High-Contrast Space Occulter

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What *DO* We Know Today

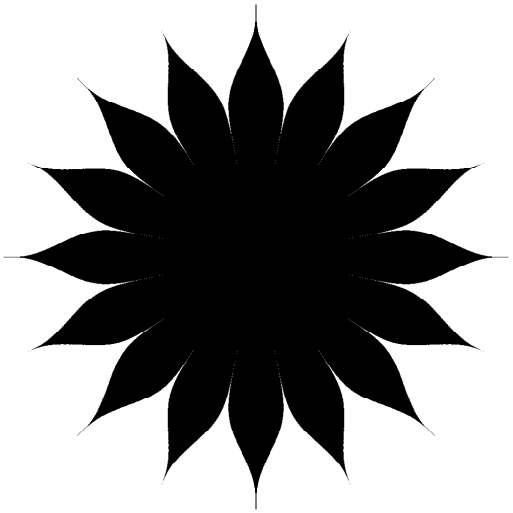
TPF-Lite Meeting
Princeton University

http://www.princeton.edu/∼rvdb

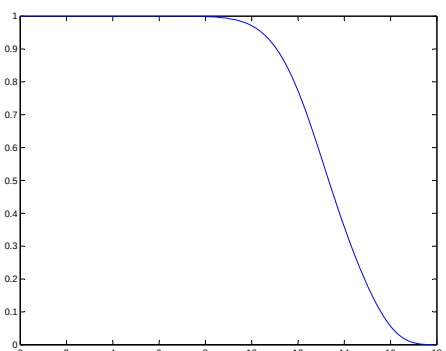
Occulters—Summary

- Block the starlight using an occulting mask placed thousands of kilometers from the telescope
- Inner working angle (iwa) not limited by the telescope aperture
- Telescope must be diffraction limited and capable of reaching mag 30
- Sophisticated wavefront control system unnecessary
- Small iwa's require very large separations
- Diffraction effects must be mitigated
- Petal-shaped mask controls diffraction
- Formation flying and fuel constraints limit the achievable iwa

Petal-Shaped Occulters



16-Petal Occulter $A(r, \theta)$



Radial Attenuation $A(r)$

- Babinet's principle plus Fresnel propagation:

$$E(\rho, \phi) = 1 - \frac{1}{i\lambda z} \int_0^{\infty} \int_0^{2\pi} e^{\frac{i\pi}{\lambda z}(r^2+\rho^2-2r\rho\cos(\theta-\phi))} A(r,\theta) r d\theta dr.$$

- From Jacobi-Anger expansion we get:

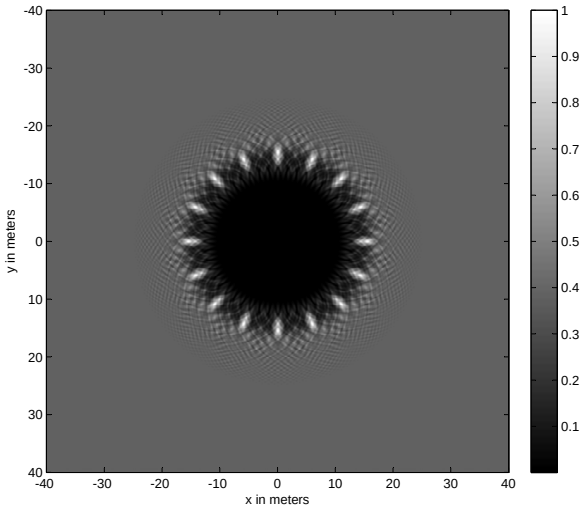
$$\begin{aligned} E(\rho,\phi) &= 1 - \frac{2\pi}{i\lambda z} \int_0^R e^{\frac{i\pi}{\lambda z}(r^2+\rho^2)} J_0\left(\frac{2\pi r\rho}{\lambda z}\right) A(r) r dr \\ &\quad - \sum_{k=1}^{\infty} \frac{2\pi(-1)^k}{i\lambda z} \left(\int_0^R e^{\frac{i\pi}{\lambda z}(r^2+\rho^2)} J_{kN}\left(\frac{2\pi r\rho}{\lambda z}\right) \frac{\sin(\pi k A(r))}{\pi k} r dr \right) \\ &\quad \times \left(2\cos(kN(\phi - \frac{\pi}{2})) \right) \end{aligned}$$

  where N is the number of petals.

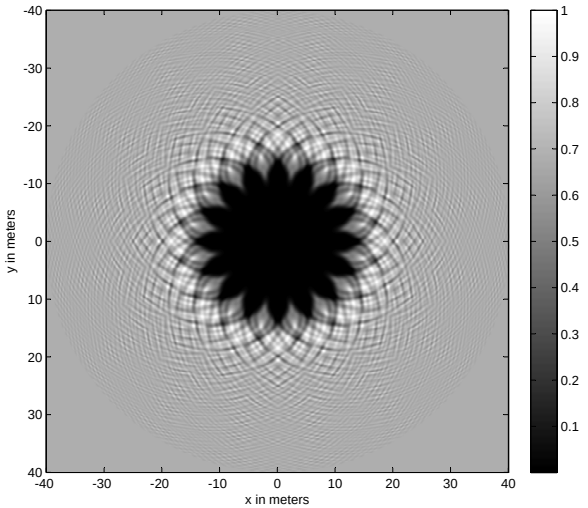
- For small ρ, truncated summation well-approximates full sum.
- Truncated after 10 terms.
- Current Baseline: $\lambda \in [0.4, 1.1]$ microns, $z = 18,000$ km, $R = 18$ m.

