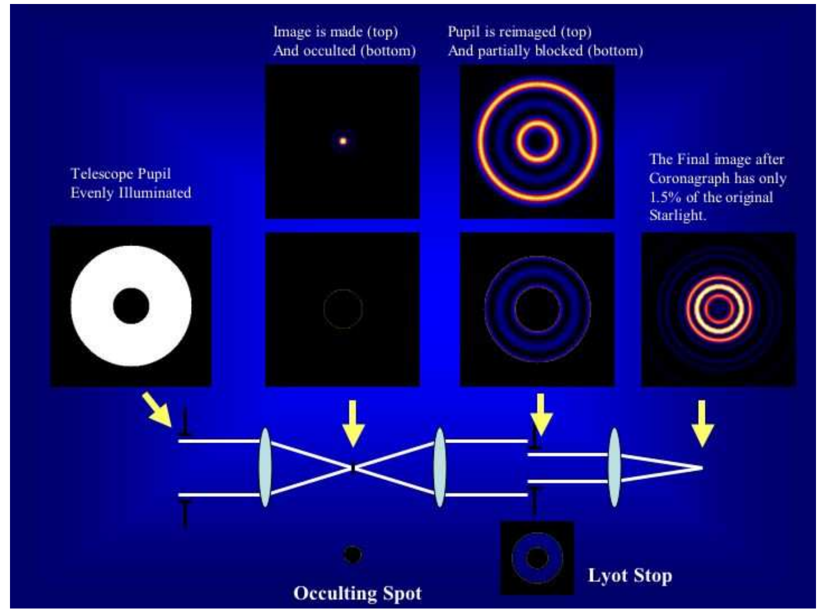
Harsh Mathur (CWRU)
Tanmay Vachaspati (CWRU)
Wendell Chun (Lockheed)
Brian Easom (Lockheed)

Jean Schneider (Obs. Paris)
Martin Lo (JPL)
James Green (U. Colo)
Howard Bond (AURA)
Kailash Sahu (AURA)
Su-Shu Huang (Northwestern)
James Elliot (Cornell)
F. Hadley Cocks (Duke)
Jeffrey E. Bischoff (Duke)
Seth A. Watkins (Duke)
Pierre Bely (AURA/STScI)
Ken Higuchi (ISAS)
Charles E. Ken Knight (Minneapolis)
G. Matloff
A J. Fennely
T. Nakamura
Mark Clampin (GSFC)
Dennis Ebbets (Ball)
Chuck Bowers (GSFC)
Alan Stern (SWRI)
Chi K. Wu (GSFC)
Chad Davis (CWRU)
David Olson (CWRU)
William Sherwin (CWRU)
David Rear (CWRU)

If your name belongs here, please email jordan@stsci.edu

Lyot: Coronagraphs for Science





The conventional coronagraph is an ‘internal’ focal plane occulter, however the technique can also be done afocally, ‘external’ to the telescope as has been known since sensor technology (light & sound detection) emerged with life’s ancient origins.

Images & diagrams courtesy of the Lyot Project, Ben R. Oppenheimer,

R. Danielson & L. Spitzer

AMERICAN SCIENTIST

VOLUME 50 SEPTEMBER 1962 NUMBER 3

PUBLISHED IN THE INTEREST OF SCIENTIFIC RESEARCH

AT TWENTIETH AND NORTHAMPTON STREETS, EASTON, PENNSYLVANIA

An astronomer with a Bachelor's degree at Yale, a student at Cambridge University, and a Ph.D. at Princeton, a National Research Fellow at Harvard, with faculty appointments at Yale and Columbia Universities, he became the Chairman of the Department of Astronomy and Director of the Observatory at Princeton University in 1947. A pioneer in the development of fusion processes for conversion of hydrogen to helium, he now takes his readers to the vast reaches of space, the problems involved in getting there, and the scientific dividends that may be expected from the effort.

Use of Occulting Disc

Fortunately there is a better way to detect planets around other stars, a method pointed out by R. Danielson at Princeton. This method involves the use of a large occulting disc far in front of the telescope to reduce the light from a star. To evaluate the possibilities of this technique we consider a semi-infinite plane sheet at a distance l from the telescope. The reduction obtainable may be computed from the standard equations of Fresnel diffraction [9]. If x represents the distance from

Advanced Space Application: Solar Coronography

Apollo Telescope Mount
Skylab Solar
Coronagraphic Camera

Flown: 1973

Built by Ball Aerospace, ballon-borne tested before Skylab.

Comet Kohoutek!

A bit of history out of order: SOHO launched 1995/12/02

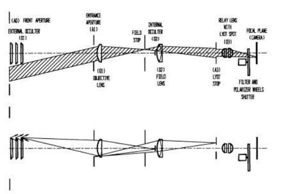


Figure 6-1:   Conceptual diagram of the C3 coronagraph. The top diagram illustrates the image paths, and the bottom diagram the supression of stray light.

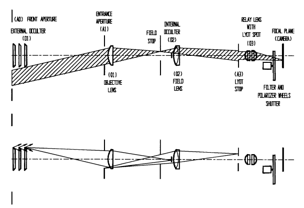


Figure 5-1:   Conceptual diagram of the C2 coronagraph. The top diagram illustrates the image paths, and the bottom diagram the supression of stray light.

SOHO External coronagraph designs & FOVs (int & ext).

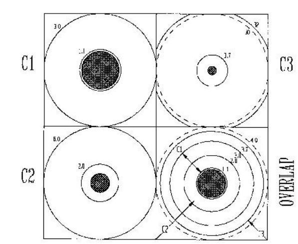


Figure 3-5:   Fields-of-view of the three LASCO telescopes, and the region of overlap. Radius is given in $R_{\odot}$ for the various circular fields shown.

Courtesy of NASA GSFC website.

G. R. Woodcock
Occulter
(deployment)

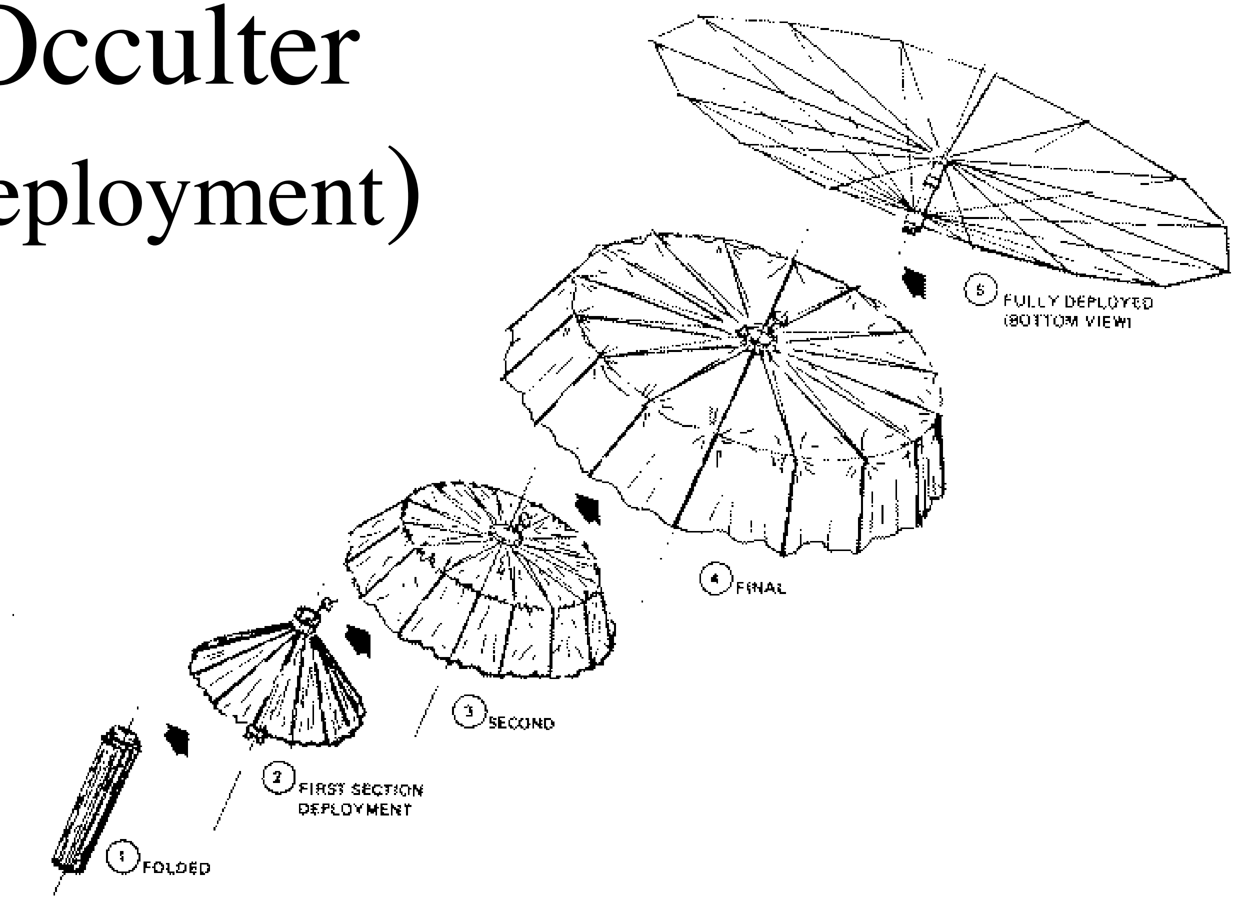


Figure D-6: Occulting Disk Spacecraft Deployment of 50-m Disk

43

D180-18501-2

G. R. Woodcock, in Future Space Transportation Systems Analysis, Contract NAS9-14323, December 11, 1974.

Gordon R. Woodcock Observability Model (Jovian)

GRW (in brief):

- Boeing T&T Engineer ramjet & rocket propulsion
- Boeing Saturn I-C development
- Boeing space shuttle preliminary design
- Future Space Transportation NASA study manager
- Key member of Boeing's winning Phase-B-D SS team
- Author <u>Solar Power Satellites</u>
- NSS Board of Directors, Executive VP

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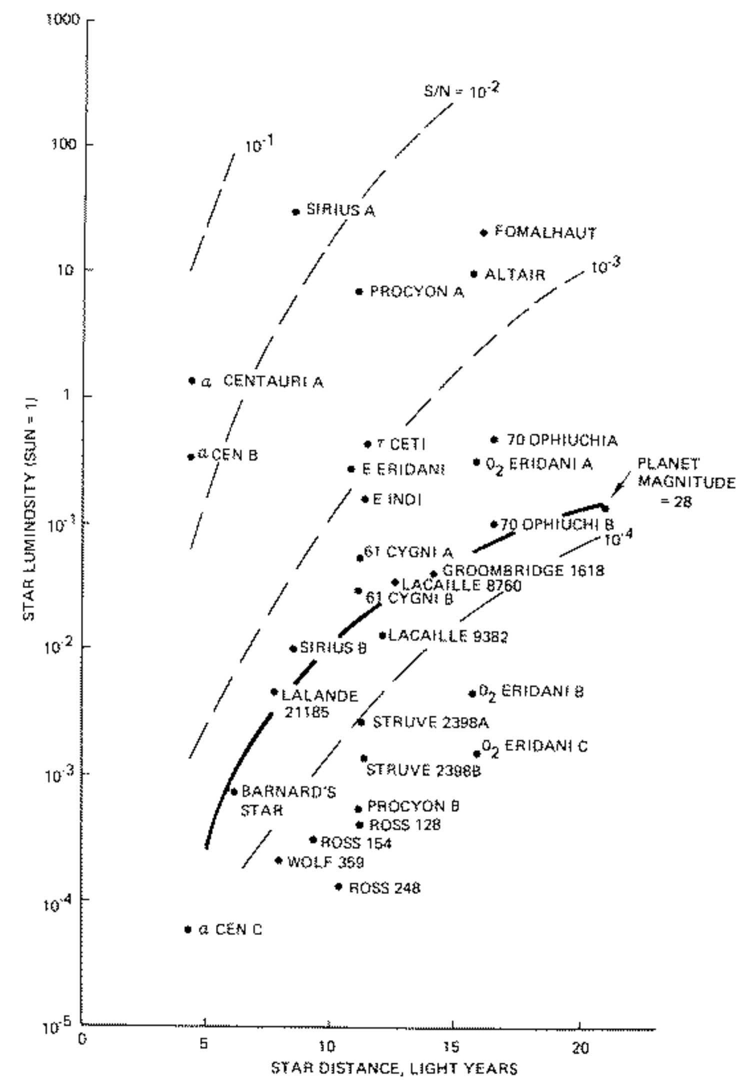
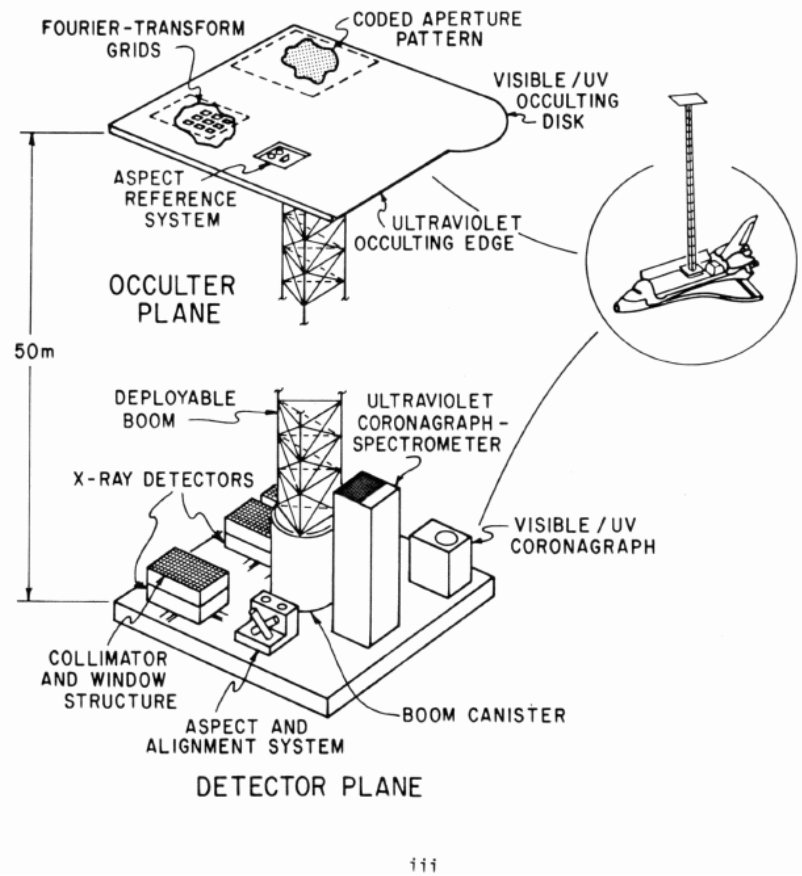


Figure D-9: Observability Model for Nearer Stars — Large Planet

D180-18501-2 Appendix to NAS Woodcock, G. R., 1974, in Future Space Transportation Systems Analysis

The X-ray Pinhole/Occulter Facility

Conceptual, never flown.



