Preferred longitudes in sunspot activity

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Outline

What have we learned from cool active stars?

- Active longitudes & Flip-flop cycles
- Migration & Differential rotation

The Sun

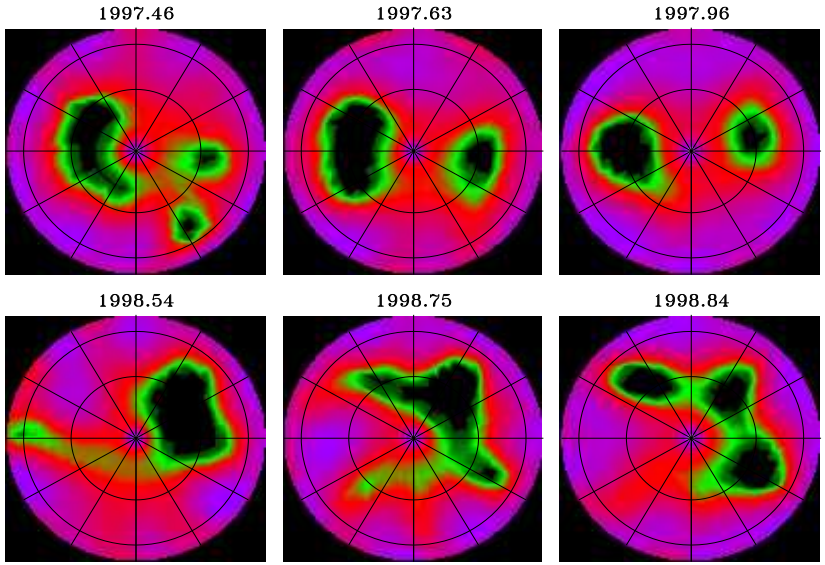
- Active longitudes & Flip-flops
- Differential rotation & Dynamic reference frame
- Stroboscopic concept

Dynamo modes

- Dipole oscillations
- Conceptual science

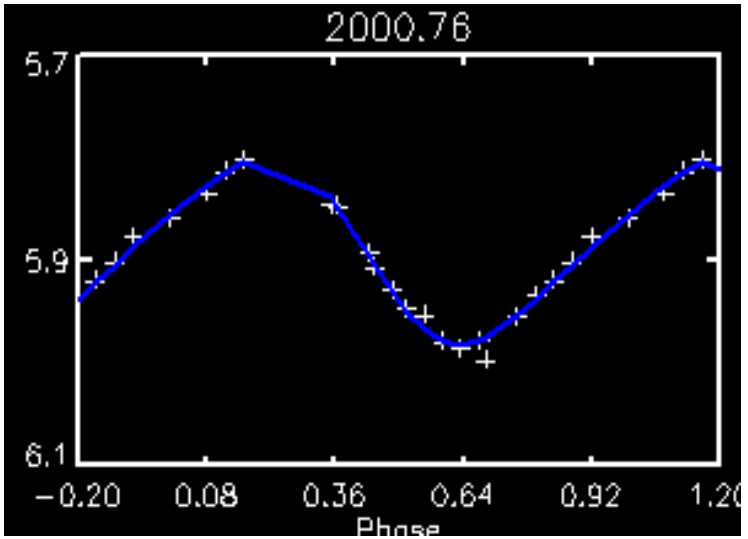
Cool stars: Active longitudes & Flip-flops

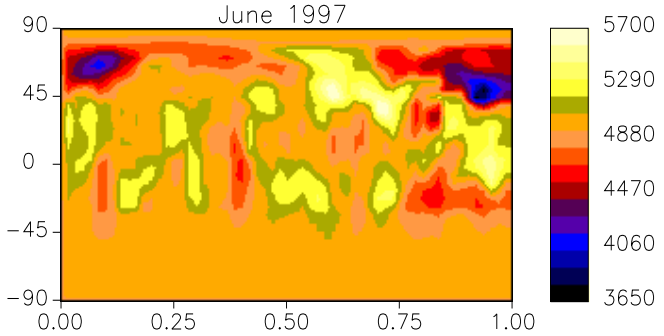
II Peg, K1 IV, RS CVn-type

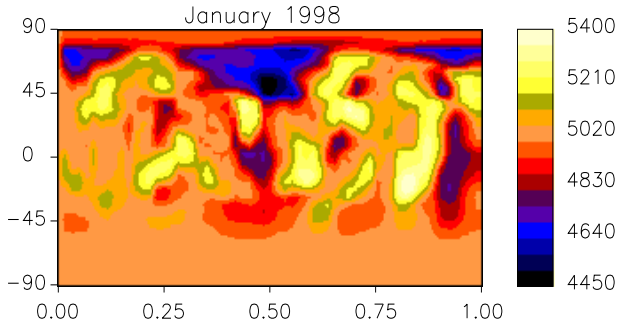


Berdyugina et al. (1999)

IM Peg, K2 III , RS CVn-type







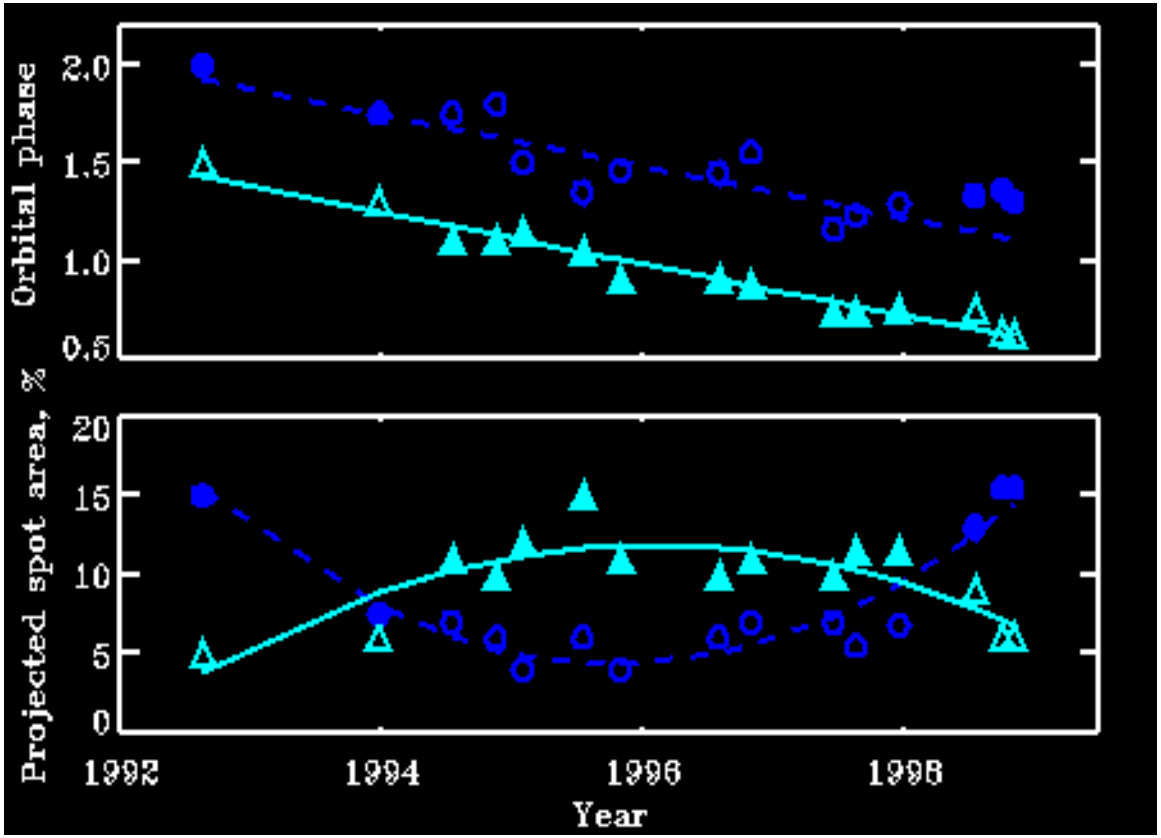
FK Com

Korhonen, Berdyugina, & Tuominen (2001)

