Update on Changing Umbral Magnetic Fields

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Outline

- Review of Livingston's observations
- Connection to F10.7
- Erfc and implications for SC23, SC24, SC25
- New fits to Livingston's data
- New observations and cross-calibration
- Future of McM/P facility?

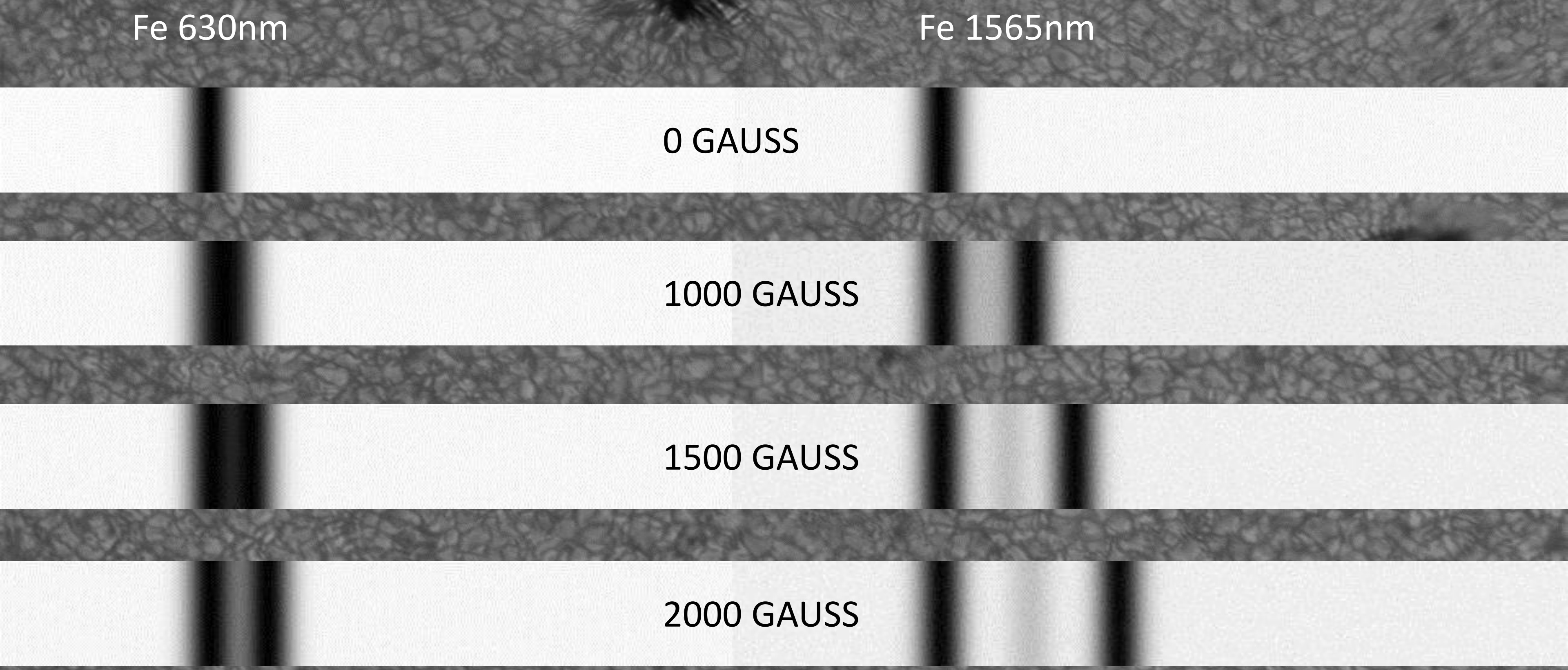
- Livingston, Penn, Svalgaard; ApJ, 2012, v757 L8
- Penn, Livingston; IAU 273, 2011, p126
- Livingston, Penn; EOS, 2009, L257
- Penn, Livingston; ApJ, 2006, v649, L45
- Livingston; Solar Physics, 2002, v207, p41

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).

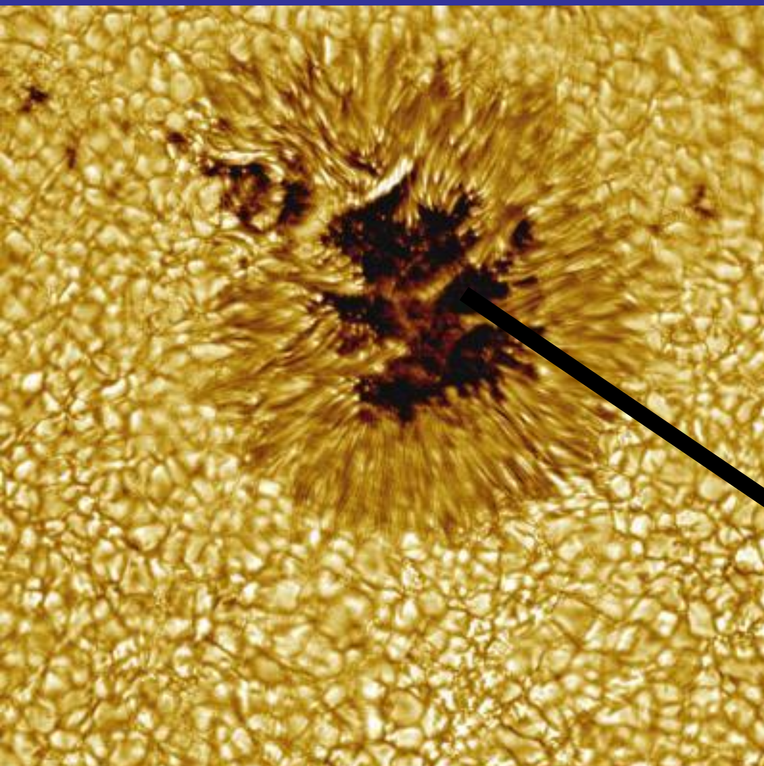
A recent study from Rezaie, Beck & Schmidt (2012) using some (99) infrared measurements combined with “visible measurements” finds a solar cycle change.

Zeeman Measurements

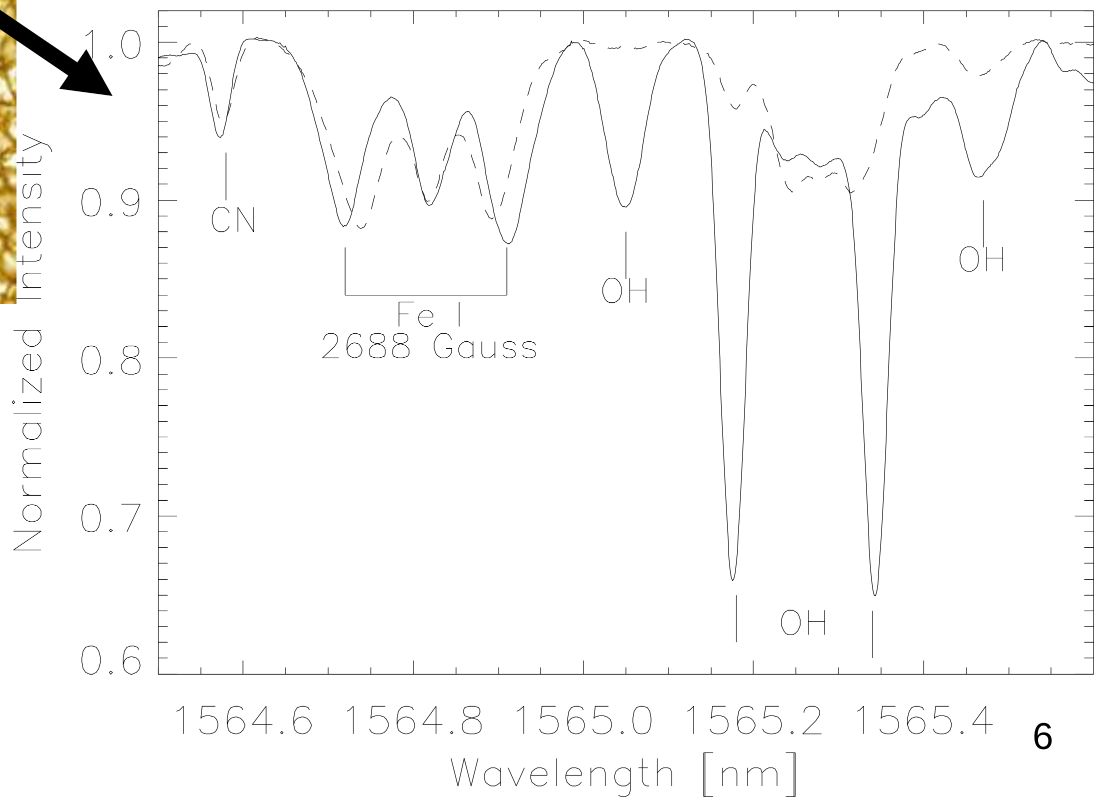


Fe 630nm is formed 170km higher than 1565nm, and with a 2G/km vertical gradient it probes fields 340G weaker than Fe 1565nm

Dark umbral cores observed



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

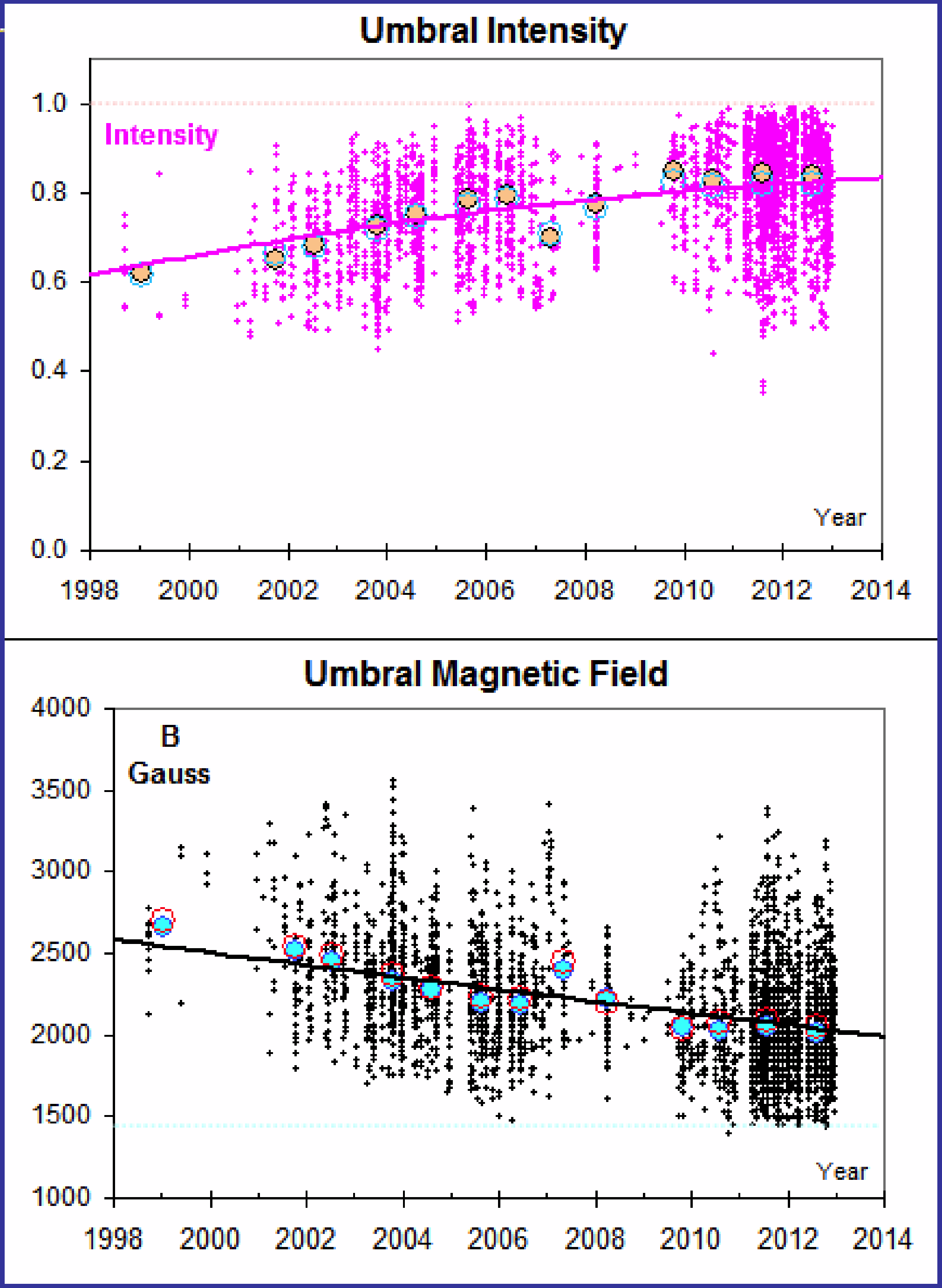


Signal to noise of Livingston’s spectra are 3000:1

1.0 Intensity threshold

Intensity increases
Fields decrease
OH line strength decreases

1500 Gauss threshold?



Kopp & Rabin(1992): only 6 spots, but predict 0 radius for IR B about 2000 Gauss

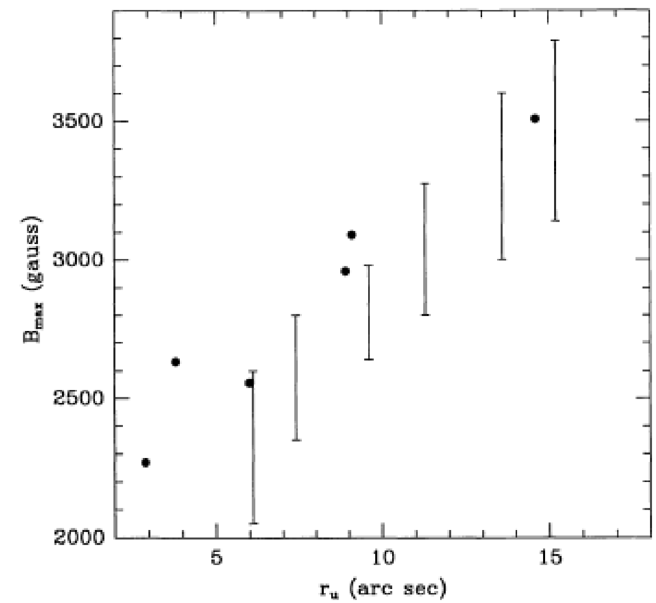
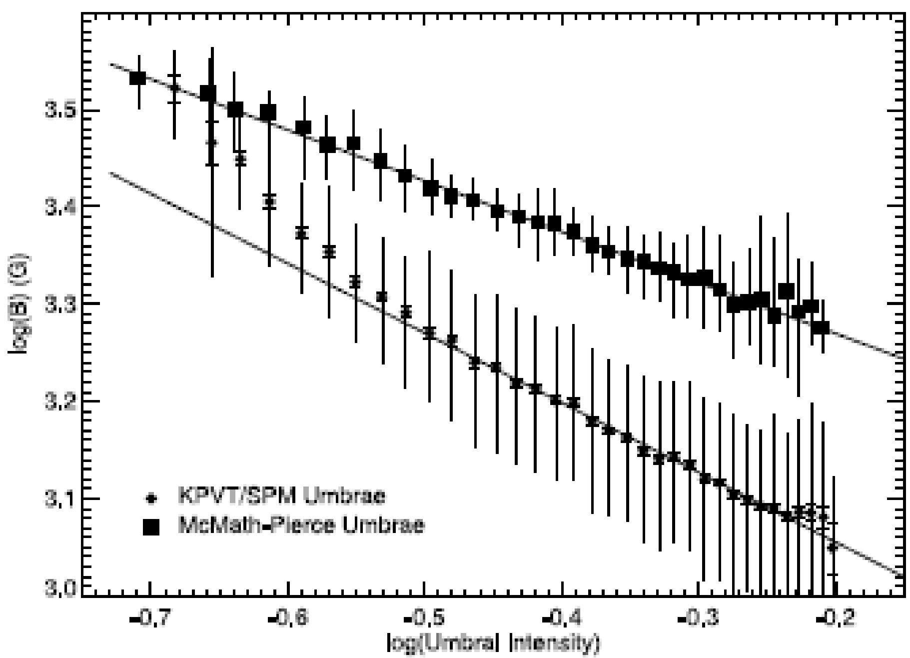


Fig. 5. Maximum magnetic field strength vs umbral radius. The points represent the six sunspots in the present sample. The vertical bars delimit the range of field strengths noted by Brants and Zwaan (1982).



