The Dial-Up Sky

Astronomers are beginning to link surveys of hundreds of millions of stars and galaxies, seen at many wavelengths, into a virtual universe that can be explored with the click of a mouse

In the 1780s, William Herschel used a homebuilt telescope to make what he called "sweeps of the sky." He discovered Uranus and found thousands of what he called nebulae, diffuse blobs that we now know as galaxies. The heavens "are now seen to resemble a luxuriant garden," he wrote in 1789, "which contains the greatest variety of productions." Since then, sky surveys like Herschel's have been finding such a variety of productions that they have become what Alan Sandage of the Carnegie Observatories calls "the backbone, the roadmaps, the census reports, the bread and butter of astronomy."

Now, a whole new crop of surveys—planned or under way—is promising a garden so luxuriant that strict management will be needed to harvest it. The largest of these surveys map anywhere from hundreds of thousands to hundreds of millions of objects, and together they will cover 14 wavelengths, from ultraviolet and optical through infrared and radio. The resulting archives of digital data will be measured in terabytes, or trillions of bytes—"a phenomenal amount of information," says George Djorgovski of the California Institute of Technology (Caltech) in Pasadena. Djorgovski then lists a litany of problems: "Now, how to store these data so they're easily accessible? And how the heck do you find what you want?" How indeed.

For the archives to be most useful, they will not only have to be accessible and searchable; they will also need to be interconnected. The goal, say survey leaders, is something like a single survey of the sky in 14 wavelengths, all accessible with links to one Web site. Alex Szalay of Johns Hopkins University calls it "dialing up the sky": Click on an astronomical object, get its image and spectrum in, say, both optical and radio wavelengths, explore its neighborhood, and identify others like it elsewhere in the sky. "Done right," says Szalay, "astronomers and the public both could have a virtual telescope."

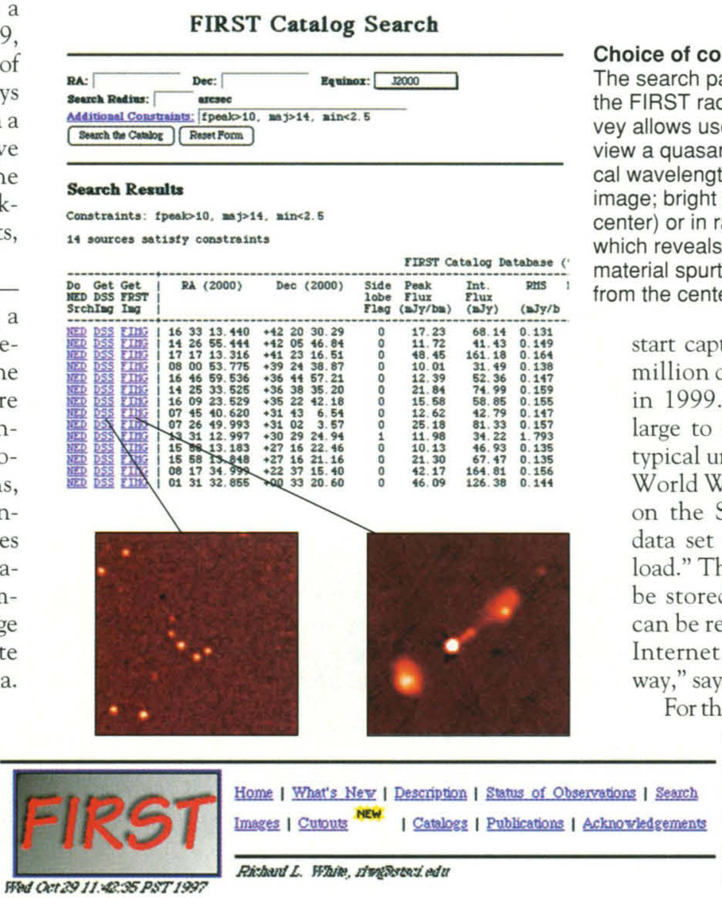
A dial-up sky is just starting to take shape. One radio survey is already linked to a catalog of galaxy images made at optical wavelengths; the so-called Digital Sky Project is laying plans for a broader confederation of surveys; and researchers throughout these projects are discussing common database structures and search schemes. "Everybody is talking in various commutations about creating an entity that will connect the various wavelengths," says Carol Lonsdale of Caltech, a member of an infrared survey called 2MASS. "We're sharing code and ideas."

