



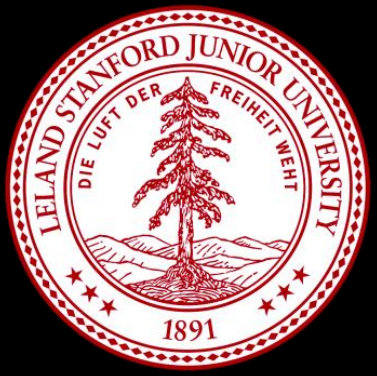


# Solar cycle & Dynamo Modeling

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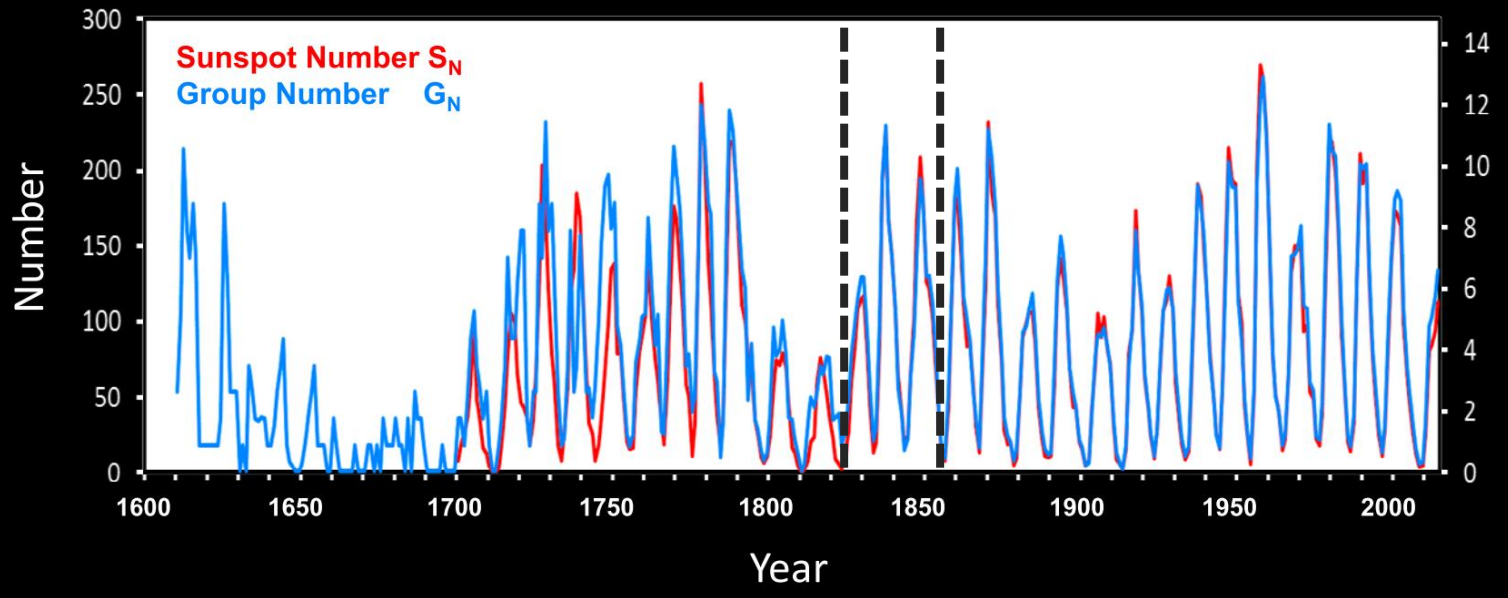
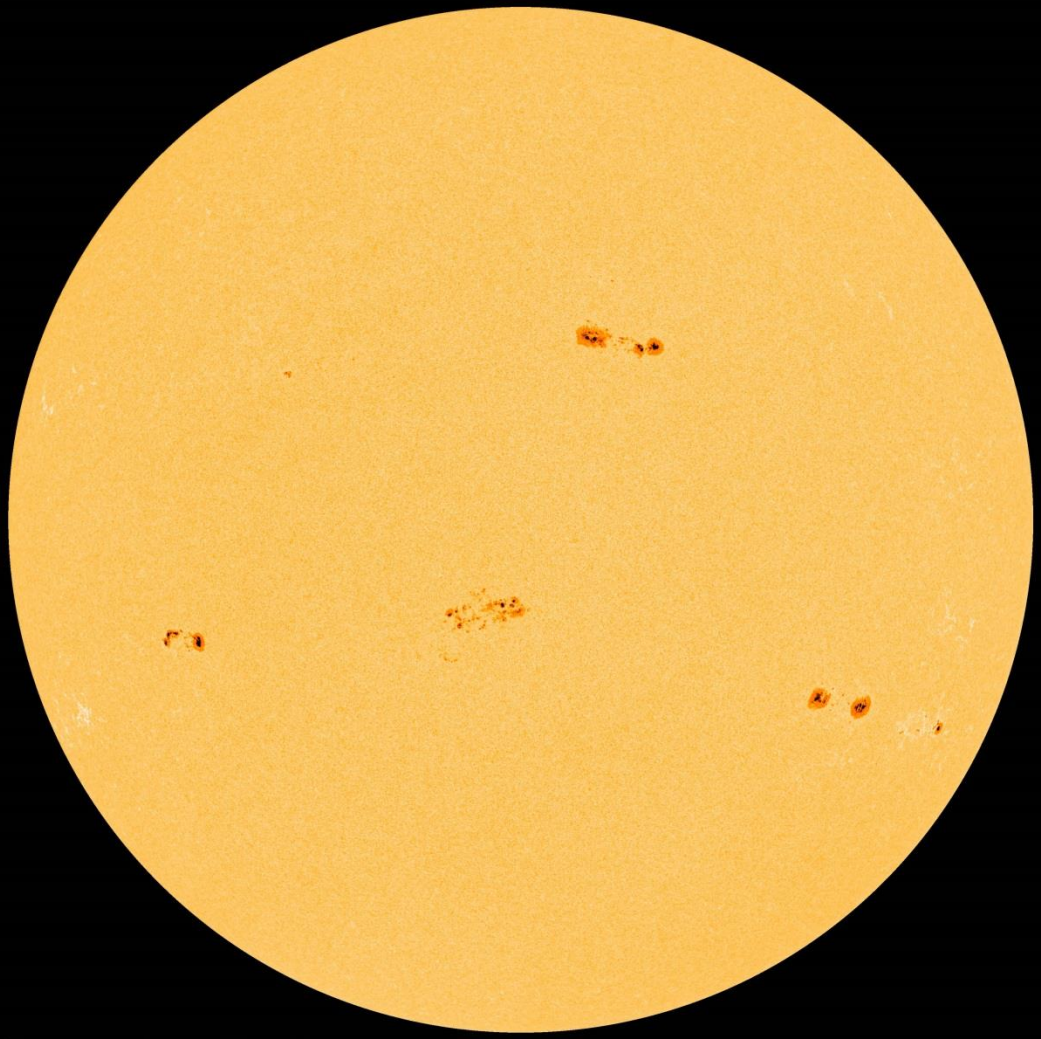
# THE SOLAR CYCLE: A MAGNETIC PHENOMENON

# The solar cycle was discovered by Schwabe 1843 when he found that sunspot numbers change in time




- Alternating peaks in solar activity (maxima), followed by quiet periods (minima).
- Time variation is predominantly cyclic, mean period is 11 years.

# Sunspots are associated with regions of very strong magnetic field (Hale 1908)




SDO/HMI

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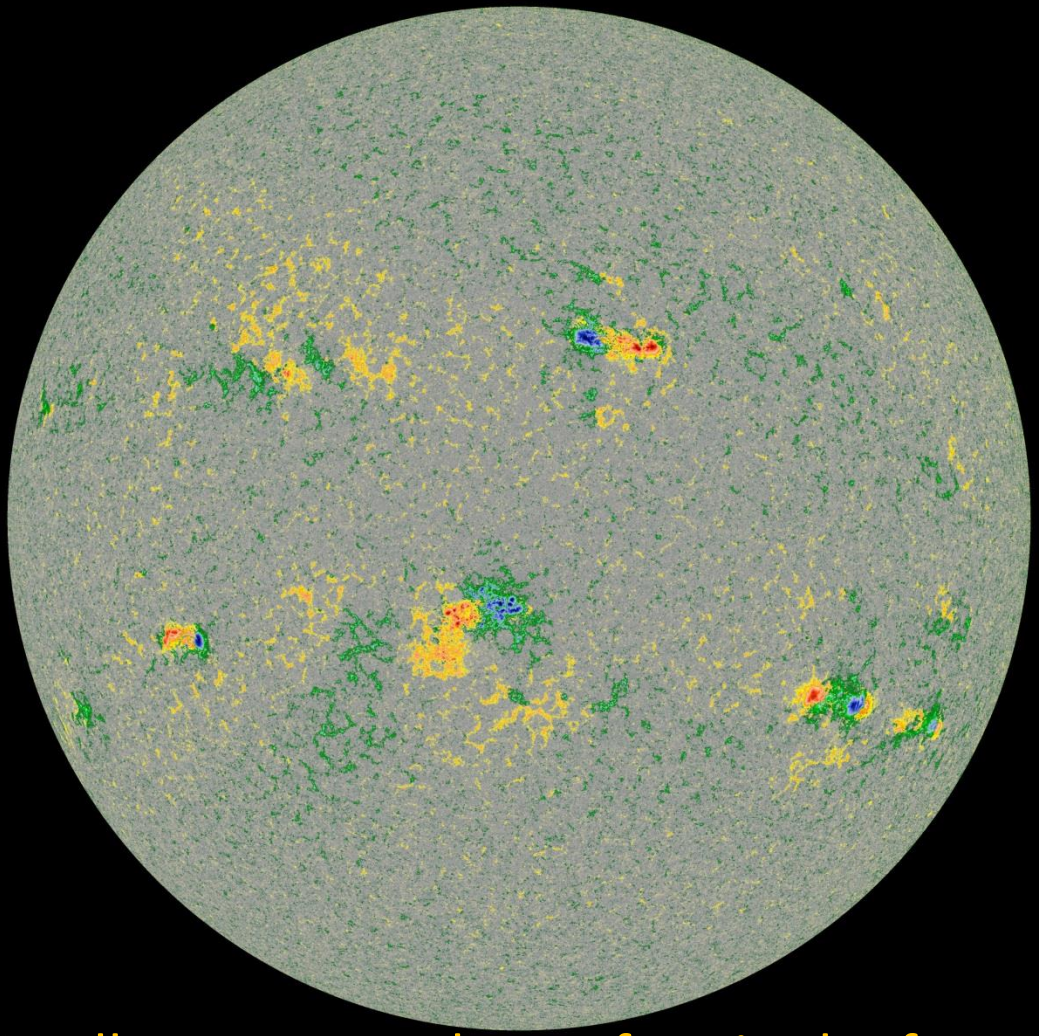

Fields generally appear at the surface in the form of bipolar structures called active regions

