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Superheavy magnetic monopoles trapped into the Sun and the solar system

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We investigate the possibility of a local enhancement in the galactic flux of magnetic monopoles. A cross section for gravitational capture in bound orbits around the Sun is evaluated as a function of the monopole's velocity and mass. An enhancement factor is calculated which is of $\mathcal{O}(10)$ near the solar surface and falls to unity beyond a few solar radii. As a result no significant enhancement of the monopole flux is expected at the Earth. On the other hand, the large number of monopoles trapped into the Sun over its lifetime can have observable consequences. Here we concentrate on the emission of a monoenergetic ν flux coming from two body nucleon decays catalyzed by means of the Rubakov effect. Such a flux can be used to extend the sensitivity of the experimental searches to monopole fluxes down to $\Phi \leq 10^{-22} \left(\frac{10^{-24} \text{ cm}^2}{\sigma} \right) \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ where σ is the catalysis cross section, for $m \sim 10^{17} \text{ GeV}/c^2$ and $\beta \leq 10^{-3}$.

I. INTRODUCTION

In the last decade there has been a great deal of interest in the possibility that a detectable flux of slowly moving, supermassive magnetic monopoles may exist in the neighborhood of the Earth. Such monopoles have been predicted to exist in many non-Abelian gauge theories [1], which include Grand Unified Theories of the weak, electromagnetic and strong forces [2]. In addition the Early Universe has been shown to have had very favorable conditions for the production of GUT monopoles [3]. Even in the framework of inflationary models a detectable flux of those particle (i.e. of the order of the Parker bound [4]) might exist in our galaxy [5], [6].

It has been argued [7] that the presence of the Sun might enhance the local flux of magnetic monopoles by gravitational trapping. In order to perform such calculation an accurate knowledge of the the energy loss processes, suffered by a supermassive monopole, in the solar interior, is needed. In [8] and [9] was used a stopping power [10] which is valid when the medium can be treated as a degenerate electron gas. However, as shown in [11], this hypothesis fails and the medium has to be considered as a non-degenerate classical electron gas.

We evaluate, by using the new stopping power formula, the enhancement factor as a function of the distance from the Sun, taking into account the possibility that magnetic monopoles might also have an electric charge. Furthermore the number of monopoles trapped into the Sun is calculated and the observable consequences are discussed. In particular, we estimate the flux of ν 's coming form two body nucleon decays catalyzed by the monopoles [12]. By looking for such a monoenergetic flux of ν 's, above the atmospheric ν background, could place stringent limits on the monopole (dyon) abundance in the solar system.

II. GUT MONOPOLES AND THE SUN

Inside the Sun monopoles are acted on by three major forces; gravitational forces directed the center of the Sun, dissipative forces (dE/dx) directed opposite to the direction of motion and magnetic forces whose magnitude and direction vary with position and time within the solar cycle.

A. The solar model

All of our knowledge concerning the physical conditions in the interior of the Sun must be obtained indirectly. Interior temperatures, densities and chemical composition must be inferred from the solar mass, luminosity, age and

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assumed initial composition through the use of a stellar model ¹. We have used one such model [14], calculated for a 4.9×10^9 y old Sun, to obtain parameters relevant to the calculation of stopping power. The radial distribution of temperature, density, interior mass fraction ($M(r)/M_{\odot}$ where M_{\odot} is the solar mass) and hydrogen mass fraction, calculated according to this model, are shown in Fig.1. These values are all that are needed to evaluate the gravitational and dissipative forces experienced by a GUT monopole of arbitrary velocity and position within the Sun.

B. The magnetic fields

Much less certain is the magnitude and distribution of magnetic fields within the Sun. A somewhat consistent picture has emerged which attempts to explain the observed large scale features of the photospheric magnetic fields in terms of a solar dynamo operating within the convective zone.

According to the dynamo theory, a combination of differential rotation and convection drives an oscillation between a toroidal and a poloidal magnetic field configuration with a fundamental period of roughly 22 years. Each configuration returns with the familiar 11 year solar cycle but with reversed polarity. The strength of the poloidal field is highly variable but the mean magnitude is estimated to be of several Gauss.

The toroidal field tends to concentrate into flux tubes which, as a result of magnetic pressure have a reduced density and rise to the surface where they erupt as the familiar dipolar regions. In order to account for the observed magnetic field in these flux tubes, the toroidal field in the lower convective zone (less than $\sim 10^5$ Km below the surface) must be at least ~ 100 Gauss. On the other hand, if the field is much larger than 100 Gauss or is generated above a depth of $\sim 10^5$ Km, the flux tubes could not remain submerged for a time greater than their generation time (~ 3 y). Very little is known concerning magnetic fields in the regions of the Sun beneath the convective zone.

Critics of the dynamo model claim that the presence of intense magnetic fields within the flux tubes reduces the efficiency of the convective dynamo to such a great extent that another explanation for the solar cycle must be sought. This has led to speculations that the solar magnetic fields originate from a primordial remnant field which lie beneath the convective zone. Indeed it has been pointed out that remnant fields of up to 10^6 Gauss could exist in the core of the Sun without altering the central pressure enough to be at odds with the observed solar neutrino flux.

