

Solar Coronal Abundances and the Stellar Connection

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Pre-Hinode paradigm

Stellar coronal composition related to fundamental properties of stars: rotation, surface gravity, spectral type.

Inverse-FIP effect only seen on late-type K- and M-dwarfs.

First Ionization Potential (FIP)

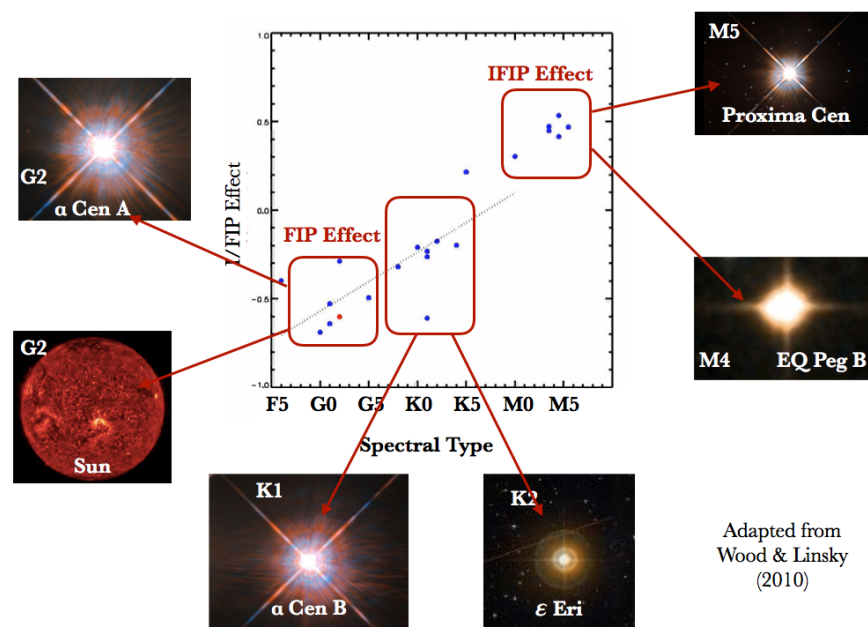
Low FIP elements (e.g. Ca, Fe, Mg) - FIP < 10 eV
High FIP elements (e.g. O, Ne, Ar) - FIP > 10 eV

FIP effect - low FIP elements are enhanced in the solar corona compared to the photosphere.

Inverse-FIP effect - low/high FIP elements are depleted/enhanced in the corona compared to the photosphere.

FIP Bias = ratio of coronal/photospheric abundance

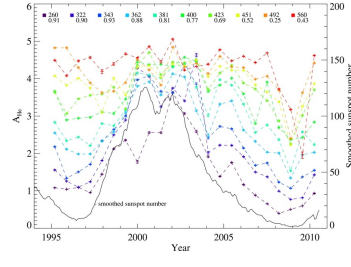
I/FIP Effects and Stellar Spectral Type Relationship



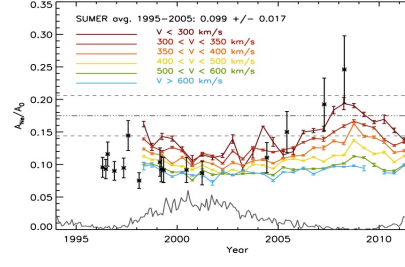
Adapted from Wood & Linsky (2010)

Some elemental abundances vary with the solar cycle

He in the slow solar wind
Kasper et al. (2012)



Ne/O in coronal streamers
Landi & Testa (2015)



Is this a property of the solar wind after heating & acceleration?

Is it a property of the solar wind source regions?

Is cyclic behaviour detectable in Sun-as-a-star observations?

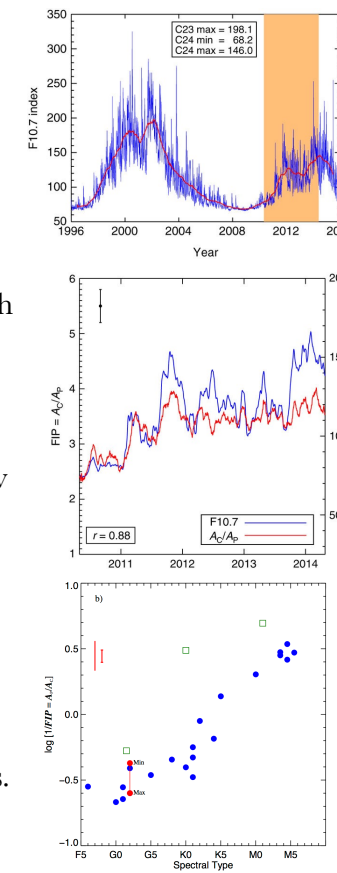
SDO/EVE observations cover the rise phase of solar cycle 24 (2010-2014).

