Coronal Heating: overview of recent observations

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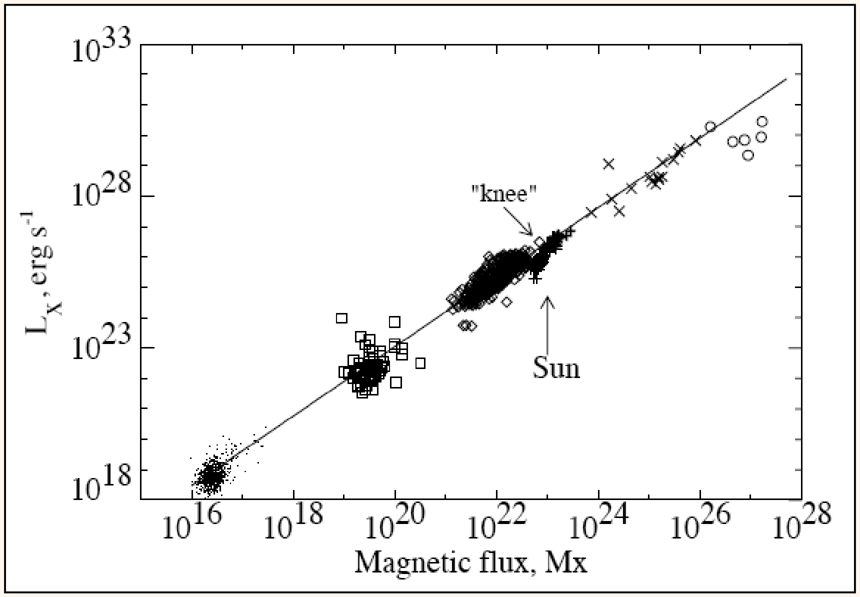
Observational approaches to coronal heating

- Coronal morphology (large scale height)
- Emission ionization states (Edlén & Grotrian, 1930s)
- Radio brightness temperatures (Pawsey 1949)
- Imaging, spectroscopy, time-series analysis



