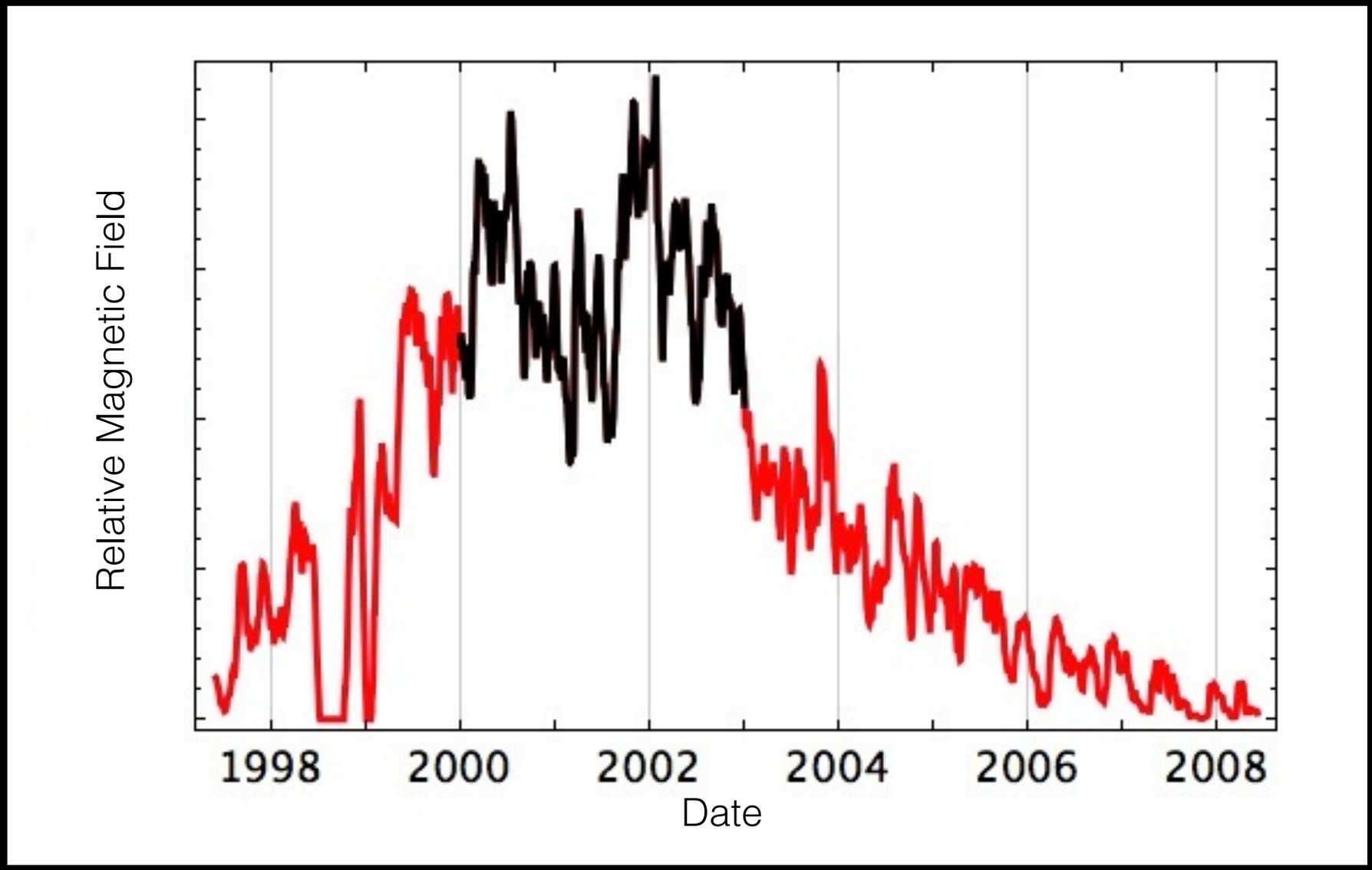
Clustering of Flares and Relations to Flux Variations

Alan Title and Marc DeRosa
Lockheed Martin Advanced Technology Center

Outline of the Talk

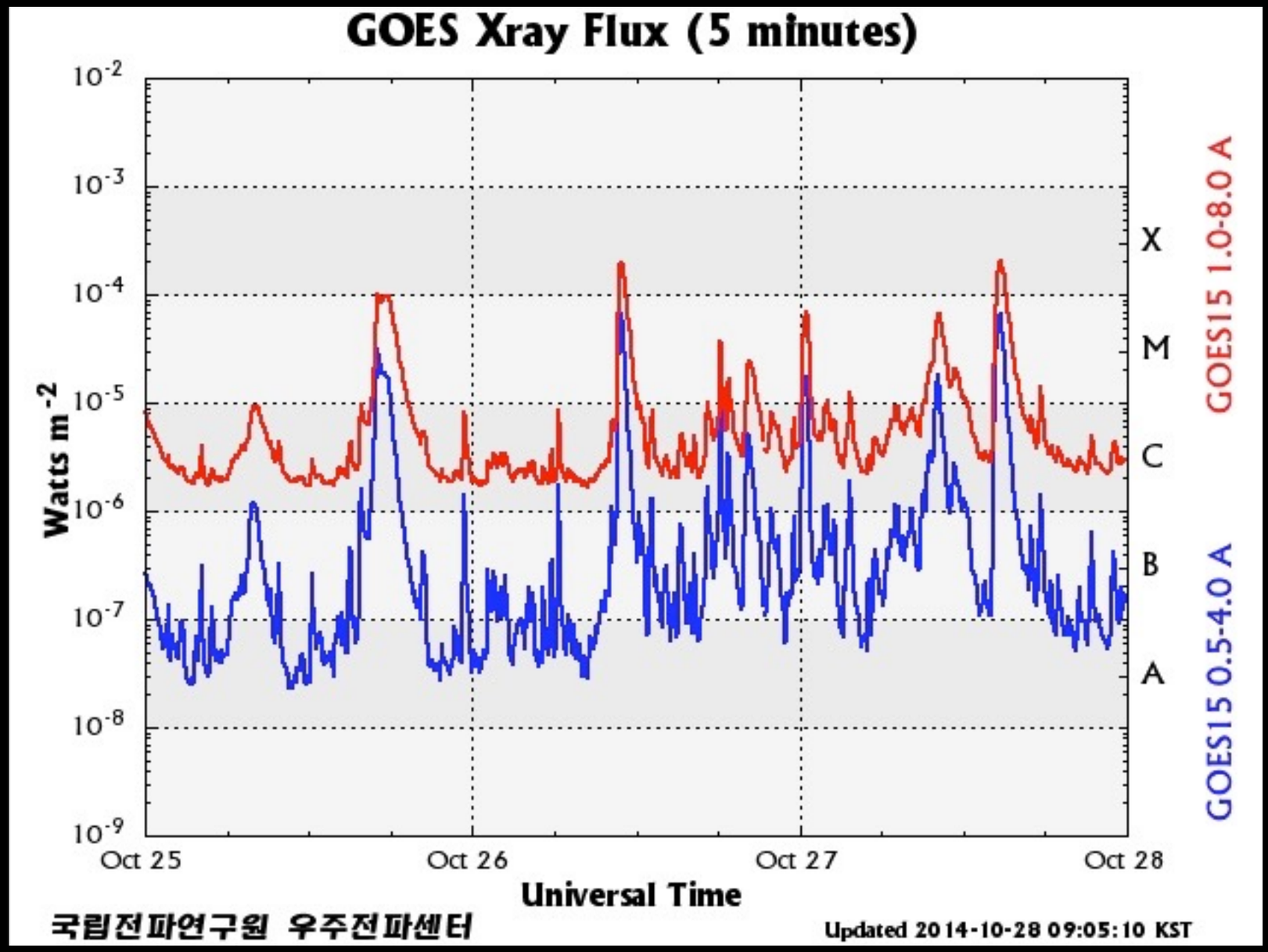
- The process used to select flare clusters
- The relationship between Clusters and Flare Rates
- The effect of the low energy cutoff on identification of clusters.
- The relations between Flare and Sunspot Clustering.
- Predictions of the Surface Flux
- Predictions of Large Flares
- Speculation on sources and consequence of nests, persistent active regions, and flare clustering.

Solar Magnetic Flux During Cycle 23



Cycle 23 Data span June 16, 1997 to June 16, 2008
Maximum Data (black) span January 1, 2000 to January 1, 2003

Sample of GOES DATA



NOAA publishes the time and strength of the peaks of x ray intensity. We generate the time separations, W, between sequential peaks, P.

