# Extrapolating Solar Dynamo Models throughout the Heliosphere

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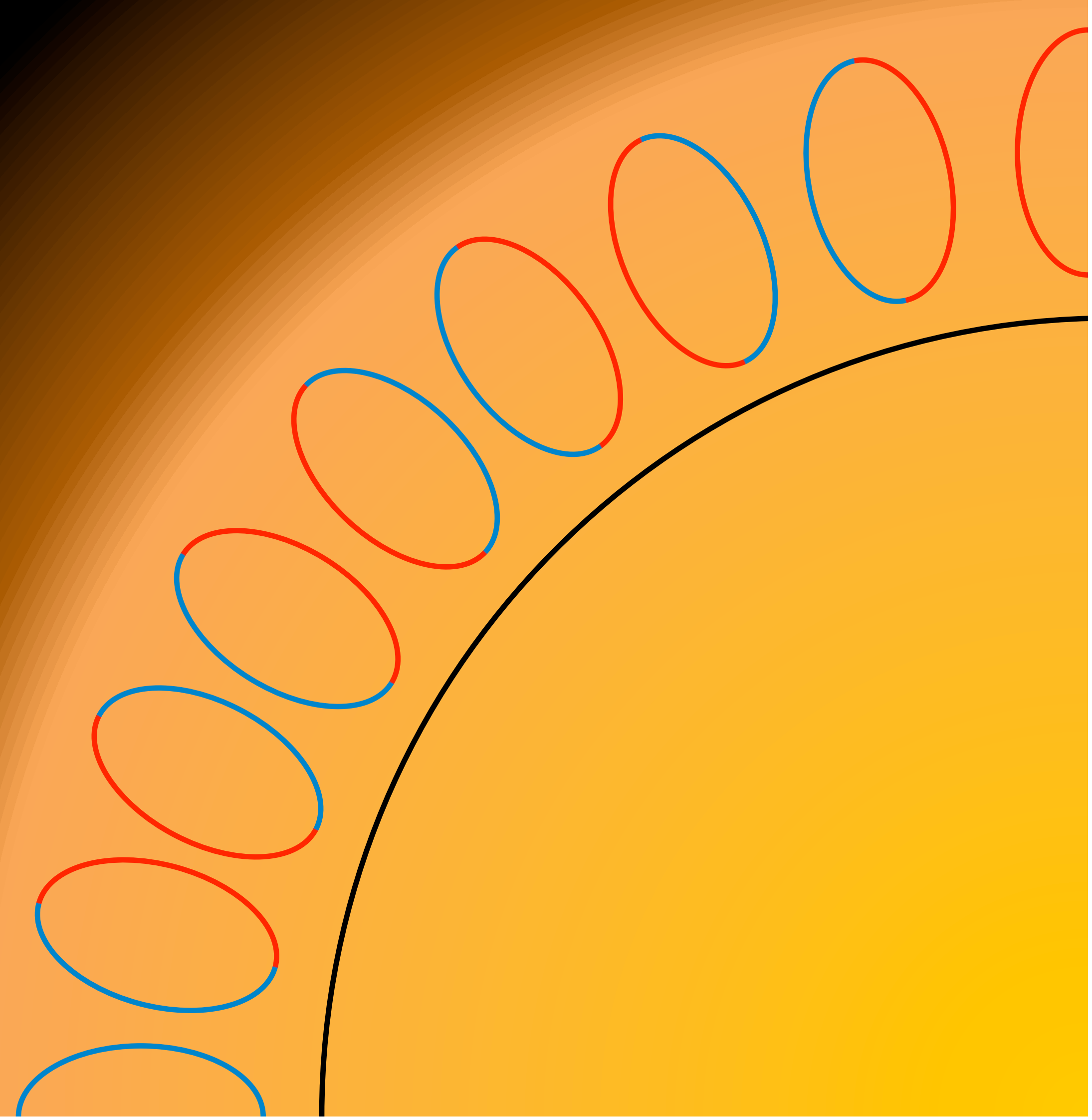
# Solar Convection

• Convection arises from heat in the Sun rising up and cooling, then sinking to heat up and rise again.

• This is manifested in the motion of plasma within the Sun's convective zone.

• The motion of this ionized plasma produces magnetic fields, and this full system is known as the solar dynamo.

