search & discovery

Silicon-monoxide masers show up in infrared stars

Radio telescopes, scanning the heavens at millimeter wavelengths, have detected maser emissions on several lines from vibrationally excited states of silicon monoxide. Until now, the only maser emissions from space have come from OH and H_2O molecules, at centimeter wavelengths. The OH and H_2O masers are located both in infrared stars and interstellar clouds, but the SiO masers have been seen only in the red giant variable stars. It is not surprising to find SiO in these regions, but it is puzzling to speculate about what processes in these stars might have sufficient energy to excite the vibrational states.

Observations. The signals from the SiO maser were first observed last December by Lewis Snyder of the Joint Institute for Laboratory Astrophysics, who was at the time a visiting fellow from the University of Virginia, and David Buhl of the Goddard Space Flight Center (NASA). They were examining a region of the Orion Nebula at a wavelength around 3.48 mm (corresponding to a frequency of 86.2 GHz)[1] with the 36-foot radio telescope of the National Radio Astronomy Observatory. The narrowness of the unidentified lines, their limited spatial extent and their complex structure suggested to Snyder and Buhl that these lines were maser emission. This idea was reinforced by Norio Kaifu of NRAO, who noted similarities with the velocity pat-

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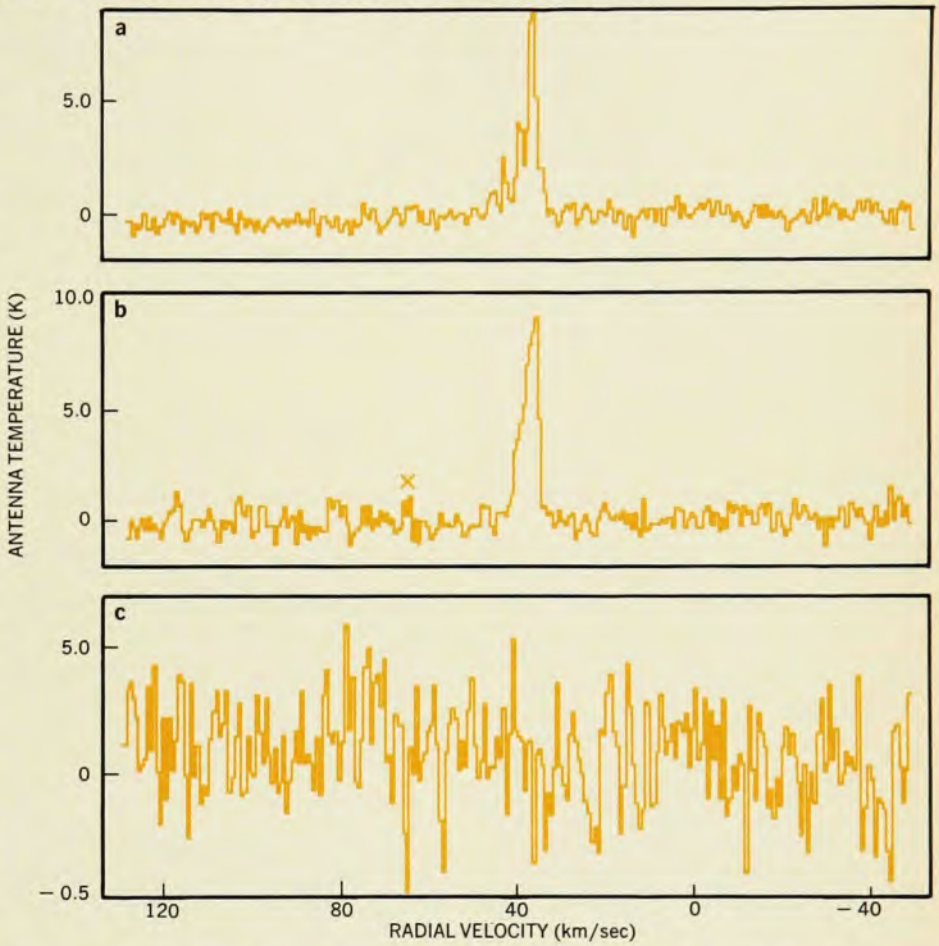


Doppler velocity patterns helped identify new signals as SiO maser emission. Observations on W Hydra (from ref. 5) indicate lines for the rotational transition $J = 1 \rightarrow 0$ in the $v = 2$ and $v = 1$ vibrational states (a,b) but not in the $v = 0$ ground state nor in the $v = 3$ state (not shown).