These astronomers hope that such links will multiply the historical powers of surveys. "Every time there's a new survey," says Lonsdale, "we change the way we think of the universe." Surveys in recent decades at optical wavelengths showed, for instance, that galaxies are distributed not randomly but in clusters and filaments. A 1960s radio survey, by finding that distant galaxies had shapes and spectra different from those nearby, provided some of the first evidence that the universe has changed with time. In the 1970s, an x-ray survey showed stars—which in optical surveys seem to lead quiet lives—exploding or being ripped apart in gravitational fields.

Partly because of new technologies—including charge-coupled device (CCD) detectors and multifiber spectrographs—that allow light from many objects to be analyzed at once, large surveys have proliferated (see sidebar on p. 1011). The databases they are amassing are among the largest in science, from about 120 gigabytes (billion bytes) at the small end—already 10 times the size of the Human Genome Project's database—to the 1.2 terabytes of processed data and 40 terabytes of raw data from the Sloan Digital Sky Survey, which will start capturing 100 million galaxies, a million quasars, and 100 million stars in 1999. These databases will be too large to be downloaded directly. "At typical university baud rates, using the World Wide Web," says Szalay, who is on the Sloan team, "a 500-gigabyte data set would take a year to download." The data archives will have to be stored in a central computer that can be reached and searched over the Internet. "It can't be done any other way," says Szalay.

For the moment, each survey is maintaining its own data archive, structured and searched its own way. DPOSS, an optical survey of tens of millions of galaxies and billions of stars, has a scheme called SKICAT that assigns each object a set of numbers based on whether it is a star or a galaxy and on its color, shape, position, and brightness—"10 to 20 useful numbers per object," says Djorgovski. The Sloan is working on a more complex scheme that will make it possible to search for objects that have certain features in their spectra, say, or colors within a chosen range. "We can carve out a complex shape in color space," says Szalay, "and find these objects over the whole sky." 2MASS will eventually use some combination of both schemes. "Right now, each survey is concentrating on its own problems," says Szalay, "but the next thing the community will want is a merger."

They want a merger because astronomical objects shine in all wavelengths and, says Jim Gunn of Princeton and the Sloan team, "in-



FIRST Catalog Search

RA: Dec: Equinox: J2000
Search Radius: arcsec
Additional Constraints: fpeak>10, maj>14, min<2.5
Search the Catalog | Reset Form

Search Results

Constraints: fpeak>10, maj>14, min<2.5

14 sources satisfy constraints

FIRST Catalog Database ('

Do NED Srch	Get DSS Img	Get FRST Img	RA (2000)	Dec (2000)	Side lobe Flag	Peak Flux (mJy/bm)	Int. Flux (mJy)	RMS (mJy/b
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NED	DSS	FIMG	14 26 55.444	+42 05 46.84	0	11.72	41.43	0.149
NED	DSS	FIMG	17 17 13.316	+41 23 16.51	0	48.45	161.18	0.164
NED	DSS	FIMG	08 00 53.775	+39 24 38.87	0	10.01	31.49	0.138
NED	DSS	FIMG	16 46 59.536	+36 44 57.21	0	12.39	52.36	0.147
NED	DSS	FIMG	14 25 33.525	+36 38 35.20	0	21.84	74.99	0.159
NED	DSS	FIMG	16 09 23.529	+35 22 42.18	0	15.58	58.85	0.155
NED	DSS	FIMG	07 45 40.620	+31 43 6.54	0	12.62	42.79	0.147
NED	DSS	FIMG	07 26 49.993	+31 02 3.57	0	25.18	81.33	0.157
NED	DSS	FIMG	13 31 12.997	+30 29 24.94	1	11.98	34.22	1.793
NED	DSS	FIMG	15 58 13.183	+27 16 22.46	0	10.13	46.93	0.135
NED	DSS	FIMG	15 58 13.848	+27 16 21.16	0	21.30	67.47	0.135
NED	DSS	FIMG	08 17 34.999	+22 37 15.40	0	42.17	164.81	0.156
NED	DSS	FIMG	01 31 32.855	+00 33 20.60	0	46.09	126.38	0.144

FIRST
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Richard L. White, rlw@stsci.edu
Wed Oct 29 11:42:35 PST 1997

Choice of colors. The search page for the FIRST radio survey allows users to view a quasar at optical wavelengths (left image; bright spot at center) or in radio, which reveals jets of material spurting from the center.

