Forecasting the Solar Drivers of Severe Space Weather from Active-Region Magnetograms

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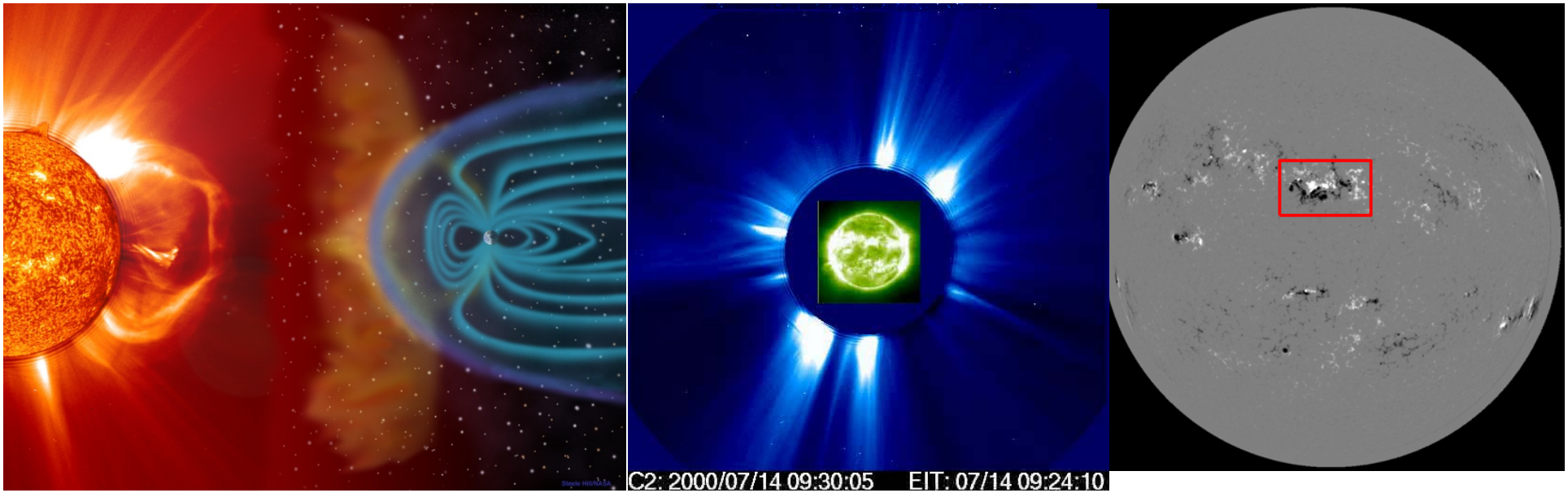


Our Main Findings:

Solar drivers of severe space weather can be predicted from line-of-sight magnetograms, via a free-energy proxy measured from the neutral lines.

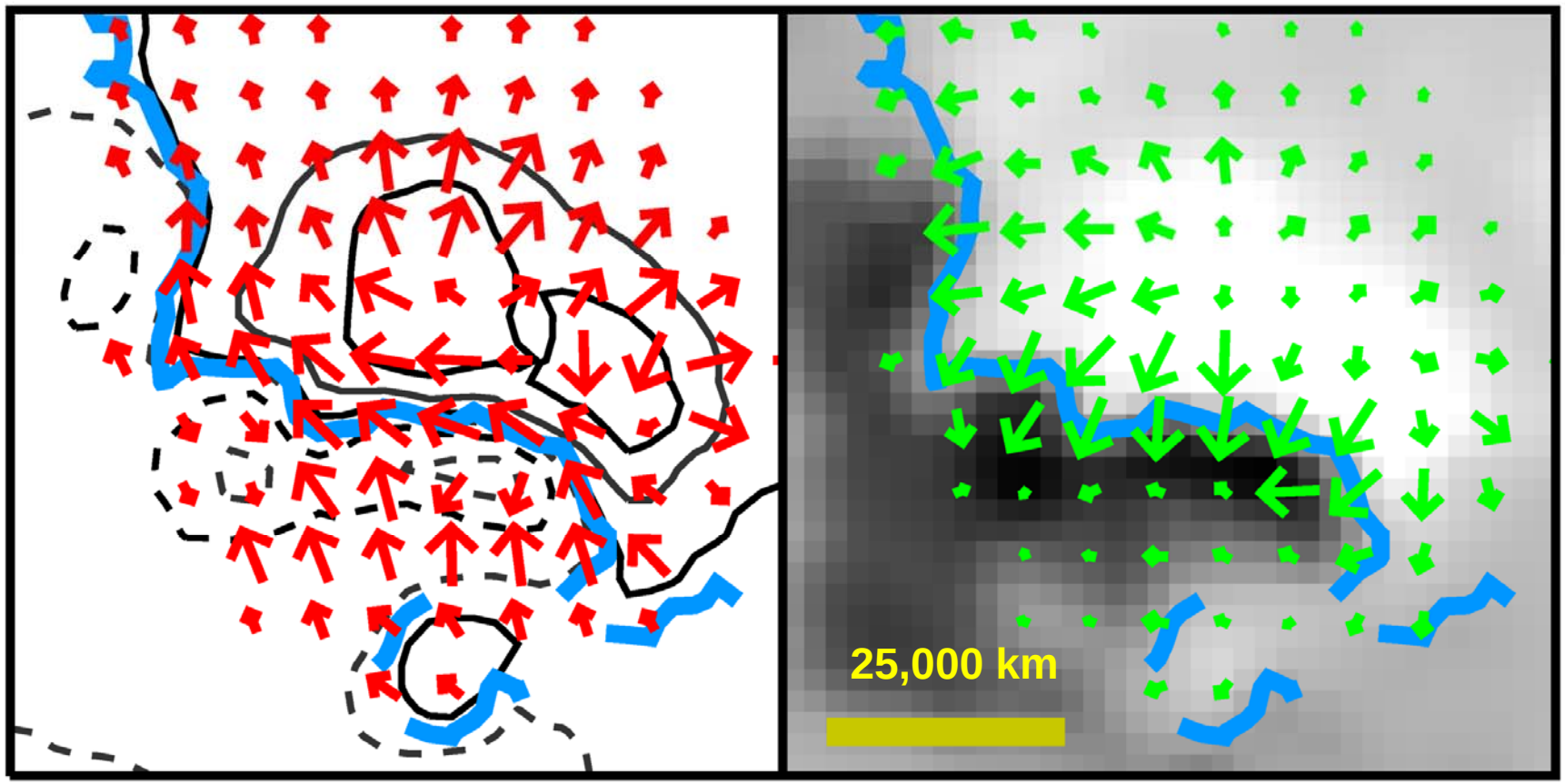
This can be done in near real time.

