Simulating Cyclic Evolution of Coronal Magnetic Fields using a Potential Field Source Surface Model Coupled with a Dynamo Model

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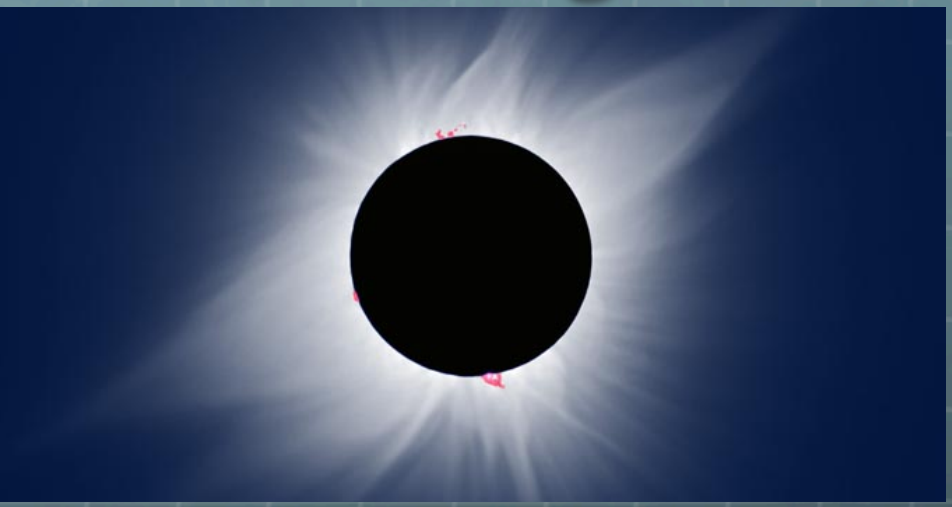
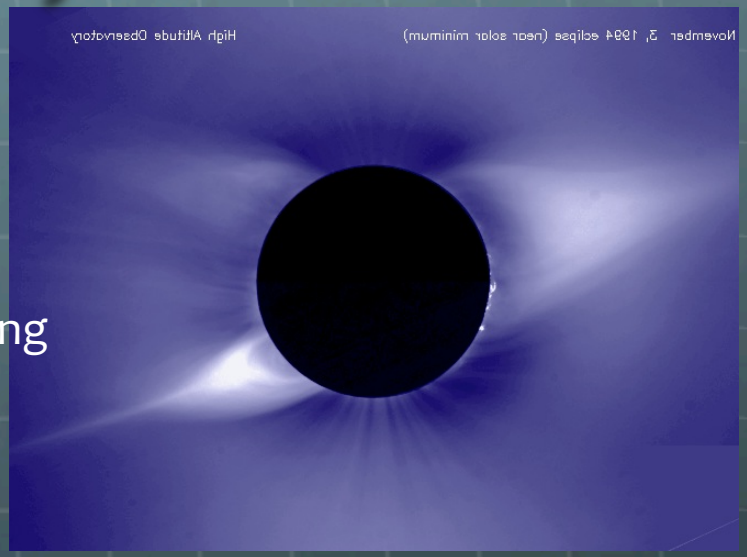
Coronal Changes through a Cycle



1991- Solar Maximum



1994- Descending Phase

1995- Solar Minimum

1998- Ascending Phase

Potential Fields

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \left(\vec{v} \times \vec{B}\right) + \eta \nabla^2 \vec{B} + S$$

$$\vec{B} = \nabla \times A\hat{e}_\phi$$

Combining the equations from the convection zone, and taking free-space assumptions for the coronal region ($\eta = \infty$ and $v = 0$), we get:

$$(\nabla^2 - \frac{1}{r^2 \sin^2 \theta})A = 0$$

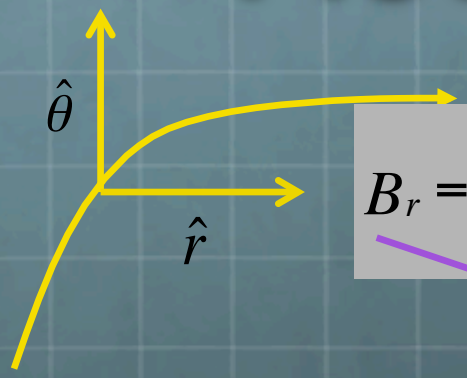
Solving for A

The potential equation is in a form for which the solution can be written as an associated Legendre Polynomial where n=1:

$$\sum_{m=1}^{\infty} \frac{a_m^1}{r^{m+1}} P_m^1(x) = A$$

We assume an axisymmetric model, where there is no phi dependence to the field and vector potential components.

Plotting Field Lines



$$B_r = \frac{1}{r^2 \sin\theta} \frac{\partial}{\partial \theta}\left(Ar\sin\theta\right)$$

$$B_\theta = \frac{-1}{r\sin\theta} \frac{\partial}{\partial r}\left(Ar\sin\theta\right)$$

Field Line Equations

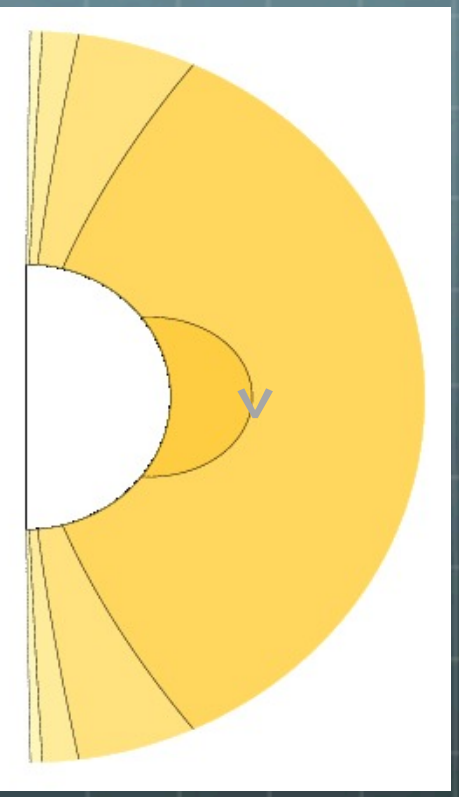
$$\frac{B_r}{dr} = \frac{B_\theta}{rd\theta}$$

$$\frac{1}{r\sin\theta} \frac{\partial}{\partial \theta}\left(Ar\sin\theta\right)d\theta + \frac{1}{r\sin\theta} \frac{\partial}{\partial r}\left(Ar\sin\theta\right)dr = 0$$

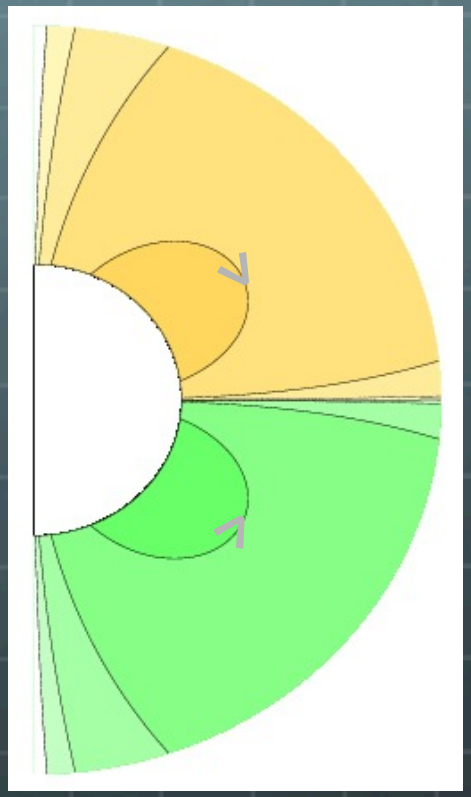
$$d(Ar\sin\theta) = 0$$

$$Ar\sin\theta = const$$

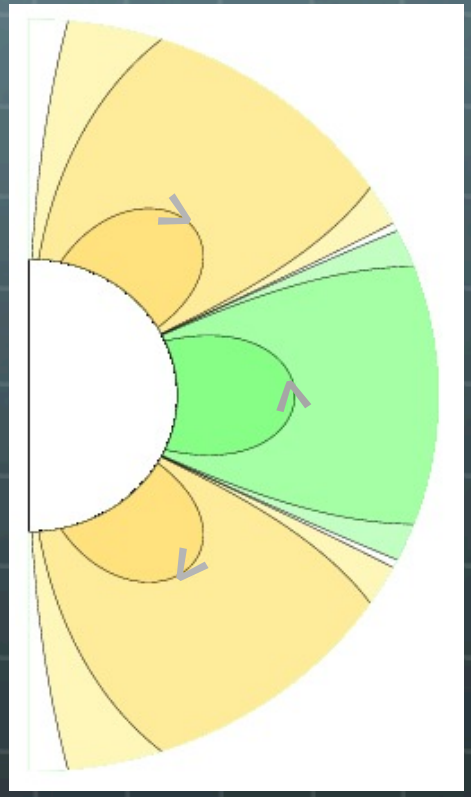
Associated Legendre Polynomials of the First Order (n=1)



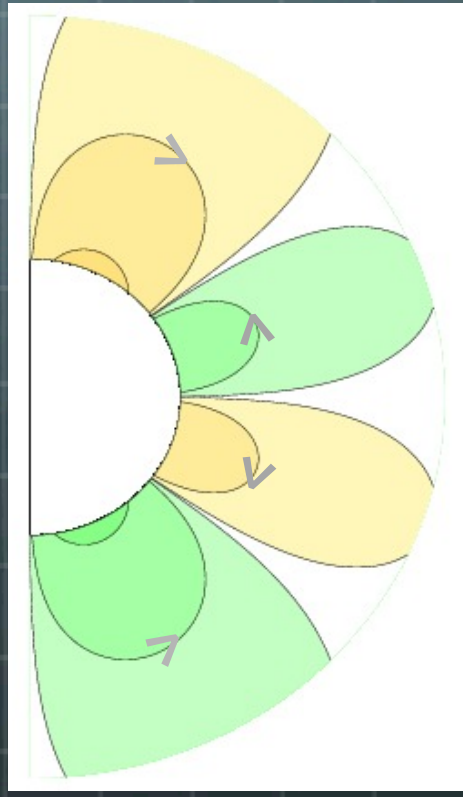
First Degree (m=1)



Second Degree (m=2)



