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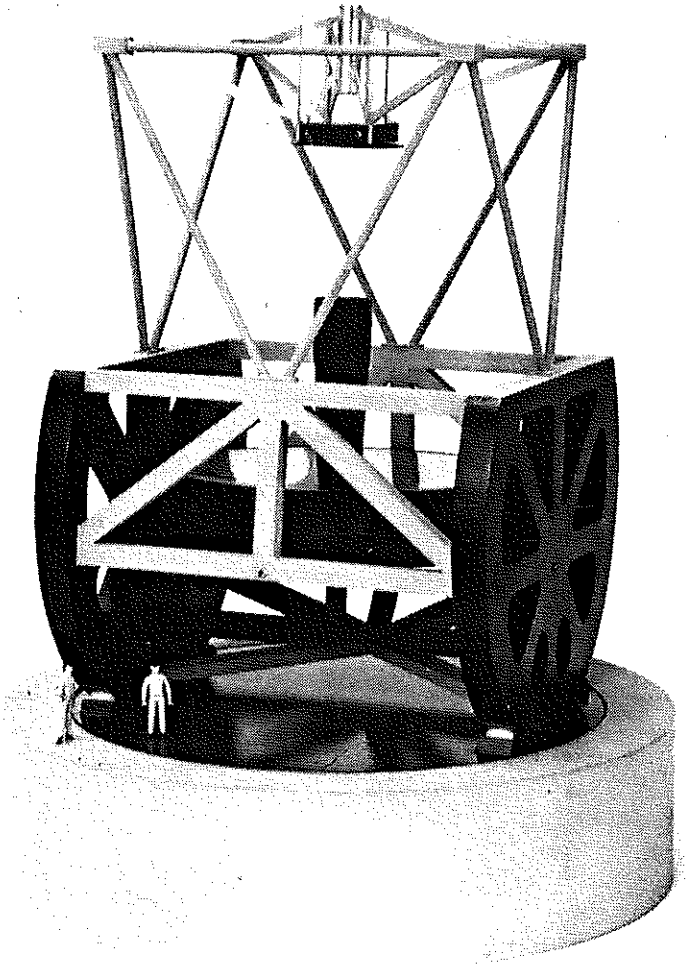

Fine Guiding by Secondary Mirror Tilt in the Magellan Wide-Field f/6.50 Cassegrain

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 as well as tracking rate errors and differential refraction will contribute overall apparent tracking errors whose amplitudes may be in the order of a few arcsec as the telescope follows a particular field for an exposure time in the order of a few hours. Some of these errors can be compensated on a time scale of minutes by open-loop table look up methods. The remainder would normally be "guided out" by actual differential motions of the whole telescope structure.

The purpose of this paper is to explore the possibility of "guiding" by tilting the secondary mirror with mechanisms which must be present in its mounting anyway for other purposes such as accurate collimation adjustment. If so, one could imagine allowing the secondary to make small fine guiding adjustments with perhaps a 2 to 3 Hertz time constant. These could be integrated and compensated "in reverse" by the telescope structure such that the secondary would always be seeking its "nominal" collimated settings on a much longer time scale.

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. 3.0-Arcsec Tracking Error Compensated by Secondary Mirror Tilt

Next, a 3.0-arcsec tracking error in the left-right direction (on the Figures) was introduced. This was compensated by tilting the secondary mirror by 0.13122 arcmin in such a way that the central image returned exactly to its original position. Thus, in effect, the central image was used as a "guide star."

Following that the polychromatic spot diagrams representing all 5 of the previously mentioned images were recalculated with no further adjustments of any kind. 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 percentage of rays encircled within 1/4 arcsec in Figure 1 and Figure 2 reveals that the secondary mirror tilt introduced for fine guiding purposes has not appreciably affected the actual image quality anywhere in the field of view.

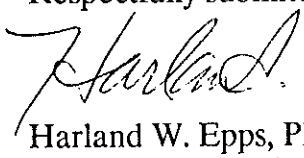
Furthermore a detailed image by image comparison of the image centroid locations before and after the 3.0-arcsec tracking error was introduced and then compensated by tilt of the secondary mirror reveals that in all cases the image centroids remain the same to a precision of +/- 0.001 arcsec.

4. Summary of Conclusions

Additional calculation revealed that the linear derivative representing the ratio of secondary mirror tilt angle to tracking error angle (0.043740 arcmin per arcsec) can be used to compensate tracking errors as great as 10 arcsec. The image centroids behave properly to a precision of +/- 0.003 arcsec, however the image quality begins to degrade appreciably. Extending this fine guiding method beyond a 10-arcsec amplitude would not be well advised.