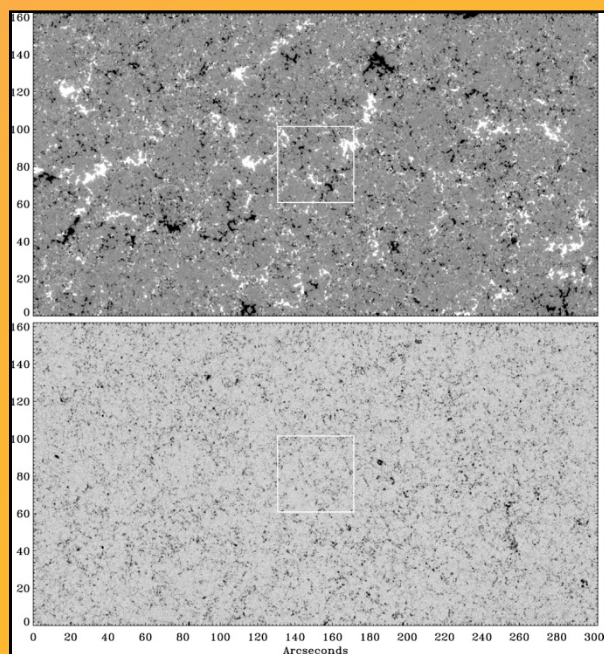


# The Necessity of Sunspots

• The magnetic fields created from the solar dynamo are contorted by the differential rotation of the Sun.

• The magnetic field is chaotically spread across the Sun's surface in the "magnetic carpet"

•The magnetic fields can also become concentrated and lead to the creation of sunspots.



# Solar Dynamo Models

## The Convective Dynamo Model

- Represents the fully nonlinear solution of the MHD equations for the solar convection zone

- Lacks the development of magnetic fields attributed to sunspot formation

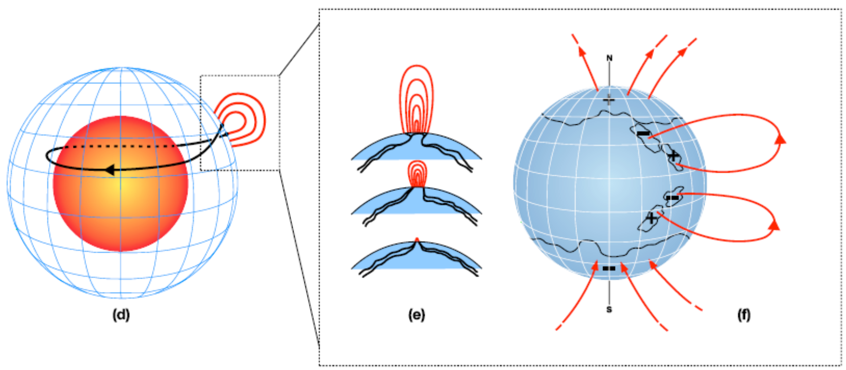
- Computers about one million times faster than today's should have the capacity to see sunspots appear in the model, keeping the model supported.

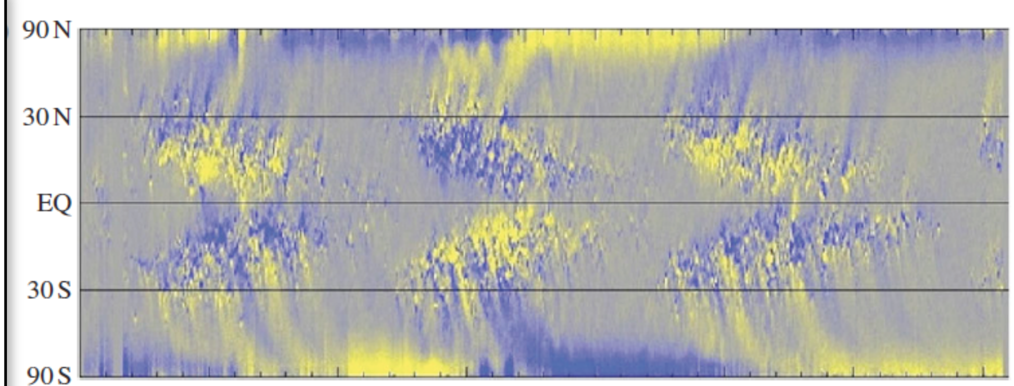
# Babcock-Leighton Model

• A kinematic dynamo model driven by sunspots

• Sunspot reconnection at the equator and dissipation to the poles results in polarity flipping at the poles

• Magnetic flows for this model are prescribed to obtain its effect, as opposed to the freely evolving convective model.



