Bertram N. Brockhouse lecturing at Chalk River in the early 1960s.

the data that you really want. To explain its utility, Gerald Dolling of Chalk River, who worked with Brockhouse in the early 1960s, invokes an analogy to hunting geese. If you wanted a particular goose out of a thousand flying overhead, you might shoot down a whole bunch with a shotgun and hope that your prey was among them—or you might get a high-powered rifle with a telescopic sight so that you could pick off just the bird you want. Brockhouse's method is that accurate firearm. One operates the spectrometer so that one collects only data corresponding to a particular value of **Q**, which for theoretical simplicity is often selected to be a symmetry direction for the crystal in **k** space. Determining the instrument settings for constant **Q**, of course, requires a lot of advance calculations; in the early days, Brockhouse told us, they had to set as many as 90 switches for each run. Eventually, however, Ed Glaser at Chalk River helped them to build computer controls.

By 1954 the triple-axis spectrometer was ready to yield quantitative data, and Brockhouse participated with others at Chalk River in exploiting his creation. In 1955, with Alec T. Stewart, he published dispersion curves for aluminum and vanadium. With his colleagues Brockhouse also used samples of magnetite to study magnons, collective wave motions among the atomic elementary magnets. And while participating in Chalk River's program on low-temperature liquids, Brockhouse found that one could use neutrons to study correlation functions, that is, how the "memory" of any particular arrangement of atoms in a fluid gradually disappears with time. Brockhouse's colleagues in the 1950s included David Woods, William Cochran, Roger A. Cowley, P. K. Iyengar and Noel K. Pope. Dolling, who was a student at Harwell in the 1950s, said that he decided to join Chalk River because Brockhouse kept beating him to results on whatever sample he chose to study.

Born in Lethbridge, Alberta, in 1918, Brockhouse did not start his formal training in physics until the age of 27. He earned a BA from the University of British Columbia in 1947 before getting his PhD from Toronto in 1950. Brockhouse stayed at Chalk River until 1962, when he went to McMaster. He served as physics department chairman there from 1967 to 1970 and became an emeritus professor in 1984.

—BARBARA GOSS LEVI

DISTANCE TO VIRGO KICKS OFF HST ASSAULT ON THE HUBBLE CONSTANT

One of the "Key Projects" intended for the Hubble Space Telescope from the start was to pin down the distance to the Virgo cluster by measuring Cepheid variable stars in that massive assemblage of galaxies some 50-million light-years away. Cepheids are the primary yardsticks for astronomical distances beyond the reach of parallax measurement. The inability to determine cosmologically relevant distances with confidence has been the principal source of confusion in our knowledge of H_0, the Hubble constant. The HST's measurement of Cepheids in the Virgo cluster was to be the opening salvo in an assault that would soon pin down this fundamental parameter of cosmology to within 10%, once and for all. Estimates of the Hubble constant in recent years have differed by as much as a factor of two, and the stakes are high. The reciprocal of H_0 is, after all, the first approximation to the age of the universe.

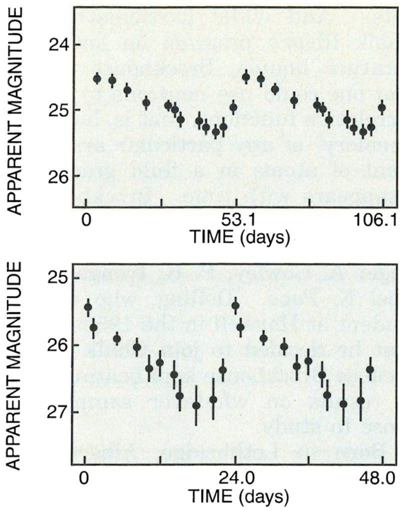
The intrinsic luminosity of a Cepheid variable star is a universal, monotonically increasing function of the period (typically weeks) of its highly regular brightness oscillation. (See the figure on page 20.) Thus one gets a distance determination simply by measuring a Cepheid's period and *apparent* average brightness. In galaxies beyond a few million light-years, however, ground-based telescopes can measure only the very brightest Cepheids, and the impaired optics of the orbiting Hubble Space Telescope, as originally launched in 1990, restricted its Cepheid measurement range to about a third of the distance to the Virgo cluster.

