

# Tests of NLFFF Models of AR 10486

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$$\frac{d}{dt} \int_V \sigma t$$

where

$$\mathbf{F} = \nabla \times (\boldsymbol{\Omega} \times \mathbf{B}) - \boldsymbol{\Omega} \times (\nabla \times \mathbf{B}) - \nabla (\boldsymbol{\Omega} \cdot \mathbf{B}) + \boldsymbol{\Omega} (\nabla \cdot \mathbf{B}) + \boldsymbol{\Omega}^2 \mathbf{B} \quad (3)$$

and

$$\boldsymbol{\Omega} = B^{-2} [(\nabla \times \mathbf{B}) \times \mathbf{B} - (\nabla \cdot \mathbf{B}) \mathbf{B}]. \quad (4)$$

(Note that  $\boldsymbol{\Omega}$  and  $F$  are zero for force-free and potential fields.)

Evolve field according to  $\partial \mathbf{B} / \partial t = \mu \mathbf{F}$ ;  $\mu > 0$ . Then

$$\frac{dL}{dt} = -2 \int_V \mu F^2 dV. \quad (5)$$

## **Optimization method (cont):**

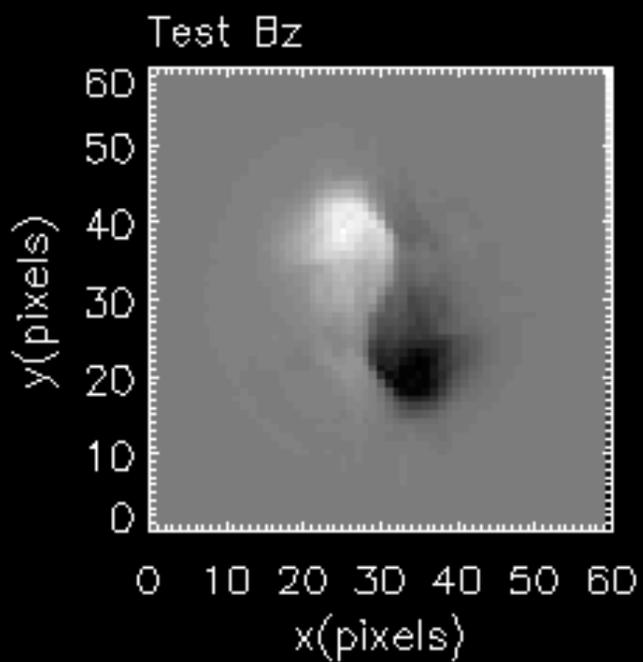
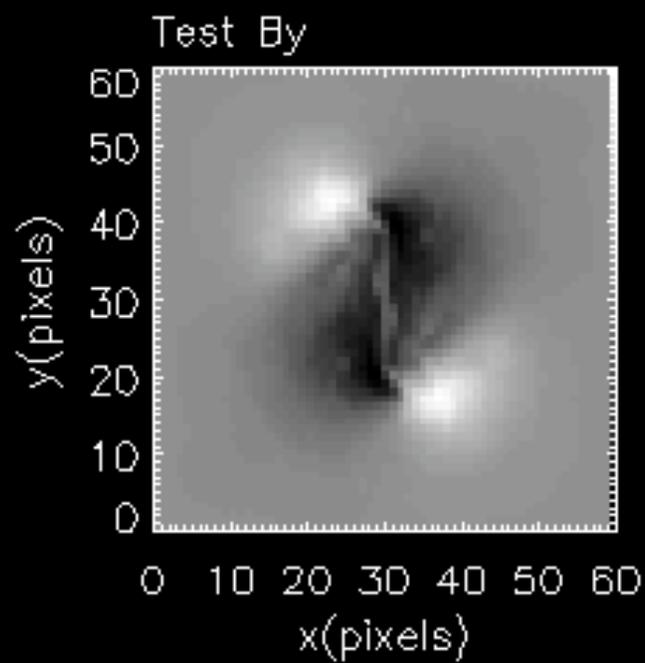
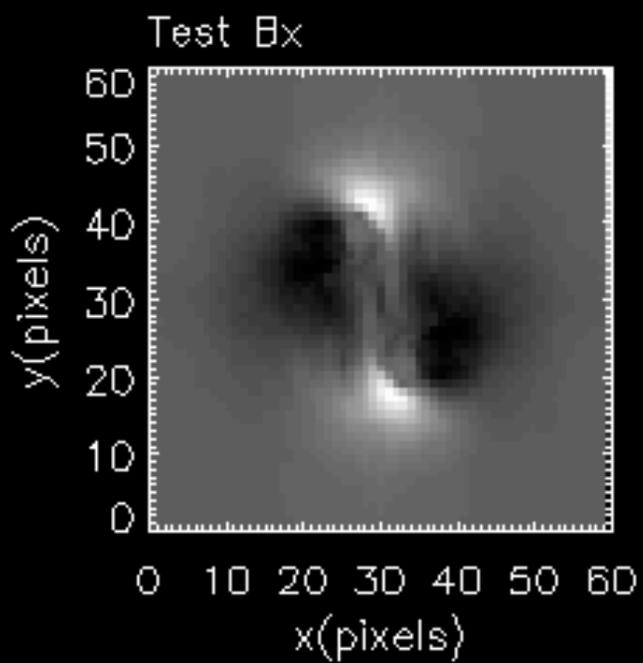
- **Iterative process, typically starts with potential field or linear FFF, extrapolated from magnetogram.**
- **B does not change on the boundary. The bottom boundary is the magnetogram, the upper and side boundaries are the initial field.**
- **Calculate F, set new  $\mathbf{B} = \mathbf{B} + \mathbf{F} \cdot dt$  (typical  $dt = 1.0e-5$ )**
- **“Objective function”, L, is guaranteed to decrease, but the change in L (dL) becomes smaller as you go.**
- **Keep going until dL approaches 0.**

## **Optimization method (cont):**

- If the initial state is a potential field or linear FFF, the quantity  $F$ , that drives the minimization, is non zero only at the bottom boundary. Differences between the calculated and initial field propagate outward as we iterate.**
- Iterations end before the difference between the calculated field and the initial field reaches upper boundary.**
- The final extrapolation is dependent on the boundary conditions and the initial conditions.**

## **Tests of NLFFF model:**

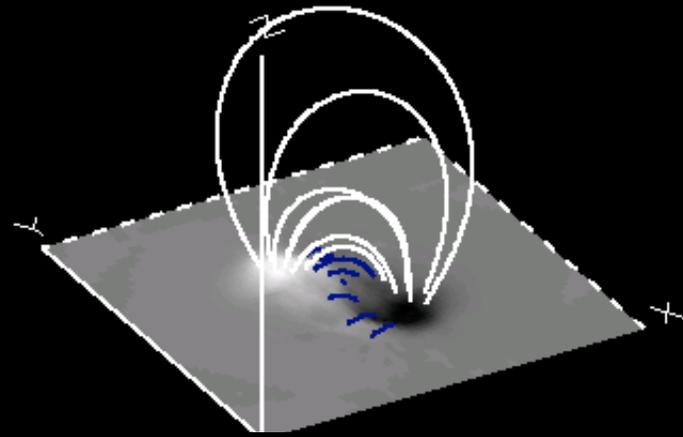
- **Test case: MHD simulation from T. Magara (via B. Abbett) of an emerging flux tube. (Homework from NLFFF workshop in May).**
- **Two ways to specify initial conditions:**
  - 1) **let initial B field determine the outer boundaries. (done here)**
  - 2) **Fix boundaries to original MHD result. (Not yet)**
- **Lower boundary is “chromospheric” field. (not quite the the bottom of the simulated field, the MHD field is closer to force-free above this point).**



