

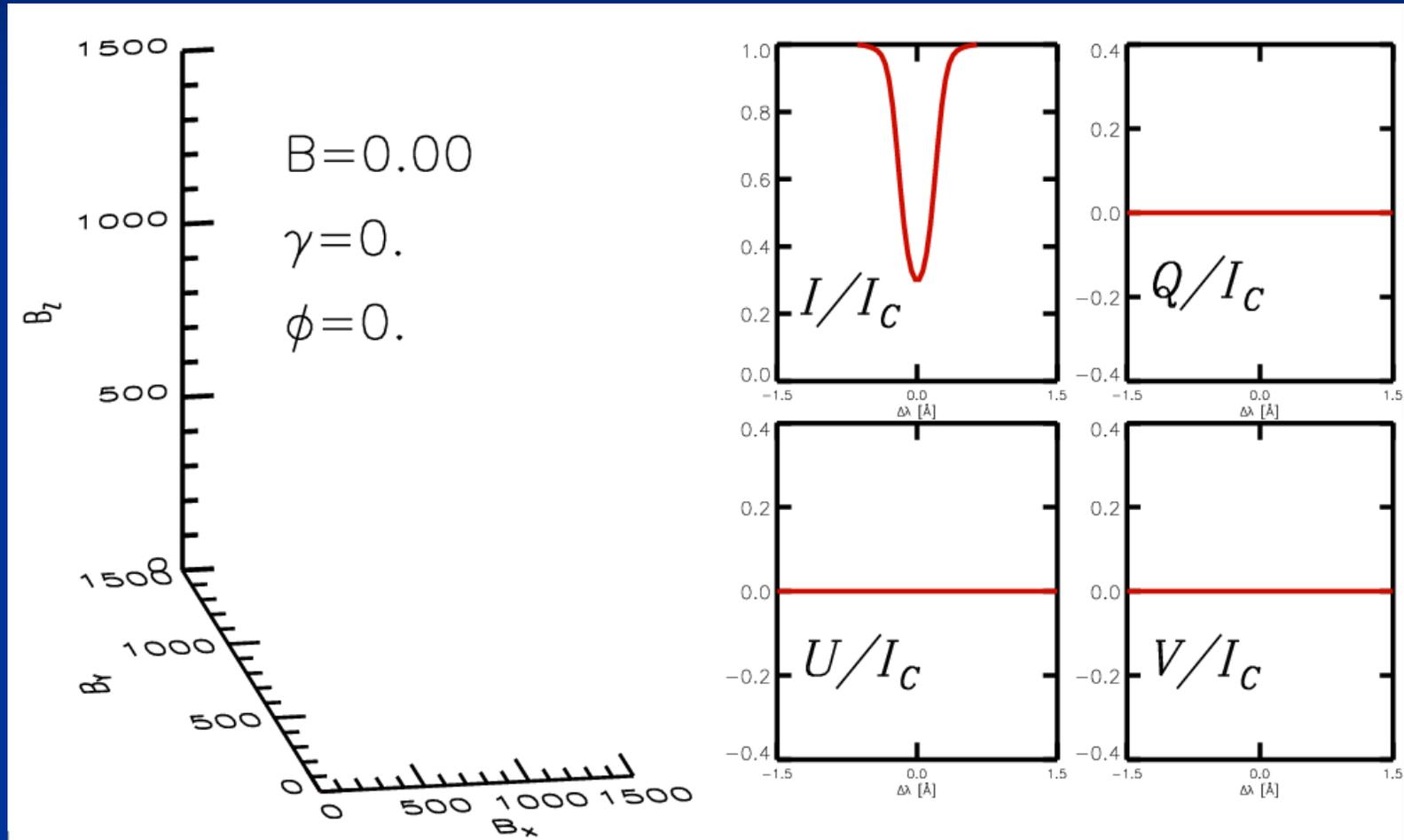
Solar Magnetic Field Measurements

Yang Liu and J. T. Hoeksema
Stanford University

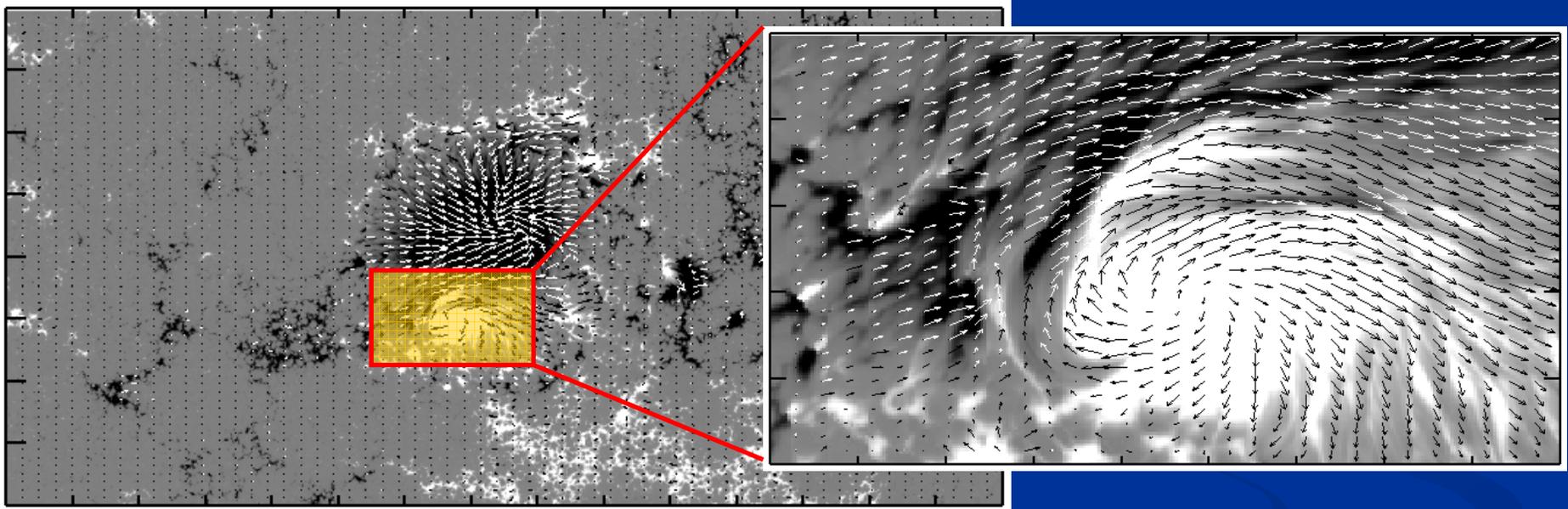
Outline

- Solar magnetic field measurements;
- Modeling magnetic field in solar corona and heliosphere;
- Evolution of solar active regions;
- Long-term variation of magnetic field in the Sun;
- SDO/HMI

Solar magnetic field measurement

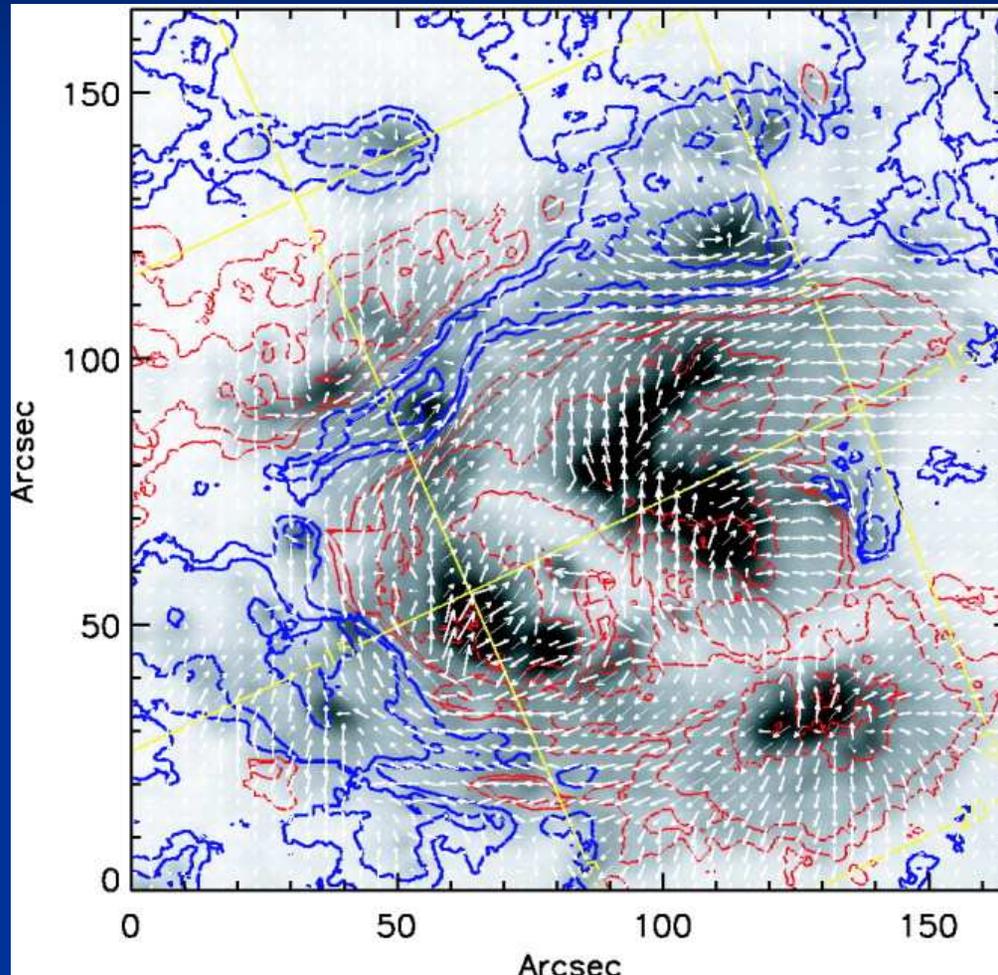


Solar magnetic field measurement (photosphere)



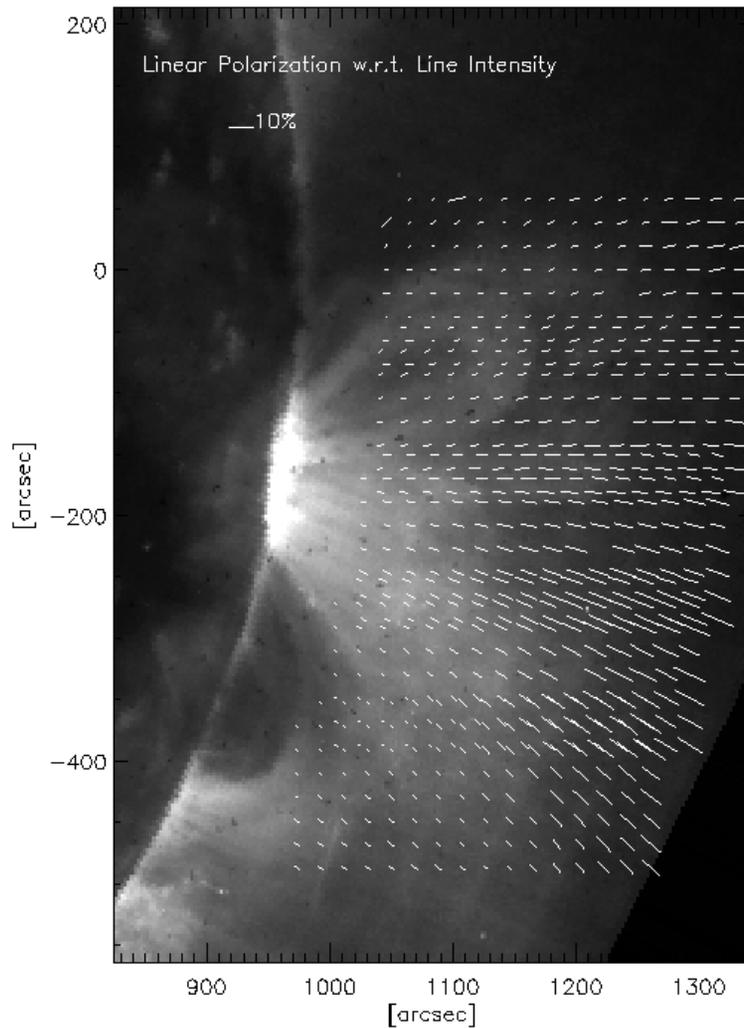
Vector magnetic field of AR10930 taken by
Hinode (Courtesy: M. Georgoulis)