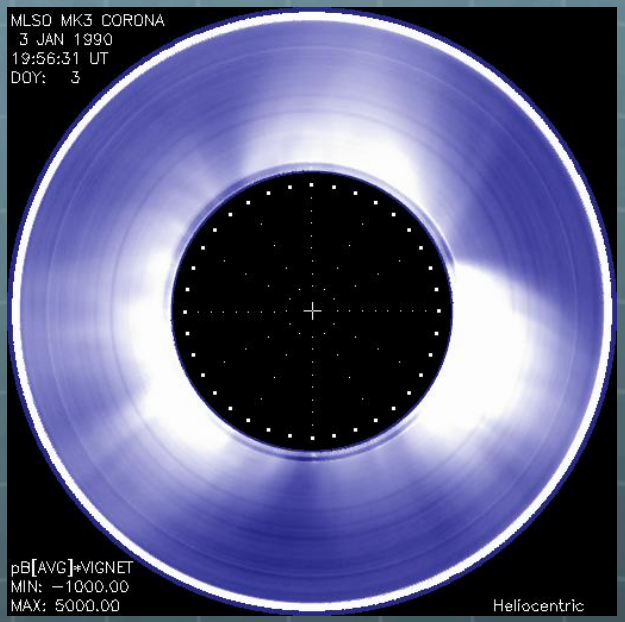
Third Degree (m=3)

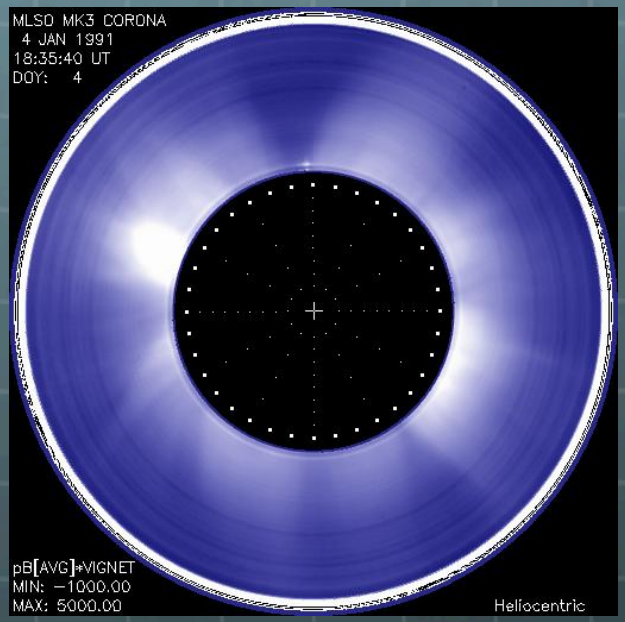


Fourth Degree (m=4)

