A

Good job

THE GALACTIC MAGNETIC FIELD

AND

IT'S INFLUENCES ON THE GEOMAGNETIC FIELD

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Astronomy A 20
May 26, 1969

Last Fall in A 10 Geology I learned of a theory of an expanding earth which involved a decrease in the universal gravitational constant, G, through time. Such an idea seemed incredible to me and for the term paper required for the course, I looked into the evidence supporting it. The major exposition of the theory is contained in Johann Steiner's "The Sequence of Geological Events and the Dynamics of the Milky Way Galaxy." (Steiner, 1967) The greater part of his paper is devoted to the correlating of of numerous geological events with the cosmic year, the period of rotation of the sun around the galaxy. He explains these correlates with two hypotheses, one of which is an empirically derived function of 'G' verses distance from the galactic center. I proposed that the effects upon which he based his function, deviation of star orbits from Keplerian predictions, could be explained by the distribution of mass in the galaxy without resorting to a variable G. (In reading for this paper, I find that magnetic stiffening of the spiral arms is another effect that may be relevant. Another interesting thing I have noticed is the remarkable similarity between Steiner's gravitational function, Figure 1 , and the B-type star plot in " a graph plotting rotational velocity of our galaxy as a solid wheel, as Keplerian rotation, and by observation of B-type stars," reproduced in Figure 2 from our text book.)

The other hypothesis, the investigation of whose tenability is the main purpose of this paper, is that long term trends in the direction of the paleo-magnetic poles are caused by galactic "seasonal" variations in our orientation to the local galactic magnetic field, and also that this field supplies the slight field needed to initiate self-exciting dynamo action in the Earth's core.

I will first present Steiner's data and arguments, and some additional background data and information, and then consider several possible criticisms of his work.

Figure 3 shows most of the aspects of the galactic model used by Steiner. The aspects of main consequence in our discussion ~~will be~~ are shown in Figures 3c and 3d, 3c shows the retrograde rotation of the major axis of the sun's orbit which causes the period from perigalacticum to perigalacticum to be less than that of one complete revolution around the galactic center. Figure 3d shows oscillation across the galactic plane of the sun as it revolves. Trumpler and Weaver (1953) give the period of this oscillation as 84 m.y. Steiner uses the latest values of velocity and galactocentric distance given in a source not available in our library. However, the values used are also given in Bok (1963). From these figures of 10,000 parsecs or 32,580 light years for the galactocentric distance and 250 Km/sec, circular velocity, Steiner computes the period of the cosmic year as 245 million years. He then assumes that since the sun is almost at its periglacticum, the observed orbital velocity is considerably higher than the mean orbital velocity. Correcting the length of the cosmic year to the value obtained by the assuption of Keplerian laws, he obtains a period of 280 million years.

One of the more successful thoeries available today for explaining the Earth's magnetic field is the "self-exciting dynamo" theory developed mainly by Elsassar and Bullard. Chapter 3 in *Debate About The Earth* (Takeuchi, Uyeda, and Kanamori, 1967), presents the theory fairly lucidly. It has been shown that under the right conditions, a rapidly rotating disk or cylinder will, when subjected to to an initial magnetic field, *however weak*, generate and sustain a current within itself, and a magnetic field around itself. The magnetic field will be parallel to its axis of rotation and <u>in a direction so as to reinforce the initial field</u>. The initial field is then no longer needed. It has furthur been shown that the interaction of assumed convection currents in the liquid outer core of the Earth and "parallel currents" generated by the rotation of Earth, could, in not too improbable circumstances, porduce self-exciting dynamo action. A convection current speed of only 10^{-2} or 10^{-1} mm/sec would be sufficient to produce currents of 10^{9} amperes and consume 2×10^{10} cal/sec in producing the approximately .5 gauss field observable on the Earth's surface.

Steiner says, rightly, that while the self-exciting dynamo theory is quite sucessful in explaining most geomagnetic phenomena, it is less successful in handling three specific problems. The first, which need not concern us here, is how it obtains the vast amount of energy needed to sustain itself. The others are where it finds the initial filed needed to start its action, and what causes any specific directionality in its field, i.e., why is the ~~north~~ south magnetic pole near the north rotational pole rather than the south. Steiner contends that the answers to both these questions may be found in the weak galactic magnetic field. That the galactic field may have supplied the initial field will not be argued by many; such an idea has been intimated by Takeuchi, Uyeda, and Kanamori themselves. Steiner's contention that, " reversal of the resulting geomagnetic field could conceivably be due to a change in the geometrical relationships of the Earth's axis and the direction of polarization of the galactic field" would meet more resistance stated in this form. It is hard to see how a field on the order of 10^{-5} to 10^{-6} gauss could cause a reversal in a field of .5 gauss on the surface andperhaps greater than 400 gauss at the core. (I think Steiner could have gotten around this problem by supposing that the convection cells supplying the energy for the dynamo may change modes or break down at times, causing a collapse of the magnetic field and making currents in reforming cells susceptible to the galactic field. Any change in orientation of of the Earth's rotational axis to this field might change the direction of repolarization.

