A Further Study of the Mixing of Relativistic Ideal Gases with Relative Relativistic Velocities: The Hot Plasma in the Sun’s Corona, the Type II Spicules and CMEs.

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Abstract. The Redefined Relativistic Thermodynamics and the conservation of the 4-vector energy–momentum predict a tremendous increment of the temperature after mixing two gases with relative sub-relativistic velocity. This phenomenon can be used to describe the heating of a cold clump with shocked jets material and to predict an improving of the ignition in a Tokamak by injecting a plasma with a sub-relativistic velocity. First, by using the same effect, the mixing of the type II spicule and Coronal Mass Ejections with the plasma of a cold Sun’s corona will explain the increase temperature of the Sun’s corona. Second, considering, in agreement with the observations, that a part of the type II spicule, fall off into the Chromosphere and that the rest of the type II spicule that shocks with the Sun’s corona possesses a higher average relative velocity, the mixing of such a part and the plasma in the Sun’s corona will maintain the high temperature of the Sun’s corona. Moreover, the shock of Coronal Mass Ejections with the Sun’s corona it is a energy source to maintain the high temperature of the Sun’s corona too.

1. Introduction
One of the biggest problems in Modern Astrophysics is the origin of the Sun’s corona temperatures ($1 \times 10^{6} K - 2 \times 10^{6} K$). There have been proposed many theories that have given an interesting advance in the understanding of the Sun’s atmosphere mechanism [1,2]. On the development of a theory of the upper solar atmosphere heating, there have to be included realistic and theoretical models about the energy release process and the plasma response to this warming. These models range from heating by accretion [1], heating by acoustic waves [3], heating by Alfvén waves, energy deposition through the damping of magnetohydrodynamics waves [4], nanoflares (arise when magnetic field is stressed, via reconnection) [5], velocity filtration [6] and spicules [7]. Moreover, most efforts have focused in attempts to explain and to find the causes for the coronal energy balance.

Indeed, it is necessary to identify and understand why the upper solar atmosphere temperature is so much higher even when the lower layers are cooler. This strange event was discovered in 1940, when Grotrian [8] and Edlén [2] realized that the emission lines during a total solar eclipse did not belong to a new hypothetical element named coronio and on the contrary, the emission lines belonged to known elements which were in high ionization states, for example, Fe $XIV$. 

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The scientific community assumed that this kind of events were induced by magnetic reconnection processes or by shock waves locally heating the plasma. However, these observations were questioned [4].

De Pontieu et al [9] were the first ones who made known chromospheric plasma jets originated in the solar quiet areas, with the following characteristics:

- Diameter: \( \sim 200 \) Km
- Ejection velocities: \( 50Km/s - 150Km/s \)
- Life time: \( 10s - 150s \).

The chromospheric plasma jets with the features just mentioned were named type II spicules and they are different from type I spicule, because the first ones are faster, thinner, and they appear more frequently. Other important detail is that a part of the type II spicule (\( \sim 10\% \)) reaches \( 1 \times 10^6K - 2 \times 10^6K \) temperatures while it is going up into the solar corona, and the coldest rest part in going back to the Chromosphere [10]. This phenomenon gave way to the heating process understanding in the upper solar atmosphere and type II spicules came to be the favourite candidate to the solar energy supply and solar mass supply. Before the discovery of the type II spicules, the type I spicules were proposed as being the mainly responsible for the solar material supply [11]. However, type I spicules are not frequent and energetic enough to meet the requirements.

De Pontieu’s [7,9] observations are not enough to know the physics of the heating. Nevertheless Klimchuk [10] proposed a classical thermodynamic model that reveals that type II spicules are not adequately energetic to heat solar corona. However Martínez-Sykora et al [12,13] think as a possibility, that the study of the spicules could help to explain the temperatures in solar corona. It is also known that the Coronal Mass Ejections [CMEs] were discovered in the early 1970s when spaceborn coronographs revealed that eruptions of plasma are ejected from the Sun. Eruptive flares, filament eruptions, CMEs and failed eruptions represent different manifestations of a disruption and reconfiguration of the coronal magnetic field, which ultimately leads to an ejection of magnetized plasma that may, or may not, propagate into the Heliosphere.

Coronal mass ejections are the sudden release of \( 10^{15}g - 10^{16}g \) of chromospheric and coronal plasma to the Heliosphere. Their speed ranges are \( 100Km/s < v < 10000Km/s \) [14]. A total of 6907 CMEs were observed from January 1996 to December 2002 [15]. Then, an average value of \( \sim 3 \) CMEs per day occur on the Sun.

In the theory of relativistic transformation laws of the thermodynamic quantities, many authors enriched the topic with different proposals. In regard to the various controversies, in 1998, Sieniutycz mentioned that the three more common and acceptable relativistic transformations of the temperature still survive as \( T = \gamma d T_0 \), where \( \gamma = \left(1 - v^2/c^2\right)^{-1/2} \), where \( d = 1, -1 \) or \( 0 \) depending on an Ott-like proposal, an Einstein-Plank-like proposal and on a Landsberg like-proposal, respectively.

On the other hand, Ares de Parga et al [17] redefined some thermodynamic quantities in order to conserve the laws of Thermodynamics in a moving frame and hence they proved the possibility of the existence of a relativistic transformation of the temperature. Then, based on Fermi’s ideas [18] about the definition of 4–vectors in Special Relativity, Gamba [19] was able to understand the meaning of physical quantities in different reference systems. With this background, Nakamura [20, 21] developed a technique in order to covariantly define some mechanic and thermodynamic quantities. Some years later, Ares de Parga et al [17,22,23] were able to match Nakamura’s ideas and the redefinition of some thermodynamic quantities in order to obtain a covariant theory of the relativistic laws of the transformation of the thermodynamic quantities and they called it the Redefined Relativistic Thermodynamics [RRT] [24]. This proposal which is based on the concept of simultaneity, permits matching it with a Relativistic Statistical Mechanics. Then Gonzalez-Narvaez et al [25] computed the final temperature of a
two ideal gases mixture with relative velocities. They considered different velocity cases, even relative relativistic velocities. Therefore, they computed the final temperature of a two ideal gases mixture with relative velocities based on the RRT and they compared the non-relativistic and the relativistic results. The differences between the non-relativistic and the relativistic results are negligible for sub-relativistic velocities.