MLSO Observations

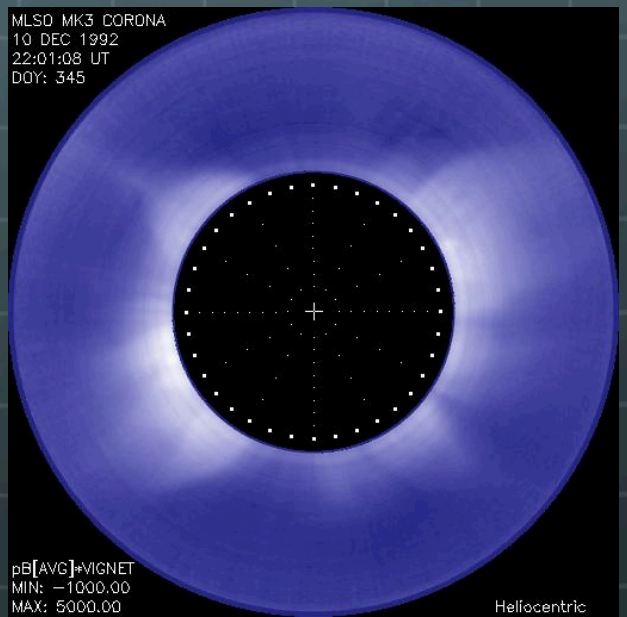
1990- Ascending Phase

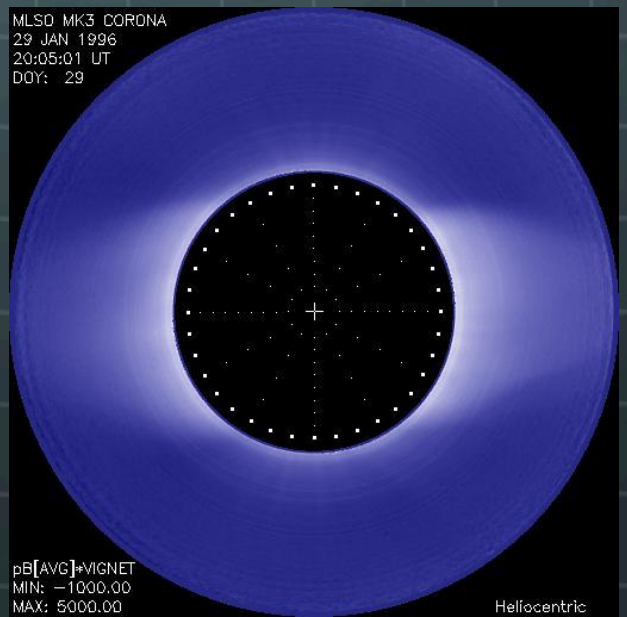




1991- Solar Maximum

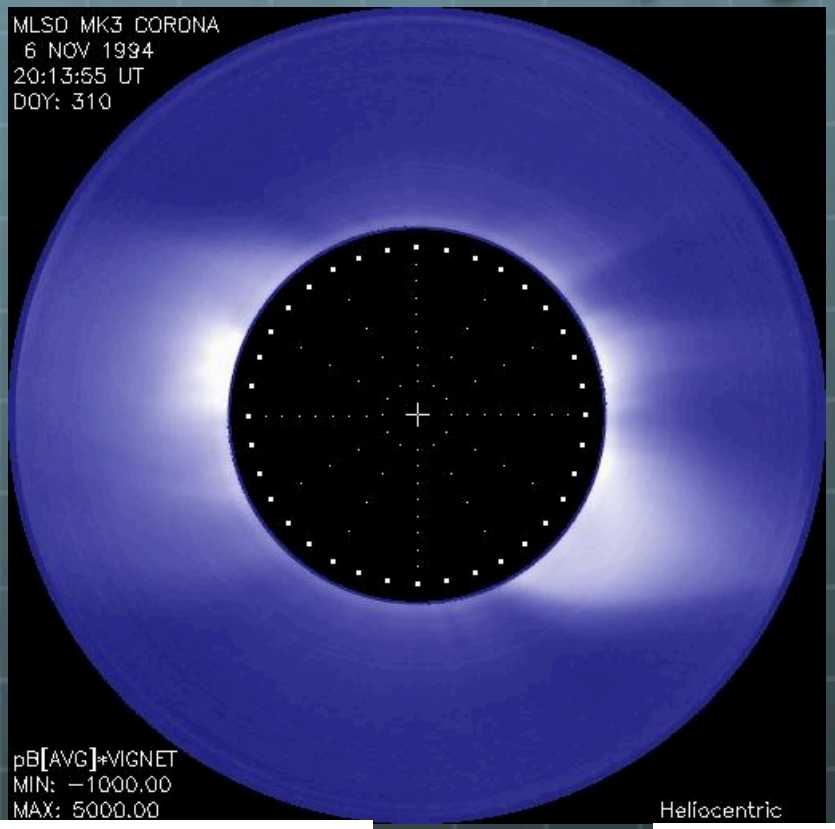
1992- Descending Phase

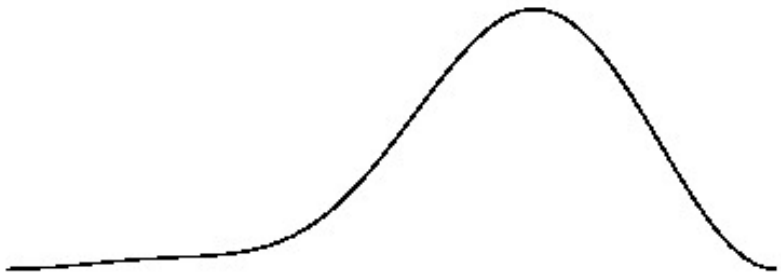


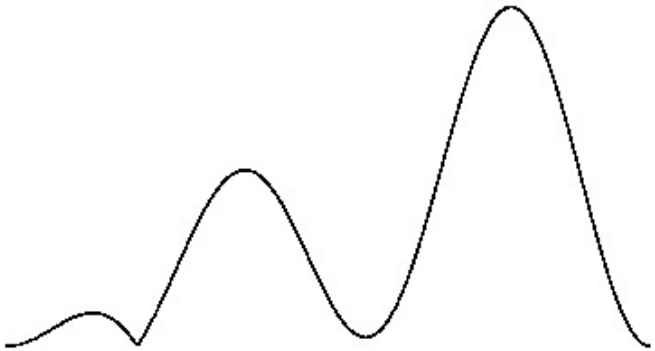


1996- Solar Minimum

November 6, 1994



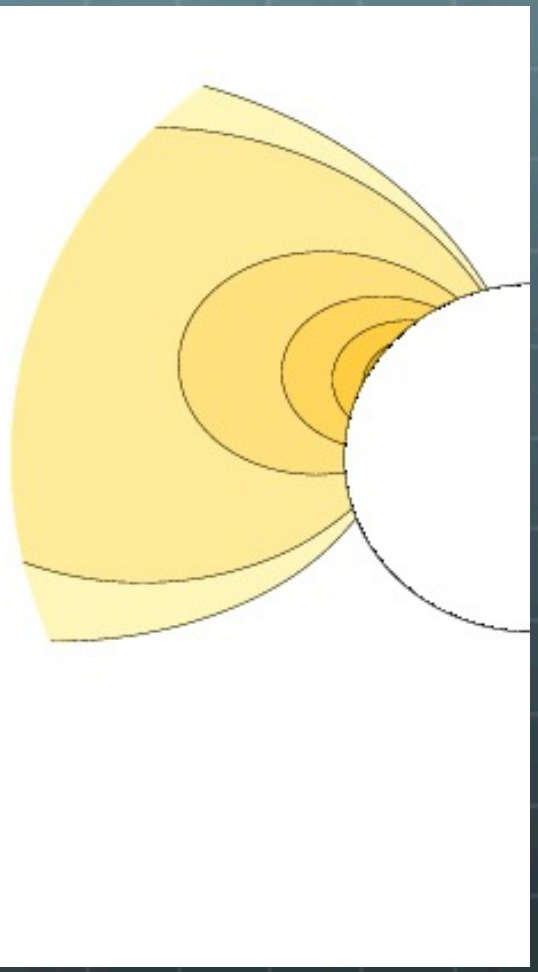


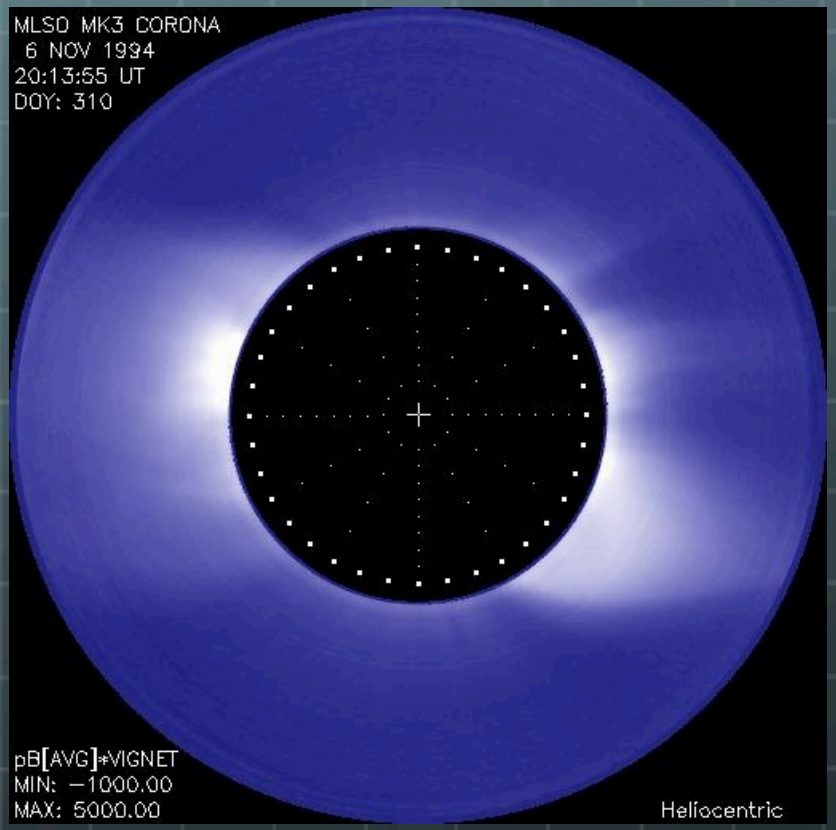


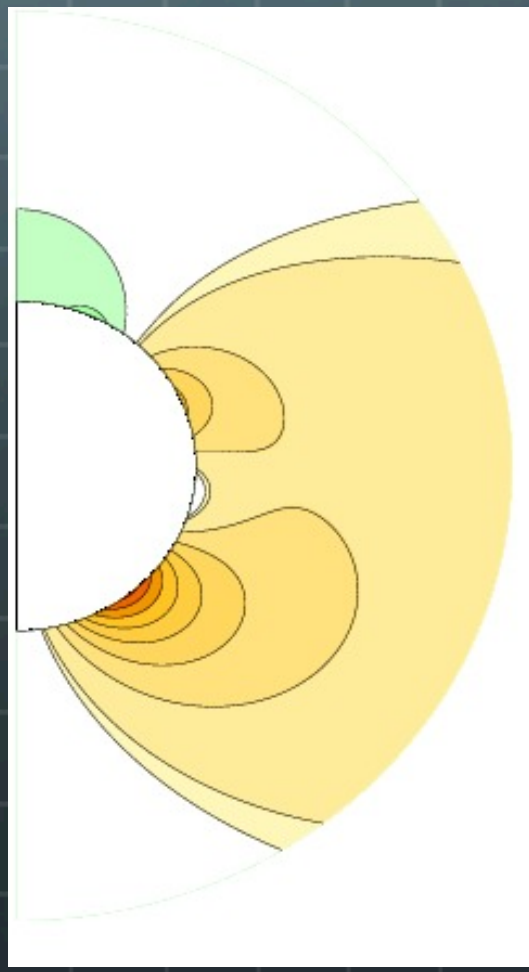
November 6, 1994

$$A = \frac{1.3P_1^1}{r^2} - \frac{5P_2^1}{r^3} + \frac{10P_3^1}{r^4}$$

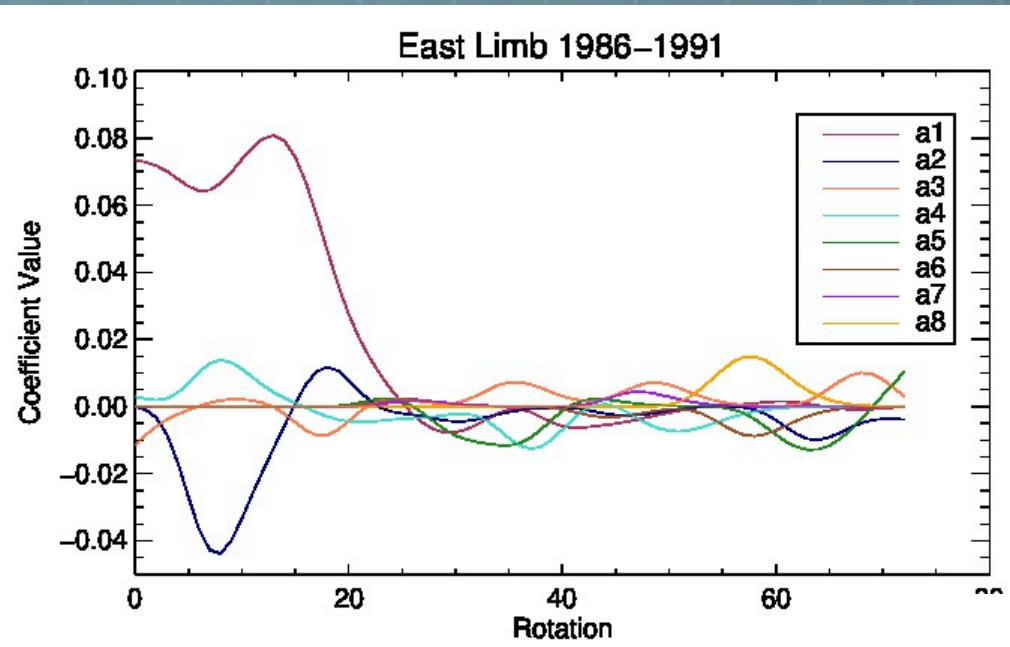
$$A = \frac{1.6P_1^1}{r^2} - \frac{5P_2^1}{r^3} + \frac{32P_3^1}{r^4} - \frac{200P_4^1}{r^5}$$





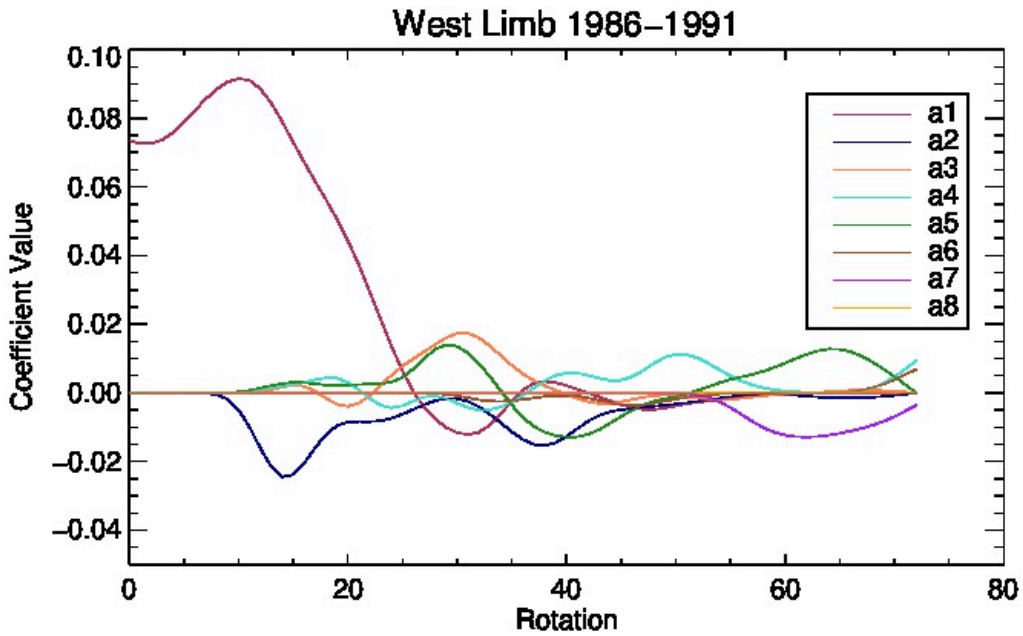


Corona Over Time

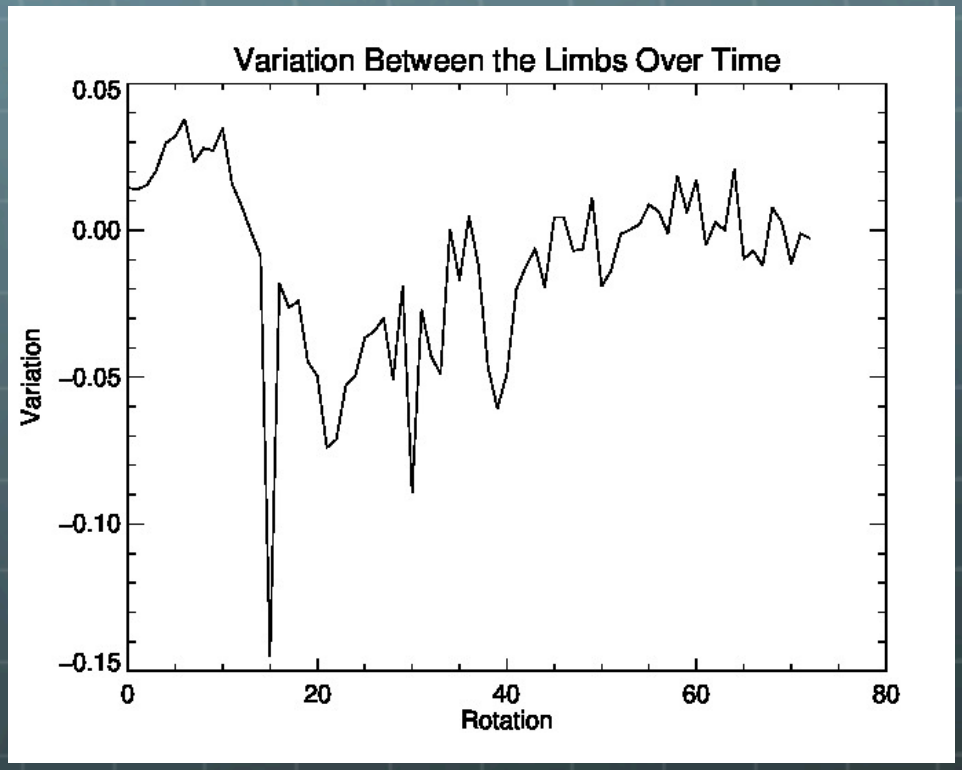


- during minimum, both limbs are dominated by the dipole term, as was reported by previous authors

- over time, this term begins to fade and higher order multipoles become dominant