In addition to depending strongly on the free magnetic energy, an active region's chance of having a major eruption depends strongly on other aspects of the evolving magnetic field (e.g., its complexity and flux emergence).

Overview

- Describe the free-energy proxy
- Show the forecasting curves for forecasting major flares, X-class flares, CMEs, fast CMEs, and Solar Energetic Particle Events from the free-energy proxy.
- HMI-to-MDI conversion of the free-energy proxy.
- Show forecast curves for active regions that have recently produced X and M class flares

MSFC Vector Magnetogram of δ-Sunspot Source Region of a Major CME/Flare Eruption (2000 June 6)



An active-region field's horizontal shear is concentrated along neutral lines where the field's horizontal component is strong and the vertical component's horizontal gradient is steep.

Observed-field upward (downward) vert. comp. is shown by solid contours or light shading (dashed contours or dark shading); red arrows show observed hor. comp. ; green arrows show hor. comp. of pot. field computed from obs. vert. comp. ; strong-observed-field (>150G) intervals of neutral lines are blue.

Free-energy proxy from vertical-field component of vector magnetogram or from line-of-sight magnetogram:

- Active-region field's free energy is concentrated in horizontal shear along neutral-line intervals on which the horizontal component is strong and the vertical component's horizontal gradient is steep.

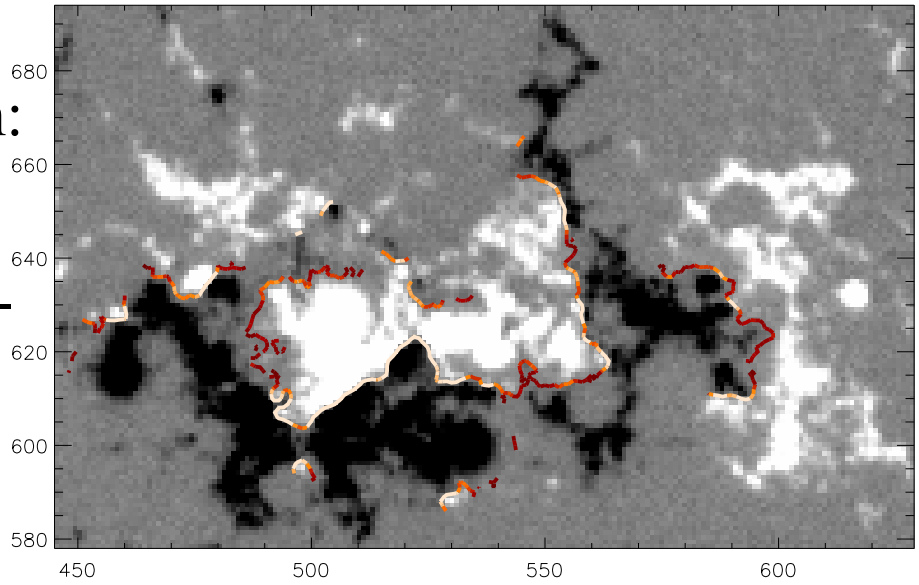
- The measurement from a deprojected vector magnetogram:

$$\mathbf{WL_{SG}=\int(\nabla B_Z)dl.}$$

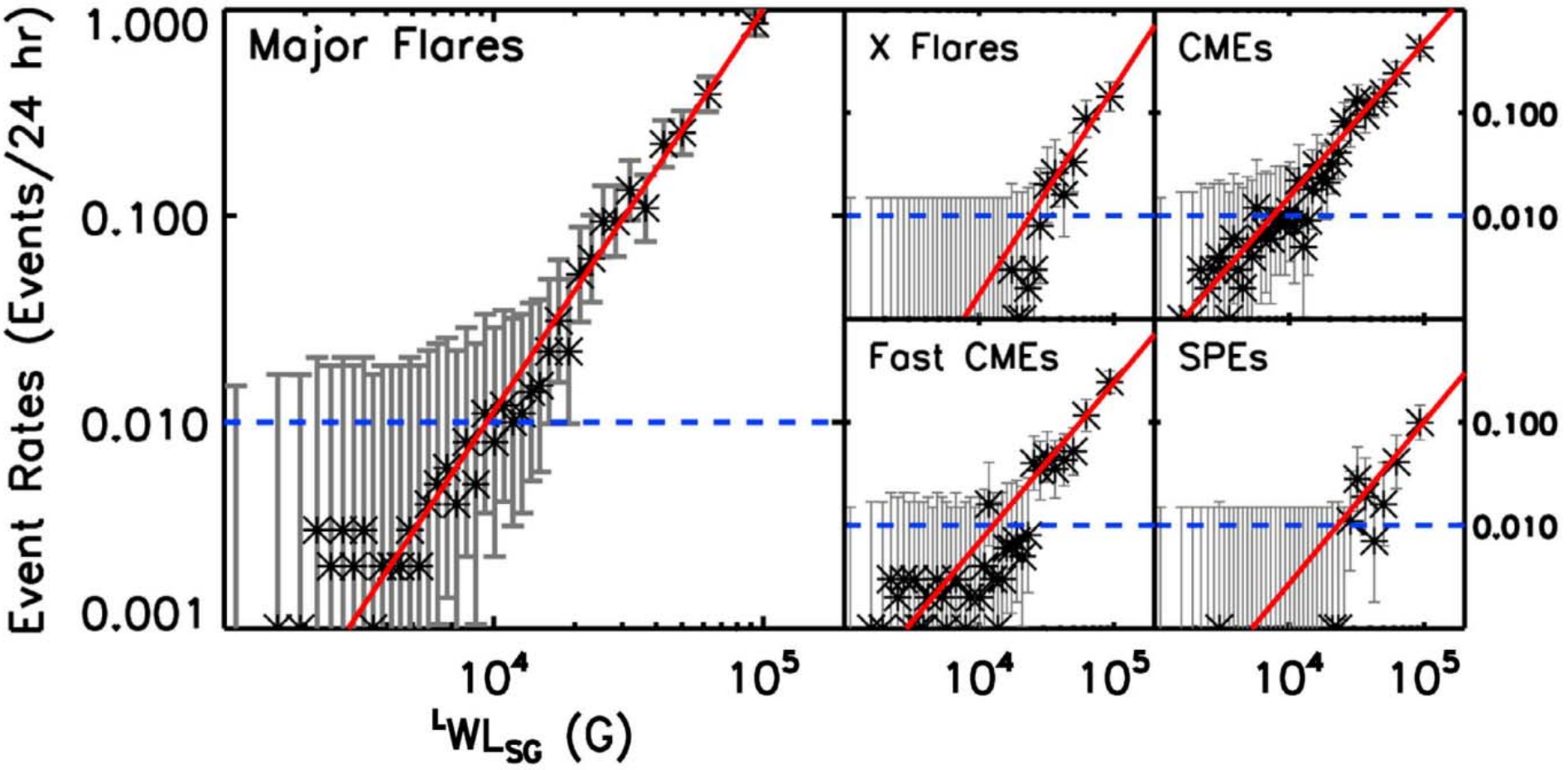
The approximation from a line-of-sight magnetogram:

$$\mathbf{{}^{L}WL_{SG}=\int(\nabla B_{LOS})dl.}$$

Integration is along strong-field intervals of the AR's neutral lines.



Forecasting Curves (Ignoring Prior Flaring)



Only active regions that have a large free energy are likely to produce major events in the next 24 hours.

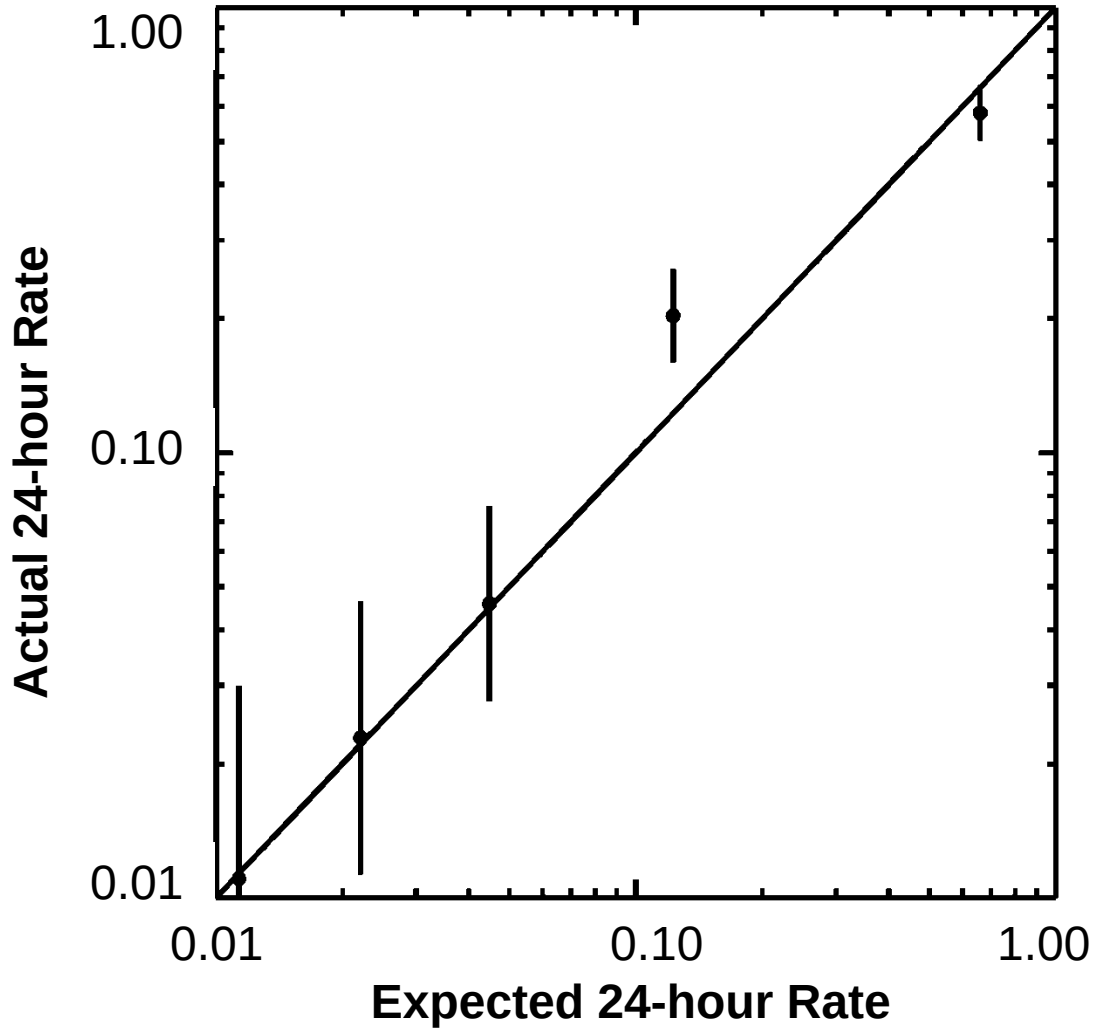
Verification of Accuracy of Forecast

Actual Performance versus Predicted Performance.

