The Search for Units:
A Gradient Distribution route to Multifractality in Solar Magnetic Fields

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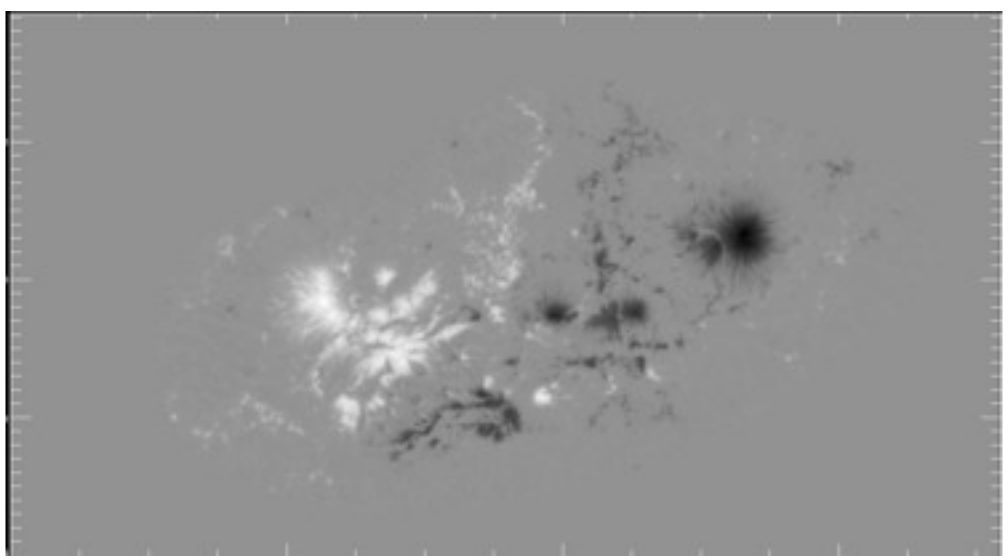
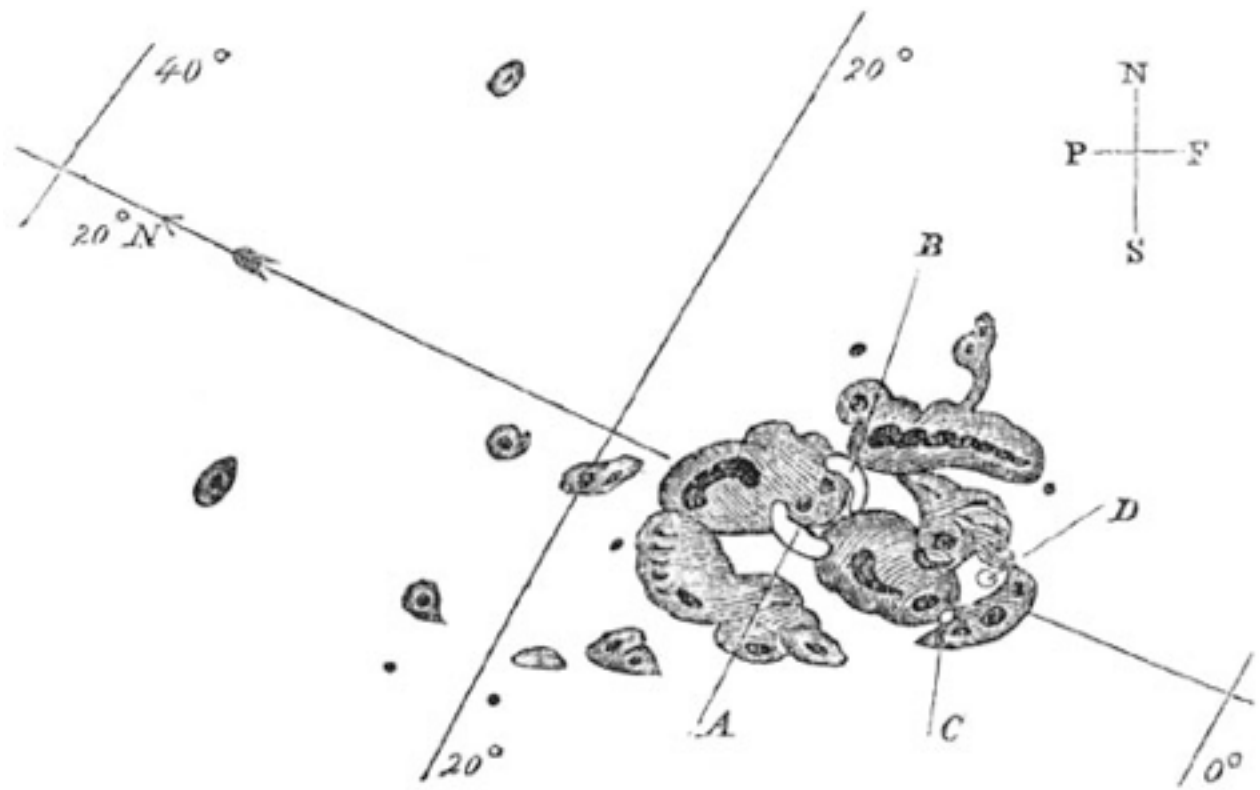
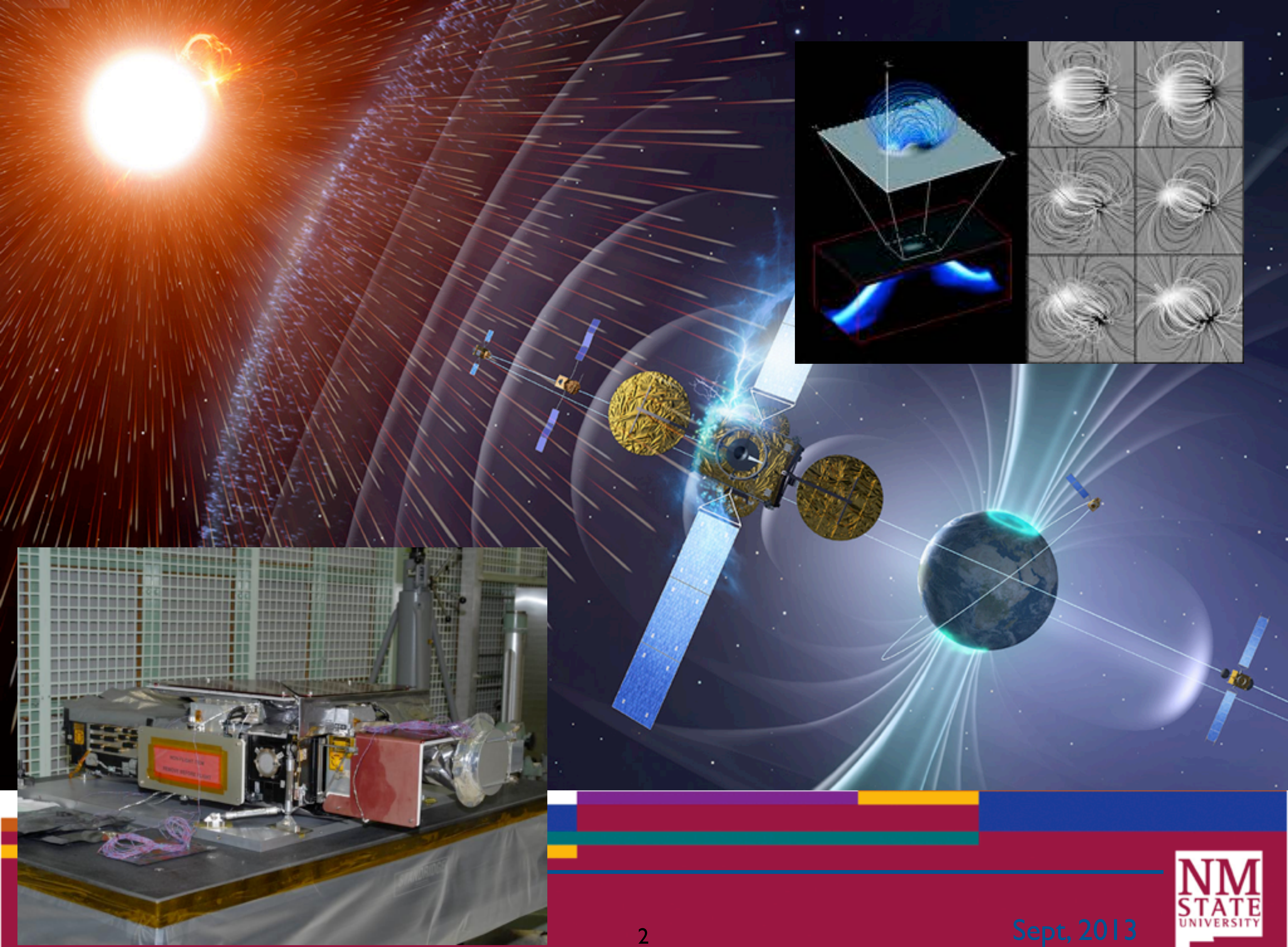






Maybe SOC?

- Scale free, maybe SOC
- Fractals, maybe SOC
- Units, in SOC

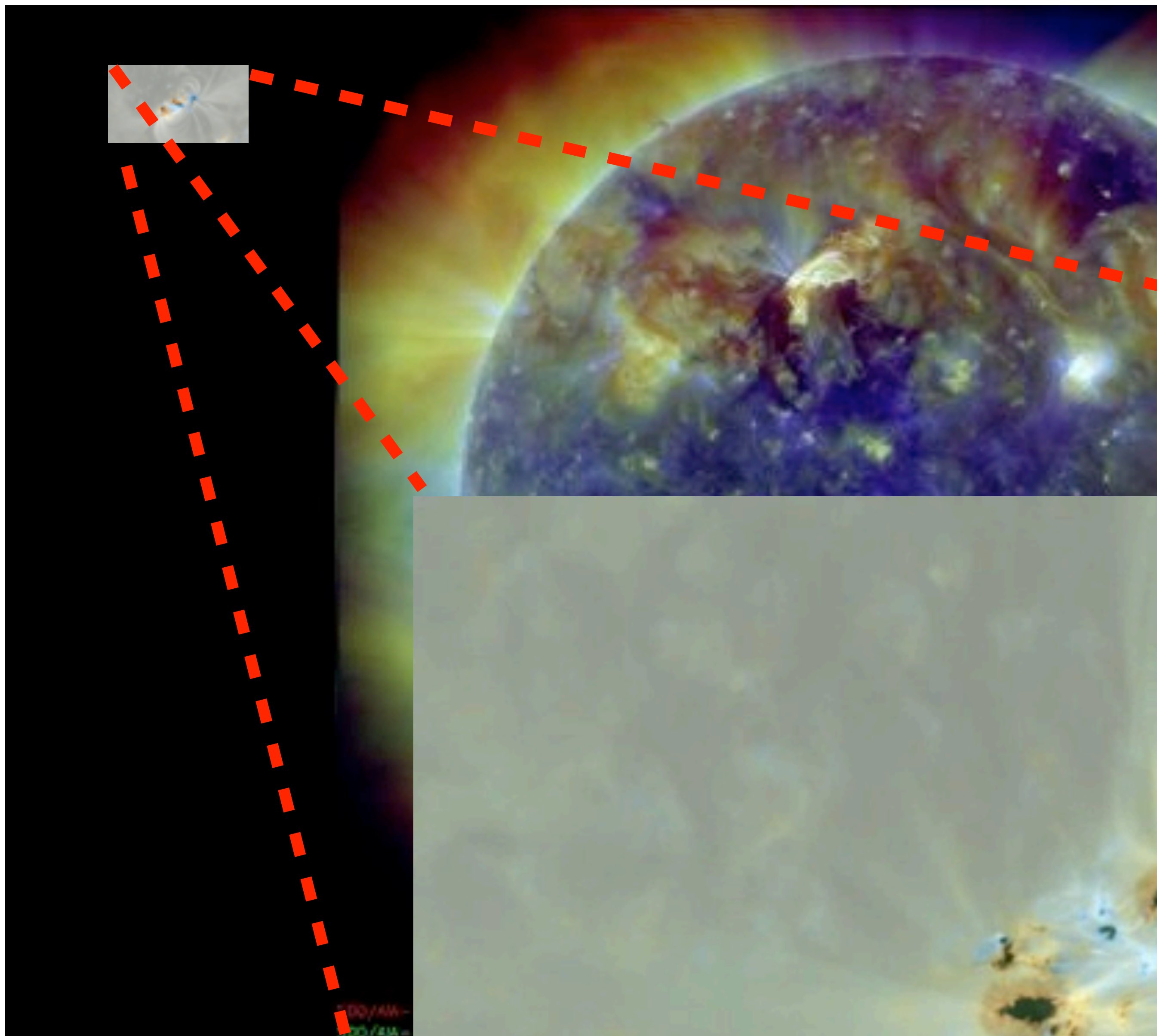
The Why and The How

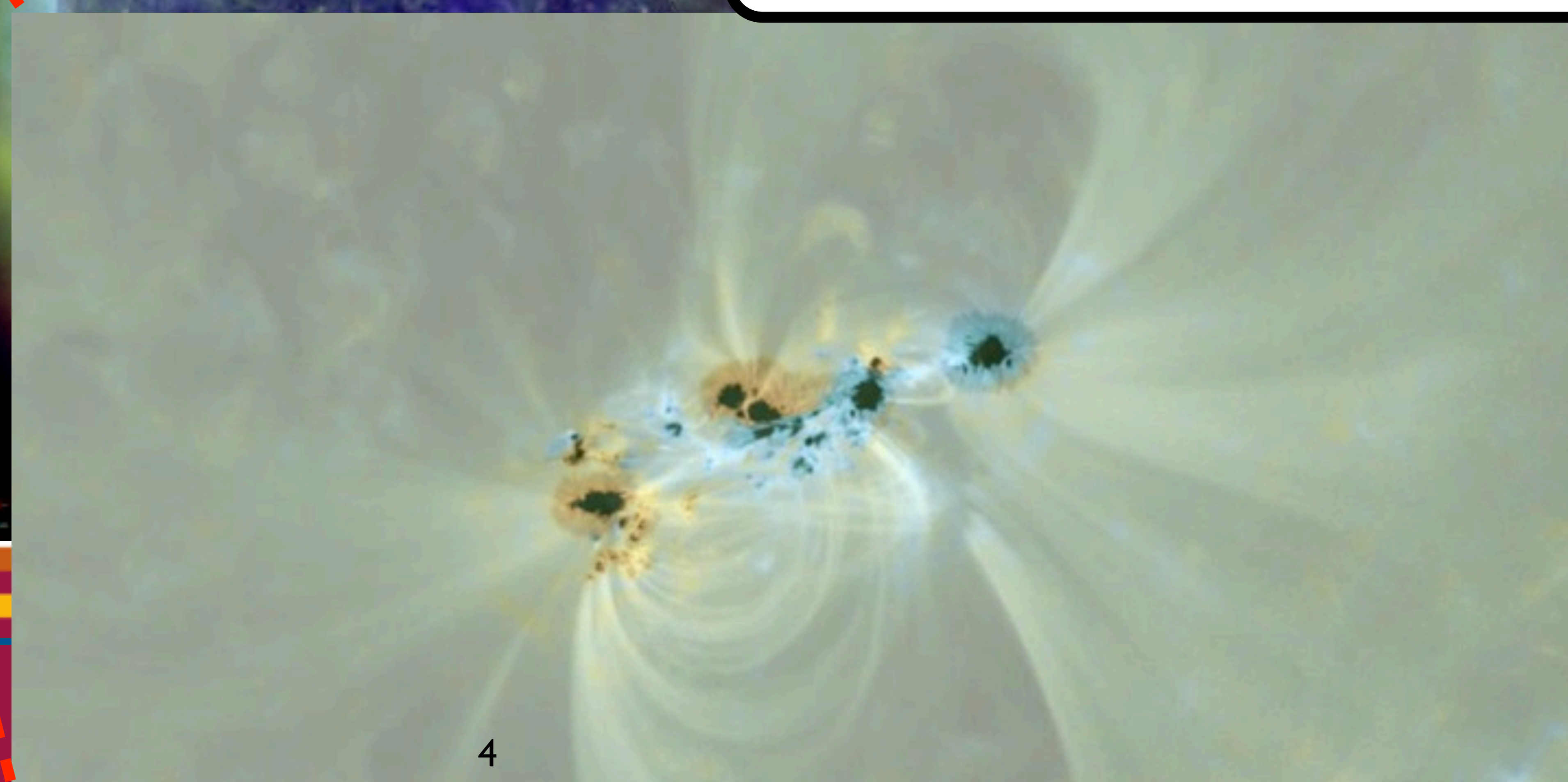
$$\nabla \cdot \mathbf{B} = 0$$

$$\frac{\partial B}{\partial t} = \nabla \times (v \times B) + \eta \nabla^2 B,$$

$$R_m = \frac{\nabla \times (v \times B)}{\eta \nabla^2 B},$$

$$\vec{\nabla} \times \vec{B} = \mu_0 J$$





Connection to SOC

- allows for energy build up over timescales much longer than energy release
- allows for a system to approach SOC
- requires a threshold in 'energy' which must be followed by a release of energy
- dictates energy output sizescales much less than spatial scale of system.

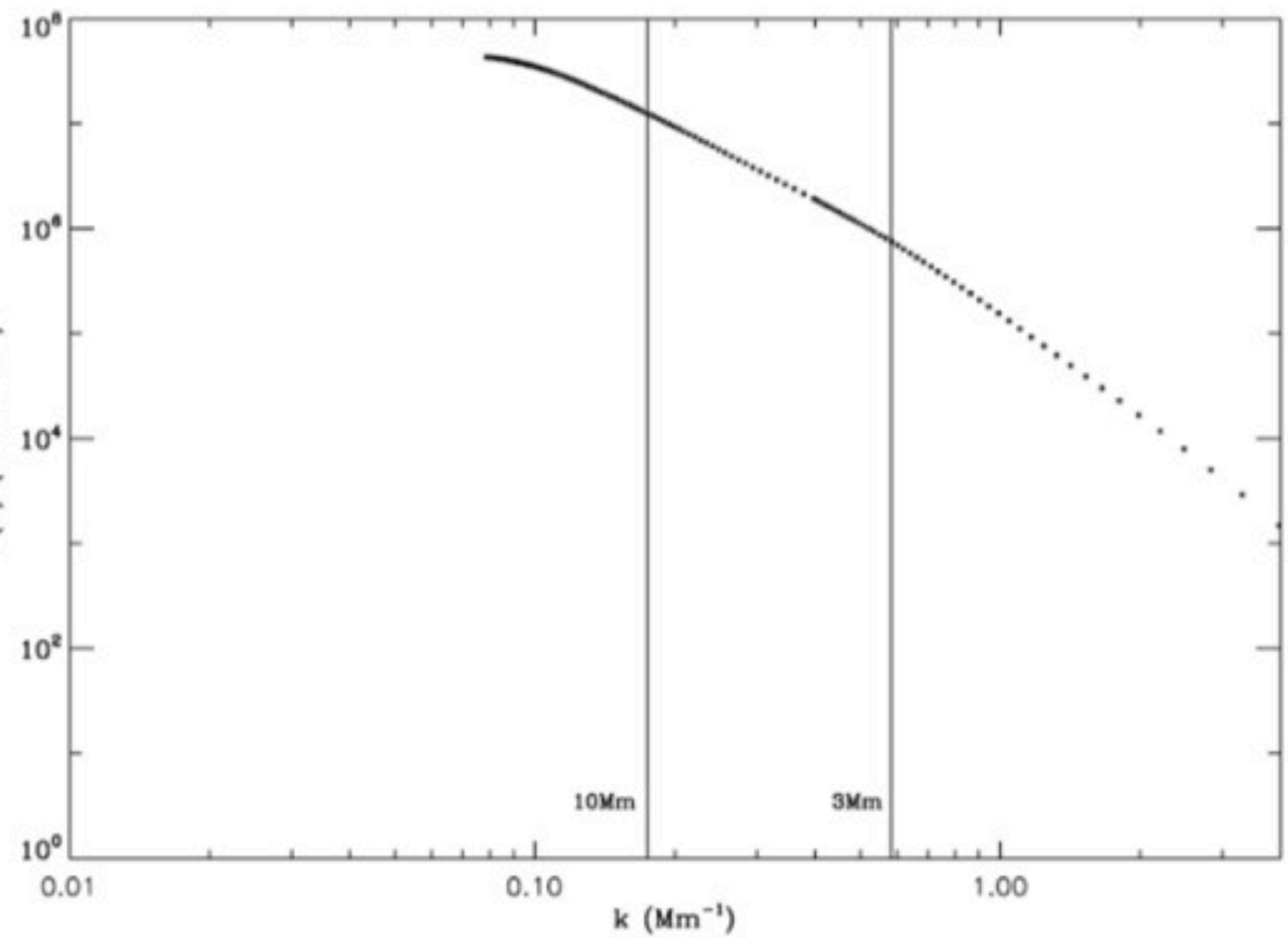
$$\nabla \cdot \mathbf{B} = 0$$

$$\frac{\partial B}{\partial t} = \nabla \times (v \times B) + \eta \nabla^2 B,$$

