AR multi-thermal emission

Giulio Del Zanna

DAMTP, University of .Cambridge (UK)

Results from two very long and detailed papers:

Del Zanna (2013a) – EIS calibration
Del Zanna (2013b) – multi-topic paper

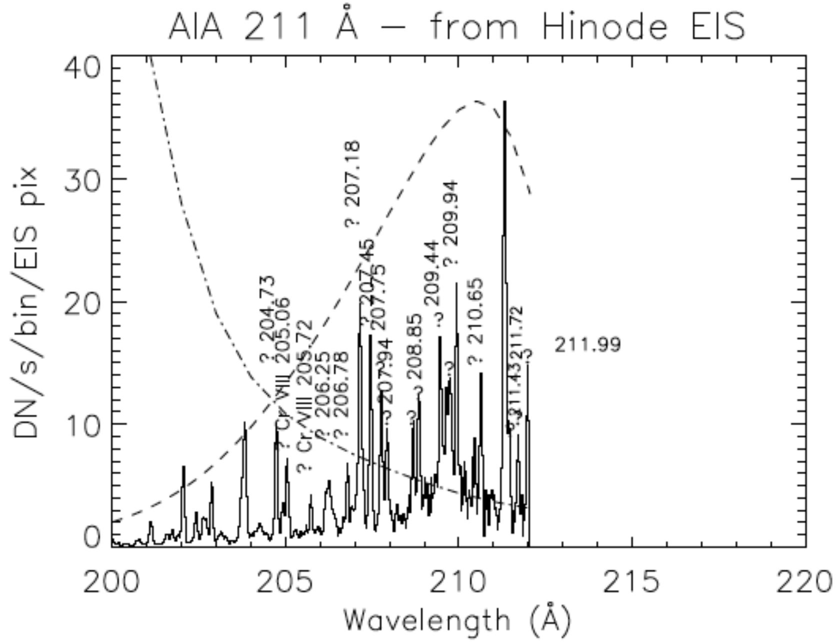
Science & Technology Facilities Council

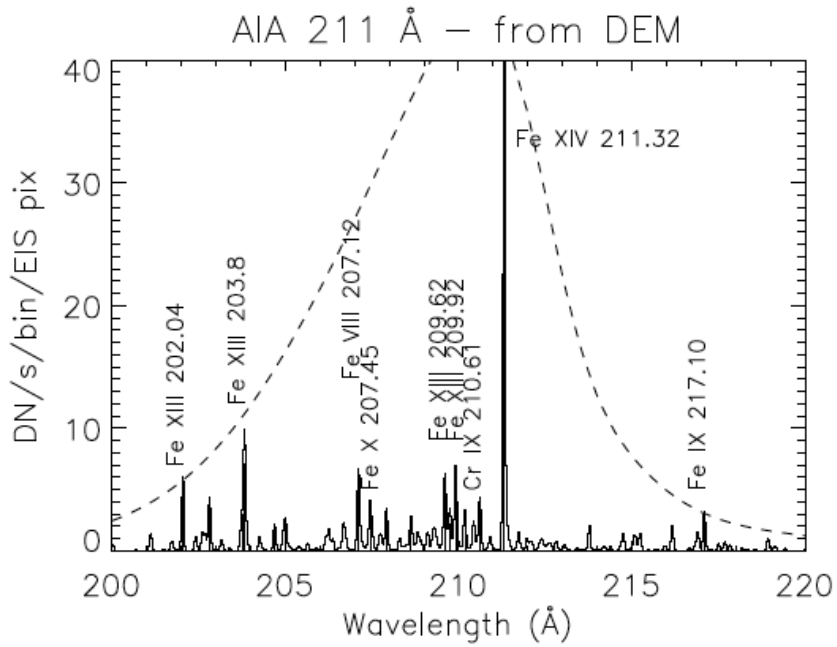
UNIVERSITY OF CAMBRIDGE

The multi-thermal nature of the AIA EUV bands

Used AIA and EIS simultaneous observations to study the AIA multi-thermal emission in AR cores, extending our previous work

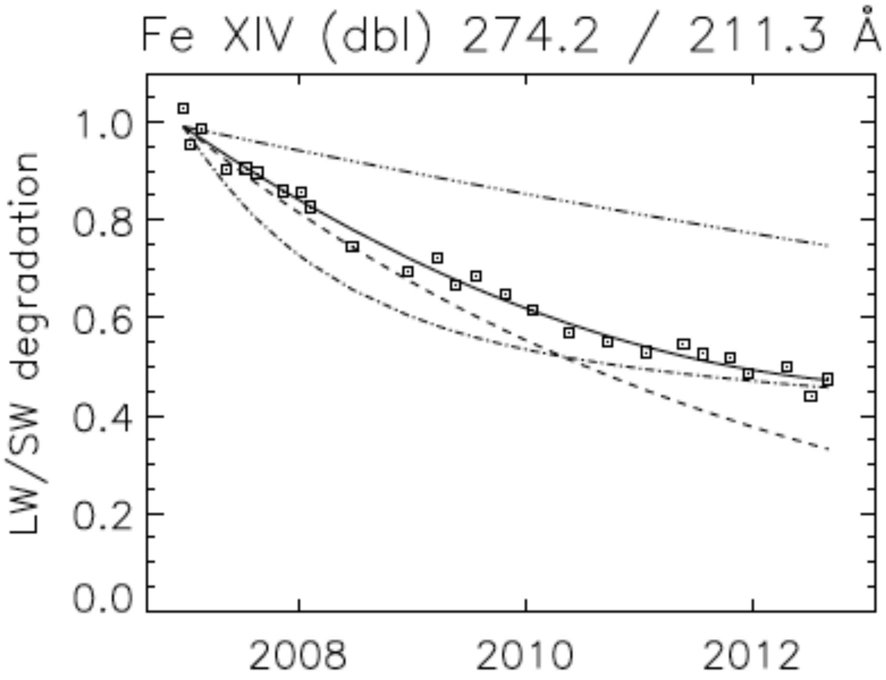
(Del Zanna O' Dwyer & Mason 2011)

