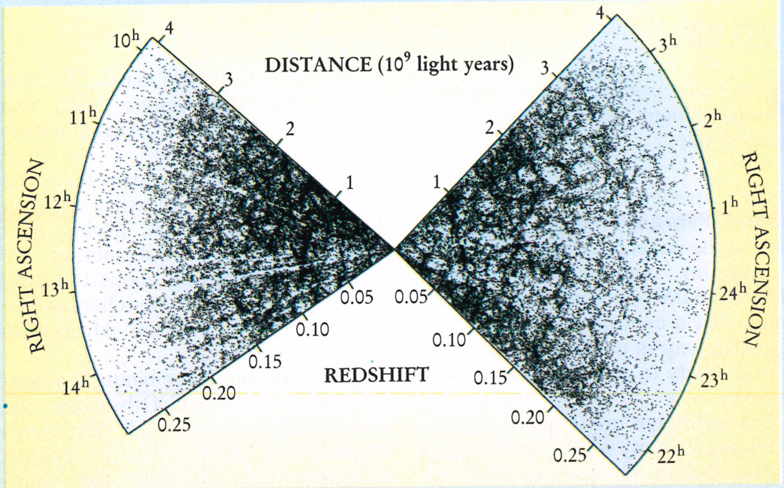
Galaxy Survey Finds Limit of Cosmic Structure Size



Each of the 106 688 points in this scatter plot of redshift against right ascension (celestial longitude) represents a galaxy. Presented by Gavin Dalton (Oxford) and Karl Glazebrook (Johns Hopkins) at the June meeting of the American Astronomical Society in Rochester, New York, this mapping of two cosmic wedges out to 4 billion light years is by far the most extensive three-dimensional galaxy survey to date. The plot summarizes the first two years of the Two Degree Field Galaxy Redshift Survey. The 2dFGRS team is a British-Australian-US collaboration that plans to have measured a total of 250 000 galactic redshifts by the end of next year.

In declination (celestial latitude), the two measured strips of sky are, thus far, only about 7° wide. The mapping is three dimensional to the extent that a galaxy's redshift is a reliable measure of its distance. Hubble's law of universal expansion tells us that this is largely true for distant galaxies. But the Hubble expansion can be gravitationally retarded in overdense regions. In fact, the 2dFGRS team exploits anomalous redshift patterns resulting from such retardation to estimate the cosmic density of dark matter.

The 2dFGRS collaboration takes its ungainly name from the instrument that makes this prodigious undertaking possible—the two-degree-field spectrograph mounted on the 3.9-meter Anglo-Australian Telescope in the mountains northwest of Sidney. Its extraordinarily capacious 2° field of view, together with its novel robotic ability to attach optical fibers to individual galaxy images, allows the group to measure 3000 redshifts per night.

It doesn't take fancy correlation functions or power spectra to glean the first important lesson from the redshift map: The galaxies form no obvious structures larger than about 300 million light years. This "greatness limit" agrees well with what one expects from standard cosmological scenarios of structure formation. And it agrees with the tentative findings of earlier redshift surveys. But the most extensive earlier surveys, not nearly as deep as 2dFGRS, were running out of statistics at 300 million light years. (All the surveys, limited by sensitivity, record only the most luminous galaxies at their farthest reaches.)

The collaboration's other principal finding, thus far, is not much of a surprise either. But, like the greatness limit, it gains reliability from the unprecedented depth and volume of the 2dF survey. From the statistical evidence of departures from the Hubble flow in overdense regions, the group deduces that the cosmological (visible plus dark) mass density parameter Ω_m is about $^1/_3$. A variety of recent studies—exploiting gravitational lensing and other observables as well as redshifts—have yielded much the same Ω_m. But there was reason to believe that the estimates might increase with increasing survey depth. The 2dF survey is the first that's deep enough to show that the measurements of Ω_m have plateaued at about $^1/_3$.

This result rounds out a neat cosmological package: Recent supernova evidence for accelerated Hubble expansion yields a value of about $^2/_3$ for Ω_Λ, the cosmic vacuum-energy-density parameter. And the latest measurements of the cosmic microwave background tell us that the *sum* $\Omega_m + \Omega_\Lambda$ is very close to 1, as required by the standard inflationary Big Bang cosmology. (See PHYSICS TODAY, July, page 17.)

The 2dF survey, when it is completed, will have covered about 5% of the sky. The bigger Sloan Digital Sky Survey, just getting under way, will cover fully 25% of the sky to slightly shallower depth, measuring the redshifts of a million galaxies.

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that below a critical stirring frequency, which depends on the steepness of the magnetic trapping potential, no vortices appear in the condensate. For a range of frequencies above the critical frequency, a single vortex is observed as a pronounced density dip in the center of the condensate, shown in figure on page 19. Recent measurements of the angular momentum of the stirred condensate confirm a jump from 0 to $\hbar$ per atom at the critical frequency, as expected for a single vortex in the center of the trap.[3] Surprisingly, the critical frequency determined experimentally is about 50% higher than expected from calculations of when the one-vortex state becomes the lowest-energy state of the rotating condensate.

At even higher stirring frequencies, multiple vortices appear and form regular arrangements that resemble those found in rotating superfluid ^{4}He and the triangular Abrikosov vortex lattices found in type-II superconductors in a magnetic field. The cores of the BEC vortices are relatively large compared to the size of the trapped condensate, and so only a small number of vortices can be cleanly observed. At sufficiently high stirring frequencies, a turbulent structure is seen instead in the condensate. Ultimately, at stirring frequencies approaching the restoring frequencies of the trapping potential, the condensate is lost.

In their more recent experiments, Dalibard and company have varied their condensate preparation protocol: Instead of cooling with the stirring laser on, they have begun stirring after the condensate is formed. In another surprise, they find the nucleation of vortices with essentially the same critical frequency as when they cool while stirring. In contrast, a higher rotation frequency is needed to nucleate vortices in superfluid ^{4}He if the spinning starts after the liquid is cooled than when the liquid is cooled while the bucket is rotating.

Open questions

The ENS work joins three other results that demonstrate the superfluid properties of condensates. By dragging a laser beam through a condensate, Wolfgang Ketterle's group at MIT has demonstrated frictionless flow below a critical dragging velocity.[4] Chris Foot and coworkers at the University of Oxford[5] have observed undamped irrotational oscillation of the condensate—the so-called scissors mode—when a slightly asymmetric trap is given a quick twist, as predict-