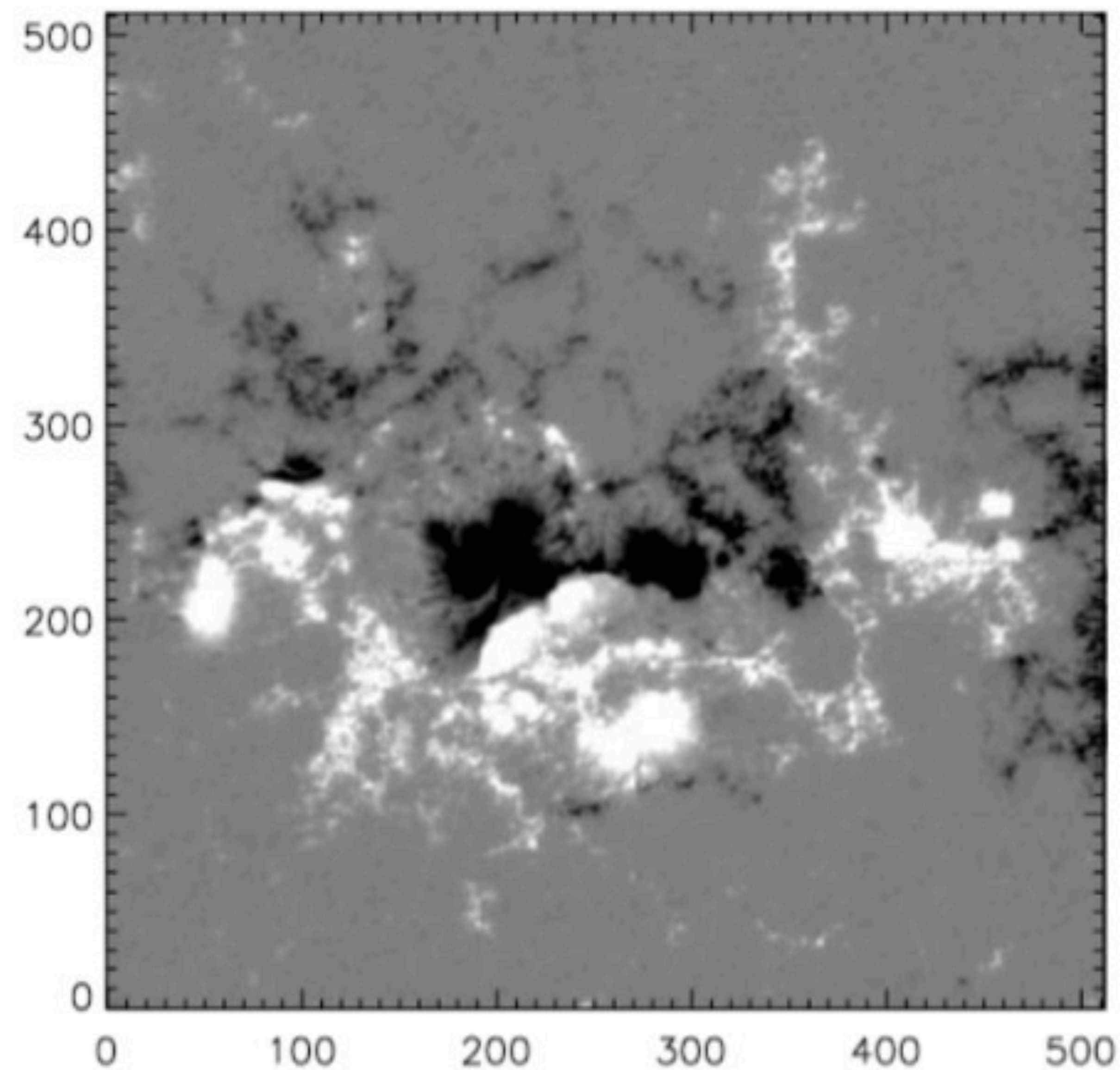
$$R_m = \frac{\nabla \times (v \times B)}{\eta \nabla^2 B},$$

$$\vec{\nabla} \times \vec{B} = \mu_0 J$$

Scale free, maybe SOC?

