Calculation of ISON Cometary Tail Temperature

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Abstract

The ion tail temperature of the comet ISON was calculated by using magneto-hydrodynamic MHD laws. From these equations the focus is concentrating on determine the ion tail temperature from the relations of dynamic and static pressures results.MHD equations are numerically solved using Matlab simulation code using cubic volume element method, based on three dimensionl Cartesian coordinates that devided into equal 15x15x15 equally spaced mesh. The simulation was performed using 3-D Lax explicit method considering normalised physical propreties relative to those of the solar wind at 1 AU. The results explained that it is possible to deduce two types of temperature, the first being the isotropic temperature which is shown to vary slowly with distance from the cometary nucleus. The second type which is the dynamic temperature is shown to change continouosly and largely with distance from the cometary nucleus.

Keywords: Comet Temperature – X-ray Spectra- Solar Wind.

حساب درجة حرارة مذنب (SONI)

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الخلاصة:

تم في هذا البحث حساب درجة حرارة الذيل الايوني للمذنب (ISON) باستخدام قوانين المغنيتوهيدروداينمك (MHD).من هذه المعادلات كان التركيز على تحديد درجة الحرارة الذيل الايوني للمذنب.من خلال علاقة الضغط الديناميكي والاستاتيكي.حيث تم حل المعادلات عدديا باستخدام محاكاة ( ) Matlabمع اختيار عنصر حجم المكعب الذي يرتكز على ثلاث احداثيات ديكارتيزية مقسمة الى شبكة ابعادها متساوية (15 × 15 × 15) تم اجراء المحاكاة باستخدام طريقة Lax−explicit −D 3) . method)

باعتبار الخصائص الفيزيائية المعيارية نسبة الى الرياح الشمسية على مسافة وحدة فلكية واحدة (1A.U) . بينت النتائج من الممكن استنتاج نوعين من درجات الحرارة . الاولى درجة حرارة (متماثلة الحجم) وتظهر اختلاف بطيء مع المسافة عن نواة المذنب . النوع الثاني يظهر تغييرا مستمرا وكبيرا لدرجة الحرارة عن نواة المذنب.

1. Introduction

In 1951, Biermann found that the interaction between cometary ion tail and solar wind contributes significantly to understand and describe the format of these comets [1]. Alfven 1957 predicted that the IMF plays an important role in the interaction process [2], while Axford in 1964 showed that it may be

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well described by the magneto-hydrodynamic (MHD) laws [3]. This assumption made possible the first simplified one dimensional hydro-dynamical models of Biermann in 1967, which demonstrated the basic physics of cometary atmospheres. Within the following two decades this type of modeling has been improved by Brosowski and Wegmann (1973) as well as Wallis (1973) [4 ,5].

In 2003, Katoh et al. [6] examined spatial and time scale of field aligned motion of cometary ions in the ion pick-up process by using simulation and the shift of the interaction region was estimated.

In 2006 Khalaf [7] showed that the interaction near the cometary nucleus is mainly affected by the new ions added to the plasma of the solar wind, which increases the average molecular weight and result in many unique characteristics of the cometary tail. These characteristics were explained in the presence of the IMF using two methods of solving the continuity equations, explicit and implicit methods. The explicit method was based on Lax finite difference scheme, while implicit method was based on the Beam-Warming method.

In 2008, Khalaf and Selman [8] showed from the interaction between the solar wind and ions comet tail in the present of MHD that temperature changes plays vital role in energy distribution of cometary tail. The study has been achieved using a simulation model of Lax-Wendroff explicit method for three dimentional space.

Mauricio et al. in 2009 compared the results of the numerical simulation of the viscous-like interaction of the solar wind with the plasma tail of comets, with velocities of H_2O ions in the tail of comet Swift-Tuttle determined by means of spectroscopic, ground based observations. They found that the flow rapidly evolves from an arbitrary initial condition to a quasi-steady state for which there is a good agreement between the simulated tail ward velocity of H_2O ions and the kinematics derived from the observation [9].

In 2014, Khalaf et al. studied the physical properties of the interaction region between the solar wind and cometary ion tail for Halley and Hall-Bopp comets, and this interaction was basically described by the MHD system. This system of partial differential equations can be numerically solved using a particular method, which in this case was Leap-Frog explicit method [10].

