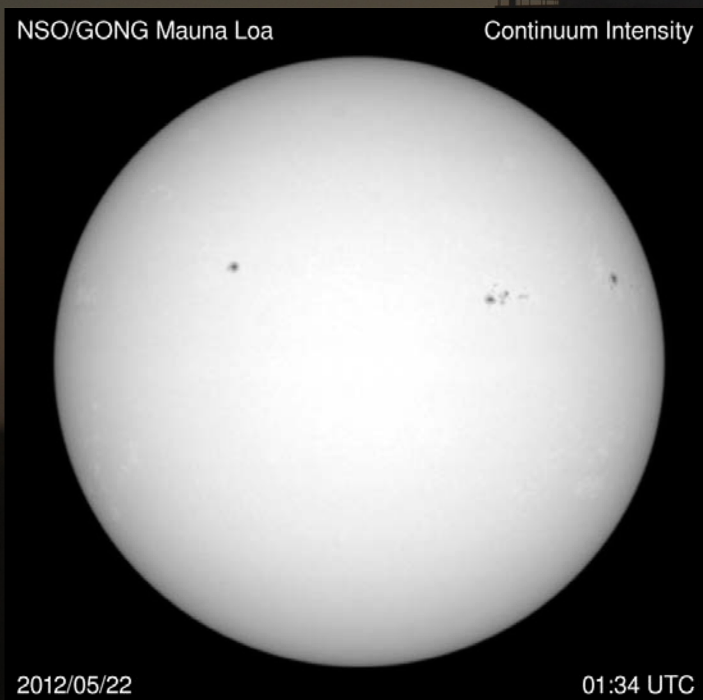
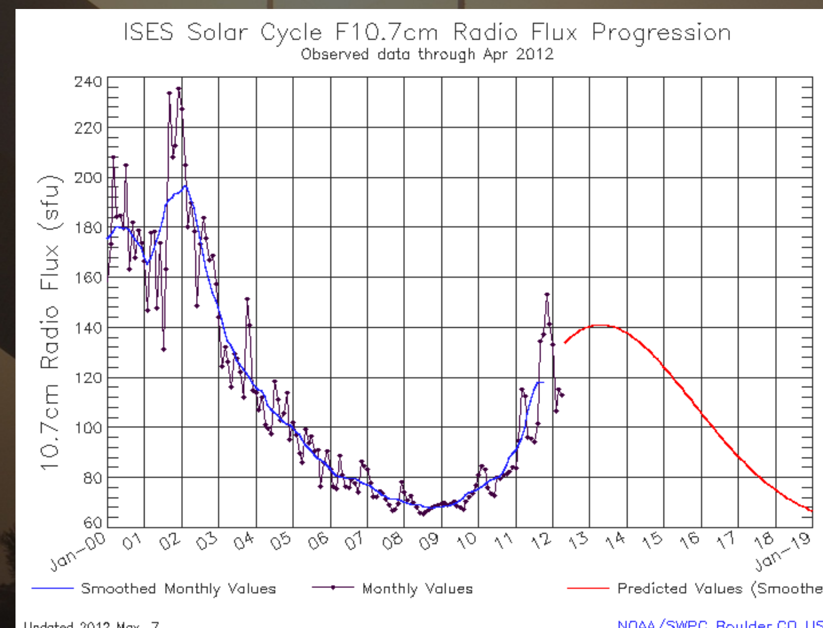
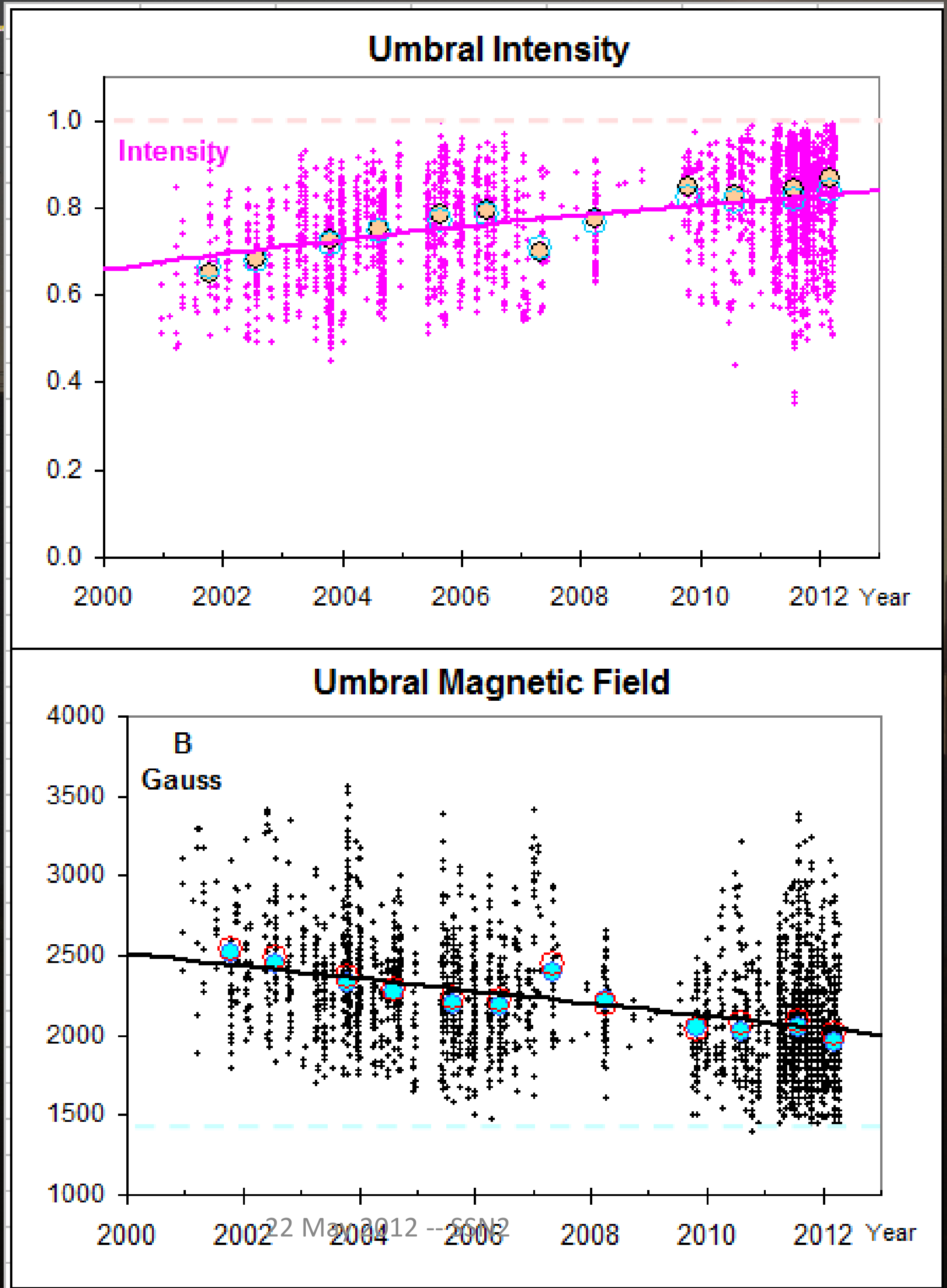
Changing Distribution of Umbral IR Magnetic Field Strengths and Application to F10.7





