International Journal of Applied and Natural Sciences (IJANS)
ISSN(P): 2319-4014; ISSN(E): 2319-4022
Vol. 3, Issue 2, Mar 2014, 107-114

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

X-RAY SPECTRA ANALYSIS OF 8P/TUTTLE AND 103P/HARTLEY COMETS

S. Z. KHALAF, A. A. SELMAN & M. I. JALEEL

Department of Astronomy, College of Science, University of Baghdad, Baghdad, Iraq

ABSTRACT

Comets emit X-ray via the process of solar wind charge exchange (SWCX). Quantitative measurements of this interaction are important to have insight about the composition of comets. The present work focuses of composition of comets depending on the interaction between both Cometary nucleus and tail with solar wind. The chemical composition of Cometary nuclei was inferred from measurements of neutral and ionized gases from the coma, tail, and dust grains. Data were obtained through space telescope spectroscopy at X-ray wavelength from Chandra space telescope and by use DS9 software 7.2 for April 15^{th} 2013, to analyze spectra that have been collected from Chandra. The results of present work showed a relation between photon count and energy for two comets, namely, 8p/Tuttle (2008) and 103p/Hartley 2**.** These two comets are thought to sustain their masses from Kuiper Belt, observed with Chandra X-ray observatory and ACIS-S spectrometer in the energy range (100-10000) eV. C, O, Si and P were significant elements in Hartley comet's nucleus whereas C, Si, P and Zn were found to be the main elements in Tuttle's.

KEYWORDS: 8p/Tuttle Comet, 103p/Hartley Comet, X-ray Spectra, Solar Wind

INTRODUCTION

Depending on their properties, most comets are thought to emit X-ray when the distance from heliocentric is about 2 AU. The emitted X-ray radiation with wavelength between about 0.01 to 10 nm are important for studies of solar system nature and astrophysical applications because the composition of comets can be definitely specified which gives a fair picture about the solar system development in its early stages. Photons are sufficiently energetic to ionize neutral atoms and molecules and the solar wind plays a central role in several of the proposed X-ray production mechanisms [1].

Particle of the solar wind are heavily charged with relatively high energy. When these particles suffer from collision with neutral gas atoms the ions will get partially neutralized by capturing one or more electrons to an excited state. These ions will decay afterward to a ground state by emitting one or more photons. This is the mechanism of Charge Exchange Emission (CXE), which naturally produces X-ray with sharp peaks at resonating energies. This ray has been observed earlier from comets, planets, interstellar medium in X-rays [2], and even moons of the solar system. Specially, high energy emissions from comets depend upon few properties of both the comet and solar wind. The parameters belonging to comets are dynamic and composition of which gas production rate has the most important rule [3].

X-rays emissions have been observed from the Sun by the U.S. Naval Research Laboratory Blossom experiment on board [4], later it detected the first X-rays from other celestial sources as Scorpius X-1[5] which gave the first source of X-ray in that constellation.

X-ray and Extreme Ultraviolet (EUV) emissions are usually associated with systems that sustain or produce high temperatures. Comets' on the other hand, are thought to be made of dirty ice, i.e., frozen water with different contaminations. Therefore, finding experimentally that comets produce and emit X-rays and EUV was a shock [6]. This on one side is in a strong contrast to models that assume comets as dirty iceballs, with temperature ranging within few tenths of Kelvins. ROSAT found that Comet Hyakutake emits X-ray, with magnitude < 12.0 at a distance ranging up to ~ 2 AU. The Emission was highly variable in time, and many of the observed comets displayed a characteristic crescent shape [7].

To explain this it was assumed that comets can emit X-rays from the process of charge exchange with the solar wind plasma. In this process, gas in the cometary coma gives up its electrons during this exchange, to a higher excited energy of a highly-charged ion of the solar wind. After certain amount of time, the excited states re-emit the excessive energy by X-rays [8].

In 1996, Lisse et al. have 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 [6]. The same event has been recorded by extreme ultraviolet explorer (EUVE) in 1997 [9]. Another discovered that Hale-Bopp comet emission X-ray by Krasnopolsky et al. in 1997 [10]. In the same year in 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 [8].

