tance. That means determining their distance without relying on redshift, a much tougher requirement. The usual strategy is to find some observable feature of galaxies that is thought to indicate their actual brightness or size, then compare it with the brightness or size observed from Earth to get distances.

In their 1994 study, Postman and Lauer simply picked the brightest galaxy in dense galaxy clusters and assumed that these galaxies had the same luminosity in each case. Parlaying those measurements into distance, they found that clusters out to a distance of 500 million light-years in every direction in the sky all appeared to be moving together at a velocity of 680 km/s in the direction of the constellation Virgo. It was a flow of an area 30 times larger than any seen before.

In trying to confirm it, Hudson's team, the Streaming Motions of Abell Clusters (SMAC) Collaboration, used a different distance measure. These researchers looked at elliptical galaxies and determined their absolute size by measuring the mean surface brightness in the central part of the galaxy and how fast stars are darting around within it—indicated by the broadening of spectral lines. They then compared these to similar known galaxies closer to home. "Once you have measured the velocity dispersion and the surface brightness, you know what the absolute radius of the galaxy should be," says Hudson. Willick's group also used the widening of spectral lines to estimate the rotation speed of about 250 spiral galaxies; comparisons to known galaxies gave their absolute size and brightness.

The two groups are in "remarkable agreement," says Willick. In next month's *Astrophysical Journal Letters*, the SMAC Collaboration reports that clusters of galaxies up to 400 million light-years from Earth are moving with a velocity of about 630 km/s in the direction of the constellation Vela. Willick's group, which has submitted its result to *Astrophysical Journal*, found that galaxy clusters in a slightly larger area flow with a speed of 720 km/s in roughly the same direction.

The problem is that direction is roughly at right angles to the direction originally measured by Postman. Worse, Giovanelli's group reported in the 1 January issue of *Astrophysical Journal* that it had studied several thousand galaxies but found no large bulk flow at all beyond a distance of 200 million light-years. Giovanelli and his colleagues used a method close to that of Willick to determine galaxy distances.

Many astronomers say the disagreement simply shows that all such distance indicators are unreliable, and the question of bulk flows is still open. But Hudson maintains that even though their distance indicators can be off target by as much as 20%, the large numbers of galaxies should cause random errors to be averaged out. "We use 700 galaxies, statistically we get a much stronger signal," says Hudson. Alan Dressler of the Carnegie Institutions in Washington, D.C., who investigated bulk flows in the 1980s using similar techniques, is not convinced. "Systematic errors tend to be big also when random errors are big … so I stopped working with these techniques," he says.

But if the bulk motions are real, astronomers will face the second puzzle: What could cause galaxies to stampede across the sky on such a large scale? One possible explanation is that some huge mass is pulling all these local clusters in one direction. Hudson mentions a couple of candidate superclusters: the Shapley Concentration and the Horologeum Reticulum, two very dense areas with a large number of clusters. "It is possible that they are pulling us in one direction, and there is a void on the other side [of the sky] that happens to push us," says Hudson. But such variations in mass density on such a large scale do not agree well with cosmologists' current model of mass distribution in the universe, says Willick. Dressler agrees: "The kind of mass concentrations necessary to make things move on big scales would make us a very rare part of the universe, much more uncommon than would be comfortable."

Before cosmologists embark on any large-scale revision of their models, the astronomers must get their results to agree. Says Willick, "We will have to try to understand why they are so different."

–ALEXANDER HELLEMANS

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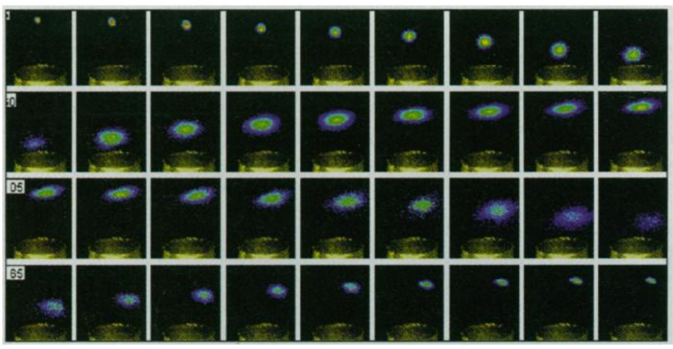
ATOM OPTICS

