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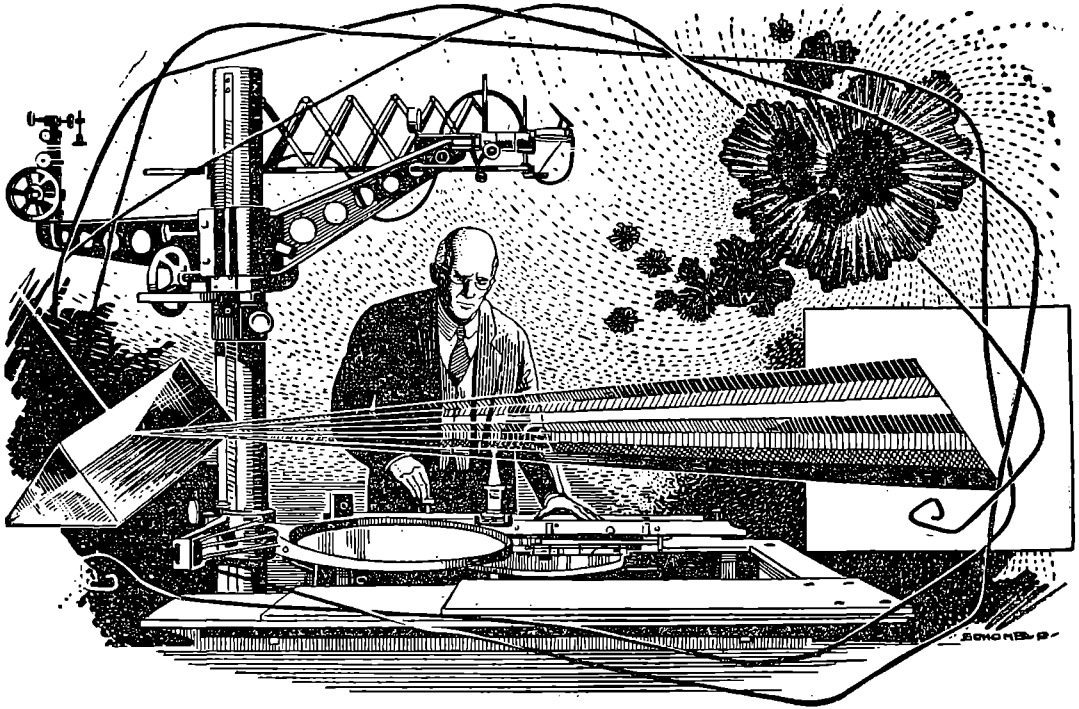


Illustration by ALEX SCHOMBURG

LOST: One Magnetic Field

By R. S. RICHARDSON

LOST: one magnetic field. In weak condition when last seen, but still alive. Finder please return to Old Sol. Liberal reward.

SOME such-news item might be taken as typifying the general attitude of astronomers today toward a problem that has kept them guessing for nearly half a century. Does the sun have a magnetic field such as was apparently found in 1913 and 1923? If so, where has it

been hiding for the last twenty-five years? Will the field return when the new sunspot cycle starts soon? Or was the field, thought to have been detected earlier, merely an illusion due to errors in the observations?

Nobody really knows the answers to these questions.

One of the least understood subjects in science today is cosmic magnetism. (Probably every scientist would make

An Informal Discussion of Sunspots and Such!

this assertion about *his* particular subject.) This is rather unusual, for cosmic magnetism got off to an exceptionally good start way back in 1600 with the publication of Sir William Gilbert's *De Magnete*, a book that has been described as the first modern scientific treatise. After long thought and experiment, Gilbert came to the conclusion that the earth behaves as if it were a big spherical magnet. This statement is as true today as when Gilbert wrote it, but we still do not know for sure *why* the earth behaves as if it were a magnet or what keeps it in that condition.

Nowhere is new knowledge so eagerly sought as in cosmic magnetism. You can bet that those first men who go to the moon are going to take a magnetometer along with them. We aren't half so interested in those minerals they are always gathering in the magazines as we are in the moon's magnetic field. It is quite possible that we might secure this information from a robot rocket, without waiting for the development of a manned rocket.

