Overview of Stray Light Part 1

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What IS stray light?

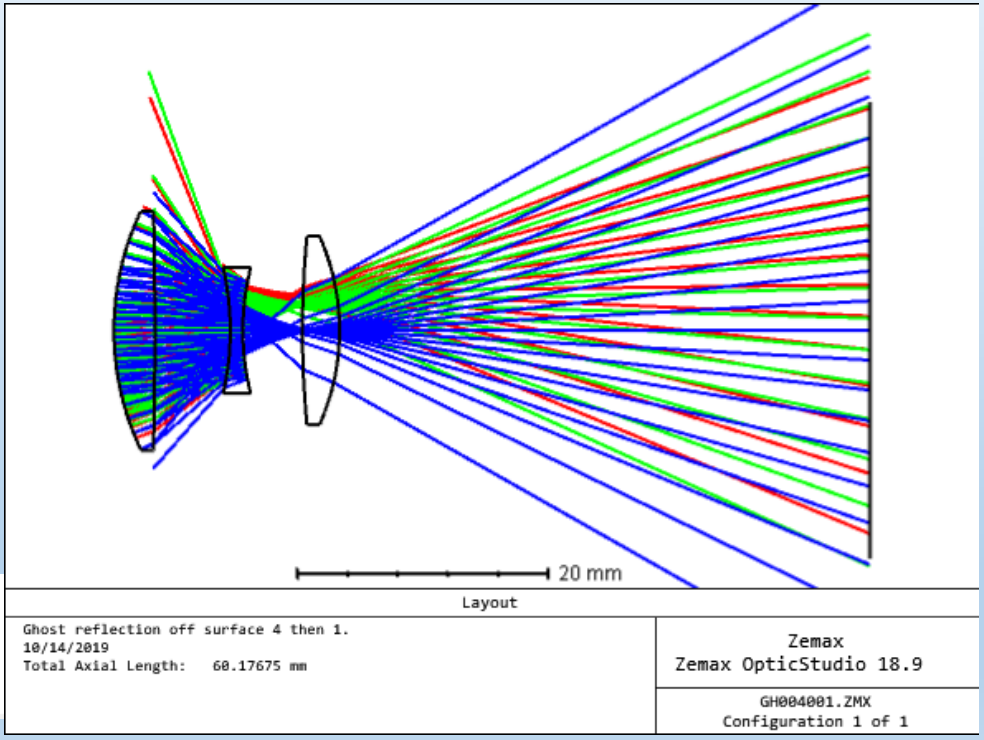
- What is stray light?
- Stray light refers to any unwanted light in an optical systems. Stray light is a problem in both imaging and non-imaging systems.
  - Generally concerned with light reaching the detector
- Stray light generally manifests itself in several different forms:
  - Ghosts
  - Scattered light
  - Straight paths due to improper baffling
  - Diffraction
  - Thermal emission

Ghosts

- Ghosts are images of bright sources
  - Usually out of focus
  - Caused by Fresnel reflections off the lens surfaces
    - Even orders of reflections can reach the image surface
  - Sources in or near the field of view can form ghosts
    - Sources outside the field of view must be considered
  - Small sources form images of the stop
  - Focused ghosts form images of the source
  - Reflection from sensor reimage on sensor

Ghosts

- A near pupil ghost creates “haze”