In 2014, Agundezet al. presented molecular observations carried out with the IRAM 30m telescope at wavelengths around 1.15 mm towards the Oort cloud comets C/2012 S1 (ISON) and C/2013 R1 (Lovejoy) when they were at 0.6 and 1 AU, respectively, from the Sun, where HCN, HNC, and CH_3OH was found in both comets, together with the ion HCO^+ in comet ISON and a few weak unidentified lines in comet Lovejoy [11]. Khalaf et al. [12] found that the intraction can be described by plasma and MHD laws based on continuities equations.The intraction near the cometary nucleus is mainaly affected by the new ions added to the plasma of the solar wind.

2. MHD Explicit Model

The thermal and kinetic energy *(E)* of particles can be written using the relationships $\mathbf{E} = \frac{1}{2}\,mv^2$ and $\mathbf{E} = \frac{3}{2}k\,T$ which lead to, after few steps, to the final equation to calculate, the temperature change with time

$$\frac{\partial T}{\partial t} - \frac{2}{v}T\frac{\partial v}{\partial t} = (T\nabla v - v\nabla T) \qquad (1)$$

v is the speed, T is the temperature, k is Boltzmann's constant, and m is the (average) particle's rest mass. This equation was driven when starting with the ideal MHD equations. If $T \neq T(r)$ when T is constant for the distance (isotropic), then

$$\frac{1}{T}\left(\frac{\partial T}{\partial t} - \frac{2}{v}\frac{\partial v}{\partial t}\right) = (\nabla v) \qquad (2)$$

If T=constant for the time and space (isothermal) when $\frac{\partial T}{\partial t} = 0$, and $\nabla T = 0$. The particles velocity distribution of gas in the case of a plasma ionization using the general law of gases and from equation (1). If another set of arguments were started from $PV = nkT$ one may reach, after few steps, to the final equation to calculate the pressure change with time.

$$\frac{\partial P}{\partial t} + \frac{2P}{v}\frac{\partial v}{\partial t} = P\nabla v - v\nabla P \qquad (3)$$

3. Simulation Details

The intraction between the solar wind and cometary ion tail can be analysed numerically by developing computer cods using Matlab 2012 to study the physical properties for this model. The

numerical method solves the continuity equatios using Explicit method. The method was based on Lax finite differance scheme. Size of elemental volume was chosen based on three dimensional Cartesian coordinates divided into 15x15x15 equally cells as shown in Table(1).

Table 1- Initial and boundary conditions[11].Parameters are dimensionless**.**

| Parameter		Initial	Boundary
Mass density	ρ	1.00×10^{-20}	0.0001
Particles velocity	v	10	10
Magnatic field	B	4.0×10^{-10}	4.0×10^{-10}
Internal energy	E	4.0×10^{-10}	4.0×10^{-10}

The intracion length can be described the size of the intraction region of cometary ionsphere, R_I [11,12].

Table 2- Input parameter of the comet and physical properties of the solar wind

| Comet Ison and solar wind Characteristics			
$\sigma = 3.5 \times 10^{-7}$ s^{-1}	$\gamma = 5/3$	$G = 1.0810^{29}$ s^{-1}	$R_I = 10^9$ m
$\rho = 5$ m$_p$	$u_\Theta = 350$ km/sec	$m_c = 20 \times$ m$_p$	$V_c = 1000$ km/sec

4. Results and Discussions

The intraction between solar wind and cometary ion tail using MHD equations are modelets . The model of sumulation used Lax- explicit method for three-dimenesional space and the simulation are results shown in figures below.

