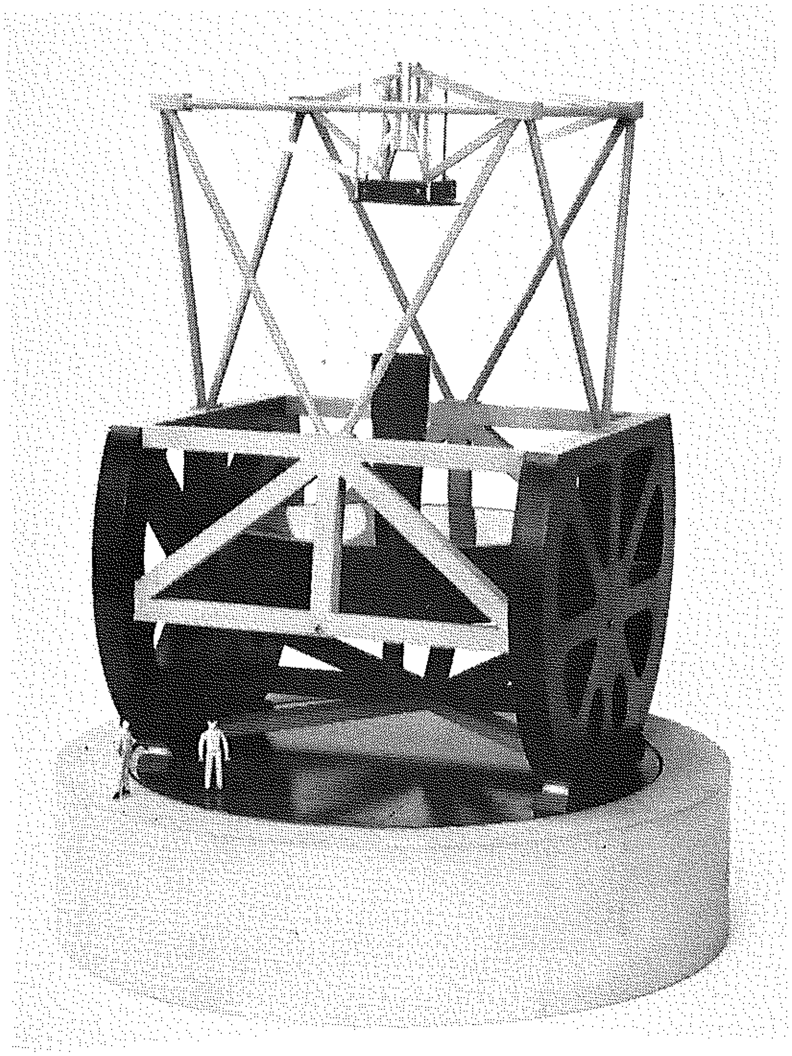
MAGELLAN PROJECT

University of Arizona	Carnegie Institution of Washington	The Johns Hopkins University



# Corrector Assembly Decollimation Effects in the Magellan Wide-Field f/6.5 Cassegrain

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## 1. Introduction

The Magellan telescope optical design currently contains an f/1.2 parabolic primary mirror and an hyperbolic secondary mirror which combines with a 3-lens-element all-spherical fused silica field corrector with ADC to yield a 40-arcmin diameter field of view over the full (0.33 to 1.10)-micron chromatic interval without refocus. The field of view has a mild concave radius (-161.11 inches) and a 24.18-inch diameter.

The field corrector lens elements and ADC prisms will be housed in a cylindrical mechanical cell approximately 2 feet tall and 3 feet in diameter. It will be possible to align the elements internally within the cell and assure that their optical axes are concentric with the mechanical axis of the cell because the entire unit can be rotated and optically centered on an element by element basis. Thus it is safe to assume that the corrector lens assembly is perfectly collimated internally.

It is anticipated that differential thermal effects and mechanical flexures within the telescope structure may cause the corrector assembly to become tilted and/or displaced relative to the primary mirror optical axis. Displacement along the optic axis would cause a focus shift and slight image scale change. However these effects are not expected to be large and they could be mitigated by dynamic focusing during an observation. In practice the largest component of axial displacement will show a cosine dependence upon the object's altitude coordinate due to the variation of gravity loading. It would be possible to make open-loop corrections for this by table look-up if necessary.

