Mode-sorting Coronagraphy

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1. Scientific context

Characterizing exo-Earths with HWO or the ELTs will require high performance coronagraphs at 1 λ/D separations.

Conventional coronagraphs struggle in the close-separation regime, especially if the telescope aperture is complicated (e.g. segmented and/or obstructed).

Coronagraphs based on spatial mode-sorting can reach the quantum optimal limit, i.e. achieve the highest S/N measurement of the planet possible given fundamental physics [1].

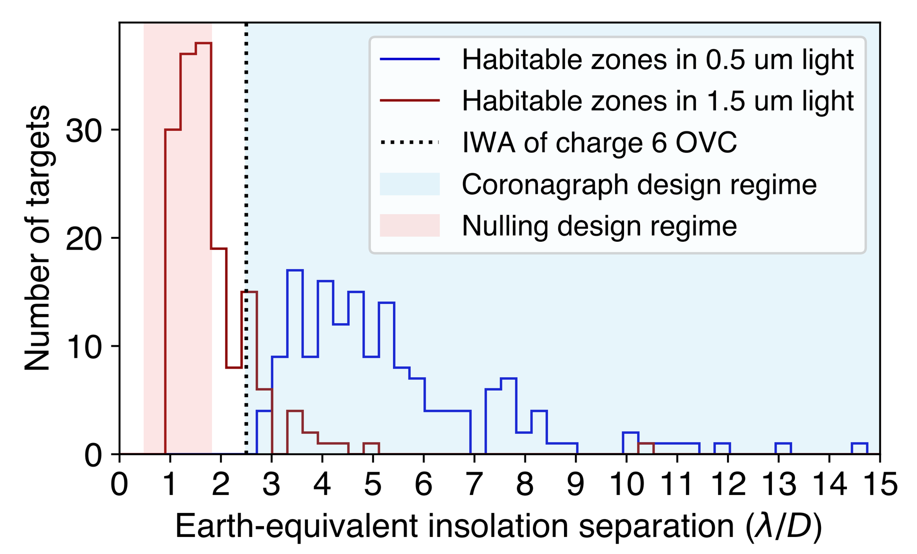

Figure 1: For HWO, target planets detectable by a conventional coronagraph at visible wavelengths will be $\sim 1\lambda/D$ at near-infrared wavelengths.

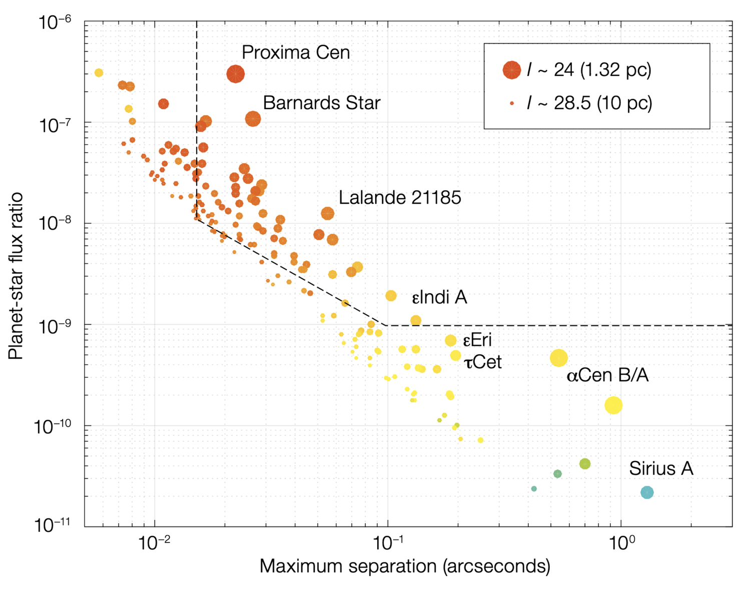

Figure 2: On the ELT, accessing rocky exoplanets with the Planetary Camera and Spectrograph instrument will require 10^{-8} contrast at 1 λ/D. Figure from [2].