- Shuttle-borne
- X-ray observatory
- 50-metre arm
- Occulting Disk + other apertures

H. S. Hudson, "The Pinhole Occulter Facility", Advanced Space Research, v. 2, pp. 307-314, 1983.

Carl Sagan in COSMOS Episode 7 “The Backbone of Night.”

Courtesy of C. Sagan, A. Druyan

Occulter Screen "Performance"

Low Performance	• Disk or rectangular screens • ASA+O • IRIS	Minimal reliance upon diffraction control through alignment tolerance and screen shape.
Medium Performance	• BOSS • Spergel petal • Schultz's Sonine petal	High degree of diffraction control, but either limited field or other light pollution issues.
High Performance	• Spitzer's scalloping? • Marchal's screen • Starkman/Copi apodization • Cash's hypergaussian	Greatest degree of diffraction suppression performance.

Christian Marchal (ONERA) 1984

Starflowers visualized!

Christian Marchal publishes drawings of high-performance binary occulter shapes based upon his solution of Maxwell’s equation (1985).

From Marchal’s 1985 paper on external occulters for studying extrasolar planets.

Courtesy of Christian Marchal, Acta Astronautica,1985 with thanks to G. Matloff, 2000 (Deep Space Probes), for bringing it to the presenter’s attention.

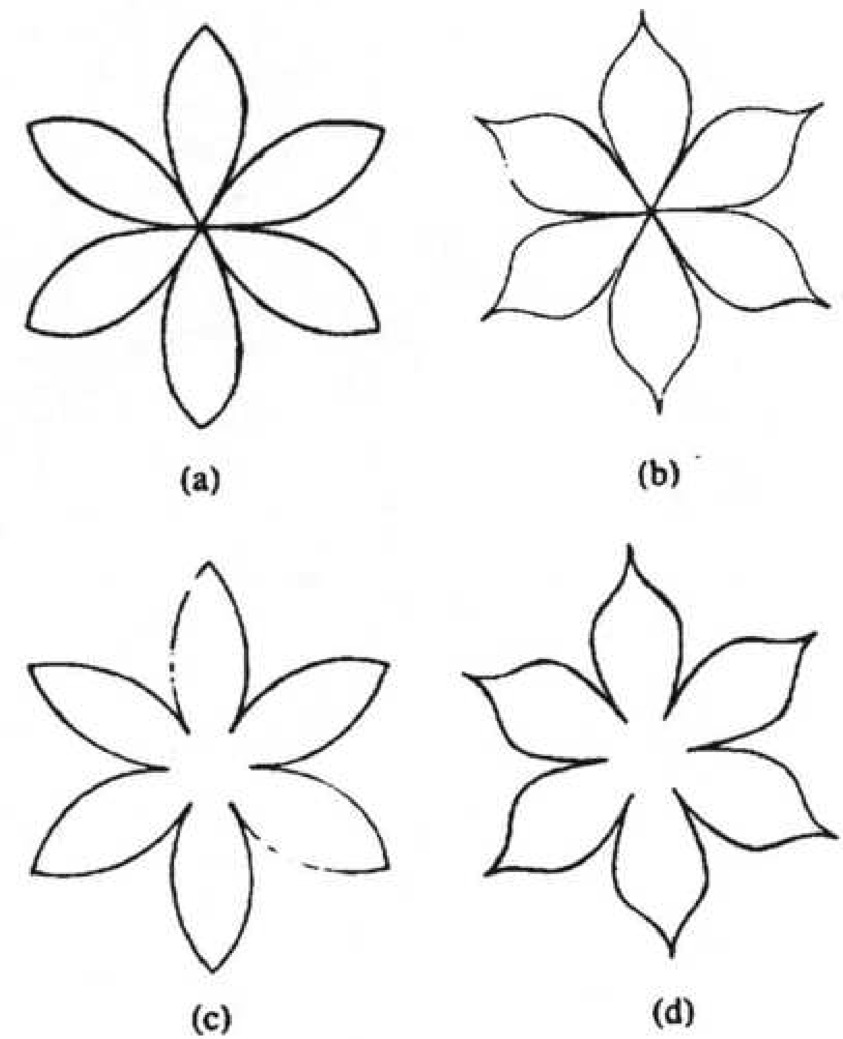


Fig. 4. The shape of some possible screens for various ψ functions. (a) $\psi = \psi_2$. (b) $\psi = \psi_3$. (c) $\psi = \psi_4$. (d) $\psi = \psi_5$.

Jean Schneider: SCODOTEP

S
Creen in
Orbit for the
D
Etection of
Terrestrial
Extrasolar
Planets

J. Schneider, "SCODETEP: A Class of Mission Concepts for the Detection and Study of Terrestrial Extra-solar Planets by Coronographic Imaging in Space", *Detection and Study of Terrestrial and Extrasolar Planets* workshop, Boulder, CO, May 15-17, 1995.

Jean Schneider, as many knows is the original curator of the extrasolar planets website http://exoplanet.eu which catalogs extrasolar planet candidates.

F. Hadley Cocks, P. Bely, et.al., 1996 Concept

Study of an Echo-like inflatable sphere with HST.

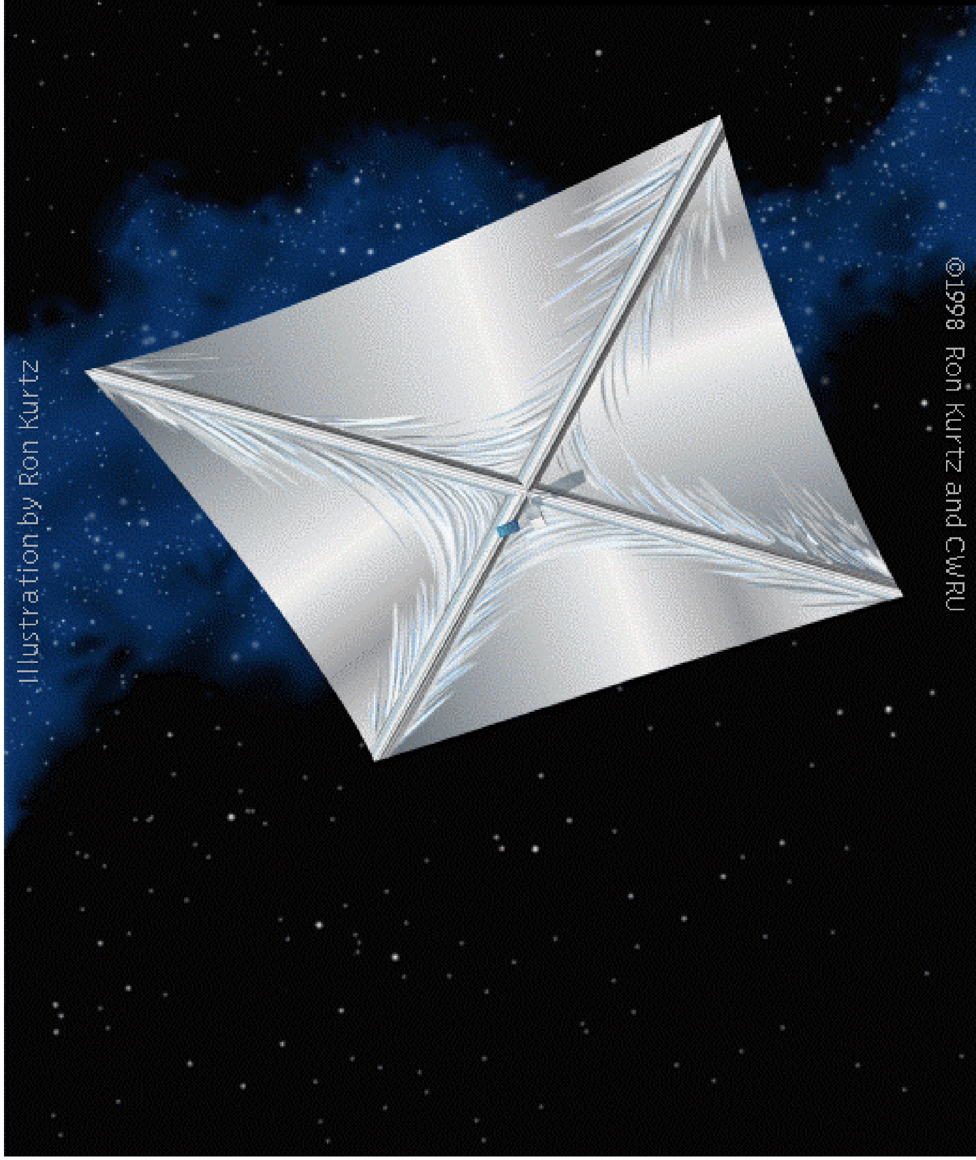
Circular or hyperbolic orbits yield up to 80-seconds of observing time.

Disadvantages:

- Shadow geometries are very restrictive.
- Formation-keeping is problematic with HST's LEO orbit.
- Difficult to orchestrate desired targets at given times.

Images courtesy of NASA & the History Channel

IRIS
(Image Resolution & Image Separation Satellite)



Case Western Reserve U.
Glenn Starkman & Craig Copi

- Opaque Occulter
- Inflatable design
- Usable in Space-Space or Ground-Space configurations

G. D. Starkman, C. J. Copi, "The Improved Resolution and Image Separation (IRIS) Satellite", *Proceedings of SPIE:* Space Telescopes and Instruments V, ed. P. Y. Bely, J. B. Breckinridge, v. 3356, pp. 608-621, August 1998

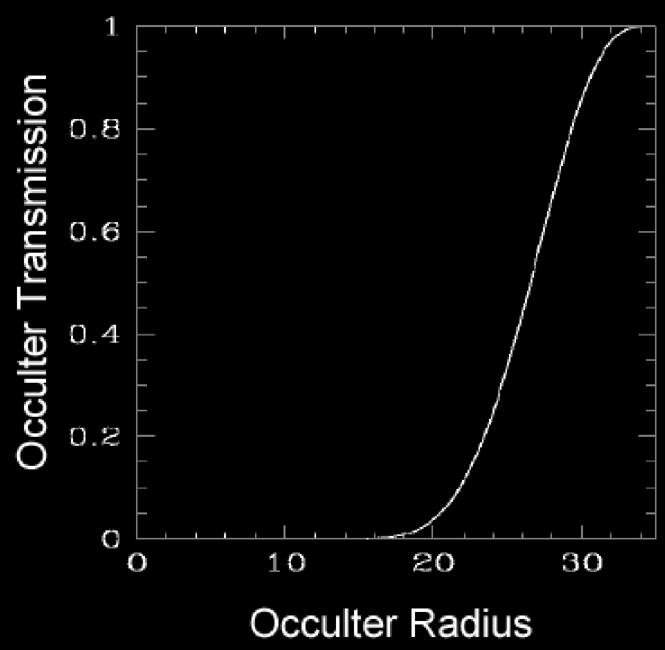
Courtesy of G. Starkman & C. Copi, CWRU

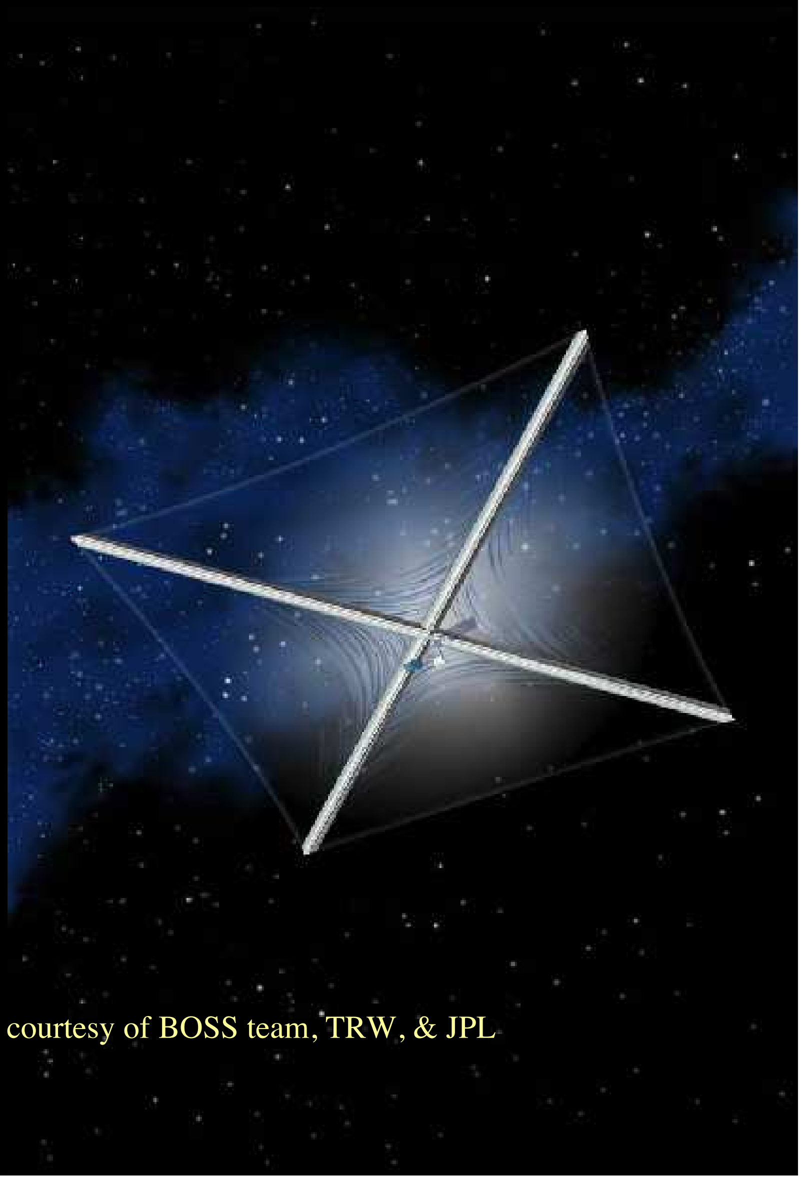
BOSS (Big Occulting Steerable Satellite)

C. Copi, G. Starkman, "The Big Occulting Steerable Satellite", Astrophysical Journal, v. 532, p. 581, 2000.

What is BOSS? -- Conceptual follow-on to IRIS.