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Closest ghost pupil    :          -8.4708   at 4 then 1
Closest ghost focus    :         -20.4985   at 6 then 1
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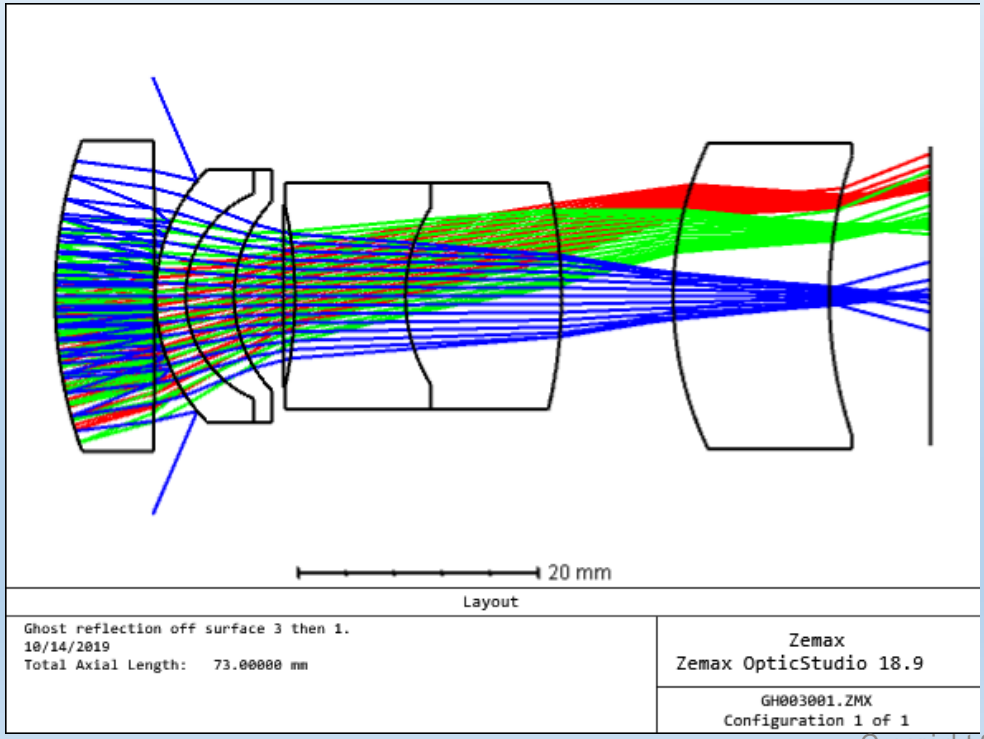
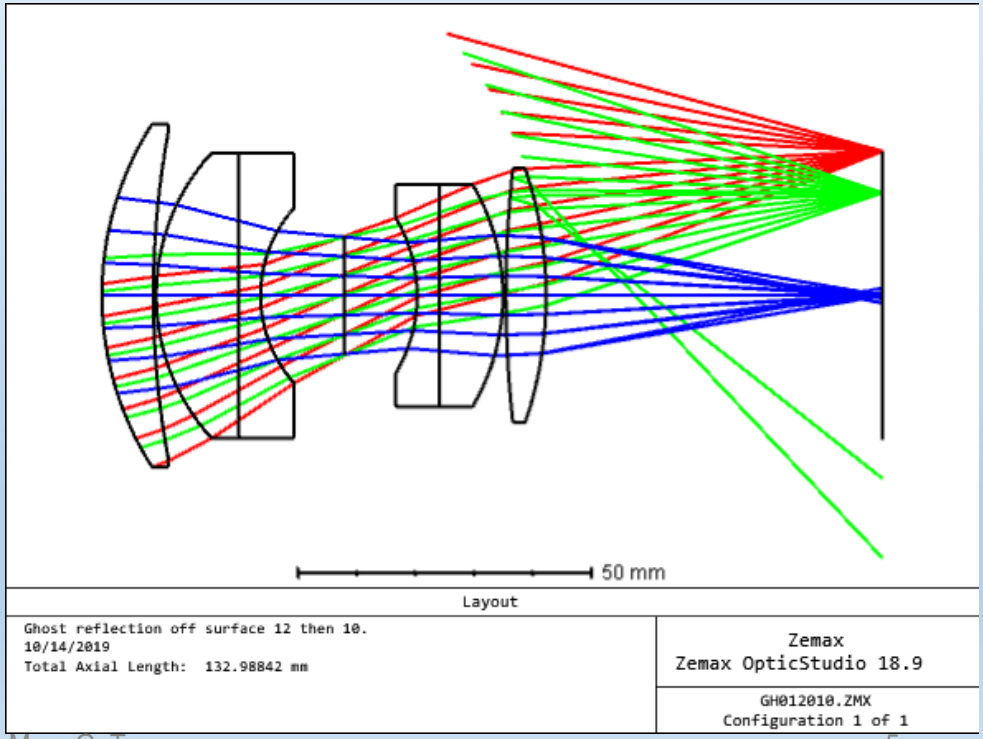
Ghosts

