Khalaf and Abrahim *Iraqi Journal of Science, 2020, Vol. 61, No. 12, pp: 3417-3433*
DOI: 10.24996/ijs.2020.61.12.30

ISSN: 0067-2904

Expansion Velocities of Elementary Gas in Comet Panstarrs Above 30000 Km from Nucleus

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Received: 11/11/2019 Accepted: 15/3/2020

Abstract

The coma gasses consist of molecules liberated from the nucleus by solar heating and relative sublimation. Once they have left the nucleus, these molecules in the coma are exposed to direct solar radiation and can be damaged in various ways due to the combined action of these reactions.

One of some complex problems facing the research in this field is that the Maxwell-Boltzmann equation gives distribution function for one kind of particles which have same masses, but the gas has multi-groups of particles (Carbon, Neon, Sodium … etc.), where all these components must be in one program to extract average velocity of all and calculate particles velocity to each band. This problem is solved here by Matlab program and the approach demonstrated good results. The study included extracting some elements of comet PanSTARRS by using X-ray spectrum with the calculation of elements' abundances in respect to Carbon and obtaining particles' velocity distribution to calculate most of the particles in the intervals of velocities.

The study shows some physical relationships of cometary heavy elements, which are larger in mass than Carbon and have roughly less abundance in the cometary gases. Using X-ray spectrum, 23 elements of comet PanSTARRS C/2011 S4 were obtained. Carbon showed the highest abundance, followed by Gold. Apparent abundance of all elements were extracted in respect to Carbon, which was correlated with the distribution function of Maxwell-Boltzmann to calculate element velocities and the bands of most particles' velocities.

Gas temperature was found to be equal to 1412 k. From this value, the velocity of each particle was obtained, as shown in the figures, where the velocity range of most particles (about 21% of total particles) was ~ 400-600 m s^{-1}, whereas extending the band to 200-800 m s^{-1} showed that the abundance includes 54% of particles.

An H_2O curve peak was found at velocity of 1142 m s^{-1}, while the highest value was ~ 1389 m s^{-1} for Carbon (relatively light element) and the lowest value was about 340 m s^{-1} for Gold particles (relatively heavy element).

Keywords: Elementary Gas, Nucleus, Panstarrs

سرعة تمدد عناصر الغاز في المذنب PanSTARRS على ارتفاع km 30000 من نواة المذنب

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الخلاصه

تتكون غازات الهالة الغاز من جزيئات متحررة من النواة عن طريق التسخين الشمسي والتسامي النسبي.

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بمجرد أن تغادر النواة تتعرض هذه الجزيئات لإشعاع شمسي مباشر ويمكن أن تتحلل بطرق مختلفة نتيجة لتأثير هذه التفاعلات.

أن احدى بعض المشاكل المعقدة في هذا البحث هي ان معادلة توزيع ماكسويل – بولتزمان التي تعطي دالة توزيع لنوع واحد من الجسيمات والتي تمتلك نفس الكتل , لكن الغاز يحتوي عدة مجاميع من الجسيمات (كاربون , نيون , صوديوم ..... الخ) , حيث كل تلك المكونات يجب ان تكون في برنامج واحد وذلك لأستخراج معدل السرعة لكل المكونات وأيضا حساب سرعة الجسيمات لكل حزمة . هذه المشكلة قد تم حلها بواسطة برنامج الماتلاب وقد أعطت نتائج جيدة , تهدف الدراسة إلى استخراج بعض عناصر المذنب PanSTARRS باستخدام طيف الأشعة السينية مع حساب وفرة العناصر نسبة الى عنصر الكربون والحصول على توزيع سرعات الجسيمات لحساب الحد الاقصى للجسيمات ضمن حزم السرع .

تُظهر الدراسة بعض العلاقات الفيزيائية للعناصر الثقيلة في المذنب الأكبر من كتلة الكربون والتي تمتلك تقريبا اقل وفرة في غازات المذنب , فمن طيف الأشعة السينية تم الحصول على 23 عنصرا حيث ظهر الكربون ذا وفرة عالية والثاني هو عنصر الذهب في ترتيب الوفرة . الوفرة الظاهرية لأي عنصر قد تم أستخراجها نسبة الى عنصر الكاربون والتي ترتبط مع دالة توزيع ماكسويل- بولتزمان لحساب سرع جسيمات العناصر وحزم سرع الجسيمات التي تمثل اغلب الجسيمات في تلك الحزم.

قد تم حساب درجة حرارة الغاز والتي تقدر ب 1412 كلفن . فمن هذه القيمة يمكن حساب سرعة كل جسيم كما موضح في الاشكال. حيث ان مدى سرعة الغالبية العظمى من الجسيمات يقع ضمن حزمة 400-600 م / ثا والتي تكون ذا وفرة 21% من عدد الجسيمات الكلية , لكن مع توسيع الحزمة الى 200-800 م/ثا ستكون وفرة هذه لجسيمات في تلك الحزمة بحدود 54% .

قيمة قمة المنحني لذرة الماء عند سرعة 1142 م/ثا بينما القيمة العظمى للسرعة كانت 1389 م/ثا لذرة الكاربون

(العنصر الخفيف نسبيا) والقيمة الاقل للسرعة هي 340 م/ثا لجسيمات عنصر الذهب (العنصر الثقيل نسبيا).

Introduction

The data used in the study of the comet C/2011 S4 were collected from Chandra X-ray observatory. Chandra satellite observed comet PanSTARRS when it came to the inner Solar System after a long period from the Oort cloud [1].

The apparent velocity distribution of the observed X-ray spectrum elements was previously extracted by a Maxwell-Boltzmann equation. The study tested some physical properties of the elements in comet gas, such as the relationship between the velocity and the apparent abundance ratio (photon number ratio) between photons of the elements to Carbon. The range of emission energy in X-ray is about 250-10000 eV [2].

The observed emission of X-ray that is coming from the comet is due to solar particles when they strike the atmosphere of the comet. Although most of the particles in the solar wind are hydrogen and helium atoms [3], the observed X-ray emission ejects from relativity heavy atoms (Oxygen or Carbon). Electrons are stripped away from these atoms, resulting in excited ions [4] that collide with neutral atoms in the comet's atmosphere. In a process called "charge exchange", an electron is exchanged between one of these neutral atoms, usually hydrogen, and a heavy atom in the solar wind. After such collision, X-ray is emitted as the captured electron that moves into a tighter orbit [5].

As a fundamental step of studying this type of events, the temperature is determined and then velocity distribution of each element is evaluated.

The gas density close to the cometary nucleus approaches about 10^{17} H_2O molecules/m^3, and drops off to a value of about 10^{13} H_2O molecules/m^3 at typical Rosetta distances of 150 km [6]. There are many relativistic heavy elements that have been observed in cometary spectrum with atomic numbers above 20, such as ${}_{24}Cr$, ${}_{25}Mn$, ${}_{26}Fe$, ${}_{28}Ni$ [7], ${}_{36}Kr$ [8] and ${}_{54}Xe$ [9], with the latter element having the isotopes ${}^{128}Xe$, ${}^{129}Xe$, ${}^{130}Xe$, ${}^{131}Xe$, ${}^{132}Xe$, ${}^{134}Xe$, and ${}^{136}Xe$ [8]. Many heavy elements are found in the cometary gasses.

Particles' velocity in comet's atmosphere at 1km/s represents an average value of the velocity [10]. Average mass value in the cometary gas is 23.3 of the proton mass [10].

Literature review

The original discovery of X-ray emissions of the comets was in 1996. The subsequent detection of X-rays from 17 other comets showed that the very soft (E < 1 keV) emission is due to an interaction between the solar wind and the comet's atmosphere. It was also demonstrated that X-ray emission is a fundamental property of comet's high energy X-ray emission, which was detected in 1996 from C/1996 B2 (Hyakutake) and represents a new class of X-ray emitting objects [11]. Thermal bremsstrahlung emission occurs due to solar wind electron collisions with neutral gas or dust in the coma [12], microdust collisions [13], cometary emissions induced by scattering and fluorescence of solar X-rays [14], and solar wind charge exchange in cometary atmospheres [15, 16].