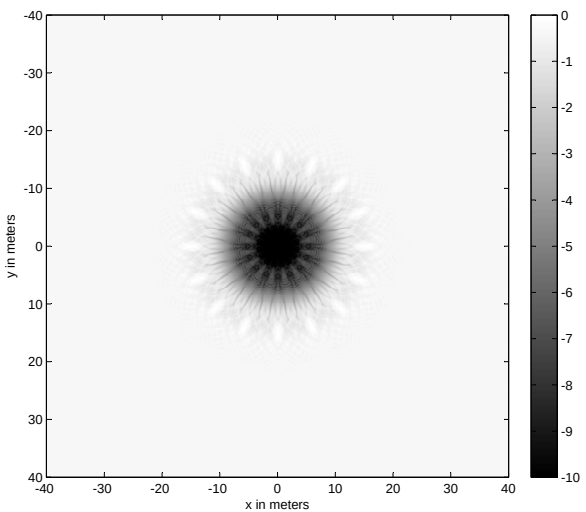
Intensity at Telescope Pupil—16 Petals

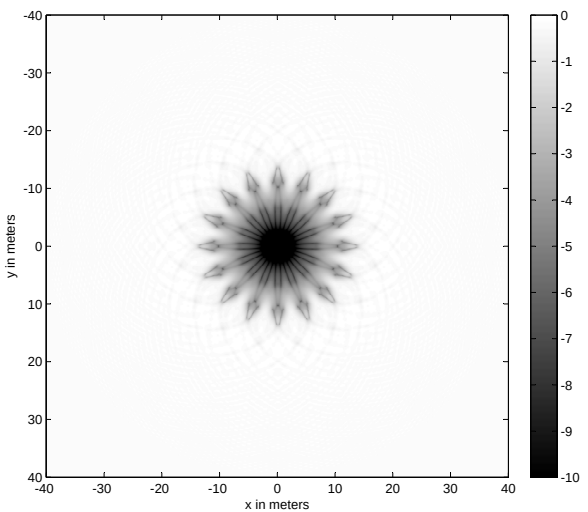
$\lambda = 0.4$ microns



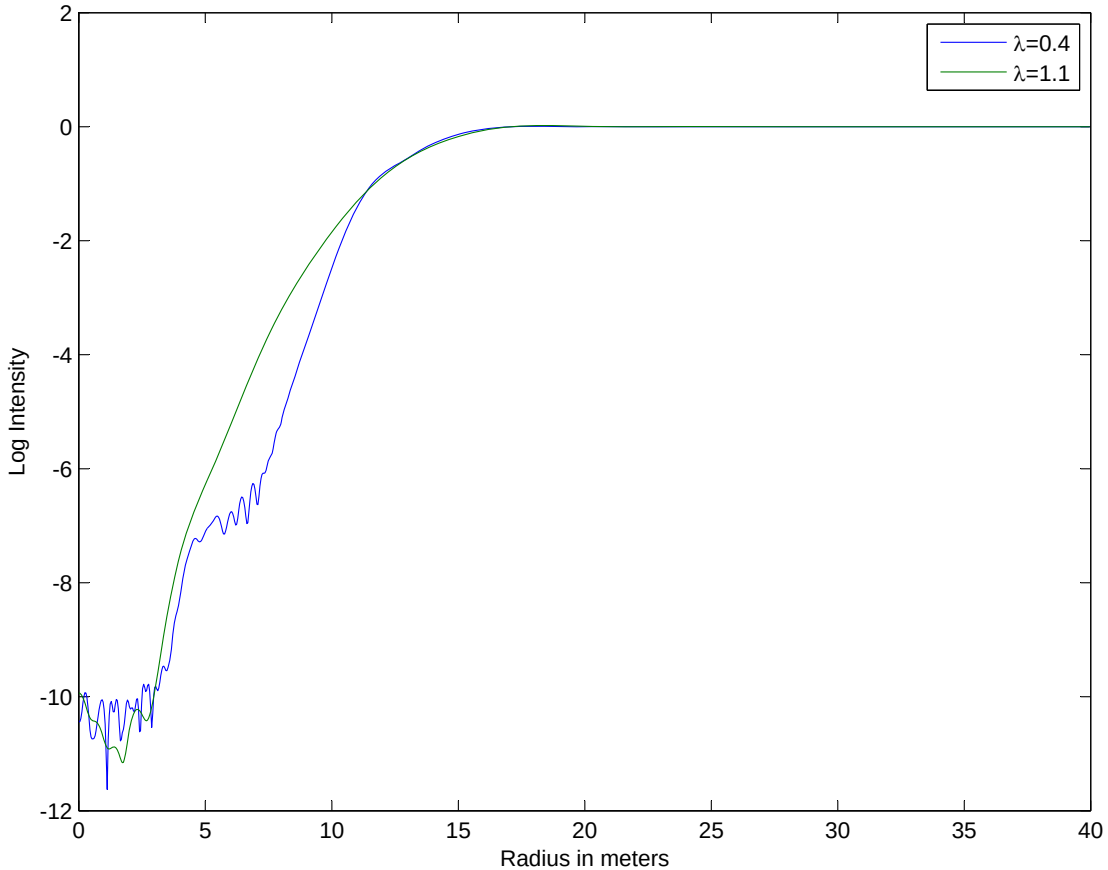
$\lambda = 1.0$ microns





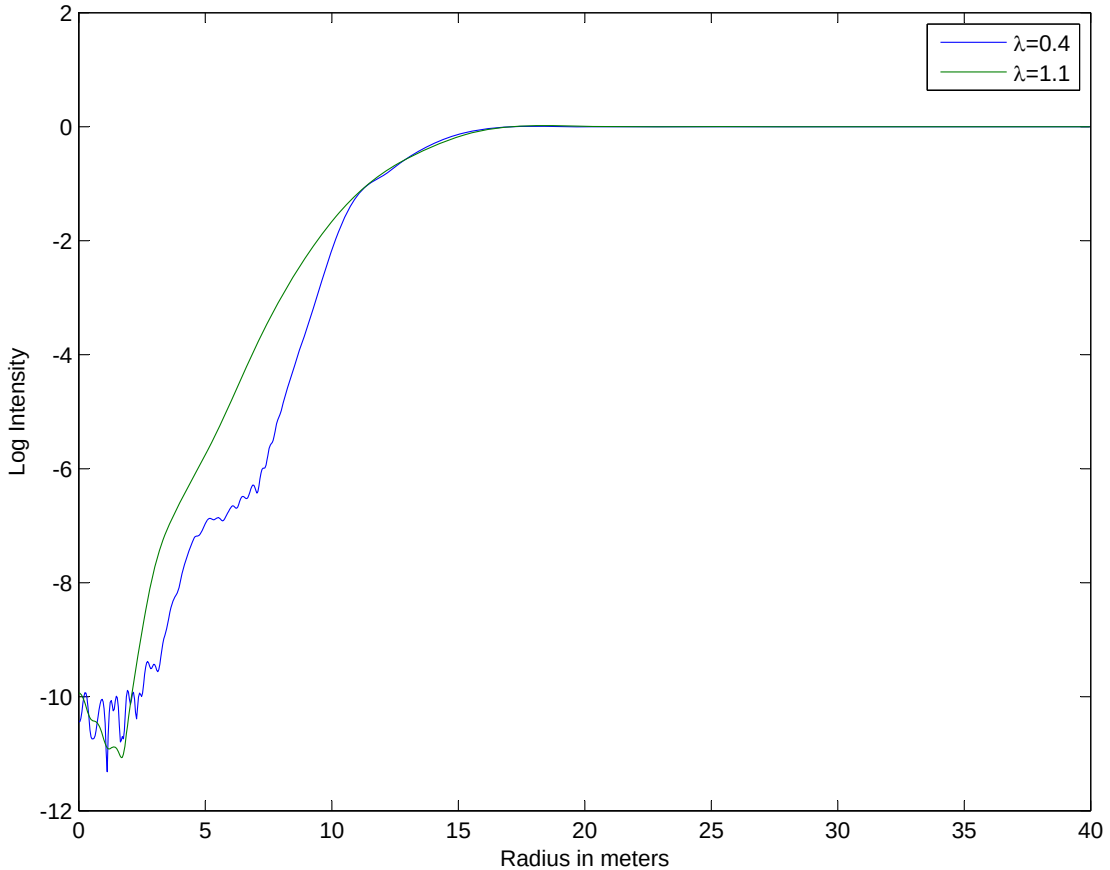


Radial Plots—16 Petals



GOOD ENOUGH!

