

Suppressing and sensing with the same mask

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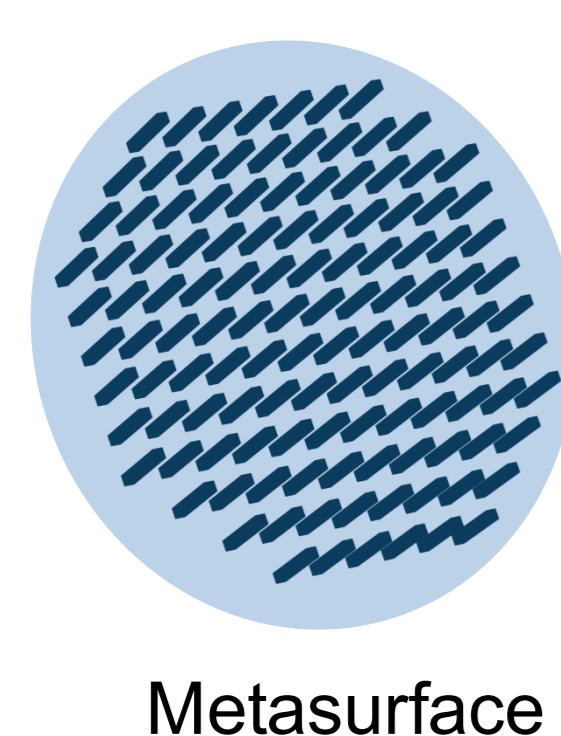
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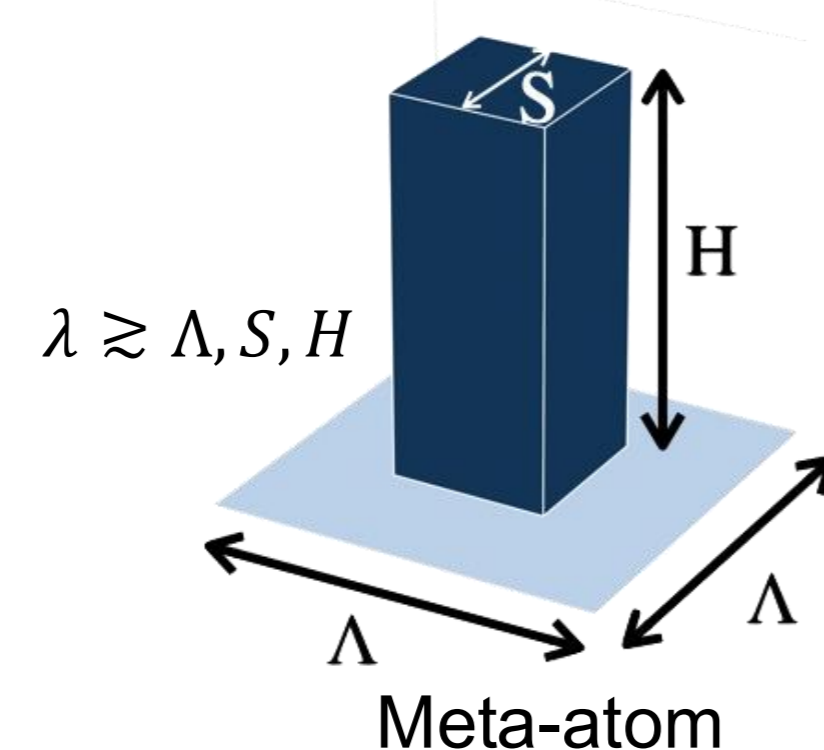
Abstract

Controlling leftover wavefront errors after an extreme adaptive optics system is a main challenge for high-contrast imaging. These errors, called non-common path aberrations (NCPAs), create slow speckles because the wavefront-sensing light and the science light follow different paths. A second-stage adaptive optics system is generally used to correct these quasi-static speckles. To further reduce NCPAs, the second-stage wavefront sensor (WFS) and the focal plane mask (FPM) of a complex mask coronagraph (CMC) system can be combined into a single focal-plane optic. The chromatic behaviour of a metasurface can be used to implement this, where it works as a ZWFS ($\pi/2$ phase shift) in one band and a CMC (π phase shift) in another band. A metasurface is designed that works as a ZWFS in the J band and a CMC in the H band.

