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ENGINEERING REPORTS ON THE MMT OSS, TRACKING, CO-ALIGNMENT AND CO-PHASING

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The following preprints are included in this report:

1. "The Optics Support Structure of the MMT," Blanco, D.R., Antebi, J., Davison, W. (1987).

2. "Tracking a 150 Ton Altitude-Azimuth Telescope to Sub-Arcsecond Accuracy," Barlow, D.J., Blanco, D.R., Poyner, A.D. (1987).

3. "Co-Phasing and Co-Aligning the Multiple Mirror Telescope," Janes, C.C., Montgomery, J.W. (1987).

The Optics Support Structure of the MMT

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Abstract

The six Cassegrain telescopes which comprise the MMT are held in place by a steel space frame called the optics support structure (OSS). The design and development of this structure, from concept to final implementation, is presented in the context of the history of the MMT project.

Background of the MMT concept

The concept of the MMT was born in an effort to build a large aperture optical telescope at low cost. The cost of constructing optical telescopes had traditionally followed a curve proportional to the cube of the primary mirror diameter. By subdividing the light gathering objective into small, easy to fabricate units, large apertures could be built at a cost proportional to the square of the diameter, rather than the cube. The idea can follow two basic forms; segmented mirror telescopes (SMT) where a single optical surface is made up of separate tiles, and multiple independent telescopes (MMT) with beam combining optics. Early efforts in the 1930's and 40's involved segmented, zenith-pointing fixed arrays, thus avoiding the gravitational flexures in an all-sky pointing telescope[1,2].

In 1970 the availability of several lightweight quartz mirror blanks of 1.8 m diameter from military surplus spurred a serious re-examination of the multiple mirror concept. A group of scientists at the University of Arizona's Lunar and Planetary Laboratories (LPL) and Steward Observatory had discussed the possibility of constructing a large aperture, low cost telescope to be used primarily for infrared observations. At the time no large telescope had been built specifically for IR use. A. Meinel at the University of Arizona (UA) proposed using six of the mirrors in an hexagonal array dubbed 'Project COLT' for its six shooter geometry[3] (figure 1). The proposed instrument combined the light from six folded Cassegrain telescopes to give the light gathering power of an equivalent conventional telescope of 4.5 m aperture. The MMT configuration was chosen rather than an SMT. Though an MMT introduces two additional reflections per telescope, it has two advantages: first, it does not require exotic and expensive off-axis optics; and second, it shortens the tube length, yielding a compact, stiff structure without fast optics.

The director of Smithsonian Astrophysical Observatory (SAO), F. Whipple, along with N. Carleton and other SAO scientists had also been interested in low cost approaches to large aperture telescopes. Discussions between G. Kuiper and F. Low of LPL, R. Weymann, director of Steward Observatory, and F. Whipple led to an agreement on a cooperative effort between UA and SAO. In December of 1971 the UA and SAO formally agreed on a joint project to be called the Multiple Mirror Telescope. Under this agreement SAO was to provide the mount, optics support structure (OSS), and building, while UA was to provide the passive and active optics and supporting cells. Additional engineering design tasks such as the control system and integration of the project as a whole were divvied between the two organizations with a major portion of the research and design work farmed out to consulting engineering firms.

Several features of the telescope were determined at the start of the project; an alt-azimuth mount was chosen because it not only yields a compact design, but also simplifies the OSS by limiting the gravity vector to act in one plane only. The telescope would use an active optics system to keep the independent telescopes aligned. This could be based on feedback either from a stellar source, or from a pinpoint artificial star. By illuminating the artificial star with coherent light the telescopes might possibly be kept in phase as well, though it was decided quite early to postpone phasing to a later development stage of the project. The infrared requirements of minimum blockage led to a slightly more conventional design using secondary spiders (figure 2).