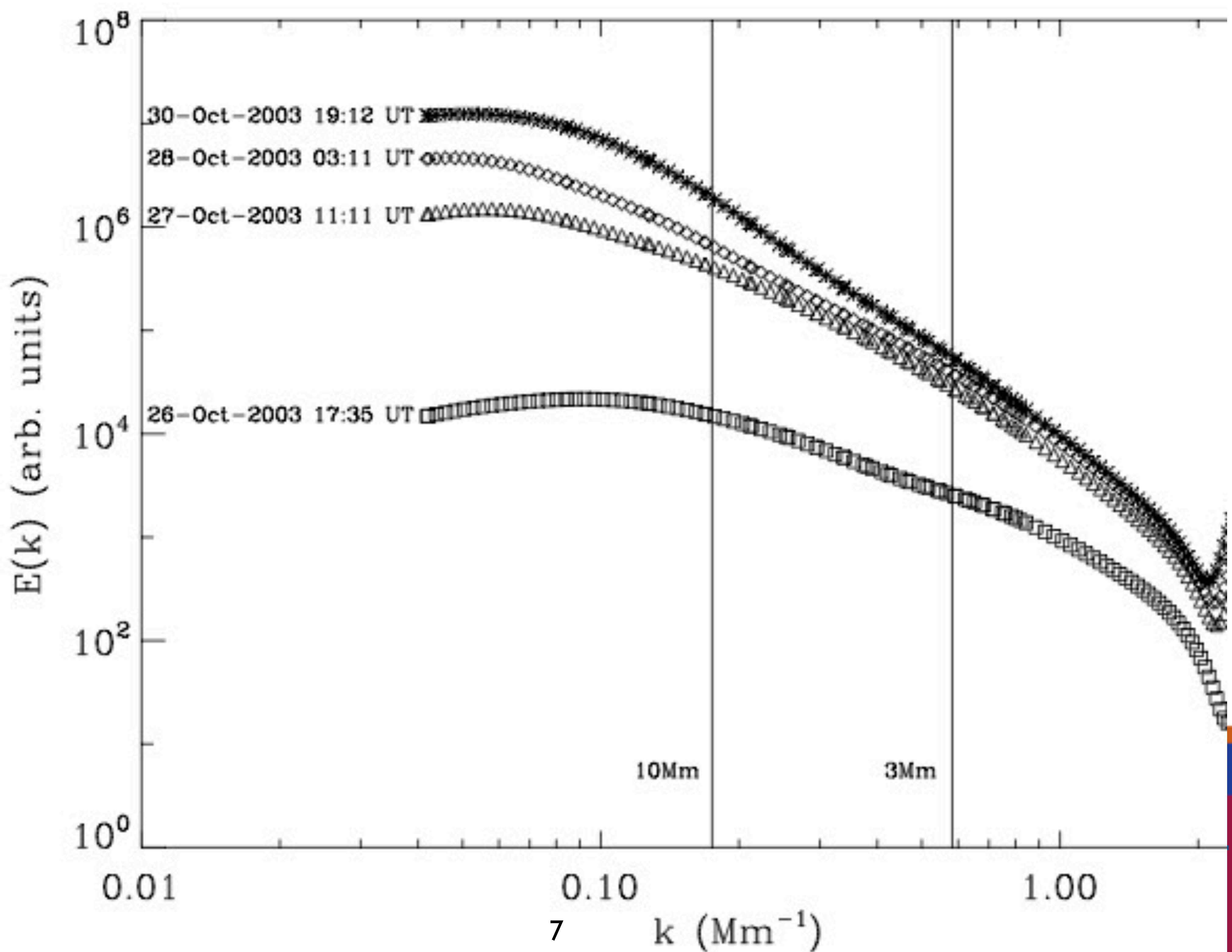


$E(k) \sim k^{-a}$

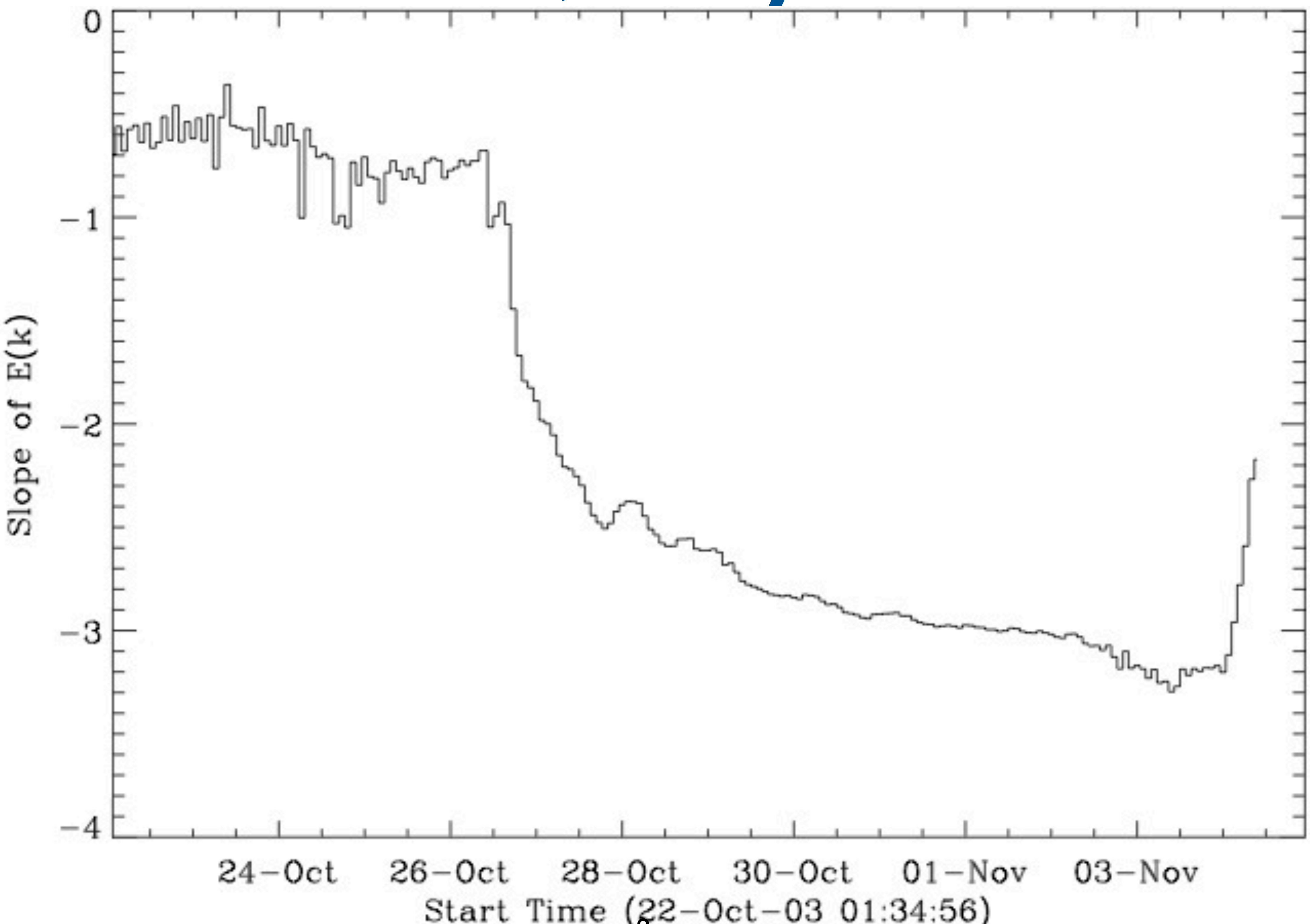


Abramenko 2002, 2005, 2006
Hewett, McAteer et al., 2008

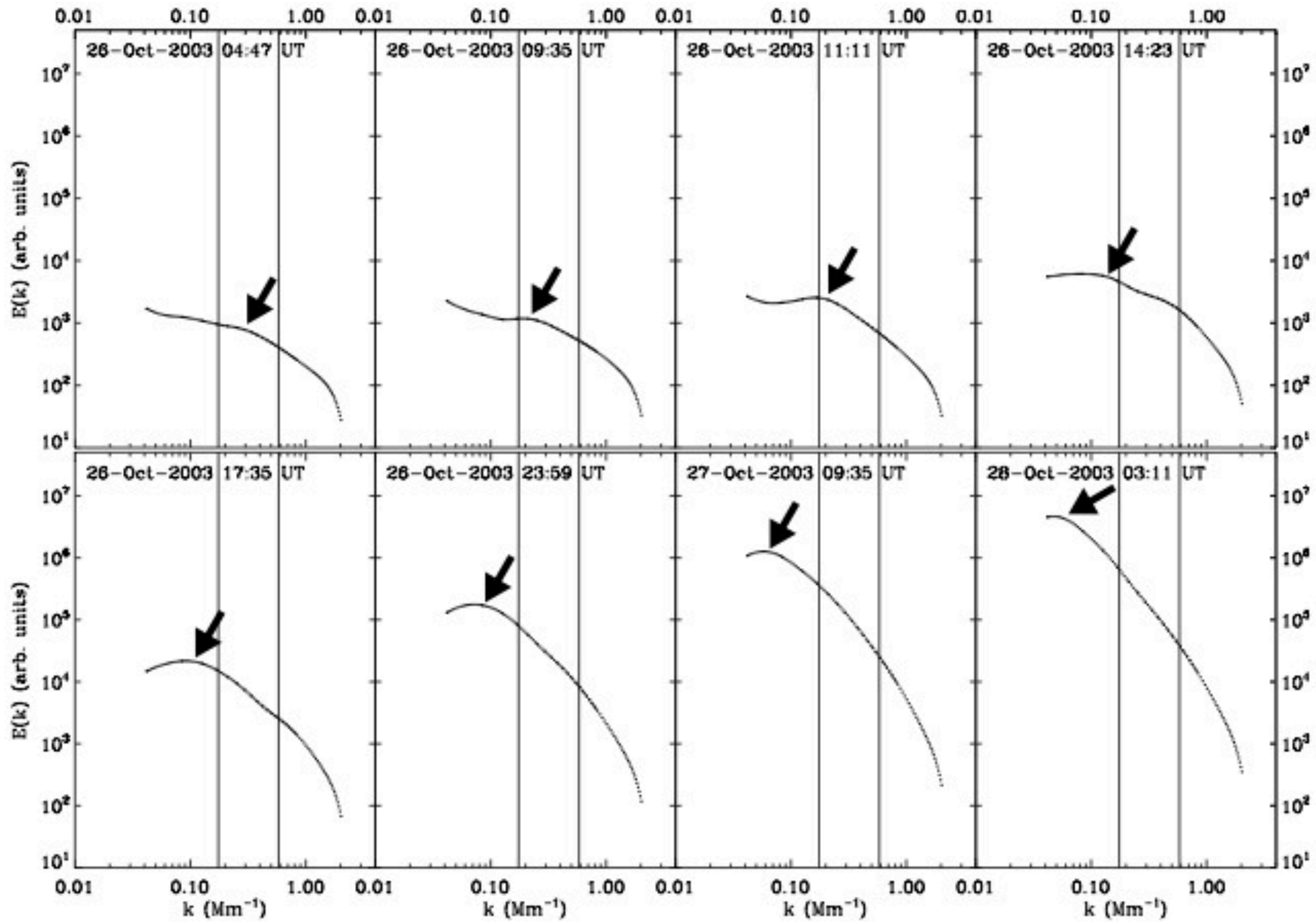
Scale free, maybe SOC



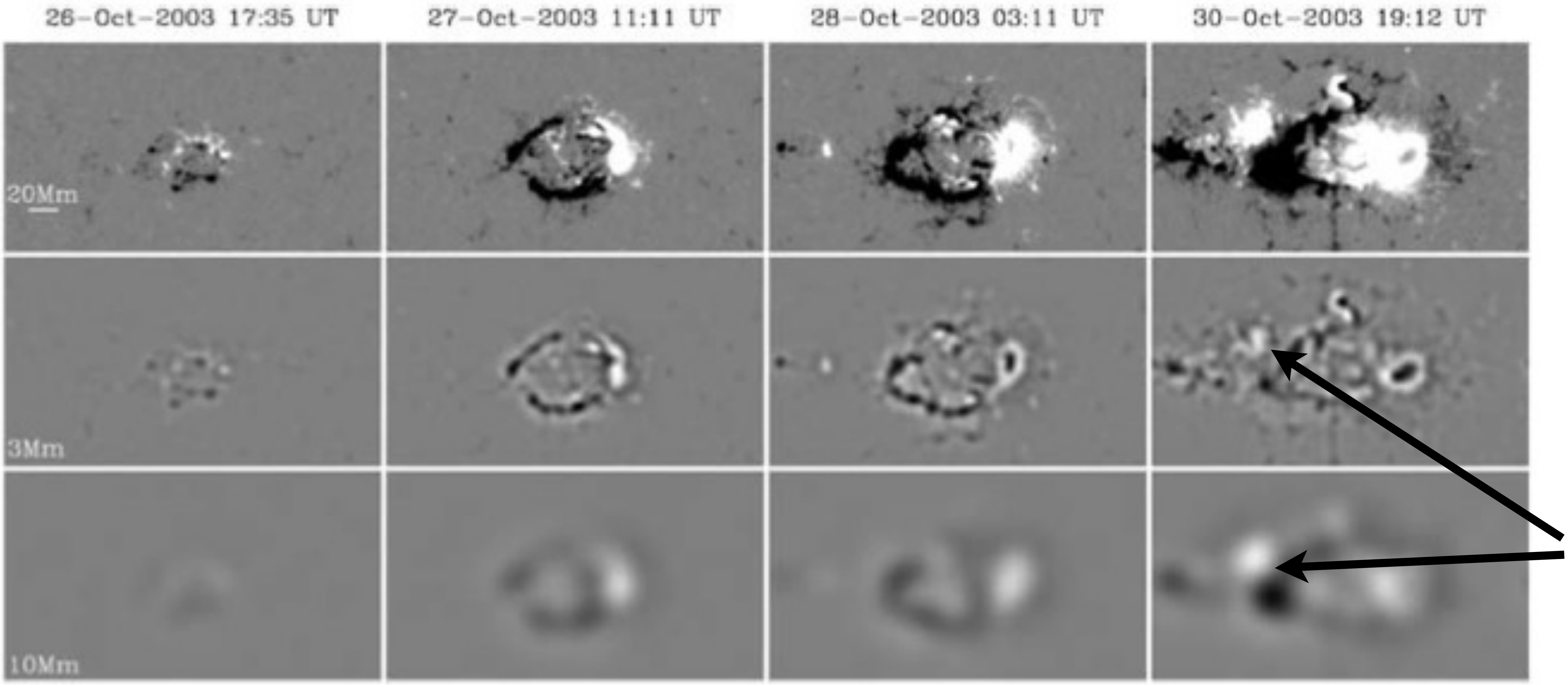
Scale free, maybe SOC



Scale free, maybe SOC



Scale free, maybe SOC



Fractals, maybe SOC

McAteer et al., 2005

TABLE 1

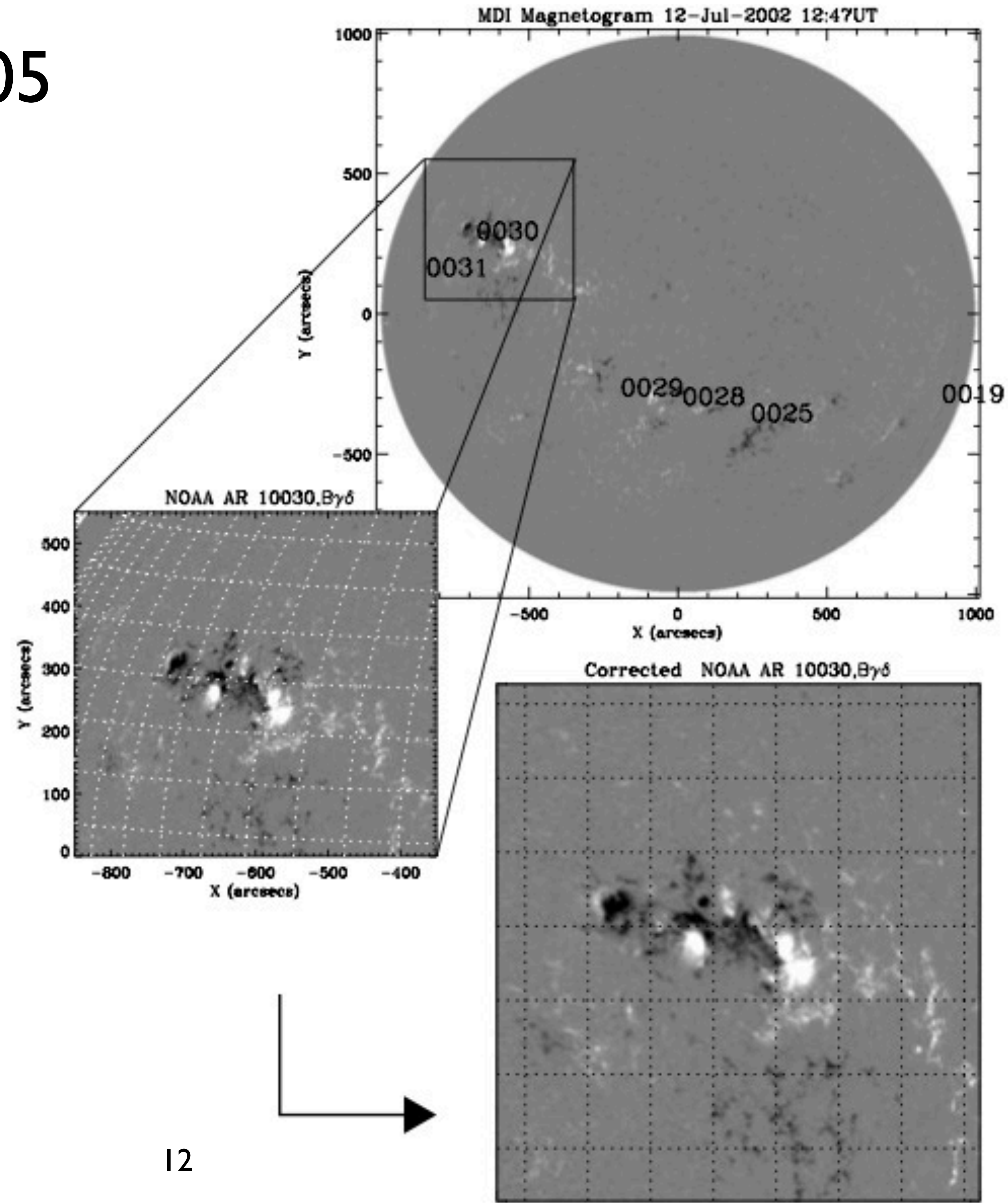
Fractal Dimension Analyses of Solar Data

Study	Data[a]	Method	FD[b]
Roudier & Muller (1987)	WL granules	D_{PA}	1.25 for $d < 1\farcs37$
Hirzberger et al. (1997)	WL granules	D_{PA}	1.30 for $d < 1\farcs39$
	WL granular cells	D_{PA}	1.16
Bovelet & Wiehr (2001).............	Wl granules	D_{PA}	1.09
Janssen et al. (2003)	B small scale	D_{PA}	1.41 ± 0.05, $d < 1\farcs8$
	S magnetoconvection	D_{PA}	1.38 ± 0.07, $d < 1\farcs8$
Tarbell et al. (1990)	B plage	D_{LA}	1.45–1.60
Lawrence (1991).........................	B active region	D_{LA}	1.56 ± 0.08
Schrijver et al. (1992)..................	S percolation theory	D_{LA}	1.56
Lawrence & Schrijver (1993)......	B active region	D_{LA}	1.56 ± 0.08
Balke et al. (1993).......................	B plage	D_{LA}	1.54 ± 0.05, $l < 3''$
Meunier (1999)	B active regions	D_{PA}	1.48–1.68
		D_{LA}	1.78–1.94
Meunier (2004)	B active regions	D_{PA}	1.35–1.70
Gallagher et al. (1998).................	EUV quiet-Sun	D_{BC}	1.30–1.70
Georgoulis et al. (2002)...............	Hα Ellerman bombs	D_{BC}	1.4
Fragos et al. (2004)	S cell automation	D_{BC}	1.5 ± 0.1
Vlahos et al. (2002).....................	S cell automation	D_{BC}	1.42 ± 0.12
Lawrence et al. (1993).................	B	D_{BC}	Multifractal
Cadavid et al. (1994)...................	B	D_{BC}	Multifractal
Lawrence et al. (1996).................	B	D_{BC}	Multifractal

[a] WL: White light; B: magnetic field; S: simulation; EUV: extreme ultraviolet.
[b] d: Diameter; l: length.

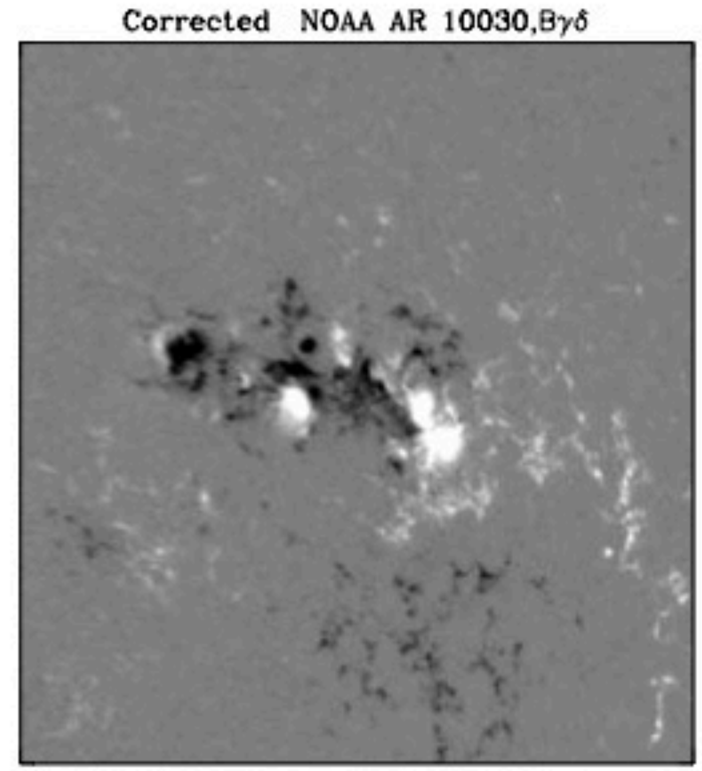
Fractals, maybe SOC

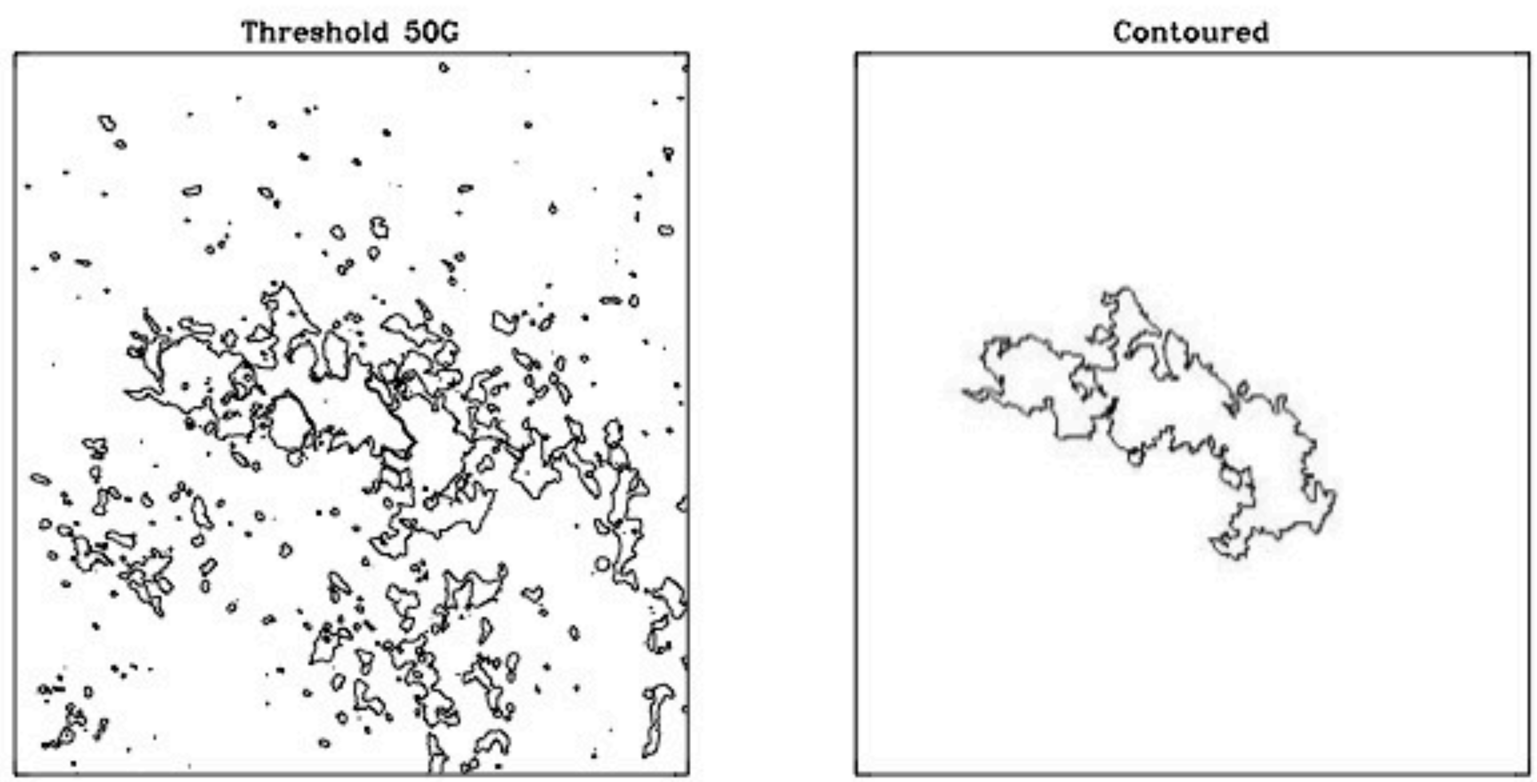
McAteer et al., 2005



Fractals, maybe SOC

McAteer et al., 2005



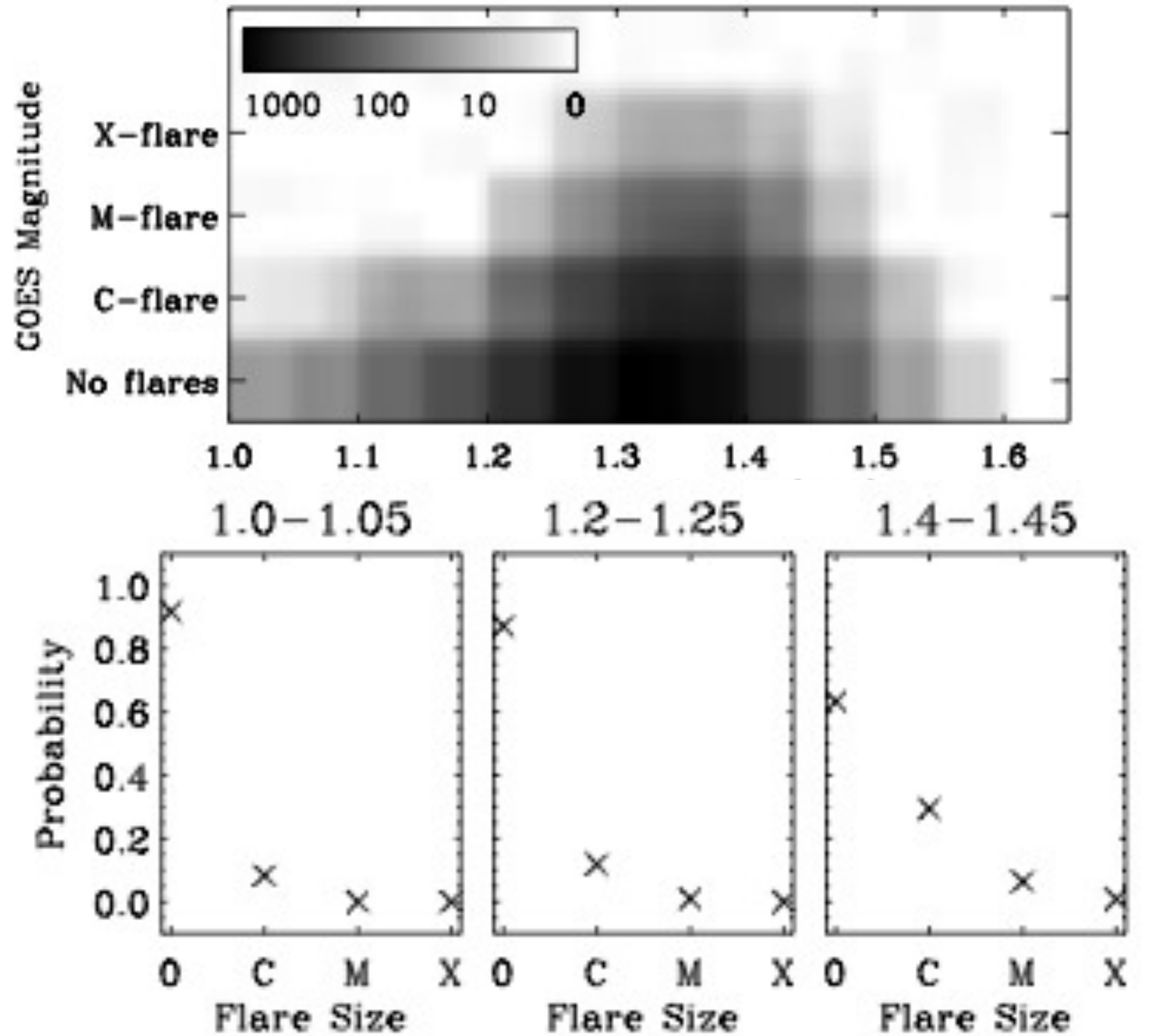


Fractals, maybe SOC

McAteer et al., 2005

2700 days

9300 images

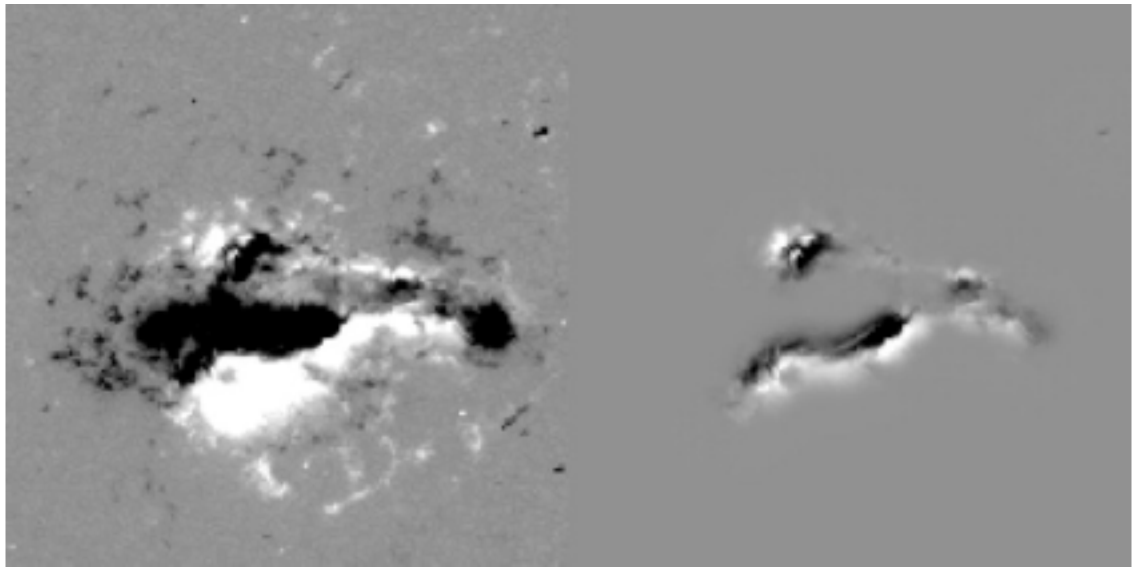


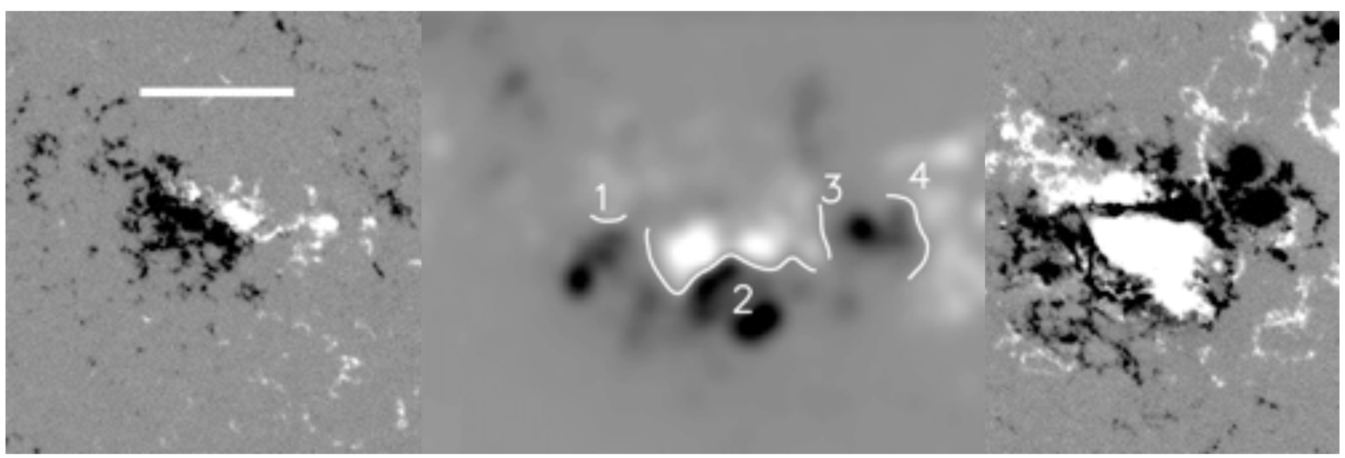
Units, in SOC

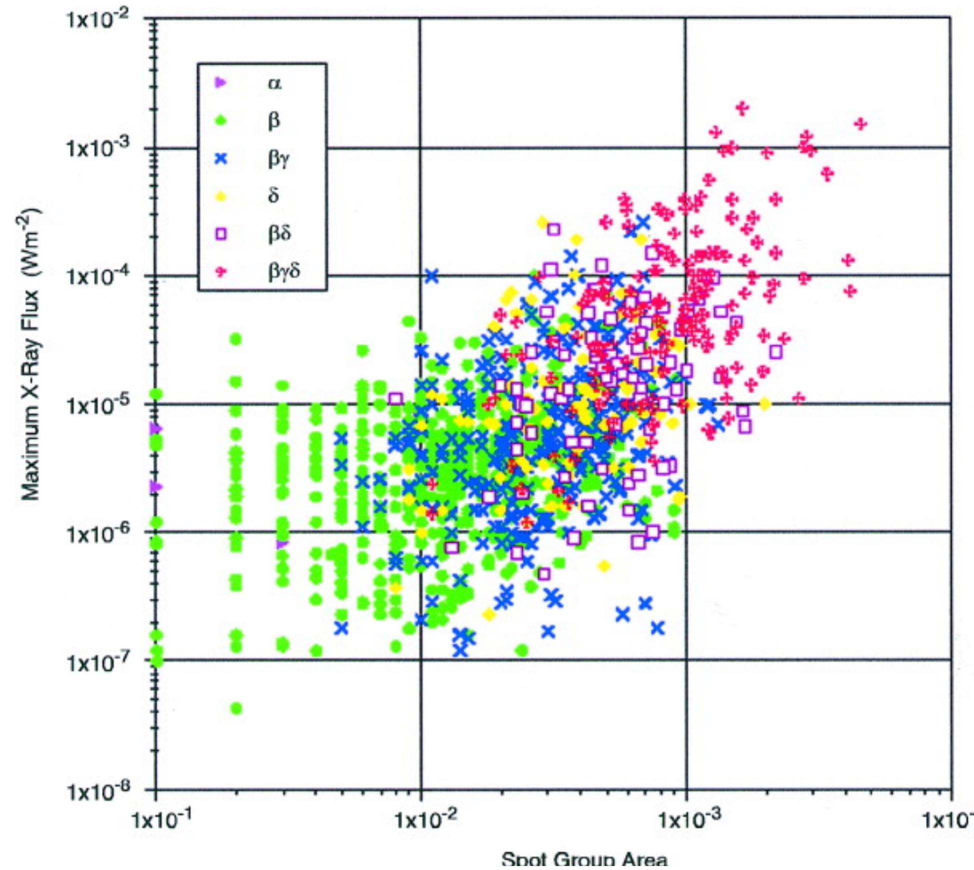
"Where is the physics?"
"Give me some units!"
"The Sun is not a vacuum."

