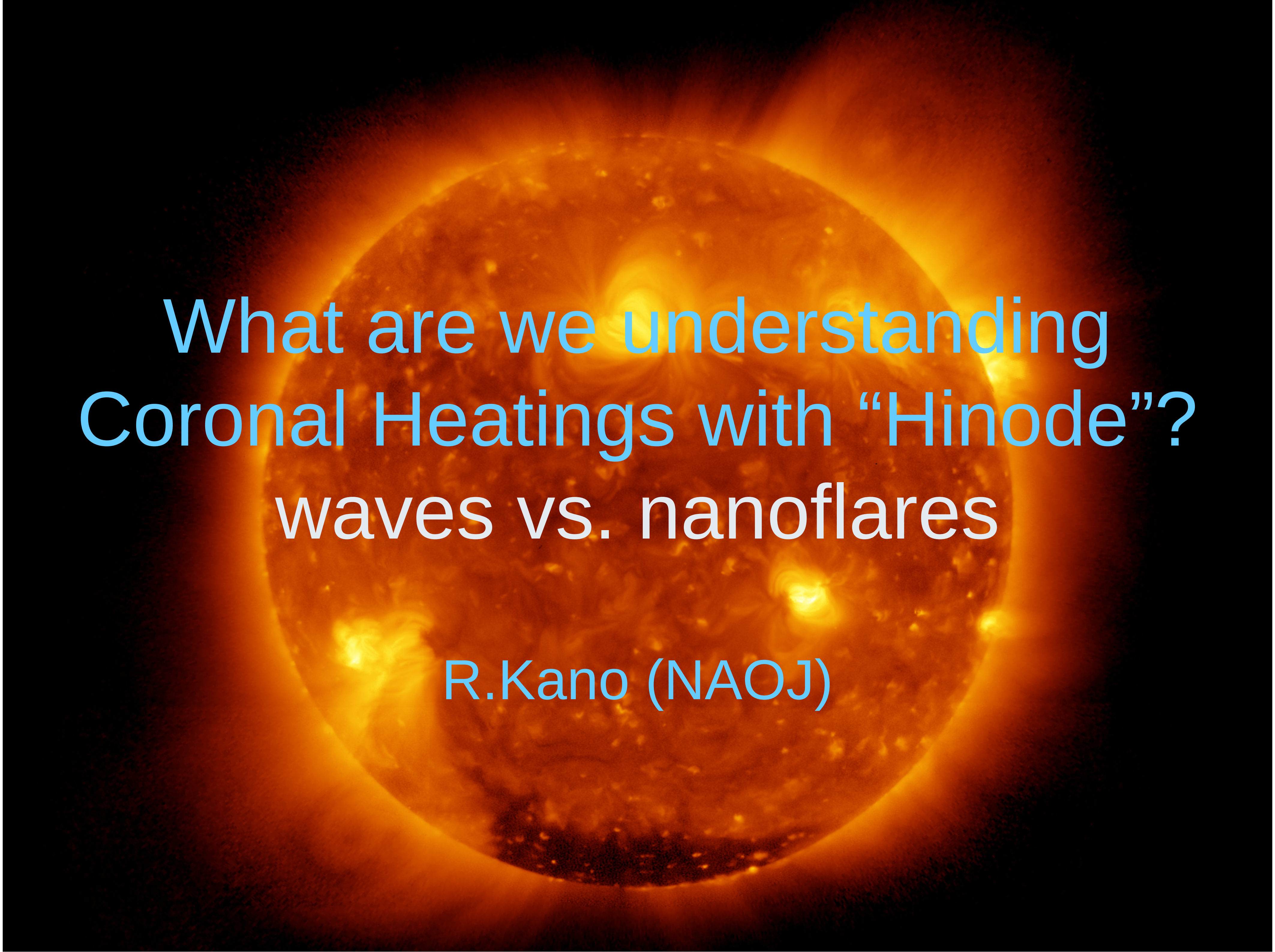


What are we understanding Coronal Heatings with “Hinode”?

waves vs. nanoflares

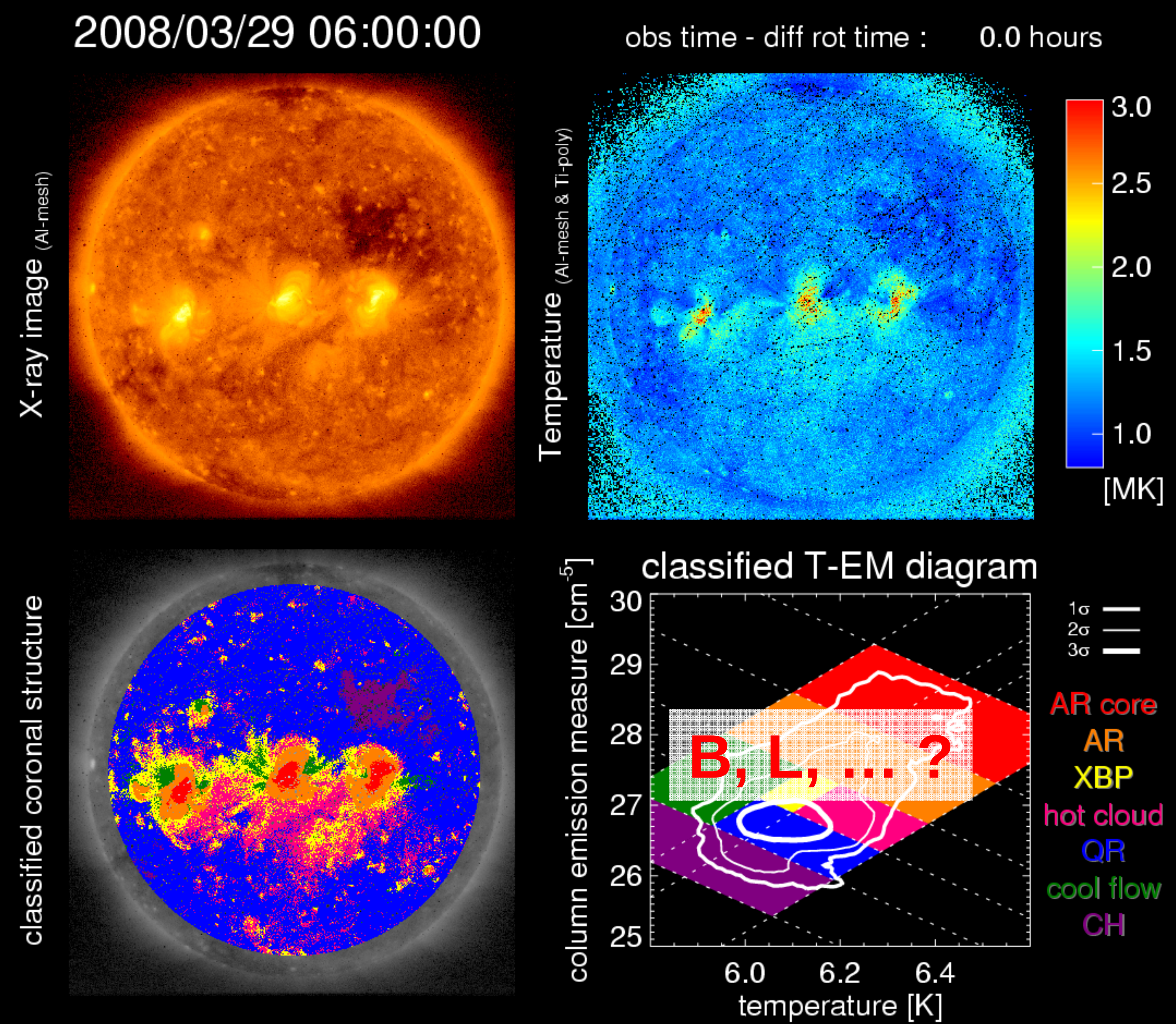
R.Kano (NAOJ)

What kinds of corona?

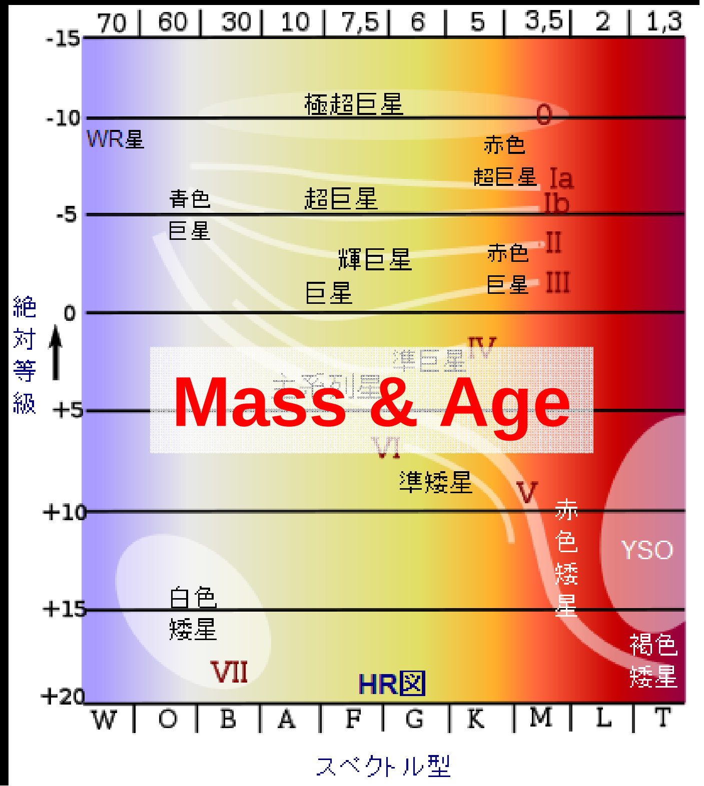
- Different regions
  - Active Regions, Quiet Sun, and Coronal Holes.
- Different magnetic topologies
  - closed fields (i.e. coronal loops) and open fields.
- Various time scales
  - (quasi-)steady structures and transient events (i.e. flares, microflares).
- Various spatial scales
  - coronal loops, diffuse extended corona, XBPs, …

Classification of Coronal Features by Physical Parameters

Narukage et al. (Hinode-3)

