MEETING AMERICAN ASTRONOMICAL SOCIETY

Cool Comets, Barren Clusters, And a Maxed-Out Universe

ROCHESTER, NEW YORK—About 900 astronomers gathered 2 weeks ago near the birthplace of Eastman Kodak Co. to share their latest pictures of the sky at the American Astronomical Society's 196th Meeting. Notable findings pointed to a cold origin for comet Hale-Bopp, a nasty environment for extrasolar planets, and a maximum size for the biggest structures in the universe.

Star Clusters Appear Hostile to Planets

Astronomers detect planets around other stars so frequently these days that each new sighting barely causes a ripple. Now, a research team has made a splash by spotting no planets at all. The Hubble Space Telescope struck out when it looked for planets within a swarm of a million suns, astronomers reported at the meeting. Although the search was tuned only to giant planets in tight orbits around their stars—the easiest kind to spot from afar—the result is still "startling and unsettling," says planetary theorist Alan Boss of the Carnegie Institution of Washington in Washington, D.C. It may mean that clusters of stars are poorer habitats for planets than even pessimistic theorists had imagined.

Hubble's target was a globular cluster called 47 Tucanae, a dense knot of stars about 12,000 light-years from Earth. Astronomer Ronald Gilliland of the Space Telescope Science Institute in Baltimore, Maryland, and a team of two dozen planet hunters and theorists observed the cluster nearly continuously for 8.3 days last July, one of the largest chunks of time granted for a single Hubble project. They monitored more than 34,000 stars, searching for slight dips in their brightnesses caused by giant planets crossing in front. Astronomers used that approach last year to spy a planet whizzing around a nearby star once every 3.5 days (*Science*, 19 November 1999, p. 1451). About 1% of stars near our sun appear to have these so-called "hot Jupiters" in tightly bound orbits.

If that same statistic applied to 47 Tucanae, Gilliland and his colleagues should have seen distinctive dimming patterns from 15 or 20 planets. Instead, they saw none. Hubble's 1300 exposures of the cluster were sensitive enough to reveal planetary transits with ease, says astronomer Tim Brown of the National Center for Atmospheric Research in Boulder, Colorado. "We're convinced that if there are real planets there, we should see them," he says. "Something is clearly different about the cluster environment."

Modelers are having a field day trying to explain why the cluster is so barren. "It's a theorist's dream," says astrophysicist Steinn Sigurdsson of Pennsylvania State University, University Park. "Nothing has been ruled out." A leading culprit, says Boss, is the cluster's composition. Compared with our sun and nearby stars, globular clusters contain far lower concentrations of elements heavier than hydrogen and helium. The ratio of iron to hydrogen in 47 Tucanae, for instance, is one-fifth that in our sun. Most other clusters have even less iron, carbon, oxygen, and other planet-building substances. Without enough grains of dust and ice to clump together and get planets started, the gas swirling around most young stars in a cluster may never have coalesced into Jupiter-sized objects.

If any planets did arise, the cluster's stars are packed so close together—about a million times more densely than in our galactic neighborhood—that passing stars might wreak gravitational havoc and fling planets from their orbits. Indeed, astronomer Rex Saffer of Villanova University in Pennsylvania reported tantalizing clues at the meeting that stars may have collided and merged in the center of another globular cluster, called NGC 6397. "A stellar flyby can disrupt a planetary system, and physical collisions can occur with amazing frequency," Saffer says. Gilliland agrees that close encounters might spell doom for planets, especially near the cores of clusters.

Still, Sigurdsson notes that hot Jupiters might survive gravitational perturbations because of their compact orbits. With astrophysicist Douglas Lin of the University of California, Santa Cruz, Sigurdsson is exploring yet another way to destroy such planets. Passing stars may jostle a gas giant enough to make its orbit slightly more eccentric. This will subject the planet to repeated bouts of tidally induced heating from its parent star, like the tugs endured by Jupiter's inner moon Io. Too many such nudges may overheat the planet, swelling it to the point of bursting.

No matter which scenario holds up, Hubble's results suggest that researchers with the Search for Extraterrestrial Intelligence project were misguided when they beamed a radio greeting toward stars in the giant globular cluster M13 in 1974. "Things are pretty hectic in a globular cluster," Boss says. "If Hubble couldn't see any hot Jupiters, there might not be any planets at all."

Planetary desert. The Hubble Space Telescope saw no signs of large planets near stars in the globular cluster 47 Tucanae.

