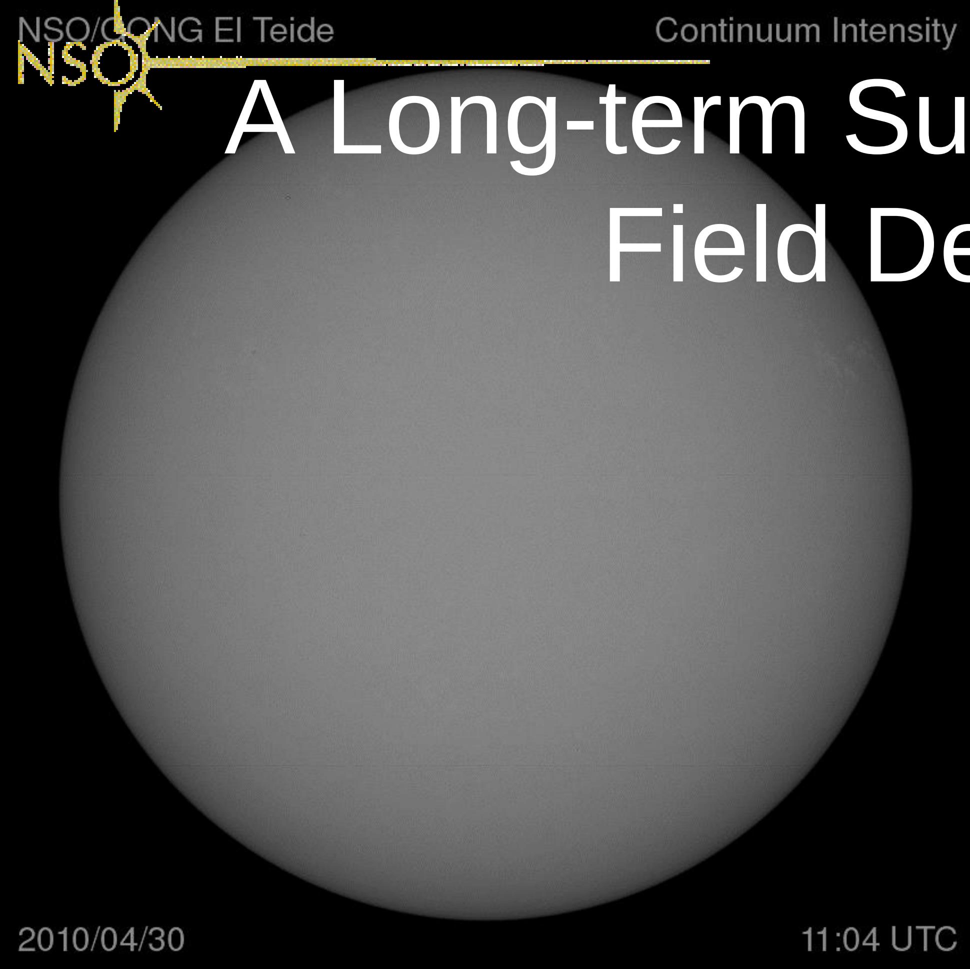
A Long-term Sunspot Magnetic Field Decrease



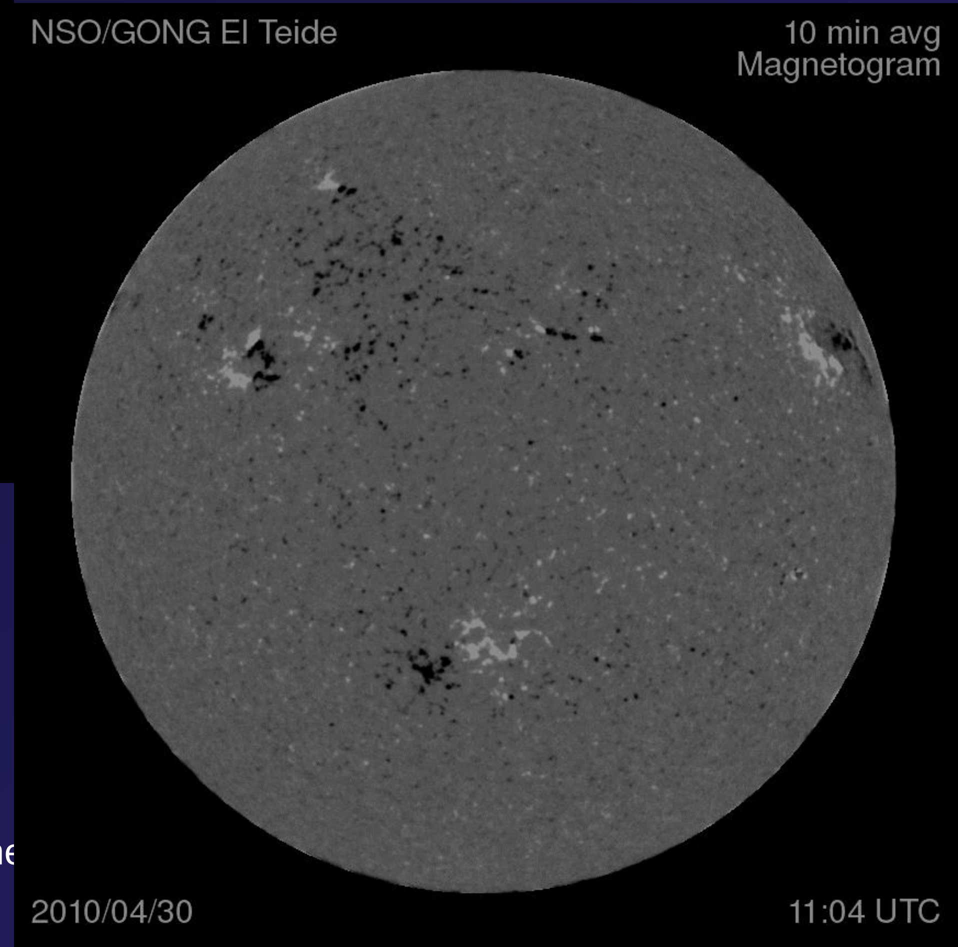
William Livingston (NSO)

Rachel MacDonald (Yale)

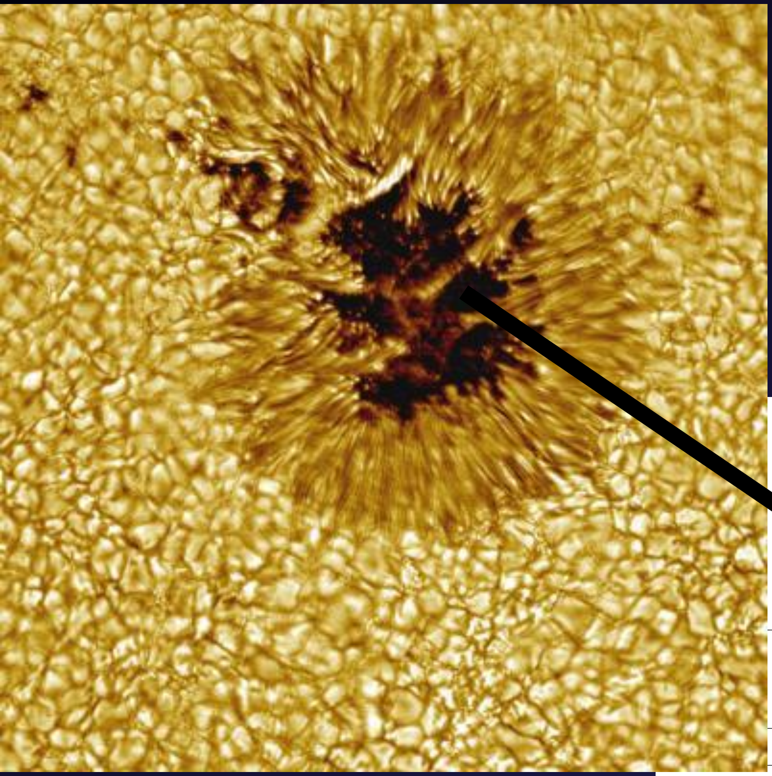
Tom Schad (UAz)

