Study of the SNAP PSF for Weak Lensing

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Introduction. I study the SNAP PSF as it relates to weak lensing. For this purpose I use a program Alex Kim has written a which creates a PSF at an arbitrary position within the SNAP field of view. I incorporate the results of numerous discussions with Alex Kim and Mike Lampton on PSF issues. I first present a sample PSF and present the effect included in the PSF model. I then discuss what is **not** included in the PSF calculations that could affect the final SNAP PSF. I then present a PSF ellipticity map over the SNAP field of view (FOV). I discuss detector distortion and the time variability of both the PSF and detector distortion. Finally, I make recommendations to optimize the PSF for a weak lensing survey.

Sample PSF. I use the most current technical specifications for SNAP to the best of my ability. The simulations are based on a primary mirror radius of 1 meter, a secondary mirror radius of 0.4 meters, 3 supporting struts of 4cm thickness, and a distance of 2.1 meters between the primary and secondary mirrors. A diffusion value of 3.5 μm is used for the CCDs. Figure 1 shows a PSF created a distance of 0.01 radians (0.57°) from the optical center of the SNAP FOV. This PSF was created with an input wavelength of 800nm. Below, I explore the dependance of PSF on wavelength. The image is a 512×512 array with each pixel equal to 0.016 arcseconds. Thus, the image measures about 8×8 arcseconds. This image shows a nearly-circular central core as well as the extended diffraction pattern caused by the struts and the aperture. Figure 2 shows the radial profile of this PSF. From this figure, it is clear that the intensity drops to 10% of the central value within 0.2 arcseconds or 2 SNAP pixels.

The PSF model from Alex Kim takes into account three effects:

- Gaussian diffusion within the CCDs
- Spot Diagram (ray tracing through the optics)
- Diffraction from the struts and the aperture

The program does not take into account several other effects, including the red defocus, which is a consequence of the fact that blue light is absorbed at the surface of the CCD while red light is absorbed throughout the thickness of the CCD. Thus, there is no optimal focal plane for red light. This is only a problem in the extreme red and thus does not effect galaxy shape measurements which will be done using optical wavelengths.

Mike Lampton (private communication, 2002) has given an extensive list of factors that might contribute to the PSF

1. ACS jitter & momentum wheel vibrations
2. ideal geometric aberrations
3. mirror manufacturing errors
4. mirror alignment errors
5. optical diffraction (depends on wavelength)

6. transparency of silicon & slant range of photons
7. CTE and image trailing in the readout direction
8. diffusion of electrons/holes within silicon

and the sizes and shapes of these effects:

1. is circular Gaussian maybe 0.02 arcsec RMS = 2 microns RMS
2. is bizarre mushrooms about 0.04 arcsec RMS = 4 microns RMS
3. is circular Gaussian maybe 0.02 arcsec RMS = 2 microns RMS
4. is circular Gaussian about 0.02 arcsec RMS = 2 microns RMS
5. is circular Airy Disk about 0.06 arcsec RMS = 6 microns RMS at one micron
6. is linear radial length < 0.10 arcsec long = 10microns x 0 microns
7. is linear sideways size < 0.01 arcsec long = 1 microns x 0 microns
8. is circular Gaussian maybe 0.05 arcsec RMS = 5 microns RMS

The largest circular effects (2,5, & 8) are included in the Alex Kim's PSF model. Item 1 is difficult to predict because the sources of telescope jitter are stochastic events. The effects of jitter will have to be measured via stellar images in orbit. Three and four are not possible to predict, but also can be easily corrected for with stellar images after SNAP has been launched. Item six is related to the red defocus discussed above. It is only about 1 micron (0.01 arcseconds) in size at 800nm (Levi, private communication, 2002). This effect increases in size as wavelength goes up. This effect can be predicted and should be added to the PSF model in the future. Finally, item 7 is a detector effect. As long as it is not time variable and is linear, this small effect should be correctible in software using data taken in orbit (Levi, private communication 2002).

PSF Field. Figures 3 to 5 show the ellipticity of the SNAP PSF over the SNAP field of view. To measure the ellipticity of the PSF I first calculate the intensity weighted second moments I_{xx}, I_{yy} and I_{xy}. These are defined as the following sum over pixels

$$I_{xy} = \frac{\sum Ixyw}{\sum I}$$

where I is the intensity in a pixel, x and y are the distances from that pixel to the centroid of the PSF and w is a gaussian weighting function with a standard deviation of 0.2 arcseconds. Similar equations hold for I_{xx} and I_{yy}. Then, the two-component ellipticity e_i is defined as

$$e_1 = \frac{I_{xx} - I_{yy}}{I_{xx} + I_{yy}}$$

$$e_2 = \frac{2I_{xy}}{I_{xx} + I_{yy}}$$

SNAP contains CCD detectors in an annulus around the center of the FOV. I have chosen to calculate the PSF across the entire FOV, but I have indicated where the annulus and the detectors are on the plots.

I have made these plots for wavelengths in the range 600-1000 nm. These figures show that the PSF at a position is highly dependent on the wavelength. The size of the PSF induced ellipticity is not large, roughly 3 % at most. By comparison the PSF induced ellipticity of WFPC2 on HST is up to 10%. The PSF does change over the FOV and in fact over a single CCD detector. Therefore a much finer grid of model PSFs would be needed to accurately model the SNAP PSF over the entire FOV. This would require enhancements to Alex Kim's program. Currently the spot diagram is only calculated at discrete intervals and no interpolation is done between these intervals. Thus, the program is currently only set up to reproduce the gross features of the SNAP PSF.

