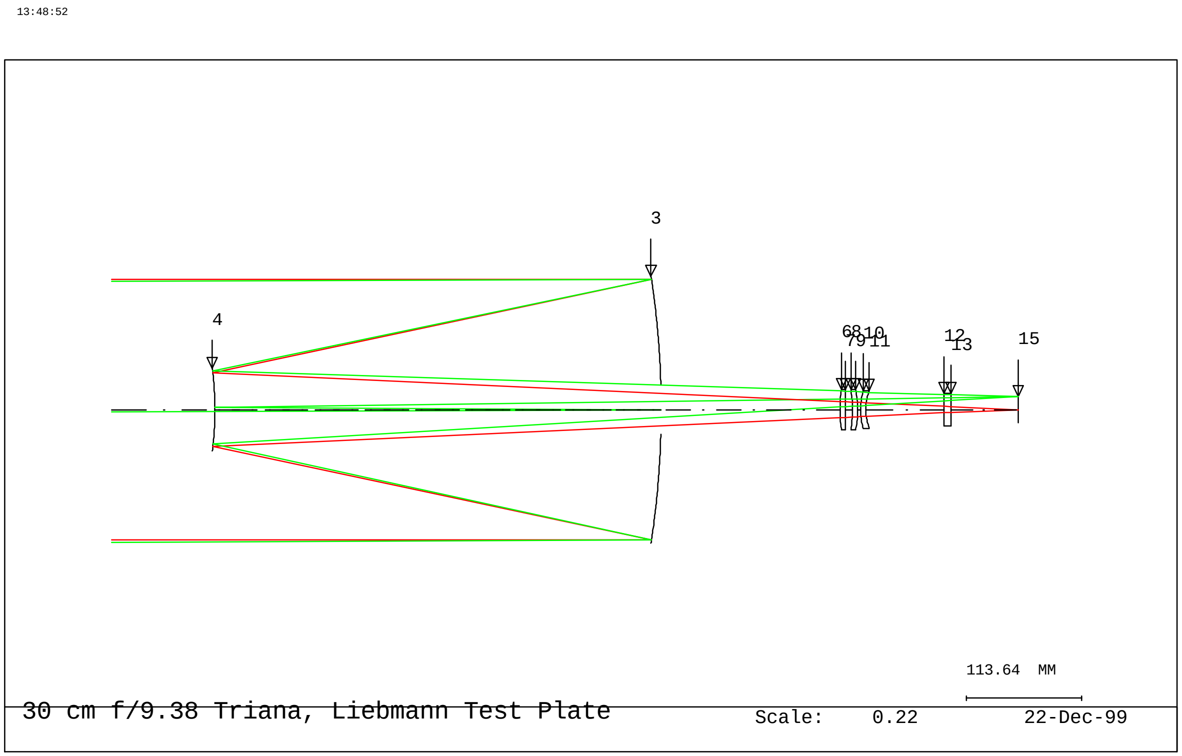
Memo

29 February, 2000

TO: Robert Smith
From: Eugene Waluschka
Subject: Triana Ghosting Analysis - Version IV

This is a repeat of the 20 December, 2000 memo. The only difference is the use of a new **Filter Reflectivity** table (from Paul Robb's 2/25/2000 "Epic Filter Reflectivity Measurements" e-mail note which was modified by the addition of a 605nm row to be consistant with the previous tables).



A schematic of the Triana optical system is shown to the right.

Eugene Waluschka

Methodology (again)

A Monte Carlo ray trace approach is used to determine the light distribution on the focal plane. A random bundle of rays enters the telescope. 10000 random points in a circle representing the Earth are the starting points of these 10000 rays. Each intersection with the unobscured entrance aperture is randomly chosen. Each ray propagates to the focal plane or spectral filter and is reflected. Each ray then propagates to each (preceding) surface and is subsequently reflected back to the focal plane. All of these ray intercepts give a good indication of the light distribution on the focal plane in the primary image and from the twice reflected (once by the focal plane and a second time by a lens surface) ghost light. Each ray's intensity is attenuated by reflections and refractions.

