

Massive Problem of Missing Dwarfs

Astronomers thought that faint stars called red dwarfs could account for our galaxy's missing mass. Now those stars are missing as well, leaving a stellar puzzle behind

One day in March, Francesco Paresce, an astronomer at the European Space Agency, was staring intently at some computer displays, waiting to be overwhelmed by stars. The screens at the Space Telescope Science Institute (STScI) in Maryland were about to show a picture taken by the Hubble Space Telescope (HST) of the globular cluster NGC 6397, a dense collection of stars in the outer reaches of our Milky Way galaxy. The faintest stars in that group, Paresce assumed, had not been spotted by ground-based telescopes struggling to peer through our atmosphere. HST, orbiting high above Earth, doesn't have that problem. As a result, says Paresce, "we expected the image to be covered wall-to-wall with stars."

Instead, Paresce saw an image with large blank areas; he could even see through the cluster and clearly pick out a number of distant galaxies. And Paresce wasn't the only astronomer drawing blanks with HST. A group led by John Bahcall of the Institute for Advanced Study in Princeton, New Jersey, and Andrew Gould

of Ohio State University has been unable to find many of these same dim stars—known as red dwarfs—in another image.

The two new HST pictures, released last week, present astronomers with two major quandaries. First, they deliver a damaging blow to the simplest explanation of the most fundamental problem in astrophysics: the dark matter question. Astronomers estimate that they can see less than 20% of the matter in the universe, and small, dim stars were a good candidate to explain that puzzling fact. "There's always been the suggestion that the missing mass in the galaxy is low mass stars we don't see," explains Hugh Harris at the U.S. Naval Observatory. But the sparseness of these stars in the HST image now makes that claim unlikely, says Bahcall, whose results appear in the 1 November issue of *Astrophysical Journal Letters*.

The second quandary is that Paresce's HST data suggest that red dwarfs tend to weigh in at one-fifth the mass of our sun—contrary to reigning models of star formation, which indicate that stars should be even more plentiful at lower masses. "It's a very exciting de-

velopment, if verified. Why does nature pick out that particular mass?" asks Steven Stahler, who works on models of star formation at the University of California, Berkeley.

Questions of stellar formation are intriguing, but the search for faint red dwarfs has always been driven by the dark matter problem. Bahcall, for instance, was among the first astronomers to conclude, by studying the velocities of stars and the amount of gravity needed to retain them within the

From these results, astronomers conclude that faint red dwarfs constitute less than 6% of the dark matter in the halo. Furthermore, says Bahcall, his team has studied 11 other HST images taken in different areas of the galaxy and found a similar dearth of small stars. "The universe is not one in which the dark matter is composed largely of faint red stars. We've given comfort and cause for celebration to those who believe dark matter is some exotic new particle," he asserts. Some

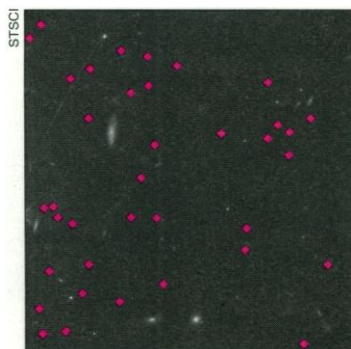
astrophysicists, for instance, have proposed that hypothetical particles known as WIMPs (weakly interacting massive particles) could account for dark matter's effects, but searches for these objects have so far been unsuccessful.

Other astronomers, however, suggest that while Bahcall's HST image is clear, his interpretation is less so. Todd Henry of STScI, who studies the mass distribution of nearby stars, points out that the estimates Bahcall has made about the amount of dark matter in the galaxy and its distribution are open to question. Some

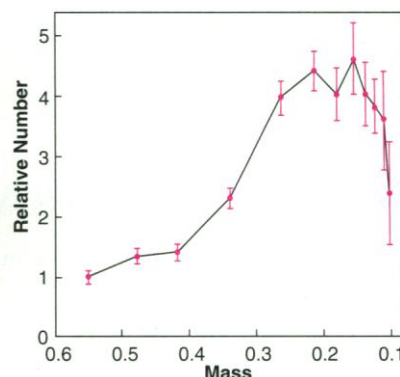
astronomers, he says, feel that much less dark matter may be needed to explain the movement of galactic stars; those researchers would then expect to find fewer dim red dwarfs than Bahcall's group posits.

