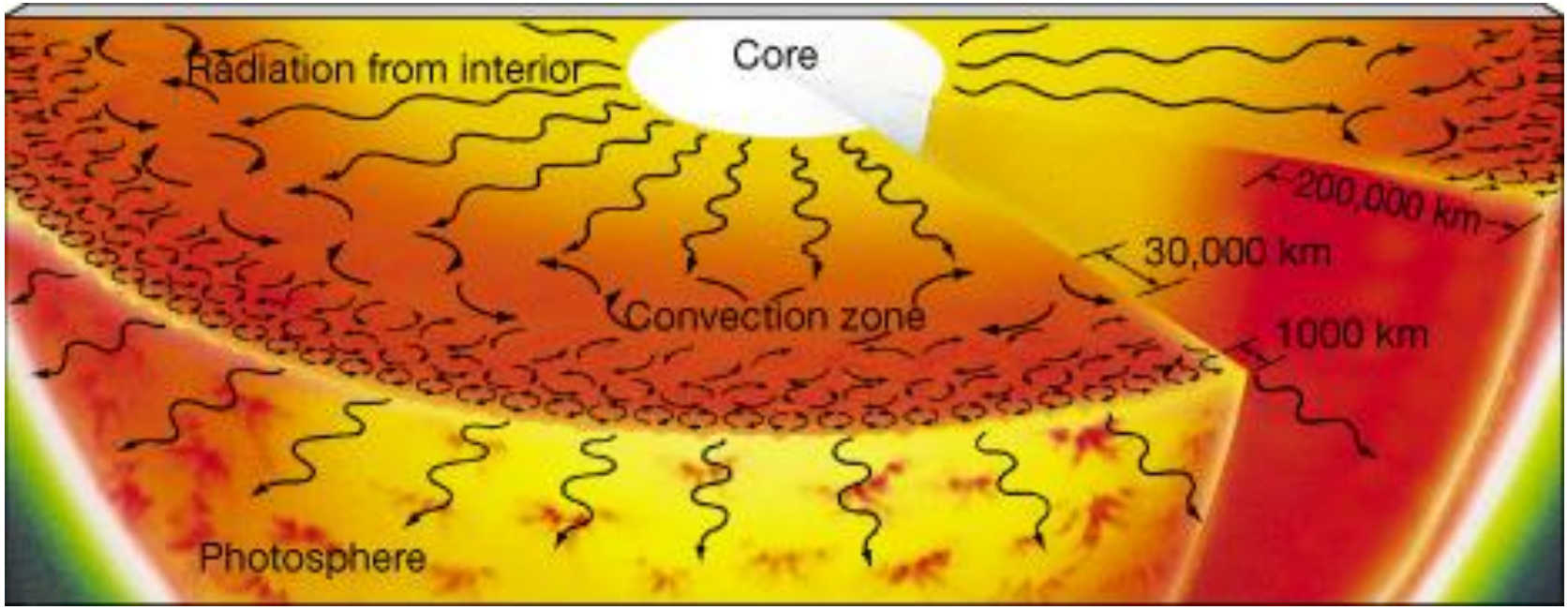
Lecture 17

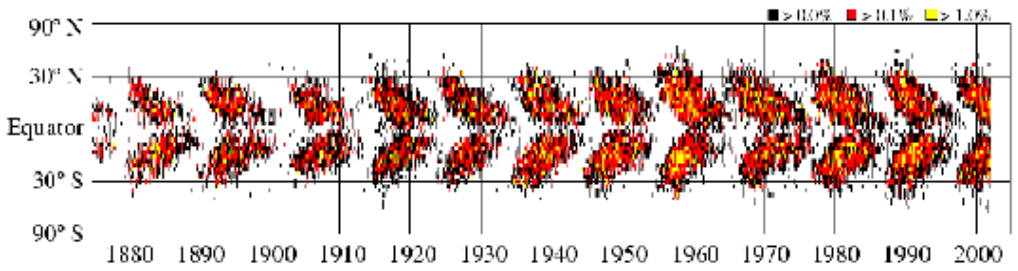
- Solar cycle
- Induction equation
- Conversion between kinetic and magnetic energy forms
- Alfven waves (beginning)

