AR heating - observational constraints

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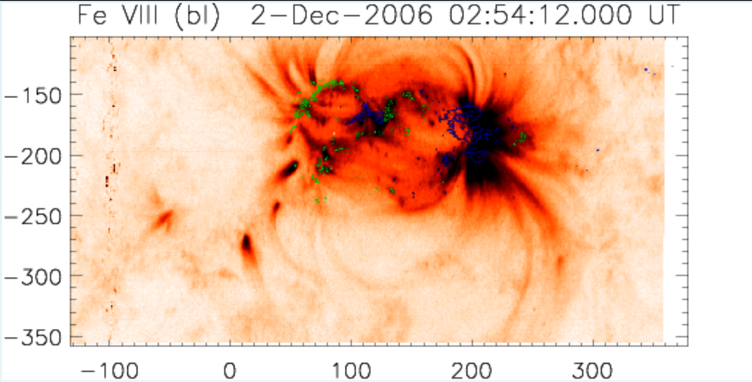
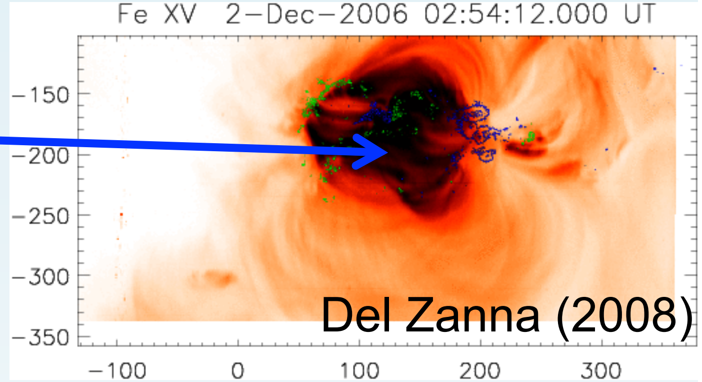
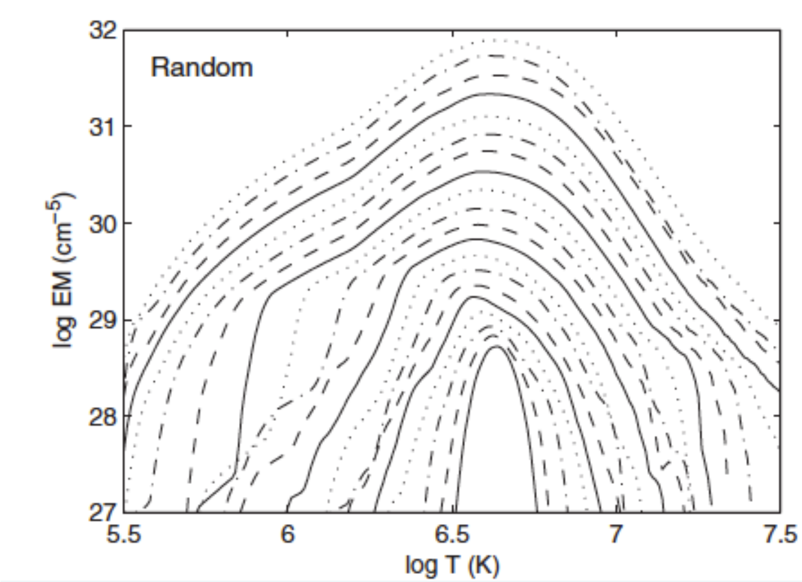
AR core `hot' loops



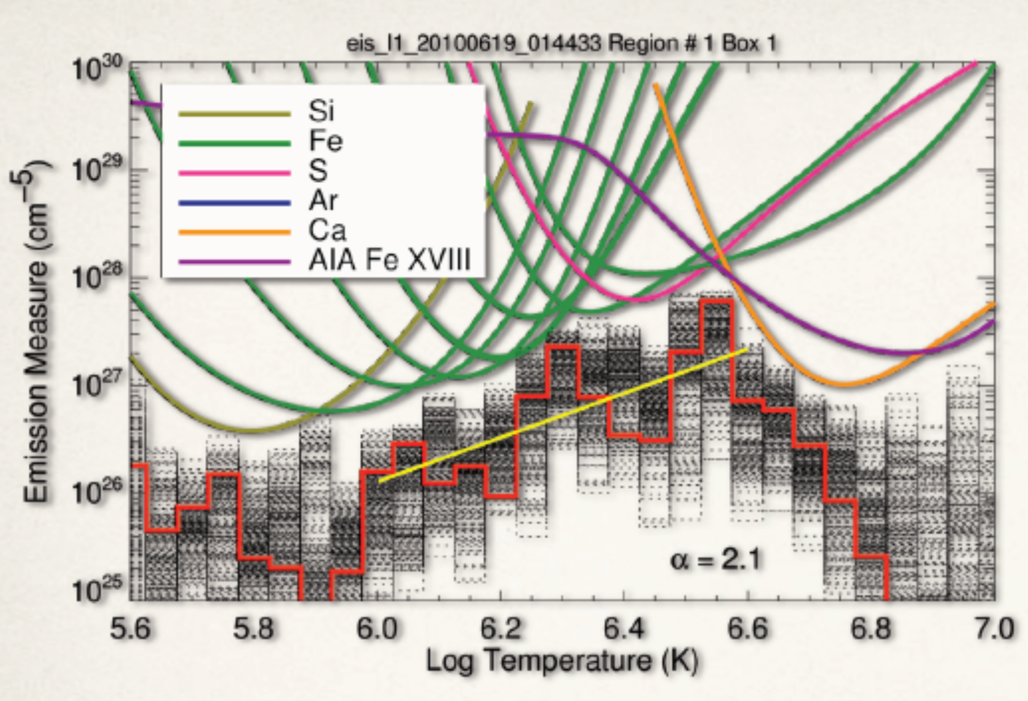


1) Nearly isothermal around 3 MK (previous observations in EUV and X-rays)
2) Hotter emission with EM at most about 3 orders of magnitude lower than EM (3 MK). Fe XVIII mostly formed around 3 MK but `microflaring' activity often present (see Parenti's talk but also Glesener's)
3) **Future instruments for 3-15 MK plasma (MaGIXS, SPICE, soft X-rays, EUNIS: Daw's talk)**
4) (Good density measurements – EIS – Young, Warren, Tripathi,Del Zanna...)
5) FIP bias about 3.2 – Iron enhanced by at least 3 over photospheric.
6) Connected to sunspots and moss, mostly unipolar areas ? (cf. Chitta's talk)
7) In moss areas small redshifts (~5 km/s) - Del Zanna, Brooks, Winebarger, Tripathi…
8) Evolution? Relation to cooler loops in the core ?
9) Relation to pre-existing corona/warm loops? (EUI, COSIE:Golub's talk)

Slope of EM at 1-3 MK in AR cores



EM from train of random nanoflares
(Cargill 2014)



Hinode EIS + SDO AIA
Warren + (2011,2012)
found slopes around 2-3.

$$EM(T) \sim T^b$$

Several studies, cf. W. Barnes talk

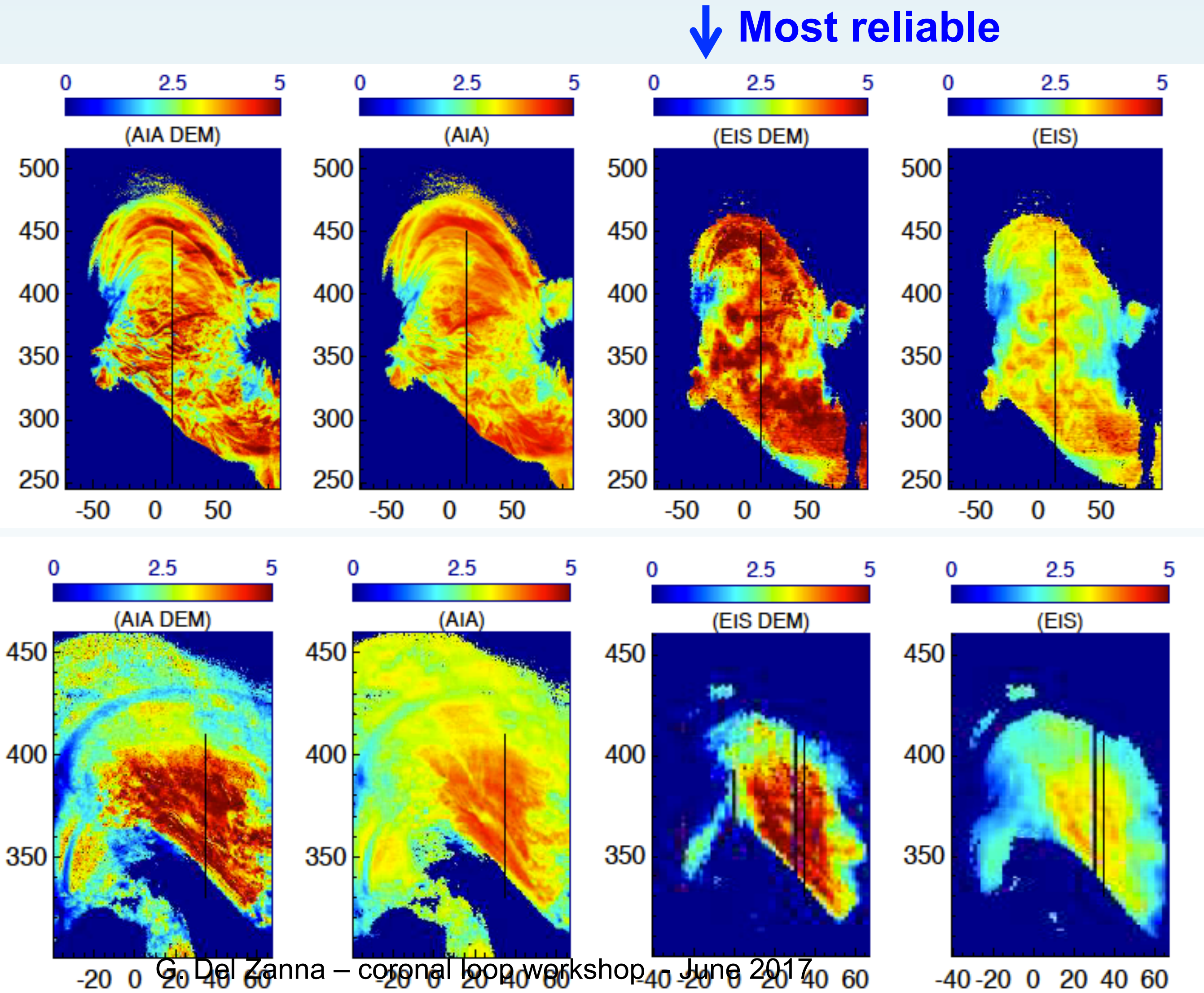
Tripathi + (2011): 2.4

Winebarger+ (2011): 3.2

Schmelz & Pathak (2012): slopes between 1.9 and 5, increasing with age

Images of the EM slopes (1-3 MK)

