EFFECTS OF MAGNETIC AND GRAVITY FIELDS ON SOLAR FLARES AND PROMINENCES

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Abstract: The evolution and structure of solar flares and prominences are explained from the characteristic behaviour of the plasma in combined magnetic and gravity fields, if only the inner particle velocity is comparable or exceeds the escape velocity.

Charged particles, spiraling along magnetic field lines in an extended gravity field, are governed by Eqs (1)—(12), valid between any two collisions. Effects repeated with a high degree of probability after any collision will be considered as characteristic features of the whole plasma stream in the considered region. Details are given in Woyk (1972a, b).

For the sake of simplicity, let us deal with a collisionless plasma. The basic symbols used in the text are shown in Fig. 1.

A particle with a velocity below the escape velocity, v_{esc}, theoretically possesses two levels of reflection: The magnetic mirror, due to the magnetic field H, which is designated by its distance from the gravity centre r_{H}, and the level r_{g} due to gravity (it is the highest point, a particle of a given path radius R and velocity v can gain in the gravity field). At these two levels r_{H} and r_{g} the deviation of the path from the magnetic field line H is $i = 90°$, while i is minimum at the level r_{W} where the velocity is about $v_{\mathrm{W}} = v_{\mathrm{esc}}/2$. (If v_{W} occurs at r_{H} or r_{g} the particle merely circles around a fix point of the magnetic field line without any shift along or across H.)

If the upper limit of the spiral path, r_{g}, were below the top of the magnetic field line the particle would perpetually spiral up and down between r_{g} and r_{H}. (If r_{g} is above the top, the particle is perpetually reflected between two conjugate magnetic mirrors.)

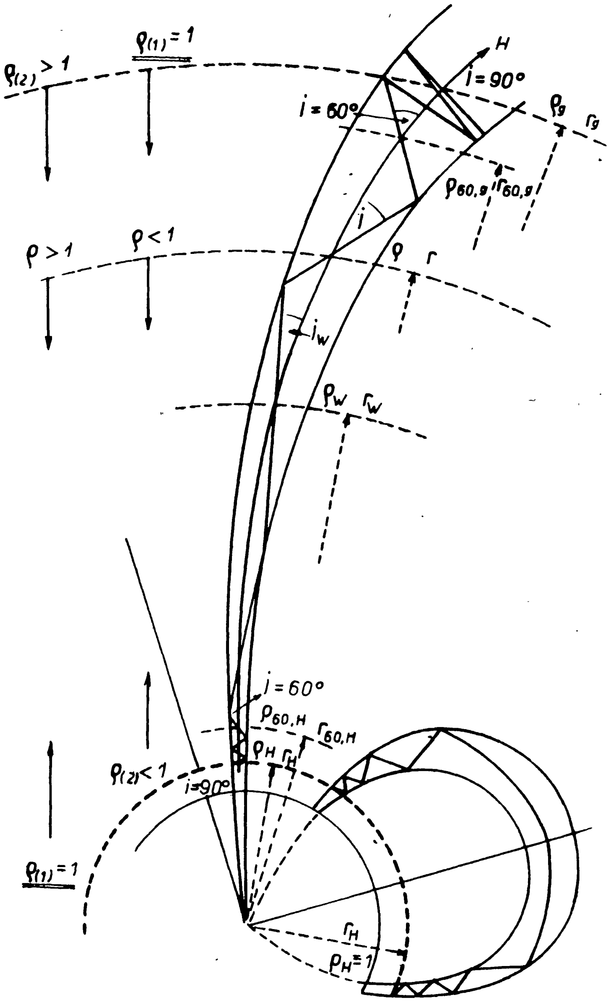

Fig. 1.