# Solar Dynamo Simulations

- The convective zone cannot be directly observed.

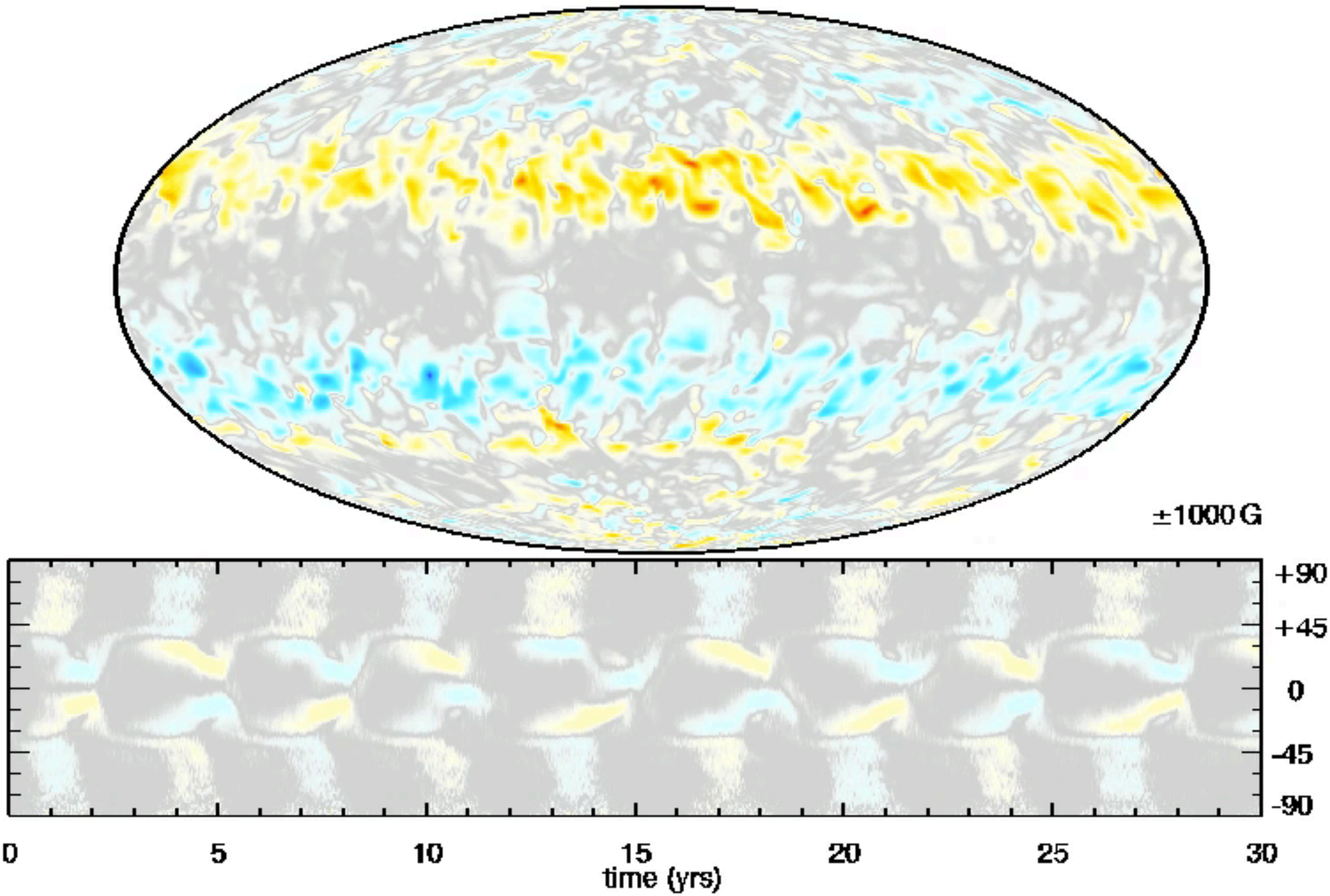
- Supercomputer simulations of the convective zone allow further modeling of the region.

