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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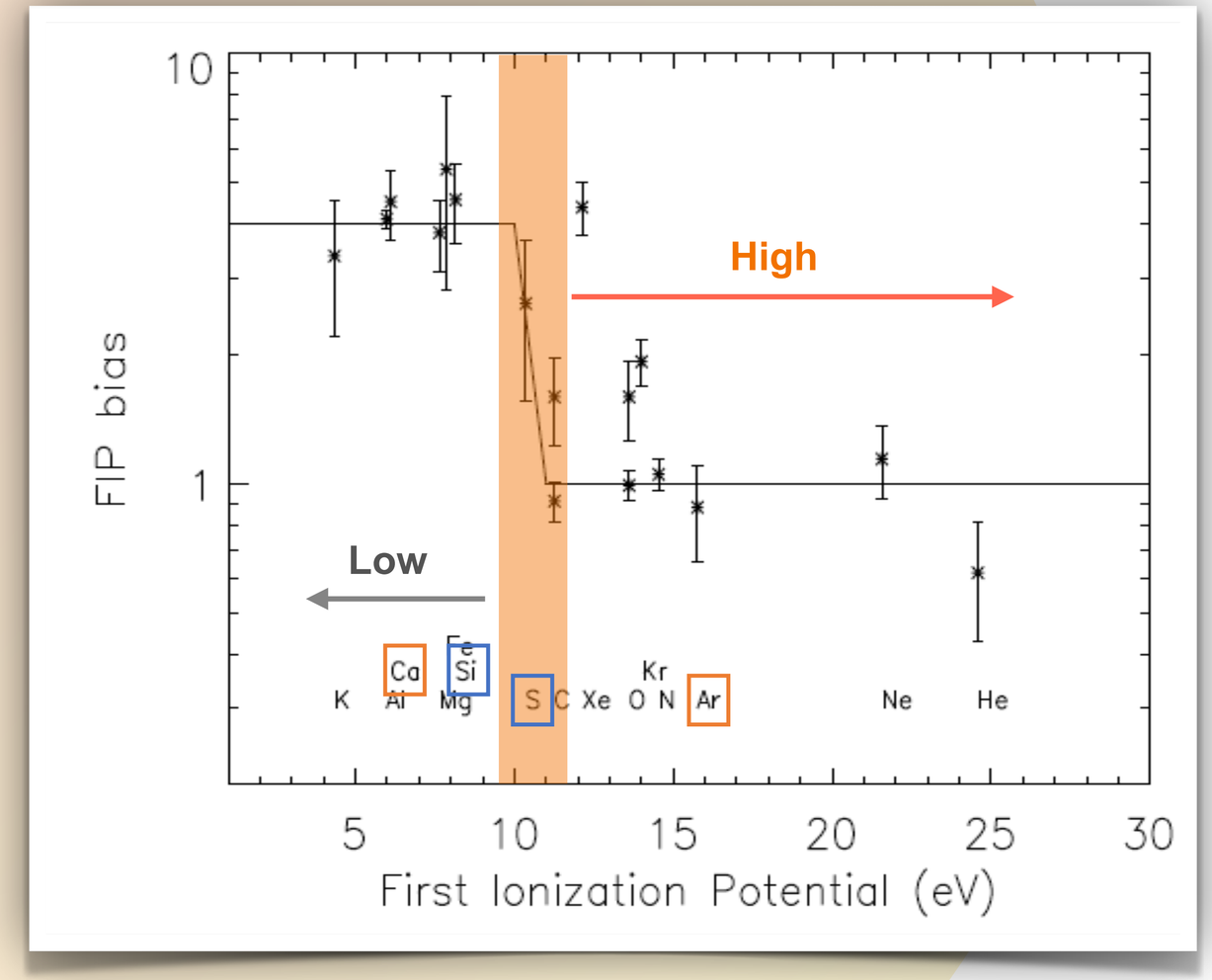
Categorising Composition



- First ionisation potential (FIP)
- Low FIP elements (< 10eV)
- High FIP elements (> 10eV)
- $FIP_{bias} = A_{SA} / A_{Ph}$

