most equal at the time of contact, and no waves are excited. "Even though the patterns go away, we still have one side of the layer staying in flight for more than one and a half cycles and then repeating, while the other side does the same thing 180 degrees out of phase, which is why we see the kink in the layer."

If the experimenters increase the acceleration amplitude further (to about 6 *g*), the layer hits harder and waves are again excited. Square and striped patterns reappear, but now, because the time between collisions is two periods, the waves oscillate at $f/4$. Part d of the figure shows that because of the degeneracy associated with period doubling, the group says, there are two domains differing in phase by π, so that one domain is taking off while the other is in mid-flight.

When the acceleration is increased so that the flight time is greater than two periods, intrinsic two-frequency forcing is restored (at $f/2$ and $f/4$) and hexagonal patterns reappear, now with four different phases (part e of the figure).

For still larger accelerations, the layer becomes disordered in both space and time. Part f of the figure shows multiple small domains of wave-like structures. "You see a random bunch of stripes," explains the Texas team. "We think the phase of the layer with respect to the cell isn't very stable. Some portions of the pattern miss the collision with the container, which changes the phase of that portion with respect to the rest of the pattern."

"The pattern formation phenomena we observe are robust," the group says. The patterns don't change qualitatively with particle restitution coefficient (0.5–0.9), density (2–11 grams per cubic centimeter) and size (0.05–3 mm); layer thickness (2–40 particles deep) and aspect ratio (2–100 pattern wavelengths); and the pressure (10^{-1}–10^{-6} torr).

"The simple one-dimensional model of a layer with inelastic collisions provides insight into the sequence of transitions in the patterns," says Swinney, "but a deeper understanding of why the different patterns are selected must await the development of an equation of motion for the granular layers."

Chicago experiments

Jaeger and his collaborators at the University of Chicago have also been doing experiments in a geometry similar to that used by the University of Texas group. Jaeger notes that the 1994 experiments by the Texas group were done at atmospheric pressure. So he feels their dispersion relation must be reevaluated at low pressure.

Two years ago Jaeger and his graduate student James Knight reported (at a meeting of Packard Fellows in Monterey, California) that they had observed surface waves oscillating at half the drive frequency. Their container was shaped like a fishbowl. Over the last year Thomas Metcalf, an undergraduate, has joined the project, and he has emphasized cylindrical containers with flat bottoms and straight sidewalls. Says Jaeger, "We find patterns just like the Texas group do in their (similarly cylindrical) system." Jaeger and his collaborators showed their patterns and the corresponding dispersion relations at the Chicago workshop in mid-May.

Jaeger and his collaborators believe that even in shallow layers, residual gas pressure above 100 millitorr modifies the collision behavior between rapidly colliding grains. The Chicago team finds that the preparation condition of the grains, in particular any residual moisture on them, affects the onset of patterns. "Under ambient conditions, these factors are not easily controlled and may change over time," says Jaeger. "That's why we systematically explored the effect of evacuation."

He continues: "We are still far from the point where we understand in detail how and why these wonderful patterns exist. I believe that ordinary hydrodynamic theory clearly fails in the limit of shallow vibrated granular layers, and that comparison to liquid results (such as dispersion relations) cannot give the needed insights. In a sense, that is good news, meaning that much still needs to be explored."

The study of pattern dynamics promises to lead to valuable insights concerning the basic mechanisms governing granular flow and to help in connecting these patterns to similar patterns found in many quite different dissipative systems driven far from equilibrium.

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Space-based Telescopes See Primordial Helium in Spectra of Distant Quasars

Looking way back in time, astronomers have found evidence of the primordial gases—first, hydrogen, and now, with the help of space-based telescopes, the more elusive helium.

According to the standard model, shortly after the Big Bang, primordial hydrogen and helium were spread nearly uniformly throughout space. After matter began to coalesce into galaxies and other structures, nuclear cooking within massive stars produced heavier elements. But researchers still expect to see traces of the primordial elements if they look far out in intergalactic space, at distances corresponding to the earliest times. In 1971 they saw signs of hydrogen clumped in clouds located billions of light-years away. Now, thanks to the availability of satellite-borne telescopes sensitive to ultraviolet radiation, they have found hydrogen's primordial companion.

