Synoptic Solar Cycle observed by Solar Dynamics Observatory

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Pulkovo Astronomical Observatory
Saint Petersburg State University

'Differential Rotation and Magnetism across the HR Diagram',
Nordita, Stockholm, Sweden, 10 April 2013

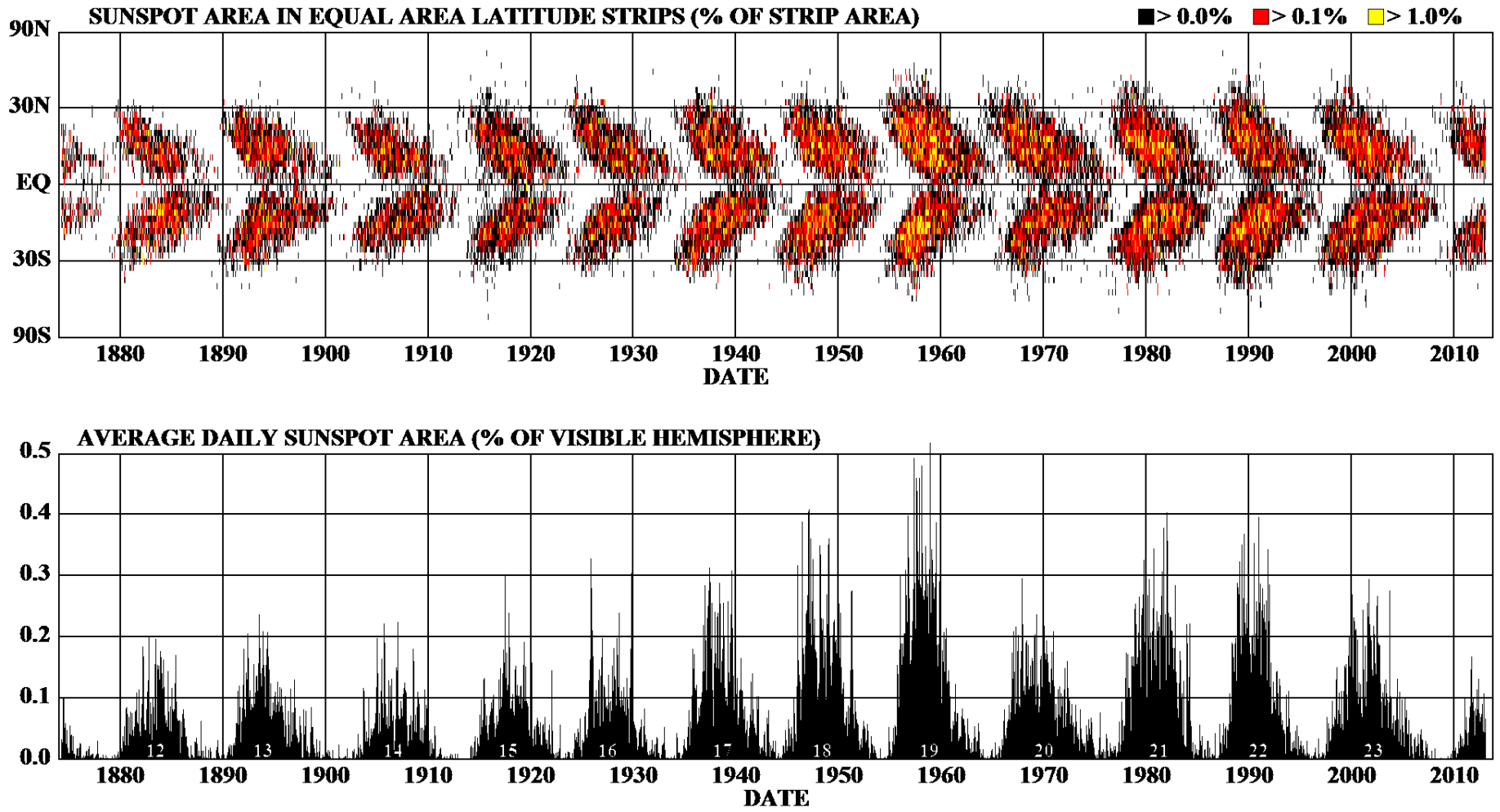
Questions

- How the transport of the magnetic flux affect the solar cycle?
- Variability of the solar activity. What processes are responsible for these effects?
- What is the role of the coronal processes in the forming of the large-scale solar magnetic field?

Main features of the solar cycle

- 11-year sunspot cycle (Shwabe-Wolf law)
- Maunder's Butterfly diagrams of sunspots in latitude-time coordinate system (Spörer law)
- Changing of the magnetic polarity in bi-polar complexes of solar activity(Hale's law)
- Joe's law (about a tilt of the bi-polar regions)

DAILY SUNSPOT AREA AVERAGED OVER INDIVIDUAL SOLAR ROTATIONS



http://solarscience.msfc.nasa.gov/

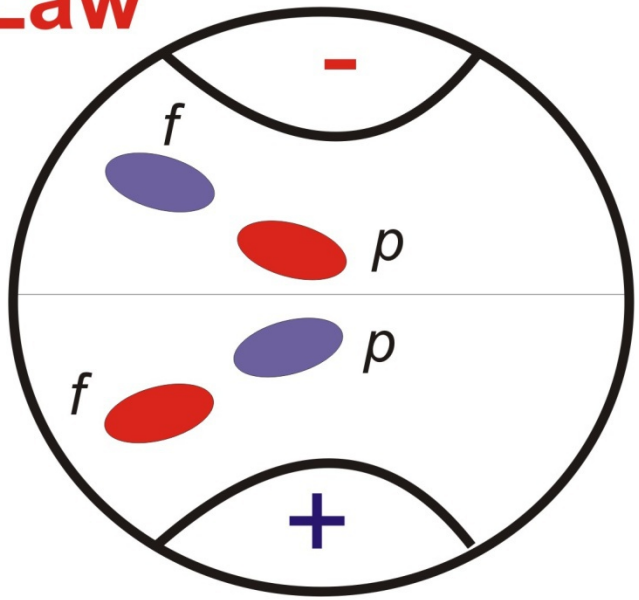
HATHAWAY/NASA/MSFC 2013/04

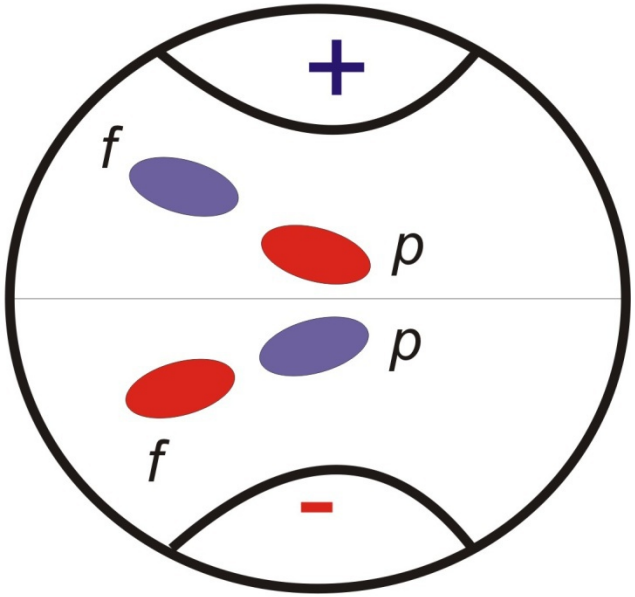
Hale's Law

Before polar reversals

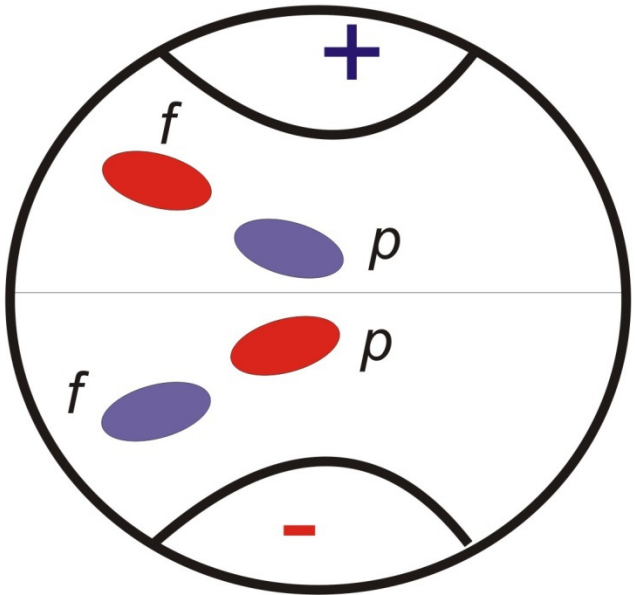
After polar reversals

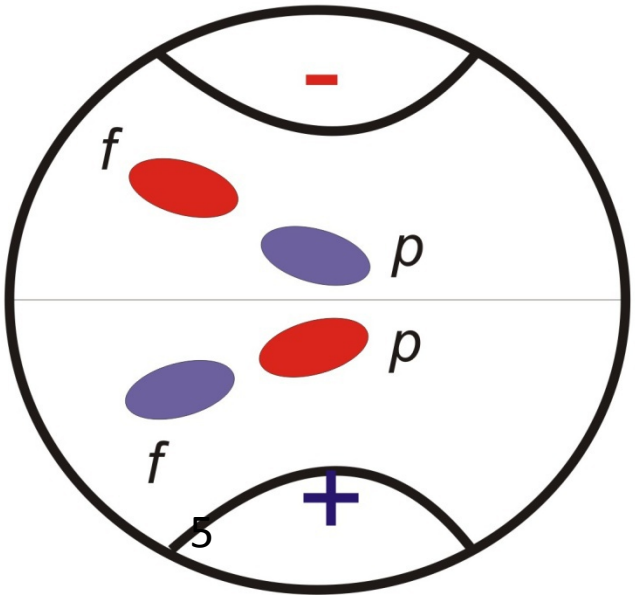
Even Cycle





Odd cycle





- **AIA(Atmospheric Imaging Assembly, ultraviolet),**
- **EVE (The Extreme ultraviolet Variability Experiment , irradiance)**
- **HMI (Helioseismic and Magnetic Imager, velocity maps, magnetic field).**

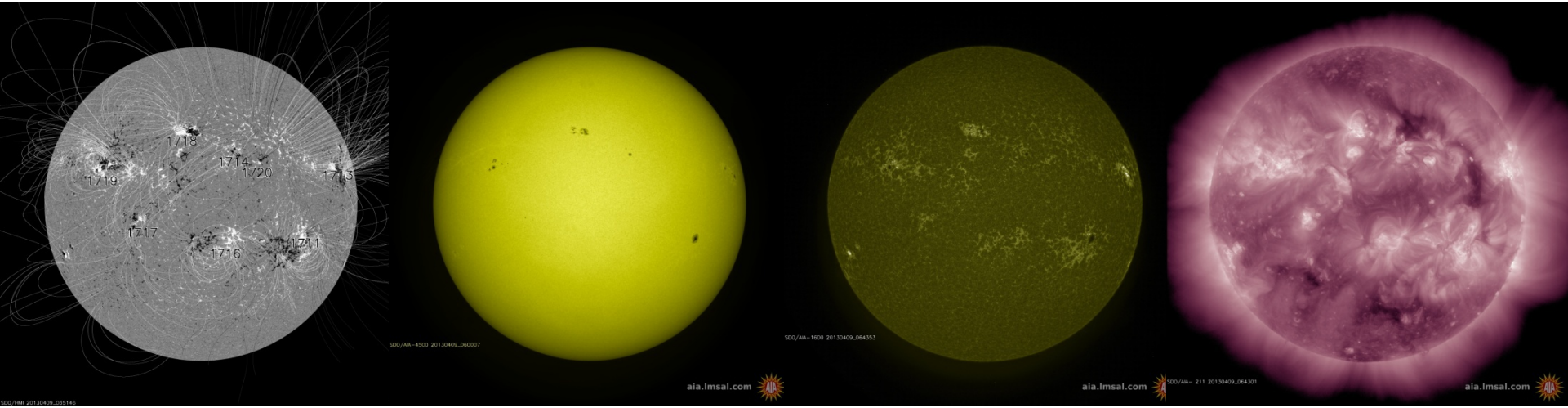
HMI provides four main types of data:
dopplergrams (maps of solar surface velocity), continuum filtergrams (broad-wavelength photographs of the solar
photosphere), and both line-of-sight and vector magnetograms (maps of the photospheric magnetic field).