The PSF fields show only indicate the ellipticity induced by the PSF, not the size of the PSF itself. The size of the PSF is crucial because only galaxies with sizes larger than the PSF can provide useful shape or size information for weak lensing. Figure 6 shows the PSF size as a function of wavelength. The size shown is the FWHM of a Gaussian fit to the PSF by the IDL procedure *Gauss2dfit*. The PSF size does not increase linearly with slope 1 with wavelength, as one would expect for a diffraction limited PSF. Clearly, factors other than diffraction are driving the PSF size at smaller wavelengths. Thus, it would be advantageous for us to measure galaxy shapes with a short wavelength. Figures 8 to 10 show the sizes of various contributions to the PSF over the wavelength range 600-1000 nm. Other simulations using 5 μm diffusion show that at this value of diffusion, the PSF size is dominated by diffusion. Thus, SNAP should aim for 3.5 μm or less diffusion. Figure 7 shows the PSF size as a function of wavelength for diffusion of 5 μm.

Detector Distortion. Another important factor affecting the measured image shapes is distortion from the detector. We have not yet developed a model for this but it is easy to calculate a correction for this effect using astrometric shifts of stellar positions (e.g., Rhodes, Refregier and Groth, ApJ, 536,79,2000, RRG).

Time Variability. The time variability of the PSF is a concern given the accuracy to which object shapes need to be measured for weak lensing. The HST's PSF changes significantly in time periods of order days (RRG). SNAP will suffer from some amount of "structural dryout creep" which is an outgassing of water from carbon fiber elements of the optical support structure. The optical supports will shrink as this outgassing occurs, but this is expected to last only a few months and then stabilize (Lampton, private communication, 2002). During this initial phase the telescope will be refocused to bring the PSF back to it's nominal value but drift from that value as the telescope goes out of focus. Thus, this will not be the optimal time for weak lensing measurements. The spacecraft will undergo thermal expansion and contraction as the amount of sunlight hitting it changes in its orbit. The currently planned high orbit will minimize this effect. The amount of this effect is not possible to predict and will have to be monitored by examining stellar data. There will also be an initial thermal contraction as the telescope cools after launch. This will take several months (Lampton, 2002, private communication) making the initial mission period even worse for weak lensing measurements. There may also be a "creaking" of the structure that supports the detectors as they cool down initially. This effect will be gone when operating temperature is reached. The Charge Transfer Efficiency (CTE) of the CCDs will degrade over time, leaving trails during readout. The SNAP CCDs are specifically designed to not suffer from significant degradation in the CTE. Finally, there will be some vibration of the spacecraft from the momentum wheels. This will hopefully be kept below 1μas, making this effect small compared to others discussed above.

Recommendations. Based on the information presented concerning the SNAP PSF, I recommend the following for a weak lensing survey:

1. A weak lensing survey NOT be conducted within the first several months of SNAP's launch

2. Galaxy shapes be measured with a filter at $\sim$ 800nm or shorter
3. Stellar images be taken at regular intervals to monitor and correct for the SNAP PSF
4. Astrometric shifts of stars be used to calculate detector distortion early in SNAP's lifetime
5. Aim for 3.5 μm diffusion or less

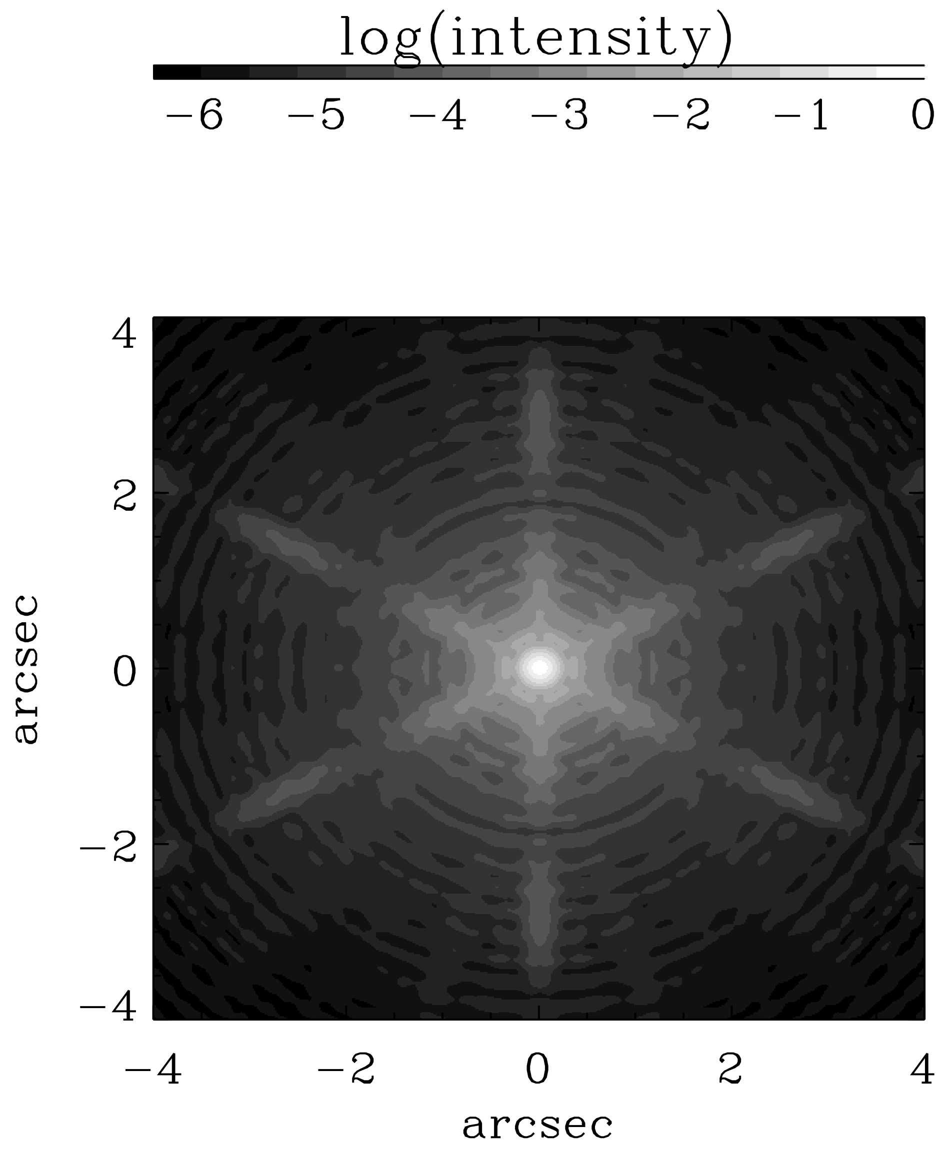

Fig. 1.— 512×512 image of the logarithm of the PSF. The image is 8 arcseconds on a side.

