Spinning Mirrors of Mercury

A Canadian astronomer tries an age-old idea for making large telescope reflectors

By MARY MURRAY

A pool of pure, silver-white mercury makes a flawless, natural mirror. Spin the pool, and centrifugal force shapes its flat surface into a parabola. Attach this concave mirror to the proper electronic equipment, aim it into the sky on a cloudless night, and it becomes a powerful optical telescope.

This is the theory behind the "liquid mirror" telescopes that astrophysicist Ermanno F. Borra has built at Université Laval in Quebec, Canada. He has made three prototypes — two of them 1 meter in diameter and the third 1.65 meters — and he is using a 1-meter model this summer to look for rapid variations in the sky. Although the concept of using spinning mercury as a telescope reflector is at least two centuries old and has been attempted many times since at least 1909, Borra claims he is the first to make it work.

He says he has learned to control precisely the speed of the mirror's rotation, to keep wind-generated waves from the surface of the mercury and to keep the poisonous mercury from harming telescope operators. Laboratory tests done in 1984 and 1985 demonstrated that his parabola of spinning mercury maintains a constant shape and a stable focus, Borra says.

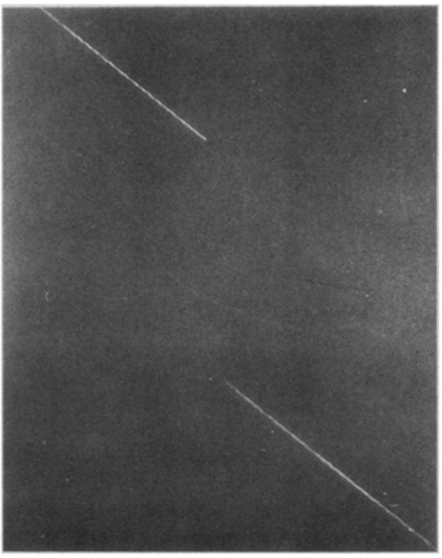
"I already have proved that the concept is sound," he told SCIENCE NEWS. "The only thing I have to prove now is that I can make very large liquid mirrors."

In fact, size is the major reason why liquid mirrors may be useful. Ever since 1668, when Isaac Newton built the first reflector telescope with a 1-inch diameter mirror made of a metal alloy, astronomers have been trying to build bigger reflectors. The bigger the mirror, the more light it can collect, and the farther and more clearly the telescope can see into the universe.

It is difficult to build very large telescope mirrors of glass, however, because of the great precision required. A large mirror tends to deform, partly because of its own weight and partly because its surface temperature varies from one edge to another.

But Borra says perfectly shaped liquid mirrors can be made as large as 30 meters (98.4 feet) in diameter — nearly four times as large as the biggest existing solid glass telescope mirror, the 6-meter (19.7-foot) reflector in the optical telescope on Mt. Semirodriki in the Soviet Union.

The potential for such a drastic increase in size suggests great promise for liquid mirror telescopes. Yet they are unlikely ever to be as useful as traditional telescopes because of their major shortcoming: They can aim in only one direction — straight up.



Photos: Université Laval/Courtesy of Borra

Light lines represent photographs of star trails taken with liquid mirror at a 1-minute exposure. The lines are smooth enough to suggest that the mirror has a constant shape and a constant focus. The slight blurring is caused by variations in the earth's atmosphere.

That means they can see a narrow slice of the sky very well, but most of it not at all. "It's just not a general purpose telescope," says Jerry Nelson of Lawrence Berkeley Laboratory in Berkeley, Calif., who is leading a team putting together a 10-meter-diameter segmented mirror for the new Keck Telescope, which is to operate atop Mauna Kea in Hawaii beginning in the early 1990s. "When a telescope points straight up only, there are many things you can't even look at, and some you have to wait around many hours to look at."

