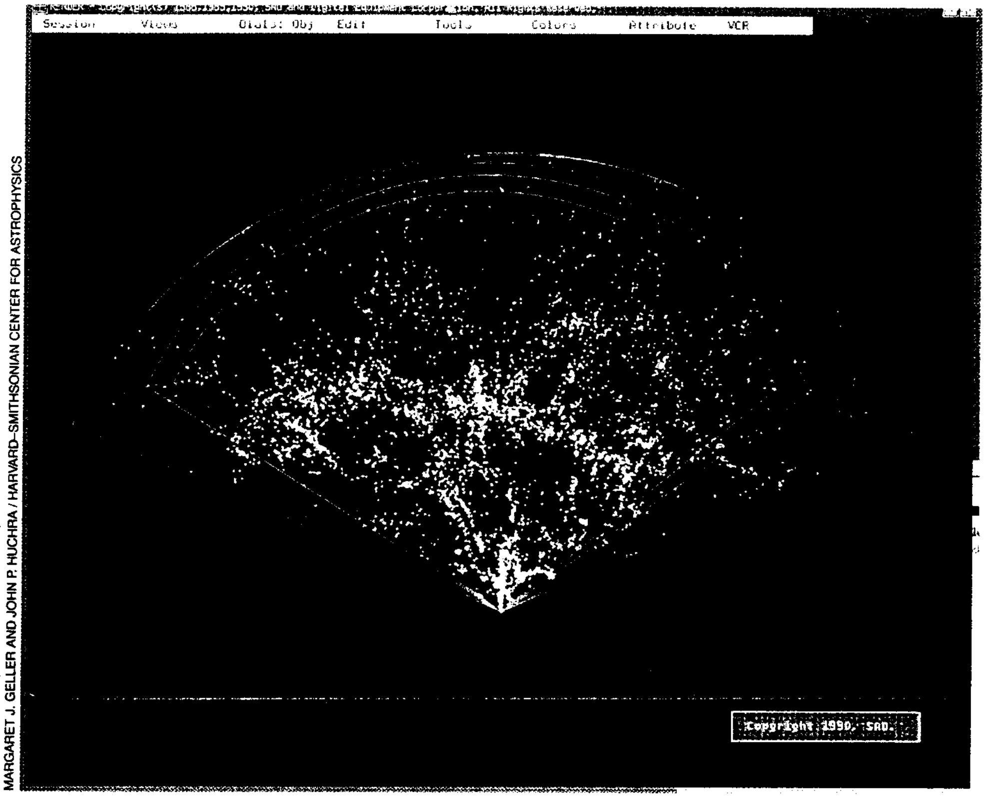
Seeing What Lies Beyond the Stars

SUMMARY: Astronomers have had a relatively nearsighted look at the universe so far, but that view will be stretched 1,000 times farther with the completion of a special new observatory. There, astrophysicists will conduct a long-term survey of space that should enable scientists to begin answering such age-old questions as: Just how big is the universe? How were galaxies formed? What is the structure of the universe?



MARGARET J. GELLER AND JOHN P. HUCHRA / HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

Map of four "slices" of the universe shows Earth at the vertex of 4,000 galaxies.

A few hours' drive southeast of Albuquerque at 9,000 feet above sea level stands Apache Point, a green peak high in the Sacramento Mountains of New Mexico. Apache Point is noteworthy, among other things, for the fact that a road goes there. Water can be found there, too. After dark, those vast Southwestern skies, like black velvet strewn with pearls, blink through the warm, thin air so crucial for good stargazing.

Already frequenting this isolated place are bearded, sweater-clad astrophysicists who make the trek to study the sun and other stars at the National Solar Observatory. Within two years, however, construction of a new observatory will begin at Apache Point. Though neither unusually large nor complex, this starlight detector will have a single special mission: to make the most comprehensive three-dimensional color map ever made of the universe.

The instrument will scan the skies for five to seven years, beginning around 1995, in an effort to create an enormous computerized data base — a digital sky survey, as it is called — that will provide astronomers and physicists with new clues as to how the universe is structured at the largest detectable scale.

"In a sense, the level of our ignorance is rather profound in some areas, which is why we want to take a good, hard look at what is, at what exists," says Richard Kron, an astronomer at the University of Chicago and director of its Yerkes Observatory in Williams Bay, Wis. "We know from existing surveys that the structure [of the universe] has an incredible degree of richness that was not suspected a decade ago. But, at the same time, the existing surveys are inadequate to describe fully just what that structure actually is.

"We know enough to know what the interesting questions are," Kron adds. "In other words, we know enough to know we need to know more."