Metasurface



Metasurface



Meta-atom

Figure 1: Schematic of a metasurface with subwavelength structures called meta-atoms. The height (H), size (S), and period (P) are optimized to achieve the required optical response.

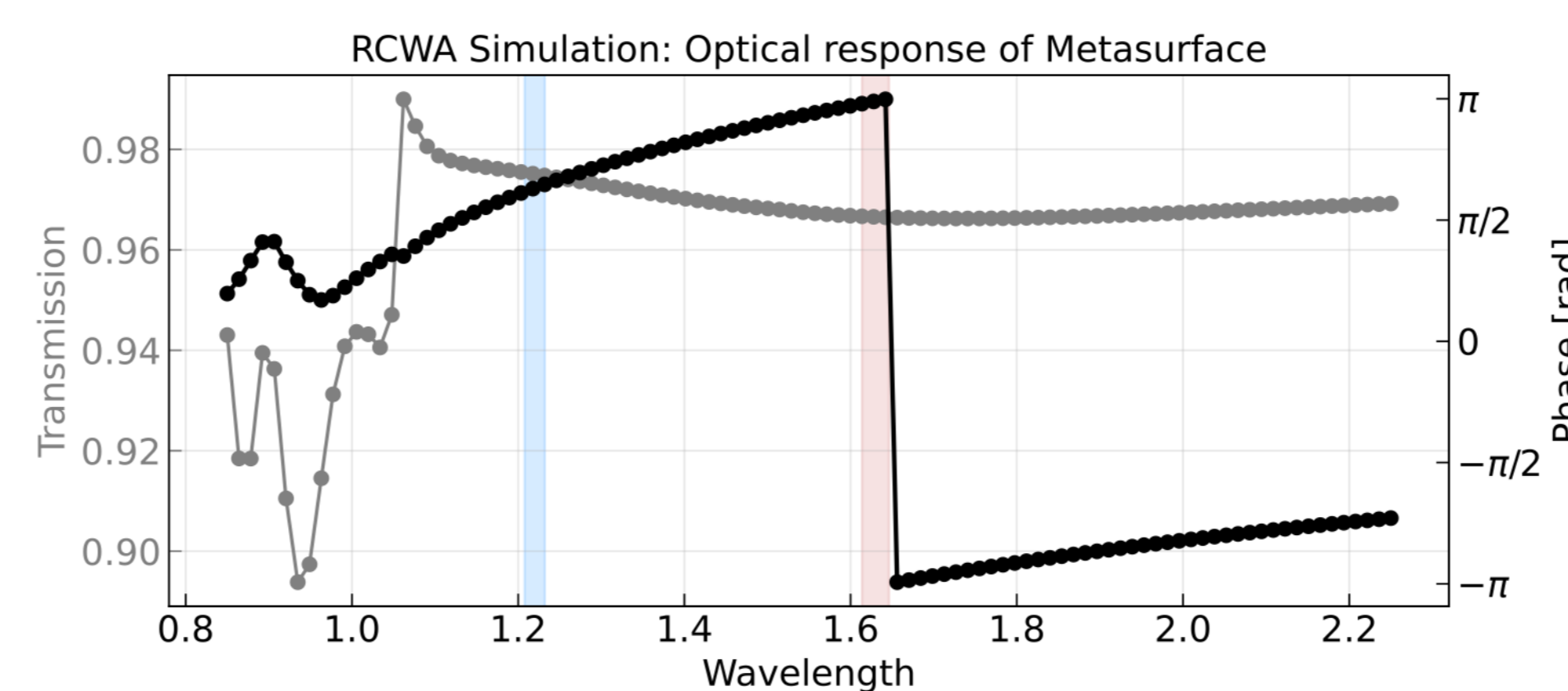


Figure 2: Broadband optical response of the meta-atom using FFM. Wavelength ranges close to the required phase and transitions are chosen for the CMC and WFS, shown in red and blue shaded regions.

