enzymes running loose in the cell," as Neufeld puts it.

Recently, Rothman, with Richard Fine of Boston University School of Medicine, acquired evidence suggesting that membrane proteins are carried to the cell surface in small vesicles coated with the protein clathrin. Coated vesicles of this type had been shown earlier to work in the opposite direction—that is, to carry large molecules picked up from outside the cell to the inside.

According to Rothman and Fine, two waves of coated vesicles carry the G protein of VSV to the cell membrane. The first wave apparently carries the protein from the ER to the Golgi apparatus, and the second wave carries it from the Golgi to the membrane. They base this conclusion on differences in the carbohydrate content of the protein in the two waves. In the first wave, G protein contains carbohydrate like that added in the ER, whereas in the second wave, it contains carbohydrate characteristic of material that has passed through the Golgi apparatus. The evidence suggests that the vesicles are reused; they continually cycle back and forth between the cell membrane and the interior structures.

Rothman and Fine hypothesize that there may be several species of coated vesicles, each with its own specifically packaged contents and destination.

In addition to the proteins made on the membrane-bound ribosomes of the ER, there are a number of cell proteins that are synthesized on ribosomes floating free in the cell cytoplasm. The latter proteins, in contrast to those produced in the ER, are usually soluble and do not contain carbohydrate. Nevertheless, investigators have detected sequences of amino acids on the amino-terminal ends of some cytoplasmic proteins that may be signal sequences.

For example, Nam-Hai Chua of Rockefeller University, in collaboration with Blobel, has detected such a sequence on a chloroplast protein. The arrangement of amino acids in the potential signal is now being determined and is turning out to be very different from that in the signal sequences of the proteins made on bound ribosomes. Blobel points out that this is not surprising since the two signals are directing the proteins bearing them to very different locations. Some mitochondrial proteins may also have signals on their amino-terminal ends.

Not all mitochondrial proteins have them, however, according to Robert Poyton of the University of Connecticut Health Center. Paul Lazarow of Rockefeller University says that the protein catalase, which is the principal enzyme found in peroxisomes, also appears to lack a signal sequence. (Peroxisomes are organelles that break down peroxides, potentially dangerous compounds formed in some biochemical reactions.)

These findings do not necessarily mean that the proteins lack directional information of some kind. After all, they find their way to the appropriate locations. But the signals for these proteins, if they exist, still remain to be identified.

—JEAN L. MARX

Double Hubble, Age in Trouble

Measurements of distances to galaxies hint that the universe may be only half as old as was thought

On the basis of data from infrared and radio astronomy, a team of scientists estimates that the universe is merely 10 billion years old, not 20, as many astronomers believe. Their new measurements of the distances to galaxies suggest that the value for the Hubble constant—one indicator of age of the universe—should be revised significantly. "We just made the universe a lot younger than it was thought to be," says one member of the team. Although the new value for the Hubble constant challenges the accepted one, it agrees with a previous but doubted finding.

Moreover, the recent measurements suggest that the neighborhood of our galaxy may not be a representative sample of the universe. If true, this observation implies that cosmology has its own "Catch-22"—whereas the vicinity of our galaxy may not be typical of the universe as a whole, only that region can be studied accurately.

The distance measurements were made with a technique introduced last spring (*1*) by Marc Aaronson of Steward Observatory in Tucson, Jeremy Mould of Kitt Peak near Tucson, and John Huchra of Harvard-Smithsonian Center for Astrophysics in Cambridge. With the new technique, distances to galaxies known to be close to each other were found to be very nearly equal. Furthermore, the method is thought to be based on physical principles. The older ways of measuring distance are based for the most part on chains of assumptions and extrapolations. Thus, many astronomers welcome the technique as a valuable additional way to measure extragalactic distances.

The technique is directly useful only for measuring distances that are quite small on a cosmic scale, although large when compared with the ranges of several of the established ways of measuring distance. The measurement of larger distances is based on the concept that the universe is expanding, and the farther apart any two objects are, the faster they recede from each other. It is assumed that distance is linearly proportional to velocity. The constant of proportionality is known as the Hubble constant, after the late Edwin Hubble of Mount Wilson Observatory (now part of Hale Observatories) near Los Angeles. Due in large part to Hubble's work 50 years ago, the concept of the expanding universe became generally accepted.