Predicted Performance from first 75% of sample.

Actual Performance of last 25% of sample.

1-sigma error bars



Forecasting from HMI using MDI Forecasting Curves

Comparison of HMI and MDI Magnetographs

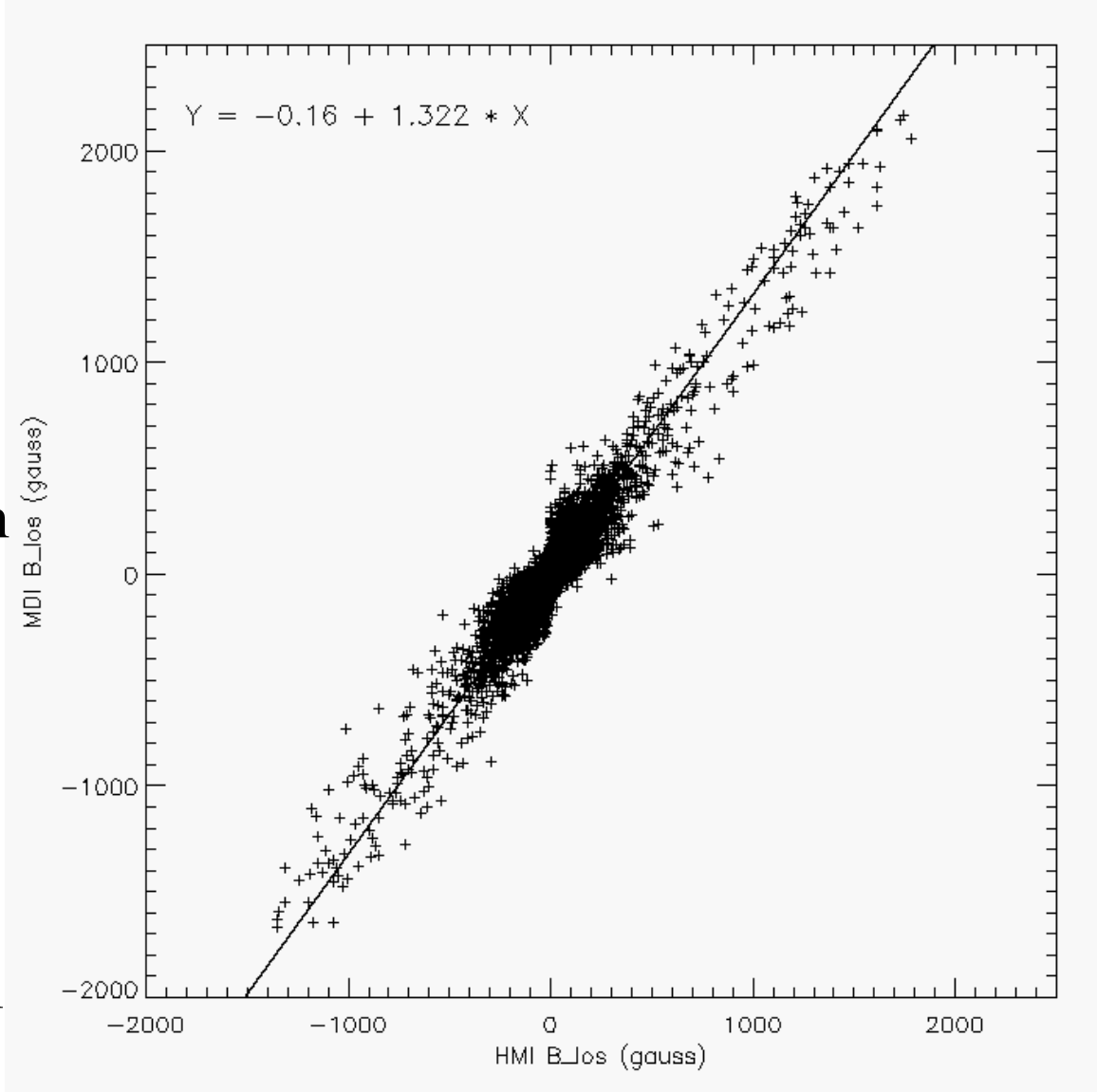
	MDI	HMI
pixels	2”	0.5”
Cadence	96 minutes	45 sec LOS, 90 sec Vector
Latency	Approximately a day	tens of minutes
Magnetograph Type	Line-of-sight	Vector
Operational	1996-Jan 2011 **Now Turned off**	May 2010 to present **Now Operating**

Calibration of HMI B_{LOS} to MDI B_{LOS}

Empirical conversion of HMI magnetic field strength to MDI magnetic field strength

Hoeksema and the HMI team has done this work.