- Near ghost images form bright spots
  - Not a problem in Cooke



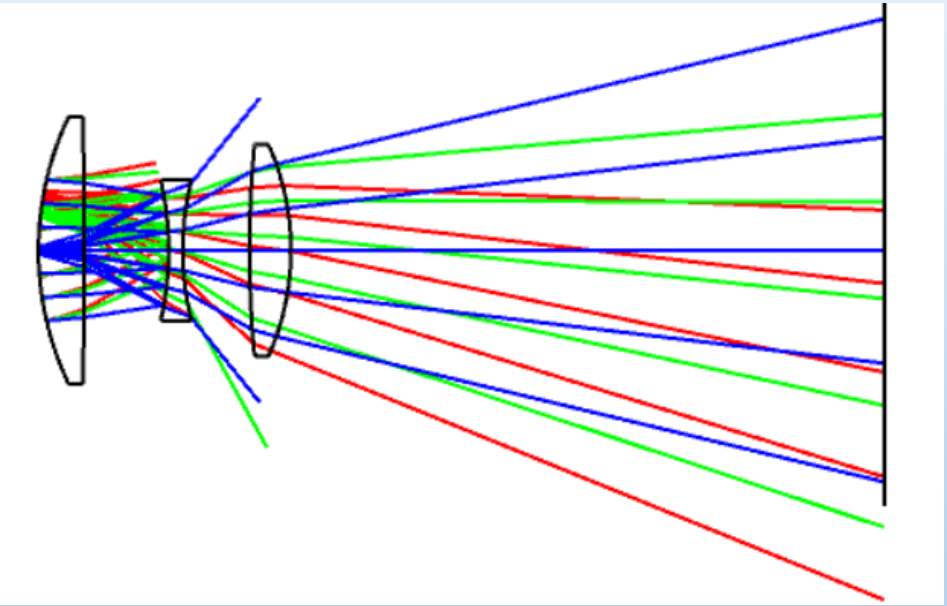


Ghosts

Ghost reflection off surface 3 then 1. (GH003001.ZMX)

Surf	Marginal	F/#	RMS	
1	5.0000E+00	5.737068	3.5355E+00	
2	4.7160E+00	3.374901	3.3570E+00	
3	3.8259E+00	1.014969	2.7384E+00	
2	8.6647E-01	1.642769	5.7186E-01	
1	-1.2544E-01	1.706675	1.4356E-01	****
2	-1.0802E+00	1.055236	8.1124E-01	
3	-3.9268E+00	1.389939	2.8192E+00	
4	-4.2865E+00	0.698504	3.2338E+00	
5	-7.6869E+00	1.237208	6.5404E+00	
6	-8.8799E+00	1.407641	6.7523E+00	
7	-2.3872E+01	1.407641	1.7567E+01	

Marginal ray height : -23.8723
Chief ray height : -16.0714
Distance to ghost pupil: -50.9613
Distance to ghost focus: -67.2073
Effective focal length : 14.0764

