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Optical Systems Design with Zemax

Prof. WANG Xuan

CNR-SPIN

School of Remote Sensing Information Engineering
Wuhan University

Email: xuan.wang@whu.edu.cn; xuan.wang@spin.cnr.it
Tel: +39 3476082305; +86 15652230007

ZEMAX

The ZEMAX Optical Design Program is a comprehensive software tool. It integrates all the features required to conceptualize, **design**, **optimize**, **analyze**, **tolerance**, and

document virtually any optical system. It is widely used in the optics industry as a **standard design tool**. This course will introduce the basics of ZEMAX.

What does ZEMAX do?

ZEMAX is a program which can **model**, **analyze**, and **assist** in the design of optical systems.

The interface to ZEMAX has been designed to be easy to use, and with a little practice it can allow very rapid interactive design.

Most ZEMAX features are accessed by selecting options from either dialog boxes or pull-down menus.

Keyboard shortcuts are provided for quickly navigating or bypassing the menu structure.

What **doesn't** ZEMAX do?

Neither the ZEMAX program nor the ZEMAX documentation will **teach** you how to design lenses or optical systems.

Although the program will do many things to **assist** you in designing and analyzing optical systems, **you** are still the **designer**.

The ZEMAX documentation is **not** a tutorial on optical design, terminology, or methodology.

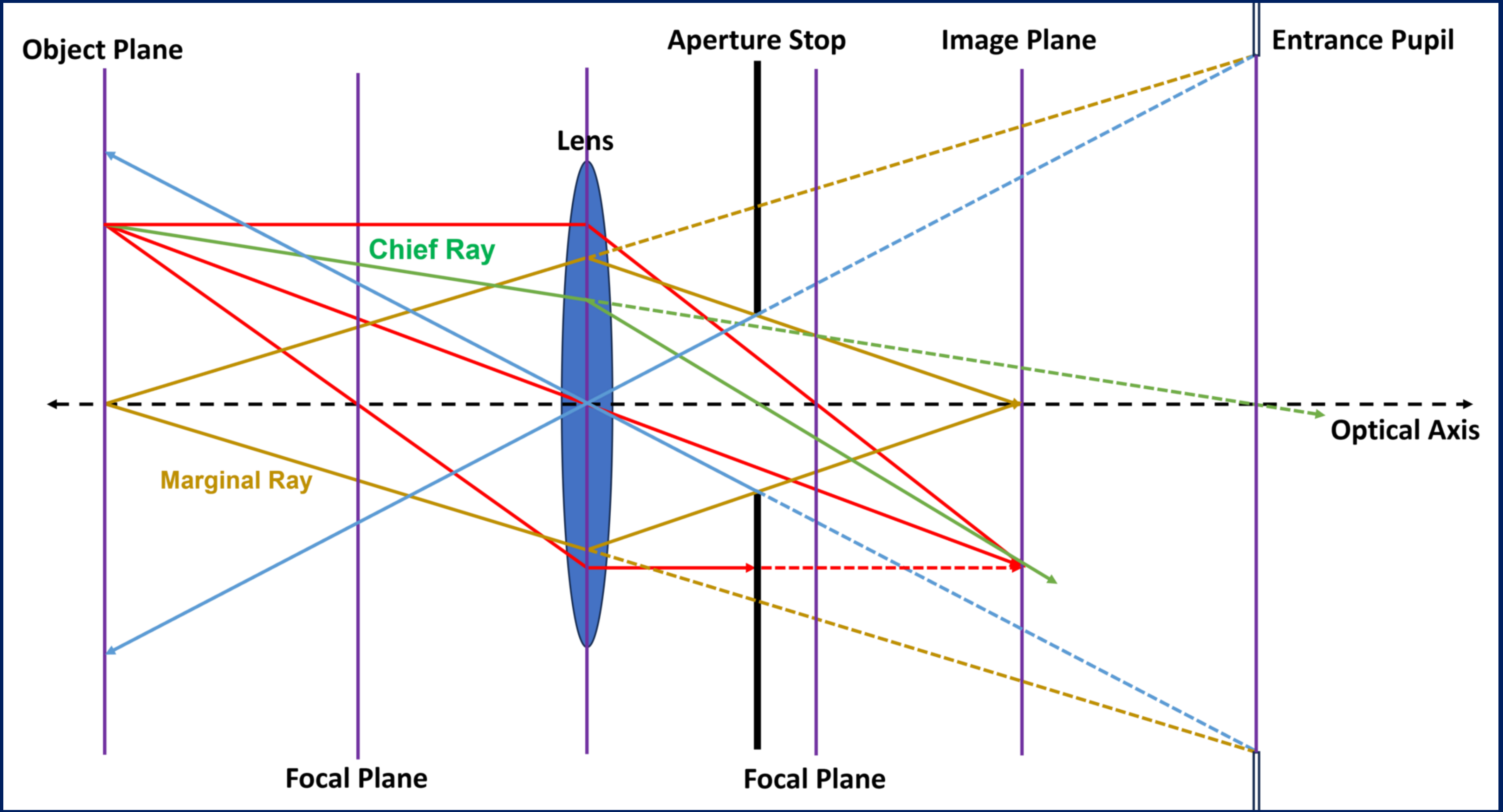
If you have little or no experience in optical design, you may

want to read up on any of the many good books available on the subject.

