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A New Theory for the Solar Cycle

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Abstract - We present here a new theory of the solar cycle which is able to explain all relevant observations connected with quasi-periodic behavior of sunspots and other associated phenomena. It is based on the interaction between planetary movements and alignments and the evolving magnetic field of the Sun. The theory provides a very natural explanation for the roughly eleven-year change in polarity of the solar magnetic field and for the Maunder Butterfly Diagram. It overcomes all objections raised against other theories in this field, including those based entirely on magneto-hydrodynamics.

1. INTRODUCTION

1.1 The need for a new theory

Very recently Lassen and Friis-Christensen (1995) established a positive correlation between the solar cycle and northern hemisphere land surface temperatures. If such a correlation is confirmed by further research, the solar cycle will become of more interest to a much wider group of scientists, and will require a redefinition of what is currently meant by solar terrestrial relationships.

Two recent papers (Charvatova and Strestik 1991, Zhigen 1991) provide evidence that planetary movements and alignments have some controlling influence on the solar cycle. These papers add weight to evidence amassed over the last century, the most important of which has been reviewed by Seymour et al (1992). If further research continues to support the correlation between solar activity and the dynamics of the solar system, attempts to understand these data in astrophysical terms should be given more weight than has been the case up to now.

Over the last five years there have been growing doubts about the usefulness of a purely magneto-hydrodynamic approach to solar activity, because it is now clear that detailed models based on this approach have failed to explain the most important features of solar magnetic behavior (Gough 1990). In 1992 a six-month program at the Isaac Newton Institute for Mathematical Sciences at Cambridge, UK focussed on the mathematical problems of dynamo theory (see Proctor et al 1993, and Proctor et al 1995). Two comments highlight the major problems that remain to be solved in connection with the solar dynamo.

"...... Magnetic flux tubes generated in the solar convective zone tend to rise and erupt through the surface. This would be fine if the time scale of rise were of the order of the 22-year sunspot cycle period; but the simplest theory of magnetic buoyancy ... suggests a much shorter time scale of the order of months or less - so short that a dynamo process located in the convective zone appears to be at variance with observed solar activity. (Moffatt, 1993)

"Computer models..... require the integration of the three dimensional fluid equations coupled with the magnetic field equations, a significantly more difficult challenge than that facing weather forecasters. Despite these difficulties... the dynamo problem has stimulated mathematicians, physicists, astronomers, and geophysicists. As with other 'grand challenge' projects, it is the ideas developed along the road that may in the end prove more significant." (Jones,1995)

It has thus become necessary to explore other ways of approaching the problem. This paper sets out a new theory of the solar cycle, based on the concept of resonant coupling between tidal forces of the planets and the evolving magnetic field of the Sun. The theory combines the advantages of simple dynamo models with the more compelling aspects of planetary influence hypotheses, and overcomes the disadvantages of the two separate conceptual classes of approach.

1.2 Observational basis of the new theory

The following sets of observation are explained-

(a) Sporer's Law, which states that at sunspot minimum the first sunspots occur at intermediate latitudes, and as the sunspot cycle progresses so the spots become more frequent and also migrate towards the equator.

(b) The Maunder Butterfly Diagram, which is an extended and detailed graphical representation of Sporer's Law.

(c) The Hale-Nicolson Laws, which state that all spots in the same hemisphere have the magnetic alignment, which is opposite to that found in the other hemisphere, and that in the next cycle the alignments are reversed.

(d) The correlation between the rate of change of angular momentum about the common center of mass of the solar system and changes in the overall envelope of the sunspot curve, including its sign (see Jose,1965). Since the angular momentum of the Sun about the common center of mass is under the control of the planets Jupiter, Saturn, Uranus and Neptune, it seems likely that these planets play the major role in the overall modulation of the solar cycle envelope.

(e) Blizard (1969) showed that on certain occasions flares correlated with ninety degree configurations of the planets as seen from the Sun, and concluded that no physical explanation was reasonable. This conclusion is valid only in the context of equilibrium theory of the tides, but it is exactly what would be expected if some resonance mechanism is involved.

(f) Calculation of tidal forces of planets on the Sun, on the basis of equilibrium theory of tides, shows clearly that these forces differ markedly from one planet to the next. For example if we take that of Jupiter as I unit, then that of Venus is 0.96, Mars 0.01 and Saturn 0.05. Yet Blizard showed that towards sunspot maximum all the planets played a part. All planets could contribute to solar activity if Some amplification mechanism were involved. This too would point to a form of resonant amplification.