Observations

Chandra observed comet PanSTARRS when it is relatively close to Earth, as shown in Figure-1.

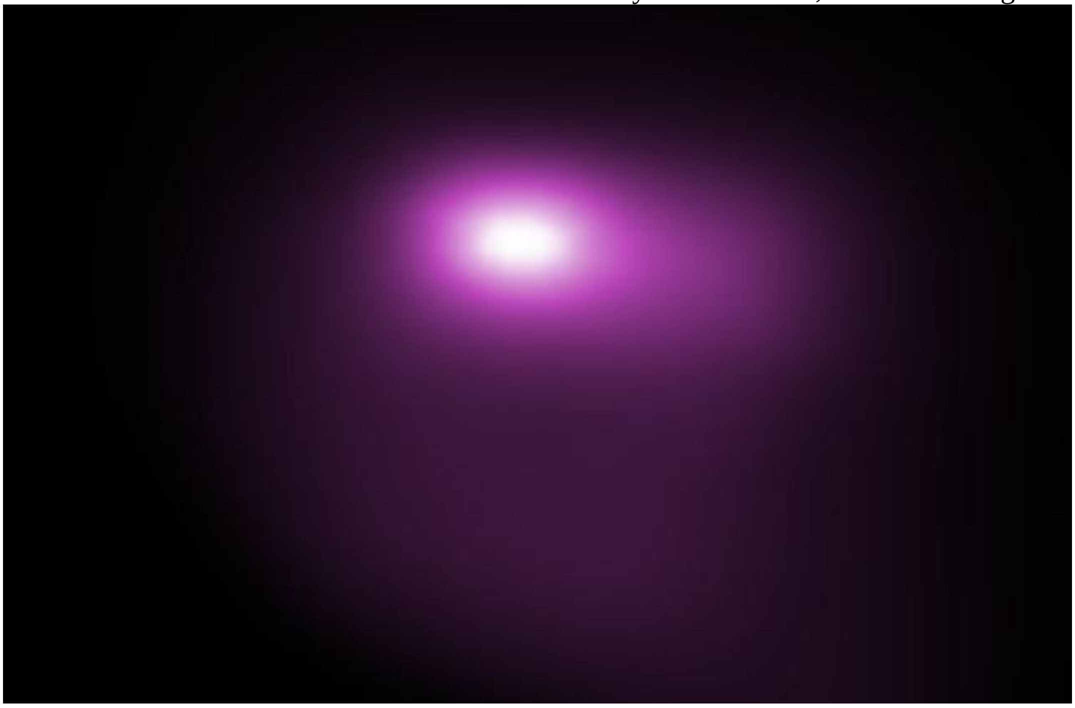

Figure 1-Comet PanSTARRS view by X-ray sensors from Chandra observatory "NASA" [2].

X-ray spectrum of comet PansTARRS was extracted using Chandra site via DS9 program. The spectrum lines of the comet are shown in Figure-2.

Figure 2-Spectrum emission lines of comet PanSTARRS extracted by ds9 program [2]

One can extract a list of information about this comet. The amount of photon intensity represents the abundance of each element in certain energy that refers to object components and can find some gaseous elements, as investigated in Figure-3.

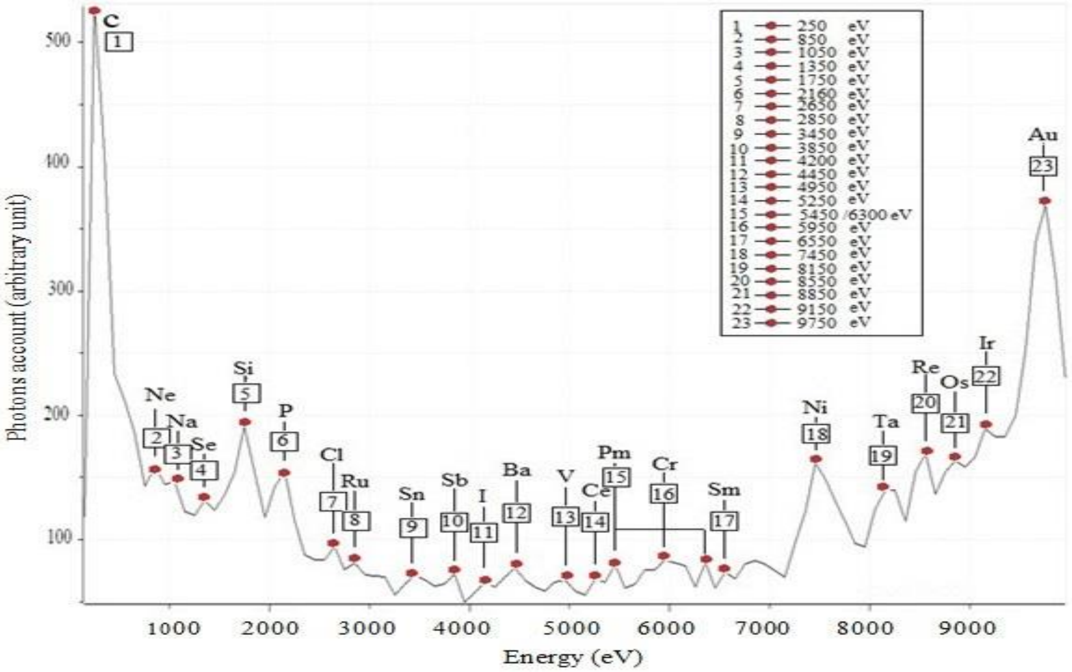

Figure 3-The elements of Comet PanSTARRS, C/2011 S4, by Chandra X-Ray energy curve.

Table-1 is related to heavy elements and shows the interpretation of curve information of X-ray emission.

Table 1-Comet PanSTARRS spectrum elements of X-ray emission lines with energy values and types of transition levels which are deduced from Figure-2

No.	**Element name**	**Atomic number**	**Photon's account (A_i)**	**Energy (eV)**	**Standard energy(eV)**	**Emission lines**
1	C - Carbon	6	530	250	277	$K_{\alpha1}$
2	Ne-Neon	10	159	850	848.60	$K_{\alpha1}\&K_{\alpha2}$
3	Na- Sodium	11	147	1050	1040.98	$K_{\alpha1}\&K_{\alpha2}$
4	Se-Selenium	34	132	1350	1379.10	$L_{\alpha1}\&L_{\alpha2}$
5	Si-Silicon	14	191	1750	1739.98	$K_{\alpha1}$
6	P-Phosphorous	15	155	2150	2139.10	$K_{\beta1}$
7	Cl- Chlorine	17	95	2650	2622.39	$K_{\alpha1}$
8	Ru-Ruthenium	44	82	2850	2834.41	$L_{\beta1}$
9	Sn-Tin	50	72	3450	3443.98	$L_{\alpha1}$
10	Sb- Antimony	51	73	3850	3843.57	$L_{\beta1}$
11	I-Iodine	53	66	4200	4220.72	$L_{\beta1}$
12	Ba-Barium	56	78	4450	4450.90	$L_{\alpha2}$
13	V-Vanadium	23	65	4950	4952.20	$K_{\alpha1}$
14	Ce-Cerium	58	69	5250	5262.20	$L_{\beta1}$
15	Pm-Promethium	61	80	5450 6300	5432.5 6339.0	$L_{\alpha1}$ $L_{\beta1}$
16	Cr-Chromium	24	83	5950	5946.71	$K_{\beta1}$
17	Sm-Samarium	62	74	6550	6586.00	$L_{\beta1}$
18	Ni-Nickel	28	162	7450	7460.89	$K_{\alpha2}$

19	Ta-Tantalum	73	139	8150	8146.10	$L_{\alpha 1}$
20	Re-Rhenium	75	169	8550	8586.20	$L_{\alpha 2}$
21	Os-Osmium	76	164	8850	8841.00	$L_{\alpha 2}$
22	Ir-Indium	77	190	9150	9175.10	$L_{\alpha 1}$
23	Au-Gold	79	270	9750	9713.3	$L_{\alpha 1}$

Important features in the curve's peaks were studies, where each peak represents one element of the cometary gas, while the number of photons refers to the number of emitted atoms with respect to others. For example, Carbon has a number of photons of 530, , whereas Neon has 159 (Table-1). The ratio between both elements (159/530) is equal to 0.3, which implies that Ne/C ~30%. Hence, one can obtain any value of relative percentage of photons numbers of two elements or for a specified element in relation to all elements.