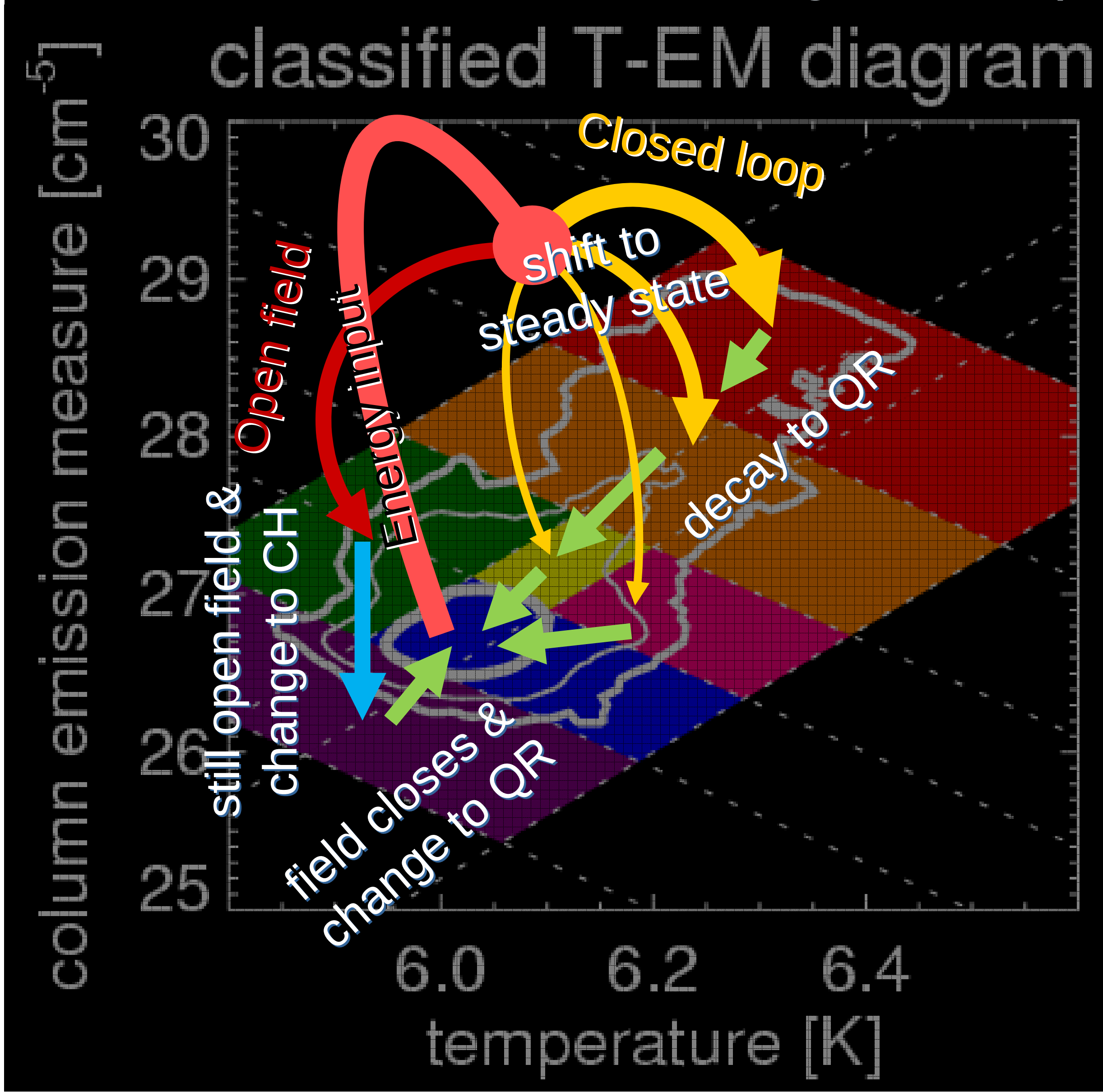


Classification of Stars HR diagram

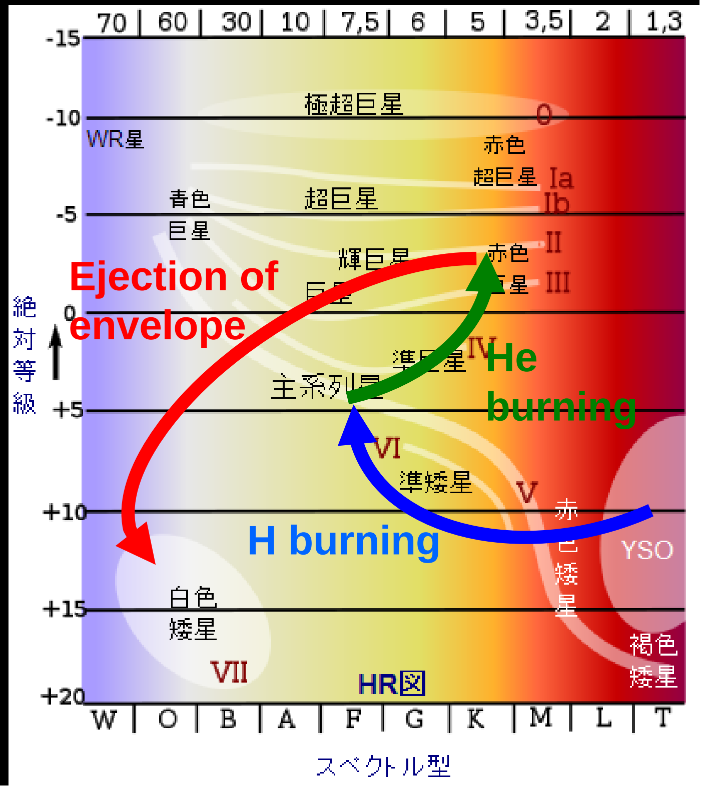


Evolution of Coronal Features on T-EM diagram

Narukage et al. (Hinode-3)



Evolution of Stars



Contents

- What topics are we studying by Hinode?
  - Heating Functions ***H(s)***.
    - Loop-top, footpoint, or uniform heatings.
  - Nanoflares.
    - Super-hot components
    - Intensity fluctuations
  - (Velocity).
  - Relation with photospheric magnetic fields.
- What topics should we study by Hinode?
- What I hope for Solar-C.

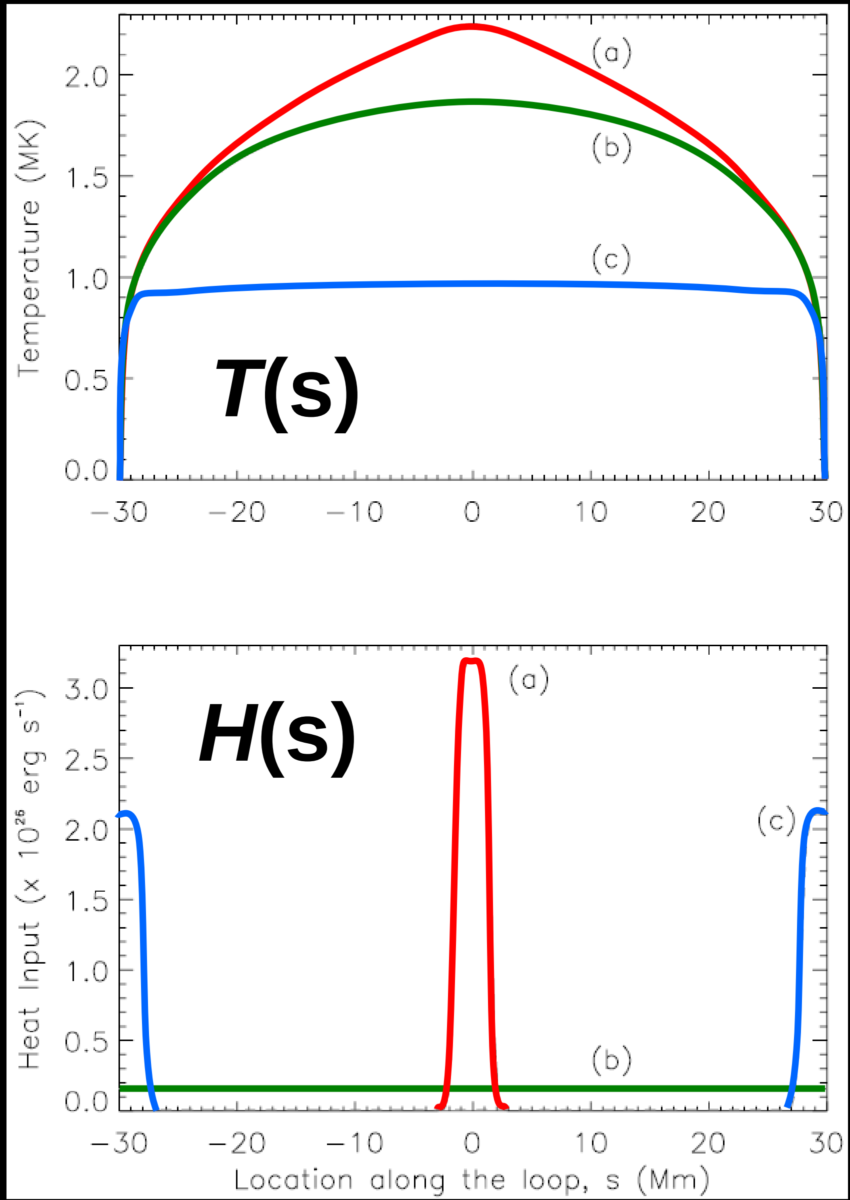
Heating Function

- In (quasi-)steady coronal loops, ***T(s)*** is coupled with ***H(s)***.

$$H(s) = n^2 \Lambda(T) - \frac{\partial}{\partial s}\left(\kappa_{\parallel} \frac{\partial T}{\partial s}\right)$$

Heating **Radiative Cooling** **Conductive Cooling**

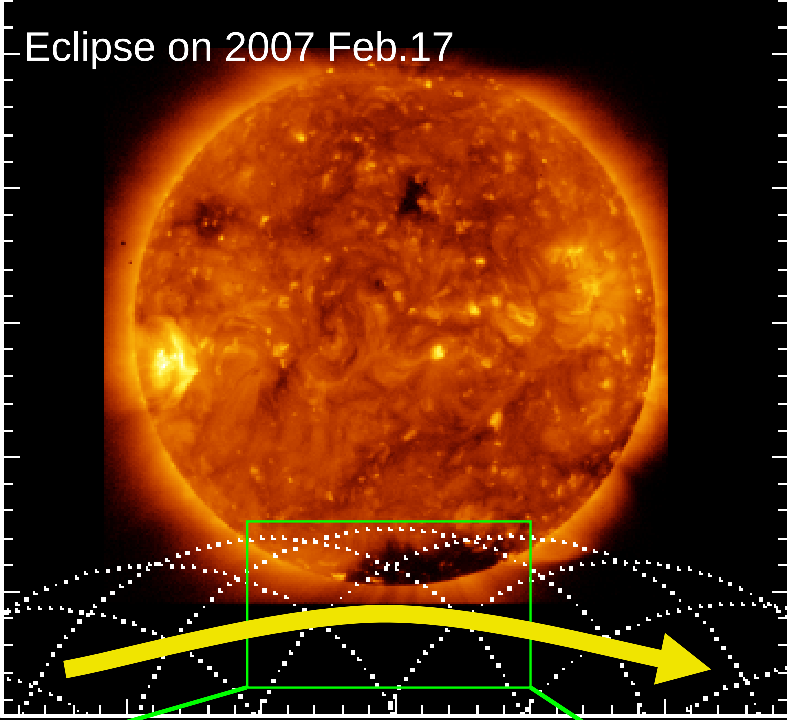
- However, there are
  - Multi-temperature structures (due to fine structures?)
  - Velocity fields
  - etc.

