Comparative Study of Si XIII and Si XIV Line Ratios at High Temperatures Using AtomDB

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1 Introduction

Silicon (Si) is abundant in astrophysical environments and exhibits strong X-ray emission lines from its helium(He)-like (Si XIII) and hydrogen(H)-like (Si XIV) ionization states. The ratios of these emission lines serve as diagnostic tools for plasma temperature, density, and ionization mechanisms (e.g., Kaastra and Mewe [1993], Smith et al. [2001]). In this study, we utilize the Atomic Database for Astrophysicists (AtomDB) (Foster et al. [2012]) to perform a comparative analysis of emission line ratios from Si XIII and Si XIV at electron temperatures of 1×10^7 K, 2×10^7 K and 5×10^7 K, representative of hot astrophysical plasmas.

2 Methodology (AtomDB Interactive Plot Setup)

We utilized the interactive plot feature of AtomDB (http://app.atomdb.org/) to obtain the necessary data. The setup details are as follows:

- **Lines**: Silicon (Si) was selected as the element of interest, focusing on the He-like (Si XIII) and H-like (Si XIV) ionization states. Specifically, the Si XIII Level $7 \to 1$ and Si XIV Level $4 \to 1$ transitions were chosen due to their strong emissivities.

- **Temperatures**: Spectra were generated at electron temperatures (T_e) of 10^7 K, 2×10^7 K and 5×10^7 K to cover a range of thermal conditions.

- **Abundance Set (XSPEC naming in brackets)**:
  Grevesse, Asplund & Sauval (2010Ap&SS.328..179G) (Grevesse et al. [2010]).

- **Response File**: Chandra/ACIS-S HEG+1 (cy22).

3 Results

The emissivity and other properties of the lines obtained from AtomDB are summarized in Table 1. The line ratios are calculated as follows:

- At 10^7 K: Line ratio = 124.1318f/45.078f $\approx$ 2.7537.

- At 2×10^7 K: Line ratio = 46.5608f/110.1227f $\approx$ 0.42281.

- At 5×10^7 K: Line ratio = 2.74086f/38.40073f $\approx$ 0.071375.

Ion	Label	Transition	λ (Å)	A (s^{-1})	f	T_e (K)	Emissivity
Si XIII	Level 7 → 1	1s2p $^1P_1 \rightarrow$ 1s^2 $^1S^o_0$	6.648	3.84×10^{13}	0.763	10^7	124.1318f
						2×10^7	46.5608f
						5×10^7	2.74086f
Si XIV	Level 4 → 1	2p $^2P_{1/2,3/2} \rightarrow$ 1s $^2S^o_{1/2}$	6.180	2.41×10^{13}	0.276	10^7	45.078f
						2×10^7	110.1227f
						5×10^7	38.40073f

Table 1: Transition properties for Si XIII and Si XIV.

4 Discussion

The observed trends in silicon ion emission line ratios highlight the significant impact of temperature on ionization equilibrium in astrophysical plasmas. At lower temperatures ($\approx 10^7$ K), Si XIII (He-like silicon) dominates because there is insufficient thermal energy to ionize it to Si XIV (H-like silicon), resulting in strong Si XIII emission lines. As the temperature increases to intermediate levels ($\approx 2 \times 10^7$ K), sufficient energy becomes available to ionize Si XIII to Si XIV, enhancing the emission lines of H-like silicon. At higher temperatures ($\approx 5 \times 10^7$ K), Si XIV becomes the predominant ionization stage as Si XIII ions are further ionized, reducing the contribution of Si XIII emission lines. This progression underscores the pivotal role of collisional ionization processes in high-temperature plasmas and demonstrates that the increasing ratio of Si XIV to Si XIII emission lines serves as a sensitive diagnostic tool for determining electron temperatures, consistent with theoretical predictions from collisional ionization equilibrium models (Mazzotta et al. [1998]).

References

A. R. Foster, L. Ji, R. K. Smith, and N. S. Brickhouse. Updated Atomic Data and Calculations for X-Ray Spectroscopy. , 756(2):128, September 2012. doi: 10.1088/0004-637X/756/2/128.

N. Grevesse, M. Asplund, A. J. Sauval, and P. Scott. The chemical composition of the Sun. , 328(1-2): 179–183, July 2010. doi: 10.1007/s10509-010-0288-z.

J. S. Kaastra and R. Mewe. X-ray emission from thin plasmas. I - Multiple Auger ionisation and fluorescence processes for Be to Zn. , 97(2):443–482, January 1993.

P. Mazzotta, G. Mazzitelli, S. Colafrancesco, and N. Vittorio. Ionization balance for optically thin plasmas: Rate coefficients for all atoms and ions of the elements H to NI. , 133:403–409, December 1998. doi: 10.1051/aas:1998330.

Randall K. Smith, Nancy S. Brickhouse, Duane A. Liedahl, and John C. Raymond. Collisional Plasma Models with APEC/APED: Emission-Line Diagnostics of Hydrogen-like and Helium-like Ions. , 556 (2):L91–L95, August 2001. doi: 10.1086/322992.