Steiner has compiled data which support a theory of interaction between the local galactic field and the geomagnetic field. Figure 4 shows these "seasonal" trends in the direction of the Earth's paleo-magnetic polarity.

There is good evidence that the galactic magnetic field bends outward and runs along the spiral arms of the galaxy as shown in Figure 5, taken from H.C. Arp (1963). G.L. Berge and G. A. Seieland (1965) give the strength of the field in the vicinity of the sun as somewhat less than 10 microgauss and its orientation as being at about 70° from the direction of the galactic center. Thus it falls right along our local spiral arm. Its direction of flow is outward, south pole to north pole, on the northern side of the galactic plane, and inward on the southern side. To quote my earlier paper, (Armstrong, 1968) :

> "Assuming a simple model in which 'the rotational axis of the Earth maintains its mean orientation with respect to the galactic standard of rest", (Steiner, p. 122) and assuming that the Earth has any sort of precessional or other movement around this mean axis; then the chances of a particular orientation of the rotational axis to the galactic magnetic field would be a function of the orientation of the mean axis of the magnetic field. This mean orientation, under this model, is a matter of galactic 'season'."

Figure 6 may show this relationship more clearly.

I would now like to look at what our orientation with respect to the local galactic magnetic field is, and to see if it supports the theory. Trumpler and Weaver give the direction of the galactic North Pole as having a declination +27.5° and a right ascension of 191.0°. Figure 7 shows the projections of the Earth's rotational axes on the galactic plane seen through the north and on a plane through the Earth, which includes the galactic axis. It will be remembered that the Earth's (and the galaxy's) magnetic poles are opposite in sign to the rotational poles. Thus, it is seen that the present polarity is in line with Steiner's theory. One problem, however, is that is apparent that the normal precessional movement of the Earth's axis is inadequate to reverse its orientation with respect to the spiral arms field. In fact, Steiner's assumed compounded precessions (Steiner pp.123-124) must be mighty big to produce the short period (.5 - 2 m.y.) polarity reversals known to occur. Such large precessions would be likely to increase the randomness of polar direction across time, and decrease the power of the very effect he is trying to explain. A much more reasonable explanation , it would seem to me, would be the assumption of anomalies in the field, especially at those times when the sun is near the galactic plane.

Steiner disregards the retrogression of the major axis of the sun's orbit in these conditions and glosses over the sun's oscillation across the galactic plane, saying no data indicates an effect from this vibration. He feels that:

> "The dating of paleo-magnetic samples...is not accurate enough to detect periodic phenomena of the order of 42 or 84 million

> years. Without the 50% overlap statistic employed in figure (4), ...the plotting interval would be 34m.y. which is insufficient to resolve periods of some 80 m. y., unless the control points coincide accidentally with some of the true maxima and minima.."

The disregarding of these points, I feel,is fatal to his theories.

The first has its main consequence for his variable 'G' theorizing. The only effect it has on the theories presently concerning us is to compress the points of apo- and perigalacticum toward the present, as indicated in Figure 4. I was not able to determine from Trumpler and Weaver whether Figure 3c (which is on page 598 in their book) was meant to be an accurate facsimile of the sun's galactic orbit, or intended to represent some other star with typical parameters in the sun's vicinity. I believe it is the latter. However, if the discrepancy between the sun's peri- apo- perigalacticum year and the rotational year is anywhere nearly as great as is indicated in the figure, Steiner should definetley differentiate between the two.

The second point destroys his hypothesis for the paleomagnetic phenomena. If he is right that his plots of polarity are too insensitive to detect a periodicity of 84 m.y., his predictions should be for a random distribution of polarities. The expected magnetic direction would change every fifth galactic year, according to Trumpler and Weaver. (Although Steiner uses their figures for the period of oscillation, he does not take into account the 20% stretching of distance and speed estimates which are reported by Bok (1963). I am guessing that the frequency of oscillation would stay constant through the change, i.e., the period would probably increase in proportion with the length of the year. The amplitude probably increases also.) These changes should be as strong as the semi-cosmic-yearly ones, and if averaged out as random noise in the data, would virtually drown out the main effect. The function expected would be the addition of the two effects and the curve shown in Figure 6. would be impossible. The fact is that the curves do not show any effect, even noise, from the oscillation across the galactic plane, and therefore, could not be responding to it. If they are not responding to this effect, how could they be responding to the yearly orientation change? Steiner's data looks terribly good, but either his hypothesis, the structure of the galactic magnetic field, or the sun's oscillation across the galactic plane has got to go.

One last point I'd like to make is to criticize the assumption of Keplerian laws in increasing his estimate of the length of the cosmic year. It is well known that the galactocentric force function is not an inverse square law, rather, it is closer to being first degree. Steiner even uses this fact to determine his 'G' function. Assuming it to be close to first degree, the period of a star's orbit calculated from circular velocity, and galactocentric distance does not vary over changes in velocity and distance. Therefore, the fact that we are now near our perigalacticum does not indicate a need for an upward correction in length of the cosmic year.