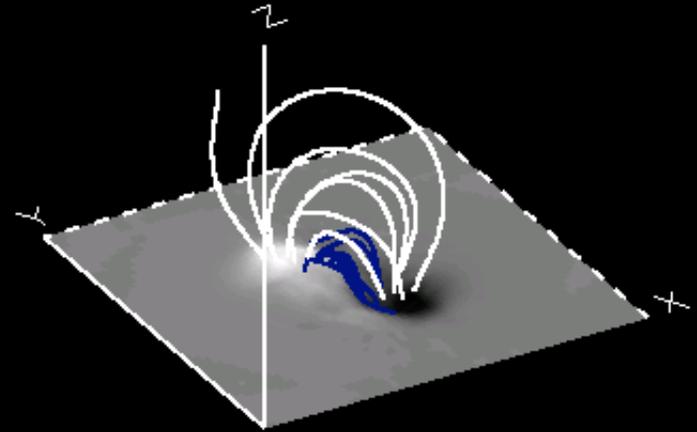
## **Tests of NLFFF model:**

- **Three different sets of initial conditions:**
  - **1) Potential field.**
  - **2) Linear FFF.**
  - **3) Combination of potential and linear FFF, purely linear FFF at origin, purely potential on the upper and side boundaries.**
- **Other sets of initial conditions, e.g., random or constant B inside boundaries, do not work at present.**