$$W(i) = P(i+1) - P(i).$$

Identifying and Counting Clusters

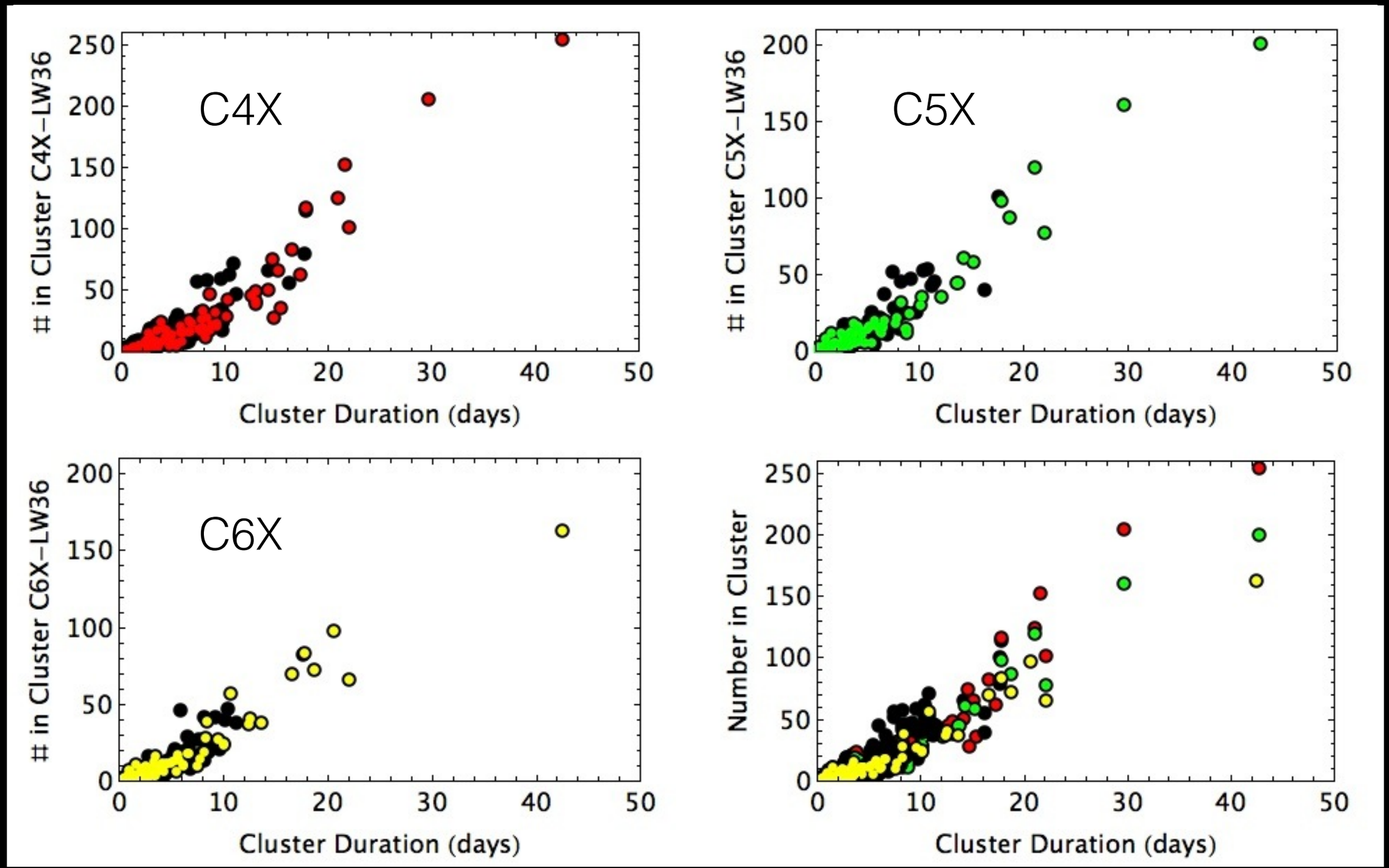
Using a list of time separations W(i), we wish to create groups of flares, flare clusters, in which the time between all sequential flares is less than some maximum time, LW. We call LW the linking window.
We form

Q_{LW} (i) = 1 if W(i) <= LW and
= 0 if W(i) > LW

Q_{LW} is then a list of 1's and 0's that consists of strings of 1's separated by strings of 0's.

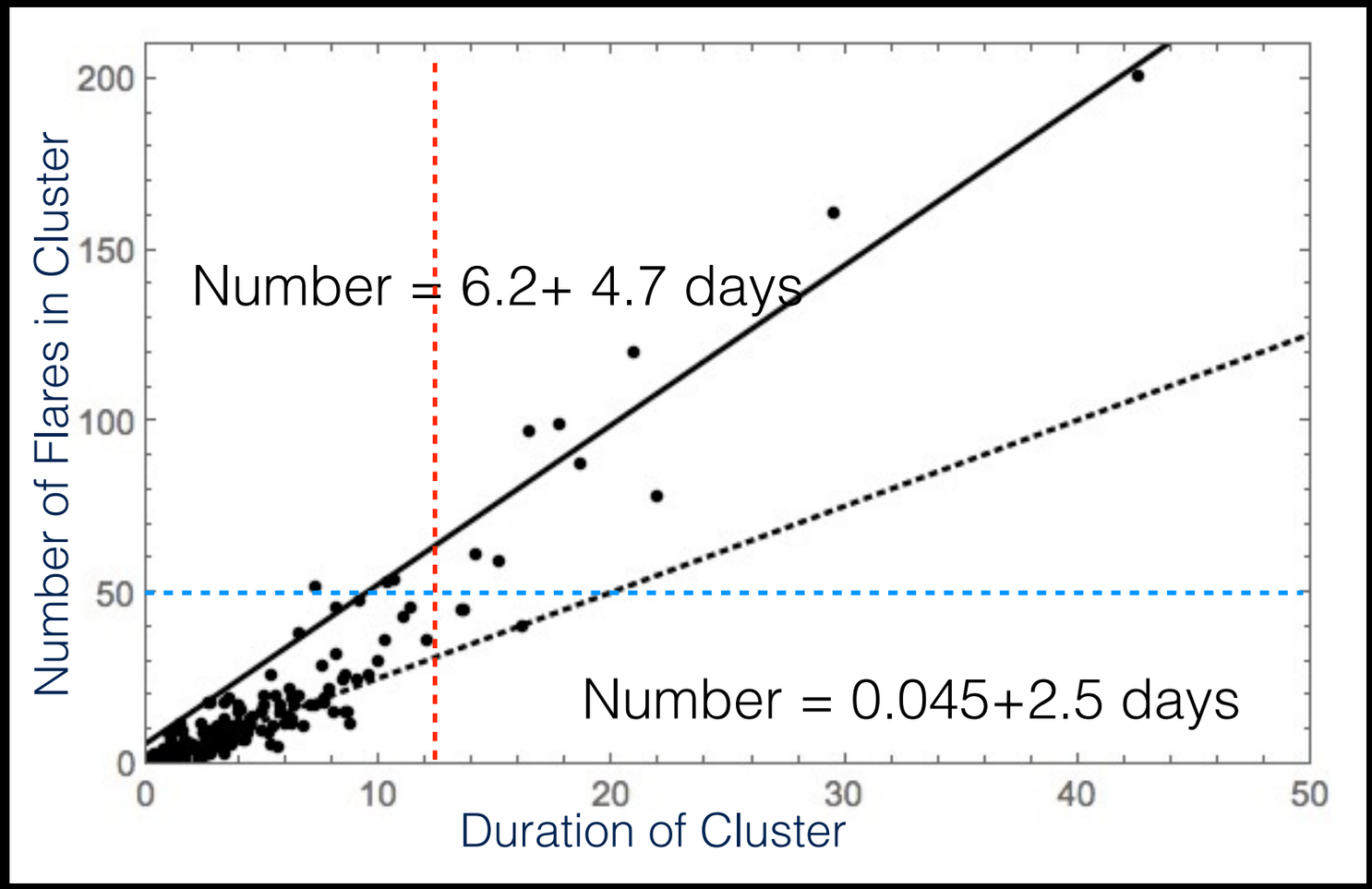
The flare clusters are indicated by the strings of 1's. By counting number of strings of 1's of length k, the cluster histogram, N(k), the number of clusters of length k selected with the linking window LW is determined.

Number of Flares in Clusters VS Duration of Clusters



The points in **black** are clusters selected with a linking windows of 36 hours for the **full cycle**. Overlaid in **color** are the clusters selected from the C4X, C5X, and C6X data during the **solar maximum**.

Number of Flares vs Cluster Duration
Case C5X



N>50 = Mean (18.8 duration (days), 5.1 flares/day)

N<50 = Mean (2.8 duration (days), 2.9 flares/day)

G>13 = Mean (20 duration (days), 4.2 flares/day)

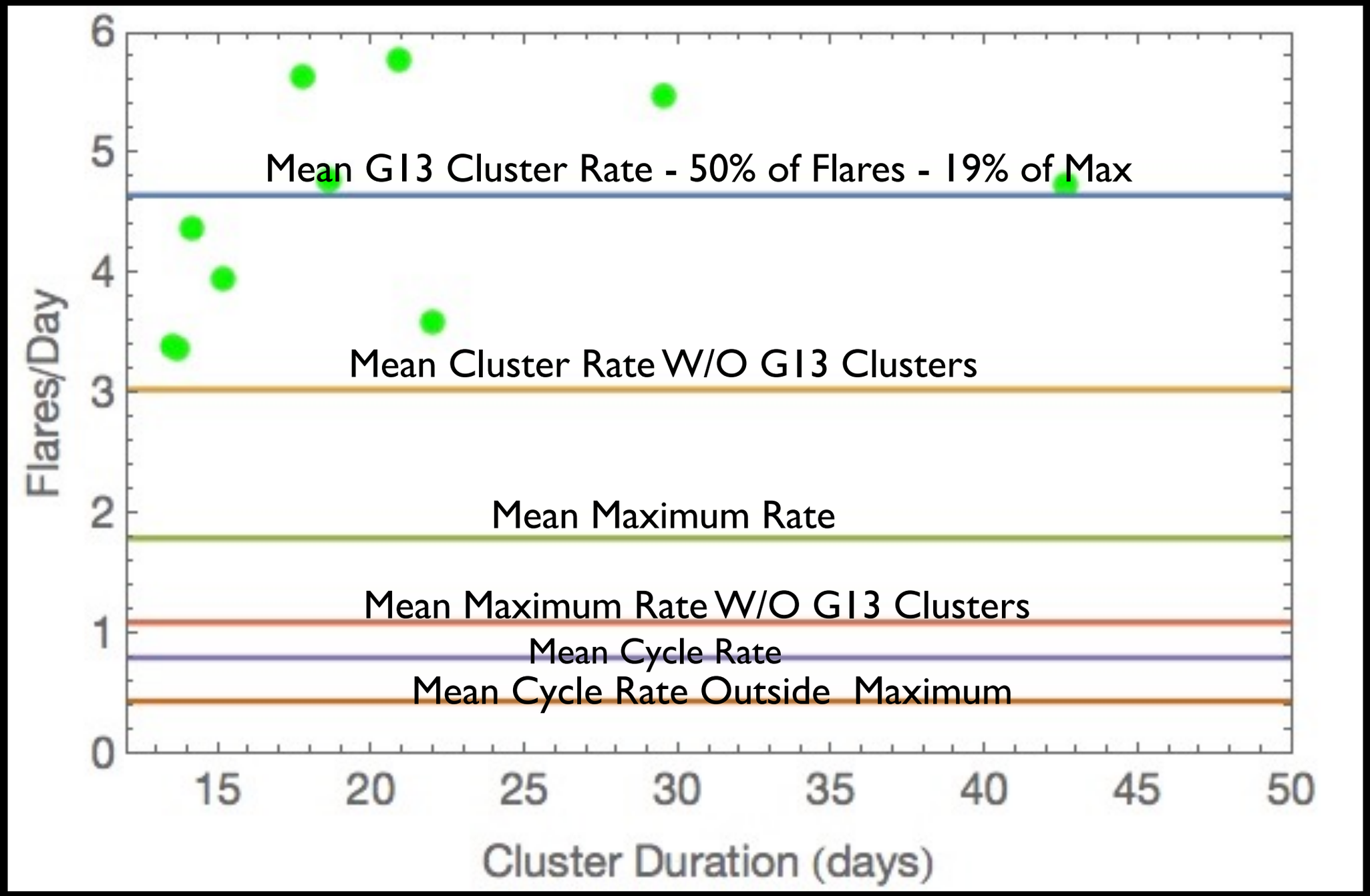
G<13 = Mean (2.7 duration (days), 2.9 flares/day)

