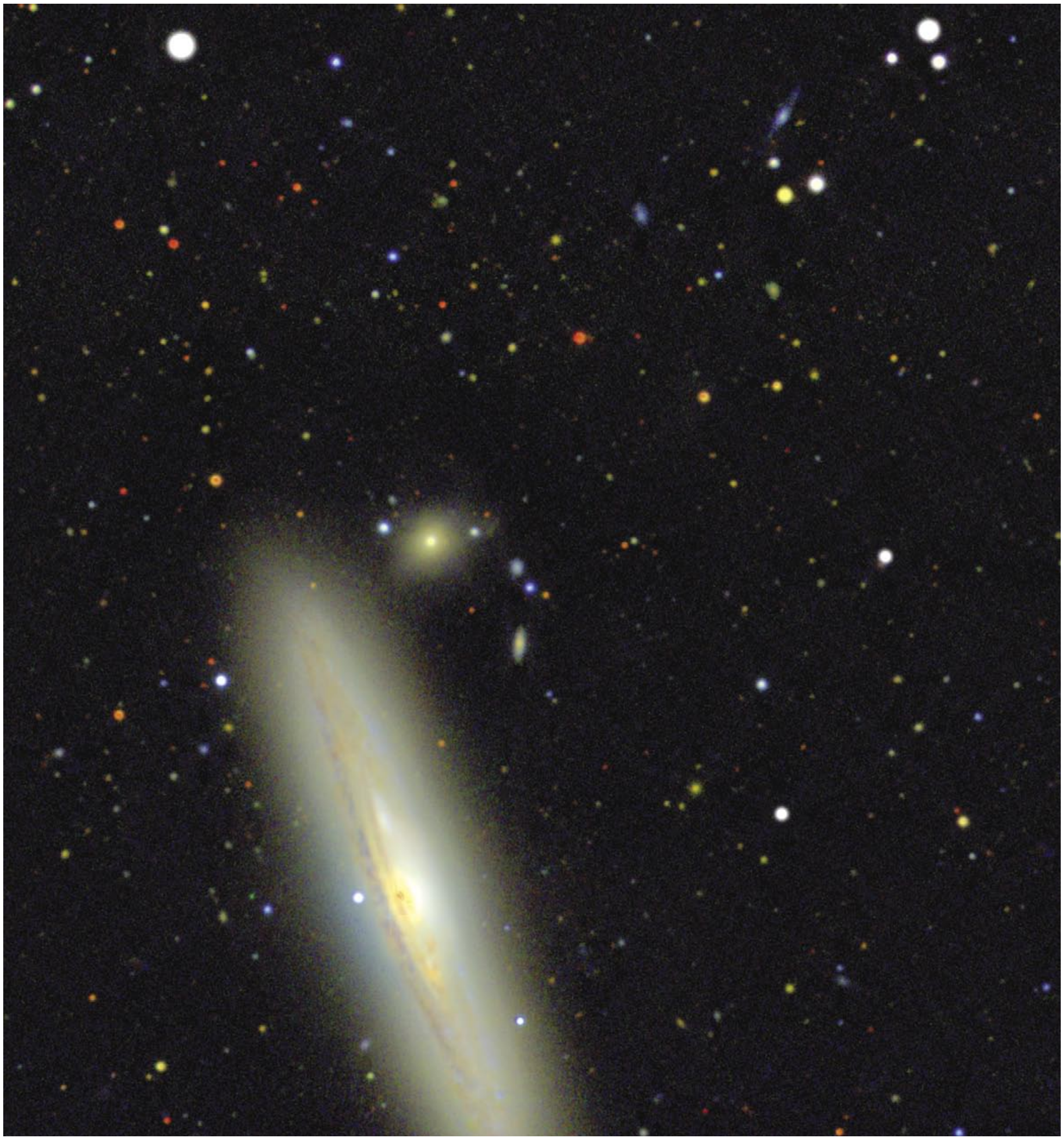
Picture This

by Douglas L. Smith



On a hilltop near the Hollywood sign stands Griffith Observatory, which director Ed Krupp calls “the hood ornament of Los Angeles.” The property of the city’s Department of Recreation and Parks, this art-deco masterpiece has Caltech all over it—the building is significantly derived from drawings by Russell Porter, a Caltech staff member who also helped design the telescopes, buildings, and grounds at Palomar Observatory. Now it has Caltech all under it as well, in the form of a 152-foot-wide, 20-foot-tall astronomical image—the largest ever made—called, appropriately enough, the Big Picture. Take the elevator down to the mezzanine of the cavernous new Gunther Depths of Space exhibit hall, and there before you is the heart of the Virgo cluster of galaxies as seen by Palomar’s 48-inch Samuel Oschin Telescope. Printed at the limit of the telescope’s resolution, this panorama fills the hall’s opposite wall; as seen in the night sky, holding your index finger horizontally a foot in front of your face would cover it—a point driven home by a life-sized bronze Einstein doing just that. Put another way, it’s about four times taller and 30 times wider than the full moon.