Some definitions

Stop：

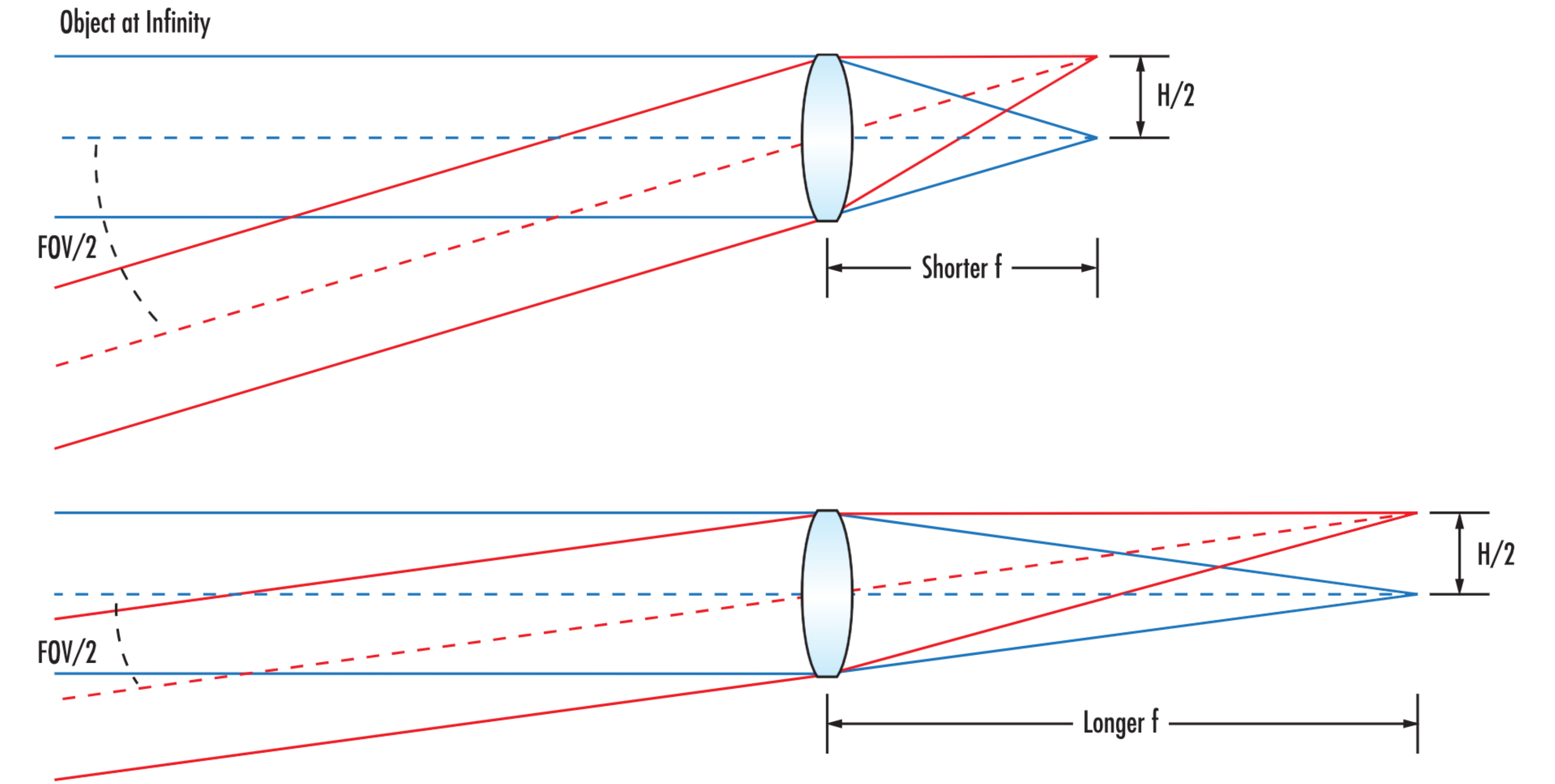
In an optical system there are physical limitations to the number of rays that can pass through it. The limit of the passing rays is called the aperture stop. This therefore controls the brightness of the image.



Some definitions

Field of View (Field):

In the focal plane instead there is the field stop: a diaphragm that delimits the region of the focal plane capable of receiving the rays. It therefore limits the Field of View (FOV).



Exercises 01: a singlet lens

To design:

- F/4 singlet lens
- f = 100 mm; BK7 glass;
- Aperture = 100/4=25 mm
- Visible spectrum;
- Field = 0 degree

Exercises 01: a singlet lens

To learn:

- System - Wavelength, Aperture
- Analysis - Layout (2D)
- Analysis - Fans - Ray Aberration (Slope=0)
- Solve
- Analysis – Spot Diagrams – Standard
- Analysis – Fans – Optical Path
- Analysis – Miscellaneous – Chromatic Focal Shift
- Editors - Merit function – EFFL …
- Tools – Optimization …

First-order chromatic aberration

Aberration: focus, spherical, spherochromatism, and axial color

Exercises 02: a doublet

To design:

- F/4 doublet lens
- f = 100 mm; BK7 + SF1 glass;
- Aperture = 100/4=25 mm + oversize
- Visible spectrum;
- Field = 0, 2, 5, 10 degree

Exercises 02: a doublet

To learn:

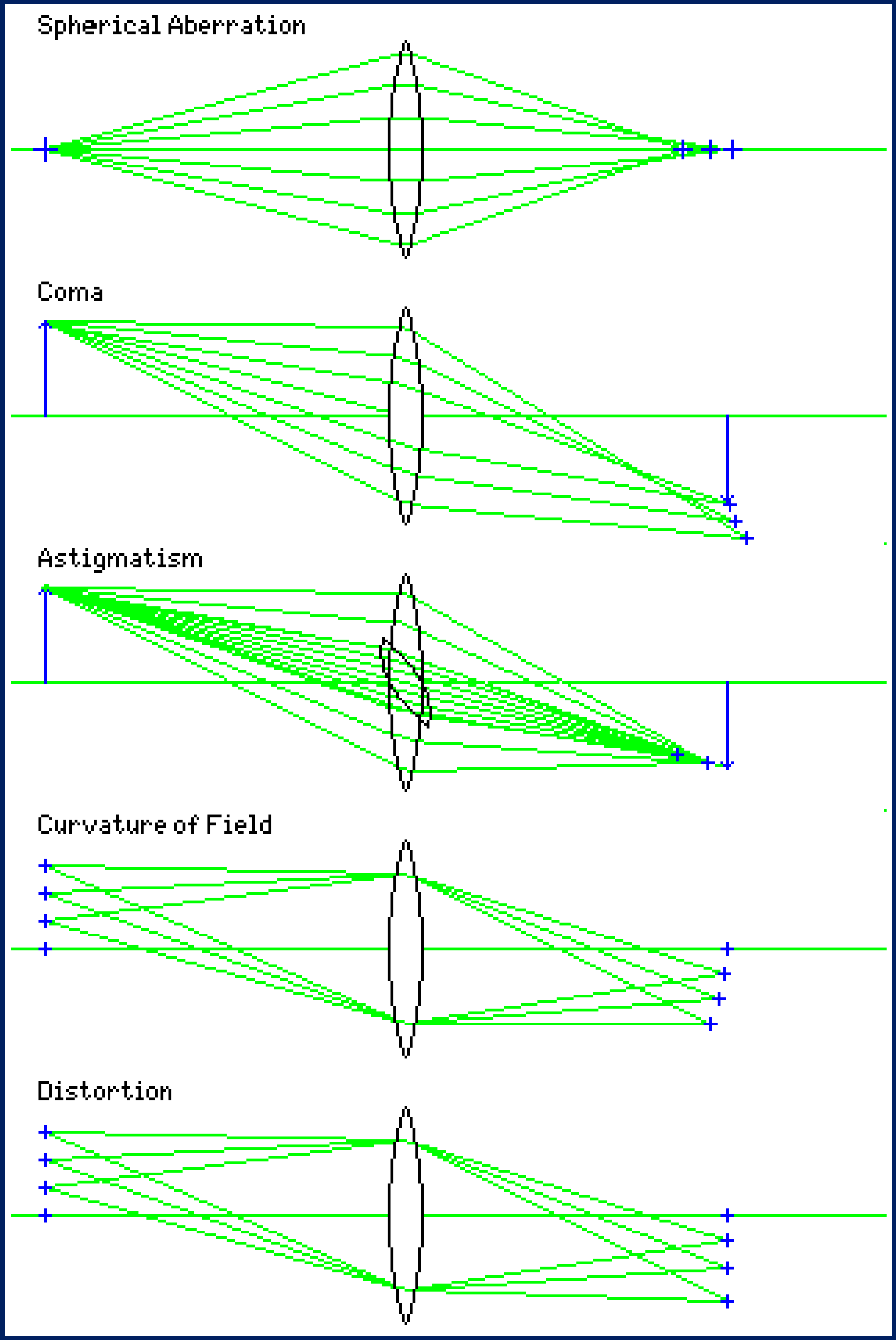
- Glass choice, BK7 and SF1
- Reports – Surface Data

  Lens real size - oversize
- Test off-axis performance

  Field = 0, 2, 5, 10 degree
- Analysis – Miscellaneous – Field Curv/Dist
- Analysis – Aberration Coefficients – Seidel Diagram

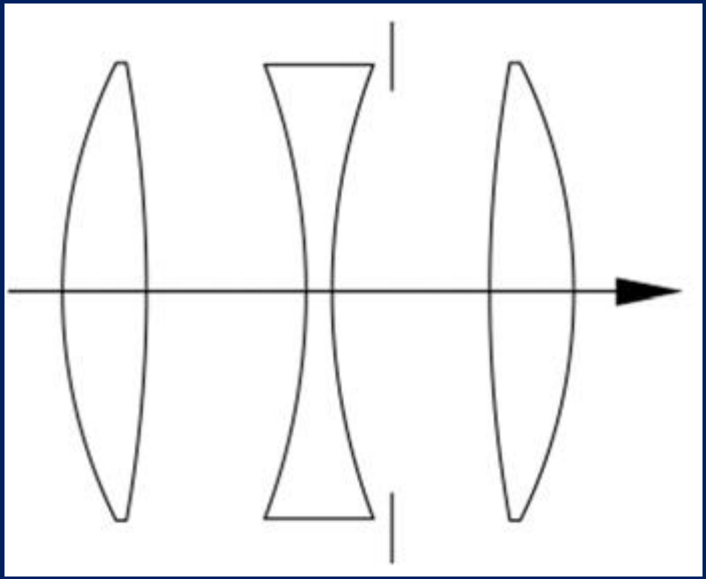
Exercises 02:

The five Seidel aberrations



Exercises 03: a Cooke Triplet

A negative lens between two positive lens



the smallest number of elements that can correct all 7 Seidel aberrations:

- Monochromatic: spherical aberration, coma, astigmatism, field curvature, distortion.
- Chromatic: axial chromatic aberration and lateral chromatic aberration

Exercises 03: a Cooke Triplet

To design:

- F/4 triplet lens
- f = 100 mm; LAK33 + BASF2 + LAK33 glass;
- Aperture = 100/4=25 mm
- Visible spectrum;
- Field = 0, 2, 5, 10 degree

