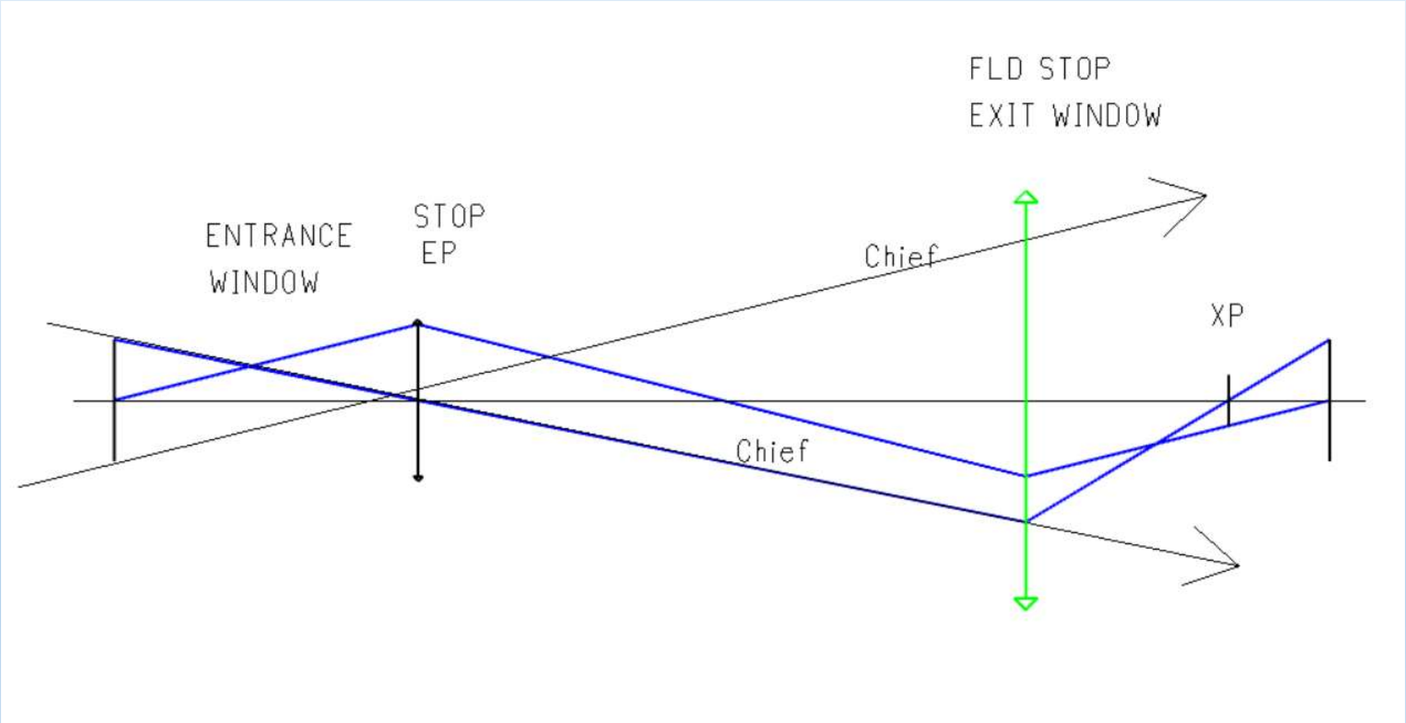
Stray light techniques

Minimizing stray light

- Two alternatives available:
- Move it: Move the object so it is no longer seen by the source of illuminated by the source
- Block it: Use baffles or vanes to prevent the object from either being seen by the detector or illuminated by the source

Optical system

- Basic optical system layout
  - With a couple additions



Stops

- A stop is a surface in an optical systems that limits the size of the light beam passing through the system
- The aperture stop limits the size of the on-axis ray bundle
  - For systems, such as telescopes, limits size of the primary
  - Location impacts aberrations as well as stray light
- A field stop limits the size of the field of view passing through the system to the sensor
  - All optical systems have at least one field stop: the image sensor
  - Additional is better

Lagrange invariant-throughput

- From ray tracing:

$$\bar{y} \cdot \omega - y \cdot \bar{\omega} = \bar{y} \cdot \omega' - y \cdot \bar{\omega'}$$

