MMTO Conversion Technical Memorandum #00-4

MMT Observatory

Smithsonian Institution &
The University of Arizona®

Expected Wavefront Errors Due to f/5 Secondary Test Plate

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1. Summary

I have estimated the errors in measurement of the MMT f/5 secondary mirror due to figure errors in the test plate. The largest component of measurement error is the combination of slope errors in the test plate and mapping error, a misregistration between pixels in the measurements of the secondary and the test plate. For a conservative estimate of mapping errors, 1% of the mirror radius, the resulting error in the secondary figure over the full mirror amounts to at worst half the specification. The error drops to 40% of the specification when evaluated over the 1.636 m diameter corresponding to a 35 arcminute field. Errors will be further reduced by averaging over several orientations of the test plate. This is an acceptable level of uncertainty in the measurement of the secondary.

2. Background

The accuracy of measurements of the f/5 secondary mirror depends on the accuracy of the holographic test plate, and is limited by two types of errors in the test plate: the computer-generated hologram and the figure of the test plate. Since we measure the figure of the test plate, and subtract it from the measurement of the secondary, this error cancels to first order. The main source of residual error comes from mapping errors in the measurement of the test plate relative to the measurement of the secondary. These mapping errors, in the form of magnification, decenter, rotation and distortion, cause us to subtract incorrect wavefront errors from the apparent secondary figure. The wavefront error is the scalar product of the slope error in the test plate (nm/mm) and the mapping error (mm).

A similar situation exists in measurements of the primary mirror, in which errors in the null lens are measured with a computer-generated hologram, and subtracted from the apparent figure error in the primary. But residual errors are likely to be worse in the case of secondary mirrors, both because the errors to be measured and subtracted are larger for secondaries, and because the test plate is measured with a separate interferometer, with independent magnification, centration, rotation and distortion.

We determine the mapping by placing markers at known locations on the test plate. Their positions in the two images are marked and used to determine the mapping relation. We expect to achieve an accuracy better than 1% of the mirror radius, or 9 mm. Previous measurements have had a resolution of only about 200 points across the mirror, but the new system supports the full resolution of the CCD camera, up to 480 points.

3. Analysis

I simulated mapping errors of three forms—magnification, decenter and rotation—and calculated the resulting wavefront structure function. (Because the worst slope errors are near the edge of the test plate, axisymmetric distortion—which peaks near the 50% zone and is zero by definition at the edge—

would be less serious than a magnification error of the same magnitude.) I did this for the most recent measurement of the test plate, made at the Optical Sciences Center with the same measuring system we will use at the Mirror Lab. The resolution is 375 pixels across the 1.72 m clear aperture of the test plate (matching the full diameter of the secondary). For this measurement, weights were placed around the perimeter of the test plate to correct astigmatism and other large-scale errors in its relaxed figure. I calculated the structure function for the full 1.72 m diameter, and for a diameter of 1.636 m which is used for a 35 arcminute field.

I determined the effect of mapping errors by resampling the data with and without the mapping errors. I resampled the 375×375 data onto a 172×172 grid (1 cm spacing) using bilinear interpolation.

4. Results

4.1 Errors over the full diameter

The first set of results is for errors evaluated over the 1.72 m clear aperture of the test plate, equal to the full diameter of the secondary. The central 0.25 m diameter is obscured. Figure 1 shows the structure function of the test plate. This is not directly relevant, but gives an idea of the magnitude of errors that must be corrected.

