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Stray Light Webinar

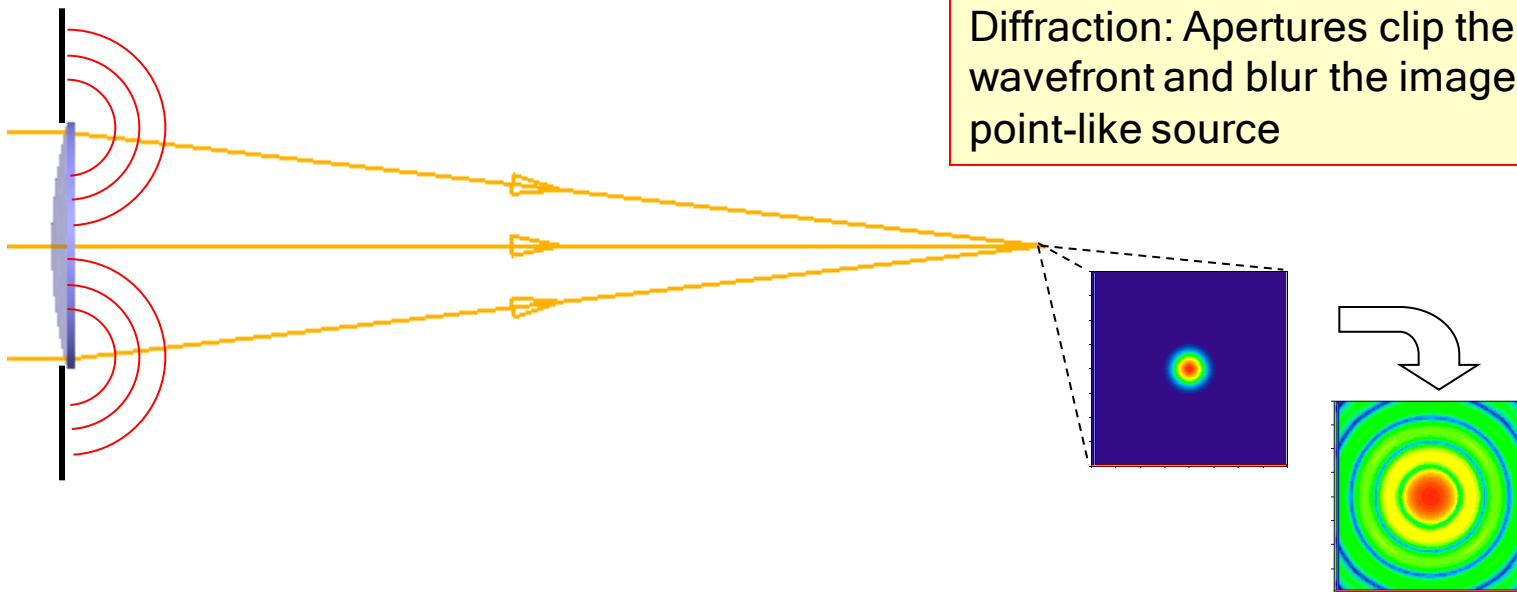
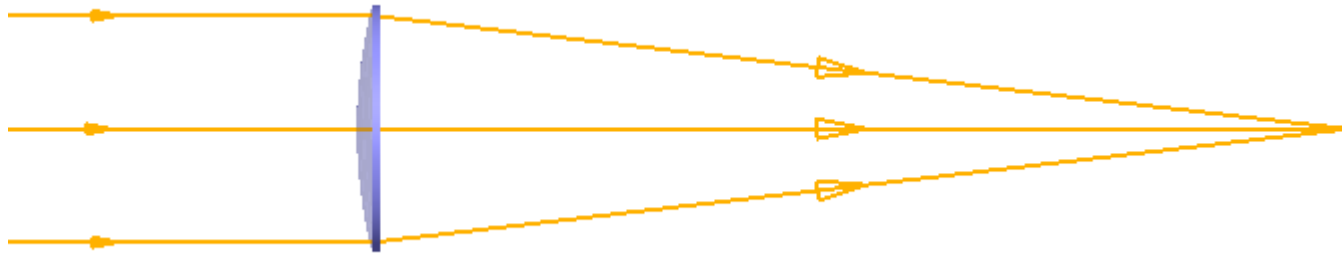
10 May 2011
Release Version

About This Webinar

- The purpose of this webinar is to introduce the topics covered in great detail during the 3-day stray light short course
- **The short course contains almost 600 charts → can't cover all of this in 30 minutes!**
- Topics we'll be talking about
 - What scatter is
 - Why do we care
 - How do we describe surface scatter
 - How do we describe system stray light characteristics
 - How do we control stray light
- Topics we won't be talking about
 - How to do stray light calculations in FRED, ASAP, TracePRO, LightTools, ZEMAX, CODEV, etc

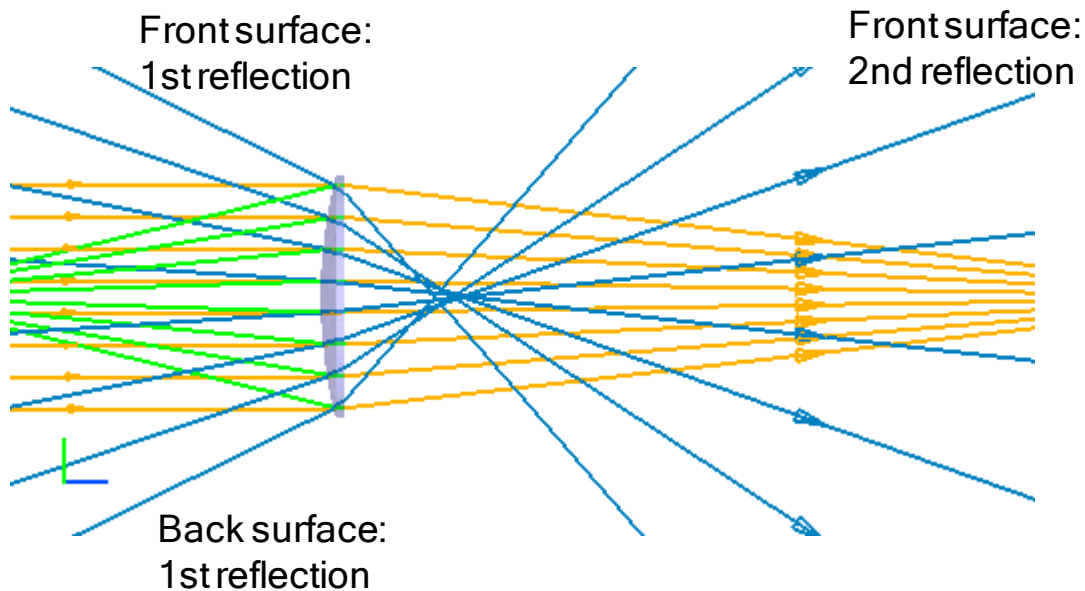
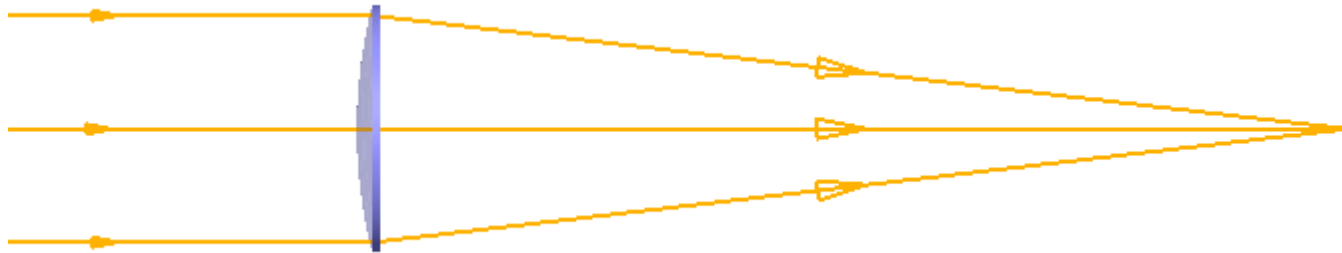
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Design vs. Reality – Aperture Diffraction



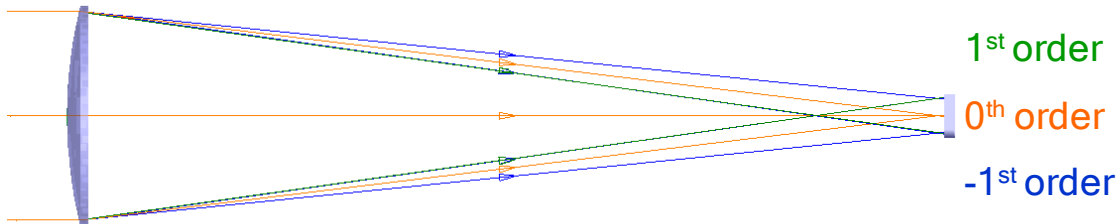
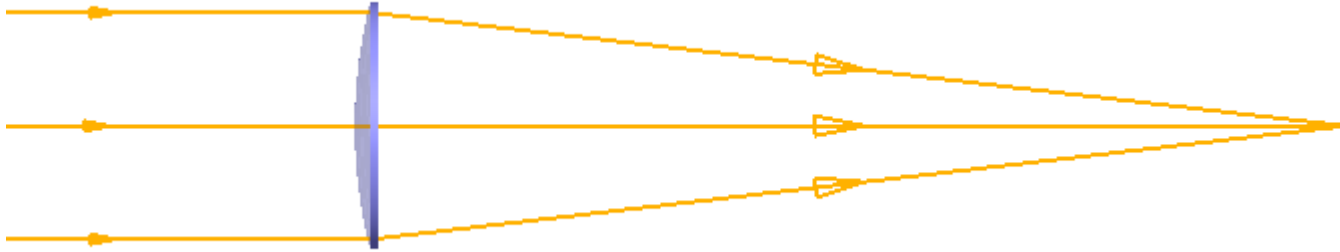
Diffraction: Apertures clip the incident wavefront and blur the image of a point-like source

Design vs. Reality – Ghosts



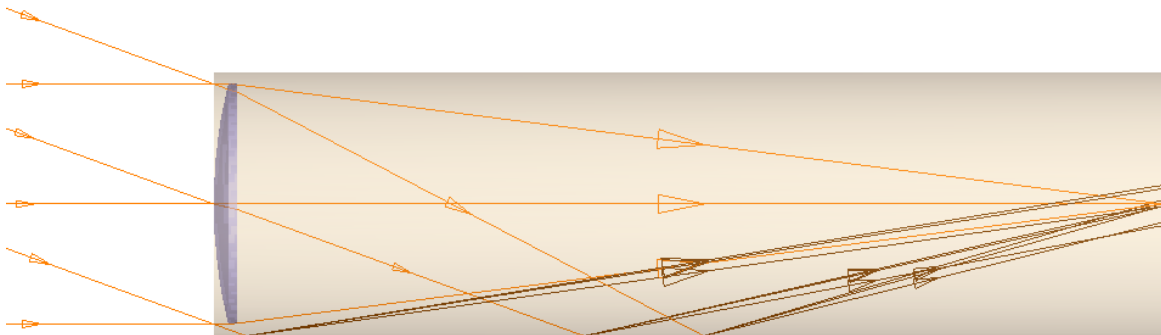
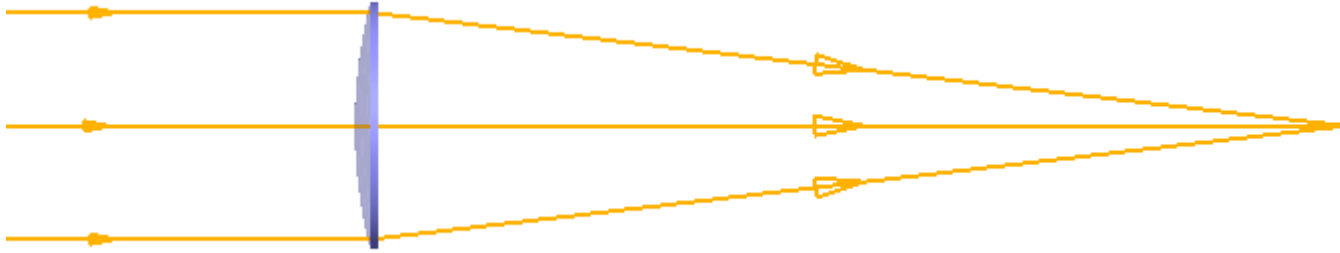
Ghosts: Specular reflections from imperfectly coated refractive surfaces produce secondary images

Design vs. Reality – Unwanted Diffraction Orders from Gratings



Unwanted diffraction orders:
imperfect diffracting surfaces
generate spurious images;
“unintentional” gratings from
diamond-turning process

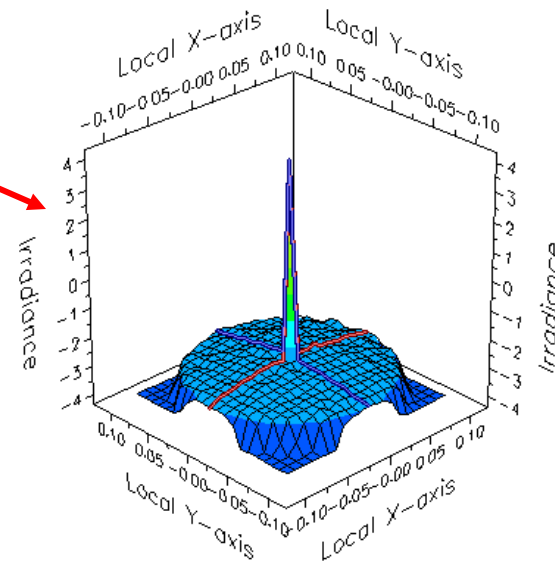
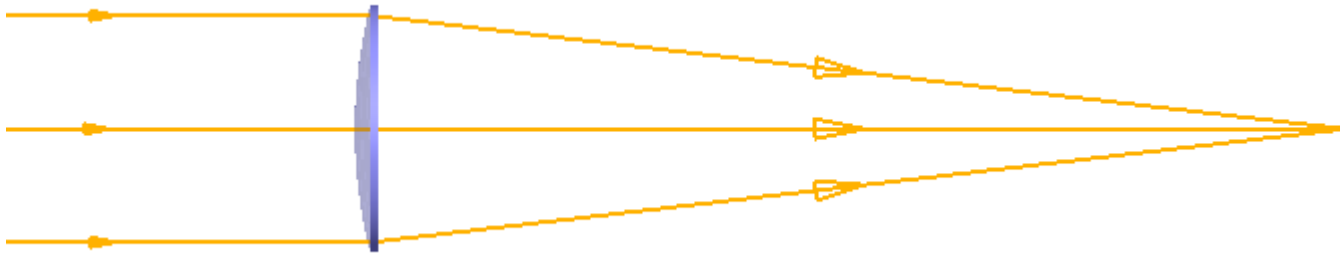
Design vs. Reality – Scatter



Scatter from main baffle

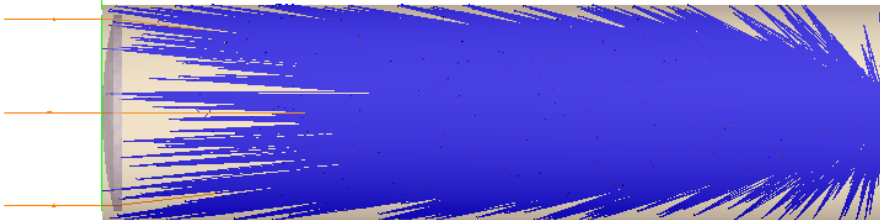
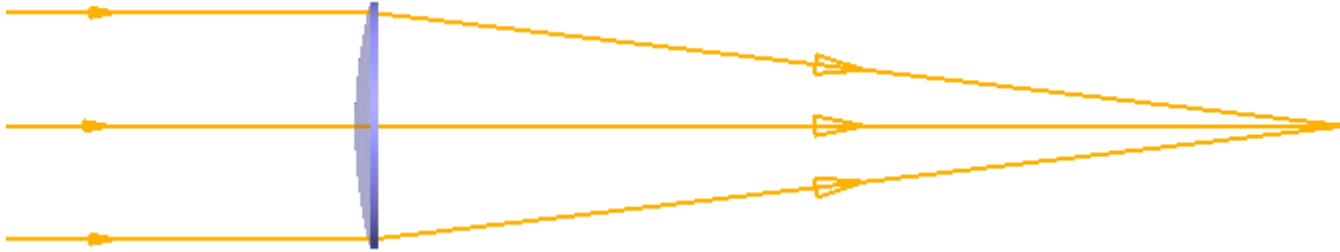
Scatter from structures: Scatter from main baffle directs out of field light to the detector plane

Design vs. Reality - Scatter (2)



Scatter: Contamination and sub-wavelength surface defects disrupt the incident wavefront

Design vs. Reality – Thermal Emission



Thermal emission: Optical and mechanical surfaces radiate thermal energy to detector

Stray Light Is...

