Plasma composition in solar active regions

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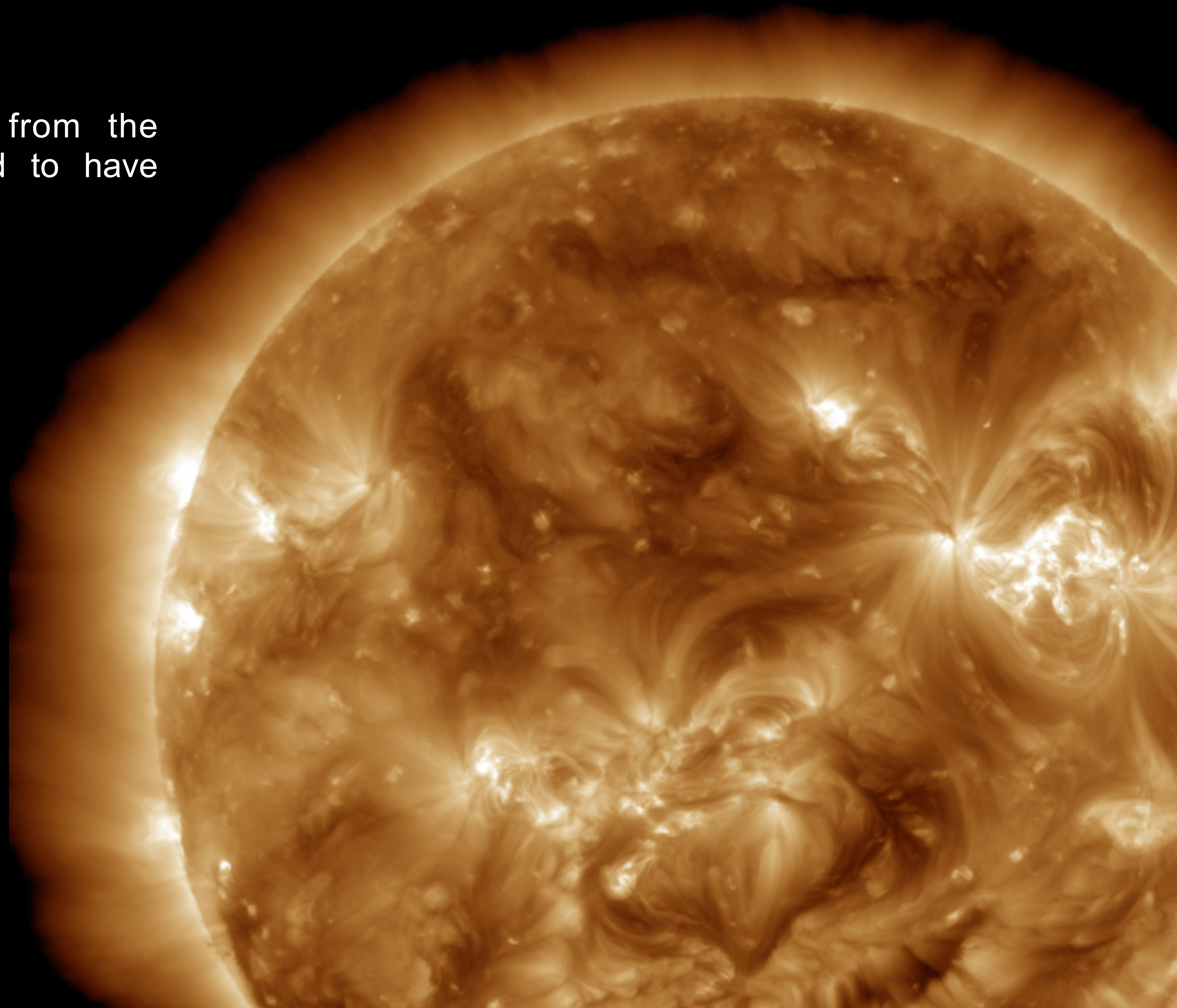
Abstract

The plasma in the solar corona originates from the photosphere and would, therefore, be expected to have similar elemental composition.

However, **elements with a low first ionisation potential (FIP) have been observed to have an increased abundance in certain regions of the corona** (Meyer, 1985a,b).

The increased elemental abundance is typically observed in active regions.