SDO/HMI

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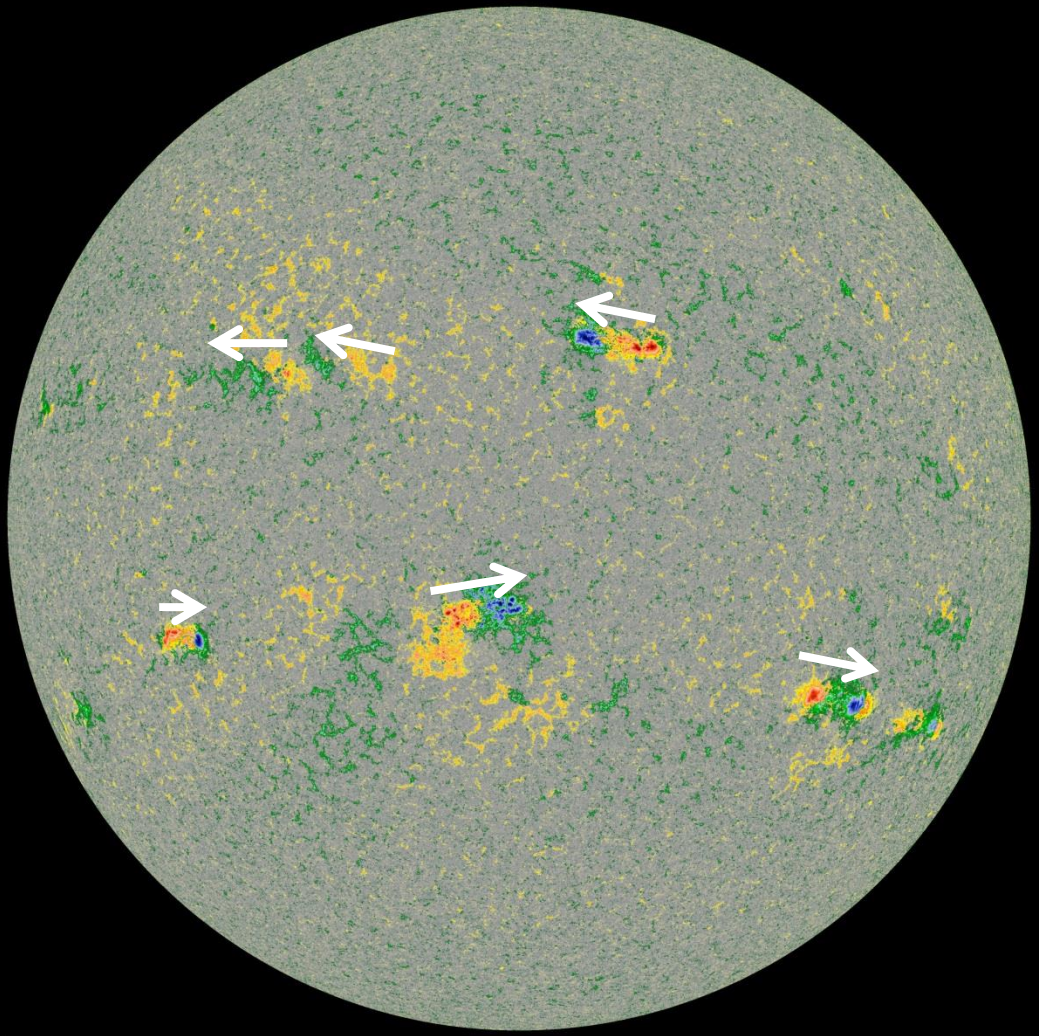
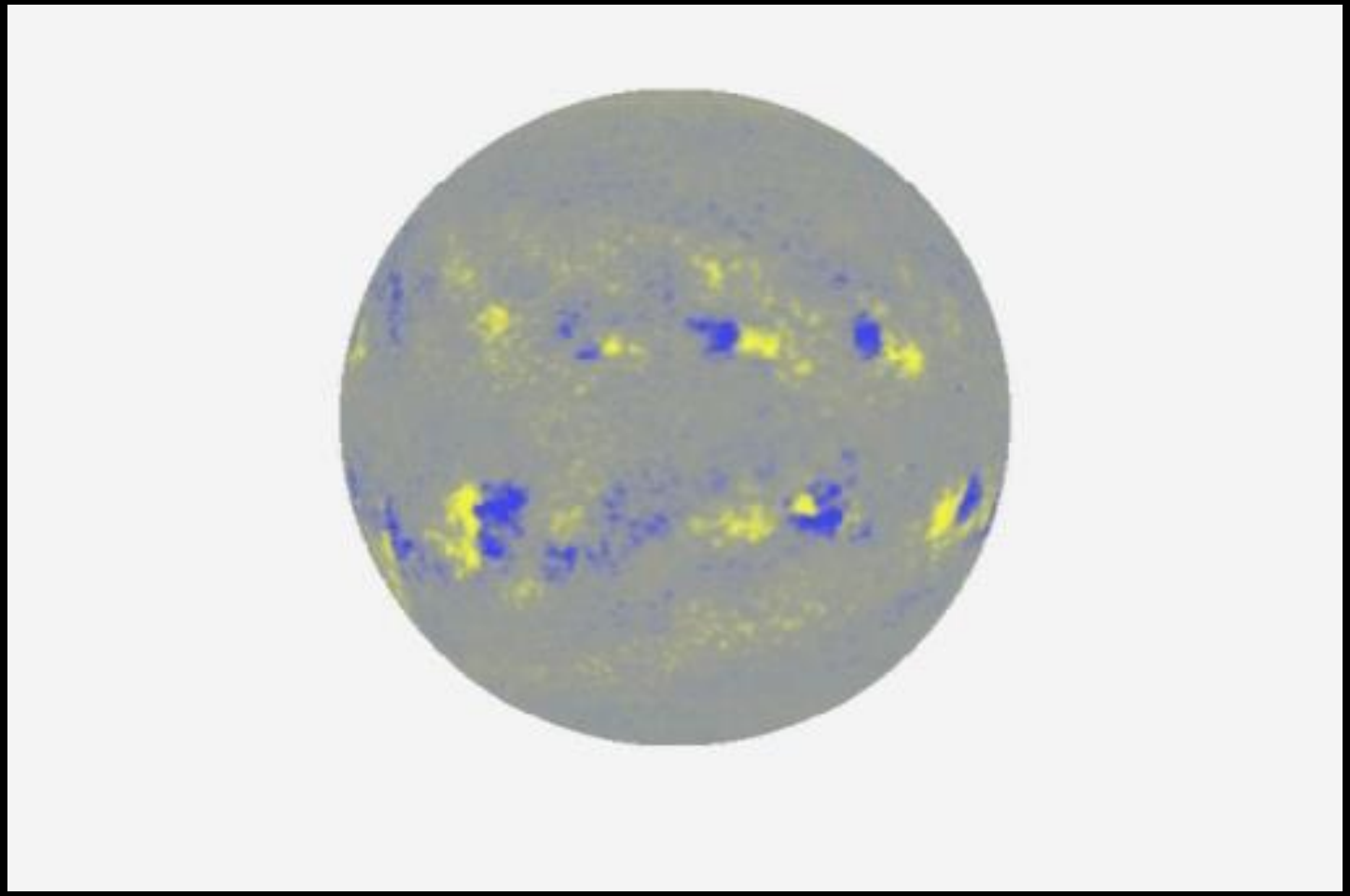



Active regions present systematic orientation and inclination

SDO/HMI

# The most visible features of the cycle are associated with active regions



Movie by David Hathaway

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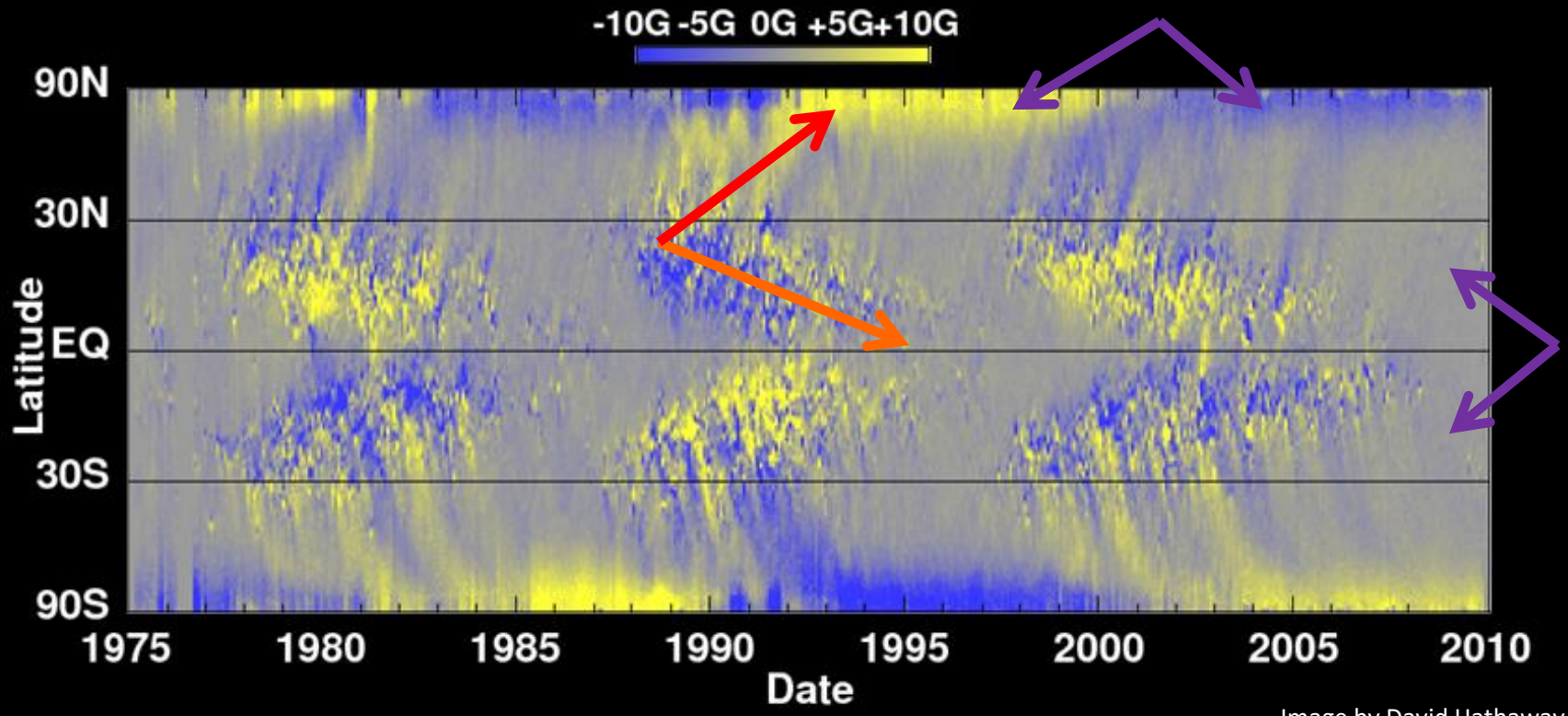
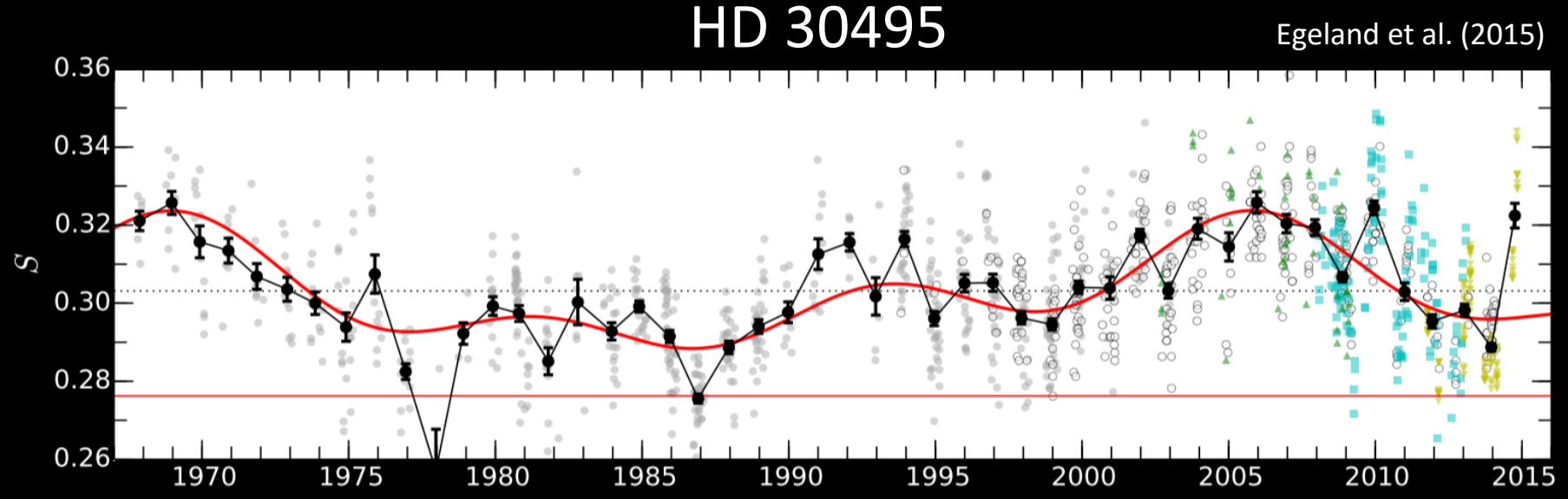
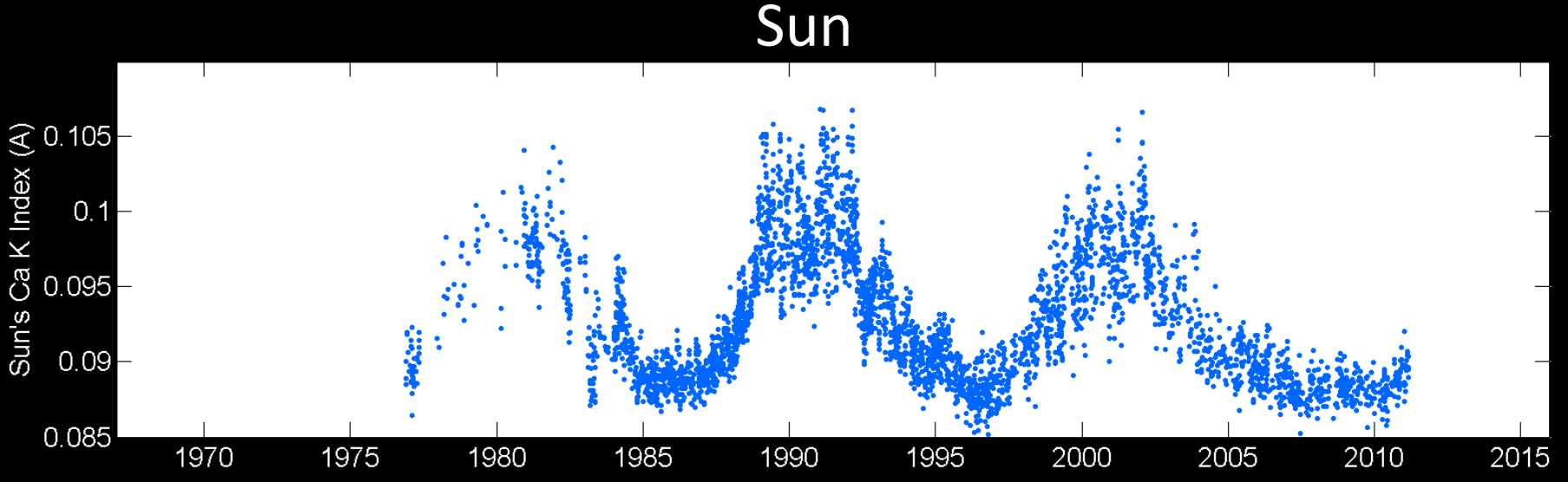



Image by David Hathaway

- Equatorward migration of active latitudes.
- Poleward migration of their decayed diffuse field
- Polar field reversal at the maximum of the cycle and across hemispheres.

