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I

AMONG the great secrets which the efforts of the International Geophysical Year (IGY) are geared to solve or to clarify is the great mystery of solar spots. Sunspots had been noticed when Christianity was still in its infancy. The Chinese had seen spots on the sun like eggs when they viewed the sun through fog.[1] By modern standards, however, the Jesuit, Father Christopher Scheiner deserves the credit for their discovery.[2] He was the first to publish the results of his observations of the sunspots with a telescope. It is of course not impossible that Fabricius and Galileo had seen them through a telescope before him.

Sunspots were a puzzle then, and though less so, still a puzzle now. They have resisted great attempts to solve their riddle completely. Philosophers who had never looked through a telescope said that sunspots argued an imperfection on the sun or that the spots must be the passage of unknown planets across the face of the sun. Initially, Father Scheiner's superiors would not let him publish his results under his own

[1] Clyde Fisher & Marian Lockwood *Astronomy* (New York 1940) p. 49.

[2] H. M. Brock "Christopher Scheiner, German Astronomer" *The Catholic Encyclopedia* XIII:526.

name lest he be exposed to ridicule.[3] After all (people argued) was not a sphere the perfect shape? And was not the sun a sphere? How therefore could it be imperfect enough to have spots? Sir William Herschel, a great astronomer almost two hundred years later, thought that sunspots were holes in the clouds around a solid sun and that very possibly sun dwellers lived below.[4]

II

One of the most assiduous observers, the Jesuit, Father Angelo Secchi, watched and recorded the most minute details of sunspots. Much that he observed was true discovery and much had been recorded before, but no one else had personally observed so many details of the sun as Father Secchi has recorded. He knew that sunspots were relatively cool regions on the sun and that they were deep, some of them almost as deep as the diameter of the earth. He watched bridges of the "penumbra," lighter than the dark center of the spot, cut across the dark center, the "umbra." He watched spots grow from little "pores," or black dots, right out of the solar "granulation" (see Plate 1), a term Father Secchi first used and which is still used for the mottled appearance of the surface of the sun. He observed that as spots approached from the edge or "limb" of the sun, the near and far walls of the sunspot, the penumbra, were foreshortened and showed that the spot was deep (see Plate 2). He saw the dent put in the disk of the sun when a sunspot passed around the edge (see Plate 3).

Much that was rediscovered later he first noticed, such as the occasional rosy tint on the inside of the spots.[5] With others, he saw the evidence of turbulence right in the blackest part of the umbra. He was one of the first to apply photo-

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[3] *Loc. cit.*

[4] Agnes M. Clerke *A Popular History of Astronomy During the Nineteenth Century* (London 1893) p. 69.

[5] "Secchi's visual drawings, although carried out with relatively crude instrumentation, still stand today as a masterpiece of visual observation. Many features of chromospheric structure which are clearly described by Secchi are currently being rediscovered more than a half century later." Leo Goldberg "Introduction" *The Sun* edited by G. P. Kuiper (Chicago 1953) p. 5.

graphy to astronomy.[6] He noted that the spectrum of sunspots was different from that of the surrounding sun.[7] After Carrington, but independently,[8] he recorded what has since been called Spoerer's law. This is the tendency of spot group latitude on the sun to move from high latitudes towards the equator as the solar cycle of ten or eleven years' duration proceeds towards a maximum.

The fact that sunspot numbers ran through a maximum and a minimum approximately every eleven years had been discovered a few years before Father Secchi began to study the sun. About every eleven years the sun has a great number of spots as in Plate 7 (a maximum). Approximately in between times the sun has very few spots (a minimum).

But there were other things left to discover after the eventful times of the mid-nineteenth century. The American, Hale, found that sunspots were strongly magnetic and that they generally occurred in bipolar groups: a "leading" group and a "following" group of opposite magnetic polarity. All magnets are bipolar, for they have a north-seeking and a south-seeking tendency located at two different places called poles. Strange to say, in one eleven-year period all the "leading" groups of spots (i.e., the most westward on the sun, which revolves from east to west) are of north magnetic polarity in the northern hemisphere of the sun, and of south polarity in the southern hemisphere of the sun. All the "following" spots are of south polarity in the northern hemisphere of the sun and of north polarity in the southern hemisphere of the sun. This condition of affairs lasts for one eleven-year cycle through minimum and maximum; but at the next cycle all the polarities of "leading" and "following" spots are exactly reversed. The magnetism of sunspots is about as great in intensity as the field between the poles of a strong horseshoe magnet, but a sunspot embraces at times an area of a thousand million square miles (see Plate 4).

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[6] Georgio Abetti *The History of Astronomy* translated by B. Abetti (New York 1952) p. 189.

[7] *Ibid.* p. 198.

[8] K.O. Kiepenheuer "Solar Activity" *The Sun* ed. Kuiper p. 335.