- **Unwanted energy** - like weeds on a lawn
- What keeps an optical system from performing as the designer intended
- An unintended consequence - the mere act of inserting an optic between two points introduces stray light
- Not sequential - although the first law of optics states that light must travel from left to right, nature is seldom so kind
- Sequential - simply following the proper path is not a guarantee of goodness
- Demonstration of our inability to perfectly control the path of light from point A to point B

Typical Stray Light Problems

- **Observing faint objects in the presence of sunlight**
 - Example: orbiting telescopes looking at faint targets in the presence of sunshine or the Earth's limb
- **Observing faint objects in the presence of moon, planets**
 - Example: observatories looking at faint objects in the presence of moon, bright planets, etc
- **High-precision radiometric measurements**
 - Example: radiometers on satellites measuring the earth to a precision of 1%
- **High contrast imaging**
 - Example: DLP projector systems, digital cameras
- **Thermal emission**
 - Example: warm lenses, mirrors, and housings emitting into the FOV of the detector of a LWIR seeker

Stray Light Analysis ...

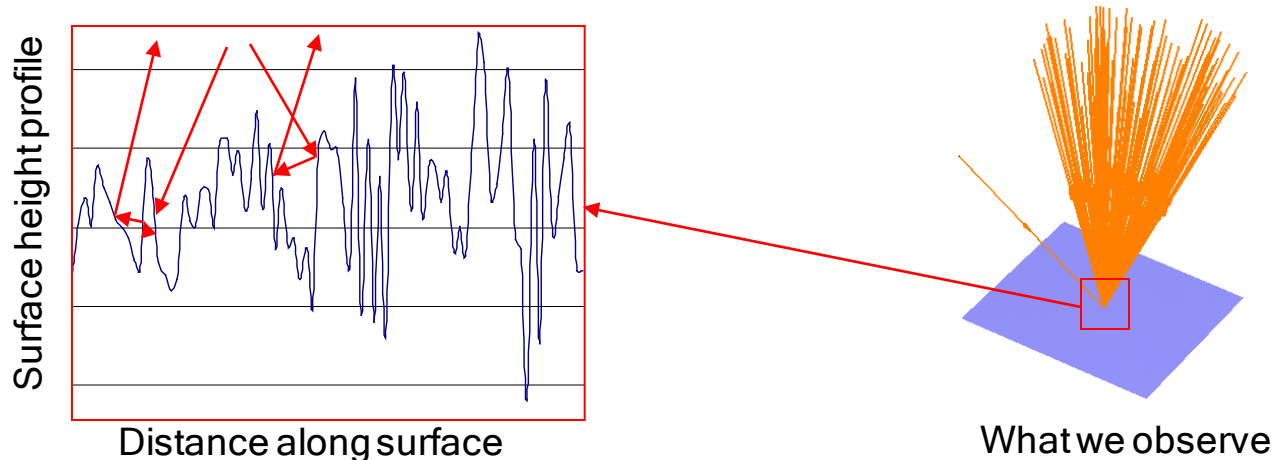
- Requires detailed knowledge of
 - Optical design
 - Mechanical structures
 - Coatings and other surface treatments
 - Surface roughness, material properties, scatter models
 - Source, scatter, diffraction phenomenology
 - Detector and (sometimes) associated signal processing
 - Environment (temperature, particulate deposition, etc)
- Determines by which path(s) unwanted light gets to a detector
- Quantifies how much gets there
- Identifies a stray light problem
 - Proposes realistic method(s) of stray light reduction
- Ascertains feasibility of meeting project goals
- Prevents costly design errors by identifying the root causes of stray light in the early phases of a design

True Statements About Stray Light Analysis

- **Stray light analysis takes time and money, plus more time and money**
 - It takes about 90% of the time and money to identify 10% of the obvious stray light sources and paths
 - It takes another 90% of the time and money to identify any missed paths
- **Stray light analysis is not exact**
 - Computerized stray light analysis is limited by resolution, run times, model complexity, etc
- **Stray light analysis is full of unknowns**
 - No guarantee that hardware is built according to the drawings
 - Scatter properties of components are rarely characterized
 - At best, you can say there is a high degree of confidence in the analysis
- **Stray light analysis is a thankless job**
 - The customer is not happy when a problem is found
 - If there are no problems, the customer regrets spending the money on the analysis!

What is Scatter?

- For the sake of a definition, we shall define scatter as *“the redirection of light by mechanisms other than Snell’s law, the law of reflection, and the grating equation”*
- To be correct, at the microscopic scale, these mechanisms may be taking place. However in the macroscopic world, we observe different behavior.
- In the scatter world, interactions are much more complex and do not lend themselves (very often) to simple mathematical treatments



Radiation Transfer Equation

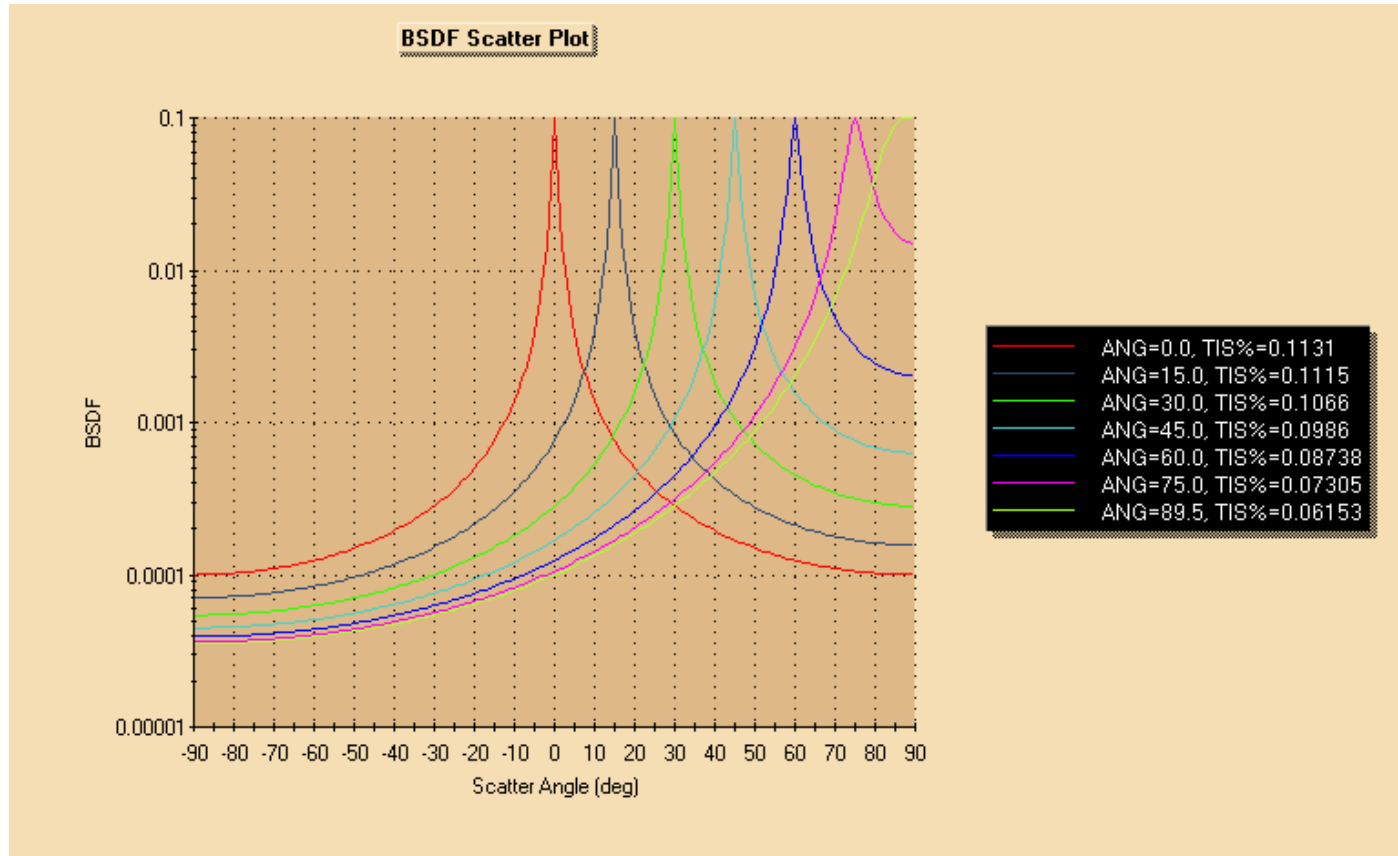
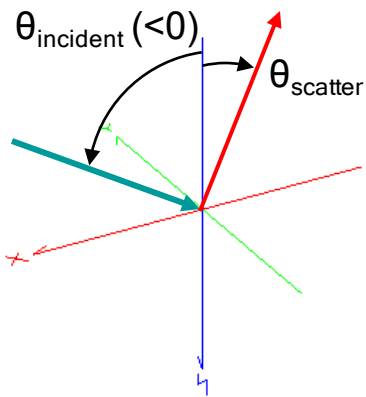
- Replacing differentials with their physical significance, we get

$$\Phi_{collector} = \Phi_{source} \cdot BSDF(\theta, \phi)_{source} \cdot \Omega_{collector}$$

- This is a really significant result because it tells us what is important when we try to control stray light

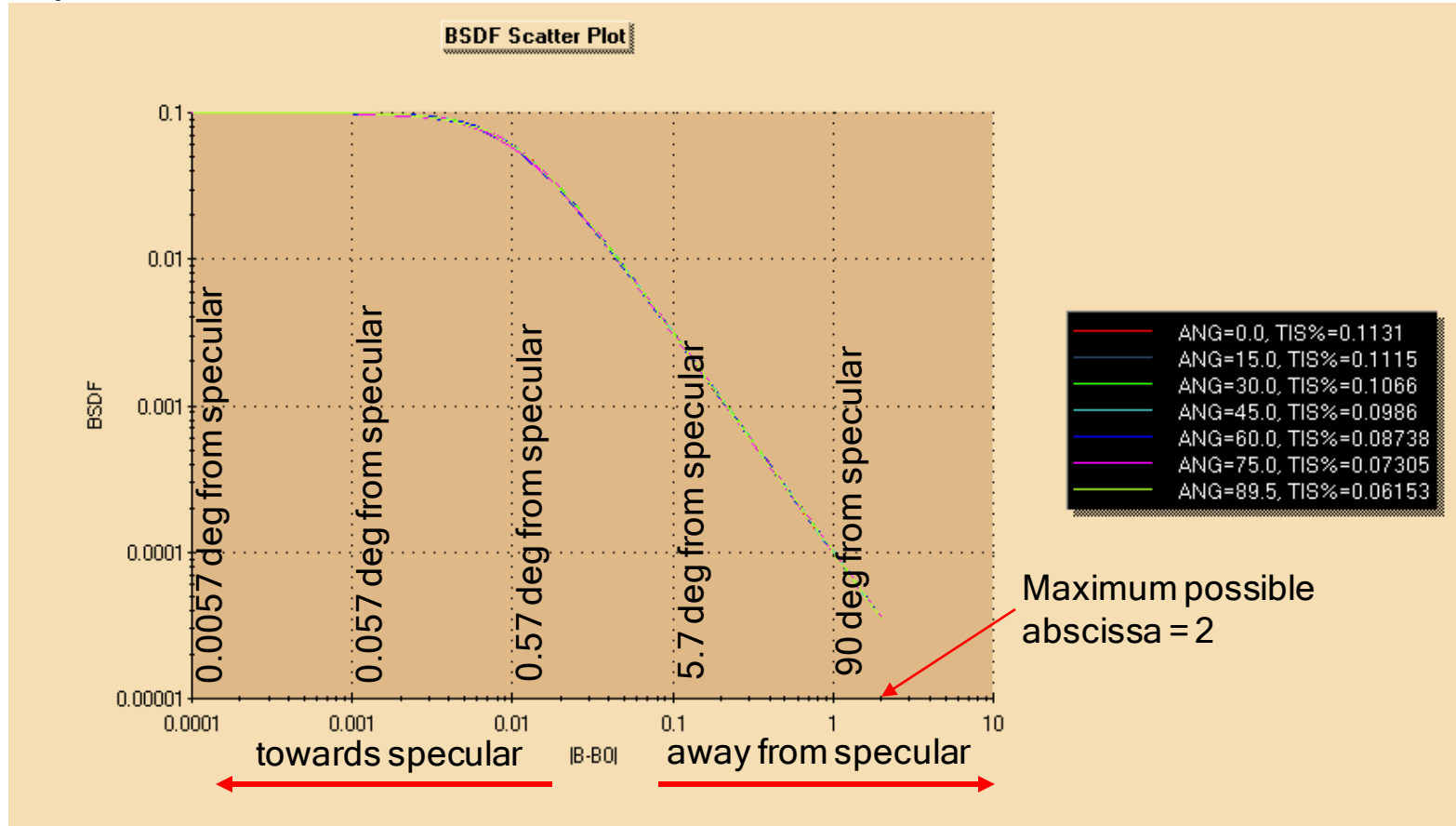
Angle BSDF Plot

- BSDF plots are shown for various incident angles; isotropy is assumed



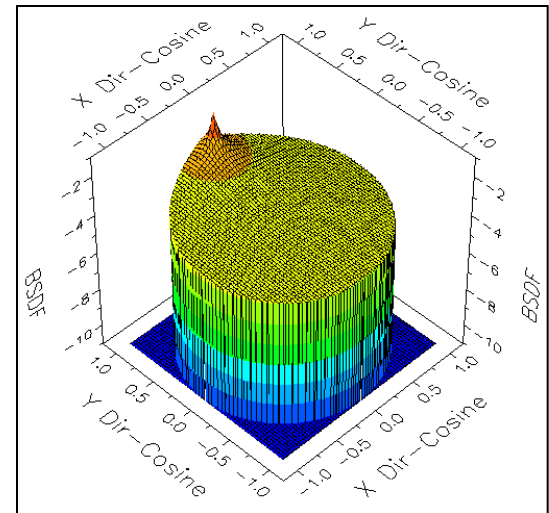
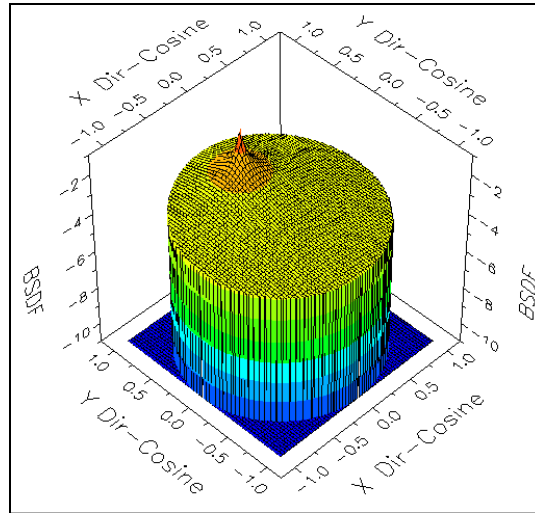
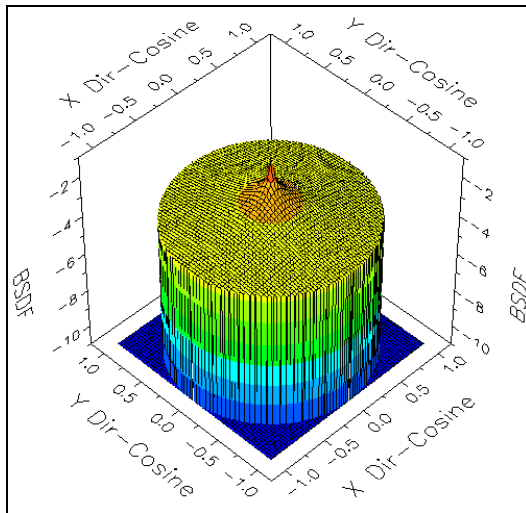
β - β_0 BSDF Plot

- Note that you can't ever get to specular since the abscissa is plotted in log space!