At the present time no self consistent "primordial" theory has been developed that can quantitatively account for the bulk of the observed solar phenomena and we will disregard such possibilities in our calculations.

C. Energy loss inside the Sun

There are several mechanisms by which magnetic monopoles lose their energy in moving through matter. The solar interior can be described as a completely ionized non degenerate electron gas. The reason for this is that the electrons in the Sun are at sufficiently high temperature and low density that the interparticle separation is larger than the thermal De Broglie wavelength. Ahlen et al. [11] have calculated the energy loss for a monopole passing through such a gas. They found that

$$\frac{dE}{dX} = 9.32\beta \left(\frac{g}{g_D}\right)^2 \cdot \frac{(1 + X_H)}{T_7^{1/2}} \cdot \ln \left[\sin \left(\frac{\psi_{min}}{2} \right) \right] \cdot F(\psi_{min}, g) \cdot C_M (17.2\beta T_7^{-1/2}) \cdot GeV cm^2/g \quad (1)$$

where

X_H is the hydrogen mass fraction of the solar matter

T_7 is the solar temperature in units of $10^7 K$

ψ_{min} is the minimum scattering angle between the monopole and the electron (few degrees [11])

F and C are two coefficient of the order of unity.

A preliminary estimate of the stopping power in eq.(1) [15] was used with a missing factor two in [16] to evaluate the dynamics of monopoles in main sequence stars. The problem of the trapping of monopoles in the Sun was also treated in [17] where the stopping power was evaluated as the sum of the one due to binary collisions in a non-degenerate

¹Helioseismology also can provide information about the temperature and density distribution within the Sun and its chemical composition [13].

electron gas (estimated in the first order approximation in the ratio of the monopole velocity to that of the electron) and the one due to collective effects. Both resulted to be one order of magnitude smaller than what is given in eq.(1)

For the case of dyons we just need to calculate $G_c(\beta_\infty)$ by using the appropriate expression for the energy loss which includes the effect due to the electric charge. However, as shown by Ahlen et al. [11], the energy loss of a $g = g_D$ dyon with electric charge e is quite similar to that of a $g = g_D$ bare monopole:

$$\frac{(dE/dX)_{dyon}}{(dE/dX)_{mono}} - 1 \simeq \begin{cases} 6.3 \times 10^{-2} T_7^{-1} & \text{if } \beta \ll 6 \times 10^{-2} T_7^{1/2} \\ 2.1 \times 10^{-4} \beta^{-2} & \text{if } \beta \gg 6 \times 10^{-2} T_7^{1/2} \end{cases} \quad (2)$$

As can be seen in the following, due to this small difference, the results of this work are also valid for the case of dyons.

D. The motion of a monopole inside the Sun

The uncertain and highly variable nature of the solar magnetic field complicates the problem of calculating the motion of GUT monopoles in the Sun.

If we neglect the possibility of large remnant magnetic fields buried below the convective zone, we find that the magnetic forces on a Dirac monopole moving with speeds in excess of $10^{-3} c$ are comparable to the dissipative forces only in the upper convective zone. Over most of the volume of the Sun magnetic forces are negligible and as a matter of convenience we shall neglect them in this calculation.

With this simplification one can evaluate the stopping power of a GUT monopole as a function of radial position r and velocity β within the Sun using Eq.1 and the model parameters from Fig.1. In this case ψ_{min} has an apparently large variation between 15.5 deg at the center of the Sun and 2 deg at the surface. However this contributes less than a factor of two variation to the stopping power since, apart from the small correction term $F(\psi_{min}, g)$, ψ_{min} appears only in a logarithmic term.

III. THE CAPTURE CROSS SECTION

We are now in a position to evaluate the geometric factor G_c , for capture of galactic GUT monopoles by the Sun into the solar system.

A typical trajectory for a monopole that passes through the Sun is shown in Fig.3. Here the monopole initially approaches the Sun with a velocity $v_\infty = \beta_\infty \cdot c$ and impact parameter b . It strikes the surface of the Sun with a velocity $v_s = \beta_s \cdot c$ and an angle θ_s , measured from the radial vector \vec{r} , given by

$$\beta_s = \sqrt{(\beta_\infty)^2 + (\beta_\odot^{esc})^2} \quad (3)$$

$$\sin\theta_s = \left(\frac{b}{R_\odot}\right) \left(\frac{\beta_\infty}{\beta_s}\right) \quad (4)$$

where $v_\odot^{esc} = \beta_\odot^{esc} \cdot c = \sqrt{2\frac{GM_\odot}{R_\odot}}$, M_\odot and R_\odot are the escape velocity, the mass and the radius of the Sun, while G is the gravitational constant. Within the Sun it is acted on by dissipative and gravitational forces:

$$\vec{F}_d = -\left|\frac{dE}{dx}\right| \cdot \hat{v} \quad (5)$$

$$\vec{F}_g = -G \frac{M(r)m}{r^2} \hat{r} \quad (6)$$

where m is the mass of the monopole.

¹It has to be noticed that the contribution due to collective effects was estimated, in [18], to be negligible. See also [11] for a discussion of this point.

