says Prewitt, is its address file. It wasn't until the mid-1990s that computer systems could carry out prompt and precise tracking of large populations. To do the job right, the Census Bureau links its master address file with a digital database of geographic features such as roads, railroads, rivers, lakes, and political boundaries, allowing the bureau to crosscheck its addresses against relevant physical features. By 2010, the bureau hopes to make databases compatible with global positioning systems, allowing fieldworkers to consult digital rather than paper maps and to update addresses instantly.

So far the results of the ACS have been heartening, says Gordon. Although the initial mail response rate of 52% is lower than the 58% for the long form—not surprising because the annual exercises won't be accompanied by the blast of publicity the decennial census generates—follow-ups have raised that to 96%. And the quality of the data is better, says demographer Joe Salvo of the New York City Planning Department. A professional staff skilled at eliciting information from reluctant citizens, he notes, has less need for imputation, the last-minute inferring of missing data.

The ACS is the linchpin of the Census Bureau's plans for "re-engineering" the census. With the long form accounting for 60% of the bureau's paperwork, Prewitt says that adoption of the ACS will hasten the day when the decennial census can be conducted via postcards and the Internet.

The ACS still must jump through a few hoops. The next challenge is winning approval of the $219 million it requested in the 2003 fiscal year to do the job right. Although that's a 77% increase over its normal off-year budget, Gordon says the new format won't cost any more in the long run: an estimated $11.25 billion, compared with $11.7 billion for the 2000 census.

Congressional reaction to the ACS has been largely favorable, although members continue to express concern about the "intrusive" and mandatory nature of the survey. The chair of the House subcommittee that oversees the bureau, Representative Dave Weldon (R–FL), has just asked the General Accounting Office to conduct an "independent investigation" of these issues as well as the ACS's cost-effectiveness.

In the meantime, Gordon says that local officials have already embraced the ACS. Salvo, for one, says efforts to help neighborhoods and businesses recover from 11 September could have benefited from more comprehensive and up-to-date workforce and employment data. "It's this kind of situation that makes the ACS so attractive to us," he says. "I really think the era of mass census-taking for the long form data is over."

In Springfield, Massachusetts, officials are already using ACS data to improve delivery of health and social services. When cancer registries at two hospitals showed a large number of women with late-stage breast cancer, health officials used the ACS to calculate rates for women over 40 for each police sector. Black or Spanish-speaking women in low-income areas turned out to have the highest rates, a preliminary finding that may help public health workers in designing information and screening campaigns.

Springfield is also using ACS to tackle teen violence. Combining data on where violent youths were arrested in 1999 with demographic data from the ACS allowed officials to map school dropout rates, work patterns, home ownership, single-parent families, and teens' work and educational status. Amy Pasini, a violence and injury prevention coordinator at Baystate Medical Center in Springfield, says all this will be useful in planning intervention strategies: "Using 10-year-old census data doesn't have much teeth to it. … We see the ACS as a gold mine."

—CONSTANCE HOLDEN

ASTRONOMY

Unusual Venture Helps Make the Sky Affordable

High-tech, assembly-line techniques are putting professional-quality telescopes within reach for a global scientific community

A new vision. This robotic, 2-meter optical telescope can serve students and professionals alike.

LIVERPOOL, U.K.—Henry Ford had the big idea: Build automobiles on a production line, and they will be cheap enough for everyone to afford. The essence of that philosophy is one of the driving forces behind Telescope Technologies Ltd. (TTL), a start-up owned by Liverpool John Moores University (JMU). Its goal is to open up the international market for optical telescopes that can do real science.

TTL's instruments are not for hobbyists to set up in their back garden. Their mirrors are 2 meters or more across, and they stand more than 7 meters tall. Most professional telescopes of this class are one-off projects, designed and built from scratch. But TTL and its original partners at the Royal Greenwich Observatory (RGO) in Cambridge had a different idea: Come up with a robust design that can be scaled up or down, and make it robotic to reduce operating costs. Price it at a fraction of the normal cost, then build it again and again and again.

