



# Fresnel Analysis of Shaped Pupil Systems for Planet Finding

Robert J. Vanderbei  
R. Belikov  
N. J. Kasdin

SPIE San Diego  
Aug 4, 2005

[Home Page](#)

[Title Page](#)

[Contents](#)



Page 1 of 16

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

Princeton University

<http://www.princeton.edu/~rvdb>



# Contents

<b>1</b>	<b>Shaped Pupils For High-Contrast</b>	<b>3</b>
<b>2</b>	<b>Ideal PSF</b>	<b>4</b>
<b>3</b>	<b>Princeton Testbed</b>	<b>5</b>
<b>4</b>	<b>PSF Measured in the Lab</b>	<b>7</b>
<b>5</b>	<b>Fresnel Propagation</b>	<b>9</b>
<b>6</b>	<b>Intensity/Phase Profiles in Front of Pupil Mask</b>	<b>10</b>
<b>7</b>	<b>Intensity Profile at Pupil Mask</b>	<b>11</b>
<b>8</b>	<b>Fresnel PSF</b>	<b>12</b>
<b>9</b>	<b>Removing the 1" Aperture Stop</b>	<b>14</b>
<b>10</b>	<b>Conclusions</b>	<b>16</b>

[Home Page](#)

[Title Page](#)

[Contents](#)



*Page 2 of 16*

[Go Back](#)

[Full Screen](#)

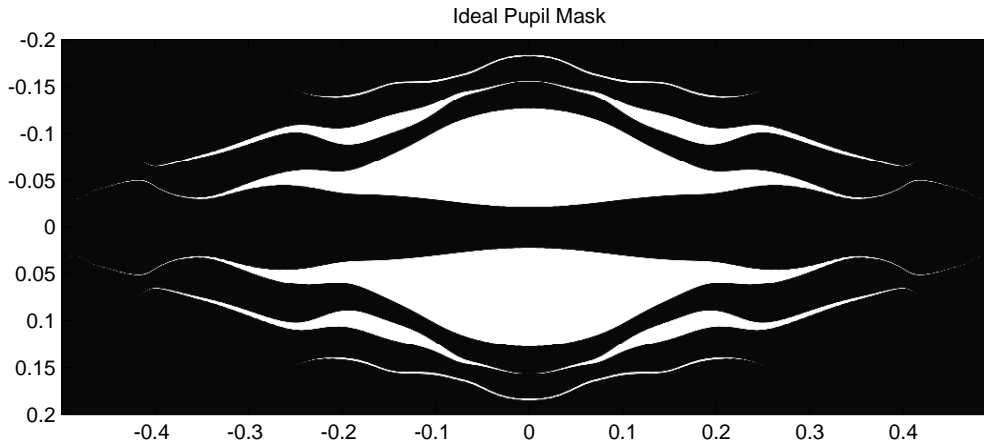
[Close](#)

[Quit](#)

# Shaped Pupils For High-Contrast



## Elliptical Shaped Pupil Mask



[Home Page](#)

[Title Page](#)

[Contents](#)



[Page 3 of 16](#)

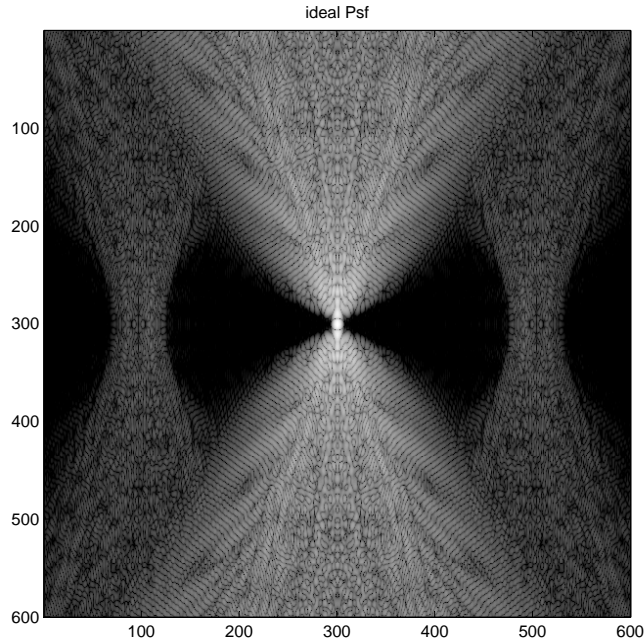
[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

# Ideal PSF



Black is  $10^{-10}$ .