In the present work, from the mixing of two ideal gases with relative velocities, the values of the final temperature, of the heating of a cold clump with shocked jets material and the ignition in a Tokamak by injecting a plasma, reported in Gonzalez-Narvaez et al [25] are computed more accurately. Moreover, this phenomenon can be used to describe the sharp increase of temperature of the Sun’s corona by the mixing of the type II spicules and CMEs. In this work, even when only relative sub-relativistic velocities are considered, the final temperature is computed based on RRT to preserve the form.

2. Mixture of two ideal gases
2.1. The Redefined Relativistic Thermodynamics

The theory is based on being aware that in a physical system which is composed of particles or a perfect fluid constrained in a volume, the definition of a 4-vector energy-momentum is subject to instantaneity in a particular reference frame. Such property may be described by noticing that to an infinite volume a normal volume 4-vector \( w^\mu \) can be associated; that is, each event \( x^\mu \) which belongs to the 3-hyper-surface \( E \) is such that

\[
(x^\mu - x^\mu_E) w_\mu = 0,
\]

being \( x^\mu_E \) any event in the volume \( V \). In the reference frame where the volume is at rest, the time is the same for all the points satisfying equation (1) (for example, if the system properties are measured in the lab frame \( K \), the instantaneity in \( K \) will be measured in a volume \( V \) and the normal volume 4-vector is \( w^\mu = (1, 0) \), measured in \( K \).) Then, covariantly, the volume is expressed as

\[
dV^\mu = \frac{w^\mu dV_0}{u^\lambda w_\lambda},
\]

with \( u^\mu \) is the corresponding 4-vector of the velocity \( u \) between \( K \) and \( K_0 \) (the rest frame of the moving system, the comoving frame) and \( V_0 \) is the volume of the system in \( K_0 \).

Now, the goal consists of defining the thermodynamic quantities in a covariant form. Before, some quantities that will permit us to recover the first, the second and the third law of Thermodynamics, are needed.

For a perfect fluid, the energy-momentum tensor is

\[
T^{\alpha\beta} = (p + \rho) u^\alpha u^\beta - n^{\alpha\beta}
\]

where \( \rho \) and \( p \) represents the energy density and the pressure in the rest frame, respectively, and \( n^{\alpha\beta} \) the Minkowsky metric. The 4-vector energy momentum is defined, with instantaneity in \( K \) (the lab frame) as

\[
P^\alpha = \int_V T^{\alpha\beta} dV_\beta
= \int_V [(p + \rho) u^\alpha - \frac{pu^\alpha}{w_\lambda u^\lambda}] dV_0.
\]

Therefore, the bulk energy is

\[
G^\mu = [(p + \rho) u^\mu n^u - (p + \rho) n^{\mu\nu}] \frac{w^\nu}{w_\lambda u^\lambda} V_0
= (E_0 + pV_0) u^\mu - (E_0 + pV_0) \frac{w^\nu}{w_\lambda u^\lambda},
\]
where $E_0$ represents the total internal energy in the rest frame. Then, a 4–vector redefined energy-momentum $\xi^\mu$ may be expressed as

$$\xi^\mu = P^\mu - G^\mu = \frac{w^\mu}{w_\lambda u^\lambda} E_0.$$  \hfill (6)

It is easy to show that with the redefined energy-momentum, the result is

$$d\xi^\mu = \bar{d}\Theta^\mu + dW^\mu,$$  \hfill (7)

where

$$d\Theta^\mu = \frac{w^\mu}{w_\lambda u^\lambda} d\Theta_0^\mu \quad \text{and} \quad dW^\mu = \frac{w^\mu}{w_\lambda u^\lambda} pdV_0.$$  \hfill (8)

Equation (7) represents the first law of Thermodynamics but in a covariant form. On the other hand, the 4–vector temperature and inverse 4–vector temperature are

$$T^\mu = u^\mu \frac{T_0}{w_\lambda u^\lambda} \quad \text{and} \quad \beta_\mu = \frac{u_\mu}{kT_0},$$  \hfill (9)

where $k$ represents the Boltzman constant. Moreover, from the definition of the entropy, which is an invariant, the second law is obtained

$$dS = \beta_\mu \frac{w_\rho V_0}{w_\lambda u^\lambda} T^{\mu\nu} + \beta_\mu pdV_0 = \frac{1}{kT_0} dE_0 + \frac{p}{kT_0} dV_0.$$  \hfill (10)

The equations of state and the laws of Thermodynamics are invariant as long as some thermodynamic quantities transform as necessary; that is, some quantities transform as the temperature, equation (9) and some parameters are invariant but the rest transform to get invariant equations.

### 2.2. Mixture of two ideal gases

The problem solved by Gonzalez-Narvaez et al [25] consists of deducing the final temperature and final velocity of the mixture of two relativistic ideal gases with different temperatures and distinct velocities.

Then, based on RRT, if the instantaneity is in $K$, the 4–velocity and the normal volume 4–vector are

$$u^\alpha = (\gamma, \gamma u) \quad \text{and} \quad w^\alpha = (1, 0),$$  \hfill (11)

the 4–vector energy momentum is

$$P^\alpha = \left(\frac{\gamma}{c} \left( E_0 + \frac{u^2}{c^2} pV_0 \right), \frac{u}{c} \left( E_0 + pV_0 \right) \right),$$  \hfill (12)

which represents the Einstein-Planck-Tolman energy-momentum. Therefore, to calculate the final state when two isolated identical ideal gases with different temperatures and relative motion are mixed, the process is divided into two parts (the process may be divided into two parts because the computation is simplified).

- First, the two systems are put in contact by using an adiabatic wall. Then the wall is replaced by a diathermic wall allowing a flux of energy, obtaining an equilibrium state with temperature which will be called the equilibrium temperature $T_{1eq}$ measured in $K_1$, the rest
frame of one of the gases which will be considered as the lab frame (The relative motion in this process is not varied).