Pevtsov et al., 2003

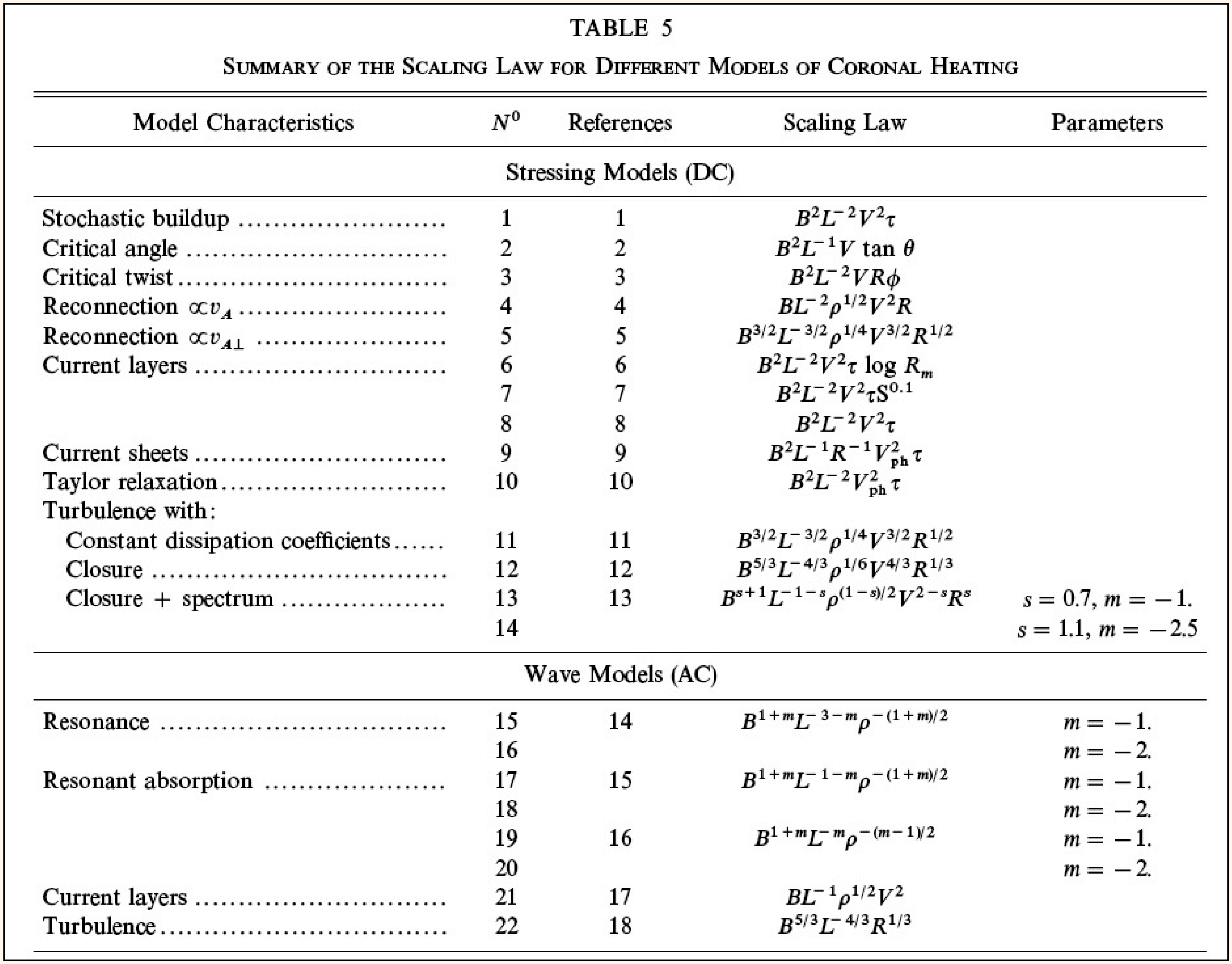


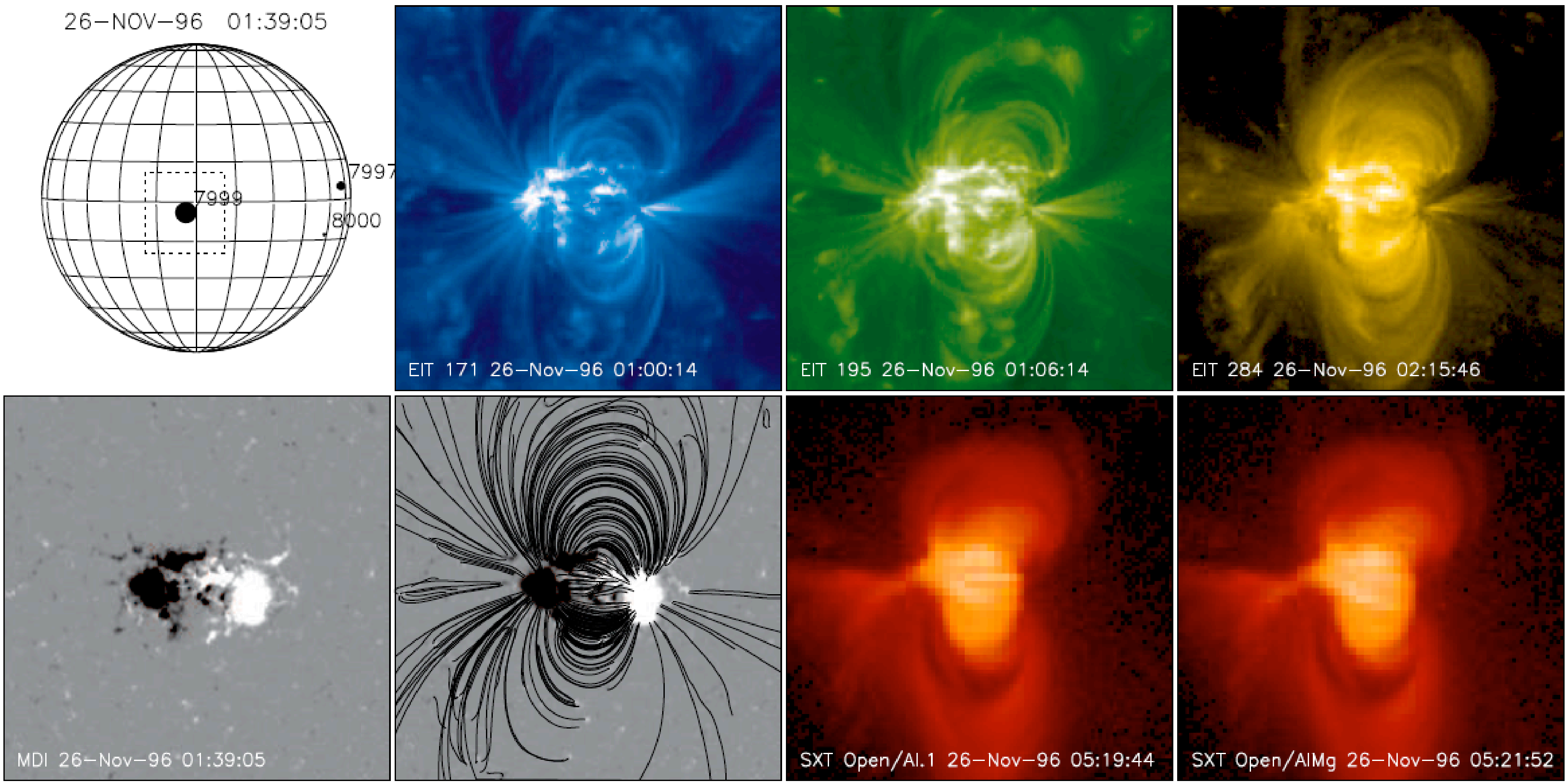
TABLE 5

SUMMARY OF THE SCALING LAW FOR DIFFERENT MODELS OF CORONAL HEATING

Model Characteristics	N^0	References	Scaling Law	Parameters
Stressing Models (DC)				
Stochastic buildup	1	1	$B^2L^{-2}V^2\tau$	
Critical angle	2	2	$B^2L^{-1}V\tan\theta$	
Critical twist	3	3	$B^2L^{-2}VR\phi$	
Reconnection $\propto v_A$	4	4	$BL^{-2}\rho^{1/2}V^2R$	
Reconnection $\propto v_{A\perp}$	5	5	$B^{3/2}L^{-3/2}\rho^{1/4}V^{3/2}R^{1/2}$	
Current layers	6	6	$B^2L^{-2}V^2\tau\log R_m$	
	7	7	$B^2L^{-2}V^2\tau S^{0.1}$	
	8	8	$B^2L^{-2}V^2\tau$	
Current sheets	9	9	$B^2L^{-1}R^{-1}V_{\mathrm{ph}}^2\tau$	
Taylor relaxation	10	10	$B^2L^{-2}V_{\mathrm{ph}}^2\tau$	
Turbulence with:				
Constant dissipation coefficients	11	11	$B^{3/2}L^{-3/2}\rho^{1/4}V^{3/2}R^{1/2}$	
Closure	12	12	$B^{5/3}L^{-4/3}\rho^{1/6}V^{4/3}R^{1/3}$	
Closure + spectrum	13	13	$B^{s+1}L^{-1-s}\rho^{(1-s)/2}V^{2-s}R^s$	$s = 0.7$, $m = -1.$
	14			$s = 1.1$, $m = -2.5$
Wave Models (AC)				
Resonance	15	14	$B^{1+m}L^{-3-m}\rho^{-(1+m)/2}$	$m = -1.$
	16			$m = -2.$
Resonant absorption	17	15	$B^{1+m}L^{-1-m}\rho^{-(1+m)/2}$	$m = -1.$
	18			$m = -2.$
	19	16	$B^{1+m}L^{-m}\rho^{-(m-1)/2}$	$m = -1.$
	20			$m = -2.$
Current layers	21	17	$BL^{-1}\rho^{1/2}V^2$	
Turbulence	22	18	$B^{5/3}L^{-4/3}R^{1/3}$	