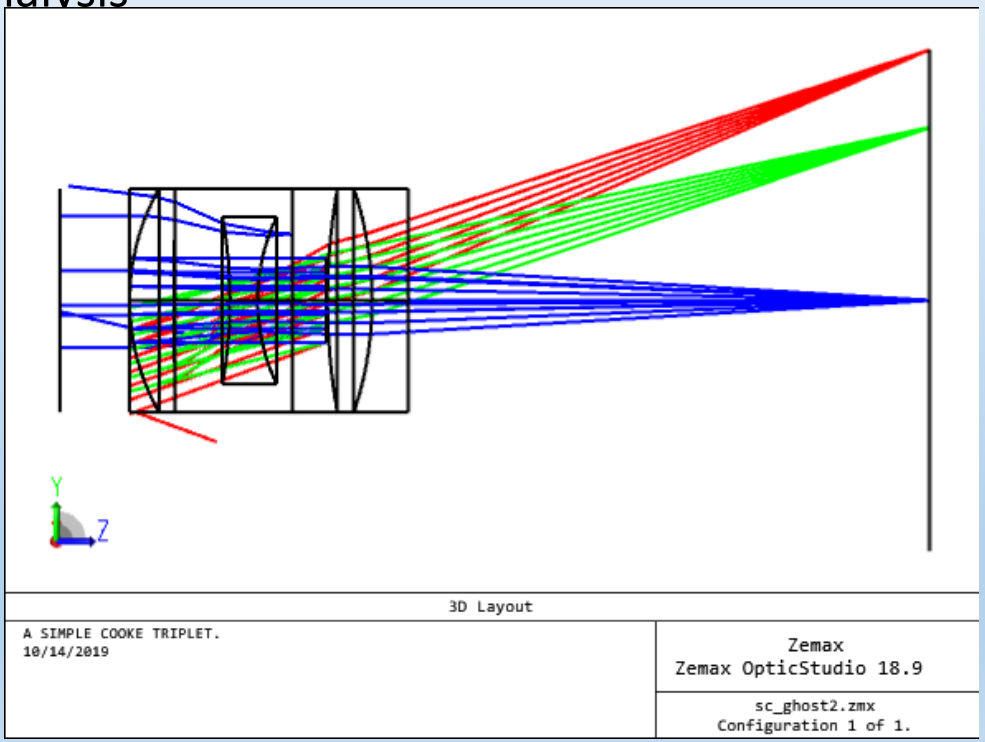


Scattered light

- Scattering can allow out-of-field source energy to reach image:
  - Eliminating results in vignetting/obscuration of true field
  - Proper baffle design minimizes vignetting and improves rejection of scattered light
    - There will always be some vignetting if baffles are used
  - Paths may require one or many scatter interfaces
  - Baffle requirements change with source location:
    - Design must be evaluated over the range of viable conditions

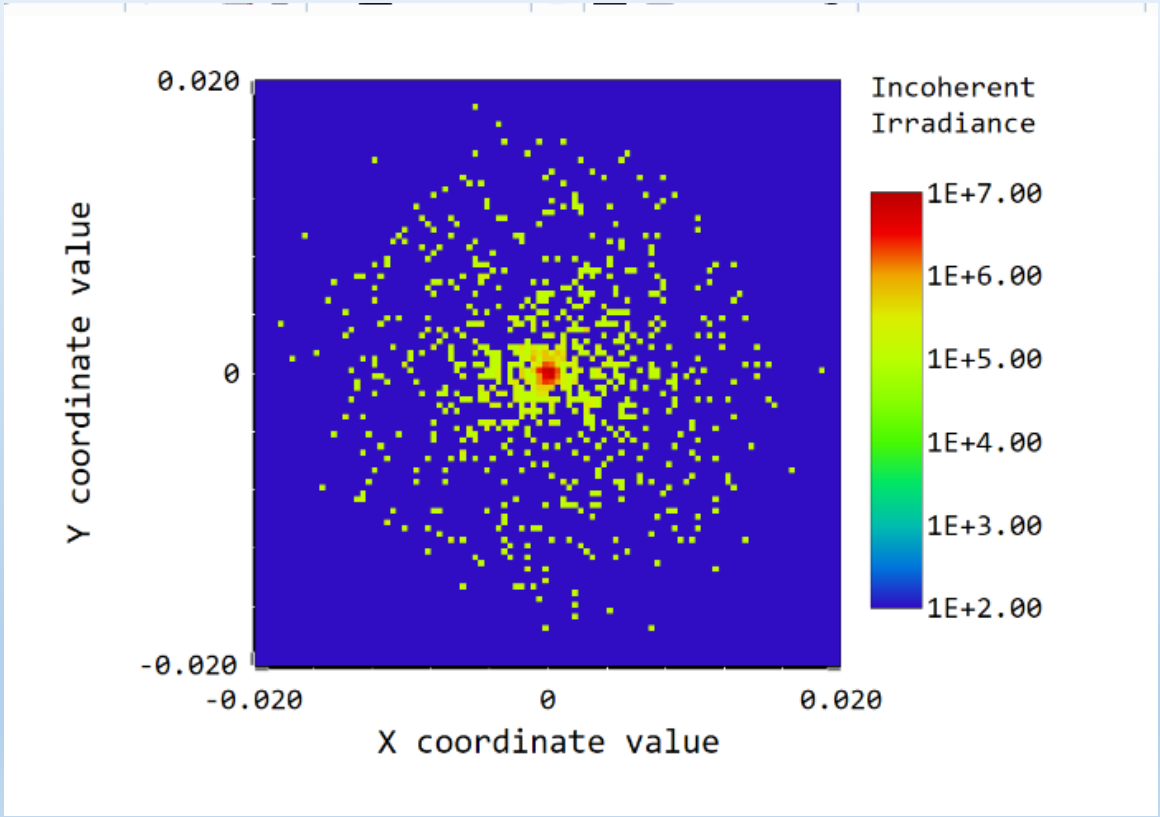
Scattered light

- Optical and mechanical components contribute
  - Here on-axis only for analysis