The survey's objective is to catalog in detail a volume of space 100 times larger than has ever been mapped before and to sparsely cover a volume 1,000 times larger. The map should include 1 million galaxies and 100,000 quasars as well as more than 1 million intergalactic gas clouds and stars within Earth's own galaxy, the Milky Way.

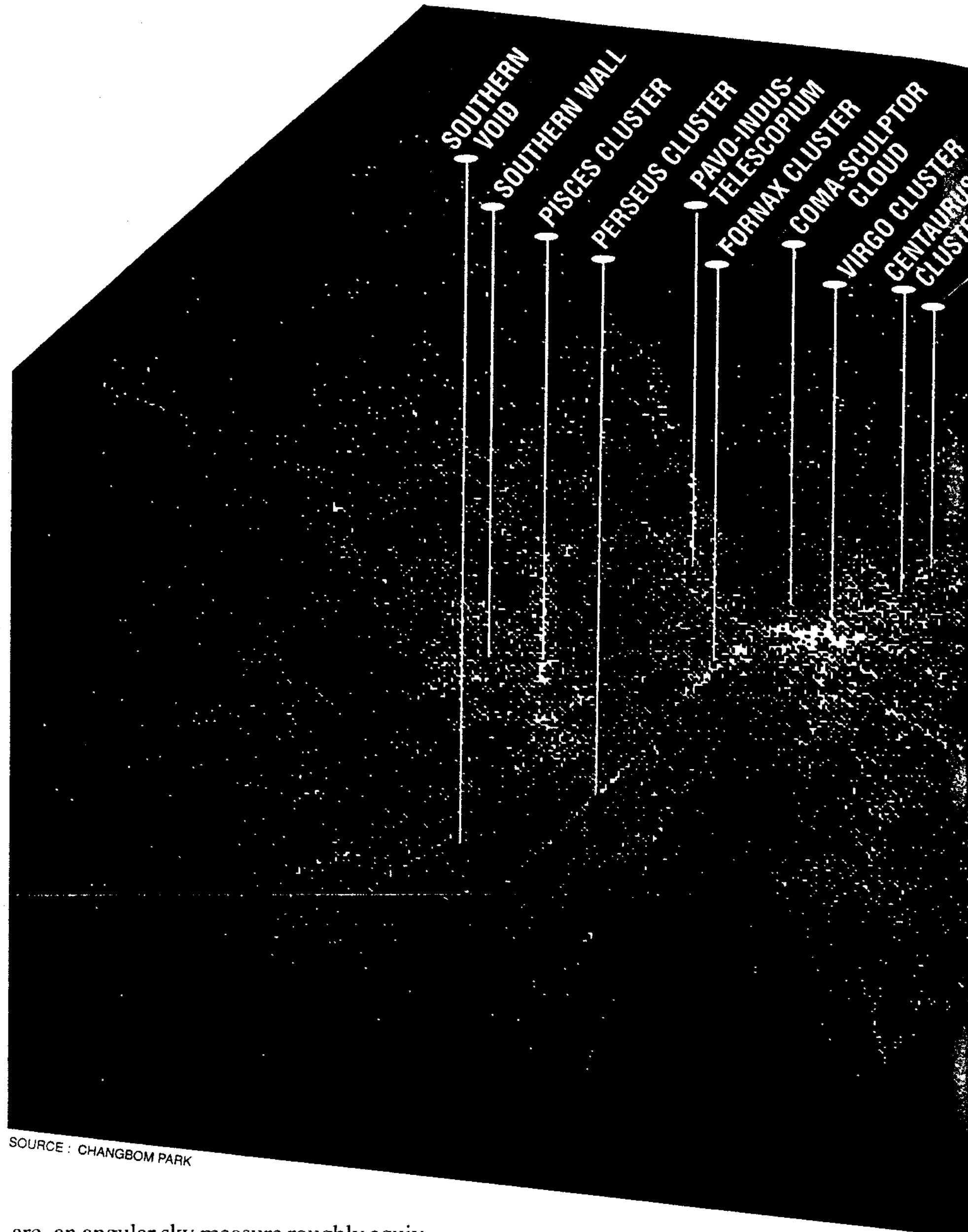
Some key questions the astronomers from the Astrophysical Research Consortium, a group of six participating institutions that will oversee the project, hope to answer: What is the large-scale structure of the universe? How has this structure evolved since the big bang? Was the structure produced primarily by gravity, or some other force?

"Because the data base will be so enormous, we'll be able to ask fairly subtle questions that have not been possible to ask before, because the statistics haven't been good enough," says Kron. "We know, for instance, that there are correlations between the characteristics of galaxies and their environments — that is, whether they occur together in clusters or whether they're off alone in space. There seem to be some systematic differences between galaxies that occur in high-density and low-density environments. We know this exists, but don't know much about why."

