



TracePro® Stray Light Simulation

What Is Stray Light?

A more descriptive term for stray light is unwanted light. In an optical imaging system, stray light is caused by light from a bright source shining into the front of the system and reaching the image in a place where it is unwanted. Stray light also occurs in non-imaging systems. Stray light is commonly manifested in two ways: ghost images and scattered light. In poorly-baffled systems, “straight shots” can also occur.

How Does TracePro Relate to Stray Light Analysis?

TracePro simulates all types of optical and illumination systems. Specifically, TracePro analyzes systems for ghost, narcissus, and scattered stray light. The product is based on Spatial Technology’s ACIS® solid modeling engine, creating compatibility with 170 other ACIS-based programs, like AutoCAD, CADKEY, IronCAD, and Solidworks. Full non-sequential ray tracing is built into the program in a fully C++, graphical-user-interface, integrated environment.

Modeling System and Source Geometry?

System and source geometry modeling is easy in TracePro, either by importing the geometry from any SAT-file compliant product (SAT is the ACIS file format), importing an IGES or STEP file, or creating the geometry inside of TracePro. TracePro is completely non-sequential, rays are emitted as source surfaces or grid emitters. These emitted rays then intersect each surface and the ray flux is tracked as the rays reflect, transmit, scatter and absorb at each surface.

TracePro Visualization

TracePro excels by showing where problem areas occur. TracePro has the capability to create rendered, wireframe, and silhouette views with rays overlaid on the system geometry to show scatter, absorption, refraction and reflection. This output continually shows you the flux reports surface by surface as the rays are propagated until they are finally absorbed.

Figure 1 – Silhouette view of a Photolithography lens with linear grid of rays traced. 73.7% of the initial light reaches the image.

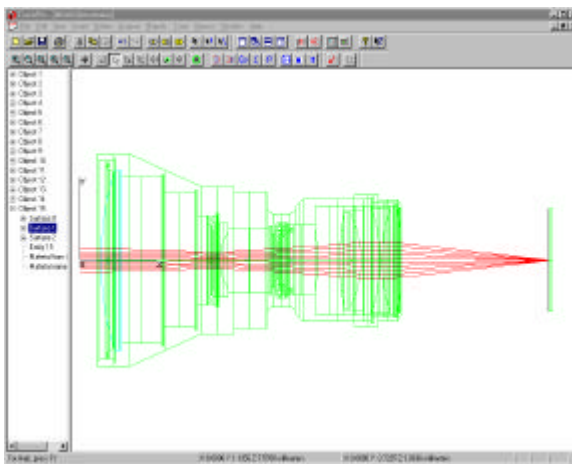
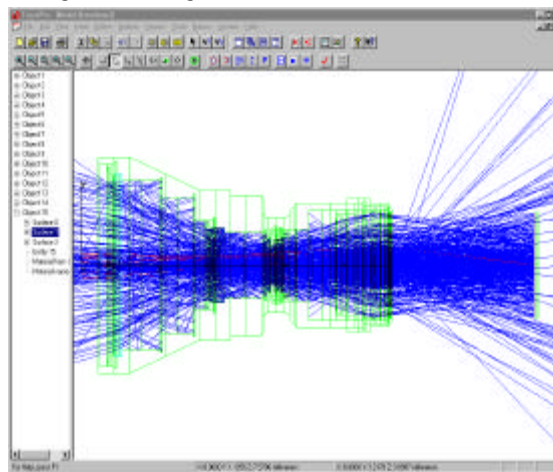


Figure 2 – Same system, same grid with scattering turned on. Notice the amount of light scattering from baffles and mounts.