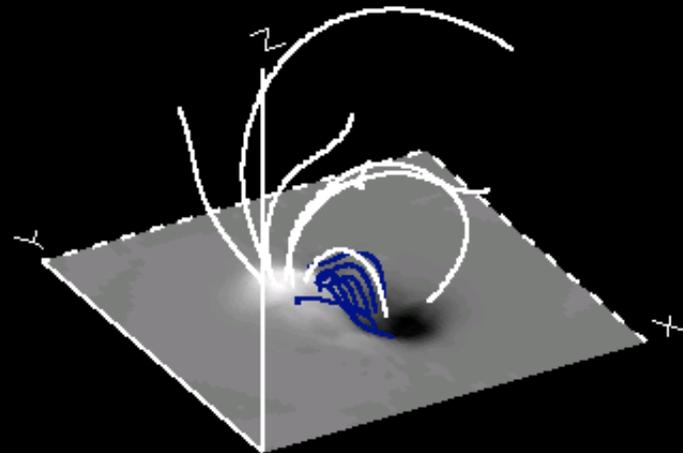
Potential Field



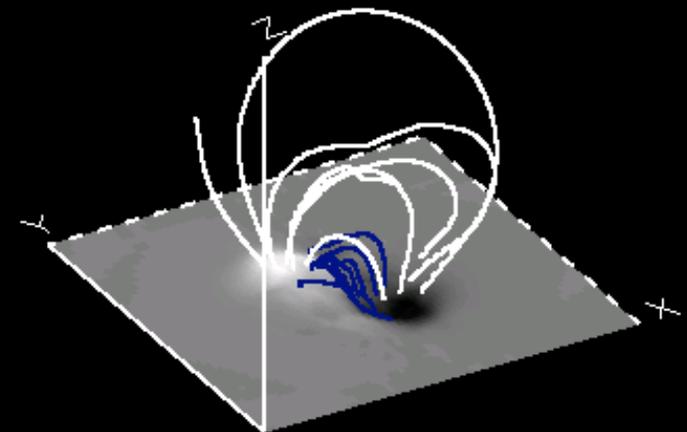
NLFFF from Potential



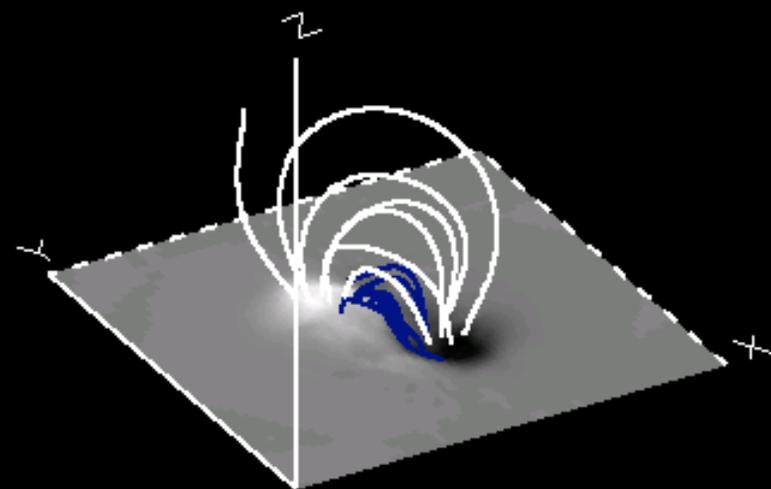
NLFFF from Linear FFF



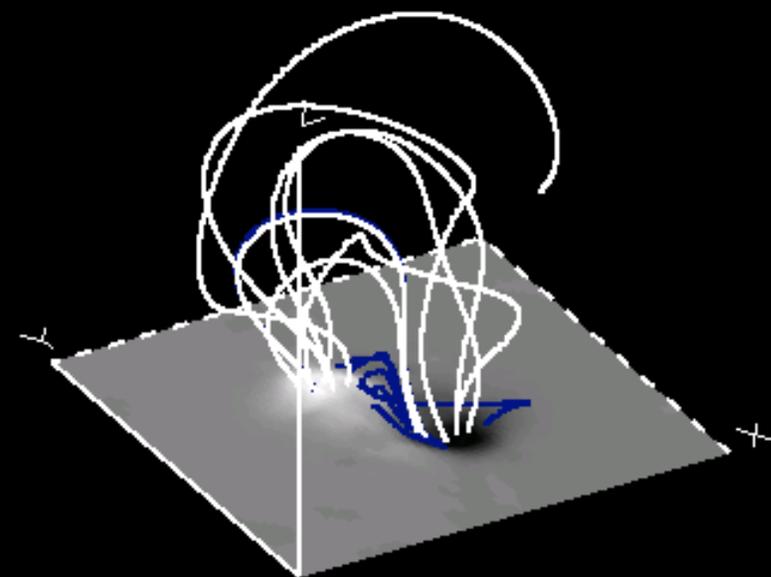
NLFFF from PotLin



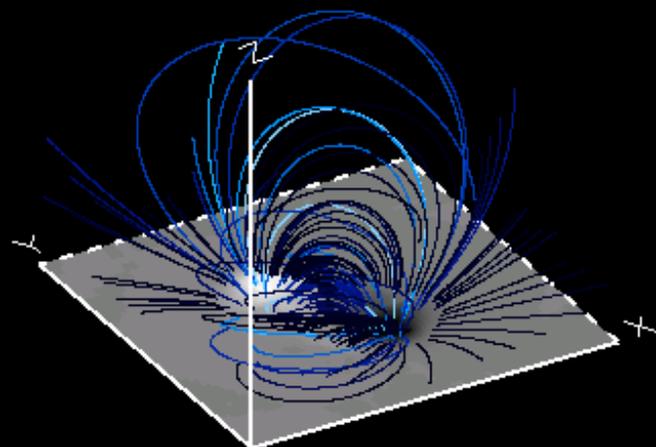
NLFFF from Potential



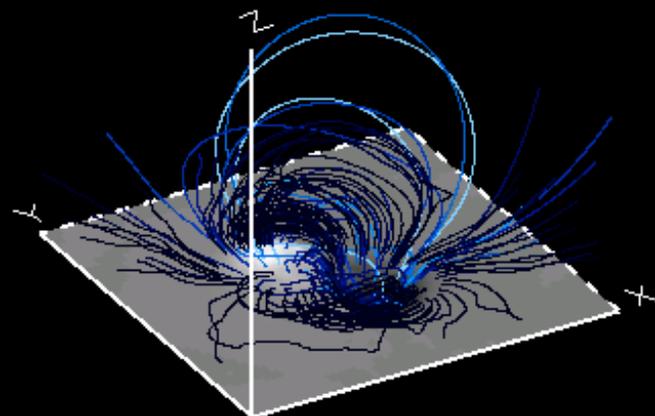
True Field



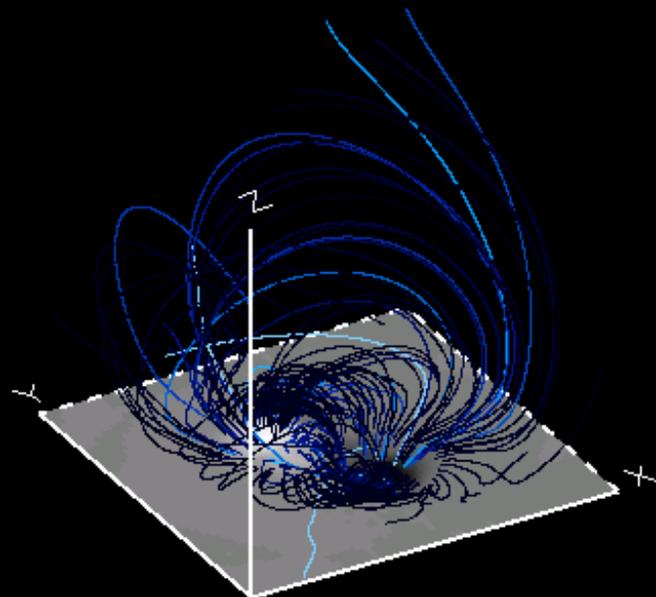
Potential Field



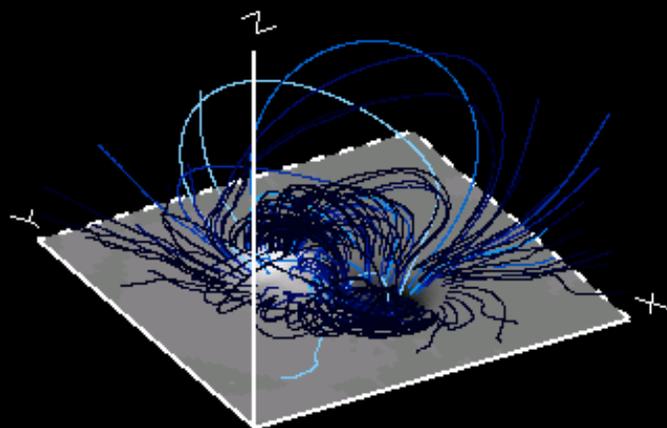
NLFFF from Potential



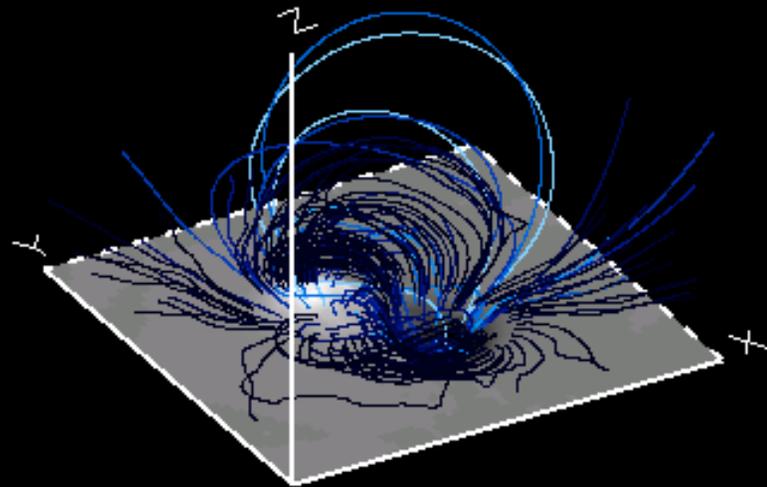
NLFFF from Linear FFF



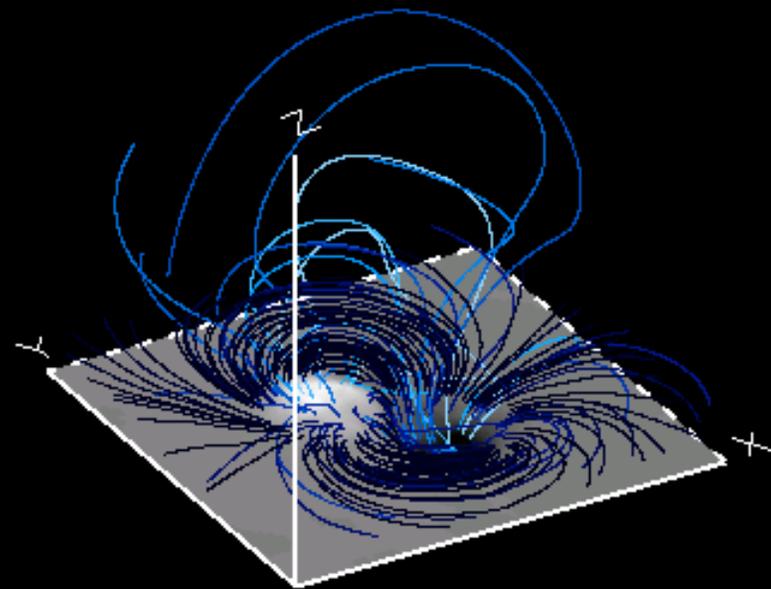
NLFFF from PotLin



NLFFF from Potential



True Field



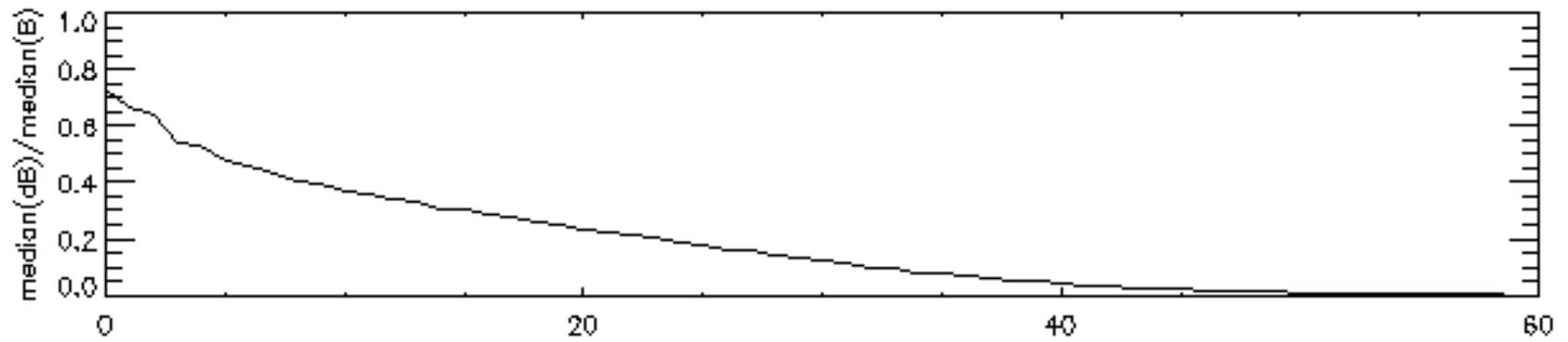
