supply of cheap, well-trained labor.

U.S. environmental activists have also begun building ties. A Berkeley, California–based nonprofit called the Nautilus Institute believes that one major cause of the famine is an energy shortage triggered when China and Russia began cutting back on fuel subsidies. Nautilus, which tracks Asian security issues, first made contact with North Korean leaders in 1991, and last fall, after 4 years of up-and-down negotiations with its Korean counterpart, a team installed seven advanced wind generators in a small village. In addition to their goal of supplying power for a clinic, irrigation pumps, and other vital functions, project leaders hope their North Korean counterparts, who are maintaining the generators, will adapt and disseminate the new technology throughout the country. "The engineers and technicians we met were well-educated, nimble-minded, and eager learners," wrote Jim Williams in the May/June issue of *The Bulletin of the Atomic Scientists*.

The most active area of science and technology in North Korea—military research—is also the most secretive. The country has developed and tested long-range missiles that could reach Japan, and it may be working on one that could threaten parts of the United States. It is also believed to have shared weapons technology with other countries. In June, Indian customs officials intercepted a North Korean ship carrying crates of blueprints, parts, and tools for making Scud missiles that was presumably headed to Pakistan. That country's Ghauri missile is thought to be an exact copy of North Korea's Rodong missile, which is based on the Russian Scud.

Ironically, the best hope for the country's neglected civilian sector may be outside pressure to curb its military activities, combined with its desperate food situation. In April North Korea allowed U.S. inspectors to visit an underground site suspected of being used to make nuclear bombs in exchange for technical help in growing potatoes. Such assistance could pave the way for stronger scientific ties with the outside world for this closed and secretive country. **–MICHAEL BAKER**

Michael Baker writes from Seoul.

ASTRONOMY

The First Step to Heaven

Every effort to survey cosmic distances relies on a common yardstick, found in our own neighborhood. But astronomers can't agree on its length

In the old Led Zeppelin song, there's a lady who is buying a stairway to heaven. Astronomers who measure distances across the glittering heavens must wish it were that easy to get what they're looking for. They have a staircase of sorts: Distance indicators that work within our galaxy and its immediate environs measure the first step, which sets the size of every subsequent step out into the cosmos. But while astronomers have gotten better at counting the distant steps, and thus getting relative distances in the distant universe, they have been unable to beg, borrow, or steal a final answer for the size of the very first step.

The almost absurd tininess of that step, cosmically speaking, is galling all by itself: The distance is the short hop between us and the Large Magellanic Cloud (LMC). One of two dwarf galaxies hovering on the outskirts of the Milky Way, it's plainly visible as a twinkling wisp in the sky of the Southern Hemisphere. In the favored units of astronomy, the LMC is somewhere between 40 kiloparsecs (or 40 kpc, about 130,000 light-years) and 60 kpc away. But because the LMC is where astronomers prepare for their next step out into the cosmos by calibrating a set of cosmic surveyors' beacons known as Cepheid variable stars, that 40% uncertainty propagates outward as far as the cosmic distance ladder can reach.

Because cosmic distances are critical to calculating the age and expansion rate of the entire universe, "the consequences of that uncertainty are enormous," says Barry Madore of the California Institute of Technology in Pasadena, a member of the Hubble Key Project, which aims to measure the cosmic expansion rate, or Hubble constant. Madore and his colleagues can now find relative distances far beyond our galaxy with such precision that their latest Hubble constant results claim a formal uncertainty of only ±10%, for a 20% spread (*Science*, 28 May, p. 1438). But the doubts about that first step in the ladder mean that the central value could change by more than that. As Alistair Walker, an astronomer at the Cerro Tololo Inter-American Observatory in La Serena, Chile, writes in a forthcoming review, "If we cannot agree upon the distance to two galaxies that are only a few tens of kpc from us, how can we be sure of the distances to more remote galaxies?"