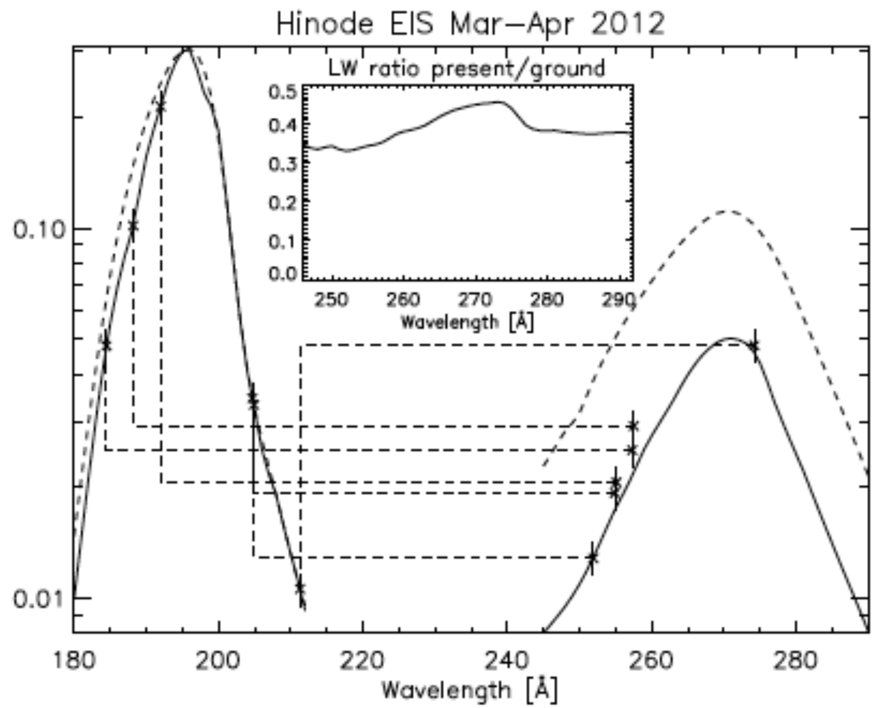




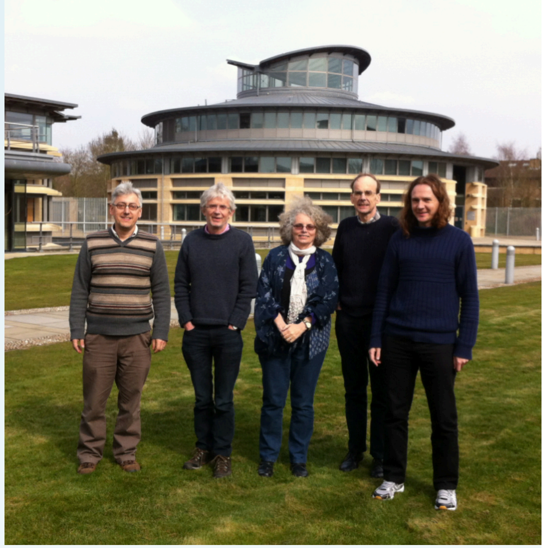
EIS and AIA calibration (Del Zanna 2013a,b)

The EIS LW sensitivity has been decreasing over time, about a factor of 2 lower by 2010, and down by a factor of 3 by 2012 .
It was already different at the start of the mission.
Cross-calibration between AIA, EVE v.3 and new EIS shows excellent agreement (NO fudge factors for AIA)





New calculations for Fe ions (CHIANTI v.8)



See poster

A) We supplemented R-matrix calculations up to n=4 with DW calculations up to n=6 (typically a few thousand levels per ion).

Fe X (Del Zanna et al. 2012)
Fe XI (Del Zanna & Storey 2011)
Fe XII (Del Zanna et al. 2012)
Fe XIII (Del Zanna & Storey 2012). We found (Fe X – 94 A):

1) The previous Fe X calculations (Malinovski et al. 1980) were incorrect.
2) DW calculations underestimate excitations $3s^2\ 3p^4$ 4s levels.
3) Decays from the 3s $3p^5$ 4s levels are much larger, lines were unidentified.

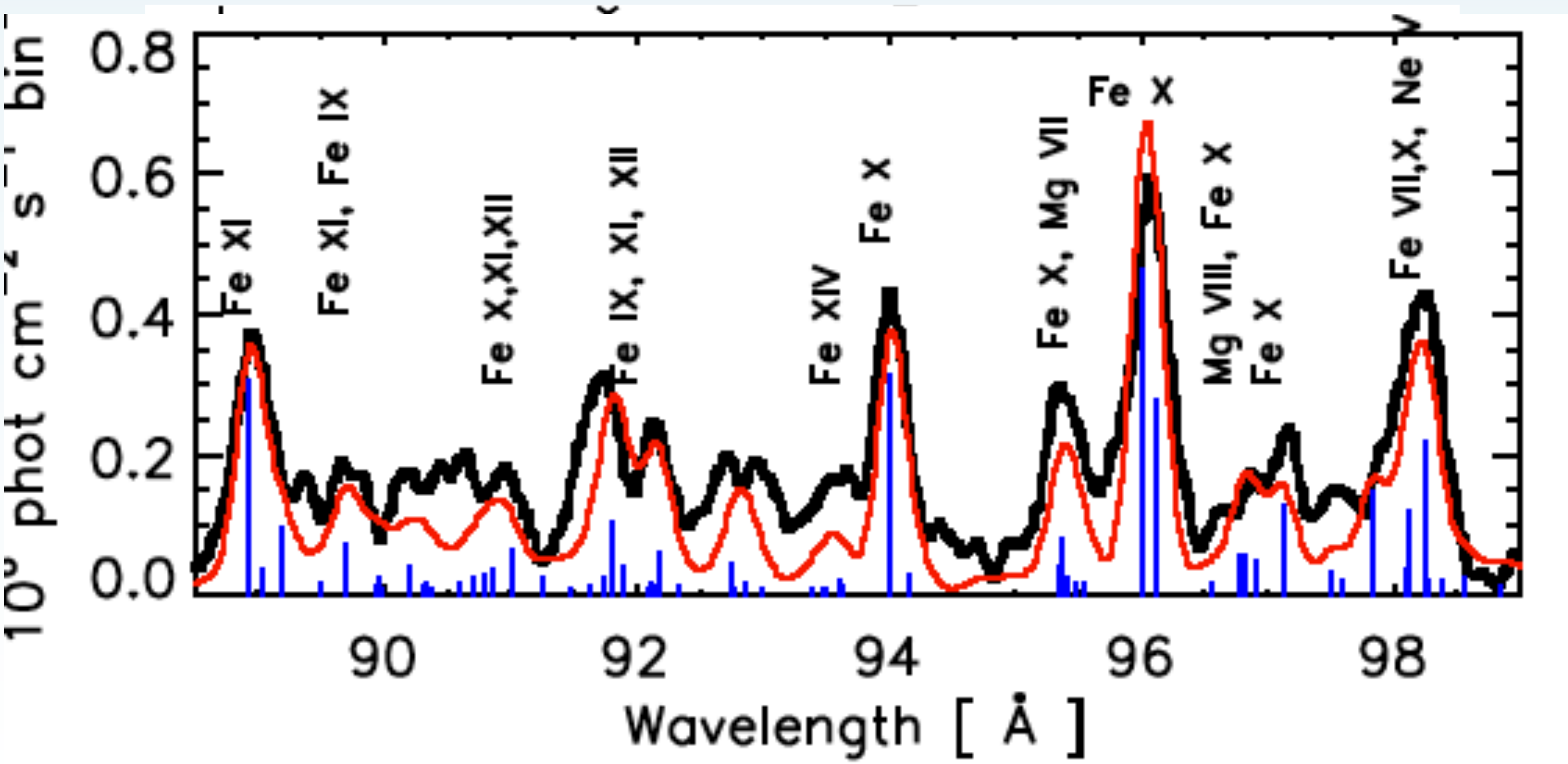
B) New calculations for Fe VIII,IX (O'Dwyer etal 2012) - v7.1

