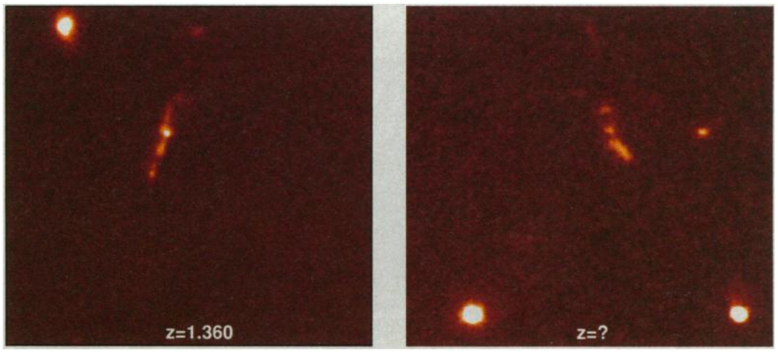
ASTRONOMY

Did Galaxies Like Our Own Start Life in Chains?

Looking for the ancestors of present-day galaxies, says Lennox Cowie, "is sort of like looking at the Burgess Shale." Like the strange animal forms in that famous 550-million-year-old fossil bed, galaxies had "all kinds of baroque morphologies" in the cosmic past, from plasma-spouting radio galaxies and quasars to ill-formed dwarfs. Obvious ancestors to the stately spirals that fill today's universe are nowhere to be found. But by digging a little deeper into the strata—farther out in space and back in time—the University of Hawaii astronomer thinks he has spotted swarms of galaxies like our own in the process of formation.



Ablaze with star formation. The bright knots on these chain galaxies, seen with the Hubble Space Telescope, may be nests of new stars.

L. COWIE, E. HU, AND A. SONGAILA/UNIVERSITY OF HAWAII, INSTITUTE FOR ASTRONOMY

The family resemblance isn't obvious, though: These protogalaxies look like strings of bright beads. Indeed, a few such structures had been spotted on earlier deep-space images, but they had attracted little notice. Only when Cowie and his Hawaii colleagues Esther Hu and Antoinette Songaila pushed their search for ancestral galaxies to fainter magnitudes with two of astronomy's most powerful instruments—the Hubble Space Telescope (HST) and the 10-meter Keck Telescope on Mauna Kea—did these "chain galaxies" proliferate and show themselves for what they are: massive galaxies like our own, furiously forming stars.

These claims, based on images made at the ragged edge of telescope resolution and detector sensitivity, have sparked controversy. Some galaxy watchers aren't sure that the chain galaxies are as common in the early universe as Cowie and his colleagues estimate in their papers, which appeared in yesterday's issue of *Nature* and in the October *Astronomical Journal*. Others doubt the ancestor-descendant link that the Hawaii group is claiming. "I'd like to reserve judgment," says Richard Ellis of Cambridge University. "It's premature to say that these are the ancestors of big galaxies like our own."

But still others think Cowie's group has filled a gap in cosmic history. As Craig Hogan of the University of Washington puts it, "We're on the threshold of accounting for all of the stars seen today. ... The conjecture is that if you took galaxies like these and waited 10 billion years, they would look like our own."

If Cowie and his colleagues are right, they will also have solved a puzzle posed by earlier studies of faint galaxies. For more than 10 years, flocks of faint blue objects had been showing up in the most sensitive images of the night sky. The blue color—the hue of hot, short-lived giant stars—showed that they were rapidly spawning new stars, and their faintness suggested that they lay at vast distances. Astronomers thought they might be seeing present-day galaxies in their infancy.

In the last 5 years or so, however, that assumption broke down. Detectors became sensitive enough for Cowie and others to collect spectra of these dim blue objects and measure the redshifts of spectral lines—an indication of distance. The redshifts averaged about 0.3, which put the galaxies no more than 3 billion or 4 billion light-years away, a result implying that their faintness is due to small size, not distance. Apparently, astronomers had been seeing only a tribe of blue dwarf galaxies that had come and gone in the recent past. "A year ago I was extremely confused about all this stuff," says Cowie.

Now, he says, "one is back to where one started." Many of the very faintest of these blue objects, he says, turn out to be massive and distant after all. The first evidence that ancestral galaxies might be hiding among the blue dwarfs came from the HST.