Cool stars: Active longitudes & Flip-flops

- Two active regions separated by ~180°
  ⇒ *active longitudes*
- Switching of dominant activity between the active longitudes
  ⇒ *flip-flops*
- Migrating in the orbital system (binaries)
  ⇒ *new RF*

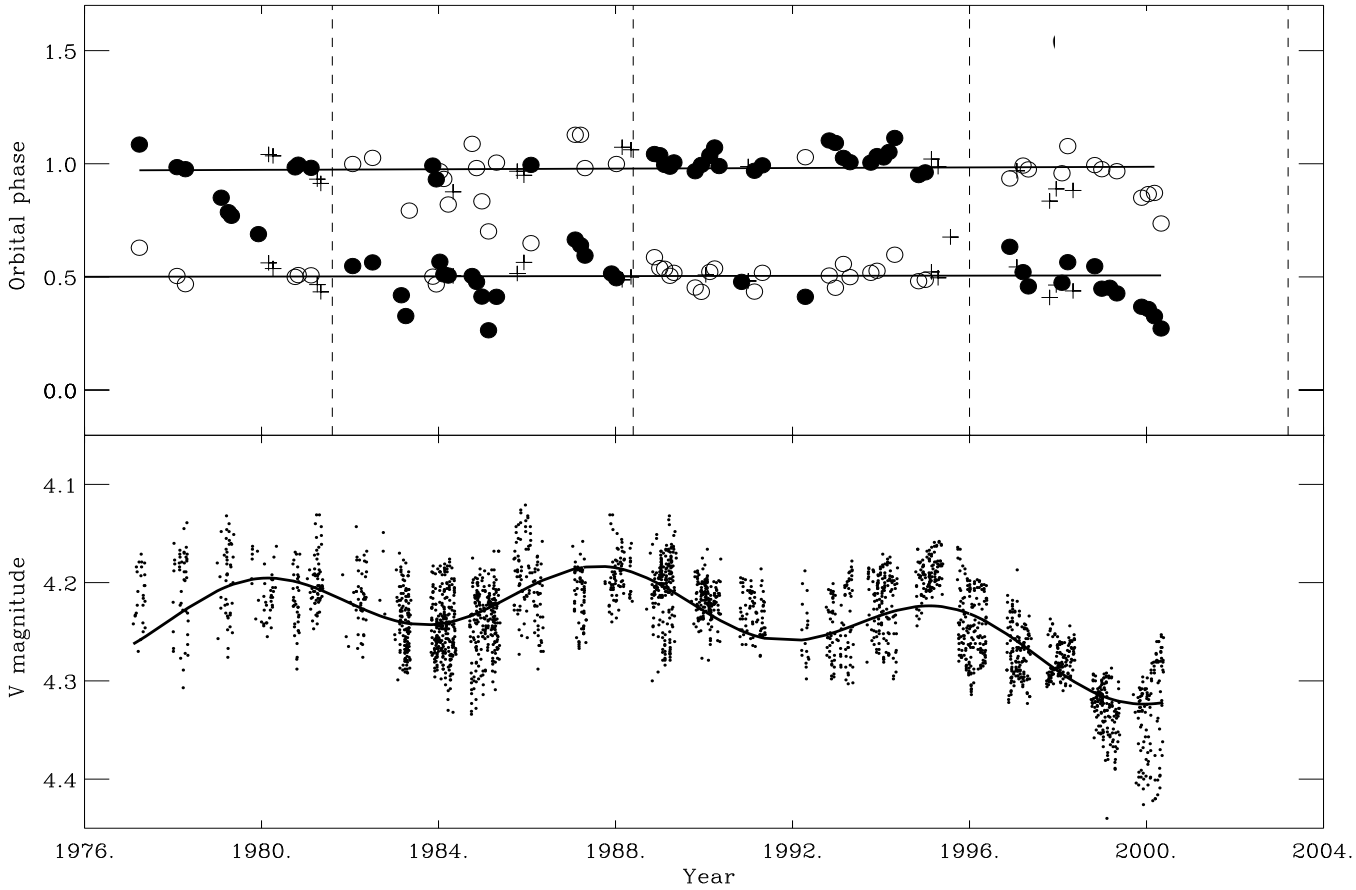
II Peg, K1 IV, RS CVn-type



Berdyugina et al. (1999)

