Status and Predicted Performance for the AstroPIC Integrated Photonic Coronagraph

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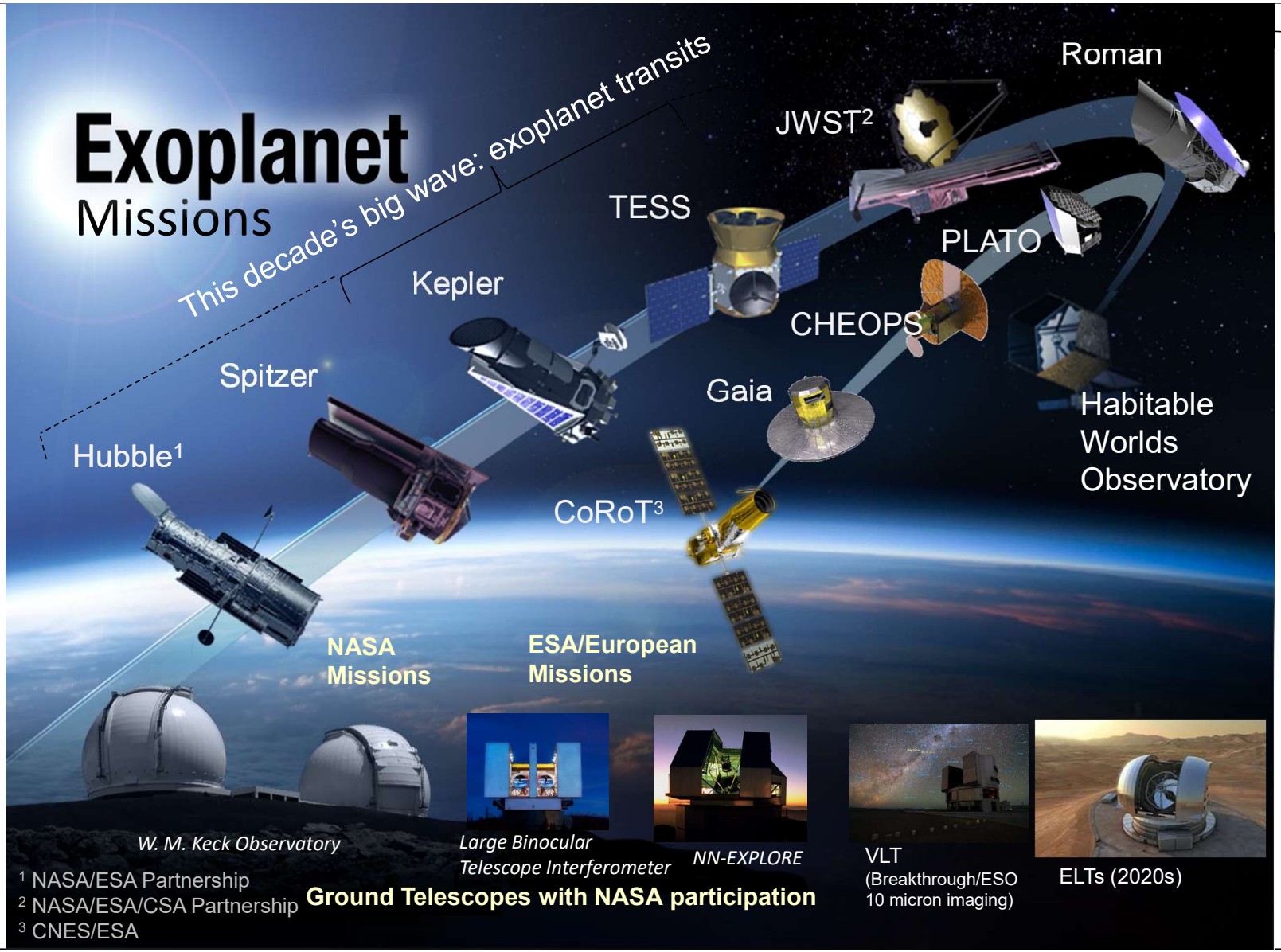


Next big wave (2020-30s): Direct imaging of exoplanets from space and from ground

To Date:
5600+ Confirmed Exoplanets
~2600 from Kepler (Ames mission)