Many Ways to Survey the Sky

Astronomical surveys are nothing new, but the late 1990s are a heyday of large surveys. Here is a handful of the largest, which may be linked into a single virtual universe (see main text).

■ *Digitized Palomar Sky Survey (DPOSS)*. At the Palomar Observatory, a Caltech team has nearly finished photographing the entire northern sky in three optical wavelength regions: green, red, and near-infrared. The Space Telescope Science Institute (STScI) is scanning the plates, converting pictures to digital information. It is identifying up to 2 billion stars and other objects with positions exact enough to be used for aiming the Hubble Space Telescope and for research on, for example, the structure of our galaxy; Caltech will use the same digitized database to catalog 50 million galaxies and 100,000 quasars. (http://www-gsss.stsci.edu/dss/dss.html)

■ *Two-Degree Field survey (2dF)*. The survey is a collaboration among astronomers from three observatories and a university in Australia and two observatories and four universities in Great Britain. They are using the Anglo-Australian Telescope in Australia to survey part of the southern sky, collecting optical spectra of 250,000 galaxies and 250,000 quasars. (http://www.aao.gov.au/local/www/2df/)

■ *Sloan Digital Sky Survey*. The Sloan is a collaboration of the University of Chicago, The Institute for Advanced Study, The Johns Hopkins University, Princeton University, the University of Washington, Fermi National Accelerator Laboratory, the U.S. Naval Observatory, and the National Optical Observatory of Japan. Starting in 1999, a dedicated 2.5-meter telescope in New Mexico will take digital pictures and spectra of 100 million galaxies and a million quasars over half of the northern sky in five colors, ranging from ultraviolet through optical to infrared. (http://www-sdss.fnal.gov:8000/)

■ *Galaxy Evolution Explorer*. GALEX, a small satellite carrying detectors for two ultraviolet wavelengths blocked by the atmosphere, is a collaboration among Caltech, The Johns Hopkins University, Laboratorie Astronomie Speciale in Marseilles, the University of Puerto Rico, the Jet Propulsion Laboratory (JPL), and Orbital Sciences Corp. Starting in 2000, GALEX will image 10 million sources of ultraviolet light, taking spectra on 100,000 of them, over the whole sky.

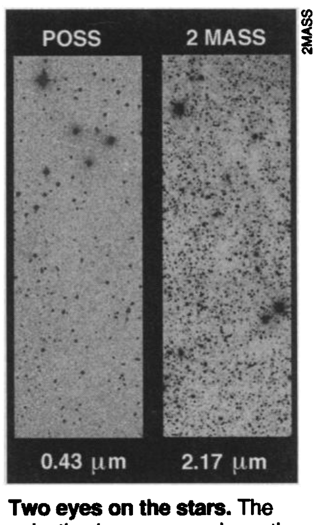
■ *Two Micron All Sky Survey*. 2MASS, a collaboration between the University of Massachusetts and the Infrared Processing and Analysis Center at Caltech and JPL, is using two telescopes, one in Arizona and one in Chile, to survey a million galaxies and 400 million stars over the entire sky at 2-micrometer near-infrared wavelengths. (http://pegasus.phast.umass.edu/2masscenter.html)

■ *Faint Images of the Radio Sky at Twenty-centimeters (FIRST)*. Astronomers at the University of California at Davis, Columbia University, and STScI have imaged hundreds of thousands of galaxies with the Very Large Array of the National Radio Astronomy Observatory (NRAO). As of mid-June, FIRST had surveyed about a sixth of the northern sky, "half the area we intended to cover," says Richard White of STScI, "but all the time NRAO gave us." NRAO recently declined to grant time for the other half. "We've learned a great deal from the 5000 square degrees of FIRST," says NRAO's director, Paul Vanden Bout, but citing a tight Very Large Array schedule, he adds, "the question was, is the increment worth the pain?" (http://sundog.stsci.edu) –A.F.

formation in any one wavelength just doesn't tell you enough." In the optical alone, for instance, quasars just look like stars. Only by combining observations in radio through gamma wavelengths have astronomers converged on a picture of quasars as active galaxies dominated by central black holes. Seeing the sky in any one wavelength is a little like listening to a symphony hearing only the horns.

