

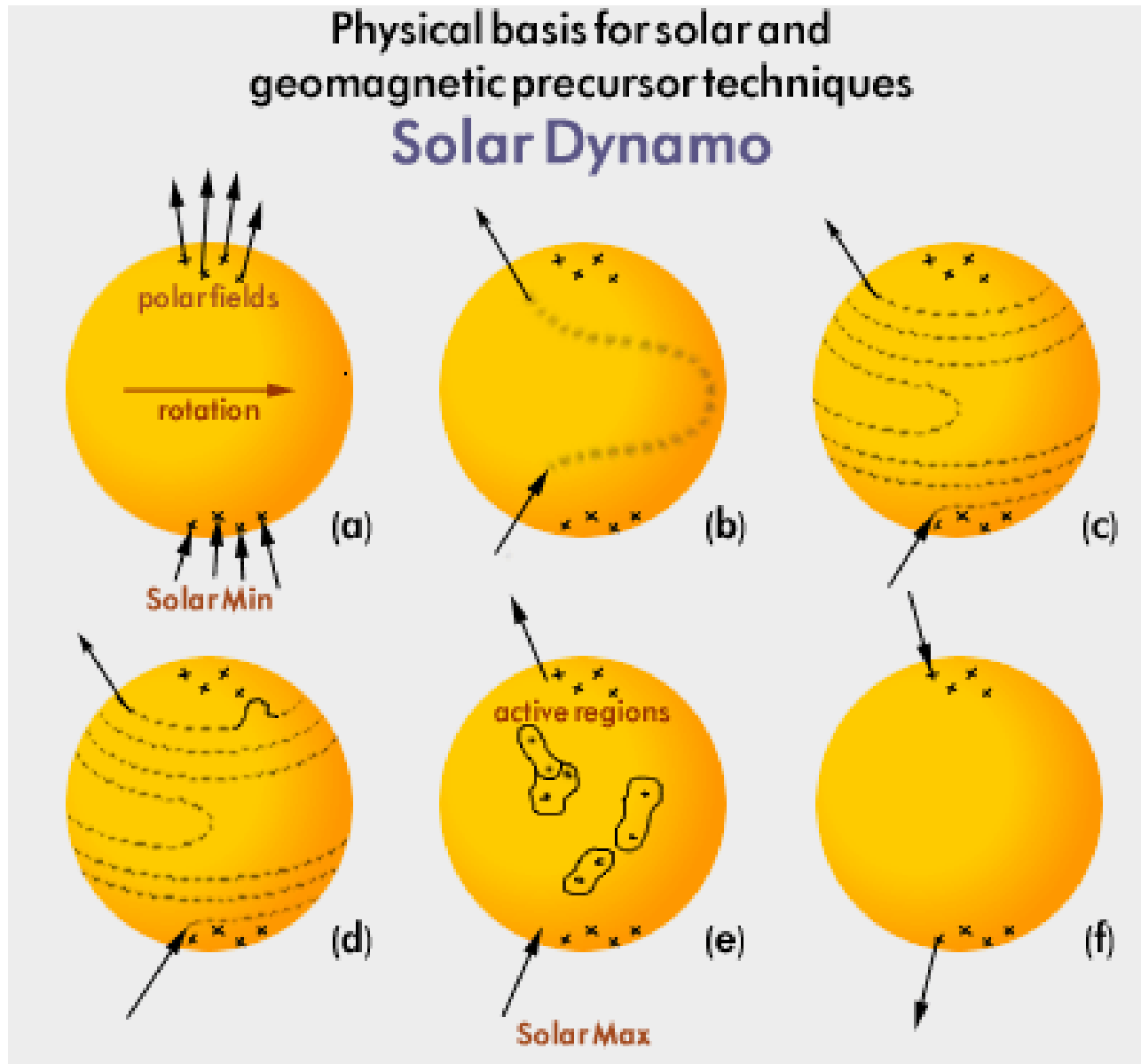
Update to the Babcock-Leighton Solar Dynamo and Activity Predictions

Kenneth Schatten
Ai-solutions

Outline

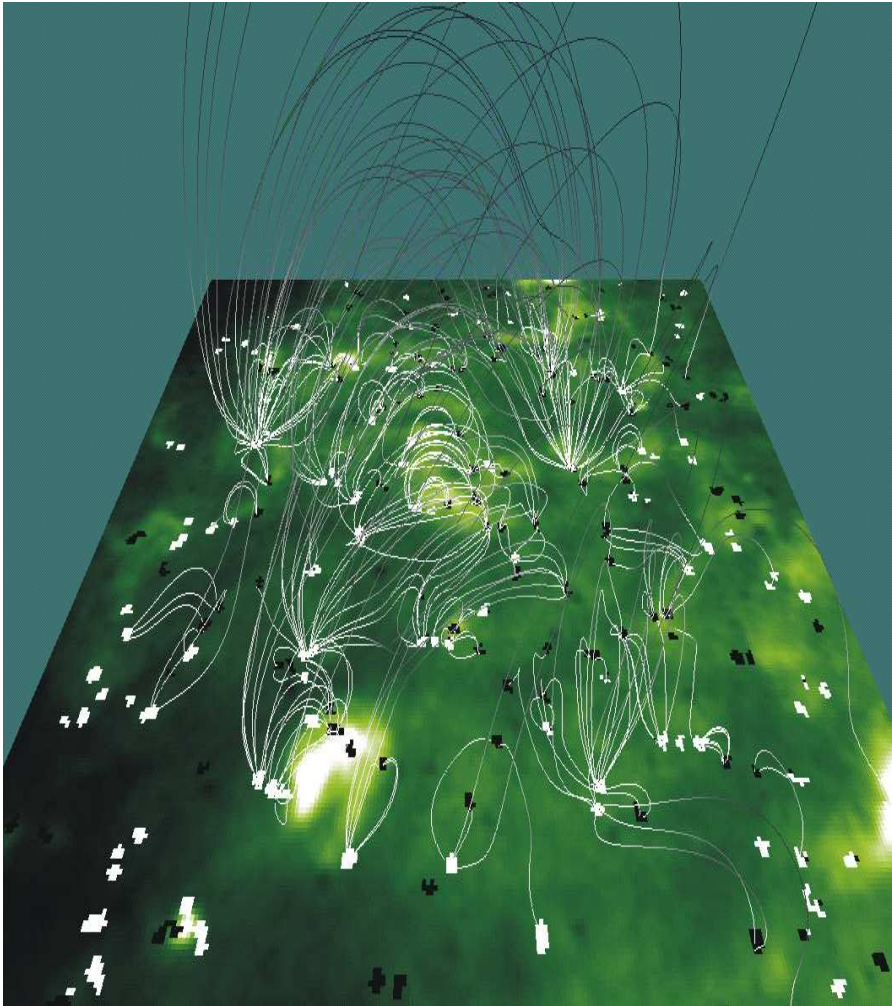
- **UPDATE BABCOCK-LEIGHTON DYNAMO**
 - 1) Shallow Dynamo
 - 2) Percolation controls small-scale motion
 - 3) Magnetic forces control large-scale motion
- **PERCOLATION COMES IN TWO FLAVORS:**
 - 1) Highly Superadiabatic:
Convection drives like-sign Ephemeral Regions (EPRs) into sunspots
 - 2) Normal:
Normal T structure: field concentrations disperse: spots-> faculae / plage
- **MODELING:**
Cellular Automata Modeling – relate to observations & solar dynamo
- **PREDICTION:**
Solar Cycle #24 $R_z \sim 75$; F10 ~ 125 in $\sim 2012-3$

Babcock-Leighton Solar Dynamo



Magnetic Carpet & Percolation

Above the Photosphere

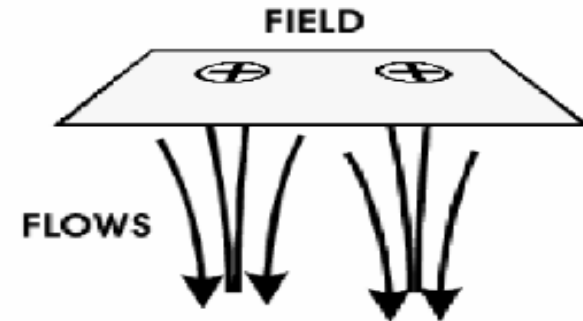


From Lockheed Group

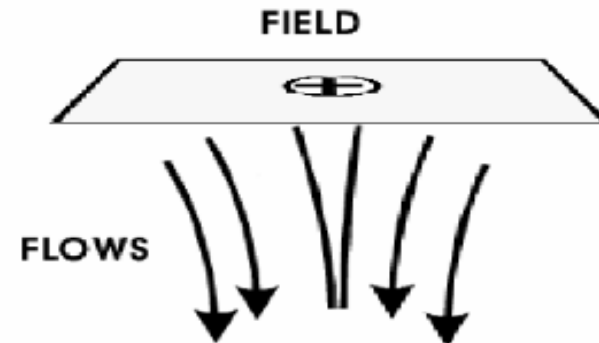
Below the Photosphere:

In regions of high superadiabaticity,
like fields drawn together

**Parker (1984) field sequestered
into fibrils by convective flow:
field drawn into tight bundles**

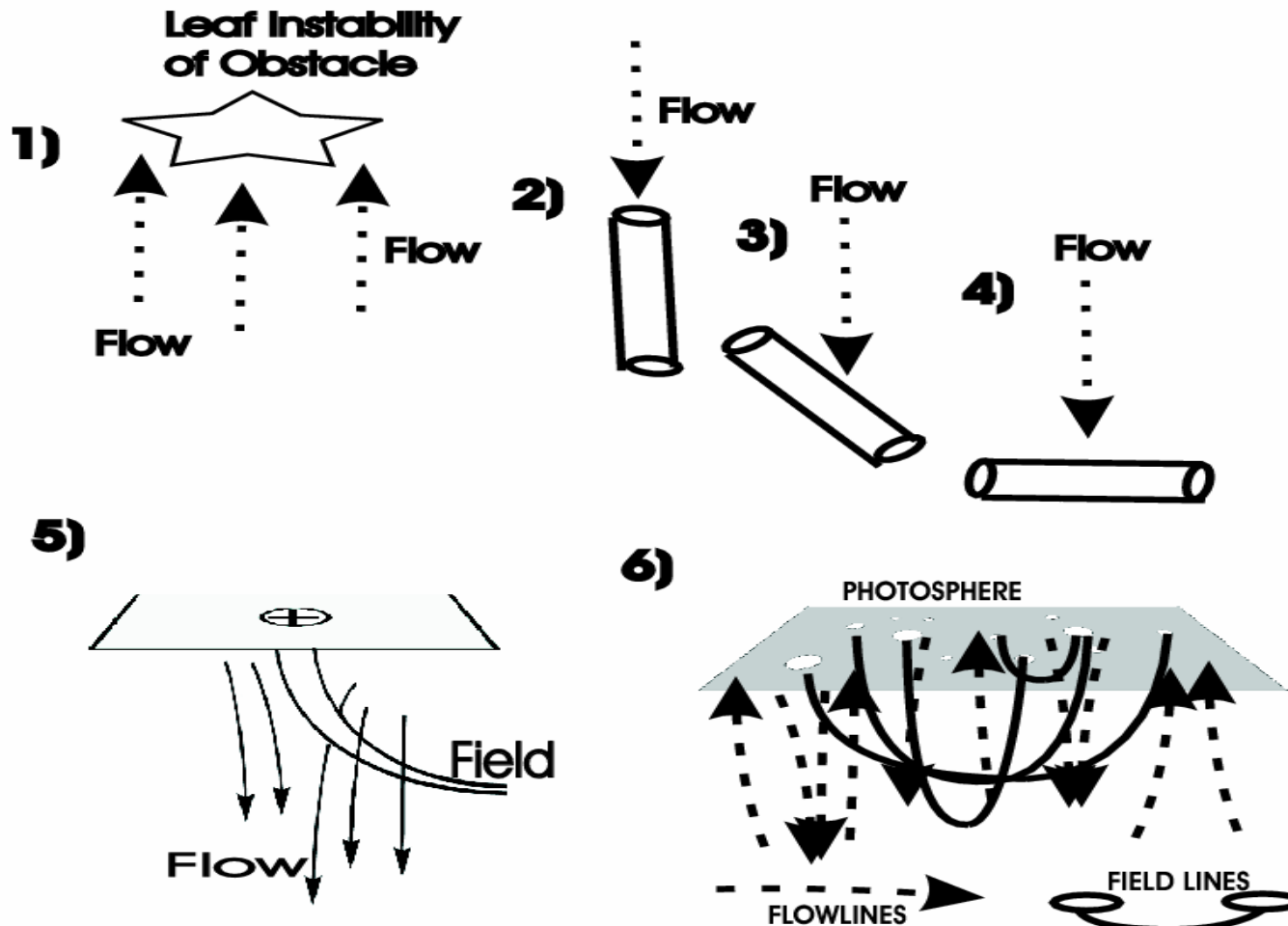


**In highly superadiabatic environment,
like-field drawn together by percolation**



Percolation Allows Field to Separate from the Flow – Remain Shallow

Falling Leaf Instability



**Flow can be diverted around field.
Flow goes deep, but field can
remain shallow!**

Superadiabatic Temperature Gradient: Large in Top Layers

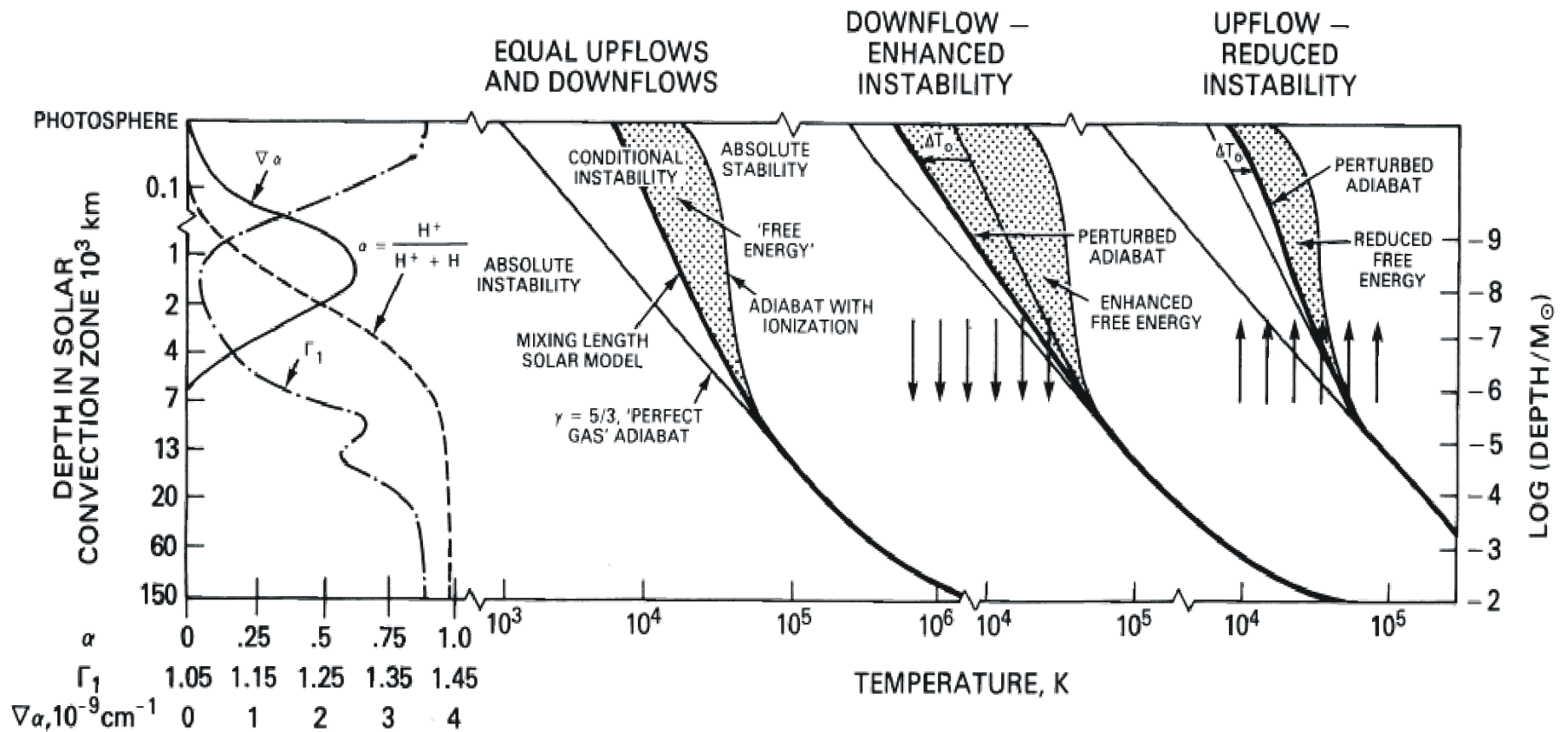
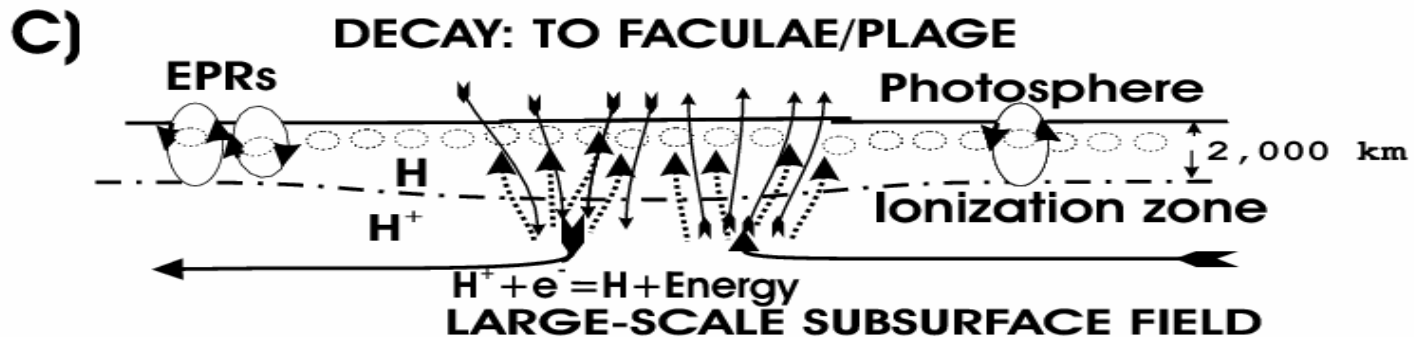
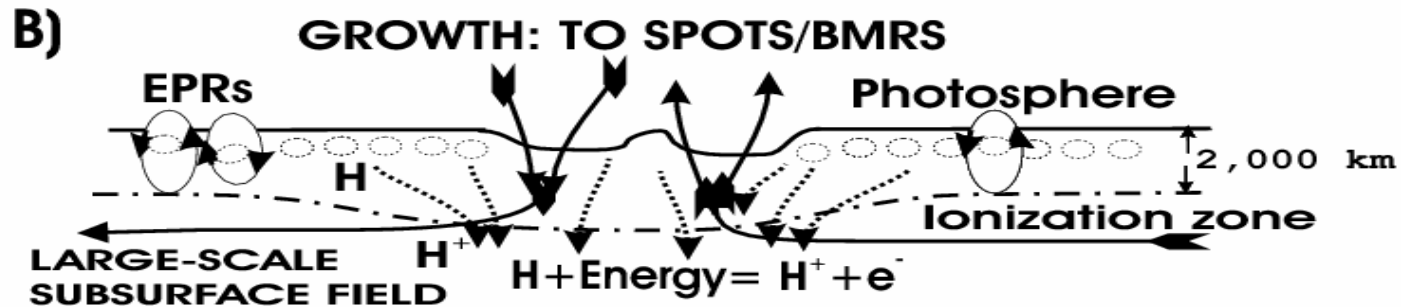
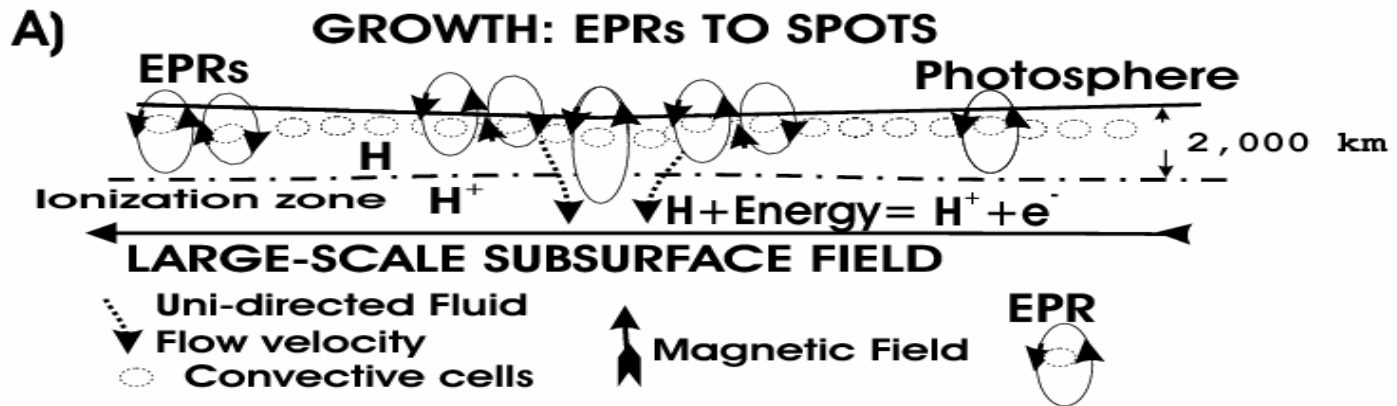


FIG. 3.—Amount of ionized hydrogen α , its gradient, and the adiabatic exponent Γ_1 are shown (left panel) throughout the convection zone. The second panel shows the “normal” temperature structure of the convection zone. The shaded area represents the superadiabatic “free energy” available to drive instabilities. Within this central zone, the material is “conditionally unstable,” depending on the amounts of neutral vs. ionized hydrogen present. A general downflow motion (third panel) and upflow motion (right) affect the superadiabatic gradient as shown. The downflow motion enhances the temperature gradient so that more free energy is available (shaded area) for instabilities, and “ion hurricanes” develop. The upflow motion (right panel), however, reduces the free energy available for instabilities, and ion hurricanes are less likely to develop.

