SPACE HAS A SPECTRUM

By R. S. Richardson

A science article on the non-emptiness of interstellar space. The void between the stars represents the most tenuous gas men have ever studied, but by weird instruments and high-power mathematics, its secrets are being determined.

"Is there anything between the stars?"

A century, or even fifty years ago, an astronomer could have answered that question with a single word. Without the slightest hesitation, he would solemnly have assured you that the space between the stars is filled with ether. Otherwise, except for an occasional meteor, it is empty.

The ether, however, by its remarkable properties easily made up for the lack of other interstellar material. More rigid than steel, more transparent than glass, it allowed the planets to pass through it without offering the slightest resistance. Perhaps its most unique feature was the impossibility of detecting its presence. You could never hope to see the ether, or smell it, or make it apparent by instrumental means. Nevertheless, scientists felt quite confident it was always there on the job, busily transmitting energy from one part of the universe to another.

The ether was long ago consigned to the scientific junk yard, along with coronium, the Thompson atom, and Helmholtz's contraction theory. Nobody seems to care any more how light manages to get from one star to another. We accept the fact that it does without feeling the necessity of assuming some means of conveyance. Indeed, the mere thought of an all-pervading luminiferous substance is highly offensive to many scientific minds. The relativitists, in particular, shudder at the mention of that awful five-letter word, the e...r!

Today, more and more, astronomers are turning their attention from the stars to the matter that lies between the stars. For it is becoming increasingly clear that interstellar space is not just something for light to travel across, but a strange laboratory where experiments can occur impossible to describe in ordinary terms. It is a region where the speed of reaction between matter and radiation has slowed down until time has virtually stopped. A region where atoms hibernate in states of infinite lifetime, and clocks tick off centuries for seconds.

Astronomers have really had much of this new knowledge in their possession for several decades, and in a sense were aware of the fact without being exactly conscious of it. Here is the picture of interstellar space as it looked from a few years back.

Certain lines were known in stellar spectra of types O to B3 whose queer behavior branded them as definitely alien in character. To the casual observer they looked as genuine as H Beta of hydrogen, or 4686 of He II, but to one trained in this work certain telltale marks definitely betrayed them as members of the fifth column.

Lines in spectra of early type are generally broad and diffuse, owing to the rapid velocity with which these stars rotate. Since half the light of a star comes from the side approaching us and the other half from the side receding, the spectrum lines will be broadened by Doppler effect. Unless, of course, its axis of rotation is pointed directly toward us. The particular lines in question, however, are sharp and clean cut in contrast to all the others. Another suspicious feature is that they are the powerful H and K lines of Ca II in the violet and the D lines of Na I in the yellow. Now when the atmosphere of a star is at a temperature of 25,000 degrees, there simply can't be enough of these atoms present to produce absorption. For when the temperature is that high, all the calcium and sodium would have been ionized up to Ca III and Na II. We are forcibly driven to the conclusion then that the lines have nothing to do with the star, but are caused by intervening clouds of sodium and calcium far outside of it, evidently in deep interstellar space.

This hypothesis was clinched by observations of such spectroscopic binaries as 9 Camelopardalis and 62 Chi-2 Orionis. As the members of the System revolve around their center of gravity, the spectrum lines periodically show a Doppler shift to the red and violet—*except for the sharp lines of Ca II and Na I.* They refuse to share in the oscillations of the helium and hydrogen lines, but remain relatively fixed in position. Because of their unco-operative attitude, they have come to be known in the literature as "stationary" or "detached" lines. At first they were thought to be peculiar to spectroscopic binaries alone, but later they were recognized in hundreds of high-temperature stars.

THE NEXT question was whether the absorption arose from one cloud fairly close to the star or from isolated clouds scattered throughout the entire galaxy.

There is some direct observational evidence to support the former idea. Long exposure photographs of the Pleaides, for example, show them meshed in a nebulous web. With the spectrohelioscope, the solar prominences can be seen stretching up into the chromosphere faster and faster, until they grow faint and vanish altogether. There is disagreement on the question of whether they disappear because they exceed the velocity of escape, or undergo a transformation that renders them invisible. But in any event, it is highly probable that the Sun is losing large amounts of calcium through radiation pressure and solar explosions. After ejection, they were assumed to become attached to the cloud so that they showed its motion instead of the star's. On this basis, the star throws out a sort of a smoke screen as it rushes through space.