# A cycle is not unique to the Sun

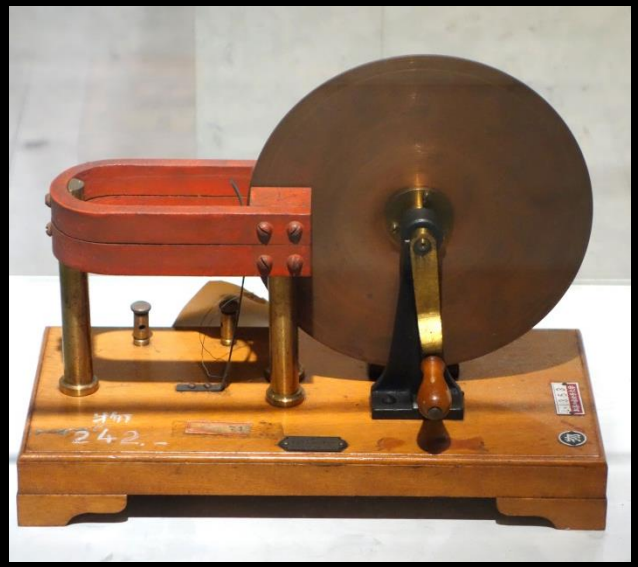


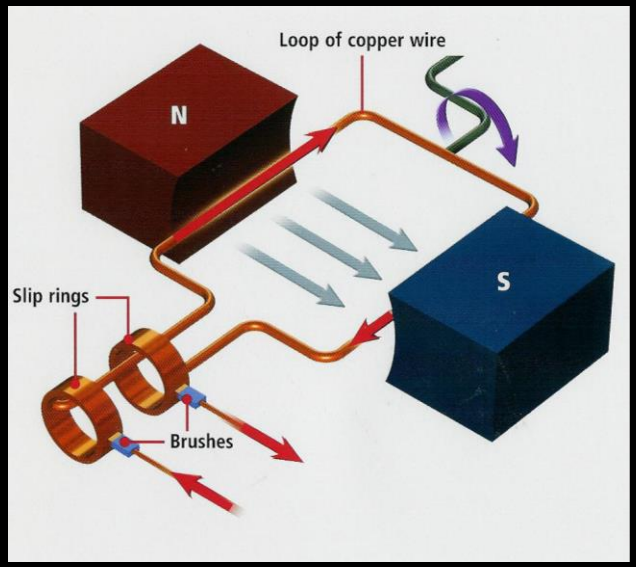



# THE STELLAR DYNAMO

# What is a Dynamo?

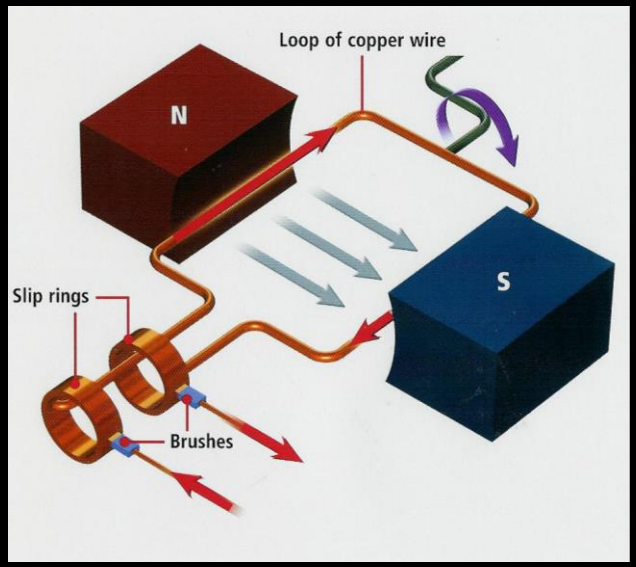
A machine that converts kinetic energy into electric energy by moving a conductor inside a magnetic field.





# In stellar dynamos things are much more complicated

- The shape of the current loop can change freely to create very stable magnetic structures.
- The magnetic field restricts the movement of particles resulting in elastic behavior.
- The magnetic field used to induce the current is sustained by the induced current.



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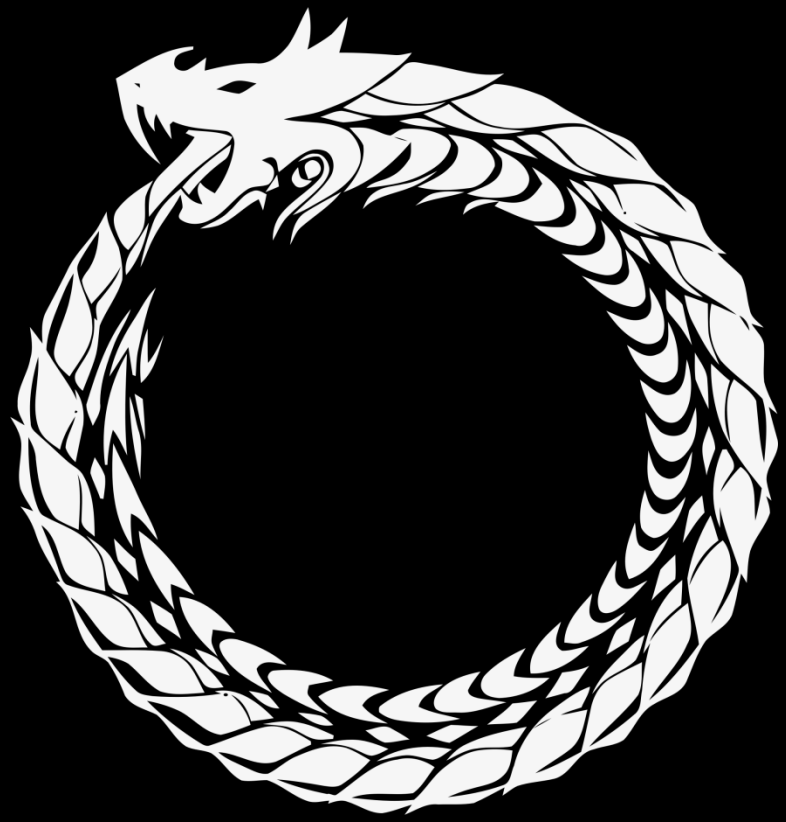
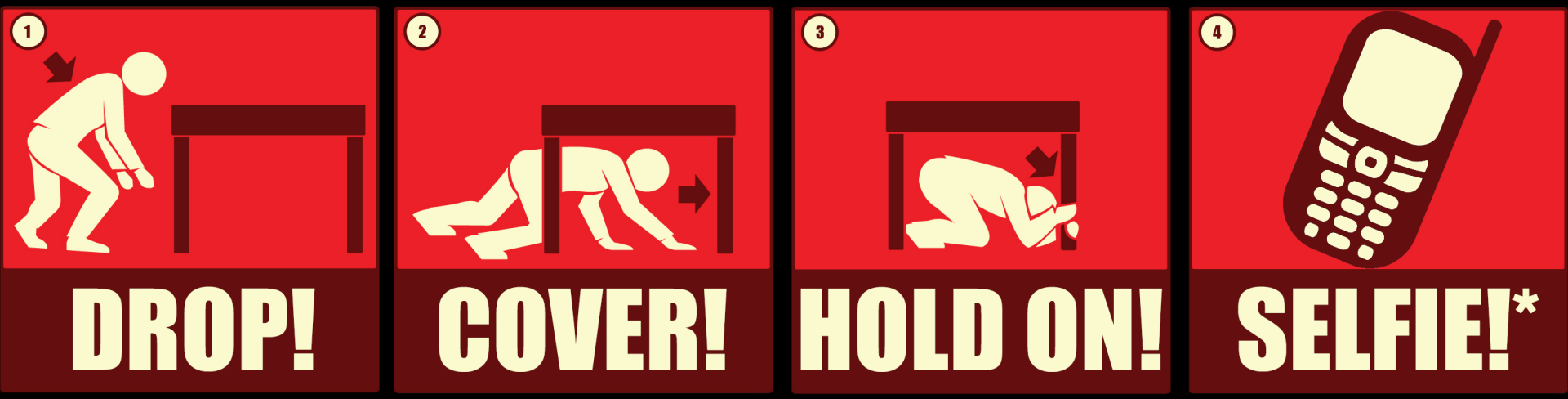
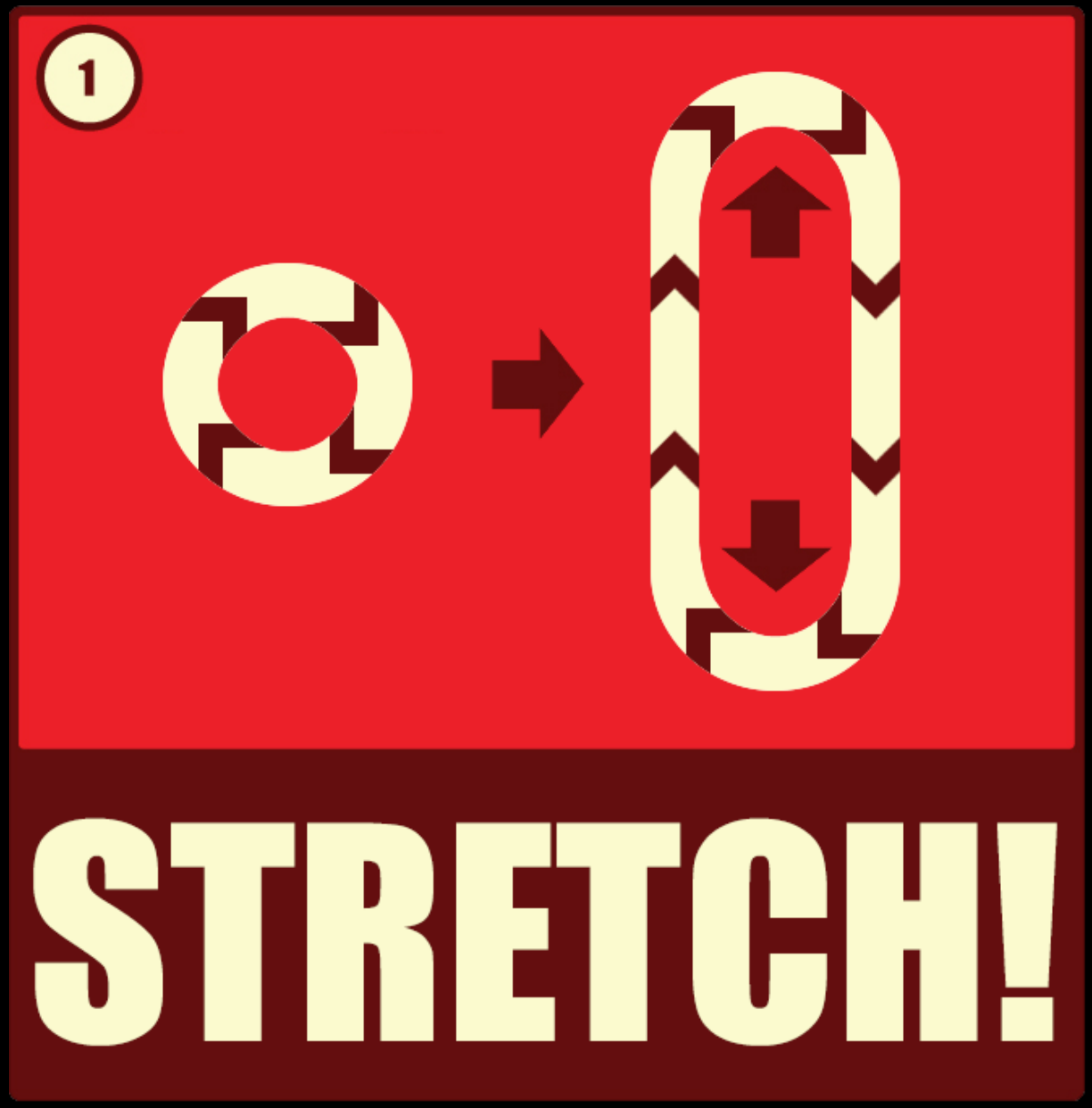


