Evaluating Magnetic Fields for the Helical Kink Instability

Ajeeta Khatiwada

Linfield College, OR

Mentor: Dr. Ashley Crouch

Colorado Research Associates

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Overview

- Introduction
  - Helical Kink Instability
  - Why study about Helical Kink Instability?
  - Theory and Objective
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  - Models
  - Artificial data
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- Interpretation of the Parameters
- Summary
- Acknowledgement

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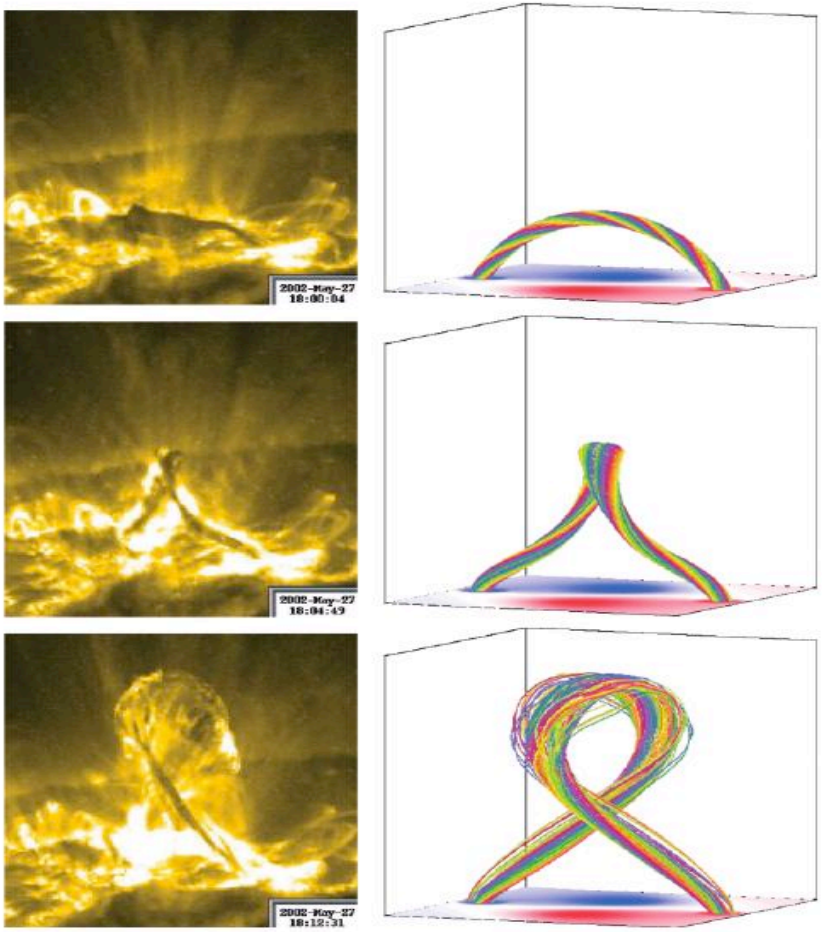
Helical Kink Instability



Left: TRACE – Images of confined filament eruption on 2002 May 27. Right: Magnetic field lines outlining the core of the kink-unstable flux rope at t = 0, 24, and 37 from top.

Courtesy: Torok & Kliem (2005, ApJ, 630, L97)

- Possible initiation mechanism for solar eruptions.
- Occurs when the # of twists exceeds a critical value and undergoes writhing.
  - Twist: Winding of magnetic field around the axis.
  - Writhe: Winding of the axis itself.

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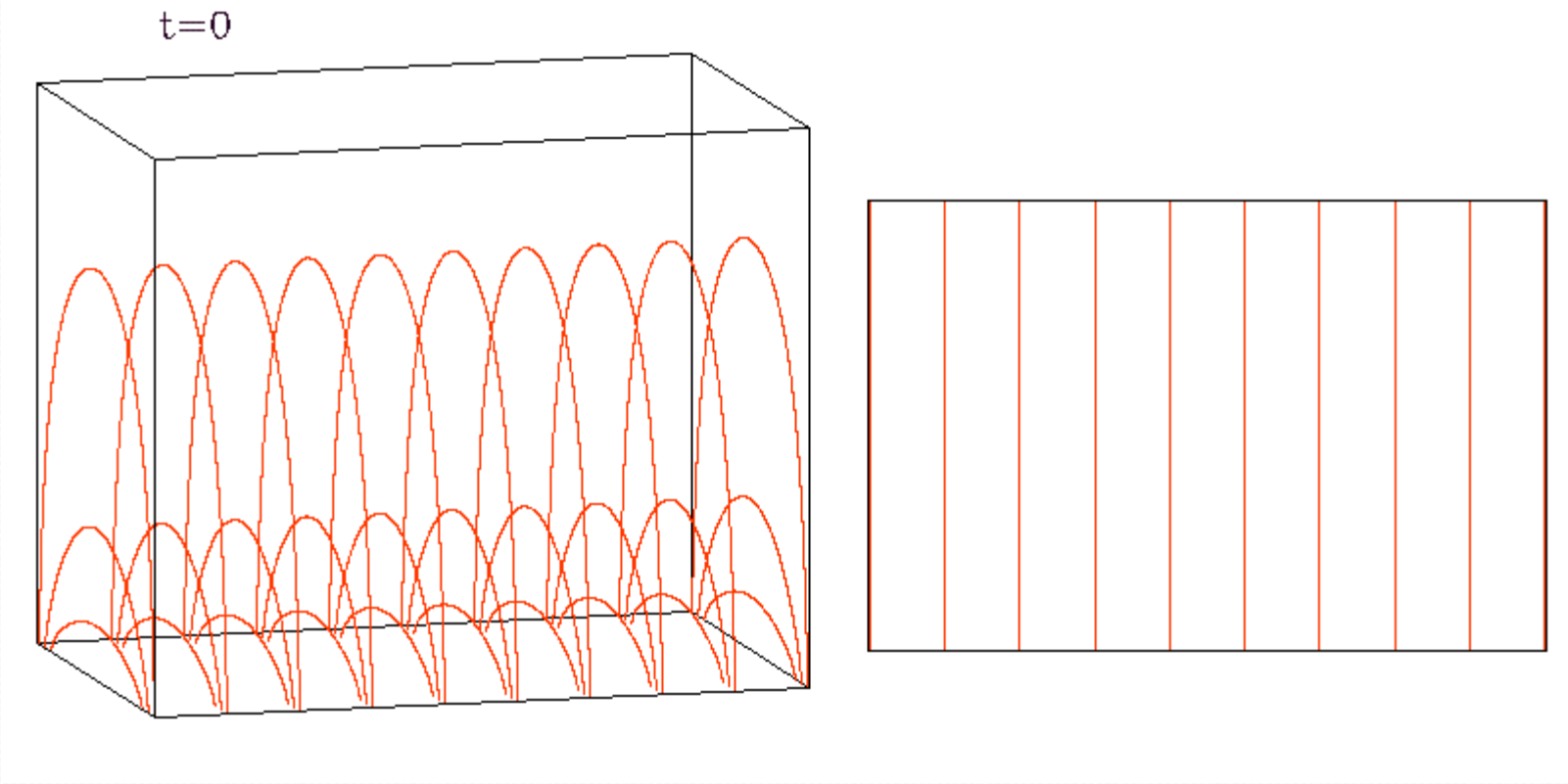
Kink Instability



Courtesy: Dr. Yuhong Fan

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Why study about Helical Kink Instability?