In order to make the formulae as general as possible, applicable to any cosmical atmosphere, dimensionless expressions have been introduced. All parameters refer to their values at one of the two levels of reflection (r_{H} or r_{g}) which will be designated by $r_{(1)}$. The radius $r_{(1)}$ will also be used as a new length unit. Thus the radii are

$$\varrho = \frac{r}{r_{(1)}}, \quad \varrho_1 = \frac{r_v}{r_{(1)}}. \tag{1}$$

After this arrangement any spiral path is defined by one basic parameter only

$$E_{(1)} = 1 \Big/ \left(\frac{v}{v_{\text{esc}}}\right)^2_{(1)} = \frac{2GM}{r_{(1)} v_{(1)}^2}, \tag{2}$$

provided the magnetic field is dipolar. $E_{(1)}$ defines the rate v/v_{esc} at the level $r_{(1)}$.

Since, however, the magnetic field is often far from being dipole, the variation of the magnetic field will rather be expressed by

$$\mathrm{H}/\mathrm{H}_{(1)} = \varrho^{-n} \quad (n > 1) \tag{3}$$

in the considered region, and n is now another basic parameter (n need not equal 3).

If (e. g., after a collision) only the velocity (E) and the direction (i) known at a given level r (in km), $E_{(1)}$ is obtained from

$$E_{(1)} = \frac{E\varrho}{E\varrho - (E-1)}, \tag{4}$$

where ϱ is gained by solving

$$\varrho^n \sin^2 i - E\varrho + E - 1 = 0 \tag{5}$$

and $r_{(1)}$ is found from (5) and (1).

The path formula (variation of i with ϱ) is

$$\sin i = 1/[E_{(1)}\varrho^{n-1} - (E_{(1)} - 1)\, \varrho^n]^{1/2} = \frac{v_\perp}{v}. \tag{6}$$

Some other path parameters like the velocity v, its component perpendicular to H, $v_\perp$, the path radius R, the other level of reflection $r_{(2)}$, the critical level r_{W} with $i =$ minimum are

$$R/R_{(1)} = \varrho^{n/2} \tag{7}$$

$$v_\perp / v_{\perp(1)} = \varrho^{-n/2} \tag{8}$$

$$v/v_{(1)} = \sqrt{[E_{(1)}/\varrho - (E_{(1)} - 1)]} \tag{9}$$

$$\Sigma_{(1)} = \sum_{j=0}^{n} \varrho_{(2)}^{-j} \qquad \left(\varrho_{(2)} = \frac{1}{E_{(1)} - 1}\right) \text{ for } n = 2 \tag{10}$$

$$\varrho_{(2)} = \frac{r_{(2)}}{r_{(1)}} = \frac{0.5 + \sqrt{(E_{(1)} - 3/4)}}{E_{(1)} - 1} \tag{10-dipole}$$

$$S_{\mathrm{W}} = \frac{E_{(1)}}{n} \cdot \frac{n-1}{E_{(1)} - 1}\,; \quad v_{\mathrm{w}} = v_{\text{esc}}/\sqrt{n}\,; \quad E_{\mathrm{W}} = n\,;$$

$$\sin i_{\mathrm{W}} = \left(\frac{E_{(1)} - 1}{n-1}\right)^{(n-1)/2} \left(\frac{n}{E_{(1)}}\right)^{n/2}. \tag{11}$$

The level at which i has a given value is found by solving

$$\varrho_i^n - \frac{E_{(1)}}{E_{(1)} - 1}\, \varrho_i^{n-1} + \frac{1}{(E_{(1)} - 1)\sin^2 i} = 0. \tag{12}$$

If collisions are taken into account (keeping in mind that before and after a collision the same number of particles gains the direction $i > 60°$ as $i < 60°$), the deductions A, B, C, can be drawn. They are briefly explained as follows: In higher, less dense regions the particle rather slides than circles (i is smaller); thus after a collision it is probable that i increase more than in deeper, more dense parts (near the magnetic mirror where i approaches 90°). After an increase of i (i. e. when the path becomes more perpendicular the spirals more squeezy) also the mean magnetic mirror shifts upwards, impeding the particles of the plasma jet in reaching the stellar surface again. Thus, the collisions near the mean magnetic mirror rather cause a downshift of the exploded gas, and the collisions which occur in the upper parts of the plasma jet contribute to its turning into apparently motionless, stable arcs, or clouds, even though their inner motion is $v \gtrsim v_{\text{esc}}$.