Values ~ 5, steeper than previously published (high frequency heating?).
With foreground subtraction, slopes steepen

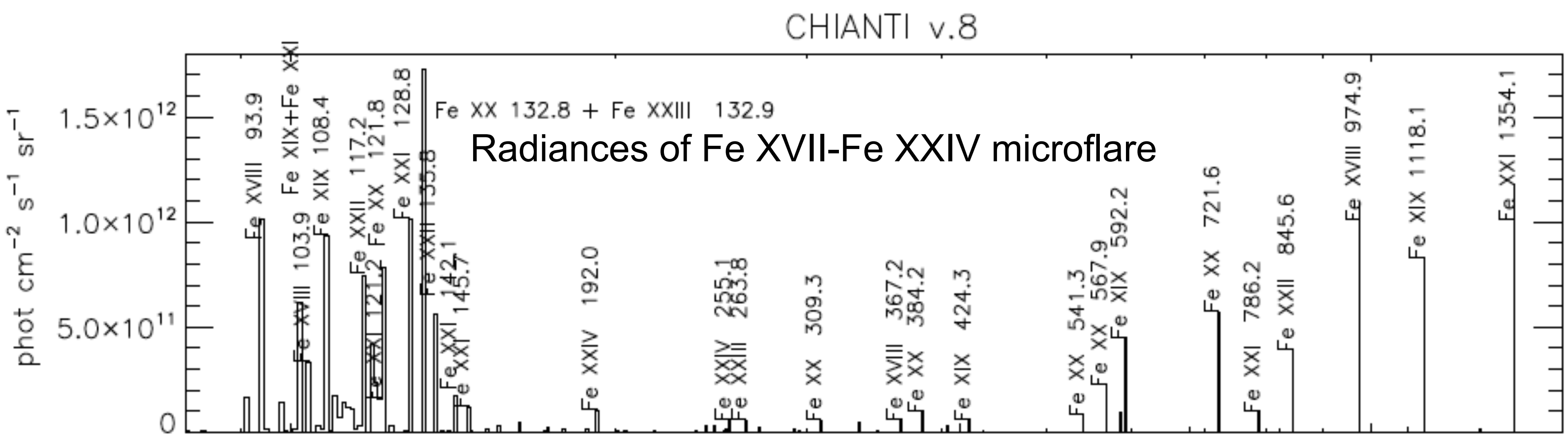


First rotation

Second rotation. **Similar!**

Del Zanna, Tripathi, Mason +(2014, A&A, 573, A104)

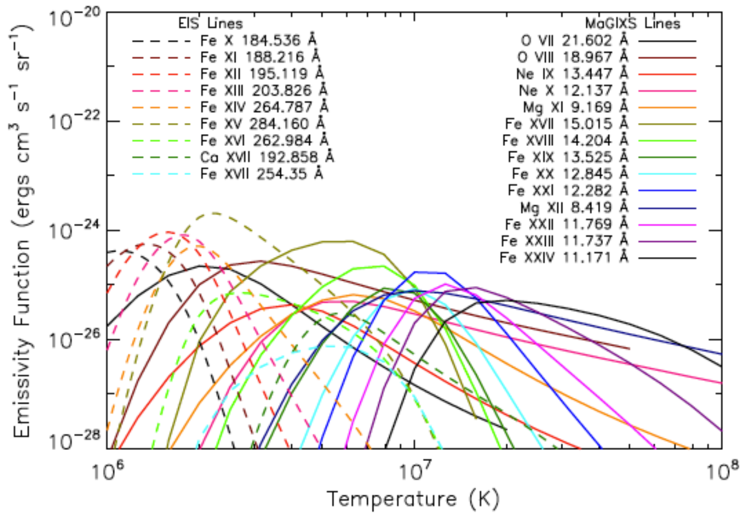
Hot (>3 MK) emission - white paper (2016)

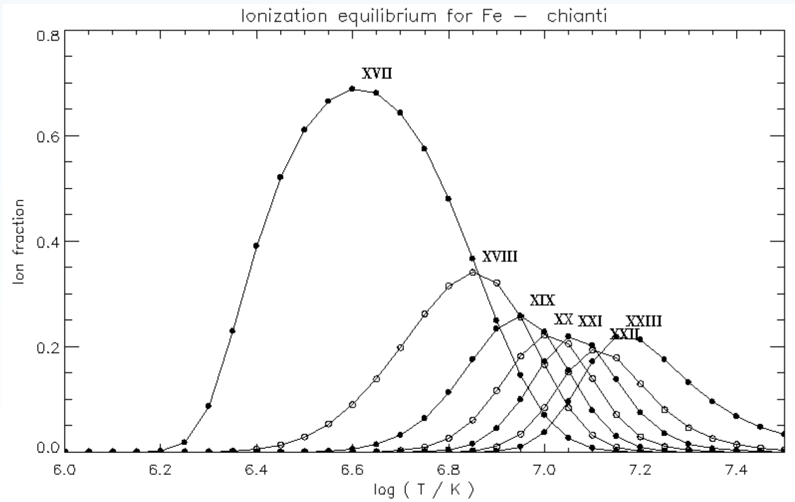


EIS CDS, EUNIS SUMER IRIS

Microflare: EM at 10 MK 1/10 of EM (2.8 MK) -- density= 10^{12} cm^{-3}

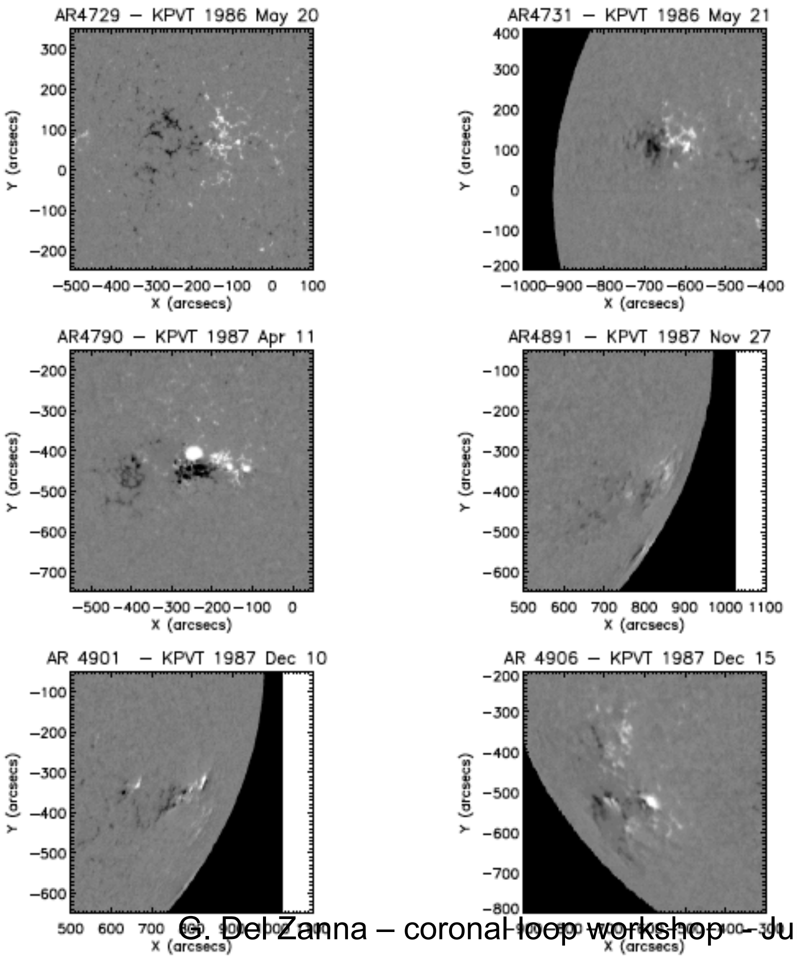
Either X-rays (e.g. MaGIXS), Soft X-rays or EUV/UV