Evershed discovered a radial outflow of gases in the low levels of a sunspot. St. John found a radial inflow in the upper layers.[9] Abetti found a circular gas flow, corresponding to cyclonic storms on the earth but not corresponding to the magnetic polarity of the spots.

III

Why, after hundreds of years of watching sunspots, does the scientific world have this special interest now? The plan of the International Geophysical Year is to study solar terrestrial relationships. Much of this work requires cooperative effort on the part of many observers throughout many parts of the world. All of the extraordinary effects of the sun on the earth are connected with sunspot activity. Sunspots are behind the varying phenomena of the sun. The year 1957 through 1958 was chosen because it coincides with the maximum of sunspot activity.[10]

Variations of the magnetic activity of the earth, ionization of the upper atmosphere of the earth, frequency of auroral displays, increase of radio noise, and probably also anomalies of the weather are all intimately related to the number and activity of sunspots. When an unusual number or formation of sunspots appears on the sun (see Plate 7), a worldwide alert will be called during the IGY because charged particles, extra ultra-violet light, radio waves and perhaps even cosmic rays will be shooting out from the sun at an enormously increased rate. The world physicists are told to watch for unusual effects.

Sunspots are the general locality for relatively stable, bright portions of the solar surface seen in white light and more extensively in calcium light. These bright regions are known as "plages." "Prominences," except those which occur near the poles of the sun, rise out from the edge of the sun, usually in the vicinity of sunspots. The shape of many prom-

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[9] C. E. St. John *Astrophysical Journal* 37 (1913) 322.

[10] On the IGY in general and the Philippine participation in particular see Father James J. Hennessey's article "The Planet Earth" in PHILIPPINE STUDIES IV (1956) 535-551.

inences follow magnetic lines of force between the sunspots. In the opposite pillars of an eruptive arch prominence (see Fig. A), gases spin in opposite directions as an ionized gas would spin if forced through the magnetic field of a great horseshoe magnet embedded in the surface of the sun. The sunspot provides the magnetism.

"Flares" which are sudden brightenings of the sun seen in hydrogen light and which occur a thousand or more kilometers above the surface of the sun, take place only in the region of sunspots. Frequently they coincide with the bright patches, the "plage" regions, which can be seen in white light around sunspots close to the edge of the sun (see Plate 5). Radio waves of high intensity originate directly above sunspots, in the solar "corona." The "corona" is the white halo of very hot gases which surrounds the sun up to great distances and which can be seen when the sun is totally eclipsed by the moon. The very corona itself is most intense above sunspot regions. The inner whirl of a sunspot may be the dynamo which moves the highly ionized gases of the corona along the magnetic lines of force and generates the million-degree heat of the corona.

Radio waves which have their origin in the corona show the influence of sunspots. These waves are circularly polarized, clockwise or counterclockwise, depending on whether a north magnetic or a south magnetic sunspot is beneath its place of origin. Ionized particles shoot out from the sunspot regions. They come to the earth a day or so after a sunspot group has passed across the central meridian of the sun. These rays seem to extend in a radially directed cone out from the sunspot region. When great explosive-like flares occur over a sunspot which is directly opposite the earth, above the surface of the sun, there are invariably magnetic and radio storms on the earth.[11]

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[11] The effects of one such explosion in the sun as observed at the Manila Observatory in Baguio have been described by Father James J. Hennessey S.J., in "The Dellinger Effect of February Twenty-third 1956" PHILIPPINE STUDIES IV (1956) 299-318.