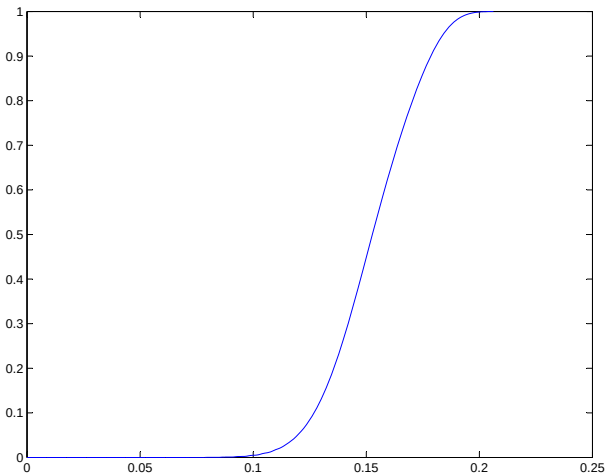
Radial Plots—12 Petals



NOT GOOD ENOUGH!

Throughput vs. Angular Separation

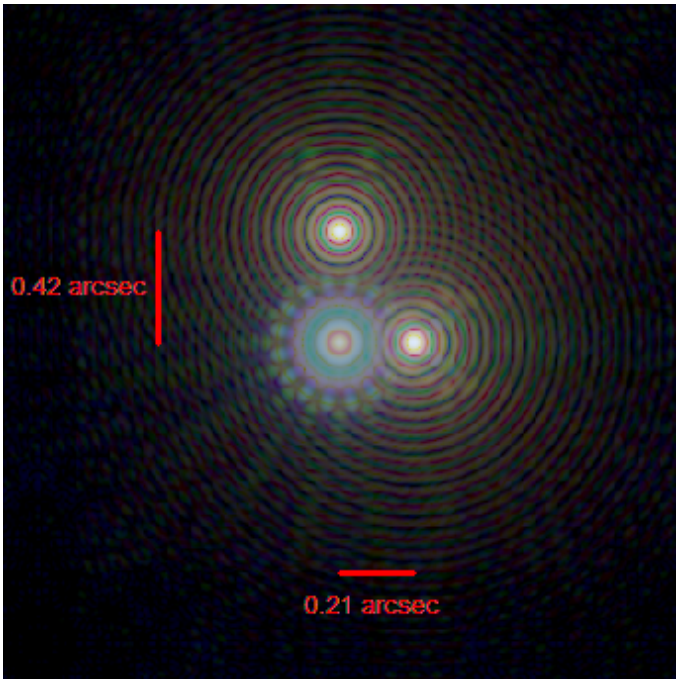
- Radius at tip: 18 m.
- Occulter distance: $18,000$ km.
- Angle between tip and on-axis: 0.2 arcseconds.
- Planet virtually unattenuated at tip.
- Throughput quickly drops to zero as separations decrease.
- 50% throughput at 0.15 arcseconds.



IS IT GOOD ENOUGH?

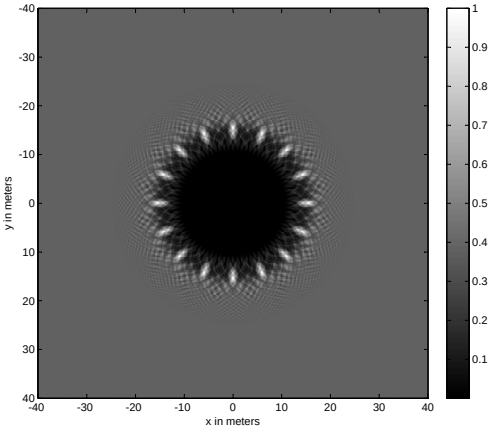
Image Plane

- Residual starlight dispersed but concentrated in center.
- Three 10^{-10} planets.
  - 0.4 arcsecond separation at 12 o'clock.
  - 0.2 arcsecond separation at 3 o'clock.
  - 0.1 arcsecond separation at 6 o'clock (INVISIBLE).
- RGB log-stretched image with
  - R $= 1.0$ microns
  - G $= 0.7$ microns
  - B $= 0.4$ microns