The result, which sells for about $3 million—less than half the cost of a similar one-off instrument—means that groups with a limited budget can now get their hands on a frontline professional telescope. Although TTL's first instrument is still waiting to be installed on the Canary Islands off Africa's Atlantic coast, the company has already completed one for a consortium of Indian universities and is building two for an educational foundation (see map). It has just won an order from China, and it has had more than 100 inquiries, including groups in Indonesia, Africa, and the Indian subcontinent.

"There are no others in the world like it," says British software entrepreneur Dill Faulkes, whose foundation is buying two 2-meter TTL telescopes that will be located in Hawaii and Australia. The instruments will be dedicated to students for real-time observations via the Internet. Robotics is the key for Chen Dong of the Yunnan Astronomical Observatory in China, which plans to install a 2.4-meter TTL scope in 2004 atop a remote 3000-meter-high mountain in southwestern China. "This is a great advantage for the [Gaomeigu] observatory," he says about what will be China's largest telescope. "It will help scientists save time and money and allow them to do international joint observations by clicking a mouse."

TTL's headquarters in Liverpool looks just like all the industrial units dotted around this former docklands, except for the sliding panels on the roof to allow factory tests of the telescopes. As three scopes currently take shape on the shop floor, the staff nervously checks a Webcam to monitor progress of the company's prototype instrument, the Liverpool Telescope. This instrument, which will be run by JMU as a U.K. national facility, has been sitting in containers at its mountaintop observatory in the Canary Islands since November as local contractors continue to pour concrete. "It's like standing on stage waiting for the curtain to go up," says Paul Rees, project manager at TTL. "Anticipation is very high."

The idea for the company grew out of an effort by Mike Bode, a JMU astrophysicist, to win government support for a robotic telescope. Bode specializes in novae, fleeting events that require rapid reprogramming of telescope time to capture. Bode was frustrated by the long lead times at most large facilities in allocating blocks of observing time. What he wanted was a large telescope that could react immediately to a sudden event or multitask so that, say, one object could be monitored for a few minutes a night over many months in the midst of other observations.

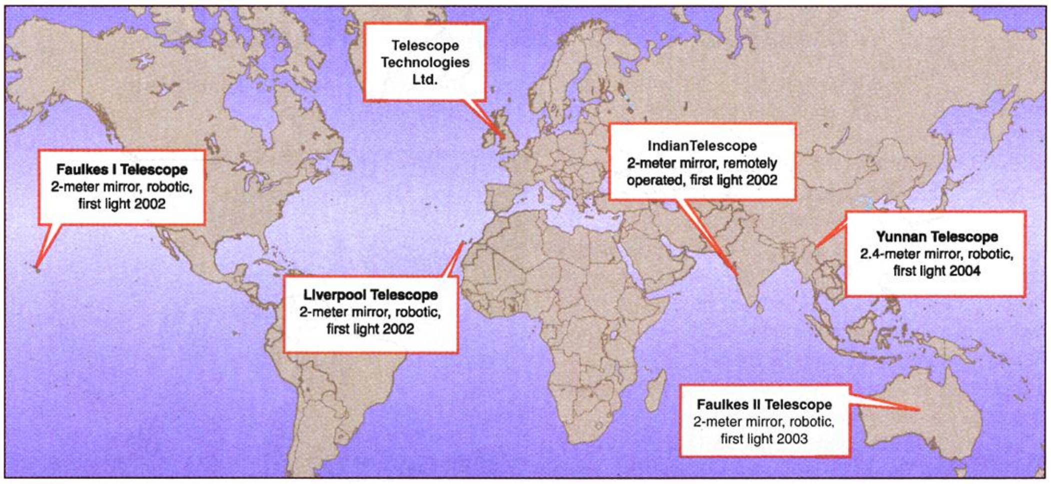
At about the same time, RGO staff wanted to use knowledge gained from helping design the international 8-meter Gemini telescopes in Hawaii and Chile to build a range of medium-sized scopes. JMU and RGO came together and founded TTL in 1996. A regional development grant of $2.3 million from the European Union helped with the start-up capital, on condition that local suppliers were to be used as much as possible. The design team was to remain at RGO, and assembly was to be carried out in a new plant in Liverpool.