Hence, taking into account the first law
\[ d\xi^0 = d\Theta^0 + dW^0, \]  
the conservation of energy implies that
\[ d\xi^0_{11} = dQ_{11} = -dQ_{12} = -d\xi^0_{12}, \]  
since no work is done. The first subscript represents the reference frame where the instantaneity is achieved and the second subscript describes the considered ideal gas. Therefore, by using the heat capacities of each gas
\[ Q_{11} = -Q_{12} \Rightarrow C_{V1}(T_{1eq} - T_{11}) = C_{V2}(T_{12} - T_{1eq}), \]  
where \( T_{11} \) is the initial temperature measured in the lab frame \( K_1 \) of the gas which is at rest in \( K_1 \) and \( T_{12} \) is the initial temperature measured in the lab frame \( K_1 \) of the gas which is at rest in \( K_2 \). \( C_{V1} \) and \( C_{V2} \) are the corresponding heat capacities (which are invariant).

In our case, since the particles are identical for both gases with mass \( m \) and each gas has particle numbers \( N_1 \) and \( N_2 \), respectively,
\[ C_{Vi} = mN_iC_{V}, \]  
with \( i = 1, 2 \). Then, equation (15) may be written as
\[ N_1(T_{1eq} - T_{11}) = N_2(T_{12} - T_{1eq}). \]  
Thereby, the equilibrium temperature is
\[ T_{1eq} = \frac{N_2T_{12} + N_1T_{11}}{N_1 + N_2}. \]  

- Second, much of the diathermic wall is eliminated to mix both gases obtaining an ideal gas with a final temperature \( T_{1f} \) and a certain final velocity \( u_f \) respect to the lab frame \( K_1 \). The action of the walls of the volumes is neglected in such a way that a final volume is obtained with the same final velocity than the final gas in \( K_1 \).

Recalling that an isolated system was the first hypothesis, the 4-vector energy-momentum must be conserved
\[ P_{\mu\text{tot}} = P_{\text{eq}1\text{tot}} = P_{\text{eq}11} + P_{\text{eq}12} = P_{\text{f}1\text{tot}}, \]  
where the subscript \( f \) represents the final state of the mixture of the ideal gases. Taking the temporary component of the last two terms of equation (19) and substituting the 4-vector energy momentum, equation (12), one finds
\[ a = P_{eq11}^0 = E_{eq11} + \gamma \left( E_{eq11} + \gamma N_2kT_{1eq} \frac{u^2}{c^2} \right) = \gamma_f \left( E_{ff} + \gamma_f NkT_{1f} \frac{u_f^2}{c^2} \right) \]  
where the value \( pV \) was replaced by \( NkT_f \), \( T_{2eq} = \gamma^{-1}T_{1eq} \), and \( N = N_1 + N_2 \). For the spatial component
\[ b = P_{eq12}^1 = \gamma \left( E_{eq22} + N_2kT_{1eq} \right) \frac{u}{c} = \gamma_f \left( E_{ff} + NkT_{1f} \gamma_f \right) \frac{u_f}{c}. \]  
The quantities \( a \) and \( b \) are known because the initial and intermediate conditions are set. Then by calculating \( au_f - b \), the final temperature may be expressed as
\[ T_{1f} = \frac{b - au_f}{Nk u_f}. \]
3. Computation improvements of final temperature $T_{1f}$

In order to deduce the final temperature $T_{1f}$, the final velocity $u_f$ must be obtained, or vice versa. For this purpose, it is necessary to express the internal energy $E_{ff}$ as a function of the temperature. The relativistic internal energy of the final gas [27] in its own rest frame is

$$E_{ff} = Nm \left( \frac{K_1 (\beta_{ff} m)}{K_2 (\beta_{ff} m)} + \frac{3}{\beta_{ff} m} \right),$$

(23)

where $\beta_{ff} = 1/kT_{ff}$ (This expression for the internal energy considers the total energy of the particles; that is, there is no subtraction of the kinetic energy of the rest mass).

Gonzalez-Narvaez et al [25] obtained the final velocity $u_f$, and then they computed the final temperature. However, as shown below, a small variation in the final velocity $u_f$, produces a great change in the final temperature $T_{1f}$.

Using the equation (22), the temperature derivative is

$$dT_{1f} = \frac{-b}{Nk u_f^2} du_f,$$

(24)

so that,

$$\Delta T_{1f} = \frac{b}{Nk u_f^2} \Delta u_f = \alpha \Delta u_f.$$

(25)

In order to know the magnitude of $\alpha$, the data and the final velocity $u_f$ used and computed, respectively, in Gonzalez-Narvaez et al [25] are take into account in such a way that the result is

$$\alpha > 10^5,$$

that is, a small variation in the final velocity $u_f$, produces a great change in the final temperature $T_{1f}$, and then a big mistake in final temperature $T_{1f}$ could be made if the final velocity $u_f$ is first computed.

Accordingly, it is more convenient to compute the final temperature $T_{1f}$ first and then to determinate the final velocity $u_f$.

From equation (22) the final velocity $u_f$ is a function of the final temperature, that is,

$$u_f = \frac{bc}{a + Nk T_{1f}},$$

(26)

then

$$\gamma_f = \frac{a + Nk T_{1f}}{\sqrt{(a + Nk T_{1f})^2 - b^2}}.$$  

(27)

On the other hand, from the last equality of equation (21), the total momentum is a function of the final velocity $u_f$ and the final temperature $T_{1f}$

$$b = \gamma_f (E_{ff} + Nk T_{1f} \gamma_f) \frac{u_f}{c}.$$  

(28)