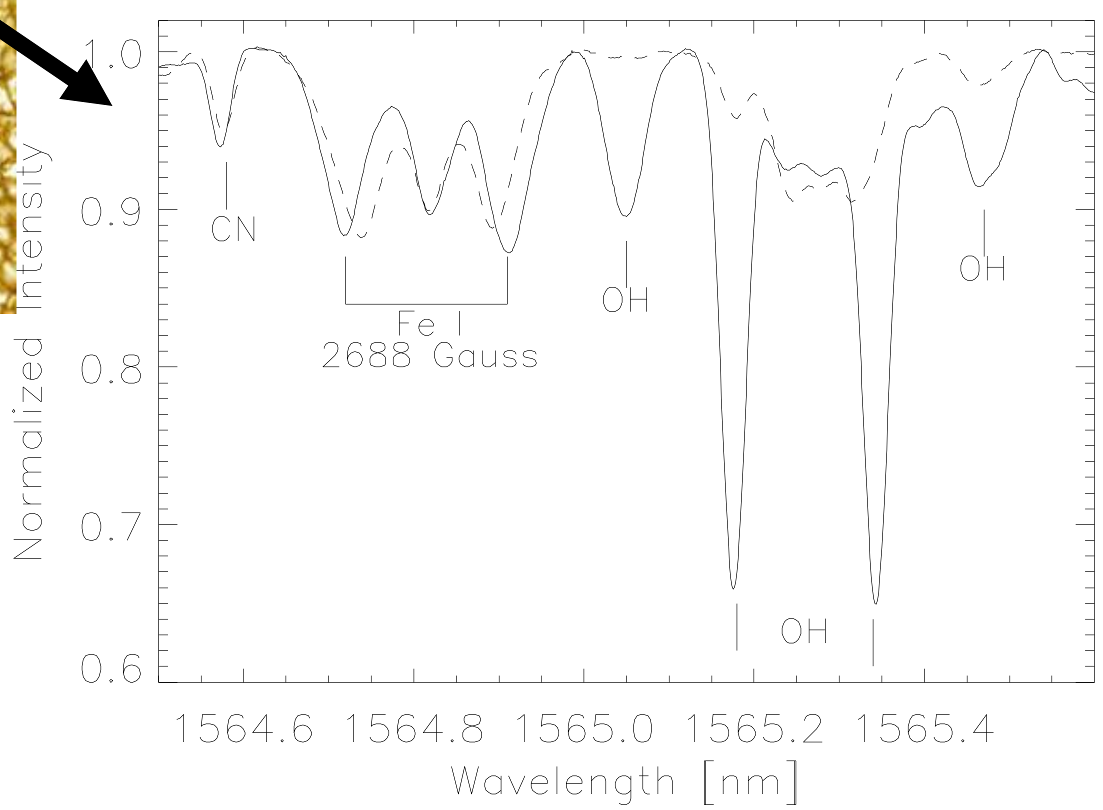
30 Apr 2010

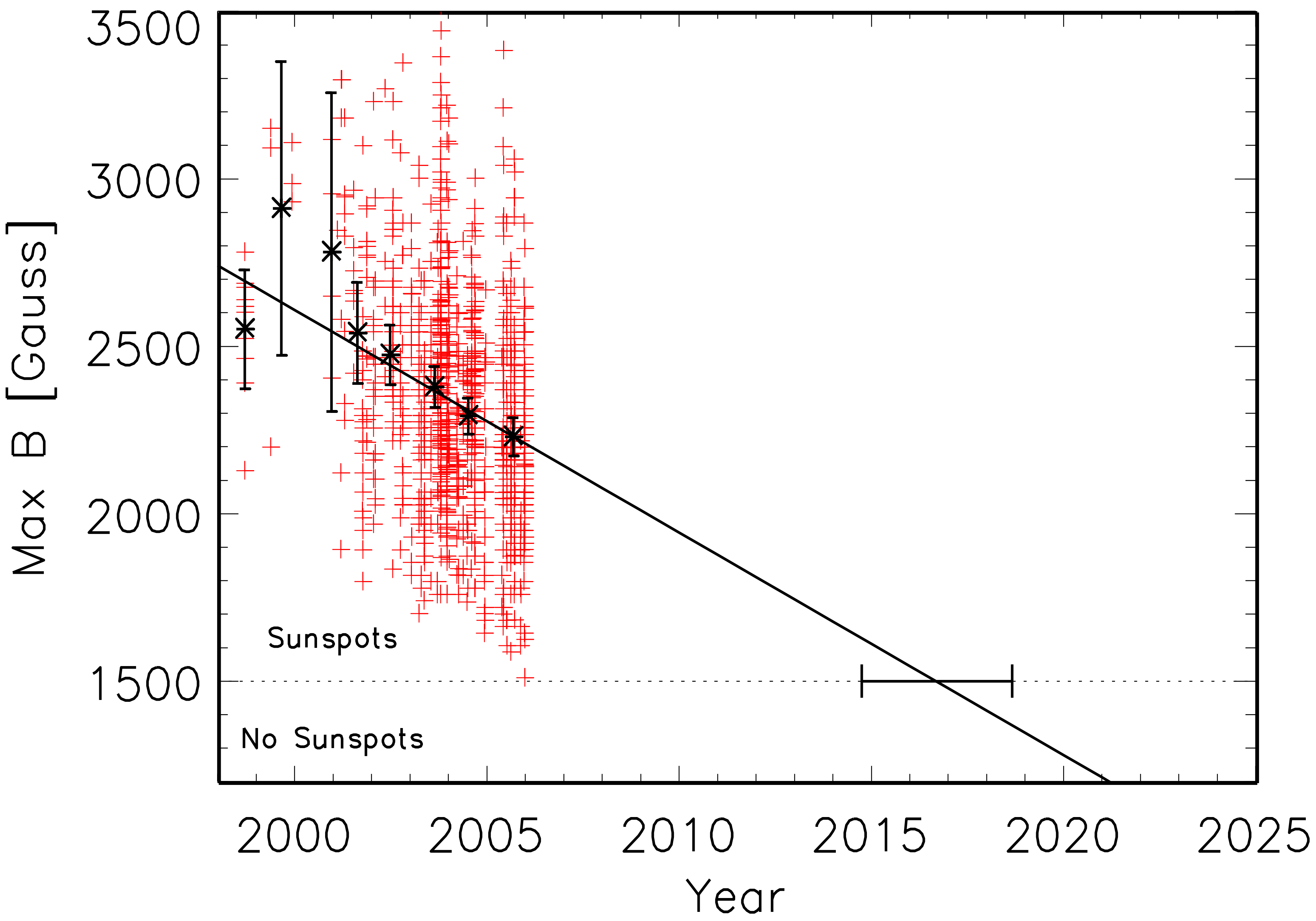
Space Weathe

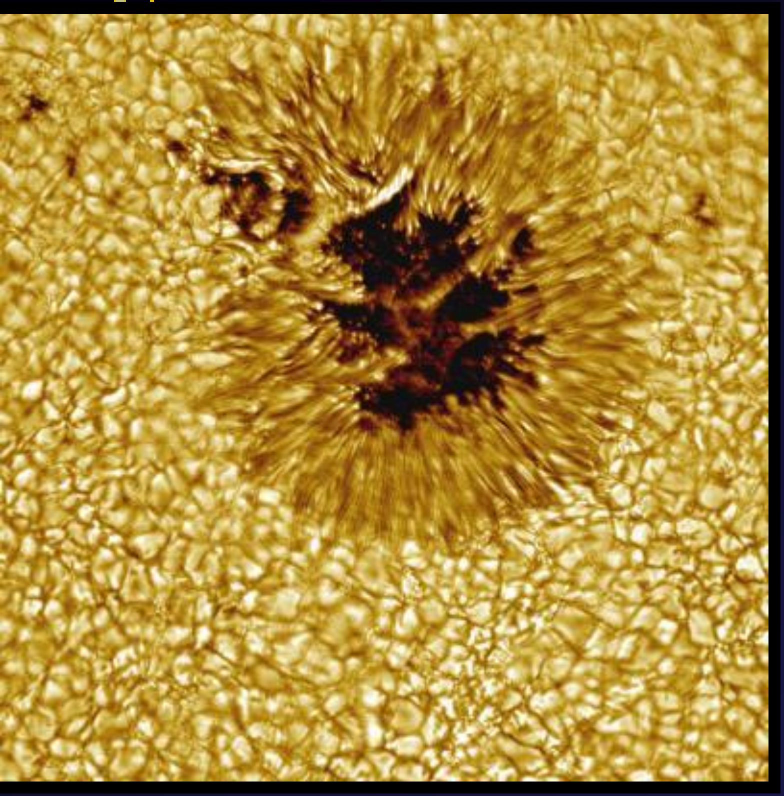


Dark umbral cores observed

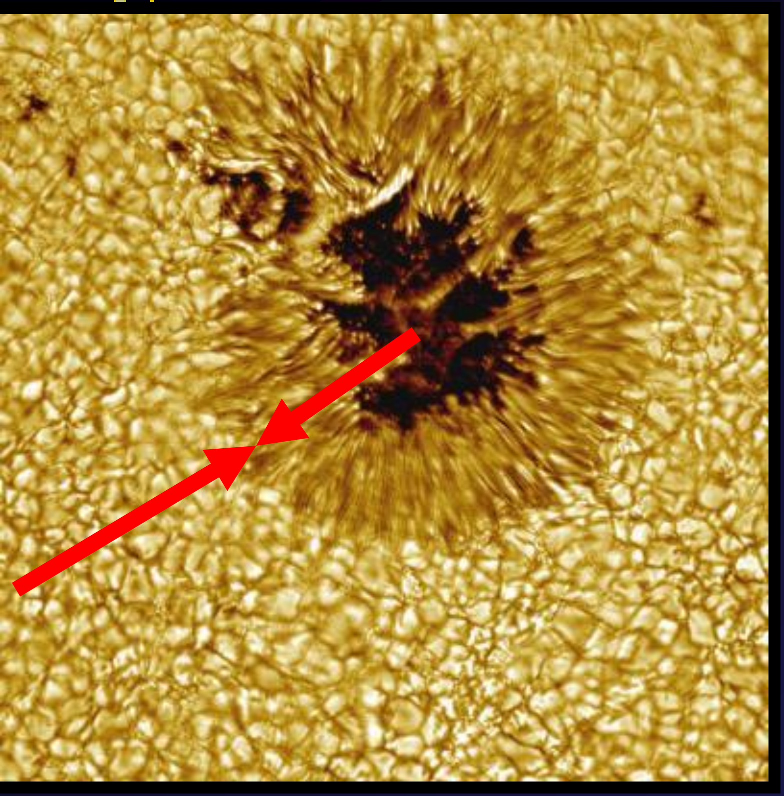





Max B [Gauss]
3500
3000
2500
2000
1500
Sunspots
No Sunspots
2000
2005
2010
2015
2020
2025
Year



- Magnetostatics can be used to describe horizontal pressure balance between spot and surrounding solar photosphere.



- Magnetostatics can be used to describe horizontal pressure balance between spot and surrounding solar photosphere.