The assumed (attenuation) transmission (T) and reflection (R) coefficients for the telescope and triplet are (the subscript indicates the surface):

$R_3 := 0.95$ $\quad T_9 := \sqrt{.975}$

$R_4 := 0.95$ $\quad T_{10} := \sqrt{.975}$

$T_6 := \sqrt{.975}$ $\quad T_{11} := \sqrt{.975}$ $\quad \sqrt{.975} = 0.98742$

$T_7 := \sqrt{.975}$

$T_8 := \sqrt{.975}$

The spectral filter's tranmissions characteristics and the ccd's reflection characteristics are read in below:

epic_filters_reflection := READPRN("C:\WINMCAD\applications\triana\updated filter reflectances (preliminary).txt")

epic_ccd := READPRN("C:\WINMCAD\applications\triana\epic_ccd.txt")

epic_filters := READPRN("C:\WINMCAD\applications\triana\epic_filters.txt")

This is the new filter reflection data

epic_filters_reflection := READPRN("C:\WINMCAD\applications\triana\full_field\EPIC FILTER REFLECTANCE 2.txt") epic_ccd =

	0	1	2	3
0	317.5	11	87	2
1	325	10	87.5	2.5
2	340	11.5	87	1.5
3	388	19	78	3
4	393.5	18.5	78.5	3
5	443	19	78.5	2.5
6	551	23	76	1
7	605	23.5	74.5	2
8	645	23.5	72.5	4
9	869.5	13.5	34	52.5
10	905	12	29	59

epic_filters_reflection =

	0	1
0	317.5	0.49
1	325	0.87
2	340	0.05
3	388	0.21
4	393.5	1.2
5	443	0.22
6	551	0.05
7	605	0.15
8	645	0.15
9	869.5	0.08
10	905	0.16

epic_filters =

	0	1	2	3
0	317.5	1	57.6	42.4
1	325.2	1	56.4	43.6
2	339.7	2.7	67.1	32.9
3	387.8	2.8	66.9	33.1
4	393.4	1.1	65.2	34.8
5	443	9	76.7	23.3
6	550.6	8.3	71.4	28.6
7	604.8	2.1	94.6	5.4
8	644.1	10.1	91.3	8.7
9	868.5	14.6	94.5	5.5
10	905.6	31.5	89.1	10.9

$$R15 := \frac{epic\_ccd^{\langle 1 \rangle}}{100}$$

$$R12 := \frac{epic\_filters\_reflection^{\langle 1 \rangle}}{100}$$

$$T12 := \frac{epic\_filters^{\langle 2 \rangle}}{100}$$

R15 =

	0
0	0.11
1	0.1
2	0.115
3	0.19
4	0.185
5	0.19
6	0.23
7	0.235
8	0.235
9	0.135
10	0.12

R12 =

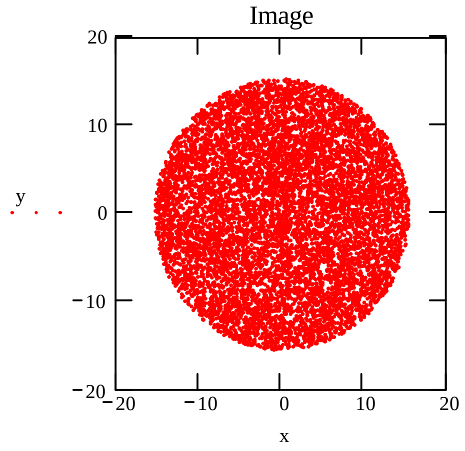
	0
0	$4.9 \cdot 10^{-3}$
1	$8.7 \cdot 10^{-3}$
2	$5 \cdot 10^{-4}$
3	$2.1 \cdot 10^{-3}$
4	0.012
5	$2.2 \cdot 10^{-3}$
6	$5 \cdot 10^{-4}$
7	$1.5 \cdot 10^{-3}$
8	$1.5 \cdot 10^{-3}$
9	$8 \cdot 10^{-4}$
10	$1.6 \cdot 10^{-3}$