AIA (ATMOSPHERIC IMAGING ASSEMBLY)

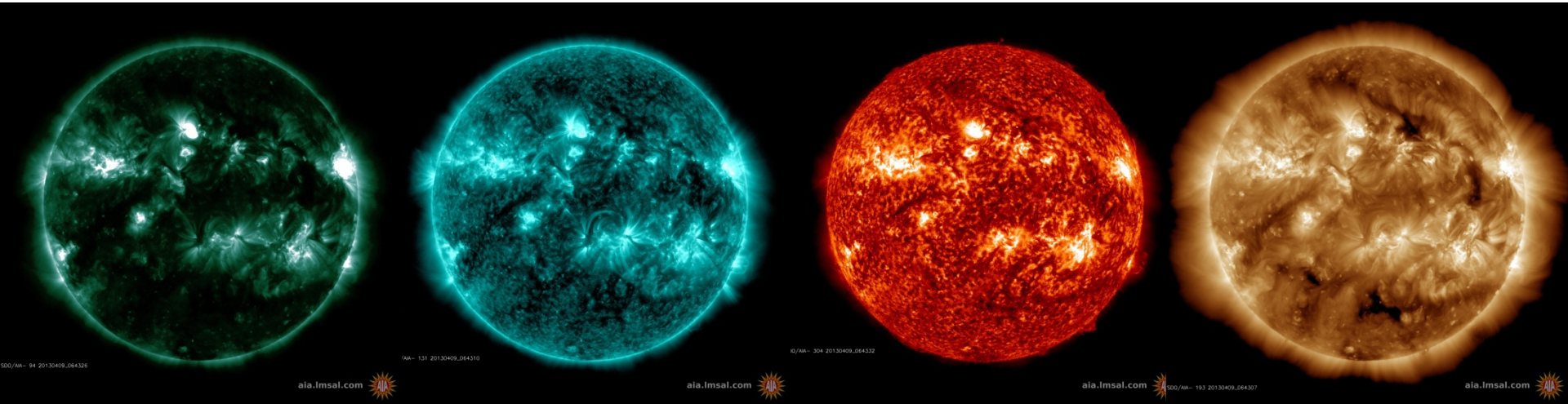
Channel name	Primary ion(s)	Region of atmosphere*	Char. log(T)
white light	continuum	photosphere	3.7
1700Å	continuum	temperature minimum, photosphere	3.7
304Å	He II	chromosphere, transition region	4.7
1600Å	C IV+cont.	transition region + upper photosphere	5.0
171Å	Fe IX	quiet corona, upper transition region	5.8
193Å	Fe XII, XXIV	corona and hot flare plasma	6.1, 7.3
211Å	Fe XIV	active-region corona	6.3
335Å	Fe XVI	active-region corona	6.4
94Å	Fe XVIII	flaring regions (partial readout possible)	6.8
131Å	Fe VIII, XX, XXIII	flaring regions (partial readout possible)	5.6, 7.0, 7.2

Sun on 9 April 2013, 6:00 -7:00 UT

HMI, LOS | AIA 4500A | AIA 1600A | AIA 211A



AIA 094A | AIA 131A | AIA 304A | AIA 193A



AIA and HMI papers

Solar Phys (2012) 275:17–40
DOI 10.1007/s11207-011-9776-8

THE SOLAR DYNAMICS OBSERVATORY

The *Atmospheric Imaging Assembly* (AIA) on the *Solar Dynamics Observatory* (SDO)

James R. Lemen · Alan M. Title · David J. Akin · Paul F. Boerner · Catherine Chou · Jerry F. Drake · Dexter W. Duncan · Christopher G. Edwards · Frank M. Friedlaender · Gary F. Heyman · Neal E. Hurlburt · Noah L. Katz · Gary D. Kushner · Michael Levay · Russell W. Lindgren · Dnyanesh P. Mathur · Edward L. McFeaters · Sarah Mitchell · Roger A. Rehse · Carolus J. Schrijver · Larry A. Springer · Robert A. Stern · Theodore D. Tarbell · Jean-Pierre Wuelser · C. Jacob Wolfson · Carl Yanari · Jay A. Bookbinder · Peter N. Cheimets · David Caldwell · Edward E. Deluca · Richard Gates · Leon Golub · Sang Park · William A. Podgorski · Rock I. Bush · Philip H. Scherrer · Mark A. Gummin · Peter Smith · Gary Auker · Paul Jerram · Peter Pool · Regina Soufli · David L. Windt · Sarah Beardsley · Matthew Clapp · James Lang · Nicholas Waltham

Solar Phys (2012) 275:3–15
DOI 10.1007/s11207-011-9841-3

THE SOLAR DYNAMICS OBSERVATORY

The *Solar Dynamics Observatory* (SDO)

W. Dean Pesnell · B.J. Thompson · P.C. Chamberlin

Solar Phys (2012) 275:207–227
DOI 10.1007/s11207-011-9834-2

THE SOLAR DYNAMICS OBSERVATORY

The *Helioseismic and Magnetic Imager* (HMI) Investigation for the *Solar Dynamics Observatory* (SDO)

P.H. Scherrer · J. Schou · R.I. Bush · A.G. Kosovichev · R.S. Bogart · J.T. Hoeksema · Y. Liu · T.L. Duvall Jr. · J. Zhao · A.M. Title · C.J. Schrijver · T.D. Tarbell · S. Tomczyk

Solar Phys (2012) 275:41–66
DOI 10.1007/s11207-011-9804-8

THE SOLAR DYNAMICS OBSERVATORY

Initial Calibration of the *Atmospheric Imaging Assembly* (AIA) on the *Solar Dynamics Observatory* (SDO)

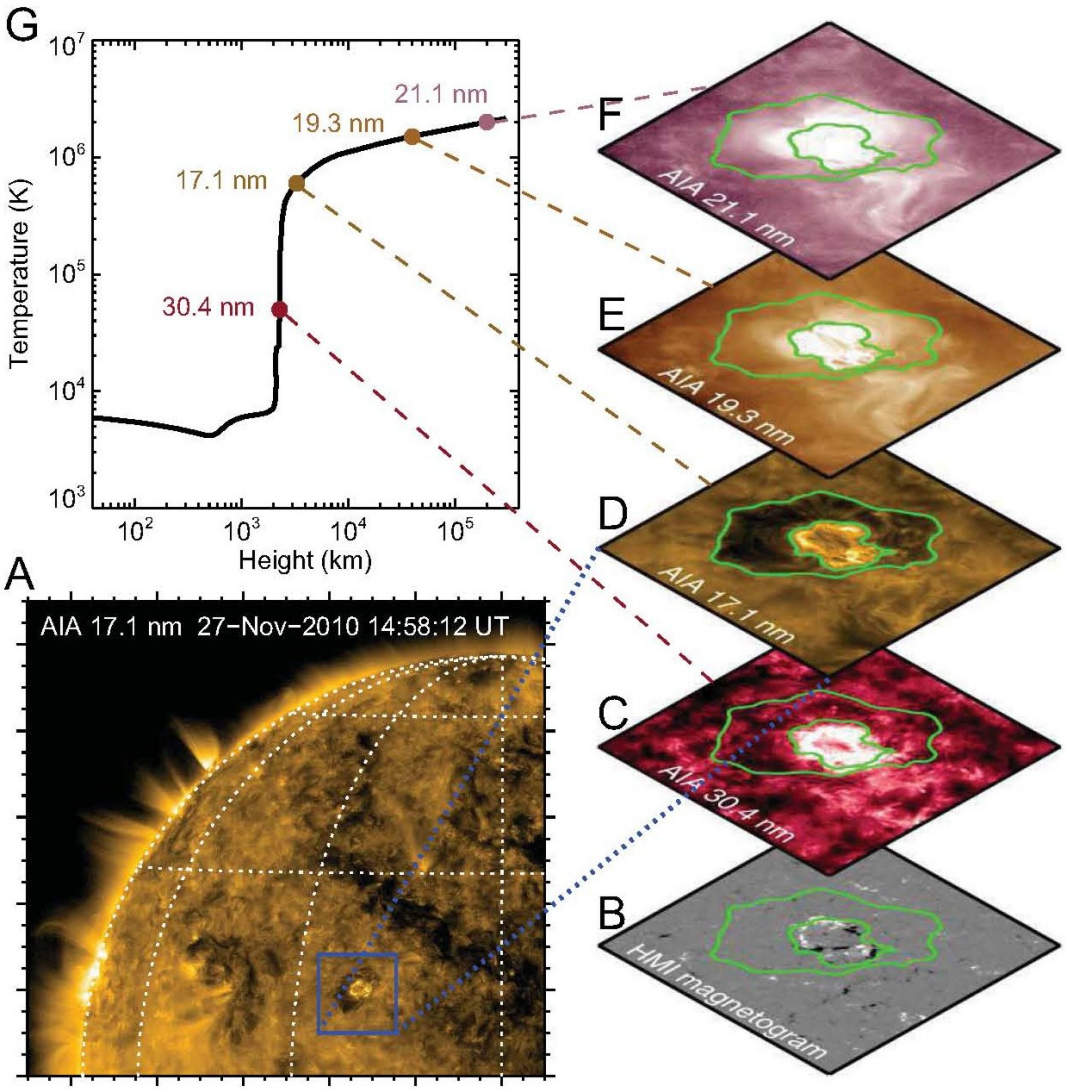
Paul Boerner · Christopher Edwards · James Lemen · Adam Rausch · Carolus Schrijver · Richard Shine · Lawrence Shing · Robert Stern · Theodore Tarbell · Alan Title · C. Jacob Wolfson · Regina Soufli · Eberhard Spiller · Eric Gullikson · David McKenzie · David Windt · Leon Golub · William Podgorski · Paola Testa · Mark Weber