$P_p = nkT_p$

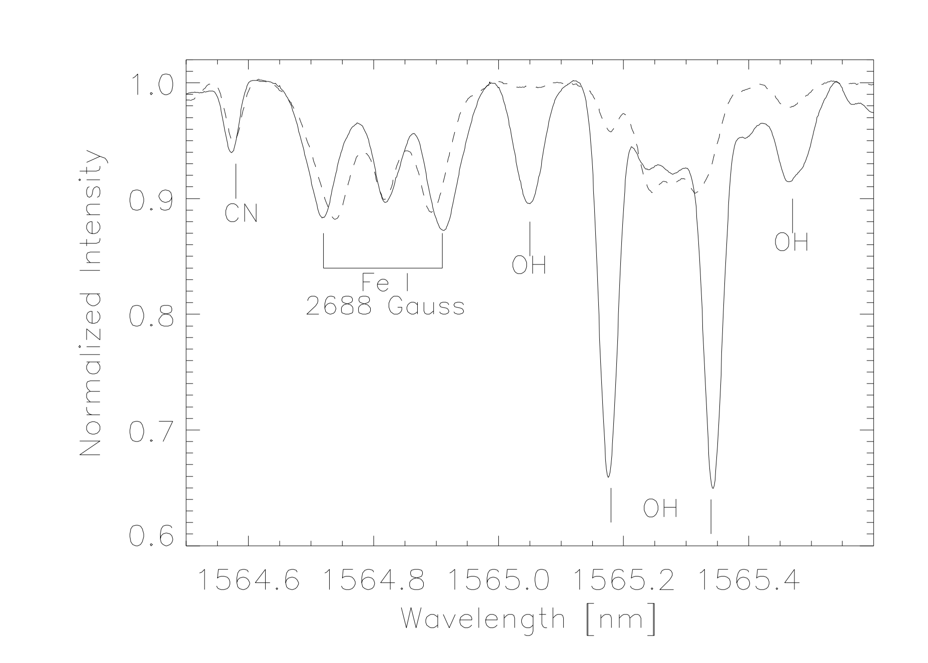
$P_s = nkT_s$ + magnetic pressure

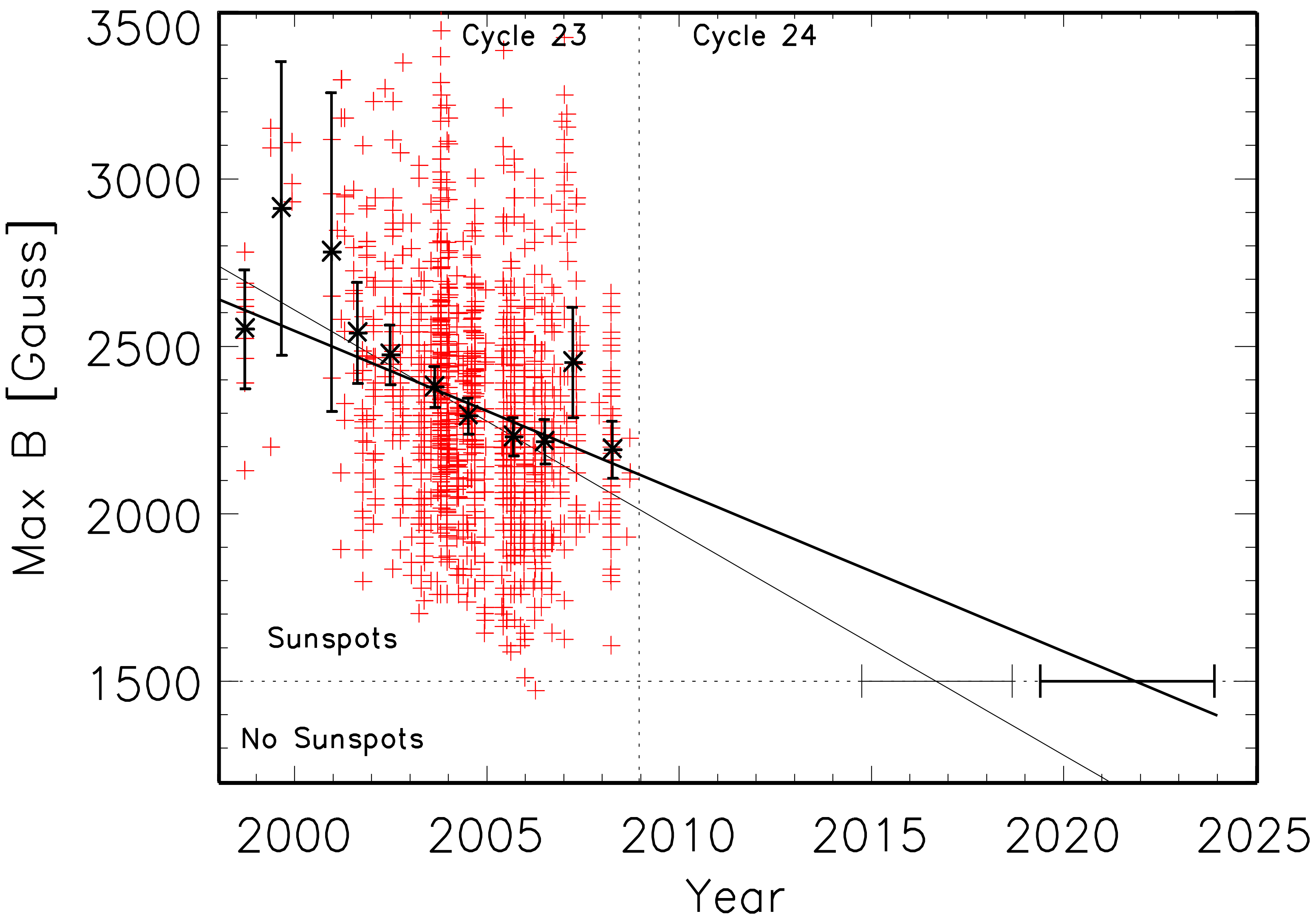
$$\frac{1}{8\pi}\left(B_z^2(r) + F_c(r)\right) = nk\left(T_p - T_s(r)\right)$$

Jaeggli 2009

- If sunspot magnetic fields changed, and the solar photosphere remained constant, then the sunspot temperatures should also change: this would impact the sunspot intensities, and the abundance of molecules.

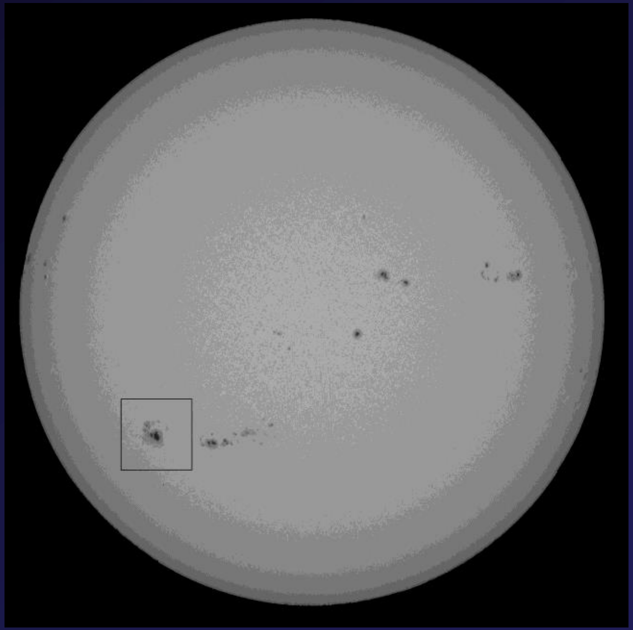
Solid: 18 Sep 98, $I = .55\ I_{qs}$
Dashed: 27 Dec 05, $I = .78\ I_{qs}$





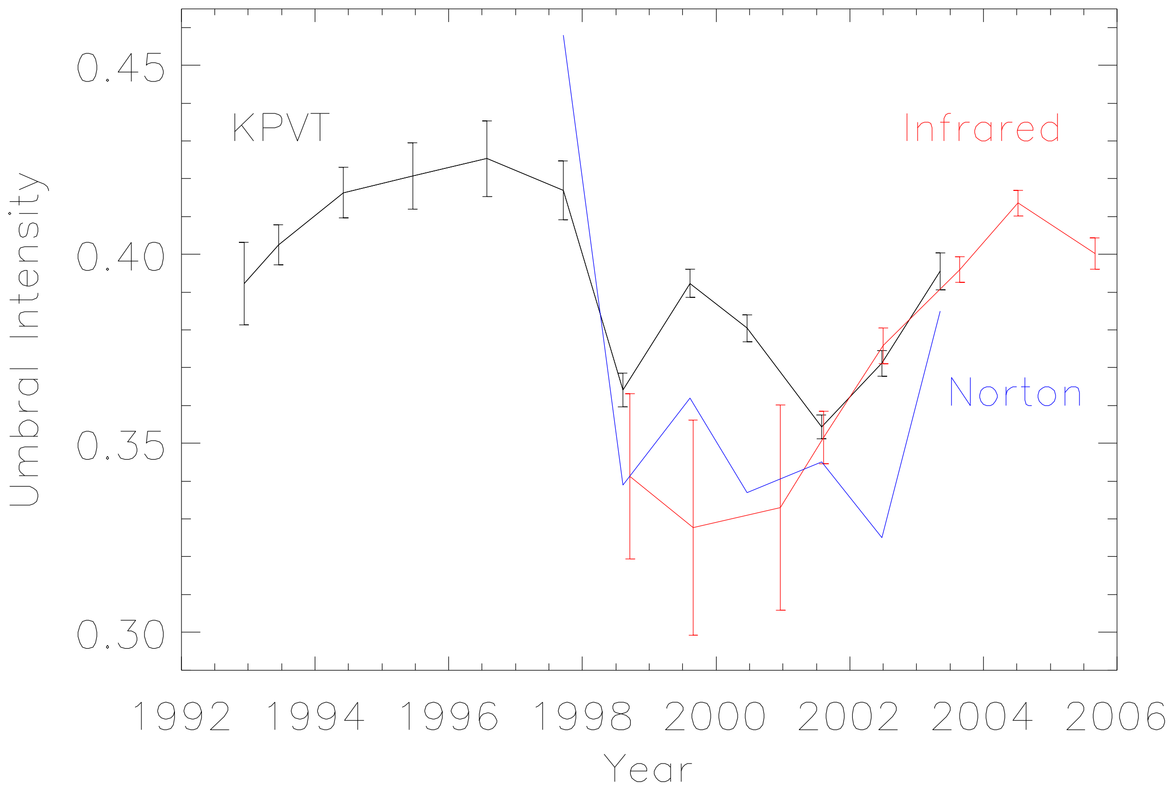
Cycle 23
Cycle 24
Sunspots
No Sunspots
Max B [Gauss]
3500
3000
2500
2000
1500
2000
2005
2010
2015
2020
2025
Year