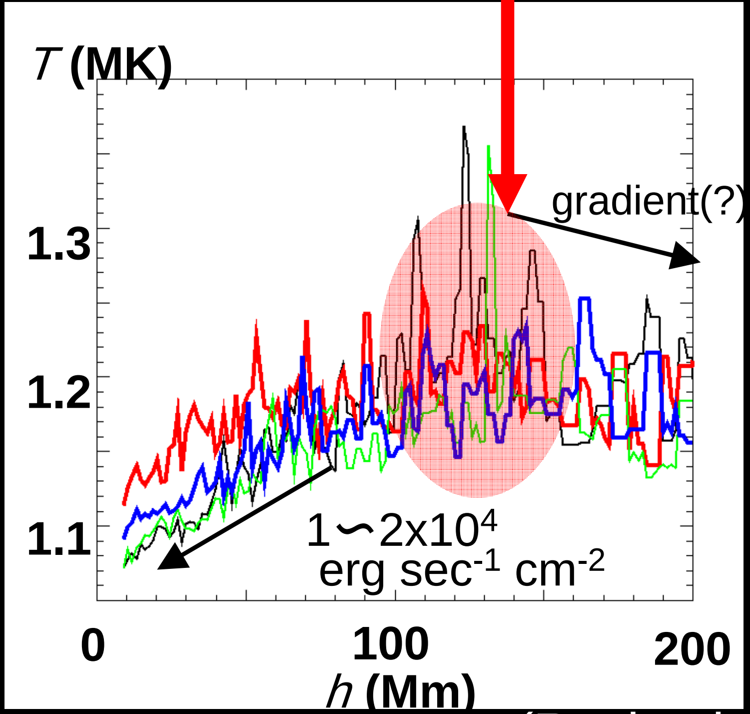


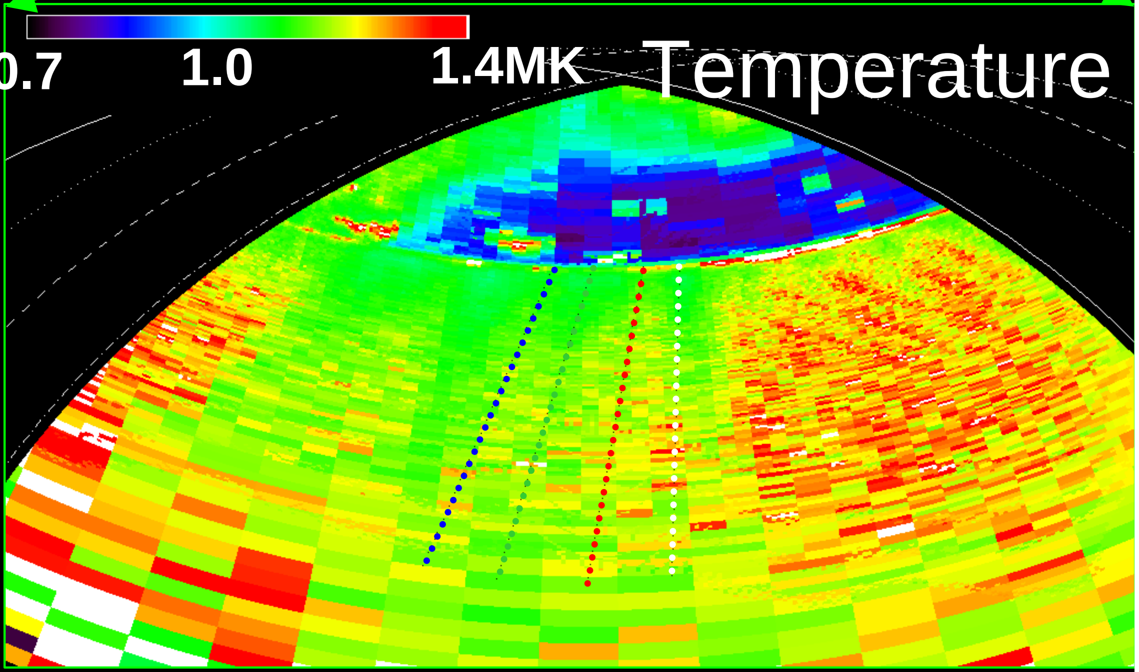
Heating Function: above polar regions

Kano et al. (2008, PASJ)

- **XRT** filter ratio temperature increased with hight above polar regions.
- The T-grad. might suggest heating not near footpoints but at high altitude.



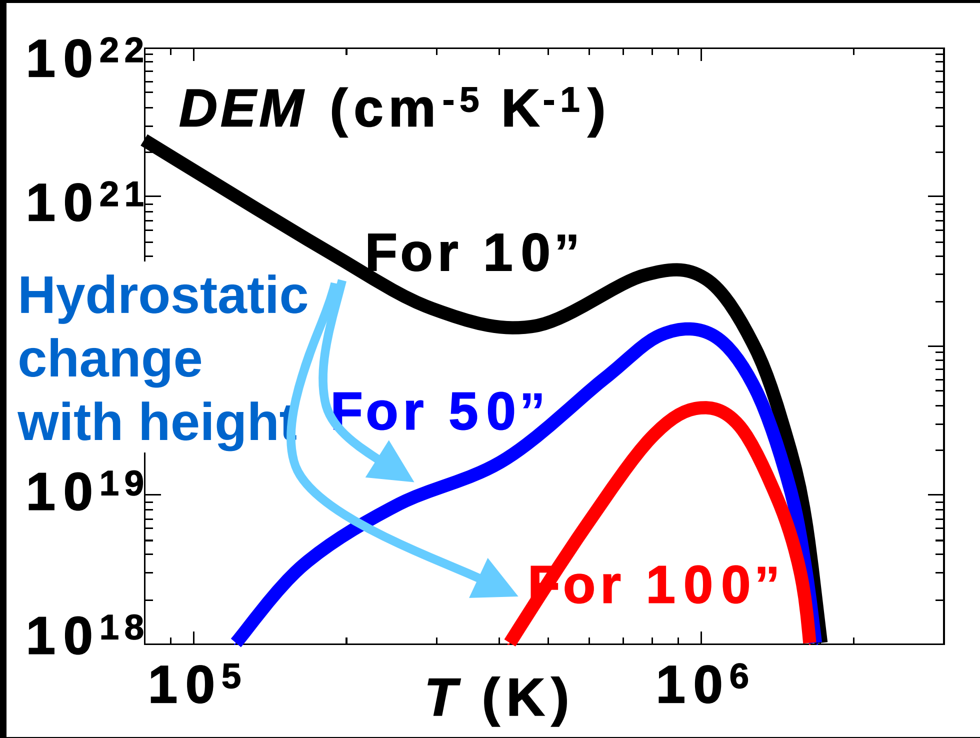




(Revised due to a new calibration data)

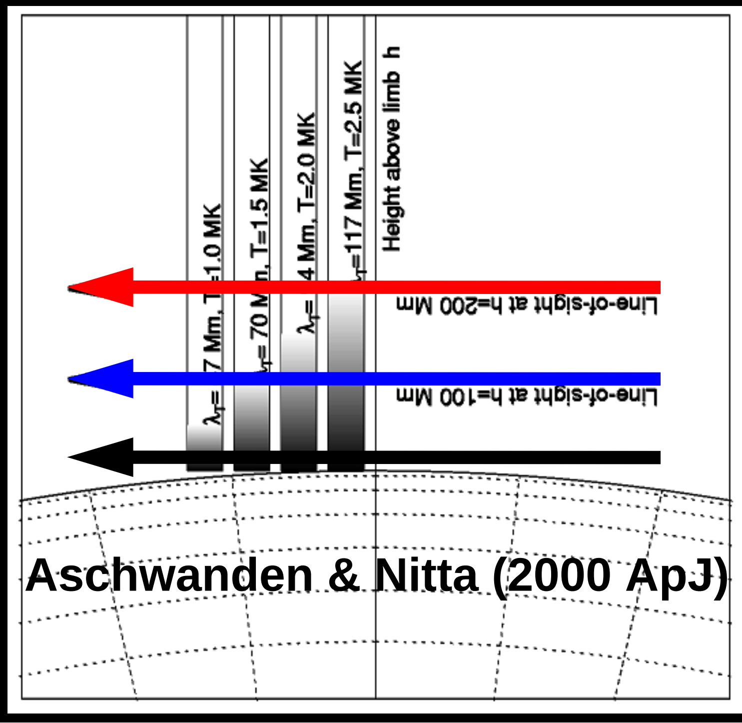
Heating Function: above polar regions with multi-T analysis

Kano (Hinode-3)



- However, based on multi-T analysis, the **EIS** & **XRT** data above polar regions are well explain with hydrostatic changes of isothermal vertical threads with several temperatures as Aschwanden & Nitta (2000 ApJ) suggested.

➔Isothermal structure suggests footpoint heating.

