search & discovery

Infrared interferometer to measure size and shape of stars

A new high-resolution device for infrared astronomy is being developed at the University of California at Berkeley by Charles Townes and his collaborators, Michael Johnson, Albert Betz and Daniel Galehouse. Applying the new techniques of quantum electronics to a concept originated by Albert A. Michelson, they have built the first infrared stellar interferometer. Townes expects its angular resolution to be orders of magnitude greater than that of an ordinary telescope. It will be used to measure the size and shape of stars and other astronomical objects.

Michelson had used a stellar interferometer with two small receiving telescopes separated by about 20 feet and became the first person to measure the diameter of a star other than our sun. He had an angular resolution of about 10^{-7} radians. The art essentially died until its rejuvenation came with long-baseline microwave interferometry, which has now progressed to intercontinental experiments. Angular resolutions of 10^{-9} have been achieved. Another technique related to Michelson's, developed over the past two decades by Hanbury-Brown in Australia, uses two separate light telescopes and measures the fluctuation in light. By cross correlation of these fluctuations he gets high angular resolution in the visible range.

With intercontinental distances, microwave interferometry has essentially achieved its ultimate resolution, Townes says, unless we put one of the telescopes into space, possibly on the moon. But in the infrared, because of the difference in wavelength, a baseline of only 1 km would give the same resolution obtainable with microwaves—10^{-9}. And an even longer baseline, say 100 km, should be possible.

In the Berkeley interferometer (see figure), a CO_2 laser serves as a local oscillator, whose output is mixed with the signal received by each telescope in a chip of photoconductive copper-doped germanium. The beat frequencies resulting from the mixing preserve the phase and amplitude information of the signal and are amplified electroni-

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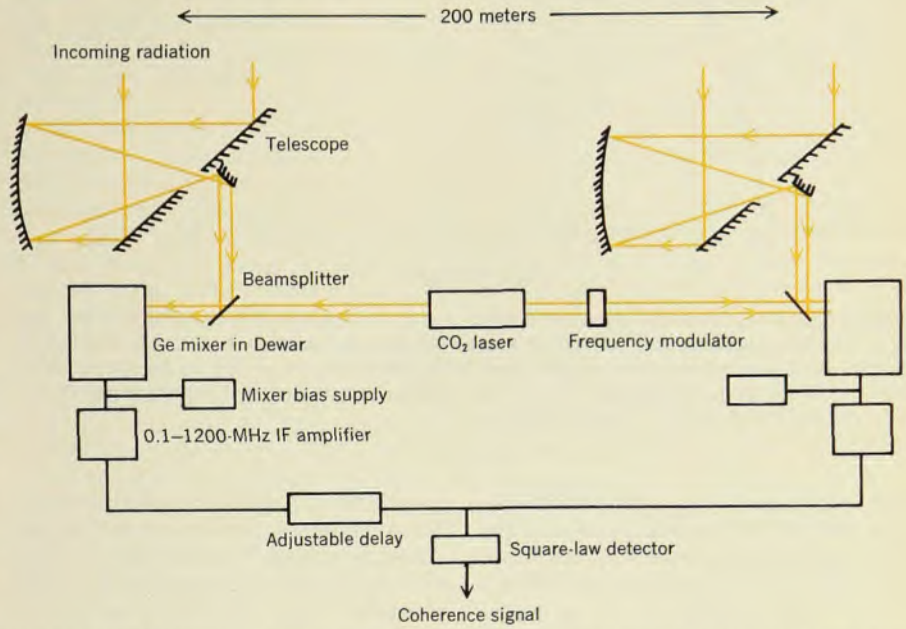