KPVT data archive



First work: 4000 spots: $I_{min,}N_{umbra}$

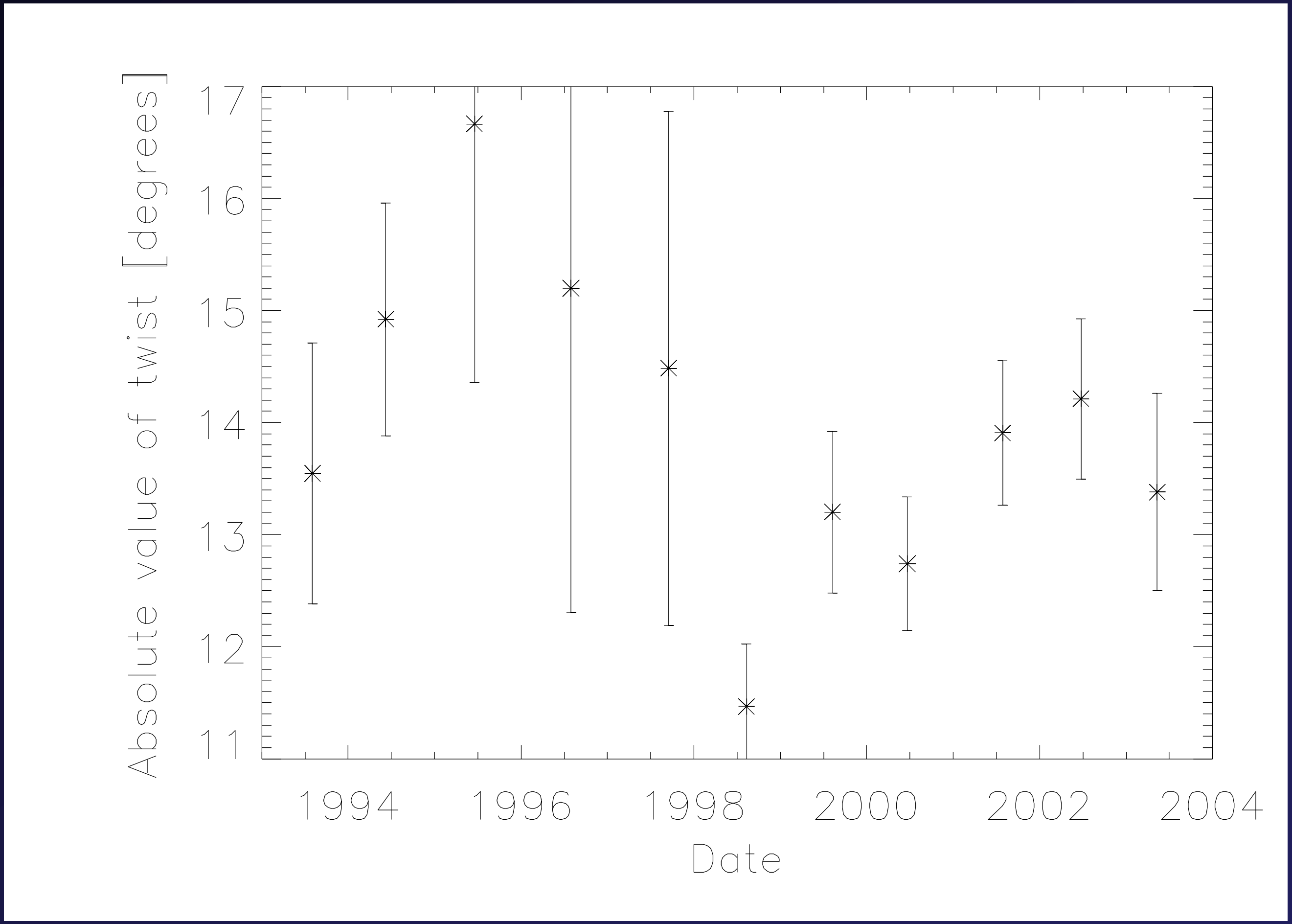
Current work: 13,000 spots, I_{min}, N_{umbra}, Magnetic Field

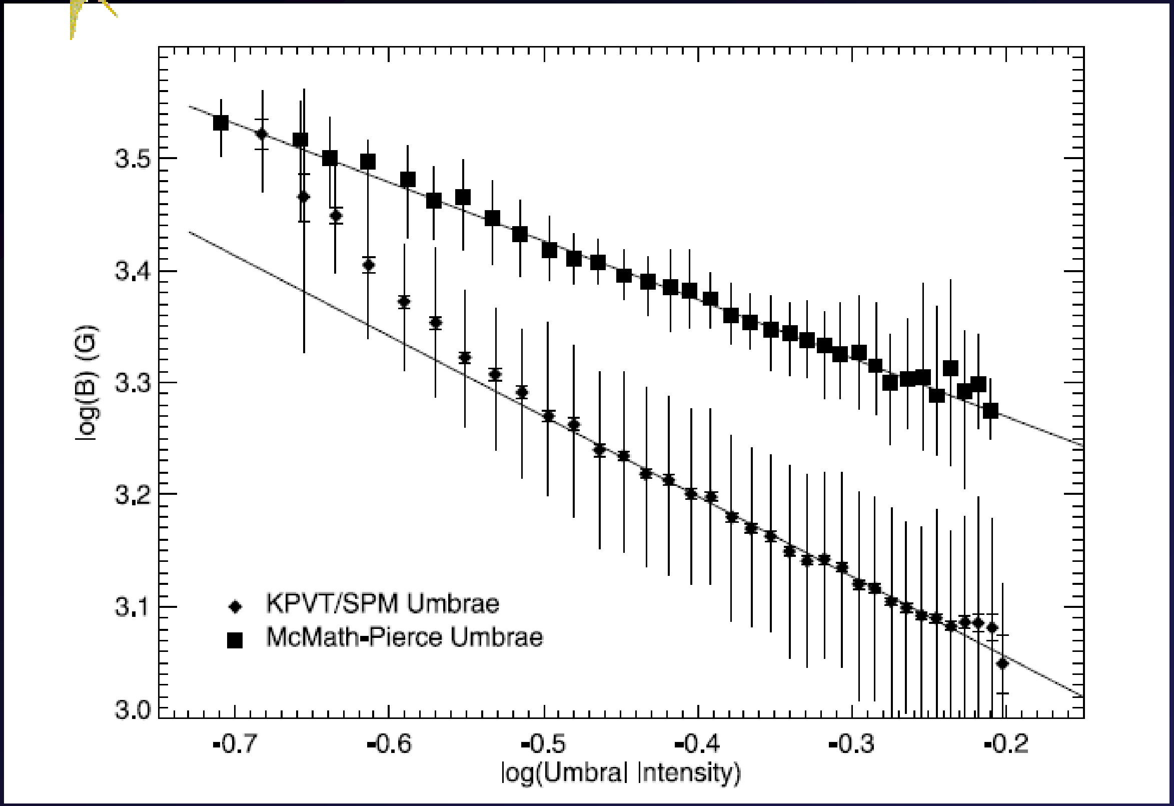


Although variations in Intensity were seen, no radius change was seen in this sample from the archive.

This was in conflict with well-known empirical B vs radius correlations.

$$\frac{1}{8\pi}(B_z^2(r) + F_c(r)) = nk(T_p - T_s(r))$$





log(B) (G)
3.5
3.4
3.3
3.2
3.1
3.0
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
log(Umbral Intensity)
KPVT/SPM Umbrae
McMath-Pierce Umbrae

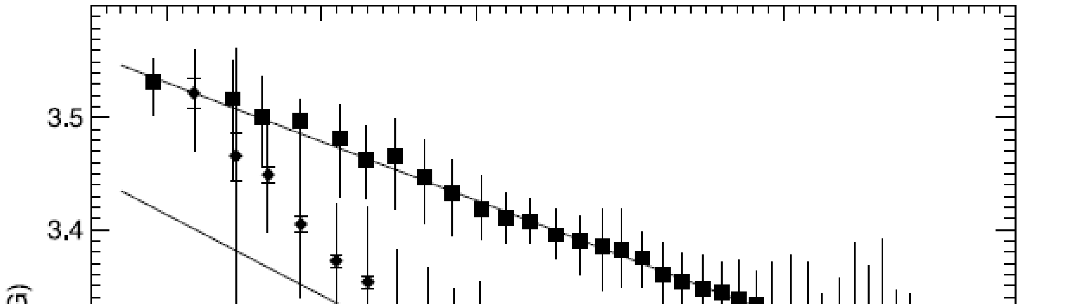


Table 2 Magnetic field *versus* intensity power-law fit parameters.