The HST's strength is its high resolution, which enables it to make images of objects that would be mere blurs from the ground. Cowie and his colleagues used exposures lasting as long as 8 hours to tease out the structures of faint blue galaxies. Most were shapeless and irregular, an appearance that other HST images have shown is typical of faint blue dwarfs. But at the very faintest magnitudes, says Cowie, "we started to pop out these ... truly bizarre-looking objects"—chain galaxies.

The string-of-beads appearance of the objects wasn't entirely new, but their numbers were; Cowie and his colleagues estimate that they account for as many as half the galaxies seen at blue-light magnitudes of 24, some 10 million times fainter than the faintest star visible on a dark night. The observers guessed they had found a whole new species in the galactic fossil beds. And when they aimed the Keck telescope at about 40 galaxies in this magnitude range—among them 12 of the chain galaxies seen by HST—their suspicions were borne out.

The Keck, with its prodigious light-gathering power and sensitive spectrograph, has an unmatched ability to dissect the light of a faint astronomical object to reveal its nature and distance. In the spectra of the faint galaxies, one feature stood out: an intense emission line from ionized oxygen. The position of the line on the spectra put the galaxies at redshifts of 1 to 1.6—perhaps 10 billion light-years away and two thirds of the way back to the big bang. And its strength compared to other lines in the spectra showed that they were making new stars at a frantic pace, says Cowie.

The line, he explains, is a signal of starbirth, because it comes from the gas surrounding young, massive stars, where intense ultraviolet radiation readily strips away electrons from oxygen atoms. Starbirth could also explain the beaded appearance of the galaxies, says Cowie. "When [a galaxy] starts making stars, it's not unusual to have it localized," creating bright knots. And starbirth at the rate implied by the line's intensity marks these galaxies as massive, or soon to be massive, he argues: "Even on the most conservative calculations many of these high-redshift objects are making stars at more than 100 solar masses per year." Keep that up for 100 million years—not long, by astronomical standards—and you will end up with a galaxy as massive as our own.

Cambridge astronomer Karl Glazebrook, who has studied faint blue galaxies, isn't fully convinced by the oxygen line. "It's not entirely obvious that these are the ancestors of massive galaxies," he says. Ellis agrees, adding, "My feeling is that these can be explained as a continuation of the star-forming [dwarf] galaxies that we see at lower redshifts." But Rogier Windhorst of Arizona State University (ASU) thinks it's hard to argue with the spectra: "Certainly these are massively star-forming galaxies."

What Windhorst and some others balk at,

however, is the claim that chain galaxies are common in the distant universe, which would make them the standard ancestral form. Analyzing an HST image as deep as the ones Cowie studied, Windhorst says that he, ASU's Simon Driver, and their colleagues have seen a few chain galaxies—but plenty of other extremely faint objects, which are not chain galaxies, lying equally far away. Windhorst says he thinks Cowie may have found just one of many ancestral forms: "It's not the whole story."

Cowie agrees that his images show "a variety of wild and wonderful morphologies—including a fair number of chains but also some other weird beasts." But if his finding is at least part of the story, says Richard Griffiths of the Space Telescope Science Institute in Baltimore, galaxies like our own may finally be gaining a coherent history. "I think there's a sort of self-consistent picture taking shape that's more plausible than anything we've had for the last 20 years," says Griffiths. If so, astronomers may finally be glimpsing some order in the cosmic fossil beds.

–Tim Appenzeller

ASTRONOMY

Hints of a Planet Orbiting Sunlike Star

The Great Square of Pegasus catches many stargazers' eyes this time of year as the steed glides above the Northern Hemisphere's horizon. This year, however, it's going to attract not just star-watchers, but planet-hunters as well. Two astronomers at the Geneva Observatory in Switzerland, Michel Mayor and Didier Queloz, believe they have found the first planet outside our solar system that orbits a sunlike star. Their putative planet, at least half the mass of Jupiter, appears to be circling in a tight orbit around the star 51 Pegasi, visible just beyond the Great Square's leading edge. "The result is obviously incredibly exciting if it's true," says Philip Nicholson, an astronomer at Cornell University.

The excitement—tinged with some skepticism—isn't just because extrasolar planets have never been seen around a sunlike star, but also because standard theories suggest that planets this large don't form so close to stars. As a result, astronomers have been frantically casting about for information on the finding. The evidence is an apparent wobble in 51 Pegasi, which could be caused by a massive planet whirling around it with a period of about 4.2 days and an orbital radius of just one-sixth that of Mercury. Further details, however, have been hard to come by: Since they first presented their results at a conference in Florence, Italy, 2 weeks ago, Mayor and Queloz have declined further comment because a paper describing their findings is under review at *Nature*.