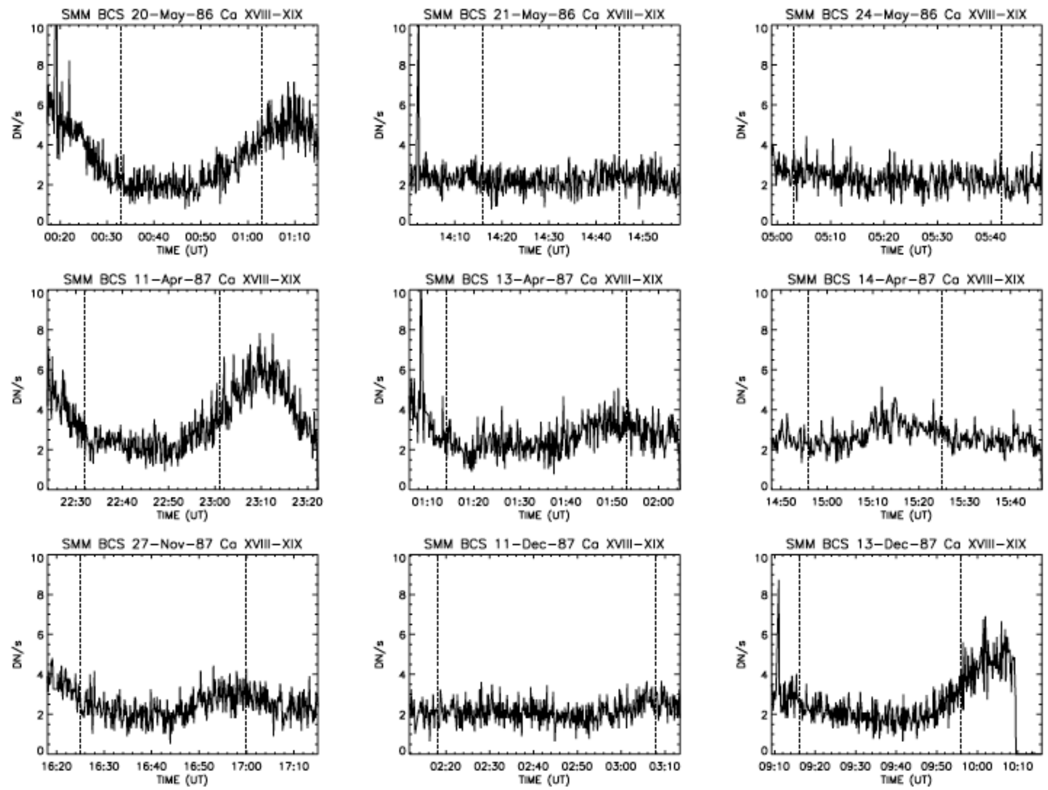




SMM quiescent AR cores

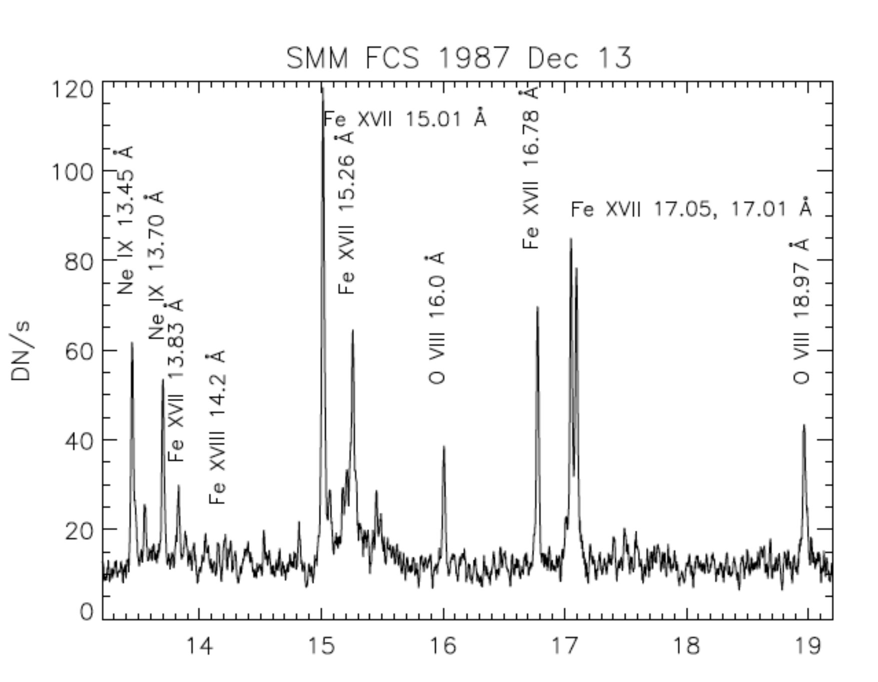
Re-analysed X-ray spectra of active region cores from SMM FCS. Used SMM BCS to select quiescent times (Del Zanna & Mason 2014, A&A).
Note: `microflaring' activity is very common, it lasts about 10minutes.

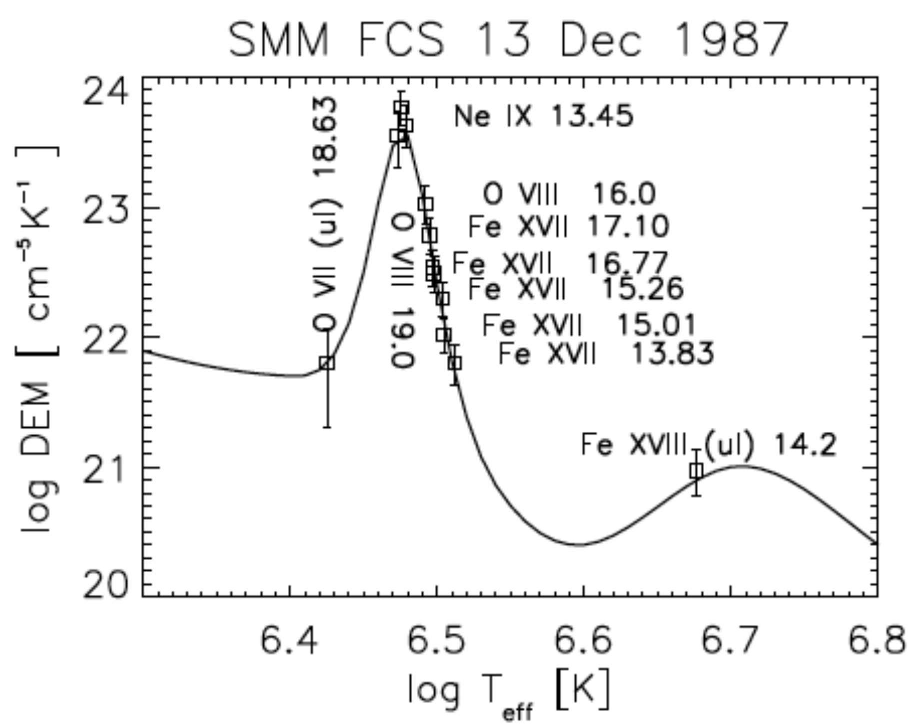




EM slopes at T > 3 MK

SMM/FCS pointed at brightest point





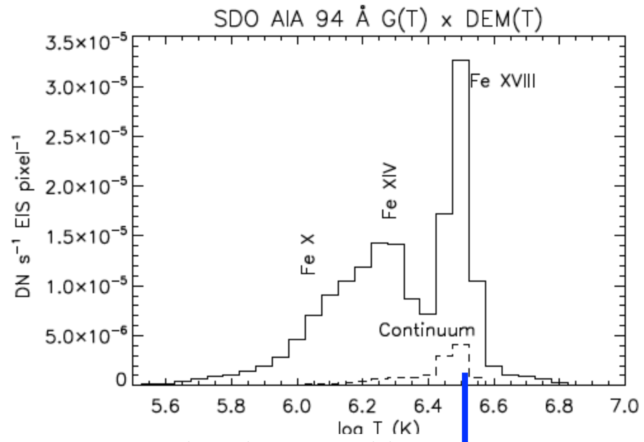
Del Zanna & Mason (2014)

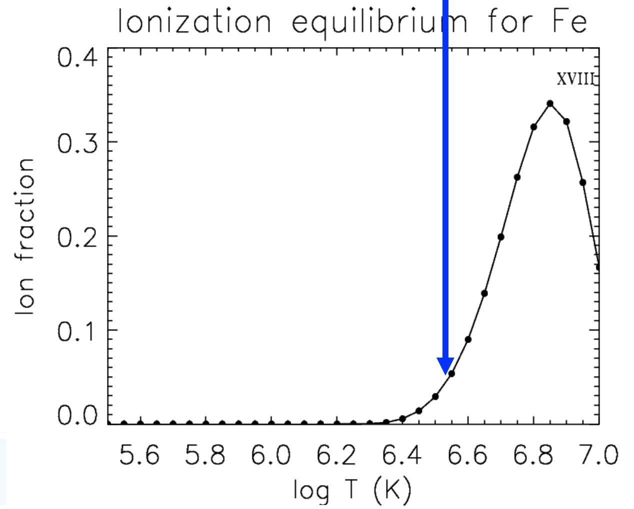
1) All quiescent AR cores showed a near-isothermal distribution
2) EM slope: about -14 or steeper. FOXI-2 results: EM slope about -10 (Ishikawa et al. 2015). Nustar: at least -8. 3 orders of magnitude between the 2.5 and 7 MK
3) Fe XVIII is often formed at 3 MK ! (see also Del Zanna 2013).
4) FIP bias = π (Fe/O and Fe/Ne).

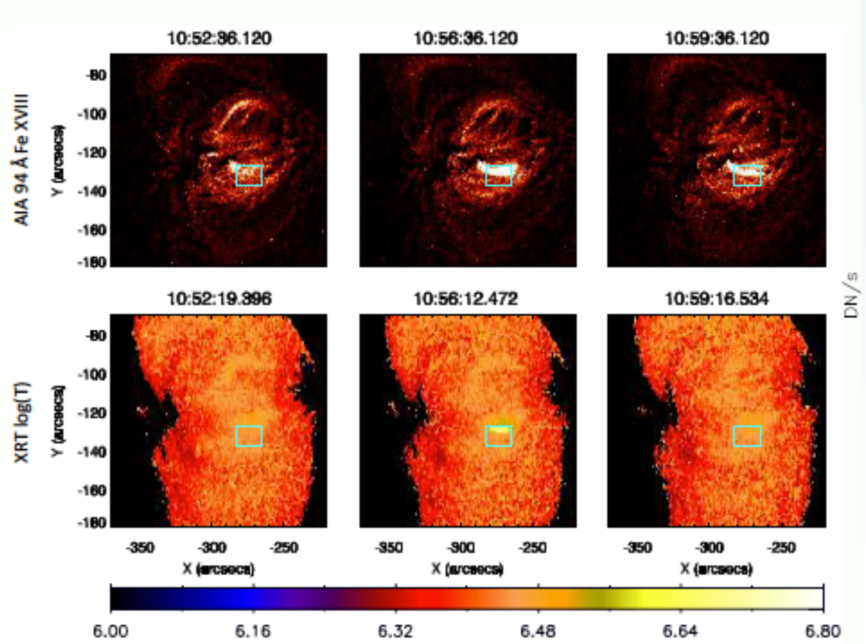
Fe XVIII and AIA 94 A

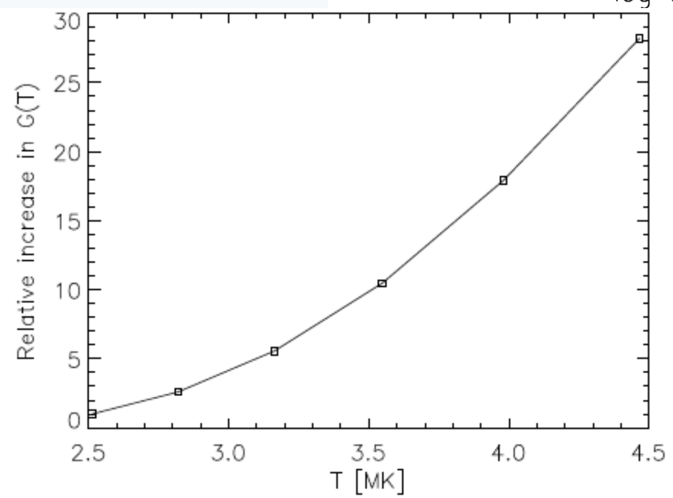
Some Fe XVIII is often present, but formed at 3 MK and not 7 MK ! (Del Zanna 2013). Confirmed by EIS/SUMER analysis of one AR (see Parenti's talk).

