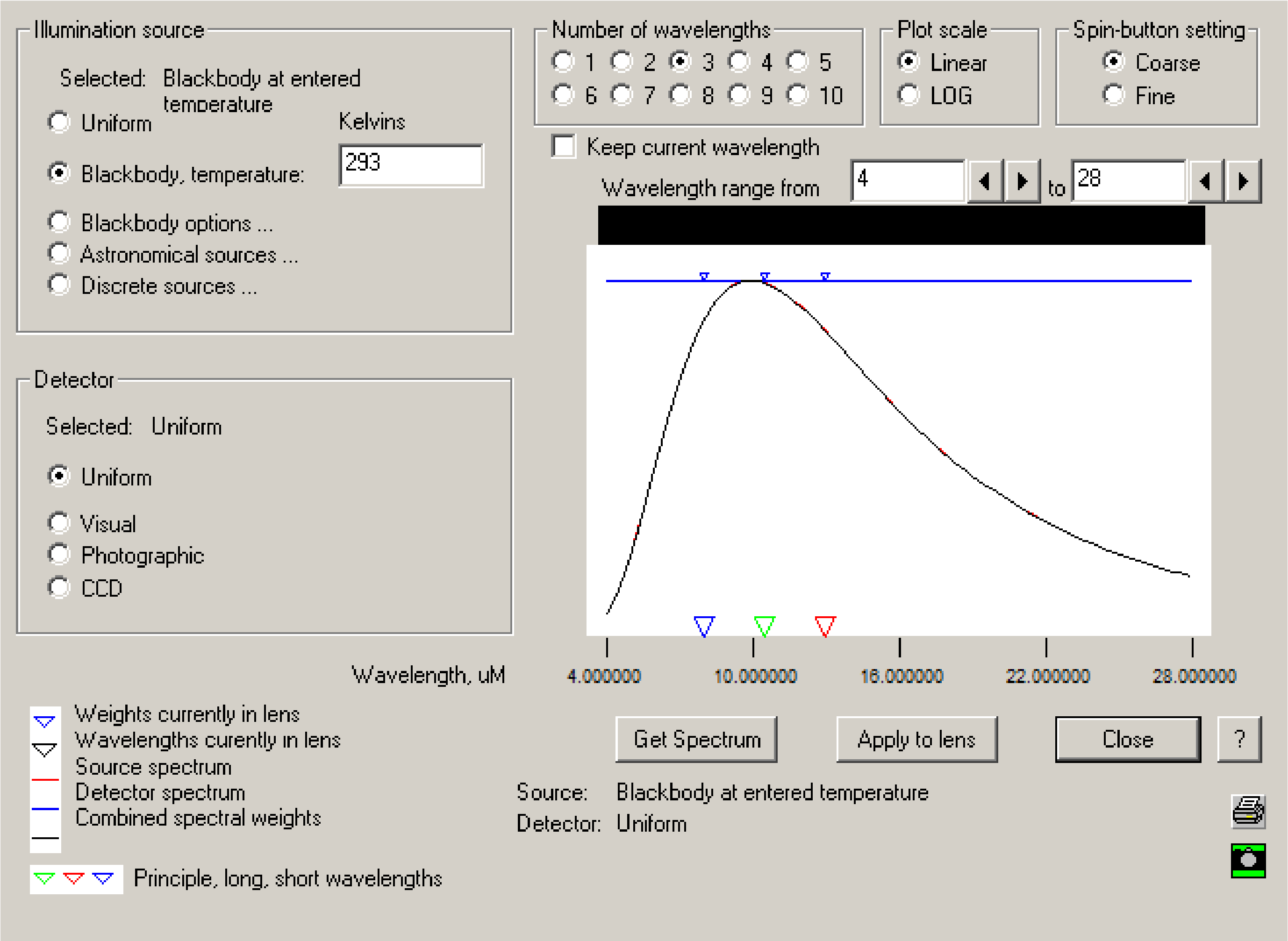
Lesson 27: Understanding the Narcissus Effect

Night-vision systems can see in total darkness. That works because all matter in the universe radiates energy in the form of photons, following the Planck function in the case of a perfect blackbody radiator, or approximating that function to some degree otherwise. Since your skin is close to room temperature at 20 degrees Celsius or 293 Kelvins, you emit radiation according to the curve shown below, as calculated by the SpectrumWizard[1]. Note the peak at about 10 microns. (Type **MSW** to open the Wizard.)



