

search & discovery

Infrared interferometer to measure size and shape of stars

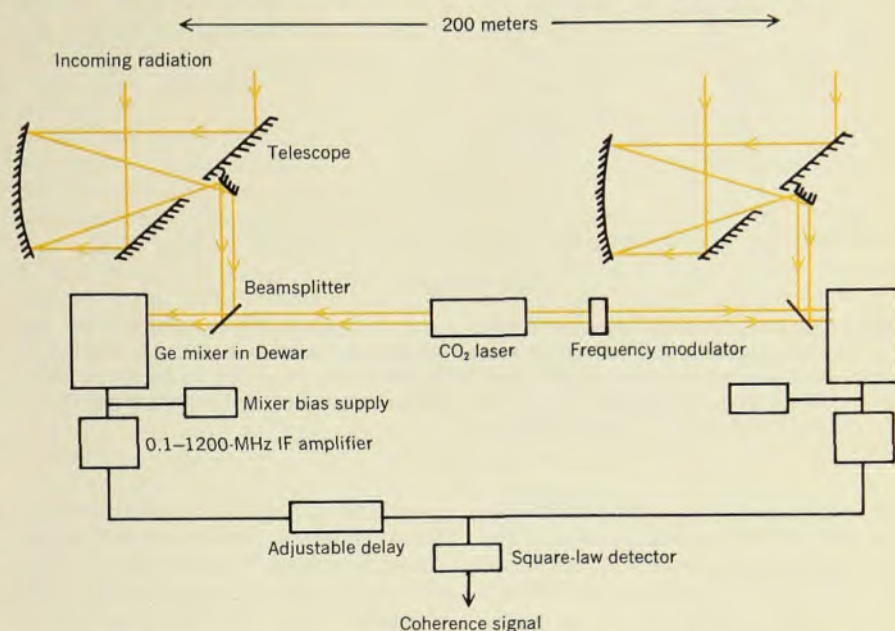
A new high-resolution device for infrared astronomy is being developed at the University of California at Berkeley by Charles Townes and his collaborators, Michael Johnson, Albert Betz and Daniel Galehouse. Applying the new techniques of quantum electronics to a concept originated by Albert A. Michelson, 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 CO₂ laser serves as a local oscillator, whose output is mixed with the signal received by each telescope on 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 electronically.

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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.

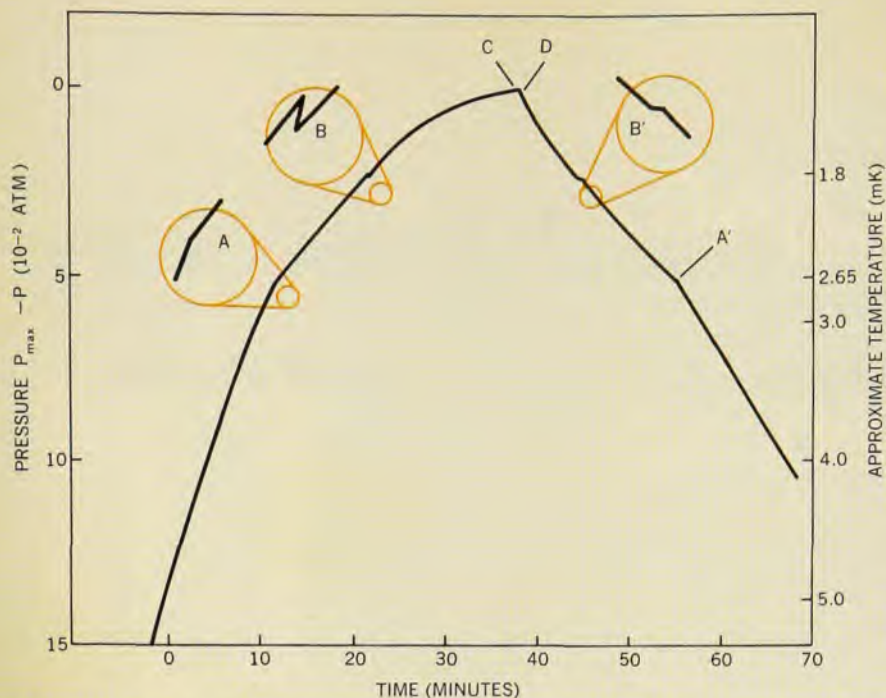
No simple antiferromagnetism for He³

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 He³ 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 He³ 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 He³ 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