A small T variation increases the Fe XVIII (Del Zanna 2013). Confirmed by AIA/XRT analysis of several ARs (Del Zanna, Molnar+ in prep.)



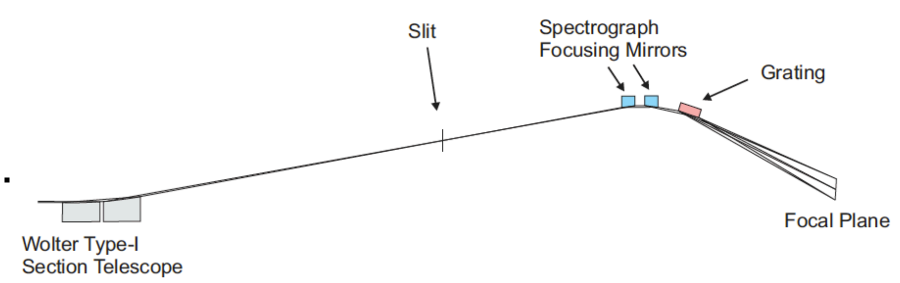






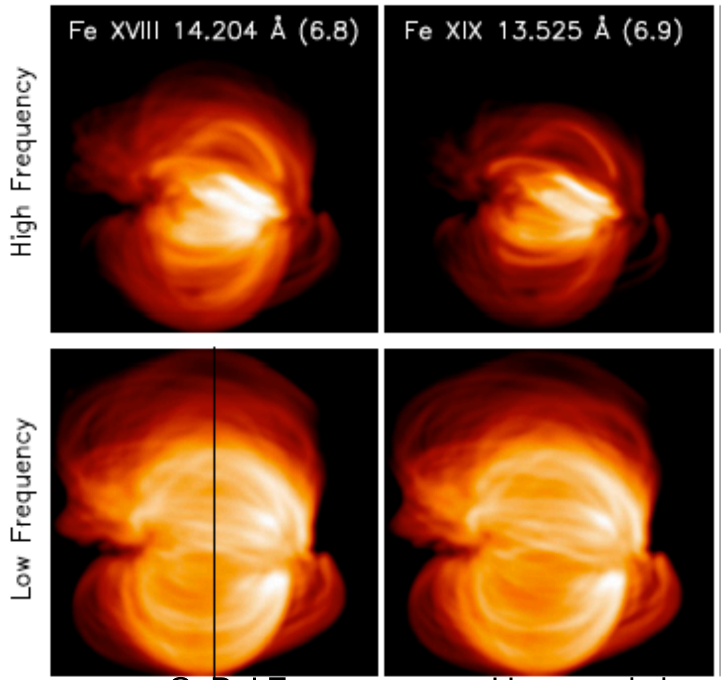
MAGIXS – an X-ray spectrometer 6-24 A

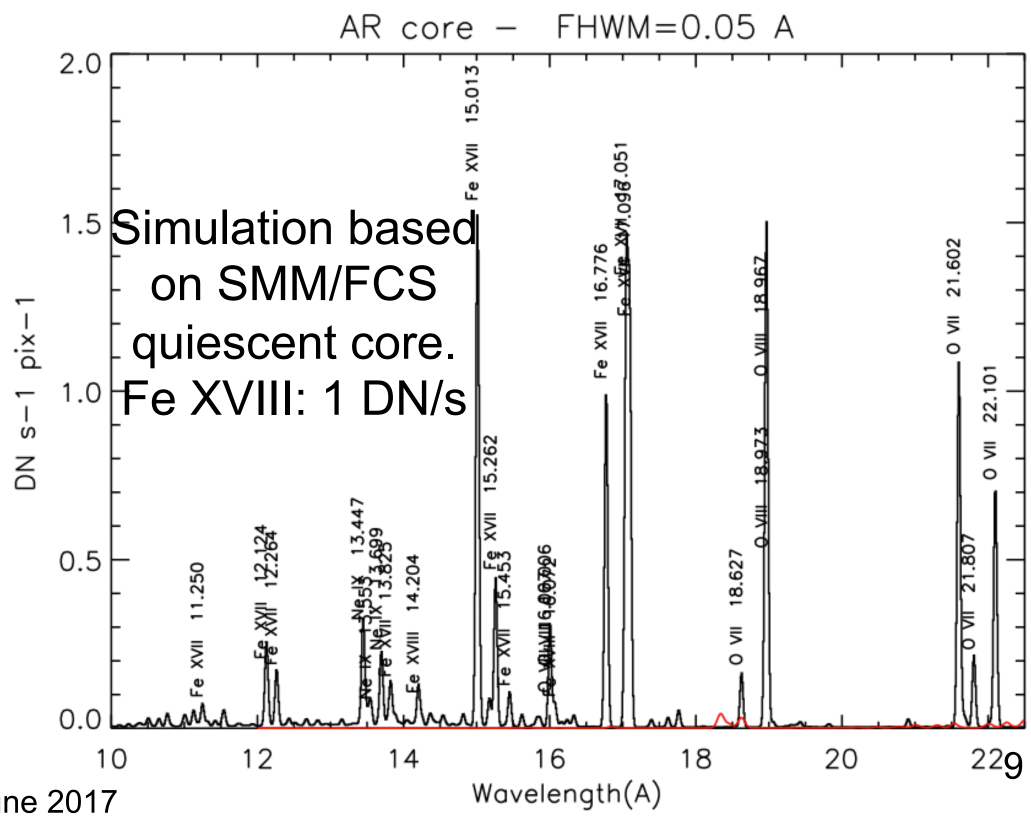
Novel design: sounding rocket led by MSFC (USA), to observe at ~5” resolution and high cadence lines emitted in the 5—10 MK region. Summer 2018 !



X-ray hot lines can differentiate between high and low-frequency heating. Drawback: low geometrical area.

- Direct Te from Fe XVII, Fe XVIII
- FIP bias in AR cores (O,Ne/Fe)

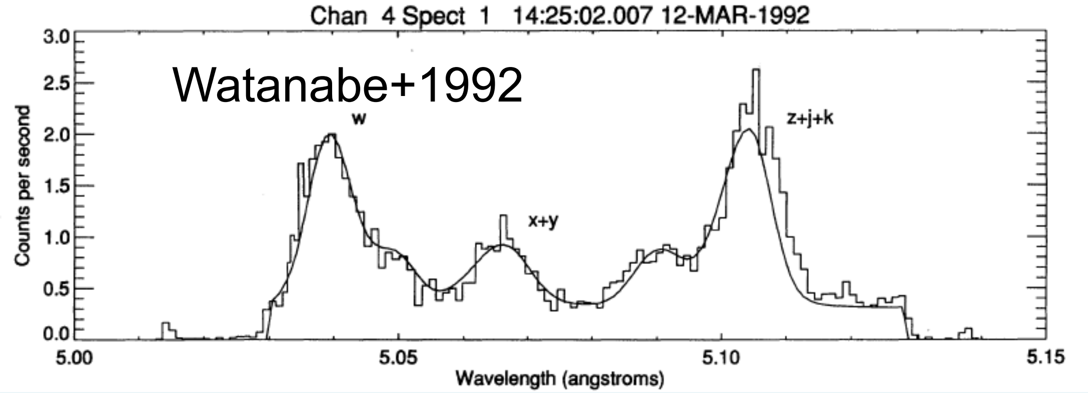




Simulation based on SMM/FCS quiescent core. Fe XVIII: 1 DN/s

Many diagnostics/results in the X-rays

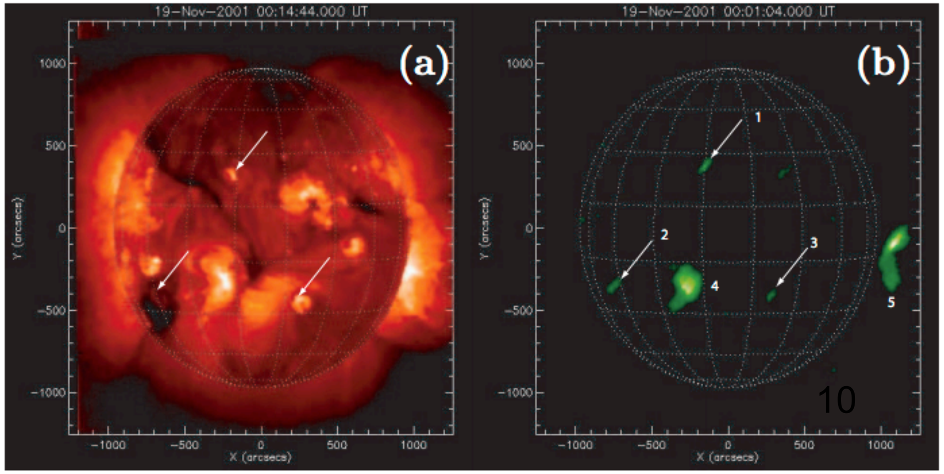
Each method has some limitations.

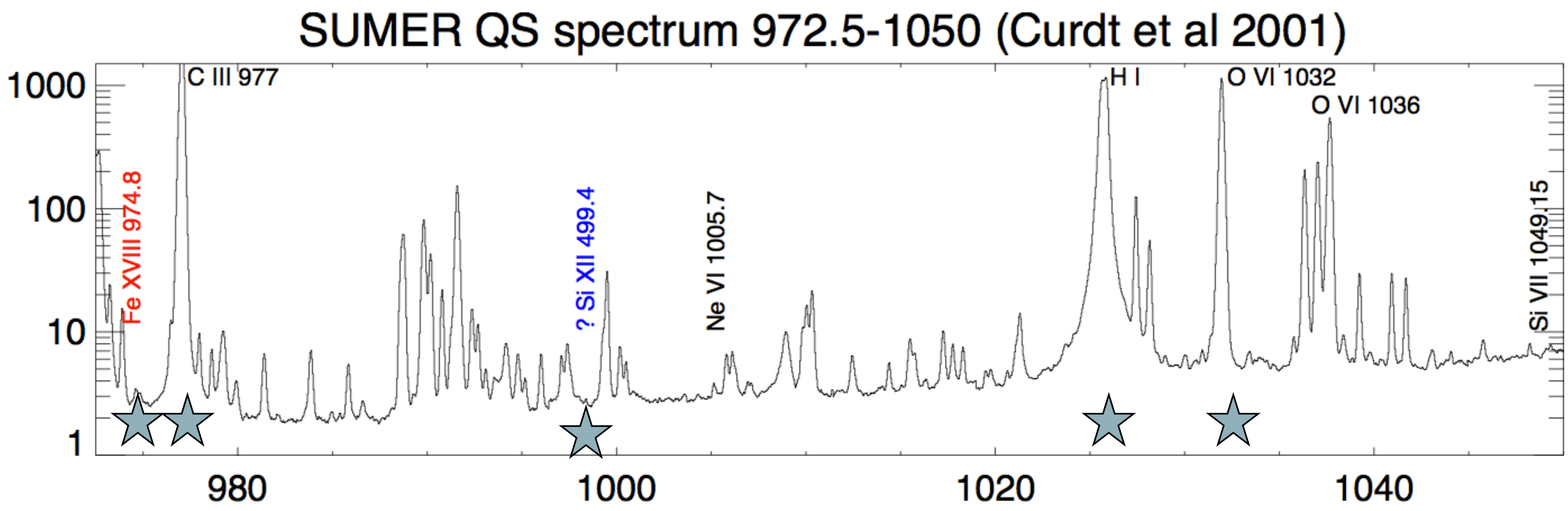


Example 1: Yohkoh BCS
He-like S XV
Te from G ratio: (x+y+z)/w
(Gabriel & Jordan 1969)

From one AR at the limb:
a steady component with T=2-3 MK and a hotter, transient component in excess of 5 MK. This hotter component is due to microflares; outside the time of microflares there is relatively little or no active region upper coronal plasma with Te > 3.5 MK (Sterling +1997).