To be captured into the solar system a monopole must exit the Sun with $\beta < \beta_{\odot}^{esc} = 2 \cdot 10^{-3}$. Unless such monopoles receive a significant perturbation to their orbit external to the Sun, they will eventually reenter the Sun and become trapped. We have evaluated G_c by solving the time reversed equations of motion to obtain b as a function of β_{∞} for monopoles leaving the Sun's surface with $\beta = \beta_{\odot}^{esc}$ and at various angles θ_e (see Fig.3).

For purposes of simplification the calculation was performed in the plane containing the velocity \vec{v} and the radial vector \vec{r} . At a given value of β_{∞} , all monopoles with an impact parameter less than $b(\beta_{\infty})$ will be captured. The geometrical factor is thus

$$G_c(\beta_{\infty}) = \pi[4\pi b(\beta_{\infty})^2] \quad (7)$$

For comparison a completely absorbing non-gravitating and gravitating Sun would have respectively

$$G_c(\beta_{\infty}) = 4\pi^2 R_{\odot}^2 \quad (8)$$

$$G_c(\beta_{\infty}) = 4\pi^2 R_{\odot}^2 [1 + (\beta_{\odot}^{esc}/\beta_{\infty})^2] \quad (9)$$

The latter was used by Dimopoulos et al. [7] to evaluate the monopole capture rates and is correct only in the low velocity limit, where all monopoles that enter the Sun become trapped.

In Fig.4 we plot values of G_c as a function of β_{∞} for monopoles with a variety of masses and magnetic charges. All values have been normalized by dividing by $4\pi^2 R_{\odot}^2$, the geometry factor for a completely absorbing non-gravitating Sun. For monopoles of Dirac charge with masses below 10^{16} GeV/ c^2 the approximation used by Dimopoulos et al. overestimate the capture rate by only a factor of two. However if the mass is greater than 10^{17} GeV/ c^2 , monopoles with $\beta_{\infty} = 10^{-3}$ will be captured into the solar system at a negligible rate. It should be noted that, at any monopole mass in the expected GUT range, the capture rate is a sensitive function of β_{∞} .

IV. THE POSSIBLE ENHANCEMENT

These results can be used to evaluate an enhancement factor to the galactic flux of magnetic monopoles within the solar system. In [8] such an enhancement was calculated to be of the order of $5 \cdot 10^3 p(\frac{m}{10^{17} \text{ GeV}/c^2})$, where p is the probability that a monopole will encounter a region with a magnetic field strength $\sim (\frac{m}{10^{17} \text{ GeV}/c^2})$ MG. In fact in that case only monopoles in orbits with perihelion greater than R_{\odot} were considered as contributing to the enhancement; thus the need of a strong magnetic field.

We neglect the possibility of large magnetic fields inside the Sun (for which there is no evidence) and thus we do not have any constraint to the perihelion of the orbit. A monopole traverses the Sun and gets trapped into the solar system if it leaves the star surface with $\beta < \beta_{\odot}^{esc}$. It will perform a certain number of orbits (traversing the Sun each time and losing energy and orbital angular momentum) before being finally trapped. During this time it contributes to the local enhancement of the monopole flux.

Let $\phi_{gal}(\beta)$ be the galactic monopole flux, as seen in the solar system. It is given by

$$\phi_{gal}(\beta) = \Phi \cdot \left(\frac{df}{d\beta} \right)_{\beta_{\odot}} \quad (10)$$

where:

$(\frac{df}{d\beta})_{\beta_{\odot}}$ is the fraction of monopoles with

velocity the interval βc and $\beta c + d\beta c$ with respect to the Sun;

$\beta_{\odot} c$ is the Sun's velocity with respect to the galactic frame;

$\Phi = \int_0^1 \phi_{gal}(\beta) d\beta$

Therefore the local monopole flux can be written as

$$\phi_{loc}(\beta) = \phi_{gal}(\beta) + \phi_{cap}(\beta) \quad (11)$$

where ϕ_{cap} is due to the capture effect. We also define the enhancement factor as the ratio (Φ_{loc}/Φ_{gal}) .

A. The calculation and its results

As stated above, the scenario is the following: a monopole with initial velocity $\beta_{\infty} c$ with respect to the Sun traverses it and become trapped in the solar system with a cross section given by $G_c(\beta_{\infty})$. At subsequent encounters with the

Sun it will lose energy and momentum. After a time $\tau(\beta_\infty)$, during which it contributed to the local enhancement, it will be captured into the Sun.

