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Calculation real abundance of gaseous elements of the comet PanSTARRS C/2011 S4

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Abstract

X-ray emission contains some of the gaseous properties is produced when the particles of the solar wind strike the atmosphere of comet PanSTARRS Comet. The data collected with NASA Chandra X-ray Observatory of the two comets, C/2012 S1 (also known as Comet (PanSTARRS)) was used in this study. The real abundance of the observed X-ray spectrum elements has been extracted by a new simple mathematic model. The study found some physical properties of these elements in the comet's gas such as a relationship between the abundance with emitted energy. The elements that have emission energy (2500-6800) eV, have abundance (0.1-0.15) %, while the elements that have emission energy (850-2500) eV and (6800-9250) eV have abundance (0.2-0.3) %. The relation between interacted energy and atomic number is formed two sets. The interacted energy of each element is increased as the atomic number increased. This case has been seen in both comets.

Key words

Comet, spectrum, abundance, X-Ray emission and atmosphere.

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حساب الوفرة الحقيقية للعناصر الغازية للمذنب PanSTARRS C/2011 S4

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الخلاصة

يحتوي انبعاث الأشعة السينية على بعض الخواص الغازية التي تنتج عندما تضرب جزيئات الرياح الشمسية الغلاف الغازي المذنبات ISON و PanSTARRS Comets. تم استخدام البيانات التي تم جمعها مع مرصد تشاندرا للأشعة السينية للمذنب (المعروف أيضًا باسم (PanSTARRS Comet C/ 2011 S4)) في هذه الدراسة. تم استخراج الوفرة الحقيقية لعناصر طيف الأشعة السينية المرصودة بواسطة نموذج رياضي بسيط جديد. وجدت الدراسة بعض الخصائص الفيزيائية لهذه العناصر في غاز المذنب مثل العلاقة بين الوفرة والطاقة المنبعثة. العناصر التي لديها طاقة انبعاث (2500-6800) الكترون فولت، لديها وفرة (0.1-0.15) ٪، في حين أن العناصر التي لديها طاقة الانبعاثات (850-2500) الكترون فولت و (6800-9250) الكترون فولت لديها وفرة (0.2-0.3) ٪. تتشكل العلاقة بين الطاقة التفاعل والعدد الذري لمجموعتين. حيث تزداد الطاقة المتفاعلة لكل عنصر مع زيادة العدد الذري. وقد شوهدت هذه الحالة في كلا المذنبات.

Introduction

Chandra satellite observed both comets ISON and PanSTARRS, where they reached to inner Solar System after a long period from the Oort cloud. A huge cloud of icy bodies extends far beyond Pluto's orbit.

The scientists have observed X-ray emission when solar wind particles strike the atmosphere of the comets. Although most of the particles in the solar wind are hydrogen and helium atoms, the observed X-ray emission is from heavy atoms (such as carbon and oxygen). These atoms have most of their electrons stripped away; 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 moves into a tighter orbit.

This study shows some physical relations of cometary heavy elements which are roughly less abundant in the cometary gasses. A fundamental step determines the amount of abundance which has an effect on the amount of the density and density number (amount of molecule per cubic meter). That depends on gas general temperature from classical thermodynamic relations and spectrum curve (Chandra analysis) of each comet which is drawing by the amount of photons from each element at particular energy in X-ray rang.

Gas's density close to the cometary nucleus approaches 10^{17} H_2O molecules/m^3 and drops off to value ~10^{13} H_2O molecules/m^3 at typical Rosetta distances of 150 km [1].

There are many relativistic heavy elements have been observed in cometary spectrum which have atomic number above 20, such as $_{24}Cr$, $_{25}Mn$, $_{26}Fe$, $_{28}Ni$ [2], $_{36}Kr$ [3], $_{54}Xe$ [4], with isotopic ^{128}Xe, ^{129}Xe, ^{130}Xe, ^{131}Xe, ^{132}Xe, ^{134}Xe, and ^{136}Xe [3]. Many heavy elements are found in cometary gasses as will be shown later.

The most speed probable of the particles by Maxwell-Boltzmann distribution is a common value of the particles velocity in comet atmosphere at 1km/s which represents an average value of the velocity [5]. The average mass of the particles at each comet gas is 23.3 proton mass [5].

Observations

The spectrum of the comets PansTARRS and ISON is obtained from Chandra site using DS9 program where the spectrum lines of the comet PanSTARRS are shown in Fig.1.