Then, equation (23), is substituted in the last equation

$$\frac{bc}{\gamma_f u_f} = Nmc^2 \left[ \frac{K_1 (mc^2 \gamma_f T_{1f})}{K_2 (mc^2 \gamma_f T_{1f})} + \frac{3 \gamma_f kT_{1f}}{mc^2} \right] + \gamma_f Nk T_{1f}$$

$$= Nmc^2 \left[ \frac{K_1 (mc^2 \gamma_f T_{1f})}{K_2 (mc^2 \gamma_f T_{1f})} + 4 \gamma_f Nk T_{1f} \right].$$
From equations (26) and (27), \( \frac{bc}{\gamma f} \),

\[
\begin{align*}
1 &= Nmc^2 \frac{K_1}{K_2} \left( \frac{mc^2}{\gamma f kT_{1f}} \right) \frac{1}{\sqrt{(a + NkT_{1f})^2 - b^2}} + \frac{4\gamma f NkT_{1f}}{\sqrt{(a + NkT_{1f})^2 - b^2}}, \\
0 &= Nmc^2 \frac{K_1}{K_2} \left( \frac{mc^2}{\gamma f kT_{1f}} \right) \frac{1}{\sqrt{(a + NkT_{1f})^2 - b^2}} + \frac{4\gamma f NkT_{1f}}{\sqrt{(a + NkT_{1f})^2 - b^2}} - 1. \tag{29}
\end{align*}
\]

The last equation will be called \( ET(T_{1f}) \). Finally, \( \gamma f \) is substituted in (29),

\[
ET = \frac{K_1}{K_2} \left( \frac{mc^2}{kT_{1f}(a + NkT_{1f})} \right) \frac{Nmc^2}{\sqrt{(a + NkT_{1f})^2 - b^2}} + \frac{4NkT_{1f}(a + NkT_{1f})}{(a + NkT_{1f})^2 - b^2} - 1
\]

So, the final temperature \( T_{1f} \) is such that \( ET(T_{1f}) = 0 \).

Now, final temperatures and final velocities are computed more accurately for two cases considered by Gonzalez-Narvaez et al [25].

- **Jet-clump**
  Gonzalez-Narvaez et al [25] considered one of the two opposite jets that are regularly launched simultaneously, such that mass deposition rate is in the \( z \) direction and shocks a dense-cool clump. The jet [26] is initially launched with a sub-relativistic velocity equal to \( u_{jet} = 9.5 \times 10^6 \text{m/s} \), the collision jet temperature is \( T_{1j} = 4 \times 10^7 \text{K} \) and the jet particle number per unit length is \( N_j = 1.9440 \times 10^{44} \). Let us consider that the clump is at rest before the collision with the initial clump temperature, \( T_{1\text{clump}} = 2 \times 10^7 \text{K} \), and the clump particle number per unit length is \( N_{\text{clump}} = 8.5355 \times 10^{43} \).

Because the jet-clump distance is \( 20 \text{Kpc} \), it is assumed the jet loses energy on the way, so that the initial collision jet velocity \( u \), is such that \( u < u_{jet} \).

* Hillel and Soker [26] obtained that the final temperature are \( T_{1f} \sim 4.9 \times 10^7 \text{K} \) and the final velocity is of the order \( 10^6 \text{m/s} \).

* Gonzalez-Narvaez et al [25] obtained that for an initial collision jet velocity, \( u = 8 \times 10^5 \text{m/s} \), the final temperature is \( T_{1f} = 4.5459 \times 10^7 \text{K} \).

* In this work (computing the final temperature \( T_f \) first and then determining the final velocity \( u_f \)) for a initial collision jet velocity \( u = 1.35 \times 10^6 \text{m/s} < u_{jet} \), a drift velocity of the same order and a final temperature, \( T_{1f} = 4.975 \times 10^7 \text{K} \), are predicted.

The result exposed by Gonzalez-Narvaez et al [25] was not so accurate, namely, the final temperature reported by them is smaller by \( 5.991 \times 10^6 \text{K} \), with an initial jet velocity which is smaller too, because in Gonzalez-Narvaez et al [25] the final drift velocity was the first quantity computed.

- **Tokamak**
  Gonzalez-Narvaez et al [25] proposed too a process for increasing the ignition Tokamak temperature. An ideal gas confined in a Tokamak at room temperature is considered, and suddenly and ideal gas at room temperature too is injected with a relative velocity to attain the ignition temperature \( T_{1f} \sim 10^8 \text{K} \), considering ITER tokamak conditions, that is, if equilibrium temperature is \( T_{1eq} = 300 \text{K} \) and particle numbers are \( N_1 = 3 \times 10^{23} \) and \( N_2 = 4 \times 10^{23} \).
* Gonzalez-Narvaez et al [25] considered an initial velocity condition \( u = 3 \times 10^6 \text{m/s} \) to get the ignition temperature order, that is, \( T_{1f} = 1.9530 \times 10^8 \text{K} \).

* In this work (computing the final temperature \( T_f \) first and then to determine the final velocity \( u_f \)) for an initial velocity \( u = 4 \times 10^6 \text{m/s} \), the final temperature is \( T_{1f} = 1.608416 \times 10^8 \text{K} \). Then, with initial velocities \( u > 4 \times 10^6 \text{m/s} \), it is possible to get the desired order of temperatures, \( T_{ITER} = 25 \text{KeV} = 3 \times 10^8 \text{K} \).

As it can be seen, Gonzalez-Narvaez et al [25] results were not so accurate because they computed final drift velocity first.

4. Type II Spicules and CMEs

In this section type II spicules and CMEs are analyzed as a possible energy sources to heat and maintain the current Sun’s corona temperatures, considering the mixture of two ideal gases exposed in section 2. That is, because the conservation of the 4-vector energy-momentum, the mixture of ideal gases on Sun’s regions, as Chromosphere (type II spicules and CMEs), Transition Region [TR] and solar corona, the solar corona is heated and maintained to temperatures of order \( > 10^8 \text{K} \).