Schad & Penn (2010): power law relation from Bill’s data between IR B and intensity extrapolates to quiet Sun intensity at 1463 +/- 13 Gauss

NSO

Back of the envelope calculation: compare magnetic energy density with photospheric gas pressure

$B^2/8\pi = (1500)^2/8\pi = 90{,}000$ dynes/cm^2

Fontenla et al 2007 1-d model => 57,065 dynes/cm^2 (at line formation height) =>1200 G

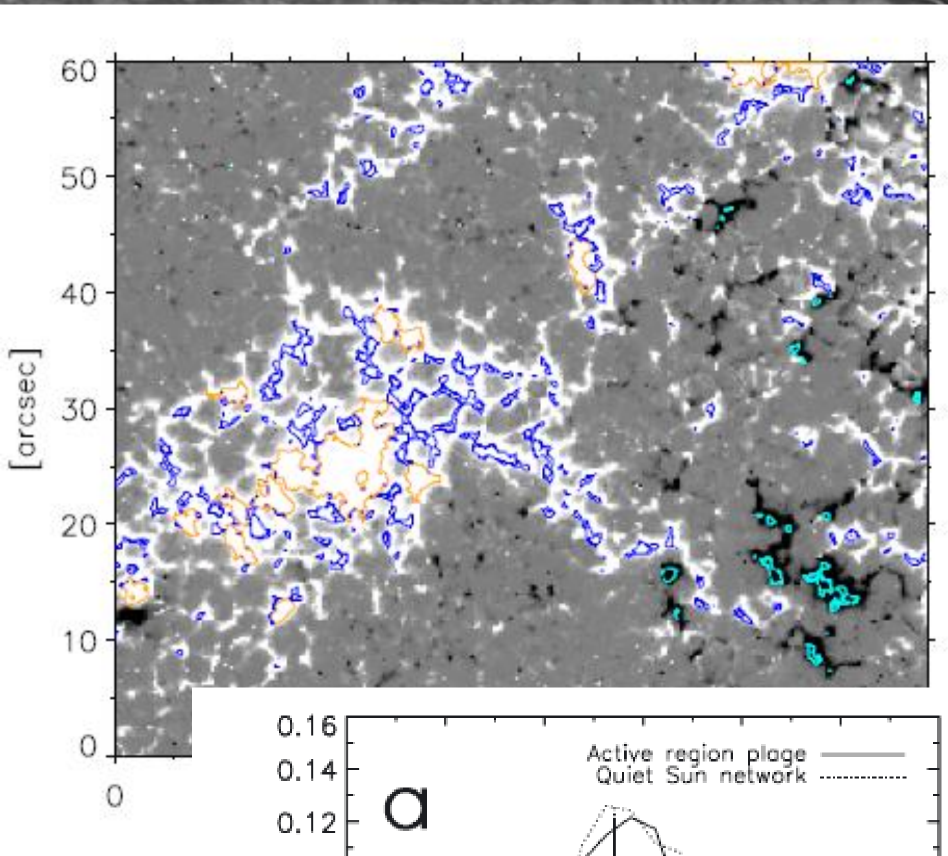
TABLE 1

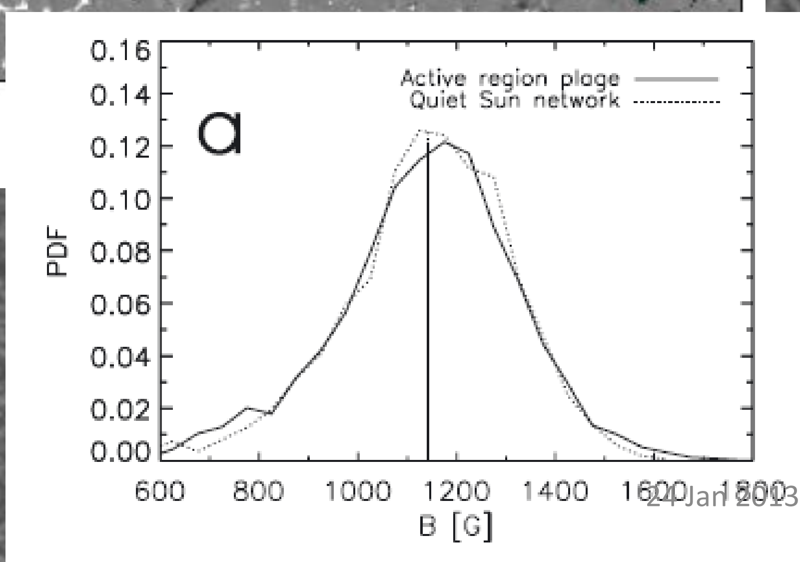
THE CURRENT MODEL OF PHOTOSPHERE AND LOW CHROMOSPHERE

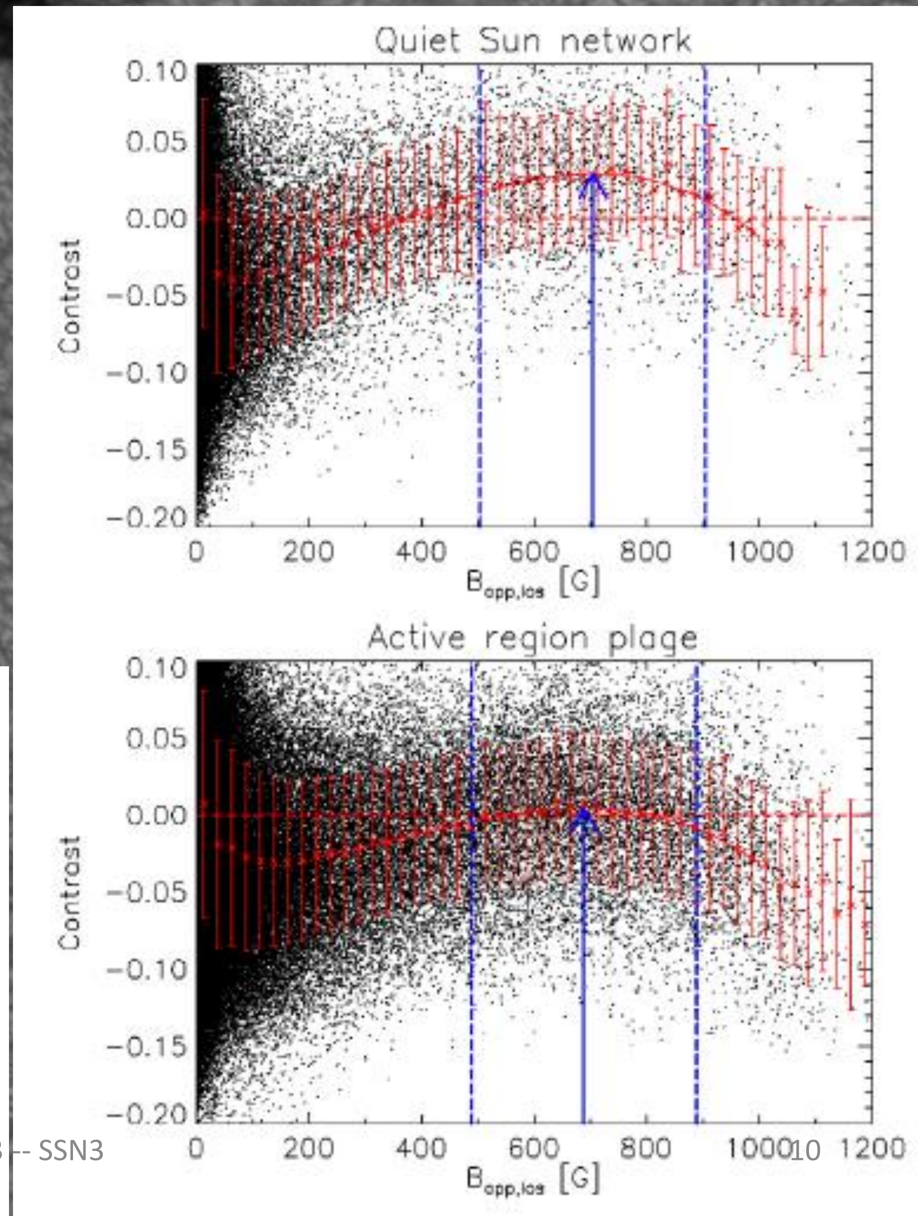
Gas Pressure (dyne cm^{-2})	Height[a] (km)	Mass Column (gr cm^{-2})	Temperature (K)	Electron Density (cm^{-3})	Turbulent Velocity[b] (km s^{-1})	Acceleration[c] (km s^{-2})	b_H
0.1865	2472	2.74E−06	7210	7.53E+10	9.7	0.1	4.716
0.2078	2425	3.96E−06	7030	8.16E+10	9.6	0.1	4.360
0.2455	2357	6.14E−06	6910	8.89E+10	9.4	0.1	4.130
0.3151	2263	1.02E−05	6830	9.84E+10	9.2	0.1	3.981
0.4473	2142	1.79E−05	6770	1.15E+11	8.9	0.1	3.871

Are fields > 1500G bright anywhere ?

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

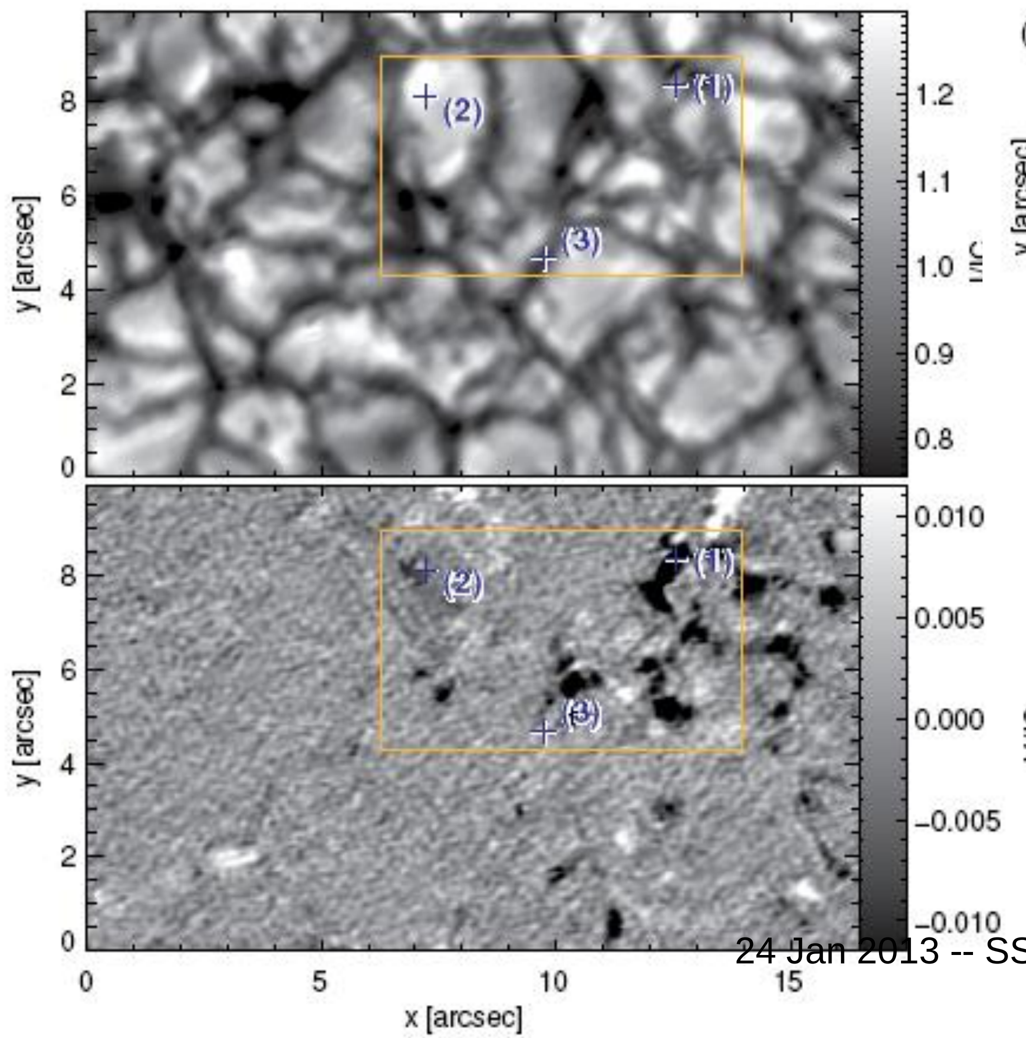


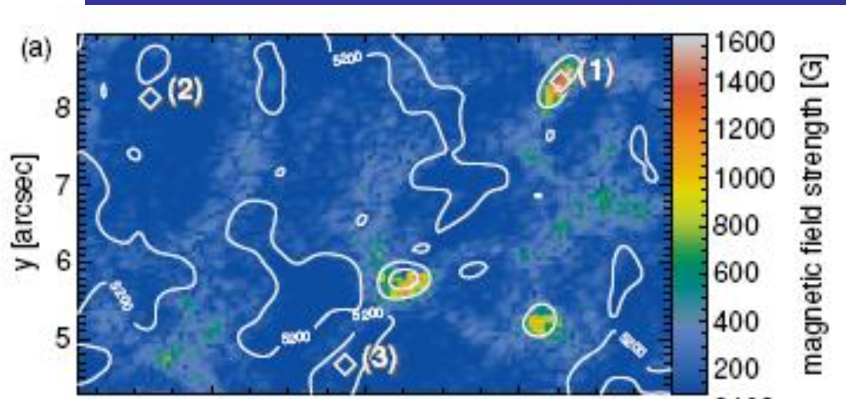




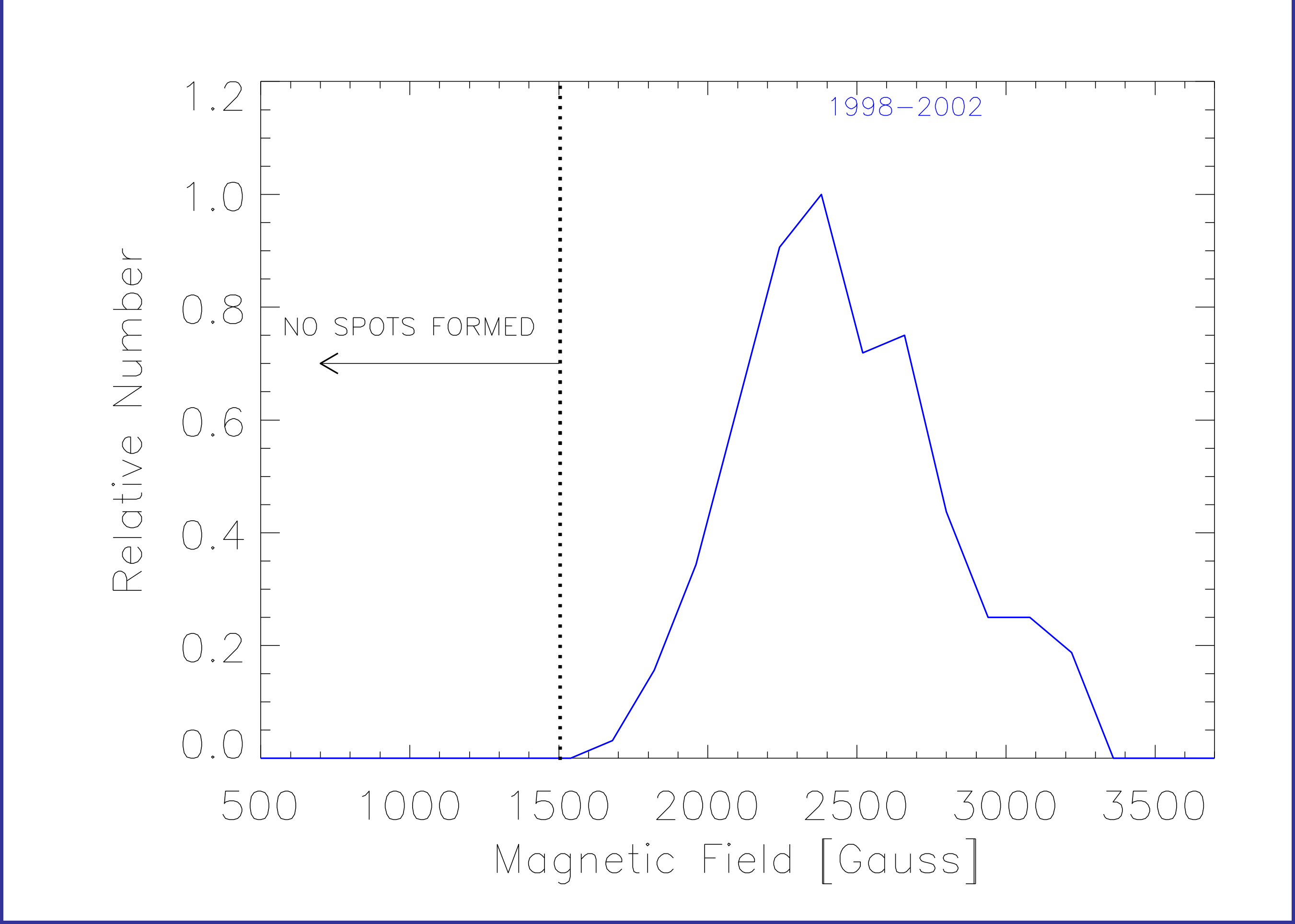
Are fields > 1500G bright anywhere else?