2. What is mode-sorting?

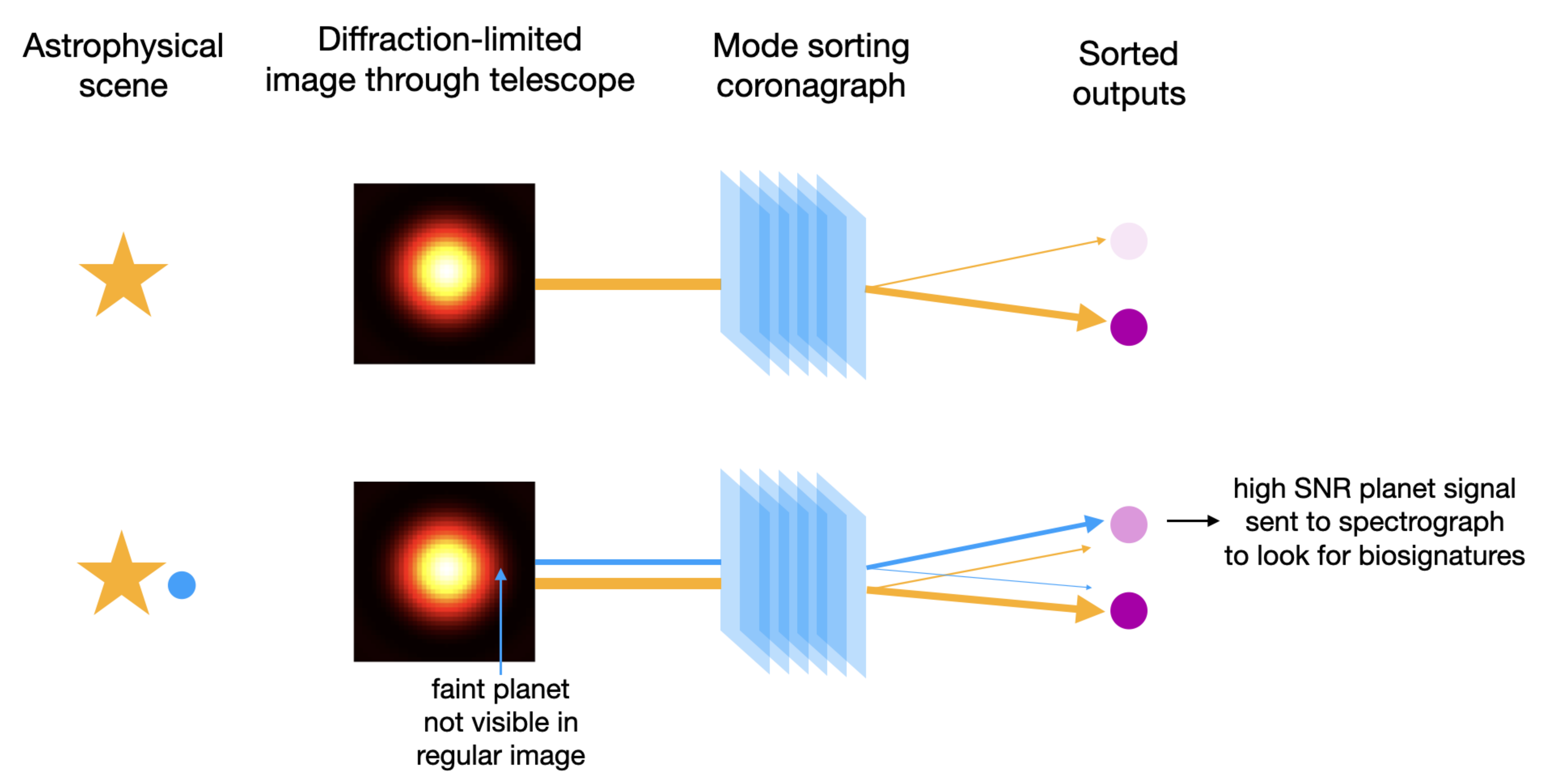

Figure 3: Diagram of a mode-sorter that sends most of the starlight to the bottom channel, and most of the planet light to the top channel. The quantum optimal coronagraph achieves the best separation of the light of the star from that of the planet, to the limit set by fundamental physics. This is a schematic; realistic optimal coronagraphs will have more than 2 channels.