FIP bias is highly correlated ($r=0.9$) with F10.7 cm radio flux.

How does this affect coronal abundance v spectral type in solar-like stars?

Sun moves with the cycle on spectral type plot.

Similar cycles likely present on other stars.
Brooks et al. (2017)

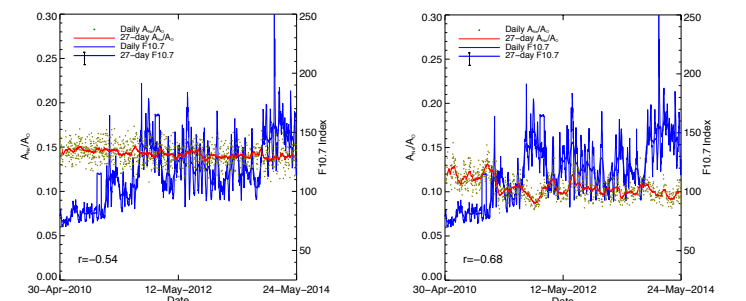


Solar Modeling Problem

Helioseismology measurements are in conflict with photospheric abundances derived from 3-D hydrodynamic models.

Could be solved if Ne abundance is larger.

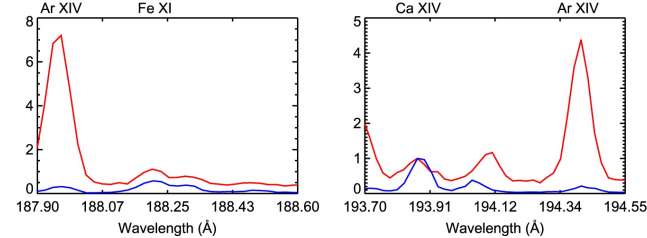
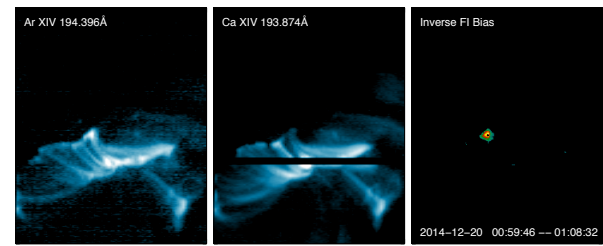
Variation of Ne/O from solar maximum to minimum in streamers is large enough. Ne abundance in some cool stars is higher.



Variation is factor of ~ 1.5 at 0.2-0.3MK & factor ~ 2 at 0.3-0.6MK

Too small to solve solar modelling problem.
Brooks et al. (2018)

First detection of the inverse-FIP effect on the Sun



Enhanced Ar/Ca observed in an X-class flare (Doschek et al. 2015).

Detailed spatial/temporal analysis of the effect has become possible.

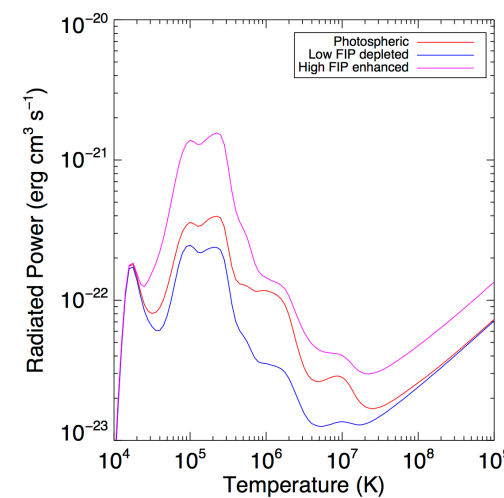
Test case: a new diagnostic of coronal element behaviour

Are low FIP elements depleted or are high FIP elements enhanced?