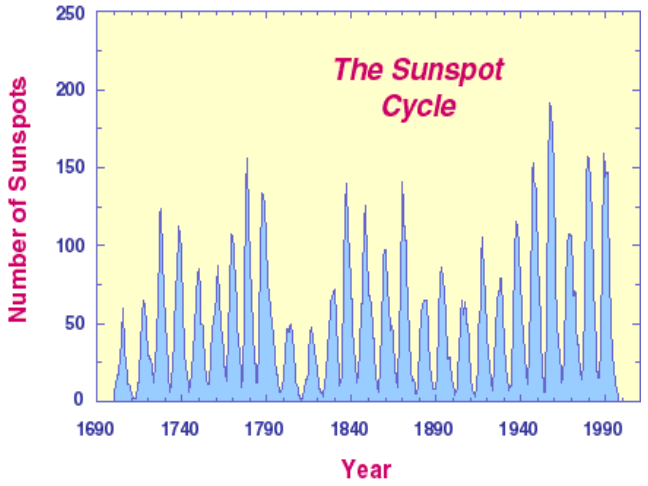
Last time

- Center to limb variation, HW2
- Entropy: what makes it change
- Buoyancy oscillations
- Energy equation

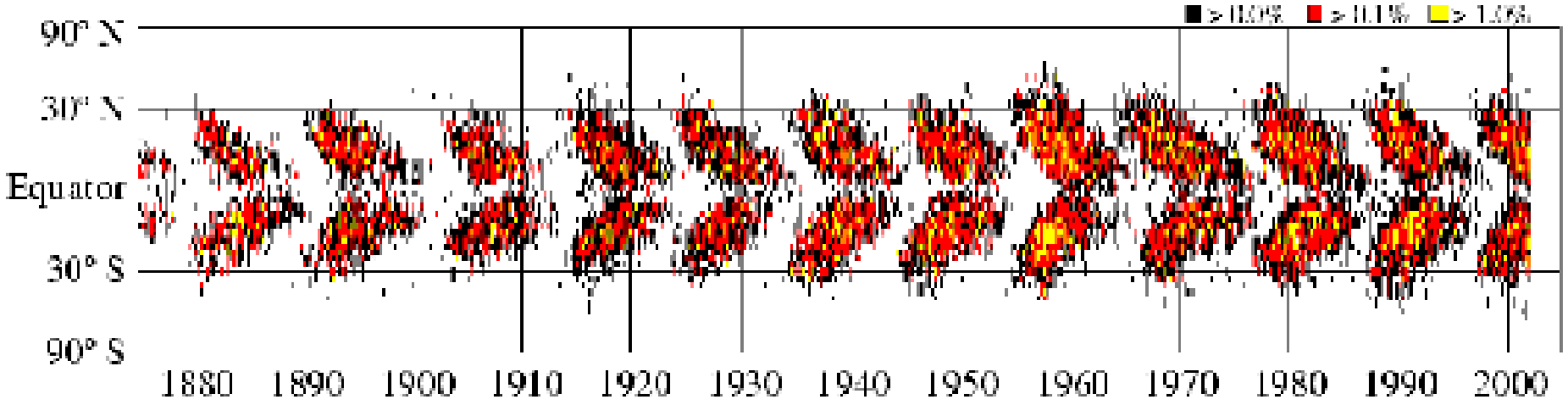
The solar cycle







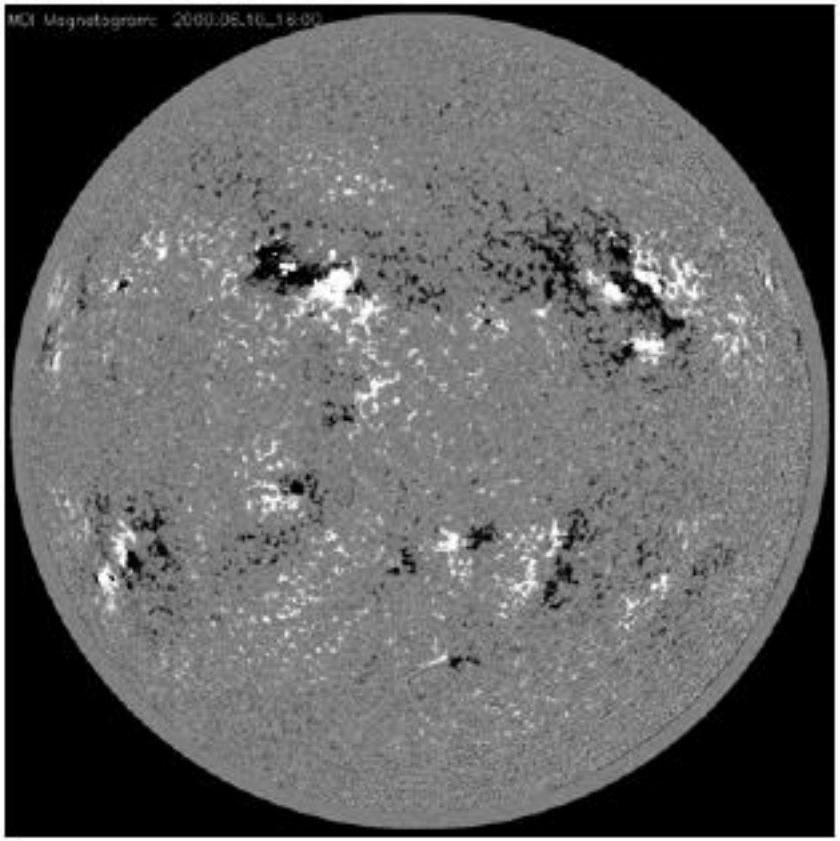