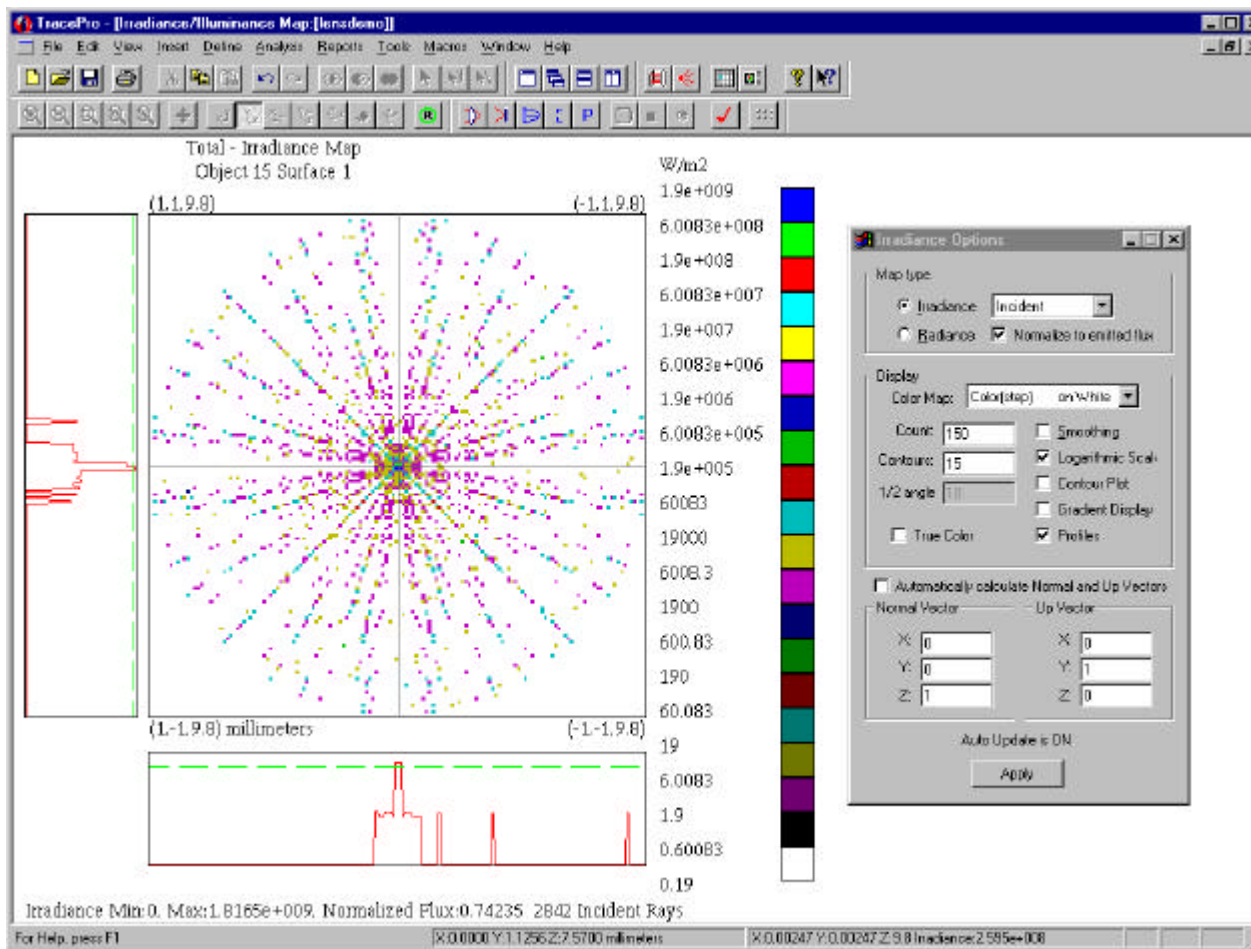


Figure 3– Irradiance map at the detector with ray splitting and scattering off the baffles and mounts reaching the detector. Energy is 5 orders of magnitude smaller than the on-axis beam. This is a logarithmic display of the flux. The size of the image is shown on the bottoms corners of the flux map.

What types of Stray Light can TracePro handle?

Ghost Images

Ghost images are so called because they are out-of-focus or ghostly-looking images of bright sources of light. Ghost images are caused by reflections from lens surfaces. To cause a ghost, light must reflect an even number of times from lens surfaces. There are two-reflection ghosts, four-reflection ghosts, etc. Optical systems consisting of only first-surface mirrors (a Cassegrain telescope, for example) do not suffer from ghost images. The sun causes ghost images in a photograph if it is in or near the field of view being photographed. Automobile headlights and streetlights cause ghost image stray light in a nighttime photograph. If the bright source is small, each ghost takes on the shape of the aperture stop of the optical system. If the ghost is focused on the image plane, though, the ghost looks like the source.