Let $N(t, \beta_\infty)$ be the number of monopoles, having initial velocity $\beta_\infty c$ with respect to the sun, which at time t are orbiting in the solar system. We can write

$$N(t + \delta t, \beta_\infty) = N(t, \beta_\infty) + G_c(\beta_\infty) \cdot \phi_{gal}(\beta_\infty) \cdot \delta t - N(t, \beta_\infty) \cdot \frac{\delta t}{\tau(\beta_\infty)} \quad (12)$$

Taking $t = 0$ as the birth of the solar system and T as its age, we can solve this equation to obtain the number of monopoles $N(T, \beta_\infty)$, whose initial velocity was $\beta_\infty c$ and are now orbiting around the Sun:

$$N(T, \beta_\infty) = G_c(\beta_\infty) \cdot \phi_{gal}(\beta_\infty) \cdot \tau(\beta_\infty) \cdot \left(1 - e^{-T/\tau(\beta_\infty)}\right) \quad (13)$$

We can estimate the enhancement factor as a function of the distance r from the center of the Sun as follows:

$$\eta(r) \simeq 1 + \int_{\beta_\infty^{min}(r)}^{\beta_\infty^{max}} G_c(\beta_\infty) \cdot \left(\frac{df}{d\beta_\infty}\right)_{\beta_\odot} \cdot \tau(\beta_\infty) \cdot \left(1 - e^{-T/\tau(\beta_\infty)}\right) \cdot \frac{\bar{\beta}(\beta_\infty) c}{4\pi} \cdot \frac{1}{\frac{4}{3}\pi[r_m^-(\beta_\infty)]^3} \cdot d\beta_\infty \quad (14)$$

where $\bar{\beta}(\beta_\infty)$ and $r_m^-(\beta_\infty)$ are, respectively, the mean values for β and the maximum distance from the Sun for an orbiting monopole with an initial velocity $\beta_\infty c$. The integration is performed between $\beta_\infty^{min}(r)$ and β_∞^{max} , the β range in which this mechanism is efficient. In particular, $\beta_\infty^{min}(r)$ is the minimum value of β needed by a monopole to be captured in orbit with mean radius r .

The factors in eq.(14) were calculated numerically by means of an iterative procedure which takes into account the energy and orbital momentum losses in each crossing of the Sun. The n^{th} orbit is then characterized by the values E_n and L_n . In particular

- Magnetic monopoles can be considered as Cold Dark Matter particles. Therefore the β distribution was assumed to be a Maxwell-Boltzman distribution in the galactic reference frame, with a mean velocity given by the virial velocity $\beta_m \sim 10^{-3}$ (see ref. [19]). The β distribution $\left(\frac{df}{d\beta}\right)_{\beta_\odot}$ is obtained by taking into account the motion of the Sun in the galaxy, with a velocity $\beta_\odot c \simeq 250$ Km/s. Following the calculations of ref. [20], we used:

$$\left(\frac{df}{d\beta}\right)_{\beta_\odot}(\beta) = \sqrt{\frac{3}{2\pi}} \left(\frac{\beta}{\beta_\odot \beta_m}\right) \left[e^{-\frac{3}{4}\left(\frac{\beta-\beta_\odot}{\beta_m}\right)^2} - e^{-\frac{3}{4}\left(\frac{\beta+\beta_\odot}{\beta_m}\right)^2} \right] \quad (15)$$

- $\tau(\beta_\infty)$ is the time spent by a monopole, with initial velocity $\beta_\infty c$ with respect to the Sun, in orbiting in the solar system before being trapped into the Sun. Given $N_{tot}(\beta_\infty)$, the total number of orbits of such a monopole, $\tau(\beta_\infty)$ is approximately given by

$$\tau(\beta_\infty) \simeq \sum_{n=1}^{N_{tot}(\beta_\infty)} T_n(\beta_\infty) \quad (16)$$

where

$$T_n^2 = \left(\frac{4\pi^2}{GM_\odot}\right) \left(\frac{GM_\odot m}{2E_n}\right)^3 \quad (17)$$

The value of the enhancement factor as a distance from the center of the Sun is plotted in Fig.5, for different values of the monopole's mass. As can be seen from that figure, the enhancement is practically confined to a region of a few solar radii. We expect a negligible enhancement to the flux of monopoles in the neighborhood of the Earth. Numerical calculations show that the local enhancement is practically absent in the case of monopole's mass lower than 10^{17} GeV. In that case they are rapidly captured in the interior of the Sun. For higher values of the monopole mass, $\eta(r)$ assumes higher values, but the existence of such heavy monopoles can be ruled out by the closure bound on the Universe [21].

V. MONOPOLES AND DYONS TRAPPED INTO THE SUN: POSSIBLE OBSERVABLE EFFECTS

Since the formation of the Sun a number of monopoles (and anti-monopoles) have been trapped into the star by means of the mechanism explained above. This number can be calculated to be

$$N_{\mathcal{M}} = \int_{\beta_{\infty}^{\min}}^{\beta_{\infty}^{\max}} N_{sun}(T, \beta_{\infty}) d\beta_{\infty} \simeq 3 \times 10^{25} \Phi_P \quad (m = 10^{17} \text{ GeV}) \quad (18)$$

where

$$N_{sun}(T, \beta_{\infty}) = G_c(\beta_{\infty}) \cdot \phi_{gal}(\beta_{\infty}) \cdot T - N(T, \beta_{\infty}) \quad (19)$$

and Φ_P is the galactic flux in units of $10^{-15} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. The value of $N_{\mathcal{M}}$ is shown in Fig.6 for different values of m .²

These GUT monopoles may have several phenomenological consequences [9] [16] [17]. One of these is the production of a ν flux from catalyzed nucleon decays by means of the Rubakov-Callan effect [12]. The cross section for such an effect can be written as [22]

$$\sigma = \frac{\sigma_0}{\beta_r} \cdot \mathcal{F}_N(\beta_r) \quad (20)$$

where σ_0 is estimated to be of the order of the hadronic cross sections, $\beta_r c$ is the relative velocity and $\mathcal{F}_N(\beta_r)$ is a correction factor due to nuclear effects. In the case of ^1H nuclei $\mathcal{F}_N(\beta_r) \simeq 0.17/\beta_r$ and $\mathcal{F}_N(\beta_r) = 1$ for neutrons. In the interior of the Sun the dominant contribution to the catalysis cross section is then given by the ^1H nuclei.

