Anomalous Evolution of Plasma Composition During a Small Solar Flare

Understanding the Composition Evolution during a flare using Hinode/EIS, SDO/AIA, SDO/HMI; and Techniques like FIP Bias Measurements and Wavelet

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Categorising Composition

First ionisation potential (FIP)
- Low FIP elements (< 10eV)
- High FIP elements (> 10eV)

FIP\_bias = \frac{A_{SA}}{A_{Ph}}
Theoretical Background

Ponderomotive Force

\[ F_i = \frac{m_i c^2}{4} \frac{d}{dz} \left( \frac{\delta E_p(z_i)^2}{B(z_i)^2} \right) \]

Acceleration is independent of mass

Created by density gradient

Reflected in coronal loops

General View of AR 11967

Constantly reconnecting
83 C-class flares, 28 M-class flares
EIS is observing with the correct spectral window

(The images were processed using the MGN technique of Morgan & Druckmüller 2014)

Flares and Observations on 2 Feb 2014

3 Flares on 2 Feb
Focus on the 3rd flare
Si X / S X FIP Bias Value Evolution

Si X / S X (1.5 MK)

FIP Bias values are roughly the same


Ca XIV / Ar XIV FIP Bias Value Evolution

Ca XIV / Ar XIV (3.5 MK)
Ratio value changes from
~2 \rightarrow 3.77
What happened? 1st Interpretation

Partial Ionisation of S
What happened? 1st Interpretation

Partial Ionisation of S

First Ionisation Potential (FIP) difference

- Si / S (2.21eV)
- Ca / Ar (9.65eV)
What happened? 1st Interpretation

Partial Ionisation of S

- Si X/S X Composition Map
- Ca XIV/Ar XIV Ratio
Fractionation occurred in the lower chromosphere

\[ f_k = \frac{\rho_k(z_u)}{\rho_k(z_l)} \]

\[ = \exp \left\{ \int_{z_l}^{z_u} \frac{2\xi_k a \nu_{kn}/\left[\xi_k \nu_{kn} + (1 - \xi_k) \nu_{ki}\right]}{2k_B T/m_k + v_{\parallel,osc}^2 + 2u_k^2} \, dz \right\} \]

\[ f_k \propto \frac{1}{\xi_k \nu_{kn} + (1 - \xi_k) \nu_{ki}} \]

- \( f_k \) = Ratio of densities for element \( k \) at upper and lower fractionation regions
- \( \nu_{kn} \) = Collision frequency of neutral elements
- \( \nu_{ki} \) = Collision frequency of ions
- \( \xi_k \) = element ionisation fraction

Conclusion

EIS observation provides a unique chance to study composition in flares.

FIP Bias determined at two different temperatures gives different results
- Unchanged composition in Si X/S X map; Significant FIP bias increase in Ca XIV/Ar XIV map.

Interpretations

- Small flare heating caused different composition changes at the lower and higher temperature line pairs.
- Fractionation happened in the lower chromosphere. S behaves like a low FIP element and got pulled out by the ponderomotive force.