In case anyone suspects that this is going to be another article like my *Aphrodite Project*, let me hasten to add that this proposal comes from Professor S. Chapman of Queen's College, Oxford, who for years has been one of the leading authorities on terrestrial magnetism. Chapman remarks that minute variations in the strength of the earth's field can now be measured and signalled back to ground stations, and it would seem to be feasible to try the same method on the moon. It would not be necessary to do any fancy guiding on the rocket—but only to get it within about a thousand miles of the moon's surface—to obtain very valuable information. Incidentally, that first moon rocket is going to have so many gadgets attached to it that it will resemble a Christmas tree.

that every sunspot is the center of a magnetic field. The strength of this field ranges from about 4000 gauss in the biggest and blackest spots down to about 200 gauss in the little one-day spots. Such fields are small compared with the fields of several hundred thousand gauss that can be produced between the pole pieces of an electromagnet, but it must be remembered that in a sunspot the field exists over millions of square miles instead of a few square inches as in the laboratory.

After the presence of a magnetic field in sunspots was firmly established, Hale began to wonder if the sun itself might have a magnetic field similar to that of the earth. He knew that such a field, if it existed, would be so weak as to be barely on the limit of detection, with the methods then available.

It may seem incredible that we can hope to detect magnetic effects on the sun ninety-three million miles away. Most people live all their lives without even knowing that the earth is magnetized. The usual way of detecting a magnetic body—by its attraction for iron—can hardly be applied to the sun. But we have another method at our disposal that is even better for luminous bodies; indeed, it is so sensitive that it can be applied, not only to the sun, but to the stars as well, as we shall see later. This method makes use of what is called the Zeeman effect (after Pieter Zeeman, the Dutchman who discovered it in 1896).

Zeeman found that atoms in the presence of a magnetic field radiate in a slightly different way than when the field is absent. It is somewhat as if the atoms became self-conscious in the presence of the field and put some extra quivers into their performance—like a man shivering with stagefright while trying to make a speech. The magnetic field causes the spectrum lines emitted by the atoms to be split into two or more parts, depending upon a variety of circumstances. As a general rule, the stronger the field, the wider the lines are split apart.

BUT to get back to the sun . . .
The first major discovery Hale made at the Mount Wilson Observatory was

In a weak field the splitting may be so slight that the lines appear only slightly widened. This is usually the case in sun-spots. In large spots the widening of the lines can be seen easily by inspection. In small spots it can barely be detected by the eye. Hale knew that the strength of the sun's field was probably only a tenth as strong as the field in the smallest spot. But the problem was so fascinating he decided to try for it, regardless.

No one was particularly disappointed, therefore, when measures on the first plates taken at the 60-foot tower telescope on Mount Wilson gave negative results. This tower was not adapted to work of this kind, and it was decided to postpone the investigation until the 150-foot sun tower was ready. This was completed in 1912 and provided a powerful research tool immediately. The lens at the top of the tower forms an image seventeen inches in diameter in the solar laboratory at the bottom. The visible spectrum of the sun in the region where the photographs would be taken forms a colored band sixty feet long. In small spectroscopes the two familiar lines of sodium vapor in the yellow are so close together that they often appear as one. But in the spectroscope at the 150-foot tower there are *eleven* other lines that can be seen between the sodium lines.

THE task of measuring the small displacements on the plates, due to the Zeeman effect, was turned over to a woman on the computing staff who had had considerable experience in this deadly-dull type of work. It is my considered opinion that measuring spectrograms is one of the most tedious jobs ever invented by man. It is certainly hard (for me at least) to measure for several hours and remain mentally alert so that my settings are not made mechanically. Also, when making measures that you know in advance should give a certain result, it is a constant struggle to keep your measures free from personal bias. Either you will unconsciously

strive to get the desired result; or else, in your anxiety, you will bend over backwards and come up with some entirely different answer.

In this case, every precaution was taken to prevent bias on the part of the observer, by marking the plates in such a way that it was impossible to tell what result should be obtained. Nevertheless, the measures indicated the presence of a weak magnetic field of about the type anticipated.