Singly-scattered light

Singly-scattered light occurs when a stray light source such as the sun directly illuminates the optics in the system. Some portion of the light will scatter in a direction that causes it to reach the focal plane. We say that it scatters into the field of view. Once light has scattered into the field of view, it becomes stray light,

and there is no way to eliminate it without also causing vignetting. Thus a basic goal of baffle design is to keep light from shining on the optics.

“Straight shots”

Straight shots can occur in a Cassegrain-type system when the central obstruction is too large and/or the telescope tube is too short. Light from outside the field of view can enter the telescope, travel past the secondary mirror, through the hole in the primary mirror, and strike the focal plane directly as stray light. This type of stray light can be a disaster if sunlight is allowed to enter the telescope.

Multiply-scattered light

Even when stray light sources do not illuminate the optics directly, they can still cause stray light indirectly, by first scattering from the baffle surfaces and then illuminating the optics. Stray light from this source will always be smaller than direct scatter, but it may still be large enough to be of concern.

Edge diffraction

When the ratio of aperture diameter to wavelength is relatively small (10^4 or smaller) edge diffraction from the aperture stop from out-of-field sources can be a significant source of stray light.

Self-Emission in Infrared Systems

Thermal infrared or thermal imaging systems can also have stray light caused by emission from the instrument itself. These systems work by detecting a small signal superimposed on a large background. At room temperature, the peak of the blackbody emission curve is at about $10\mu\text{m}$. Thus the world “glows” at this wavelength, and small variations in this glow indicate differences in temperature or emissivity. Thermal imaging systems normally subtract the background to enhance the contrast of the variations in the infrared scene. When the background is not uniform, as in the presence of narcissus, a stray signal is produced. Specifically, when an image of the cooled detector is imaged back on itself, a locally strong absence of background occurs. This typically appears as a dark spot in the center of the image. One might call this “stray dark” instead of stray light.

In infrared radiometers that measure absolute radiance instead of a relative signal, background radiation is highly undesirable. The background can be “calibrated out” to some degree, but for the most accurate measurements it is necessary to cool the entire instrument to cryogenic temperatures to minimize or eliminate the stray light caused by self-emission.

Combinations of the above

Combinations of the above effects, i.e. higher order effects, occur as well, and become important when first-order effects have been reduced or eliminated due to careful system design. For example, self-emitted light may then scatter from optics into the field of view. Light diffracted at an aperture may then scatter from optics into the field of view.

How does TracePro handle unusual geometry?

The program can handle unusual system geometry like struts, mounts, baffles, and hexagonal mirrors because TracePro is a CAD system. Anything that can be created in a CAD system is available in TracePro, either as a primitive or created using our macro Scheme language. The most important aspect of TracePro is its ease of use. Moving and copying objects are mouse drag and drop operations. With our system tree that details, object type, object name, surface and material properties it is easy to delete, modify and add system geometry on the fly. Boolean logic is built into the program to intersect, unite and subtract system geometry primitives to create all new geometry. With the undo and redo icons it is a simple task to go back to a start point and iterate through system creation.

How easy is it to learn TracePro?

Typical users learn TracePro from our 50-page tutorial in PDF format within a week. But specialized training in the stray light aspect is recommended. Most stray light users either sign up for one-on-one training or our stray light tutorial given every few months in Littleton, MA.

What Visualization and Output is in TracePro?

TracePro's complete 3D visualization of the system, including system geometry, overlaid rays showing flux intensity, and complete directional and position output, enable you to find and fix problem areas in your design. The flux intensity visualization is accomplished by showing high energy rays in red, medium in green and low energy rays in blue. The program can show a complete tabular breakdown of how the energy propagates through the system with easy output to any Windows-clipboard-compliant product.