Cycle Phase	N spots	Const.	Exponent	χ^2/N
KPVT/SPM Data				
Falling (March 93 – September 96)	884	855 ± 20.1	-0.680 ± 0.029	0.0319
Rising (October 96 – March 01)	3832	824 ± 10.0	-0.731 ± 0.015	0.0096
Falling (April 01 – September 03)	3360	797 ± 9.9	-0.711 ± 0.015	0.0090
Minimum (1995 – 1997)	435	858 ± 29.4	-0.703 ± 0.042	0.0909
Maximum (2000 – 2002)	4268	813 ± 8.9	-0.710 ± 0.013	0.0064
All data (1993 – 2003)	8076	817 ± 6.8	-0.716 ± 0.010	0.0042
McMath-Pierce IR Data				
Falling (April 01 – June 05)	698	1465 ± 22.6	-0.520 ± 0.014	0.0291
Maximum (2000 – 2002)	156	1317 ± 144	-0.612 ± 0.083	0.0364
Minimum (2005 – 2007)	340	1467 ± 77.6	-0.522 ± 0.071	0.0084
All data (April 90 – March 08)	1084	1463 ± 13.3	-0.523 ± 0.009	0.0270

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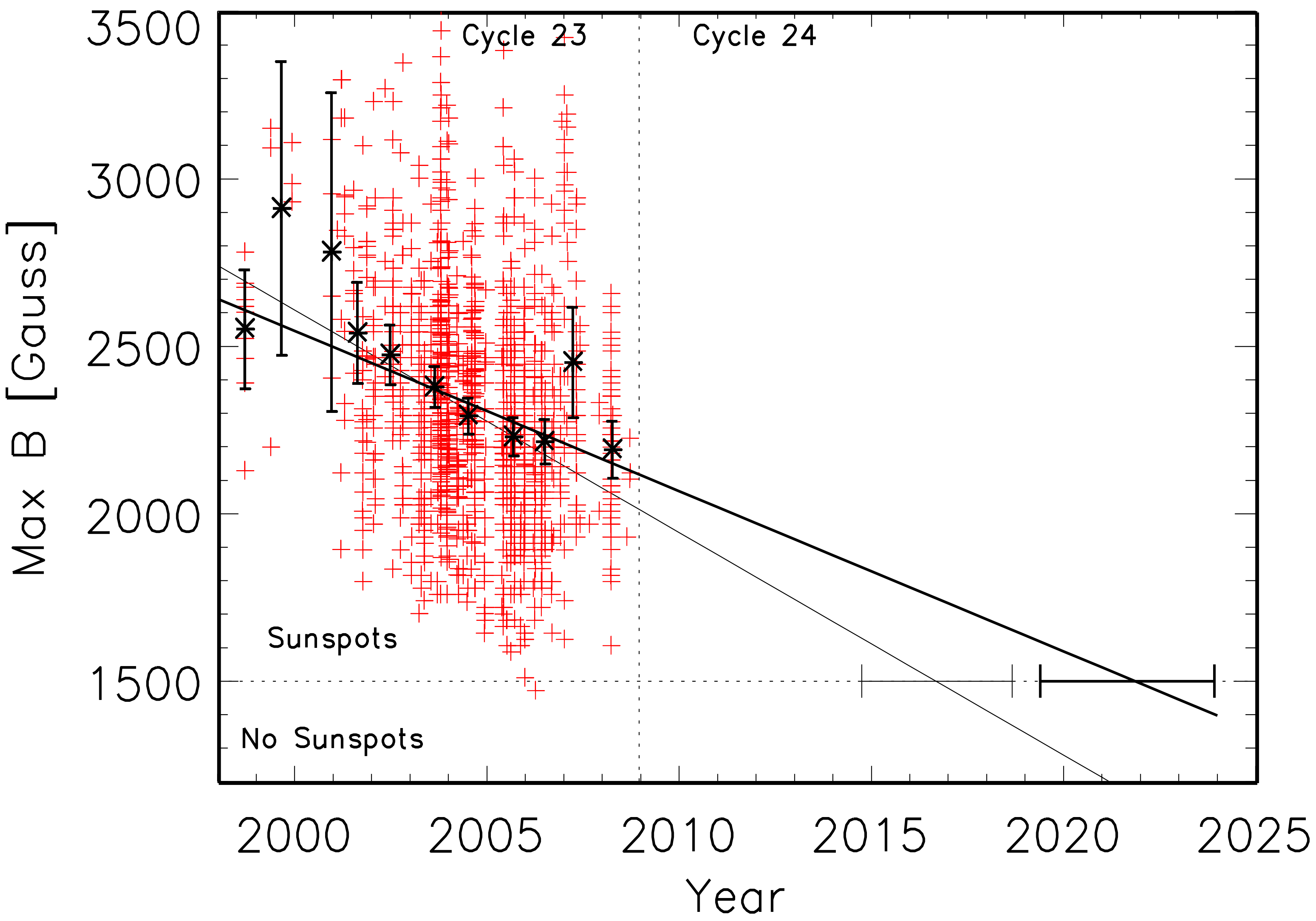
- Only small changes were seen in I and B vs. time in the larger sample, but importantly the change seen were fully accounted for by changes in the radius
- Conclusion: the fundamental structure of a sunspot doesn’t change through the cycle… the only support for the IR measurements is a slightly changing mean radius.