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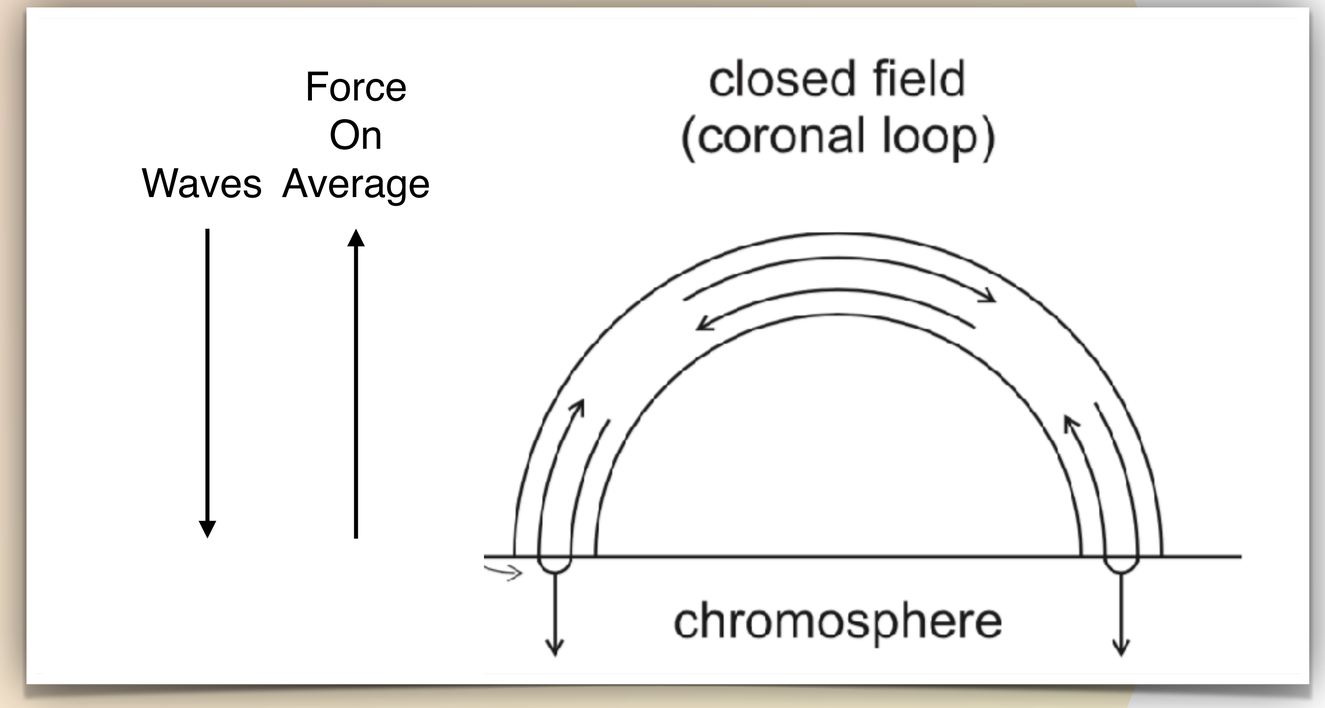
Theoretical Background



Ponderomotive Force

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

Acceleration is independent of mass

Created by density gradient

Reflected in coronal loops

Laming, J.M. The FIP and Inverse FIP Effects in Solar and Stellar Coronae. Living Rev. Sol. Phys. 12, 2 (2015).

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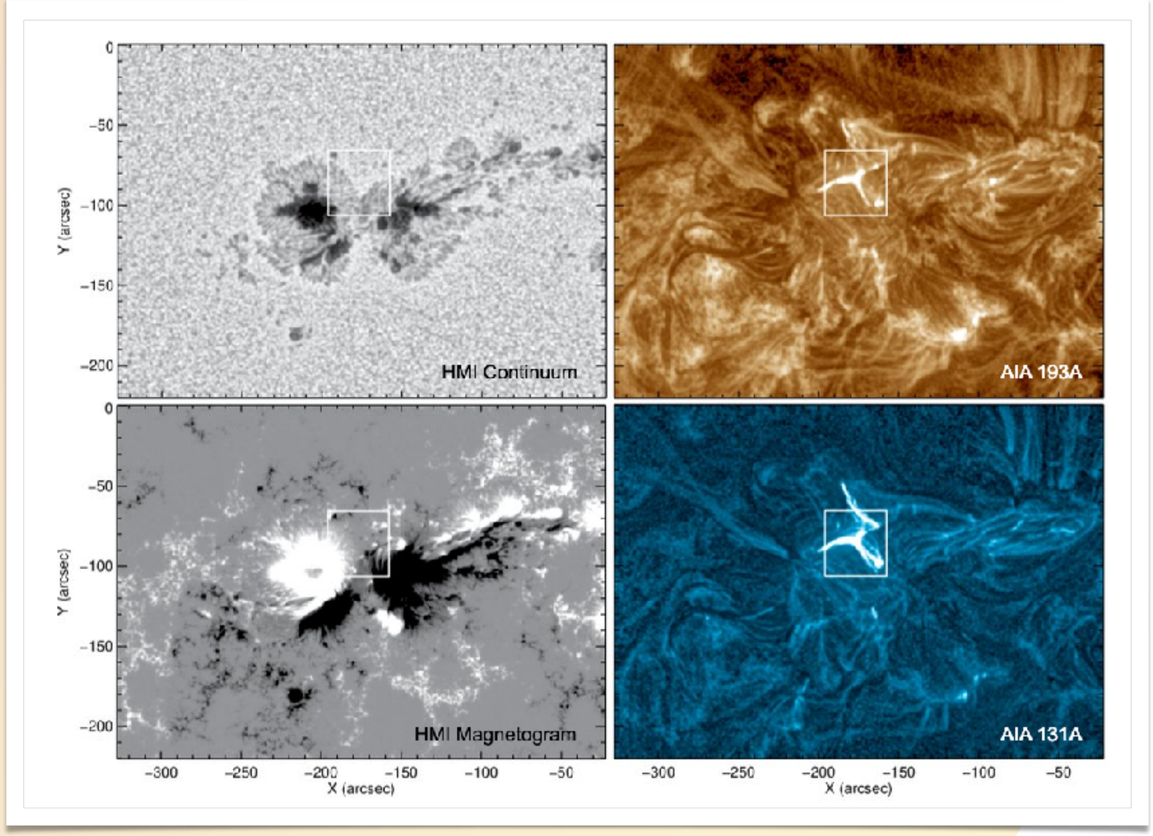
General View of AR 11967