But now, with the corrective optics of the HST's new Wide Field–Planetary Camera, installed by visiting astronauts just a year ago, the Key Project group led by Wendy Freedman (Carnegie Observatories, Pasadena, California) has managed to obtain high-quality light curves for 20 Cepheids in M100, a prominent spiral galaxy in the Virgo cluster. These observations[1] yield a distance of 17.1 megaparsecs to M100, with an uncertainty of only 10%. (A megaparsec is 3.26×10^6 light-years.)

The Hubble constant

Hubble's law of universal expansion asserts that at sufficiently large distances all celestial objects are receding from one another with velocities proportional to the distance between them. H_0 is the universal proportionality constant. To determine the Hubble constant from the observation of a remote object, one must have both its recessional velocity, measured by redshift, and some independent measure of its distance. In recent years contending observers have argued for values of H_0 as low as 50 and as high as 90 km/sec per megaparsec. Values higher than about 50 make cosmologists nervous, because they seem to imply a universe younger than the oldest stars in our own Milky Way. (See PHYSICS TODAY, November 1992, page 17.)

The Key Project's Cepheid measurement of the distance to M100 yields a value of 82 ± 17 km/sec-Mpc for H_0. That number comes from using the average redshift of many galaxies in the Virgo cluster. The redshift of M100 alone, or of any other single galaxy in Virgo, is likely to have a significant non-Hubble component due to internal motion within the cluster. Thus the principal uncertainty in this new determination of H_0 comes from not knowing the position of M100 relative to the central core of the widely dispersed Virgo cluster. There is, however, some evidence that M100 is neither very far



Periodic light curves for two of the 20 Cepheid variable stars in the distant galaxy M100 recently recorded by the Hubble Space Telescope. The longer a Cepheid's period, the greater is its intrinsic luminosity. (Adapted from ref. 1.)

in front of or behind the core.

Another source of uncertainty is the fact that, given the Virgo cluster's enormous mass, it's not really far enough away for a straightforward determination of the Hubble constant. The cluster's gravitational pull is impeding the Milky Way galaxy's Hubble flow by several hundred kilometers per second. Though this non-Hubble component of our relative motion is not very well determined, it must nonetheless be taken into account in deducing H_0 from the Virgo measurements.

Freedman and company cite corroborative evidence that their correction for our "infall" toward Virgo has not led them very far astray: The Coma cluster of galaxies is six times farther away than the Virgo cluster, certainly far enough for us to neglect gravitational pulls and other "peculiar" velocities. On the other hand, the Coma cluster is much too far away for measuring Cepheid distances, even with the repaired Hubble telescope. Happily, the *ratio* of our distances from the Virgo and Coma clusters is known rather well. Therefore the new Cepheid distance measurements to Virgo, together with redshift data from the Coma cluster, yield a second determination of H_0, this time untroubled by non-Hubble components of the relative motion. That turns out to be 77 ± 16 km/sec-Mpc, reassuringly close to the value the group gets from the Virgo data alone. Taking both numbers into account, the Key Project group reports 80 ± 17 km/sec-Mpc as its best value for H_0, for the time being.

Stealing a bit of the Hubble telescope's thunder, Michael Pierce (University of Indiana) and collaborators have succeeded in measuring three Cepheids in another Virgo-cluster galaxy with the 3.5-meter Canada–France–Hawaii telescope on Mauna Kea. Their result is quite consistent with that of the Hubble telescope team.[2] They managed the impressive feat of measuring such distant Cepheids from the ground by employing an adaptive-optics camera with a mirror that moves rapidly to compensate for atmospheric jitter. (See the article by Laird Thompson on page 24.) Their result, with only three Cepheids, complements the Hubble telescope data, Pierce told us, because their galaxy is closer than M100 to the Virgo cluster's core.

