Building My Dream Observatory

A quintessential telescope maker spent four years building this novel 32-inch reflector and home observatory.

MARIO MOTTA

Perched at the highest point in the area, Mario Motta's observatory has a commanding 360° view of the sky.

AS A TEENAGER, I started grinding mirrors and building telescopes because my dreams always exceeded my budget. My projects include a 16-inch Newtonian reflector and backyard observatory finished in the 1980s, and a 32-inch Newtonian and another observatory built in the '90s. When my wife, Joyce, and I planned a move to Gloucester, Massachusetts (her for the natural beauty of the beach, and I for the darker sky), we agreed that an observatory would be an integral part of our new house.

Given today's plethora of commercial telescopes, some people wonder why I still build my own. The answers are simple: for large telescopes, it can be very cost effective, you control the quality, and there's real pride in making and using your own instrument.

As a galaxy hunter, I find that the views through an optically excellent, large telescope are beyond my wildest dreams. So my initial plan was to build another, better 32-inch Newtonian, since I'd become relatively adept at making parabolic mirrors. But a close friend and optical designer, Scott Milligan, changed my mind. He had been perfecting a radical new design for a "relay telescope," building on the work of others, particularly Donald Dilworth, who described his 16-inch relay telescope in this magazine's November and December 1977 issues.

It's a story played out countless times in the last century: an amateur astronomer's quest for a dream telescope becomes a journey through the world of telescope making and surplus materials. Only a few of these stories, however, end as dramatically as the one told here. The author is pictured with his unusual 32-inch f/6 relay telescope in an observatory that is part of his hilltop house.

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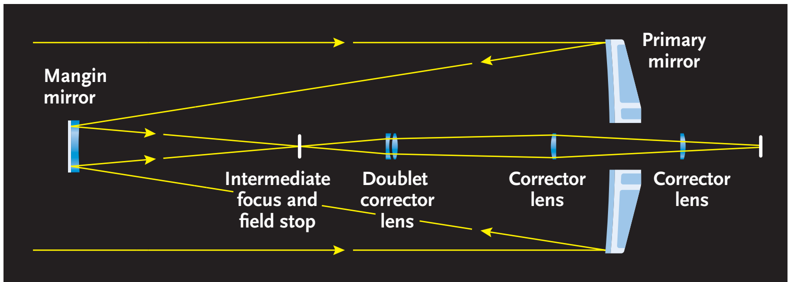
Using advanced ray tracing, Scott settled on a system with four correcting elements. It promised many advantages over a simple Newtonian, not the least of which was a very sharp and flat focal plane. I was intrigued, and to further sweeten the deal, Scott offered to help build the telescope. It was an offer I simply couldn't refuse.

Built at the same time as the house's foundation, a massive 23-foot-tall pier of reinforced concrete provides a stable base for the telescope even when there is considerable activity in the adjacent rooms.



Described in detail in the accompanying text, the scope has 11 optical surfaces, all of which are either spherical or flat. This greatly simplifies their fabrication. The primary mirror's intermediate focal point falls inside the tube, where it is "relayed" to a Cassegrain focus by a set of corrector lenses mounted within a baffle tube.

S&T: GREGG DINDERMAN, SOURCE: SCOTT MILLIGAN

First, the Optics

Outwardly the scope has the appearance of a large Cassegrain. The primary mirror is f/3, and the final image is f/6 with an effective focal length of 4,800 millimeters. Scott's design, however, can be easily modified to produce scopes from f/4 to f/12.

The system has six elements, 11 optical surfaces, and a field stop. It sounds complicated, and in some ways it is. But I had already suffered through the extreme difficulty of grinding and polishing a 32-inch mirror to a paraboloid. The best I could manage was a surface accuracy of about ⅕ wave after 2½ years of effort. I wanted my new scope to be even better, and a big advantage of Scott's design is that all the curved optical surfaces are spherical, including the 32-inch primary mirror. As any glass pusher knows, it's much easier to grind and polish a perfect sphere than a paraboloid. Indeed, from start to finish, work on the new primary was completed in about six months.