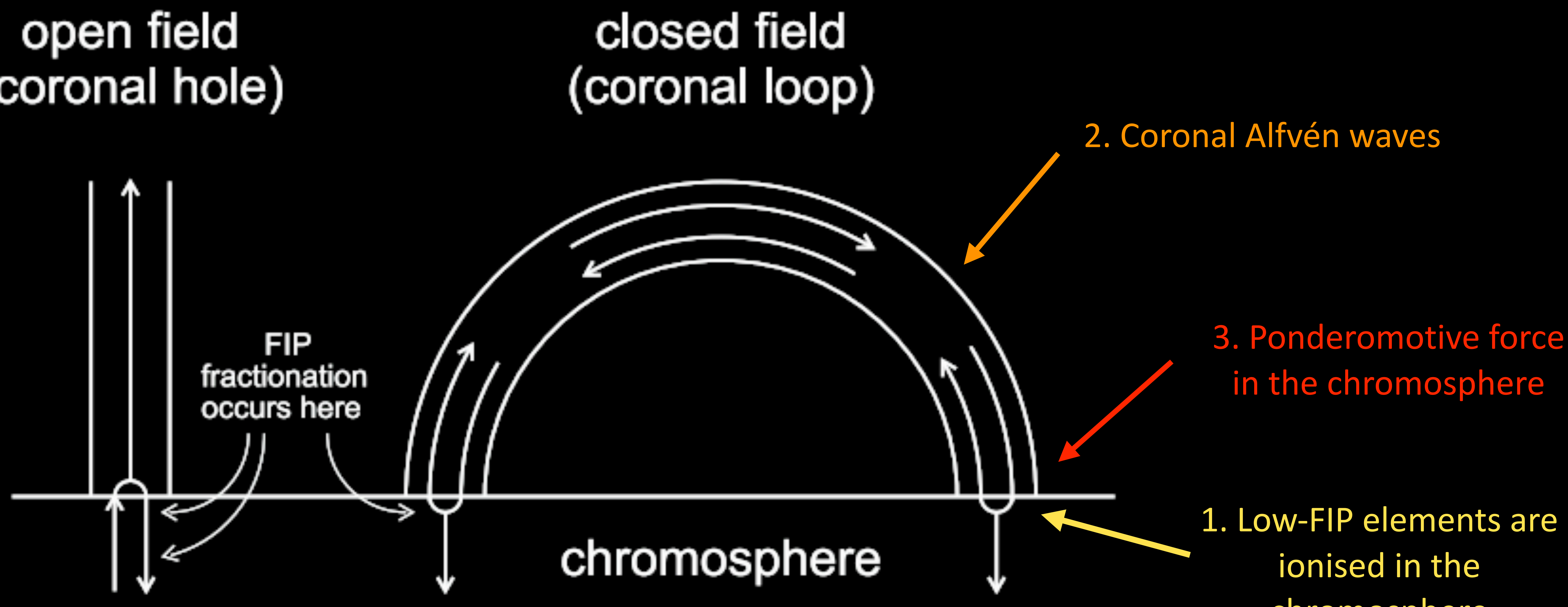
We analyze the first full Sun composition map (Brooks et al., Nat. Comms., 6, 5947, 2015) to statistically investigate how plasma composition is linked to active regions, their evolution and the photospheric magnetic field at the scale of an active region.



The fractionation process

In the chromosphere, low-FIP elements become ionized at the footpoints of magnetic field loops, while high-FIP elements remain neutral at chromospheric temperatures. The cutoff energy is at approximately 10eV, which corresponds to a temperature of approximately 120,000 K.

In the corona, nanoflares can give rise to Alfvén waves, which may resonate with the loop. When getting refracted and reflected in the high density gradient of the chromosphere, Alfvén waves generate an upward-pointing ponderomotive force. This force separates the ions from the neutrals and the ionized material is brought up into the corona (Laming, LRSP, 12:1, 2015).