Overview – Shallow Dynamo:

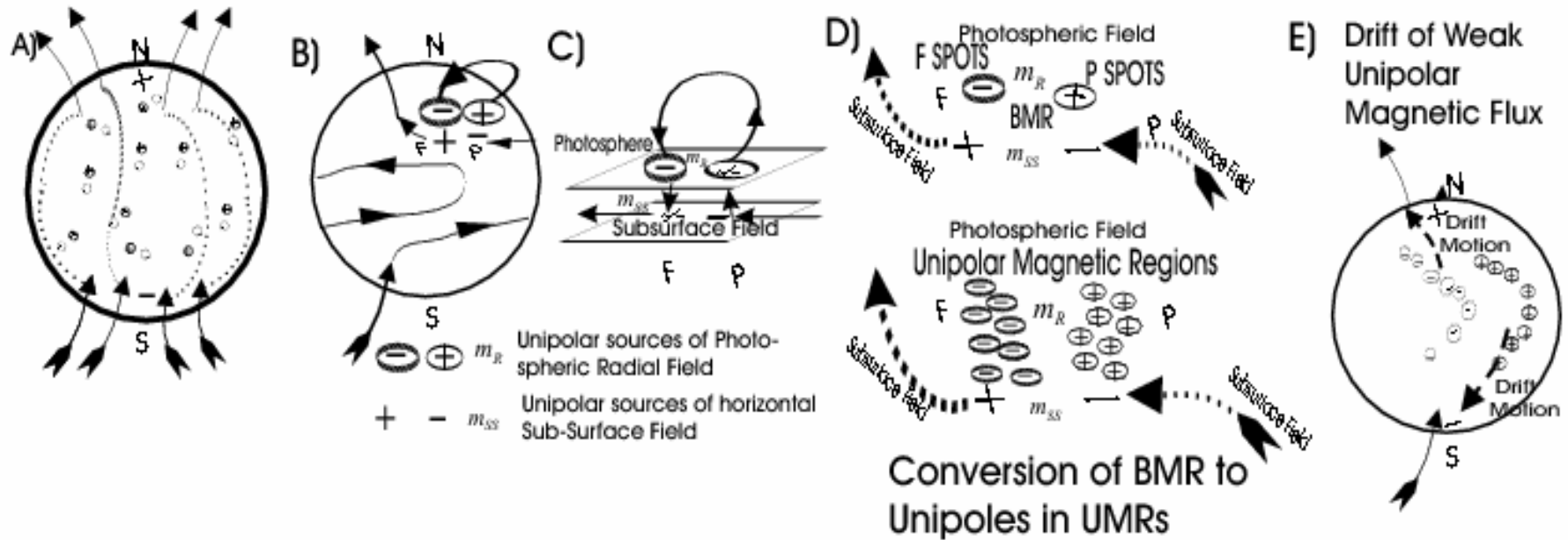
A) and B) – Superadiabatic Percolation

C) Normal Percolation



Overview – Shallow Dynamo

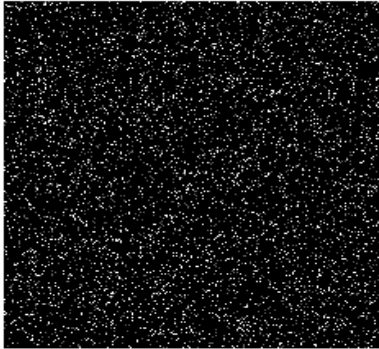
Like Babcock-Leighton, but with 1) EPRs and 2) motion from B forces



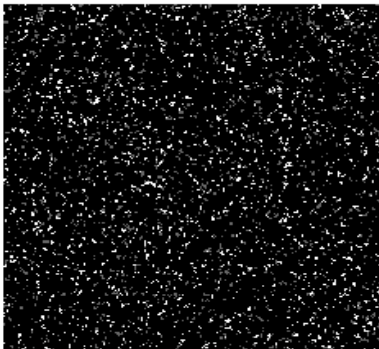
Development of Fields During an Odd # Cycle:

NH Following Flux => NH pole; NH Preceding Flux => SH pole
 Vice Versa for SH Fluxes, and Even # Cycles

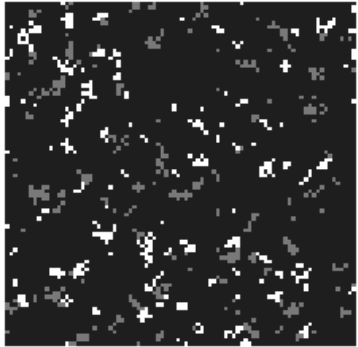
Superadiabatic Percolation Model



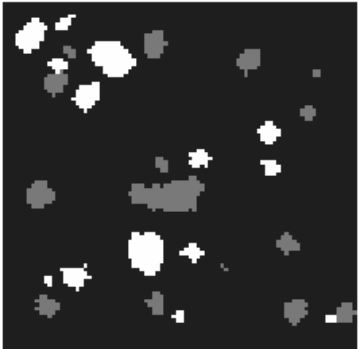
10% Fill, Random Fields, of Two Signs amidst null field



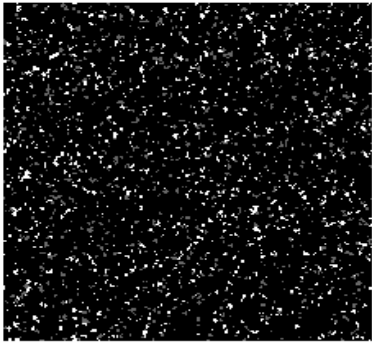
3 motion steps with Energy reduction



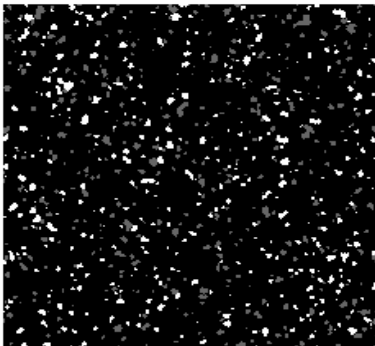
10% Fill, Random Field, of Two Signs in a null Background



