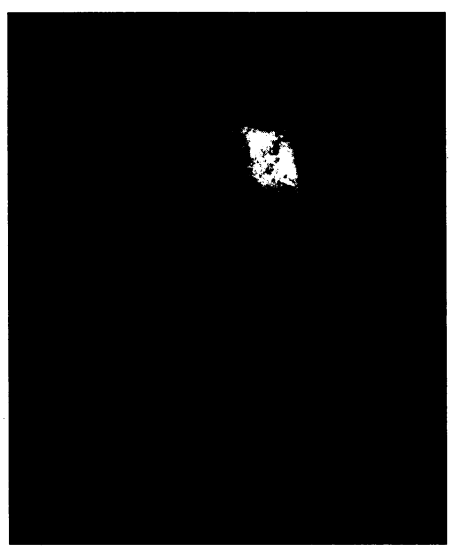
ASTROPHYSICS

Images and Model Catch Planets As They Form

The story of how planets are built is getting down and dirty. In recent years, the Hubble Space Telescope has produced striking images of the doughnut-shaped disks of gas and dust ringing distant stars—the raw material of planet creation. Meanwhile, detections of extrasolar planets prove that planets form readily under many conditions. What's been missing is evidence of the actual process by which protoplanetary ingredients grow into the finished product.

Now astronomers think they've spotted it. In a paper published online today by *Science* (www.sciencexpress.org), researchers from the Southwest Research Institute (SwRI) in Boulder, Colorado, and the University of Colorado there report on the first stage of planet formation: the growth of dust grains into significantly larger particles



True grit. Light from circumstellar disks *(above)* shows that dust can grow into planets even in the hostile Orion nebula (*right*).

in the circumstellar dust and gas disks of the Orion nebula. They also describe a model showing how these larger particles can survive and grow in the often harsh environments where planets coalesce.

"This work is important—really the first rigorous empirical look at the process by which nature converts dust in the disks into planets," says Geoff Marcy, a leading planet hunter at the University of California, Berkeley. Henry Throop, a planetary scientist at SwRI and the first author of the paper, calls it "a missing link ... the intermediate stage between the dust that is all around and the planets we see out there."

The study began when workers led by coauthor John Bally of the University of Colorado observed that six protoplanetary disks in the Orion nebula were invisible in the 1.3-mm radio band. That seemed to imply that particles in the disk had an unexpectedly low total surface area—as they would if they were as large as a few centimeters across, Throop says. Intrigued, the researchers examined Hubble Space Telescope images to see how visible and near-infrared light in the region passed through the largest circumstellar disk in the Orion nebula, known as 114-426. By measuring how dust in the disk scattered light of different wavelengths, the scientists calculated that typical particles in the disk are at least 5 micrometers across, 25 to 50 times larger than common circumstellar dust. In the 100,000 years since 114-426 formed, the scientists concluded, dust particles have begun the agglomeration that ultimately generates planets.

That raised a harder question: How? To cohere, particles in the Orion nebula must withstand fierce ultraviolet radiation from the nebula's hottest, most massive young stars. In dense clusters like the Orion nebula, Throop notes, high-energy light from type O and B stars tears apart floating dust and gas disks like a cosmic leaf blower, wreaking havoc with nascent planetesimals. Yet clearly some survive and thrive.

To understand how, Throop and colleagues made a mathematical model that pitted circumstellar disks against the hostile nebular environment. By inputting typical disk masses, initial dust grain sizes, and ionizing sources, the researchers tracked the abundance and size distribution of ices, silicates, and gas over time. After 1 million years, the modelers found, photoevaporation had blown away virtually all the raw materials more than 40 astronomical units from the disk's central star—the distance from our sun to Pluto—that are needed to form planets. In the inner rings of the disk, however, where gravity is strong and dust clouds dense, colliding grains formed meter-sized silicate chunks within 100,000 years. Those boulders were easily large enough to survive the star's photon bombardment, although after 1 million years no ice or gas could last in the inner regions either. The message, Throop says, is "if you want to make planets, you'd better do it fast. You've only got about a million years before the disks are destroyed."