A critical test was made by comparing the radial velocities of the stellar and detached lines, and by noting whether there was an increase of intensity with distance. The results were conclusive in favor of isolated clouds distributed throughout our system. Many stars showed differences in velocity amounting to 60 km per second, clear proof of no possible connection between star and cloud. And the relation between line intensity and distance turned out to be so good, it is now one of our handiest methods of getting distances of bright objects, such as galactic novae.

Stationary lines cannot be detected in stars later than B 3 because the temperature is low enough for true sodium and calcium lines to appear, which easily blot out the faint interstellar lines. They are still there, just strong enough to spoil radial velocity measurements.

THE characteristic that distinguishes scientists as a whole from the rest of mankind is their constant desire to upset the status quo. Unless it happens to be one of their own ideas, they are never content to get something firmly established and then leave it alone. And so after everyone was agreed about the interstellar sodium and calcium clouds, certain astronomers began to worry because interstellar lines of other elements had not been found. About three years ago they started an energetic attack on the problem, striking almost simultaneously on two different fronts. One party desired to detect new atoms in space by their absorption of the starlight passing through them. The other hoped to find evidence of light emitted from atoms in huge interstellar clouds covering hundreds of square degrees in the sky. In both cases success was due to "new weapons" far more effective than any ever employed before in this work.

The search for the absorption lines will be told first, as it proceeded along more familiar channels than the discovery of the emission lines, which brought out some of the weirdest-looking apparatus so far on record.

It seemed obvious that the search for such lines could be limited to rather abundant elements, and of these only their ultimate, rock-bottom lines were worth bothering about. Alone in the depths of space, an atom is in no position to pick and choose among the quanta passing by. Eddington has shown that the light from the whole galaxy received by us is roughly equal to the radiation from 2,000 stars at a distance of 10 parsecs. This would give a density of energy corresponding to an effective temperature of 3 K; that is, a black-bulb thermometer suspended in space and in equilibrium with its surroundings would register 3 K. As a result, interstellar atoms are all down in their very lowest energy level, owing to lack of excitation. It may seem strange that calcium is found in the ionized state, but this is purely a photochemical and not a temperature effect. If an electron is lost, there is little hope of picking up another one again. As a matter of fact, almost all the interstellar calcium and sodium are in the Ca III and Na II state. It is only because their ultimate lines are so easily excited that we are aware of the minute amounts of Ca II and Na I present.

ANOTHER condition to be met is that the ultimate lines of the space elements must be between wave lengths 2,900 and 12,000 angstroms. The spectrum on the violet side is limited by the atmospheric ozone bands, and until our observatory on the Moon is functioning there is nothing anyone can do about it. At the other end, the dye zenocyanine has pushed the photographically observable infrared region out to about 12,000, and the search for new sensitizers goes on continually. But right now 2,900 and 12,000 mark the limits within which we are compelled to work.

These restrictions cut down the possibilities tremendously. Common elements like hydrogen, helium, silicon, carbon, and oxygen with their strongest lines in the ultraviolet are eliminated right at the start. In fact, very few elements are able to meet all the requirements. Out of the more than 100,000 spectrum lines now known, only the following seemed likely to appear: 7,665 and 7,669 of K I, 4,227 of Ca I, 4,078 of Sr II, 3,643 of Se II, 3,720 of Fe I, 3,994 of Al I, and several lines of Ti II near 3,300.

With the 200-inch mirror still in the optical shop, to find even these most favorable cases meant that our present instruments must be pushed to the limit, called upon to "play over their heads," as it were. Advantage would have to be taken of every detail in method and design that might be of the slightest aid.

The program was limited to five hand-picked stars already known to have exceptionally strong interstellar calcium and sodium lines. Included was one O-type and four supergiant B's, all distant objects, but so intensely luminous that all were brighter than apparent magnitude six.

The plates were taken at the coudé focus of the 100-inch reflector. The spectrograph consisted of a Schmidt camera of 32 inches focal length. By mounting it off-axis it was possible to have the plate holder outside of the incident beam so as not to obstruct the light. Absorption in the ultraviolet by the correcting lens was largely avoided by making it out of a thin piece of Vitaglass which gives good transmission down to 3,100. With a mirror for a collimator, the spectrograph was rendered nearly achromatic, and any region could be easily photographed by merely rotating the grating.

