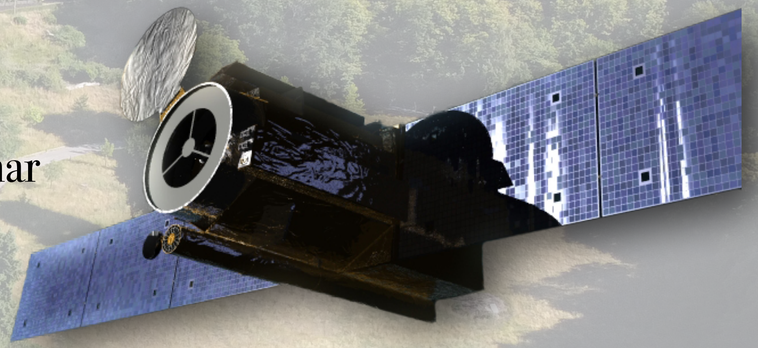
Mullard Space Science Laboratory
University College London
United Kingdom

Plasma composition in solar active regions

Astronomical Institute of the Romanian Academy Seminar

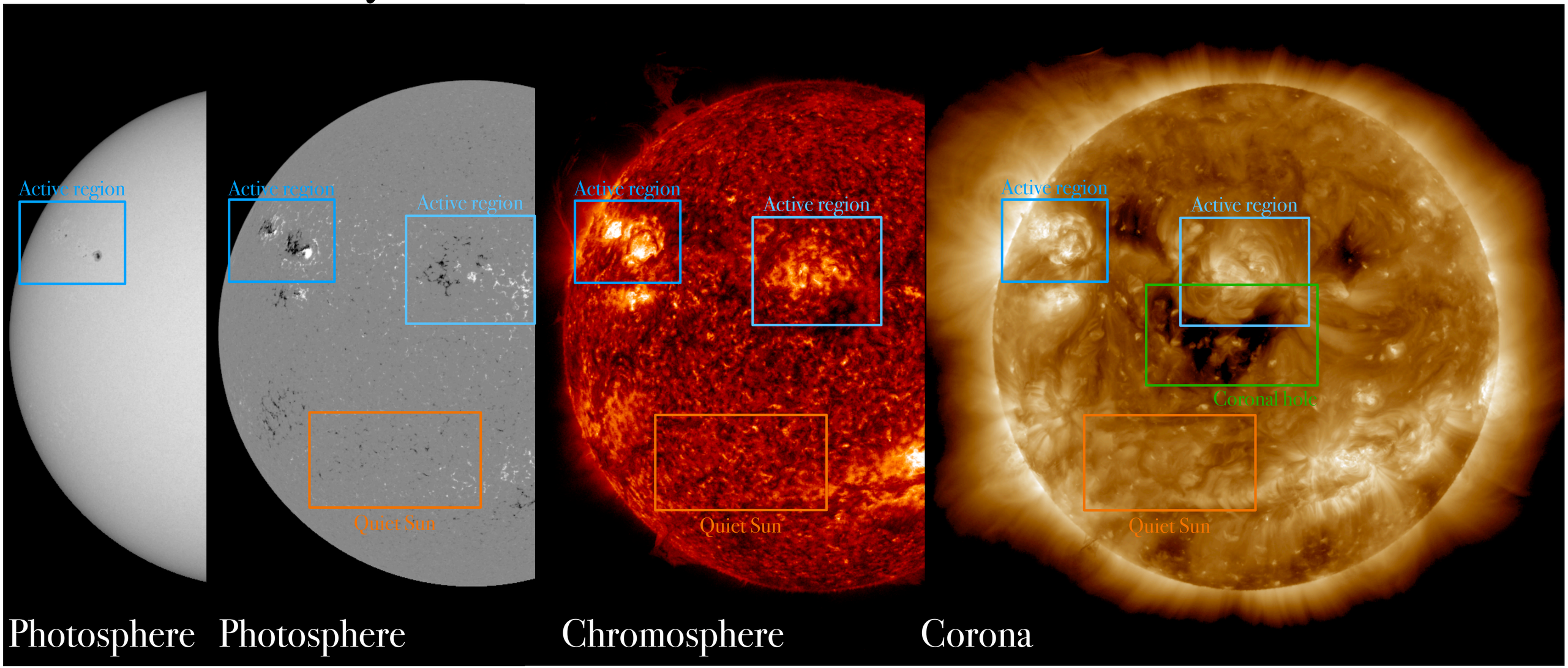


Teodora (Teia) Mihăilescu

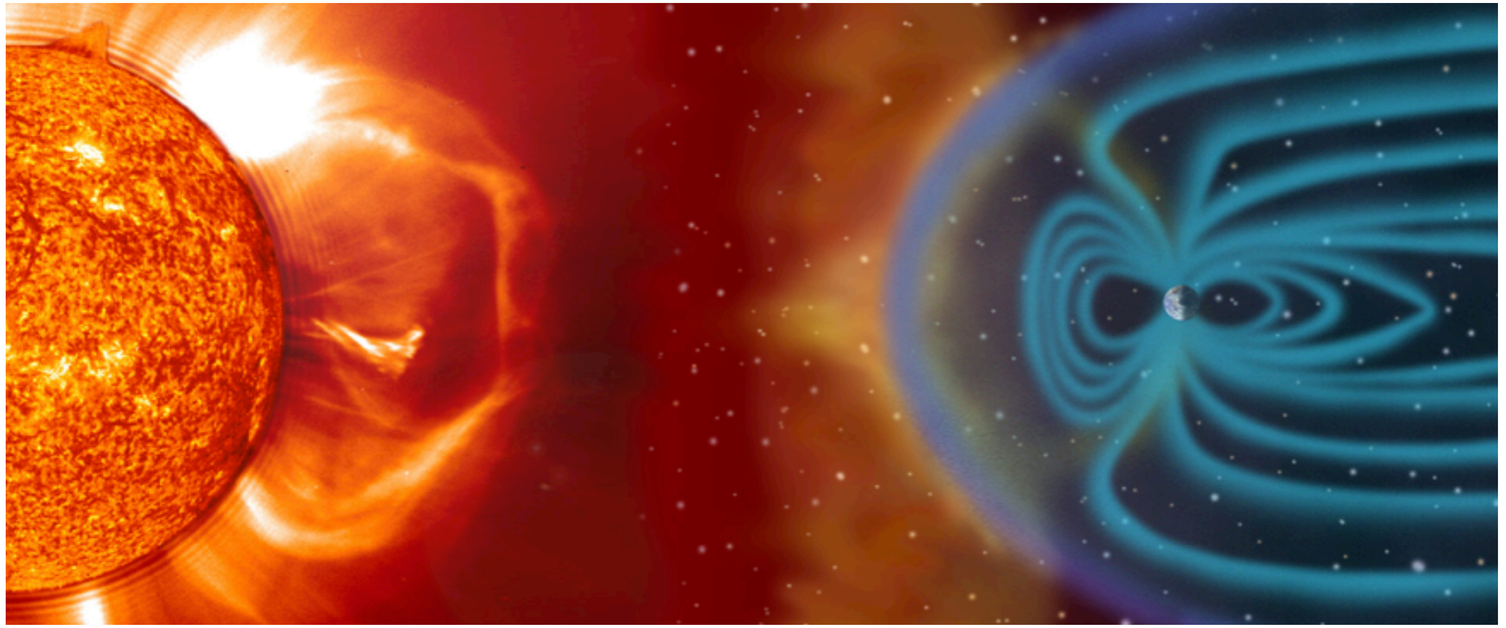
Lucie Green, Deborah Baker, Lidia van Driel-Gesztelyi, David Long, David Brooks, Andy To

2nd November 2022

The Sun's layers



Solar plasma composition



Composition by Particle Number		
Hydrogen 91.2%	Helium 8.7%	Metals 0.1%

Composition by Mass		
Hydrogen 71.0%	Helium 27.1%	Metals 1.9%

Approx 6,000 Earth masses

Composition of the photosphere	Composition of the chromosphere	Composition of the corona	Composition of the solar wind/coronal mass ejections
Helioseismology	???	EUV spectroscopy	In situ particle measurements
constant	???	variable	variable

The plasma in the corona and the solar wind originates from the photosphere.

So, why is the composition different?

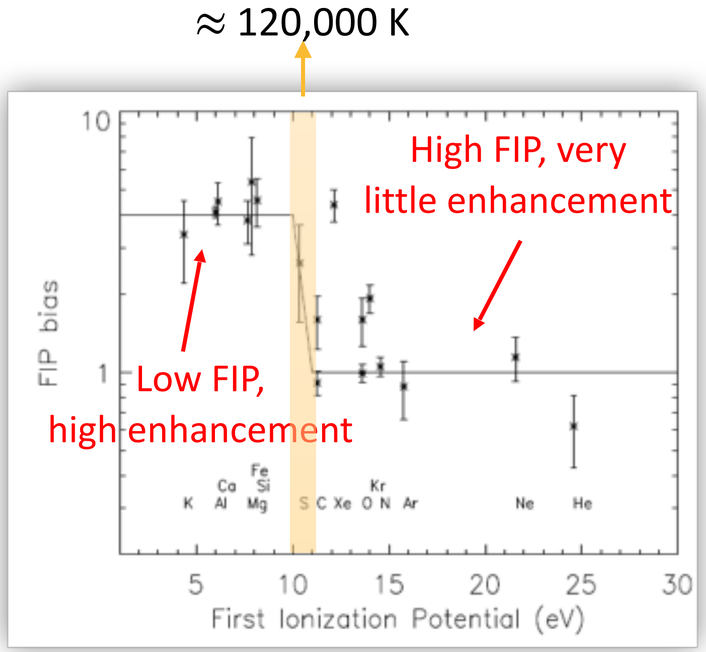
The FIP effect

- Variation of coronal composition is linked to the first ionization potential (FIP) and not other paramenters
- Elements with a low FIP show variable relative abundances in the corona
- Low-FIP elements become enhanced in the corona, while high-FIP elements retain their photospheric abundances
- The degree of enhancement is quantified using the FIP bias parameter:

$$\text{FIP}_{\text{bias}} = \frac{\text{relative coronal abundance}}{\text{relative photospheric abundance}}$$

= 1, i.e. photospheric composition

> 1, i.e. coronal composition



Geiss et al. (1989)

Where do we observe this?

