Small telescopes can thrive in the shadow of giant new observatories—but only if astronomers adapt them to specialized projects

Astronomers Overcome 'Aperture Envy'

Last year, Michael Castelaz published an extrapolation that would change the face of astronomy if it ever came to pass. With his tongue firmly in his cheek, the East Tennessee State University astronomer examined the trend toward building bigger and bolder ground-based telescopes in the United States. Funding agencies would pay for their operation by shutting down smaller instruments, he predicted, eventually leading to a $1.2 billion, 42-meter "Ultimate Telescope" at the expense of all other facilities. Just 44 astronomers per year would have access to this behemoth, Castelaz wrote,* noting that "at least journals would be a bit lighter."

The humor had an edge to it. Castelaz captured the feelings of many users of small telescopes, who are gritting their teeth at perceived slights from those who dispense astronomy's budgetary morsels. For instance, the National Optical Astronomy Observatories (NOAO) of Tucson, Arizona, is transferring its 1-meter-class telescopes to private consortia of universities, thus taking them out of circulation for the community as a whole. Most recently, the National Research Council's "decadal review" of priorities in astronomy (*Science*, 26 May, p. 1310) scarcely mentioned what some astronomers view as the critical role of small telescopes in modern research. Instead, the report focused on giant projects such as a proposed 30-meter segmented-mirror telescope, which would cost the United States and international partners at least $500 million to build.

Robot farm. Small telescopes at the Fairborn Observatory in southern Arizona can collect data with little or no human input.

Will these events make Castelaz more prophet than parodist? Probably not, says astronomer John Huchra of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. "You won't get a half-billion dollars by closing small telescopes," he says. "If you use the right tools for the job, small telescopes can be incredibly cost effective. You can still do major things." Indeed, many argue that small telescopes are playing a more—not less—important role these days, complementing the work of the giant facilities and performing observations for which only they are suited.

Astronomers have learned to call upon the unique abilities of telescopes with apertures of 2 meters or less to monitor broad swaths of the sky and stare at the same objects night after night, sometimes for years. Various teams are turning small telescopes into robots, creating networks of scopes that span the globe and devoting them to survey projects that big telescopes don't have a prayer of tackling. Furthermore, serious amateurs now use electronic detectors as good as those used by professional astronomers a decade ago, making amateur-professional collaborations a growth industry.

"Small telescopes may not make much front-page news, but they are the backbone of astronomy," says Janet Mattei, director of the American Association of Variable Star Observers (AAVSO) in Cambridge, Massachusetts. Engineer Lou Boyd, who runs a fleet of robotic telescopes at the private Fairborn Observatory in southern Arizona, makes the same point more colorfully: "If you have a hospital lab with a CAT scanner, you still need to have people doing the blood work."

A growing voice

Mattei, Boyd, and their colleagues are passionate about small telescopes, but until recently it was a quiet passion. "The voice of this majority of the astronomical community has been minimal," says Terry Oswalt, program director for stellar astronomy and astrophysics at the National Science Foundation (NSF) and an astronomer at the Florida Institute of Technology in Melbourne. "It's nowhere near what you would expect for the number of people involved." Astronomers began to tout the advantages of small telescopes en masse in October 1996 at a meeting at Lowell Observatory in Flagstaff, Arizona, where Percival Lowell gazed upon Mars at the turn of the century with a 0.6-meter refractor. Since then, most of the biannual meetings of the American Astronomical Society (AAS) have featured at least one session devoted to small-telescope issues.

Clear themes have emerged from these gatherings. At the AAS meeting last month in Rochester, New York, several astronomers described the merits of fully automated small telescopes. These systems are designed to open the dome on their own when conditions are right and take data. Once running, they zip among preprogrammed targets in the sky more quickly and make observations more consistently than human operators ever could. "Robotic telescopes are ideal for performing repetitive tasks that require many nights throughout the year," says astronomer Alex Filippenko of the University of California (UC), Berkeley. Astronomers might get just a few nights per year on large telescopes, he notes—not nearly enough to monitor the sky for rare events or track the long-term behavior of objects.

