tation. The other, lasting about 5 seconds, preceded the predicted event by about 2 minutes. Bowell and A'Hearn took particular interest in this secondary drop when James McMahon, an amateur observer, reported a similar experience. While waiting near Boron, California, to make visual observations through a small, portable telescope of the same occultation, McMahon also saw a secondary event of about the same duration and at the right time to coincide with the Lowell secondary event.

"Taken at face value," Bowell says, the observations "pretty strongly indicate the presence of a secondary body at Herculina." An unseen satellite, to be responsible for the secondary event, would have to be at least 45 kilometers in diameter, a quarter of the size of Herculina, and at an apparent distance of 990 kilometers from the asteroid at the time.

Once the Herculina event caught the attention of observers, apparent secondary occultations became a bit more respectable—and more commonly reported. New reports of both visual and photoelectric observations came from amateurs and professionals alike. A positive report, made on the basis of photographs, has arrived from as far away as the Purple Mountain Observatory in the People's Republic of China. Researchers there have submitted a paper to the American astronomical journal *Icarus* claiming that they have discovered a bulge on the photographic image of the asteroid Metis, which they take to be a 60-kilometer satellite at a distance of 1100 kilometers from Metis. By identifying the bulge seven times over a few months, they found that it circles Metis every 4.6 days. According to David Dunham, an astronomer at Computer Sciences Corporation in Silver Spring, Maryland, and president of the International Occultation Timing Association, the Chinese calculations "seem to match up pretty well" with a visual secondary occultation reported by amateurs observing Metis in Venezuela in late 1979.

As interest burgeoned, less direct evidence supporting the existence of asteroidal satellites surfaced. Edward Tedesco of the University of Arizona suggested that the variable brightness of the asteroids Ophelia and Pales can be best explained if each is a pair of asteroids, circling each other as double stars do. When one member of a pair passes in front of the other, the observed brightness would drop, he notes. Another bit of evidence, says Peter Noerdlinger of Michigan State University is the existence of neighboring, large craters on Earth that were formed at the same time. The Clearwater Lakes craters in Canada, a pair of craters 32 and 24 kilometers in diameter, are 31 kilometers apart and apparently formed simultaneously. But his calculations and those of others suggest that a single asteroid could not have split in two as it approached Earth and still moved far enough apart to produce such widely separated craters. The best explanation, he says, is that a binary asteroid system fell to Earth.

This accumulated evidence, and in particular the apparent secondary occultations, has given some researchers considerable confidence in the existence of asteroidal satellites. "I would be very surprised at this point," says Dunham, "if we don't [have asteroidal satellites]. I admit that we don't have 100 percent confidence yet. But it seemed very solid for Herculina at the time." Thomas Van Flandern of the U.S. Naval Observatory in Washington, D.C., terms the Herculina satellite "confirmed," 12 others as probable, and another 10 as suggested. He concludes that asteroidal satellites are "numerous and commonplace."

A number of other researchers cannot

Extending the Known Universe

Four giant elliptical galaxies—10 billion light-years from Earth and the most distant celestial bodies ever studied—have been identified by astronomers from the University of California, Berkeley, and the Kitt Peak National Observatory, Arizona. The remotest galaxies known previously were reported 6 years ago and are at a distance of 8 billion light-years. Detection of the new objects thus increases the size of the observable universe by 25 percent; it also means that astronomers have now seen galaxies more than halfway back in time to the Big Bang, some 18 billion years ago.

"These galaxies were already pretty old looking," says Berkeley astronomer Hyron Spinrad, who coauthored the report on the findings in the 2 March *Astrophysical Journal*, along with doctoral candidate John Stauffer and Kitt Peak astronomer Harvey Butcher. The spectroscopic properties of the galaxies are most consistent with an age of 6 billion years, he explains; adding on the 10 billion years it took their light to reach Earth gives a total age of 16 billion years.

"This tells you that, at least for the large ellipticals, the burst of galaxy formation happened very quickly after the Big Bang," says Spinrad. The universe was only 2 billion years old when these objects formed. "And it was over quickly, within about 1 billion years," he adds. "Otherwise we'd be seeing a lot more light from young, blue stars than we do."

Such arguments are prey to the uncertainties in galactic and stellar evolution models, he admits, but such models are thought to be fairly well understood.

The problem with doing spectroscopy on such distant and faint objects is that the light of the galaxy is swamped by the background light of the night sky, says Spinrad. He, Stauffer, and Butcher made their observations at California's Lick Observatory, which suffers from, among other things, the street lights of nearby San Jose. "The signal from the galaxies being studied was less than 2 percent of the total signal," says Spinrad. "You can still get the spectra, but it takes a long time."

Their technique was to use a Wampler scanner, a digital image tube that allowed them to subtract out the background. To collect enough light they had to repoint the telescope to the same galaxies again and again, building up a total of 40 hours of exposure on 23 separate nights over 3 years.

It has taken 20 years for astronomers to double the size of the observed universe from 5 billion to 10 billion light-years, says Spinrad. But new detectors based on CCD's (charge-coupled devices), which have good quantum efficiency at the longer wavelengths, should soon enable astronomers to push 20 to 30 percent farther yet. "Newly forming galaxies, if they could be seen from distances up to 16 billion light-years, should be spectacularly luminous," he says.—M. MITCHELL WALDROP

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