3D BSDF Plot

- Yet another way to plot a BSDF is to sample the function over the unit circle (hemisphere) in direction cosine space. This is useful because it brings out out-of-plane detail.
- Anisotropic BSDF functions **MUST** be plotted in this format



Harvey Scatter Model at 0 deg, 30 deg, and 60 deg incidence angle

Types of BSDF Functions

- Theoretical
 - Lambertian
- Smooth optical surface
 - Harvey-Shack
 - ABg
 - K-correlation
 - PSD
- Paints
- Particulates
- Polynomial forms
- Tabulated data
- Composites
- Very rough surfaces
- What surfaces look like

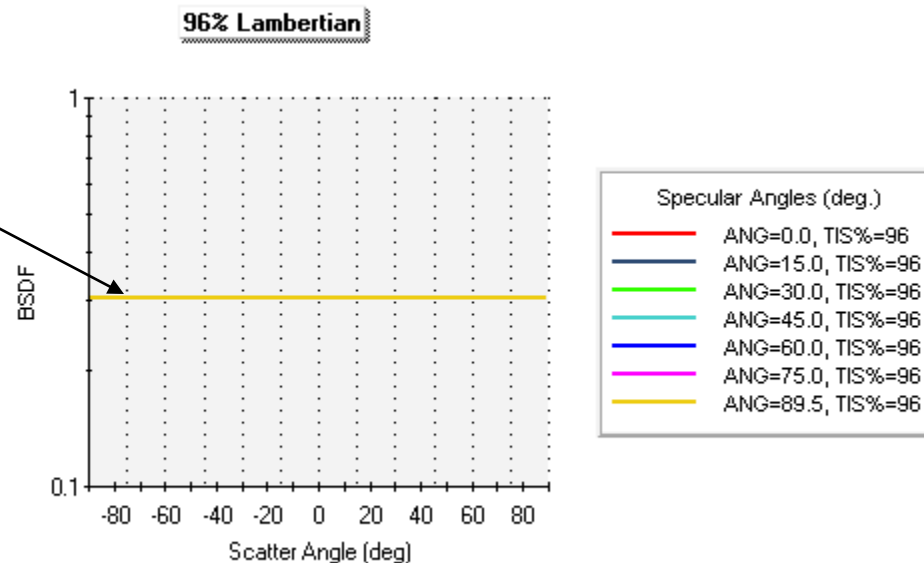
Lambertian BSDF

- This model describes diffuse scatter that is independent of incident and scatter angles but there may be a wavelength-dependence
- White, black, gray, $\rho = \rho(\lambda)$

$$BSDF(\lambda) = \frac{\rho(\lambda)}{\pi}, \quad 0 \leq \rho(\lambda) \leq 1$$

$$TIS\%(\lambda) = 100\% \cdot \rho(\lambda)$$

Diffuse: BSDF is flat (or slowly varying) for all scatter angles



Harvey-Shack and ABg BSDF

- Empirically derived from measurement
- No intrinsic wavelength dependence
- Lorentzian around specular ray
- *Linear-shift invariant*. BSDF depends on the difference $(\beta - \beta_0)$ between the specular and scattered rays

Harvey-Shack

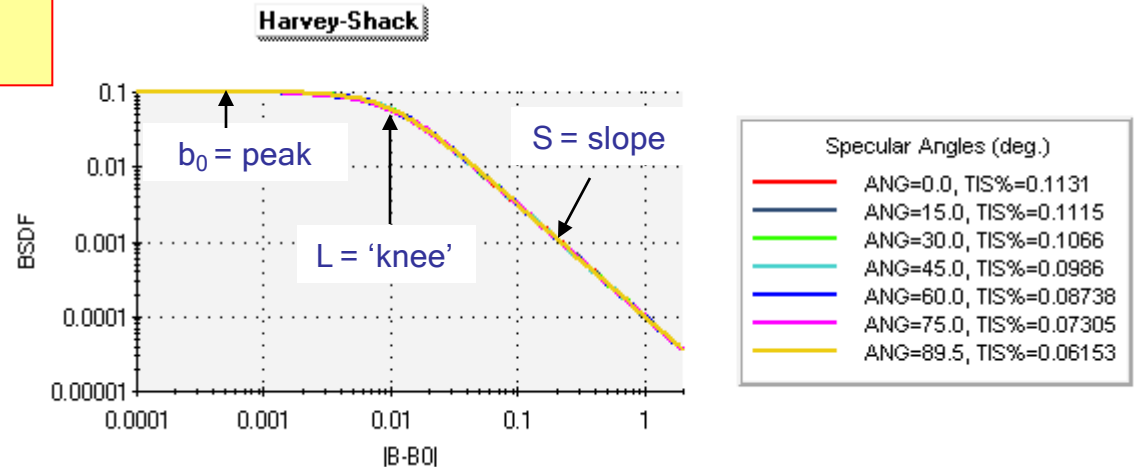
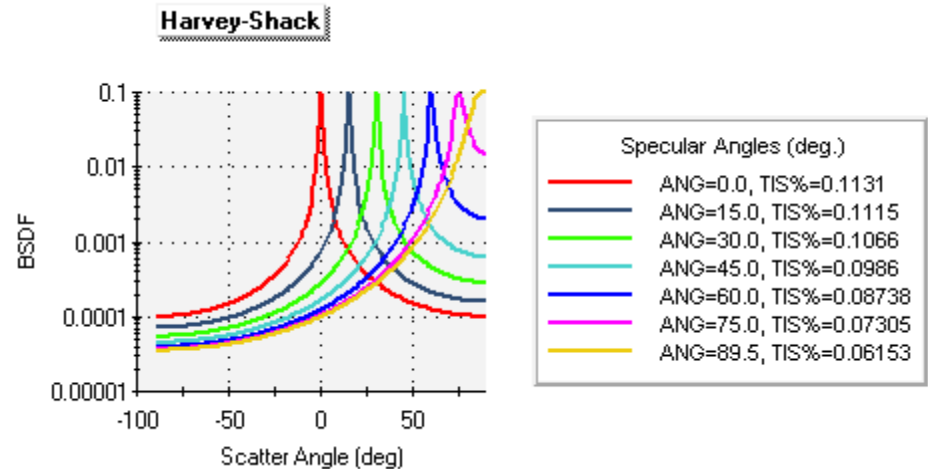
$$BSDF(\beta, \beta_0) = b_0 \left(1 + \left(\frac{\beta - \beta_0}{L} \right)^2 \right)^{S/2}$$

specular peak = b_0

ABg

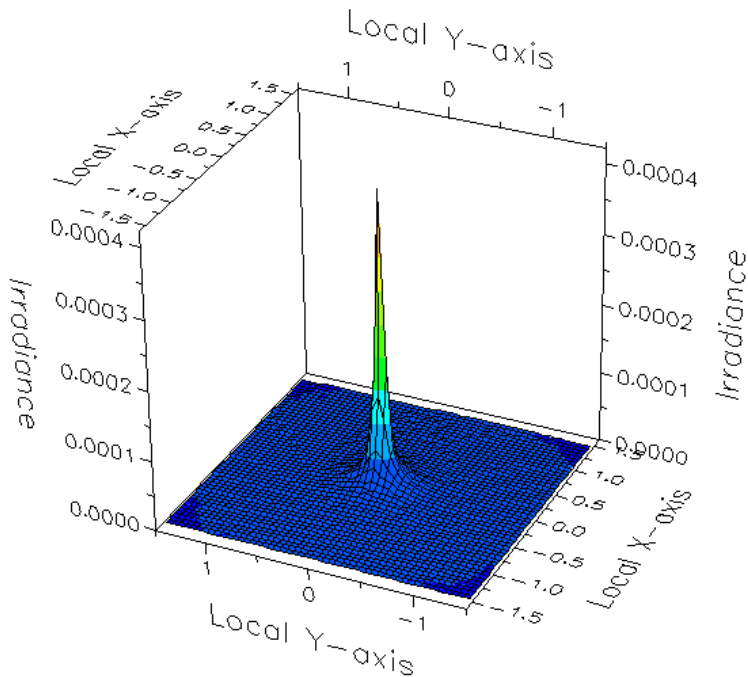
$$BSDF(\beta, \beta_0) = \frac{A}{B + (\beta - \beta_0)^g}$$

specular peak = A/B

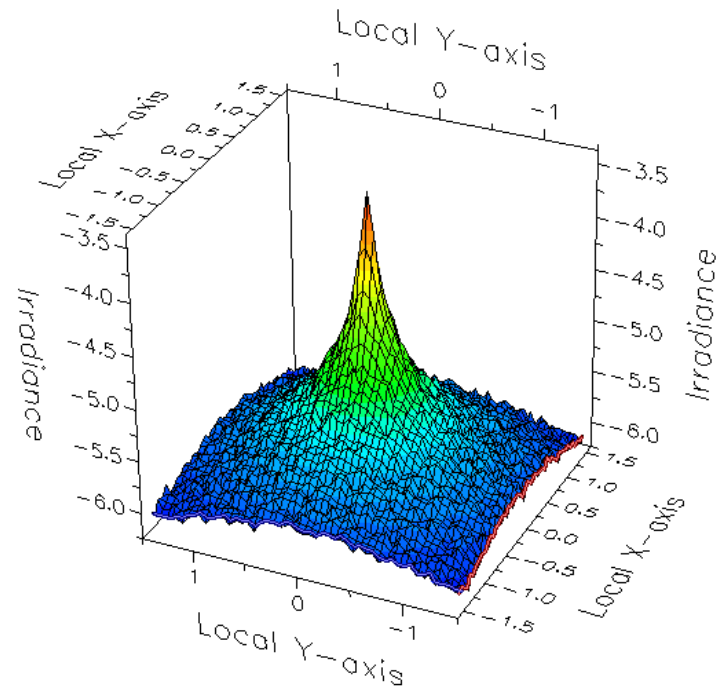


Scatter PSF for Harvey-Shack Model (5.3 Å Mirror)

- 5.3 Å equivalent roughness ($b_0 = 0.34 \text{ sr}^{-1}$, $L = 0.001 \text{ rads}$, $S = -1.5$, $\lambda = 0.5876 \mu\text{m}$)
- 10 inch diameter, $f/2$ parabolic mirror, at focus



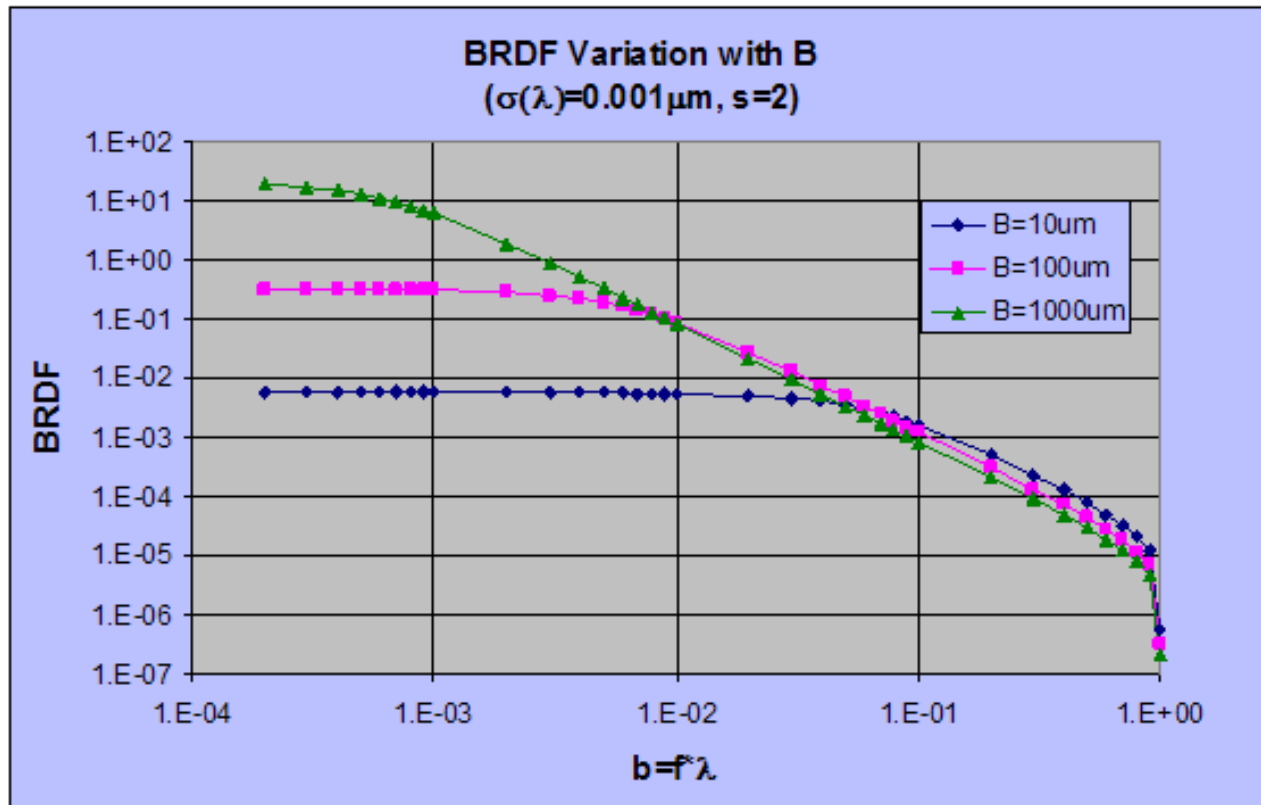
Linear Plot of Scatter PSF



Log Plot of Scatter PSF

K-Correlation BSDF Example

- Mirror ($\Delta n = 2$), $\lambda = 0.6328 \mu\text{m}$, $\sigma = 0.001 \mu\text{m}$, $S = 2$, $B = 10, 100, 1000 \mu\text{m}$ (approx. 9.7 \AA equivalent roughness)

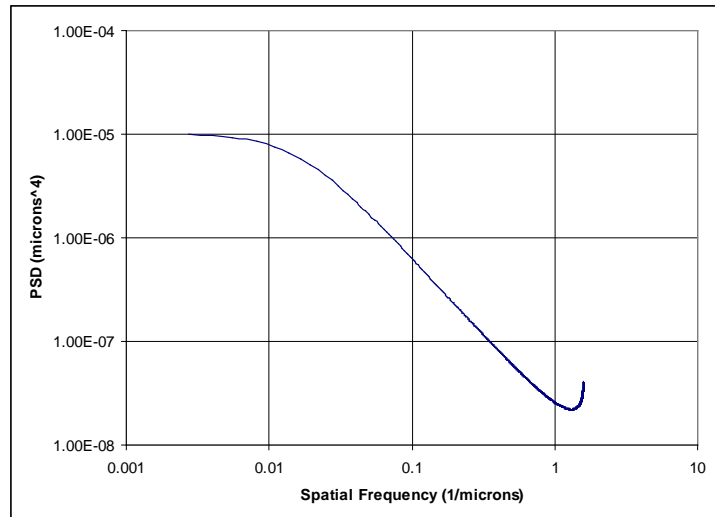


PSD-Based BSDF

- Harvey has argued that the more physically correct relationship between PSD and BSDF is given by

$$BSDF(\beta - \beta_0) = \frac{\pi^2 \Delta n^2 R}{\lambda^4} [\cos(\theta_i) + \cos(\theta_s)]^2 Q PSD(f)$$

This obliquity factor results in a more physically correct result, viz.



Ref: Krywonos, A., "Predicting Surface Scatter Using A Linear Systems Formulation of Non-Paraxial Scalar Diffraction", Ph.D. dissertation, University of Central Florida (2006)

Paint/Surface Treatment BSDF

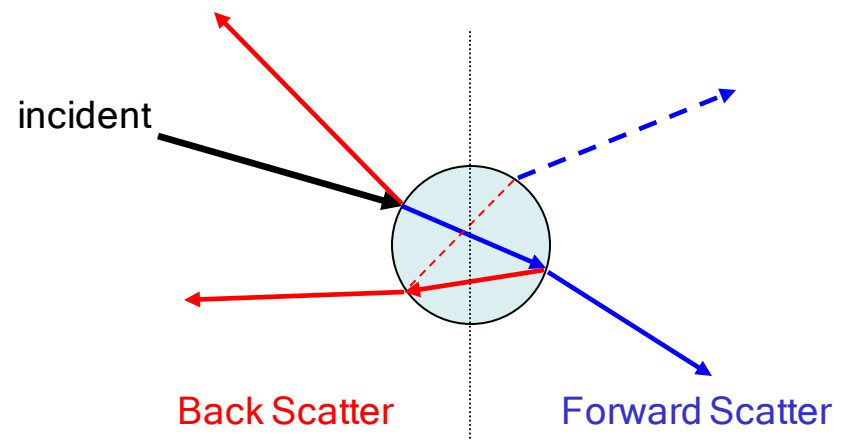
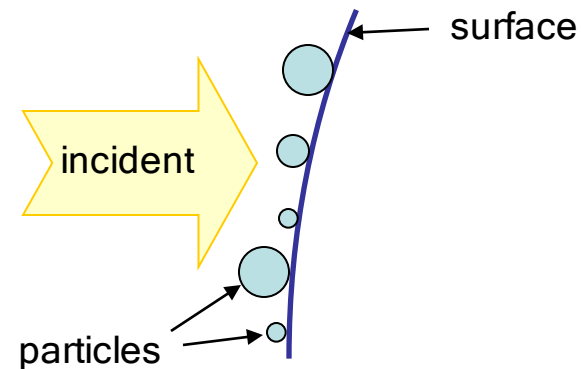
- Paints/surface treatments rely on pigmentation and microscopic surface structure to absorb or trap light → complex phenomenology
- Generally scatter is less wavelength-dependent than optical surfaces
- Four broad categories
 - **Diffuse (matte) black:** Aeroglaze Z306
 - Typically diffuse at near-normal incidence, but acquires some degree of specularly at large incident angles
 - TIS increases with angle of incidence
 - Can have significant outgassing properties
 - Particulates can become embedded in paint
 - **Usual choice in systems**
 - **Specular (gloss) black:** Cat-a-lac Black, Aeroglaze Z302, black “mirrors”
 - High degree of specularly at all incident angles
 - Used in beam dumps or other controlled beam paths to attenuate light
 - Can have significant outgassing properties
 - Particulates can become embedded in paint

Paint/Surface Treatment BSDF

- Four broad categories (continued)
 - **Anodized black:** Martin Black, chemical etch on aluminum (not a paint)
 - Considerable variation from diffuse to gloss
 - Can get very specular at high AOI
 - Limited substrates: aluminum, titanium, zinc, magnesium, and niobium
 - Other substrates can sometimes be used if they can be plated prior to anodization
 - **Other:** microscopic structures “grown” onto surface, etc
 - Fragile surface structures → may not be space-qualified
 - Potential source of particulates, outgassing, etc

Particulate Contamination: Mie

- Spherical dielectric particles distributed on a surface according to a particle size distribution function
 - MIL-STD-1246C, IEST-STD-1246D, Uniform, etc.
 - BSDF is accumulated effect of all particles - individual particle interactions are not modeled
- Particles produce both forward- and back-scatter components
 - Forward scatter interacts with the optical surface
 - Back scatter is particle only
 - TIS is computed over 4π steradians
- Angular scatter properties are very definitely wavelength-dependent; TIS is not!



