Research in Progress

Core Temperature

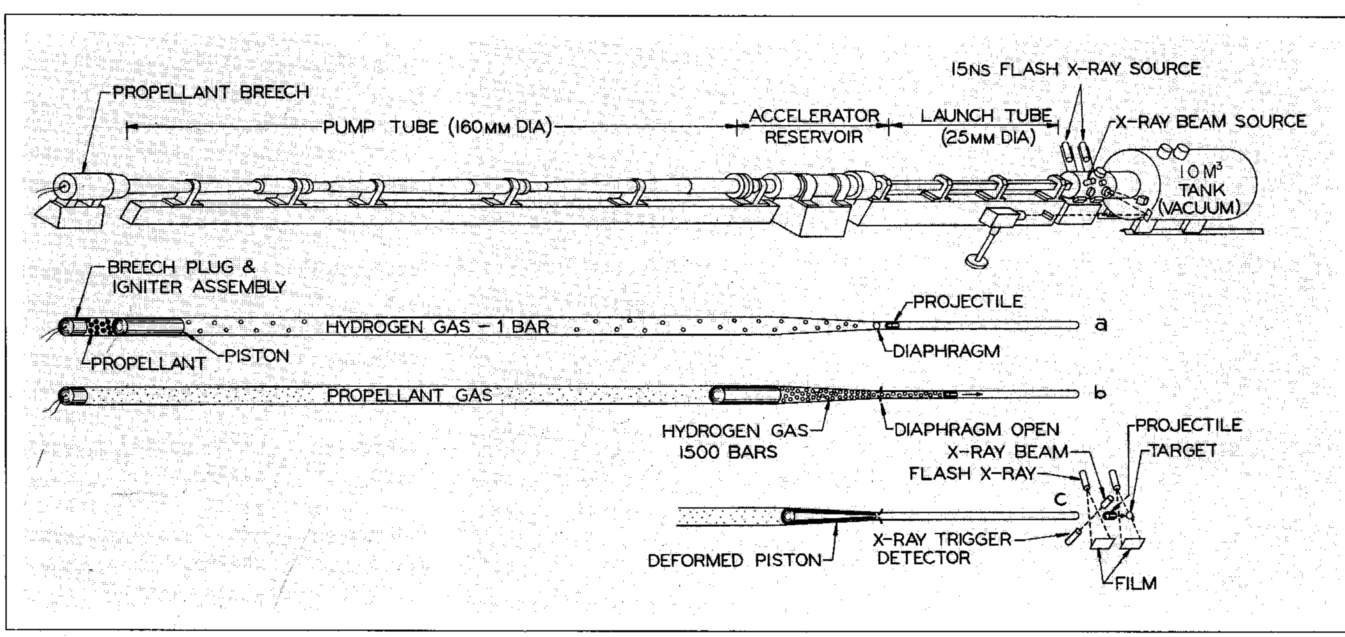
Sometimes one particular scientific instrument or technique proves enormously varied in its applications — far beyond original expectations. Such is the case with the instruments and techniques that Thomas J. Ahrens, professor of geophysics, uses in the Helen and Roland Lindhurst Laboratory of Experimental Geophysics.

In this laboratory are three powerful guns capable of accelerating projectiles to enormous speeds. Firing off one of these guns is not a casual affair. The largest is 106 feet long, weighs 35 tons, and is capable of accelerating one-ounce plastic and tantalum bullets to speeds of 16,000 miles per hour. Before firing it, the researchers have to go through an elaborate and detailed checklist, as well as a NASA-style countdown. And when it finally fires, all of South Mudd shakes.

All this trouble seems to be worth it, though. In past years Ahrens and his group have: compressed the gemstone garnet, altering its crystal structure into a form never before seen (*E&S*, May-June 1971); discovered major phase changes in calcium and iron oxide; fired bullets at targets of solid hydrogen, simulating the environment deep in the interior of Jupiter and Saturn; located the earth's "missing" sulfur in the molten outer core; shed new light on the possible cause of the mysterious Tunguska explosion, which took place in the USSR in 1908; lent credence to the theory that a gigantic meteorite hit the earth 65 million years ago, leading to the extinction of the dinosaurs; illuminated the structure of the ice craters on the surfaces of such satellites as Ganymede and Callisto; and developed a plausible hypothesis explaining how pieces of Mars may have been blasted into space by a meteorite impact, eventually to find their way to earth (*E&S*, March 1985).

These projects all share a common thread, however. Says Ahrens, "We usually think of processes occuring in the solar system as being rather gentle, like wind, for example. But impact turns out to play a far greater role than previously thought."

This year, Ahrens and his group, collaborating with researchers at UC Berkeley, have determined that the earth's core is thousands of degrees hotter than was previously thought. This new value for the core temperature — 6,900 Kelvin (almost 12,000° Fahrenheit) — implies that there may be a non-convecting layer at the core-mantle boundary, or else the rest of the earth would be much hotter than it actually is. The core is even hotter than the surface of the sun.