The transverse components of corrector assembly displacement (called decentration) as well as any corrector tilt about its leading vertex will cause the image quality to degrade. The leading aberration term causes a coma-like flair to elongate the outermost images on the side of the field that is in the "direction" of the image shift. Depending upon the relative vector orientation, a combination of tilt and decentration may yield aberration contributions which tend to add to or tend to cancel each other.

The purpose of this paper is to establish the quantitative amplitude of image degradation for given small amounts of corrector assembly tilt and decentration, and to show their combined effects when a worst-case addition occurs. These data will provide a basis for establishing mechanical tolerances for corrector assembly alignment maintenance relative to the primary mirror, under operational conditions.

## 2. Initial Alignment: Telescope Collimated with ADC Full-Off

For the purpose of this ray trace experiment, an initial dataset was constructed from all-spherical corrector Run No. 7708 (1/18/89) with a fully implement ADC consisting of a pair of FK5/LLF2 zero-deviation prisms. This dataset was used to compute 5 polychromatic images including equal numbers of rays in 7 colors whose wavelengths are (0.33, 0.35, 0.385, 0.435, 0.52, 0.70, 1.10) microns. The images are located on-axis and at 4 equally spaced locations 20 arcmin from the field center. The numerical system prescription for the on-axis image is given in Table 1.

The ADC was set to its full-off position which would be suitable for observations at the zenith. In that setting it becomes, in effect, a plane parallel plate which is slightly non-orthogonal to the telescope's optic axis. This results in a slight asymmetry in the "collimated" images which can be seen in the spot diagrams shown in Figure 1. The ADC was not articulated during the calculations which follow.

Spot diagrams representing the 5 aforementioned polychromatic images are displayed in Figure 1 to scale. The numbers in parentheses associated with each spot indicate its rms image diameter in arcsec and the percent of rays encircled within 1/4 arcsec centered on the image centroid. The remarkable polychromatic imaging capability of the corrector is well documented by Figure 1.

## 3. Images Degraded by Corrector Assembly Tilt

Next the corrector assembly was tilted about its leading vertex by 1.80 arcmin which resulted in a lateral displacement of the on-axis image by 0.01 arcsec at the detector.

Following that the polychromatic spot diagrams representing all 5 of the previously mentioned images were recalculated. These spot diagrams are displayed in Figure 2. A quantitative comparison of the rms image diameters and the percent of rays encircled within 1/4 arcsec in Figure 1 and Figure 2 reveals that a noticeable, though acceptable amount of image decay has occurred in the outermost image on the righthand side of the figure, in the "direction" of the on-axis image shift. Images in other areas are little affected and even improved slightly in some cases. A detailed comparison of the X average and Y average coordinates of respective image centers of gravity in collimated images in Figure 1 relative to those in Figure 2 reveals that when the corrector assembly is tilted, a complicated pattern of differential image motions occurs relative to the lateral shift of the on-axis image. The maximum amplitude of these relative motions is roughly 0.17 arcsec. These differential image motions can not be "guided out."

These image degradation factors taken together suggest that the corrector assembly tilt should be held to a tolerance of approximately +/- 1.5 arcmin during telescope operation.

## 4. Images Degraded by Corrector Assembly Decentration

Next the corrector assembly tilt was reset to zero and the assembly was then decentered by an amount 0.100 inches. This resulted in a lateral displacement of the on-axis image by 0.45 arcsec at the detector and produced an image decay amplitude approximately equal to that in the prior tilt experiment.

Following that the polychromatic spot diagrams representing all 5 of the previously mentioned images were recalculated. These spot diagrams are displayed in Figure 3. The induced image degradation is very similar in magnitude to that in the tilt experiment, except that the maximum amplitude of the differential image motion is roughly 0.55 arcsec, some 3 times worse than in the tilt experiment. This suggests that the absolute decentration of the corrector assembly should be held to a tolerance of approximately +/- 0.100 inches, and that changes in the decentration should be held to a tolerance of +/- 0.025 inches during telescope operation.

