Differential Rotation and Magnetism across the HR Diagram
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A new dynamo pattern revealed by the tilt angle of bipolar sunspot groups

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Solar dynamo

$$B_P \xrightarrow{\Omega} B_T$$ - differential rotation

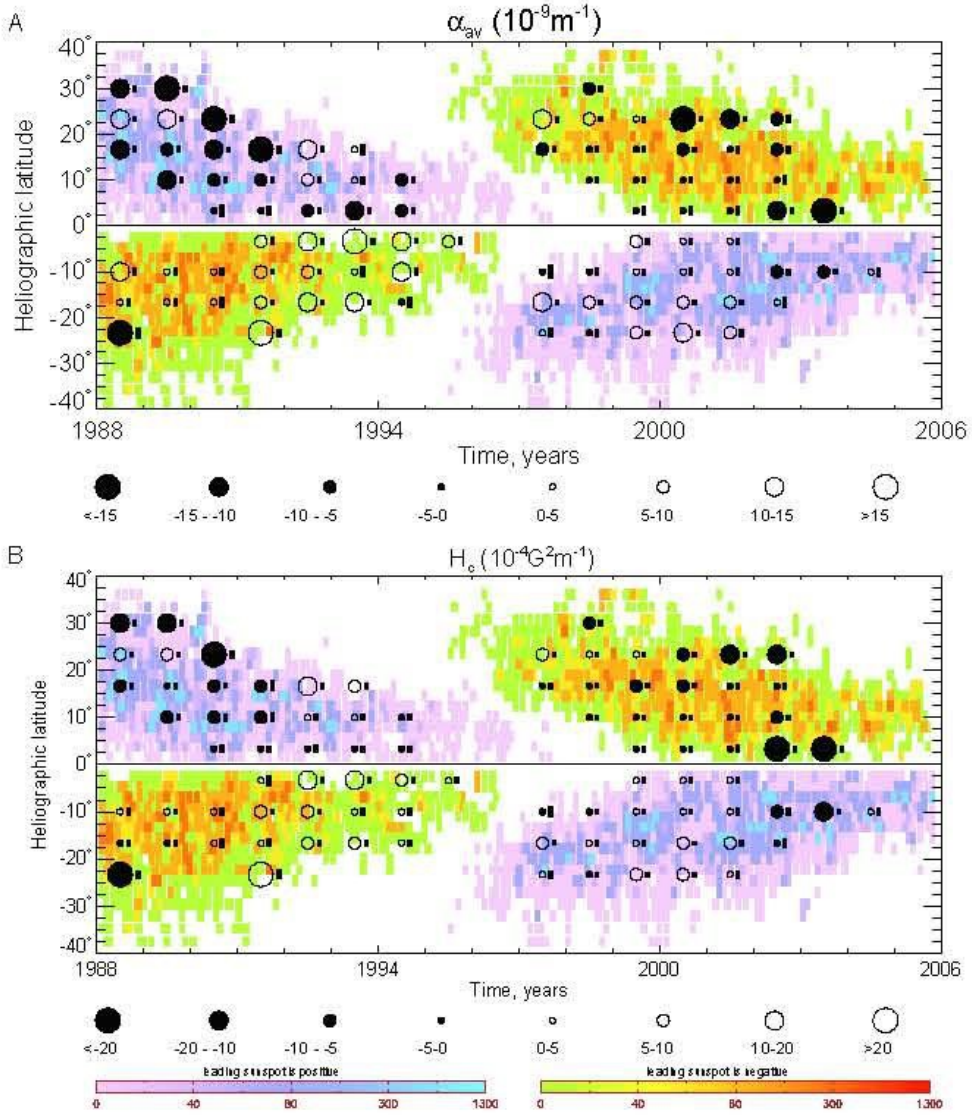
$$B_T \xrightarrow{\alpha} B_P$$ - mirror asymmetry (α-effect)

Mean-field dynamo equation:

$$\frac{\partial B}{\partial t} = \nabla \times (U \times B + E - \eta \nabla \times B)$$

$$E = \alpha B + \ldots$$

Current helicity: Zhang et al. 2010



$\alpha_{av}=<(B,curlB)_z/B_z^2>=<j_z/B_z>$

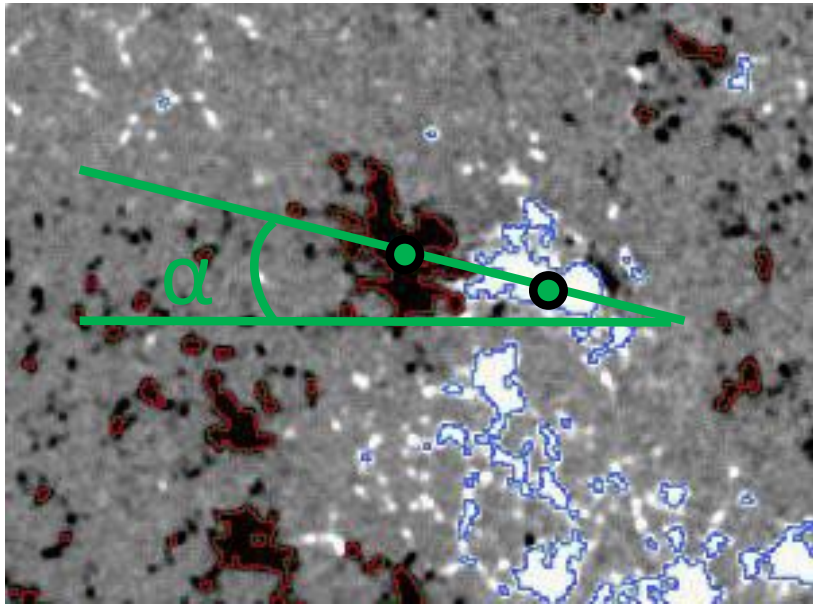
$H_c=<(B,curlB)_z>=<B_z j_z>$

Tilt

- Tilt is a possible link between toroidal and poloidal magnetic field
- Joy's law and Hale polarity law: bipolar regions are tilted with preferred polarity
- Stenflo and Kosovichev (2012) gave effective method for algorithmic isolation of bipoles
- Tlatov et al. (2010) suggested more general approach to this problem

