own experiment at the time because upgrades were being made on their accelerator and separator. But the GSI team provided Berkeley with some material, such as a target wheel and silicon detectors, and shared the experience they had gained with a recoil separator and various correlation techniques. By the time that members of GSI's heavy ion group heard of Berkeley's results, they were able to get 8.5 days of beam time for an attempt at confirmation. In that time, they saw no candidates for ^{293}118. If the run had yielded a single atom, the production cross section would be 1.6 pb, Hofmann told us. He and his coworkers have set an upper limit of 2.8 pb, a value that falls within Berkeley's uncertainty range. They are planning to try again as soon as possible.

Buoyed by the unexpected success, the Berkeley group may go on to explore other predictions by Smolańczuk, possibly the reaction of rubidium-87 projectiles on a ^{208}Pb target to produce ^{294}119. Although testing some of these newly promising reactions has moved up on their priority list, the Berkeley experimenters still plan to look for element 114, as a check on the Dubna results. To do that experiment, the Berkeley team needs to develop the means to handle the radioactive target (plutonium-244) and increase the efficiency of their ion beam source because the target projectile (calcium-48) is so rare.

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References

1. V. Ninov, K. E. Gregorich, W. Loveland, A. Ghiorso, D. C. Hoffman, D. M. Lee, H. Nitsche, W. J. Swiatecki, U. W. Kirbach, C. A. Laue, J. L. Adams, J. B. Patin, D. A. Shaughnessy, D. A. Strellis, P. A. Wilk, http://user88.lbl.gov/e118/paper.html.
2. R. Smolańczuk, Phys. Rev. C **59**, 2634 (1999). R. Smolańczuk, to appear in Phys. Rev. C **60**.
3. S. Hofmann, Rep. Prog. Phys. **61, 639 (1998).**

Space Telescope Key Project Completes Task of Measuring the Hubble Constant within 10%

> By measuring hundreds of periodically varying stars out to 80 million light-years, the Hubble telescope has calibrated much brighter cosmological yardsticks that we can see billions of light-years away.

Five years before the Hubble Space Telescope was launched in 1990, NASA designated a "Key Project" for the orbiting telescope. The project's goal was to pin down the Hubble constant H_0 to within 10%. At the time, H_0, a fundamental cosmological parameter that measures the universe's present rate of expansion, was uncertain to within a factor of two. Estimates ranged from 50 to 100 km/s per megaparsec. (Hubble's law of universal expansion asserts that, at cosmological distances, recessional velocity is proportional to distance; 1 Mpc is about 3 million light-years.)

The Hubble constant is crucial to the calculation of the age of the universe, its geometry, and the abundance of the light elements produced in the first few minutes after the Big Bang. The more tightly one can pin down the key observational parameters, the more stringently one can test cosmological theories.

At the recent centennial meeting of the American Astronomical Society in Chicago, the HST H_0 Key Project team, headed by Wendy Freedman (Carnegie Observatories), Robert Kennicutt (University of Arizona), and Jeremy Mould (Australian National University), announced that the task had been successfully completed. The team reported[1] a Hubble constant of 71 ± 7 km/(s Mpc).

One determines H_0 by observing the Doppler recessional velocities of distant objects and then measuring their distances by means independent of redshift. At the heart of the HST H_0 Key Project was the determination of the distances to 18 galaxies—out to 25 Mpc—by measuring the periods and apparent luminosities of almost 800 Cepheid variable stars in them. Cepheids are very bright young stars, found mostly in spiral galaxies, whose luminosities vary cyclically, with periods on the order of days or weeks. Because one can deduce the intrinsic luminosity of a Cepheid with impressive precision from its period, Cepheids have become the primary yardsticks for extragalactic distances. The more Cepheids one can measure in a given galaxy, the smaller is the statistical uncertainty of the distance to that galaxy.

But even the Hubble telescope can't find and measure Cepheids much farther away than 25 Mpc. (When the HST was still on the drawing board, the frugal downsizing of the primary mirror's diameter was halted at 2.4 meters, because that was thought to be the minimum size for adequately measuring Cepheids in the important Virgo cluster of galaxies, whose center is about 17 Mpc away.) So, for purposes of determining H_0, the Key Project Cepheid distances serve primarily to calibrate more luminous secondary yardsticks, such as Type Ia supernovae and rotating spiral galaxies, that are still visible at the much greater distances where non-Hubble random and streaming velocities are presumed to be negligible.