Measures made on the plates by other members of the staff, however, gave results that differed so widely among themselves that it was hard to know what to believe. It seemed desirable to find some method of measurement that would give more consistent results, regardless of whether they showed the presence of a solar field or not. A device that looked hopeful was a machine with which the displacements were measured by tipping a thin parallel plate of glass, rather than by turning a micrometer screw and making settings with a crosshair. But when the tipping plate micrometer was tried by two members of the staff the results were also negative.

Such was the state of affairs when Dr. Adrian van Maanen, a parallax expert, joined the staff. Since he was experienced in making fine measurements, he was asked to try his hand on the plates taken for general magnetic field. His first measures with the new machine gave negative results like the others. But, with more practice, his measures became more consistent, and gradually began to reveal displacements indicating a magnetic field. By 1913 he had obtained results of such a definite character that the evidence for a field seemed quite strong. Additional measures made in 1918 yielded essentially the same result as before.

This led Hale to announce, in February, 1918, that the results "seem to place beyond reasonable doubt the conclusion that the sun behaves approximately as a uniformly-magnetized

sphere, with the magnetic axis only slightly inclined to the solar axis of rotation and a polarity corresponding to that of the earth." The vertical intensity of the field at the poles was about 25 gauss.

Although this sounds as if the problem were all settled, Hale never seemed entirely satisfied about it in his own mind. The problem continued to occupy him practically up to the time of his death in 1938. It is interesting to examine his remarks, from time to time in the *Annual Report* of the Director. At one time he will refer to the problem of the sun's magnetic field as if the results were conclusive. Then a few years later there will be a note that he has asked some member of the staff to try measuring the plates by a new method.

HALE'S confidence in the reality of the early measures seems to have been badly shaken about 1932, by some results obtained by J. Evershed, a well-known English astronomer who specialized in solar work. In 1909 Evershed had discovered, from small shifts in the position of lines in the penumbra of a sunspot, that gases are flowing outward from the center of the spot—a phenomenon properly known as the "Evershed effect." (One of the best ways to secure enduring fame in science is to discover an effect of some sort). Hale had given Evershed several of the original plates taken in 1913 to measure. Evershed had found small displacements on nine of the plates, but he did not believe they could be due to a magnetic field. He attributed them to Doppler shifts arising from the motion of gas in the solar atmosphere.

Hale now decided to reopen the whole investigation. This time he had measures made on plates taken at the 150-foot tower during the minimum of sunspot activity of 1922-23. Plates for general magnetic field have usually been taken at sunspot minimum, when the surface is not disturbed by the magnetic fields due to spots. These measures were

made by R. M. Langer, a physicist working in Hale's private solar laboratory in Pasadena. Langer used a tipping-plate micrometer as before, but with an automatic device attached to it for registering the settings automatically. He found it necessary to average a large number of measures to smooth out accidental errors, but still the result was about the same: the sun apparently had a magnetic field in 1922-23 of the same sign and intensity as that found in 1913.

Hale also made some measures on plates, taken at the minimum of 1933, which gave negative results. Evidently the measures were not very extensive, as they were never formally written up and published, but only mentioned briefly in the *Annual Report*. But the results—such as they were—led Hale to suggest that possibly the magnetic field of the sun might be variable.

Beginning about 1940 there was a revival of interest in the problem, both in this country and abroad. Previously, observers had concentrated their efforts upon trying to perfect the methods of measurement. Now they began to concentrate upon new methods of observation. It is impossible to describe all the ingenious schemes which various observers have invented for making the Zeeman effect more conspicuous. Some involve electronic devices by which a weak field can be rendered immediately apparent, when it would have taken hours of measuring by the old method. These devices are so sensitive that a field of 1 or 2 gauss can be measured readily. All observers agree that, if the sun has had a field within the last five years or so, it is too small to be detected with certainty.

THE latest report on this subject was made in December, 1952, by Horace W. Babcock and Harold D. Babcock, working at the Hale Laboratory with an electronic method devised by them. They state that the principal impression derived from a study of their records is that the magnetic pattern of

the sun is remarkably complex. Even when visible spots are few and small, or absent altogether, a rather striking amount of detailed magnetic activity is often revealed. Persistent fields not associated with visible spots may sometimes be identified with regions marked by calcium clouds. Fields of this type have been followed day by day for a week, sharing in the general rotation of the sun, and varying in strength. Abrupt reversals in polarity similar to those occurring in spot groups may appear in these fields.