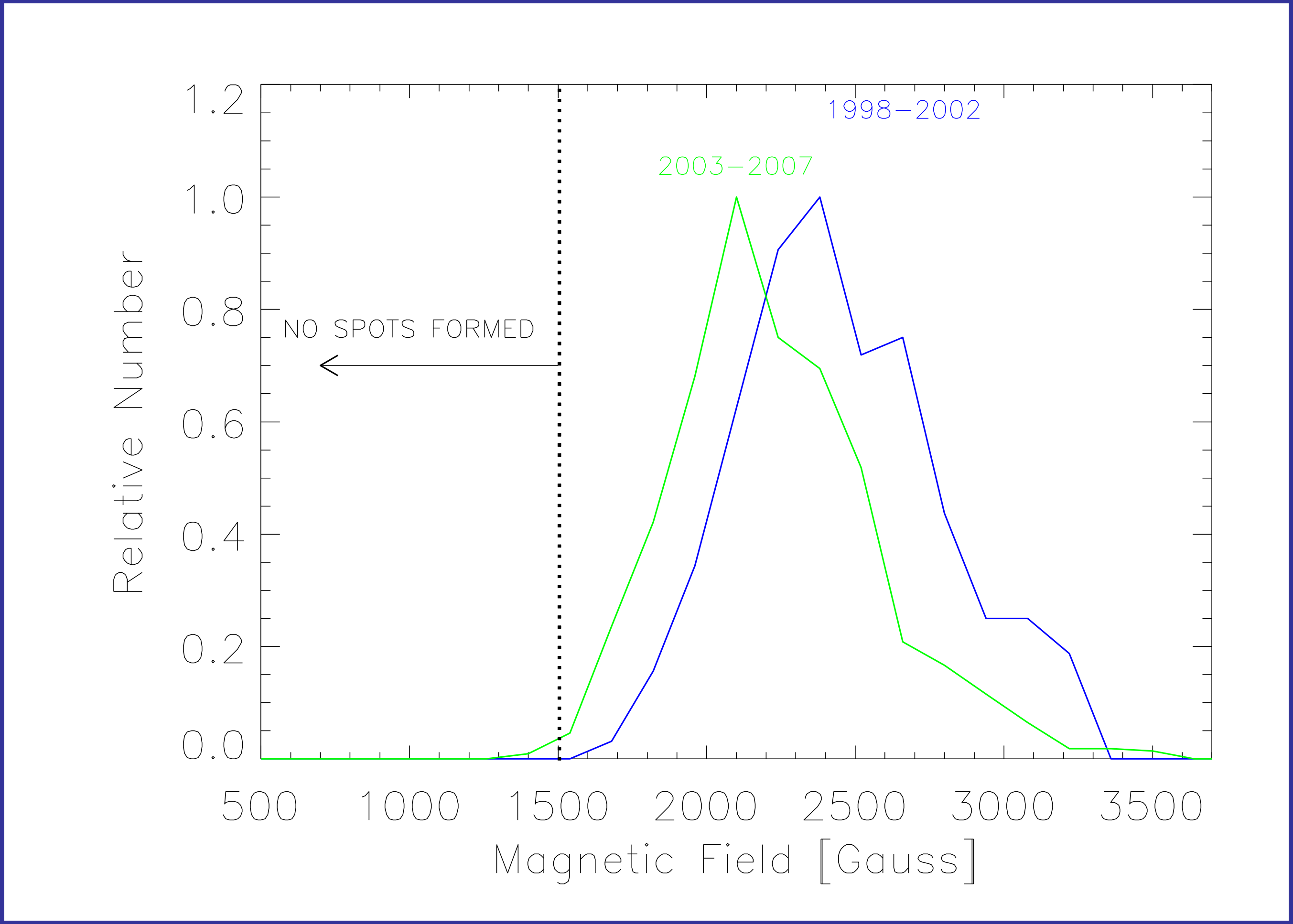
Lagg et al. (2010) studied quiet Sun using SunRise;
max B = 1450G



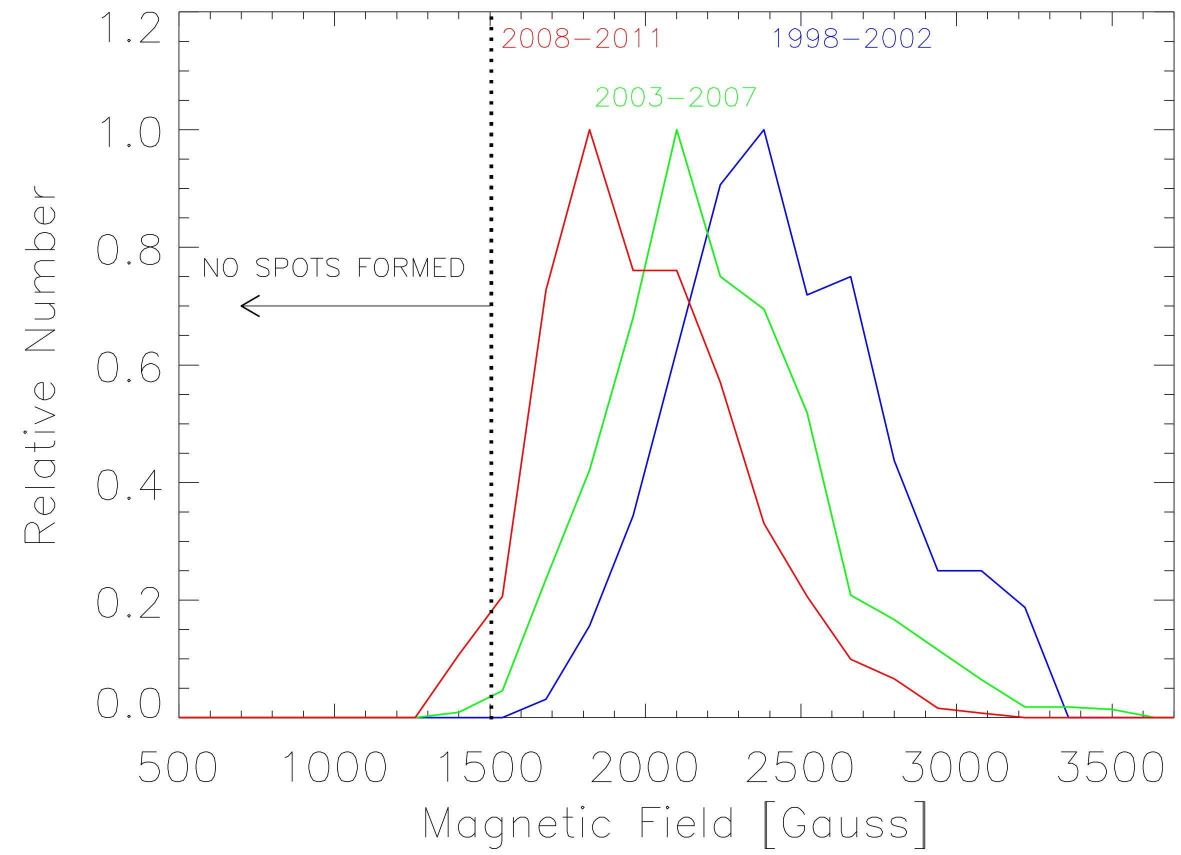


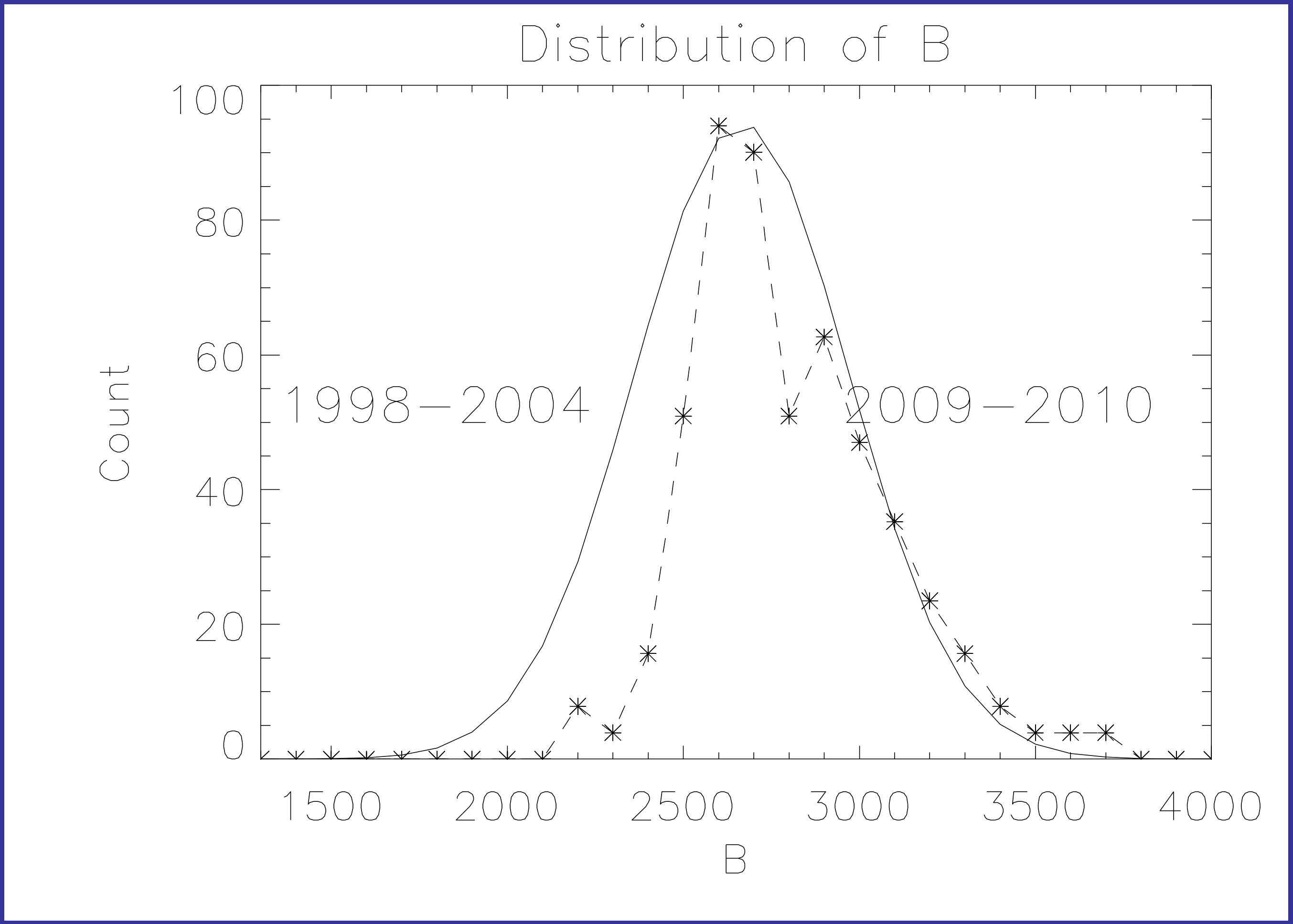
These are *<u>not all sunspot fields</u>*, these are maximum umbral fields.

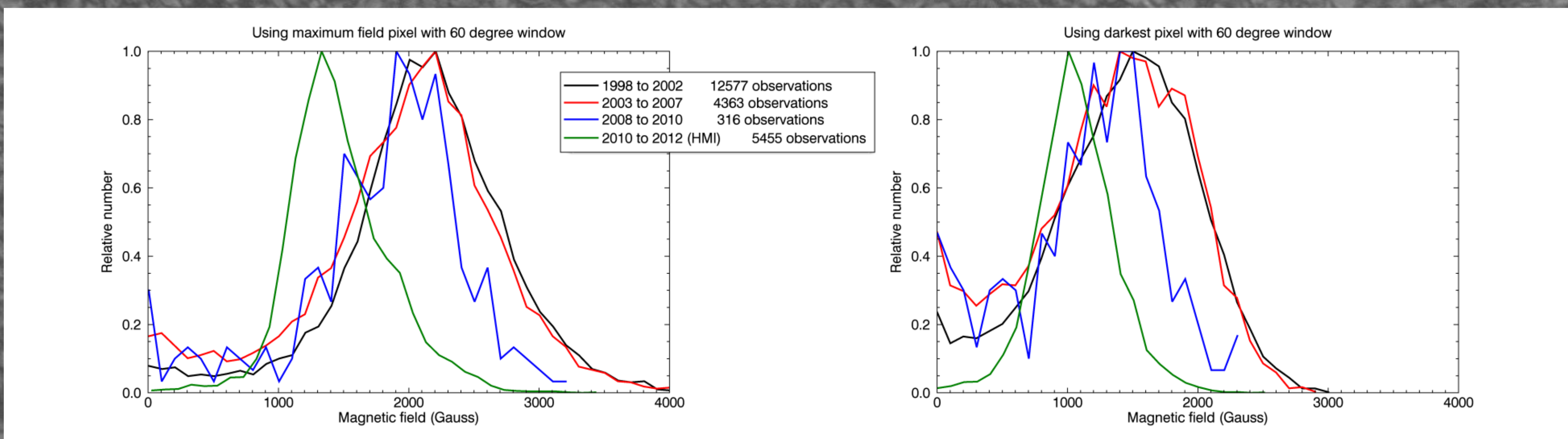



1.2
1.0
0.8
0.6
0.4
0.2
0.0
Relative Number
500
1000
1500
2000
2500
3000
3500
Magnetic Field [Gauss]
NO SPOTS FORMED
1998–2002
2003–2007

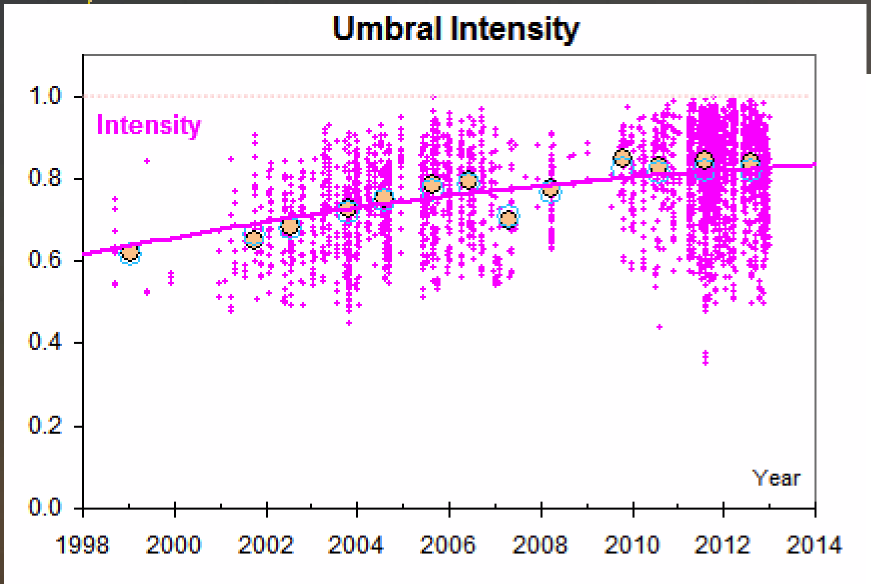
dB/dt is about 46 Gauss per year; width is 320 Gauss

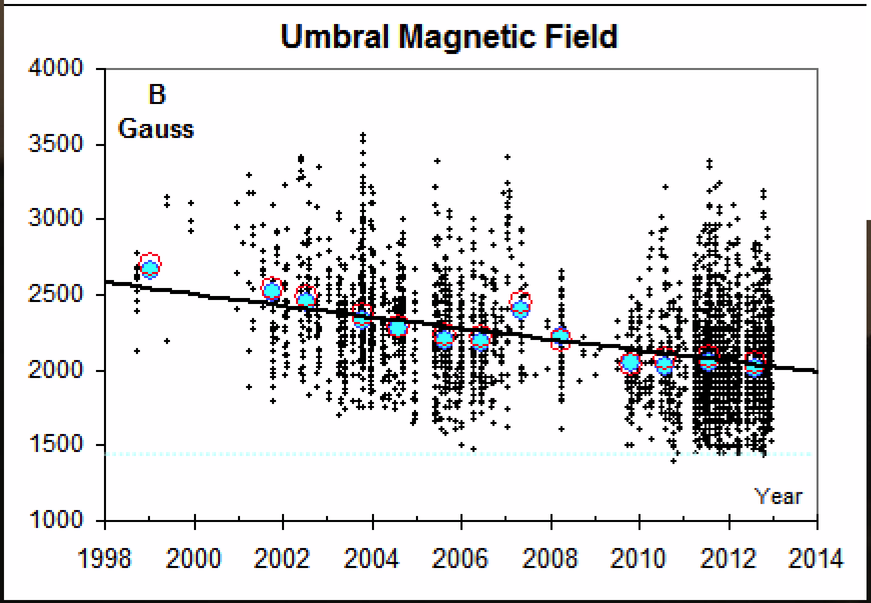


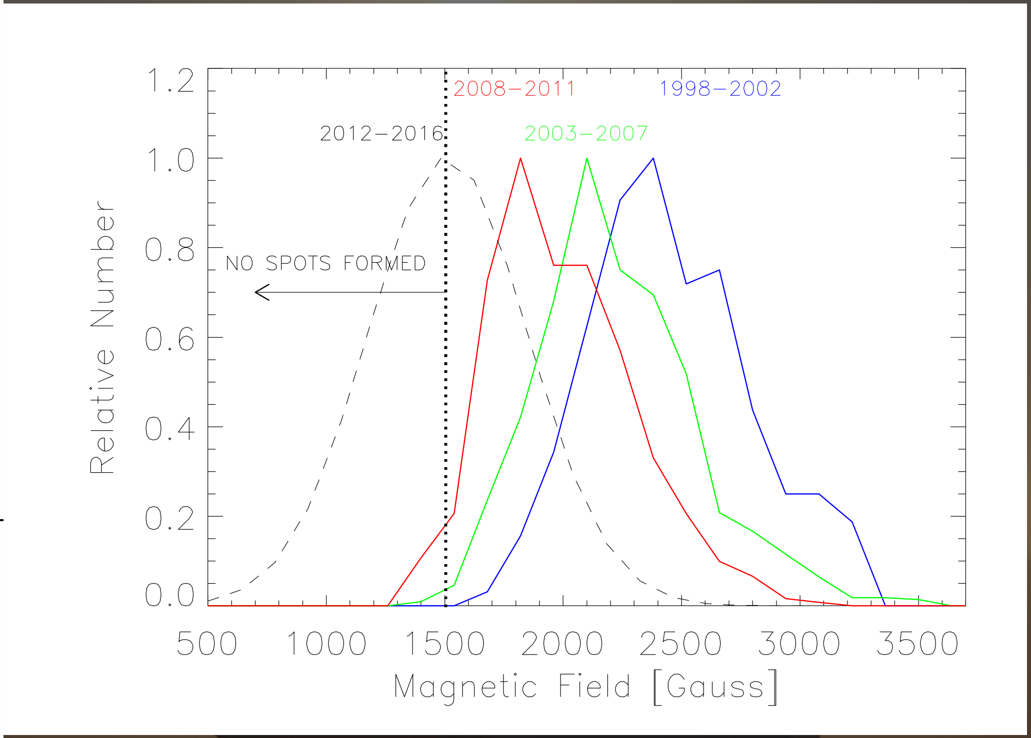

Distribution of B
100
80
60
40
20
0
Count
1998–2004
2009–2010
1500
2000
2500
3000
3500
4000
B



Using maximum field pixel with 60 degree window
Using darkest pixel with 60 degree window
1998 to 2002 12577 observations
2003 to 2007 4363 observations
2008 to 2010 316 observations
2010 to 2012 (HMI) 5455 observations
Relative number
Magnetic field (Gauss)
0.0
0.2
0.4
0.6
0.8
1.0
0
1000
2000
3000
4000


Umbral Intensity
Intensity
1.0
0.8
0.6
0.4
0.2
0.0
Year
1998
2000
2002
2004
2006
2008
2010
2012
2014


Umbral Magnetic Field
B
Gauss
4000
3500
3000
2500
2000
1500
1000
Year
1998
2000
2002
2004
2006
2008
2010
2012
2014


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]

Summary

- Sunspot magnetic fields are weakening and approaching the observed lower limit value of 1500 Gauss.
- We propose a *sunspot formation fraction* -- active region magnetic fields erupt with a normal distribution, and the fields in this distribution great than 1500 Gauss form sunspots, but the fields less than 1500 Gauss do not.
- We develop an analytical form for the sunspot formation fraction, and quantitatively fit an observational measurement of this quantity using solar radio emission at 10.7cm.
- Our fit quantitatively reconciles statistical predictions of SSN for Cycle 23 and Cycle 24 maxima with observed values, and show that the function predicts a very small or absent Cycle 25.