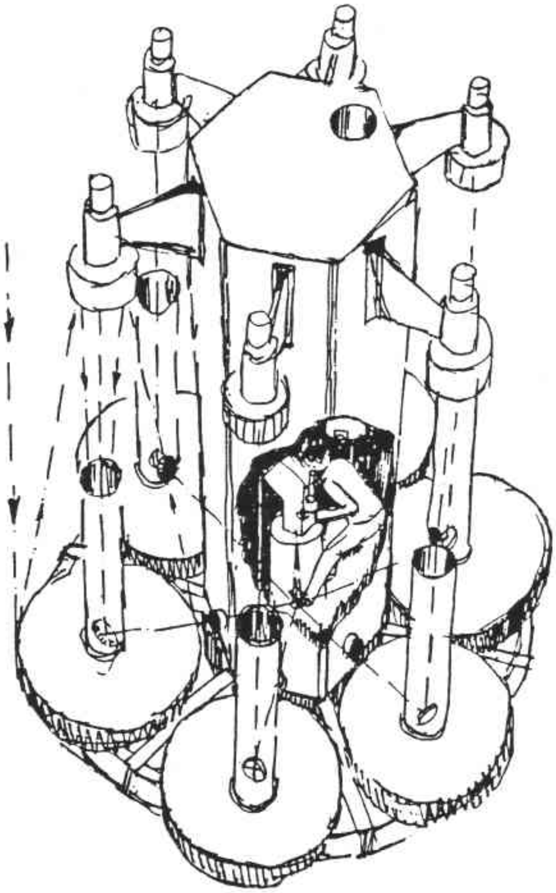

Figure 1. 'Project COLT', an early concept of the MMT c. 1970

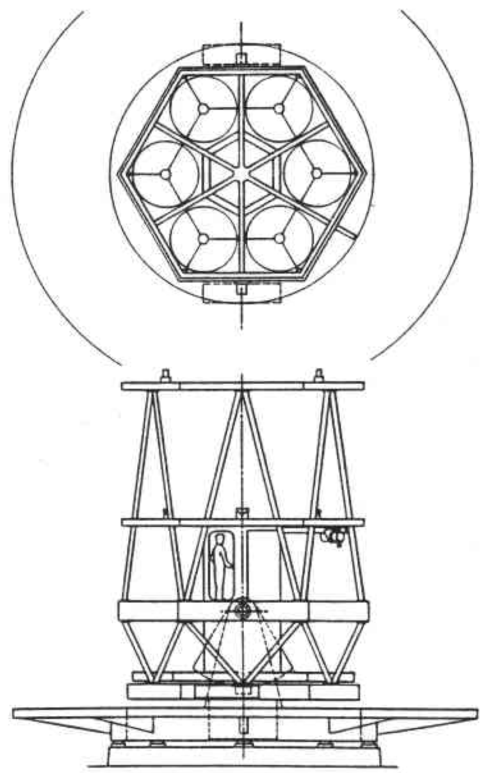

Figure 2. Second generation conceptual design of the MMT c. 1971.

The proposed modes of observation included six separate foci, a combined focus, pairs of Michelson interferometers, a fully phased array to produce images comparable to those of a diffraction limited single telescope of the seven meter class, and a six element image stacker for use with a high resolution spectrograph. The image stacker involves placing individual telescope images in a line along the spectrograph slit. Small prisms are used to realign the beams parallel to the collimator axis. The spectrograph thus sees six superimposed slow beams instead of an unfilled fast beam, with consequently improved resolution[4,5].

The mount and optical design

The design proceeded from the ground up. One of the first questions to be addressed was whether existing alt-azimuth telescope technology used in radio astronomy could achieve the fine tracking and pointing requirements of an optical telescope. In 1972, T. Hoffman, then director of engineering at SAO, and N. Carleton, SAO project scientist on the MMT, contracted Philco Ford corporation, a company with considerable experience in antenna construction, to examine the feasibility of rolling element bearings for the MMT azimuth turntable. Roller bearings, as opposed to the more traditional hydrostatic oil pad bearings, offered the attractive advantages of low initial cost and ease of maintenance. The results of the study indicated that though no roller bearing had ever been fabricated with the required capacity, smoothness, and accuracy, ball bearings did have the potential to meet the requirements with current fabrication techniques[6]. In view of the potential advantages and relatively small risk, ball bearings were selected.