Solar 11 year sunspot cycle

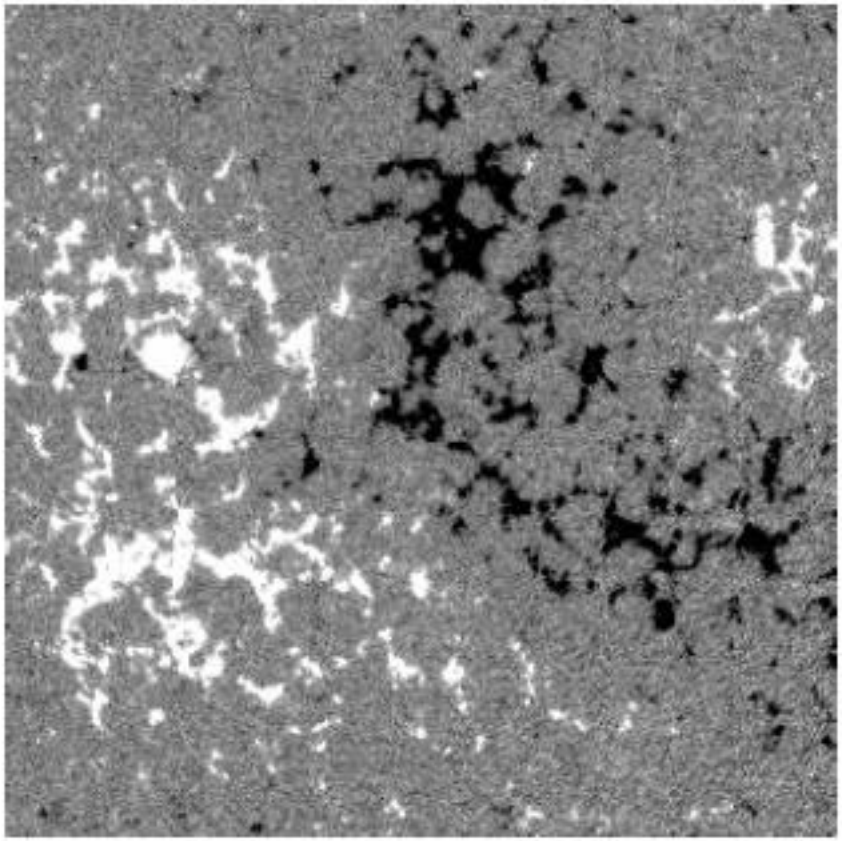


butterfly diagram

- Sunspots between +/- 30 degrees around equator
- New cycle begins at high latitude
- Ends at low latitudes
  - equatorward migration