## **Tests of NLFFF model:**

- **All three models look similar near the bottom boundary, and give a sense of the emerging flux tube.**
- **The different models look different from each other farther from the bottom.**
- **The model with the potential field initial condition does not give the same result as the model with the combination potential – linear FFF initial condition, even though the boundaries are the same.**

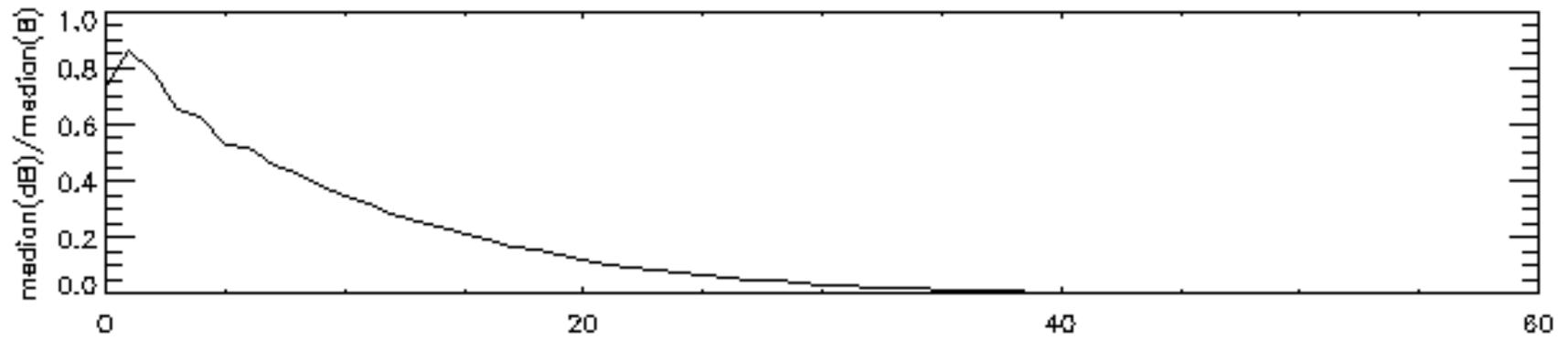
## **Tests of NLFFF model:**

- **Fieldline comparisons aren't very quantitative. For a more quantitative result:**
- **Plot median(Difference between B's)/median(B) as a function of z (height), for:**
- **Comparisons of final state with initial state for different models.**
- **Comparisons of final result for the models with each other.**