Measurements of photons number differ from an instrument to another. The reason is the different materials used into each tool, observation state, type of the measurement, observation time, and weather state, but the ratio between these variables remain constant.

The errors in the measurements such as spectrum energy specify each element from the nearest energy value of certain emission line, where the normal error in some emission lines of one experiment was natural line widths of O_2 and O_3 determined upper levels equal 2.9 eV and 1.9 eV, respectively, with ±0.4 eV random error and ±0.3 eV as systematic error ~13% [17]. In addition, comet PanSTARRS spectrum lines showed a maximum error of ~2% for Selenium, which implies that the measurements are accurate, as shown in Table-1.

Physical model: Determination of velocity distribution

The state of thermal equilibrium of gas has constant temperature of all components as average, the plasma system is at thermal equilibrium as entire. The probable function density of plank as illustrated in Figure-4.

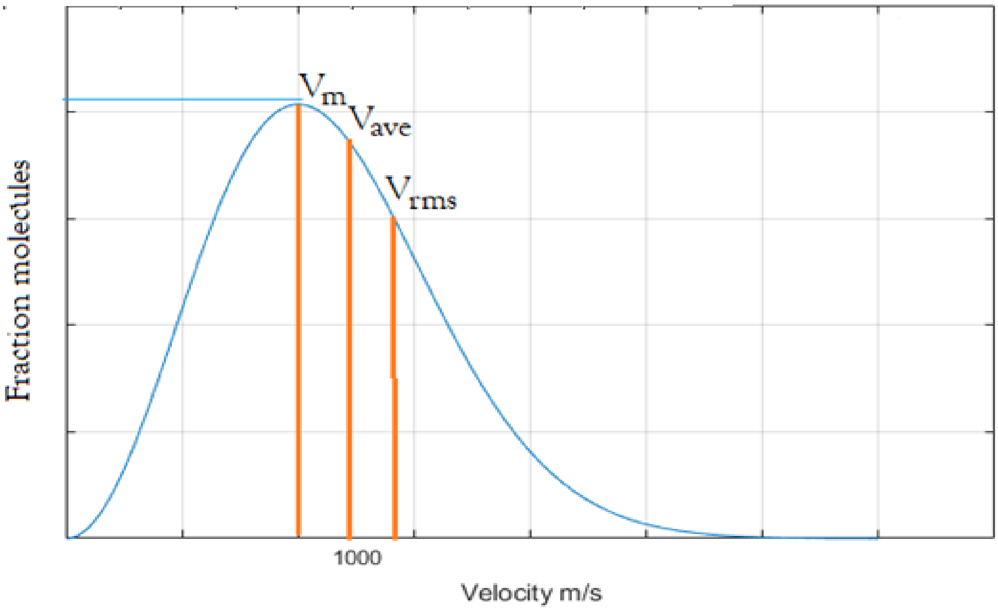

Figure 4-Three quantities of velocities of most probable, average, and root mean square velocities.

The peaks distribution indicates the maximum number of the molecules in a particular velocity [18]. There are three types of distribution velocity of cometary components, as in the following equations [18].

1- Most probable velocity $v_{mp} = \sqrt{\frac{2kT_g}{m}}$ (1)

2- Average particles velocity $v_{av} = \int_0^\infty v f(v) dv = \sqrt{\frac{8kT_g}{\pi m}}$ (2)

3- Root mean square velocity $v_{rms} = \sqrt{\sum v^2} = \sqrt{\frac{3kT_g}{m}}$ (3)

The resulted temperature from equation (1) is the most probable velocity, where T_g represents average gas temperature of all components. But the particles in the gas contain a mixture of elements which have various masses, after extracting average temperature of the entire gas components. However, there is another step, by using equation (1), to extract the velocity of each element.

At a distance of 30000 km from the cometary nucleus, values of several constants were found; particles' velocity was ~1000 m s^{-1} and average mass of total particles was $23.3m_p$ [9], as calculated based on the following equation:

$$T_g = (\frac{1}{2}23.3m_p v^2)/K \tag{4}$$

$$T_g = \frac{0.5x23.3x1.6x10^{-27}x1000^2}{1.38x10^{-23}} = 1412\ k$$

T_g is the gas temperature, which is constant at this distance for all gas components in any comets at heliocentric distance 1AU (distance Sun-comet) .

$$v = \sqrt{\frac{2kT_g}{m}} = \frac{1.9744x10^{-10}}{\sqrt{m}} \tag{5}$$

1- Velocity of H_2O molecules

$$v_{H2O} = \frac{1.9744x10^{-10}}{\sqrt{m_{H2O}}} \tag{6}$$

2- Velocity of X-ray spectrum elements, which is represented by peaks of curve in fig.(4), for the 23 elements of PanSTARRS, were calculated by:

$$v_{el} = \frac{1.9744x10^{-10}}{\sqrt{m_{el}}} \tag{7}$$

3- Velocity of undetected components. Mass of undetected components roughly equal average mass $23.3m_p$ as had been explained.

$$v_{av} = \frac{1.9744x10^{-10}}{\sqrt{23.3m_p}} = 1000\ \text{m s}^{-1}$$

where $m_P \sim m_H = 1.0079$ amu, proton mass ~= hydrogen element mass (1 atomic mass unit (amu) = 1.66053904 $x10^{-27}$ kg).

It is worthy to note that cometary gases consist of many groups of components, each having a certain most probable velocity. Using Maxwell-Boltzmann distribution equation, *n(v)* value is determined as follows [18]:

$$n(v) = 4\pi v^2 (\frac{m}{2\pi kT})^{\frac{3}{2}}\ \exp(\frac{-mv^2}{2kT}) \tag{8}$$

where $n(v)$ is the molecule fraction of one type of components that have the same mass, i.e. there is one velocity function of each mass with respect to all components in thermal equilibrium (constant temperature).

The abundance of X-ray spectrum's elements

The number of photons indicates the intensity of total photons coming from the source. The spectrum curve has many photonic peaks of each component in the gas. Thus, the peak is the number of photons (photons count), which has a linear relation with the number of atoms. Therefore, whenever the number of atoms increases, the emitted photons will be increased, i.e. the abundance relates to photons number where any increase in photons number means increasing the abundance. Thus, a high peak implies a high abundance, where the ratio between any two peaks represents the ratio between both abundances of these components, as in the following equation [19]:

$$x_i = \frac{A_i}{A_C} \tag{9}$$

where A_i , A_C are photons numbers of the element and Carbon, respectively, while x_i is the relative abundance of any element to Carbon abundance . The value of x_i is between 0-1, while *Ac* (photons number of Carbon) is the largest value in the curve. Equation (9) calculates the ratio between the elements, which is not the real abundance of each element. Equation (8) indicates the velocity distribution to fraction of molecules that follows normalization as simple relation:

$$n(v) = \frac{n(v)}{\max(n(v))} \tag{10}$$

The maximum function does not reflect one value, rather it has 23 values for 23 elements. By the modification of eq. (10) with element's abundance, it will become:

$$n(v) = x_i \frac{n(v)}{\max(n(v))} \tag{11}$$

Results and discussion

Maxwell-Boltzmann distribution equation (8) gives many functions for many masses, where the elements in PanSTARRS spectrum have contrast masses from 6-79 of atomic numbers. Figure-5 shows the 23 functions of the spectrum for PanSTARRS elements.