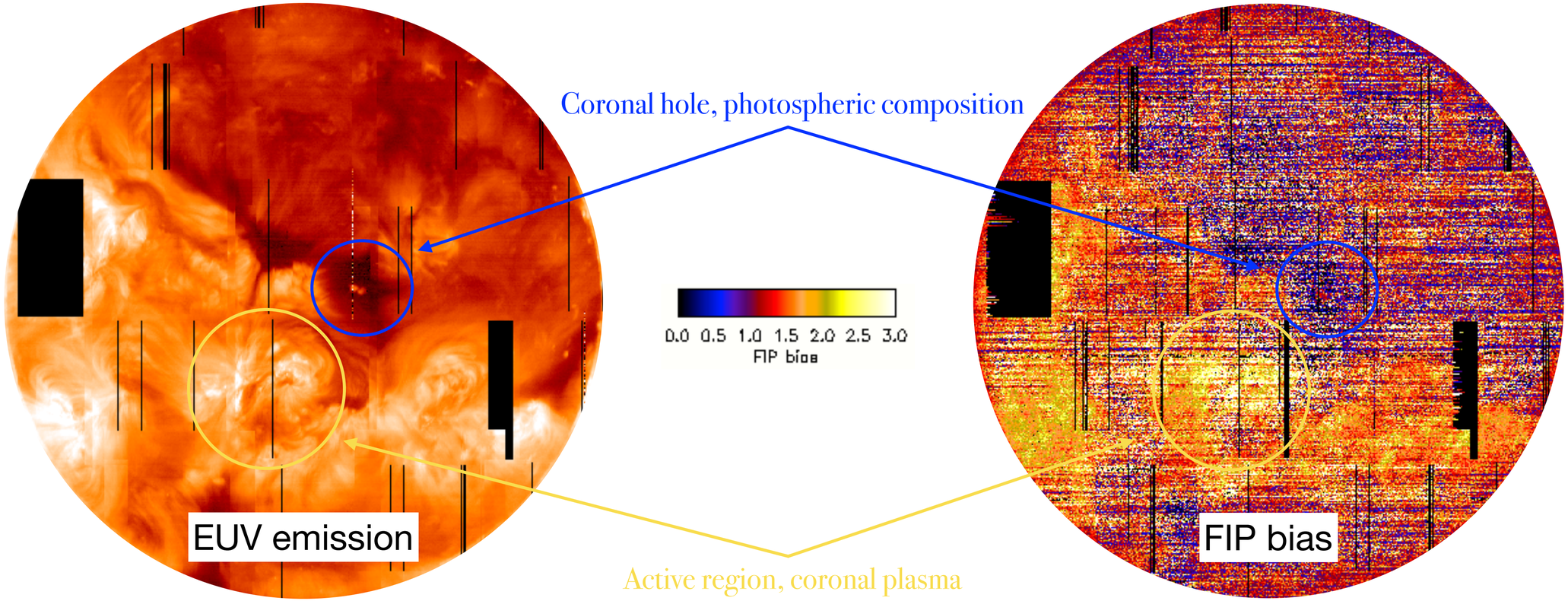
The FIP effect on the Sun

$$\text{FIP}_{\text{bias}} = \frac{\text{relative coronal abundance}}{\text{relative photospheric abundance}}$$

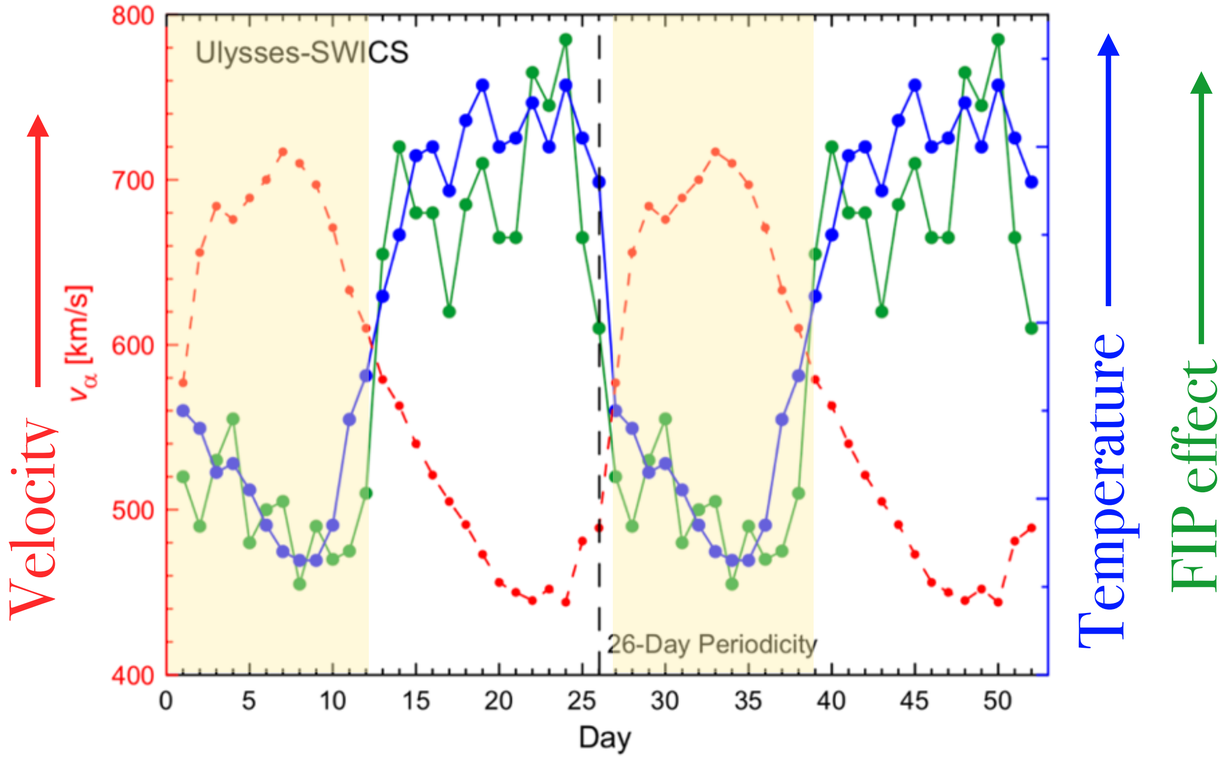
$= 1$, i.e. photospheric composition

> 1, i.e. coronal composition

Region	Typical FIP bias
Coronal holes	1
Quiet Sun	1.5-2
Active regions	2-4



The FIP effect in the solar wind

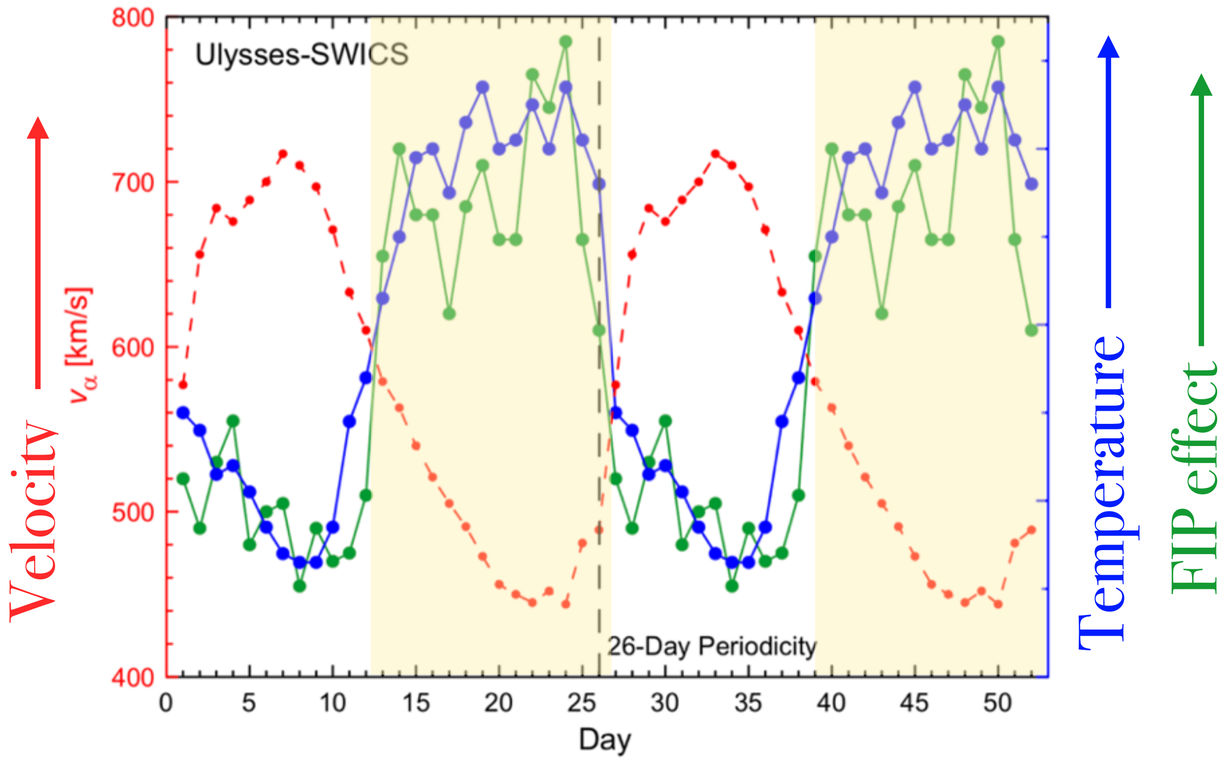


Geiss, Gloeckler & von Steiger (1995)