Laming, ApJ, 879:124 (2019)

This is observed in the corona as an enhancement in the relative abundances of low-FIP elements. The degree of enhancement given by the FIP bias parameter:

$$\mathrm{FIP_{bias}} = \frac{\textbf{coronal elemental abundance}}{\textbf{photospheric elemental abundance}}$$

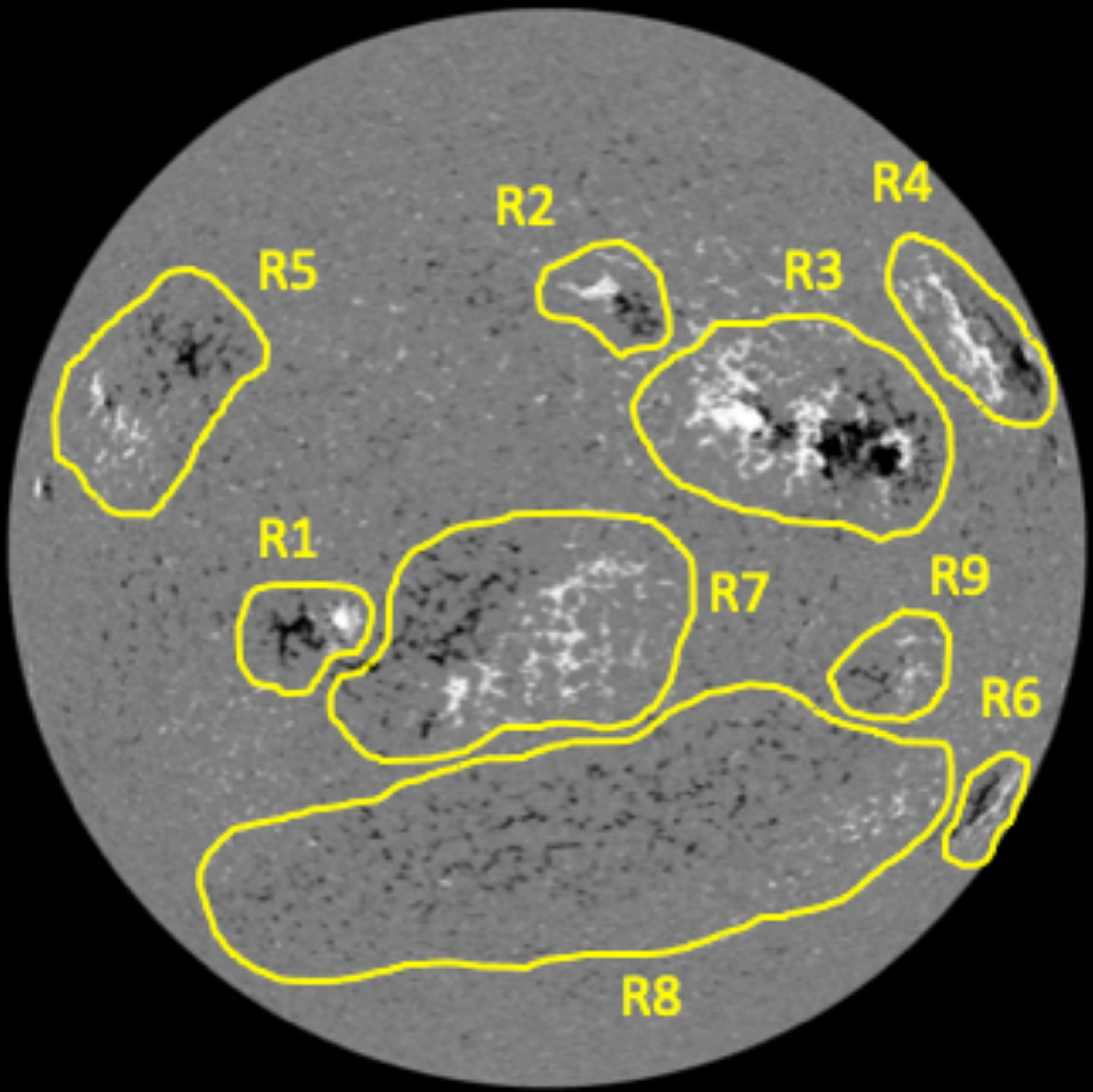
Typical FIP bias values are 2-4 in active regions, 1-2 in quiet Sun regions and 1 in coronal holes (i.e. no fractionation). High FIP bias values of up to 3-4 have been observed in the solar wind as well, providing a link to potential slow solar wind source regions.