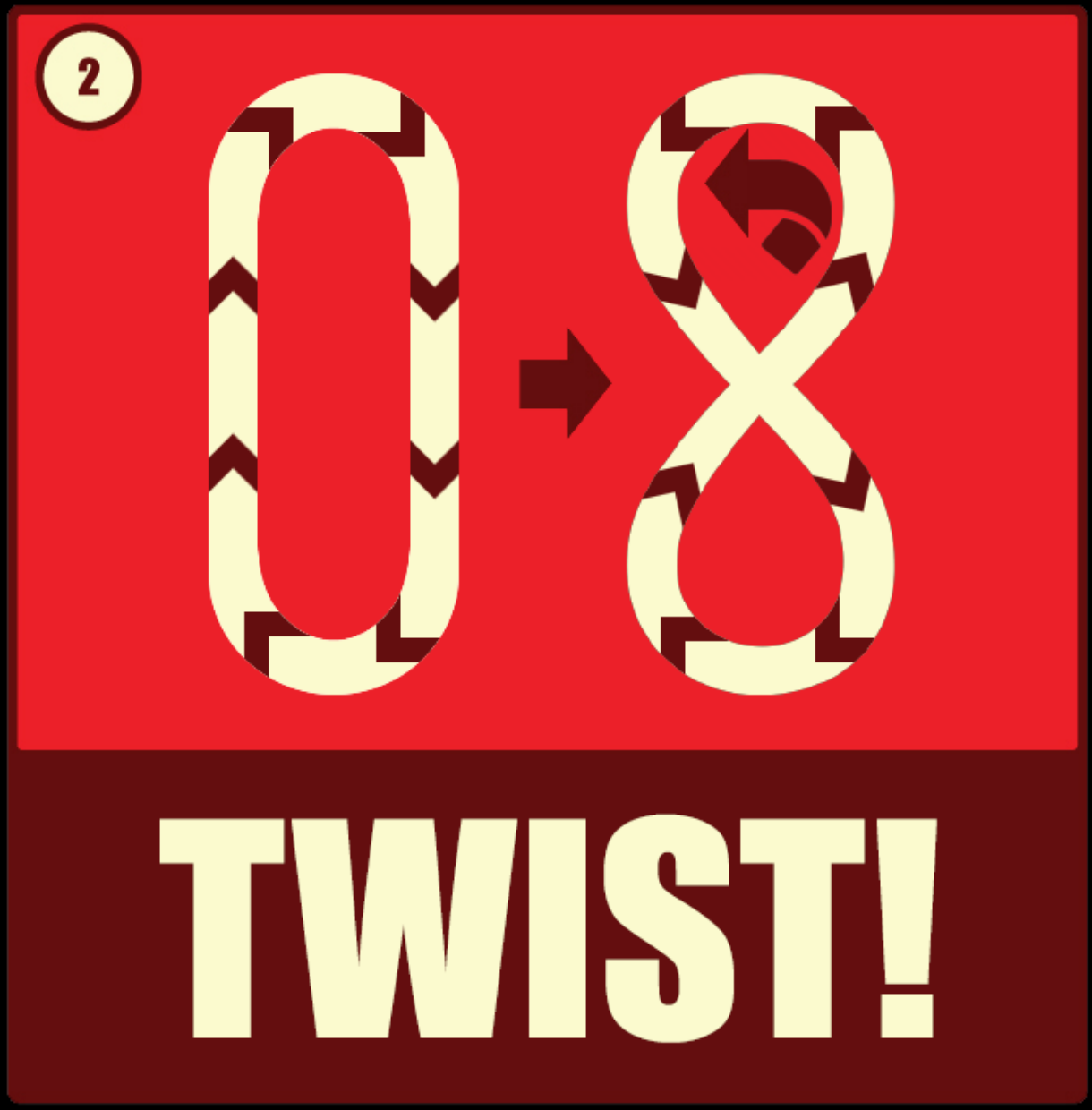
# BASIC NECESSARY STEPS FOR A SAFE AND FULFILLING DYNAMO EXPERIENCE



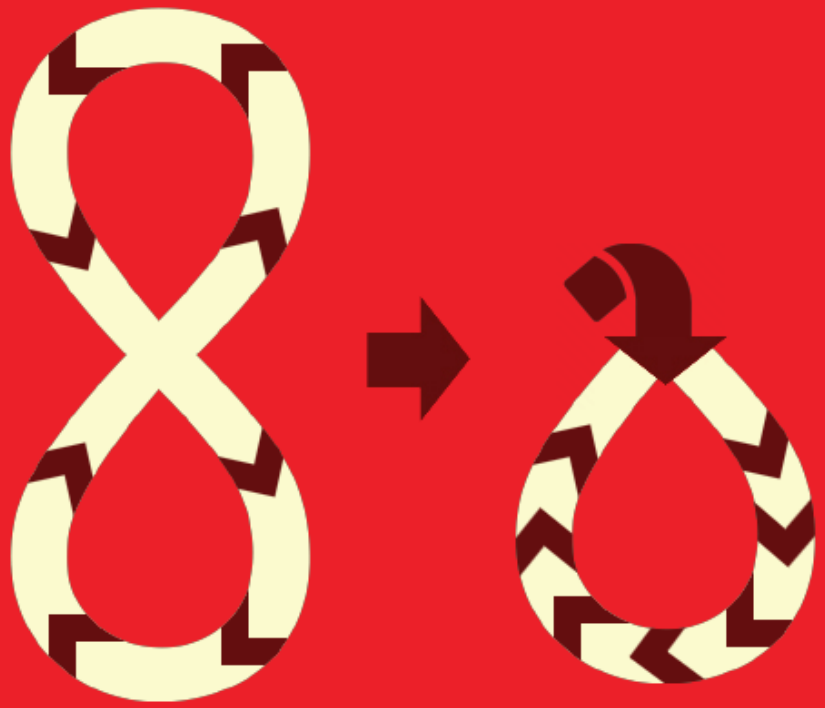

*NOT RECOMMENDED IN AN ACTUAL EMERGENCY

# Silly Putty Time!

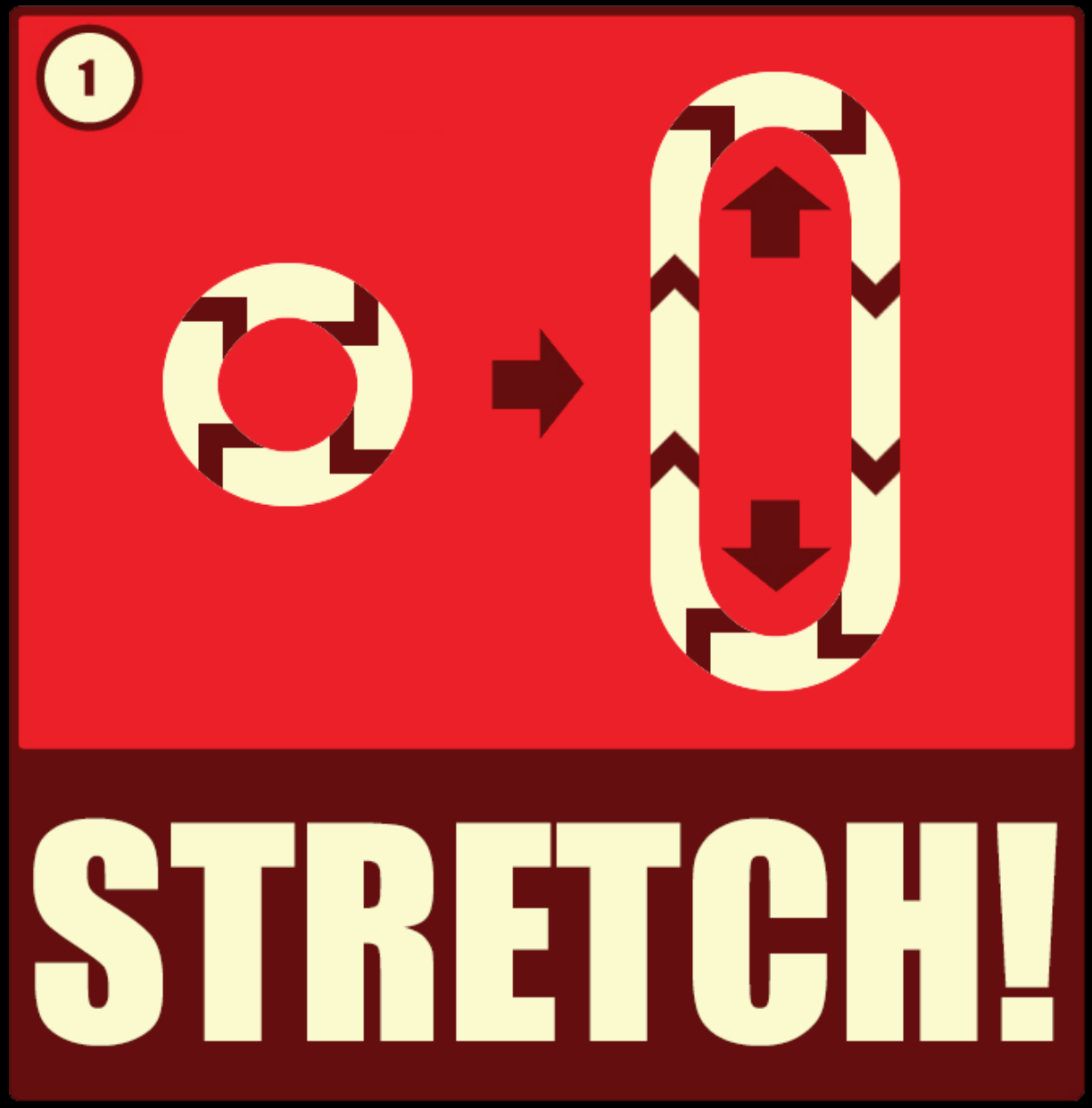

1
STRETCH!


2
0 8
TWIST!

3



FOLD!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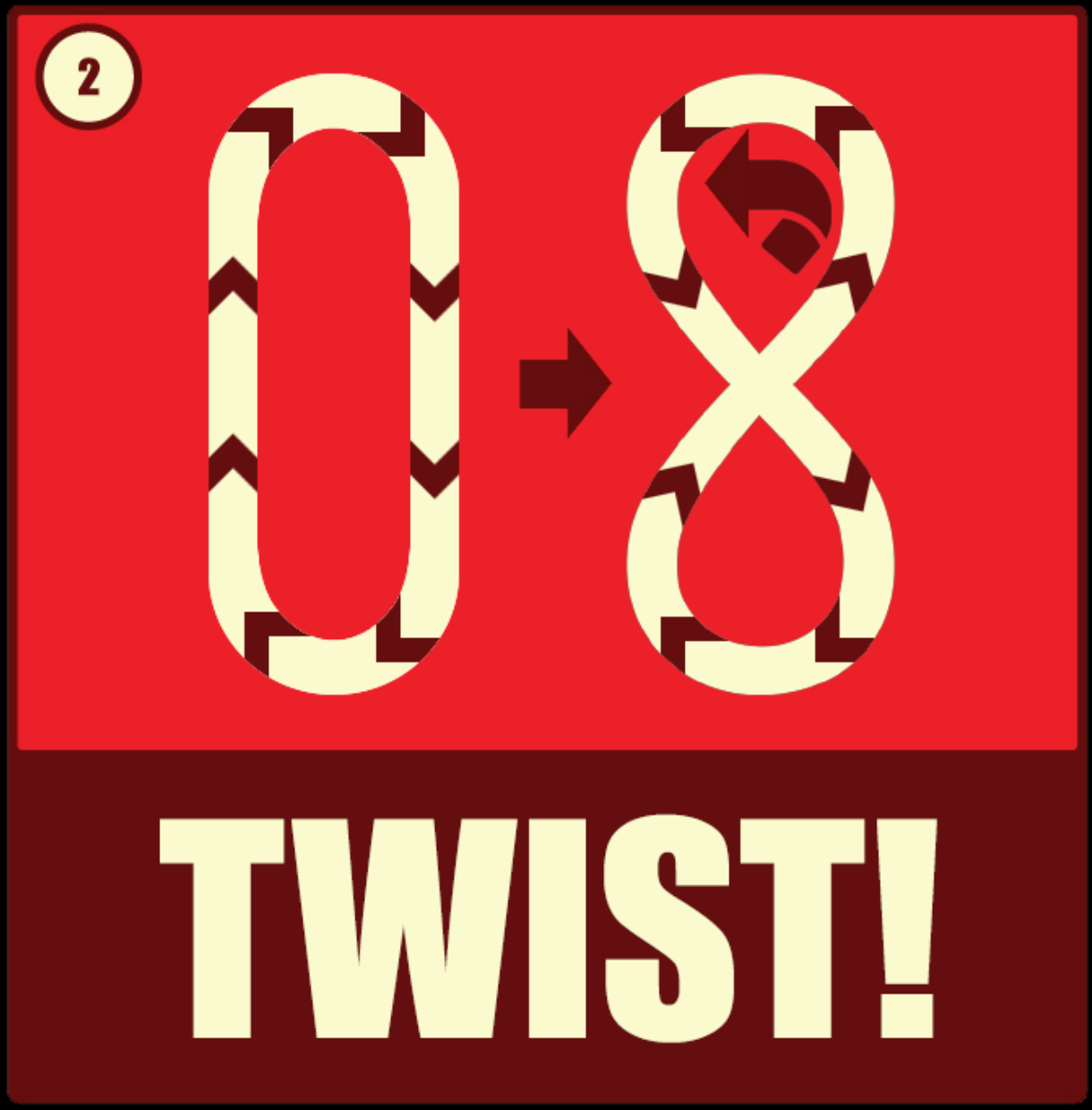
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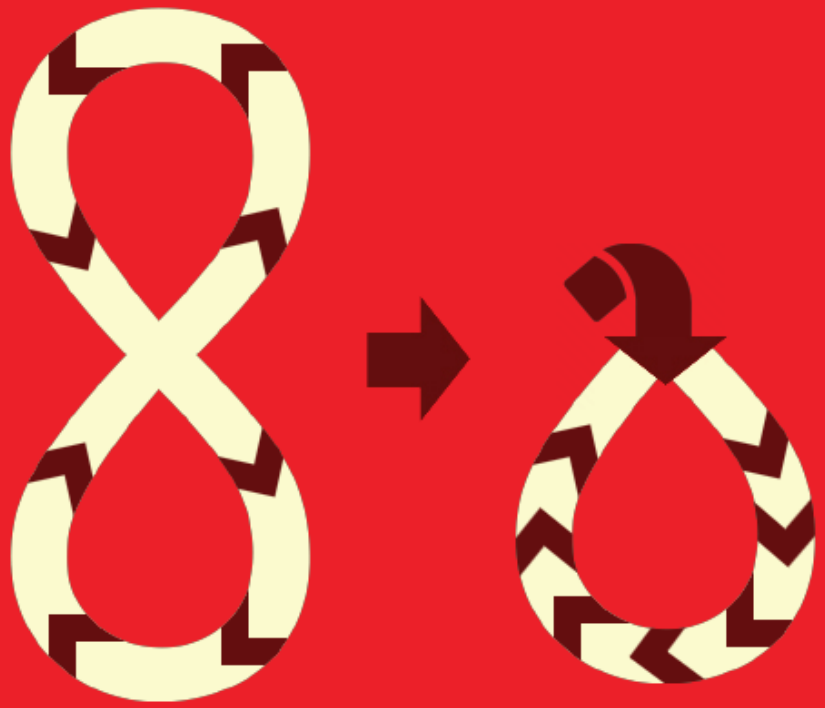
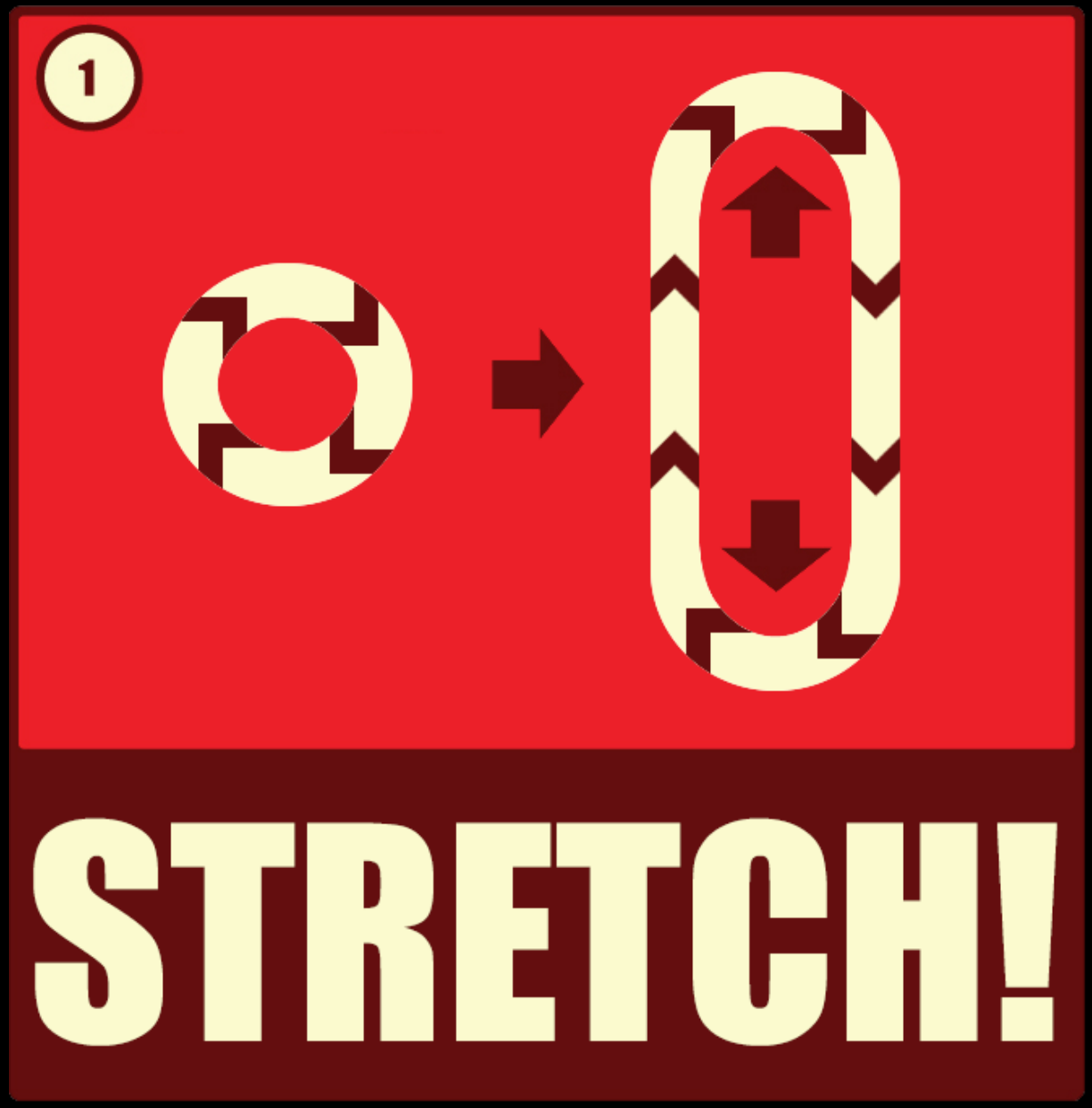