25 motion steps with Energy reduction

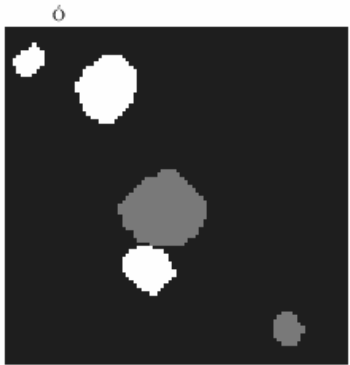


7 motion steps with Energy reduction

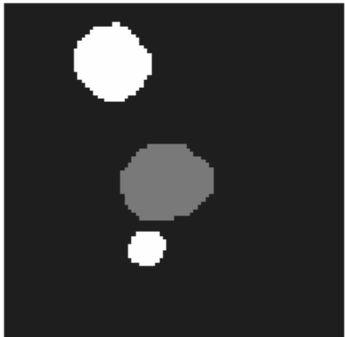


30 motion steps with Energy reduction

The Percolation Process



200 motion steps with Energy reduction

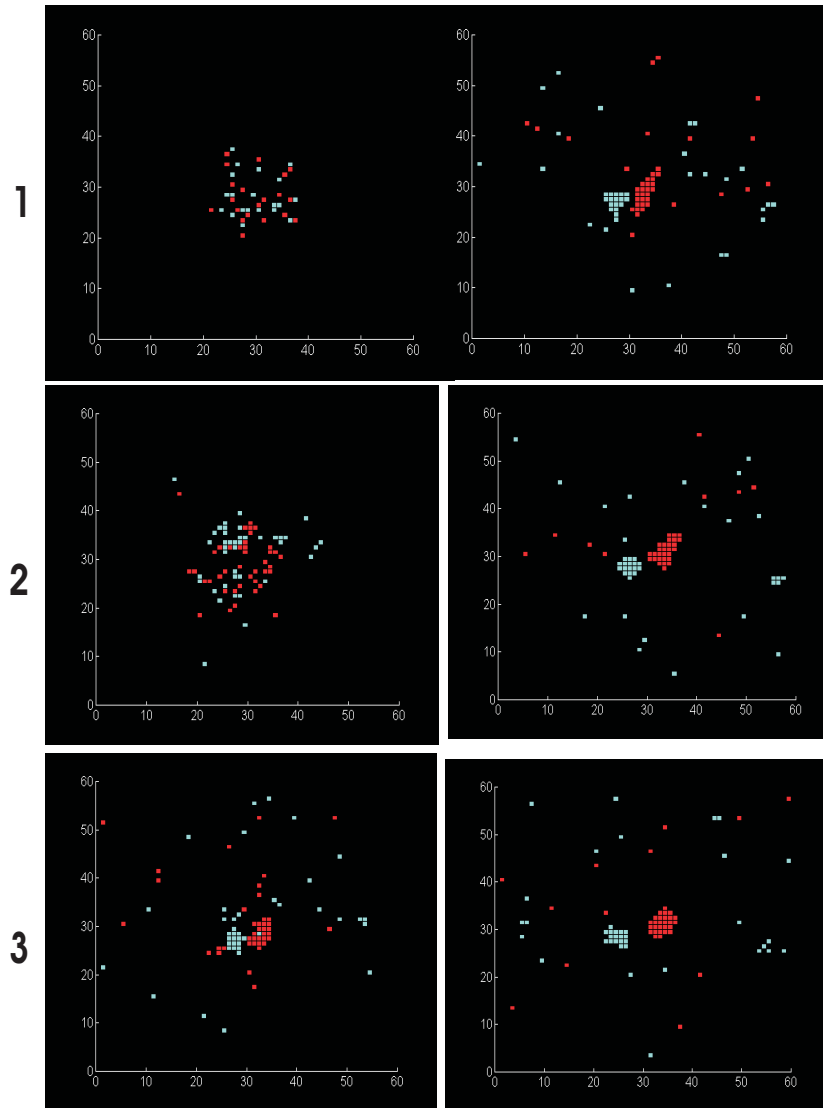


1000 motion steps with Energy reduction

The Percolation Process

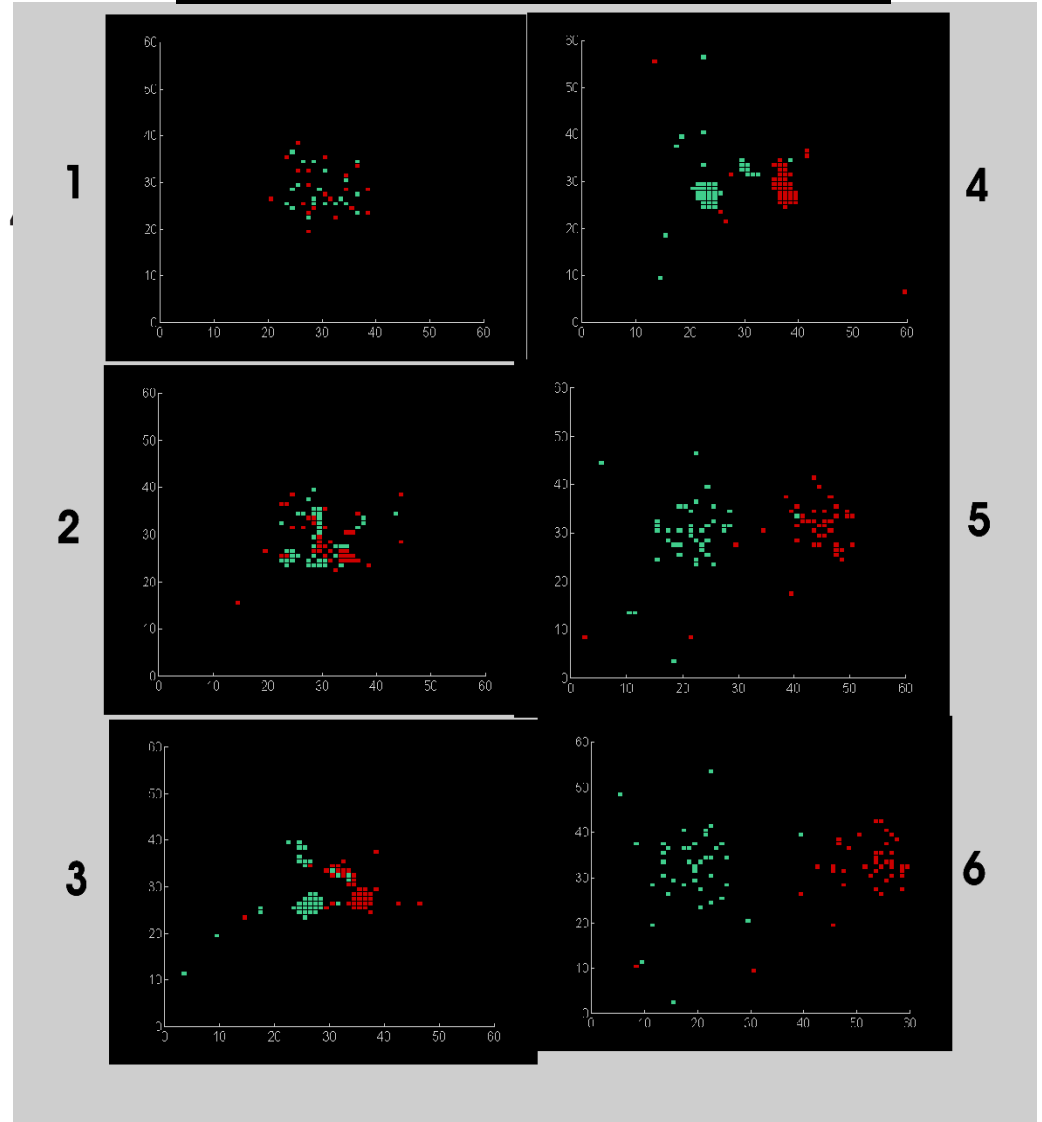
Percolation

Superadiabatic



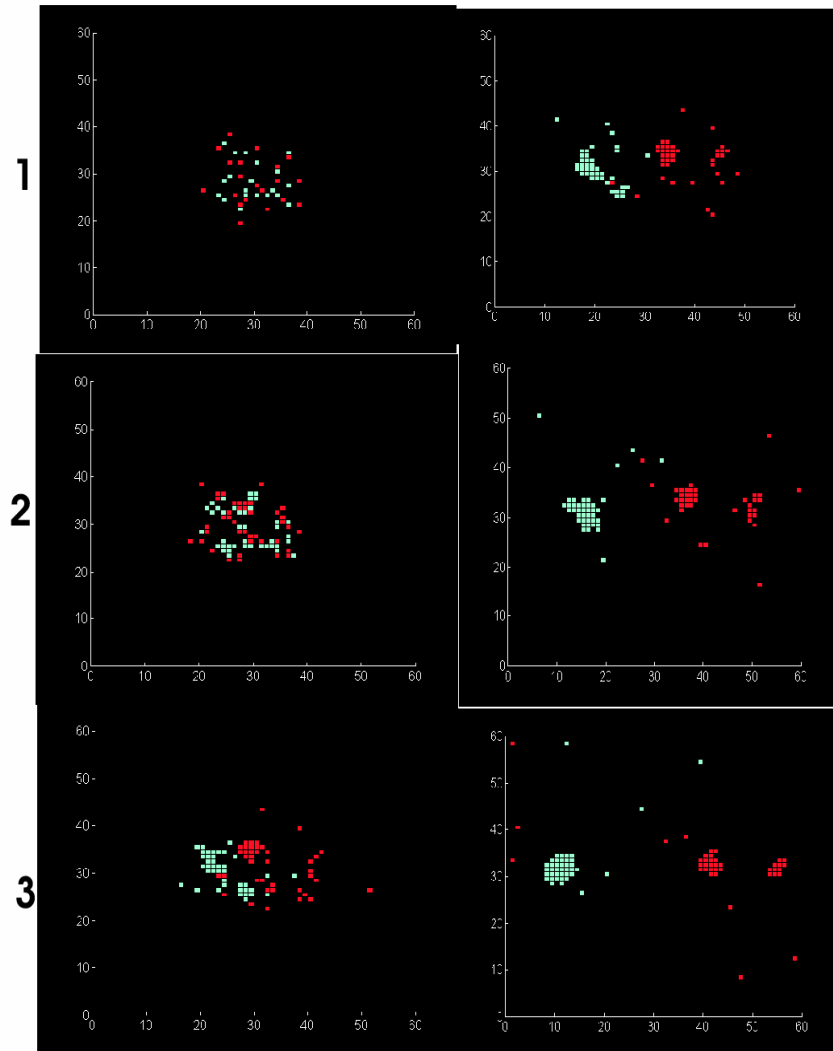
Time Series of Superadiabatic Percolation of Ephemeral Region

Super + Drift → Normal + Drift

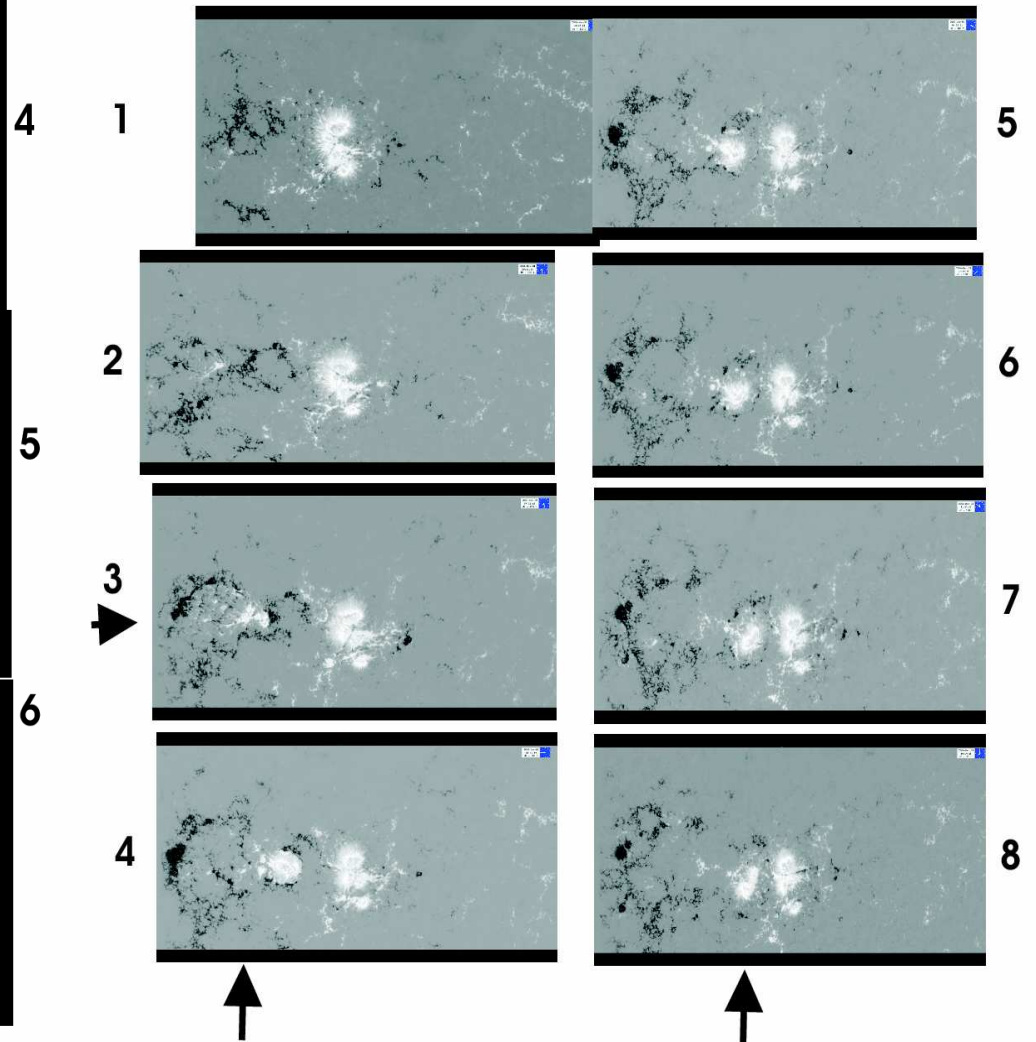


Superadiabatic Percolation, Field Drift, and Normal Percolation into Unipolar Magnetic Regions (UMRs)