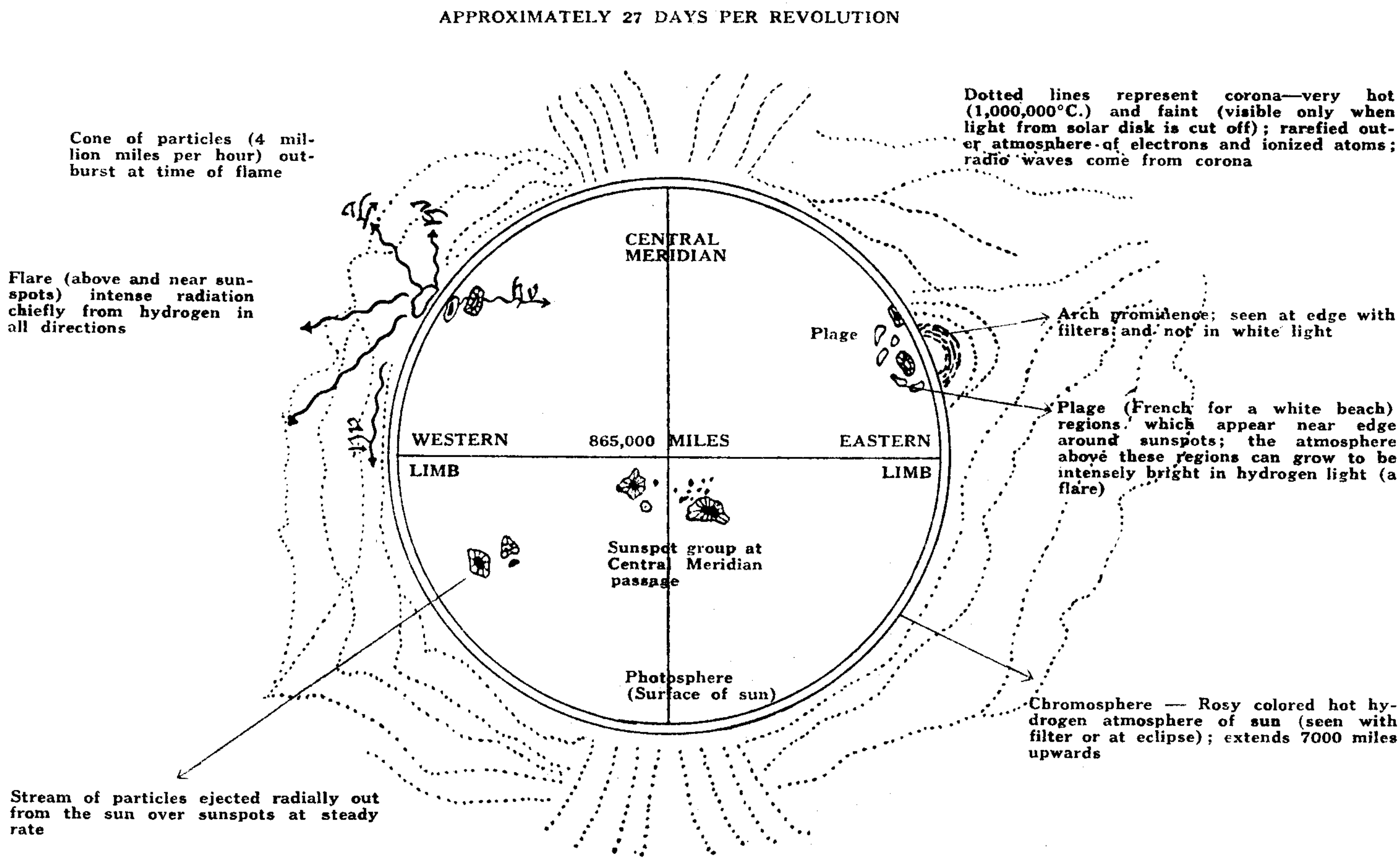


FIG. A. SOLAR DIAGRAM

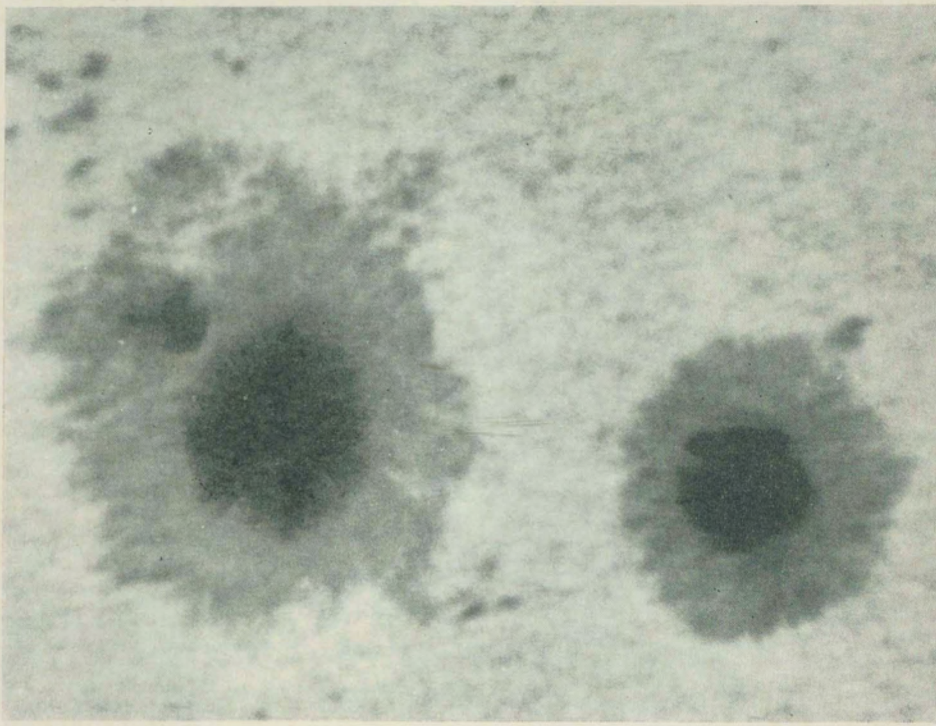


Plate 1. Enlargement of a sunspot group photographed at Mirador, Baguio, 21 June 1957. *Umbra* is darkest area of spot. *Penumbra* with striations is lighter area of spot, but still darker than the rest of the surface. Speckles are *granulation*. Tiny dark specks are *pores*.