Just how astronomers can hear the whole orchestra, however, is still uncertain. So far the idea seems to be that each survey team will maintain its own archives at home but link to a common search mechanism. "We are building the data warehouse at the site of the survey," Lonsdale says, "then layering on the top the software needed to query it." FIRST, a radio survey, is already linked to an old optical survey done at Mount Palomar by software that queries by position: A user can get on FIRST's Web site, type in the coordinates of a galaxy to get its radio image, then click on the Palomar survey to get its optical image. "By matching bright [Palomar] objects with radio," says Richard White of the Space Telescope Science Institute (STScI) in Baltimore and FIRST, "we found 400 new quasars. We can dial up the sky right now."

But astronomers want to navigate the multiwavelength sky not just by coordinates but also by neighborhood. For the Sloan database, Szalay's team has a scheme called sky tessellation, which covers the sky with triangles. To learn a galaxy's neighborhood, locate its position in a particular triangle, then call up the occupants of the whole triangle. A similar tessellation might group galaxies not by location but by color: Specify a color, and get all objects in the whole sky with similar colors. Or combine color with position and ask for everything with similar colors in a specific neighborhood. Szalay argues that tessellation could be the basis of the superstructure needed to query all archives: Calling up, say, triangle S2 in the optical will allow you to call up the same neighborhood in the radio and infrared. "We propose identical subdivisions of the sky," says Szalay: "One shoe fits all."



Two eyes on the stars. The galactic plane as seen by optical (left) and infrared surveys.

Tessellation has the community's attention. STScI's second Guide Star Catalog, made up mostly of stars extracted from DPOSS data and an Anglo-Australian Observatory survey, may use tessellation: "We listened to Alex," says STScI's Barry Lasker, "and said, 'Why not just do what they're doing?' " GALEX, an ultraviolet survey done from a satellite, will use tessellation; 2MASS and FIRST have agreed to try it; and DPOSS, says Djorgovski, may join in. "Six institutions with the same design concept is a landslide," says Lasker—although nothing is yet in writing.

Meanwhile, a consortium of astronomers based at the University of California, San Diego, has begun the Digital Sky Project, which will integrate 2MASS, DPOSS, FIRST, a second all-sky radio survey, and eventually, perhaps, the Sloan. The project will develop software to link the archives, probably via tessellation, and also provide a mechanism for storing each new link its users discover. An astronomer who identifies the same object in, say, the radio, infrared, and optical archives will store the new multiwavelength object in a sort of superarchive. When the Digital Sky will be up and running, says project leader Thomas Prince at

Amateur Sky Survey Keeps It Simple

At the other end of the spectrum from the $54 million, 100-astronomer Sloan Digital Sky Survey is The Amateur Sky Survey (TASS): $50,000 so far, and 10 to 12 people from varying professions. About all TASS shares with the new large surveys is a fondness for acronyms and astronomy.

TASS is a product of the imagination and bank account of Tom Droege, a semiretired engineer at Fermi National Accelerator Laboratory in Batavia, Illinois, who builds cameras out of 135-millimeter lenses and reject charge-coupled device (CCD) chips, then gives them away to anybody willing to operate them and, more important, collaborate on the software that links them into a survey. Droege advertised his offer over the Internet*—"where the programmers are," he says. So far, he has sent out 23 cameras to amateur astronomer-programmers in California, Maryland, Canada, and points between. The amateurs set the cameras out in their backyards, uncover the lenses at night, let the sky rotate over the lenses, then cover them up again in the morning. The sky's movement and the readout from the CCDs are synchronized, so the resulting image is sharp—a method also used by the Sloan.

TASS's amateurs, says Droege, come from the cadre of good scientists who can't find jobs doing research and are, he says, "just itching for an excuse to do science." The science is a survey of a 3-degree-wide strip of the sky in which, with any luck, TASS will find 1000 unmapped variable stars, which astronomers will study to fill out their theories of stellar life history. The observations will go into a digital database at the Rochester Institute of Technology in New York and will eventually be searchable over the Internet. When TASS gets all its talent trained, it will go on to watch for asteroids that might be aiming at Earth.