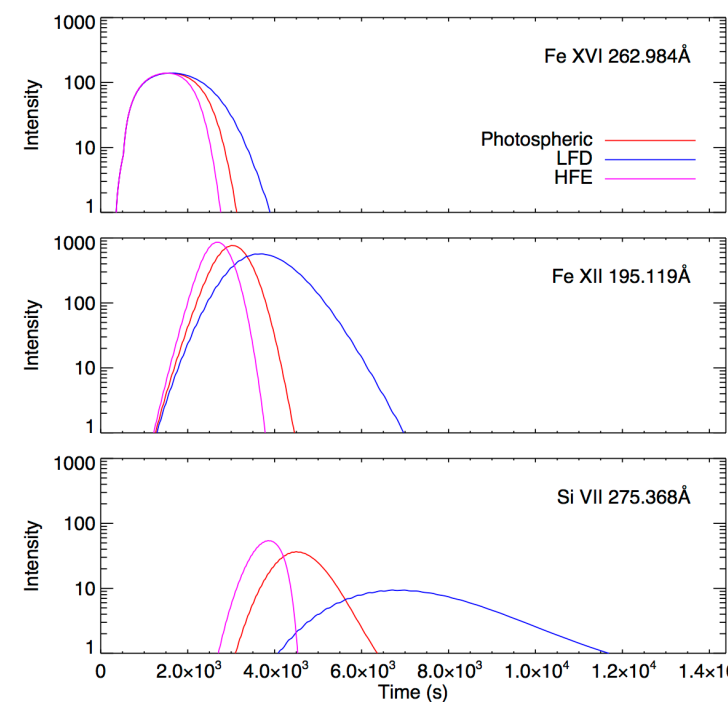
Post-flare arcade of loops with similar properties (lengths, widths, densities) is created by the same energy release process, but the coronal abundance behaviour is different in the IFIP region.

What measurable property of the loops will it affect?

Radiative loss function, and therefore cooling time.



0-D Hydro (EBTEL+CHIANTI) simulation of loop cooling

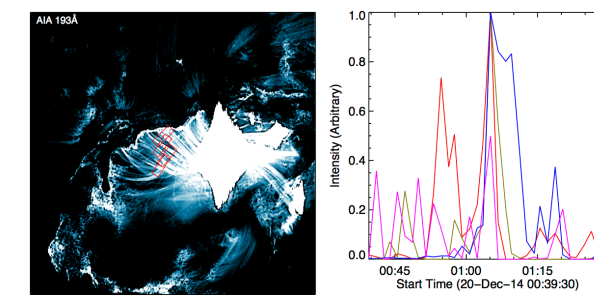


High FIP enhanced > shorter lifetime.

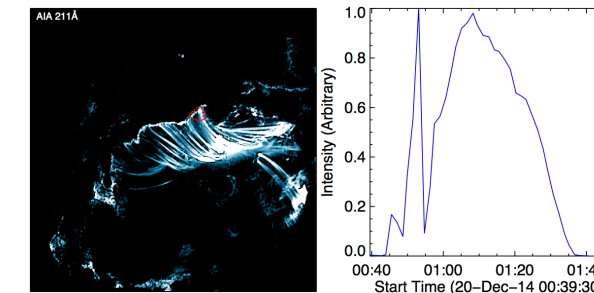
Low FIP depleted > longer lifetime.

AIA observations

Flare loop lifetime: 5-10 mins.



IFIP region lifetime: 42 minutes (at least 4 times longer!)



Low FIP elements are depleted (in this case).
Brooks (2018)

IFIP observed transiently in localized patches in decay phase of M2 flare

This active region was complex: 3-bipoles, highly sheared field, significant flux emergence. Detailed study of the magnetic environment where IFIP effect is present.

IFIP is observed above forming (coalescing) umbrae when the flare ribbons cross.

