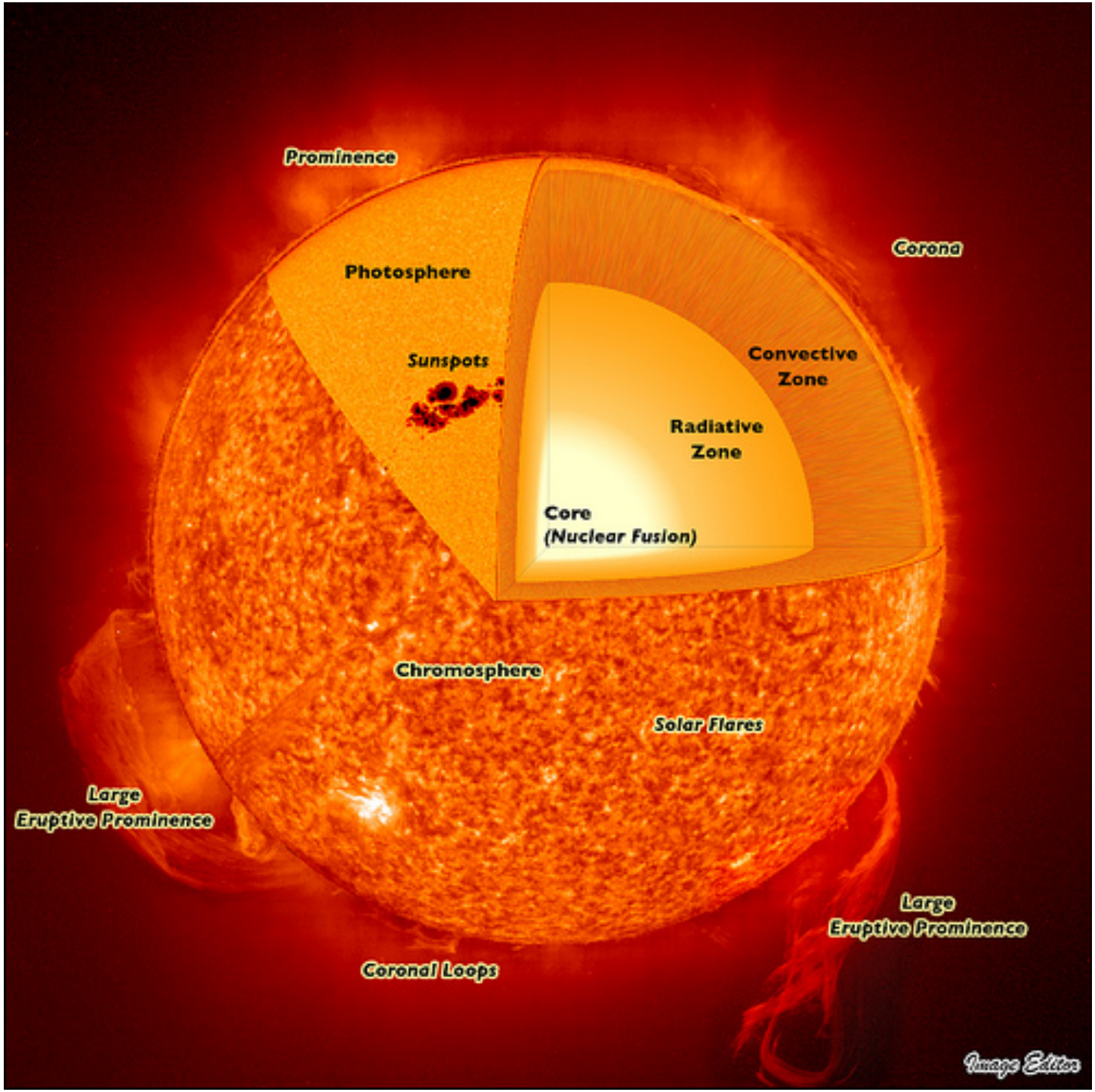
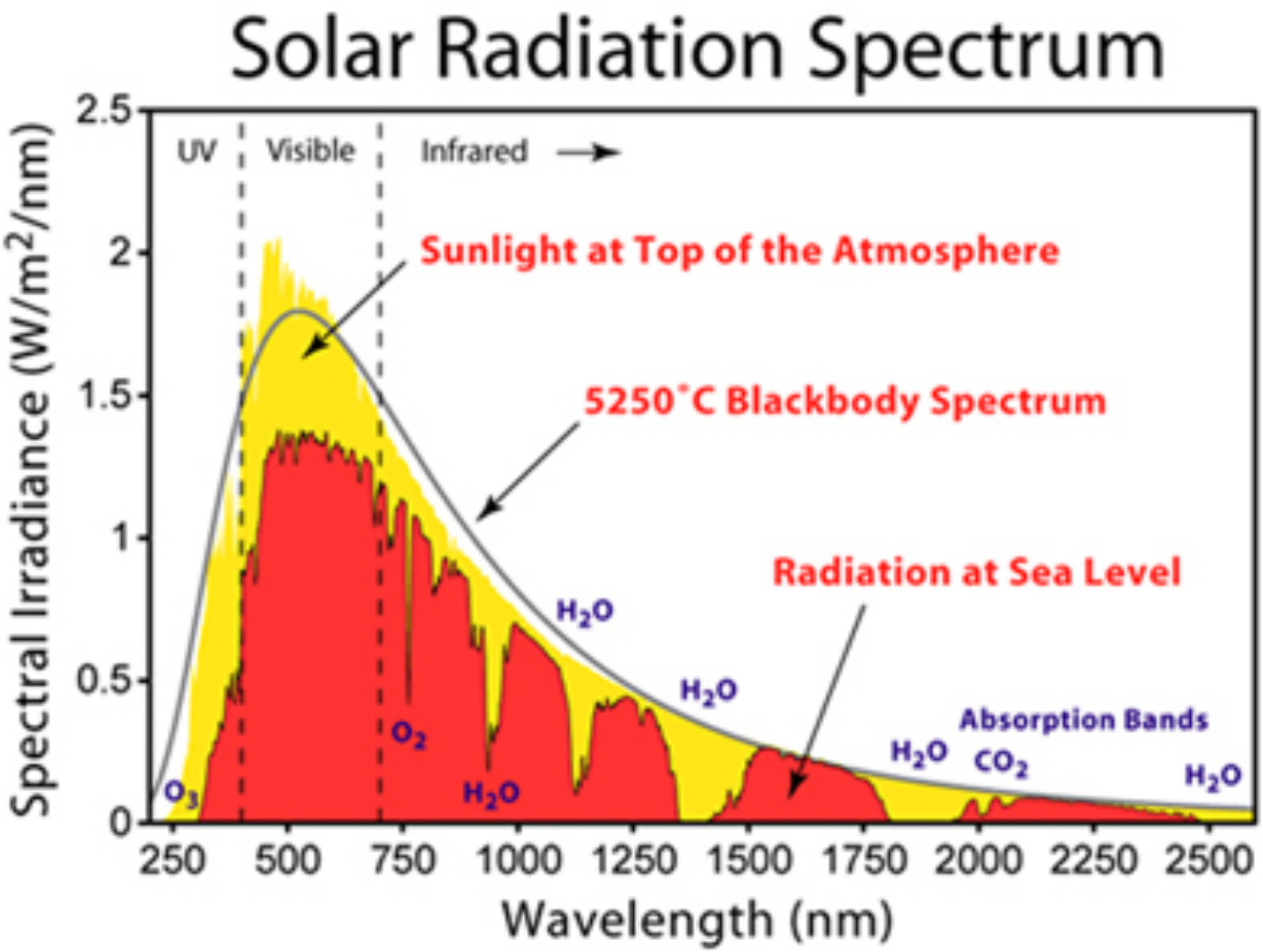
Trends in the short-term SSI variability over 100 Carrington Rotations