telescopes stabilized by solar sails," Labeyrie says. This project is named Trio after its original design of three components.

And ever ready with new ideas, Labeyrie suggests using molecules trapped by lasers—gaseous mirrors—instead of conventional mirror materials. "In space huge mirrors may become feasible in this way, but the principle does not seem applicable to ground-based telescopes," Labeyrie tells us. "The recent success of Arthur Ashkin at Bell Labs [see David Wineland and Wayne Itano's article on page 34] in cooling sodium atoms with laser interference patterns may be a step toward implementing such gaseous mirrors, although considerable work is still required to develop workable schemes. The principle involves a standing wave pattern of laser light with paraboloidal nodal surfaces. Molecules are trapped on these surfaces, producing the equivalent of a Lippmann–Bragg hologram that focuses starlight."

—Per H. Andersen

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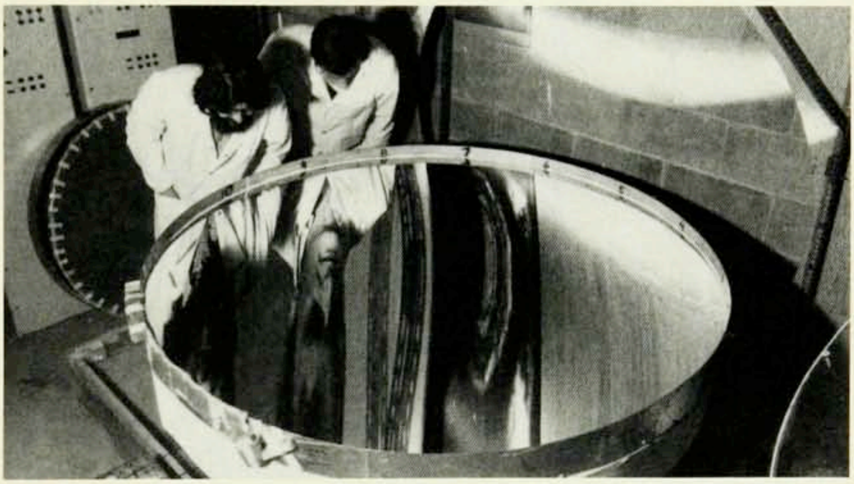
Will future astronomers observe with liquid mirrors?



A liquid mercury mirror having a diameter of 1.65 m and focal length of 1.5 m is shown in this photograph (reproduced by permission of E. F. Borra).

Experiments with liquid-mirror prototypes go back at least to the early 1800s. Isaac Newton, who invented the reflecting telescope and certainly thought about spinning liquids, may be the originator of the concept. In 1908 Robert Wood (Johns Hopkins University) made a 0.5-m liquid-mirror telescope. Vulnerable to jarring motions, Wood's mirror could detect "the footsteps of a person running 50 yards from the telescope house." The problems were serious: Variable motor speed caused distorting ripples on the fluid surface and such a transit telescope is unable to point in any direction other than the zenith, that is, straight up. Hence a liquid-mirror telescope would seem impractical.

Although a liquid-mirror telescope could observe only what is directly overhead, it could make deep-sky surveys of galaxies while sweeping a strip of sky as the Earth's rotation moved the instrument. Despite a similar restriction in pointing ability, the 305-m (1000-foot) diameter Arecibo radiotelescope in Puerto Rico has proved its worth with quasar observations, for example. Surveys with presently available telescopes are restricted by either the telescope's faintness limit or its angular field size, but nowadays charge-coupled devices and image-reduction software on large-scale computers permit massive data accumulation and analysis. Slitless spectroscopy in deep-sky surveys under conditions of excellent astronomical seeing would be a boon to observational cosmology in particular.

Recently Ermanno Borra (Université Laval, Québec) has revived[1] interest in making mirrors from surfaces of spinning liquids. Modern vibrationless air bearings and synchronous motors can overcome the problem of surface ripples. A layer of silicon lubricant can be used to damp out vibrations, which in any case turn out to be only a minor problem. Since June 1986, after extensive optical shop testing, Borra's team has operated a 1-m mercury liquid-mirror telescope, getting 180 hours of data on 38 nights and obtaining stellar images comparable to those from conventional imaging. A thin Mylar cover eliminates wind disturbances without affecting image quality. Examination of 2-minute star trails recorded with a 35-mm camera and the prototype mirror suggests that the basic concept is sound.

As the container holding the mercury rotates around an axis of symmetry perpendicular to the Earth's surface, the liquid forms a paraboloidal equipotential (surface). For a given value of the local acceleration due to gravity, the focal length of the liquid mirror is uniquely determined by the angular velocity. A person walking could keep up with the motion of a point on the rim of an $f/2$ 5-m mirror and a runner could follow a rotating $f/1$ 30-m mirror.

Detailed plans already exist for 3-m-diameter liquid-mirror telescopes. Eventually one may be able to scale up the mirror size to as much as 30 m. A liquid-mirror telescope is cost effective: The 1-m prototype costs about $7500. Although liquid-mirror telescopes could be built at a range of latitudes for maximum sky coverage, their restricted pointing ability remains a serious limitation.

—Per H. Andersen

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