Modeling and Observations

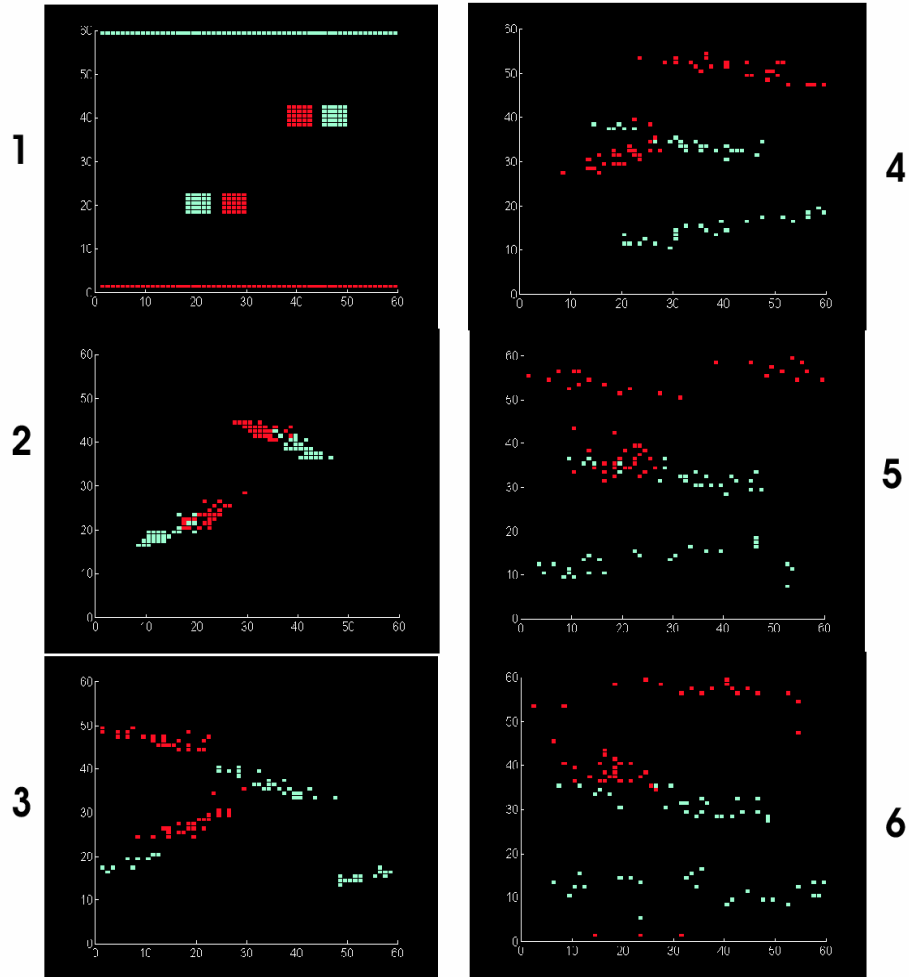
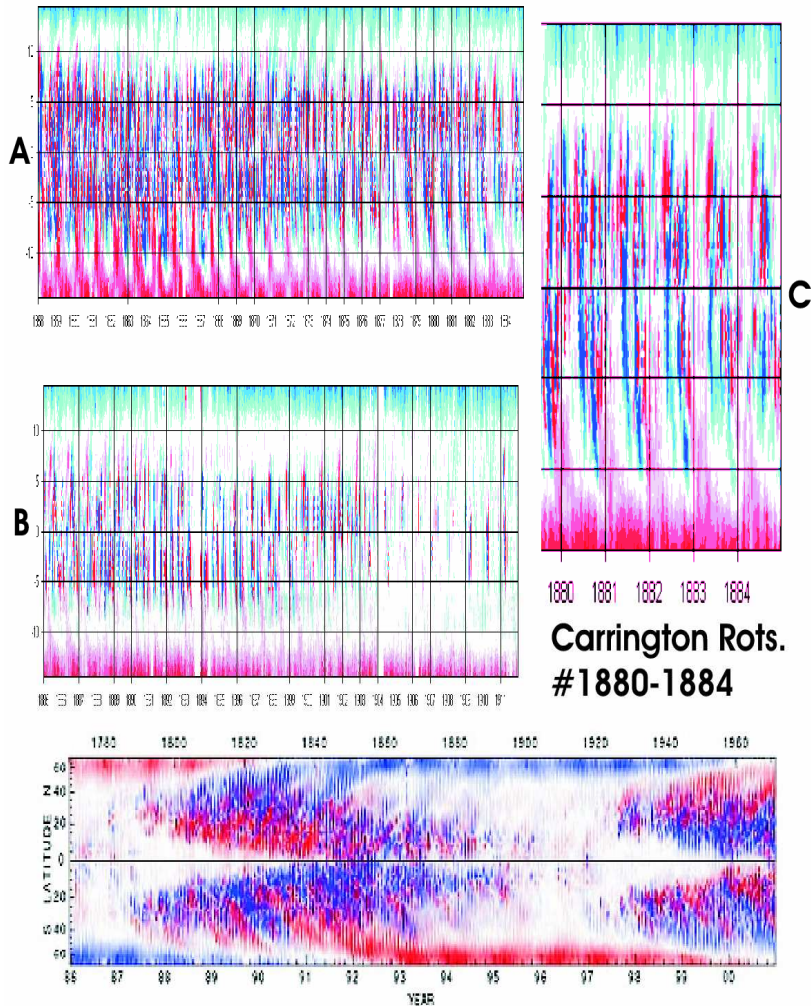


Percolation of Ephemeral Regions
in an External Subsurface Field



Hinode "Trilobite" Movie

Modeling and Observations

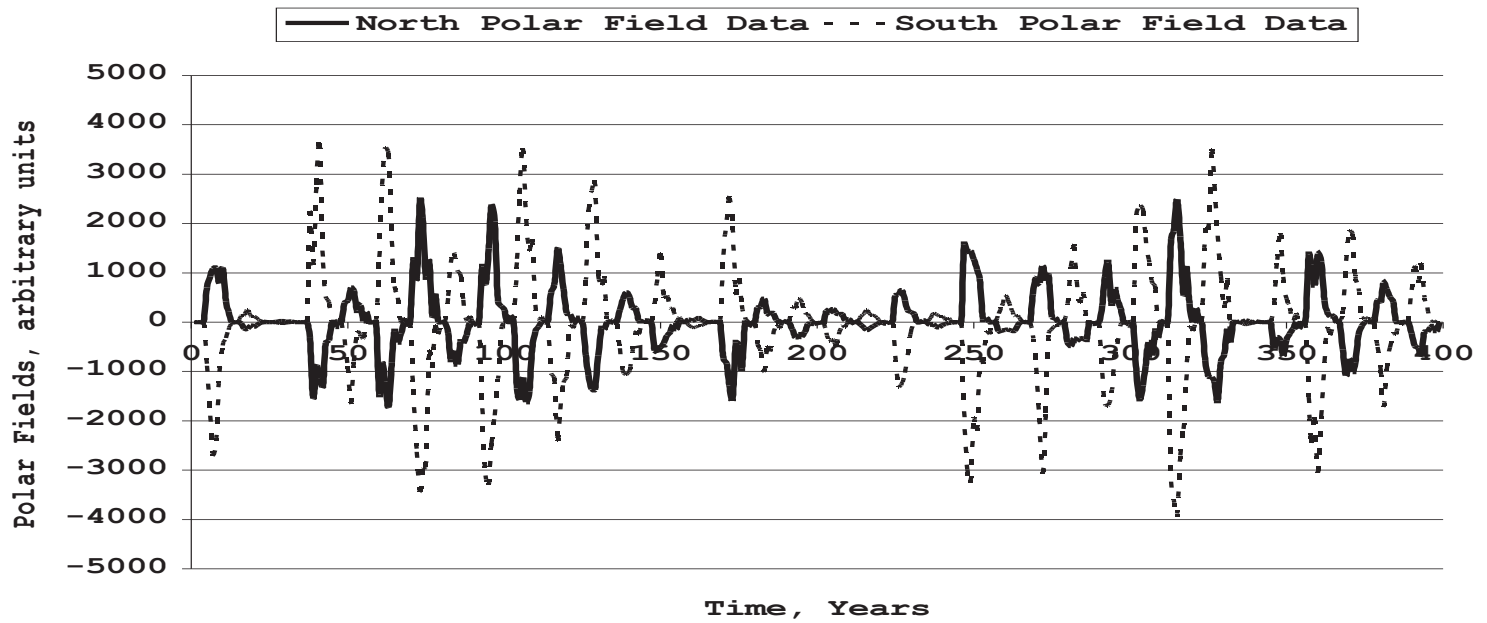


D SUPERSYNOPTIC & SYNOPTIC MAPS OF THE SUN'S MAGNETIC FIELDS : SOLAR CYCLE #22

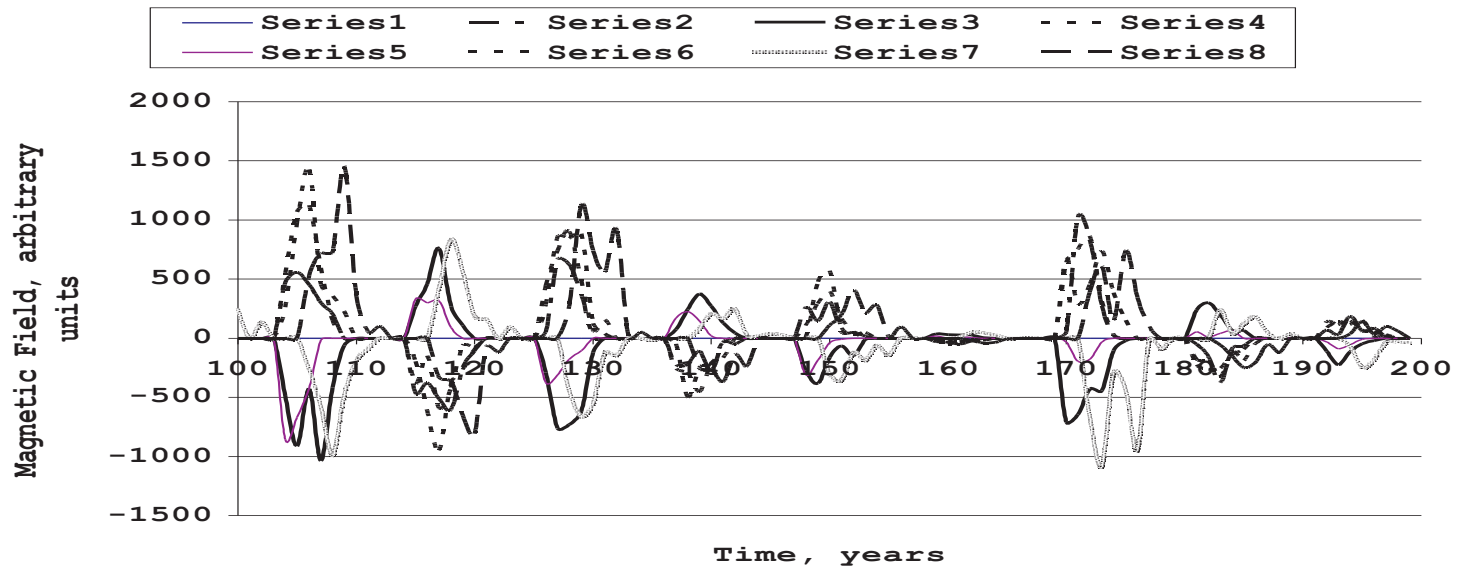
MODELED BIPOLAR MAGNETIC REGIONS (BMRs): PERCOLATION WITH SUBADIABATIC GRADIENT + DRIFT FROM DIPOLE FIELD + DIFFERENTIAL ROTATION