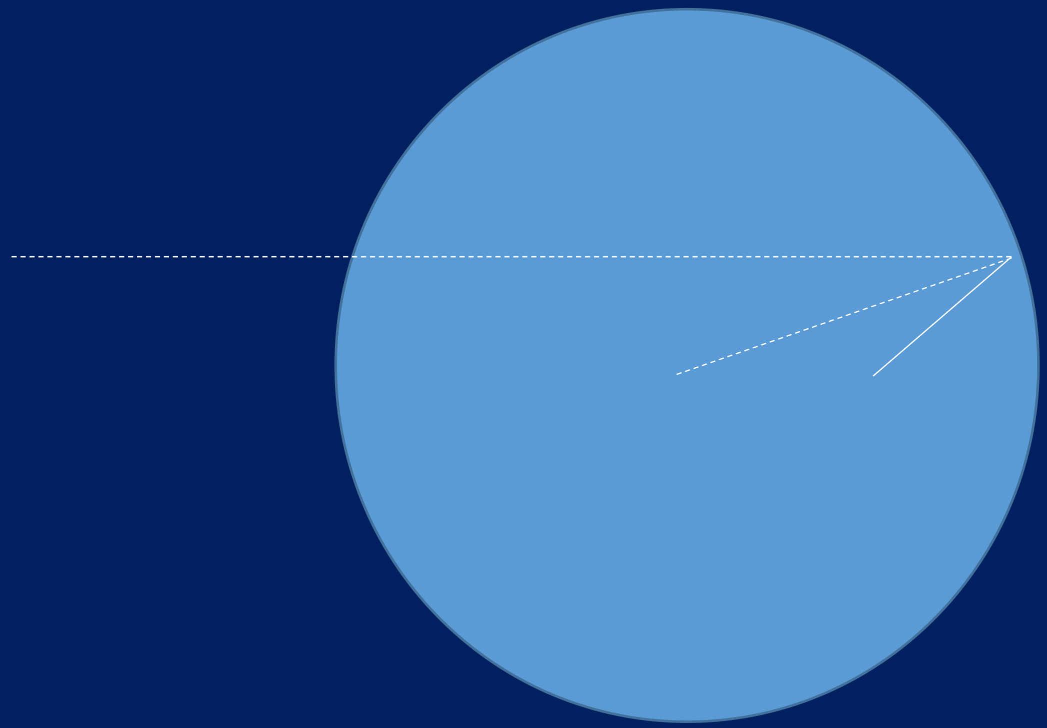
Surf	Radius	Thickness	Glass
1	40	6	LAK33
2	Inf	10	
3	-40	1	BASF2
4	40	10	
5	inf	6	LAK33
6	-40	100	

Exercises 04: a Newtonian Telescope

To design:

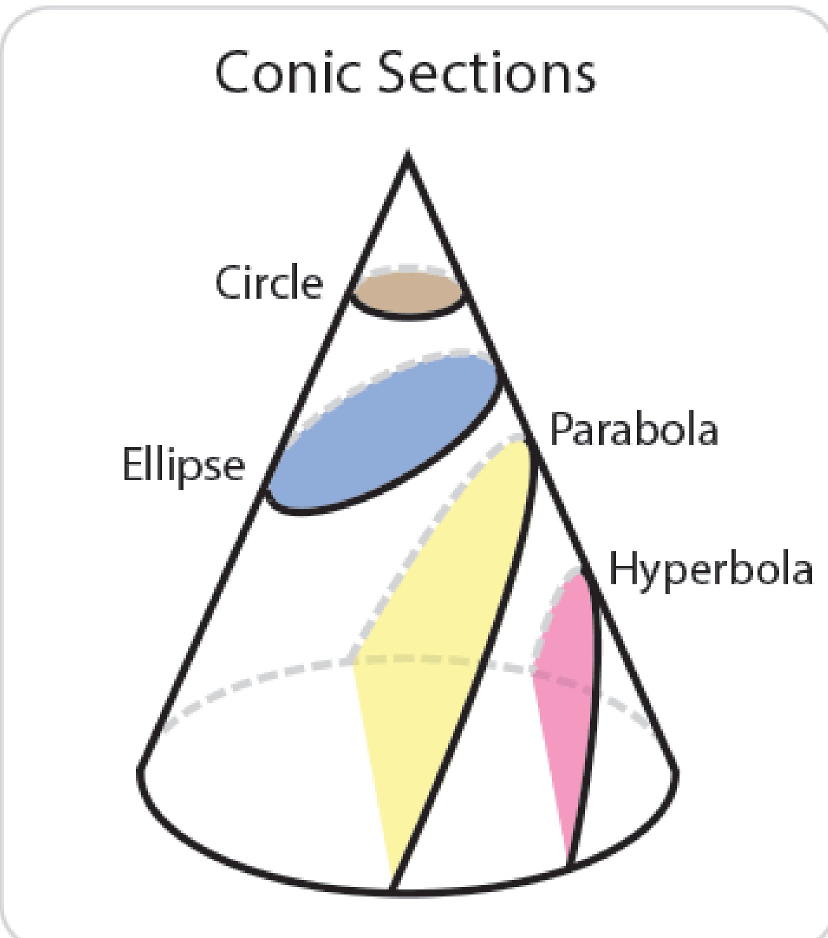
- F/5
- f = 1000 mm; the radius of mirror = 2000 mm
- Aperture = 1000/5=200 mm
- Visible spectrum;
- Field = 0, 0.2°, 0.5°