### 5. Images Degraded by Combined Corrector Assembly Tilt and Decentration

Next the decentered corrector assembly was tilted again about its leading vertex by 1.80 arcmin in such a way that the tilt and decentration aberrations added in a worst-case fashion. This resulted in a lateral displacement of the on-axis image by 0.46 arcsec at the detector.

Following that the polychromatic spot diagrams representing all 5 of the previously mentioned images were recalculated. These spot diagrams are displayed in Figure 4. The expected unfavorable addition has produced images which show marginally acceptable 0.42-arcsec rms diameters with scarcely 20% of the rays contained within 1/4 arcsec. The differential image motion seen in a comparison of the X average and Y average coordinates of the collimated and non-collimated images mimics the behavior of the previous case but the maximum amplitude is slightly worse. These results further emphasize that the previously established +/- 1.5-arcmin tilt and +/-0.025-inch decentration tolerances are upper limits to the allowable corrector assembly alignment errors during telescope operation.

### 6. Summary and Conclusions

Corrector assembly motion along the optic axis can be compensated by open loop correction and by dynamic focusing, if necessary, in order to prevent defocus and changes in image scale during telescope operation.

Corrector assembly tilt and decentration will cause minor image degradation effects in the rms image diameters which can add or tend to cancel each other. Tilt is more critical in this regard than decentration. There will be a complicated pattern of differential image motions, relative to the on-axis image, which result from tilt and decentration. Decentration is the dominant factor in this regard.

In practice it will be necessary to maintain corrector assembly alignment to tolerances of approximately +/- 1.5 arcmin in tilt about the leading vertex and +/- 0.025 inches in decentration relative to the primary mirror optical axis during telescope operation. This is required in order to preserve acceptable wide-field polychromatic imaging at the field-corrected f/6.5 Cassegrain.

Respectfully submitted,

Harland

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Consultant in Optical Design

# APPENDIX

## A. Referenced Tables

1. System Prescription: f/6.50 All-Spherical Corrector Run No. 7708 (01/18/89)

## B. Referenced Figures

1. Magellan Telescope: Collimated with ADC Full Off
2. Magellan Telescope: Corrector Assembly Tilted 1.80 Arcmin About Leading Vertex
3. Magellan Telescope: Corrector Assembly Decentered 0.100 Inches
4. Magellan Telescope: Corrector Assembly Tilted 1.80 Arcmin About Leading Vertex and Decentered 0.100 Inches (Worst-Case Addition of Aberrations)

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OPTICAL RAY TRACE RUN----PROGRAM GEOMRAY(04/26/88 VERSION)----EPPS/ASTRONOMY/UCLA

315-INCH F/1.2 PARABOLA WITH F/6.5 WIDE CASS FOCUS          CONTROL DATASET DATE:  3/ 2/89

   RAPERT     XSMAPR     ROBSTR     XSMOBS     XSMAX1     YSMAX1     XSMAX2     YSMAX2     XCENTR     YCENTR
  157.500      0.000     50.000      0.000    157.500    157.500      0.000      0.000      0.000      0.000

   XEGMAX     XEGMIN     YEGMAX     YEGMIN     SCALES      SCINC        REF      PIXEL
    0.000      0.000      0.000      0.000     1.0000      84.00       84.0       63.0

   NOS   NSHOW NVIEWS NSTEPS  NDISP  NTILT NAPERT NOBSTR   MMT   KECK  NEDGX  NEDGY  NOTES INTENS NOYRMS NOAXES NODATA NOPLOT
   14     15      1      0      0      5      1      1      0      0      0      0     18      1      0      0      0      1

   LAS CAMPANAS 315-INCH TELESCOPE      CURVED (R= -161.11-INCH) F.O.V.
   WITH AN F/1.2 PARABOLIC PRIMARY.
   NAKED (B=+79.33 IN) CASS FOCUS       COLOR CORRECTED 0.33 TO 1.10 MI.
   IS F/6.242, CORRECTED TO F/6.50.     40.0-ARCMIN FULL FIELD DIAMETER.