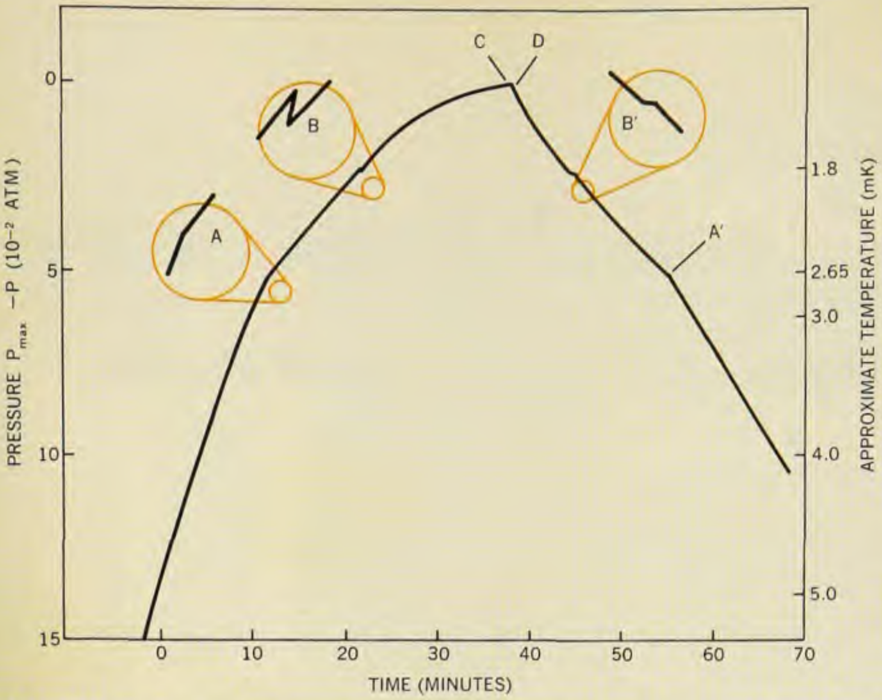
Infrared interferometer. Laser output is mixed with signal from each telescope in germanium mixer. Signals from each heterodyne detector are brought together by cable; their interference is detected by the square-law detector. Telescopes are of Pfund type.

No simple antiferromagnetism for He^3

If you squeeze helium-three along its melting curve, the temperature of the liquid–solid system drops. This unusual but well established cooling occurs because the transition from liquid to solid is, in this case, a change from an ordered to a disordered state; the liquid is a spin-ordered Fermi liquid, with low entropy, whereas the solid, which has many degrees of freedom, is a high-entropy state. Theorists predicted that, if compressive cooling were carried down to low enough temperatures, about 2.1 mK, a spin-ordering transition would occur in the solid, and it would become a nuclear antiferromagnet. But some recent observations at Cornell indicate that the behavior of He^3 is much more complicated than had been anticipated: The experiments, in which temperatures low enough to order the nuclear spins were reached for the first time, show not one but two transitions, and the evidence goes against the existence of a simple antiferromagnetic phase.

The Cornell group, Douglas D. Osheroff, Robert C. Richardson and David M. Lee, describe in *Physical Review Letters*[1] how they compressed He^3 in a "Pomeranchuk" apparatus. A beryllium–copper capacitance strain gauge measured pressure changes, and temperature was followed by measuring the nuclear magnetic susceptibility of a platinum wire. A typical rate of solidification during the compression was about 10^{-3} moles per minute, with a resultant cooling of about 0.25 mK per minute. The thermometer was calibrated with a previously determined He^3 melting curve[2,3]; accurate thermometry was, in fact, the most severe problem in the experiment.

A pressurization curve (pressure versus time) was plotted by compressing the helium at a steady rate until a maximum pressure was reached, then decompressing the helium at the same



Pressurization curve for He^3 shows a sudden change in slope at 33.9 atm and 2.65 mK that is highly reproducible during both compression (A) and decompression (A′). Second slope change (B,B′) is complicated by hysteresis during the compressive part of the cycle, which may be caused by supercooling. The behavior of this system does not appear to agree with a simple antiferromagnetic phase transition.

rate (see figure). At 33.9 atmospheres and 2.65 mK (point A) the slope of the curve suddenly changed. This change in dP/dt, about a factor of 1.8 within 3×10^{-4} atmospheres, is highly reproducible during both cooling and warming (compression and decompression, see point A′). At a pressure 0.0226 atmospheres higher than A (B), the pressure suddenly drops upon cooling, then moves upward again with no change in slope of the curve. This phenomenon at B shows hysteresis when the pressurization rate is varied, and, during the expansion part of the cycle, the change occurred rather differently (B′), with no sudden rise in pressure and no hysteresis. To explain the differences between B and B′, the group proposes that, during the compression, the hysteresis at B is caused by supercooling of the phase that makes a transition at B and B′.

What do these unexpectedly abrupt changes mean in terms of the phase structure of He^3? Assuming that most of the cooling goes on in the liquid—as the long solid relaxation times and the extreme sharpness of the transition at A indicate—and that the molar volume V_s of the solid does not change much at A, the Cornell group applies the standard Clausius-Clapeyron equation to their thermodynamic system:

$$dP/dT = (S_{\text{solid}} - S_{\text{liq}})/(V_{\text{solid}} - V_{\text{liq}}).$$

Because S_{liq} is negligible at 2.7 mK, a sudden change in dP/dt must be caused by a large change in the solid entropy. The experimenters estimate that the decrease in entropy must be about 0.15 R within a pressure interval of 3×10^{-4} atmosphere and a temperature interval of about 10^{-5} K, indicating a rather sudden ordering of the solid, perhaps even a first-order transition.