Observations

The first full disk FIP bias map included 9 active regions, at different stages in their evolution. The composition analysis was performed using data taken by the Hinode Extreme-Ultraviolet Imaging Spectrometer (EIS).

The FIP bias measurement uses the ratio of Si X 258.37 Å (low FIP) and S X 264.23 Å (high FIP) emission lines. These are bright lines with very similar temperature dependencies and close emissivity values, observing plasma at log(T) ≈ 6.1 (quiescent, i.e. non flaring, active regions and the quiet Sun).

16 January 2013



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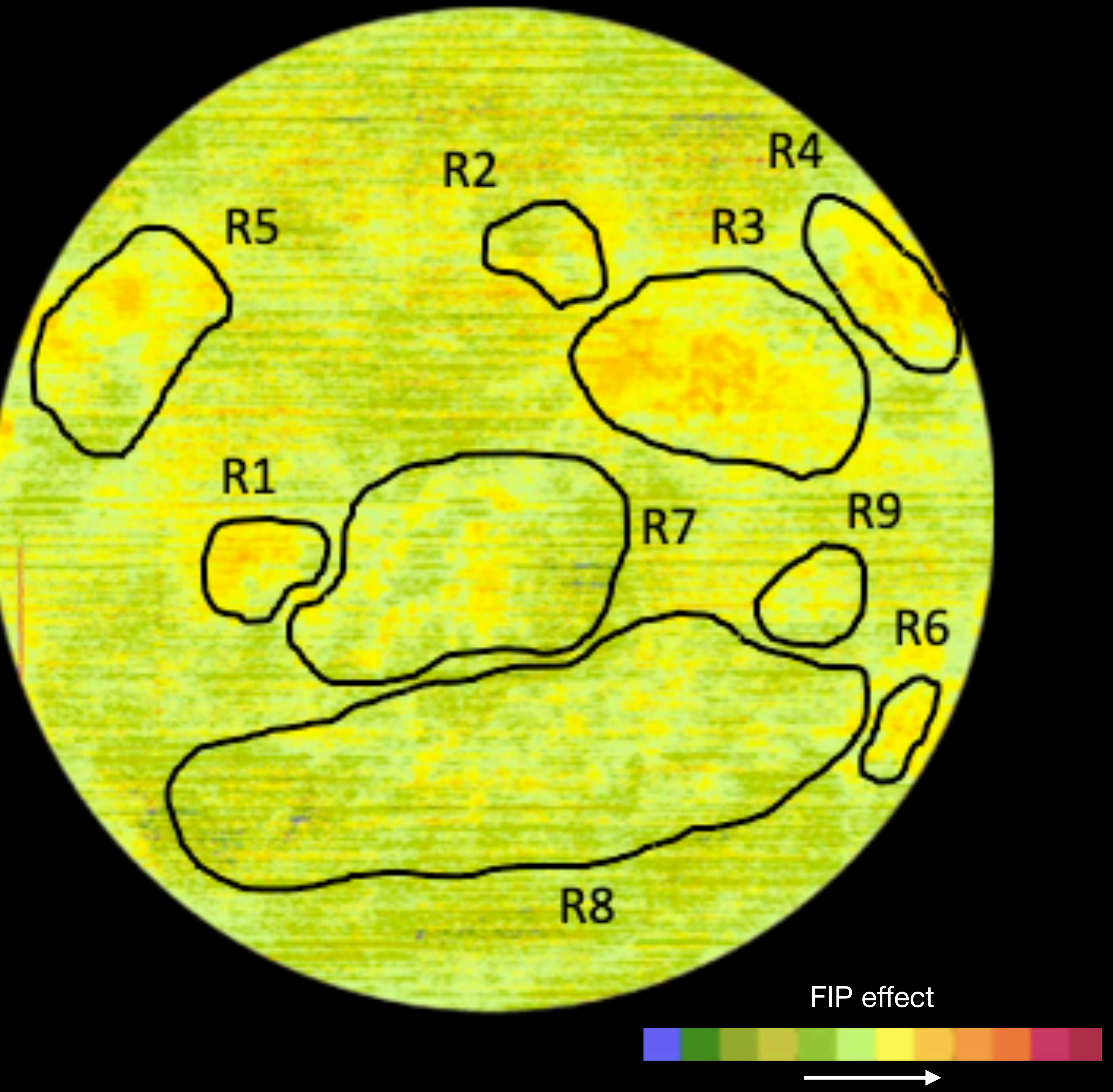