Flare Rates and Ratios Between Rates

Table 1

Characteristic	C4X	C5X	C6X	C7X
Mean G13 Flare Rate (Flares/day)	4.91	4.71	4.15	3.49
Mean Flare Rate Maximum (Flares/day)	2.36	1.79	1.46	1.20
Mean Flare Rate Maximum W/O G13 (Flares/day)	1.28	1.08	1.03	0.989
Mean Flare Rate Cycle (Flares/day)	1.19	0.921	0.747	0.631
Mean Flare Rate Cycle minumum (Flares/day)	0.722	0.578	0.463	0.407
Ratio Flare Rate G13/Flare Rate Maximum	2.08	2.64	2.82	2.92
Ratio Flare Rate G13/Flare Rate Maximum W/O	3.84	4.35	4.03	3.52
Ratio Flare Rate G13/ Flare Rate Minimum	6.80	8.15	8.98	8.57
Fraction of time in G13 During Maximum	0.297	0.194	0.140	0.828

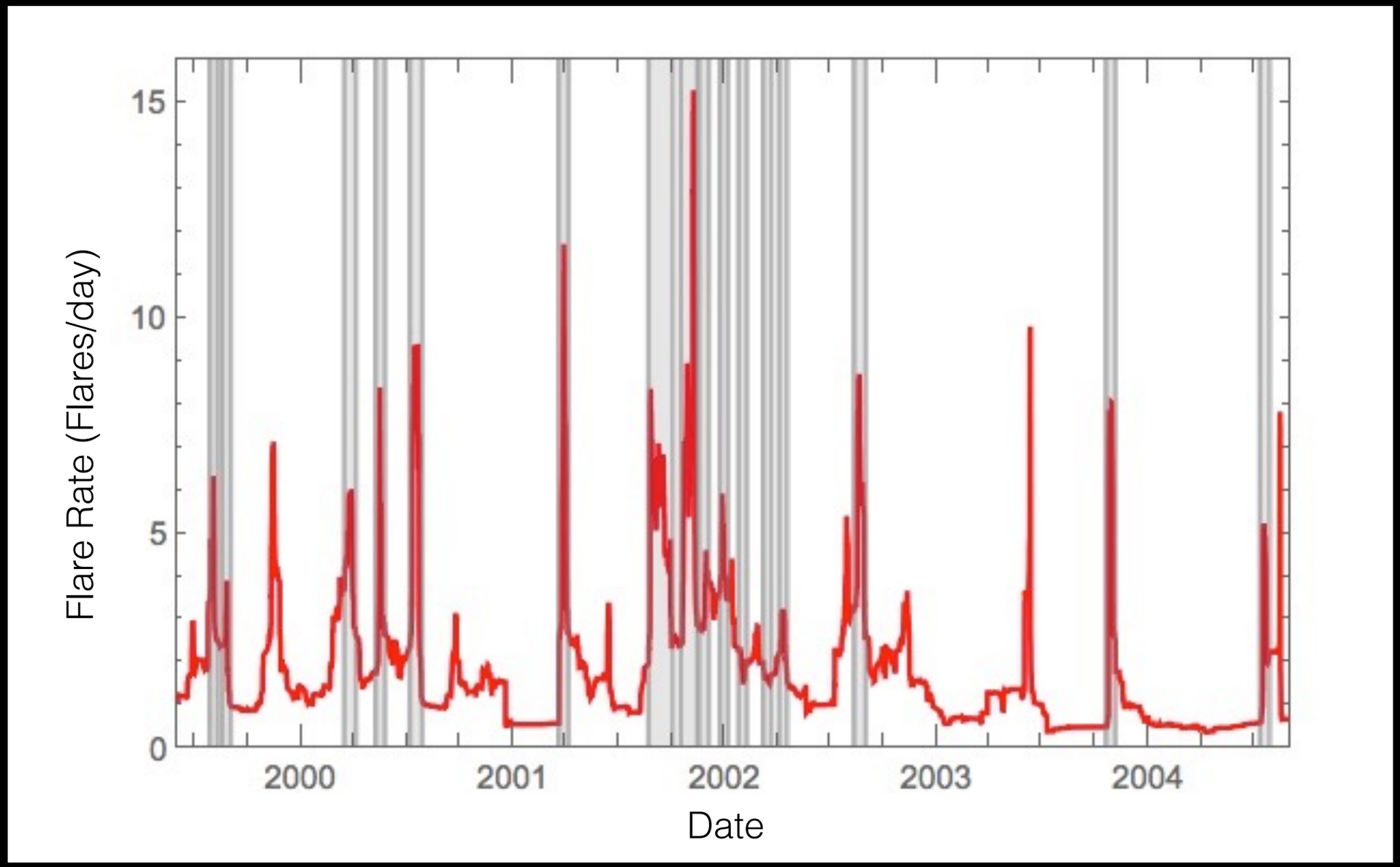
Comparison of the G13 Cluster Flare Rates (C5X) Compared to Other Components of the Cycle



The mean rate of flaring in the G13 Clusters is 4.7 times the rate in the maximum outside of these clusters.

51 Flare Running Average C4X Flare Rate

with respect to Flare the Cluster Bands



Most of the high flare rates occur in the G13 clusters.

Properties of Sunspot Nests, Persistent Active Regions, and Magnetic Clustering

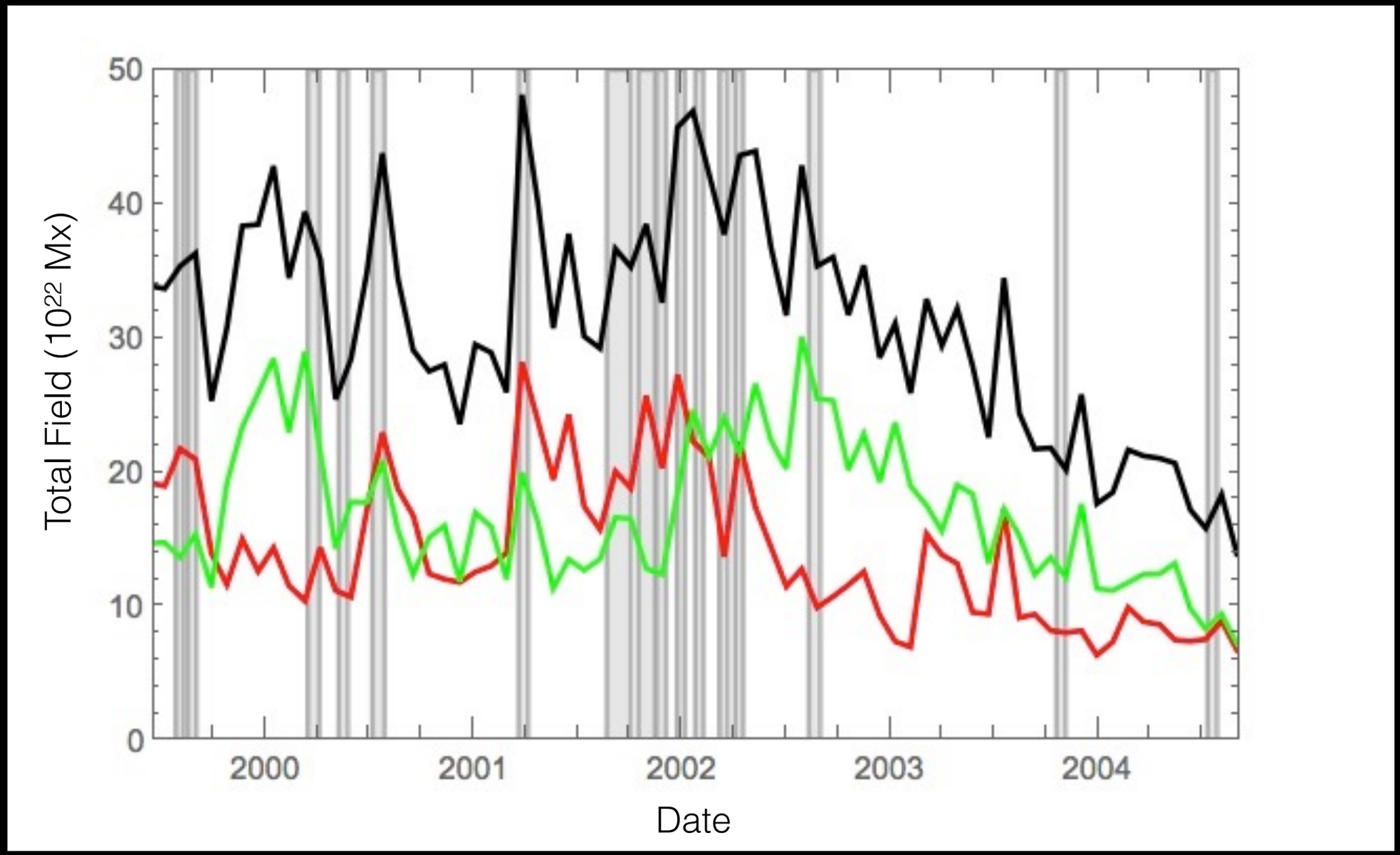
Carrington noted that sunspots tended to repeat at the same position on the Sun

Karen Harvey show that half the new flux emerged in previously existing active regions and these regions lasted multiple solar rotations and their total flux was constant to within a factor of two.

Since Karen's work several authors have verified that the tendency of spots to occur at the same position repeatedly was not chance. Also they have shown that at least half the flux that emerges on the solar surface occurs in these clusters -nests-centers of activity.