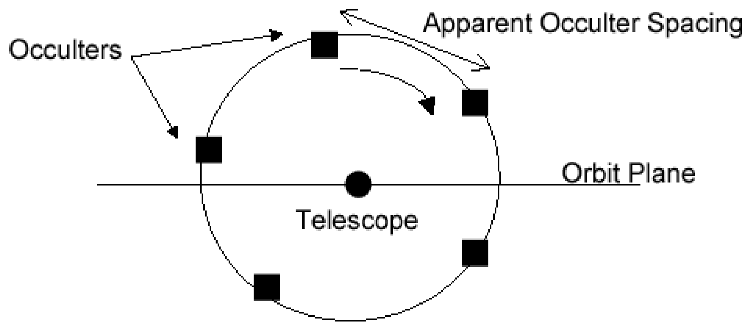
BOSS employs an apodizing occulter to enhance diffraction suppression.



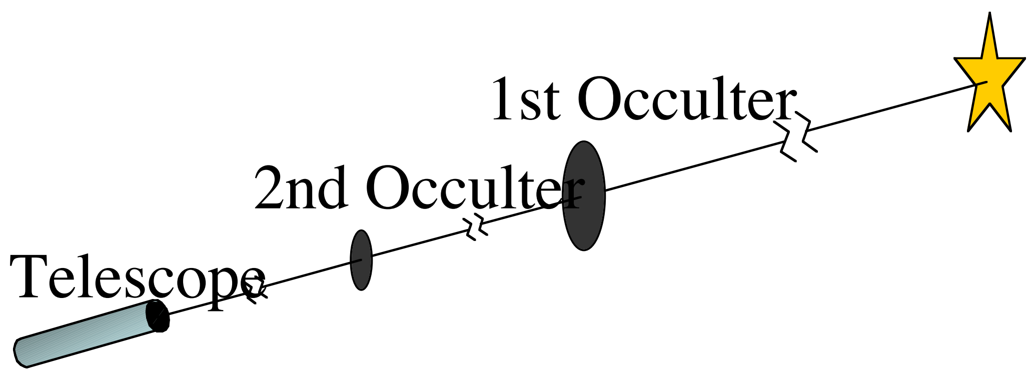


Plot & Image courtesy of BOSS team, TRW, & JPL

Multiple Occulters--In Parallel



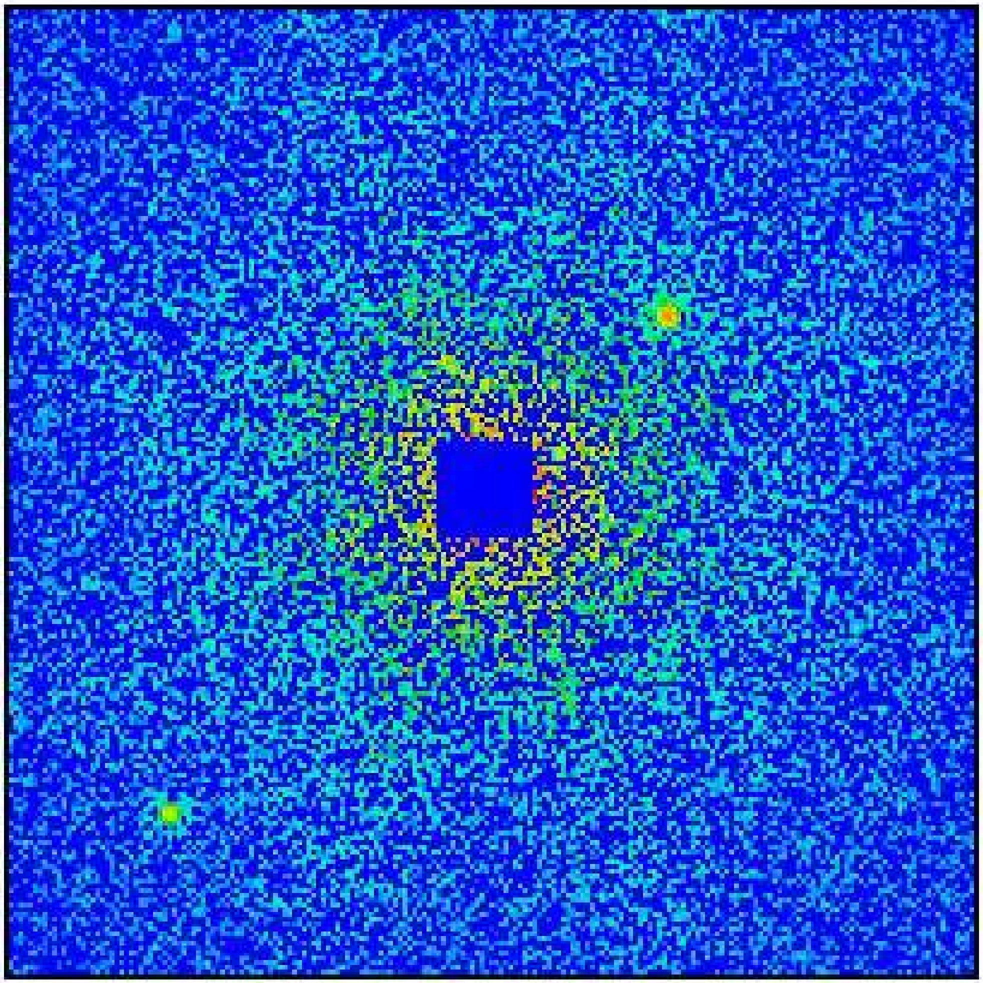
Multiple Occulters--In Series



Conceptual suggestions and top diagram Courtesy of G. Starkman, CWRU, & TRW, in the TPF Preliminary Architecture Report, 00s005516.09-occu-154A

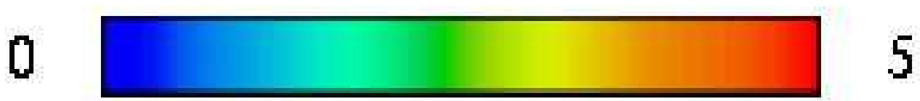
10 pc

Our Solar System at 10 parsecs.



Here is what our Solar System would like as viewed by NGST with the aid of BOSS if the Sun was 10 parsecs away from us. In the image Jupiter (upper right) and Saturn (lower left) are clearly visible.

This image shows a 2 arcsecond by 2 arcsecond region around the star. The central portion of the image (roughly where boss would be) has been cut out by hand to avoid saturating pixels in the middle of image. This image assumes a 3000 second exposure, a 70 meter by 70 meter BOSS as described elsewhere, and a separation between NGST and BOSS of 100,000 kilometers. In the image we have subtracted off what the occulted star is expected to look like. The left over light from the star is due to counting noise and our uncertainty in the point spread function of the telescope.



Courtesy of the BOSS team from
http://erebus.boss.cwru.edu

UMBRAS

- **Established to study the external occultation technique, STScI, Spring 1998.**
- **Original goal: find out why external occultation could not work (*<u>failed</u>*).**
- **Pan-institutional; open publication policy, open collaboration.**
- **Conservative engineering principles.**
- **Originally balked at TPF-utility because high-performance screens were ‘too hard’ or ‘too costly’ (I.e., we started out as *<u>Jovian Hunters</u>*!).**

UMBRAS: A cast of characters

Alfred B. Schultz (CSC/STScI/GSFC),
Richard G. Lyon (GSFC)
Dan Schroeder (Beloit College),
Helen M. Hart (CSC/JHU/APL),
Dorothy Fraquelli (CSC/STScI)
Chi-Chao Wu (CSC/STScI)
Fred Bruehweiler (IACS/CUA)
Kenneth Carpenter (GSFC)
Robert Woodruff (LMMSC)
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Zolt Levay (AURA),
Forrest Hamilton (CSC/STScI),
Ian J.E. Jordan (CSC/STScI),
George Sauter (WASI),
Paul Henze (WASI),
Brian Eney (WASI),
Peter Chen (GSFC),
Melodi Rodrigue (UNR)
Jesse Leitner (GSFC),

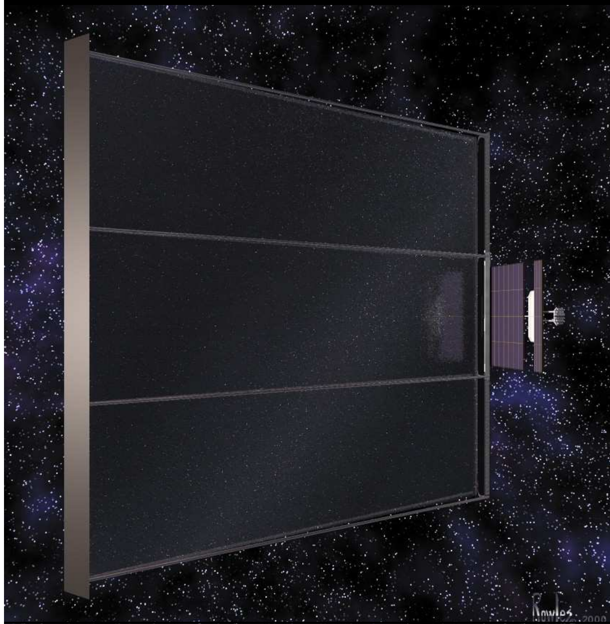
Part of the efforts and studies were supported under NAS 5-26555

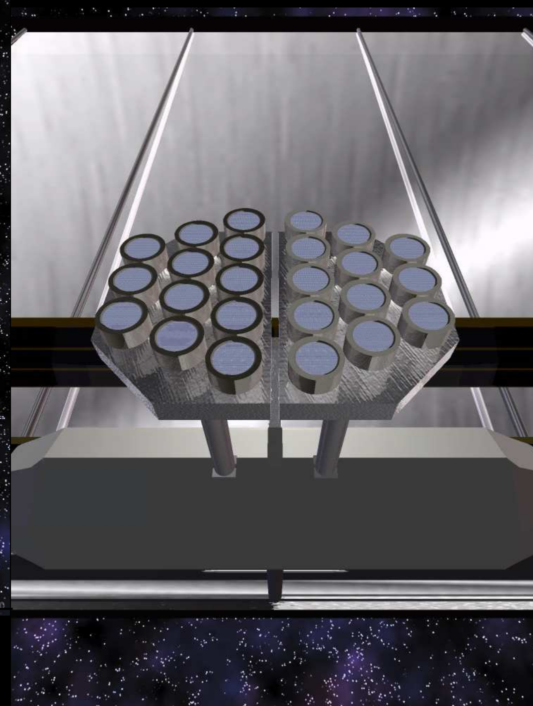
Early UMBRosiAS

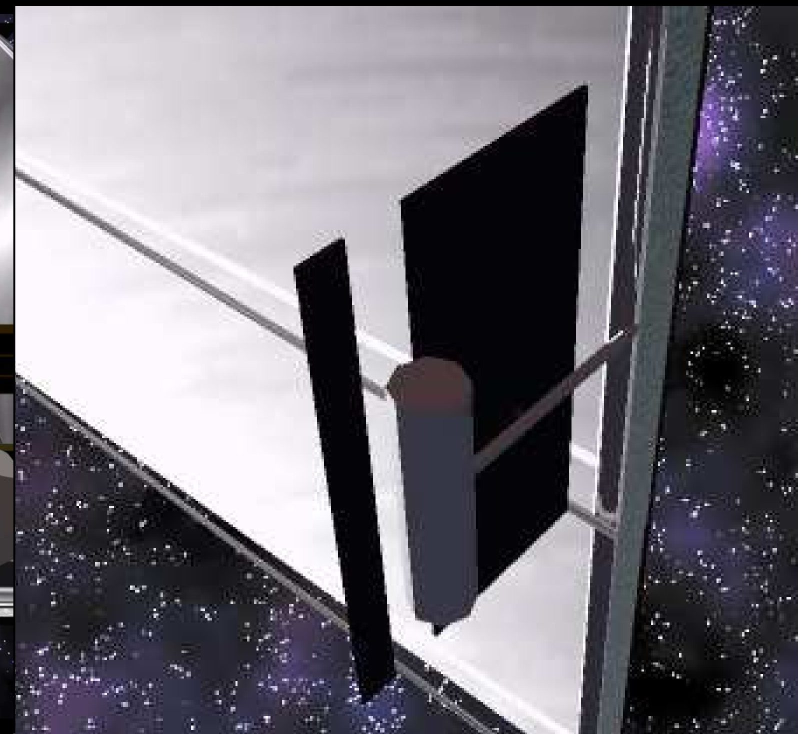
Innovations:

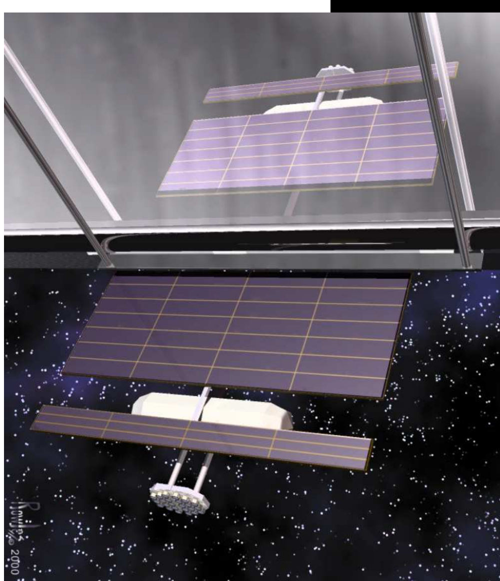
- Suggested mitigating scattered sunlight with the ‘shack roof’.
- Originally proposed *only* opaque rectangles for Jovian-finding due to their ease of manufacture and packaging for launch fairings.
- Proposed MLI binary screens to mitigate micrometeoroids, scattered sunlight, and space weathering (solar wind & CR).
- Edge-mounted ‘flyswatter’ architectures as opposed to ‘Unibody’ (for formation & attitude control and screen erosion minimization advantages)

