

PHYSICS COMMUNITY

Two Surveys Begin to Map the Universe in Three Dimensions

Last fall, a British–Australian team began collecting spectra for the biggest survey of galaxies to date, the 2dF Galaxy Redshift Survey, which aims to obtain distances—by measuring redshifts—to a quarter of a million galaxies, and thus to map the universe in three dimensions. Not far behind the 2dF survey is an even bigger undertaking, the Sloan Digital Sky Survey, which aims to catalog some 50 million galaxies, and to measure redshifts to about a million of them. The American–Japanese SDSS collaboration expects to see first light in May, and to begin collecting spectra in 2000. SDSS is by far the more ambitious of the two surveys, but scientists from both projects say that the smaller and cheaper 2dF survey is likely to be the first to provide answers to some of the most compelling scientific questions.

A major objective of both projects is to study the large-scale structure of the universe. They will look at galaxy clustering on scales up to about 1.5 billion light-years, and thus close the gap between data on small-scale structure from similar but smaller surveys and data on large-scale structure from microwave background measurements of the early universe (see “The Cosmic Rosetta Stone,” *PHYSICS TODAY*, November 1997, page 32). Astronomers are especially excited about the possibility of connecting the past to the present. They hope to learn about the evolution of galaxies and of the universe, and whether the universe will continue to expand or whether a big crunch lies ahead. A key question is whether galaxy distribution traces the distribution of dark matter in the universe. Among other things, the surveys will study the distribution of galaxies as a function of type (spiral and elliptical), luminosity and other traits.

A little big-sky survey

Up to now, it's been “very difficult to map the universe on large scales using relatively nearby galaxies,” says 2dF survey project scientist Keith Taylor, because “it requires enormous amounts of data on galaxies that traditionally could only be observed one at a time. 2dF transforms that situation and makes

Scientists seek to answer fundamental cosmological questions by mapping the heavens; one comparatively modest survey is poised to reap the first results, while another, larger in scope, will eventually bring in more comprehensive data.

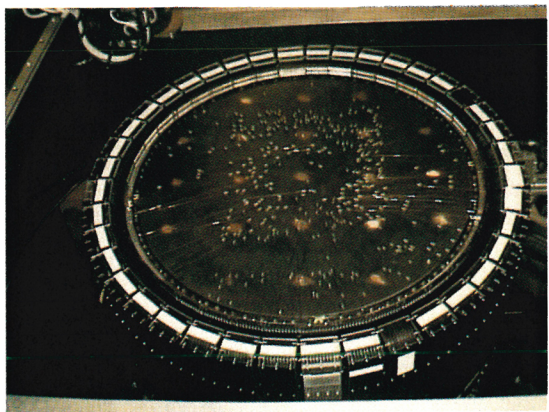
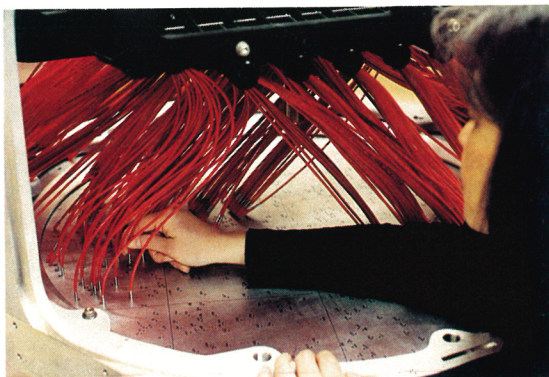
observing many hundreds of galaxies in a single shot possible.”

Built on a tight budget, the 2dF survey makes do largely with preexisting equipment. For spectroscopic measurements, it uses the Anglo–Australian Observatory's 3.9-meter telescope atop Siding Spring Mountain, near Coonabarabran in New South Wales, Australia, and the 1980s Automated Plate Measuring Machine photographic catalog to select galaxies of magnitude 19.7 or brighter—several

HUNDREDS OF REDSHIFTS can be measured simultaneously by both the Sloan Digital Sky Survey and the 2dF Galaxy Redshift Survey. SDSS's optical fibers (upper photo) are plugged by hand into holes in a plate that correspond to positions of galaxies. The plate is then placed in the focal plane of the telescope. With 2dF's instrument, a robot positions the optical fibers on the focal plane plate, to which they are held by magnetic buttons (bright dots in lower photo). In each experiment, the signals from the optical fibers are routed for analysis to either of two spectrographs.

hundred thousand times fainter than magnitude 6, which is barely visible to the naked eye. A total of 250 000 spectra will be collected because, says AAO director Brian Boyle, “that's the minimum required to yield statistically significant results for the major goals of the project.”

The 2dF instrument collects spectra from 400 galaxies (or other objects) at a time. The signals are fed by optical fibers—one for each galaxy in a given field of view—into two spectrographs. To make the most of a night, during each 45-minute exposure, a robot configures a spare set of optical fibers on a second focal plane plate, which sits at the opposite end of a barrel-shaped tumbling device from the one in use, and can be flipped into place for the next field of view. When *PHYSICS TODAY* went to press, the 2dF survey had collected spectra for about 5000 galaxies



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and 1000 quasars, according to astronomer Karl Glazebrook, the survey's instrument scientist—"Not enough to say anything yet about the universe's large-scale structure, but the news is all good. Everything has been made to work." Or almost everything. The robot was working at about half its target speed of 5 seconds per fiber, and 2dF was collecting about 2000 spectra a night. Glazebrook expects the robot to be up to full speed (and 2dF to collect 4000 spectra per night) by April.