2. THE NEW THEORY

2.1. Theoretical principles

The basic concept employed is that of kinematic approximation.. In this approach the effect of the field on the plasma is at first ignored, but the distortion of the field by the plasma is calculated. When the field has been sufficiently amplified by the fluid motion we then consider what effect it has on the motion of the plasma. This is a valid approach for the Sun because measurements of the field and the fluid motions show that in the early stages of the solar cycle the energy in the field is weak compared with in the fluid motions.

The normal ideas of dynamo theory apply, in which a basically dipolar field is distorted, by differential rotation, into a field with a substantial toroidal component which becomes more noticeable near the equator. Small-scale cyclonic motions twist loops into this field, and the loops combine to produce the new dipole field. We suggest that near the poles, sometime between solar maxima and minima, the small-scale cyclonic motions near the poles are reversed, thus eventually giving rise to a field of opposite polarity. This reversal is caused by the movement of the Sun about the common center of mass of the whole Solar System. The principle evidence to support this proposal is that of Jose (1965).

Near the poles the Sun spins on its own axis once in about 33 Earth solar days Jupiter is moving the Sun about the common center of mass of the Solar System

about once every 12 years. At maximum displacement the center of the Sun is about two solar radii from the center of mass of the Solar System, and at such a time the material within two degrees of the poles has two comparable Coriolis effects acting on it - one due to solar rotation and one due to movement about the center of mass. It is known from observations that the dipole field starts to change polarity in the polar cap region, so we would expect this to occur when the pole of the Sun has a maximum displacement from the center of mass. This is in keeping with Jose's observations.

When the Sun's magnetic field begins to emerge in the form of sunspot pairs linked by solar prominences, the field lines between intermediate latitudes and the equator begin to be nearly parallel to the equator. We have made the assumption that at this stage it is more appropriate to use Airy's canal theory of tides to discuss possible planetary effects on the formation of sunspots, because we are interested in the interaction between the tidal forces of the planets and the canal-like magnetic structures on the Sun, rather than their effect on the whole Sun.

The emergence of magnetic tubes of flux are normally attributed to 'magnetic buoyancy' but as already noted, buoyancy is embarrassingly effective, leading to a solar cycle which is far too short. This difficulty can be avoided if we assume that the tubes of flux have been twisted into largely force free helical-like magnetic structures by the small-scale cyclonic motions. The properties of such force free fields were investigated by Freire (1966). The twisting of the field lines would considerably reduce the effects of buoyancy, and the helical magnetic tubes of force would be in a state of unstable equilibrium. Thus the tidal forces of the planets, amplified by magneto-tidal resonance, could very easily provide the necessary additional impulse to cause such structures to rise to the surface.

Magneto-tidal resonance is an important factor in this theory, therefore we explain in detail how it works. Airy (1845) (see also Lamb, 1932) showed that tides in a fluid canal parallel to the equator could be much higher than that calculated on the basis of equilibrium theory, provided the speed of a free wave in such a canal matched the speed of the sub-lunar point. We assume that the speed of the free wave in the helical magnetic tubes of flux which form nearly parallel to the Sun's equator is given by the Alfven speed. When this speed matches the speed of the sub-planetary point of a given planet, then tides due to the influence of this planet will be considerably magnified. Since the Alfven speed increases as the magnetic field increases, so the planet which plays the dominant role will change. Initially influence will come from the inner planets, but towards the end of the cycle the outer planets will dominate.

2.2. Mathematical modeling of the theory

Consider a 'magnetic canal' parallel to the Sun's equator, with a colatitude 8. Suppose the velocity of the free wave in such a canal can be characterized by the Alfven speed (where 8 is the magnetic field strength, and p is the density), then

V = 8/(4pi p)1/2 (1)

so the velocity of the free wave will be directly proportional to the strength of the magnetic field. Let n p be the speed of a planet with respect to an element of matter on the rotating Sun. If M is the mass of a planet, r the distance of the planet from the Sun, a the radius of the Sun and g ' its surface gravity, then the planetary tidal force will be given by

f = 3GMa /2D3 (2)

and the height of the equilibrium tide is given by

H = af /g' (3)

The tidal height in a 'magnetic canal' is given by

u = [V 2 H sin2 8 cos2(n p +o = e)] / 2(V2 - n2p a 2 sin2 8) (4)

where o is the solar longitude under consideration. If V is very nearly equal to anpsin28 then the contribution of the tide due to this particular planet will tend to infinity. The tide will be direct if V is greater than anpsin0 and inverted if V is less than anpsin8. Since the magnetic field B increases in such a canal due to the winding up of field lines, the Alfven speed will also increase, so the tide due to a given planet will change from being direct to being inverted as the solar cycle builds to a maximum.