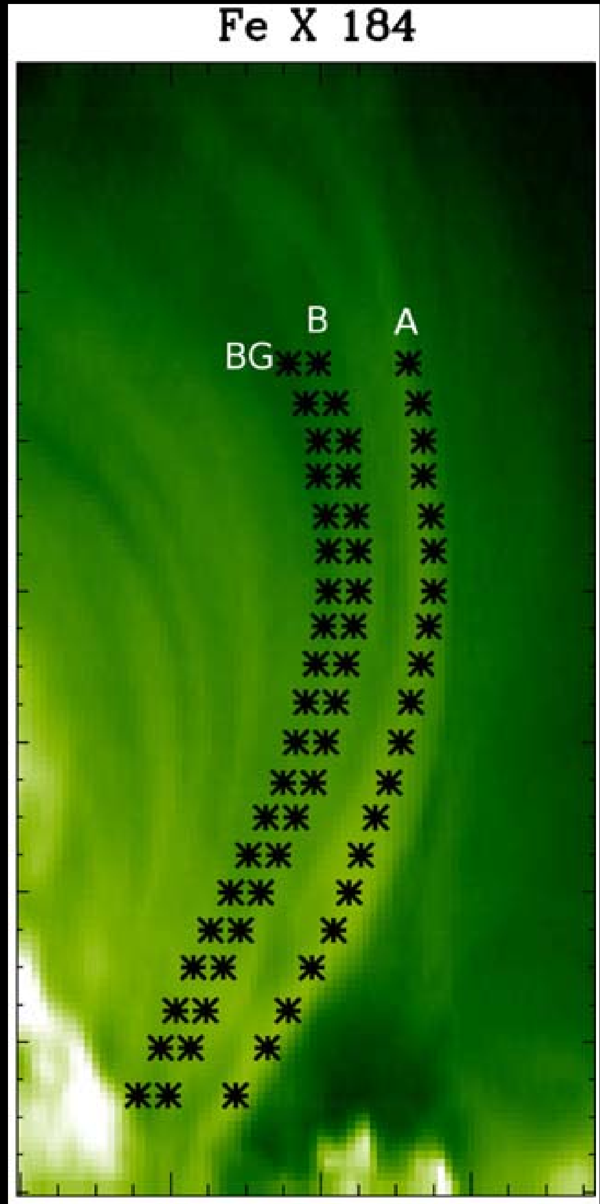


Heating Function:
in Loops with multi-temperature analysis

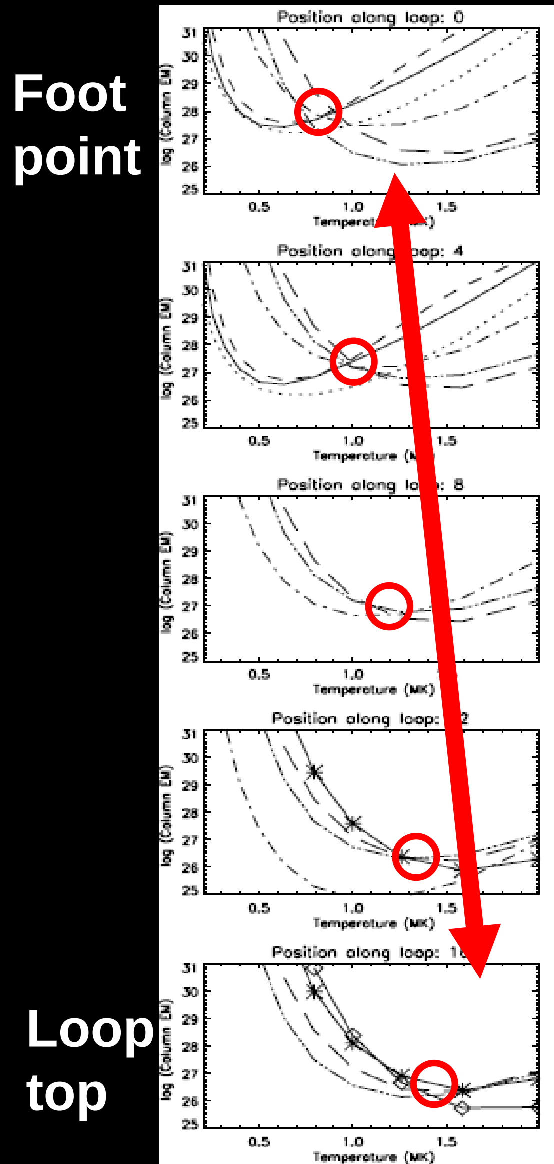
Tripathi et al. (2009, ApJ)

- Single temperature along LOS.
- dT/ds > 0.
- Filling factor around foot points
  - 0.02 @ FeXII, SiX
  - ~1 @ MgVII

➔T-grad. suggests loop-top heating.

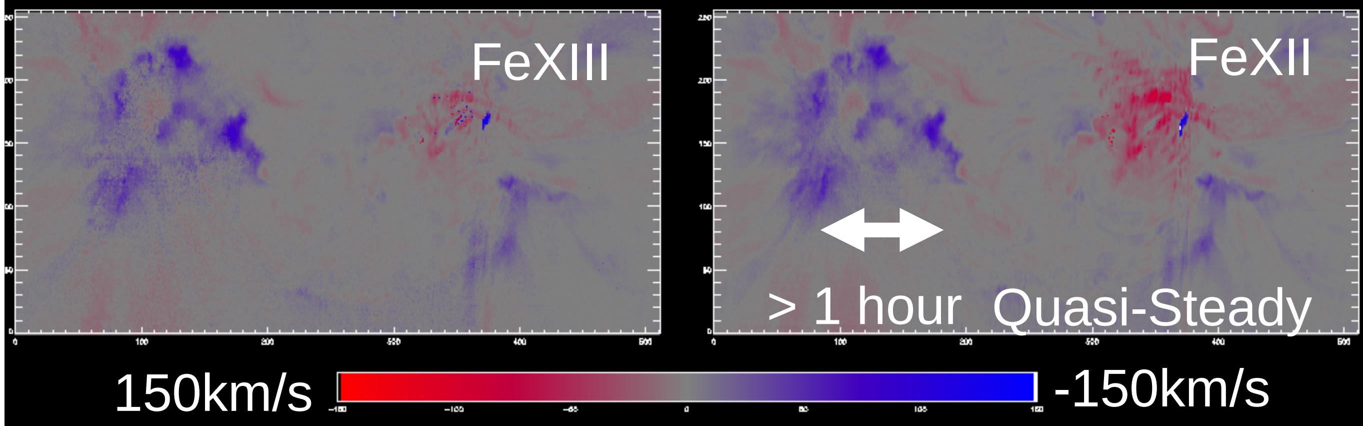


EM Loci plots

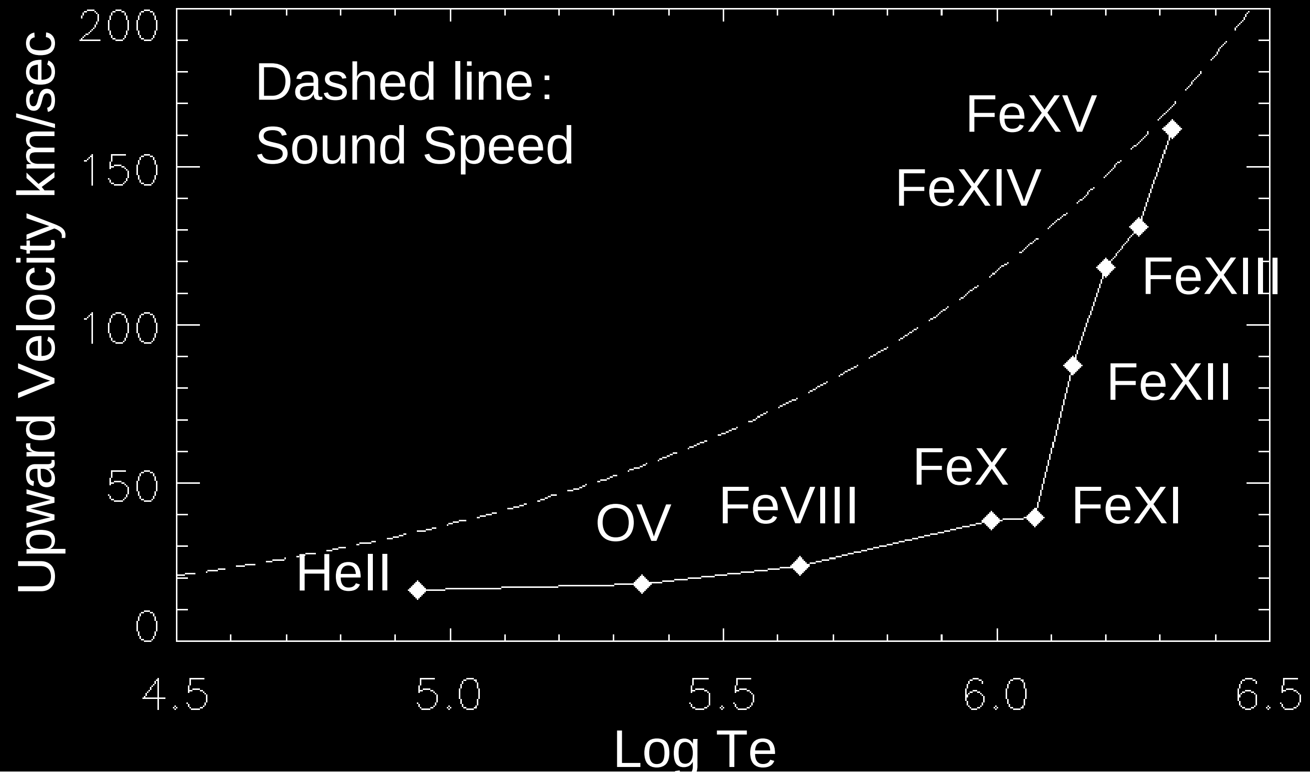


Heating Function: in Quasi-Steady Upflow

Imada et al. (2007, PASJ), Imada et al. (2007, ASJ meeting)

