DOING PHYSICS WITH PYTHON

COMPUTATIONAL OPTICS

RS1 DIFFRACTION INTEGRAL

CIRCULAR APERTURE

FOCUSED BEAM

SEIDEL ABERRATIONS

COMA

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Please email me any corrections, comments, suggestions or additions: **matlabvisualphysics@gmail.com**

DOWNLOAD DIRECTORIES FOR PYTHON CODE

[Google drive]

[GitHub]

emRSFBXY.py

Calculation of the radiant flux density (irradiance) in a plane perpendicular to the optical axis for the radiant flux of convergent beam emitted from a circular aperture.

emFBZX.py

Calculation of the irradiance in the meridional (ZX plane) for the radiant flux of convergent beam emitted from a circular aperture.

emRSFBZ.py

Calculation of the radiant flux density (irradiance) along the optical axis for the radiant flux of convergent beams emitted from a circular aperture.

Warning: The results of the integration may look OK but they may not be accurate if you have used insufficient number of partitions for the aperture space and observation space. It is best to check the convergence of the results as the number partitions is increased. Note: as the number of partitions increases, the calculation time **rapidly** increases.

It is necessary to modify the Python Codes and comment or uncomment lines of code to run the simulations with different input and output parameters, and for different aperture functions. Input: **A = 5** for comatic aberration

Link: essential reference

RS1 diffraction integral: Focused beam from a circular aperture

SEIDEL ABERRATIONS

Seidel aberrations are monochromatic optical aberrations that arise in centred optical systems. These aberrations, named after Philipp Ludwig von Seidel, describe deviations from ideal imaging conditions, affecting image quality and precision. The Siedel aberrations characterize the departure from the Gaussian reference sphere along the direction of the ray.

The aberrations can be defined in terms of a zonal radius ρ (distance from the optical axis to an aperture point Q) and the azimuthal angle ϕ. Thus, the aberrations can be described by an aberration function Φ that produces a change in phase of $\exp(ik\Phi)$ throughout the aperture space

The five main Seidel aberrations are: spherical aberration, coma, astigmatism, field curvature, and distortion.

1. **Spherical Aberration**: occurs when rays entering the lens at different distances from the centre focus at different points, resulting in a blurred image.

   $$\Phi \propto \rho^4$$

2. **Coma**: caused by rays entering the lens at an angle, not converging to a single point but forming a comet-like tail.

   $$\Phi \propto \rho^3 \cos\phi$$

3. **Astigmatism**: rays entering the lens at different angles (meridians) focus at different points, causing a point object to appear as a line or ellipse.

   $$\Phi \propto \rho^2 \cos^2 \phi$$

4. **Field Curvature**: image plane is not flat, requiring a curved surface to focus all parts of the image simultaneously.

   $$\Phi \propto \rho^2$$

5. **Distortion**: change in the magnification of the image across the field of view, causing straight lines to appear curved.

   $$\Phi \propto \rho \cos \phi$$

COMA

Comatic aberration or coma in an optical system refers to aberration inherent to certain optical designs or due to imperfection in the lens or other components that results in off-axis point sources where the image is distorted, producing a series of asymmetrical spot shapes of increasing size that result in a comet-like, hence, the term coma shape to the Airy pattern. Coma is often considered the most problematic aberration due to the asymmetry it produces in images.

Coma is a primary aberration where meridional rays traversing the extremities of a lens cross the image plane either nearer or further away from the optical axis than the principal ray. The aberration function for coma is both a function of ρ and ϕ where $\Phi \propto \rho^3 \cos\phi$. The following figures show plots of the irradiance in the presence of coma. The irradiance distribution is no longer the familiar Airy disk but a highly distorted one.

For comatic aberration, the **aberration function** is

$$\Phi = 6\pi \rho^3 \cos\phi$$

where ρ is the radial distance from the centre of the aperture and ϕ is the aperture angle measured with respect to the X axis.