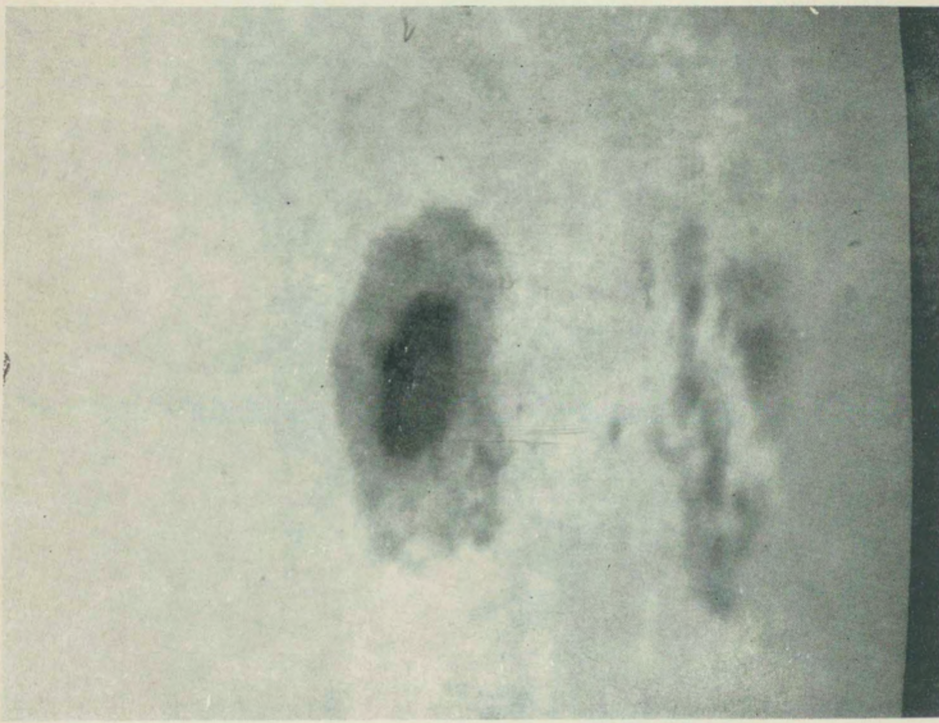


Plate 2. Spot group just appearing around edge of sun. Sun rotates every 27 days, and spots move with rotation from east to west across face of sun. Perspective and the depth of spots foreshorten one dimension. Photographed at Mirador, Baguio, 20 June 1957.

WEST

TH

Plate 3. Dent at edge of disk is caused by a sunspot (a depression in the surface of the sun) disappearing at western limb. Taken at Mirador, Baguio, 27 June 1957.