The observers were fortunate in securing a large plane grating of unusual brightness ruled on an aluminized Pyrex disk by R. W. Wood. This is the same Wood who got the navy to train seals during World War I for the purpose of tracking down submarines. The rulings were shaped so that light was concentrated in the first order red and the second order violet. This powerful combination of camera and grating, together with some fine grain contrasty emulsions, resulted in stellar spectra that are probably among the best ever obtained at this dispersion—about 10 angstroms per mm.

After suitable plates had been secured, the next step was to take them down to the office, where they could be examined under the measuring machine. Here again advantage was taken of every device that might aid in ferreting out the lines. One of the biggest obstacles encountered in work of this type is trying to decide whether a faint streak is a real spectrum line or just some silver grains that happen to lie in a row. This was mostly overcome by inserting a weak cylindrical lens above the microscope objective. Its action was such that defects and irregularities in plate grain showed as lines that crossed less than half the width of the spectrum, while genuine lines extended over the entire spectrum. Another test was to superpose two plates face to face and then slide them along each other. True lines stood out for a moment as the plates slid past the point where they coincided in wave length.

Our of the lines listed as good possibilities, the following were found: six lines of Ti II, the two lines of K I, and the line of Ca I in the blue.

Of these, the six lines of Ti II were by far the biggest prize. For a close study of the transitions involved led to a development no one could possibly have foreseen. It was evident that in addition to the six lines in the ultraviolet, the Ti II atom must also be emitting two lines in the far infrared impossible to produce in the laboratory—lines labeled *forbidden* in letters five feet high.

It was expected, of course, that the six lines would all arise from the ground state. But the ground state really consists of four sublevels very close together. And the six lines originate from the *lowest* sublevel of the *lowest* level in the atom. Not a trace could be found of lines from the next highest sublevel only 0.012 volts above the ground state.

Normally, there are 28 transitions allowed between the four sublevels and the strong triad, zDFG. But the fact that all but the lowest, or aF 3/2, level are inactive means that 15 of the 28 possible transitions are ruled out. The remaining 13 are shown in the diagram.

This greatly limits the changes the atom can make among the various energy states. For consider the variety of jumps it is free to make in a hot gas when all 28 are available. Suppose it has just made the transition from the aF 3/2 level to zD 5/2, and then dropped back to aF 5/2. Assume the atom desires to return to the ground state from where it came, just 0.012 volts away. But it cannot make this little leap directly, for the lifetime of aF 5/2 is 7 hours; that is, on the average 7 hours would have to pass before the atom would make this transition spontaneously. Now 7 hours is like an eternity in the life of an atom when something is happening to it every millionth of a second. No sooner does it reach one energy level than a collision with an atom or electron knocks it into another one. Or it is lifted to a higher state by absorbing a quantum from the stream of energy sweeping past. Thus the atom might get back to the ground level by jumping from aF 5/2 to zF 7/2, dropping down to aF 7/2, then going to zG 5/2, and from there finally making the transition back home to aF 3/2 by emitting the line 3,3883.

In general, an atom in the atmosphere of a star will spend most of its time giving and receiving energy, seldom remaining undisturbed for more than the tiniest fraction of a second.

In interstellar space, however, exactly the opposite conditions prevail. Consider again the situation confronting an atom that has made the transition of aF 3/2 to zD 3/2 to aF 5/2. The prospect of returning to aF 3/2 by leaping from one level to another as before is now practically nil, for the necessary energy is nowhere forthcoming. The atom is in somewhat the same predicament as a motorist who has run out of gasoline on a lonely road in the middle of the night. The density of space is too low to make a collision likely for months or possibly years. Stellar radiation is so dilute that rescue by absorbing a quantum may be a matter of centuries. A million years might pass before a cosmic ray scores a direct hit. In fact, there is but one passage to the ground state still open—the little "forbidden" transition with a lifetime of 7 hours. Now this seems like an instant, as if time had been slowed down enormously. The impossibly difficult road in the atmosphere of a star becomes by far the quickest and easiest rout in interstellar space.

The quantum jumps between sublevels of the same term indicated by arrows in the diagram from aF 5/2 —aF 3/2 and from aF 7/2—aF5/2 produce emission lines at wave lengths 76,000 and 106,000 angstroms, almost out in the short-wave wireless region.

THE EXPERIENCE gained from the Ti II lines has been of the greatest value, for it has at least served as a sort of guide in unraveling some new data that at the present writing have astrophysicists pretty well stopped.