If the entering wavefront has no amplitude/phase error, then this is what you get.

Let's go planet hunting!!!



[Home Page](#)

[Title Page](#)

[Contents](#)



Page 4 of 16

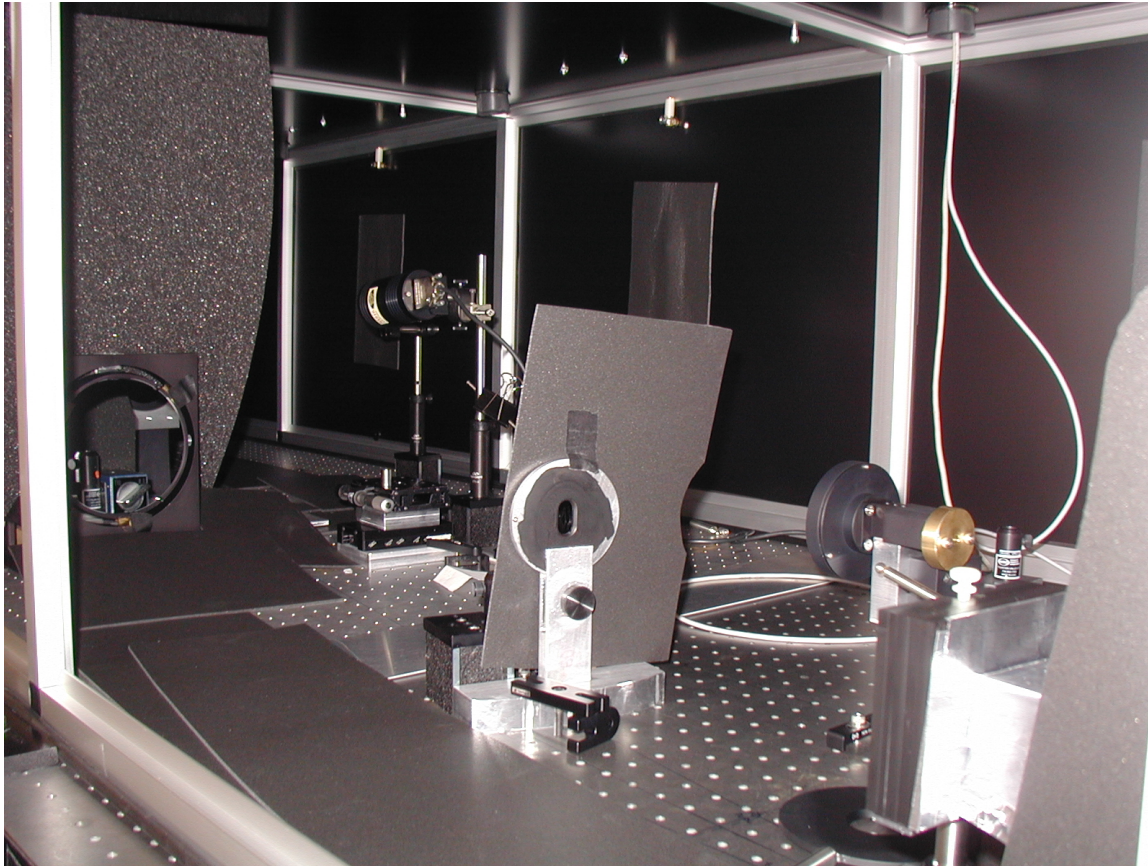
[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

# Princeton Testbed



[Home Page](#)

[Title Page](#)

[Contents](#)



[Page 5 of 16](#)