Then came a near-fatal blow. In 1997, the government closed RGO and consolidated British astronomy facilities in Edinburgh. JMU, with little experience in telescope design, had to decide whether to take on the whole operation. "There was a lot of navel gazing," says TTL managing director Michael Daly, before JMU decided to take the plunge into running the commercial venture.

Although the episode caused a year's delay in the project, the decision to move key design staff to Liverpool and locate the whole team under one roof paid handsome dividends when it came to honing down the design. Conventional scopes are usually deliberately "overengineered" to eliminate unwanted movement. In contrast, TTL's designers used a detailed computer modeling technique known as finite element analysis to predict how key components would behave. This high-tech approach allowed them to make the structure lighter, which increases its resonant frequency —its natural wobble—and allows the control system to effectively cancel out the effect of the wind, keeping the scope rock steady. Result: The fast-moving telescope can operate in the open air, without a cumbersome dome.

Other key technologies include the motors and computers that rotate the telescope. TTL has relied heavily on off-the-shelf equipment from industrial robotics, which reduces costs and makes maintenance simpler. "[Our telescopes] couldn't have been built 10 years ago," says Rees. "We use less metal and glass but more activation."

That painstaking design "really pays off" when first light arrives, says TTL optics designer Patrick Conway. The team took less than an hour to capture its first image of a known star after pointing the newly completed Liverpool Telescope through a hole in the factory roof one night last year. "Other large telescopes have taken weeks to acquire their first identifiable object," says Conway.



Economies of scale. TTL's shop floor in Liverpool is churning out telescopes for customers around the world (*left*).

As well as providing scientists with excellent vision, TTL hopes its robotic scopes will wow them with their ease of use. In TTL's definition, robotics doesn't just mean that an astronomer can control the telescope from some distant and hospitable location. Rather, it means that astronomers can go to bed at night and wake up the next morning with data. Astronomers send observation requests to a "virtual astronomer": one of eight onsite computers that control the telescope. The virtual astronomer ranks the requests by importance. "Taking astronomers away from the telescope makes it more efficient," says Daly. TTL estimates that a robotic scope will squeeze almost twice as much observing time into a night.

Robotic control, combined with the ability to find a new target in an average of 23 seconds, also makes the scopes ideal for the sort of time-critical observations that Bode envisaged. Today's top targets are gamma ray bursts, mysterious high-energy blasts from deep space that reach us about once per day and are only detectable from space. To understand them, astronomers need a fast-moving telescope that can catch the faint and short-lived optical glow associated with a gamma ray burst. An alerting network that allows orbiting gamma ray observatories to steer small robotic telescopes to the targets already exists, but it will get a huge boost from NASA's pending Swift satellite and the Liverpool Telescope, which will be the world's largest robotic scope. "The Liverpool Telescope could then catch one gamma ray burst per week," says Bode.

The prototype Liverpool Telescope will also take orders from British schoolchildren. Under another project being developed by

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JMU, dubbed the National Schools Observatory, 5% of the telescope's observing time will be allocated to schools. Registered groups can request observations from the telescope using a comprehensive Web site stuffed with astronomical information and activities. And thanks to the virtual astronomer, the students won't get pushed aside by "proper" researchers. "We'll get equal footing," says astronomer Andy Newsam, who is developing the school's Web site at JMU.

Faulkes is also planning an ambitious educational project with his two telescopes. The sites were chosen so that U.K. students would have dark sky when they are in the classroom. His plan is to offer 700 schools a chance to control the telescopes themselves, often collaborating with researchers on real science projects. "It's all about understanding science as it happens," he says.

Although juggling all these projects is creating anxious moments for the TTL staff, they track precisely with what the company's founders hoped to achieve, namely, to serve a universe of customers. "This is not just a university design exercise, it's a business," says Daly. "We succeed or fail as a business. If we fail, we close." Henry Ford would be proud.