- Solar events influence our space weather.
- May cause power outages, radiation hazards, damage to satellites, radio transmissions etc.
- Hence, imperative to be able to predict solar energetic events.

Theory and Objective

Theory

- Measuring the winding rate (q) of the field lines around the flux tube may help us determine whether a flux tube is susceptible to a Kink Instability or not.

Objective

- To fit a model field to an observed field from the flux tube in the sun.
- Run Genetic Algorithm optimization code to determine best set of parameters.
- Interpret the result in order to determine the stability of the flux tube.

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Genetic Algorithm

G.A.: Based on the Theory of Evolution and used to find global maximum.

- Encoding: Drop the decimal point and concatenate the resulting set from the parameters, which are defined by floating point no.s
  Eg: P(P1) x = 0.14429628 y= 0.72317247
  S(P1) = 1442962872317247

- Breeding:
  - Crossover: Cutting point randomly selected and string on the right of the cutting point are interchanged.
    Eg: S(P1) = 1442962872317247 S(P2) = 7462864878372131
    S(O1) = 1442864878372131 S(O2) = 7462962872317247
  - Mutation: Randomly selected digits replaced by new randomly selected digits.
    Eg: S(O2) = 7462962872317247
    S(O2) = 7462963872317247

- Decoding: Split into different parameters and turned back into floating point no.s
  Eg: S(O2) = 7462963872317247
  x = 0.74629638 y= 0.72317247

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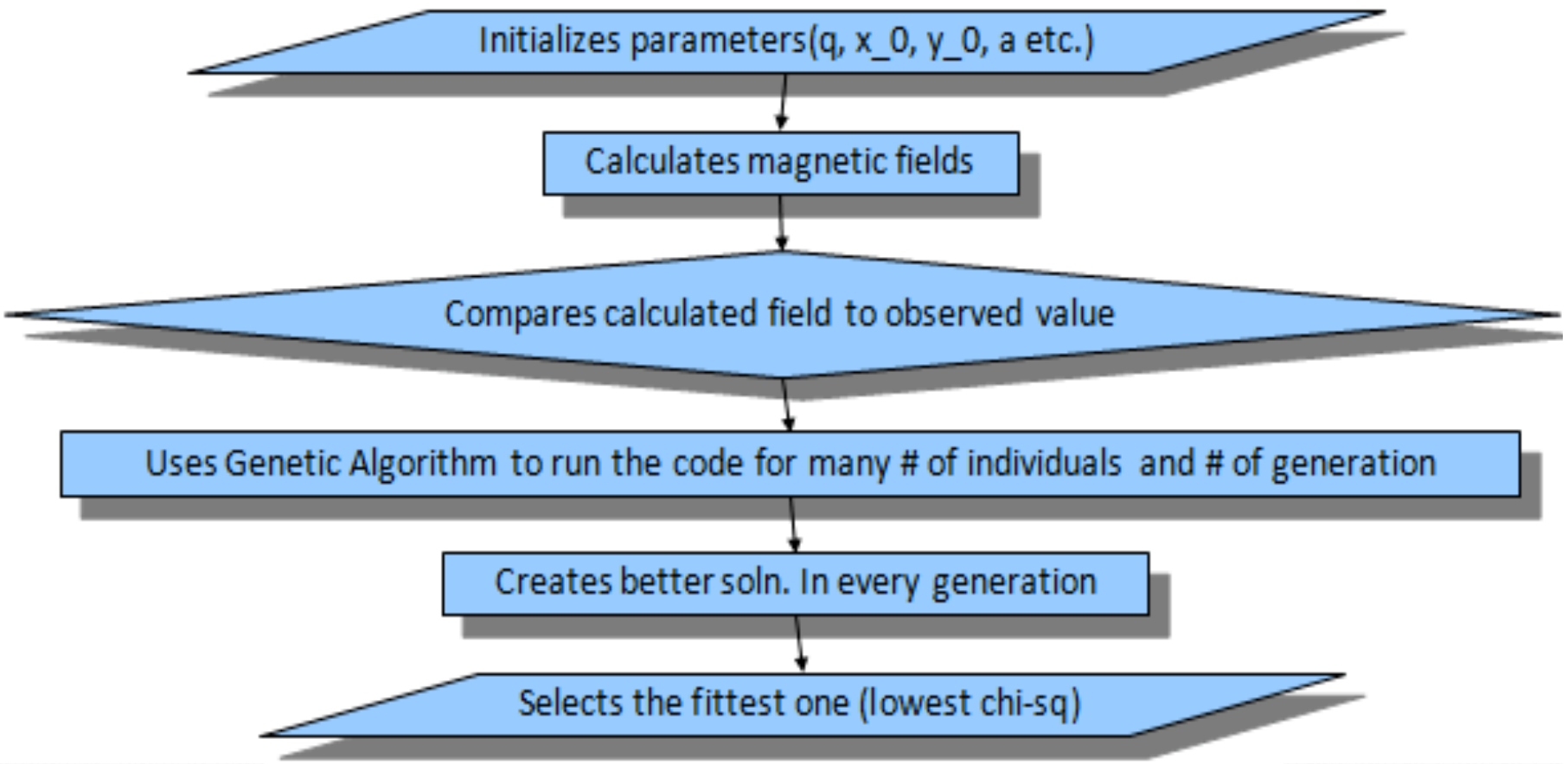
Procedure



$$\chi^2(q,x) = \frac{1}{N-d}\sum_{i=1}^{N}\left(\frac{B_i(q,x) - B_i^{obs}}{\sigma_i}\right)^2$$

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Experimental Approach

- Use simulated data as observation data (for self consistency check) with and without noise + external field.
- Constrain the parameter ranges within reasonable limits.
- Run program for different time steps of the emergence of the flux tube.
- Look at the fields independently for x, y and z direction (by adding weighting factors to the chi-square equation).
- Use different models ('Gold & Hoyle' and 'Torus') and compare the results.
- Do all above things for real observation from the Sun.