Challenges

Almost before the applause had died down at the June AAS meeting, two other groups reported divergent results that appeared to challenge the Key Project result. In a novel use of very-long-baseline interferometry, a National Radio Astronomy Observatory group reported[2] a purely geometric measurement of the distance to a galaxy some 8 Mpc away with an uncertainty of only 4%. But that radio-interferometry distance appears to be 15% less than the Cepheid distance to that same galaxy (NGC 4258) recently measured by Eyal Maoz (NASA Ames Research Center) and coworkers.[3] This would suggest that the Key Project's H_0 might be too small by 15%.

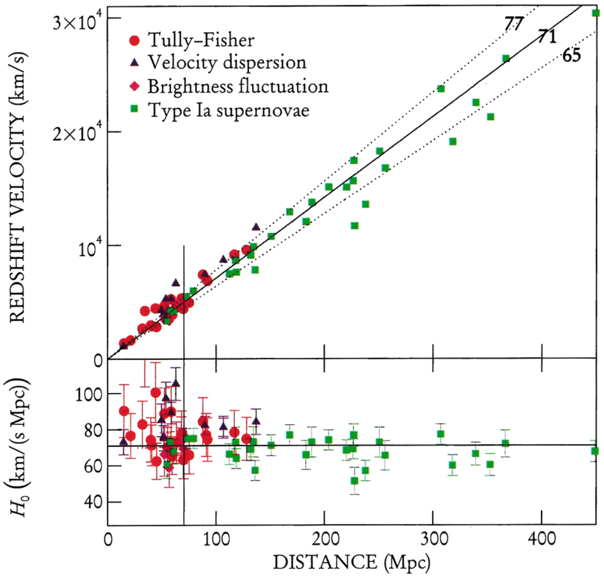
However, an even more recent very-long-baseline radio measurement, by Norbert Bartel (York University, Toronto) and coworkers, of an expanding Type II supernova shell in the galaxy M81, only 4 Mpc from us, yields a geometric distance that agrees very well with the Key Project's Cepheid distance to M81.

At the other extreme, claiming that the Key Project's Hubble constant is too big by 18%, was a not unexpected report[4] from Allan Sandage (Carnegie Observatories) and coworkers, reporting an H_0 of about 60 km/(s Mpc). Sandage and company have, for many years now, been holding out for a significantly smaller Hubble constant, and hence an older universe, than most other workers in the field. They base their result on their calibration of Type Ia supernovae. They used the Hubble telescope to measure Cepheid distances to the very few galaxies within 25 Mpc for which there are historical measurements of Type Ia explosions—going all the way back to the year 1895. But whereas Sandage's group used Cepheids only to calibrate Type Ia supernovae, the Key Project bases its determination of the Hubble constant on the Cepheid calibration of three other kinds of secondary distance indicators in addition to its own calibration of the Type Ia supernovae.

Age of the cosmos

As recently as three years ago, the difference between Sandage's 60 km/(s Mpc) and the Key Project's 71 km/(s Mpc) would have seemed more critical than it does now. The Hubble constant (which has the dimension of a reciprocal time) is a first approximation to the age of the universe. Until recently, it was fashionable to assume (1) that ρ_0, the present mass density of the universe, precisely equals ρ_c, the critical density above which, in the absence of a complicating "cosmological constant," the expanding universe must eventually recontract, and (2) that there is in fact no cosmological constant. In that particularly clean case, t_0, the time since the Big Bang, would be simply $\frac{2}{3}H_0^{-1}$.

For a Hubble constant of 71 km/(s Mpc), that translates into a t_0 of barely 9 billion years. A cosmos so young would be a severe embarrassment, because astronomers believe that ancient globular star clusters in our own galaxy are at least 11 billion years old. Nowadays, however, things look different. Recent studies of the Hubble constant's time derivative by observation of very distant Type Ia supernovae suggest that there is indeed a cosmological constant acting against gravitational braking of the Hubble expansion, and that ρ_0 is only about 30% of ρ_c. (See PHYSICS TODAY, June 1998, page 17.) That would bring the age of the universe, for $H_0 = 71$ km/(s Mpc), up to a much more comfortable 13.5 billion years.



HUBBLE PLOT of recessional velocity against distance for various kinds of secondary distance indicators (shown in different colors) calibrated by the HST H_0 Key Project's Cepheid measurements. The best-fit slope (solid diagonal), yielding a Hubble constant $H_0 = 71 \pm 7$ km/(s Mpc), is flanked, for comparison, by dotted lines with slopes of 65 and 77 km/(s Mpc). The bottom panel, plotting the H_0 from each individual observation, shows how the different secondary indicators scatter around the overall best value. Points to the right of the vertical line near 70 Mpc, having recessional velocities greater than 5000 km/s, exhibit less scatter, presumably because they are less sensitive to local non-Hubble velocities. (Plot courtesy of W. Freedman.)