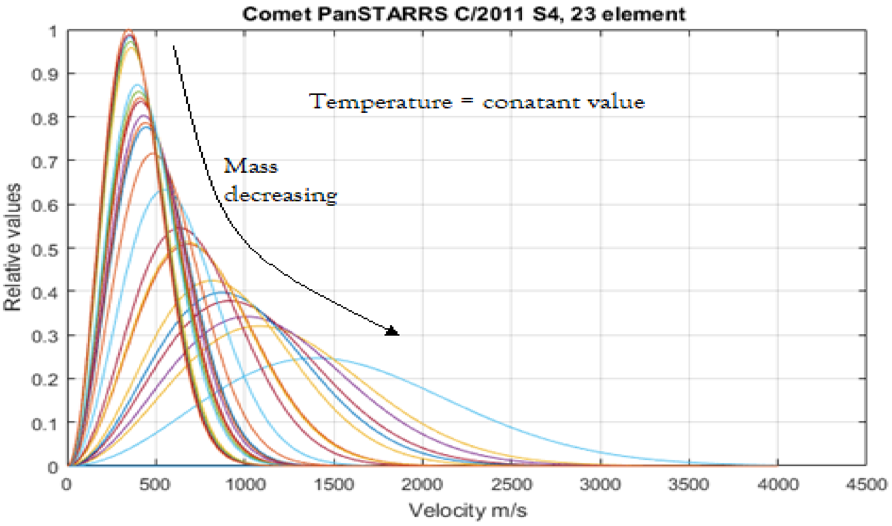

Figure 5-Maxwell-Boltzmann distribution of the cometary elements with constant temperature.

The y-axis represents the fraction of particles in the gas. Whenever the mass of the gas increases, the mass number of most particles increases too. However, this is not true in our case; in fact, if the elements have the same abundance per volume, the curves in the above figure must have the same peaks for all elements with respect to each peak which has different velocity, i.e. the change in velocity occurs when the particle's mass is changed. Thus, when distribution functions are normalized as in equation (10), then the distribution of velocities will be as shown in Figure-6.

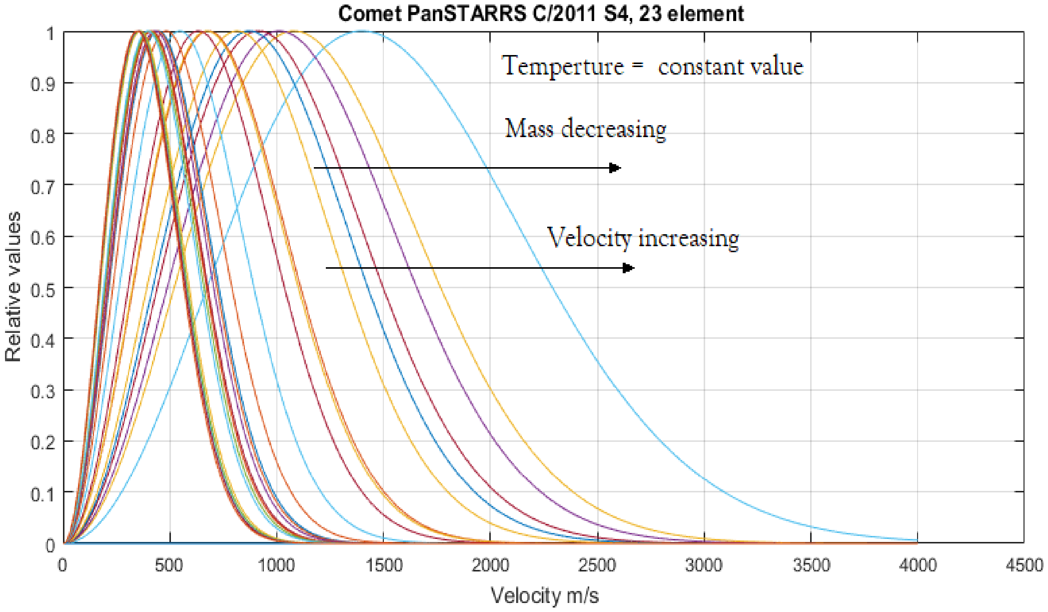

Figure 6-The distribution of velocities of gas elements in comet PanSTARRS depending upon their masses . The peaks represent symmetric values of numbers density in all elements.

The abundance of components in the above figure has similar peak values, which means that each component has the same number of particles per cubic meter. This case does not occur in the nature because the elements certainly have various values of abundance. Thus, eq. (10) gives 23 curves that are shown in Figure-6, without abundance values, because this equation has normalization to equal one unity in its peaks .

Eq.(10), after normalization, with existence varies values of abundance , must multiply by abundances values to gives varies peak of abundance , where highest value of photons account mean highest values of number density of the elements , and this equation will take finale form after multiply by abundance values of each element with respect to the Carbon element , equation(11) ,which will give Figure-7.

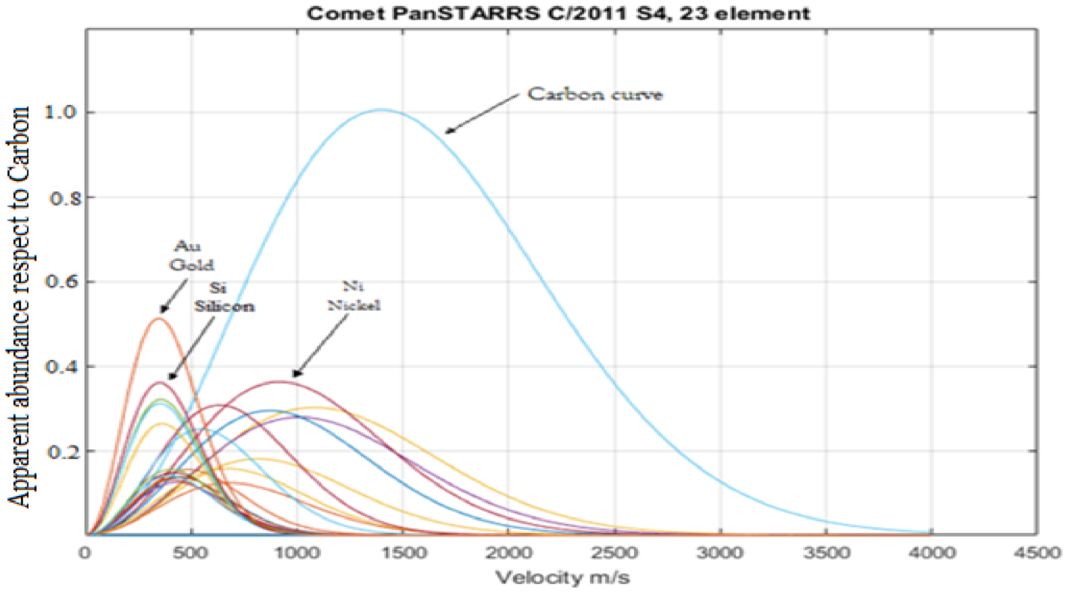

Figure 7-23 elements of comet PanSTARRS in two variables the abundance respect to the Carbon versus the velocities where the low mass means fast speed.

The velocity decreases with increasing mass, where Carbon has a lower mass than that of the other elements and, hence, it has the highest velocity (1398 m s^{-1}), while Gold has the lowest velocity (345 m s^{-1}). The average velocity of the 23 elements is ~ 600 m s^{-1}, and the most probable velocities are around 500 m s^{-1}. These velocity values are in a good agreement with those reported earlier.

The curves show a range that is consistent with previously reported values. The numerical calculated velocity of gas at large distances from the comet nucleus are usually between 0.5 - 2 km s^{-1}”.

In order to describe the results in more details, a band by band analysis of the elements in comet PanSTARRSmust was conducted, as shown in Figures-(8-15).