from the UV through the near IR

Lauren Bearden, Colgate University
Odele Coddington, LASP
Erik Richard, LASP
Martin Snow, LASP

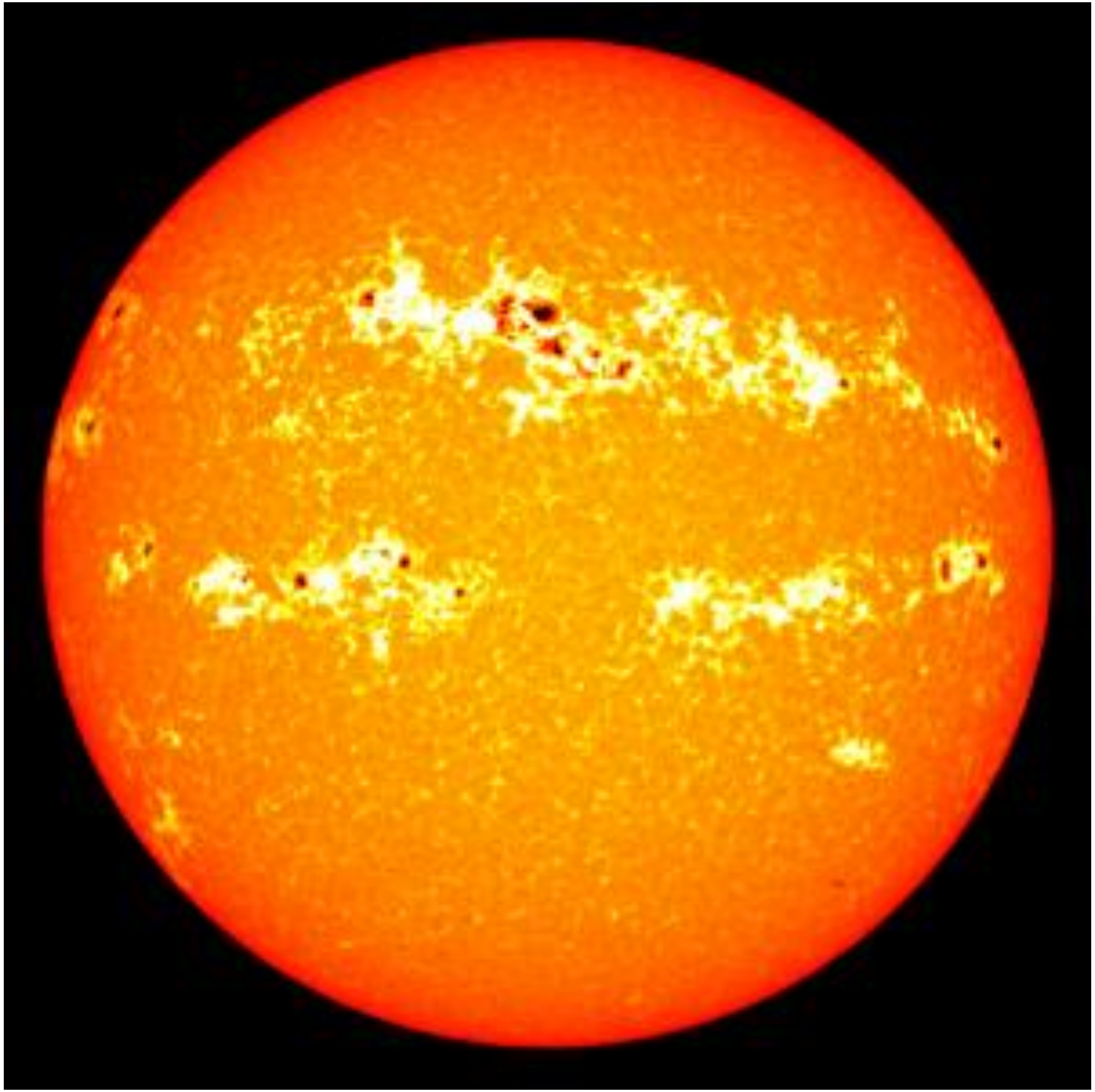