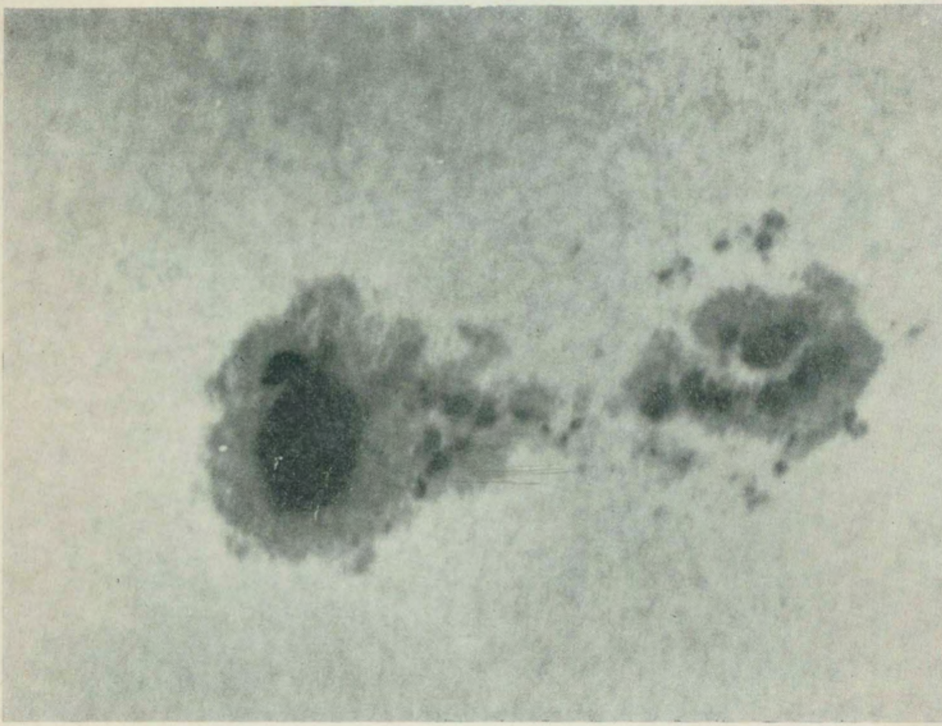
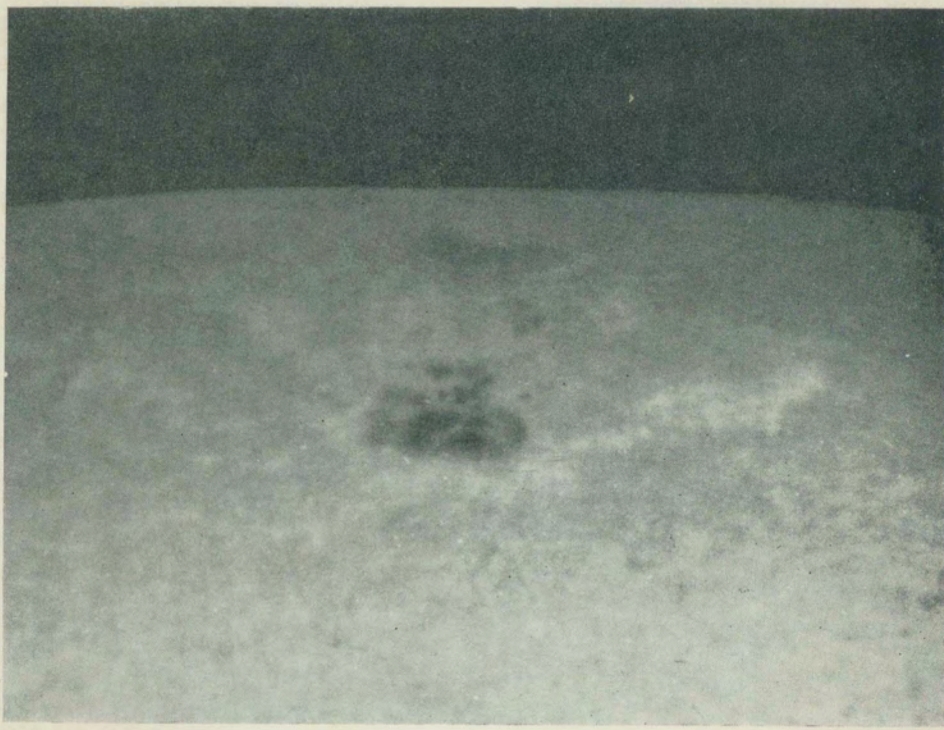


Plate 4. The area of the largest spot of this group is close to one billion square miles. This is the same group that appears in Plate 2. Taken at Mirador, Baguio, 26 June 1957 six days after the photo in Plate 2 was taken.

EAST



WEST

Plate 5. White areas around sunspots near edge of sun are *plage* areas. These white areas lead from one spot to another like magnetic lines of force and are the locus of explosive-like brightenings in hydrogen light. Photographed at Mirador, Baguio, 6 May 1957.