Some experts are withholding judgment about the group's instant-planets scenario. "The work is potentially significant, but it's so concisely presented that it's hard to assess," says C. Robert O'Dell, a professor of physics and astronomy at Vanderbilt University in Nashville, Tennessee. Although more details are needed for the results to win acceptance, O'Dell says, he is willing to be persuaded that even in tough stellar neighborhoods, new worlds can emerge faster than anybody thought. **–MARK MURO**

Mark Muro writes from Tucson, Arizona.

ASTRONOMY

Critics of 'Halo Matter' Outrace the Presses

The deliberate, patient world of traditional astronomy has run headlong into its high-speed future. The crunch came when astronomers announced the discovery of a new population of dim old stars called white dwarfs. In a paper published online by *Science* on 23 March, the team concluded that the stars are an important source of galactic dark matter, the mysterious substance that provides 90% of the gravitational force that binds the Milky Way together. If confirmed, it would be the first direct sighting in the 30-year search for dark matter.

But the behind-the-scenes struggle to verify the discovery has been as bruising as a hotly contested Cabinet nominee's Senate hearing. In the month between online publication of the paper (on *Science* Express) and its appearance in print (on p. 698 of this issue), its authors have weathered criticism that typographical errors and misinterpreted data inflated their estimate of the dark matter density. The critics are also taking some heat for posting their papers online before their peers had an opportunity to review them.

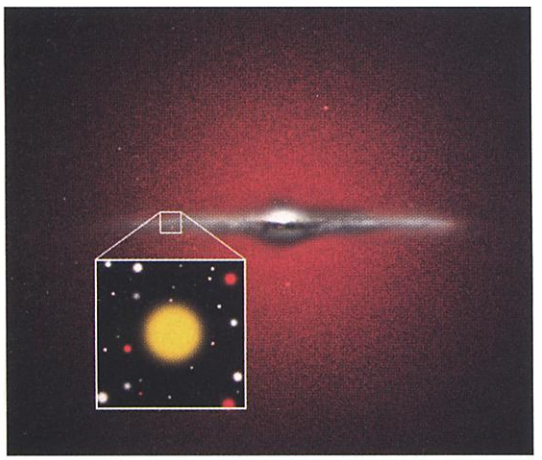
One thing everyone agrees on is that the Internet, specifically the Los Alamos National Laboratory (LANL) preprint server, catalyzed the debate by doing what it was set up to do: giving preliminary results a speedy public forum. "If the LANL server did not exist, [*Science*] probably would not be writing this article," says the lead author of the *Science* paper, astronomer Ben R. Oppenheimer of the University of California, Berkeley.

The dispute started innocuously when a team including Oppenheimer claimed to have discovered 38 white dwarfs orbiting in the halo of material that surrounds the disk-

CREDITS: (LEFT TO RIGHT) NASA, J. BALLY (UNIVERSITY OF COLORADO), H. THROOP (SWRI), C. R. O'DELL (VANDERBILT UNIVERSITY); BILL AND SALLY FLETCHER

like Milky Way. But there is a possible catch: Their survey covered a nearby part of the galactic disk in which disk residents mingle with halo stars that just happen to be passing through. Indirect observations show that almost all of the galaxy's dark matter is native to the halo, making disk stars nearly useless for explaining it.

In principle, disk and halo dwarfs are easy to tell apart. Disk dwarfs are whirling around the galactic center at an average speed of 220 km/s, the same as the sun; halo dwarfs are, on average, standing still. Applying that test to separate out halo dwarfs and then extrapolating their density to the entire galactic halo, Oppenheimer and his collaborators estimated that white dwarfs could account for at least 2% of the dark matter known to make up 90% of the halo's mass. Suspected halo dwarfs currently too faint to be seen could boost their estimate to as much as a third of the dark matter.



Mixed message. Near the sun, mingled stars from our galaxy's disk (white) and halo (red) complicate the quest for dark matter.

Shortly after their paper appeared on *Science* Express, however, several scientists fired back a barrage of electronic critiques. On 5 April, a team led by astronomer Neill Reid of the Space Telescope Science Institute in Baltimore posted a paper destined for the *Astrophysical Journal Letters* on the LANL server. Reid and collaborators argued that Oppenheimer's criterion was not stringent enough to remove all of the disk white dwarfs from his sample. In Reid's view, the white dwarfs are not dark matter at all, but merely a part of a previously known population of stars in the galactic disk. "It is a gaping hole in their argument," Reid says.