Illumination source

Selected: Blackbody at entered temperature

○ Uniform

● Blackbody, temperature: 293 Kelvins

○ Blackbody options ...

○ Astronomical sources ...

○ Discrete sources ...

Detector

Selected: Uniform

● Uniform

○ Visual

○ Photographic

○ CCD

Number of wavelengths: ○ 1 ○ 2 ● 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Plot scale: ● Linear ○ LOG

Spin-button setting: ● Coarse ○ Fine

☐ Keep current wavelength

Wavelength range from 4 to 28

Source: Blackbody at entered temperature

Detector: Uniform

Although the atmosphere absorbs much infrared radiation, it has a window of transparency centered at a wavelength of just over 10 microns, which nicely fits the spectrum shown above.

Night-vision systems sense this radiation by means of a detector that converts IR photons into an electrical current. A common material for this purpose is HgCdTe, which has a spectral sensitivity as shown below (this figure is from *The Infrared Handbook*, by Wolfe and Zissis. The exact sensitivity range depends on the relative proportions of the ingredients). We are fortunate that the source, atmosphere, and detector all work well over the required spectral window.

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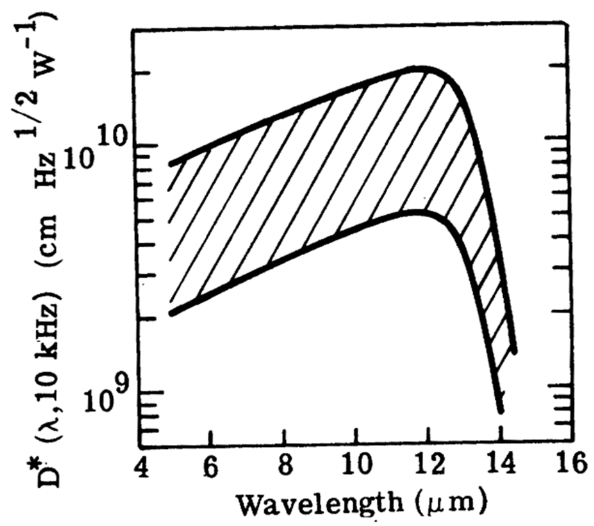
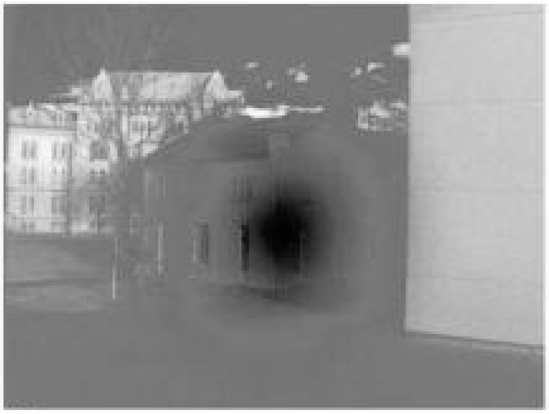
[1] SpectrumWizard is a trademark of Optical Systems Design, Inc., a Maine, USA corporation.



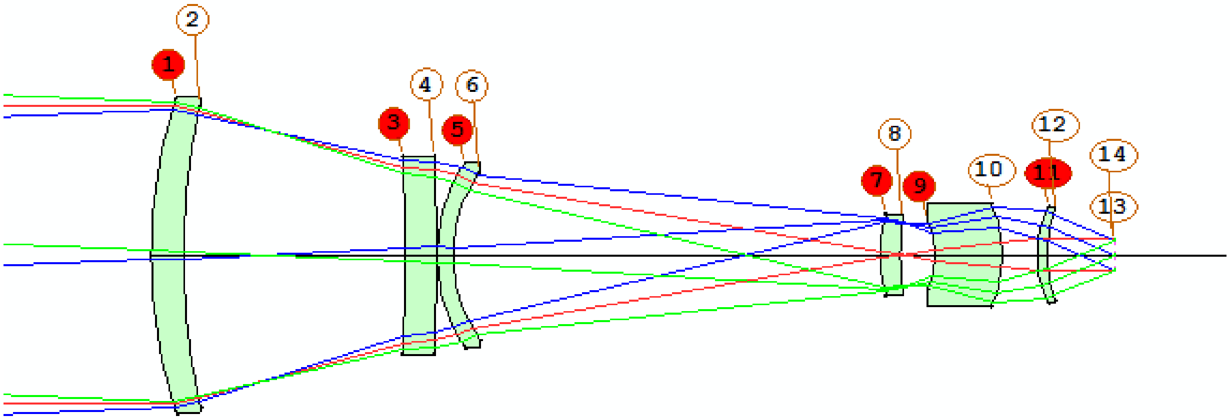
In order to get a high signal-to-noise ratio, one must ensure that the optics, and even the detector itself, do not radiate unwanted flux at the same wavelengths. This is accomplished by cooling the detector to a very low temperature, often with liquid nitrogen, and using high-quality anti-reflection coatings on the lens surfaces. If these steps are not taken, the situation is similar to what you would see looking through a telescope where the lenses and housing were all white hot: it would be hard to distinguish what you are looking at.