   THIS ALL-SPHERICAL CORRECTOR HAS     RUN NO. 7708 (01/18/89).
   3 QUARTZ LENS ELEMENTS, TWO (2)
   FK5/LLF2 ZERO-DEVIATION PRISMS       (ADC) IS 'FULL-OFF' IN THIS RUN.
   FOR ATMOSPHERIC DISP COMP (ADC)
   DOWN TO Z=60.0 DEGREES, AND A

 WAVELENGTH =  3300.0 ANGSTROMS

 OBJECT LOCATION OR FIELD ANGLE INPUT DATA                OBJECT SPACE INDEX= 1.000000    FOCUS STEP=  0.0010 (INCHES)

    1)  OBJECT AT INFINITY   ZETA=      0.000 (DEGREES)    GAMMA=     0.000 (ARC MIN)

 SURFACE  THICKNESS     INDEX      CURVATURE        A2              A4               A6               A8               A10
    1     -304.3526  -1.000000  -0.001322751   -1.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
    2      307.1987   1.000000  -0.005476749   -2.17858660   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   -3        0.0000   1.000000   0.000000000    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
    4        3.5000   1.480591   0.038849651    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
    5        4.0684   1.000000   0.033240927    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
    6        1.1092   1.480591   0.022913295    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
    7        6.0000   1.000000   0.040870968    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
    8        1.2000   1.510276   0.000000000    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
    9        0.7000   1.583105   0.000000000    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
  -10        0.7000   1.583105   0.000000000    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   11        1.2000   1.510276   0.000000000    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   12        1.6766   1.000000   0.000000000    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   13        1.7840   1.480591  -0.002799818    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   14       55.2114   1.000000  -0.009961576    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
  FOCAL                         -0.006206971    0.00000000   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00

 SYSTEM OPTIC AXIS AND COLLIMATION CHARACTERISTICS

    THE OPTIC AXIS IS DIVERTED AS FOLLOWS...  LENGTHS IN (INCHES)  ANGLES IN (DEGREES)

       SURFACE     XPVOT        YPVOT        ALPHA        BETA          ZROT
          7       0.0000       0.0000      0.000000     0.000000     90.000000
         10       0.0000       0.0000      0.000000     0.000000   -180.000000
         12       0.0000       0.0000      0.000000     0.000000     90.000000

    TILTED SURFACE(S) WILL APPEAR AS FOLLOWS...  ANGLES IN (ARC MIN)
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Table 1

```
SURFACE     THETA         PHI      NUMTH     THINC    NUMPHI     PHIINC
   2        0.0000       0.0000      0       0.0000      0       0.0000
   8       -6.1140       0.0000      0       0.0000      0       0.0000
   9       52.2690       0.0000      0       0.0000      0       0.0000
  11      -52.2690       0.0000      0       0.0000      0       0.0000
  12        6.1140       0.0000      0       0.0000      0       0.0000
```

