

# Analysis of Cometary X-ray Spectra

S. Z.Khalaf and M. I.Jaleel

**Abstract:** The compositions of comets depend on the interaction between cometary nucleus and tail with solar wind. The chemical composition of cometary nuclei is inferred from measurements of neutral and ionized gases from the coma, tail, and dust grains. The comets images have been taken from Chandra space telescope site and analyses by SAO ds9 software (version 7.2 April 15, 2013) to obtain the spectroscopic data. The results illustrate the relationship between the photon count and the observed energy for two comets (C/Linear 1999 and, C/NEAT 2001). These two comets come from Oort cloud, observed with Chandra X-ray observatory and ACIS-S spectrometer in the energy range (100-10000) eV. The results of this interaction are important to know composition of two comets, we found that main materials are C, Si, O, Ne, Mg, and S in C/Linear comet, and C, Si, P and O were significant elements in C/ NEAT comet's nucleus .

**Keyword:** Comets (C/Linear 1999, C/NEAT 2001) - X-ray spectroscopy- Charge Exchange Emission.

## 1 INTRODUCTION

X-rays have been observed emanating from the Sun since the 1940s by the U.S. Naval Research Laboratory Blossom experiment on board [1]. On June 12, 1962 it detected the first X-rays from other celestial sources (Scorpius X-1) [2]. It is the first X-ray source found in that constellation.

X-ray and Extreme Ultraviolet (EUV) emission is usually associated with high temperature environments. The discovery that comets are bright emitters in this spectral regime was therefore a big surprise [3], and is in strong contrast to our understanding that comets are dirty snowballs surrounded by a gaseous coma with a temperature of approximately 50 K. After the first discovery by ROSAT of the X-ray emission from Comet Hyakutake, a search through the observatory's archives proved that in fact all comets have total visual magnitude  $m_v < 12.0$  at a distance 2 AU emitted X-rays. The Emission was highly variable in time, and many of the observed comets displayed a characteristic crescent shape [4]. Comets emit X-rays via the process of solar wind charge exchange (SWCX). Gas in the coma of the comet donates one or more electrons into an excited energy level of a highly-charged ion of the solar wind. In the subsequent relaxation of the ion, a UV or X-ray photon is emitted [5].

In the early of (1996) lisse et al. have been discovered a new phenomenon the first Soft X-ray emission from comet C/Hyakutake by Rontgen satellite (ROSAT) and she suggested that the emission could be explained by thermal bremsstrahlung associated with hot electrons, due to solar wind interaction effects [3].

The same event has been recorded by extreme ultraviolet explorer (EUVE) in (1997) [6]. Another discovered that Hale-Bopp comet emission X-ray by Krasnopolsky et al. in (1997) [7]. In the same year in (January 1, 1997) Cravens proposed an alternate emission mechanism, the solar wind contains a large number of heavy ion species with a range of charge state. These ions will readily charge transfer with cometary neutrals, producing ions which can be highly excited and consequently emit photons in the extreme ultraviolet and X-ray part of spectrum [5].

Shapiro et al. in (1999) also explained the X-ray emission from comets by bremsstrahlung of electron produced by lower hybrid waves. The direct measurements of electron energy distributions in comet Halley from the Vega and Giotto spacecraft preclude bremsstrahlung at a level exceeding equal 1% of the observed X-ray emission [8]. Vladimir et al. in (2000) they observed comet Hale –Bopp post perihelion in November 1997 and studied observing data on three comets Encke, Mueller (C/1993 A1), Borrelly from EUVE archive [9]. In the same year Green wood et al. (2000) they measurement of charge exchange and X-ray emission cross section for solar wind – comet interactions and they have been gotten results are compared to cross section values used in recent comet models. The importance of applying accurate cross sections, including double charge exchange, to obtain absolute line-emission intensities was emphasized [10]. Krasnopolsky in (2001) He determined a peak X-ray volume emission rate in comet Hyakutake during the Roentgen satellite (ROSAT) observation. He found that scaling of the electron fluxes observed in comet Halley from the Vega probe to the known properties of the solar wind electrons agrees with theory of electron acceleration by lower hybrid waves in comets [11,12]. Russo, Fernandez, Mumma et al. in (2001,2003,20034) studies have shown the spectra of comets from the infrared to the X-ray regions, provided a wealth of data on the molecular composition of