4.1. Mixture type II spicules ideal gas and Sun’s corona ideal gas

Type II spicules are chromospheric plasma jets with velocities of the order \( u \sim 10^5 \text{m/s} \) and they occur thousands of times a day. Martínez-Sykora et al [12,13] showed that the interactions between magnetic field and solar atmosphere partially ionized gas, with charged and neutral particles, generate spicules. Moreover, they think as a possibility, that the study of the spicules could help to explain the temperatures in solar corona (see figure 1 in Martínez-Sykora et al [12]). Then, when these plasma jets are ejected, they have to go through two layers which are the TR and solar corona. Therefore, the model proposed in this work, to understand the temperature increment and the current temperature of the solar corona, two subprocess must be considered, namely, the mixture of a type II spicule ideal gas with the TR ideal gas and the mixture of the resulting ideal gas of the first subprocess and the solar corona ideal gas (quantities of the second subprocess; that is, in the solar corona, are primed). Moreover, there are considered columns of ideal gas such that the bases have a radius of \( 2 \times 10^5 \text{m} \), and the heights depend on the size of the shock object and the size of the layer.

The average height of a type II spicule is \( h_{IIS} = 10^6 \text{m} \) (which is considered equal to the corona column height \( h_{IIS} = h_{SC} \)), the height of the TR is \( h_{TR} = 3 \times 10^5 \text{m} \), the particle density of Chromosphere and TR are considered equal, that is, \( n_{TR} = n_{IIS} = 10^{15} \text{m}^{-3} \), and the particle density of solar corona is \( n_{SC} = 5.5 \times 10^{14} \text{m}^{-3} \). It is known, from the observations that the plasma ejected velocities going into the solar corona are in ranges \( 5 \times 10^4 \text{m/s} - 1.5 \times 10^5 \text{m/s} \). Accordingly, the initial velocities of spicules are proposed in order to consider the observed velocity ranges as the final velocities of this first subprocess.

- Subprocess 1. Mixture of type II spicule ideal gas with the TR ideal gas.

The TR ideal gas with \( N_{TR} = N_1 \) particles and initial temperature \( T_{1TR} = T_{11} \), is at rest in the TR reference frame(or lab frame), \( K_{TR} = K_1 \), while the spicule ideal gas with \( N_{IIS} = N_2 \) particles and initial temperature \( T_{1IIS} = T_{12} \), is at rest in the spicule reference frame \( K_{IIS} = K_2 \) and \( K_2 \) moving with initial relative velocity \( u \) respect to reference frame \( K_1 \).

When spicule ideal gas shocks and come into contact with the TR ideal gas (assuming that this happen in a negligible time period), there is only a energy flow (heat), so the system spicule-TR reaches an intermediate thermal equilibrium, with an equilibrium temperature, \( T_{1eq} \), equation (18). Then, ideal gases get mixed, and the final ideal gas has a final tem-
perature $T_1 f$, equation (22), and final velocity $u_f$, with respect to the lab frame, $K_1$. The results are shown in Table 1.

| $u(\times10^4 \text{m/s})$ | Process | $u_f(\times10^4 \text{m/s})$ | $T_1 f(\times10^4 \text{K})$ |
|-----------------------------|---------|-----------------------------|-------------------------------|
| 6.5                         | NR      | 5                           | 7.0783                        |
|                             | R       | 5                           | 7.0783                        |
| 9.75                        | NR      | 7.5                         | 10.9263                       |
|                             | R       | 7.5                         | 10.9263                       |
| 13                          | NR      | 10                          | 16.3134                       |
|                             | R       | 10                          | 16.3134                       |
| 16.25                       | NR      | 12.5                        | 23.2398                       |
|                             | R       | 12.5                        | 23.2398                       |
| 19.5                        | NR      | 15                          | 31.7053                       |
|                             | R       | 15                          | 31.7053                       |

Table 1. Subprocess 1. Mixture of type II spicule ideal gas with the TR ideal gas, where $T_{1TR} = 4 \times 10^4 \text{K}$, $T_{1IISC} = 4 \times 10^4 \text{K}$, $T_{eq} = 4 \times 10^4 \text{K}$, $N_1 = 9.424777961 \times 10^{30}$ and $N_2 = 3.141592641 \times 10^{31}$. There is no difference between nonrelativistic (NR) and the relativistic (R) computation because relative velocities are sub-relativistic.

The mixing of this subprocess, is called total spicule for convenience.

• Subprocess 2. Mixture total spicule ideal gas and the solar corona ideal gas.

The solar corona ideal gas with $N_{SC} = N'_1$ particles and initial temperature $T_{1SC} = T'_{11}$, is at rest in the solar corona reference frame (or lab frame too), $K_{SC} = K'_1 = K_1$, while the total spicule ideal gas with $N_{IITS} = N'_2$ particles and initial temperature $T_{1IITS} = T'_{12}$, is at rest in the total spicule reference frame $K_{IITS} = K'_2$ and $K'_2$ moving with initial relative velocity, $u' = u_f$, respect to reference frame $K_1$.

When total spicule ideal gas shocks and come into contact with the solar corona ideal gas, the system total spicule-solar corona reaches an intermediate thermal equilibrium, with an equilibrium temperature, $T'_{1eq}$, equation (18). Then, ideal gases get mixed, and the final ideal gas has a final temperature $T'_{1f}$, equation (22), and final velocity $u'_{f}$, respect to the lab frame, $K_1$. The final temperature, $T'_{1f}$, is the the quantity that has to have the same order of temperature of the current solar corona.

In Table 2, solar corona temperature $T_{1SC} = 2 \times 10^4 \text{K}$ is considered; that is: it is assumed that in the beginning of time the solar corona was cool, and it got to higher temperatures with time.

Now, because the shock of the total spicule and the solar corona results in an increment in the solar corona temperature, it is assumed the fastest total spicule shocks the solar corona once again in order to look for the temperature reached. This process is repeated several times with the purpose of knowing the maximum temperature reached by the solar corona. The results are shown in Table 3.

Then, the maximum temperature reached with consecutive total spicule shocks is $\sim 0.59 \times 10^9 \text{K}$, which is more than a half of the current solar corona temperature.