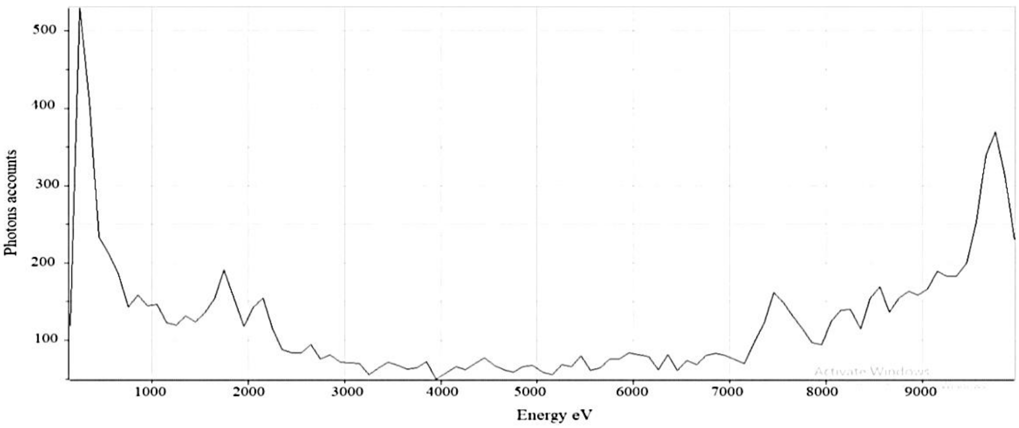

Fig.1: Spectrum emission lines of comet PanSTARRS which is taken from Chandra data analysis.

From Fig.1, the amount of intensity that represents the abundance of each element in a particular energy that refers to object components and can find some gaseous elements as investigated in Fig.2 shows interpretation of the curve information.

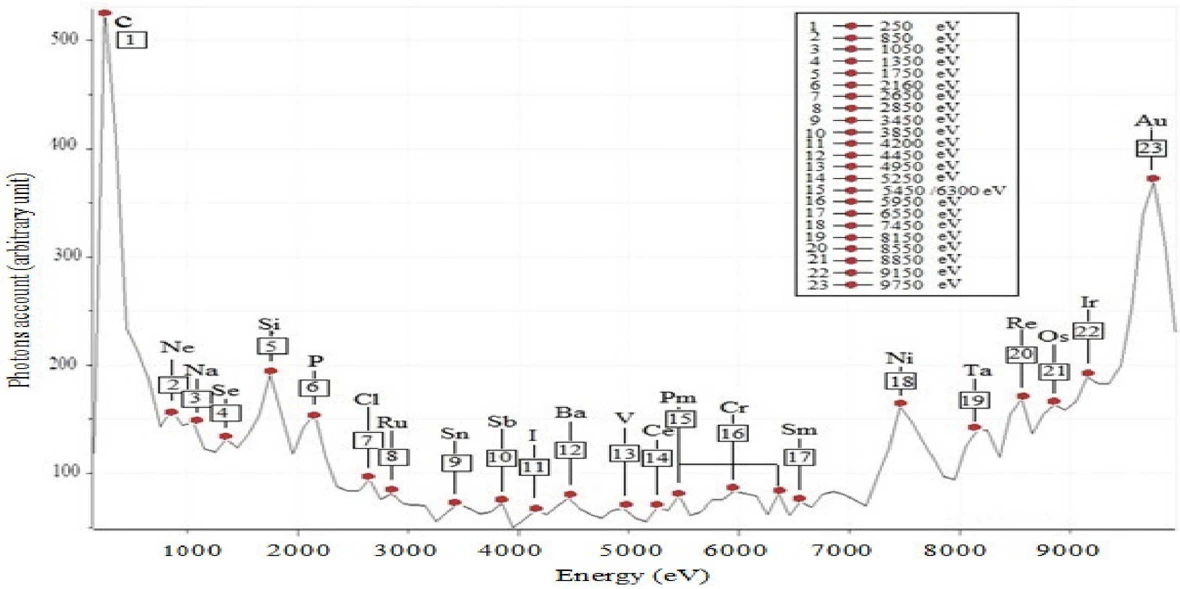

***Fig.2:** The elements of Comet PanSTARRS, C/2011 S4, by Chandra X-Ray energy curve, the elements' energies available in reference [6].*

The curve has important features of each element of the coma's gas, where the photons account refers to the amount of number of emitted atoms with respect to others, for example: Carbon has account value equals 530, and Neon element has 159. The ratio between both elements 159/530 equals 0.3, which means Ne/C ~30% and one can obtain any percent of two elements or all the elements to the specified element.

Measurements of photons account differ in various instruments. The reason is that different materials are used for each tool and observation case and even type of the measurement and observation time or even weather case. At the end, the ratio between varies remains constant.

There are some errors in each measurement such as energy measurement. One can obtain each element from the nearest emission line energy value, where 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 systematic error ~13% [7], while in comet PanSTARRS spectrum lines here maximum error was ~2% at Selenium element, means the measurements in a saf side, as shown in Table 1.