Supernova yardsticks

Type Ia supernovae are the best secondary distance indicators we have. They can be seen very far away, and they are almost (but not quite) "standard candles." Their peak intrinsic luminosities—a few days after the explosion—are spread over a very small range. That's presumably because the initiating stellar masses of these exploding white dwarfs are always quite close to the critical Chandrasekhar mass—about 1.4 solar masses. The initiating masses of Type II supernovae, by contrast, are much greater and more varied. The observer distinguishes different supernova types by their spectra.

Happily, one can further narrow the small dispersion among the intrinsic peak luminosities of Type Ia supernovae by correcting for the duration of the supernova. One exploits the well-established relation between temporal light curves and peak luminosities: The brightest outbursts take longest to fade out. Having made this correction, one simply invokes the inverse square law to deduce the *relative* distances of different Type Ia supernovae by their apparent peak brightnesses.

To pin down the *absolute* distances needed for determining the Hubble constant, however, one has to calibrate the intrinsic luminosity of the quasi-standard candle. That's where the Cepheids come in. From the handful of historical Type Ia supernovae that have been recorded in galaxies close enough for the Hubble telescope to measure Cepheid distances, one calibrates the more distant explosions. "Before the Hubble telescope," Freedman told us, "there were absolutely no measurable Cepheid calibrators available for the Type Ia supernovae."

Other secondary yardsticks

Another important secondary distance indicator is provided by the Tully–Fisher relation, which quantifies the excellent correlation between the rotation speed of a spiral galaxy and its intrinsic luminosity. Roughly speaking, the more massive a galaxy, the faster it must spin to avoid collapse. Rotational velocity is measured by the change in Doppler shift across the galaxy's face. To get a good measure of apparent luminosity, one needs to see the galaxy more or less face-on. As with all the other secondary yardsticks, absolute distance calibration of the Tully–Fisher relation requires Cepheid measurements.

The empirical dispersion of the spin–luminosity correlation makes for about a 15% statistical uncertainty in the Tully–Fisher distance determination to a single galaxy. But one can get a much better measurement of the distance to a tight cluster by measuring a few dozen spiral galaxies in that cluster.

For elliptical galaxies, one can exploit the dispersion of stellar velocities in place of spiral-galaxy rotation. Galaxy size and intrinsic surface brightness are tightly correlated with velocity dispersion. As one would expect from the virial theorem, the velocity dispersion increases with the galaxy's apparent mass, as manifested by its size and brightness.

Rounding out the repertoire of secondary yardsticks calibrated by the HST H_0 Key Project is the spatial fluctuation of galactic surface brightness. The closer we are to a galaxy, the more easily a telescope can resolve individual stars. Thus the surface brightnesses of galaxies appear less grainy with increasing distance. The Poisson fluctuations, from pixel to pixel, of photons intercepted by a telescope's CCD detector, thus serve as a measure of relative distance.

The figure above shows the contribution of each of these secondary distance indicators to the Key Project's Hubble plot of redshift velocity versus distance, whose fitted linear slope gives H_0. In addition to the statistical spread within each secondary technique, there are overall offsets between them, presumably indicative of systematic errors due to a variety of astrophysical effects.

For example, if one takes only the Key Project's supernova points, one gets an H_0 of 68 km/(s Mpc), somewhat lower than the project's overall best fit of 71 km/(s Mpc). In fact, with a statistical uncertainty of ± 2 and an estimated systematic uncertainty of ± 5, the Key Project's Type Ia supernova result is not seriously inconsistent with Sandage's independent estimate of 60 km/(s Mpc). "I'm pleased to see that we're beginning to converge," says Freedman. An independent Type 1a determination of the Hubble constant, by Saurabh Jha (Harvard-Smithsonian Center for Astrophysics) and collaborators,[5] has recently yielded $H_0 = 65 \pm 7$ km/(s Mpc).

Addressing the systematic errors of the individual techniques, and of the overall enterprise, has been a crucial issue for the Key Project team. What are the insidious effects, for example, of intervening dust or of varying galactic light-to-mass ratios? How far out does one have to look to get beyond non-Hubble streaming velocities toward local mass concentrations? How well, ultimately, is the underlying Cepheid period–luminosity relation itself calibrated?

Eventually we will learn more from new methods of determining H_0 that do not depend on the classical extragalactic distance scale. For example, the positions and amplitudes of the "acoustic peaks" of the power spectrum of fluctuations in the cosmic microwave background provide a measure of H_0. (See PHYSICS TODAY, November 1997, page 32.) So do time delays in gravitional lensing. One can also measure the Hubble constant by observing the Sunyaev–Zel'dovich effect—that is, the distortion of the cosmic microwave background in some directions by hot gas in intervening large clusters of galaxies.