T12 =

	0
0	0.576
1	0.564
2	0.671
3	0.669
4	0.652
5	0.767
6	0.714
7	0.946
8	0.913
9	0.945
10	0.891

Image spot diagrams (again)

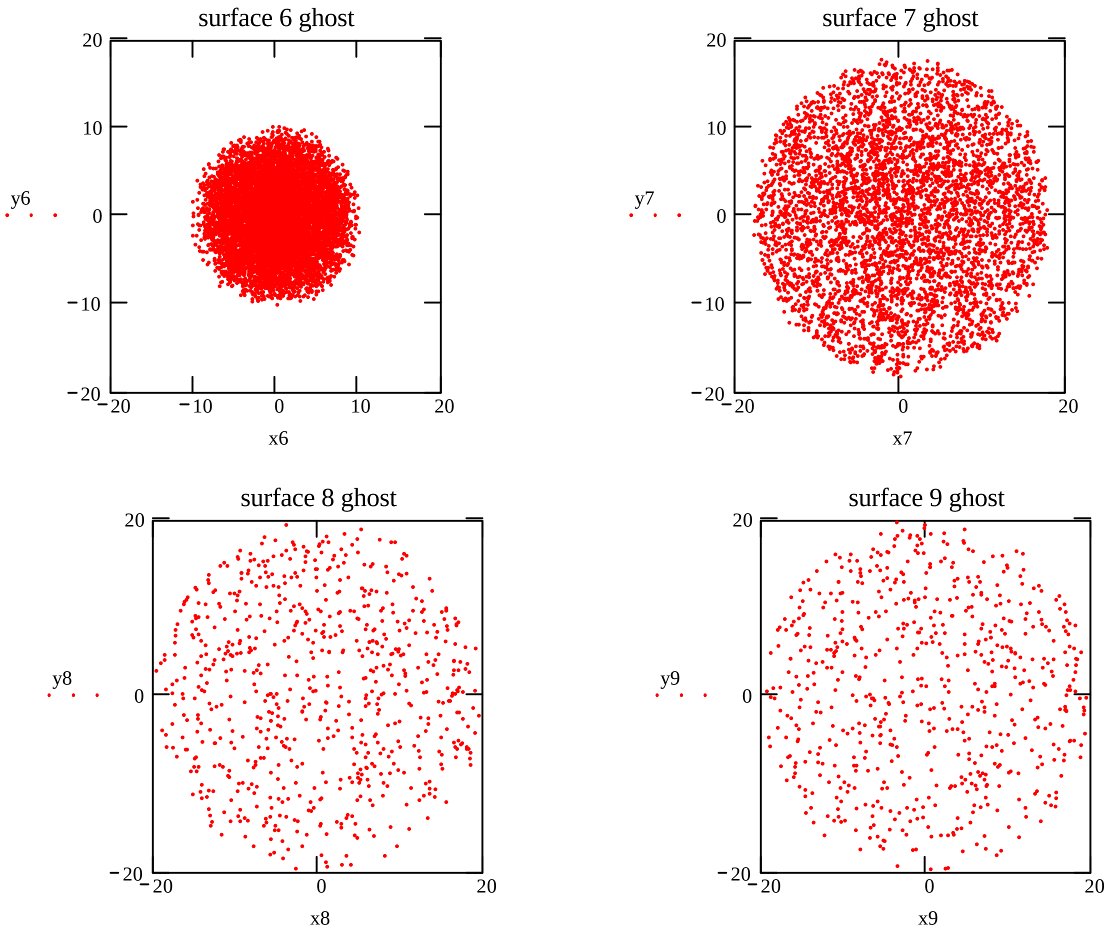
The focal plane random spot diagram (9649 spots of a total of 10000 used in computation, the rest went outside of a aperture) is shown below. The X and Y units are millimeters. This is the image of the source.