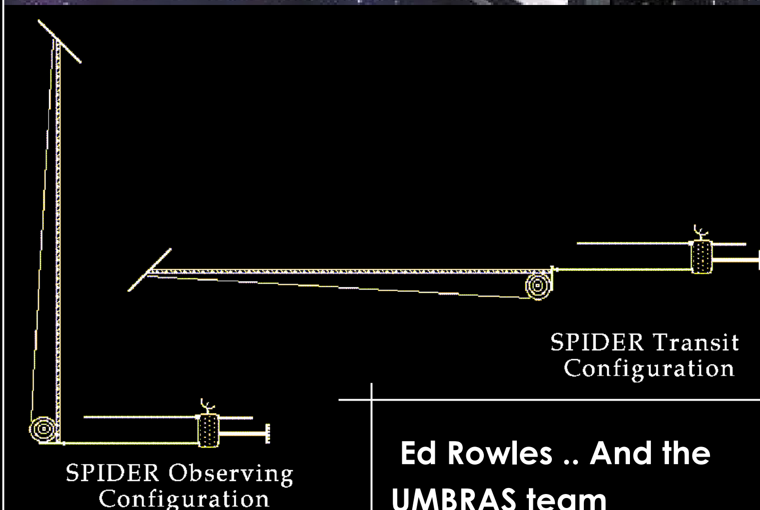
UMBRAS: Mid-life Design





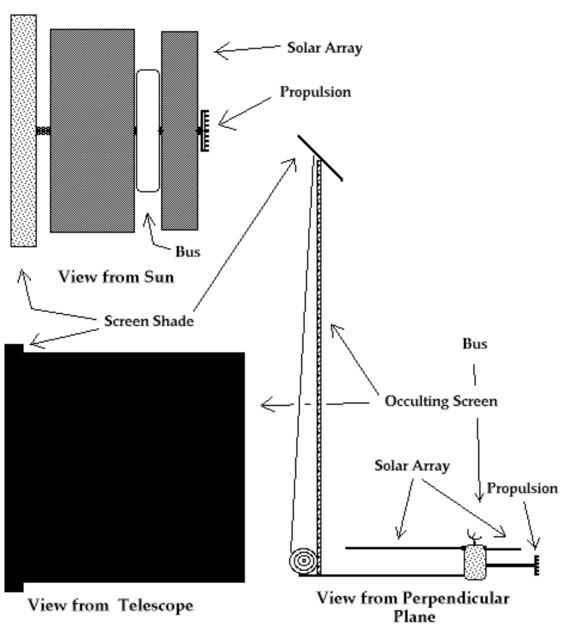






Ed Rowles .. And the UMBRAS team

Coronagraph &
Occulting
Rover
Visible
Exoplanet
Telescope



CORVET

- Single Launcher (both craft), Atlas IIAS-class
- Near-earth Solar Orbit
- 1-metre space telescope ~ 1000kg
  - Unoccluded off-axis primary mirror
  - Focal Plane coronagraphic imager
- Occulter w/ 5-10 metre occulting screen (<1300 kg)
  - 1 NSTAR XIPS engine
  - Fuel for 1-2 year mission
  - 50+ bright targets, at least 2-visits each
  - Jovian search 0.25"-4" at λ=0.5μ

From http://umbras.org

Spergel Petals, and Schultz-Sonine Petals

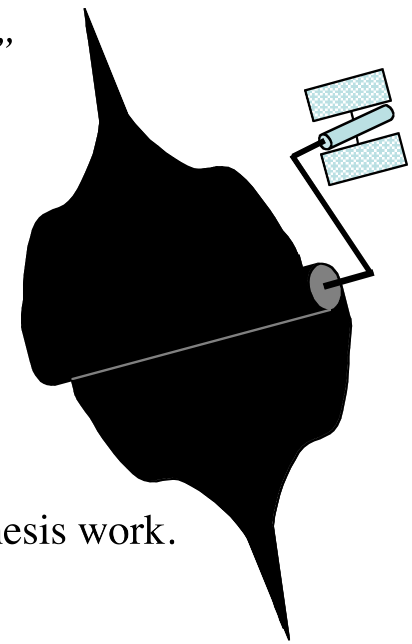
Suggestions for employing optimized shapes to enhance diffraction suppression.

Spergel Mask Occulter

2000; Courtesy of Ball Aerospace, TPF-Architecture Reviews & JPL

Schultz-Sonine Occulter

"Paint-brush-roller" model



Based upon
A. Schultz's Ph.D thesis work.

Problems:

Thought to be as difficult to build as a starflower.
Part of the field around the target is diffraction polluted.

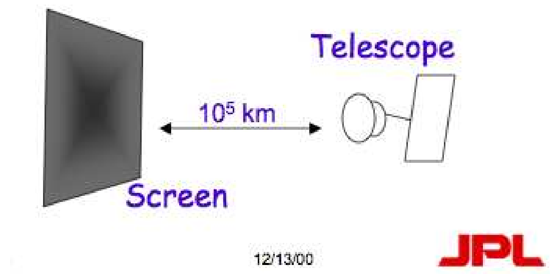
Summary: TPF Architecture Reviews 1998-2000

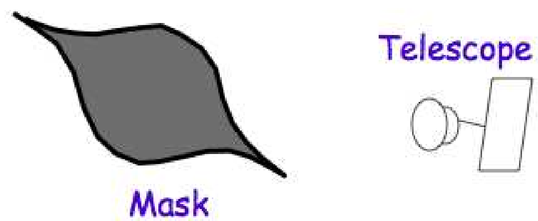
Boeing SVS:

- Review of BOSS, UMBRAS, and SCODOTEP

Ball Aerospace:

- Square and Petal Occulters



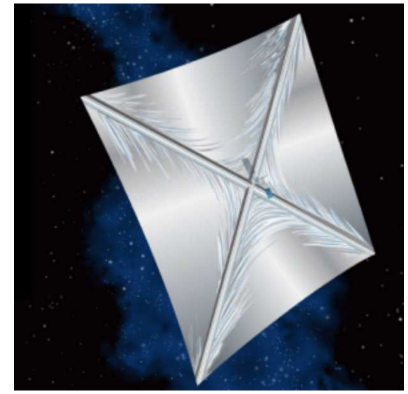


TRW (led by Starkman):

- Single apodized occulters
- Bottlebrush suggestion

Courtesy of JPL and the TPF Architecture Reviews

SOXS

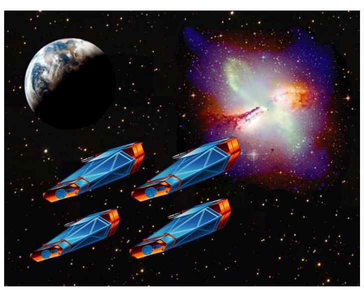


Steerable Occulting X-ray Satellite

NIAC Phase I study on use of an occulter with Chandra, XMM, Constellation-X or similar.

Relies on image reconstruction (a-la IRIS), rather than the contrast enhancement.

http://www.niac.usra.edu/files/studies/final_report/668Starkman.pdf

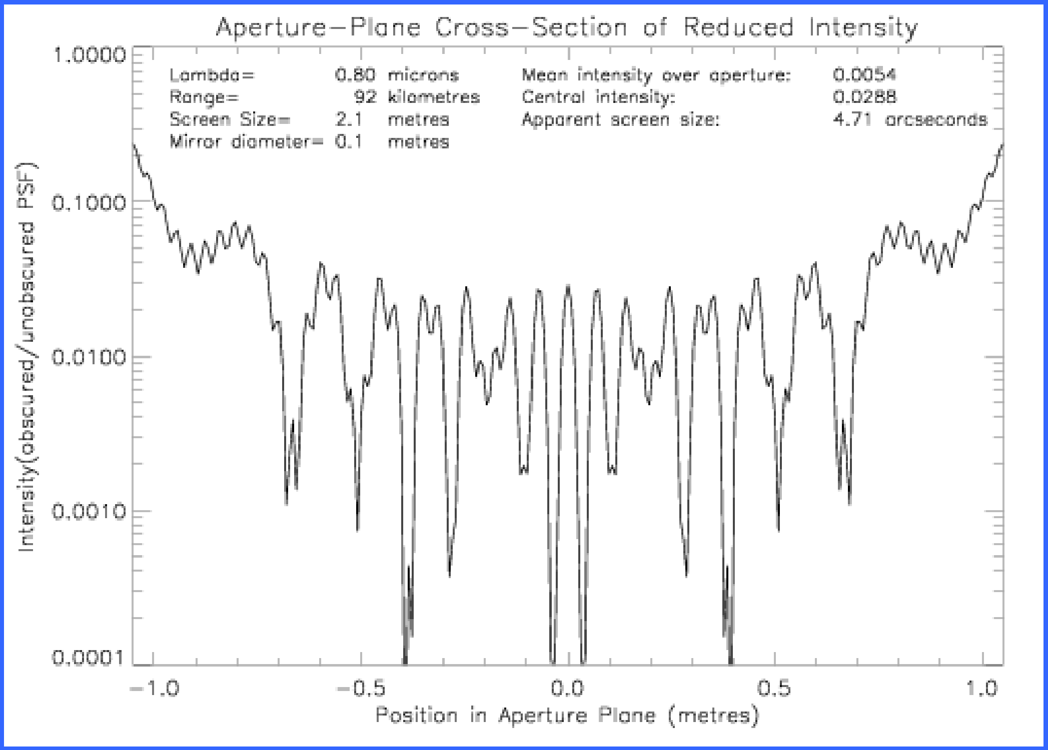


PI: **Starkman**, Glenn D, “Ultra-high Resolution X-Ray Astronomy using Steerable Occulting Satellites”, November 2001.

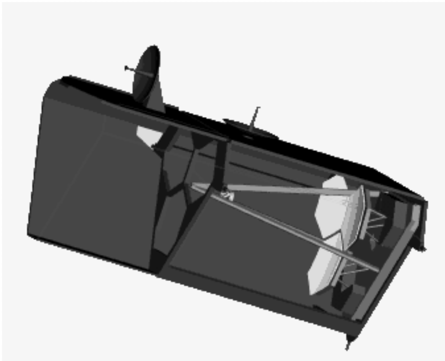
Images courtesy of NASA, ESA, and CWRU

"StarLight" End-of-Mission Occulter Test

Near the end of the StarLight (DS-3 or ST-3) mission, the two craft would separate by 50-100 km, and the collector spacecraft would function as an occulter for the combiner-telescope spacecraft, occulting a star and testing the basic operating principles of occulters.



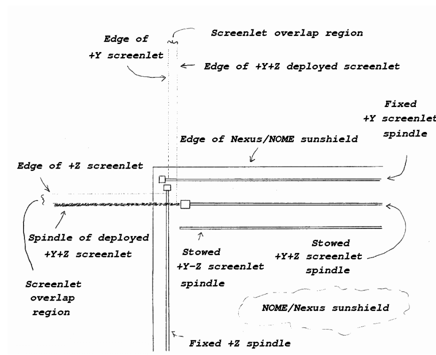
(Lindensmith, Noecker, Duren, Schroeder, UMBRAS, 2001)

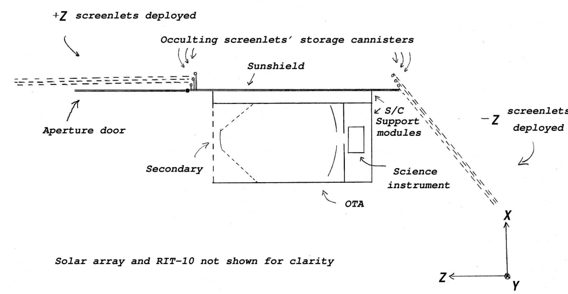


Originally suggested by Chi-Chao Wu, Sept. 2000

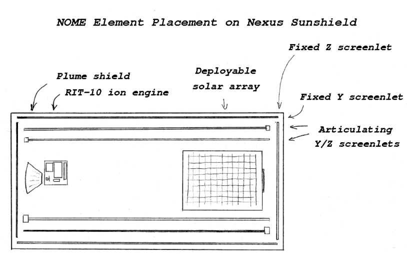
Nexus Occultation Mission Extension

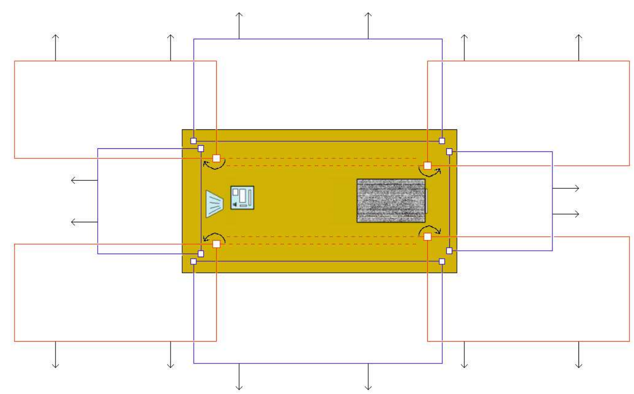
- Modify a planned L2 mission
- "piggyback extension"
- Carry an occulter as a package
- Modest increase in mass/cost of prime mission
- Deploy & operate after prime mission.
- Use with NGST (JWST)!





NOME Semi-cupped Deployment Scheme

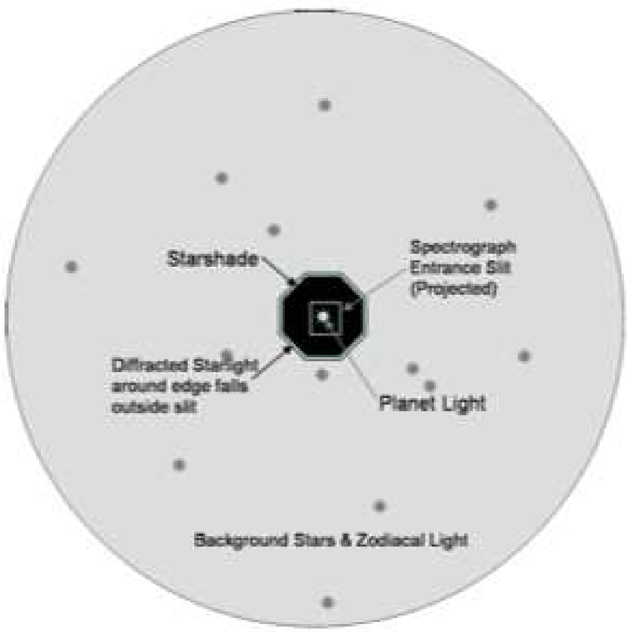




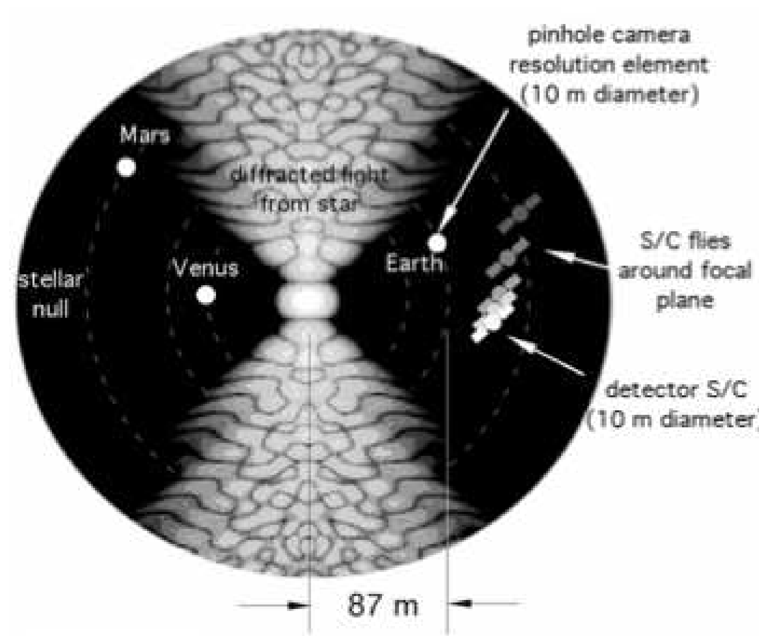
I. J. E. Jordan, C.-C. Wu, et.al., "NOME: Modifying Nexus into an occulter for use with NGST", *Journal of the British Interplanetary Society,* v. 56, no. 7/8, 2003.