Helium-three magnetic behavior becomes more complicated

Evidence is mounting that the correct model of solid helium-three cannot be the simple one that long seemed adequate. The He^3 nucleus, consisting of two protons and one neutron, is a fermion of spin ½. Because of the large probability of individual He^3 atoms exchanging places, the solid acts as a kind of atomic magnet. Until only a few years ago theorists were able to treat solid He^3 in terms of an extremely simple magnetic model—a Heisenberg Hamiltonian that included only interactions between nearest-neighbor atoms, neglecting higher-order interactions and coupling with phonons—and no experimental data contradicted them. In 1971, however, some studies of magnetic pressure versus temperature at high magnetic fields[1] could not be fitted into the theory, and efforts were made to revise the theory by adding higher-order interactions.[2] And now, two groups of experiments, one at Cornell University (William Halperin, Charles Archie, Finn Rasmussen, Robert Buhrman and Robert Richardson)[3] and the other at the University of California, La Jolla (Jeffrey Dundon and John Goodkind)[4] indicate that the magnetic behavior of solid He^3 is much more complicated than the He^3 theorists had presumed. The Cornell adiabatic-solidification studies suggest that the magnetic ordering transition in the solid occurs at about half the predicted temperature and that it is a much sharper transition than expected. The La Jolla group sees unexpected structure in the variation of heat capacity with temperature and also infers that the transition temperature T_s is below the predicted value.

Halperin and his colleagues measured the latent heat of solidification of He^3 at a point on its melting curve and found a sharp decrease in the magnetic entropy of the solid (from 0.5 R log 2 to 0.1 R log 2 within 1×10^{-4} K, where R is the gas constant) as it is cooled through a transition temperature of 1.17 mK. Dundon and Goodkind, measuring the specific heat of solid He^3 between 1 mK and 25 mK, found a variety of unexpected changes in heat capacity

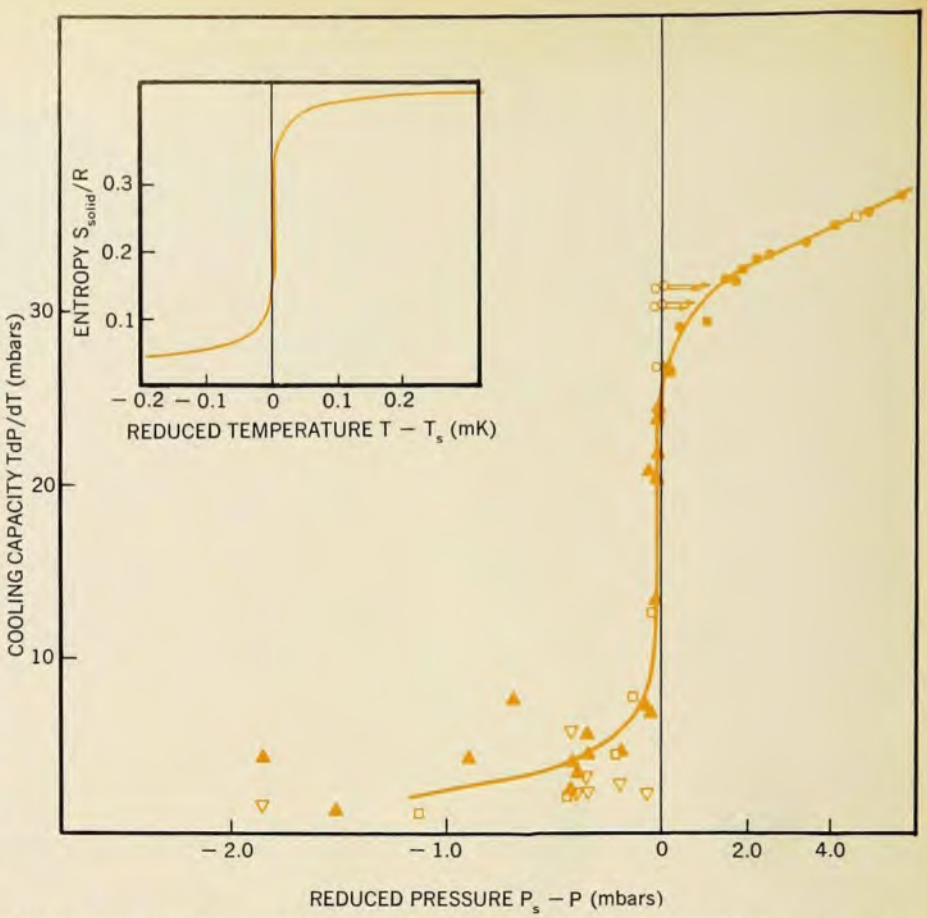
between 1 mK and 4 mK, also indicating that the nuclear spin ordering occurs with a rather complicated temperature dependence. Above 5 mK, the data fitted an acceptable theoretical curve, but with a "wrong" sign for one of the terms in the power series.

