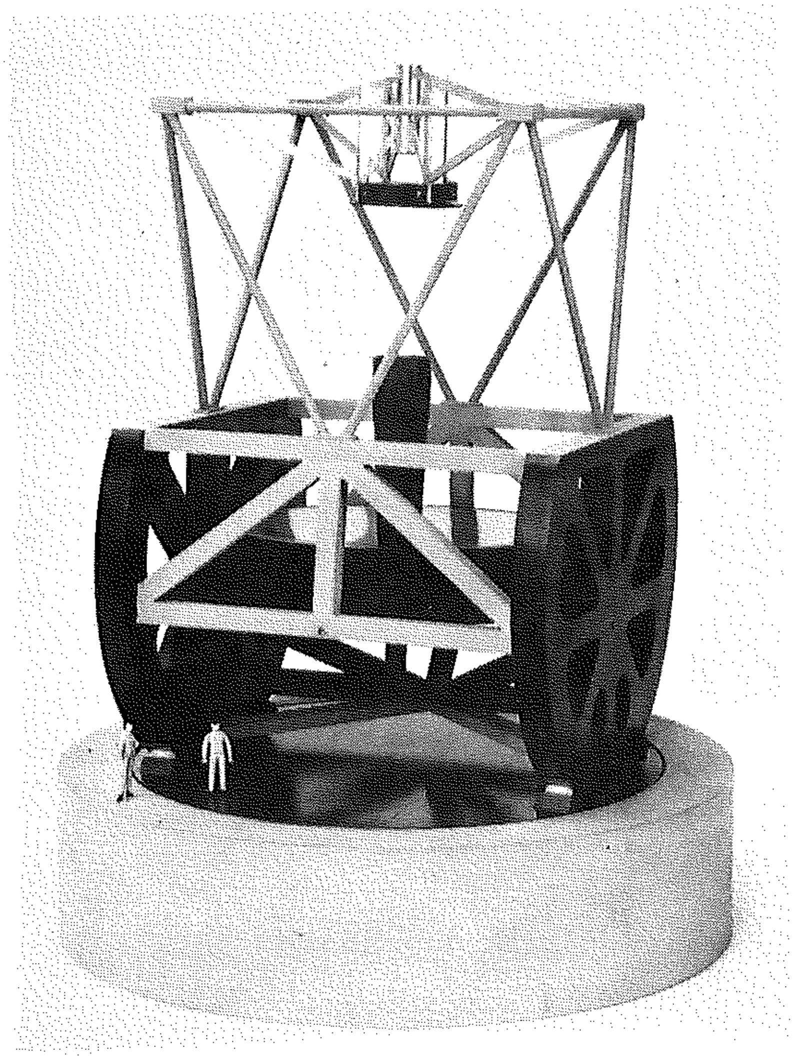

Secondary Mirror Decollimation Effects in the Magellan Wide-Field f/6.5 Cassegrain

Harland W. Epps
The Observatories
Carnegie Institution of Washington
Pasadena, California

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CONTENTS

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.

It is anticipated that differential thermal effects and mechanical flexures within the telescope structure will cause the secondary mirror to become tilted and or displaced relative to the primary mirror optical axis. Displacement along the optic axis will cause a focus shift and slight image scale change. However these effects can 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 variation of gravity loading. It will be possible to make open-loop corrections for this by table look-up.

The transverse components of secondary mirror displacement (called decentration) as well as any secondary mirror tilt about its vertex will cause the image quality to degrade. The leading aberration term will add comatic effects, similar to classical 3rd order transverse coma but roughly independent of position in the field of view. 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 secondary mirror 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 secondary mirror alignment maintenance 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 Secondary Mirror Tilt

Next the secondary mirror was tilted about its vertex by 0.21870 arcmin which resulted in a lateral displacement of the on-axis image by 5.000 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. The expected induced coma is apparent in the central image and is present in all the others as well. However 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, particularly with regard to the percent of rays encircled within 1/4 arcsec. Thus it is established that secondary mirror tilt should be held to a tolerance of approximately +/- 0.22 arcmin during telescope operation.

