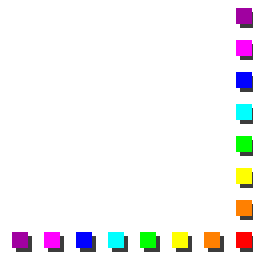


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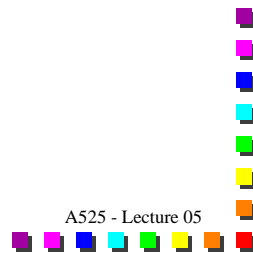
Astronomy 525

Lecture 05



Outline

- Ray tracing with “Ray”
 - Introduction to Ray
 - Using the program
- Worked example
 - HBO example



Ray Trace Tutorial

- Starting ray
 - Entering the prescription
 - Saving the prescription
- Tracing rays
 - Spot diagrams
 - Refocusing
 - System plots
 - Off-axis points and number of panels
- Miscellaneous
 - Adding an obscuration
 - View surface illumination
 - Tilting and offsetting surfaces

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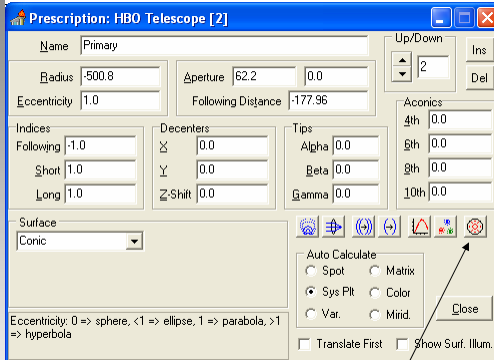
Start-up
Screen

Pop-up help appears when cursor is over a button.

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Modify Prescription Screen



Item	Description
Name	Surface name
Radius	Vertex curvature
Eccentricity	$\text{Sqr}(a^2 \pm b^2) / a$
Aperture	Diameter
Following Dist.	To next surface
Indices	Index of refraction, up to three "colors"
Decenters	Offset surface
Tips	Tilt surface
Surface	Select surface type
Trans. First	Do translations before surface rotation

This button is used to view illumination of the current surface. Auto calculate performs checked task when <cr> is done.

Note: Use the "edit" menu on the main window to change "prescription name"

Use ^F and ^B to move quickly between surfaces.



```

File : HBO.RAY      Name : HBO Telescope      Page 1

Surface Number ..      1          2          3
Name .....            Primary    Secondary focal plan
Radius .....          -500.800000 -207.900000  0.000000
Eccentricity .....    1.000000    1.870000    0.000000
Aperture .....         62.200000    20.000000    1.500000
Follow. Thckns ..     -177.960000    238.970000    0.000000

Follow. Index ...      -1.000000    1.000000    0.000000
Short Index .....     1.000000    1.000000    1.000000
Long Index .....      1.000000    1.000000    1.000000

Fourth Aconic ...      0.0E+0000    0.0E+0000    0.0E+0000
Sixth Aconic ...       0.0E+0000    0.0E+0000    0.0E+0000
Eighth Aconic ...      0.0E+0000    0.0E+0000    0.0E+0000
Tenth Aconic ...       0.0E+0000    0.0E+0000    0.0E+0000

Alpha Tip .....        0.000000    0.000000    0.000000
Beta Tip .....         0.000000    0.000000    0.000000
Gamma Tip .....        0.000000    0.000000    0.000000

X-Decenter .....       0.000000    0.000000    0.000000
Y-Decenter .....       0.000000    0.000000    0.000000
Z Shift .....          0.000000    0.000000    0.000000

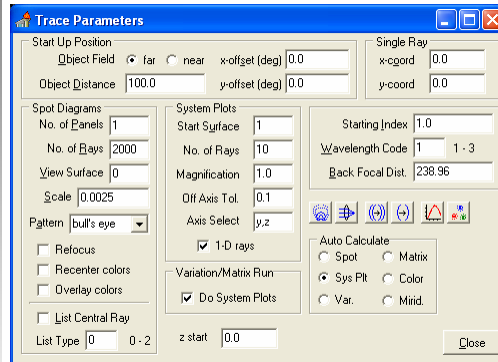
Sp. Surface .....      Conic Surf  Conic Surf  Conic Surf
Sp. Coef1. ....        0.000000    0.000000    0.000000
Sp. Coef2. ....        0.000000    0.000000    0.000000
Sp. Coef3. ....        0.0E+0000    0.0E+0000    0.0E+0000
    
```

Surface Prescriptions

Simple Cassegrain telescope using HBO as the example.