Solar magnetic field measurement (chromosphere)

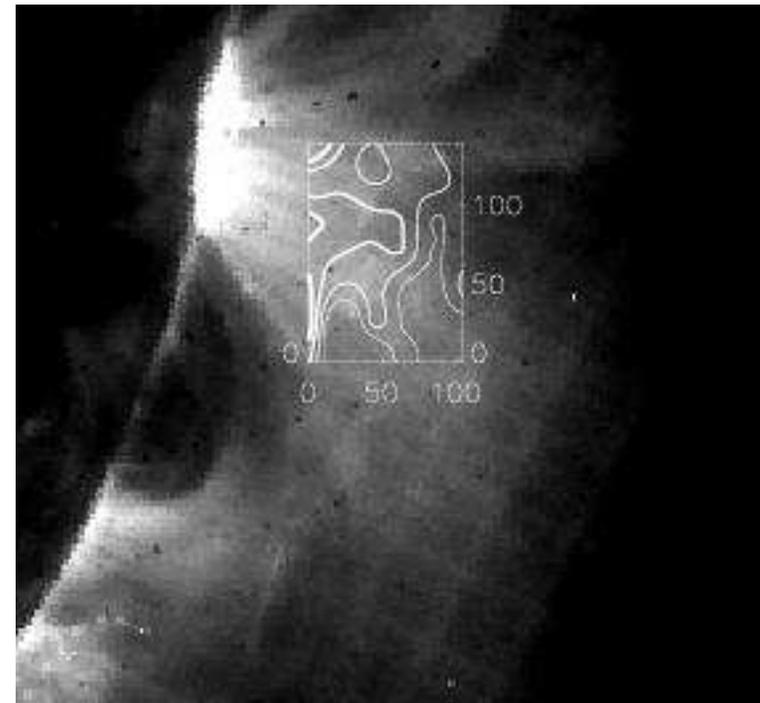


The First 'Vector' Coronal Magnetogram by SOLARC at U. of Hawaii, 2004 (Courtesy: H. Lin)

Transverse field orientation



Longitudinal Field Strength

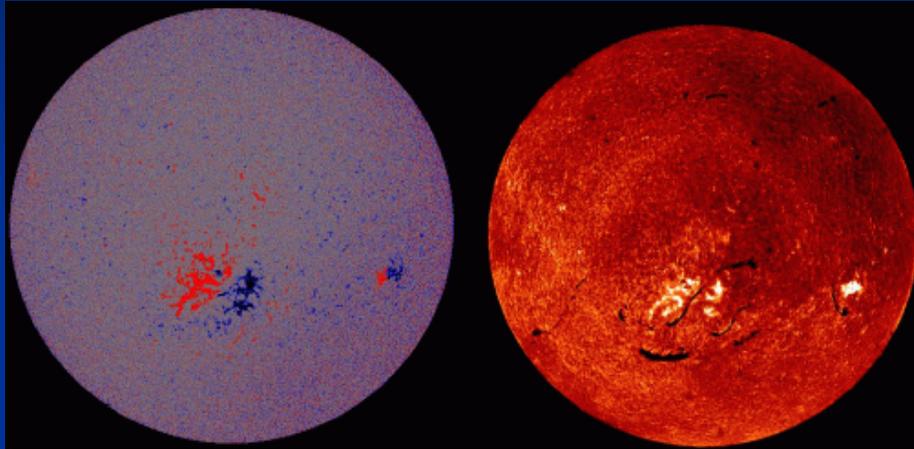


Contour plot of the line-of-sight magnetogram over-plotted on the SOHO/EIT FeXVI 284 A image. The contours are 5G, 3G, and 1G.

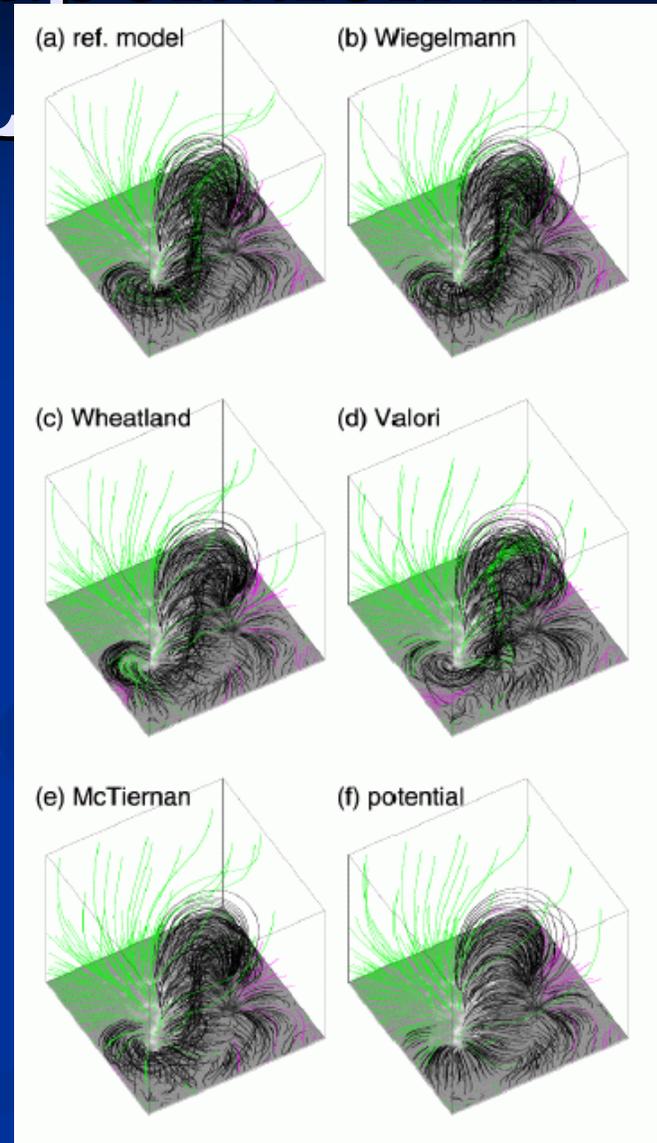
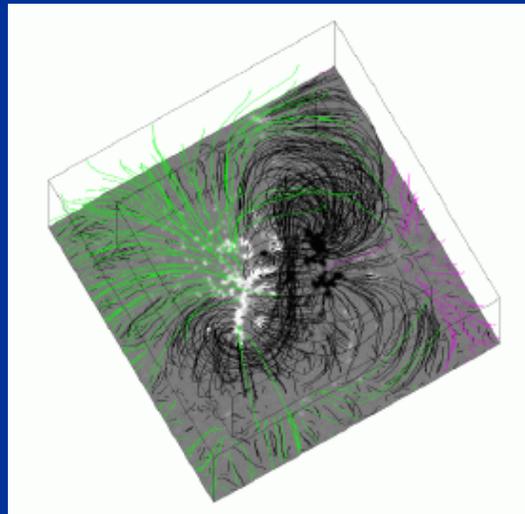
Modeling magnetic field in the corona and heliosphere

- Various models and techniques.
 - Potential field model;
 - Linear force free field model;
 - Non-linear force free field model;
 - MHD simulations.

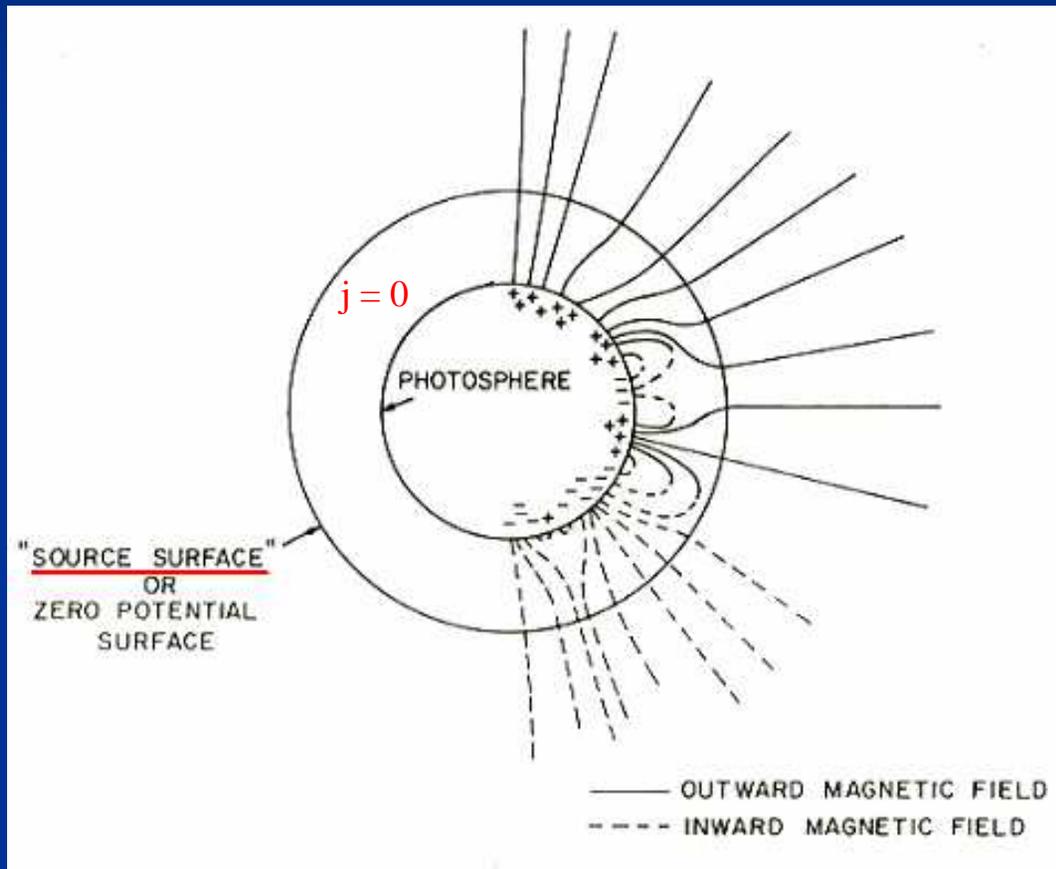
Coronal field extrapolation in active regions (NL)



Metcalf et al
(2008)



Coronal/Heliospheric field extrapolation (potential field source surface (PFSS) model)



$$\nabla^2 \psi = 0$$

where,

$$\psi(r, \theta, \phi) = \sum_{l=0}^{\infty} \sum_{m=-l}^l [A_{lm} r^l + B_{lm} r^{-(l+1)}] Y_{lm}(\theta, \phi)$$