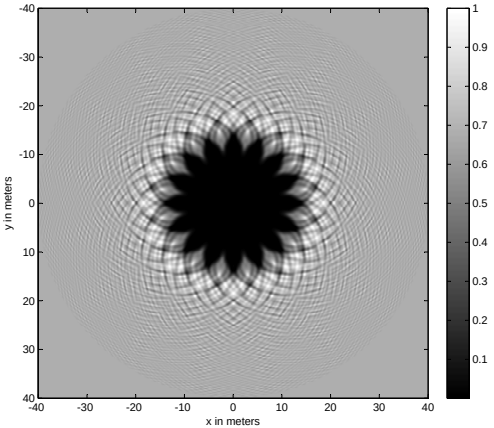


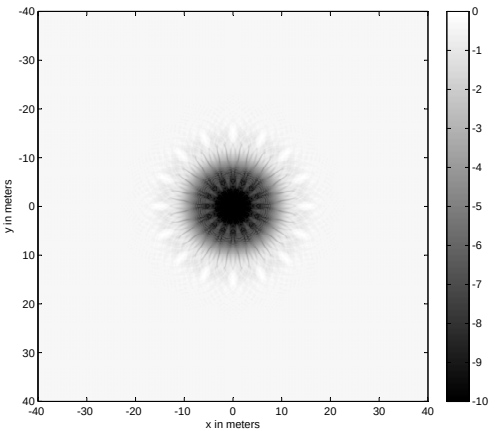
$z = 18000$ **km,** $R = 18$ **m**

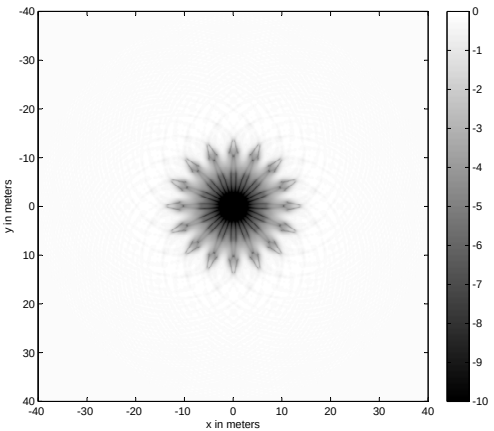
$\lambda = 0.4$ microns

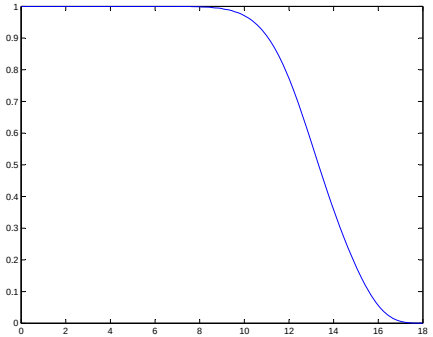


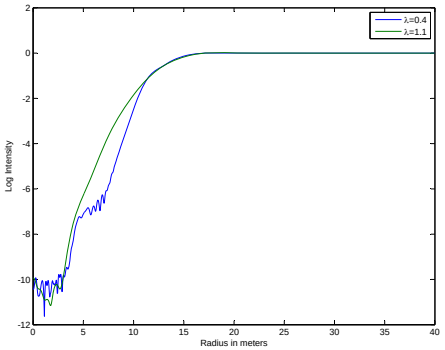
$\lambda = 1.0$ microns

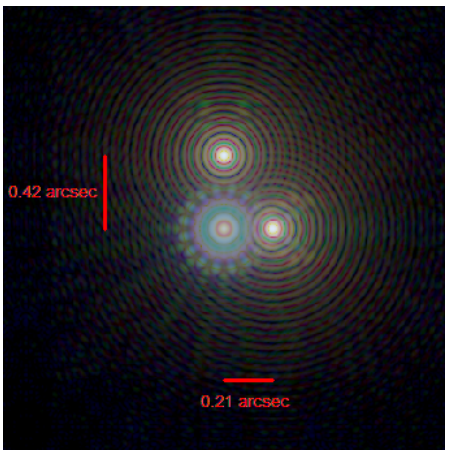






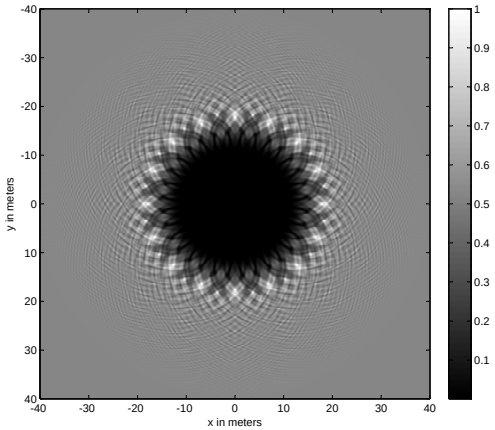




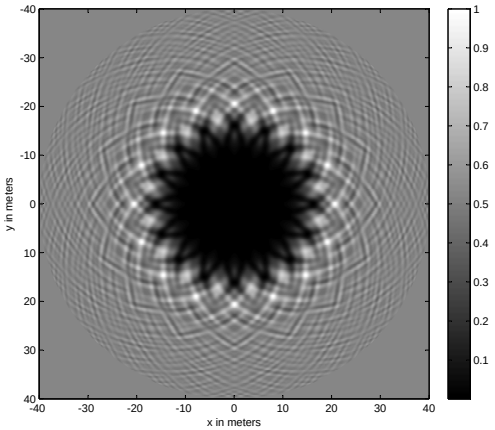


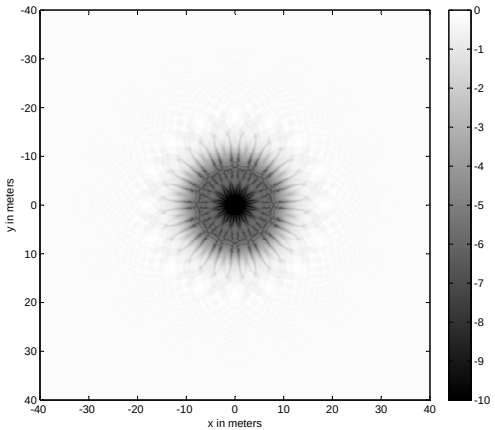
$z = 36000$ **km,** $R = 20$ **m**

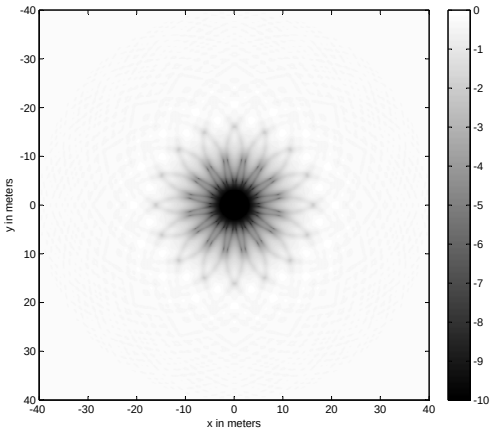