A subtle requirement, sometimes overlooked, is to avoid the so-called “narcissus” effect, which shows up in scanning IR systems as a dark smudge in the center of the displayed image:



This effect occurs because at the center of the field the detector can see a ghost image of itself, reflected from a lens surface somewhere. This ghost is very cold – because the detector is very cold – and the total background signal seen by the detector is therefore lower at the center than it is at other parts of the field, where the ghost image is vignetted by other lens apertures, scanned out of the field, or so aberrated that it cannot form a sharp image.

To illustrate this effect and show how it can be controlled, we will use a lens bundled with SYNOPSYS™. Type, in the CW, FETCH X12.

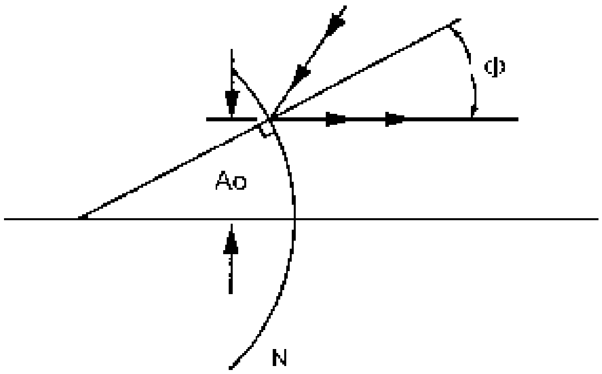


This is an infrared system, designed for the 8 to 13 um band, that uses AFOCAL mode, which means that ray output is given in *angles* instead of transverse coordinates, and the last two surfaces are flat, coincident dummies. That's where the program converts ray heights to angles, and it also marks the location of a scanning prism or other moving components that sample the image one pixel at a time. To analyze the narcissus properties of this lens, use the command **NAR**.