HWO to survey nearby ~100 stars with the goal of characterizing 25 Exoearths

The challenge: 10^{-10} contrast

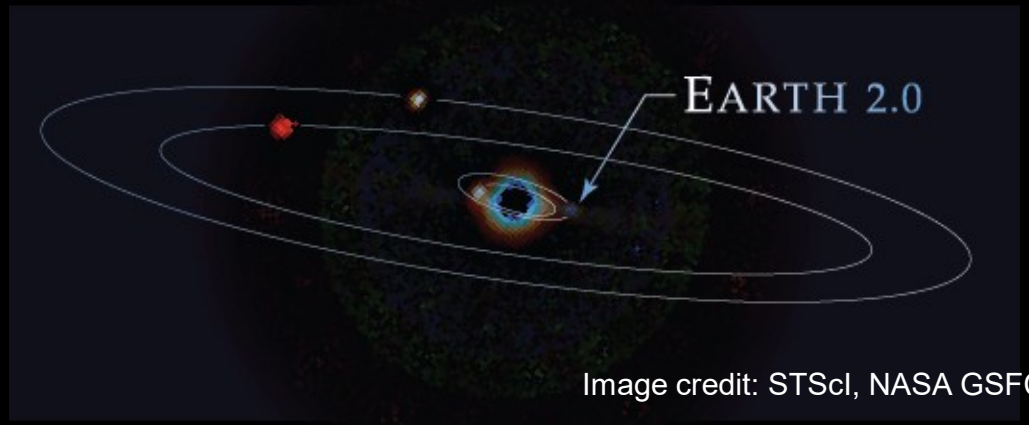


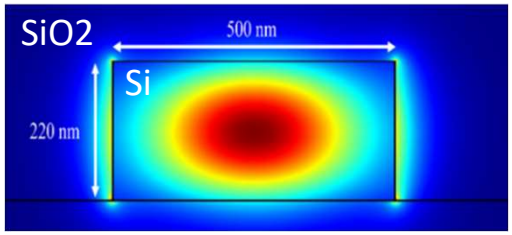
Image credit: STScI, NASA GSFC

- HWO aims to characterize 25 exo-Earths
- This requires contrast levels of 10^{-10} → pm-level wavefront control requirements
- Complications:
  - On-axis pupil shape
  - Mechanical imperfections
  - Thermal effects

How can integrated photonics help?

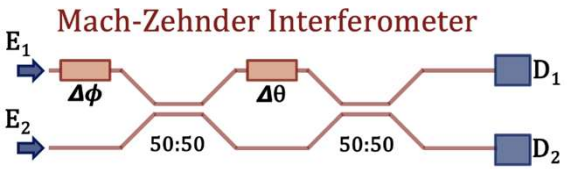
- Photonic integrated circuits (PICs):
  - Leverage CMOS manufacturing techniques + telecom technology
  - Fabricate many optical components on a common substrate
  - Benefits: extreme miniaturization and robustness
- Meshes of Mach-Zehnder interferometers can implement any linear optical operator
  - Active tuning allows for reconfigurability
  - Agnostic to pupil shape
  - Path to theoretically optimal coronagraph design!
- AstroPIC project is investigating usefulness of PIC technology for high-contrast exoplanet measurements

Silicon Photonics waveguide:

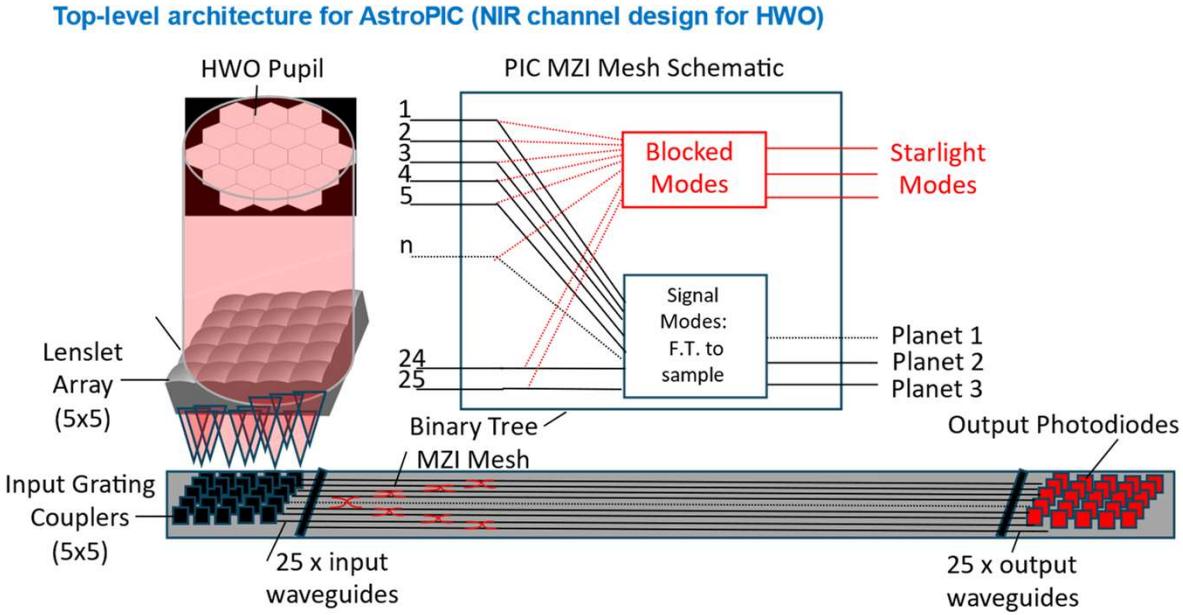


Credit: Moynihan 2024 UCC

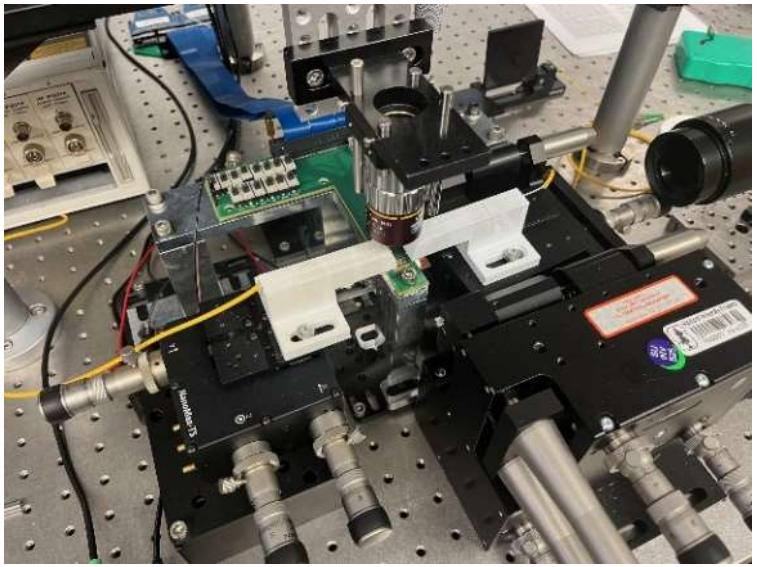
Key building block:



Credit: Carson Valdez, Stanford

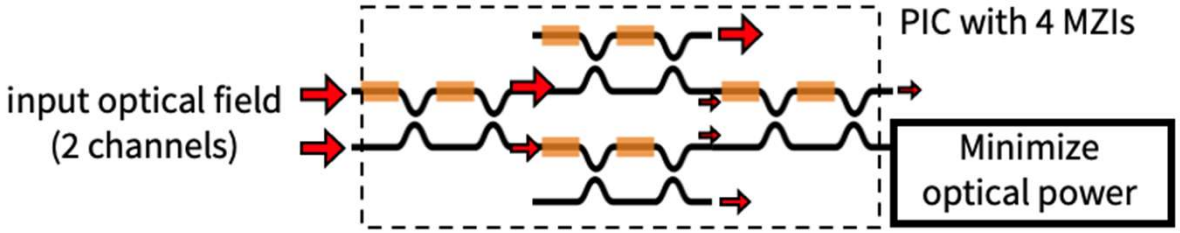


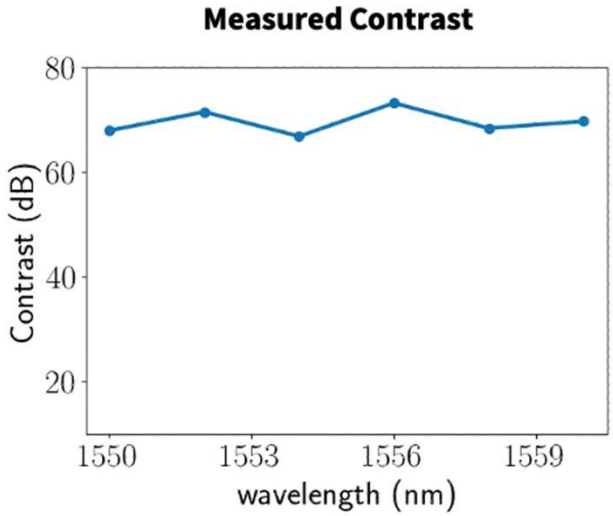
Laboratory Testing – 70 dB contrast over 10 nm bandwidth