RQ = (XQ**2 + YQ**2)**0.5 $\rightarrow \rho$

cosT = YQ/(RQ) $\rightarrow \cos\phi$

phi = 6*pi*RQ**3*cosT

T = exp(ik*phi)

EQ = T*EQ

Simulation: Aperture space   emRSFBZcoma.py

Console summary of simulation parameters (inputs & results)

NQ = 299   NP = 299   nQ = 599   nP = 599
wavelength wL = 500 nm
aperture outside radius a = 20.000 mm
aperture inside radius   aI = 19.000 mm
Source
  xS = 0.000 m yS = 0.000 m zS = 1.000 m
  Focal length f = 1.000 m
Numerical aperture NA = 0.0200

Fresnel number NF = 800.000
axial limits: u1 = -60.10 u2 = 60.20
Imax = 7.82e+22 a.u.
Max irradiance at uP = -37.3677
Uncertainty in uP, du = 0.10
Execution time 31 s

Figure 1 shows the aperture irradiance in the X and Y axes directions and figure 2 shows the phase of the aperture electric field (rad / π).

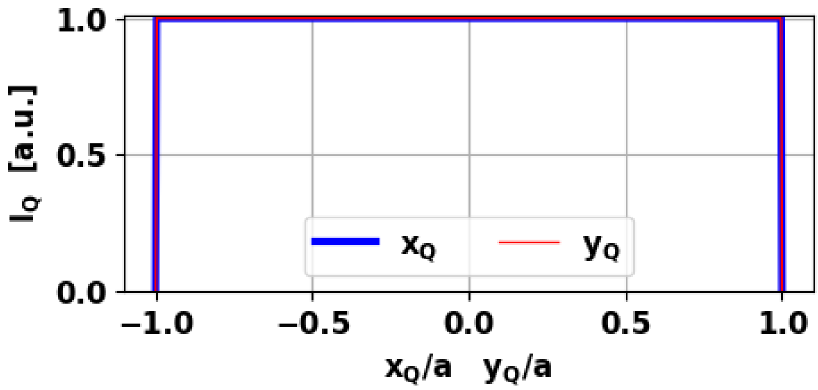


Fig. 1. Aperture space: Irradiance pattern along the X and Y axes.

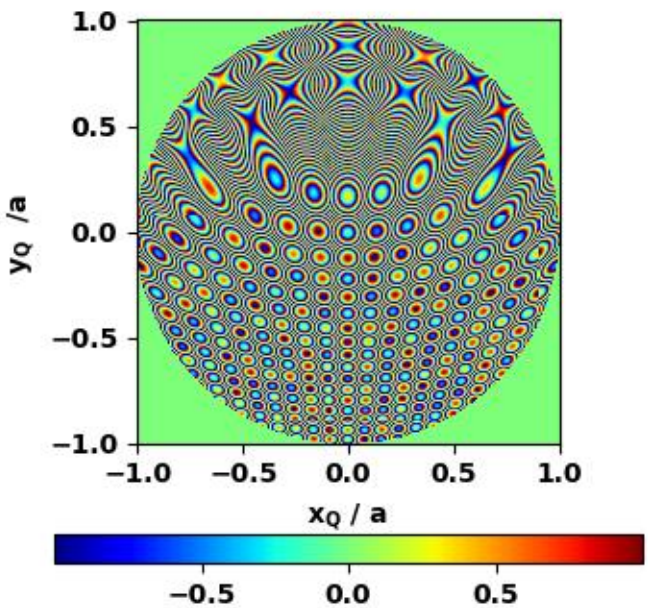


Fig. 2. Aperture space: phase of the electric field (rad / π).