3. Example with a complex pupil

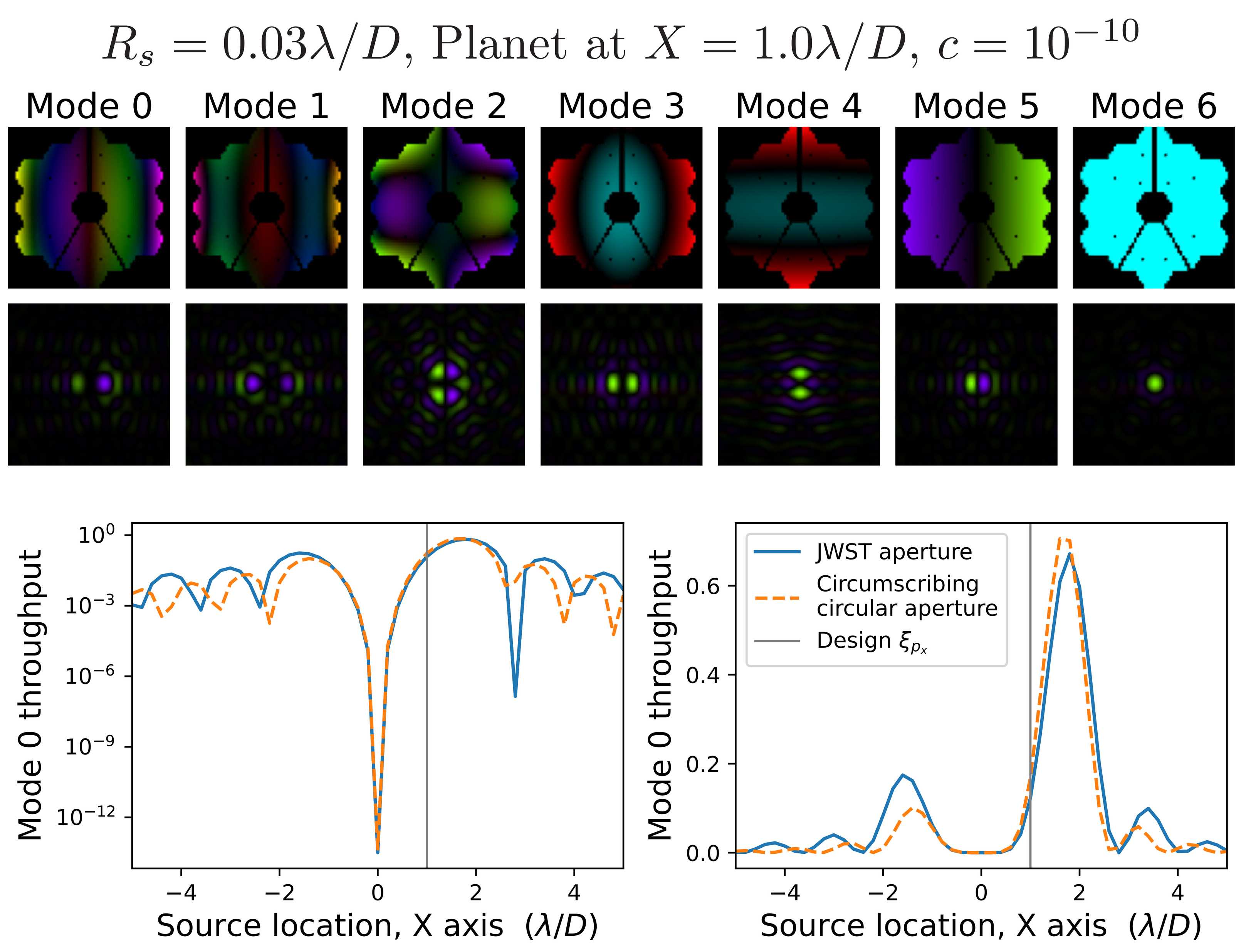

Figure 4: Top) The modes of a quantum optimal coronagraph in the pupil plane (top row) and in the focal plane from -10 to 10 λ/D (bottom row). Bottom) Throughput in Mode 0 as a function of source location along the X axis. The equivalent mode with a circular pupil is also plotted, showing that aperture shape does not significantly impact results.