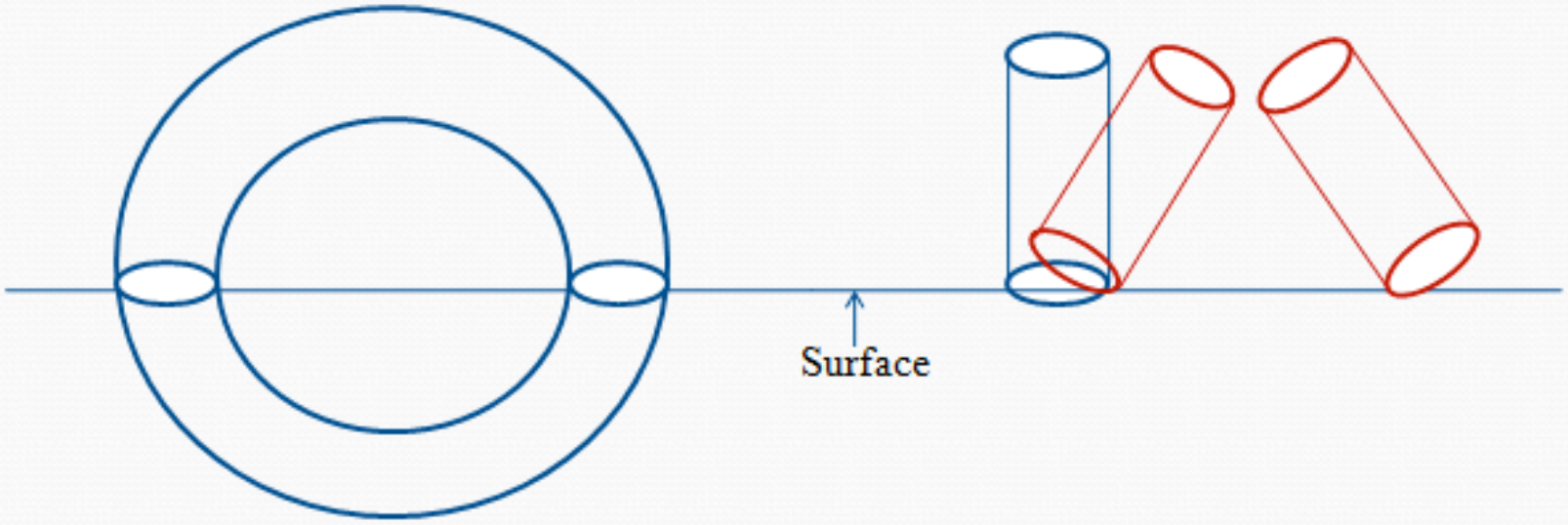
Models

Torus

- Semi-circular flux tube
- Two roots
- Non-uniform rate of winding

Gold and Hoyle

- Cylindrical flux tube
- Single root
- Constant twist



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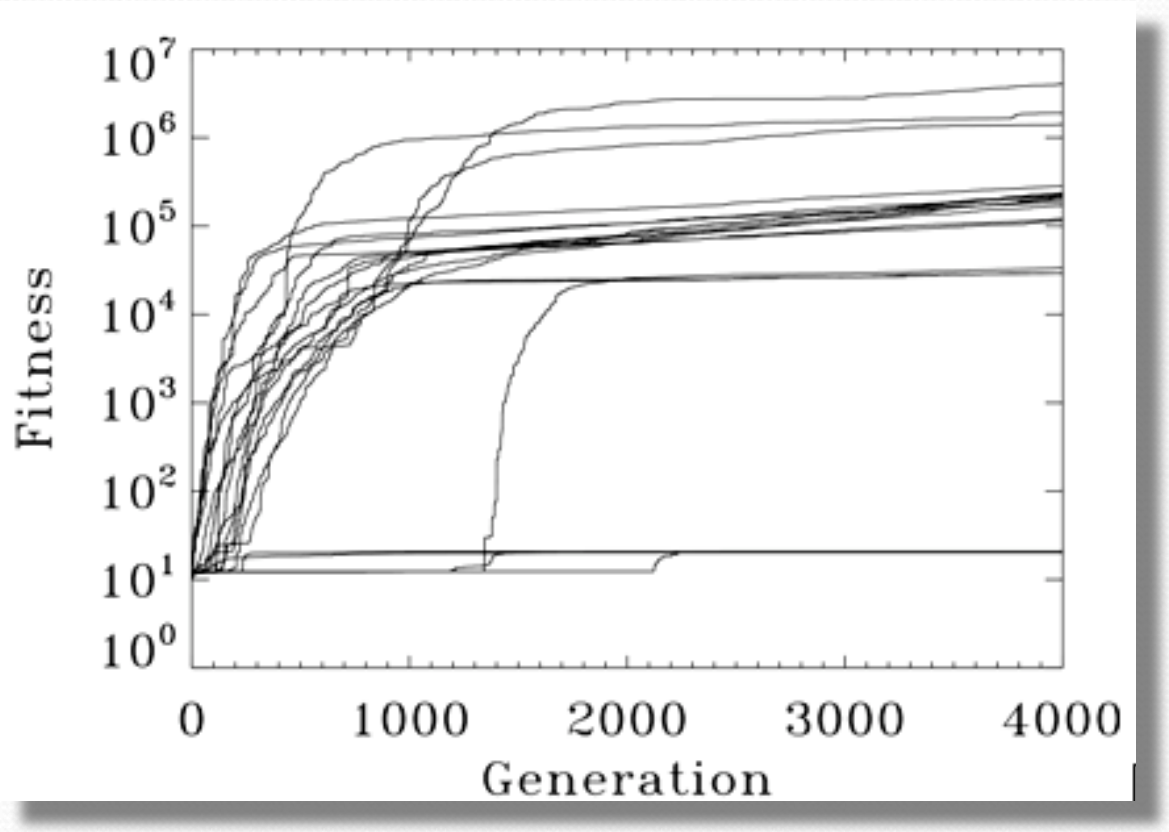
Fitness Evolution for Artificial Data



Model: Torus
Observation file: test.dat (artificial data)
X-axis: No. Of generations
Y-axis: Fitness values