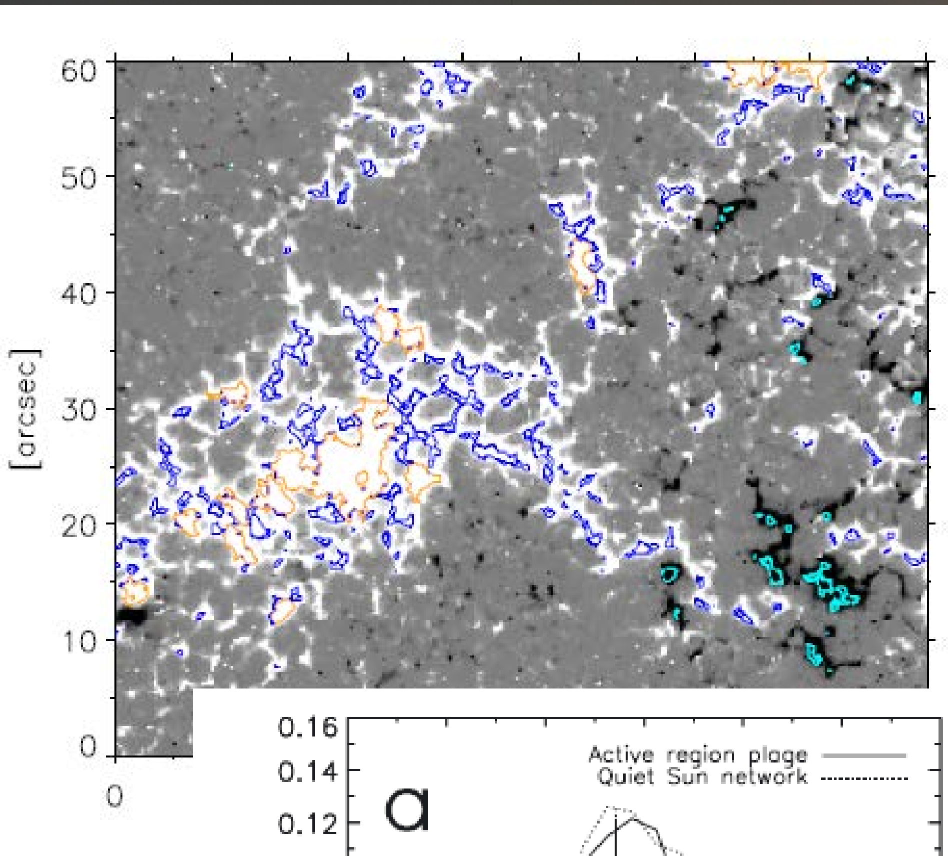
W Livingston, L Svalgaard

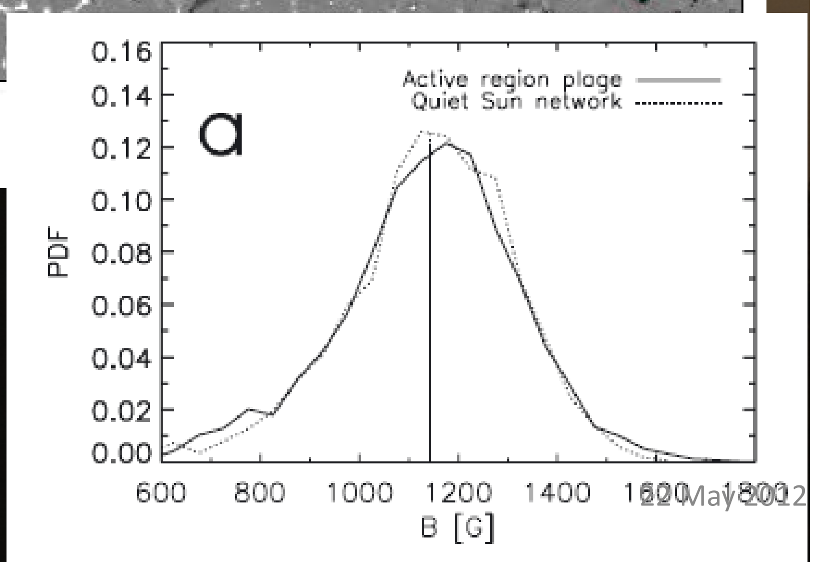


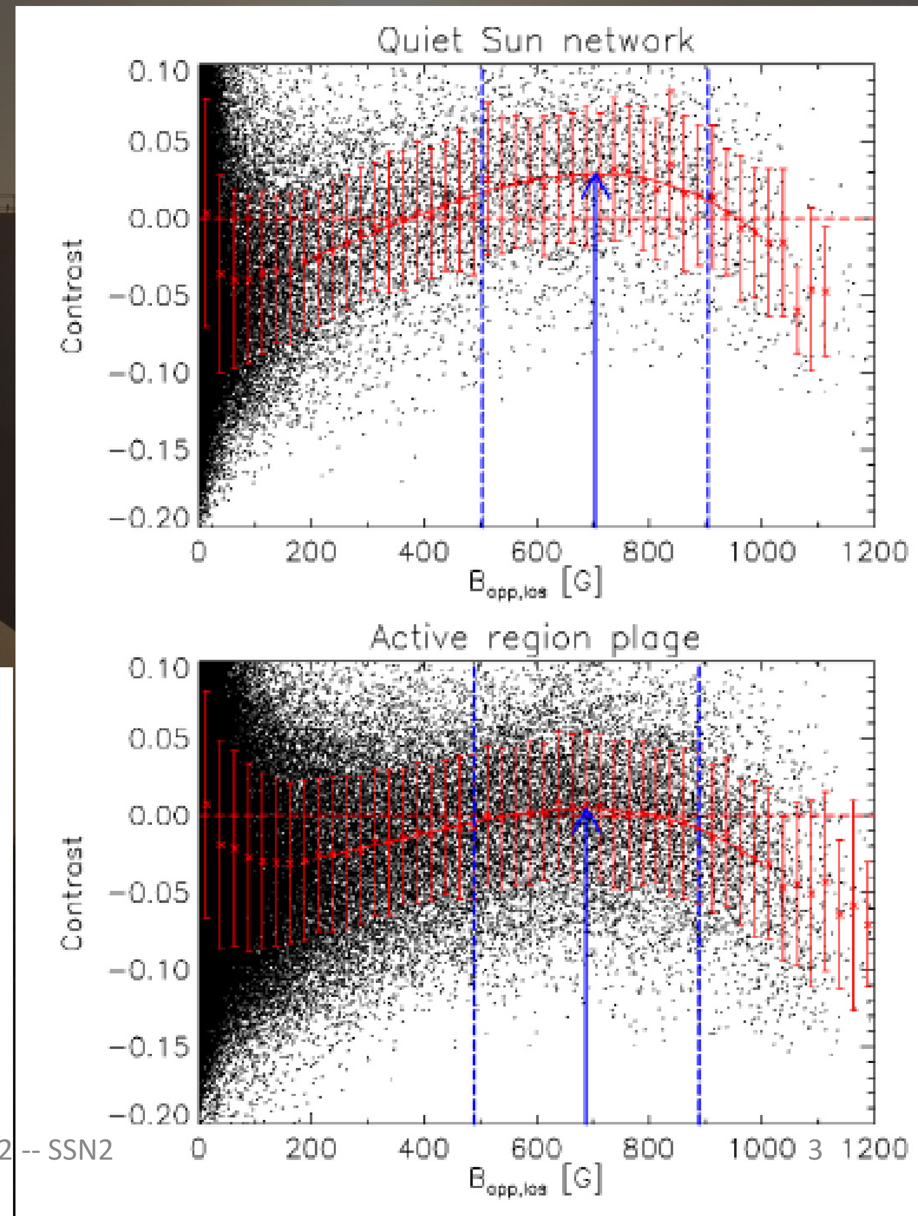
Umbral Intensity
Intensity
1.0
0.8
0.6
0.4
0.2
0.0
2000
2002
2004
2006
2008
2010
2012
Year
Umbral Magnetic Field
B
Gauss
4000
3500
3000
2500
2000
1500
1000
2000
2002
2004
2006
2008
2010
2012
Year

