

## SPO-Spot Diagram

The Spot Diagram option (SPO) generates plots of ray intersections with the image surface(s) to represent image characteristics, and calculates and lists RMS spot size and 100% spot size. Diffraction is ignored.

### When to Use the Spot Diagram Option

Use the Spot Diagram (SPO) option for the following purposes:

- To plot the geometrical structure of the polychromatic image at all fields and at several adjacent focal surfaces, if desired.
- To list the image centroid coordinates and RMS spot size at each of the field points.
- To list the 100% spot size and center coordinates.
- To list the ray coordinates of the spot diagram for diagnostic purposes or processing by macros or by other programs.

Diffraction is ignored; only geometrical images are displayed. Use the Point Spread Function (PSF) option to have point images that include diffraction.

### Default Operation

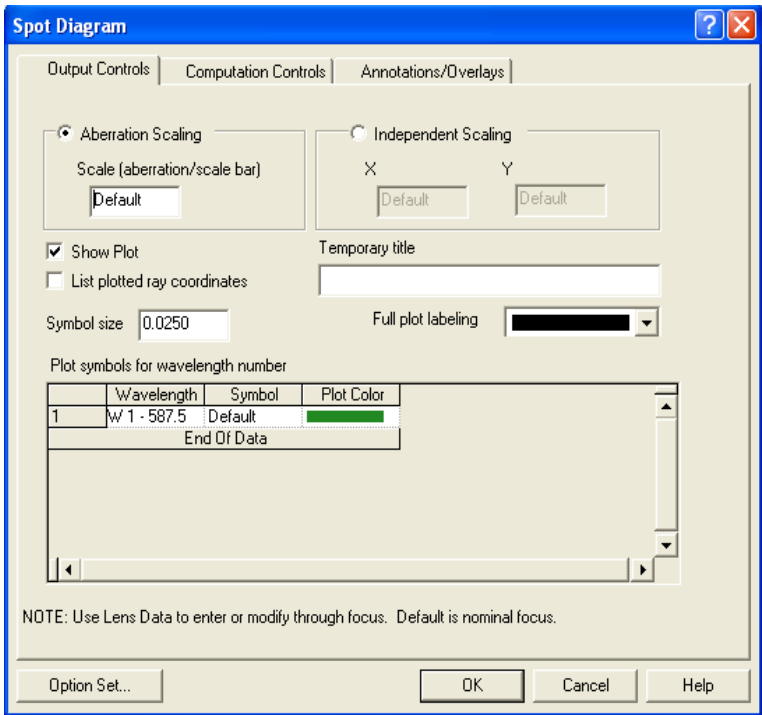
Spot diagrams are generated for all fields and focus positions designated by depth-of-focus values defined in the LDM (FFO,IFO,NFO), one plot per zoom position. Images are scaled automatically to fit the available space with no overlap. The default behavior is that a total of approximately 316 rays are plotted. The relative number of rays traced for each wavelength is determined by the wavelength weights. For a single wavelength, this corresponds to a value of 20 for the number of rays across the diameter. The RMS and 100% spot sizes are also computed, using a ray grid to yield an approximate 1% accuracy in the RMS spot size. The spot sizes are listed in the text and on the spot diagram.

### Command Mnemonics (alphabetical)

|     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|
| AIR | ANN | DET | DOT | DSI | LAB |
| LIS | NRD | PAT | PLO | RL  | RTL |
| SSI | SSX | SSY | TIT | WVL |     |

## Defining Output Controls

To define output controls for Spot Diagram (SPO), choose the **Analysis > Geometrical > Spot Diagram** menu. The **Spot Diagram** dialog box displays, with the **Output Controls** tab automatically selected; define the controls on the **Output Controls** tab as described in the table below.



| Command Syntax                    |                                                                                                                                                                                                                                                                                                                                                                                                                                     |                          |
|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| Screen Control                    | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                         | Default                  |
| SSI image_size_per_scale_bar....z |                                                                                                                                                                                                                                                                                                                                                                                                                                     |                          |
| Aberration Scaling                | For the spot diagram, allows you to specify, in the <b>Scale</b> field, the aberration scale size in X and Y per scale bar (when printed, the scale bar is 25 mm for M, C lens units, 1 inch for I lens units). Any user-entered value overrides the default behavior of automatic scaling that fits each spot into a square plot area small enough to allow all field points to fit into the long dimension of a single page plot. | Automatic scaling.       |
| SSX image_size_per_scale_bar....z |                                                                                                                                                                                                                                                                                                                                                                                                                                     |                          |
| Independent scaling/X             | Overrides aberration scaling (SSI) in X dimension so a highly distorted image can be fitted on the plot.                                                                                                                                                                                                                                                                                                                            | Aberration scaling (SSI) |
| SSY image_size_per_scale_bar....z |                                                                                                                                                                                                                                                                                                                                                                                                                                     |                          |
| Independent scaling/Y             | Overrides aberration scaling (SSI) in Y dimension so a highly distorted image can be fitted on the plot.                                                                                                                                                                                                                                                                                                                            | Aberration scaling (SSI) |