The rate of energy production by nucleon decay is given by [23]

$$\left(\frac{d\epsilon}{dt}\right) = \rho \sigma \beta_r c N_{\mathcal{M}} \simeq 2.4 N_{\mathcal{M}} \left(\frac{\sigma}{0.1 \text{ mb}}\right) \left(\frac{\beta_r}{10^{-3}}\right) \left(\frac{\rho}{\text{g/cm}^3}\right) \text{ erg/s} \quad (21)$$

where ρ is the nucleon mass density and $\beta_r c$ is the thermal velocity of the nucleons at $T \simeq 10^7 \text{ K}$.

The number of high energy neutrinos emitted as a consequence of the two-body decay

$$\mathcal{M} + N \rightarrow \mathcal{M} + X + \nu$$

with branching ratio $BR_{N \rightarrow X \nu}$, is

$$\left(\frac{dN_{\nu}}{dt}\right) = \frac{BR_{N \rightarrow X \nu}}{m_N c^2} \left(\frac{d\epsilon}{dt}\right) \sim \quad (22)$$

$$\sim 1.2 \times 10^{29} \left(\frac{\sigma}{0.1 \text{ mb}}\right) \left(\frac{\beta_r}{10^{-3}}\right) \left(\frac{\rho}{50 \text{ g/cm}^3}\right) \left(\frac{BR_{N \rightarrow X \nu}}{5\%}\right) \left(\frac{N_{\mathcal{M}}}{3 \times 10^{25} \Phi_P}\right) \Phi_P \text{ s}^{-1} \quad (23)$$

where m_N is the nucleon mass. At the distance of the Earth there is a monochromatic flux of neutrinos with energy

$$E_{\nu} = \frac{1}{2} m_N - \frac{1}{2} \frac{m_X^2}{m_N} \quad (24)$$

which is given by

$$\begin{aligned} \phi_{\nu} &= \frac{1}{4\pi R_{\odot-\oplus}^2} \cdot \left(\frac{dN_{\nu}}{dt}\right) \sim \quad (25) \\ &\sim 7.2 \times 10^6 \left(\frac{\sigma_0}{0.1 \text{ mb}}\right) \left(\frac{10^{-3}}{\beta_r}\right) \left(\frac{\rho}{50 \text{ g/cm}^3}\right) \left(\frac{BR_{N \rightarrow X \nu}}{5\%}\right) \left(\frac{N_{\mathcal{M}}}{3 \times 10^{25} \Phi_P}\right) \Phi_P \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \end{aligned}$$

²Similar results were obtained in ref. [16] in a different way. The discrepancies are due to the different velocity distribution used for galactic monopoles (they assumed a flat one with a cut-off at the escape velocity from the galaxy [8]) and to a missing factor of two in the energy loss inside the Sun.

By requiring such a ν flux to be smaller than the flux of atmospheric neutrinos integrated in a given energy region, we obtain

$$\sigma_0 \cdot N_{\mathcal{M}} \lesssim 4\pi R_{\odot}^2 \frac{1}{BR_{N \rightarrow X \nu}} \frac{m_N c^2}{\rho c \mathcal{F}_N(\beta_r)} \int_{E_{\min}}^{E_{\max}} \left(\frac{d\phi_{\nu_{atm}}}{dE_\nu} \right) dE_\nu \quad (26)$$

which reduces to

$$\left(\frac{\Phi}{10^{-15} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}} \right) \left(\frac{\sigma_0}{0.1 \text{ mb}} \right) \lesssim 1.2 \times 10^{-7} \phi_{\nu_{atm}}(200 - 400 \text{ MeV}) \sim 6 \times 10^{-9} \quad (27)$$

where we used for $\left(\frac{d\phi_{\nu_{atm}}}{dE_\nu} \right)$ values taken from [24] and we integrated roughly around $E_\nu = 339.3 \text{ MeV}$ which is the neutrino energy in the case of $p \rightarrow K^+ \nu$. The flux of magnetic monopoles in our galaxy is then required to be several orders of magnitude below the Parker bound (even the extended one [25])

$$\Phi \lesssim 10^{-22} \left(\frac{10^{-24} \text{ cm}^2}{\sigma} \right) \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \quad (28)$$

for values of the monopole's velocity such that $\beta \leq 10^{-3}$.