Recognizing bipolar groups

- Smoothing $3^{\times}3$ pixels
- Selection domains with $|B|>B_{min}$
- Compute center and flux, define search area
- Find the nearest domain of opposite polarity with similar flux:
  $||F_1|-|F_2||/(|F_1|+|F_2|)<\varepsilon$
- Repeat the search
- Coincide => bipole
- Compute tilt

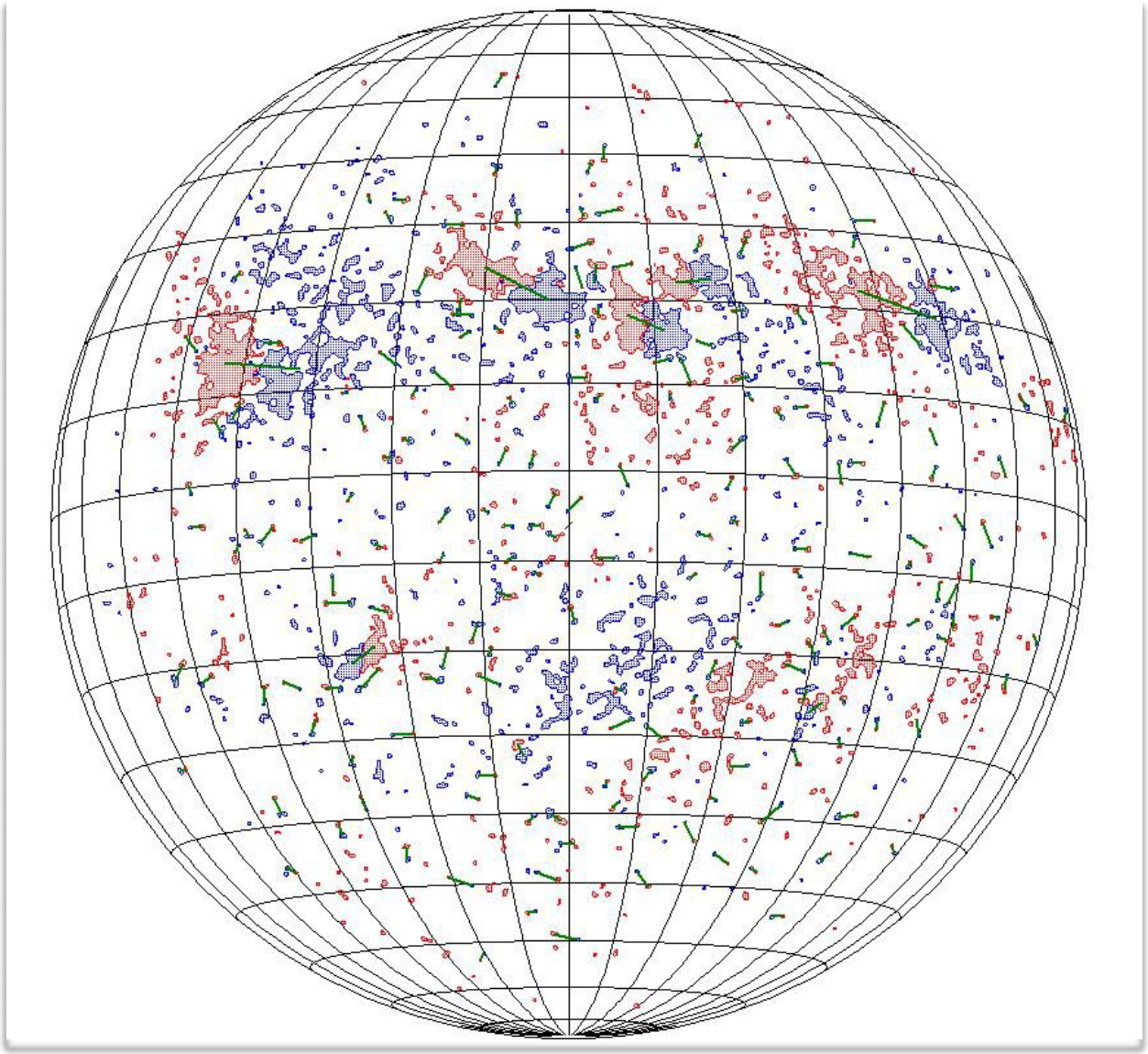


Key features

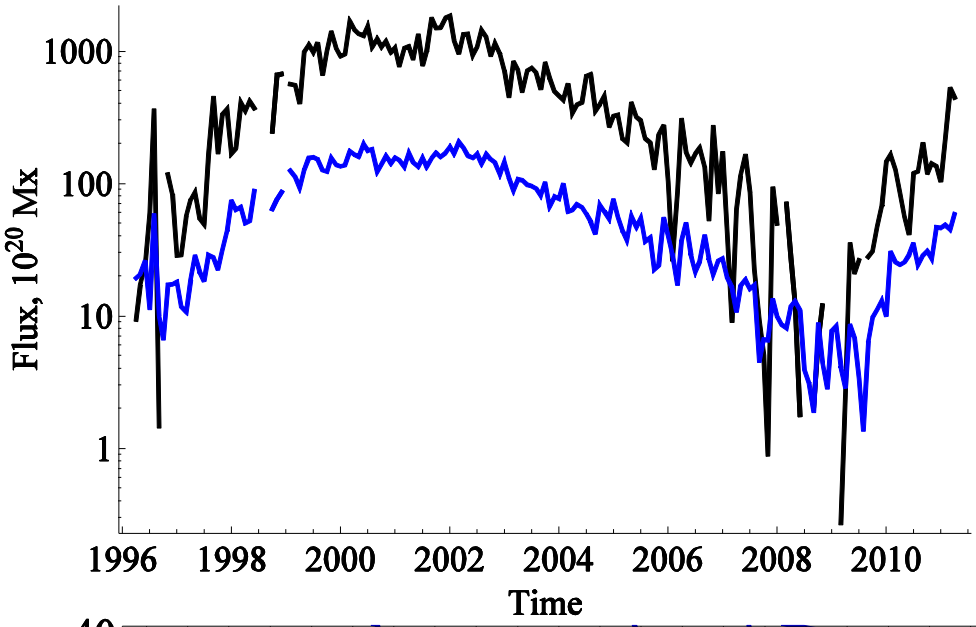
- Rich data sample: AR + ER (up to 50 MSH[1])
- KPVT, MDI and HMI data (Cycles 21-24)
- 1 magnetogram per day
- 15 bipoles per day
- Tilt corresponds to substantive domains

[1] 1 MSH= 3.044×10^6 km^2. The round shaped spot with area S (in MSH) has a diameter d = $1969\sqrt{S}$ km.