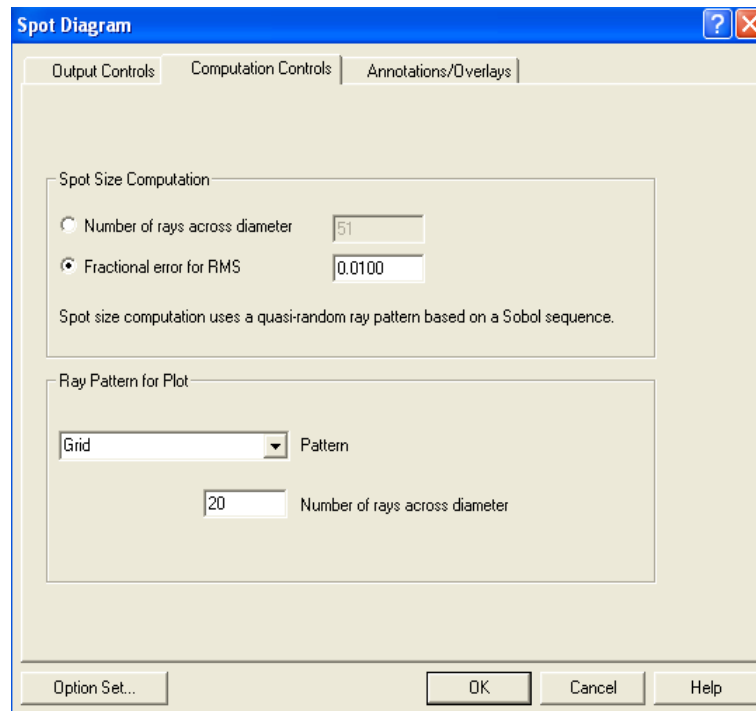
| Command Syntax                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                     |
|--------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Screen Control                                                           | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Default                                                                             |
| PLO Yes   No....z                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                     |
| <b>Show Plot</b>                                                         | Plots the spot diagram. If the <b>Show Plot</b> checkbox is not selected (PLO NO), then the plot will be suppressed, and the only output will be text listings of the centroid, RMS spot size, 100% spot size, and ray statistics.                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Yes. (Plot is produced.)                                                            |
| LIS Yes   No....z                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                     |
| <b>List plotted ray coordinates</b>                                      | Generates listing of ray coordinates, for checking or for editing and input to another program. Note that the ray coordinates are generated based on the plotting controls, not the spot size computation controls.                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Not selected.                                                                       |
| TIT 'temporary_title'(40)....z                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                     |
| <b>Temporary title</b>                                                   | Specifies up to 40 characters that are plotted for the title of designated zoom position; if no zoom position is designated, the title is applied to all.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Uses the first 40 characters of the system title.                                   |
| LAB Yes   No   color....z                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                     |
| <b>Full plot labeling</b>                                                | Designates the spot diagram labeling method: <ul style="list-style-type: none"> <li>• Select <b>Yes</b> in the <b>Full plot labeling</b> dropdown list (LAB Yes) to label plot in the standard manner.</li> <li>• Select <b>No</b> in the <b>Full plot labeling</b> dropdown list (LAB No) to eliminate plotting of title, scale factor, and date for that zoom position (quick plot). To suppress the automatic time and date stamp on plots, use the TAD No command. See “Plot Labeling” on page 1-87 for details.</li> <li>• Select a color in the <b>Full plot labeling</b> dropdown list (LAB color) to select full plot labeling and to designate the title color.</li> </ul> | Labeling is included.                                                               |
| DSI dot_size_fraction_of_scale_bar                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                     |
| <b>Symbol size</b>                                                       | Use with the <b>Plot symbols for wavelength number</b> table (DOT command). Changes the size of dot shapes used to plot wavelengths.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Size set by DTS.                                                                    |
| WVL Yes   No   color....w                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                     |
| <b>Plot symbols for wavelength number:<br/>Wavelength<br/>Plot Color</b> | Specifies the wavelengths included in the spot diagram and in the RMS and 100% spot computations. Color and symbol used for wavelengths may be designated. Use of <b>No</b> in the <b>Color</b> field eliminates plotting of that wavelength. <p><b>Wavelength</b><br/>Selects the wavelength to be plotted.</p> <p><b>Plot Color</b><br/>Selects the color for the corresponding plotted wavelength. Select <b>No</b> in this dropdown list to eliminate plotting of the corresponding wavelength.</p>                                                                                                                                                                             | Colors set in the <b>System Data</b> dialog box, under <b>Wavelengths</b> (CLS WVL) |

| Command Syntax                                                                                                                   |                                                                            |                                                                                   |                     |                                                                                         |
|----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------|---------------------|-----------------------------------------------------------------------------------------|
| Screen Control                                                                                                                   | Explanation                                                                |                                                                                   | Default             |                                                                                         |
| DOT No   num_dot_symbol...w                                                                                                      |                                                                            |                                                                                   |                     |                                                                                         |
| Plot symbols for wavelength number:<br>Symbol                                                                                    | Designates the dot shape used to plot each wavelength in the spot diagram. |                                                                                   | Symbols set by DTL. |                                                                                         |
|                                                                                                                                  | 1                                                                          |  |                     | 1 0    |
|                                                                                                                                  | 2                                                                          |  |                     | 1 1    |
|                                                                                                                                  | 3                                                                          |  |                     | 1 2    |
|                                                                                                                                  | 4                                                                          |  |                     | 1 3    |
|                                                                                                                                  | 5                                                                          |  |                     | 1 4    |
|                                                                                                                                  | 6                                                                          |  |                     | 1 5    |
|                                                                                                                                  | 7                                                                          |  |                     | 1 6    |
|                                                                                                                                  | 8                                                                          |  |                     | 1 7    |
|                                                                                                                                  | 9                                                                          |  |                     | > 1 7  |
| On the command line, use DOT No to force the use of the default for that wavelength; in the GUI, you can select <b>Default</b> . |                                                                            |                                                                                   |                     |                                                                                         |

For more details about how these controls are used, go to “Scaling” on page 19-398 and “Plot Labels, Color and Dot Shape” on page 19-398.

## Defining Computation Controls

To define computation controls for Spot Diagram (SPO), choose the **Analysis > Geometrical > Spot Diagram** menu. The **Spot Diagram** dialog box displays. Click the **Computation Controls** tab and define the fields as described in the following table.



The image shows the 'Spot Diagram' dialog box with the 'Computation Controls' tab selected. The dialog has three tabs: 'Output Controls', 'Computation Controls', and 'Annotations/Overlays'. The 'Computation Controls' tab contains two main sections: 'Spot Size Computation' and 'Ray Pattern for Plot'. In the 'Spot Size Computation' section, there are two radio buttons: 'Number of rays across diameter' (unselected) and 'Fractional error for RMS' (selected). The 'Number of rays across diameter' has a text box with the value '51'. The 'Fractional error for RMS' has a text box with the value '0.0100'. Below these is a note: 'Spot size computation uses a quasi-random ray pattern based on a Sobol sequence.' The 'Ray Pattern for Plot' section has a dropdown menu set to 'Grid' and a text box with the value '20' next to the label 'Number of rays across diameter'. At the bottom of the dialog are four buttons: 'Option Set...', 'OK', 'Cancel', and 'Help'.