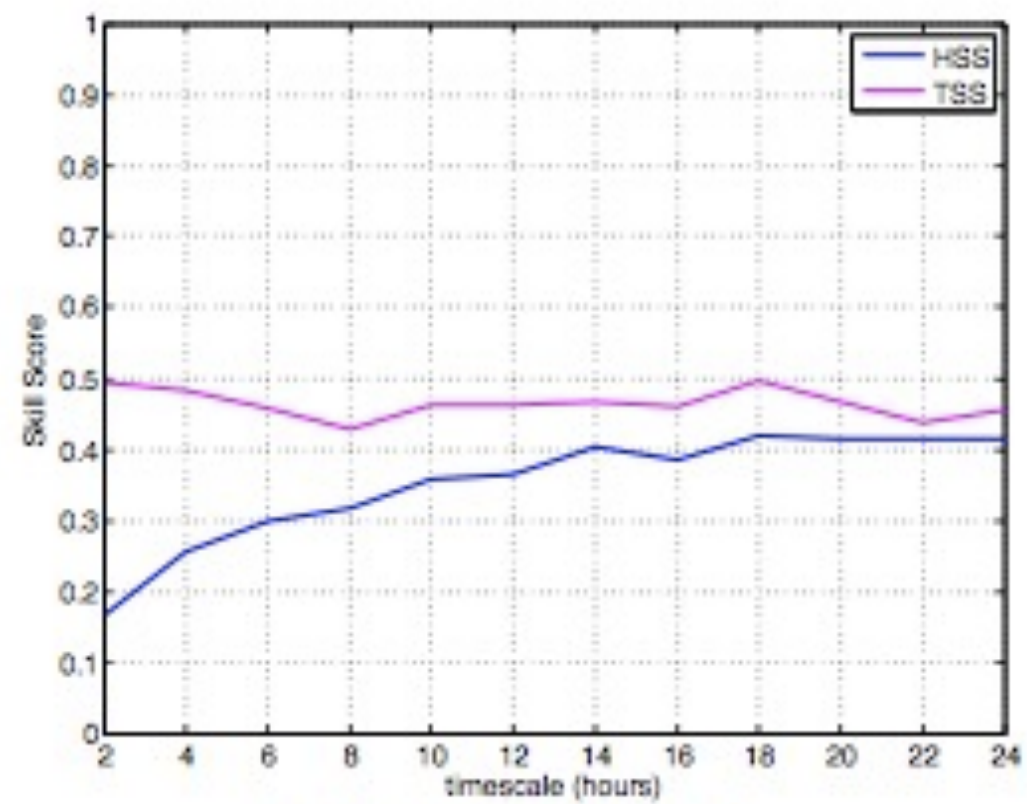
Strong gradients in the photosphere produce currents in the corona. Flares occur in the corona where currents build up.

gradients, gradients, gradients,...





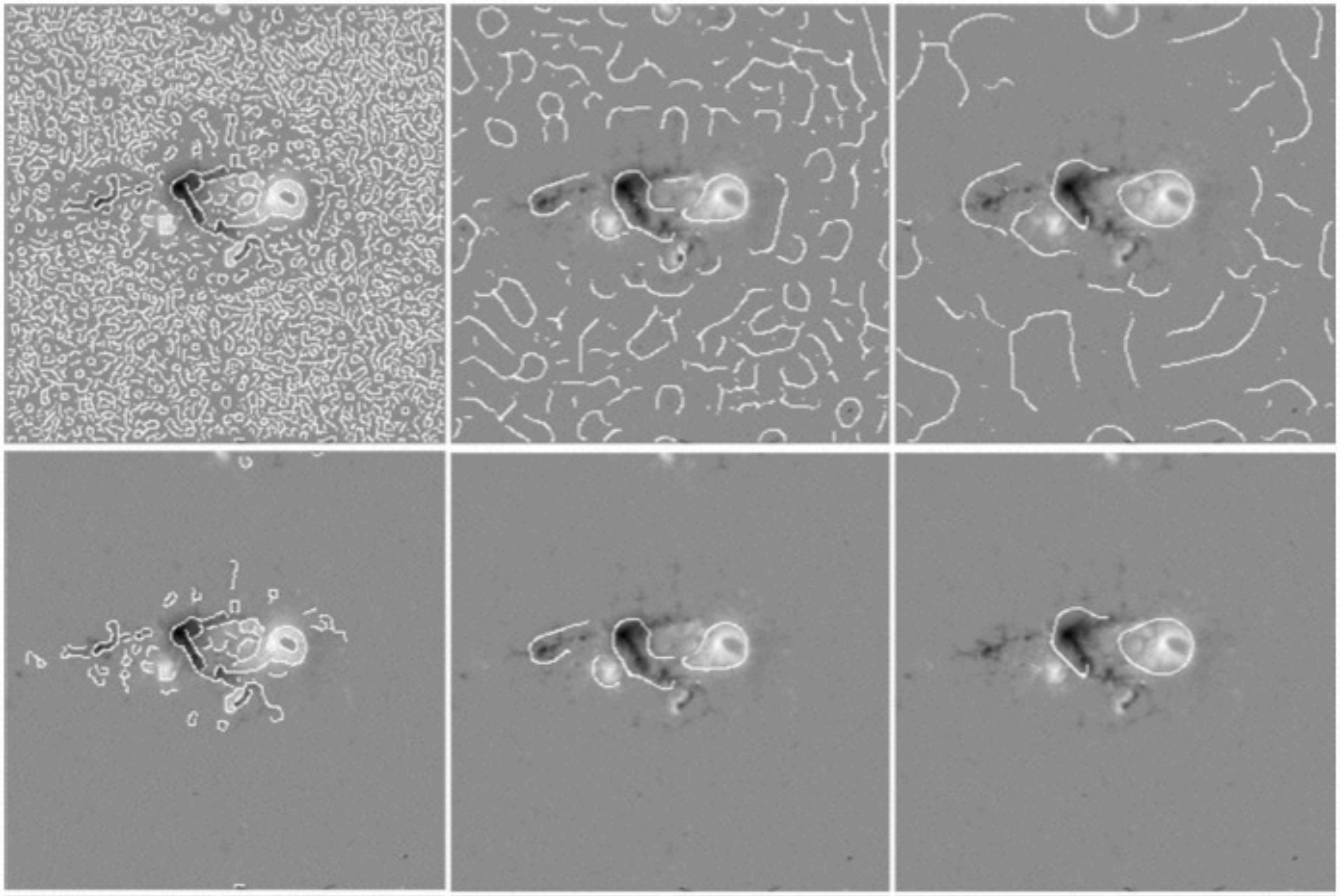


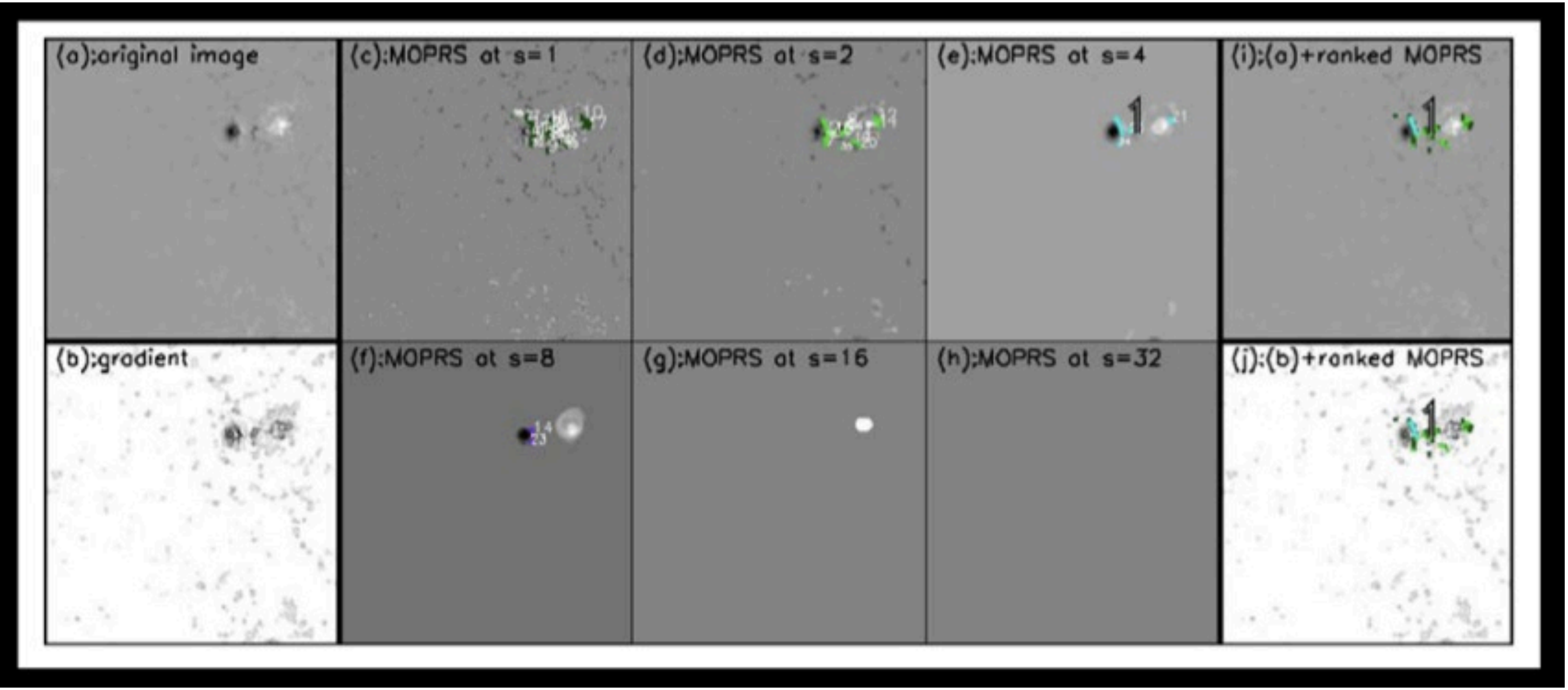


(b) HSS and TSS.

Sammis et al, ApJ, 2000, 540, 587
Schrijver, ApJ, 2007, 655, L117
Falconer et al., ApJ, 2008, 689, 1433
Al-Ghraibai, Boucheron, McAteer, ApJ, 2013

gradients, gradients, gradients





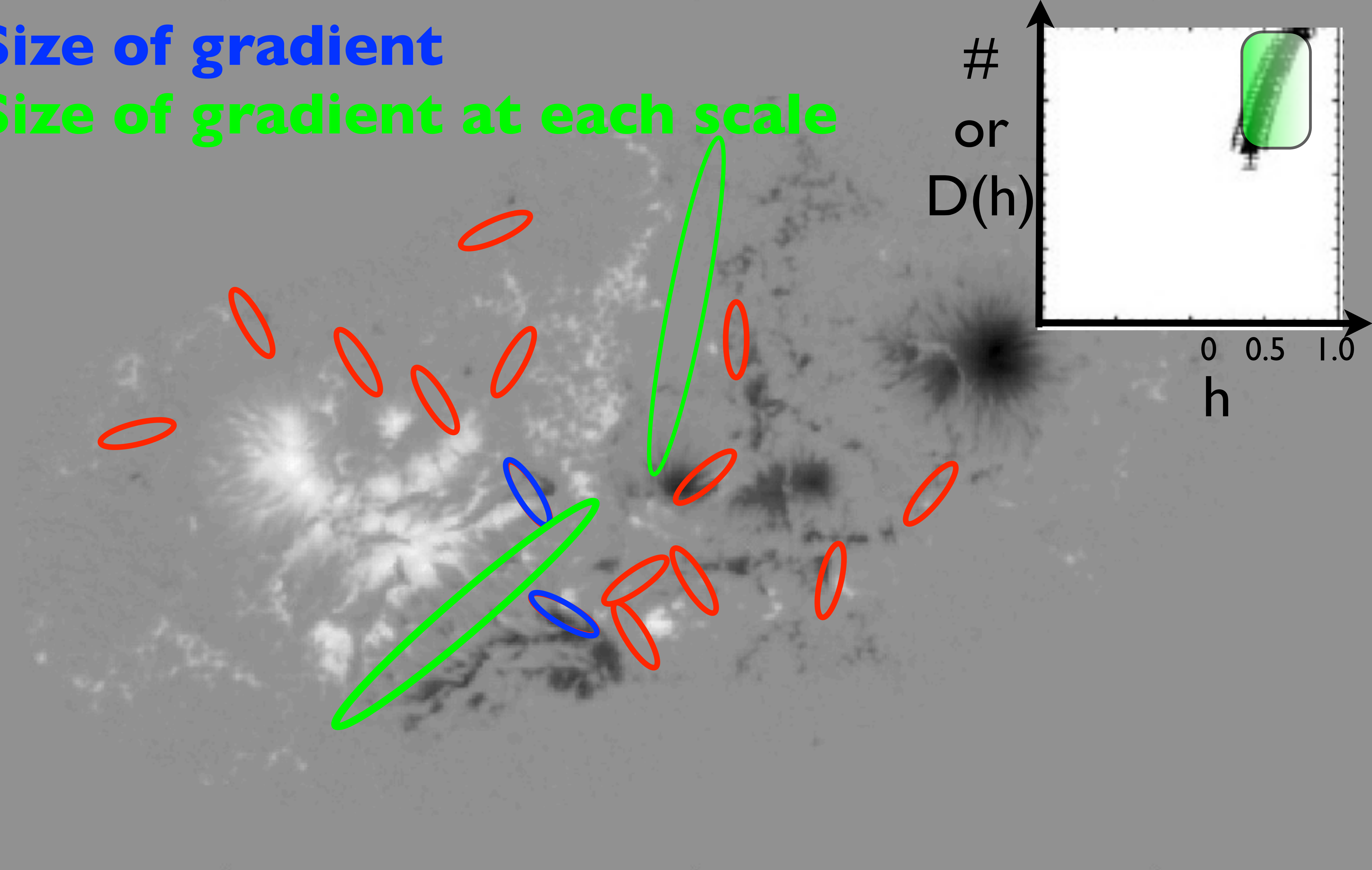
dB/dx, dB/dy

Data is resolution dependent

J_z

Size of gradient

Size of gradient at each scale



Wavelet Transform Modulus Maxima

(1) Take a *multiscale* gradient
(2) At the smallest spatial, detect a strong gradient.
(3) Track this gradient up through each size scale.
(4) Calculate partition function

$$\mathbf{T}_{\psi}[f](\mathbf{b}, a) = \begin{pmatrix} T_{\psi_1}[f] = a^{-2} \int d^2\mathbf{x}\ \psi_1(a^{-1}(\mathbf{x}-\mathbf{b}))f(\mathbf{x}) \\ T_{\psi_2}[f] = a^{-2} \int d^2\mathbf{x}\ \psi_2(a^{-1}(\mathbf{x}-\mathbf{b}))f(\mathbf{x}) \end{pmatrix}, = \nabla\{T_{\phi}[f](\mathbf{b}, a)\} = \nabla\{\phi_{\mathbf{b},a} * f\}, \quad (1)$$

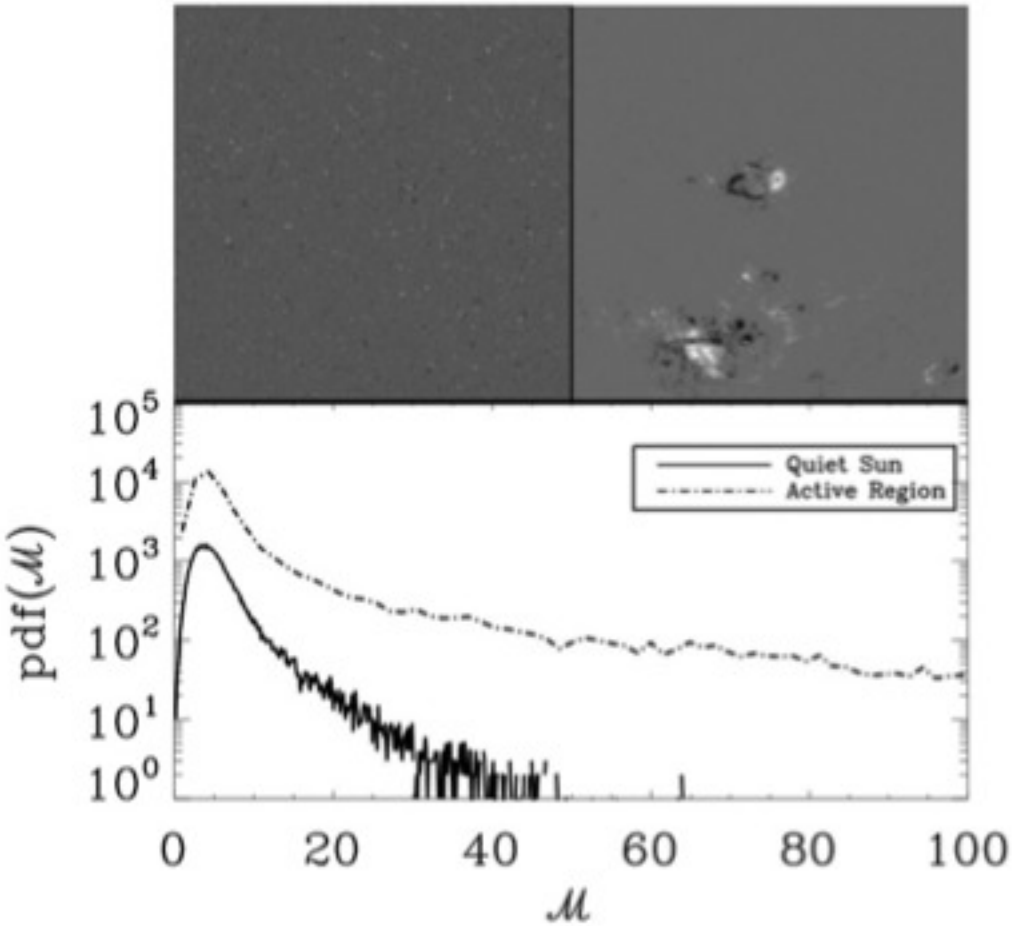
$$\mathcal{M}_{\psi}[f][\mathcal{L}_{\mathbf{x}_0}(a)] \sim a^{h(\mathbf{x}_0)},$$