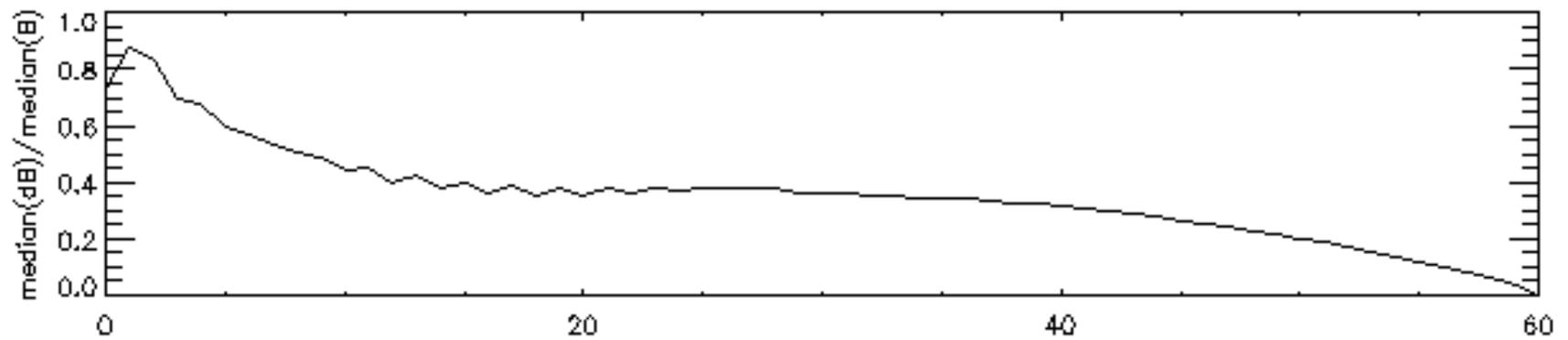
NLFFF from Potential & Potential Field



NLFFF from Linear FFF & Linear FFF



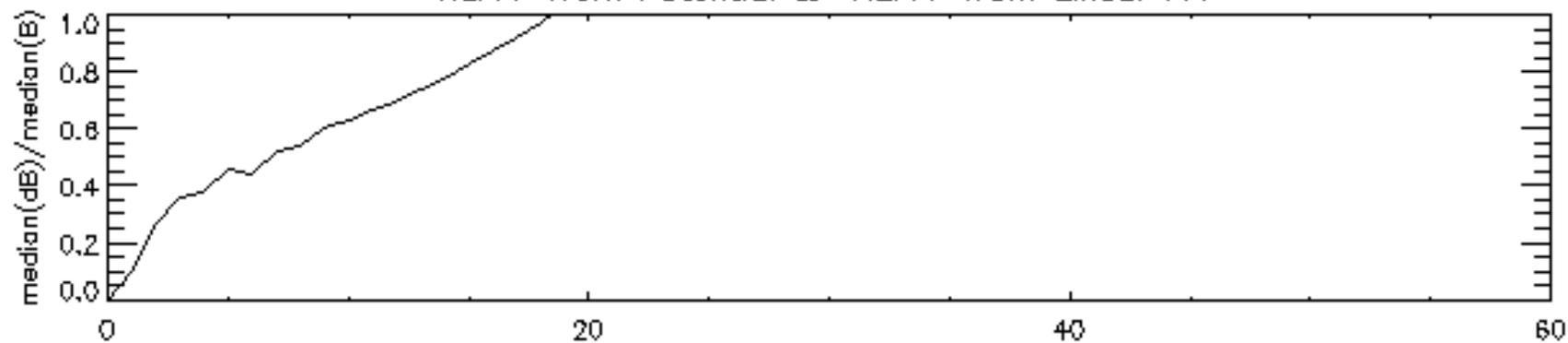
NLFFF from PotLin & Pot-Lin FFF



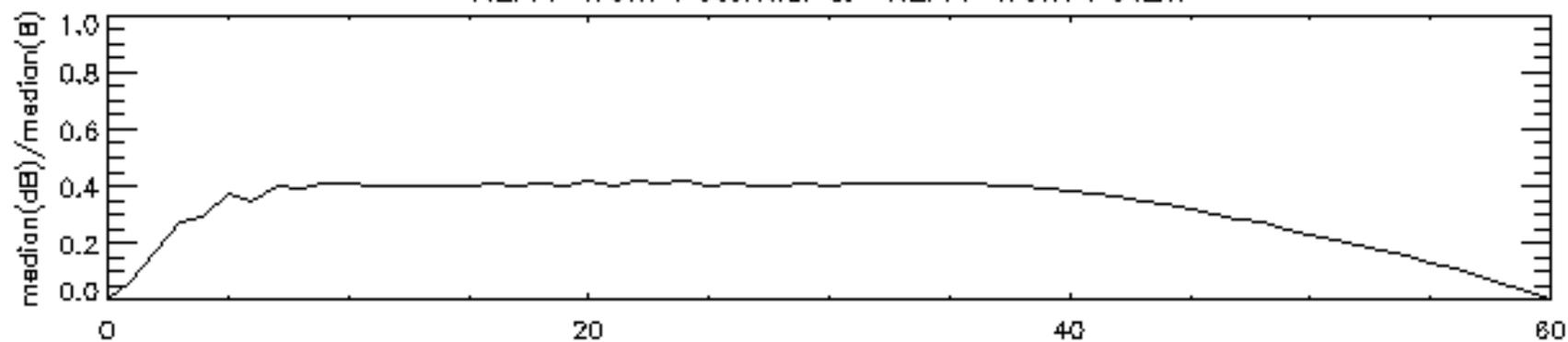
## **Tests of NLFFF model:**

- **The difference between initial and final states decreases with height. For the potential-linear model, this is less pronounced, since for this model, the quantity  $F$ , which drives the minimization, is initially non-zero throughout the volume.**

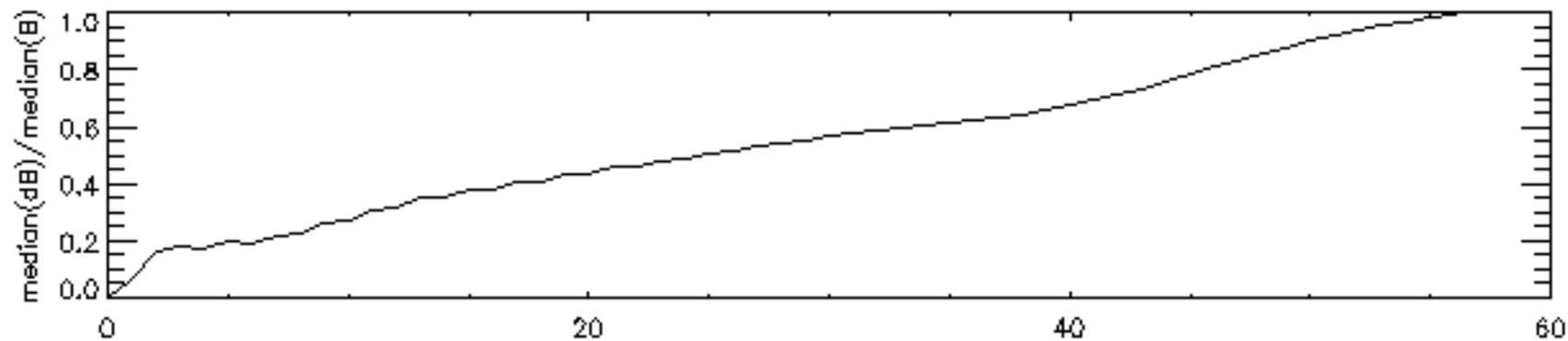
NLFFF from Potential & NLFFF from Linear FFF