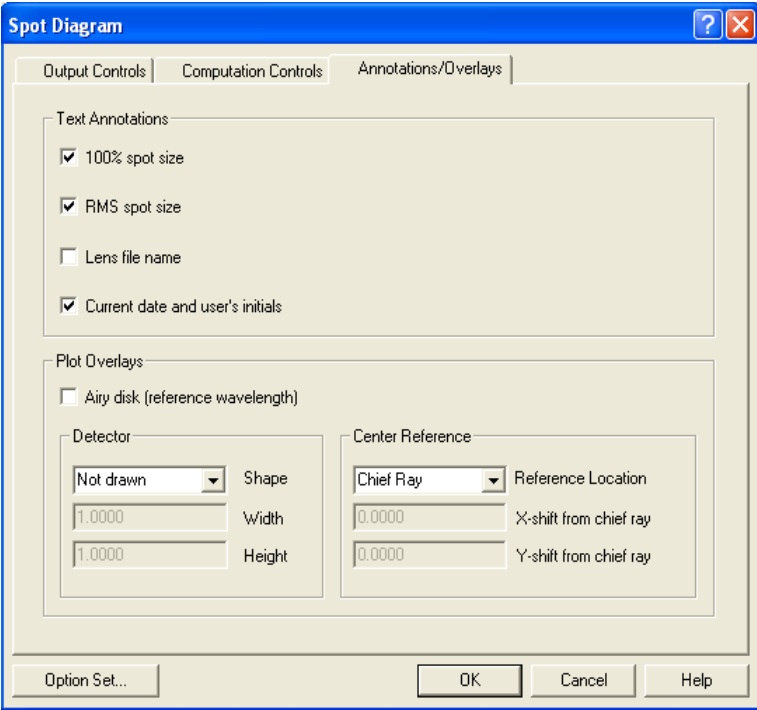
| Section               | Control                        | Value  |
|-----------------------|--------------------------------|--------|
| Spot Size Computation | Number of rays across diameter | 51     |
|                       | Fractional error for RMS       | 0.0100 |
| Ray Pattern for Plot  | Pattern                        | Grid   |
|                       | Number of rays across diameter | 20     |

| Command Syntax                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |          |
|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| Screen Control                                                                                           | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Default  |
| RTL [NRD] n                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |          |
| <b>Spot Size Computation:</b><br><b>Number of ray across diameter</b><br><b>Fractional error for RMS</b> | <p>Specifies how the RMS spot size is calculated: either based on the number of rays across the diameter or based on a fractional error level. The spot size computation uses a quasi-random ray grid based on a Sobol algorithm.</p> <p><b>Number of rays across diameter</b></p> <p>In the number of rays across diameter control (or RTL NRD command), the value <i>n</i> specifies the approximate number of rays across the diameter of the entrance pupil. This form of the RTL command is primarily useful when comparing the results of separate SPO runs (for example, during finite difference tolerancing), since it forces the same ray pattern to be generated in the entrance pupil. Note that the upper limit for RTL NRD is 4,000 rays across the pupil, or approximately 16 million rays total.</p> <p><b>Fractional error for RMS</b></p> <p>When you select the fractional error for RMS (i.e., omit the NRD qualifier from the RTL command), the value <i>n</i> specifies the fractional error estimate for the RMS spot size calculation (e.g., 0.01 represents a 1% error). The RMS spot size computation continues to trace rays until an internal estimate for the error level is below the specified error level. However, this error estimate is not an exact measure of the error in the computation and may not be accurate for some systems. Therefore, while it is not typical, the actual error in the RMS spot diameter calculation may exceed the level specified. The error estimate works best if the spot is reasonably well focused.</p> <p>Also note that the error estimate is based on the RMS spot size computation. The same ray grid is used to compute the 100% spot size, but the error estimate only applies to the RMS spot size.</p> <p>For more details about the RTL command, see “Spot Size Computations and Centroid Data” on page 19-400.</p> | RTL 0.01 |

| Command Syntax                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                           |
|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Screen Control                                              | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Default                                                                                                   |
| PAT GRD   SOB   CIR                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                           |
| <b>Ray Pattern for Plot: Pattern</b>                        | <p>Specifies the pattern of rays across the entrance pupil that are traced to the image surface.</p> <ul style="list-style-type: none"> <li>• <b>Grid (GRD)</b> - Traces an evenly spaced rectangular grid of rays.</li> <li>• <b>Circular (CIR)</b> - Traces a circular ray pattern. Note that the number of rays across the diameter (NRD command) represents 2*(the number of rings), which is approximately the number of rays across the diameter for a circular pattern.</li> <li>• <b>Quasi-Random (SOB)</b> - Traces a quasi-random (Sobol) pattern that uniformly samples the X,Y ray origin space while giving the appearance of a random sample. This method eliminates spot diagram artifacts that can result from the symmetrical patterns generated with GRD or CIR.</li> </ul> <p>See “Plotted Ray Density” on page 19-399 for more details about the ray patterns.</p> | PAT GRD<br>(rectangular grid)                                                                             |
| NRD num_rays_across_diameter....z                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                           |
| <b>Ray Pattern for Plot: Number of rays across diameter</b> | <p>Specifies the number of rays used to generate the spot diagram.</p> <p>Specifically, this command designates the number of rays across the grid traced through the pupil for the wavelength with the largest weight. The relative number of rays traced for each wavelength is determined by the wavelength weights. For a single wavelength, this corresponds to a value of 20 for the number of rays across the diameter.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Approximately 360 rays are started; those reaching the image plane are used to generate the spot diagram. |

Defining Annotations and Overlays

To define annotations and overlays for Spot Diagram (SPO), choose the **Analysis > Geometrical > Spot Diagram** menu. The **Spot Diagram** dialog box displays. Click the **Annotations/Overlays** tab and define the fields on that tab as described in the following table.



| Command Syntax                                        |                                                                                                                               |         |
|-------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|---------|
| Screen Control                                        | Explanation                                                                                                                   | Default |
| ANN SPO Yes   No                                      |                                                                                                                               |         |
| Text Annotations:<br>100% spot size                   | Displays a text annotation in the plot specifying the full spot diameter.                                                     | Yes     |
| ANN RMS Yes   No                                      |                                                                                                                               |         |
| Text Annotations:<br>RMS spot size                    | Displays a text annotation in the plot specifying the RMS spot diameter.                                                      | Yes     |
| ANN LEN Yes   No                                      |                                                                                                                               |         |
| Text Annotations:<br>Lens file name                   | Displays a text annotation in the plot listing the lens file name.                                                            | No      |
| ANN INI Yes   No                                      |                                                                                                                               |         |
| Text Annotations:<br>Current date and user's initials | Displays the current date and designer initials (as defined in the <b>System Data</b> dialog box or INI command) in the plot. | Yes     |