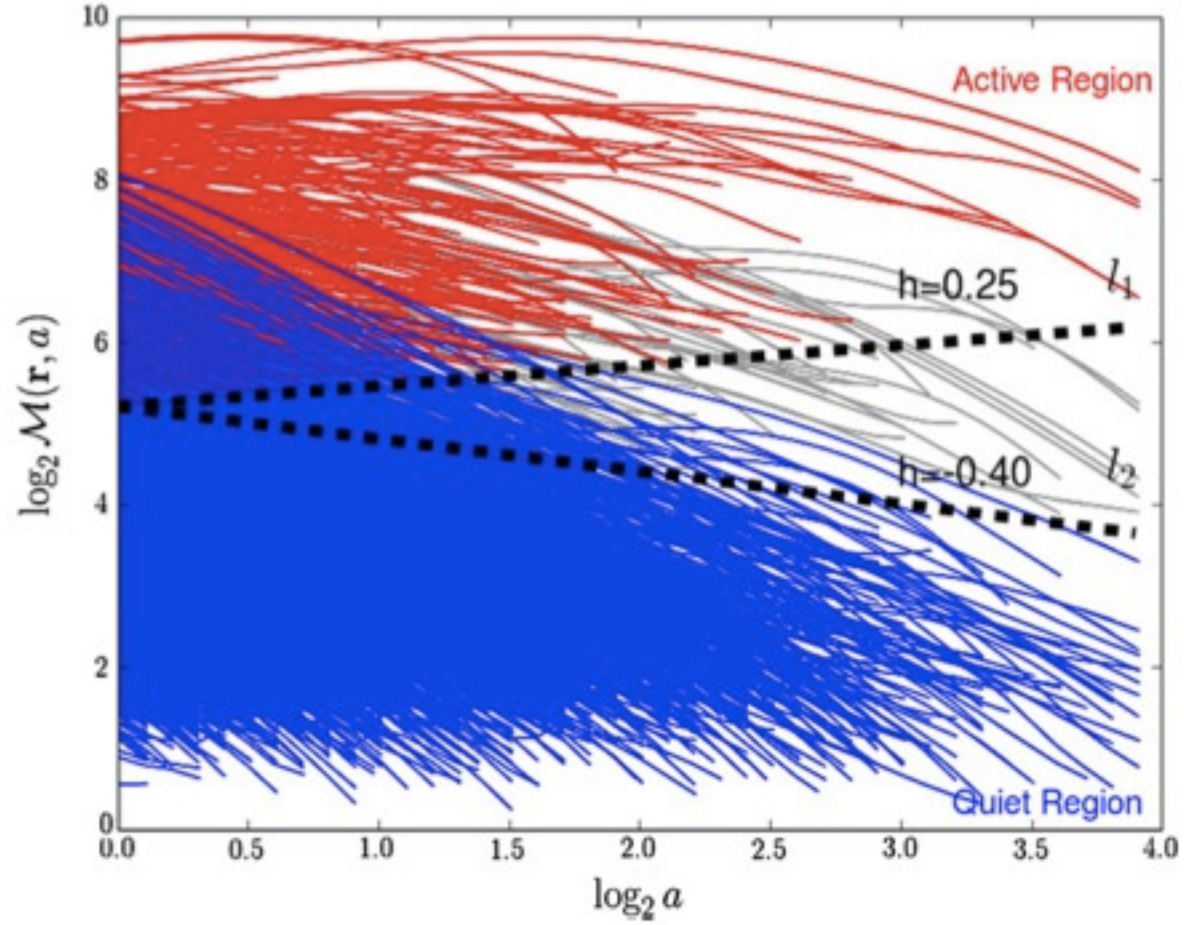
$$\mathcal{Z}(q, a) = \sum_{\mathcal{L}\in\mathcal{L}(a)} [\mathcal{M}_{\psi}[f](\mathbf{x} \in \mathcal{L}, a)]^q,$$

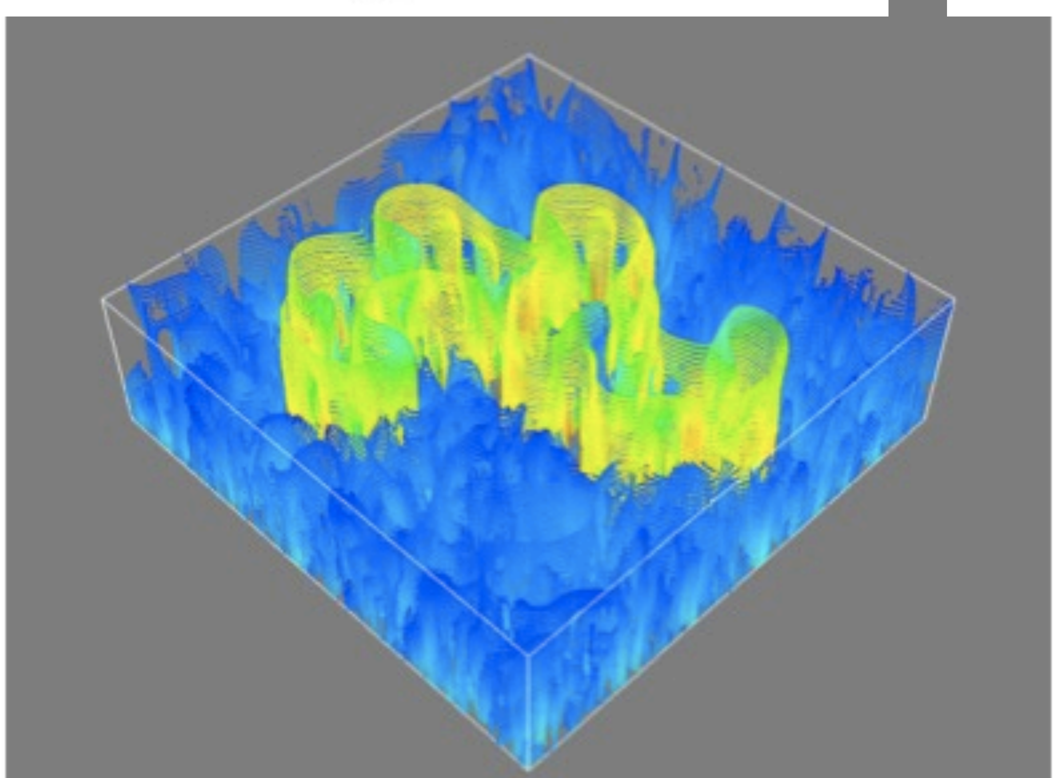
$$h(q, a) = \sum_{\mathcal{L}\in\mathcal{L}(a)} \ln|\mathcal{M}_{\psi}[f](\mathbf{x}, a)|\ W_{\psi}[f](q, \mathcal{L}, a) \sim a^{h(q)}, \quad (5)$$

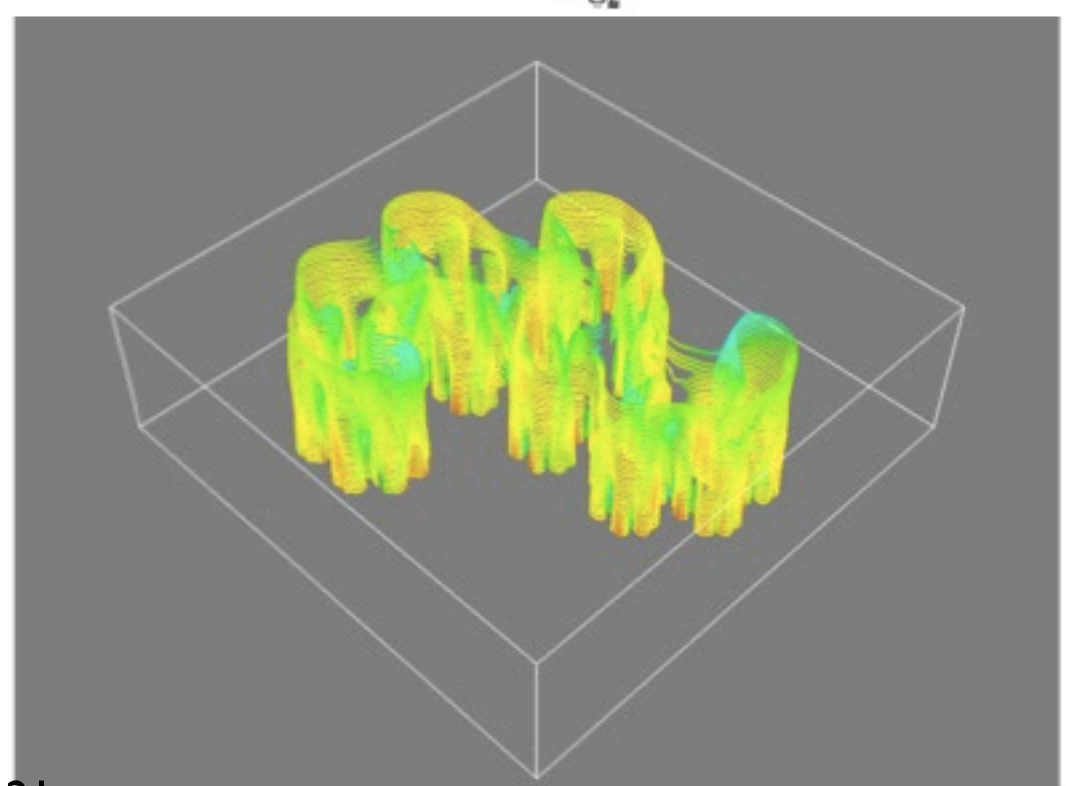
$$D(q, a) = \sum_{\mathcal{L}\in\mathcal{L}(a)} W_{\psi}[f](q, \mathcal{L}, a)\ \ln\big(W_{\psi}[f](q, \mathcal{L}, a)\big) \sim a^{D(q)}, \quad (6)$$

The quiet Sun

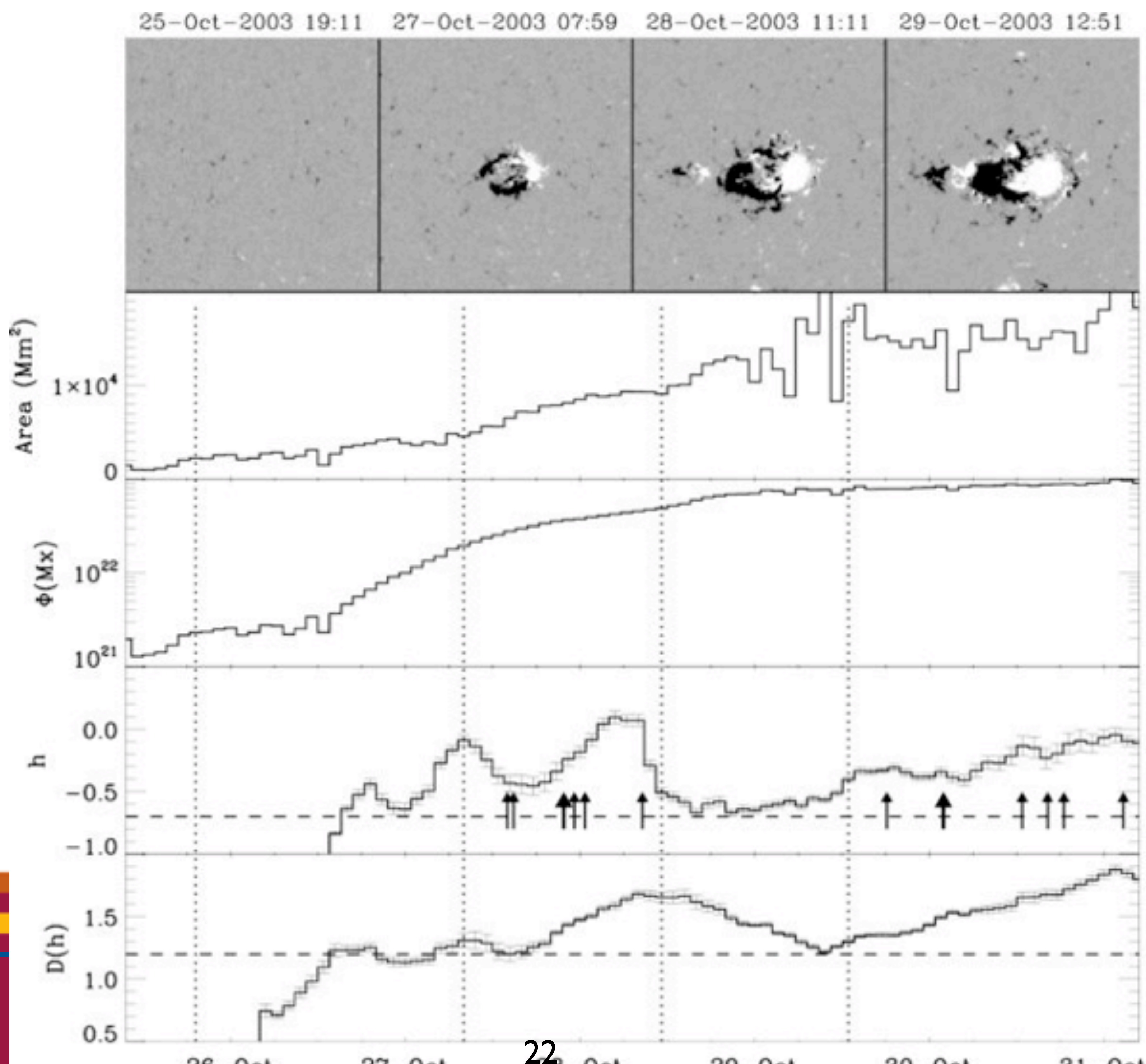




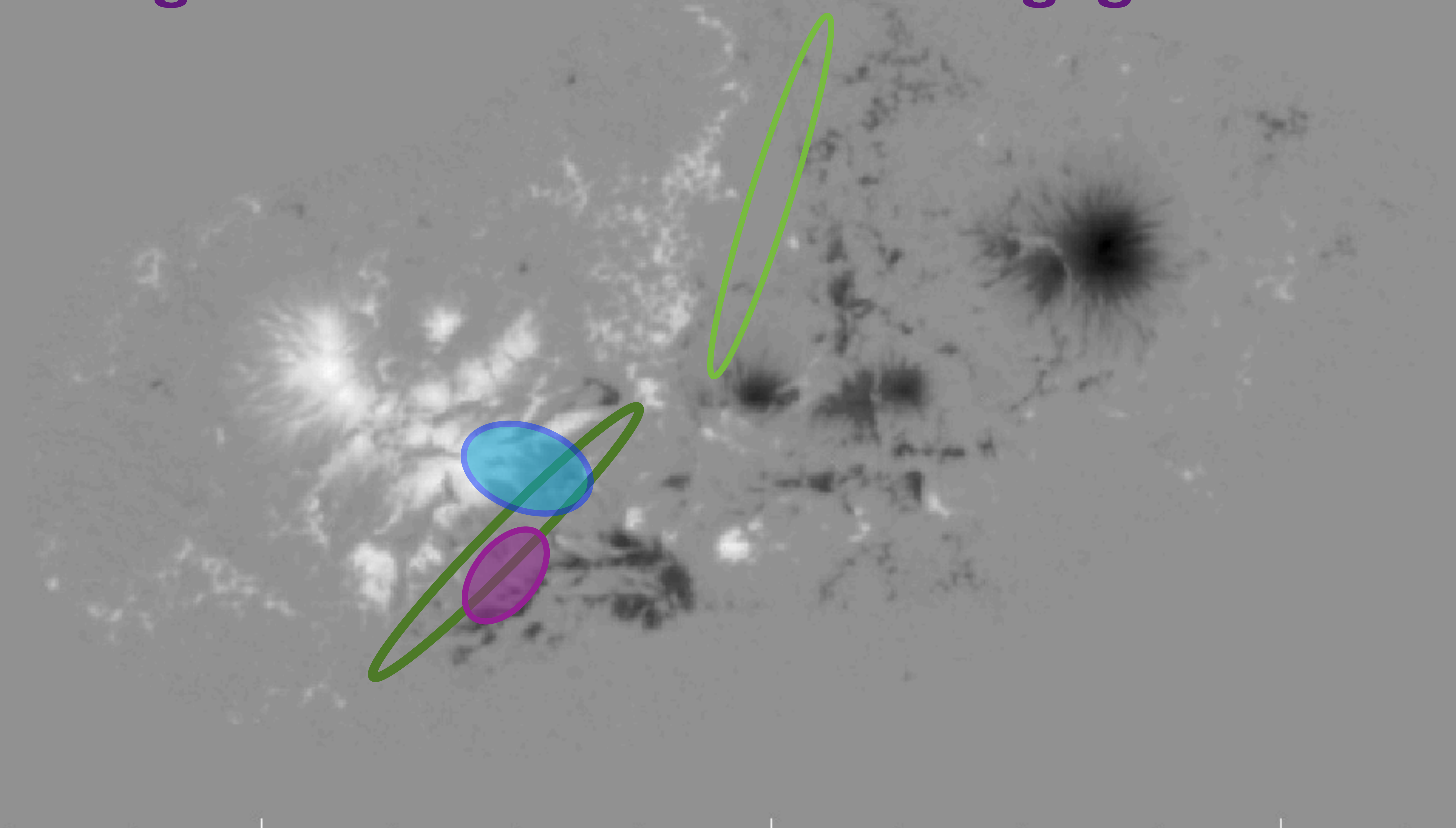




Wavelet Transform Modulus Maxima



New flux arises near to ‘strong’ gradients
New gradients arise near ‘strong’ gradients



Maybe SOC?

- Scale free, maybe SOC
- Fractals, maybe SOC
- Units, in SOC

Problems

- We're measuring the wrong part of the active region?
  - Energy build up in ***transverse*** component of magnetic field.
  - Magnetic field in ***corona*** is where the flare occurs.
  - We only measure the ***driver*** of the build up of energy.
- What is the appropriate time scale?
  - Sun doesn't care what is happening on ***24 hour timescale***.
  - Is there a strong ***solar cycle*** dependence?
  - Flaring is non-Poisson - events are not ***independent***.
- What is a big flare?
  - What is the ***total*** energy in an event? How is this distributed between radiation, particle, coronal mass ejection, etc..?
  - Careful not to succumb to big-flare syndrome

Conclusions

- The multifractal spectrum is a number distribution of gradient persistence to high spatial scales
  - higher h, higher D, more energy build up
  - pointer to further flux emergence and gradient build up
    - this may the connection to resulting flares.
- Is there a maximum predictive timescale of each measure?

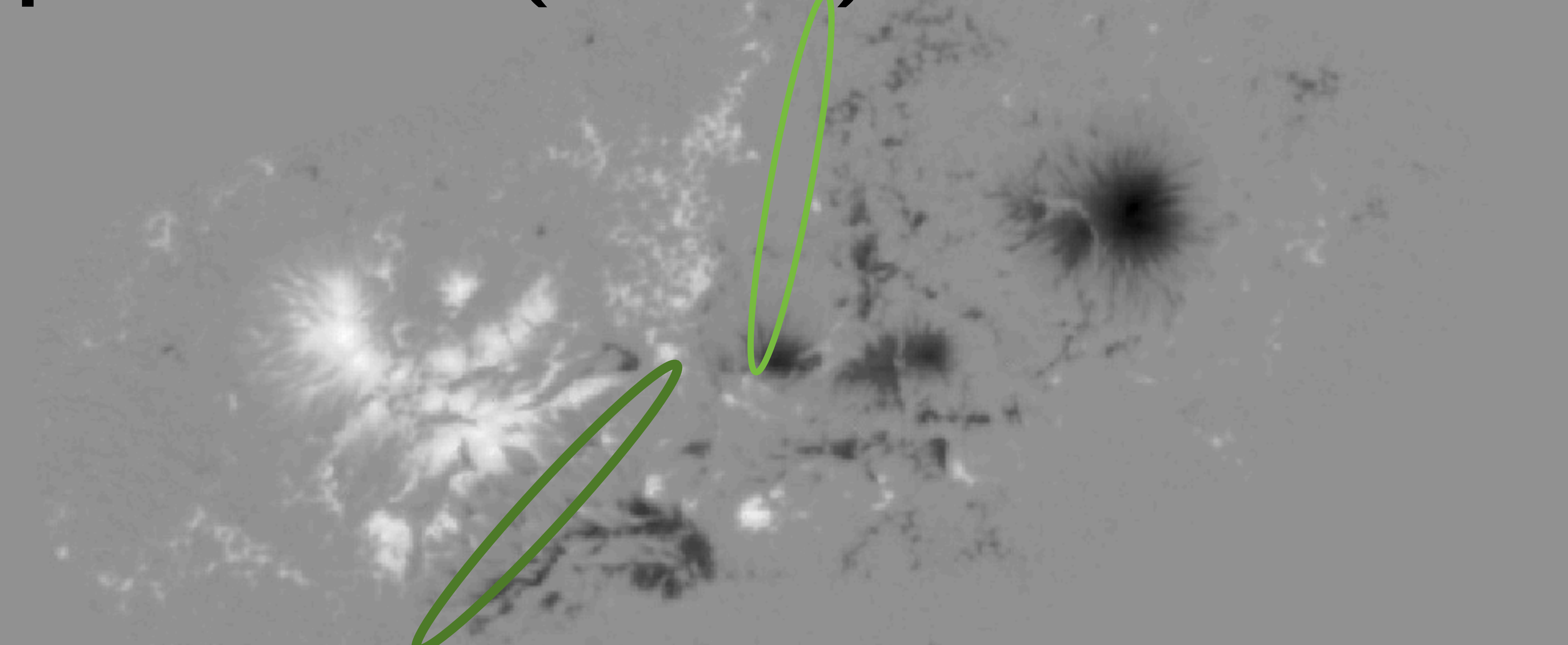
Looking forward

- Detection of energy release mechanism.
  - how much energy is available?
  - how much energy is released?
  - how much energy is needed to maintain a stable active region?
- Predictions over appropriate timescales.
  - How do we combine the maximum predictive timescale of each measure and flare size?