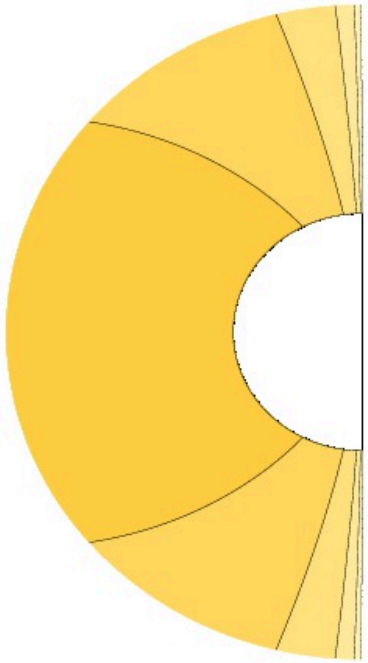
Variation Between Limbs

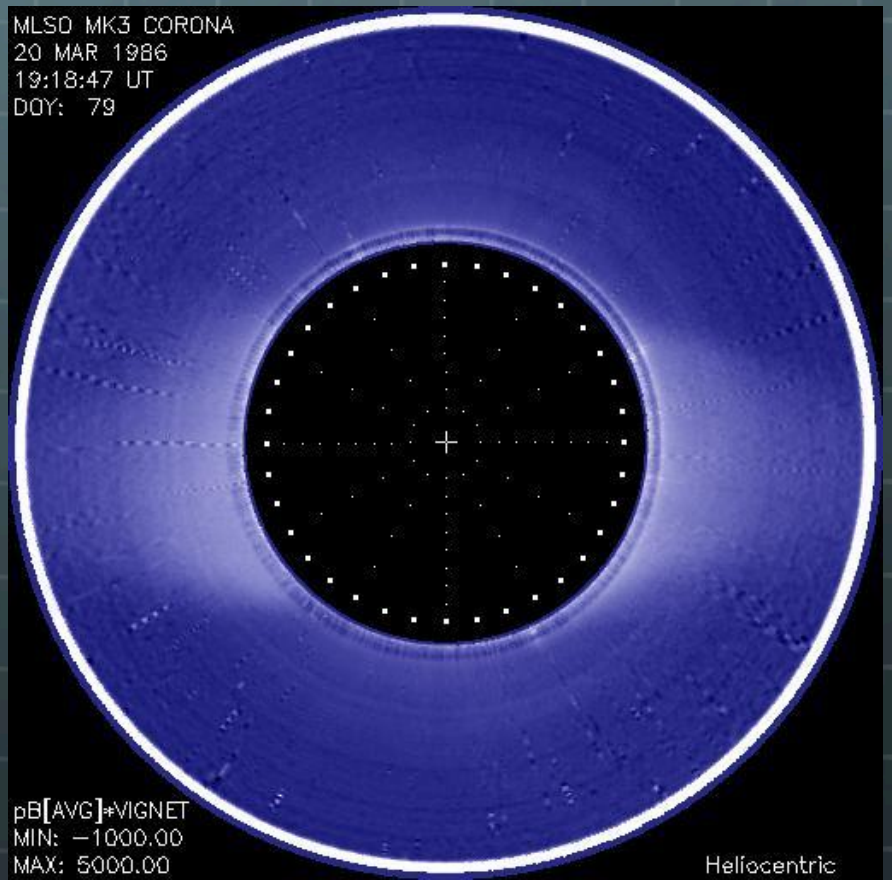


- computing the difference between east limb and west limb coefficients, we see the two limbs are not perfectly symmetric, with the difference being greatest at minimum, showing a φ dependence that changes with time

March 20, 1986

$$A = \frac{3P_1^1}{r^2}$$





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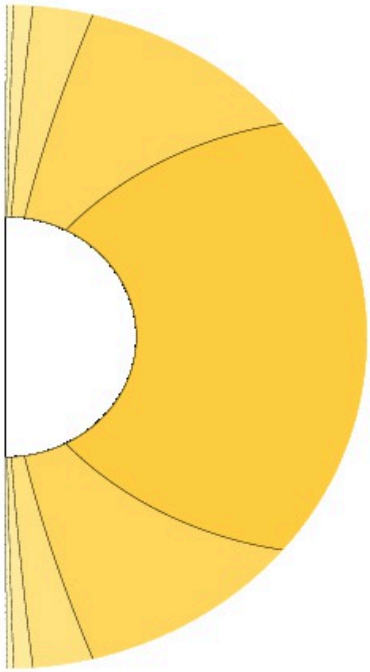
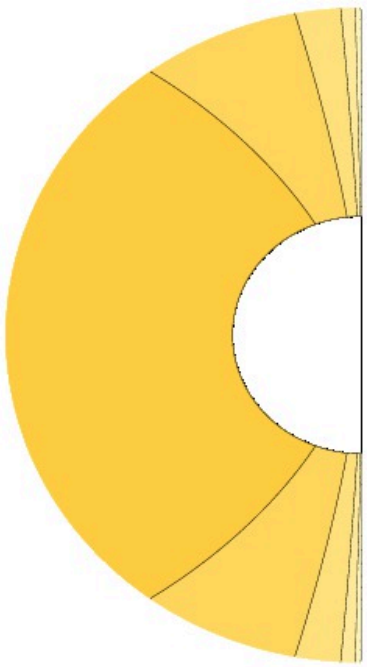
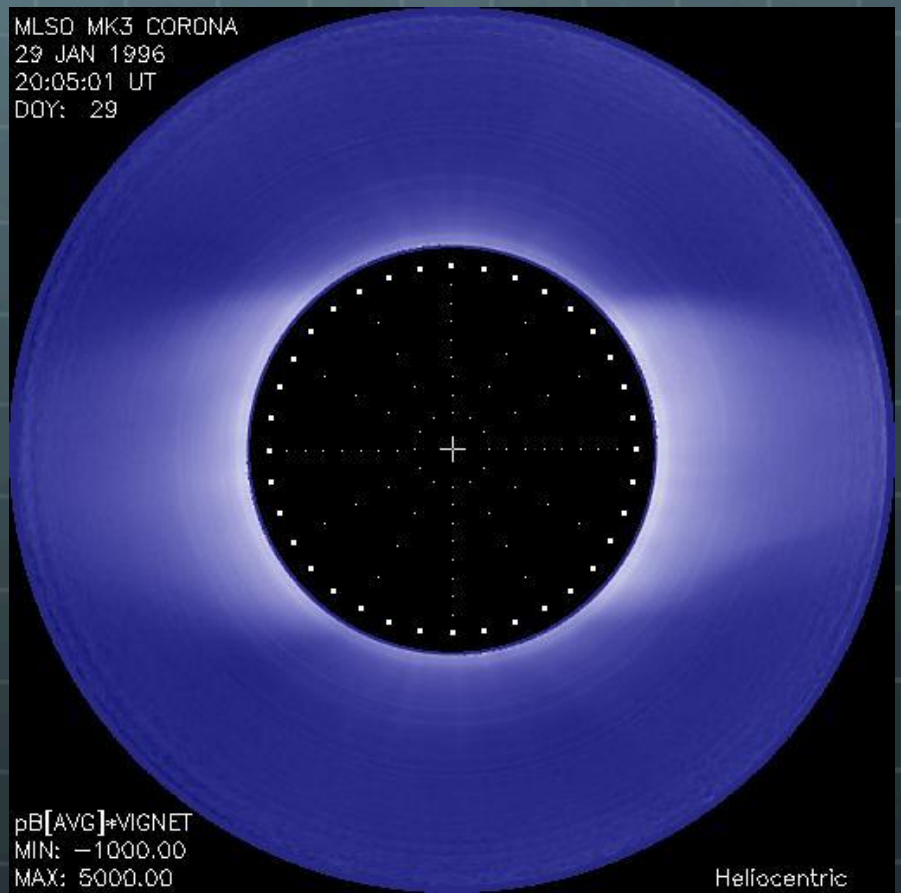


January 29, 1996

$$A = \frac{5P_1^1}{r^2}$$





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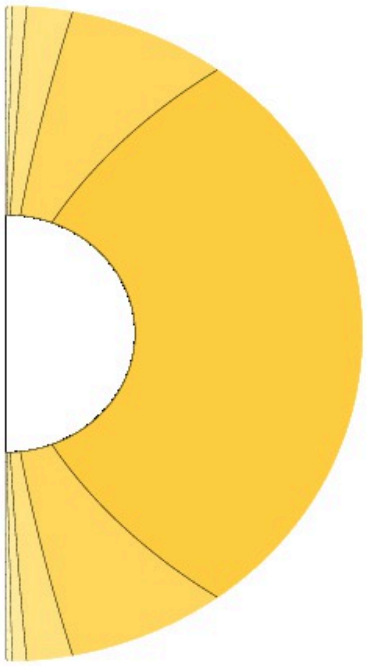
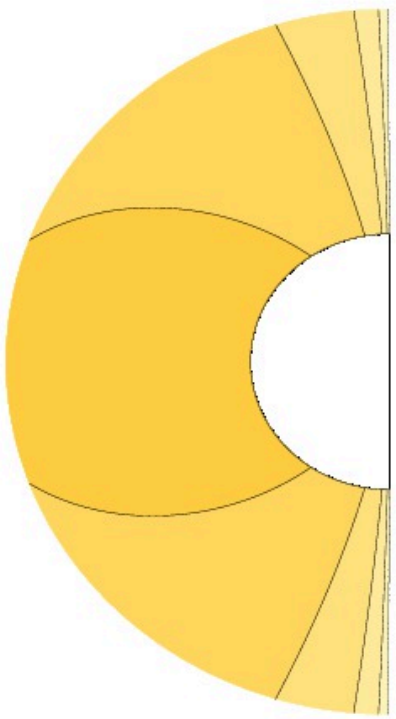
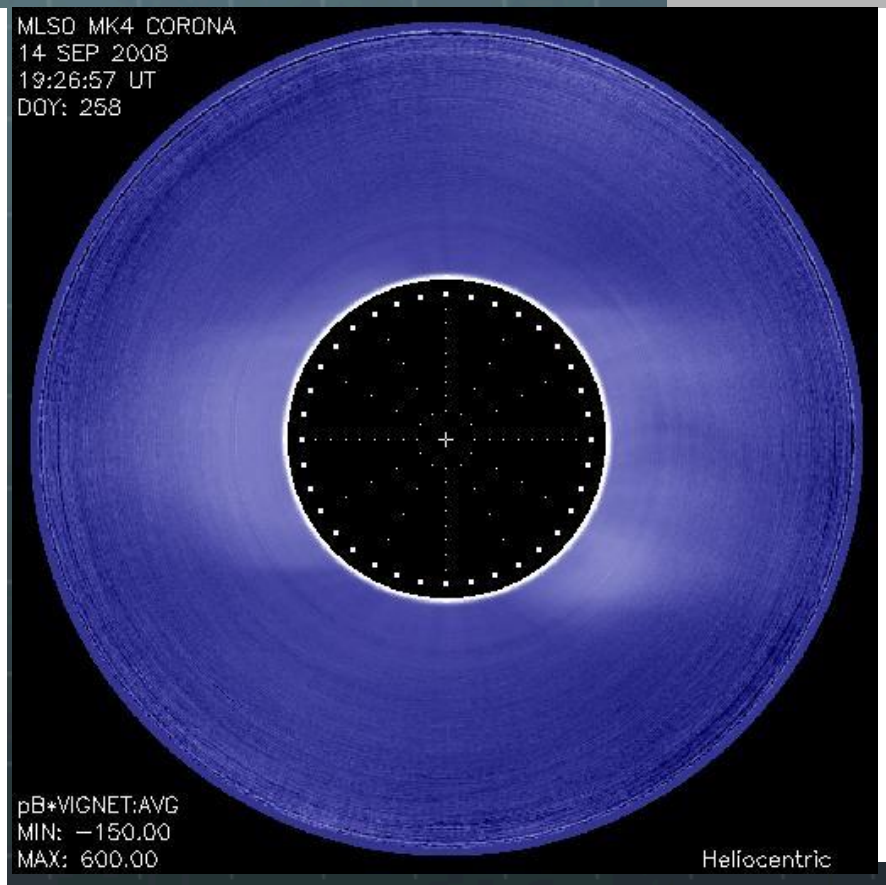