Solar Phys (2012) 275:327–355
DOI 10.1007/s11207-010-9639-8

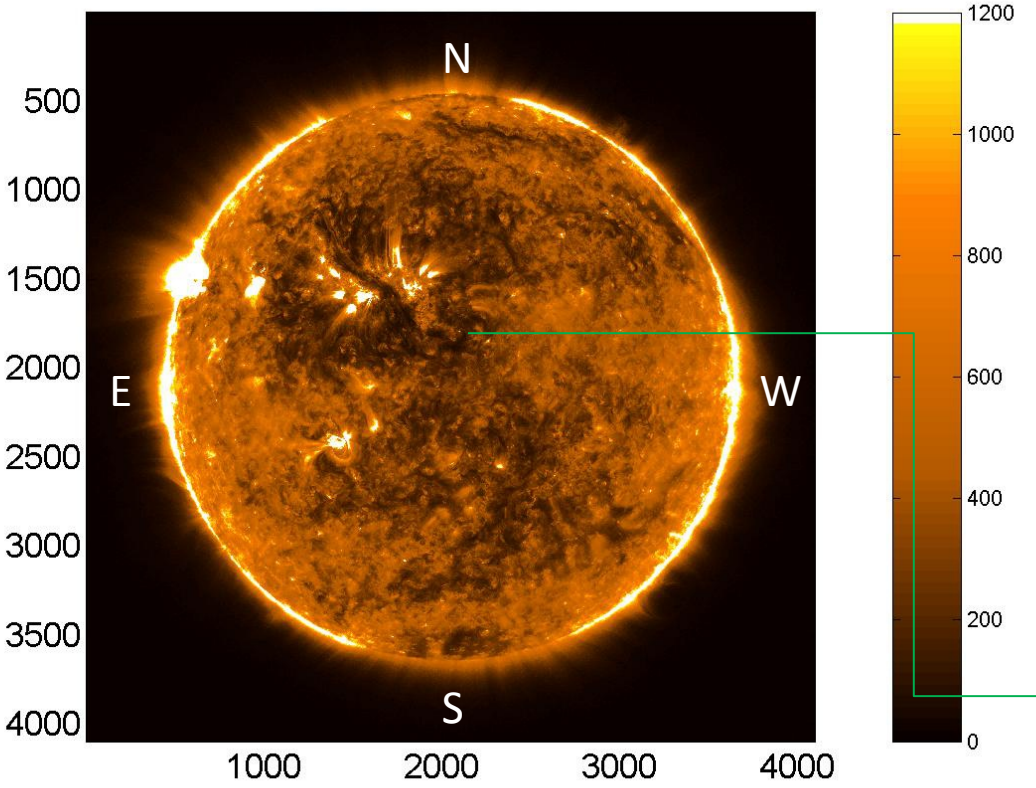
THE SOLAR DYNAMICS OBSERVATORY

Polarization Calibration of the *Helioseismic and Magnetic Imager* (HMI) onboard the *Solar Dynamics Observatory* (SDO)

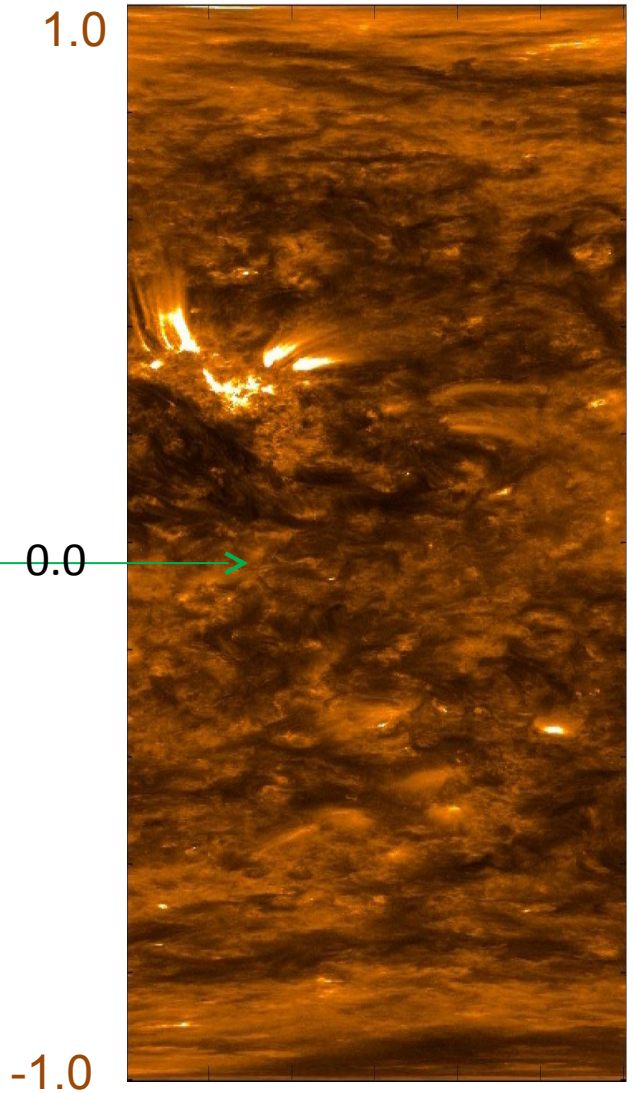
J. Schou · J.M. Borrero · A.A. Norton · S. Tomczyk · D. Elmore · G.L. Card