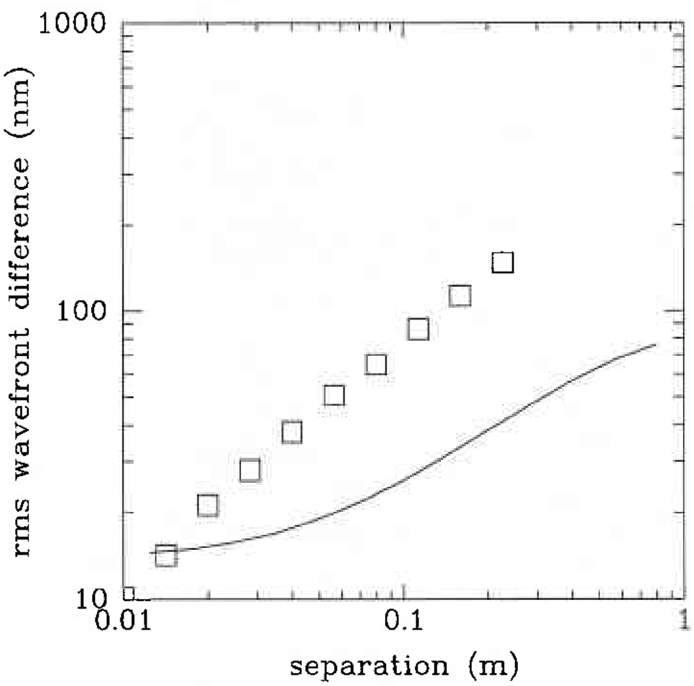

Figure 1. Structure function for the test plate, evaluated over its 1.72 m clear aperture.

For Figure 2, I introduced an error of 1% in magnification. Shown are the measured figure with and without the mapping error, and the difference amplified by a factor of 10. In this and all similar figures, the grayscale spans 1 micron peak-to-valley for the measured wavefronts and 100 nm for the difference. The vertical ripples in the difference map may be an artifact of the resampling. Figure 3 shows the structure function of the difference along with the structure function specification for the secondary mirror. The specification is for an atmosphere with 0.022 arcsecond seeing (FWHM) and a scattering loss of 1.5% at 500 nm, and the usual elimination of global tilt.

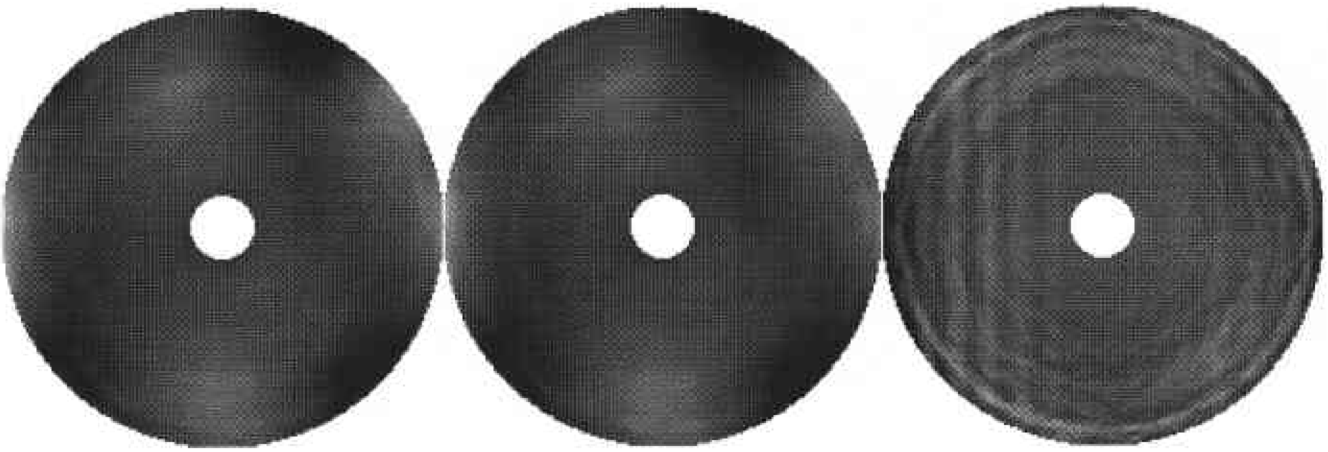

Figure 2. Wavefront error caused by a mapping error of 1% in magnification. From left to right: test plate wavefront without mapping error, test plate wavefront with mapping error, and difference. The aperture shown has an OD of 1.72 m and ID of 0.25 m. The grayscale is 1 micron peak-to-valley for the measured wavefronts and 100 nm for the difference.