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 [11]. Vladimir et al. in 2000 observed comet Hale-Bopp post perihelion, observed in 1997 and studied observing data on three comets, viz., Encke, Mueller (C/1993 A1), and Borrelly from EUVE archive [12]. Greenwood et al. in 2000 performed measurement of charge exchange and X-ray emission cross sections for solar wind –comet interactions and they compared their results to the cross section values used in recent comet models, and the importance of applying accurate cross sections, including double charge exchange, to obtain absolute line-emission intensities was emphasized [13]. Krasnopolsky in 2001 determined an X-ray peak volume emission 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 [14, 15].

Few other groups in 2001 to 2005 studied the cometary spectra, which provided a good amount of data on the molecular composition of comet atmosphere. Characteristic X-ray emission lines have been found from simulations of comet surfaces as they went through collisions with highly charged ions. It was found that the emission of X-ray characteristic from K-L and K-M shells appeared to proceed during positive charging of the surface by the beam [16]. D. Bodewits et al. in 2007 presented results of the analysis of cometary X-ray spectra with an extended version of our charge exchange emission model [7]. 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 [3]. In 2012 and since the initial discovery of Cometary charge exchange emission, there were more than 20 comets that have been observed with a variety emissions of X-rays and UV observatories. They reviewed the possibilities and limitations of each of those in their contribution [7]. They have analysis of simultaneous X-Ray and UV observations of comet C/2007 N3 (Lulin) taken on three days between January 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 [17]. 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 [18].

Most x-ray studies use facilities provided from Chandra, which is a space telescope that 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).

In this work, X-ray emissions have been taken for two comets, 103p/Hartley and 8P/Tuttle, using Chandra images.

DATA ACQUISITION

Two comets have been taken in this work. The first comet is comet 103p/Hartley. This **is** a small Jupiter-family comet having an orbital period of 6.46 years. It was discovered by Malcolm Hartley in 1986 with perihelion near the Earth's orbit at 1.05 AU from the Sun [19]. This comet has passed within 0.12 AU of Earth on 20thOctober 2010 [21]. The next perihelion will be on 20thApril 2017 [20, 22]. This comet observed by Wolk with parameters shown in Table 1 and total X-ray image shown in Figure 1.

The second comet is 8P/Tuttle. It's another Jupiter-family comet with an orbital period 13.6 years. It was discovered by Horace Parnell Tuttle. On January 2008 it passed Earth at a distance of 0.252 AU and it appeared again on August 27th2012 [19, 22]. This comet was observed by Christian with a parameter shown in Table 1 the total X-ray image shown in Figure 2.

Table 1: The Coordinates of Comets

	103p/Hartley	8p/ Tuttle
Obs ID	12320	9778
RA	05 25 00.0	01 36 13.00
DEC	+39 00 00.0	+26 13 11.00
Instrument	ACI-S	ACI-S
Observation Date	17/10/2010	4/1/2008

Figure 1: X-ray Emission Image of Comet 103p/Hartley

FITS images have been taken from Chandra X-ray telescope, then using SAO image ds9 software, the total image have been taken. Images were analyzed for X-ray emissions, and using spread sheet the chart were determined as shown in Figure 3 for Hartley comet and Figure 4 for Tuttle comet. These analyses led to the results as explained in the discussions.

Figure 1 and 2 show the total image of X-ray of Hartley and Tuttle comets. These images are divided into square arrays because Chandra telescope consists of several sensors in a matrix each of these sensors receive energy within certain range. When all the energies are collected from these sensors we will have the spectrum of the comet. Depending on the shell energy of the element, each material has specific energy similar to a fingerprint. Therefore defining the X-ray emission peaks will define a certain natural element.