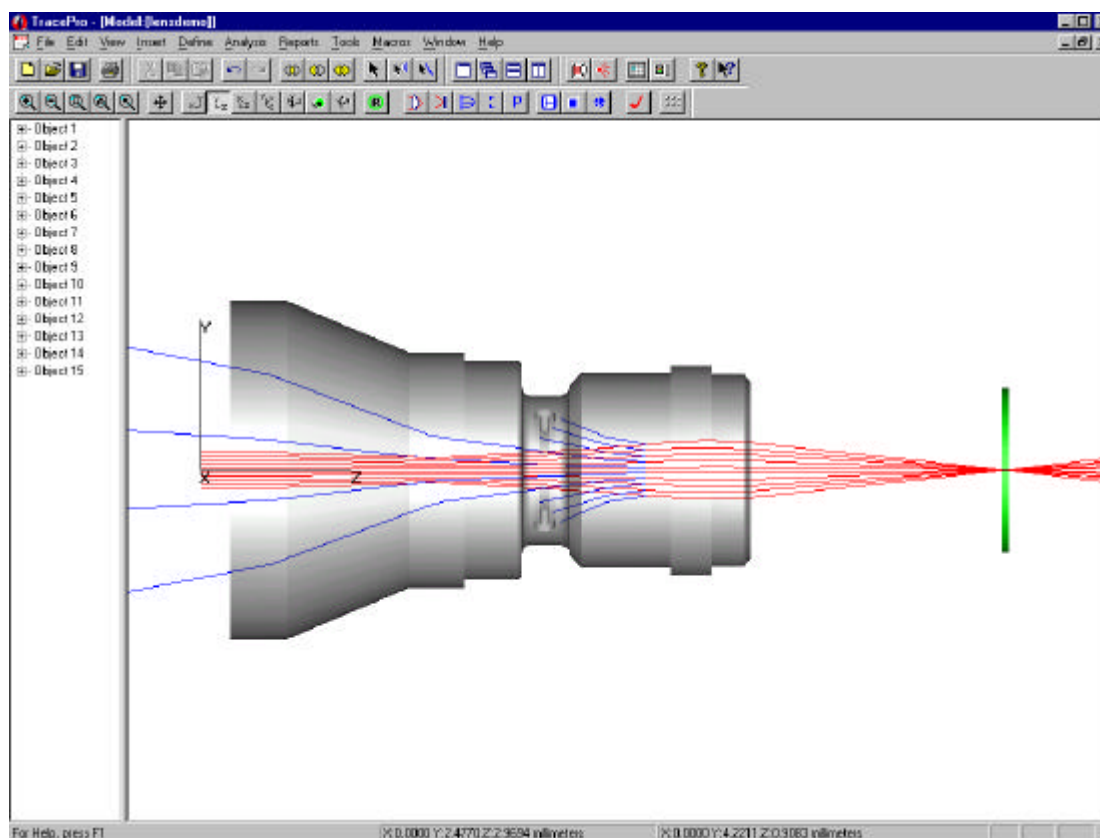
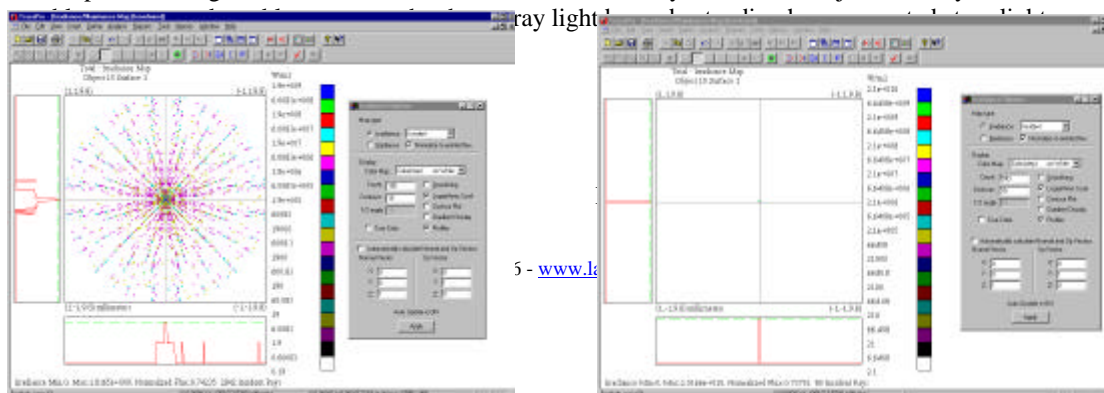


Figure 4 – Rendered view with rays overlaid

TracePro's outputs include both the standard 2D and 3D irradiance/illuminance and iso-candela plots, but go further with direct output to any Windows-clipboard-compliant product. TracePro is the only program to produce 3D irradiance plots on curved surface geometry. The program can also track down exact information using incident surface statistics and ray propagation path history. The program has a complete flux report detailing the lost, absorbed and incident flux on every surface and object in the system. This