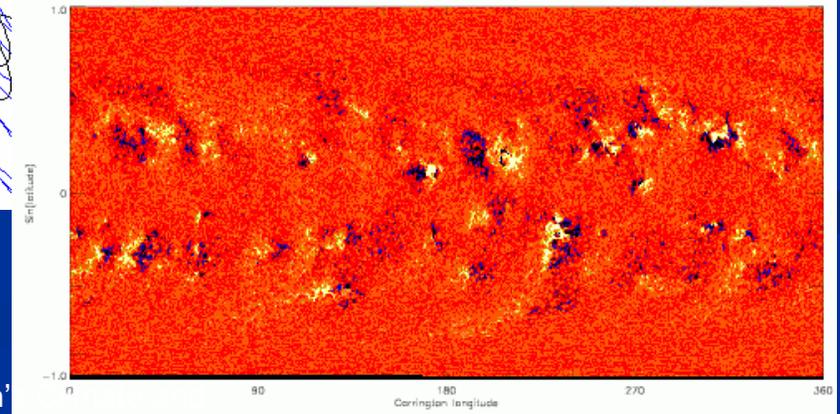
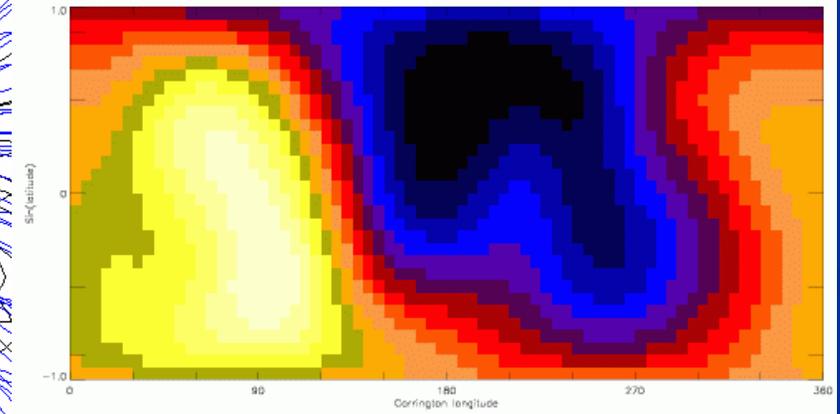
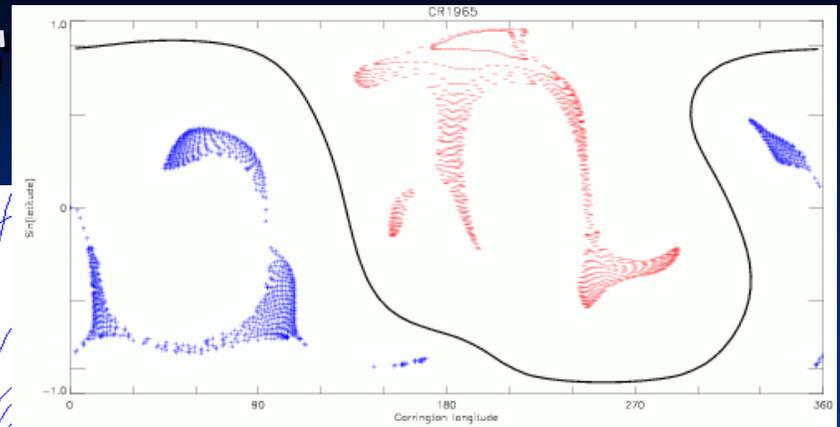
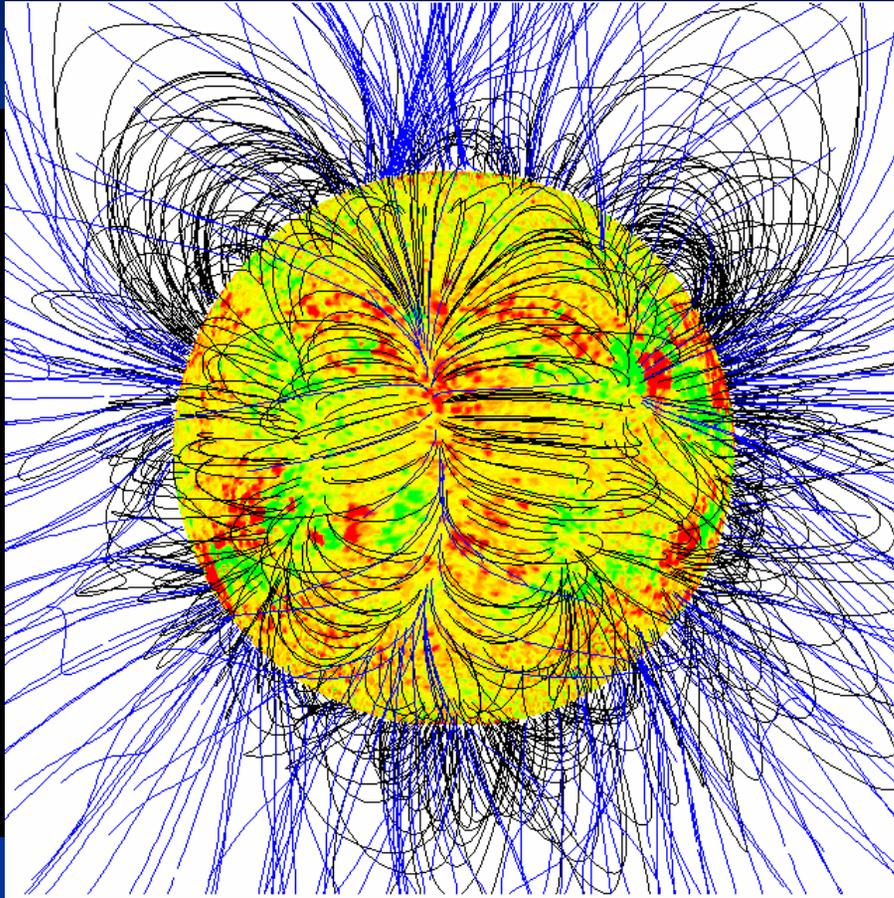
Coefficients A_{lm} and B_{lm} are determined from the *boundary conditions*.

Schatten, Cosmic Electrodynamics, 2, 232, 1971.

7/9/2008

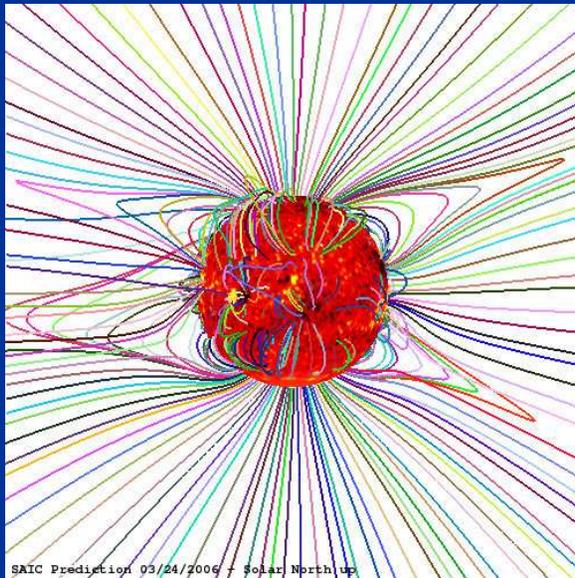
From Arge 2005.

Present PF

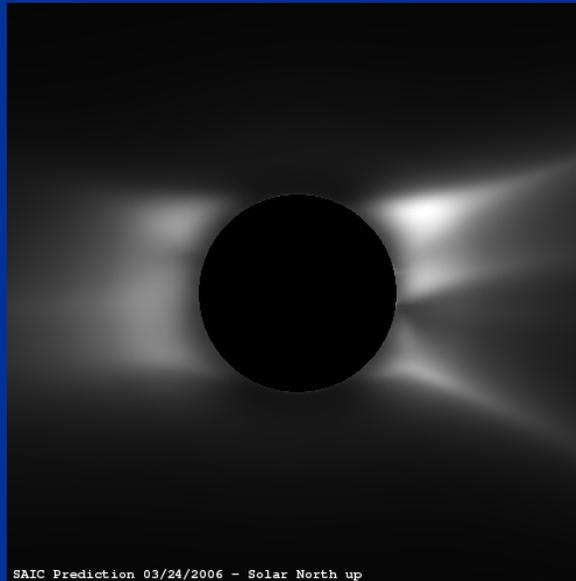


Coronal/heliospheric field (MHD simulation)

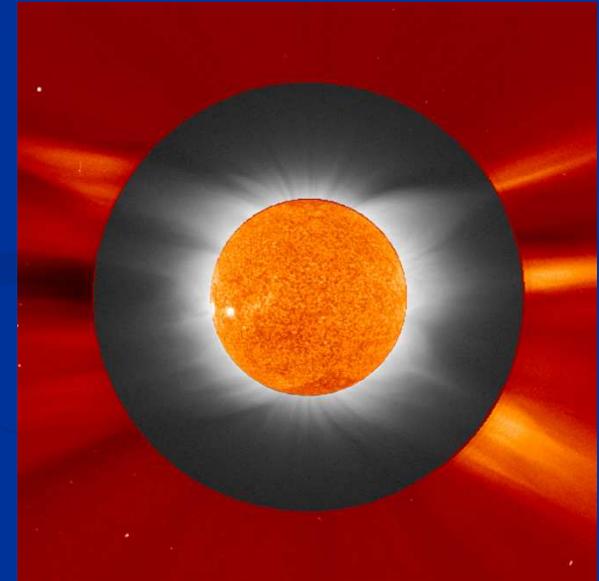
Solar eclipse on March 29, 2006. Prediction was done by Linker et al at Science Application International Corporation.



Magnetic Field Lines
(MHD Model)

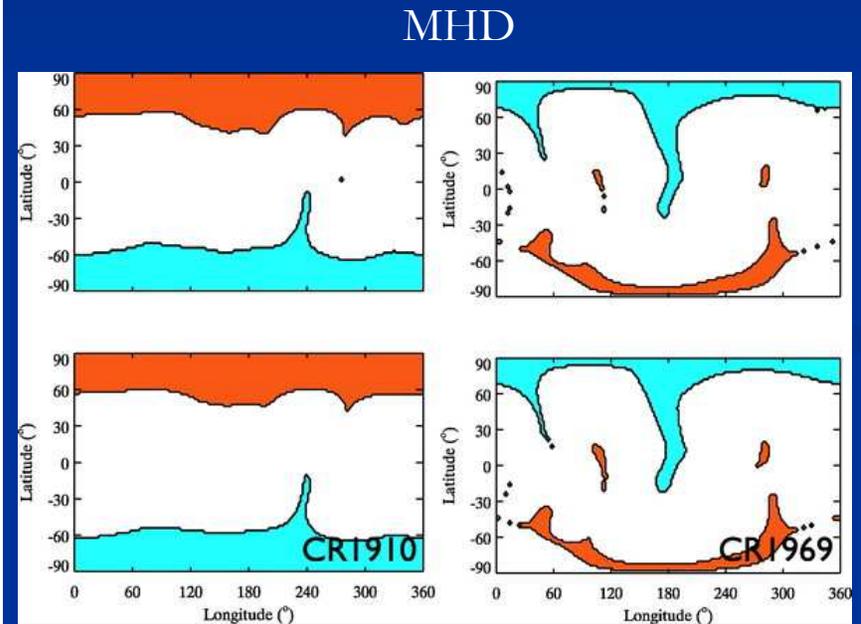
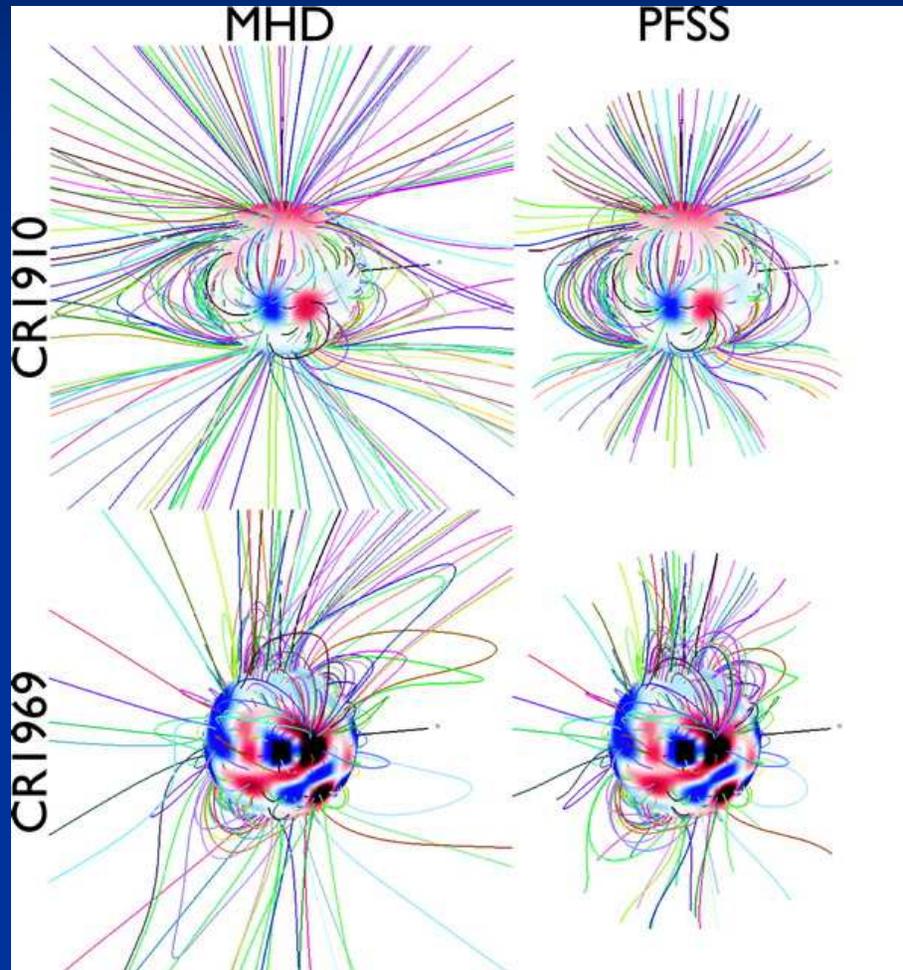