$\lambda = 0.4$ microns

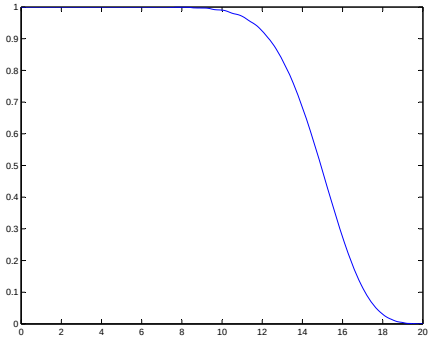


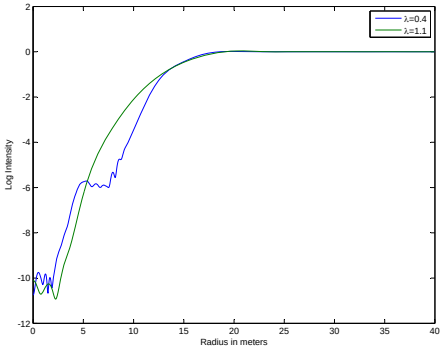
$\lambda = 1.0$ microns

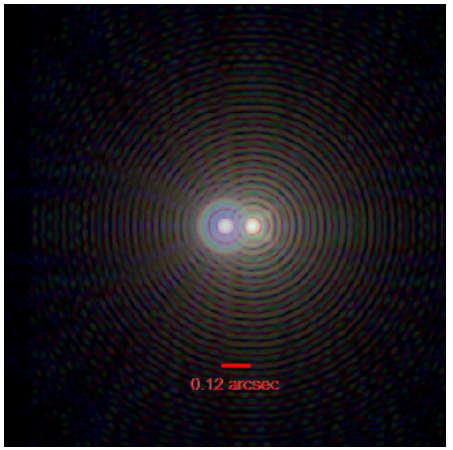






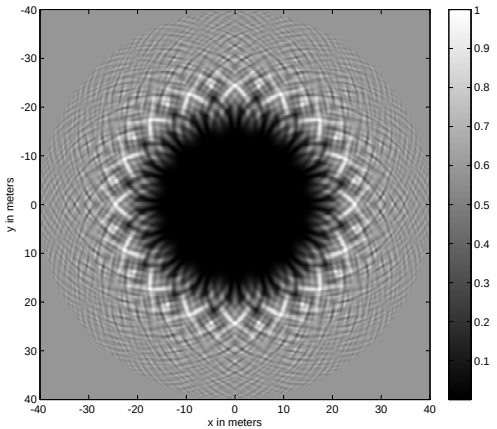




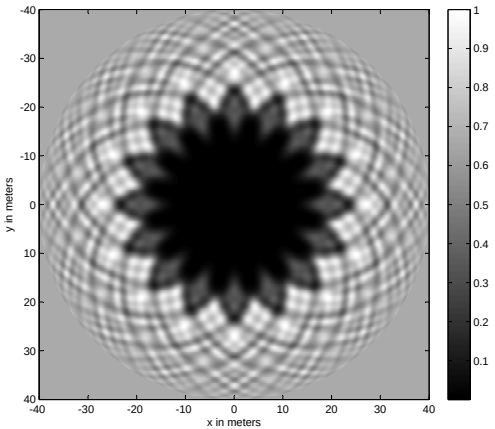


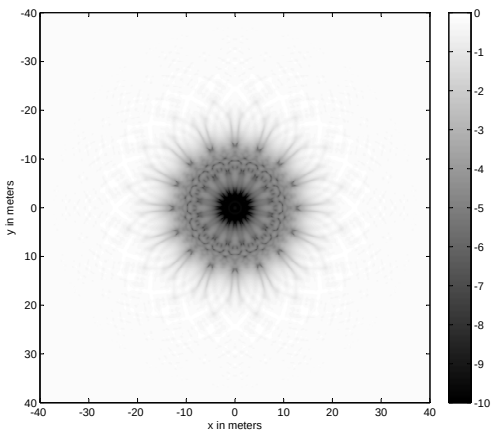
$z = 72000$ **km**, $R = 25$ **m**

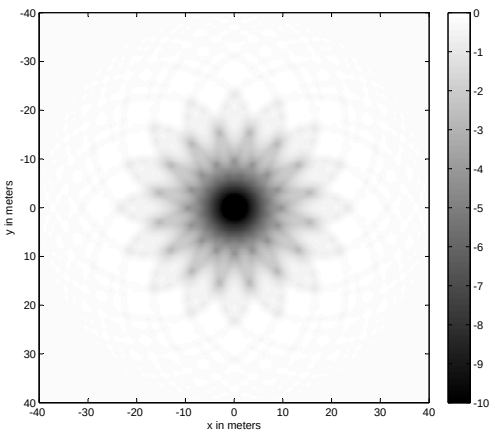
$\lambda = 0.4$ microns

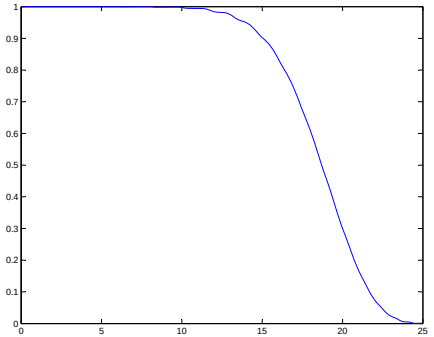


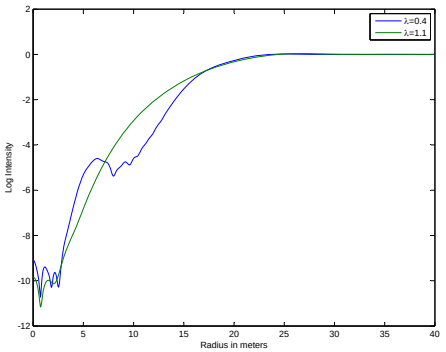
$\lambda = 1.0$ microns

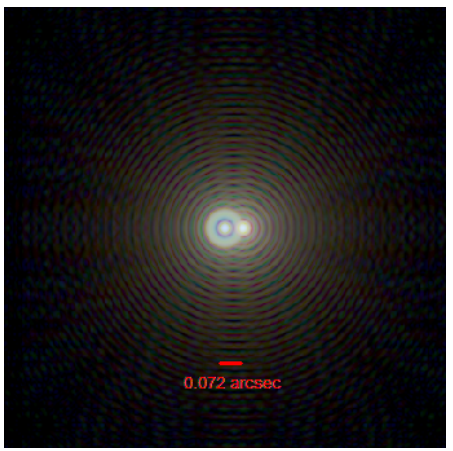