FOLD!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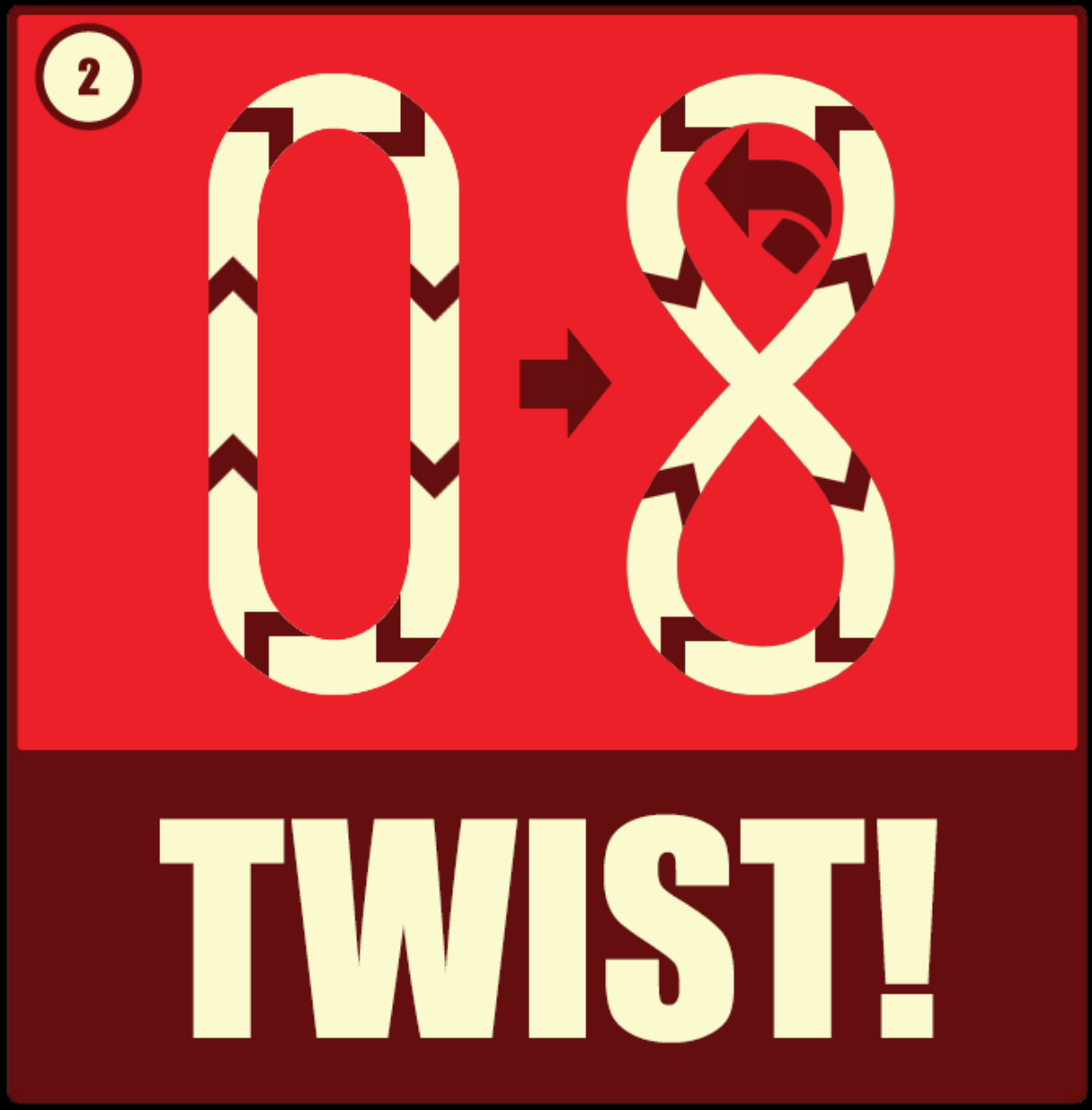
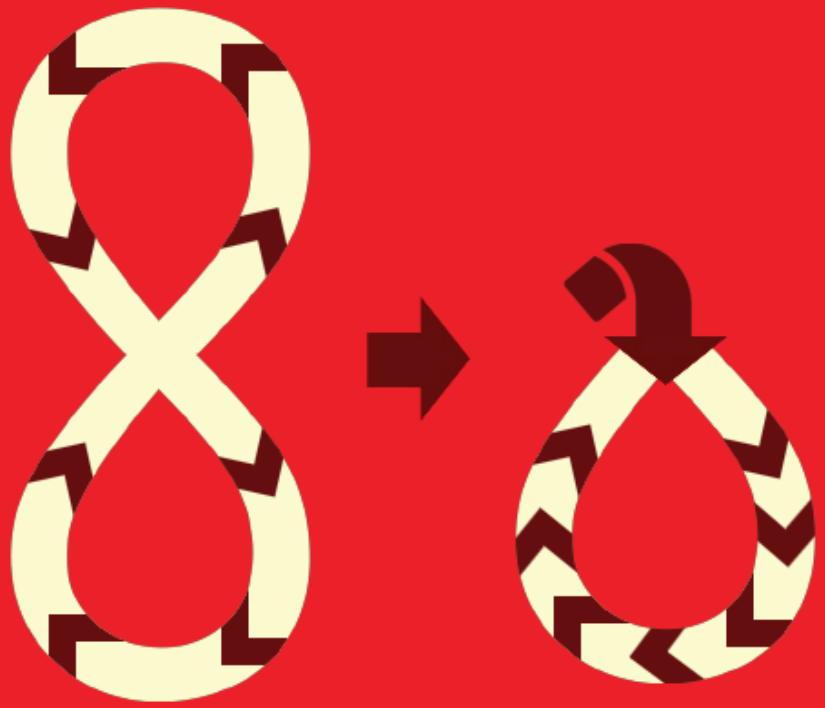

2
0 8
TWIST!

3



FOLD!

4

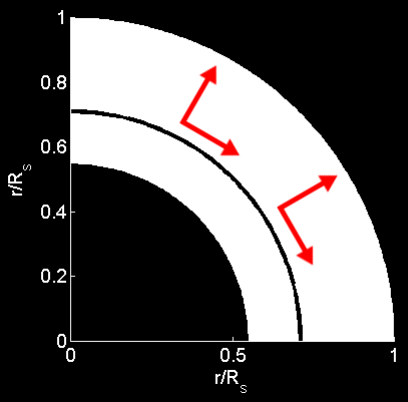
# SELFIE!

