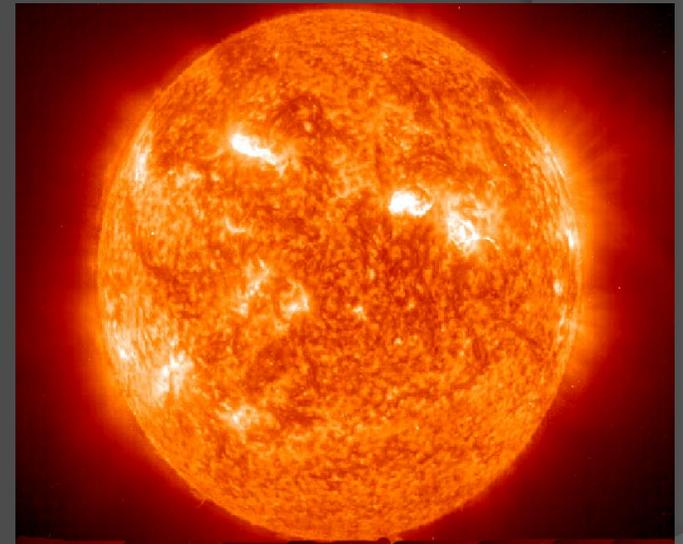


QUIET SUN MAGNETIC FIELDS

Presented By: Codie Gladney – University of Georgia
Advisors: Rebecca Centeno, Matthias Rempel, Alfred de Wijn

Introduction

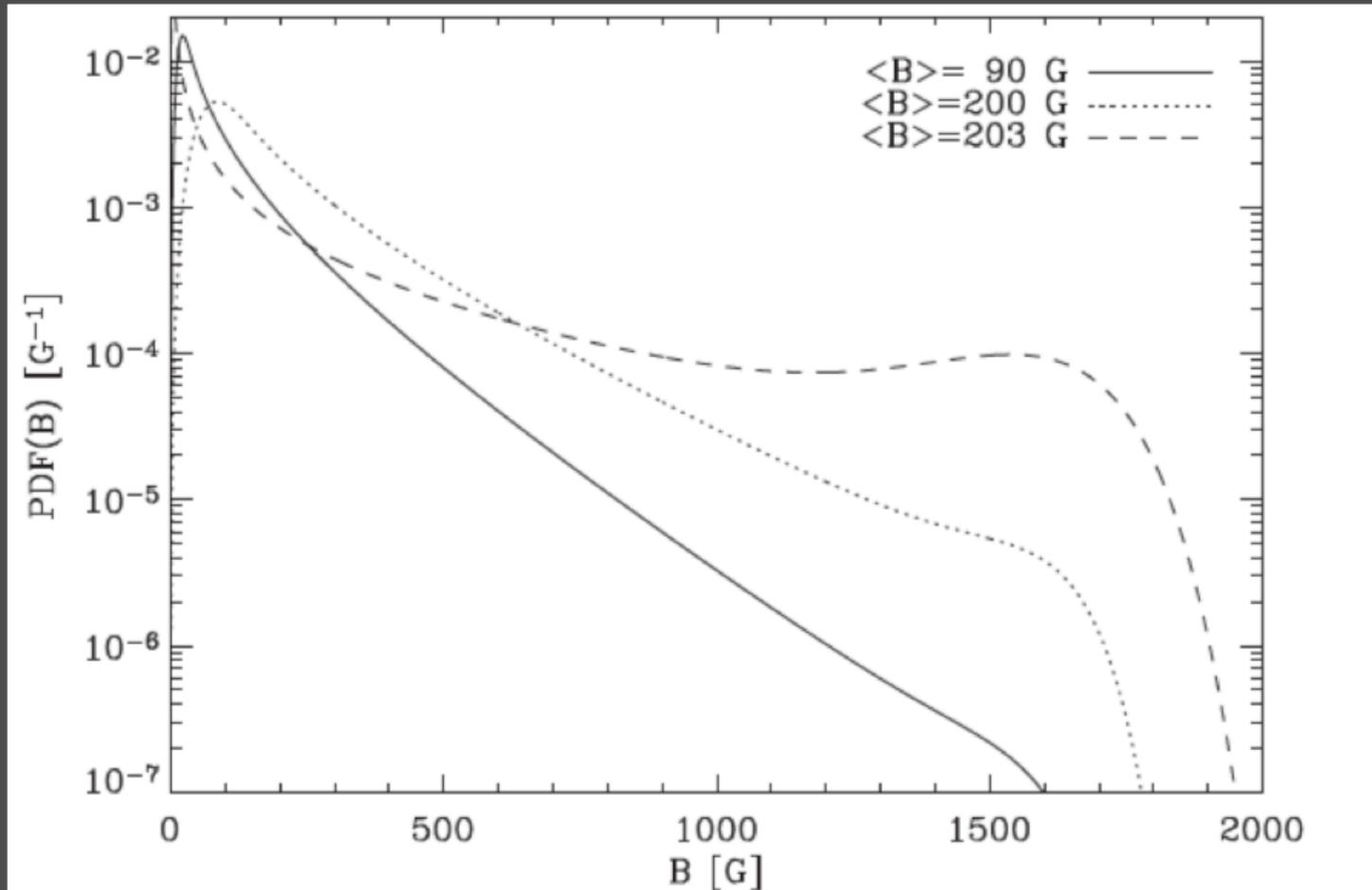
- Until recently, it was thought that Solar magnetic fields existed only within Active Regions of the Sun (where we find Sunspots). The remainder of the Sun was termed the “Quiet Sun” because it was considered to be magnetically “quiet.”
- Advances in instrumentation were accompanied with the discovery of weak magnetic fields that were previously undetectable. These magnetic fields pervade the entire solar surface.
- The net effect of the Quiet sun’s magnetic fields dominates the magnetic flux and energy budget of the Sun - even during solar maxima (when sunspot counts are at their highest).



What is the distribution of Quiet Sun magnetic fields?

- What does the magnetic field distribution look like in the Quiet Sun? What percentage of the Quiet Sun contains weak magnetic fields? What percentage has strong fields?
- Observational data has been obtained from separate instruments, using different analysis techniques, and distinctly different distribution curves were obtained.