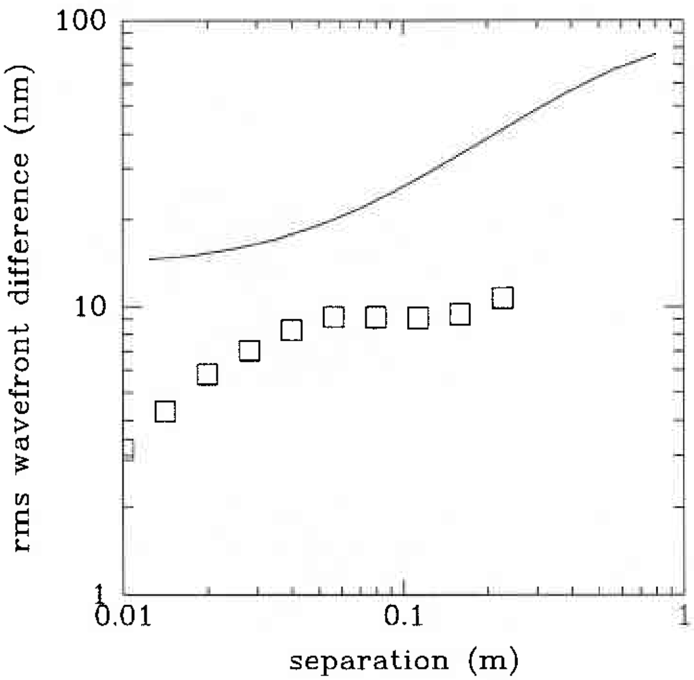

Figure 3. Structure function for the difference map for a 1% magnification error, over the 1.72 m clear aperture of the test plate.

Figures 4 and 5, and 6 and 7, show the results for mapping errors of 9 mm decenter in x and y. Figures 8 and 9 show the results for a mapping error of 0.01 rad rotation.

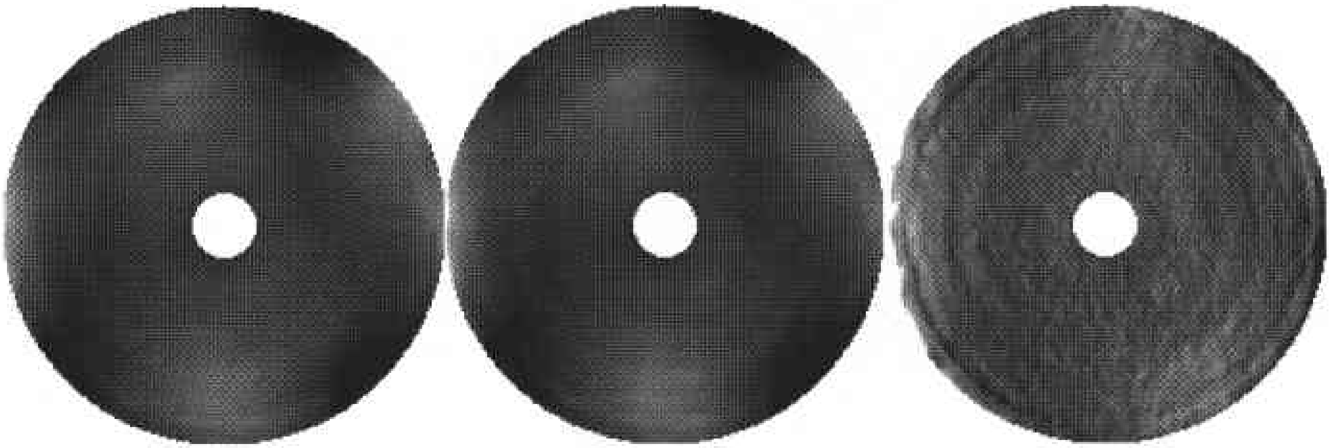

Figure 4. Wavefront error caused by a mapping error of 9 mm decenter in x. Format is the same as Figure 2.