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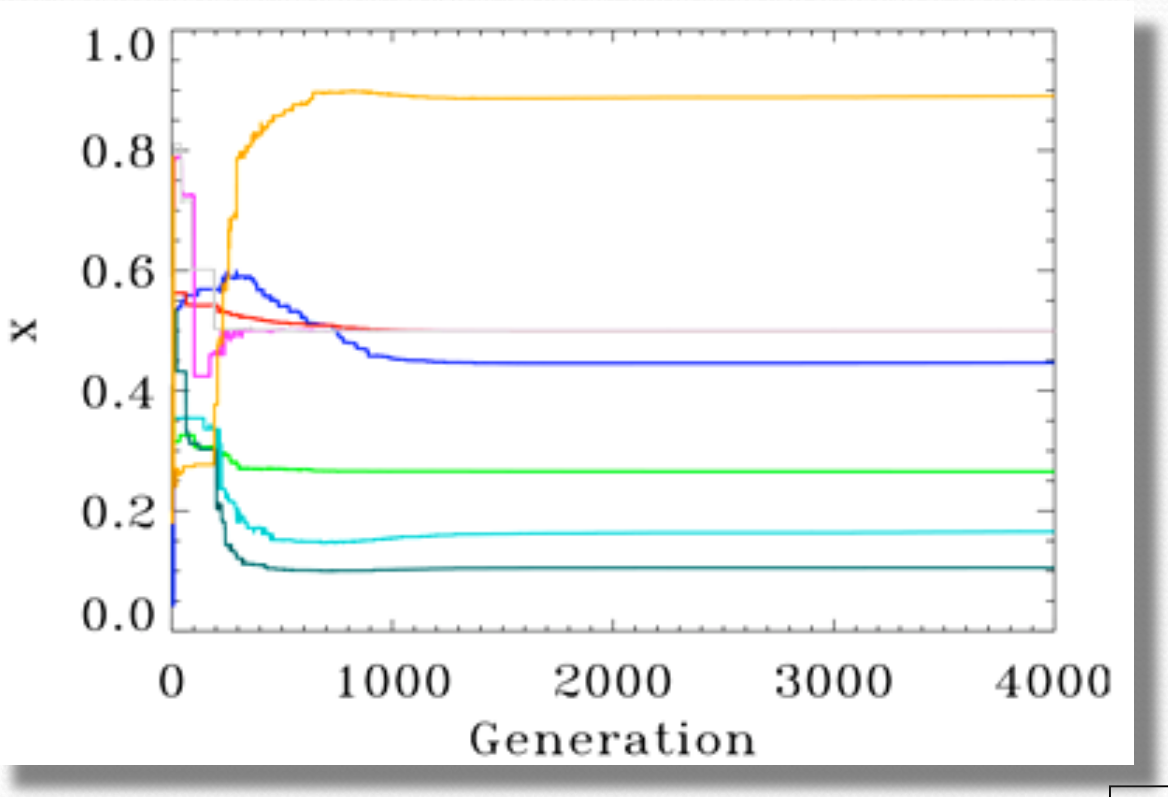
Parameter Evolution for Artificial Data



Model: Torus
Observation file: test.dat (artificial data)
X-axis: No. Of Generations
Y-axis: Parameter values as floating pt. no. between 0 and 1.

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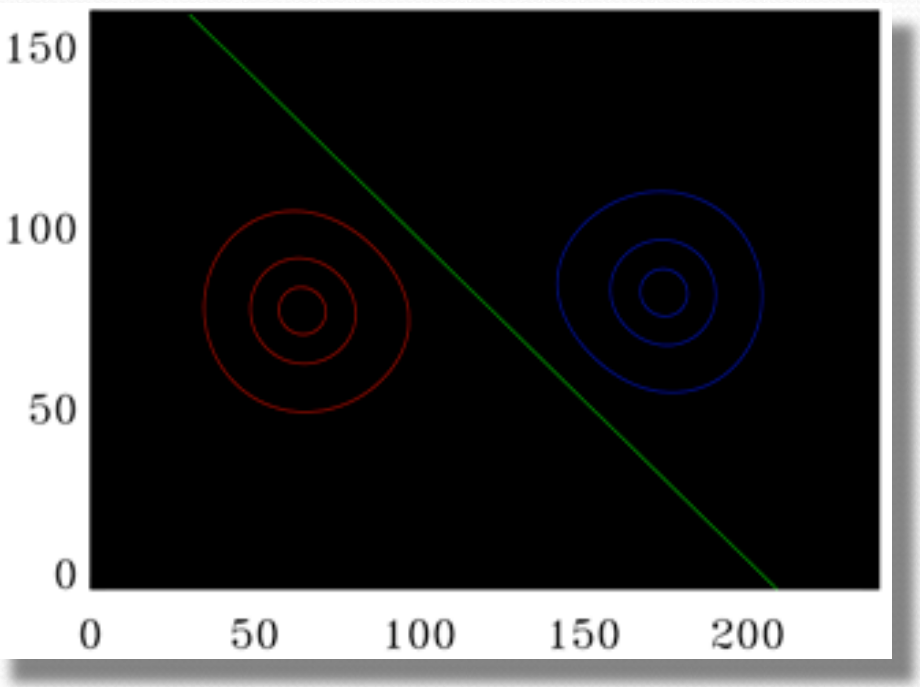
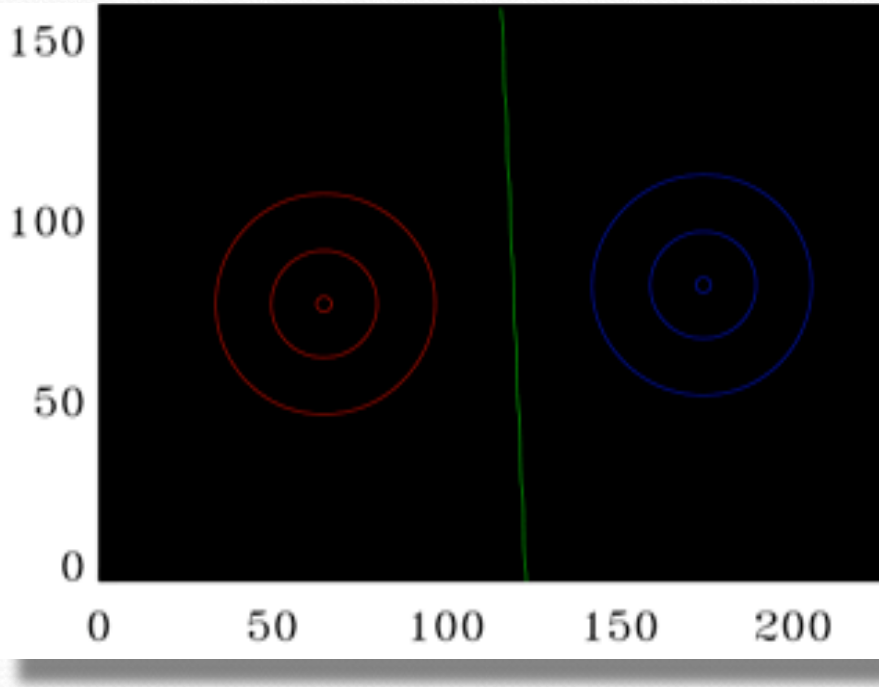
Observation(Artificial) vs. Model Field

B_z in xy-plane for observed data



B_z in xy-plane for model data



Model: Torus
Observation file: test.dat (artificial data)
X-axis: X-position in pixels
Y-axis: Y-position in pixels