Distribution Curve

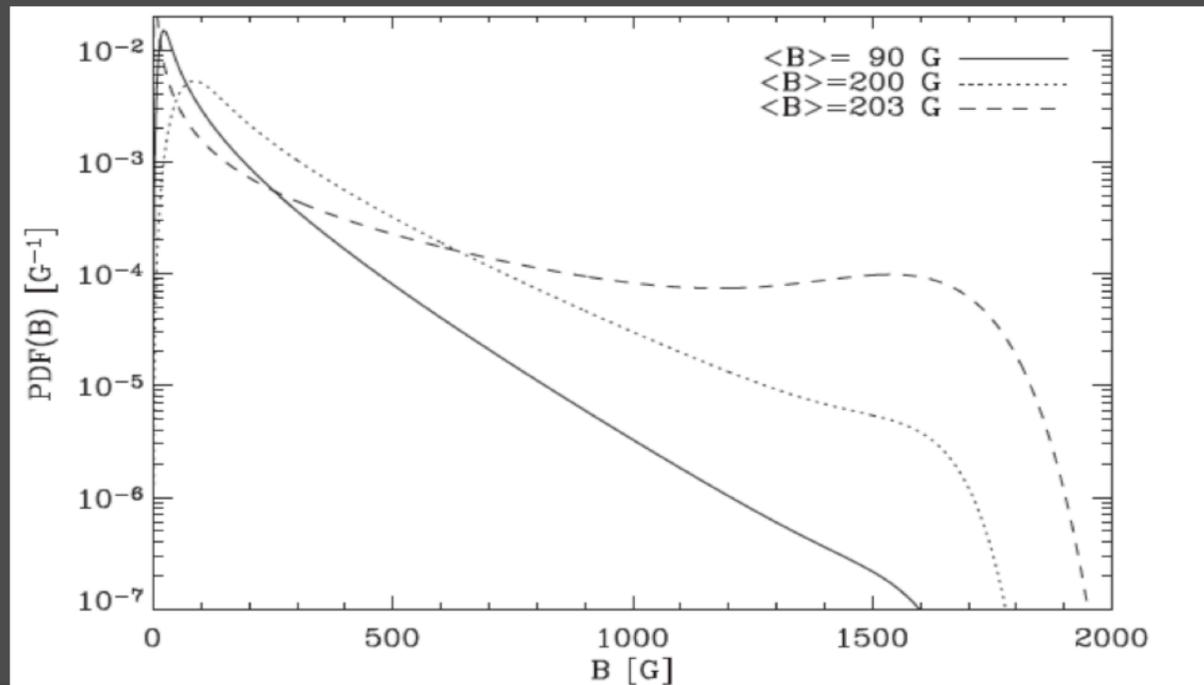


Motivation

- The Quiet Sun's magnetic fields are individually weak, but their net effect dominates the magnetic flux and energy budget of the entire Sun.
- An understanding of the solar magnetic flux is an essential piece of the solar puzzle.
- We wish to determine the distribution of the magnetic field strengths in the Quiet Sun and put the dispute to rest.

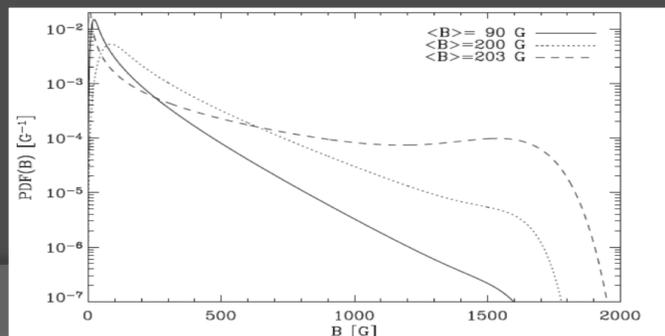
Why is there a discrepancy?

- Observational instruments and analysis procedures introduce numerous errors.



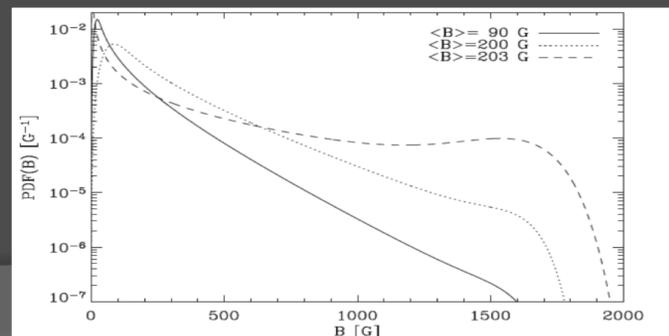
Methodology

- Let's examine exactly how analysis techniques and observational errors affect a given distribution curve.
- Matthias Rempel has created magnetohydrodynamic (MHD) simulations of the Sun.
- The simulations provide us with a synthetic, solar atmosphere that has known physical properties.
- From the MHD simulations, we calculate spectral lines in the Quiet Sun.
- We then degrade the spectral lines so that they are subject to the same errors that observations are subject to. (So we make our data look like an observation)
- Next, we apply analysis techniques to the degraded data in order to retrieve the "observational" values for parameters such as the magnetic field strength.
 - These analysis techniques also introduce some errors.
- Finally, we generate two magnetic field distribution curves:
 - One from the magnetic field strengths known from the simulated solar atmosphere
 - Another magnetic field distribution curve from the magnetic field strength we retrieved from analyzing the degraded, synthetic spectral line information
- We then compare the two curves and observe exactly how analysis techniques and observational errors affect a given distribution curve.