Trace Parameters



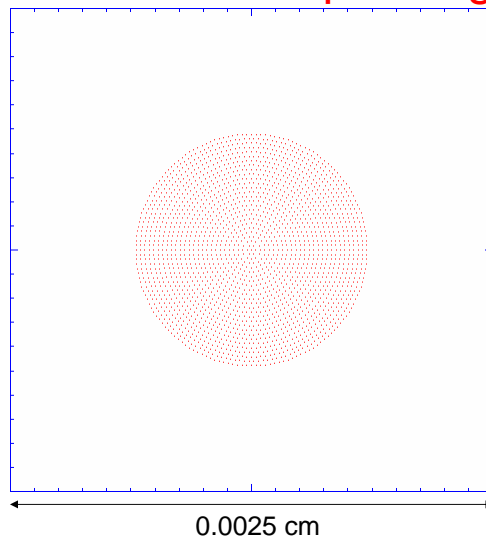
Item	Description
Object field	Location of source
Distance	Applies to near field
x, y offsets	Amount off axis
No. of Panels	Trace $\pm x, \pm y$ if > 1
Rays to do	Usually > 200
Scale	For spot diagram
Pattern	bull's eye, square, random
Refocus	Spot diagram for best focus for each panel
Start surface	Where to start system plots

Use No. of Panels = 9 for 3x3 grid over a finite field ($x, y \neq 0$). $NP \leq 81$.

Back focal distance can be changed here or as the following thickness for the last surface before the focus. You can also refocus from main window.



Spot diagram



Telescope is out of focus. Traced 2000 rays.

Scale = 0.000125 cm per tic



Statistics output

```

File : HBO.RAY      Name: HBO Telescope

Average Spot Position:  X =   0.000000   Y =   0.000000

Central Ray Values:
  X =   0.000000   Y =   0.000000   Z =   0.000000
  Cx =  0.000000   Cy =  0.000000   Cz=  1.000000

Spot Statistics: (2107 rays traced in 2107 tries)
RMS   = 0.000432  Sm_RMS  = 0.000000  Delta_Z  = 0.016084
RMS_x = 0.000305  Sm_RMS_x = 0.000000  Delta_Zx = 0.016084
RMS_y = 0.000305  Sm_RMS_y = 0.000000  Delta_Zy = 0.016084

Circumscribed grid pattern traced.
    
```

Gives average position of spot, central ray values, and statistics (total and x and y separately). The smallest rms and focus distance to achieve this are listed. A refocus option is given in the main window.