Max B [Gauss]
3500
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Cycle 23
Cycle 24
Sunspots
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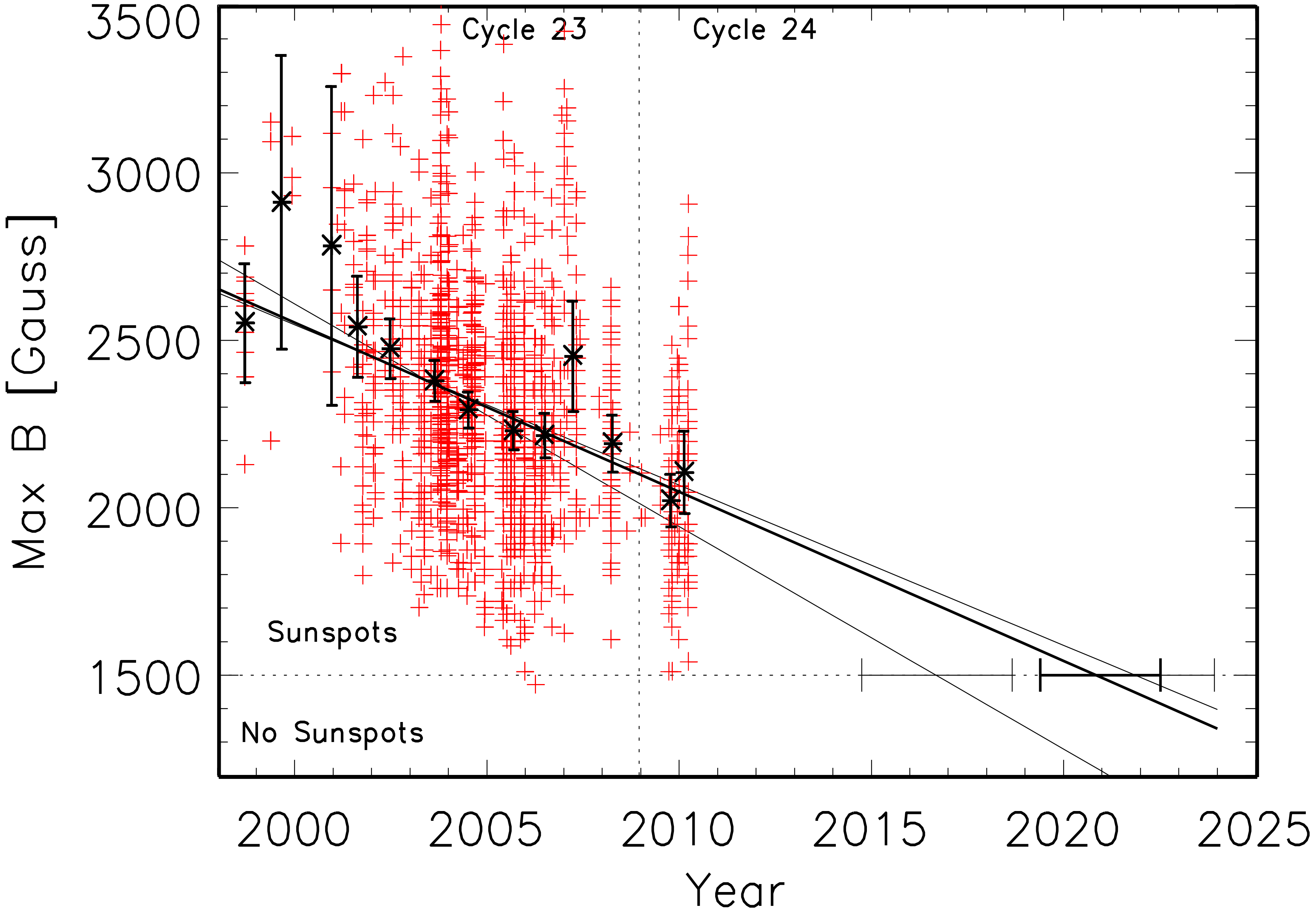
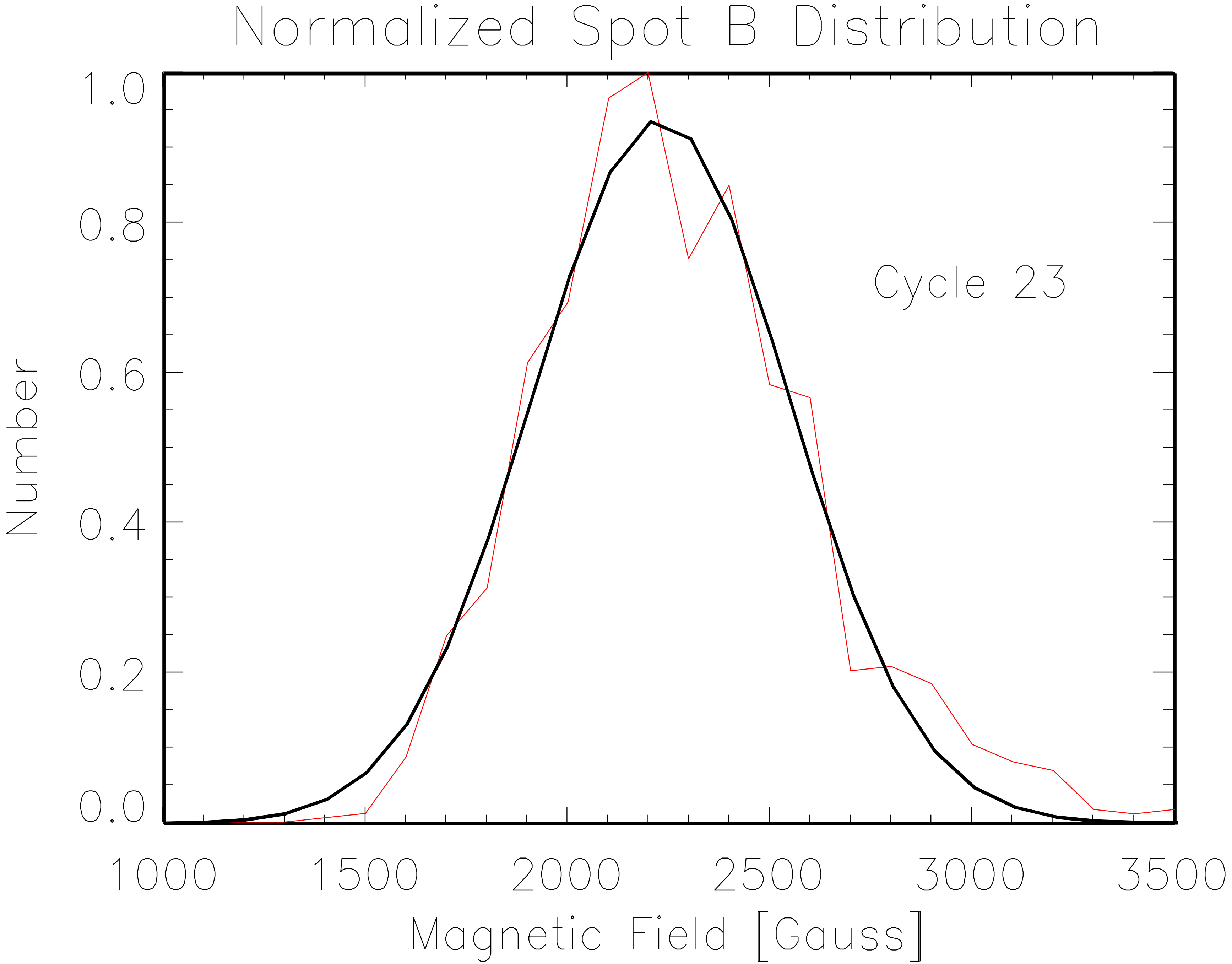
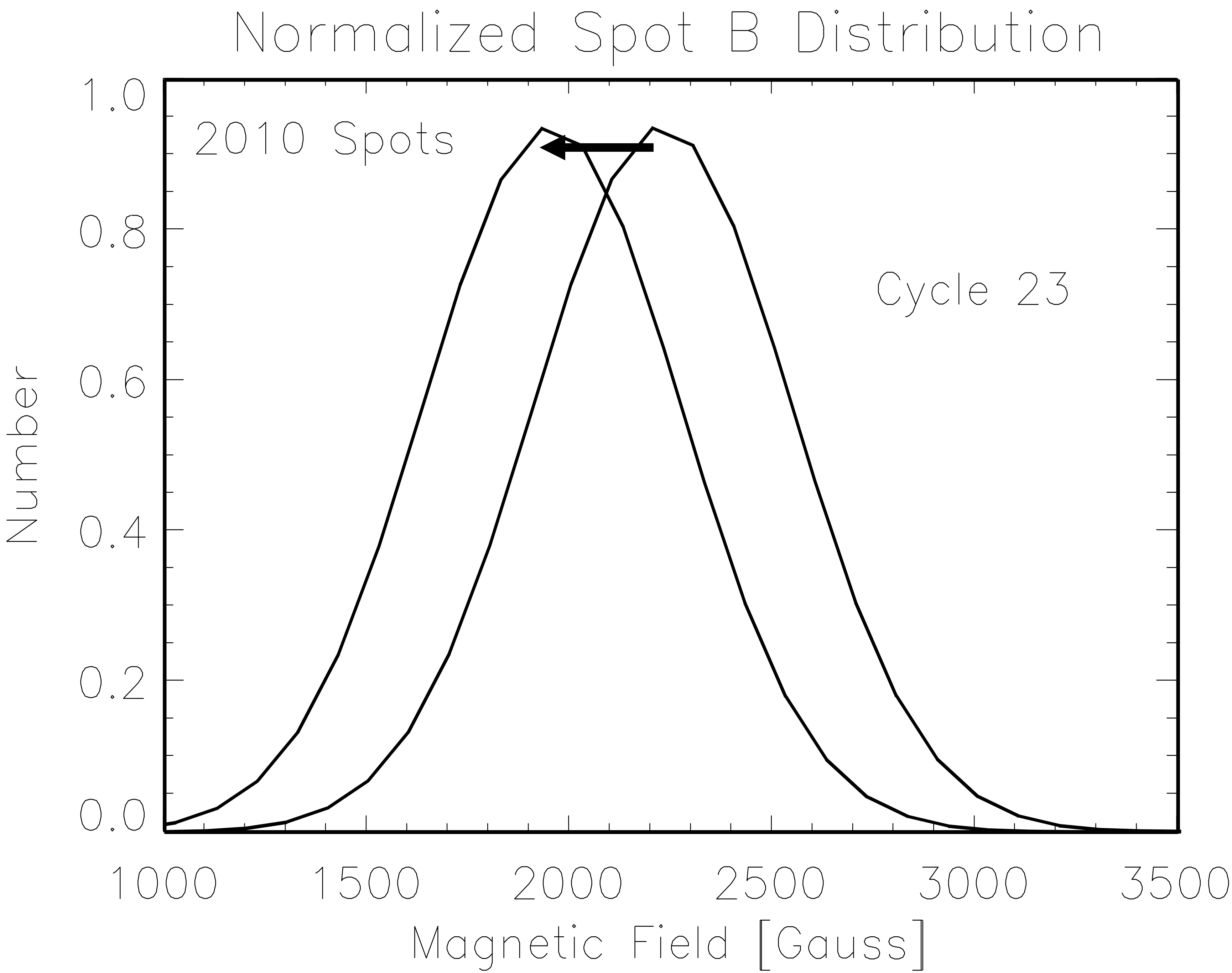
2025
Year