At Cornell the work was done with a compressional cooling cell. Because liquid He^3 is a highly ordered Fermi liquid with low entropy, whereas solid He^3 (at least at relatively high temperatures) is a high-entropy state, squeezing the He^3 to form more solid results in absorption of heat by the system. During measurements along the melting curve, the Cornell group first noticed that the compressional cooling rate showed an anomaly at a pressure corresponding to a T_s of 1.17 mK. (Temperature is uniquely related to vapor pressure on the melting curve. Measurement of the latent heat of solidification versus pressure on the melting curve thus permits establishing a thermodynamic temperature at any melting pressure.) This is below the temperatures of the two superfluid transitions in the liquid, also discovered recently at Cornell; see PHYSICS TODAY, July 1972 (page 17) and November 1972 (page 17). In a subsequent group of experiments, they added just enough heat to the system to maintain the temperature of the solid constant during the steady compression; that is, the heat needed compensates for the (negative) latent heat of solidification for He^3 at T_s.

In these experiments the He^3 is contained in a pancake-shaped region directly below a beryllium–copper diaphragm. Compression of the liquid He^4 contained in the upper part of the cell produces the volume change and resultant adiabatic solidification of the He^3. In this cell, volume can be measured to within 1% and pressure to within 0.01%. The heater is copper wire woven in a uniform web about the sample region, and its power is measured with 0.3% accuracy. The He^3 volume is 4.34 cm^3, which contains 0.169 moles of liquid at 19 mK, the temperature at which compressional cooling is begun. In a typical run, 22% of the sample is solidified during the hour needed to reach P_s (34.394 bar), where the cooling rate decreases abruptly.

The experimenters are able to measure the solid entropy S_{sol} by adiabatic solidification. They maintain the He^3 at constant pressure (and thus at constant temperature) by balancing dQ, the total heat introduced into the He^3, with an appropriate solidification rate. Under these conditions, for every mole of He^3 converted from liquid to solid, a latent heat $T\,(S_{liq} - S_{sol})$ is absorbed with a corresponding volume change $(V_{liq} - V_{sol})$. In other words

$$dQ/dV = T\,(S_{liq} - S_{sol})/(V_{liq} - V_{sol})$$



Cooling capacity versus reduced pressure for adiabatic solidification of helium three. The sharp increase in $T\,(dP/dT)$ at P_s indicates that a phase change—from ordinary solid to magnetically ordered solid—is occurring. The different symbols correspond to different ways of treating the heat leak in the system. Note the change in pressure scale at P_s—$P = 0$. The plot of S_{sol}/R versus reduced temperature, postulated from the cooling-capacity curve, indicates that the phase change is either a narrow second-order transition or a first-order transition, and occurs at a temperature well below that predicted. (From W. P. Halperin et al., reference 3.)