The largest of the Lindhurst Lab guns is 106 ft. long. When the chemical propellant ignites (a), a 20-kg plastic piston compresses hydrogen in the pump tube. As the projectile enters the high-pressure reservoir section (b), the diaphragm ruptures, and the projectile begins to accelerate down the launch tube. As a result of the deformation of the plastic piston in the high-pressure reservoir (c), gas pressure is maintained on the projectile until it clears the launch tube. A continuous x-ray beam measures the projectile's velocity.

Geophysicists have long known that the earth's core is composed of molten iron (with some impurities) at pressures of over 350 gigapascals (GPa) — 3.5 million atmospheres. What they haven't known, at least not accurately, is the melting point of iron at these great pressures, which provides a lower limit for the temperature of the core. Previous studies were able to measure iron's melting point only to relatively modest pressures. Extrapolations from these low-pressure measurements led to upper estimates of about 3,000 K to 4,000 K for the core's temperature.

In the recent experiments, the melting point of iron was measured using two techniques. In the first, the UC Berkeley researchers — graduate student Quentin Williams and Professor of Geology and Geophysics Raymond Jeanloz — made continuous measurements of iron's melting point up to about 100 GPa in a laser-heated diamond cell. In this novel apparatus, a thin foil, 0.003 inches square, of 99.99 percent pure iron was within a matrix of powdered ruby. Diamond anvils then compress this iron sandwich as it is being heated by a tightly focused laser beam. To determine the temperature, the researchers measured the light radiated by the heated iron. And to determine whether the sample had melted, they used two criteria: the disappearance of the sample's surface texture after heating and the observation of fluid-like motion of the sample when held at high temperature.

For pressures up to about 300 GPa, the Caltech researchers — Ahrens, Visiting Associate Professor in Geophysics Jay Bass, and graduate student Robert Svendsen — used the Lindhurst Lab guns. The bullets were aimed at a target of single crystal aluminum oxide (sapphire) on which a thin film of iron had been deposited. For less than one microsecond, the impact produced the intense pressures required. To measure the temperature during this brief period, the researchers relied on an instrument known as a four-color optical pyrometer in a technique that is quite similar in its details to one astronomers use to measure the temperature of stars.

Taking into account the fact that the core is not made up of pure iron, the researchers arrived at a temperature of about 6,900 K for the solid inner core. The temperature at the boundary between the inner and outer core is about 6,600 K and the temperature of the core-mantle boundary is about 4,800 K.

These temperatures imply the existence of a major boundary layer at the base of the mantle that acts something like a pressure cooker, holding the heat in. This layer does conduct heat but may not itself be convecting. Therefore, a great deal of the heat generated within the core may remain in the core. If the boundary layer did convect, the core would be cooler and the mantle hotter.

"It will be difficult to settle this issue of the boundary layer," notes Ahrens. "The thermal conductivity of the layer appears to be a factor of five less than previously thought. However, some of my colleagues still believe it is convecting." □ — *RF*

Clouds, Not Comets

CHRISTINE WILSON'S NAME is associated with the discovery of a comet, but the second-year Caltech graduate student is really more interested in galaxies — their structure and their history and precisely how far from earth they are. During the past year, while media attention focused on Comet Wilson, Wilson herself was focusing telescopes on the spiral galaxies M33 and M101 to trace the dynamics of star formation there. Her project, done in collaboration with Caltech astronomer Nick Scoville and Carnegie Observatories astronomer Wendy Freedman, is one of the first studies of individual star-forming regions outside the Milky Way. Understanding how stars are born — whether singly or in flocks, as half of a binary system or as the center of a planetary one — is considered crucial to understanding the dynamics and evolution of galaxies. In addition to shedding some light on these topics, Wilson's research could help to determine whether models of star formation proposed for the Milky Way can reliably be applied to similar galaxies in other parts of the universe.