Photonic coronagraph test-stand
at Stanford laboratory

Demonstration of single-channel suppression using 2 channel 4-MZI mesh:



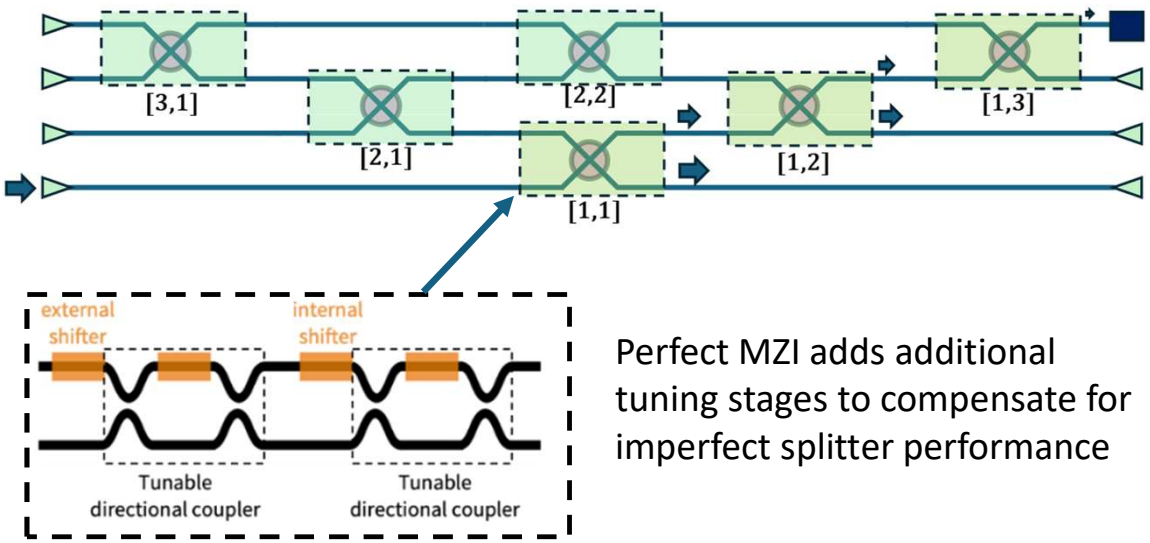


Sun and Valdez / Stanford (Fall 2023)

1e-7 contrast (70 dB) over 10 nm bandpass demonstrated

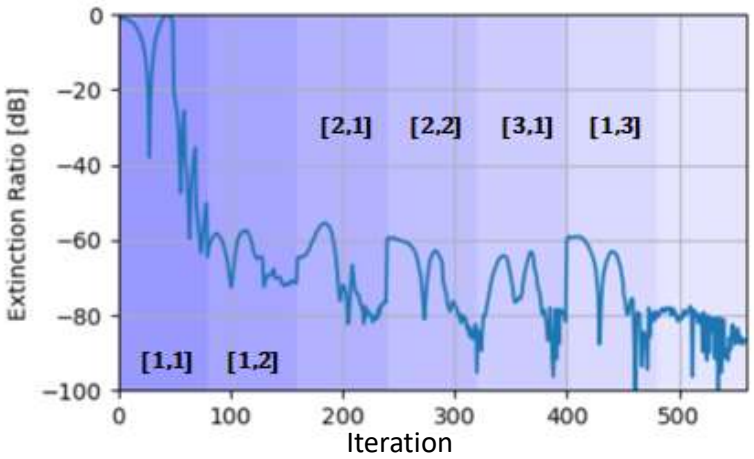
Laboratory Testing – 81 dB contrast demonstration

Demonstration of deep photonic nulling of a single channel using 4-channel full triangular perfect MZI mesh:



Perfect MZI adds additional tuning stages to compensate for imperfect splitter performance