Cool stars: Active longitudes & Flip-flops

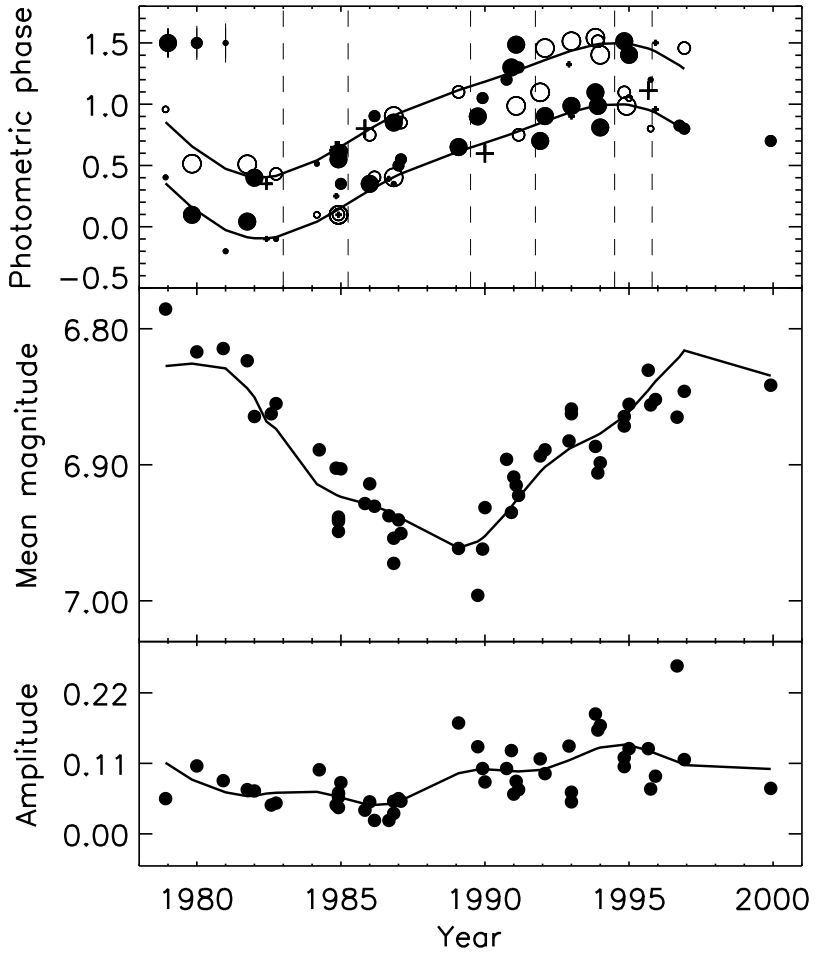
σ Gem, K2 III, RS CVn-type



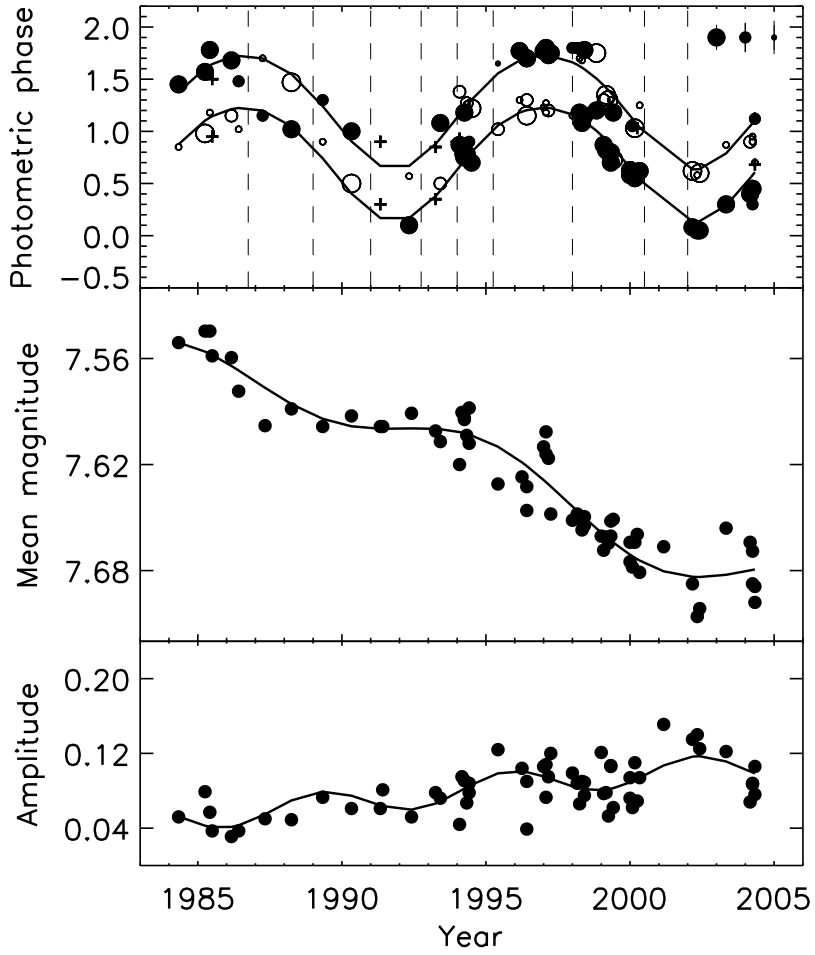
Berdyugina & Tuominen (1998)
Berdyugina & Henry (2007)

Young dwarfs: Active longitudes & Flip-flops

AB Dor, K1 V



EK Dra, G1 V



Järvinen et al. (2005a,b)

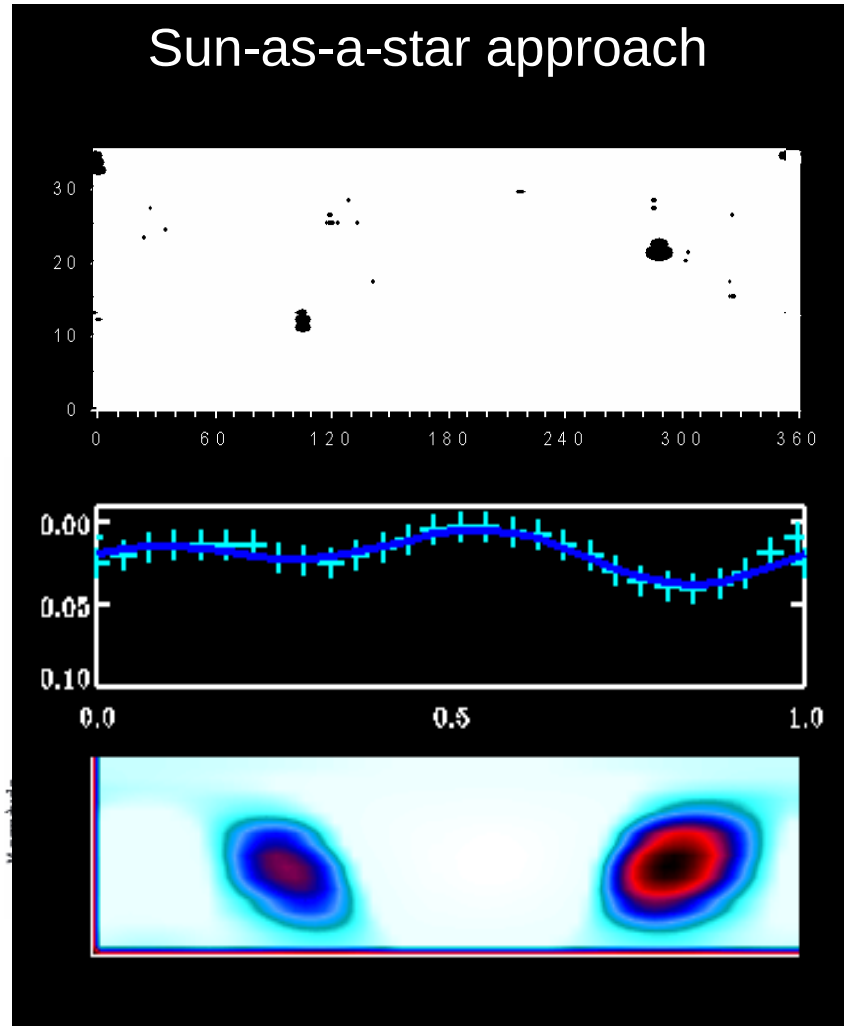
Cool stars: Active longitudes & Flip-flops

- Persistent migrating active longitudes ~180° apart
- Migration rate:
  - Variable ⇒ differential rotation
  - Constant ⇒ no differential rotation
- Flip-flop cycles
- Total spottedness variations ⇒ sunspot-like cycle
- Cycle length ratio (flip-fllop / spottedness):
  - 2:1 in binaries
  - 1:3 in single stars

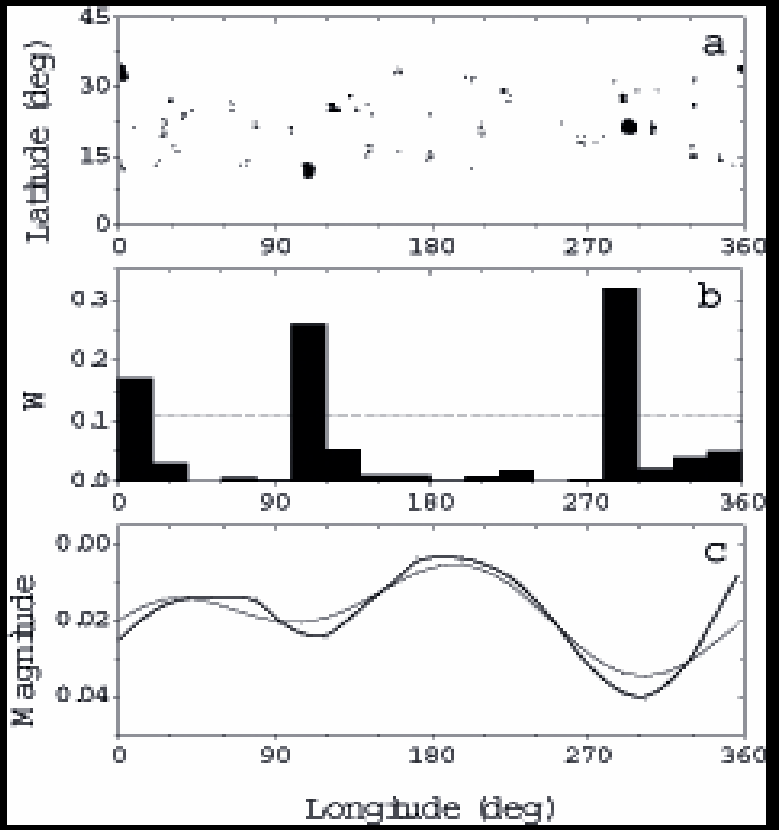
The Sun: Active longitudes & Flip-flops

Berdyugina & Usoskin (2003)

