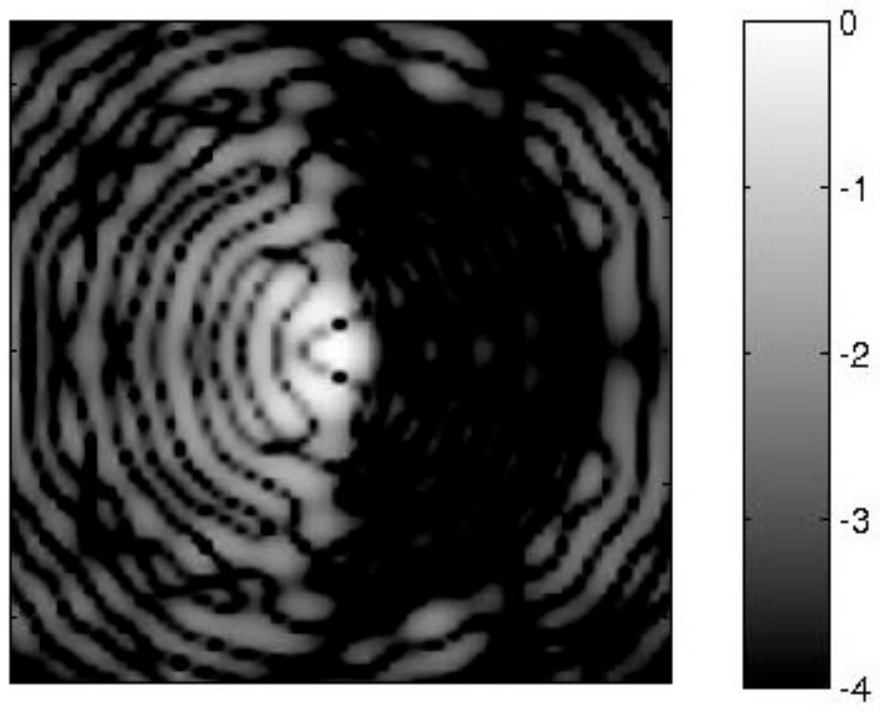

A Phase Apodization Coronagraph for the JWST

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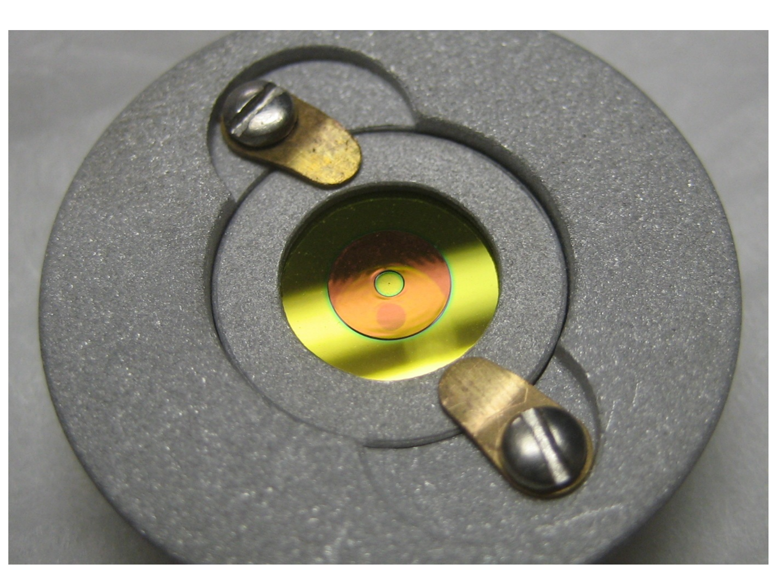
Introduction

We propose a simple coronagraphic optic for the JWST that will allow high contrast observations in the region of 2-10 λ/D around a target star. It requires no field stop, and can be implemented as an optic in the pupil filter wheel. There is also no special telescope pointing alignment above that needed for direct imaging. The technique has been demonstrated on-sky with a 5 micron imaging camera on a 6.5m ground based telescope at the University of Arizona.