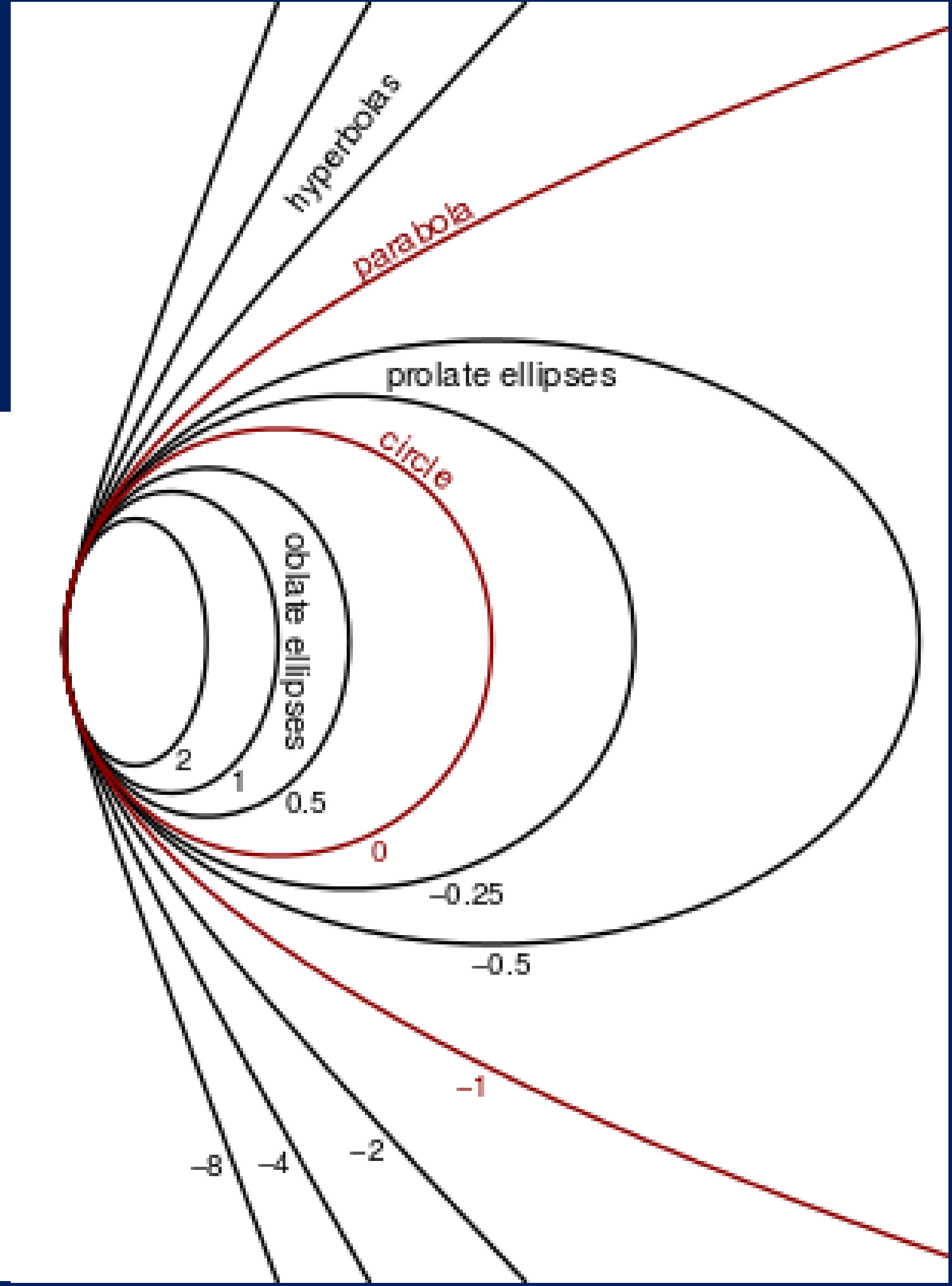
Angular diameter of moon is 29.3′ – 34.1′



Exercises 04:

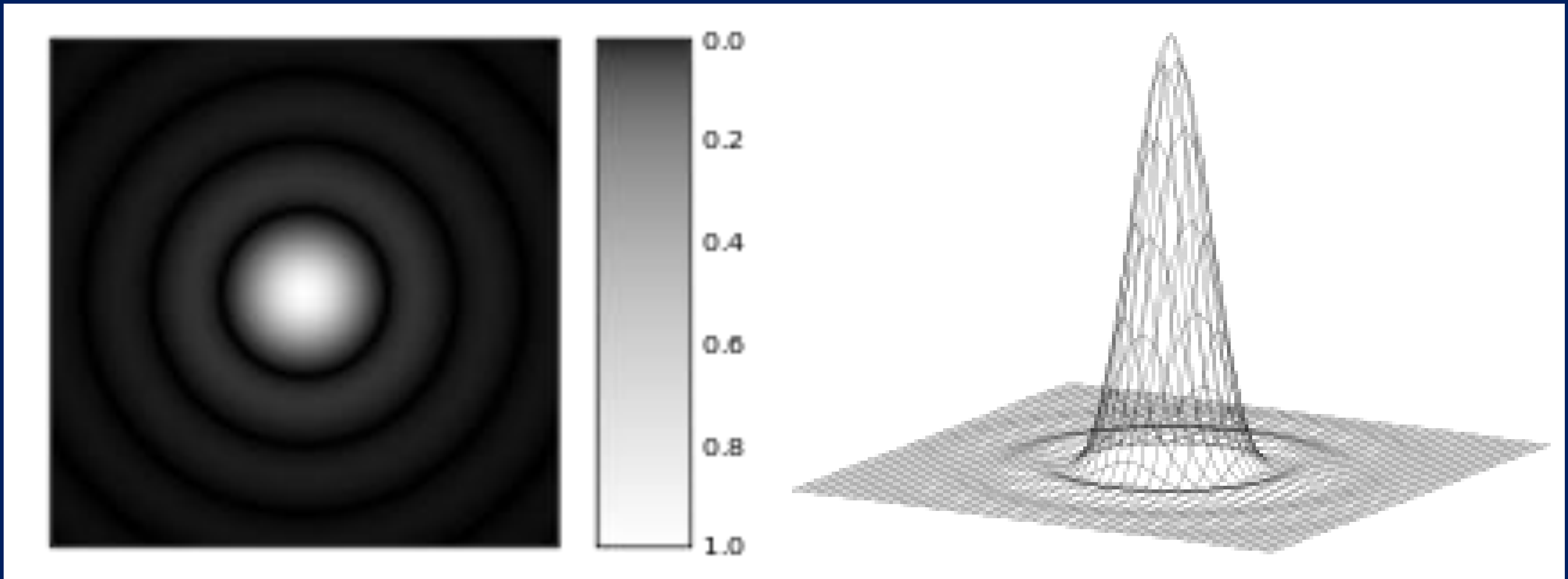
Conic = 0 Circle
Conic = -1 Parabola





Airy disk

In optics, the Airy disk (or Airy disc) and Airy pattern are descriptions of the best focused spot of light that a perfect lens with a circular aperture can make, limited by the diffraction of light.