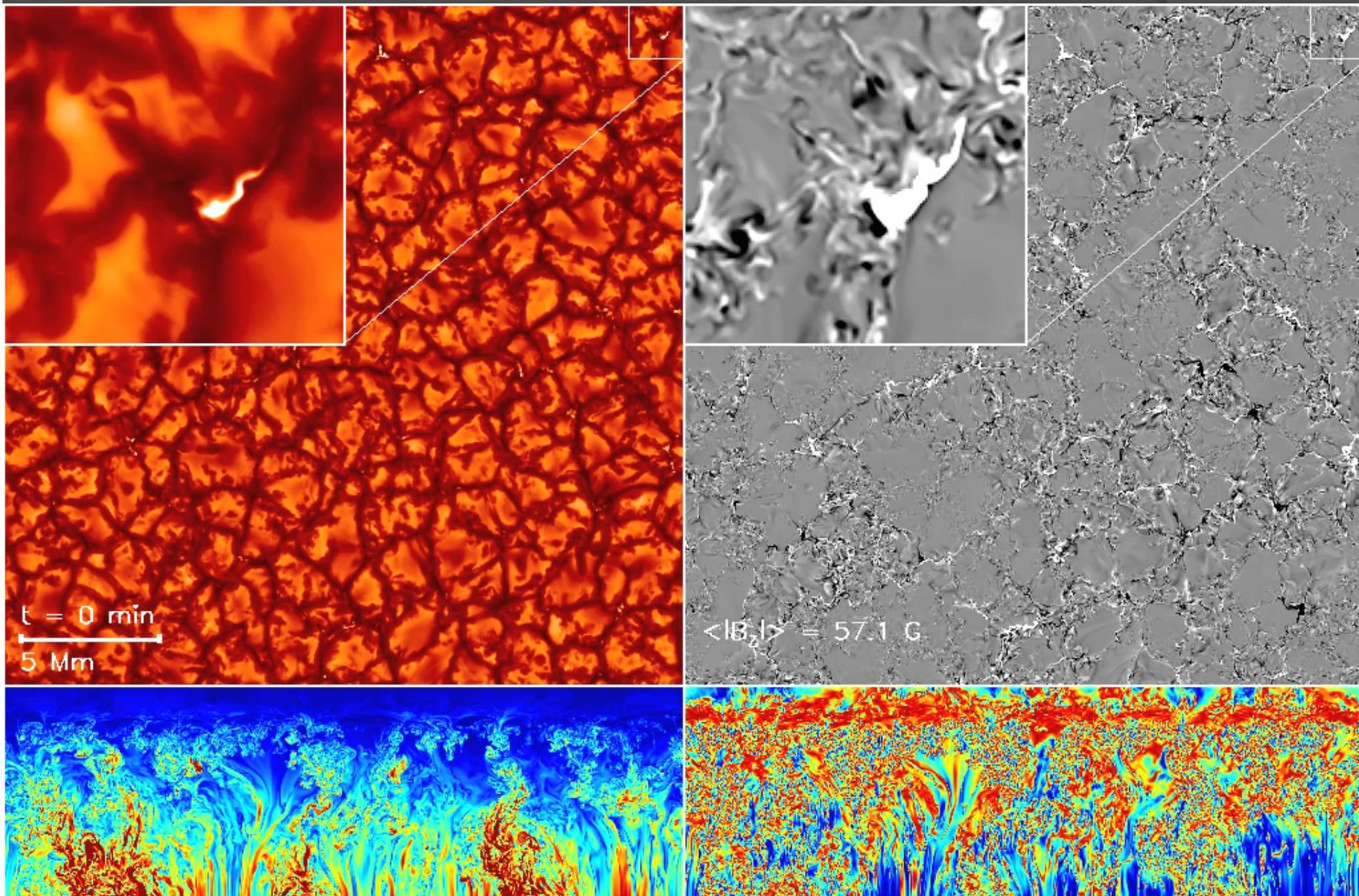


Big Picture Methodology

- 1) Create a simulation of our Sun.
- 2) Take spectral data from this simulation and degrade it so it looks like an observation.
- 3) Retrieve values of the magnetic field strength in this “observation.”
- 4) Plot the magnetic field distribution.
- 5) We also plot the magnetic field distribution for the unaltered, simulated Sun.
- 6) Compare the two plots and observe how this whole process (degradation and analysis procedures) affects the magnetic field distribution curve.

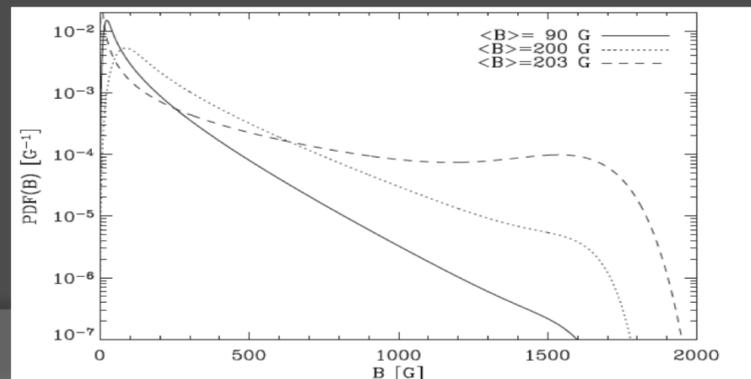


Simulations



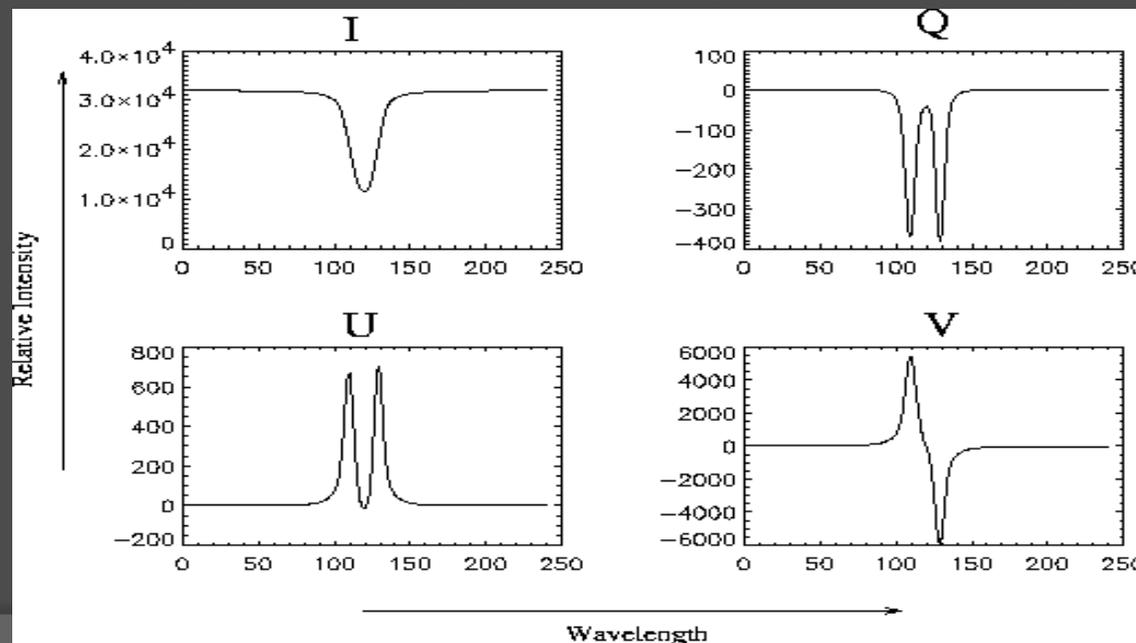
Methodology

- Matthias' unaltered simulations yield a distribution curve that looks similar to the bottom distribution curve.
- If the bump in the distribution curve appears once we degrade the data, then it is clear that the degradation process and/or the analysis techniques created this bump.
- If, after using all combinations of analysis techniques and simulated data, we still see no bump, then the bump is not an error.