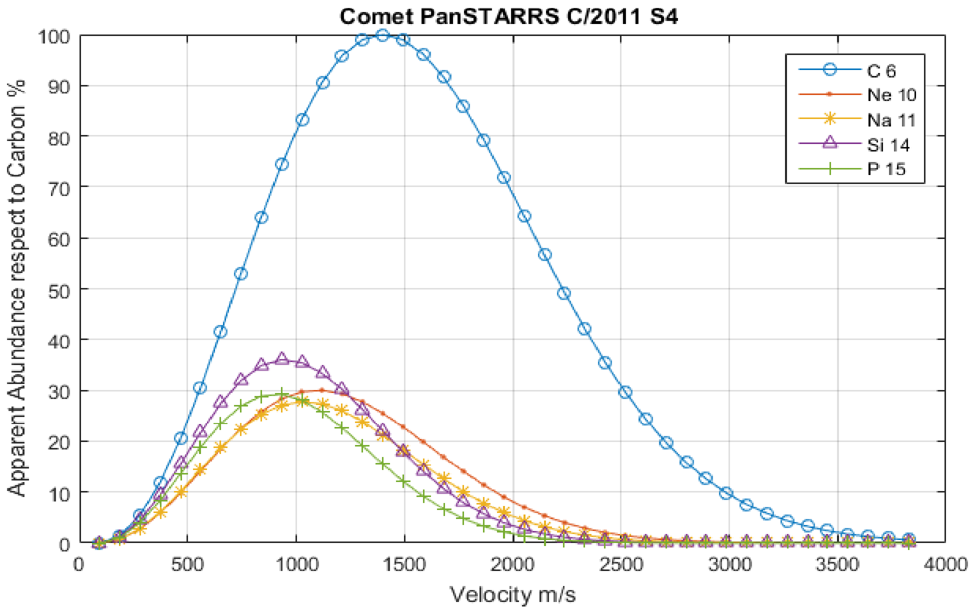

Figure 8-5 elements in comet PanSTARRS ,4 elements have velocity roughly colse to1km s^{-1}. Carbon atoms have highest velocity among them because it has low atomic mass.

The curves' heights are determined by their abundance with respect to Carbon, which represents the difference in the density of each element. While, if the elements have similar abundances, they will have the same number of atoms per volume (eq.10). Therefore, the patterns shown in fig.(8) will develop to those shown in Figure-9.

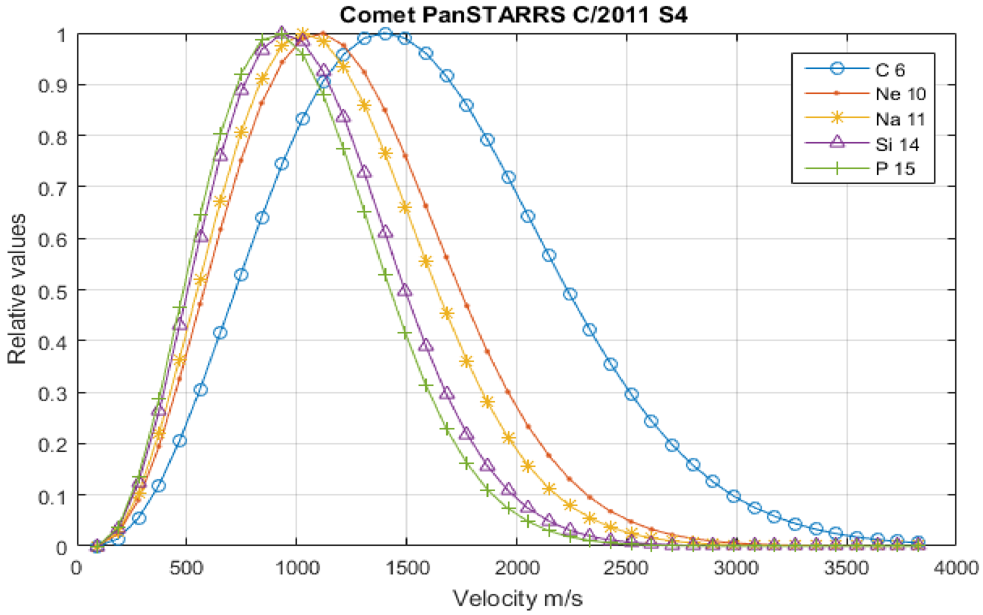

Figure 9-The elements have same number density when they have same abundance.

The second group of elements in comet PanSTARRS are shown in Figure-10.

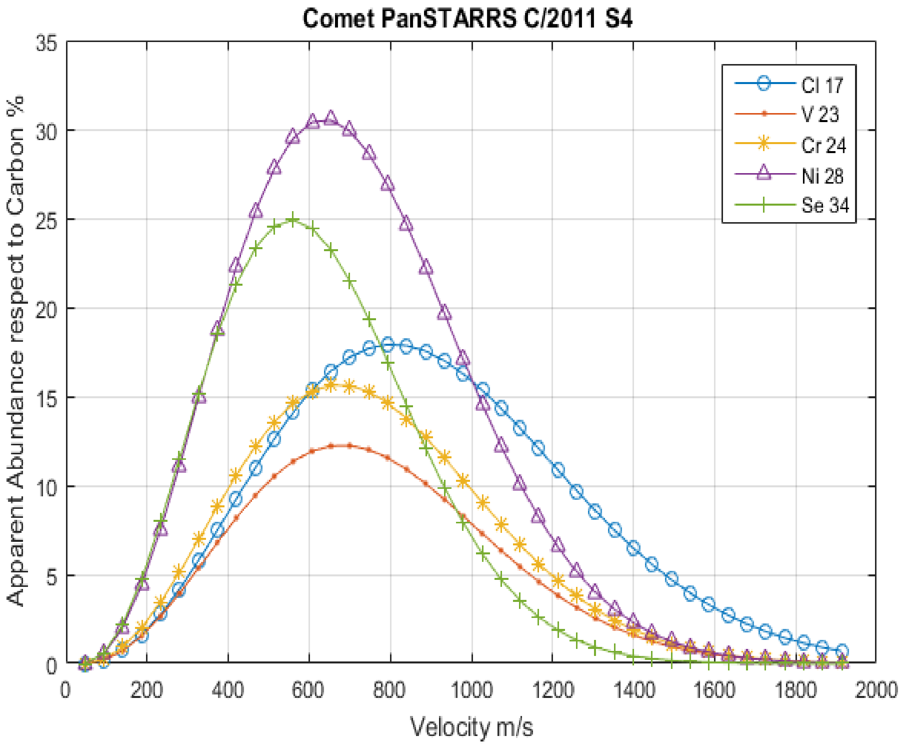

Figure 10-The elements have very low density number (low abundance), then their velocities are below 1km s^{-1} because they have atomic mass larger than first group.

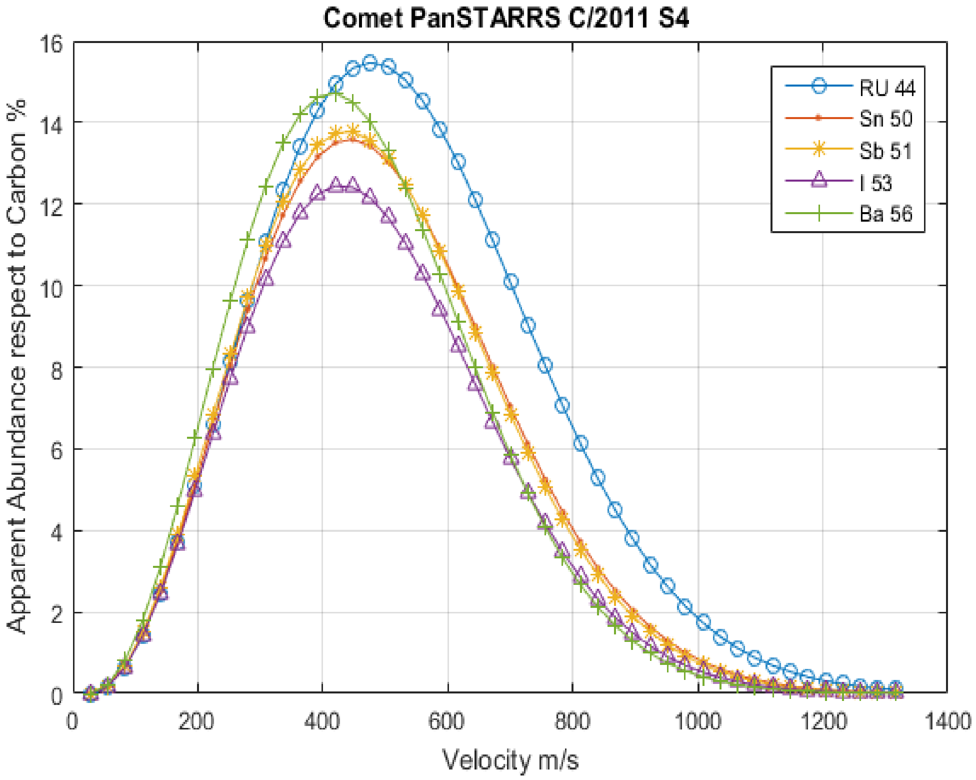

Figure 11-Heavy elements have converging velocities around 400 m s^{-1}.