Physical model

The rate of an abundance of each element in the spectrum curve to Carbon element is the rate of photons account in y-axis of each element to photons account of the Carbon,

$$x_i = \frac{A_i}{A_C} \quad (1)$$

where x_i is the ratio of each element with respect to the Carbon. A_i is an account of the element i includes the number of the elements in the curve 23 element. A_c is the Carbon photons account in the spectral curve. The value of x_i equals 0-1 since Ac the value of Carbon is the largest value represents only the ratio between the elements. It does not represent the real abundance of each element. Real Carbon abundance x_C in the comet's gas must be known to calculate the abundance of all elements by multiply Eq.(1) by x_C value.

$$x_i = \frac{A_i}{A_C}\, x_c \quad (2)$$

x_i is a real abundance of any element i. The total abundance for all elements is,

$$X = \sum_{1}^{23} x_i = \sum_{i=1}^{23} \frac{A_i}{A_c} x_c = \frac{x_c}{A_c} \sum_{i=1}^{23} A_i \qquad (3)$$

The limit $(A_1 + A_2 + A_3 + \cdots + A_{23})$ is known from photons account of spectral curve, includes photons account of Carbon, in fact, $A_1=A_C$, the first element in the x-spectrum and second element A_2 is a photon account of the Neon and etc…

x_i, x_c is a real abundance of the elements and Carbon respectively. A_i, A_C are the photons account of the elements and Carbon respectively.

The total abundance of all components

$$X + X_{H_2O} + X_{un} = 1 \qquad (4)$$

X_{H_2O} ~ 0.8 is a real abundance of water molecules in the cometary gas [8], X_{un} is a real abundance of undetected elements.

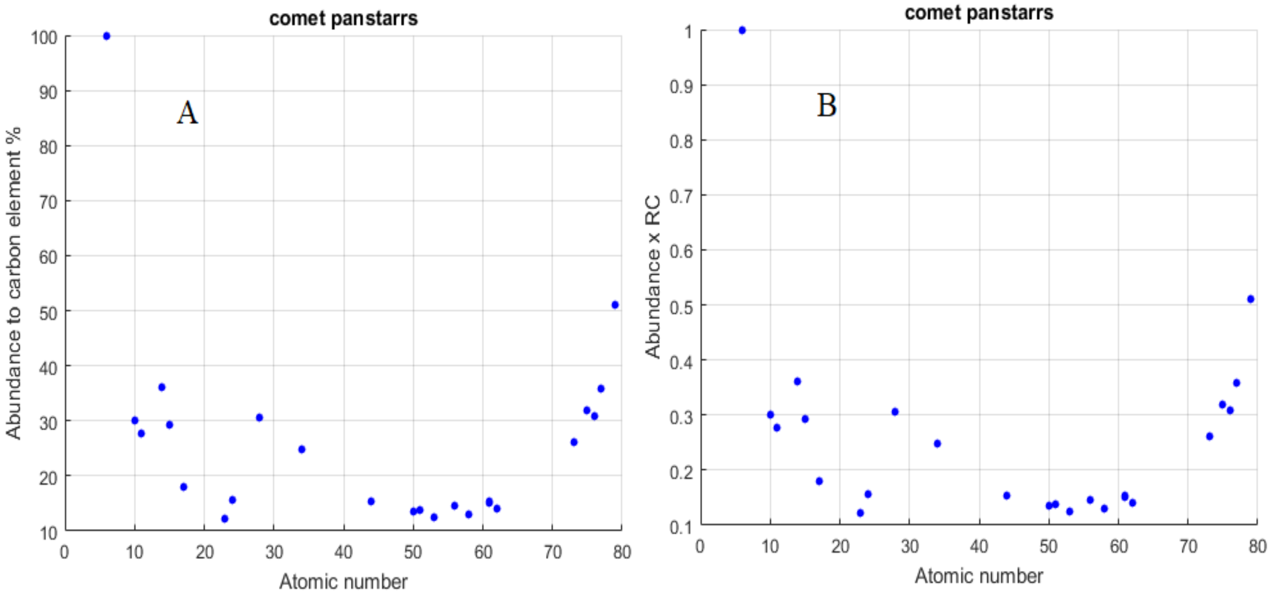

Fig.3: (A) Elements' abundance with respect to abundance of the Carbon $\frac{A_i}{A_C}$, (B) has the same arrangement of the elements but in true abundance after multiplying by a true abundance of Carbon x_c which is not extracted yet.

The x_c value of Carbon must be extracted from some simple mathematical derivatives. The total number of the molecules N_T per unit volume is,

$$N_T = N_i + N_{H_2O} + N_{un} \qquad (5)$$

The N_{H_2O} is the number of water molecules which are equivalent ~ 0.8 of the total molecule's number, N_i is a present spectral elements which equal 23 elements, N_i =23 atoms and N_{un} is undetected elements which do not appear in our observation.

The simple rate of the number of water molecules N_{H2O} has an abundance of 0.8. N_i is the elements of the spectrum, so, how much abundance of these elements. As shown in Fig.3.

Table 1: The number of water molecules has proportion to the number of spectral elements, to create simple relation with a real abundance of the elements.

	Water	Spectral elements
Number of particles	N_{H_2O}	N_i
Real abundance	0.8	X

where $N_i = 23$, proportion and fit can get:

$$N_{H_2O} = \frac{N_i\ x0.8}{X} \quad (6)$$

The average mass of all gaseous components is a mass of all particles divided by the total number of particles ~ 23.3 m_p [5], which is the mass constant of the cometary particles.

m_P ~ m_H= 1.0079 amu(atomic mass unit), proton mass ~ hydrogen element mass.