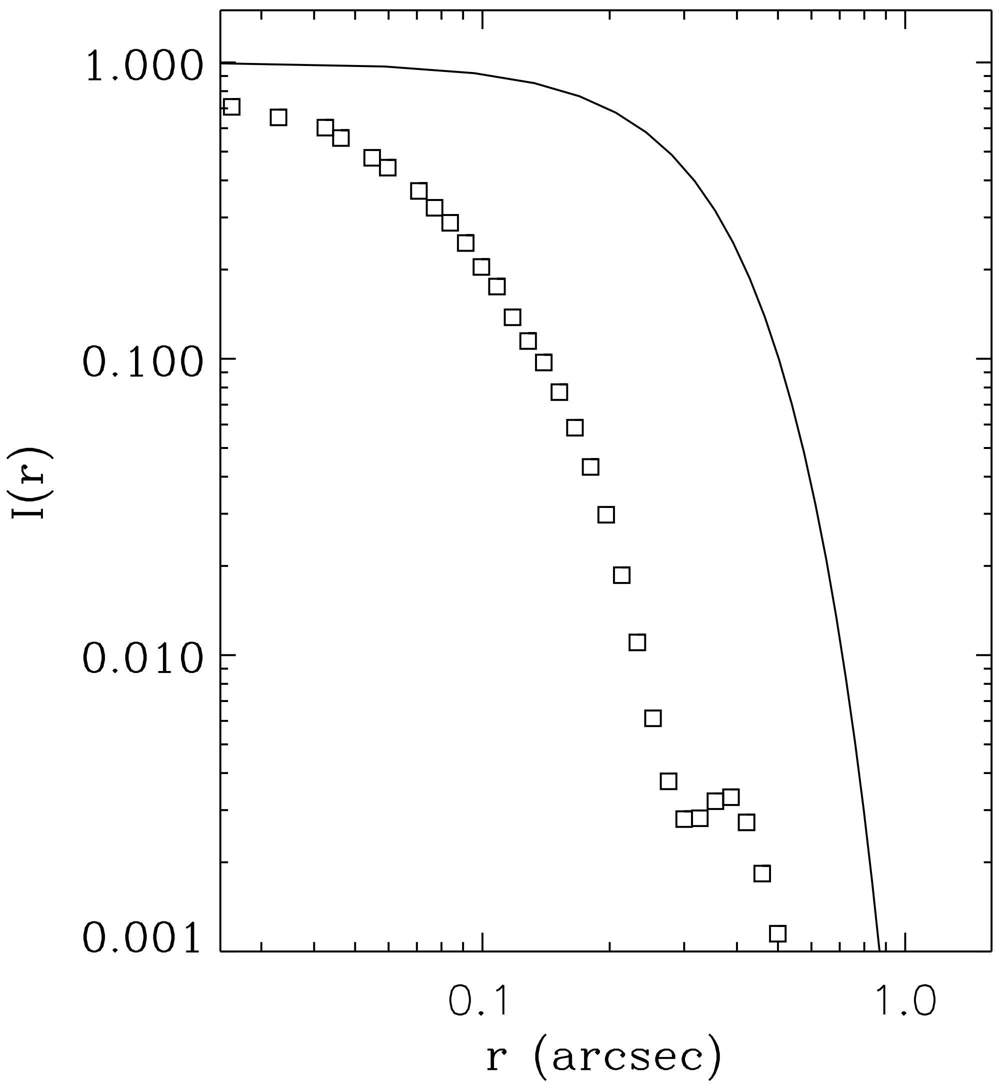

Fig. 2.— Radial profile of the SNAP PSF for 3.5 μm diffusion. This logarithmic plot shows the the intensity I as a function of the radius from the center of the PSF (boxes). The curve is a Gaussian representing a FWHM of 0.55 arcseconds, the best seeing consistently available at the Keck Telescope.