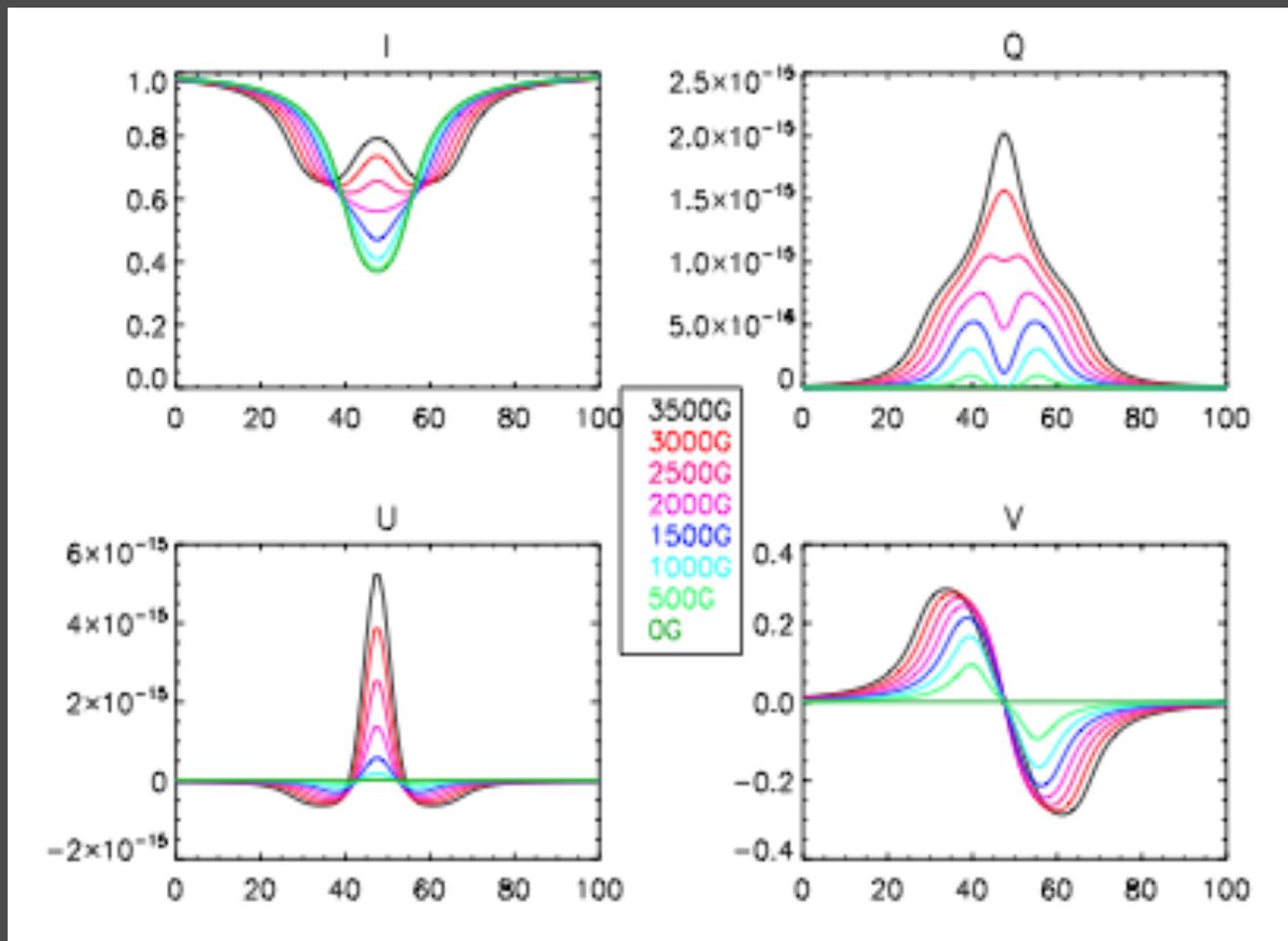


Stokes Profiles

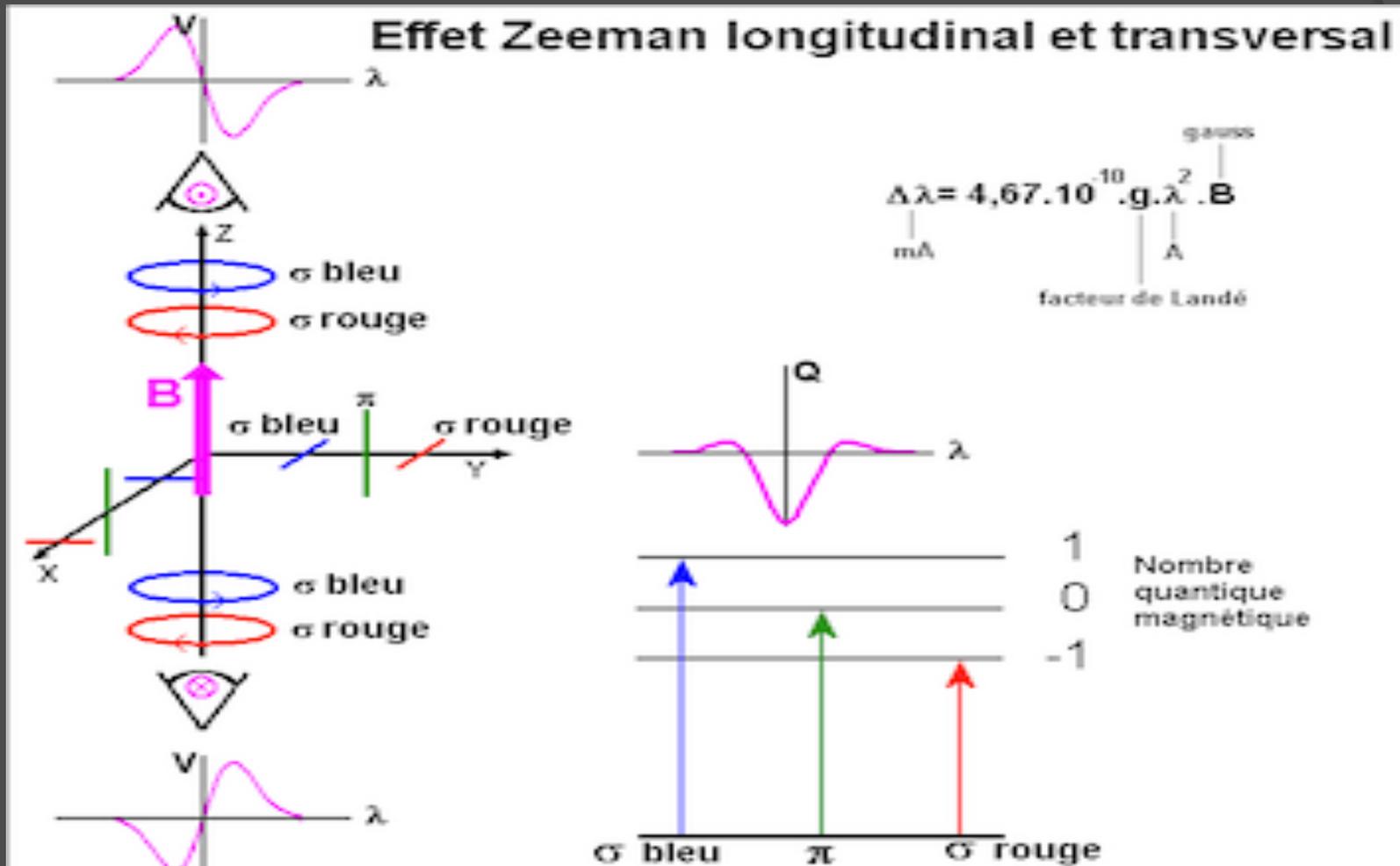
- Stokes profiles are the data retrieved from simulations that I have degraded to assist in determining the Quiet Sun magnetic field distribution. The Stokes profiles are labeled I (intensity), Q (linear polarization), U (also linear polarization), and V (circular polarization)