Jun Zhang, Shuhong Yang, Yang Liu, and Xudong Sun, 2012

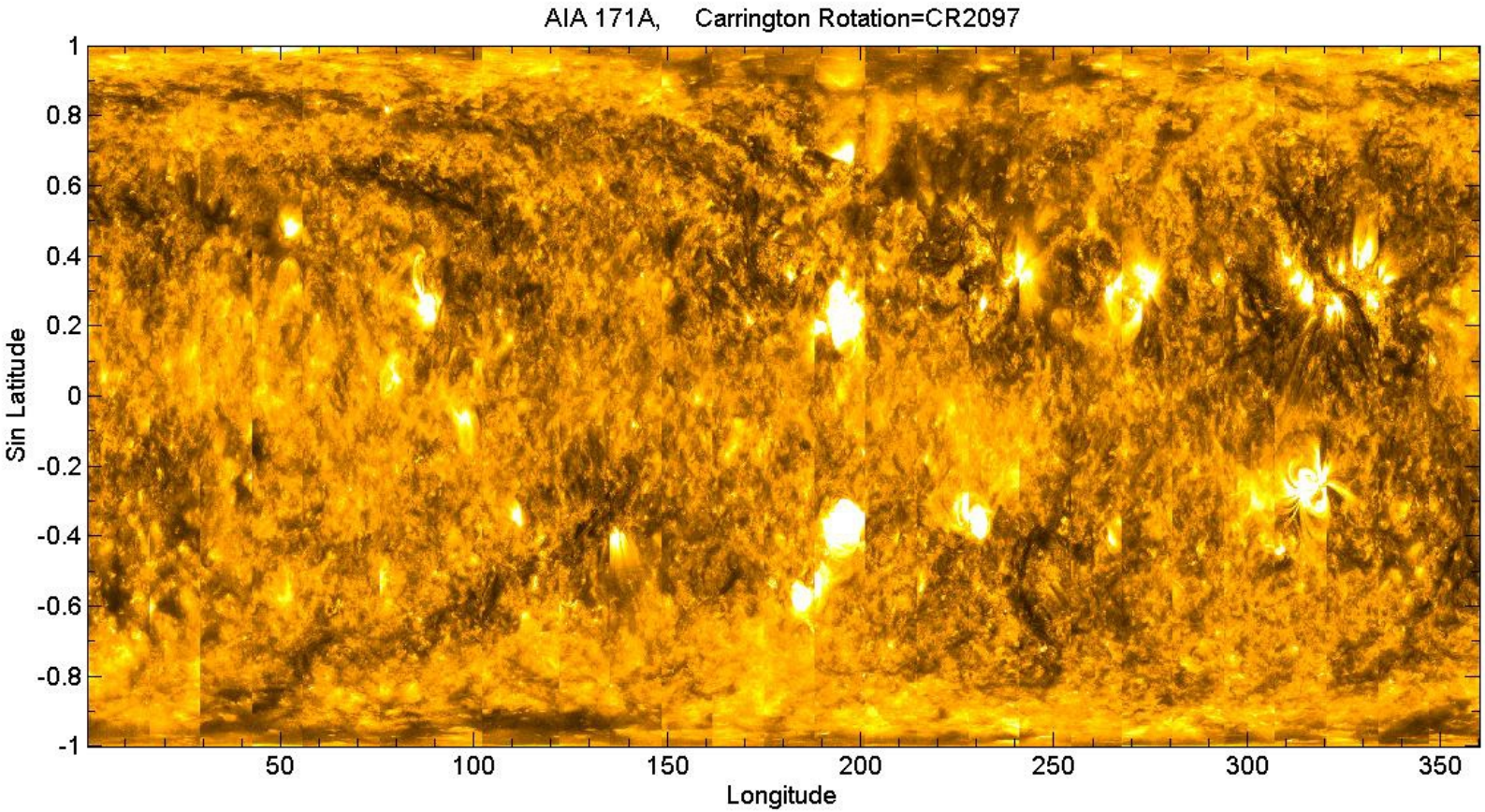


AIA 171A, 21 May 2010, 12:00UT

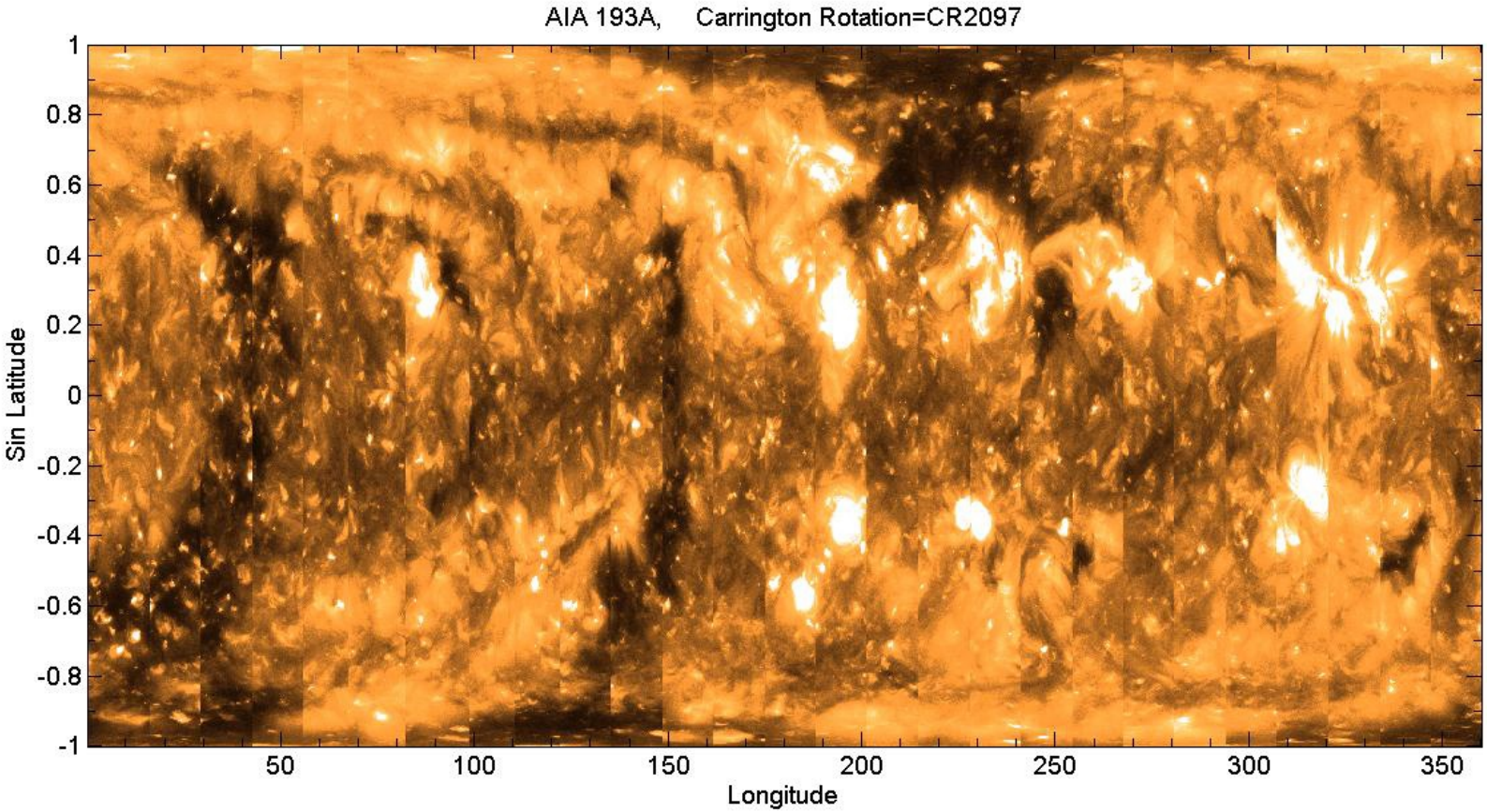


Sine Latitude from -1.0 to 1.0
With resolution 0.001

Longitude ±15o
with resolution of 0.1o.


AIA 171A, Carrington Rotation=CR2097
Sin Latitude
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
50
100
150
200
250
300
350
Longitude

Time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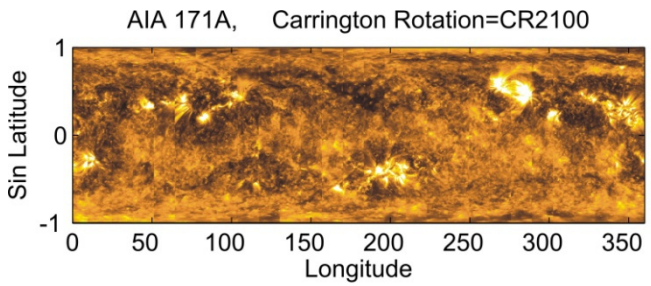
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
50
100
150
200
250
300
350
Longitude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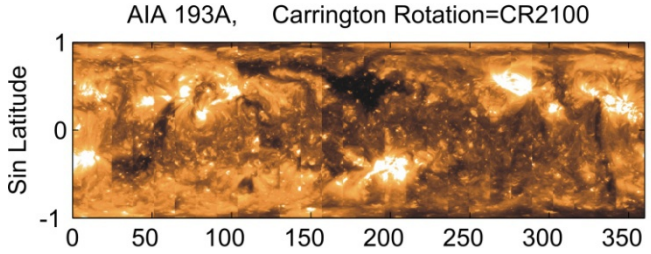
Sin Latitude
Longitude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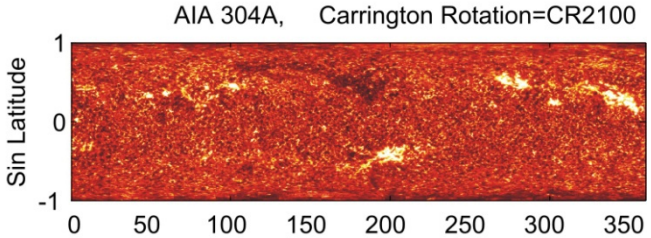
Sin Latitude
Longitude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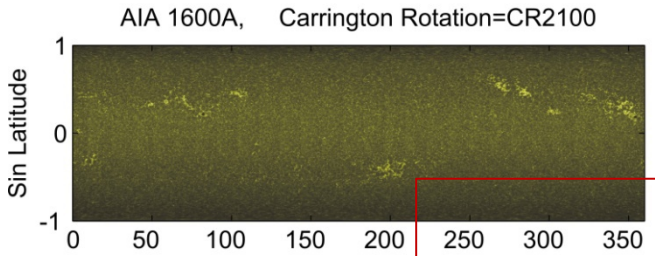
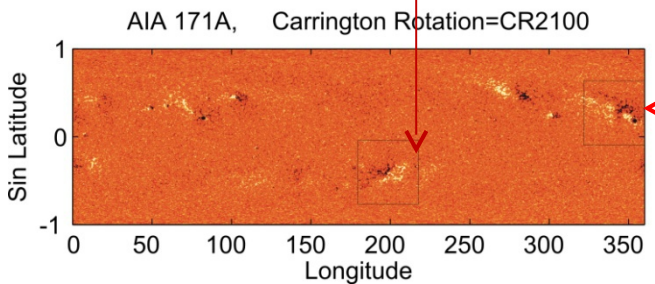
Sin Latitude
Longitude


AIA 1600A, Carrington Rotation=CR2100
Sin Latitude
Longitude


AIA 171A, Carrington Rotation=CR2100
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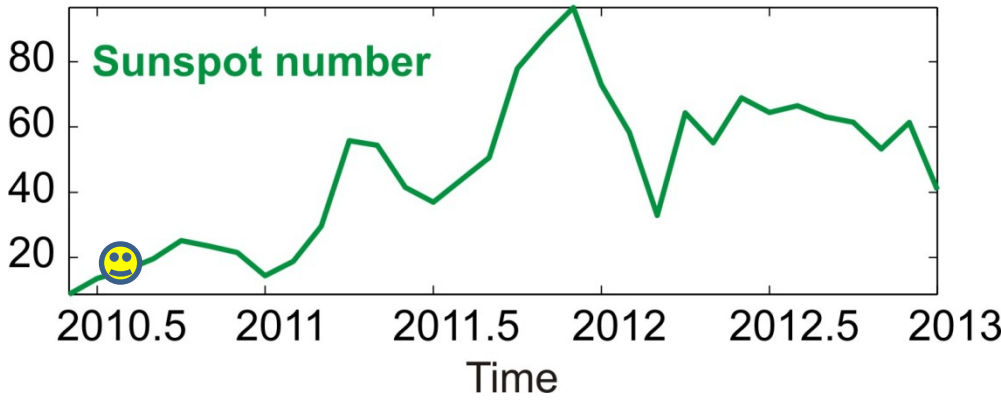
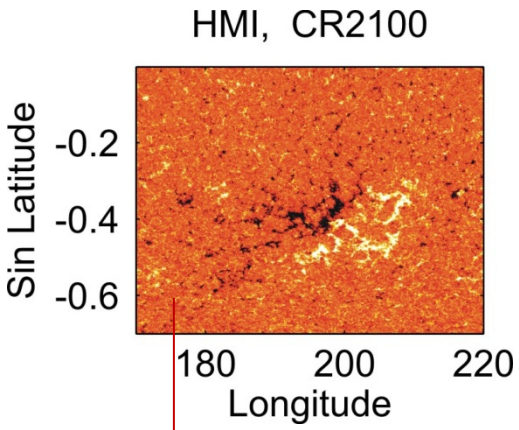
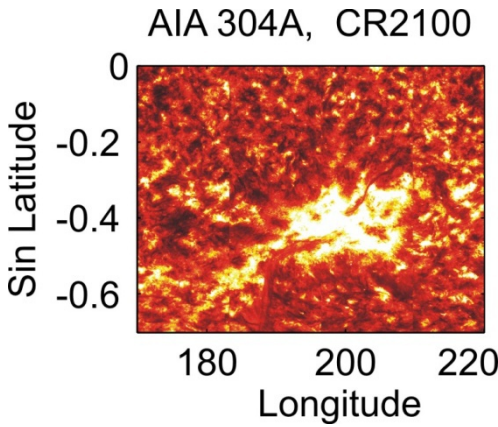
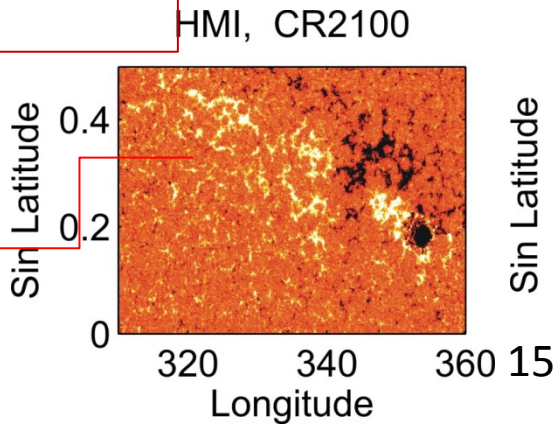
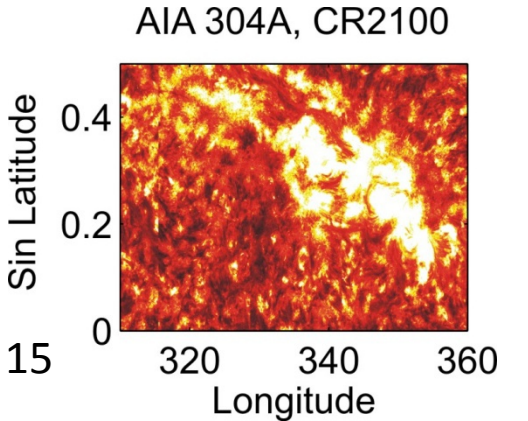
Longitude