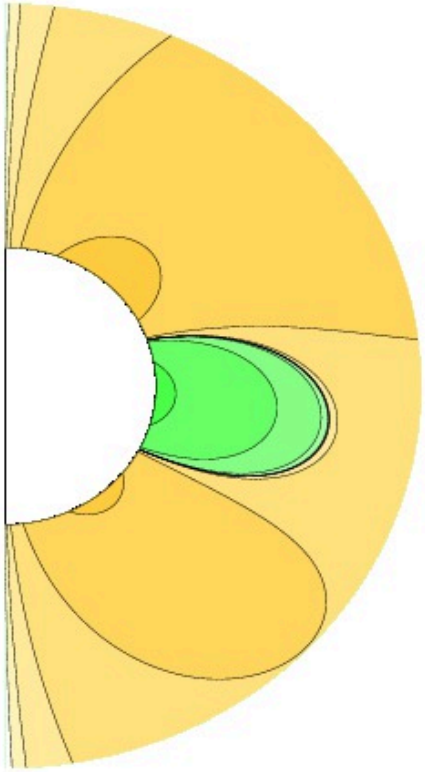
September 14, 2008

$$A = \frac{2P_1^1}{r^2}$$

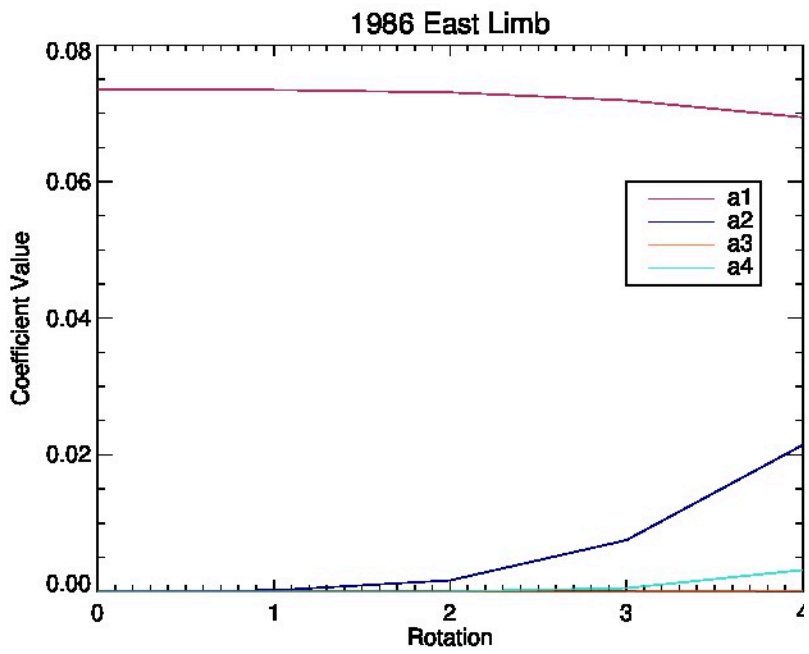
$$A = \frac{0.3P_1^1}{r^2} + \frac{1.7P_2^1}{r^3} + \frac{35P_3^1}{r^4}$$





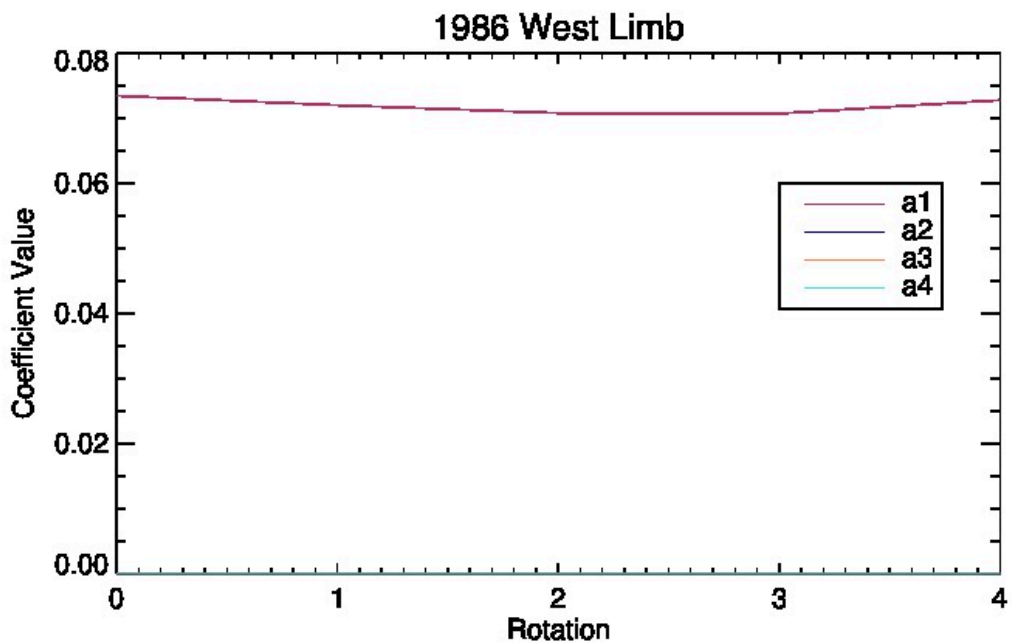


Comparing Minima- 1986

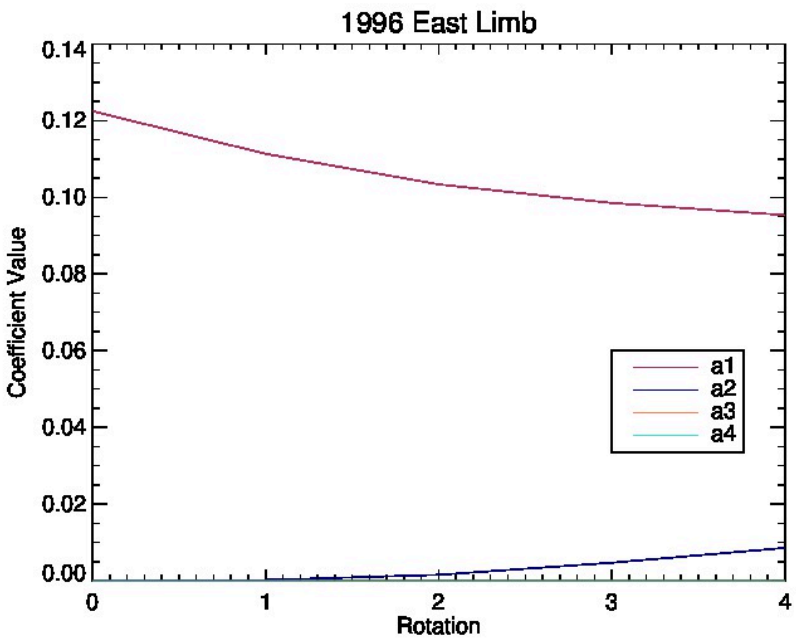


- sustained dipole structure over 5 Carrington rotations
- high a1 coefficients for both east and west wings