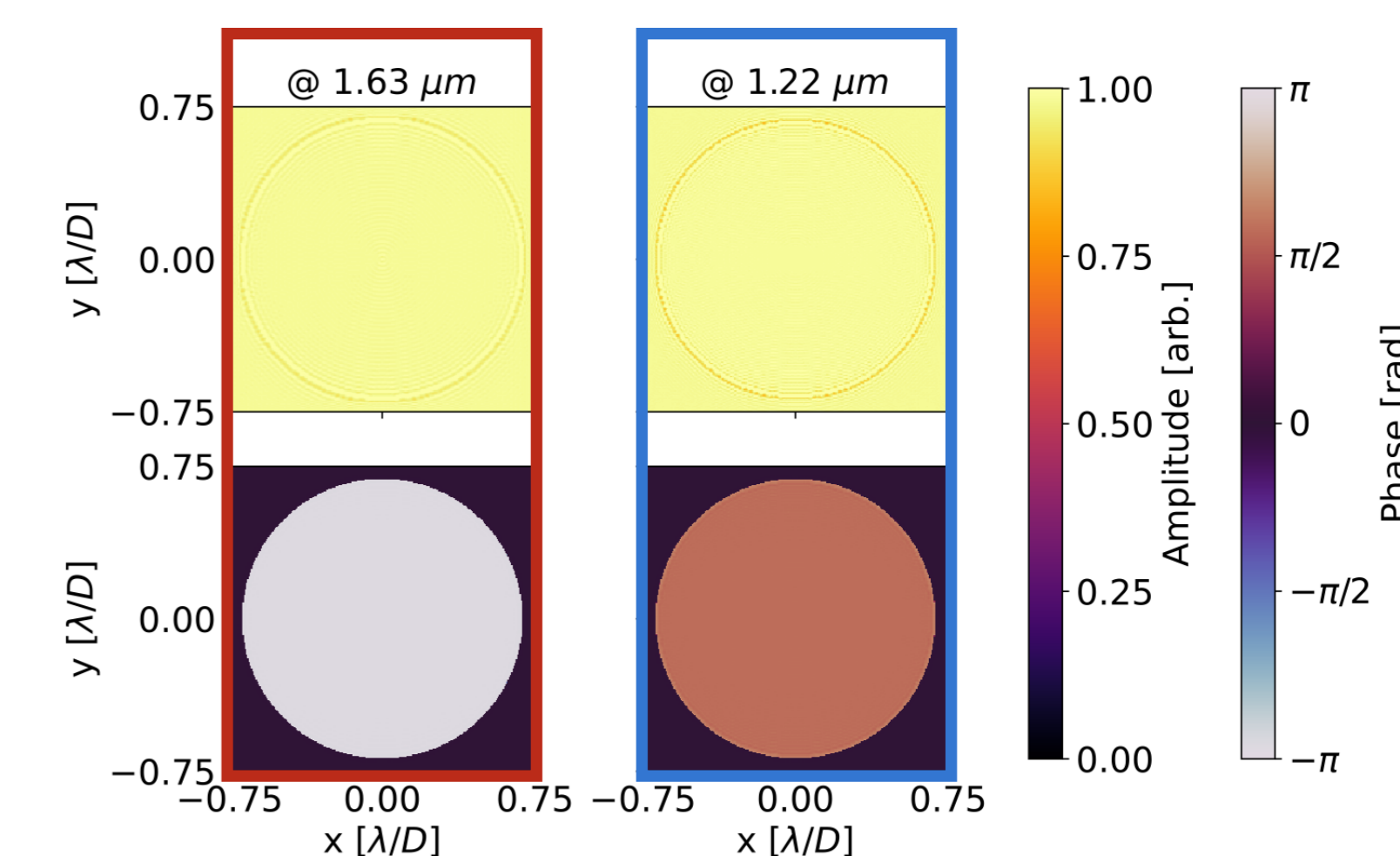


Figure 3: Full-wave simulation of the designed mask using FDTD. Amplitude and phase from the metasurface at the central wavelength of each band.

