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THE PERFORMANCE OF THE
MULTIPLE MIRROR TELESCOPE

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The performance of the Multiple Mirror Telescope

I. The MMT, the first of the advanced technology telescopes

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Abstract

The Multiple Mirror Telescope (MMT) incorporates many new technological features because its designers wanted to construct as large and as good as possible a telescope at as low as possible an expense. They did succeed at this and as a result the MMT may be viewed as the first of the new generation of Advanced Technology Telescopes. A substantial effort is given by the MMT Observatory staff and by the staff of the two sponsoring institutions (Smithsonian Astrophysical Observatory and University of Arizona Observatories) to optimize the performance of the MMT especially in those areas where it serves as a test bed or prototype of the telescopes of the future. Notable features in this respect are (i) the MMT altitude-over-azimuth mount, (ii) the corotating MMT building, (iii) the light weight honey-comb primary mirrors, (iv) the multiple mirror optics configuration, (v) the coalignment system for these mirrors, (vi) the seeing associated with the unconventional telescope and building and (vii) the capability to do interferometry using two or more of the MMT telescopes. This introductory paper will summarize the properties and performance of the MMT in these and other respects. It will set the stage for the in-depth description by the other papers in this sequence.

Introduction

Conventional large telescopes of the 4 meter class cost 25-35 million U.S. dollars. With the cost of telescopes going up with the 2.5 to 3 power of the aperture, the cost of very large astronomical facilities (10 meter or larger) becomes prohibitive. All plans for future large telescopes therefore deviate in major ways from conventional telescope design. Specifically they include the following technological concepts^{1,2}:

- (a) Altitude-over-azimuth mounts rather than equatorial mounts. This regression to the days of William Herschell and before (Figure 1) was made possible by the rapidly

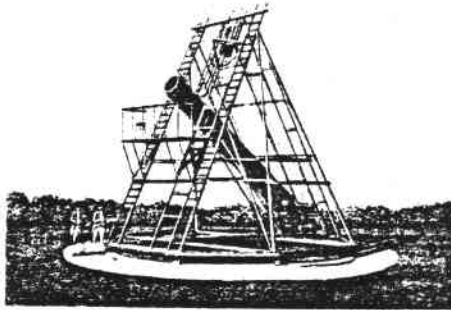


Figure 1. Early alt-azimuth telescope by W. Herschell.

developing digital computer technology. The advantage of this type of mount lies in the weight and size reduction associated with it as well as the higher precision achievable in modelling telescope flexure effects.

- (b) Lightweight Mirrors rather than the solid, thick mirrors used in the past. Such lightweight mirrors are either hollow, eggcrate type mirrors or thin meniscus mirrors. Their use both reduces telescope weight and improves image quality because their small thermal inertia reduces mirror associated seeing and thermal surface distortion.
- (c) Multiple Primary Mirrors rather than a single primary mirror. The largest single

mirror, the 6 meter BTA telescope in the USSR, is near the limit of mirror building technology. Multiple objectives whether consisting of segmented mirrors with a common prime focus image (called type A by Beckers et al³) or of multiple telescopes with the images combined later (called type B), present a way of increasing the telescope aperture well beyond the present 6 meter limit.

- (d) Active Optical Coalignment is inherent in the use of multiple primary mirrors. Coalignment aims at both combining the collected light geometrically in as small as possible stellar images and at combining the light coherently to gain angular resolution.
- (e) Different Buildings housing the telescopes. The size decrease of the new telescopes as well as the alt-azimuth mounts permit different conceptualizations and decreased sizes of the buildings shrouding the telescopes and hence a cost reduction.

The designers of the Multiple Mirror Telescope used all of these concepts to produce a powerful telescope (collecting area equivalent to a 4.5 meter telescope) at a cost less than 50% of the cost of a conventional telescope. The MMT (Figure 2) can therefore correctly be viewed as the first of a new breed of advanced technology telescopes. Its

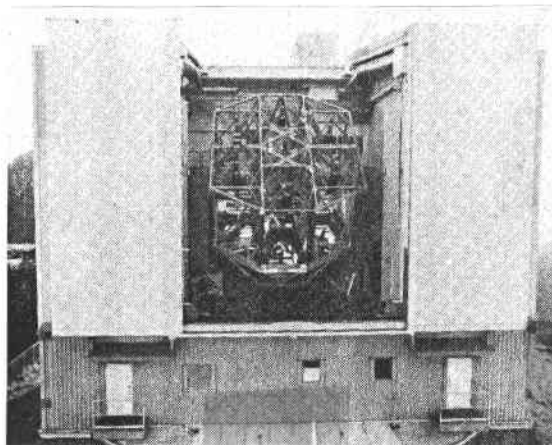


Figure 2. The Multiple Mirror Telescope is located on Mt. Hopkins at an elevation of 2600 meters. It contains six 180 cm f/2.7 cassegrain telescopes which form the MMT proper and a 75 cm central guide telescope.

successful completion is a credit to the courage of the designers of the MMT who followed unconventional, novel approaches towards building an outstanding facility. We are now refining many of these approaches in an effort to fully exploit the MMT both as a quality telescope and as a prototype for telescopes of the future. In this introductory article we will give an overall review of the MMT's capabilities. In other papers of this sequence an in-depth description will be given of many of the engineering aspects of the MMT. Since the ultimate success of a facility has to be measured by its product, this set of papers will conclude with a discussion of the science done with the MMT. We refer to a recent extensive description of the MMT and to the MMT dedication symposium⁴ for a full description of the history of the MMT and of the many aspects of the MMT not covered here.