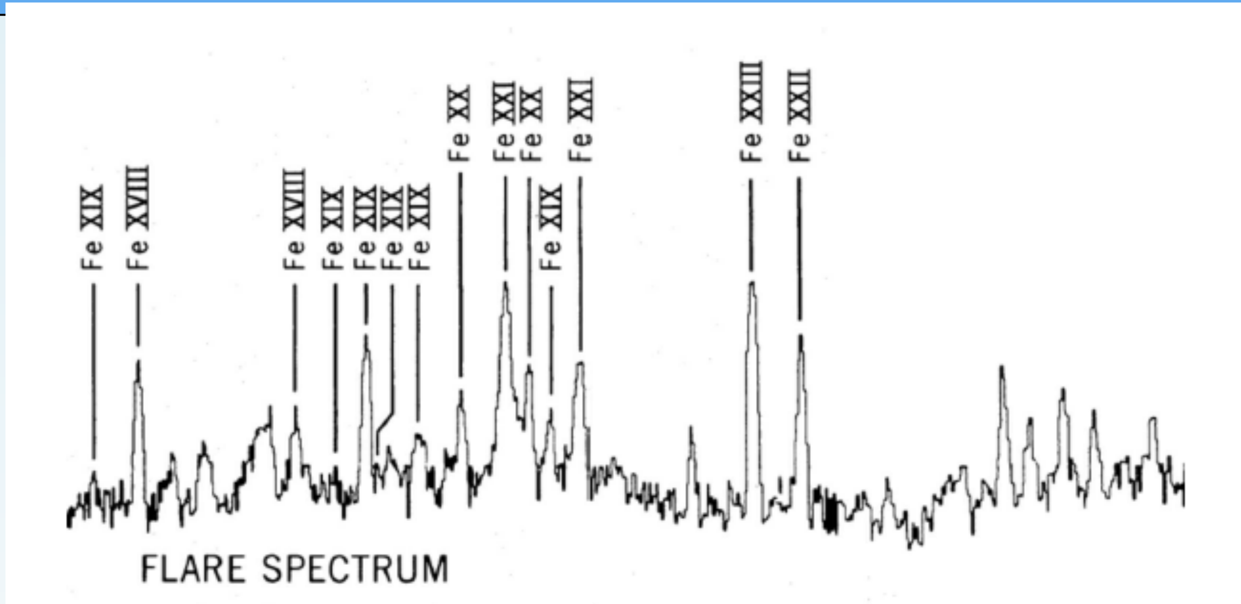
Example 2: CORONAS-F SPIRIT Mg XII
(see A. Reva's presentation)



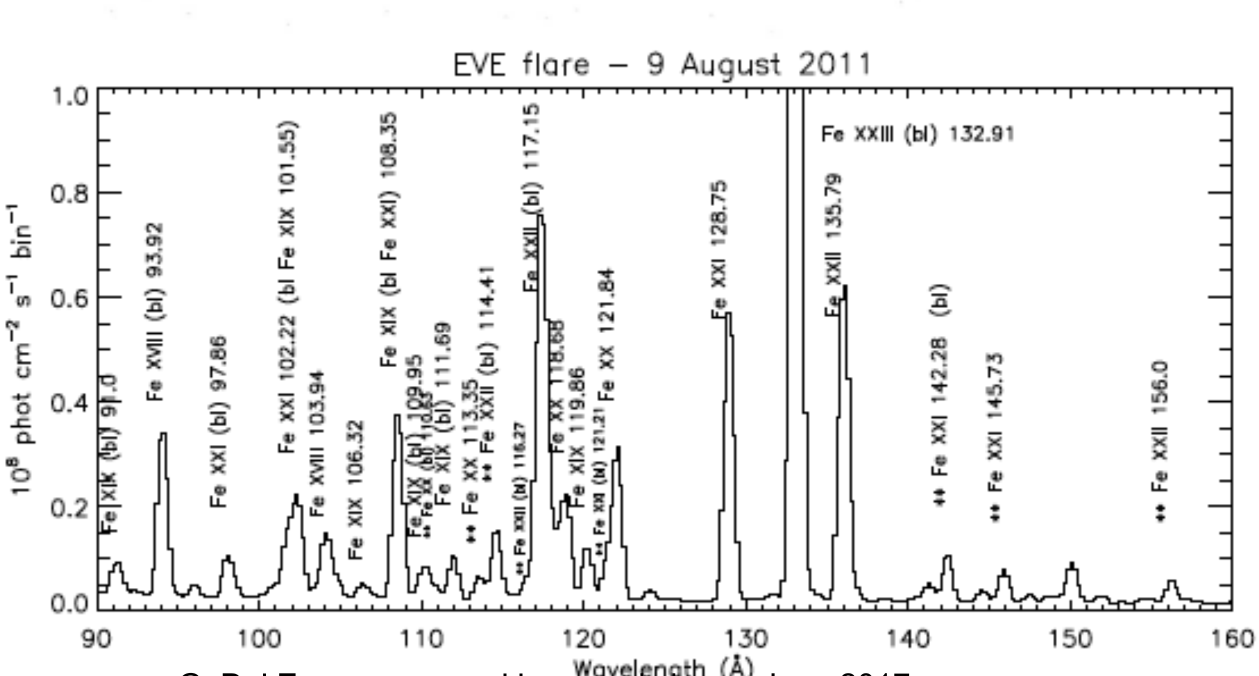


One of the Solar Orbiter SPICE channels.

Fe XVIII will be observed regularly with SPICE.
However, will likely be the only high-T line → limited info



OSO-5
(Kastner+1974)



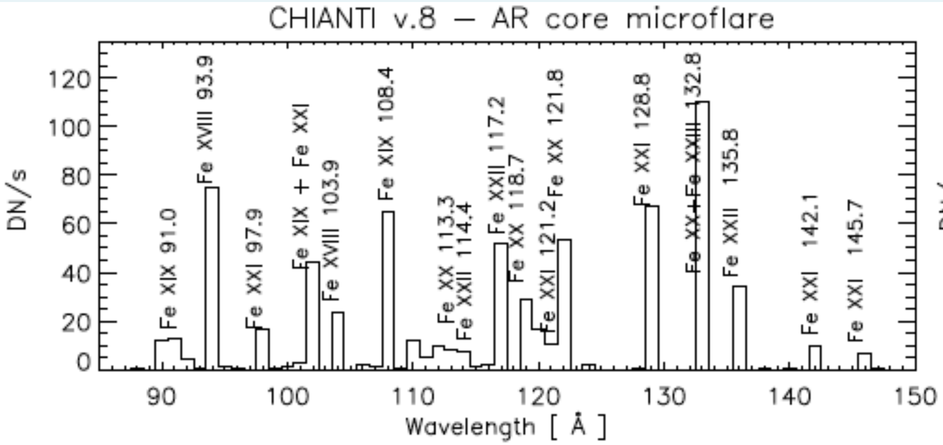
The Soft X-rays have the best diagnostics of high-T plasma around 7-12 MK.

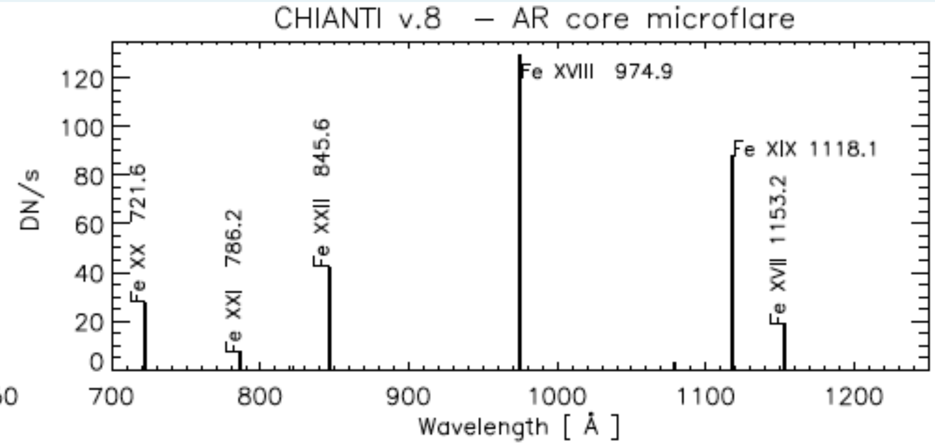
Also: allow measurements of densities!
(Mason+1986, Del Zanna & Woods 2013)

SDO EVE

Soft X-rays (SXR)

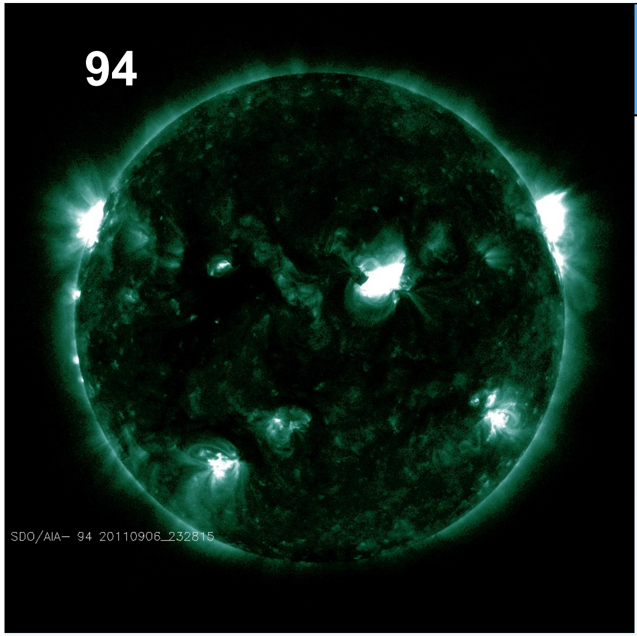
Modified the Solar C LEMUR concept by adding an extra SXR channel