Calibrating secondary yardsticks

These first reports of new H_0 determinations from the Virgo Cepheids, provocative as they may be in the ongoing cosmological debate, are not really the Key Project's *raison d'être*. Determining the Hubble constant within 10% will require reliable distance measurements far beyond the Virgo cluster and the Hubble telescope's range for measuring Cepheids. The principal purpose of the group's undertaking to measure Cepheids in the Virgo cluster and other galaxies at comparable distances is the calibration and verification of so-called secondary distance indicators. The unique precision provided by Cepheid variable stars makes them the "primary" distance indicators beyond the reach of parallax. But they're too faint to be of any use at distances of 100 megapasecs, where one can be fairly confident that local streaming of galaxies will not distort attempts to measure the Hubble constant.

Astronomers do have secondary distance indicators visible at such great distances. But they are all, thus far, much less reliable than the well-understood Cepheids. The trick will be to exploit the very well calibrated Cepheid period–luminosity relation to fine-tune secondary yardsticks in regions where Cepheids can still be measured.

The Key Project's M100 paper reports their first forays at checking secondary distance indicators: The M100 galaxy was home to a type-II supernova recorded in 1979. Type-II supernovae exhibit a great range of intrinsic luminosities; they cannot serve as "standard candles" for distance determination. But Brian Schmidt, Robert Kirshner and Ronald Eastman at Harvard have developed the so-called expanding-photosphere method for estimating the intrinsic luminosity of a type-II supernova from the time dependence of its optical spectrum. Applying this method to the data from the 1979 supernova in M100 yields a distance consistent with the Cepheid results. Schmidt and coworkers now claim a Hubble constant of 73 ± 9 km/sec-Mpc, based on the recorded spectra of 18 type-II supernovae.[3] The most distant of these is ten times farther out than the Virgo cluster. But partisans of an H_0 closer to 50 km/sec-Mpc will not be convinced until the Hubble telescope has checked several more type-II supernova records against Cepheid measurements.

Another important secondary distance indicator is the empirical Tully–Fisher relation between the intrinsic luminosity of a spiral galaxy and its rotation rate, as measured by Doppler variation across its profile. Tully-Fisher measurements in recent decades have provided the principal evidence favoring an H_0 closer to 80 than to the 50 km/sec-Mpc that would make life easier for the theorists. But adherents of the lower value point out that the Tully–Fisher relation badly needs calibration against Cepheid distances. The new Cepheid results from the Hubble telescope are consistent with Tully–Fisher measurements of M100. But the very fact that we see M100 almost face-on, which contributes to its beauty and facilitates the measurement of its Cepheids, frustrates the Doppler measurement of its rotation. Therefore the Key Project is busily looking for Cepheids in spiral galaxies more inclined to the line of sight.

Holdout

Freedman's Pasadena colleague Allan Sandage is the most prominent astronomer holding out for a Hubble constant near 50 km/sec-Mpc. That's about the largest H_0 that can accommodate the 14-billion-year-old globular-cluster stars in our Galaxy within the currently fashionable inflationary Big Bang scenario. But Sandage argues not from theory but from observation. There is good reason to believe, he contends, that type-Ia supernovae, unlike their type-II cousins, *are* monoenergetic and can therefore serve as standard candles for distance determination. Sandage and coworkers succeeded in calibrating two recorded type-Ia supernovae (from 1937 and 1972) in galaxies about 5 Mpc away by means of Cepheid distance measurements they made with the Hubble telescope *before* its optics were corrected. Those measurements, wrung from badly blurred Cepheid images, are admired as a *tour de force*. Assuming that all other nonpathological type-Ia supernovae have the same intrinsic luminosity as the two they calibrated against Cepheids, Sandage and his colleagues arrive at a Hubble constant of 52±8 km/sec-Mpc.[4]

Kirshner, now wearing his type-Ia hat, disagrees. He and Harvard colleagues Adam Riess and William Press contend that type-Ia supernovae are not in fact standard candles, but something else just as useful. In a new paper[5] they argue that, although type-Ia supernovae are not monoenergetic, one can deduce the intrinsic luminosity of any one explosion from the time dependence of its observed brightness. Applying this technique to the records of 13 supernovae out to several hundred megaparsecs, they get a Hubble constant of 67 ± 7 km/sec-Mpc.