The design specifications of the mount were completed with an acceptable level of confidence by 1972, and Philco Ford was contracted to detail and fabricate the mount, all before any detailed study of the OSS began. Meanwhile G. Sanger and M. Reed of UA Optical Sciences Center developed a design for the active optics system[7]. In this scheme the secondary mirrors are articulated with two tilts and a focus motion, all driven with an optical error-sensing feedback system. Feedback from a stellar source, it was felt, would be too limited. Given the small field of view of 5 arcminutes, the chance of a sufficiently bright guide star was slight, so the laser alignment system was chosen. A seventh, central telescope was added to collimate the laser beams and to serve as a guide telescope. A series of pentaprisms and elongated corner cube reflectors, chosen for their insensitivity to small structural deflections, would distribute the laser beams through the telescopes and return to a central sensing location. The automated algorithm involved first coaligning the telescopes by stacking the images of a bright star, then positioning the 12 laser beams on the centers of the four-channel photocell detectors by rotating steering wedge prisms in the laser light paths. After this, error signals generated by a shift of the laser beams on the photosensors would drive tilt and focus motions of the articulated secondaries at a 10 Hz rate. This greatly complicated the telescope, adding more than 100 optical elements, both passive and active, all of which had to be initially aligned and kept in collimation. Despite the added complication of this scheme, the project probably would not have proceeded without this or some similar plan. The laser alignment scheme became a major publicity feature for the telescope[8].

Development of the OSS

SAO selected Simpson Gumpertz & Heger Inc. (SGH), a structural engineering firm with experience in the accurate analysis of the deflections of radio-telescopes, to perform conceptual studies and to develop a preliminary design of the OSS. SAO defined the constraints and specifications. Close contact was maintained between SAO and SGH so that constraints found to be unduly restrictive could be modified to make them less burdensome while still satisfying the design objectives.

The requirements that controlled the design were: the alignment of the optical elements had to remain within specified limits as the telescope moved from zenith to horizon, and, for servo-control purposes, the lowest natural frequency had to be greater than 25 Hz. Clearances for the light paths had to be provided, through each of the six Cassegrain telescopes, to the centrally located beam combiner and instrument support flange, and also along the elevation axis to the Nasmyth foci. In addition, the alignment tolerances had to be satisfied under nominal wind and thermal conditions. The structure also had to fit in the already designed mount, and the layout of the six apertures and of the guide telescope and instrument support precluded simple efficient structural layouts such as a simple truss spanning between the elevation bearings.

SGH first developed and analyzed several structural concepts. As a result of these studies several deflection compensation schemes were developed, and it was determined that the design objectives with respect to relative deflections were achievable, but all of the configurations had natural frequencies well below 25 Hz. Consequently, a new set of configurations was investigated without paying particular attention to deflections and light path constraints until a configuration was developed with sufficiently high lowest natural frequency. This configuration was then developed into a preliminary design that incorporated deflection compensation concepts and satisfied the other requirements.

The governing deflection budgets were expressed in terms of combinations of primary mirror tilt and relative displacement of primary to secondary for each telescope. These requirements implied that the relative displacements across the diameter of a primary mirror and of primary to secondary had each to be less than about 2 mils, (0.002 in.). However, the constraint on displacements of the six telescopes with respect to each other and to the beam combiner did not control the design.

To obtain displacements that can be predicted to sufficient accuracy that they can be reliably matched to within 2 mils, the absolute displacements should be no more than 10 times larger, that is about 20 mils. If due to gravity loads a structure sags 20 mils, it can be shown that the frequency of the mode corresponding to this sagging deflection is