C) New atomic data for Fe VIII

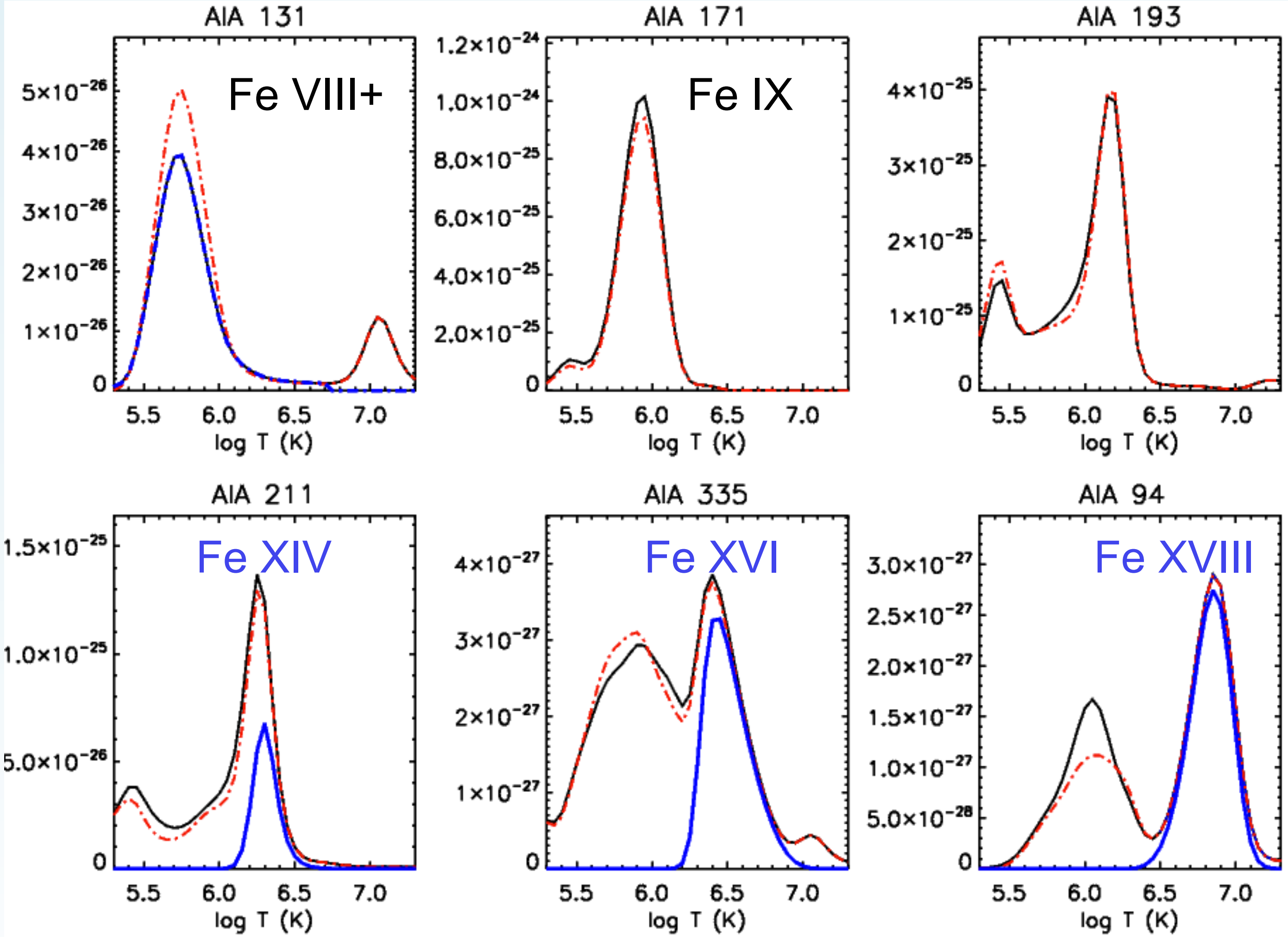
Fe ions in the soft X-rays

A full benchmark has led to many new identifications (Del Zanna 2012)

- **Black: calibrated quiet Sun spectrum from Manson (1972).**
- **Red: theoretical spectrum obtained with the new atomic data and identifications.**



New AIA responses for DEM analysis



Black: new responses

Red: CHIANTI v.7.1 (note: 131 A 30% higher, 94 A lower)

Blue: adjusted

** Some differences with el. abundances and densities.

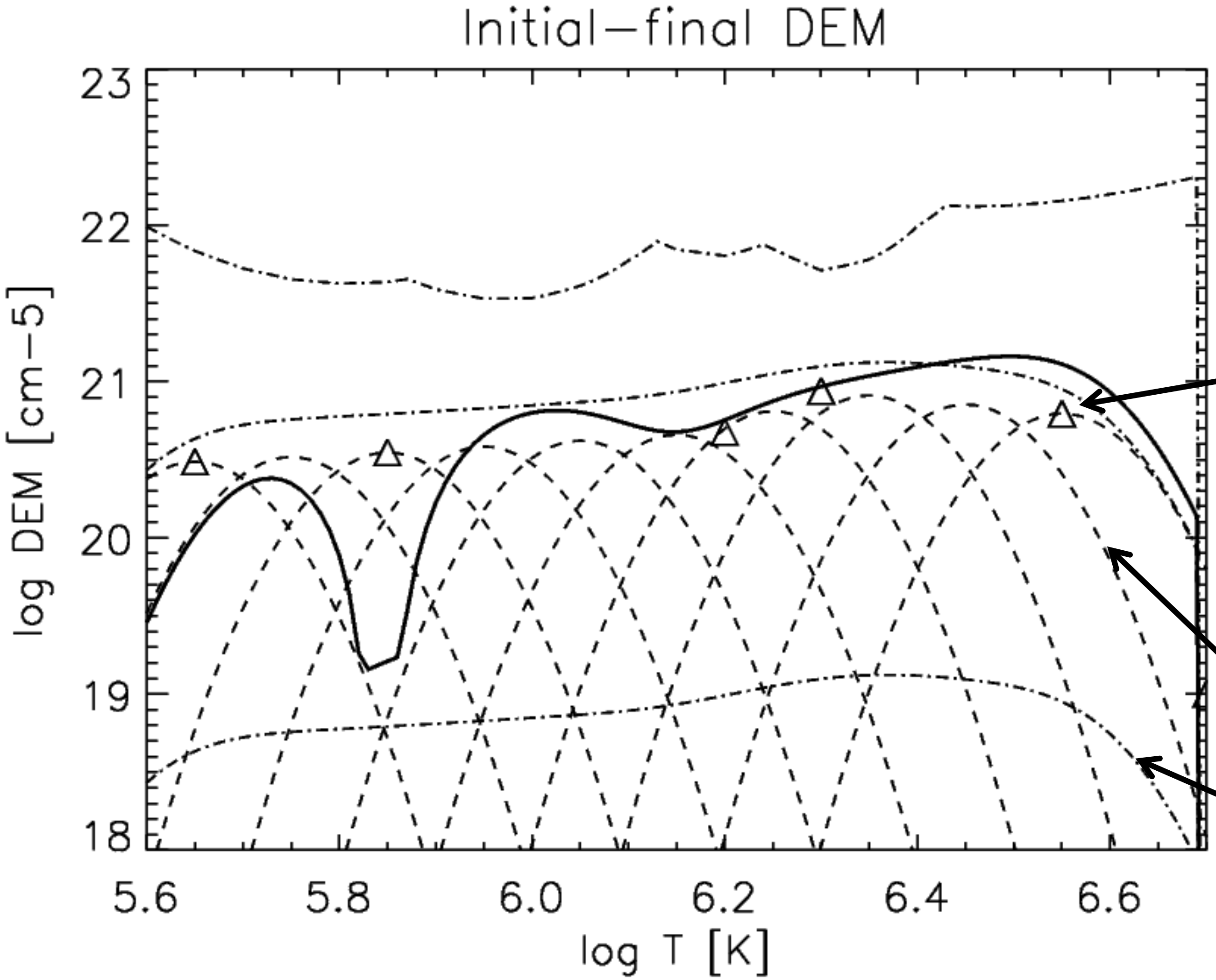
AIA DEM inversion codes..