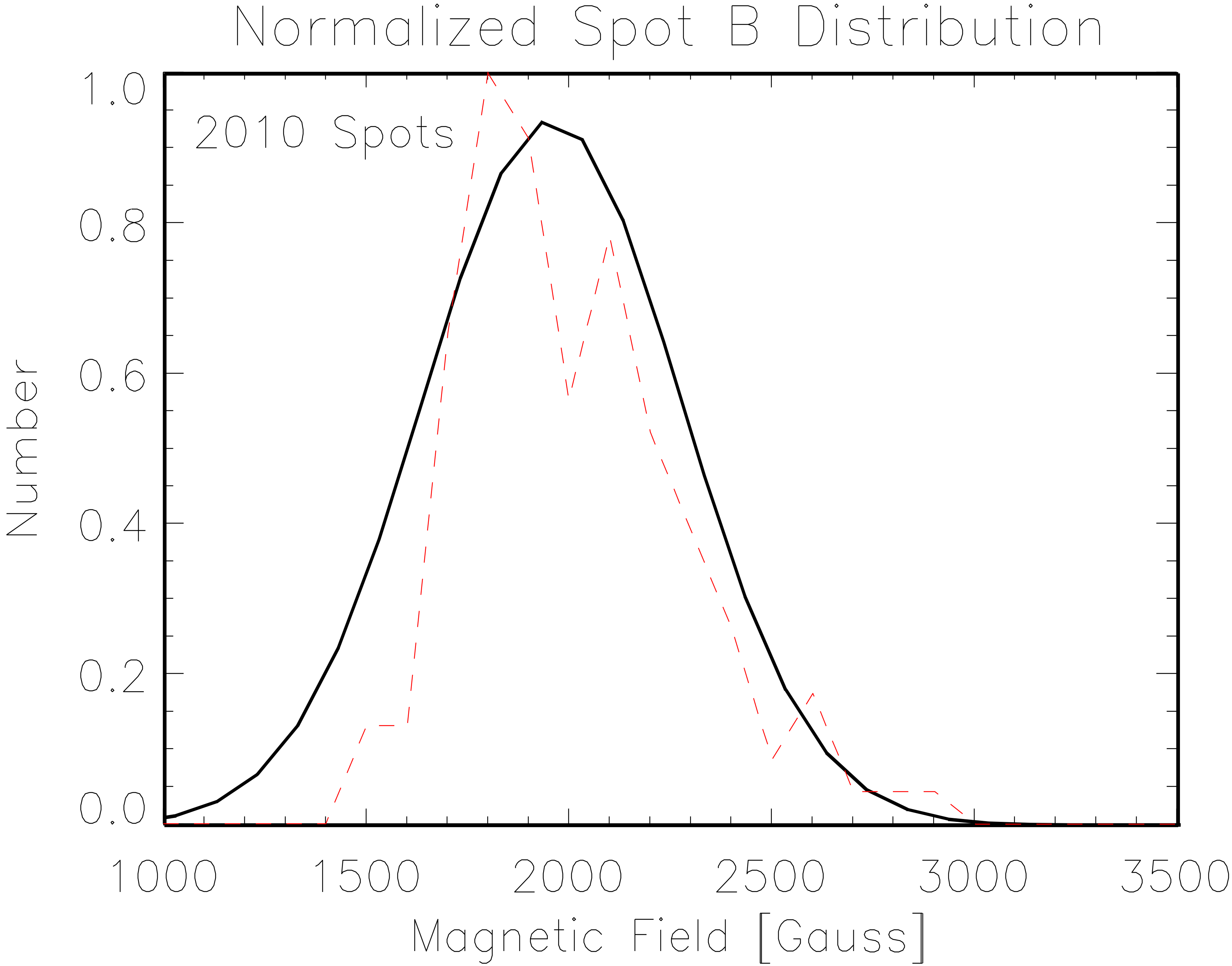


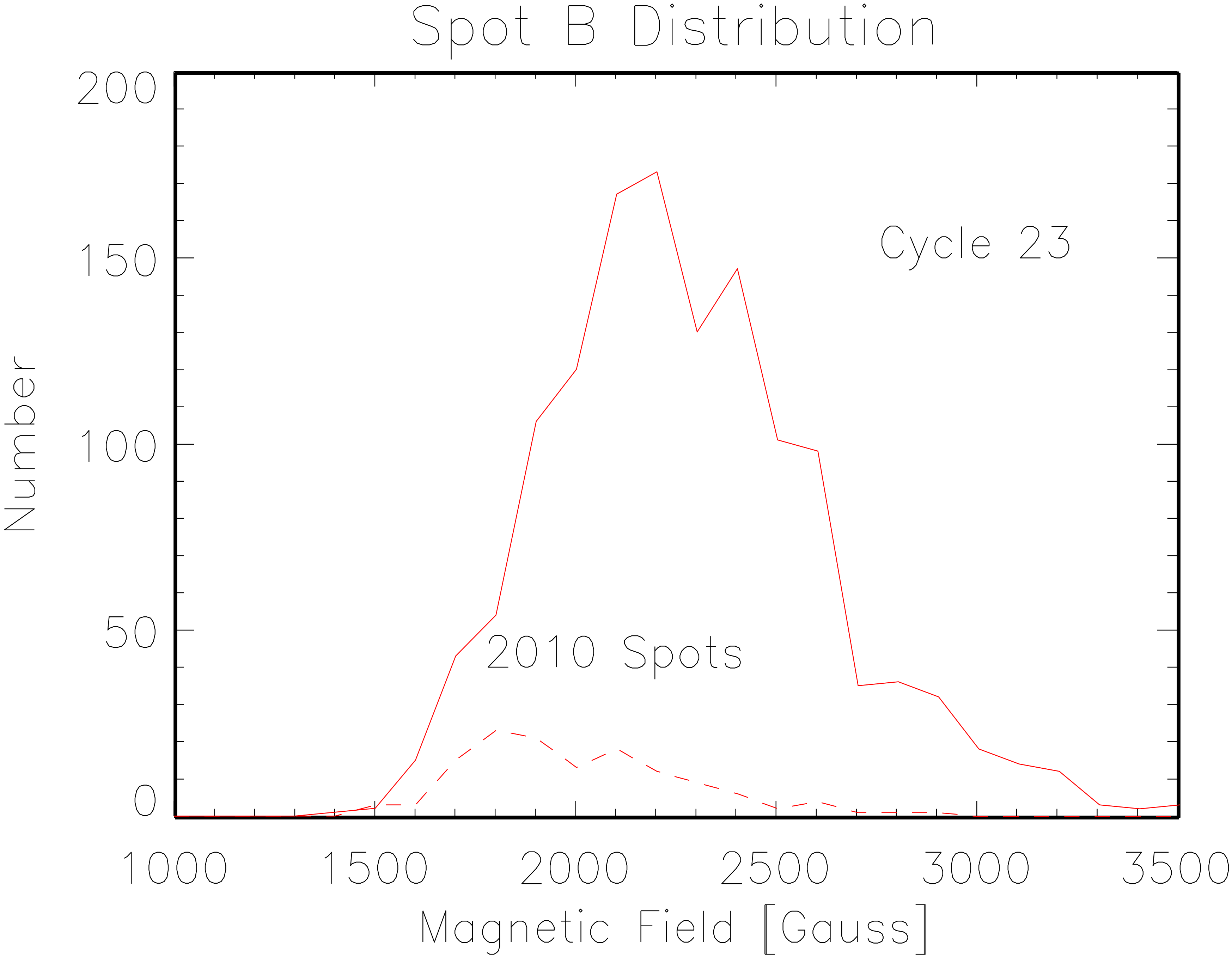
Cycle 23
Cycle 24
Sunspots
No Sunspots
Max B [Gauss]
Year
3500
3000
2500
2000
1500
2000
2005
2010
2015
2020
2025



Normalized Spot B Distribution
Cycle 23
Number
Magnetic Field [Gauss]
1.0
0.8
0.6
0.4
0.2
0.0
1000
1500
2000
2500
3000
3500

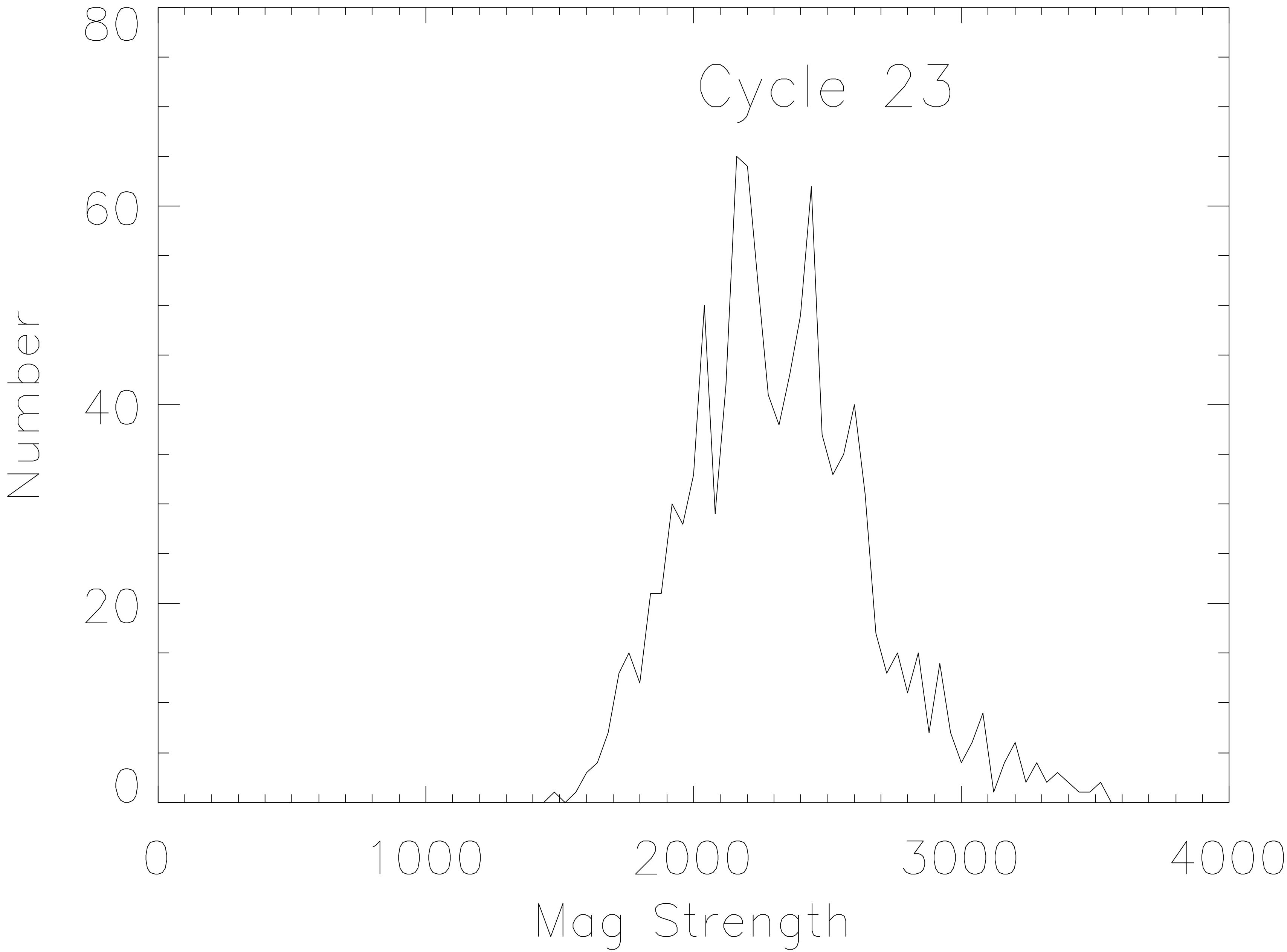

Normalized Spot B Distribution
2010 Spots
Cycle 23
Number
Magnetic Field [Gauss]
0.0
0.2
0.4
0.6
0.8
1.0
1000
1500
2000
2500
3000
3500