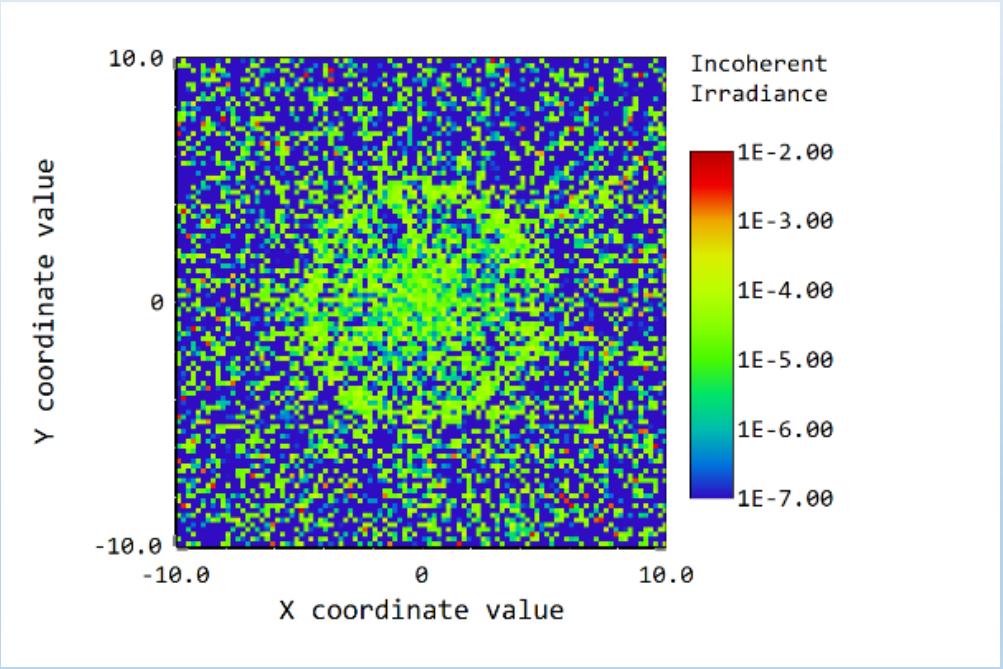
Stray light

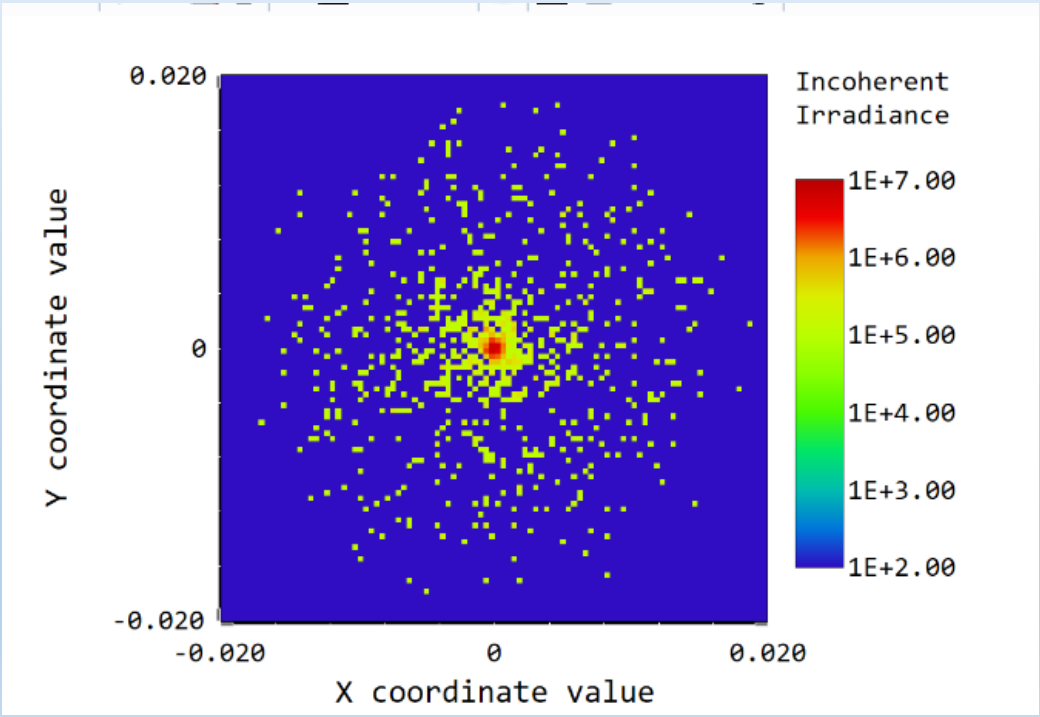
- Primary and Fresnels
  - 40um x 40um



Stray light

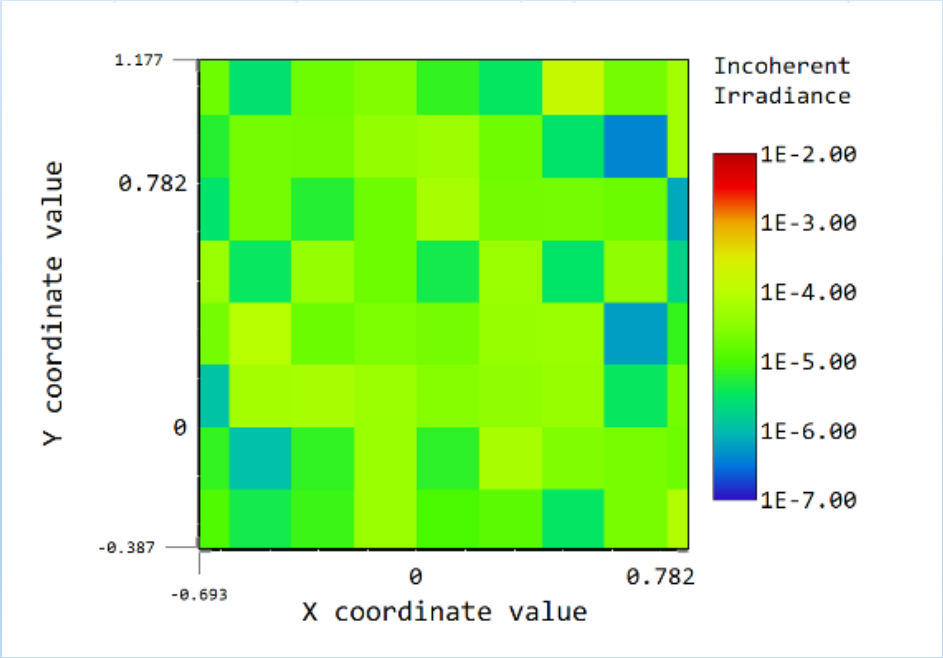
- Allowing for scattering effects





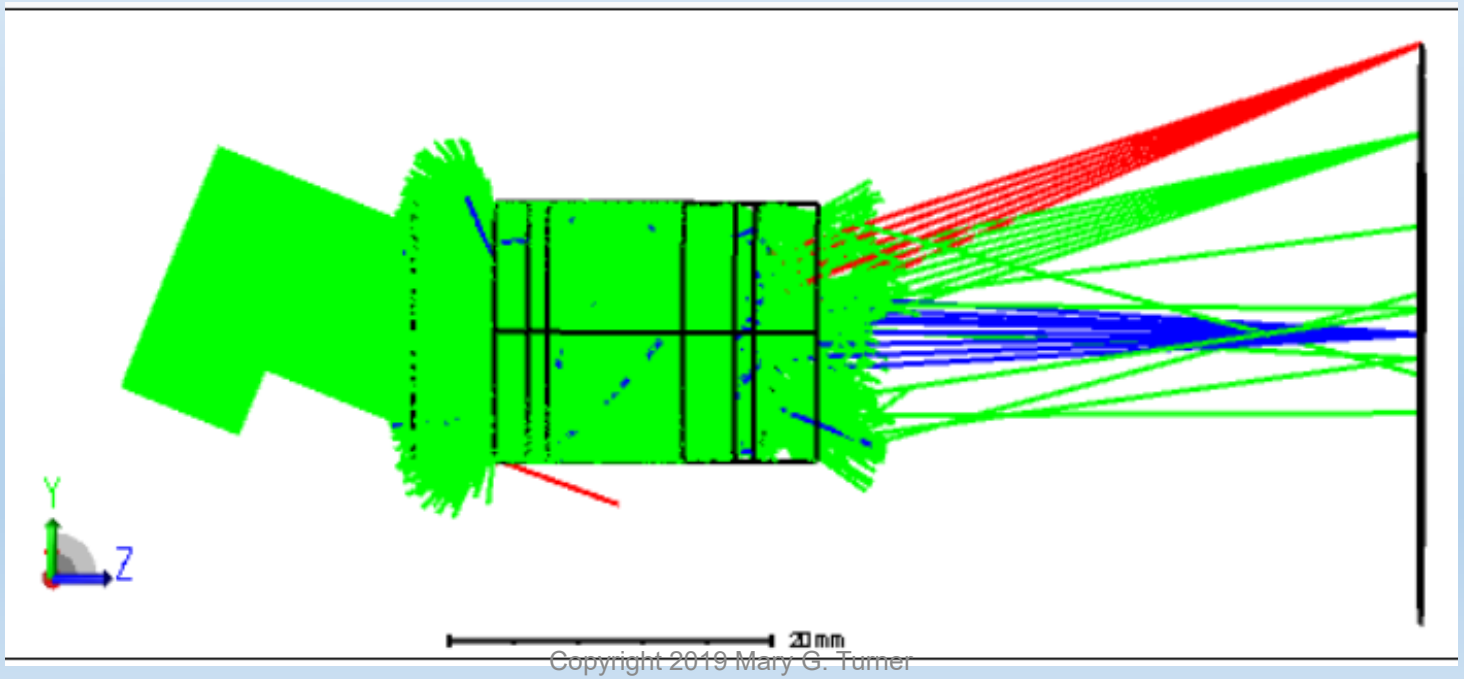
Stray light

- Signal lost in the noise
  - More pixels on large detector would help some, but…



Direct paths

- Light from out-of-field sources can reach detector if baffles are not properly designed.
  - "Properly designed" involve tradeoffs



Stray light

- https://www.camerahacker.com/Forums/Tips/Why_I_always_use_a_lens_hood.files.hidden/small_cropped%20light%20on%20lens.jpg

Here I was lucky enough to get some ghost images of the lens aperture due to sunlight falling on lens. Trail of ghosts falls along a line between center of image and the sun's position—even though sun is out of view.