From the Clausius–Clapeyron equation this is equal to $T\,(dP/dT)$; (see figure). Note that the terms on the right-hand side are, with the exception of S_{sol}, measured quantities. The data show that a narrow, nonhysteretic transition occurs at 1.17 mK after which less than 8% of the R log 2 magnetic entropy remains in the solid.

Dundon and Goodkind, working with solid He^3 only, measured its specific heat C_v through the temperature at which the ordering transition had been expected. In the La Jolla experiments 1.0 cm^3 of He^3 was contained in a sintered-copper sponge and a nuclear magnetic resonance thermometer measured the temperature. Since the He^3 temperature could not be measured directly, the thermal time constants for the cell were determined at various temperatures. The applied heat pulses ranged between 50 and 200 ergs at power levels between ¼ and 2 ergs per second. For each heating pulse, the warm-up curve after a time corresponding to five thermal time constants was extrapolated back to time zero. This procedure gives the actual temperature rise produced by the pulse.

The equation found for the heat-capacity curve, from data taken above 5 mK, can be reconciled with the model of a Heisenberg magnet, but only if second-nearest neighbor interactions are antiferromagnetic. But this inference contradicts the studies at high magnetic fields, done by W. P. Kirk and E. D. Adams,[1] which—again only to fit the theory—indicate that these interactions must be ferromagnetic.

Below 4 mK, the heat-capacity data for the largest molar volumes depart sharply from the curve, showing a relatively small temperature dependence between 4 mK and 2 mK, a rapid increase at 2 mK, and a decrease below 1.2 mK. The results appear to indicate one or more phase transitions, but they are not consistent with simple antiferromagnetic spin-ordering transitions because the entropy change is too small. Dundon and Goodkind conclude that at temperatures down to 1 mK a major portion of the entropy still remains, indicating that the predicted antiferromagnetic transition has not yet occurred. Their results appear to disagree quantitatively with the Cornell results but, Dundon and Goodkind

note, this apparent disagreement may be a result of thermal disequilibrium.

The original simple theory was borne out by many kinds of experiments (all done above the expected T_s) during the past decade. As recently as 1969, for example, some magnetic-susceptibility studies led to confidence in the prediction of a simple antiferromagnetic ordering transition at about 2.7 mK. There had, however, been other high-temperature work to suggest that the He^3 transition might be a little unusual. John Wheatley, Orest Symko and Richard Johnson (at La Jolla) had studied[5] diffusion constants, and their results have been qualitatively interpreted as indicating that something unusual might be going on. And several susceptibility measurements, most recently those of Douglas Osheroff, Richardson and David Lee,[6] have in fact found more magnetization in the solid than would be expected if the phase trasition occurred at 2.7 mK. Now that experimenters have reached sufficiently low temperatures, theorists will very likely receive a good deal more information to work with. —MSR

References

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US and Soviet claims for element 106

A new element—number 106—may have been synthesized nearly simultaneously by two groups, one from the Joint Institute for Nuclear Research in Dubna, USSR[1] and the other from the Lawrence Berkeley Laboratory and the Lawrence Livermore Laboratory.[2] The Dubna team mentioned their discovery at the Heavy Ion Conference in Nashville, Tennessee, last June, and the LBL–LLL group reported their findings to a meeting of the American Chemical Society in Atlantic City, N.J. in September.

The Dubna group consists of Yu. Ts. Oganessian, Yu. P. Tretyakov, A. J. Iljinov, A. G. Demin, A. A. Pleve, S. P. Tretyakova, V. M. Plotko, M. P. Ivanov, N. A. Danilov, Yu. S. Korotkin and Georgi N. Flerov. Members of the California team are Albert Ghiorso, Joachim N. Nitschke, Jose R. Alonso, Carol T. Alonso, Matti Nurmia and Glenn T. Seaborg of LBL, and Kenneth Hulet and Ronald W. Lougheed of LLL.