Fast solar wind

- Origin: coronal holes
- Low FIP effect (composition similar to the photsphere)

The FIP effect in the solar wind

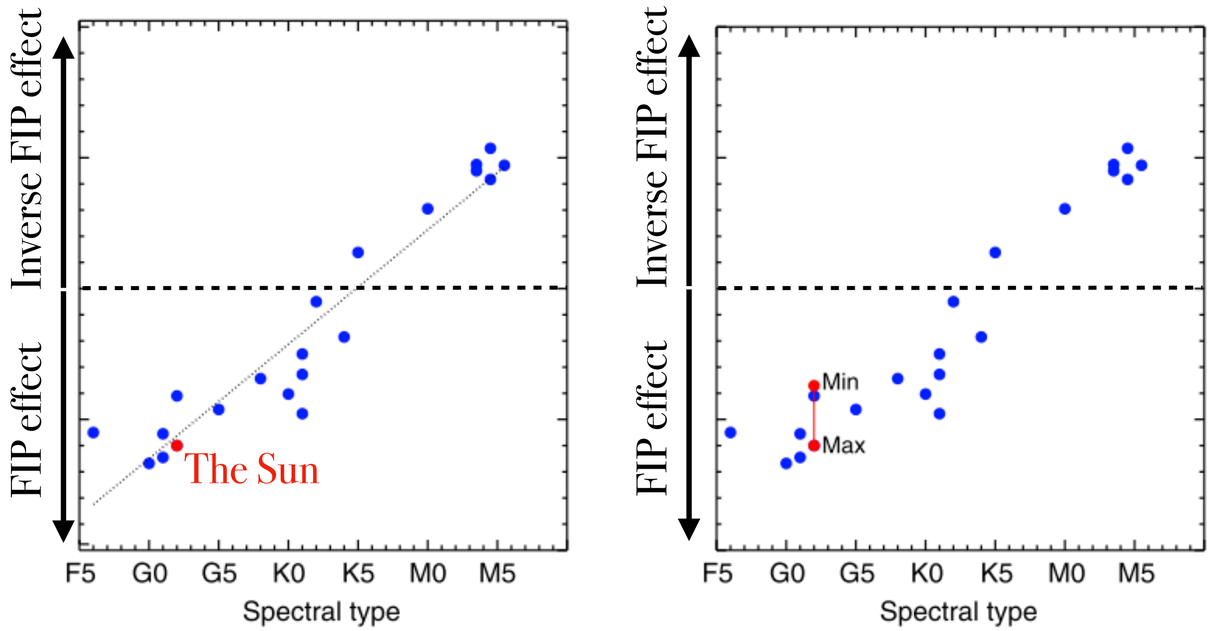


Geiss, Gloeckler & von Steiger (1995)

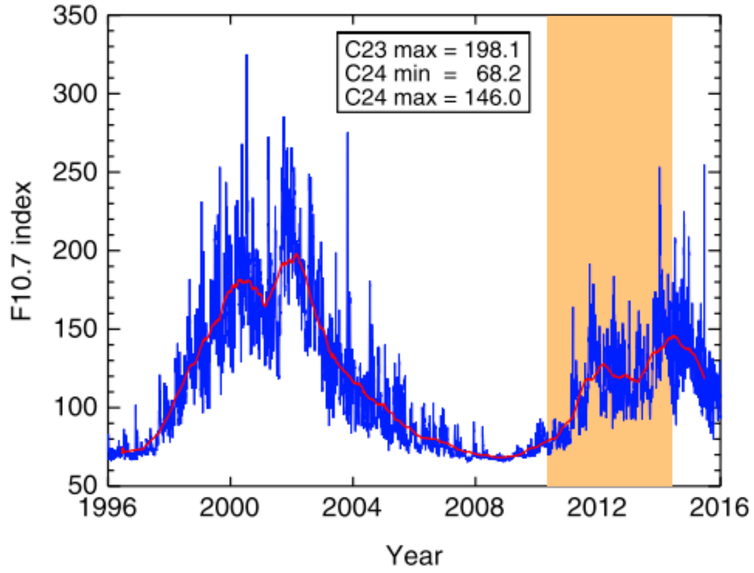
Fast solar wind
- Origin: coronal holes
- Low FIP effect (composition similar to the photsphere)

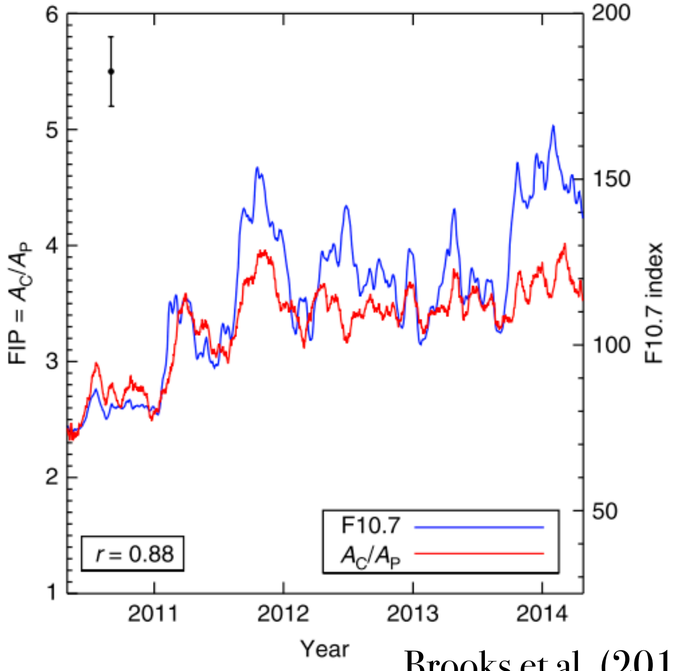
Slow solar wind
- Origin: unknown
- High FIP effect (composition very different from the photosphere)

The FIP effect for the Sun as a Star



Brooks et al. (2017)



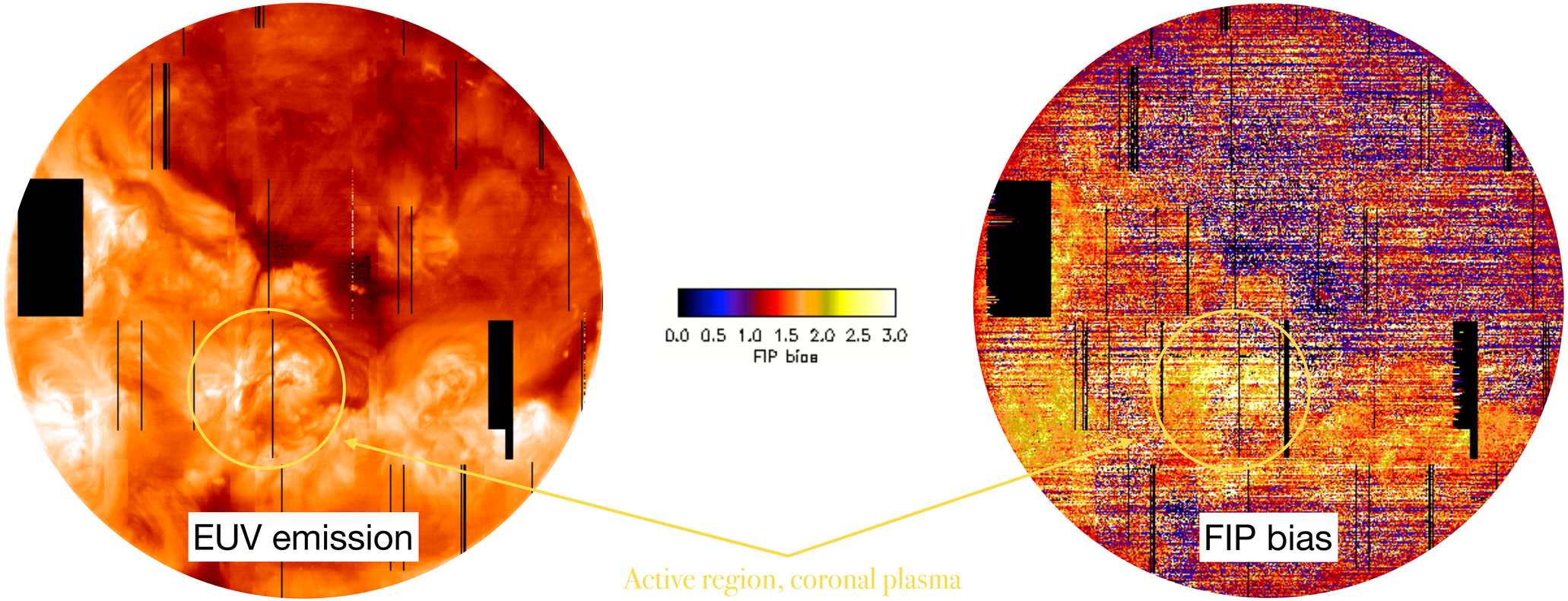


Brooks et al. (2017)

- The FIP effect varies with stellar type
  - The FIP effect varies with solar cycle

Active region plasma composition

- In active regions, FIP bias > 1, i.e. composition is very different from the photosphere



Strongest FIP effect in active regions - but is it the same in all active regions?