Polarization Brightness
(MHD Model)



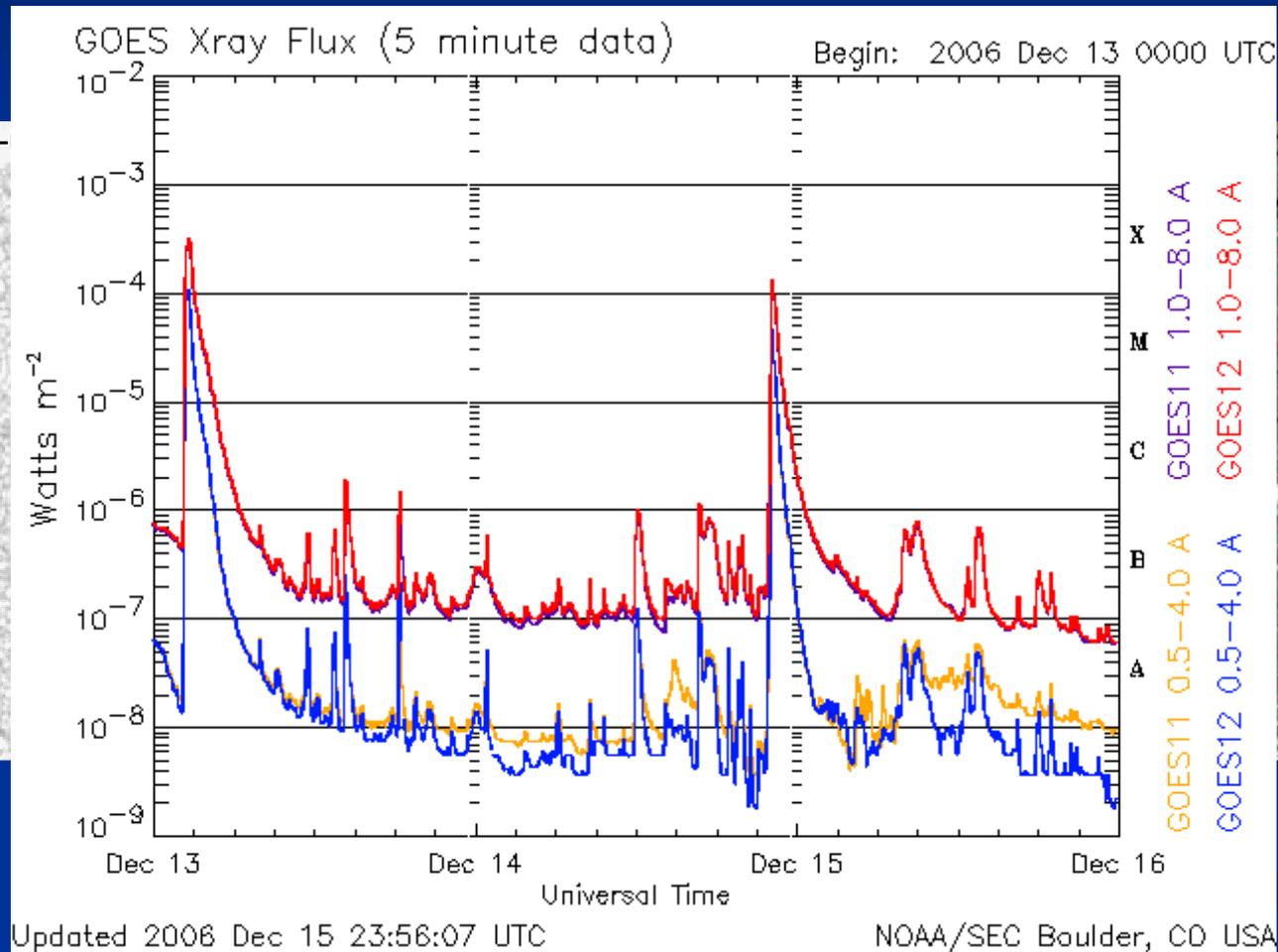
Eclipse (Williams College)*
& SOHO LASCO C2 Images

Comparison of MHD and PFSS

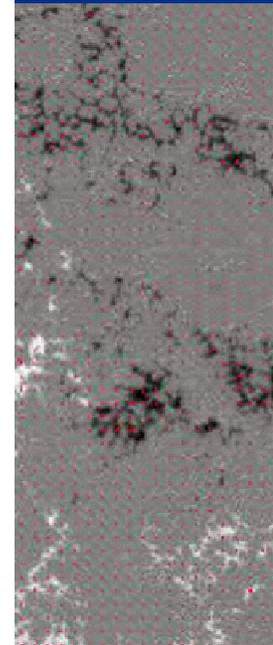


From Riley et al, 2006, ApJ.

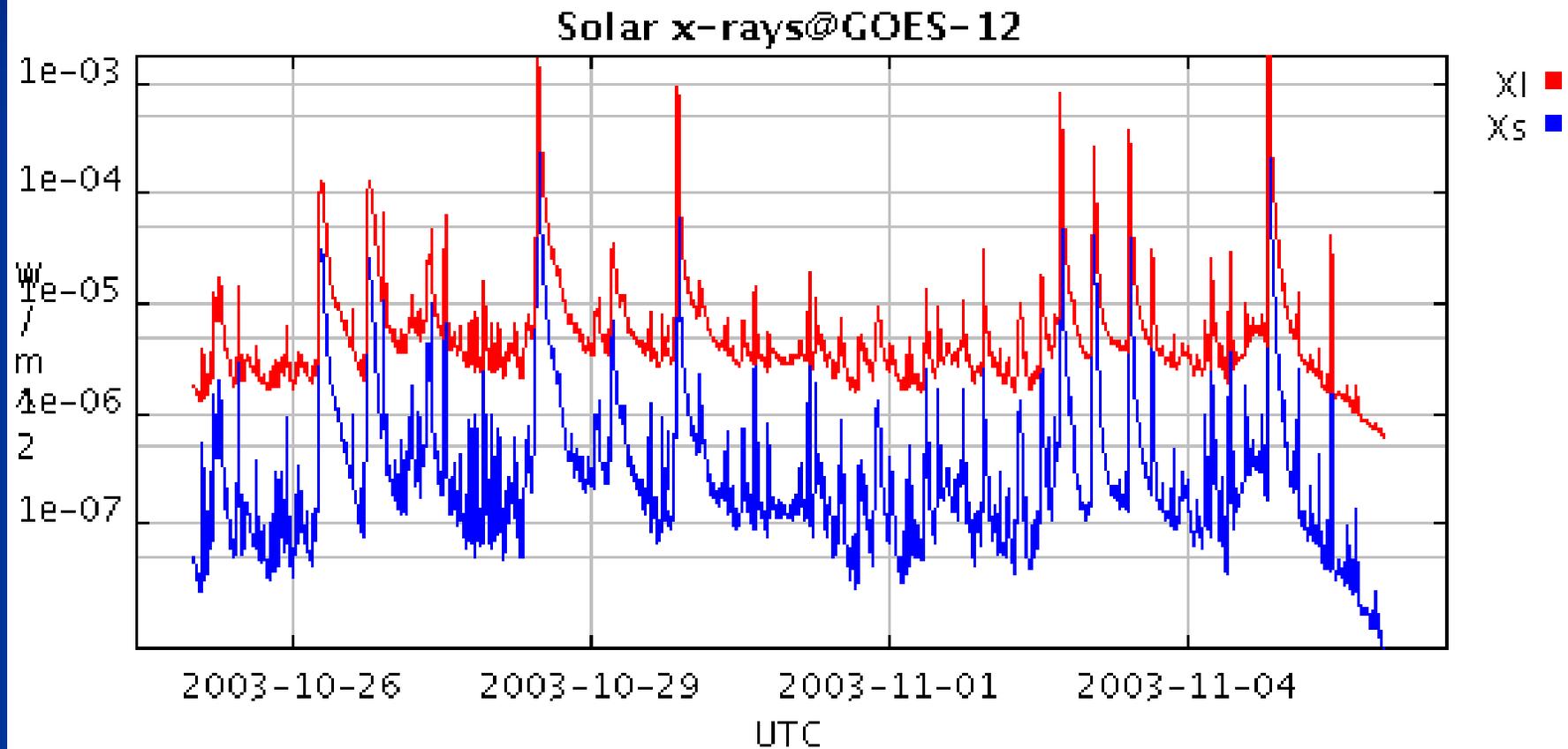
Evolution of magnetic field in active regions