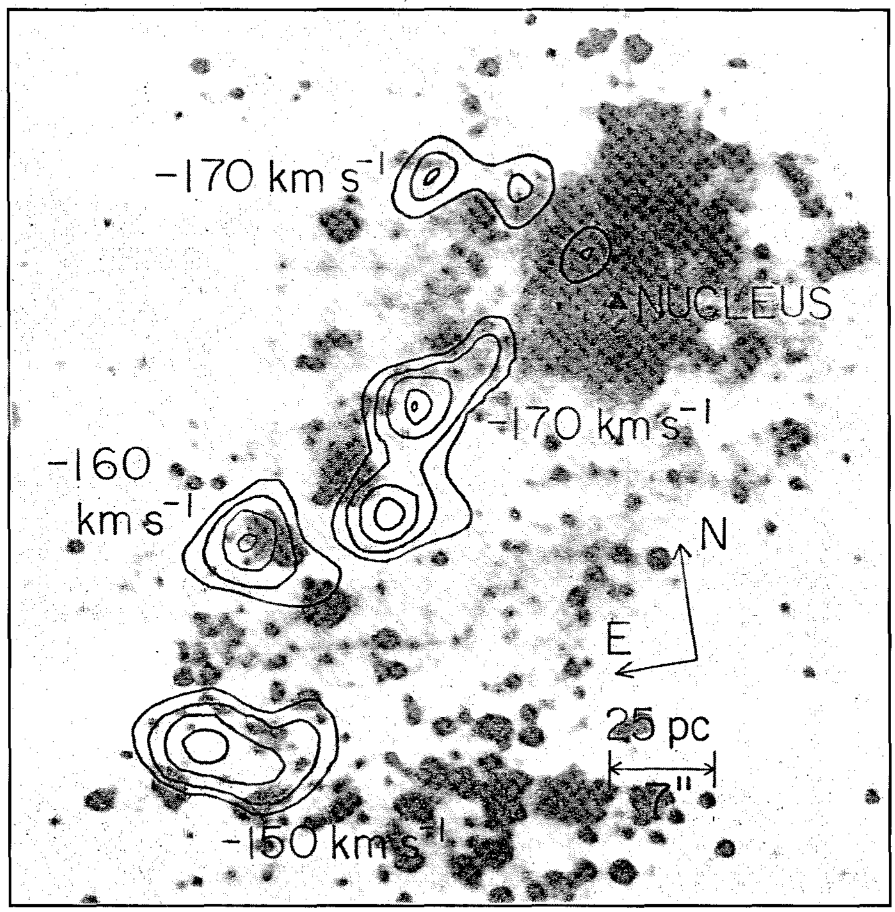
Stars originate inside gigantic clouds of molecular gas and dust that congregate by the thousands in the central regions and pinwheel arms of spiral systems like the Milky Way. Close to 99 percent of this gas is molecular hydrogen. Shielded by dust that absorbs nearly all visible light, molecular hydrogen is also mute in the radio band of the spectrum. Thus, studies of star-forming regions require the use of several tools in the astronomer's kit — optical telescopes that observe the blaze of blue and red light from massive young stars; infrared instruments to study the dust that engulfs stars in the embryonic and newborn phase; and radio dishes that track emissions from the fraction of gas that isn't molecular hydrogen. The most abundant of these compounds, carbon monoxide, radiates strongly at microwave (millimeter and submillimeter) frequencies and is considered a highly dependable tracer of the structure and dynamics of the hydrogen.

Until recently, these properties could not be studied in much detail extragalactically because of the limited resolution of single-dish telescopes. Single-dish studies of the relatively nearby spirals M33 and M101 had detected moderate CO emissions in the galaxies' centers and in one of the spiral arms of M101, roughly corresponding to what has been observed for our own galaxy. But at such distances (current estimates place M33 about 3 million light years from earth, M101 four to seven times as far), the CO emissions that signaled their kinship with the Milky Way were too weak to encourage closer studies of the resemblance.

Wilson's studies make use of the higher resolution provided by the Millimeter Wave Interferometer, a newly constructed three-dish array at Caltech's Owens Valley Radio Observatory. Deployed at designated points along a 100-meter track, the three telescopes can function as a single dish whose diameter equals the greatest extent of their separation. Using the interferometer, Wilson has begun to resolve the gas in the centers of M33 and M101 into individual molecular clouds, ranging from 150 to 200 light years in size. She's also started to measure velocity dispersions for the individual clouds, data that can be used to compute their mass.

Previous optical studies of these galaxies have detected large amounts of blue light in the neighborhood of the CO concentrations, presumably emanating from very hot young stars that have formed from the collapse and condensation of the molecular gas and dust. Using calculations that constrain the distance a star can be from a molecular cloud and still be viewed as a product of that cloud, Wilson would like to extend these observations to see how the number of stars correlates with specific quantities of gas. "Enough single-dish studies have been done so that we now know roughly how much molecular hydrogen there is in a number of external galaxies. But until now, nobody's really looked at these systems on a smaller scale. We'd like to have a much more precise estimate of how much CO in these systems equals how many stars, and then plot that result against data we have for the Milky Way. We do know that gas in our galaxy is being converted into stars much more slowly than theoretical calculations would indicate. It would be interesting to find out if this is occuring in other spirals as well."

Wilson would also like to determine how the masses, size, and numbers of the individual clouds in M33 and M101 compare to the measurements that have been obtained for nearby star-forming regions and the nucleus of the Milky Way. Attempts to study these properties locally can also be impeded by interstellar dust and by the earthbound astronomer's position within the galaxy. "When we look at the center of the Milky Way, we're looking through the galactic disk and seeing the nucleus edge-on," says Wilson. "But we see M33 and M101 in cross section, so we can look directly into the centers of these galaxies to see how the gas and stars are distributed there. We can also pinpoint the position of the clouds relative to the spiral arms, which imposes constraint on theories of how these arms are formed. In the Milky Way, we're sitting in one of the arms, and can't easily make these observations."
□ — *Heidi Aspaturian*



An interferometer map of several molecular clouds in the center of the spiral galaxy M33 is shown superimposed on an optical photo of the same region. The dark patches in the photo are bright young stars believed to have formed from the clouds.

In this Palomar Observatory photo, M33, 3 million light years from earth, displays its spiral structure. The galaxy is thought to resemble the Milky Way, although smaller.