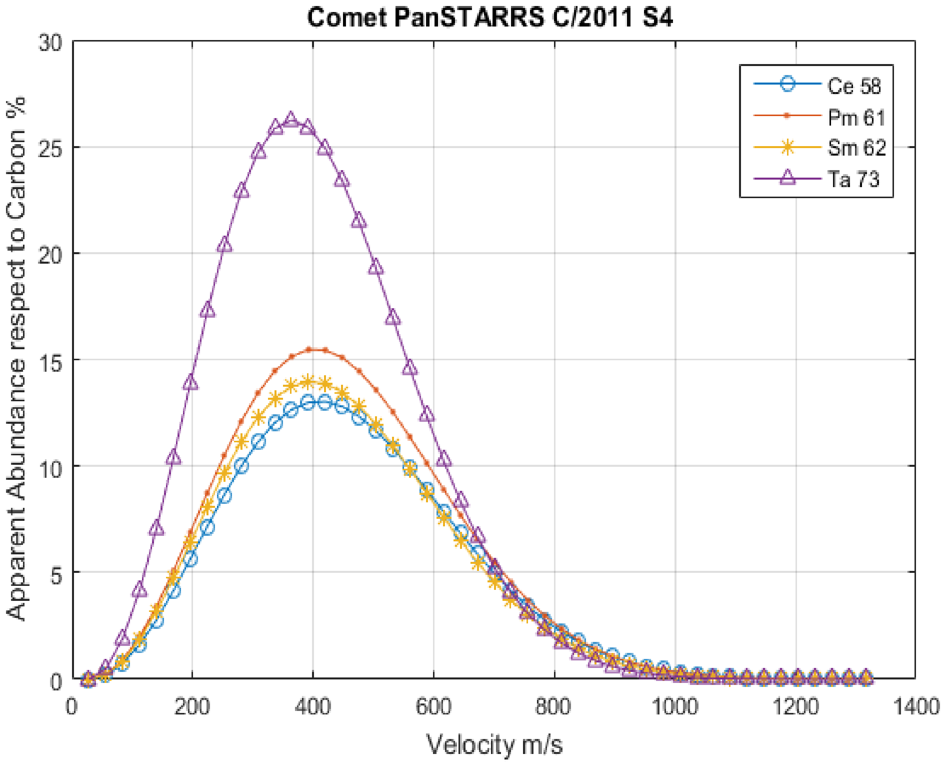

Figure 12-Three elements of the group have velocity 400 m s^{-1} with abundances less than 17% respect to Carbon abundance

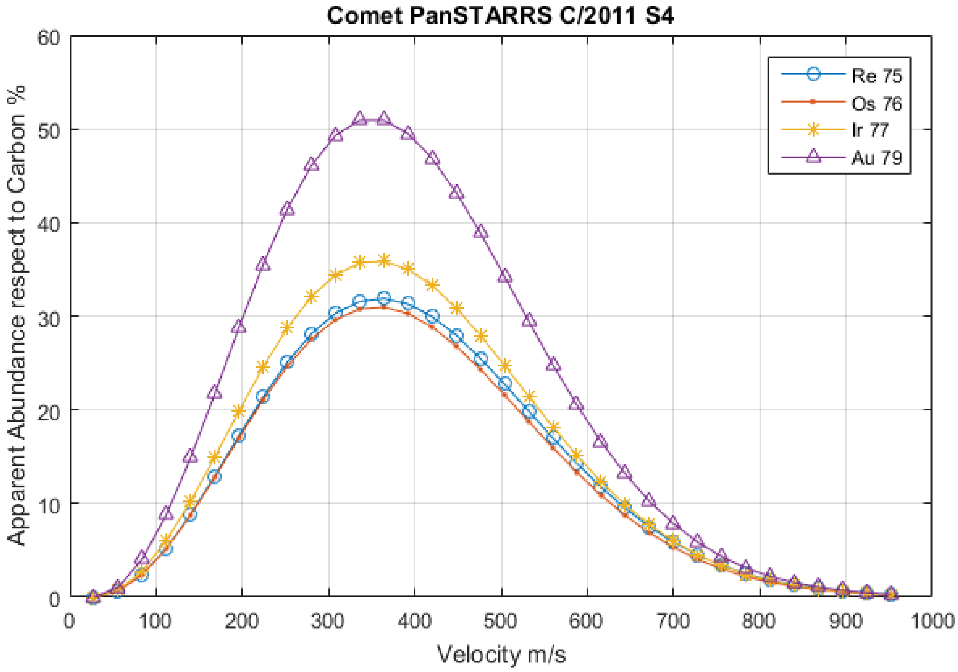

Figure 13-All elements of the group have velocities nearby 350 m s^{-1} with high relativity abundances of the Gold element to the Carbon ~55 %.

The above distribution figures can be arranged in one frame (3D coordinates), as shown in Figure -14, or 2D coordinates, as shown in Figure-15.

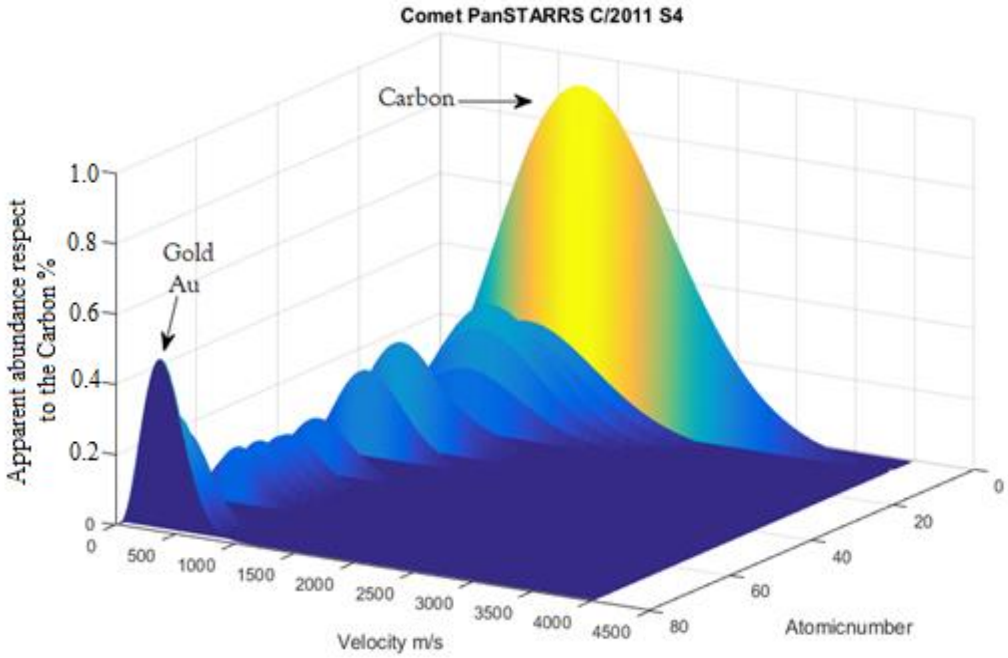

Figure 14-3D functions appear the elements concentrate average velocity at 600 m s^{-1}.