Videotape Brings Atoms To a Focus

With videotape, a cylinder, a lens, and some glue, researchers have made a focusing mirror that heralds a new age of atom optics

Physicists have known for decades that atoms can behave like light waves, and that they should be able to guide and focus them like beams of light. But researchers in the emerging field of atom optics have found this to be easier said than done: Creating an atom version of even simple optical elements, such as the humble mirror, has proven surprisingly challenging, and progress has been painstakingly slow. But in the 18 January issue of *Physical Review Letters*, a British team reports a major step forward with the first high-quality curved, focusing atom mirror. Such a mirror is likely to be an important ingredient in the creation of a controllable atom beam that could be used to create integrated circuits and other nanostructures many times smaller than those possible today.



Atom trampoline. The atom mirror is accurate enough to reassemble a cloud of atoms after two bounces.

CREDIT: IFAN HUGHES/UNIVERSITY OF SUSSEX

The new mirror, developed by Ed Hinds and colleagues at the University of Sussex, near Brighton, U.K., deflects atoms using magnetic signals recorded onto commercial videotape. The tape is formed into a concave shape, giving a spherical mirror that can bring a beam of atoms to a sharp focus, a development Keith Burnett of Oxford University calls "a significant advance." The mirror is a "breakthrough," agrees Alain Aspect of the Institute of Optics in Orsay, Paris.

The problem with controlling atom beams is that atoms are electrically neutral, so they cannot be focused with electric fields as electrons and ions can, explains Peter Hannaford of Australia's CSIRO research agency in Melbourne. "Also, normally one cannot bounce neutral atoms from surfaces, as most atoms will stick to the surface," he adds. Over the past few years, researchers have devised ways around these problems to create mirrors, using light or magnets to repel atoms from a surface. For example, 4 years ago Hinds's group produced the first magnetic mirror by recording a sine wave audio signal on magnetic tape, producing an alternating magnetic field at the tape's surface. Physicists turn each atom into a miniature bar magnet by exciting them with lasers, imparting the inherent magnetic properties of one of the atom's electrons to the atom as a whole. As each suitably prepared atom approaches the mirror, it is repelled by the field.

Focusing atom beams adds a whole new level of complexity, however, because the mirror must be curved very precisely in three dimensions. To make their focusing mirror, Hinds's team first used a specially designed recording head to imprint an audio sine wave onto the tape. This tape they then glued across the end of a hollow ceramic cylinder, creating a drum. They then pressed a high-quality optical lens into the tape to form a lens shape and backfilled the cylinder with epoxy resin to hold the tape in that shape when the optical lens was removed. "It's a simple technique, but it's the result of probably 4 years of farting about doing things not right," says Hinds. The resulting curved tape surface is still not perfectly smooth, but the team got around this roughness, which would blur the reflection, by ensuring that the field is strong enough to stop atoms from getting close to the surface. Far from the tape, any roughness fades away, leaving a smooth field.

Hinds and his group tested the mirror by using it as an atom trampoline. They positioned the mirror horizontally and, using a magneto-optical trap that confines atoms in space, released a millimeter-wide cloud of atoms from a height above the surface equal to a quarter of the mirror's radius of curvature. After the first bounce, the atoms formed a flat disk above the mirror, and on the second bounce they recombined back into a cloud, exactly as predicted by the rules of atom optics, which take account of the fact that atoms follow curved paths as they fall under the influence of gravity. "The ability to reconstruct the initial atom cloud quite closely after many focused reflections indicates that the quality of the reflection process is quite good," says Hannaford.

Meanwhile, other teams are devising novel ways of creating magnetic mirrors. Hannaford and Geoff Opat at the University of Melbourne and their colleagues have made a prototype mirror of a fine wire grid that will be published next month in *European Physical Journal D*. The mirror is not unlike a miniature version of a car's rear window demister, with gold wires spaced 0.1 millimeters apart. The grid produces an alternating magnetic field when a current passes through, repelling atoms by the same principle as Hinds's mirror. Two teams at Harvard, led by Mara Prentiss and Robert Westervelt, have taken a similar tack with a grid shrunk by 40%. They have now joined forces with Bill Phillips at the National Institute of Standards and Technology in Gaithersburg, Maryland, and with Aspect in Orsay and, in work yet to be published, have measured how well their mirror reflects atoms. "It really is a very good mirror," says Aspect.

