

Ripples in the universal Hubble flow

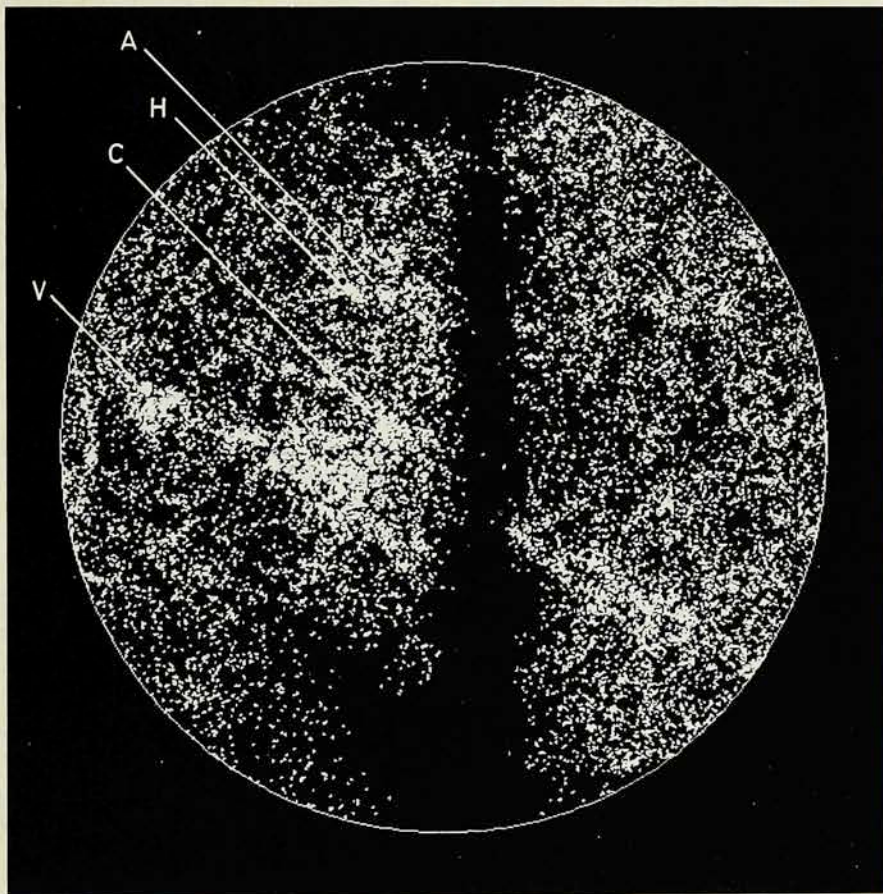
Large streaming velocities indicate bulk motions on scales as large as superclusters—clusters of clusters of galaxies—in addition to a smooth cosmological Hubble expansion. The existence of such motion has long been controversial. “None of the standard models can easily explain streaming,” says Jeremiah Ostriker (Princeton). “One might say that the velocities are not just Doppler shifts, but that would be iconoclastic.”

For a long time cosmologists have assumed a uniform Hubble flow, because residual (peculiar) velocities appeared negligible. In 1976 the pioneering study of 96 spiral galaxies by Vera Rubin, W. Kent Ford Jr (both Carnegie Institution) and coworkers was the first to indicate large-scale bulk motion. Soon afterward accurate determination of the microwave background radiation showed a vector pointing about 90° away from the Rubin-Ford bulk motion vector. This discovery led to considerable skepticism about the Rubin-Ford results.

What was causing motion with respect to the microwave background? Some motion could be accounted for by a gravitational infall center at the Virgo cluster—a cluster of galaxies centrally located in the Local Supercluster. To proceed further cosmologists could

- ▶ collect observational data to support or reject large-scale streaming motions
- ▶ locate the hidden mass excess causing much of the bulk motion responsible for the dipole anisotropy of the microwave background
- ▶ establish the scale at which the universe becomes homogeneous.

Return of the ‘Seven Samurai.’ Last year a group of seven astrophysicists concluded from a well-distributed sample across the sky of about 400 elliptical galaxies that a bulk motion of about 600 km/sec exists out to distances as great as 100 megaparsecs (see *PHYSICS TODAY*, November 1986, page 17). The ‘seven samurai’ are David Burstein



The ‘great attractor’ occupies the central region of the sky hemisphere (shown in equal area projection) in the direction of a streaming of elliptical galaxies observed by seven astrophysicists. The figure shows the Antlia, Hydra, Centaurus and Virgo clusters of galaxies. Absorption in the plane of the Milky Way cuts away the supergalactic band of galaxies in the Centaurus region—an obvious clustering of galaxies of which the great attractor appears to be the main part. (Courtesy of Ofer Lahav, Institute of Astronomy, Cambridge, UK.)