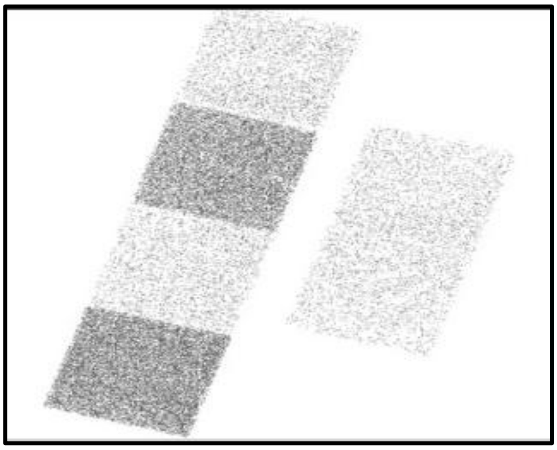

Figure 2: The Total X-ray Image for Six Sensors of 8p/Tuttle Comet

RESULTS AND DISCUSSIONS

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 photons counted per second as a function of energy in eV. This relationship shows the spectrum of the comet, each peak in the spectrum represents a material that we have found in these comet depend on the standard energy of materials which each materials have line emission in particular energy.

Elements found in the two comets are shown in Tables 2 and 3, where there is a difference between the observed and standard energy. This difference because these materials do not exist in a free chemical state, but as composition with other elements arrived in the state of stability because they are not saturated.

Table 2: The Results of the Materials Found in Two Comets

103p/Hartley	8P/Tuttle
C	C
O	
Si	Si
P	P
	Zn

Table 3: Observed and Standard Energy of Materials

Materials	Energy Observed (eV)		Standard (eV)[23]
	Hartley	Tuttle	
Carbon	255	259	277
Oxygen	553		524.9
Silicon	1760	1763	1739.98
Phosphor	2155	2155	2139.1
Zinc		9756	9572

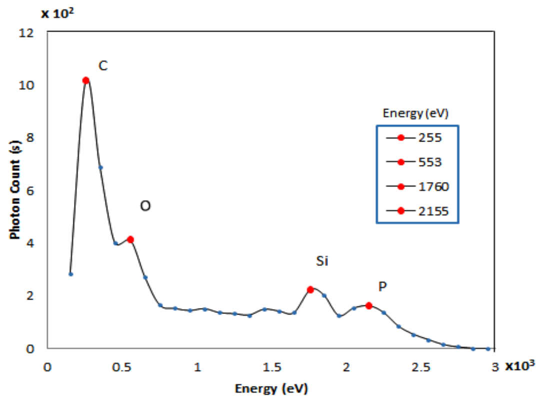

Figure 3: Photon Counts as a Function of Energy (eV) for the 103p/Hartley Comet

Figure 3 shows the spectrum of 103p/Hartley comet. Note that there are four clear peaks and each vertex

Represents a specific substance. When the energy was equal to 255 eV which is due to Carbon C. The transition type is $K_{\alpha 1}$. The second vertex took place when the energy was 553 eV and the substance is Oxygen O, with transition type $K_{\alpha 1}$. The third peak energy was equal to 1760 eV and the material is Silicon Si, from $K_{\alpha 1}$.The last peak has energy 2155 eV of $K_{\beta 1}$ and the element is Phosphor P.

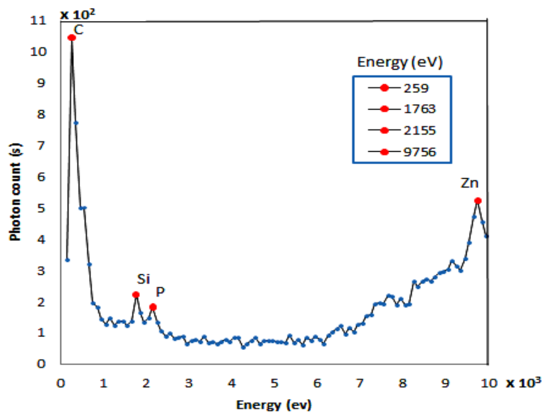

Figure 4: Photon Counts as a Function of Energy (eV) for the 8p/Tuttle Comet

8p/Tuttle (2008) comet. The materials that have been found are C at energy 259 eV from $K_{\alpha1}$, Si at energy 1763 eV from $K_{\alpha1}$, P at energy 2155 eV from $K_{\beta1}$, and Zn at energy 9756 eV from $K_{\beta1}$. Table 3 shows the energy that have been observed by Chandra telescope and the standard energy of each material.