A second indication that the change at A is not the simple antiferromagnetic one is the large melting pressure change below about 2.7 mK. Through the Clausius-Clapeyron equation, Osheroff, Richardson and Lee deduce that the entropy of the solid must change very slowly over a broad temperature region below the 2.7 mK transition. In a nuclear antiferromagnetic phase, a rapid decrease in entropy is expected. The Cornell group points to the large values for the nuclear magnetic susceptibility of solid He^3 below 2.65 mK, measured in other studies at their laboratory,[4] as being incompatible with an antiferromagnetic transition at that temperature; these values are thought to indicate a strongly paramagnetic or ferromagnetic substance in the new phase.

Commenting that they know of no other physical system that behaves this way, the experimenters surmise that the 2.65-mK transition may include a crystallographic phase change, induced by some sort of coupling between the nuclear-spin and phonon systems. The new phase may have magnetic properties rather different from those of the high-temperature solid. Improved thermometry and additional susceptibility studies could clarify the nature of the newly discovered phase. —MSR

References

1. D. D. Osheroff, R. C. Richardson, D. M. Lee, Phys. Rev. Lett. **14**, 885 (1972).
2. R. A. Scribner, E. D. Adams, *Proceedings* of the Fifth Symposium on Temperature, Washington, D. C., 1971 (to be published).
3. R. T. Johnson, O. V. Lounasmaa, R. Rosenbaum, O. G. Symko, J. C. Wheatley, J. Low Temp. Phys. **2**, 403 (1970).
4. J. R. Sites, D. D. Osheroff, R. C. Richardson, D. M. Lee, Phys. Rev. Lett. **23**, 836 (1969).

Three US proposals for heavy-ion accelerator

A special evening session on heavy-ion accelerators was held during the Washington APS meeting to discuss three proposals to build such machines—at Argonne National Laboratory, Oak Ridge National Laboratory and Los Alamos Scientific Laboratory. Although over the years many proposals have been put forth, the field in the US appears to have narrowed down to the three discussed at the meeting.

Argonne proposes to build an accelerator consisting of a 20-MV Pelletron tandem electrostatic accelerator coupled to a superconducting helical linac. The tandem by itself would be valuable for heavy-ion research in nuclear, atomic and solid-state physics; the tandem-linac system would produce the intense high-energy beams required for isotope production in nuclear-chemistry research.

According to John Schiffer, who spoke at the meeting, recent results at Siemens in Germany and at Argonne indicate that the stability of the surface of superconducting cavities can be dramatically improved when the niobium structures are anodized to form a thin coating of niobium pentoxide. Because of this single development, Argonne now believes a superconducting helical linac operating at 1.8 K could easily attain the required accelerating field gradient (2 MV/m). Problems associated with mechanical stability and the very high Q of such a linac are under investigation, and promising approaches to them have already been found, Schiffer said. The linac would take any ion from the tandem and accelerate it to 10 MeV/nucleon, an energy sufficient to overcome the Coulomb barrier between two uranium nuclei.

The Argonne facility would be scheduled by a users committee much in the way high-energy facilities are operated. Its cost is estimated at about $13 million, including additional building space needed to allow the beam to enter four independent target areas; the building from the present tandem facility at Argonne would be converted to use with the heavy-ion machine. Additional operating costs for the physics and chemistry divisions at Argonne would be under $1 million per year, Schiffer said.

Oak Ridge proposes a National Heavy-Ion Laboratory with three accelerators. The main accelerator would be a large (40 feet across) separated-sector (four sectors) isochronous cyclotron patterned after the Indiana cyclotron now under construction. The main accelerator would provide the second stage of acceleration for beams injected from either a 20-MV tandem or from the existing Oak Ridge Isochronous Cyclotron (ORIC). For experiments with ions around mass 100, the two cyclotrons would be used; for ions around mass 200 the tandem and the big cyclotron would be used. For uranium ions hitting uranium, the machine could yield 10 MeV/nucleon.

Paul Stelson, who spoke at the meeting, said the energy resolution, energy variability and beam quality are expected to be similar to those now available from tandems. The facility would take five years to build.

Like the Argonne proposal, the Oak Ridge one provides for a strong users organization. Stelson said sufficient experimental area (20 000 ft^2) and an extensive beam transport system are planned to provide 10 experimental stations initially with the possibility of expanding to 25 or more.

In 1973 dollars, the total cost of the lab is $20 million. It is anticipated that the incremental increase in yearly operating funds (based on 1973 dollars) would be about $1.8 million (to support the operation of the facility but not the research programs).