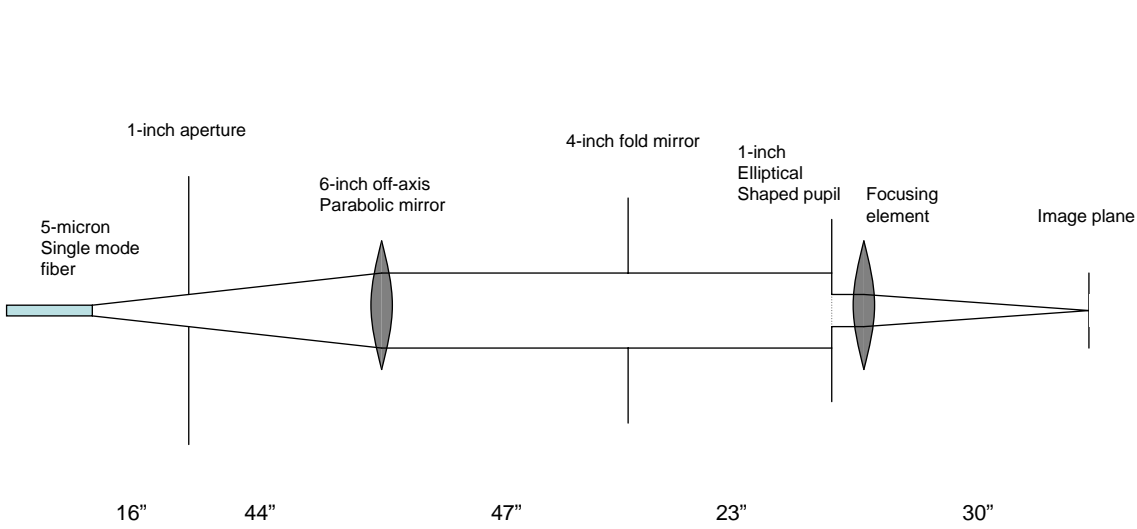
[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

# Idealized Upstream Layout



[Home Page](#)

[Title Page](#)

[Contents](#)



[Page 6 of 16](#)

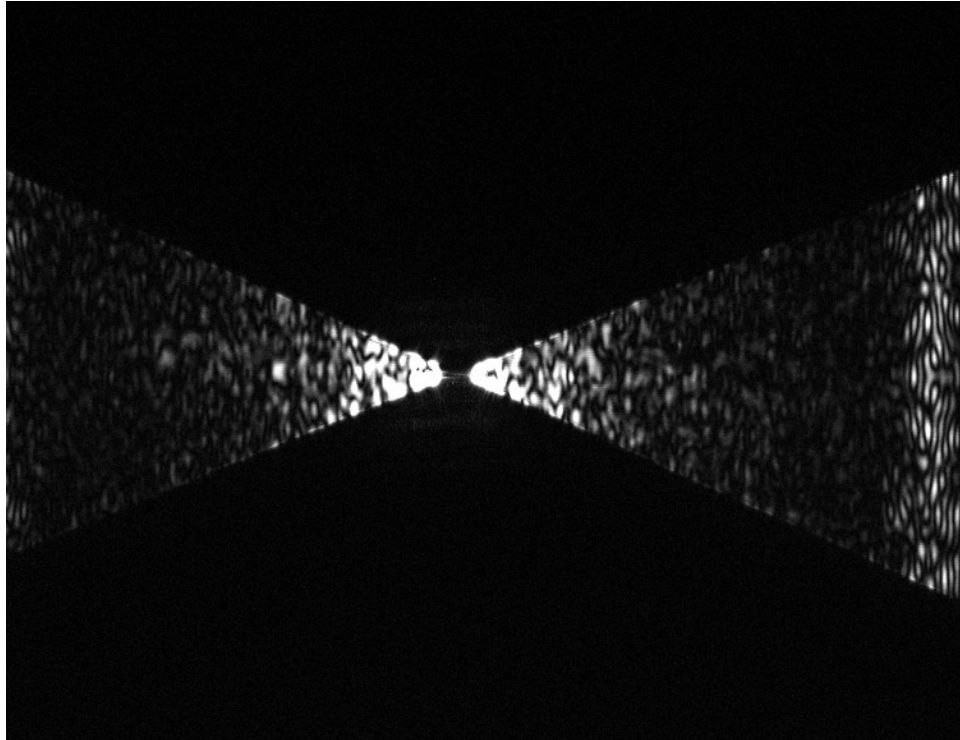
[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