MAGELLAN TELESCOPE
COLLIMATED WITH ADC FULL OFF

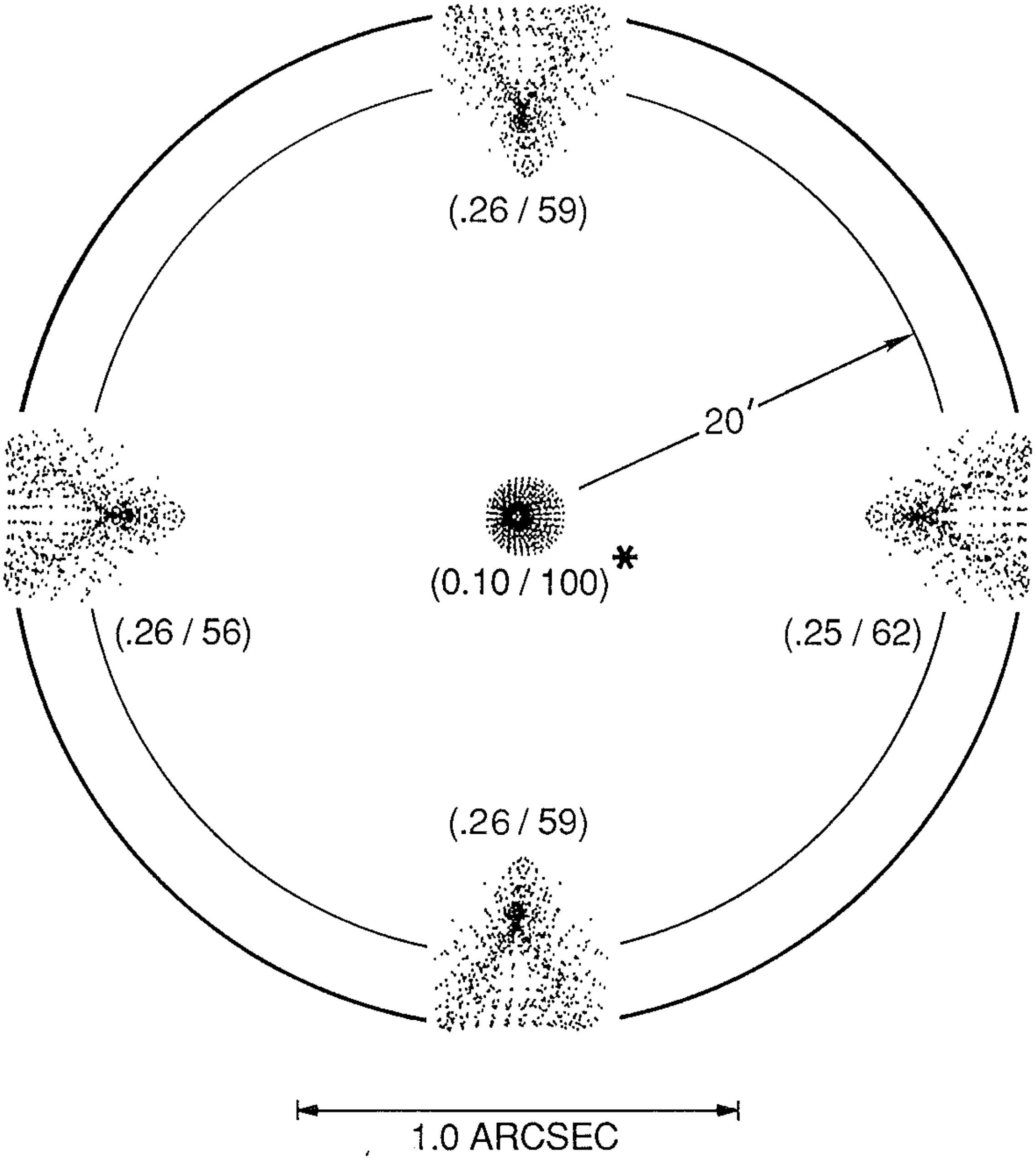

**Figure 1**

EPPS/ASTRONOMY/UCLA
CORRECTOR RUN NO. 7708 (1/18/89)
*{RMS IMAGE DIAMETER (ARCSEC)
{RAYS WITHIN 1/4 ARCSEC (%)
POLYCHROMATIC: WL'S = .33, .35, .385, .435,
.52, .70, 1.10 MICRONS