NLFFF from Potential & NLFFF from PotLin



NLFFF from Linear FFF & NLFFF from PotLin

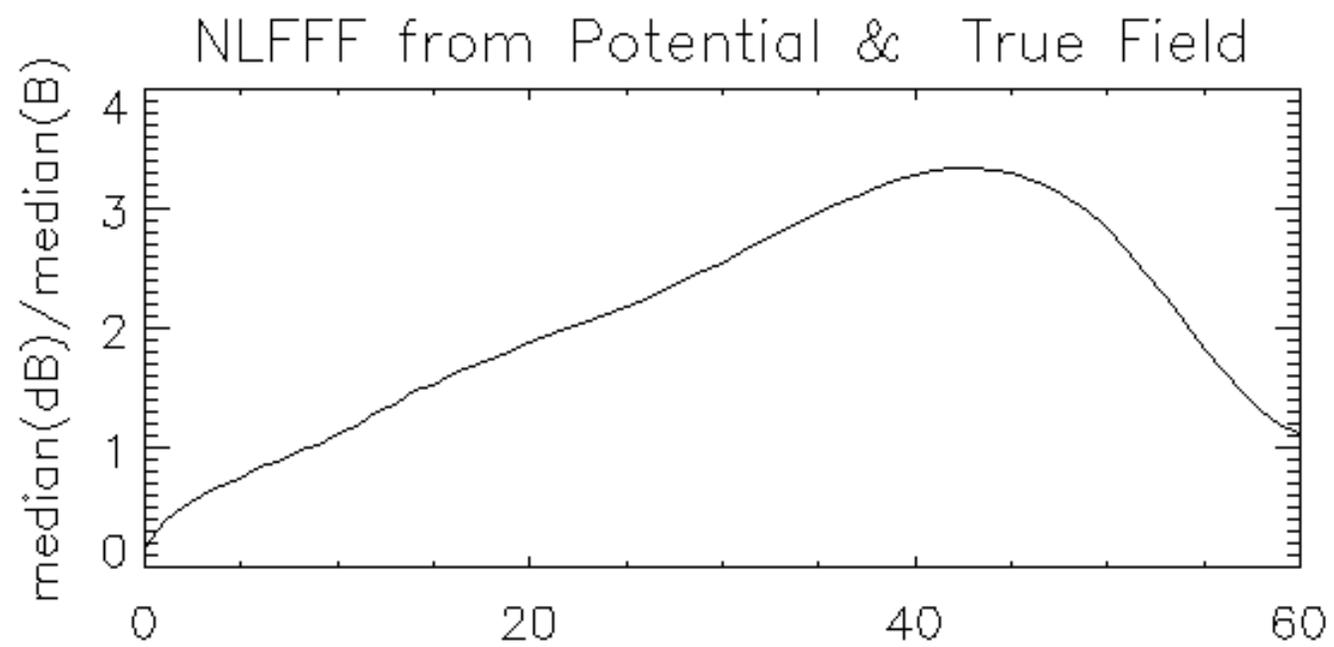


## **Tests of NLFFF model:**

- **The differences between models are not small by this measure, except at the very bottom.**
- **The difference between the initial potential model and the initial potential-linear model is not zero, even though the boundary conditions are the same.**

## **Tests of NLFFF model:**

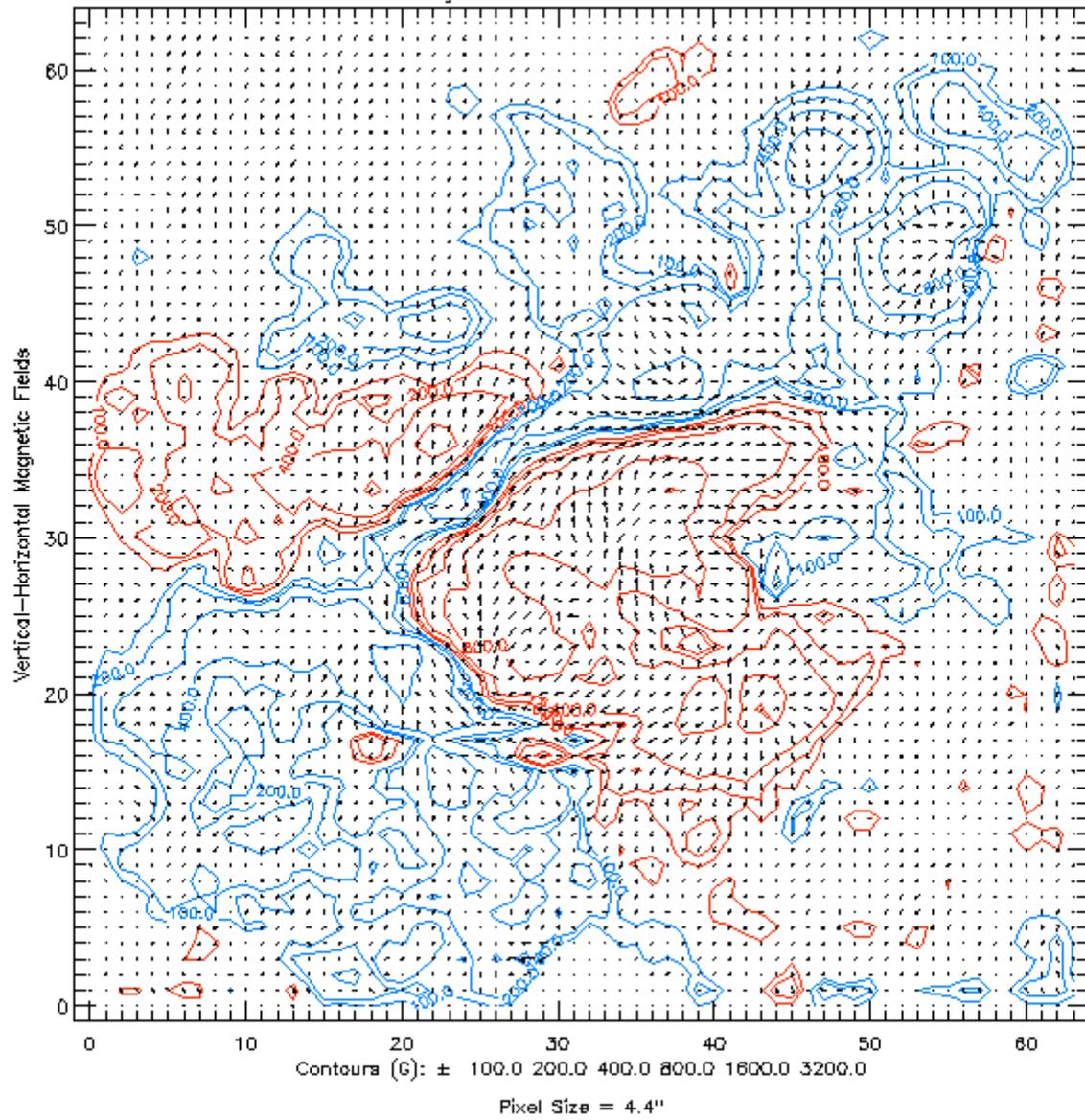
- **Energy comparison:**
- **$E[\text{NLFFF, initial potential}] = 2.05 * E[\text{potential}]$**
- **$E[\text{NLFFF, initial linear}] = 2.07 * E[\text{potential}]$**
- **$E[\text{NLFFF, initial pot-lin}] = 2.05 * E[\text{potential}]$**



## **AR 10486:**

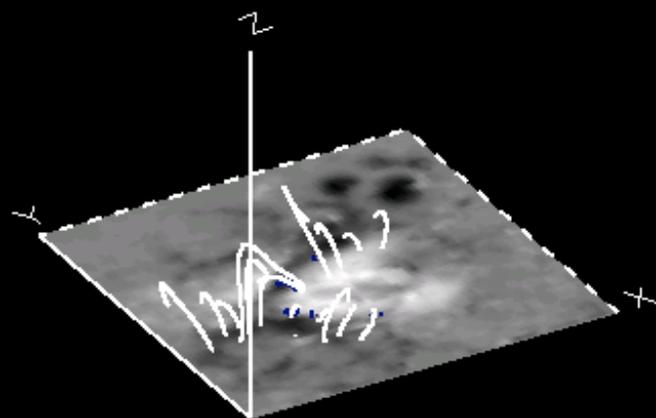
- **What happens with real data?**
- **Chromospheric magnetogram of AR 10486 obtained on 29-Oct-2003 18:46 UT. (See Metcalf presentation) For these calculations, the resolution was reduced from 0.55 arcsec to 4.4 arcsec.**