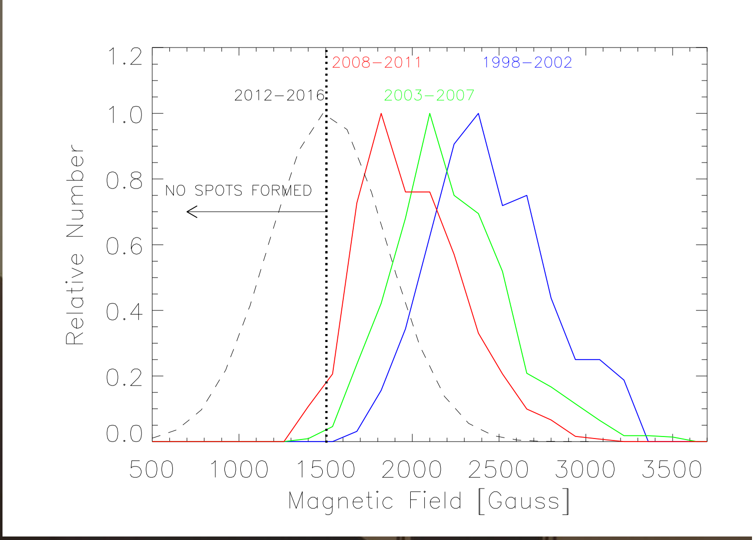
We assume that all magnetic fields form 10.7cm radio emission, but only fields above magnetic threshold (1500G) form sunspots

Sunspot formation fraction is defined as:

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

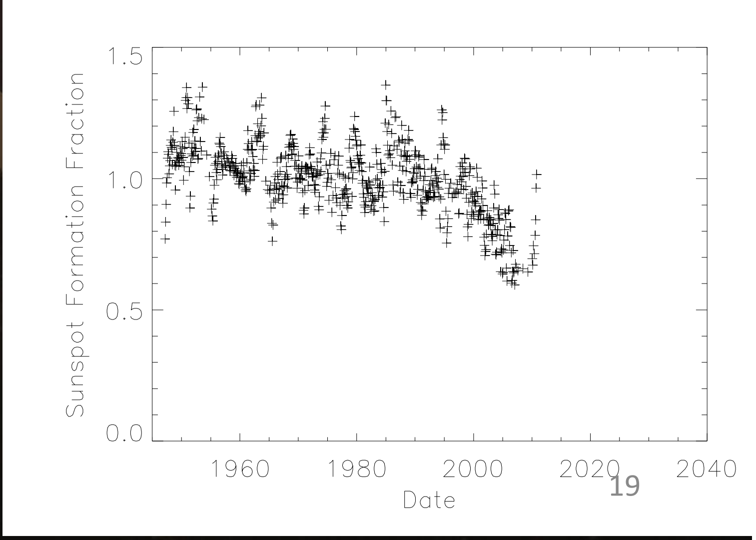
We approximate the Magnetic PDF with a Gaussian:

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



Sunspots are formed only above magnetic threshold:

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



Formation fraction should be an erfc:

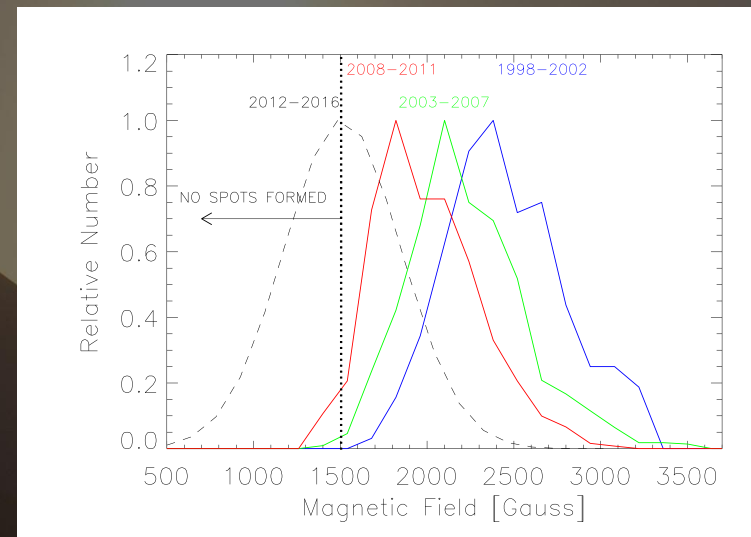
$$f_{spot} \approx erfc(B_t)$$

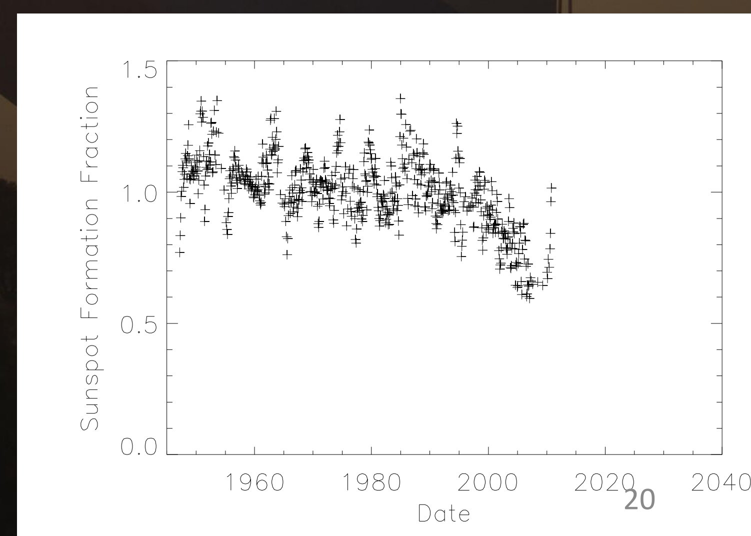
Second assumption: the underlying distribution doesn't change shape with time, and so B_t can be expressed as a function of time

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

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

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

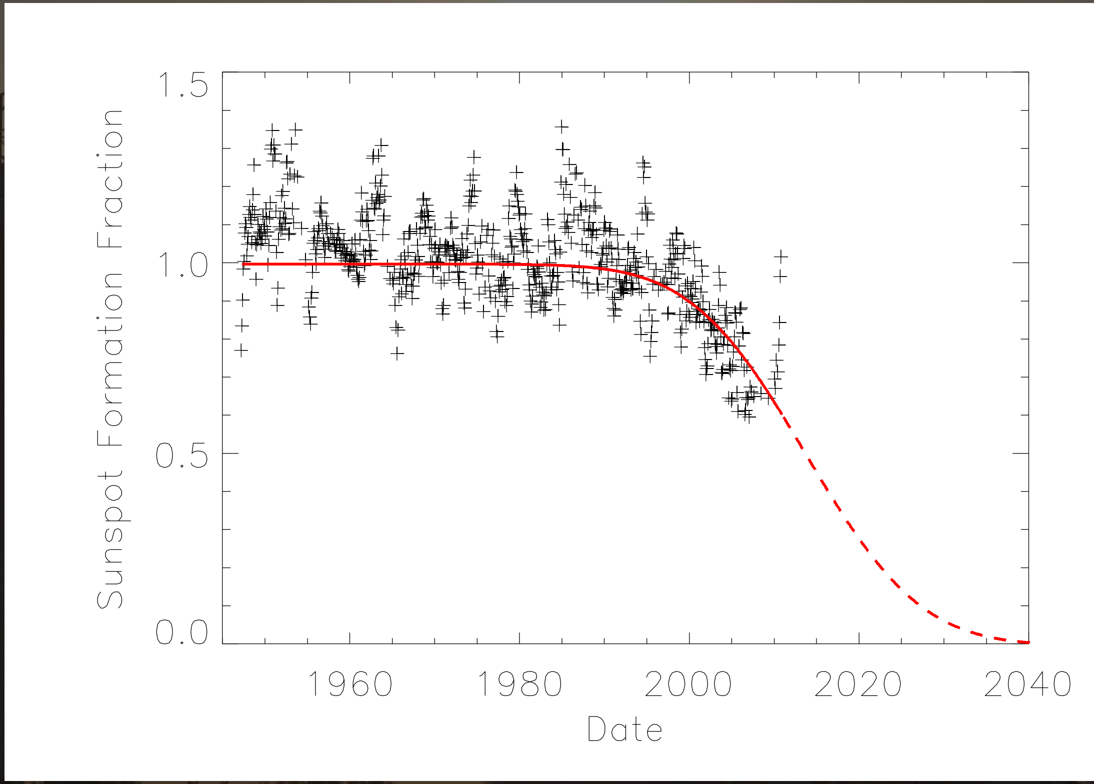




Best fit gives distribution for f_{spot} :

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

σ = 500 +/- 20 Gauss

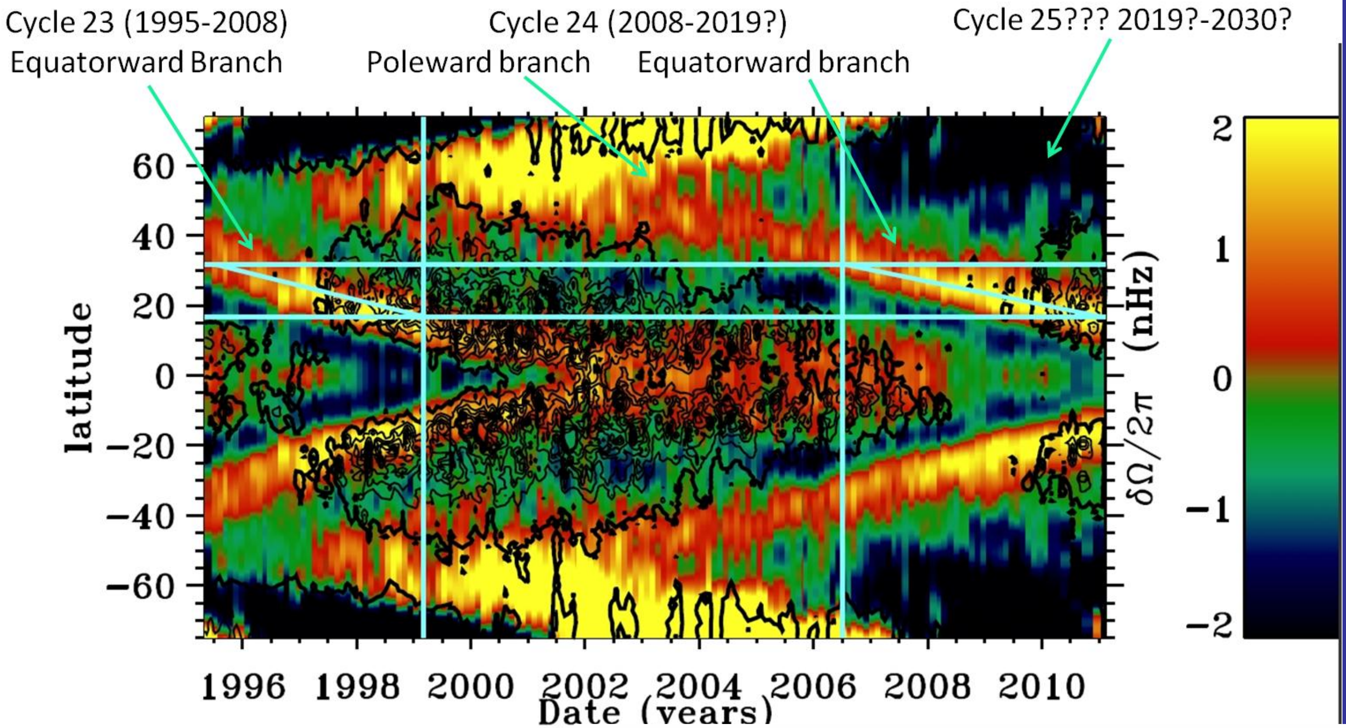


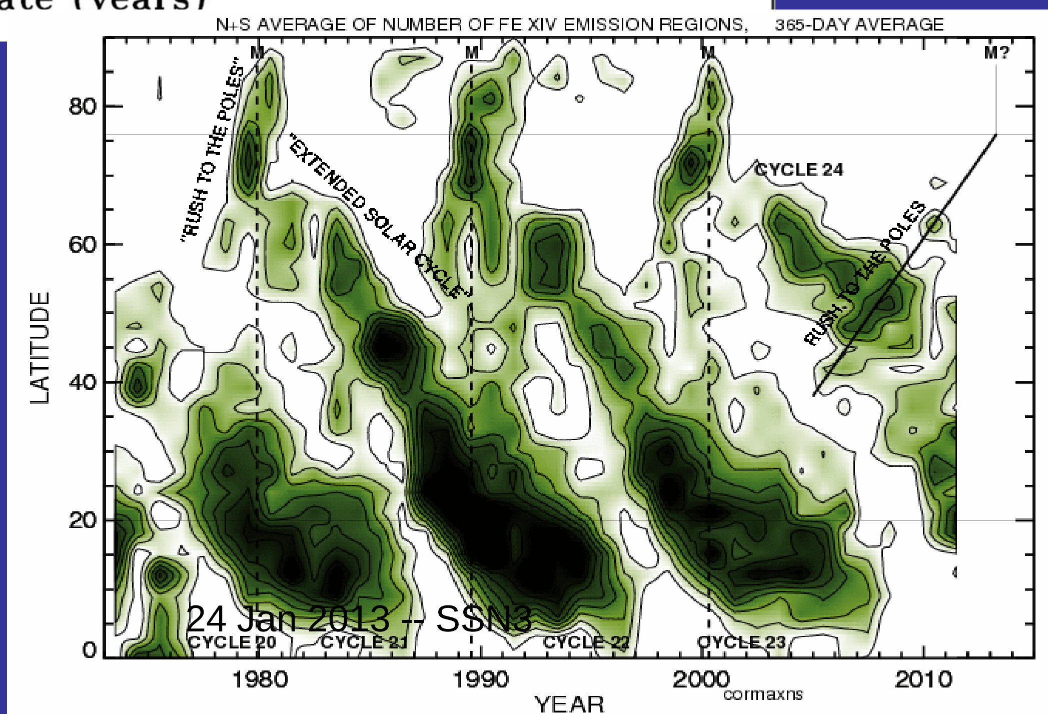
IR magnetic distribution:

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

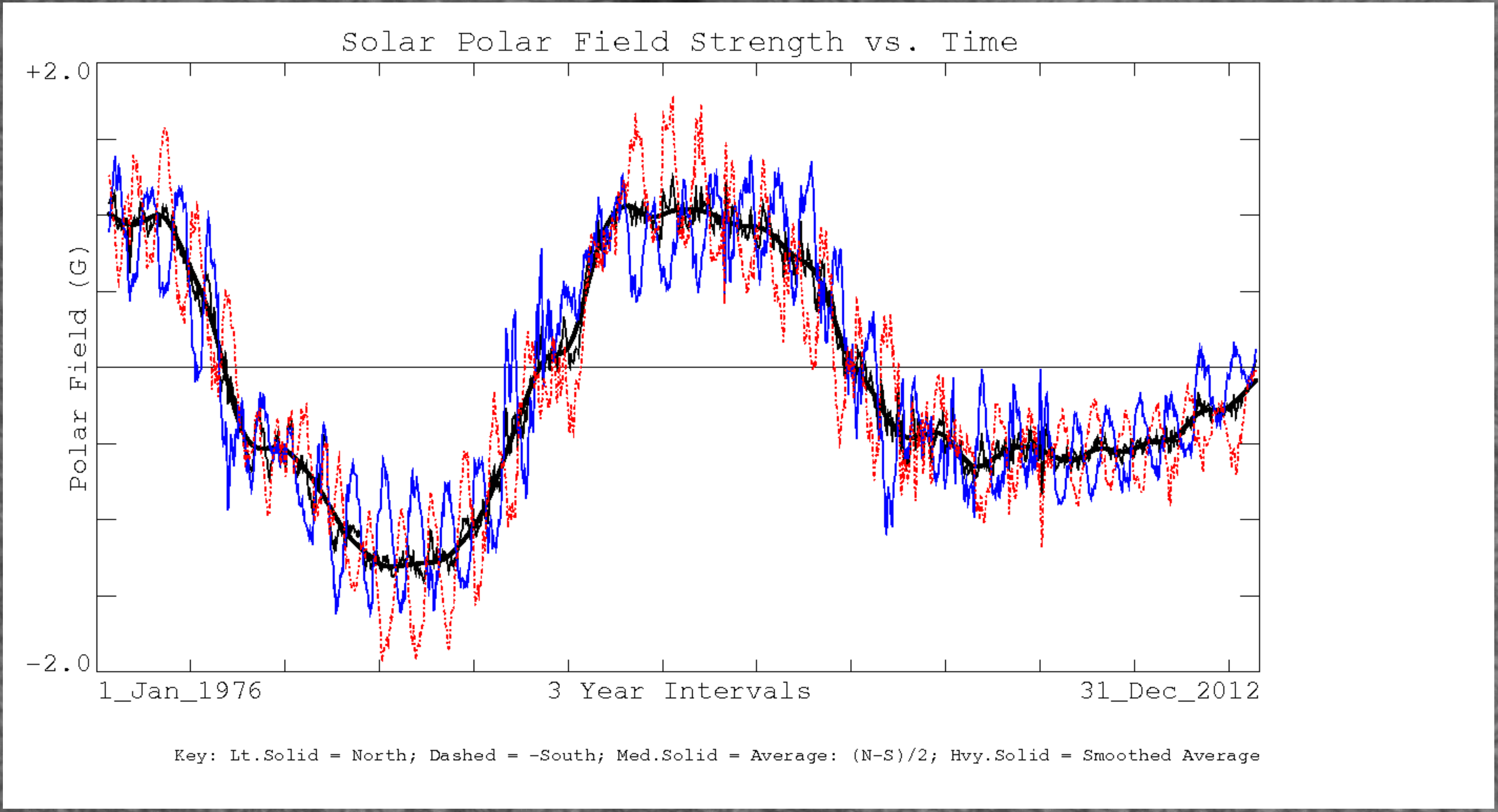
σ = 323 +/- 20 Gauss

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

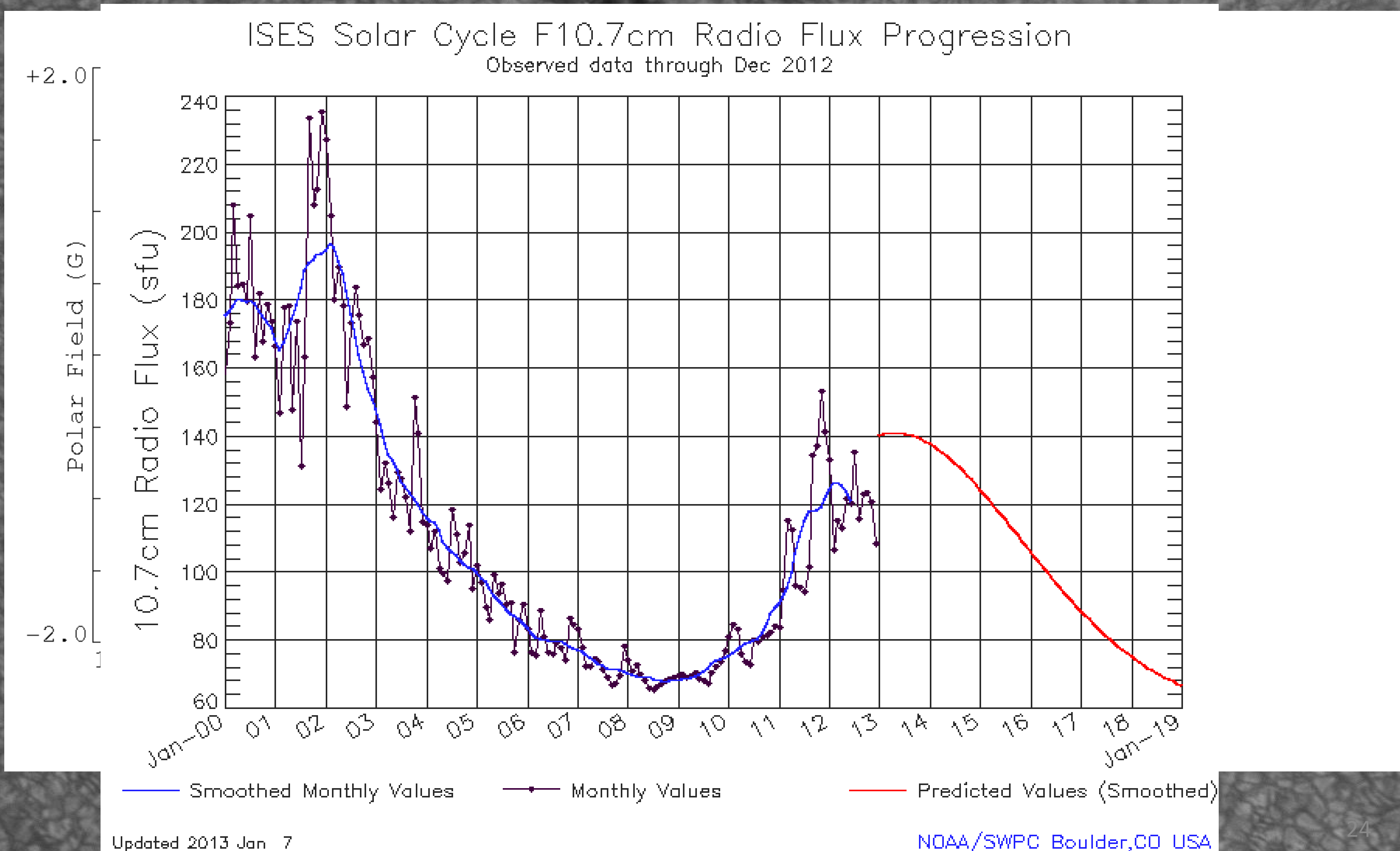

Cycle 23 (1995-2008)
Equatorward Branch
Cycle 24 (2008-2019?)
Poleward branch
Equatorward branch
Cycle 25??? 2019?-2030?
latitude
Date (years)
δΩ/2π (nHz)


N+S AVERAGE OF NUMBER OF FE XIV EMISSION REGIONS, 365-DAY AVERAGE
"RUSH TO THE POLES"
"EXTENDED SOLAR CYCLE"
CYCLE 24
RUSH TO THE POLES
M
M?
CYCLE 20
CYCLE 21
CYCLE 22
CYCLE 23
LATITUDE
YEAR
cormaxns

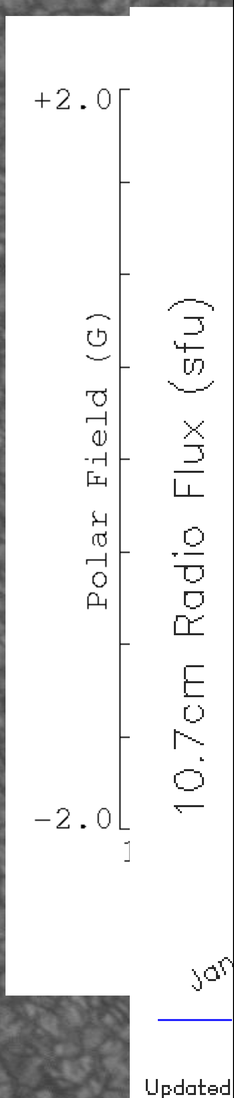
Welcome to sunspot maximum…

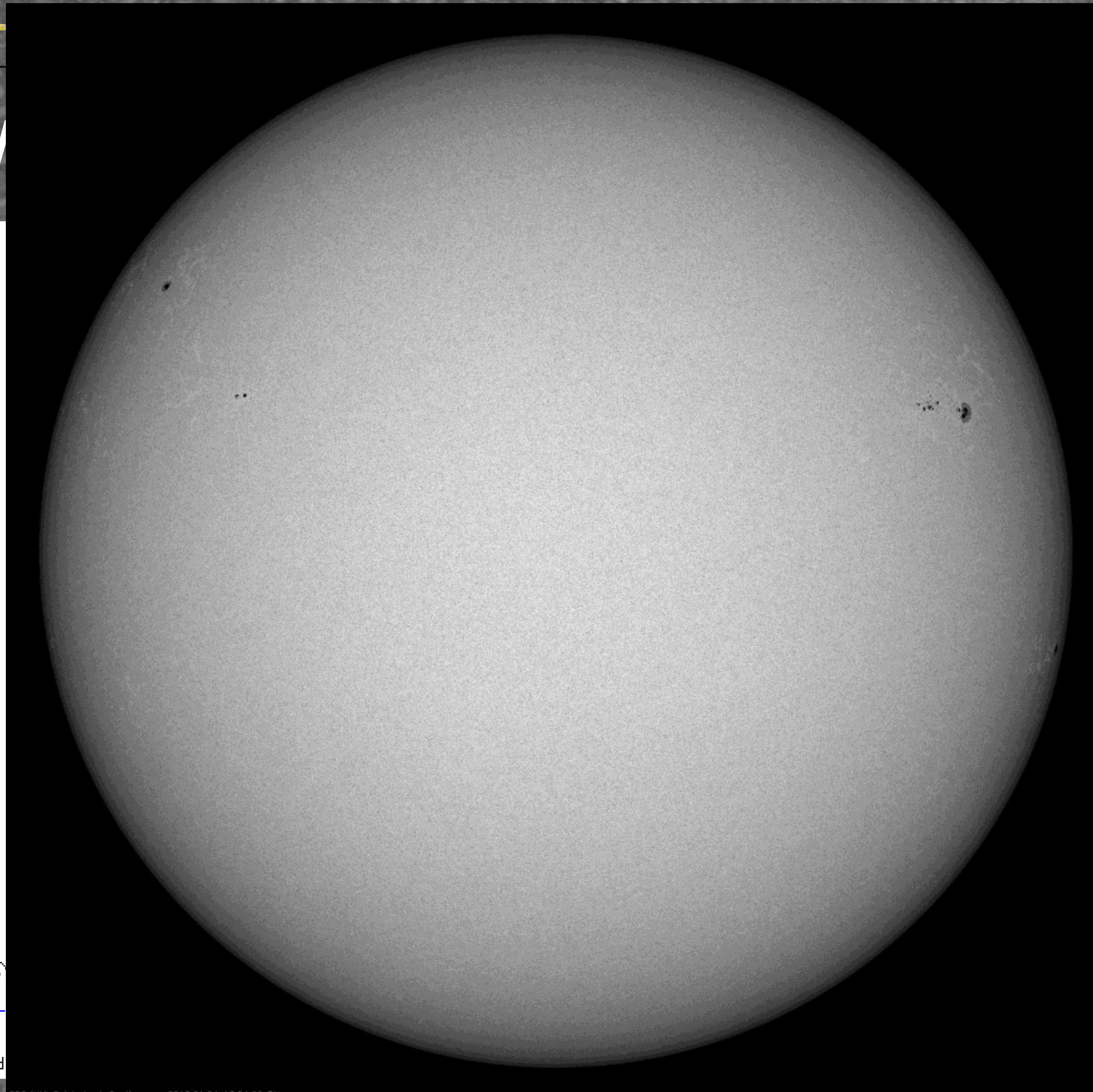


Welcome to sunspot maximum…



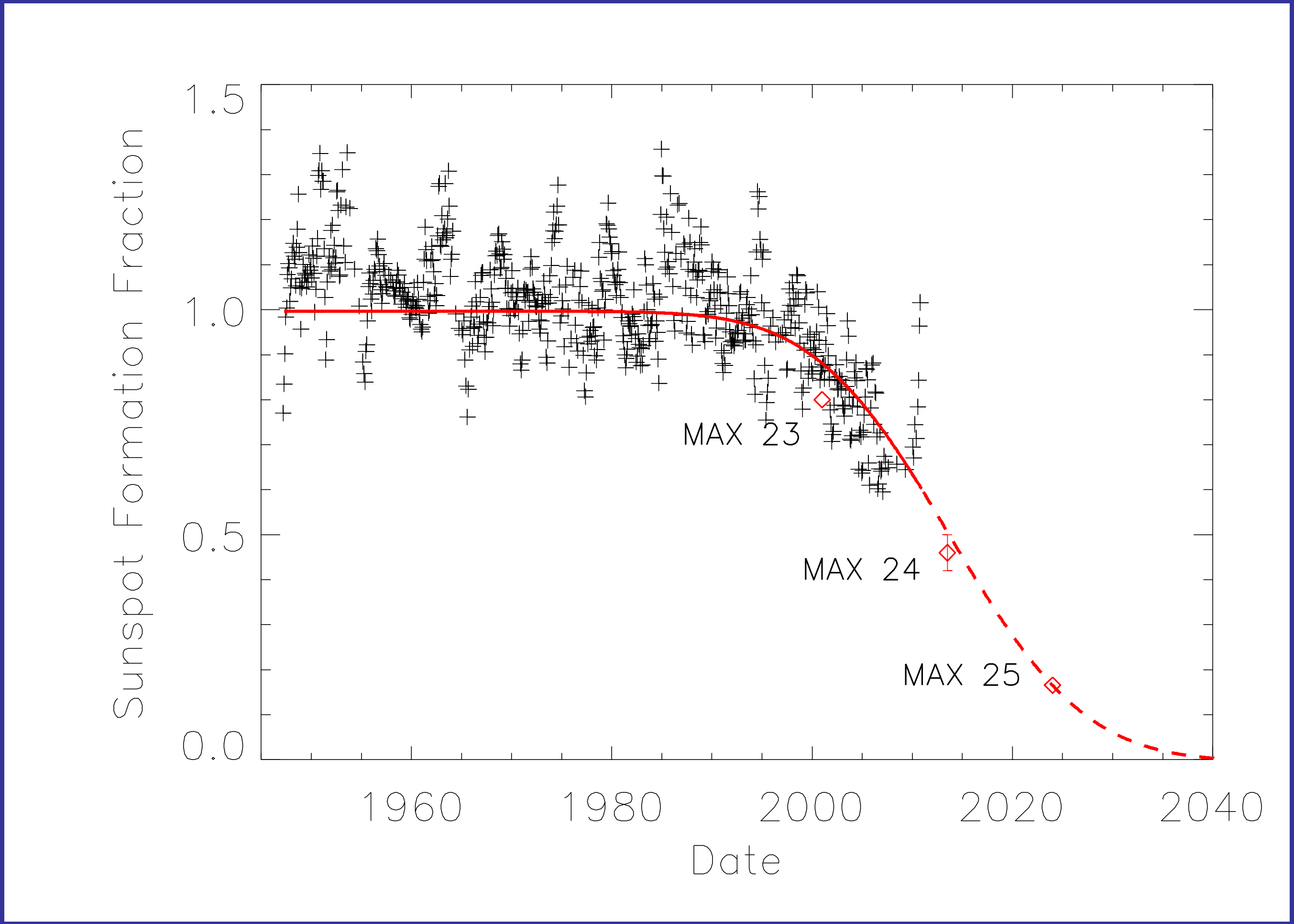
W …


+2.0
Polar Field (G)
10.7cm Radio Flux (sfu)
-2.0
Jan
Updated


SDO/HMI Quick-Look Continuum: 2013.01.24_13:54:00_TAI

How could the statistical methods be getting worse?

	Cycle 23	Cycle 24	
Committee	150	90	
Solanki et al. 2002		139	
Hathaway & Wilson 2004		145	
Du 2006		150	
Observed	119	69	
Fraction	0.79	0.46 - 0.76	
Erfc(x)			


1.5
1.0
0.5
0.0
Sunspot Formation Fraction
MAX 23
MAX 24
MAX 25
1960
1980
2000
2020
2040
Date

	Cycle 23	Cycle 24	Cycle 25
Committee	150	90	
Solanki et al. 2002		139	159
Hathaway & Wilson 2004		145	70
Du 2006		150	102
Observed	119	65	
Fraction	0.79	0.43 - 0.72	
Erfc(x)	0.85	0.5	0.2

Speculations about "How?"

- Toroidal field is being produced continuously during the cycle; is/has the poloidal seed field varying with time?