The clouds in which the hydrogen was seen are presumably at or before the early stages of galaxy formation. No one has seen signs of relatively uniformly distributed hydrogen, corresponding to an even earlier era before any condensation. The absence of a hydrogen signal does not mean the gas is not there. Rather, in the harsh intergalactic region between the clouds, hydrogen appears to be almost totally ionized to single protons that do not absorb light and hence cannot be seen. Researchers had hoped that helium might fare better in the intense radiation; enough nuclei might retain single electrons to permit detection of these hydrogen-like ions.

The hopes of seeing helium have been realized in the recent measurements that found the singly ionized species. It is not clear, however, how smoothly the gas is distributed—that is, how much lies in discrete clouds and how much, if any, resides in a more uniform region between the clouds. Furthermore the distinction between clouds and a uniform intergalactic medium between them is becoming blurred as clouds are discovered with very low column densities and the intergalactic medium is thought not to be perfectly uniform.

The first two sightings of helium were made through "eyes" aboard the Hubble Space Telescope: One group used the satellite's Faint Object Camera[1] and the other used both the FOC and the Faint Object Spectrograph.[2] This summer a team from Johns Hopkins University has unveiled even stronger evidence from the Hopkins Ultraviolet Telescope aboard NASA's space shuttle (see the photograph on page 21), which looked considerably deeper into the ultraviolet than the Hubble instruments.[3]

The Lyman-alpha forest

To search for either hydrogen or helium, researchers look at the spectrum of light coming to Earth from a distant quasar. The approach was proposed some 30 years ago by James E. Gunn and Bruce Peterson and, independently, by Peter Sheuer and Iosef Shklovsky.

As quasar light travels toward Earth, atoms of helium or hydrogen absorb some of the photons, leaving dips in the quasar spectrum at telltale wavelengths. (See PHYSICS TODAY, November 1987, page 17.) For example, neutral hydrogen is identified by its characteristic Lyman-alpha line at a wavelength $\lambda_0 = 1216$ angstroms, corresponding to the transition of an atom from the ground level to the first excited state. Neutral helium absorbs at a much shorter wavelength, 584 Å, and singly ionized helium at an even shorter 304 Å. The absorption dips caused by hydrogen or helium in clouds are not seen at their rest frame wavelengths, however. Instead the wavelengths are redshifted by a factor of $(1+z)$, where z is the cloud's redshift, because of the motion of the clouds away from Earth. The Lyman-alpha line from a hydrogen cloud at $z = 3$ would appear, for example, at 4864 Å. There can be hundreds of clouds along the path from the quasar, each with a different redshift, so the hydrogen clouds are seen as a series of absorption lines starting with that corresponding to the redshift of the quasar and extending down on the shortwave side of that line as the light is absorbed by ever-closer hydrogen clouds with smaller redshifts. This jumbled series of lines is called the Lyman-alpha forest.

If neutral hydrogen resided in the diffuse intergalactic medium as well as in the Lyman-alpha forest clouds, it would show up in the absorption spectrum as a continuous trough rather than a series of discrete lines. No such trough has been seen, presumably because nearly all the hydrogen between the clouds has been ionized. But the singly ionized helium could produce a noticeable trough in a quasar's spectrum just below its redshifted wavelength for absorption by this ion. That's what the observing groups have been looking for.

Helium detection

Until recently, primordial helium had not been detected in the Lyman-alpha forest clouds, because, for quasars with redshifts of two or three, its redshifted absorption lines fall into the ultraviolet, which is too strongly absorbed by our atmosphere to be seen by Earth-bound telescopes. The Hubble's FOC, which is sensitive to wavelengths above 1200 Å, can detect absorption by singly ionized helium ions only by sighting on those quasars with redshifts greater than about three. At such large redshifts there are few quasars intense enough to be detected from Earth and even fewer located along a line of sight reasonably clear of clouds, which further dim the flux.

Peter Jakobsen of the European Space Agency in Noordwijk, the Netherlands, headed a collaboration that used a prism on the FOC to locate a quasar suitable for measuring helium's weak signal.[1] Other team members hailed from the Royal Greenwich Observatory; the Laboratory of Space Astronomy in Marseille, France; and the Space Telescope Science Institute in Baltimore, Maryland. Once they found a suitable quasar (Q0302-003 with $z = 3.286$), they measured its spectrum and found that the flux disappeared below the redshifted 304-Å line. From this strong absorption, the group estimated that the optical depth, a measure of the absorption along a path from the source, must be greater than 1.7 at a redshift of 3.2. (The optical depth is the natural log of the ratio of the initial flux to the transmitted flux.)