- Etendue, or angle-area product (A*Ω):
- Determined by stops:
  - Aperture stop sets A
  - Field stop sets Ω

Windows

- Windows are the field equivalents to pupils:
- Entrance pupil is image of the aperture stop seen from object space
- Entrance window is the image of the field stop seen from object space

- Exit pupil is the image of the aperture stop as seen from image space
- Exit window is the image of the field stop as seen from image space

How much power

- Power on the sensor from stray light depends on:
  - Power from the stray light source (scattering surface)
  - Scattering characteristics of surfaces in light path
    - BSDF
  - Geometrical Configuration Factor (GCF)

$$\Phi_{det} = \Phi_{source} * BSDF_{source} * GCF_{source-det} * \pi$$

- Reducing any or all will reduce power to detector

Aperture stop

- Design locates to minimize aberrations
- Stray light considerations:
  - Most objects in optical space before the stop are not “seen” by the detector
    - Objects to the left of stop not seen
  - Limits the number of critical objects
  - Further in is better (stray light considerations)
  - Exceptions:
    - Optical components, obscurations, vignetting apertures
  - Baffles after stop are seen by detector

Field stops

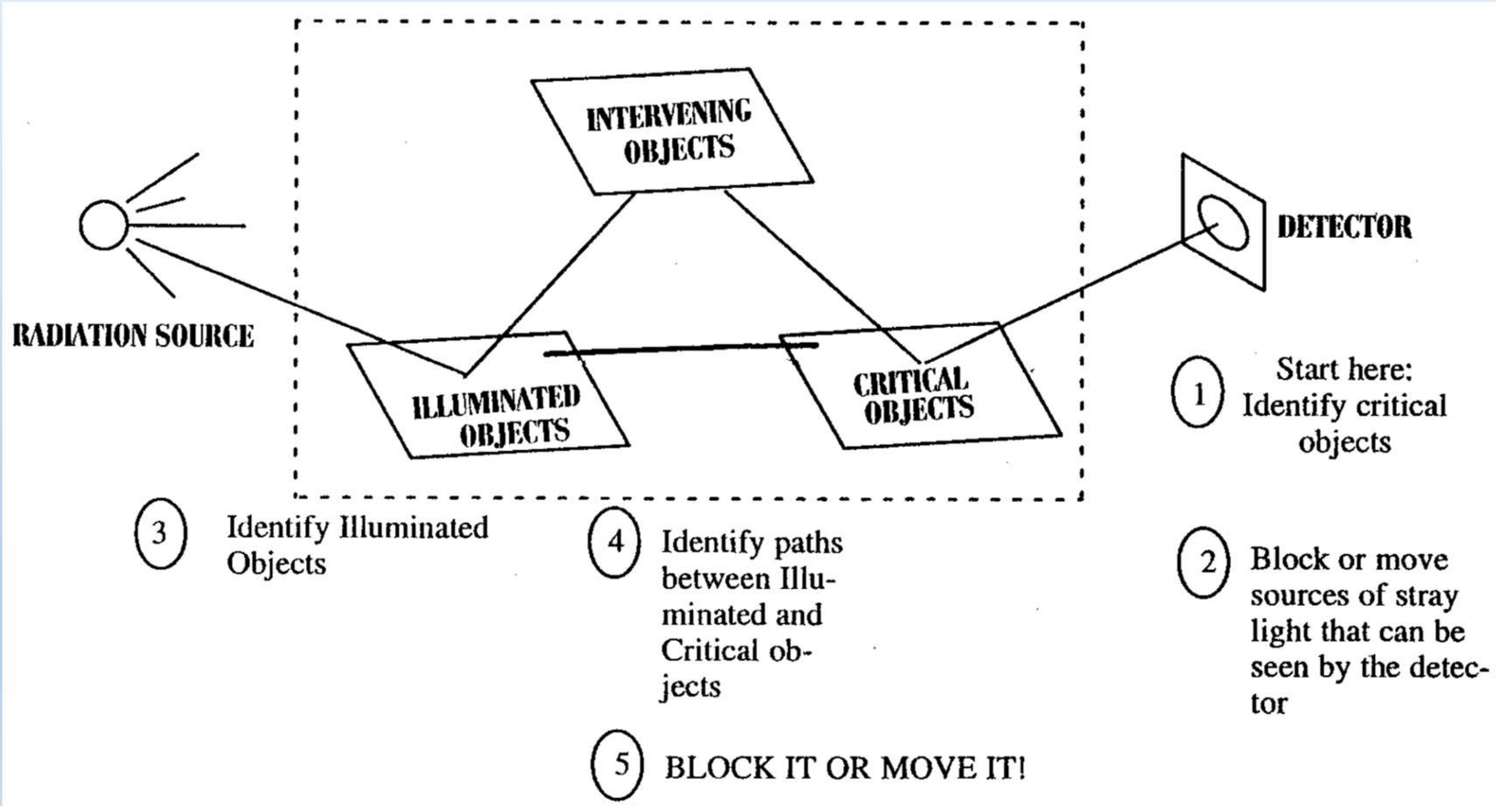
- Aperture at intermediate images to limit the field of view
- Prevents stray light from outside the field of view can not be directly imaged
- Baffles following the field stop can not be seen outside the field of view of object plane
- Reduce the number of illuminated surfaces: objects to the right of the field stop can not be directly illuminated