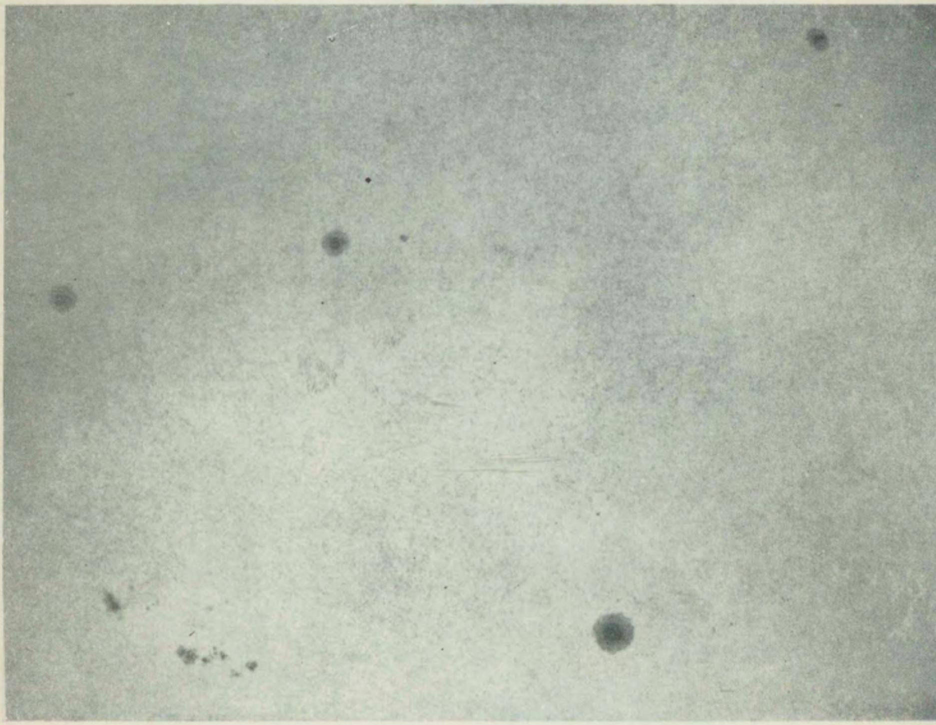
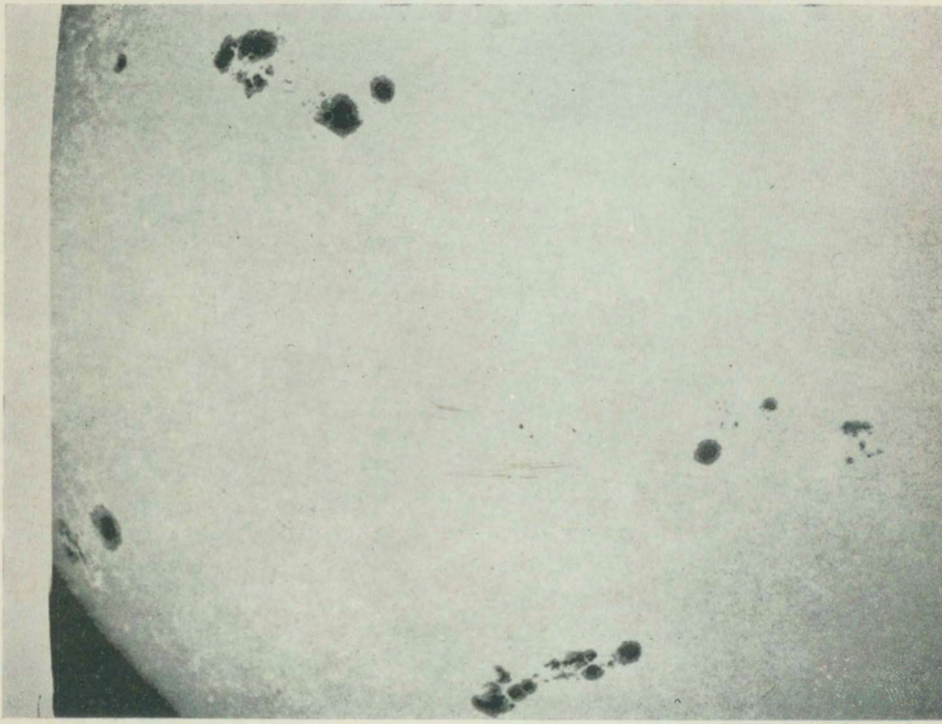


Plate 6. V-formation or flying geese formation of sunspots across solar disk is very ccmmon. Formation moves from right to left, that is, from east to west across sun. Taken at Mirador, Baguio, 26 May 1957.

SOUTH



NORTH

Plate 7. The great number of these sunspots called for a world-wide IGY alert. Note again the V-formation. Taken at Mirador, Baguio, 20 June 1957.