# MAGELLAN TELESCOPE
# CORRECTOR ASSEMBLY COLLIMATION
## (TILT = 1.80 arcmin; DISPLACEMENT = 0.0 inches)

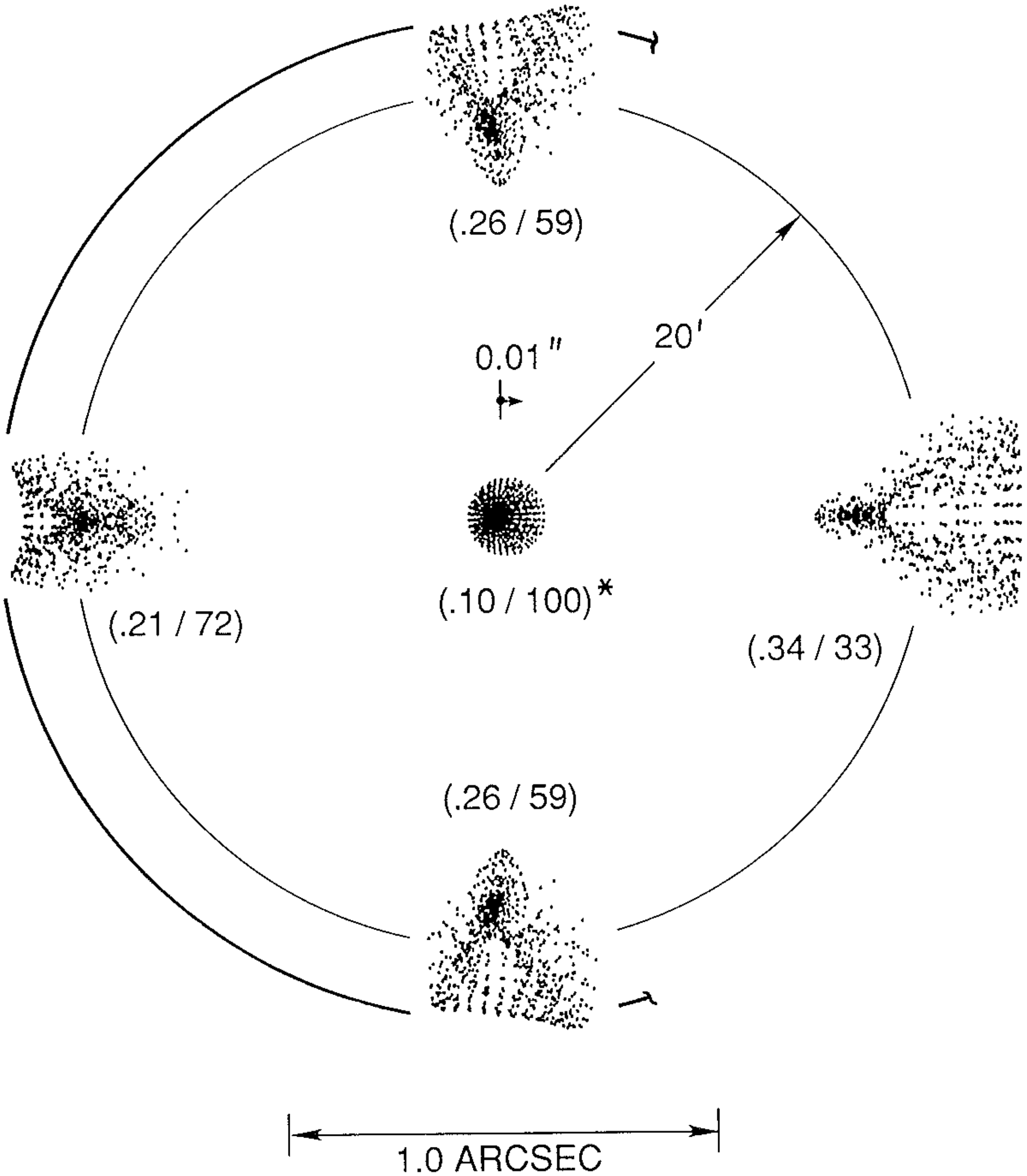

**Figure 2**

EPPS/ASTRONOMY/UCLA
CORRECTOR RUN NO. 7708 (1/18/89)
* {RMS IMAGE DIAMETER (ARCSEC)
{RAYS WITHIN 1/4 ARCSEC (%)
POLYCHROMATIC: WL'S = .33, .35, .385, .435,
.52, .70, 1.10 MICRONS