Los Alamos proposes to construct a heavy-ion linear accelerator operating at room temperature. A 4-MV single-ended electrostatic machine would be used to inject highly charged positive ions into an array of helical waveguide resonators. The resonators would be independently phased to provide variable energy beams of a wide range of ions. Richard Stokes, who spoke at the meeting, said that the linac would use a single stripper to increase the ion charge. This produces a greater intensity at high energy compared to arrangements using a tandem injector and two strippers, he said. Beams with either good energy resolution or good time resolution would be available for a wide range of studies in heavy elements, nuclear structure and fission physics.

Stokes stressed that Los Alamos is proposing a modest-sized accelerator, which if necessary could be extended at a later time. Because research on the possible formation of superheavy elements is of the greatest interest, the accelerator is scaled for this use. The calculations of J. R. Nix (PHYSICS TODAY, April, page 30) strongly suggest that Ca^{48} or Ge^{76} ions would be optimal projectiles rather than uranium. For such ions the machine would produce 6–7.5 MeV/nucleon, sufficient to surmount the Coulomb barrier in appropriate targets.

The facility is being proposed as part of the Los Alamos FY 1974 budget through the AEC Division of Military Applications. This is the route through which all existing Los Alamos low-energy nuclear physics facilities have been funded. (Argonne and Oak Ridge have applied to AEC's Division of Research.)

Uses for heavy ions. At the meeting Arthur Kerman (MIT) discussed the value of heavy ions for atomic and solid-state physics, nuclear physics and technology. Among many other things, one could study the spectra of excited atoms (which have astrophysical applications), use the heavy ions to dope materials in ways that are otherwise very difficult, and use them to study the radiation damage caused by neutrons in breeder reactors. One should also be able to obtain a variety of interesting new radioisotopes.

For nuclear physics, the whole subject of the interaction of one heavy nucleus with another heavy nucleus is new. Kerman feels this study will have a big impact on the rest of nuclear physics. The heavy ions can be used to study nuclear spectra in new ways. They can be used to make exotic nuclei that are off the line of stability—either proton rich or neutron rich. Finally there is the goal of making superheavy elements or at least studying superheavy systems.

Despite the enthusiasm for a new heavy-ion facility, some members of the nuclear-physics community have questioned the wisdom of building expensive equipment at a time when it is not clear where experimenters will be able to get the money to operate existing facilities.

Other facilities. Many other heavy-ion devices are in various stages of development throughout the world. In Berkeley the superHILAC is working well and is in the debugging stage, according to Albert Ghiorso. It will have 2.5–8.5 MeV/nucleon with continuously variable energy for ions of all masses between 1 through 238. If it turns out that foil strippers don't hold up well enough, some observers believe that the superHILAC beams of ions heavier than xenon would be limited in current. Funds are requested for the Bevalac in the FY 1973 budget; it would produce somewhat over 2000 MeV/nucleon for ions up to iron.

Several heavy-ion proposals have included copies of the Indiana cyclotron or variations of its design. The Indiana facility is scheduled for initial operation in November 1973. As now being constructed this machine will be able to accelerate ions primarily up to the region of Ca^{48} to 7.5 MeV/nucleon or higher, but the possibility of adding an alternate injector for heavier ions has been planned for since the project's inception.

In Germany, UNILAC is scheduled to be finished in 1975. It is expected to get up to 8.5 MeV/nucleon with a gas stripper and up to 10.2 MeV/nucleon with a foil stripper.

Two smaller facilities are also under consideration in West Germany. Studies are in progress at the Hahn-Meitner Institute in West Berlin and at the Max Planck Institute in Heidelberg.

In France, at Orsay, ALICE, which has been running for two years, has produced 480-MeV krypton ions, and some very interesting new results have been produced.

In the Soviet Union, Dubna has hooked its 200-cm and 300-cm cyclotrons together and run them in tandem (PHYSICS TODAY, January, page 19), getting around 7 MeV/nucleon xenon ions out.

Elsewhere, the National University in Canberra, Australia is getting a 15-MV Pelletron. —GBL

Interferometer

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cally. The infrared receiver is sensitive to radiation in a bandwidth of 10^9 Hz, centered at a wavelength of 10 microns. The signals from each heterodyne detector, which lie in the radiofrequency range, are brought together by cable; then their interference is detected by a square-law detector.

As the star swings overhead the difference in path length through the two telescopes changes. To keep the path difference fixed, the new device simply switches in various lengths of cables; the precision required for the 10^9-Hz bandwidth is a few centimeters.

Tests will soon be underway at Kitt Peak with two existing telescopes separated by 20 feet. This interferometer will give a factor of two improvement in resolution over the 200-inch telescope. If all goes well the Berkeley group will then use the three large Kitt Peak telescopes, two at a time; these are arranged in a triangle whose legs are 500 to 800 feet. The telescopes are 60, 84 and 90 inches. The big interferometer will improve resolution by a factor of 25 or more over the small interferometer, putting the experimenters in a whole new realm of observation.