The mural includes objects down to about 23rd magnitude. Unlike earthquakes, the higher the astronomical magnitude, the dimmer the star. Says Professor of Astronomy S. George Djorgovski, “The human eye sees to sixth magnitude, so this is on the order of six million times fainter than somebody with perfect vision would see at a perfectly dark site on a perfect night. And it’s infinitely fainter than an average person would see on an average night in Pasadena. On the other hand, the Hubble Space Telescope can see down to maybe 29th magnitude, which is about 250 times fainter than that.” Dotting the wall are some half-million stars from our own galaxy; nearly a million other galaxies, most of which are barely perceptible blobs; a thousand or so quasars; hundreds of asteroids; and at least one comet. “Essentially every little speck bigger than a single pixel is a real object. They range from a hundred million miles away—solar-system stuff passing nearby—back almost to the beginning of time itself. A few light-minutes to 12 billion light-years.”

That’s the mind-boggling part. The eye-popping part is the couple hundred nice, big, photogenic galaxies—several of them are more than a foot across, and the giant elliptical M 87 is four feet wide—rendered in lush, loving, *National Geographic* color on three rows of 38 porcelain enamel panels.

The Depths of Space exhibit is part of a nearly five year, $93 million renovation of the most visited public observatory in the United States. Because of the building’s landmark appearance, the 40,000 square feet of new exhibit space, obligatory gift shop, and a Wolfgang Puck eatery (named the Café at the End of the Universe) had to go underground. Says Mark Pine, Griffith Observatory’s deputy director and the program manager for the exhibit program, “I think it’s cool that, in a building, underneath the lawn, people can look at something through a telescope. They’re looking at a representation of the sky from 65 feet away.” Several small telescopes, about as powerful as the coin-op binoculars you find in national parks, look out at the Big Picture from the mezzanine rail. Some are aimed at particular points of interest, while others swivel freely so that visitors can explore the wall for themselves. Descending from the mezzanine to the exhibit floor, anybody wanting a closer look can walk right up and touch the sky, as it were. Which is a big part of the reason why porcelain instead of the more traditional paper or posterboard was the medium of choice—nose- and fingerprints wipe right off.

“It’s not an artwork,” says Pine, “and it’s not intended to be beautiful, even though it is both. It is an accurate rendition of scientific data.” “It was very important to them to have a real data set and not an artist’s impression,” says Djorgovski. “They wanted a single, continuous, digital sky

Opposite: The Big Picture at Griffith Observatory includes the edge-on spiral galaxy NGC 4216, seen here at one-quarter of the size that it appears on the wall.

The Samuel Oschin Telescope at Caltech's Palomar Observatory took the Big Picture over 20 nights in "drift scan mode," with the telescope locked down and the sky wheeling overhead.

image from *real data*. And it didn't take them very long to figure out that Sky Surveys 'R' Us, and so they came to us." Says Pine, "Our exhibit designers, C&G Partners, formulated the idea of the Big Picture as a way of creating an immersive experience. Our premise was to have monumental things. We didn't want to give people the same experience that they could have sitting in front of their computer."

Krupp and Djorgovski quickly chose the Virgo cluster "because it is the nearest major cluster of galaxies," says Pine. "It's our immediate neighborhood, in the cosmic sense. It's both spectacular and relevant." Says Djorgovski, "We wanted Markarian's Chain of galaxies to be the centerpiece, to quickly draw your attention. And M 87, with its black hole and the jet of matter coming from it, we positioned at child's-eye level."

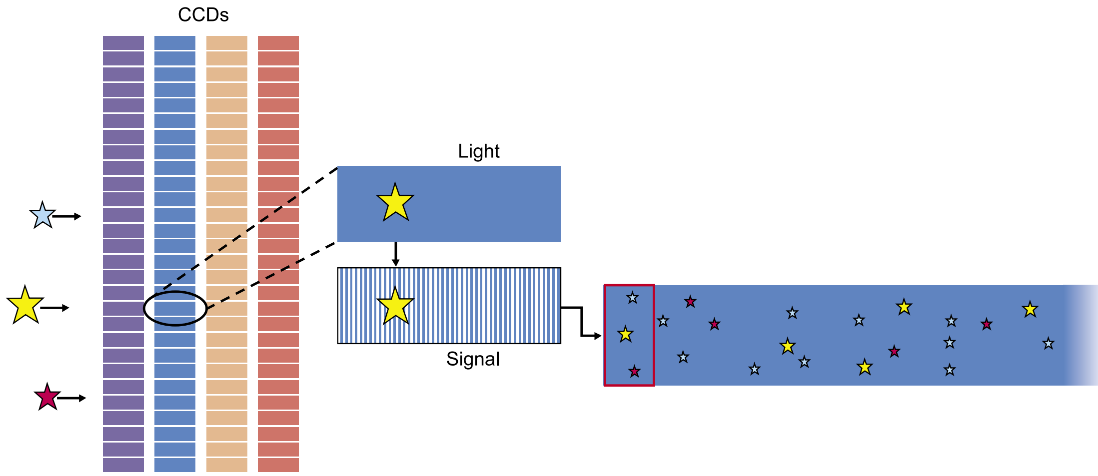
This tiny piece of celestial real estate covers roughly 100,000 times the acreage of the Hubble Space Telescope's famous Deep Field image, which contains some 3,000 galaxies going out to 12.7 billion light-years. Says Djorgovski, "The big guns like Hubble or Keck have a very narrow field of view, and they bore really deep. A panoramic sky survey is more like a census, just to see what's out there." The two types of imaging work hand-in-glove—astronomers sift through the survey data to select interesting objects or places for a closer look. At survey depths, the Deep Field is an apparently blank patch of sky, so the idea was to look as far back as possible to see what might be seen—a census in time rather than area.