## MAGELLAN TELESCOPE
## CORRECTOR ASSEMBLY COLLIMATION
### (TILT = 0.0 arcmin; DISPLACEMENT = 0.100 inches)

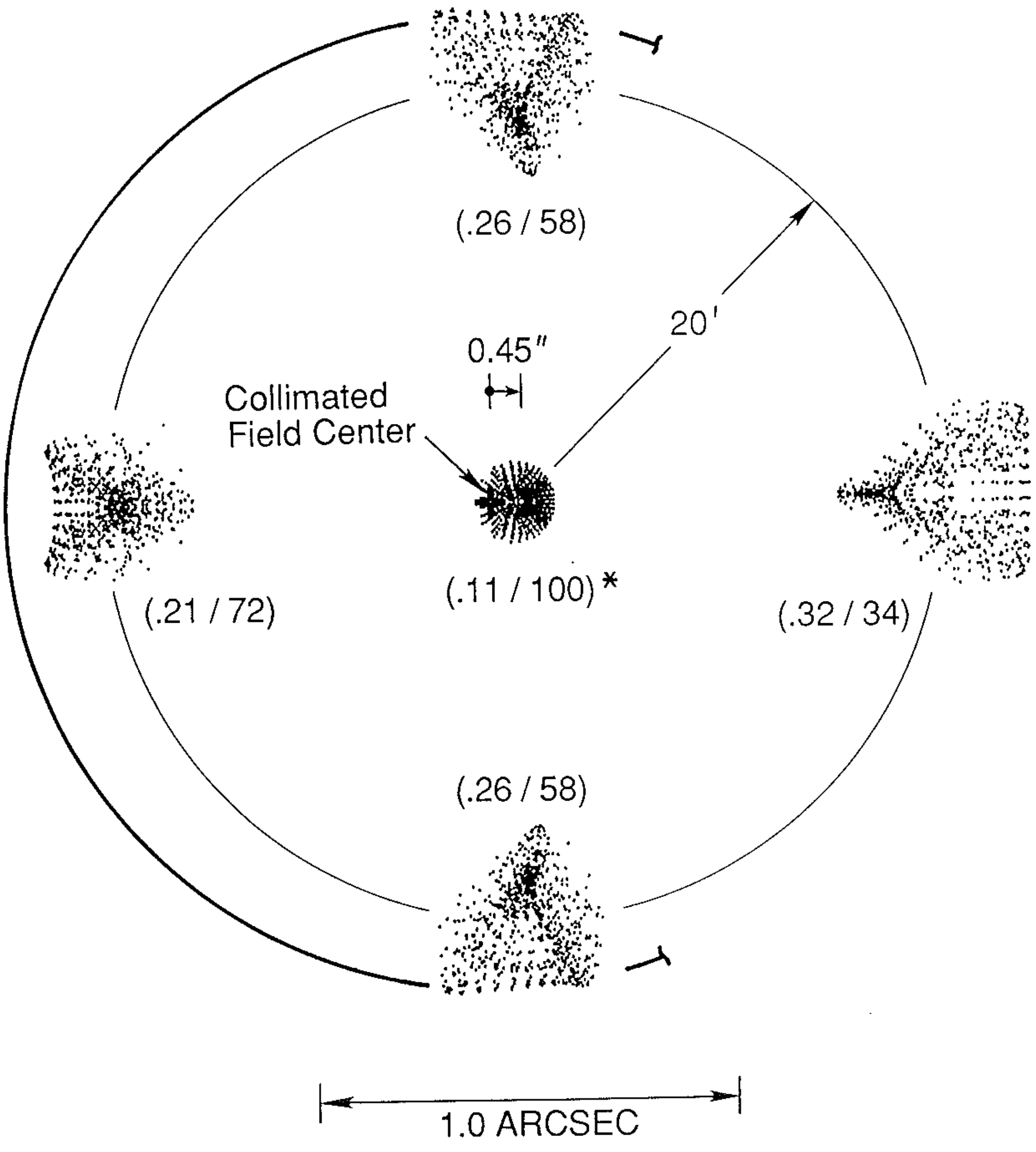

**Figure 3**

EPPS/ASTRONOMY/UCLA
CORRECTOR RUN NO. 7708 (1/18/89)
* { RMS IMAGE DIAMETER (ARCSEC)
RAYS WITHIN 1/4 ARCSEC (%)
POLYCHROMATIC: WL'S = .33, .35, .385, .435,
.52, .70, 1.10 MICRONS