- These simulations can then be compared to the behavior of the Sun itself to determine the pros and cons of a given model.

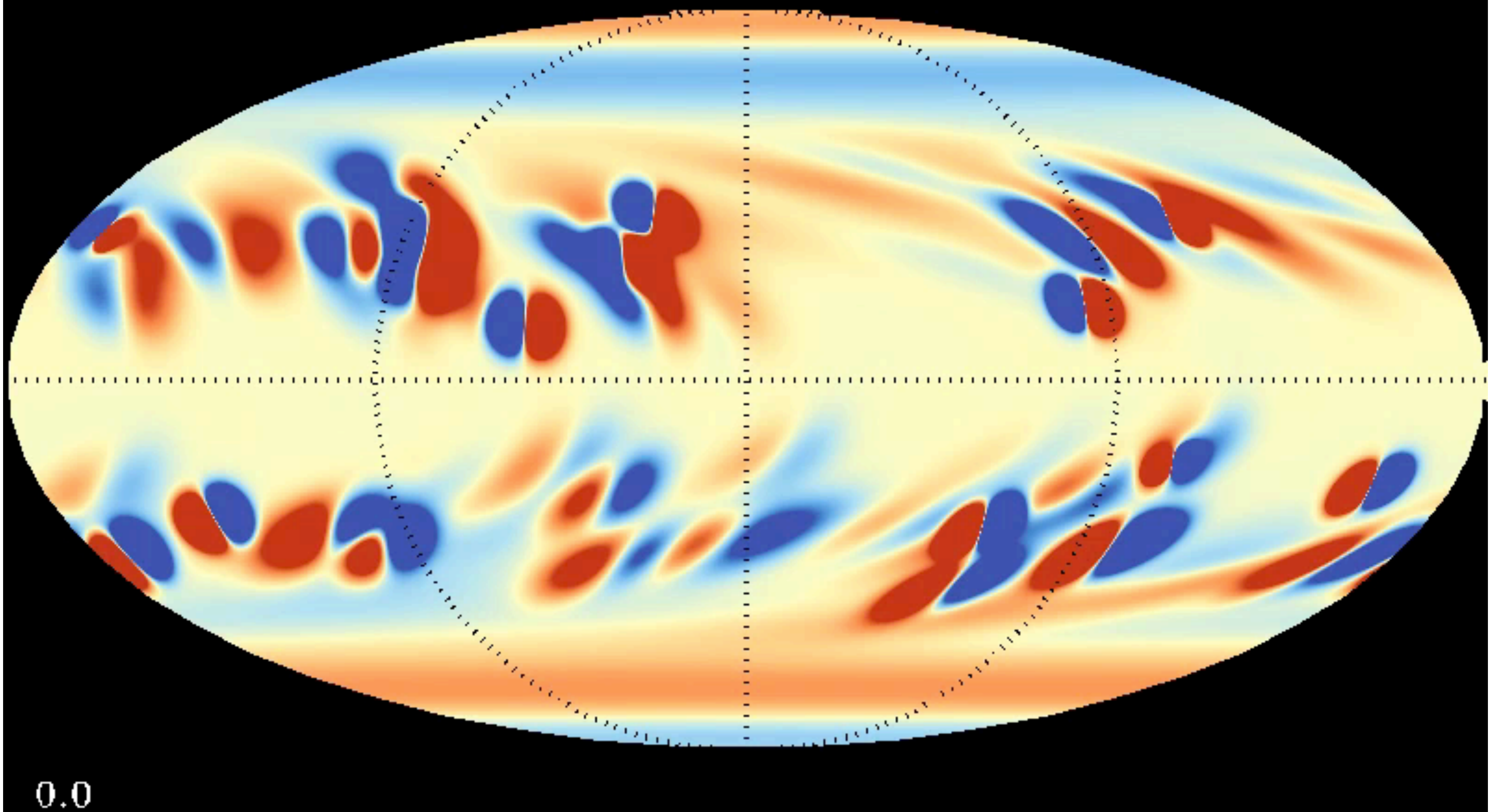
Here, the supercomputer simulation ASH formed the data used.

CASH models represent models of the Convective Dynamo, while BASH models represent models of the Babcock-Leighton Dynamo.