(A) Conditions favourable for trapping an exploded gas are:

(A1) Velocity at the magnetic mirror high above $v_{\mathrm{W}} \approx 1/2\ v_{\text{esc}}$

(A2) Collisions far from r_{H} and r_{g}: Between the two levels with $i = 60°$.

(A3) The mean velocity must not decrease for other reasons than gravity.

(A4) The top of the field line must be high above the lower level with $i = 60°$.

(A5) The magnetic field varies so that n increases.

(B) An expansion and falling of the exploded stream is expected when opposite phenomena occur (B1) — (B5).

(B6) In polar regions, where the top of the field line is practically infinite, trapping is exluded on account of the rapid spread of the plasma jet towards the interstellar space.

(C) With respect to (A4) and (B6), a plasma exploded from the whole stellar surface becomes trapped and condensed only when it streams from relatively high latitudes but far from the poles. Thus usually a thin, hollow torroid is created, which hovers apparently motionless above the stellar equator.

Also phenomena observed above the photosphere are usually governed by the above theorem. (Below the photosphere a rather chaotic motion prevails, $p_{\mathrm{kin}} > p_{\mathrm{magn}}$). If we consider the big magnetic tubes situated below the photosphere, which increase in intensity during the solar cycle, we reach the following conclusions; when $p_{\mathrm{grav}} < p_{\mathrm{kin}} + p_{\mathrm{magn}}$ the region should explode. The surrounding space impedes an immediate explosion. When, however, the magnetic tube rises and expands slightly, it is far from the dipolar case. A very slight decrease of the intensity H (about 1%) which occurs between the levels r_0 and 1.001 r_0 represents an extremely high value of $n \approx 10$. As to (A5), the trapping and squeezing towards the top of the magnetic field line is very strong.

Prominences: When particle velocities inside an explode plasma jet exceed the velocity $v_{\mathrm{W}} \approx \frac{1}{2} v_{\mathrm{esc}}$, the stream becomes trapped and turns into an apparently motionless stable prominence or filament. When the squeezing towards the top is too high, so high that $p_{\mathrm{kin}} > p_{\mathrm{magn}}$, the whole configuration collapses, some parts are ejected, afterwards they fall down freely, to levels of sufficiently high H.

Flares: An increase of the subphotospheric magnetic field with a very high n brings about strong squeezing towards the magnetic zero-line, which represents the top of the magnetic loops. A brilliant point arises in the middle between two sunspots of different polarity.

Proton flares: If many big magnetic "tubes" are compressed above the surface, the uppermost parts can disolve into the outer parts of the chromosphere in the form of prominences, while in the most inner region the trapping is weak (the top is too low, the time m sufficient for real trapping and squeezing towards the top). Thus, again, a large tunnel, or a large bubble, arises, in which the inner plasma is compressed severely towards the magnetic zero-line where a filamentary flare develops. After a relatively short time either the magnetic field lines deform so that n shifts from about 10 towards 3, or the particle velocity decreases (due to losses by energy exchange). Both effects result in a downward shift of the mean magnetic mirror. The maximum plasma density shifts downwards along the field lines and, since one sees more particles tangentially to the field line, than when looking across, the central filament splits into two filaments, slightly deviating from each other. They can be observed well just above the chain of sunspots, because we are now looking tangentially to the shell.

Some details showing, e. g., how the character of the stream changes, if the velocity, the magnetic field variation (n-) and the direction gradually change at the points of collision, are given in several tables by Woyk (1972b) and the derivation of the mentioned formulae is indicates by Woyk (1972a).

References

WOYK, E. (1972a): Bull. Astron. Inst. Czech., *23*, 272.

WOYK, E. (1972b): Bull. Astron. Inst. Czech., *23*, 279.