Sun-as-a-star approach



Rectangular filter



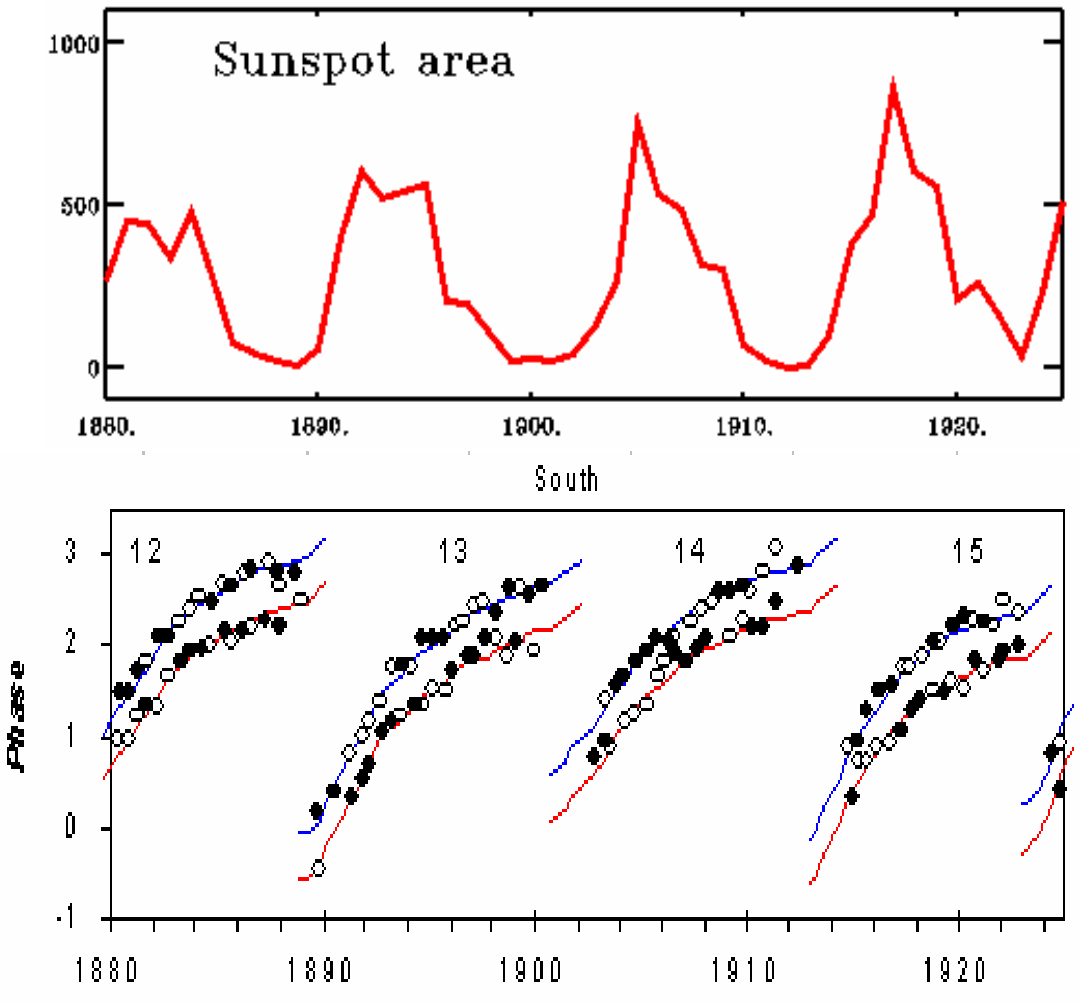
The Sun: Active longitudes & Flip-flops

- two active longitudes separated by 180° in both North & South persistent for 120 yrs

- non-linear migration due to surface differential rotation and changes of mean spot latitude ⇒ 11 yr cycle

- flip-flop phenomenon: switching of dominant activity between the active longitudes ⇒ 3.7 yr cycle

- cycle frequency ratio 1:3



Berdyugina & Usoskin (2003)

The Sun: Active longitudes & Flip-flops

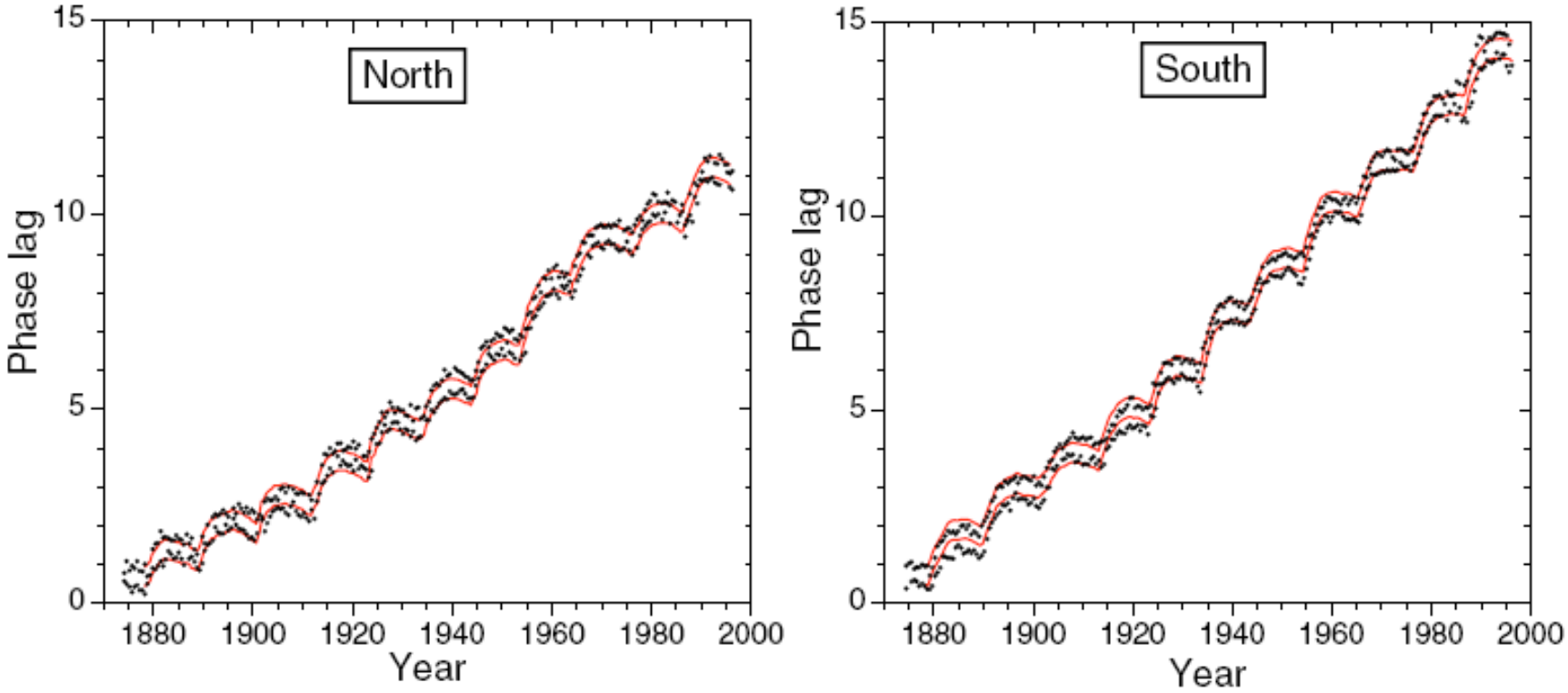
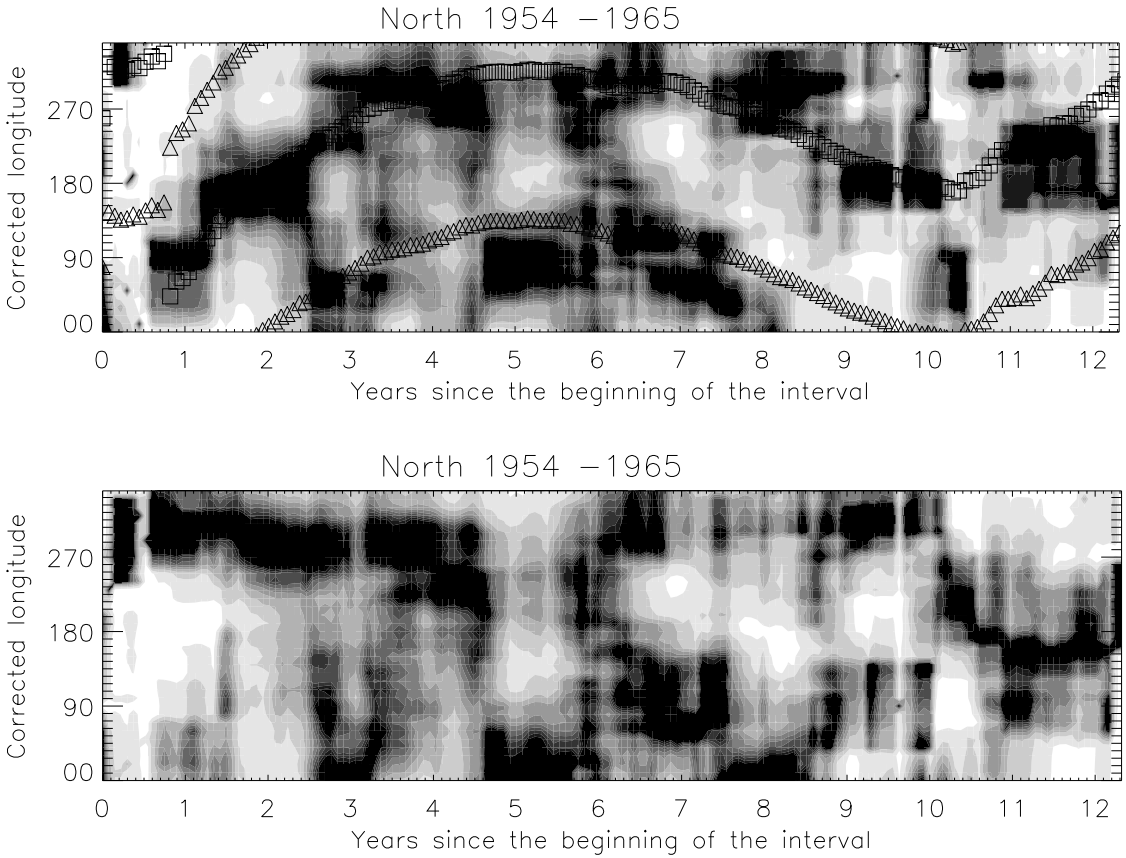
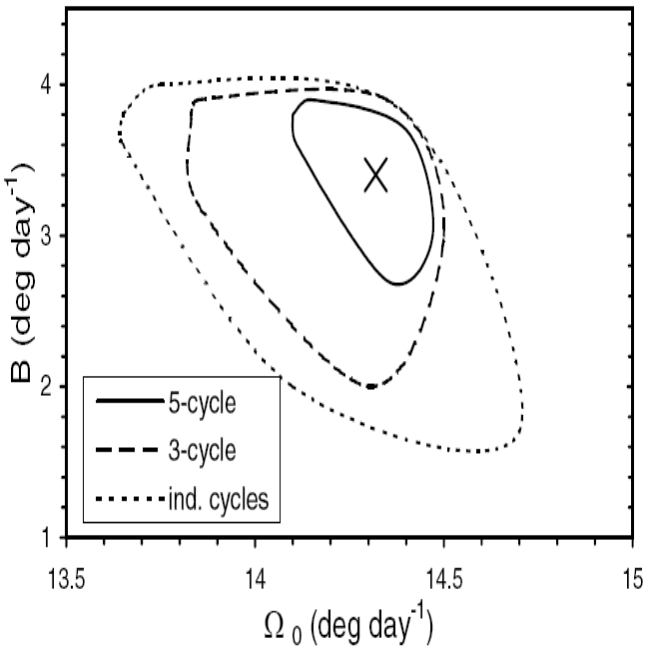