In the beginning, they felt that putting their finger on the right interstellar lines to look for should be a fairly simple matter, since they would be ultimate lines of abundant elements and therefore as familiar as the members of their own family. But, as frequently happens, the way it turned out was not according to form at all. It is true that some of the predicted lines were found. But in addition, a whole batch of new ones turned up that nobody had ever heard of before.

There is nothing that arouses the bloodhound in an astrophysicist like a strange spectrum line produced under extreme conditions. They got out their catalogue of wave lengths and their tables of multiplets. Anything that looked hopeful was given thorough consideration. They even calculated frequencies from known energy relations within the atom. After a while some of them began to wonder. They were faced with the fact that apparently no one in the history of spectroscopy had ever observed these lines either in absorption or emission.

Then several people seemed to get the same idea at once. They argued, perhaps these aren't atomic lines at all. Perhaps they come from the next step up in the organization of matter—the diatomic molecule.

This would seem like grasping at straws if it were not for the knowledge already gained from Ti II. Molecular spectra, it will be recalled, are characterized by long series of bands often composed of hundreds of fine lines closely packed together. Their complexity arises from the wide variety of energy changes this dumbbell-shaped oscillator can make. In addition to undergoing changes in electron configuration similar to the atom, there are dozens of ways the two atoms can vibrate, and hundreds of speeds with which they can rotate. These changes all going on at once produce the long columns of lines thousands of angstroms in length. The different bands overlap, and their lines intermingle and get generally tangled up together. Analyzing band spectra is one of the most formidable jobs in spectroscopy. Those who make their living that way form a little closed group with a language unintelligible to their associates, who generally regard them with much the same awe that one feels toward a time bomb disposal squad.

IN INTERSTELLAR space a molecule would be expected to behave in a manner corresponding precisely to the atom. That is, it would be in the lowest rotational level of the zero vibrational level of its ground electronic state. Instead of being able to absorb hundreds or even thousands of lines it is now reduced to two or three at the most.

The diatomic molecules most likely to occur are such ubiquitous compounds as OH, CH, NH, NaH, CO, and CN. Many hydrides would be expected since as we shall see later hydrogen is almost certainly the most abundant element of space.

A comparison of the lowest lines of these compounds with the interstellar lines has resulted in several tentative identification. CH looks especially good.

The evidence for the others is more uncertain. One line of CN and one of NaH agree well with interstellar lines, but there is always the danger of accidental coincidence when the identification rests with a single line. The case for NaH is strengthened a little by the fact that the two stars which show the suspected NaH line also have exceptionally strong detached sodium lines.

But the most baffling lines of all are six that appear in the yellow just on the limit of visibility. In contrast to other interstellar lines, these are rather diffiuse instead of sharp and narrow. Astronomers at first were doubtful how to classify them, but evidence of their interstellar origin is now conclusive. They definitely do not participate in the periodic shift of lines in the spectroscopic binary Boss 6,142, and they show a decided increase in intensity with distance.

So far not a single genuine clue to the origin of these lines exists. Their unusual width indicates they may be fragments of band spectra. Two of the lines are near calculated positions of carbon-dioxide bands. But a spectogram of Chi 2 Orionis which covers the Venus bands shows no absorption there, and the Venus bands should certainly be much stronger than any hypothetical bands of carbon dioxide in the yellow.

Attention has also been called to a fairly good agreement in position with a low-level line of molecular sodium, and the compound NaK. But so little is known of the structure of these bands that the question is still wide open.

A possibility that should not be overlooked is the absorption of light by solids. At room temperatures, solids ordinarily do not show narrow absorption lines, but near absolute zero many substances have sharp absorption lines that may be thought of as displaced atomic lines. Thus at 3 K clouds of dust particles or crystals in space might conceivable act as narrow absorbers.

This is the type of thing in which a person in a. related field can sometimes make a contribution. Suggestions?

SPEAKING of a temperature of interstellar space of 3 K can be very dangerous unless everyone knows what kind of a "temperature" we mean. Temperature is so closely tied up in our minds with hot and cold that we are unable to view it in the same aloof way we do other thermodynamic functions, such as entropy. But in between the stars, temperature becomes little more than abstraction, a parameter in a formula to be juggled around until it fits the facts.

How easily the "temperature of interstellar space" can be twisted around to suit our purposes is shown by a recent report on the sodium clouds. The investigation was made in the hope of finding out something about their size and velocity from the width of the stationary D lines.