# PSF Measured in the Lab



[Home Page](#)

[Title Page](#)

[Contents](#)



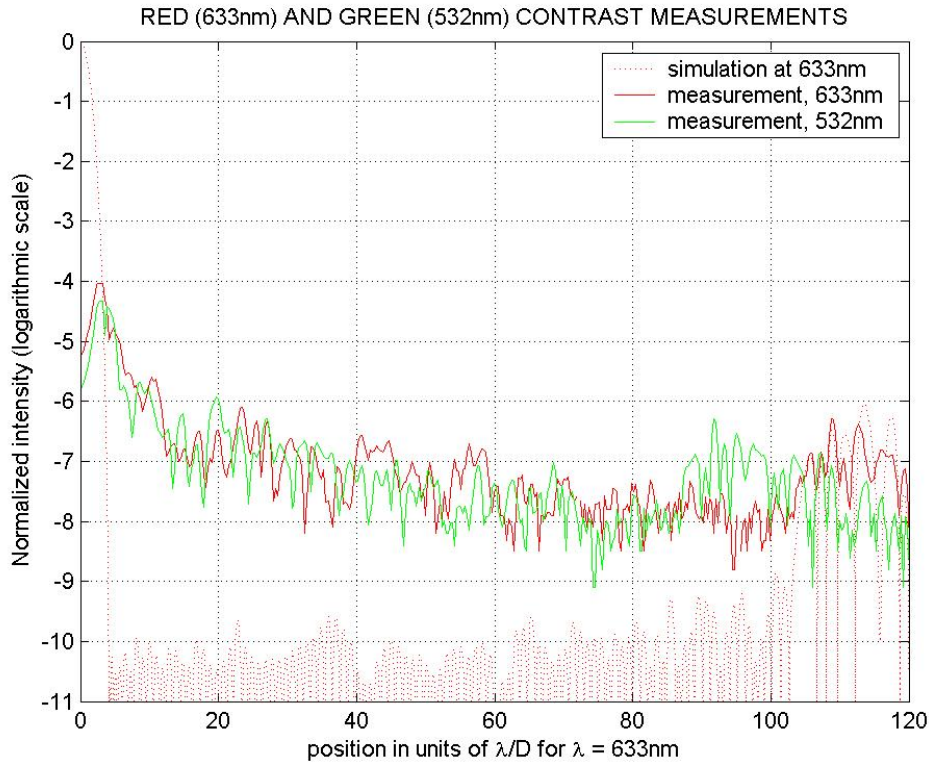
[Page 7 of 16](#)

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)



Home Page

Title Page

Contents



Page 8 of 16

Go Back

Full Screen

Close

Quit

Error is mostly phase/amplitude errors (1/20-th wave mirrors).

Need DMs to correct these errors.

Don't have them yet. While waiting, we ask...

How much is caused by fundamental physics—i.e., *diffraction*?

# Fresnel Propagation



Fresnel propagation of an electric field  $E_0$  a distance  $z$  after a lens/mirror of focal length  $f$ :

$$E_1(\tilde{x}, \tilde{y}) = \frac{i}{\lambda z} e^{\frac{\pi i}{\lambda z}(\tilde{x}^2 + \tilde{y}^2)} \iint e^{\frac{\pi i}{\lambda z}(x^2 + y^2)} e^{-\frac{\pi i}{\lambda f}(x^2 + y^2)} e^{-\frac{2\pi i}{\lambda z}(x\tilde{x} + y\tilde{y})} E_0(x, y) dy dx.$$

If the lens/mirror is absent, then  $f = \infty$  and the middle exponential term in the integral disappears.