| Command Syntax                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |            |
|------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Screen Control                                                   | Explanation                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Default    |
| AIR Yes   No                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |            |
| <b>Plot Overlays:</b><br><b>Airy disk (reference wavelength)</b> | Adds a circle or ellipse to the spot diagram that corresponds to the Airy disk diameter based on the X and Y f-numbers (determined from real ray tracing) and the reference wavelength.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | No         |
| DET RET   CIR width height                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |            |
| <b>Plot Overlays:</b><br><b>Detector</b>                         | <p>Superimposes a detector of a specified size on the spot diagram, which shows the spot size relative to the detector. The detector is centered on the reference location (as specified in the <b>Reference Location for Overlays</b> area, or RL command).</p> <p><b>Shape: Circular (CIR)</b></p> <p>Selects a circular detector with a dimension equal to the value specified in the <b>Width</b> field. For the width, specify the full X dimension of the detector.</p> <p><b>Shape: Rectangular (RET)</b></p> <p>Selects a rectangular detector of the dimensions given in the <b>Width</b> and <b>Height</b> fields. For the width and height, specify the full X and Y dimensions of the detector.</p>                                                                                                                                     | Not drawn  |
| RL CRA   CEN   USR user_defined_x user_defined_y                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |            |
| <b>Plot Overlays:</b><br><b>Center Reference</b>                 | <p>Specifies the reference location for the center of the detector or Airy disk to be superimposed on the spot diagram.</p> <ul style="list-style-type: none"> <li>• <b>Reference Location</b> - You can select whether the center of the detector or Airy disk is referenced to the chief ray (CRA), spot centroid (CEN), which is the unweighted average of the rays traced, or user-defined (USR) X and Y offsets from the chief ray.</li> <li>• <b>X-shift from chief ray</b> - Defines the X offset to which the detector or Airy disk is referenced.</li> <li>• <b>Y-shift from chief ray</b> - Defines the Y offset to which the detector or Airy disk is referenced.</li> </ul> <p>Note that if the special form of reference ray aiming is used (CRA Fk SI or RRA Fk R1 SI), this overrides the chief ray location on the image plane.</p> | RL CRA 0 0 |

## Discussion of Input and Computations

### What to Include in the LDM Data

No additional LDM data is required for the Spot Diagram option. If you wish to do through-focus analyses, enter the LDM data for depth of focus (FFO, IFO, NFO). The **NRD** command (see “Plotted Ray Density” on page 19-399) and the wavelength weights (WTW) control how many rays are traced when generating the spot diagram.

### Usage

Spot diagrams show the geometrical structure of the image. They are particularly useful for non-diffraction-limited systems and are often helpful in reports and presentations.

Spot diagrams are generated by tracing a rectangular, circular, or quasi-random (Sobol) grid of rays on the entrance pupil from each wavelength for each object point. The resulting distribution on the real image surface (including any defocus value) is then plotted at a suitable scale. A diagram will be generated containing all field angles, defined focus positions, and zoom positions. Unless overridden, the scale factor is determined automatically from the size of the first field, first focus position spot or scaled to show any detector or Airy disk overlay. The minimum scale factors allowed by automatic scaling are 0.001 inch, 0.005 cm, or 0.05 mm, depending on the system units.

### Through-Focus Plots

By defining through-focus parameters in the LDM (**Through Focus** settings in the **System Data** dialog box or FFO, IFO, NFO from the command line), you can run through-focus spot diagrams. The focal shifted distributions for all fields are plotted at the same scale for easy comparison (see Example 4). Up to 18 focal positions may be plotted in this manner.

### Scaling

For the Spot Diagram option, the default program-determined scale size can be altered (**Aberration scaling** setting or **SSI**), and independently scaled in the X (**Independent scaling/X** or **SSX**) and Y (**Independent scaling/Y** or **SSY**) directions, so a highly distorted image can be fitted on the plot. Go to “Defining Output Controls” on page 19-390 for details.

### Plot Labels, Color and Dot Shape

The Spot Diagram option also allows you to generate a quick plot without labeling (**Full plot labeling** **No** or **LAB N**); this eliminates plotting of title, scale factor, and date for that zoom position. You can designate color titles for the plot (**Full plot labeling** **Color** or **LAB** color - BLA, RED, GRE, BLU, MAG, YEL, CYA, WHI). Up to 40 characters are plotted for the title of designated zoom positions (**Temporary title** or **TIT**); if no zoom position is designated, the title is applied to all. Go to “Defining Output Controls” on page 19-390 for details.

Each wavelength that has been defined for the system in the LDM may be plotted in a different color (**Plot symbols for wavelength number** spreadsheet or **WVL** color). Alternatively, you can enter **No** in the **Plot symbols for wavelength number** spreadsheet’s **Plot Color** field or use **WVL N** for a specified wavelength to eliminate it from the plot as well as the RMS and 100% spot computations. Go to “Defining Output Controls” on page 19-390 for details.

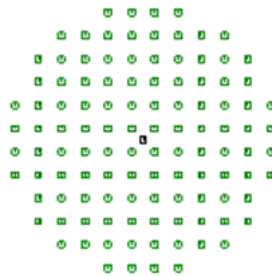
The default plotting dot representing each ray-image intersection in the spot diagram is an “L” shaped character with a dimension of 0.005 inches or 0.125 mm. You can select different shapes (**Plot symbols for wavelength number** spreadsheet or **DOT**) and sizes (**Symbol size** or **DSI**) for the dot as desired. Note that using **DOT** alone increases the default size so the different shapes are distinguishable.

## Plotted Ray Density

The number of rays used to generate the spot diagram is controlled by the **Number of rays across diameter** field (**Ray Pattern for Plot** area on the **Computation Controls** tab), or the NRD command. This command designates the number of rays across the grid traced through the pupil for the wavelength with the largest weight. The relative number of rays traced for each wavelength is determined by the wavelength weights. For a single wavelength, this corresponds to a value of 20 for the number of rays across the diameter.

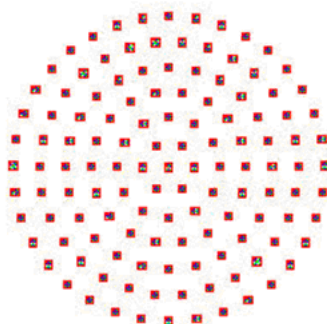
The effect on the spot diagram of specifying an NRD value depends on the type of ray pattern you select:

- For a grid pattern (PAT GRD), the NRD specifies only the number of rays across the diameter. The following figure shows a representative ray distribution for PAT GRD with an NRD of 12.

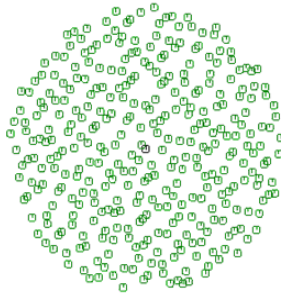


- For a circular pattern (PAT CIR), the NRD represents  $2 \times (\text{the number of rings})$ , which is approximately the number of rays across the diameter for a circular pattern. For an odd NRD, the number of rings is  $(\text{NRD}-1)/2$ . The number of rays in each ring is  $6 \times (\text{the number of rings})$ . For example, an NRD of 12 results in 6 rings evenly spaced in the radius, where the first ring out from the center contains 6 rays evenly spaced around the circumference, the second ring out from the center contains 12 rays evenly spaced around the circumference, and so on.