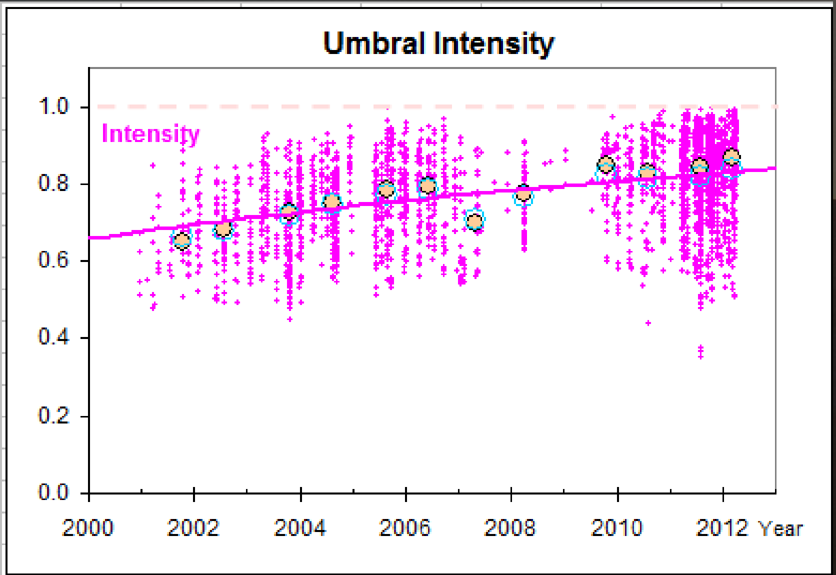
Are fields > 1500G bright anywhere ?

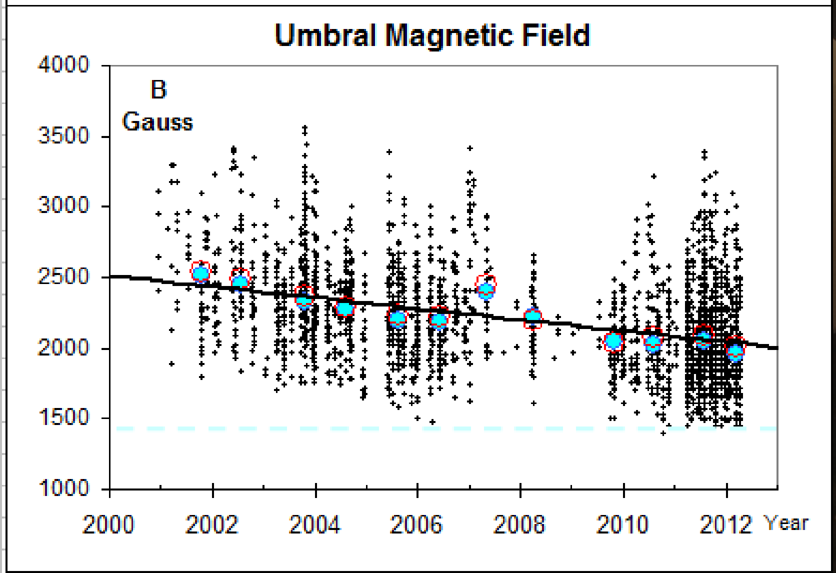
Kobel, Solanki & Borrero (2011) studied quiet Sun using Hinode

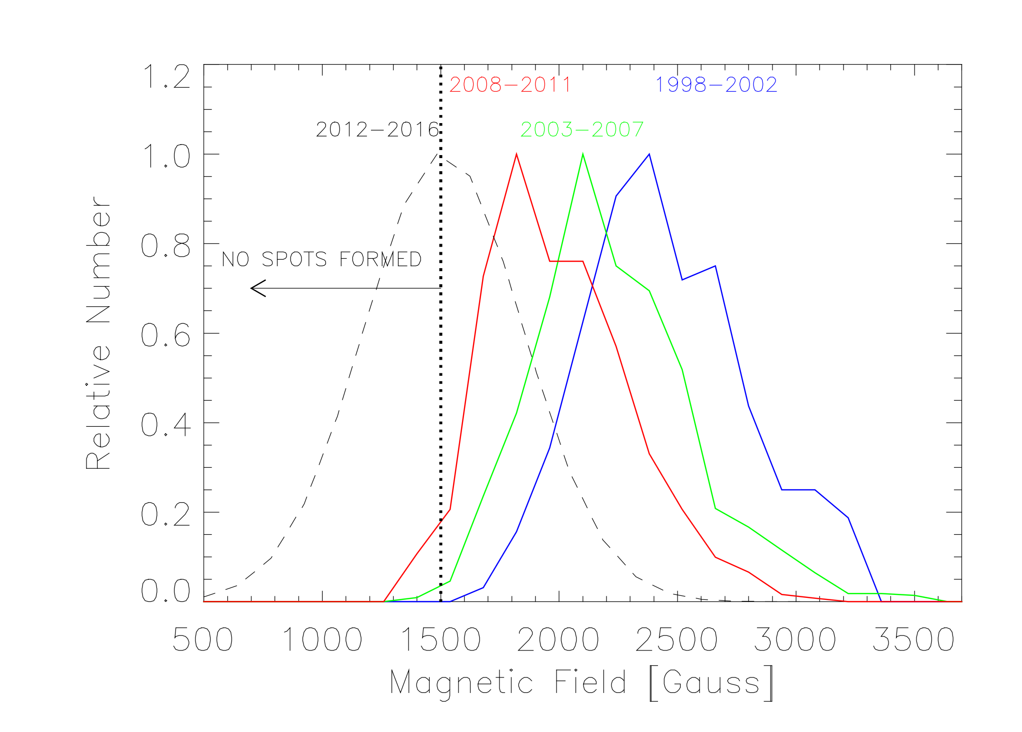


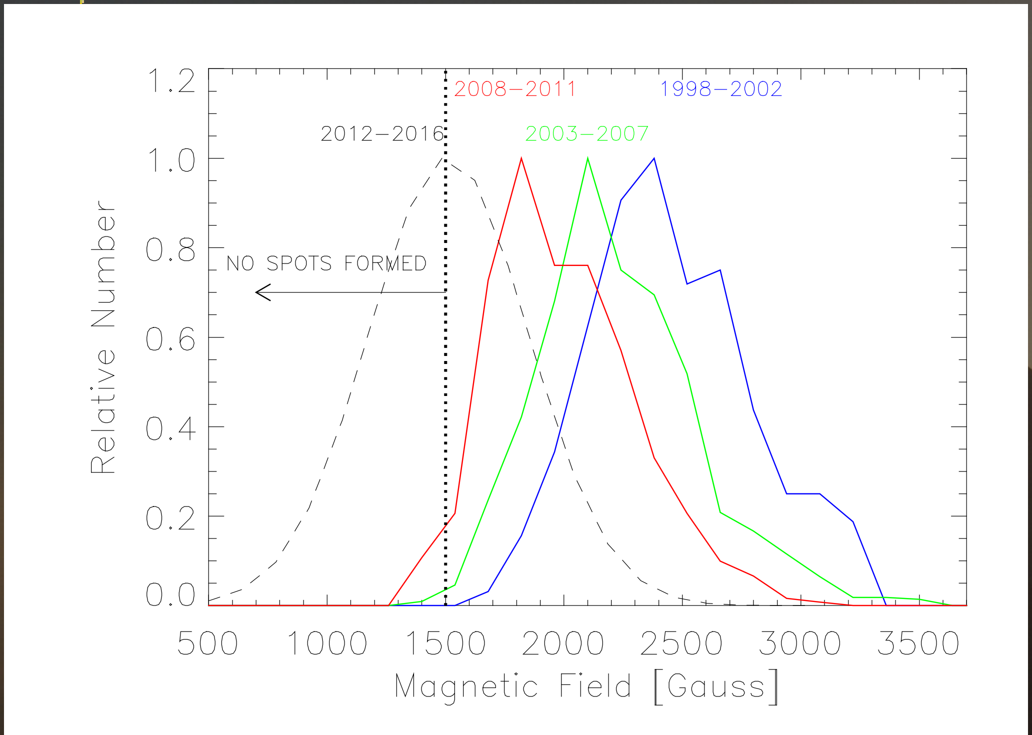





Umbral Intensity
Intensity
1.0
0.8
0.6
0.4
0.2
0.0
2000
2002
2004
2006
2008
2010
2012 Year