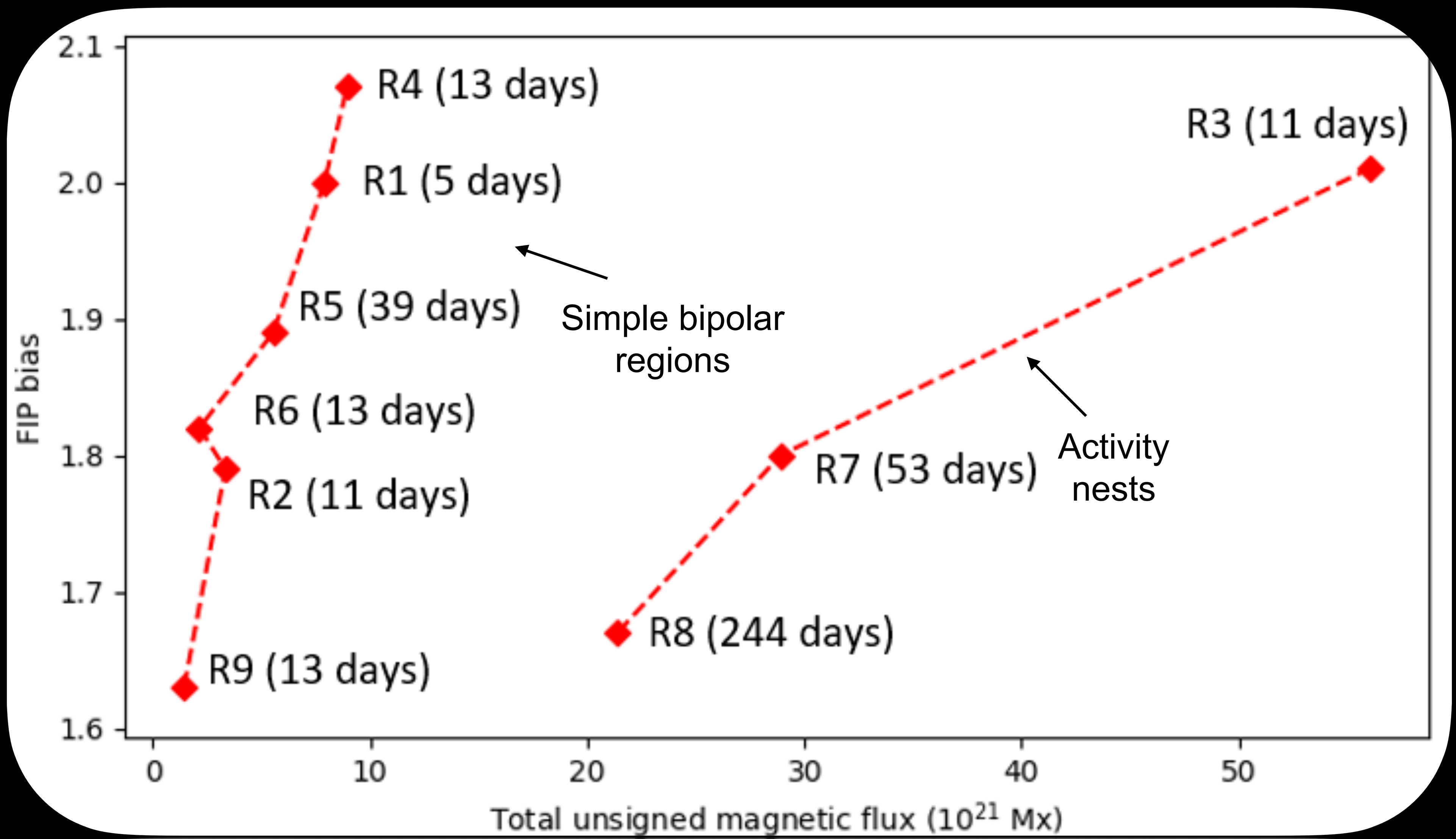
Brooks et al., Nat. Comms., 6, 5947 (2015)

Questions

- How does the age of the active region or stage in its evolution influence composition?
- How does strength, flux and configuration of the magnetic field influence composition?
- Do leading and following polarities of active regions have similar composition?