- 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)

Morgan, H., & Druckmüller, M. (2014). Multi-Scale Gaussian Normalization for Solar Image Processing. SoPh, 289(8),2945-2955.

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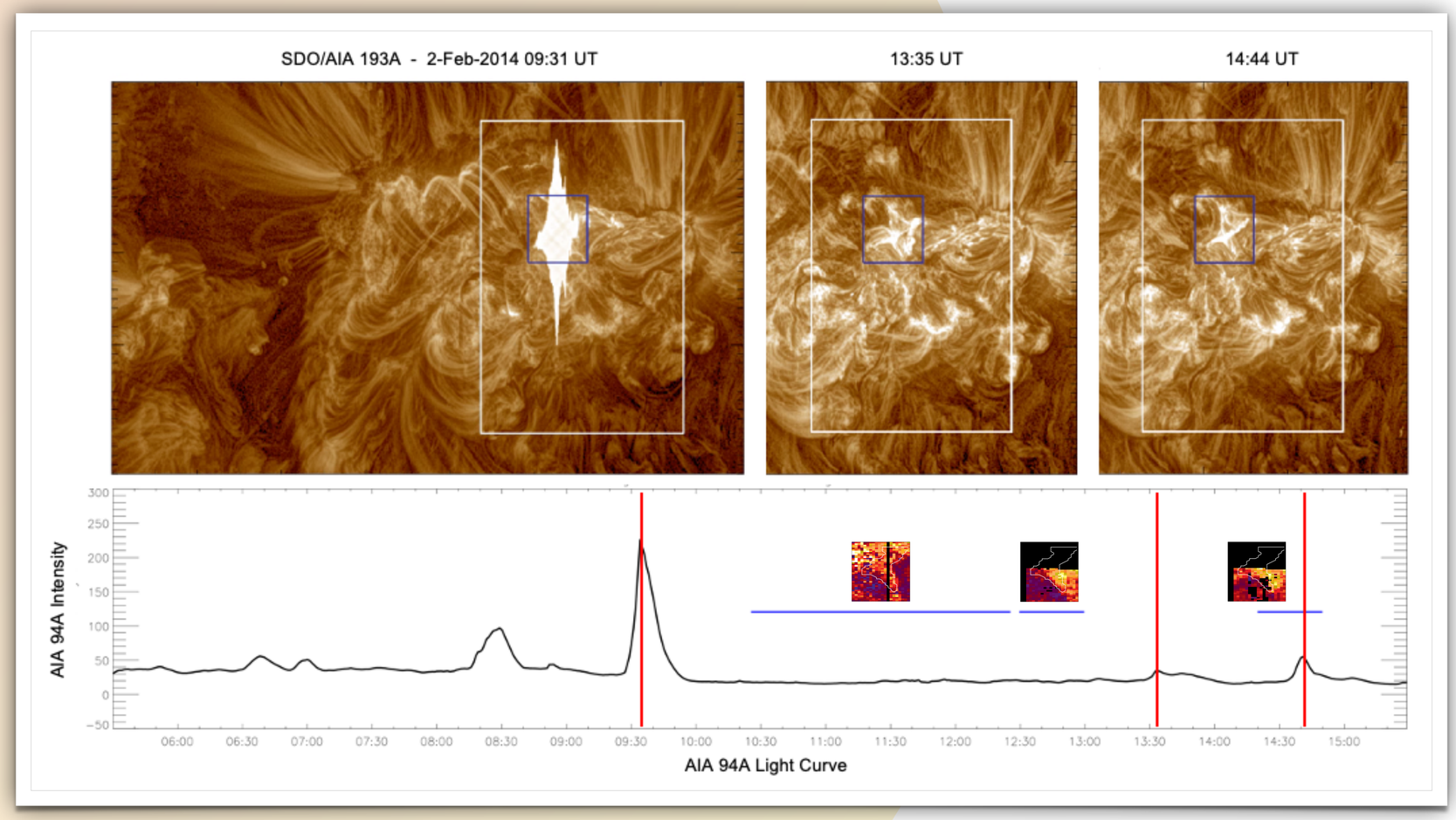
Flares and Observations on 2 Feb 2014