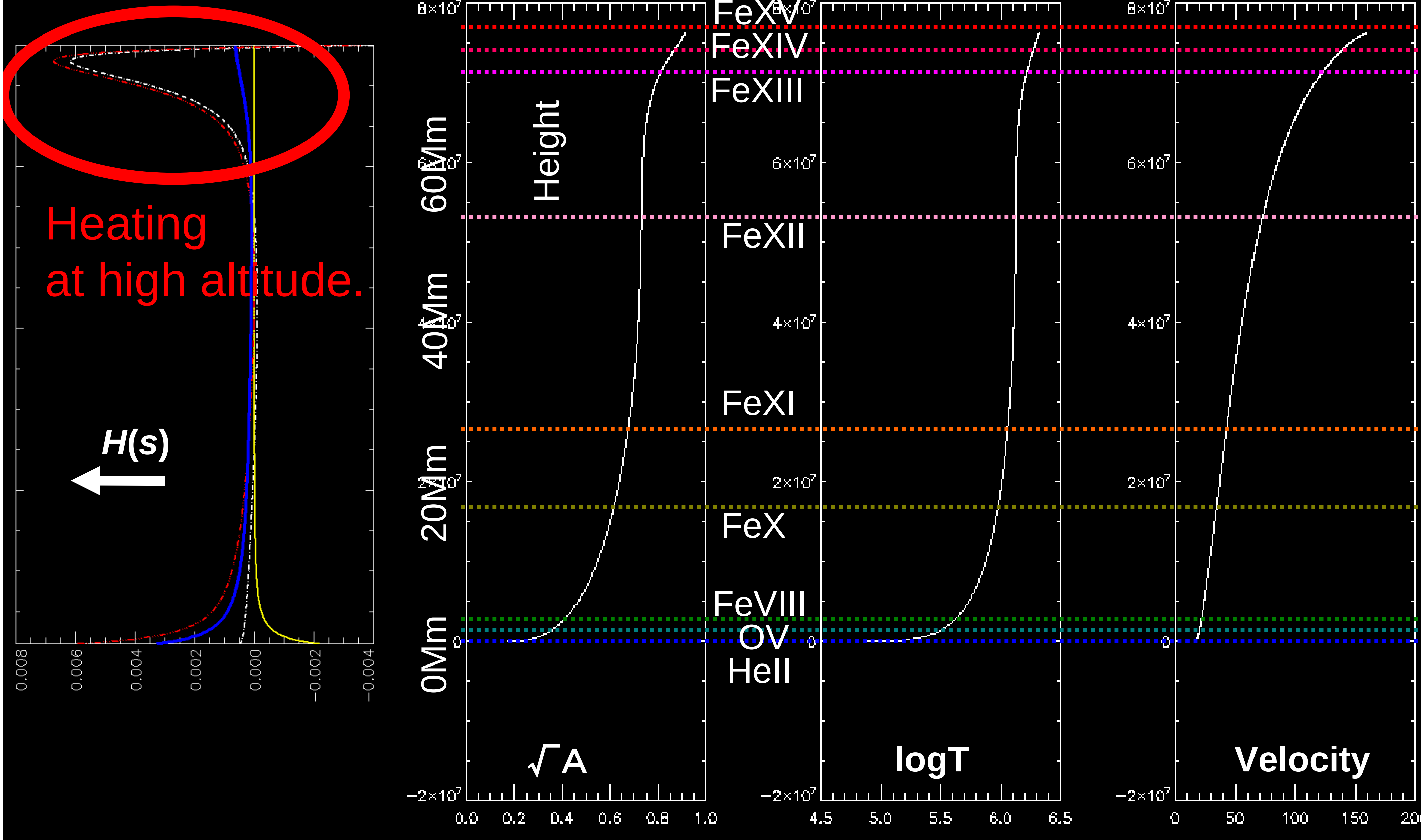


- T-dependence of upflow triggered with a flare.



- ***H(s)*** was derived
  - by assuming a cross-section model of vertical fields,
  - and using energy-eq. momentum-eq. and mass conservation.

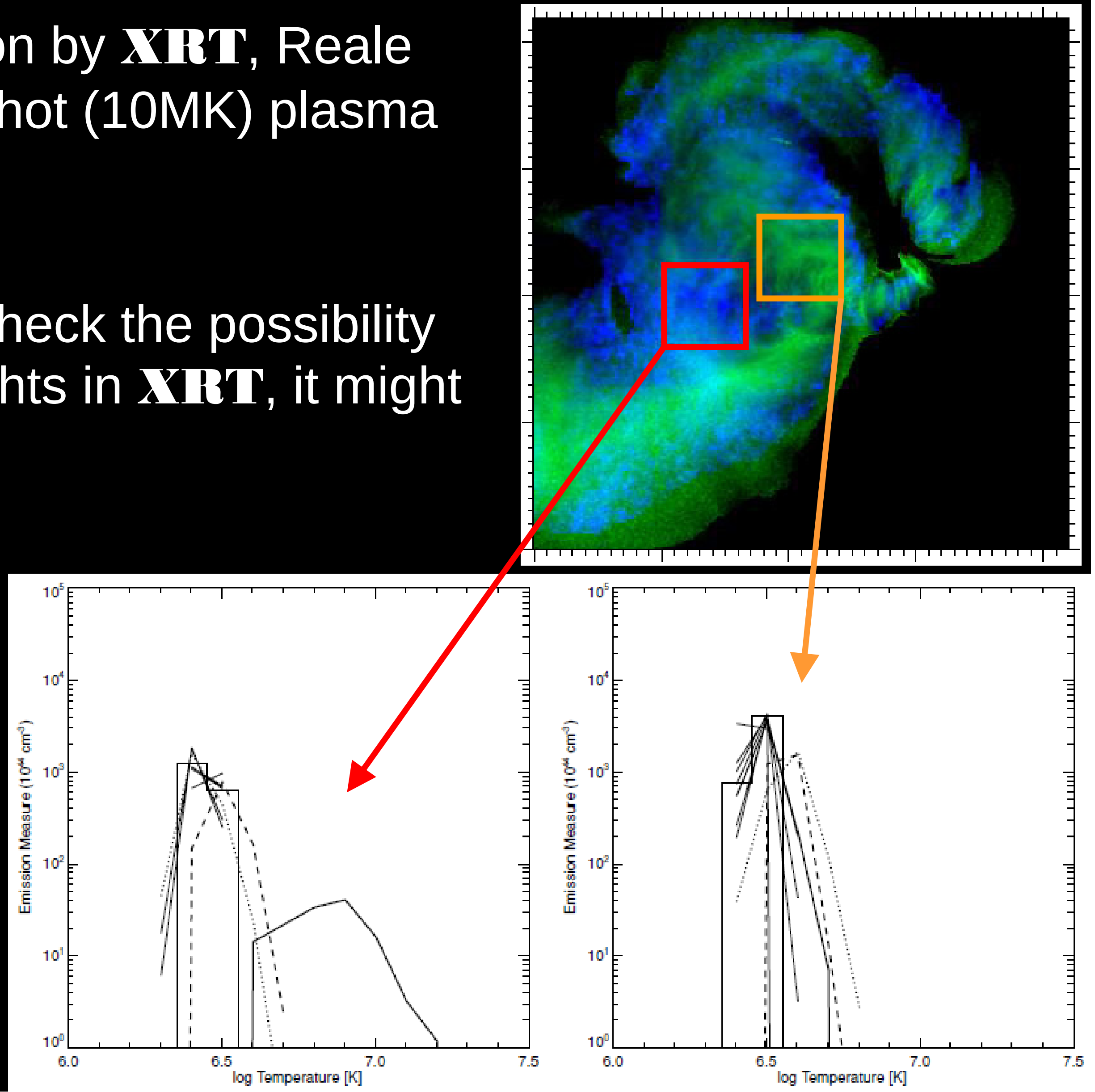
$$\frac{mnv}{A}\frac{\partial}{\partial s}(eA) + \frac{p}{A}\frac{\partial}{\partial s}(vA) = H(s) - n^2\Lambda(T) + \frac{1}{A}\frac{\partial}{\partial s}\left(A\kappa_{\parallel}\frac{\partial T}{\partial s}\right)$$



Nanoflare studies: Super-Hot Plasma(1)

Reale et al. (2009, ApJ)

- From a multi-filter observation by **XRT**, Reale et al. (2009) reported super-hot (10MK) plasma in non-flaring active region.
- Although it is necessary to check the possibility of an artifact by scattered lights in **XRT**, it might suggest nanoflare heatings.



Nanoflare studies: Super-Hot Plasma(2)

Ishibashi et al. (Hinode2 & Hinode3)

- In Hinode-2, Ishibashi reported that 15MK component was found in quiet-Sun with the filter-ratio analysis of **XRT**.

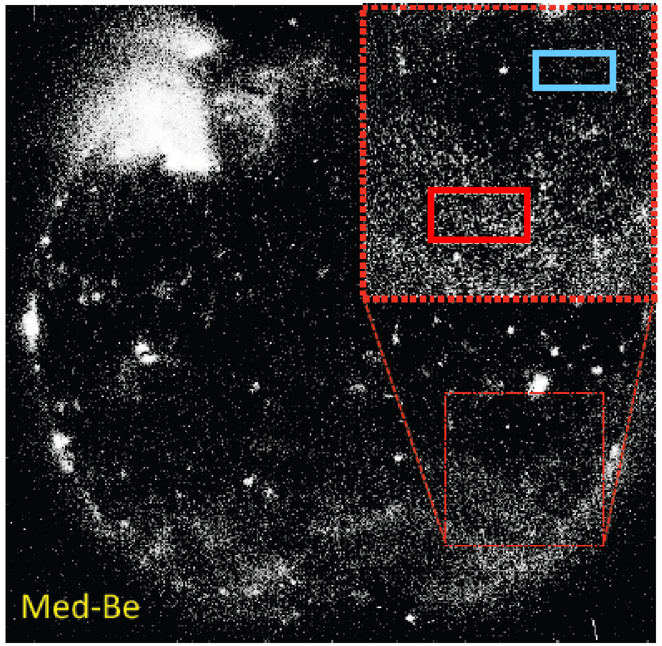
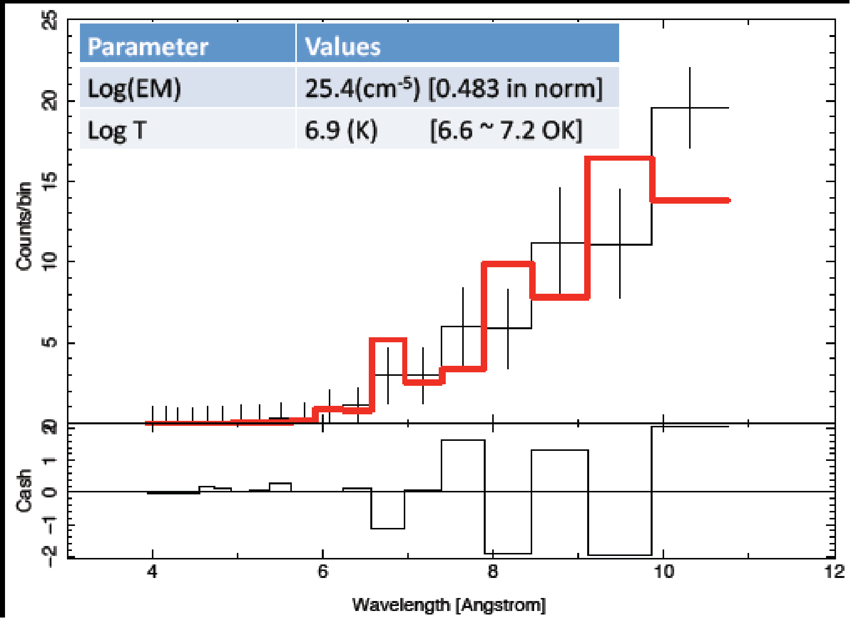


