End-to-end sparse to segmented aperture R&D efforts toward high-resolution and high-contrast imaging capability – space-based visions re-seeding the ground

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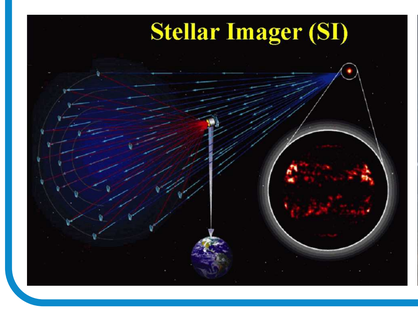
Motivation

Future large space telescope exoplanet coronagraphic instruments may be limited to a segmented aperture. The Visible Nulling Coronagraph (VNC)[2] is a starlight suppression system for high-contrast imaging. VNC development aims to demonstrate high-contrast imaging near the diffraction limit of a bright source using an active segmented telescope as a source feed in a system called the Segmented Aperture Interferometric Nulling Testbed (SAINT)[3]. The VNC and SAINT build on previous space mission concepts, testbeds, and technology needs for missions such as the Stellar Imager[1] and Terrestrial Planet Finder.

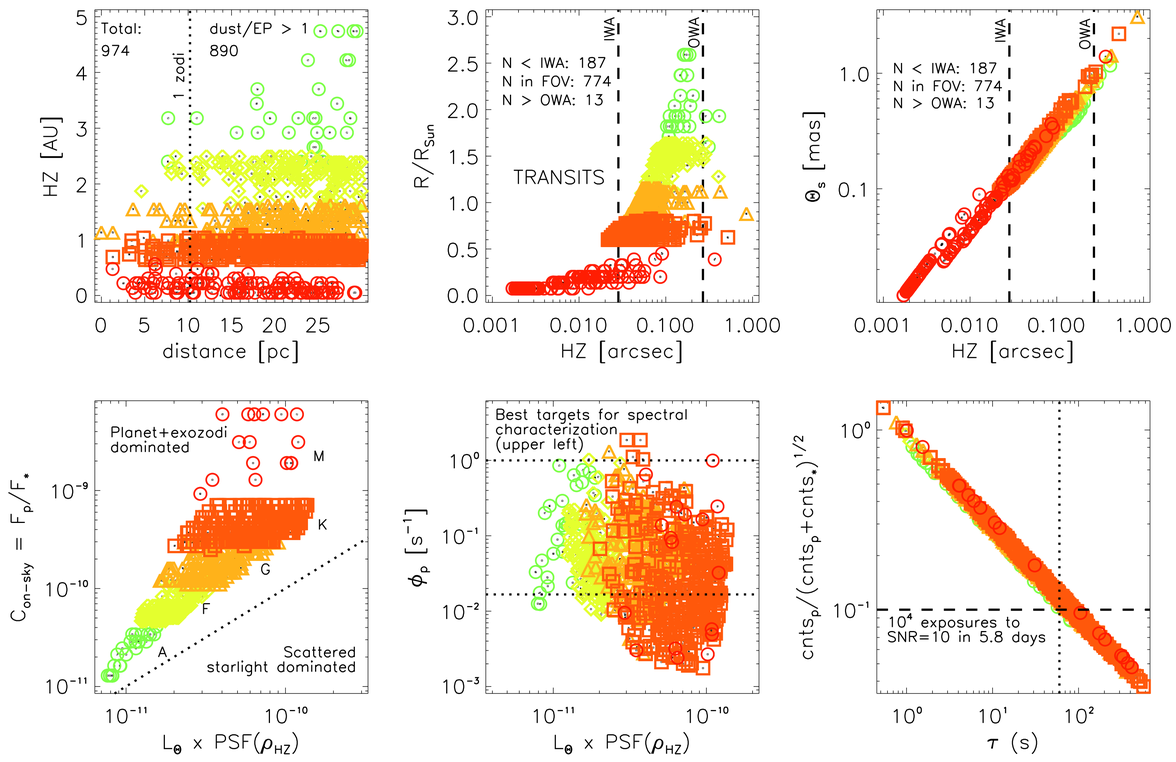


Targeted science: exoplanet direct imaging detection and classification

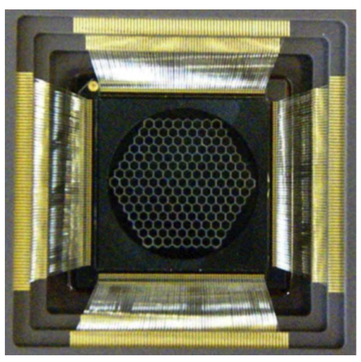
The accessibility of habitable zones around A, F, G, K, and M stars based on system resolution, contrast, and photometric capability.

Assumptions include:

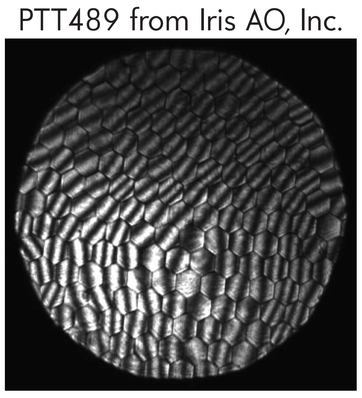
- 11.7-m aperture
- Central $\lambda = 760$ nm
- 10% bandwidth
- 5% throughput
- θ^4 suppression
- D/9 shears
- 0.5 mas pointing
- $2.12\lambda/D$ IWA
- $20\lambda/D$ OWA
- PSF$\propto \rho^{-2.5}$



Deformable mirror

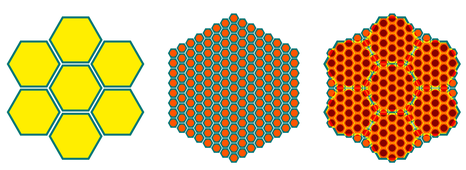


PTT489 from Iris AO, Inc.

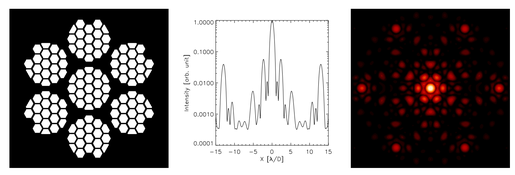


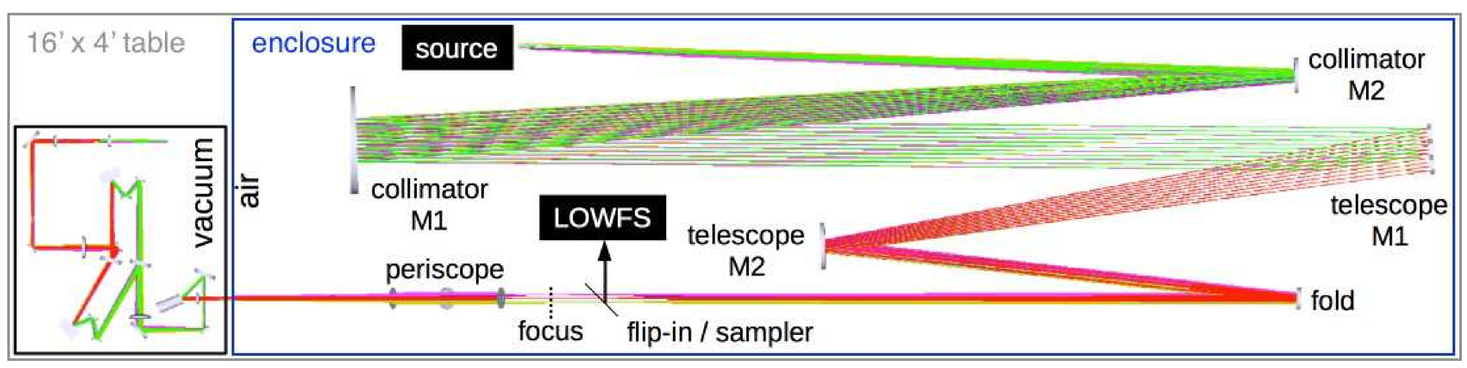
Broadband (40 nm) interference fringes from an unflattened 100% yield DM observed in the "bright" wavefront sensor output of the VNC