Umbral Magnetic Field
B
Gauss
4000
3500
3000
2500
2000
1500
1000
2000
2002
2004
2006
2008
2010
2012 Year


2008–2011
1998–2002
2012–2016
2003–2007
NO SPOTS FORMED
Relative Number
1.2
1.0
0.8
0.6
0.4
0.2
0.0
500
1000
1500
2000
2500
3000
3500
Magnetic Field [Gauss]



Observed umbral magnetic field distributions

dB/dt = -46 +/- 6 Gauss / yr

Gaussian Fits to Distributions:

Date	Mean	Width
1998-2002	2436 +/- 26	323 +/- 20
2003-2007	2204 +/- 10	296 +/- 7
2008-2011	1999 +/- 13	276 +/- 9

Many studies of sunspot magnetic fields which use visible spectral lines have found a solar cycle dependence of the average magnetic field… dating back to Albregtsen and Maltby (1981), and including Penn and MacDonald (2007).

Some studies using visible spectral measurements find no change, including Mathew et al. (2007) and Schad and Penn (2010).

A recent study from Rezaie, Beck & Schmidt (2012) using some (99) infrared measurements combined with “visible measurements” finds a solar cycle change.

Rezaie, Beck & Schmidt

Table 1. Atomic properties of the observed spectral lines (Nave et al. 1994).

Line	λ (nm)	Exc pot (eV)	$\log(gf)$	g-effective
Fe I	1564.852	5.426	-0.669	3.00
Fe I	1089.630	3.071	-2.845	1.50
Si I	1082.709	4.954	0.363	1.50

Each data set consists of full Stokes profiles in magnetically sensitive infrared lines such as Fe I 1564.8 m, Fe I 1089.6 nm, or Si I 1082.7 nm. Table 1 summarizes the atomic parameters of the selected spectral lines. Out of the 231 maps, 99 were observed at 1.56 μm and 84 at 1.1 μm. The remaining 48 maps mainly come from the earliest observations with TIP-I and were taken in some uncommon wavelength ranges, often covering molecular lines. These data could therefore not be used without considerable effort. We thus only selected those observations in which one of the three spectral lines listed in Table 1 was recorded. That amounted to 183 full Stokes sunspot maps covering the descending phase of cycle no. 23 and the rise of cycle no. 24.