Magnetic Field Stokes Contributions

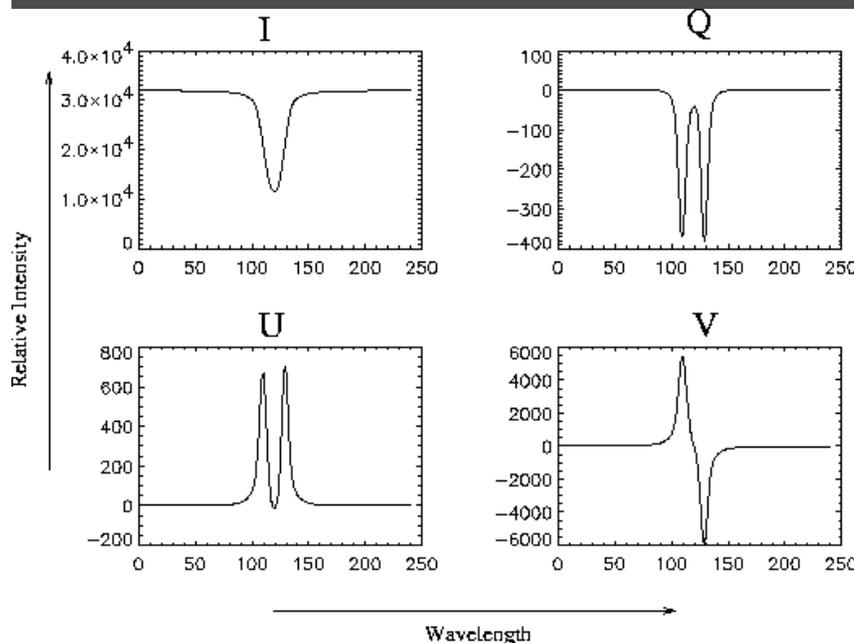


Zeeman Effect



Inversion

- Spectral line inversion codes are tools that allow the extraction of the Sun's atmospheric, physical properties, from Stokes profiles.



Inversion



B (magnetic field)
T (temperature)
P (pressure)

...

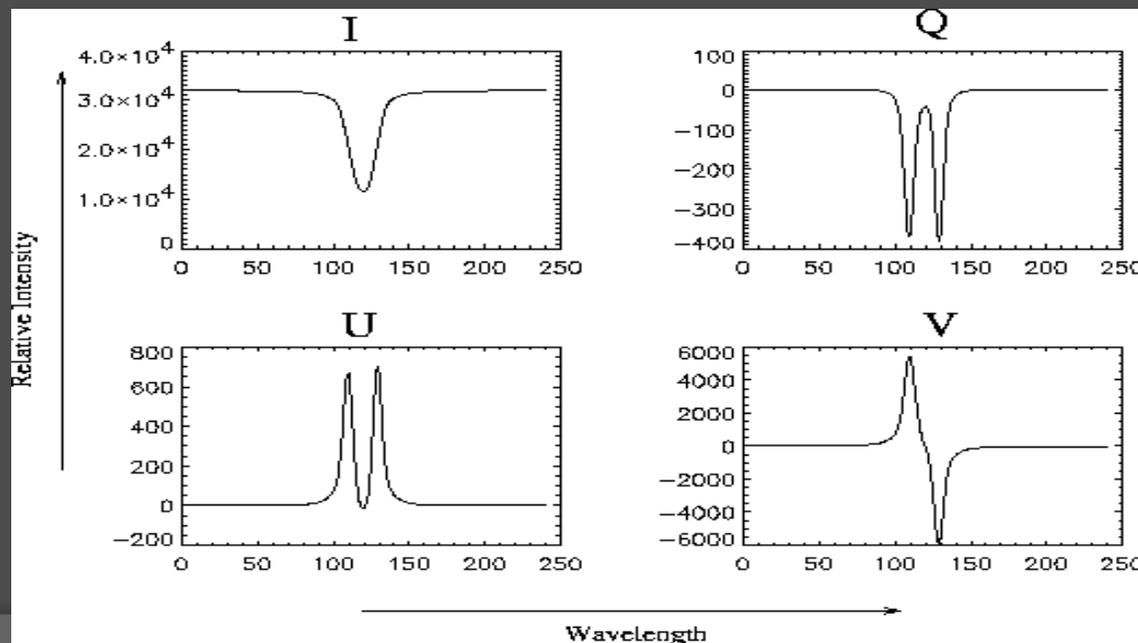
...

5-Step Process

- ① 1) Take simulated data and generate Stokes profiles
- ② 2) Degrade Stokes profiles
- ③ 3) Run our spectral line inversion code on the degraded profiles.
 - This returns magnetic field strength values (amongst other parameter values)
- ④ 4) Create histograms, which display the distribution of these magnetic field strengths in the Quiet Sun.
- ⑤ 5) Compare the degraded distribution curve with the unaltered curve