Early HMI Magnetic Field Observations Hoeksema et al



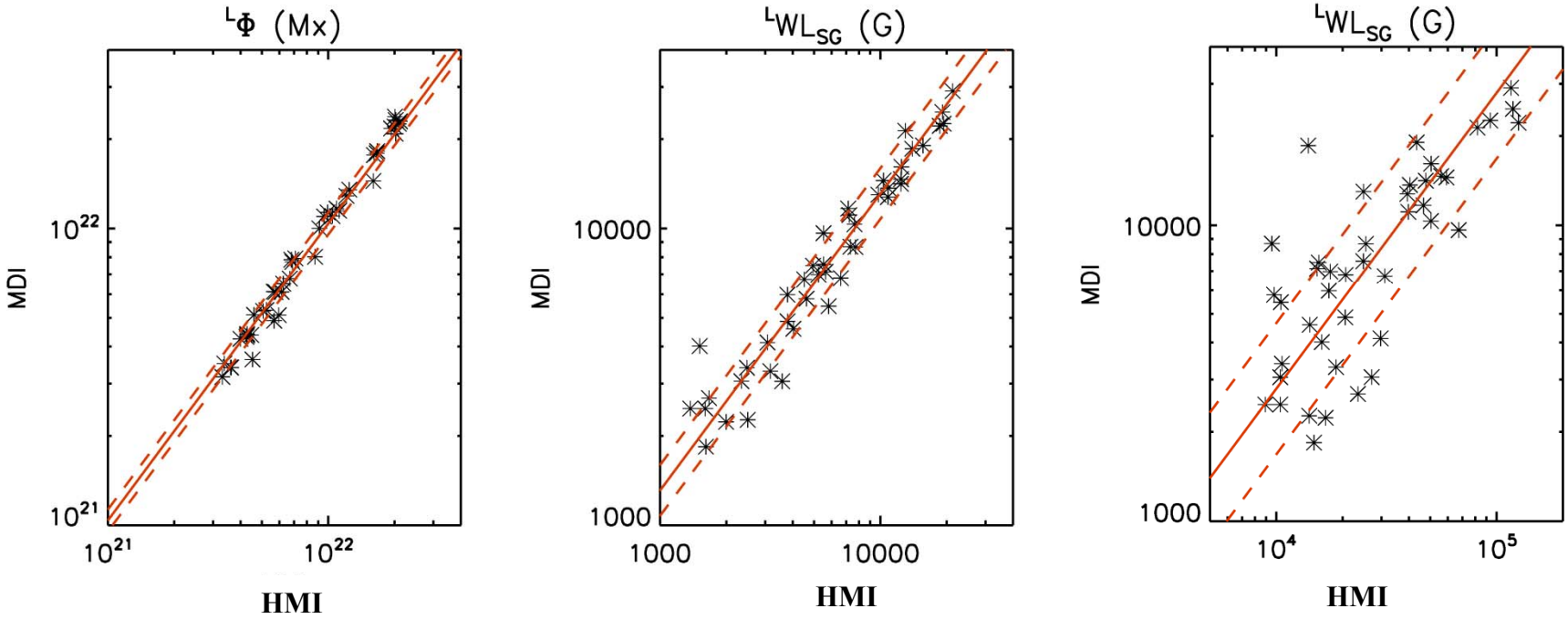
Conversion of the HMI Value of $^{L}WL_{SG}$ to the MDI Value

For MDI resolution

- $^{L}WL_{SG}$(MDI)=1.31*$^{L}WL_{SG}$ (HMI)
- Multiplicative uncertainty is 1.22

1σ Multiplicative uncertainty in forecast event rate due to for different instruments and spatial resolutions			
Event Type	MDI	**HMI-MDI-res**	HMI-full res
X and M Flares	1.07	**1.48**	2.71
X Flares	1.29	**1.60**	2.86
CMEs	1.10	**1.36**	2.16
Fast CMEs	1.17	**1.41**	2.24
SPEs	1.32	**1.51**	2.33

HMI Smoothed to MDI Resolution Unsmoothed



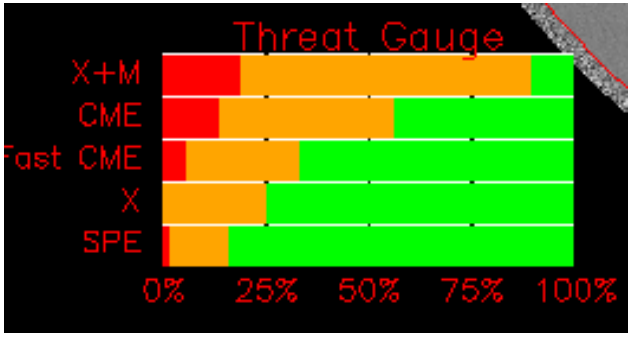
Forecasting from GONG using MDI Forecasting Curves

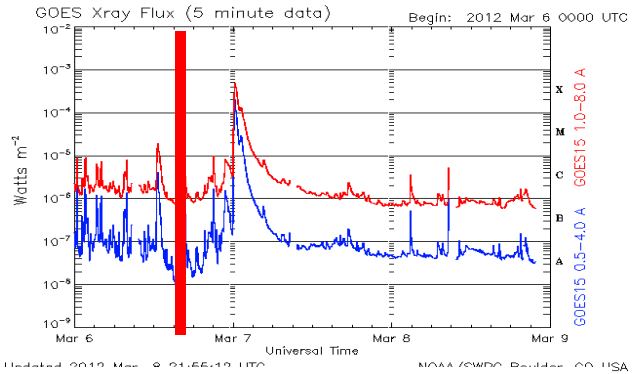
- For each GONG Telescope have to determine cross-calibration and 1σ noise level of the active-region magnetograms to convert GONG measured ${}^{L}WL_{SG}$ to MDI ${}^{L}WL_{SG}$, similar as shown for HMI.
- This allows using the 6 ground-based GONG telescopes to be used as a backup for HMI.
- Due to variable seeing need to determine useful way to determine which observations are of acceptable quality (seeing) and which are unacceptable to improve conversion factors and better estimate conversion uncertainties.