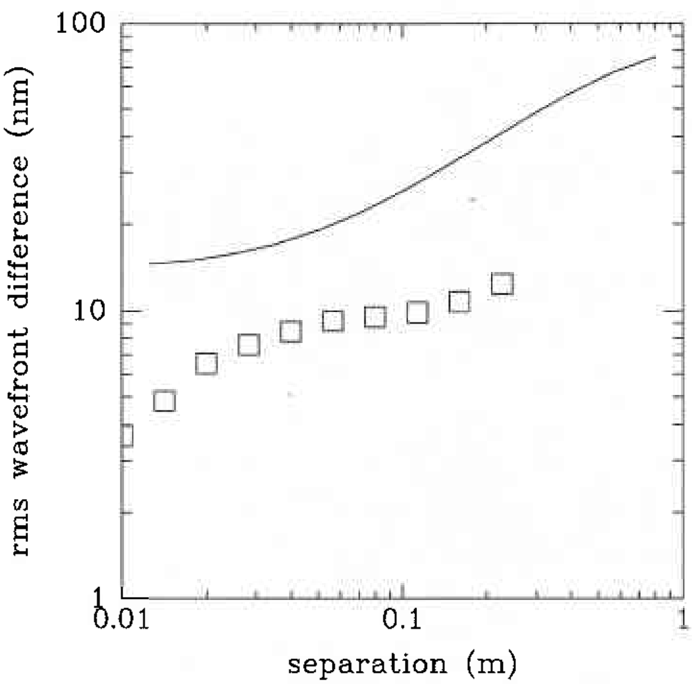

Figure 5. Structure function for the difference map for a 9 mm decenter in x, over the 1.72 m clear aperture of the test plate.

4.2 Errors over the diameter used for a 35 arcminute field

I evaluated the same quantities over the 1.636 m diameter used for a 35 arcminute field of view. Figure 10 shows the structure function of the test plate. Figures 11-14 show the structure functions for the mapping errors. The wavefront maps are not repeated, as they are just trimmed versions of the 1.72 m maps.

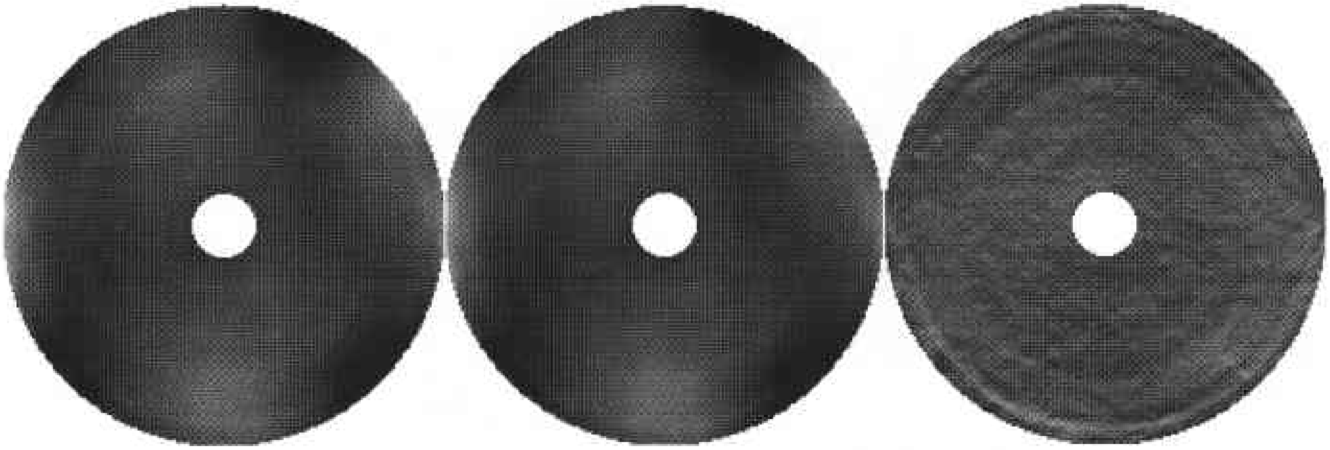

Figure 6. Wavefront error caused by a mapping error of 9 mm decenter in *y*. Format is the same as Figure 2.

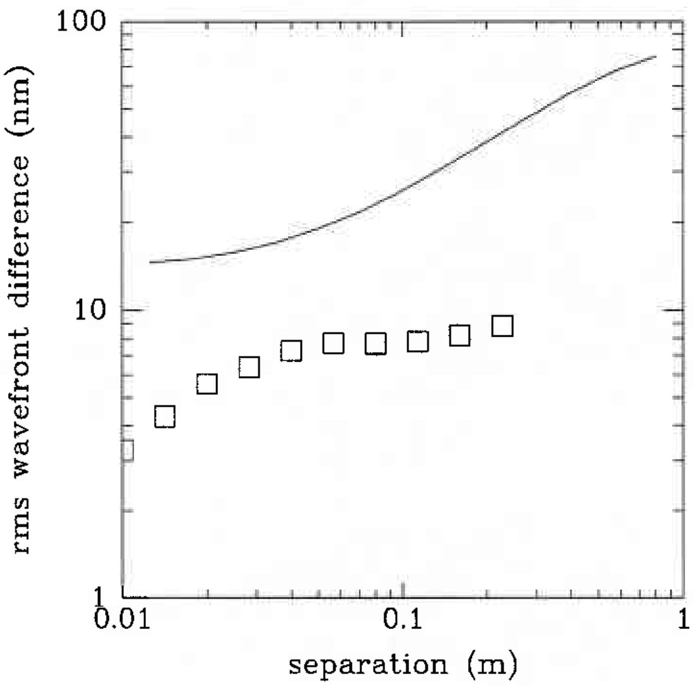

Figure 7. Structure function for the difference map for a 9 mm decenter in *y*, over the 1.72 m clear aperture of the test plate.