- higher multipole coefficients were very small



Comparing Minima- 1996



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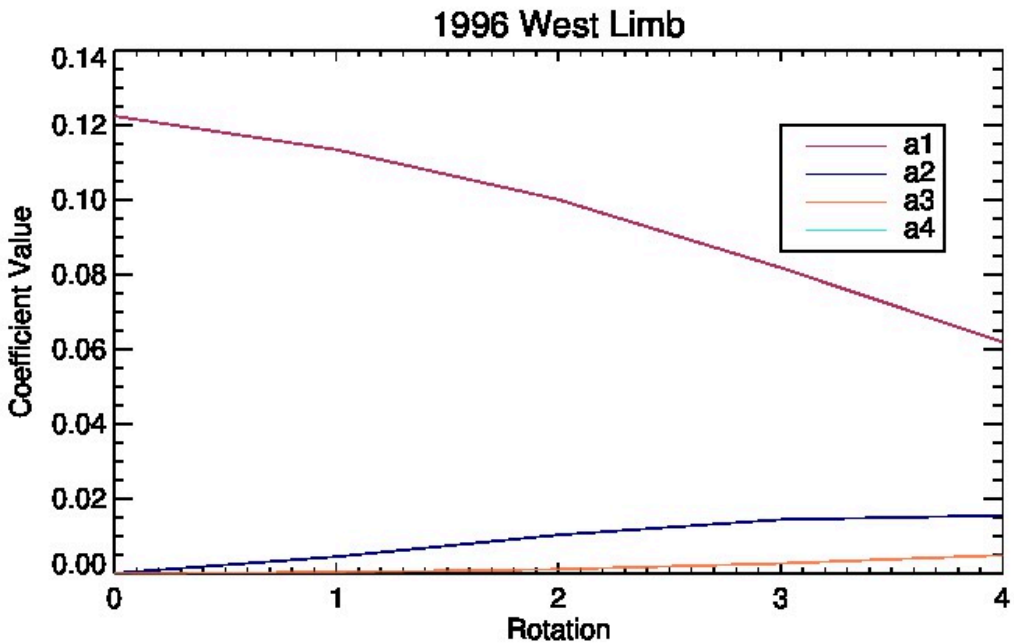
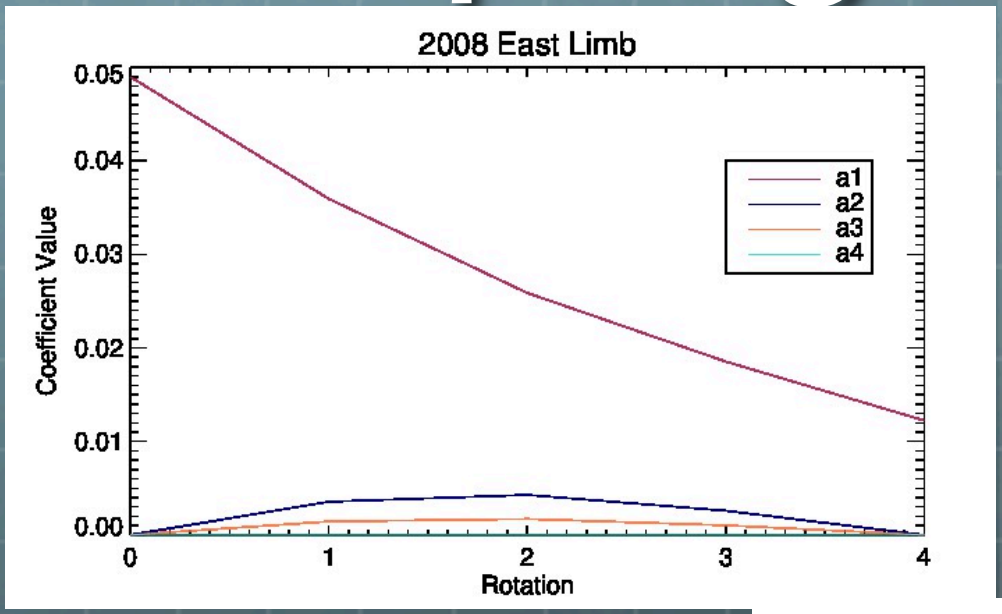
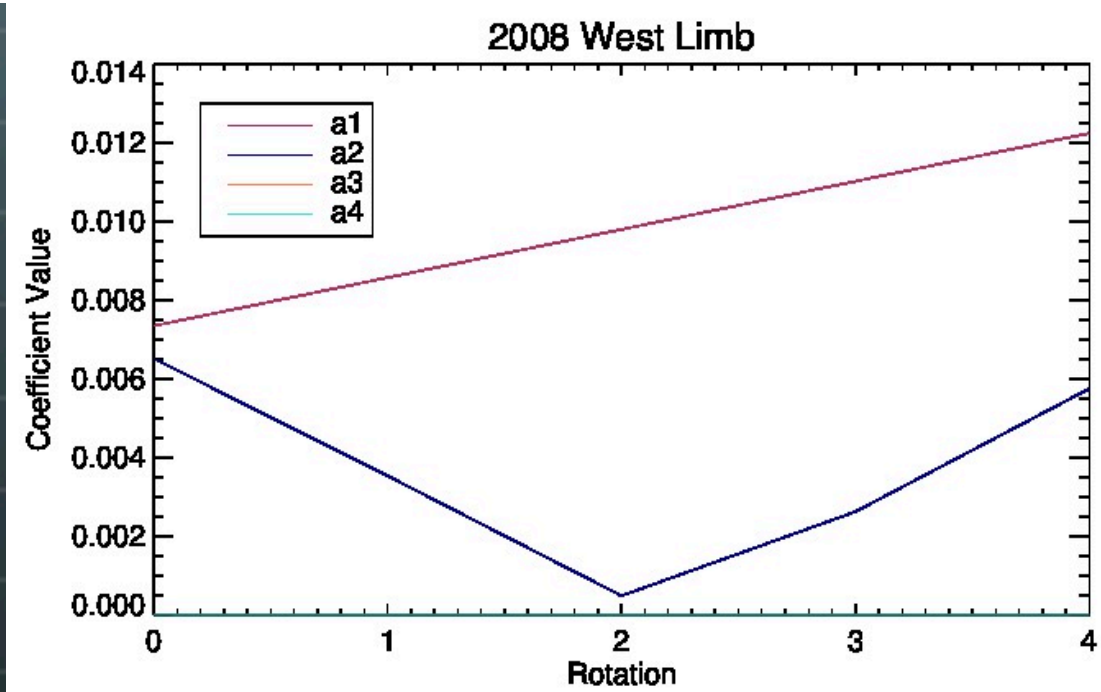


Comparing Minima- 2008

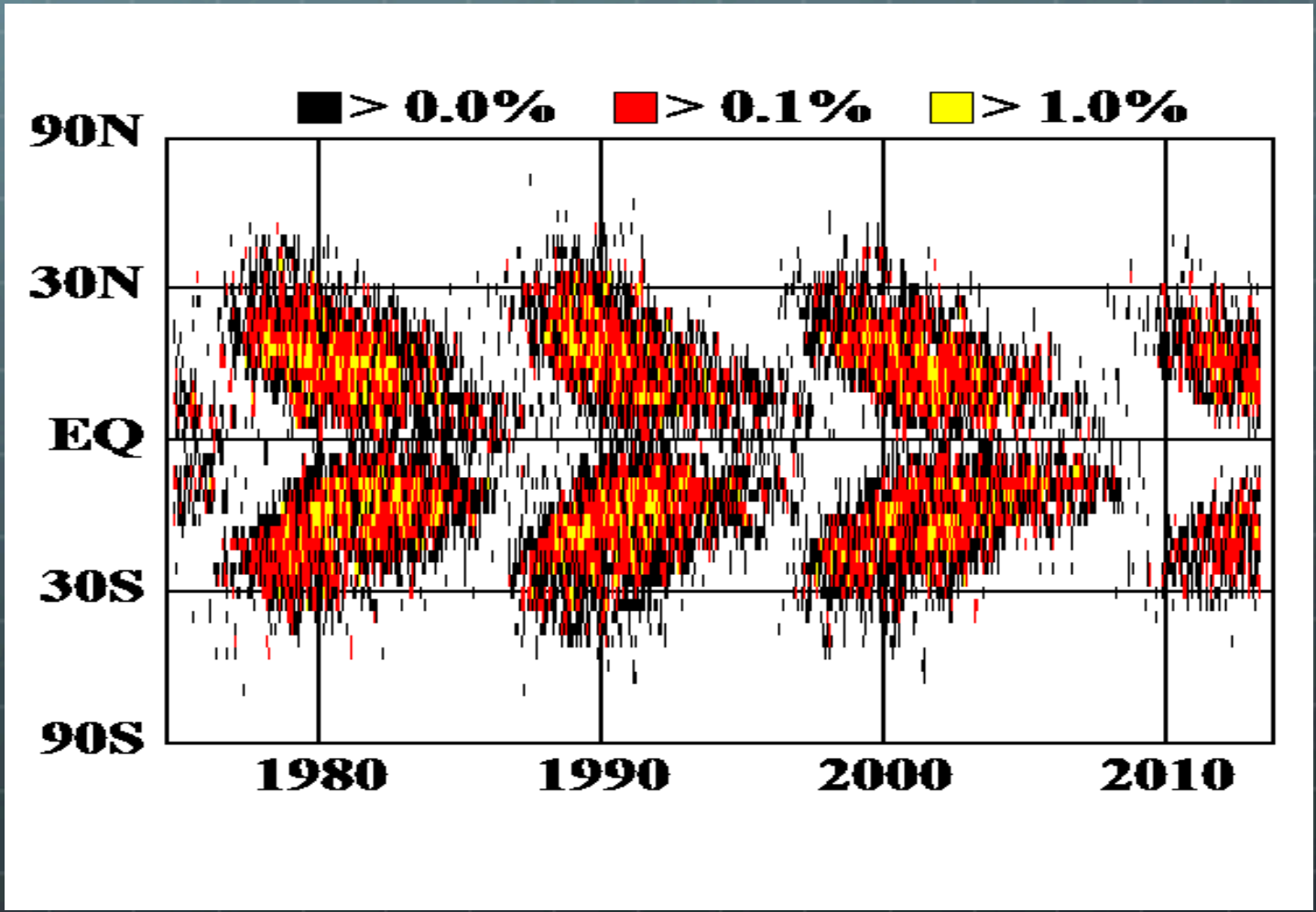


- no rotations in which both limbs were perfectly dipolar

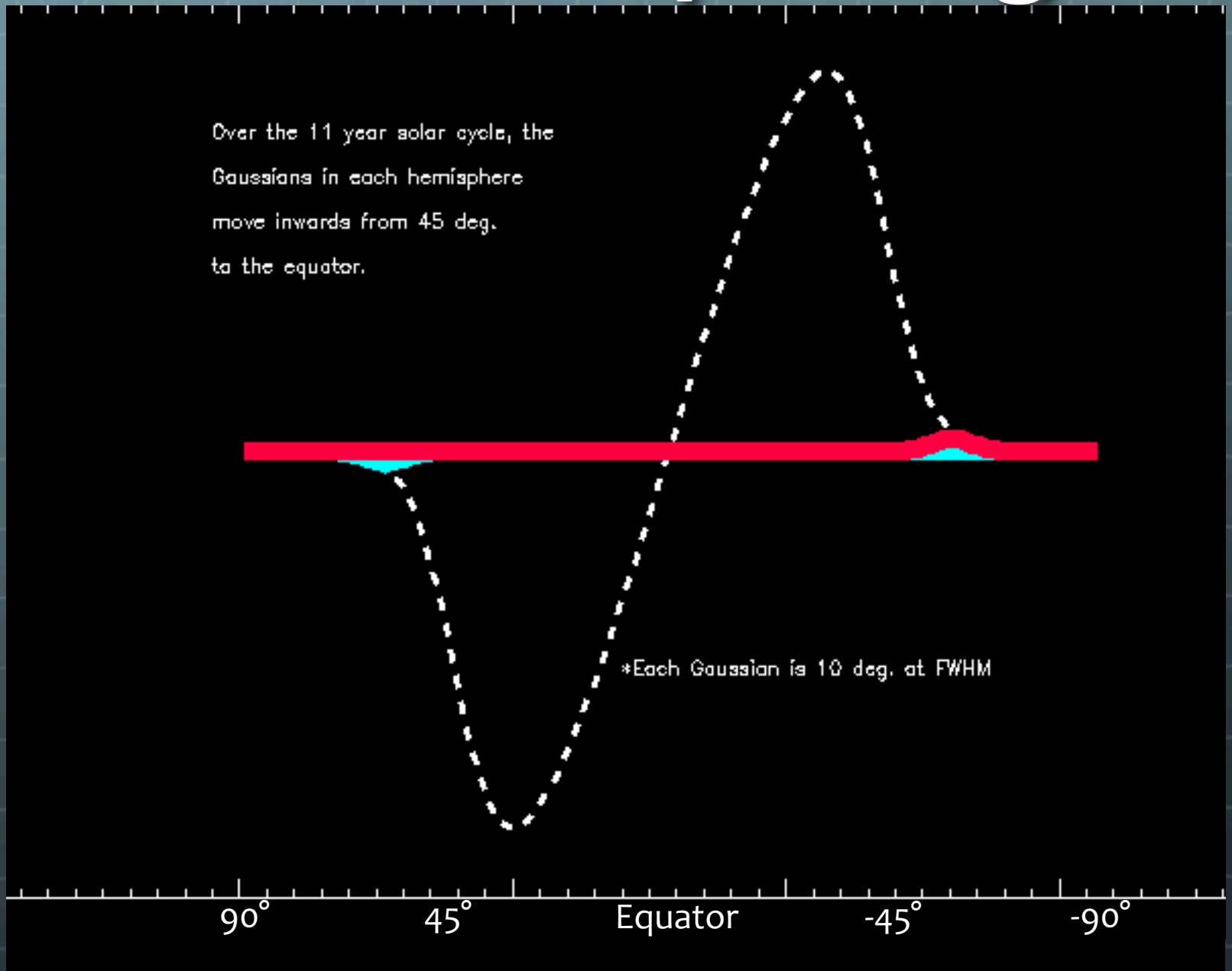
- multipoles present with significant amplitude