The Babcocks emphasize that their results are only preliminary, and they caution against attempting to interpret the smaller deflections that rise only a little above the noise level. The magnetic characteristics of the sun are evidently so complex that some of the questions about them cannot be answered until magnetic mapping has been carried for a considerable length of time, probably for one or two sunspot cycles.

By means of the Zeeman effect magnetic fields have been detected in stars far more powerful than those in the sun. The broadening of the lines in the spectrum of a star is complicated by the fact that the lines are also broadened, due to rotation. The strongest magnetic fields have been found in white stars that are rotating the fastest. Whereas a yellow star like the sun rotates at only about a mile a second at its equator, some white stars spin at the rate of a 100 miles a second. Thus, one edge of the star may be receding from us at 100 miles a second, and the opposite edge approaching at 100 miles a second, with the result that the lines in its spectrum are greatly widened or "washed out" due to the Doppler effect. This will not be true for a white star—no matter how fast it is rotating—if its axis happens to be pointed toward us, for then there is no motion either toward or away from the earth.

Observations on white stars with sharp spectrum lines have revealed magnetic fields stronger than those in the

largest sunspots—up to 9000 gauss in the sixth magnitude star, known by its catalogue number of HD 133029. More remarkable still is the fact that in many of these stars the magnetic field varies rapidly. Thus another sixth magnitude star, HD 125248, shows at one time a magnetic field with a positive extreme of 7600 gauss. The field decreases to zero in three days, reaches the negative extreme of 7600 gauss 1.5 days later, then begins to reverse until it reaches the positive extreme again, going through the whole cycle in only nine days.

If a rapidly-rotating white star has a powerful magnetic field that varies in a period of a few days, it is conceivable that a sluggishly-rotating yellow star like the sun might have a weak field that varies in a period of years. If the magnetic field of the sun is variable, we should expect it to be related in some way to the 11-year sunspot cycle. But on the basis of our present observations, it is hard to see what the connection is. Thus the sun seemed to have a magnetic field at the minima of 1913 and 1923, but none at the minima of 1933 and 1944, and none today. It is possible that the field escaped detection at the last two minima owing to lack of observations. But if one appears in 1954 or 1955 it will have no chance of escaping, with the high-powered methods now available.

IT WOULD be nice to endow the sun with even a weak magnetic field, if for no other reason than that the cosmic-ray people badly need one in their business. Readers will remember the bitter dispute that once raged as to whether cosmic rays are high-frequency photons or very energetic charged particles. The question was settled by determining whether the rays are deflected by the earth's magnetic field or not. If the rays consist of photons, then they should be unaffected by our magnetic field. But if they are charged particles, they should be deflected away from the equator but should penetrate more easily at the

poles so that there should be an increase in the intensity of cosmic radiation with latitude. Here we refer, of course, to the *magnetic poles* of the earth, and not the *geographical poles* of rotation.

The measures showed that the intensity of cosmic radiation did increase with latitude, in about the way expected if they are charged particles *up to latitude* 50°. From there on the intensity remained practically constant.

This so-called "shoulder" in the curve was ultimately explained by the deflecting action of the sun's magnetic field. Calculations made by Lemaitre and others showed that a solar magnetic field of 25 gauss such as Hale had found would be sufficient to deflect particles below a certain energy away from the earth's orbit. (It was Lemaitre who originated the "big bang" hypothesis of the origin of the universe). Hence, all particles that are capable of reaching the

earth have already done so at latitude 50°, so that it is impossible for the number to increase any more.

This prediction from theory agreed so well with the astronomical observations that they came to be regarded as one of the strongest arguments in favor of a magnetic field for the sun. The cosmic-ray people went blithely ahead, oblivious of the fact that nobody had been able to find a solar magnetic field of 25 gauss since 1923. Only recently have they begun to awaken to the fact that this field, which fitted in so nicely with their results, apparently evaporated long ago. I have discussed this anomaly with some of them recently, and find that they still don't seem particularly disturbed about it. They tell me in conversation that they could struggle along with only a gauss or two—an amount which the astronomers probably would be willing to grant them.