Simulation: Axial irradiance emRSFBZcoma.py

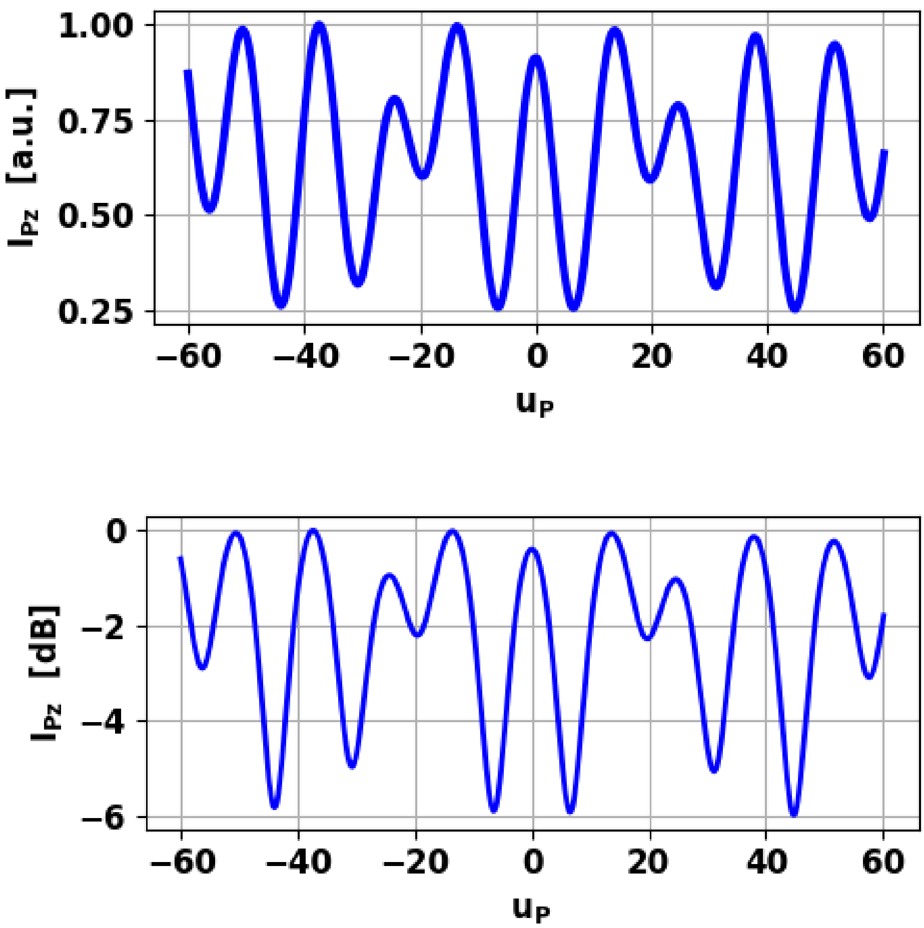


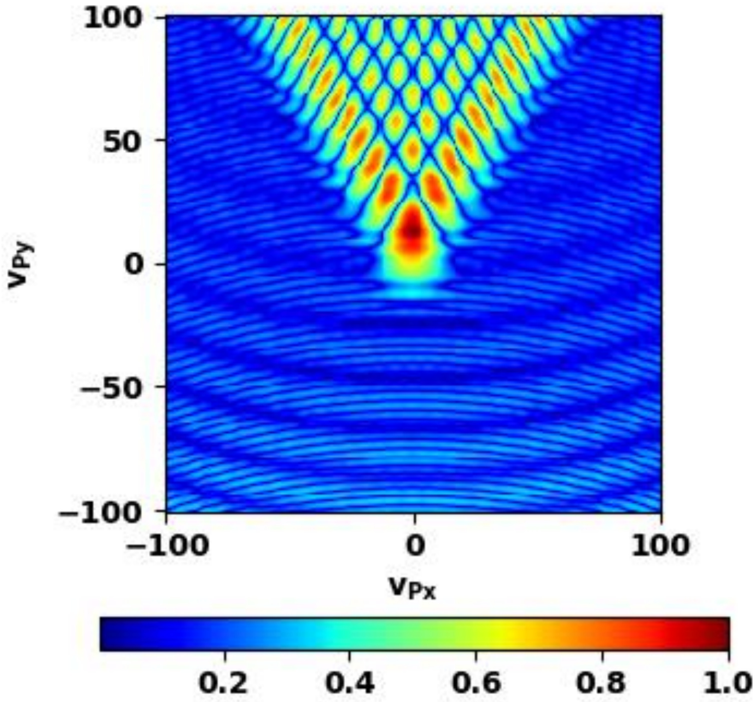
Fig. 3. Axial irradiance near the focal point with comatic aberration. There is no predominant peak in the axial irradiance.

Min at uP

-56.5 -44.0 -30.7 -19.7 -6.6 6.5 19.8 31.2 44.9 57.8

Simulation: radial irradiance in XY focal plane

Figure X show a [2D] and [3D] view of the radial irradiance patterns in the XY focal plane.