- 3 Flares on 2 Feb
- Focus on the 3rd flare

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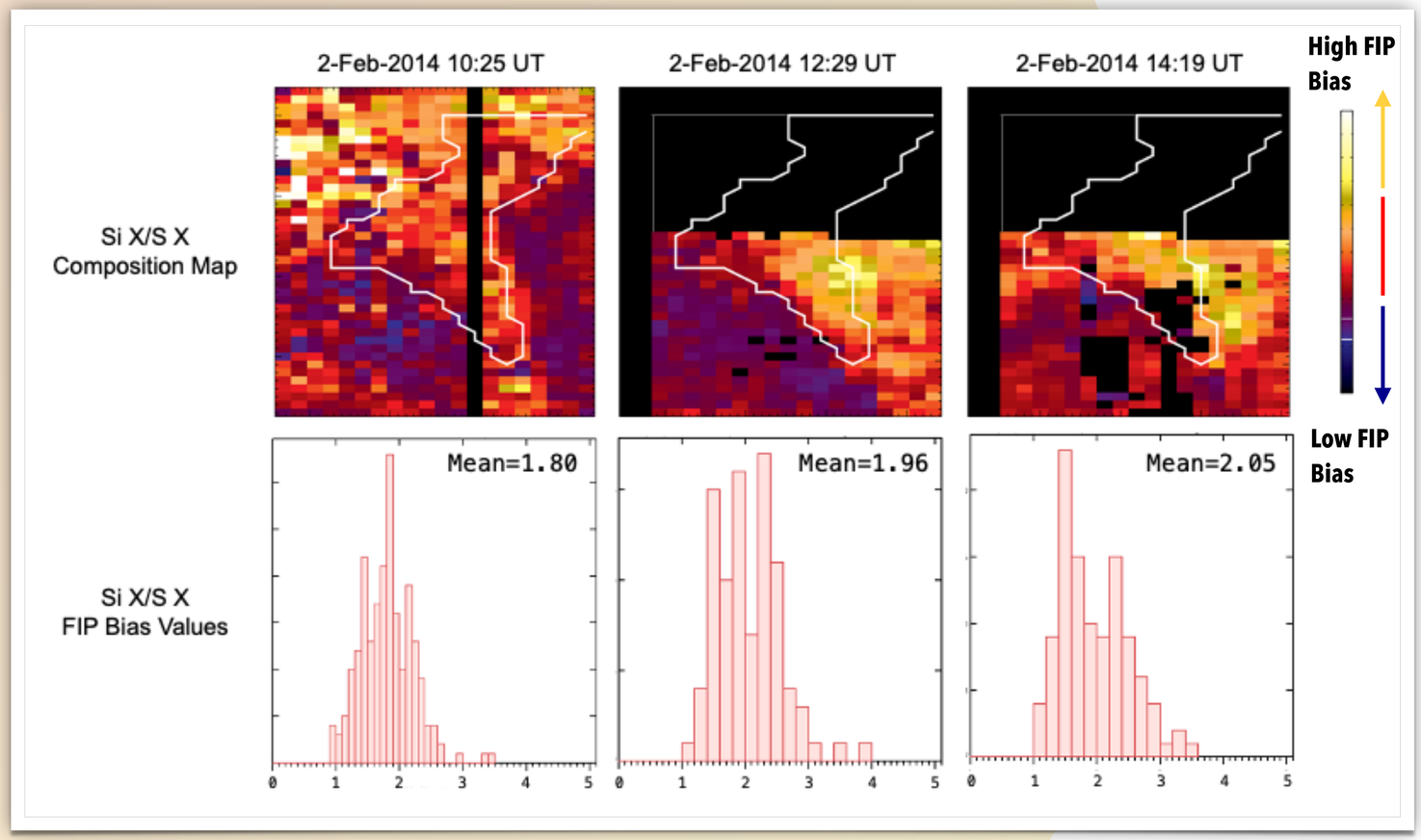
Si X / S X FIP Bias Value Evolution



- Si X / S X (1.5 MK)
- FIP Bias values are roughly the same

[1]Del Zanna, G., & Mason, H. E. (2014). Elemental abundances and temperatures of quiescent solar active region cores from x-ray observations. A&A, 565 A14.