They did, however, authorize Douglas Duncan, an astronomer at the University of Chicago who is familiar with the work, to present an outline of their results at an astrophysics conference in College Park, Maryland, early last week. And *Science* has learned that astronomers Geoff Marcy and Paul Butler of San Francisco State University and the University of California, Berkeley, have already verified the detection of wobble—or "radial velocity"—of 51 Peg during a 4-day observing run on the Lick Observatory's 3-meter telescope just last week. The observations add up to "the first reliable detection of a planet orbiting another [sunlike] star," says Duncan.

The wobble the two groups have seen in 51 Peg is characteristic of the kind of motion an orbiting mass would produce. Like the balls of a bola thrown through space, all members of a planetary system whirl about each other, faster for the lighter planets and much slower for the heavier, central star. The star's wobble can be detected because atoms at the star's surface emit photons of light at discrete wavelengths, forming spectral "lines" that shift to shorter wavelength when the star is moving toward us and longer wavelength when it is moving away. Although the picture is blurred by the star's rotation, which causes photons emitted from different points to have slightly different wavelengths, Duncan says Mayor and Queloz managed see the wobble by monitoring about 5000 lines throughout the visible spectrum.

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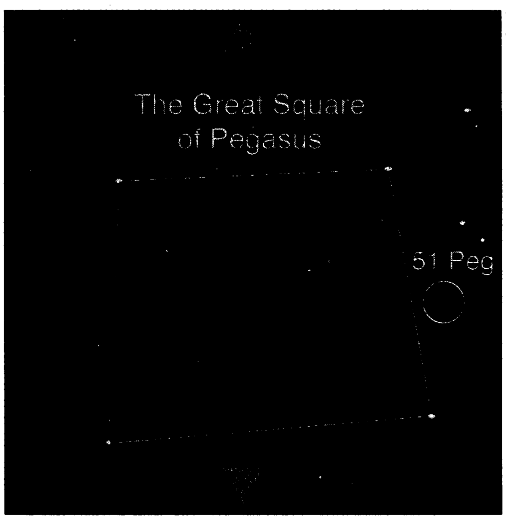
—Philip Nicholson



JIM SEEVERS/ALDER PLANETARIUM & ASTRONOMY MUSEUM

Square dance. An apparent wobble in the star 51 Peg may be caused by a giant planet.

Mayor has been using these techniques to make "radial-velocity surveys" of dozens of stars for more than a decade, says Duncan. But 16 months ago the team upgraded its setup at the 1.9-meter telescope at Haute-Provence near Nice, France, isolating their spectrograph in a temperature-controlled room and operating it remotely via fiber optics. Then 51 Peg's wobble velocity of roughly 50 meters per second—much faster than would be produced by a lighter planet or one further from the star—leapt out of the data. But why wasn't the star seen by other groups with comparable or better accuracy making similar surveys? "That star was not being monitored by anyone else—including us," says Marcy, who says his measurements last week "confirmed everything [Mayor and Queloz] have discovered."

A canvas of half a dozen planetary scientists last week suggested that they will pore through Mayor and Queloz's data when they are published, looking for an effect that could be mimicking the signature of an orbiting planet. Among the possibilities: a previously unknown type of stellar pulsation; a large spot on the star's surface that might rhythmically suppress one side of the broadened emission lines, then the other, creating the appearance of a wobble; or an unseen binary companion whose orbit is seen nearly face-on from Earth. Although arguments can be made that each of these possibilities is unlikely, astronomers will "start out with a pretty skeptical view," says Cornell's Nicholson.

If the Geneva group's interpretation holds up, planetary scientists will have to confront a difficult question: How did the planet get there in the first place? Standard models of planetary evolution suggest that giant planets form with ice-and-rock cores much further away from a star. But Alexander Wolszczan of Pennsylvania State University, who last year found the first extrasolar planets orbiting a pulsar, is keeping an open mind. Wolszczan points out that his own discovery defied conventional thinking about where planets should exist. "I think it is important to be cautious about expecting, by default, to find an exact copy of the solar system," he says. "We should really keep our eyes open and expect anything."

–James Glanz