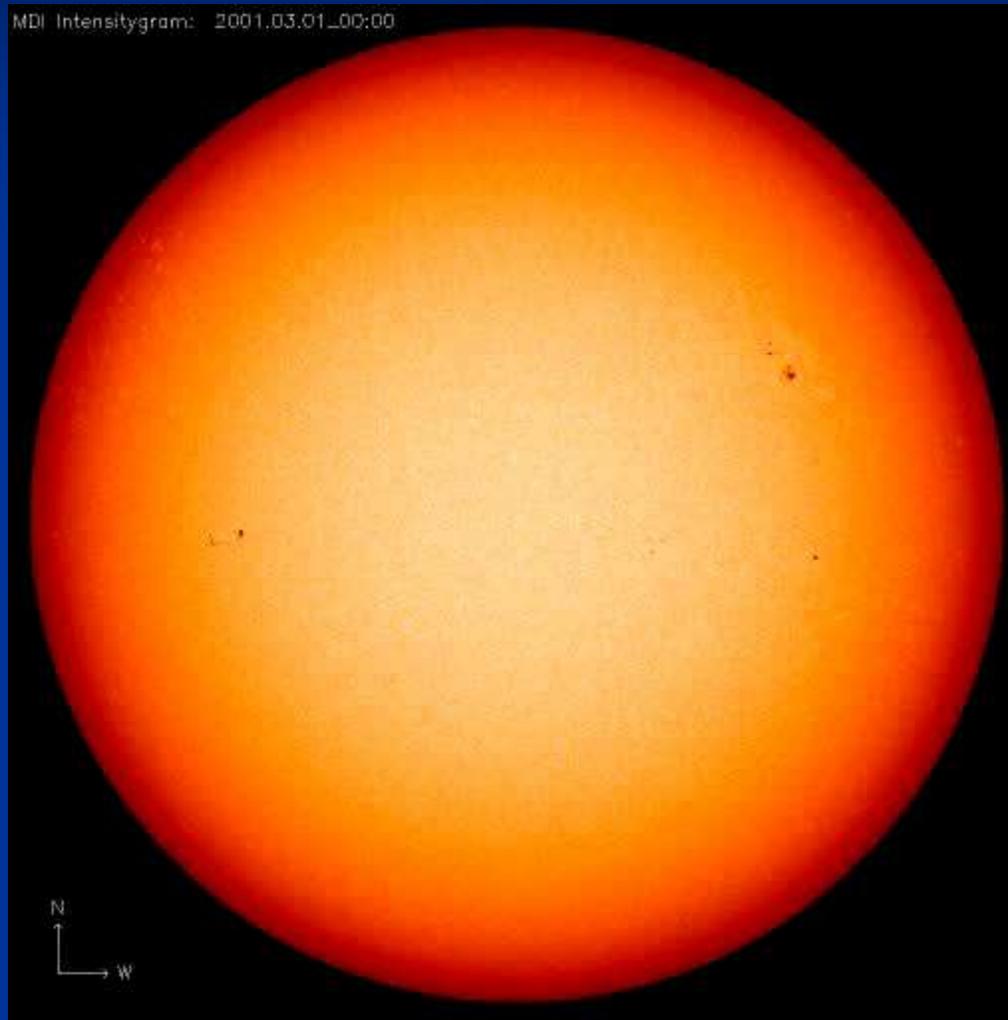
2006-12-



Evolution of magnetic field (Emerging of an active region)

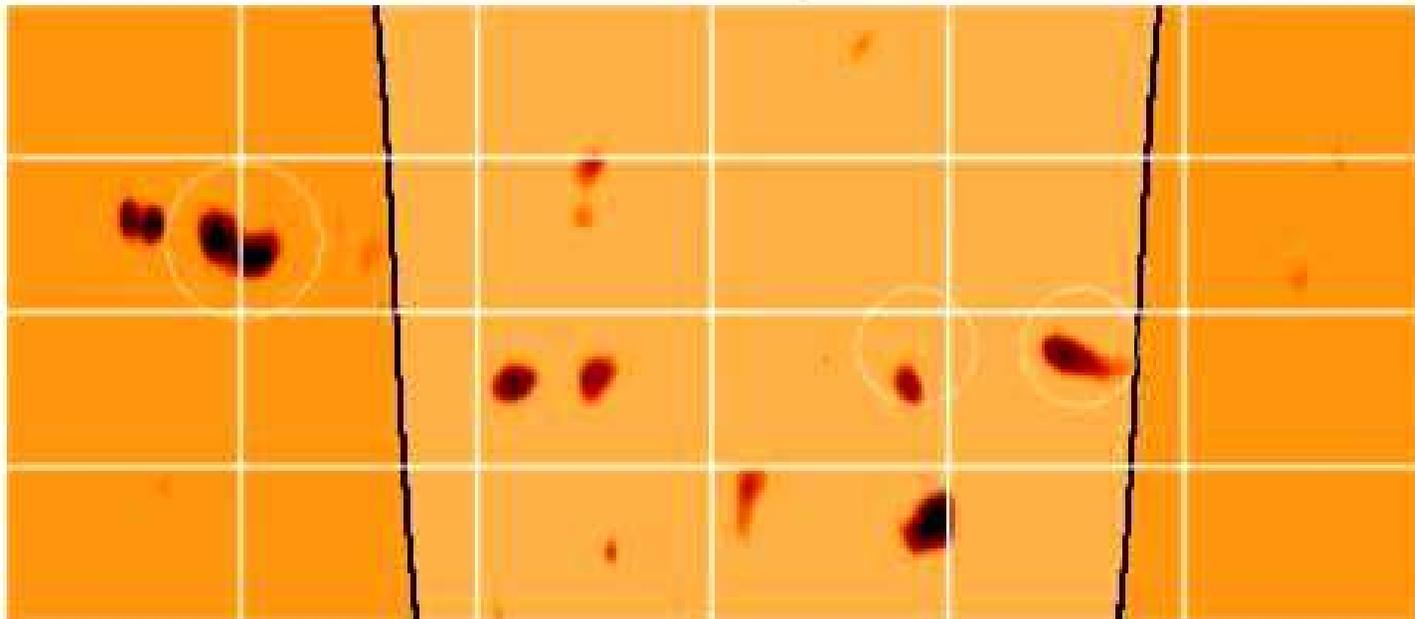


Evolution of active regions



Evolution of active regions

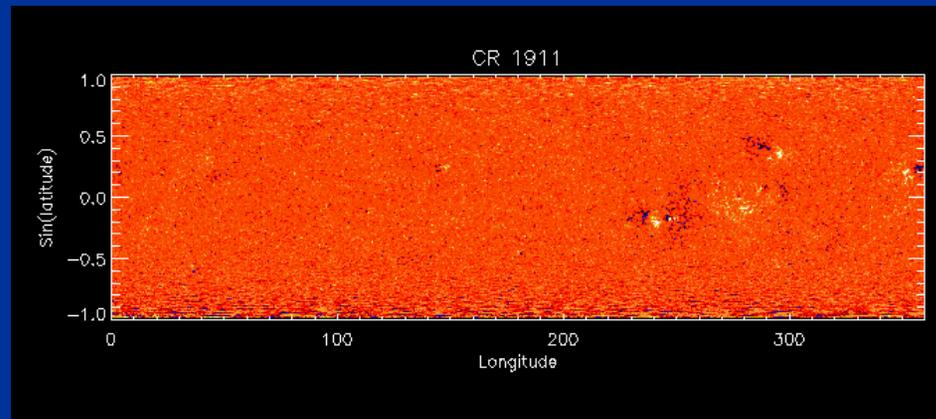
12:00UT January 16 2001



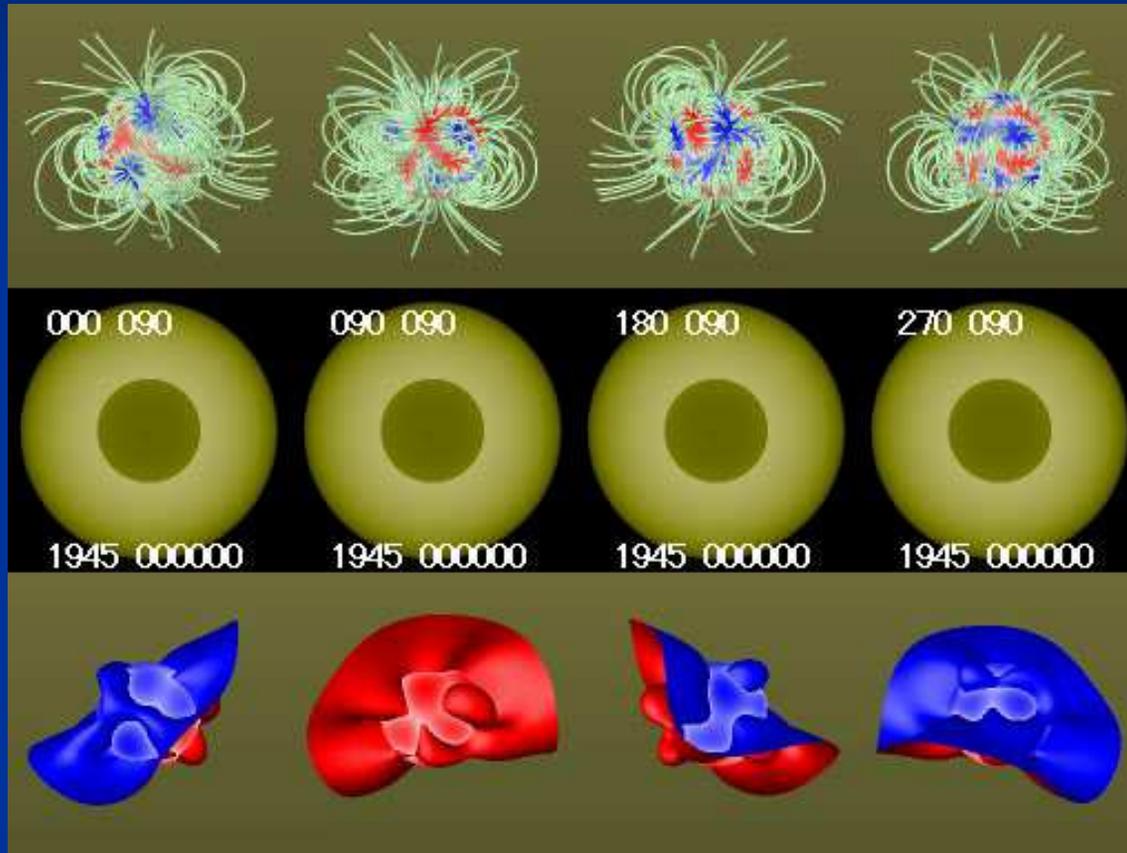
Courtesy: J. Zhao

Solar Variability, Earth's Climate and
the Space Environment

Magnetic field variation (long-term)

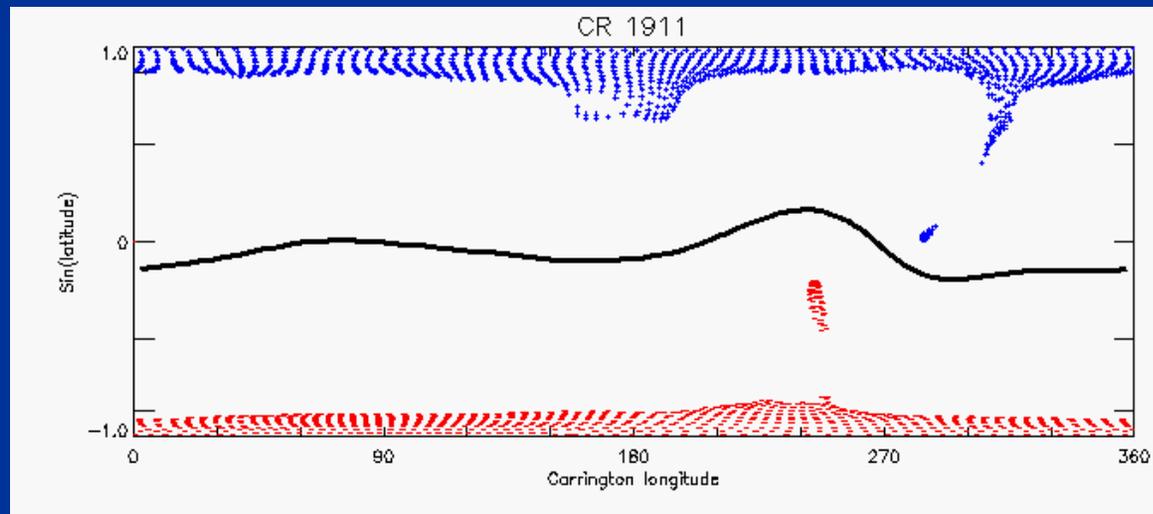


Magnetic field variation (MHD modeling)