Example: MDI, 11/04/2011



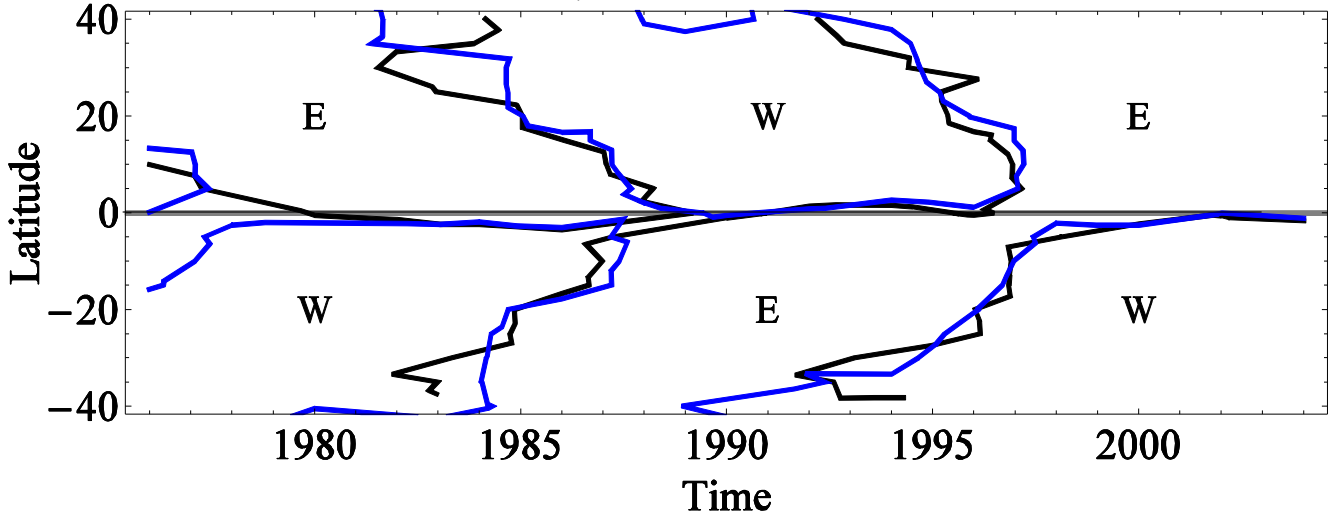
Simple tests



Flux, MDI data

50-300 MSH

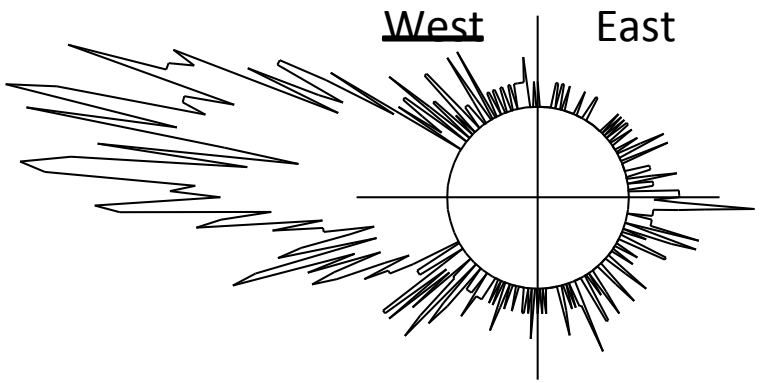
>300 MSH

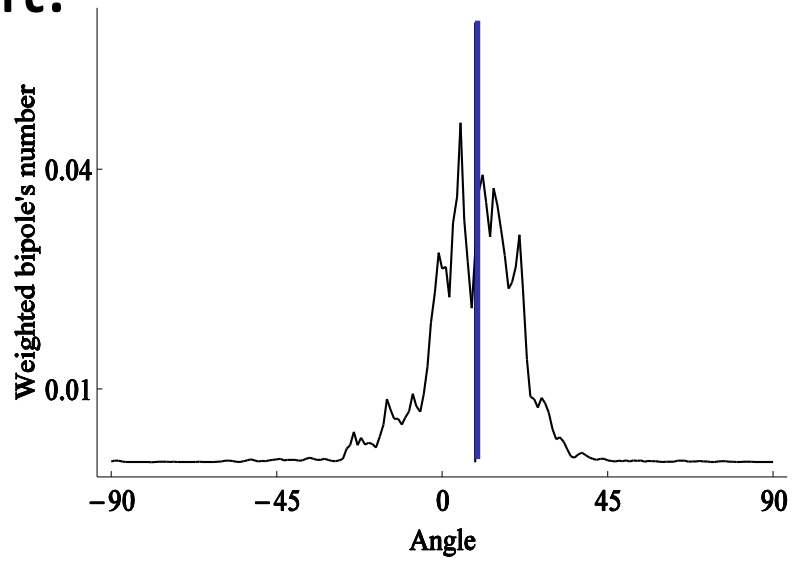


Prevalent E-W direction of tilt, KPVT data, B_{min}=10 G