Preliminary conclusions

The average FIP bias in the selected regions was found to depend on three main factors:



1. Age and total magnetic flux

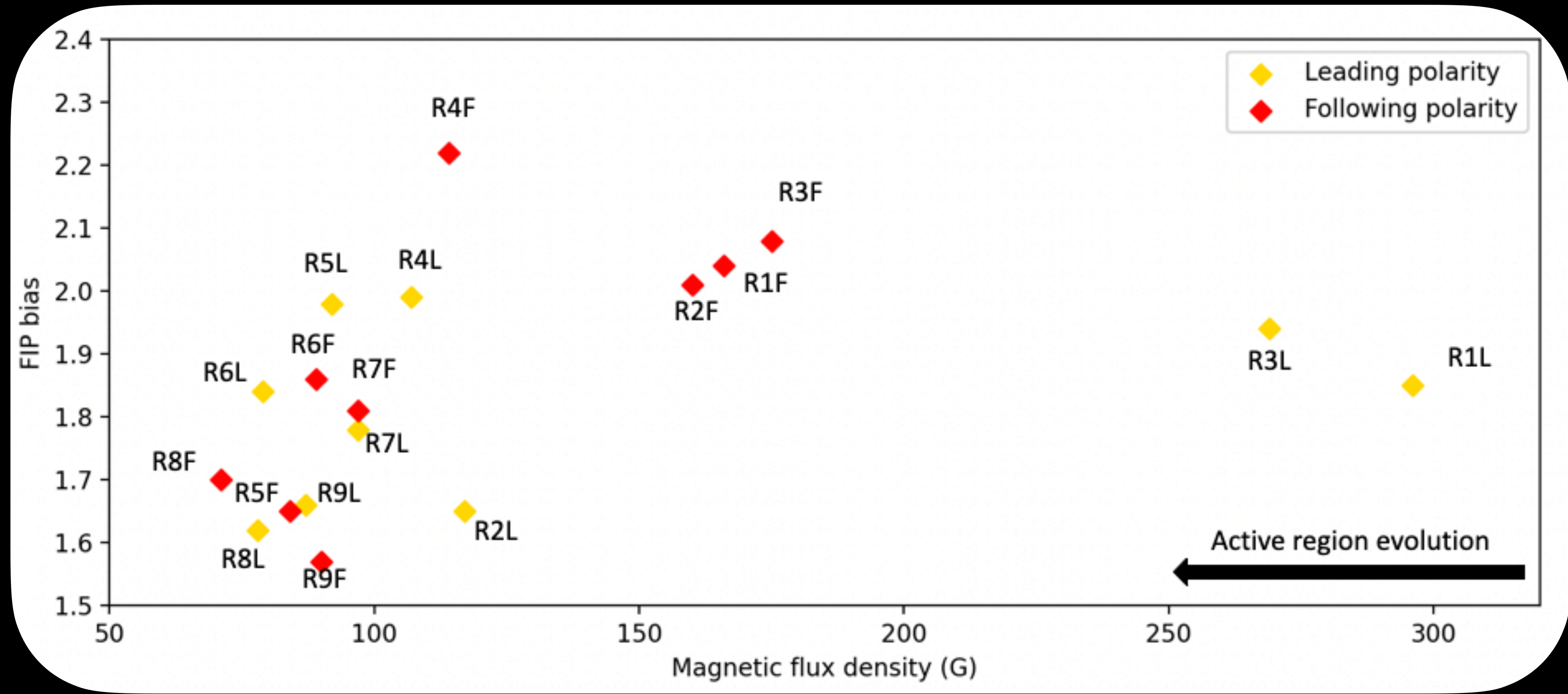
Magnetic flux varies as active regions age and FIP bias is proportional to total magnetic flux:

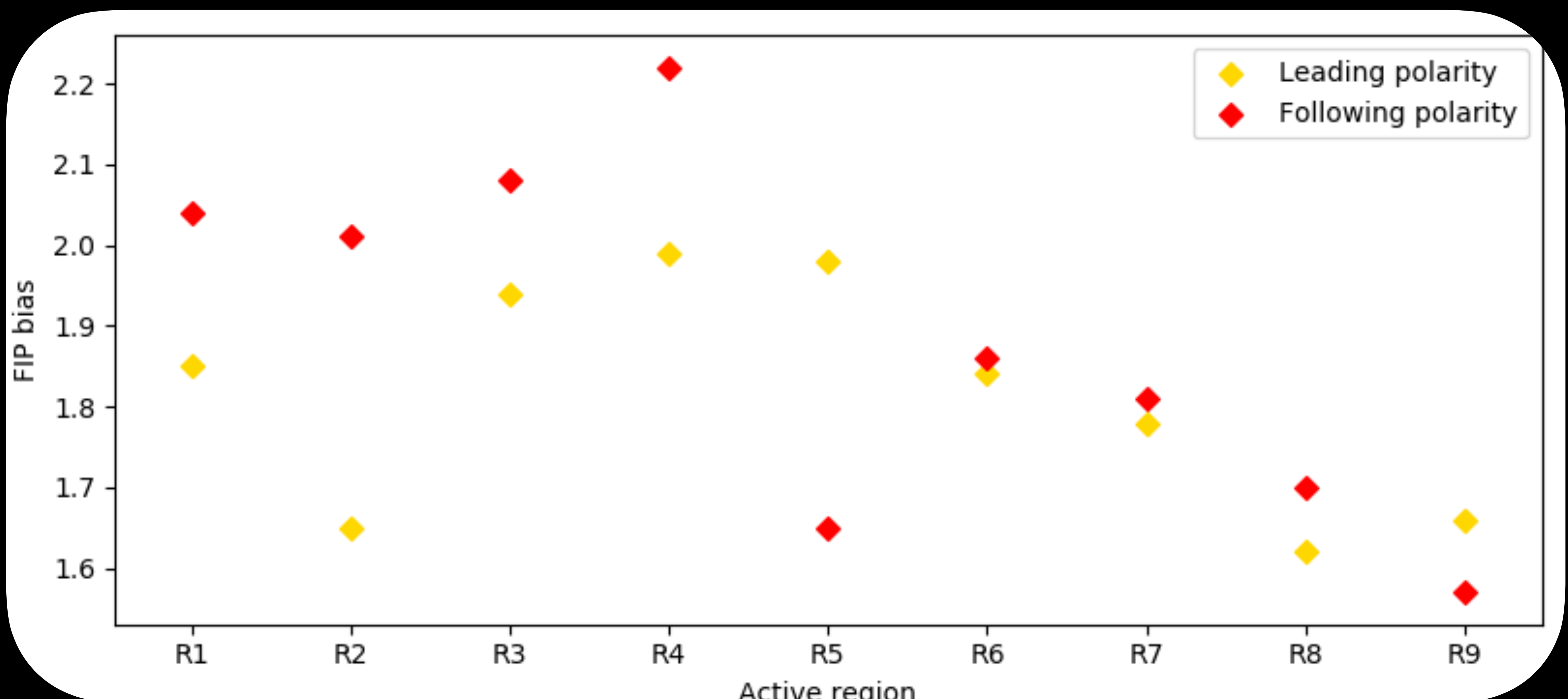
- In bipolar regions, the fractionation process is driven by the internal nanoflare-type reconnection within the evolving (emerging and then dispersing) magnetic flux.
- In an activity nest, magnetic flux is added several times via new flux emergence during the evolution. The higher heating rate associated with the emerging flux leads to an increased fractionation process raising the FIP bias for a few days, thus the FIP bias decreases slower with age than in simple bipoles.

2. Magnetic flux density

Below 200G, FIP bias increases with averaged magnetic flux density. Higher flux density drives a more vigorous heating and fractionation process, thus increasing FIP bias.

Above 200G, FIP bias decreases with averaged magnetic flux density. The high magnetic field concentration inhibits convection, causing the temperature, and consequently the ionized fraction of low-FIP elements at chromospheric height, to decrease, leading to lower observed FIP bias.





3. Leading and following polarities

Leading polarities have lower FIP bias values than following polarities:

- Following polarities become dispersed quicker than the leading polarity and, therefore, the fractionation process is driven continuously.
- Leading polarities are more coherent and above the sunspot umbra the magnetic field is more concentrated. The decreased temperature at chromospheric height leads to fewer atoms being ionized and, therefore, lower FIP bias.