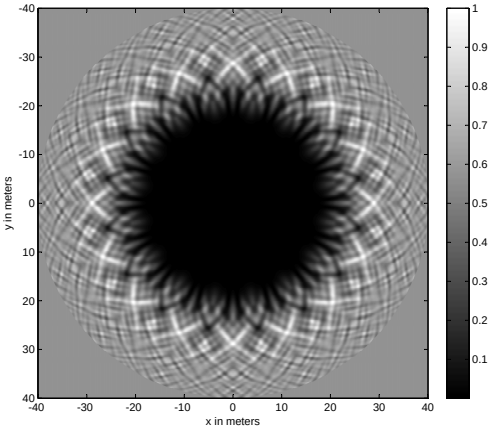




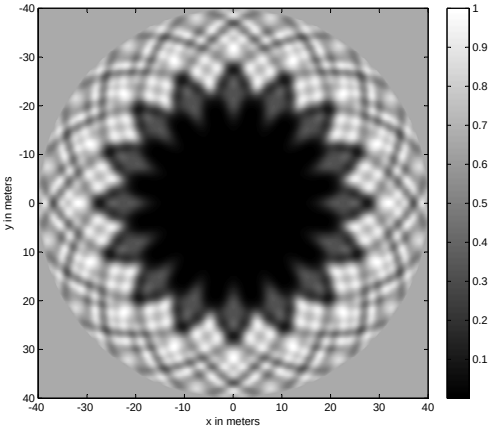


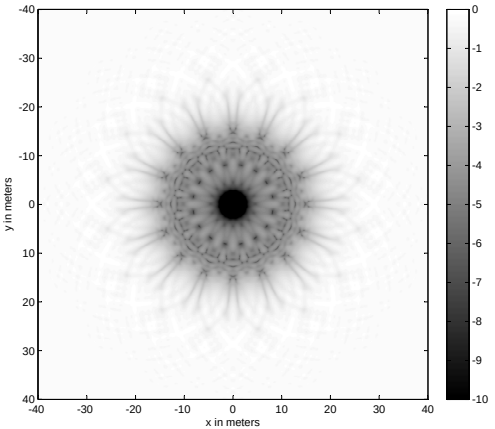
$z = 100000$ **km,** $R = 30$ **m**

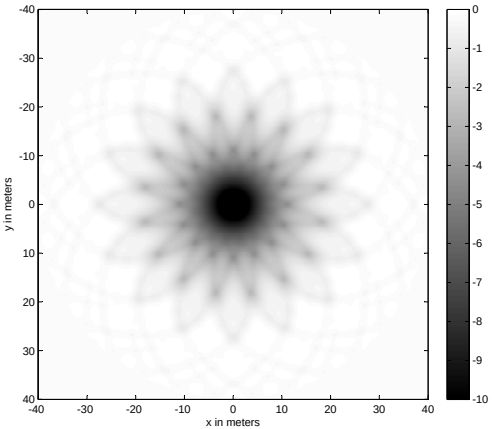
$\lambda = 0.4$ microns

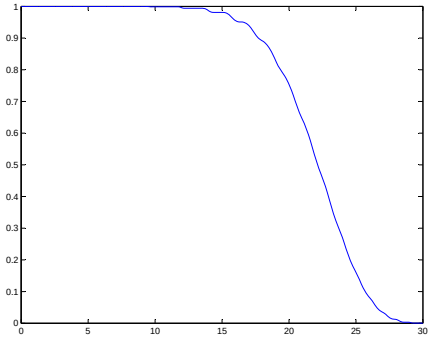


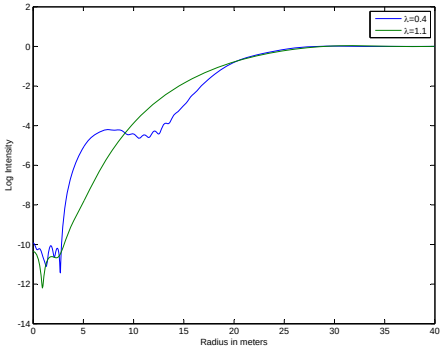
$\lambda = 1.0$ microns

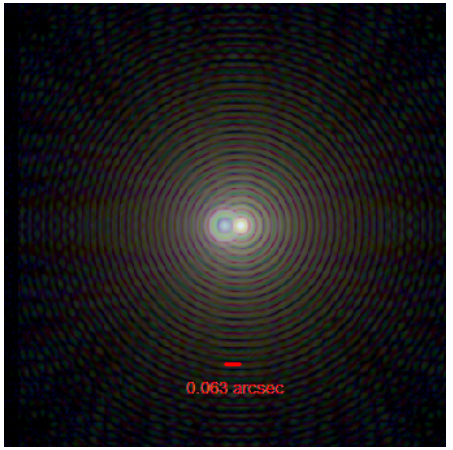






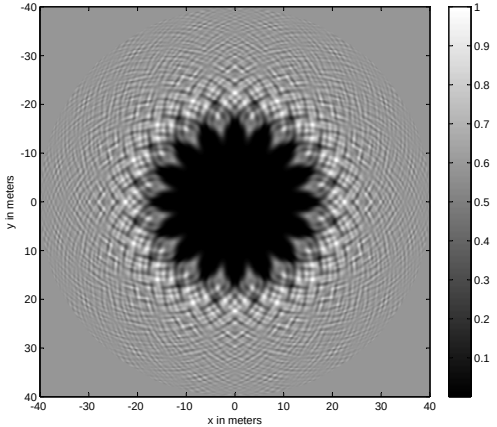




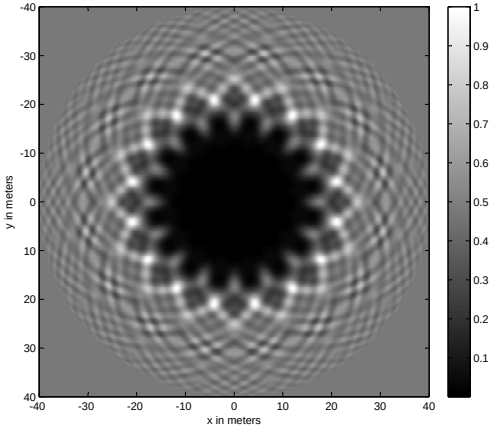


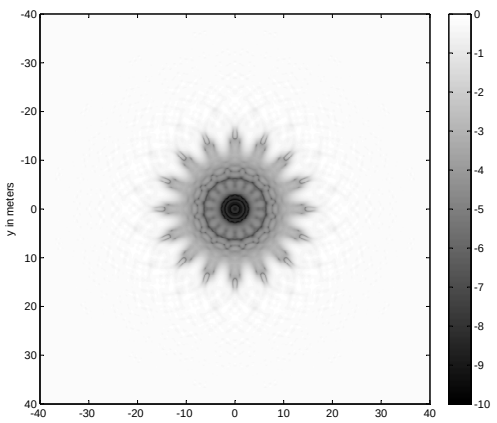
$z = 66000$ **km**, $R = 22$ **m**, $Q = 1$