Pinhole Camera

(Simmons & Cash)



starshade plane



focal plane

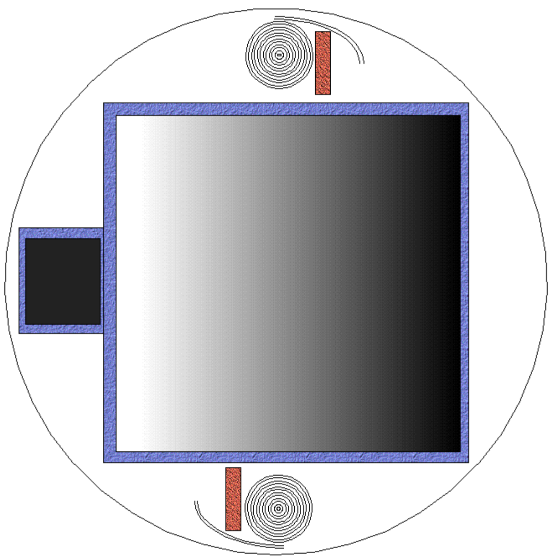
Disadvantages:

- Screen is very big (dynamics issues).
- Extremely inefficient for observing time.
- Moving telescope around focal plane is also problematic.

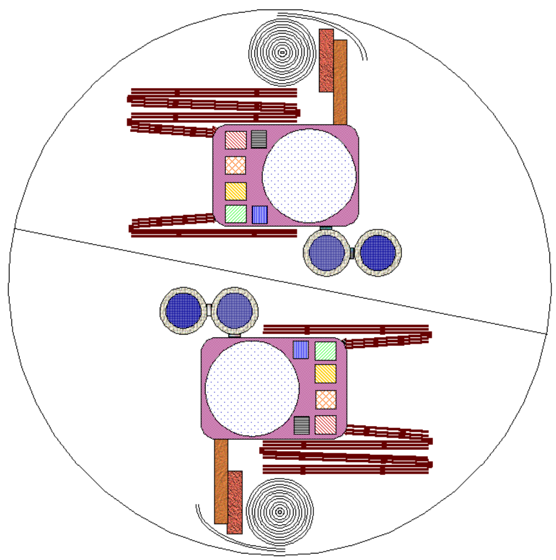
Courtesy of W. Simmons, SPIE, 2004

ASA+O

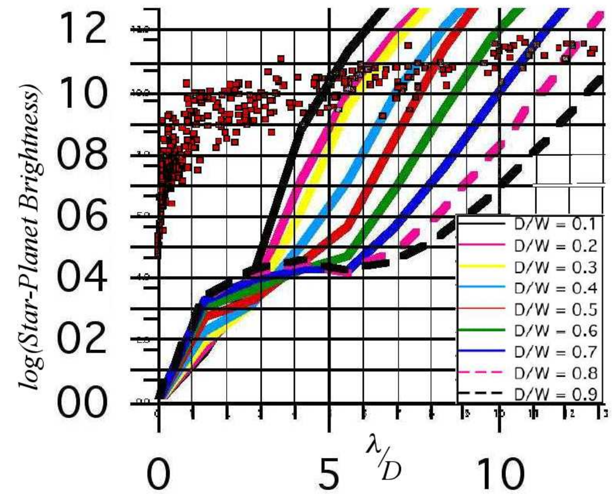
(Apodized Square Aperture plus Occulter)



Square
Aperture
Telescope



Pair of
Rectangular
Occulters



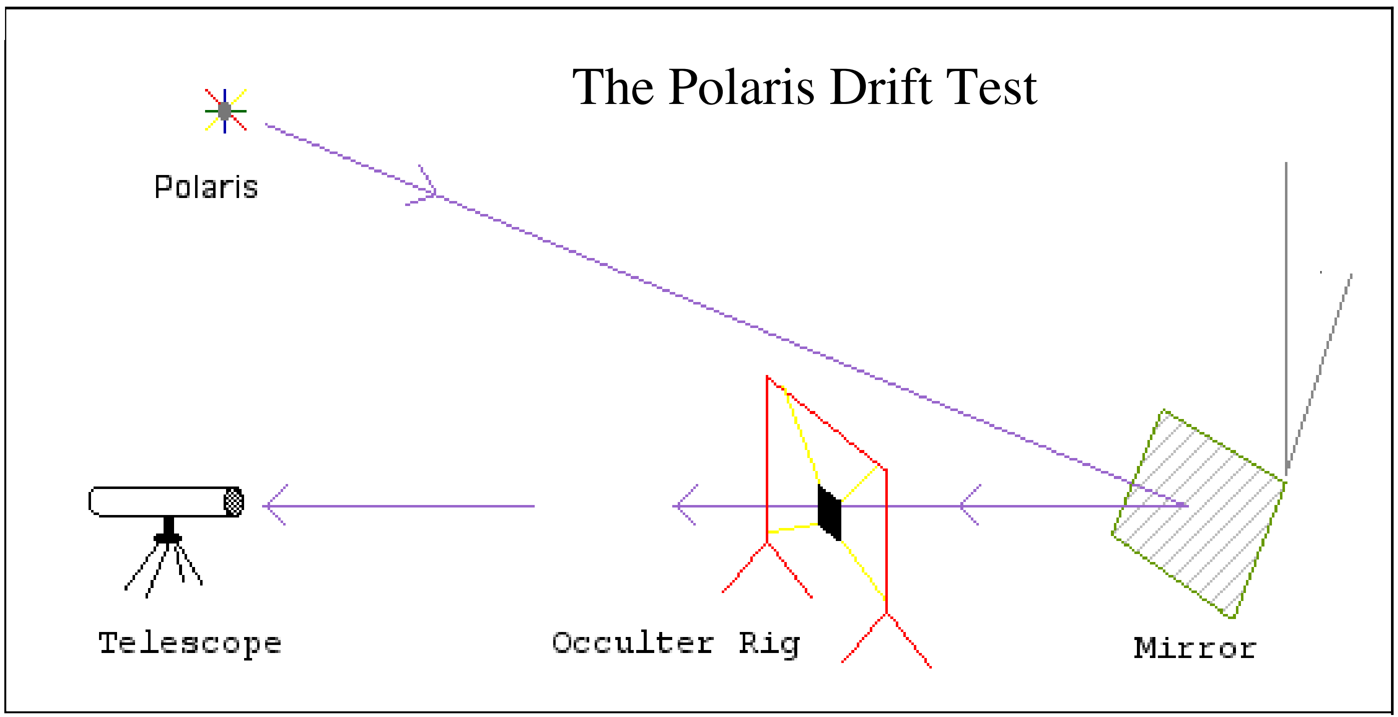
Lyon, R. G., Schultz, A. B., Jordan, I. J. E., Hart, H. M., et.al., 2004, “Apodized Square Aperture Plus Occulter Concept for TPF”, SPIE v.5487, no. 194, Glasgow, UK, July 2004.

Ground Tests of Occulters

$$F_N = \frac{W^2}{z \cdot \lambda} \quad \Rightarrow \quad W = \sqrt{F_N \cdot z \cdot \lambda}$$

$W/_D$ = constant

W=occulter width; z=separation; λ=wavelength; D=aperture.



$$D \propto \sqrt{z}$$

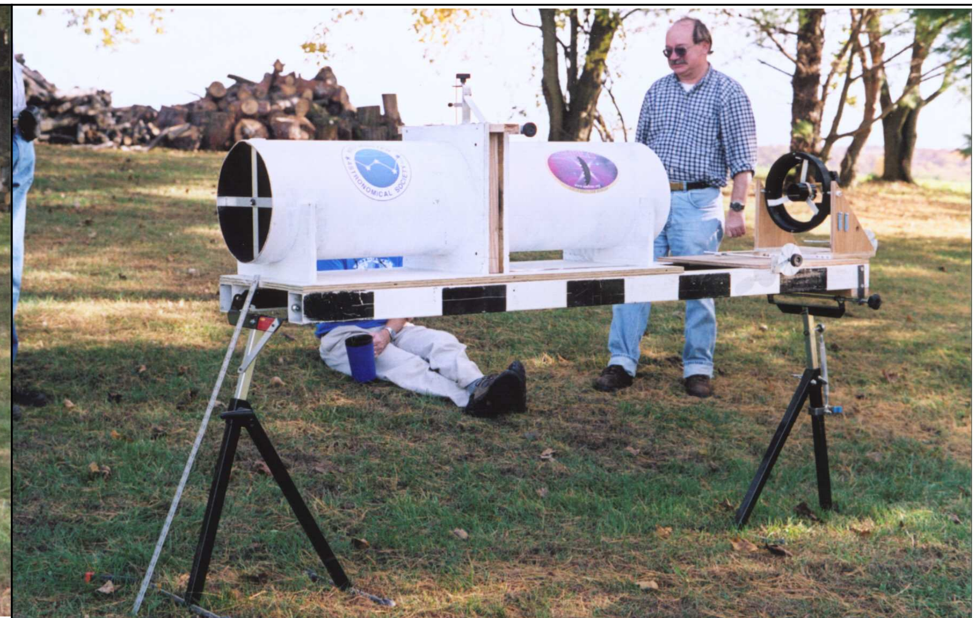
D=4m;
z=20,000 km

D=9mm;
z=100m

I. Jordan, November 28, 2003, "The Occulter Polaris Field Test"

WASI-UMBRAS Ground Test Equipment

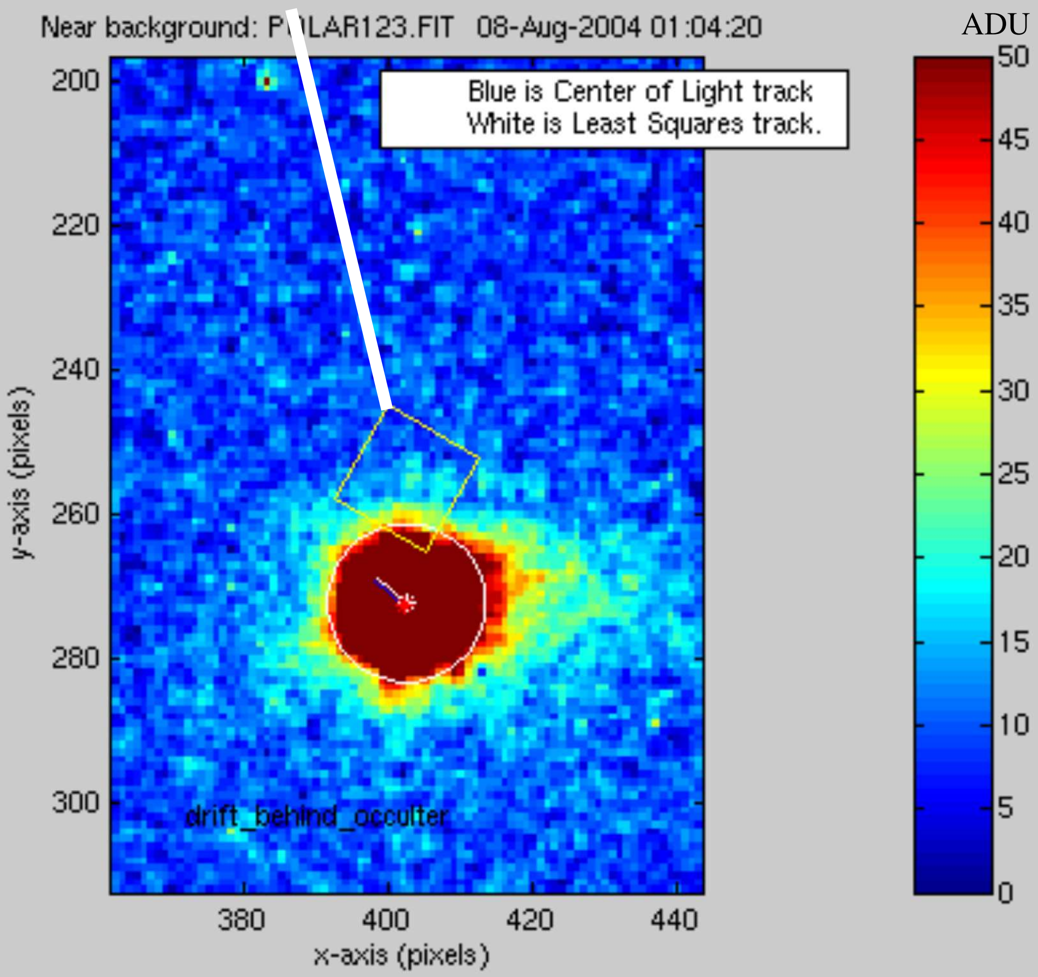
- F/5 Televue 101-mm refractor.
- Masked down to 11 & 24 mm.
- Optional Barlow: system f/# from 50 - 100.
- Mounted atop 8” + alt/az for stability.
- ST-7X, TEC-cooled, 768x512 CCD camera.
- M675X laptop data acquisition/storage.
- Green laser for optical alignment.



- Hand-crafted (P. Henze) occulter-rig.
- 12-inch diameter light shroud tube.
- Square-rail optical bench.
- Mid-tube occulter placement slot.
- 1- and 2-inch square occulters.
- 9” 1/10th-wave flat & mirror cell (GSFC).
- Alt-az mirror mount.
- Red laser for optical alignment.