Printed at the limit of the telescope's resolution, this panorama fills the hall's opposite wall; as seen in the night sky, holding your index finger horizontally a foot in front of your face would cover it—a point driven home by a life-sized bronze Einstein doing just that.

Sky Surveys 'R' Us

Palomar Observatory got into the sky-survey business in 1936, when Associate Professor of Theoretical Physics Fritz Zwicky began scanning the sky for supernovas with an 18-inch Schmidt telescope. The newly invented Schmidt design was a radical one that emphasized breadth, rather than depth, of field—a wide-angle lens instead of a telephoto. The 18-incher revealed whole classes of new objects, including dwarf galaxies, and a staggering number of galactic clusters—one of the first strong pieces of evidence that the universe is "lumpy," in a cosmic sense. It became obvious that a complete inventory of everything as far as a decent-sized telescope could see would be an invaluable astronomical tool, and George Ellery Hale extracted $450,000 from the Rockefeller Foundation to build a 48-inch Schmidt—the largest of its type in the world at the time—to go along with the $6 million they had already given to build the 200-inch telescope that now bears his name. With a field of view nearly three thousand times that of the Hale, said an *E&S* article in June 1948, "this then places the Schmidt in the position of acting more or less as a 'scout' for the 200-inch—a sort of astronomical bird dog."

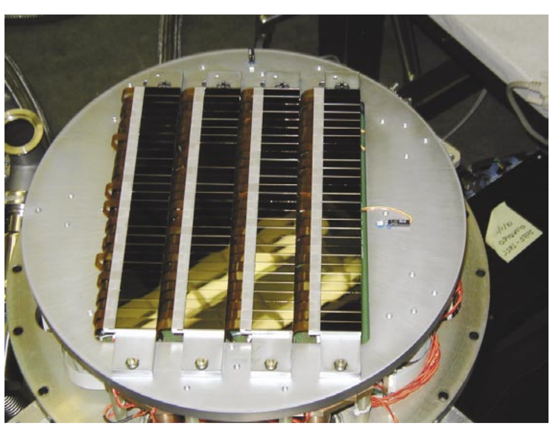
The first Palomar Observatory Sky Survey, later known as POSS I, began in 1949. By the time it wound down in the late 1950s, POSS I had covered nearly two-thirds of the celestial sphere and included everything down to about 20th magnitude. Says Djorgovski, "It had a tremendous impact. There had been other surveys, of sorts, but there was no detailed, extensive, widely available sky atlas reaching out to such a depth before. It was as if you were to publish a comprehensive road atlas of the United States for the first time. It was



In a drift scan, stars and galaxies drift across the four columns of CCDs, each with a different-colored filter. The computer reads the signal off each CCD at the rate of forward travel. The result is a long, thin image that Djorgovski calls "fettuccini on the sky."

the road map of northern-hemisphere astronomy for decades."

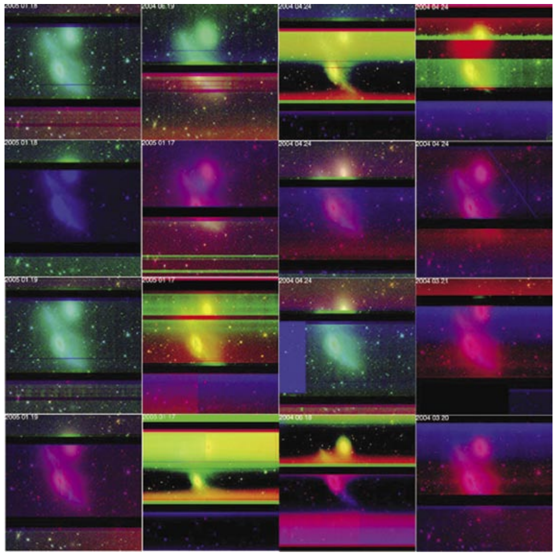
With POSS I completed, the 48-inch was used for several special-purpose surveys, including Zwicky's continuing hunt for supernovas and a survey to catalog guide stars for the Hubble. It was renamed the Samuel Oschin Telescope in 1987, while deep in the middle of POSS II—the world's last major photographic sky survey. POSS II wrapped up in 2000, at the dawn of the digital age. The Charge-Coupled Device (CCD), which now makes cell-phone cameras possible, had been pioneered for astronomical uses at Palomar a quarter of a century earlier. So Caltech's Jet Propulsion Lab, which builds interplanetary explorers for NASA, fitted the Oschin with a state-of-the-art digital camera named "Three-Shooter." "It was simply three CCDs in a row," says Djorgovski. "That wasted most of the focal plane, because you couldn't afford to pave it with detectors." Things have changed—the QUEST (Quasar Equatorial Survey Team) camera currently affixed to the telescope has 112 CCDs in four rows of 28; that's a 161-megapixel camera, if you do the math. The QUEST camera was built by Yale physics professor Charles Baltay's lab, and the Palomar-QUEST Sky Survey, sponsored by the National Science Foundation, gets about 45 percent of the Oschin's observing time. (JPL, which refurbished the telescope and built its computer-controlled pointing and tracking systems, gets 40 percent of the telescope's time for the Near-Earth Asteroid Tracking project; Yale gets 40 percent; and Caltech gets 20 percent—the Yale time and Djorgovski's share of the Caltech time go toward the survey.) If POSS I was a road atlas, Palomar-QUEST is the GPS in your SUV.