General Polynomial BSDF

- Several researchers have tried to develop general polynomial functions to describe scatter based upon measurements of “real world” surfaces
- Greynolds proposed the following functions based upon symmetries, scatter reciprocity, and observations of actual measurements:

$$\log(\text{BSDF}) = \sum_{k=0}^{\infty} \left\{ \overbrace{\sum_{i=0}^{\infty} c_{ik} (\sqrt{T})^i}^{\text{diffuse}} + \overbrace{\frac{1}{2} \sum_{i=1}^i c_{ik} \log(1 + d^i T)}^{\text{Lorentzian}} \right\} V^k$$

“binomial” form

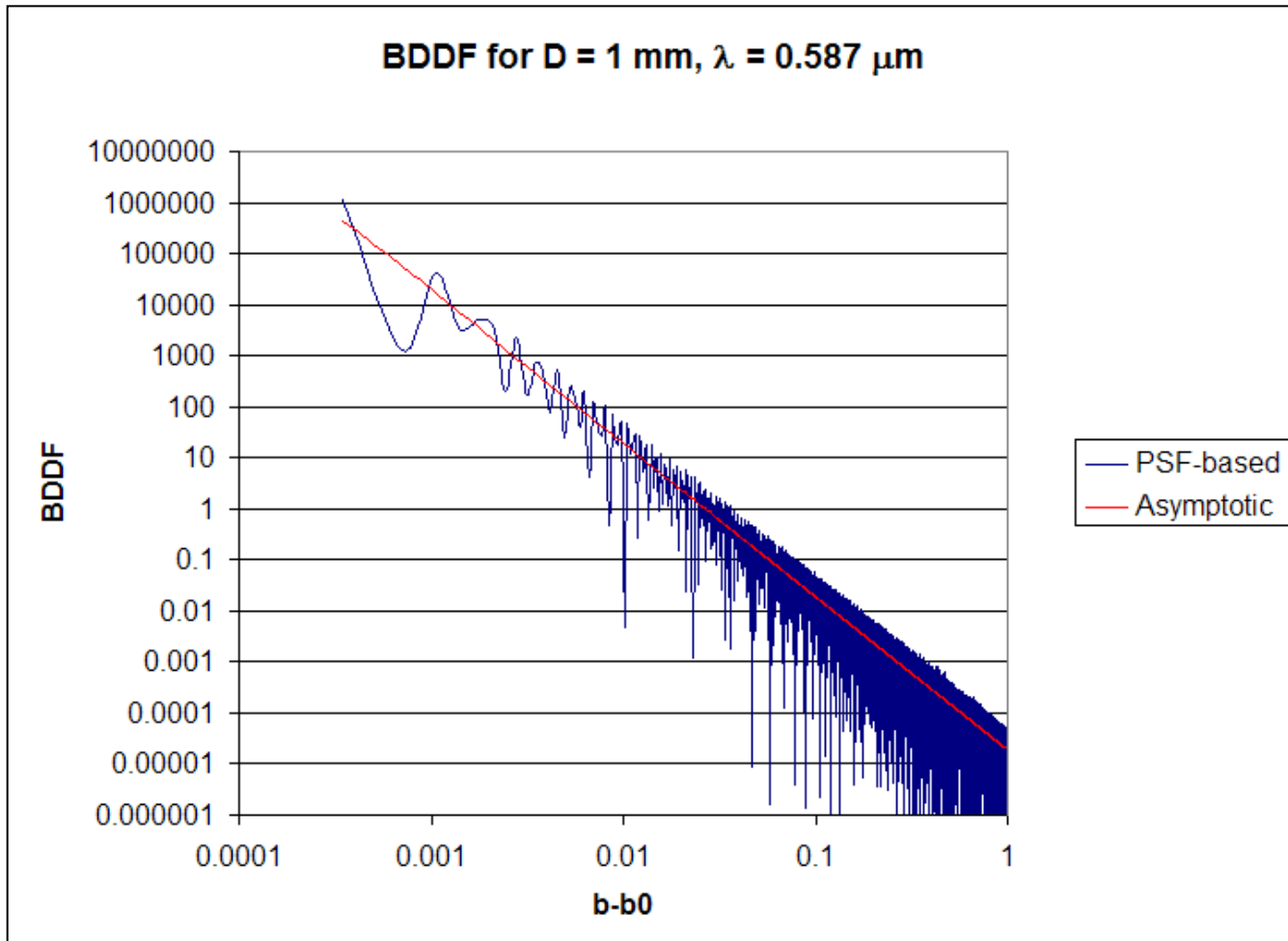
$$\log(\text{BSDF}) = \sum_{k=0}^{\infty} \left\{ \overbrace{\sum_{i=0}^{\infty} \sum_{j=0}^i c_{ijk} (U^i W^j + U^j W^i)}^{\text{diffuse}} + \overbrace{\sum_{i=1}^i c_{ik} \log(1 + d^i T)}^{\text{Lorentzian}} \right\} \frac{V^k}{2}$$

“polynomial” form

Tabular BSDF Functions

- If raw BSDF data cannot be fit easily to a polynomial form, how do we use it?
- For the stray light analysis of 3D hardware, scatter data must be available over 2π sr and for multiple angles of incidence, and so some interpolation scheme must be used
- Since BSDF must obey reciprocity to conserve energy, we cannot simply interpolate raw BSDF data
- *The “correct” solution is to employ reciprocity-obeying interpolation schemes that are fast enough to be used during raytracing*
 - Transformation of variables ensures reciprocity
 - Transformation of variables ensures symmetries for isotropic scatter (This is very difficult to implement for anisotropic scatter!)
- Tabular BSDF has become the most commonly used scatter model for measurement data

BDDF: Diffraction BSDF



Composite BSDF Models

- In most “real world” systems, optical surfaces are assigned multiple scatter models to simulate various optical effects
 - Smooth optical surface scatter → intrinsic surface microroughness
 - Particulates → contamination
 - TBD** scatter model → non-volatile residue (NVR)
 - 2nd smooth optical surface scatter → localized damage area on optical surface
- Very often analysts assign a single scatter model such as a paint to mechanical structures
 - Paint scatter properties usually dominate over particulates, NVR

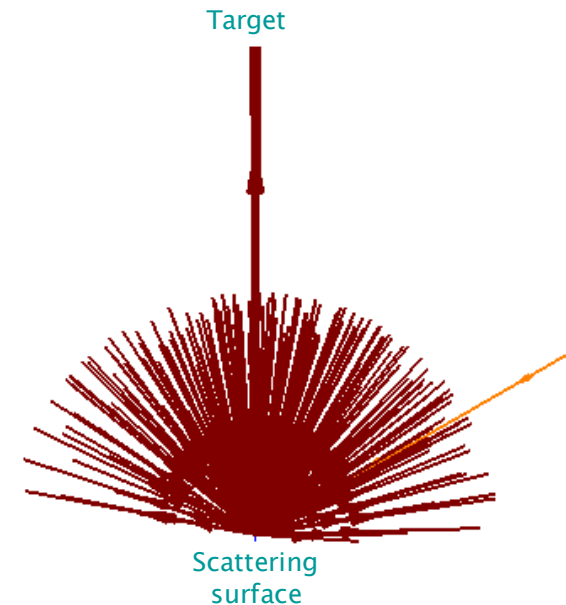
** Depends on the functional form of the residue scatter contribution

Very Rough Surfaces

- In almost all of the scatter models presented, the assumption was made that $\text{rms } \sigma \ll \lambda$
- For discussion, we will define “very rough surfaces” as those surfaces for which $\text{rms } \sigma \approx \lambda$
- Surfaces exhibiting this property are generally machined metal surfaces whose $\text{rms } \sigma$ is on the order of 100’s of microinches
- Currently there is no theoretical model that can simulate these surfaces from 1st principles
 - Harvey is working on a theoretical model that describes very rough surfaces as phase gratings with multiple diffraction orders... this work is not yet published
- PSD BSDF model can NOT model these surfaces even if measurement data is available because it also assumes that $\text{rms } \sigma \ll \lambda$

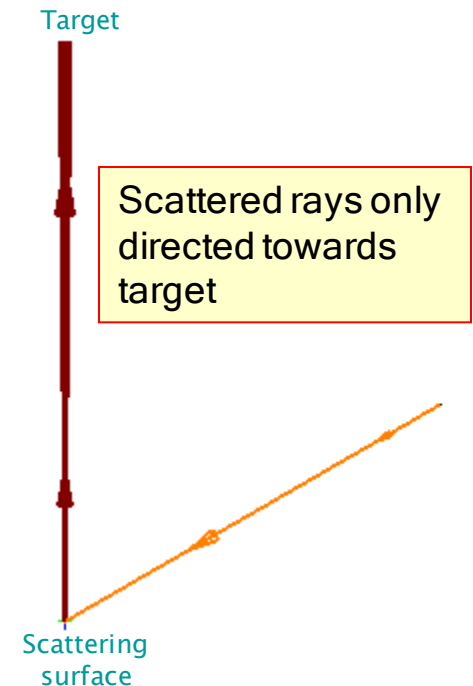
Why Scatter Importance Sampling?

- Scatter has no preferred direction → rays scattered from a surface can propagate in any direction (i.e., 2π sr)
- If computers were infinitely fast, we would generate scatter rays into 2π sr...
- However this is not the case and so we have to pay attention to efficiency!
- The relative efficiency of the calculation is the ratio of the solid angle of the target surface to 2π :
R.E. $\approx \Omega_{\text{target}} / 2\pi$
 - Example: 2cm diameter target 100cm away from the scattering surface
 - Relative efficiency is $\approx \pi \sin^2(0.573^\circ) / 2\pi = 5.0\text{e-}5$
 - Put another way, for every 1 million scattered rays traced, only 50 rays (on average) strike the target
 - This approach is very slow to converge



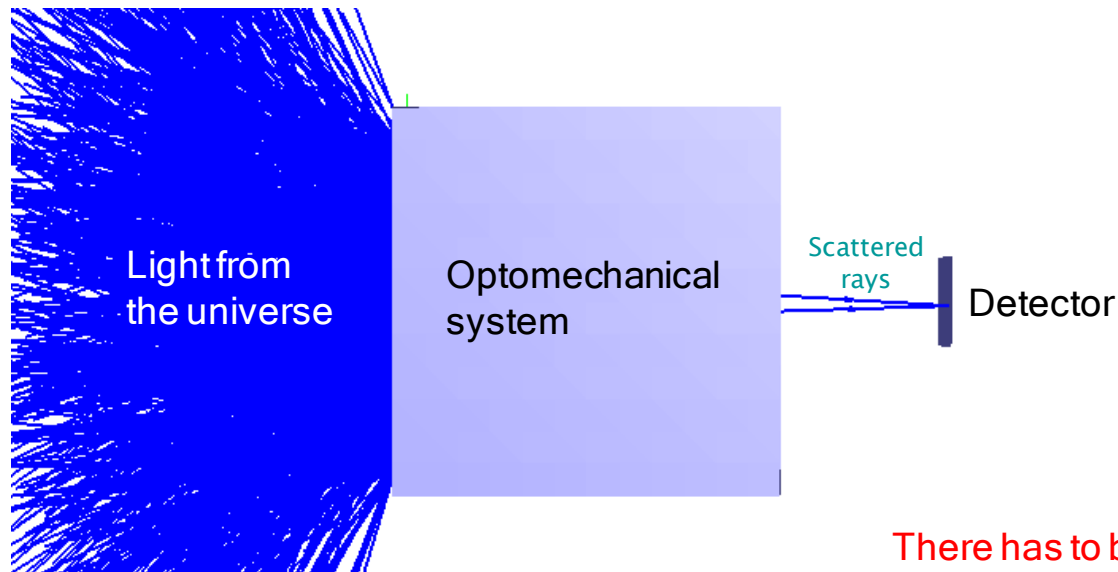
Why Scatter Importance Sampling?

- Instead, we can use importance samples to force the scattered rays to go only in the direction of interest
 - Dramatically more efficient
 - No ‘approximations’: scattered power transfer is scaled for actual solid angle
 - **CAVEATS**
 - Use care to ensure all paths from the scatter surface to the detector are accounted for
 - Overlapping importance samples can lead to analysis errors, since the overlapped regions are doubled up
- **Usually the direction of interest is the detector**



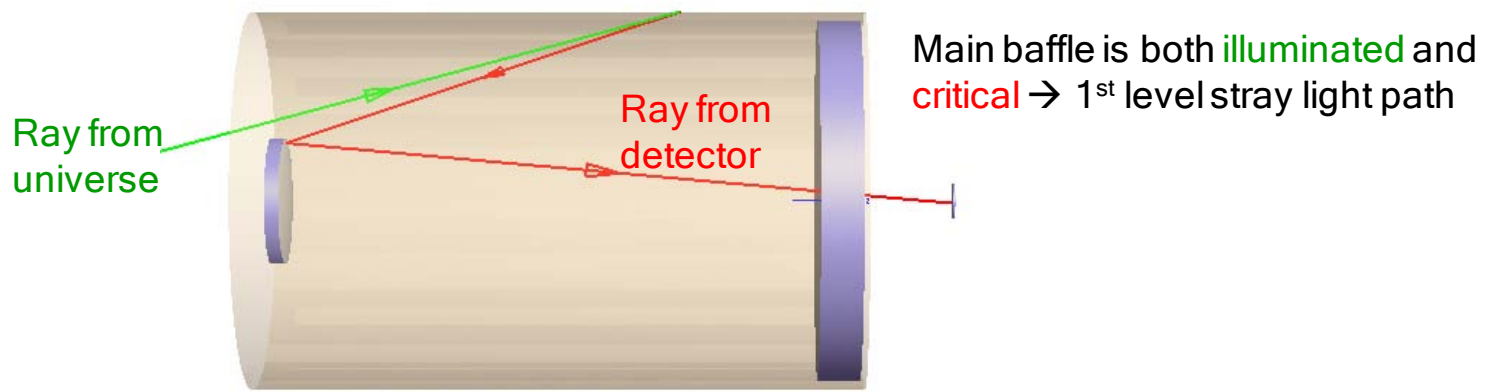
How NOT to do Stray Light Calculations

- By far the most obvious way to approach a stray light analysis is to flood the entrance aperture with rays representing light from all fields, generate scattered rays within the system, and count how many reach the image plane.
- While this may be obvious and easy to setup, doesn't require a knowledge of optics, and simulates the "real world", it is inefficient, very prone to sampling error, and time consuming! **It doesn't work!**