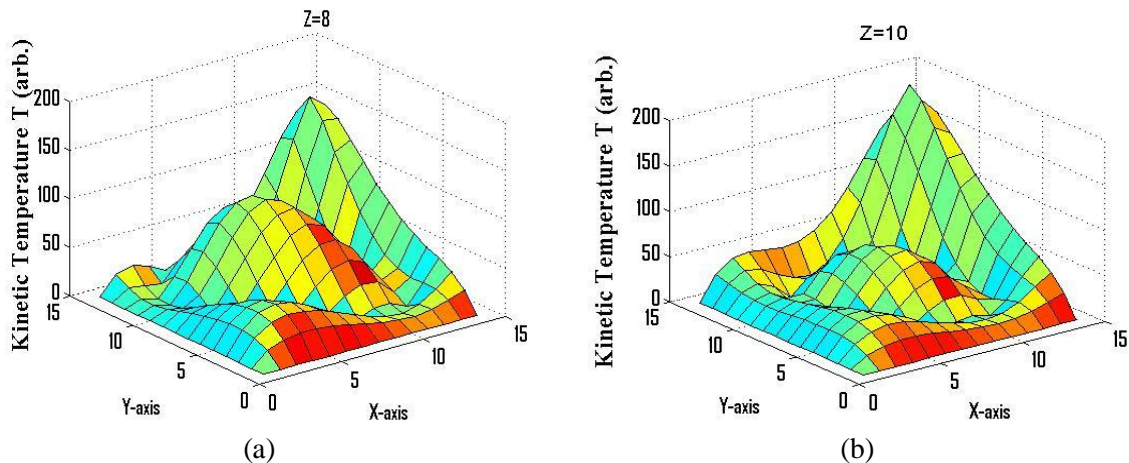(a)   (b)
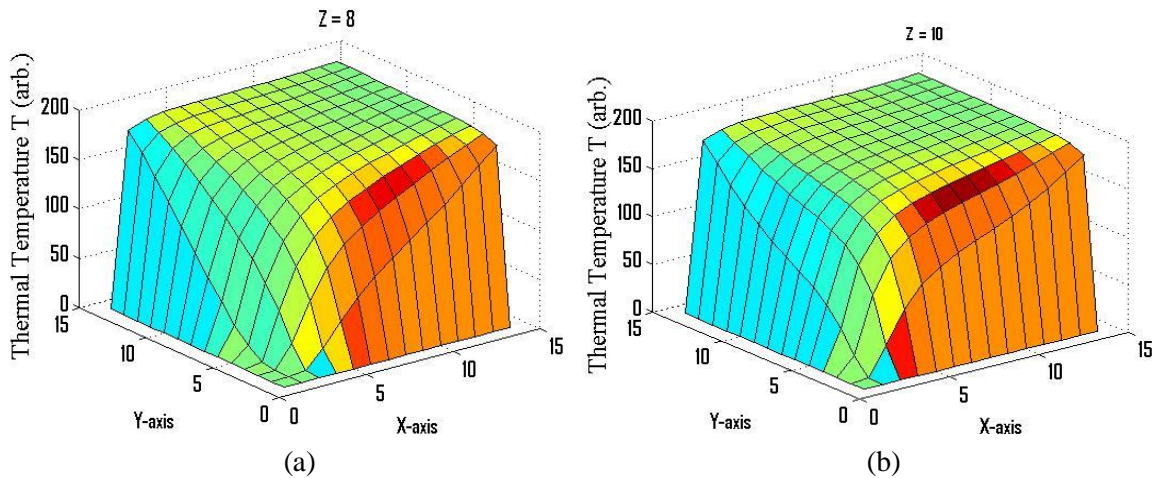
Figure 1- Relation between thermal temprature for three-dimensional magnetoh-ydrodynamic simulation and space, using Lax explicit method, with source. The distancce is in units of RI when Z= 8 and 10**.**