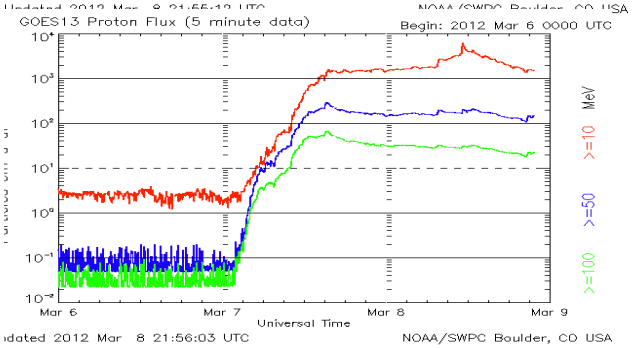
SRAG MAG4 Forecast Tool

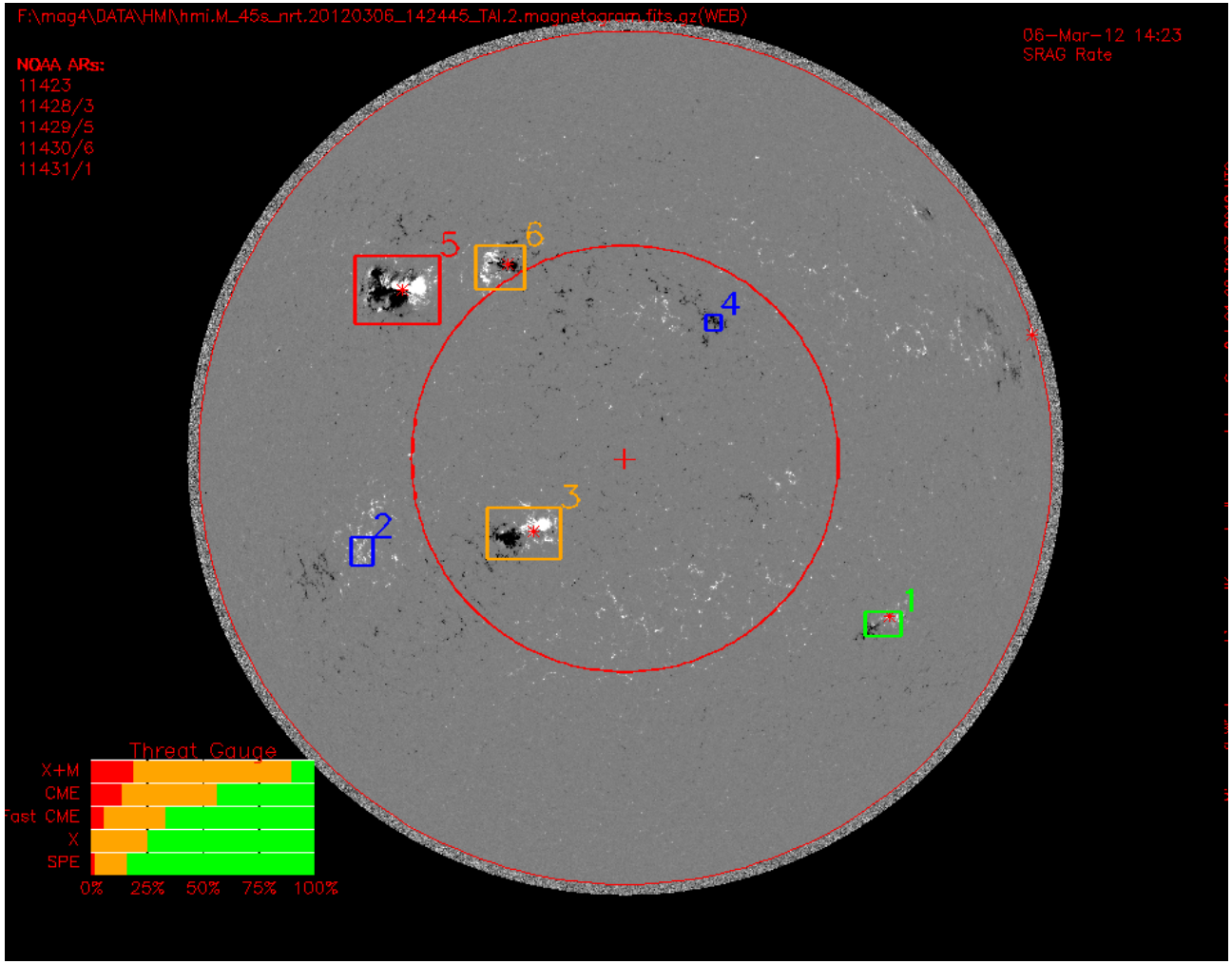
Example Display (March 6, 2012)

- The largest active region on the disk produced the March 7 X Flare, Solar Energetic Particle event, and geo-effective CME