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Stray light turned on and logarithmic scale

Figure 7 – Incident ray table showing all 25 rays that are incident on the detector plane. Shown are Flux, ray position and directions of the rays striking the surface

Ray Num	Wavelength	Start Ray	Ray Node	Type	History	Flux	X Pos	Y Pos	Z Pos	X Vec	Y Vec	Z Vec
1	0.5461	1	1.4	SpecTran		0.73748	-2.70062e-01	-0.000157109	9.804	-1.23619e	0.115677	0.993287
2	0.5461	2	1.4	SpecTran		0.737493	-2.69894e-01	-0.00036771	9.804	-1.23655e	0.106023	0.994064
3	0.5461	3	1.4	SpecTran		0.737593	-2.69736e-01	-0.000530162	9.804	-1.23687e	0.0963686	0.995346
4	0.5461	4	1.4	SpecTran		0.73751	-2.6959e-014	-0.000647051	9.804	-1.23716e	0.0867148	0.996233
5	0.5461	5	1.4	SpecTran		0.737515	-2.69458e-01	-0.000721534	9.804	-1.23742e	0.0770615	0.997026
6	0.5461	6	1.4	SpecTran		0.737519	-2.69339e-01	-0.000757252	9.804	-1.23764e	0.0674089	0.997725
7	0.5461	7	1.4	SpecTran		0.737521	-2.69234e-01	-0.000758255	9.804	-1.23783e	0.057757	0.998331
8	0.5461	8	1.4	SpecTran		0.737522	-2.69145e-01	-0.000758932	9.804	-1.23799e	0.0481056	0.998842
9	0.5461	9	1.4	SpecTran		0.737523	-2.69072e-01	-0.00073951	9.804	-1.23812e	0.0384549	0.99926
10	0.5461	10	1.4	SpecTran		0.737523	-2.69014e-01	-0.000598203	9.804	-1.23822e	0.0288046	0.999585
11	0.5461	11	1.4	SpecTran		0.737524	-2.68973e-01	-0.000506753	9.804	-1.23829e	0.0191547	0.999817
12	0.5461	12	1.4	SpecTran		0.737524	-2.68948e-01	-0.000404792	9.804	-1.23833e	0.0095051	0.999955
13	0.5461	13	1.4	SpecTran		0.737524	-2.6894e-014	-0.000297596	9.804	-1.23834e	-0.0001441	1
14	0.5461	14	1.4	SpecTran		0.737524	-2.68948e-01	-0.00019048	9.804	-1.23833e	-0.009793	0.999952
15	0.5461	15	1.4	SpecTran		0.737524	-2.68974e-01	-8.67974e-005	9.804	-1.23829e	-0.013443	0.999811
16	0.5461	16	1.4	SpecTran		0.737523	-2.69015e-01	2.29772e-005	9.804	-1.23821e	-0.029093	0.999577
17	0.5461	17	1.4	SpecTran		0.737523	-2.69074e-01	7.74971e-005	9.804	-1.23811e	-0.038743	0.999249
18	0.5461	18	1.4	SpecTran		0.737522	-2.69148e-01	0.000131781	9.804	-1.23798e	-0.048394	0.998828
19	0.5461	19	1.4	SpecTran		0.737521	-2.69237e-01	0.000160262	9.804	-1.23782e	-0.0580458	0.998314
20	0.5461	20	1.4	SpecTran		0.737519	-2.69342e-01	0.000158283	9.804	-1.23763e	-0.067897	0.997706
21	0.5461	21	1.4	SpecTran		0.737515	-2.69461e-01	0.000121462	9.804	-1.23741e	-0.077350	0.997004
22	0.5461	22	1.4	SpecTran		0.73751	-2.69595e-01	4.57607e-005	9.804	-1.23715e	-0.087003	0.996208
23	0.5461	23	1.4	SpecTran		0.737500	-2.69741e-01	-7.24464e-005	9.804	-1.23686e	-0.096657	0.995310
24	0.5461	24	1.4	SpecTran		0.737493	-2.69899e-01	-0.000236307	9.804	-1.23654e	-0.106312	0.994333
25	0.5461	25	1.4	SpecTran		0.737479	-2.70067e-01	-0.000448381	9.804	-1.23618e	-0.115966	0.993253