The imaging shown in Figure 1 and Figure 2 fully supports the idea of fine guiding by secondary mirror tilt, even under the conditions of very best seeing, providing the integrated secondary mirror tilt amplitude does not exceed 3.0 arcsec or perhaps a bit more depending on the observer's discretion. If this method is used, it will be necessary to monitor the instantaneous secondary mirror tilt relative to the nominal "collimated" settings and to compensate on a longer time scale by changing telescope drive rates and other parameters such that the secondary mirror always tends to seek its nominal (0.0 arcsec tilt-amplitude) position.

Respectfully submitted,



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: 3.0-Arcsec Secondary-Compensated Tracking Error

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

Table 1

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
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

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

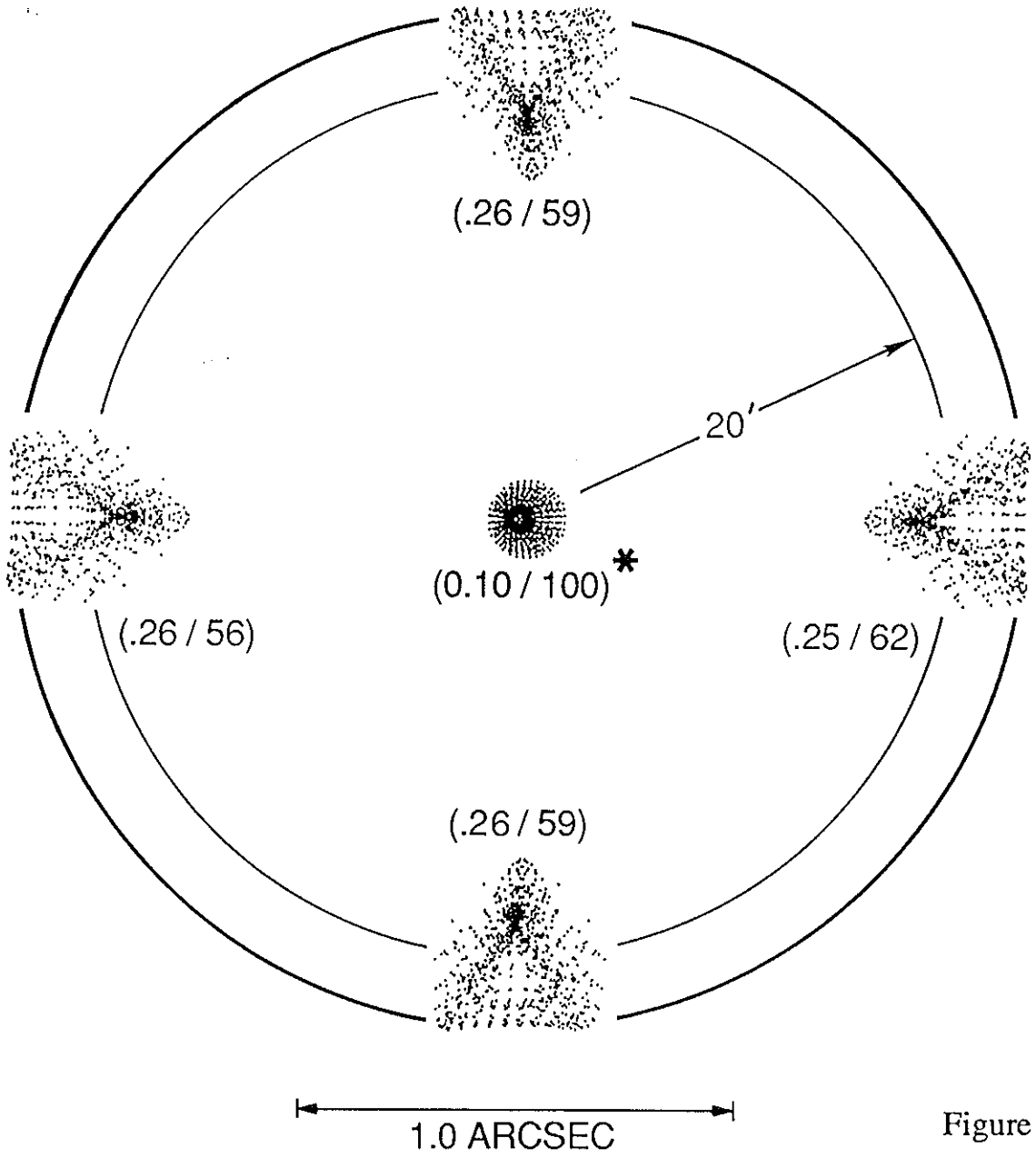


Figure 1

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
3.0 – ARCSEC SECONDARY –
COMPENSATED TRACKING ERROR

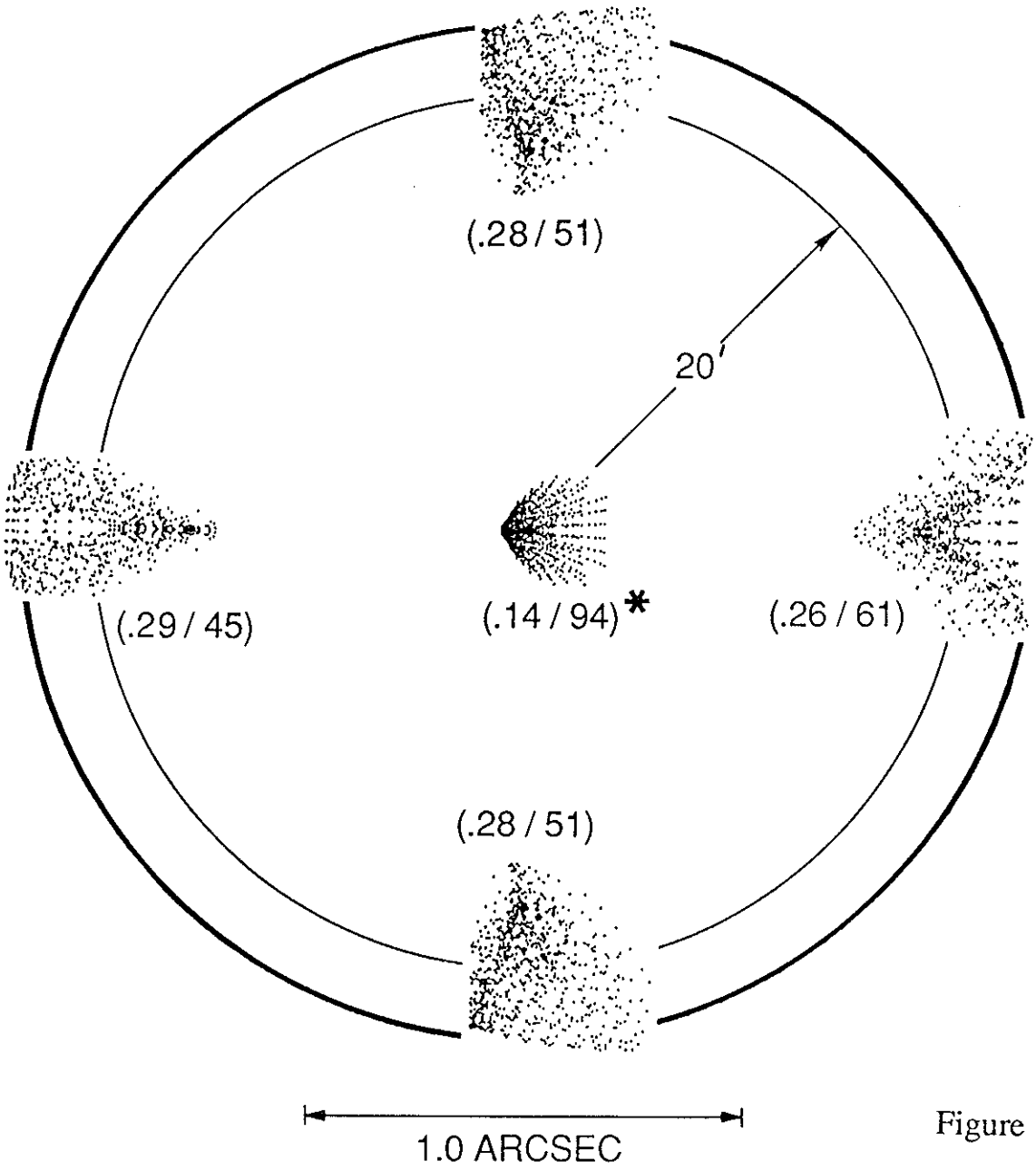


Figure 2

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
ALL IMAGE CENTERS OF GRAVITY REPEAT COLLIMATED
VALUES TO A PRECISION OF +/– 0.001 ARCSEC