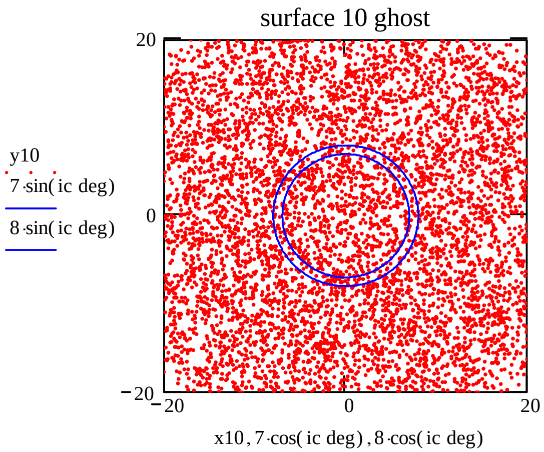


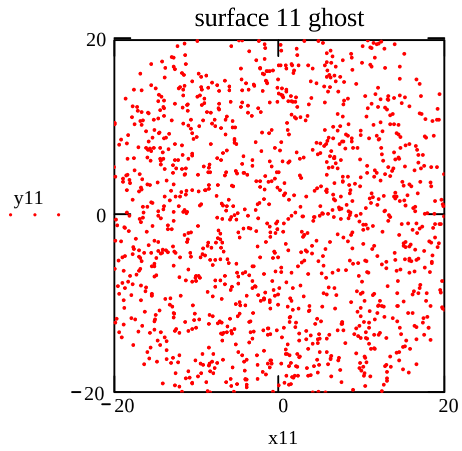
As can be seen the image has a uniform random spot distribution.

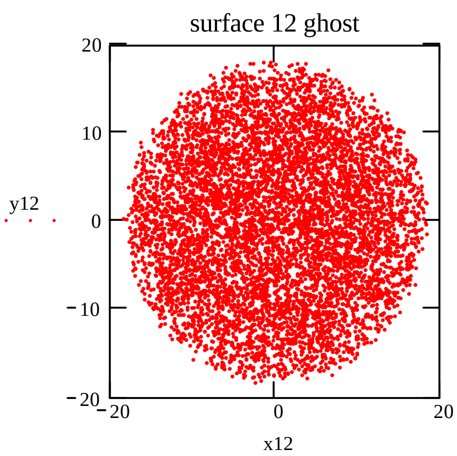
Surface ghost images

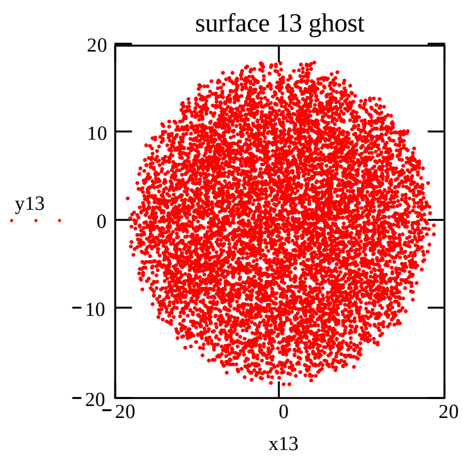
The spot diagrams on the focal plane of rays reflected from the focal plane then a particular surface (as indicated) and then back to the focal plane are shown below. These are the surface "ghosts" of the above image.