# 3D STELLAR DYNAMO SIMULATION

# Poloidal and Toroidal Fields

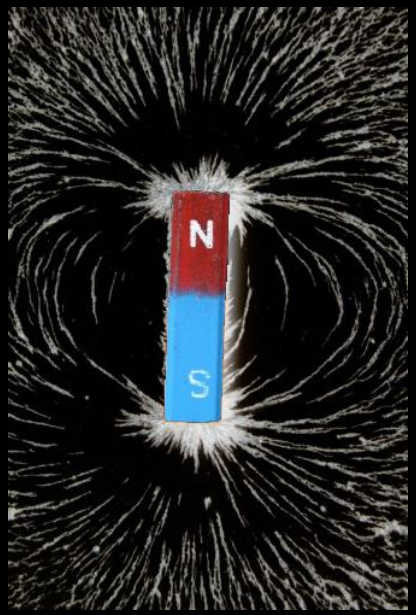
Poloidal

r - θ

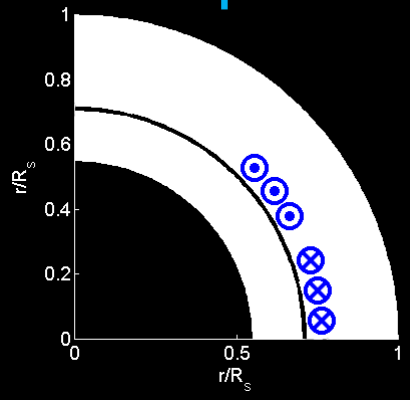


# Poloidal and Toroidal Fields

## Poloidal
## r - θ



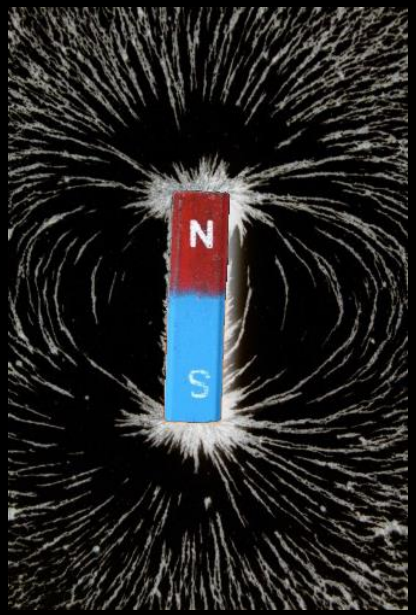

## Toroidal
## ϕ

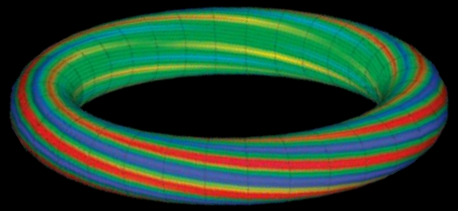


# Current understanding of the solar cycle

Poloidal

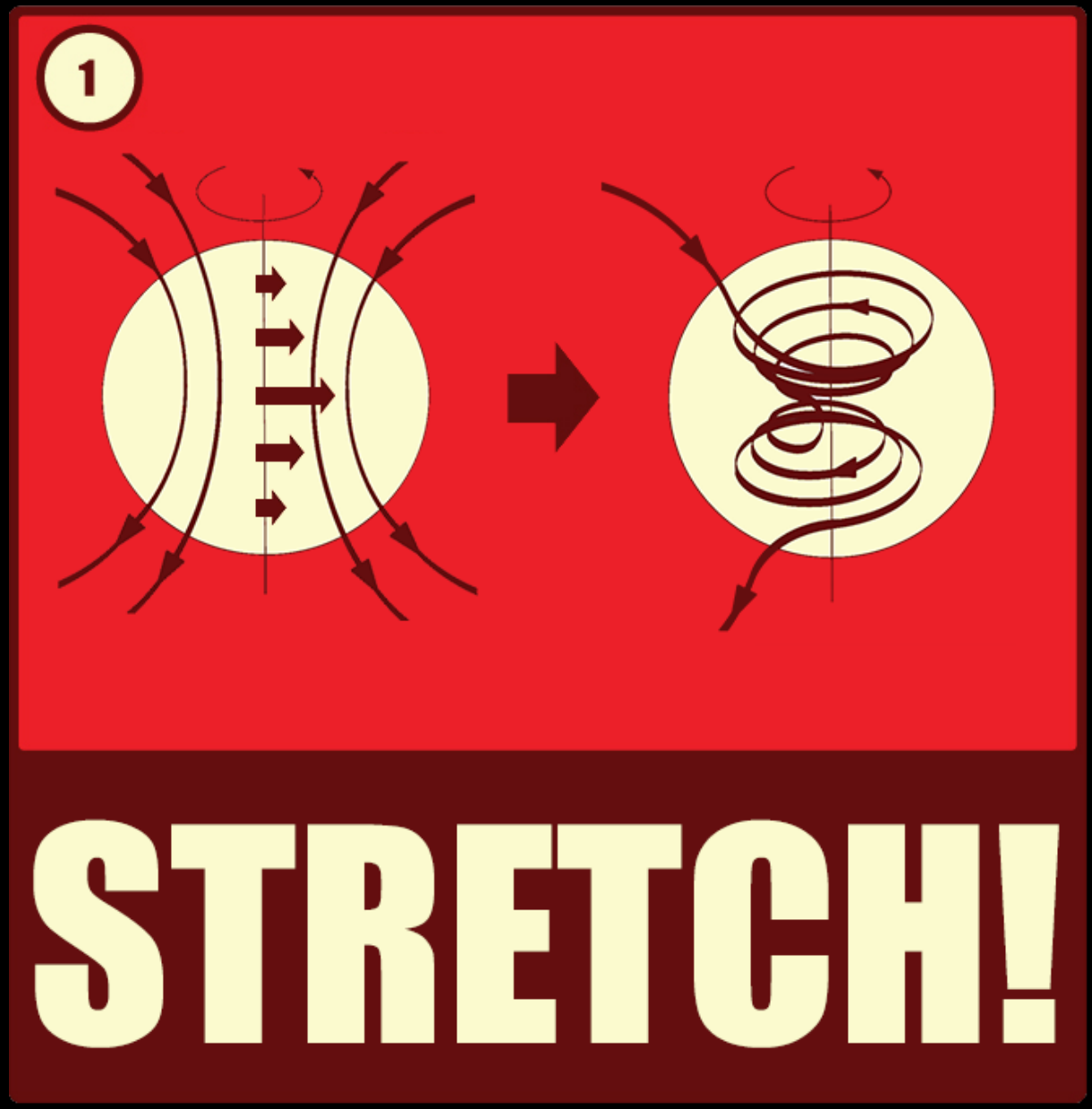
$r - \theta$



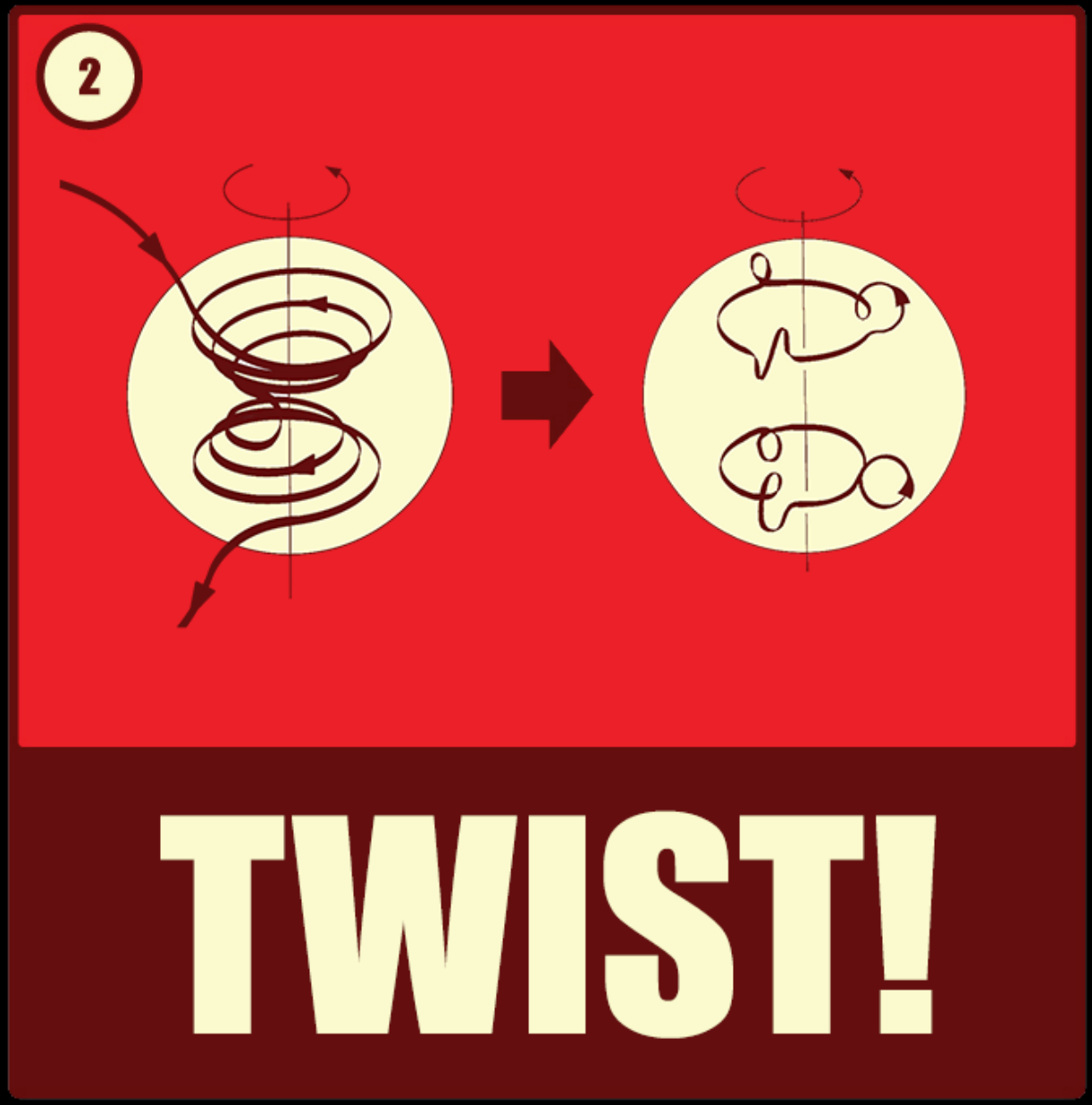



Toroidal

$\phi$




Schematic by J. J. Love

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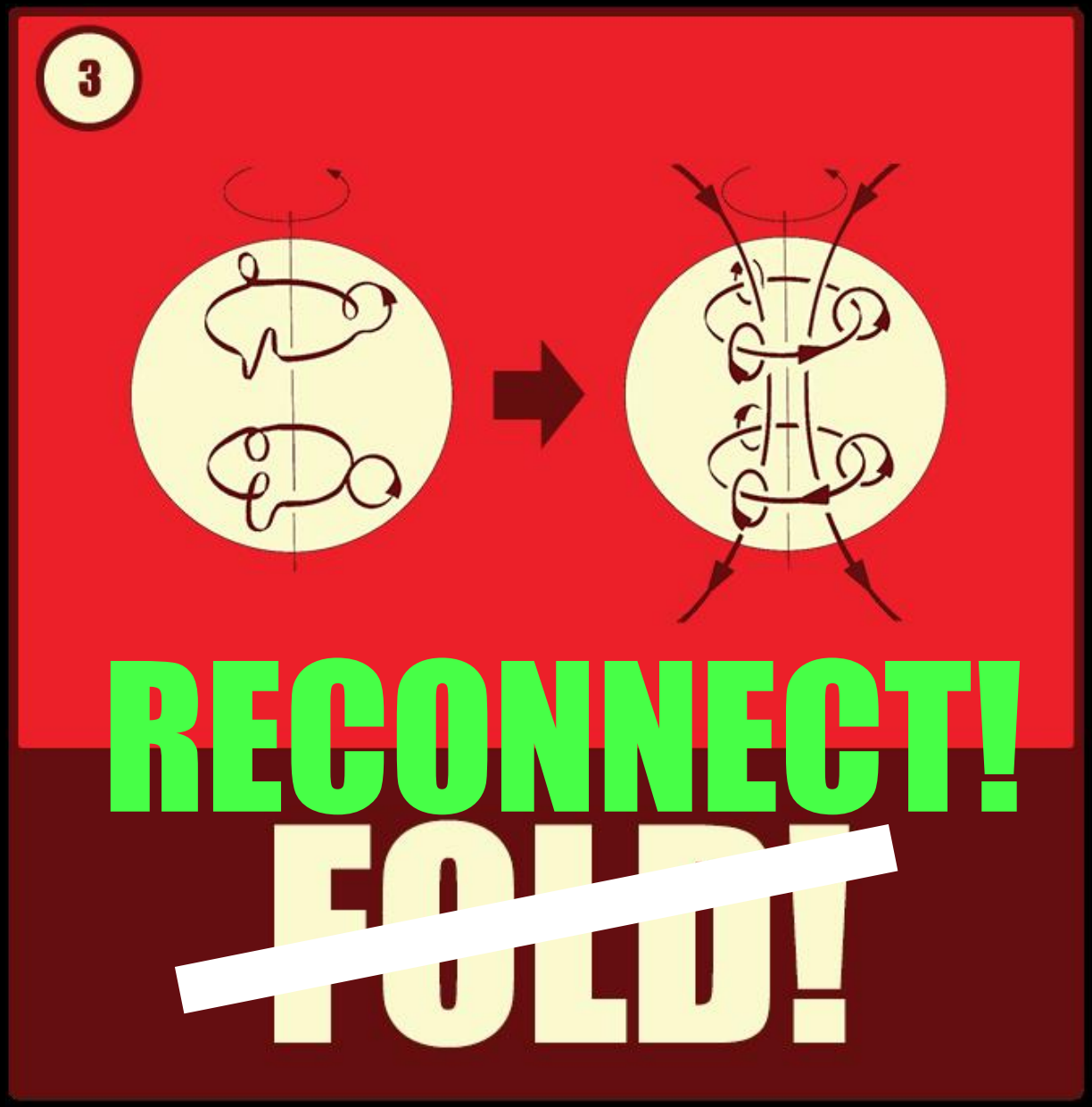


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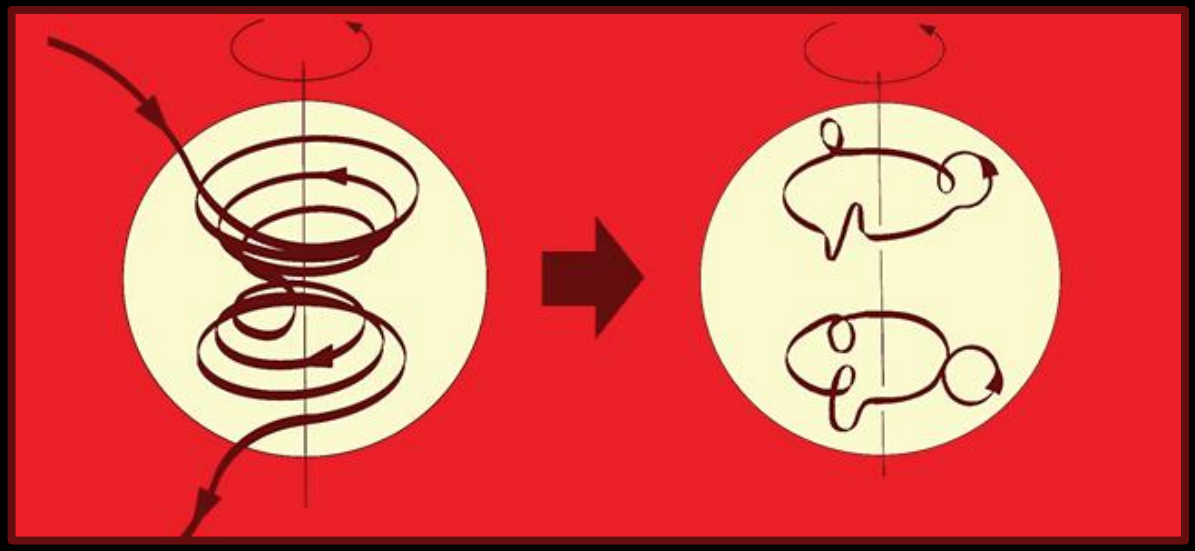
# Small-scale vs. Large-scale "Twist"