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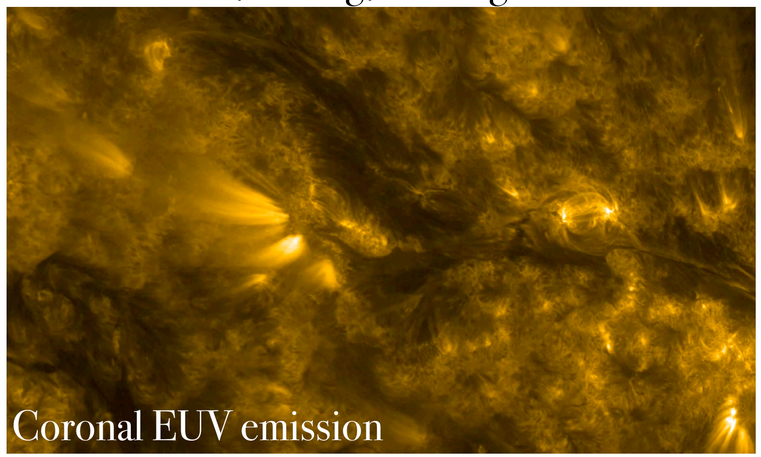
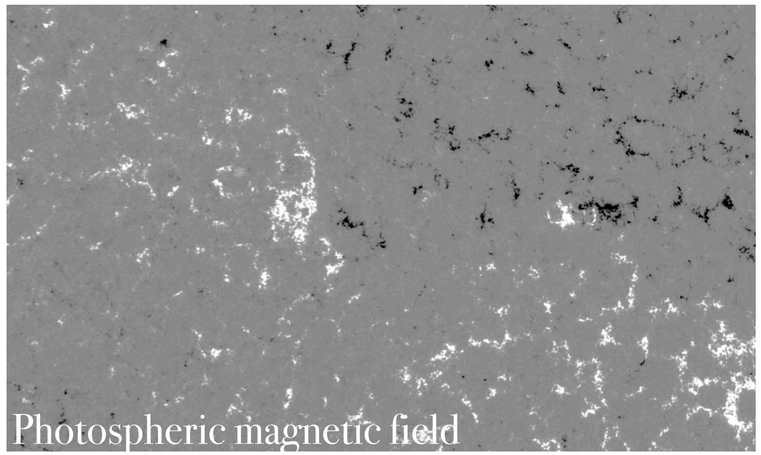
@teiamih

Composition variation in active regions

Emergence phase

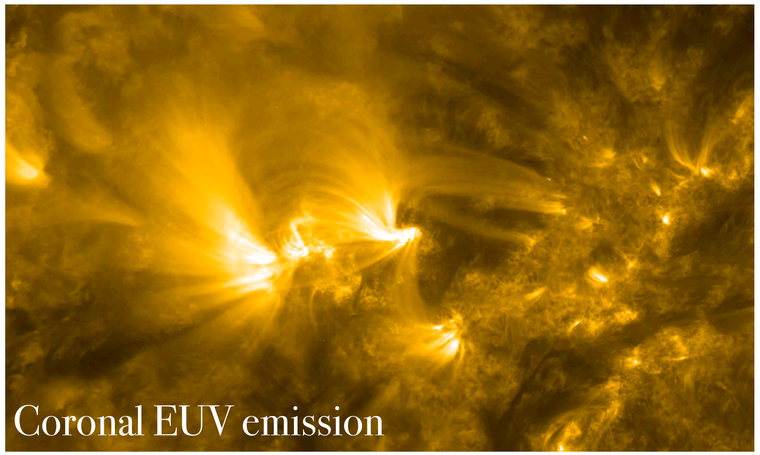
- reconnection, heating, reconfiguration of the field
-

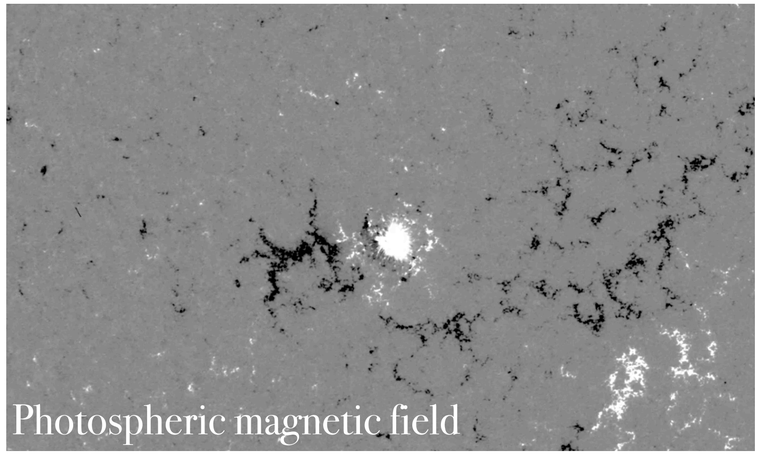




Decay phase

- Field dispersal, less heating, small bipole emergence, reconnection
-

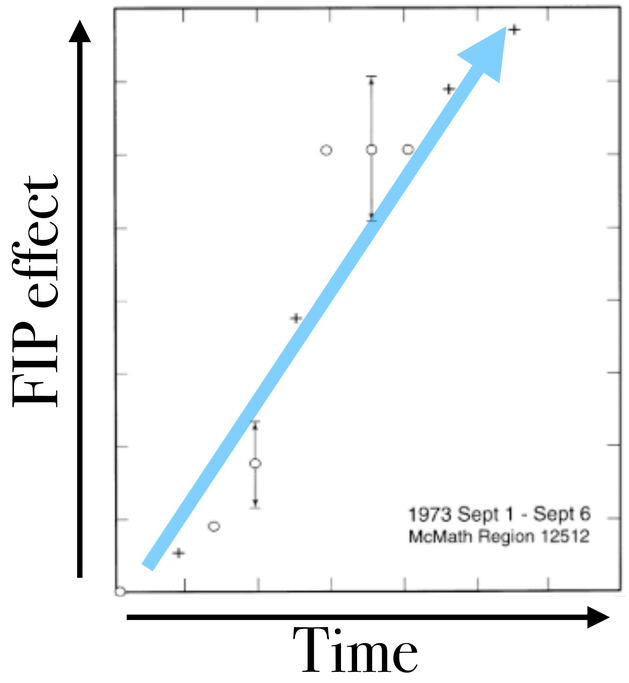




Composition variation in active regions

Emergence phase

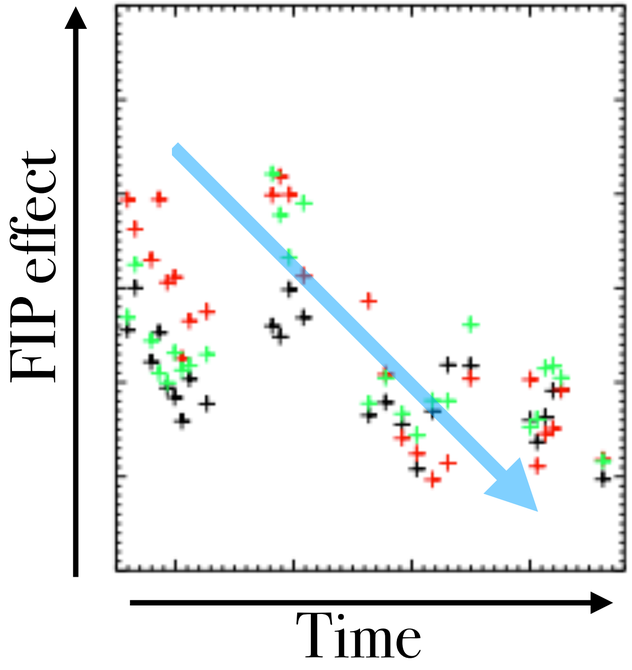
- reconnection, heating, reconfiguration of the field
- FIP bias increases (Widing and Feldman, 2001)



Widing and Feldman (2001)

Decay phase

- Field dispersal, less heating, small bipole emergence, reconnection
- FIP bias decreases (Baker et al., 2015)

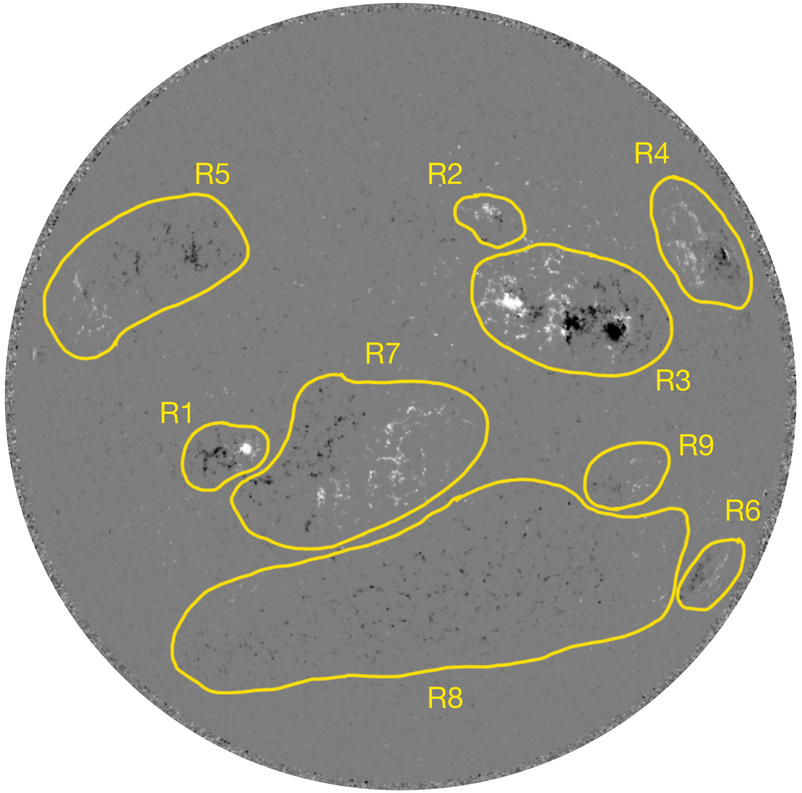


Ko et al. (2016)