Johann Steiner's paper has been an interesting spur to my curiosity this year, but I am yet to be convinced of the validity of its arguments.

For the purposes of this model it is assumed that the central galactic force law is an inverse square law with a varying gravitational "constant" G. According to Ogorodnikov, approximately 80% of the central galactic force $K(R)$ is given by

$$K(R) = \frac{G\,M_g}{R^2} \quad \text{(Ogorodnikov, 1965, equation 3·53, pp. 82-85; Trumpler \& Weaver, 1953)} \qquad (1)$$

where M_g is the mass of the galaxy (Table III) and R the galactocentric distance. On the basis of equation (1) the relationship

$$G = \frac{R\,V_c^2}{M_g} \qquad (2)$$

is given where V_c represents the empirical circular orbital velocity at the given galactocentric distance R, since $K(R)$ is also given by

$$K(R) = \frac{V_c^2}{R} \quad \text{(Ogorodnikov, 1965, equation 3·48, p. 82)} \qquad (3)$$

Equation (2) and Bok & Bok's somewhat out-of-date empirical data (Table II) permit the calculation of G as a function of R (Fig. 2).

Under the assumptions made, and owing to numerous necessary approximations and uncertainties*, only the general shape of this function may be considered valid, at best. The absolute value of G must be treated with caution. In Figure 2, G tends toward zero near the centre of the galaxy, rises to a maximum of approximately $7 \cdot 0.10^{-8}$ c.g.s. units near its edge, and presumably tends toward zero at an infinite distance. This function

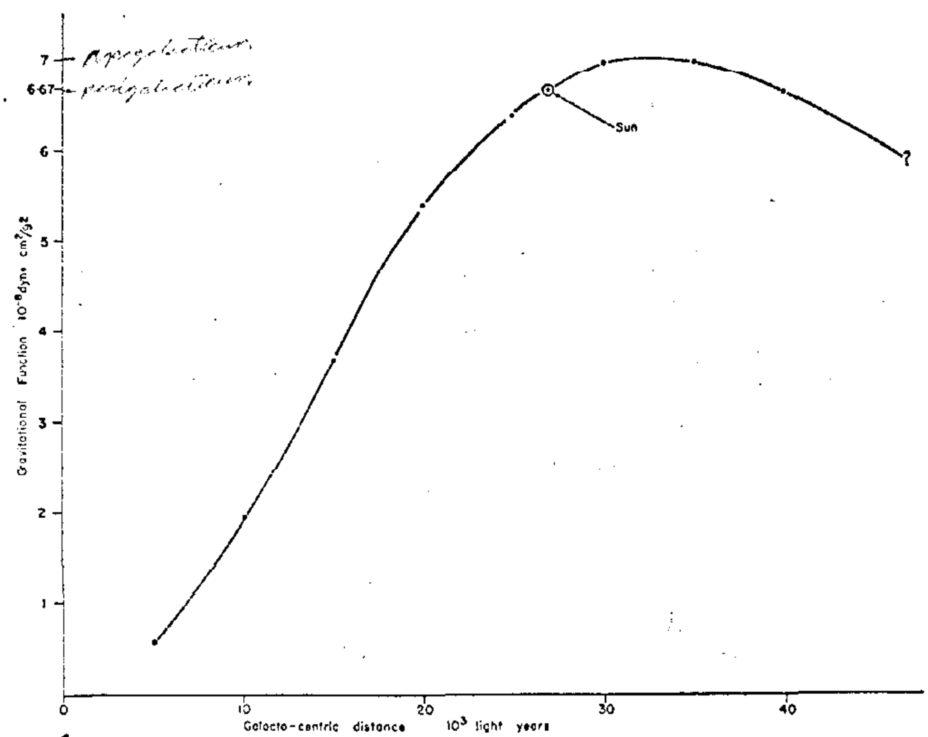
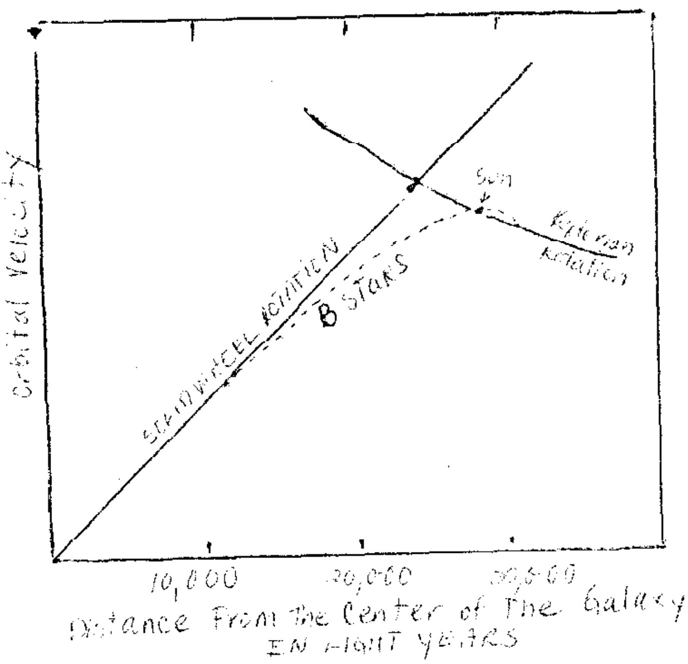


Fig. 1 An empirical gravitational function calculated on the basis of 1957 galactic data. Gravitational function in 10^{-8} dyne cm²/g² which, at the present time, has the value of 6·67 c.g.s. units in the vicinity of the Sun. These calculations assume that the Newtonian "constant" of gravitation is a function of time and space, or a scalar field variable.