Phase Apodization Coronagraphy (PAC)

- >50% throughput and 2λ/D inner working angle
- Preserves spatial resolution of telescope
- Works for any arbitrary pupil shape
- Tolerant to chromatic variations
- No focal plane masks!



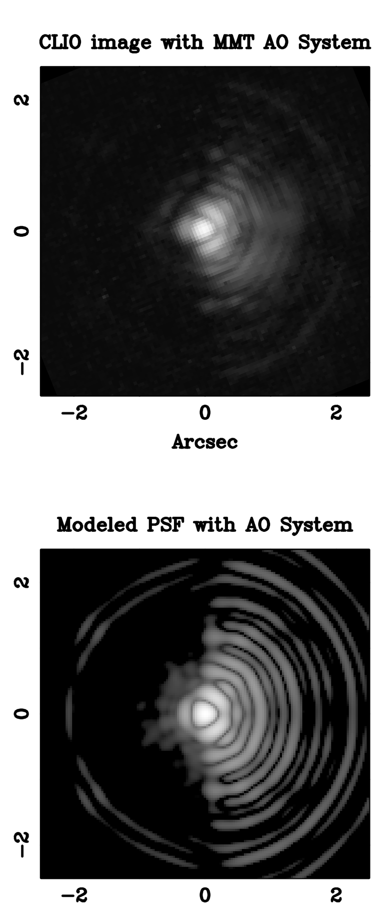


Fig. 1 APP manufactured for the MMT. The plate provides 2 to 9 λ/D suppression for the Clio imaging camera at 5 microns.

Phase Apodization Coronagraphy is a developed theory of using phase modulations in a pupil plane to suppress diffraction in a subsequent image plane. Symmetry considerations limit PAC to nulling a D shaped region of scientific interest around a bright star, in a manner similar to classical coronagraphs.

The physical optic that realises the ideal PAC phase pattern is called an Apodizing Phase Plate (APP).

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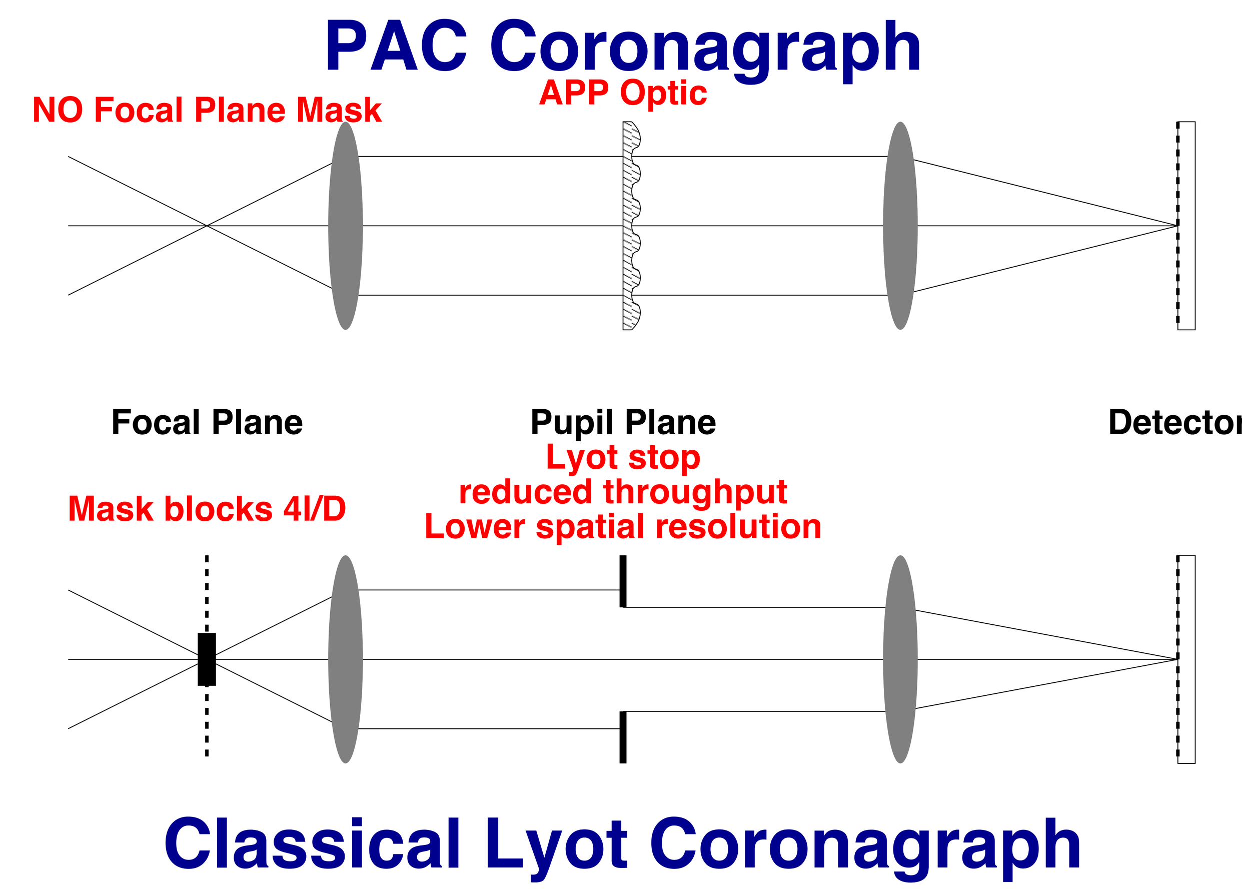