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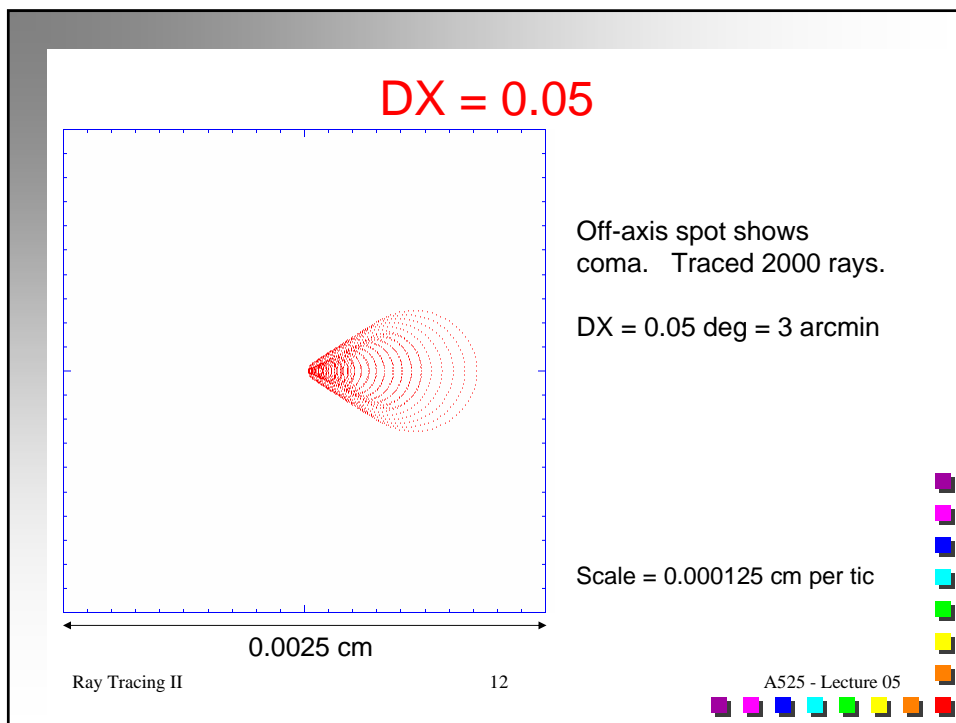
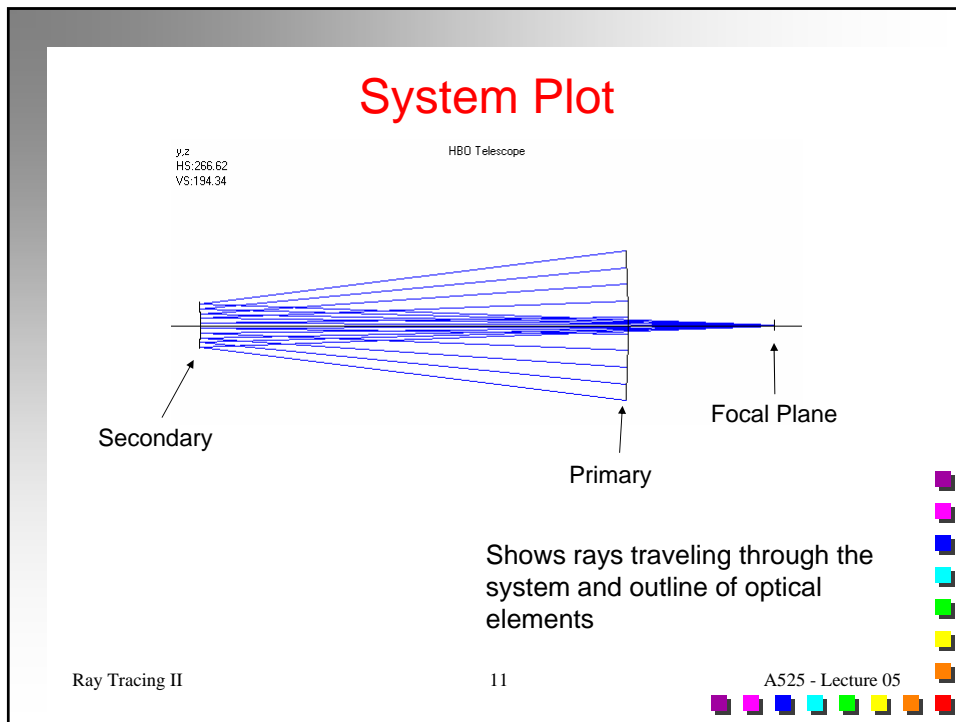
Refocused spot

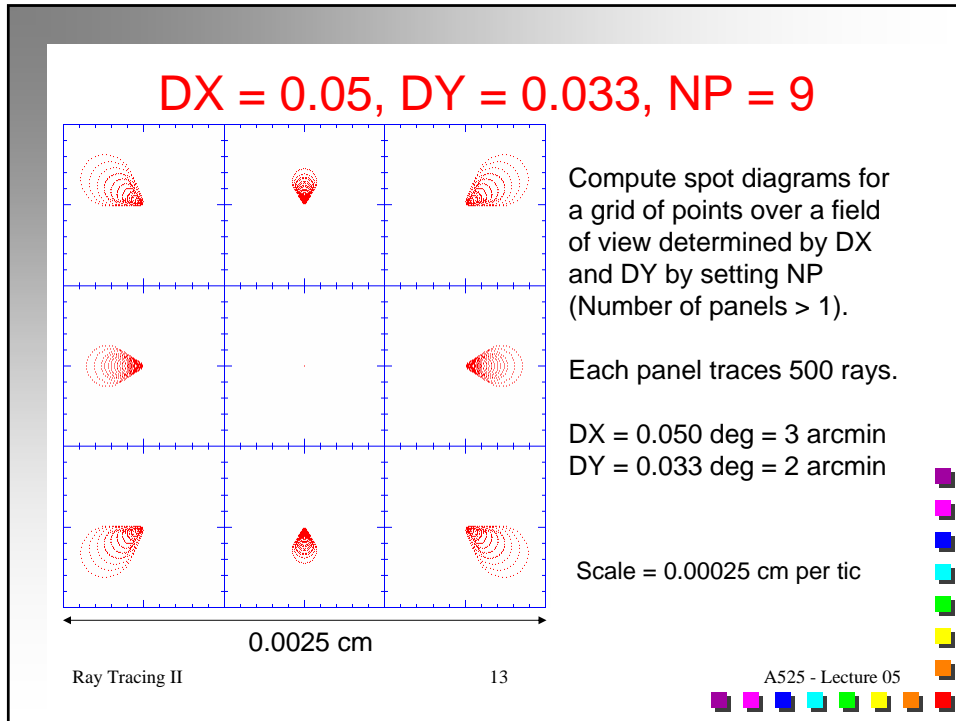
There really is a spot there – look in the circle.