400 & 100 Year Modeling

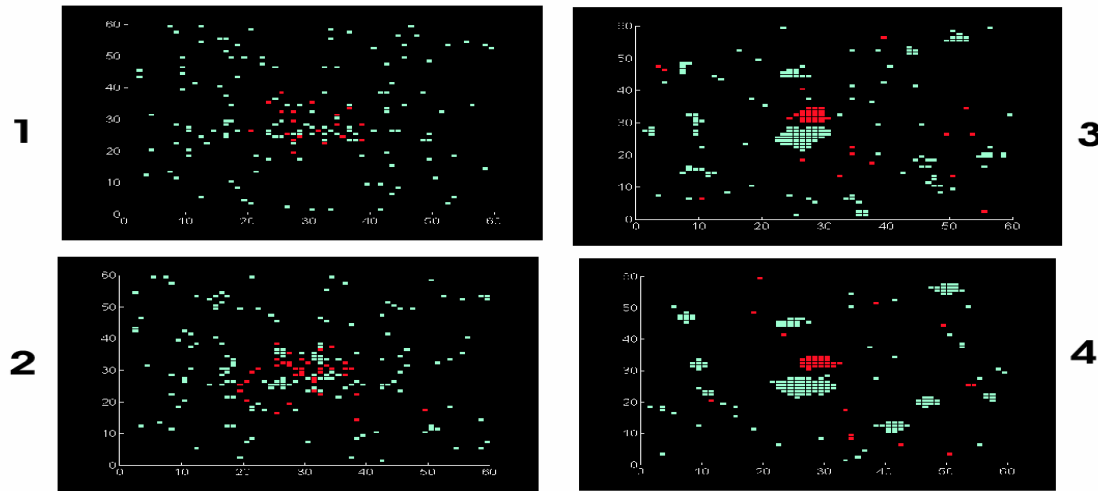
Polar Fields vs. Time



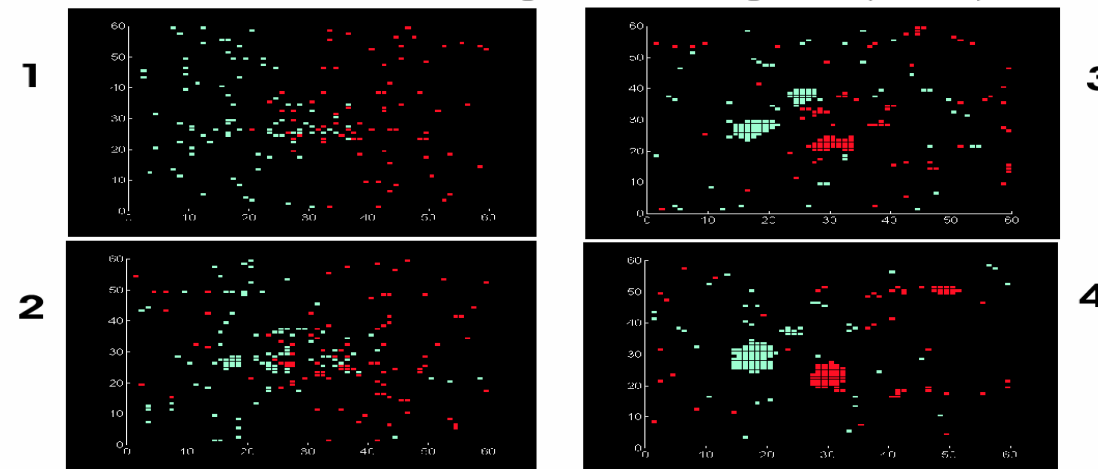
Different Longitudes, Both Polar Fields



How Spot Flux Imbalances Form (Why spots are not all equal bipoles)