Lyot stop

- An aperture placed at pupil location
- Limits critical objects to those after the Lyot (or glare) stop
  - Similar effect to shifting aperture stop further in to system
  - Usually slightly undersized

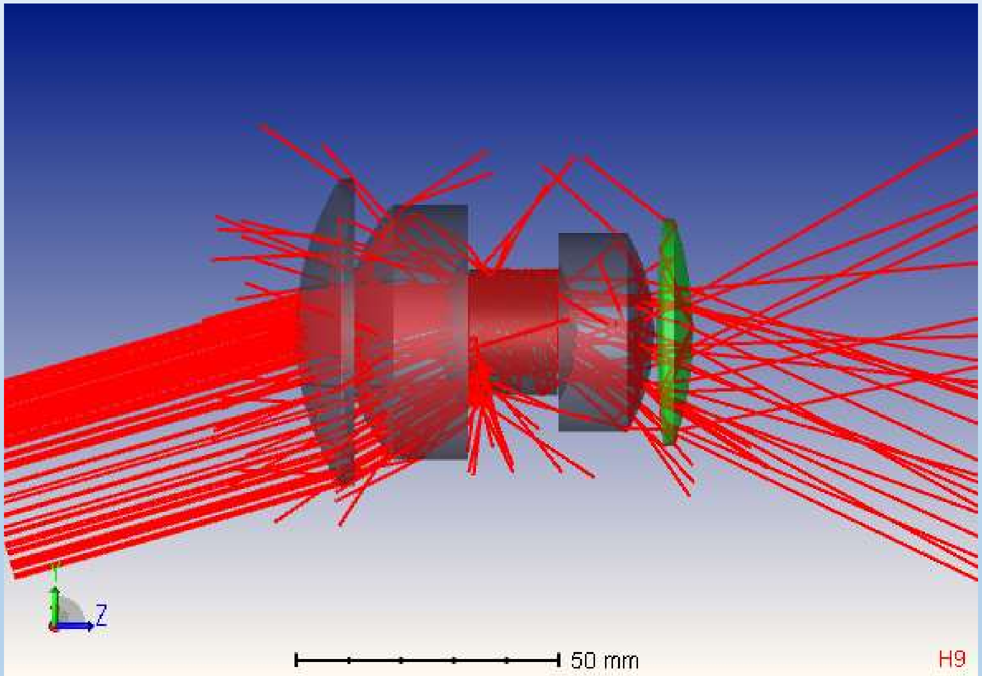
Controlling stray light

- Handbook of Optics, Volume 1, Chapter 38



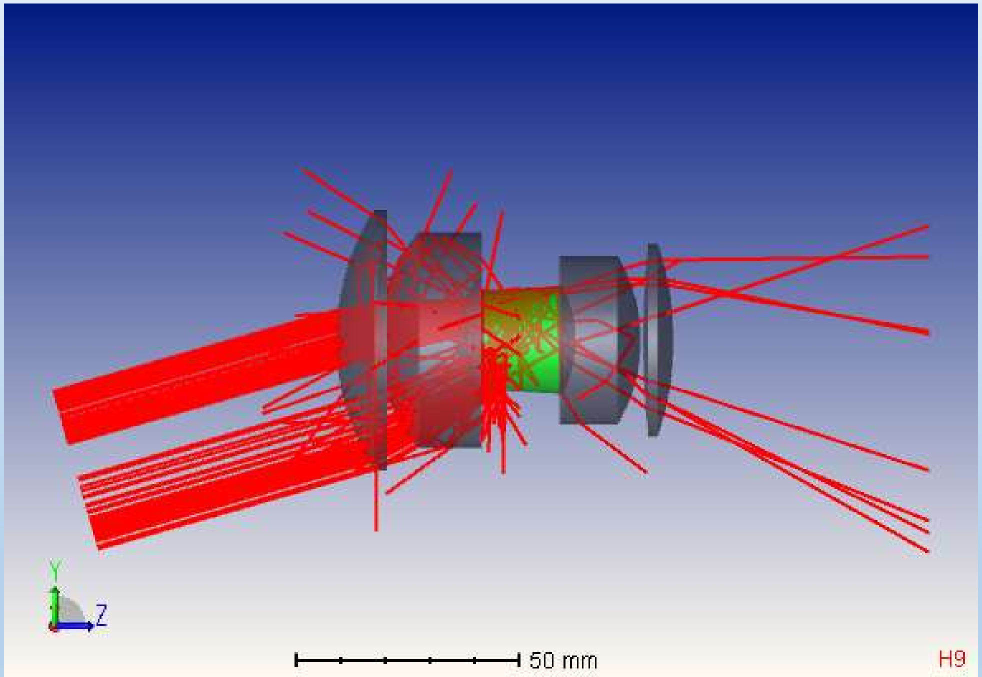
Scattered rays

- How to limit?



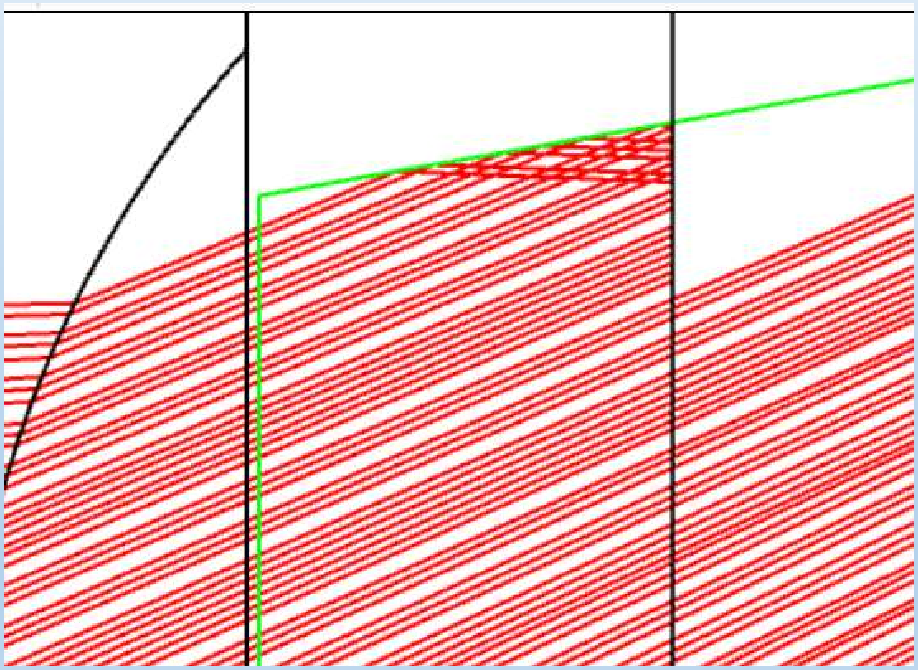
Mechanical stop

- Adding a physical stop surface helps



Mechanical stop

- The stop limits the light from the barrel that can reach the detector



Radiometry

- Irradiance: Power per unit area incident of a surface
  - W/m^2
- Intensity: Power per unit solid angle exiting a source
  - W/sr
- Radiance: Power per unit solid angle per unit area coming from a surface
  - Brightness, luminance
  - W/(m^2-sr)