Many critical, yet so far unresolvable, issues remain in the field of cosmology, which deals with the origin and structure of the universe. Therefore, astrophysicists have had difficulty discerning the reliability of different models. For instance, they wonder: Why are some galaxies, like the Milky Way, spiral in structure, while others are amorphous? Why do some galaxies seem to clump together in superclusters? Are there structures larger than the ones that can now be observed?

Speculation exists that the universe may actually be structured in terms of what scientists call bubbles, defined by groups of galaxies in a honeycomb pattern in space. However, insufficient data exist to prove, or disprove, this hypothesis or other competing ones that describe what kind of shape the universe ultimately has.

"This is very much an empirical study," says Kron. "We don't have a strong theoretical understanding of galaxies, for instance, why some have disks and others don't. We have a universe where about 50 percent of the light comes from the disks of galaxies and about the other half comes from the galaxies' central bulges. No one is quite sure why that should be the case. It's just a fact. With this very large data



SOURCE: CHANGBOM PARK

base, we could pin down those correlations very accurately. And, no doubt, other correlations will appear that we don't yet know about."

To construct what the astronomers describe as a uniform, contiguous, three-dimensional map, they will use an automated telescope with a 100-inch diameter, offering an unusually wide field of view. They also will use two special instruments: a wide-field electronic camera and a spectrograph.

The observatory's camera will scan the sky with special color filters, allowing scientists to make color maps. The spectrograph can observe hundreds of galaxies simultaneously and scrutinize quasars, those quasi-stellar, distant sources of radiation. It will detect spectral lines to determine the redshift, or the change in the apparent color of stars that can be used to estimate their relative motion away from the center of the universe.

Objects at the farthest known edge of the universe appear to be moving away from each other faster than objects nearer to Earth do. The greater this redshift, the farther away the object is and the older it is, scientists generally believe. From the measured redshifts of radiation emanating from these objects, astronomers can estimate the distances to them. Thus, redshift data from galaxies and quasars are crucial to a correct map of the universe, identifying the relative positions and proportions of the many objects that fill its space.

The spectrograph will be able to detect and measure stellar light that would have to be 200,000 times brighter for the naked eye to see, including galaxies that are 1.5 billion light-years from Earth.

It should discover new quasars, which are 10 times brighter than most galaxies. Quasars are the oldest, most distant, fastest moving and most poorly understood objects in the universe. More information about quasars is needed to understand the universe's large-scale structure.

In terms of the main telescope, the total area of its light-sensitive focal plane will be larger than anything built so far. Its light sensors are called charge-coupled devices, or CCDs, each a solid-state chip with 4 million separate diodes to record the sky image as an electronic signal.

As the telescope slowly negotiates a section of the sky, it focuses radiation to scan over the CCDs. Scientists will digitally reassemble the individual strips of sky in a computer system to yield a seamless map. In the end, the multicolor map will resolve the picture down to 0.4 second of arc, an angular sky measure roughly equivalent in scale to mapping the Earth's surface within an accuracy of 40 feet.

The enormous amount of raw information gleaned from this cosmic survey will be handled by the Fermi National Accelerator Laboratory in Batavia, Ill. Its computer facilities can handle huge quantities of electronic data, and it has an experienced group of scientists who are especially interested in the connection between physics at the smallest scale, subatomic particles, and at the largest scale, the forces that cause galaxies to cluster. Managing all these data, which could add up to the equivalent of a telephone book listing 250 billion people, will require a farm of smaller computers.

Once this galactic encyclopedia is completed, scientists can peruse it at their leisure. In the long run, the information — a complete catalog of everything that emits light within a certain range of brightness — could be compressed into a set of computer disks available for widespread scientific and ambitious amateur consumption for as little as a few hundred dollars.

To date, the most complete catalog is the work of Margaret Geller and John Huchra of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass. They have spent more than a decade mapping the universe galaxy by galaxy, a heroic but tedious process involving measuring redshifts one by one, then calculating distances. They have amassed a sketch based on several thousand galaxies, out to a distance of 500 million light-years. But the picture is still vague, which is why astronomers feel so strongly that a specialized, comprehensive survey is needed.

"We know a lot about a few regions of the sky but don't have a very good big picture right now," says Donald G. York, professor of astronomy and astrophysics at the University of Chicago. "This survey should give us a much better sense of that."