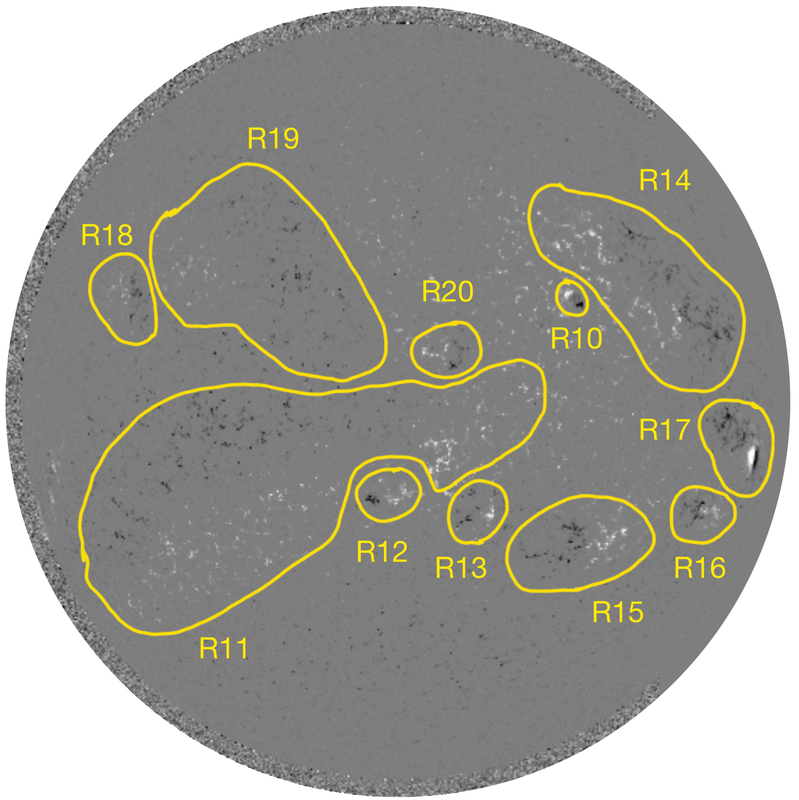
Active region survey

Can we see any links between composition and general active region characteristics?

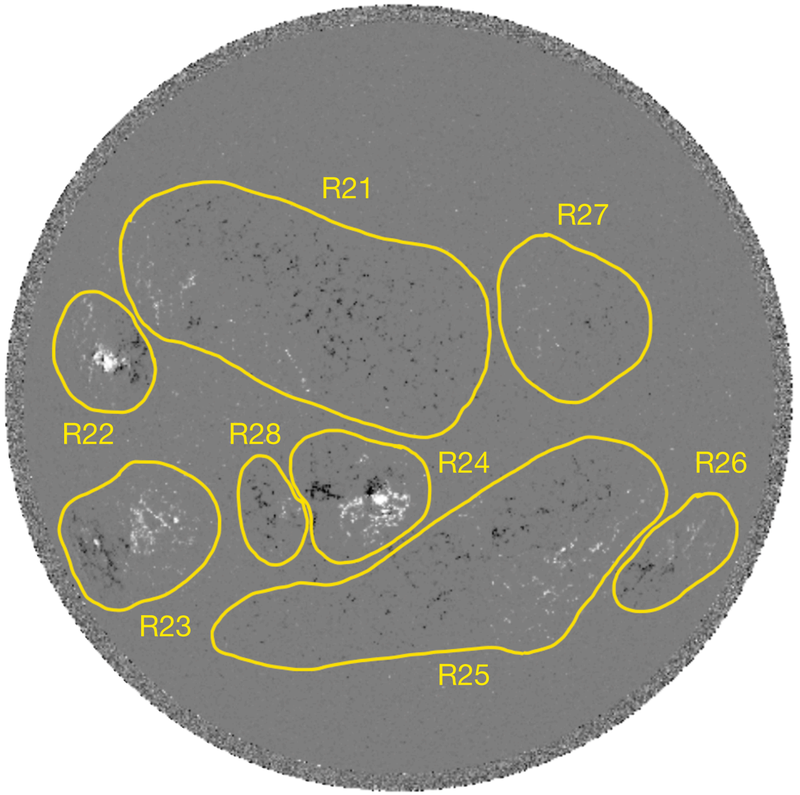
- 3 EIS full Sun composition scans
- 28 active regions
- Ages 0.5 to 189 days
- Magnetic flux: (100 – 3,640) × 10^{19} Mx (small and large ARs)



Scan 1



Scan 2



Scan 3

Results

1. Correlation to size and age?

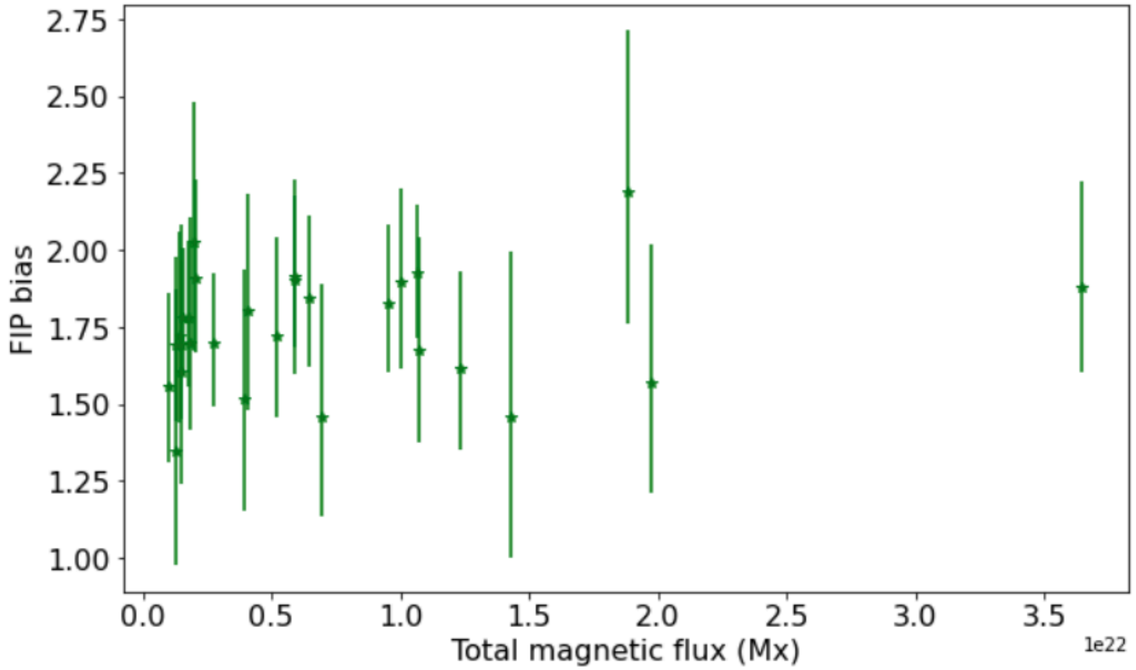
Magnetic flux range: $(100 - 3{,}640) \times 10^{19}$ Mx
FIP bias range: 1.4– 2.2

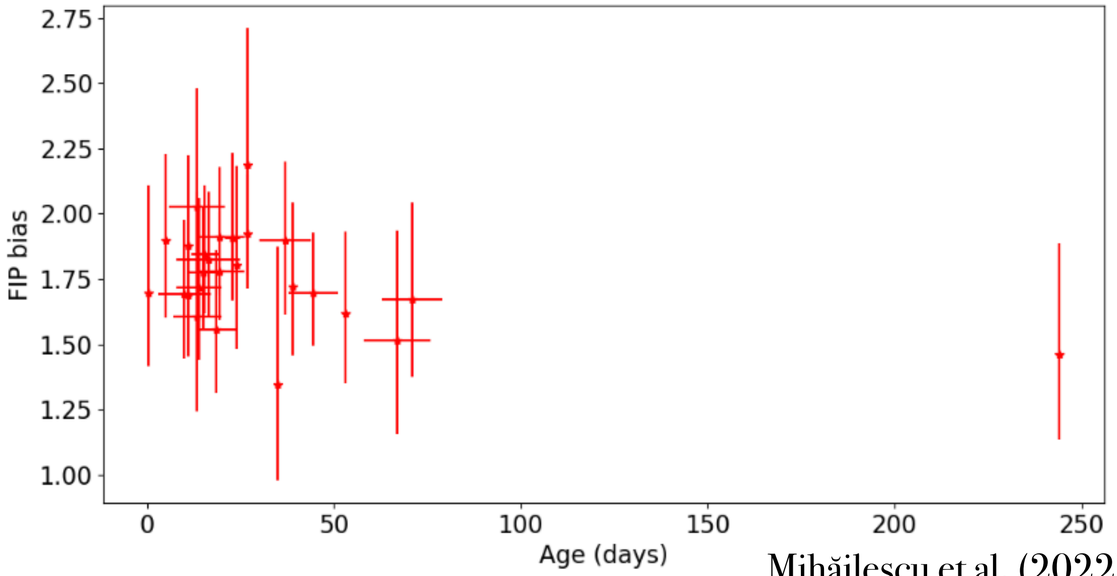
Magnetic flux range: $(1.3 - 380) \times 10^{19}$ Mx
FIP bias range: 1.2 - 2.0

Baker et al. (2018)

FIP bias is not dependent on the magnetic flux content of the active region.

FIP bias does not follow a simple trend with age.