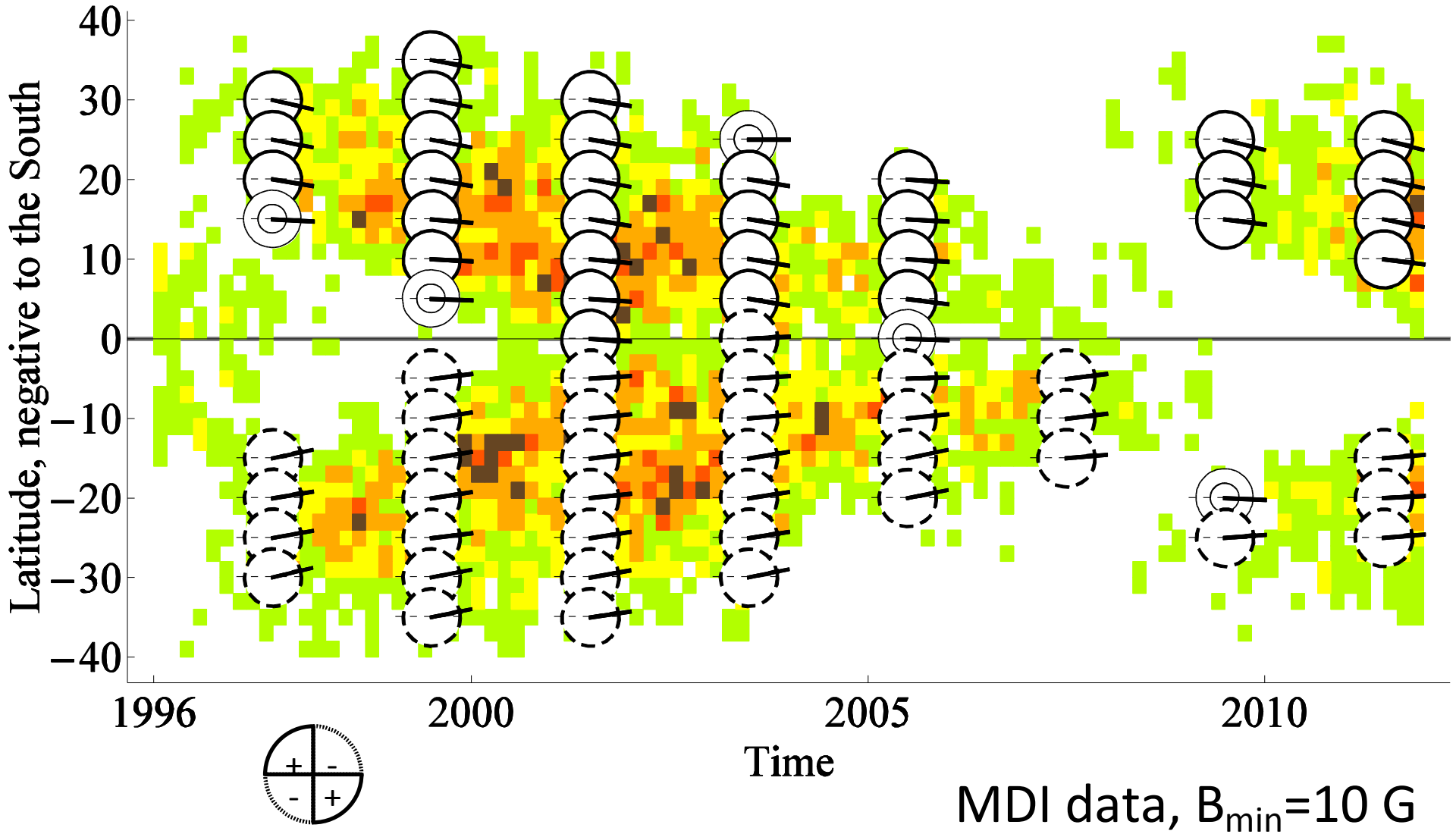
Averaging tilt

- 2-year time bins and 5° latitudinal bins
- Amplitude of Gaussian approximation defines hemisphere (East-West) for averaging
- Mean tilt is a median of sample (robust statistic)
- Student criteria for conf. int.



