# Analysis of nulling phase functions suitable to image plane coronagraphy

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**Goal**: Identify new types of phase functions suitable to a phase-mask coronagraph (phase mask in the image plane). Find alternative to the well-known Optical Vortex

**Method**: Start from a set of continuous analytical functions having the property to cancel the Strehl ratio of an uniformly illuminated optical system (Ref. [1]). Establish necessary conditions for those functions to fit the coronagraph requirements. Investigate the properties of azimuthally-invariant and centro-symmetric phase functions, including azimuthal cosine-modulated phase functions and circular phase gratings

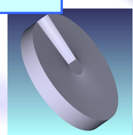
Results: Azimuthal cosine-modulated phase functions are good alternative to the Optical Vortex, because they have comparable performance and can be manufactured as phase plates without surface discontinuities

**[1] F. Hénault, "Strehl ratio: a tool for optimizing optical nulls and singularities," JOSA A vol. 32, p. 1276-1287 (2015)**

### Necessary condition for azimuthal phase functions $\varphi'_a(\theta') = 2\pi \dot{\delta}'_a(\theta')/\lambda$

$$A''_a(0,0) = \int_0^{2\pi} \exp\left[2i\pi \dot{\delta}'_a(\theta')/\lambda\right] d\theta' = 0$$

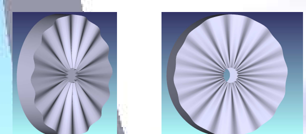
**Optical Vortex:** $\dot{\delta}'_a(\theta') = \frac{\lambda}{2\pi} k\theta'$



**Cosine-modulated phase function:**

$$\dot{\delta}'_a(\theta') = \frac{\lambda}{2\pi} z_n \cos(k\theta')$$

with $z_n$ the n[th] zero of type-J Bessel function $J_0$



### Necessary condition for azimuthal phase functions $\varphi_r(\rho) = 2\pi \delta_r(\rho)/\lambda$

$$A''_r(0,0) = \int_0^{+\infty} \hat{B}_D(\rho')B'_f(\rho')\exp\left[2i\pi \dot{\delta}'_r(\rho')/\lambda\right]\rho' d\rho' = 0$$

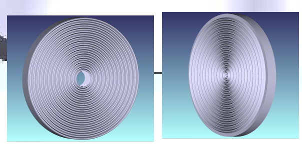
**and**

$$A''_r(0,0) = \int_0^{+\infty} \hat{B}_D(\rho')\hat{B}''_L(\rho')B'_f(\rho')\exp\left[2i\pi \dot{\delta}'_r(\rho')/\lambda\right]\rho' d\rho' = 0$$

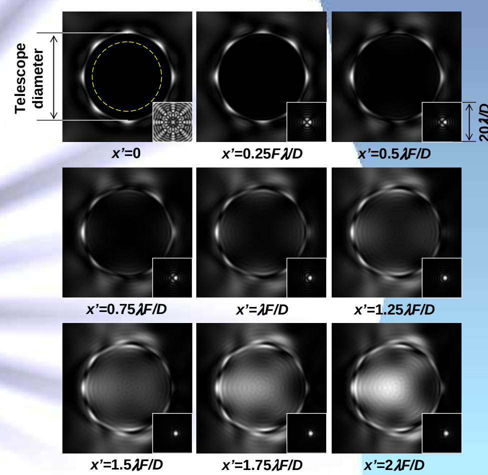
**with** $\hat{B}_D(\rho') = \frac{2J_1(\pi D\rho'/\lambda F)}{\pi D\rho'/\lambda F}$

**Circular phase gratings:** $\delta_r(\rho) = \frac{\lambda}{2\pi} a\cos(2\pi f\rho + \varphi)$

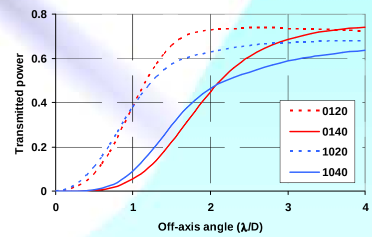
are not simple analytic solutions. They must be optimized numerically

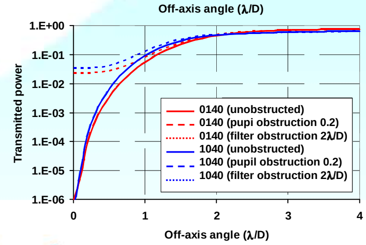


### Irradiances at Lyot stop and coronagraphic planes vs. pointing errors




### Comparison with Optical Vortex (without/with obscurations)

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