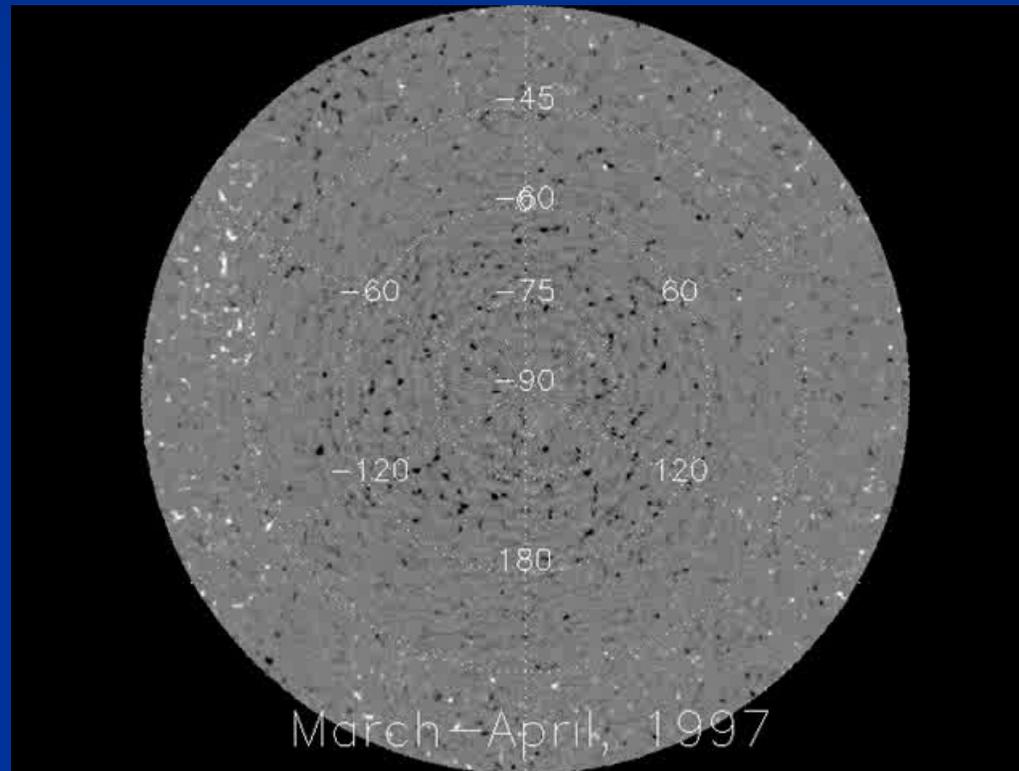
Courtesy: K. Hayashi

Magnetic field variation (long-term)



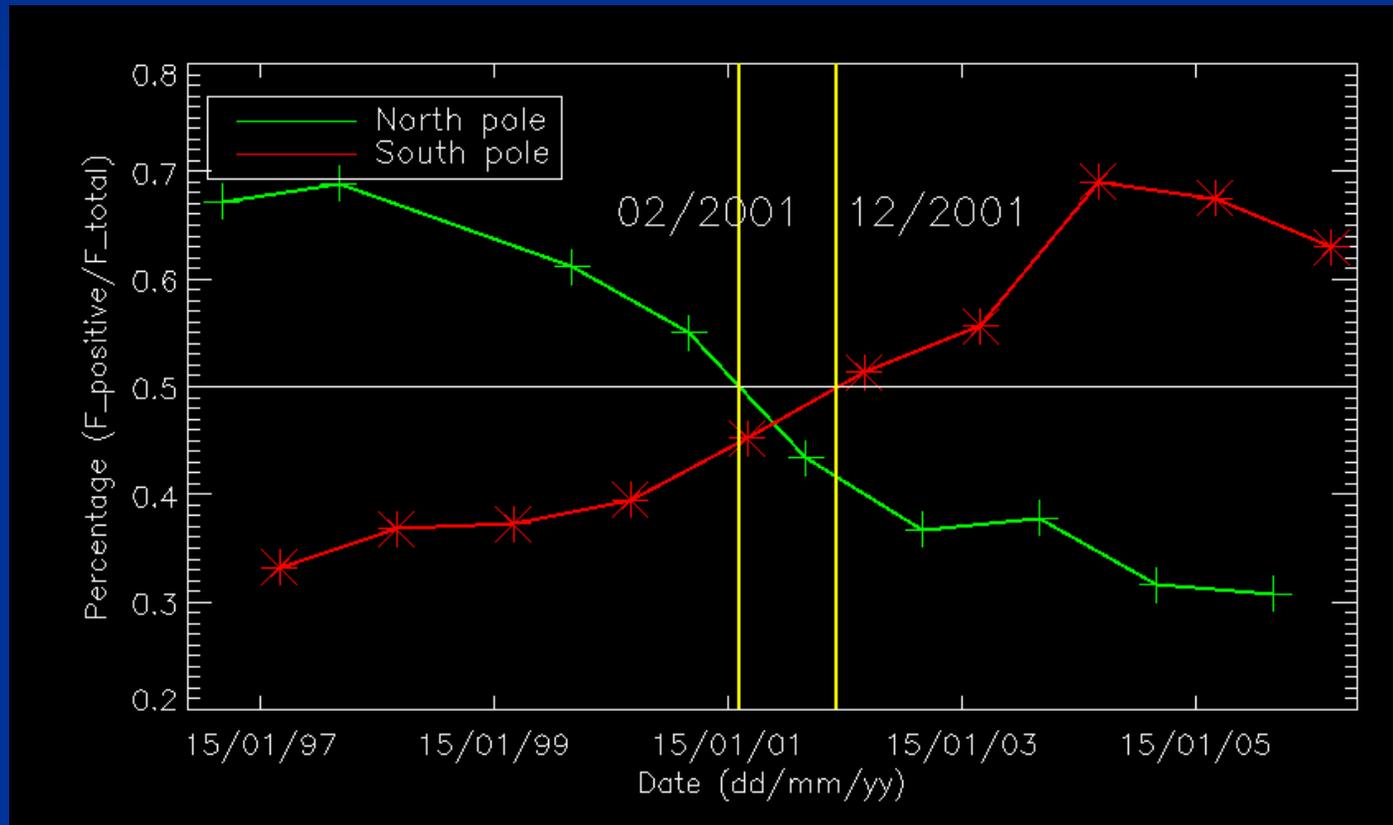
Magnetic field variation (long-term)

- Evolution of polar field (southern pole).



Magnetic field variation (long-term)

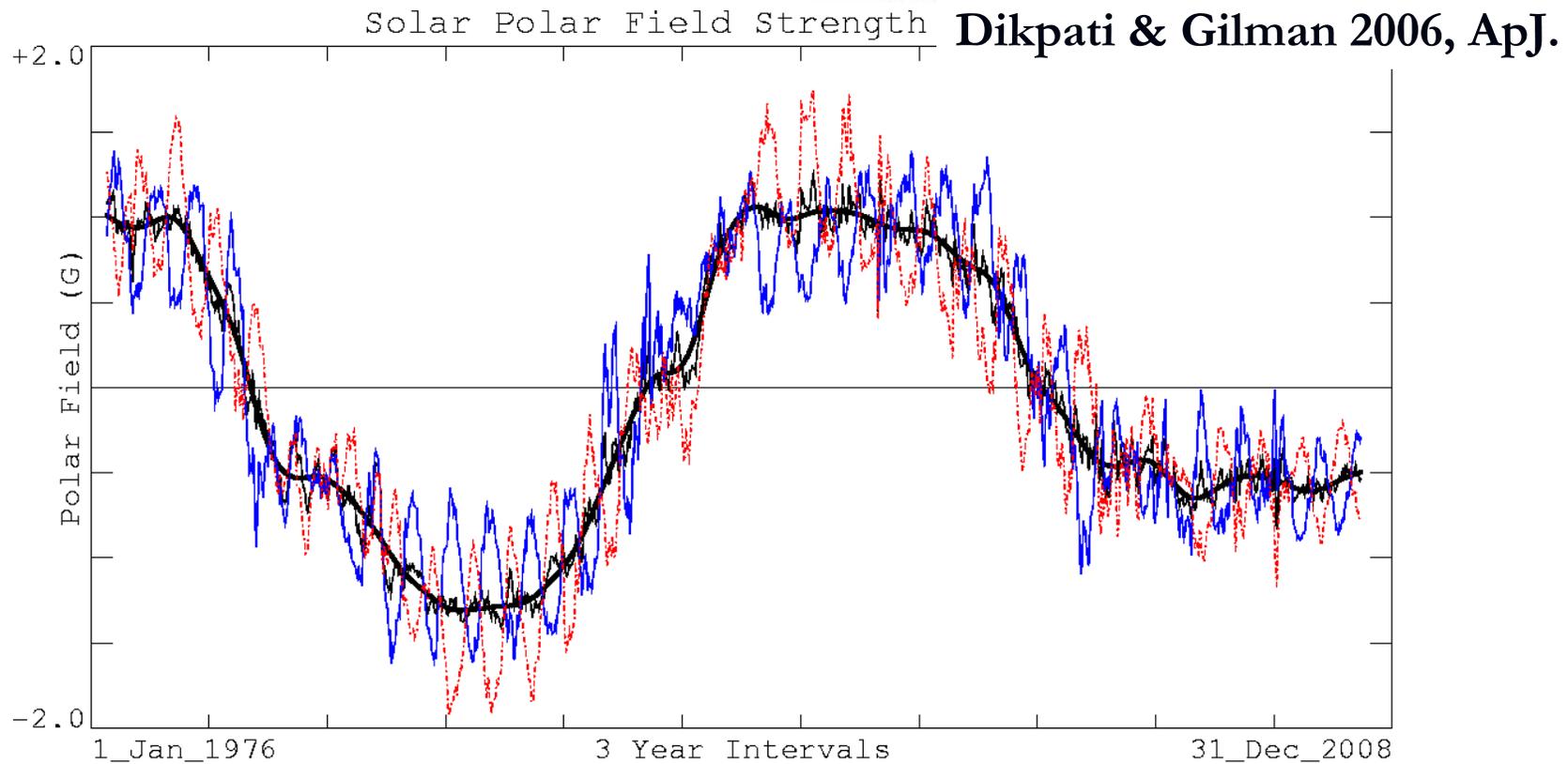
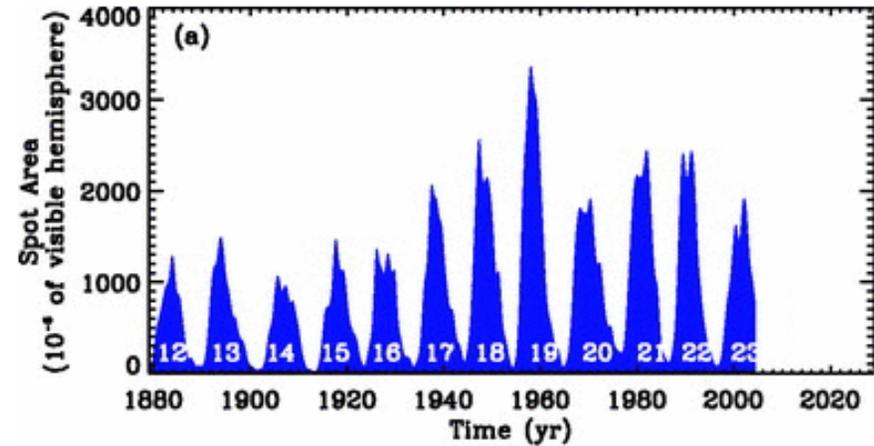
- Polar field reversal (from MDI observation).