Yale's QUEST camera was among the largest astronomical CCD cameras in the world when it was built.

Recalls Roy Williams (PhD '83), a member of the professional staff at Caltech's Center for Advanced Computing Research (CACR), which does all the data processing for the Palomar-QUEST survey at Caltech, "Griffith Observatory called and said, 'we want to make this huge great image,' and George said 'We can do that with Palomar-QUEST.' I would have assumed that they would have used one of the old photographic surveys. You could make a fabulous job of that. But George had confidence." Trouble was, the QUEST survey had been designed to catalog sources, not make pretty pictures of them. The survey had been going for about a year and a half, and had already logged several terabytes of data. While the astronomers had agreed that it would be nice to have visuals at some point, "images were too computationally intensive," says grad student Milan Bogosavljevic, "because we pass across each piece of the sky so many times."

The data-reduction software had been designed to perform a sequence of operations. It scanned each camera frame, removed the various instrumental artifacts, and masked out any bad regions; extracted all the sources and measured their properties, such as brightness, size, and shape, which would help sort them into galaxies, quasars, and so forth later; determined their coordinates; entered them into a database; and cross-matched them against anything previously seen at those coordi-



Sixteen raw scans (left) from 16 different observations of the interacting galaxy pair NGC 4435 and NGC 4438. Says Williams, "The stately galaxies [below left] are what comes out of data cleaning and coaddition. The software is what converts the pigs' ears into the silk purse."

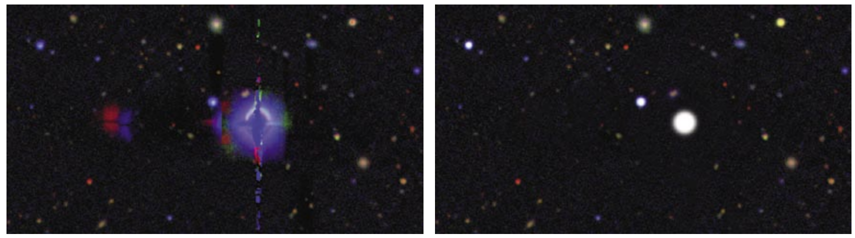
nates. Says Bogosavljevic, "We were still feeling out how to deal with this huge amount of data ourselves. We were forced to speed up the development of tools to find our way around our own data, because for this job we had to access it in a different manner." Until then, the frames had been logged sequentially in order of exposure, so postdoc Ashish Mahabal (now a staff scientist) created a sorting database organized by celestial coordinates.

The Cosmic Beauty Pageant

The Big Picture concept meetings were in early 2001, but it was July 2004 by the time the money had been raised and the contracts to build the exhibits were let. In the meantime, a new kid had arrived on the block—the Sloan Digital Sky Survey, which uses a 98-inch telescope with a 120-megapixel camera on Apache Point, New Mexico. So Pine emceed a beauty contest—both teams were asked to prepare four-foot-square renderings of M 87 and NGC 4216, the aforementioned elliptical and an edge-on spiral galaxy respectively. Both have a large brightness range, and each is a distinct color. M 87, being made mostly of mature stars, is yellowish-red, while NGC 4216 is ablaze with the blue light of hot, young stars. The teams had a couple of weeks of frantic data processing to put their best shot forward, and in a blind judging—perhaps not the mot juste for this very visual competition—a panel consisting of half a dozen people, including exhibit scientist Bruce Bohannan, an astronomer recently retired from the Kitt Peak National Observatory; Krupp (who has a PhD in astronomy from UCLA); and Mathew Malkan (PhD '83), an astronomy professor at UCLA, chose Caltech's pictures. Says Pine, "The Sloan data set is a fantastic data set. So it's not like we chose the good one and didn't choose the other one. We had the luxury of choosing between two great data sets."

"Frantic" really doesn't do justice to the effort that went into the renderings. Says Djorgovski, "It's actually much more demanding to produce a pretty picture than a scientific data set. Our programs recognize bad pixels and simply don't use them." For one thing, because the camera was designed to soak up every available photon, any bright star in the field of view saturated the CCDs. This spilled over into the adjoining pixels, leaving trails across the image. Says Williams, "When you're looking for faint sources, you don't care about the bleed trails. The bright stars are just pollution." But here's where CCDs beat the socks off of photographic plates—you can, with clever software, merge any number of frames into one image. So the gaps were filled with data from other scans of the same region. Says Williams, "By carefully removing the bad areas and saving all the saveable areas, it's possible to get the best of all the scans, rather than the worst of everything. If you add fifteen good images and one bad one, you end

Once the software has done its best, human eyes finish the job. Below left is a bright star and the artifacts caused by its internal reflections within the telescope's optical train. Below right is the same star after Maxfield's ministrations in Photoshop.



up with a bad image."