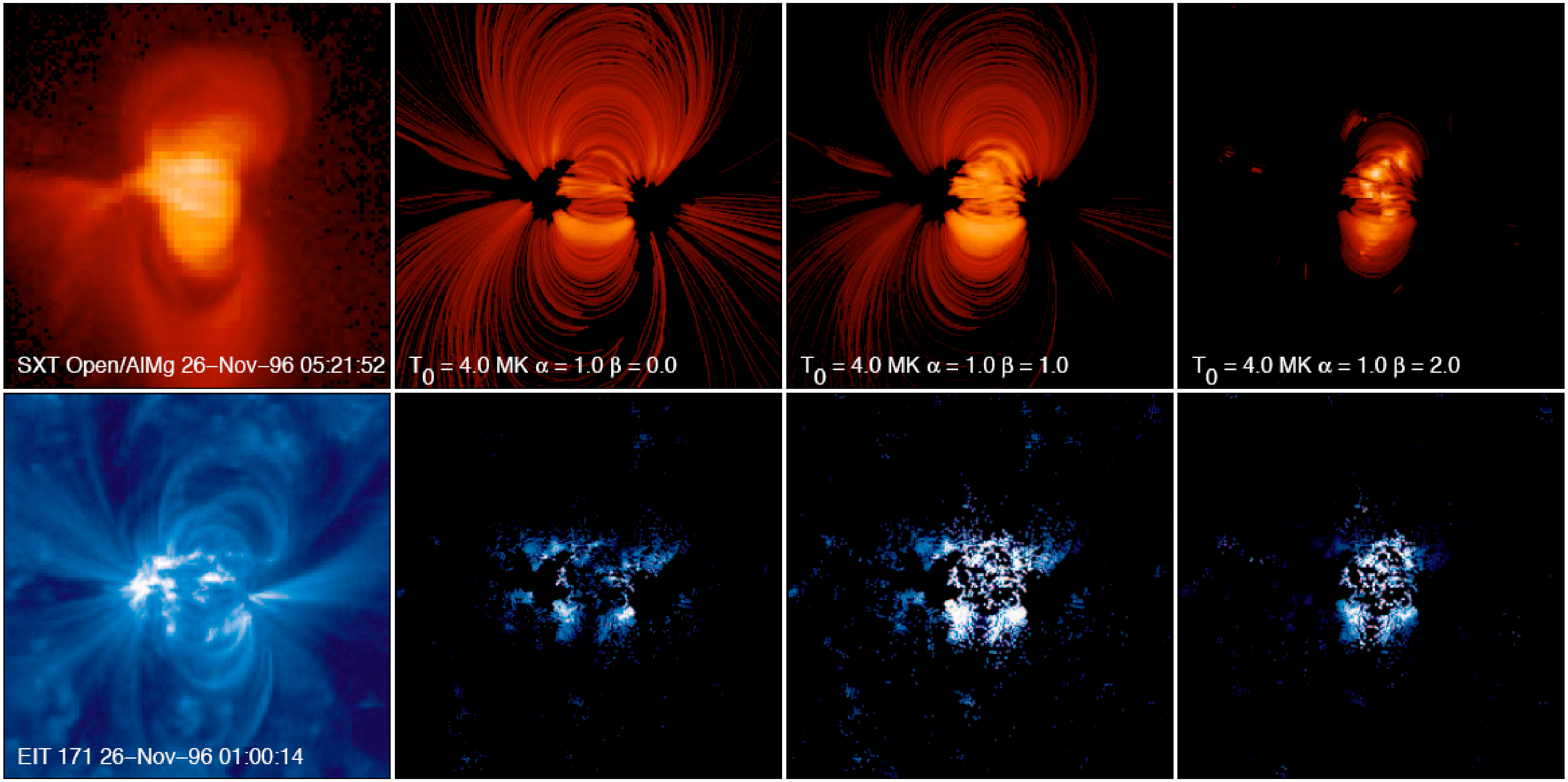
From Mandrini et al. 2000

Synthetic image decomposition



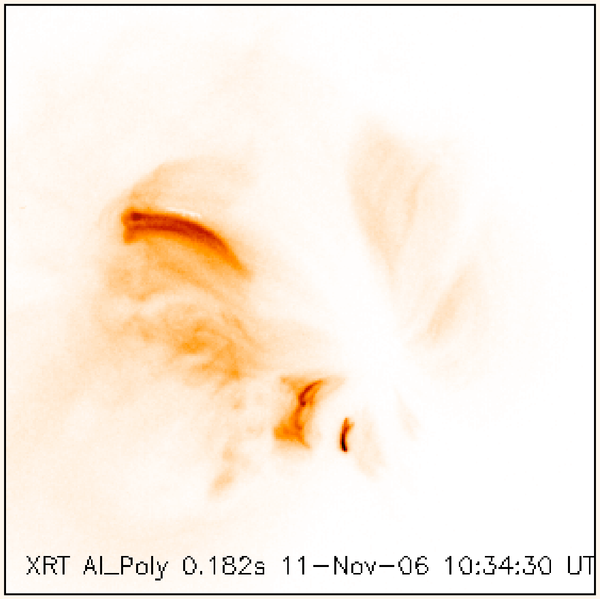
Warren & Winebarger 2006

$$\boxed{\epsilon_H \sim \bar{B}^\alpha / L^\beta}$$



Warren & Winebarger 2006
cf Lorraine Lundquist's thesis

But does this parametrization make theoretical sense?



- AR filling factor is small
- Plasma beta is low
- Adjacent flux tubes will have identical (B, L)