CREDIT: W. KEEL/UNIVERSITY OF ALABAMA, TUSCALOOSA *ET AL.*

Galaxy Survey Surpasses the Biggest Clusters

When your car's odometer rolls past 100,000 miles, you might buy a new car. Or you might just cheer and keep driving. Astronomers are choosing the latter option to applaud an Australian-British project called the 2dF Galaxy Redshift Survey, the first survey to gauge the motions in space of more than 100,000 galaxies. That figure—four times the number of galaxies charted in any pre-

vious survey—is more than an arbitrary milestone. It also marks the first time that astronomers have clearly extended their vision far beyond the largest coherent groups of galaxies that exist, known as superclusters. "We've seen the end of the biggest structures in the universe," says team member Karl Glazebrook of Johns Hopkins University in Baltimore, Maryland. And as the survey pushes toward its goal of 250,000 galaxies, it is sharpening estimates of the amount of mass in the universe.

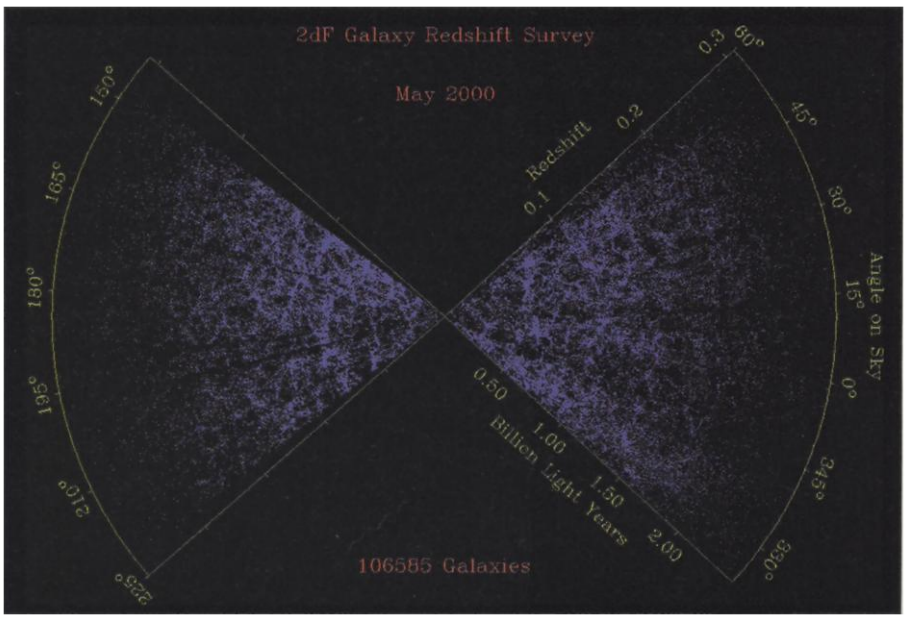
The survey, named for the Two-Degree Field spectrograph at the 3.9-meter Anglo-Australian Telescope in New South Wales, Australia, sees hundreds of superclusters with typical sizes of 200 million light-years across. The first such structure, the famed "Great Wall," surfaced in the 1980s during a survey of our cosmic neighborhood by astronomers at the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. Since then, more extensive surveys have seen filaments of similar size, notably the Las Campanas Redshift Survey at the Carnegie Observatories in Chile. That survey of 25,000 galaxies, completed in 1994, suggested that superclusters did not grow larger on ever-grander scales. "The 2dF maps confirm and strengthen that qualitative conclusion," says astrophysicist David Weinberg of Ohio State University in Columbus.

Other researchers are pleased to see 2dF cross the six-digit galaxy threshold. "For a long time, this will be the standard in the field," says CfA astronomer John Huchra, who with colleague Margaret Geller detected the first Great Wall. "2dF is a major step forward," agrees astronomer David Helfand of Columbia University in New York City. Because the survey extends about five times more broadly and deeply into the universe, he says, "we now have a much more confident understanding of what the large-scale structures are like."

At the meeting, 2dF researchers drew upon their observations to announce an independent new measure of how much matter the universe contains. The estimate relies upon the degree to which superclusters are "flattened" by the gravitational attraction of all of the matter within, including dark matter that telescopes cannot see. That flattening is evident as distortions in the redshifts, which measure how fast galaxies recede from us as the universe expands. Superclusters exert a pull toward their centers, says astronomer Gavin Dalton of the University of Oxford. That causes galaxies on the near sides of the structures to move away from us faster than they otherwise would, while galaxies on the far sides are slightly impeded.