Accuracy depends:

predict X class / fast CME (HSS 0.7) 12 hours

predict C class (HSS 0.65) over 72 hours.



Bloomfield et al, ApJ, 2012

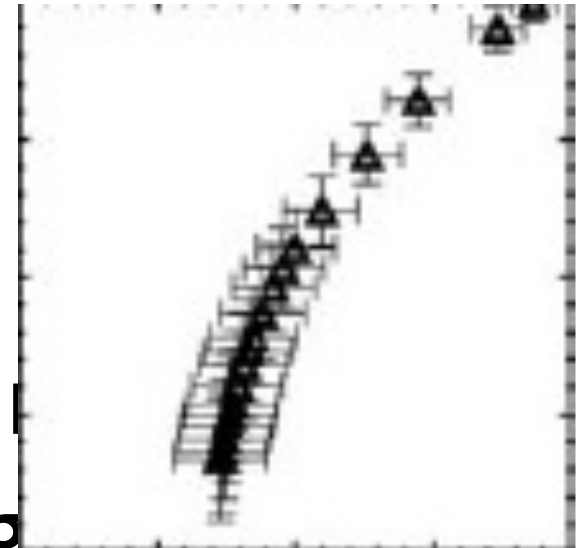
Also Poster Session 6.1

Questions

Albuquerque
Tucumcari
40
El Malpais National Monument
Belen
Clovis
Portales
285
380
Alamogordo
Artesia
82
Hobbs
62
25
Carlsbad
Deming
Las Cruces
85
Carlsbad Caverns
Pecos
Monahans

What about ... Units?

- Multifractal spectrum ... related to the distribution of gradients



2 pixels
4 pixels
6 pixels

Magnetic Gradients (G / Mm)

Magnetic Gradients (G / Mm)

Magnetic Gradients (G / Mm)

Strength

Str...

300

300

5

4

#

#

#

2

D=1.3

D=1.0

D=1.4

D=1.0

25

D=1.45

D=1.2

20

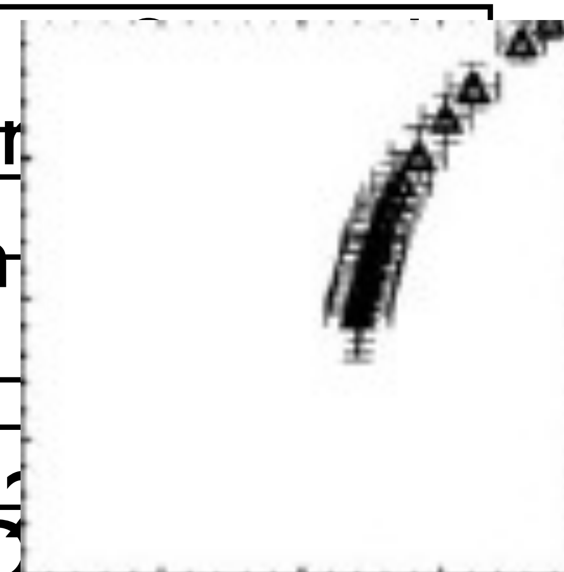
D=1.45

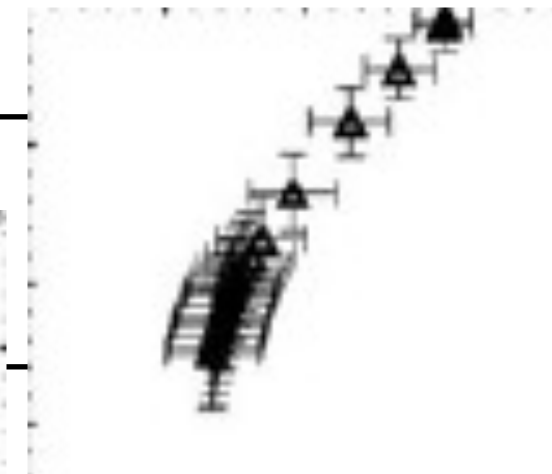
D=1.1

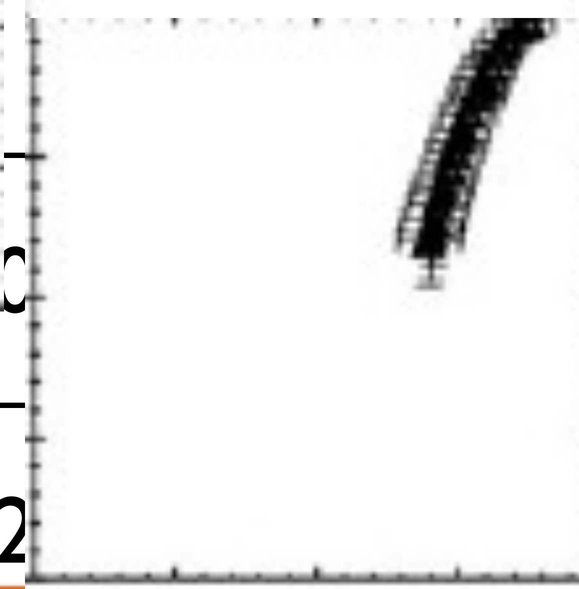
10

D=1.45

D=1.05



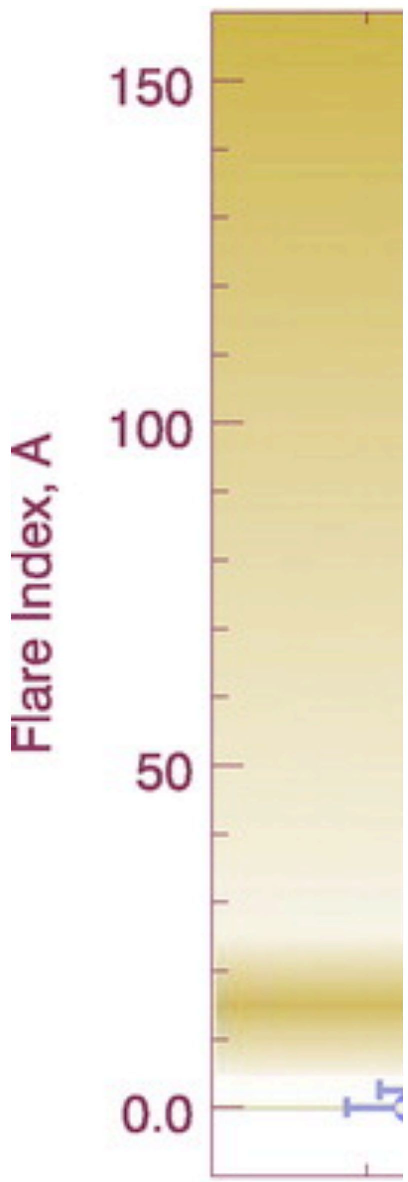




Where are the gradients?

Abramenko, 2005, ApJ

Size Scaling index related to structure function



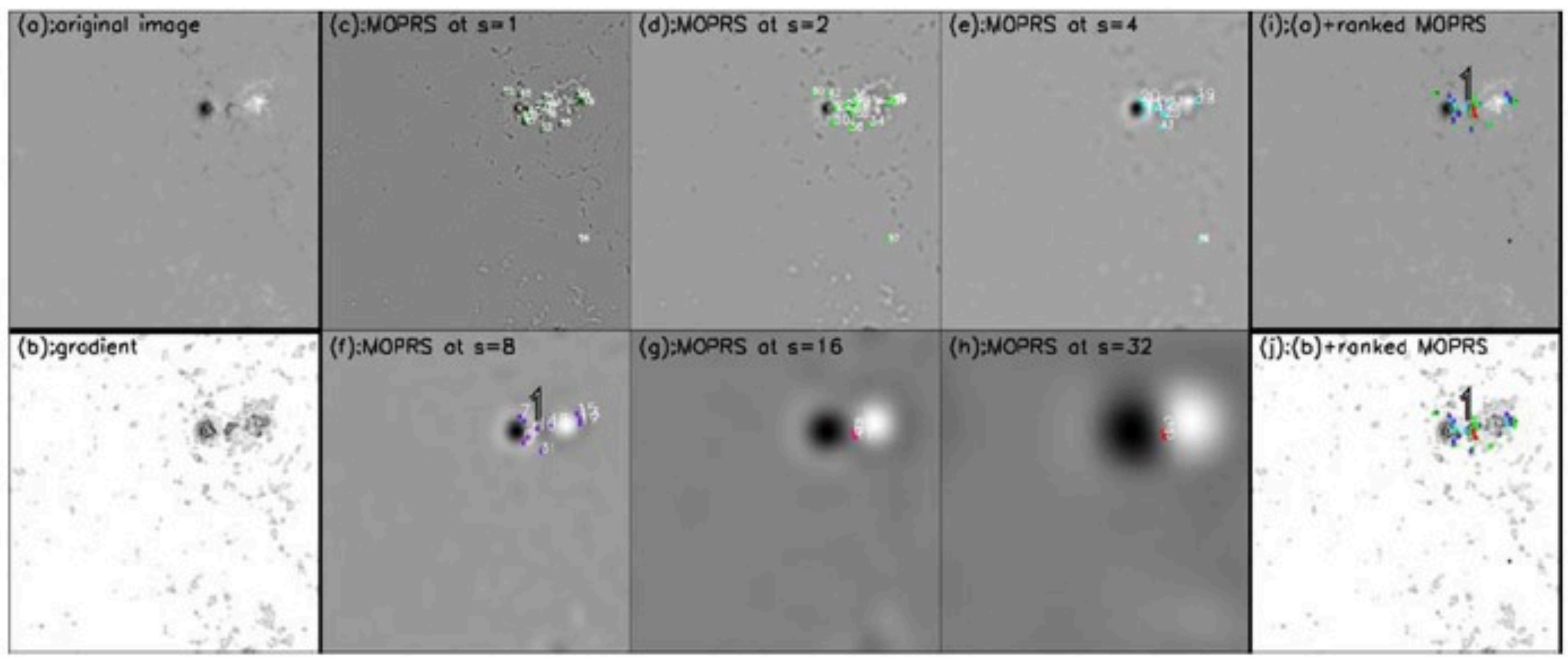
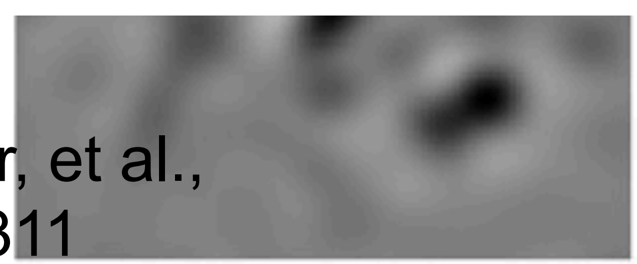
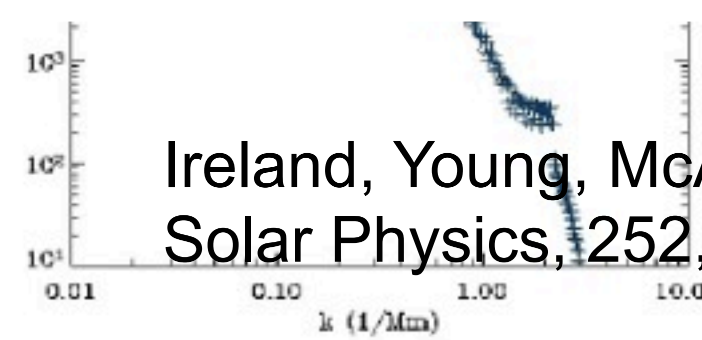


Figure 7 MOPRS found using the Mexican-hat transform, for a $\beta\gamma\delta$ region (NOAA AR 10551, 10 February 2004 12:51 UT). See Figure 3 for a description of the ordering of the plots. The Mexican-hat transform appears to slice the large scale structure of the region better than the median transform.





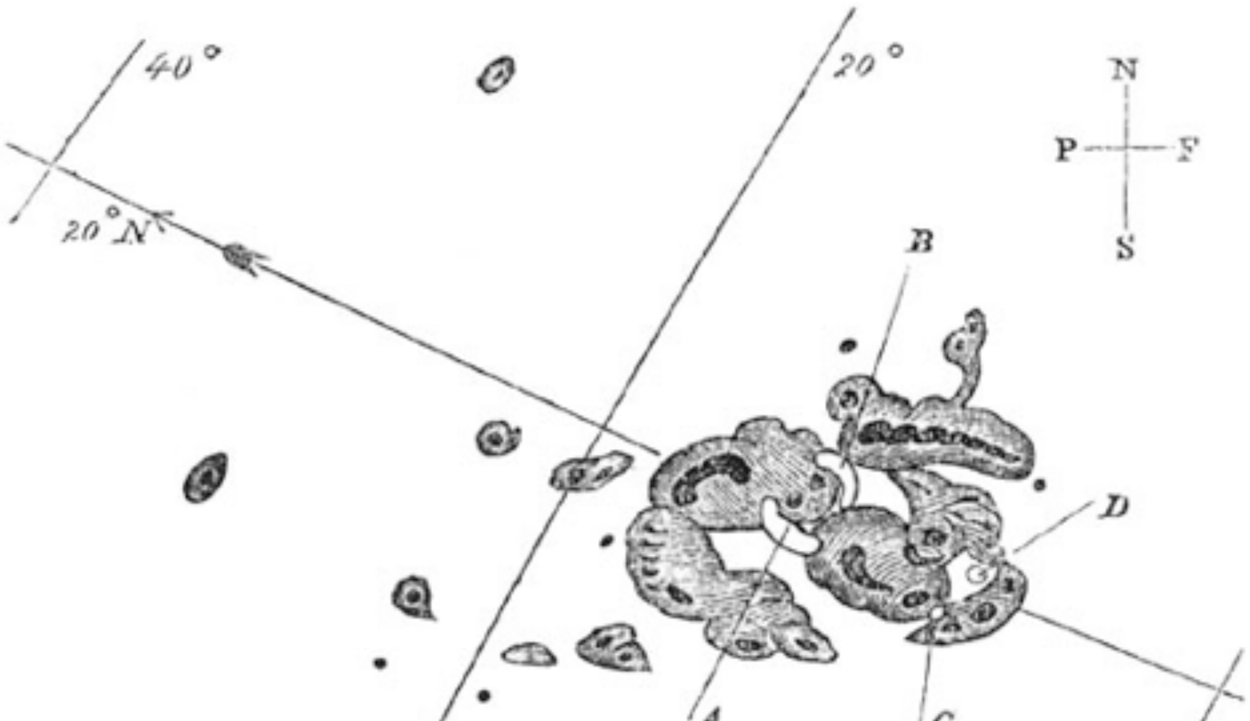
Hewett, Gallagher, McAteer, et al., 2008, Solar Physics, 248, 311

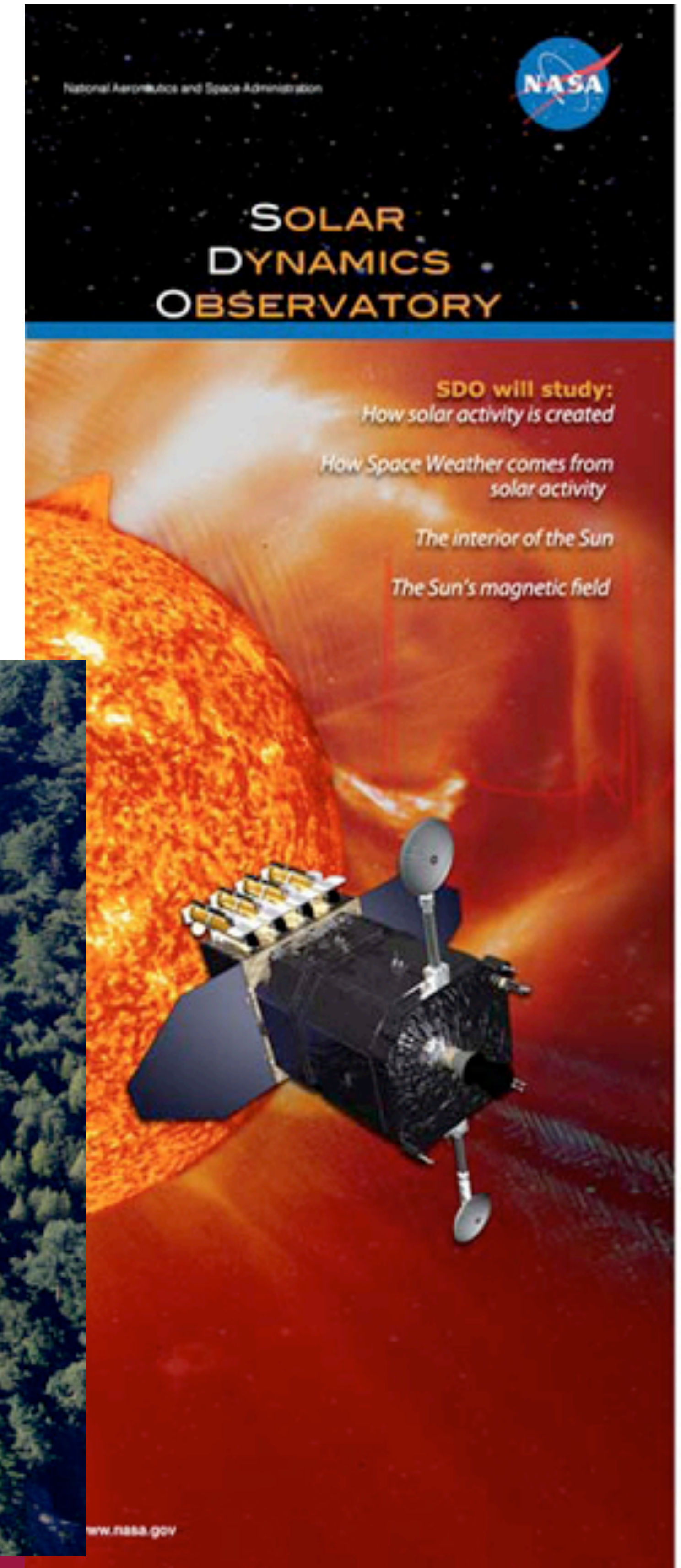
Ireland, Young, McAteer, et al., 2008, Solar Physics, 252, 121