Filippenko's own robotic system, the 0.75-meter Katzman Automatic Imaging Telescope (KAIT), is setting new records for finding nearby supernovae, the explosions of massive stars. KAIT replaced a small manual telescope at UC's Lick Observatory near San Jose. The telescope records images of several thousand galaxies, one by one, then

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CREDIT: GREG HENRY/TENNESSEE STATE UNIVERSITY repeats its observations every three to five clear nights. An analysis program flags whether any new flares of light have appeared in the galaxies since the previous images were taken. Undergraduates at UC Berkeley check KAIT's identifications the next morning to make sure they aren't asteroids, electronic blips, or other artifacts. In this way KAIT found 40 supernovae in 1999, more than twice the number spotted by any similar system. These explosions provide the calibration necessary to show whether much more distant supernovae have any odd features that would undercut their role as cosmic yardsticks. So far, says Filippenko, the nearby and distant supernovae display some differences, but none serious enough to scuttle the conclusion that the universe will expand more quickly as time passes (*Science*, 18 December 1998, p. 2156).

Another automated system gaining renown is the Robotic Optical Transient Search Experiment (ROTSE) at Los Alamos National Laboratory in New Mexico. ROTSE uses small telescopes indeed: four paparazzi-style telephoto lenses mounted on a platform that can swivel quickly to any part of the sky. Astronomers built ROTSE to pursue the optical flashes associated with gamma ray bursts, powerful explosions in the distant universe that satellites can detect. Its most spectacular success came on 23 January 1999, when it triggered on an alert from a detector in orbit on NASA's Compton Gamma-Ray Observatory. Within 22 seconds, ROTSE captured the light from an extraordinarily bright burst several billion light-years from Earth (*Science*, 26 March 1999, p. 2003). Such early detections will help astrophysicists devise better models of the fantastically powerful blasts. A similar apparatus, the Livermore Optical Transient Imaging System (LOTIS), watches for flashes from the Lawrence Livermore National Laboratory in California.

The nation's hotbed for robotic telescopes is Fairborn Observatory, 6 kilometers from the Mexican border near Nogales, Arizona. Boyd, the observatory's sole staff member, oversees eight scopes ranging from 0.25 meters to 0.8 meters across; five more are on the way. Astronomers from South Carolina to Vienna, Austria, receive data from the machines over the Internet. Greg Henry of Tennessee State University in Nashville has seen his career transformed by his four telescopes currently operating at Fairborn. "I'm literally getting 50 to 100 years' worth of data now compared to what I would get in a single year working manually," says Henry. "And the cost of operation is a tiny fraction of what it was."

Henry's forte is examining long-term changes in the brightnesses of stars like our sun, which are vital for understanding how the sun may influence Earth's climate. The precision of each robot's data from night to night enables Henry to calculate fluctuations as small as one 10-thousandth of a stellar magnitude, the most precise readings ever achieved. That specialty landed Henry on front pages last November when one of his telescopes spotted the dip in light caused by a Jupiter-sized planet passing in front of another star (*Science*, 19 November 1999, p. 1451). Perhaps the best part, he says, is his observing schedule: "I program them and go home and get a good night's sleep."

In a flash. LOTIS (*above*) and ROTSE (*right*, with team members Jim Wren and Robert Keyhoe) use telephoto lenses to watch for gamma ray bursts.

CREDITS: (LEFT TO RIGHT) HYE-SOOK PARK/LAWRENCE LIVERMORE NATIONAL LABORATORY; CARL AKERLOF

Fixed stare

Henry's observations illustrate a big advantage that small telescopes have over their behemoth brethren: They can be used for long-term observations that watch for changes over time. Such observations would be unthinkable with instruments at the Keck Observatory on Mauna Kea in Hawaii, where viewing time is in fierce demand and is booked months in advance.

Astronomer G. Wesley Lockwood of Lowell Observatory has made good use of one small telescope's long, fixed stare. Since 1971, he has used a 0.55-meter telescope to monitor changes in the brightness of Saturn's large moon Titan. Last year, astronomer Ralph Lorenz and colleagues from the University of Arizona in Tucson combined this 30-year stretch of data with their own Hubble Space Telescope observations of Titan in 1994 and 1997 to devise a new model of how a 14.5-year seasonal cycle affects the moon's hazy atmosphere. The results appeared in the December 1999 issue of *Icarus*. Lockwood also uses the telescope to monitor the changing light levels from Uranus and Neptune.