Exercises 05:
a Schmidt-Cassegrain with aspheric corrector

To design:

- Aperture = 10 inches
- Back focus = 10 inches
- Visible spectrum;
- Field = 0, 0.2°, 0.5°

Exercises 05:
a Schmidt-Cassegrain with aspheric corrector

To learn:

- Change the units
- Surface type: Even Asphere
- Aperture type: Circular aperture, Circular obscuration
- Analysis – MTF – FFT MTF
  (Modulation Transfer Function)

Modulation Transfer Function

Una caratteristica fondamentale per gli OS è di poter "contrastare" efficientemente gli oggetti. Un oggetto possiamo immaginarlo scomposto in infiniti componenti di Fourier, cioè di chiaro-scuri a frequenza spaziale crescente. Basandosi su quest'approccio, nel 1946 il francese P.M. Duffieux ha introdotto una funzione complessa per descrivere la risposta in frequenze spaziali di un OS: la *Optical Transfer function* (OTF):

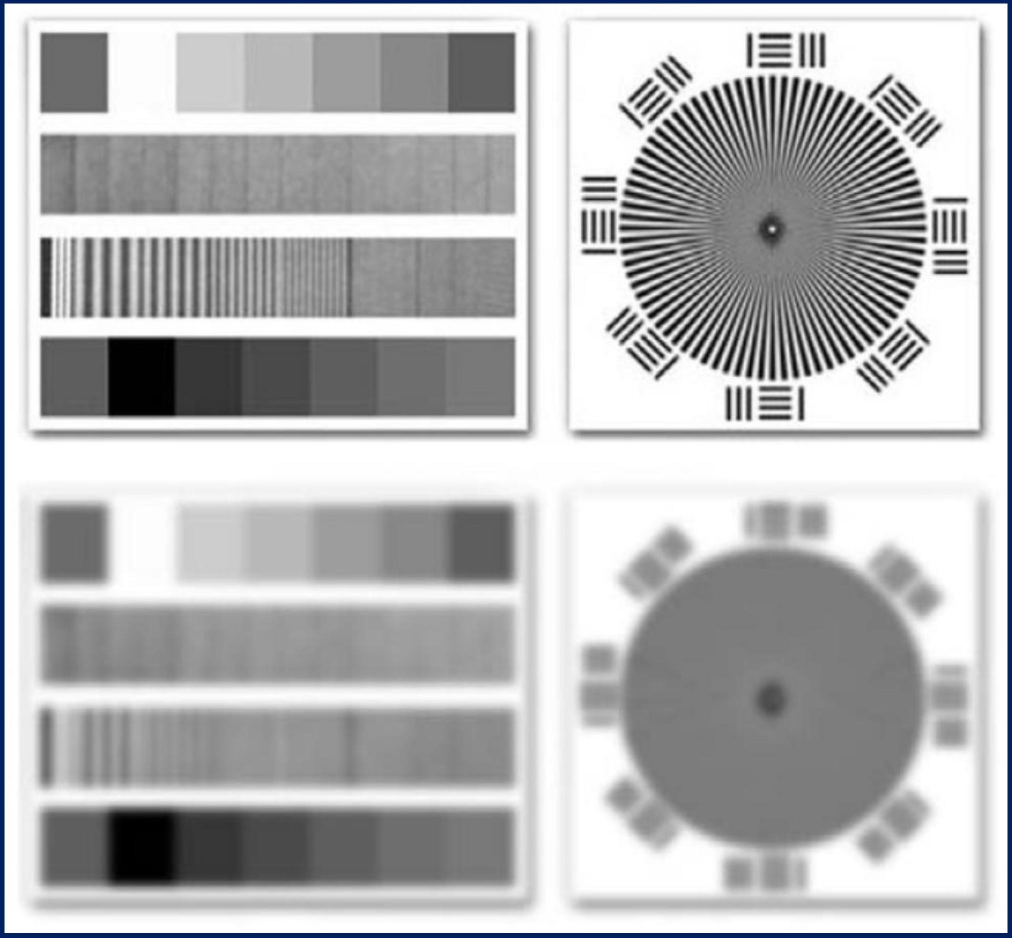
$$OTF(u,v) = \frac{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} PSF(x,y)\, e^{2\pi i(ux+vy)}\, dxdy}{\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} PSF(x,y)\, dxdy}$$

Ove x,y sono coordinate spaziali cui sono associate le frequenze u,v. Dunque la OTF è la trasformata normalizzata della PSF, dipendente dalla scelta del piano immagine. Il modulo della OTF è ciò che si chiama la *Modulation Transfer Function* (MTF), e rappresenta la degradazione del contrasto al variare delle frequenze. Nel caso unidimensionale si ha dunque:

$$MTF = \sqrt{\left[OTF_{re}(u)^2\right] + \left[OTF_{im}(u)^2\right]}$$

Modulation Transfer Function

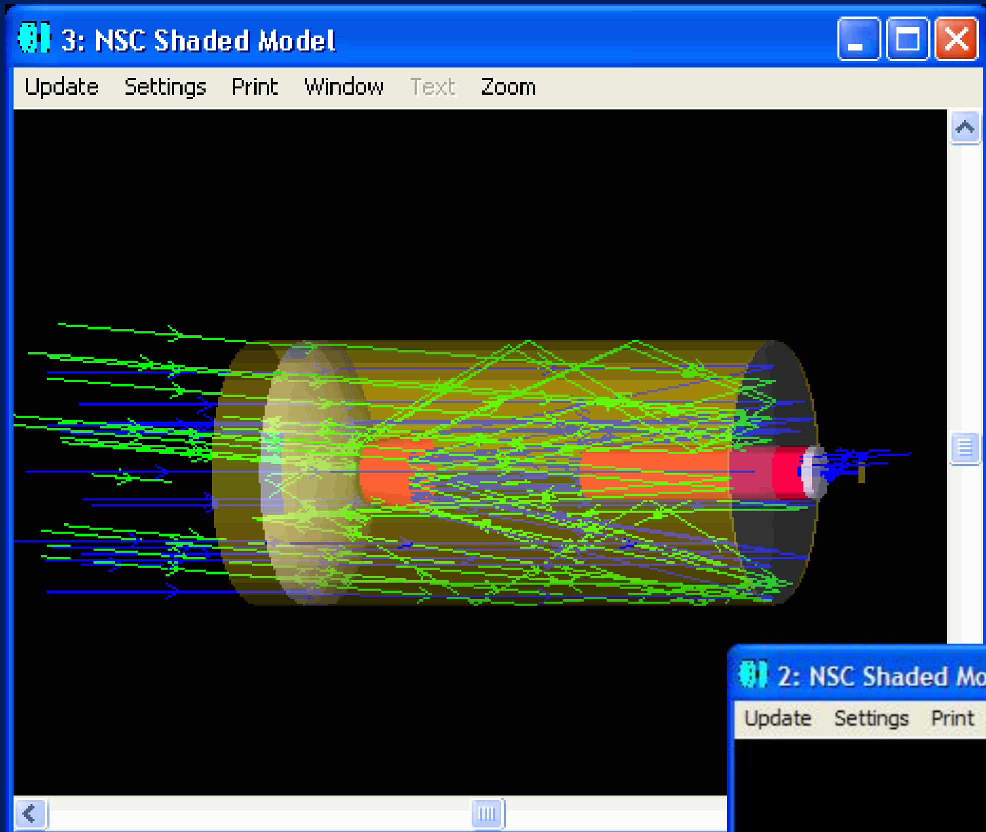
Allo scopo di verificare la capacità di contrasto di un OS, (esempio semplice: la messa a fuoco degli obiettivi di una camera fotografica), si utilizza come oggetto un disegno detto test chart: in questo modo si riesce a capire qual è il potere risolutivo del sistema in termini di max frequenza spaziale distinguibile in righe o linee per mm [l/mm]. Oltre un certo valore le righe B/N si confonderanno in un'unica tonalità di grigio. In genere il contrasto si ritiene accettabile per valori della MTF > 5%.

