

Long Periodic Variations of Magnetic Stars caused by Precession

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Abstract. Long-time observations give evidence of secular variations of the effective magnetic fields for some Ap stars. These secular variations may be interpreted by a precessional motion of the star. The precession of the rotationally flattened star is assumed to be caused either by the orbital motion of a satellite where the plane of the orbit is inclined to the axis of rotation of the star or by rotation of the inner and outer layers of the star around differently inclined axes. ¹

Key words: Magnetic stars, secular variations, precession

With the progression in time of observing and investigating magnetic stars it becomes more and more evident that the effective magnetic field strength of some Ap stars – besides the well-known variation in the time scale of days connected with the rotational period – exhibits secular variations.

One of the first reports on long time variations of the magnetic field of an Ap star (β CrB) was given by PRESTON and STURCH in 1967. They found a period of 10.5 a, which was called in question by WOLFF and BONSACK (1972). BORRA and DVORETSKY (1973) referred the apparent secular variations only due to exposure effects. Later WOLFF and PRESTON (1978) gave a report on secular variations in the case of the star 52 Her, but did not exclude the possibility of measuring artifacts.

In the meantime we have compiled and measured in our observatory 159 Zeeman spectrograms (mainly from Tautenburg) of this star covering the time interval from 1971 to 1983, which – together with the results of WOLFF and PRESTON (1978) as well as those of BORRA and LANDSTREET (1980) – clearly confirm the long-time variation of the magnetic field strength with a period of 13 a, as reported already in ZELENCHUK (1981). The radial velocity, varying with the rotational period of 3.8575 d, beats with the long-time period of 13 a, which can be attributed to a modulation effect. But there is some evidence for a further period of 14 d so that it would be reasonable to assume the presence of a nearby companion resulting in a precession motion.

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But the precession does not demand necessarily an inclined orbital motion of a companion of the rotationally flattened star. So already MESTEL in 1967 and later STIFT in 1977 proposed as a possible explanation of the secular variation of the magnetic field of β CrB the precession of the oblique rotator flattened by magnetic forces around the invariant axis of the angular momentum. There is no necessity for a companion. But it has to be assumed a large oblateness for obtaining the right period so that such an explanation does not prove realistic.

These authors did not mention the paper of BROSCHE (1967) on magnetic variability of stars by precession. BROSCHE discussed a binary star system with a main component flattened by rotation and a companion with less mass, which revolves in an inclined orbit around the primary star. With such a system BROSCHE completely explained the long-time magnetic variations by precession, but there difficulties arise in explaining the short-time variations of days, because he then must assume unrealistic values for the oblateness of the primary star and the mass of the secondary. In BROSCHE's precession formula for the derivation of the torque moment only the gravitation is used. In regard to the fluid bodies with rotational deformation he referred to KOPAL (1965).

In our discussions we studied the precession model further and investigated it in different manner independently of special observed stars, since we believe that it would be certainly valuable to consider this possibility, which may be realized in nature with some probability and does not rule out others, say the dynamo model.

Certainly, an external force acts on a fluid body with a density increasing to the center in such a manner that the torque moment effecting on the outer layers predominates that of the inner layers, resulting in a depth-dependent precession of the star. In analogy to the *differential rotation* in this case a *differential precession* occurs. In the viscose medium of the stellar plasma the differential layers will slide each over the other, while the line of connection of the differential angular momenta is spiralling around the direction of the total angular momentum. Evidently, the more powerful interaction occurs between the companion and the outer layers than between the companion and the inner layers. Consequently, the visible outer layers should undergo a remarkable precession even in the case of a relative insignificant oblateness of the main star. So the observable precessional period is essentially shorter than in the case of a rigid stellar body.

The limiting case of oblateness is a circular disk with the relative difference of the momenta of inertia parallel Φ_1 and perpendicular Φ_2 to the axis of rotation,

$$f = \frac{\Phi_1 - \Phi_2}{\Phi_1} = 0.5 . \quad (1)$$

This relation is valid for a circular ring, too. For the effective outer layers of a fluid stellar body we can assume values of $(\Phi_1 - \Phi_2)/\Phi_1$, not essentially lying under 0.5. (Remind that Saturn has a factor of oblateness of 0.1.)

The deviation of the star configuration from the spherical symmetry is the premise for the effect of a torque moment. For producing the torque moment we have to consider several possibilities:

1. Flattened and inclined top in an inhomogeneous gravitational field of a companion
2. Centrifugal forces of a binary System acting on the rotationally flattened and inclined top
3. Tidal flows and brake effect produced by a companion
4. Top with a magnetic dipole component in direction of its axis of rotation in an external magnetic field (which may be the interstellar field or the field outgoing from a companion)
5. Exchange of masses and stellar wind

The last point is of less importance, because we find a considerable exchange of masses only in special objects. In an interstellar field of the magnitude of 10^{-6} Oe a star with a period of 5 d and a radius of $1 R_{\odot}$ and a polar field strength of $B = 2000 \Gamma$ would have a precessional period of $T \approx 10^{13}$ a; with a nearby companion in a field of 100 Oe we have $T \approx 10^5$ a, so we can rule out this possibility.

The tidal flows are of greater importance, so they should be taken into account as done by DOLGINOV and YAKOVLEV (1975) who interpreted the generation of a magnetic moment in a star revolved around by a companion as a dynamo mechanism. Later we come back to this point, considering now only the first two most important possibilities for the torque moment.