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comet atmosphere. In (2005) they have been detected characteristic X-ray emission lines from simulants of comet surfaces as they undergo collisions with highly charged ions (HCIs). It is found that the emission of characteristic K L, K M X-rays appears to proceed during positive charging of the surface by the HCI beam [13]. D. Bodewits et al. in (2007) they presented results of the analysis of cometary X-ray spectra with an extended version of our charge exchange emission model [4]. They have applied this model to the sample of 8 comets thus far observed with the Chandra X-ray observatory and ACIS spectrometer in the 300–1000 eV range. Their analysis showed that spectral differences can be ascribed to different solar wind states; furthermore they predict the existence of a fourth spectral class, associated with the cool, fast high latitude wind [16]. In (2012) since the initial discovery of Cometary charge exchange emission, more than 20 comets have been observed with a variety of X-ray and UV observatories. They reviewed the possibilities and limitations of each of those in their contribution [4]. They have analysis of simultaneous X-Ray and UV observations of comet C/2007 N3 (Lulin) taken on three days between January 2009 and March 2009 using the Swift observatory. They compared and discussed the X-ray and UV morphology of the comet and showed that the peak of the cometary X-ray emission is offset sunward of the UV peak emission, assumed to be the nucleus, by approximately 35,000 km. They showed that the measured X-ray light curve can be very well explained by variations in the comet's gas production rates, the observing geometry and variations in the solar wind flux [14]. Ewing et al., in 2013 they have been presented the detection of new Cometary X-ray emission lines in the 1-2 KeV range, they have selected five comets from the Chandra sample. They modeled the spectra with an extended version of our solar wind charge exchange emission model [15].

## 2 OBSERVATION

The first comet that has been taken in this research C/linear 1999 is a long period comet; Linear has been discovered on September, 27, 1999. The comet made its closest approach to the Earth on July, 22, 2000 at a distance of 0.3724 AU (5571000Km). It came to perihelion on July 26, 2000 at a distance of 0.765 AU from the sun [17]. This comet observed by Lisse with a parameter shown in table (1).

The second comet that has been taken C/ NEAT (2001) is a long period comet discovered on August 24, 2001 by the Near-Earth Asteroid Tracking program (NEAT). The comet approached within 0.32 AU of the Earth on May 6, 2004. And on May 12, 2004 detects by Chandra telescope with a parameter as shown in table (1).

We have been taken FITS image from Chandra X-ray telescope. The Chandra X-ray Observatory is a space telescope; it is sensitive to X-ray sources 100 times fainter than any previous X-ray telescope, enabled by the high angular resolution of

its mirrors. Chandra consists of two X-ray detecting devices the High Resolution Camera (HRC) and the Advanced X-ray Astrophysics Facility CCD Imaging Spectrometer (ACIS). There are two sets of CCDs on the device: 4 imaging chips (ACIS-I) and 6 spectrometer chips (ACIS-S).

Then we have been taken the total image and by using SAO image ds9 software we have been analysis X-ray image after that we get the data for comet and by using spread sheet we get the chart as shown in figure (1) for C/linear 1999 comet and figure (2) for C/NEAT 2001 comet these analysis leads to get the results as explained in the result and discussion.

TABLE 1  
THE COORDINATES OF COMETS

Comets	C/linear 1999	C/NEAT 2001
Obs ID	584	5321
RA	04 22 16.99	08 17 18.31
DEC	+60 18 20.66	+10 36 19.31
Instrument	ACI-S	ACI-S
observation date	17/10/2010	4/1/2008

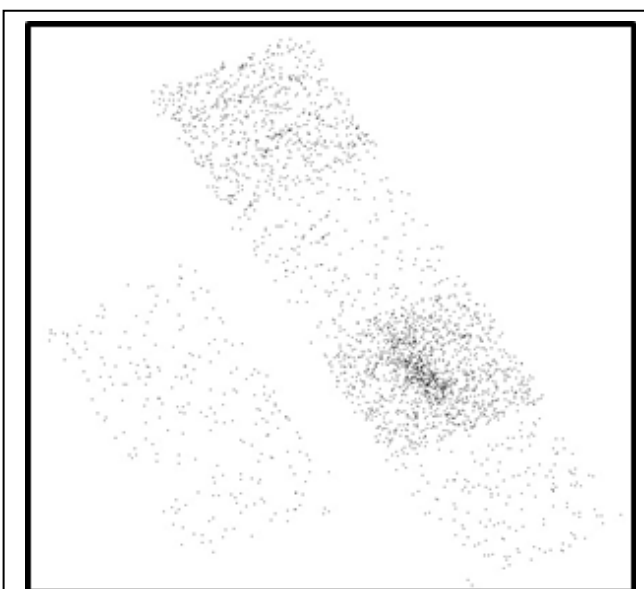


Fig. 1. The total X-ray image of C/ Linear 1999 comet.