4. Theoretical limits

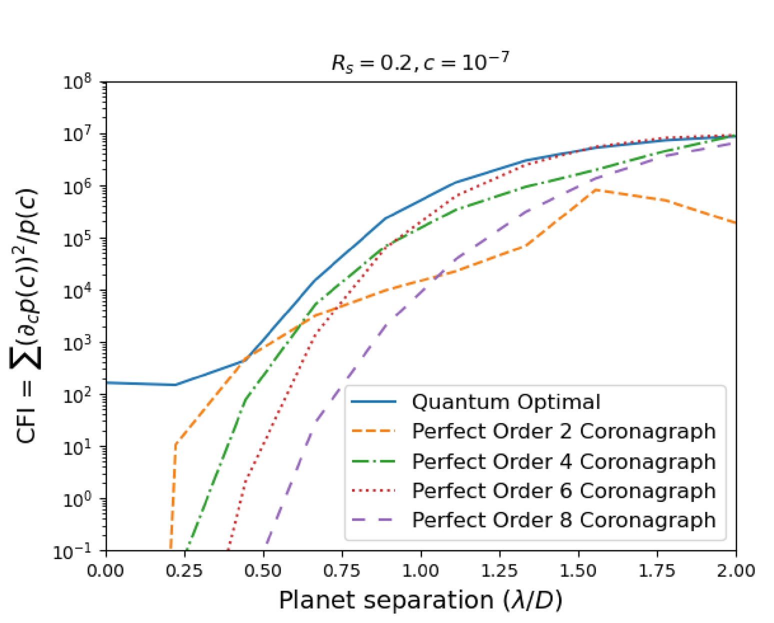

Figure 5: The Fisher information (a measure of sensitivity related to S/N) for the planet flux ratio with various coronagraphs. The quantum optimal coronagraph achieves the Quantum Fisher Information, the supremum of Fisher information.

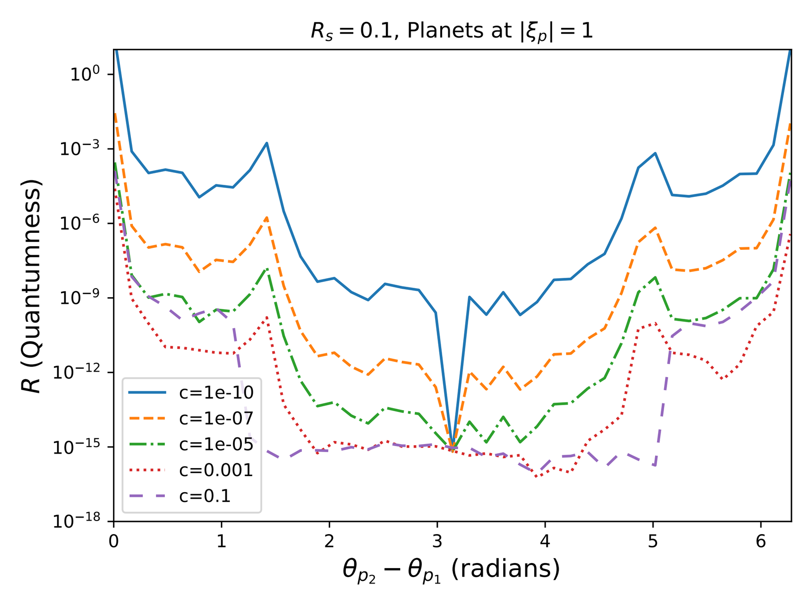

Figure 6: The quantumness parameter encodes measurement incompatibility between different planet signals. Optimal measurements of multiple planets are not simultaneously realizable. Tradeoffs in S/N exist for coronagraphs with finite fields of view.

5. Future Work

1. Manufacturing a prototype using multi-plane light converters
2. Investigating wavefront sensing approaches
3. Investigating wavefront calibration approaches
4. Yield-motivated coronagraph design

Acknowledgments

The authors acknowledge support from NWO Award 184.036.004.

References

1. N. Deshler+, 2024. arXiv:2403.17988
2. M. Kapser+, 2021. arXiv:2103.11196