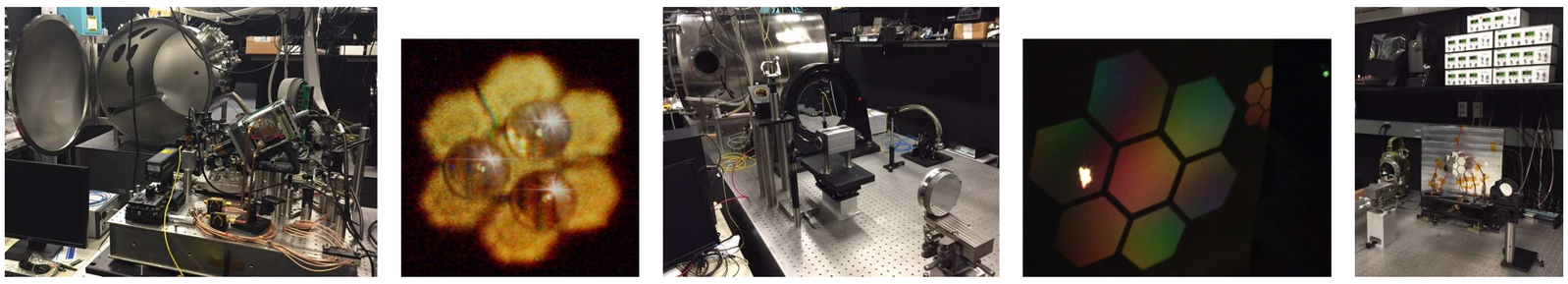
Sequential segmented aperture wavefront control



Aperture =
Active primary (M1) ∩
Deformable Mirror (DM)

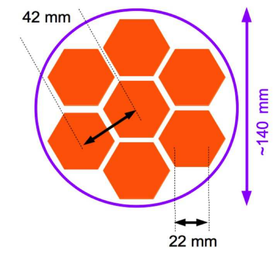




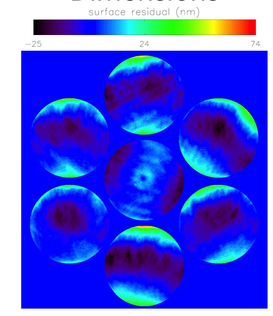


SAINT is a scalable system for studying innovative approaches to end-to-end coronagraphic wavefront sensing and control - a pathfinder to developing mission technology for the discovery and characterization of Earth-like exoplanets around nearby stars.