Architecture

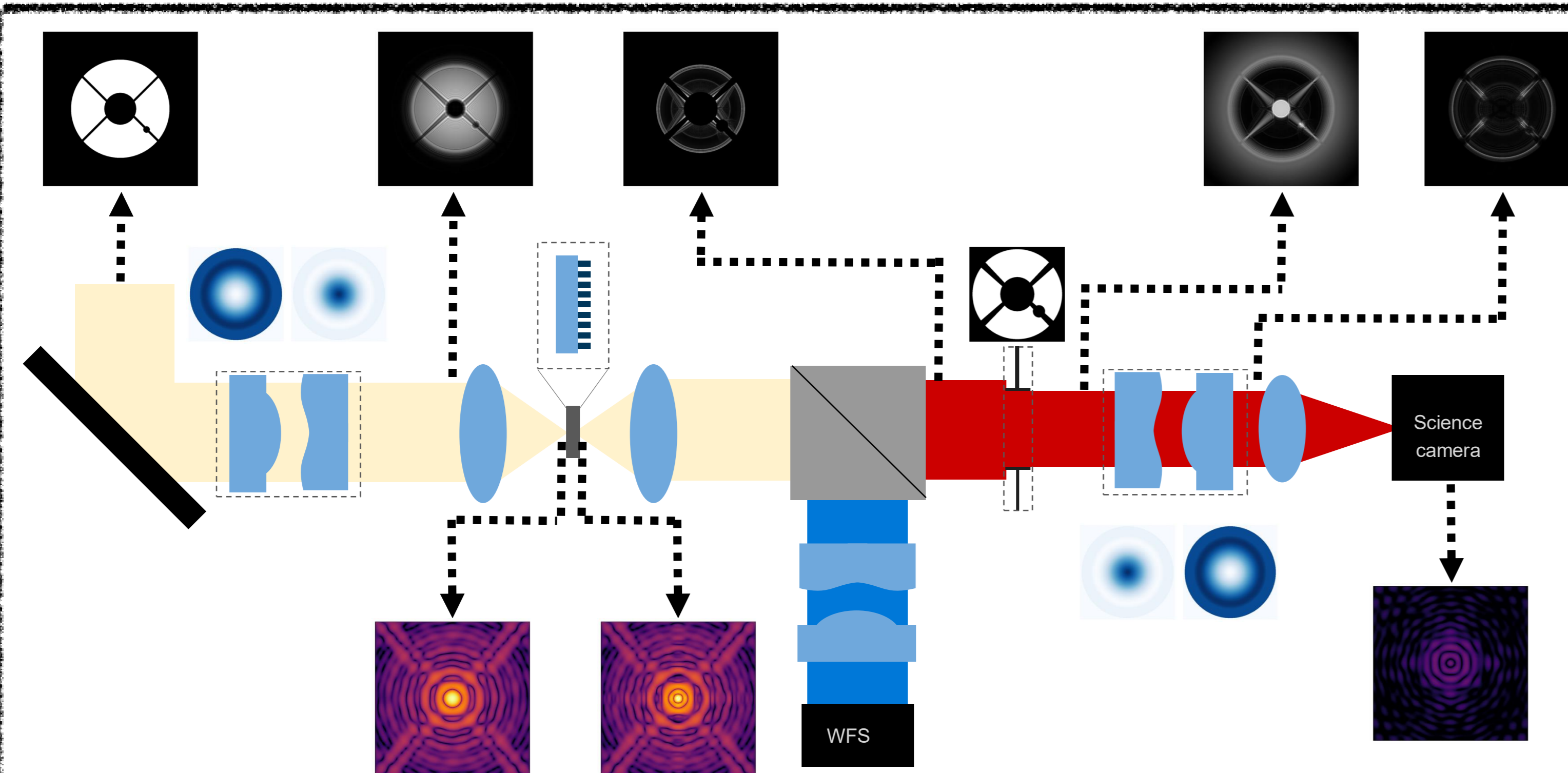


Figure 4: Schematic of the optical system simulated end-to-end to characterize the designed mask. Light from the MagAO-X pupil is apodized using a set of PIAA lenses and then focused onto the FPM, where it receives a wavelength-dependent phase shift. The light is then split into the wavefront sensing channel and the science channel. The science channel includes a pupil-plane mask to filter