So much for the technological end. The human eye reigned in the all-important issue of color. The QUEST camera has four filters—near-ultraviolet, which honeybees can see but we can't; blue; "near red," which is a sort of orangey-red, and "far red," which is actually in the near-infrared, just beyond our vision. So to approximate a space tourist's view using the standard red-green-blue format of computer monitors, the ultraviolet data was ignored, the blue remained blue, the near-red stood in for green, and the far-red was nudged back a bit to our red. Says Williams, "It's an *exaggerated* color. But it is the *right* color, if that means anything. I was doing quite a bit of the colorizing, and I remember George saying to me once, 'Just remember, there are no green stars.' If you get the balance wrong, you output green stars, and you have to go back and try again."

The final touch-ups were made in Photoshop by Leslie Maxfield (BS '95), who works at Caltech's Digital Media Center and also happens to be Djorgovski's wife. She went through the images pixel by pixel and removed any remaining bleed trails, all the airplane lights that were too dim to be caught by the processing software, and internal camera reflections, which look sort of like those trails of bright circles emanating from the sun that you see in vacation snapshots. She also checked the alignments. "In some of the early versions I'd see little cloverleaf stars here and there," she says. "They'd have a red lobe, a blue lobe, and a green one. So I'd have to go back and tell them, 'Hey, the astrometry's not right. You'd better run that one again." She also did the final color corrections, and the Digital Media Center printed the posters.

The raw data is unprepossessing—bright blobs intermixed with lights from passing airplanes, bleed trails, camera noise, and the occasional cosmic-ray hit.

Adrift in a Sea of Pixels

Having gotten the nod by combining some eight exposures each of a couple of galaxies, the team looked at the Virgo cluster in earnest over a span of 20 nights between March 2004 and April 2005. This produced an average of a dozen or so passes over every pixel of the Big Picture. The raw data is unprepossessing—bright blobs intermixed with bleed trails, camera noise, lights from passing airplanes, and the occasional cosmic-ray hit. Streaks of all persuasions are removed by a computer running a "median filter," which removes things with sharp edges. Now the slight blurring caused by the atmosphere for once becomes an asset, because even bright stars have fuzzy boundaries. So the filter takes small groups of adjacent pixels, finds their median brightness, and rejects all the pixels in the group that are considerably brighter or dimmer than that median value. "We had an average of about 16 passes over this huge area of sky, about 200 gigabytes of pixels, and we had to do this to every pixel," says Bogosavljevic. "Normally you don't have to process such an amount of data in such detail. If you had one image you could do it on your own PC just fine. If you have a million, it's a problem."

But the biggest challenge was even more basic. Photographic sky surveys are "point-and-stare"—you aim the telescope at a certain spot, and as the earth rotates the telescope tracks its target's westward progress. This slow, methodical approach eventually allows you to tile the heavens in a mosaic of overlapping plates within which the position of every pinprick of light is precisely known. But in order to see as much of the sky as you can as quickly as possible, the Palomar-QUEST and Sloan

Comet P/Tsuchinshan as seen on two successive nights—once as a pair of fuzzballs directly above this caption, and again as a similar pair of fuzzballs below and to the left of the galaxies on the opposite page—again, at one-quarter the size of the Big Picture.

surveys operate in "drift-scan mode," in which the telescope is locked down as the sky wheels overhead. The QUEST camera is oriented so that its columns of four CCDs, each with a different color filter, are parallel to the direction of drift, and in the space of about 15 minutes the photons from a single star march from one edge of the array to the other. Over the course of a night's observing, a ribbon-like image emerges that Djorgovski calls "fettuccini on the sky."

The computations to bundle the pixels back into their stationary sources are reasonably straightforward, but try to wallpaper the celestial dome, and you'll quickly discover that the strips are warped. Earth plows along in its orbit, and incoming photons change their angles ever so slightly from each strip's beginning to its end. This is called "differential aberration," says Djorgovski, who compares it to driving a car in the rain—the drops look like they're coming toward you. "We know how to account for it, but we have to do it in a way that we normally don't bother with for pictures of small pieces of sky." When you're creating a catalog, all you have to do to move the stars back into their proper positions is tweak their coordinates. But to make the Big Picture, all the pixels had to be scrunched up and over, as it were, one hair's breadth at a time along each ribbon's length.

The final alignments were double-checked by comparing the astrometry—the measured positions—with a catalog maintained by the United States Navy. In a throwback to the days of sextants and dead reckoning, "the U.S. Naval Observatory has the world's best position catalog, at its depth of field, of the entire sky," says Williams. "They have so many stars that even in a small image you can find 30 that are covered. And since we know approximately where we are to begin with, we can check the astrometry automatically by pattern-recognition software."