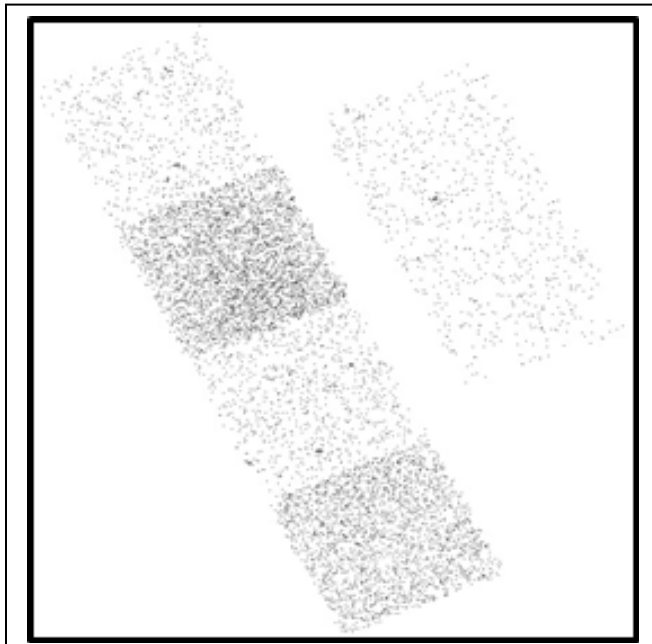


Fig. 2. The total X-ray image of C/ NEAT 2001 comet.

Figure (1) and (2) shows the total image of X-ray of Hartley and Tuttle comets. It has been shown that these images are divided into square arrays. The reason as explains above is the Chandra telescope consists of several sensors in a matrix each of these sensors receive energy within certain energies. When all the energies are collected from these sensors, we will have the spectrum of the comet.

### 3 ANALYSIS RESULTS

When highly charged ions from the solar wind collide on a neutral gas in comet the result is emission one or more photons in the range of X-ray energy these photon counted per second as a function of energy in eV is the spectrum of comet each peaks in these spectrum is a material that we have been found in these comet, which each materials have line emission in particular energy like a fingerprint [18].

TABLE 2  
THE RESULTS OF THE MATERIALS FOUND IN TWO COMETS

Comet name	C/linear 1999	C/NEAT 2001
The materials	C	C
	Si	Si
	O	O
		P
	Ne	
	Mg	
	S	

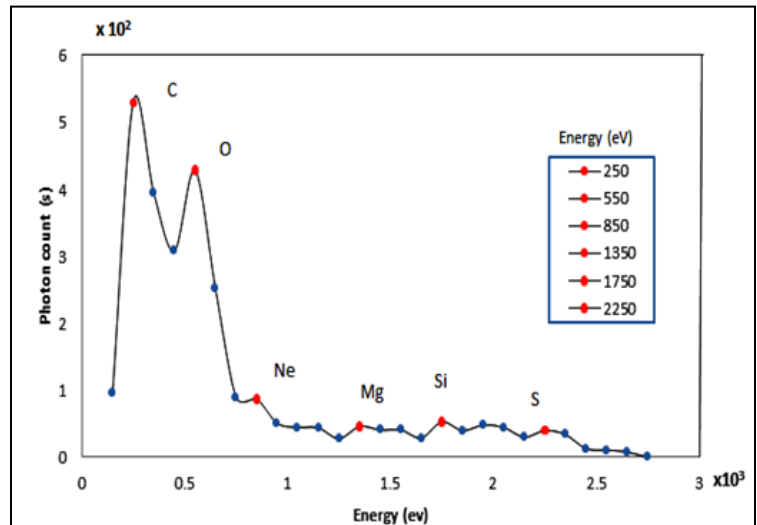


Fig . 3. Relation between Photon count (s) and Energy (eV) for C/linear 1999 comet.

Note in Figure (3) there are six clear peaks each vertex represents a specific substance. These substances are Carbon (C) at energy 250 eV  $K\alpha_1$ , oxygen (O) at energy 550 eV  $K\alpha_1$ , Neon (Ne) at energy 850 eV  $K\alpha_1$ , Magnesium (Mg) at energy 1350 eV, Silicon (Si) at energy 1750 eV  $K\alpha_1$ , Sulfur (S) at energy 2250 eV  $K\beta_1$ . The observed energy and standard for material as shown in table (3) .