[Home Page](#)[Title Page](#)[Contents](#)[Page 9 of 16](#)[Go Back](#)[Full Screen](#)[Close](#)[Quit](#)

# Intensity/Phase Profiles in Front of Pupil Mask



[Home Page](#)

[Title Page](#)

[Contents](#)



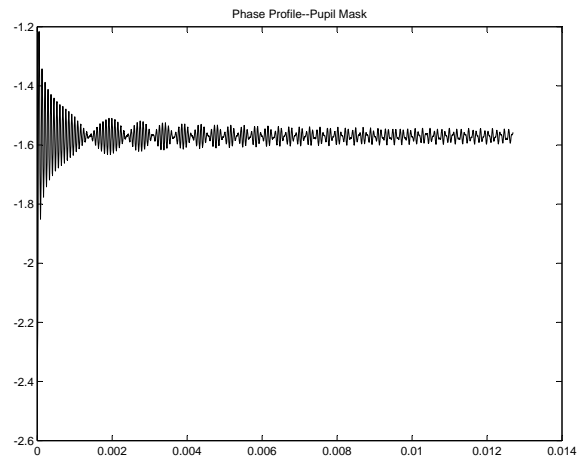
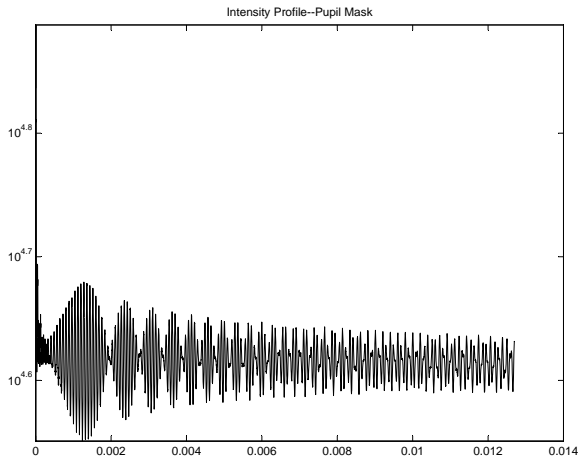
Page 10 of 16

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)



# Intensity Profile at Pupil Mask



[Home Page](#)

[Title Page](#)

[Contents](#)



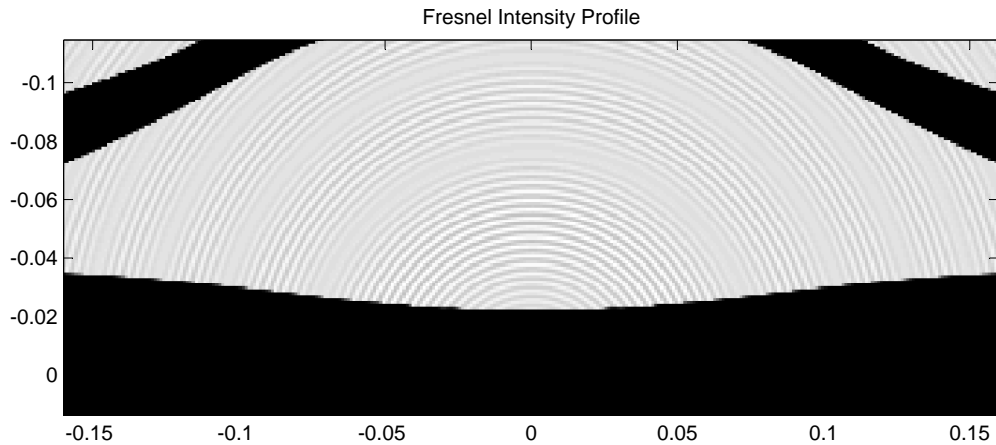
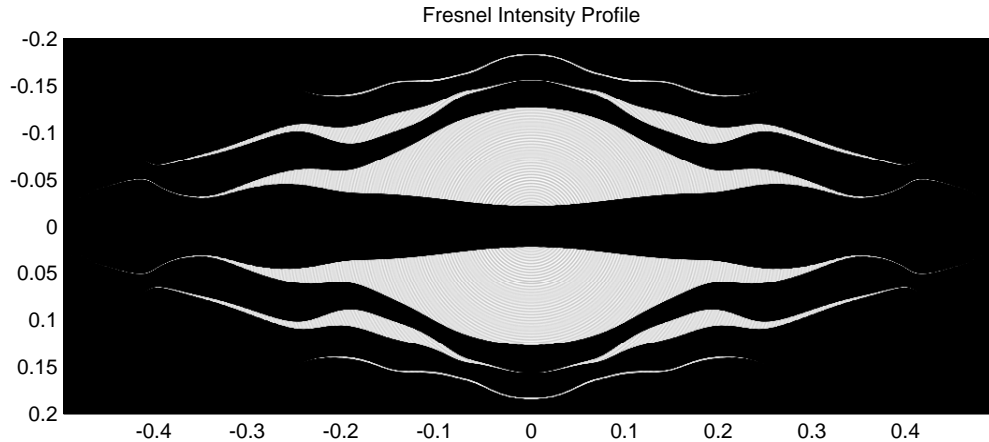
Page 11 of 16