Wavelength	Ray Node	Start Ray	X Pos	Y Pos	Z Pos	Flux	DPL	X Vec	Y Vec	Z Vec	Type	History	Object	Surface
0.5451	1	20	0	0.14	0	1	0	0	0	1				
0.5451	2	20	0	0.14	0.435853	1	0	0.435853	-1.61207e-0	-0.0109492	0.99994	SpecTran	Object 4	Surface 2
0.5451	3	20	-7.09904e-0	0.13518	0.876099	0.979723	1.20537	-2.06295e-0	-0.0191388	0.999817	SpecTran		Object 4	Surface 1
0.5451	4	20	-1.10934e-0	0.0981949	2.80818	0.999896	3.13993	-9.14174e-0	-0.00863892	0.999953	SpecTran		Object 5	Surface 3
0.5451	5	20	-1.22356e-0	0.0971268	2.9378	0.940383	3.32193	4.89889e-0	0.0963194	0.99994	SpecTran		Object 5	Surface 2
0.5451	6	20	8.75468e-0	0.171385	4.97531	0.921324	5.36678	4.29779e-0	0.0404853	0.99991	SpecTran		Object 8	Surface 4
0.5451	7	20	1.08579e-0	0.190817	5.45489	0.902542	6.21234	1.42509e-0	0.0969376	0.999293	SpecTran		Object 8	Surface 0
0.5451	8	20	1.08589e-0	0.190827	5.45499	0.833877	6.21244	6.88658e-0	0.0540163	0.99854	SpecTran		Object 9	Surface 2
0.5451	9	20	1.37188e-0	0.21353	5.88207	0.817067	6.84935	3.01443e-0	0.0263785	0.998822	SpecTran		Object 9	Surface 0
0.5451	10	20	1.38723e-0	0.215272	5.93294	0.800499	6.90025	8.7715e-0	0.0177138	0.99843	SpecTran		Object 1	Surface 2
0.5451	11	20	1.41796e-0	0.221479	6.38828	0.784387	7.42302	3.22862e-0	-0.0119016	0.998025	SpecTran		Object 1	Surface 0
0.5451	12	20	1.40034e-0	0.220828	6.33797	0.768384	7.47672	-7.08771e-0	-0.030434	0.998537	SpecTran		Object 14	Surface 2
0.5451	13	20	1.12484e-0	0.209015	6.72594	0.792783	8.10663	-1.23763e-0	-0.0676877	0.997705	SpecTran		Object 14	Surface 0
0.5451	14	20	-2.69342e-0	0.00015828	9.804	0.737519	11.1918	0	0	0		All Surfaces	Object 15	Surface 1

Figure 8 – Ray history tables are also available that show how each ray propagates through the system. There is a separate table for each ray - this example shows the 20th ray. This table is extremely important because it shows where flux loss occurs and how problem areas may occur in this stray light analysis.

TracePro Version: 1 4 0
Flux Report for C:\TracePro\lensdemo.oml
Data generated at 14:33:06 April 13, 1999

Number of Rays	Incident Flux [Watts]	Absorbed Flux [Watts]	Lost Flux [Watts]	Surface Area [sq mm]	Object Name : Material Property Surface Name : Surface Property
25	19.60652353	0.196065235	0.201503881	3.6800088862	Object 1 : FK5 Surface 0 : Lens
0	0	0	0	1.020645720229	Object 3 : <None> Surface 1 : <None>
25	20.01232108	0.200123211	0.205674421	3.546563581592	Object 3 : <None> Surface 2 : Lens
0	0	0	0	3.426790361674	Object 4 : LAF2 Surface 55 : Black Paint
1	0.064568108	0.058111297	0.00645681	8.493845517694	Surface 56 : Black Paint
0	0	0	0	3.402246669067	Surface 57 : Black Paint
0	0	0	0	1.714227652864	Object 4 : LAF2 Surface 0 : Black Paint
35	25.13873607	0.251387361	0.258360585	9.593658200854	Surface 1 : Lens
35	25.6325782	0.256325782	0.883187163	9.850403989365	Surface 2 : Lens

Figure 9 – Partial Surface Flux Report that shows the incident, absorbed and lost flux surface by surface. Each surface's material, surface and area attributes are also shown.