Another group has been studying quasar spectra from Hubble's Faint Object Spectrograph. In November 1994, at a conference organized by the European Southern Observatory in Munich, Germany, David Tytler of the University of California, San Diego, reported that he and his colleagues had found a quasar, Q1935-6914, with $z = 3.185$, that was twice as bright as Q0302-003. From the spectrum of this new quasar, the group estimated the optical depth to be 1.0 ± 0.2, below the lower limit determined by Jakobsen's team. The discrepancy between the two may point to a patchiness in the intergalactic medium at this high redshift.

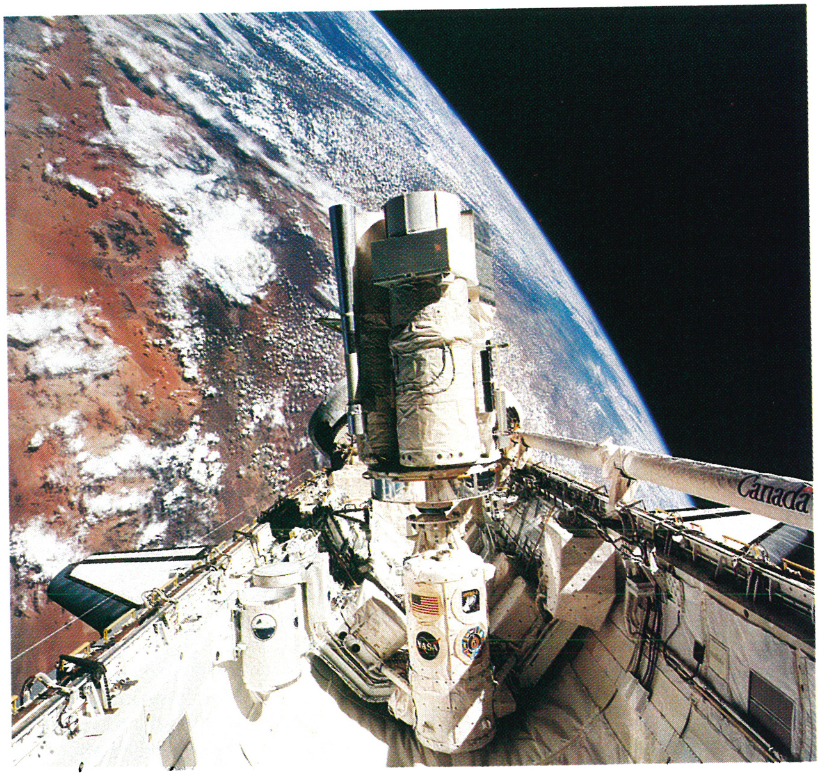
Arthur Davidsen and his colleagues from Johns Hopkins have now collected considerably more data on helium absorption than Jakobsen's and Tytler's groups. They reported the results at a meeting of the American Astronomical Society in Pittsburgh in June. Starting 17 years ago Davidsen designed the Hopkins Ultraviolet Telescope to be sensitive to the wavelength range from 800 to 1800 Å, so that he and his colleagues could study the helium absorption spectrum over a much wider range of redshifts than afforded by instruments aboard the Hubble. The lower z quasars that can be seen by HUT are closer and their radiation more intense, so that the data have a much better signal-to-noise ratio than the Hubble measurements.

HUT flew on the Astro-2 observatory in the payload bay of the space shuttle Endeavour during a 17-day mission that ended on 18 March. Davidsen and his group focused on quasar HS1700+6414 ($z = 2.74$), which is one of the brightest quasars known. From their data, the members of the Hopkins team determined an optical depth of 1.0 ± 0.07, averaged over redshifts from 2.2 to 2.6. A naive model suggests that the optical depth should increase with redshift, so the Hopkins team's result is consistent with that of Jakobsen's group.

The Hopkins researchers have enough data to look at the variation in optical depth as a function of redshift. They have found that the optical depth increases, as expected, over the range $z = 2.2$–2.7.

Cloud or continuum?