Photos courtesy of P. Henze, G. Sauter, M. Kochte, & Bryce

WASI-UMBRAS Occultation Movie



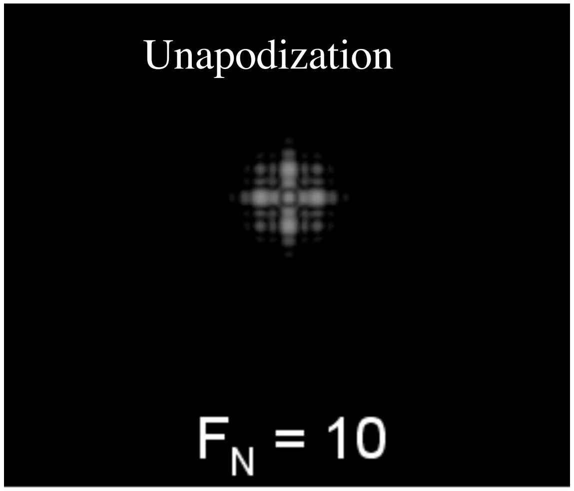
August 8, 2004

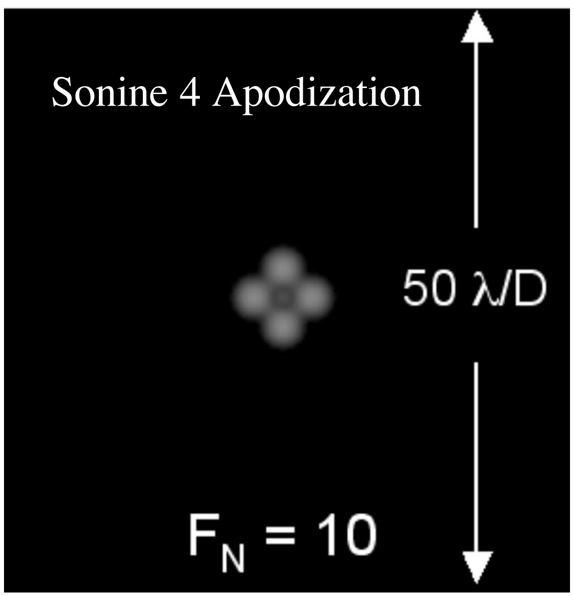
Watch for diffraction lobes!

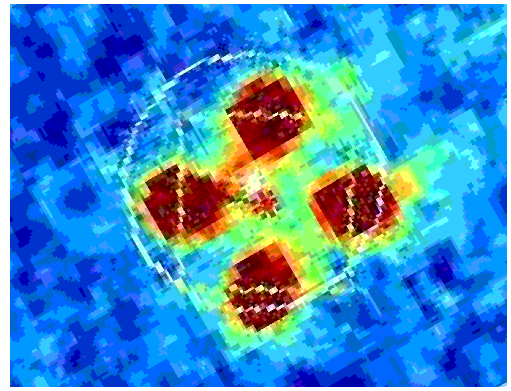
3-second broad-band integrations, 5-second interval between starts. PSF peak ~ 20,000 ADU.

Theory & Experiment: Comparison

Admittedly, this is red and green apples, but . . . .







- Polychromatic $\Delta\lambda/\lambda \sim 0.5$,
- Circular aperture,
- Atmospheric induced wavefront error,
- Atmospheric smearing

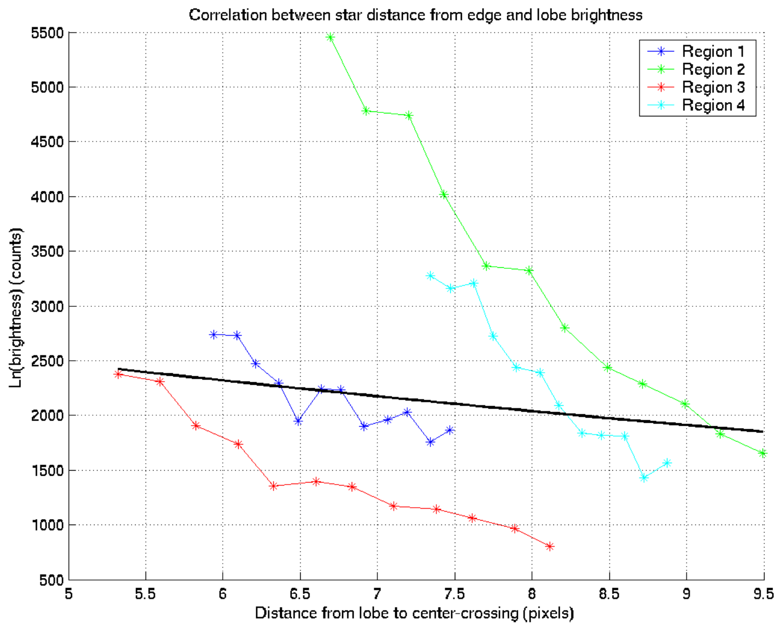
- Monochromatic,
- Square aperture,
- No wavefront error

Courtesy of R. Lyon, WASI, UMBRAS

Relative Lobe Intensity Measures Alignment

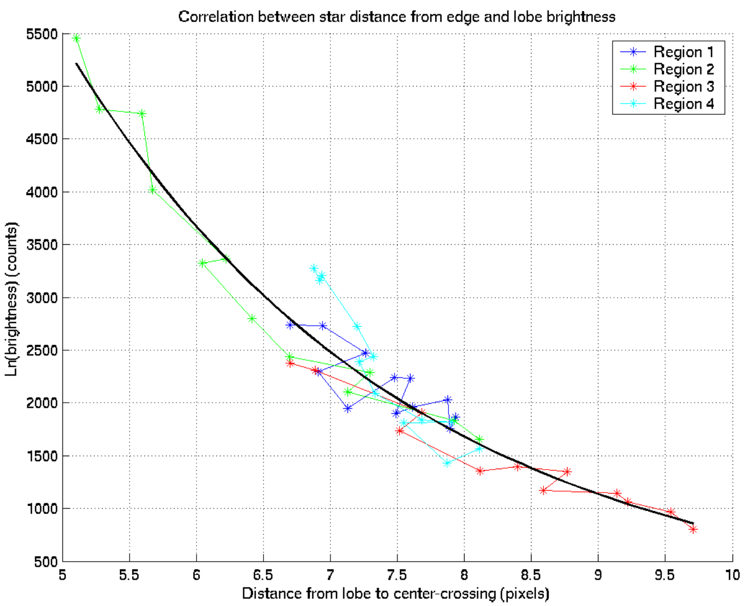
Plotting lobe strength vs. its distance from a presumed star position behind the occulter shows how close that is to the true line-of-sight to the star.

Least-squares path: Erroneous predicted location



A line connecting opposite diffraction lobe centers-of-light is an accurate measure of star position behind the occulter.

It is easy to determine star location behind the occulter!

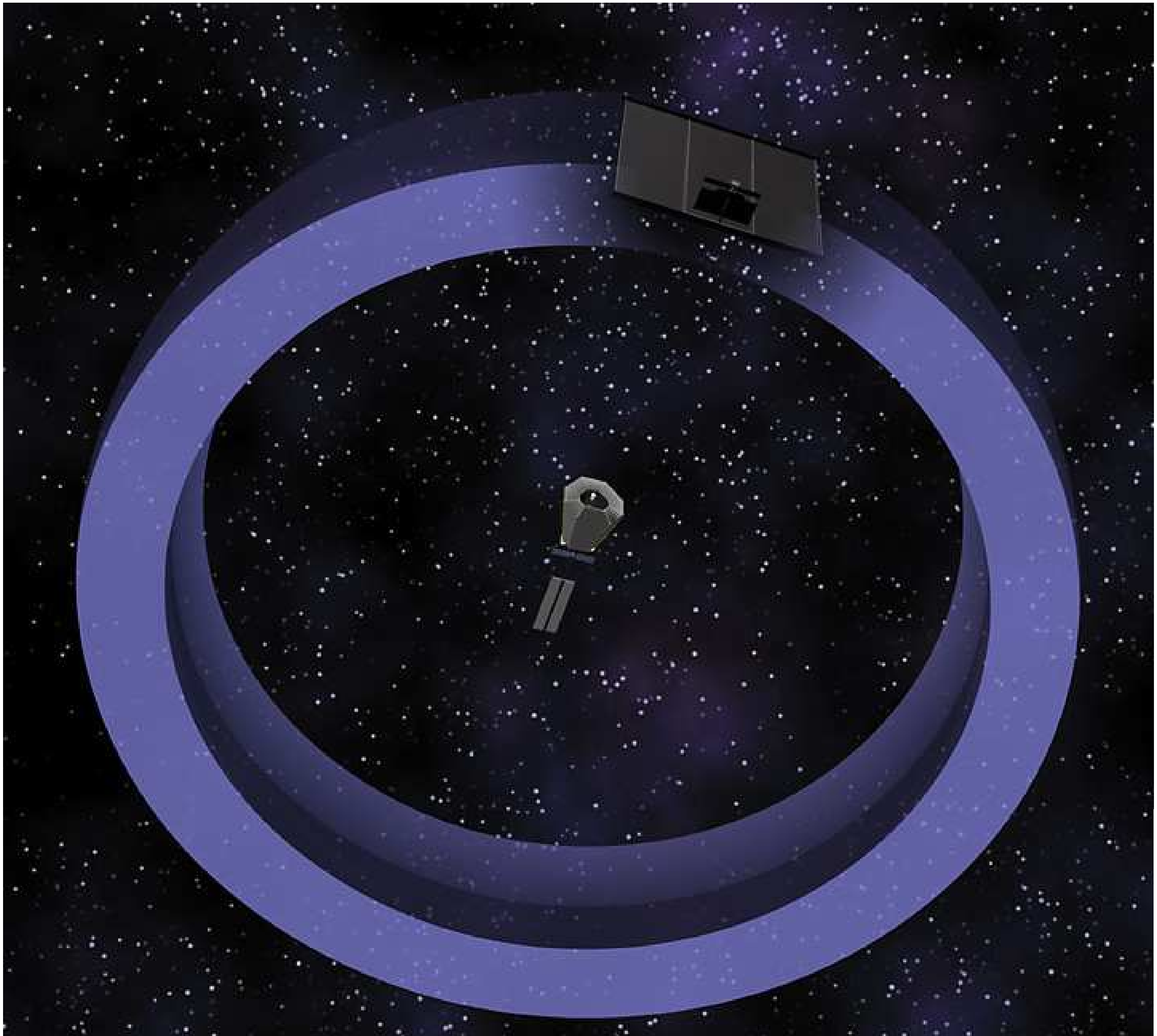


Jordan, Henze, Sauter, et.al. June 2006, AAS," Optically External Occulter Data Analysis"

http://umbras.org/publications.html

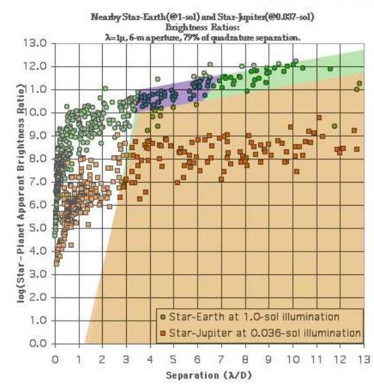
UMBRAS/WASI Occulter Demonstration Team. Westminster, Md, October 31, 2004 picnic

Clockwise from leftt: Ian Jordan, George Sauter, Mark Kochte, Alfred Schultz, Brian Eney, Helen Hart, Peter Chen, Paul Henze, Ron Smith, Scott Jordan

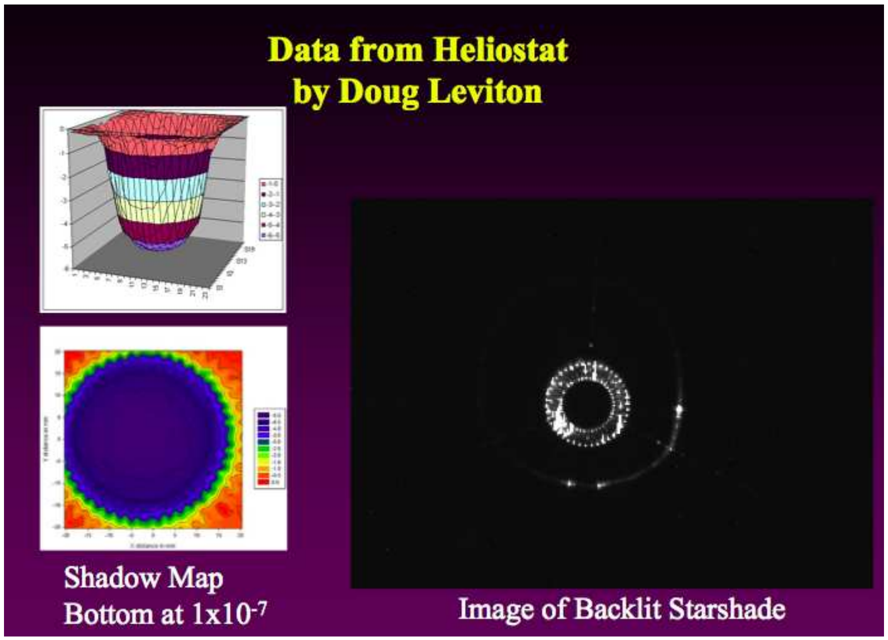


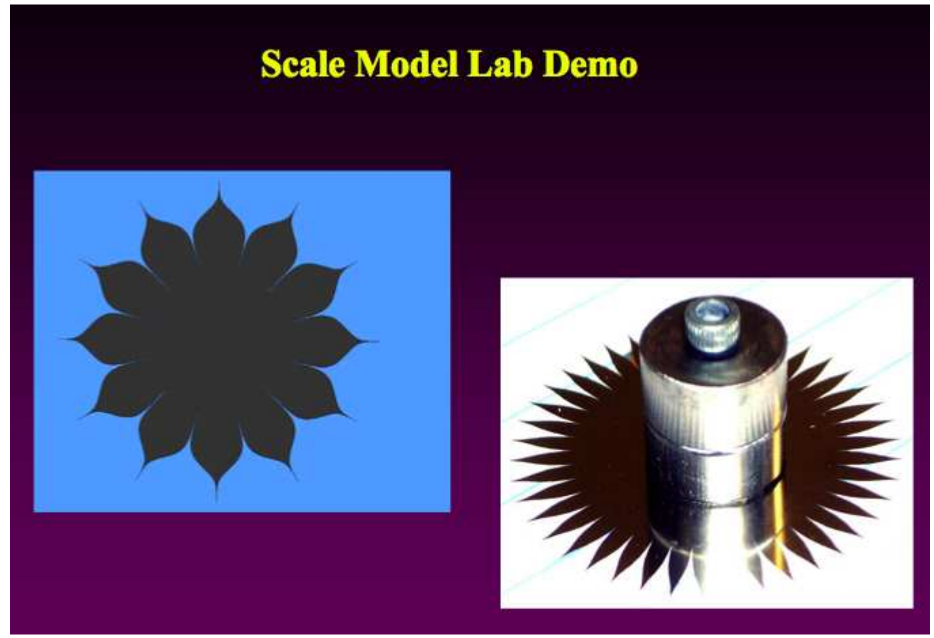
http://planetquest1.jpl.nasa.gov/TPFDarwinConf/proceedings/posters/p092.pdf