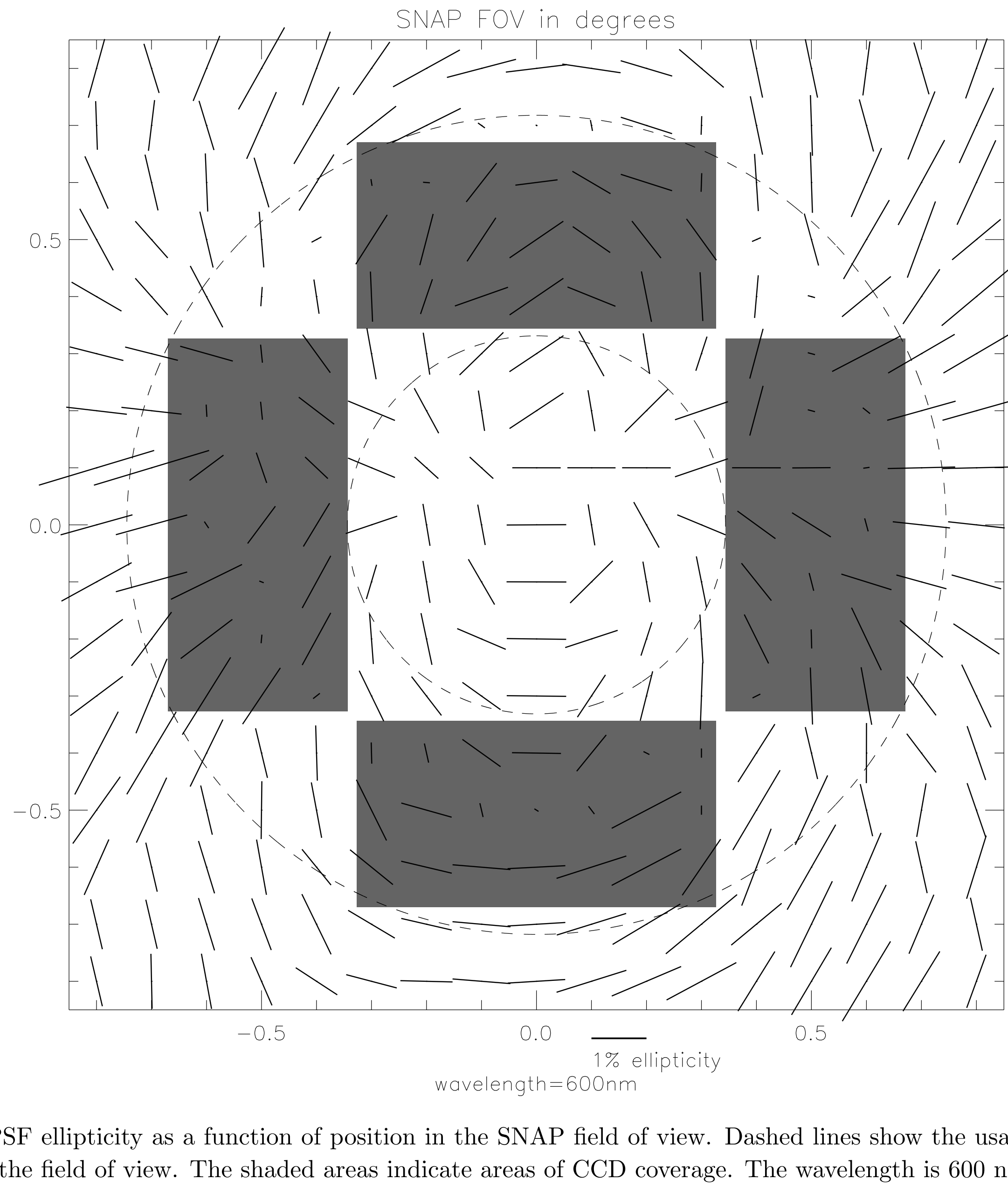

Fig. 3.— PSF ellipticity as a function of position in the SNAP field of view. Dashed lines show the usable annulus of the field of view. The shaded areas indicate areas of CCD coverage. The wavelength is 600 nm.

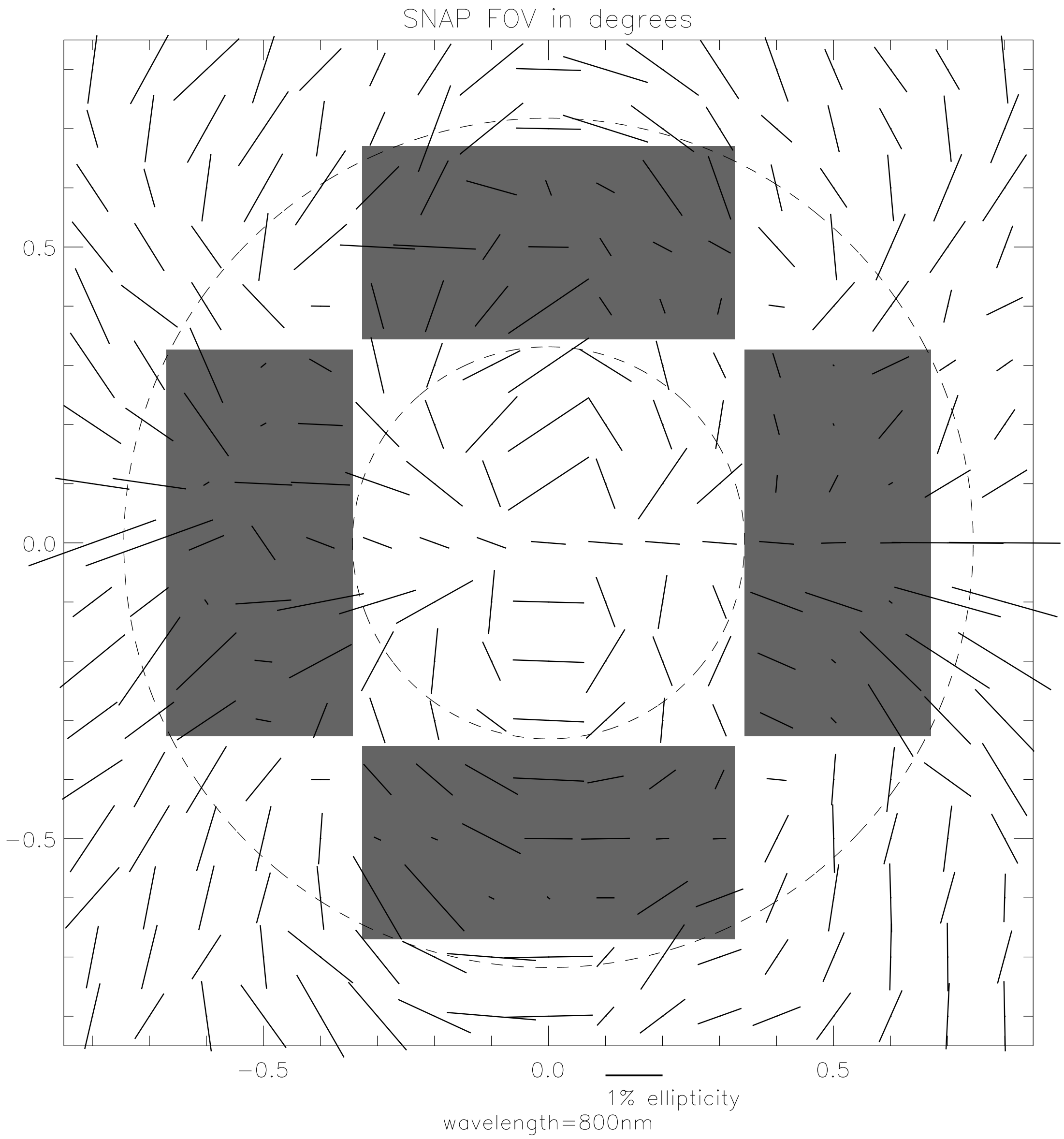

Fig. 4.— Same as previous figure but with wavelength 800 nm.