(Arizona State), Roger Davies (Kitt Peak National Observatory), Alan Dressler (Mount Wilson and Las Campanas Observatories), Sandra Faber (University of California, Santa Cruz), Donald Lynden-Bell (Institute of Astronomy, Cambridge, UK), Roberto Terlevich (Royal Greenwich Observatory, UK) and Gary Wegner (Dart-

mouth College).

This February at a meeting of the Royal Astronomical Society, Lynden-Bell gave as his presidential address an analysis of the elliptical-galaxy data that is consistent with a simple spherically symmetric mass concentration (with $1/r^2$ density distribution) acting as a perturbation on the Hubble flow.¹

Because of smaller residual velocities, the new kinematic solution seems more satisfactory than the bulk motion initially reported.

Is the mass concentration observable? The model says there is an infall center, similar to Virgocentric motion. Is there any evidence for it on the sky? From the direction of the bulk flow one gets the direction to the center of the mass concentration. Working with Ofer Lahav (Institute of Astronomy, Cambridge, UK), Lynden-Bell and Faber looked for excess counts of galaxies in catalogs after failing to locate such a cluster on Schmidt wide-angle photographic plates and concluded that there is a marked density enhancement in the supergalactic band of galaxies near Centaurus. "We found an obvious concentration and then checked that it had the right redshift from published redshifts," Lynden-Bell tells us. "This gave us agreement in distance to that predicted from the kinematic model." A higher density of galaxies could indeed draw mass toward it.

Dressler has made observations to locate what he calls the 'great attractor.' He is completing measurement of the histogram of radial velocities for a well-defined diameter-limited sample of 1400 galaxies. To the extent that radial velocities are good indicators of distances, he sees a peak in the galaxy distribution in a steradian-sized region in a direction and at a distance consistent with the new kinematic solution. (He sees another peak at a lower redshift indicating that the Hydra-Centaurus supercluster is falling into the more distant object.) By sheer bad luck the bulk-motion vector is close to the Galactic plane, so perhaps as much as 30% of the mass of the great attractor could be obscured (see the figure on page 17).

The great attractor plus the nearer inflow center in the Virgo cluster seem to be adequate for systematic large-scale effects. The kinematic solution has a spherically symmetric inflow pattern that falls off as $1/r$ in velocity from the center of the mass concentration. At our distance the streaming speed for the model is 570 ± 60 km/sec toward a mass concentration centered at galactic longitude 307° and galactic latitude 9° . The concentration is estimated to be at a distance corresponding to a velocity of 4350 ± 350 km/sec (about three times as far away as the Virgo cluster) with the streaming motion in the vicinity of the mass concentration rising to about 1000 km/sec, or more.²

The excess mass (overdensity of a smoothed mass distribution) of the great attractor within a spherical volume centered on it and with radius

equal to our distance from its center can be computed from the inflow speed at our distance to be about 5×10^{16} solar masses, comparable to the largest known superclusters. This is the total mass between us and its center; the mass may be underestimated by a factor of about two. The mass is spread over a large volume about 10 times as big as the Local Supercluster.

Is the great attractor at rest with respect to the microwave background? To answer this question we need to know how the mass is placed spatially; just finding the mass necessary to explain the streaming is not enough. (See the box on this page.) For example, Perseus-Pisces, a similar supercluster, is on the opposite side of the sky, 180° away, at about the same distance—why don't the two gravitational effects cancel out? A huge region empty of galaxies—a void—in that direction may account for our net infall toward the great attractor.

Because of selection effects in catalogs, the southern hemisphere observations do not penetrate as deeply as the observations made by the seven samurai in the north. "This is a big disappointment to us," Faber says. Dressler and Faber plan to look at a statistically valid sample in the direction of the great attractor to see if they can detect infalling motion in the line-of-sight toward the great attractor on its far side from us. "If the galaxies are there, but they do not show such motion, then the great attractor interpretation would be in trouble," says Dressler.

Marc Aaronson (University of Arizona)—killed in April in an accident at Kitt Peak Observatory—and his group³ had been observing spiral galaxies in clusters from Arecibo (Puerto Rico) and interpreting the data using the correlation between the observed 21-cm width of neutral hydrogen and infrared galactic luminosity—what is called the Tully-Fisher relation. Aaronson's group found that the Local Supercluster as a whole (including the Local Group containing the Milky Way) is moving toward the Hydra-Centaurus supercluster, which they assumed provides the acceleration.