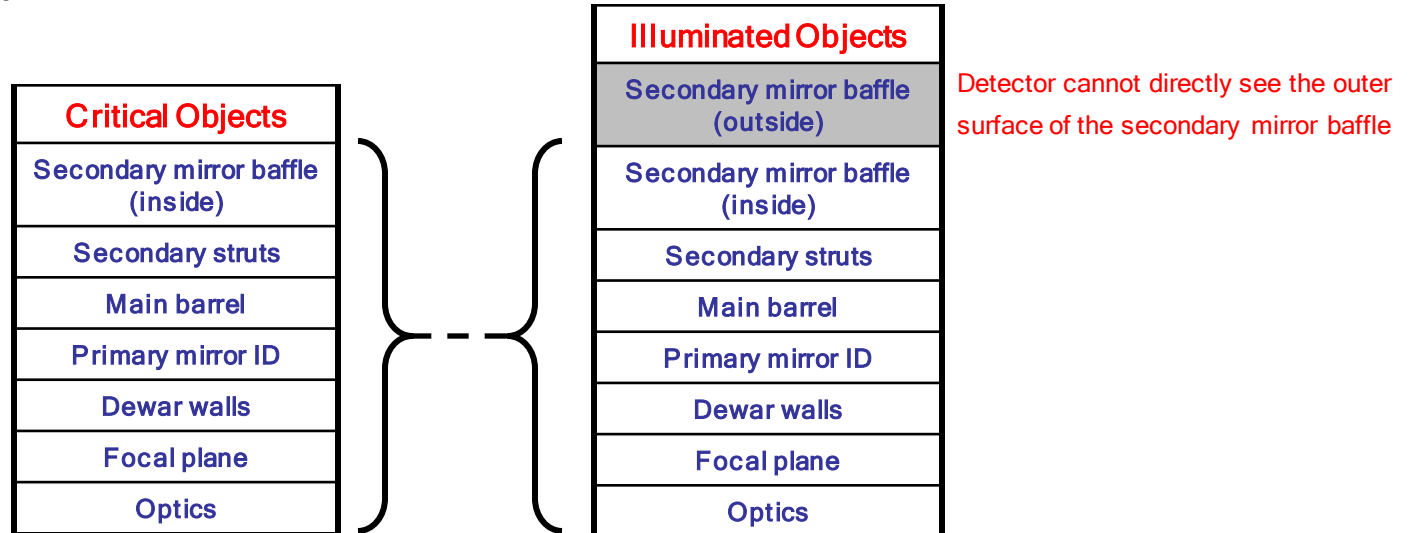
A Rational Strategy: Critical and Illuminated Objects

- Strategy is to identify surfaces that can be 'seen' simultaneously by the detector and the universe
 - **Critical objects** have one or more direct paths to the detector
 - **Illuminated objects** have one or more direct paths to the outside world
- **Objects (surfaces) that are both critical and illuminated can provide a direct path for unwanted energy to reach the detector**
- Primarily of use for direct and single level scatter events (nearly always the most significant)



Comparing the Tables → 1st Level Paths

- In this simple model, almost all of the critical objects are illuminated as well → usually not the case



- Objects (surfaces) that are both critical and illuminated can provide a direct 1st level path for unwanted energy to reach the detector
- Sides matter
 - Define front and back sides to structures (such as vanes) that can be seen from both directions

PSNIT and NDI Calculations

- The most common (and perhaps most useful) definition of PST is Point Source Normalized Irradiance Transmittance (PSNIT) or Normalized Detector Irradiance (NDI)
- It is the ratio of the average detector irradiance to the incident irradiance, computed as a function of angle:

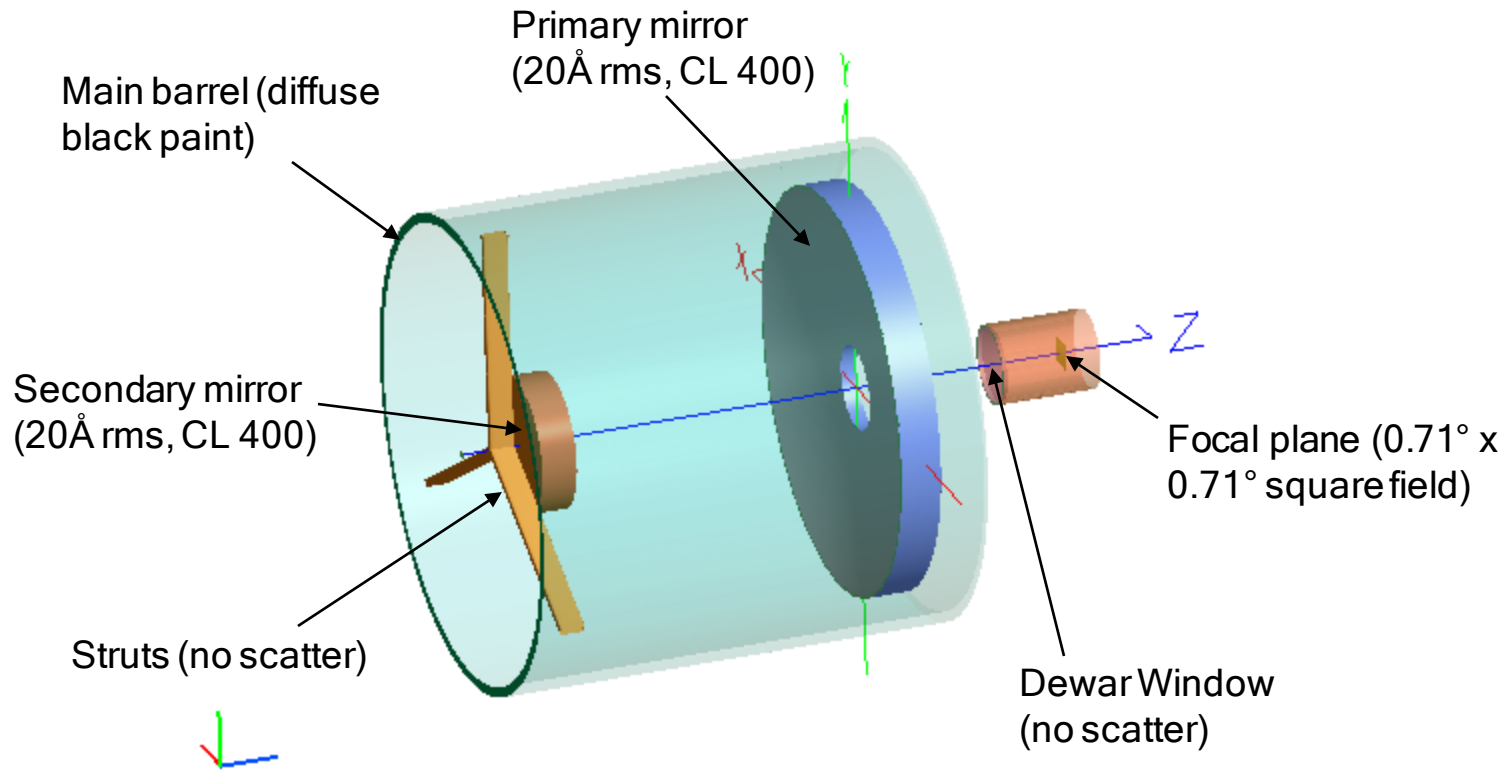
$$PST(\theta, \phi) = \frac{E_{det}(\theta, \phi)}{E_{inc}(\theta, \phi)} = \frac{E_{det}(\theta, \phi)}{P_{inc, norm} \cdot \cos(\theta) / A_{entrance}}$$

- The source irradiance at normal incidence is typically set to unity
- This PST can be used as a transfer function: the total amount of light (stray or otherwise) reaching the focal plane is

$$P_{det}(\theta, \phi) = E_{inc}(\theta, \phi) \cdot PST(\theta, \phi) \cdot A_{det}$$

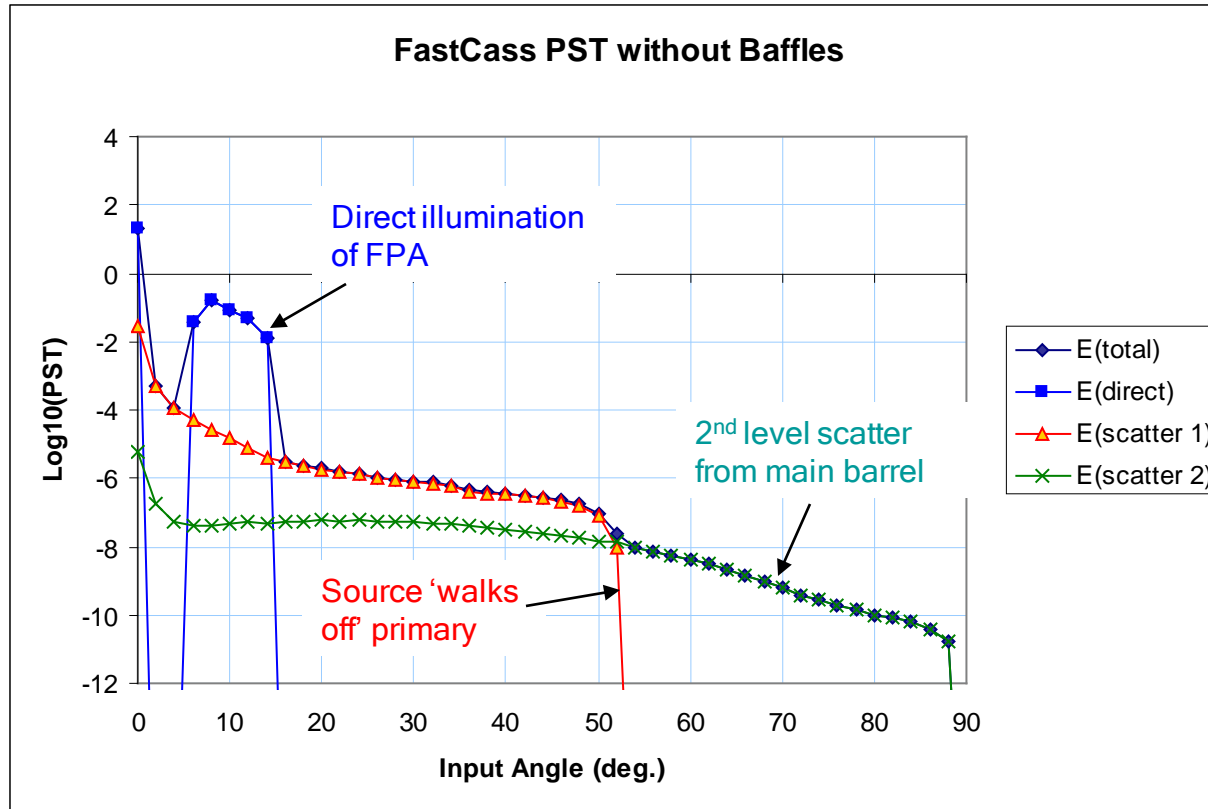
- The main advantage of this definition is that the PST is not adversely affected by obscurations, unusual apertures, vignetting, etc

Simple Cassegrain: Surface Properties



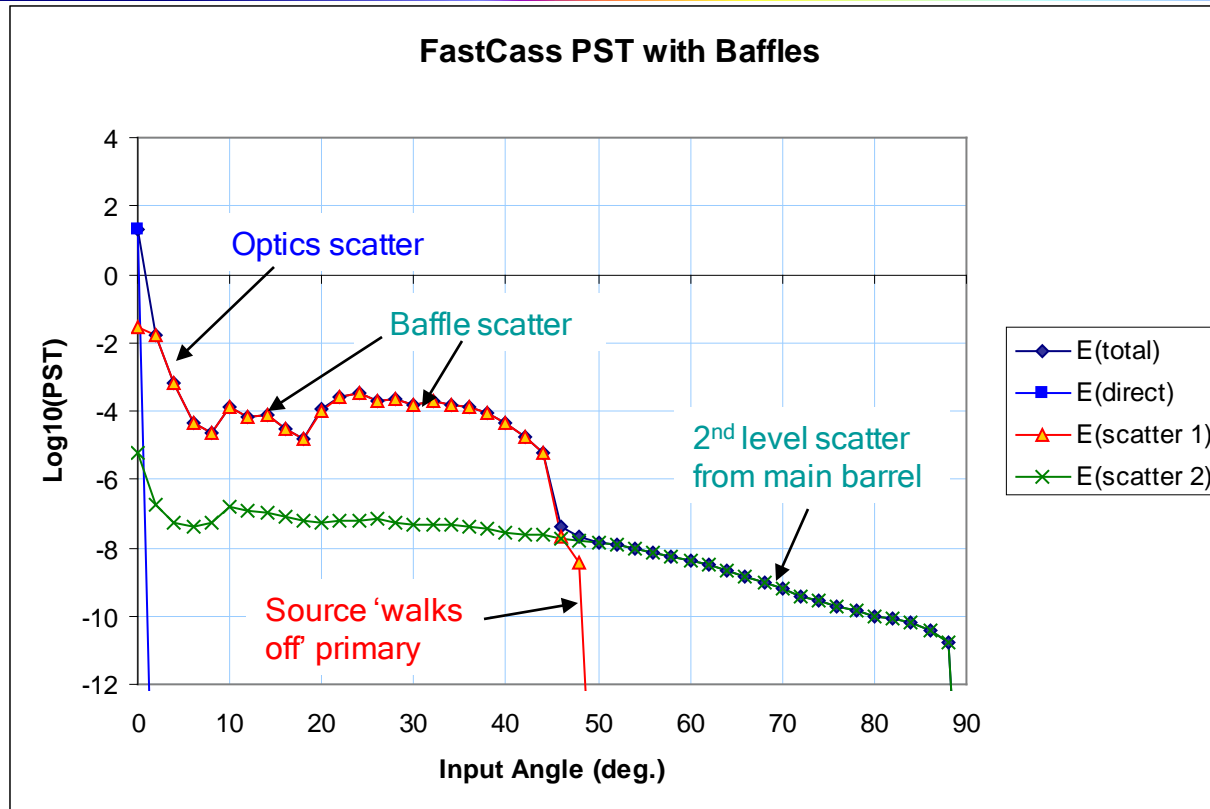
No baffles - a bad configuration!

PST Output – Simple Cassegrain



- Scatter dominated by single level events from primary and secondary mirrors
- Scatter from barrel is scattered a second time from the mirrors → dominant effect at large angles