4. Images Degraded by Secondary Mirror Decentration

Next the secondary mirror tilt was reset to zero and the mirror was then decentered by an amount -0.005 inches. This resulted in a lateral displacement of the on-axis image by 2.09 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 coma is very similar in magnitude to that in the tilt experiment and thus indicates that secondary mirror decentration should be held to a tolerance of +/- 0.005 inches during telescope operation.

5. Images Degraded by Combined Secondary Mirror Tilt and Decentration

Next the decentered secondary mirror was tilted again by 0.2187 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 7.09 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 0.44-arcsec rms diameters with scarcely 25% of the rays contained within 1/4 arcsec. These results further emphasize that the previously established +/- 0.22-arcmin and +/- 0.005-inch tilt and decentration tolerances are upper limits to the allowable secondary mirror alignment errors during telescope operation.

6. <u>Summary of Conclusions</u>

Secondary mirror 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.

Secondary mirror tilt and decentration will cause coma-like image degradation effects which can add or tend to cancel each other. In practice it will be necessary to maintain secondary mirror alignment to tolerances of +/- 0.22 arcmin in tilt about the vertex and +/- 0.005 inches in decentration relative to the primary mirror optical axis. This is required in order to preserve acceptable wide-field polychromatic imaging at the field corrected f/6.5 Cassegrain.

Respectfully submitted,

Harland.

Harland W. Epps, Ph.D.
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: Secondary Mirror Tilted 0.22 Arcmin
3. Magellan Telescope: Secondary Mirror Decentered -0.005 Inches
4. Magellan Telescope: Secondary Mirror Tilted 0.22 Arcmin and Decentered -0.005 Inches (Worst-Case Addition of Aberrations)

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: 4/25/89

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
13	14	1	0	0	5	1	1	0	0	0	0	18	1	0	0	0	1

LAS CAMPANAS 315-INCH TELESCOPE
WITH AN F/1.2 PARABOLIC PRIMARY.
NAKED (B=+79.33 IN) CASS FOCUS
IS F/6.242, CORRECTED TO F/6.50.

THIS ALL-SPHERICAL CORRECTOR HAS
3 QUARTZ LENS ELEMENTS, TWO (2)
FK5/LLF2 ZERO-DEVIATION PRISMS
FOR ATMOSPHERIC DISP COMP (ADC)
DOWN TO Z=60.0 DEGREES, AND A

CURVED (R= -161.11-INCH) F.O.V.

COLOR CORRECTED 0.33 TO 1.10 MI.
40.0-ARCMIN FULL FIELD DIAMETER.

RUN NO. 7708 (01/18/89).

(ADC) IS 'FULL-OFF' IN THIS RUN.

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	3.5000	1.480591	0.038849651	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
4	4.0684	1.000000	0.033240927	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
5	1.1092	1.480591	0.022913295	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
6	6.0000	1.000000	0.040870968	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
7	1.2000	1.510276	0.000000000	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
8	0.7000	1.583105	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	1.2000	1.510276	0.000000000	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
11	1.6766	1.000000	0.000000000	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
12	1.7840	1.480591	-0.002799818	0.00000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
13	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
6	0.0000	0.0000	0.000000	0.000000	90.000000
9	0.0000	0.0000	0.000000	0.000000	-180.000000
11	0.0000	0.0000	0.000000	0.000000	90.000000