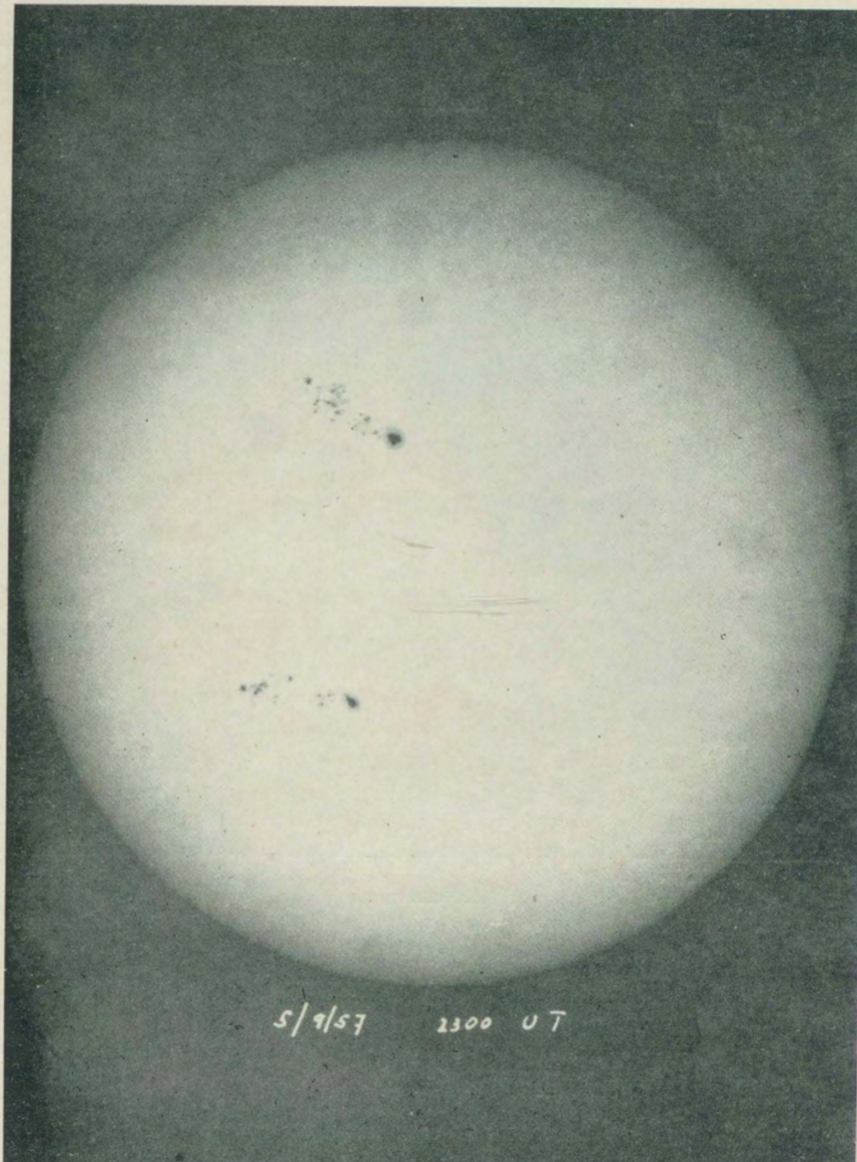


Plate 8. Great symmetrical groups of sunspots. In each the leading spots are slanted in towards the solar equator. This photograph was taken by Hans Arber with a 6" refractor in Manila, 10 June 1957.

Coronal rays seem to be trajectories of charged particles which occasionally reach out as far as the earth's surface. Sunspot fields provide the exit corridor by which these coronal particles make their exit from the sun. Possibly, so many coronal particles escape at sunspot maximum that the corona is actually smaller at sunspot maximum than at minimum. These particles cause magnetic disturbances when they reach the magnetic field of the earth. The disturbances often come at intervals of twenty-seven days, which is the time taken by the sun to make one complete revolution relative to the earth. More often than the recurrent type of magnetic storm come the non-recurrent more violent magnetic storms during sunspot maximum. Lindberg in his trans-Atlantic flight of 1927 found for a disconcerting period of his trip that the compass needle on which his life depended swung wildly from side to side. The earth seems to have been experiencing a magnetic storm.

The ionizing power of solar radiation on the earth's atmosphere is proportional to the varying sunspot number. This has held for the last twenty-five years, i.e. for all the time that measurements of atmospheric ionization have been made by radio measurements, such as those made by the ionosonde of the Manila Observatory in Baguio for the past five years.[12] Radio communication depends on the condition of the ionosphere and consequently on the sunspot cycle.

IV

Dr. W. Waldmeier of Zurich, Switzerland will collect the sunspot data observed throughout the world during the International Geophysical Year. He has written to the Fathers of the Manila Observatory:

> The photographs enclosed prove that you obtain very good pictures... Of course this is only possible if the image quality is good, which seems to occur very often with you. This is further reason why your photographs are so valuable for program of sunspot-observation.

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[12] See Father Hennessey's "Ionosphere Research at the Manila Observatory" PHILIPPINE STUDIES III (1955) 164-186.

Dr. Waldmeier hopes for a continuous series of pictures of the sun. The pictures must be sufficiently frequent to show the development of various sunspot groups, and they must be of high enough quality to show the minutest detail. He needs at least twenty stations to secure his program, and these must be scattered throughout the world. There are twenty-eight stations throughout the world which are taking such pictures.

The Manila Observatory conducted by the Jesuits in the Philippines and located at Baguio enjoys a great advantage because of its high elevation and because of the fact that the best seeing comes at the time of the worst seeing in northern America and in Europe, and also because daytime in the Philippines is nighttime where most other observatories are located. Hence the work of the Observatory at Baguio has the possibility of making a substantial contribution to scientists' knowledge of the sun. The program does not only consist in taking pictures but also in counting the spots and recording their location and type. Any unusually interesting pictures are reproduced.

The Jesuits are not the only ones studying sunspots in the Philippines. Mr. Hans Arber, who loaned the four-inch Unitron refractor telescope to the Manila Observatory for taking sunspot pictures, is himself engaged in similar work in Manila. The Philippine Weather Bureau under Dr. Casimiro del Rosario, is similarly cooperating in Manila.

In accordance with the part of the IGY program which hopes to solve the puzzle of sunspots, we are seeking to know just what the fundamental mechanism is on the sun which causes the sun to be more "active" at one time than at another. Dr. T. G. Cowling, after devoting many pages to the theories of sunspot formation, writes that the number of theories, each with its own difficulties, is bewildering.[13]

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[13] T. G. Cowling "Solar Electrodynamics" *The Sun* ed. Kuiper p. 577. This volume is the first of a four-volume series entitled *The Solar System* published by the University of Chicago Press (1953) of which to our knowledge only the first two volumes have appeared.

V

Have all the clues been exhausted for the understanding of the fundamental mechanism of sunspots? Probably not. Here are a few more.