out the diffracted on-axis light. Each channel has a separate pair of inverse PIAA lenses to restore the reshaped pupil before being imaged onto the detectors.

Characterisation

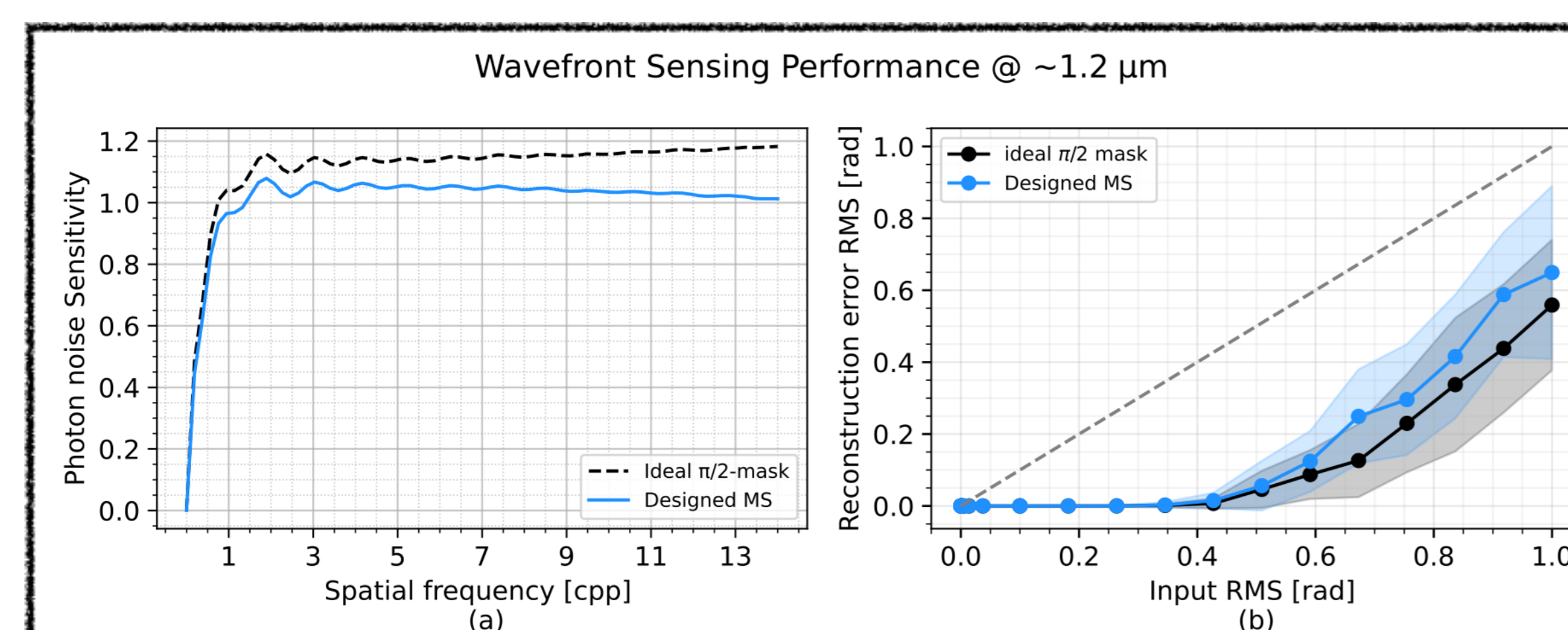


Figure 4: Wavefront-sensing performance. Sensitivity as a function of spatial frequency in (a). Dynamic range in (b), with reconstruction error RMS as a function of input RMS. The performance is compared to an ideal $\pi/2$ mask.