# A CASH Simulation



# A BASH Simulation



# Current Limitations

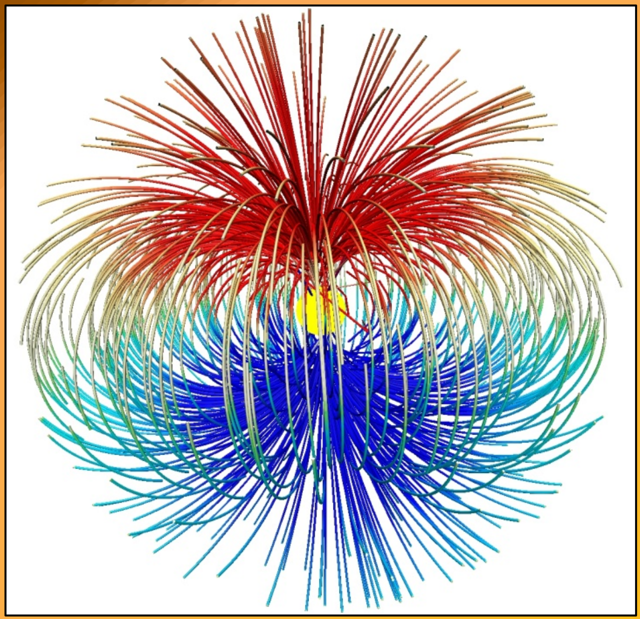
One key inconvenience: CASH and BASH only simulate data at the edge of the convective zone of the sun, while the behavior of the magnetic fields they generate throughout the heliosphere would be very useful in comparing coronal consequences the two models.

My job became to make code that would extrapolate the simulation data to make that viewing possible.

# Potential Field Source Surface Extrapolations

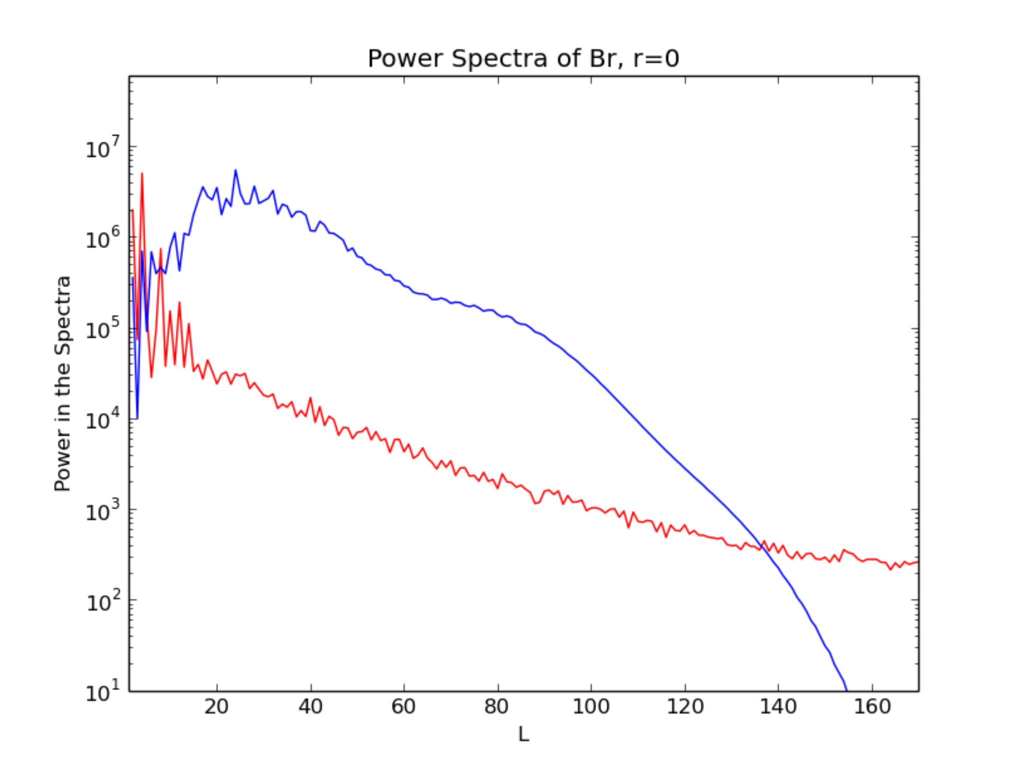
- This method relies first and foremost on the assumption that there are no currents in space.