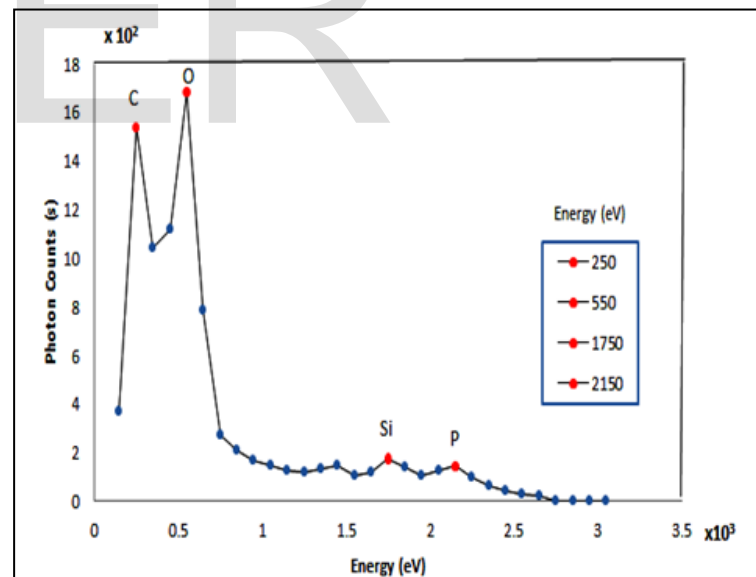


Fig. 4. Relation between Photon count (s) and Energy (eV) for C/NEAT 2001 comet.

Figure (4) demonstrates the spectrum of C/NEAT 2001 comet. The materials that have been found are Carbon (C) at energy 250 eV  $K\alpha_1$ , oxygen (O) at energy 550 eV  $K\alpha_1$ , Silicon (Si) at energy 1750 eV  $K\alpha_1$ , and Phosphorus (P) at energy 2150 eV  $K\beta_1$ . The materials of C/NEAT 2001 comet and there standards energy shown in table (3).

From table (3), we can recognize that there is a difference

**TABLE 3**  
**OBSERVED AND STANDARD ENERGY OF MATERIALS**

Materials	Energy observed(ev)	Standard(ev)[20]
<b>Carbon</b>	<b>250</b>	<b>277</b>
<b>Oxygen</b>	<b>550</b>	<b>524.9</b>
<b>neon</b>	<b>850</b>	<b>848.6</b>
<b>Magnesium</b>	<b>1350</b>	<b>1486.7</b>
<b>Silicon</b>	<b>1750</b>	<b>1739.98</b>
<b>Phosphor</b>	<b>2150</b>	<b>2139.1</b>
<b>Sulfur</b>	<b>2250</b>	<b>2307.8</b>

between the observed and standard energy. This difference is attributed that these materials do not exist free, but they are united with the others.

Depend on the mechanism to get the X-ray spectrum the transition of electrons between main and sub shells of atoms, each of these transition denoted by the specific symbols. Usually only the K-lines are useful in X-ray diffraction. There are several lines in the K-set. The strongest are  $K\alpha_1$ ,  $K\alpha_2$ , and  $K\beta_1$ . from the results we have been gotten transition type  $K\alpha_1$  and  $K\beta_1$ .

We have been noted in the spectrum for two comets used in this research, that both of them contain of Carbon with high abundance depend on the photon counts, and low energy. So when the energy increases we have been gotten heavier elements with lower abundance.

The dominant chemical elements found in comet are (H,C,O,N,S,Si) forming the different components [19]. When we have been analyzed the spectrum of comet, we found another elements appeared like, Neon and Magnesium in C/linear comet. From these results noted that the abundance of these materials is few depend on the value of the photon counts.

Comet composed mostly of mixture of water ice, dust, and compounds of carbon and silicates, that had been found in these two comets as shown in table (2). Water consists of 70% to 90% of the comet; it means that the Hydrogen percent is very high in spite of the percentage of the Hydrogen atom doesn't appear in results because the hydrogen atom has one proton and one electron. So we can calculate exactly what the energy of electron has in each shell. But hydrogen is also the least energetic element. Even the most energetic line hydrogen emits (when an electron drops down from the second shell to the first) has only enough energy to be an ultraviolet photon. So hydrogen atoms do not emit X- rays. But another element have more electron, so it can be emitted photons in the range of X-ray like Carbon has six electrons but Carbon lines are at low energy of X-ray as shown in figure (3 , 4).