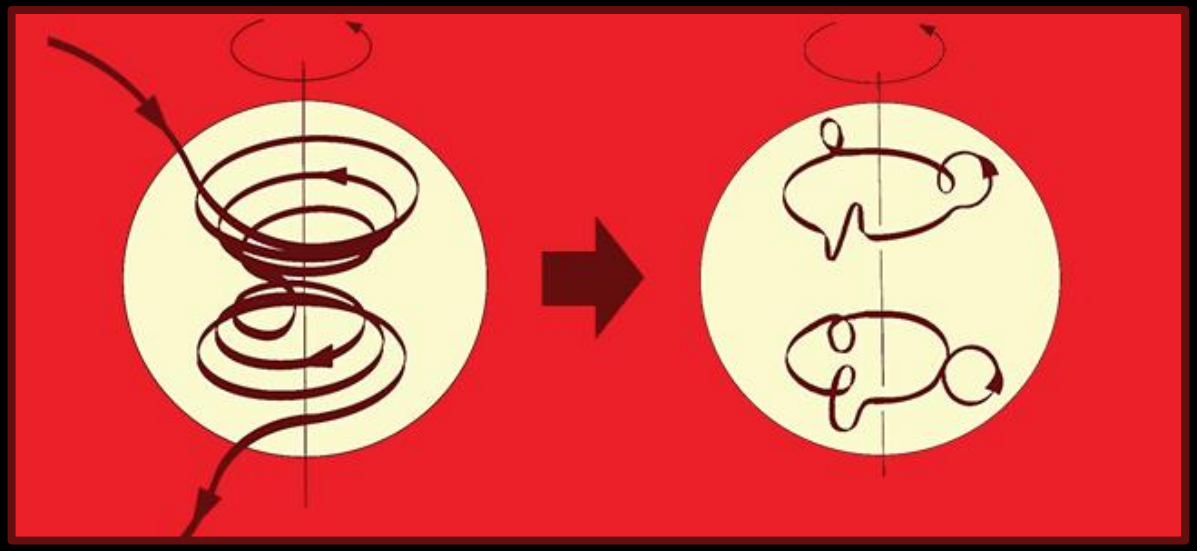
## Small-Scale and Local

- Helical convection acting on the magnetic field.
- Also known as $\alpha$-effect.
- Limited by the relative amount energy available in convection.

## Large-Scale and Global

- Coriolis force acting on rising flux-tubes.
- Also known as Babcock-Leighton effect.
- Limited to strong flux-tubes.

# Small-scale vs. Large-scale "Twist"



Small-Scale and Local

Large-Scale and Global

$\alpha\Omega$ Dynamo

Babcock-Leighton Dynamo

# BALANCE AND COUNTERBALANCE OF COMPETING EFFECTS


LICENSED BY Nintendo®

CAPCOM® USA

Official Nintendo Seal of Quality®

SUPER NINTENDO® ENTERTAINMENT SYSTEM

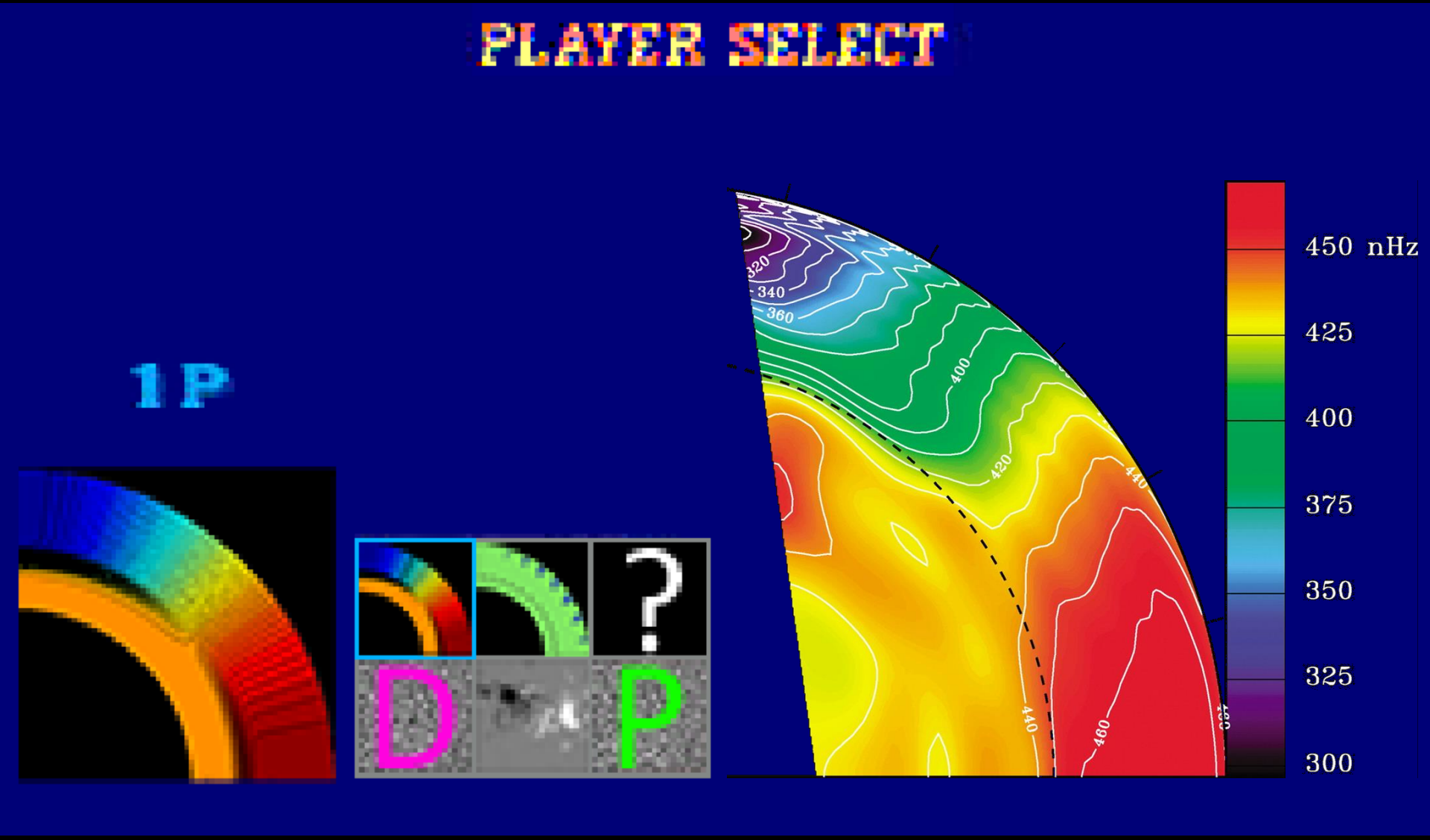

THE WORLD WARRIOR

DYNAMO FIGHTER™II IS A REGISTERED
TRADEMARK OF CAPCOM USA INC

1 PLAYER OR 2 PLAYERS ?


PLAYER SELECT
1P
?
?
D
P

# Differential Rotation



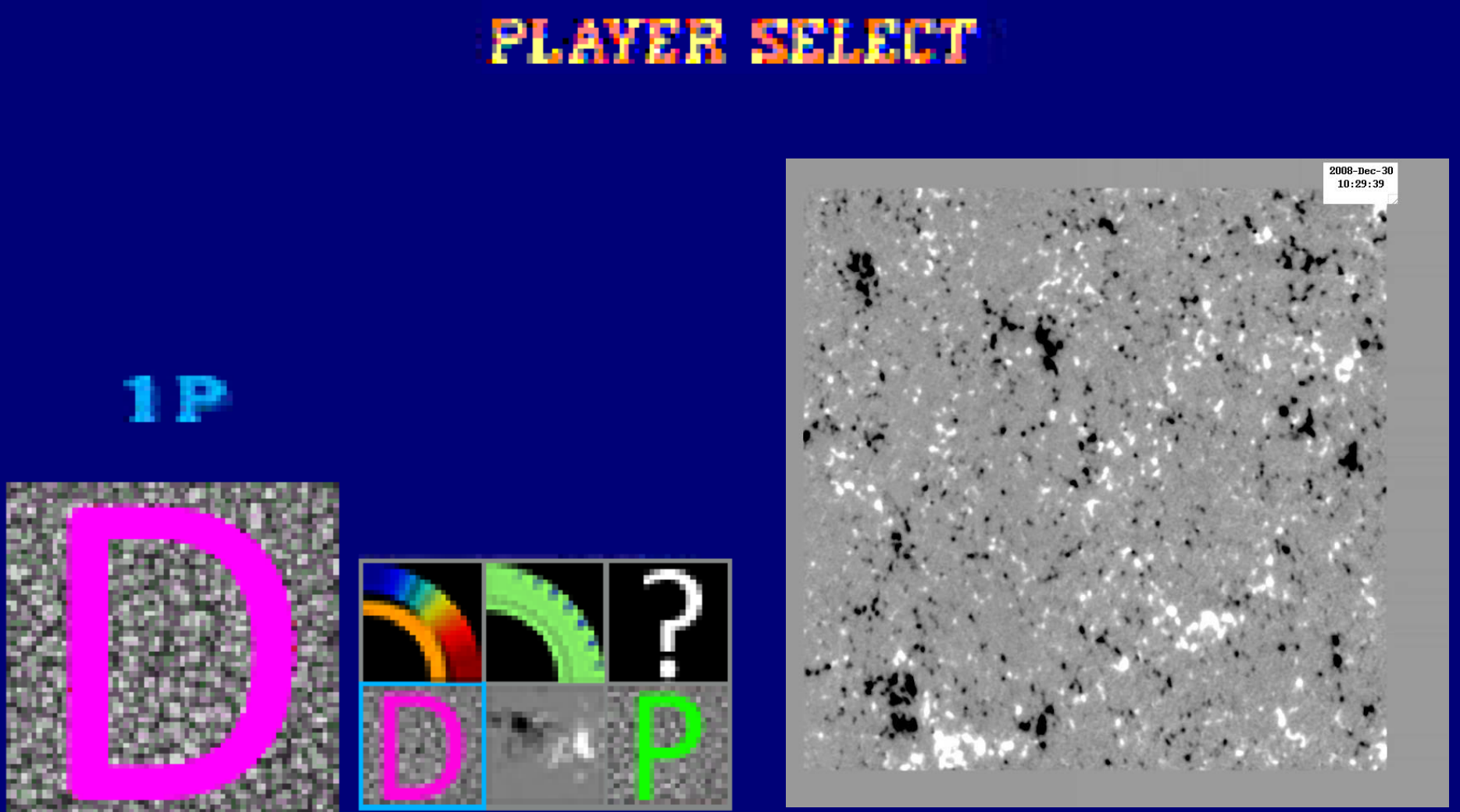

Stretches poloidal fields. Main source of energy for the dynamo.

# Meridional Flow


Jackiewicz et al. (2015)

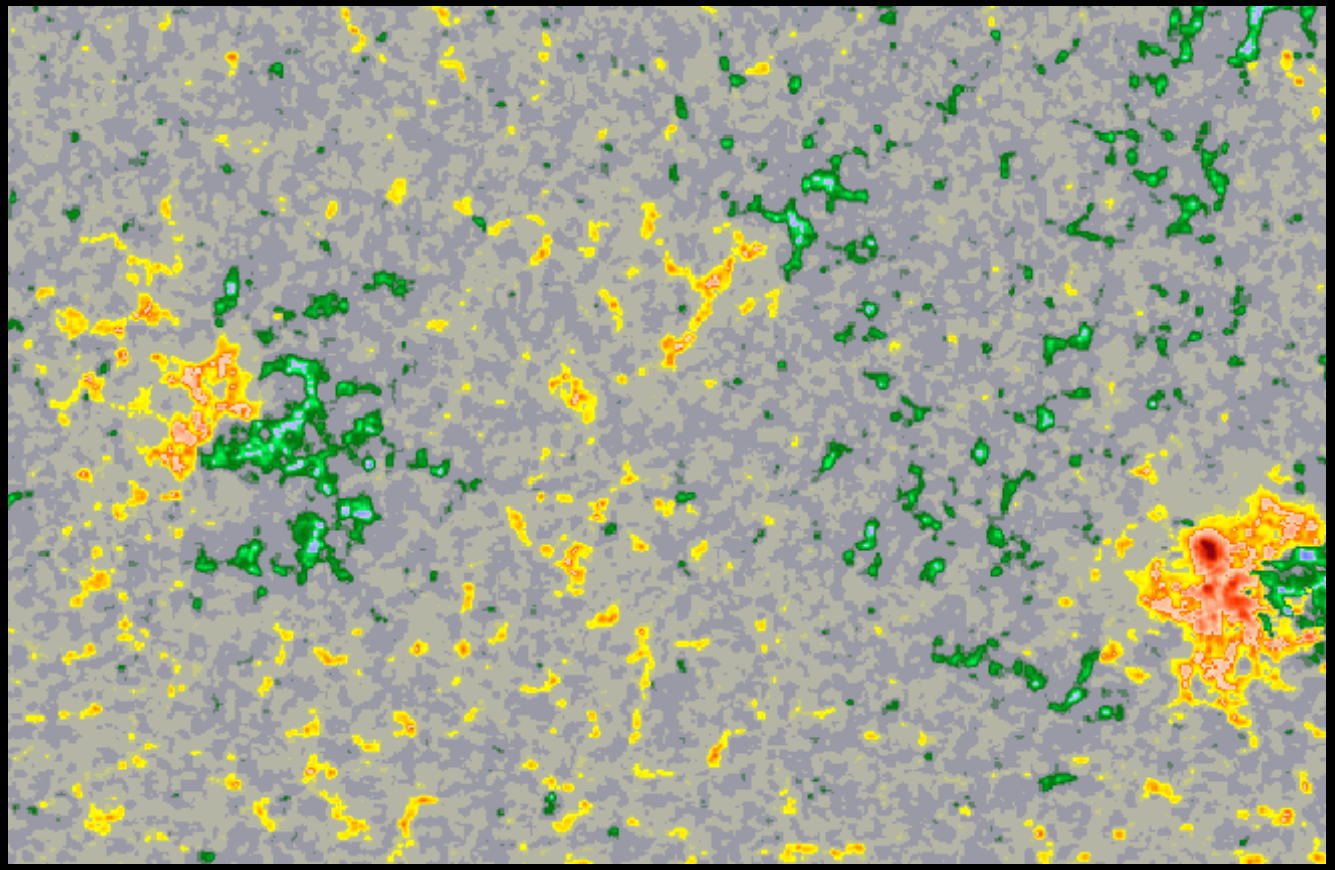
Connects different layers in the convection zone and drives period.