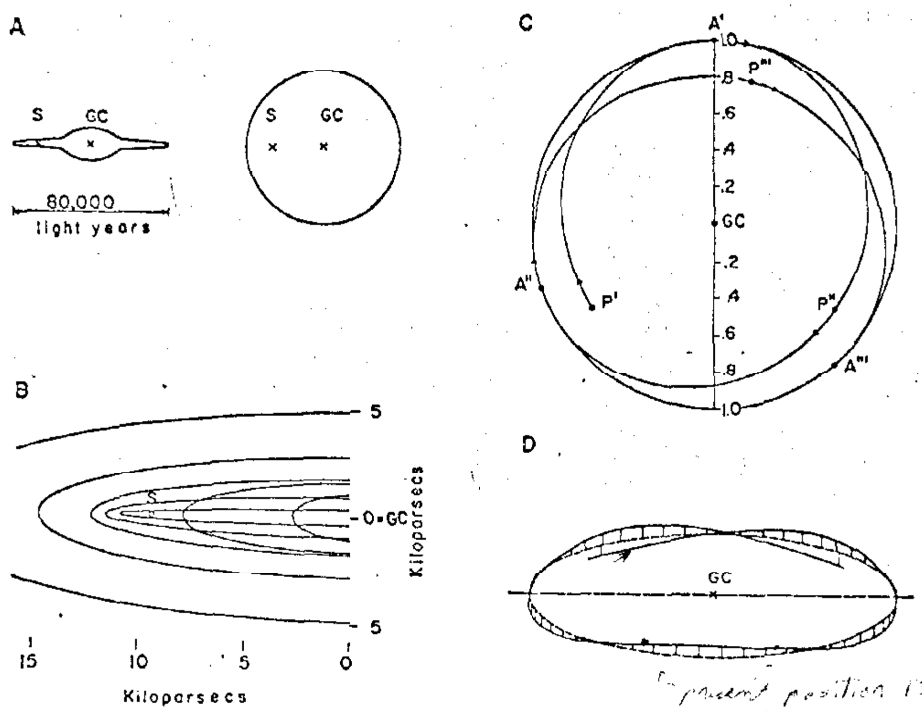
* The galactic orbits are calculated on the assumption of a constant G, but are utilised in a model employing a variable G. It needs to be assessed whether these calculations have to be revised and, if so, how does it change the variable G model and the comparison with geological phenomena.

Figure 1

FIGURE 2



FROM: Inglis, Stuart J., Planets, Stars, and Galaxies, An Introduction to Astronomy, John Wiley and Sons, Inc., New York, N.Y. 1967, p. 417.



"present position 13.5 pc North of galactic plane, sun not near such position (T+W p. 23)"

Fig. 3. *The Milky Way Galaxy.*

A. A schematic model of our galaxy. The contours enclose a great majority of the stars of our Milky Way (after Bok & Bok, 1957).
Left—side view. Right—view from galactic pole. GC—galactic centre. S—sun.

B. A schematic model of the galactic system by Oort. The diagram shows a section perpendicular to the galactic plane, through the centre and the Sun. The position of the Sun is indicated by a small circle. The large central ellipsoid has axes of lengths 8 and 1·61 kiloparsecs and a density of 2·15 (using the density near the Sun as a unit): the small central ellipsoid, with axes of lengths 2·8 and 1 kiloparsecs, has a density of 3·13. (The reader is reminded that 1 kiloparsec = 3258 light-years.) The lengths of the axes (kiloparsecs) and the densities of the five outer ellipsoids are as follows:

Axes	11·0, 0·3	Density 0·446
	11·6, 0·9	0·104
	12·3, 1·7	0·026
	14·8, 2·8	0·007
	20·3, 4·9	0·003

The ellipsoids are superimposed upon one another (after Bok & Bok, 1957).

C. Galactic orbit calculated on the basis of 1953 galactic data for a star in the vicinity of the Sun. Orbit is shown in the galactic plane viewed from one of the galactic poles (after Trumpler & Weaver, 1953). Normalised to apogalactical distance equal to 1·0.
A: Apogalacticum. P: Perigalacticum.