–DANIEL CLERY

With reporting by Ding Yimin in Beijing.

BIOENGINEERING

Working Outside the Protein-Synthesis Rules

Proteins built in the ribosome are subject to certain restrictions, so researchers are harnessing a nonribosomal system that might one day make new drugs

Most proteins are built according to a set of rules as strict as any list of "don'ts" posted at a public swimming pool. Only 21 types of amino acids are permitted. Proteins must not loop. Non–amino acids may not be included in the protein.

Life has gotten by pretty well with these restrictions. They are imposed on all proteins built by a cell's ribosomes, and for higher organisms, that means all proteins. But many bacteria and fungi can turn to an alternative system that allows them to toss aside the standard rules of molecular biology. Bypassing the ribosome, they manufacture some of their most important short proteins using giant enzymes that recognize amino acids and link them directly into chains.

Because the so-called nonribosomal peptide synthetases (NRPSs) are not bound by the ribosome's rulebook, they are able to produce an array of peptides with unusual properties. Peptides manufactured by NRPSs include some of the most potent pharmaceuticals known, from penicillin to the immunosuppressant cyclosporin. Researchers have known about this alternative protein-construction system for decades, but only recently have they begun to build a solid molecular understanding of how the system works. With this knowledge, they hope to alter the NRPS machinery to make even more effective variants of powerful existing drugs as well as novel drugs built along the same lines. Although the goal of designing drug-factory enzymes is still a long way off, recently researchers have begun to engineer new nonribosomal proteins.

An alternative system

Bacteria and fungi use nonribosomal peptides for critical tasks such as killing parasites, communicating with members of their own species, and regulating the movements of ions. The peptides are ideal for these delicate tasks because they resist degradation and are unlikely to be mistaken for other compounds. These properties are a result of their unique composition: Scientists have spotted several hundred different molecular ingredients in various nonribosomally manufactured peptides, most of which the ribosomes have never heard of. These compounds include so-called right-handed amino acids, the rare twins of the standard left-handed model, as well as molecular relatives of amino acids such as acyl acids. But it's not just strange starting materials that make these peptides unconventional. They frequently contain loops, which are almost never found in standard proteins. The eccentric structures of these proteins foil protein-eating enzymes called proteases, which prefer to digest conventional strings of amino acids.

Who needs the ribosome? This mold uses nonribosomal peptide synthetase to make penicillin.

CREDIT: ANDREW SYRED, SPL/PHOTO RESEARCHERS INC.

The NRPSs that build these odd peptides are the largest enzymes known in nature. They're made up of a series of modules, each of which is responsible for adding one particular unit—be it a specific left- or right-handed amino acid or some other compound—to a growing peptide chain.

Each module in the NRPS consists of three subunits. The first is an adenylation (A) element that recognizes a free-floating amino acid, say, and prepares it for incorporation into the chain. Next are two subunits that attach the new amino acid to its neighbors in the chain, known as the condensation (C) and thiolation (T or PCP) domains. The sequence of modules in an enzyme constitutes a unique blueprint designed to produce a particular protein. The final module of the chain has a special termination (Te) domain that releases the protein, sometimes drawing it into a loop.

Most NRPSs consist of four to 10 modules, but the enzymes—and therefore the peptides they produce—can reach up to 50 units in length. NRPSs can be enormous, for an enzyme. The 11-module cyclosporin NRPS, for example, weighs in at a whopping 1700 kilodaltons (kD), compared to about 20 kD for myoglobin, a ribosomally produced protein that helps the body store oxygen.

Each species of bacterium or fungus that relies on the enzymes carries just one or two different NRPSs, in part because they are so unwieldy. But given the diversity of species that use the alternative protein-building system, researchers expect that a wealth of NRPS diversity must be out there. Figuring out how the modules recognize their target molecules and string them together might allow researchers to build on one of the existing NRPS plans.

Breaking down the problem

The immense size of NRPSs has prevented scientists from deducing their structure—a key to understanding how the enzymes work—using the standard tricks. "Some people think they are impossible to crystallize," says biochemist Hans von Dohren of the