If we consider two planets 1 and 2 with angular speeds of np1 and np 2 respectively with reference to an element of matter with co-latitude 8, then the situation could arise when V is greater than np1 asin8 and V is less than np2 asin8. In this case the tide due to the one planet would be inverted and that due to the other planet would be direct. This means that the tidal effects of the two planets would be additive when they are separated by 90 degrees of solar longitude. This explains very naturally point (e) in section 1.2, i.e.., violent events on the Sun sometimes correlate with ninety degree configurations as seen from the Sun. At other times helio-centric conjunctions and oppositions can play a similar role.

2.3. Summary of 1st stage testing of mathematical model

In all initial models Seymour et al (1992) input the average solar period as an arbitrary constant, and in some of the models investigated they assumed that the magnetic field strength in the 'canals' varied as a sign wave - zero at sunspot minimum, reaching a peak at solar maximum. The calculations showed that for resonance between the Alfven waves in solar 'magnetic canals' and the tides due to planetary influence, a maximum Alfven speed of the order of 2000 meters per second was required. We can therefore calculate the magnetic field strength required, if the canals are assumed to be in the convective zone of the Sun. At the

top of the convective zone the field strength required is of the order of 700 Gauss and near the bottom of the zone it is of the order of 7000 Gauss.

The measured field strengths in sunspots are between 1000 and 3000 Gauss, so estimates based on the above calculations are consistent with the 'magnetic canals' lying well within the convective zone. All models described above are restricted to 'magnetic canals' confined to the solar equator.

2.4 Tides in 'canals' parallel to the equator

Our most recent investigations concern tides in 'magnetic canals' parallel to the equator. We set out to find regions in which resonance would occur for some simple models for the increase of the solar magnetic field. In the first model the field strength rose and fell with a frequency of about eleven years. This gave the familiar butterfly effect in the build up to solar maximum, but was followed by a mirror image of the butterfly in the fall from maximum to minimum. Clearly this was not in keeping with observations. The fall from maximum field strength after the expulsion of most of the field as a result of magneto-tidal resonance, to almost zero field strength, must be relatively rapid (of the order of a few months). This would keep the normal butterfly but completely suppress the mirror image.

In the next model investigated the change in field strength is represented by a saw-tooth wave, with a steady linear rise and very rapid linear fall. During the linear rise the change in the Alfven speed will also be linear and it will take the form

V = kt (5)

where k is a constant.

In considering the effect of resonance away from the equator, at co-latitude 8, it is necessary to take into account the differential rotation of the Sun. This is because at different co-latitudes the apparent movements of a given planet will be different, and this will alter the resonant conditions. We will assume that the sidereal differential rotation of the Sun can be represented by the following formula:

2.5(radians) - 0.052(radians) cos2 8 (6)

If n pi is the sidereal angular speed of the planet as seen from the Sun then the rotation of the Sun with respect to the planet will be given by

(2.5-n pi)-0.052 cos2 8 (7)

Resonance will arise when

V =a [(2.5 - n pi) - 0.052cos2 8]sin 8 (8)

The sidereal periods of the planets vary from 0.07 radians per day, for Mercury, to 0.0001 per day for Neptune, so sidereal planetary terms are small in comparison with the rotation rate of the Sun. The second term in the square brackets of equation (8) varies from 0.026 at co-latitude of 45 degrees to zero at the equator, so in comparison with the first term in the round brackets it too is small. If we neglect the first term in the round brackets and the second term in the square brackets, then we have, making use of (5)

kt = 2.5a sin 8 (9)

Rewriting this we get

8 = sin-1(kt /2.5a) (10)

Equation (10) means that in the build up to solar maximum sunspots will migrate towards the equator along the first part of a sign curve. This is in keeping with Sporer's Law.

3. CONCLUSIONS

The results of our earlier calculations together with these recent tests show clearly that the theory is able to explain the salient features of the solar cycle: it also incorporates data which shows a link between sunspot activity, planetary movements and alignments. So far we have restricted ourselves to circular co-planar orbits and to the assumption that the rotation axis of the Sun is at right angles to the mean orbital plane of the planets. We have now started investigating the consequences of non-coplanar elliptical orbits and the tilt of the Sun's rotation axis.

It is already evident that the tilt provides an explanation of the observational fact that the reverse of the dipole field does not necessarily occur at the two poles at the same time. The equations governing tidal theory have a more complex form when the planets are not in the equatorial plane of the Sun. There is then an asymmetry of tidal forces with respect to the solar equator. This too is in keeping with observational data on the number of sunspots in the two hemispheres. The complexity of the equations under these new conditions seems to offer other possibilities concerning variations in sunspot activity, and may lead to an explanation for the Maunder and other observed minima in solar activity.

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