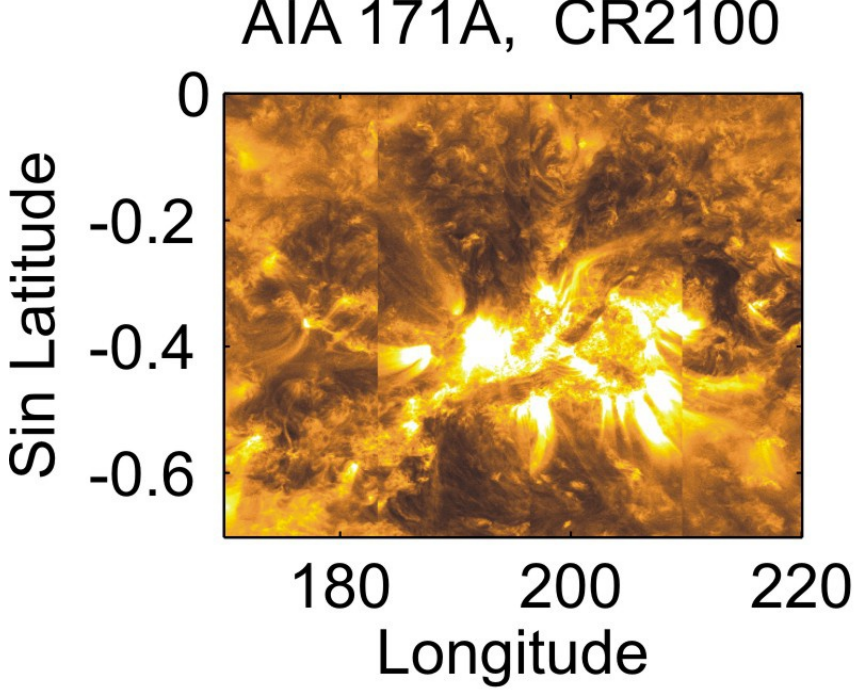

Cycle 24
Sunspot number
Time

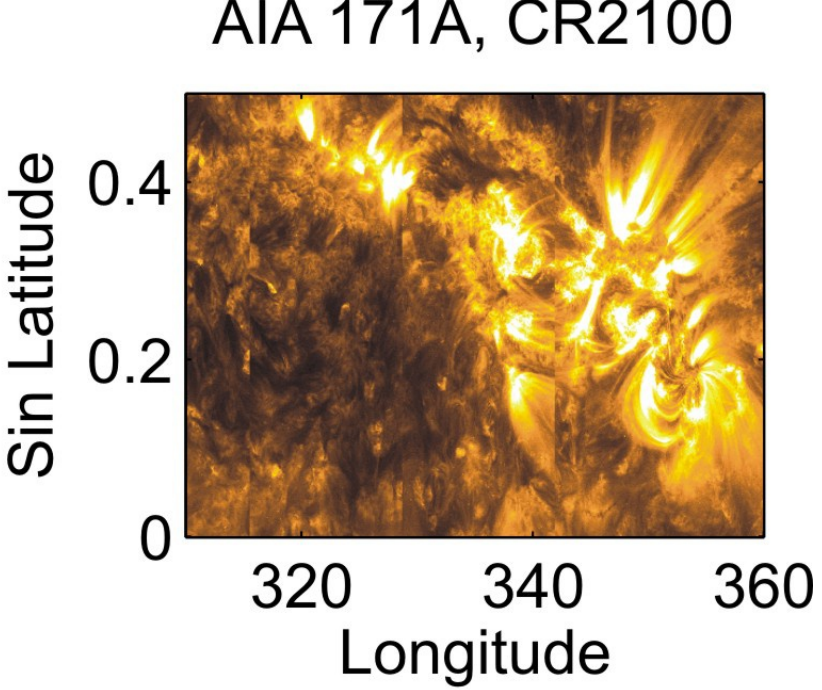

HMI, CR2100
Sin Latitude
Longitude

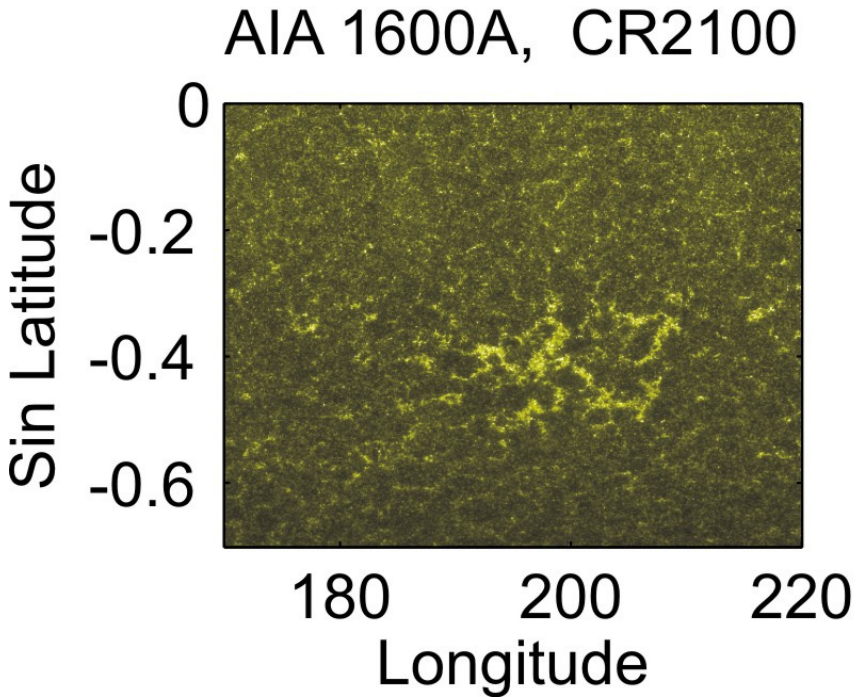

AIA 304A, CR2100
Sin Latitude
Longitude

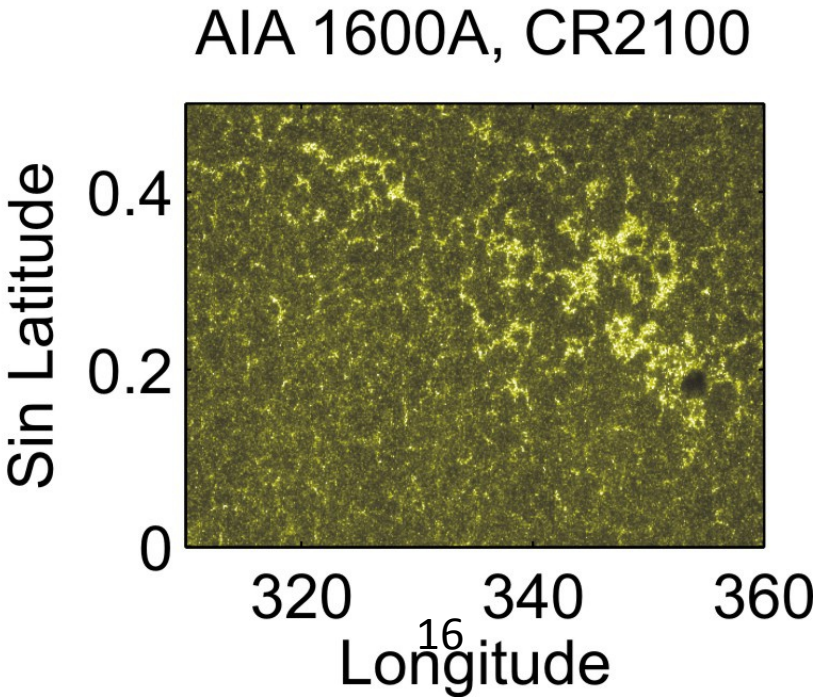

HMI, CR2100
Sin Latitude
Longitude


AIA 304A, CR2100
Sin Latitude
Longitude

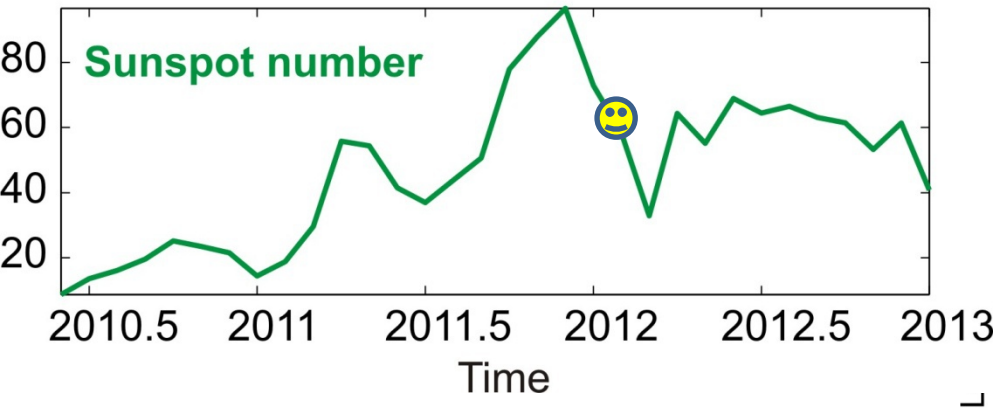

AIA 171A, CR2100
Sin Latitude
0
-0.2
-0.4
-0.6
180
200
220
Longitude

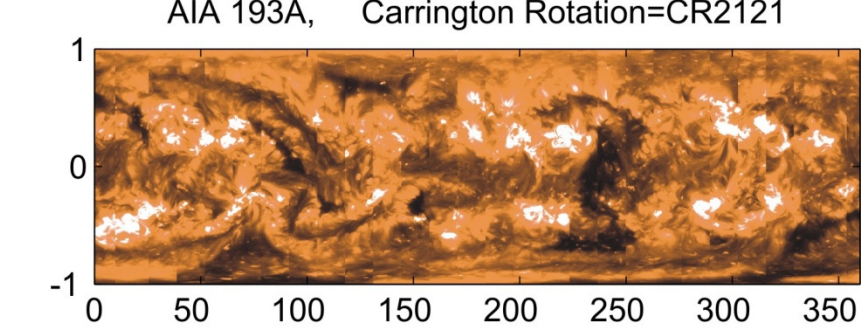

AIA 171A, CR2100
Sin Latitude
0.4
0.2
0
320
340
360
Longitude

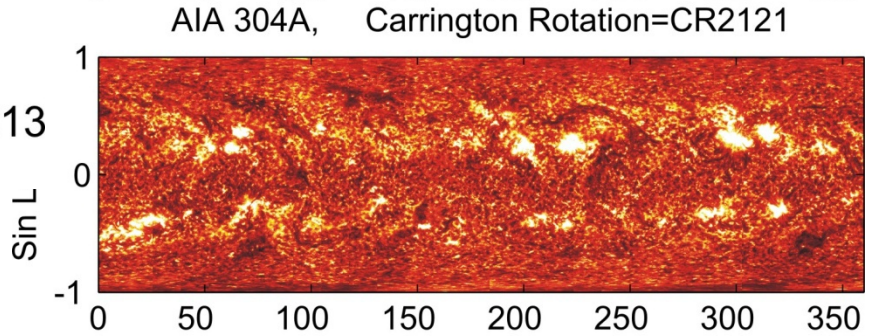

AIA 1600A, CR2100
Sin Latitude