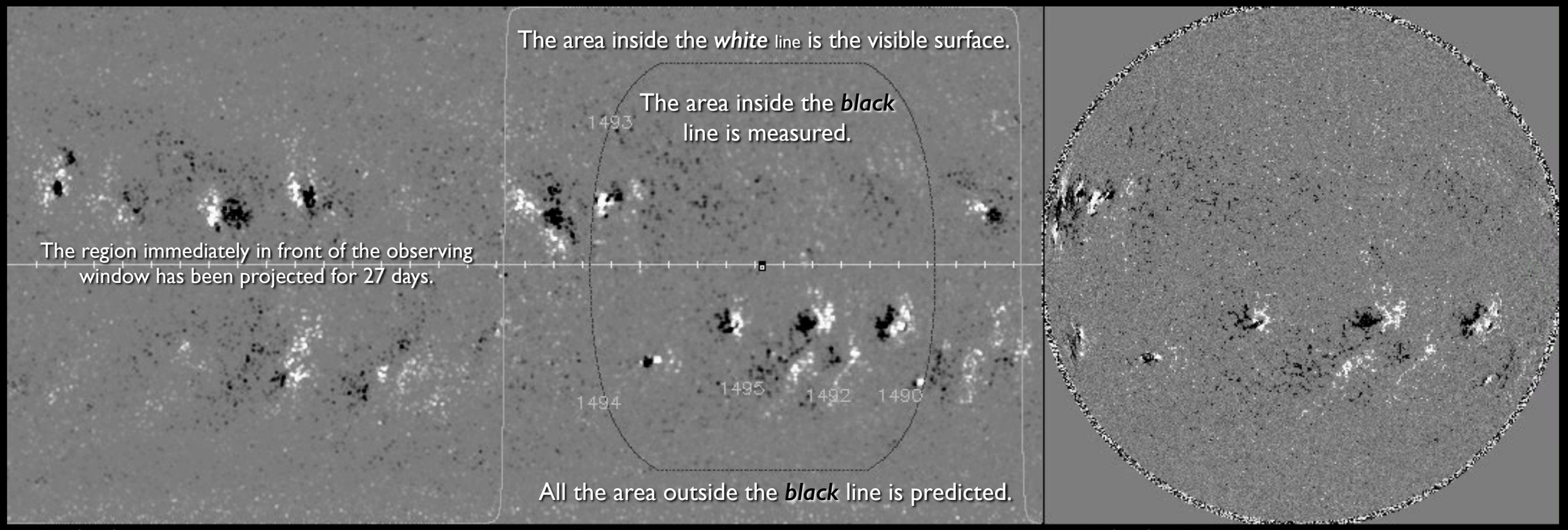
Gekto has shown that peaks in the total flux are due to the presence of multiple nests on surface. He also showed that there are not special longitude bands for nests.

Total Magnetic Flux on Flare Cluster Bands



The peaks in the total magnetic flux (Black) of the full Sun are the result of separate peaks in the northern (Red) and southern (Green) hemispheres.

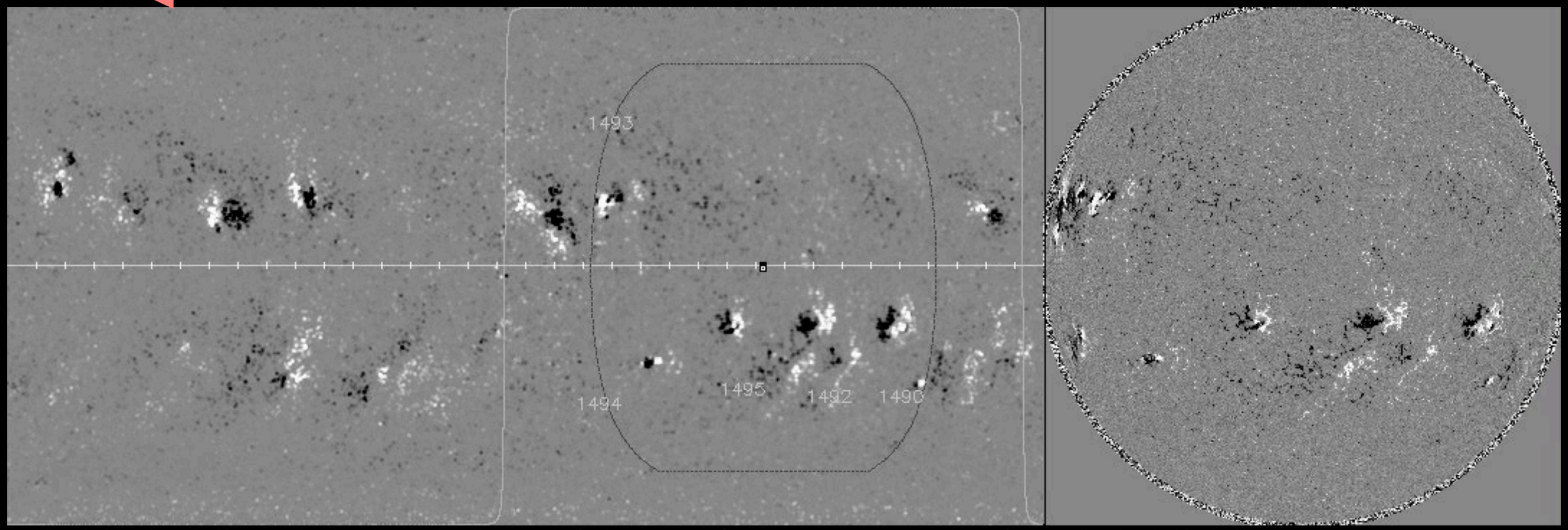
Assimilated Synoptic Map of the Surface Line of Sight Magnetic Field



Prediction is based on known properties of the solar flows and magnetic diffusion.

Evolution of the Assimilated Synoptic Map

Time

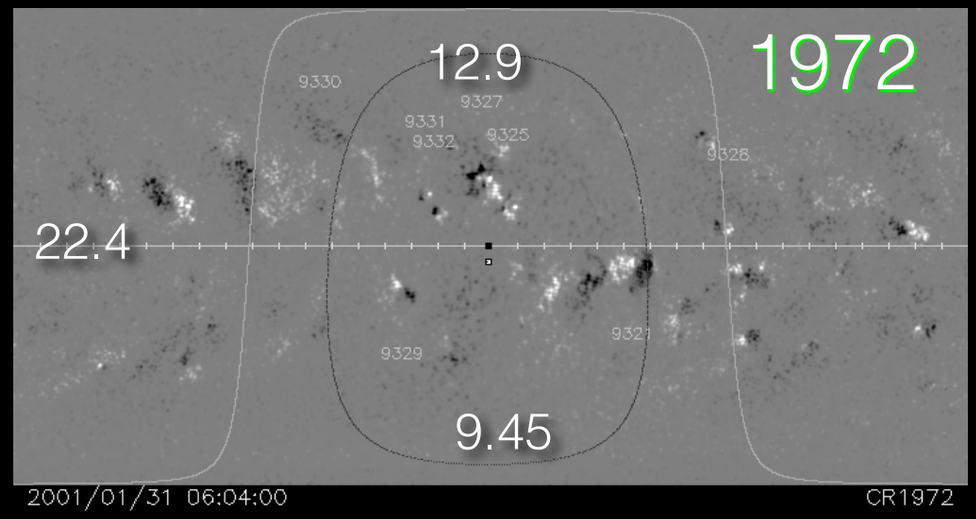


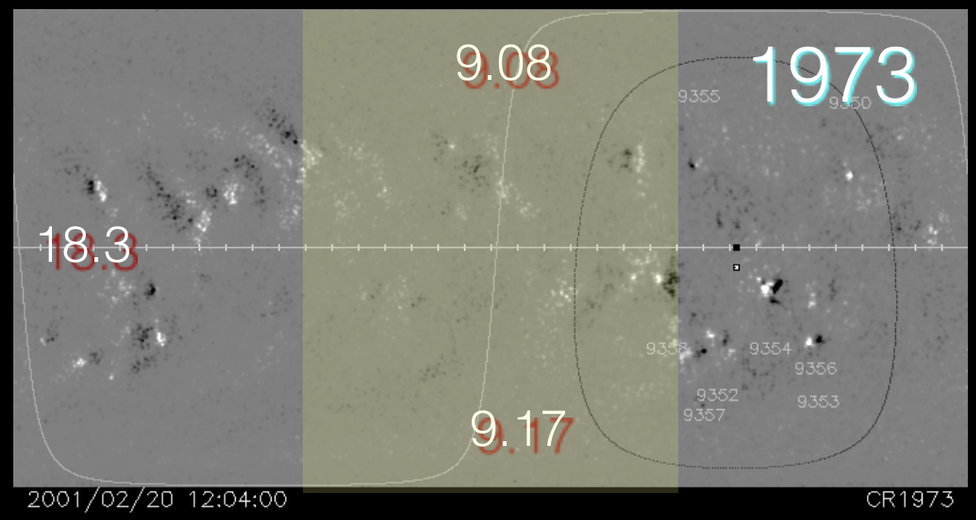
The Prediction of the Line of Sight Fields

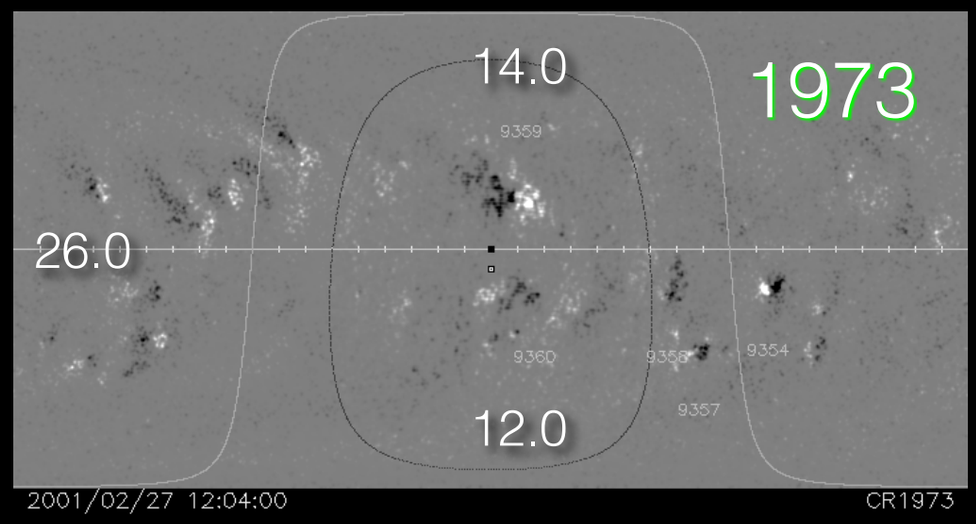
The top and bottom maps (green) are sequential Carrington Rotations with the region measured from Earth centered at 180°.