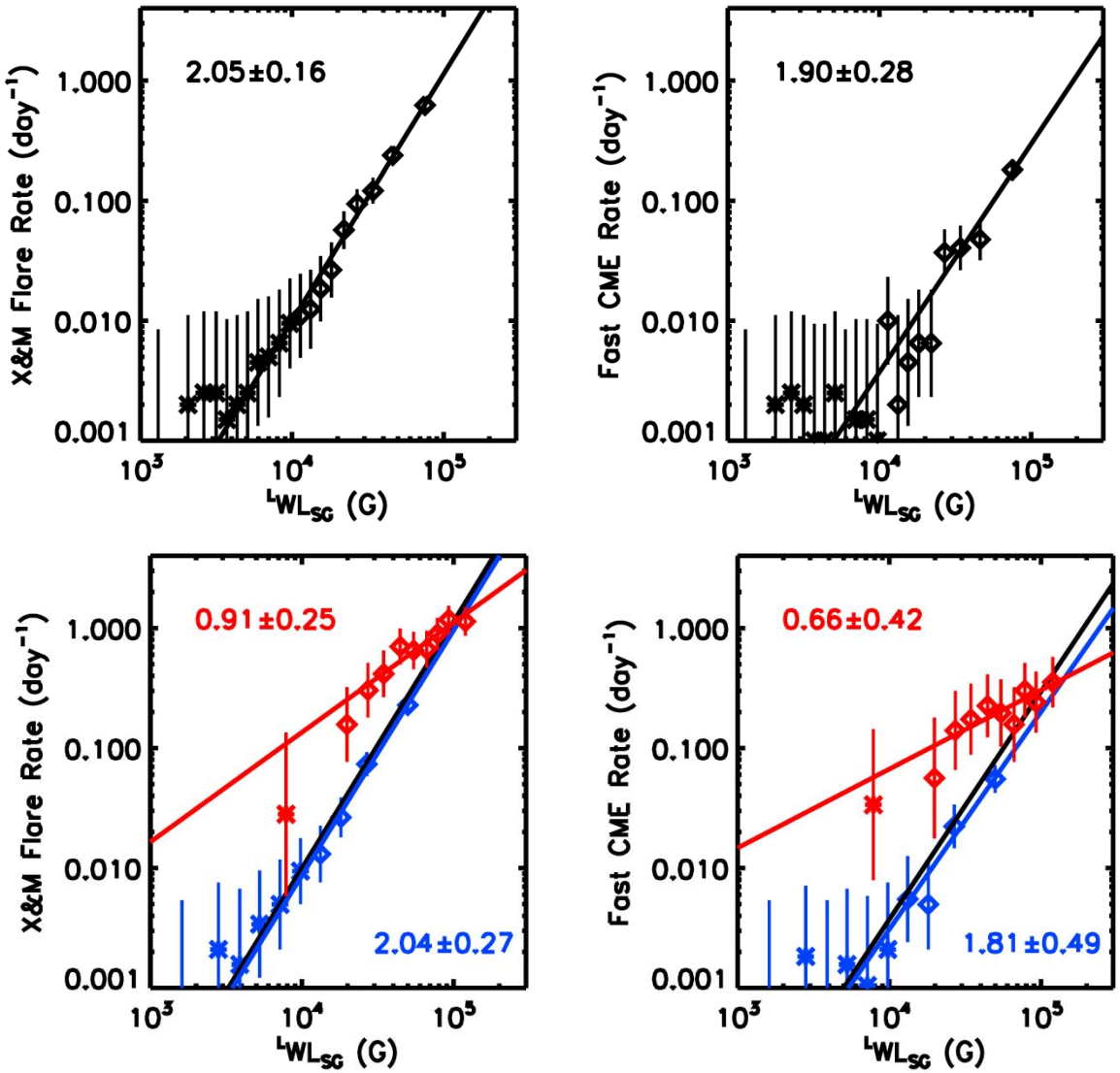








Prior Flaring is Partly Separate from Free Energy as a Predictor of an Active Region's CME/Flare Productivity



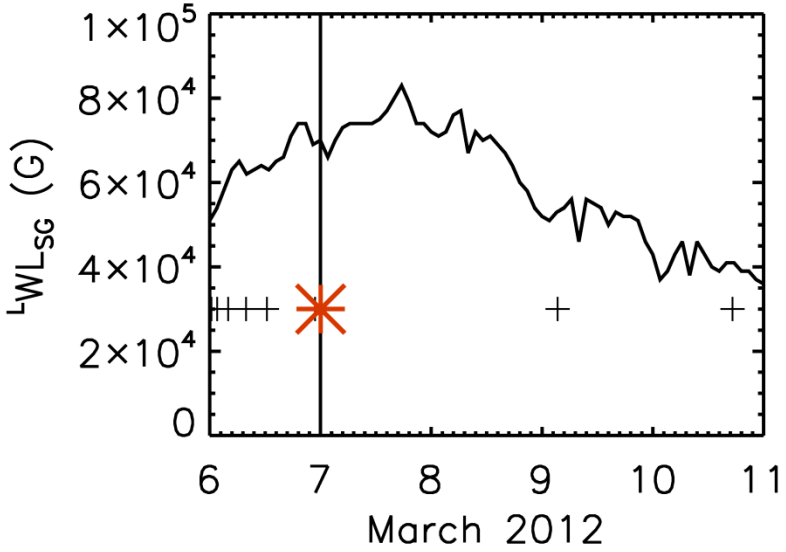
Free Energy Only

Recently Flaring

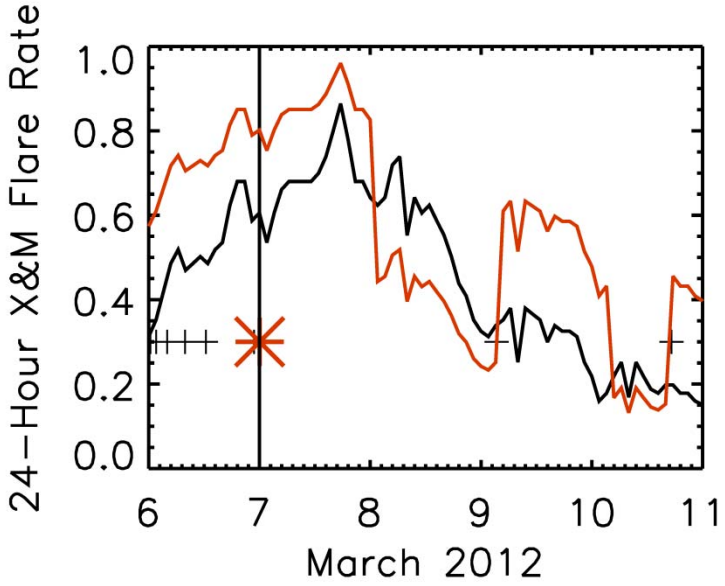
Recently Non-flaring

Forecast of March 7 X-Flare/SEP Eruption

- **Top panel:** Free Energy proxy level and evolution.