For a first result it is convenient to construct a simplified model, which bears the main features of the real object. A simplified but idealized model of the main star may consist in a circular ring influenced by the external gravitational force of the companion and the major part of the mass of the star concentrated in the center of the ring. By means of such an idealization the precession formula is to be derived easily.

The basic formula for the precessional period comes from the well-known curl product of the torque moment of the top

$$\vec{M} = L(\vec{\omega} \times \vec{k}) \quad (2)$$

(L angular momentum, $\vec{\omega}$ angular velocity around the axis of the angular momentum, \vec{k} unity vector of the figure axis) and yields

$$T_p = \frac{L}{M} 2\pi \sin \varepsilon \quad (3)$$

(T_p precessional period, ε angle of inclination).

For a circular ring with its angular momentum

$$L = m_1 R^2 \frac{2\pi}{T_r} \quad (4)$$

(m_1 mass of the ring, R radius of the ring, T_r rotational period) we have

$$T_p = \frac{m_1 R^2 \frac{2\pi}{T_r}}{\frac{m_1}{2} R^2 \left(3 \frac{\gamma m_2}{r^3} + \frac{m_2}{m_1 + m_2} \frac{4\pi^2}{T_b^2} \right) \cos \varepsilon} \quad (5)$$

(γ gravitational constant, r distance between the center of the ring and the companion, T_b orbital period).

Inserting

$$\frac{\frac{1}{2} m_1 R^2}{m_1 R^2} = \frac{\Phi_1 - \Phi_2}{\Phi_1} \quad (6)$$

– being valid primarily only for the presumed circular ring – and using the third KEPLERian law for deriving the orbital period and taking into consideration that we have a mean torque moment acting during the whole revolution by the factor $\cos \varphi$, which is valid approximately for the projection of the torque moment into the main section of the top (that means: to find the mean progression of time of the precession we have to integrate the \cos^2 -function over the whole circle) the precessional period is

$$T_p = \frac{1}{2 \cos \varepsilon} \frac{\Phi_1}{\Phi_1 - \Phi_2} \frac{m_1 + m_2}{m_2} \frac{T_b^2}{T_r}. \quad (7)$$

After inserting (6) equation (7) holds also for any other form of a top.

Especially for the circular ring, there is valid the equation

$$\frac{m_1 + m_2}{m_2} = \frac{T_p T_r}{T_b^2} \cos \varepsilon, \quad (8)$$

which renders the possibility of computing the mass relation out of the observable periods and the angle of inclination.

Since m_1 , m_2 , and ε are constants for a given system, the relation between the periods of any binary system

$$\frac{T_p T_r}{T_b^2} = \text{const} \quad (9)$$

is an invariant.

In real binary systems the constant contains some uncertain factors. From observation we have no direct information about the mass relation, the relation between the momenta of inertia (oblateness) and the angle of inclination. In several cases this information is achievable otherwise, eventually per estimation. But with the knowledge of any of these parameters it would be possible to determine the others.

The most delicate problem is the determination of the torque moment causing the precession motion of a real astrophysical object. Hitherto we have considered only the effect of the gravitational and the centrifugal forces, neglecting the other above mentioned forces.

If, moreover, we take into account the torque moment by the brake effect of the tidal flows, the parameters in our analytical representation of the precession have to share with some more physical quantities.

DOLGINOV and YAKOVLEV (1975) showed a way for solving this problem. In spite of the fact that the aim of their investigation was to prove the possibility

of generating a magnetic field by the appreciable powerful plasma streams invoked by the tides, we can utilize it for solving further problems connected with deformations of the star body by internal and external mechanical forces.

This leads to the question, if it must be necessarily a binary system, when we observe all signs of a precessional motion. In connection with this question the hypothesis of STIFT – an oblique rotator asymmetrically flattened by magnetic forces – gains new interest. Neglecting the insignificant magnetic deformation we ask, whether a single star without external forces may produce an observable precessional motion. If the star is deformable as a fluid body and if there a “*differential precession*” takes place, we can assume that the layers sliding each over the other may interact in an opposite precession with a complicate coupling of gravitational, centrifugal and brake forces. So the demand for a companion in the case of an observed precession is irrelevant.

Summarizing we can draw some important conclusions:

1. A precessional motion claims a deviation of the interacting parts of the star system from the rotational symmetry. There must be an appreciable angle between the axes of the angular momenta of the constituents, what can only be the consequence of an perturbation after the generation of the star. What kind of perturbation it may be we do not ask here. As well known, all motions in a star system are going to an equilibrium by dissipation, rendering the axes parallel and synchronizing the angular momenta. So a star exhibiting precession must be a “case of pathology”.
2. The precessional motion is accompanied with a change of the aspect of the star producing variations of several observable quantities, of which the magnetic field strength is only one. Precession may occur even without a significant magnetic field. On the other hand the presence of a magnetic field does not lead necessarily to the assumption of a precessional motion as it is realized by the Sun as a single star – neglecting the influence of the planets. The variation of the magnetic field by precession at first sight gives no information about the origin of the field, for it may be frozen in the plasma since the creation of the star.
3. In the whole body of the star powerful motions take place, which can be the cause for generating magnetic fields. Here we propose that not only the *differential rotation* in connection with turbulence (KRAUSE, RÄDLER 1971) and the tidal forces (DOLGINOV, YAKOVLEV 1974, 1975), but also the *differential precession* may be responsible for the generation of magnetic fields on stars.

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