More recently, a new form of long-term observation has come into vogue: Astronomers have orchestrated globe-girdling networks to conduct uninterrupted studies of specific stars around the clock. One such array is the Whole Earth Telescope (WET), directed by astronomer Steven Kawaler at Iowa State University in Ames. The network consists of a dozen or more observatories worldwide that collaborate twice a year for about 2 weeks at a time. The network includes 1-meter to 2-meter-class telescopes in countries such as China, Honduras, Lithuania, and Brazil, where astronomers otherwise might not get the chance to participate in international projects.

WET's main quarries are pulsating white dwarfs, the dense remnants of stars like our sun that have consumed their nuclear fuel. Some of these dead stars pulsate with periods of minutes to hours; no single observatory could follow their repeated cycles. "The idea behind WET is the inverse of the British Empire: The sun never rises on it," says one of the network's coordinators, astronomer Donald Winget of the University of Texas, Austin. "We can keep an object in continuous view." An unbroken stream of observations enables the WET team to conduct "asteroseismology" on the distant dwarfs, using their pulsations to gauge their internal structures. This, in turn, helps the researchers calibrate the ages of the dwarfs, which are among the best chronometers in the galaxy because they cool predictably, like Earth-sized cinders.

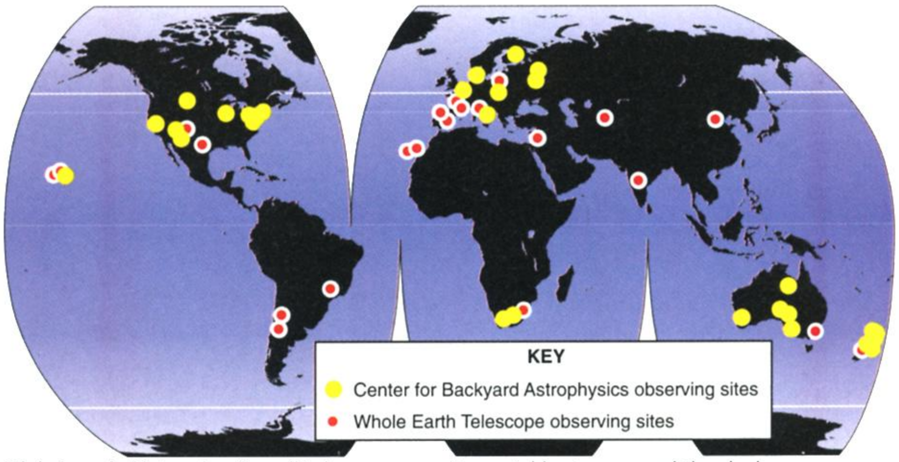
Although WET's members are professionals, a similar global network draws mostly upon talented amateurs. Astronomer Joseph Patterson of Columbia University in New York City established the Center for Backyard Astrophysics (CBA) to study cataclysmic variables, binary star systems in which a disk of gas spiraling onto a white dwarf periodically unleashes energetic bursts. Patterson organizes science campaigns for the 20 or so members of his collaboration, who typically use 0.25-meter to 0.7-meter telescopes. "The CBA is more effective than any telescope I've ever used," he says. "We focus on individual stars for hundreds of hours, which makes us very good at finding all of their rotation periods." That intensive monitoring lets the team scrutinize curious wobbles and instabilities within many disks, which may control when the energy spigots from white dwarfs turn on and off.

Patterson lauds his amateur assemblage. "It's a tool that virtually nobody else has," he says. "In every country in the world, there are well-equipped amateurs interested in participating in research. They can be tremendous assets." AAVSO's Mattei concurs. In May, she notes, some of her 600 observers worldwide monitored the fluctuations of a cataclysmic variable to help a team using the Hubble decide whether to observe it. If the star had gotten too bright, Hubble's operators would have postponed the study to avoid harming its detectors. "If not for amateur astronomers observing in their backyards with small telescopes, a lot of very successful observing runs with satellites would not be possible," Mattei says.