$m_{H2O}=m_H+m_H+m_O$=(1.0079+1.0079+15.9994) =18.0152 amu

Spectral elements mass $=\sum_1^{23} m_i = m_{1+}m_{2+}m_{3+} \dots\dots m_{23}$ (7)

Eq.(7) represents X-ray spectral elements mass, or all the elements mass which have been extracted from the X-ray spectrum. The number of water molecules by mass of one molecule M_{H_2O}, Total water mass =

$$M_{H_2O} = N_{H_2O}.m_{H_2O} \quad (8)$$

The total mass of molecules is,

$$M_T = N_{H_2O}.m_{H_2O} + N_{un}.m_{un+\sum_1^{23} mi} \quad (9)$$

where N_{un} and m_{un} are the numbers of undetected elements and the average mass of these elements respectively. The value of m_{un} ~ $23.3m_p$ because it is the average mass of the particles in the cometary gases.

The average mass m_{av},

$$m_{av} = \frac{M_T}{N_T} = \frac{N_{H_2O}.m_{H_2O}+N_{un}.m_{un+}\sum_1^{23} m_i}{N_i+N_{H_2O}+N_{un}} \sim 23.3mp \sim m_{av} \quad (10)$$

The constant average mass of comets gaseous particles ~ 23.3m_p [5]

From Eq.(10).

$$N_{H_2O}.m_{H_2O} + N_{um}.m_{av} + \sum_1^{23} m_i = 23.3m_p(N_i + N_{H_2O} + N_{un}) \quad (11)$$

But $N_{un}.m_{un} = 23.3m_pN_{un}$

$$N_{H_2O}(23.3m_p - m_{H_2O}) = [\sum_1^{23} m_i] - 23.3m_p\ N_i \quad (12)$$

where N_i = 23 elements

23.3m_p =23.3x1.0079= 23.4841=m_{av}

$m_{H_2O} = 18.0152\ amu,$

$\sum_1^{23} m_i = 2.3781x10^3$ amu

The relation between the group of observed elements abundance and their atomic mass and the number of these elements consist of two equations Eqs.(12) and (6)

$$N_{H_2O} = \frac{[\sum_1^{23} m_i]-23.3m_p\ N_i}{23.3m_p-m_{H_2O}} = \frac{0.8N_i}{X} \quad (13)$$

$23.3m_p - m_{H_2O}$ =5.4689 amu

$$X = \frac{4.37512N_i}{[\sum_1^{n} m_i]-23.4841\ N_i} \quad (14)$$

Eq.(14) is a general formula of any elements group have known atomic mass m_i and their number N_i. The number of elements N_i= 23 and the sum of the elements mass $\sum_1^{n} m_i$= 2.3781x10^3 amu, then an abundance of 23 element is X ~ 0.055 which represents a real abundance of the sum elements. The elements are extracted by X-ray spectrum have X ~ 0.055 with respect to all the components of the cometary gases. From Eq.(2),

$$X_{un} \sim 0.145$$

The abundance of the Carbon x_C has determined from Eq.(3),

$$x_c = \frac{X_iA_C}{\sum_{i=1}^{23} A_i} = \frac{0.055x530}{3327} \sim 0.87\ \%$$

where Ai represents photons account of the spectral elements and A_C is the photons account of the Carbon element which equals 530.

x_C value is a real abundance of the Carbon which represents a key of most the work, this value is important to extract many physical values where Eq.(4) determines abundance of each element as shown in Table 2.

Verification

The average mass of gaseous particles,

$$m_{av} = \frac{M_T}{N_T} = \frac{N_{H_2O}.m_{H_2O}+N_{un}.m_{un}+\sum_1^{23} m_i}{N_i+N_{H_2O}+N_{un}} \quad (15)$$

$m_{H_2O} = 18.0152\ amu$,
$m_{av} = 23.3m_p = 23.48407$,
$\sum_1^{23} m_i = 2.3781\text{x}10^3$
$N_{H_2O} = \frac{23x0.8}{X} = \frac{23x0.8}{0.055} = 335.$
$N_i = 23$
N_{un} can be determined by from proportion and fit process, as shown in Table 2.

Table 2: Simple mathematical proportion to extract the number of undetected particles of the cometary gases.

	Water	undetected particles
Number of particles	335	N_{un}
Real abundance	0.8	0.15

$N_{un} = \frac{335x0.145}{0.8} = 61$. This value is a mixture of natural molecules, atoms and ions.
That means for each 23 atoms of spectrum elements there are 335 molecules of water and 61 undetected molecules.
The total number of particles,
N_T = 23+335+61 = 419

Abundance of spectrum elements = 23 / 419 = 0.0584 ~ 0.055
Abundance of water molecules = 335 / 419 = 0.7995 ~ 0.8
Abundance of undetected molecules = 61/ 419 = 0.1455 ~ 0.145
The general form of N_{un},

$$N_{um} = \frac{N_{H_2O}\,.X_{un}}{0.8} \quad (16)$$

Thus m_{av},

$$m_{av} = \frac{N_{H_2O}.m_{H_2O}+N_{un}.m_{av}+\sum_1^{23} m_i}{N_i+N_{H_2O}+N_{un}} = \frac{335x18.0152+61x23.484+2.3781x10^3}{419} =$$

23.497 amu
The simple difference between the value 23.497 and the standard value 23.484 was consequence our approximation number of water molecules and undetected particles.