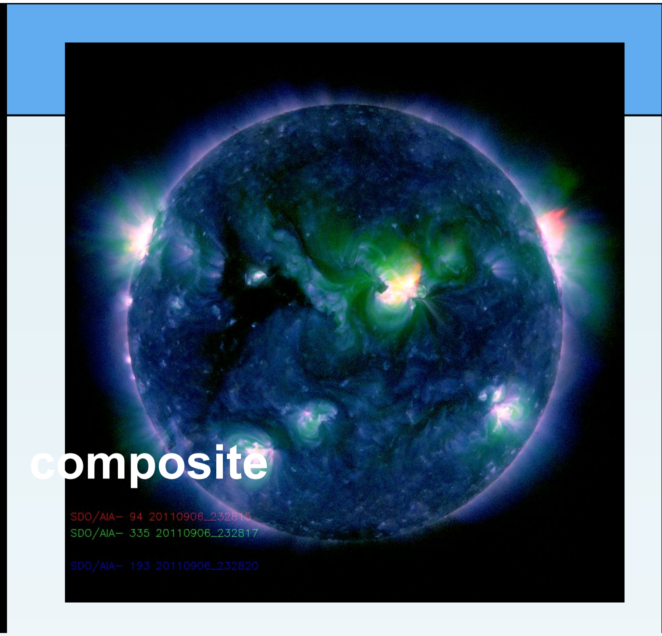


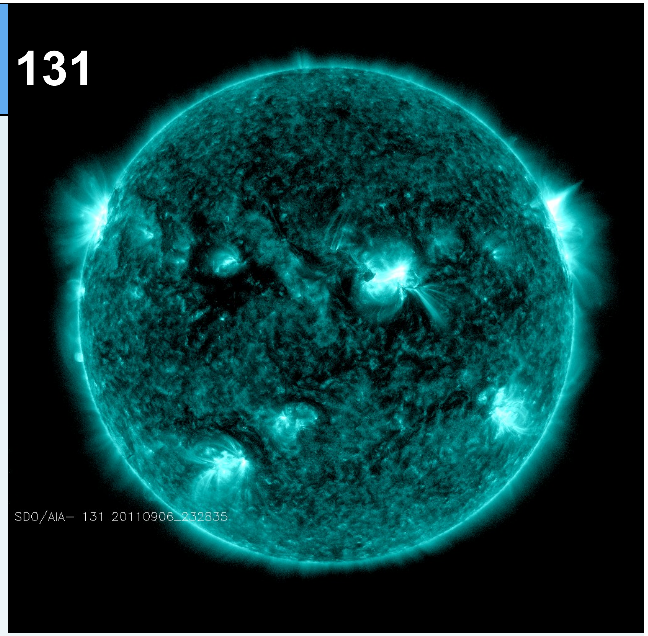


- Good diagnostics: direct measurements of Ne, Te, non-thermal electrons

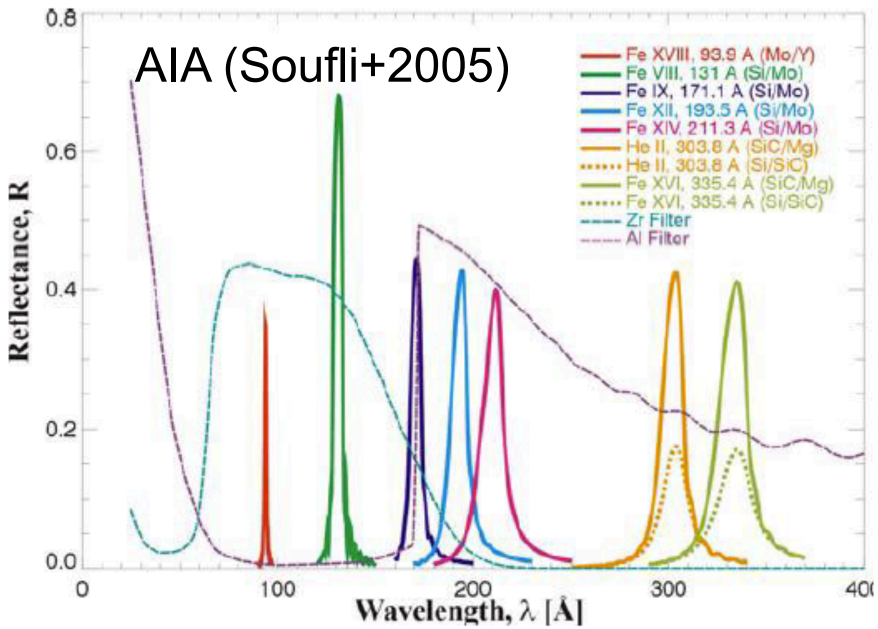
- Technology used before (cf. AIA multilayers)
- Can easily provide stigmatic images at 1” or better (cf. AIA)
- High throughput



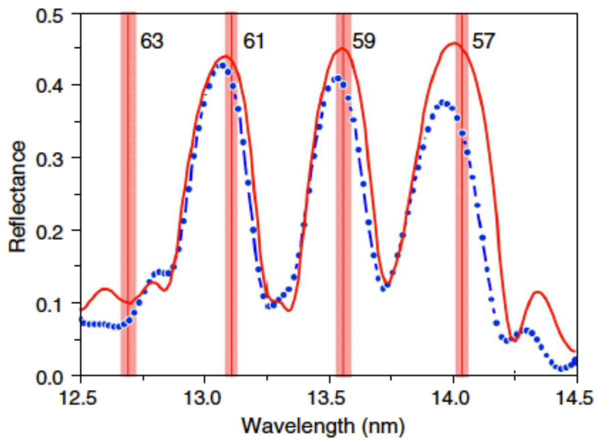




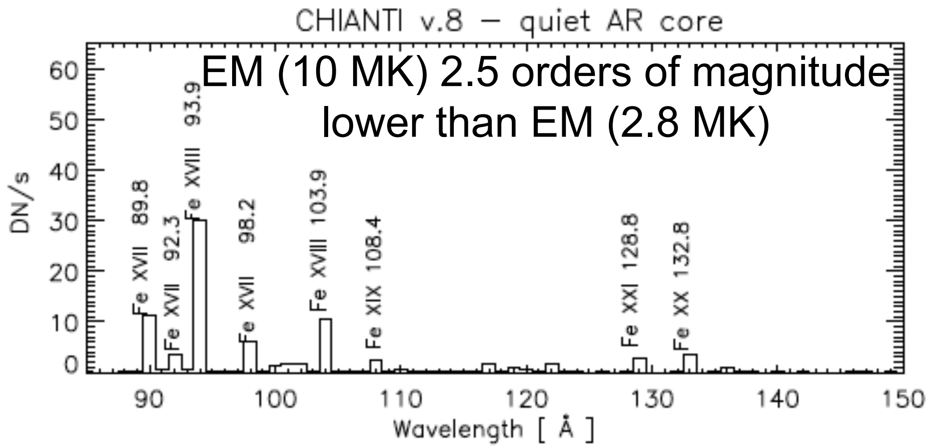
Conservative design: reflectance= 0.3, grating groove efficiency=0.4, Zr filter as in AIA.
Mirror: half of the LEMUR 30cm.
Resolution= 1” and not 0.3” (what for ?)

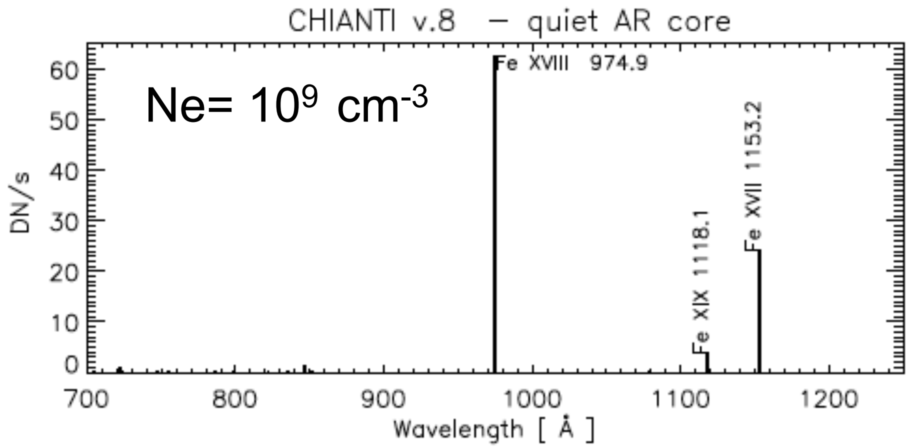


Aperiodic multilayer Gullikson +2015



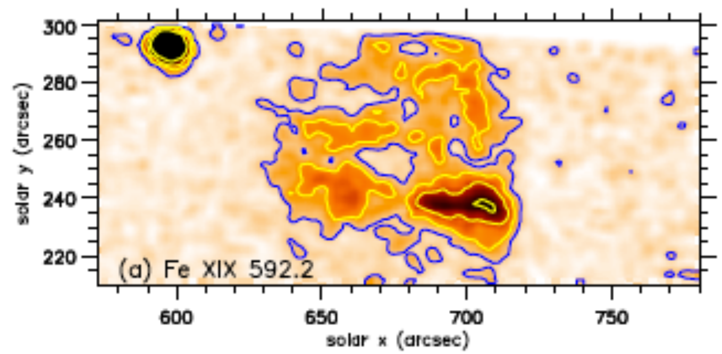
Quiescent AR core

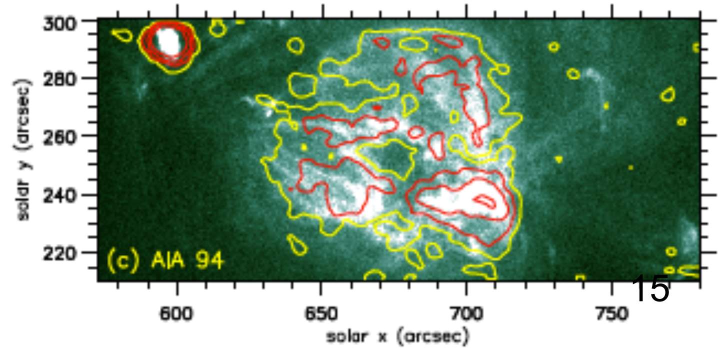




Fe XVIII 974 A: 11 (erg units):
3.7 DN/s in SUMER (at the limit)
Fe XVIII 94 A: 4.6 DN/s (AIA pixel) vs. 30 in SXR
Fe XVIII 14.2 A: 0.6 (phot units): > 10 times weaker than signal in SMM/FCS
→ 0.07 DN/s MaGIXS

Fe XIX 1118, 108 A: about 4 DN/s in UV/SXR
Fe XIX 592 A: 0.1 (erg), similar to SUMER results (Parenti's talk, 0.4). Observable by EUNIS-13?