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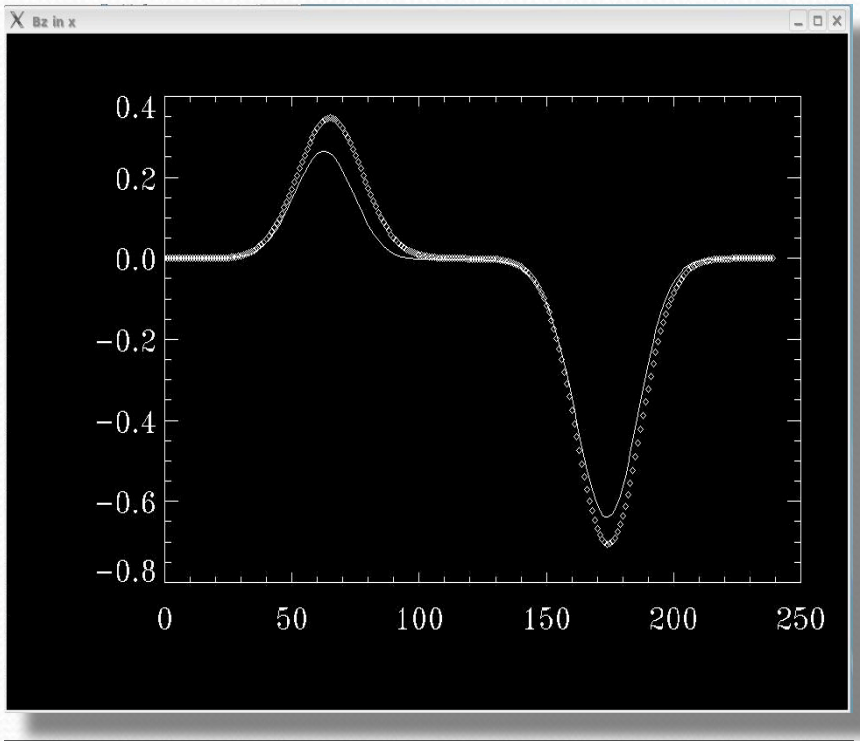
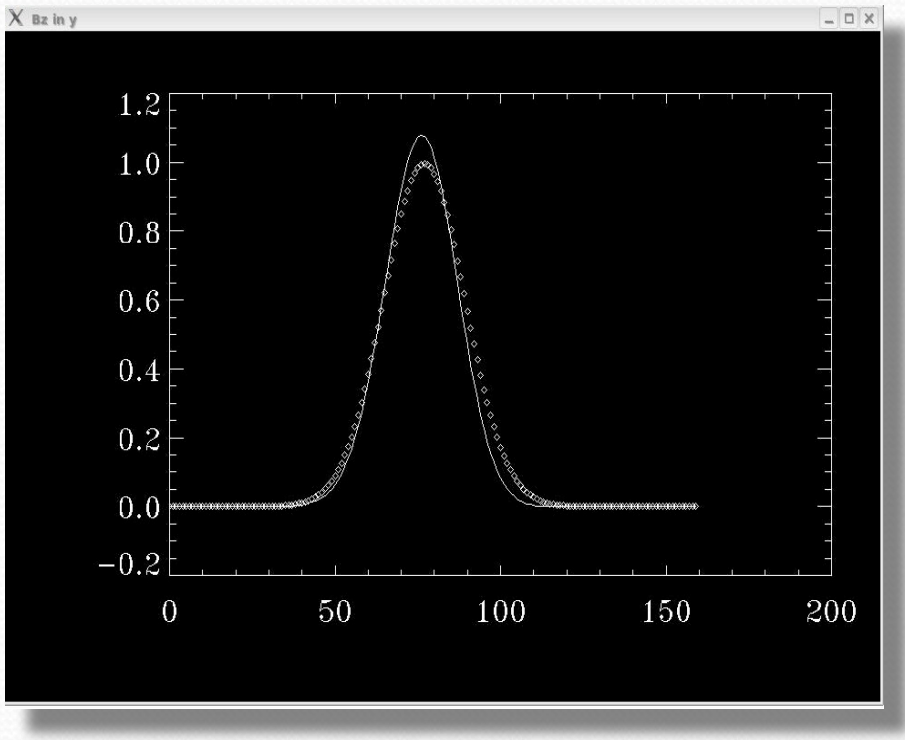
Magnetic Field (B_z) along x & y direction

Plot of B_z along y = a



Model: Torus
Observation file: test.dat (fake data)
X-axis: X-position in pixels
Y-axis: B_z

Plot of B_z along x = b



Model: Torus
Observation file: test.dat (fake data)
X-axis: Y-position in pixels
Y-axis: B_z

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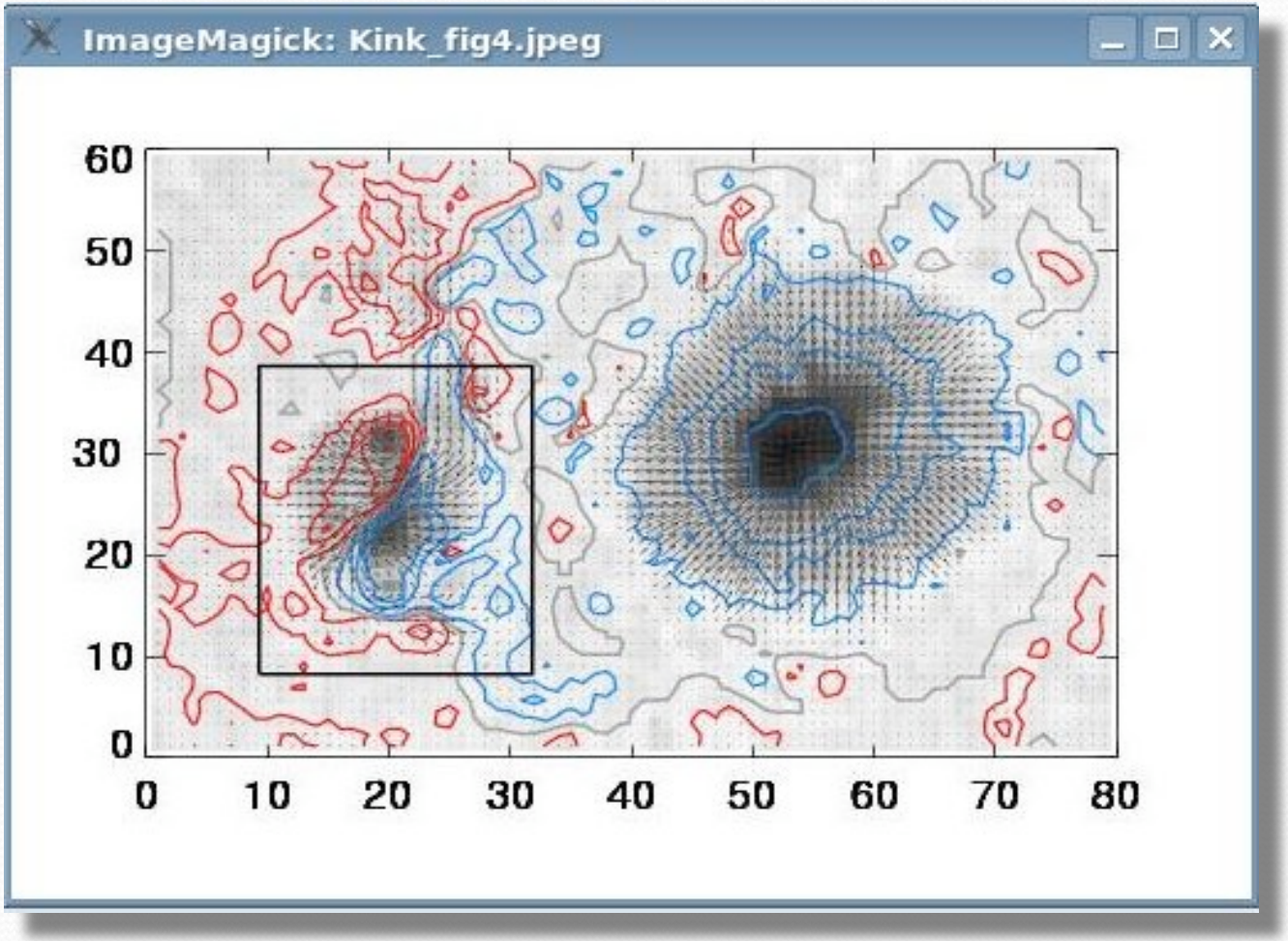
Observational Data