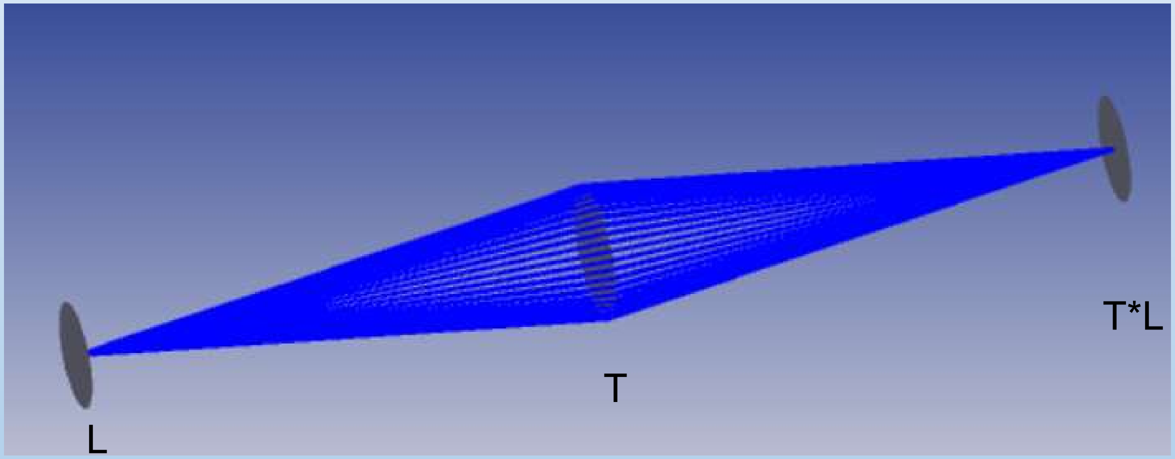
Irradiance

- The irradiance (E) on a surface is equal to the brightness (L) of the source times the solid angle (Ω) subtended by the source:

$$E = L\Omega$$

Brightness theorum

- The radiance of a source is the same as the radiance of its image
  - Ignoring losses



Bidirectional Scatter Distribution Function

$$BSDF(\theta, \phi; \theta_0, \phi_0) = \frac{L(\theta, \phi; \theta_0, \phi_0)}{E}$$

Brightness divided by irradiance at scattering surface

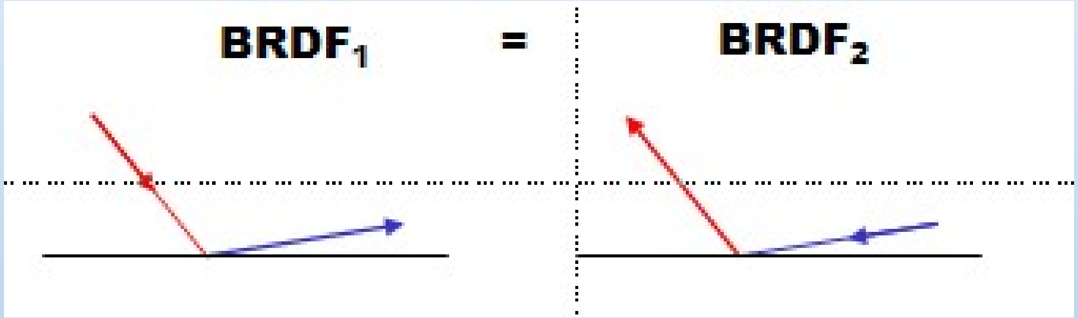
4-dimensional function depending on scatter direction(θ, ϕ) and specular direction (θ_0, ϕ_0)

Types of surfaces

- Isotropic scatter: does not depend on surface orientation
- Anisotropic scatter: depends surface orientation
  - Easy to understand: diffraction grating

Reciprocity

- The BRDF for a given incident and scatter direction is equal to the BRDF when the incident and scatter directions reversed



- For isotropic surface, the BSDF is symmetric in specular and scatter directions