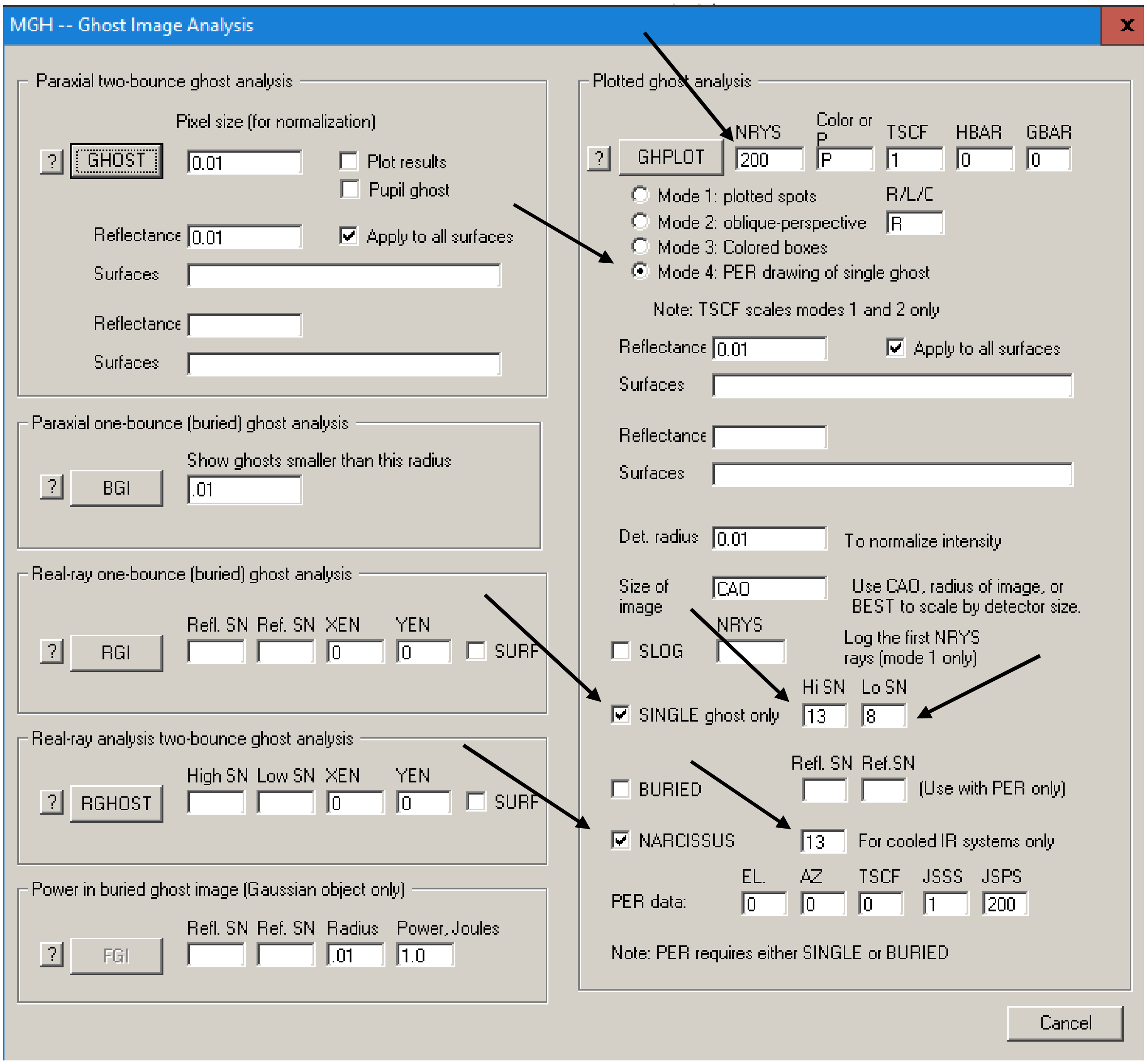
```
SYNOPSYS AI>NAR

ID AFOCAL ZOOM REFR TELESC 3 OF P1488

NARCISSUS ANALYSIS

SURF            YNI  Imarg/Ichief
_______________________________
  1         14.8452        9.4157
  2          2.3679       -1.1389
  3          8.7548       -6.8424
  4          7.2618       -5.4735
  5          7.1414        2.6471
  6          8.5985        2.9948
  7          0.1047       -0.5733
  8          0.0591        3.8062
  9          0.2625        0.2929
 10          0.0773        0.0431
 11          1.4544       -2.2463
 12          0.6135        0.6606
 13      9.6691E-04    4.7994E-04
```

The column "NYI" shows the value of the quantity ϕ Ao N, where the arguments are defined in the figure below. From this we can calculate the approximate size of the retroreflected blur on the detector: Y1 = 2 ϕ Ao N / α, where α is the half-angle of the converging beam at the detector, and Y1 is the ray height of the blur at the image after reflection at the given surface.

The principle of narcissus correction is to ensure that the value of YNI never gets lower than a given value determined by the sensitivity of the scanner and user acceptance. A larger value means the ghost image is more out of focus and therefore less intense.



According to the above table, the worse narcissus is from surface 8, where the value is 0.0591. We can use the GHPLOT program to visualize what this means. Type **MGH** in the CW, or navigate to that dialog in **MLI**. Enter the data shown and then click the GHPLOT button.