Continuum image of NOAA AR 7201 observed 1992 June 19 with the NSO/HAO Advanced Stokes Polarimeter.
Courtesy: Leka, Fan and Barnes (2005, ApJ, 626, 1091)

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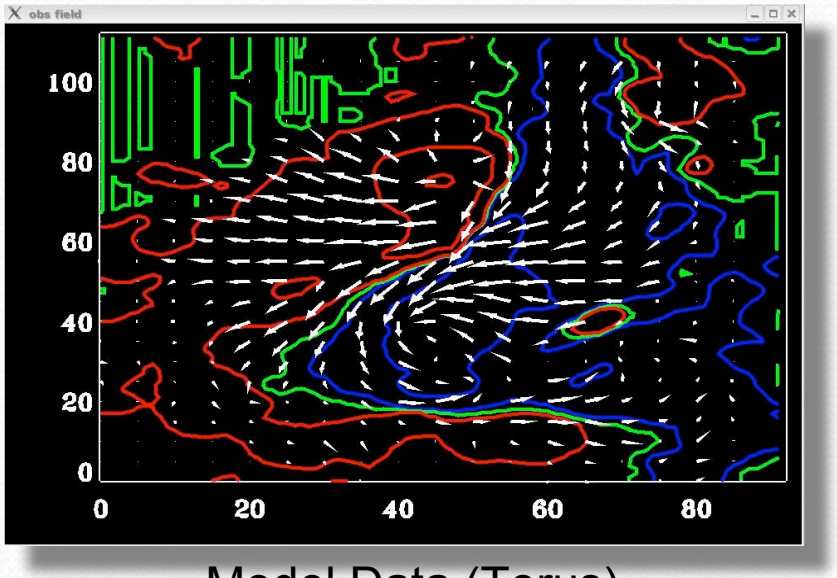
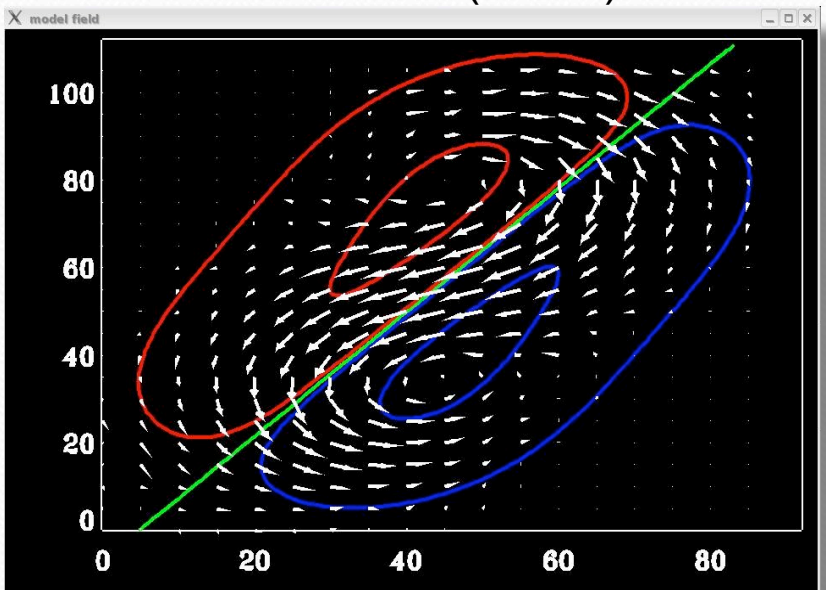
Contour plot of B_z for Observation & Mod Data

Observation Data

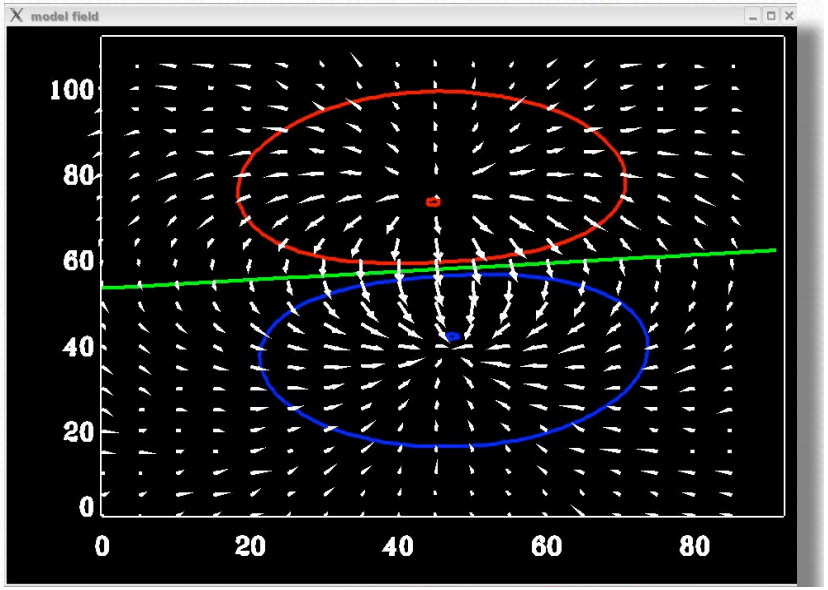


X-axis: X position in pixels
Y-axis: Y position in pixels

Model Data (Torus)