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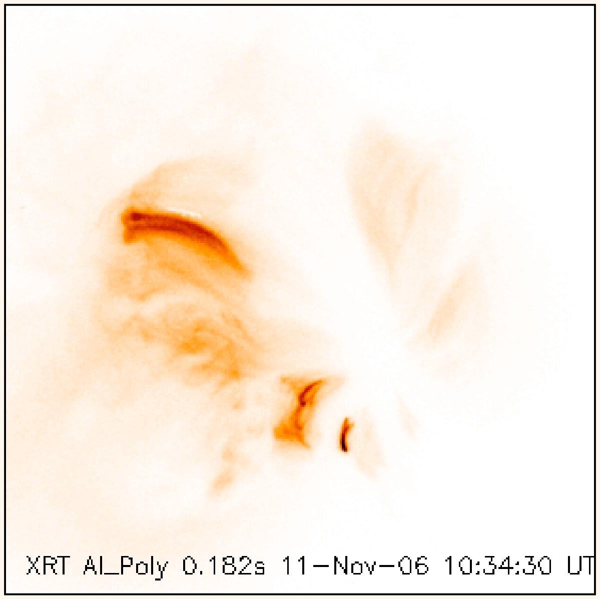
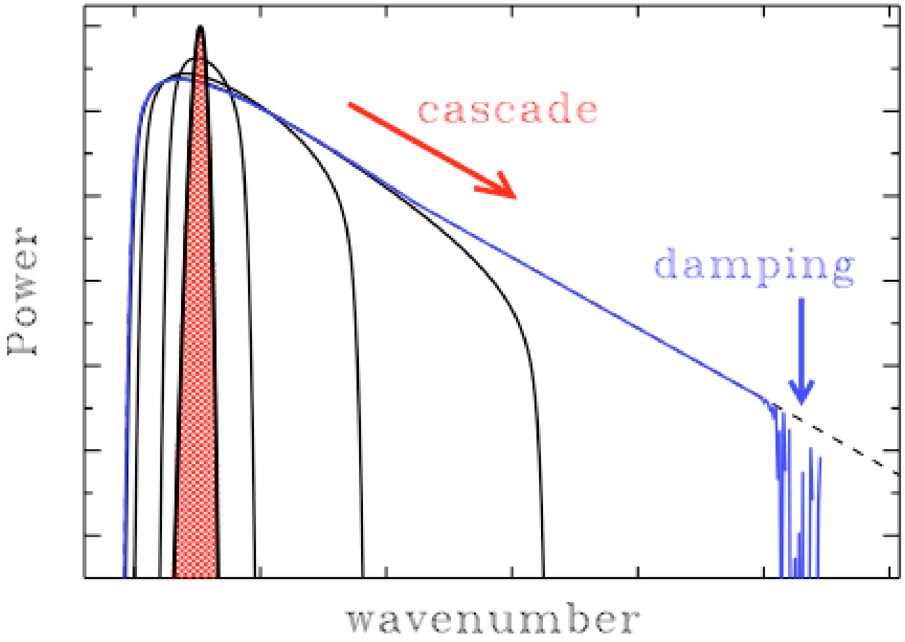
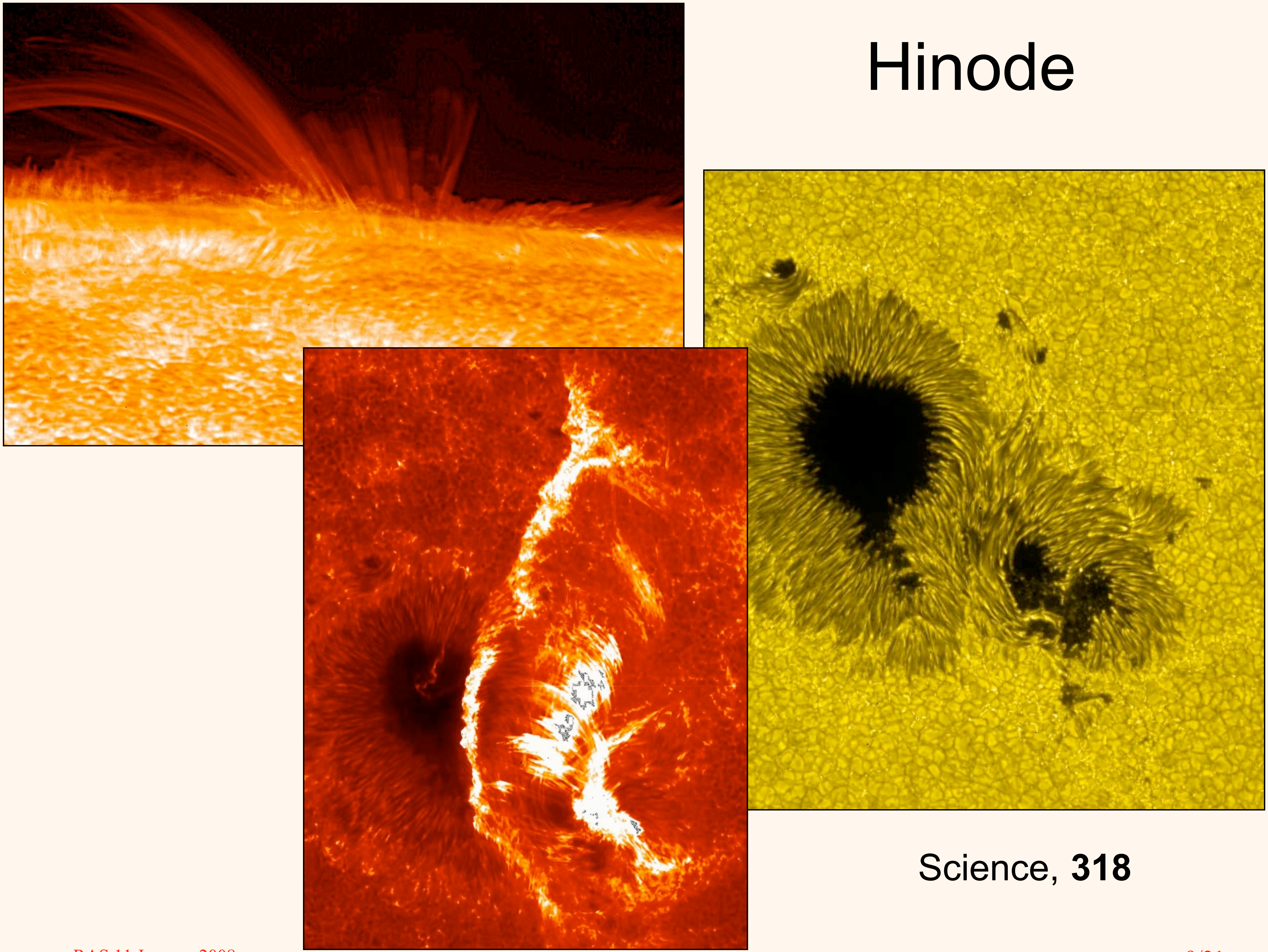


- AR filling factor is small
- Plasma beta is low
- Adjacent flux tubes will have identical (B, L)
- Simple $B^{\alpha}L^{\beta}$ models cannot have this filamentary structure

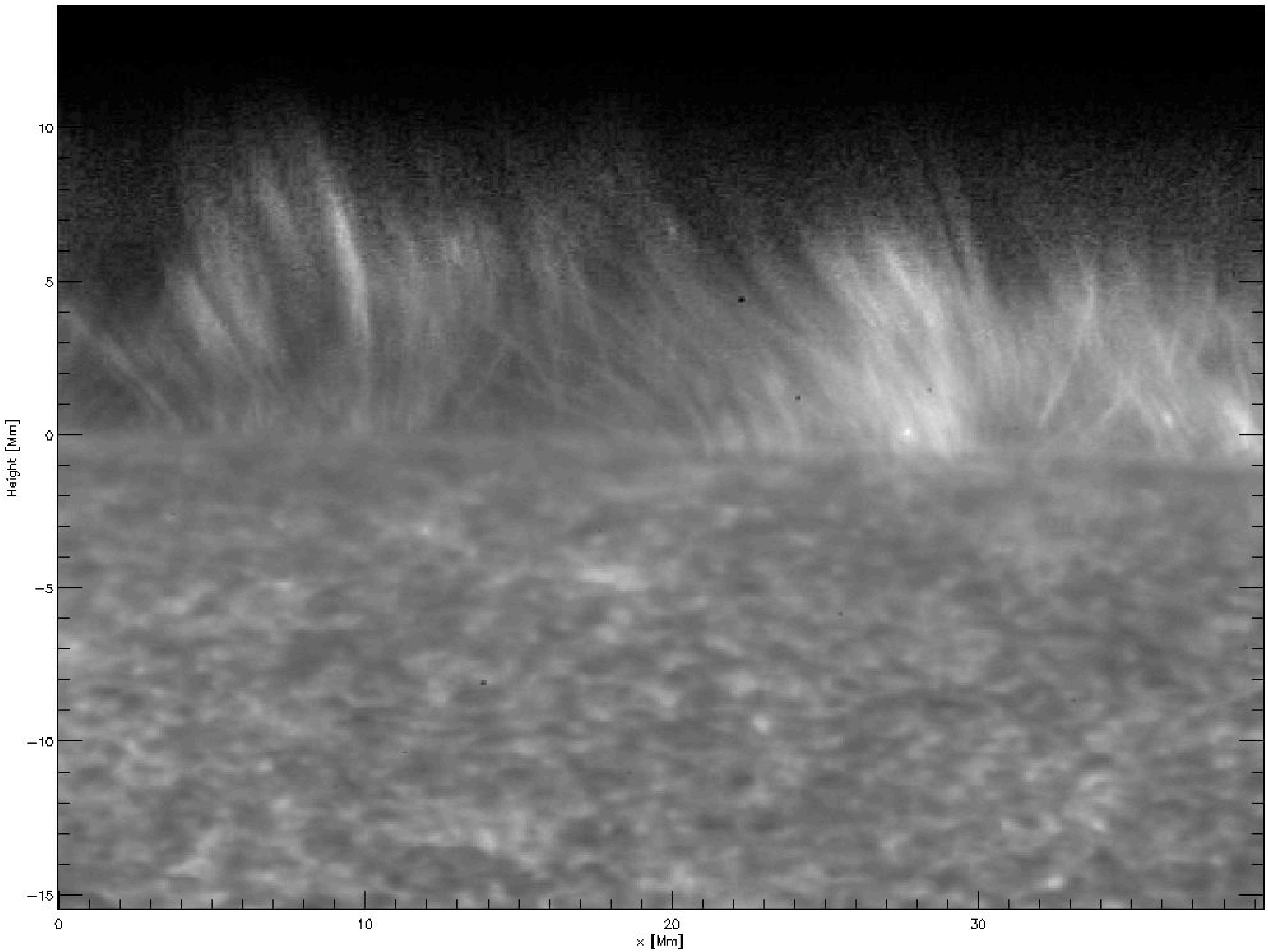
Wave heating (thanks to S. Cranmer's SOHO-15 presentation)