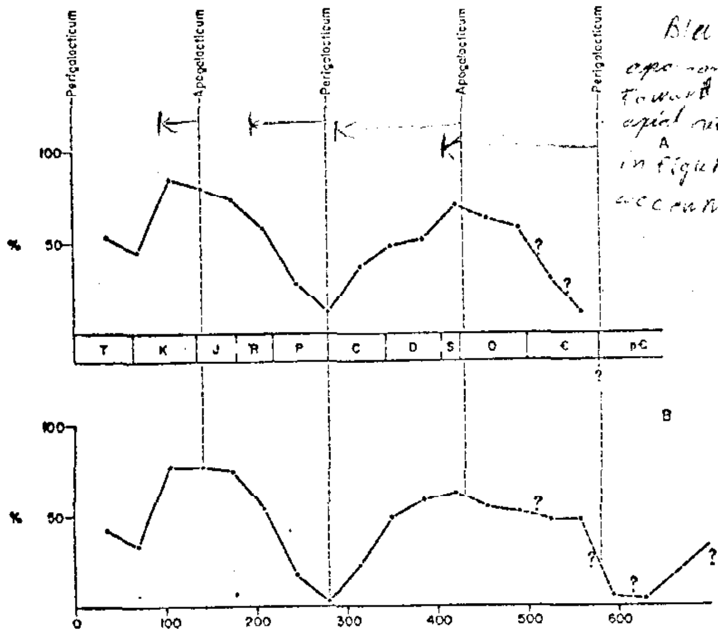
D. Galactic orbit with a motion perpendicular to the galactic plane (after Trumpler & Weaver, 1953).

0·07, and the orbital positions farthest from and nearest to the galactic centre are termed apogalacticum and perigalacticum respectively (i.e. the apsides). At these limiting orbital positions the galactocentric distances are 1·145 R_0 and 0·995 R_0, where R_0 represents the present galactocentric distance of the Sun. These data and other considerations (Trumpler & Weaver, 1953, p. 601) imply that the Sun is now rapidly approaching its perigalacticum and will pass it in a matter of a few millions of years. If it is assumed that Kepler's second

Figure 3

to have reversed magnetisation on either side of the galactic plane. The terrestrial magnetic field is generally attributed to complex hydrodynamic phenomena in the outer core of the Earth. This theory of the self-exciting dynamo, which in recent years has been developed further by Elsasser (1950) and Bullard (1950), explains most phenomena of the main dipole field, but is less successful in three respects. One is the source of energy that keeps the dynamo going without a breakdown, started the self-exciting dynamo going, then a reversal of the resulting geomagnetic field could conceivably be due to a change of the geometric relationship of the Earth's axis and the direction of polarisation of the galactic field.

If such a consequential interaction of the galactic and the terrestrial magnetic field can be visualised, it is not difficult to devise a model that would satisfy the data indicated by Figure 10. The simplest model might assume



Blue; movement of apo- and peri-galactica when toward present axial retrogression indicated in figure 3C is taken into account.

Fig. ~~10~~ 11. Major palaeomagnetic polarity epochs. Percentage of virtual geomagnetic South poles in Northern Hemisphere (North-American convention), based on percentage number of samples (perigalactical passage approximated to present time zero).
A. Based on data compiled by Cox & Doell (1960).
B. Based on continuous compilations of Irving (1964).

Holmes (1965, p. 991) lists briefly the explanations that have been put forward in this regard, in particular by Ramsey (1949) and Egyed (1957). The second shortcoming concerns the need for an original, possibly very weak magnetic field which initiates the process of the self-exciting dynamo. Finally, the theory provides no reason for any given direction of magnetisation or reversals of the geomagnetic field, as indicated by palaeomagnetic data.

It is the purpose of this section to show that the answer to the last two questions may lie in the weak galactic field. If the galactic field that the direction of magnetisation of the galactic field can cause the terrestrial field to reverse itself and further assume that the rotational axis of the Earth maintains its mean orientation with respect to the galactic standard of rest, while the solar system is orbiting around it. If the changing gravitational field of the galaxy or other random or systematic gravitational disturbances induce precessional movements analogous to the precession of the equinoxes, the spatial relationship of the Earth's rotational axis to the direction of magnetisation in the spiral arms would systematically change.