Large scale coherence

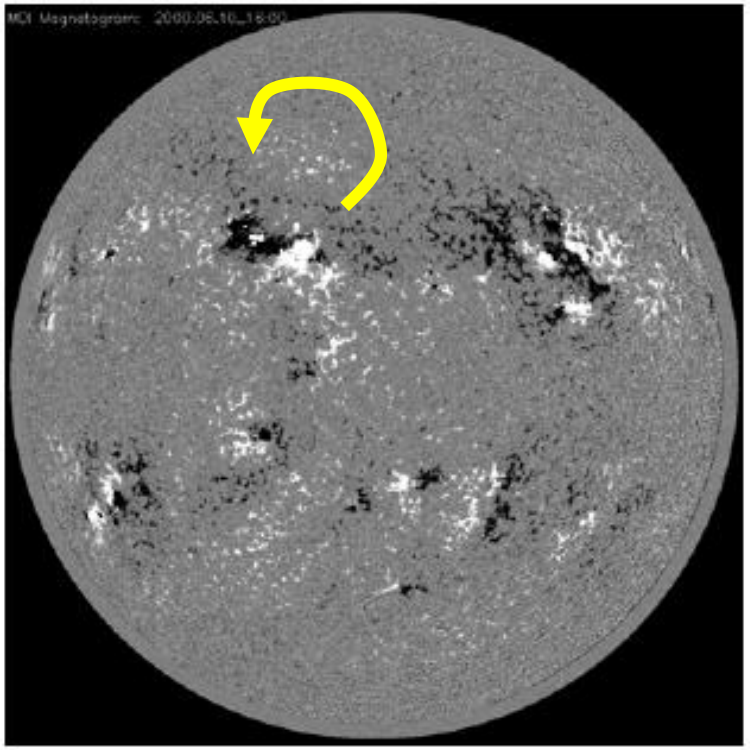




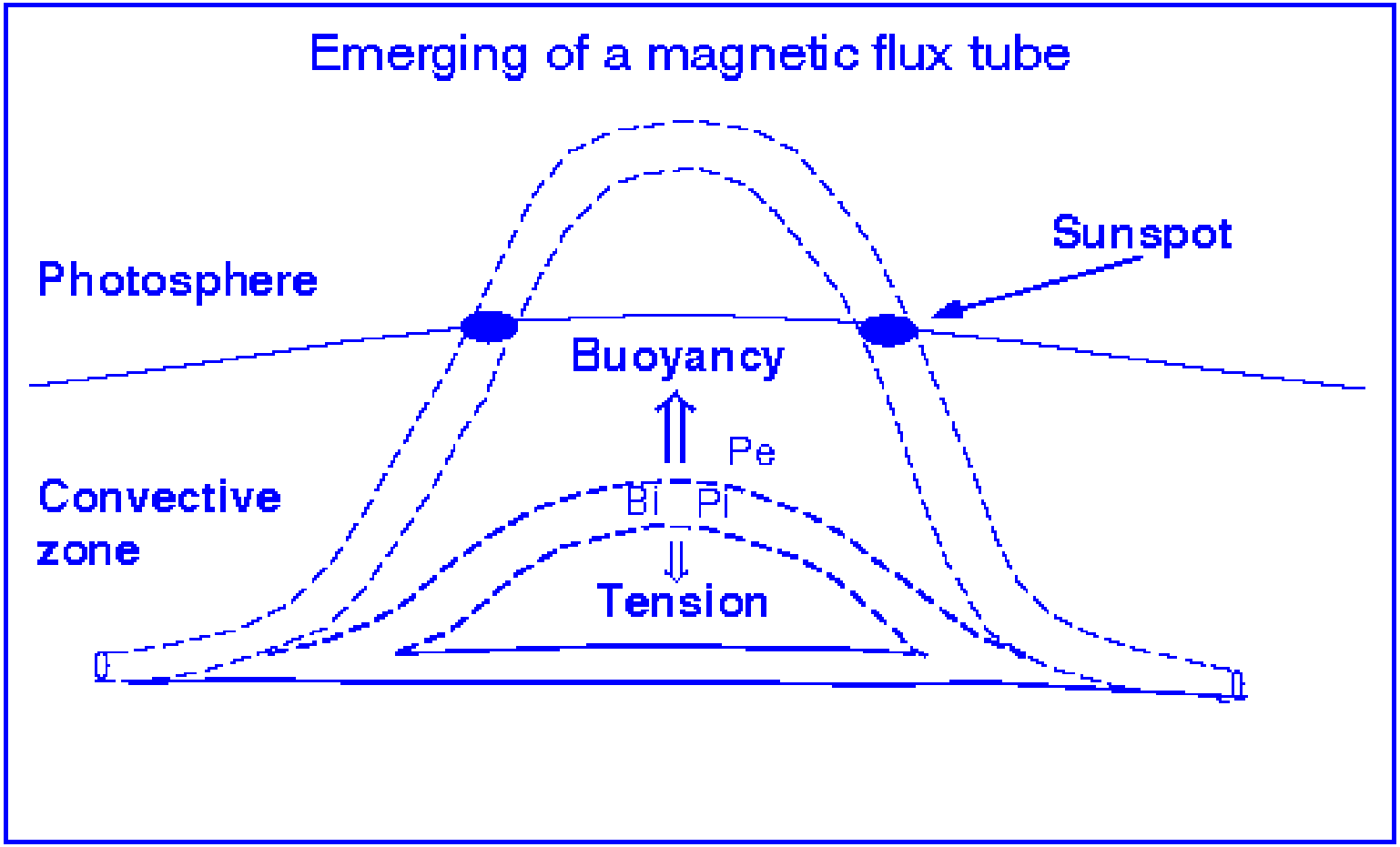
Active regions, bi-polarity
systematic east-west orientation
opposite in the south