As pointed out in ref. [16] it should be noted however, that monopoles at the center of the Sun might be thermally supported without any separation between \mathcal{M} and $\bar{\mathcal{M}}$ distributions, allowing a large number of $\mathcal{M}\bar{\mathcal{M}}$ annihilations to occur. This clearly results in a weaker flux limit (of the order of the Parker bound).

VI. SUMMARY

In this paper we have presented calculations concerning a possible local enhancement in the galactic flux of superheavy magnetic monopoles due to the presence of the Sun. The enhancement factor was evaluated as a function of the distance from the center of the Sun. No significant effects are predicted at the Earth since such a factor was shown to be dropping to one at few solar radii from the center of the Sun.

We also investigated some observable effects due to the large number of monopoles trapped into the Sun. In particular we have calculated the number of high energy neutrinos (hundreds of MeV) emitted as a consequence of two body nucleon decays catalyzed by the presence of the monopoles by means of the Rubakov-Callan effect. Such a flux can be used to extend the sensitivity of experimental searches several orders of magnitude below the Parker bound by looking for an excess of ν 's from the direction of the Sun.

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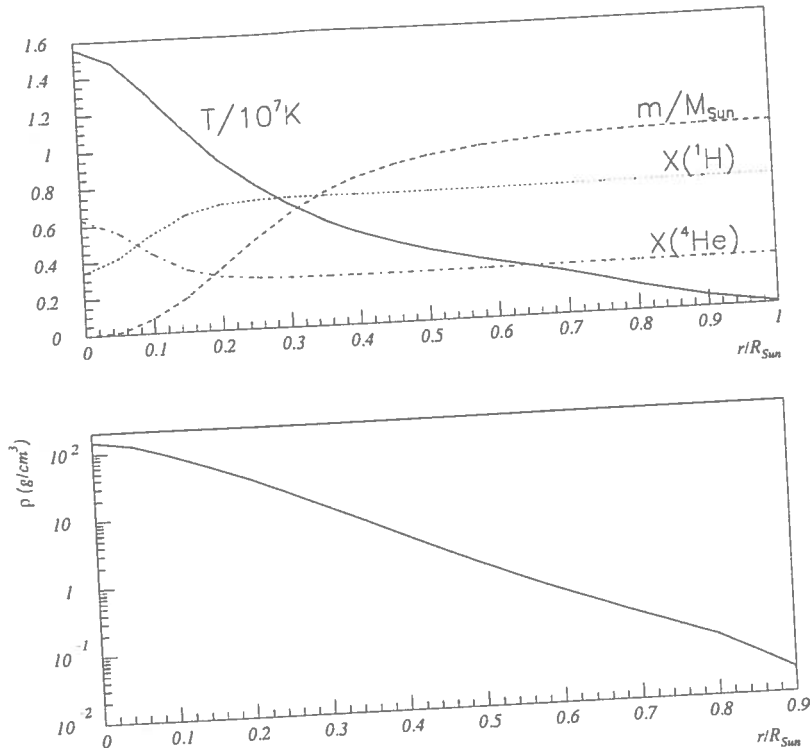


FIG. 1. Solar parameters from [13].

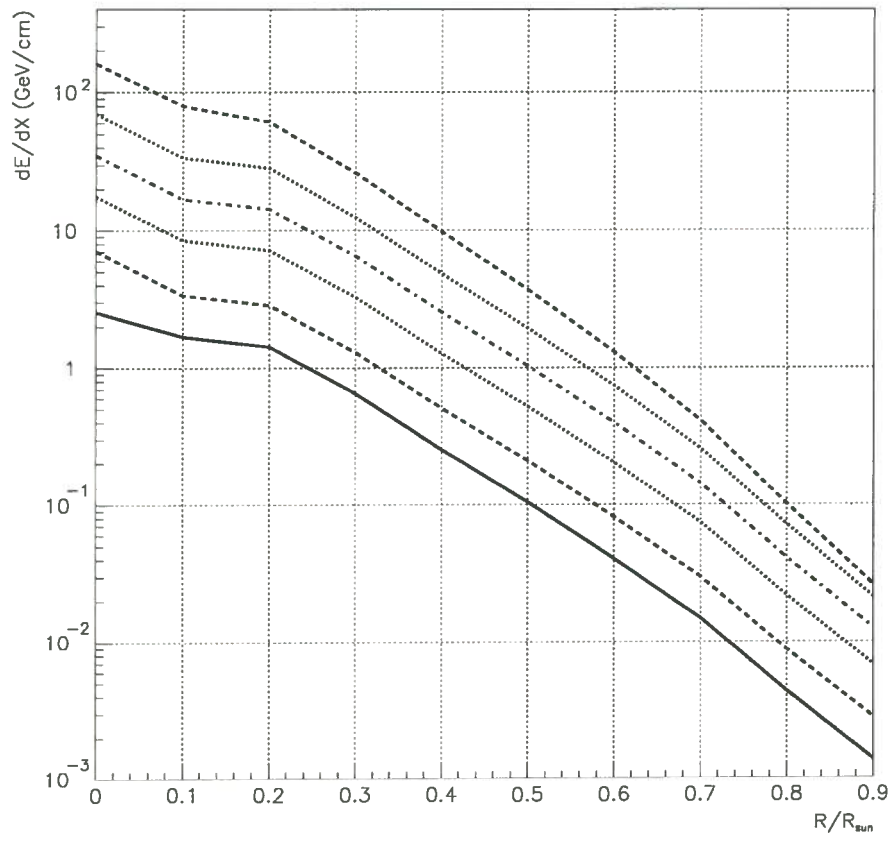


FIG. 2. Monopole's energy loss, as a function of the distance from the center of the Sun, for different values of β : 10^{-3} , 2×10^{-3} , 5×10^{-3} , 10^{-2} , 2×10^{-2} and 5×10^{-2} .

