Innovative aperture segmentation controls image plane diffraction

ICSO
2020
-300

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Abstract: All large aperture ground and space telescopes today use a hexagonal segment pattern to tile the aperture. These tiles are optically phased to synthesize a single large aperture. This hexagonal pattern produces fixed pattern noise across the image which masks important astrophysics and exoplanet details. We present a new segment topology we call the pinwheel which eliminates this fixed pattern noise while enabling a cost-effective aperture fabrication process. We evaluate this new topology for applications in exoplanet characterization science.

PSF Components: Several end-to-end optical system factors interact to affect the PSF shape distortion and its spatial structure. These are:

1. Geometric wavefront aberrations controlled using innovative opto-mechanical layouts & adaptive optics (A/O),
2. Polarization aberrations controlled using innovative opto-mechanical layouts, optical coatings & spatially variable wave plates,
3. Diffraction controlled by adjusting the shape of shadows and segment gaps across the end-to-end optical system
4. Scattered light understood using scalar and vector wave scattering models & controlled via innovative opto-mechanical layouts, surface polishing technologies and coatings.

Segment Topology: Space telescope apertures of 15 to 30 meters are needed to provide the angular resolution and the radiation-gathering power to produce a significant statistical sample of terrestrial exoplanets. A telescope aperture of this size cannot be placed in orbit fully erected, rather mirror segments are either folded into a smaller volume (as was done for JWST) or in the future may be assembled in space.

NASA's next generation Large UV Optical IR uses a primary mirror that is divided into regular hexagonal shaped segments. The telescope entrance pupil is discontinuous because of both the segment gaps and the secondary support shadows.

With curved secondary support structures and curved sides to nest the segments, we nearly eliminate the image plane "diffraction-noise" by disrupting the diffraction pattern and creating a nearly uniform background across the image plane.

The **advantages** of implementing curved secondary supports & curved segment edges are:

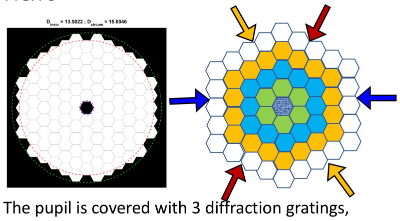
1. Eliminate the need for exotic and absorbing apodizing masks to control segment gap diffraction
2. Increase exoplanet characterization data quality,
3. Improve radiometric calibration,
4. More accurate image restoration, … PSF is both rotationally symmetric & isoplanatic over FOV.

WHERE ARE THE TERRESTRIAL EXOPLANETS?

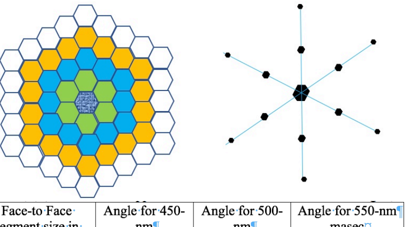
Detectability →telescope aperture in meters needed to place the Earth twin at the first and third ring of the Airy diffraction pattern at the image plane

Distance Parsecs PC	Angle between star & Earth twin in milli-arc - sec	Aperture in meters Diffraction limited at 500nm	Aperture in meters third Airy diffraction ring
10	100.0	1.2	3.7
20	50.0	2.5	7.5
30	33.3	3.7	11.1
40	25.0	5.0	15.0
50	20.0	6.2	18.6
60	16.7	7.4	22.2
70	14.3	8.7	26.1
80	12.5	9.9	29.7
90	11.1	11.1	33.3
100	10.0	12.0	36.0

The LUVOIR pupil has several-rings of Hex's



The pupil is covered with 3 diffraction gratings, each clocked 60 degrees relative to the other

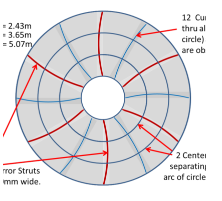


Face-to-Face segment size in meters	Angle for 450-nm masec	Angle for 500-nm masec	Angle for 550-nm masec
1	93	103	113
2	47	52	57
3	31	34	38
4	23	26	28

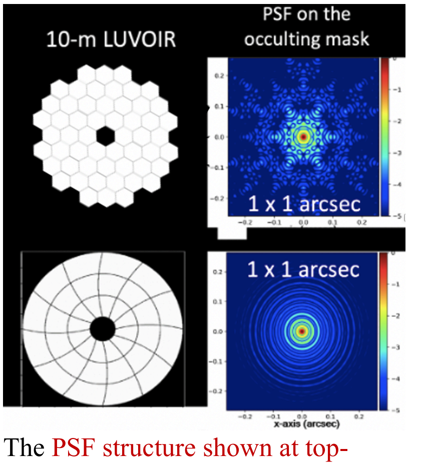
Comparing the two tables, the unwanted diffraction images of the parent star fall within the same FOV region as the exoplanets!

Pupil architecture of topology

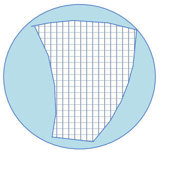
Based on our intuitive understanding of diffraction from curved segments we designed a pupil topology for a "first look" at the diffraction effects.



Here the blue designates edge of segments of a 10-m entrance pupil & the red, secondary mirror supports.



The PSF structure shown at top-center indicates that many false-positive identifications of exoplanets may occur & exoplanets can be masked if a hex segmented aperture is used.



Curved segments may be made using similar techniques used to fabricate ESO's ELT ZERODUR® hex segments, first polished as a roundel then cut to shape, and any changes corrected by small tool techniques.

SPIE Proc. 10698-1P, -60,-188; 11115-17; JATIS V.2; PASP 127; Appl. Opt. 34

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