Figure 2b: med-Be image

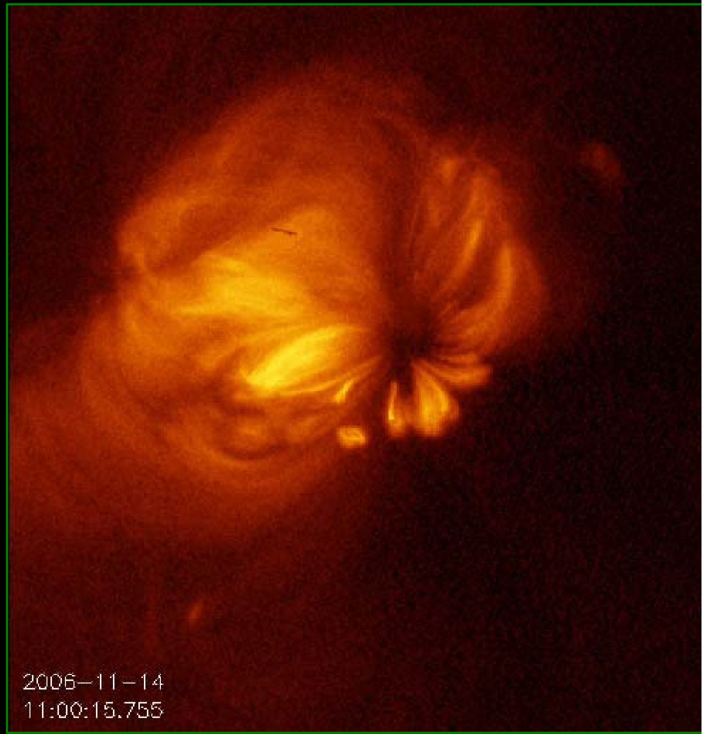
- In Hinode-3, he made assurance double sure with the photon-counting analysis by **XRT**, and detected X-ray spectrum from ~10MK plasma in quiet-Sun.



X-ray spectrum in [red box] – [blue box]

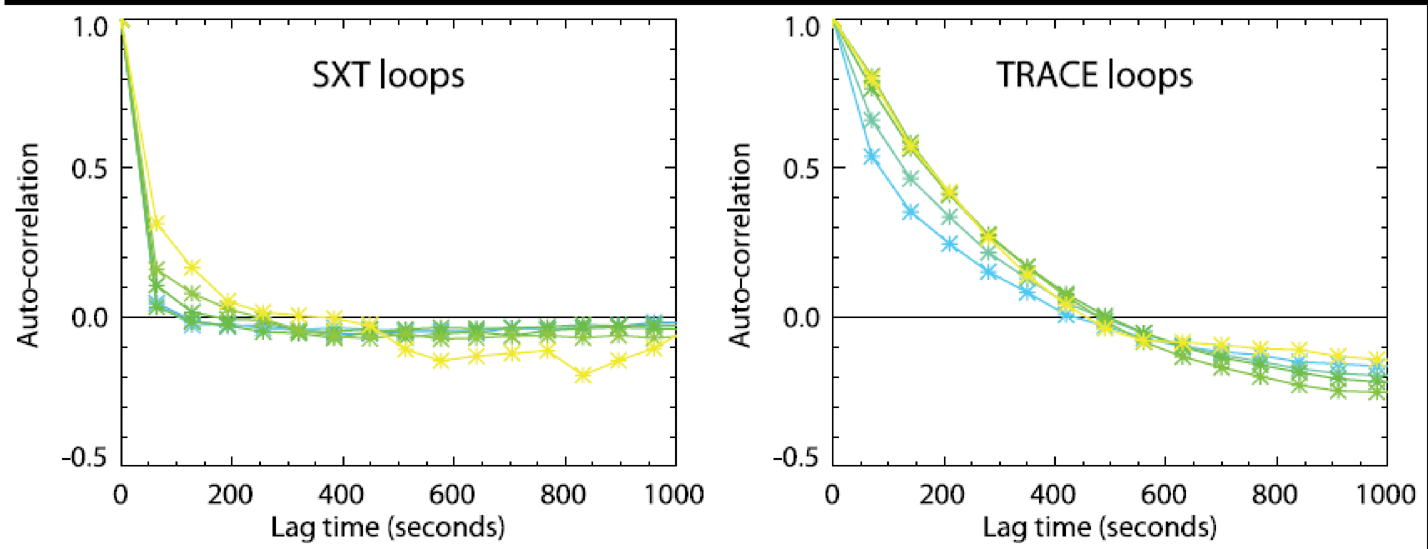
Nanoflare studies: Intensity fluctuations

Terzo (TBD)



- He just started this topic.
- From **XRT**'s high-cadence (~3 sec) observations, auto-correlation of intensity fluctuations may reveal a typical timescale of nanoflare events.

Sakamoto et al. (2008, ApJ)



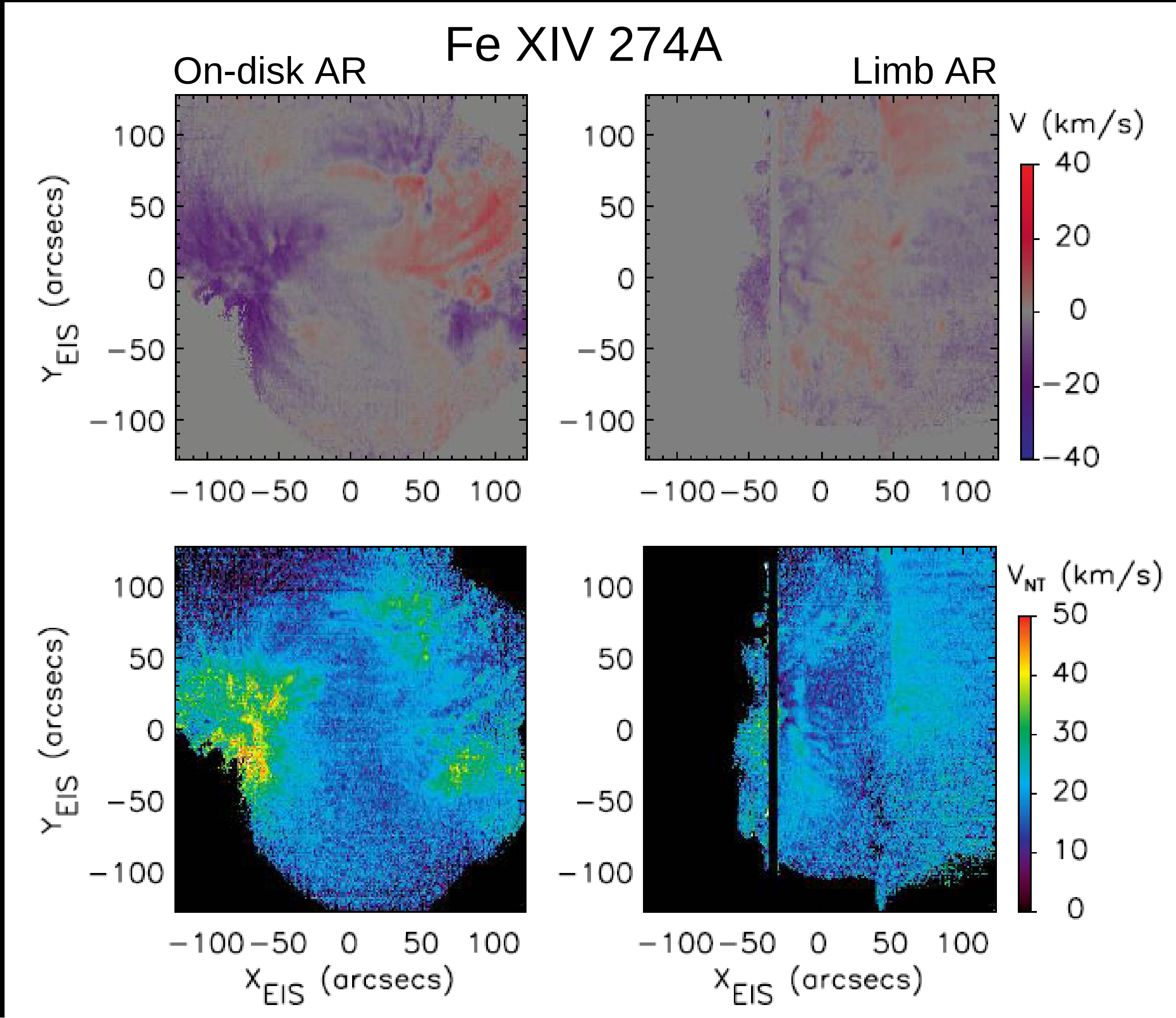
Upflow & NT-Velocity in AR Loops

Hara et al. (2008, ApJ)

- Upflow of hot plasma was observed near the footpoints.
- Large NT-velocity was also observed near the footpoints in on-disk active regions. It is probably a superposition of many upflow components.

➔The hot plasma upflows suggest nanoflare heating.