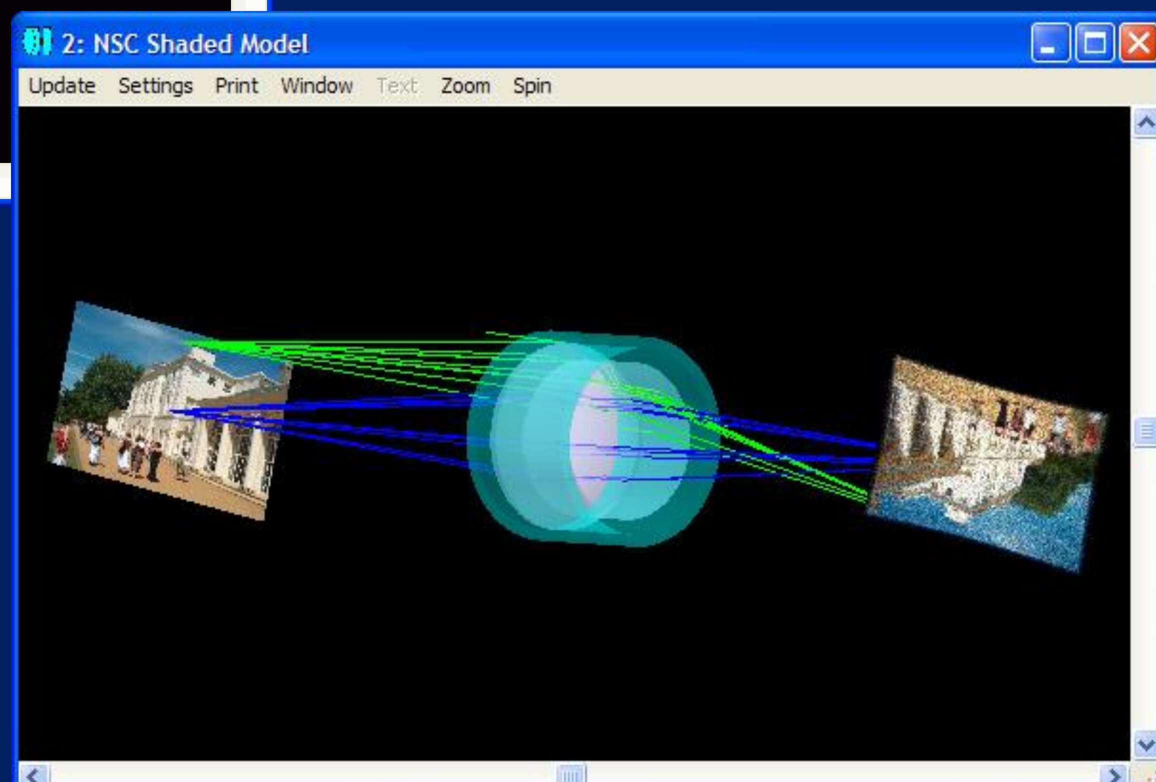


Non-Sequential Ray Tracing

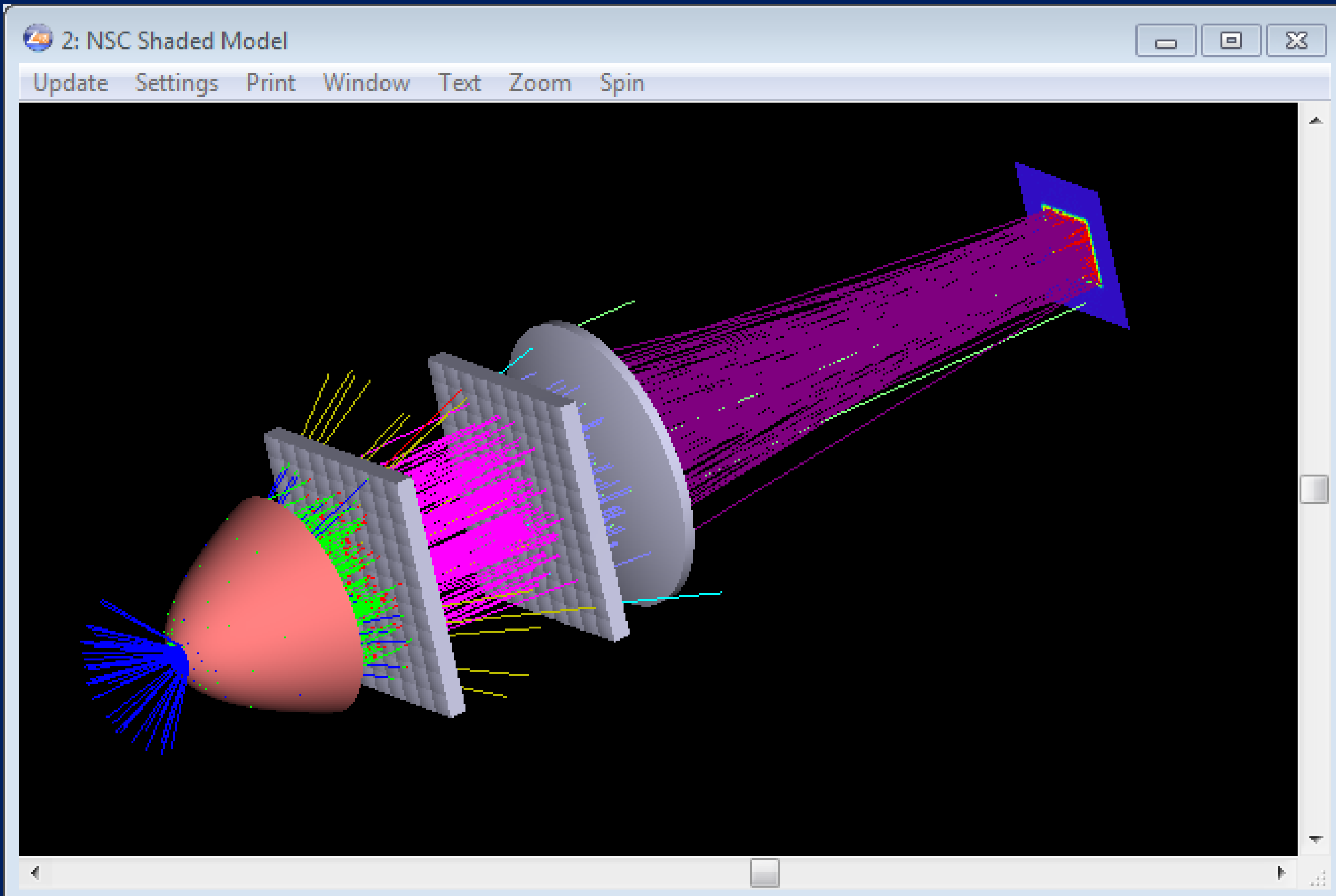
Non-sequential ray-tracing is a powerful and general technology for tracing rays in systems where there are multiple optical paths. Typical uses include:

- Illumination systems, especially those with multiple or complex optical sources
- Systems such as interferometers, in which light that has travelled through several different optical systems must be coherently recombined
- Opto-mechanical stray light analysis in otherwise sequential optical systems
- LCD backlighting
- Bio-optical systems, particularly those based on scattering from tissue or fluorescent scattering


3: NSC Shaded Model
Update Settings Print Window Text Zoom


2: NSC Shaded Model
Update Settings Print Window Text Zoom Spin

Zemax Illumination



Non-Sequential Ray Tracing

Non-sequential ray tracing assumes that there is no pre-defined path for any ray. A ray is launched and hits whatever object is in its path, and it may then reflect, refract, diffract, scatter, split into child rays, etc.

It is a far more general technology than sequential ray-tracing, and is therefore somewhat slower in terms of ray-tracing speed.

There is no (limited) optimization, less analysis tools…

Exercises 06:
LED illumination system

To design:

- Reflector + LED + lens …

Exercises 06:
LED illumination system

To learn:

- Standard lens, mirror
- Source volume rectangle
- Detector rect
- Analysis – Layout - NSC 3D Layout
- Analysis – Detectors – Detector Viewer
- Analysis – Detectors – Ray Trace/Detector Control…

Exercises 07:
Beam splitter – Prism 45

To design:

- Beam splitter – Cube (2 x Prism 45)

Exercises 07:
Beam splitter – Prism 45

To learn:

- Source Ellipse
- Poly Object – Prism45
- Coat/Scatter
  - Face 0:
  Coating – NONE,
  Scatter – Gaussian (Factor 0.1, Sigma 0.1)

  - Splitter Face:
  Coating – I.50, I.95
  Scatter - NONE

Exercises 08:
Color mixing system

To design:

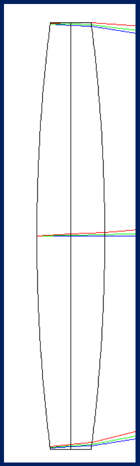
- Red, green, and blue color mixing …

Exercises 08:
Color mixing system

To learn:

- Source Ellipse
- Detector Color
- Analysis – Layout - NSC Standard Model
- Analysis – Detectors – Detector Viewer
- Analysis – Detectors – Ray Trace/Detector Control…

Test: a doublet



To design:

- f = 150 mm; with BK7 + SF1 glass;
- Aperture = 25 mm
- Visible spectrum; Field = 0, 2, 5 degree

Starting parameters:

Surf	Type	Comment	Radius	Thickness	Glass
OBJ	Standard		Infinity	Infinity	
STO	Standard		150.000	3.000	BK7
2	Standard		Infinity	3.000	SF1
3	Standard		-150.000	150.000	
IMA	Standard		Infinity	-	

To study:

- 2D Layout
- Spot diagrams
- Fans – Ray aberration
- Chromatic Focal Shift
- Aberration Coefficients – Seidel Diagram
- Optimization