—BERTRAM SCHWARZSCHILD

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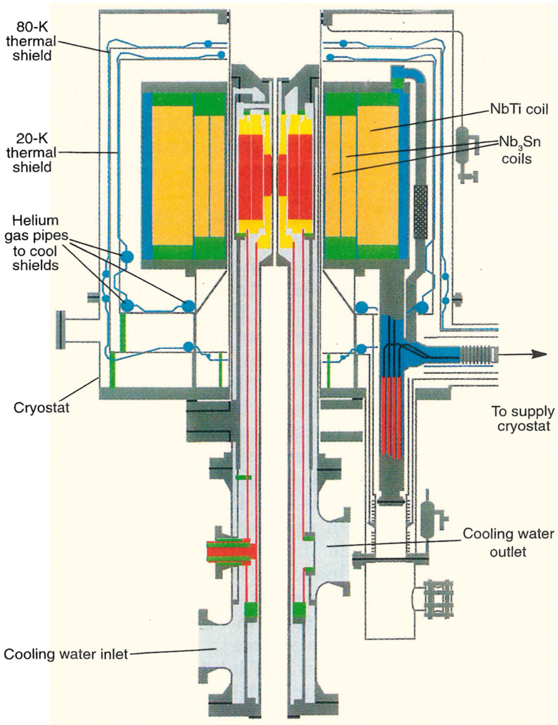
FLORIDA DEDICATES NATIONAL HIGH MAGNETIC FIELD LABORATORY

On 1 October, four years after the National Science Foundation chose to build a new high-magnetic-field laboratory at Florida State University rather than upgrade the existing Francis Bitter National Magnet Laboratory at MIT (see PHYSICS TODAY, January 1991, page 53), the new laboratory was dedicated in Tallahassee.

At the dedication Vice President Al Gore praised the creation of "the world's preeminent magnetic laboratory," whose 300 000-square-foot building was finished on time and on budget. The lab is billed as a partnership of the Federal government, the state of Florida, the University of Florida, Florida State University, Los Alamos National Laboratory and private industry. Gore noted that the National High Magnetic Field Laboratory is an example of the full and equal partnership advocated in the Clinton Administration's recently released white paper on science policy (see PHYSICS TODAY, September, page 79). Former NSF director Erich Bloch, who was largely responsible for the decision to build the new facility in Florida, said that the partnership "gains leverage" for NSF and allows Florida to enhance its prestige.

Once the NHMFL is fully operational, the lab anticipates over 400 users annually. The facility cost the state of Florida $65 million to construct and $11 million for instrumentation. NSF is providing $12 million per year for the first five years to cover operating costs (to power the magnets and support the magnet development group), and Florida is kicking in an additional $7.4 million in operating costs annually.

The National High Magnetic Field Laboratory will have a variety of high-field magnets and advanced instruments for research in condensed matter, biology, chemistry and materials science, most of which will be done in Tallahassee; the lab's other facilities are at Los Alamos and the University of Florida, Gainesville.



45-T hybrid magnet being constructed at the National High Magnetic Field Lab in Tallahassee, Florida. The experiment is placed in the center of the magnet, which has a 32-mm room-temperature bore. Because the user platform is at the same level as the top of the cryostat, it is convenient to arrange equipment on and around the magnet. The red indicates water-cooled Bitter coils and superconducting magnet current leads. Dark blue shows liquid helium; light blue shows cooling water. Dark gray shows stainless-steel cryostat, water-cooled magnet housing and support structures.

The 45-tesla hybrid

At Tallahassee the most dramatic equipment is a 45-tesla hybrid magnet system, intended to provide users with a world-record steady field of 45 T in a 32-mm bore. The hybrid magnet consists of a Bitter resistive magnet, a cryostat and three nested superconducting solenoids. It's being built by a collaboration between NHMFL and the Bitter Laboratory. MIT is building the Bitter insert and one of the solenoids, made of NbTi. Florida State has overall responsibility for design and administration and is building the other two solenoids, made of Nb_3Sn, as well as the cryogenic system and the control electronics.

The present record for a continu-