The results

All the derived equations in the previous steps represent a new simple model to determine the abundance of any observed spectrum elements group, regardless of the observation type or the range of the observed wavelength band.
Eq.(15) gives a real abundance value of each element which is investigated in the Fig.4.

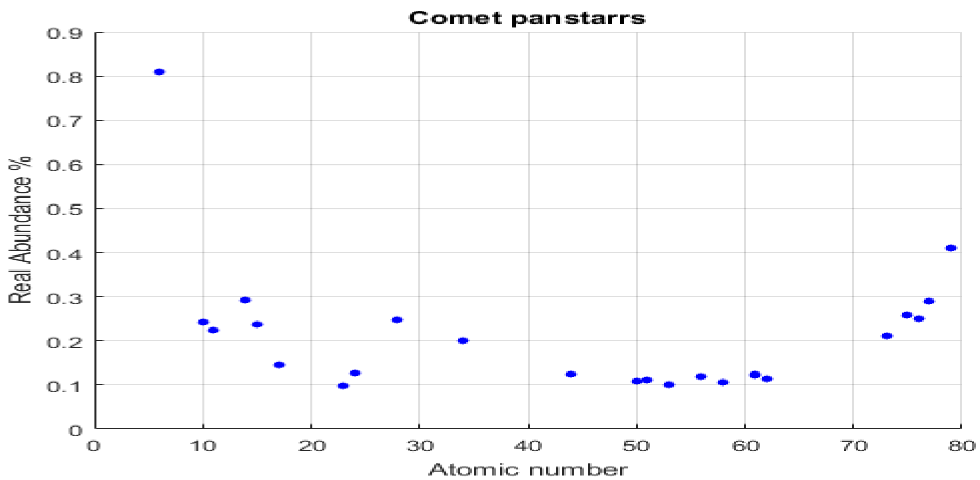

Fig.4: Comet PanSTTARS'S real abundance of 23 elements (by X-ray band), shows there is some relation between atomic number and the abundance specially the atomic numbers above 28 (for nickel element).

There are many mathematical models of this distribution depend on the comparison with other comets, there is one relation to identical, such distribution is investigated in Fig.5.

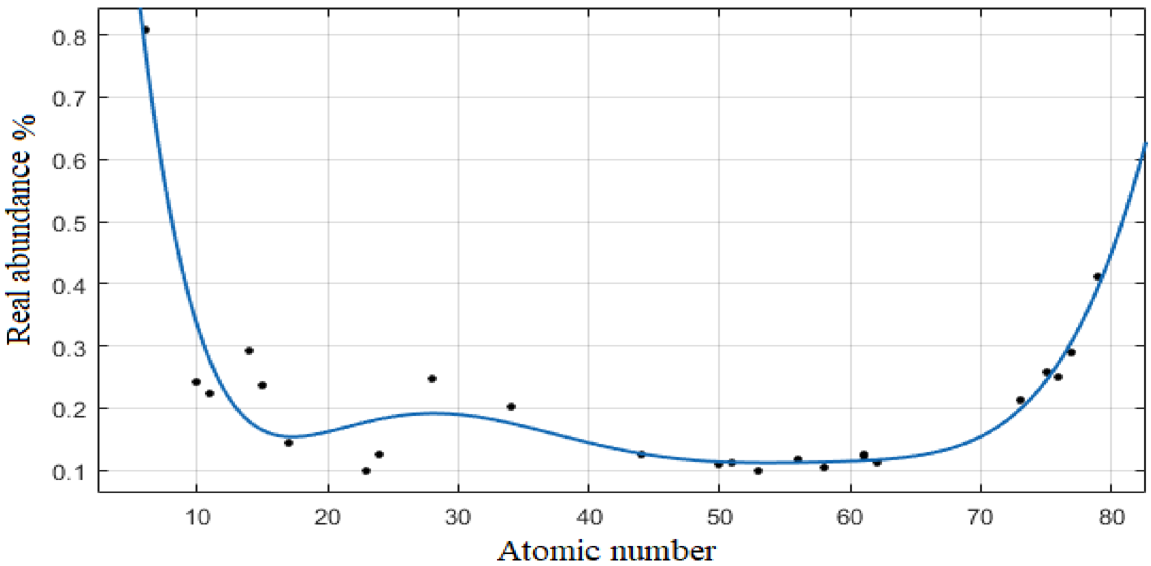

Fig.5: The suitable curve of the real abundance distribution of comet PanSTARRS C/2011 S4.

This curve has been extracted by the same way of the previous steps of abundance relations. The curve of comet PanSTTARS from lower atomic number to 40 is almost identical with comet ISON curve, as shown Fig.6.