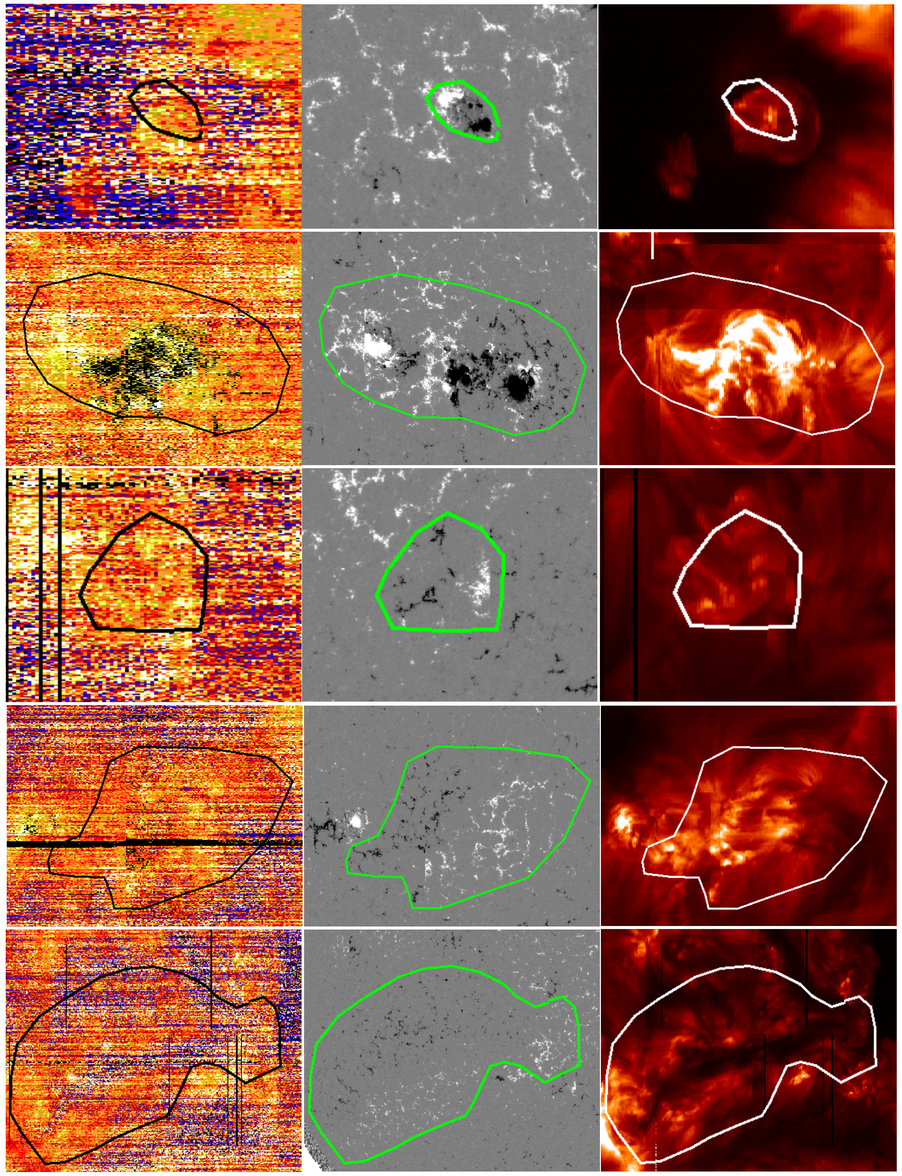




Mihăilescu et al. (2022)

2. Correlation to evolutionary stage?

Active region evolution



Emerging active region
(median FIP bias = 1.7)

→ Relatively low FIP bias

Active regions with spots
(median FIP bias = 1.9 - 2.2)

→ Highest median FIP bias

Decayed active regions
(median FIP bias range = 1.6 - 2.0)

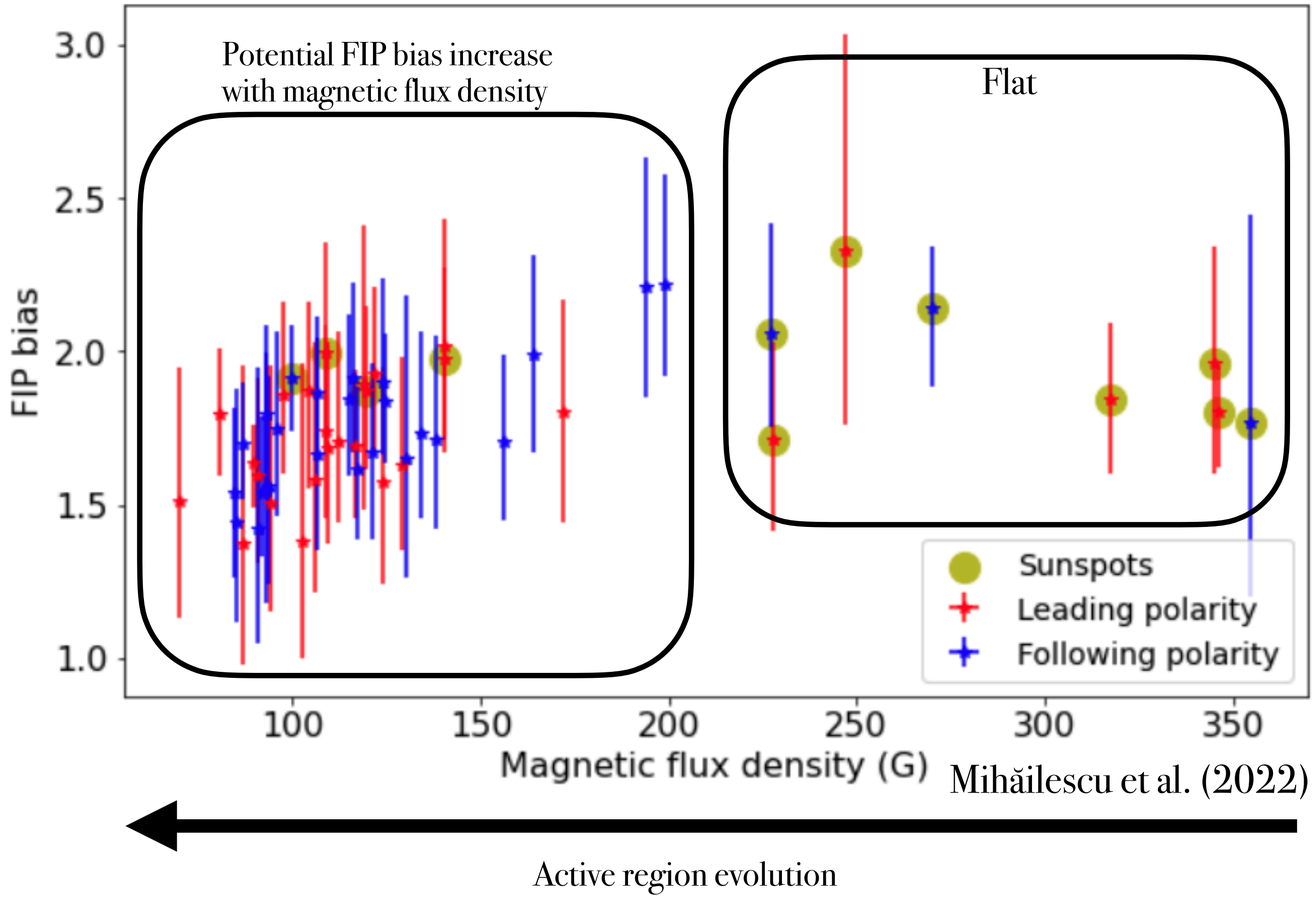
Extended, very dispersed active regions
(median FIP bias range = 1.4 - 1.8)

Active regions with filament channel
(median FIP bias range = 1.5 - 1.6)

→ Progressively lower median FIP bias

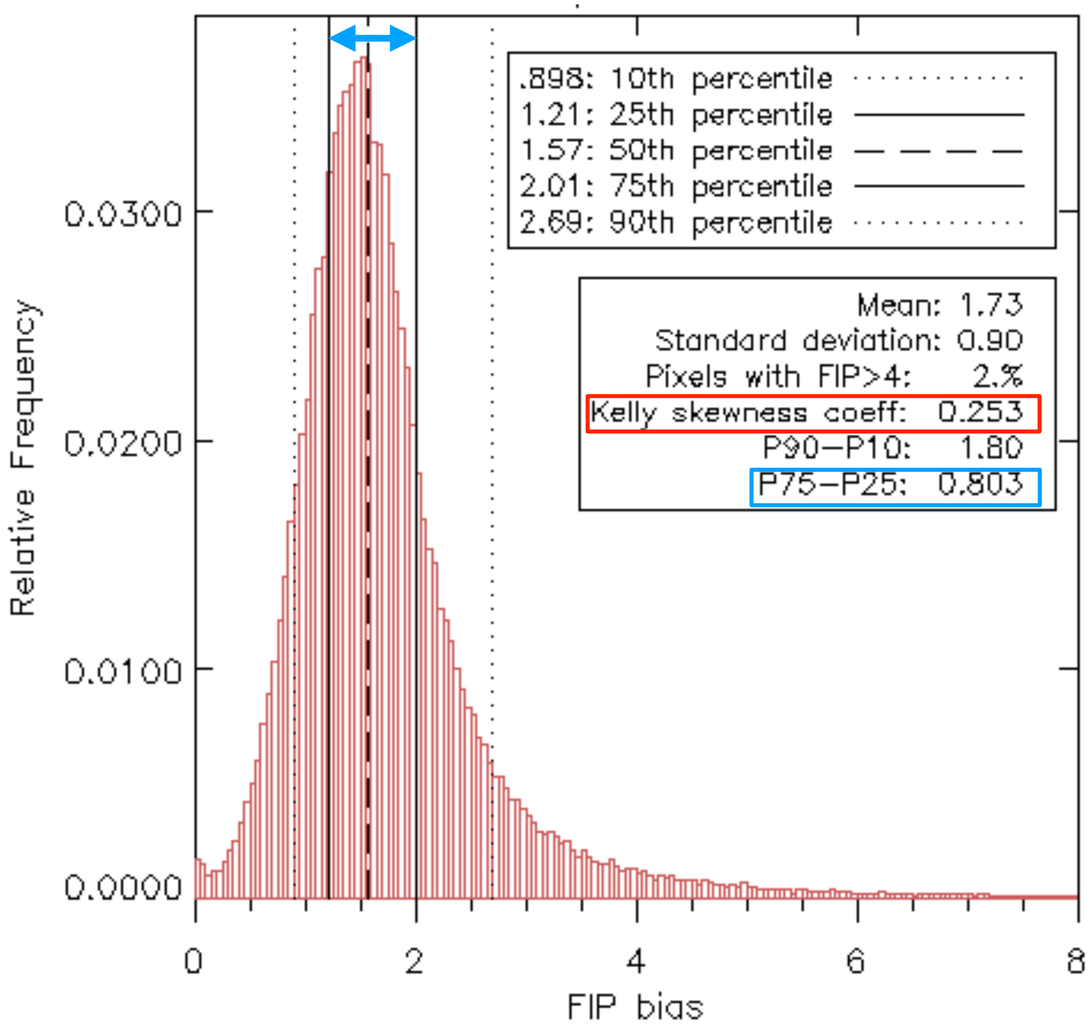
Mihăilescu et al. (2022)