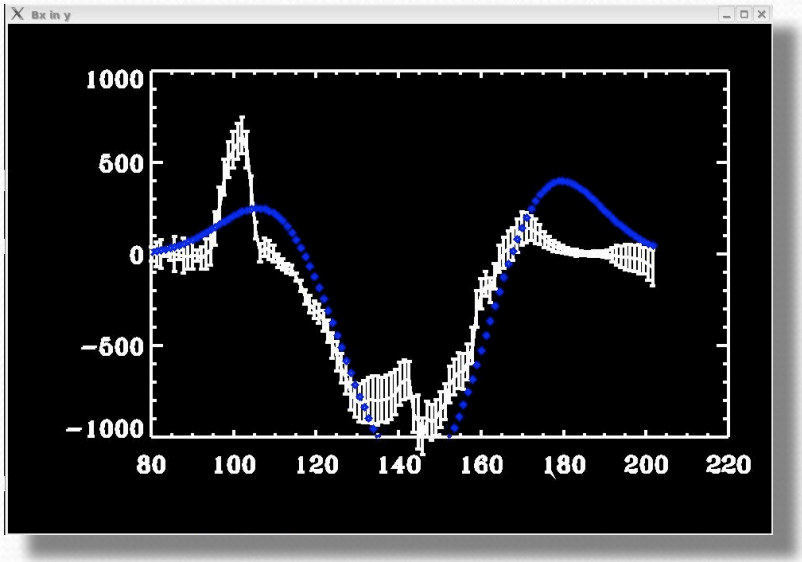
Model Data (Gold-Hoyle)



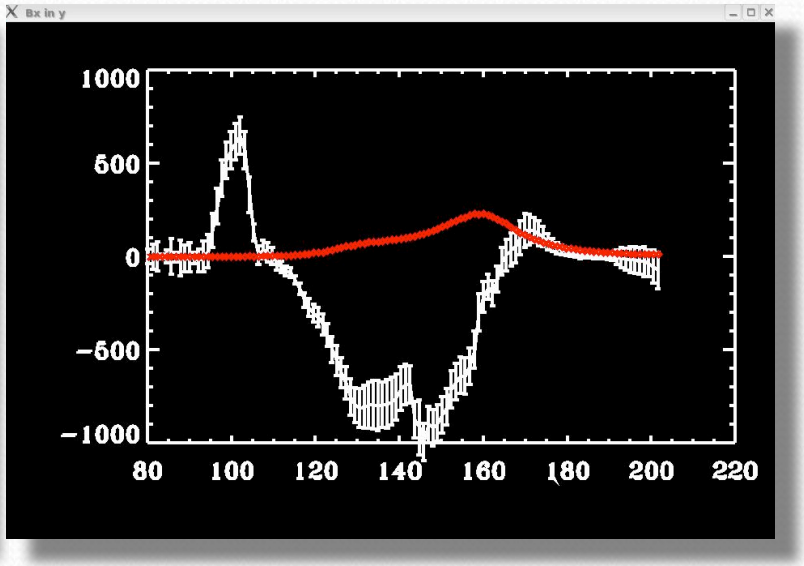
Plot of B (x component) along Y-directio