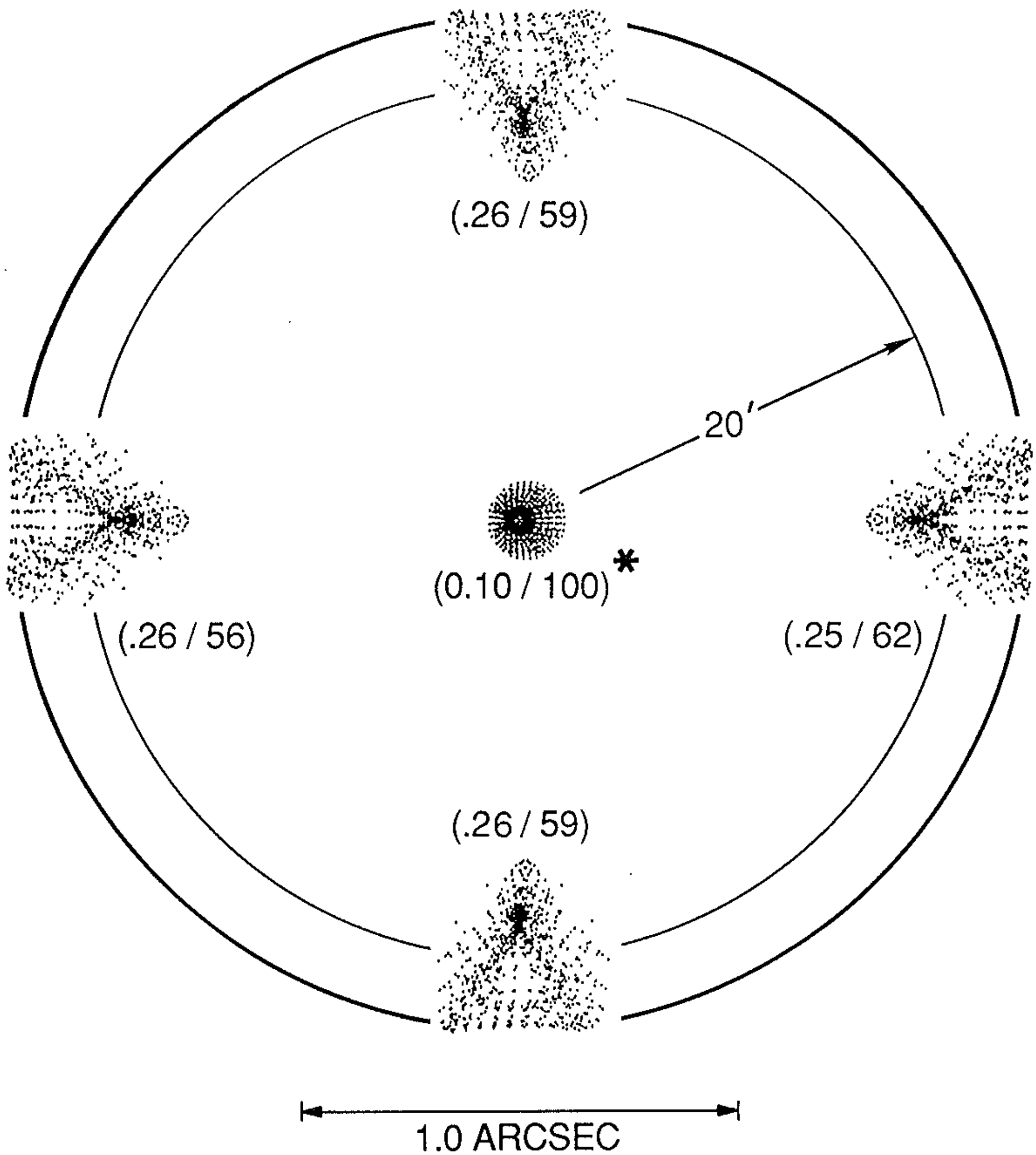
TILTED SURFACE(S) WILL APPEAR AS FOLLOWS... ANGLES IN (ARC MIN)

SURFACE	THETA	PHI	NUMTH	THINC	NUMPHI	PHIINC

Table 1

2	0.0000	0.0000	0	0.0000	0	0.0000
7	-6.1140	0.0000	0	0.0000	0	0.0000
8	52.2690	0.0000	0	0.0000	0	0.0000
10	-52.2690	0.0000	0	0.0000	0	0.0000
11	6.1140	0.0000	0	0.0000	0	0.0000