Scale = 0.000125 cm per tic

0.0025 cm

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Stats for DX=0.05, DY=0.033

File : HBO.RAY Name: HBO Telescope

Panel Mode: 9 panels computed 547 rays attempted in bull's eye pattern.

Avg x,y,dz = 0.000000 0.000000 -0.002902
alpha and beta tilts = -0.03 0.00 deg

	DX	DY	NumRays	Avg. X	Avg. Y	Z-Center	RMS	sm_RMS	Delta_Z
1	-0.05000	0.03300	486	-0.72117	0.47597	0.00000	2.88e-04	2.59e-04	-0.00435
2	0.00000	0.03300	486	0.00000	0.47597	0.00000	1.47e-04	1.42e-04	-0.00132
3	0.05000	0.03300	486	0.72117	0.47597	0.00000	2.88e-04	2.59e-04	-0.00435
4	-0.05000	0.00000	486	-0.72117	0.00000	0.00000	2.33e-04	2.16e-04	-0.00303
5	0.00000	0.00000	486	0.00000	0.00000	0.00000	5.08e-07	5.05e-07	-1.89e-06
6	0.05000	0.00000	486	0.72117	0.00000	0.00000	2.33e-04	2.16e-04	-0.00303
7	-0.05000	-0.03300	486	-0.72117	-0.47597	0.00000	2.88e-04	2.59e-04	-0.00435
8	0.00000	-0.03300	486	0.00000	-0.47597	0.00000	1.47e-04	1.42e-04	-0.00132
9	0.05000	-0.03300	486	0.72117	-0.47597	0.00000	2.88e-04	2.59e-04	-0.00435

Avg x,y,dz are estimates of the average spot position over the field.
Alpha and beta tilts are estimates of the focal plane tilt.

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File : HBO.RAY Name : HBO Telescope Page 1

Surface Number ..	1	2	3	4
Name	Sec. Obsc	Primary	Secondary	focal plan
Radius	0.000000	-500.800000	-207.900000	0.000000
Eccentricity	0.000000	1.000000	1.870000	0.000000
Aperture	62.200000	62.200000	20.000000	1.500000
Follow. Thckns ..	177.960000	-177.960000	238.976084	0.000000
Follow. Index ...	1.000000	-1.000000	1.000000	0.000000
Short Index	1.000000	1.000000	1.000000	1.000000
Long Index	1.000000	1.000000	1.000000	1.000000
Fourth Aconic ...	0.0E+0000	0.0E+0000	0.0E+0000	0.0E+0000
Sixth Aconic	0.0E+0000	0.0E+0000	0.0E+0000	0.0E+0000
Eighth Aconic ...	0.0E+0000	0.0E+0000	0.0E+0000	0.0E+0000
Tenth Aconic ...	0.0E+0000	0.0E+0000	0.0E+0000	0.0E+0000
Alpha Tip	0.000000	0.000000	0.000000	0.000000
Beta Tip	0.000000	0.000000	0.000000	0.000000
Gamma Tip	0.000000	0.000000	0.000000	0.000000
X-Decenter	0.000000	0.000000	0.000000	0.000000
Y-Decenter	0.000000	0.000000	0.000000	0.000000
Z Shift	0.000000	0.000000	0.000000	0.000000
Sp. Surface	Centrl Obs	Conic Surf	Conic Surf	Conic Surf
Sp. Coef1.	20.000000	0.000000	0.000000	0.000000
Sp. Coef2.	0.000000	0.000000	0.000000	0.000000
Sp. Coef3.	0.0E+0000	0.0E+0000	0.0E+0000	0.0E+0000

Surface Prescriptions with an obscuration

A secondary obscuration is added before the primary mirror at the distance of the secondary.