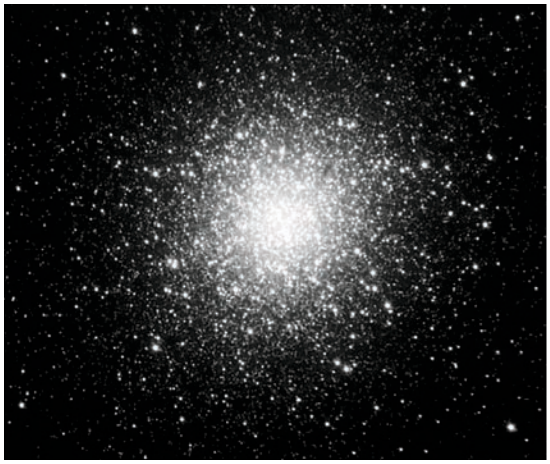
The next challenge was the scope's 7.8-inch-diameter Mangin secondary, which is a combination lens and mirror. It has a concave surface facing the primary mirror and a flat back surface that is silvered. The light path from the primary passes through the Mangin's glass and curved surface twice, correcting the primary's inherent spherical aberration. But because it is a lens as well as a mirror, it introduces some color aberration to the system.

The Mangin secondary folds the light path back to an intermediate focus falling near the middle of the telescope tube. At this point there is a field stop 1.8 inches in diameter, which preserves the scope's high contrast by preventing stray light from reaching the focal plane. The field stop is very effective, and as proof, someone can shine a flashlight down the tube toward the primary when I'm observing and it will lighten the field of view only a little bit.

From the intermediate focus at the field stop, the light path is "relayed" through four corrector lenses to the final focus behind the primary mirror. The lenses are held rigidly in a long baffle tube and are set up as a doublet and two singles. They correct the system's color aberration as well as flatten the focal plane.

In the past, optical designers might have shied away from a system with this many optical surfaces because it could be compromised by internal reflections and a significant loss of light and image contrast. But modern antireflective coatings on all the lenses keep light loss to less than 0.25% on each air-to-glass lens surface.

There are some significant mechanical constraints to this optical design that require careful consideration. The most significant one involves the spacing between the primary and the secondary mirrors, which cannot vary by more than 0.025 inch. As such, the structural elements holding the mirrors apart cannot be made from



***Left*: After six months of making parts for the dome, the author enlisted the help of a dozen members from the Amateur Telescope Makers of Boston for a "very long weekend" spent assembling the dome atop the observatory walls. *Right*: The telescope's pinpoint star images are apparent in this image of the globular star cluster Messier 13 in Hercules.**

aluminum or other common materials, since thermal expansion and contraction would badly defocus the image in a way that isn't correctable by merely refocusing the eyepiece. The telescope's optical collimation is also quite sensitive and requires that the Mangin secondary not tilt or sag laterally.

These are serious constraints, and we overcame them by using structural carbon-fiber materials for the scope's truss construction and cross bracing. Thanks to a friend in the optics industry, I was fortunate in obtaining a large cache of scrap carbon-fiber tubing left over from a satellite project. The baffle tube holding the corrector lenses is also carbon fiber, with only the lens cells being made from aluminum.

The primary mirror's support proved to be an issue. The lightweight mirror blank was cast by Wangsness Optics in Tucson, Arizona. Its back is a conical shape, tapering from 4½ inches thick at the center to 1½ inches at the periphery. Weighing only 97 pounds, it was originally mounted on a support passing through a 5-inch hole cast in the center of the blank. In the end, however, this method of supporting the mirror caused some flexure that resulted in an optical error amounting to nearly ⅓ wave. It took finite-element analysis to realize that I needed to make a more traditional 18-point support for the back of the mirror. Fortunately, that solved the flexure problem, and the scope has a final wave-front accuracy of about 1⁄12 wave — quite a feat for a telescope of this size.