Magnetic field

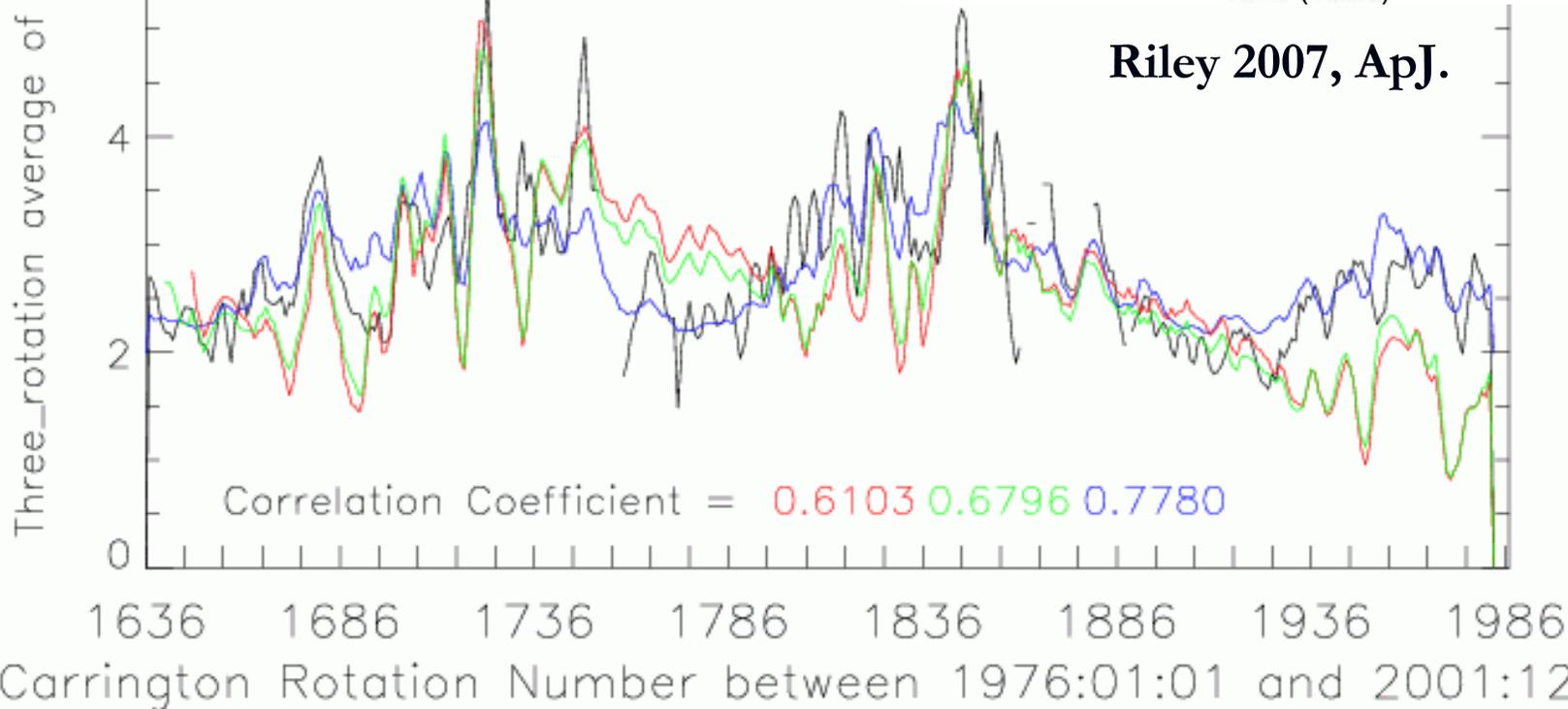
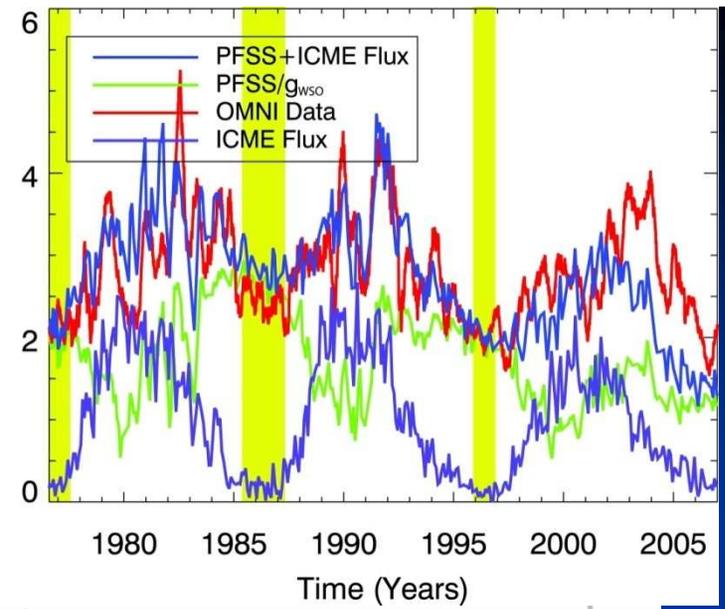
te

- Solar polar field vs time



Key: Lt.Solid = North; Dashed = -South; Med.Solid = Average: $(N-S)/2$; Hvy.Solid = Smoothed Average

Observed Br at 1 AU
 Computed Br using WSO da
 Computed Br using WSO da
 Computed Br using WSO me



Riley 2007, ApJ.



HMI/SDO

• Observables:

- Full disk Doppler velocity with a resolution of 1 arcsec;
- Full disk light-of-sight magnetograms;
- Full disk continuum intensity; and
- Full disk vector magnetograms.

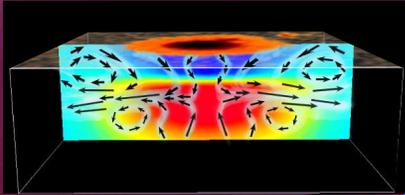
HMI Observables

Doppler Velocity	
Cadence	45 s
Precision	13 m/s
Zero point accuracy	0.05 m/s
Dynamic range	± 6.5 km/s
Line-of-Sight Magnetic Flux	
Cadence	45 s
Precision	10 G
Zero point accuracy	0.05 G
Dynamic range	± 4 kG
Continuum Intensity	
Cadence	45 s
Precision	0.3%
Accuracy pixel to pixel	0.1%

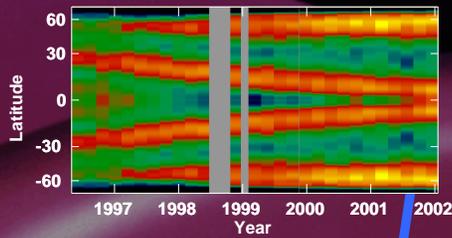
Vector Magnetic Field	
Cadence	90 s
Precision:	
Polarization	0.22%
Sunspots ($1\text{kG} < B < 4\text{kG}$) *	
B	18G
Azimuth	0.6°
Inclination	1.4°
Quiet Sun ($0.1\text{kG} < B < 2\text{kG}$) *	
B	220 G
Total flux density	35 G
Azimuth	15°
Inclination	18°