0
-0.2
-0.4
-0.6
180
200
220
Longitude

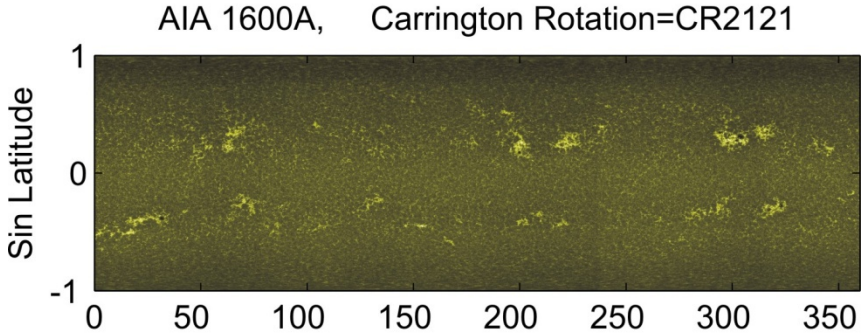

AIA 1600A, CR2100
Sin Latitude
0.4
0.2
0
320
340
360
Longitude

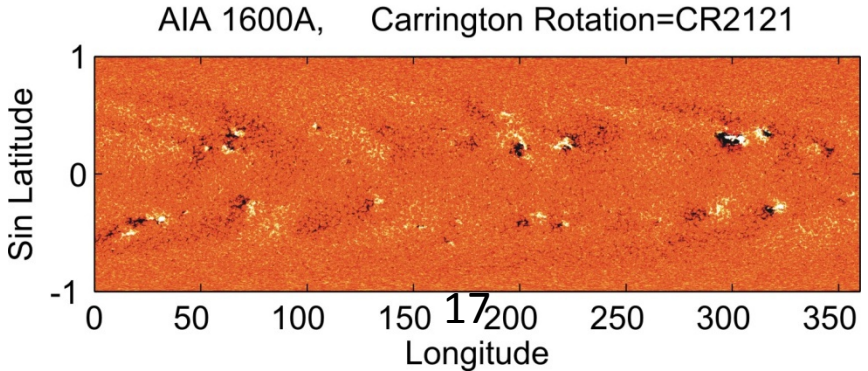
Cycle 24


Sunspot number
80
60
40
20
2010.5
2011
2011.5
2012
2012.5
2013
Time

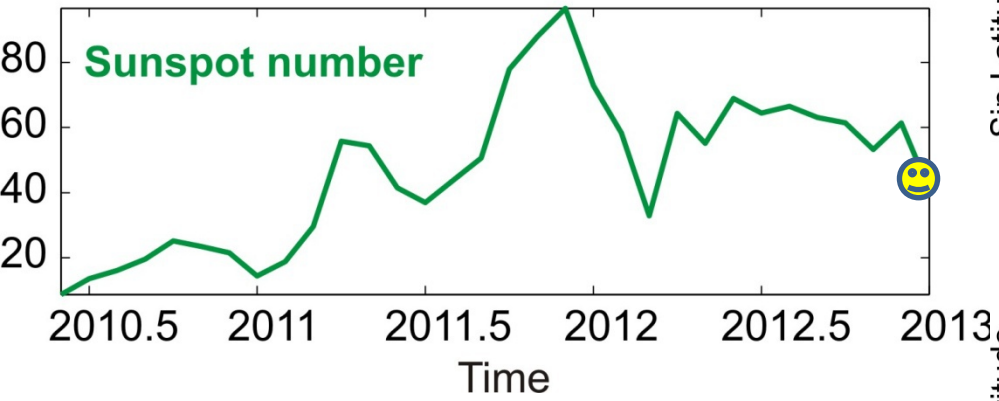

AIA 193A, Carrington Rotation=CR2121
1
0
-1
0
50
100
150
200
250
300
350

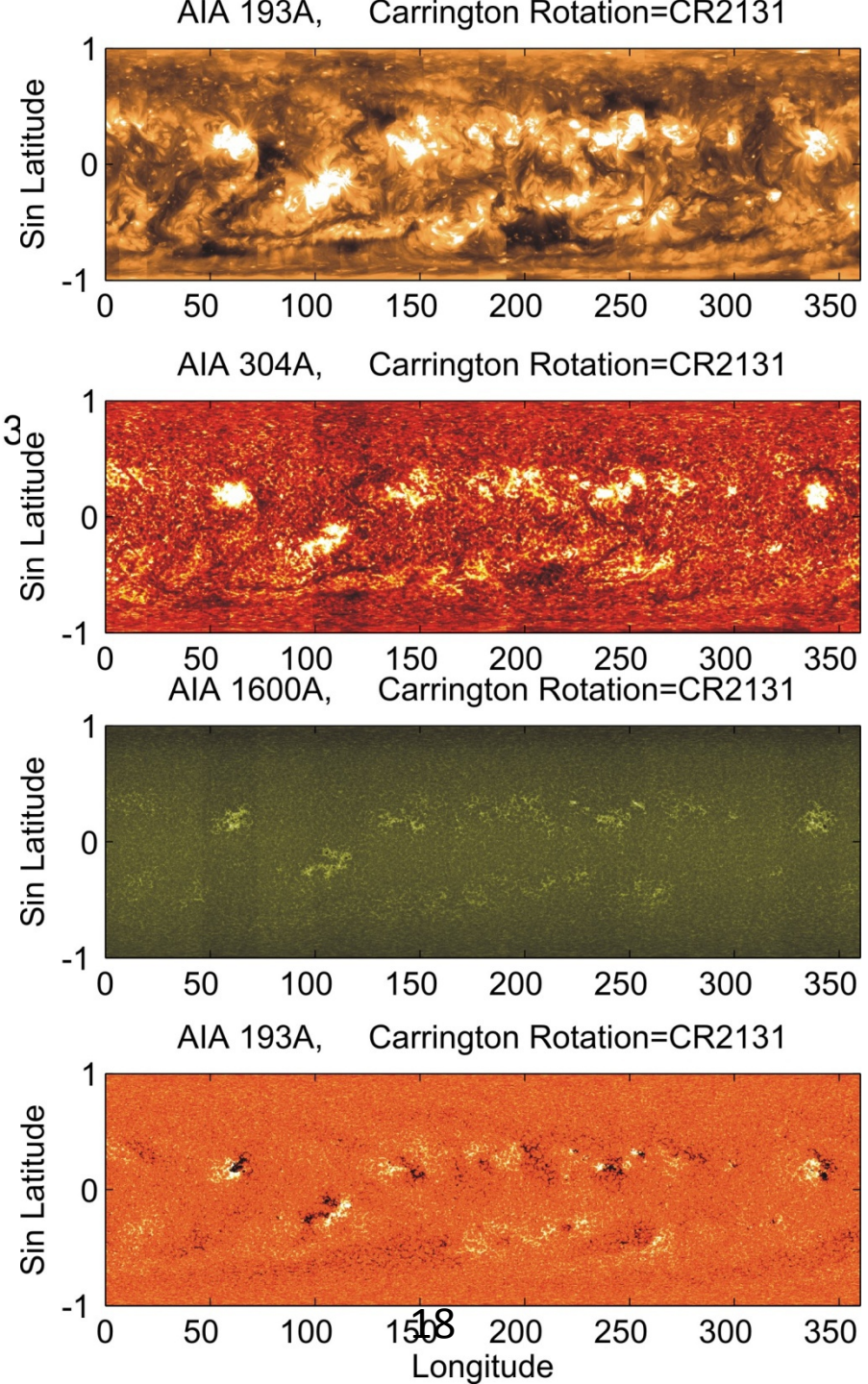

AIA 304A, Carrington Rotation=CR2121
Sin L
1
0
-1
0
50
100
150
200
250
300
350

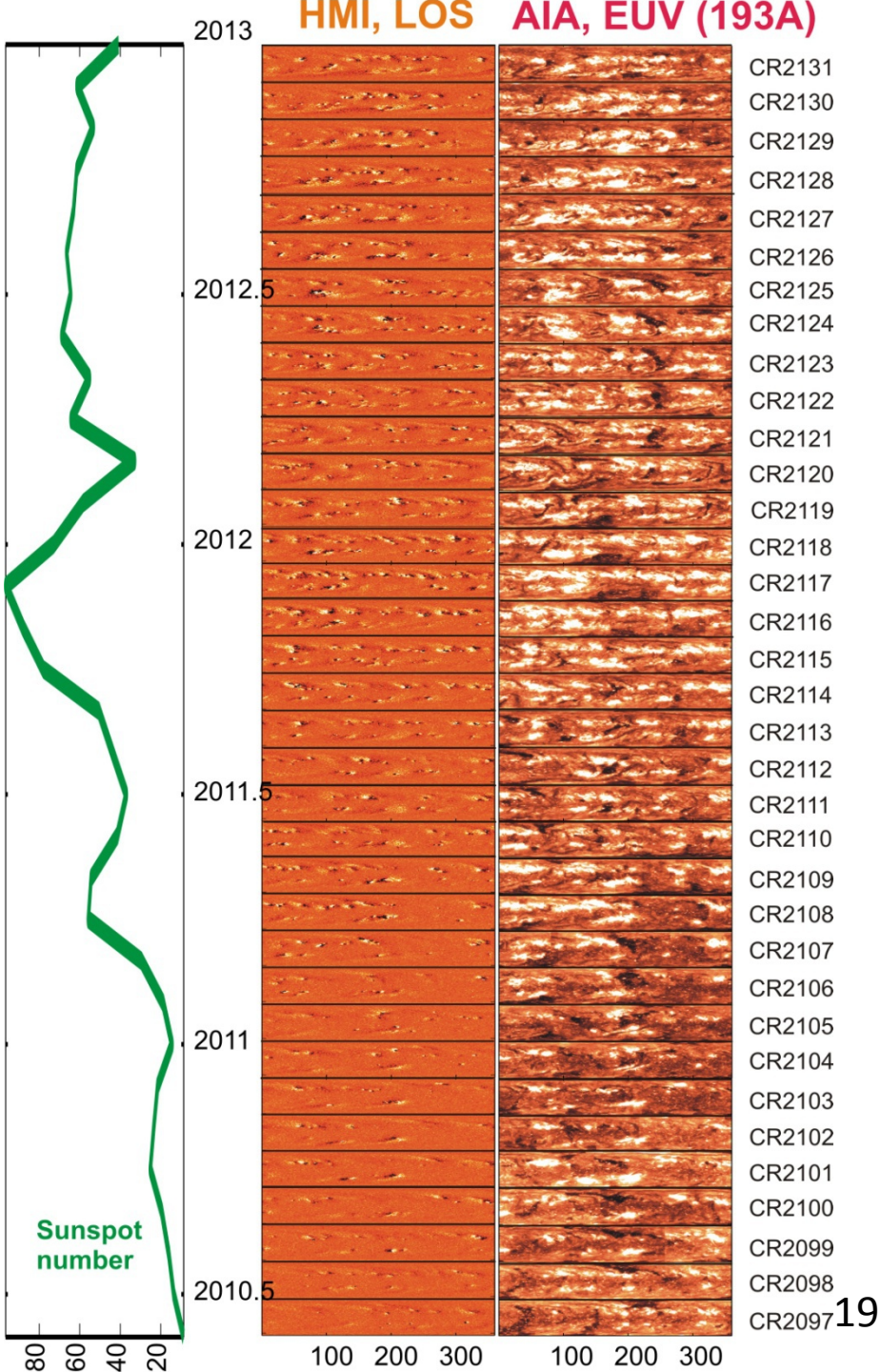

AIA 1600A, Carrington Rotation=CR2121
Sin Latitude
1
0
-1
0
50
100
150
200
250
300
350