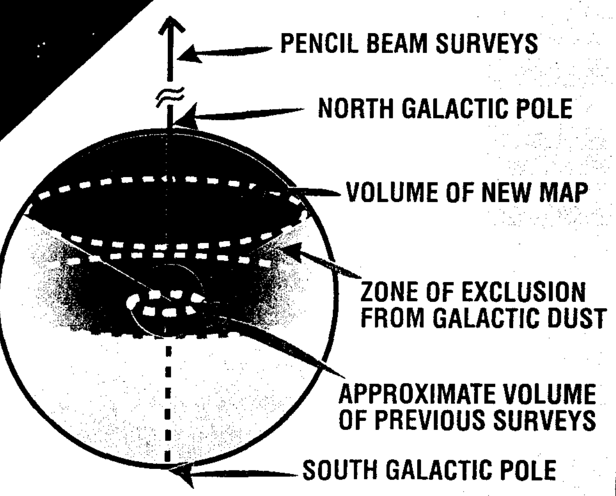
“Strangely, many people hope we don’t find anything too interesting.” It could “wreck a lot of our current theories.”

In astronomy, “the surprise of the last decade is that there is a strong clustering of galaxies, unpredicted and unexplainable in terms of modern physics. But that observation is based on a very small survey, and we still don’t have a very good understanding of galaxies yet,” says York. “We’re still looking for evidence of changes in galaxies at different points in their evolution. Every time someone finds what they think is evidence, it turns out to be a false discovery.

“We have to be complete,” York adds. “Otherwise, the patterns we miss will suggest false structure on the map.”

During the coming year, astronomers will finish detailing designs for the telescope itself. Participating institutions are the University of Chicago, Princeton University, the Institute for Advanced Study at Princeton, New Mexico State University, Washington State University and the University of Washington. Then the mirror, now being manufactured by Hextek Corp. in Tucson, Ariz., will be polished and tested. The charge-coupled devices also must be painstakingly fabricated. The quality requirements are exceptionally high for this type of instrument, usually limited to use in equipment such as spy satellites.

If all goes well, the entire system should be up and running by the summer of 1994. A yearlong shakedown of all systems will follow, then data accumulation will begin. Total cost: $14 million to set up and another $1 million a year to operate.



The survey will offer a wide-eyed view of the universe, greatly expanding the pencil-beam-width peeks of the past. Astrophysicists will map a galactic volume up to 1,000 times larger than previously charted. The distribution of 14,235 galaxies in our neighborhood (above left) reveals voids, clusters and other large-scale structures. Our Milky Way galaxy is in the center of the box, under the cross.

INSIGHT

There is so much interest in the wider structure of the universe because “so far the evidence has shown that every time we look at larger scales, we’ve found larger structures,” says Princeton astrophysicist Jeremiah P. Ostriker. “And every time this happens, people have been surprised.

“Strangely, many people hope we don’t find anything too interesting,” he says. The reason: It could “wreck a lot of our current theories.”

Right now, “The large-scale structures we know about are on the verge of causing trouble for the current theories,” he says. “The fact that we keep finding bigger structures as we survey larger volumes of space implies that there may be yet bigger structures that we haven’t yet thought of.” This survey will either “fully invalidate or confirm” currently held ideas.

The survey also will give astronomers a deeper grasp of quasars, which emit huge amounts of radiation in the form of ultraviolet and bright blue light and powerful radio waves.

Quasars “enable us to see far back in time and do cosmology directly,” says Ostriker. “But our sample of quasars is so small that it creates a lot of problems.”

Only 5,000 of these distant quasi-stellar objects have been detected so far.

The oldest known quasar is more than 14 billion light-years away, and dates back to what scientists call 93 percent of the age of the universe, which means that if the universe were 100 years old, it would have formed during the first seven years. Astronomers, however, are still not quite sure how old the universe really is; current guesses generally put it at about 14 or 15 billion years.

The field of cosmology is rich in interesting theories and ideas, but poor in data to confirm or deny some of the more intriguing notions, says Ostriker. In essence, each theory involves a mathematical model linking cosmic evolution of the largest and smallest structures and their relation to the formation of the universe at the beginning of time. Yet without concrete observations to back up the models, several of these theories are hanging in the balance.

“Why do we think Einstein’s theory of general relativity is correct?” he asks. “Because it predicts events we can measure, such as the orbit of Mercury and the bending of light, which prove it to be correct. Similarly, to test a theory in cosmology, you make predictions, work them out in computer models, then compare the models with reality, with the information you obtain in a survey. Do they agree or not? We can never tell unless we make predictions, then test them with measurements.

“That’s why this survey is so important,” Ostriker observes. “It will weed out lots of weak theories, put the final coffin nails in. But it will also give us the basic factual information we need to find the correct theory.”

— Richard Lipkin