But while stars and galaxies are fixed, some things do move. Thus, in the middle row of porcelain panels, near the top of the twelfth one from the left, are two images of Comet P/Tsuchinshan—a fuzzy, predominantly blue ball a few inches away from its equally fuzzy, but mostly green twin, captured in two scans made about an hour and a half apart. (To further complicate the color-balancing problem, you don't necessarily always have every color in every scan.) Then, some three and a half feet farther down to the right, there it is again—another pair of images captured in two passes the following night. Says Djorgovski, "We thought about reassembling the comet, but we said, 'No. This tells a story. This is real data.'" Ditto for the asteroids, which Maxfield called "stoplights" because each one appears as a green, a red, and a blue dot lined up nose to nose.

The computational heavy lifting was done on a cluster of 16 Intel Itanium 2 processors donated to CACR by Hewlett-Packard. Bogosavljevic had created a data-processing "pipeline" for the beauty contest. "I wrote an ugly mixture of several programming languages, stitching together some standard filtering procedures. We had to figure out the best way to make the pictures pretty in the first place, so we were changing the code as we went along." Adds Djorgovski, "Nearly everything we did for the pipeline would have to have been done for the survey in any case. But many of the things we ended up needing we did not anticipate, and some things we thought we would need we decided to give up on, all as a product of the experience gained as we were pushing along."

The code was awkward, and not easily expandable to run on many processors at once, so grad student Ciro Donalek adapted it for supercomputer use. Says Mahabal, "IRAF, which is one of the software packages, can sometimes be a bit moody. If that happens in a large pipeline and you don't know what's going wrong, that's not a good thing." IRAF, which stands for Image Reduction and Analysis Facility, is written in an obscure language called SPP. This is fine if you don't have to tinker with it, and you usually don't—"IRAF covers almost all the standard things you would need in your daily astronomical-image-dealing life," says Bogosavljevic. But IRAF turned dyspeptic when force-fed. If it ran into a picture it couldn't digest, it belched up a cryptic error number and died. "If you want to do something to images number 1 to 30,000, and it dies on image 2,985, it's tedious to keep restarting it saying, 'OK, now run from 2,986 to 30,000,' and then having it die again somewhere else. What you want is a code that will run the 30,000 images and then tell you nicely, 'I could not do 2,985 and 24,576.' For a while, the code was instructed to send an e-mail to all of us every time something would crash. Seems kind of funny, getting an e-mail asking for help from a computer." Donalek wound up writing counterparts for many of IRAF's processes in C, which is the vernacular of high-end computing, and he and Mahabal figured out how to make the pipeline spit out unpalatable images rather than gagging on them.

The team spent six months refining the pipeline. Says Bogosavljevic, "We never ran the entire data set, just a small piece, and we'd see an error and go back. Ciro is a good programmer, and he optimized his codes so it became faster as we went along. But even so, it would have taken a week to run the entire Big Picture data set." Adds Mahabal, "Sometimes an algorithm would do what we wanted it to do, but then we would find out something else that we should also do." "There was a lot of, 'Oh, Ciro's made a new blah-de-blah filter.

Let's run it all again!'" chuckles Williams. "That happened all the time. All the time!" The effort has paid off big time for the survey as a whole. The pipeline now runs three to five times faster than it did originally—fast enough to process the incoming data in real time.

But even with all this computational firepower, the Big Picture's final cleanup still had to be done by hand. "[Observatory director] Ed Krupp decided how big and fuzzy he wanted the foreground stars to be," says Maxfield. "Bright stars are bigger and bleed more, so I had to bring them back to size." Maxfield processed the first half of the Big Picture with Simona Cianciulli, Ciro's wife, working long into the night while Djorgovski watched the kids. "I think I discovered podcasts during that time," she laughs. Then, realizing that they weren't going to make deadline, Maxfield recruited Radica Bogosavljevic, Milan's wife, as well. The trio spent the next six weeks pixel by pixel, panel by panel, making the last cosmetic adjustments and checking the alignments. Galaxies, and even stars, frequently spilled over from one panel onto the adjoining one, and the match had to be flawless in both color and alignment.

Griffith Observatory director Ed Krupp inspects panels depicting the Markarian Chain on the factory floor at Winsor Fireform.