[Go Back](#)

[Full Screen](#)

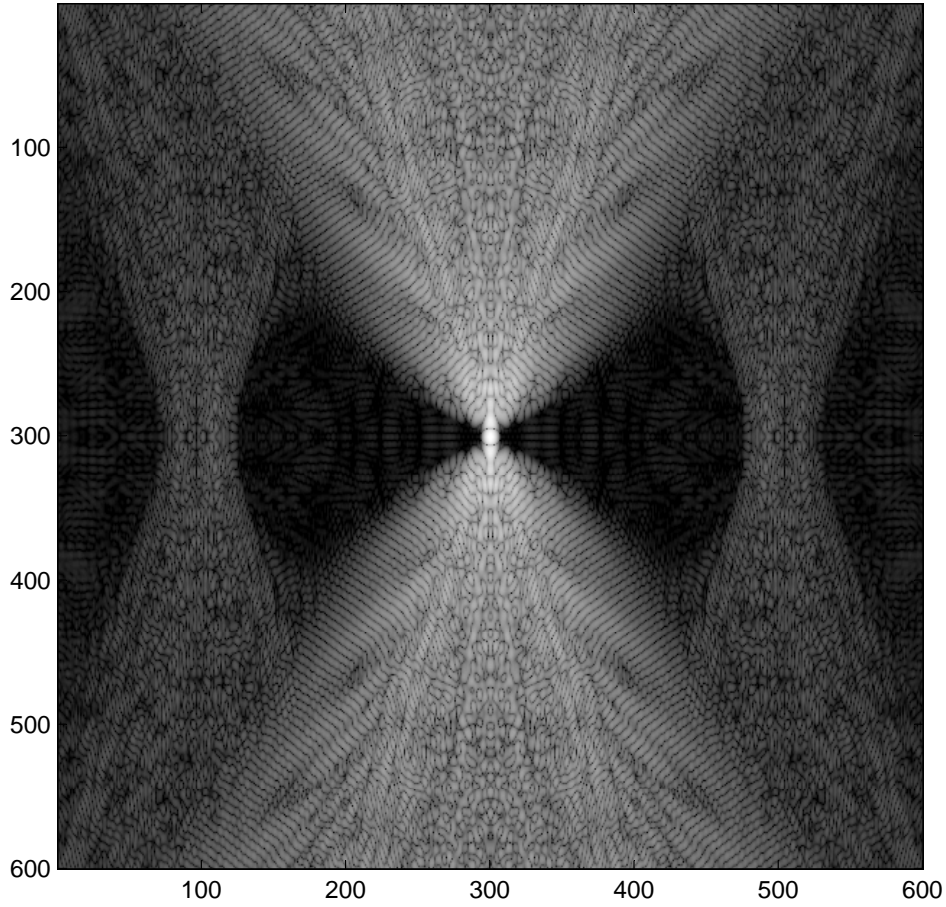
[Close](#)

[Quit](#)



# Fresnel PSF

true Psf



[Home Page](#)

[Title Page](#)

[Contents](#)

[◀](#) [▶](#)

[◀](#) [▶](#)