Normalized Spot B Distribution
2010 Spots
Number
Magnetic Field [Gauss]
0.0
0.2
0.4
0.6
0.8
1.0
1000
1500
2000
2500
3000
3500

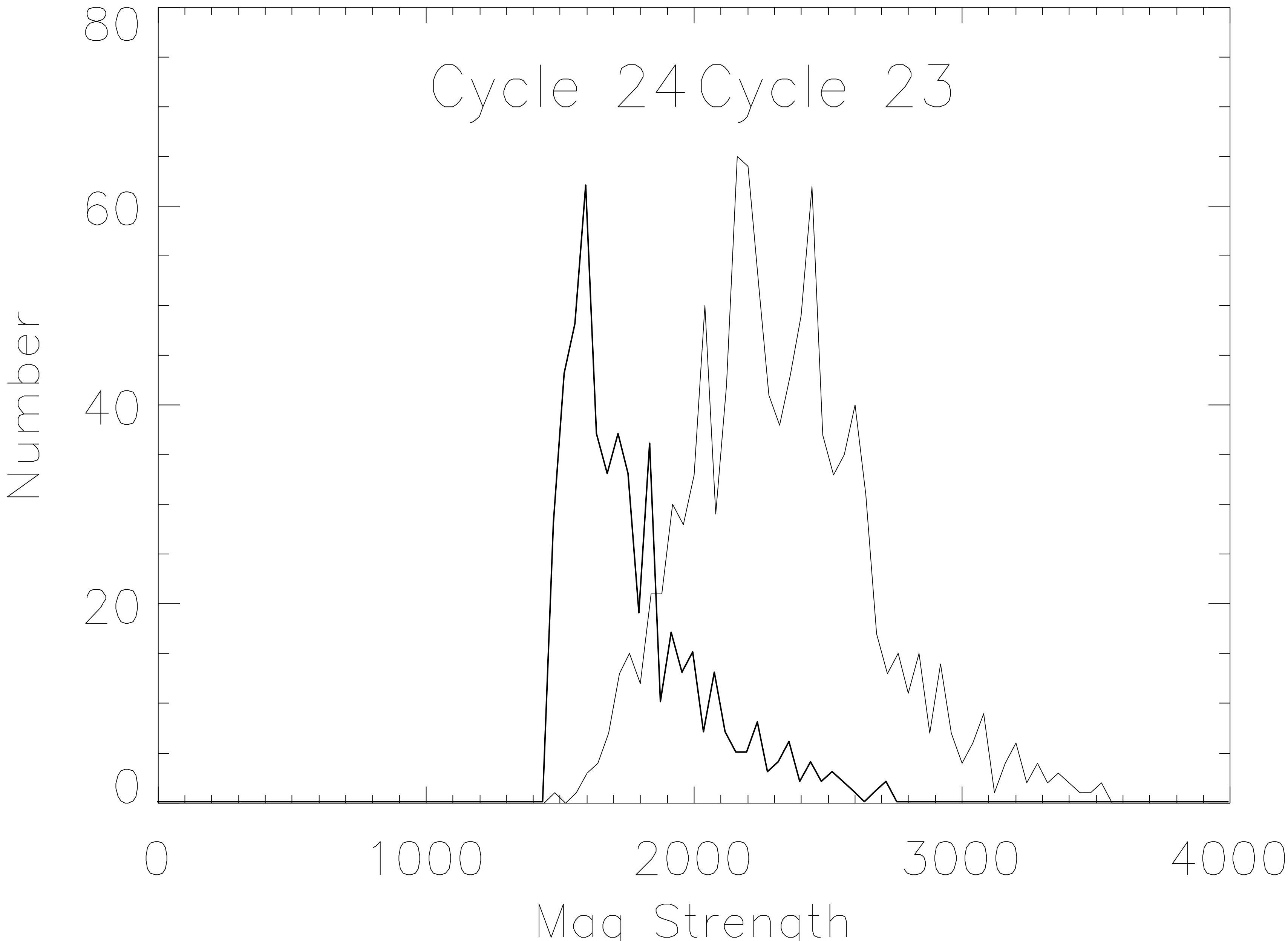

Spot B Distribution
200
150
100
50
0
Number
Cycle 23
2010 Spots
1000
1500
2000
2500
3000
3500
Magnetic Field [Gauss]

Conservative interpretation

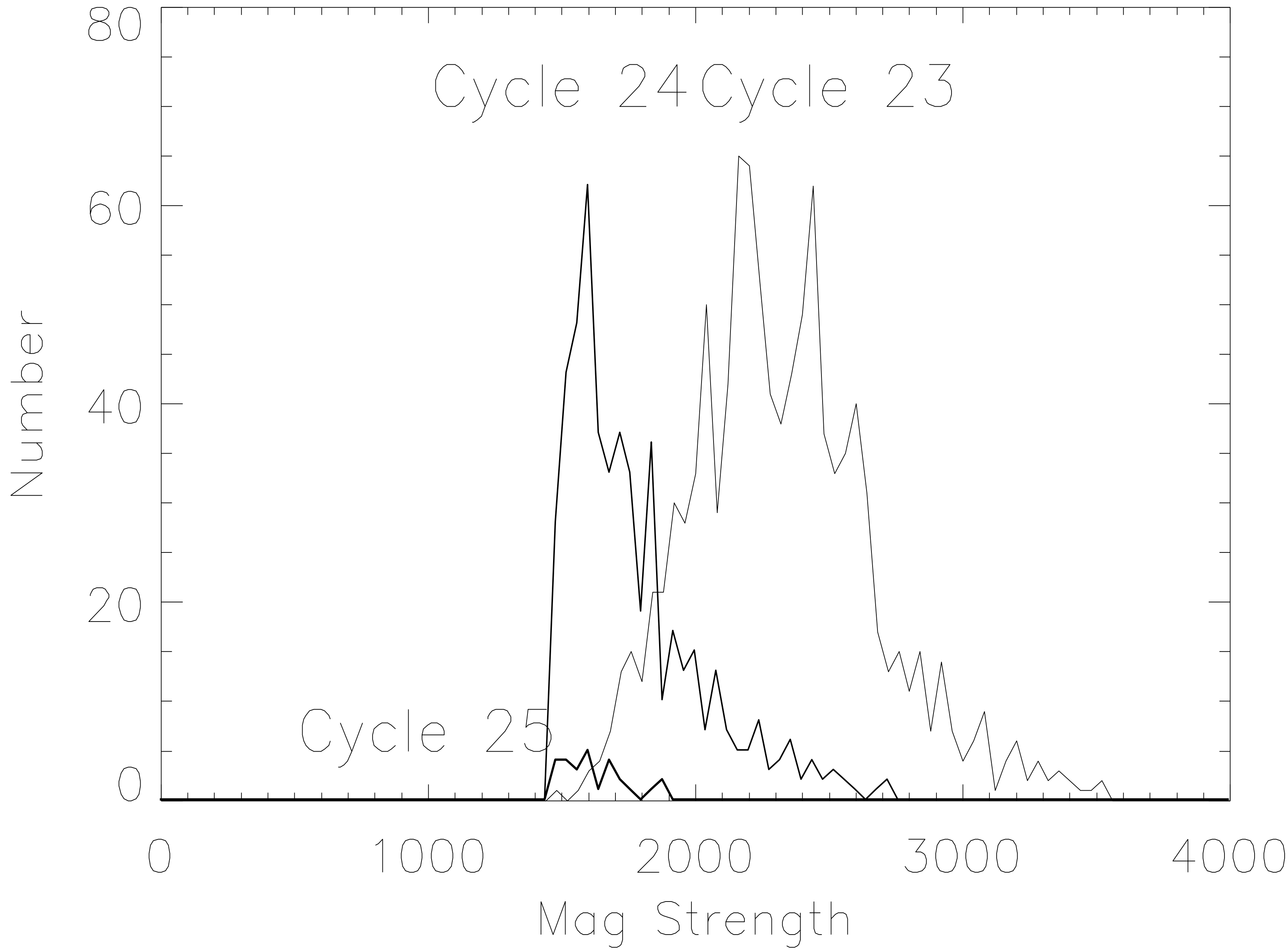
- The distribution of the sunspot magnetic fields during the declining phase of the sunspot cycle are different from the fields during the rise phase of the sunspot cycle.



Cycle 23
Number
Mag Strength
0
20
40
60
80
0
1000
2000
3000
4000



Cycle 24
Cycle 23
Number
Mag Strength
0
20
40
60
80
0
1000
2000
3000
4000



Cycle 24
Cycle 23
Cycle 25
Number
Mag Strength
0
20
40
60
80
0
1000
2000
3000
4000

…possible implication

- Making three assumptions:
  - Livingston's cycle 23 IR measurements represent the "true" sunspot magnetic field probability distribution function
  - There is a real physical cut-off so that no sunspots form with maximum magnetic fields less than 1500G
  - The decrease in the mean field continues
- …then Solar cycle 24 will peak with a spot number of 57, and cycle 25 will peak with a spot number of 3.

Critical observations

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- IR measurements of the true B field strength in sunspots must be made in the next sunspot cycle
  - Will umbrae with B>3000G return?
  - Will most cycle 24 spots have B<2000G?
- Efforts are underway to cross-calibrate Livingston's observations with 2-D maps of the IR sunspot magnetic fields from the NAC.