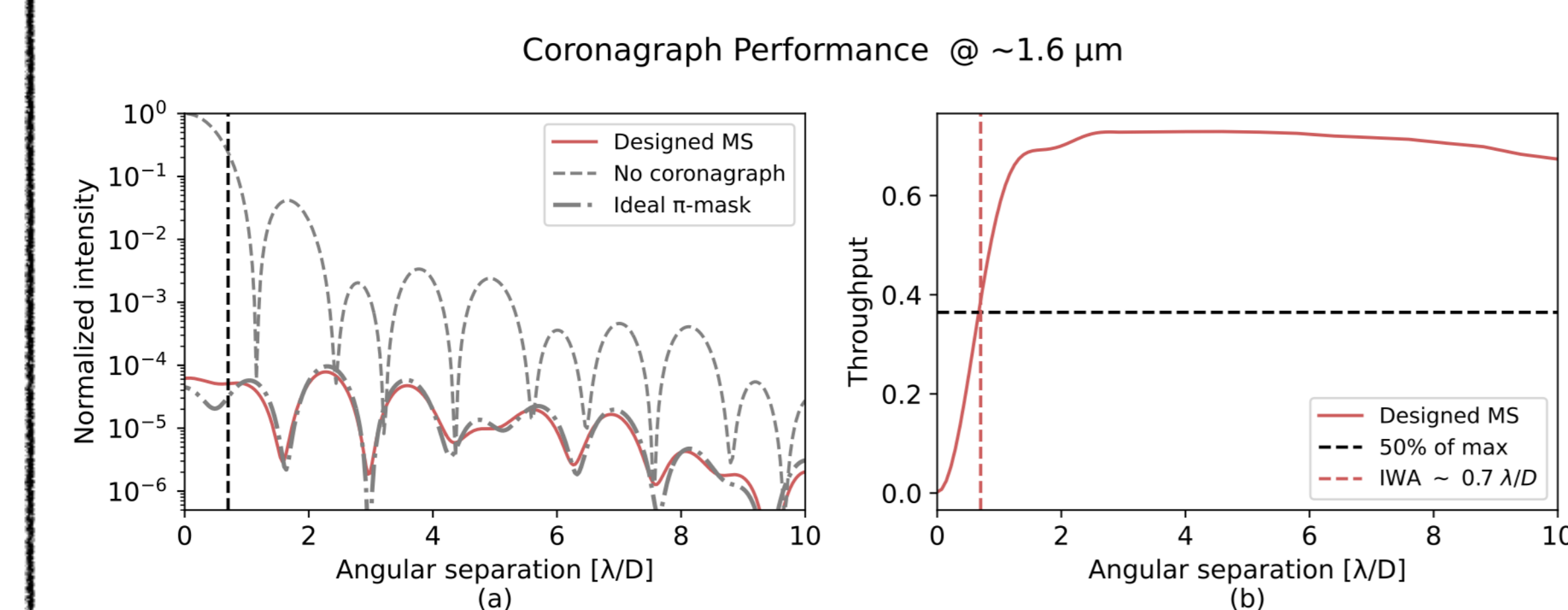


Figure 5: Coronagraphic performance. Contrast curves as a radial profile through the centre of the coronagraphic PSF in (a). Throughput as a function of the angular separation of the object. The performance is compared to an ideal π mask.