The Sun today and 9 years ago

Solar magnetograms:
Line of sight B-field from circularly polarized light



Buoyant rise of flux tubes



Is charge accelerated by B field

A. Yes

B. No

Is charge accelerated by E field

A. Yes

B. No

in S and S' are equal, and we analyze the Lorentz force on the charged particle (as measured in both frames) as follows:

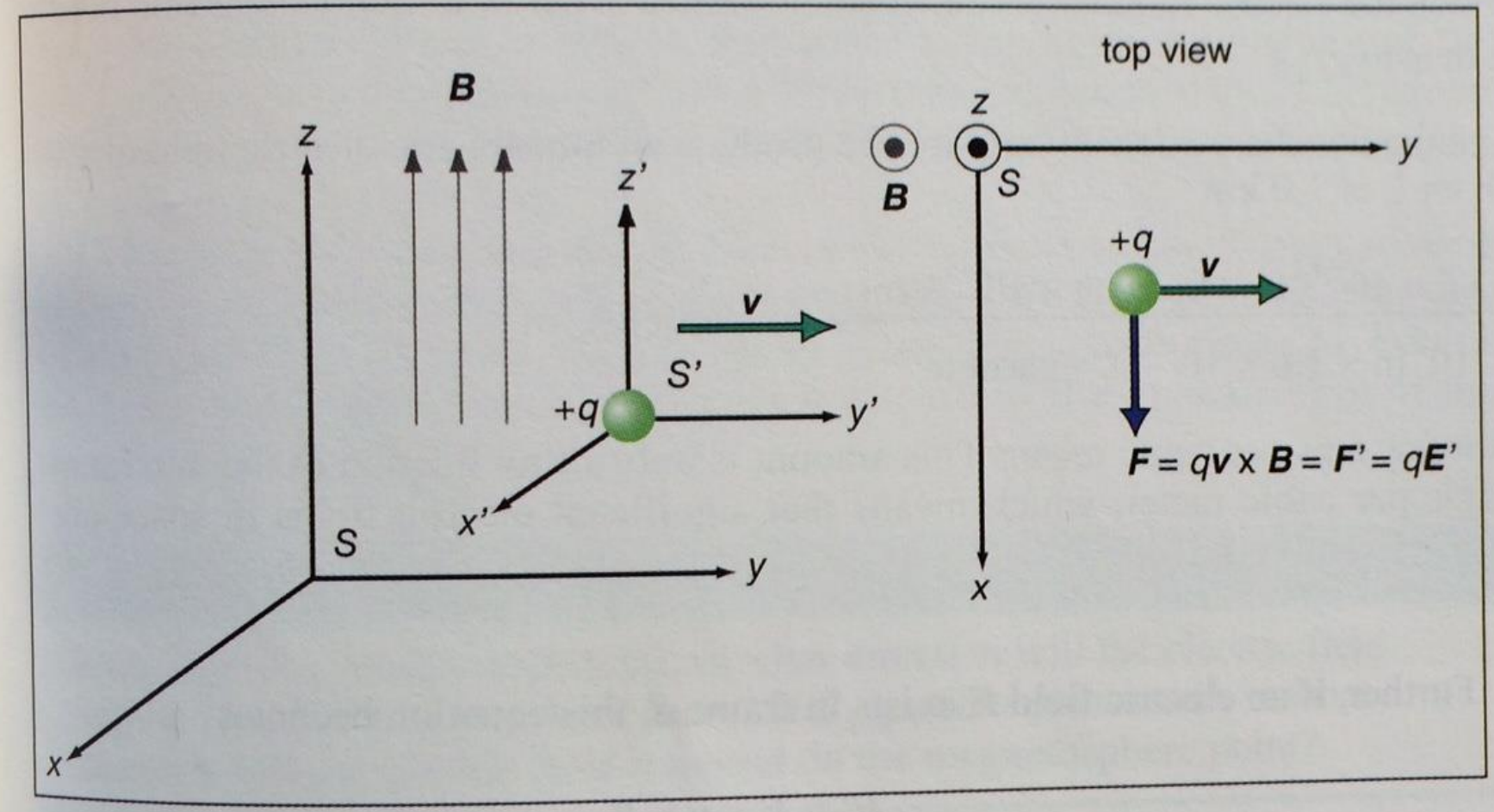


Fig. 4
as Vi
left pa
velocit
field, p
z-axis
a top-
charg
charg
mome
force
frame
unprir
refere

Suppose the particle is initially restrained by the observer in S', and then released. Because both observers are in inertial frames, they must agree on the