In addition, for an even number of rings, the first ray is located at 0-degree azimuth (i.e., straight above the center point). For an odd number of rings, the pattern is rotated by  $180/(\text{the number of rays in the ring})$ . For example, the first ring, which contains 6 rays, is rotated by 30 degrees ( $180/6$ ). The third ring, which contains 12 rays, is rotated by 15 degrees ( $180/12$ ). The following figure shows a representative ray distribution for PAT CIR with an NRD of 12.



- For a quasi-random pattern (PAT SOB), the NRD determines the ray density (e.g., a higher NRD increases the ray density). The following figure shows a representative ray distribution for PAT SOB with an NRD of 20.



## Spot Size Computations and Centroid Data

The Spot Diagram option automatically lists, for each field point and zoom position, the following: the centroid data (position of the centroid with respect to the chief ray) and the minimum RMS spot size diameter; the displacement of the 100% spot center from the chief ray and the minimum 100% spot size diameter; and the number of rays in the grid used to compute the spot sizes. Note, if chief ray aiming at the image surface is specified (i.e., CRA SI, or, RRA R1 SI), the centroid and 100% spot center displacements are relative to the specified chief ray aiming values. In addition, you can annotate the plotted output with both the RMS spot size and 100% spot size data; see “Defining Annotations and Overlays” on page 19-396 for details.

The 100% spot size computation represents the size of a circle that encompasses all of the rays intersecting the image, and is computed independent of the chief ray or RMS centroid location. The RMS spot size is computed relative to the spot centroid. The spot size computations use a quasi-random (Sobol) ray grid for greater accuracy.

For both the RMS spot size and 100% spot size computations, the total number of rays traced is by default based on the desired accuracy in the RMS spot size computation, which you can specify using the **Fractional error for RMS field (Spot Size Computation area on the Computation Controls tab)**, or the **RTL** command. Rays are traced until the standard deviation of the mean percentage (i.e., the standard deviation of the samples divided by the square root of the number of samples) in the RMS spot size is below the RTL value. Note that standard deviation of the mean is an estimated error, and the actual error could be greater. The effect of wavelength weighting is modeled the same as in the plotted output; that is, CODE V traces fewer total rays for wavelengths with lower weights.

Another way that you can specify the total number of rays traced for the spot size computations is by defining a value in the **Number of rays across diameter** field (**Spot Size Computation area on the Computation Controls tab**), or by specifying an NRD value in the RTL command. This NRD value represents the approximate number of rays across the diameter of the entrance pupil, and is helpful to use when comparing the results from separate SPO runs (e.g., during finite difference tolerancing).

For more details about the commands used for the spot size computations, see “Defining Computation Controls” on page 19-393.

## Ray Listings

You may request, using **List plotted ray coordinates** or the **LIS** command, a listing of the ray coordinates for diagnostic purposes or for input to macros or another program. Go to “Defining Output Controls” on page 19-390 for details.

## Plot Overlays

You can enhance your spot diagram with several additional types of information. These selections are available on the **Annotations/Overlays** tab (see “Defining Annotations and Overlays” on page 19-396 for GUI control and command syntax details):

- 100% spot size (ANN SPO command)
- RMS spot size (ANN RMS command)
- Lens file name (ANN LEN command)
- Current date and user’s initials (ANN INI command)
- Airy disk (AIR command). This adds a circle or ellipse to the spot diagram that corresponds to the Airy disk diameter based on the X and Y f-numbers (determined from real ray tracing) and the reference wavelength. Additional controls allow you to define the reference location (RL command) of the Airy disk: chief ray, spot centroid, or a user-defined X- and Y-shift from the chief ray.
- Detector (DET command). This superimposes a detector of a specified size on the spot diagram. You can choose a circular or rectangular detector, and also define the reference location (RL command) of the detector: chief ray, spot centroid, or a user-defined X- and Y-shift from the chief ray.

## Description of Output

The spot diagrams are the principal output; because Y coordinates are plotted up and X to the right (relative to format), the spots appear as seen from behind the image surface. A table comparing the number of rays traced to the number reaching the image surface is also produced for diagnostic purposes. The difference between columns in that table indicates rays blocked by apertures. Any apertures (including obscurations) that have been defined in the LDM for the system are considered in determining rays passed, unless you set the Clear Aperture flag (CA) to “No” in the LDM (in Apertures/Obscurations/Edges).

Spot diagrams from neighboring fields or focus positions are not allowed to overlap. If any rays are too far from the center to be conveniently plotted, they are omitted and a message is printed.

In addition to the graphical output, the Spot Diagram option will also compute and list the following: the centroid data (position of the centroid with respect to the chief ray) and the minimum RMS spot size diameter; the displacement of the 100% spot center from the chief ray and the minimum 100% spot size diameter; and the number of rays in the grid used to compute the spot sizes. See Example 5.

If requested (**List plotted ray coordinates** or **LIS**), a printed listing of all rays is provided.

A related option, Footprint Analysis (FOO), can produce outline or “spot diagram” “footprints” of ray bundles on any specified surface. Go to “FOO - Footprint Plot” on page 18-91 for more information.

Go to “Examples” on page 19-402 to see sample plots and their corresponding commands.

## Examples

### Example 1. Default case on the Cooke triplet

Since no scale size is given, automatic scaling based on the first field is done. The scale factor calculated is approximately 0.05 mm/scale bar (Figure 1).