After testing and rejecting several hypotheses a combination was found at last that accounted for the observed width of the lines without doing too much damage to current astronomical belief. Briefly, the widths could be explained on the basis of sodium clouds with linear dimensions of the order of 700 parsecs, which shared in the rotation of the galaxy and also had velocities up to 20 km per second. The density was set at three billionths of an atom per cubic centimeter. And the temperature came out somewhat higher than the value of 3 K previously quoted—just 43,997 degrees higher to be exact. The difference, of course, depends upon whether you are referring to the temperature of the energy density of radiation or the velocities of the atoms themselves.

OUT of an investigation that started as a survey of a few faint nebulous patches with a small Schmidt camera, has come the discovery that in addition to the dark clouds of space there are hundreds of square degrees of sky covered with very faintly luminous interstellar clouds. But so feeble is the light they emit that when attempts were made to photograph their spectrum in the usual way the lines were blotted out by the general illumination of the night sky. Not until a new type of nebular spectrograph of unheard-of dimensions was developed was the amazing extent of these clouds revealed. By their study, elements in space have been found which were impossible to catch by the stationary-line method.

The clouds were discerned originally on direct photographs taken with an emulsion having a narrow band of high sensitivity at the red H Alpha line of hydrogen. It was previously known that these nebulosities emitted this line, and by using a special plate combined with a suitable filter, practically all the scattered skylight was eliminated, leaving only the light of H Alpha. In this way background fog was prevented, but the nebular emission was transmitted freely, and contrast between nebula and sky thus greatly enhanced. The photographs showed strong nebulosity among the stars that was almost completely absent on exposures made in light of other colors.

More desirable than direct photographs, however, was a method of obtaining the spectra of the nebulosities. The instruments already on hand failed completely in this respect. What was needed most of all for this type of spectroscopy was speed. A very fast slit spectrograph was indicated with a short camera and strong dispersing units.

The instrument finally evolved to fill this need, which is now in use by the Macdonald Observatory, is a 150-foot nebular spectrograph built out in the open on a side of Mount Locke, Texas. It must cause the natives some tall speculation, for even an astronomer would be puzzled at his first glimpse.

The spectograph is unique in that the slit is exposed directly to the sky; there is no large lens or mirror in the instrument. This method can be used to advantage when the object under observation covers an appreciable area in the sky, such as a nebula. And there is no collimating lens because the slit is so far from the prisms that the light is close enough to parallelism when it strikes the first prism face.

Reduced to bare essentials to avoid confusion of detail, the spectrograph consists of two piers set 75 feet apart on the side of a hill. The upper pier carries a stationary flat mirror 24 inches in diameter. Behind it is a large wooden shield to cut off surrounding skylight. This mirror faces down the hill in the direction of the south pole. Halfway between the two piers is another large shield with a square hole in the center that acts as a diaphragm.

On the lower pier is a polar axis to which is attached in very compact form the vital optical parts of the spectrograph. The first part to receive light from the sky is the "slit," which consists of a long plane mirror over which can be drawn two adjustable curtains. By moving the curtains back and forth, a long, rectangular section of the mirror can be secured varying in width from zero to ten inches. Light from this mirror or slit is reflected up the hill to the second fixed mirror, and from there back down to the other end of the pier. Here it is received by two quartz prisms which bend the light or spectrum into a Schmidt camera of 94 mm. aperture. Also attached to the pier are guide telescopes, gears for orienting the mirror, a driving mechanism, et cetera.

WITH this odd-looking but powerful hillside spectrograph, 35 regions in the Milky Way have been explored. Perhaps the chief result, among others, is to emphasize the enormous abundance of hydrogen scattered throughout space. In the large star clouds of the Cygnus and Sepheus regions, faint hydrogen emission is found over hundreds of square degrees. Apparently the gas is excited by the ultraviolet rad6ia- tion from the many hot stars in these densely populated areas. This is absorbed by the Lyman series of hydrogen raising the atoms to a higher energy state. In returning to the ground level, some of the atoms will not drop back directly, but by an intermediate transition will emit the red H Alpha line of the Balmer series. Other lines found besides those of hydrogen are the forbidden line of O II at 3,727 and in rare eases lines of O III as well.

The inhabitants of space now make up a fairly good-sized group, with others undoubtedly to be added in the future. Here is the census according to the latest count, which is admittedly of a highly uncertain nature.

This is the population per cubic meter:

Hydrogen atoms	8,000,000
Electrons	7,000,000
Na	103
K	5
Ca	3
Ti	One atom per 50 cubic meters

THE END