Jeremy Mould (Caltech), reporting for the group at a recent meeting in Hungary on preliminary southern hemisphere observations from the Parkes radiotelescope in Australia, told us that his new data "broadly confirm the velocity field" as measured by the seven samurai, although he is not ready to say anything definite about the 'great-attractor' interpretation.

"The essence of the Parkes results is that clusters in Hydra-Centaurus,

IRAS Observations

Interest in galaxies observed by the Infrared Astronomical Satellite increased two years ago when the dipole anisotropy of IRAS galaxies was found to point close to the microwave dipole vector; now Ofer Lahav (Institute of Astronomy, Cambridge, UK) has found a dipole also in the distribution of optical galaxies that points in the same direction as the microwave dipole. Although redshifts have been available since April for the 2200 brightest IRAS sources, individual redshifts cannot be separated into the Hubble flow and a peculiar velocity because independent distance estimators are lacking.

In a universe with a uniform mass distribution there is no net acceleration on a test mass. But if the inhomogeneous distribution of IRAS sources traces the mass distribution in the universe, a net residual gravitational acceleration may result. To find the cumulative net gravitational acceleration vector one must sum the contributions by IRAS sources in shells at different distances. "From the IRAS data we see no effect by a great attractor," Marc Davis (Berkeley) says.

"If the seven samurai are correct, we should get convergence to a solution for the gravitational acceleration vector only well past the great attractor," says Amos Yahil (SUNY, Stony Brook). But already at a redshift of 3000–4000 km/sec, corresponding to a distance closer than the great attractor (at redshift 4350 ± 350 km/sec), the magnitude of the gravitational acceleration vector converges to a solution (having already converged in direction). Apparently an excess mass associated with the IRAS attractor is closer to us than the great attractor. "Perhaps the seven samurai kinematic model is too simplistic," Yahil says. "Or perhaps IRAS galaxies do not trace matter."

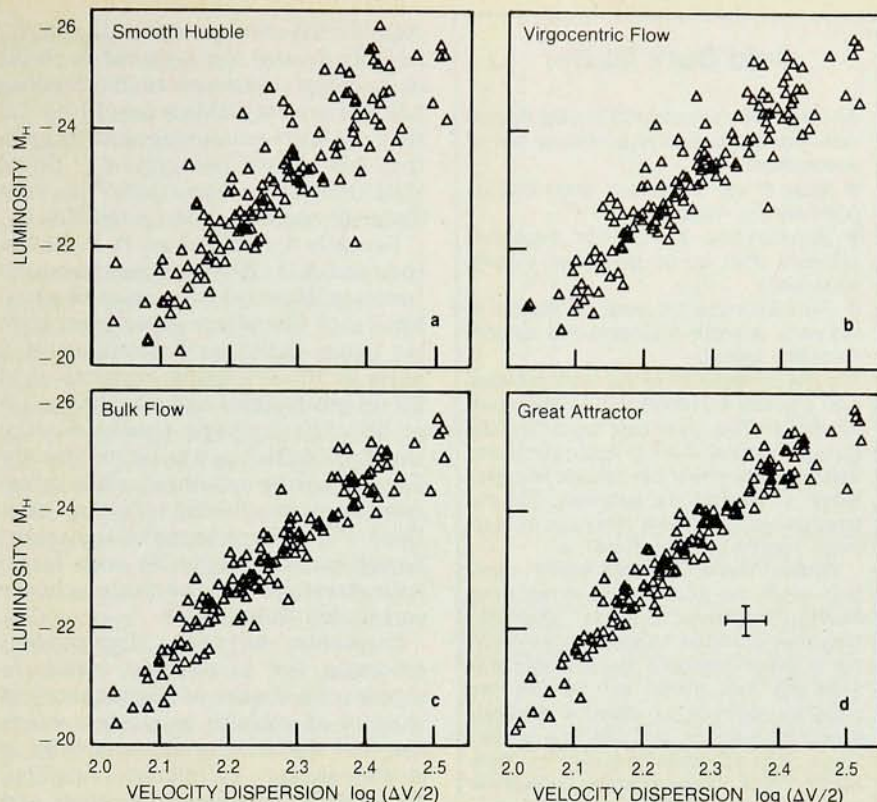
There is a known bias in the IRAS study: IRAS cannot see elliptical galaxies, only (gas-rich) spirals. And because clusters consist largely of ellipticals with spirals far from central regions, galaxy cluster cores are under-represented. To calculate the number densities of IRAS galaxies in shells at different distances, Davis and Yahil assume that the distribution of intrinsic luminosities of IRAS galaxies is the same everywhere. For elliptical galaxies the luminosity function is roughly the same both in rich clusters and in the general field. But galaxies segregate both by luminosity and by galaxy type. Unless both factors are taken into account galaxies would be tracing different mass distributions. The IRAS galaxies, which are largely gas-rich spirals, are not as likely to be found in clusters of galaxies as in the general field. Also studies of IRAS galaxies are incomplete near the galactic plane. Davis, Michael Strauss (Berkeley), Yahil, John Tonry (MIT) and John Huchra (Harvard-Smithsonian Center for Astrophysics) are busy checking for biases and other systematic effects.