Measured Contrast



(1) Measured **7.9e-9 contrast** (**81 dB suppression)** at thermal equilibrium
(2) Improvement from off-diagonal phase shifters indicates light leakage/cross talk

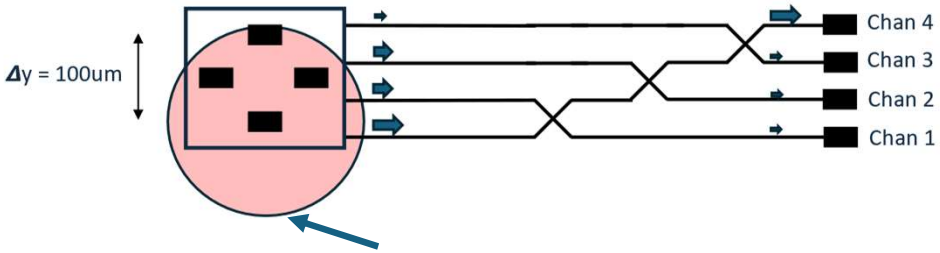
➔ Additional diagonal lines will likely improve contrast

➔ ~10% measured throughput

Valdez et al (in prep) / Stanford (Spring 2024)

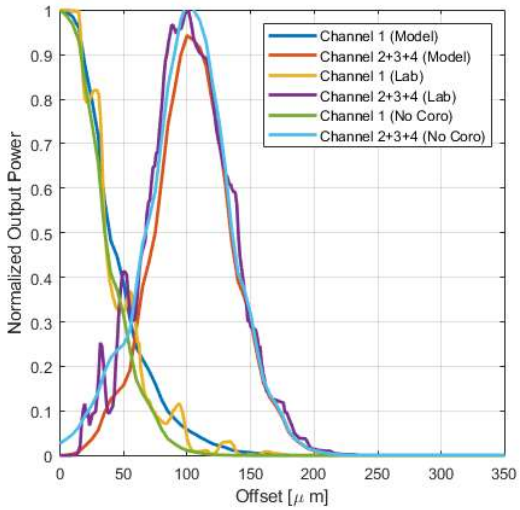
Laboratory testing – Free space coupling + model comparison

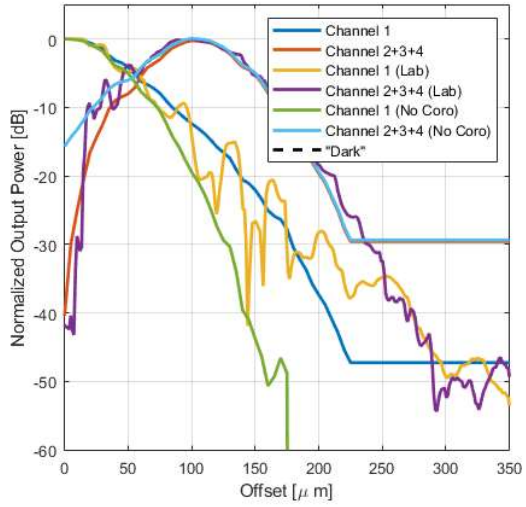
Demonstration of contrast between spatially separated sources using 4-channel diagonal mesh:



Free-space input beam is moved to mimic spatial separation between star/planet

Measured Contrast





Comparison of experimental data with photonic coronagraph mesh model shows good agreement

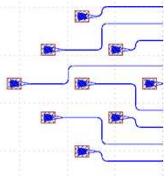
Stanford experiment: Carson Valdez
Ames model: Kevin Fogarty

2024 AstroPIC Tapeout

Additional component exploration devices:

- Measure bandwidth/splitting of directional couplers and assess impact of polarization