Brooks, D. H., Ugarte-Urra, I., & Warren, H. P. (2015). Full-Sun observations for identifying the source of the slow solar wind. Nat. Commun., 6(5947), 1–9. doi: 10.1038/ncomms6947

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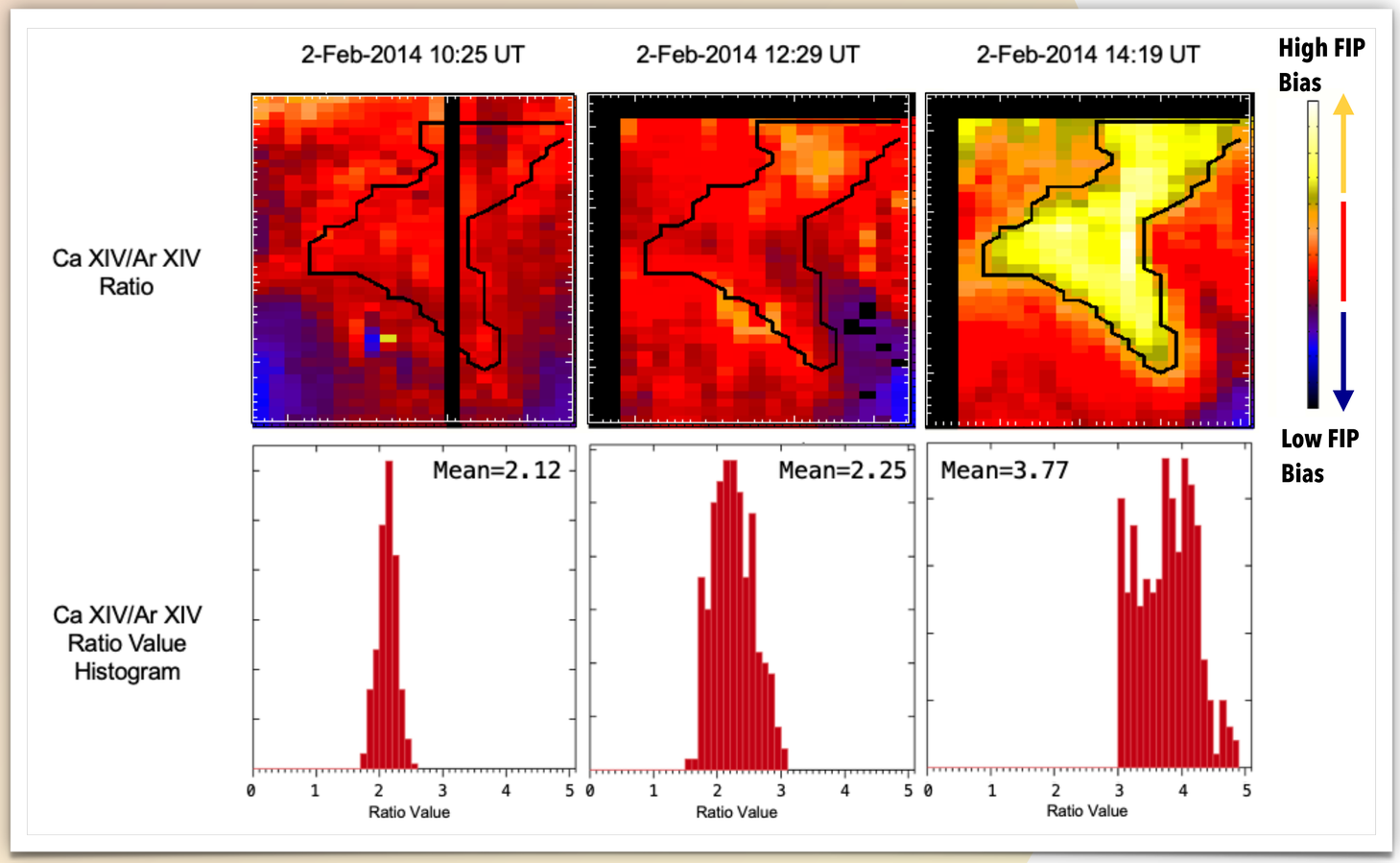
Ca XIV / Ar XIV FIP Bias Value Evolution