The center map (blue) has the measured region centered at 90° west of the fields visible from the Earth. Marked in Yellow on the center map is the region that will appear visible from the Earth in 7 days.

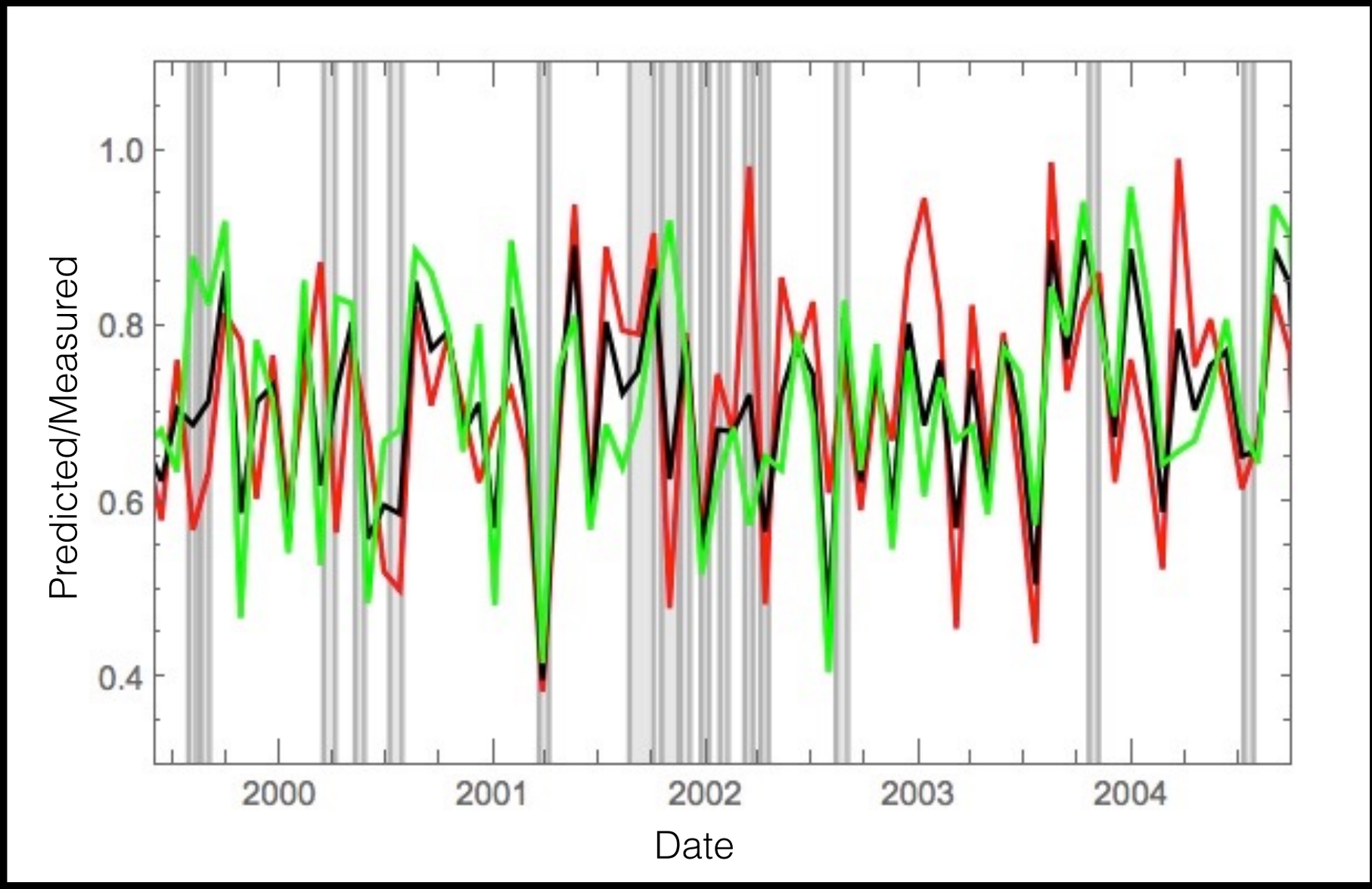
We call the magnetic field box in yellow the PREDICTION of the magnetic field seen from Earth in rotation 1973 based on the assimilation of fields from rotation 1972.





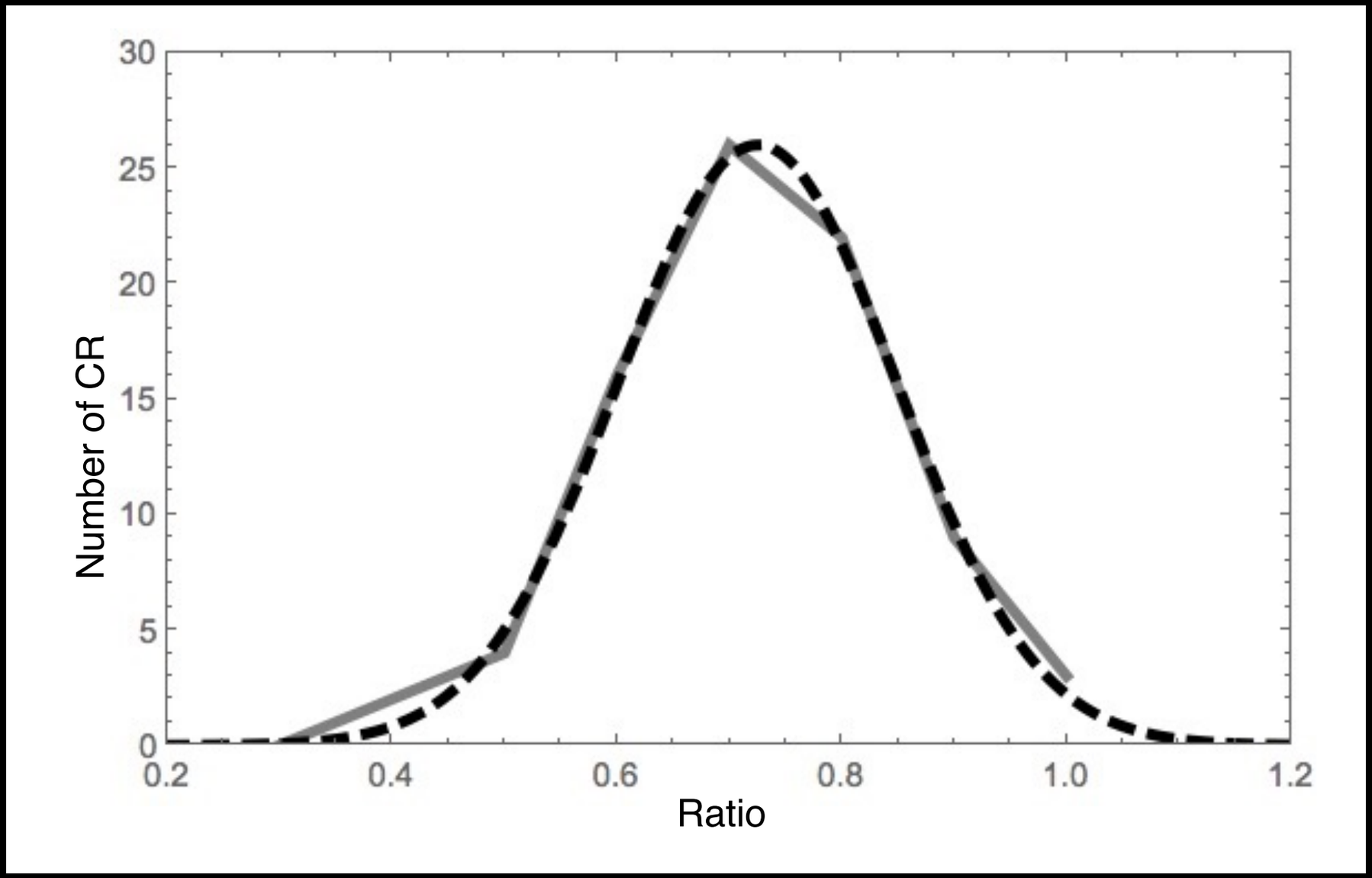


Ratio of Predicted tot Measured Flux in the Northern (red), Southern (green), and Both (black) Hemispheres