MGH -- Ghost Image Analysis

Paraxial two-bounce ghost analysis
Pixel size (for normalization) 0.01
☐ Plot results
☐ Pupil ghost
Reflectance 0.01
☑ Apply to all surfaces
Surfaces
Reflectance
Surfaces

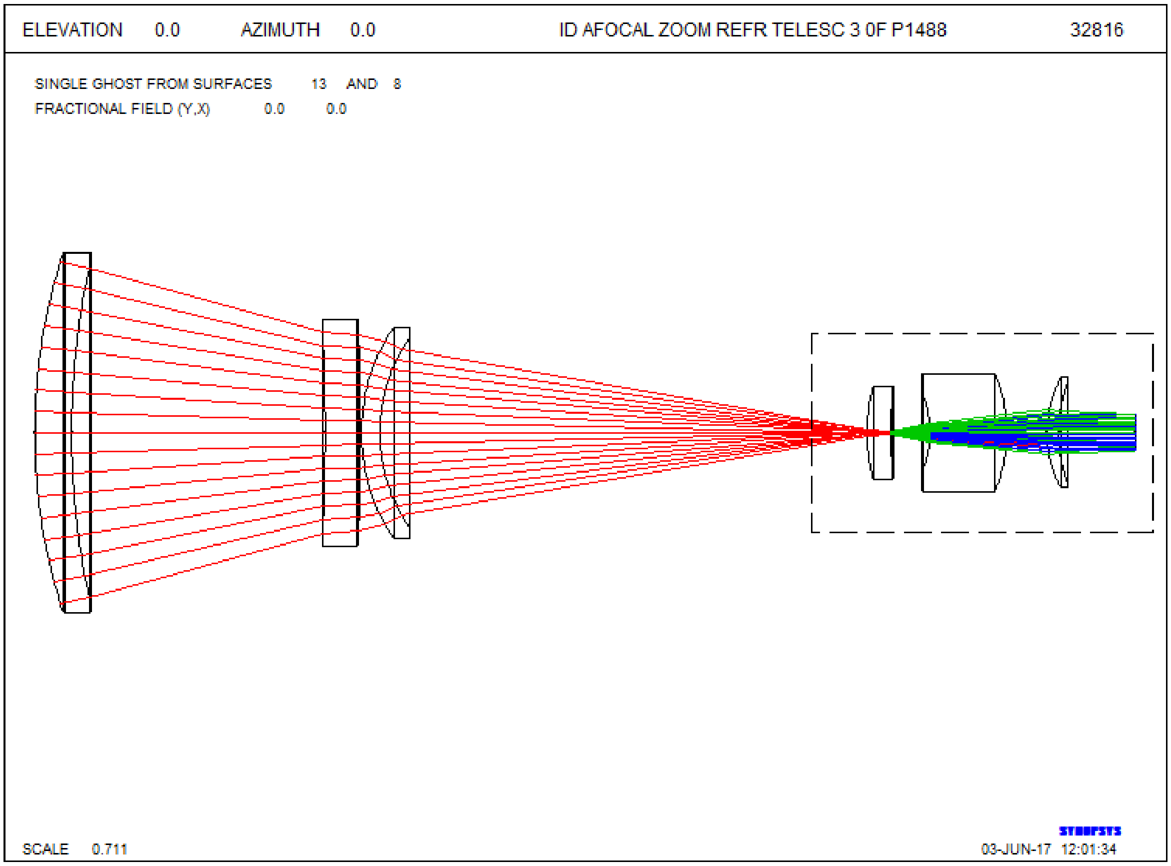
Paraxial one-bounce (buried) ghost analysis
Show ghosts smaller than this radius .01

Real-ray one-bounce (buried) ghost analysis
Refl. SN
Ref. SN
XEN 0
YEN 0
☐ SURF

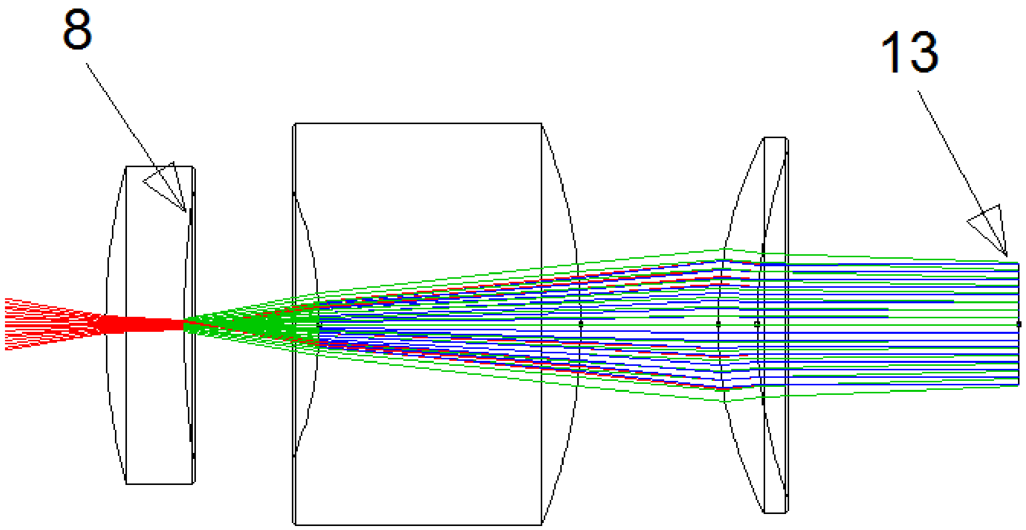
Real-ray analysis two-bounce ghost analysis
High SN
Low SN
XEN 0
YEN 0
☐ SURF