- With this assumption, spherical harmonic transforms may be used to extrapolate the data from a particular source surface.



This model of CASH data extrapolates the magnetic field out to 10 solar radii, where the field is predominately a dipole.

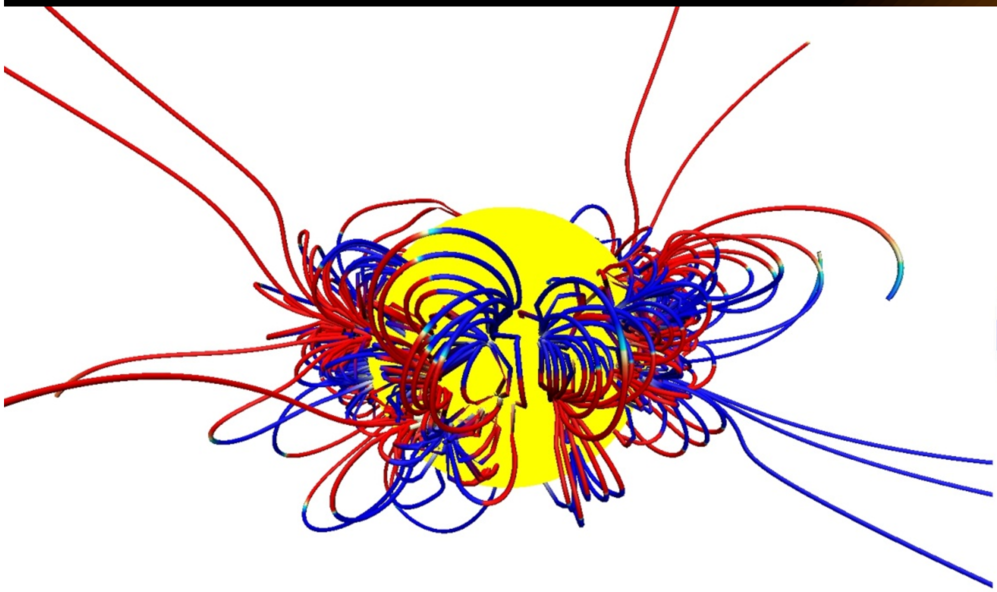
# Power Spectra



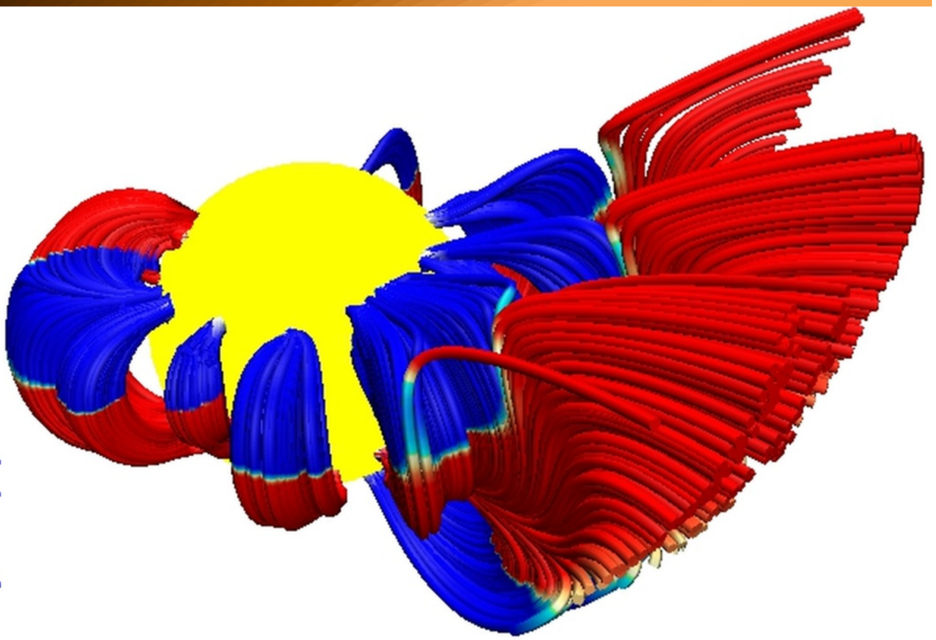

The power in each spherical harmonic degree can be used to visualize the complexity of the magnetic field. The BASH model data is represented in blue, and the CASH data is in red.