Tested various recent ones with the same input responses but they all failed to represent all the AR structures

Yet another AIA DEM code

Upper limit: from the EM Loci

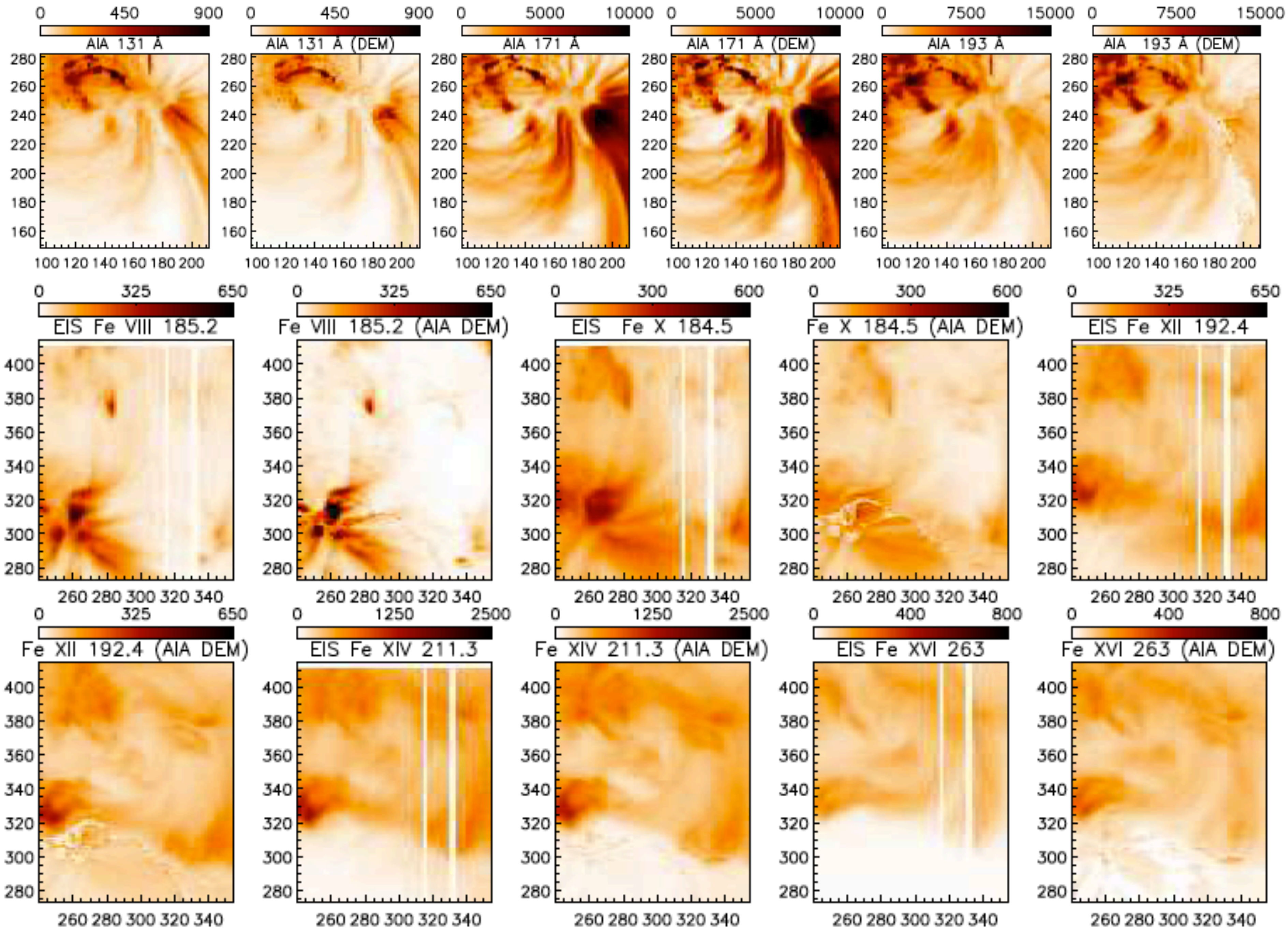
DEM starting estimate (triangles, dot-dash)



$$\mathrm{DEM_L} \equiv \frac{I_{\mathrm{ob}}}{Ab(X)\int_T C(T)dT}$$

DEM sum of Gaussian functions

Lower limit


AIA 131 Å
AIA 131 Å (DEM)
AIA 171 Å
AIA 171 Å (DEM)
AIA 193 Å
AIA 193 Å (DEM)
EIS Fe VIII 185.2
Fe VIII 185.2 (AIA DEM)
EIS Fe X 184.5
Fe X 184.5 (AIA DEM)
EIS Fe XII 192.4
Fe XII 192.4 (AIA DEM)
EIS Fe XIV 211.3
Fe XIV 211.3 (AIA DEM)
EIS Fe XVI 263
Fe XVI 263 (AIA DEM)

Contributions to the AIA EUV band – AR cores

- 94 mostly a new Fe XIV (Del Zanna 2012)

$$I(\mathbf{Fe}\,\textsc{xviii}) = I(94\ \text{Å}) - I(211\ \text{Å})/120. - I(171\ \text{Å})/450.$$

- 131 multi-thermal, continuum
- 171 mostly Fe IX (0.6-1.2 MK)
- 193 only about 50% Fe XII

$$I(\mathbf{Fe}\,\textsc{xii}) = 0.7 \times (I(193\ \text{Å}) - I(171\ \text{Å})/2)$$