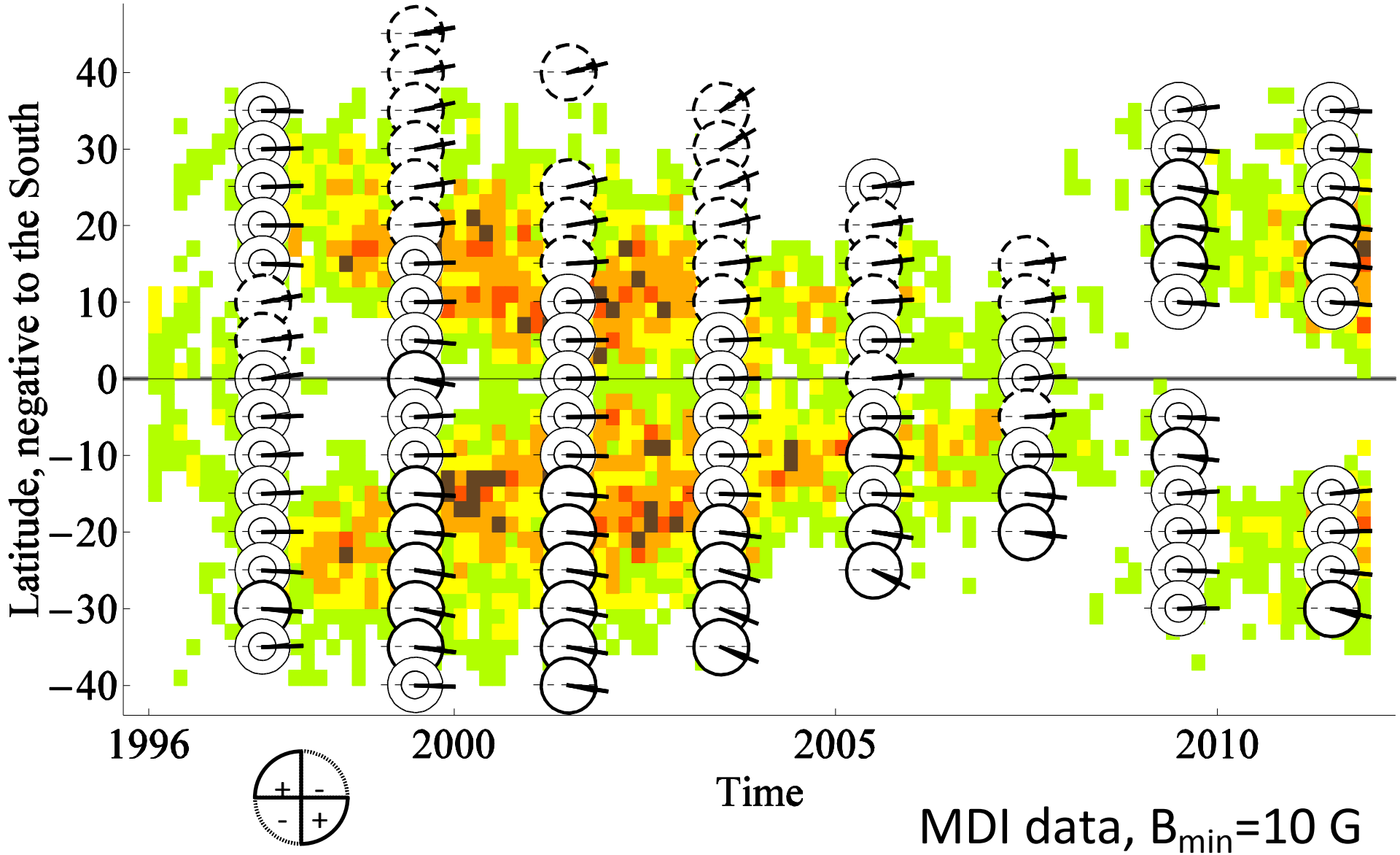


Butterfly diagram: >300 MSH



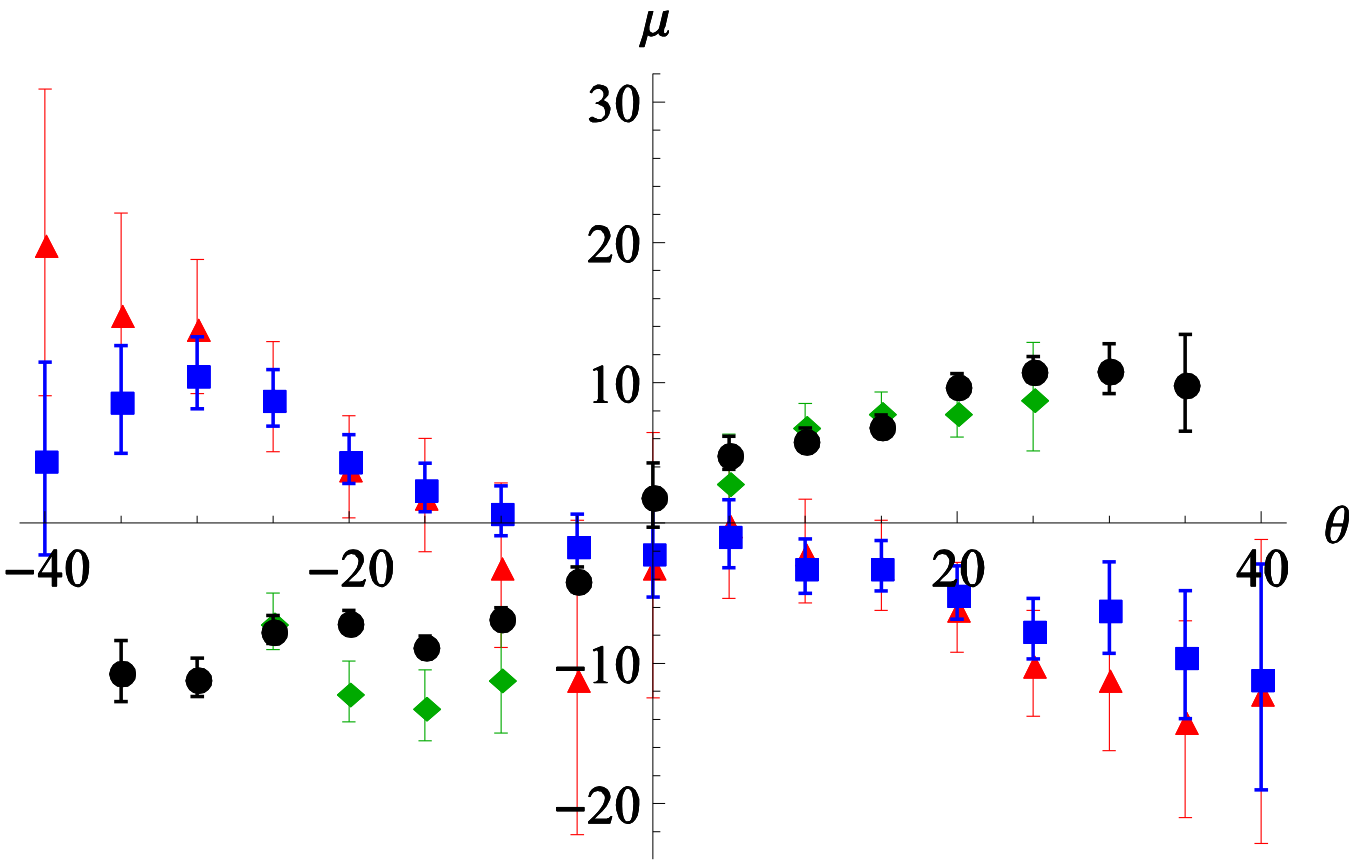
MDI data, B_{min}=10 G

Butterfly diagram: 50-300 MSH



MDI data, B_{min}=10 G

Joy's law: MDI & HMI



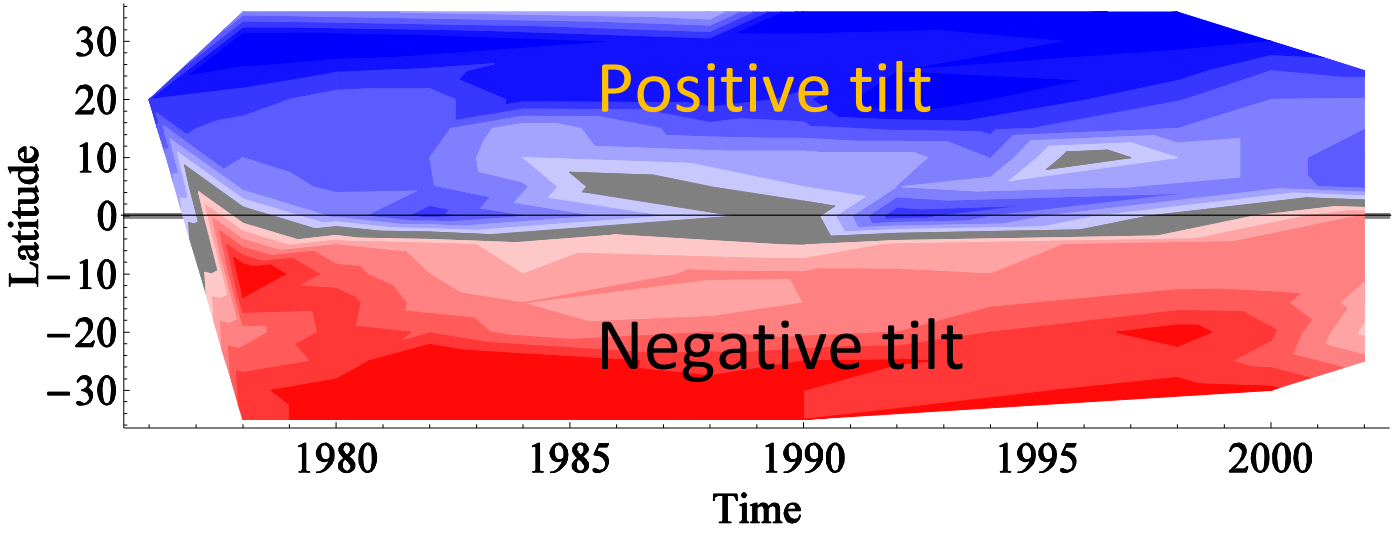
MDI data, B_{min}=10 G

- ● - S>300 MSH
- ■ - 50<S<300 MSH