University of Hawaii Stokes Polarimeter

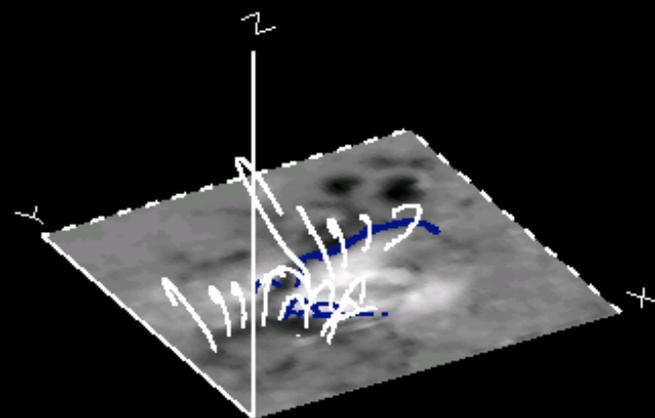


- B negative
- B positive
- B horizontal (500.0 G)

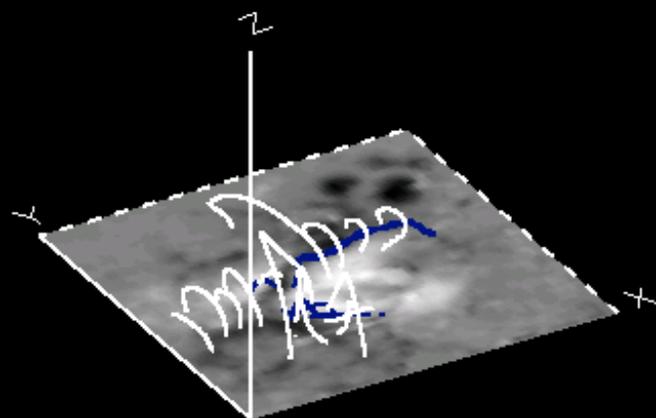
Potential Field



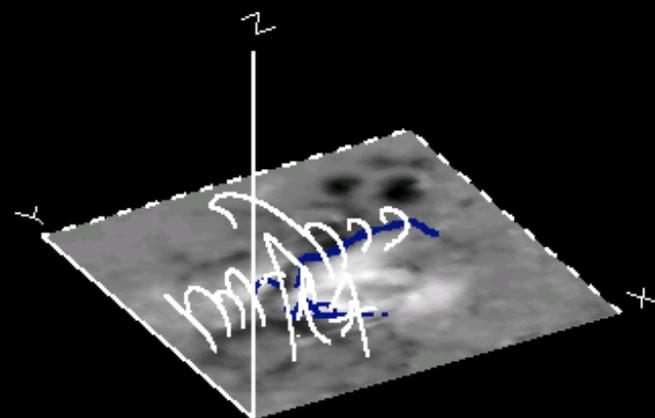
NLFFF from Potential



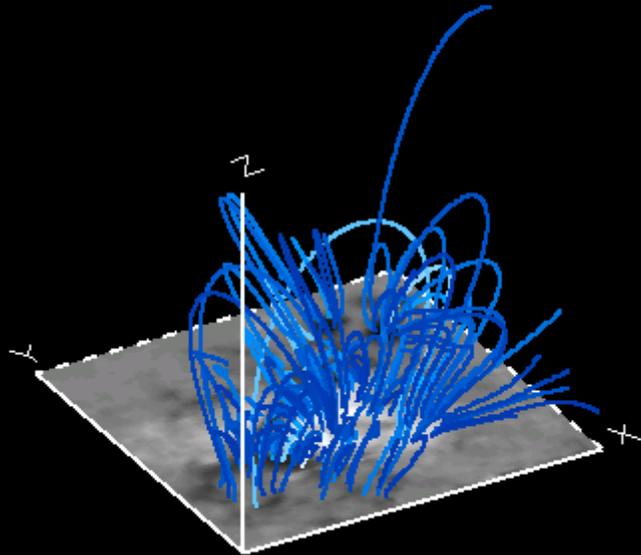
NLFFF from Linear FFF



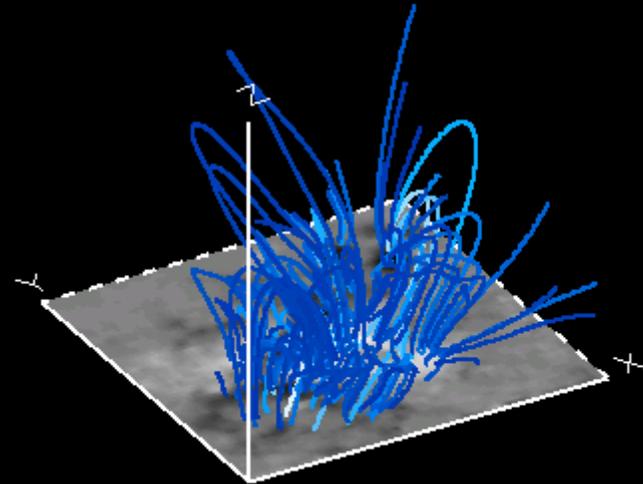
NLFFF from PotLin



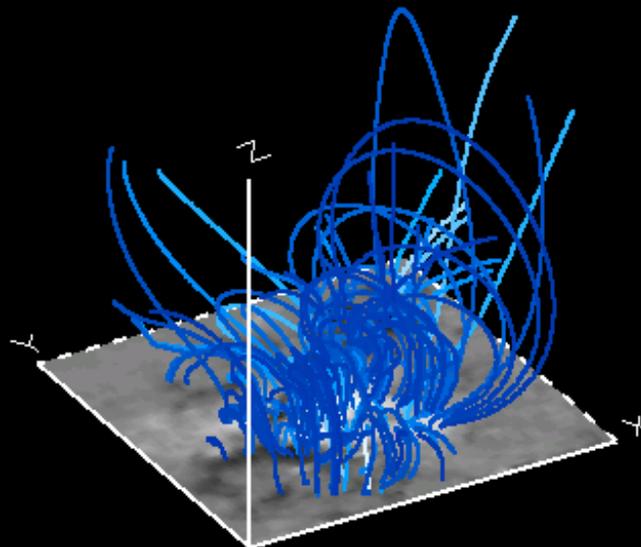
Potential Field



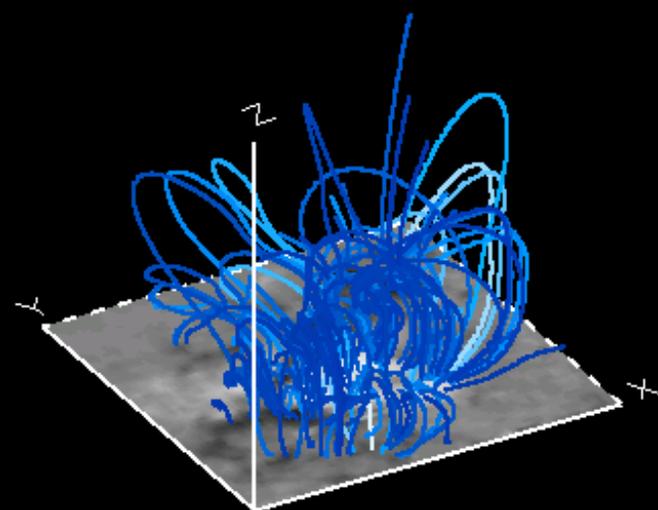
NLFFF from Potential



NLFFF from Linear FFF

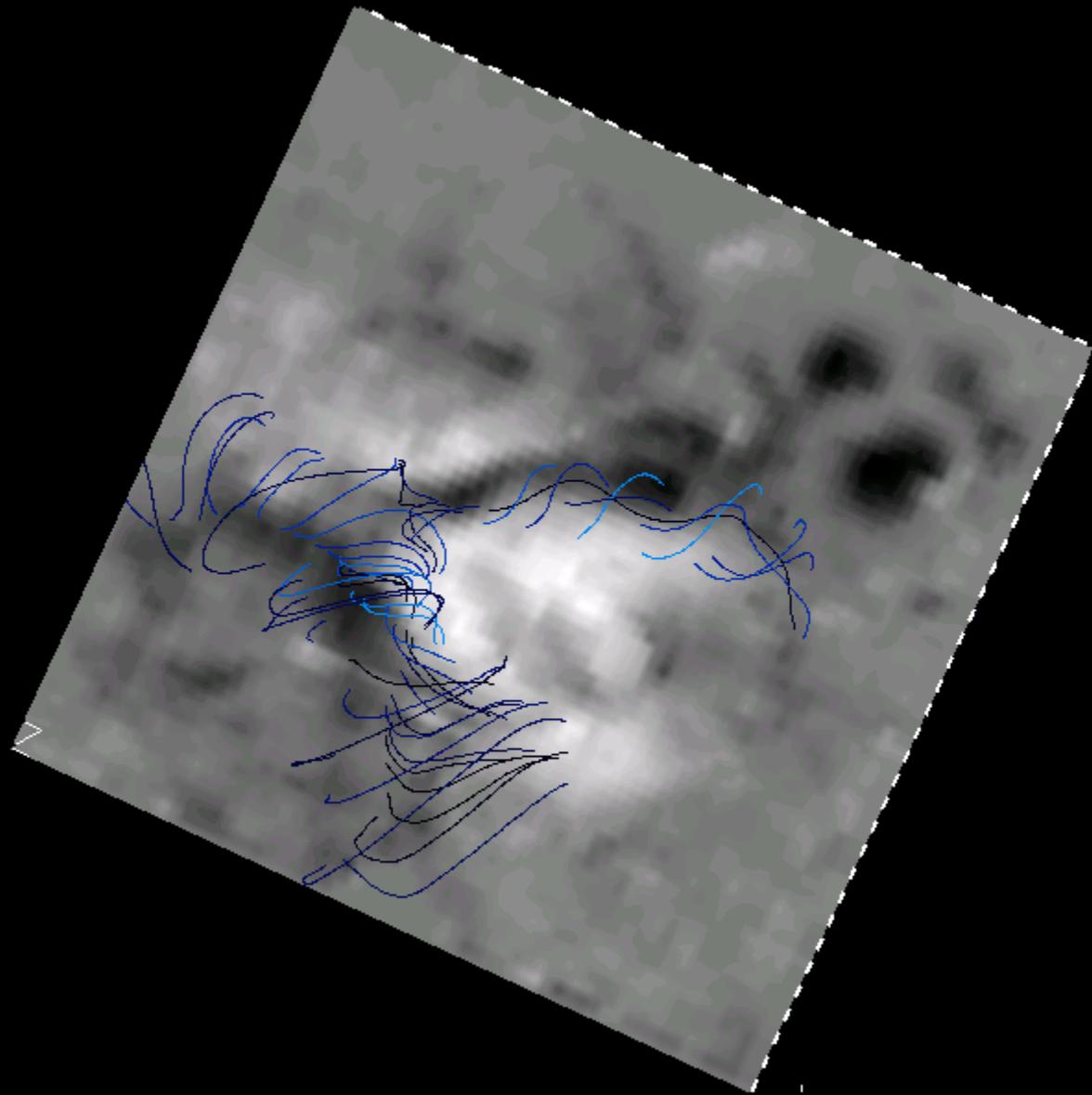


NLFFF from PotLin

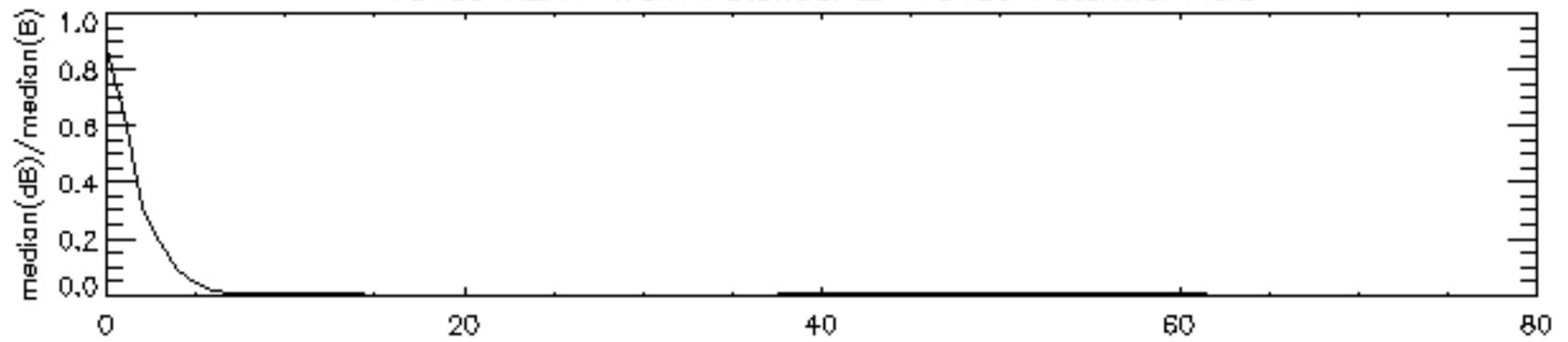


## **AR 10486:**

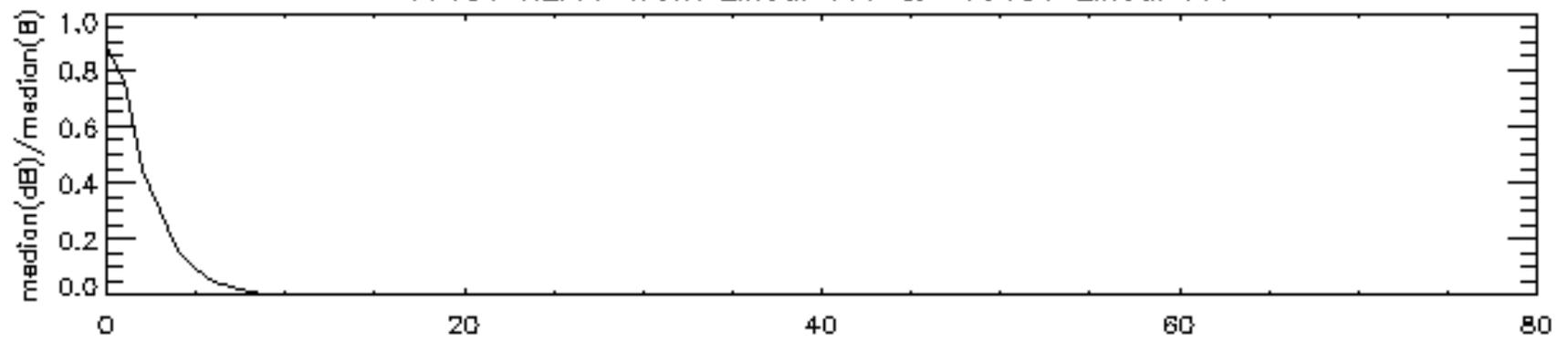
- **Fieldline comparisons are similar to the test case, models look similar close to the bottom boundary, not so similar farther away.**
- **All of the extrapolations show long non-potential fieldlines. These are very close ( $< 10000$  km) to the lower boundary.**