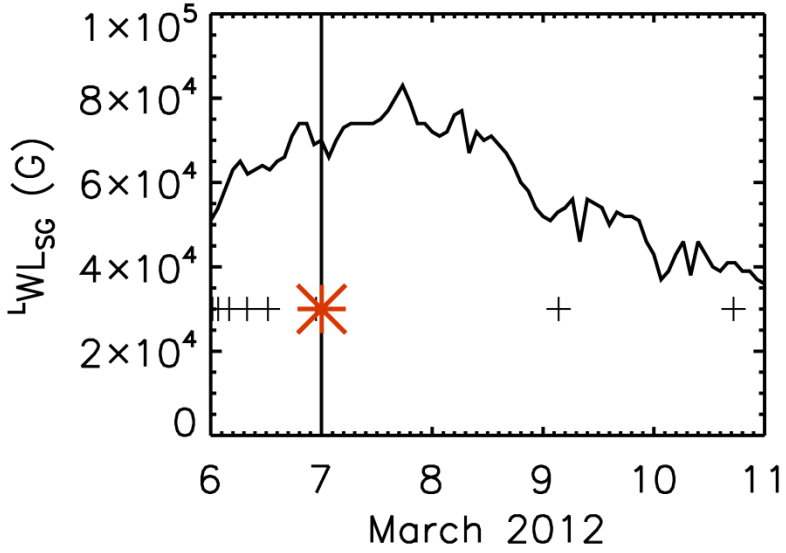
- **Lower Panel:** Forecast M&X flare rate
  - Forecast using free-energy proxy only
  - Forecast using Free-energy proxy and previous Flare History



- **Symbols**
  - \+ M-class Flares
  - * X-class Flare & SEP

In Addition to Free-Energy, Other Aspects of the AR that Persist on Periods of Days are Important Determinants of an AR's CME/Flare rate

- Previous-day flaring reflects all rate determinants that persist on time periods of days.
- We have long shown that one of these factors is AR's free-energy proxy.



- We have now shown that free-energy is not the only important factor.
- There are other persistent factors that are strong determinants of an AR's flare productivity.

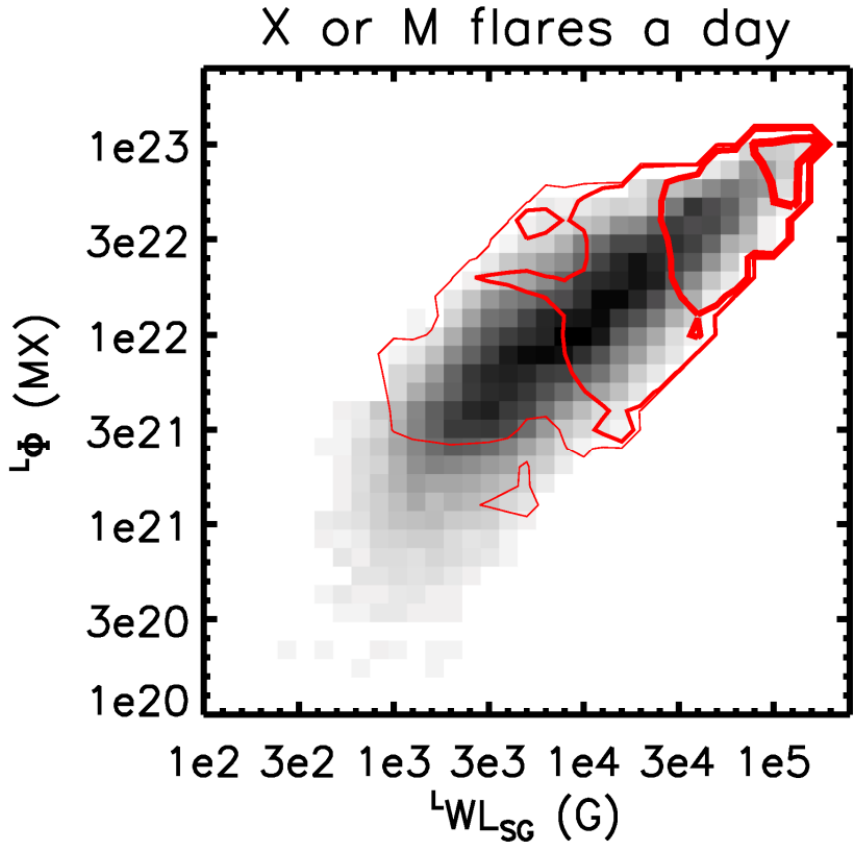
Next Step: Find the additional Factors

- Study active regions that have similar values of the free-energy proxy.
- Identify which active regions are more flare productive and which active regions are less productive.
- Determine what factors differ between these subsets
  - (not total magnetic flux)
  - Magnetic Evolution (emergence, cancelation, flows)
  - Magnetic Complexity (bipolar, multipolar, nullpoints)
  - Need to win funding to support this research.

Backup Slides

Flux Content is Not an Important Additional Determinant

Gray scale plot shows free energy/magnetic size distribution of 40,000 magnetograms of 1,300 active regions. Red contours are 0.001, 0.01, and 0.1, and 0.5 event/day levels.



Backup
SRAG MAG4 Tool Forecast Before X5 Flare

2012/03/06 22:23

#	AR#	WL!DSG!N (kG)	Lng (deg)	Lat	24 Hour Event Rate M&X	CME	FCME	X	SPE	Dist (deg)
3	11428	8	-21	-17	0.010	0.020	0.007	0.002	0.003	27
5	**11429**	**69**	**-41**	**17**	**0.800**	**0.400**	**0.200**	**0.100**	**0.090**	**44!**
6	11430	14	-25	20	0.040	0.040	0.020	0.006	0.007	32!
				Disk Forecast Rates	0.900	0.500	0.200	0.100	0.100	
				Multiplicative Uncertainties	2.7x	2.1x	2.3x	3.0x	2.5x	
				Disk All-Clear Forecast Probabilities	40.00%	60.00%	80.00%	90.00%	91.00%	
				Uncertainties	40.00%	20.00%	10.00%	10.00%	8.00%	