Hinode



Science, **318**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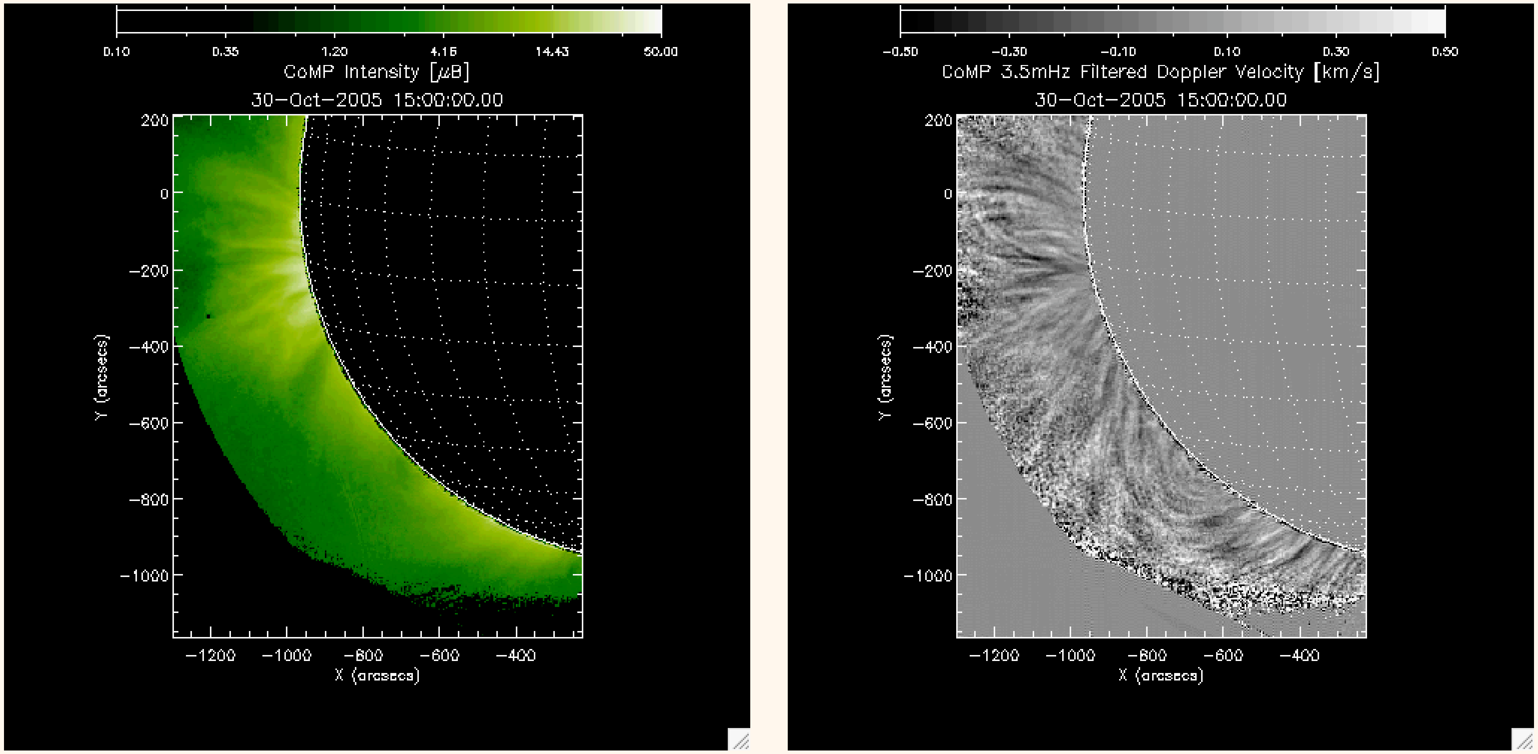
Coronal Alfvén waves?



Two movies from the CoMP coronagraph, @ 1074.7 nm, NSO. From Tomczyk et al., Science ***317****, 1192 (2007)*