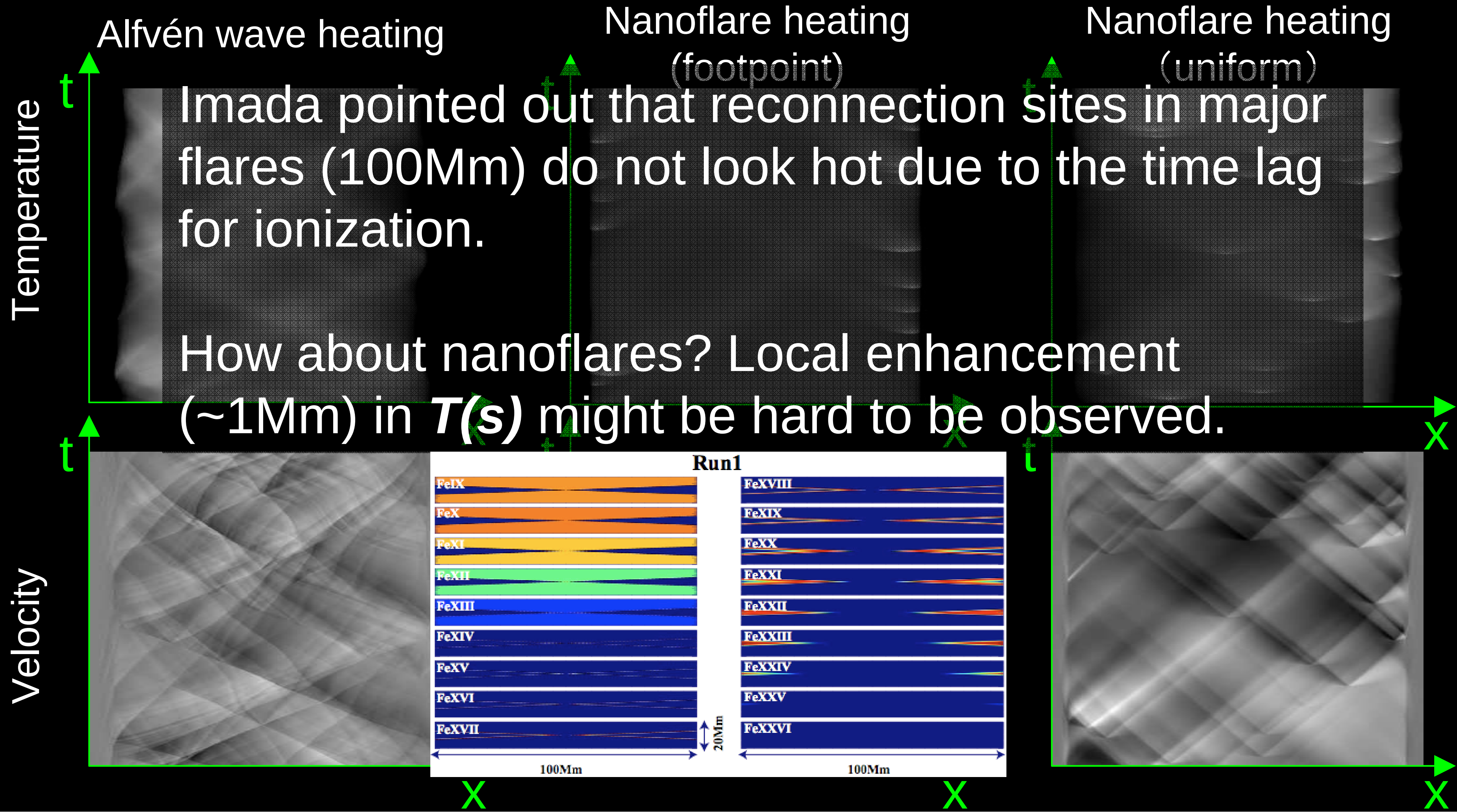
Small NT-velocity (~20km/s) in limb ARs gives a constraint to Alfven-wave heating.



Hint from simulations

Antolin et al. (2008, ApJ)

Temporal variation of ***T(s)*** or ***V(s)*** along loops is important.



Imada pointed out that reconnection sites in major flares (100Mm) do not look hot due to the time lag for ionization.

How about nanoflares? Local enhancement (~1Mm) in ***T(s)*** might be hard to be observed.

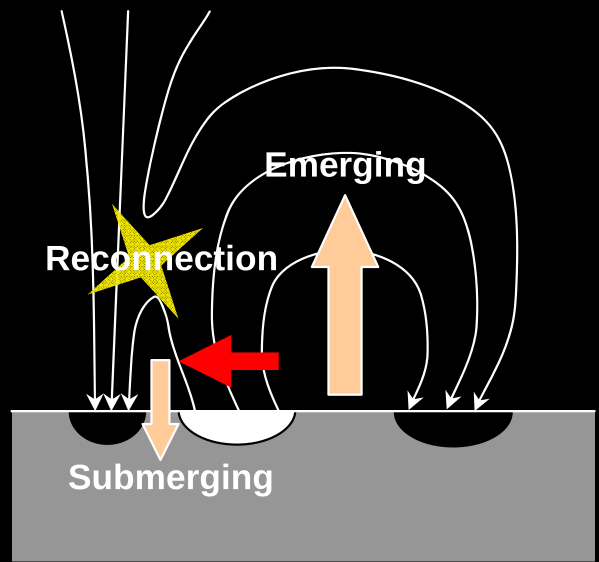
Relation between Coronal Activities & Photospheric Magnetic Fields

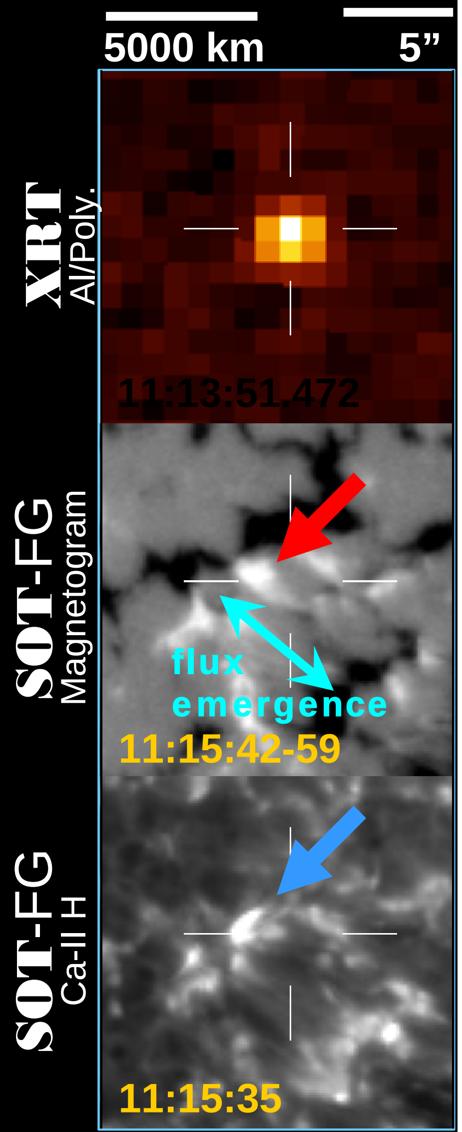
eg. Kano et al. (2010, submitted)

- Microflares around a spot were accompanied with magnetic cancellations, some of which were formed with EMF and MMF.

- Although magnetic buoyancy may prevent the submergence of coronal fields under the photosphere, why magnetic cancellations are associated with microflares?

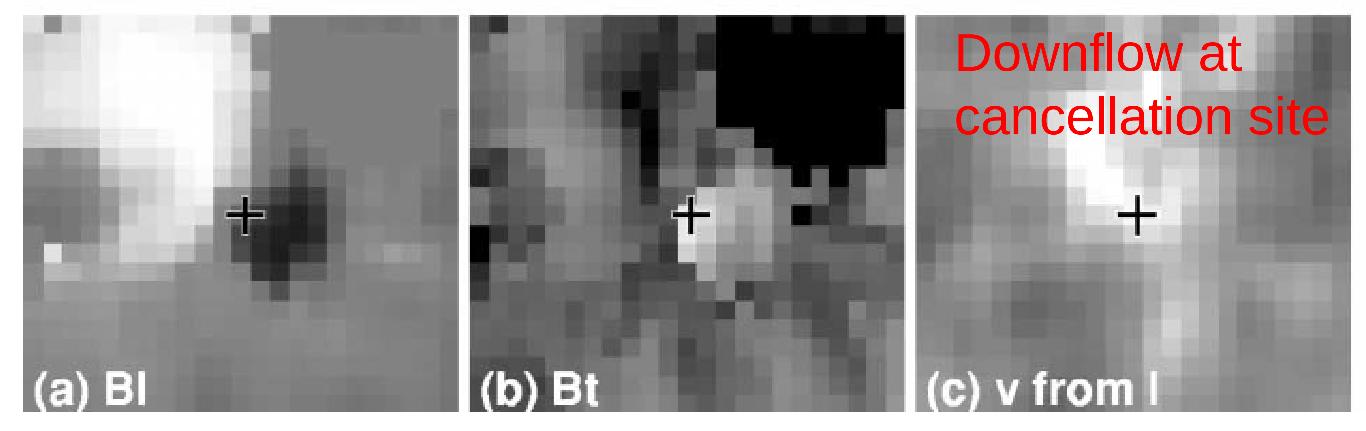
→Multiple reconnections may happen not only corona but also in chromosphere or transition region.