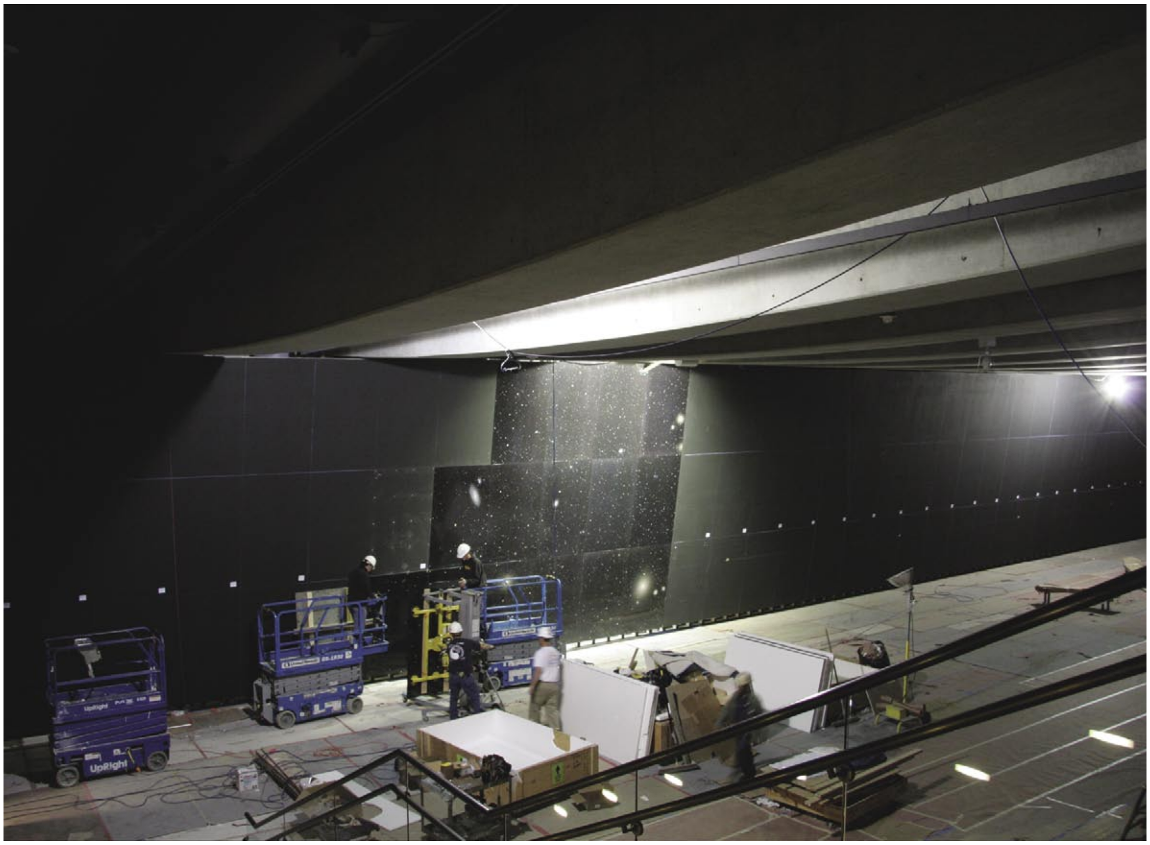
Fire When Ready

All 114 of the six-foot, eight-inch by four-foot panels were manufactured by Winsor Fireform of Tumwater, Washington, whose usual line of work is making somewhat smaller weatherproof signs and public art. If you've been to the White House, the Grand Canyon, Times Square, or any of a number of major metropolitan zoos, you've seen their work; they've also been a prime producer of interpretive displays for the National Park Service for more than two decades.

The production process is conceptually similar to printing the color pictures in this magazine. Each steel-backed panel gets a pure-white porcelain base coat to which are applied successive layers of enamel—pigmented glass, essentially—the mineral equivalents of cyan, magenta, yellow, and black inks. "We have a black base coat we could have used," says Bryan Stockdale, Winsor's president, "but there was so much white all over the image that it just wasn't a good idea. White is such a faint color that we would have had to apply two layers of it, both in perfect dot-on-dot registration with each other."

There may be a lot of white in the image, but there's even more black, and getting the black right was, if you'll pardon the expression, a black art. Among other issues, there's a tradeoff between getting the black of space as black as possible without making faint objects disappear. This was especially true for elliptical galaxies, which are basically giant fuzzballs of stars—bright at the core and fading off into nothingness in all directions. Make the black too black, and these galaxies shrink alarmingly. It took half a year of testing to get it right.

The black had to be absolutely uniform from



The galaxies begin to go up on the wall. M 87 is at lower right, and the spiral galaxy above the worker on the scissors lift is M 90.

panel to panel, because the plan called for the mural's central portion and focal point, Markarian's Chain, to be done first as proof of concept, followed by the left-hand side and then the right. Keeping the colors consistent over a six-month production run was an unprecedented feat, says Stockdale. Besides finding the proper mineral mixes, the length of each firing is calculated based on panel size, the number of firings still to come, and such arcana as the ambient humidity—Tumwater is on the shores of Puget Sound, which may be the rainfall capital of the continental United States. There are seven firings per panel: the "ground coat," which is a sort of primer that adheres to steel, and is basically that off-black substance you see on the underside of enamel sinks; the base coat; the four pigment coats; and a final clear coat to seal everything on and protect the finish. "The first firing is at over 1470 degrees Fahrenheit," says Stockdale, "and each firing after has to be done at a successively lower temperature. You don't want the underlying layers to go molten again, but you still have to melt the layer you're firing. The colors shift—the color you put in is not the color you get out, depending on the dwell time—and our experience tells us how to compensate for that, but you can't actually see the result until after the final firing."

A lot of frequent-flyer miles were logged over the summer of 2005, as test panels were fired and the color balance worked out. Exhibit scientist Bruce Bohannan was the best traveled, winging from the New York exhibit designers to Pasadena to meet with the Caltech and Griffith folks and to Tumwater to consult with Winsor, providing the crucial link between high concept, science, and appearance. The 10 panels featuring much of Markarian's Chain were approved in October 2005, and production began in earnest thereafter. Even so, Bohannan and Camille Lombardo, executive director of Friends Of The Observatory—two pairs of eyes with very different points of view—made regular pilgrimages to the factory to approve every single panel before it was shipped south.