## MAGELLAN TELESCOPE
## CORRECTOR ASSEMBLY COLLIMATION
### (TILT = 1.80 arcmin; DISPLACEMENT = 0.100 inches)

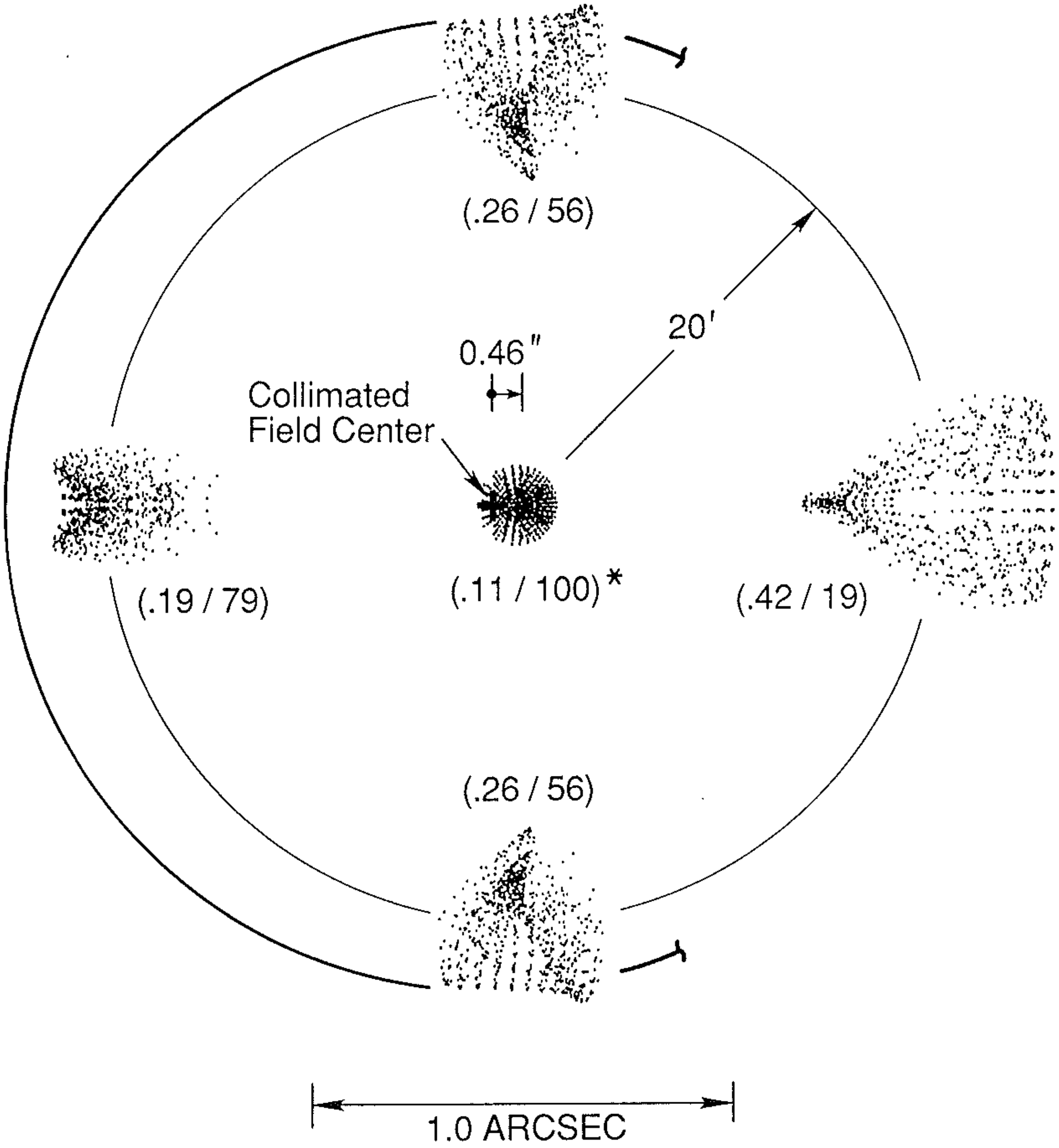

**Figure 4**

EPPS/ASTRONOMY/UCLA
CORRECTOR RUN NO. 7708 (1/18/89)
*{ RMS IMAGE DIAMETER (ARCSEC)
RAYS WITHIN 1/4 ARCSEC (%)
POLYCHROMATIC: WL'S = .33, .35, .385, .435,
.52, .70, 1.10 MICRONS