Diffraction

- Unwanted grating orders
- Edge diffraction sends energy in unwanted directions

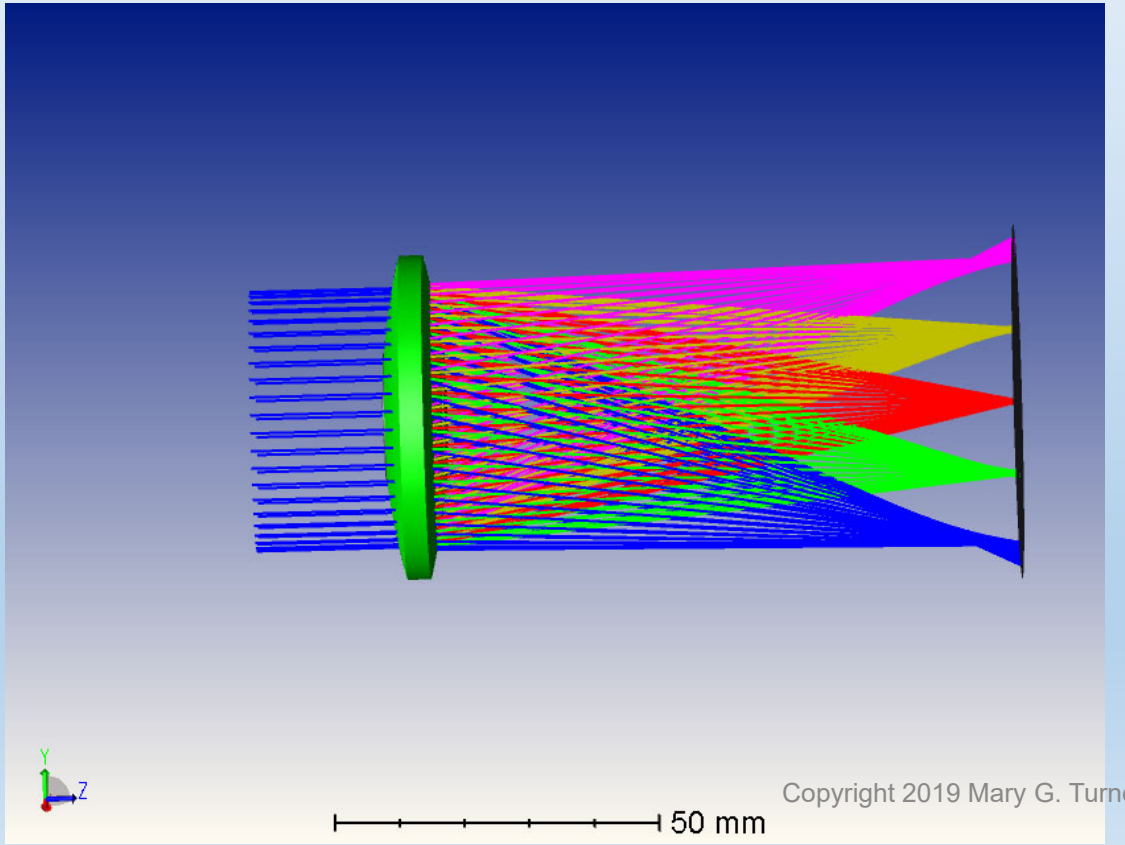
Edge diffraction

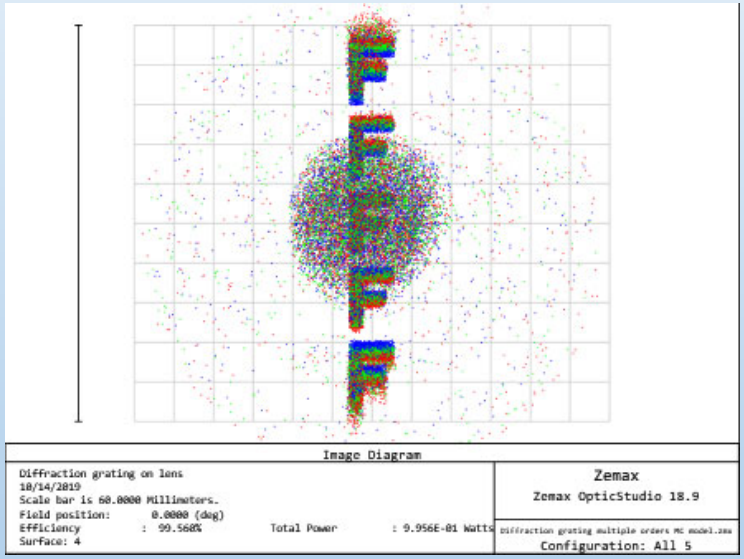
- With spiders

https://thumbs.gfycat.com/PepperyAgreeableDevilfish-mobile.mp4

Gratings

- Optical codes do not model gratings “physically”





Thermal emission

- All surfaces above 0K emit are blackbody radiators
  - Emitted energy has spectral distribution

Why is stray light a problem?

- In imaging systems, stray light reduces the overall contrast in the image:
  - Overall background is increased
  - Details can be “washed out”
  - Glare can obscure the real image
  - Auto-focus systems may not work properly
  - False signal (positives and negatives) can be produced
  - Radiometric measurements will be inaccurate
  - Components can be damaged (or destroyed)

When is it a problem?

- Stray light is always a concern in systems that
  - Require high contrast
  - Image faint objects
  - Make radiometric measurements
  - Transfer high power (such as laser beams)

(And any system where it was completely ignored)

Stray light analysis

- A systematic process used to isolate any unwanted light on the detector.
  - How much is there?
  - How did it get there?

- Carefully performed stray light analysis allows the designer to
  - Quantitatively determine the performance degradation due to stray light
    - Are the performance metrics compromised?
  - Determine the appropriate method(s) to fix any necessary problems
    - Not all stray light is “worth” fixing

Stray light analysis