Figure-1 express the results of thermal temperature using Lax explicit method of three dimensional spaces. The Z-axis values are chosen for Z=8 and Z=14 respectively. From these figures, it can be seen that the elevation of the spectral has effects on the value of temperature. Hence from the temperature is sharply increses at the beginning of the intraction and then becoues slightly increses after words . The interaction between the plasma of the solar wind and ion tail as it shown in figures above can be used to describe this intraction using MHD model.
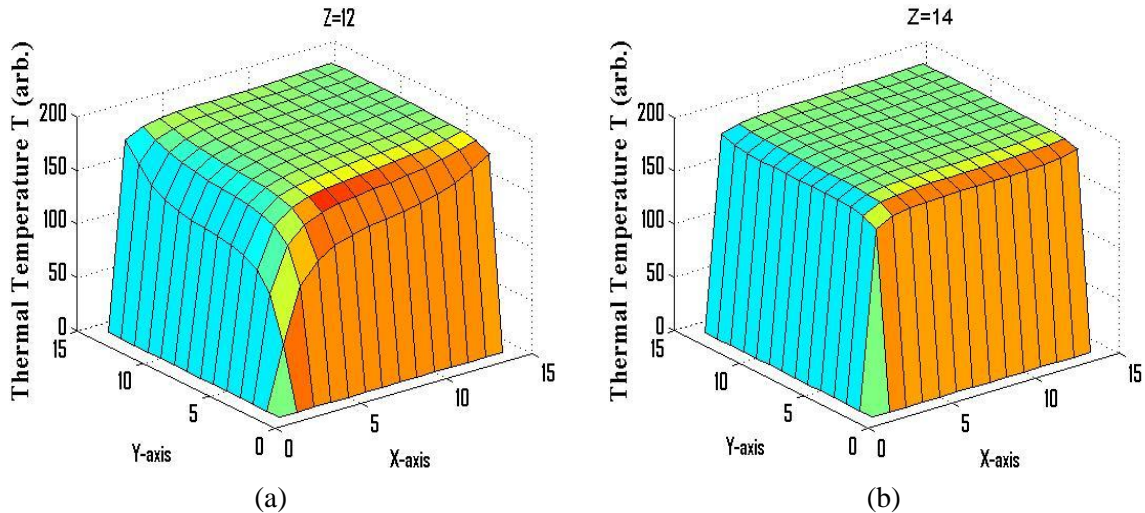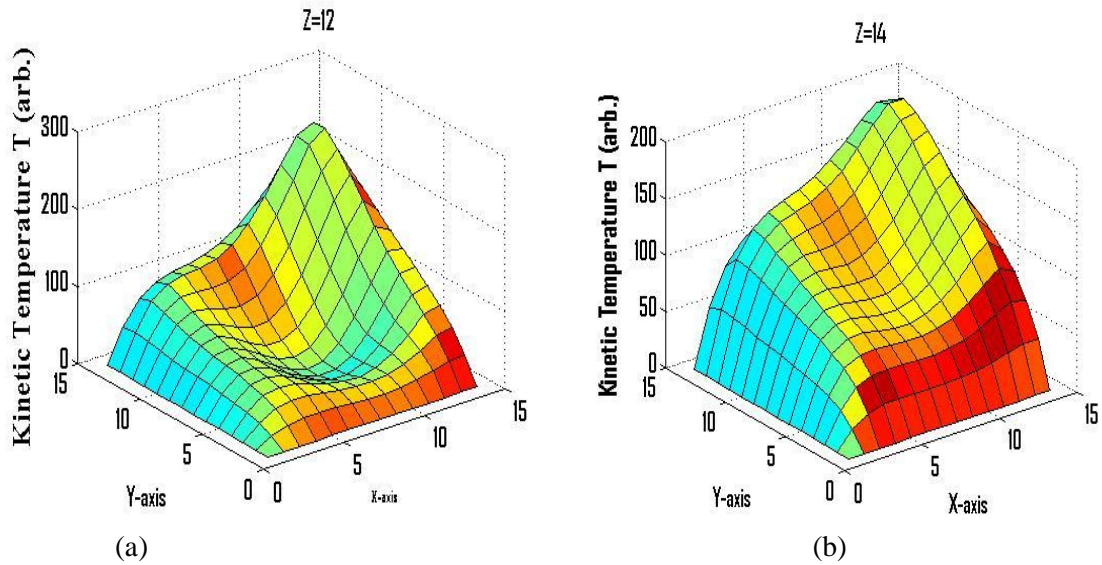
Figure 2- Relation between thermal temprature for three-dimensionalmagnetohydrodynamic simulation and space, using Lax explicit method, with source. The distancce is in units of the RI when Z=12 and14**.**

From figure-2 it can be noticed that if the temperature is constant, the (z) increasing, the temprature becomes uniformaly distributed. This is called isothermal region which represent the conservation internal total energy and by physically meaning called the stability of thermal equilibrium of particles of cometary ion tail. The solar wind particles play an important role on the dominant force that shapes and urges the cometary ion tail to have its shape and properties. The temperature occurring is due to the interaction of the stream of the solar wind with the plasma flow of the cometary ions. This is seen from figure-2.a when the temperature was gradually decreasing at low mesh values, that is at Z=12. Where at Z=14 shown in (2.b) the temperature was almost constant for the entire mesh.