The lack of a resolution "is not for lack of trying," says Wendy Freedman, an astronomer at the Carnegie Observatories in Pasadena, California, and a leader of the Key Project. At least 10 different indicators have been applied to the problem. They include "standard candle" stars thought to have a known intrinsic brightness, so that their faintness as seen from Earth gives a distance measure, as well as clever geometric techniques that derive distance from the apparent size of objects with known dimensions—in effect, cosmic yardsticks. The results are all over the map, a situation that only worsened 2 years ago, when results came in from a European spacecraft called Hipparcos. Designed to settle the issue of galactic distances, Hipparcos instead "produced a lot of confusion," says Princeton University's Bohdan Paczyński.

A cloudy view

For most of this century, the two dwarf galaxies named for the Portuguese navigator Ferdinand Magellan, one of the first Europeans to see them, have played a crucial role in astronomy. Around 1910, while studying photographic plates of the Small Magellanic Cloud, Harvard's Henrietta Leavitt discovered the period-luminosity relation for Cepheids: Those that flicker more slowly are brighter. Since then, Cepheids have become the linchpin of cosmologists' efforts to survey the universe. By using the period of a Cepheid as a proxy for its actual brightness, then measuring its apparent brightness, astronomers can infer how far away it is. They can thus arrive at a distance to the galaxy containing the Cepheid, which allows them to calibrate standard candles that can be seen at even greater distances, such as the exploding stars called supernovae.

But Cepheids themselves have to be calibrated. Astronomers have to determine the absolute brightness of Cepheids with different periods—the so-called zero point of the Cepheid distance scale.

They've traditionally done so by measuring the distance to a handful of Cepheids in our own galaxy. Few Cepheids are close enough for observers to apply the only truly direct technique for determining astronomical distances, called parallax—measuring how much the stars seem to move back and forth in the sky as Earth orbits the sun. So observers made parallax measurements of nearby "main-sequence" stars, garden-variety stars like our sun, which have a characteristic relationship between color and brightness. Using stars at various points of the main sequence as rough standard candles, they estimated the distance to star clusters within our galaxy that also contain Cepheids. This rough galactic calibration could then be applied to the numerous, easily observed Cepheids in the LMC to find its distance and determine the zero point for the entire

CREDITS: (TOP TO BOTTOM) LUKE DODD/PHOTO RESEARCHERS; NASA

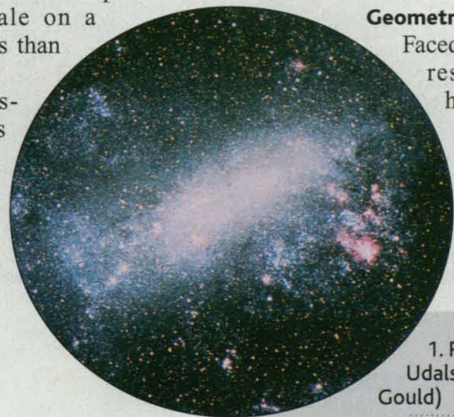
range of Cepheids.

But astronomers never placed great confidence in this multistage process. "The galactic calibration is very uncertain," says Andrzej Udalski of the Warsaw University Observatory, in part because obscuring dust in the plane of the galaxy confuses matters. And applying that calibration to Cepheids in the Magellanic Clouds is still more uncertain. Stars in the Milky Way tend to have a greater complement of "metals," or elements heavier than helium, than those in the Magellanic Clouds, and some theorists think metals can change the brightness of a Cepheid that has a specific period.

But with the launch of the Hubble Space Telescope in 1990 and other gains in instrumentation and theory, measures of relative distances into the far reaches of the cosmos —based on the relative brightness of supernovae, whole galaxies, and other objects— got better and better. The importance of Cepheids for calibrating these indicators grew. So in 1992, Madore and Freedman wrote a paper that took into account all existing evidence and argued that the zero point should be fixed by setting the LMC distance at 50.1 kpc. "We just decided, we'll move the battlefield away from the whole galactic situation, where things are uncertain," says Madore. "Rather than trying to solve the problem, we just deferred it and said … 'This is our zero point; if that changes, then everything goes with it,' " says Madore.