On-sky Demonstration

An earlier version of the PAC theory has been successfully demonstrated with the Clio camera (Hinz et al. 2006) at the MMT in M-band (Kenworthy et al, 2007, Codona et al, 2006). The PAC phase profile was implemented using a diamond-turned ZnSe Apodizing Phase Plate (see Figure 1). With this APP we did not use the PAC theory to take into account the secondary support structure of the telescope, and was designed with an outer circular pupil mask and an inner circular secondary mask. The resulting sensitivity was estimated to be in excess of 11 magnitudes contrast for a 5σ detection at 3λ/D in an hour. Because the PAC is limited to a 50% field around the star, it might be expected to have efficiency handicap relative to a Lyot coronagraph, but this is not so. First, the current coronagraph design blocks details within 4λ/D, rendering it insensitive to the closest regions of a star.

APP Options for JWST

As a baseline for a JWST APP, we used the same concept to see how well it would work. Since the spiders and gaps are to be ignored, the placement of the dark D is best when placed centered on the 120° gap. To free ourselves from the rotational asymmetry of the pupil, we would use an integrated circular pupil mask inscribed within the outer edge of the pupil, and a circular secondary mask fully obscuring the actual hexagonal one. There would be some under and over sizing of the pupil mask to allow for some pupil misalignment, with an inner to outer ratio of 30%.