Astronomers get a clue to the distance of a faraway galaxy by measuring how fast it is receding from us. They can estimate the distance accurately if they know the Hubble constant. Consequently, a major quest of cosmologists has been to determine the value of the Hubble constant on the basis of the velocities of galaxies which are close enough to the earth that their distances can be measured directly. As yet, astronomers making such meaurements have not been able to agree on the value of the Hubble constant appropriate for the universe as a whole.

The new data of Aaronson, Mould, and Huchra suggest that the Hubble constant changes with distance. This observation supports the idea that there might be a local blemish in the expansion of the universe. The Hubble constant calculated from data on the galaxies in the nearby Virgo cluster of galaxies is much

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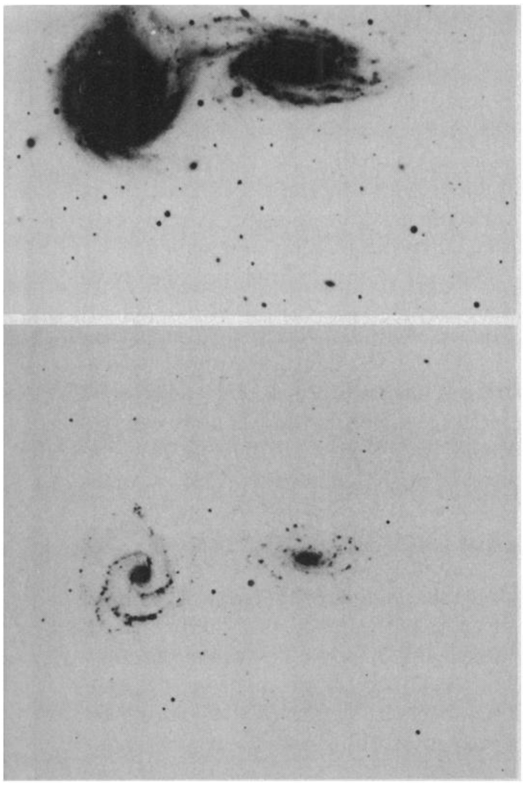

In the southern sky a face-on spiral galaxy (NGC 5426 on the left) is adjacent to a nearly edge-on one (NGC 5427). These galaxies are more distant than the Virgo cluster, but not as far away as the distant clusters studied by Aaronson and colleagues. (Top) The galaxies in blue light; (bottom) at a wavelength of 6563 angstroms (Hα) the spiral structure is more apparent. [Negative image from the Cerro Tololo Inter-American Observatory 4-meter telescope]

less than the value obtained from distances to galaxies in more remote clusters. With extensive observations of many nearby galaxies in all directions, Gerard de Vaucouleurs and Gerald Bollinger of the University of Texas, Austin, recently determined (*2*) that in our neighborhood the Hubble constant—or Hubble ratio, as he prefers to call it, because a constant should not change with distance or direction—is lowest in a direction slightly north of the Virgo cluster.

Both de Vaucouleurs and the three younger astronomers postulate that our galaxy is falling toward Virgo, relative to the expansion of the rest of the universe. Aaronson, Mould, and Huchra's measurements indicate that the Virgo cluster is receding from us about 400 to 500 kilometers per second more slowly than it ought to be in a universe expanding at the rate suggested by the motions of more distant galaxies. To de Vaucouleurs, the discrepancy appears to be slightly smaller—only 300 to 400 kilometers per second. Huchra imagines that the motion toward Virgo really is falling, and is caused by the gravitational pull of the massive cluster.

Recent measurements of the microwave background radiation remaining from the "big bang" birth of the universe also suggest that our galaxy is falling toward Virgo. With these completely independent data George Smoot of the University of California, Berkeley, estimates the falling velocity at 400 to 500 kilometers per second.

The anomalous local flow could be one source of the difficulty cosmologists have in evaluating the Hubble constant to the satisfaction of their peers. In the past decade, several estimates of the Hubble constant, each with a stated uncertainty of 10 percent, have been published. The trouble is that the values differ by more than a factor of 2. Different values were obtained for different sets of nearby galaxies, and for different ways of measuring distance.

If, in fact, there is a flow anomaly in our neighborhood, then the Hubble constant for the universe cannot be evaluated on the basis of data from nearby galaxies. As Vera Rubin of the Department of Terrestrial Magnetism, Carnegie Institution of Washington, says, "in the long run, if you want to find out what the distant universe is like, you have to look at the distant universe."