Fig. 1. Phase lags ($\Delta\Lambda/360^{\circ}$) of the semi-annual averaged longitudes of the two pronounced centres of sunspot activity (dots). Integers were added to the fractional phases in order to display the migration as a continuous curve (see Berdyugina & Usoskin 2003). Lines depict the migration paths of the two active longitudes calculated from the best fit parameters of the differential rotation and mean latitude of sunspot occurrence, according to Eqs. (1) and (2). Data for the Northern and Southern hemisphere are analysed separately. The "cycloid" shape of the paths is a signature of the differential rotation: the lag in longitude is increasing with respect to the Carrington frame in the beginning of the cycle when sunspots appear at high, slower rotating latitudes and then start decreasing as the sunspot belt approaches the more rapidly rotating equator. Because of the 11-year cycle in sunspot latitudes, the migration pattern has a clear 11-year periodicity.

The Sun: Dynamic reference frame

Usoskin, Berdyugina & Poutanen (2005)



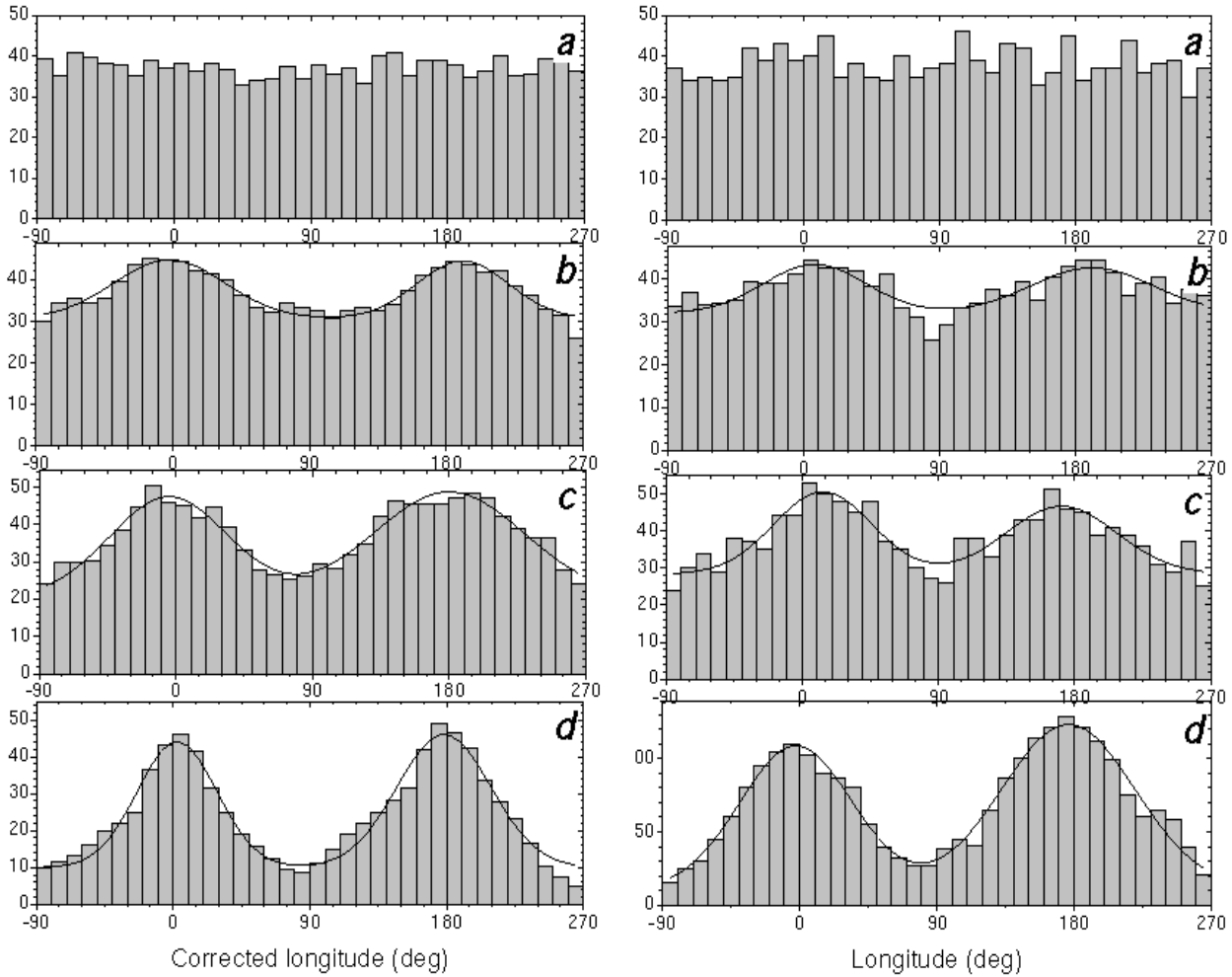


The Sun: Dynamic reference frame

North

South

120 years



Carrington RF

Dynamic RF:
all spots

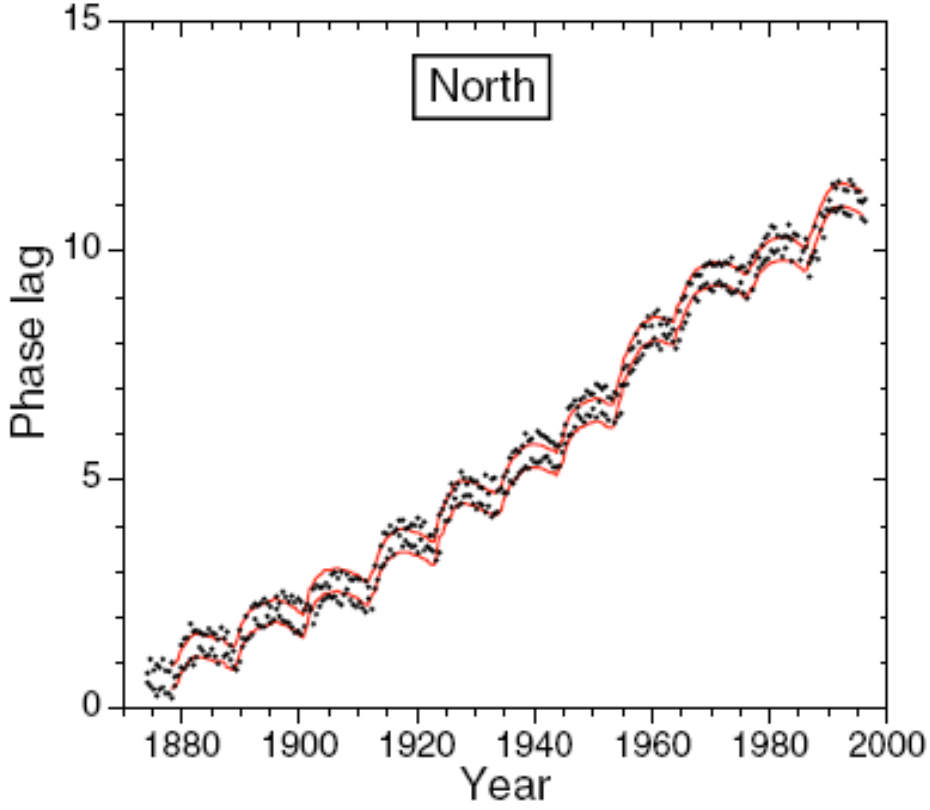
Dynamic RF: one,
largest spot group

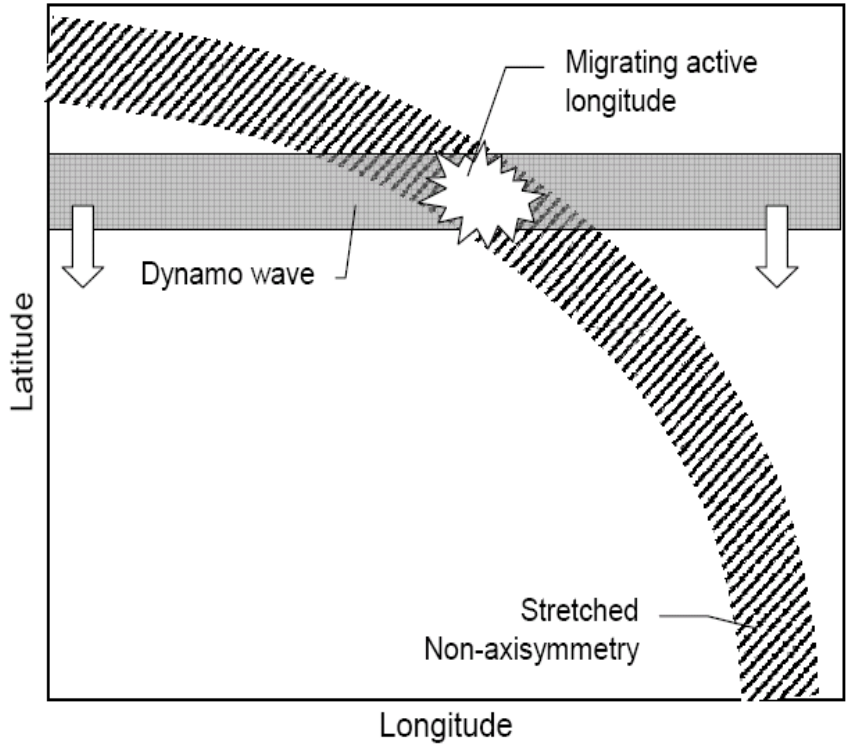
Dynamic RF: one,
largest spot group,
half-year averages

The Sun: Stroboscopic concept

Berdyugina, Moss, Sokoloff, Usoskin (2006)

Phase coherence between the cycles:

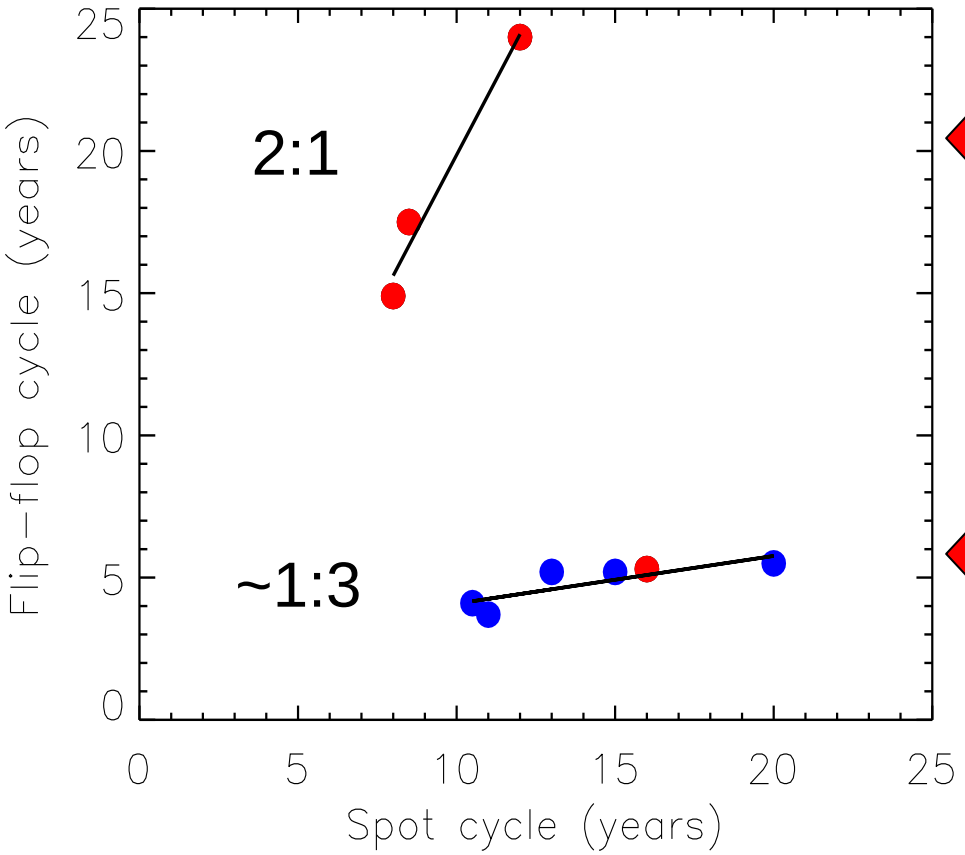




The Sun: Main features

- Large-scale structures (~90°)
- Separated by ~180°
- Migrating with local differential rotation
- Phase coherence during 120 years
- Switching the dominant activity $\Rightarrow$ flip-flops
- 3.7-yr flip-flop cycle = 1/3 of the sunspot cycle