Figure 3- Relation between kinetic temprature for three-dimensional magnetohydrodynamic simulation and space, using Lax explicit method, with source. The distancce is in units of RI when Z=8 and 10.

From the results shown in Figure (3.a and b), it can be seen that there are few important remarks. The overall behavior is represents a polynomial function of distance that has maxima at three positions. As the z elevation incearses, the inner maxima value decrease and the last (farthest) maxima increase. The reason behind this is that the new added particles near the cometary nucleus interact with each other in the main stream of the cometary tail resulting in more energy loss. As the distance increase the particles seem to have more freedom thus appear as if they have more value of kinetic energy that is represented by temperature.

(a)   (b)

Figure 4- Relation between kinatic temprature for three-dimensional magnetohydrodynamic simulation and space, using Lax explicit method,with source. The distancce is in units of RI when Z= 12 and 14**.**

The source of the code have shown that z=14 continue to maintain larger values than z=12 as shown in Figure (4). Figure (5), shows the distribution of the total kinetic energy of the cometary tail of this system as obtained from the three dimensions of the simulations. The important indication from these figures is the increase of temperature when the value of z-axis increases. This temperature increament is expected as a result of an increment in the kinatic energy of the comet nucleus where the plasma ions near the nucleus added mass to cometary tail which leads to increase the molecular weight for the structure of the tail.There is a significant change during the interaction of the solar wind with the comet's nucleus as shown in the figure above.
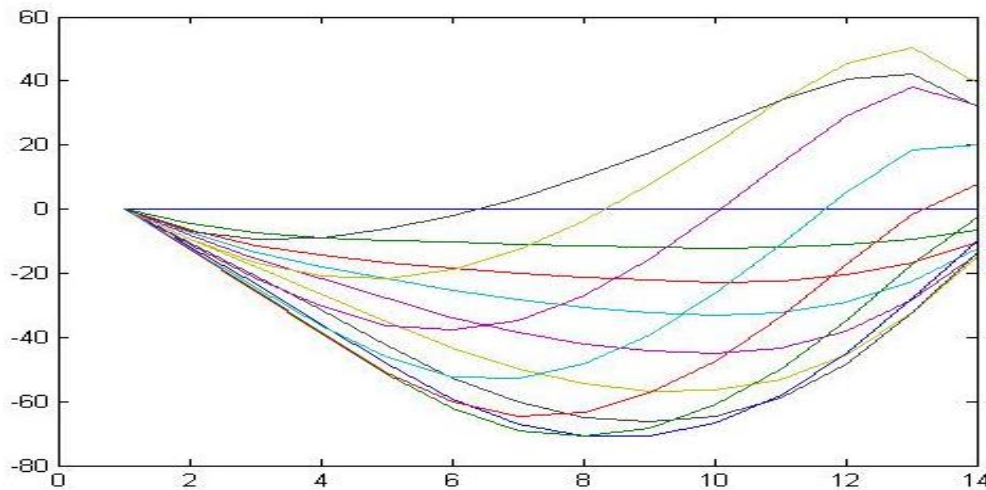
Figure 5- The numerical differences of T(X,Y,Z=12) and T(Z,Y,Z=14) for all values of X and Y.

5. Conclusions
Temperature of the cometary ion tail was calculated based on two approachs, kinetic and isotropic. Statistical simulation results showed that thermal temperature reached a saturation level soon after few time steps while the kinetic temperature had a nonlinear relationship with distance. That was attributed to the role of kinetic energy of ions of the comet tail, when denser regions contribute more to total kinetic temperature than elsewhere. The behavior of the statistics was seen to be continuous with spatial coordinates which was expected if the mass added by cometary nucleus is considered.

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