Closed-loop performance

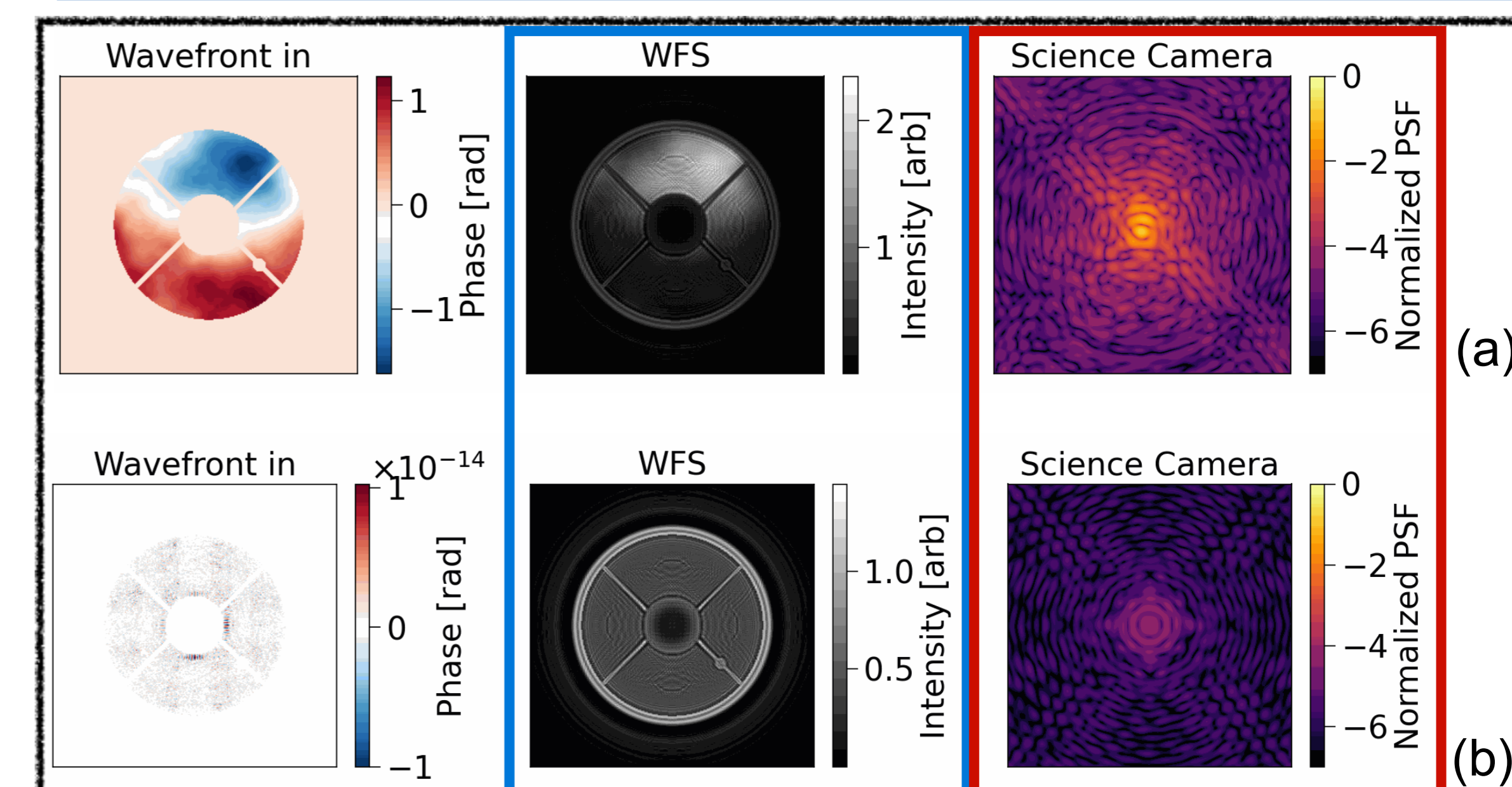


Figure 7: Phase in the pupil-plane, WFS and coronagraphic PSF before and after closing the loop in (a) and (b) respectively

In short

Non-common path aberrations can be mitigated by using a single focal-plane optic based on a metasurface. The metasurface provides a chromatic response, allowing it to operate as a ZWFS in one wavelength range and a CMC in another. A proof of concept is shown by characterizing a designed metasurface using end-to-end simulations with the MagAO-X system.