- Inherently nonsequential or unconstrained analysis
  - Fresnel reflections
    - Most sequential design programs can model to some level of accuracy
    - Good 1st step
    - Don't wait until design is finished
  - Surface scatter
  - Scatter or reflection from non-optical components
    - Tubes, spacers, baffles, physical aperture stop, etc
  - Out-of-field sources
    - Direct (oversize of optics)
    - Indirect (Fresnel, scatter)

Limits to the analysis

- Any analysis of stray light is limited by :
  - The ability to properly model scatter from optical and mechanical surfaces
    - Proper measurements of the scatter from all components must be made
      - Almost never the case in “real world”
      - Estimates or generic data useful, but dangerous
  - The accuracy of the computer model
    - Modeling of all necessary optical, mechanical components
    - Tools in software used for the simulation
  - The time available to study the problem
    - Analysis runs take time
    - Analyzing the data takes time
    - An “infinite” number of possibilities exist…

A bit on stray light

- Most of the stray light issues can be found relatively quickly
- Most of the effort is spent looking for what was missed the first time
- Your customers will never be happy:
  - They are not happy if you find any problems:
    - Problems cost money to fix
  - They are not happy if you find no problems:
    - How much time and money did we waste to find nothing?
- There is a certain personal satisfaction a designer gets from knowing more fully that the design will work to the customers expectations (or better)