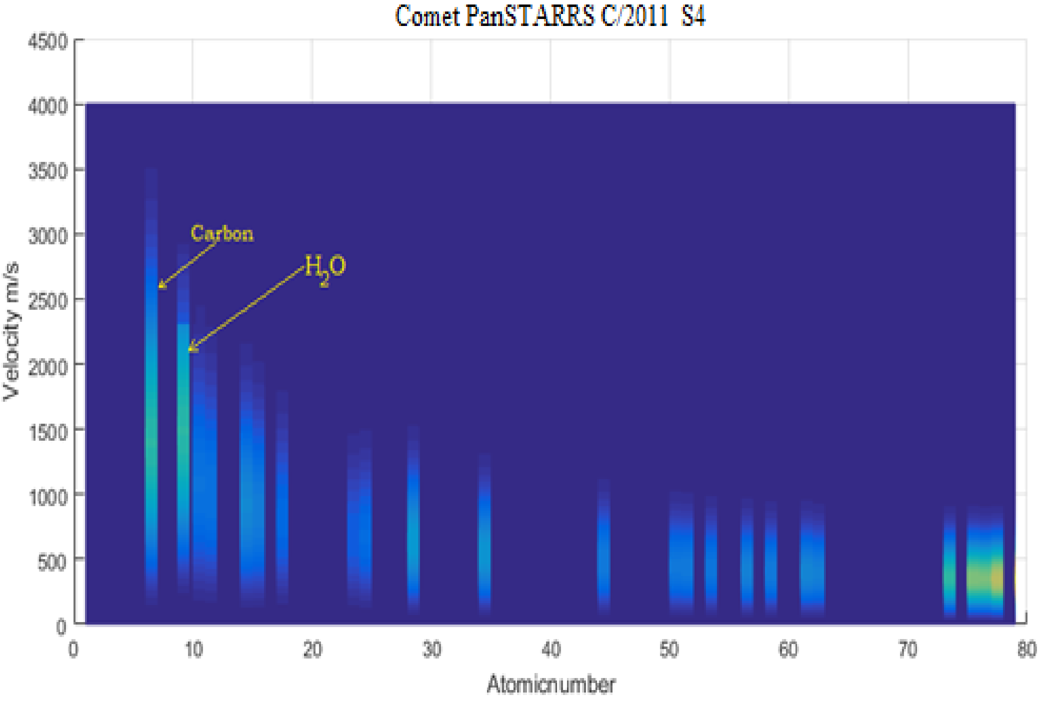

Figure 15-A 2D frame showing the 23 elements in comet PanSTARRS. Each element has a band of velocities, but has one peak value of most probable velocity.

The velocity details of gas elements in the above figures are listed in Table-2.

Table 2-The results of four variables of cometary elements in Comet PanSTTARS at gas temperature of 1412 k .

Element	Atomic number	Photons account to Carbon *i / C %*	Velocity km s^{-1}	Kinetic energy eV.
C - Carbon	6	100.0	1.3983	0.1827
Ne-Neon	10	30.0	1.0788	0.1827

Na- Sodium	11	27.7	1.0107	0.1827
Se-Selenium	34	24.9	0.5454	0.1827
Si-Silicon	14	36.0	0.9144	0.1827
P-Phosphorous	15	29.3	0.8707	0.1827
Cl- Chlorine	17	17.9	0.8139	0.1827
Ru-Ruthenium	44	15.5	0.4820	0.1827
Sn-Tin	50	13.6	0.4448	0.1827
Sb- Antimony	51	13.7	0.4392	0.1827
I-Iodine	53	12.5	0.4302	0.1827
Ba-Barium	56	14.7	0.4135	0.1827
V-Vanadium	23	12.3	0.6790	0.1827
Ce-Cerium	58	13.0	0.4094	0.1827
Pm-Promethium	61	15.5	0.4024	0.1827
Cr-Chromium	24	15.7	0.6720	0.1827
Sm-Samarium	62	14.0	0.3952	0.1827
Ni-Nickel	28	30.6	0.6325	0.1827
Ta-Tantalum	73	26.3	0.3603	0.1827
Re-Rhenium	75	31.9	0.3551	0.1827
Os-Osmium	76	31.0	0.3514	0.1827
Ir-Indium	77	35.9	0.3495	0.1827
Au-Gold	79	50.9	0.3453	0.1827

Velocity bands

The results of the velocities of the elements showed a wide band. However, the light elements have a wider band than that for heavy elements, whereas the heavy elements have a narrower band and their peaks tend to have low velocity. Most intersects of the velocity curve are around 500 m s^{-1}, as shown in Figure-16. The intersecting point of two curves represents the same velocity of both elements in this point, which indicates equilibrium velocities between these elements, i.e. most of thermal equilibrium velocities in the gaseous system occur between 400-600 m s^{-1}.

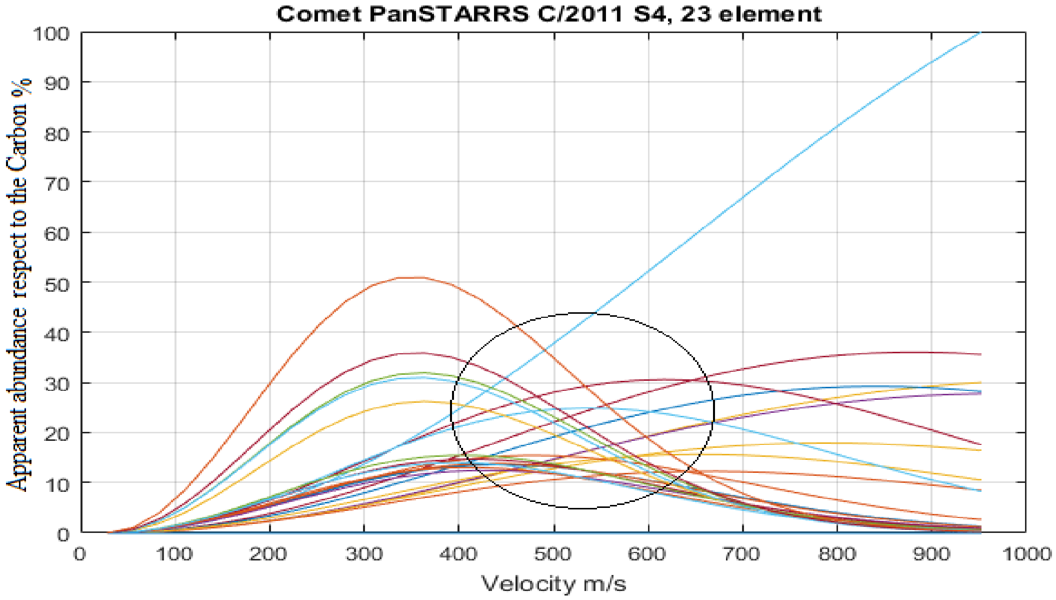

Figure 16-Intersects of elements curves mean that the elements intersected have same velocity in every intersecting point. Most cross states occurs around 500 m s^{-1}.

Figure-16 can be divided into many partitions, each with a group of particles that has velocities' space of Δv ~100 m s^{-1}, as shown in Figure-17.

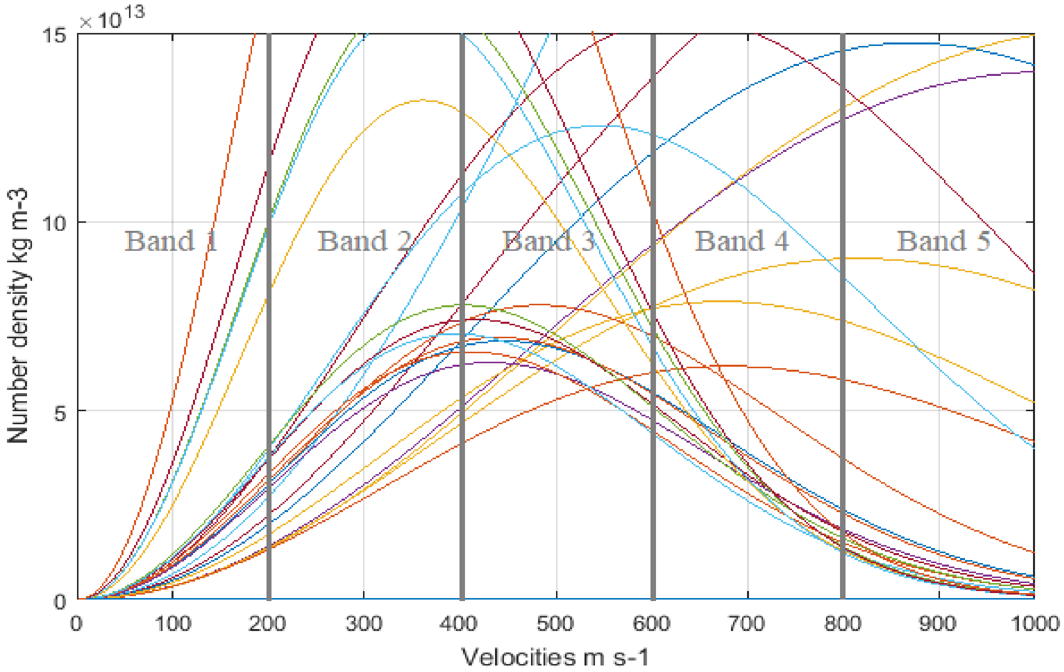

Figure 17-Every band of the velocities is a summation of areas below 23 curves, where each curve has group of similar mass of particles. The bands are a collection of number density of all particles in space Δv that equal 100 m s^{-1}.