On the other hand, the current temperature contribution of spicules to solar corona is also analyzed. If the solar corona temperature is $T_{1SC} = T'_{11} = 1 \times 10^6 \text{K}$, final temperatures
| $u\times10^4\ m/s$ | $T_{eq}\times10^4K$ | Process | $u_f\times10^4\ m/s$ | $T_{f1}\times10^4K$ |
|----------------|----------------|--------|----------------|----------------|
| 5              | 5.5685         | NR     | 3.5135         | 7.7122         |
| 75             | 8.2725         | NR     | 5.2702         | 13.9558        |
| 10             | 12.0581        | NR     | 7.0270         | 20.6328        |
| 12.5           | 16.9252        | NR     | 8.7837         | 30.3233        |
| 15             | 22.8740        | NR     | 10.5405        | 42.1672        |
|                |                | R      | 10.5405        | 42.1672        |

Table 2. Subprocess 2. Mixture total spicule ideal gas and the solar corona ideal gas where $T_{1SC} = T_{11} = 2 \times 10^4K$, $T_{1f} = T_{12} = T_{1IITS}$, $N_1' = 1.727875859 \times 10^{31}$ and $N_2' = 4.084070437 \times 10^{31}$. There is no difference between nonrelativistic (NR) and the relativistic (R) computation because relative velocities are sub-relativistic.

| $n$--shock | $T_{eq}^{'}\times10^4K$ | $u_f^{'\times10^4)m/s}$ | $T_{f1}^{'}\times10^4K$ |
|------------|-----------------|----------------|----------------|
| 2          | 3.48156         | 1.05405        | 5.41088        |
| 3          | 3.83658         | 1.05405        | 5.76590        |
| 4          | 3.94213         | 1.05405        | 5.87145        |
| 5          | 3.97351         | 1.05405        | 5.90283        |

Table 3. Subprocess 2. Mixture total spicule ideal gas and the solar corona ideal gas where $T_{11}^{'}$ is the previous shock considered temperature. $T_{1f}^{'} = T_{12}^{'} = T_{1IITS}$, $N_1' = 1.727875859 \times 10^{31}$, $N_2' = 4.084070437 \times 10^{31}$ and $u' = 150000.0035625011\ m/s$. In this table are showed five consecutive shocks.

are shown in Table 4. Final temperatures are lower than $1 \times 10^6K$.

| $u\times10^4\ m/s$ | $T_{eq}^{'}\times10^4K$ | Process | $u_f^{'\times10^4)m/s}$ | $T_{f1}^{'}\times10^4K$ |
|----------------|----------------|--------|----------------|----------------|
| 5              | 3.47037         | NR     | 3.5135         | 3.68474        |
| 7.5            | 3.74076         | NR     | 5.2702         | 4.22310        |
| 10             | 4.11932         | NR     | 7.0270         | 4.97680        |
| 12.5           | 4.60604         | NR     | 8.7837         | 5.94584        |
| 15             | 5.20091         | NR     | 10.5405        | 7.13023        |
|                |                 | R      | 10.5405        | 7.13023        |

Table 4. Subprocess 2. Mixture total spicule ideal gas and the solar corona ideal gas where $T_{1SC} = T_{11} = 1 \times 10^6K$, $T_{1f} = T_{12} = T_{1IITS}$, $N_1' = 1.727875859 \times 10^{31}$ and $N_2' = 4.084070437 \times 10^{31}$. There is no difference between nonrelativistic (NR) and the relativistic (R) computation because relative velocities are sub-relativistic.

Moreover, if solar corona temperature is $T_{1SC} = T_{11} = 2 \times 10^6K$, final temperatures are shown in Table 5. Final temperatures are lower than $2\times10^6K$. Therefore, the actual spicule contribution to solar corona temperature consists of cooling a little the solar corona.
Table 5. Subprocess 2. Mixture total spicule ideal gas and the solar corona ideal gas where $T_{1,SC} = T_{11} = 2 \times 10^6 K$, $T_{1,f} = T_{12} = T_{1,HTS}$, $N_1 = 1.727875859 \times 10^{31}$ and $N_2 = 4.084070437 \times 10^{31}$. There is no difference between nonrelativistic (NR) and the relativistic (R) computation because relative velocities are sub-relativistic.

| $u(\times 10^8 m/s)$ | $T_{eq}(\times 10^9 K)$ | Process | $u_f(\times 10^8 m/s)$ | $T_{1,f}(\times 10^9 K)$ |
|----------------------|-------------------------|---------|------------------------|------------------------|
| 5                    | 6.44334                 | NR      | 3.5135                 | 6.65741                |
| 7.5                  | 6.71374                 | NR      | 5.2702                 | 7.19607                |
| 10                   | 7.09229                 | NR      | 7.0270                 | 7.94977                |
| 12.5                 | 7.57901                 | NR      | 8.7837                 | 8.91882                |
| 15                   | 8.17388                 | NR      | 10.5405                | 10.10321               |
|                      |                         | R       | 10.5405                | 10.10321               |

Table 6. Subprocess 1. Mixture of type II spicule ideal gas with the TR ideal gas, where $T_{1,TR} = 4 \times 10^4 K$, $T_{1,HTS} = 4 \times 10^4 K$, $T_{eq} = 4 \times 10^4 K$, $N_1 = 9.424777961 \times 10^{30}$ and $N_2 = 3.141592641 \times 10^{31}$.

| $u(\times 10^8 m/s)$ | Process | $u_f(\times 10^8 m/s)$ | $T_{1,f}(\times 10^9 K)$ |
|----------------------|---------|------------------------|------------------------|
| 2.6                  | NR      | 2                      | 4.9253                 |
|                      | R       | 2.1770                 | 7.6252                 |

Table 7. Subprocess 2. Mixture total spicule ideal gas and the solar corona ideal gas where $T_{1,SC} = T_{11} = 2 \times 10^4 K$, $T_{1,f} = T_{12} = T_{1,HTS}$, $N_1 = 1.727875859 \times 10^{31}$ and $N_2 = 4.084070437 \times 10^{31}$.

| $u(\times 10^8 m/s)$ | $T_{eq}(\times 10^4 K)$ | Process | $u_f(\times 10^8 m/s)$ | $T_{1,f}(\times 10^4 K)$ |
|----------------------|-------------------------|---------|------------------------|------------------------|
| 2.1770               | 5.3582                  | NR      | 1.5298                 | 9.4222                 |
|                      |                         | R       | 1.6457                 | 11.5607                |

However, the idea of a total spicule material with relativistic velocities is not so out of place. Klimchuk [10] observed that while spicule go up and go through the solar corona, a spicule fraction ($\sim 10\%$) is heated to temperatures $1 - 2MK$. Moreover, the rest and cooler spicule go back to the Chromosphere.