surface 10 ghost
20
0
−20
−20
0
20
y10
7·sin(ic deg)
8·sin(ic deg)
x10 , 7·cos(ic deg) , 8·cos(ic deg)


surface 11 ghost
20
0
−20
−20
0
20
y11
x11


surface 12 ghost
20
10
0
−10
−20
−20
0
20
y12
x12


surface 13 ghost
20
10
0
−10
−20
−20
0
20
y13
x13

Spot intensities

Each spot in the above diagrams represents a certain amount of attenuated radiant flux reaching the focal plane. The attenuation factors are (treating surfaces 12 and 13 as one surface):

$$a_{image} := R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12$$

$$a_6 := \overrightarrow{\left[R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12 \cdot R15 \cdot T12 \cdot T_{11} \cdot T_{10} \cdot T_9 \cdot T_8 \cdot T_7 \cdot \left(1 - T_6\right) \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12\right]}$$

$$a_7 := \overrightarrow{\left[R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12 \cdot R15 \cdot T12 \cdot T_{11} \cdot T_{10} \cdot T_9 \cdot T_8 \cdot \left(1 - T_7\right) \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12\right]}$$

$$a_8 := \overrightarrow{\left[R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12 \cdot R15 \cdot T12 \cdot T_{11} \cdot T_{10} \cdot T_9 \cdot \left(1 - T_8\right) \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12\right]}$$

$$a_9 := \overrightarrow{\left[R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12 \cdot R15 \cdot T12 \cdot T_{11} \cdot T_{10} \cdot \left(1 - T_9\right) \cdot T_{10} \cdot T_{11} \cdot T12\right]}$$

$$a_{10} := \overrightarrow{\left[R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12 \cdot R15 \cdot T12 \cdot T_{11} \cdot \left(1 - T_{10}\right) T_{11} \cdot T12\right]}$$

$$a_{11} := \overrightarrow{\left[R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12 \cdot R15 \cdot T12 \cdot \left(1 - T_{11}\right) \cdot T12\right]}$$

$$a_{12} := \overrightarrow{\left(R_3 \cdot R_4 \cdot T_6 \cdot T_7 \cdot T_8 \cdot T_9 \cdot T_{10} \cdot T_{11} \cdot T12 \cdot R15 \cdot R12\right)}$$

Now because there are 11 wavelengths we have

$a_{image} =$

	0
0	0.48182
1	0.47178
2	0.56129
3	0.55961
4	0.54539
5	0.64159
6	0.59725
7	0.79132
8	0.76372
9	0.79048
10	0.74531

Focal plane illumination variations

All of the spot diagrams are circularly symmetric about the focal plane origin. The focal plane illumination in this case will only be function of radial distance, r , from its center. If $\rho_i(r)$ is density of points (suitable averaging because the points are sparse) in the above spot diagrams, then the number of points, f_i , in a ring of radius r_n and thickness Δr (as shown in the surface 10 plot above) is given by

$$f_i = \int_{r_n}^{r_n + \Delta R} 2\,\pi \cdot r \cdot \rho_i(r)\,dr$$

and

$$r_{n+1} = r_n + \Delta r$$

With this we have that the total ghost flux in any particular ring is given my

$$ghost\_flux := a_6 \cdot f_6^T + a_7 \cdot f_7^T + a_8 \cdot f_8^T + a_9 \cdot f_9^T + a_{10} \cdot f_{10}^T + a_{11} \cdot f_{11}^T + a_{12} \cdot f_{12}^T$$