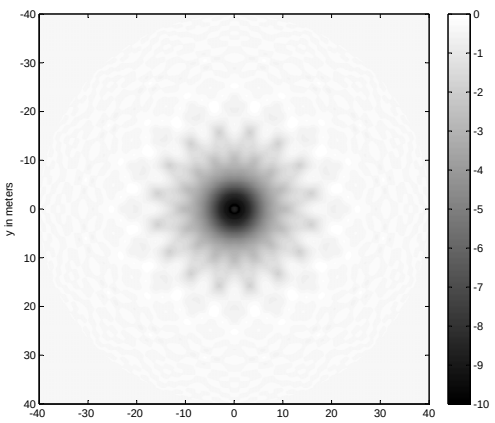
$\lambda = 0.4$ microns

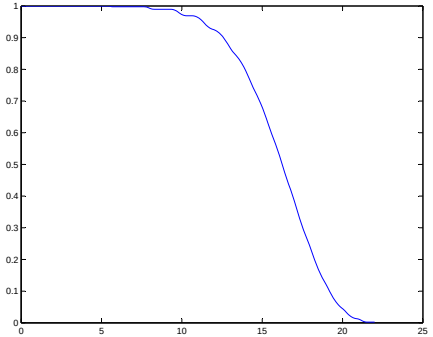


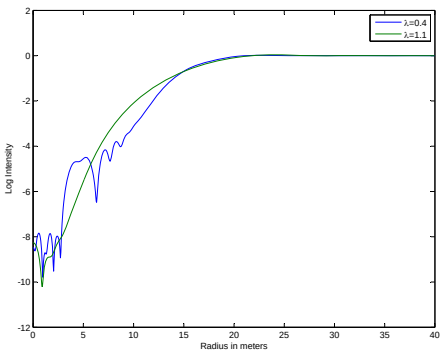
$\lambda = 1.0$ microns

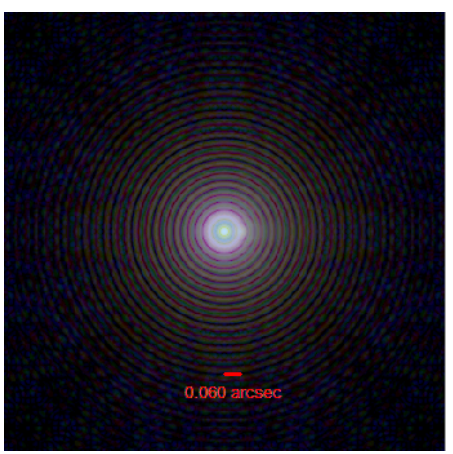








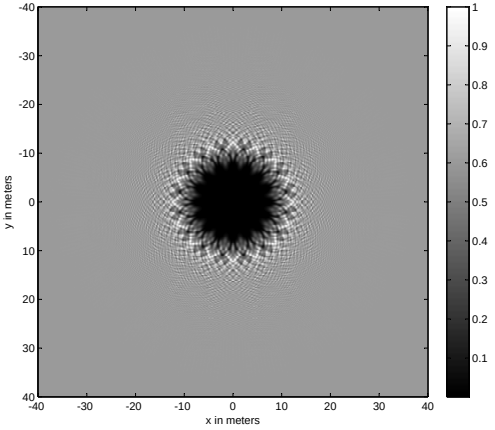




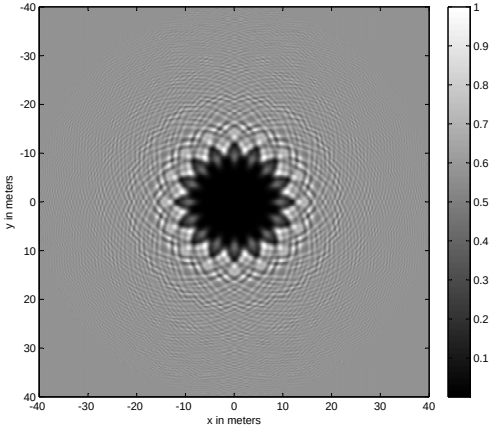
$z = 18000$ **km,** $R = 12.5$ **m**

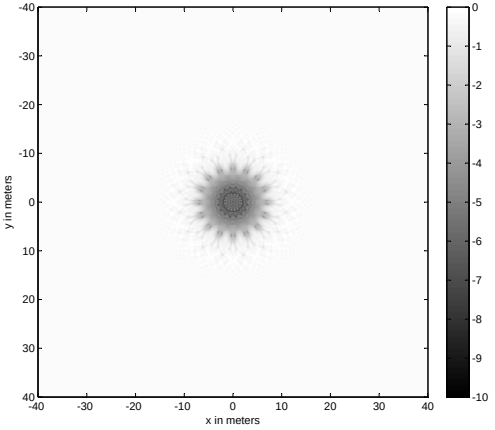
NWD Baseline: Flat Bottom for 4m aperture plus

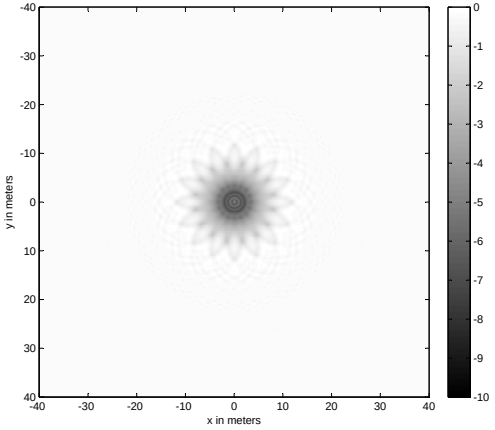
$\lambda = 0.4$ microns

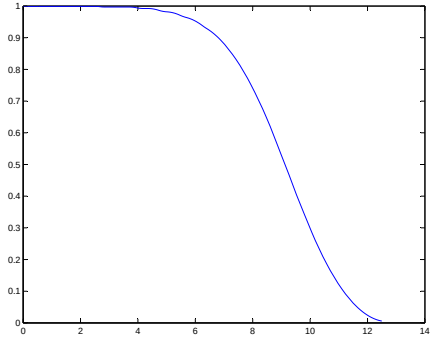


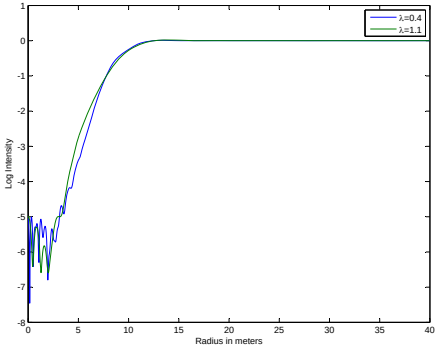
$\lambda = 1.0$ microns

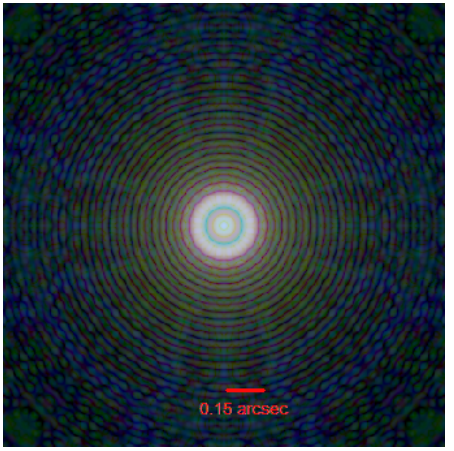








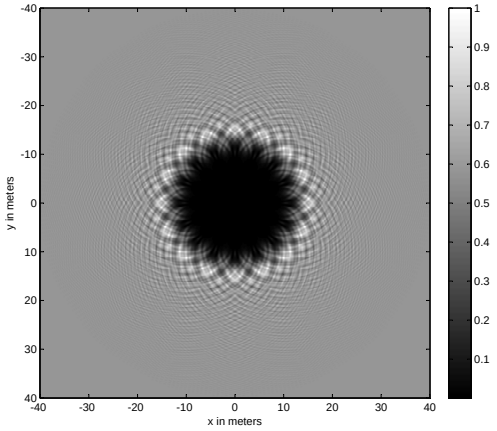




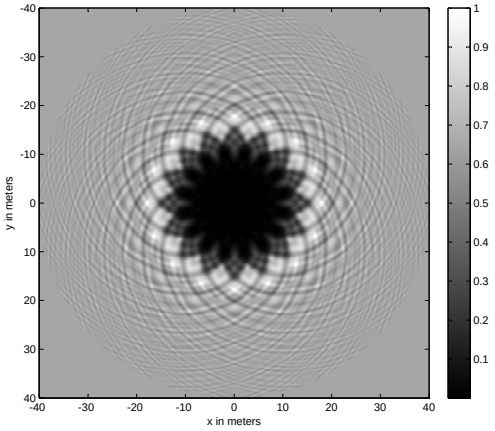
$z = 30000$ km, $R = 15$ m, HyperGaussian