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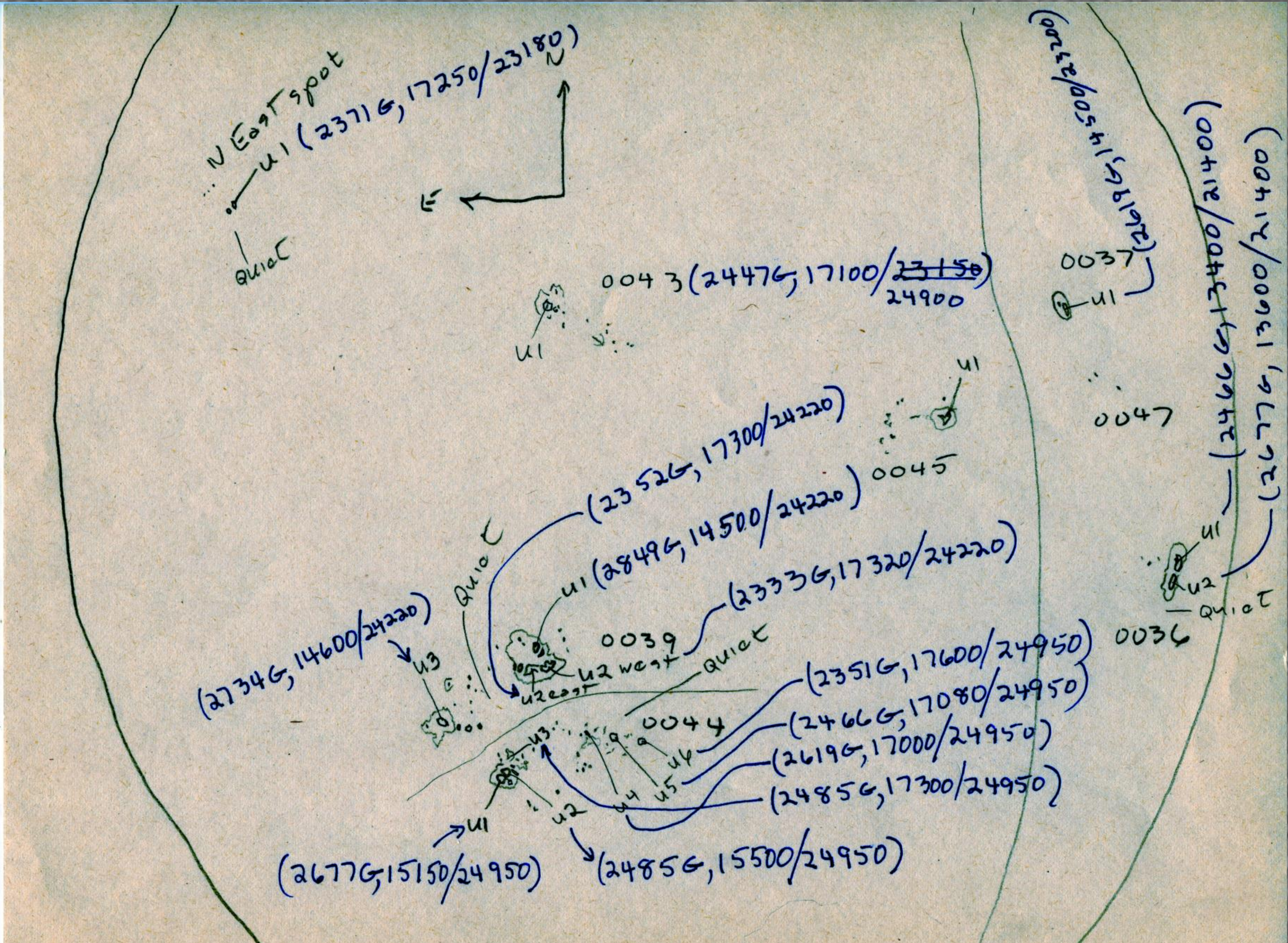
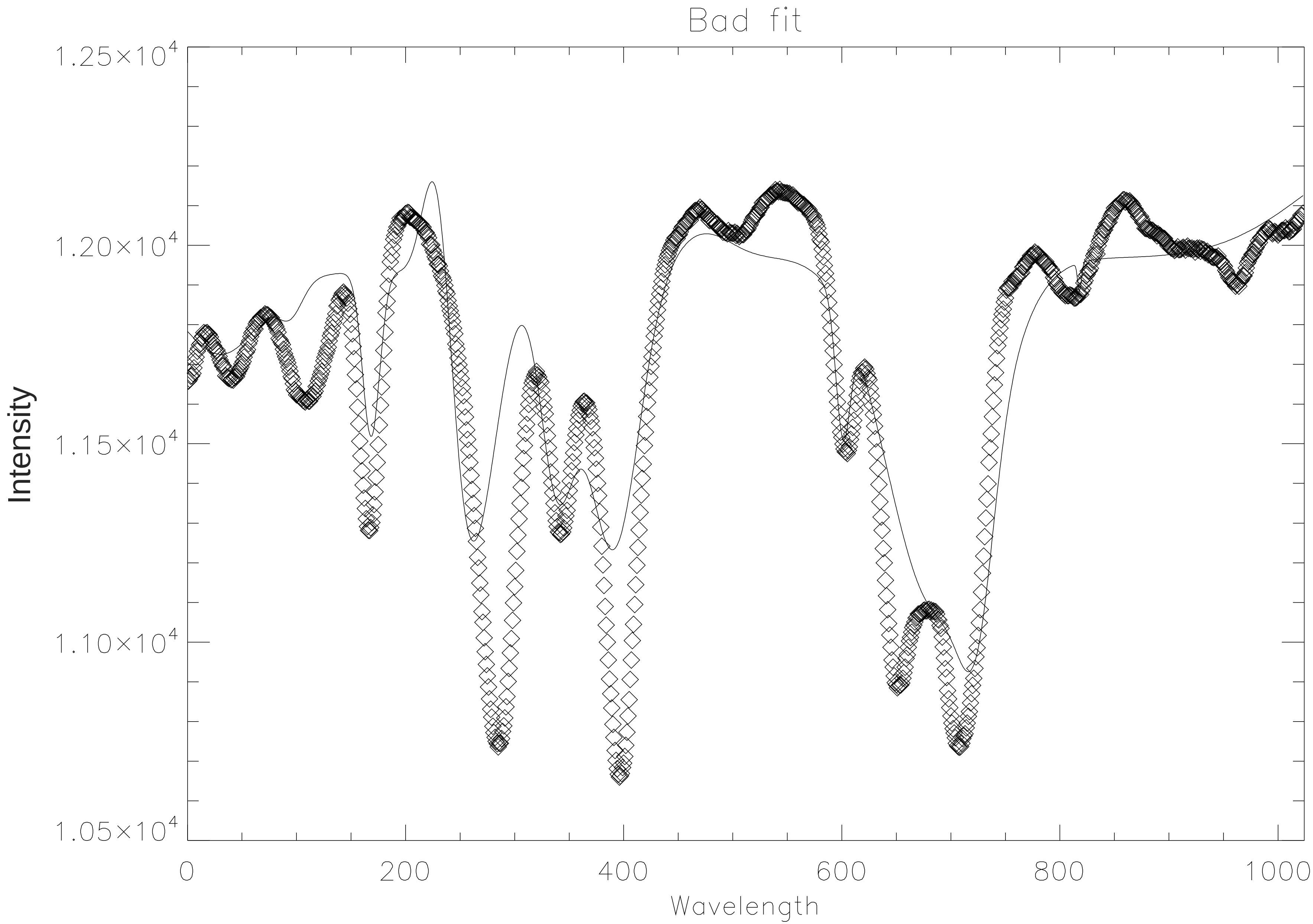
  - If the memory is n+1 cycles, can we look at the old magnetic data and see when this started?
  - If we see the seed field continuing to decrease now, can we predict n+1 cycles more of this drop?
- Differential rotation produces the toroidal field; is this constant with time?

New Look at Data

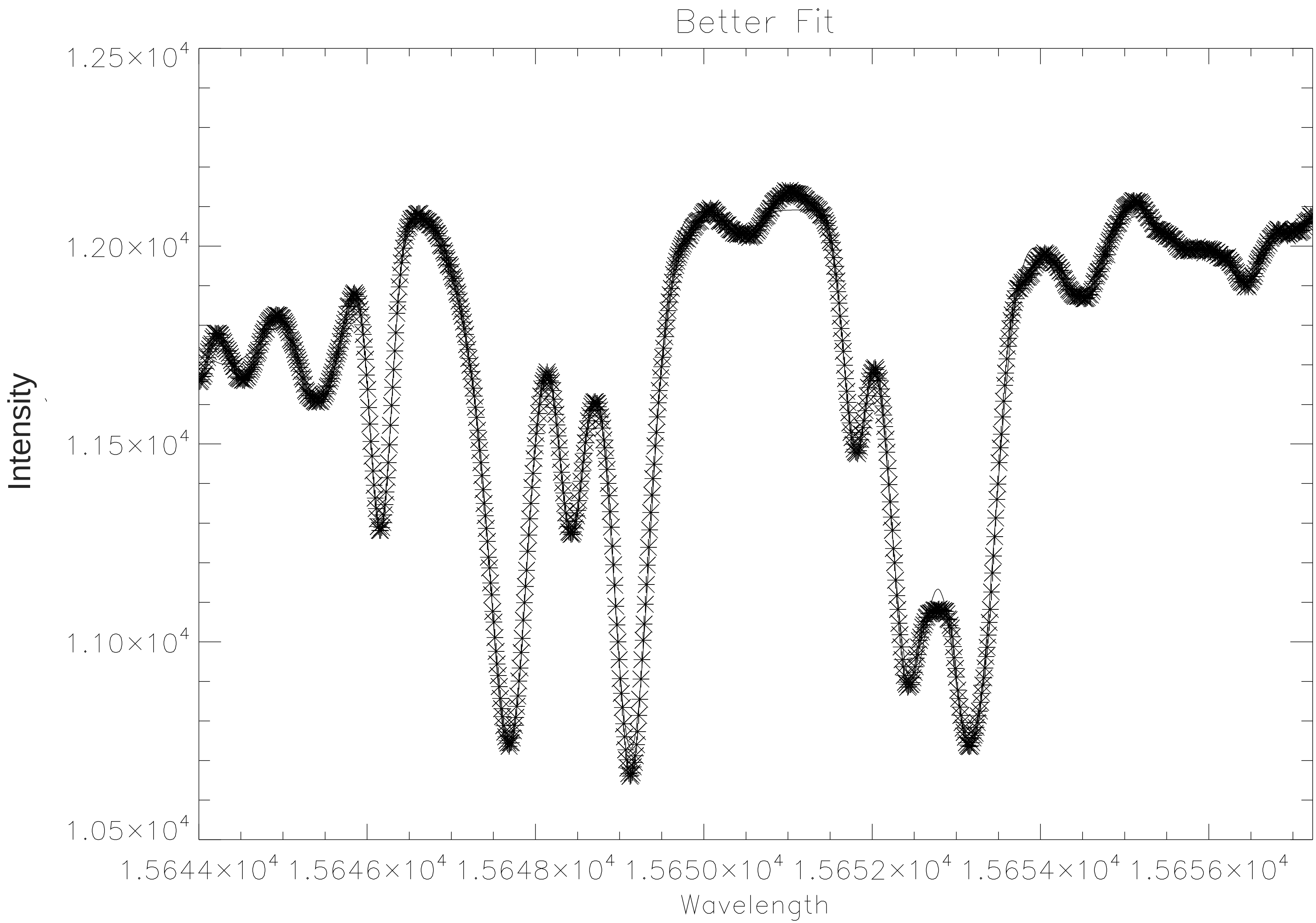
- REU student Amy Gottlieb (freshman U Maryland)
- Fitting Livingston's spectra with multiple Gaussians
  - Check magnetic field measurements
  - NEW: get Doppler velocity information
  - Develop faster data reduction
- Digitize Livingston's drawings (RET teacher Sarah Streb) and develop archive with associated spectra



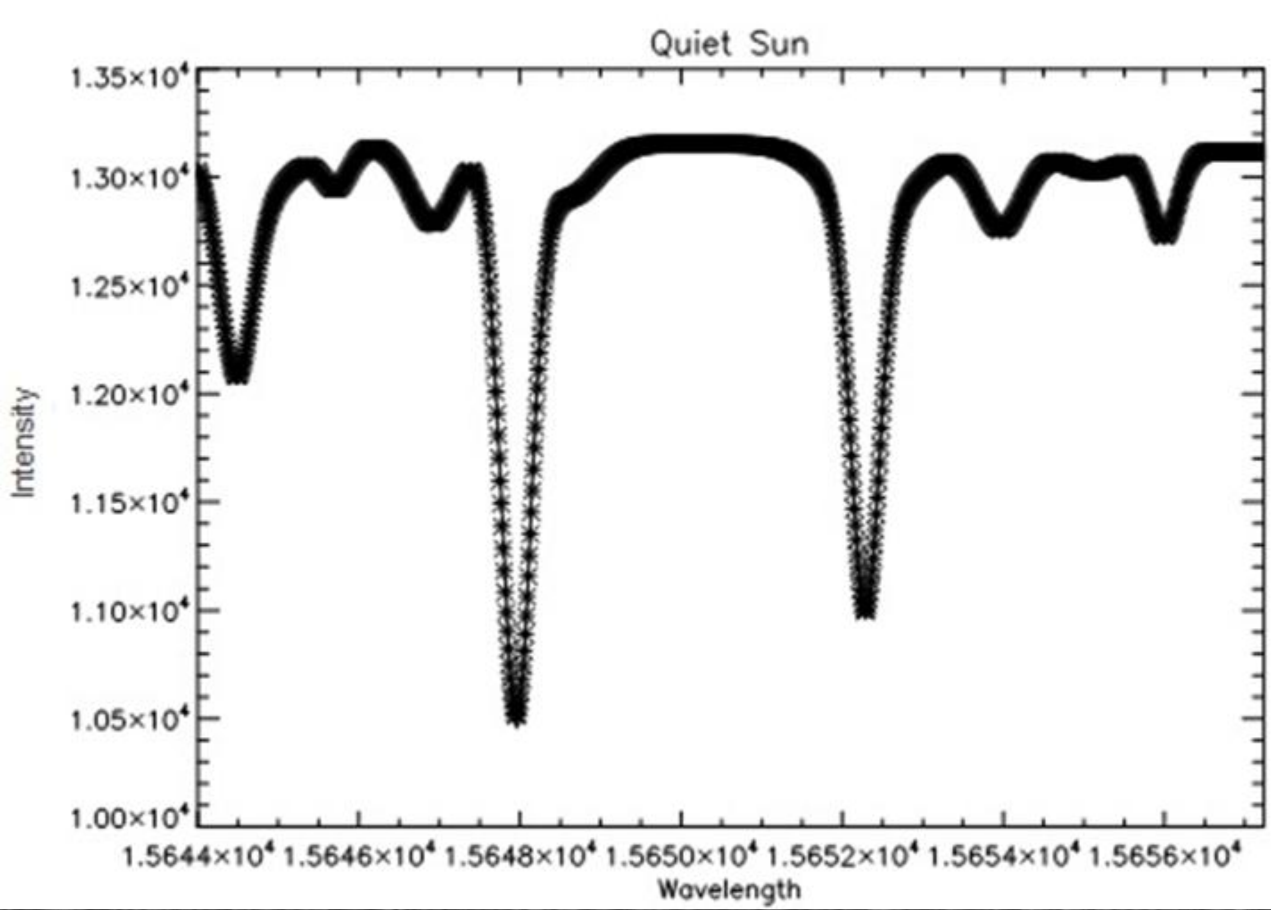
26 Jul 02 0700



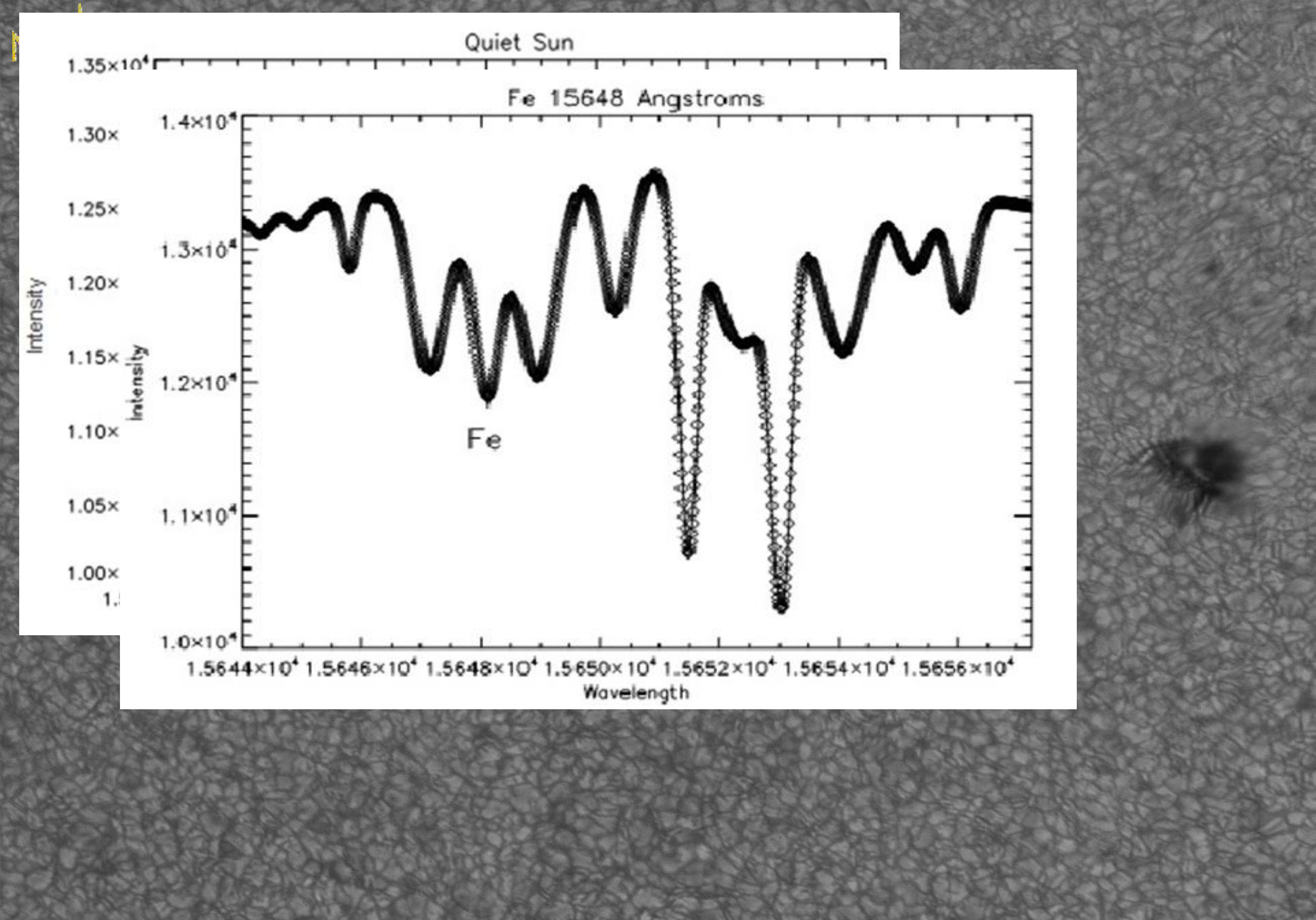
Bad fit
1.25×10^4
1.20×10^4
1.15×10^4
1.10×10^4
1.05×10^4
Intensity
0
200
400
600
800
1000
Wavelength