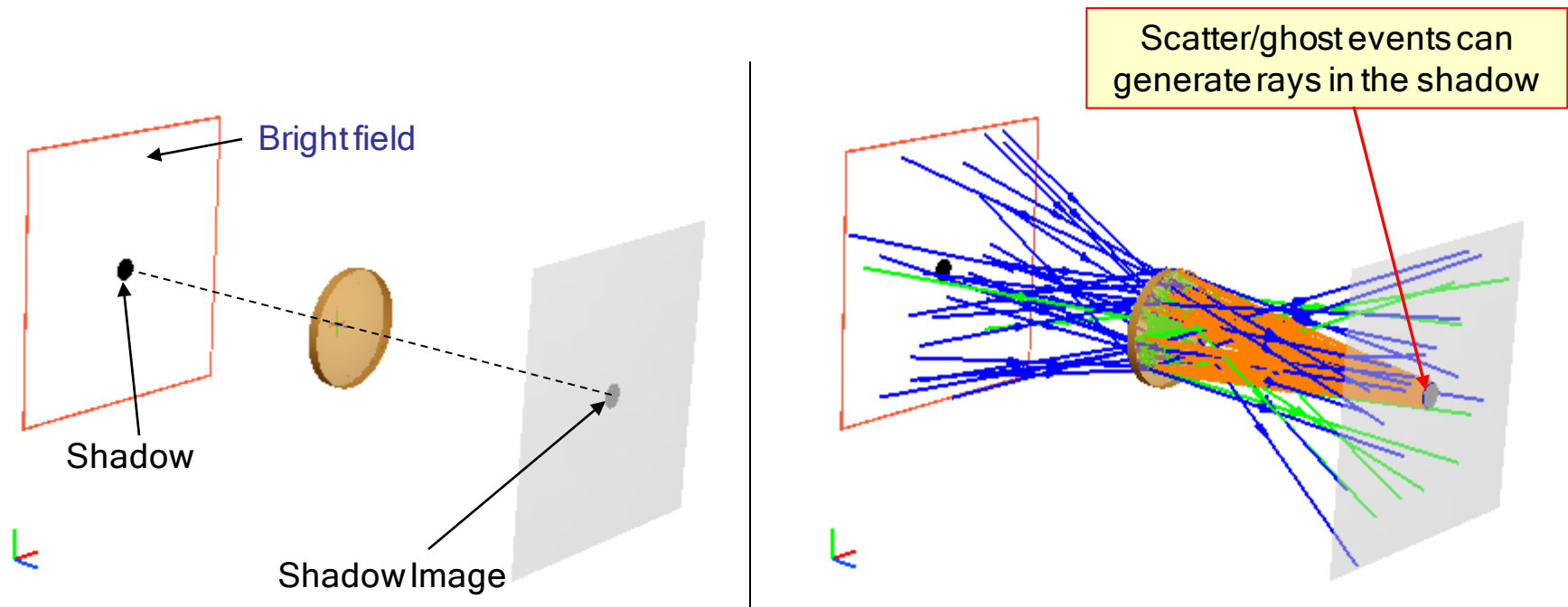
Simple Cassegrain PST with Baffles



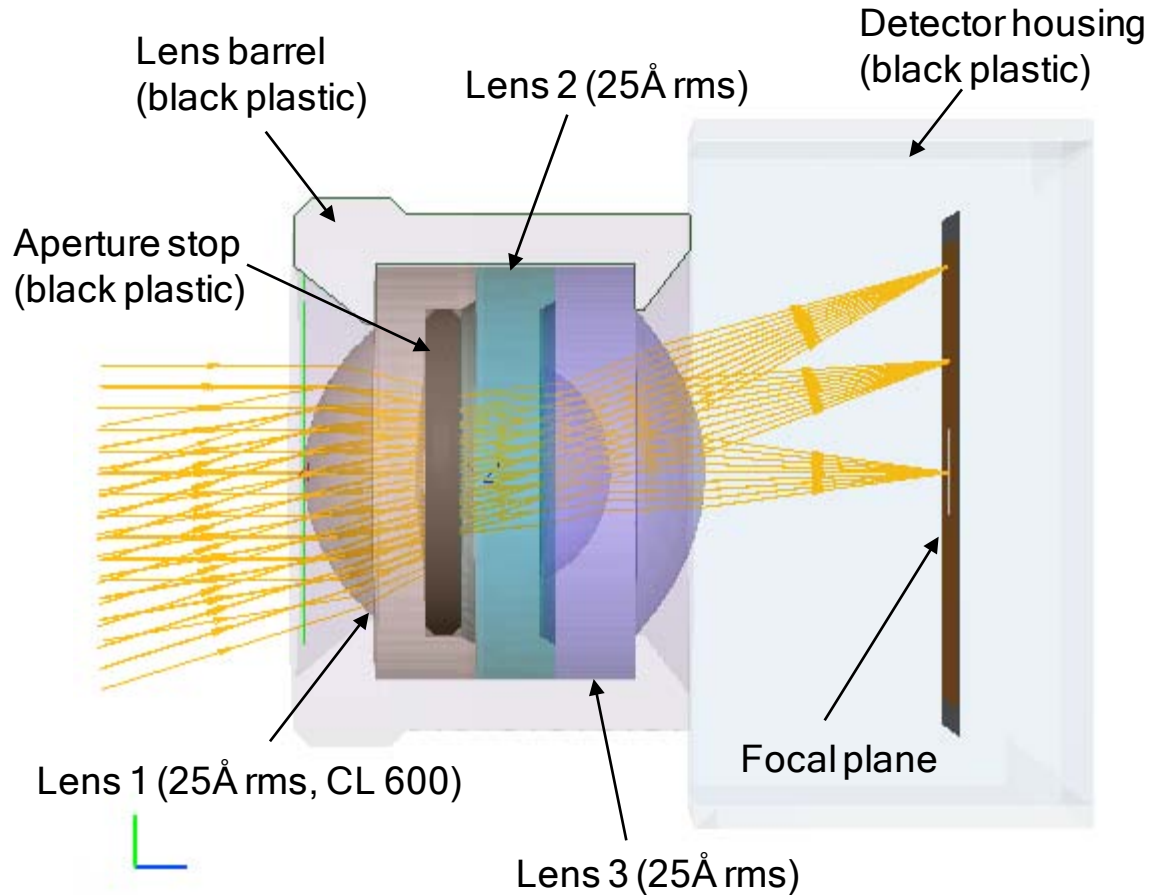
- Near FOV scatter dominated by single level events from primary and secondary mirrors
- Baffles are close to beam path (grazing incidence), contribute primarily at mid-range angles
- Second level scatter from main barrel is largely unaffected

Contrast or Veiling Glare

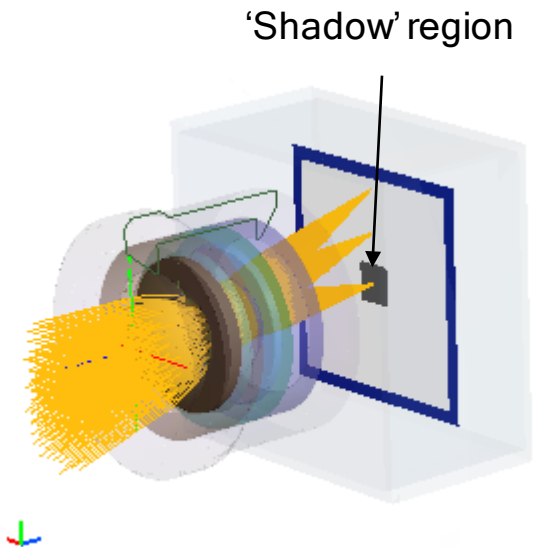
- Typical bright field test setup has a source with a uniformly bright scene with a 'hole' in it
- Imaging path does not fill any part of image of the hole on the detector



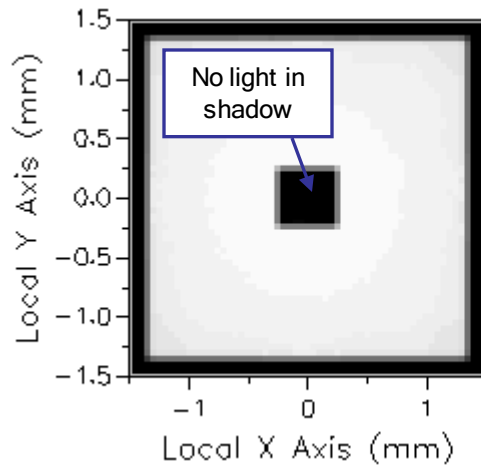
Example: Molded Plastic Camera Lens



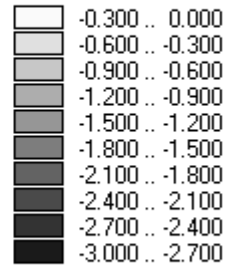
- For simplicity, contamination model applied only to first surface
- All lens surfaces are AR coated
- Lenses stack (edges are in contact)
- Scatter rays are aimed towards shadow region



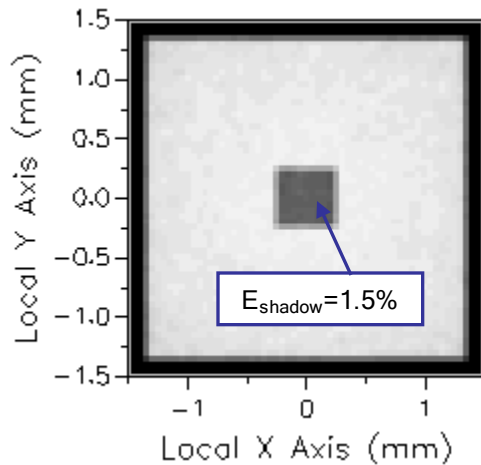
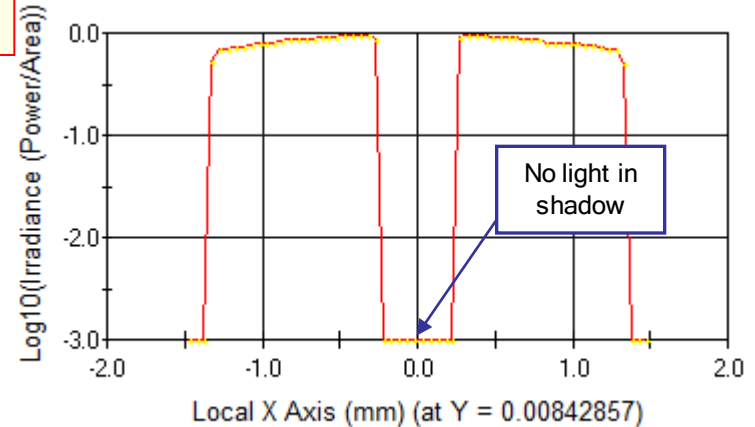
Veiling Glare Irradiance



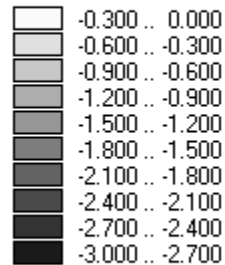
Log10(Irradiance (flux/area))



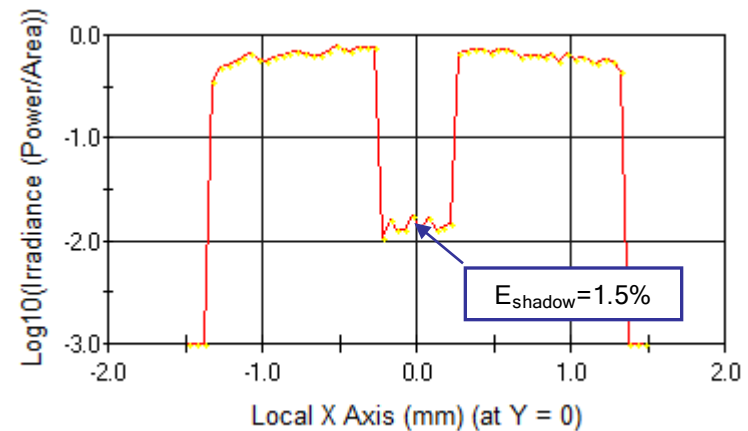
Before



Log10(Irradiance (flux/area))

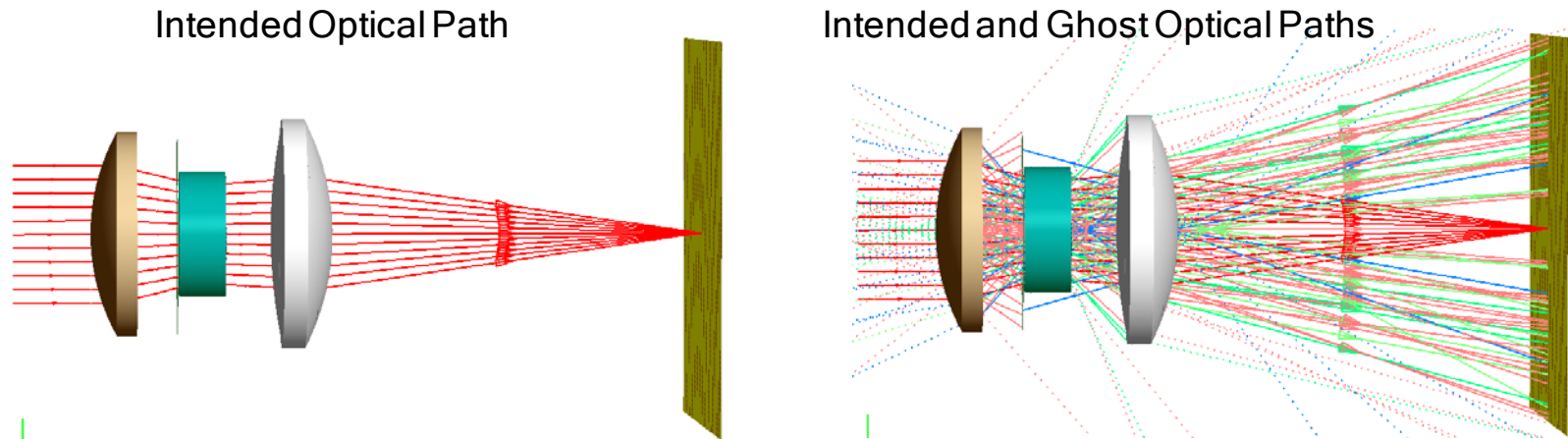


After



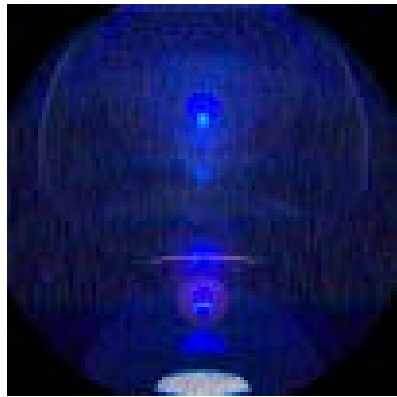
Ghost Image Analysis

- Since ghosts are based on specular processes, their morphology is fundamentally different from that of scatter
 - Scatter is essentially a continuous distribution of energy
 - Ghosts
 - are generally specific structures w/definite edges, foci, etc
 - can coherently sum \rightarrow high energy densities \rightarrow exploding optics!

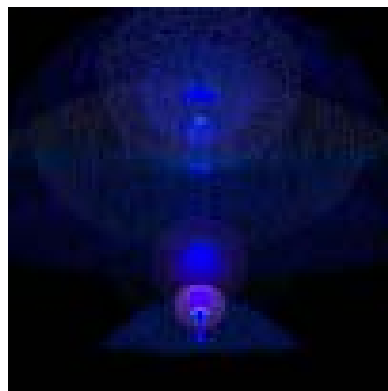


Polychromatic Ghosts

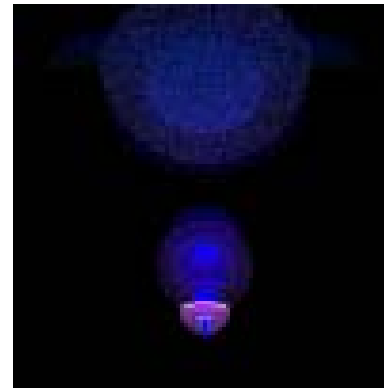
- In many cases, it is necessary to trace enough wavelengths to reconstruct a polychromatic image at each off-axis angle



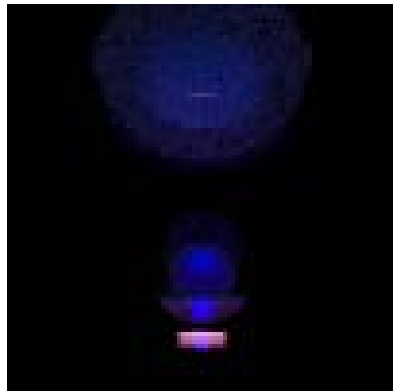
40 deg



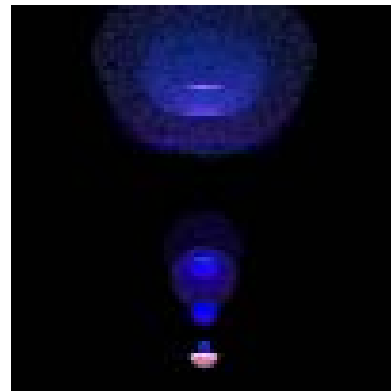
42 deg



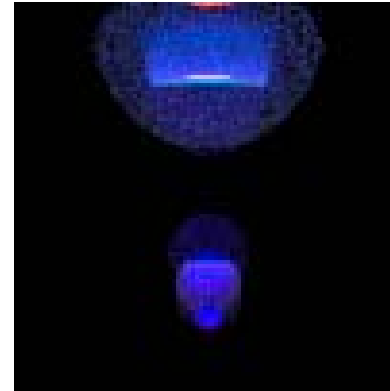
44 deg



46 deg

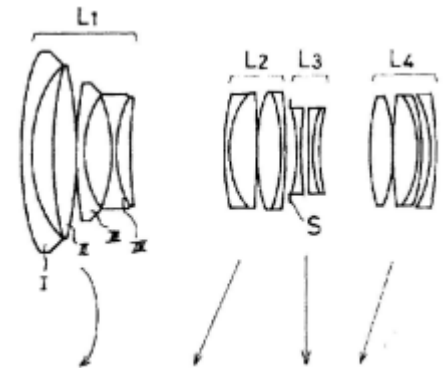


48 deg



50 deg

Polychromatic ghost images for 16 element camera lens

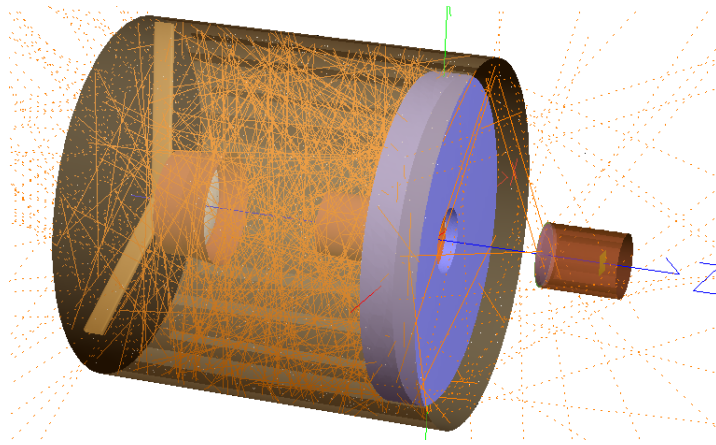


Which Path Caused Which Structure?