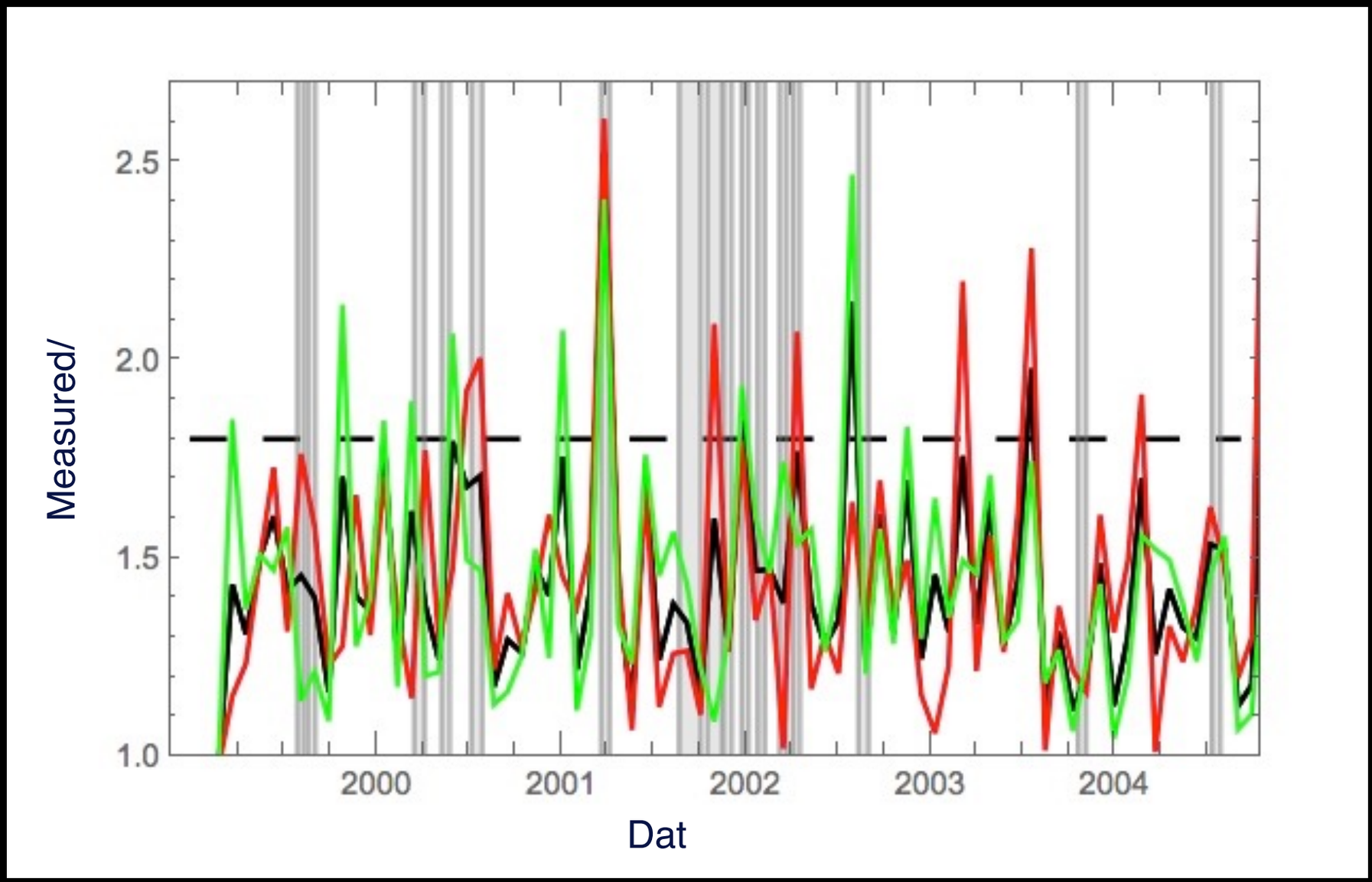


This shows that in most of Cycle 23 the estimate of the flux in each hemisphere is on average 73% of what will be measured on the next CR.

Gaussian Fit to the Histogram of Predicted to Measured Flux for 76 Carrington Rotations

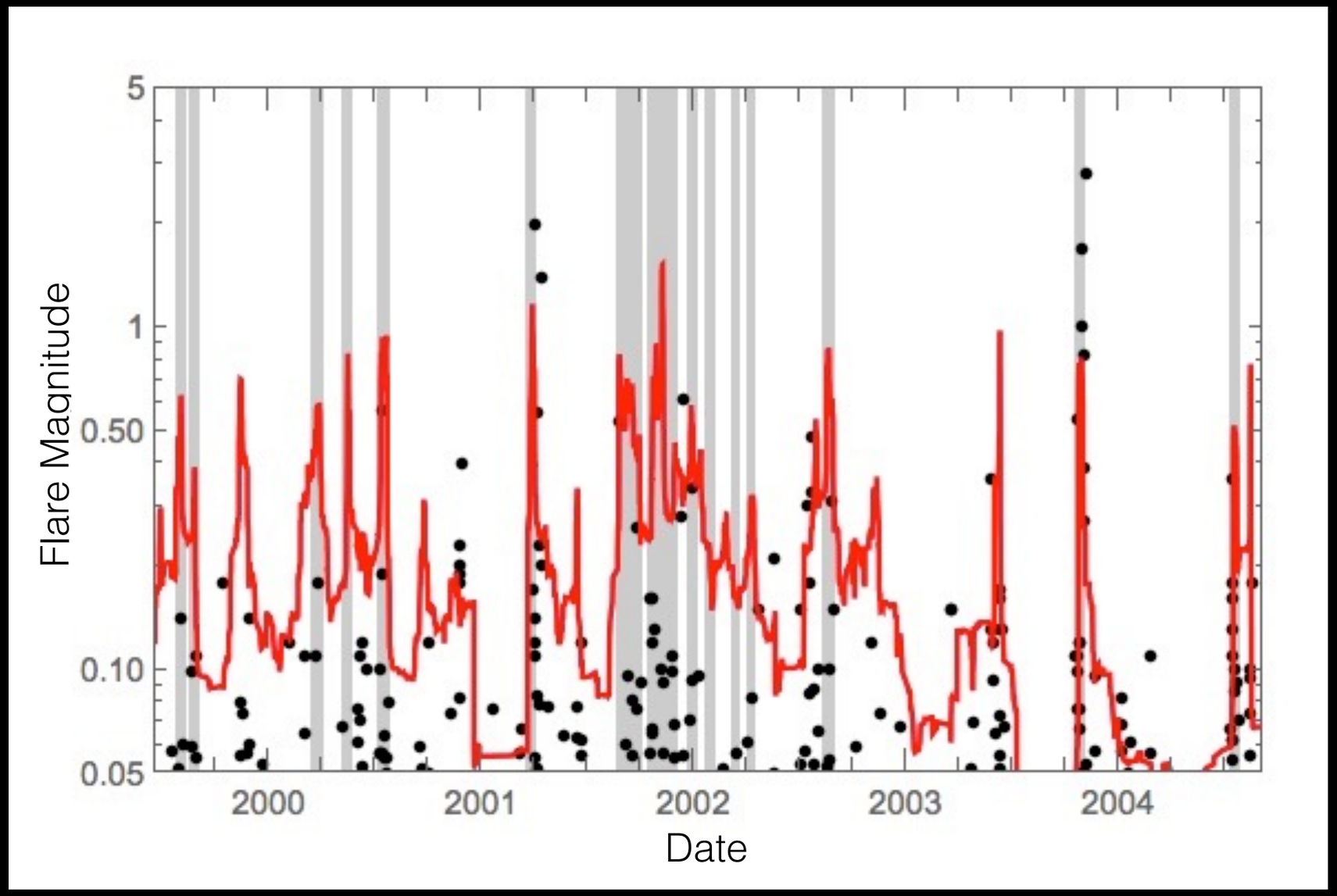


The Ratio of Measured/Predicted Total Flux in the Northern (red), Southern (green), and Both (Black) Hemispheres



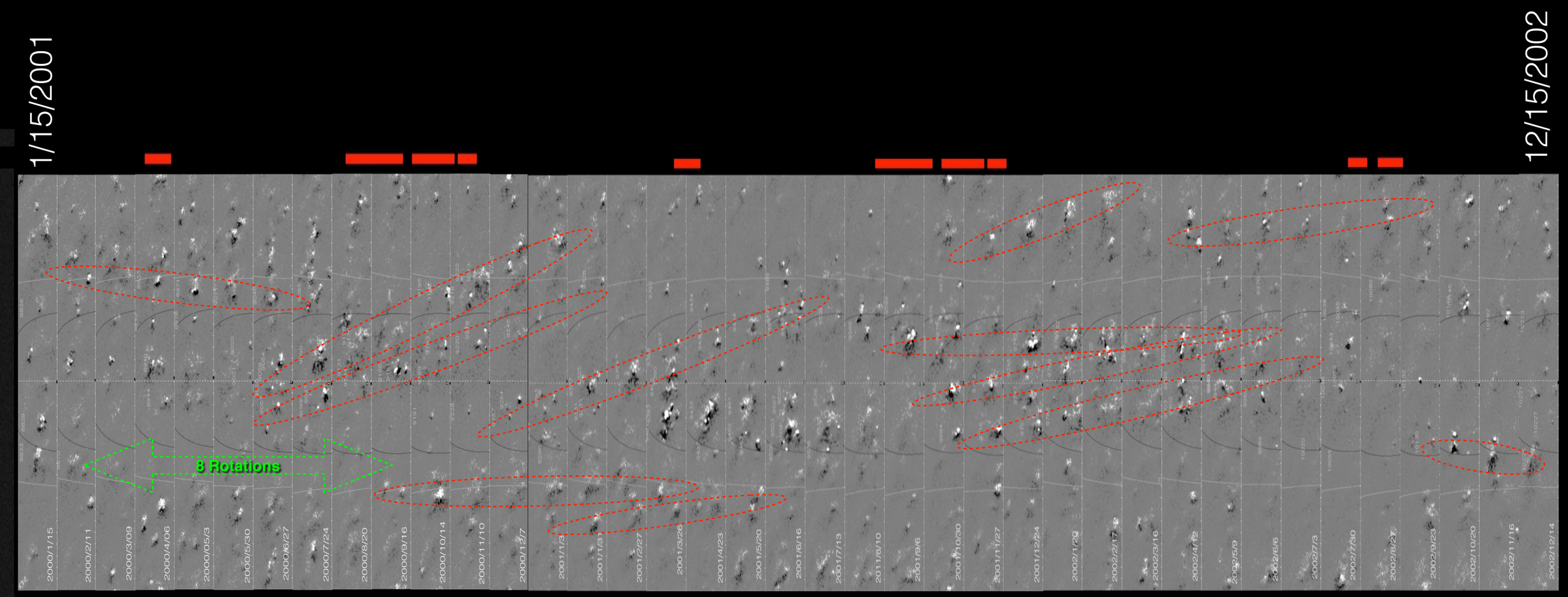
It is 7.5 times more likely that a one sigma excursion occurs in a cluster band