When Droege goes to meetings and hears astronomers lamenting the lack of funding for instruments and salaries, he says, "I just smirk inside." With cheap instruments and no salaries, he says, "we amateurs are setting out to take over the world." Such amateurs do "strong and competitive science," agrees Alex Szalay of Johns Hopkins University and the Sloan Survey. "They give us a run for our money." –A.F.

* http://p674p06.isc.rit.edu/tass/tass.html

Caltech, is "a little hard to say but within a couple of years definitely."

However they're designed, public databases with a common searching scheme will mean that astronomers and anyone else with access to the Internet can, in Szalay's words, dial up the sky in 14 wavelengths and ask it questions. Lonsdale, for example, would like to look for quasars that are hidden by dust, which would make them bright in the infrared but faint in the ultraviolet where quasars are usually prominent. The question, she says, is, "Have we missed a large population of quasars because dust hides the nucleus?" Gunn wants to study star birth in nearby spiral galaxies by combining radio observations—sensitive to the compressed gas that spawns stars—with far-infrared, near-infrared, and optical observations that trace the stars' early lives. "You can get the whole history of star birth," he says.

A multiwavelength, publicly accessible universe is a couple of years off, says Szalay, "but it's gonna come, it's gonna come. All this information at our fingertips will change the way we do astronomy. It's going to be more democratic. It's a totally different world, and it's exciting to be there shaping it."

–Ann Finkbeiner

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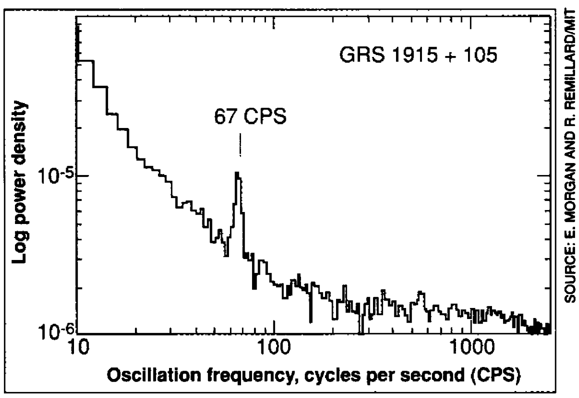
ASTROPHYSICS

X-rays Hint at Space Pirouette

If you spin in your office chair while holding a full cup of coffee, centrifugal force is likely to leave you wet—even if the entire office building and the surrounding city should somehow spin with you and hide any hint that you are moving. That's because, according to one of the more baffling concepts from Einstein's theory of relativity, the spin is measured against an abstract "frame of reference" determined by the average positions of all the stars in the universe—not a nearby speck of matter like a city. But if a chunk of matter is dense and massive enough—say, a planet or, better yet, a superdense star—all bets are off: Relativity predicts that such objects can "drag" reference frames right along with them.

Measurements announced this week may back up that claim. At a meeting of the American Astronomical Society's High Energy Astrophysics Division in Estes Park, Colorado, two teams announced their analyses of data from the 2-year-old Rossi X-ray Timing Explorer, a satellite carrying sensitive detectors that allow it to observe faint, rapidly varying x-ray signals. They found that tiny wobbles in the x-rays from matter being sucked into stellar cinders called neutron stars, and perhaps into even denser black holes, appear to be signs of "frame dragging"—as if space, like black coffee, were a substance that could be stirred and swirled.



What a drag. The jump in x-ray intensity at 67 CPS may reveal a spinning black hole dragging the space surrounding it.

"It's an intriguing interpretation," says Mitchell Begelman, an astrophysicist at the University of Colorado, Boulder. "It would be very important if it turns out to be the correct one." If so, he says, it could mean that reference-frame dragging might serve as a tool for studying black holes, objects now observed only indirectly.

In one presentation, Luigi Stella of the Astronomical Observatory of Rome gave an analysis of x-rays from matter spinning around several neutron stars. As this matter—probably torn from a companion star by each neutron star's powerful gravity—spirals into a spinning accretion disk and sporadically plunges toward the neutron star, fluctuations in its x-ray glow tip off astronomers to how fast the matter in the accretion disk is moving and even how fast the neutron star is spinning.

But the Rossi's sensitive detectors have also picked up much slower jitters, explains Stella. That got him and his colleague Mario Vietri of the University of Rome thinking about frame dragging.