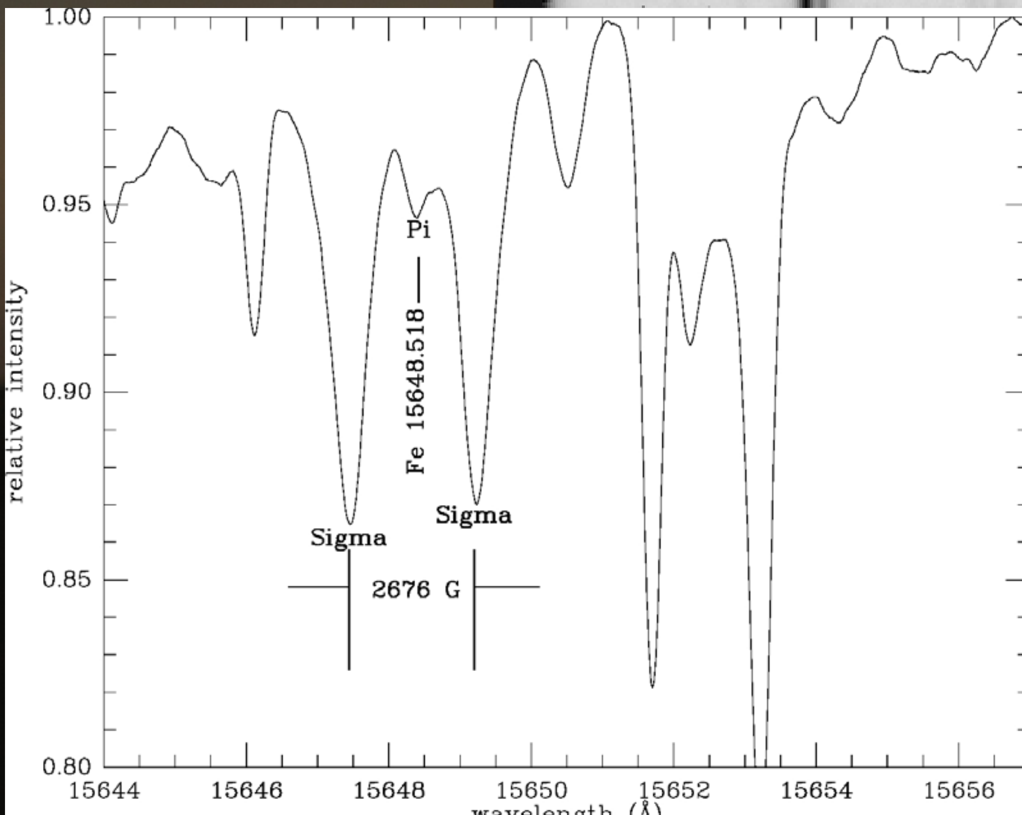
1565nm $g\lambda$ = 4695

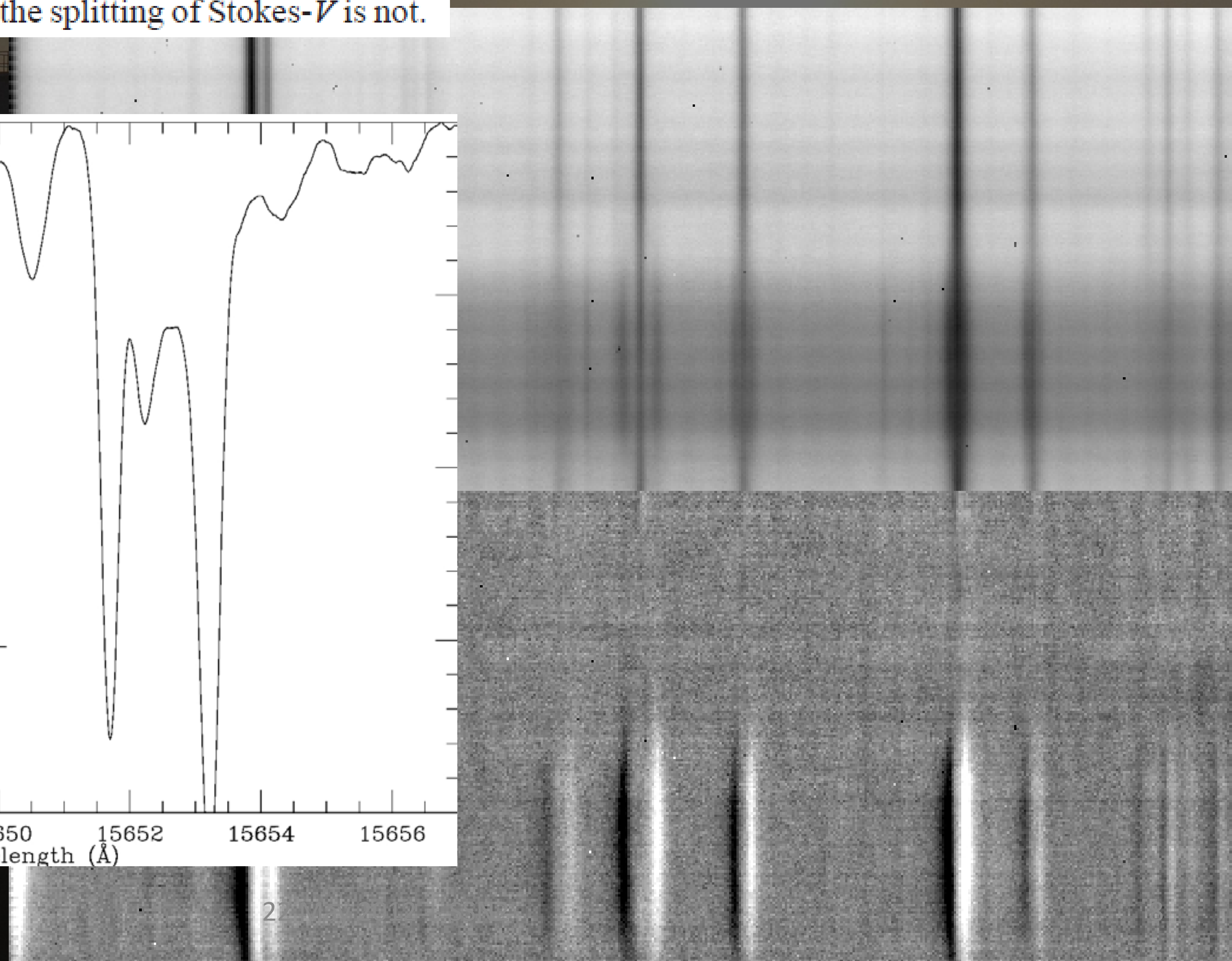
1090nm $g\lambda$ = 1635

1083nm $g\lambda$ = 1625

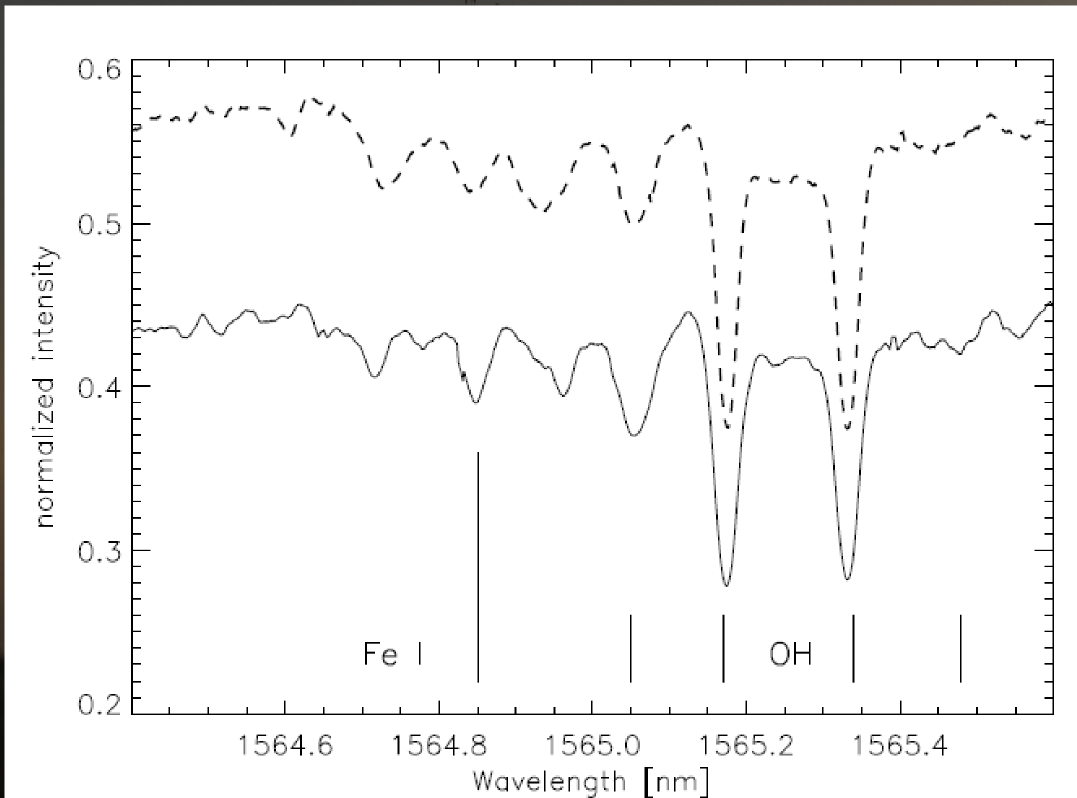
630nm $g\lambda$ = 1575

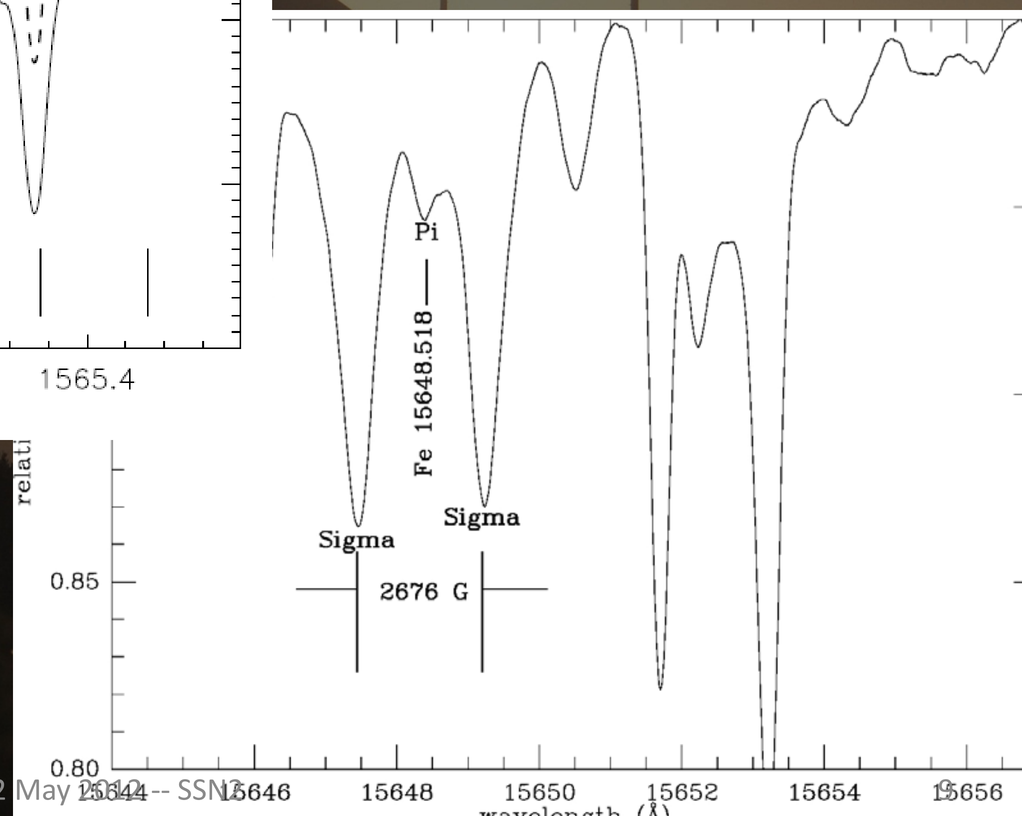
than solely using the intensity profiles. The advantage with respect to the stray light contamination is that the intensity in the quiet Sun (QS) surroundings is higher than in the umbra, whereas exactly the opposite relation holds for the polarization signal. Therefore intensity spectra in the umbra are contaminated by contributions from the QS, but the splitting of Stokes-V is not.