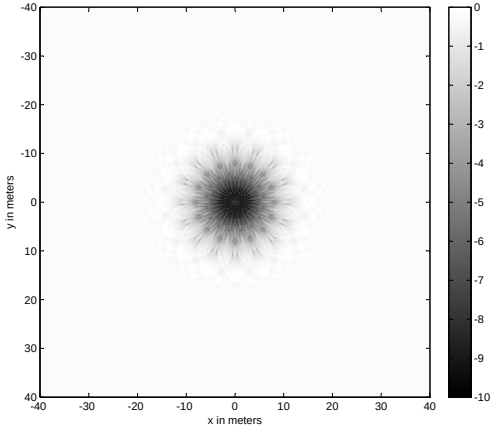
Dark (10^{-8}) hole at 0.4 microns but brightens quickly at longer wavelengths

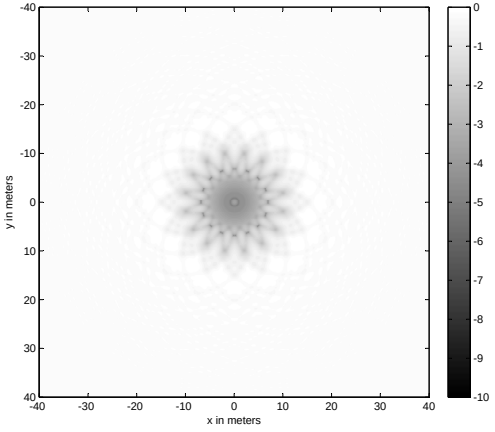
$\lambda = 0.4$ microns

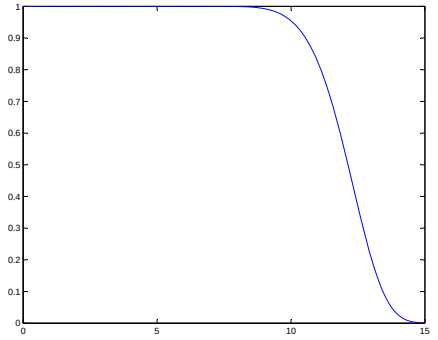


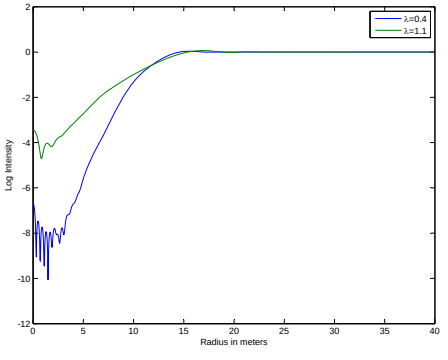
$\lambda = 1.0$ microns









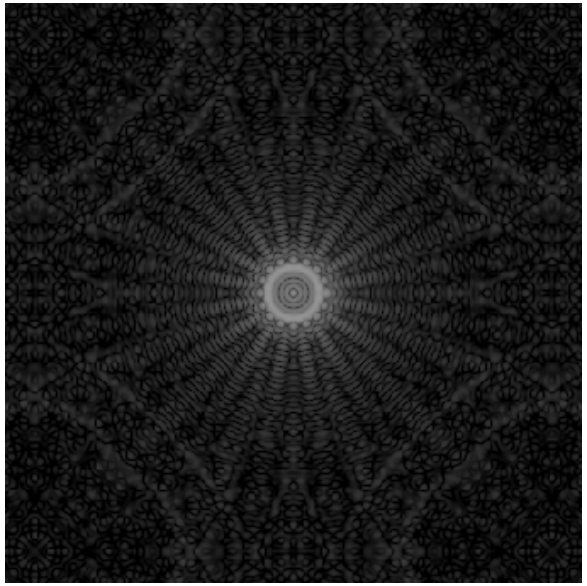


Hypergaussian, $\lambda = 0.4$ microns

This page and the next shows the 0.4 micron star-planet image. The planet, separated by 0.060 arcseconds is in the 3-o'clock position.

Blink this page with the next to see that the planet is barely detected ($Q = 1$).

NOTE: This image is qualitatively consistent with images produced by the team at Univ. of Colorado and at Northrup Grumman.

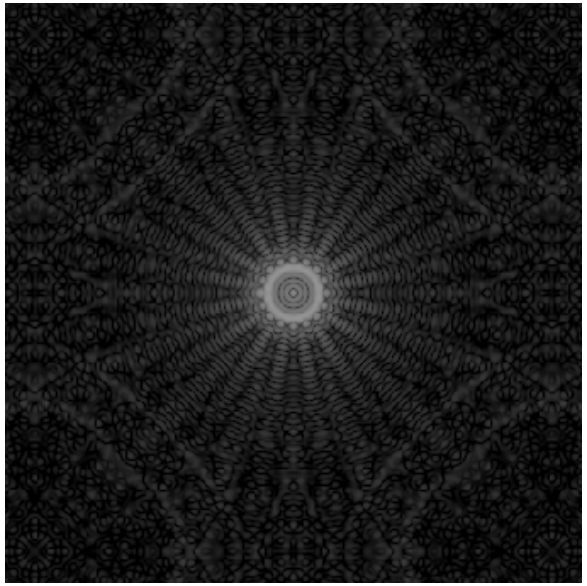


Hypergaussian, $\lambda = 0.4$ microns, Mirror Image

This page and the previous shows the 0.4 micron star-planet image. The planet, separated by 0.060 arcseconds is in the 9-o'clock position.

Blink this page with the previous to see that the planet is barely detected ($Q = 1$).

NOTE: This image is qualitatively consistent with images produced by the team at Univ. of Colorado and at Northrup Grumman.



Mission Comparisons

For 30 stars, 75 visits, 2 week travel time.

	Separation/Mask radius	
	$18000/15$	$72000/25$
Retargeting Δv (m/s)	700	2500
Total Δv (m/s)	1600	4250
Mass (kg)	2111	3300