Outline

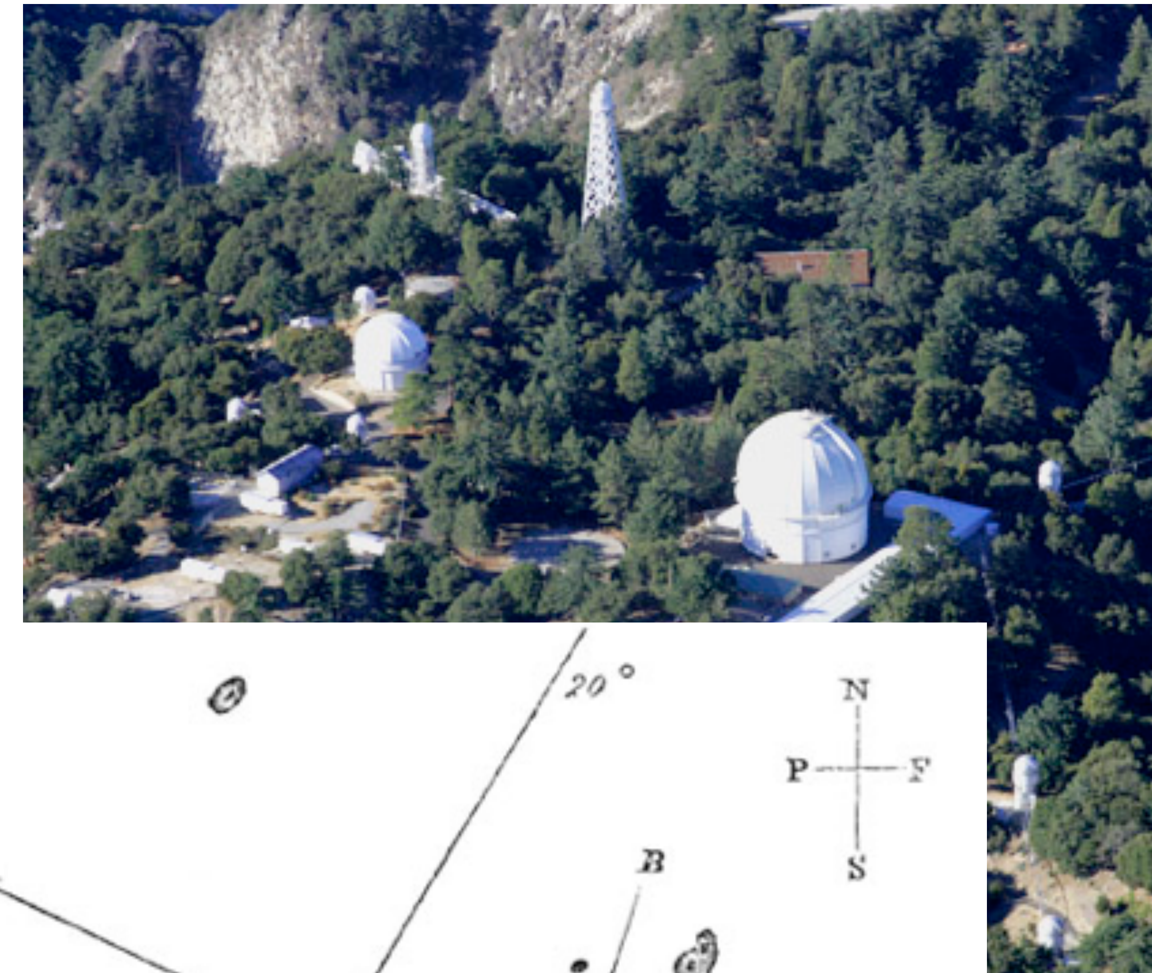
- The promise of flare prediction
- The premise of flare prediction
- The problems of flare prediction

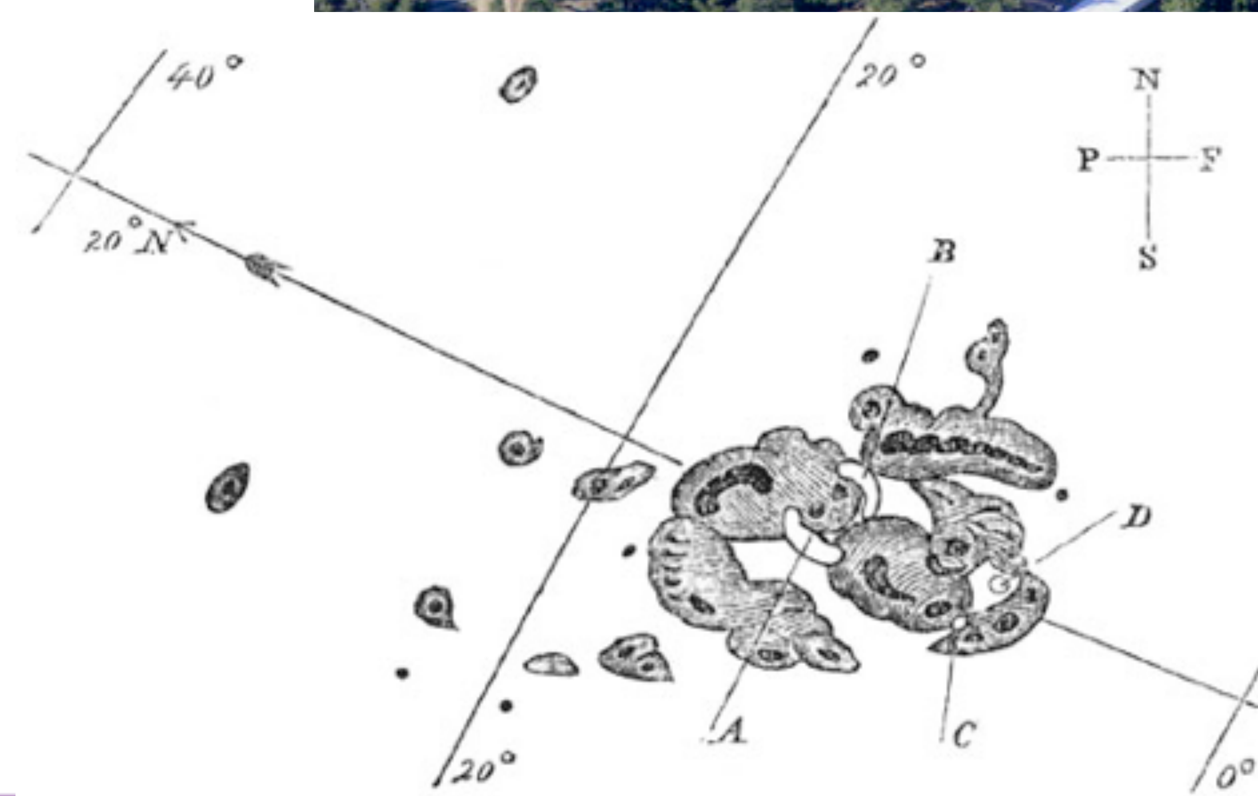
The promise of flare prediction

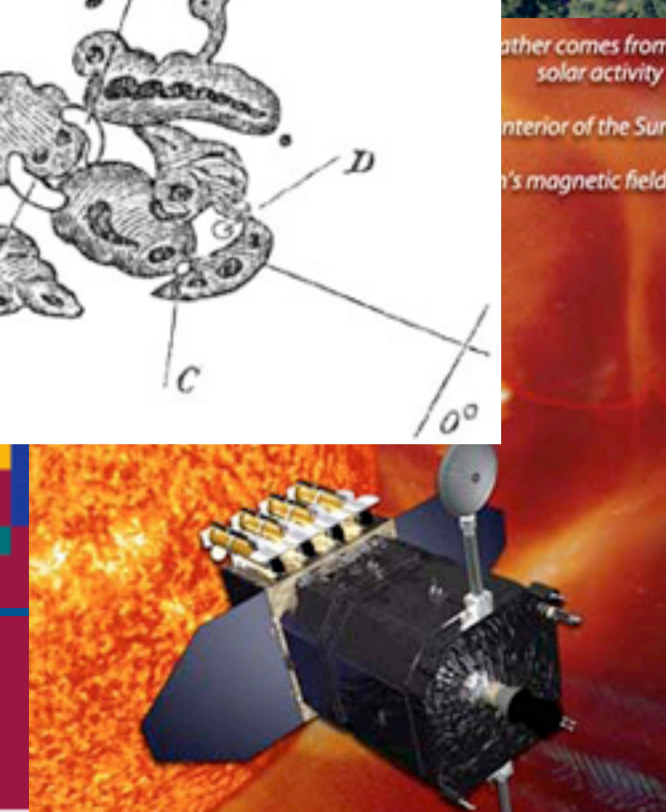




The promise of flare prediction







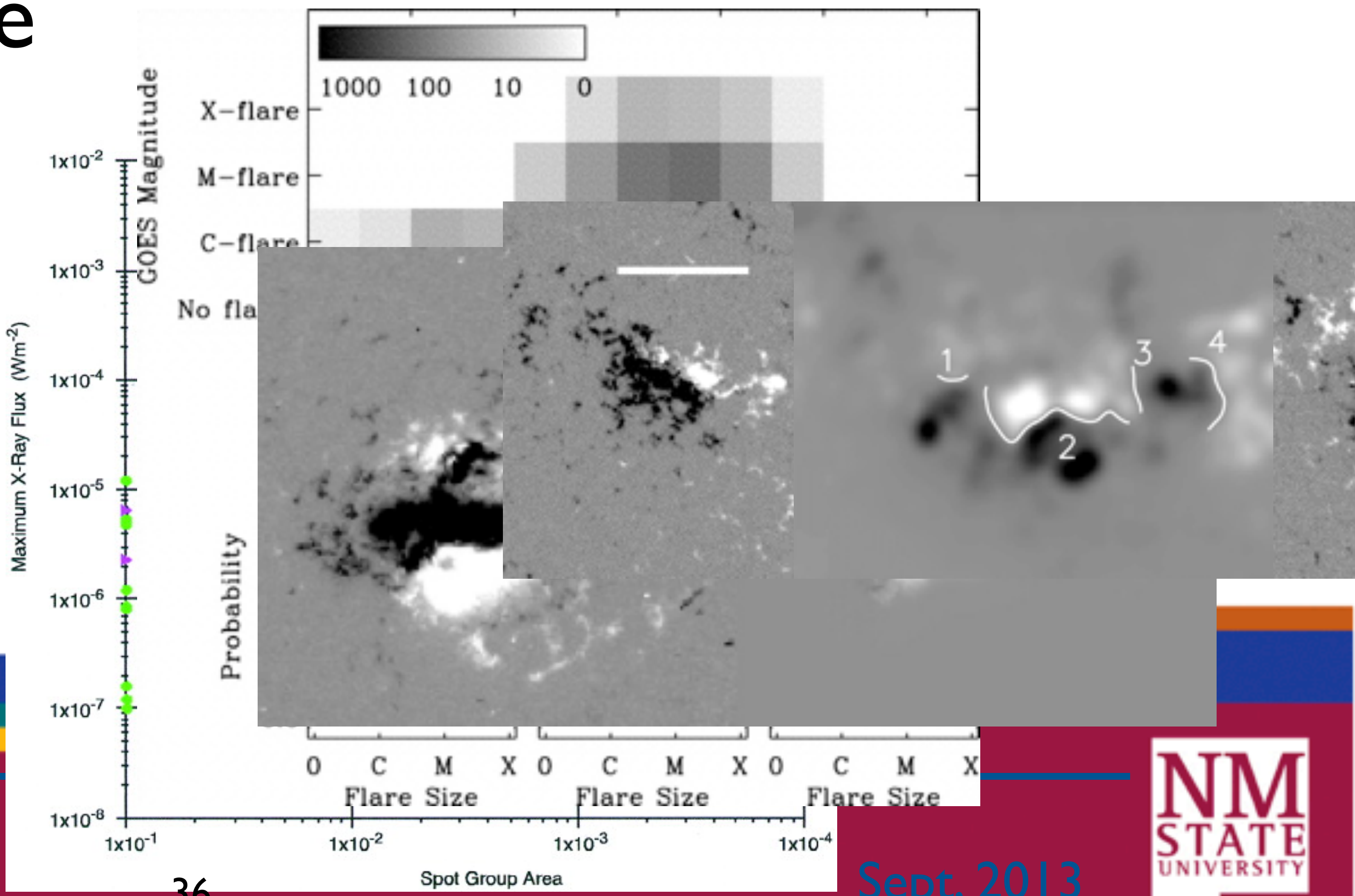
- “Big and Ugly’
- Prediction requires understanding

Outline

- The promise of flare prediction
- The premise of flare prediction
- The problems of flare prediction

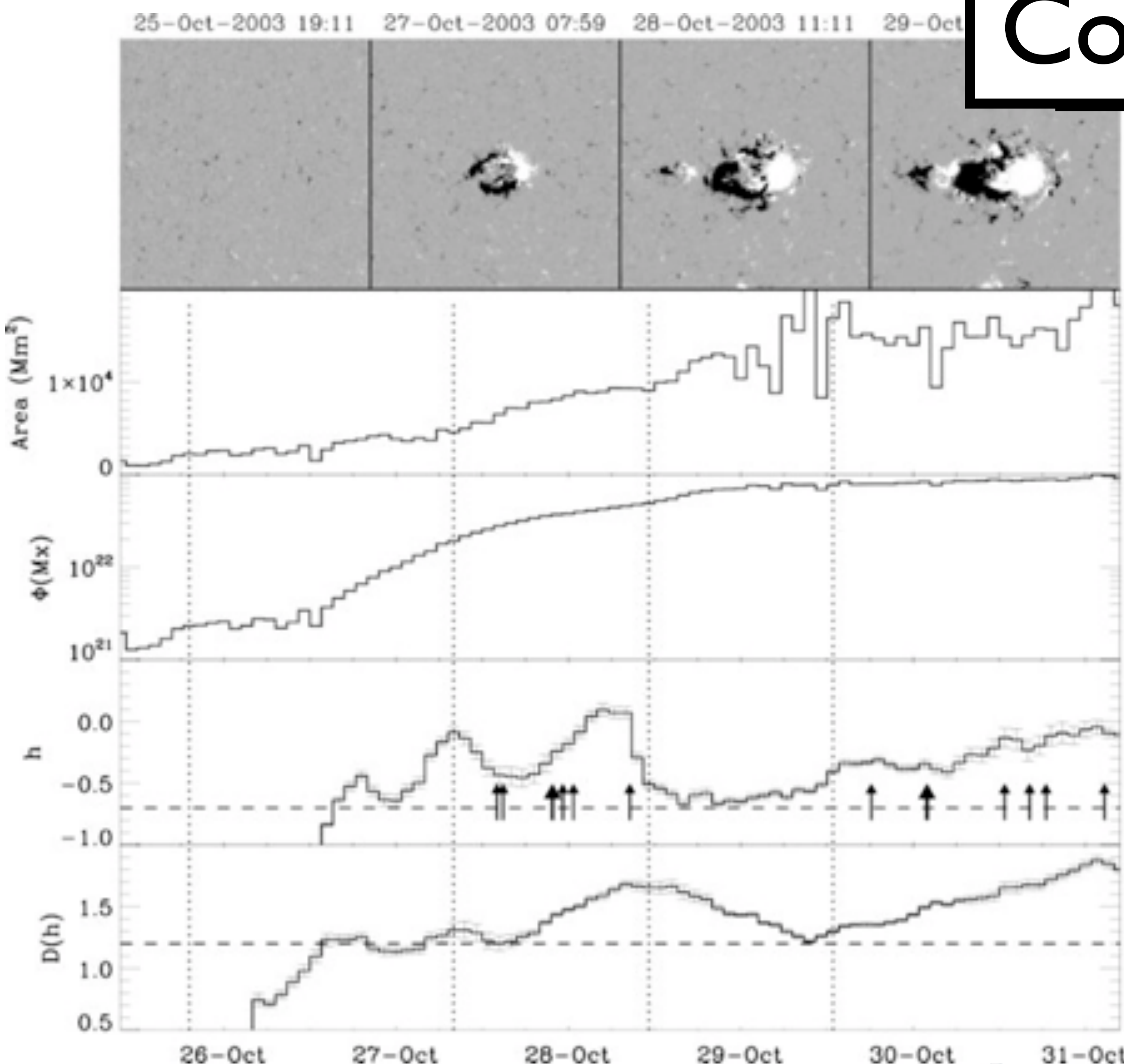
The premise of flare prediction

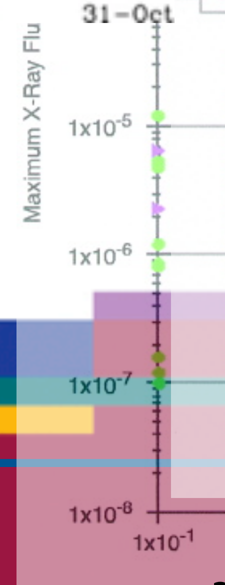
- Big and Ugly?
- Global properties are useful
- Local properties are key