# 4 Solar Radii

BASH



CASH

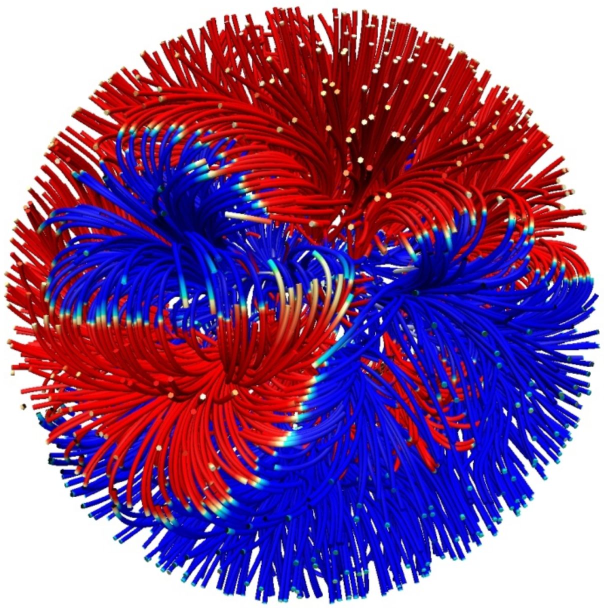


At 4 solar radii, complex field still visible, magnetic loops indicative of sunspots. (Only equatorial region shown).

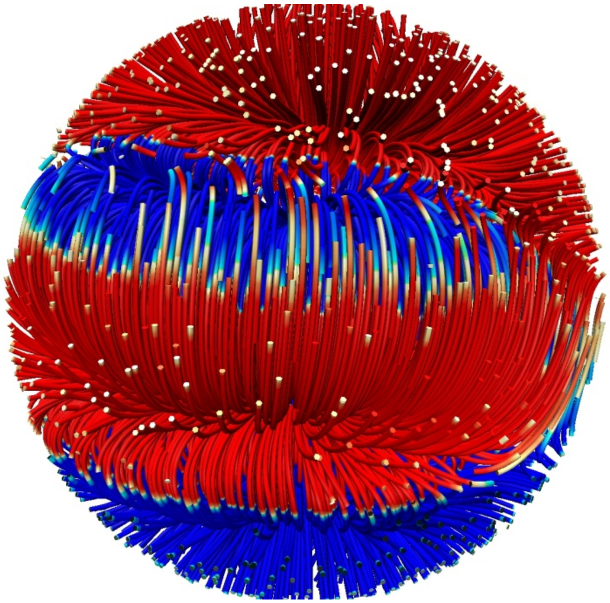
At 4 solar radii, field has become simplified, and already begins to exhibit dipole-like behavior.

# 2 Solar Radii

BASH



CASH



At 2 solar radii, magnetic field is very much nonuniform, and patches of opposing field indicative of sunspots may be seen.

The CASH model at 2 solar radii has much more activity than is evident further away, as another layer of opposing magnetic can be seen pushing out from where there is just a dipole farther out.

[redacted]

# CASH Time-Evolving Data

## 4 Solar Radii

At 4 solar radii, most changes at the surface are already mitigated to a rather steady dipole.

The 4 radii cross-section also shows a rather steady field, but the more active internal field can be seen.

# BASH Time-Evolving Data

## 4 Solar Radii

The BASH data is very much inconsistent on the surface, as the sunspot areas can be seen everywhere. This being at 4 radii, BASH is still quite complex.

The cross-section for the time evolving BASH data reveals more consistency, with a standard shape for the sunspot appearances being evident, and the overall effect at great distances shown here.

# CASH Time-Evolving Data

## 2 Solar Radii

At 2 solar radii the sun is clearly more dynamic with its closest field gaining and losing strength regularly, and the latitude where the two polarities meet rising and falling.

Here the cross-sectional view presents an excellent vantage point of the magnetic behavior near the sun during a pole-reversal.

# Results

- The implementation of sunspots at the surface does in fact result in a more complex field throughout the heliosphere

- As can be seen in data from 4 solar radii, the CASH model falls into a strong dipole field much closer to the Sun than does the BASH model.

- The CASH model does not produce readily evident magnetic loops to be associated with sunspots, even near the surface, as is to be expected from the current technological limit faced by the convective model.