5. Conclusion

The dominant error anticipated in the measurement of the f/5 secondary will be less than half the secondary specification at all spatial scales. This level of uncertainty in the measurement will not add significantly to the final figure error.

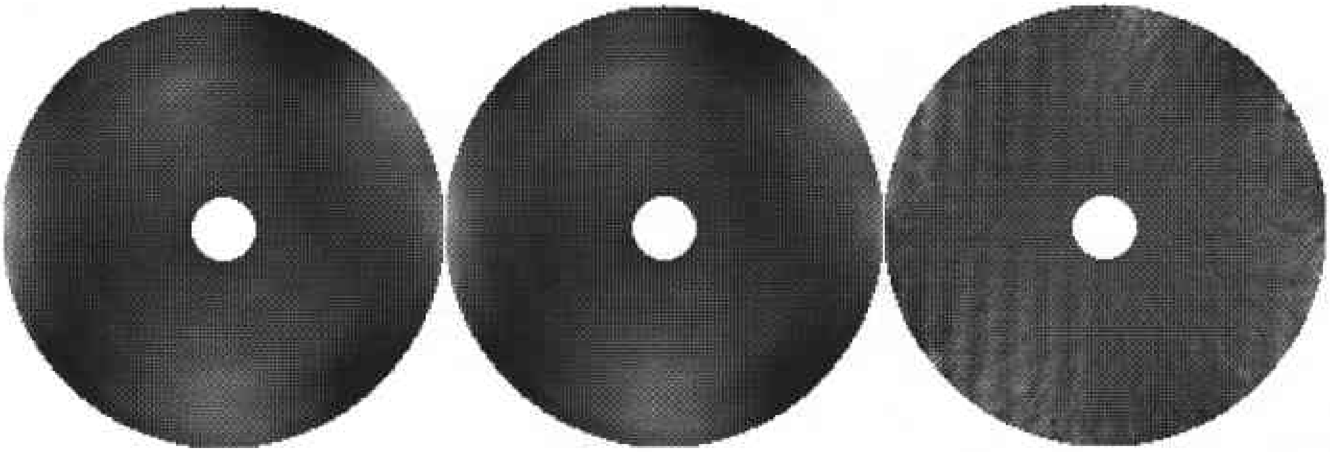

Figure 8. Wavefront error caused by a mapping error of 0.01 rad rotation. Format is the same as Figure 2.

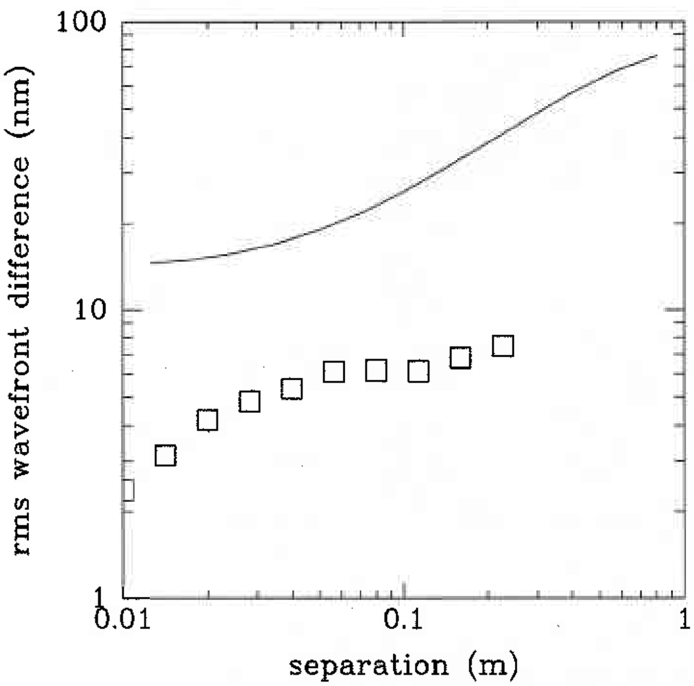

Figure 9. Structure function for the difference map for a rotation of 0.01 rad, over the 1.72 m clear aperture of the test plate.