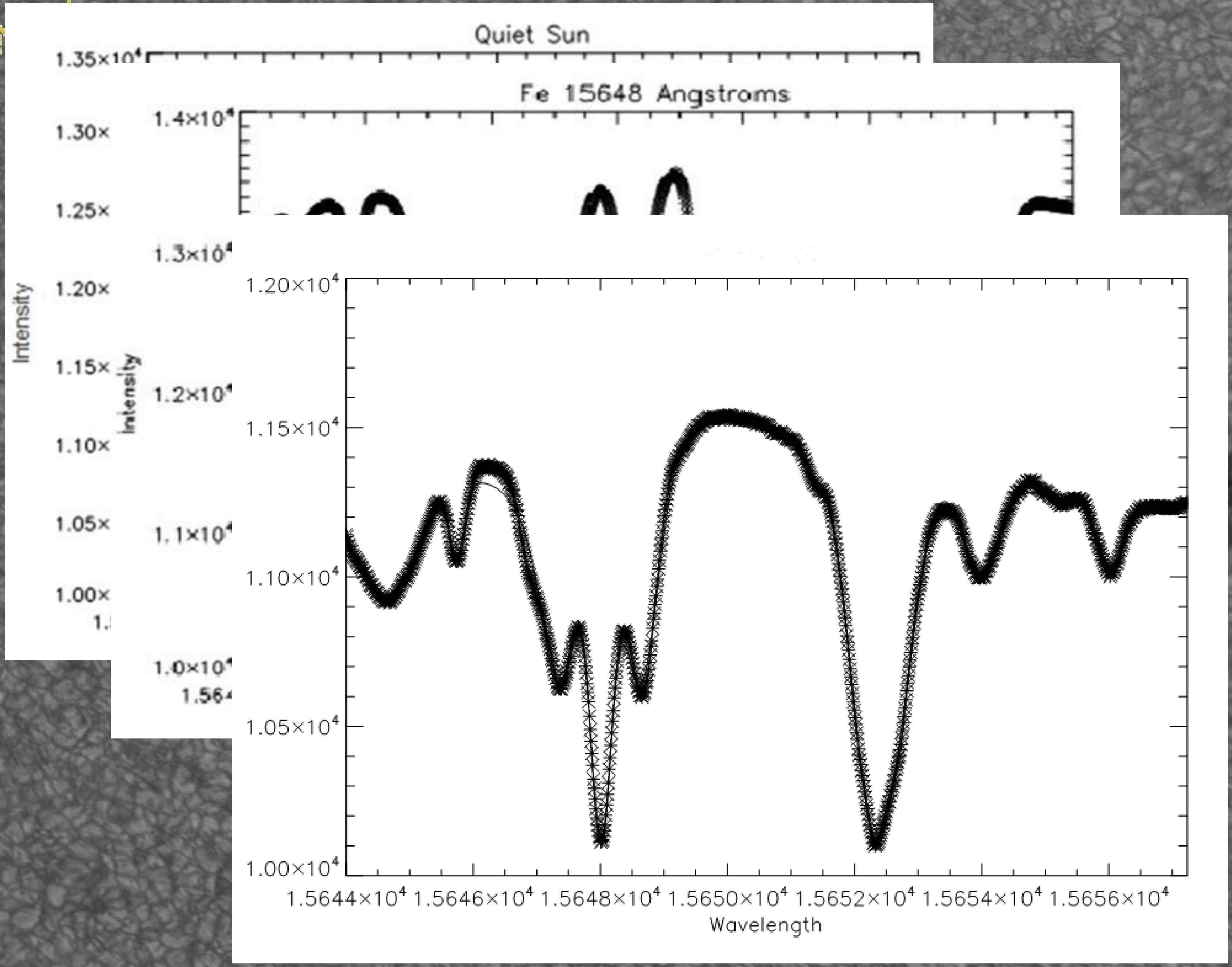


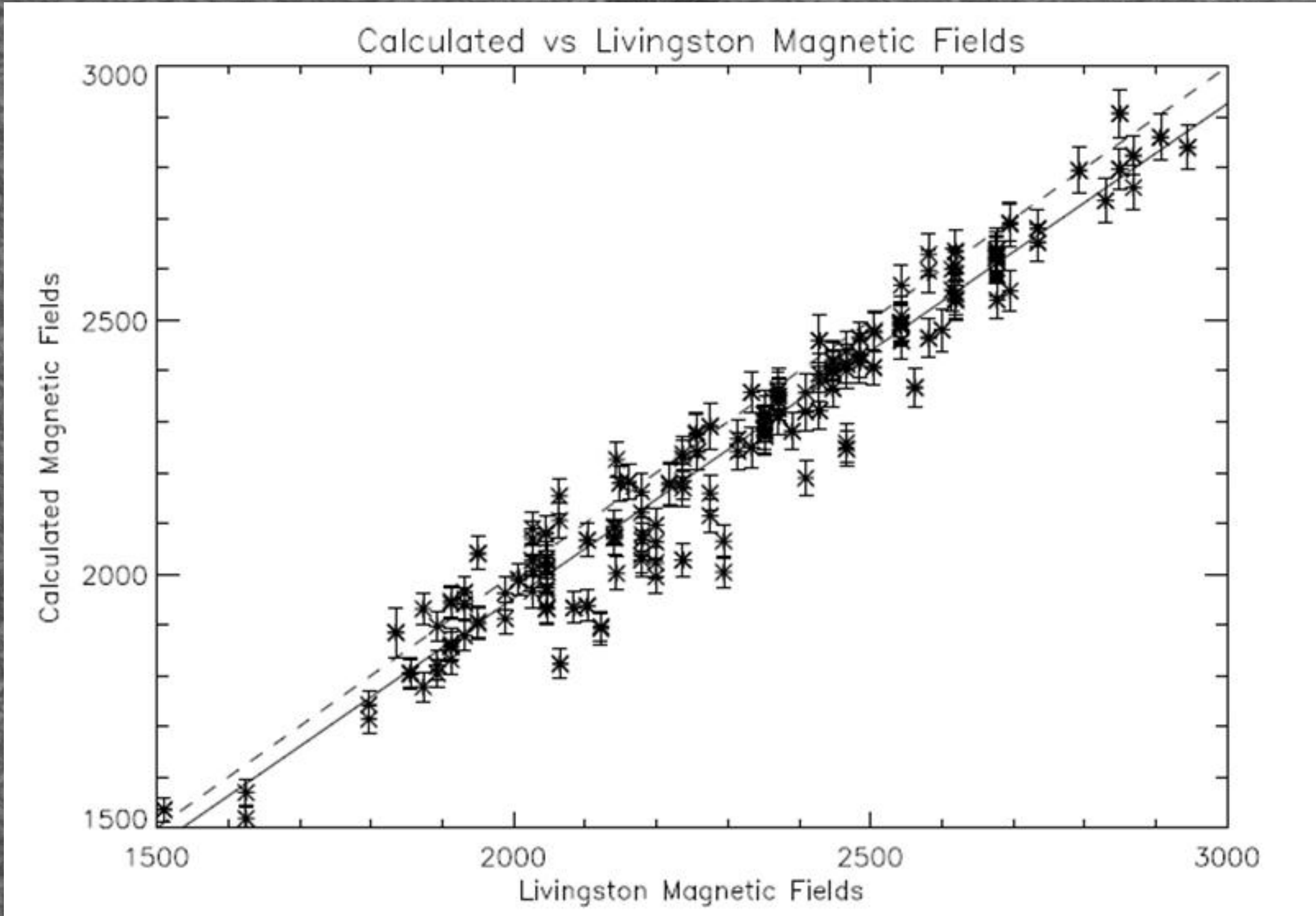
Better Fit
Intensity
Wavelength
1.25×10^4
1.20×10^4
1.15×10^4
1.10×10^4
1.05×10^4
1.5644×10^4
1.5646×10^4
1.5648×10^4
1.5650×10^4
1.5652×10^4
1.5654×10^4
1.5656×10^4

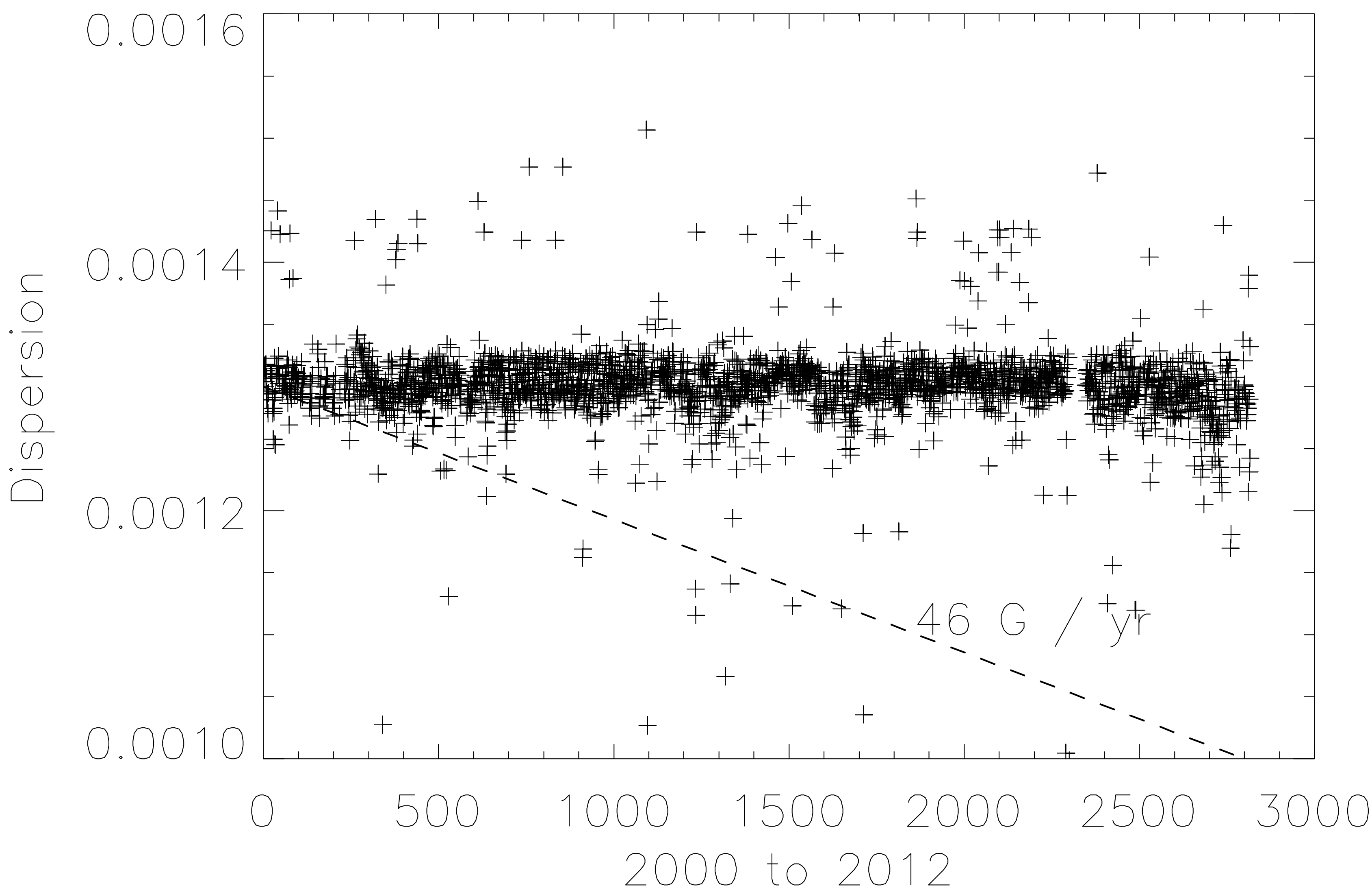


Quiet Sun
Intensity
Wavelength
1.35×10⁴
1.30×10⁴
1.25×10⁴
1.20×10⁴
1.15×10⁴
1.10×10⁴
1.05×10⁴
1.00×10⁴
1.5644×10⁴
1.5646×10⁴
1.5648×10⁴
1.5650×10⁴
1.5652×10⁴
1.5654×10⁴
1.5656×10⁴

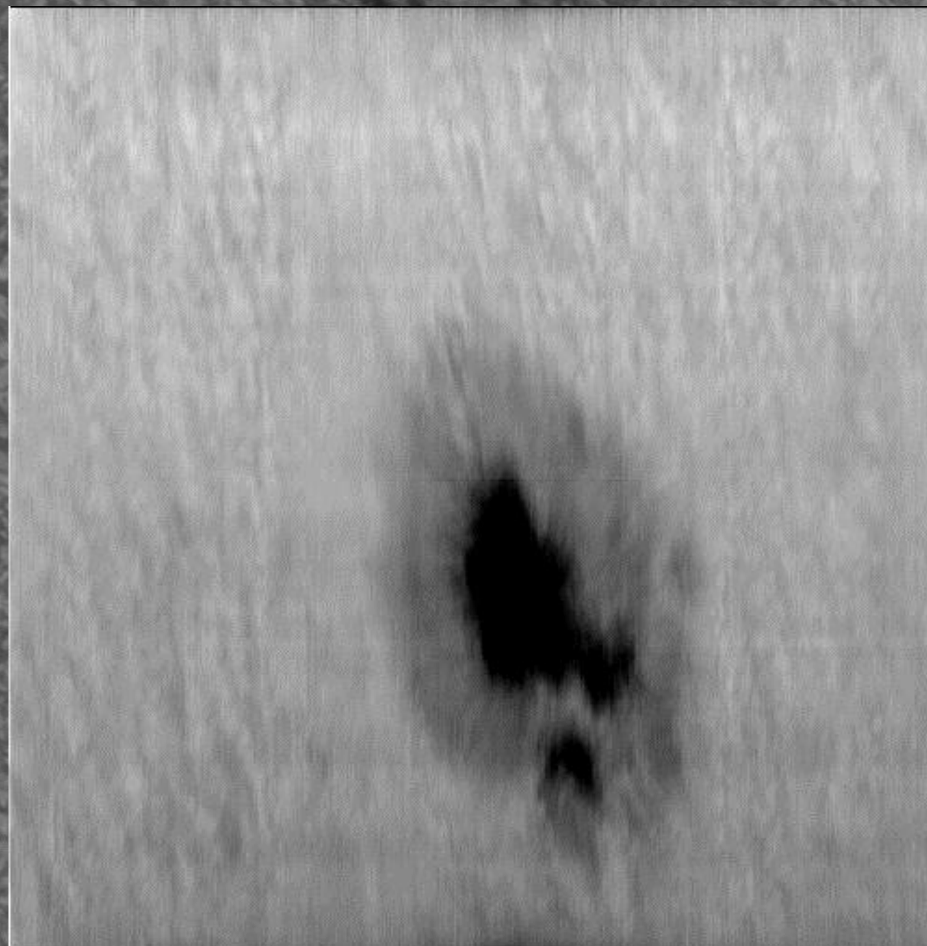

Quiet Sun
1.35×10⁴
1.30×
1.25×
1.20×
1.15×
1.10×
1.05×
1.00×
Intensity
Fe 15648 Angstroms
1.4×10⁴
1.3×10⁴
1.2×10⁴
1.1×10⁴
1.0×10⁴
Intensity
Fe
1.5644×10⁴ 1.5646×10⁴ 1.5648×10⁴ 1.5650×10⁴ 1.5652×10⁴ 1.5654×10⁴ 1.5656×10⁴
Wavelength


Quiet Sun
Fe 15648 Angstroms
Intensity
Intensity
1.35×10⁴
1.30×
1.25×
1.20×
1.15×
1.10×
1.05×
1.00×
1.4×10⁴
1.3×10⁴
1.2×10⁴
1.1×10⁴
1.0×10⁴
1.20×10⁴
1.15×10⁴
1.10×10⁴
1.05×10⁴
1.00×10⁴
1.5644×10⁴ 1.5646×10⁴ 1.5648×10⁴ 1.5650×10⁴ 1.5652×10⁴ 1.5654×10⁴ 1.5656×10⁴
Wavelength


Calculated vs Livingston Magnetic Fields
Calculated Magnetic Fields
Livingston Magnetic Fields
1500
2000
2500
3000
1500
2000
2500
3000