- Ca XIV / Ar XIV (3.5 MK)
- Ratio value changes from ~2 → 3.77

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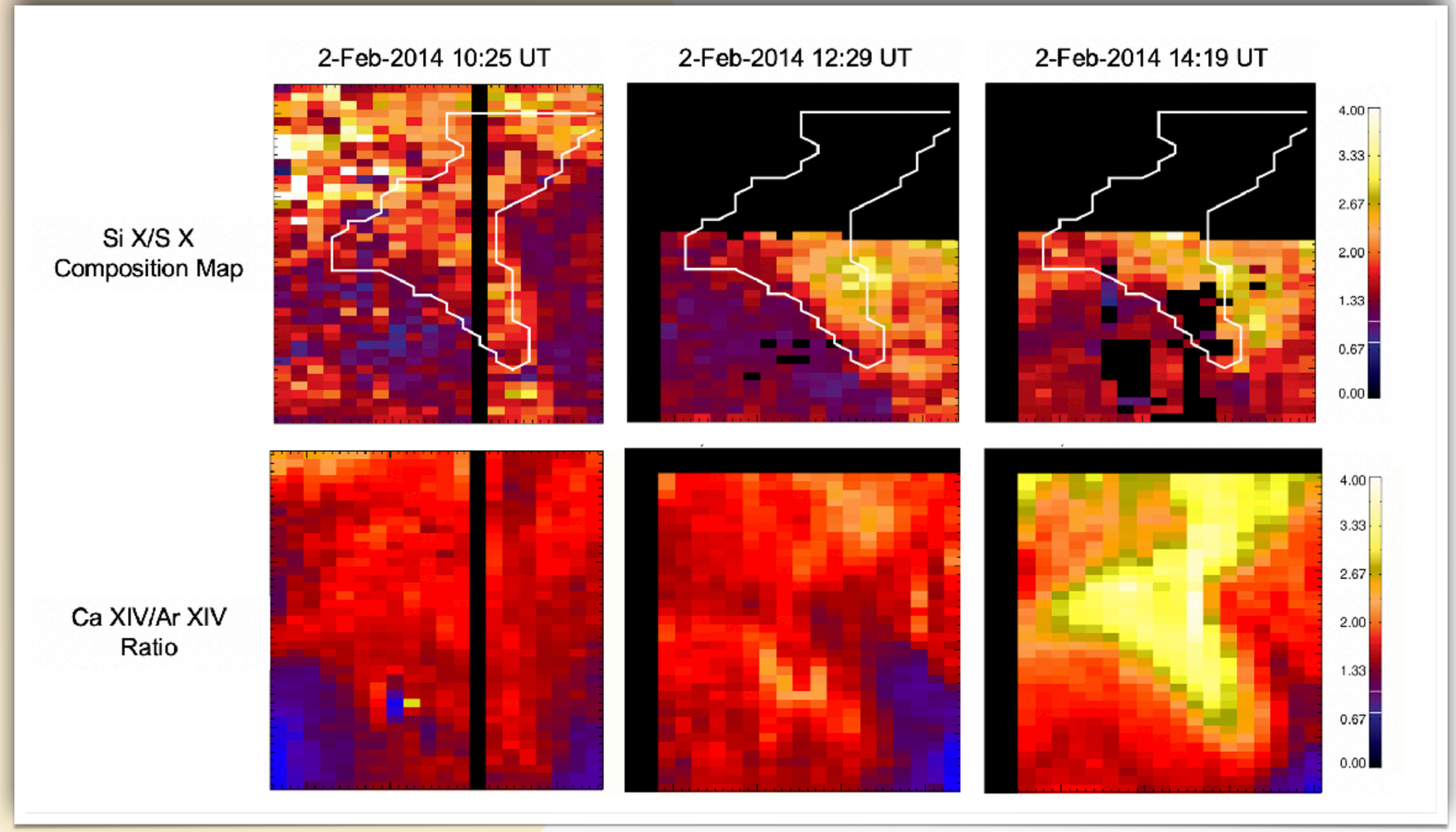
What happened? 1st Interpretation

Partial Ionisation of S



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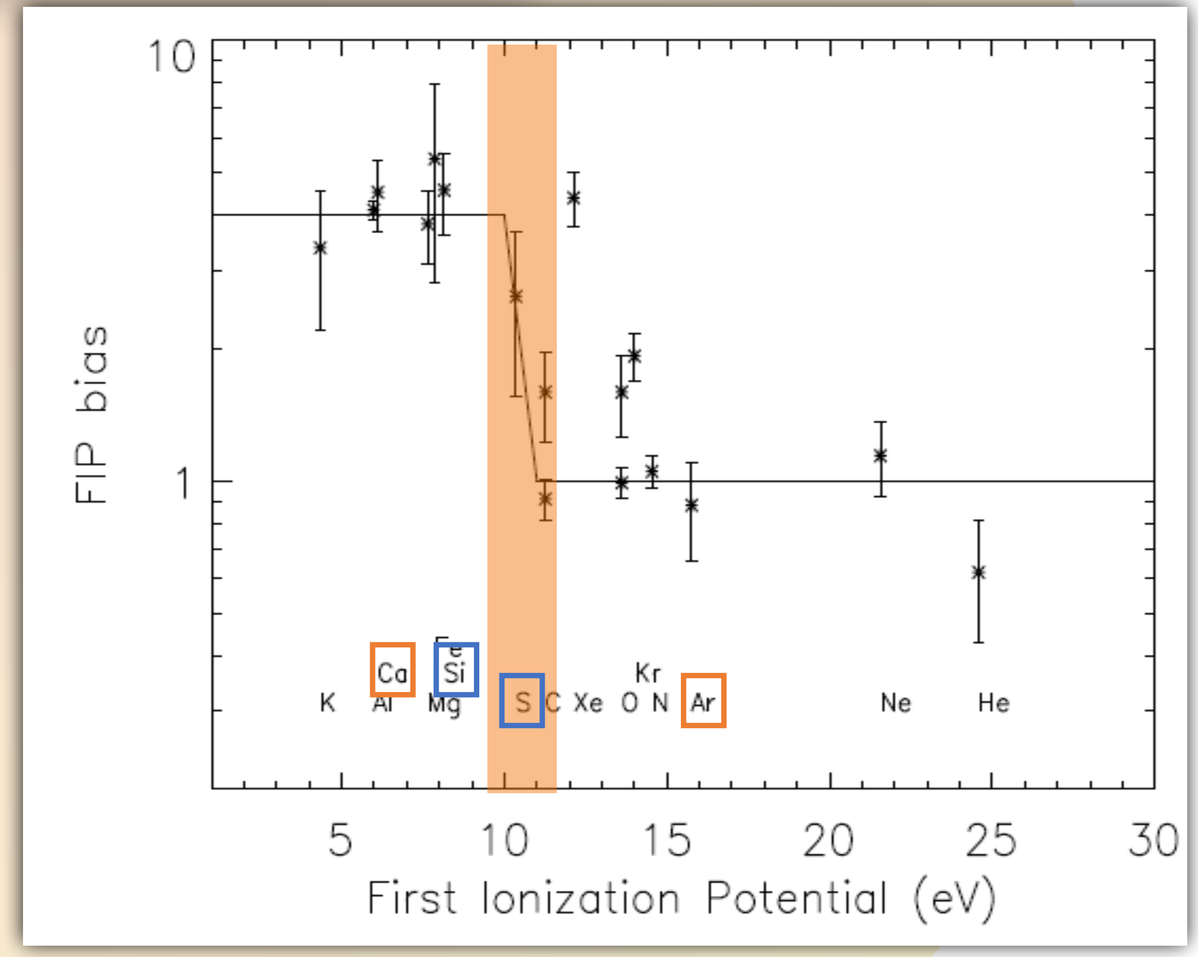
What happened? 1st Interpretation