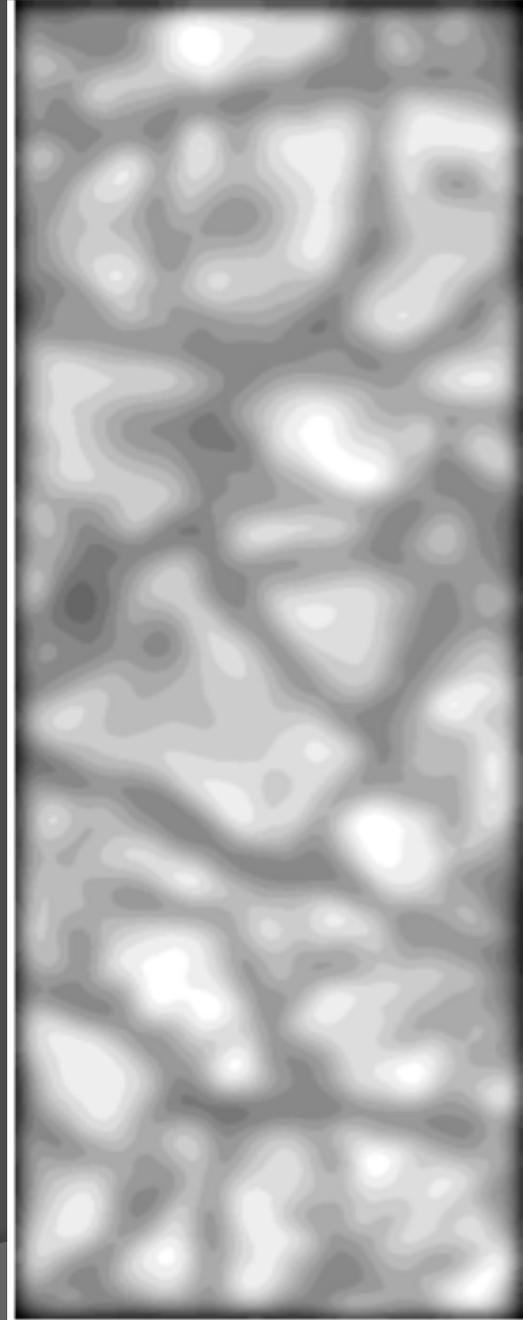
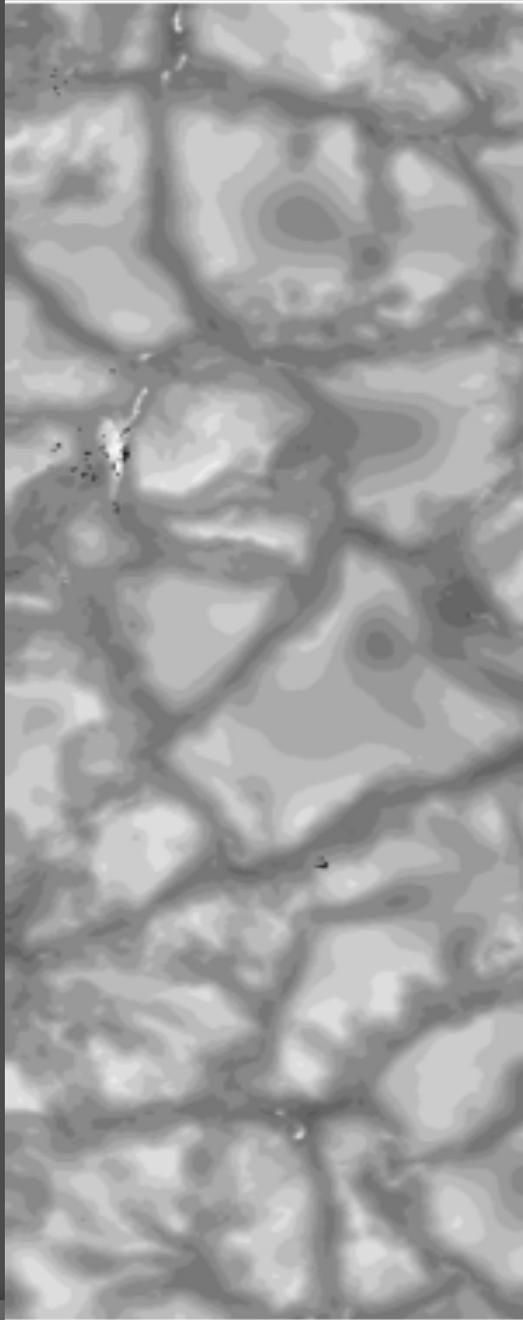
Step 1: Generate Stokes Profiles

- This was done by simply running a spectral line synthesis code that generated Stokes profiles for every position in the MHD Quiet Sun simulation (separated by 16km).



Step 2: Degrade the Stokes Profiles

- I first degraded the synthetic stokes profiles spatially (x and y directions) by convolving them with a Gaussian profile.
 - This was done by creating a Gaussian profile with a FWHM (full width at half maximum) of 240km and convolving this Gaussian with our simulated spectral data



Spectral Smearing

- Next, I degraded the profiles spectrally, in the wavelength direction.
- The spatial and spectral smearing were done in order to replicate the limitations of Hinode's instruments.

Hinode

- ◉ Hinode is a Japanese mission, in collaboration with the United States and the United Kingdom, designed to study the magnetic fields of the Sun.
- ◉ Hinode has three main instruments:
 - SOT (Solar Optical Telescope)
 - XRT (X-ray Telescope)
 - EIS (Extreme-Ultraviolet Imaging Spectrometer)



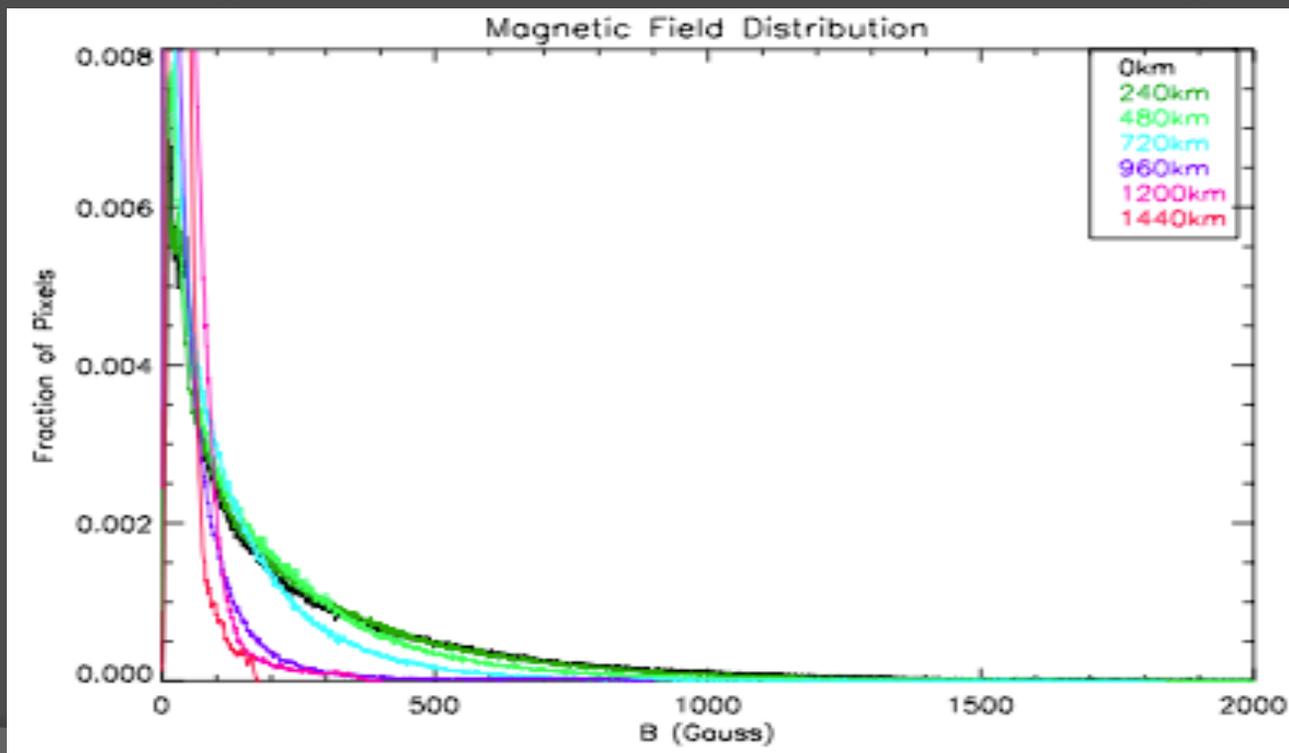
Step 3: Run the Spectral Line Inversion Code

- ⦿ Now that we have degraded the Stokes profiles so that the data is subject to the same errors that observations are subject to, we run the HEXIC spectral line inversion code, which analyzes the Stokes profiles and returns the parameter values of the simulated Sun's atmosphere.
- ⦿ The parameter we are most interested in is the magnetic field strength, B , at every point on our simulated, solar surface.