Despite the criticism, the Bahcall camp has received a strong vote of confidence from the observations of Paresce and his colleagues. Instead of random snapshots of the sky, they focused on NGC 6397. Such globular clusters, of which there are some 200 in the Milky Way, are a favorite target of astronomers interested in star formation, because they contain up to a million stars believed to have been created from similar materials at about the same time. That provides astronomers with a natural testing ground for ideas about the distribution of star masses. For example, astronomers know that bright red dwarfs of about 0.5 solar masses outnumber stars like our sun by 100 to 1 and therefore should be abundant in the population of a globular cluster. And the belief was that smaller red dwarfs would be even more plentiful in the cluster, if only astronomers could see them all.

There were some data pointing in that



Unexpected absence. If dark matter consisted of faint stars called red dwarfs, astronomers expected to see 38 more of them (pink diamonds in photo) than actually appear in this swatch of sky. And data from a dense star cluster (right) reveal that the number of such stars drops off precipitously when they get small and faint, making them an unlikely dark matter source.



SOURCE: FRANCESCO PARESCE

galaxy, that an unseen halo of dark matter must surround the Milky Way; the gravity of visible matter was simply not sufficient to explain the stellar speeds. In our galaxy, says Bahcall, dark matter may account for more than half of the total mass. Peering above the central disk of the Milky Way with the HST, he and his colleagues hoped to find that stars too faint and too red to be seen efficiently from the ground were crowding the galactic halo. Drove of such stars, says Bahcall, would have been the "easiest, most conservative" solution to the dark matter question.

But, he ruefully notes, "we looked; we didn't see them." His group used the HST's wide-field camera to snap an image of essentially a random piece of sky above the central disk, then counted the faint red stars. They compared this number to the number of dim red dwarfs needed to account for the effects of dark matter—and the resulting disparity was substantial. His team expected to find seven of the faintest red dwarfs, says Bahcall, but they saw none. And the number of slightly brighter red dwarfs was only 1/30th what had been predicted.

direction. NGC 6397 has been studied intensively from the ground, and in 1992, Canadian astronomers Harvey Richer and Gregory Fahlman published a report in *Nature* on that cluster, claiming that the numbers of stars increased sharply and inversely with stellar mass. (They still concluded that red dwarfs were not abundant enough to solve the galactic dark matter problem, however.)

When Paresce, Guido De Marchi of STScI, and the rest of their colleagues analyzed the HST image of NGC 6397, however, the data told a different story. Down to a certain level of brightness, the number of red dwarfs rose. Beyond that point, however, the number of fainter stars quickly dropped to zero. Paresce's group converted each star's brightness to an estimated mass and found that most of the red dwarfs in their picture were about 0.2 solar masses. At lower masses (down to about 0.08 solar masses, the smallest star that can sustain hydrogen fusion), it appears that red dwarfs are rarely made, says Paresce, whose team will publish their work in the 10 February issue of *Astrophysical Journal*.

Paresce attributes the stark conflict with the earlier results to the nearsightedness of ground-based telescopes. Those instruments, he says, have trouble picking faint stars out of crowded fields and discriminating between distant galaxies and blurry stars. To correct for this myopia, ground-based astronomers modify their star counts based on knowledge of the equipment's limits. Those corrections have always been suspect, argues Paresce.

Astronomers are now starting to wonder how far the work on NGC 6397 can be generalized. Does it apply to the rest of the galaxy and the universe? Researchers generally classify stars into two categories, Population I and Population II. Globular clusters contain Population II stars, which are much older than those of Population I and contain fewer metal elements. While very low mass Population II stars may be rare, that might not be true for Population I, says STScI's Henry. His own work on much closer stars, most of which are Population I, shows the number of stars increasing with lower mass right down to the hydrogen-burning limit of

0.08 solar masses. The conflicting data, says Henry, could hint that Population I and II stars form in slightly different ways. "It could be that you just can't make low mass stars with low metallicity," he says.

Even as stellar theorists try to incorporate these latest results into their models of how pockets of gases collapse to form stars, cosmologists continue to scratch their heads about the mystery of dark matter. Not only do the new images suggest that faint red dwarfs are not the solution; they cast doubt on related notions, such as the idea that dark matter consists of hordes of brown dwarfs, invisible starlike objects with masses below the hydrogen-burning limit. It would be "very odd," argues Bruce Margon, an astronomer at the University of Washington, if the universe rarely made objects between 0.2 and 0.08 solar masses, but instead made lots of even smaller starlike objects. Yet the surprising absence of red dwarfs suggests that astronomers should continue to expect the unexpected from the universe.