Another element appear the in results is the Oxygen

( $Z=8$ ), so it line's energy greater than Carbon line. This is because the Oxygen have more electrons, therefore increasing the atomic number of the materials leads to increase the amount of the observed energy. This is demonstrate in our results that started from Carbon ( $Z=6$ ), energy (250 eV) and ending with Sulfur has ( $Z=16$ ), energy (2250 eV) as shown in figure (4).

The ten most common elements in the Milky Way Galaxy it's not depend on the atomic number so hydrogen is the most abundant element in the known Universe, although hydrogen has the atomic number equal one. These ten element as shown in reference [21] most of the material that we found in comets correspond to the most abundant material in the universe, according to the rankings of materials, except phosphor, which appeared in C/NEAT 2001 as showed in figure (4).

#### 4. CONCLUSIONS

The conclusion could be drawn as follows:

1. Both of comets contain Carbon because it is the fourth most abundant element in the universe.
2. The strongest line emission is  $K\alpha_1$  and  $K\beta_1$ .
3. We have been gotten emission spectrum as a result of the interaction between solar wind and Cometary ion tail.

#### REFERENCES

- [1] S. Mandel'stam, 1965, " X-Ray Emission of the Sun". Space Science Reviews, v. 4, p. 587.
- [2] G.Riccardo, 2003, "Nobel lecture: the dawn of x-ray astronomy". Reviews of modern physics, v.75, pp.995-1010.
- [3] C. Lisse et al., 1996, "Discovery of X-ray and extreme ultraviolet emission from comet c/Hyakutake 1996 B2". Science, v. 274, pp. 205-209.
- [4] D.Bodwits et al., 2012, "Cometary charge exchange diagnostics in uv and X-ray". Astronomische Nachrichten, v.333, p.335.
- [5] T.Cravens, 1997, "comet Hyakutake X-ray source: charge transfer of solar wind heavy ions". Geophys. v.24, pp.105-108.
- [6] M.Mumma et al., 1997, "Soft X-rays from four comet observed with EUVE", Astrophys. v.491, pp.125-128.
- [7] V.Krasnopolsky et al., 1997, "Detection of soft X-rays and a sensitive search for noble gases in comet Hale-Bopp c/1995". Science, v. 277, pp. 1488-1491.
- [8] Shapiro et al. 1999, "Energetic electrons produced by lower hybrid waves in the cometary environment and soft x-ray emission". Geophys. v.104, pp.2537-2554.
- [9] V.Krasnopolsky et al., 2000, "EUVE search for X-rays from comets Encke, Mueller (C/1993A1), Borrelly, and Postperihelion Hale-Bopp". v.146, pp.152-160.
- [10] J. Greenwood et al. 2000, "Measurement of charge exchange and x-ray emission cross sections for solar wind -

- comet interactions". *Astrophys. v.533*, pp.175-178.
- [11] V.Krasnopolsky, 1998, "Excitation of X-rays in comet Hyakutake (C/1996B2)". *Geophys.v.103*, pp.2069-2075.
- [12] V.Krasnopolsky, 2001, "Production of cometary x-rays by electron impact and bremsstrahlung processes". *Gephys.v.106*, pp.741-749.
- [13] N.Djuric et al., 2005, "Surface charging and x-ray emission from insulator surfaces induced by collisions with highly charged ions". *Astrophys.v.635*, pp.718-722.
- [14] J.Carter et al., 2012, "Simultaneous swift x-ray and UV views of comet C/2007 N3 (Lulin)". *Astronomy and astrophysics*, v.541.
- [15] I. Ewing, 2013, "Emission lines between 1 and 2 KeV in cometary X-ray spectra". *Astrophys.v.763*.
- [16] D.Bodwits et al., 2008, "Spectral analysis of the Chandra comet survey". *Astronomy and astrophysics*, v469, pp.1183-1195.
- [17] T. Franham et al., 2001, "Imaging and Photometry of comet c/1999(linear) before perihelion and after breakup", *science*, vol 292. p.p 1349-1352.
- [18] M.Torney, 2007. "Modeling Cometary X-rays", PhD thesis, Department of Physics, University of Strathclyde.
- [19] A.Hearn and M.Festou, 1990. "The neutral coma. In physics and chemistry of comet". Springer Verlag: Berlin, pp.69-110.
- [20] A. Thompson et al., Editor, 2009 "X-ray data booklet". University of California Berkeley, p.p 9-20.
- [21] J. Newsome, 2008. "Life in the universe", Boca Raton, Florida USA. P.49.