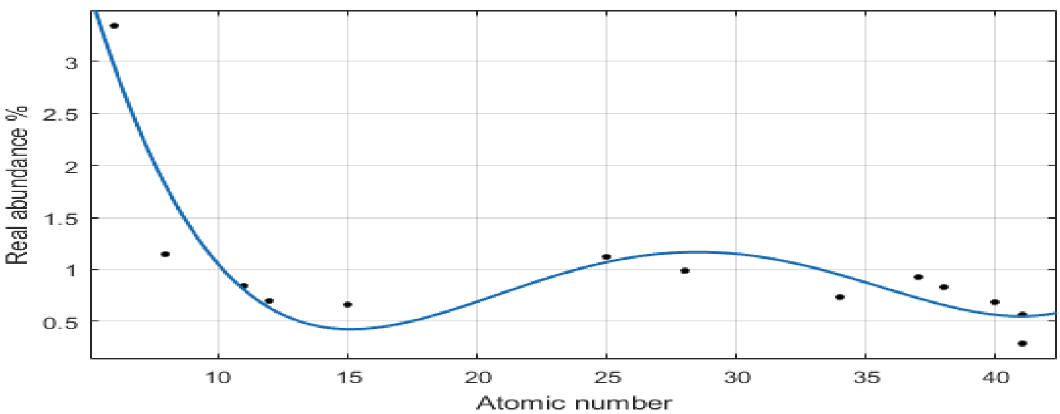

Fig.6: Elements abundance of comet Ison C/2012 S1 has the same shape PanSTARSS's curve from atomic number 6 to 41, (but certainly is not the same abundance values), take to one sense that both comets were as in one body since early solar time.

The abundance balance relation of comet PanSTARRS and ISON. There are some figures for the energy emission lines with atomic number and the abundance as shown in Figs.7 and 8 respectively.

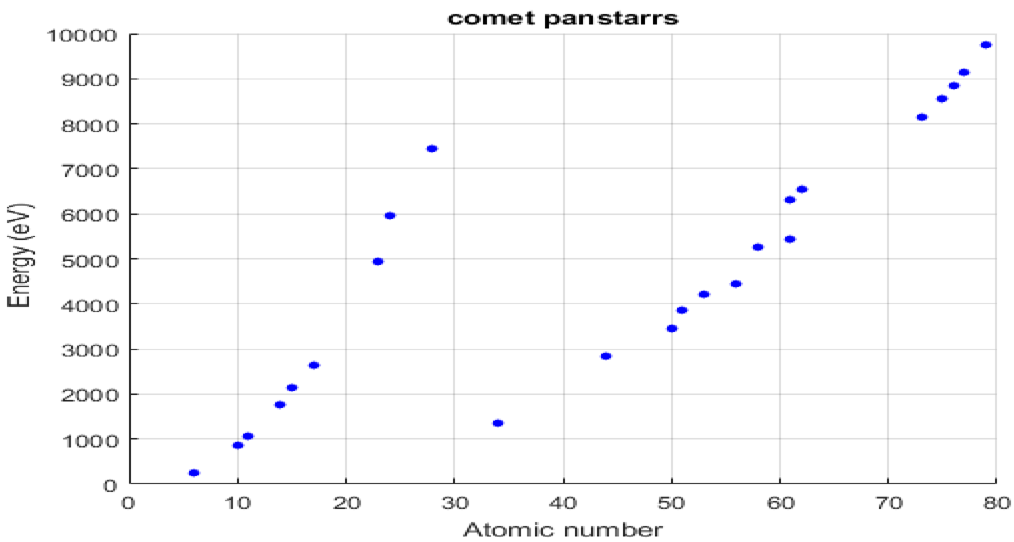

Fig.7: Energy emission lines as a function of atomic number of the elements, arrangement as two relations, each part has a particular set of atomic number, <30 & >30.

The energy has a particular relation of each group of the atoms depending on the atomic number, where from the notation of two curves there is a same shape also of the energy-atomic number of the comet ISON as investigate in Fig.9.

Also, the energy has particular relations with the abundance of the elements as following:

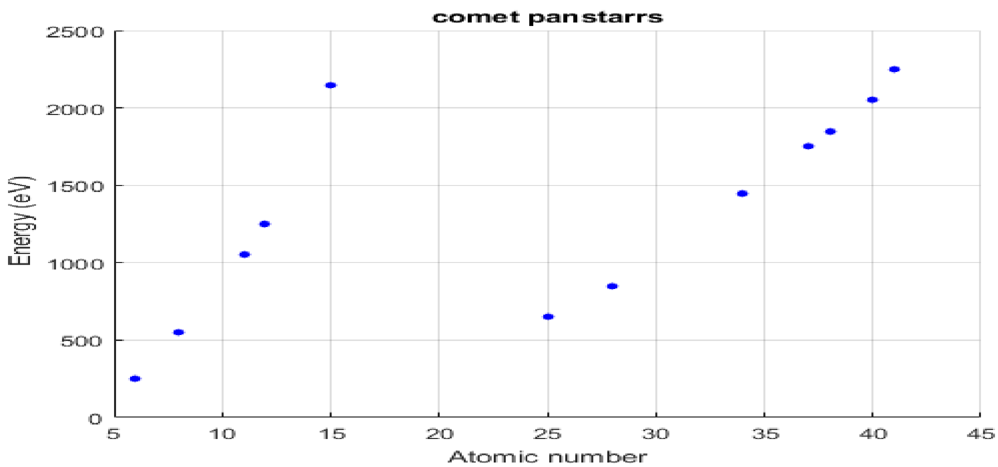

Fig.8: Analysis of comet Ison has also two sets of atoms (depending on atomic number) which have different interactions with the solar wind and high-power radiations.