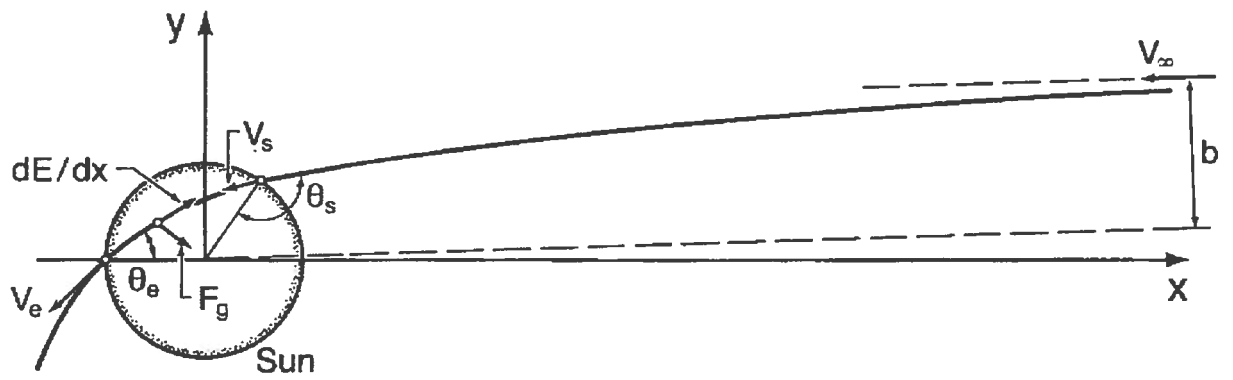


FIG. 3. Trajectory of a monopole approaching the Sun.

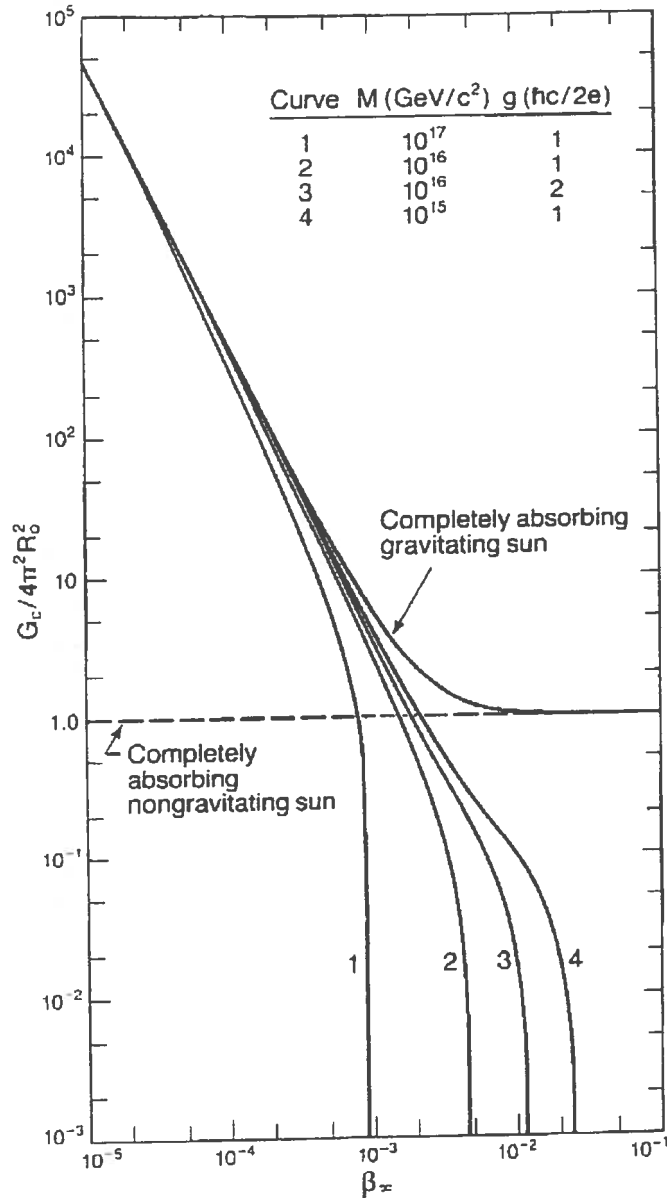


FIG. 4. G_c as a function of β_∞ for monopoles with a variety of masses and magnetic charges