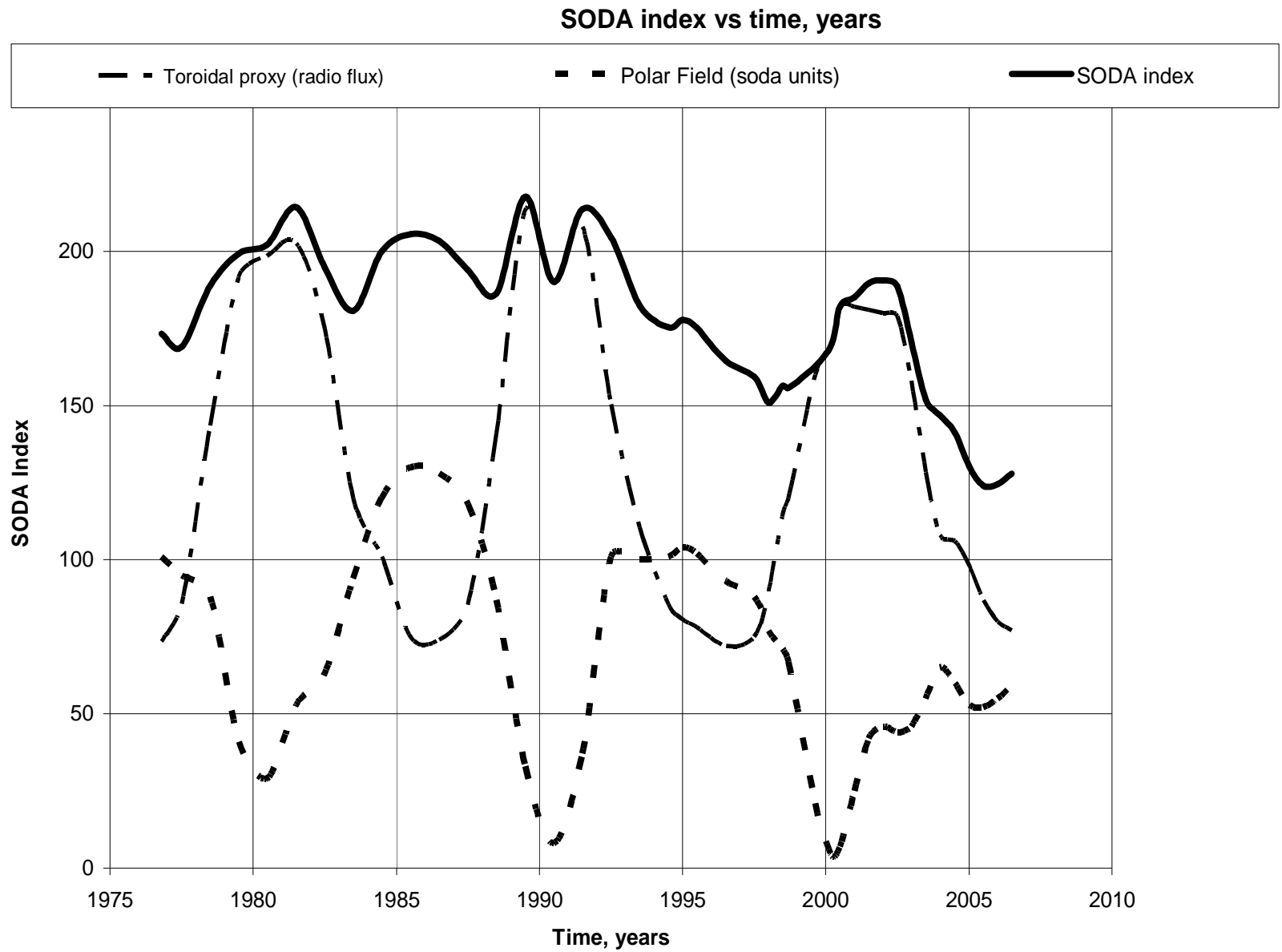


**Superadiabatic Percolation of EPRs
in a Unipolar Magnetic Region (UMR)**



**Superadiabatic Percolation of EPRs
at a (UMR/Sector) Magnetic Boundary**

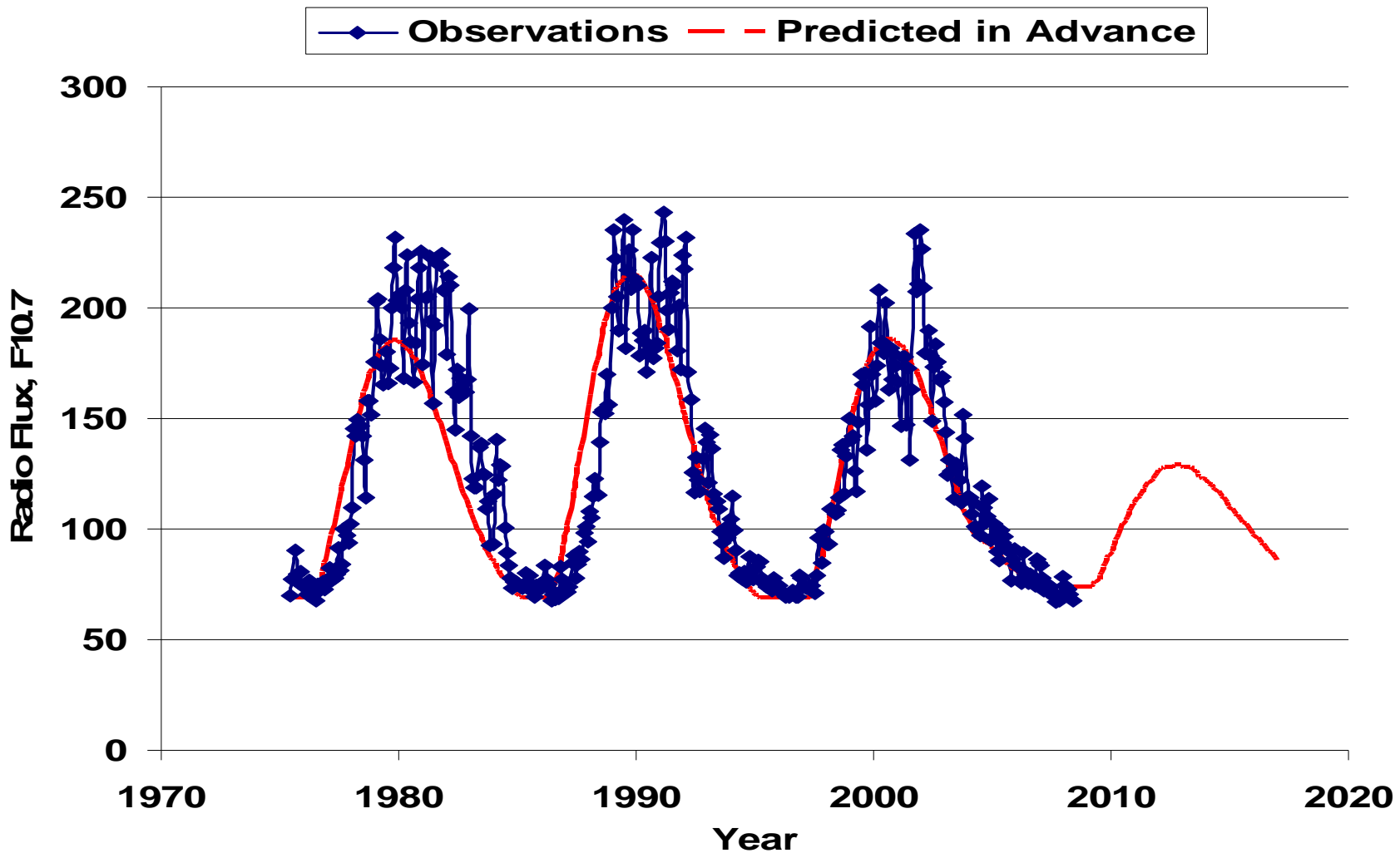
SODA (Solar Dynamo Amplitude) Index



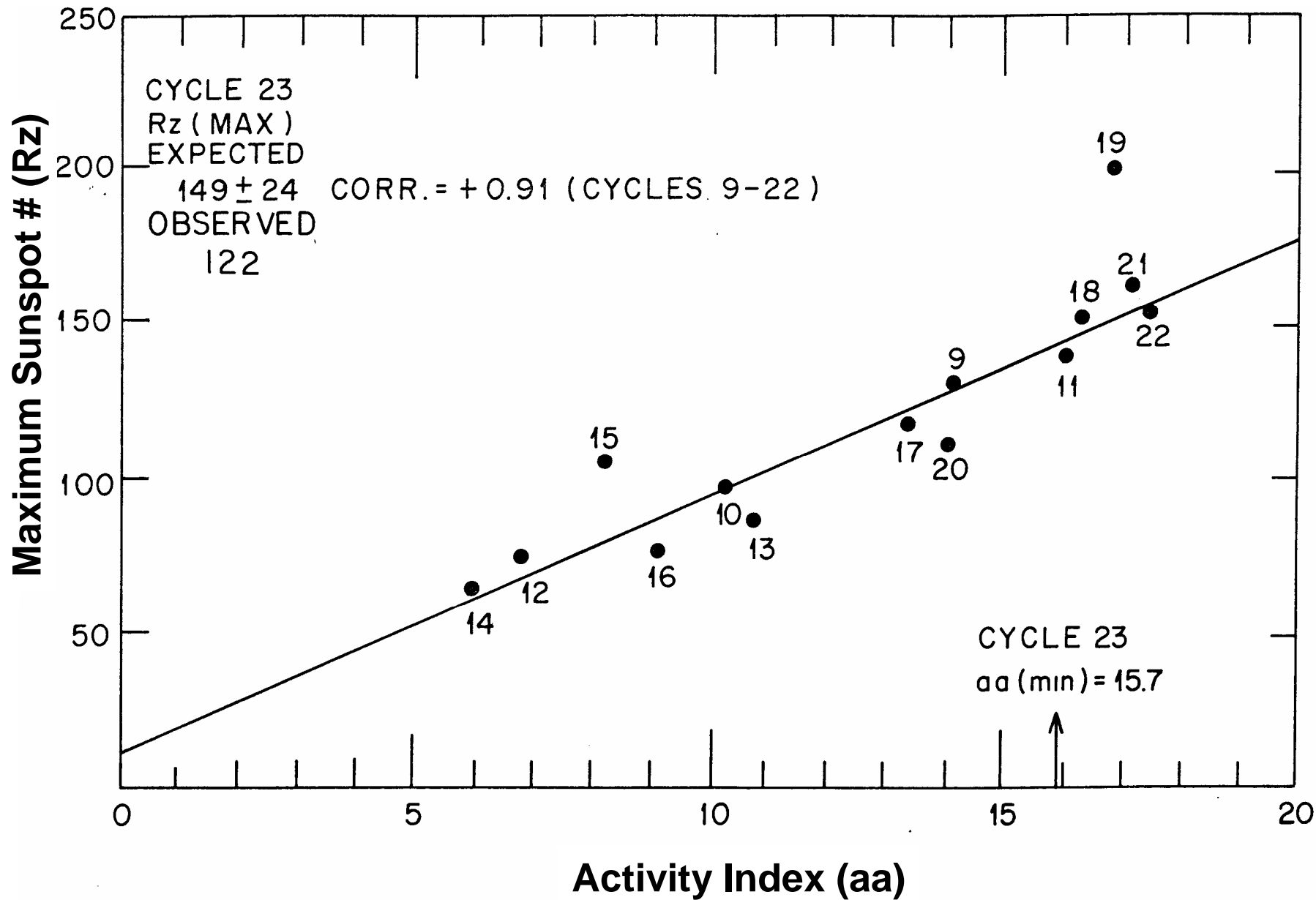
Schatten Prediction: Weak Solar Cycle 24

Use of the idea that the Sun's polar field is a precursor for the next cycle's activity level [Schatten et al. (1978)]; Svalgaard et al. (GRL, 32, L01104, 2005); Schatten (GRL,32,L21106, 2005)

F10.7 Observations and Predicts



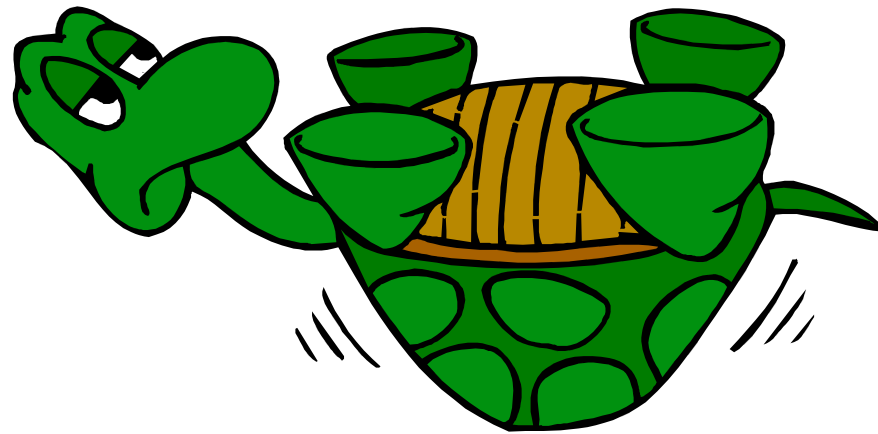
Geomagnetic Activity - Sunspot Correlation