The survey will scan strips of sky in the southern and northern galactic caps—the regions of the sky for which the view is least blocked by the disk of our own galaxy—and, in the southern sky, 100 randomly selected 2° fields (the diameter of the telescope's field of view; hence the name of the survey). The project will require about 100 nights and is scheduled to be completed late next year.

There are about 25 scientists involved in the 2dF survey—20 in the galaxy survey and the rest in a quasar redshift survey. Construction costs came to about \$1.6 million, not including "in-house manpower," says Taylor, and was paid for by the British and Australian governments.

A big big-sky survey

The Sloan Digital Sky Survey is actually two surveys rolled into one. In addition to the galaxy redshift survey, it will include a photometric survey—designed to be the largest and most detailed digital map of the sky to date. The photometric data will be used to select galaxies brighter than magnitude 18.3 for spectroscopic analysis. The advantage of this method over using photographic plates is that "we know that we can control systematic effects, and we can ask more detailed questions in the selection of data," says Princeton University's Michael Strauss, cochair (with the University of Tokyo's Sadanori Okamura) of SDSS's galaxy working group. Moreover, according to Jim Gunn, also at Princeton, who designed the photometric camera, many of the questions about galaxies and galaxy distribution "are nonsensical and ill-posed without detailed morphological data for each object in a sample."

Indeed, the camera (see cover of this issue) was the trickiest and, at about \$5 million, the single most expensive part of the project. With it, Gunn says, "we will measure magnitudes and colors for about 200 million objects." The camera will scan the sky with six columns of 5 (2048 × 2048-pixel) charge-coupled devices, each row with a different optical filter, so that objects will each be im-

aged from infrared to ultraviolet wavelengths (925, 769, 628, 476 and 354 nm). In addition, 22 smaller CCDs with neutral-density filters will be used for positioning, and 2 more will be used for focusing. Things are coming together on the mountain, says University of Chicago astronomer Don York, who is the former head of SDSS and the current director of the Apache Point Observatory, in southeastern New Mexico, the site of SDSS's dedicated 2.5-meter telescope. The telescope, camera, software, data analysis and operations will be tested and adjusted over the next year or so, York says. Imaging is expected to begin in 1999, and spectroscopic measurements in 2000.

Once SDSS is up and running, its photometric and redshift surveys will run in a staggered mode. Each night's imaging data haul will be sent to Fermilab, where, the plan goes, the data will be analyzed within a week to produce lists with positions of galaxies (and other objects) for spectroscopic analysis. Next, aluminum plates to be placed at the telescope's focal plane will be drilled with holes corresponding to these positions—640 for each field of view. And, back at Apache Point, the holes will be fitted by hand with optical fibers. On a good night, more than 5000 spectra will be collected. These data, as well as the more than 12 terabytes of photometric data, will be analyzed and archived at Fermilab—and eventually will be made available to the scientific community. (Fermilab joined the project because of its experience in handling vast data sets. But the lab's director, John Peoples, says the interest is really broader than that. "In astrophysics and high-energy physics, there is convergence in some areas. It's hard to keep physical sciences in boxes. They leak out.")

The main part of SDSS will cover the northern galactic cap, or about a quarter of the sky. In addition, a narrow slice of the southern sky will be repeatedly scanned to get a deeper image (to magnitude 25) that will be used, among other things, to look for variations in brightness and position of celestial objects. SDSS's photometric and redshift surveys are expected to take about five years to complete.

Besides Fermilab, the SDSS partners are Princeton University, the Institute for Advanced Study, the University of Chicago, the University of Washington, Johns Hopkins University, the US Naval Observatory and the Japanese Participation Group, which includes 12 scientists from five Japanese institutions.

The Alfred P. Sloan Foundation, for which the survey is named, provided

an initial \$8 million, the National Science Foundation gave \$5 million, and the member institutions also have contributed. But SDSS is at least three years behind schedule, and the estimated cost, including both cash and in-kind contributions, has more than doubled, to about \$70–80 million.

SDSS is late because it's "much bigger than anyone envisioned. And it's above budget because it's behind schedule," says York. "A big problem is the fact that it's been a loosely knit consortium," adds Gunn. "We have suffered terribly from not having had strong, unifying project management, but have belatedly taken that plunge for the crucial integration and commissioning phases," he continues, referring to a management shake-up in December that resulted in a more formal organizational structure. Among other changes, Jim Crocker, the former head of program management at the European Southern Observatory and the architect and manager of the corrective optics for the Hubble Space Telescope repair mission, is now SDSS's director for program management, and in June, Fermilab's Peoples will take over as CEO. Meanwhile, says acting CEO Tim Heckman, of Johns Hopkins University, with the project not yet paid for, "we are going out and aggressively looking for more sources of funding."

Friendly rivalry

The 2dF survey is in every way a smaller experiment than SDSS—it will collect less data, catalog fewer galaxies and quasars, be cheaper and faster (though it, too, fell about two years behind schedule) and involve fewer people. But SDSS scientists feel that the different scopes of the two surveys make it inappropriate to compare them. "2dF is a subset of SDSS," says Heckman.

Although the galaxy redshift survey has gotten more media hype, SDSS scientists say that the photometric survey is the more important part of their project. "It will be an incredible resource that will contribute to almost every branch of astronomy. It will be revolutionary, a digital sky that you can dial up on your computer," Heckman says. Adds Princeton's Strauss, "[2dF] designed their survey to answer specific questions—maybe even the most sexy ones—but we will be able to answer them in more detail." 2dF's Glazebrook agrees that SDSS will get better data, but he says his project's "main science goals—large-scale clustering—will not be hampered by photographic selection. And it means we start sooner."

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