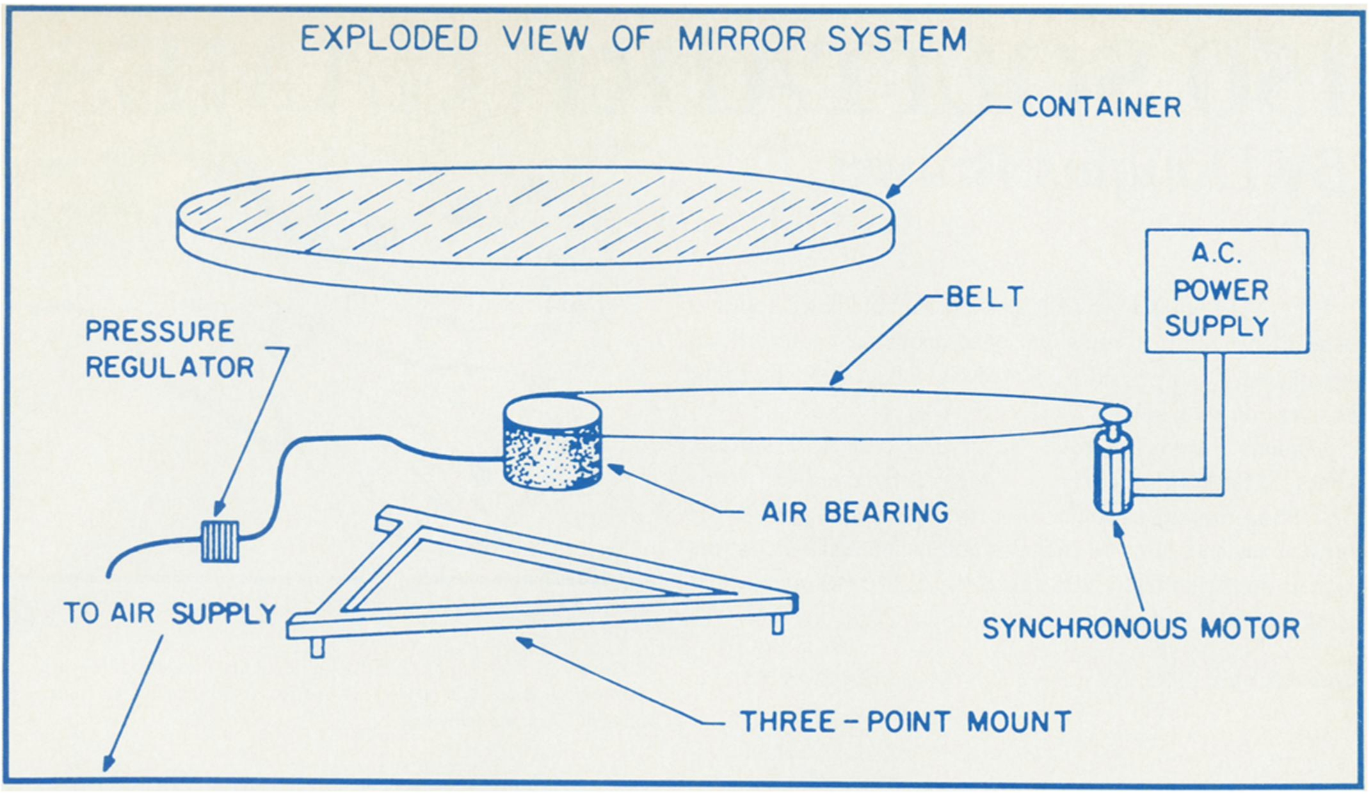
Borra acknowledges that his 1-meter mirror can view only a 1°-wide area of the sky, which limits what it can do. If the telescope operates for eight consecutive hours on a given night, it can see a 120°-long strip of the sky, 1° wide. But Borra and other astronomers point out that for some kinds of astronomical work — especially some aspects of cosmology, the study of the evolution of the universe — it doesn't matter which part of the sky you look at. Astronomer John T. McGraw of the Steward Observatory at the University of Arizona explains: "The way you find out about the universe is by doing statistical counts of galaxies and quasars very, very far away. If you look almost anywhere, you will see some distribution of galaxies and quasars."

Borra has used his mirror to photograph "star trails," the transit lines of stars crossing the zenith as the earth rotates. The fact that the lines in his photographs are rather smooth proves that the liquid mirror keeps a steady shape and a steady focus, he says.

Although he has not yet done so, Borra also can use his mirror to take photographs of discrete stars, without the moving trails, by using a standard astronomical "charge-coupled device" or CCD. The CCD, a cousin of the computer memory chip, allows the camera to steadily shift its focus as the earth rotates.