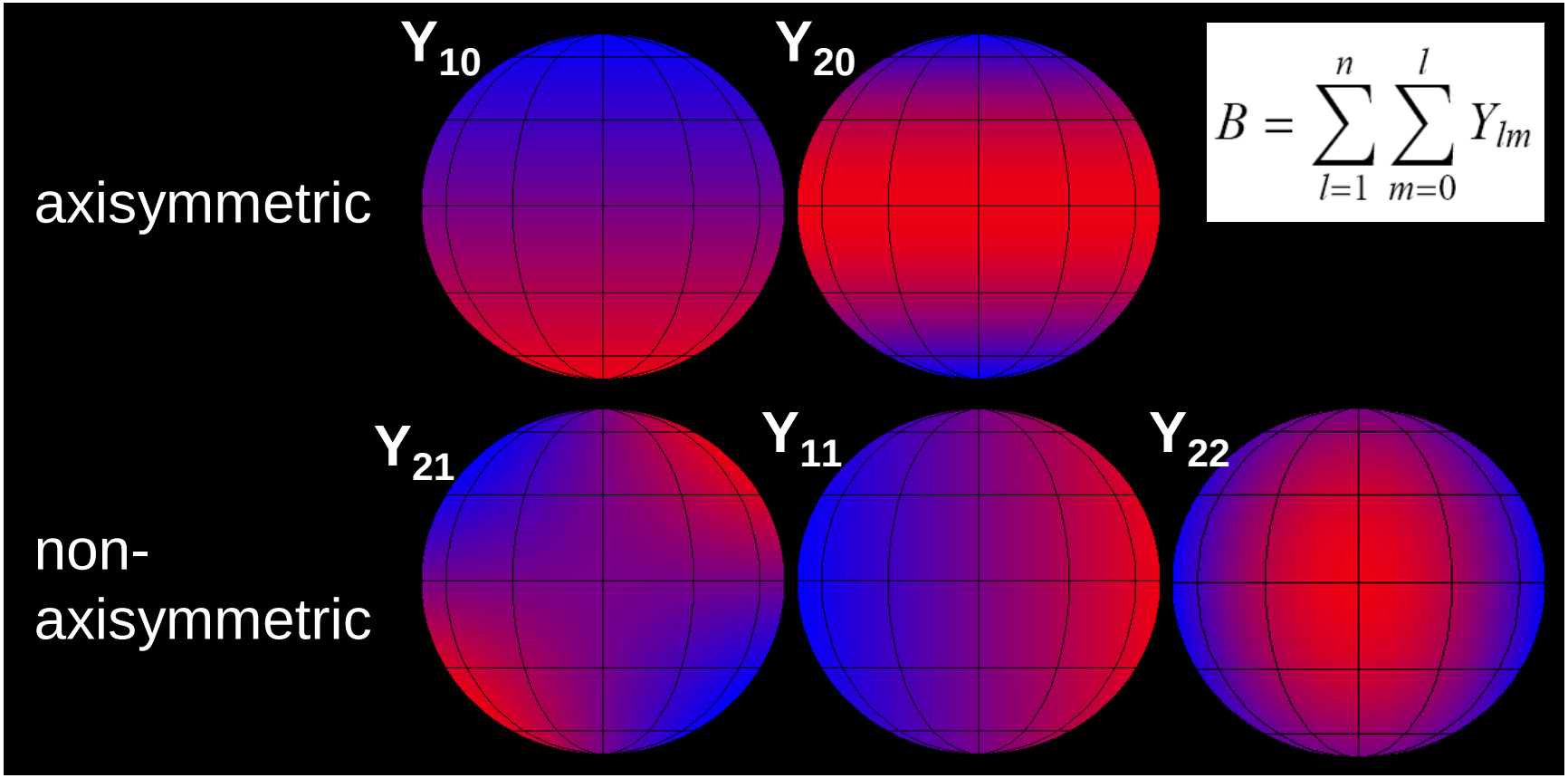
Flip-flop cycle vs Spot cycle



$\Omega/\Delta\Omega \sim 1000$

$\Omega/\Delta\Omega \sim 100$

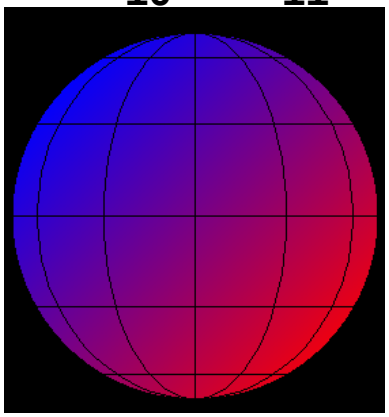
Dynamo modes

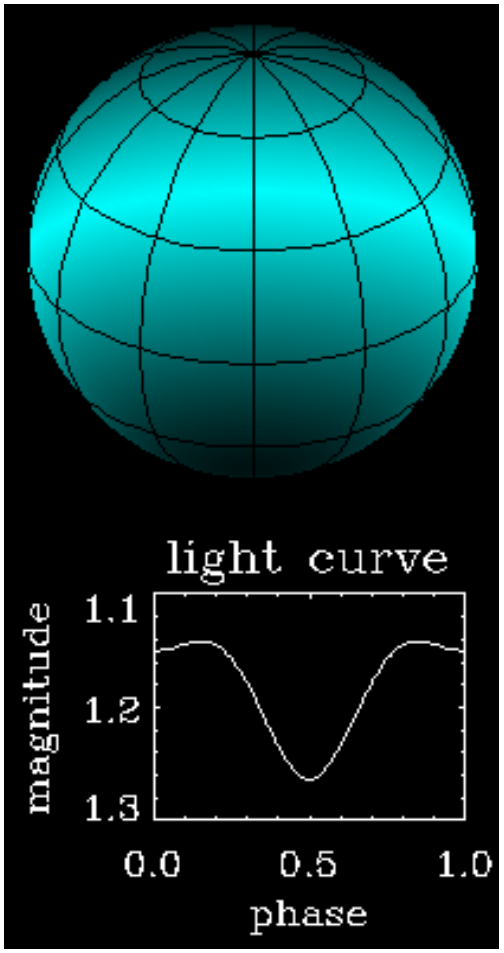


Modeling brightness variations

- Superposition of modes
- Non-axisym. mode
  $\Rightarrow$ preferred longitudes
- *B*-field $\Rightarrow$ dark spot
- Inclination
  $\Rightarrow$ mainly one hemisphere observed