On the other hand there exists magnetic fields, therefore taking into account these two facts, it is achievable to think of in the existence of an image apparatus in the upper spicule.

4.1.1. Image Apparatus. In astrophysical and thermonuclear applications (terrestrial and stellar magnetic fields) it is of considerable interest to know how particles behave in magnetic
fields that vary in space. Often the variation are such that a perturbation solution for the motion, that is, the distance over which $\vec{B}$ changes appreciably in magnitude or direction is large compared to the gyration radius of the particle.

Let us consider a simple situation in which a static magnetic field $\vec{B}$ acts mainly in the $z$ direction, but has a small positive gradient in that direction. In addition to the $z$ component of field there is a small radial component due to the curvature of the lines of force [28]. This happens in the image apparatus.

The image apparatus configuration is as follows: the central part magnetic field $\vec{B}_1$ is weaker than extreme part magnetic field $\vec{B}_2$. A charged particle in a magnetic field satisfactorily follows the magnetic field lines if

$$r_L \frac{\left| \nabla B \right|}{B} \ll 1,$$

where $r_L$ is the Larmor radius. This condition means the particle spin radii are much smaller than the magnetic field spin radios ($\left| \nabla B \right|/B = 1/R$).

From the charged particle movement equation, an adiabatic invariant is obtained

$$\frac{V^2}{B} = cte \quad \Rightarrow \quad \mu = \frac{\gamma m V^2}{2B}.$$  \hspace{1cm} (32)

Considering this adiabatic invariant, as in the image apparatus, one obtains

$$\frac{V^2}{B} = cte \quad \Rightarrow \quad \frac{V^2_{12}}{V^2_{11}} = \frac{B_2}{B_1}.$$  \hspace{1cm} (33)

and

$$V^2_1 + V^2_z = cte.$$  \hspace{1cm} (34)

From equations (33) and (34) is obtained that all the particles which satisfied the condition

$$V^2_{11} \left( \frac{B_2}{B_1} - 1 \right) \leq V^2_z$$  \hspace{1cm} (35)

will escape from region 2 (see Figure 1) as it happens in the image apparatus.

Then, if there exists an image apparatus effect in the upper spicule, it plays a selecting mechanism role for the spicule particles which satisfy equation (35); that is: all these particles with such

Figure 1. Lines represent lines magnetic field.
velocities, may be the $\sim 10\%$ that remains in the solar corona. Moreover, this particular particles are much more energetic, so their mean kinetic energy is bigger and the temperature of this set is greater than the remaining spicule. Furthermore, because these particles impact with the solar corona, there will be an amazing solar corona temperature increment. Accordingly, if these particles have a bigger mean kinetic energy, they are faster and it is not irrational to think that particles have relativistic velocities and hence the Redefined Relativistic Thermodynamics has to be considered for the system analysis.

4.2. Mixture CME ideal gas and Sun’s corona ideal gas

CMEs are coronal mass ejections, that is, an ejection of magnetized chromospheric plasma that may or may not propagate into the Heliosphere. Therefore, it is valid to considerer the mechanism exposed in section 2 as a possible cause of the temperature order in the solar corona. The model proposed to understand the temperature increment and the current temperature of solar corona, unlike how it was done with spicules, is just one process, because the TR height is negligible respect to the CMEs height [16]. There are considered columns of ideal gas such that the bases have a radius of $2 \times 10^5$ m, and the heights depend on the size of the shock object. The range height of CMEs is $h_{\text{CME}} > R_s$ (which is considered equal to the corona column height $h_{\text{SC}} = h_{\text{IS}}$, and $R_s = 6.957 \times 10^8$ m ), the particle density of the Chromosphere is $n_{\text{TR}} = n_{\text{IIS}} = 10^{-15}$ m$^{-3}$, and the particle density of the solar corona is $n_{\text{SC}} = 5.5 \times 10^{14}$ m$^{-3}$. It is known, from the observations that the plasma ejected velocities going into the solar corona are in ranges $> 4 \times 10^8$ m/s [16].

The CME ideal gas with $N_{\text{SC}} = N_1$ particles and initial temperature $T_{1\text{CS}} = T_{11}$, is at rest in the solar corona reference frame (or lab frame), $K_{\text{SC}} = K_1$, while CME ideal gas with $N_{\text{CME}} = N_2$ particles and initial temperature $T_{1\text{CME}} = T_{12}$, is at rest in CME reference frame $K_{\text{CME}} = K_2$ and $K_2$ moving with initial relative velocity $u$ respect to reference frame $K_1$. When the CME ideal gas shocks and comes into contact with the solar corona ideal gas (assuming that this happen in a negligible time period), there is only an energy flow (heat), so the system CME-solar corona reaches an intermediate thermal equilibrium, with an equilibrium temperature, $T_{1\text{eq}}$, equation (18). Then, ideal gases get mixed, and equation (22), and final velocity $u_f$, respect to the lab frame, $K_1$. When the solar corona is cool, $T_{\text{SC}} = 2 \times 10^4$ K (that is, it is assumed that in the beginning of the time solar corona was at the same Chromosphere temperature) solar corona final temperatures resulting from the shock of a CME and solar corona are shown in Table 8.

On the other hand, when solar corona is at the current temperature, that is, $T_{\text{SC}} = 1 \times 10^6$ K, solar corona final temperatures resulting from the shock of a CME and solar corona are shown in Table 9.

Finally, solar corona final temperatures, even when the solar corona is cool, are much bigger than $1 \times 10^6 K - 2 \times 10^6 K$, because a CME shock. In fact, there are final temperatures of order $\sim 10^7 K$.