MAGELLAN TELESCOPE
COLLIMATED WITH ADC FULL OFF



EPPS/ASTRONOMY/UCLA

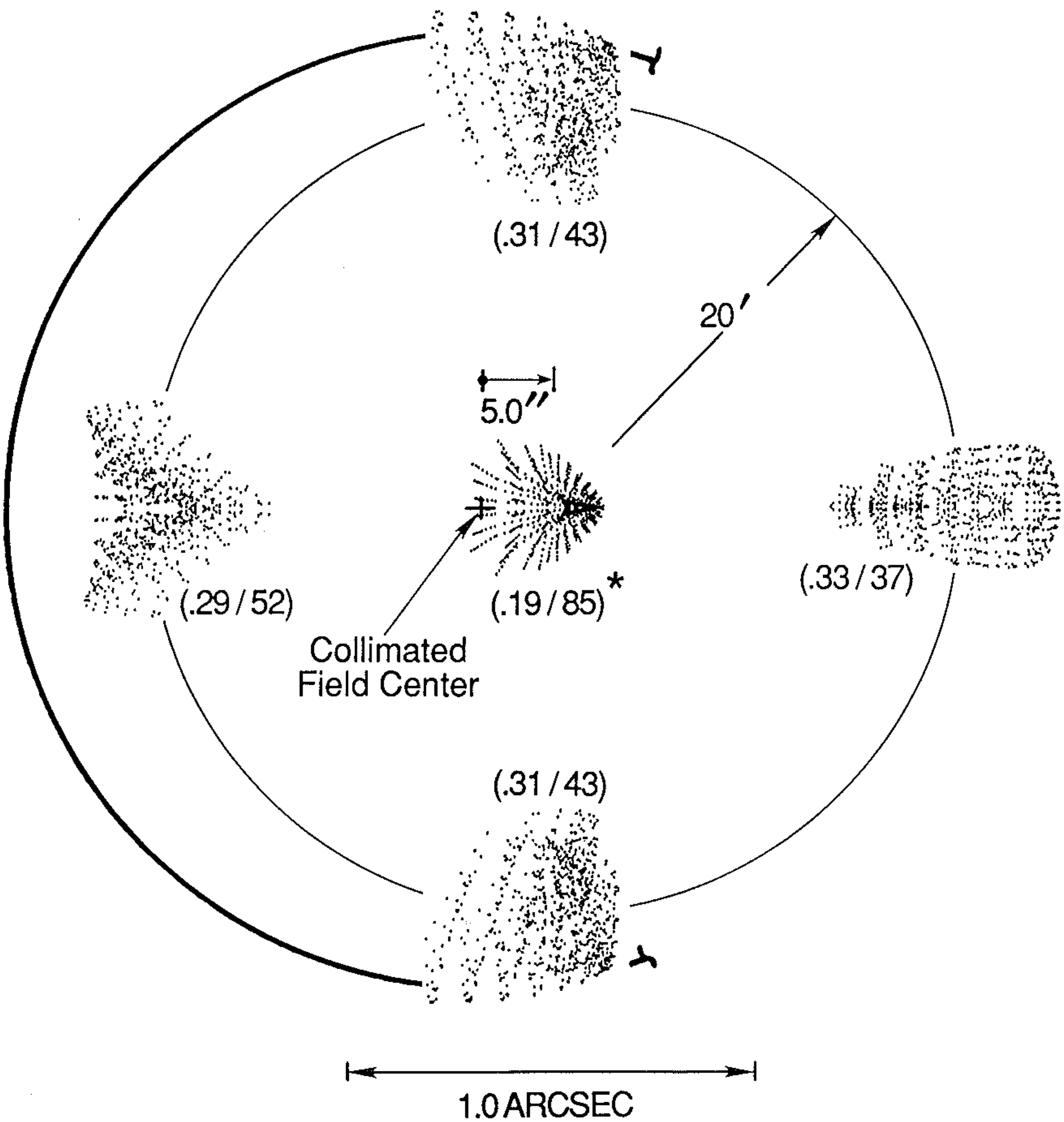
CORRECTOR RUN NO. 7708 (1/18/89)