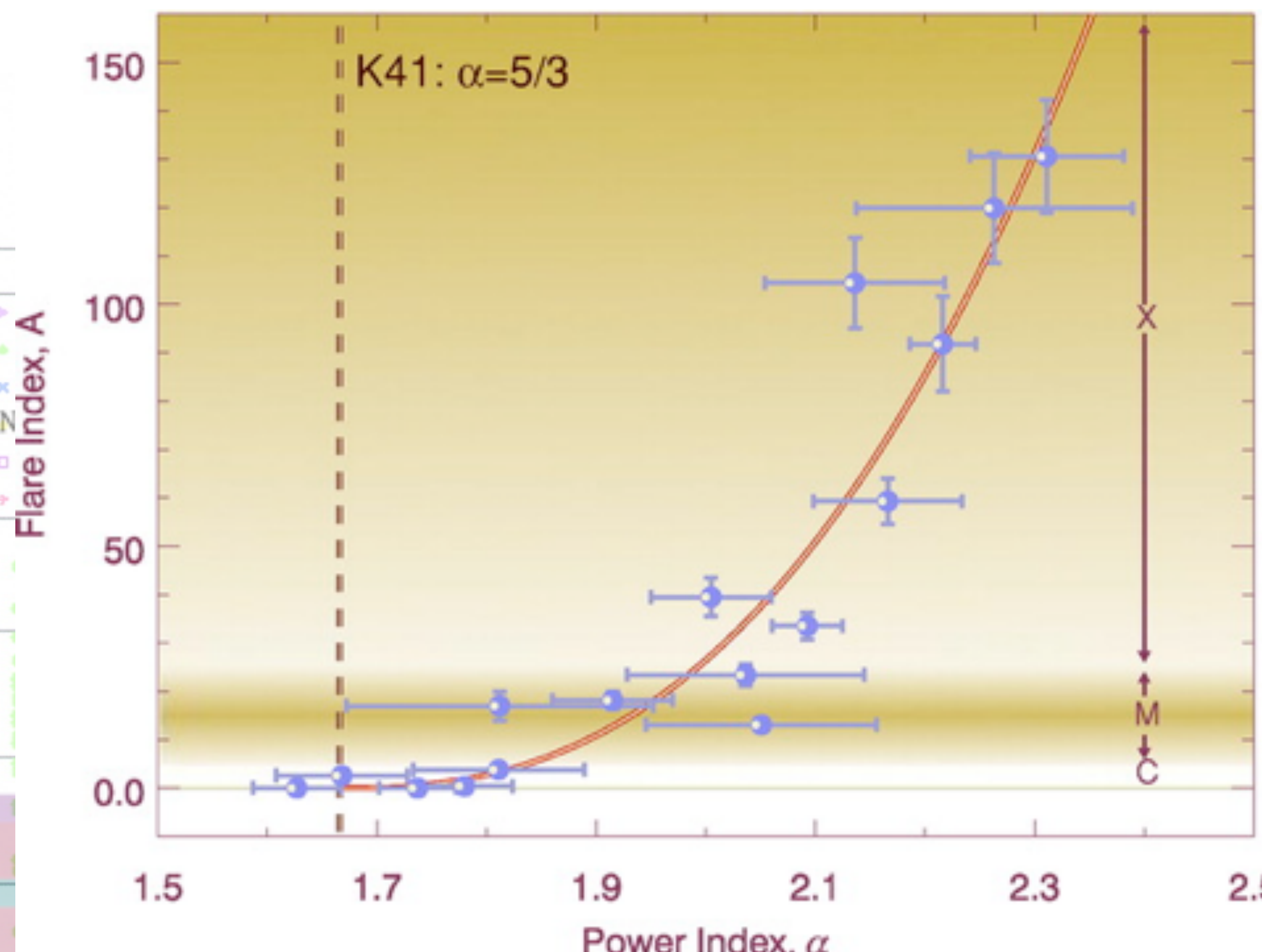


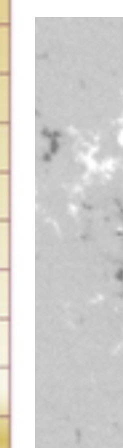
The premise of flare prediction

Conlon, McAteer et al., ApJ, 2010

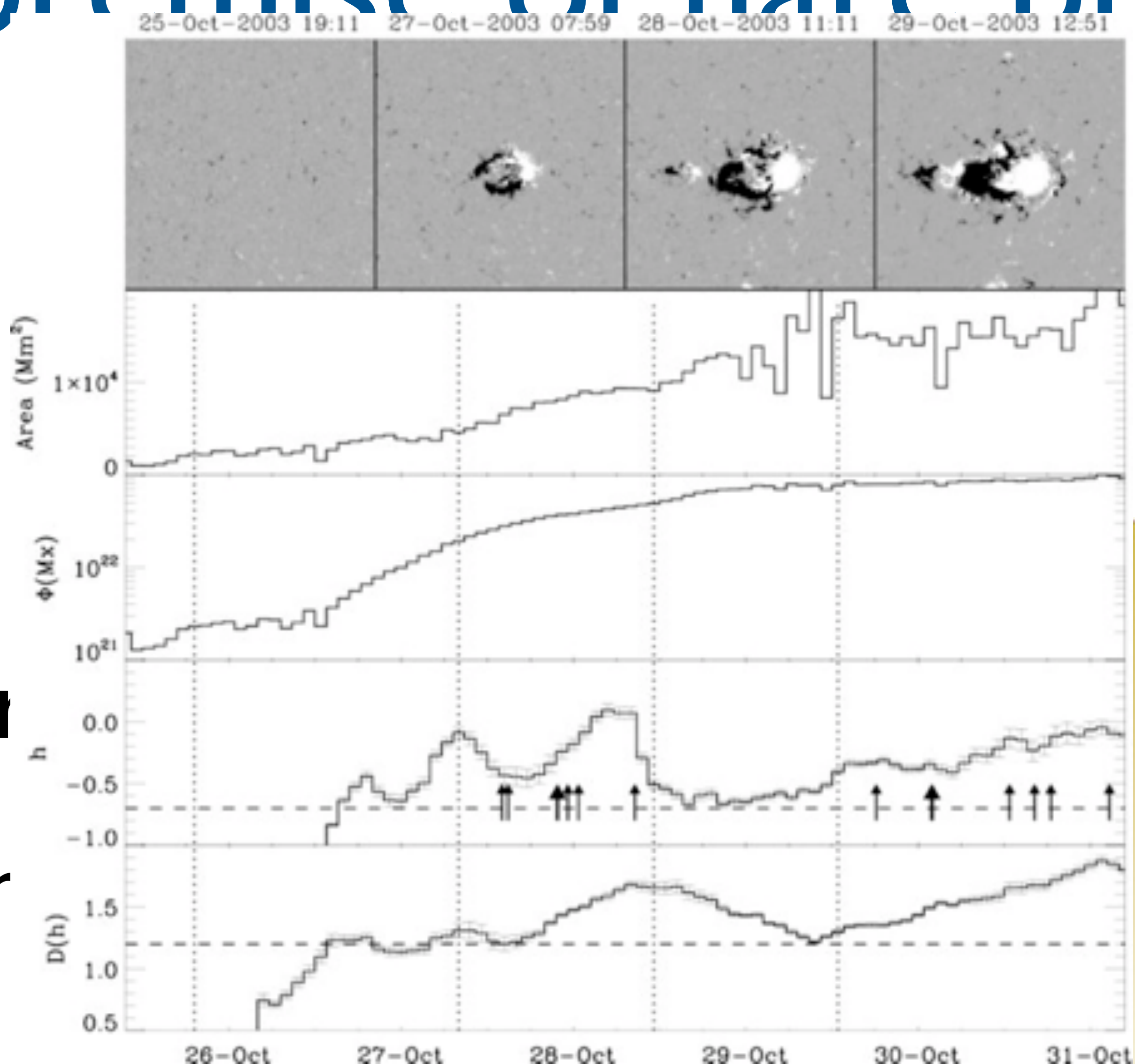




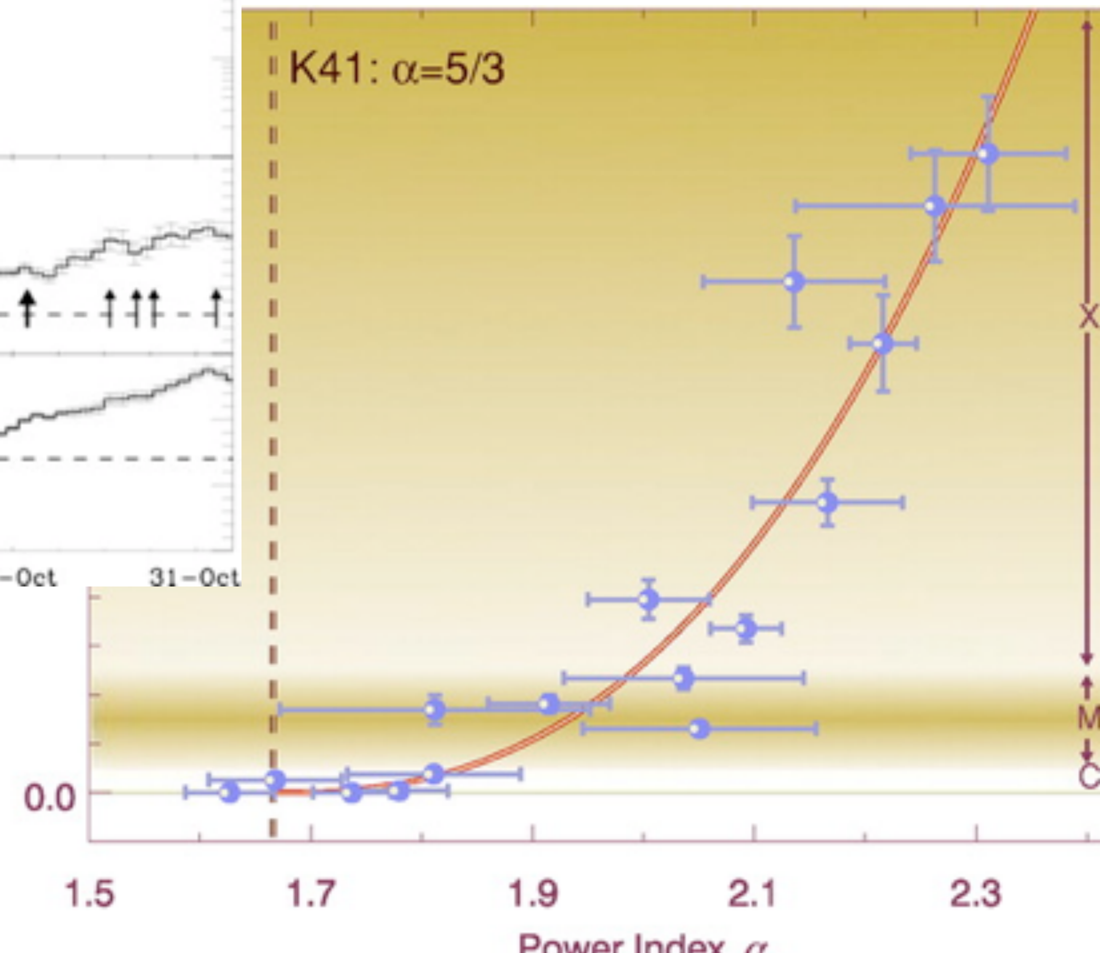


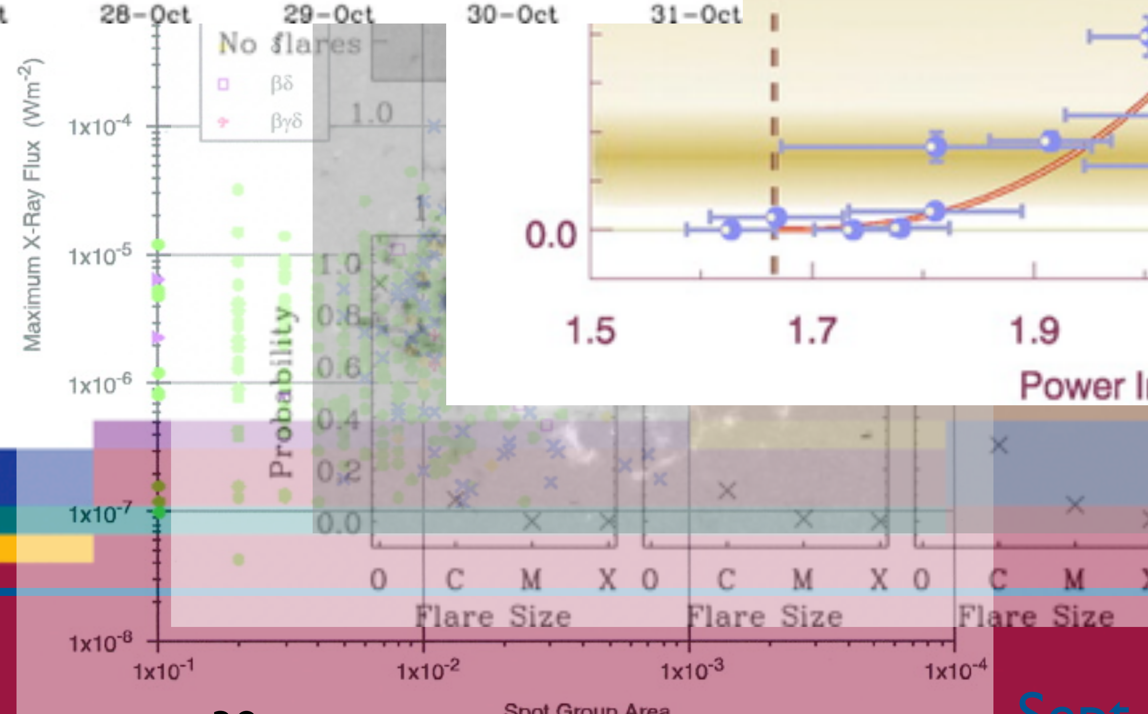


The premise of flare prediction



- What flar
- What tim





The premise of flare prediction

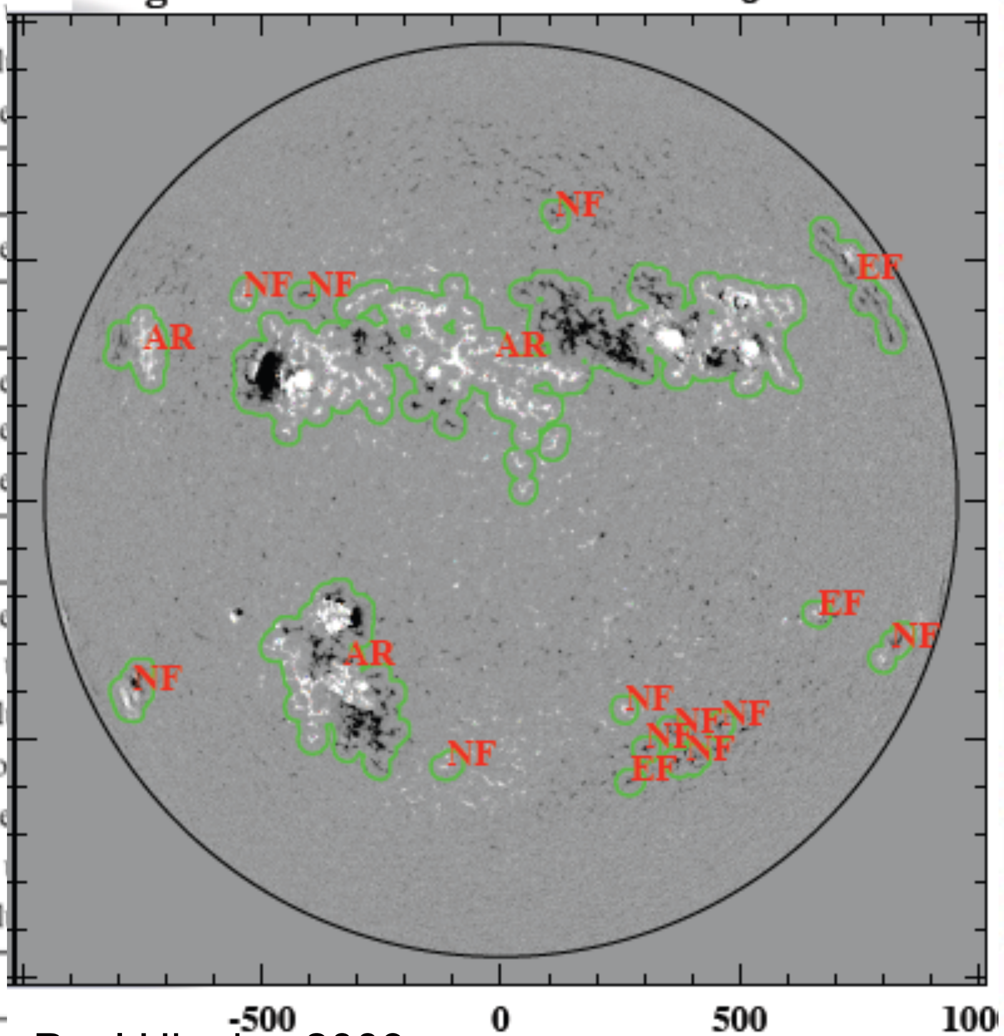
Higgins et al, ASR, 2010

TABLE

Parameters Used in the Dis

Description
Atmospheric
Median of the granulation contrast ....
Distribution of Ma
Mom
Total
Absol
Mom
Mom
Mom
Mom
Mom
Mom
Total
Absol
Sum o
Mom
Total
Absol
Momen
Best-fit force-free twist parameter[b] ....
Distribution of Current Helicity

Magnetic Structure Detections 1-Jun-1999

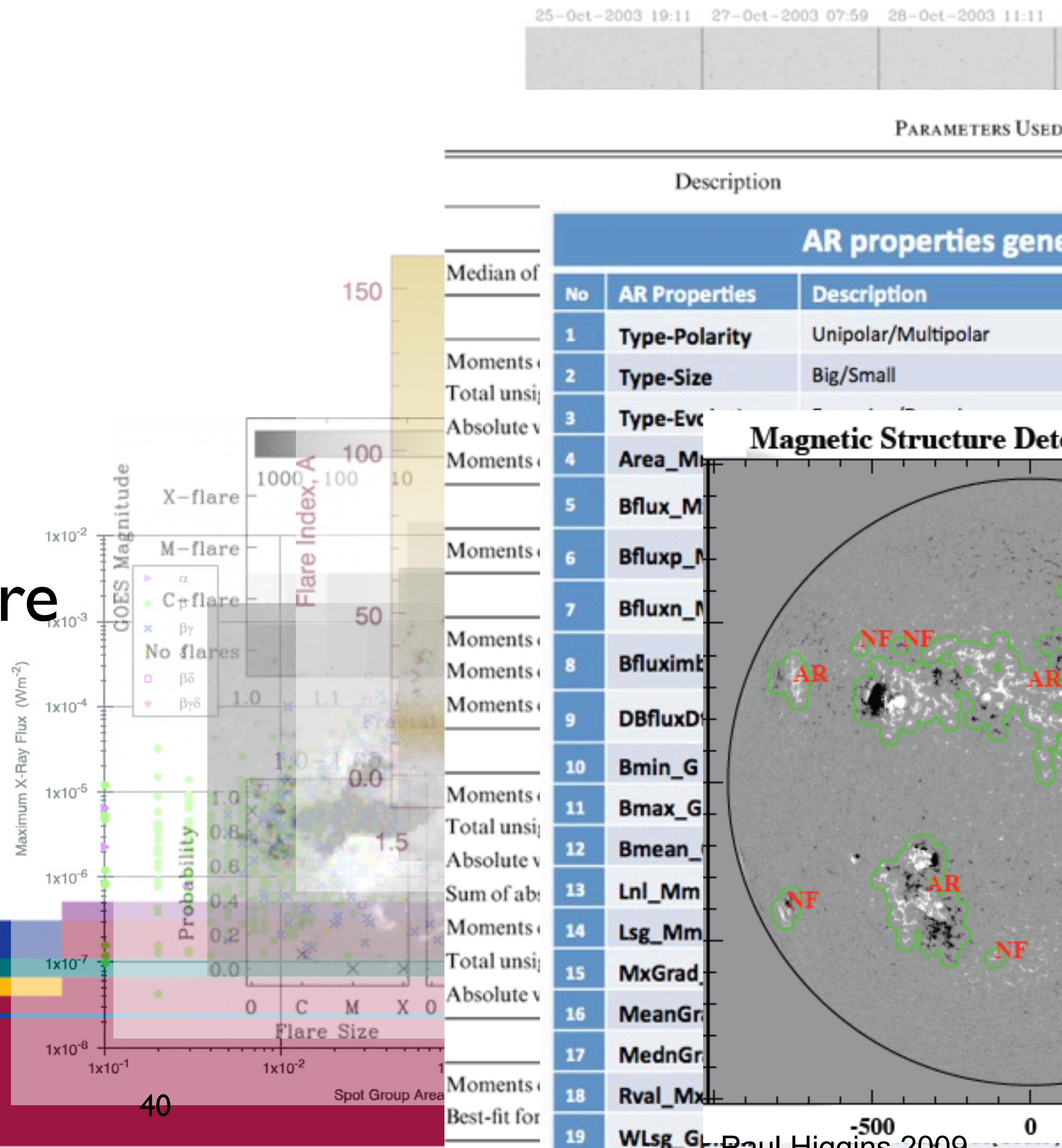


AR properties generated by SMART

No	AR Properties	Description
1	Type-Polarity	Unipolar/Multipolar
2	Type-Size	Big/Small
3	Type-Evolution	Emerging/Decaying
4	Area_Mmsq	Area of the region [Megameters squared].
5	Bflux_Mx	Total Unsigned Magnetic Flux of the region [Maxwells]. $\Phi_{uns,t,i} = \sum_{pix}\|\Phi_{t,i}\|$
6	Bfluxp_Mx	Total Positive Flux in the region [Maxwells]. $\Phi_{+,t,i} = \sum_{pix}(\Phi_{t,i} > 0)$
7	Bfluxn_Mx	Total Negative Flux in the region [Maxwells]. $\Phi_{-,t,i} = \sum_{pix}(\Phi_{t,i} < 0)$
8	Bfluximb	Flux Imbalance Fraction in the region [Fraction]. $\Phi_{imb,t,i} = \frac{\|(\Phi_{+,t,i} - \|\Phi_{-,t,i}\|)\|}{\Phi_{uns,t,i}}$
9	DBfluxDt_Mx	Flux Emergence Rate [Mx/second]. $\frac{d\Phi}{dt}\|_{t,i} = \frac{(\|B_t\| - \|B_{t-\Delta t}\|) \times A_{cos,t,i}}{\Delta t}$
10	Bmin_G	Minimum B value in the region[Gauss].
11	Bmax_G	Maximum B value in the region [Gauss].
12	Bmean_G	Mean B value in the region [Gauss].
13	Lnl_Mm	Neutral Line Length in the region [Mega meters].
14	Lsg_Mm	High Gradient Neutral Line Length in the region [Mega meters].
15	MxGrad_GpMm	Maximum Gradient along the Neutral Line [Gauss / Megameter].
16	MeanGrad	Mean Gradient along the Neutral Line [Gauss / Megameter].
17	MednGrad	Median Gradient along the Neutral Line[Gauss / Megameter].
18	Rval_Mx	Schrijver R-Value[Maxwells],(Schrijver, 2007).
19	WLsg_GpMm	Falconer WLsg value[Gauss / Megameter], (Falconer et al., 2008).
20	R_Str	Schrijver R-Value with a lower threshold for summing flux[Maxwells].
21	WLsg_Str	A modified version of WLsg.

The premise of flare prediction

- What flare size?
- What timescale?
- What parameters matter?
- What is accurate flare prediction?



Outline

- The promise of flare prediction
- The premise of flare prediction
- The problems of flare prediction

Conclusions

- Progress is significant
  - solar cycle of synoptic data
- Combination of local and global properties works at HSS score of 0.8
- Looking forward to full disk vector data.