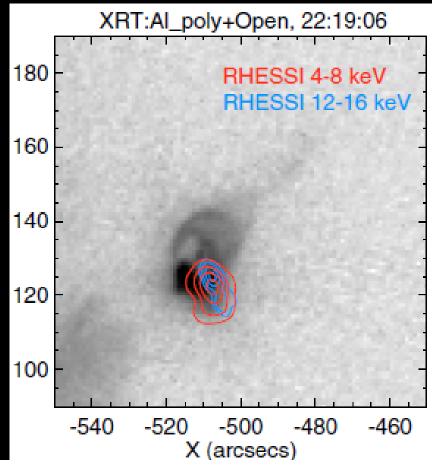


Magnetic Submergences

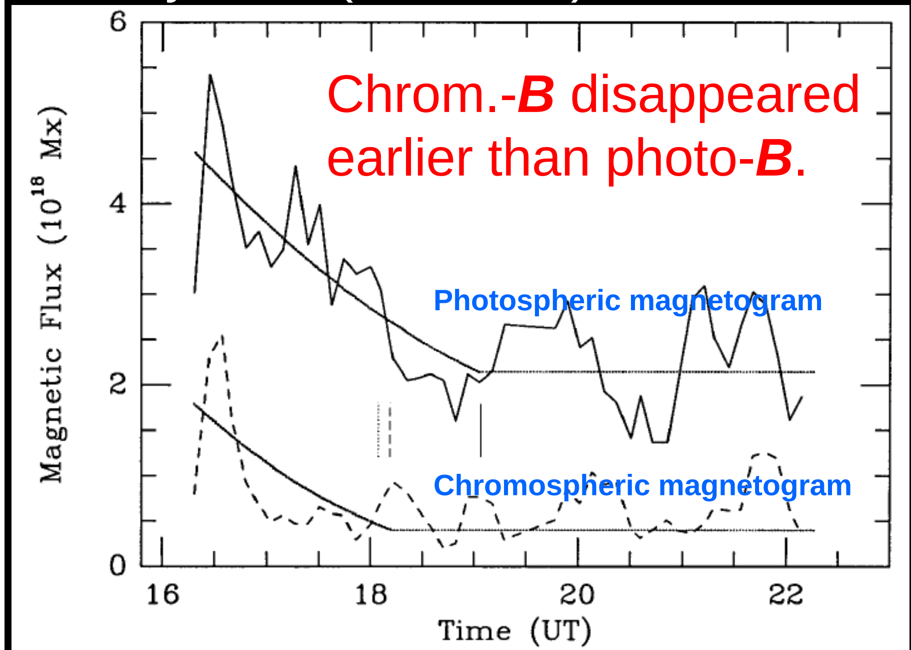
Submergence of photospheric ***B***: Chae et al. (2004, ApJ)



Chifor et al. (2008, AA)



Submergence of chromospheric ***B***:
Harvey et al. (1999, SP)

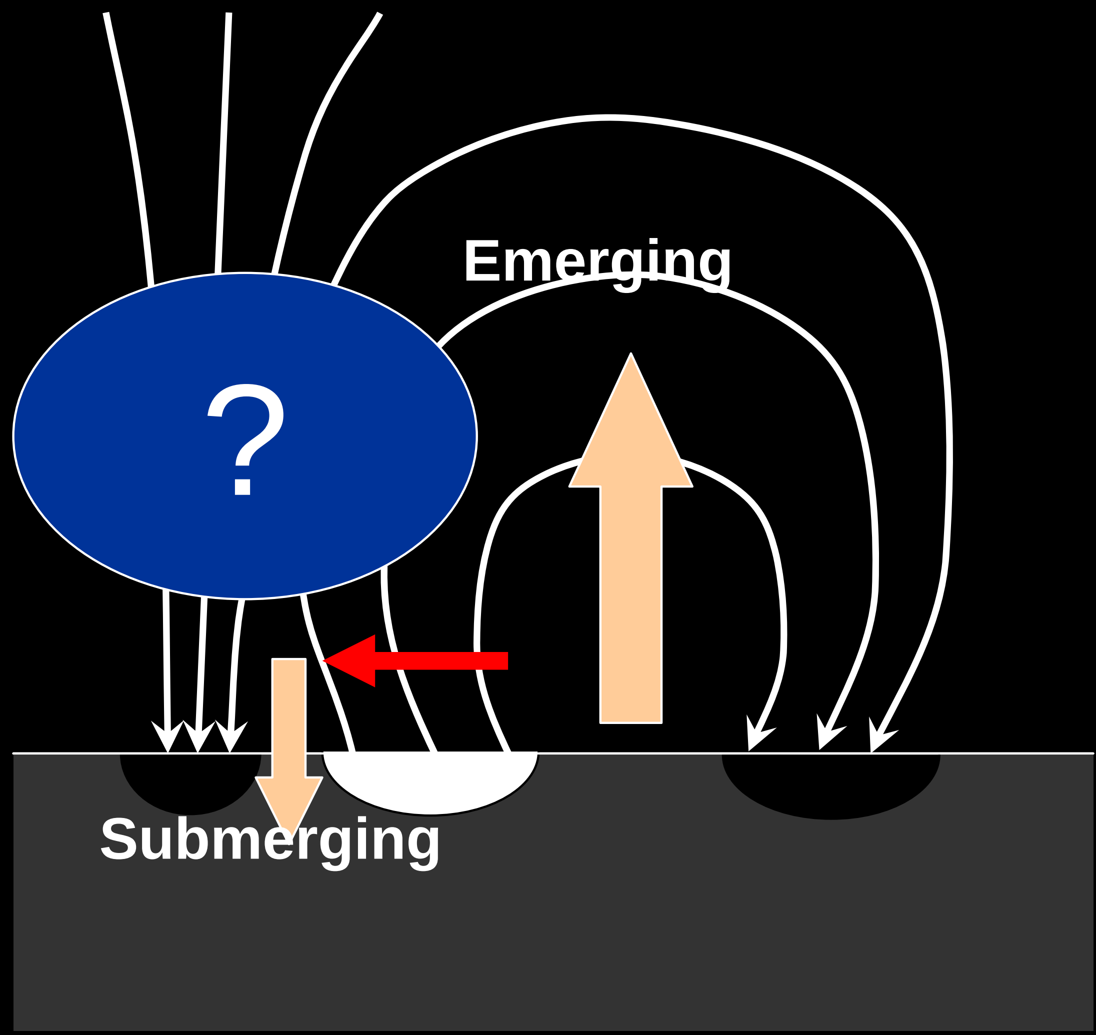


- The Submergence of photospheric and chromospheric magnetic fields were observed.
- Non-thermal emission observed with RHESSI above cancellations suggests that reconnection occurred in the corona.
- However, no evidence for the submergence of coronal fields.

Interaction regions would like to be observed.

- Velocity fields in chromosphere, transition layer, and lower corona.
- Magnetic configuration in chromosphere.

With Hinode/**EIS** and Solar-C/Plan-B.

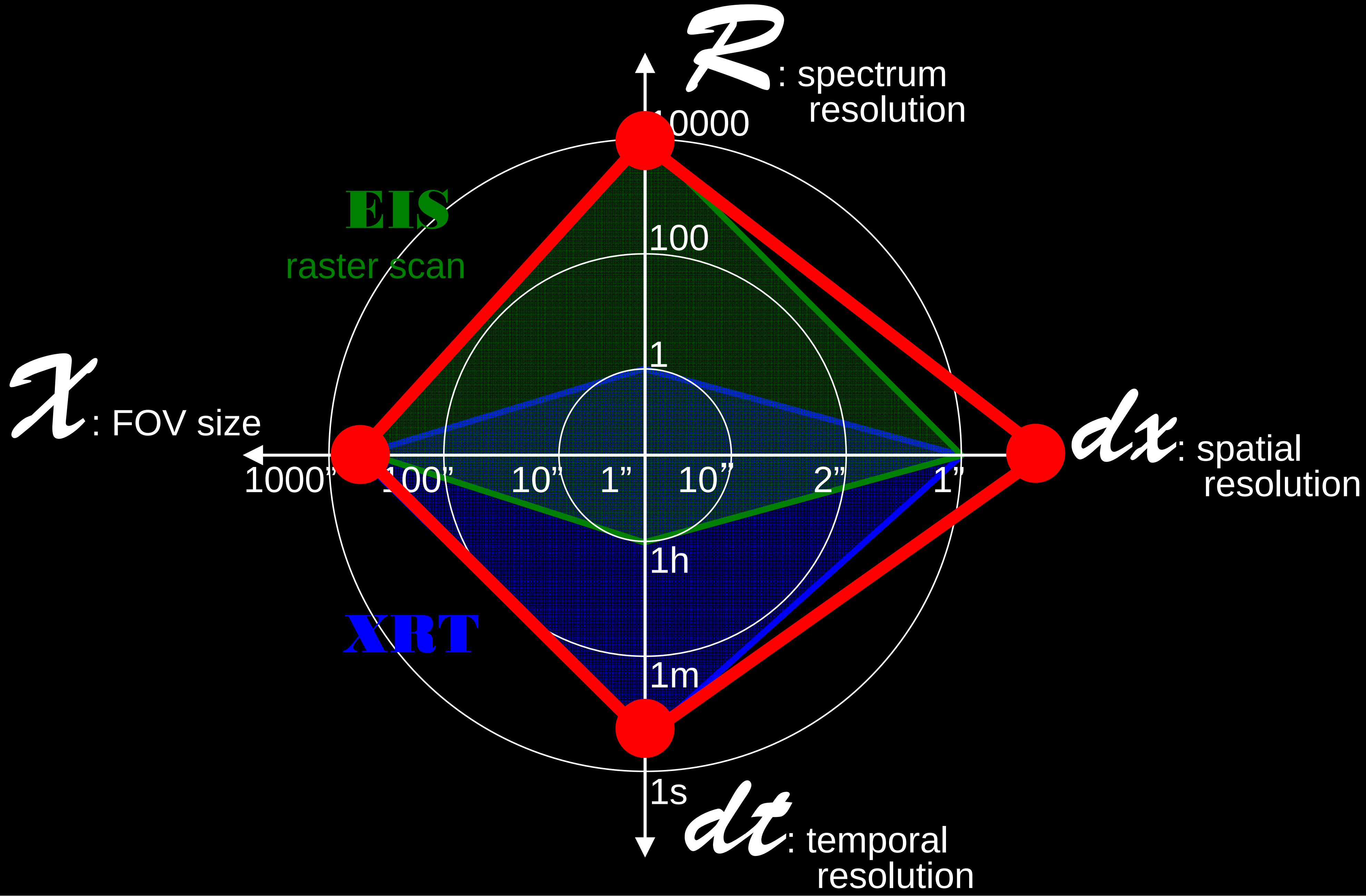


Studies of Coronal Heating with Hinode
(personal view)

- Heating Functions along magnetic fields.
  - To analyze ***T(s)*** in many quasi-steady features for understanding ***H(s)***. But, we have to consider velocity fields.
  - To find short-lived small increases in ***T(s)*** for understanding localized elemental events in quasi-steady features.
- Nanoflare vs. Wave
  - To find super-hot plasma in non-flaring features.
  - Autocorrelation of temporal/spatial variations may reveal some properties of nanoflares.
  - To find relations between NT-width and coronal-T for dissipation of for waves.

- Relations with lower atmospheres
  - Where do energetic events happen?
    - Magnetic configurations.
    - Wave excitations or reconnections.

What I hope for Solar-C.



Interaction regions would like to be observed.

- Velocity fields in chromosphere, transition layer, and lower corona.
- Magnetic configuration in chromosphere.

With Hinode/**EIS**
and Solar-C/Plan-B.