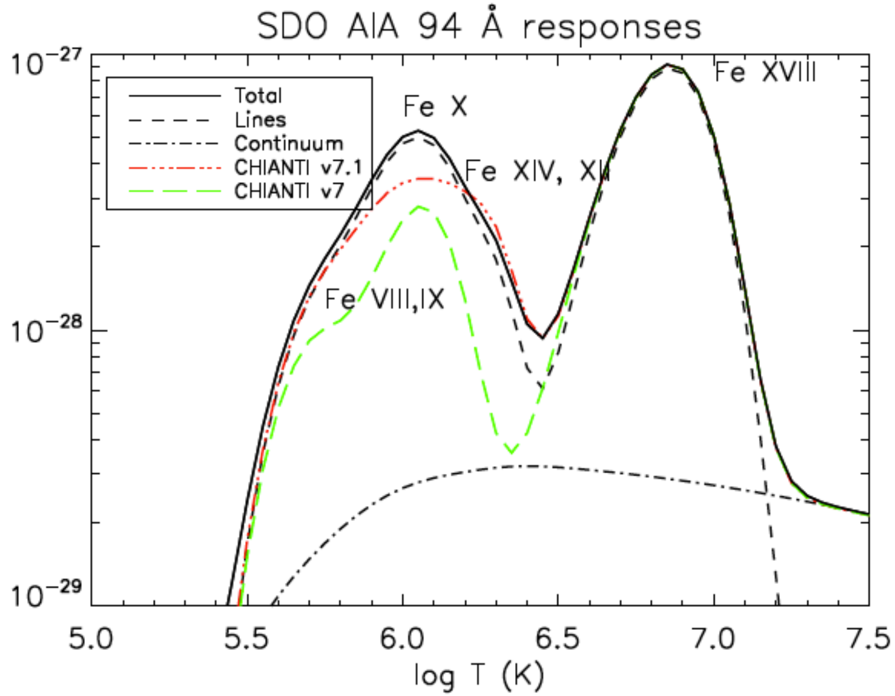
- 211 only about 50% from Fe XIV

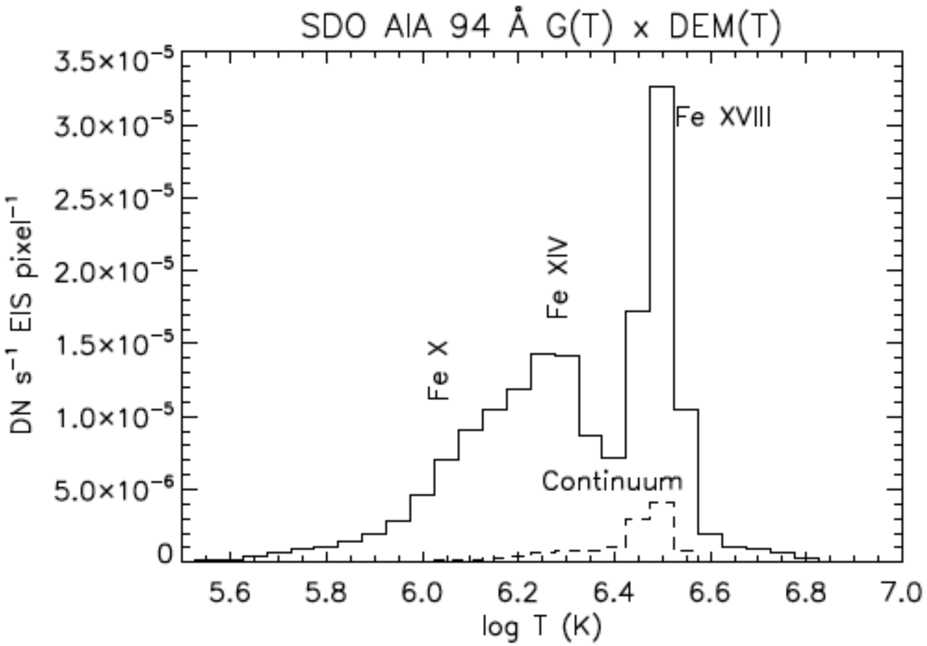
$$I(\mathbf{Fe}\,\textsc{xiv}) = I(211\ \text{Å}) - I(171\ \text{Å})/17 - I(193\ \text{Å})/5$$

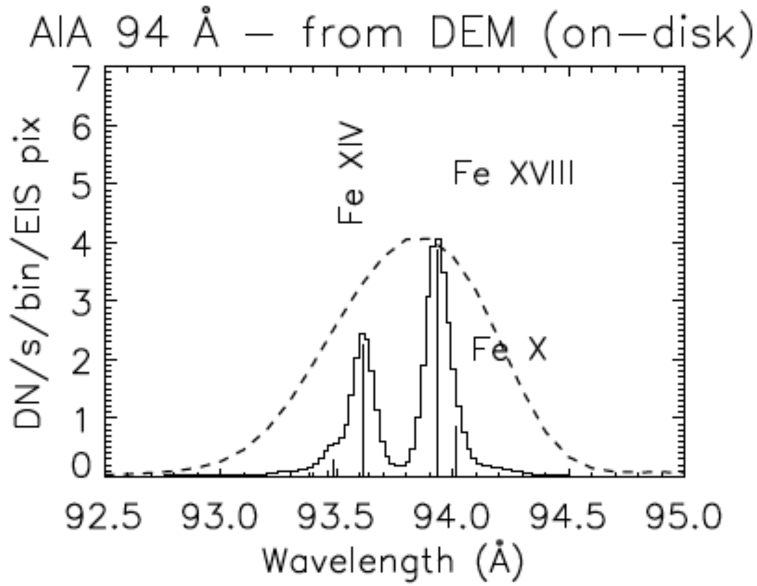
- 335 mostly Fe XVI (3 MK)