HMI Major Science Objectives

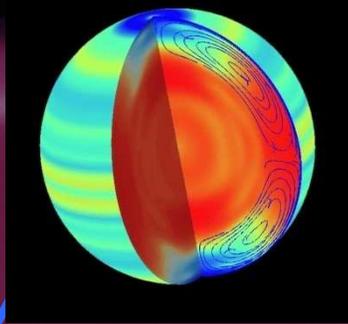
1.J – Sunspot Dynamics



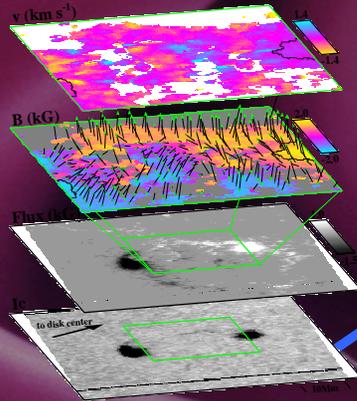
1.B – Solar Dynamo



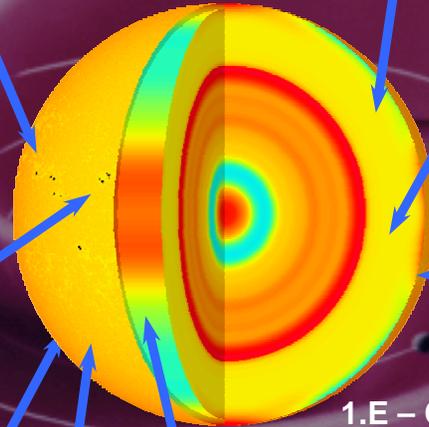
1.C – Global Circulation



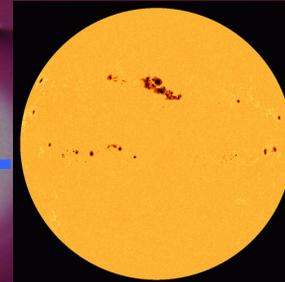
1.I – Magnetic Connectivity



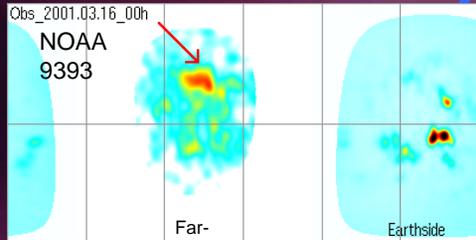
1.A – Interior Structure



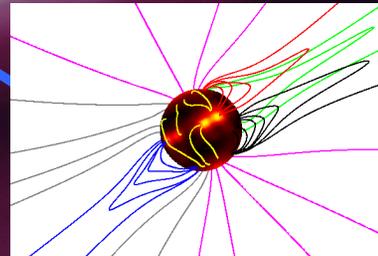
1.D – Irradiance Sources



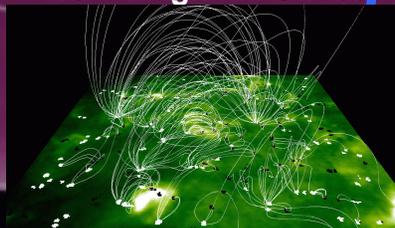
1.H – Far-side Imaging



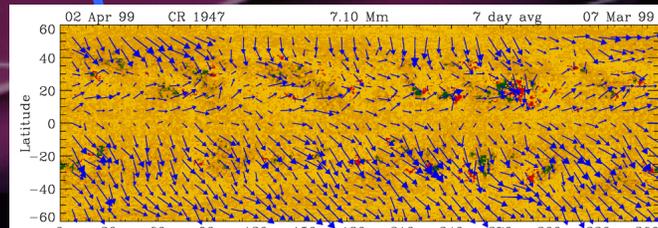
1.E – Coronal Magnetic Field



1.G – Magnetic Stresses

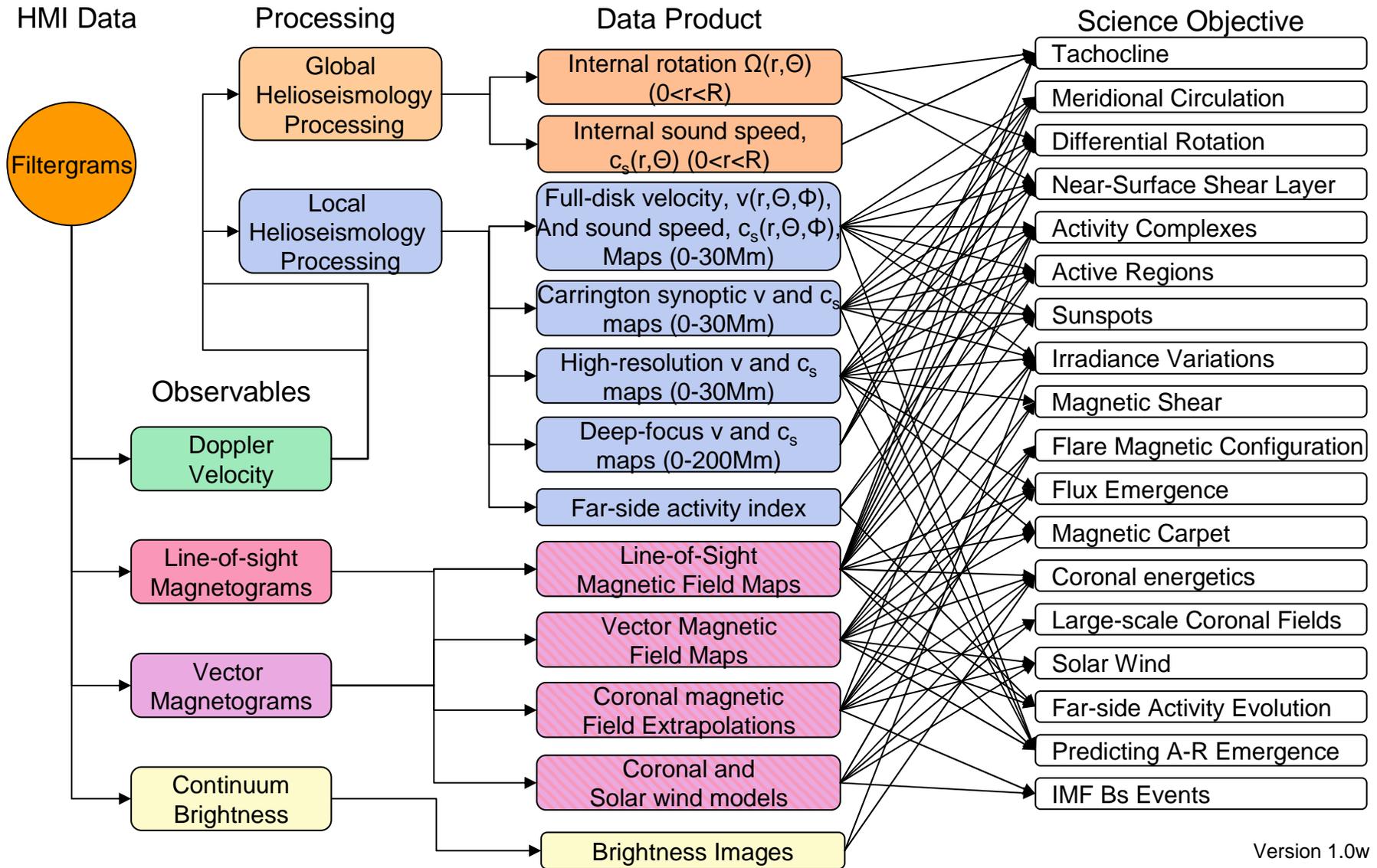


1.F – Solar Subsurface Weather



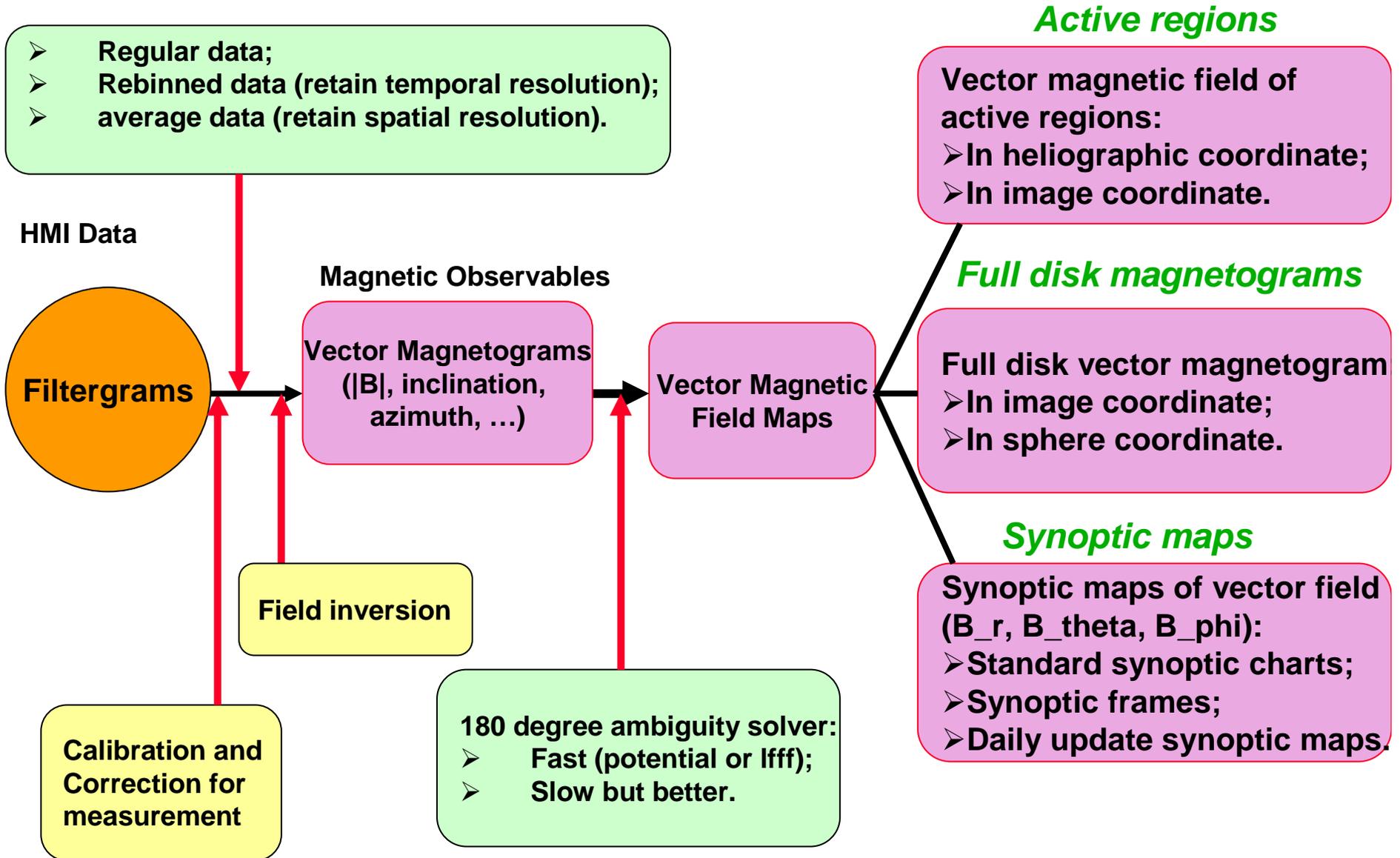


HMI Science Analysis Plan

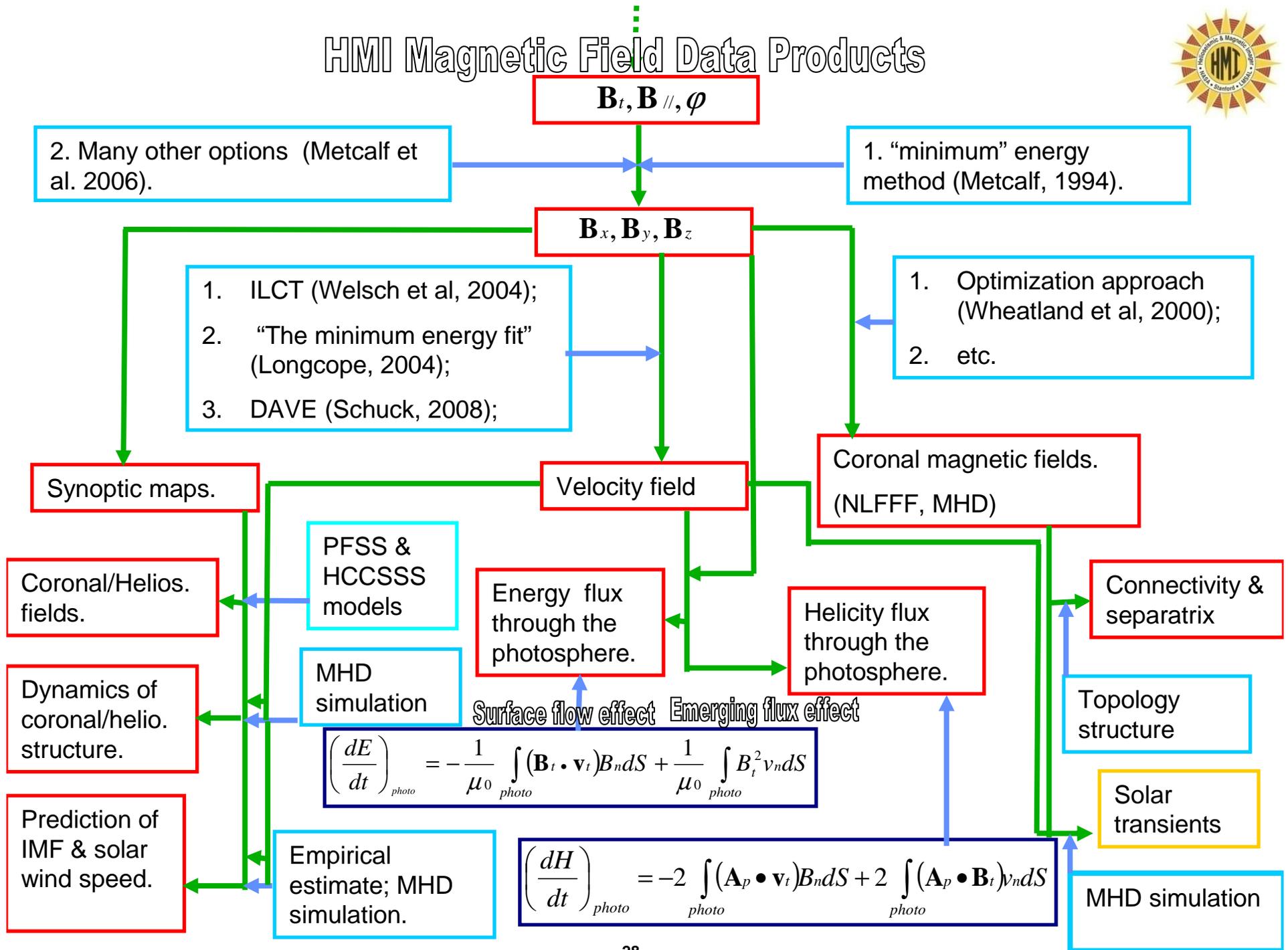


Version 1.0w

HMI Vector Field Data Flow



HMI Magnetic Field Data Products



HMI Science Production Plan: vector B

- **Quick-look data products** (almost in real time): mostly used for helping operating instruments and forecasting space weather.
- **Science data products:**
 - **Standard data products:** routinely completed for all data on regular cadence. Serve as monitor or reference to meet basic research needs .
 - **On-demand data products** (for most cases): Completed for small fraction of data when interesting things happen or whenever requested.
 - **On-request data products:** Completed when system resources allow.

HMI Production Plan: vector B (detail)

■ Quick Look data:

- One minute (Doppler cadence, 50 s)
 - 1-minute line-of-sight velocity;
 - 1-minute line-of-sight magnetic field (either radial or line-of-sight);
 - 1-minute continuum intensity;
 - 1-minute indices for solar activity computed by TBD algorithm;
- 10-minute (fastest vector field cadence averaged over 6 cycles);
 - 10-minute global quick-look inversion;
 - Indices for patches computed from 10-minute field values;
- 1-hour
 - Synoptic maps of radial B at lower resolution (TBD; probably 1 degree);
 - Vector field updated only in patches.
- 6-hour
 - Quick-look full disk disambiguated vector field.

■ Science data products:

- Standard:
 - One-minute
 - Signed line-of-sight B on full disk;
 - Magnetic line-of-sight velocity on full disk;
 - Continuum intensity on full disk.
 - 10-minute
 - Inverted B on full disk;
 - Disambiguated vector field on selected patches.
 - 3-hour
 - Disambiguated vector field on full disk;
 - Some higher level products.
- On demand:
 - 3-second level 1.5 filtergrams;
 - 3-minute spatially binned, disambiguated vector field patches;
 - 6-minute disambiguated patches;
 - 10-minute full disk disambiguated vector field;
 - Some higher level data products.
- On request
 - 100-second disambiguated patches;
 - 100-second IQUV;
 - Higher level data products;
 - Anything else.