2. Correlation to evolutionary stage?



Mihăilescu et al. (2022)

3. FIP bias distribution



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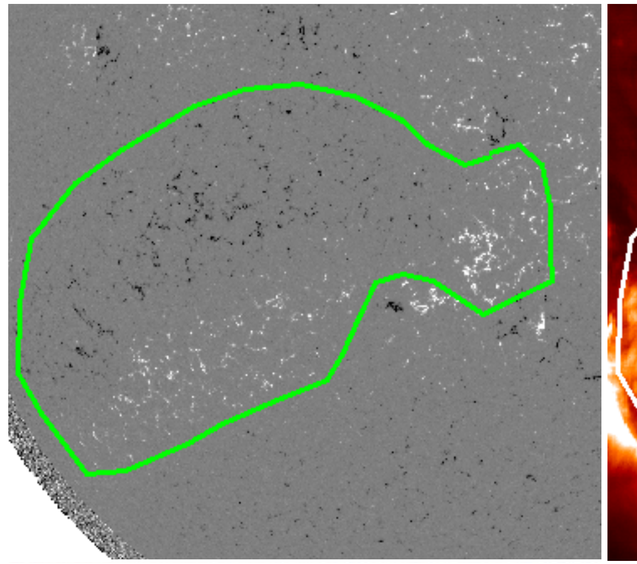
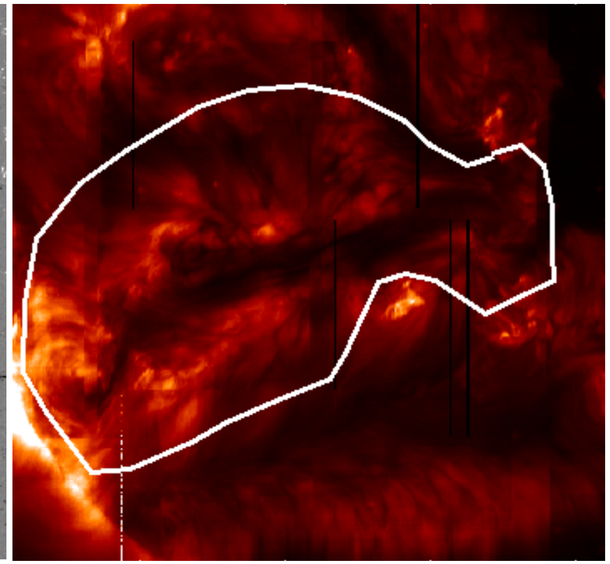
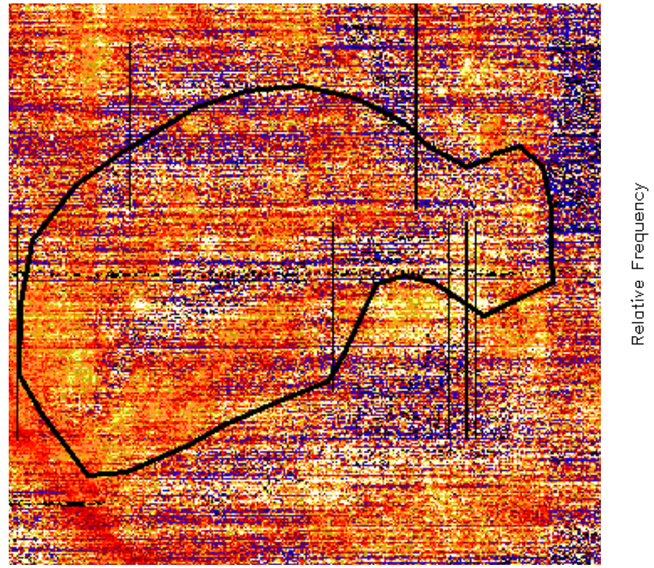
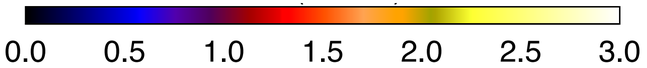
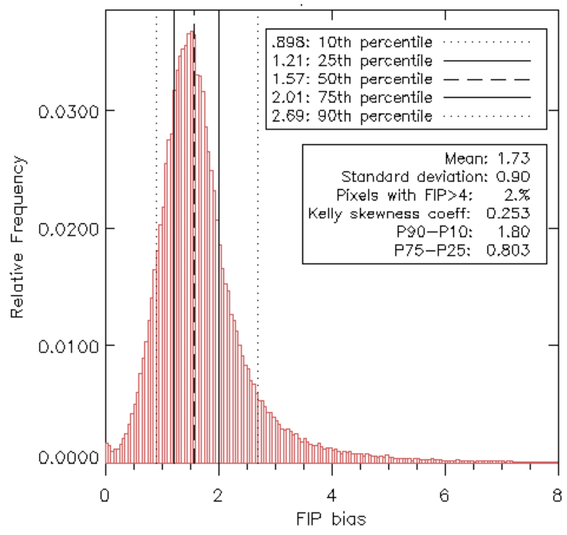










Mihăilescu et al. (2022)

Conclusions

- FIP bias is not correlated with total magnetic flux (size) or age of the active region
- FIP bias correlated with active region evolutionary stage
  - Supported by potential trend with magnetic flux density
- FIP bias has a significant spread → range of structures within an active region

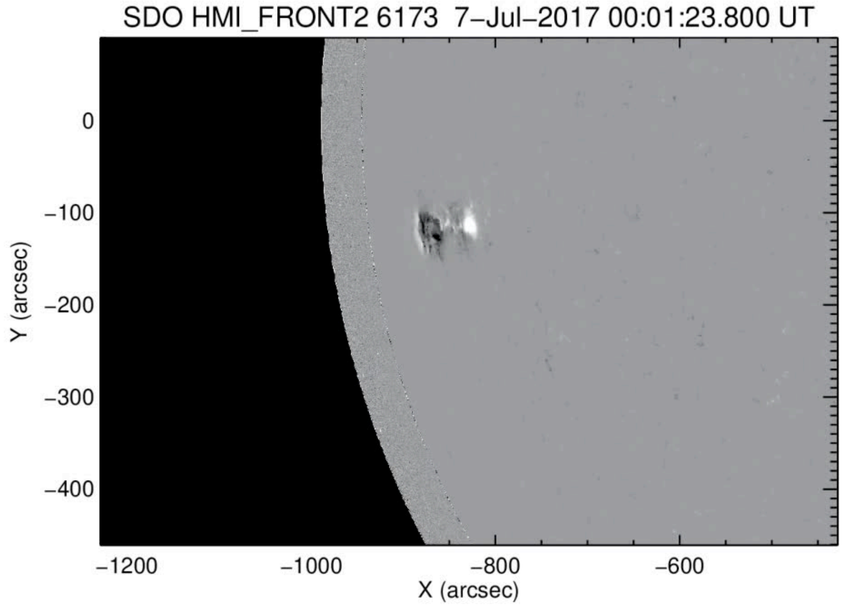
Mihailescu et al. (2022)

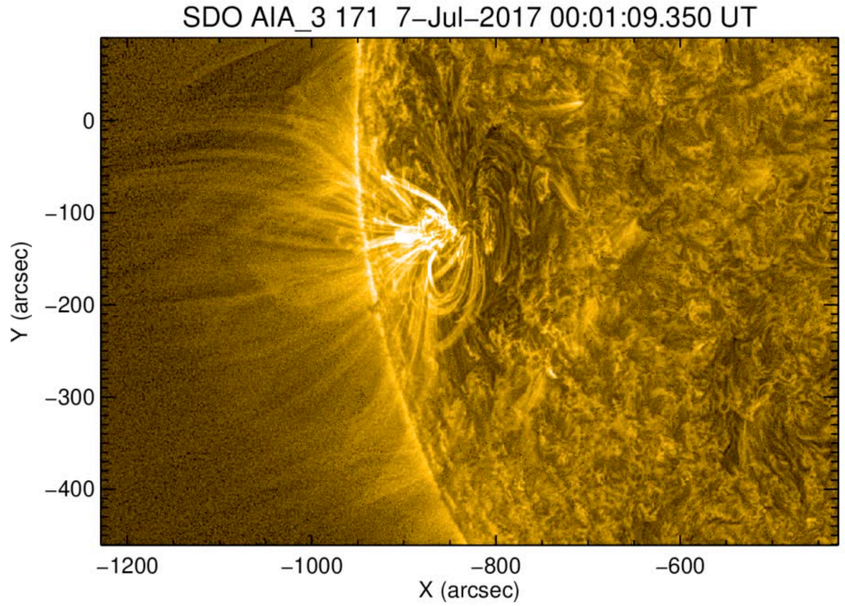
What's next?