- With such clear delineation of structures in the detector irradiance, it begs the question: *which ghost path caused which irradiance structure?*
- Unfortunately software has no way of knowing what a structure looks like in order to identify it. Consequently automatic identification is algorithmically very difficult to implement.
- Analysts have developed several techniques for ghost identification
 - Ghost ray path statistics
 - Graphical review of data
 - Ray path trajectories
 - Spot diagrams
 - Irradiance distributions
 - Tabular review of data
 - Average irradiance calculations
 - “RMS” irradiance calculations
 - Artifact diagnostics
 - Identification of rays contributing to an artifact, and then determining the path(s) of these rays

Thermal Self-Emission (TSE)

- At mid-to-long-infrared wavelengths (roughly $3\mu\text{m}$ to $20\mu\text{m}$), the optics and structural components become radiant objects (blackbody Lambertian radiators)
- Self-emission background limits sensitivity
- Forward raytracing (objects \rightarrow detector) is very inefficient



In most “real” systems, the detector subtends a very small solid angle relative to the hardware \rightarrow lots of rays, bad statistics!

- A better approach is to trace backwards from the detector (or detector pixel element)

Radiometry of TSE (con't)

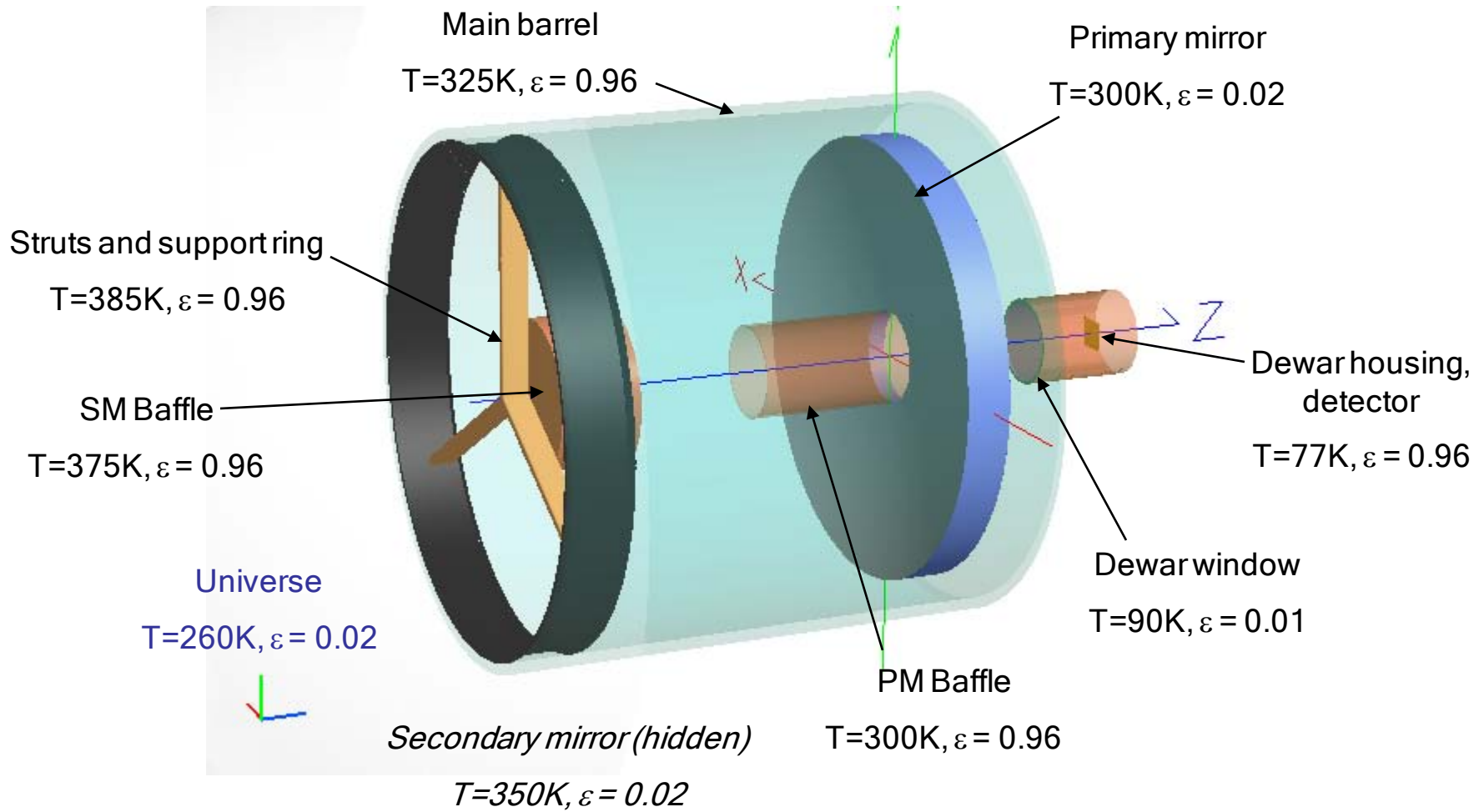
- The term GCF has its root in radiative transfer theory. It is the geometric projection of one surface onto another.
- The GCF is given by

$$GCF_{object} = \frac{\Omega_{object}}{\pi}$$

- We can move π from one side of the equation to the other. Therefore the final equation for TSE is given by

$$TSE = \sum_{all\ objects} \varepsilon f \sigma T^4 A_{detector} \frac{\Omega_{object}}{\pi} = \sum_{all\ objects} \varepsilon f \sigma T^4 A_{detector} GCF_{object}$$

TSE Example



Baffled Cassegrain TSE

Thermal Self Emission Summary

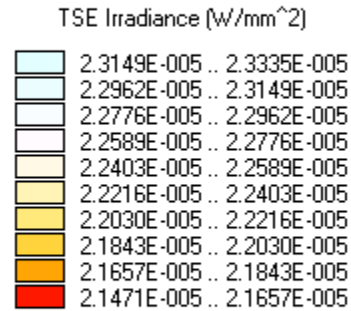
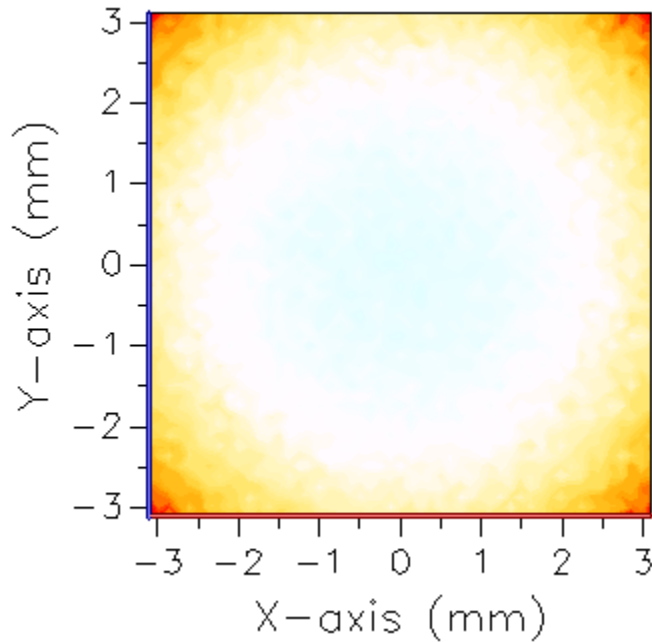
cassys_thermal.frd

Spectral band: 7-11 microns
Detector area: 40.3225 square mm

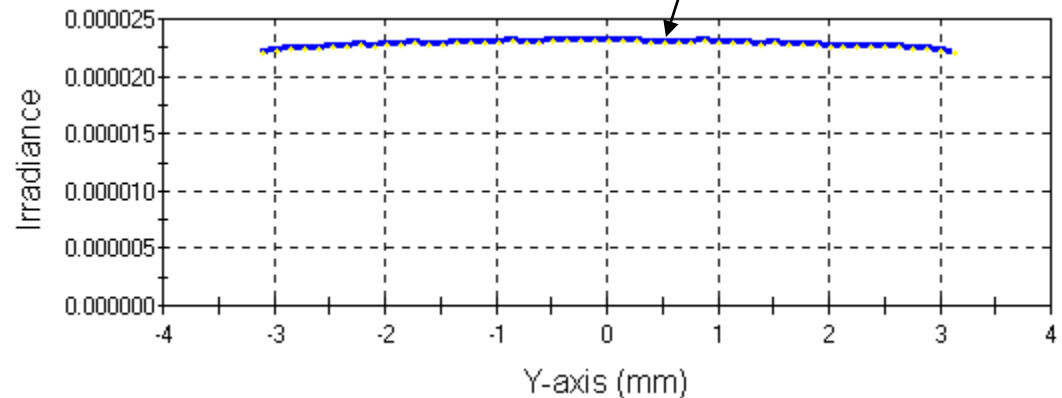
Looks like a spreadsheet → can be a spreadsheet!

Surface	Parent	Temperature	Emissivity	FBB	GCF	Contribution	Percent
back surface	main barrel	300	0.96	0.2570627	1.394E-01	6.37E-04	70.68
inner surface	Primary baffle	300	0.96	0.2570627	4.610E-02	2.11E-04	23.37
inner cone	Secondary baffle	375	0.96	0.3144701	2.329E-03	3.18E-05	3.53
inner cylinder	Secondary baffle	375	0.96	0.3144701	4.281E-04	5.84E-06	0.65
front edge	Secondary baffle	375	0.96	3.14E-01	2.968E-04	4.05E-06	0.45
inner surface	main barrel	325	0.96	0.2833507	3.813E-04	2.65E-06	0.29
Reflecting Surface	Secondary mirror	350	0.02	0.302264	1.204E-02	2.50E-06	0.28
end cap	Secondary baffle	375	0.96	0.3144701	1.138E-04	1.55E-06	0.17
Surf 6	strut b	385	0.96	0.3176795	7.631E-05	1.17E-06	0.13
Surf 6	strut c	385	0.96	0.3176795	7.171E-05	1.10E-06	0.12
Surf 6	strut a	385	0.96	0.3176795	7.079E-05	1.08E-06	0.12
Reflecting Surface	Primary mirror	300	0.02	0.2570627	8.150E-03	7.76E-07	0.09
front edge	Primary baffle	300	0.96	0.2570627	8.743E-05	4.00E-07	0.04
outer cone	Secondary baffle	375	0.96	0.3144701	2.850E-05	3.89E-07	0.04
barrel wall	dewar housing	77	0.96	3.80E-05	7.752E-01	2.27E-09	0.00
retaining ring	dewar housing	90	0.96	0.000285	1.286E-02	5.28E-10	0.00
Surface 2	dewar window	90	0.01	0.000285	2.122E-01	9.07E-11	0.00
Surface 1	dewar window	90	0.01	0.000285	2.038E-01	8.71E-11	0.00
detector array	FPA	77	1	3.80E-05	1.838E-05	5.61E-14	0.00
Total TSE (W)						0.000901602	

Baffled Cassegrain – TSE Irradiance

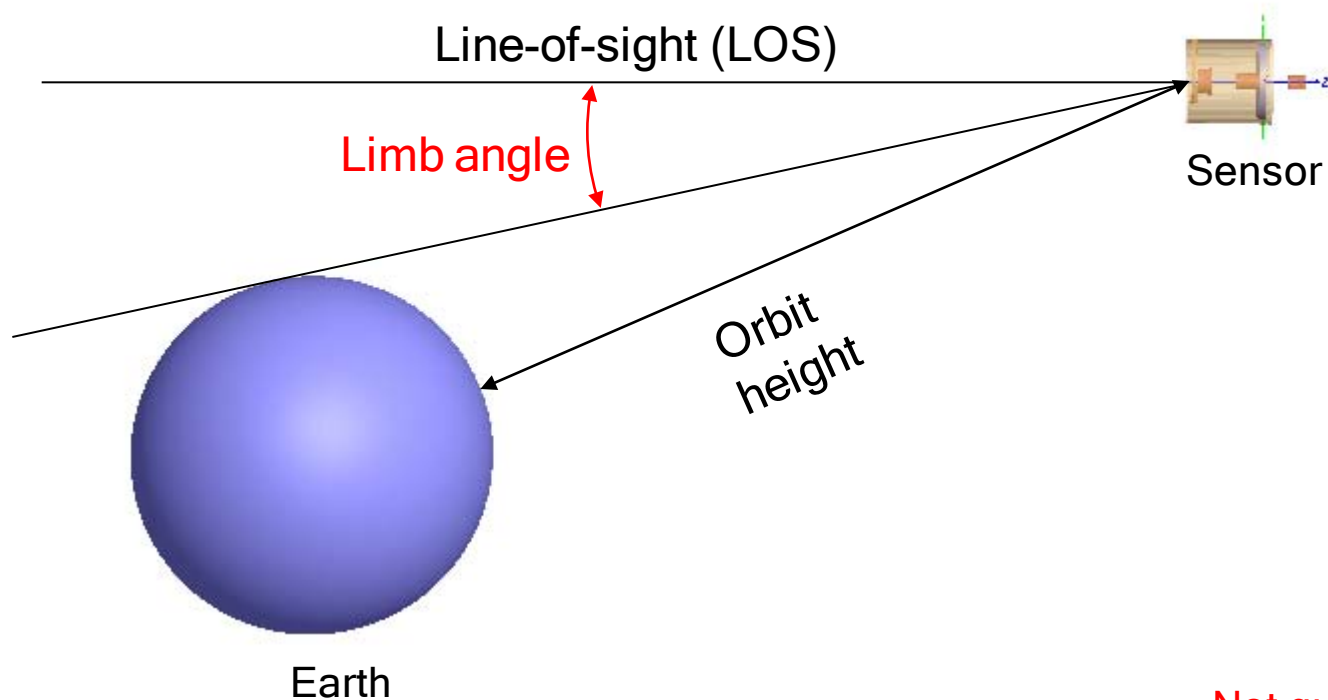


• Very little variation across the focal plane → hot objects are not in focus



Extended Source Stray Light Calculations

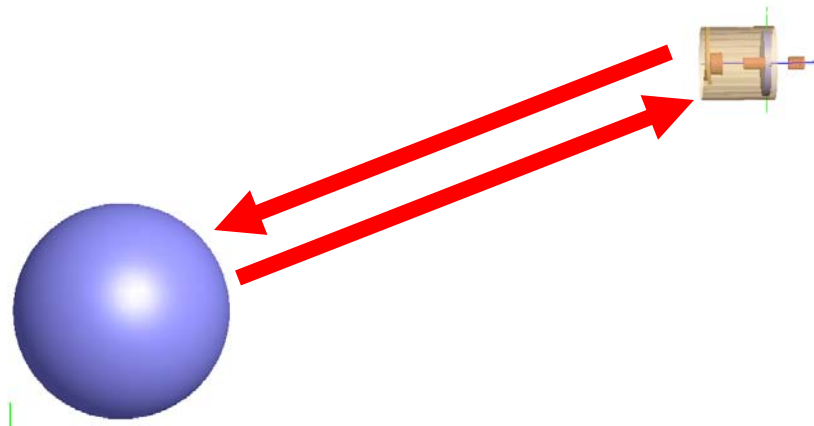
- In many aerospace applications, it is necessary to compute the stray light contributions from a large extended source such as the earth or moon



Not quite to scale!