How can one tell whether the helium absorbers are part of the Lyman-alpha forest clouds or reside in the more diffuse intergalactic medium between the clouds? The spectra obtained to date do not have the combination of fine resolution and high signal-to-noise ratio needed to sort out completely the trough from the lines. Some analysts have tried to estimate how much of the optical depth can be attributed to the helium within the Lyman-alpha clouds and then, by subtraction, determine how much helium remains between the clouds. Such calculations, however, require a number of assumptions, a major one being an estimate of how many clouds there are with a given column den-



THE HOPKINS ULTRAVIOLET TELESCOPE was part of the Astro-2 Observatory, shown here in the payload bay of the space shuttle Endeavour. HUT viewed the spectra of quasars well into the ultraviolet and provided high-quality evidence of primordial helium. (Courtesy of Johns Hopkins University.)

sity of hydrogen.

The density distribution of Lyman-alpha forest clouds comes from the extensive measurements of hydrogen absorption spectra done with Earth-bound telescopes. Such hydrogen spectra are far more finely resolved than the helium measurements made from space, because optical telescopes have much larger collecting areas. Until recently, none of these optical telescopes had seen Lyman-alpha forest clouds with hydrogen column densities below 5×10^{13} per square centimeter. But this year Antoinette Songaila, Esther M. Hu and Lennox Cowie at the University of Hawaii at Manoa, in Honolulu, used the Keck 10-meter optical telescope to extend[3] that lower limit down to 2×10^{12} cm^{-2}.

The Hawaii group finds that it can account for all the absorption seen in the Hubble measurements by including helium in the very low-column-density clouds and making certain assumptions, without requiring additional helium in the diffuse intergalactic medium. These results jibe with theoretical predictions of Michael Shull, Mark Giroux and Mark Fardal of the Joint Institute for Laboratory Astrophysics and the University of Colorado,[4] in Boulder, and by Piero Madau of the Space Telescope Science Institute and Avery Meiksin of the University of Chicago. Shull and his colleagues have recently reached a similar conclusion for the optical depth seen by HUT.

Davidsen and his colleagues have chosen to make a cutoff at a column density of 10^{13} cm^{-2}, contending that clouds with densities below that value are virtually indistinguishable from an inhomogeneous intergalactic medium. They have calculated that helium in the clouds below that cutoff accounts for about two-thirds of the total absorption. (All these calculations depend on assumptions such as the spectral distribution of ionizing radiation.)

Distinguishing between a diffuse intergalactic medium and clouds, as the column density gets ever smaller, becomes almost a semantic question. However, the answer is of importance to cosmologists concerned with the formation of structure in the universe. Measuring the difference poses quite a challenge, requiring improvements in both resolution and collecting area. At least a tenfold improvement in resolution is promised from the Far Ultraviolet Spectroscopic Explorer satellite, scheduled for launching in 1998 by NASA, with participation by the Canadian Space Agency and France's National Center of Space Studies.

One ultimate goal of all these measurements is to estimate the contribution of the primordial gases to the mass of the universe. Even if one could clearly distinguish how much absorption came from gases in clouds as opposed to those in relatively smooth intergalactic regions, it is difficult to make a quantitative estimate of the total mass of hydrogen and helium. Among the factors one has to estimate are the ionization fractions of hydrogen and helium, which depend on the intensity and spectral shape of the diffuse ultraviolet radiation field at high z.

Present estimates already indicate the existence of far more matter in the intergalactic clouds than in the stars. Jeremiah Ostriker of Princeton told PHYSICS TODAY that better measurements will tell us if the total intergalactic medium is cosmologically significant or, as expected, still far below the cherished value needed for closure.

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German Neutron Source Gets Go-Ahead

Neutron scattering research in Germany should get a boost from the construction of a new research reactor, called the FRM-2, at the Technical University of Munich. The German federal government and the state of Bavaria have approved funding for the reactor, which, together with the beam hall and instruments, is expected to cost DM720 million. Although the reactor will have only about one-third the power of the 57-megawatt facility at the Institut Laue–Langevin in Grenoble, France—the research reactor with the highest neutron flux—the FRM-2 will have somewhat over half its flux (8×10^{14} neutrons per square centimeter per second compared to 1.5×10^{15} cm^{-2} s^{-1} at the ILL). With a capacity for 30–35 instruments, the reactor will provide ad-