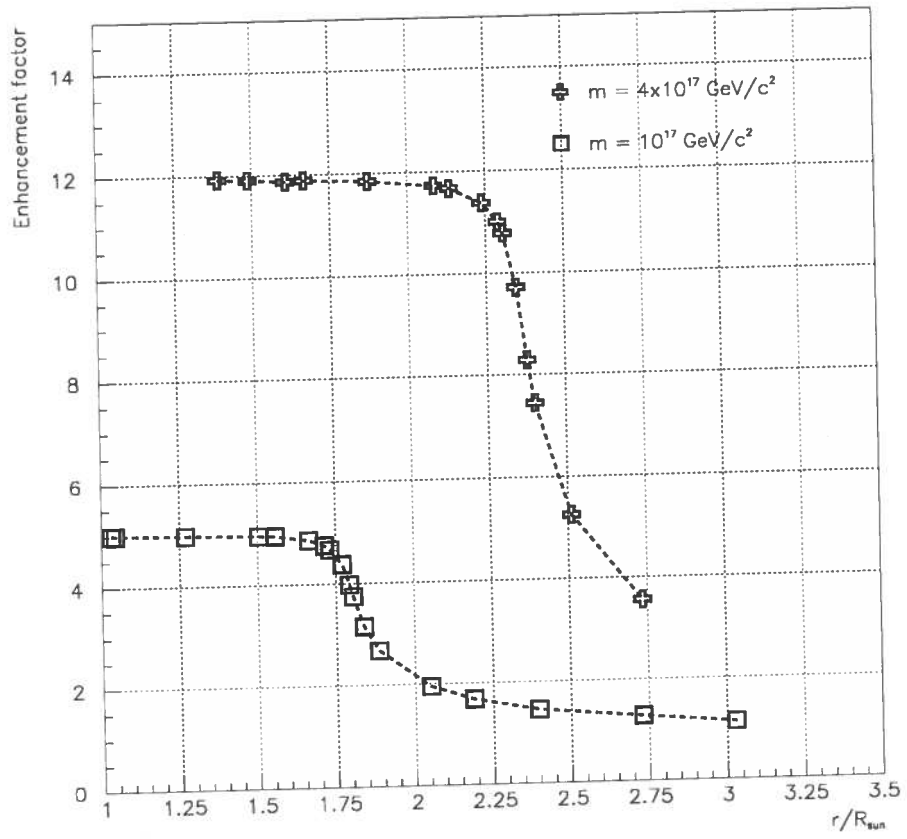


FIG. 5. Enhancement factor as a function of the distance from the center of the Sun (in R_{\odot} units), for different values of the monopole's mass.

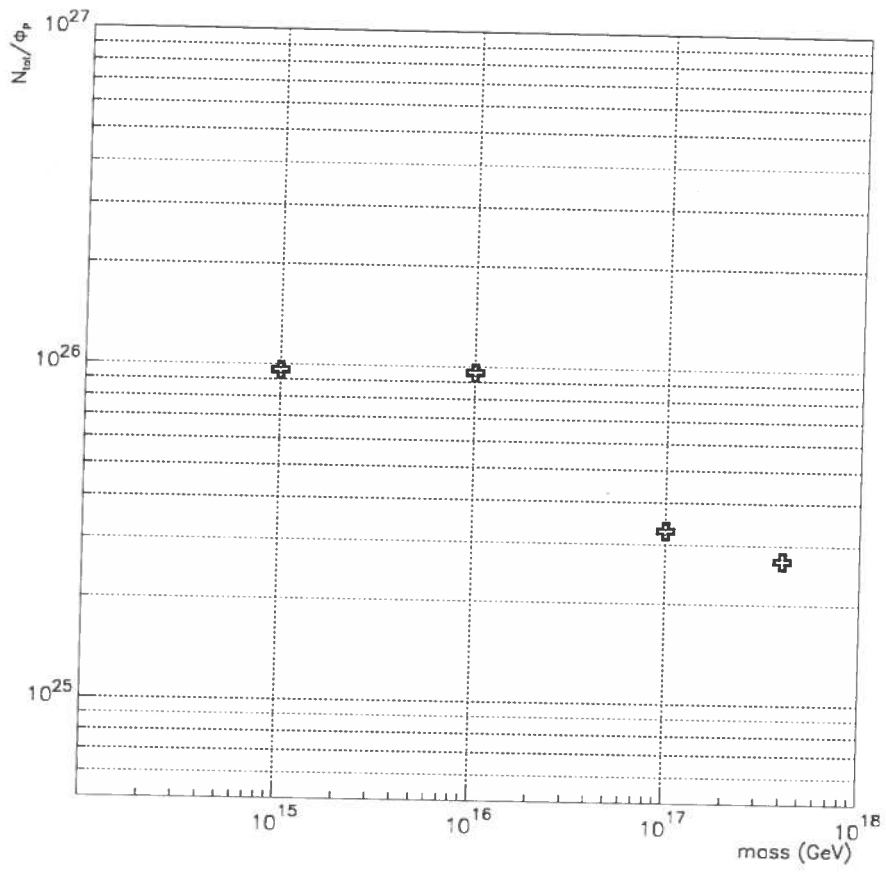


FIG. 6. Total number of monopoles (and anti-monopoles) trapped into the Sun as a function of their mass