* { RMS IMAGE DIAMETER (ARCSEC)
RAYS WITHIN 1/4 ARCSEC (%) }

POLYCHROMATIC: WL'S = .33, .35, .385, .435, .52, .70, 1.10 MICRONS

Figure 1

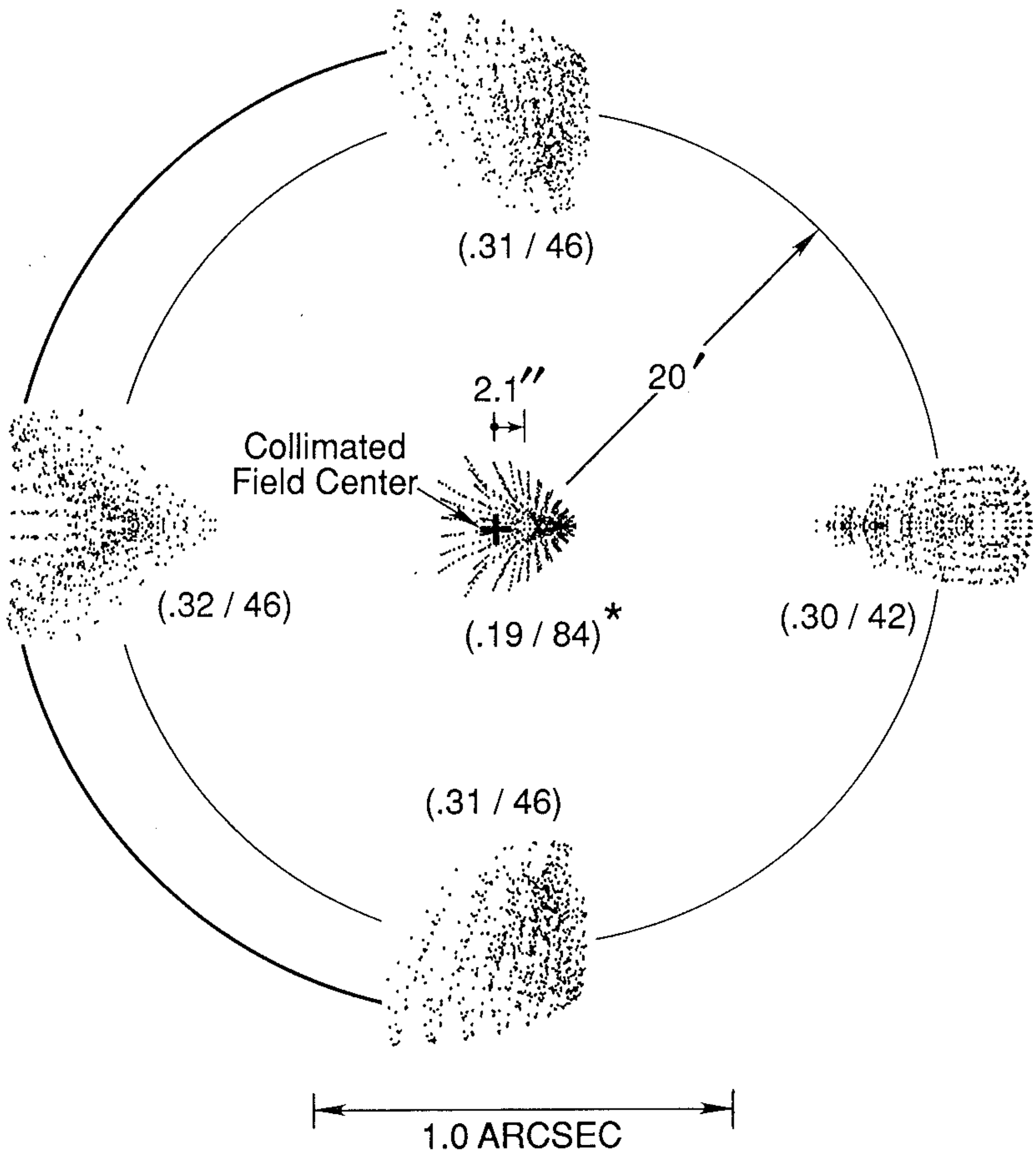
MAGELLAN TELESCOPE
SECONDARY MIRROR COLLIMATION
(TILT = 0.22 arcmin; DISPLACEMENT = 0.0 inches)



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

Figure 2

MAGELLAN TELESCOPE
SECONDARY MIRROR COLLIMATION
(TILT = 0.0 arcmin; DISPLACEMENT = 0.005 inches)