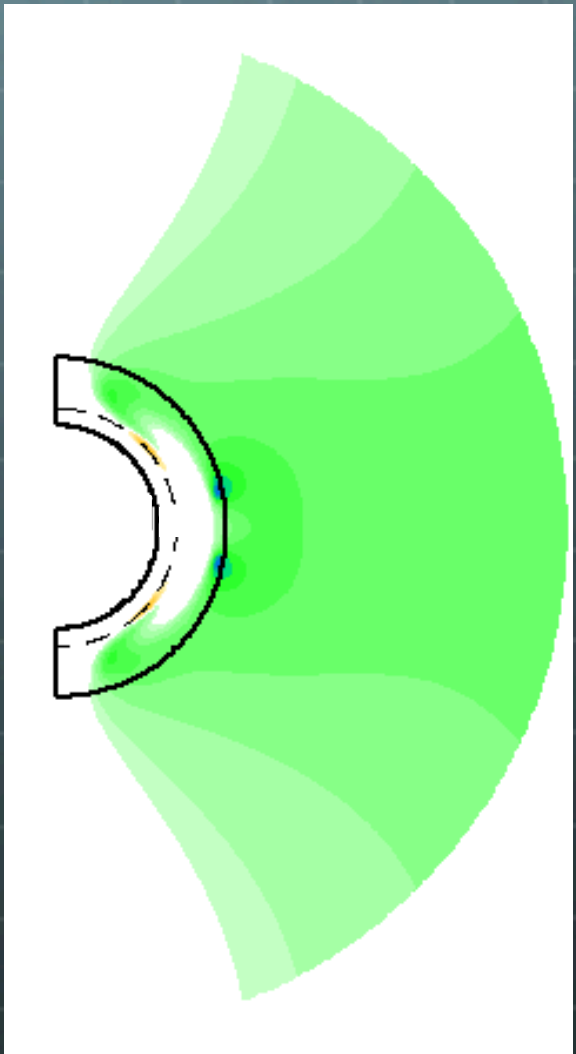
Butterfly Diagram



Symmetric Sunspot Migration

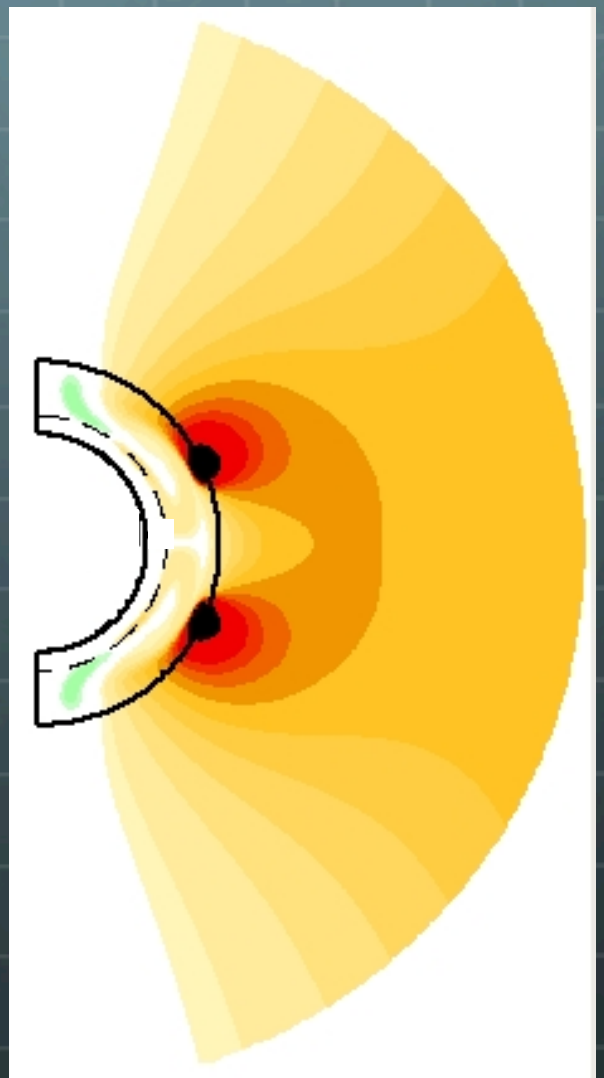


Symmetric Cycle

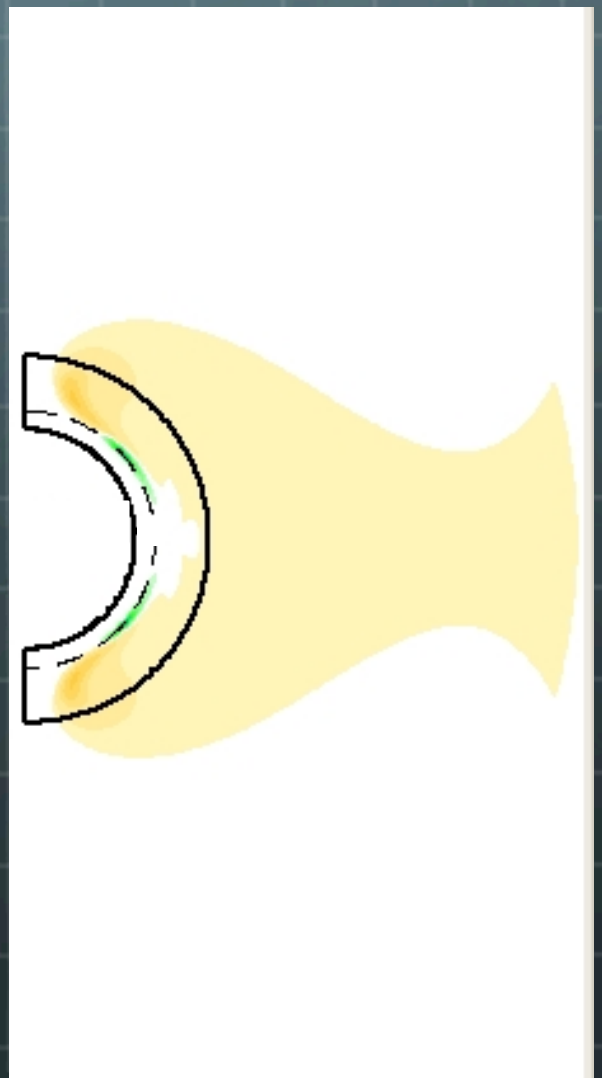


Symmetric Cycle

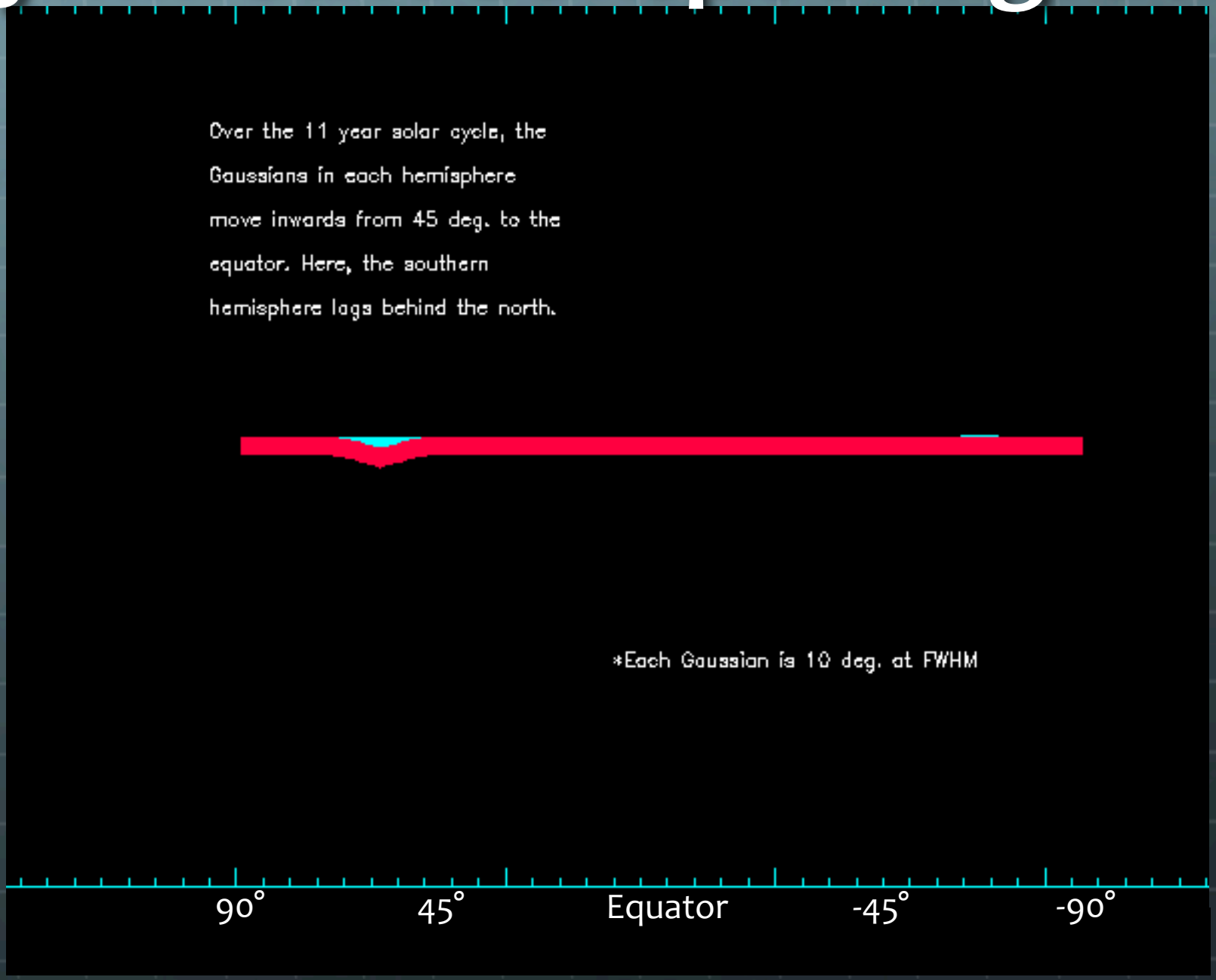
Solar Maximum



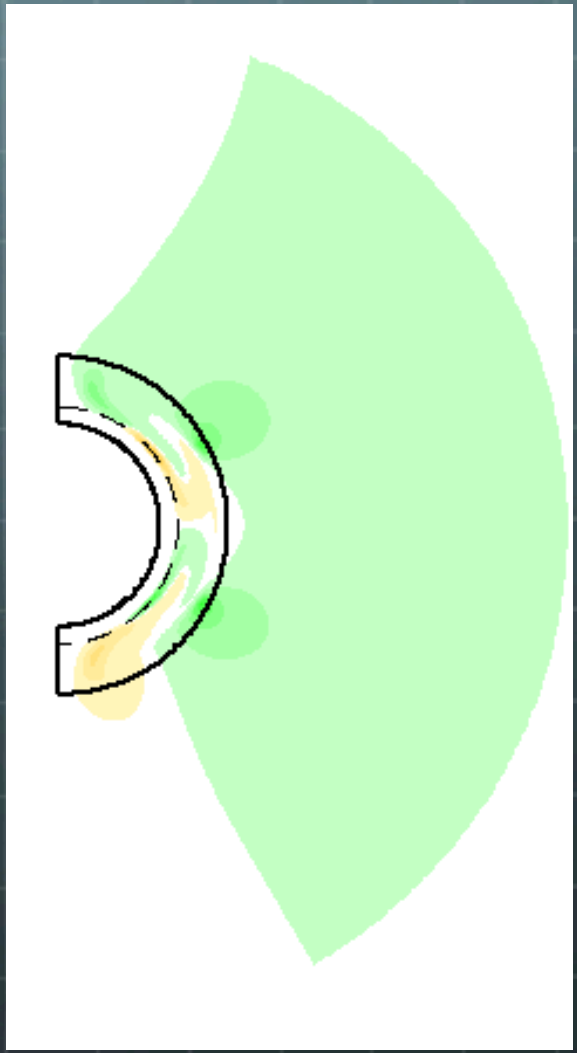
Solar Minimum



Asymmetric Sunspot Migration

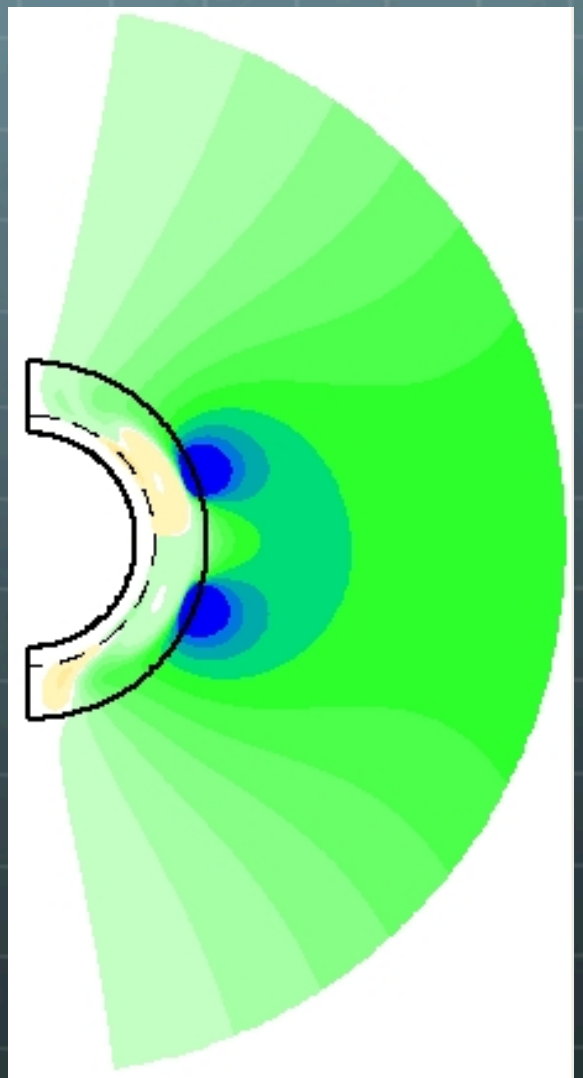


Asymmetric Cycle

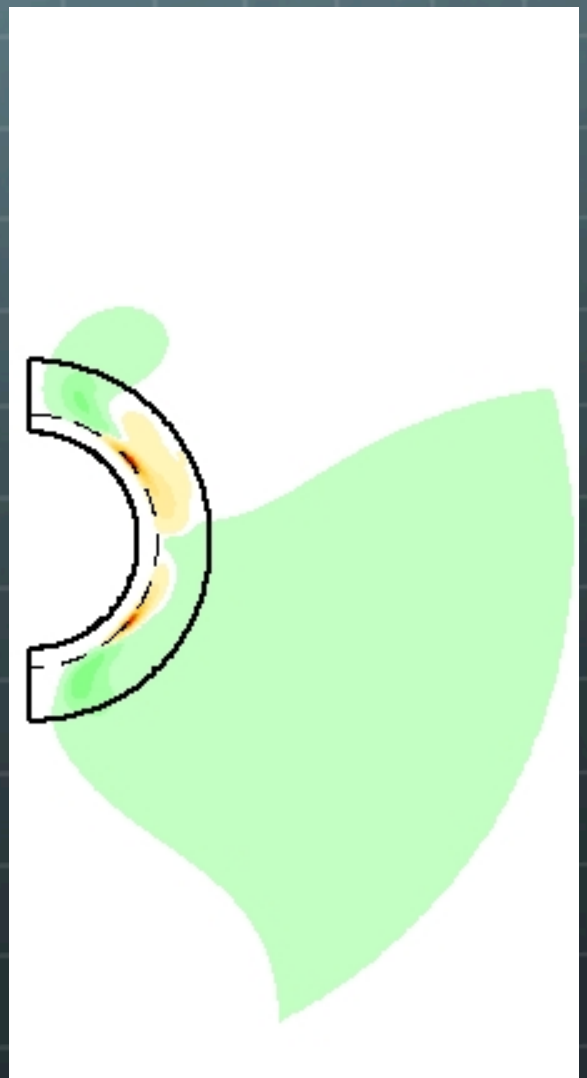


Asymmetric Cycle

Solar Maximum

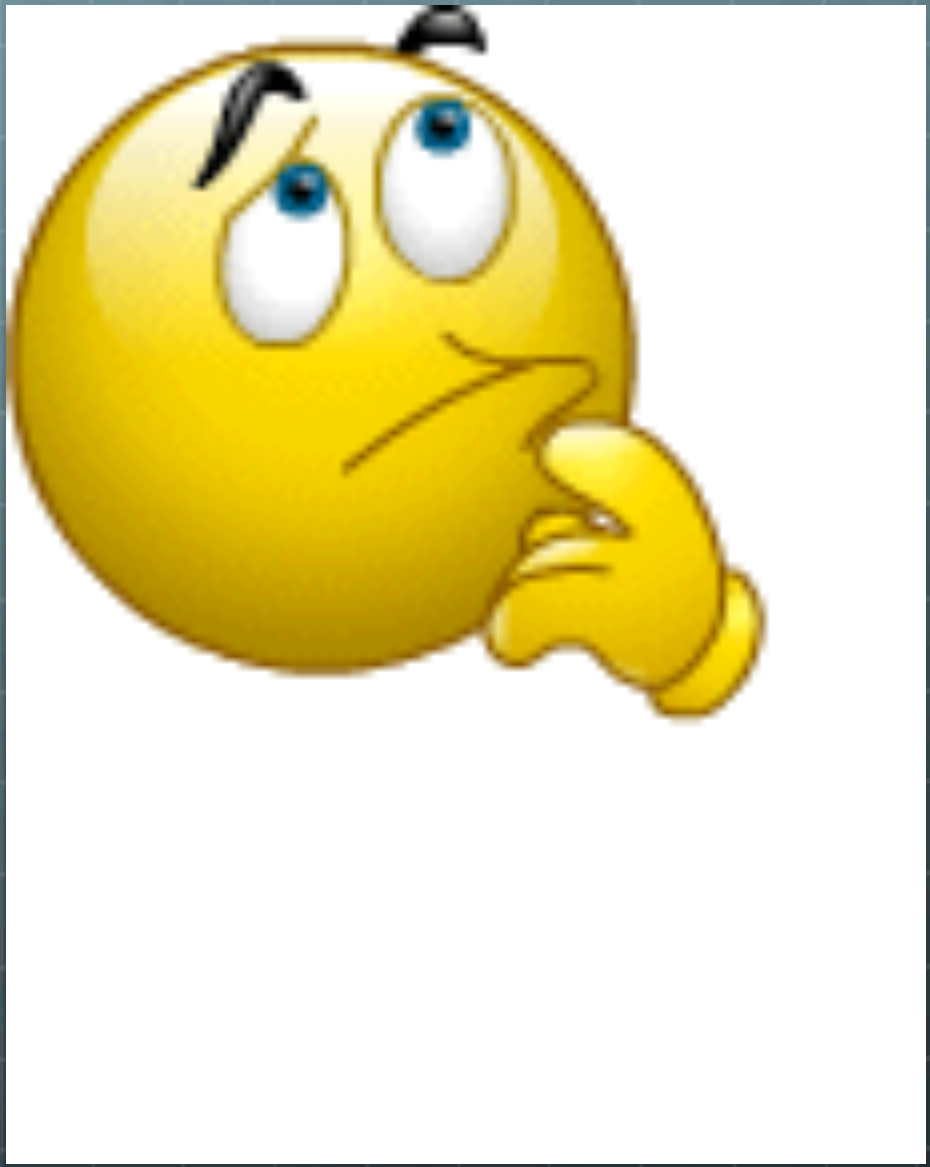


Solar Minimum



Summary

- By matching the theoretical solution from the potential field model with the MLSO observations, we first reproduce previous results that the solar minimum corona is primarily dipolar whereas higher multipoles come in during solar maximum
- The difference between east and west limbs is greatest during solar minimum and smallest during solar maximum
- Comparing the three past minima (1986, 1996, and 2008), we find that for five rotations in 1986 and 1996 the corona remained in a dipolar state, but that in 2008 there was no single rotation in which both limbs exhibited dipolar structure
- Simulating the evolution of the solar corona using a potential field source surface model by implementing the dynamo generated cyclic field as the boundary condition, we find that north-south asymmetry could be one of the sources for the departure from dipole corona during the end of cycle 23

Future Work

- We will investigate how much the low strength of Cycle 23 contributed to the departure from dipolar structure in the solar minimum
- We will further investigate whether the combination of low strength and large north-south asymmetry together can give us a good estimate of this departure from dipole