Step 4: Create Histograms

- A histogram is a graphical representation of the distribution of data.

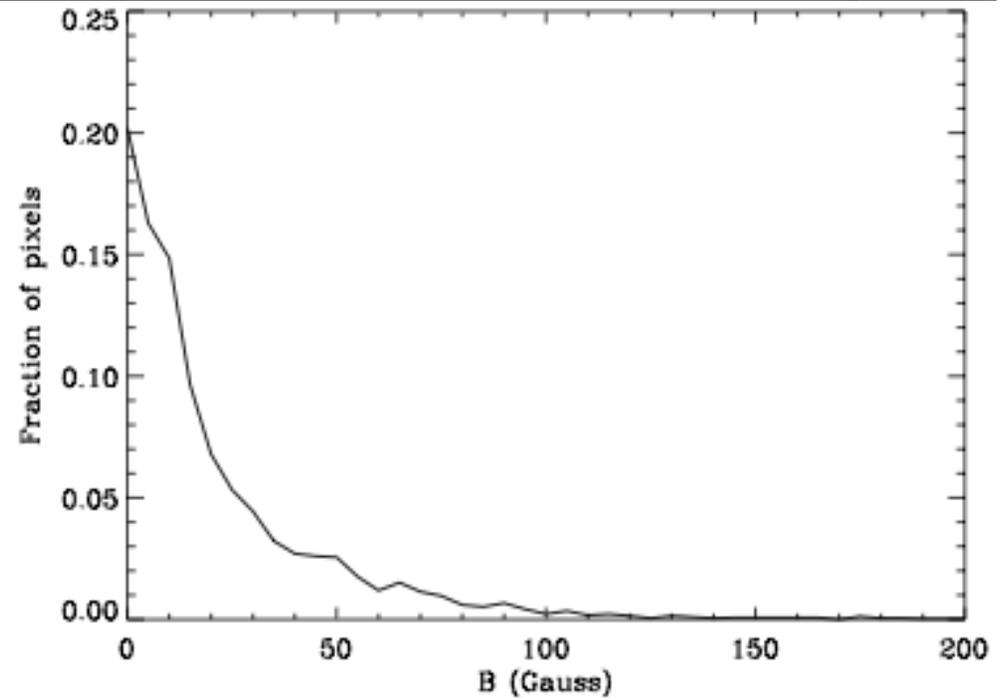
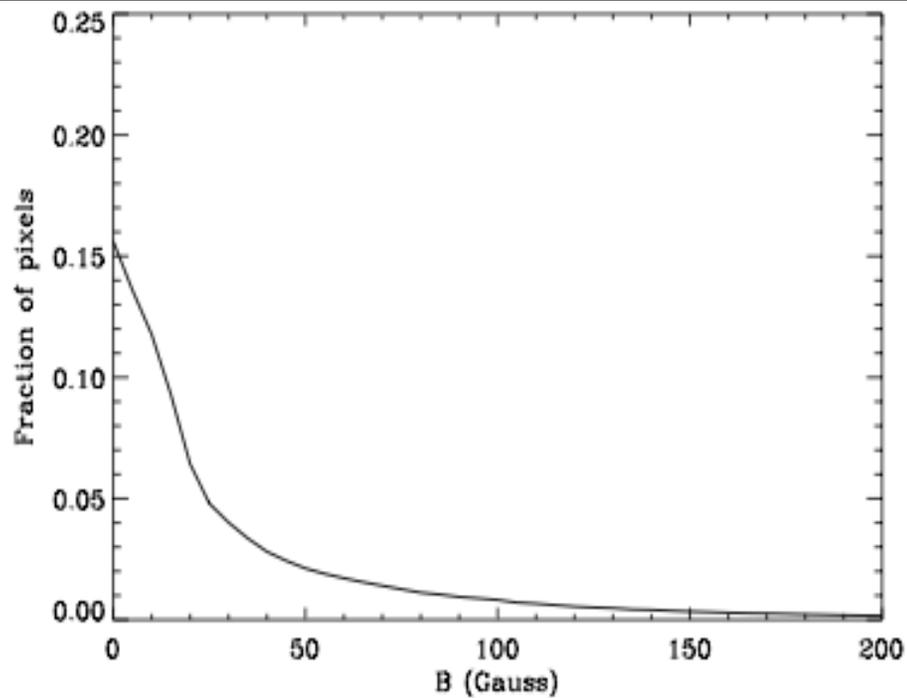
MHD Magnetic Field Distribution Curves at Various Heights



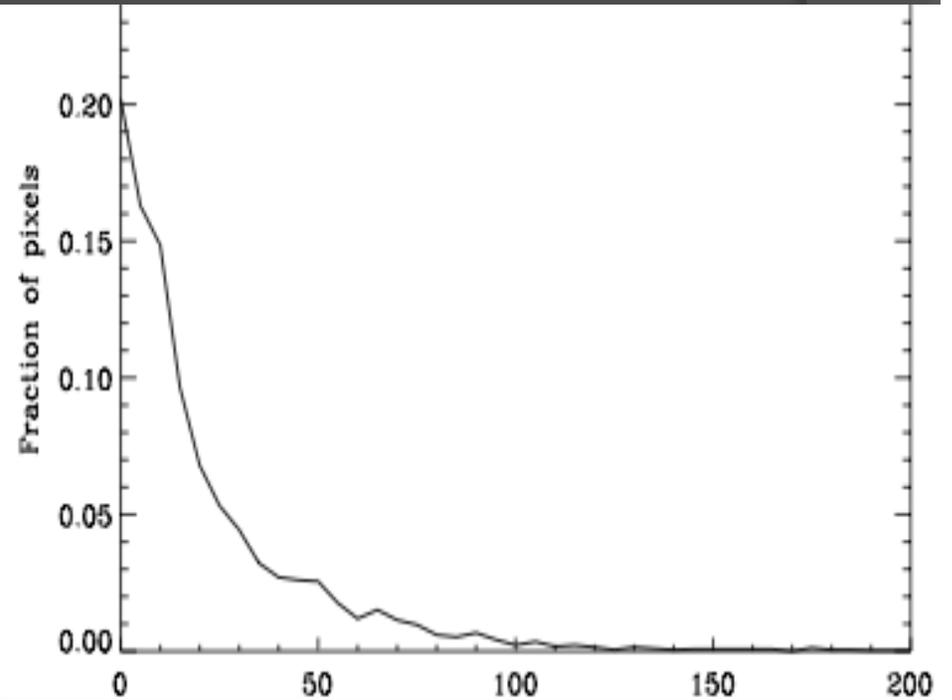
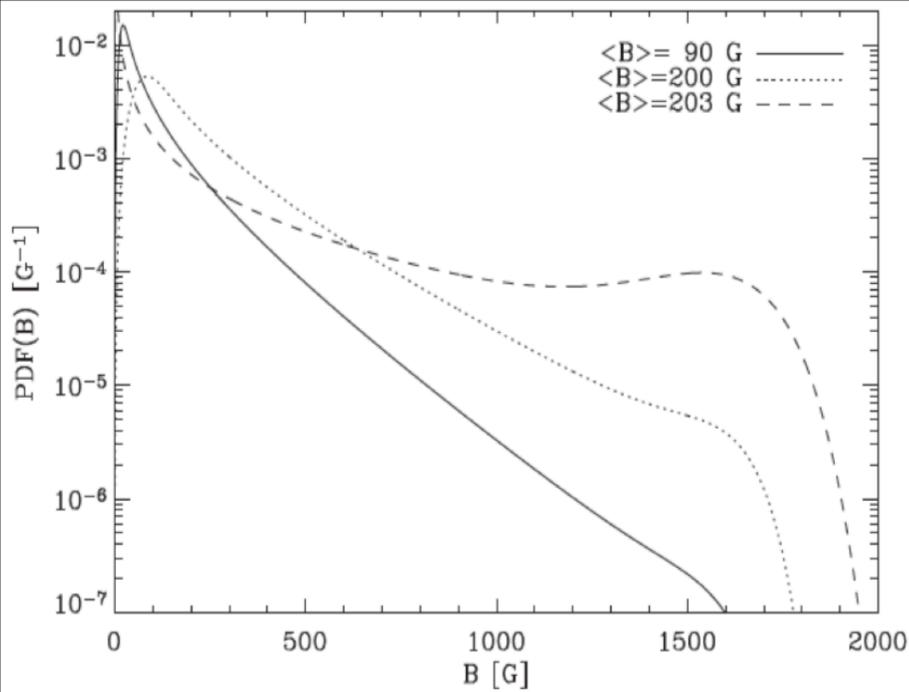
Step 5: Comparisons