Rezaie, Beck & Schmidt





Rezaie, Beck & Schmidt

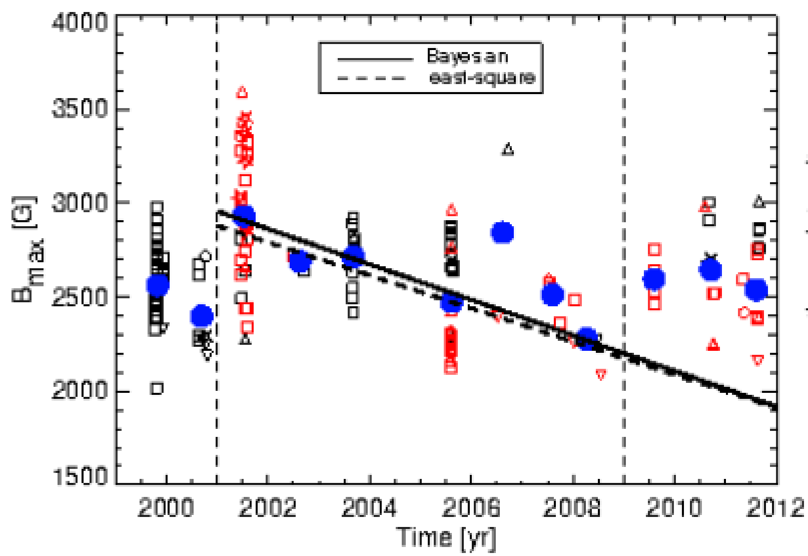
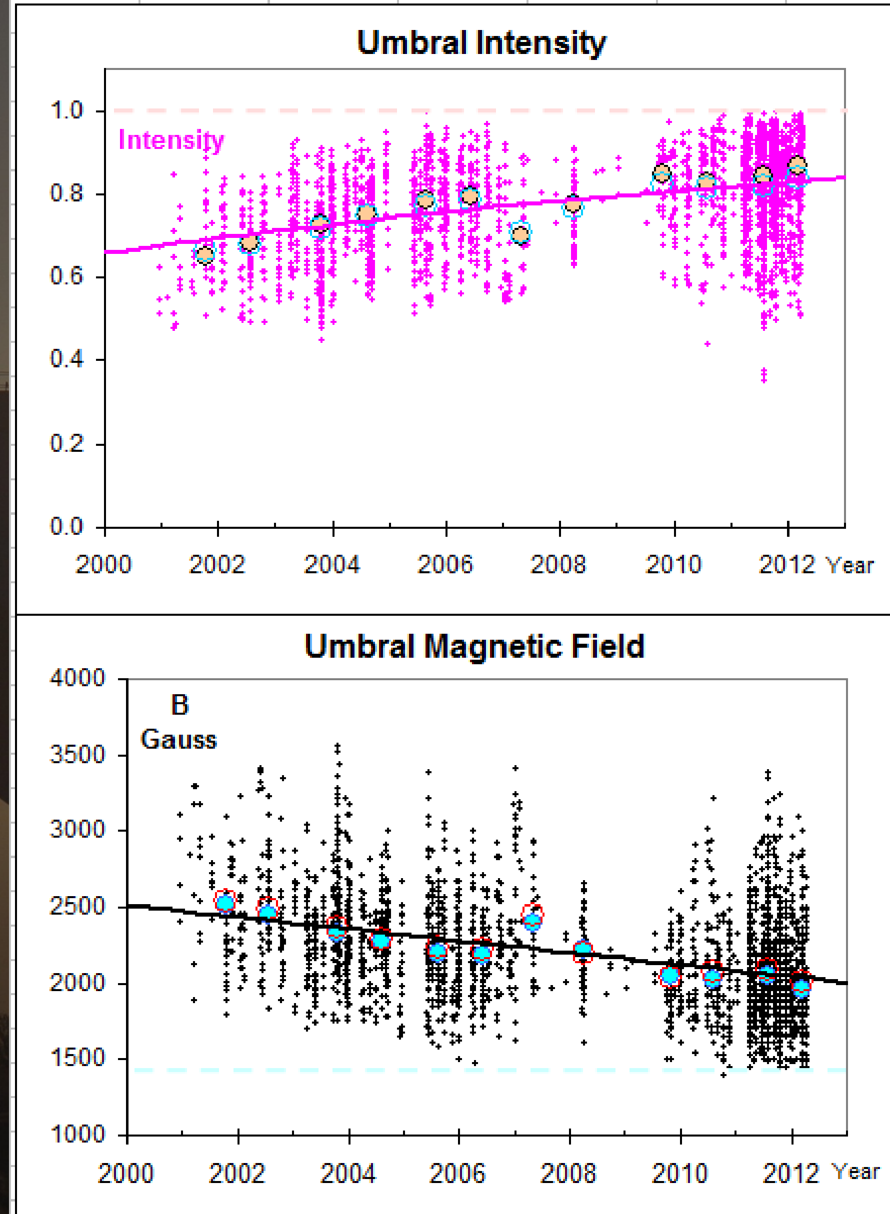


Fig. 6. Variation in the maximum magnetic fi
time. Symbols show the individual sunspots v



We assume that all magnetic fields form 10.7cm radio emission, but only fields above magnetic threshold (1500G) form sunspots

Sunspot formation fraction is defined as:

$$f_{spot} = \frac{SSN}{F10.7} = \frac{\int_{B_t}^{\infty} \mathrm{N(B)dB}}{\int_{-\infty}^{\infty} \mathrm{N(B)dB}}$$

We approximate the Magnetic PDF with a Gaussian:

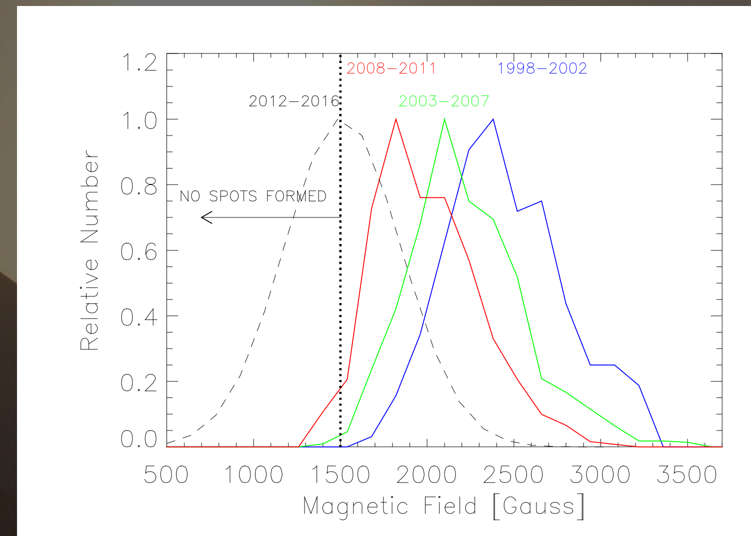
$$\mathrm{N(B)} = \mathrm{e}^{-\frac{(\mathrm{B}-\mathrm{B_m})^2}{2\sigma_\mathrm{B}{}^2}}$$