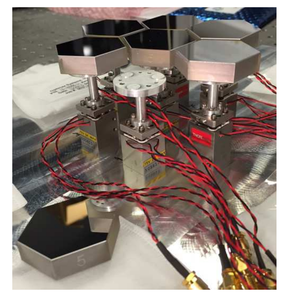
Active primary



Dimensions



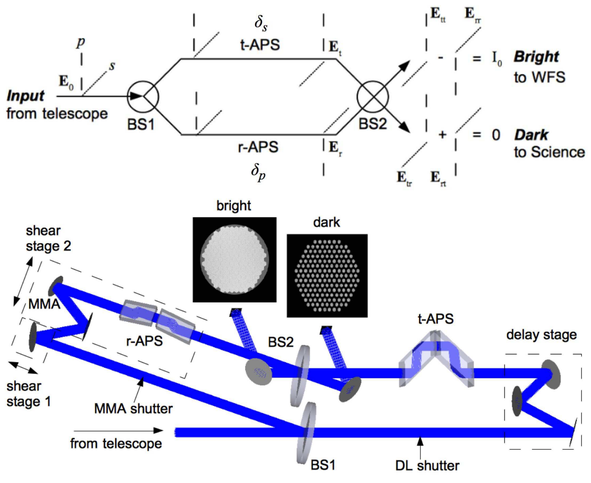
Measured surfaces



Array assembly

Broadband nulling coronography

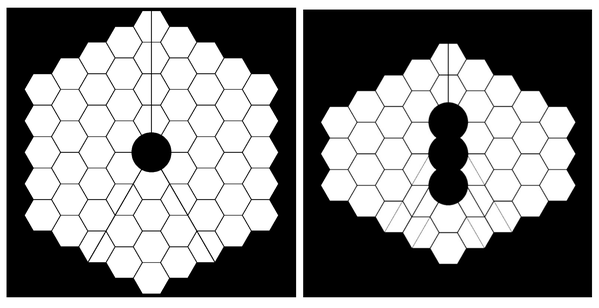
The Visible Nulling Coronagraph (VNC) has previously demonstrated $\sim 5 \times 10^{-9}$ nulling using a fiber source with a 1 nm wide bandpass centered at 633 nm and a segmented DM.[2] An effort is underway to demonstrate 1×10^{-9} contrast over a 40 nm (6%) bandpass using Fresnel rhomb retarders as Achromatic Phase Shifters (APS).[4] The concept of polarization-based broadband nulling is shown to the right above the layout for the laboratory VNC that will be used with SAINT. In practice, two nullers are needed to achieve θ^4 starlight suppression - the output of the first nuller serves as the input for the second nuller.



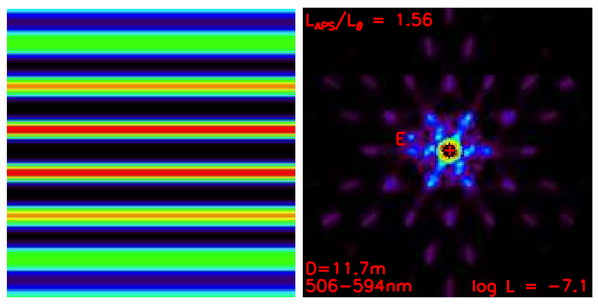
The VNC is a lateral shearing nuller

A favorable future segmented telescope aperture

Various segmented mirror architectures have been considered for optimizing science return from a future large-scale space telescope. A 4-ring hexagonal array consisting of segments similar in size to those of JWST would yield the science capability shown at the top of this poster.



Left: A segmented aperture assuming a "Y-shaped" secondary support truss and an $\epsilon = 0.14$ secondary obscuration ratio. *Right:* The same aperture sheared two times preserving approximately 60% throughput.



Left: The on-sky transmission pattern resulting from two parallel shears. *Right:* Resulting simulated image of the Earth observed at 10 pc around a G2V star, including chromatic effects.

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References

[1] Carpenter, K. G., Schrijver, C. J., and Karovska, M., "The Stellar Imager (SI) project: a deep space UV/Optical Interferometer (UVOI) to observe the Universe at 0.1 milli-arcsec angular resolution," *Ap&SS* **320**, (2009).

[2] Lyon, R., Clampin, M., Petrone, P., Mallik, U., Madison, T., and Bolcar, M., "High contrast vacuum nuller testbed (VNT) contrast, performance, and null control," *Proc. SPIE* **8442**, (2012).

[3] Hicks, B., Lyon, R., Petrone, P., Ballard, M., Bolcar, M., Bolognese, J., Clampin, M., Dogoda, P., Dworzanski, D., Helmbrecht, M., Koca, C., Shiri, R., "The Segmented Aperture Interferometric Nulling Testbed (SAINT) I: overview and air-side system description," *Proc. SPIE* **9904**, (2016).

[4] Hicks, B., Lyon, R., Petrone, P., Miller, I., Bolcar, M., Clampin, M., Helmbrecht, M., and Mallik, U., "Demonstrating broadband billion-to-one contrast with the Visible Nulling Coronagraph," *Proc. SPIE* **9605**, 9605-19 (2015).