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System Plot For Obscured System

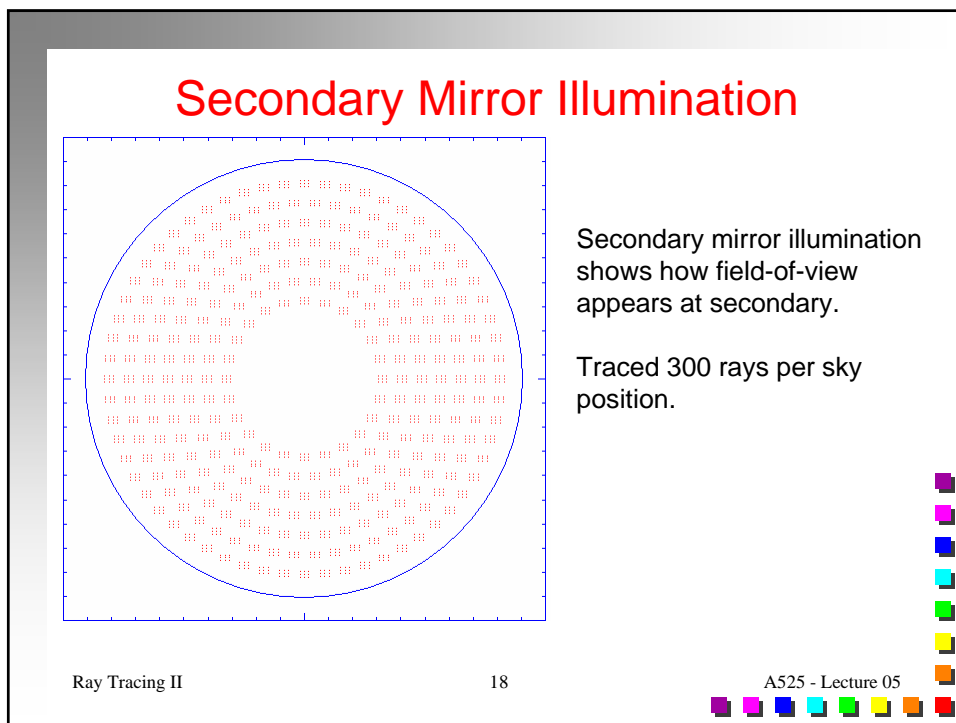
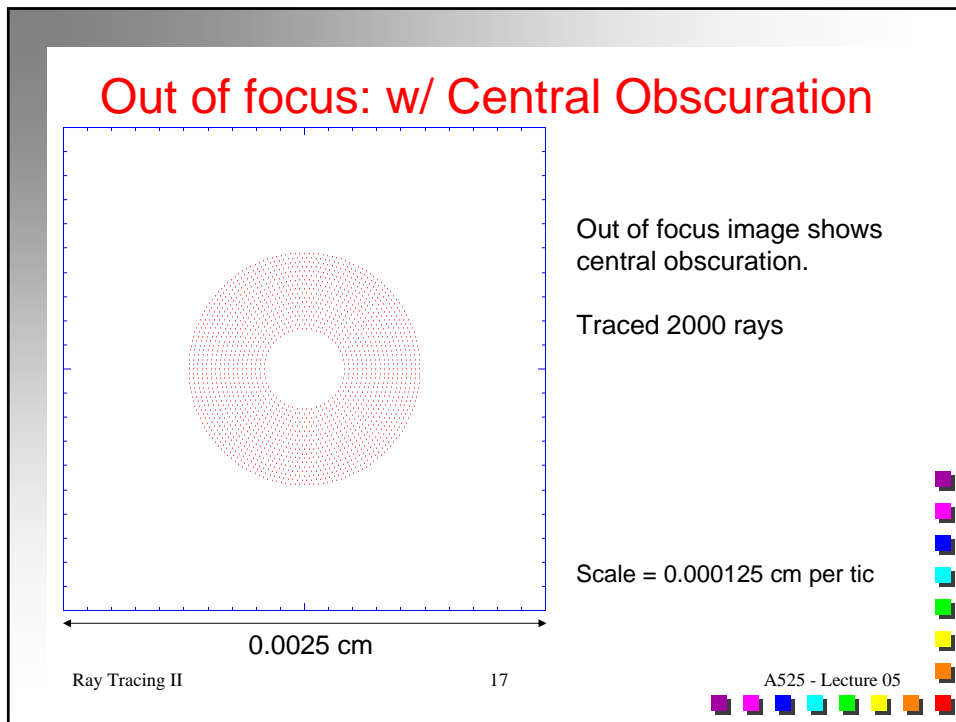
y,z
HS:266.62
VS:194.35