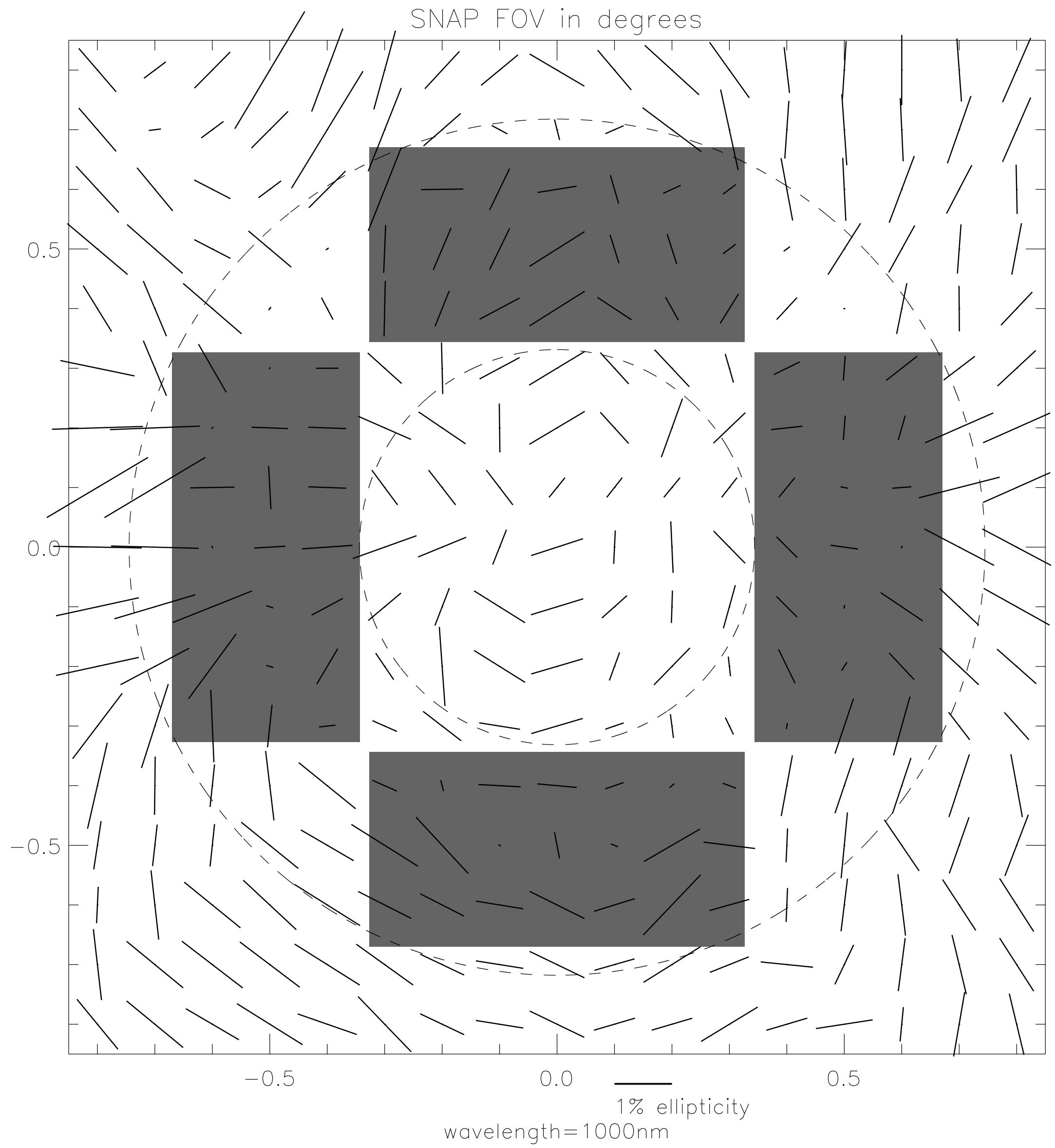

Fig. 5.— Same as previous figure but with wavelength 1000 nm.