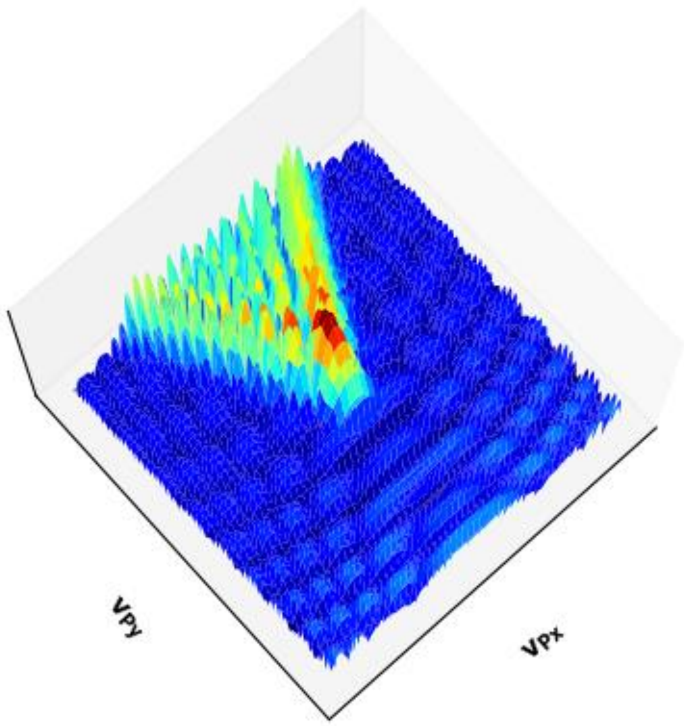
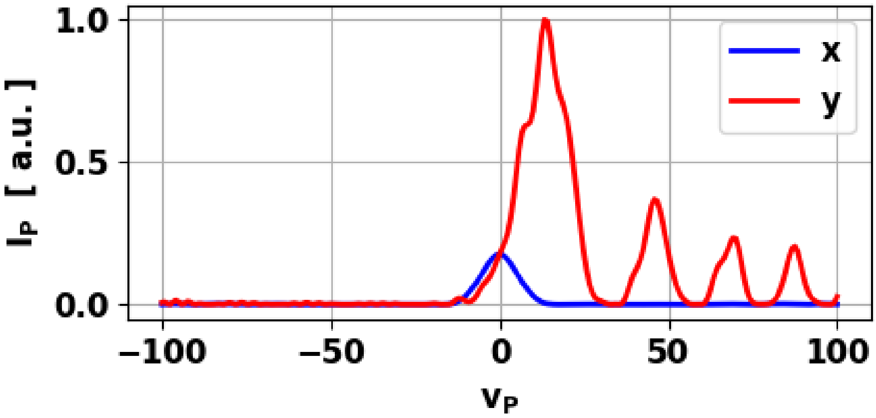


Fig. X. Radial irradiance in the XY focal plane.



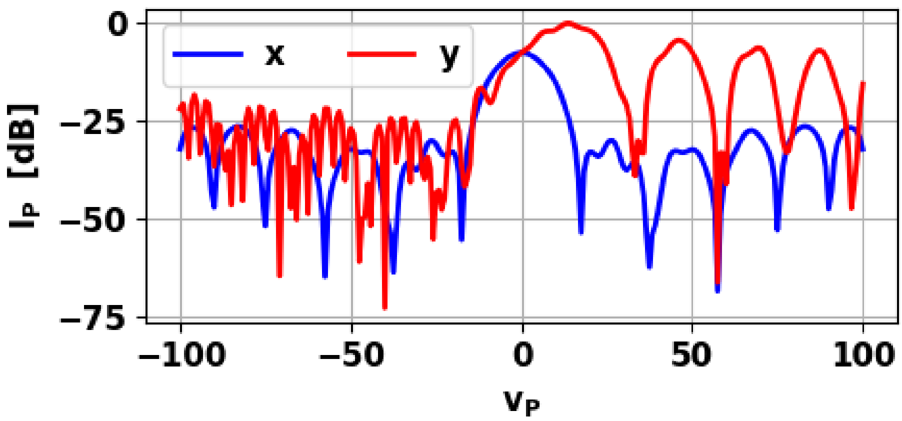


Fig. x.