magnitude and direction of the force vector acting on the charged particle at the moment it is released. However, the two observers will disagree on the cause of

Lab (S) and comoving (S') frames

Observer in S sees charge moving

$$\mathbf{F} = q\mathbf{u} \times \mathbf{B}$$

Observer in S' sees charge moving sideways

$$\mathbf{F}' = q\mathbf{E}'$$

Therefore, because F=F',

$$\mathbf{E}' = \mathbf{u} \times \mathbf{B}$$

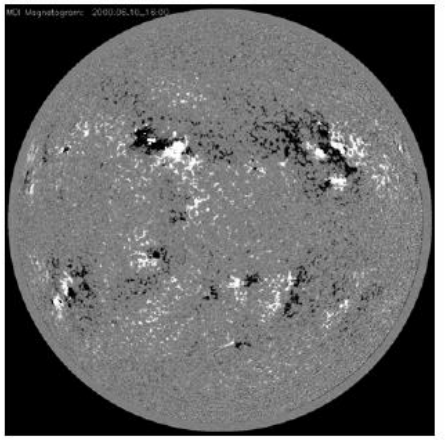
If additional background field

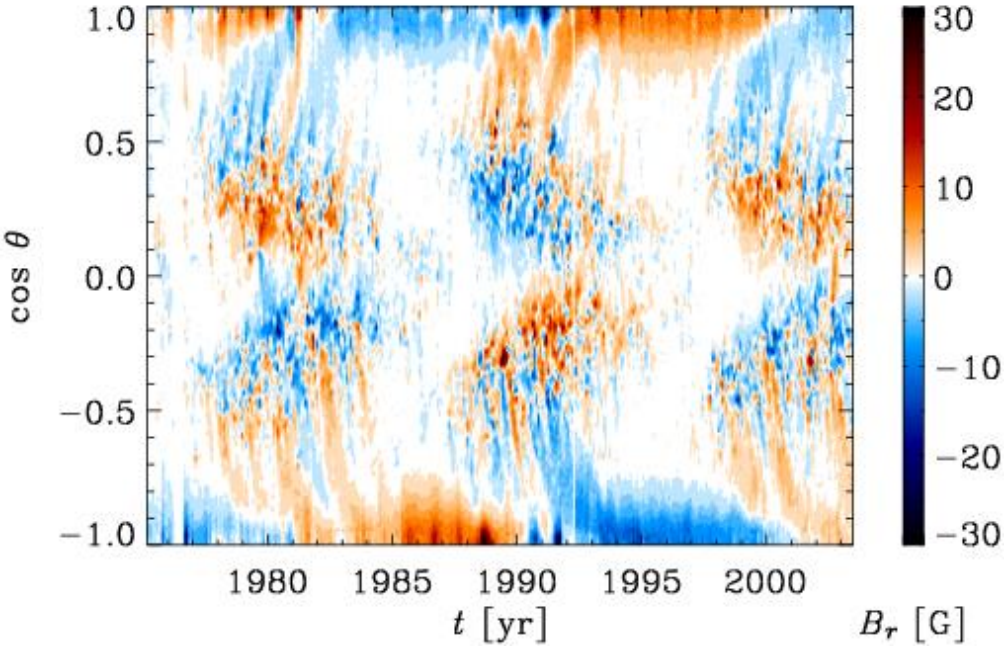
Therefore

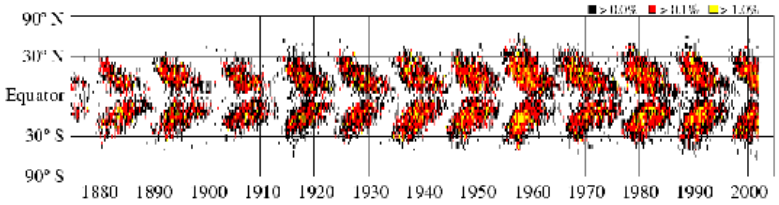
$$\mathbf{E}' = \mathbf{E} + \mathbf{u} \times \mathbf{B}$$