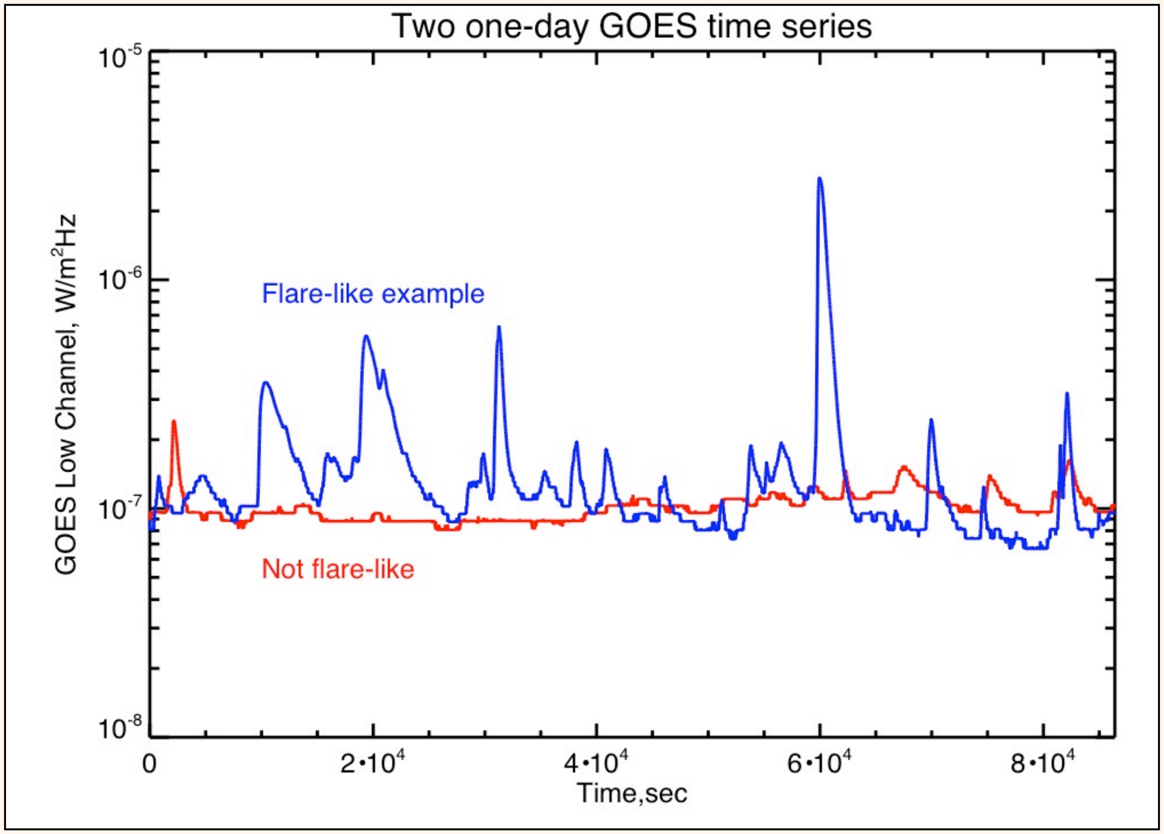
The active-region corona

- Bright X-ray loops resulting from large pressures
- Much larger heating rate (in ergs/cm^{2}sec)
- Intermittency in space and time
- Quiescent structures as well as flaring structures

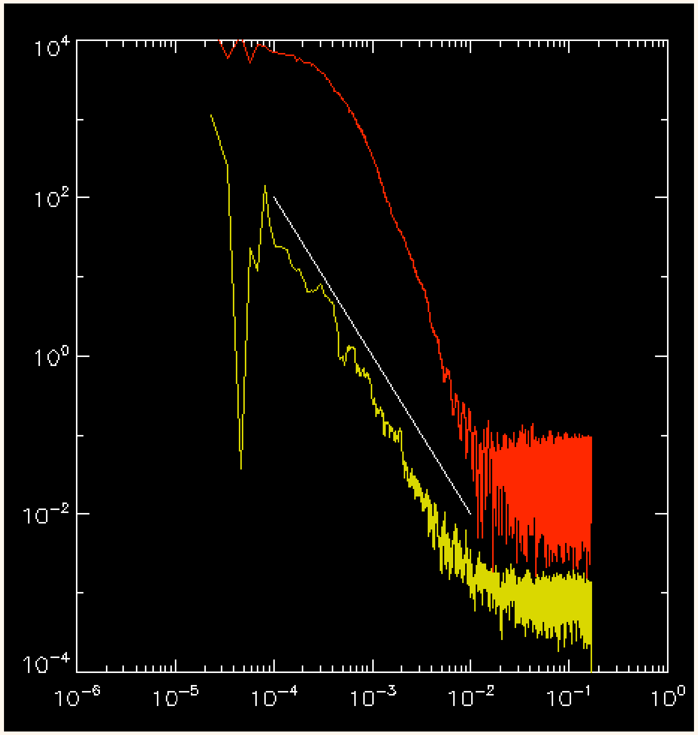
Nb, AR heating may be as intense as $10^{-4} \mathcal{L}_0$, rather than merely $10^{-6} \mathcal{L}_0$ as in the quiet Sun.