$$I(\mathbf{Fe}\,\textsc{xvi}) = I(335\ \text{Å}) - I(171\ \text{Å})/70$$

AIA 94 A

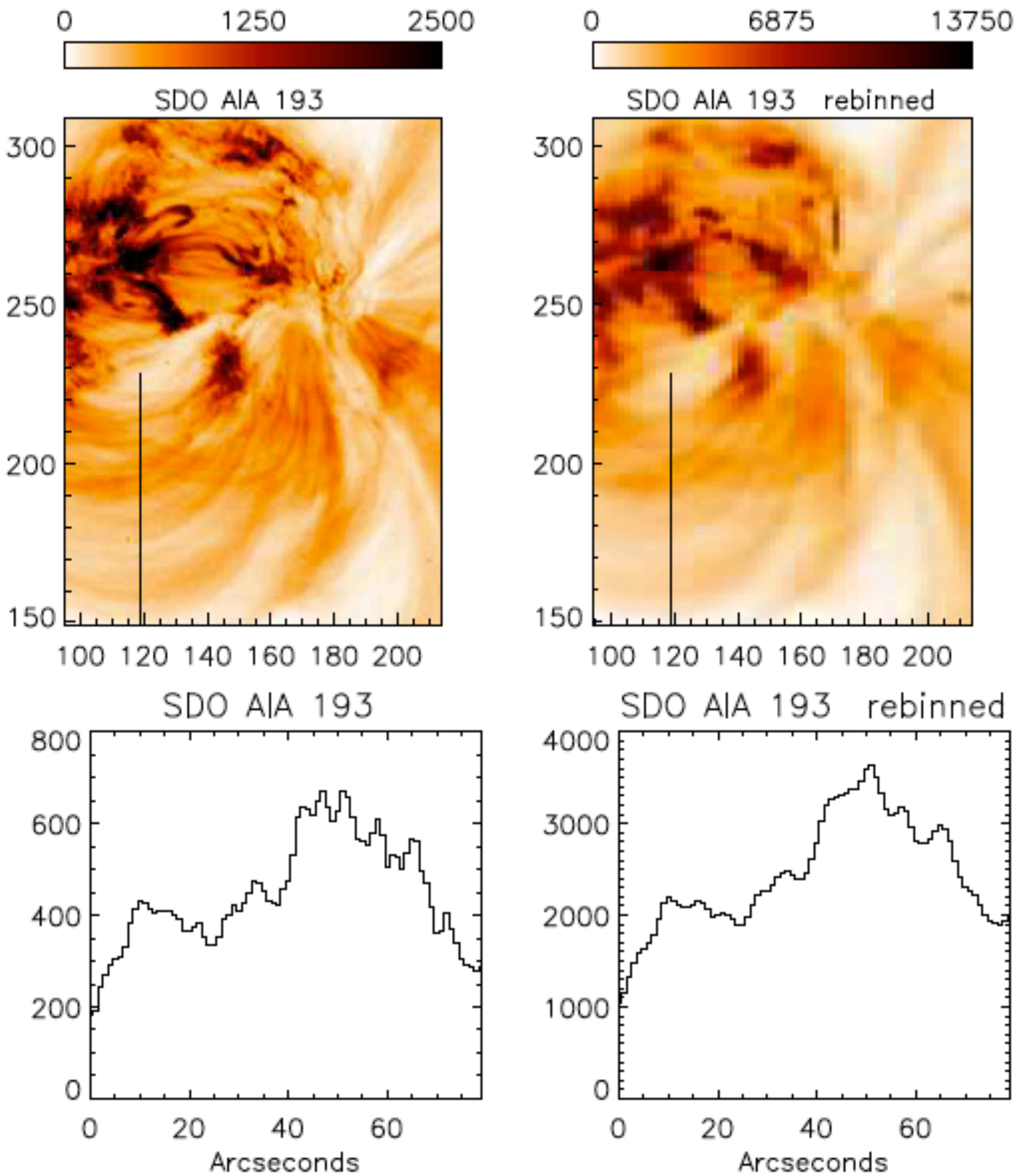


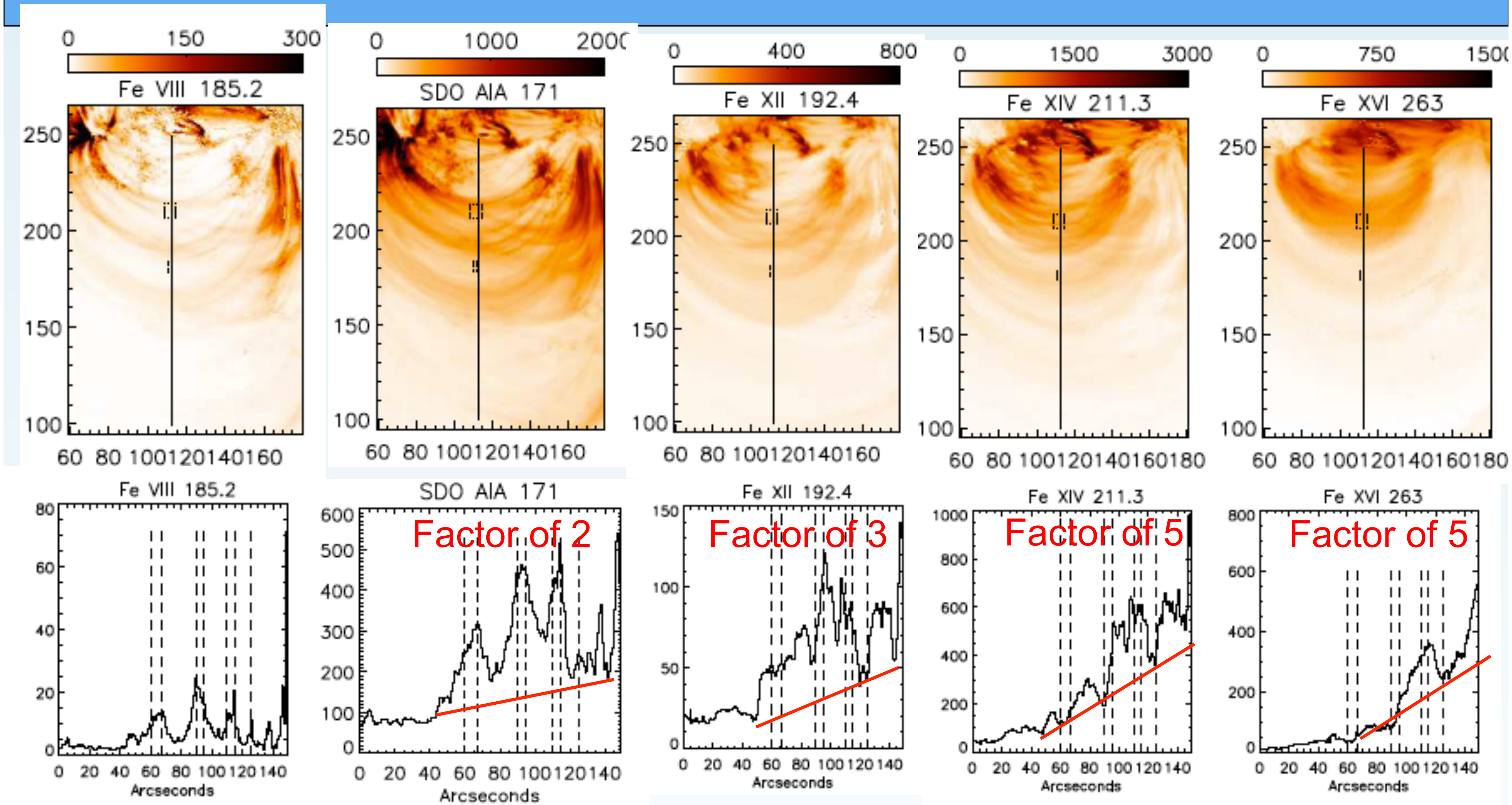




- Fe XIV strongest contribution (except when Fe XVIII is present)
- Fe XVIII is often present, but in many cases it is formed at 3 MK and not 7 MK!

AIA 193, original and rebinned to Hinode EIS spatio-temporal resolution.





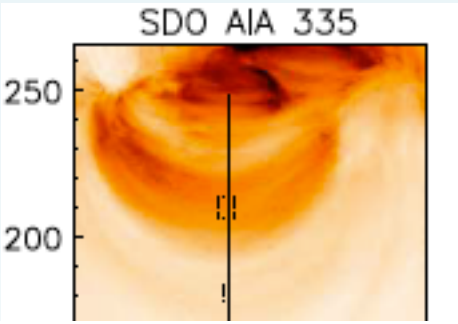
Loops at different temperatures are not co-spatial.

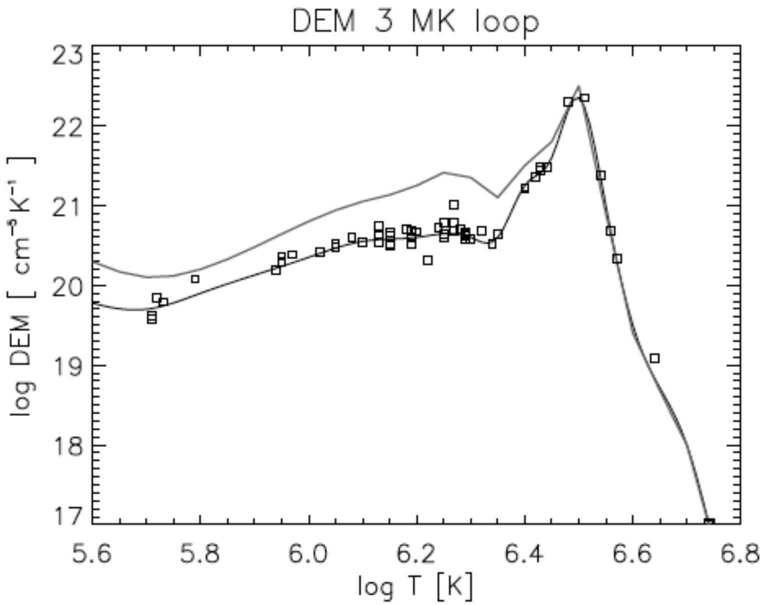
Unresolved 1-3 MK emission (Del Zanna & Mason 2003):

- much lower at AIA resolution (compared to TRACE)
- nearly absent < 1 MK, progressive increase
- increase of a factor of 2 is due to increased iron abundance (Del Zanna 2012)