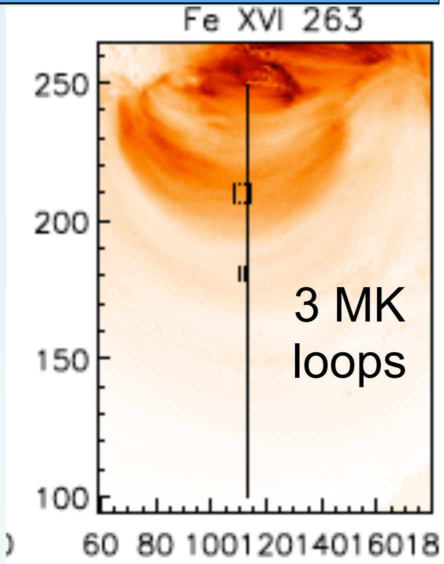


Brosius+2014: Fe XIX contours at 4 (blue), 8,16, 32 (yellow) (erg units)

FIP bias in AR cores

1) FIP bias of π ! (Fe/S and Fe/Ar in EUV and Fe/O, Fe/Ne in X-rays)

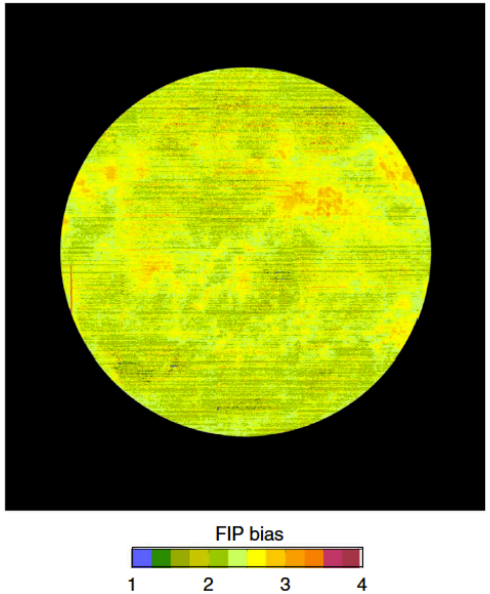
2) Fe must be enhanced by at least a factor of 3 over photospheric (Del Zanna 2013).



El.	FIP (eV)	AR core	"Photospheric" Asplund+(2009)	FIP bias	
Fe/Ne	7.9/21.5	1.2	*0.37*	3.2	SMM/FCS
Fe/Ar	7.9/15.8	50	*12.6*	4	Hinode/EIS
Fe/O	7.9/13.6	0.2	0.065	3.1	SMM/FCS
Fe/S	7.9/10.4	6.8	2.4	2.8	Hinode/EIS
Fe/Si	7.9/8.1	1.0	1.0	1.0	Hinode/EIS
Fe/Ni	7.9/7.6	29.5	19.1	1.5	Hinode/EIS
Fe/Ca	7.9/6.1	13.5	14.5	0.93	Hinode/EIS

Why bother?

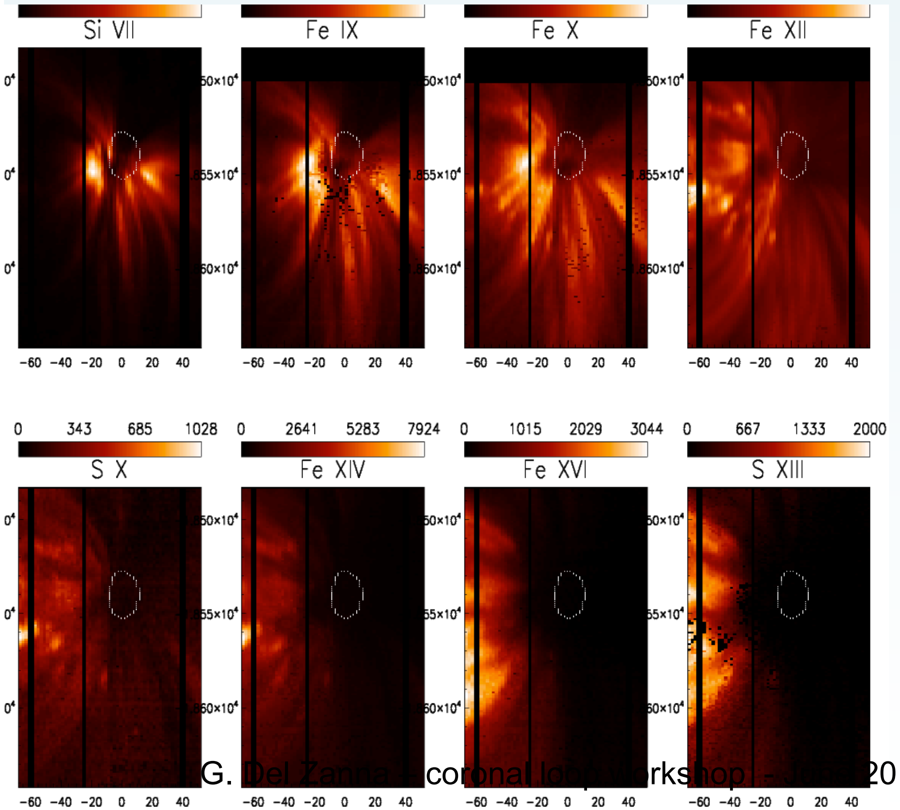
The abundances are tracers into solar wind and are related to physical processes (cf Laming model: the ponderomotive force of Alfven waves in closed loops)



FIP bias from EIS

Various papers used Si X and S X (1-2 MK):
Brooks + 2011,2012, 2015
Baker+2013, 2015

Some differences with other measurements of 1-2 MK (e.g. Del Zanna 2012) FIP bias=2--3
quiet Sun: FIP bias about 1.



Coronal outflows:
measurements are difficult, for the low signal.

In this case: FIP bias=3.2
from S XIII

sometimes the FIP bias =1

(Del Zanna, unpublished)

Coronal Outflows

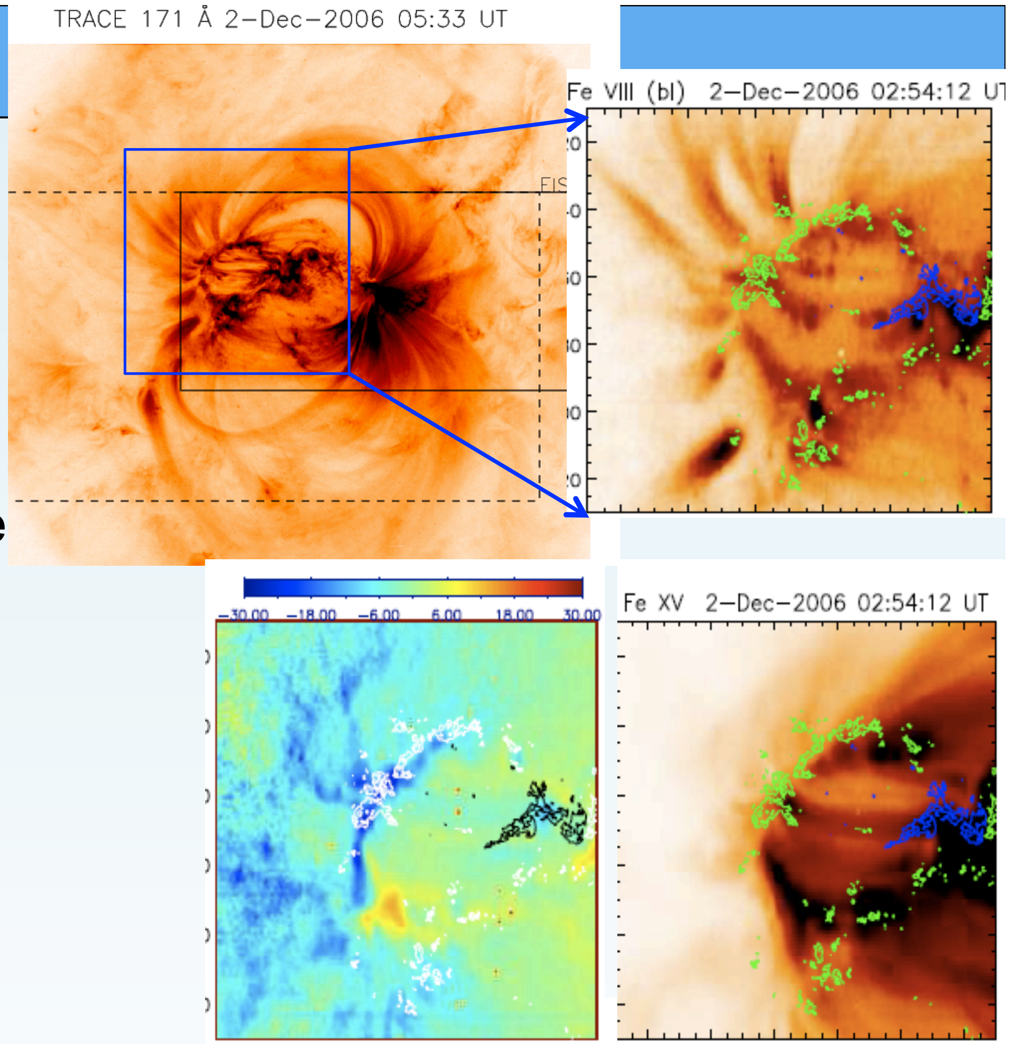
1) Located in the middle of sunspots and plage

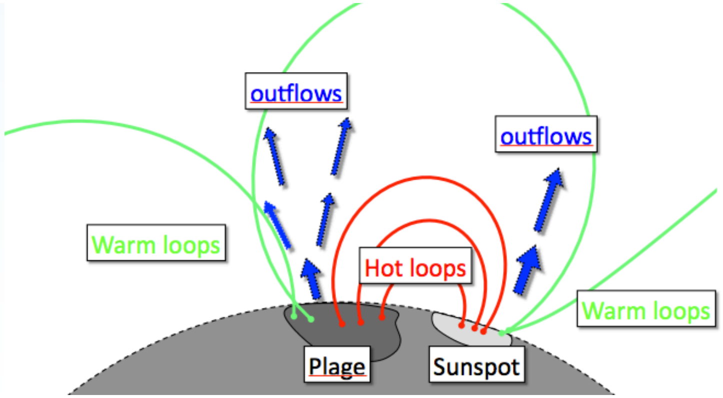
2) Have a large spatial expansion (Del Zanna 2007,2008).