HMI data, B_{min}=15 G

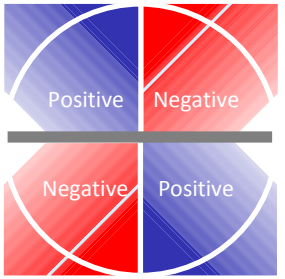
- ◆ - S>300 MSH
- ▲ - 20<S<100 MSH

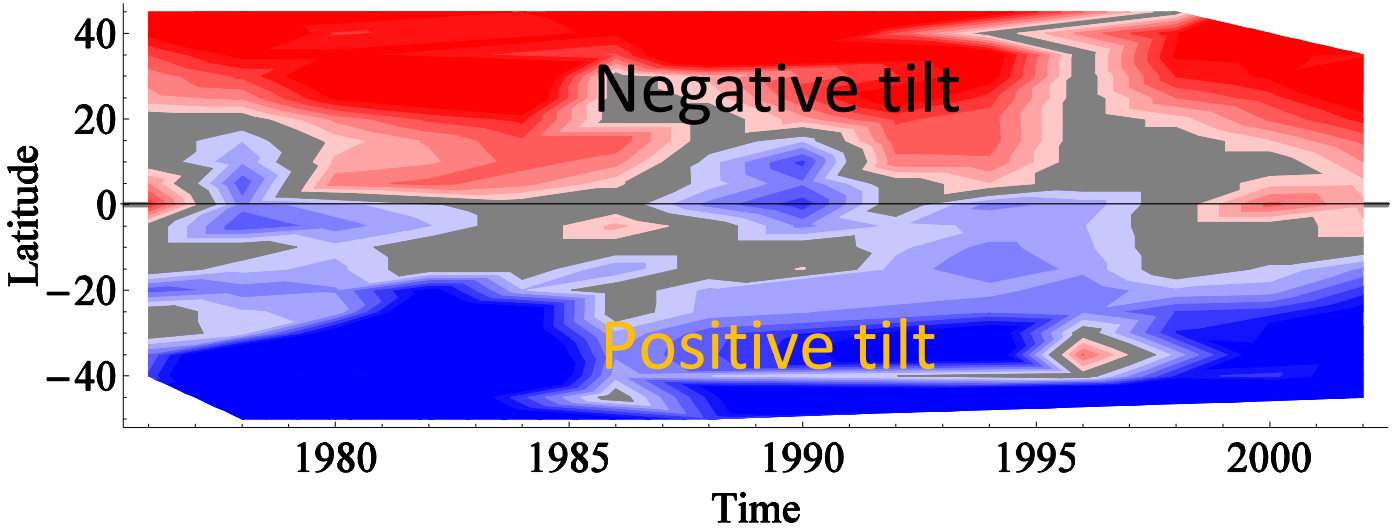
Tilt data, KPVT



>100 MSH

B_{min}=100 G

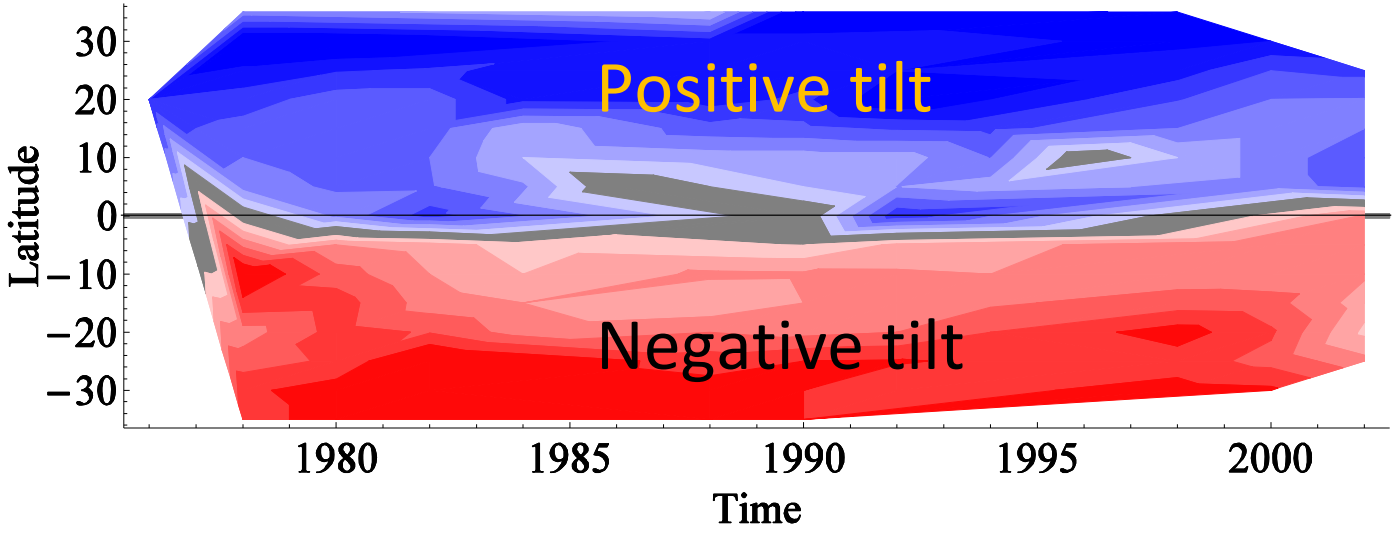




50-300 MSH

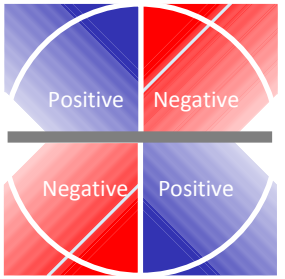
B_{min}=10 G

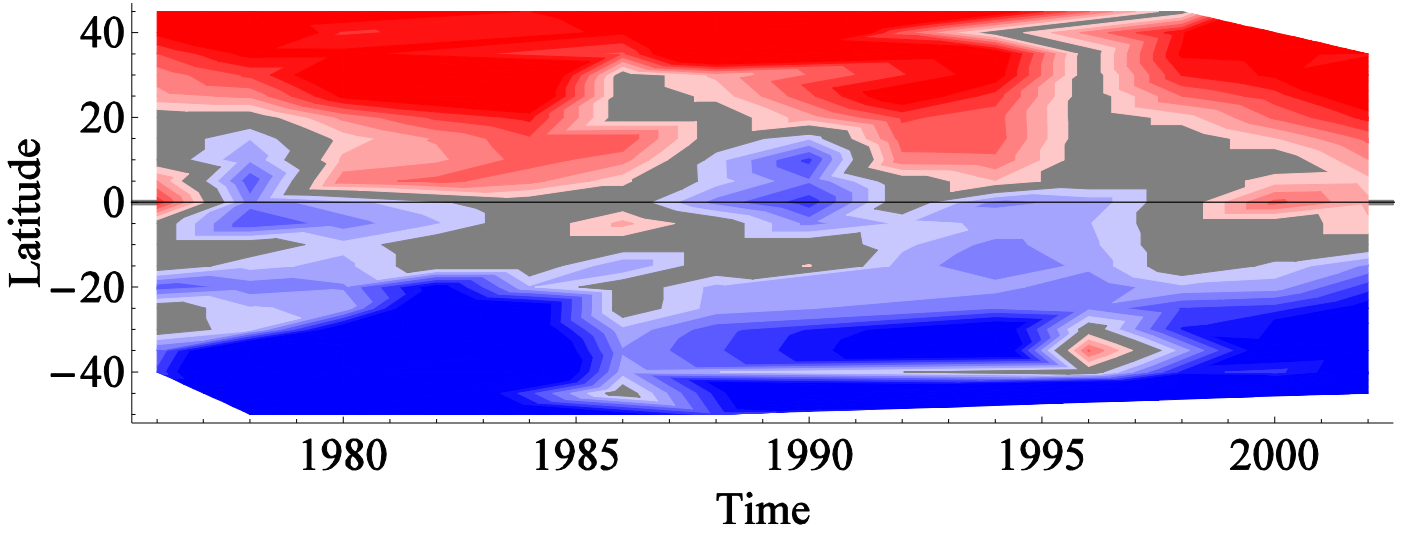