Conclusions

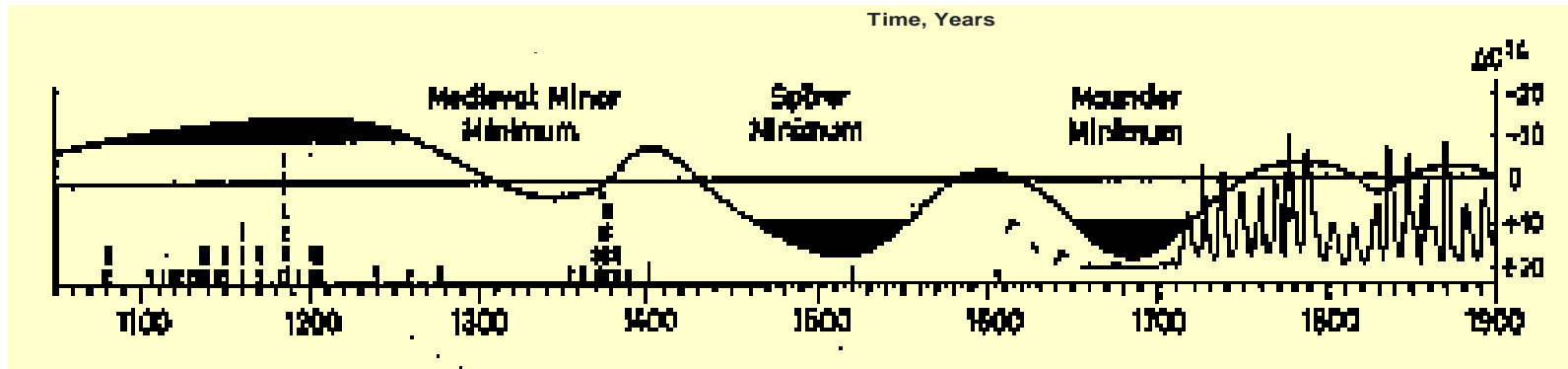
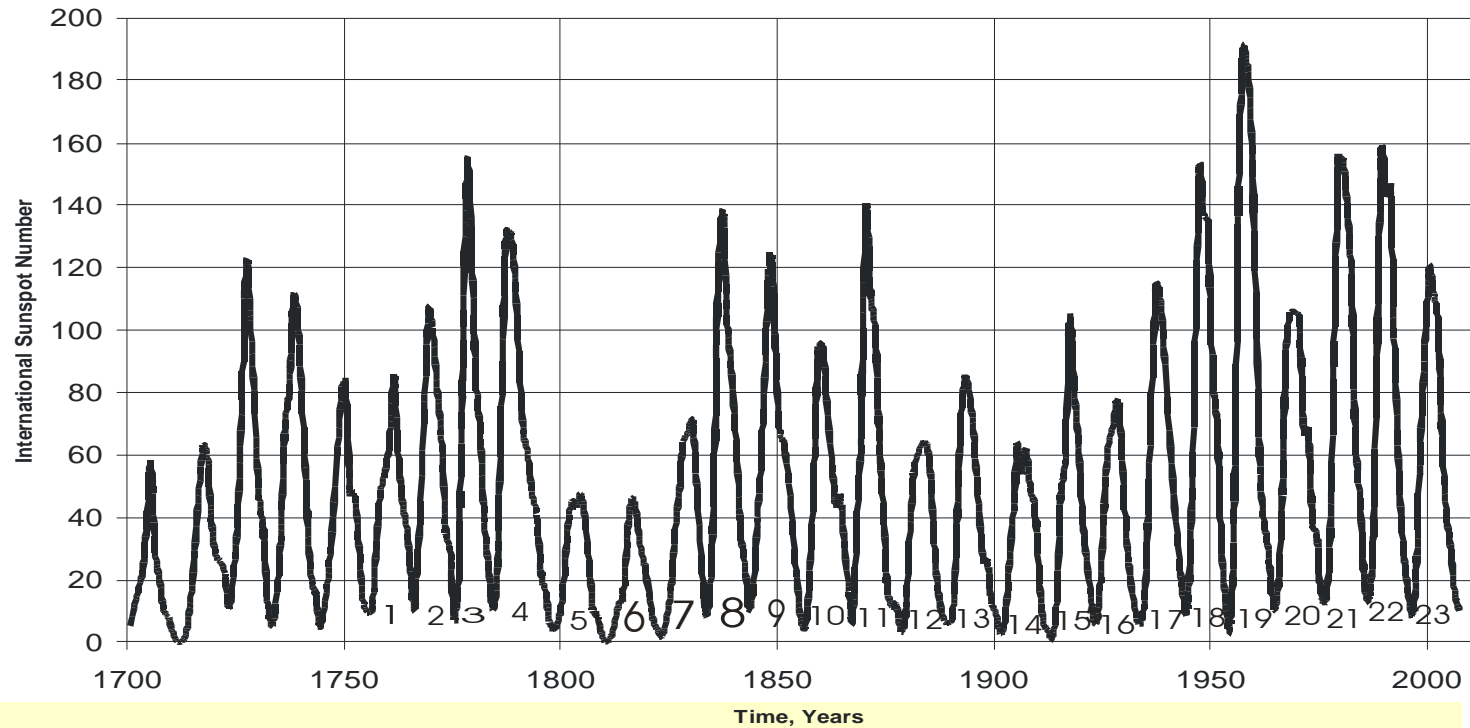
- **UPDATE BABCOCK-LEIGHTON DYNAMO:**
We update with 3 ideas:
 - 1) Shallow Dynamo, 2) Percolation in two flavors, and
 - 3) Magnetic forces help drive faculae/plage towards poles
- **PERCOLATION IN TWO FLAVORS:**
 - 1) Highly Superadiabatic:
Convection drives like-sign Ephemeral Regions (EPRs) into sunspots
 - 2) Normal:
Normal T structure: field concentrations disperse: spots-> faculae
- **MAGNETIC FORCES:** Rather than fields moving towards poles via diffusion/meridional transport, we suggest magnetic forces, mB, on subsurface field elements play a prominent role– yield dynamo
- **MODELING:** Cellular Automata Modeling seems to fit solar dynamo
- **PREDICTION:** Solar Cycle #24 Rz~75; F10 ~125 in ~2012-3

Backup

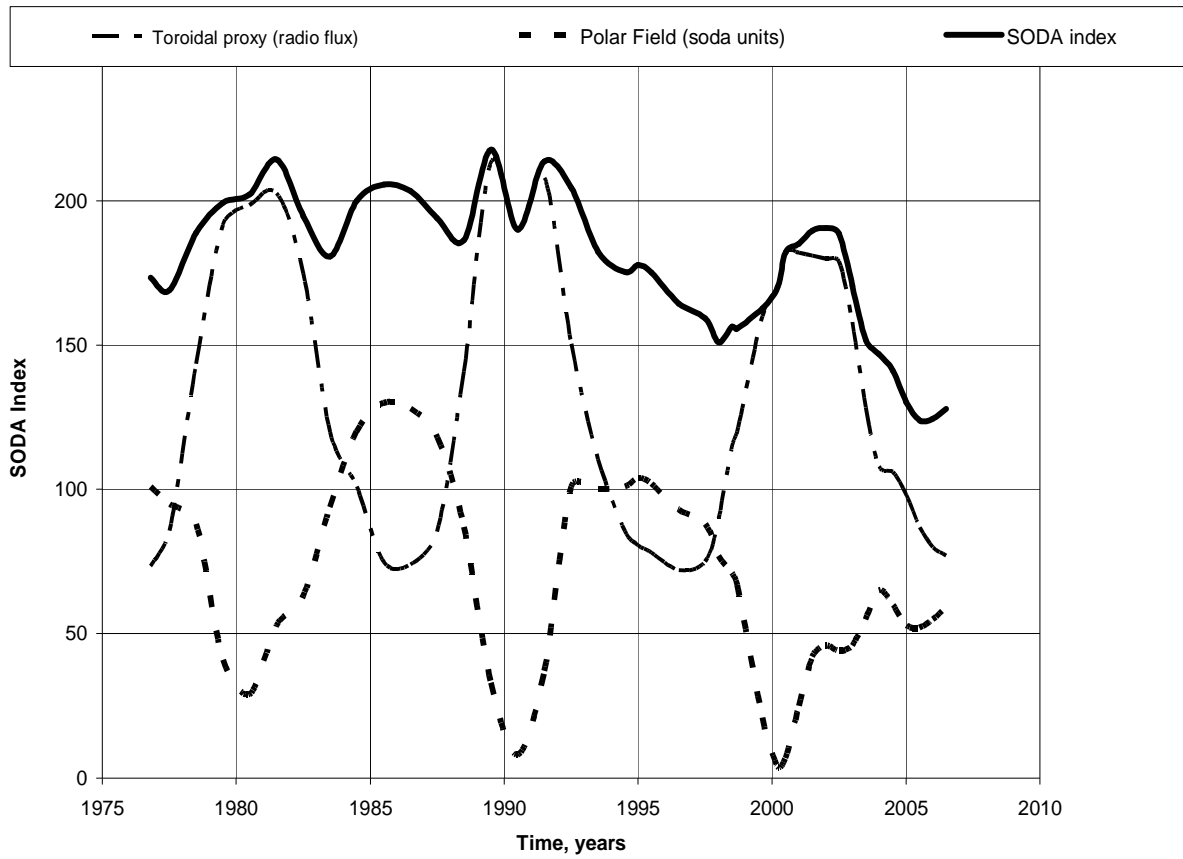


LONG-TERM SOLAR OBSERVATIONS

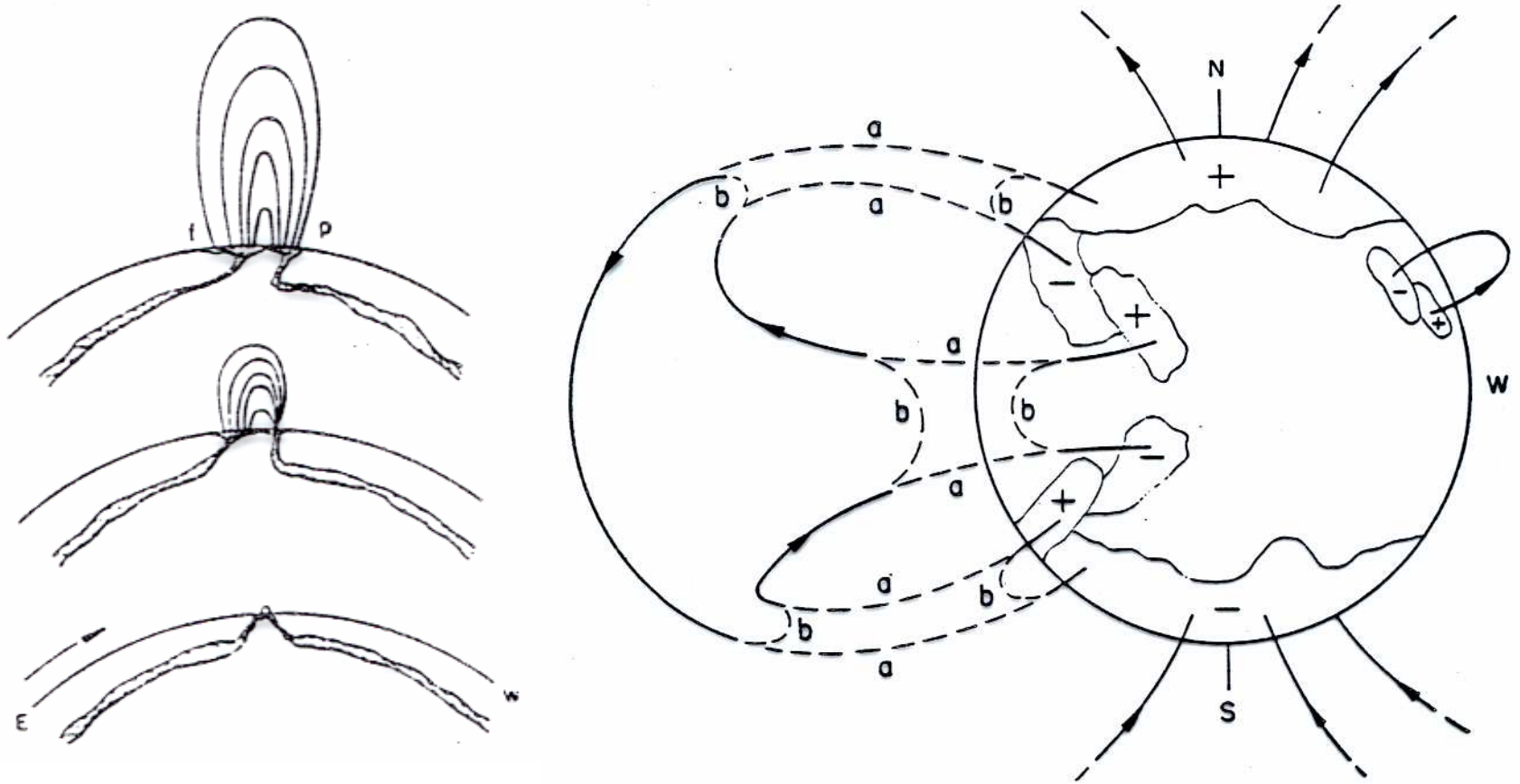
International/Zurich Sunspot Number vs. Year



SODA index vs time, years



Babcock's shallow dynamo view



Babcock 1961, ApJ, 133, 572

Why Field Separates From Flow: Leaf Instability, and Stays Near Photosphere