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References

1. W. Freedman *et al.*, Phys. Reports, David Schramm Memorial Volume, in press (1999).
2. J. Herrnstein *et al.*, http://xxx.lanl.gov/abs/astro-ph/9907013, to appear in Nature (1999).
3. E. Maoz *et al.*, U. C. Berkeley, Astronomy Dept. preprint (1999).
4. A. Saha, A. Sandage, G. Tammann, L. Labhardt, F. Macchetto, N. Panagia, to appear in Astrophys. J. (1999).
5. S. Jha *et al.*, http://xxx.lanl.gov/abs/astro-ph/9906220, to appear in Astrophys. J. (1999).

Model Suggests Deep-Mantle Topography Goes with the Flow

As geochemists, modelers, and seismologists try to make sense of data from Earth's mantle, a new model poses challenges to each group and suggests that progress in understanding the deepest regions of the mantle can occur only on a broad front.

In 1996 and 1997, when seismic tomography began producing much improved images of Earth's mantle, many researchers thought they were witnessing the resolution of the debate over whether mantle convection takes place across the entire mantle, or rather within—but not across—chemically distinct layers. The images revealed convincing evidence of slabs of subducted oceanic lithosphere penetrating through the boundary between the upper and lower mantle at a depth of 670 km. If slabs of oceanic crust, which formed, in part, from the upper mantle, could penetrate so easily into the lower mantle, it was difficult to see how the two regions could differ dramatically in composition. (See PHYSICS TODAY, August 1997, page 17.) High-pressure mineral physicists had already provided a suitable explanation for the discontinuity in seismic-wave speeds at the boundary: The boundary corresponded well to the pressure where the dominant phase in the mantle changes from spinel to perovskite—an isochemical, pressure-induced phase transformation.

Yet the idea of a layered, differentiated mantle has proved to have many lives. This is largely because different mantle-derived materials—that is, materials whose source is, at least in part, in the mantle—have very different trace-element signatures, making it very difficult to construct a self-consistent model of a homogeneous mantle that accounts for all the geochemical diversity. Measurements of element and isotope ratios in different mantle-derived materials seem to require at least four distinct reservoirs of material in the mantle. Although some of the diversity of materials can be accounted for by mixing recycled, subducted crust and lithosphere into the mantle, other measurements seem to favor a source of material that has remained isolated over long stretches of geologic time.

Recently, Robert van der Hilst, Hrafnkell Kárason, Bradford Hager (all at MIT), Louise Kellogg (University of California, Davis), and Francis Albarède (Ecole Normale Supérieure de Lyon in France) began developing a mantle model[1,2] that could explain some of the geochemical data and still be consistent with seismological evidence. The researchers suggest the existence of an isolated layer in the bottom 1000 km of the 2900 km thick mantle that is enriched in heavy elements compared to the upper and lower mantle, and therefore slightly denser. (See the figure on page 22.) Preliminary simulations of the model show that even slightly greater density of the deep layer relative to those above it would inhibit mixing and overturn of the layers.

The deep layer is distinguished from those above it by compositional differences, increased heating and thermal expansion, and perhaps even by phase changes. These effects compete and combine to determine the deep layer's density and elastic properties. Because seismic-wave speeds in a medium are determined by that medium's density and elastic properties, detecting the boundary between the deep layer and the lower mantle as a discontinuity in seismic-wave speeds could be quite difficult. Moreover, the nearly equal densities of the lower mantle and the deep mantle could result in a boundary with very complex topography. These complex topologies have prompted some researchers to refer to this model as the "Lava-lamp model," after the 1960s curiosity that gave many physicists a lasting interest in fluid mechanics.

Why a differentiated mantle?

Although the Lava-lamp model is an attempt to reconcile the compelling geochemical arguments for a chemically differentiated mantle with the seismological data, the motivation for the model extends beyond simply understanding mantle dynamics and structure. Understanding the mantle is key to understanding how the process of differentiation gave rise to Earth in its present form.

In the simplest view, the primordial Earth began as an undifferentiated mass. Early in its history, the iron and related siderophilic (literally, iron-loving) elements sank to the planet's center to form the core. Then, the light, lithophilic (stone-loving) elements floated up out of the mantle, or some portion thereof, to form the crust. The leftover middle region was the mantle—or, if the crust formed primarily from material in the upper portion, the mantle could be divided into an upper