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Conjectures Concerning Planetary Deuterium Enrichment from Solar Wind or Galactic Clouds Driven by Planetary Magnetic Fields

Francisco J. Arias[1]
[1] Department of Fluid Mechanics, University of Catalonia,
ESEIAAT C/ Colom 11, 08222 Barcelona, Spain

Abstract

Until now mechanisms responsible for the observed deuterium enrichment in some planets or celestial bodies are the result of several thermal (Jeans escape) as well as non-thermal escape mechanisms. In this work, we will conjecture the possible contribution from the solar wind interacting with the magnetic fields of the planet or celestial body. The most interesting feature of this hypothesis, is that the enrichment of deuterium is not due to the preferential escape of hydrogen from the atmosphere, but rather, the enrichment is generated by external injection of deuterium into the atmosphere with solar wind or galactic clouds as sources.

The hypothesis also open the possibility that planets and celestial bodies may have been enriched with deuterium in the past when solar system passed through a galactic cloud. If so, there is the speculative possibility of geological records where an abrupt enrichment of deuterium may disclose the transit of the solar system through such a galactic cloud in the past, and then a sort of "$deuterium - age$" could be suggested.

1 Planetary deuterium enrichment driven by planetary magnetic fields

Let us consider Fig. 1 in which a stream of charged particles of deuterium D^+ and ordinary hydrogen H^+ are interacting with the planetary magnetic field (the dot lines representing a dipole field). Referring to this figure, it is seen that at first approximation only when the following relationship is satisfied

$$R - R_p > R_L \quad (1)$$

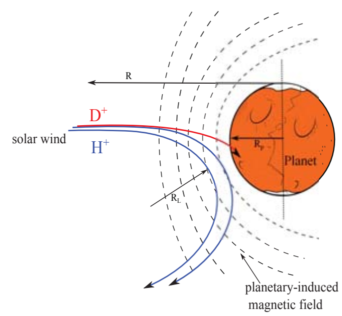

Figure 1: Physical model of isotopic planetary separation driven by the planetary magnetic field.

the particle could be magnetically deviated without interacting with the surface or planetary atmosphere (if R_p includes the thickness of the atmosphere). The radius R_L in Eq.(1) is the Larmor radius, gyro radius or the radius of the circular motion of the charged particle in the presence of the magnetic field which is given by

$$R_L = \frac{m_i v_\perp}{qB} \quad (2)$$

where m_i is the mass of the particle i, $v_\perp$ is the component of the solar wind velocity perpendicular to the direction of the magnetic field, q is the electric charge of the particle, and B is the strength of the magnetic field.

If condition given by Eq.(1) is satisfied, then the charged particle will be magnetically deflected, otherwise will impact the surface or being accreted by the planetary atmosphere. Thus inserting Eq.(2) into Eq.(1) yields,

$$R - R_p \geq \frac{m_i V_{sw}}{qB} \quad (3)$$

where for the sake of simplicity it was assumed $v_{\perp} = V_{sw}$ being V_{sw} the total velocity of the solar wind
On the other hand since the dipole magnetic field strength varies with the distance as $\frac{1}{r^3}$ the magnetic field strength may be written as

$$B(r) \propto B_{surf} \frac{R_p^3}{R^3} \tag{4}$$

where B_{surf} is the magnetic field at the surface of the planet. Thus, Eq.(3) becomes as

$$\frac{R - R_p}{R^3} \geq \frac{m_i V_{sw}}{q B_{surf} R_p^3} \tag{5}$$

Differentiating Eq.(5) with respect to R and solving for the value which maximizes $\frac{R-R_p}{R^3}$, one obtains

$$R^* = \frac{3}{2} \cdot R_p \tag{6}$$

If Eq.(5) is satisfied for a certain value $\frac{R-R_p}{R^3}$, then, it will be certainly satisfied when attain its maximum value i.e, $\frac{R^*-R_p}{R^3}$. Inserting R^* from Eq.(6) into Eq.(5) and solving for R_p yields