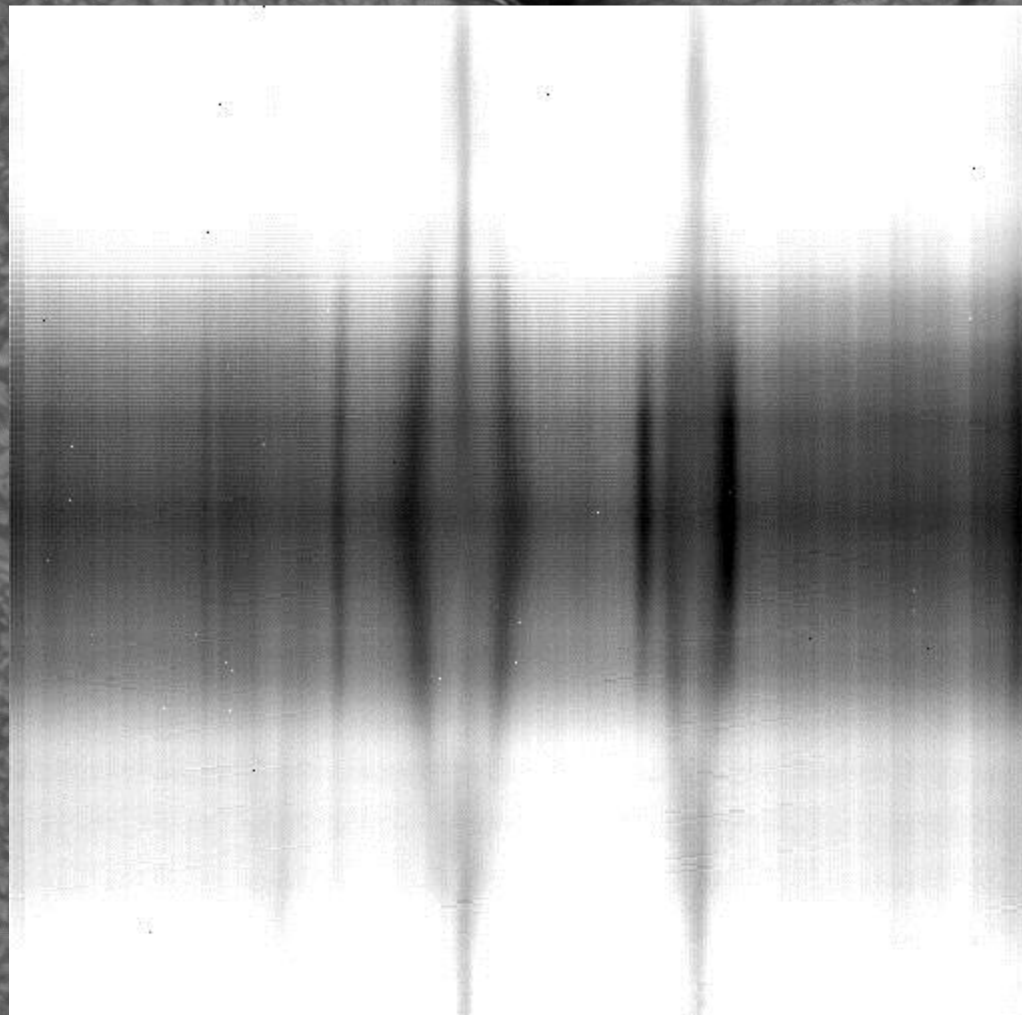

0.0016
0.0014
0.0012
0.0010
Dispersion
46 G / yr
0
500
1000
1500
2000
2500
3000
2000 to 2012

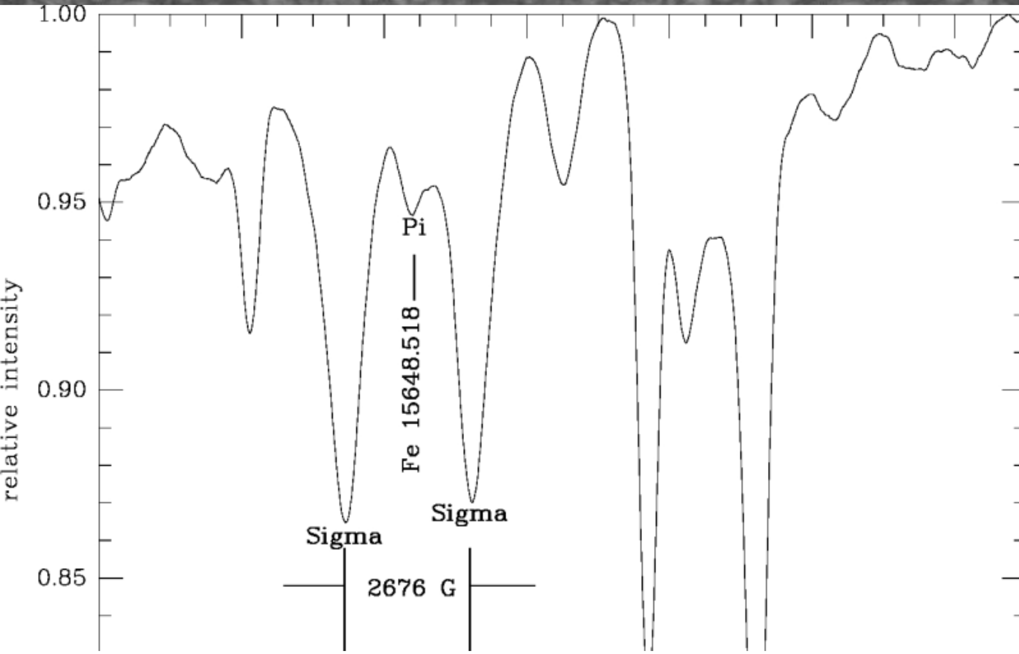
New observations

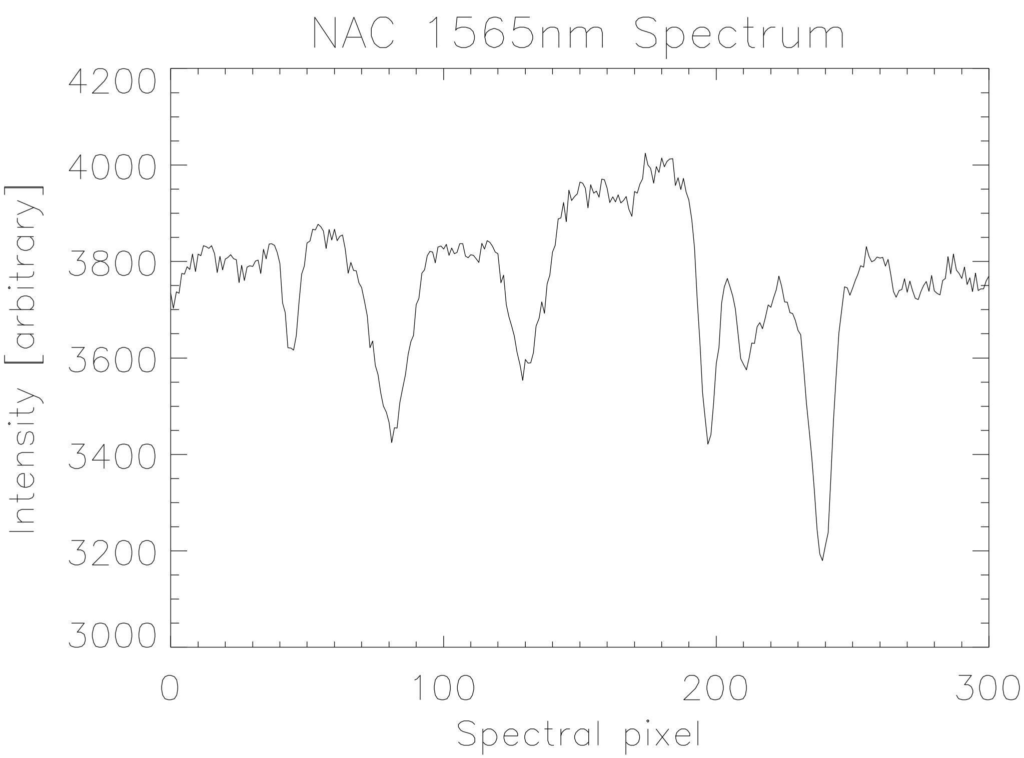


Outline

Outline







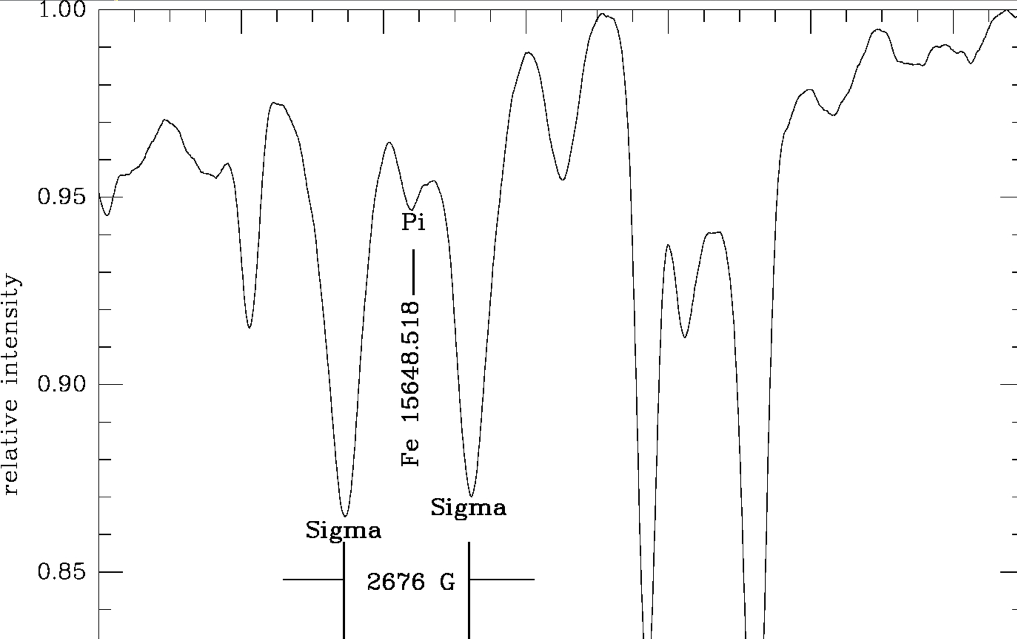
Comparision with Livingston’s spectrum (different spots) shows the NAC spectra have considerably worse signal to noise.

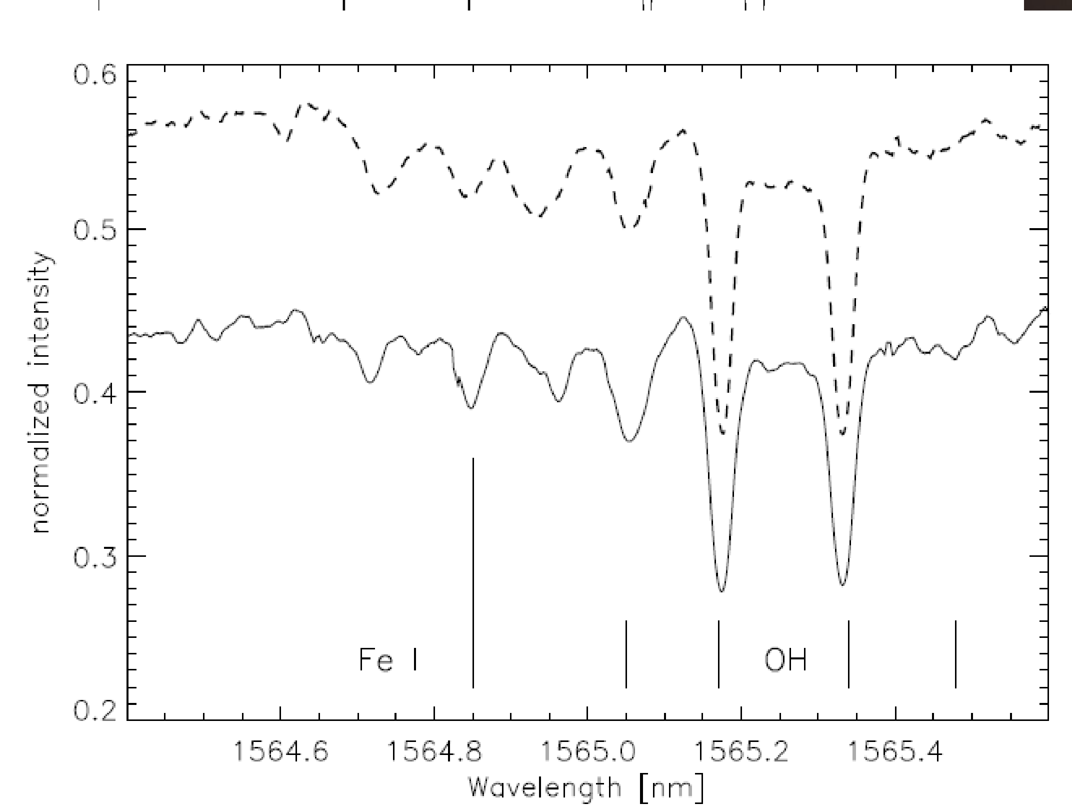
Livingston S/N =3000

Raw NAC S/N = 250

Summing (25*13=325) spectra should improve NAC S/N to about 4000

Systematics currently dominate





Rezaie, Beck & Schmidt

Future of the McM/P?

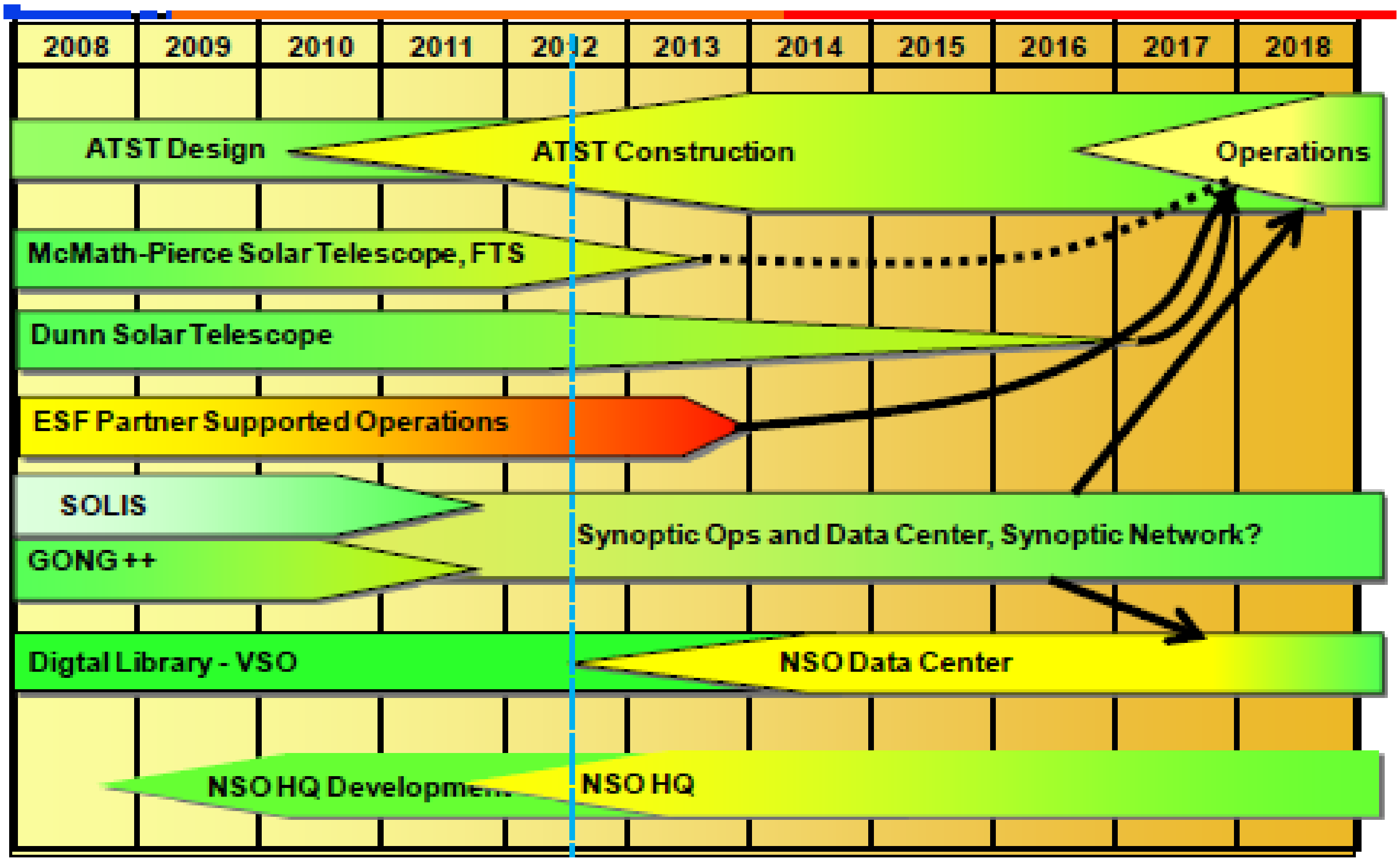


Figure 1. Strategic road map for NSO facilities.

Future of the McM/P?

- Best current estimate is that the McM/P facility could be operated in “survival” mode at a cost of \$160k - \$190k per year.

- ***This is 2.2 % of the NSO budget.***

- A McM/P Consortium Workshop will be held in Tucson on 7 Feb for parties interested in continuing to operate the telescope

Future of the McM/P?

- Another approach is to operate the facility as an "instrument" to collect sunspot magnetic field data.

- NASA funding opportunities exist to take ground-based data in support of space missions; i.e. using McM/P data to support HMI. This is the H-IDEE program, and letter of intent is due 15 May

- I would like to form a group to submit such a proposal; please speak to me here or email.

End