A week later, astrophysicist David Graff of Ohio State University in Columbus made a similar argument in an LANL posting that was also submitted to *Science* as a Technical Comment. And on 16 April, in another paper posted on the LANL server and submitted to *Science* as a Technical Comment, astronomers Brad Gibson of Swinburne University in Australia and Chris Flynn of the Tuorla Observatory in Finland pointed out typographical errors in Oppenheimer's online paper. (The printed version of the paper in this issue includes minor corrections.)

Oppenheimer says he welcomes the criticism but that public release of the preprints before they had been peer reviewed distorted the debate. "Our paper went through the standard channels of scrutiny, with two referee reports that were very favorable," he says. "None of these comments or papers have been properly refereed." And rapid-fire online publication, he says, left no time to make a considered response. As a result, Oppenheimer says, "the playing field was unfair."

On 20 April, editors at *Science* asked the authors of the two Technical Comments to withdraw their preprints from the LANL server until they appeared in the journal. Gibson and Flynn complied with the request, although they say that it disrupts the normal flow of scientific discussion. "I'm quite stunned that *Science* is more concerned with being first than they are with being correct," Gibson says.

But the proverbial cat is out of the bag. Every one of the several experts *Science* contacted was already intimately familiar with the preprints in question. And their consensus on the white dwarf controversy is that the new survey has turned up some dark matter, but maybe not as much as the team claims. "I'd say that the Oppenheimer team makes a few assumptions that tend to increase the number of their white dwarfs attributed to the halo," says astrophysicist Dave Bennett of the University of Notre Dame in South Bend, Indiana. "The Reid team does the opposite." Astrophysicist Brad Hansen of Princeton University agrees. "Bottom line, these white dwarfs are definitely interesting, and I'm not sure anyone has the right picture yet."

–MARK SINCELL

Mark Sincell is a science writer in Houston.

MIDDLE EAST

Two Pledges Boost SESAME Project

ANKARA—A long-planned synchrotron project for the Middle East took a major step forward last month after its Jordanian hosts pledged the money to house the instrument and its German donors agreed to ship it.

SESAME (Synchrotron Radiation for Experimental Science and Applications in the Middle East) was founded in 1999 to implement Germany's donation of BESSY-I,

ScienceScope

Appealing Case A state court judge has delivered a surprising setback to a Harvard researcher hoping to prove job discrimination. After a 3-week trial, a Massachusetts jury last month found in favor of biomathematician Tamara Awerbuch-Friedlander, who claimed that Harvard's School of Public Health denied her a promised slot on the tenure track and then retaliated against her for complaining (*Science*, 23 February, p. 1466). But before the jury could set damages, Judge Diane Kottmyer surprised both sides by dismissing the case, ruling that Awerbuch-Friedlander's 1994 complaint missed a filing deadline. Harvard officials declined comment. But Awerbuch-Friedlander says she will appeal, arguing that the timing issue is moot because Harvard actively dissuaded her from filing the complaint.

Fined Example Spurred by a government fine for violating pollution laws, the Massachusetts Institute of Technology (MIT) plans to become a model environmental citizen. The Environmental Protection Agency (EPA) has been battling the Cambridge, Massachusetts, university since 1998 over sloppy hazardous waste handling at more than 200 of its 2200 labs, and on 18 April the agency fined the school $150,000. But the same day, MIT announced that it will spend an additional $405,000 to build a Web-based "environmental campus" which will demonstrate how other schools can cope with complex environmental laws. Funds will also go to an education program at Cambridge public schools and a biofiltration storm water management system.

In a letter to MIT President Charles Vest, EPA official Sam Silverman wrote that MIT's plan "to go beyond its compliance obligations by taking on far-reaching green initiatives is laudable."

Italian Living Researchers worried about the future of science aboard the international space station got some good news on 19 April. A month after NASA said it would cancel a planned crew quarters module to save money (*Science*, 9 March, p. 1883), the Italian Space Agency said it might take on the project in return for greater access to the station for its astronauts and scientists. Researchers say the quarters are essential, because they will house the larger crew needed to run planned experiments. NASA and Italian officials warn that it may take months to nail down a deal.

Contributors: David Malakoff, Andrew Lawler, Jocelyn Kaiser