$$R_p \geq \frac{27}{4} \cdot \frac{m_i V_{sw}}{q B_{surf}} \tag{7}$$

Because we are working with isotopes, in the above expression it is better to put the mass of the atom as function of its number mass A_i. We can assume as first approximation that the mass of the neutron m_n is equal than the mass of the proton m_p and then we can use $m_i = A_i \cdot m_p$. In this way, equation Eq.(7) becomes

$$R_p \geq \frac{27}{4} \cdot \frac{m_p A_i V_{sw}}{q B_{surf}} \tag{8}$$

where A_i is the numbers mass of the isotope with mass m_i. Now the condition for isotopic separation between deuterium and ordinary hydrogen is as follows: According with Eq.(7), given the radius of the planet R_p, there must be a sort of "magnetic band" or region in which Eq.(7) is accomplished for ordinary hydrogen but is not simultaneously accomplished for deuterium. Such a region can be defined by the magnetic boundaries B^+ and B^- which are directly derived from Eq. (7).

Therefore, if we have two isotopes with number mass, say, A_1 and A_2 being $A_1 < A_1$ being separated by the conjectured mechanism, this only occurs if the planet is crossing -or had crossed in the past-, a magnetic band given by,

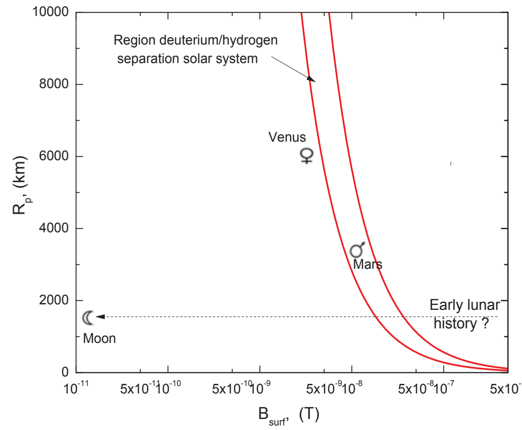

Figure 2: The Deuterium Age predicted by Eq.(9) for Venus, Mars and the Moon.

$$B^- \leq B_{surf} \leq B^+ \tag{9}$$

with

$$B^- = \frac{27}{4} \cdot \frac{A_1 m_p V_{sw}}{q_p R_p} \tag{10}$$

and

$$B^+ = \frac{27}{4} \cdot \frac{A_2 m_p V_{sw}}{q_p R_p} \tag{11}$$

which for the specific system deuterium-protium using $A_1 = 1$ and $A_2 = 2$, becomes

$$B^- = \frac{27}{4} \cdot \frac{m_p V_{sw}}{q R_p} \quad with \quad A_1 = 1 \tag{12}$$

and

$$B^+ = \frac{27}{2} \cdot \frac{m_p V_{sw}}{q_p R_p} \quad with \quad A_2 = 2 \tag{13}$$

Fig. 2 shows the plot of planetary radius versus magnetic field and the narrow range where deuterium age takes place predicted by Eq.(9), Eq.(10) and Eq.(11) and using a typical solar wind $V_{sw} = 400 km/s$ and the available data for the magnetic field of Venus, Mars and the Moon.

It is seen that according with the proposed mechanism, Venus, Mars and the Moon, they may have had a sort of *"deuterium age"* where the body could be enriched with deuterium by magnetic planetary separation.

NOMENCLATURE

A = number mass of the isotope
R_p = radius of the planet
R_L = Larmor radius
R_{sp} = radial distance sun-planet
R = radial distance
$R*$ = radius defined Eq.(6)
B_{surf} = magnetic field on the surface of the planet
B = magnetic field
B^+ = upper limit separation magnetic-band
B^- = lower limit separation magnetic-band
m = mass of particle
q = charge of electron

Subscripts
i = isotope
sw = solar wind
p = planet
sp = sun-planet
o = initial

Superscripts
$+$ = upper limit
$-$ = lower limit

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