All-sky watchers

When it comes to bright objects and broad patches of the sky, small telescopes are the only games in town. That point was made clear in a paper posted in May on the Los Alamos preprint archive (xxx.lanl.gov/abs/astro-ph/0005236) by astronomer Grzegorz Pojmanski of Warsaw University in Poland. Using a telescope with a mere 8-centimeter lens at Las Campanas Observatory in Chile, Pojmanski's project, the All-Sky Automated Survey, unveiled 3400 new variable stars in a typical slice of the Southern Hemisphere sky. Incredibly, just 11% of those stars were previously cataloged as variable. Pojmanski's robot has thus far examined less than 1% of the sky, so nearly a half-million bright variable stars may await discovery. "It's sort of embarrassing to the astronomical community that the bright sky is so poorly mapped," says astrophysicist Bohdan Paczyński of Princeton University.

Other established surveys also use small telescopes to tile the sky systemically. For example, the Two Micron All-Sky Survey (2MASS), led by astronomers at the University of Massachusetts, Amherst, and the California Institute of Technology in Pasadena, is using automated 1.3-meter telescopes in Arizona and Chile to compile the most complete census of the cosmos to date at near-infrared wavelengths. That's the domain of relatively cool objects, such as red dwarf stars, as well as galaxies and galactic structures that ordinarily lie behind the Milky Way's obscuring bands of dust.



Global reach. Networks of small telescopes monitor variable stars around the clock.

Several ongoing programs scour space for dangerous asteroids using 1-meter or smaller telescopes, such as the University of Arizona's Spacewatch and the Air Force–sponsored Lincoln Near-Earth Asteroid Research (LINEAR) program at the White Sands Missile Range in New Mexico. And when they are not zeroing in on gamma ray bursts, both ROTSE and LOTIS take images of the whole sky at least twice each night, revealing a slew of variable stars, asteroids, and other transient objects. "There's a unique new niche here for small telescopes: the time domain," says astronomer Jeff Bloch of Los Alamos, a member of the ROTSE team. "With new equipment and greater bandwidth, it will become economically feasible to do all the sky all the time."

Small glass, big glass. A 0.9-meter telescope (second from left) at Kitt Peak in Arizona is run by a private consortium of universities.

Caught in the squeeze

Such innovative tools may keep small telescopes in the scientific game. Nevertheless, at the large national and international observatories, the momentum clearly belongs to the growing fleet of 8-meter to 10-meter glass giants. "NOAO needs to focus on large facilities that transcend the capability of single universities," says director Sidney Wolff. "It's not that small telescopes produce bad science, but the kinds of forefront questions we're asking today require us to choose more powerful instruments and multi-institutional collaborations." That choice, she says, was forced by a steady erosion of NOAO's purchasing power—now 40% lower than it was 15 years ago.

NOAO's main outpost, the Kitt Peak National Observatory (KPNO) southwest of Tucson, transferred two small telescopes to universities in the 1990s. The Southeastern Association for Research in Astronomy (SARA) refurbished one of them, a 0.9-meter telescope, and moved it to a new spot at Kitt Peak. Researchers at six SARA institutions, led by the Florida Institute of Technology, perform observations remotely over the Internet. A consortium led by Western Kentucky University in Bowling Green is preparing to roboticize an outdated 1.3-meter telescope at KPNO for research and real-time online astronomy education. However, two more popular 0.9-meter telescopes at Kitt Peak are on the auction block. NOAO also is likely to phase out some of its smaller telescopes at its Southern Hemisphere station at Cerro Tololo, Chile, after a new 4-meter telescope comes online there, Wolff says.

Concerned astronomers have succeeded in saving most of the small telescopes that appeared to face extinction less than a decade ago. But the struggle to keep them open may continue, and their supporters wonder why. "I think it's essential to maintain a few well-instrumented small telescopes at the major sites," CfA's Huchra says. "This trend hurts students the most. We're beginning to produce students who have never been to a telescope." Lockwood agrees: "Small telescopes aren't as glamorous as the ones on Millionaire's Row in the exhibit hall, but they still carry much of the load in astronomy," he said at a January meeting of the AAS in Atlanta. "We all have them in our blood."

–ROBERT IRION

CREDITS (TOP TO BOTTOM): A. STONEBRAKER (ADAPTED FROM WET AND CBA WEB SITES); TERRY OSWALT/FLORIDA INSTITUTE OF TECHNOLOGY