And there were mechanical challenges: the panels had to hang perfectly flat in the kiln, but they expanded by an inch or more in each direction during firing. Drilling holes for hooks was not an option, so special jigs needed to be built to support the panels, a feat complicated by the fact that the porcelain is curved around the edges of the underlying steel to keep it from rusting. Says Pine, "We looked at making flush edges, which would have essentially required them to cut the porcelain and expose the steel. It would have looked more seamless, but it would have compromised durability." Protected as they are, the panels should last hundreds of years.

To top it off, the mural slopes out over its viewers at a 10-degree angle, in order to minimize glare from the ceiling lights. But the porcelain alone

The upper panels were installed using a lift equipped with those suction cups you normally see in bank-heist movies when a plate-glass window needs to be cut.

weighs nearly four tons, which is an awful lot of teacups. "It's not like a normal exhibit," says Pine. "Most exhibits are like refrigerators. You bring them into your home, you unbox them, you plug them in, and boom—welcome to your exhibit. This one not so much. It had to be reviewed by the city's Department of Building and Safety to make sure that it met all code requirements for earthquake safety, fire safety, all those kinds of things." Maltbie, Inc., the exhibit fabricators, had built an angled steel frame, bolted into the cement wall and floor, that supports a wood-and-drywall skin to which each panel is attached by four rows of five two-inch threaded studs and a good slather of industrial-strength adhesive. The studs were welded to the steel backsides of the panels before their first firings, making them "like porcupines," says Stockdale. "They were very hard to move around the shop. And the studs all had to be kept perfectly straight, so they'd line up with the holes in the wood." The company wound up backing the panels with two-and-a-half-inch-thick Styrofoam slabs. These were stacked, club-sandwich-style, in lots of a dozen in heavily reinforced three-quarter-inch plywood crates for the journey south. "You could almost build a condo out of the amount of wood we shipped down there," Stockdale laughs. The panels were trucked south as they were approved, and the last panel went up on the wall on April 26, 2006.

"It was a huge, huge undertaking," says Pine. "No one had ever done anything like this before. There's no reference book to go to and say, 'Hey, how do you build a gigantic porcelain wall?' It's not a miracle though, because miracles are things you can't explain. A lot of people worked very, very, very hard to make this happen." Stockdale agrees. "When you take on a job like this, which is literally one of a kind, you don't know at the start how you're actually going to do some of it. You're dealing with problems you've never had to consider before, even though you've done tens of thousands

The Winsor Fireform crew. Back row, from left: Tony Elhardt, Jon Colt, Avet Waldrop, Chris Heiting, Nelson Dan, Bryan Stockdale, Josh Kessel, Brandle Strand, Jerry Forrester. Front row: Diane Chamberlain, Leslie Tikka (production manager), Tom Rose, Nathan Ereth, Randy McAllister, Rachel McAuley, Patrick Horsfal. Missing: Joan Fulton, Virginia Viehmann.

of panels. You just have to rely on your team to rise to the challenge."

The Big Picture "is a testament to observational astronomy," says Pine. "And I can think of no better place for it than this place, which is oriented to sharing observational astronomy with the public. People don't look up any more. Especially in L.A.. You know, the sky here is something of an endangered species. But if we can get people to walk out of the building, and look up at the night sky, then the observatory has done its job." □—*DS*

PICTURE CREDITS: 23 — Doug Cummings; 20, 23, 24, 25, 26–27, 31 — Palomar-QUEST Survey Team; 22 — Scott Kardel; 28, 31 — Winsor Fireform; 29, 30 — Anthony Cook, Griffith Observatory

Griffith Observatory is open to the public from noon to 10:00 p.m. on Tuesdays through Fridays, and from 10:00 a.m. to 10:00 p.m. on Saturdays and Sundays. Reservations are required. Visit www.GriffithObservatory.org for more information and to make a shuttle reservation. (Tickets are also available at 1-888-695-0888.) There is no parking at the observatory; hikers and cyclists may brave the winding road to it, but the rest of us can catch the shuttle at the L.A. Zoo in Griffith Park or at Orange Court on the west side of the Hollywood and Highland entertainment complex in Hollywood.

More information on the Big Picture, including an interactive tour of it, can be found at bigpicture.caltech.edu. □

The Caltech team (and a couple of ringers) behind the Big Picture. Back row, from left: Simona Cianciulli; Ciro Donalek; CACR staff scientist Matthew Graham, who helped develop the database; Milan Bogosavljevic; CACR staff scientist Andrew Drake, who works on the new pipeline; Radica Bogosavljevic; Leslie Maxfield; Yale grad student Anne Bauer, who helped with the data acquisition; Roy Williams; George Djorgovski; Charles Baltay, whose lab built the camera; and Ashish Mahabal. Missing is Yale research scientist David Rabinowitz, who is best known to *E&S* readers as a codiscoverer of Eris, Sedna, and other dwarf planets in collaboration with Caltech Professor of Planetary Astronomy Mike Brown.