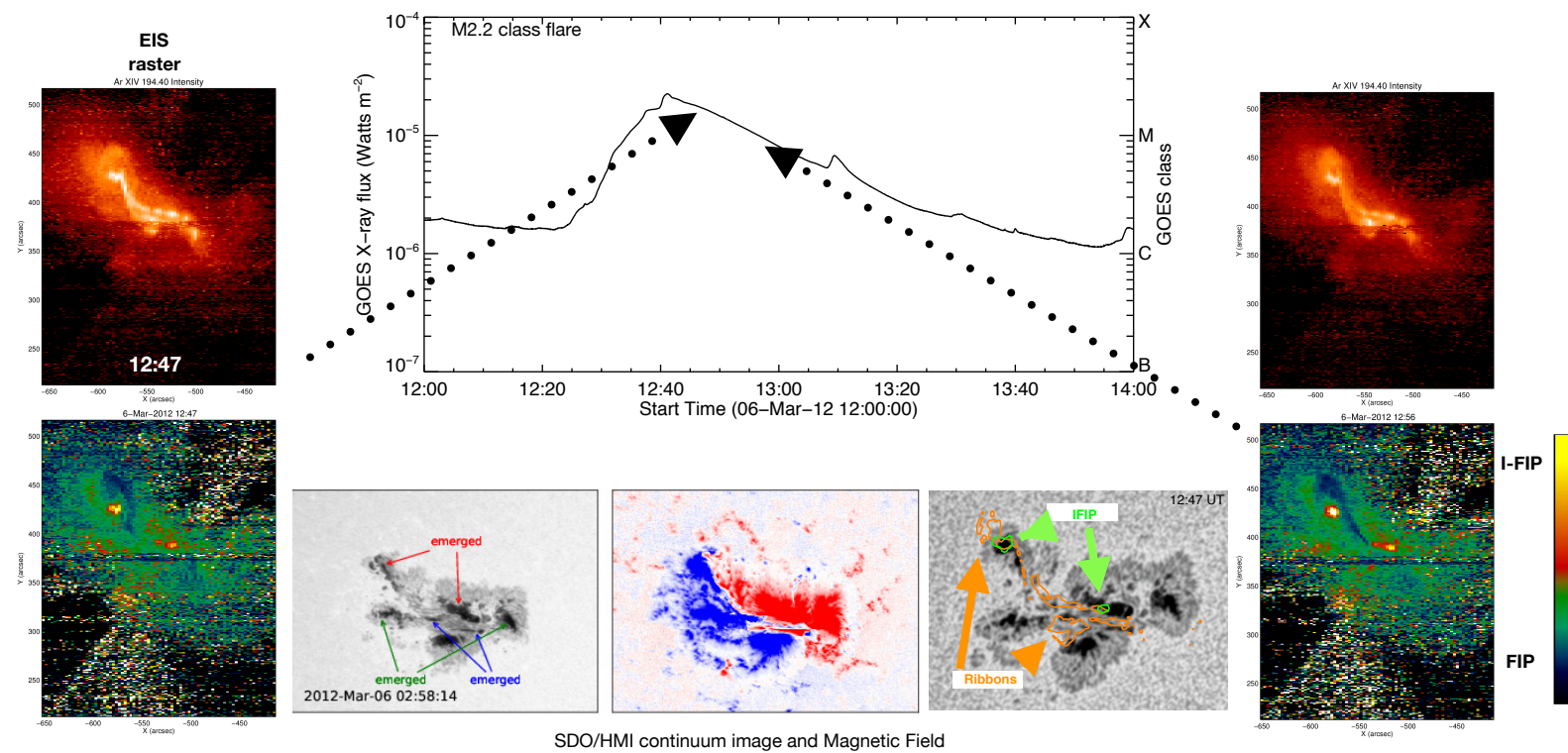
What is special about these locations? Why is the plasma composition different?
What role does the flare play?

High shear in coalescing strands of the same polarity.
> sub-chromospheric reconnection as they collide.

Reconnection leads to increased wave flux from below.
> IFIP effect.

IFIP plasma was already present above the umbra, the flare ribbons reach temperatures that reveal it.

M-stars have IFIP dominated coronae all the time - not due to large flares.

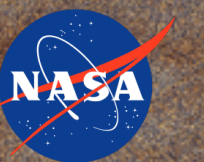


Baker et al. (2019)

Poster & Literature



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Implications

Magnetic activity

A significant role in determining plasma composition in ARs, flares, Sun-as-a-star, solar analogs.

Stellar coronal composition is not just a function of fixed stellar properties.

The solar-cycle effect is likely to be present on other solar-like stars.

Inverse-FIP effect

What we observe in small patches on the Sun, in a FIP effect dominated corona, may be the dominant process on cool dwarfs.

FIP and IFIP effect both act on low FIP elements - agrees with Laming (2004) MHD wave model.

Sun is the rosetta stone for stellar astrophysics