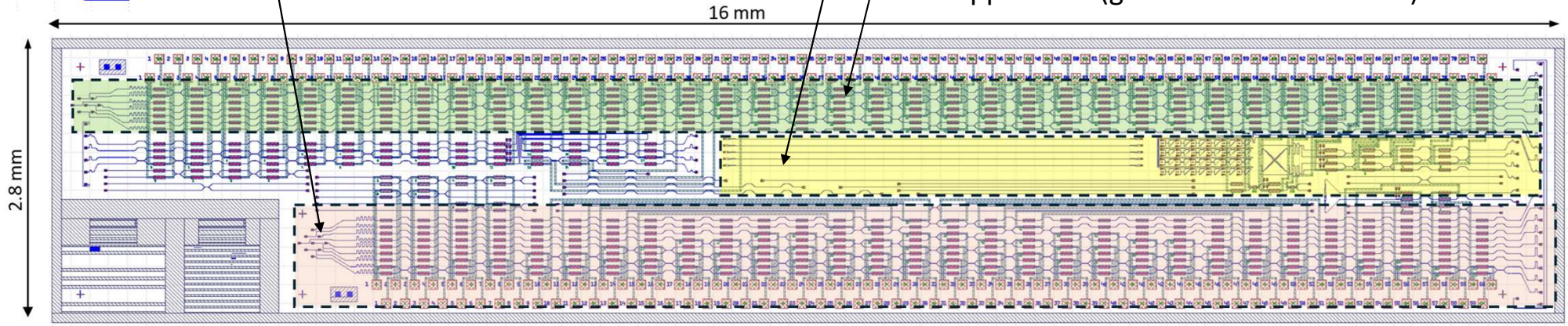
9 Input x 9 diagonal Full Triangular Mesh:

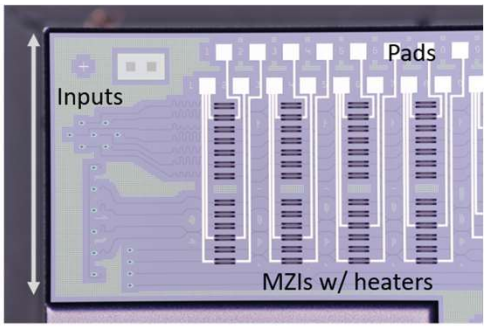


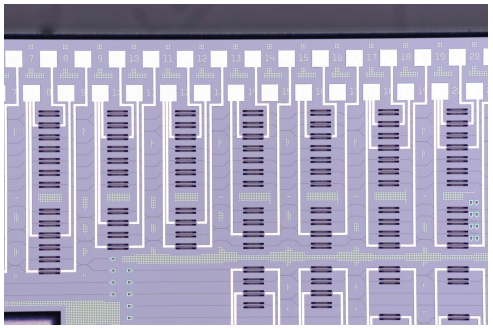
- 9 Input channels (grating couplers)
- Lenslet array will increase coupling efficiency

7 input x 4 diagonal PMZI device:

- "Perfect" MZIs compensate for fabrication/design uncertainty to enable deeper suppression (goal: 1e-9 contrast level)



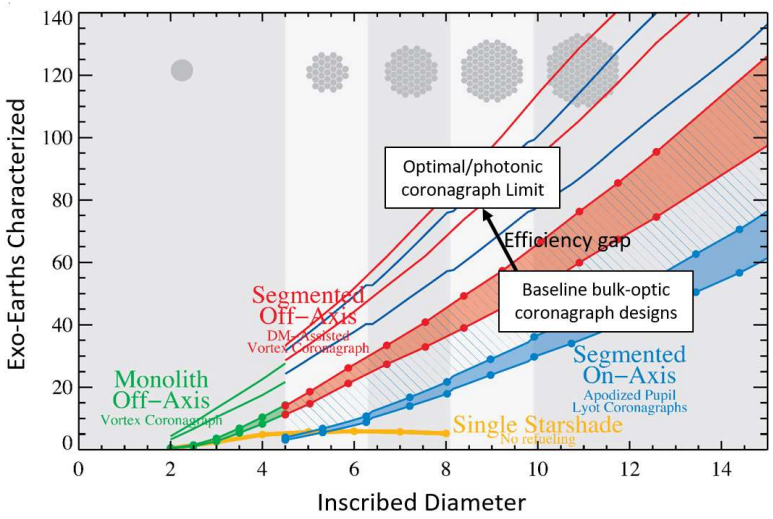




Tape-out: June 2024
Delivered: Fall 2024
Foundry: AMF
Silicon-on-SiO2 passive run

Conclusions

- PIC technology is a promising approach to achieve an optimal coronagraph instrument for HWO
- Early experiments with few channels have already demonstrated promising 81 dB contrast level
- Next steps:
  - Testing with recently fabricated chip at Stanford/Ames
  - Simulations to evaluate architecture options
  - Long term: scale to many channels, improve throughput



Based on Stark 2021

Stay tuned! Next talk: Dan Sirbu "Science yield estimates and sensitivities with the AstroPIC Integrated Photonic Coronagraph for the Habitable Worlds Observatory"

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