Simulation: irradiance in the ZX meridional plane

Figures 5 and 6 show the irradiance in the ZX meridional plane about the geometric focus without and with spherical aberration. The aberration function $\Phi = -\pi\,\rho^4$ is independent of angle position within the aperture. Therefore, the irradiance is rotationally symmetric about the optical axis. For the aperture radius **a = 10.0 mm** the ZX meridional plane irradiance distributions appear to be very similar. However, for the aperture radius **a = 20.0 mm**, the irradiance pattern is significantly altered by the spherical aberration.

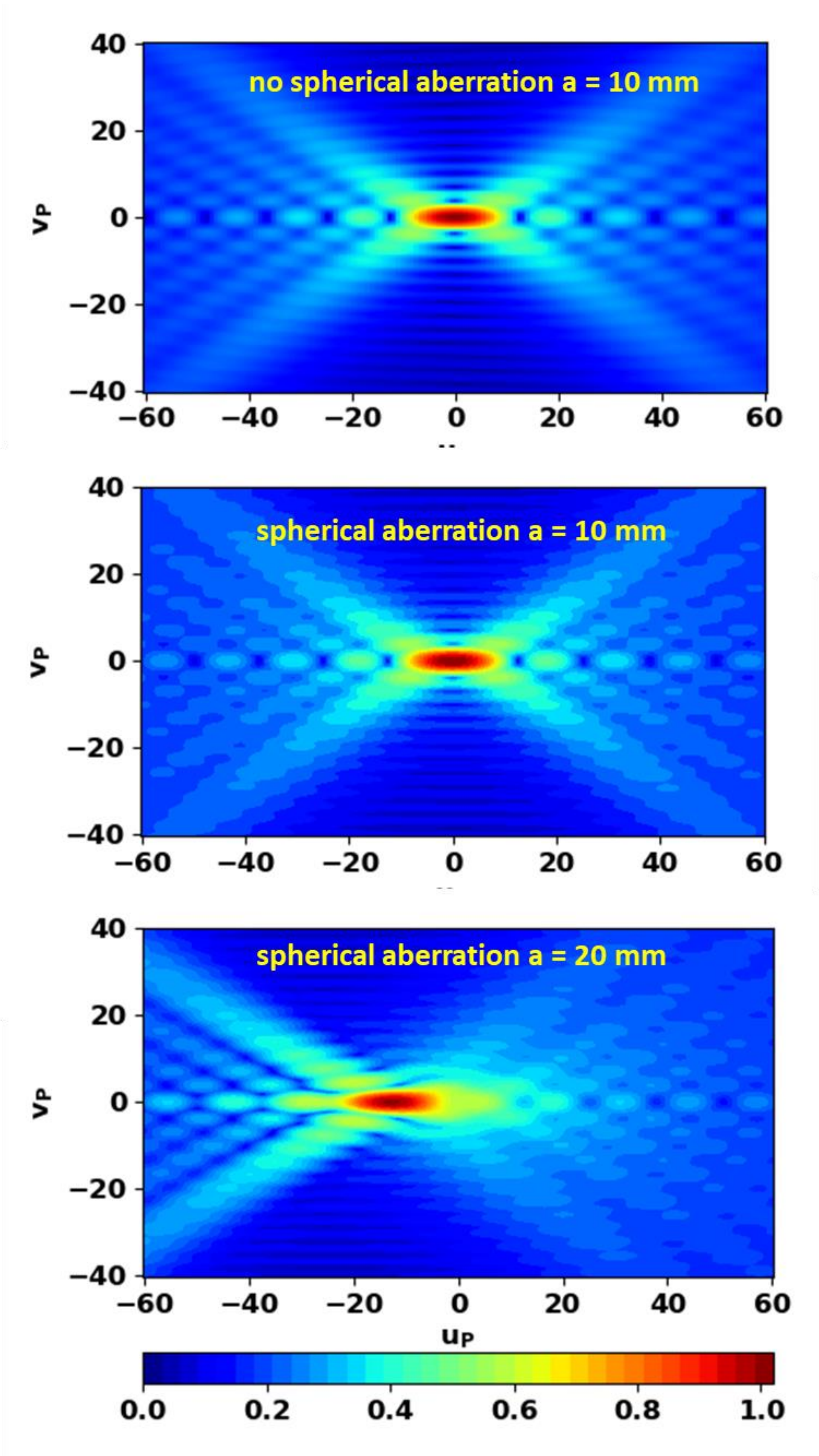


Fig 5. Irradiance in the ZX meridional plane.

```
cf = ax.contourf(UP,VP,IZX**sf, 32,cmap='jet')
cf = ax.pcolormesh(UP,VP,IZX**sf, cmap='jet')
```

