A MECHANICAL ALIGNMENT METHODOLOGY FOR SUBMILLIMETER-WAVE OPTICS

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Abstract Submission Form

2004 National Radio Science Meeting

Abstract: stark7901

Date Received: September 24, 2004

Millimeter- and submillimeter-wave detector systems often contain many optical elements which must be accurately aligned to function correctly. For the AST/RO project (A. A. Stark et al., *PASP*, **113**, 567), an alignment method was developed which worked well and has potential application to other systems where the optical elements are separated by distances of no more than a few meters.

AST/RO is a 1.7-m diameter offset Gregorian. Both the primary and secondary mirrors were fabricated with four polished and hardened steel reference balls, 5 mm diameter, mounted with roughly equal spacing around the edge of each mirror, several centimeters outside the active optical surface. The positions of the balls with respect to the mirror surface were measured together with the mirror surface during post-fabrication verification. The positions of the centers of the balls are therefore accurately known with respect to the best-fit curve for each mirror surface. Consider each pair of balls consisting of one ball on the primary and one ball on the secondary; there are 16 such pairs. For each pair, there is a well-determined minimum distance between the surfaces of the two balls. From the optical design and the shop measurements, it is possible to calculate what these distances would be if the two mirrors were accurately aligned. The mirrors are placed on their mounts in rough alignment. A large inside micrometer is then used to measure the actual separation between each pair of balls. Inside micrometers capable of measuring with a precision of 10 μm over distances of a few meters are commercially available. These values are input to a computer program which solves for the current position of the two mirrors and calculates the adjustment to their mounts needed to bring them into alignment. Usually, one mirror is left fixed (from some prior alignment) and the other is moved in order to improve the alignment. The program uses a nonlinear least-squares method to fit for the 3 rotations and 3 translations of the non-fixed mirror which connect its current position to its aligned position. These 6 motions are overdetermined by the 16 measurements, allowing an estimate of the errors. Not all 16 measurements are needed; any subset of 6 or more will determine a solution. The cycle of measurement and adjustment is iterated, until all measurements are correct within the measurement errors. In practice, this method has proven very robust. Only 3 or 4 interations are needed. The geometric model of the mirror mounts can be crude—it is enough to be able to calculate the direction and approximate magnitude of each adjustment. On AST/RO, the residual rms errors after alignment are less than 200 μm.

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4. I - Invited Paper, Program chair: Padin

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