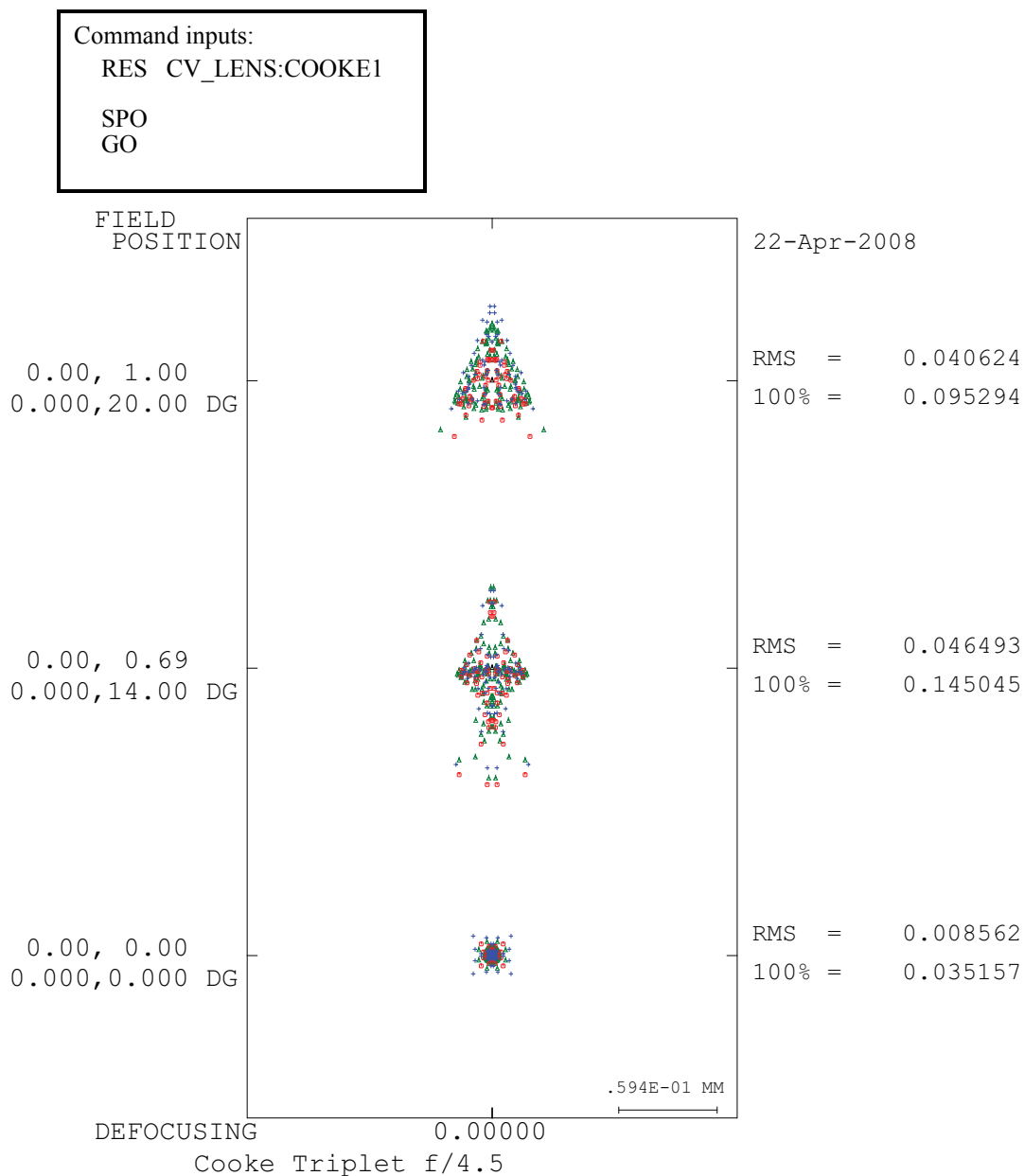
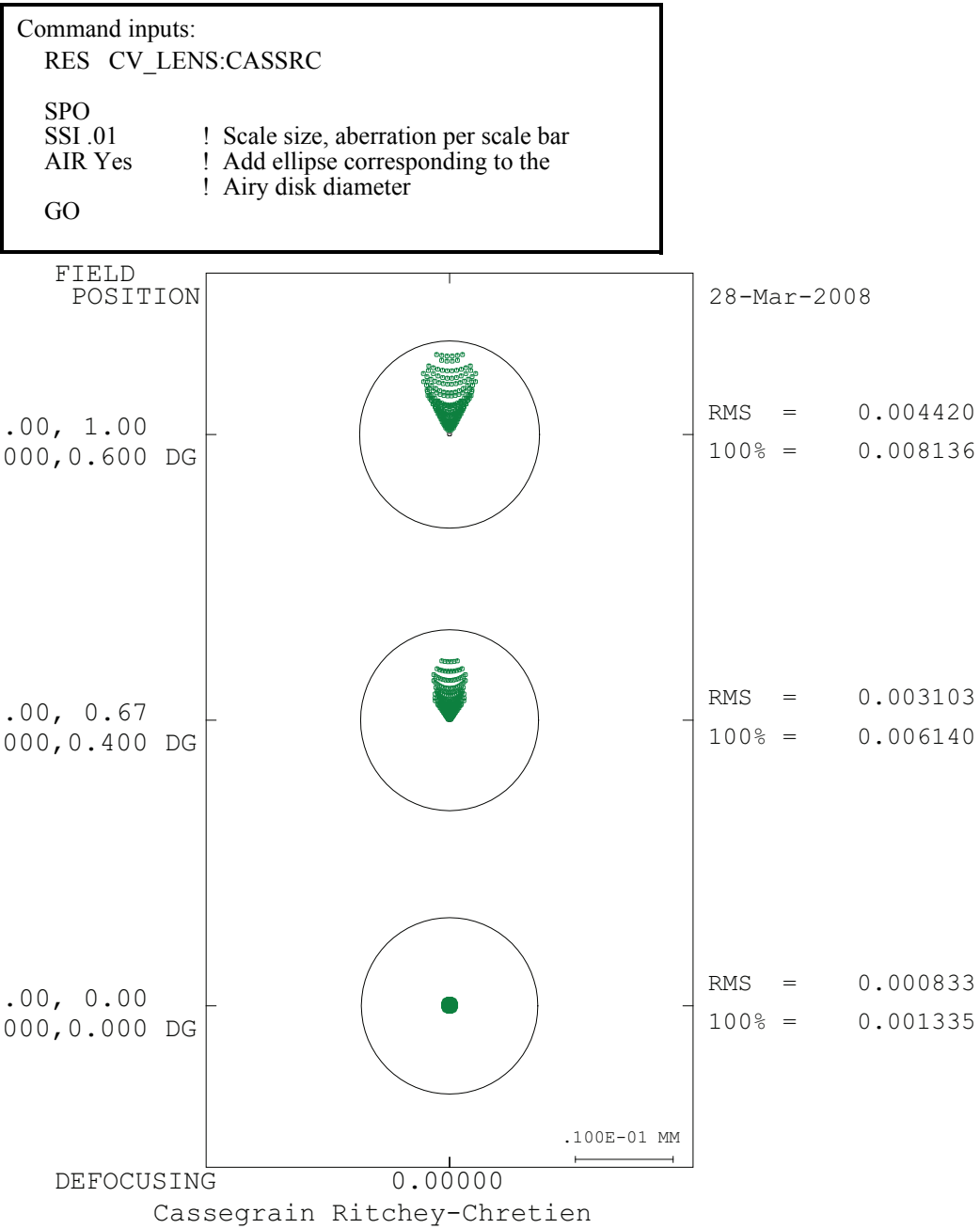