HBO Telescope

Secondary Primary Focal Plane

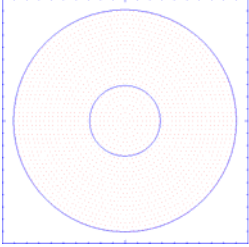
Note that rays start at secondary obscuration – which has been placed here at the distance of the secondary mirror.

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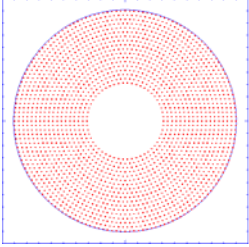


Illuminating Views

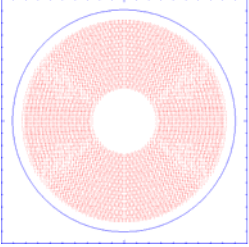
Obscuration surface

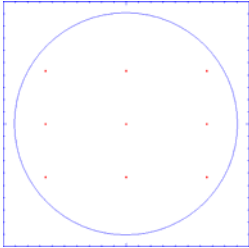


Primary Mirror



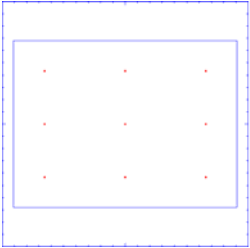
Secondary Mirror





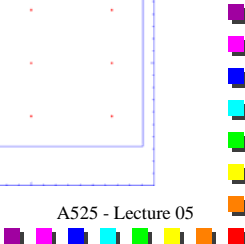
Focal plane views
(purposefully defocused)

Before and after setting
aperture size.

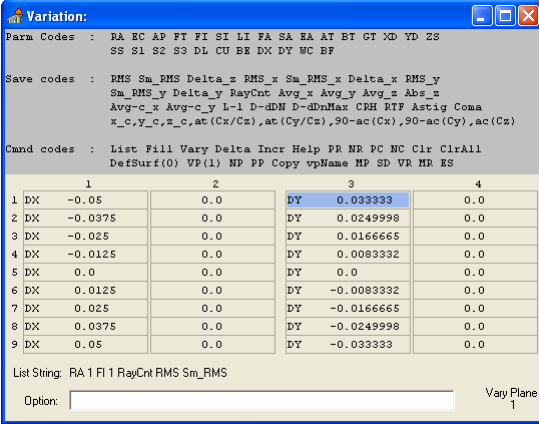


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Parameter Optimization Screen



	1	2	3	4
1 DX	-0.05	0.0	DY 0.033333	0.0
2 DX	-0.0375	0.0	DY 0.0249998	0.0
3 DX	-0.025	0.0	DY 0.0166665	0.0
4 DX	-0.0125	0.0	DY 0.0083332	0.0
5 DX	0.0	0.0	DY 0.0	0.0
6 DX	0.0125	0.0	DY -0.0083332	0.0
7 DX	0.025	0.0	DY -0.0166665	0.0
8 DX	0.0375	0.0	DY -0.0249998	0.0
9 DX	0.05	0.0	DY -0.033333	0.0

Parm codes:
change surface parameter,
e.g. RA 3 5.76 changes
radius of surface 3 to 5.76.

Save codes:
Parameter for output listing
(in addition to parm codes)
e.g. List DX DY RA 3 rms
sm_rms delta

Command codes:
fill in values, move to next
plane, etc.

Allows parameters to be varied in a systematic way.

- Matrix run => (1,2) x (3,4) parameter
- Variation run => 1, 2, 3, 4 change together (line by line)

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