While Flerov, the leader of the Dubna group, was in the US last summer, he met with Ghiorso and Seaborg at Berkeley. Perhaps partly because of that meeting, neither side has proposed a name for the new element, as has been the case in the past when conflicting claims have arisen between these same two groups. The priority question will be settled by the International Union of Pure and Applied Chemistry, which has just formed a committee to rule on the claims over elements 104 and 105. Aside from the priority question, the findings of the two groups do not contradict one another because they pertain to different isotopes of element 106.

The synthesis of elements at the upper end of the periodic table is difficult because of the low production rates and the uncertainties regarding their nuclear properties. The experiments of the LBL–LLL and Dubna groups met this challenge in very different ways. The LBL–LLL group chose to identify the new element by producing an alpha emitter of the new element and by then establishing a direct genetic link between it and recognizable daughter and granddaughter nuclides. The Dubna team set out to produce an isotope of the new element that would decay by spontaneous fission. By studying the theoretical and experimental properties of neighboring elements, they extrapolate to predict the behavior of element 106. Dubna obtains a fission-active nuclide by accelerating much heavier ions than the standard carbon, oxygen and neon ions, and bombarding a relatively light target such as lead. Such a method holds perhaps the most hope for producing still heavier nuclei.

Experimental details. In the LBL–LLL experiment, the SuperHILAC accelerated O^{18} ions onto a Cf^{249} target. According to their report, element 106 was formed by the reaction Cf^{249} $(O^{18}$ $4n)_{106}X^{263}$. It then decayed by alpha emission to rutherfordium, which then decayed by alpha emission to nobelium, which in turn decayed by alpha emission. An elaborate detection system sought for correlations not only between the new element and its daughter but also between the daughter and granddaughter. The element thus identified had alpha energies of 9.06 and 9.25 MeV and a half life of 0.9 ± 0.2 sec. It was produced at a beam energy of 95 MeV but not at 91 or 100 MeV. The LBL–LLL team calculated a formation cross section of 0.3 nb. These observations are consistent with a calculated excitation function that predicts a half width of 7 MeV and a maximum cross section of 0.2 nb.

In the Dubna experiment, 280-MeV ions of Cr^{54} from the 310-cm cyclotron struck targets of Pb^{206}, Pb^{207} and Pb^{208}, in separate runs. Spontaneous fission activities were detected by means of foils exposed to a rotating target disk. The foils were etched and scanned with a microscope to detect the number of fission tracks and the half life of spontaneous fission activity. According to both Ghiorso and Lee Grodzins (MIT), the main difficulty in using spontaneous fission activity in new element research is that the nuclei of the new element are destroyed in the fission process without leaving a daughter nucleus. Thus it is not possible to detect the atomic number and mass number of the original nucleus by means of a genetic link to a known nuclide.

In order to circumvent the problem, the Dubna group studied the excitation of compound nuclei formed when lead was bombarded with various projectiles. They found that the excitation energy is lowest when projectiles having a mass number in the range from 40 to 60 were used. Thus, the Russians feel that the compound nucleus created when Cr^{54} strikes a lead target is most likely to be formed in the ground state and is not likely to deexcite by emission of alphas or protons prior to the fission.

Next, by bombarding lead with Ar^{40}, the Dubna group studied fission activity they believed was caused by fermium isotopes formed with the emission of one, two, three and four neutrons. They found that the compound nucleus is most likely to emit two or three neutrons. Similar measurements were made on activities that, the Russians state, belong to element 104. Noting that a fission activity with a half life of 4 to 10 msec was formed when Cr^{54} struck Pb^{207} or Pb^{208} but not Pb^{206}, they extrapolated the above results to production of element 106 and concluded that isotope 259 was formed. The measured cross section was 1 nb for both Pb^{207} and Pb^{208} targets.

Of course, both experiments are subject to some criticism, the most basic centering around the Russian experiment. Because, in Grodzins's words, fission is "not a specific signature" of an element, the Dubna evidence is not direct but depends heavily on inferences. Grodzins feels the Dubna group has certainly found some new spontaneous fission activity but that further work is required to clarify its source.

Grodzins believes that the LBL–LLL