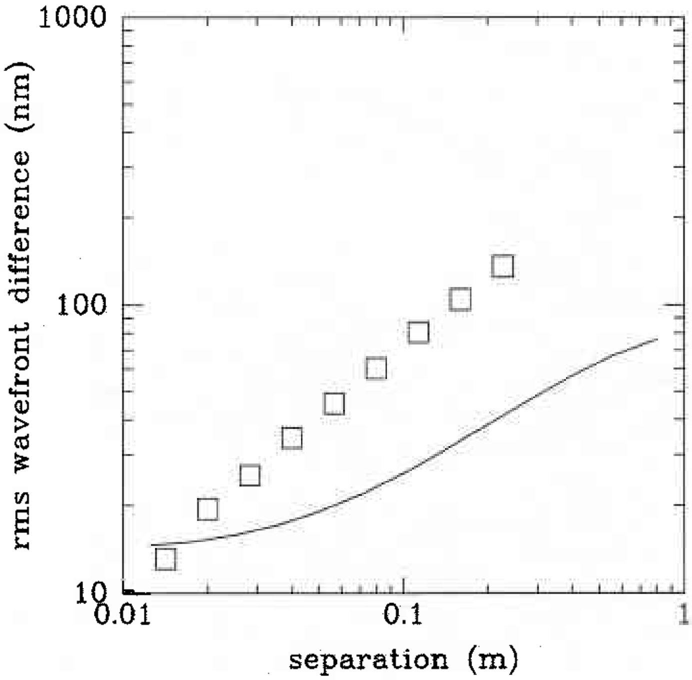

Figure 10. Structure function for the test plate, evaluated over the 1.636 m aperture.

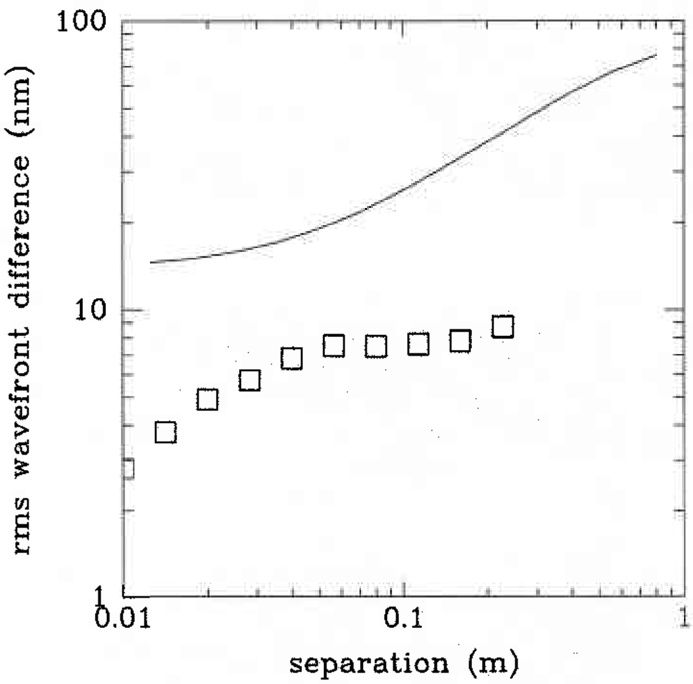

Figure 11. Structure function for the difference map for a 1% magnification error, over the 1.636 m aperture.