Model fits using the 150 best-observed spirals from a survey by Marc Aaronson, John Huchra, Jeremy Mould, Paul Schechter and Brent Tully (*Astrophys. J.* **258**, 64, 1982) show progressive

improvements in the scatter of the infrared Tully-Fisher correlation that is a distance indicator for spiral galaxies: Infrared luminosity (in absolute magnitude, M_H) correlates with spectral linewidth (given as $\Delta V/2$ in km/sec) of 21-cm neutral hydrogen. The models are: (a) a smooth Hubble flow; (b) a Virgocentric infall with motion of 250 km/sec at our position in the Local Group; (c) bulk motion of 400 km/sec and a Virgocentric motion of 200 km/sec; (d) mass-concentration (great attractor) model including motion of 570 km/sec at our position and a Virgocentric motion of 200 km/sec. (From results presented at a recent meeting in Hungary courtesy of David Burstein, Arizona State.)

which we had supposed to be at rest in comoving coordinates, proved to be moving, just as the seven samurai say they are," Mould tells us. "Originally they claimed that the whole of their sample was in bulk motion. This was in conflict with our Arecibo results. But now they are talking about a concentration of peculiar velocities in the Hydra-Centaurus region, and we now see that too."

"From a smooth velocity field in 1978, to Virgocentric motion in 1982, to a motion of the Local Group and Virgo in 1986, to a large-scale velocity field in 1987, each time the previous results were incorporated in a more comprehensive model. The bottom-line for any model is its predictive power," says Burstein. "Does our model improve the scatter in the Tully-Fisher relation for spirals if we use the Aaronson data?—Yes." (See the figure at right.)



"There are very few people who are skeptical now regarding the interpretation of the observations indicating cosmic drift," Joseph Silk (Berkeley) tells us. "The recent observations are very good." Although theorists find the streaming observations plausible, the great attractor is too large to be reconciled with the cold dark matter theory of galaxy formation (see Silk's article in *PHYSICS TODAY*, April, page 28 and the following news story).

—PER H. ANDERSEN

References

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Large-scale structure, streaming and galaxy formation

"Observational results indicating large-scale streaming motions in the universe might be real giant-killers of theories," says theorist Richard Bond (Canadian Institute for Theoretical Astrophysics). (See news story on page 17.) Models based on the inflationary paradigm (see Andrei Linde's article in *PHYSICS TODAY*, September, page 61) are severely strained by the recent observations, Bond told us: "If true, the large-scale streaming puts in jeopardy the assumed initial spectrum of density fluctuations coming out of inflation. But the microwave background is, I think, ultimately the best probe of fluctuations and structure."

Recent theoretical models of galaxy formation have relied on dark matter and two alternative sets of initial

conditions

- inflation-generated scale-invariant fluctuations—those without any initial length scale (see the box on page 20)
- fluctuations driven by cosmic strings (topological defects from the early universe).

Another idea, developed by Jeremiah Ostriker (Princeton) and others, is an explosion model in which matter gets pushed from the center of a bubble and rearranged locally (see *PHYSICS TODAY*, May 1986, page 17). But both large-scale fluctuations in gravitational fields and velocity fields are small in amplitude, inconsistent with large-scale streaming.

The microwave background anisotropy should tell us about density fluctuation levels coming out of the Big Bang and

constrain galaxy formation scenarios.

Earlier this year in Tenerife, Rod Davies (Jodrell Bank, University of Manchester, UK), Anthony Lasenby (Mullard Radio Astronomy Observatory, Cambridge, UK) and coworkers¹ used a frequency of about 10 gigahertz on a small radiotelescope with an 8°–10° field to find temperature fluctuations of 3.7 parts in 10⁵ in the sky signal. They could subtract out Galactic emission because of its spectral shape: Because they did not observe the greater emission expected at the lower frequency of 5 gigahertz, they concluded that Galactic emission was not the origin of the fluctuations. Their observation is inconsistent with the cold dark matter model. According to Joseph Silk (Berkeley) the large-scale