However, some astronomers, notably Allan Sandage of Hale Observatories, Gustav Tammann of the University of Basel, Switzerland, and Amos Yahil of the State University of New York, Stony Brook, disagree with Rubin's philosophy. They are trying to use local measurements to determine the Hubble constant. In addition, they want to determine the ultimate fate of the universe—whether it will continue to expand forever, or will eventually collapse due to gravitational forces. In defense of their approach, they point out that only in our neighborhood can accurate observations be made. They claim that studies of distant galaxies are biased, because the faintest ones cannot be seen at all, and the lack of faint galaxies skews the sample. Furthermore, their data do not support significant anomalous motions in our locale.

To determine a value for the Hubble constant Aaronson, Mould, and Huchra have used their technique to measure the distances to galaxies that are much farther away than the Virgo cluster, but still nearby on a cosmic scale (*3*). For many of these galaxies, radio wave observations had never been made before. They were made specially for this project by Woodruff Sullivan III, Robert Schommer, and Gregory Bothun of the University of Washington.

Aaronson says that these galaxies, members of other large clusters, do not appear to be involved in the local flow pattern. In fact, the Hubble ratios for all the clusters are very nearly equal, although the clusters lie in radically different directions and one of them is much more distant than the others. By using only galaxies in clusters, the astronomers have avoided the biases Sandage and colleagues warn of. In particular, the brightest galaxies in each cluster were chosen, and faint galaxies, whose counterparts in distant clusters cannot be seen, were not studied, even in nearby clusters.

The new Hubble constant is 95 ± 5 kilometers per second per megaparsec (1 megaparsec is 3.26 million light years), consistent with the value of 100 ± 10 obtained by de Vaucouleurs. Both are about twice the value advanced by Sandage and Tammann, whose measurements have dominated cosmology for the past several years. Sandage and Tammann's data, however, come primarily from observations of galaxies in the Virgo cluster, which is inside the allegedly anomalous locale.

If the new Hubble constant is correct, then the universe is only 10 billion years old. Some researchers consider Sandage's estimate of 20 billion years to be more in line with estimates based on evidence from radioactive nuclei with extremely long half-lives. According to de Vaucouleurs, whose extensive analysis also indicates a 10-billion-year age for the universe, the nuclear time scale has recently been corrected; the new age estimate is much lower than the old one, and is consistent with either a 10- or 20-billion-year age for the universe.

Aaronson, Mould, and Huchra's method is a modification of one pioneered in 1975 at the National Radio Astronomy Observatory in Green Bank, West Virginia. Brent Tully of the University of Hawaii and Richard Fisher of the National Observatory, now on leave at the Commonwealth Scientific and Industrial Research Organisation in Canberra, Australia, noted a good empirical correlation between the brightness of a spiral galaxy and the shape of an emission line in its radio spectrum. The spectral line studied has a wavelength of 21 centimeters and is emitted by hydrogen atoms—common constitutents of gas clouds in galaxies.

The 21-centimeter line is split into a "two-horned profile" or broadened in the spectra of many spiral galaxies. As the galaxy rotates, gas on one side of the center moves in one direction, while gas on the other side moves in the opposite direction. The radio waves emitted by the hydrogen in different regions of the galaxy are Doppler-shifted by different amounts, producing the split or broadened line. The faster the galaxy is rotating, the greater the splitting of the line. Thus the width of the line gives an indication of the rotational speed of the galaxy.

Astronomers have found that more massive galaxies usually rotate faster and emit more light than less massive ones. By measuring the broadening of the 21-centimeter line, which is independent of distance for a given rotation rate, Tully and Fisher get a clue to the mass of the galaxy and therefore how bright it ought to be. Galaxies that rotate faster than other galaxies but appear fainter must be farther away. Thus, by comparing the broadening of the hydrogen line with the apparent brightness, or magnitude, of the galaxy in blue light (the standard spectral region for measuring the brightness of astronomical objects), Tully and Fisher were able to measure the relative distances to a number of spiral galaxies.