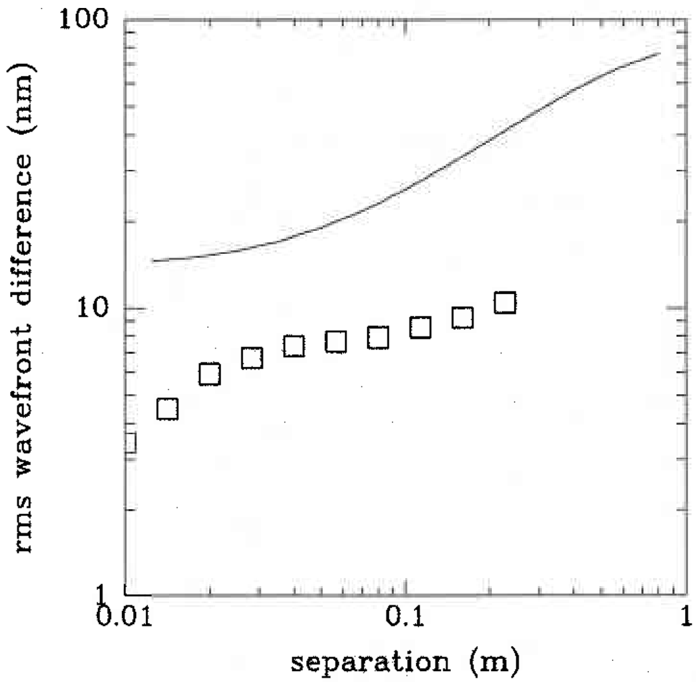

Figure 12. Structure function for the difference map for a 9 mm decenter in *x*, over the 1.636 m aperture.

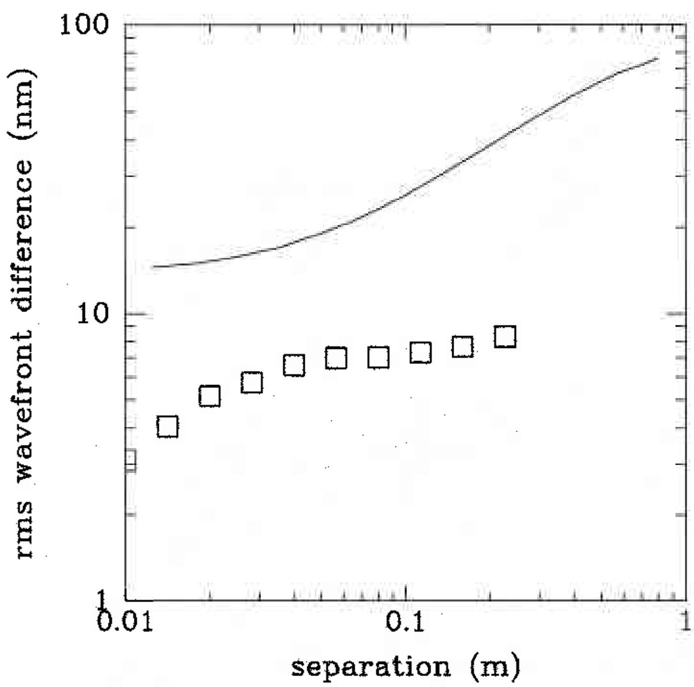

Figure 13. Structure function for the difference map for a 9 mm decenter in *y*, over the 1.636 m aperture.

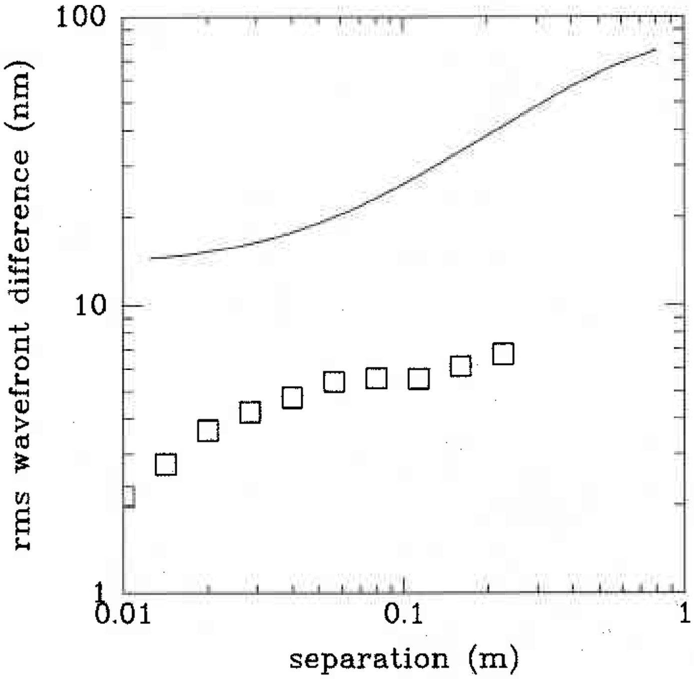

Figure 14. Structure function for the difference map for a rotation error of 0.01 rad, over the 1.636 m aperture.