Partial Ionisation of S



- First Ionisation Potential (FIP) difference
- Si / S (2.21eV)
- Ca / Ar (9.65eV)

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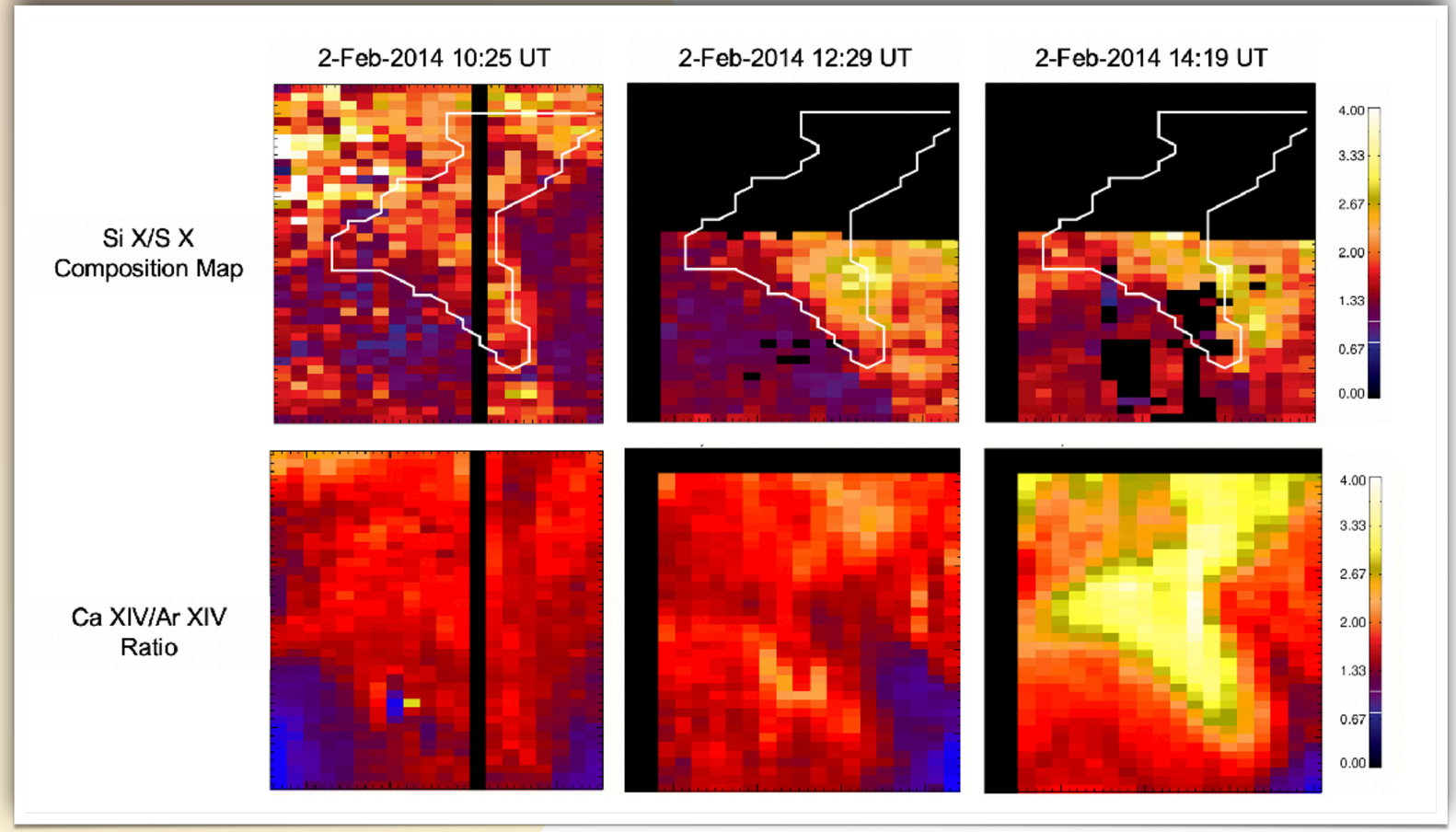
What happened? 1st Interpretation

