### Surface constraints on the solar dynamo



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#### **Babcock-Leighton Flux Transport Dynamo**

flows and fields at the surface



#### The Sun's open flux at minimum



# is correlated with the strength of the subsequent cycle

Wang & Sheeley 2009

Similar: polar field, axial dipole at minimum

#### The average tilt angle of bipolar active regions



is anticorrelated with the strength of the cycle Dasi-Espuig et al. 2010

#### Inflows into active regions



Gizon et al 2001



#### Gizon & Rempel 2008

### **Surface Flux Transport**



Wang & Sheeley, ...

#### **Evolution of magnetic fields at the solar surface**



Features emerge, then diffuse and get advected

#### **Evolution of a single bipolar region**



Jiang et al. 2010

#### Surface distribution of the solar magnetic field



Jiang et al. 2010

### **Butterfly diagrams**



1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 Baumann et al. 2006

#### The polar magnetic field and open flux



Cameron et al. 2010

#### **Cross-equatorial rushes**



A single cross-equatorial rush can affect the polar fields of the following minimum by up to 60% (Cameron et al., in preparation)

#### Effect of the inflows on the polar field



Jiang et al. 2010

# Nonlinear feedback of the inflows in a surface flux transport model



Cameron & Schüssler 2010, 2012

#### Surface contraints for flux transport dynamos

Evolution of an azimuthally averaged bipolar region



Requirements:

vertical magnetic field at outer boundary
sufficient downward pumping (Re = 5)

Cameron et al. 2012

#### Modeling solar cycles 15-21 using a flux transport dynamo



Source term for the poloidal field based on the RGO sunspot record



Jiang et al. 2013

Correlation coefficient of the maxima of the polar fields and the subsequent maximum of the sunspot number is 0.85

#### ... continued



Correlation coefficient between maxima of the toroidal field at the base of the convection zone and the maxima of the observed sunspot number is 0.93



Correlation coefficients for various pumping velocities and turbulent diffusivities

### Conclusions

- The Sun's open flux at minimum is correlated with the strength of the subsequent cycle.
- The open flux is determined by the surface distribution of the magnetic field.
- The surface distribution is determined by the emerging active regions and the surface flows.
- Because of the tilt of active regions, part of the leading polarity flux diffuses across the equator and of the following polarity flux is advected towards the poles.
- Only a tiny fraction of emerging active regions contribute to the polar fields and open flux at minimum.
- Near-surface inflows into active regions affect the tilt angles, depend on the field strength and can explain the cycle-to-cycle variations of solar activity.