Comet composed mostly of mixture of water ice, dust, and compounds of C, Si, and silicates that had been found in these two comets has shown in Table 2. Comets consist of 70% to 90% of water, but in spite of high percentage Hydrogen it doesn't appear in results because X-ray emission is not likely. 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. Other heavier abundant elements that have more electrons can emit photons in the range of X-ray. Another element appears the in results are the O with lines energy greater than C line. This is attributed that O has more electrons affinity. Ionization energy of O is found in 103p/Hartley comet is shown in Figure 3. Therefore increasing the atomic number of the materials leads to increase the amount of the observed energy. This demonstrates that spectra started from C at energy 255 eV and ended with Zn at energy 9756 eV as shown in Figure 4.

The ten most common elements in the Milky Way Galaxy have scattered atomic numbers, but hydrogen is the most abundant element in the Universe. These ten element as shown in reference [24] 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 both comets and zinc which appeared in 8p/Tuttle comet.

CONCLUSIONS

Both of comets contain C element. We found that the two studied comets contain roughly the same material and the reason that the both comets are short period comets suggesting that they came from the same inter-planetary environment which explains the similarities in the materials therein. From the spectra that have been observed from two comets information on the composition of the region where the comet came from could also be deduced.

REFERENCES

1. Cravens, 2002, "X-ray Emission from Comets", Science v. 296, p.1042.
2. M. Uchida et al., 1998, "X-ray spectra of comets". Astrophys. v.498, pp.863-870.
3. D. Bodwits et al., 2008, "Spectral analysis of the Chandra comet survey". Astr. Astrophys., v. 469, pp.1183-1195.
4. S. Mandel'stam, 1965, "X-Ray Emission of the Sun". Sp. Sci. Rev., v. 4, p. 587.
5. G. Riccardo, 2003, "Nobel lecture: the dawn of X-ray astronomy". Rev. Mod. Phys., v.75, pp.995-1010.
6. C. Lisse et al., 1996, "Discovery of X-ray and extreme ultraviolet emission from comet c/Hyakutake1996 B2". Science, v. 274, pp. 205-209.
7. D. Bodwits et al., 2012, "Cometary charge exchange diagnostics in UV and X-ray". Astronomische Nachrichten, v.333, p. 335.
8. T. Cravens, 1997, "Comet Hyakutake X-ray source: charge transfer of solar wind heavy ions". Geophys. v.24, pp.105-108.

9. M. Mumma et al., 1997, “Soft X-rays from four comet observed with EUVE”, Astrophys. v.491, pp.125-128.
10. 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.
11. 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.
12. V. Krasnopolsky et al., 2000, “EUVE search for X-rays from comets Encke, Mueller (C/1993A1), Borrelly, and Post perihelion Hale-Bopp”. v.146, pp.152-160.
13. 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.
14. V. Krasnopolsky, 1998, “Excitation of X-rays in comet Hyakutake (C/1996B2)”. Geophys. v.103, pp.2069-2075.
15. V. Krasnopolsky, 2001, “Production of cometary X-rays by electron impact and bremsstrahlung processes”. Geophys. v.106, pp.741-749.
16. 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.
17. J. Carter et al., 2012, “Simultaneous swift X-ray and UV views of comet C/2007 N3 (Lulin)”. Astro. Astrophys. v.541, pp. 309-316.
18. I. Ewing, 2013, “Emission lines between 1 and 2 keV in cometary X-ray spectra”. Astrophys. v.763, pp.740-743.
19. "JPL Small-Body Database Browser: 103P/Hartley 2". Jet Propulsion Laboratory. JPL website, Retrieved 7 November 2010, www.ssd.jpl.nasa.gov.
20. S. Nakano, 2010, "103P/Hartley 2 (NK 2000)". OAA Computing and Minor Planet Sections". Retrieved 20 February 2012, www.ssd.jpl.nasa.gov.
21. "JPL Close-Approach Data: 103P/Hartley 2". Retrieved 23 February 2010, www.ssd.jpl.nasa.gov.
22. Yoshida, Seiichi, 2006. "103P/Hartley 2". Seiichi Yoshida's Comet Catalog. Archived from the original on 25 March 2010. Retrieved 23 February 2010, www.nasa.gov.
23. A. Thompson et al., Editor, 2009 "X-ray data booklet". University of California Berkeley, pp. 9-20.
24. J. Newsome, 2008."Life in the universe”, Boca Raton, Florida USA. P.49.