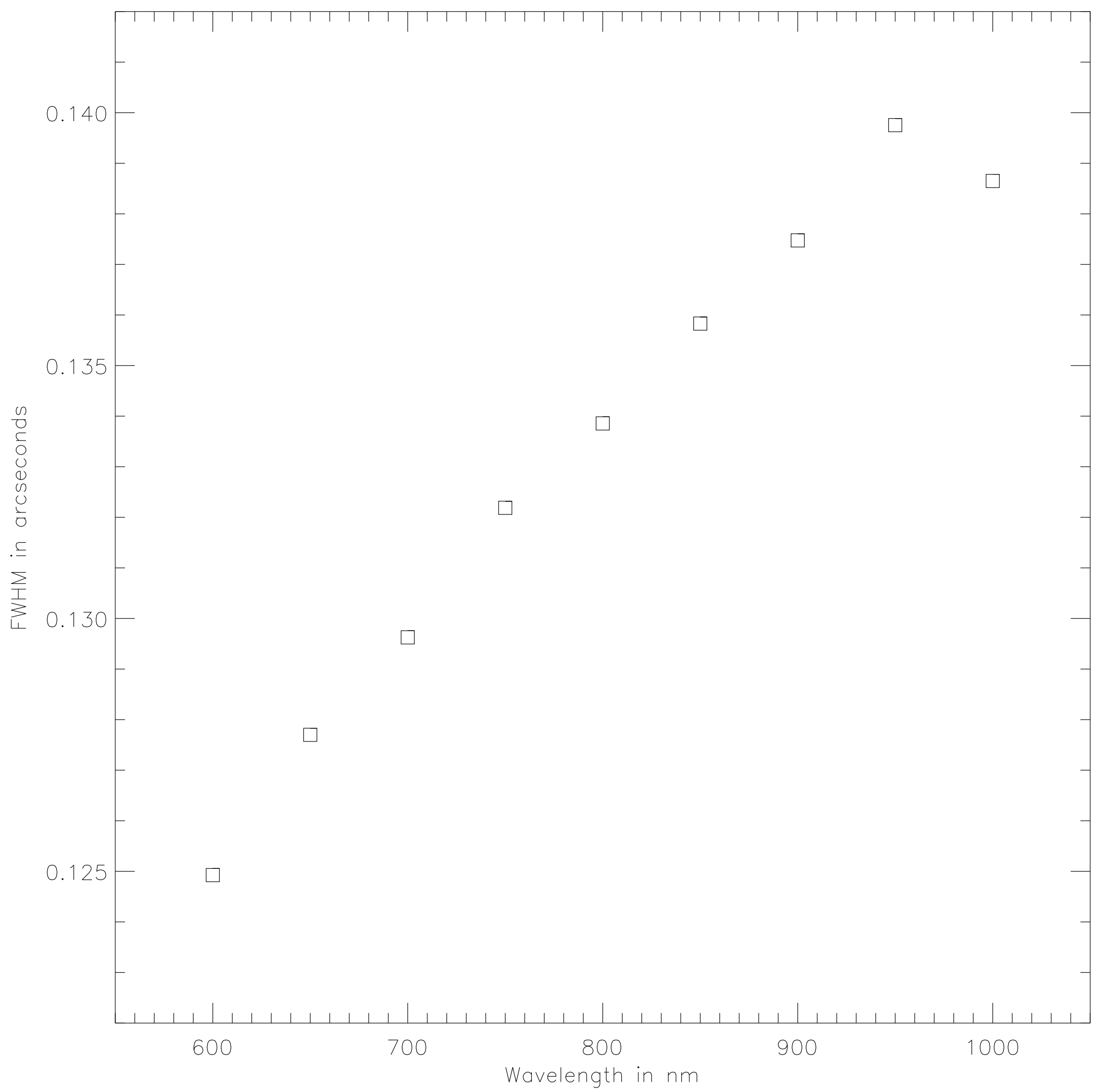

Fig. 6.— The FWHM in arcseconds of a Gaussian fit to the PSF as a function of wavelength for 3.5μ m diffusion.

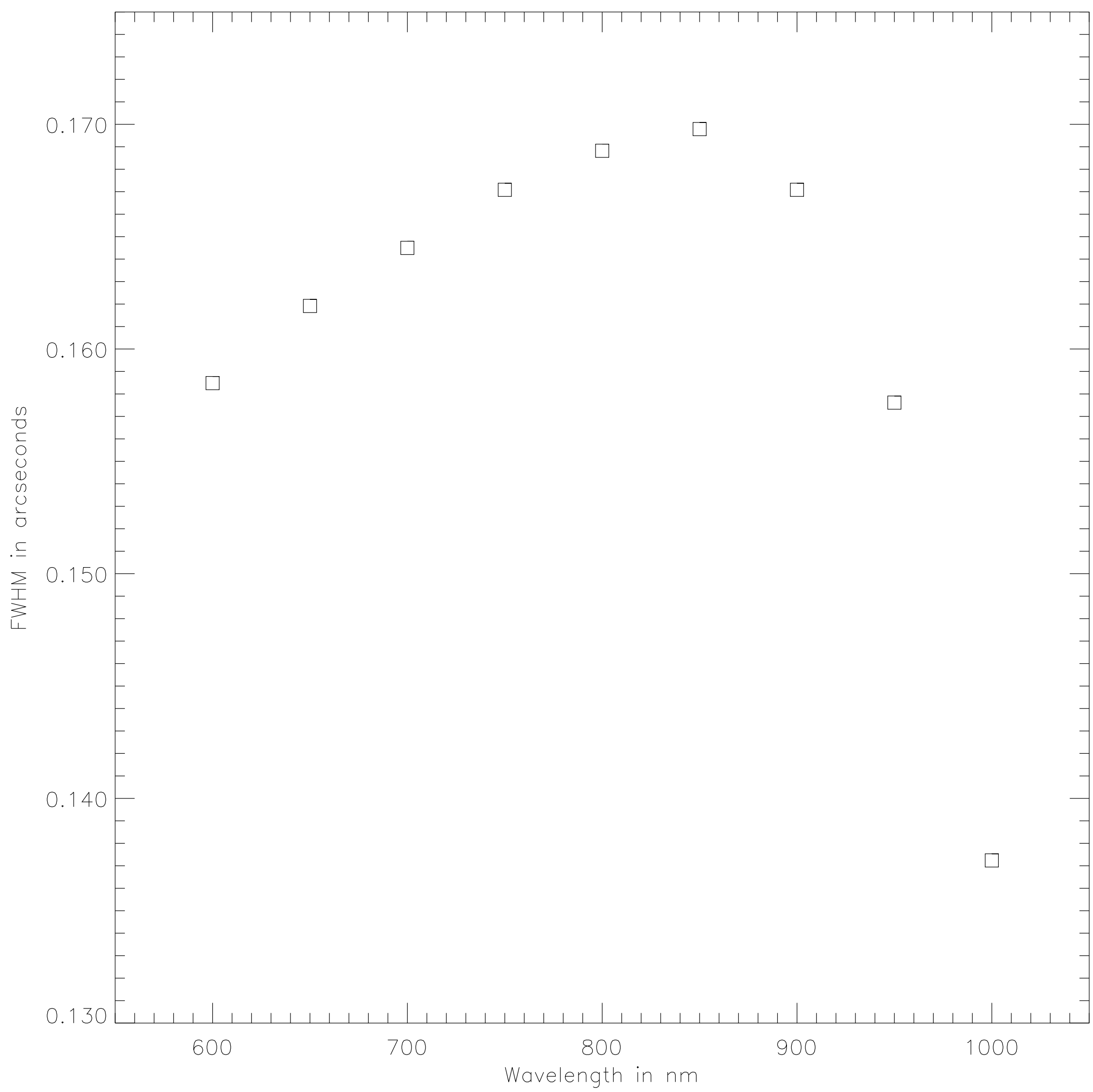

Fig. 7.— PSF size as a function of wavelength for 5μm diffusion.