Figure 4

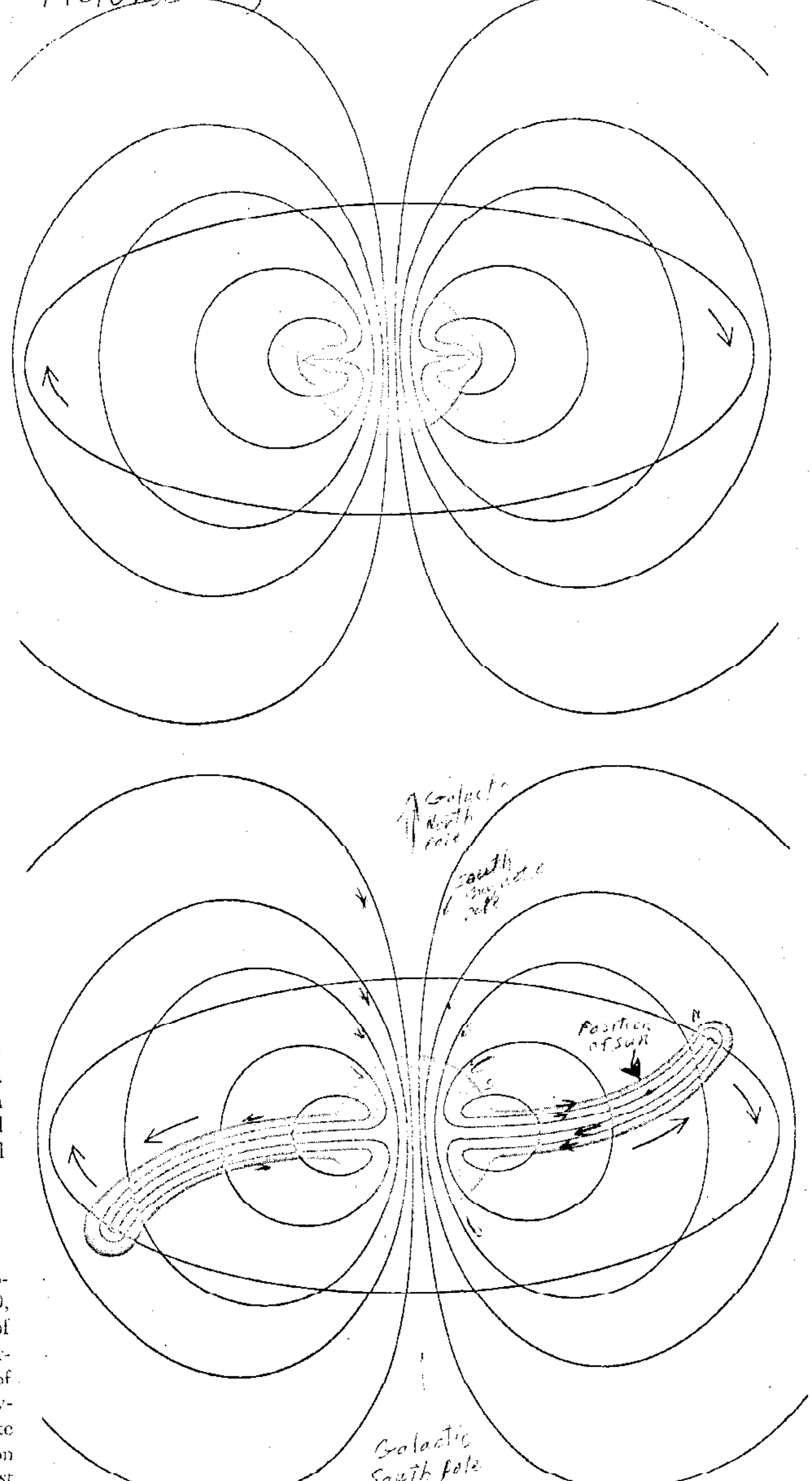
the spiral arms sparkle with stars that are hot, blue and from 10,000 to 100,000 times brighter than the sun. Stars can radiate at this rate for only one million to 10 million years, a short time compared with the estimated age of the universe. These supergiant stars are strung out along the spiral arms like beads on a string. Similarly restricted to the arms are great clouds and filaments of dust. Recent radio observations have shown that the spiral arms in our own galaxy are also outlined by hydrogen gas. Clearly this dust and gas furnish material for the formation of the bright new stars that illuminate the spiral arms. In fact, it is possible to observe nearby regions in the spiral arms of our galaxy where stars are in the process of being formed [see "The Pleiades," by D. Nelson Limber; SCIENTIFIC AMERICAN, November, 1962].

But just as the lifetime of very hot stars is limited, so too the supply of dust and gas for creating new stars would seem to be limited. Sidney van den Bergh of the David Dunlap Observatory in Toronto has estimated that at the present rate of star formation the gas in the vicinity of the sun would be exhausted in less than a billion years. He has suggested that the gas was perhaps replenished from the central regions of the galaxy. Subsequently Maarten Schmidt of the California Institute of Technology worked out a galactic model in which sufficient gas was originally present so that a decreasing rate of star formation would still leave about a fifth of the original gas not yet formed into stars. But regardless of whether new material flows in to replenish the old or the spiral arms are simply supplied with a large initial amount of gas, the problem remains of explaining how the material is kept from diffusing out of the spiral arms and away into space.

Evidence for Magnetic Fields

One clue to the solution of the problem may have been provided in 1949, when John Hall and W. A. Hiltner of the Yerkes Observatory observed polarization of the light from nearby arms of the galaxy. Jesse L. Greenstein and Leverett Davis, Jr., of the California Institute of Technology showed that polarization is probably caused by elongated dust particles, all aligned in the same direction, which preferentially absorb the light whose vibration is parallel to the long axis of the particles. The important outcome of this work seems to be that only a magnetic field aligned along the

FIGURE 5



MAGNETIC FIELD OF GALAXY might originally have the general form shown in the top illustration. In the nucleus ionized, or electrically charged, particles of gas would be tightly bound to lines of magnetic force (*color*). If the gas were thrown outward by rotation of the galaxy, the ejected mass would pull the lines of magnetic force with it, as shown in the bottom illustration. Thereafter ejected material would tend to follow these lines and form arms.