But challenges to that value began mounting in 1997, when Michael Feast of the University of Cape Town in South Africa and Robin Catchpole of the Royal Greenwich Observatory in Cambridge, U.K., announced results from the Hipparcos satellite, designed for high-precision cosmic surveying. Hipparcos could measure parallaxes to far more Cepheids in our galaxy than ever before—more than 200 of them. The measurements, said Feast and Catchpole, pushed the most likely LMC distance to about 55 kpc (*Science*, 21 February 1997, p. 1064).

The result has failed to gain much traction among astronomers, however. "The solution is completely dominated" by the three to five Cepheids that are closest to the sun, says Floor van Leeuwen of Cambridge University's Institute of Astronomy. "The question then remains: How representative can this sample be for the entire population?" Feast defends his findings, saying there is no reason to think those Cepheids are atypical: "The Hipparcos results place the Cepheid scale on a much firmer basis than hitherto," he says.



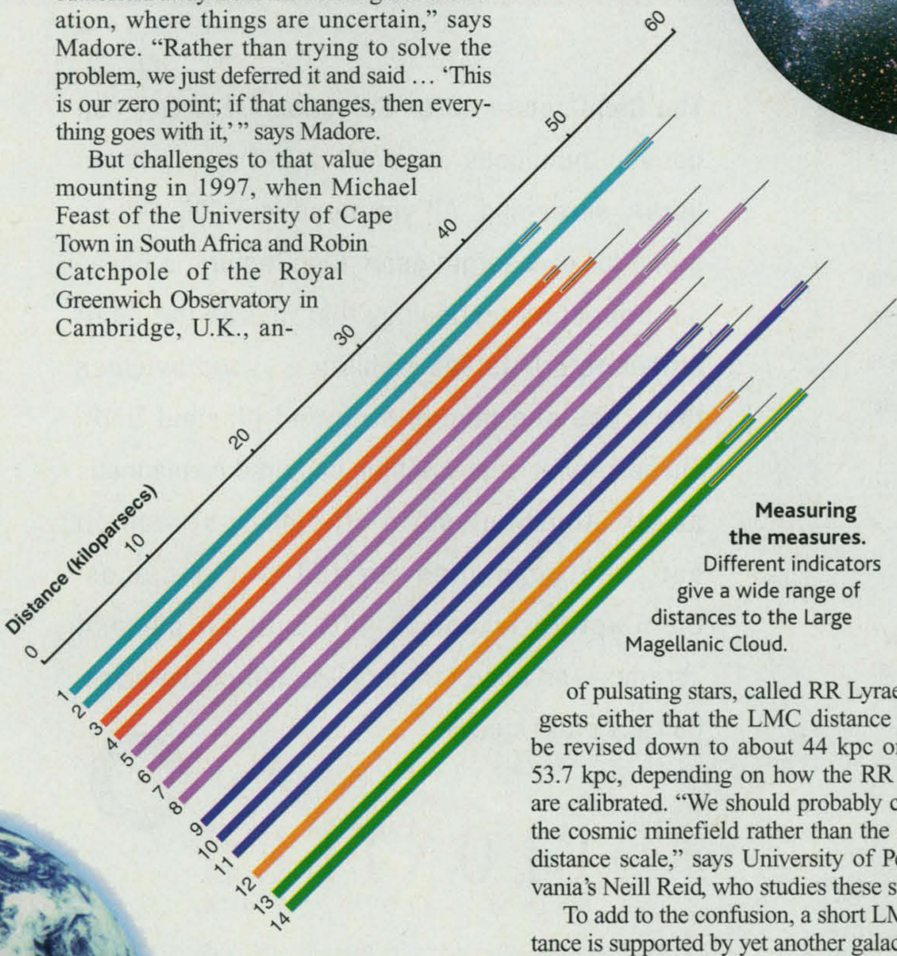
But other distance indicators aren't falling into line. Another set of pulsating stars, called RR Lyraes, suggests either that the LMC distance should be revised down to about 44 kpc or up to 53.7 kpc, depending on how the RR Lyraes are calibrated. "We should probably call this the cosmic minefield rather than the cosmic distance scale," says University of Pennsylvania's Neill Reid, who studies these stars.