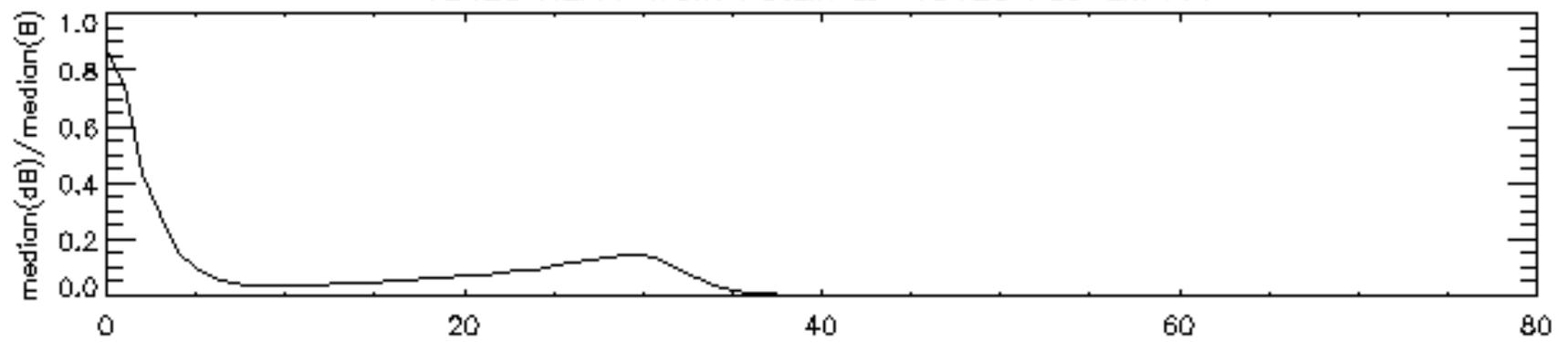
10486 NLFFF from Potential & 10486 Potential Field



10486 NLFFF from Linear FFF & 10486 Linear FFF



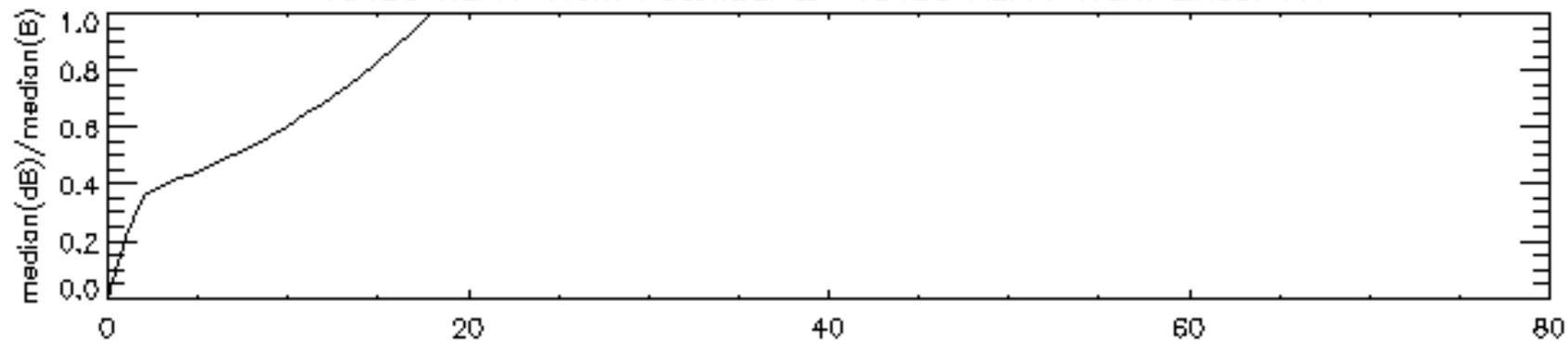
10486 NLFFF from PotLin & 10486 Pot-Lin FFF



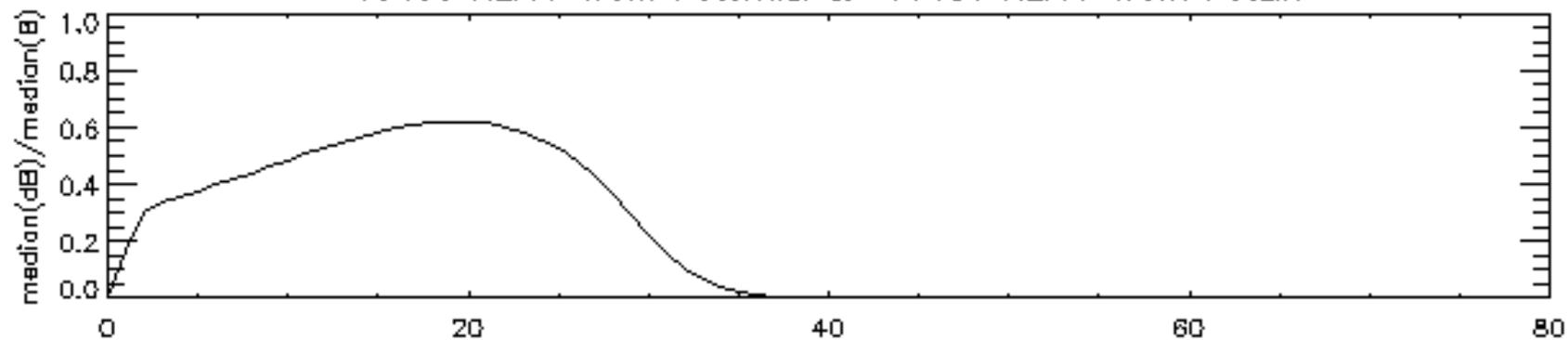
## **AR 10486:**

- **Similar to test data, the difference between initial and final states decreases with height. For the potential and linear FFF initial states, the difference is negligible above 30000 km (10 grid points = 3220 km). Potential-linear combination shows difference out to 120000 km.**

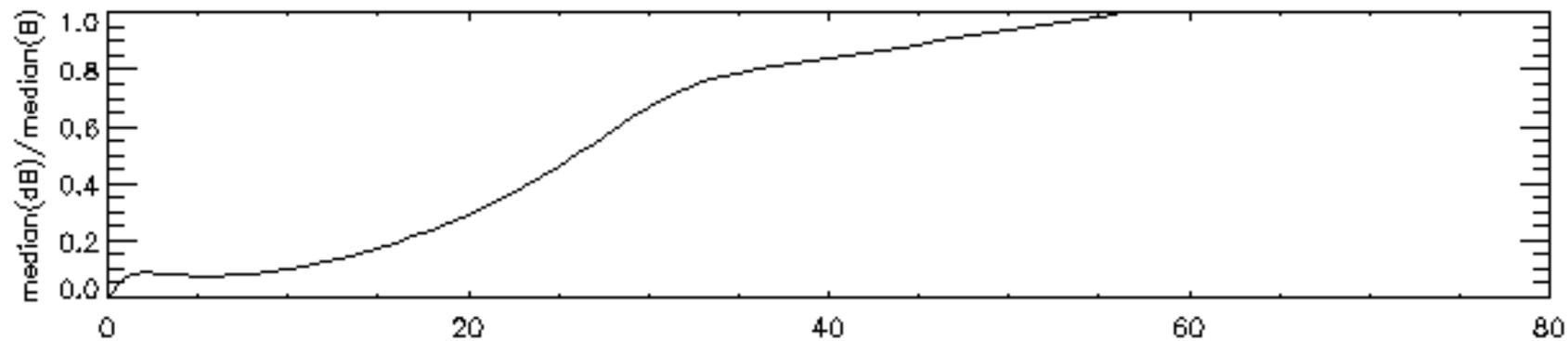
10486 NLFFF from Potential & 10486 NLFFF from Linear FFF



10486 NLFFF from Potential & 10486 NLFFF from PotLin



10486 NLFFF from Linear FFF & 10486 NLFFF from PotLin



## **AR 10486:**

- **Similar to test data, the difference between models increases with height. The difference is relatively large above 10000 km.**

## **AR 10486:**

- **Energy Comparison**
- **$E[\text{NLFFF, initial linear}] = 1.44 * E[\text{potential}]$**
- **$E[\text{NLFFF, initial potential}] = 1.29 * E[\text{potential}]$**
- **$E[\text{NLFFF, initial pot-lin}] = 1.38 * E[\text{potential}]$**
  
- **$E[\text{potential}] = 3.43 \text{ e}33 \text{ ergs}$**
- **$E[\text{NLFFF, initial linear}] = 4.30 \text{ e}33 \text{ ergs}$**
- **$E[\text{NLFFF, initial potential}] = 4.80 \text{ e}33 \text{ ergs}$**
- **$E[\text{NLFFF, initial pot-lin}] = 4.61 \text{ e}33 \text{ ergs}$**

## **Conclusions:**

- **Models need more work:**
- **But, near the lower boundary, the models do give similar results, relatively independent of initial and boundary conditions.**
- **Can a solution that is independent of initial conditions be found? Is the dependence on initial conditions due to non-uniqueness of solution or is it a problem with the code?**