AIA 1600A, Carrington Rotation=CR2121
Sin Latitude
1
0
-1
0
50
100
150
200
250
300
350
Longitude

Cycle 24


Sunspot number
80
60
40
20
2010.5
2011
2011.5
2012
2012.5
2013
Time


AIA 193A, Carrington Rotation=CR2131
AIA 304A, Carrington Rotation=CR2131
AIA 1600A, Carrington Rotation=CR2131
AIA 193A, Carrington Rotation=CR2131
Sin Latitude
1
0
-1
0
50
100
150
200
250
300
350
Longitude


HMI, LOS
AIA, EUV (193A)
2013
2012.5
2012
2011.5
2011
2010.5
CR2131
CR2130
CR2129
CR2128
CR2127
CR2126
CR2125
CR2124
CR2123
CR2122
CR2121
CR2120
CR2119
CR2118
CR2117
CR2116
CR2115
CR2114
CR2113
CR2112
CR2111
CR2110
CR2109
CR2108
CR2107
CR2106
CR2105
CR2104
CR2103
CR2102
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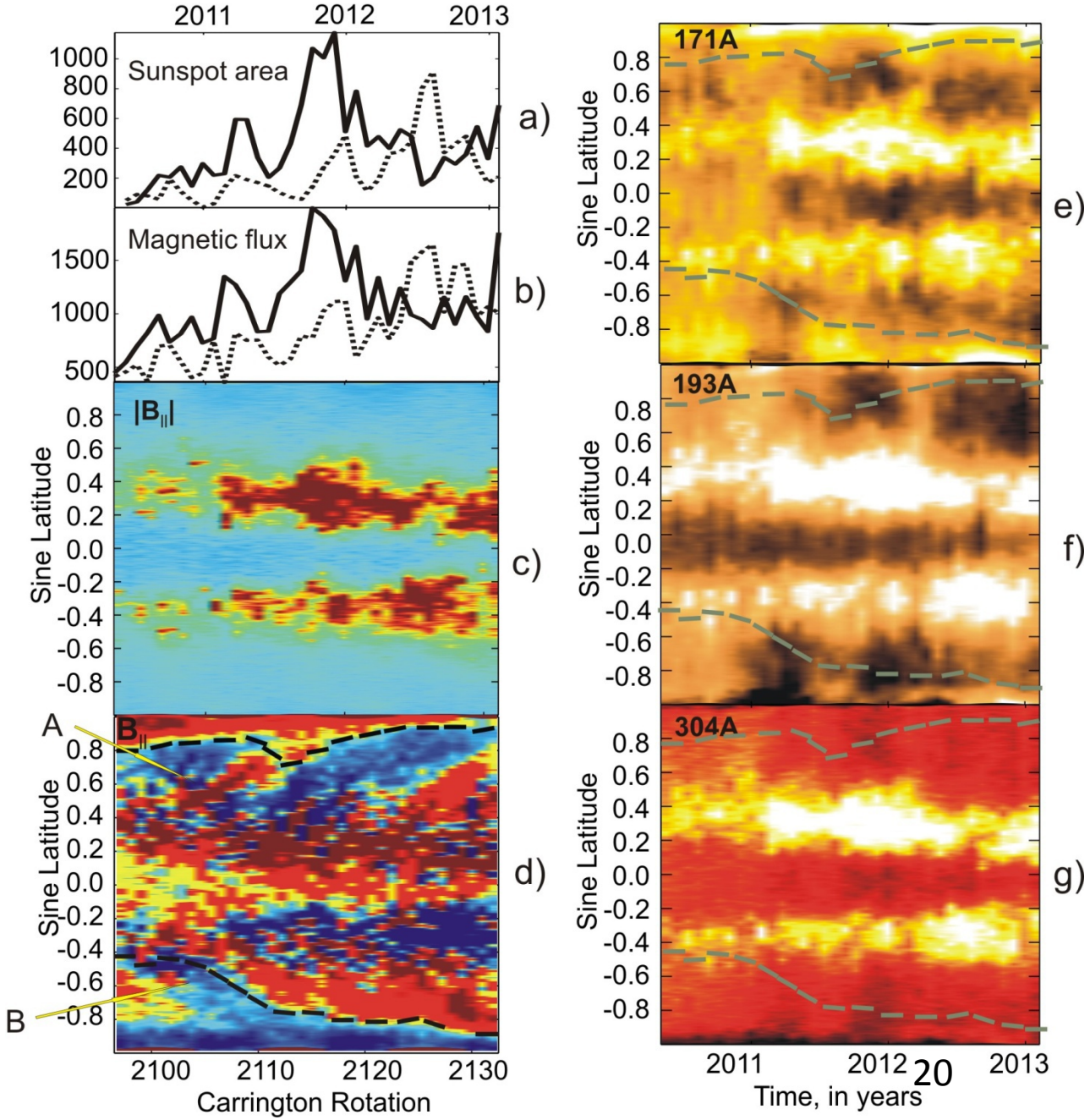
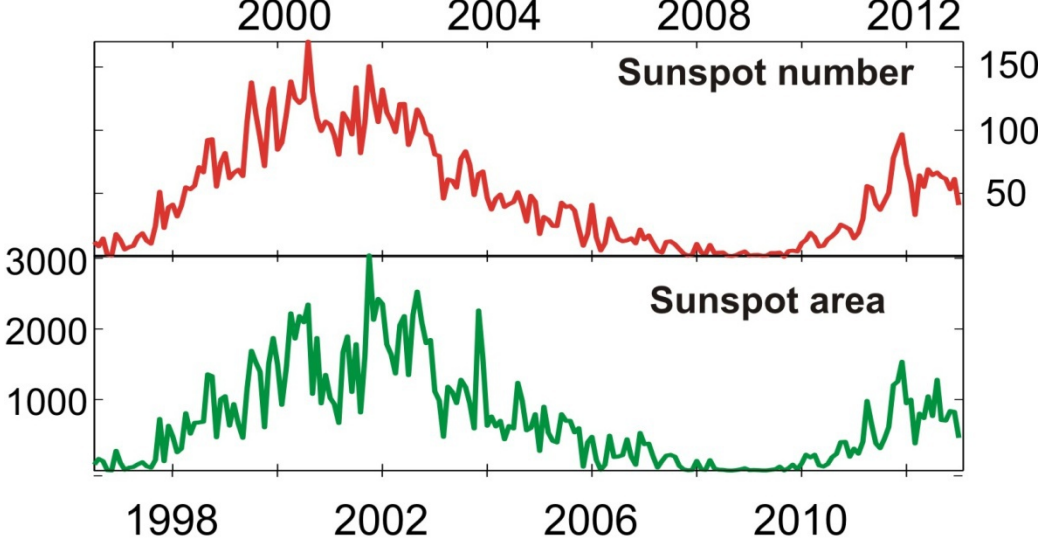
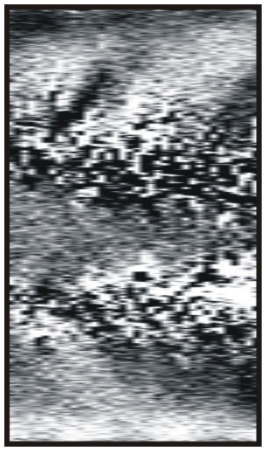
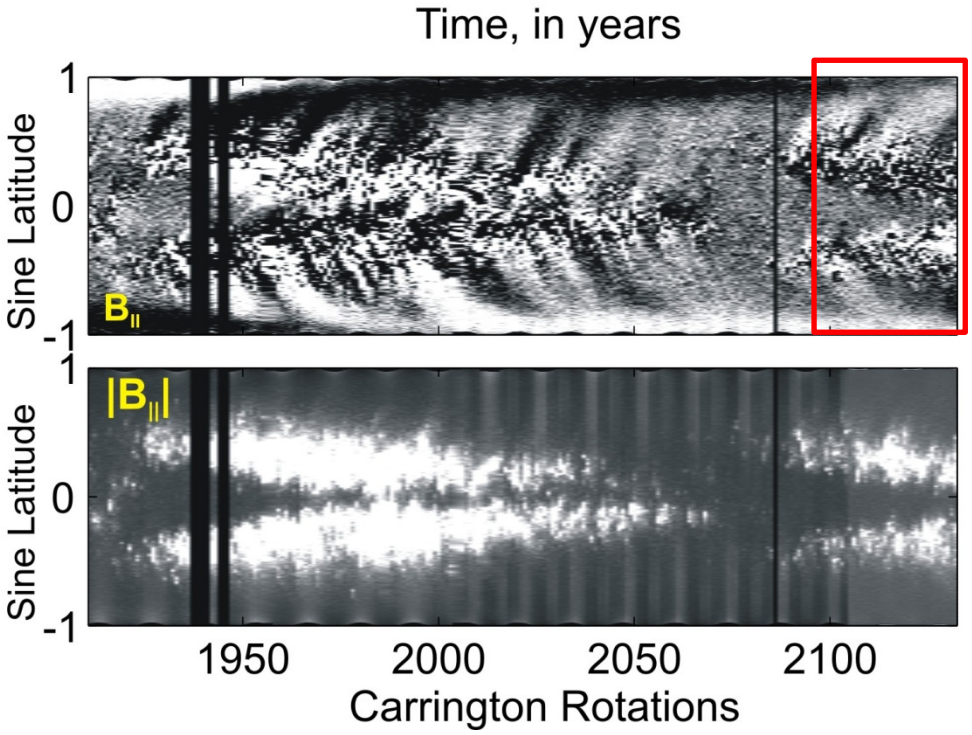
Sunspot number
80
60
40
20
100
200
300
100
200
300

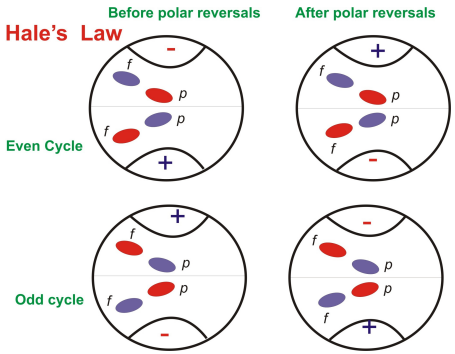

2011
2012
2013
Sunspot area
a)
Magnetic flux
b)
|B||
c)
Sine Latitude
B||
A
B
d)
2100
2110
2120
2130
Carrington Rotation
171A
e)
193A
f)
304A
g)
Time, in years