Partial Ionisation of S



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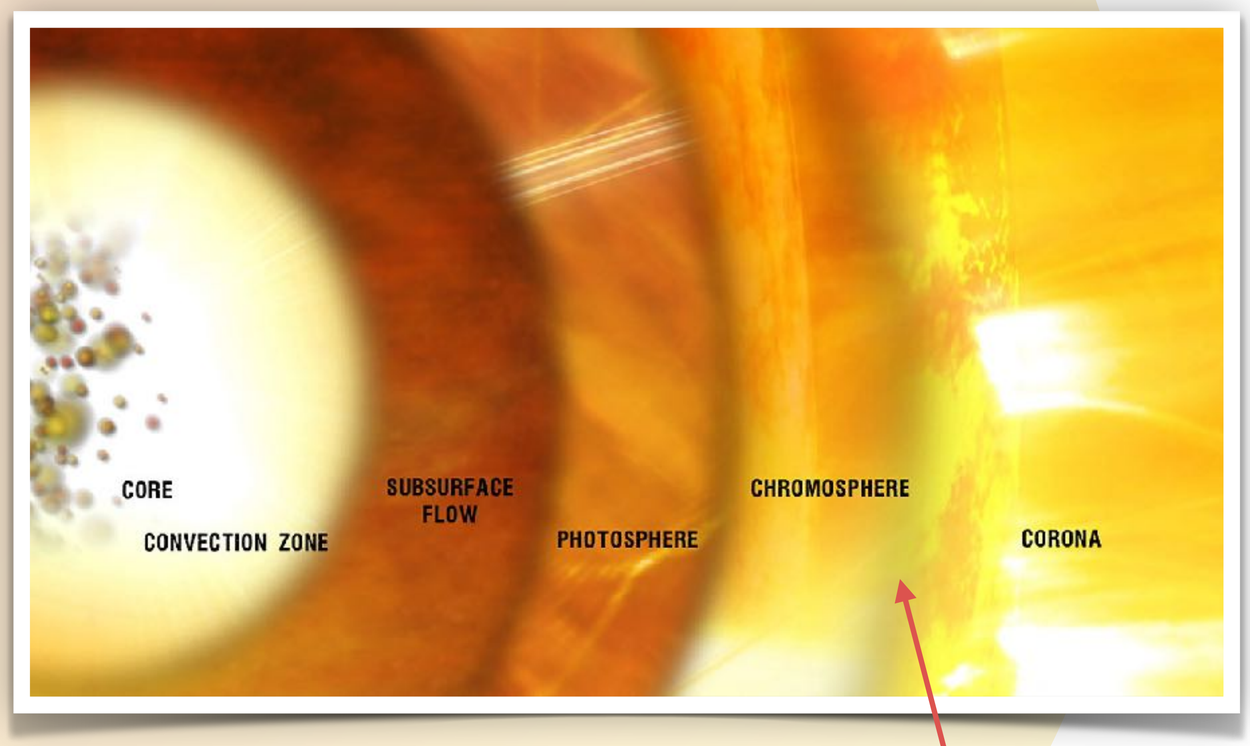
What happened? 2nd Interpretation

Fractionation occurred in the lower chromosphere



$$\nu_{ki} >> \nu_{kn}$$

$$f_k = \frac{\rho_k\left(z_u\right)}{\rho_k\left(z_l\right)}$$

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

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

f_k = Ratio of densities for element k at upper and lower fractionation regions

ν_{kn} = Collision frequency of neutral elements

ν_{ki} = Collision frequency of ions

ξ_k = element ionisation fraction

Laming, J. M., Vourlidas, A., Korendyke, C., Chua, D., Cranmer, S. R., Ko, Y.-K., ...Wood, B. E. (2019). Element Abundances: A New Diagnostic for the Solar Wind. Astrophys. J., 879(2), 124. doi: 10.3847/1538-4357/ab23f1

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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.

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