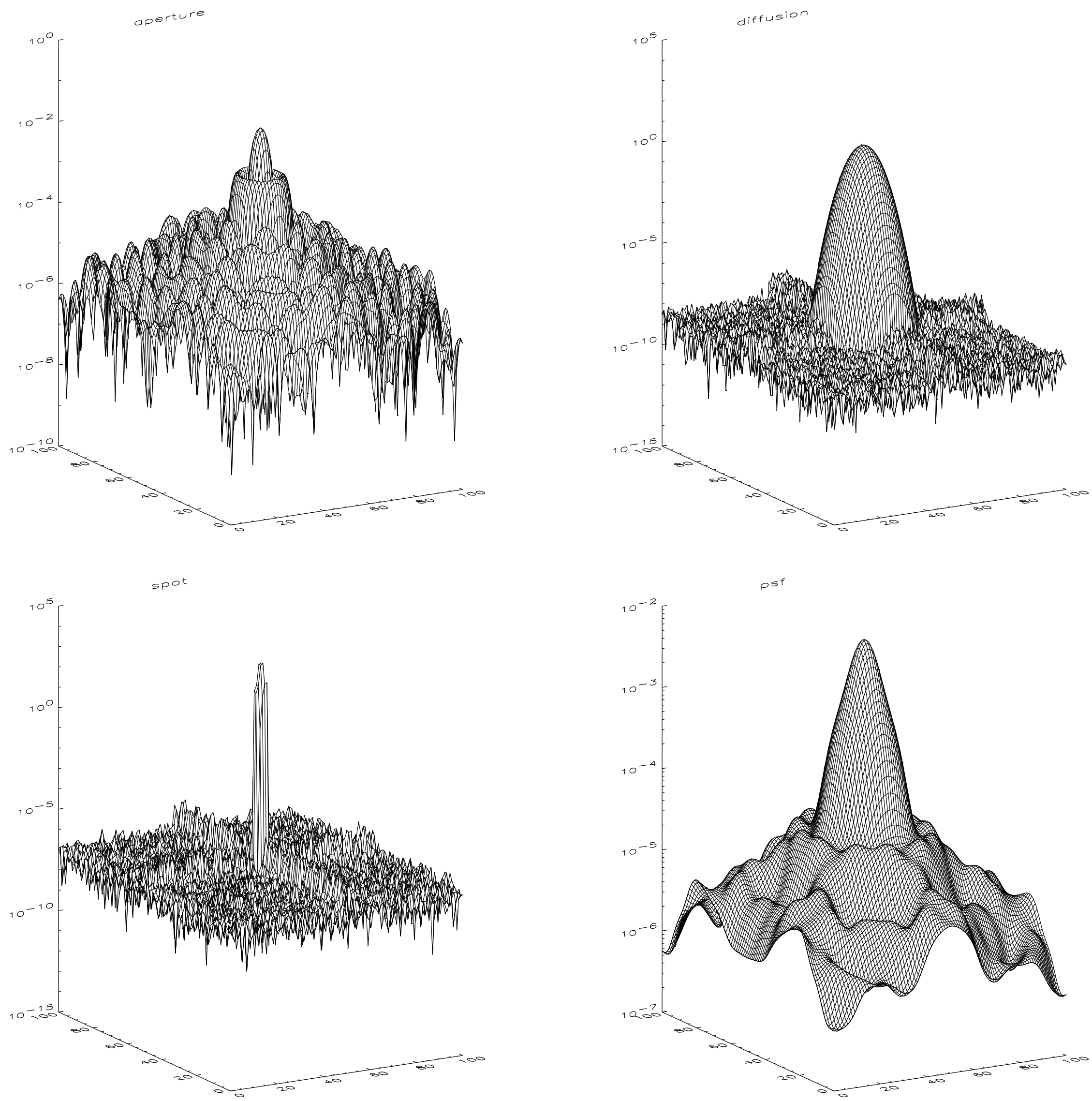

Fig. 8.— Various contributions to the PSF at 600nm. Aperture, diffusion, spot diagram, total PSF.