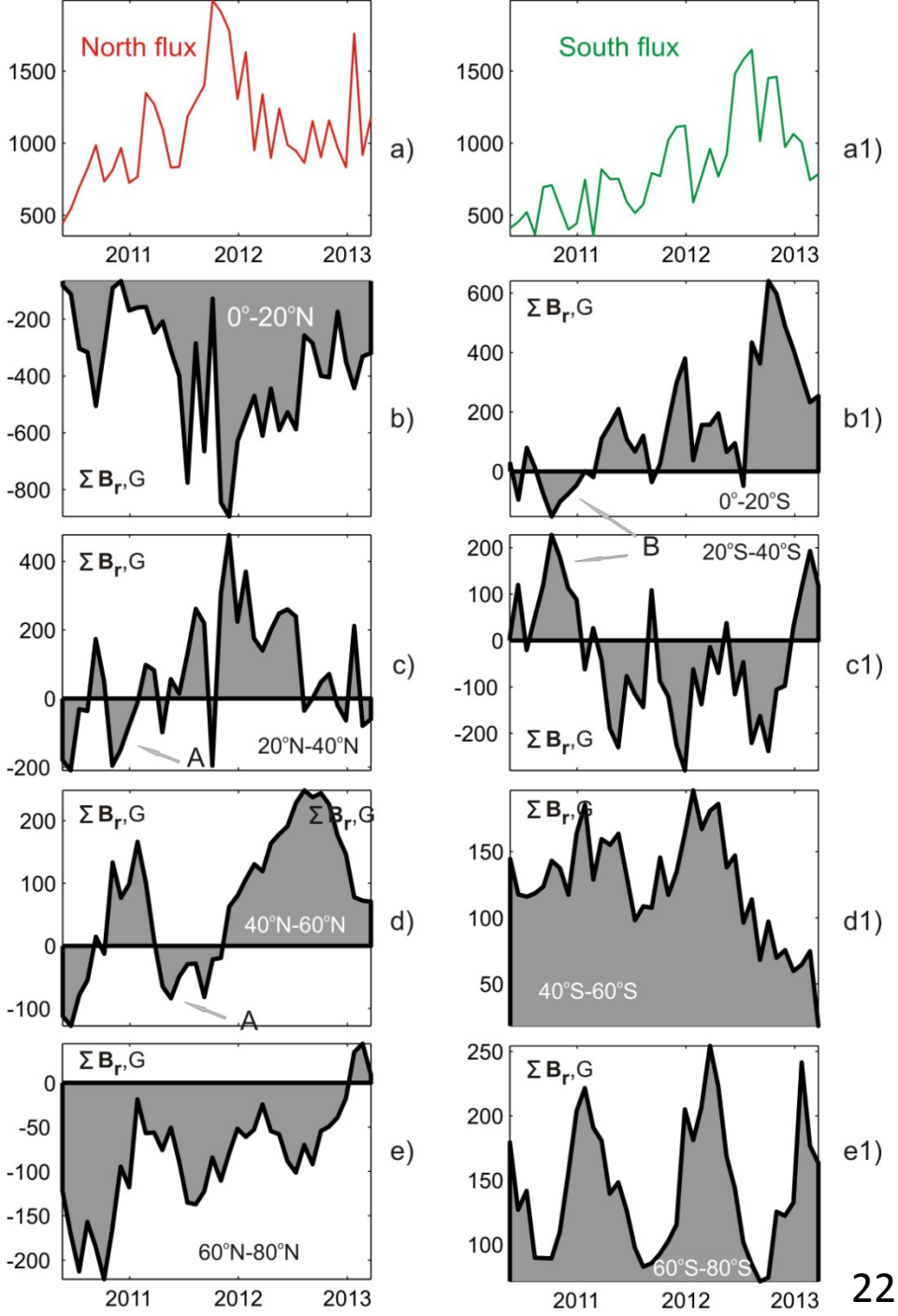
MDI + HMI


2000
2004
2008
2012
Sunspot number
150
100
50
3000
2000
1000
Sunspot area
1998
2002
2006
2010



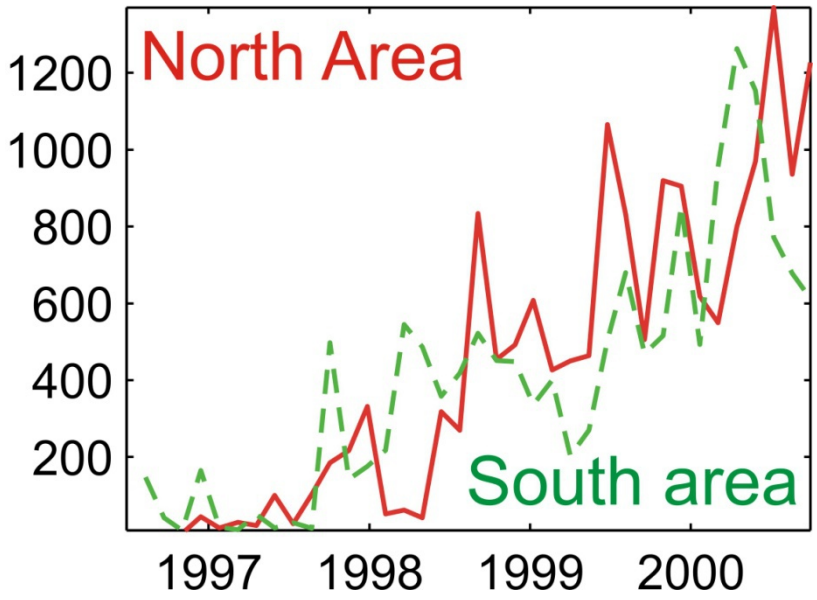

Time, in years
Sine Latitude
1
0
-1
$B_{||}$
$|B_{||}|$
1950
2000
2050
2100
Carrington Rotations

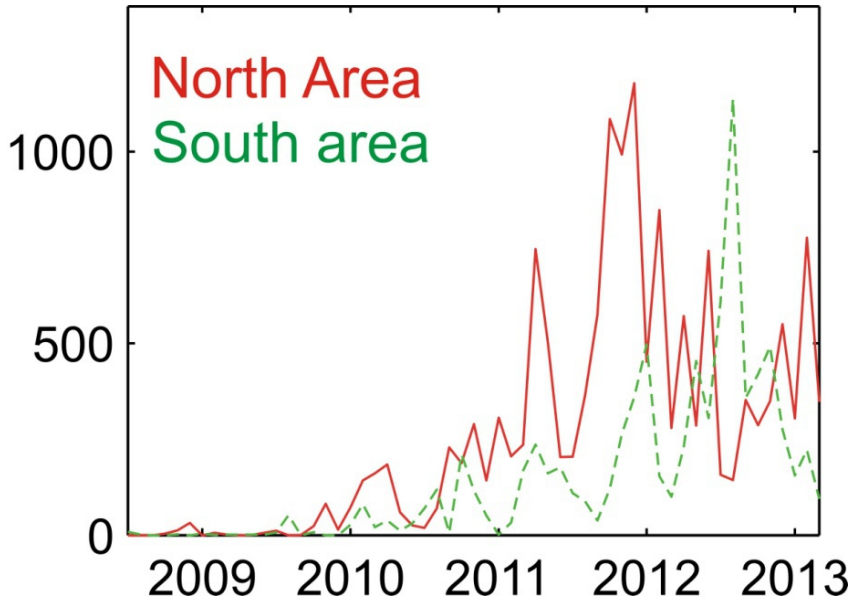

Hale's Law
Before polar reversals
After polar reversals
Even Cycle
Odd cycle


North flux
South flux
a)
a1)
b)
b1)
c)
c1)
d)
d1)
e)
e1)
0°-20°N
0°-20°S
20°N-40°N
20°S-40°S
40°N-60°N
40°S-60°S
60°N-80°N
60°S-80°S
A
B
ΣBr,G
2011
2012
2013
Time in years

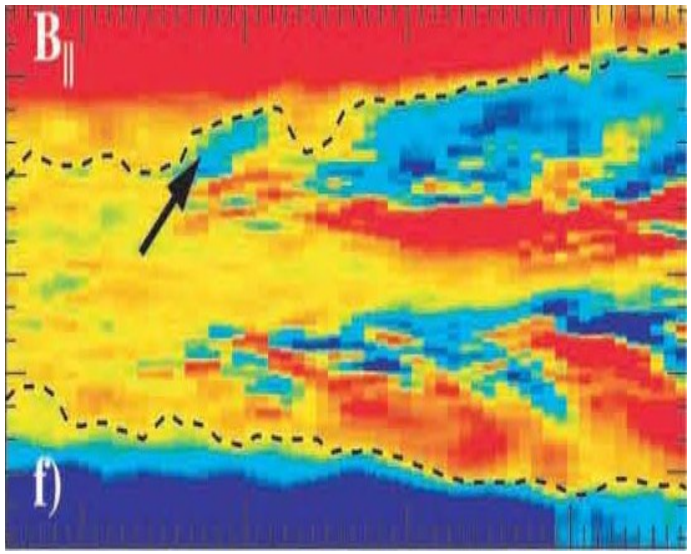
In the Northern hemisphere, the polar magnetic field varies close to zero and reaches the small negative values in September 2012 (CR2127), but the noticeable changing of the polar magnetic field occurs only in January 2013 within latitudinal region 60o-80o North.

In South, the situation is more complicated, The south pole is still positive for the all investigated period (May 2010-March 2013).

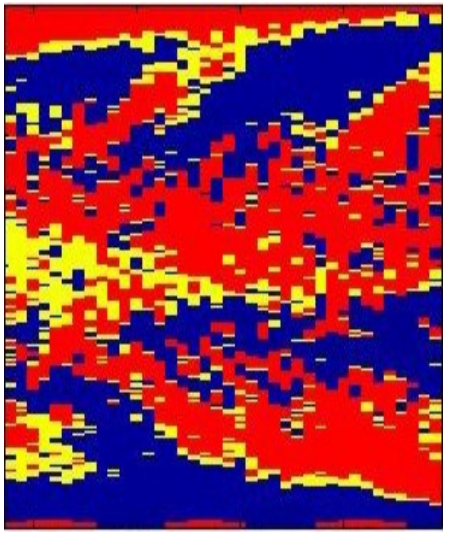

North Area
South area
1200
1000
800
600
400
200
1997
1998
1999
2000


North Area
South area
1000
500
0
2009
2010
2011
2012
2013

MDI


B||
f)

HMI



Conclusions

Nature of the solar activity and the solar cycle, correspondingly, requires a knowledge about dynamics of the magnetic field and the convection under the photosphere, the internal rotation rate, the meridional circulation with an accurate temporal and space resolution. And, of cause, it is important to investigate the coronal processes.

These problems are topical for the current and future space missions: **Hinode, Solar Dynamics Observatory, Solar Orbiter** and **Interheliozond.**