Figure 69

(adapted from Steiner, 1967)

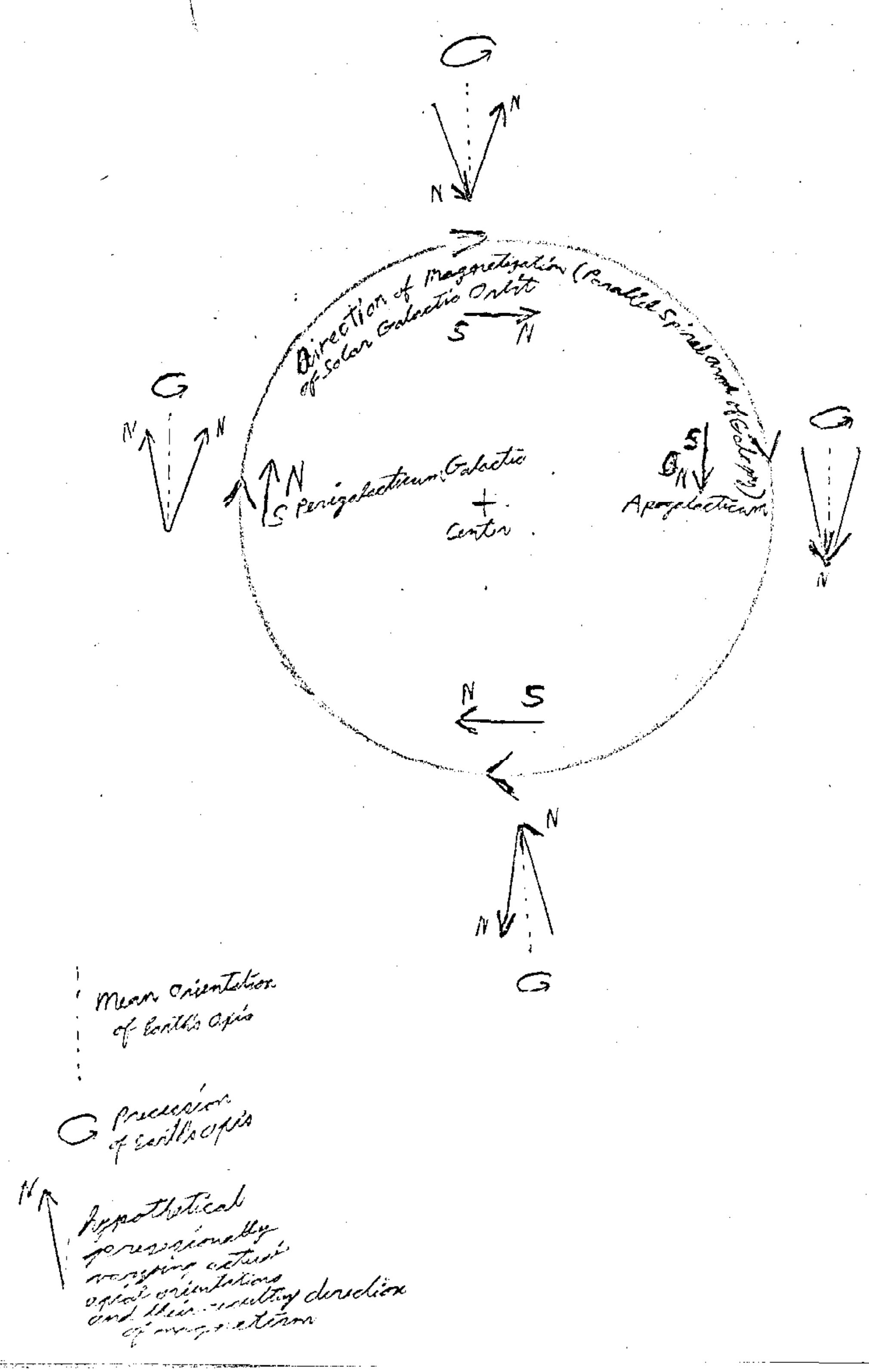
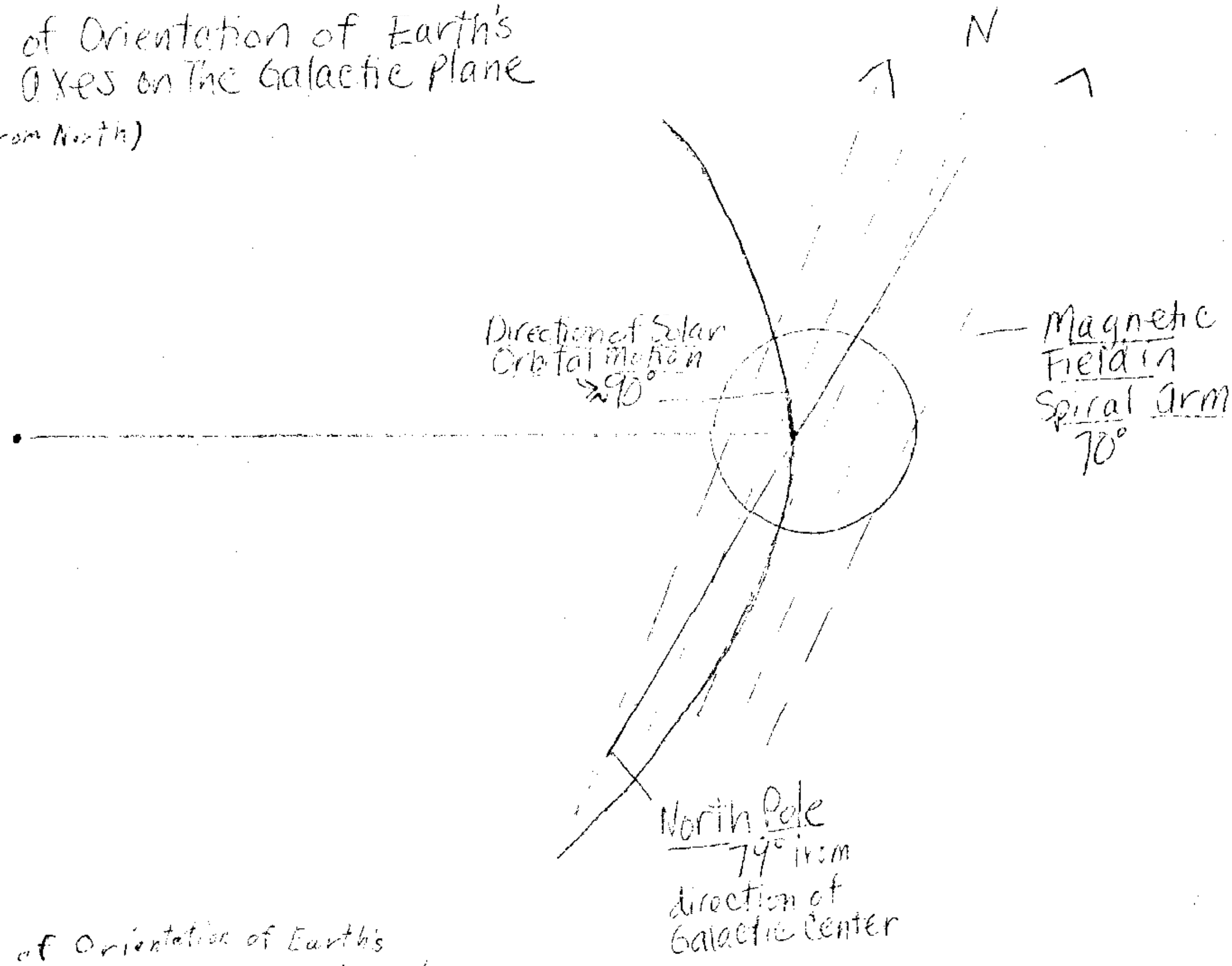
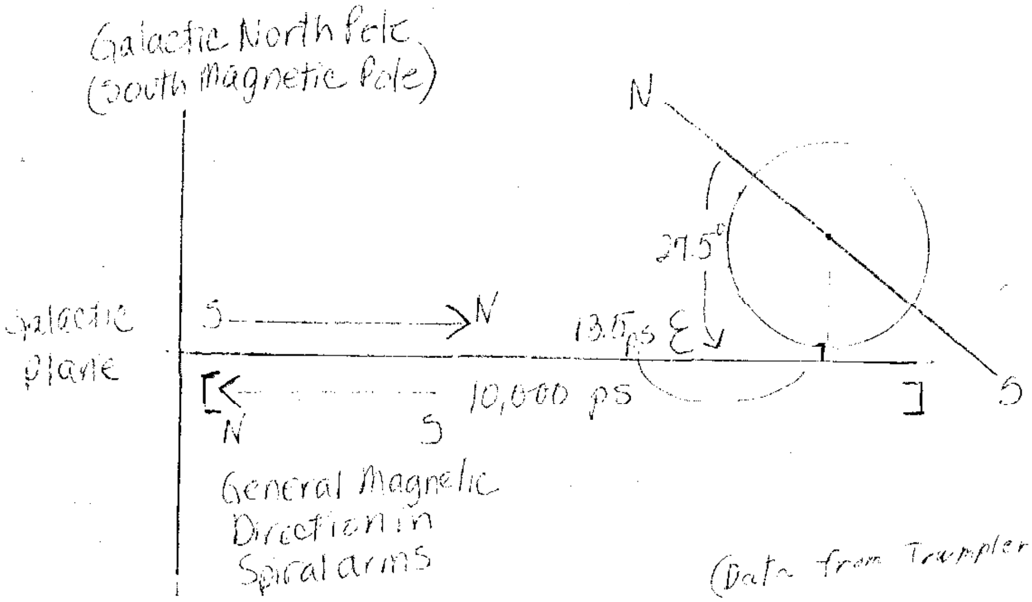


FIGURE 7

Projection of Orientation of Earth's Rotational axes on the Galactic plane
(view from North)



Projection of Orientation of Earth's Rotational axis on Plane Passing through the Earth and Containing the Galactic Rotational axis.
(view from West)



(Data from Trumpler and Weaver, 1953)

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