3) Outflows and warm loops are not co-spatial

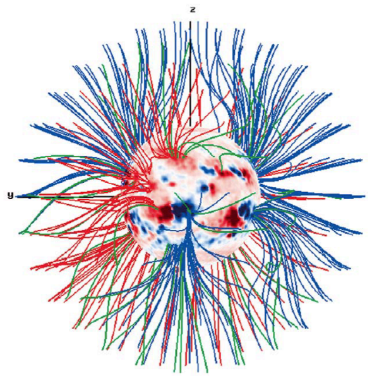
(Del Zanna 2007,2008)

See also Doschek, Harra, Baker, Demoulin, Culhane, Warren, Brooks, Ugarte-Urra, etc..)



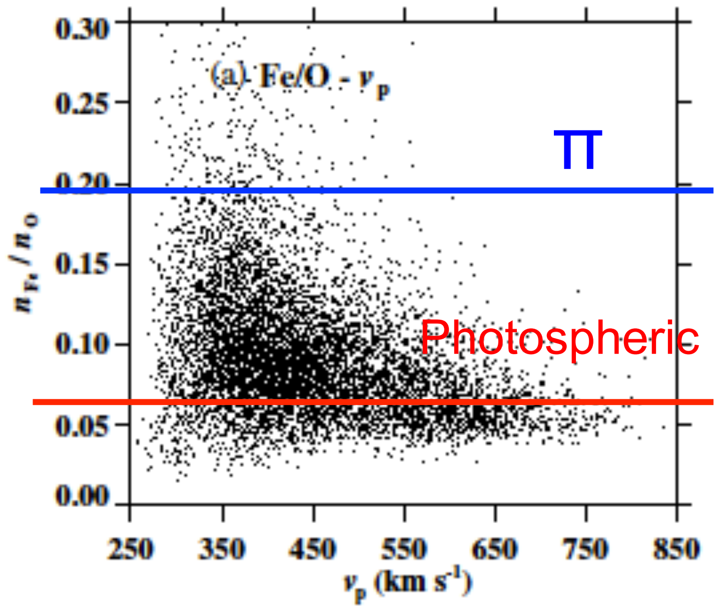


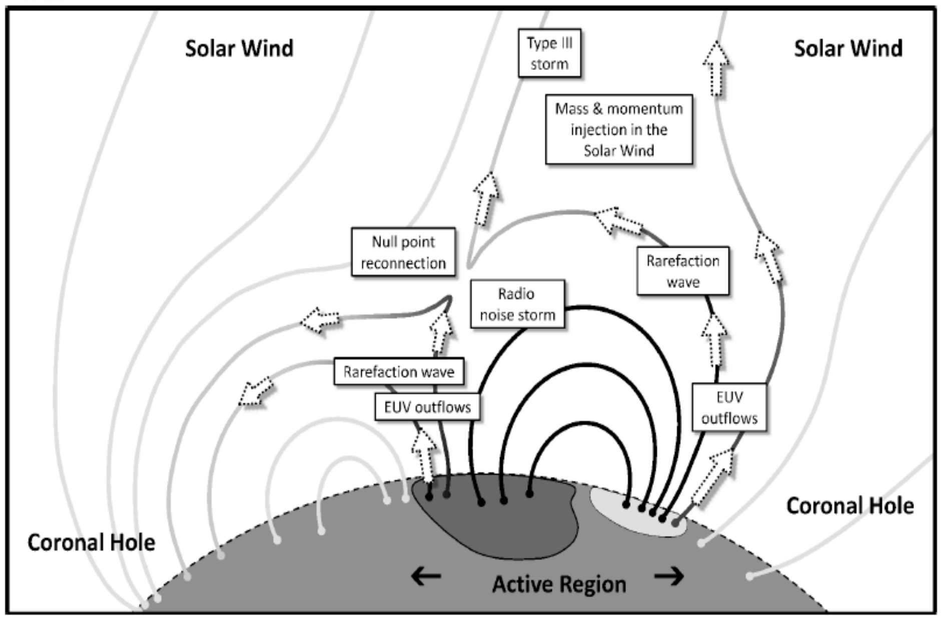
Abundances and the solar wind



Important for Solar Orbiter

Open field regions near ARs (e.g. Liewer et al. 2004).

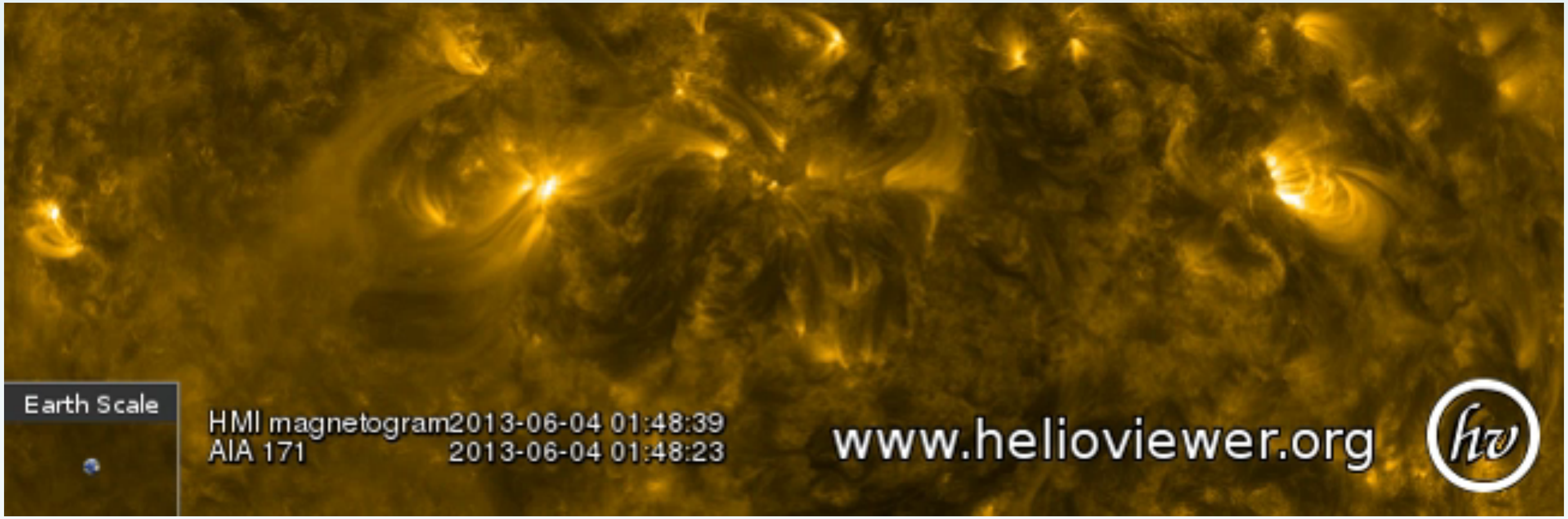




ACE: high Fe/O ratios at low wind speeds near active regions (Wang, Ko, Grappin 2009).

We developed a physical model to explain coronal outflows. Field lines open into the heliosphere (Del Zanna + 2011;Bradshaw, Aulanier, Del Zanna 2011), hence Fe/O FIP bias should be between 1 and 3.2 (as observed ?).

Thank you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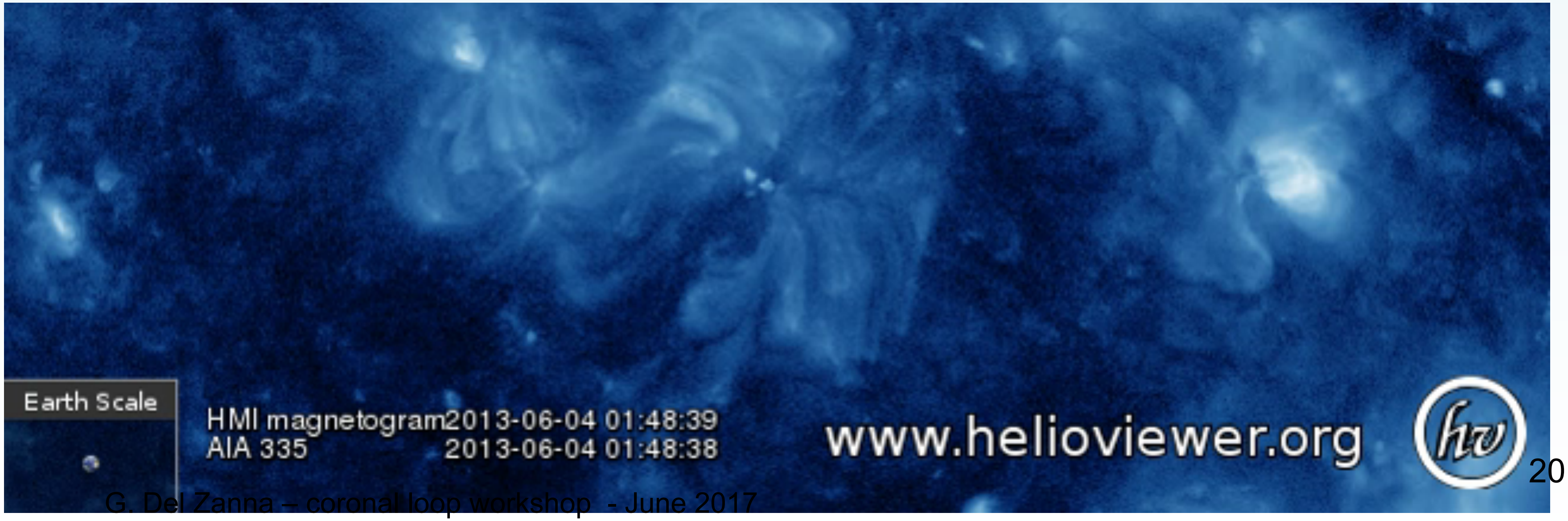
AIA 171 2013-06-04 01:48:23
www.helioviewer.org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