Groupings of solar spots are often in a V-formation like a flock of geese flying across the face of the sun (see Plate 6). The "leading" spots are most often closer to the equator than the "following" spots (see Plate 7). Calcium "plage" areas which follow closely the regions of sunspots and which persist often weeks after a sunspot group under the plage area has died, very often spread out over the sun in this V-formation. This seems to be a very important clue. There is a differential rotation of the sun, i.e. the equatorial regions of the surface of the sun move or spin around the axis of the sun more rapidly than the solar regions at higher latitudes, nearer the poles. This information is obtained by timing the sunspots at various latitudes as they march across the face of the solar disk.

Is it possible that deeper down in the sun than we can see, there is a more substantial body of matter which is not spinning with the surface layers, but whose angular velocity is greater on the average than that of the lighter gases farther out from the center of the solar mass? The rotation of the heavy interior of the sun would exert a greater frictional drag on the outer gases near the equator than on the outer gases near the poles because the tangential velocity at the equator is much greater than at the poles. This velocity would decrease as the cosine of the latitude. Kepler's law that for planets the square of the period divided by the cube of the mean distance is a constant could well have some meaning for some of the gases of which the sun is composed. This faster spinning inner sun would drag the equatorial outer gases around at a greater angular velocity than it would the polar gases.

Another consequence of the faster spinning inner sun which exerts the most friction on the equatorial outer layer of gases would be to start a spinning whirl of gases. The inner gases at the equator, travelling at a greater angular velocity than the outer gases at the equator, would start a toroidal current under the surface of the sun, in the equatorial region.

This toroidal current would spread out in the familiar V-formation, because of the differential rotation of the solar gas layer, faster in the lower latitudes than in the higher. This toroid would break through to the surface first in high latitudes while still deep in equatorial regions. As the magnetic field would pick up in intensity, with increased whirling of the toroid, the internal magnetic pressure of the toroidal current would push outward much of the gas of the toroid, causing it to lighten and rise closer to the surface. Thus, as the cycle would proceed, sunspots would break out at lower latitudes, and account for the progression which has been observed of sunspots from higher to lower latitudes. Finally the magnetism of the spot would restrict the convection of hot gases into the region of the toroidal current. With the consequent cooling, the toroid would grow denser and slowly sink. The sunspots would disappear.

VI

What can the mechanism be which accounts for the apparent reversal of the toroidal current? Most have thought that there is no reversal of an individual toroidal current. Dr. Cowling has shown that left to themselves magnetic fields comparable to those on the sun would take three hundred years to decay. Probably then there are two toroidal currents revolving in opposite directions.

Alfén and Walén of Sweden have done away with toroidal currents entirely. They have argued to a concentration of the magnetic lines of force of the general solar magnetic field. The difficulty is that this field has been found by the Babcocks to be no larger at best than the field of the earth. Such a weak field hardly seems adequate.

It would seem quite possible that the differential rotation of the interior heavier mass of the sun sets up a primary toroidal current such as we have briefly explained above. Then this primary toroidal current sets up an oppositely directed parasitic toroid or whirl which rises as the main toroidal current sinks, and vice versa. Cowling has objections to any whirling motion of mass to account for the magnetic field. The properly directed whirling mass has not been observed. We may wonder however whether, because of its depth in the sun, it would ever be possible to observe it. We can only see a hundred kilometers into the sun at best.

Cowling also maintains that the electrostatic charge which a whirling mass possesses is much too slight to account for the magnetism.[14] He seems to forget that an electrostatic charge is not necessary. All that is necessary is a differential or relative motion of charge. Electrostatic charges in conducting copper wires are negligible, but the electrons are in motion relative to the positive ions of the wire. A toroidal current in the sun could well be caused by protons moving about the magnetic field of the toroid much faster than electrons, because the conductivity of protons (that is, their ability to move) is much higher in a magnetic field across which they pass than for electrons. The net electrostatic charge would still be zero.

VII

The problems are tantalizing. The sun is the nearest star to us. No other star offers its surface for such close scrutiny. An understanding of the sun will help much to understand better not only the universe but the earth on which we live. An understanding of the earth will probably make it a better place to live in at least physically.

Father Secchi with unusual perspicacity wrote nearly one hundred years ago:

> The contemplation of the works of God is one of the noblest occupations of the spirit, and it is the main purpose of the study of nature. But this study often brings us to useful results which we would not cast aside. The study of the sun, for the moment, does not seem to give us this advantage. Whatever our research may be and the knowledge we

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[14] *Ibid.* p. 568.

may acquire, we will never have the power to control the influence of the sun; nevertheless, the effect of this body is too closely linked with the phenomena of life, heat, and light to render useless our attempts to investigate the nature of its effect. And besides, who knows but that a close correlation may exist between certain solar phenomena and some terrestrial phenomena, which it would be important to foresee with some certainty?[15]

What cannot be fathomed remains a challenge and a reason for humility before the wonderful things which God has wrought.

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[15] G. Abetti *The History of Astronomy* p. 197.