22 year magnetic cycle

- Longitudinally averaged radial field
- Spatio-temporal coherence
  - 22 yr cycle, equatorward migration

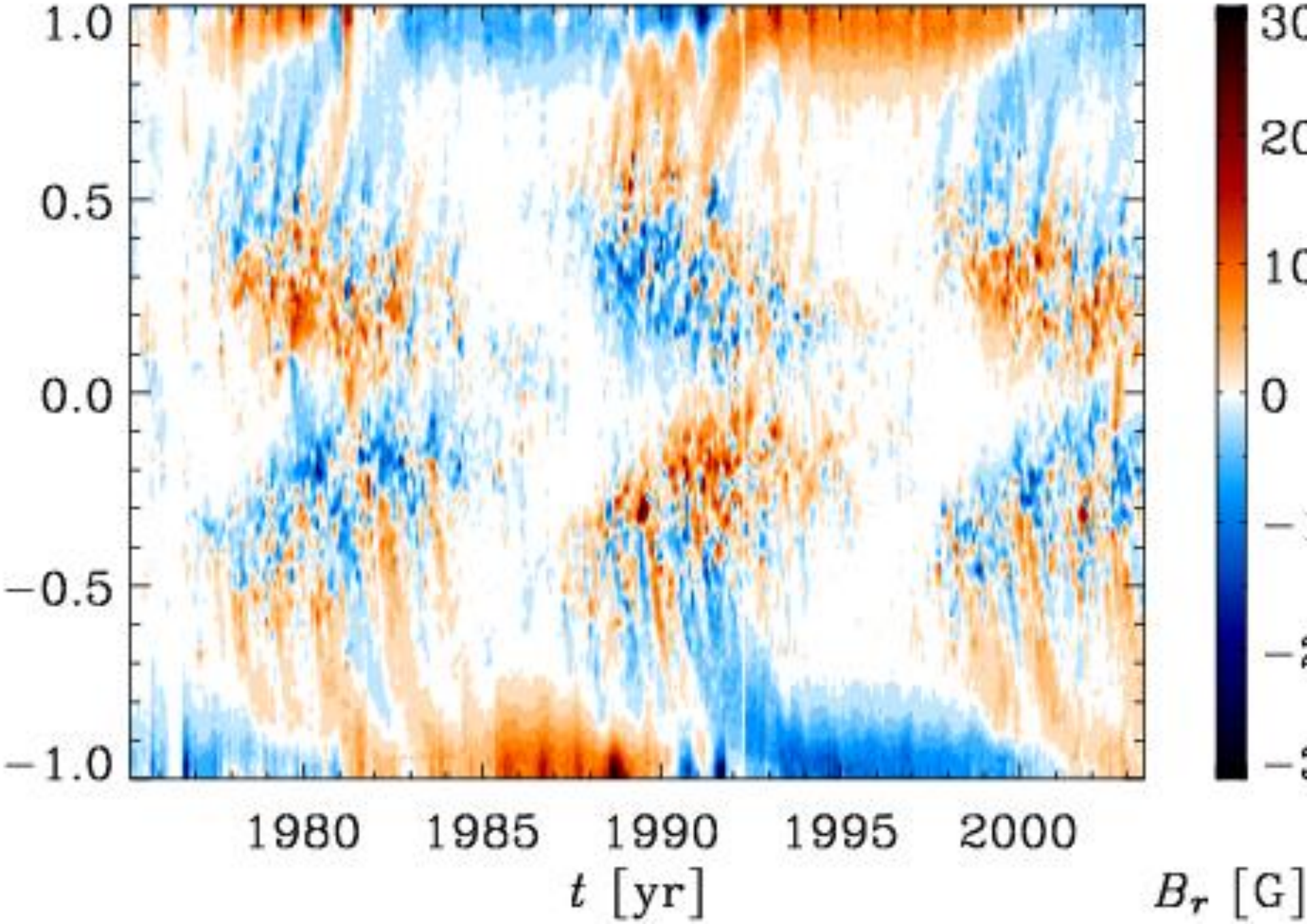




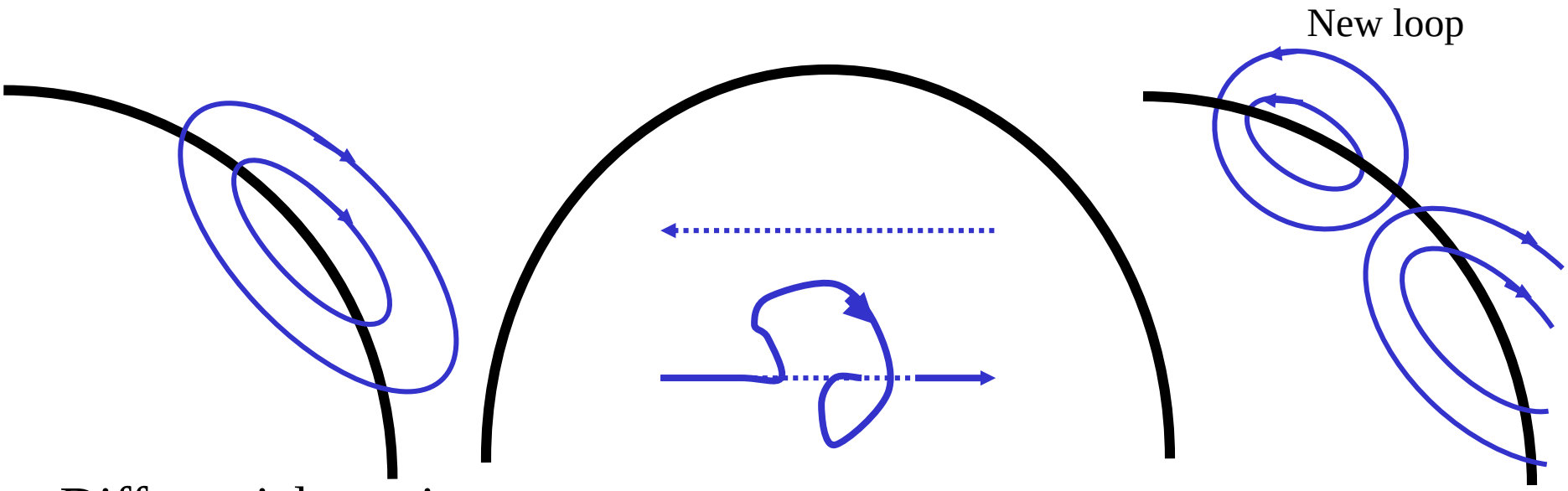


butterfly diagram

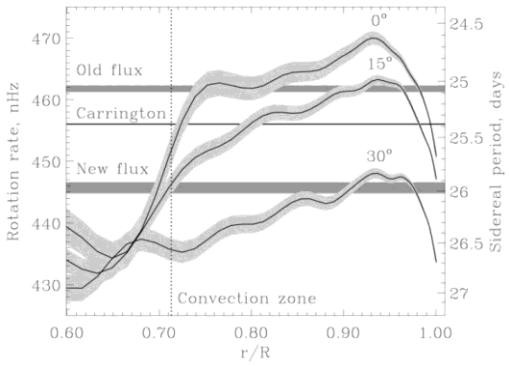
Poleward branch or poleward drift?


1.0
0.5
0.0
−0.5
−1.0
1980
1985
1990
1995
2000
t [yr]
B_r [G]

α-effect dynamos (large scale)

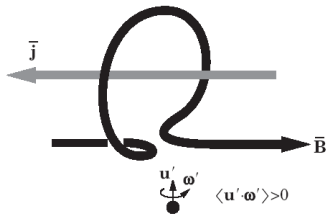


Differential rotation
(faster inside)

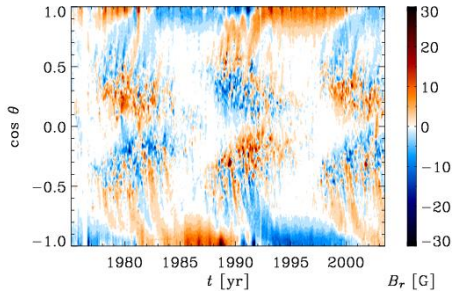


Cyclonic convection;
Buoyant flux tubes

→ α-effect



Equatorward
migration



What we learned

- Conversion of kinetic into magnetic energy
- How magnetic fields get advected