Figure 1. Default output from SPO

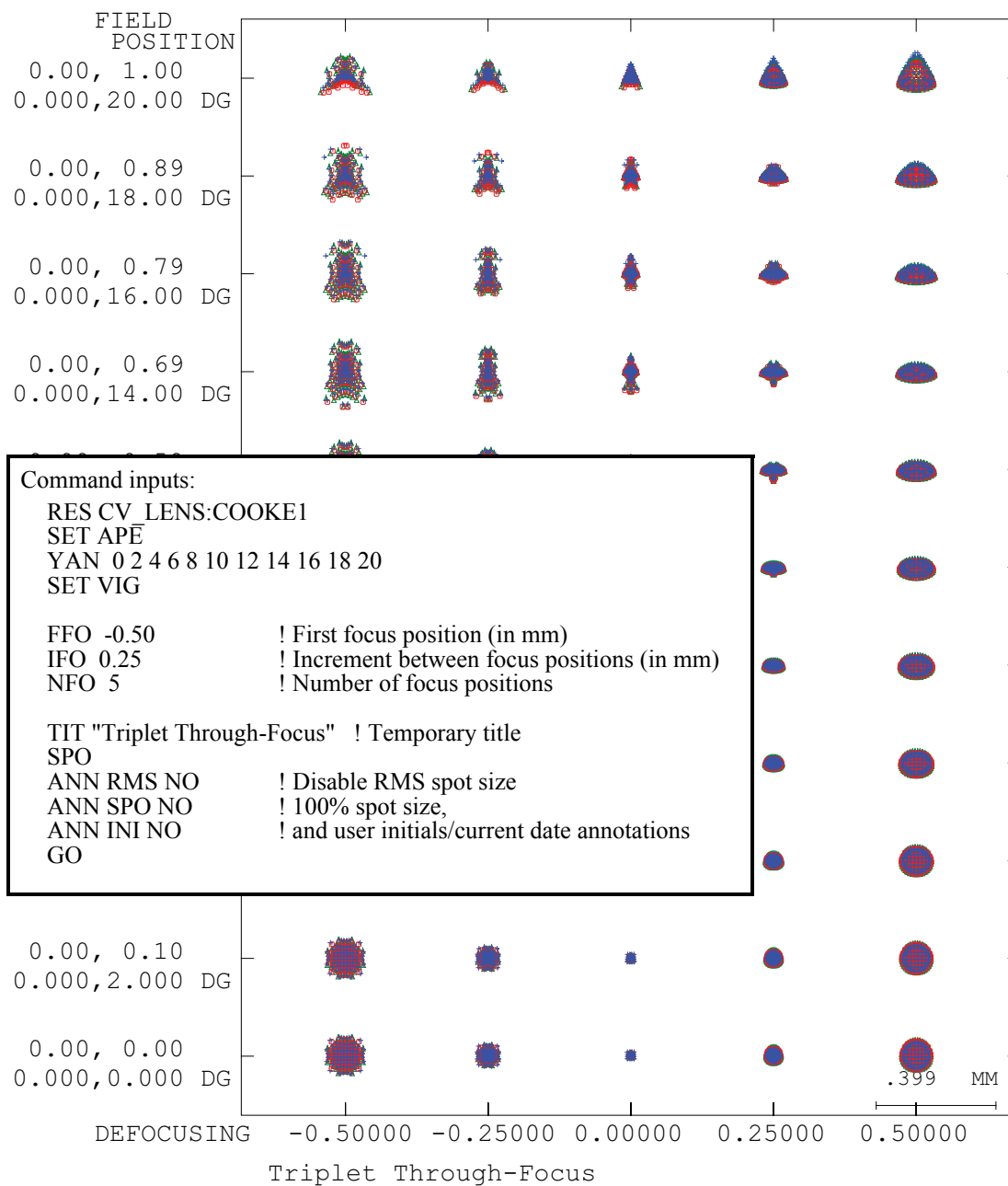
**Example 2. Spot diagram of a Cassegrain telescope with Airy disk overlay**



**Figure 2. Spot diagram with Airy disk overlay**

**Example 3. Through-focus spot diagram with multiple fields and multiple focus positions  
(Figure 3)**

For this example, some text annotations, including date and spot size data, have been disabled to simplify the spot diagram.



**Figure 3. Through-focus spot diagram**

#### Example 4. Through-focus (defined in LDM) spot diagram with specified scale factor

This example shows separate plot colors and symbols for each wavelength and plot overlays for RMS spot size, 100% spot size, and a detector (Figure 4).

```

Command inputs:
RES CV LENS:COOKE1
FFO -0.25          ! mm, First focus
IFO 0.25           ! mm, Increment of focus
NFO 2              ! Number of focus positions

SPO
! Note: SPO uses focus data defined in LDM
SSI .04           ! Scale size, aberration per scale bar
WVL RED GRE BLU   ! Plot wavelengths in colors
DOT 1 2 3         ! Plot wavelengths with unique symbols
DSI 0.050         ! Dot size in scale bars
TIT 'Triplet Through-Focus' ! Temporary title
NRD 30            ! Ray density control for plot
PAT SOB           ! Quasi-random ray pattern for plot
ANN SPO Yes       ! Add 100% spot size annotation
ANN RMS Yes       ! Add RMS spot size annotation
DET REC .05 .075  ! Add rectangular detector of specified
                  ! X and Y dimensions
RL USR 0 .02      ! User-defined reference location for
                  ! detector, offset from chief ray

GO