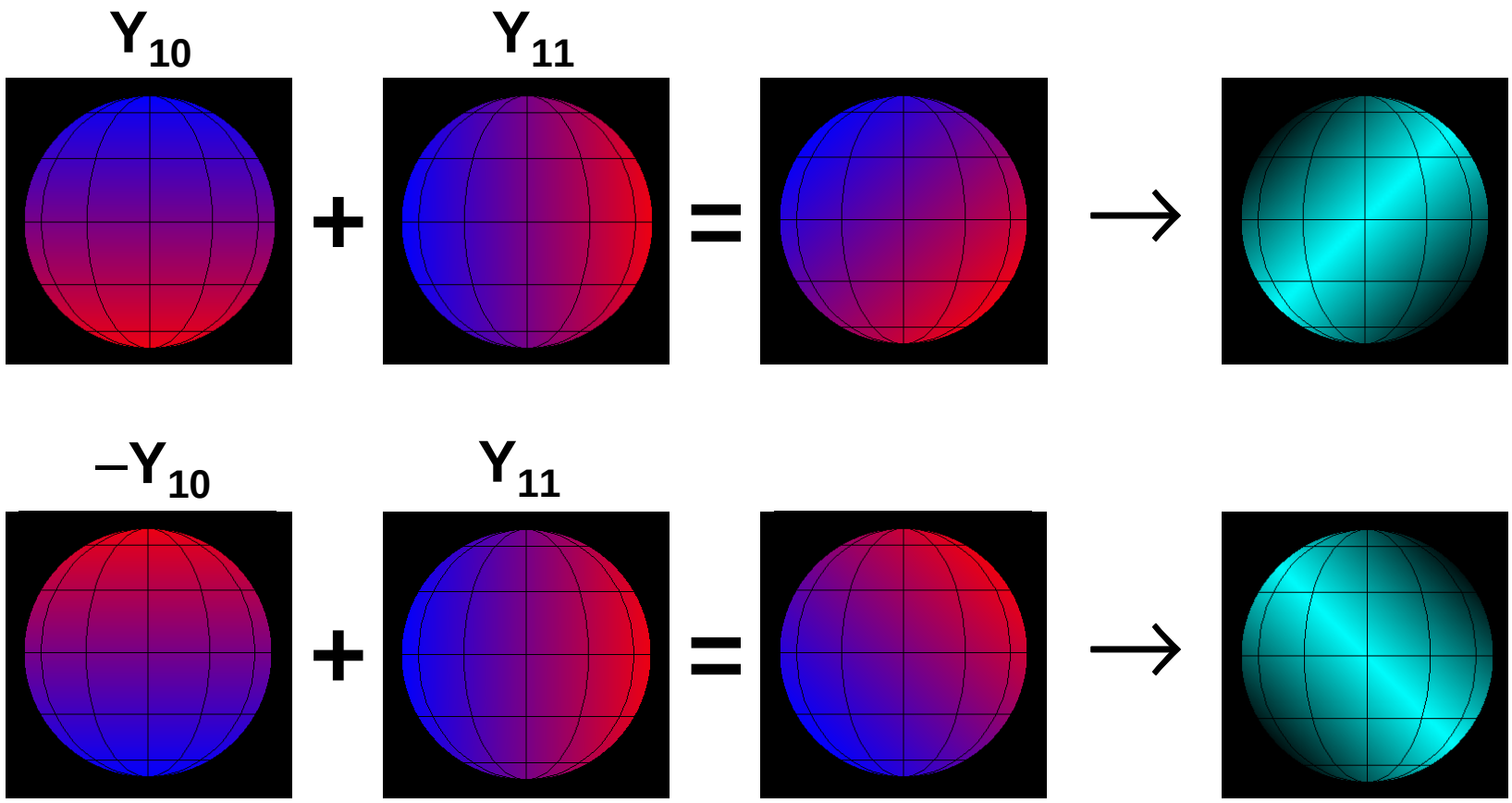
$Y_{10} + Y_{11}$



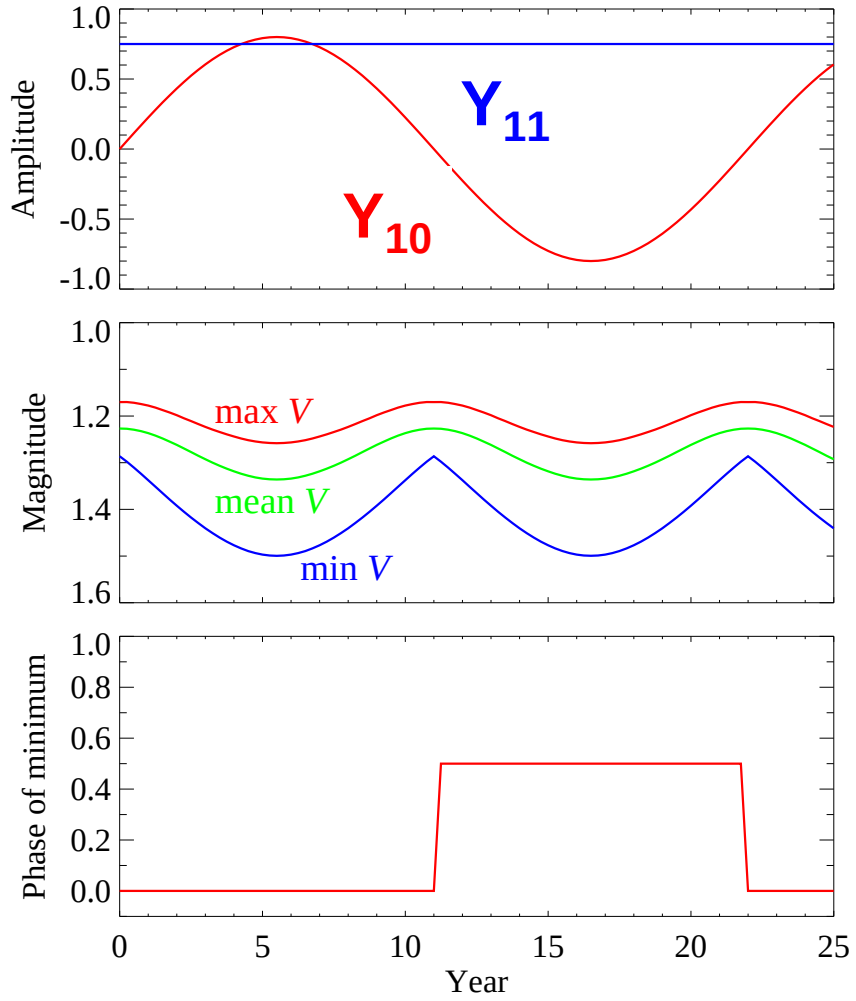


Fluri & Berdyugina (2004)

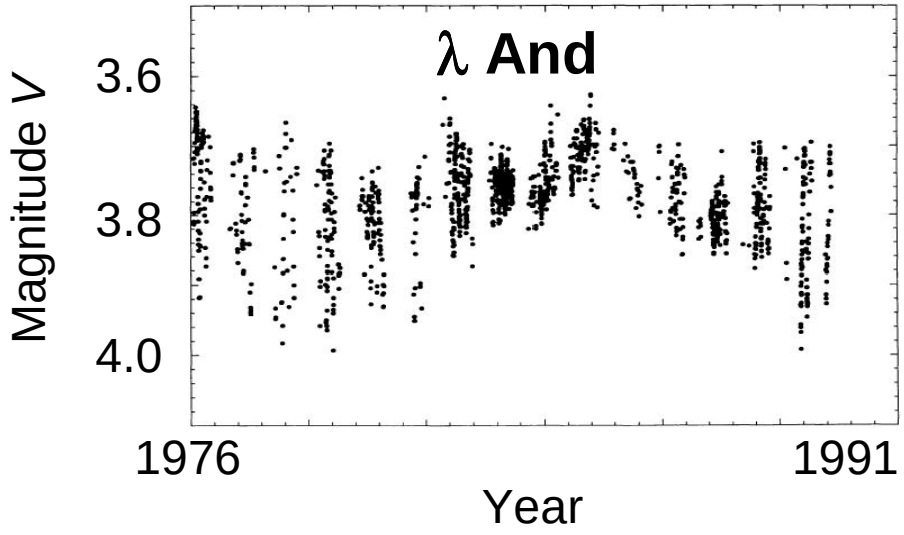
Flip-flop by sign change of an m=0 mode



Flip-flop by sign change of an m=0 mode



Fluri & Berdyugina (2004)



Henry et al. (1995)

Conceptual science

Eigenfunctions