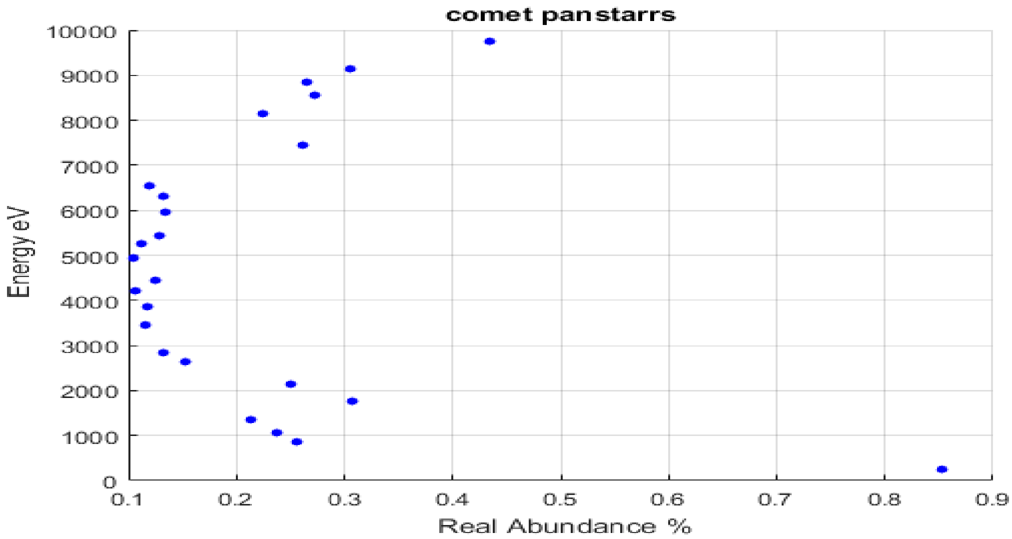

Fig.9: The 23 element of comet PanSTARRS have a center abundance distribution >3000 (eV) and < 7000 (eV) which has a minimum abundance.

Fig.10 shows there are two groups of elements, the first set (6-30) and the second (30-79), each group has a particular interaction with the solar wind. The elements that have lower atomic number interact with solar wind and solar high-power radiations at low energies and as atomic number increase will increase in interacted energy. That means as atomic number increases, the level energy will increase. This case returns again in the second group of elements > 30 atomic numbers, where begins from lower level energy and increase as the atomic number increased.

The reported transition levels displays transitions type $K_{\alpha 1}$ and $L_{\beta 1}$ (~ 23%), as shown Fig.11.

The Summary of the important physical relations and details of their terms in Table 3.

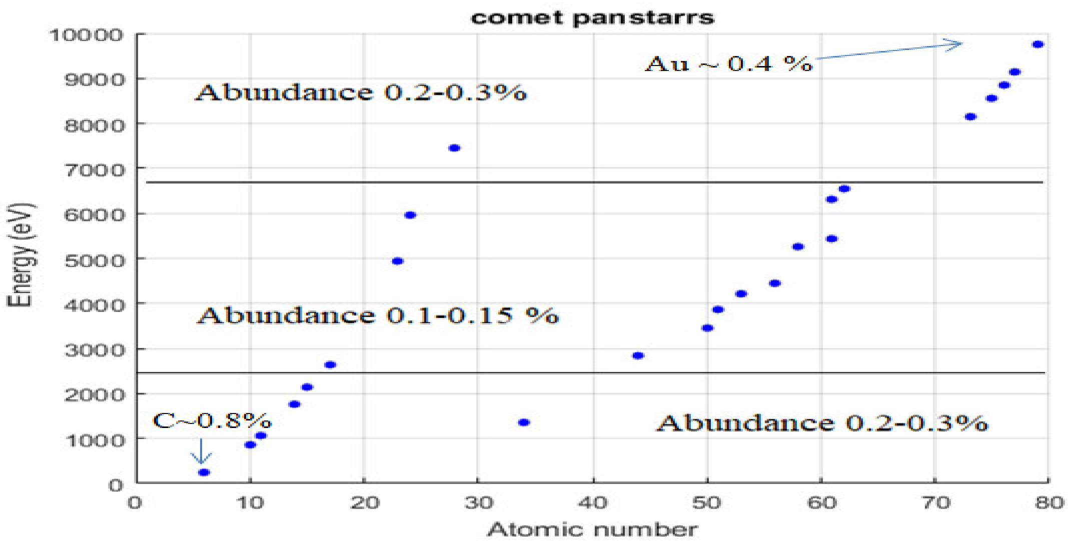

Fig.10: Displays three regions of elements' abundance of comet PanSTARRS with irregular two elements of this case where the Carbon element has ~0.8% and Au has~ 0.4% while total real abundance of these 23 elements have only ~5%, H_2O at ~ 80% and the unobserved elements have 15%.