```

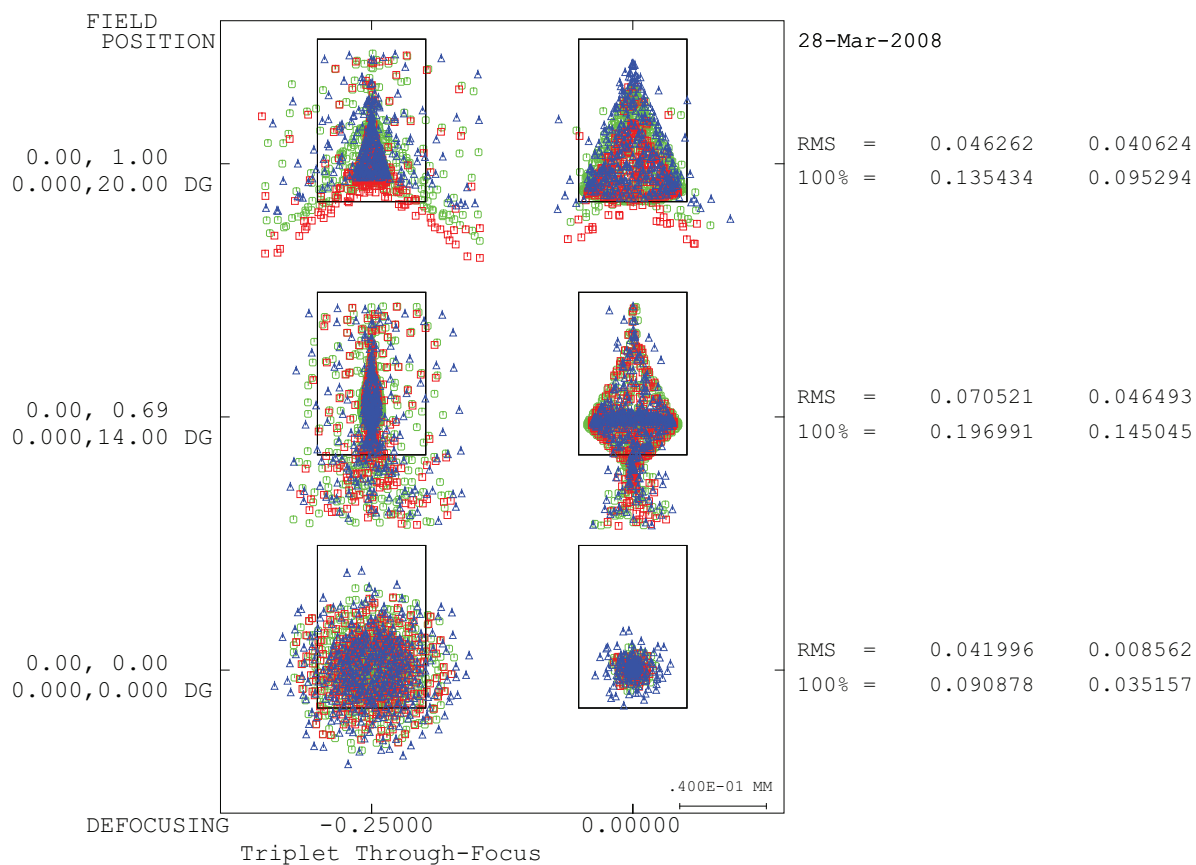


Figure 4. Enhanced SPO output

### Example 5. Listing from SPO

The listing in this example shows the centroid data (position of the centroid with respect to the chief ray), the minimum RMS spot size diameter, the displacement of the 100% spot center from the chief ray, the minimum 100% spot size diameter, and the number of rays in the grid used to compute the spot sizes. This data corresponds to the spot diagram shown in Example 4.

Command inputs:

```
RES CV LENS:COOKE1
FFO -.25      ! First focus (in mm)
IFO .25       ! Increment of focus (in mm)
NFO 2         ! Number of focus positions.

SPO
RTL NRD 30    ! Number of rays across diameter for spot size computation
PLO NO       ! Suppress the graphical output
GO
```

RAY STATISTICS FOR FIELD 1 ZOOM 1 ON PLOT:

| WAVELENGTH | WEIGHT | POINTS<br>TRACED | POINTS<br>ATTEMPTED |
|------------|--------|------------------|---------------------|
| 656.3      | 1      | 80               | 104                 |
| 546.1      | 2      | 156              | 188                 |
| 486.1      | 1      | 80               | 104                 |

All displacements are listed relative to the chief ray at the reference wavelength for each field.

```
Field 1, ( 0.00, 0.00) degrees. Focus -0.25000      704 Rays
Displacement of centroid           Minimum RMS spot diameter
X: 0.00000E+00 Y: 0.00000E+00      0.40846E-01 MM
Displacement of center of 100% Spot Minimum 100% spot diameter
X: 0.00000E+00 Y: 0.00000E+00      0.85513E-01

Field 1, ( 0.00, 0.00) degrees. Focus 0.00000      704 Rays
Displacement of centroid           Minimum RMS spot diameter
X: 0.00000E+00 Y: 0.00000E+00      0.78958E-02 MM
Displacement of center of 100% Spot Minimum 100% spot diameter
X: 0.00000E+00 Y: 0.00000E+00      0.30647E-01

Field 2, ( 0.00, 14.00) degrees. Focus -0.25000      692 Rays
Displacement of centroid           Minimum RMS spot diameter
X: 0.00000E+00 Y: -0.62347E-02      0.69685E-01 MM
Displacement of center of 100% Spot Minimum 100% spot diameter
X: 0.12548E-17 Y: -0.55957E-02      0.18848E+00

Field 2, ( 0.00, 14.00) degrees. Focus 0.00000      692 Rays
Displacement of centroid           Minimum RMS spot diameter
X: 0.00000E+00 Y: -0.64481E-02      0.45943E-01 MM
Displacement of center of 100% Spot Minimum 100% spot diameter
X: 0.00000E+00 Y: -0.54070E-02      0.13705E+00

Field 3, ( 0.00, 20.00) degrees. Focus -0.25000      600 Rays
Displacement of centroid           Minimum RMS spot diameter
X: 0.00000E+00 Y: 0.17003E-02      0.45760E-01 MM
Displacement of center of 100% Spot Minimum 100% spot diameter
X: 0.00000E+00 Y: -0.58237E-02      0.12729E+00

Field 3, ( 0.00, 20.00) degrees. Focus 0.00000      600 Rays
Displacement of centroid           Minimum RMS spot diameter
X: 0.00000E+00 Y: 0.91287E-03      0.40215E-01 MM
Displacement of center of 100% Spot Minimum 100% spot diameter
X: 0.00000E+00 Y: 0.20566E-02      0.86304E-01
```

## Technical Notes

The RMS spot diameter is computed for each field and zoom position. This is computed as twice the square root of the mean squared spot radius  $\sigma^2$ . The usual definition of mean squared spot radius  $\sigma^2$  is

$$\sigma^2 = \frac{\sum_{\lambda} \left\{ W_{\lambda} \iint \left[ (x(\lambda; x_p, y_p) - \bar{x})^2 + (y(\lambda; x_p, y_p) - \bar{y})^2 \right] dx_p dy_p \right\}}{\sum_{\lambda} W_{\lambda}}$$

Where  $x(\lambda; x_p, y_p)$  is the image plane x coordinate of the ray, traced at wavelength  $\lambda$ , that passes through the pupil point  $(x_p, y_p)$ , and  $y(\lambda; x_p, y_p)$  is the image plane y coordinate of the ray, traced at wavelength  $\lambda$ , that passes through the pupil point  $(x_p, y_p)$ . The double integral in the equation above is approximated by sampling the pupil with a finite number of rays in each wavelength. Also,  $\bar{x}$  and  $\bar{y}$  are the x and y centroids of the rays at the image plane at wavelength  $\lambda$ . These two quantities are defined as:

$$\bar{x} = \frac{\sum_{\lambda} W_{\lambda} \iint [x(\lambda; x_p, y_p)] dx_p dy_p}{\sum_{\lambda} W_{\lambda}}$$

$$\bar{y} = \frac{\sum_{\lambda} W_{\lambda} \iint [y(\lambda; x_p, y_p)] dx_p dy_p}{\sum_{\lambda} W_{\lambda}}$$

where  $\bar{x}$  and  $\bar{y}$  are the mean values of x and y.