—John Travis

MATHEMATICAL BIOLOGY

Hints of a Language in Junk DNA

As molecular biologists unraveled the mysteries of the genes, they were startled to find that only a small fraction of DNA actually carries the code for making proteins. Fully 97% of the DNA in human cells looks like meaningless filler, and researchers have struggled to explain why it is there. Physicist Eugene Stanley of Boston University thinks his group has found a clue: Even if it doesn't encode proteins, says Stanley, the "junk" DNA may carry some kind of message.

Using statistical techniques borrowed from linguistics, Stanley says he and his colleagues Rosario Mantegna, Sergey Buldyrev, and Shlomo Havlin, along with C.-K. Peng, Ary Goldberger, and Michael Simons from Harvard Medical School, "have shown fairly clearly that the 'junk' has all the features of a language." The analysis, which will appear in the 5 December issue of *Physical Review Letters*, says nothing about how that language works. But biologists, already pursuing other hints of functions for junk DNA (*Science*, 4 February, p. 608), are intrigued. "It sounds extraordinarily interesting," says University of Cambridge geneticist Lawrence Hurst, "though it might be hard to tell what it means."

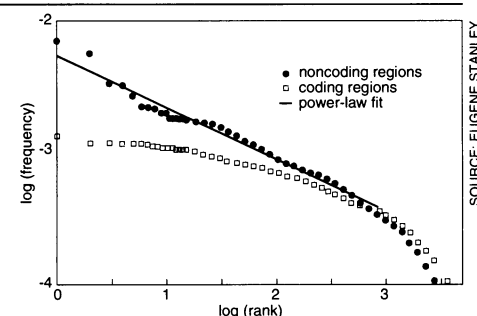
The group first looked into the junk DNA problem several years ago by applying statistical techniques to the sequences of nucleotide bases in the junk. The analysis seemed to show that junk sequences could not be completely random, because the chance of finding a particular base at a given point in a sequence showed a weak, statistical dependence on nearby bases. No one knew what

these correlations meant, but Stanley took them as "a hint that something interesting was lurking in the junk."

In an attempt to find out what that something might be, the Boston researchers applied two standard linguistic tests to junk sequences from a variety of organisms. One test was developed 45 years ago, when linguist George Zipf took texts in several languages and ranked the words in order of frequency. He then created a histogram, plotting the log of the actual frequency of occurrence against the log of the rank. Surprisingly, this procedure yields a linear plot with a slope of -1 for every human language. "This is really remarkable," says Stanley. "There's no rhyme or reason why that should be true."

When the group arbitrarily divided up their samples of junk into "words" between 3 and 8 bases long and applied the Zipf test, the telltale linear plot emerged. They then tried a second test developed by information theorist Claude Shannon in the 1950s to quantify the "redundancy" of any string of characters. Languages are redundant sequences, explains Stanley: You can fill in a typographical error by noting nearby characters. A random sequence, in contrast, has no redundancy. Applied to junk DNA, Shannon's formula revealed a surprising amount of redundancy—another sign that something was written in these mysterious stretches.

The familiar coding regions of the genes fail both tests—an expected result, Stanley says, because the "language" of the genes lacks key features of ordinary languages. "The cod-



Line of evidence. Plotting frequency against rank for arbitrary "words" in noncoding yeast DNA yields the linear plot found in human languages.

ing part has no grammar—each triplet [of bases] corresponds to an amino acid [in a protein]. There's no higher structure to it." In contrast, junk DNA's similarity to ordinary languages may imply that it carries different kinds of messages, says Stanley.

Although these findings are surprising, the idea that junk DNA has a function is not. "I think that what we call 'junk DNA' will have a number of uses," says Harvard biologist Walter Gilbert. He notes that, among other recent hints, Leroy Hood of the University of Washington and Ben Koop of Canada's University of Victoria recently found a long stretch of "junk" that is common to both humans and mice, implying that it and perhaps other junk sequences have some important function in the cell. Among the possibilities under discussion, he says, are roles in protecting and repairing the genetic material and in regulating genes. "I think the junk is like the stuff in a junk shop," Gilbert says. "You can find lovely things in it."

—Faye Flam