Power in buried ghost image (Gaussian object only)
Refl. SN
Ref. SN
Radius .01
Power, Joules 1.0

Plotted ghost analysis
NRYS 200
Color or P: P
TSCF 1
HBAR 0
GBAR 0
○ Mode 1: plotted spots
○ Mode 2: oblique-perspective
○ Mode 3: Colored boxes
● Mode 4: PER drawing of single ghost
R/L/C: R
Note: TSCF scales modes 1 and 2 only
Reflectance 0.01
☑ Apply to all surfaces
Surfaces
Reflectance
Surfaces
Det. radius 0.01 To normalize intensity
Size of image CAO Use CAO, radius of image, or BEST to scale by detector size.
☐ SLOG
NRYS
Log the first NRYS rays (mode 1 only)
☑ SINGLE ghost only
Hi SN 13
Lo SN 8
☐ BURIED
Refl. SN
Ref.SN
(Use with PER only)
☑ NARCISSUS 13 For cooled IR systems only
PER data:
EL. 0
AZ 0
TSCF 0
JSSS 1
JSPS 200
Note: PER requires either SINGLE or BURIED

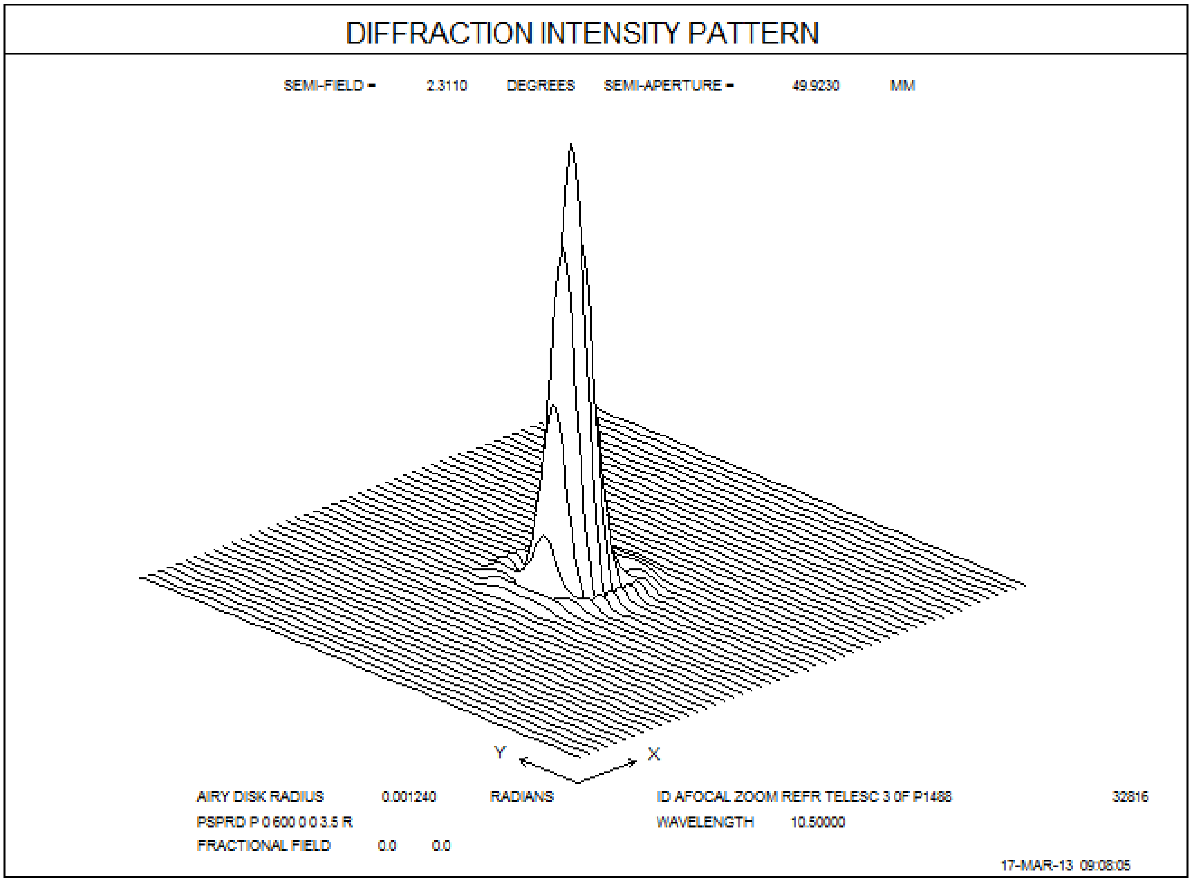


Select the area shown on the right, and click inside the selection rectangle to zoom in to that portion.



Light comes in from the left until it reaches surface 13, the flat surface on the right, which we declared a NAR surface on the dialog. (That assigns a reflection coefficient of 1.0.) We also requested a single ghost, from 13 back to 8, and from there to the last surface again. The signal flux there is collimated, and we assume that any light that returns there and is again collimated will show up on the