Matlab program was used to collect areas under curves within these regions to investigate the range of relative densities with respect to other regions; i.e., the range of 0-200 m s^{-1} is for groups of particles which have contrast areas of densities (every curve represents a group of particles that have the same mass), in the range of 0-200 m s^{-1}. There are 23 curves that have varies peaks. The area under any curve has a number density and, by summation, these areas will represent the sum of the particles in this range.

Moreover, the number density of particles is not exactly familiar relative value between photons account of each velocity's region with respect to sum total areas. By using Matlab program, the sum of total areas of the 23 curves in the range of 0 to 2600 m s^{-1} is equal to 1.6471x10^4 (arbitrary unit). Thus, for example, it is assumed that there are only 1.6471x10^4 particles under these 23 curves. The particle velocity values are listed in Table-3 and represented in Figure-18.

Table 3-Bands velocity with areas under curves for equal fractions of particles

Band velocity m s^{-1}	Number of particles equal sum areas below curves x 10^2	Ratio of particles number to total number of all particles %
0 - 200	6.33	3.9
200 - 400	28.32	17.2
400 - 600	35.19	21.4
600 - 800	27.32	16.7
800 - 1000	19.63	11.9
1000 - 1200	14.63	8.8
1200 - 1400	10.85	6.6
1400 -1600	7.77	4.7
1600 - 1800	5.37	3.3
1800 - 2000	3.67	2.2
2000 - 2200	2.36	1.4
2200 - 2400	1.52	0.9
2400 - 2600	0.96	0.6

The number of particles equal to the summation of areas under the curves does not reflect the exact values of particle numbers; rather, the ratio of each area to the other areas provides excellent results of the element's abundance with respect to other element's abundance.

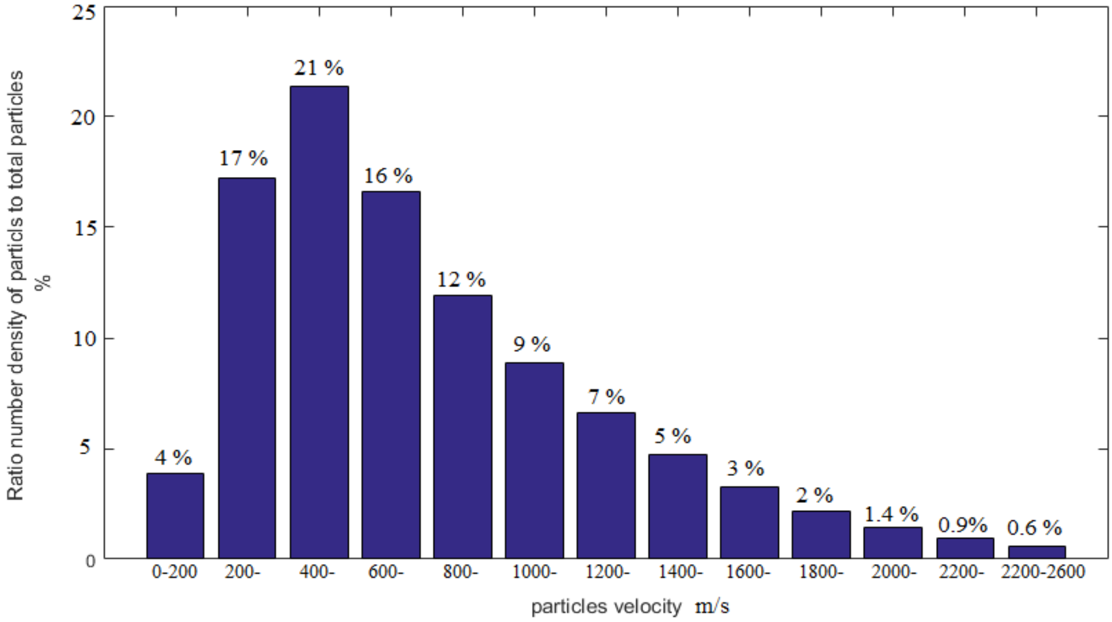

Figure 18-Velocity bands of gas particles. Most particles at band 400-600 m s^{-1}, 21% of total particles (consist of 23 element), wide velocity band between 200-800 m s^{-1} which has 54% of particles

Most particles of the 23 elements have velocities in the range of 400-600 m s^{-1} but these velocities do not contribute to the expansion of velocity of all gaseous components, because they represent heavy elements for which the expansion velocity value is 900 ± 200 ms^{-1}. H_2O curve peak is observed at a velocity of 1142 m s^{-1}, as shown in Figure-19, while the peak of Carbon's is ~1389 m s^{-1}, depending on their mass.

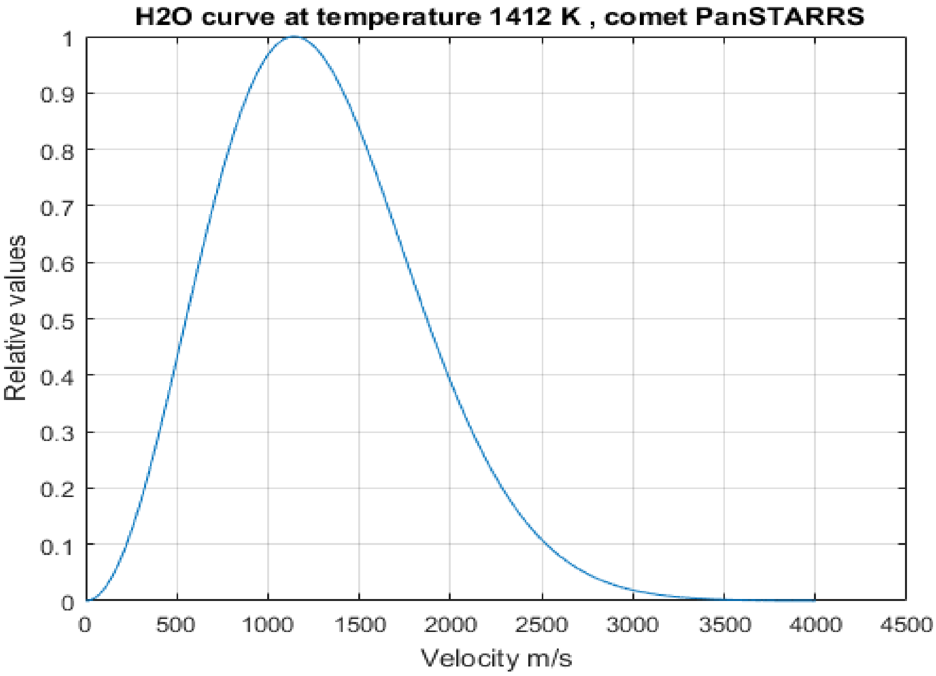

Figure 19-H_2O velocity curve, with a peak at 1142 m s^{-1}.

Conclusions

Figure-16 has Intersects of elements' curves in interval 400-600 m s^{-1} which is mean there were highest number of particles in this band of the velocity, as shown in histogram of Figure-18.Where the most particles of total heavy components ~ 66 % which have velocity band 200-1000 m s^{-1}.

In fact, the particles which have velocities less than 700 m s^{-1} do not contribute to coma gas expansion, because gas expansion velocities at band 700-1100 m s^{-1}, of the elements which have atomic number lower than 23 (lighter than Vanadium element), while most H_2O molecules have velocities larger than 1000 m s^{-1}, as shown in Figure-19. Since these molecules represent the largest part of the gas components, then H_2O molecules contribute to most gas expansion velocity.

The study shows that the kinetic energy of gas particles at a distance of 30,000 km from comet's nucleus is a constant value of all gas components, which is equal 0.1827 eV, because particles with small mass values have high velocity and vice versa.

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