But there were problems with the method, which Sandage and Tammann were quick to point out. To measure accurately the brightness of a spiral galaxy, one must look at it "face-on" to see all its stars and gas clouds. Yet to measure its rotation rate accurately, the galaxy must be looked at "edge-on"—in the face-on orientation the motions are in a plane perpendicular to the observer, so spectral lines emitted by gas and stars in different regions of the galaxy will not be Doppler-shifted differently. Tully and Fisher used galaxies of intermediate orientation and corrected their observations to a face-on magnitude and an edge-on rotation rate. Such correction can be fraught with error, according to Sandage and Tammann.

Another problem brought out by Sandage and Tammann is that there are several types of spiral galaxies, and Tully and Fisher lumped together all the types for which they had data. According to Tammann, "the correlation between line width and luminosity is strongly dependent on galaxian type. It is not permissible to mix different types." Rubin has data that support this criticism, at least for brightness in blue light. She says that for one type of spiral galaxy included in Fisher and Tully's survey "there does not seem to be any relation" between rotation rate and blue luminosity.

By using the infrared brightness of a galaxy instead of its blue brightness, Aaronson, Mould, and Huchra attempted to overcome some of the problems raised by Sandage and Tammann. One advantage of infrared is that it penetrates through interstellar and intergalactic dust and gas with very little attenuation. Therefore, the edge-on magnitude will be very nearly equal to the face-on magnitude: dust and gas within the galaxy will not hide stars in the background. (Stars in a galaxy are so far apart that they do not obscure each other.)

Furthermore, the vast majority of stars in a spiral galaxy are reddish—they do not emit very much blue light. As Rubin says, in principle "it is not very bright to measure a blue magnitude for a red object." But astronomers traditionally have measured blue brightnesses for all objects because photographic plates are sensitive to blue light.

Many astronomers welcome the technique as a valuable additional way to measure extragalactic distances.

By measuring the infrared magnitude, Aaronson, Mould, and Huchra are gauging how bright the galaxy is in the color that dominates its spectrum. As Huchra puts it, "in the blue, 50 percent of the light comes from 1 percent of the mass; while in the infrared, 90 percent of the light gives clues to 99 percent of the mass." Thus the infrared brightness is closely linked with the mass of the galaxy. Furthermore, the new data suggest that the relationship between rotation velocity and infrared luminosity is nearly independent of galactic type.

However, unlike blue magnitudes, infrared magnitudes are not tabulated in reference catalogs. Until recently, in fact, the technology for measuring infrared brightness was not available. The three astronomers had to make the measurements themselves, using a solid-state detector that Aaronson designed and built as part of his dissertation project.

It took about $2^1/_2$ months of observing time during the past $1^1/_2$ years to make and double-check all the brightness measurements. Fortunately, says Aaronson, "this project has gone extremely well." At Kitt Peak, where the bulk of the work was done, roughly one-third of the nights are normally clear enough for photometry. "It may be a sign from the gods," says Aaronson in jest, but for this project there were excellent conditions 70 percent of the time.

Once the correlation between infrared luminosity and rotation rate was established, the astronomers determined the formula linking the two parameters and proceeded to calibrate the method so that it would yield absolute distances. Since the rotation rate of a spiral galaxy is related to its mass, and the mass of the galaxy is linked to its light output, the technique was calibrated by looking at a few very nearby galaxies whose distances had been measured (although not unambiguously) by other methods. (According to Aaronson "it is a pathetic comment on the state of astronomical distance measurements that researchers cannot even agree on the distances to our nearest neighbor galaxies.") After measuring the apparent infrared brightnesses of these galaxies, Aaronson, Mould, and Huchra could determine their intrinsic brightnesses by using the well-known inverse square law of light.

The three astronomers based their calibration on the nearby distance scale of Sandage and Tammann. Had they selected de Vaucouleurs' scale, according to which the nearby galaxies are 20 percent closer, the new value for the Hubble constant would be 20 percent larger, and the universe would be similarly younger, says Aaronson.

Despite (and even fueled by) the new method and its results, the long-running controversy over the value of the Hubble constant, the distances to extragalactic objects, and the age of the universe continues unabated. Sandage says, "I am not convinced by the [new] results. They disagree with a large body of contrary evidence." Aaronson, however, is confident in the results, which he says "are consistent or only marginally inconsistent with all the evidence." When asked how to resolve the controversy, Sandage answers, "by returning to the telescope to develop more decisive methods, free from ad hoc assumptions, that are convincing to responsible people." Time will tell whether the new method and its results, which have yet to be published, prove convincing to astronomers.

—BEVERLY KARPLUS HARTLINE

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