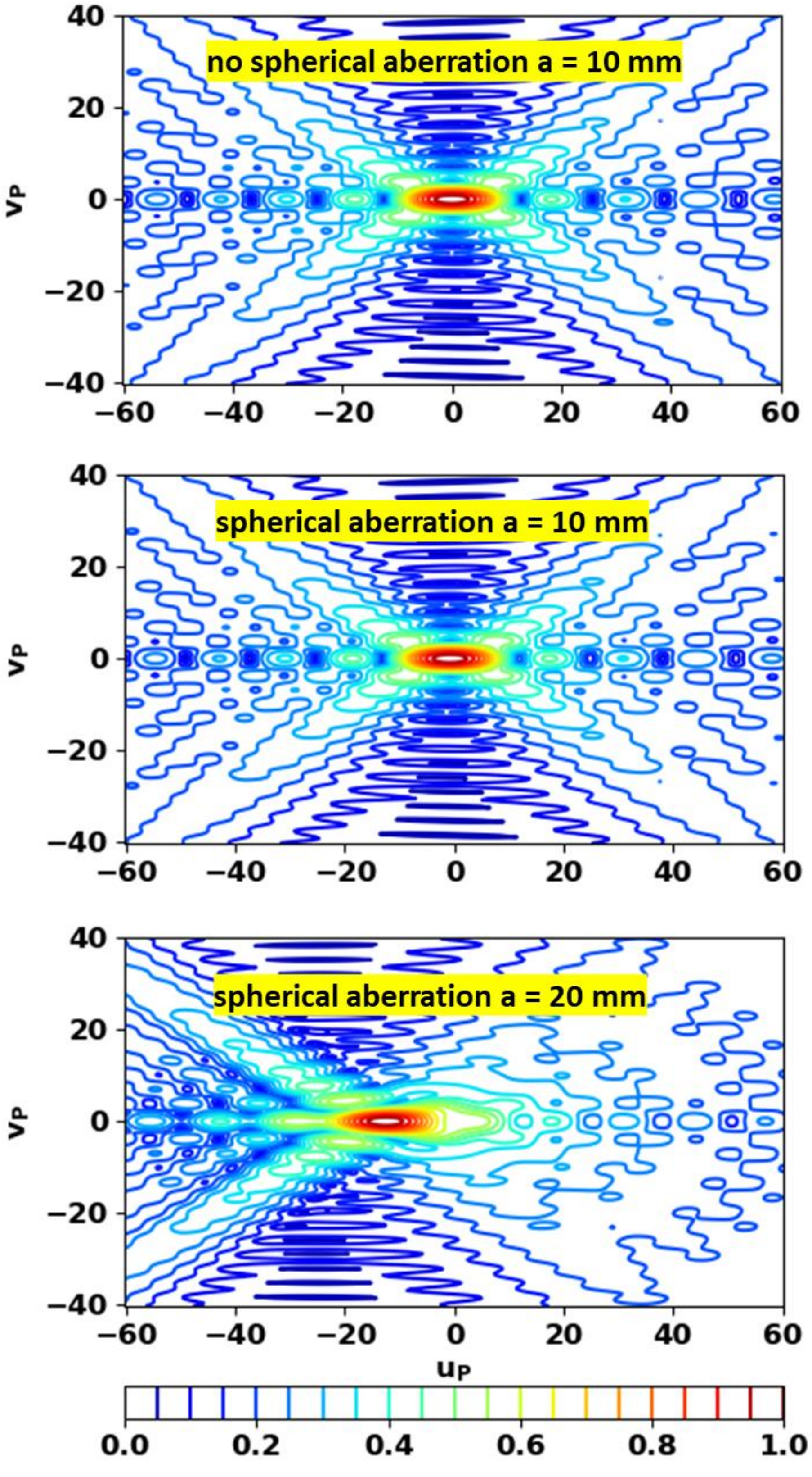


Fig 6. Irradiance in the ZX meridional plane.

cf = ax.contour(UP,VP,IZX**sf, 20,cmap='jet')