Location of X and M5 Flares to Flare Cluster Bands and the Flare rate



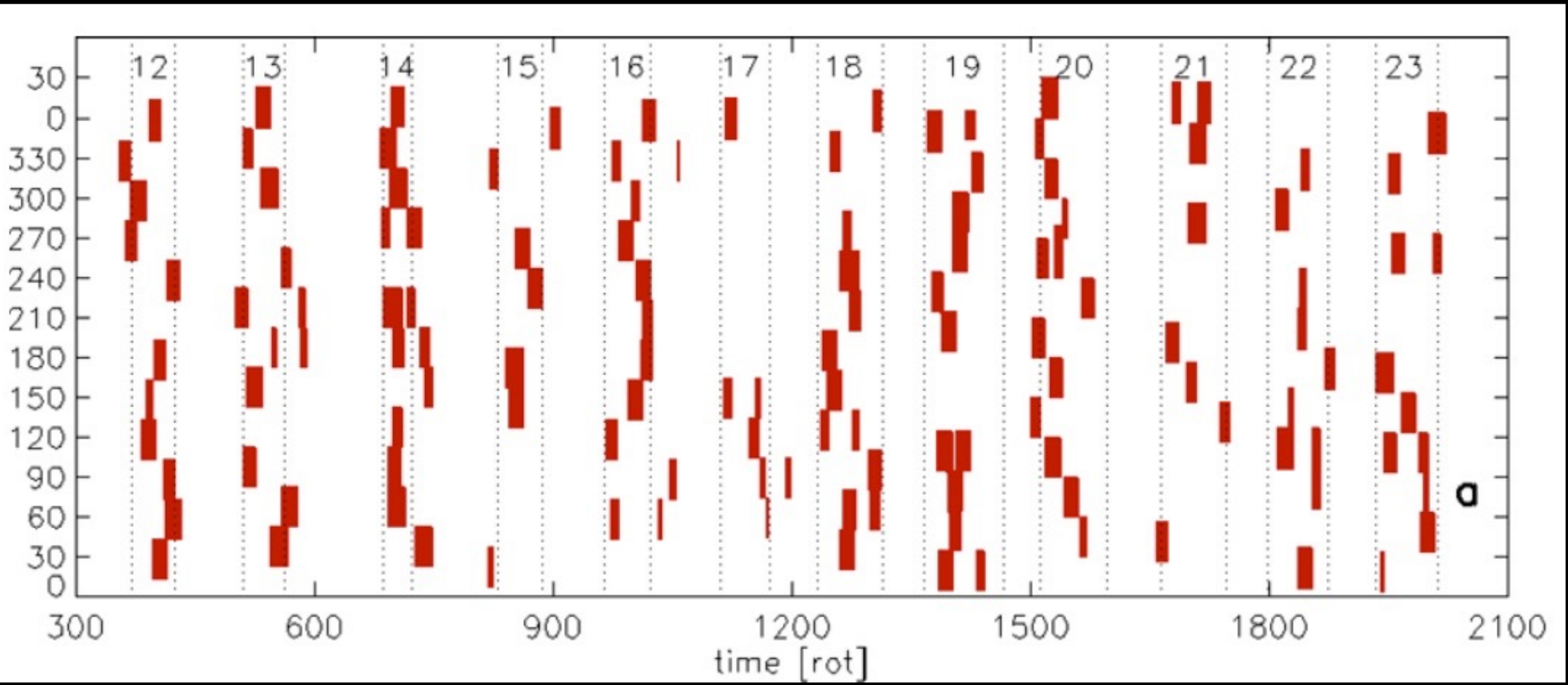
75% of the M5X flares occur in the cluster bands, Virtually all of them occur in regions with high flare rates. From 1 July 1999 to 9 September 2004 it was 15 time more likely that an M5X Flare occurred in cluster band.

An Example of a Set of Stacked ASC Charts for the Northern Hemisphere



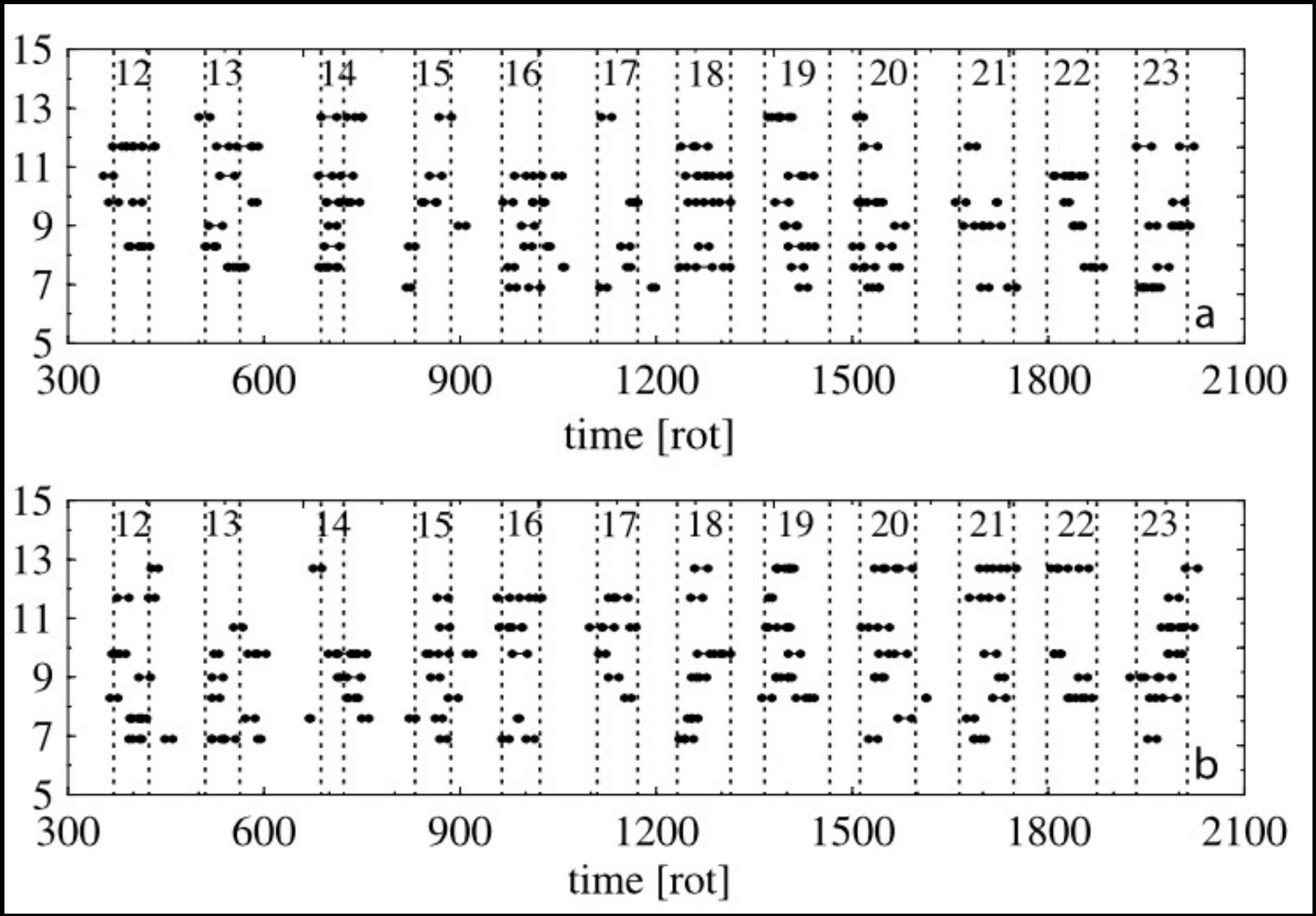
The red bars indicate cluster regions. The ASC have been rotated 90°. 360° longitude is on the top and 0° is on the bottom of the band. The red ovals indicate some of the longer nests.

Location of Nest in 300 Longitude Bands



Getko 2014

Duration of Clusters (Carrington Rotations)