T P F - C + O



U. Colorado Testing, 2005-6

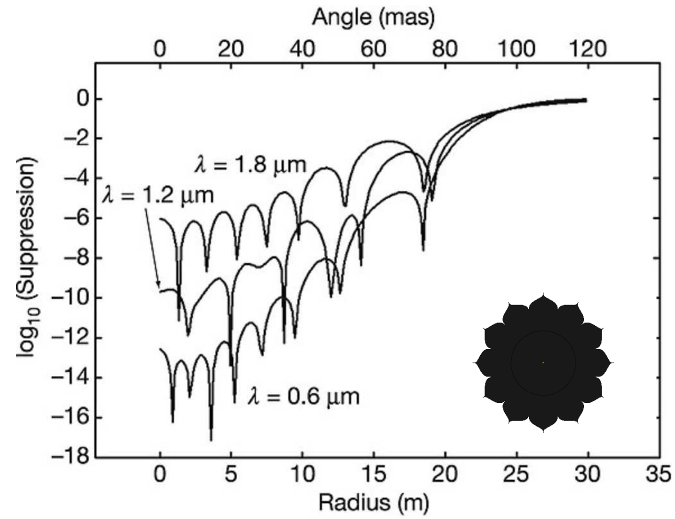


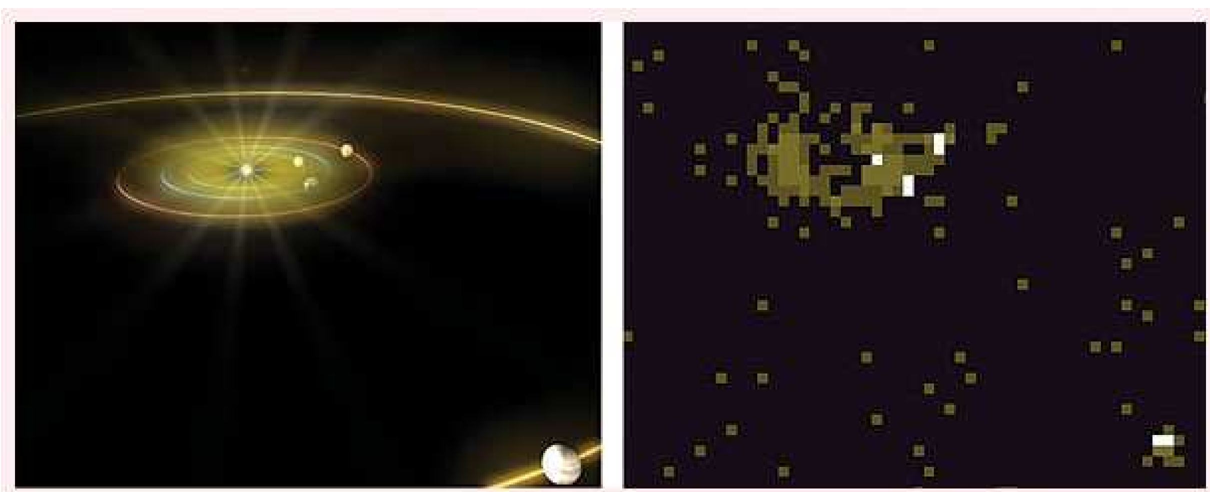


The ability to test external occultation has not been lost on other groups. The U. Colorado-lead team conducted high-performance occulter testing using a heliostat.

Images and plots courtesty of Doug Leviton, Webster Cash, U. Colorado, NGST, GSFC, and the New Worlds team.

New Worlds Discoverer



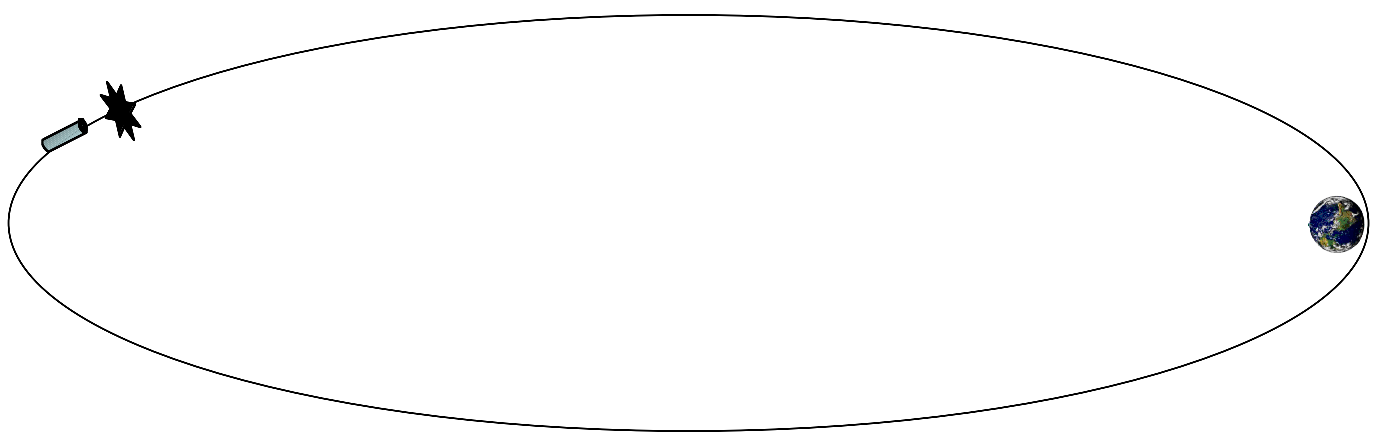


Courtesy of
W. Cash, U. Colorado;
NGST, Ball Aerospace,
GSFC,
Nature 2006, &
http://newworlds.colorado.edu

Woodcock’s Student Occulter

Gordon Woodcock’s occulter test concept:

- Occulter concept demonstration in high elliptical earth orbit, using a commercial-class telescope (16” or smaller) at lowest possible cost.
- Small launcher, ‘rigid screen’ occulter with minimal deployment.
- Possible student project for Stanford, Utah, AF, UNM, etc.

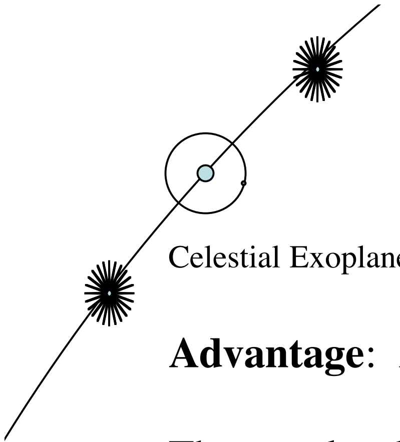


DEEPRO / TPF-O

GOAL:

Refinement of previous external occulter ideas to synthesize the best possible option for placement into the next decadal survey in astronomy and astrophysics.

NASA field center initiative, with participation by academia, and industry.



CESO (Jansen)

Celestial Exoplanet Survey Occulter (2007, PASP 119:214-227) concept.

Advantage: An IRIS-like innovation using a Ground-Space configuration.

The occulter lies in an earth-trailing or earth-leading orbit, ~ 1.6 Mkm distant (occulter subtends ~ 15 mas).

The occulter is placed in a ~ 0.25° inclination solar orbit, node at solstice to match ground velocities.

Drawback: Ground observations always occur in the winter due to geometry and lighting. Northern and southern observatories are used--only a single observatory can use the occulter at a time (size of shadow).

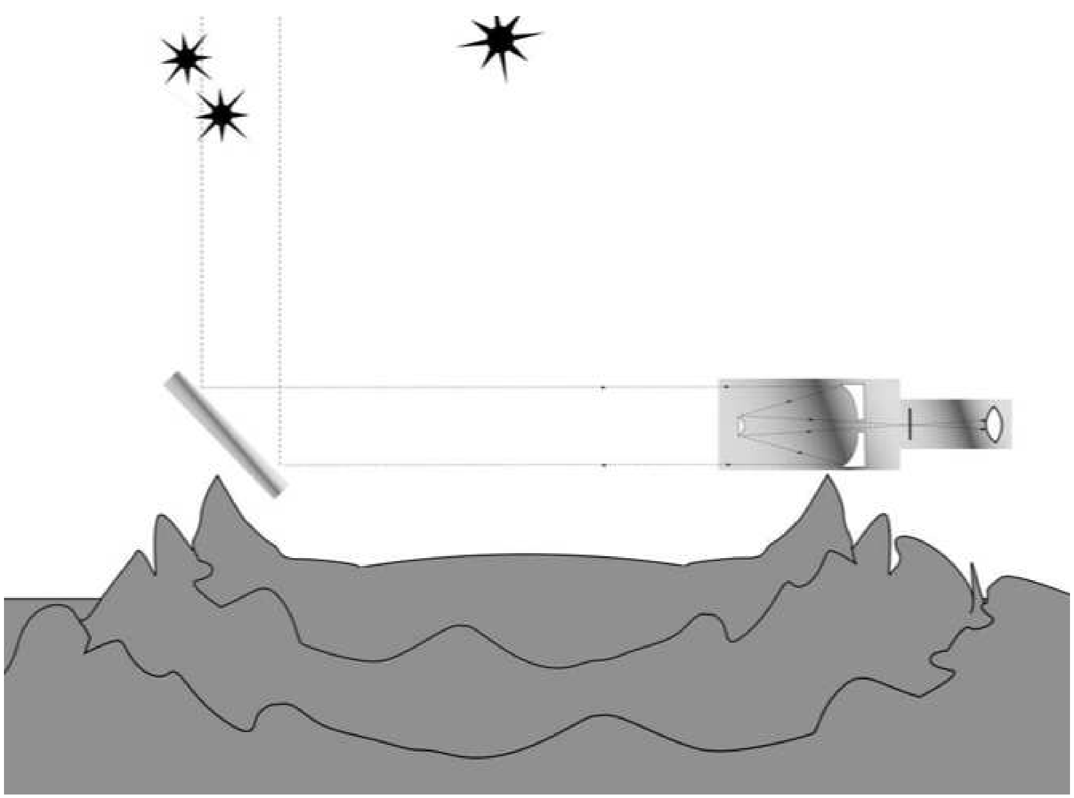
Drawback: Formation-keeping thrust is ~ 100 N (5-tonne s/c), requiring high-power (~ 1MW). Lightweight solar power technology not yet developed.

Drawback: Ground observatories will likely require laser-guide star AO systems to produce high-resolution for exo-planet discrimination.

Advantage: Target selection out to many tens of parsecs is possible.

Courtesy of M. Jansen & PASP, 2007

A Lunar-Based Occulter

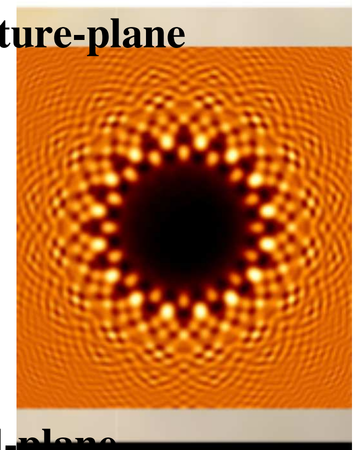


- ‘Direct scaling’ could allow a few sites on the lunar surface to support a lunar-based external occulter and telescope.
- High-performance screens with small blocking radii may allow useful scientific investigation.

(Schultz, Lyon AERM, 2006) http://umbras.org/publications.html

Occulter-plane

Aperture-plane



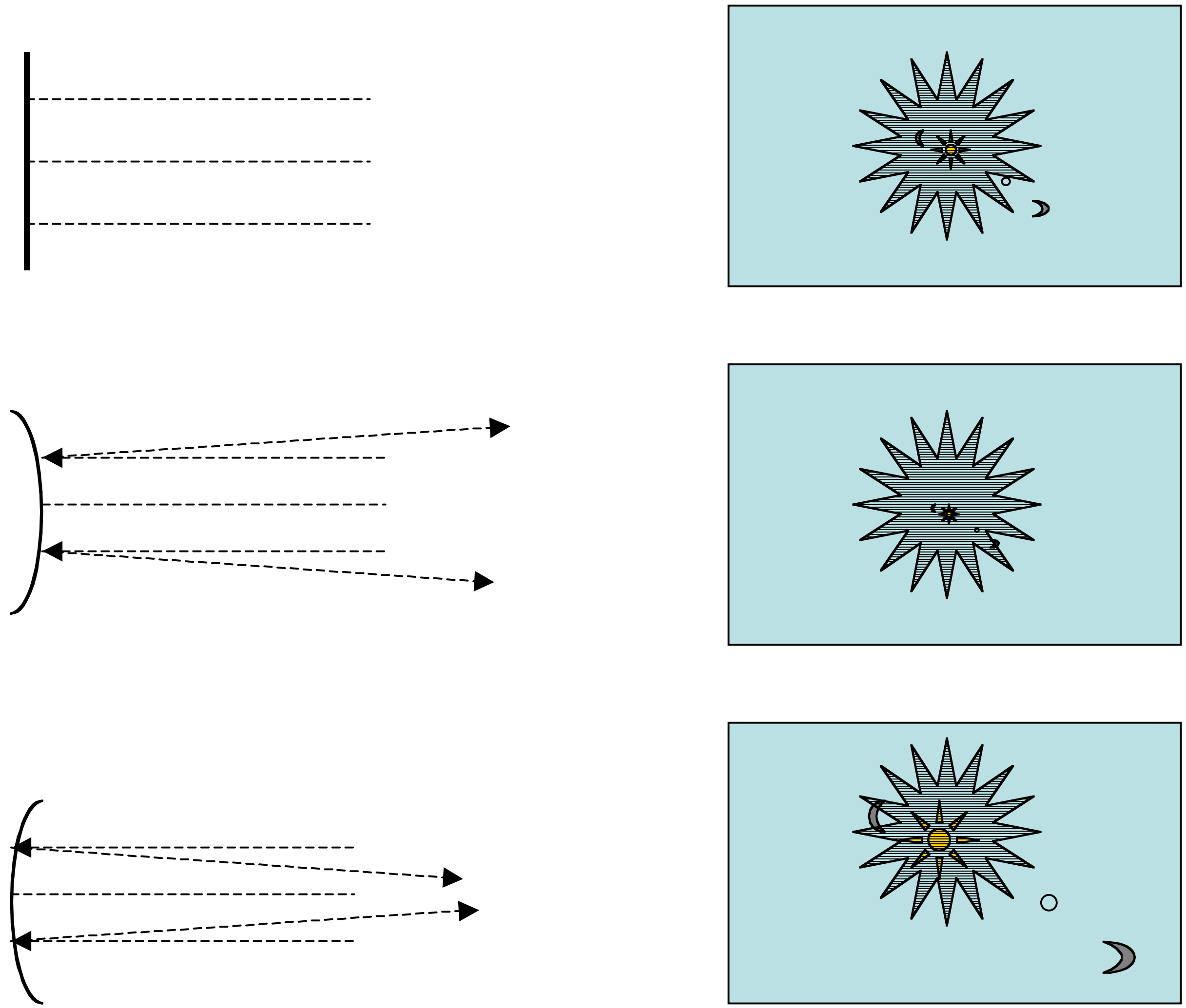
Focal-plane

Field Magnification: A Simple Concept

Plane Mirror
(Flat, no magnification)