Its images are nothing short of spectacular. Viewing with a Tele Vue 41-mm Panoptic eyepiece at 117×, I see an evenly illuminated true field that is 31 arcminutes across. The image is sharp, has rich contrast, and tolerates high magnifications very well. The scope is far more than just a big light bucket, and it's a real joy to use it for observing planetary detail.

Next, the Mechanics

All 584 mechanical parts for this telescope were hand made, many with a lathe and milling machine that I acquired secondhand years ago for telescope projects. The pieces were also made from mostly scrap materials, thus keeping costs very low for a project of this size. Some items were donated by friends, such as a 40-inch-diameter aluminum disk that was originally part of an industrial centrifuge. This now serves me quite well as the mount's

The relay telescope's novel optical design is the handiwork of Scott Milligan, who also did much of the optical fabrication as "incentive" for the author to select the design for his project. Note the primary mirror's lightweight structure described in the text.

This view of the well-known spiral galaxy Messier 81 in Ursa Major was assembled from separate CCD exposures through red, green, and blue filters.

polar disk supporting the steel fork arms. The disk rides on pillow block ball bearings, while the south end of the polar axis rests on a surplus 6-inch Timken thrust bearing.

The telescope's drive motors are computer controlled thanks to another friend, Chris Houghton of Astrometrics. His electronic design allows me to accurately slew to and track objects with the precision needed for deep-sky astrophotography. I use an SBIG STL-1001E as my primary camera, since its 24-micron pixels have an image scale of 1 arcsecond per pixel with this scope.

A self-proclaimed galaxy hunter, the author recorded dozens of island universes in this ¼°-wide photograph of the Hercules Supercluster, Abell 2151.

Finally, the Observatory

We designed the observatory as an integral part of our new house. As such, a massive 23-foot-tall pier made of reinforced concrete with a 2-by-6-foot cross section was constructed along with the foundation. The house was built around the pier, making sure that there was no contact between floors and the pier. This is critical in preventing any vibration from shaking the telescope when people are walking around inside the house.

Because the top of the dome exceeded normal height restrictions for our local zoning, we had to get a building variance from the neighbors. But the result is a dome that is the highest point around, and I don't have to worry about trees. I was also fortunate in convincing my hometown to adopt a light-pollution ordinance!

I made the frame for the 20-foot dome from plywood struts that were cut with a router. The outer covering is 0.052-inch-thick fiberglass sheets that I obtained for free from a local manufacturer's pile of discarded material. Several friends and I cut the sheets to shape and attached them to the plywood skeleton with screws, each of which we fitted with a small rubber sink washer to make a watertight seal. We bonded the fiberglass seams with Phenoseal Vinyl Adhesive Caulk to make the dome waterproof.

The dome has 24 sets of wheels riding on a base ring made of wood and covered with ¼-inch-thick aluminum plate. Four ⅛-horsepower motors move the dome very nicely. Although it took me six months to make the dome's wood and fiberglass pieces, it required only one very long weekend to assemble it thanks to help from a dozen members of the Amateur Telescope Makers of Boston. Since the fiberglass was free, the dome cost only about $2,000 for the plywood, motors, and minor parts. One large order of pizzas covered the labor costs.

All told, it took me about four years to build the telescope and observatory. Was it worth the effort? Absolutely. Views through this scope are simply amazing, with high-contrast, razor-sharp stars across the field. On nights of good seeing, I can use very high magnifications with no breakdown of the image. Detail on planets is excellent. And galaxies, which are my favorite objects, really look like galaxies rather than "faint fuzzies." The project did indeed create the dream telescope I've been wanting since I was a teenager. ✦

Mario Motta is a Massachusetts-based cardiologist. The past president of the Massachusetts Medical Society, he currently serves on the American Medical Association's Council of Science and Public Health. Adding to his many astronomical credentials, he is a recipient of the Astronomical Society of the Pacific's Las Cumbres Amateur Outreach Award.