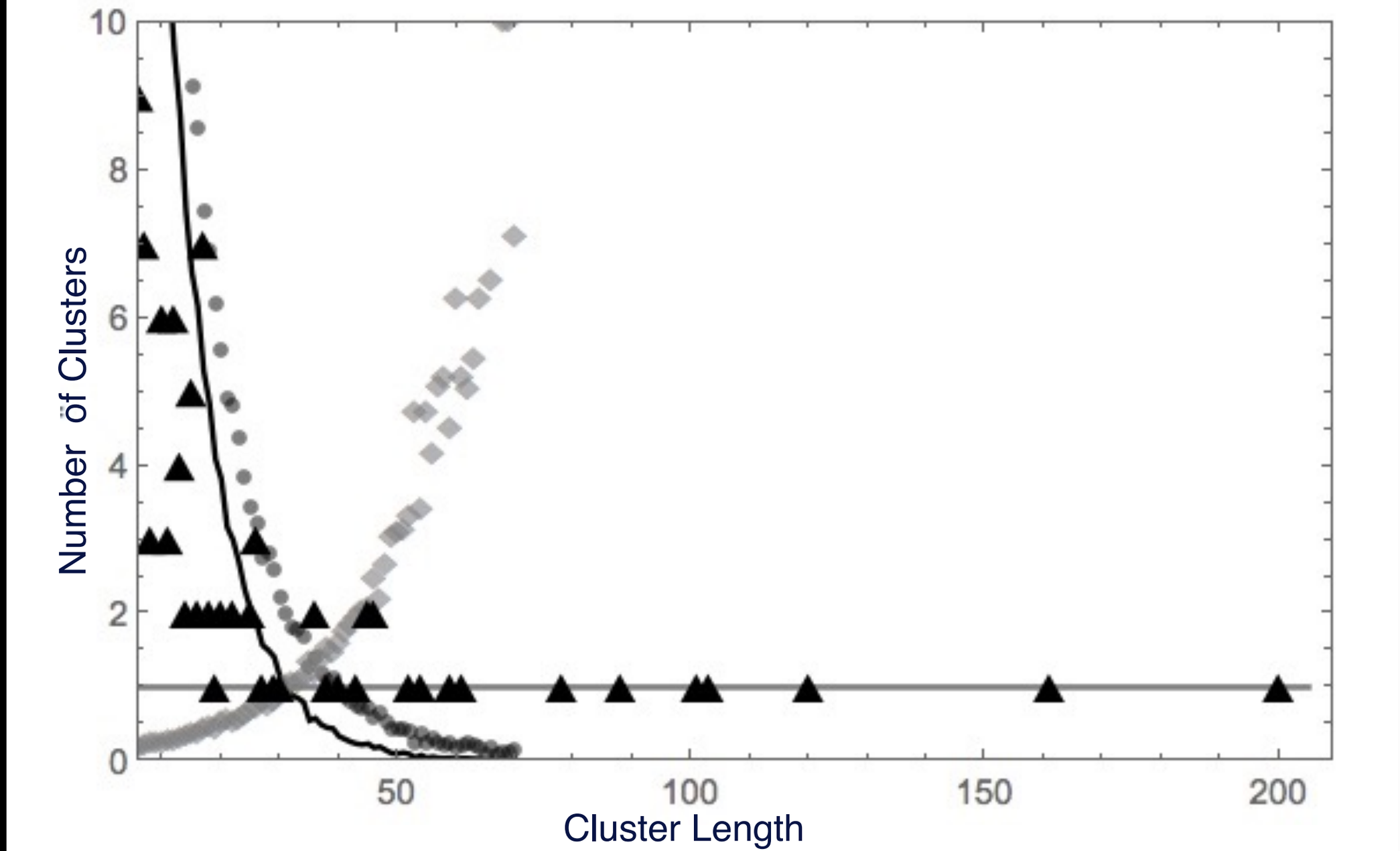
Getko 2014

Comments

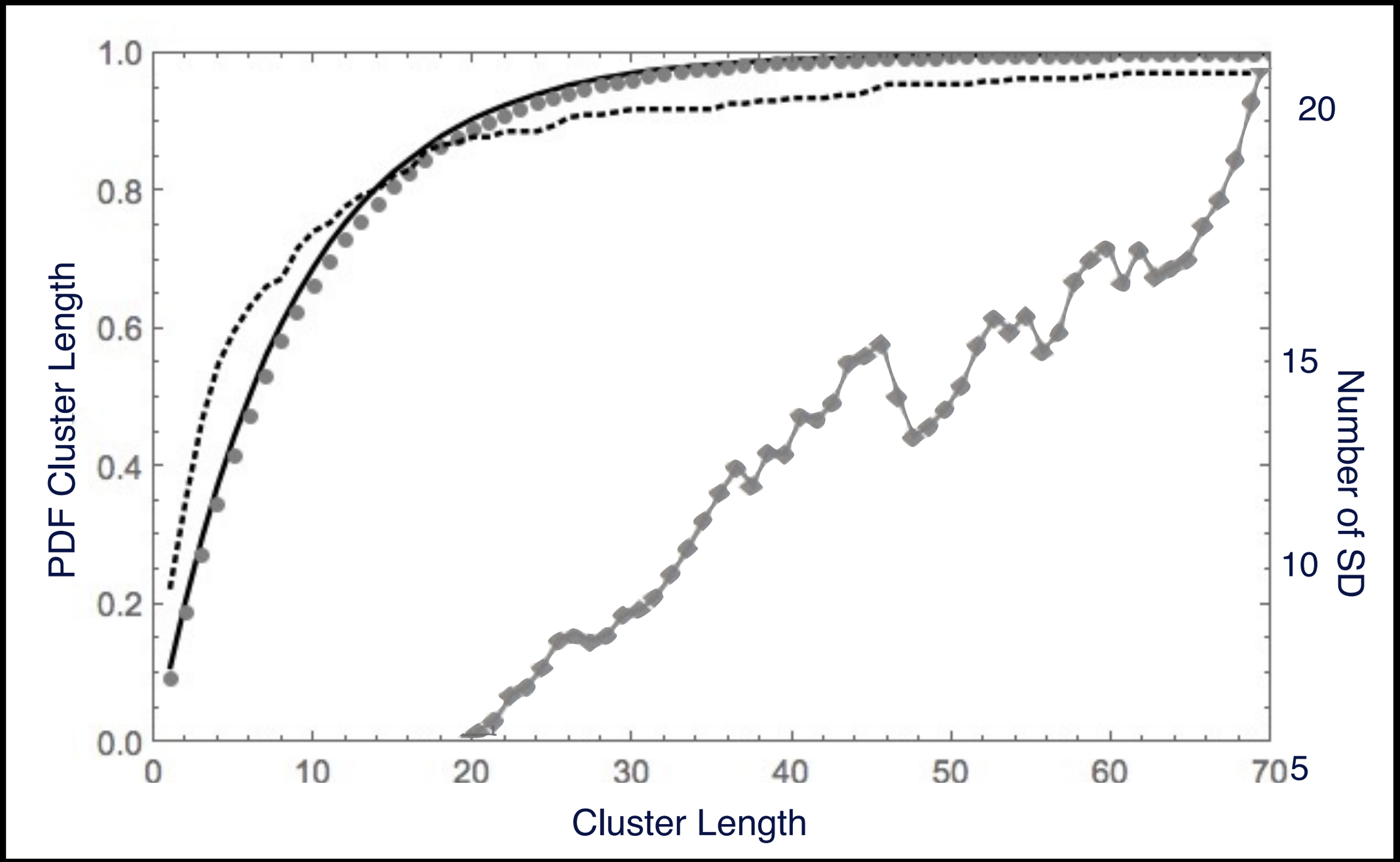
- Flare Clusters are much rarer than both nests and recurrent active regions. There are usually 4 nests on the Sun at anytime in the maximum, but there are only 5.6 C4X clusters/year.
- The Flare clusters occur when there are multiple nests on the entire solar surface.
- In the cluster periods the “best” current predictions of the total flux on the Sun can be in error by a factor of two or more.
- The existence of both clusters and nests implies that there are long lived subsurface sources.

Speculations on the Origins and Consequences of Clustering

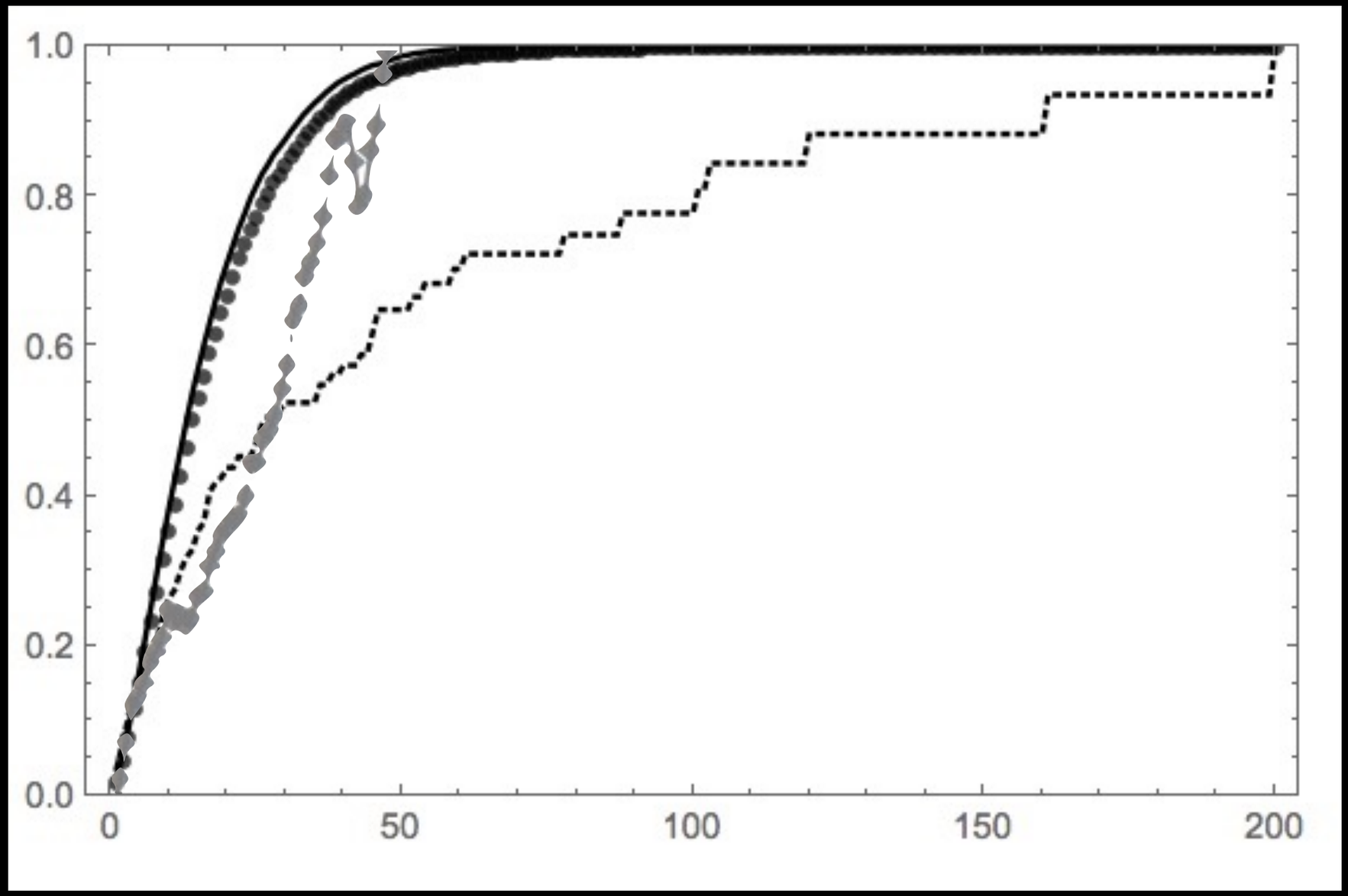
- The fact that some clusters last more than three disk passages requires groups of flaring active regions distributed around the Sun. This could be caused by multiple magnetic nests. Is this a property of the solar dynamo like nests?
- The fact that the rate of flaring in clusters is greater by a factor between 4 and 6 times the rate of flaring in solar maximum outside of the clusters indicates that rate of flaring may have a global component.
- It may be possible to predict the occurrence of high magnitude from early on by a increase in flare rate and an accompanying _thressignificant increment in the total solar flux in either or both hemispheres.



Coin Flip (solid), upper SD(dots), Number of SD from Unity(diamonds), measure number of clusters(triangles)



Cumulative Contribution Clusters CoinFlip (black), Observed (small dots), lower Standard Deviation CoinFlip (dots), and separation in Standard Deviations of the observations and the CoinFlip (diamonds)



Cumulative Contribution Flares in Clusters CoinFlip (black), Observed (small dots), lower Standard Deviation CoinFlip (dots), and separation in Standard Deviations of the observations and the CoinFlip (diamonds)