To add to the confusion, a short LMC distance is supported by yet another galactic distance indicator calibrated by Hipparcos: so-called red clump stars. These old, giant stars, from 2 billion to 10 billion years in age, fired by a core of slightly less than half a solar mass of helium, "are very consistent in brightness," making them good standard candles, says Krzysztof Stanek of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. Hipparcos measured parallaxes to better than 10% accuracy for over 1000 red clump stars within a few hundred light-years of Earth. Because Udalski and his colleagues had observed tens of thousands of red clumps in the LMC, the Hipparcos calibration led directly to a distance. The result: 43.3 kpc. "That method is intriguing," says Andrew Gould of Ohio State University in Columbus, although he adds, "It's a young method, and you have to worry that the bugs aren't worked out yet."

Geometric certainty?

Faced with all these conflicting results, some astronomers have looked for certainty from geometric methods—akin to using the apparent size of the Sears Tower to measure your distance from downtown Chicago. Although most agree that geometry is "the wave of the future," says Paczyński, its apparent simplicity can be hazardous. Astronomy has very few Sears Towers, whose actual size can be looked up or measured directly. Instead, the size of something seen in a telescope often has to be deduced from secondary observations.

Take the ring of gas around the supernova that exploded in the LMC over 10 years ago, called 1987A. In principle, the true ring size should have popped out when astronomers measured the time delay between the bur-



1. RR Lyraes (Layden *et al.*; Udalski *et al.*; Popowski and Gould)
2. RR Lyraes (Reid; Gratton *et al.*)
3. Red clump stars (Udalski; Stanek *et al.*)
4. Red clump stars (Girardi *et al.*)
5. Cepheids (Madore and Freedman; Walker)
6. Cepheids (Hubble Key Project)
7. Cepheids (Feast and Catchpole)
8. Cepheids (Luri *et al.*)
9. Supernova 1987A (Gould and Uza)—upper limit
10. Supernova 1987A (Sonneborn, Kirshner *et al.*)
11. Supernova 1987A (Lundqvist and Fransson)
12. Eclipsing binary HV2274 (Guinan *et al.*)
13. Accretion disk in NGC 4258 (Herrnstein *et al.*; Maoz *et al.*)—implied distance
14. Supernova in M81 (Bartel *et al.*; Freedman *et al.*)—implied distance

Measuring the measures. Different indicators give a wide range of distances to the Large Magellanic Cloud.

Bypassing the Magellanic Cloud

Traditionally, the first stop in surveying cosmic distances is the Large Magellanic Cloud (LMC), a satellite galaxy of the Milky Way studded with flickering stars called Cepheids. By measuring the distance to the LMC, astronomers can determine how the flicker period of Cepheids relates to their brightness, turning them into standard candles that can reveal more distant objects. But as the tug-of-war over the distance to the LMC continues (see main text), a few astronomers have boldly tried to leapfrog it by using more remote galaxies.

Bypassing the LMC requires the help of clever geometric techniques for directly measuring distances to other galaxies, such as the one Jimmy Herrnstein of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts, described at a recent American Astronomical Society press conference. Herrnstein announced that his team had finally found the "golden rod" that would settle the cosmic distance debate once and for all. It's an accretion disk, a whirling platter of gas and dust thought to be circling a black hole, at the center of a galaxy known as NGC 4258.

The team, which included CfA's James Moran and Lincoln Greenhill, clocked how fast bright clumps of radio-emitting gas in the disk, called masers, appeared to creep across the line of sight, like traffic on a distant highway. They also measured the actual speed of masers at the edges of the disk, where they are moving toward or away from Earth, creating a Doppler shift in their radiation. Comparing the angular speed of the masers to their true speed gives the distance to the galaxy, because nearby objects move across the line of sight more quickly than distant objects going at the same speed. The result, 7.2 megaparsecs, is the most precise distance ever measured to a remote galaxy, Herrnstein claimed.

And it could have implications for other cosmic distances. A team led by Eyal Maoz of the University of California, Berkeley, which has studied Cepheids in the same galaxy, puts NGC 4258's distance at 8.1 megaparsecs, based on the LMC calibration, with wide error bars. Herrnstein's measurement, if correct, would force a substantial downward revision of that distance, and hence of the entire Cepheid distance scale.