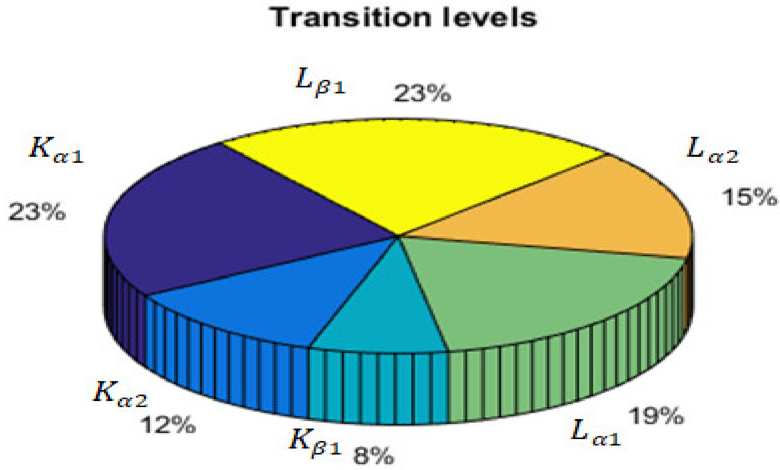

Fig.11: Recent of transitions types of cometary gases in comet PanSTARRS C/2011 S4.

Table 3: Explains important fundamental relations which are divided in the search to extract real element's abundance of any spectral emission curve.

Relation	Details of terms
$X_i = \frac{x_c}{A_c}\sum_{i=1}^{23} A_i$ General form: $X_i = \frac{x_{mx}}{A_{mx}}\sum_{i=1}^{23} A_i$ $X_i = \frac{4.37512N_i}{[\sum_1^n m_i] - 23.4841\ N_i}$	X_i –Sum real abundance of i elements A_c -is a photons account of the Carbon x_c - is a real abundance of the Carbon element A_{mx} -is a maximum photon account on the spectral curve. x_{mx} -is a real abundance of one element which has maximum photons account N_i – is a number of spectral elements $\sum_1^n m_i$ – Sum of elements' atomic mass in amu
$x_i = \frac{A_i}{A_C} x_c$ General form : $x_i = \frac{A_i}{A_{mx}} x_{mx}$	x_i – is a real abundance of any element to Carbon. A_i – is a photon account in the spectral curve A_{mx} - is a maximum photon account on the spectral curve.
$N_{H_2O} = \frac{0.8N_i}{X_i}$	N_{H_2O} - is a number of water molecules which are compared with the elements' atoms
$X_i + X_{H_2O} + X_a = 1$	Sum of all components equal one, X_{H_2O} – is a real abundance of the water =0.8 X_a – is a real abundance of undetected components which are not seen in the measurements
$N_a = \frac{N_{H_2O}.X_a}{0.8}$	N_a – is a number of undetected components which are not seen in the measurements
$m_{av} = \frac{N_{H_2O}.m_{H_2O} + N_a.m_a + \sum_1^{23} m_i}{N_i + N_{H_2O} + N_a}$	m_{H_2O} – is a water molecules mass=18.0152 amu m_a - is an average other components mass Where $m_a = m_{av} = 23.3m_p$=23.484 amu

Conclusions

Some of the comet PanSTARRS 23 elements have an abundance about 5 % and the other components have an abundance 15 %. That means there are many composites do not appear in X-ray analysis. This is because that the X-ray emission lines give large energies which include most of the information from the inner level of atoms (near a nucleus of the atom), therefore do not show any molecules such as NH_3 or water molecules H_2O which have a strong emission lines near $2\,\mu m$. The minimum energy of X-ray emission lines in Chandra analysis has 100–10000eV, wavelength $12.3-0.123\,nm$, that are represented far from the emission lines of H_2O, beside the complex composites which emit rays below H_2O lines.

Most observed elements in the X-ray curve have abundance below 0.3% as investigated in Fig.3, where the middle elements have low abundance compared to the elements that have low and large atomic numbers. The elements which have large values of atomic number also have relatively large abundance such as Au element ~0.4%, while the set of elements in the range 45-65 atomic number (mid-region) have less abundance ~ 0.1%.

Fig.9 has some arrangement of the elements abundance where the elements that include low abundance have energies between roughly (2500 – 6500) eV with abundance 0.1-0.15% whereas interacted elements at low and high energy have large abundance relatively 0.2-0.4%. Figs.7 and 8 and Fig.9 explain some elements of behavior in Fig.10.

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