The limitation of zenith focus may be tolerable to some astronomers as long as the cost of liquid mirrors is low enough. And Borra says it probably will be. He has done a "back-of-an-envelope" calculation on the cost of building a 6-meter liquid mirror — excluding instrumentation and shelter — and has come up with a price tag of about $200,000. By comparison, the cost of building the segmented mirror for the Keck Telescope on Mauna Kea is estimated at about $25 million, Nelson says.

Borra has overcome many of the other limitations that have confounded others who have tried to make liquid telescopes. The idea of using spinning mercury as a parabolic telescope reflector has been traced back to 1800, but by then it was well known, Borra says. He thinks the concept may be as old as the reflector telescope itself. "It is my very strong suspicion that it goes as far back as Newton," he says. "Newton invented the reflector telescope, and he also knew that spinning liquid was hollow."



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The essential components of Borra's liquid mirror.

The late Robert W. Wood, a physicist at John Hopkins University in Baltimore who in 1909 built the first experimental liquid mirror, could not make it work because he could not control the velocity of his turntable. Wood was able to photograph some star trails, but because he could not keep a perfect shape to his mirror, the trails were spotty – sharply focused in places, but mostly too fuzzy to be valuable.

Subsequent experimenters had the same problem controlling the speed of rotation. Borra says he solved it by using precise, modern-day equipment and materials. The 1-meter mirror he is using this summer spins in a shallow, plywood tub rimmed with metal. (In future models, Borra plans to make the tub of the kind of layered fiberglass used to make speedboat hulls.) Borra prepared the tub for the mercury by spinning it and pouring in a 1-centimeter layer of liquid polyester resin. As it spun, the resin dried into the shape of a parabola.

Astronomer Mario Beauchemin checks position of prototype liquid mirror underneath the scaffolding that holds the telescope camera.

He then poured in enough mercury to make a 5-millimeter parabolic layer over the resin while the mirror is spinning. The mercury must be at least 3 mm deep, Borra says, or it tends to pull apart into puddles. It took 80 kilograms of mercury (at about $30 a kilo) to fill his 1-meter parabola. On top of the mirror tub, Borra stretches a 8-micron-thin layer of transparent mylar in order to keep winds from making waves in the mercury.

He has found he can use the same quantity of mercury for many months by cleaning it once a week. The liquid metal is relatively easy to clean because all the dirt floats on the surface. Borra drags a piece of plastic tubing over the surface, pulling the impurities to one side, and then he suctions them off.

Borra has had to ensure that it is safe to work with such a great quantity of mercury. "Mercury poisoning has been a concern, and it's someting I've heard a lot about," he says. "Every time people hear I'm working on a liquid mirror, it's the first question they ask."

However, because mercury is so heavy and evaporates so slowly, there is very little danger that telescope operators will breathe it in, Borra says. The people who work near the mercury pool wear lab coats, gloves and, when they are handling the mercury, face masks.

The tub of mercury rests on a turntable, which is rotated with an air bearing. A synchronous motor used to power the turntable is connected to the bearing with a loop of magnetic tape cut from a discarded audio cassette. It was important to have a loop of lightweight material that would automatically loosen itself if the motor stopped operating, Borra says.

The 1-meter mirror rotates one complete turn every 6 seconds, which is just fast enough to produce a parabolic mirror with a focal length of 4.7 meters (about 15.4 feet).

The mirror stands in a box of sand near Borra's laboratory building on the Université Laval campus. The sand works to give the mirror a level surface and to protect against ground vibration, he says. A simple scaffolding rises above the mirror to hold the 35-millimeter camera at the focal point, 4.7 meters up.

Technically, Borra and his associates are using the liquid mirror this summer to look for rapid variations in stars. The star trail photographs would provide evidence of such variation by showing an exceptionally bright spot in a trail or an unusually short trail.

But the primary reason for operating the mirror this summer is to see how it works day after day. "We want to see the problems you run into in practice over a long time," Borra says.

His next challenge will be building bigger and bigger liquid mirrors. "At this point, it has become an engineering problem," he says. "It's not a science problem at all anymore because the important things already are proved – that it is possible to generate an optical-quality surface on a spinning liquid and that it is possible to do science with a liquid mirror." ☐