With all this activity, researchers are looking forward to more adventurous atom optics. Hannaford and Opat envisage cylinders for piping atoms about and a new generation of atom microtraps. Hinds hopes to build a kind of magnetic table on which atoms can roll around. With microfabrication, "you can make something like a printed circuit for atom optics," says Hinds. Adds Wolfgang Ketterle of the Massachusetts Institute of Technology, "I think we are experiencing a golden age of atomic physics."

–ANDREW WATSON

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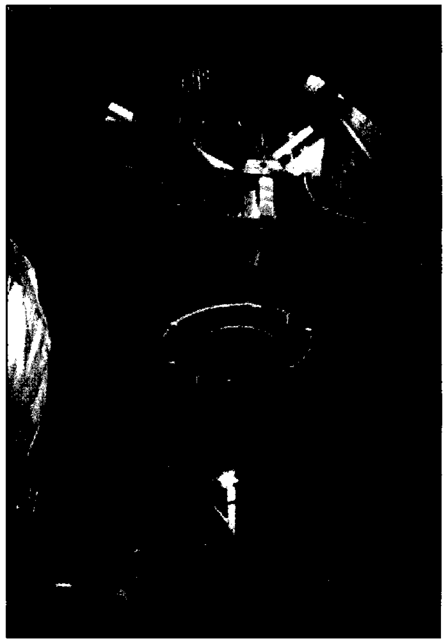
ASTRONOMY

Subaru Opens Up World for Japan

TOKYO—This week, Japanese astronomers hope to capture the first scientific images from the country's new Subaru Telescope atop Mauna Kea in Hawaii. Its 8.3-meter mirror makes it the world's largest single-mirror telescope, and one of a handful of telescopes globally in the 8- to 10-meter range. As the country's first major scientific project ever built on foreign soil, Subaru also marks Japan's entry into the top tier of scientific nations with a global scientific reach. "It's a symbol of a new stage for basic science in Japan," boasts Keiichi Kodaira, director-general of the Tokyo-based National Astronomical Observatory, which built Subaru. "We are contributing to worldwide efforts with a scientific facility that is truly up to international levels."



A new vision. Subaru's primary mirror being moved into place in preparation for "first light" this week.

Kodaira says Subaru will let Japanese scientists work on "an equal footing" with colleagues in the United States and Europe. The $348 million optical-infrared Subaru is expected to make vital contributions to sky surveys and the search for planets orbiting nearby stars. It will also stand out among the thicket of domes atop Mauna Kea, with an innovative cylindrical enclosure that is expected to minimize wind turbulence around the telescope.

Equally novel, but less obvious, is the use of 261 computer-controlled actuators to push and pull the mirror to counter the distortions of temperature and gravity. That's nearly 50% more than are being used for the 8-meter Gemini telescope on Mauna Kea, a multinational consortium that is also preparing to capture its first images. "The larger the number of actuators, the better the control of the surface," says Subaru's director, Norio Kaifu. They are used in combination with the telescope's adaptive optics system, which filters out the flicker that results from Earth's atmosphere.

This kind of accuracy will be critical for some of the ambitious observations astronomers hope to make with the telescope's instruments. A coronagraphic imager, for example, has a mask that blocks the light from the center of a star to allow astronomers to search for orbiting planets or protoplanetary discs. "We now have only indirect evidence of planetary systems around nearby stars," Kaifu says. "Our objective is to get direct images of those planetary systems."

Another unique instrument is the Subaru prime focus camera. It will have the widest field of view among 8-meter-class telescopes and capture images quickly, making it particularly valuable for sky surveys.

The observatory plans to offer international use of Subaru after its yearlong shakedown period. "Subaru is going to be a key component in worldwide efforts to take astronomical observations to the next level," says Matt Mountain, director of the Gemini Observatory. Access to Subaru will be particularly important to Asian colleagues, adds Tsay Wean-shun, an optical astronomer at the Institute of Astronomy at Taiwan's National Central University in Chung-Li. "It means we will be able to compete with astronomers in Europe and America," he says.

–DENNIS NORMILE