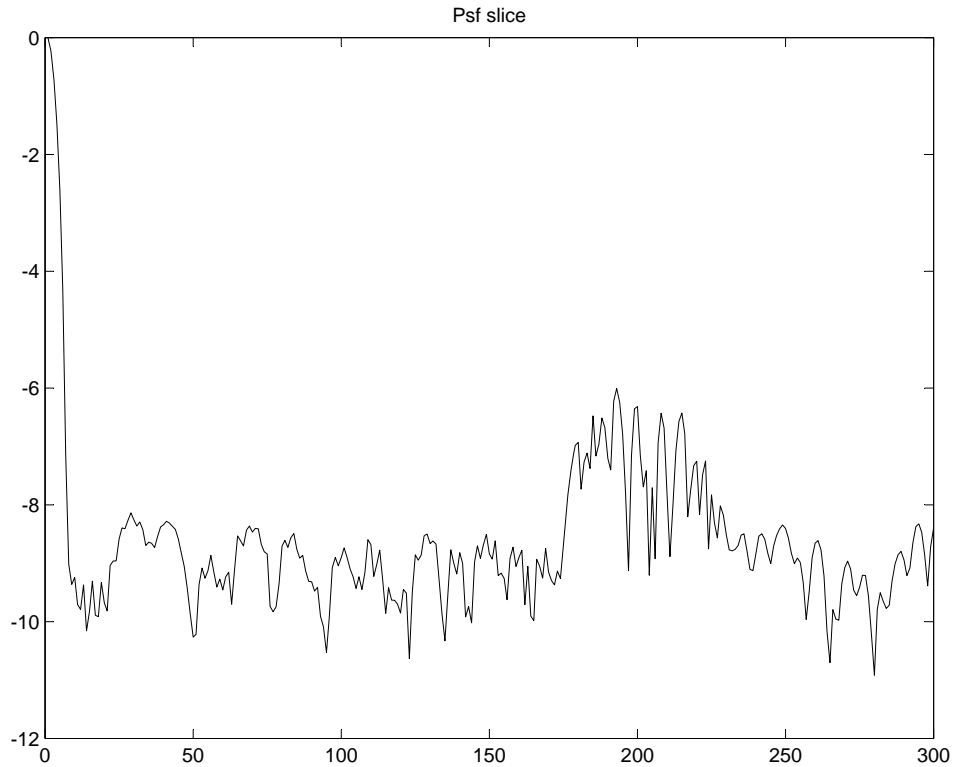
[Page 12 of 16](#)

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)



[Home Page](#)

[Title Page](#)

[Contents](#)



Page 13 of 16

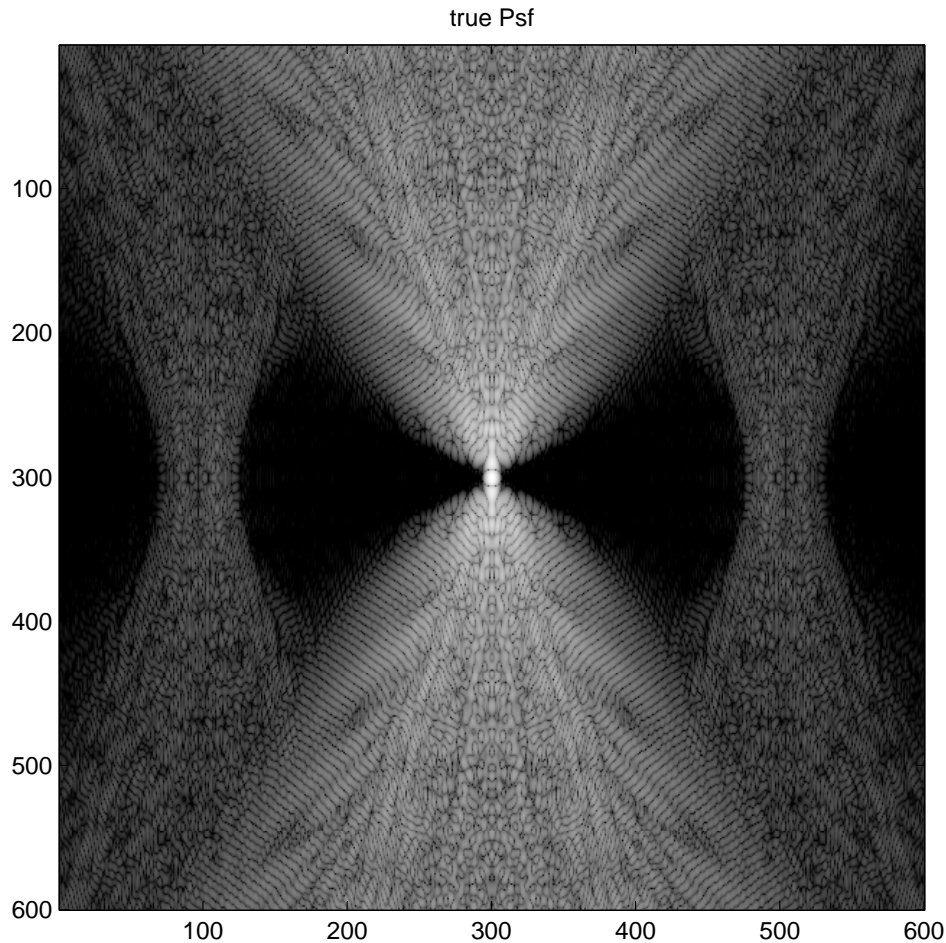
[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