Utilizing Reciprocity for Stray Light Calculations

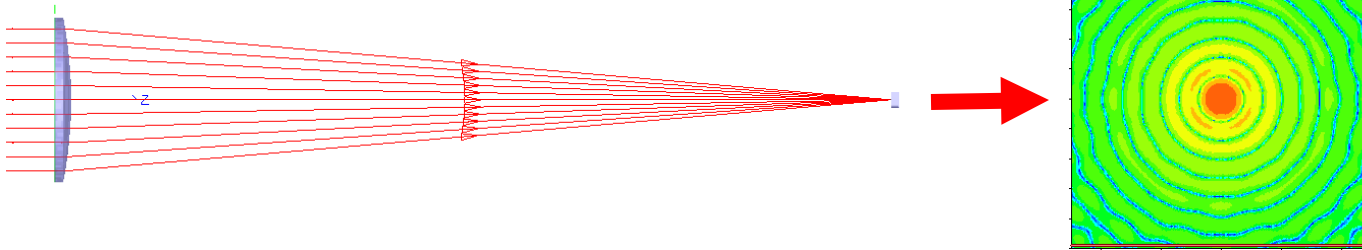
- At the beginning of this tutorial, we derived an expression for a more general radiance theorem: $P_s L_s = P_c L_c$
- We can use this and take advantage of the tremendous size difference between the earth and the sensor to develop an accurate and efficient method to calculate the stray light contribution from the earth
- Conservation of energy states that the energy flow from the earth to the detector has to be identical to the energy flow from the detector back to the earth



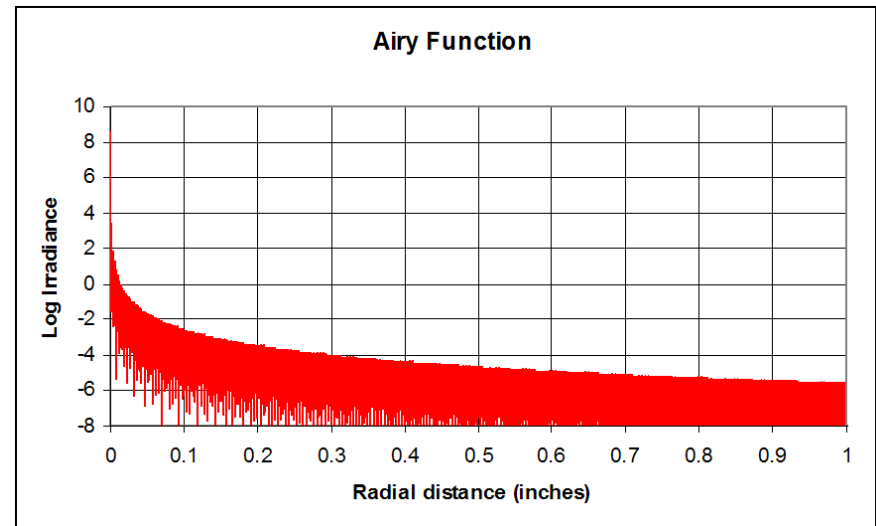
- To be more specific: the stray light from the earth to the sensor must equal the stray light from the sensor to the earth

Stray Light Near the PSF

- Since the image of a point source is not itself a point, but a distribution of energy, there is always “stray light” around the PSF → we call these “diffraction rings”

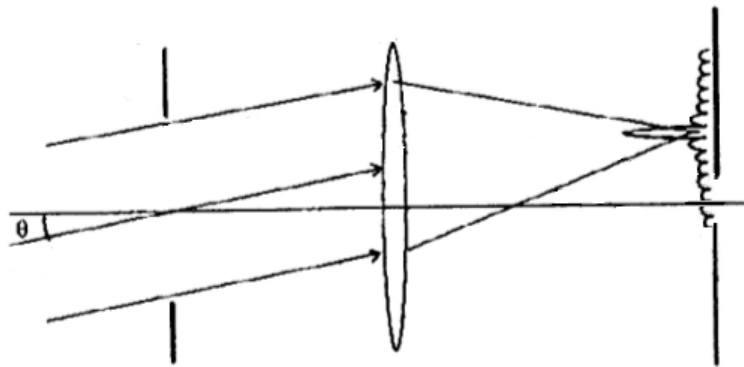


- Theoretically the diffraction rings go out to infinity → note how slowly the PSF falls off



Stray Light Away from PSF

- From a mathematical standpoint, determining the diffraction ring structure away from the Airy core is simply a matter of evaluating the PSF at an off-axis angle



What portion of the optical field passes through the stop?

- From an analysis standpoint, however, several issues can become problematic:
 - Airy function is rapidly oscillating and has wavelength dependence
 - Finite sampling of detector
 - Optical field propagation technique
 - Finite sampling of optical field
 - Complex opto-mechanical geometry

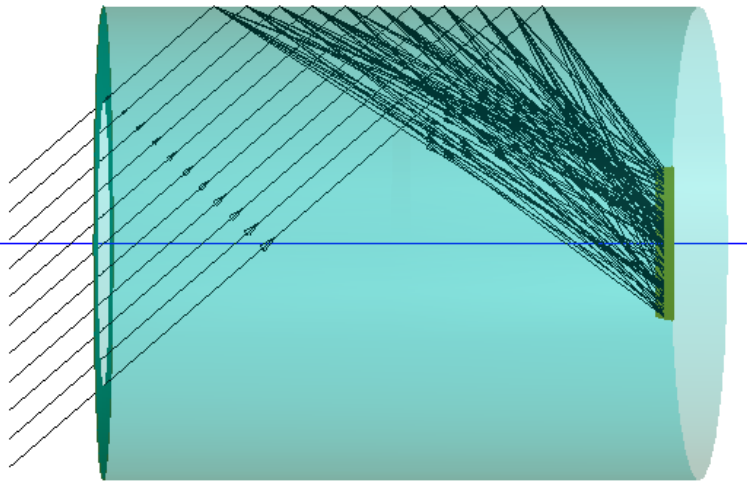
Reducing Stray Light

Move it or Block it or Paint/coat it or Clean it

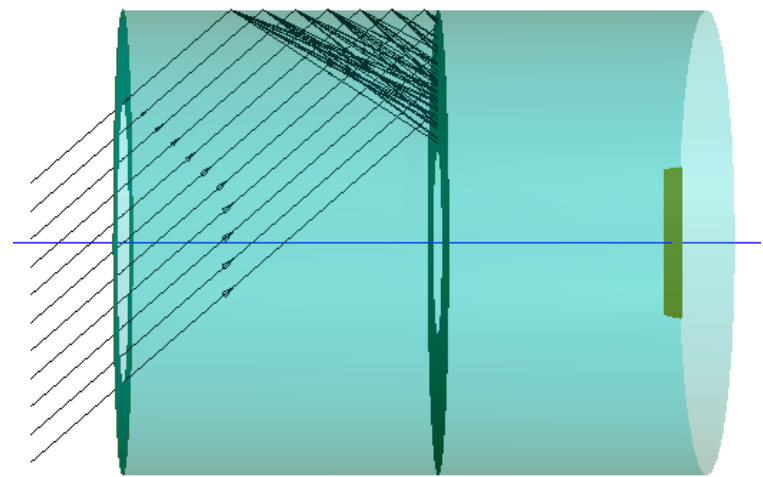
- **Move it**
 - Move the critical object away from the detector's FOV
 - Move the critical object so it is not illuminated
- **Block it**
 - Insert a baffle/vane to block the detector's view of the object
 - Insert a baffle/vane to block direct illumination of the object
- **Paint/coat it**
 - Apply a less scattering paint or surface treatment
 - Apply a coating w/less residual reflectivity
 - Get a smoother surface
- **Clean it**
 - Remove particulates, NVR

Vanes

- Vanes are mechanical structures positioned along a baffle to block specular and scattered rays originating at the baffle from reaching the detector



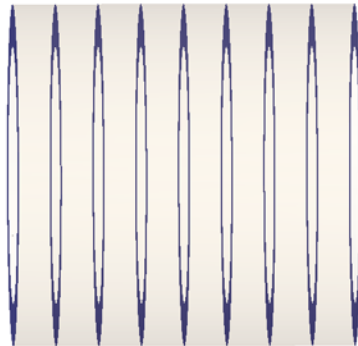
No vanes → direct scatter path



Vane added to block scattered light

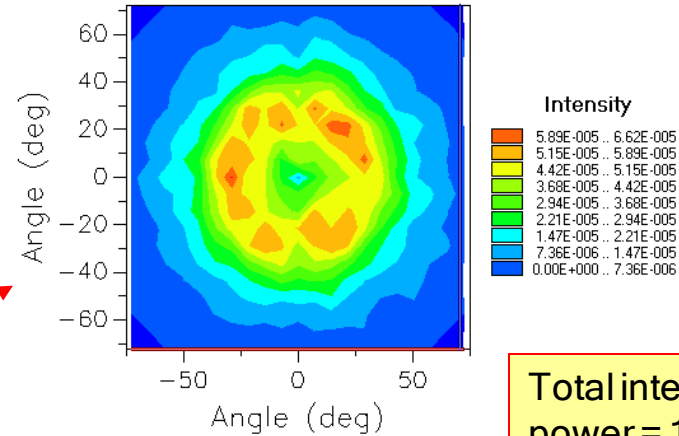
Scatter Intensity Distributions from Diffuse and Black Reflective Vane Cavities

2π sr
Lambertian
source input

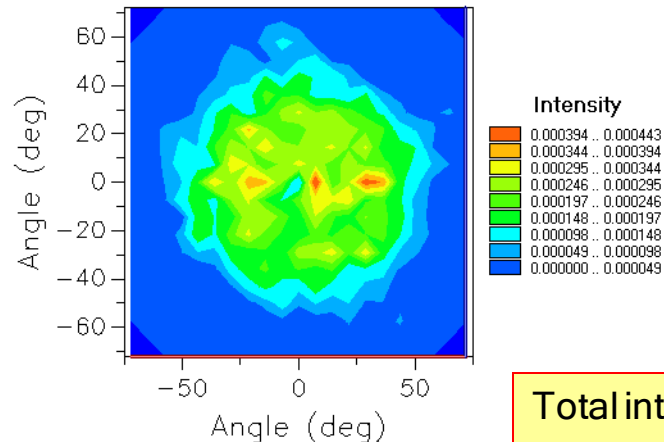


Diffuse

Specular



Total integrated
power = 114e-6



Total integrated
power = 557e-6

Note: Don't forget the edge effects when doing these kinds of comparisons! Edges can intercept and reflect/scatter a great deal of energy into the direction of the optics.

What about Modifying the Surface Property?

- The *least* effective methods for reducing stray light:

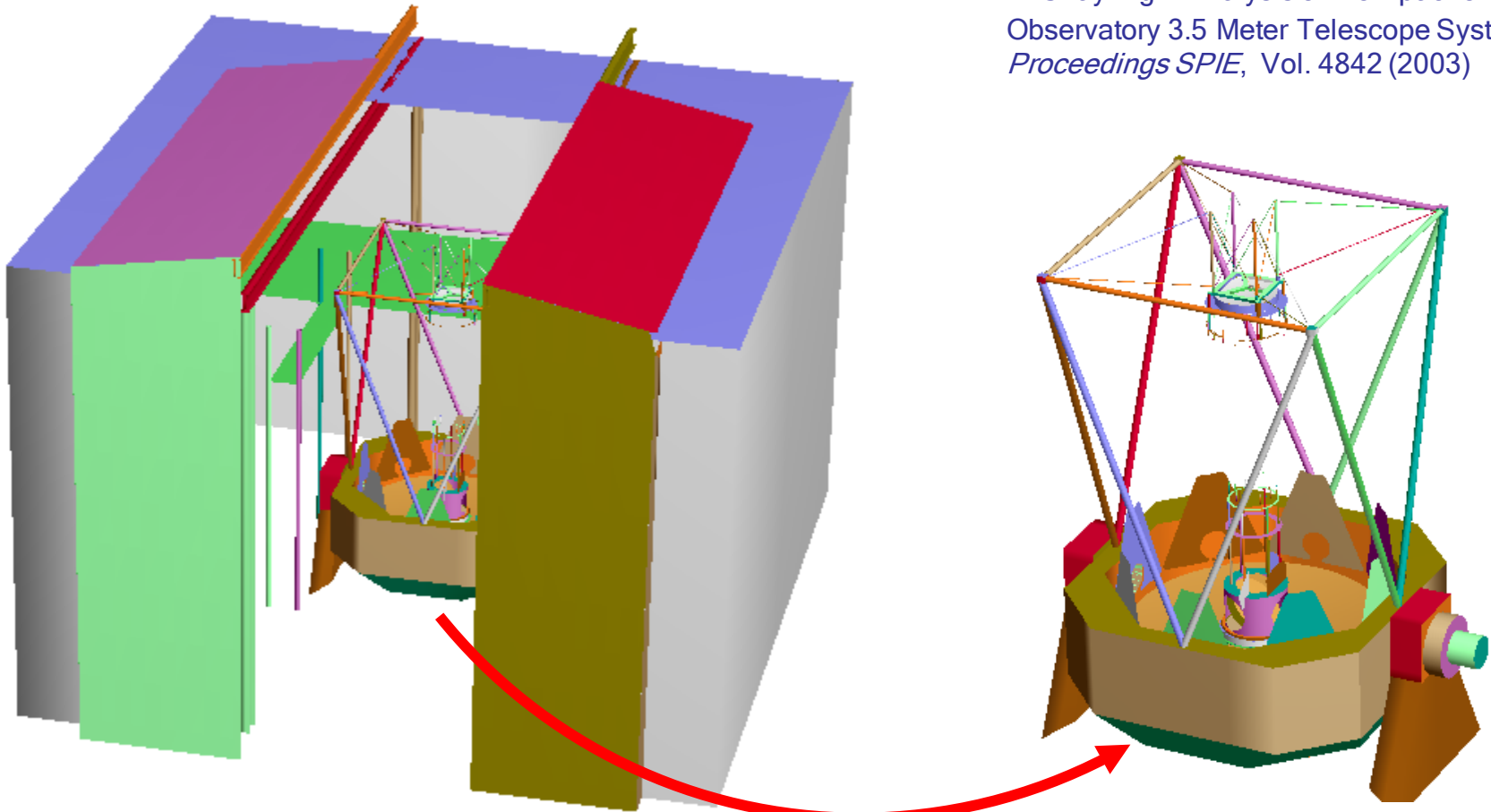
Ask for ...	What Will Happen ...
Lower surface roughness	Surfaces will get dirty
Tighter specification of scratch/dig	Surfaces will get dirty
Lower scattering paint/surface treatment	Only incremental improvements are possible
Better contamination control	Adds cost, schedule impact; exposure naturally increases particulate contamination; launching into space significantly increases particulate contamination

- Bottom line → can't get there from here!

Does It Work?...

Apache Point Observatory - New Mexico, US

Ref: Pompea, S., Pfisterer, R., Morgan, J.,
"A Stray Light Analysis of the Apache Point
Observatory 3.5 Meter Telescope System",
Proceedings SPIE, Vol. 4842 (2003)



Does It Work?... Yes!

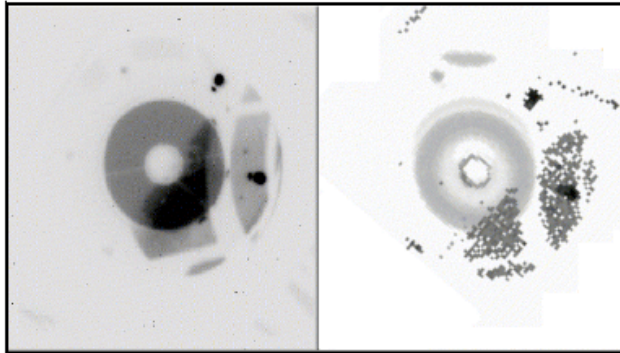


Figure 6 Actual (left) and Simulated (right) EN01.009 Images. Telescope 1 degree north of Jupiter.

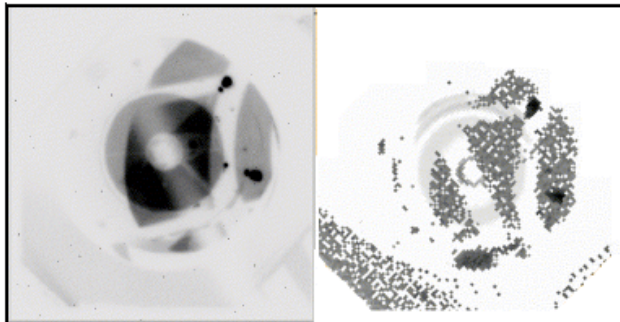


Figure 7 Actual (left) and Simulated (right) EN01.011 Images. Telescope 2 degrees north of Jupiter.

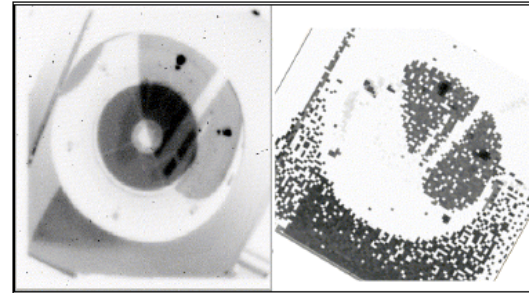


Figure 8 Actual (left) and Simulated (right) EN01.013 Images (A power threshold settings was responsible for the missing image of the primary mirror in the simulated image.) Telescope 30 degrees north of Jupiter.

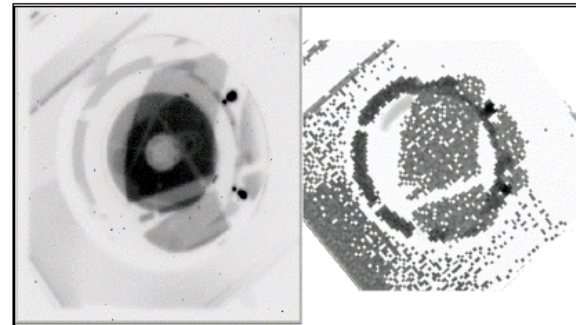


Figure 9 Actual (left) and Simulated (right) EN01.017 Images (A power threshold settings was responsible for the missing image of the primary mirror in the simulated image.) Telescope 4 degrees north of Jupiter.