Time-series analysis

e.g., on GOES data

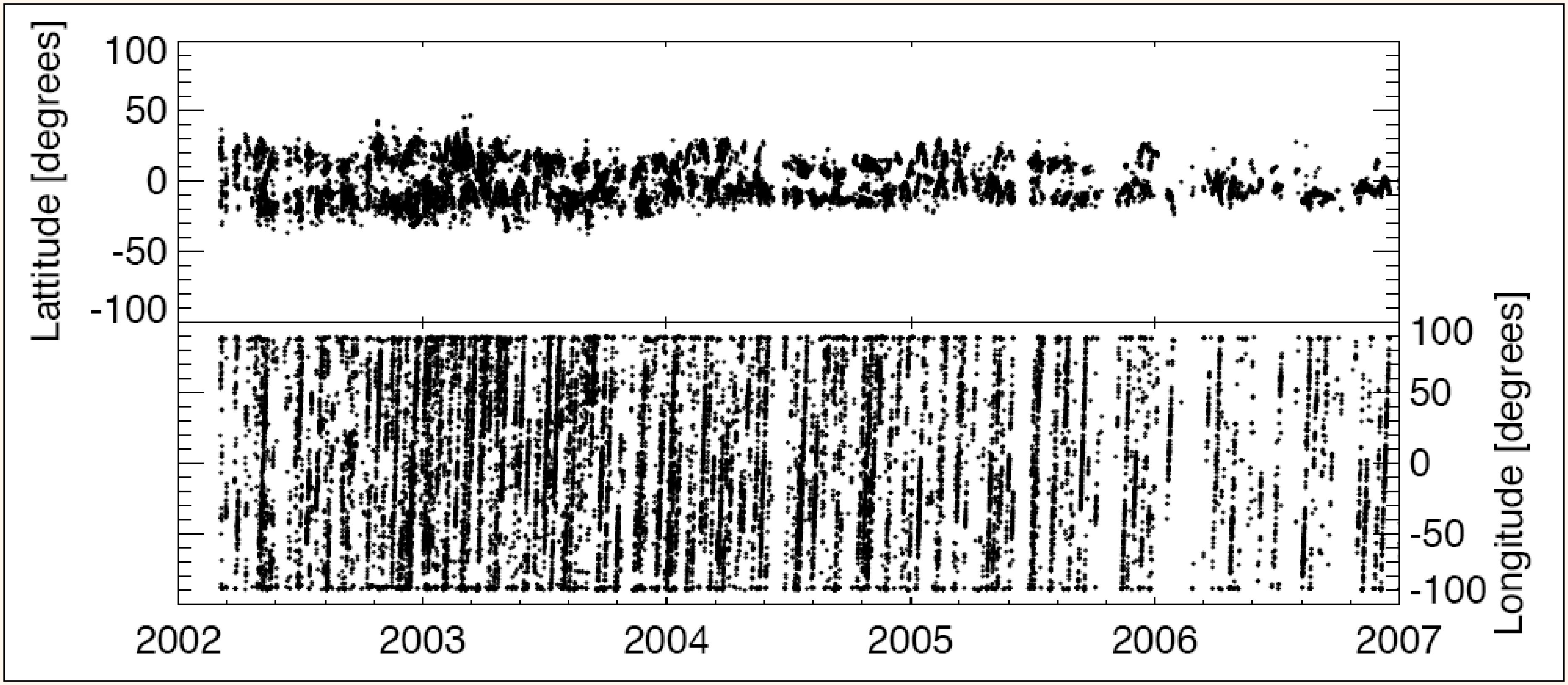


Distinctly different time series



Distinctly different spectra

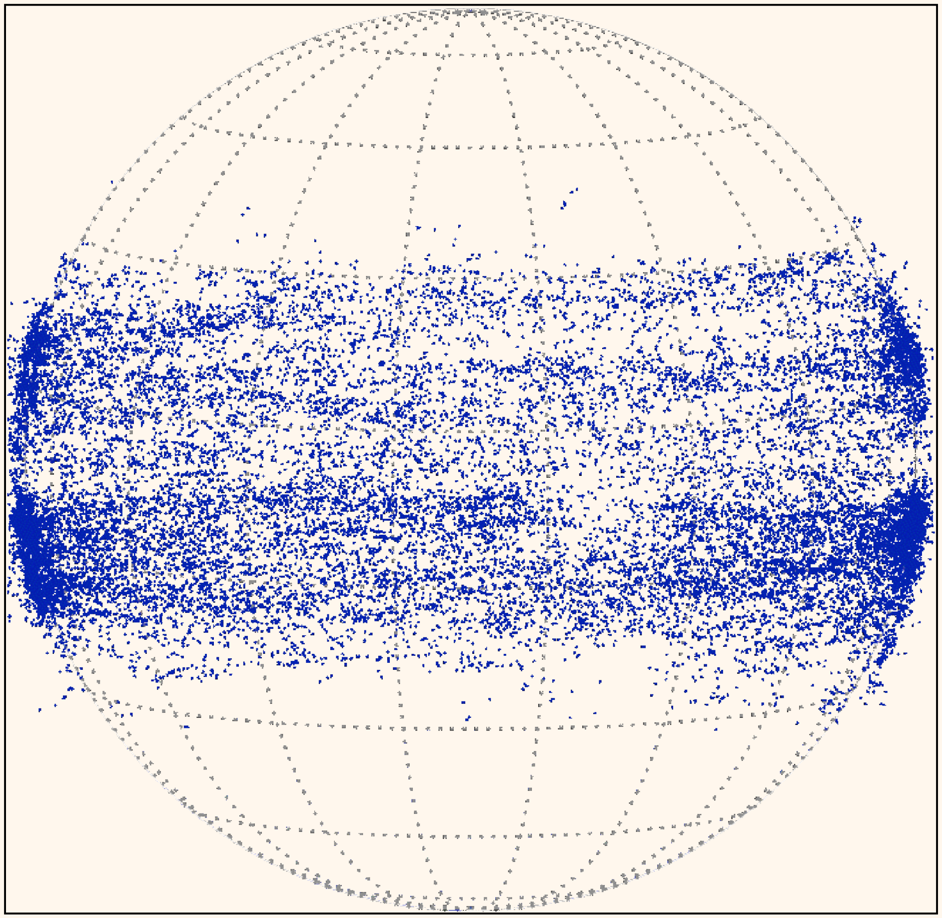
RHESSI's 25,000 microflares*

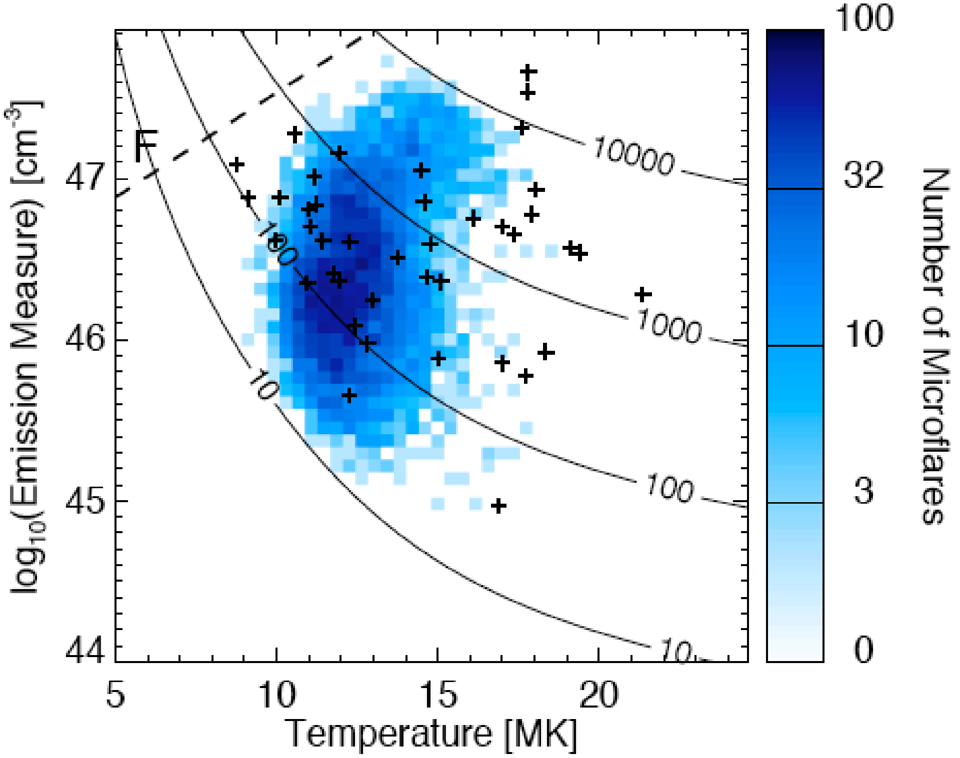


Christe et al. 2008

**See Hannah poster*

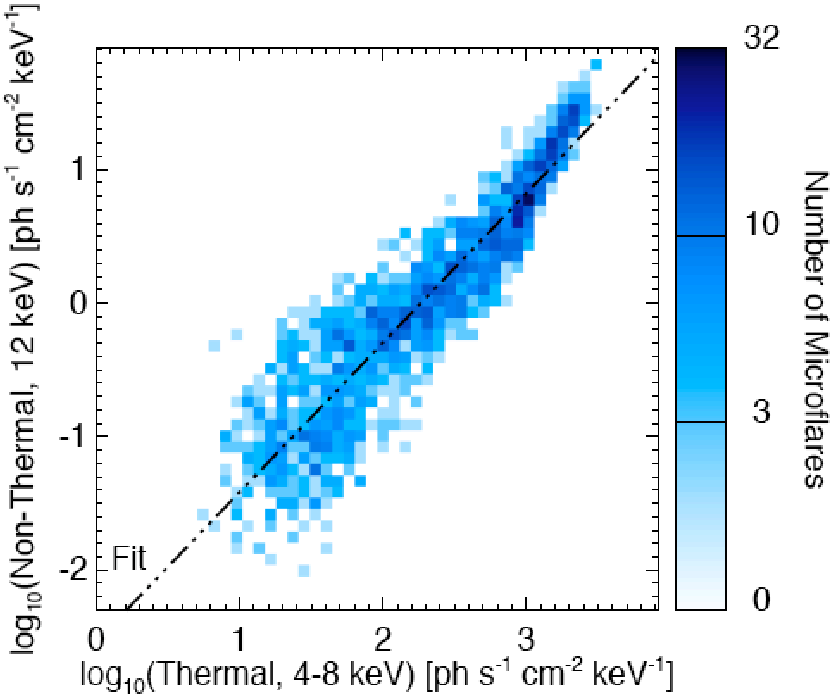
RHESSI’s 25,000 microflares





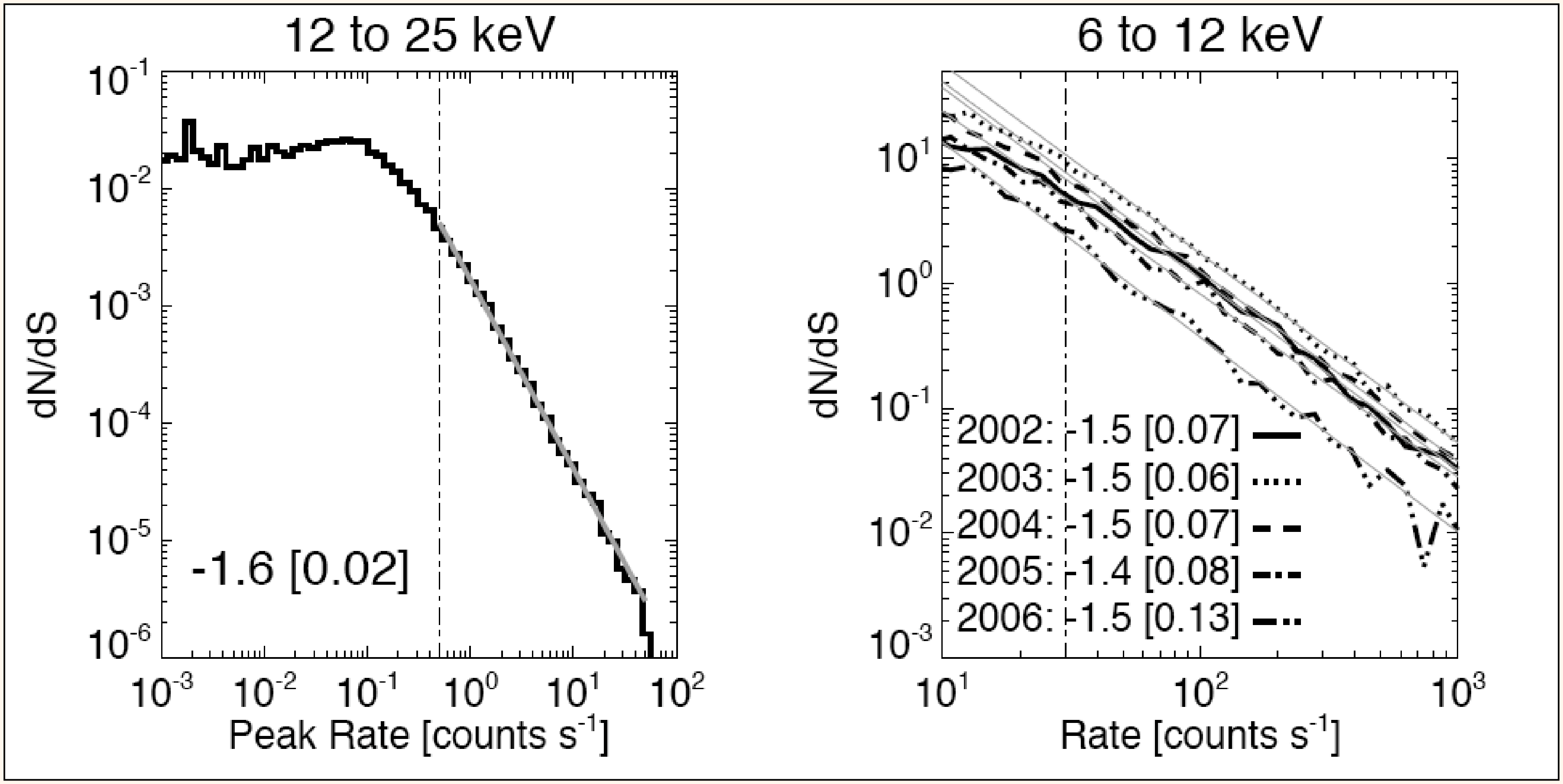
Thermal

Thermal/nonthermal



Hannah et al. 2008

Frequency distributions (“logN/logS”)



RHESSI microflare summary

- The microflares all exhibit high temperatures (Fe feature appears)
- All, where detectable, have non-thermal components
- All occur within active regions
- The standard flare-like distribution function persists
- Microflares are temporally and spatially incapable of "explaining" coronal heating

See Iain Hannah's poster

Microflare cooling/ nanoflare heating?

- A flare brightening represents a net energy loss from coronal magnetic storage
- This requires a reduction in the mean $\mathbf{B}^2$.
- Empirically, we know that $|\mathbf{B}|$ correlates well with the appearance of heating.
- Therefore, flares serve to *reduce* the heating and to *cool* the corona, rather than heat it.
- Nanoflares must represent different physics.

Conclusions

- RHESSI observations now reject the hypothesis of “microflare heating”
- Nanoflares - something different - could still be involved
- The striking inhomogeneities of the active-region corona should lead us to question whether or not the concept of distributed coronal heating is realistic

Questions

- What is the minimum temperature/density/pressure in an active-region magnetic loop?
- What can we learn from time-series analysis of X-ray brightness (*cf* Hudson 1991)?
- What about the electrodynamics of the chromosphere (*cf* M. L. Goodman, ApJ 533, 501, 2000, plus recent work in Arber's group)?