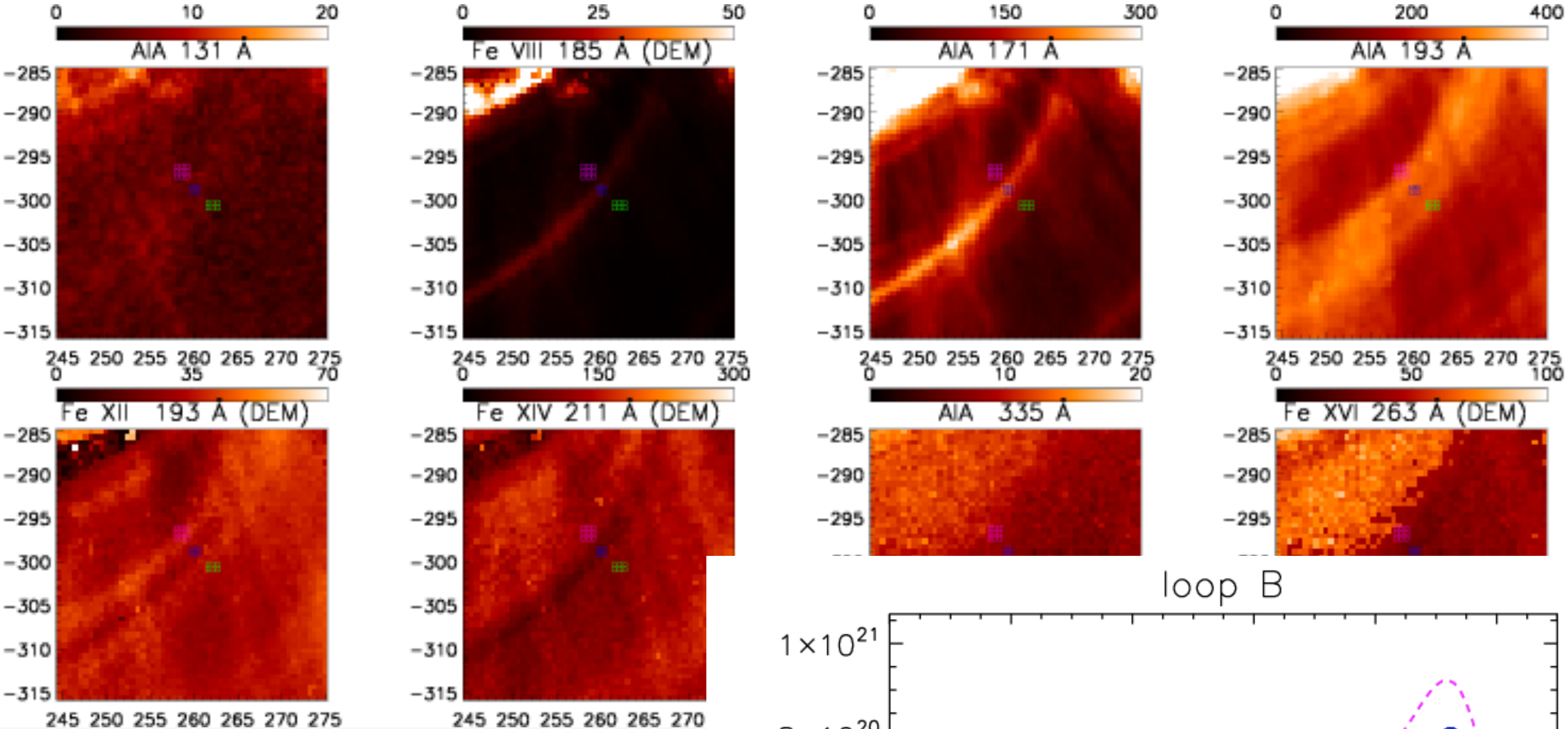
New abundances for 3 MK loops

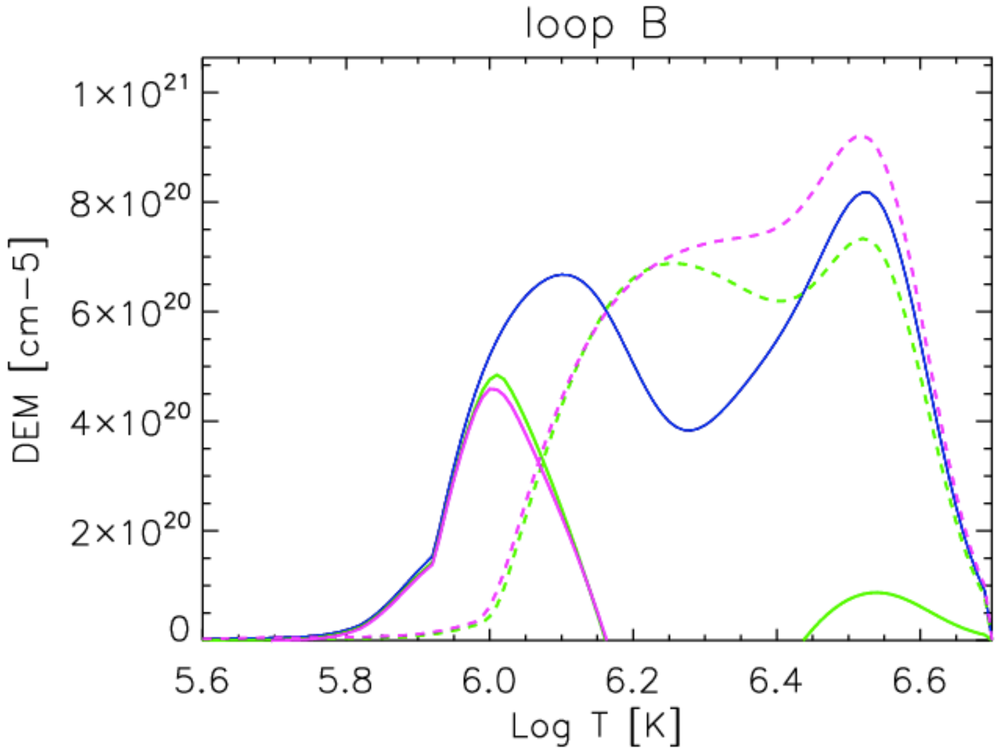
Hot core loops nearly isothermal
New EM and Ne →
Path lengths → at least an increased Fe by a factor of 3.16
FIP bias about 3