# Turbulent Diffusion




Spreads magnetic flux, but also leads to flux cancellation.

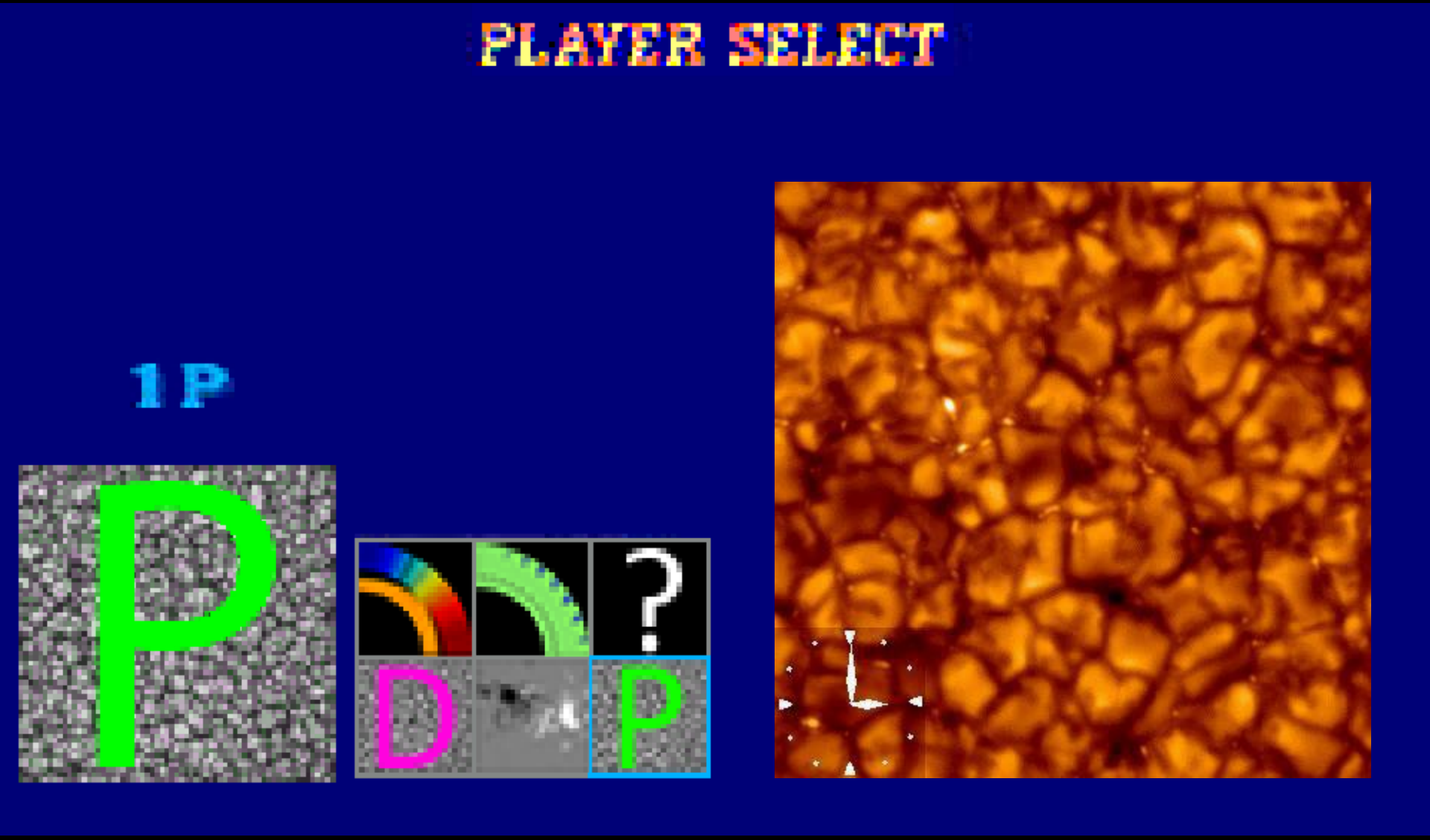
# Turbulent Diffusion



SDO/HMI

Spreads magnetic flux, but also leads to flux cancellation.

# Turbulent Pumping



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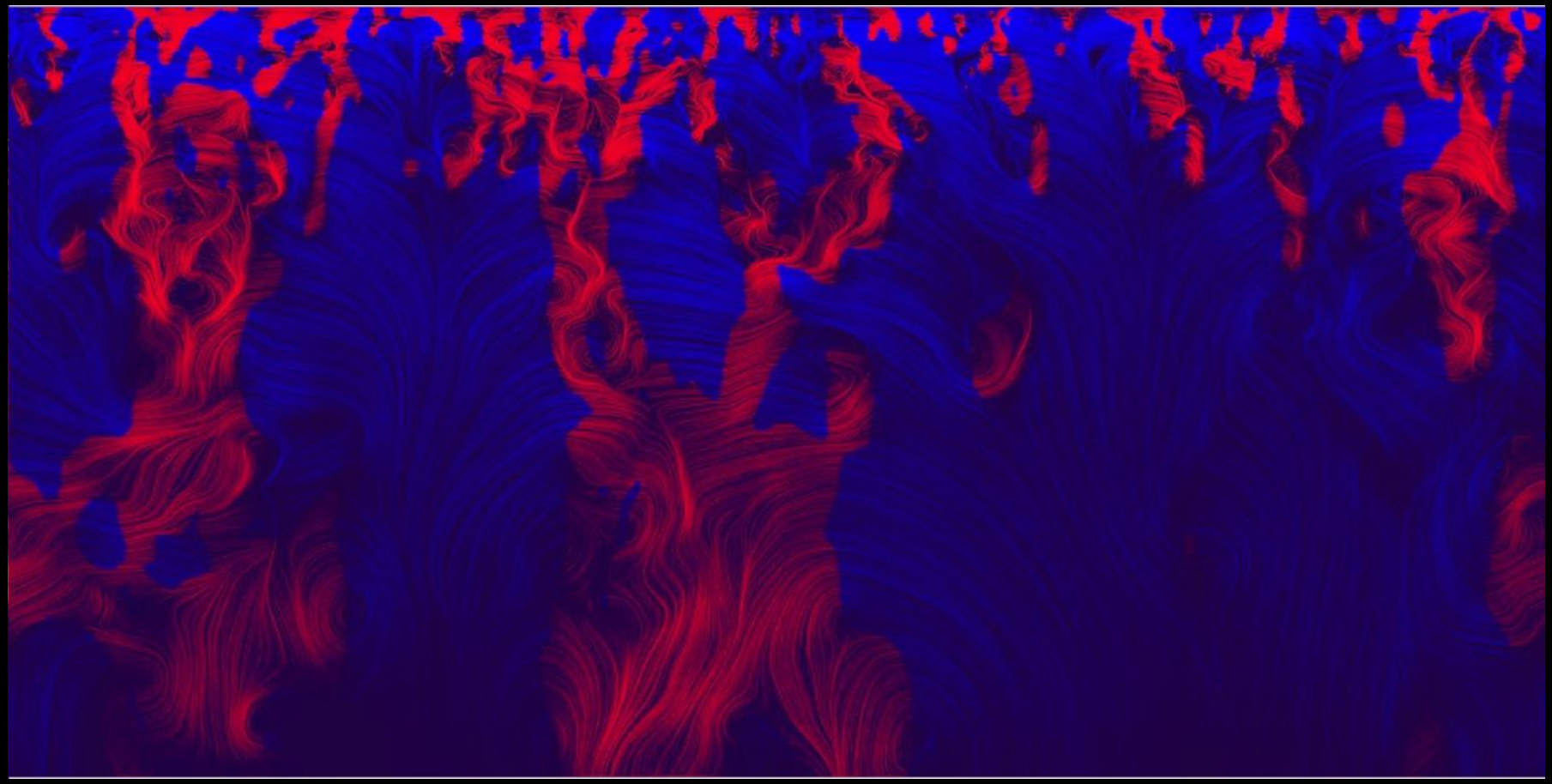
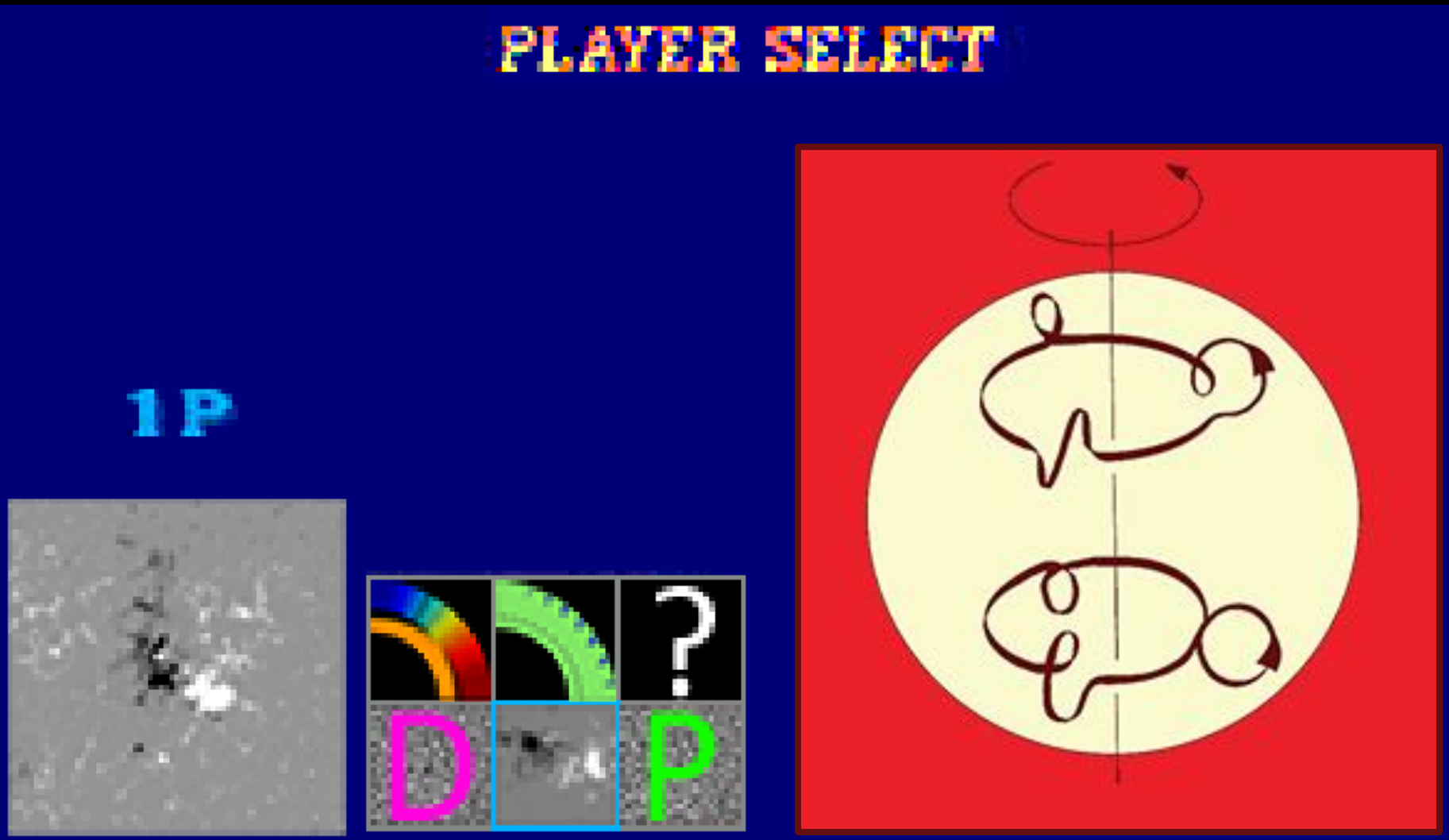


Image by Bob Stein

Fast downflows and slow upflows result in net downward magnetic transport.

# Poloidal Sources




Closes the solar cycle and sets the stage for the next one

# BALANCE AND COUNTERBALANCE OF COMPETING EFFECTS


PLAYER SELECT
VS.
1P
2P
?
?
?
?
D
P
D
P

# Magnetic Sources vs. Decay

# Advective vs. Diffuse Transport

# Summary

- Solar and Stellar cycles are magnetic in nature and are powered by a dynamo mechanism.

- Differential rotation, helical turbulence, and the twist of emergent flux-tubes by Coriolis are main mechanisms that keep stellar cycles going.

- The relative importance of the different mechanisms involved in magnetic field generation and transport determine the properties of each dynamo.