- Composition evolution in the emergence phase
- Look at substructures within the active region

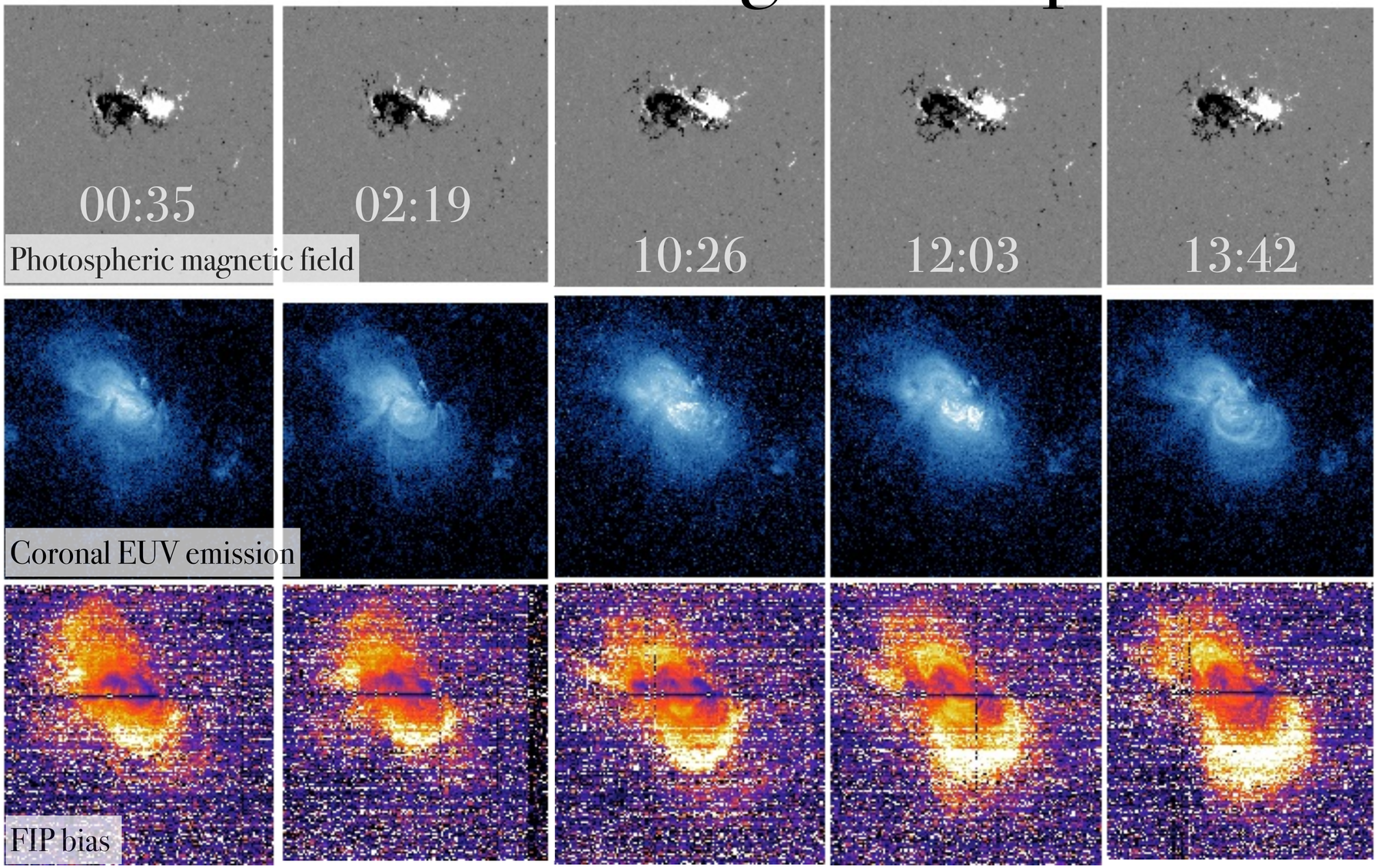
Temporal evolution of active region composition

- Emergence phase of an active region
  - FIP bias increases
  - Temperature increases
- Temporal evolution with spatially resolved observations



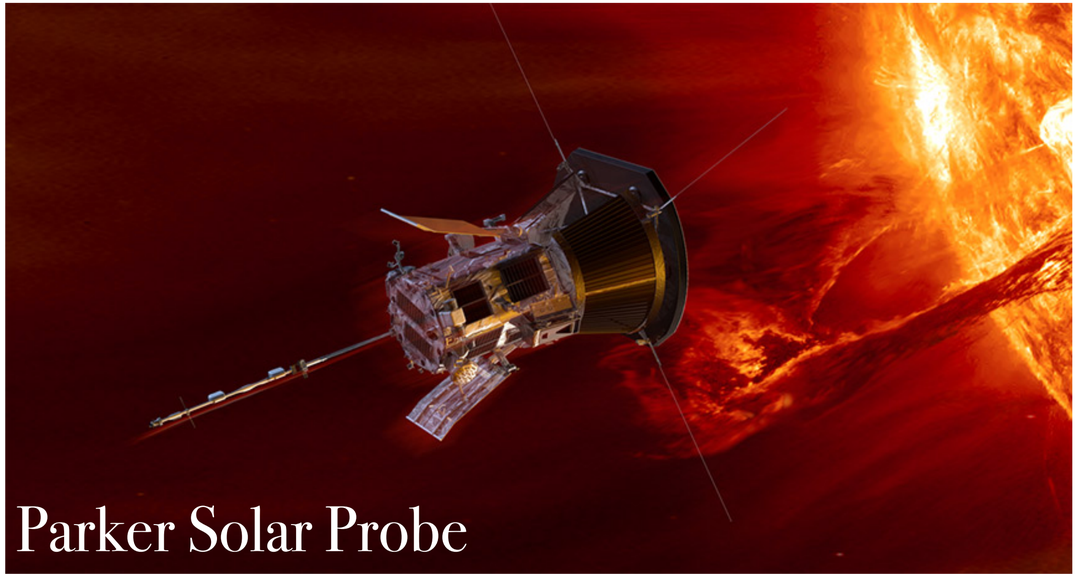


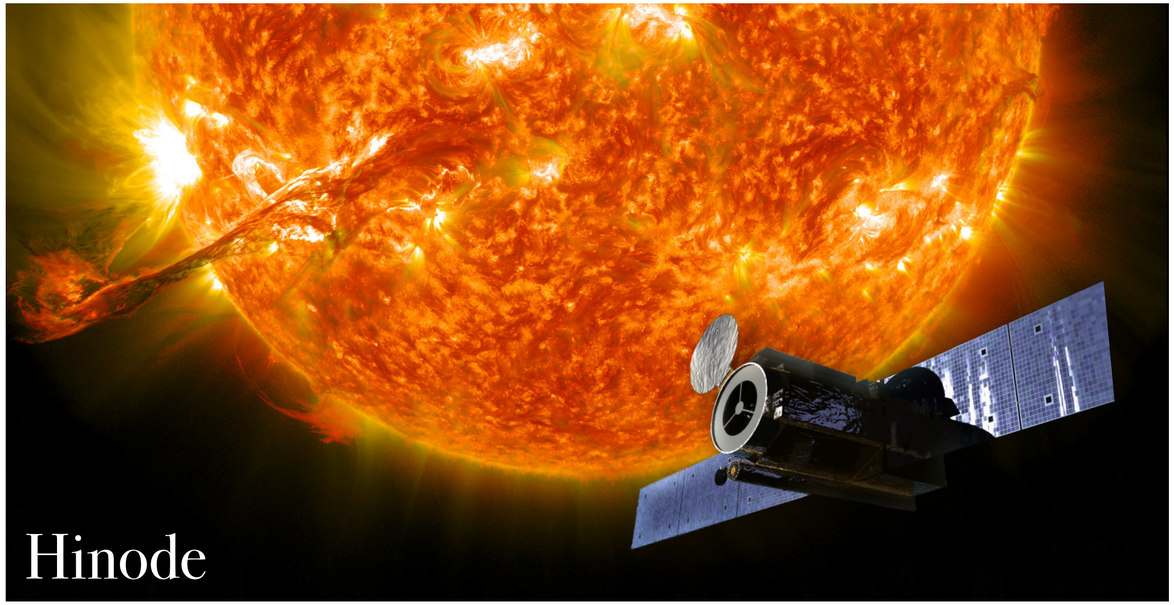
Temporal evolution of active region composition

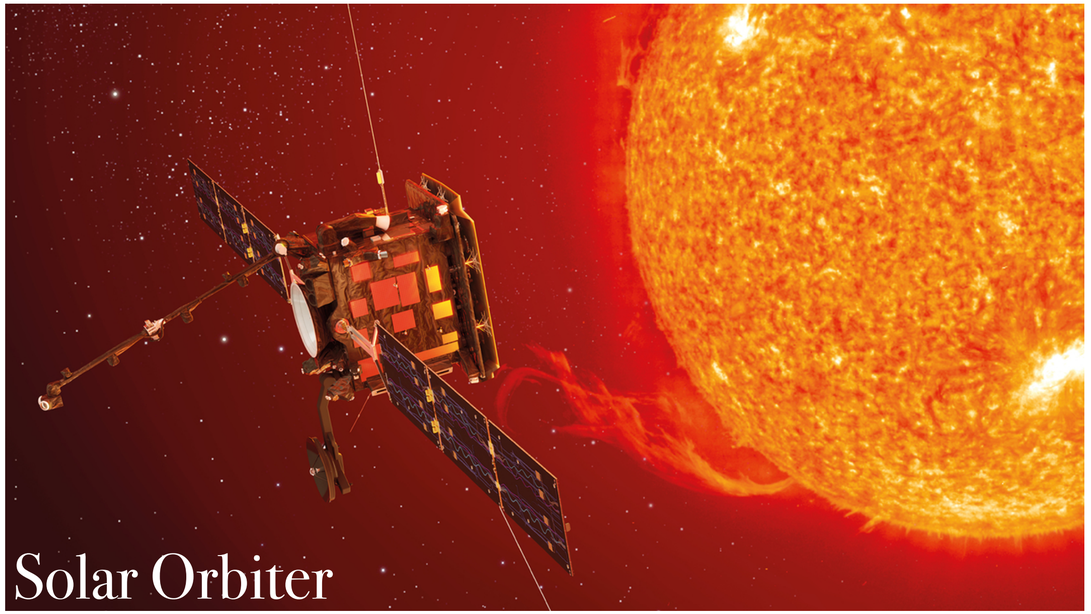


Conclusions

- Composition is a tracer of energy and mass in the solar corona and through the heliosphere
  - but first we need to understand it better!


Parker Solar Probe


Hinode


Solar Orbiter