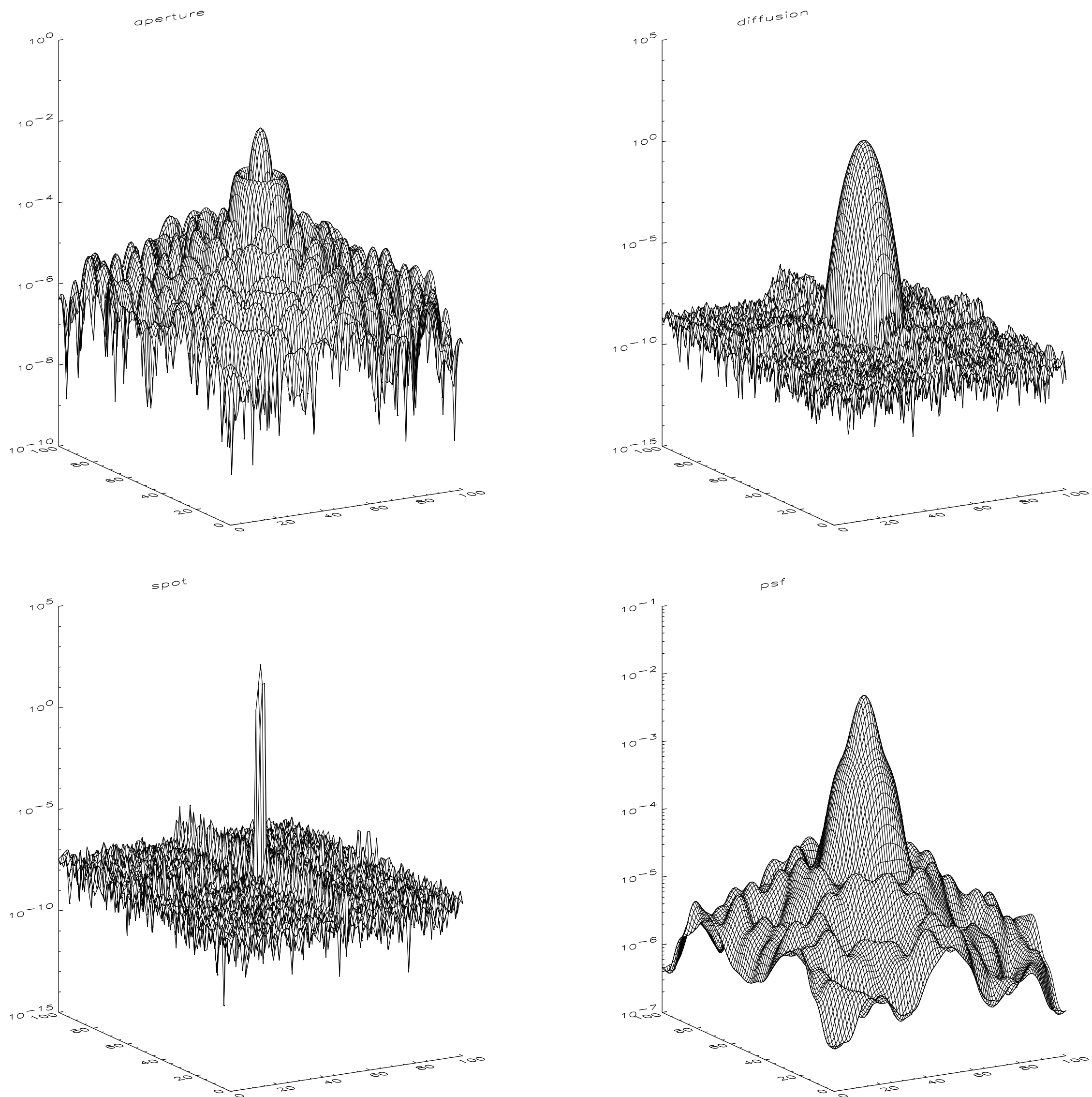

Fig. 9.— Various contributions to the PSF at 800nm

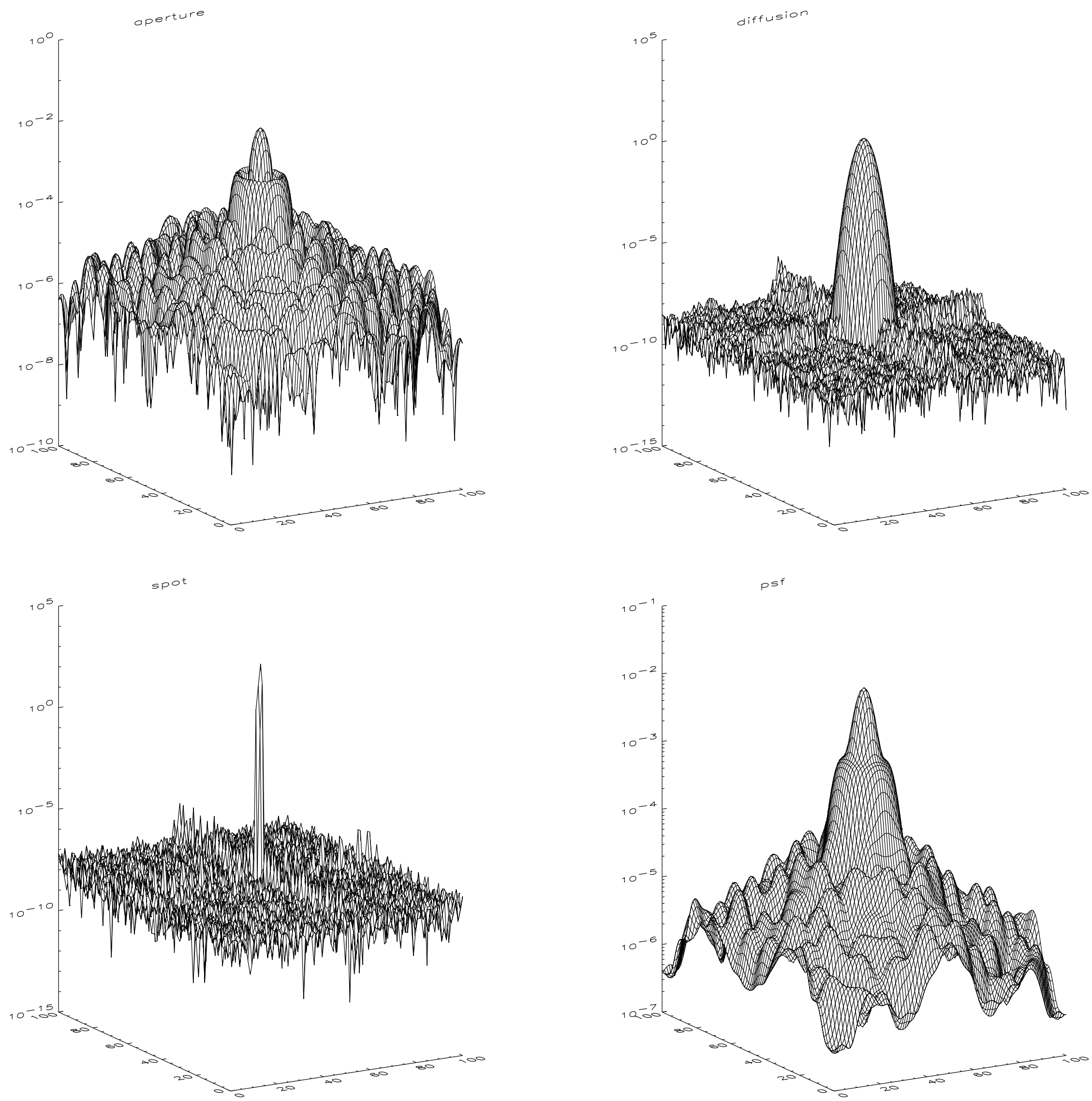

Fig. 10.— Various contributions to the PSF at 1000nm