MHD Simulated Magnetic Field
Distribution Curve

Degraded, "Observational"
Magnetic Field Distribution Curve



No bump!



Conclusions

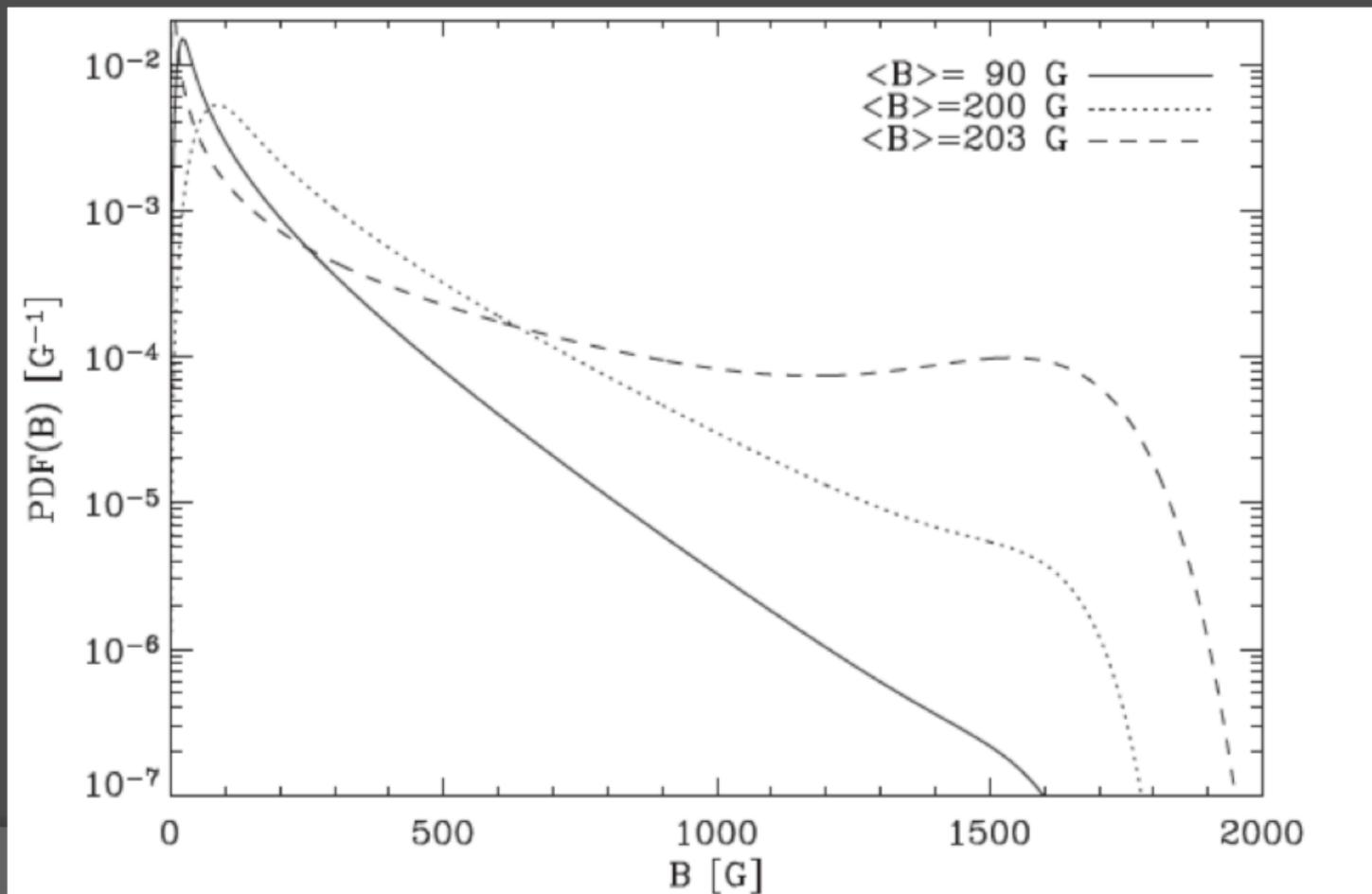
- The distribution curve obtained from the “observational” data was shifted towards weaker magnetic field strengths, so our analysis and observational techniques are certainly not perfect.
- After introducing observational errors and using our specific analysis technique of the data, no bump at high field strengths in the magnetic field distribution curve was reproduced.
 - This validates our analysis technique, despite the minor errors it introduced.

Future

- Given more time, we would extend this process of analyzing different analysis procedures in order to validate or discredit them.
- This would be done by simulating all combinations of spectral lines and different spectral line inversion codes.
- These validations are necessary in order to determine the accuracy of our analysis of real, observational data.

What about the bump?

- ◉ We would need to examine the literature to determine which spectral lines, instruments, and spectral line inversion codes were used when this bump was produced. We could then repeat the steps I took this Summer with these new observational errors and analysis techniques to check if the bump is created.



Acknowledgements

- Rebecca Centeno
- Matthias Rempel
- Alfred de Wijn
- Martin Snow
- Erin Wood
- LASP (Laboratory for Atmospheric and Space Sciences)
- NSF (National Science Foundation)
- HAO (High Altitude Observatory/UCAR)