

# Multiple Mirror Telescope Observatory

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## MMT TECHNICAL MEMORANDUM 87-3

**FROM:** D. R. Blanco

**RE:** Specifying and Holding Collimation Tolerances on Fast Cassegrain Telescopes

**DATE:** August 10, 1987

**Abstract:** This memo presents a method of specifying telescope collimation tolerances which allows a maximum flexural error budget based on image size criteria. Formulae are given for calculating tolerances, and sample error budgets are given for the SAO 48-inch upgrade, the VATT 1.82-m, the current MMT, and for a 6.5-m MMT upgrade. A possible scheme of open-loop collimation control is also described.

We are currently considering large Cassegrain telescopes with very fast primary focal ratios — as fast as  $f/1$ . Epps and others have pointed out the severe collimation tolerances needed to produce high-quality images with these telescopes. Tight tolerances translate directly to increased costs, so we must specify collimation tolerances in a way which exactly achieves the desired image criteria while allowing the largest possible error budget.

Traditional methods of specifying collimation for a Cassegrain telescope state an allowance for the tilt, decenter and defocus of the secondary mirror with respect to the primary mirror measured at the secondary mirror vertex. At the secondary vertex the effects of tilt and decenter on the focal image are not independent, which often leads to an overly conservative collimation error budget.

Excellent discussions of this problem can be found in references 2, 3, 4, and 5. This memo is a summary of these and other references presented from an engineer's point of view.

There are two cardinal points located on the axis of the secondary mirror where the effects of tilt and decenter act independently; one is its center of curvature, the other is the so called neutral, or zero coma point (zcp). The premise of this memo is that collimation

tolerances should be expressed as tilts and decenters from the primary axis referenced to these cardinal points.

It is intuitively obvious that tilting the secondary mirror through a small angle about its center of curvature will have negligible effect on the position of the image at the focal plane. Any image shift can therefore be directly related to a pure decenter away from the primary axis measured at the secondary center of curvature.

Similarly, tilting the secondary about the zcp has no effect on the comatic aberration of the focal images. At fast primary focal ratios coma is the dominant aberration resulting from miscollimation in any Cassegrain or Gregorian telescope. An increase in coma, which is evenly distributed over the image field, is therefore directly proportional to a pure decenter away from the primary axis measured at the zcp.

Tilting the secondary about the zcp introduces astigmatism which varies linearly across the field. Image enlargement due to astigmatism limits the range of permissible tilt. Tilt about the zcp will also displace the secondary center of curvature causing an image shift. Since this is done with a minimum of aberration, it seems possible to use this effect to guide the telescope to a tolerance better than the mount tracking.

Specifying the collimation tolerances as tilts and decenters measured at the cardinal points maintains the image criteria while allowing the greatest possible mechanical flexure for the telescope. Furthermore, this approach suggests gravity and wind shake compensation schemes (e.g. Wong, 1985), as well as active alignment mechanisms and control techniques for tracking and collimating the telescope.

The zcp is located on the secondary axis a distance  $L_o$  behind the vertex (i.e. away from the primary), and close to the prime focus. For any Cassegrain telescope this distance can be found from:

$$L_o = \frac{R_s(m+1)}{m+1-k_2(m-1)} \quad (1)$$

where:  $R_s$  is the secondary vertex radius of curvature,  
 $m$  is the system magnification,  
 $k_2$  is the conic constant for the secondary.

( $k_2 = 0$  indicates a spherical surface;  $k_2 = -1$ , paraboloidal;  $k_2 < -1$ , hyperboloidal.)

The references contain derivations for the collimation tolerances for two mirror telescopes. More complicated systems, such as a Cassegrain with a multi-element field corrector, require ray tracing to establish exact collimation error budgets. Exact studies should be done prior to any final design specification. The following discussions can, however, be used to establish first order approximations useful for first cut designs.