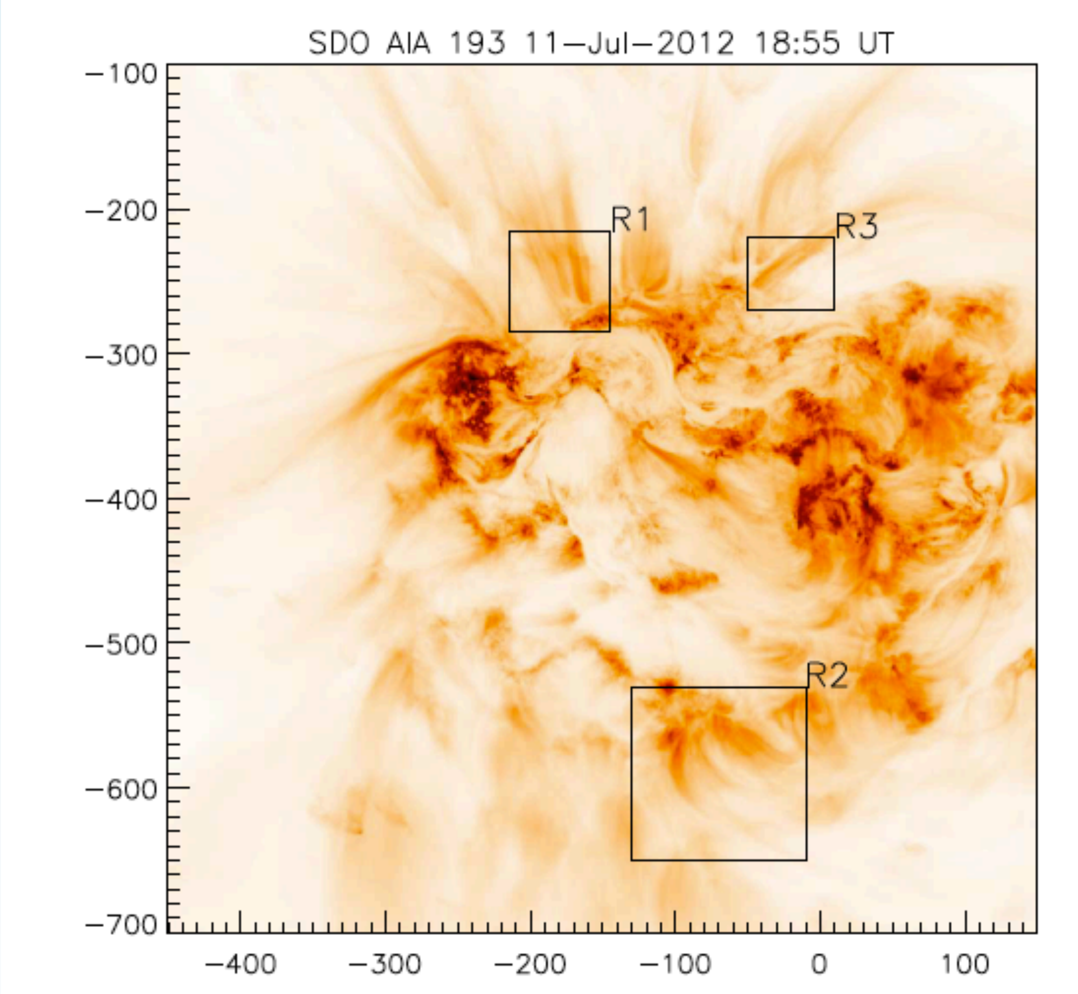
El.	Phot.	Coronal	Present	FIP (eV)
H	12	12	12	13.56
C	8.43	8.59	-	11.26
N	7.83	8.0	-	14.53
O	8.69	8.89	-	13.61
Ne	7.93*	8.08	-	21.56
Mg	7.6	8.15	8.10	7.64
Al	6.45	7.04	6.95	5.98
Si	7.51	8.10	8.00	8.15
P	5.41	-	5.41	10.49
S	7.12	7.27	7.17	10.36
Ar	6.40*	6.58	6.30	15.76
K	5.03	-	5.53	4.34
Ca	6.34	6.93	6.87	6.11
Cr	5.64	-	6.14	6.78
Mn	5.43	-	5.93	7.43
Fe	7.50	8.10	8.00	7.87
Ni	6.22	6.84	6.53	7.63





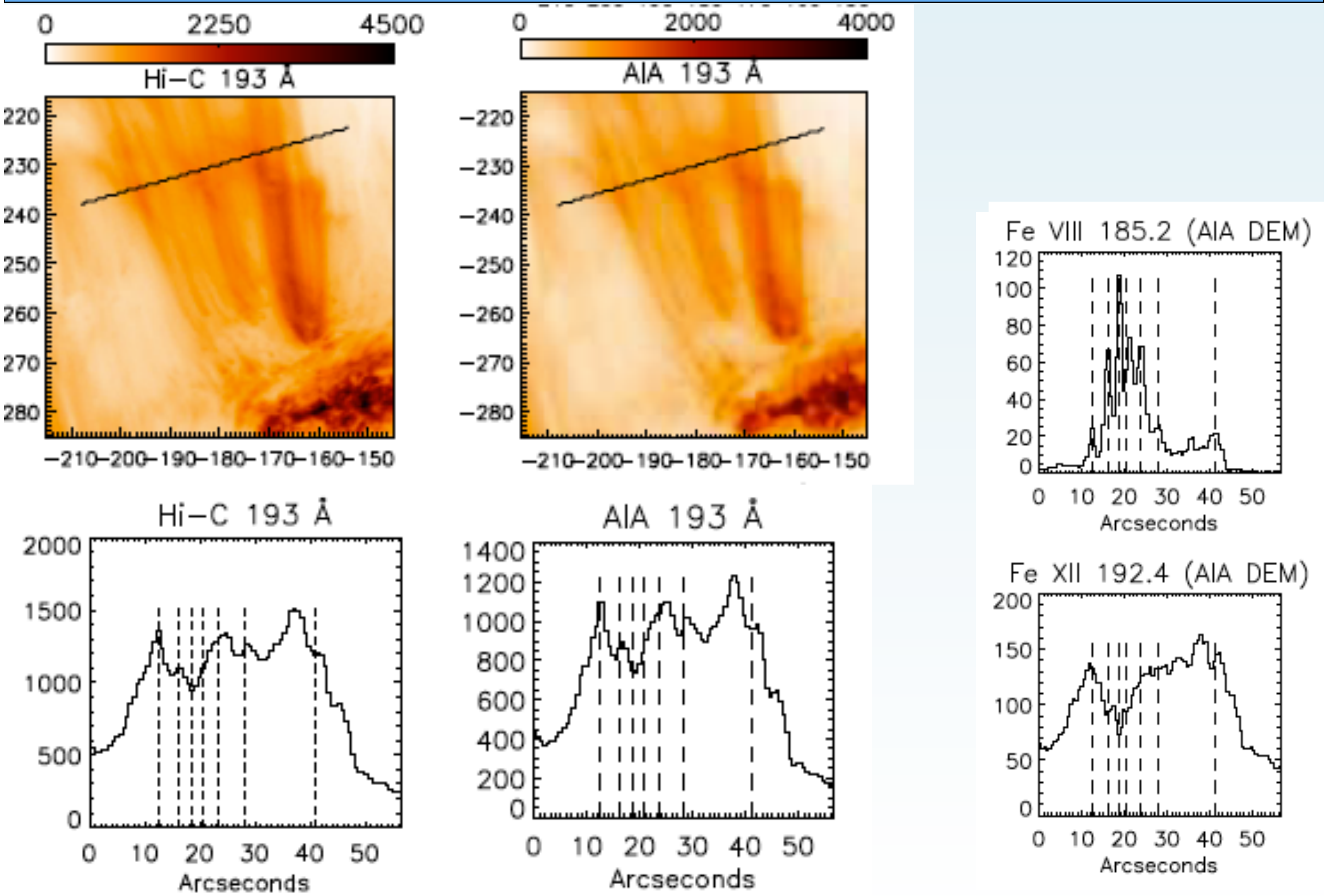
Warm loops as seen in AIA 171 A (Fe IX) are nearly isothermal even with AIA DEM analysis (cf. Del Zanna 2003, Del Zanna & Mason 2003) But the DEBATE is still going (cf. Schmelz et al. 2013)

Hi-C



AIA DEM on full Hi-C FOV. Main result: 1-2 MK coronal emission still unresolved at Hi-C resolution (0.25”) in most places ☹

R1



Hi–C 193 Å
AIA 193 Å
Hi–C 193 Å
AIA 193 Å
Arcseconds
Fe VIII 185.2 (AIA DEM)
Fe XII 192.4 (AIA DEM)

Conclusions

- Most `quiescent' hot core and warm loops are nearly isothermal in their cross-section.
- Most loops at different temperatures are intermingled (not cospatial)
- The emission above 1 MK is largely unresolved even at Hi-C resolution. Below 1 MK is nearly resolved by AIA.
- The unresolved 1.5-2.5 MK emission is much lower than previously observed (TRACE, CDS). Largely due to increased iron abundance.
- The iron abundance varies in different AR structures. Hot core loops have FIP enhancement of 3-4.
- 2-3 MK emission is important in the AIA 94 A (even for Fe XVIII)