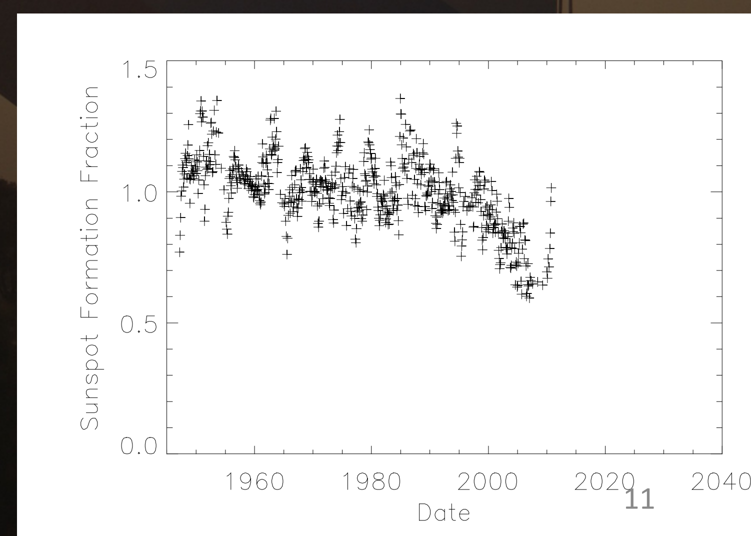
Sunspots are formed only above magnetic threshold:

$$SSN \approx \int_{B_t}^{\infty} exp^{-\frac{(\mathrm{B}-\mathrm{B_m})^2}{2\sigma_\mathrm{B}{}^2}} dB \approx erfc(B_t)$$

Formation fraction should be an erfc:

$$f_{spot} \approx erfc(B_t)$$



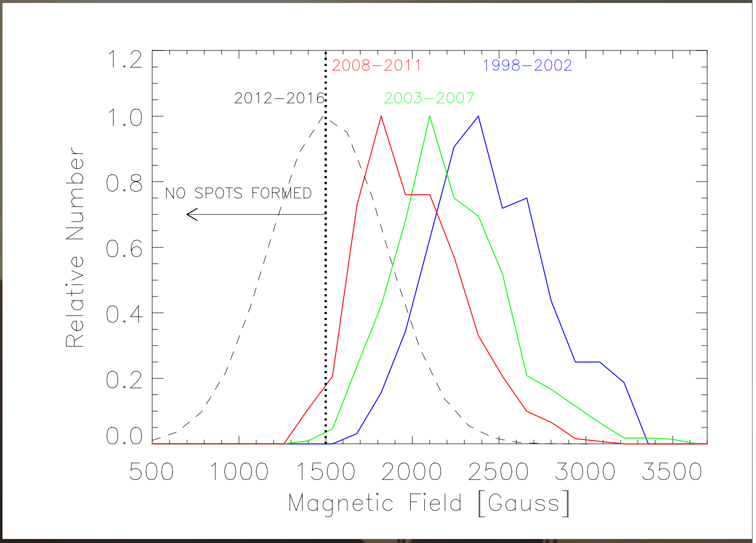


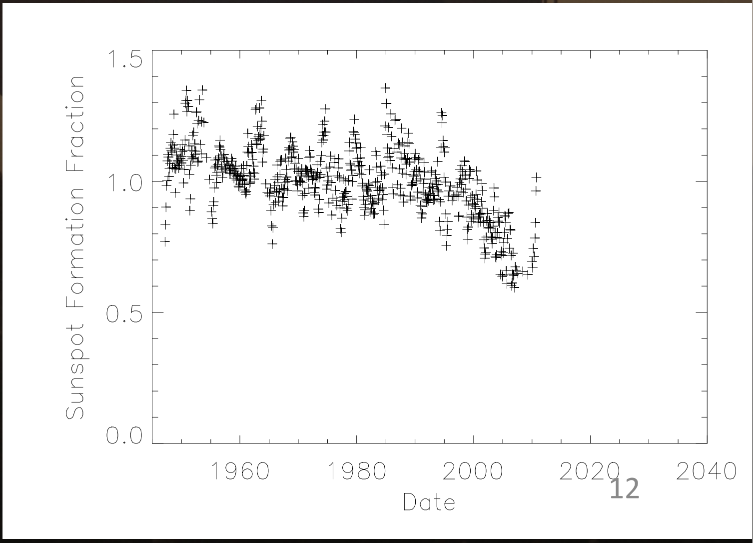
Second assumption: the underlying distribution doesn't change shape with time, and so B_t can be expressed as a function of time

$$B_t = (1500 - \bar{B}(t))/(\sqrt{2}\sigma)$$

$$= (B_0 - dB/dt\ \Delta t)/(\sqrt{2}\sigma)$$

This is scale invariant, but using the boundary condition that $\bar{B}(2000)$=2436 Gauss allows us to fit with a least squares technique for dB/dt and σ





Best fit gives distribution for f_{spot} :

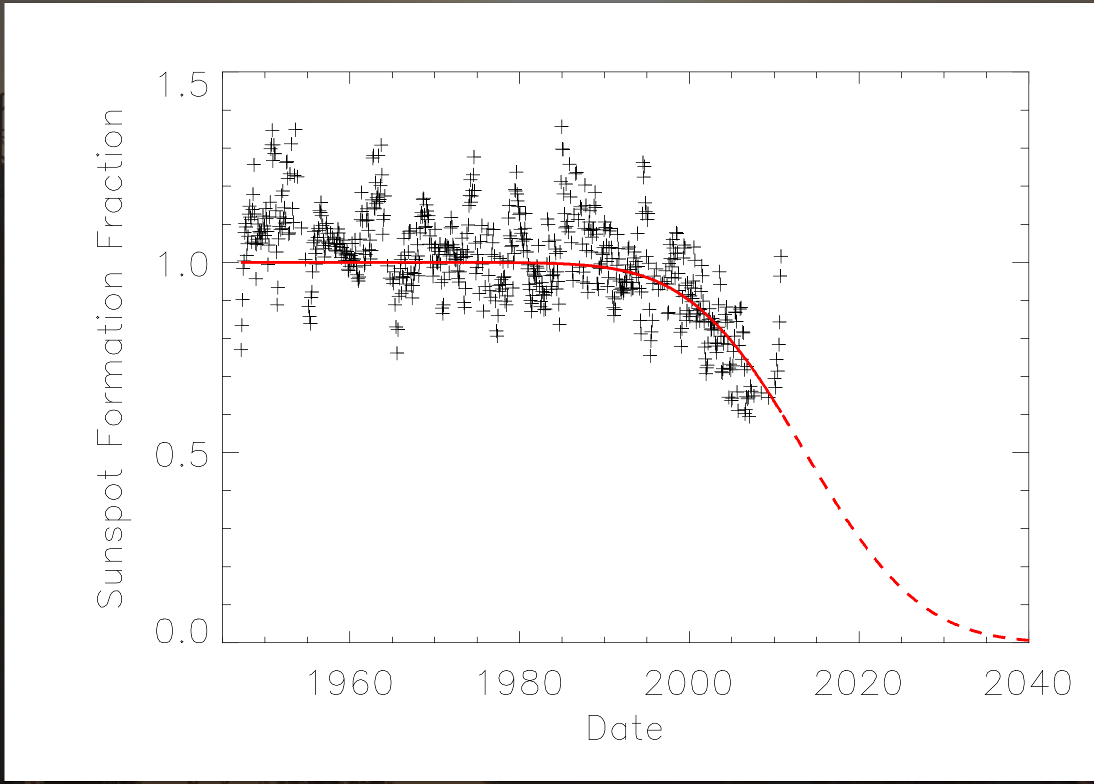
dB/dt = -27 +/- 4 Gauss / yr

σ = 500 +/- 20 Gauss

IR magnetic distribution:

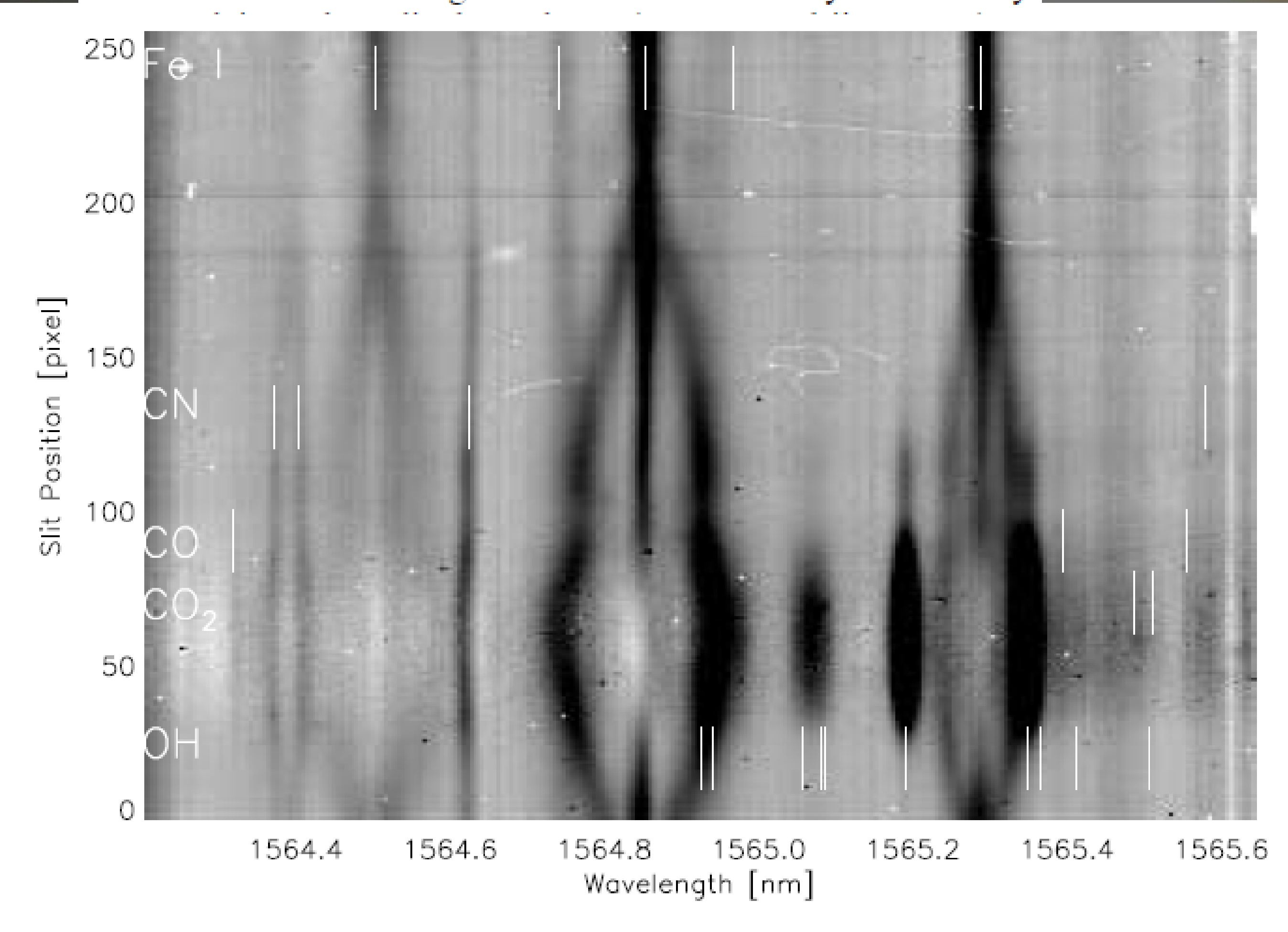
dB/dt = -46 +/- 6 Gauss / yr

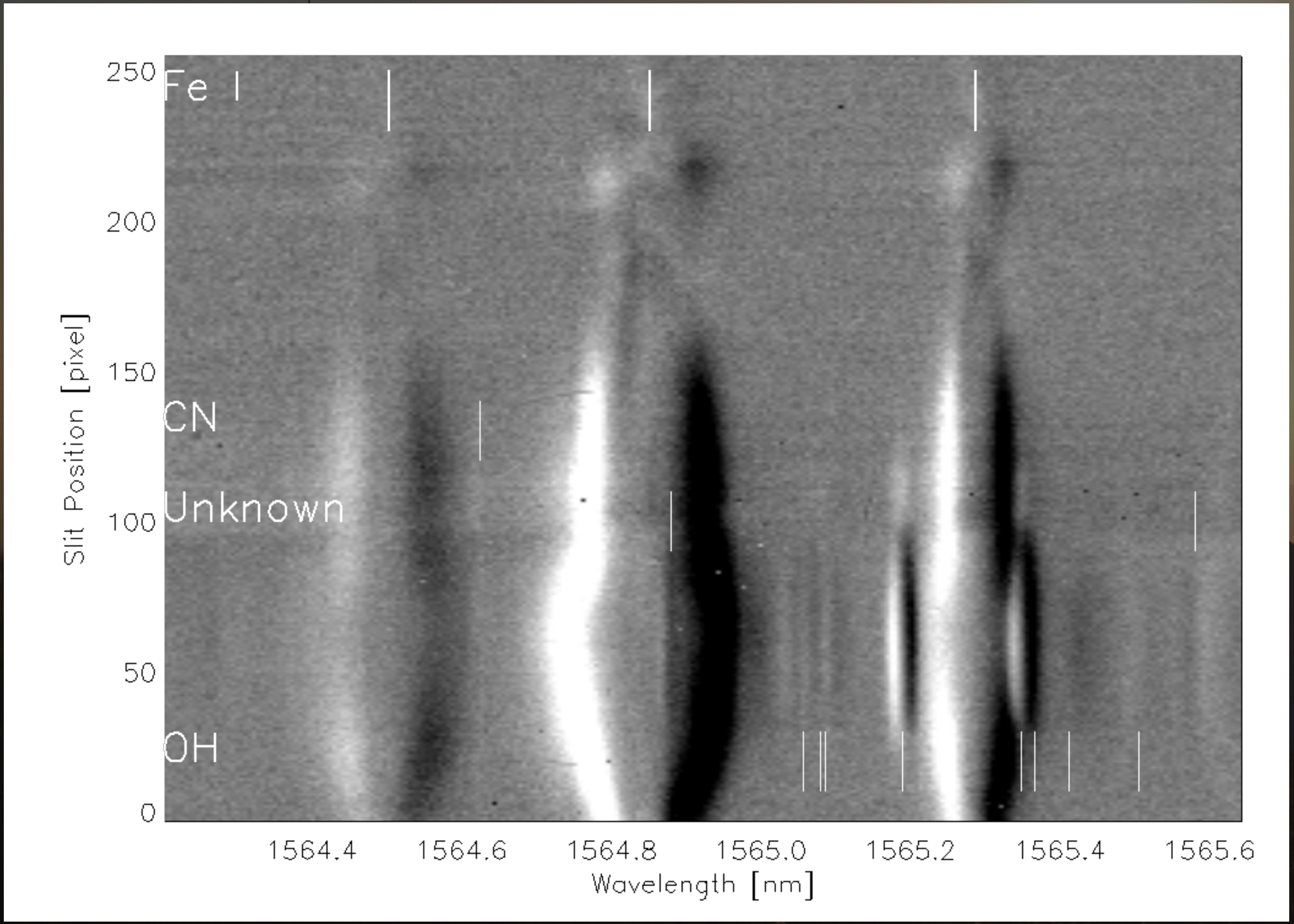
σ = 323 +/- 20 Gauss



Extrapolating this trend predicts Cycle 24 only half as large as Cycle 23, and Cycle 25 will have two sunspot groups.

than at its end. Although the magnetic sensitivity of the infrared Fe I 1564.8 nm line is high (Rüedi et al. 1995), the influences of scattered light and line blends in the intensity profiles on the measurement motivates one to employ more accurate methods to derive the field strength. It is not clear how dynamo theory




Fe I
CN
Unknown
OH
250
200
150
100
50
0
Slit Position [pixel]
1564.4
1564.6
1564.8
1565.0
1565.2
1565.4
1565.6
Wavelength [nm]