The MMT alt-azimuth mount

The USSR 6 meter telescope and the MMT are the only large optical telescopes which use alt-azimuth mounts. This type of mount has of course been used extensively in radio astronomy, however with much less stringent demands on telescope pointing and tracking. All large telescopes being planned (e.g. 4.2 meter Hershell telescope, 7.5 meter Texas telescope, 10 meter UC Berkeley telescope, U.S. 15 meter telescope, Crimean 25 meter telescope) intend to use alt-azimuth mounts because of the substantial cost saving associated with their construction as compared to equatorial mounts. Modern computer technology makes the conversion of equatorial to alt-azimuth coordinates straightforward and the additional complexity of the rotation of the field of view is offset by the simplification of keeping the slit vertical as is desired by most spectroscopic investigations.

Figure 3 shows a scatter diagram of the MMT pointing. After correction for systematic flexure effects, for imperfections in the telescope axes orientation, for systematic encoder errors and for atmospheric refraction, we find that the MMT points and tracks to a precision of about one arc second without the use of stellar autoguider. The remaining errors are to a large extent due to residual encoder errors which appear to be nonrepeatable

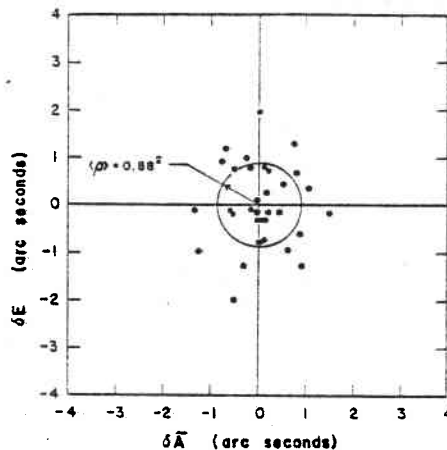


Figure 3. Scatter diagram showing pointing errors of the MMT. These data refer to the central guide telescope.

with time. Figure 4 shows typical periodic tracking errors resulting from encoder imperfections. The dead reckoning pointing accuracy is better than any other existing telescope; it is largely due to the simplicity of the gravitational flexure effects and to the benign thermal environment of the telescope mount. We continue to improve the MMT pointing and tracking, and we are giving special attention to the improvement of the absolute encoder readouts. This is of interest not only for future alt-azimuth drives but also for improving the blind tracking of the MMT which is important if there is no field star in the small MMT field of view (4×4 arc minutes). The maximum tracking speed of the MMT equals 90° /minute per axis which enables us to track objects to within 10 arc minutes of the zenith.

MMT optics support structure

The special optical configuration makes it possible to make the Optics Support Structure (OSS) exceedingly rigid because the space between the mirrors can be used and because the overall length of the MMT is about equal to its diameter. The stiffnesses of critical OSS members have been tuned to minimize the flexure and to make the residual flexures as identical as possible among the six 1.8 meter telescopes. The flexure now amounts to ± 18 arc seconds.

More important than the amount of flexure is the repeatability of the flexure from hour to hour and from day to day. If repeatable, it can be removed by slight systematic tilts of the telescope secondary mirrors. Under thermally stable conditions the flexure is repeatable to ± 2 arc second or better. By careful examination and tightening of joints of the OSS we have reduced the mechanical hysteresis and slippage of the mount to less than 0.3 arc seconds. When the temperature changes the pointing variations are several arc seconds. The OSS has, however, a very short thermal time constant (2-10 min) so that it adjusts rapidly to thermal changes.

We have found one very interesting and unexpected source of thermal changes in the OSS whose elimination will result, we hope, in even better repeatability of the pointing changes of the individual telescopes with elevation changes. This source of thermal changes is radiation cooling. Since the titanium dioxide paint with which the OSS is covered has a high infrared emittance, the OSS couples very efficiently by radiation to the cold sky. The OSS has therefore in its exposed parts temperatures below the air temperature, the amount of the temperature difference ($\sim 2^\circ\text{C}$) depending on the sky IR transparency, on the wind velocity (the latter determines the amount of convective coupling with the air), and on the degree of exposure to the sky. These radiative thermal changes cause misalignments of 1-2 arc second. We have reduced the radiative cooling effects by covering the OSS with reflective aluminum foil which reduces the cooling by an order of magnitude.

The MMT building

One of the most unusual departures from conventional telescope technology is the MMT building. It closely surrounds the telescope, being almost an integral part of it. It follows the azimuth rotation of the MMT by means of an electronic sensor. The relatively large shutters of the building leave the MMT very exposed to the outside air. The absence of a narrow dome slit and of a windscreens we believe to be a major factor in giving the often excellent seeing experienced at the MMT. This exposure demands of course a very high immunity to windbuffeting of the telescope itself.