But other astronomers aren't ready to trim their cosmic yardsticks yet. The CfA result, they note, is built on a pyramid of debatable assumptions, among them that the masers orbit the black hole at a steady pace like planets around the sun. That argument, Moran later conceded, "is a little hard to make," although he strongly supports the conclusions. "It's a method that holds enormous potential and promise," agrees Wendy Freedman of the Carnegie Observatories in Pasadena, California. "But we just can't tell with a sample of one."

Freedman and others who support the existing Cepheid distance scale point out that another geometric distance to a remote galaxy—a technique that compares the true and angular speeds of radio emissions from the expanding shock front of a supernova that exploded in 1993—closely agrees with the existing scale. Norbert Bartel of York University in Canada, who led the radio measurements, says the discrepancy between his result and Herrnstein's is no surprise, given all the uncertainties. "I look at it from the relaxed point of view," he says. For now, it appears that there's no sure way to bypass the LMC.

–J.G.

geoning flash of the supernova and the later reflection off the ring. The speed of light times the delay would give the size. Then, Hubble or ground-based measurements of the ring's angular size would yield the LMC distance. "That's pretty comforting," says Gould.

But it's not that easy. "The first real snag comes from the fact that light is not reflected —it's fluorescing," says Gould, and fluorescence takes time to develop, adding a lag that has to be calculated. Worse, the ring is not face-on but tilted, meaning that the secondary bursts of light are further spread out in time because of the varying distances they have to travel from the ring to Earth. Although initial estimates were all over the map, several recent calculations, including one by Gould, come up with similar distances to the LMC, about 47 kpc.

Perhaps the most promising geometric method relies on eclipsing binaries in the LMC—mutually orbiting stars that regularly pass in front of each other as seen from Earth. In essence, this method uses geometry to turn the stars into standard candles. The duration and frequency of the eclipses combined with the speed at which the stars are orbiting each other (which can be found from the Doppler shifts of their light) reveals the stellar sizes. By combining that information with the temperatures of the stars—indicated by their colors—astrophysicists can calculate their absolute brightness, which can be compared with the observed brightness to get distance.

The procedure has been refined over the last couple of years, says Edward Guinan of Villanova University in Pennsylvania, who led the first detailed observations of a binary in the LMC, and he thinks it is now on solid footing. "Our determination from the first target does favor the 'short' distance," he says—45.7 kpc. With a dozen new targets scheduled for observation, Guinan thinks eclipsing binaries could eventually nail down the distance to within a percentage point or so.

Many astronomers agree that eclipsing binaries are the best hope for pinning down the LMC distance once and for all, simply because times and angles are easier to measure than absolute luminosities. But there is also great promise in planned interferometers—essentially arrays of telescopes operating in synchrony—that would fly in space and be able to measure parallaxes much more precisely than Hipparcos did. For example, NASA's Space Interferometry Mission, tentatively scheduled to fly by 2005, might be able to pin down parallax distances to the LMC or more distant galaxies, bypassing all the indirect methods and fixing the distances in one fell swoop.

Ring of truth? The time it took light from supernova 1987A to reach the surrounding gas indicated the ring's size, turning it into a cosmic distance measure.

CREDIT: KIRSHNER *ET AL.*

Until then, the Hubble constant will bounce up whenever the estimated LMC distance shrinks, and vice versa. The upward Hubble bounce causes the most consternation among astronomers. That's because a fast expansion rate indicates a universe that is young, conceivably younger than its oldest stars. Recent evidence of a bizarre energy in empty space, which may be speeding up the expansion of an older universe (*Science*, 18 December 1998, p. 2156), could ease the so-called age crisis, however. "Quite often, the reaction I have heard to our low distance to the LMC is, 'It can't be right, because the age of the universe would be too low,' or something in a similar spirit," says CfA's Stanek. But he thinks that reasoning is flawed. "Astronomers should measure the distances as best they can," says Stanek, "and let the cosmological consequences fall where they may."

–JAMES GLANZ