EPPS/ASTRONOMY/UCLA

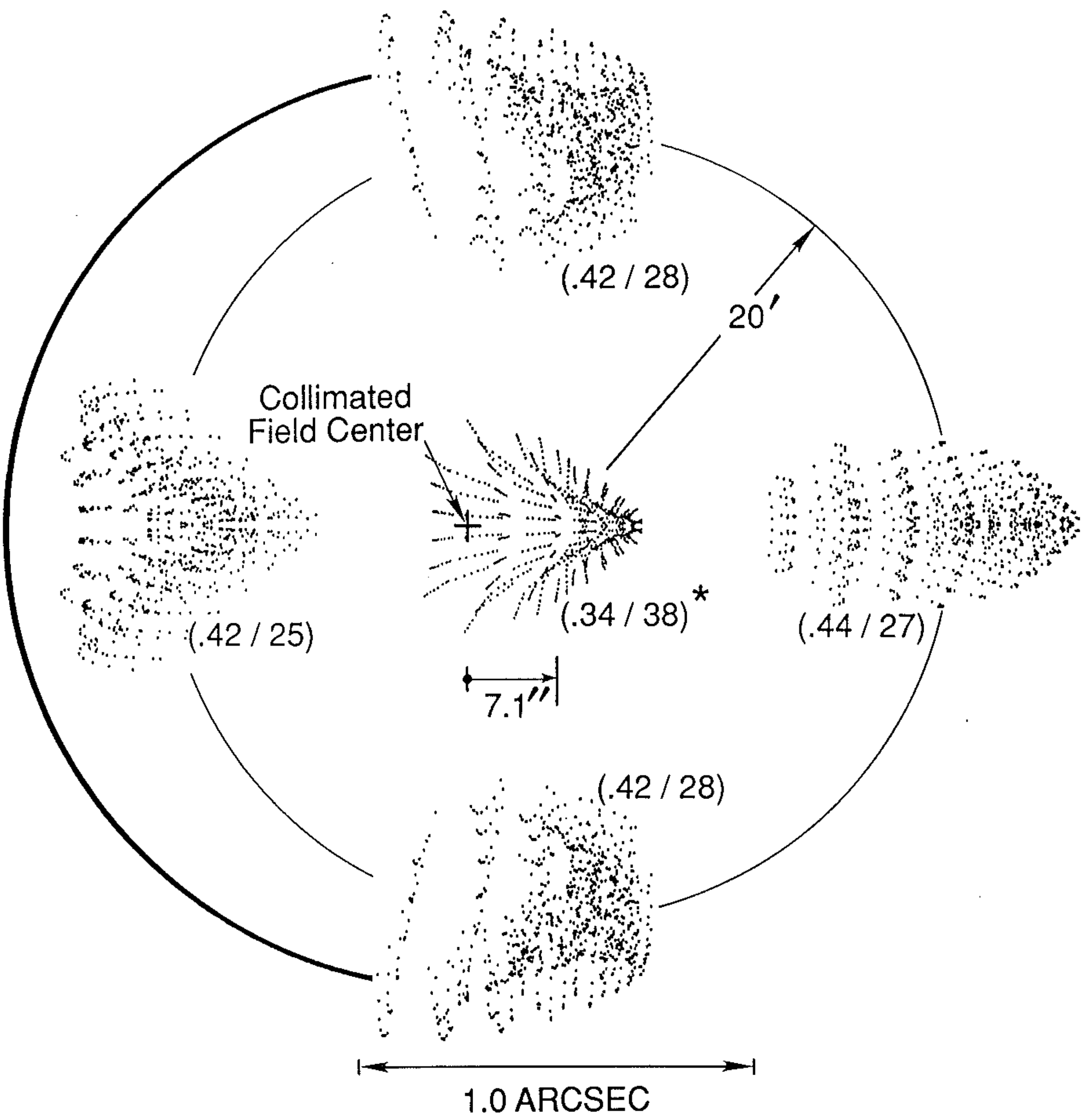
Figure 3

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
SECONDARY MIRROR COLLIMATION
(TILT = 0.22 arcmin; DISPLACEMENT = 0.005 inches)



EPPS/ASTRONOMY/UCLA

Figure 4

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