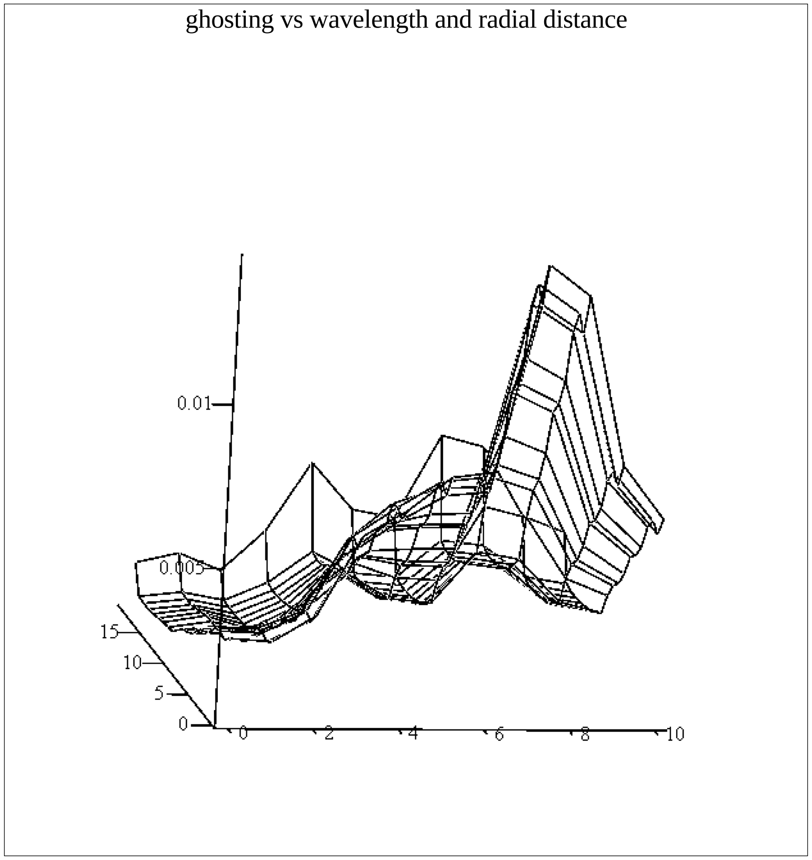
The image flux is $image\_flux := a_{image} \cdot f_{image}^T$

and the ratio of the two is shown in the table below where the horizontal scale represents radial (zone) distance from the center of the focal plane to the edge of the image and vertically the dependence is on wavelength.

$$\overrightarrow{\frac{ghost\_flux}{image\_flux}} =$$

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
1	0.003	0.002	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002
2	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
3	0.006	0.005	0.006	0.005	0.004	0.004	0.004	0.003	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003
4	0.007	0.006	0.006	0.006	0.006	0.005	0.005	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.005
5	0.008	0.007	0.007	0.007	0.006	0.005	0.005	0.004	0.004	0.003	0.003	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.003
6	0.008	0.007	0.007	0.007	0.006	0.005	0.005	0.004	0.004	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.003
7	0.014	0.013	0.013	0.012	0.011	0.01	0.009	0.008	0.007	0.006	0.005	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.005
8	0.013	0.012	0.012	0.012	0.01	0.009	0.009	0.007	0.006	0.006	0.005	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.005
9	0.008	0.007	0.008	0.007	0.006	0.005	0.005	0.004	0.004	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.003
10	0.006	0.006	0.006	0.006	0.005	0.004	0.004	0.003	0.003	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002

Plotting this array we see that the edges of the image at the two longest wavelengths have the ratio in excess of about 5%.



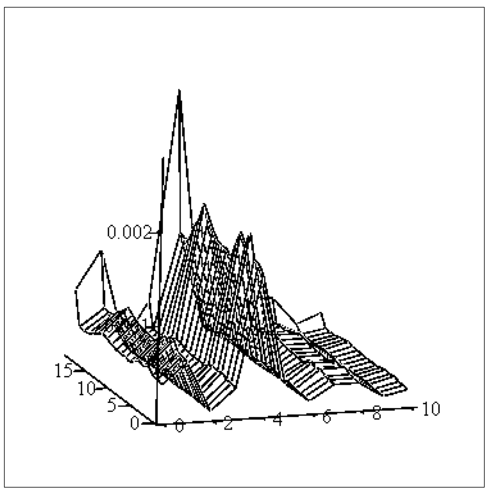
$$\overrightarrow{\frac{ghost\_flux}{image\_flux}}$$

Looking at just the filter contribution to the ghosting $filter\_flux := a_{12} \cdot f_{12}^{T}$ we have

$\overrightarrow{\frac{filter\_flux}{image\_flux}} =$

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
1	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0	0	0	0.001
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.003
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

or



$\overrightarrow{\frac{filter\_flux}{image\_flux}}$

Conclusion

Is this my final answer?