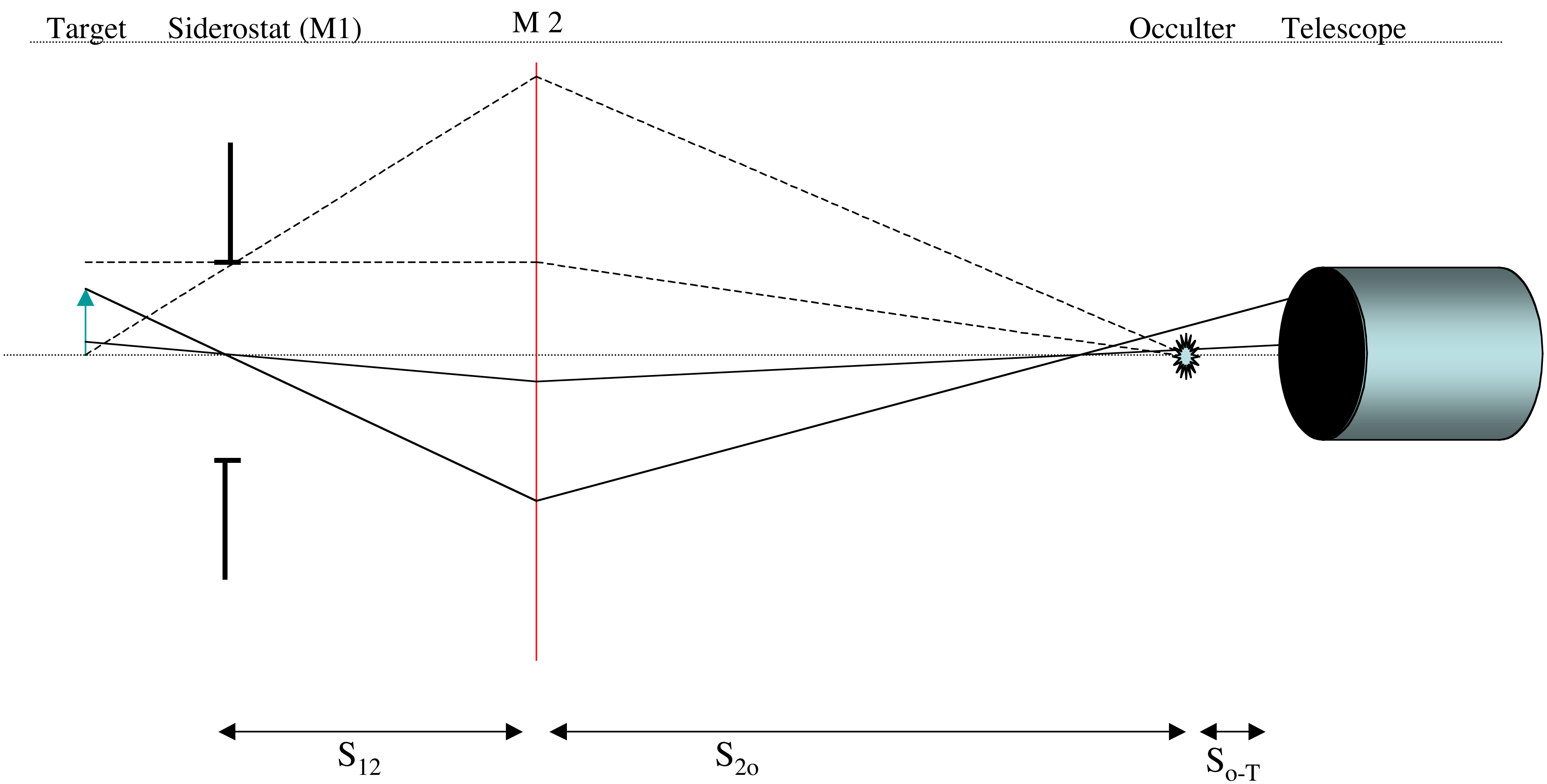
Convex Mirror
(Curved outward,
negative magnification)

Concave Mirror
(Curved inward,
Positive magnification



Place the magnified field-of-view behind the occulter…

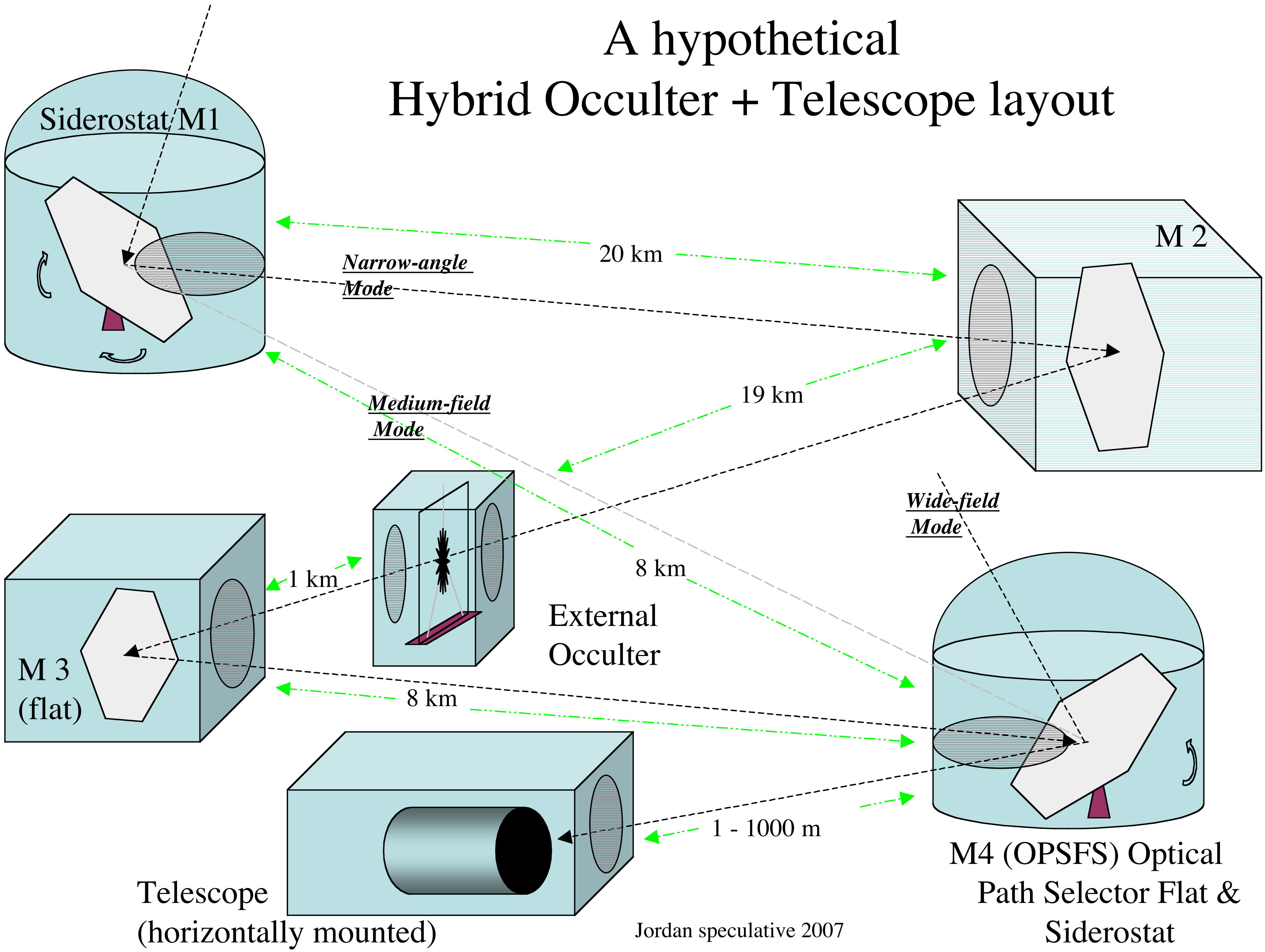
Hybrid (Giant Tubeless Internal) Occulter



(Simplified conceptual ray-trace)

i. jordan

A hypothetical
Hybrid Occulter + Telescope layout

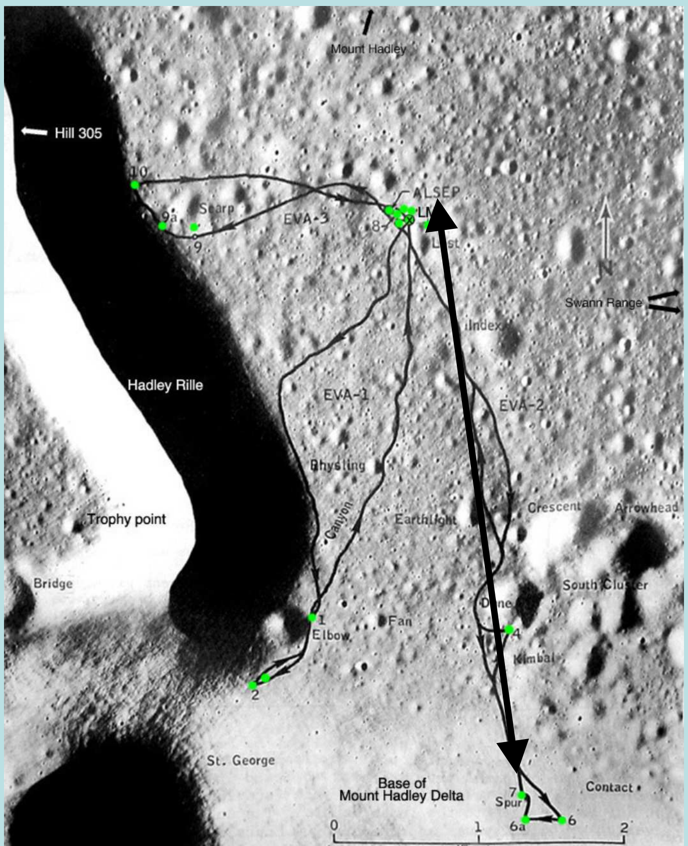


Jordan speculative 2007

Q: Is the indicated traverse scale reasonable on the moon?

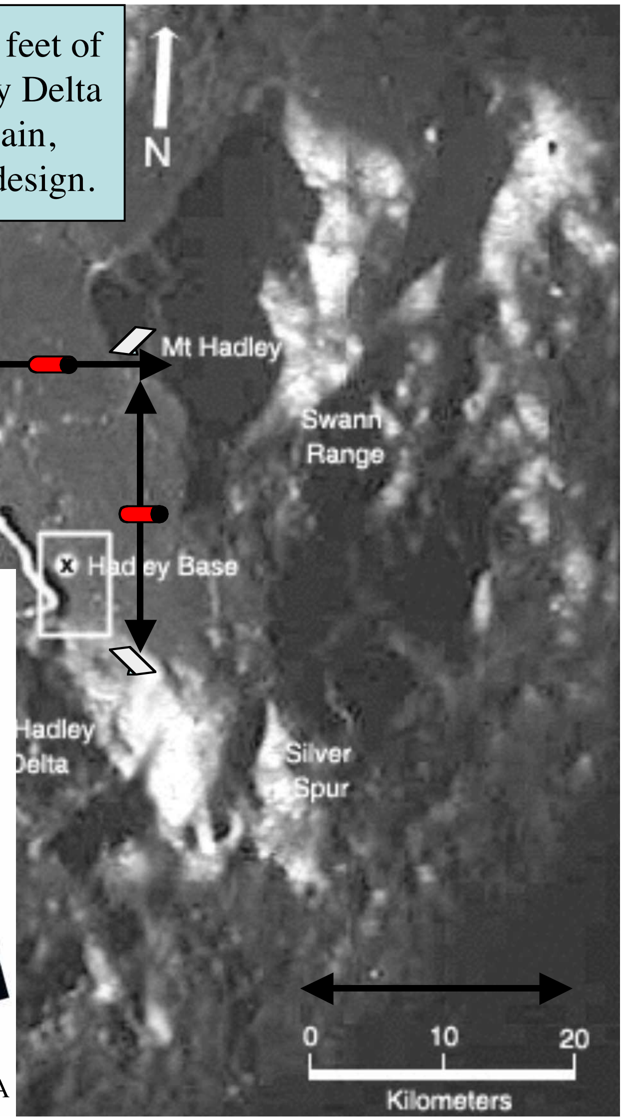
A: Maybe. 10 km one-way is ~ 2x longer than Apollo traverses which were at most ~ 4 km one-way.

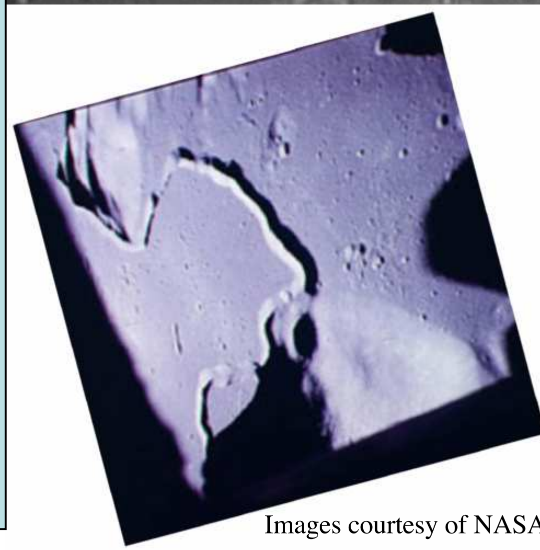
Apollo 15 EVA Site



2 km = 4 cm

Mirror-, and siderostat-sites at the feet of Mt. Hadley and Hill 305 or Hadley Delta with the telescope in Hadley Plain, scales compatibly with the HOT design.





Images courtesy of NASA

Internal/Hybrid/External Comparison

	Objective-Occulter Separation	Occulter Size
Internal	N x 10^1 m	N x 10^-4 m
Hybrid	N x 10^4 m	N x 10^-2 m
External	N x 10^7 m	N x 10^1 m

- The Hybrid is akin to the internal occulter because it is essentially an internal occulter whose primary telescope has no ‘tube’ and whose objective optic has an extremely long focal length.

- The Hybrid is akin to the external occulter because the occulter is external to a conventional telescope placed far from the occulter.

- The Hybrid advantages include stationarity of the occulter w/ respect to the ‘telescope’, potentially higher frequency feedback tracking control, superior manufacturability (tolerances) of precision occulters, sites distributed at reasonable separations for servicing from a single habitat.

- Hybrids are largely unstudied and unknown, but their disadvantages include the multiple buildings, possible need for ‘Lyot masks’, and extremely large number of actuators on the long-focal-length optic.

UMBRAS

Nominal End GSFC 07/03/29

Thank you!

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http://umbras.org

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