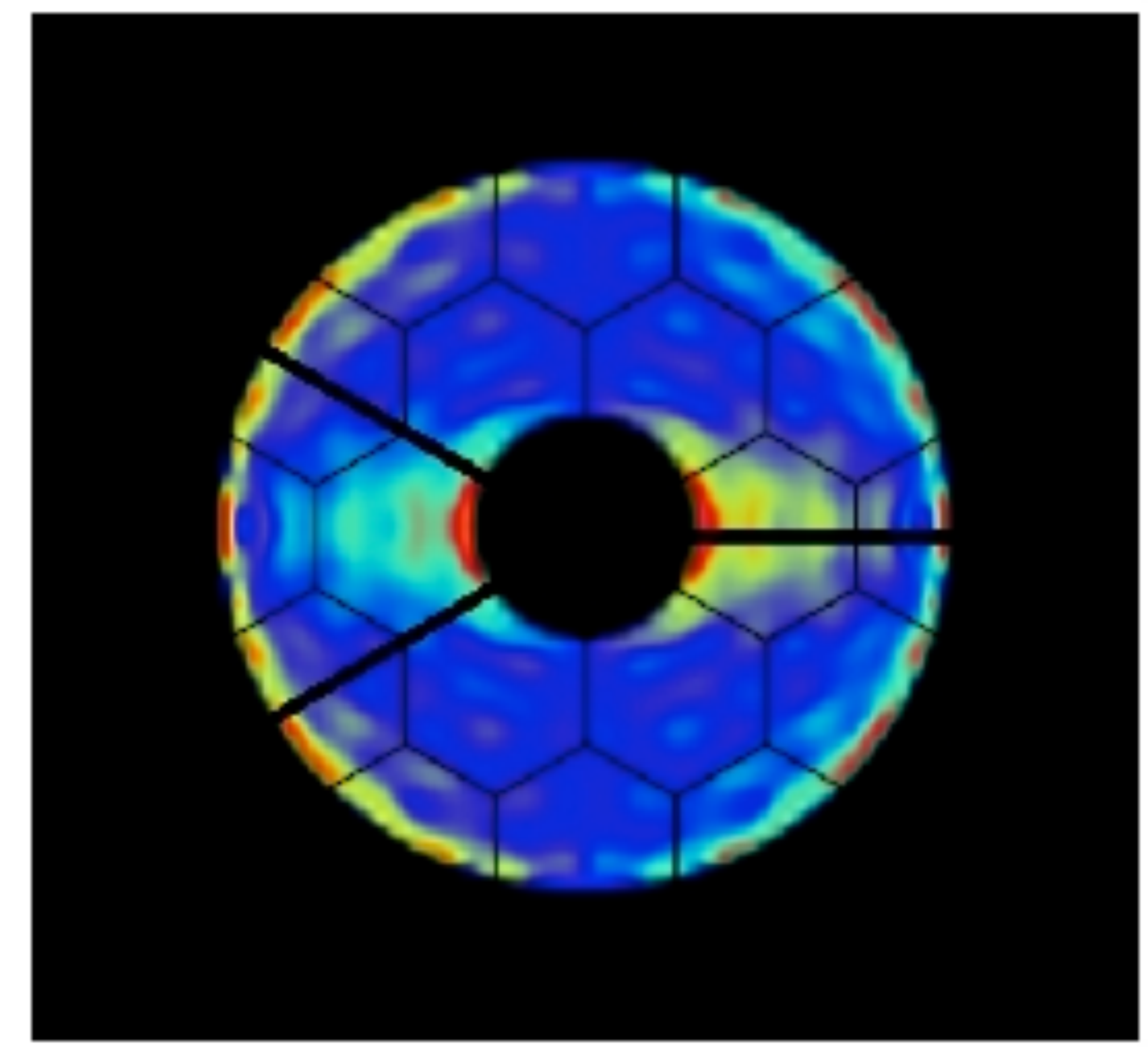

Fig. 2 Proposed APP for the JWST, with current pupil superimposed along with inner and outer mask edges.

Simulations of the APP in the JWST pupil show that moving the APP relative to the pupil moves speckles around in the focal plane, but at levels comparable with the best expected phasing error speckles.

Depending on the specific choices in the design, we find an APP design 50% of the light in the core with contrasts of 10^{-4}-10^{-5} as close as 2\lambda/D from the star. The remaining halo will be dominated by segment phasing, but there is even the possibility that the segments could be adjusted even more finely, given the better view of the halo speckles with suppressed diffraction. The best sensitivity will be achieved when the PAC halo suppression is adjusted to be slightly fainter than the unknown or uncontrollable halo. At 5 microns with a segment phasing WFE of 111 nm rms, we might expect speckles at 10^{-3} of the star, while segment manufacturing errors of 31 nm rms mean that it is unlikely that the speckles can be adjusted to below 10^{-4}. If the performance is tuned to its very best, very close-in observations will be dominated by the pupil diffraction pattern, ~10^{-2} of the star.