If superclusters were extremely massive, Dalton says, this effect would squash the redshifts of galaxies around them much more than the 2dF survey reveals. To date, the team's analysis suggests that the total mass associated with galaxies accounts for just one-third of the "critical density" needed for the gravitational pull of matter to halt the expansion of space. That's consistent with recent studies of the light from distant supernova explosions and the faint glow of microwaves from the early universe that bathes the entire sky (*Science*, 28 April, p. 595). The mass estimates will improve as the 2dF group collects more galaxies—the 250,000 goal should be reached by the end of 2001, Dalton notes, with a robotic spectrograph that can capture up to 400 redshifts per hour.

Astronomers with a competing project now under way, the Sloan Digital Sky Survey, hope to surpass 2dF by tracking the redshifts of up to 1 million galaxies within 5 years. Dalton welcomes the chance for the teams to compare their statistics on galaxy clustering. "If you're going to measure something this complicated, it's a good idea to measure it twice," he says. Still, Helfand thinks 2dF might have played the trump card: "I suspect 2dF is going to tell us everything about large-scale structures that Sloan will tell us."



Galactic web. More than 100,000 galaxies form vast clumps and leave dark voids on this map from the 2dF Galaxy Redshift Survey, the most extensive such survey to date.

CREDIT: 2DF GALAXY REDSHIFT SURVEY TEAM

Rare Gas Pinpoints Hale-Bopp's Cradle

Comet Hale-Bopp, which lit the sky gloriously 3 years ago, apparently was born in a frigid region of the outer solar system. Hale-Bopp journeyed toward the sun from a vast reservoir of comets called the Oort Cloud. Trillions of dark bodies may drift within this sphere, which extends at least a light-year into space. Comets didn't begin their lives there, however; astronomers think they arose among the gas-giant planets when the solar system coalesced. Gravitational kicks then expelled comets to the Oort Cloud, where they preserve traces of the solar system's early composition. Now, the first faint whiff of one primordial gas from a comet suggests that Hale-Bopp formed near Neptune, farther from the warmth of the sun than some astronomers expected.

The gas is argon, a "noble gas" with the same inert chemistry as helium, neon, and krypton. These substances don't interact with other elements or compounds, so they remain unaltered within a comet's icy matrix for billions of years unless they diffuse out of the nucleus. They boil into space if temperatures get too high—more than about 25 kelvin (–248°C) for neon and 40 kelvin for argon. This property makes the gases sensitive indicators of a comet's temperature history. But noble gases are notoriously difficult to detect in space, so astronomers had tried in vain for years to spot one in a comet's ethereal glow.

It took the bright spectacle of Hale-Bopp for the signature of argon to become "weak but unmistakable," planetary scientist Alan Stern of the Southwest Research Institute (SwRI) in Boulder, Colorado, reported at the meeting. Others are delighted by the discovery, although interpreting the noisy data still leaves some room for doubt. "If the argon detection is valid, it would be very significant for constraining where the comet arose," says astronomer Michael Mumma of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Chilly childhood. Traces of argon indicate that Hale-Bopp formed near Neptune's orbit.

Stern and a half-dozen collaborators launched a sounding rocket 300 kilometers above the White Sands Missile Range in New Mexico to study Hale-Bopp on 29 March 1997, within a day of its closest approach to the sun. The rocket carried a small telescope and a spectrograph that Stern aimed at the comet for just 5 minutes, using a joystick and radio telemetry. In the complex spectrum of sunlight reflected by the comet, the team found a pair of faint wiggles at ultraviolet wavelengths characteristic of argon. "Hale-Bopp was such a boomer that there was just enough argon for us to detect," Stern says.

The implication, he maintains, is that the comet arose between the orbits of Uranus and Neptune, where temperatures in the embryonic solar system hovered around 40 kelvin. That places tighter limits on Hale-Bopp's cradle than research by Mumma and others in 1997 with the Extreme Ultraviolet Explorer satellite, which found that neon was depleted in Hale-Bopp by a factor of at least 25 compared with the sun. If all of Hale-Bopp's neon burned off, its birthplace must have been warmer than 25 kelvin (*Science*, 5 September 1997, p. 1488).

Recent models by SwRI planetary scientist Harold Levison and colleagues suggest that Jupiter, Saturn, Uranus, and Neptune each may have injected comparable numbers of comets to the Oort Cloud. However, the solar system's disk of gas and dust was so much warmer near Jupiter that all of Hale-Bopp's argon would have wafted into space if it spent much time there, Stern says. "This comet must have been in a deep freeze," he says, until some slight perturbation—perhaps from a passing star—nudged it inward from the Oort Cloud relatively recently.