# Removing the 1" Aperture Stop



[Home Page](#)

[Title Page](#)

[Contents](#)



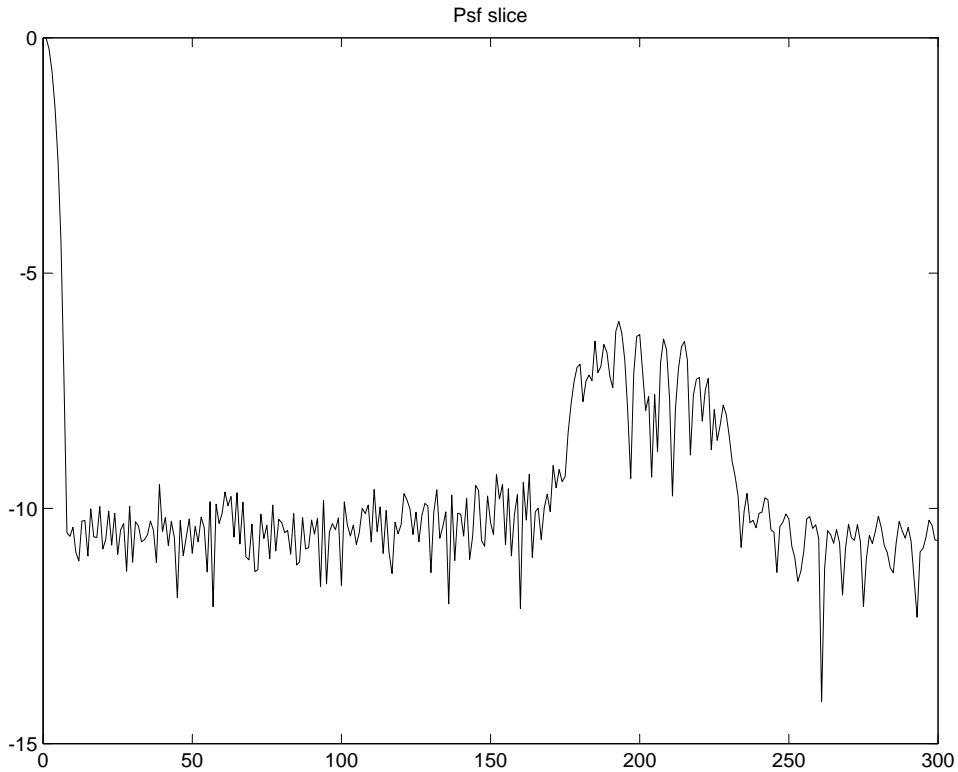
Page 14 of 16

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)



[Home Page](#)

[Title Page](#)

[Contents](#)



Page 15 of 16

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)

# Conclusions

- Mirror errors limit contrast to about  $10^{-6}$  at  $5\lambda/D$ .
- Diffraction effects limit contrast to about  $10^{-8}$  for 1 inch apertures.
- Consider placing  $8 \times 3.5$  meter shaped pupil at entrance pupil.
- Consider activating primary and secondary mirrors.
- All other designs might be too hard or even impossible.



[Home Page](#)

[Title Page](#)

[Contents](#)



Page 16 of 16

[Go Back](#)

[Full Screen](#)

[Close](#)

[Quit](#)