detector sharply focused. After reflecting from 13, the rays are shown in blue, and following the second reflection at surface 8 they are drawn in green. The retroreflected beam is somewhat out of focus, as you can see visually by the change in ray angles – but not by very much. Is that defocus good enough?

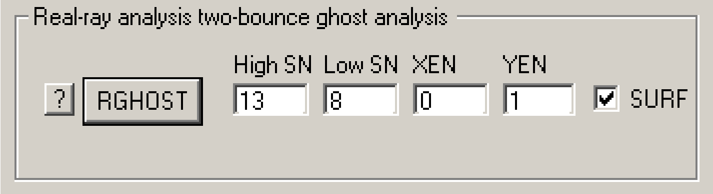
To answer that question, we need to know the angular size of the Airy diffraction disk. Ask for a PSPRD analysis, on axis. Go to the dialog **MDI** and click the **PSPRD** button.



```
SEMI-FIELD =     2.3110    DEGREES   SEMI-APERTURE =     49.9230     MM

AIRY DISK RADIUS     0.001240     RADIANS       ID AFOCAL ZOOM REFR TELESC 3 0F P1488            32816
PSPRD P 0 600 0 0 3.5 R                         WAVELENGTH     10.50000
FRACTIONAL FIELD     0.0     0.0
                                                                               17-MAR-13  09:08:05
```

Note the value of the Airy disk radius: 0.00124. That's an angular value, since the lens is declared AFOCAL. We know that if the narcissus beam returns with an angle equal or less than that value the beam will be in sharp focus and cause a very objectionable narcissus.

So what is the current value of the returning beam angle? Go back to the MGH dialog, and this time run the RGHOST feature, with data shown below:



Real-ray analysis two-bounce ghost analysis

High SN 13
Low SN 8
XEN 0
YEN 1
☑ SURF

```
 --- RGHOST 13 8 0 1 SURF

SURF            X            Y            Z           ZZ           HH          UNI
_____________________________________________________________________________________________
  OBJ      0.000000     0.000000     0.000000     0.000000     0.000000
    1      0.000000    49.923000     7.594350     0.000000    -0.231568    17.299187
    2      0.000000    47.988888     5.162597     0.000000    -0.273829     0.757635
    3      0.000000    29.334061    -0.757131     0.000000    -0.074802    18.270864
```

```
    4        0.000000     28.540801     -0.464576      0.000000     -0.241640      6.143003
    5        0.000000     26.692097      6.849079      0.000000     -0.466878     15.198191
    6        0.000000     24.332967      6.510073      0.000000     -0.173480      4.929564
    7        0.000000      0.765834      0.005466      0.000000     -0.053527      9.023819
    8        0.000000      0.404576      0.001029      0.000000     -0.202598      2.772402
    9        0.000000     -1.929381     -0.060130      0.000000     -0.096889      7.882820
   10        0.000000     -4.093014     -0.186656      0.000000     -0.113411      0.311856
   11        0.000000     -5.501135      0.434421      0.000000      0.091033     15.500818
   12        0.000000     -5.205378      0.313305      0.000000      0.002118      1.687304
 --- RAY REVERSES AFTER NEXT SURFACE ---
   13        0.000000     -5.158509      0.000000      0.000000      0.002118
   12        0.000000     -5.111617     -0.302080      0.000000     -0.088324
   11        0.000000     -5.399001     -0.418344      0.000000      0.115298
   10        0.000000     -3.970582      0.175635      0.000000      0.095288
    9        0.000000     -1.842140      0.054811      0.000000      0.204857
    8        0.000000      0.518795      0.001693      0.000000      0.191294
    9        0.000000      2.711172     -0.118846      0.000000      0.113392
   10        0.000000      5.236490     -0.305925      0.000000      0.101850
   11        0.000000      6.531506      0.613980      0.000000     -0.116719
   12        0.000000      6.158564      0.439191      0.000000     -0.037396
   13        0.000000      5.335925      0.000000      0.000000     -0.037396
GHOST REFLECTED FROM SURFACES    8   13 AT SURFACE   14
     X             Y              ZZ             HH
---------------------------------------------------------------
   0.00000      -0.373782E-01     0.00000       -0.373956E-01
 SYNOPSYS AI>
```

The program creates and runs the RGHOST command for you, and you see the tangent of the ray (HH) when it returns to surface 14 equals -0.0374. Divide that by the Airy disk radius of 0.00124, and you see that the narcissus blur from surface 8 is 30.2 times larger than the Airy disk. In our experience, that difference is not enough, and this lens will display a moderately severe narcissus smudge on the display. We have to do better.

Again, from experience, we have learned that the minimum value of the YNI should be about 0.009 if the lens is in units of inches, and 0.229 for a lens in millimeters. (Even though the lens is AFOCAL and ray output is in angular units – which are independent of lens units, the quantity YNI has units of length, and therefore scales with those units.)

So let us correct this lens, hoping to get a better narcissus value. Here are the PANT and AANT files:

```
LOG
STORE 9
CHG
APS 1         ! put the stop on 1
12 YPT 0      ! keep the output dummies at the exit pupil
CFREE
END

PANT
VLIST RAD ALL
VLIST TH ALL AIR
END

AANT
M -0.42835 50 A P HH 1   ! maintain current magnification
LLL 0.23 1 .01 A NAR 8   ! keep the narcissus on 8 greater than 0.23
M 22.437 1 A TH 12       ! maintain space for the scanning prism
M 347.3 .1 A TOTL
AEC
ACC
M 0 1 A P YA 1 0 0 0 13 ! control pupil aberrations too
GSO .5 10 3 P 0
GNO .5 2 3 P .75
```

```
GNO .5 1 3 P 1
END

SNAP
SYNOPSYS 30END

SNAP
SYNOPSYS 30
```

Run this job, and the lens changes very little. What happened to the narcissus?

```
SYNOPSYS AI>NAR

ID AFOCAL ZOOM REFR TELESC 3 0F P1488

NARCISSUS ANALYSIS

SURF           YNI  Imarg/Ichief
________________________________
  1        14.3090        7.1022
  2         1.9897       -0.9898
  3         7.6347       -6.9897
  4         6.0211       -4.9277
  5         7.0617        2.2978
  6         8.4359        2.5435
  7         0.2334       -0.9406
  8         0.2605        0.7269
  9         0.0936        0.3047
 10         0.1604        0.1859
 11         1.2579       -5.1481
 12         0.3695        0.2689
 13         0.0012    5.7973E-04
SYNOPSYS AI>
```

The lens is much improved. In fact, the narcussus on surface 8 became *larger* than our target. Why? This lens came from the patent literature, and we suspect that the original designer simply *ignored* the narcissus. When we reoptimized it, we found it easy to control.

But now the narcissus from surface 9 is below our limit. That happens. So we add a target for that surface as well and reoptimize, and then do the same at surface 10, which also becomes a problem. Reoptimize and – great! Now all surfaces are close to or above the limit. That's how it's done: indentify the problem and fix it.

So that's what the narcissus is all about. It is usually not difficult to control, but if you forget to look at the NAR listing, and do not control the values, you might end up with a very poor display without expecting it.