That scenario is feasible, says planetary scientist Jonathan Lunine of the University of Arizona, Tucson. However, he warns that comets may have undergone chemical processing after their birth. Such modifications could have changed the original gas contents of comets in ways that astronomers still don't understand. "We cannot yet say that the comet formed at 20 or 30 kelvin just because we see argon," he says. Stern notes that even if such changes occurred, the presence of argon shows that the comet's interior never rose above 40 kelvin, pointing to a quick exit from the solar system.

Astronomer Lucy McFadden of the University of Maryland, College Park, and others had hoped to see argon from Halley's Comet in 1986 with a shuttle mission, but the Challenger explosion foiled those plans. Stern's team produced "a very high return for a cost-effective observation," she says. "These are remarkable results." **–ROBERT IRION**

PALEONTOLOGY

Feathers, or Flight of Fancy?

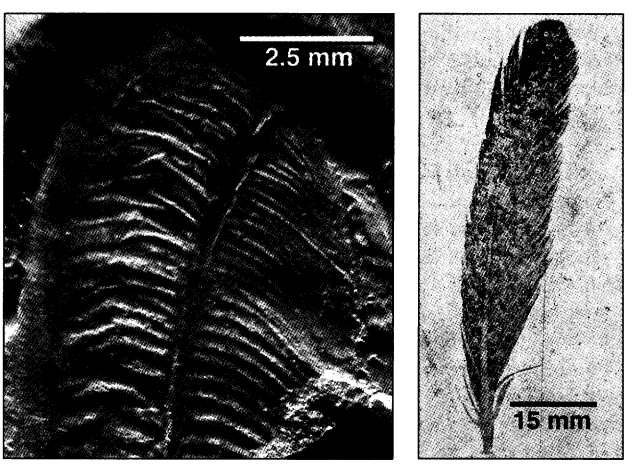
A controversial paper aims to turn avian origins on its head. But mainstream paleontologists say "put up or shut up"

Longisquama insignis never asked for all this fuss. Some 220 million years ago, the squat, mouse-sized reptile eked out an unassuming existence in what is now central Asia, gobbling Triassic insects and minding its business. But *Longisquama* was marked by destiny: Sprouting from its spine were at least six vanelike appendages up to 12 centimeters long—features unlike anything known to have graced a reptile before or since. Scientists disagree whether the creature used its plumes for gliding; they may have been a sexual display. Now, after decades in a Russian research institute, the appendages have propelled *Longisquama*'s fossilized remains from relative obscurity and thrust it dead center into a bitter debate.

On page 2202, a team led by John Ruben of Oregon State University in Corvallis describes *Longisquama*'s curious appendages in the greatest detail yet. In a radical interpretation of the fossil evidence, the authors argue that the appendages are feathers much like those of modern birds. Outside the paper, Ruben and his iconoclastic band go much further, touting the fossil as "an ideal bird ancestor." That conclusion has infuriated paleontologists—not just because it challenges the prevalent theory that birds evolved from theropod dinosaurs, but because they say it does so in an unscientific way.

The minority of scientists who reject the dinosaurian origin of birds are elated by the new description of *Longisquama*. "It's almost too good to be true," says Storrs Olson, curator of birds at the Smithsonian Institution, who did not contribute to the paper. "This is a bigger step forward to understanding the origin of birds than *Archaeopteryx*"—the 145-million-year-old fossil bird whose teeth, scales, and other primitive features forged an unequivocal link between birds and reptiles. The dinosaur advocates' response to this new nontheropod ancestor to birds? "Nonsense." "Nuts." "Rubbish"—not to mention several unprintable comments.

The fossil causing the flap was discovered decades ago in an ancient lake bed in what is now Kyrgyzstan. The Russian paleontologist Alexander Sharov published the first description in 1970. Since then, the specimen has remained at the Russian Academy of Sciences' Paleontological Institute in Moscow, where few Western paleontologists have had a chance to examine it. Ruben and his graduate student Terry Jones first saw it in early 1999, when *Longisquama* was touring the United States as part of a privately sponsored fossil show. After the tour ended, Russian paleontologists brought the fossil to Larry Martin's lab at the University of Kansas, Lawrence, where they examined it with



Birds of a ...? Some argue that *Longisquama*'s appendages (*left*) were feathers, like those of the fossil bird *Archaeopteryx (right).*

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