As an example, if an hypothetical relativistic CME is considered, that is, e.g., for initial velocity $u = 2.6 \times 10^8$ m/s, the discrepancy between nonrelativistic and the relativistic results is awesome as shown below

5. Energy balance

Considering the results presented in the last sections, there has to be an energy balance between spicules, CMEs, and the radiation due to the temperature to get the current solar corona temper-
Table 8. Mixture CME ideal gas and the solar corona ideal gas where $T_{SC} = T_{11} = 2 \times 10^4K$ and $T_{CME} = T_{12} = 4 \times 10^4K$. There is no difference between nonrelativistic (NR) and the relativistic (R) computation because relative velocities are sub-relativistic.

| $b_{CME}(R_e)$ | $u(\times10^3 m/s)$ | $N_{SC}(\times10^{24})$ | $N_{CME}(\times10^{24})$ | $T_{eq}(K)(\times10^4)$ | Process | $u_f(\times10^3 m/s)$ | $T_{f}(\times10^4 K)$ |
|-----------------|---------------------|--------------------------|--------------------------|--------------------------|---------|----------------------|----------------------|
| 3.33            | 8.62                | 4.002937406              | 7.27806801               | 3.2903                   | NR      | 5.5612               | 7.014803             |
|                 |                     |                          |                          |                          | R       | 5.5612               | 7.014825             |
| 4.21            | 11.97               | 5.060770714              | 9.201401298              | 3.2903                   | NR      | 7.7225               | 13.490675            |
|                 |                     |                          |                          |                          | R       | 7.7225               | 13.490658            |
| 5.98            | 21.32               | 7.188458164              | 13.06992393              | 3.2903                   | NR      | 13.7548              | 12.743288            |
|                 |                     |                          |                          |                          | R       | 13.7548              | 12.743288            |
| 6.06            | 7.61                | 7.284624828              | 13.24477242              | 3.2903                   | NR      | 4.9096               | 5.474525             |
|                 |                     |                          |                          |                          | R       | 4.9096               | 5.474593             |
| 11.7            | 14                  | 14.06437467              | 25.57159031              | 3.2903                   | NR      | 9.0322               | 18.449745            |
|                 |                     |                          |                          |                          | R       | 9.0322               | 18.449901            |
| 14.89           | 20.67               | 17.89902041              | 32.54367348              | 3.2903                   | NR      | 13.3354               | 40.179438            |
|                 |                     |                          |                          |                          | R       | 13.3354               | 40.179438            |

Table 9. Mixture CME ideal gas and the solar corona ideal gas where $T_{SC} = T_{11} = 1 \times 10^6K$ and $T_{CME} = T_{12} = 4 \times 10^4K$. There is no difference between nonrelativistic (NR) and the relativistic (R) computation because relative velocities are sub-relativistic.

| $b_{CME}(R_e)$ | $u(\times10^3 m/s)$ | $N_{SC}(\times10^{24})$ | $N_{CME}(\times10^{24})$ | $T_{eq}(K)(\times10^4)$ | Process | $u_f(\times10^3 m/s)$ | $T_{f}(\times10^4 K)$ |
|-----------------|---------------------|--------------------------|--------------------------|--------------------------|---------|----------------------|----------------------|
| 14.89           | 2.6                 | 17.89902041              | 32.54367348              | 3.2903                   | NR      | 1.6774               | 6.3519               |
|                 |                     |                          |                          |                          | R       | 1.9293               | 10.4038              |

Table 10. Mixture CME ideal gas and the solar corona ideal gas where $T_{SC} = T_{11} = 2 \times 10^4K$ and $T_{CME} = T_{12} = 4 \times 10^4K$.

• Spicules.
  De Pontieu et. al. [7] exploited the detection of the disk counterpart of type II spicules: rapid blueshifted events (RBEs). Using an automated detection code, they found 2434 RBEs occurring in an active-region plage footprints of coronal loops during 1-hour-long time series on 25 April 2010. The chromospheric mass flux that spicules propel to coronal heights is estimated to be two orders of magnitude larger than the mass flux of the solar wind [29].

Based in the ubiquity of these events and the observed coronal intensities, De Pontieu et.
al. [7] estimated that these events carry a mass flux density of $1.5 \times 10^{-9} \text{g/cm}^2/\text{s}$ and an energy flux density of $\sim 2 \times 10^9 \text{erg/cm}^2/\text{s}$ into the corona. This is of the order that is required to sustain the energy lost from the active region corona [30].

- CMEs.
  The Solar and Heliospheric Observatory (SOHO) mission’s white light coronographs have observed a total of 6907 CMEs, from January 1996 to December 2002, that is $\sim 3$ CMEs per day, [15].

- Radiation due to the temperature.
  The solar corona lose energy by the photon emission and the heat conduction to the active region of the base. The cooling rate varies from the $10^5 \text{erg/cm}^2/\text{s}$ in quiet regions to $10^7 \text{erg/cm}^2/\text{s}$ in active regions [5].
  Moreover, solar corona would get cool by radiation due to the temperature in just 10min. Given the conservative nature of the De Pontieu et al. [7] estimation, type II spicules are likely to play a substantial role in the coronal energy balance, because the contrast of the energy flux density of spicules is the same order of the cooling rates by the radiation due to the temperature. On the other hand, CMEs supply energy to the solar corona if some of the ejected mass is kept in the solar corona. If some CMEs are so energetic that the total mass is ejected into the space, they will not contribute to the balance of energy because, in the limiting case, what enters the solar corona will come out without interfering. At best, some CMEs particles will collide with particles of the solar corona and the temperature of the latter will tend to grow.

6. Conclusions
The mixing of ideal gases with relative velocities results in an amazing increment in the mixture final temperature. Type II Spicules can locally heat solar corona to the maximum temperature $\sim 0.59 \times 10^6 K$, which is more than a half of the current solar corona temperature, but it is not enough, while CMEs cause final temperatures of order $\sim 10^7 K$.
Furthermore, when the solar corona is at the current temperature $1 \times 10^6 K - 2 \times 10^6 K$, type II spicules cool the solar corona temperature whereas CMEs are still heating it and ejecting mass to the space.

The use of The Redefined Relativistic Thermodynamics is relevant when relativistic velocities appear, as in the ($\sim 10\%$) selected by the possible image apparatus in the upper spicule part.

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