Total integrated scatter

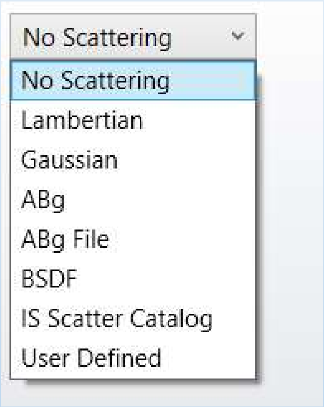
- Integrating the BSDF over angles yields the total integrated scatter or TIS
  - $TIS = \frac{Total\ scattered\ power}{Incident\ power}$

Lambertian scatter

- A Lambertian surface has constant brightness for all scatter directions
  - BSDF is constant
  - Brightness (Power/unit area-sr) is constant
  - Intensity (power/sr) changes as cosine θ, projected surface area changes

Scatter models

- Zemax has the following models for surface scatter:



Lambertian

- **Lambertian** In the Lambertian scattering model, the scattered ray projection vector has equal probability anywhere in the unit circle, and the BSDF is just $1/\pi$. The scattered intensity is proportional to the cosine of the angle between the normal vector and the scattered ray angle. Note Lambertian scattering is independent of the ray incident angle. Most diffuse surfaces are nearly Lambertian. Although Lambertian is a valid option on the sequential surface dialog, rays which scatter using this model may go in any forward direction, which may cause rays to scatter at large enough angles so that they do not correctly propagate through the rest of the optical system.

Gaussian

- **Gaussian** In the Gaussian scattering model, the scattering distribution is rotationally symmetric in direction cosine space, no matter what angle the specular ray makes with respect to the surface normal. The BSDF expression (see “Scattering”) contains a dimensionless value σ, which determines the width of the Gaussian distribution on the projected plane. Values of σ greater than about 5.0 yield a BSDF that is nearly Lambertian. For this reason, the maximum allowed value of σ is 5.0.

ABg

- **ABg** The ABg scattering model is a widely used method for defining the BSDF. This scattering model is generally a good model to use when the scattering is mainly due to random isotropic surface roughness, and the scale of the roughness is small compared to wavelength of light being scattered. These assumptions are generally valid for polished optical surfaces. See “Scattering” for a detailed technical description.

ABg sum

- **ABg File** The ABg File scattering model allows a sum of ABg profiles to be used to define the scattering properties of a surface. The profiles to use are specified in a text file. The text file must have a .ABGF extension and must be located in the <data>\ABg_Data folder (see “Folders”). All of the profiles specified in the ABGF file must be defined in the currently loaded ABg Data File (see “ABg Data File”), and all profiles must be specified using upper case letters (regardless of capitalization of the profile name in the ABg Data File). description.

BSDF model

- **BSDF** The BSDF scattering model allows the use of tabular BSDF data for defining the scattering properties of a surface. Data are provided via text files. Files must follow the BSDF Data Interchange file format described in the article entitled “BSDF Data Interchange File Format Specification”, which may be found in the OpticStudio Part Knowledge Base. OpticStudio Part allows definition of separate BSDF data for reflection and refraction. If the specular ray reflects or refracts, the ray is subsequently scattered using data from the appropriate input file. For a file to be available for use in this scatter model, it must have a .BSDF extension (as indicated in the article describing the file format), and be located in the <data>\Scatterdata folder (see “Folders”). A full description of the model and its use is provided in the Knowledge Base article entitled “How to Use Tabular Data to Define the Surface Scattering Distribution” also available on the OpticStudio Part web site. description. description.

User DLL

- **User defined scattering** Completely general surface scattering may be defined via an external program called a Dynamic Link Library (DLL). Sample DLLs are provided with OpticStudio Part with source code. New DLLs may be easily created with a suitable compiler. See also "Comments about DLLs" and "Scattering – User defined scattering" for a detailed description.

IS catalog

- **IS Scatter Catalog** The IS Scatter Catalog scatter model allows the use of data measured with the OpticStudio Part IS-SA™ device for defining the scattering properties of a surface. Data are provided via binary ISX files, a library of which is provided with OpticStudio Part (see “Download IS® Scatter Catalog Data”). This scattering model is only available in the Premium edition of OpticStudio.