Tilt data, KPVT



>100 MSH

B_{min}=100 G

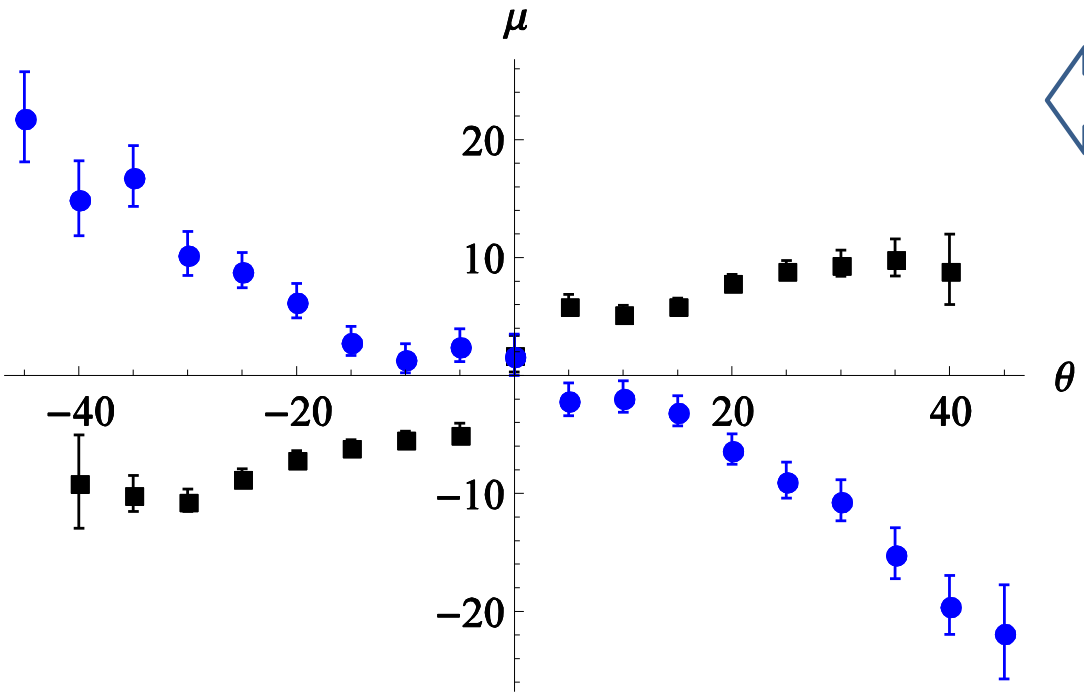




50-300 MSH

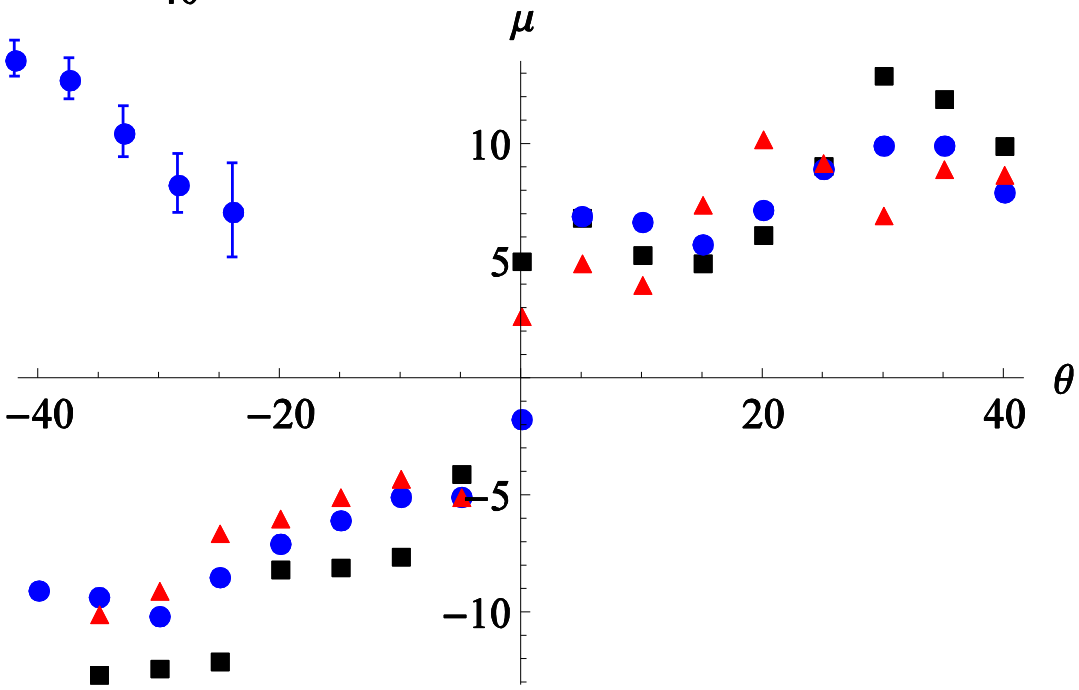
B_{min}=10 G

Joy's law: KPVT, B_{min}=10 G



- S>300 MSH
- 50<S<300 MSH

S>300 MSH
- Cycle 21
- Cycle 22
- Cycle 23



Main results

- Tilt data with high time-latitude resolution for wide area range (AR & ER)
- For large bipoles tilt is positive in the Northern and negative in the Southern hemisphere with latitudinal profile $\mu=27\sin\theta$
- No pronounced variations of tilt angle between cycles and inside cycles (as opposed to current helicity)
- Inverse Joy's law for small bipoles