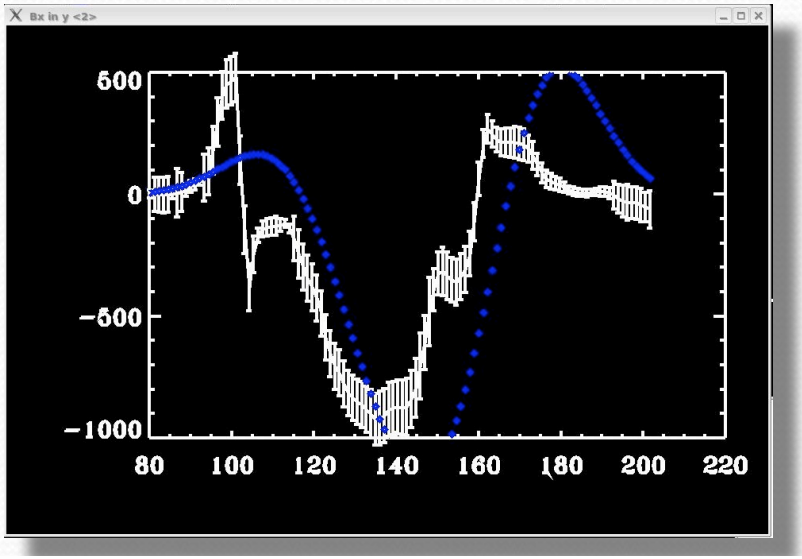
X-axis: Y-pos
Y-axis: B_x

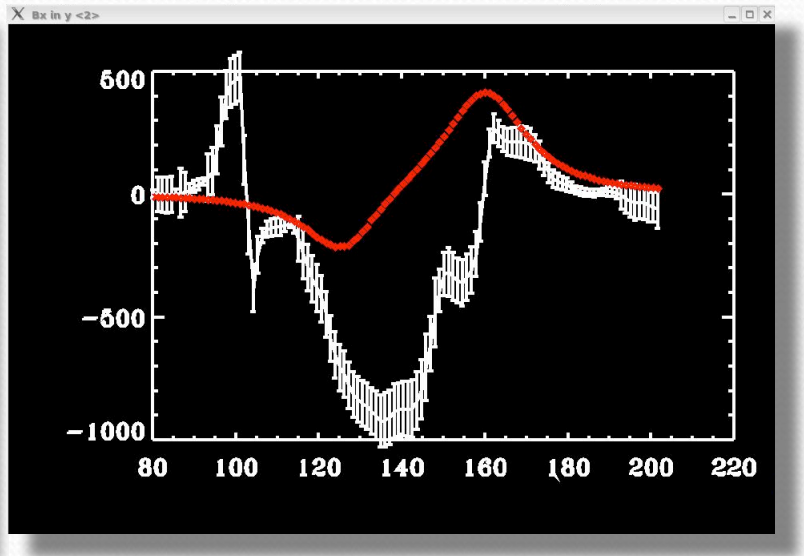
Torus Model



Gold-Hoyle Model







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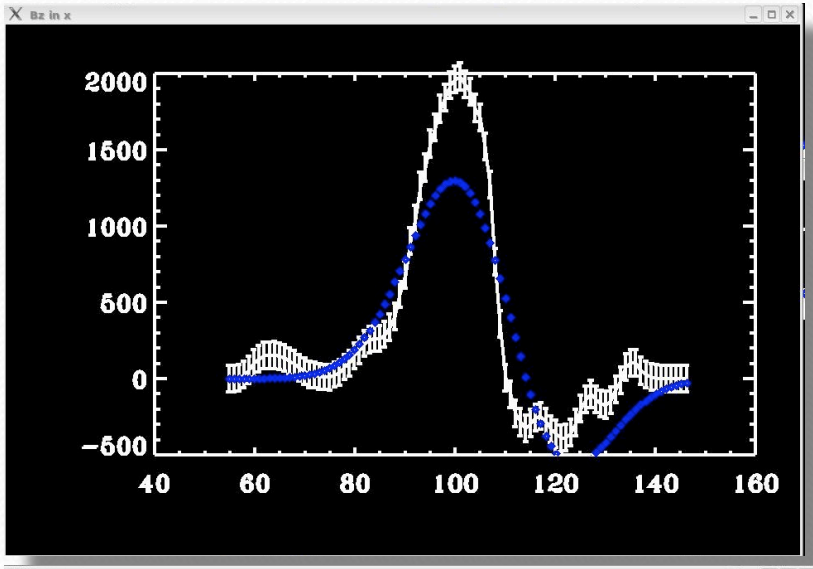
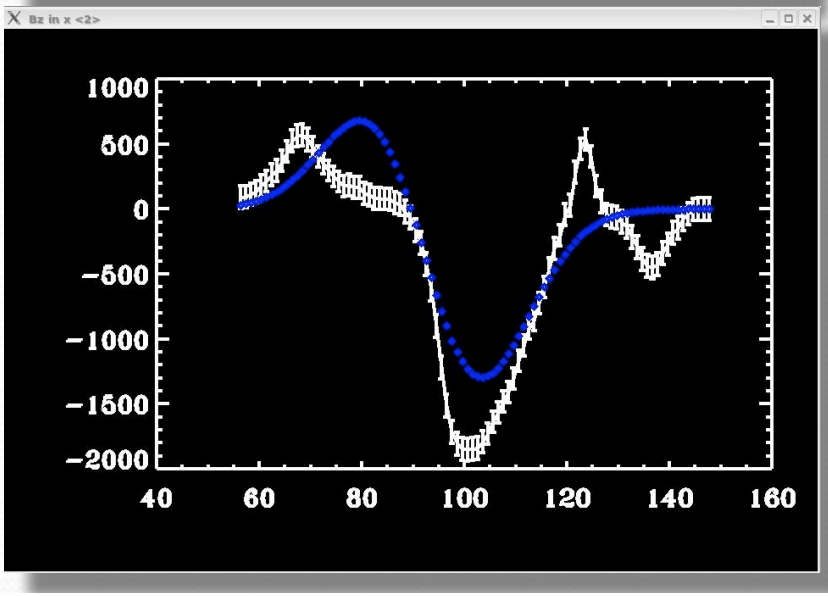
Plot of B (z component) along X-direction

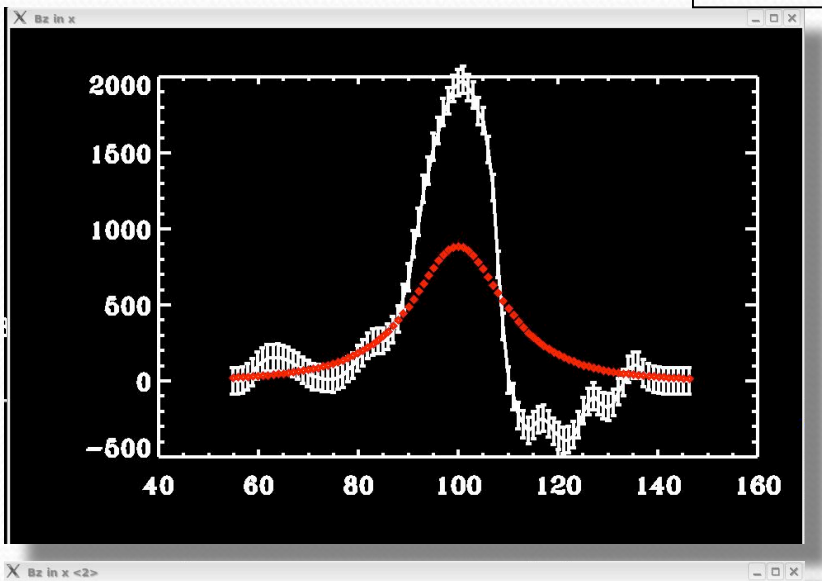
X-axis: X-positi
Y-axis: B_z

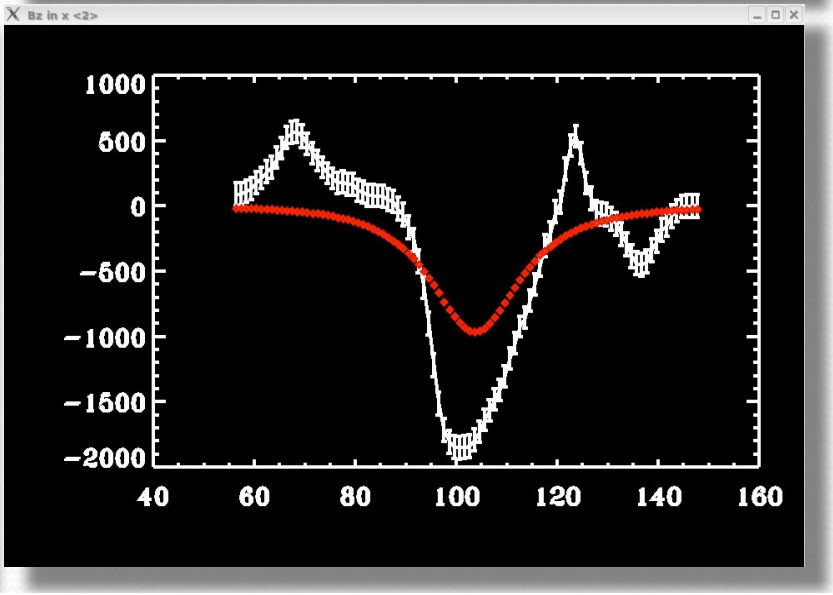
Torus Model





Gold-Hoyle Model





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Interpretation of the Parameters

- The number of twist contained by a flux tube exceeds one ($T/2\Pi > 1$), which is consistent with results obtained by Leka, Barnes and Fan in a separate research.

$$T/2\Pi = q * L / a$$

$T/2\Pi$ = no. of twist
q = winding rate
L = length of the flux tube above the surface
a = radius of the tube

- The center of the torus (the circular structure of flux tube) is emerged out from the photosphere.

- The radius of the flux tube is large compared to the radius of the whole structure.

Summary

- Self consistency check was successful for both the models with and without noise or/and external field.
  - Use model to construct artificial data
  - Use the same model to fit the fake data
- Testing the validity of the model was unsuccessful.
  - Use one model Fit one model to another
- Data obtained by fitting Torus model was better chi-sq. than those obtained by Gold & Hoyle model.
- Parameters obtained from fitting Torus model to the observation show that the flux tube is susceptible to Kink instability.
- More work needs to be done with other models.

Acknowledgement

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- Dr. Graham Barnes
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- LASP
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