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

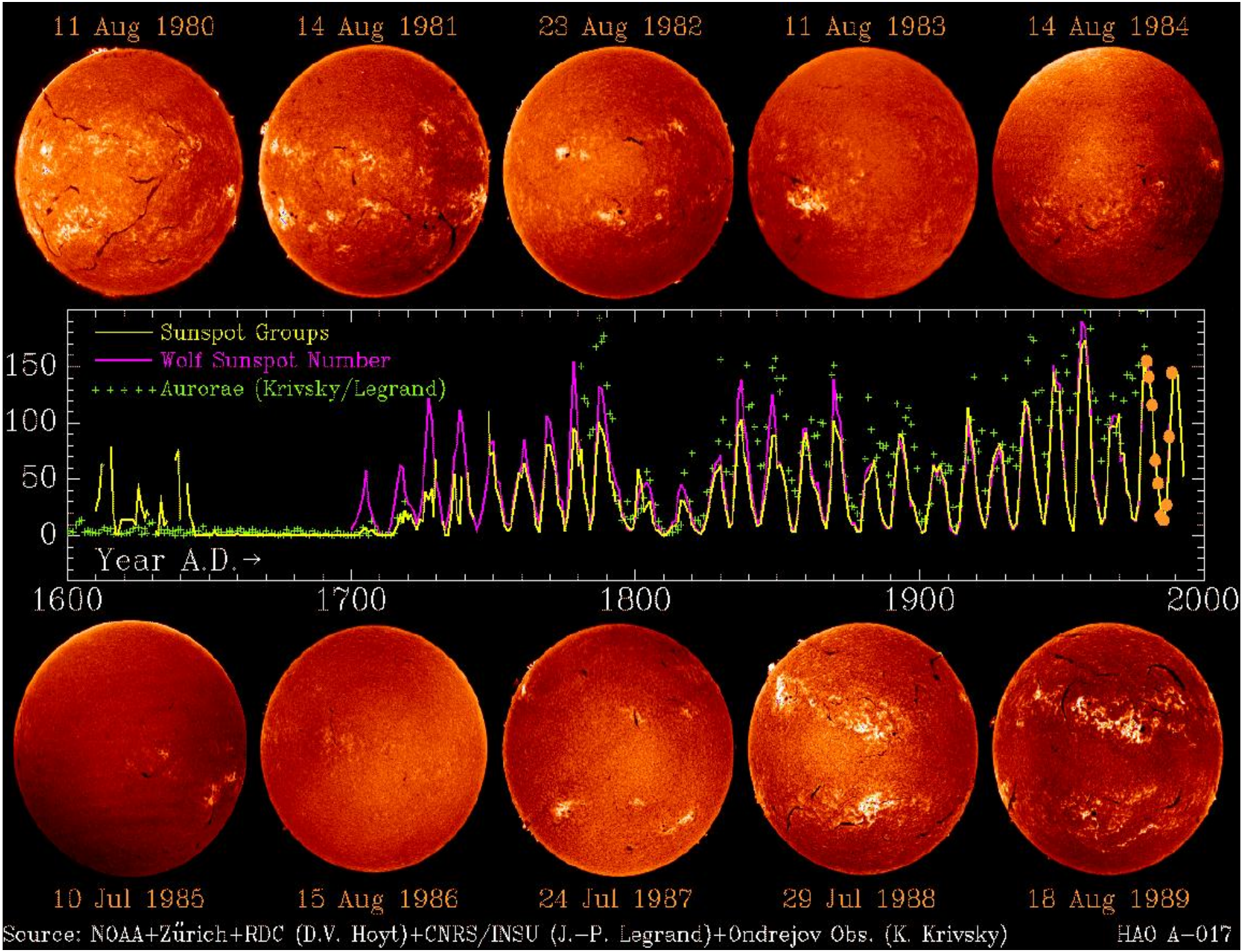

Prominence
Photosphere
Corona
Sunspots
Convective Zone
Radiative Zone
Core (Nuclear Fusion)
Chromosphere
Solar Flares
Large Eruptive Prominence
Large Eruptive Prominence
Coronal Loops
Image Editor

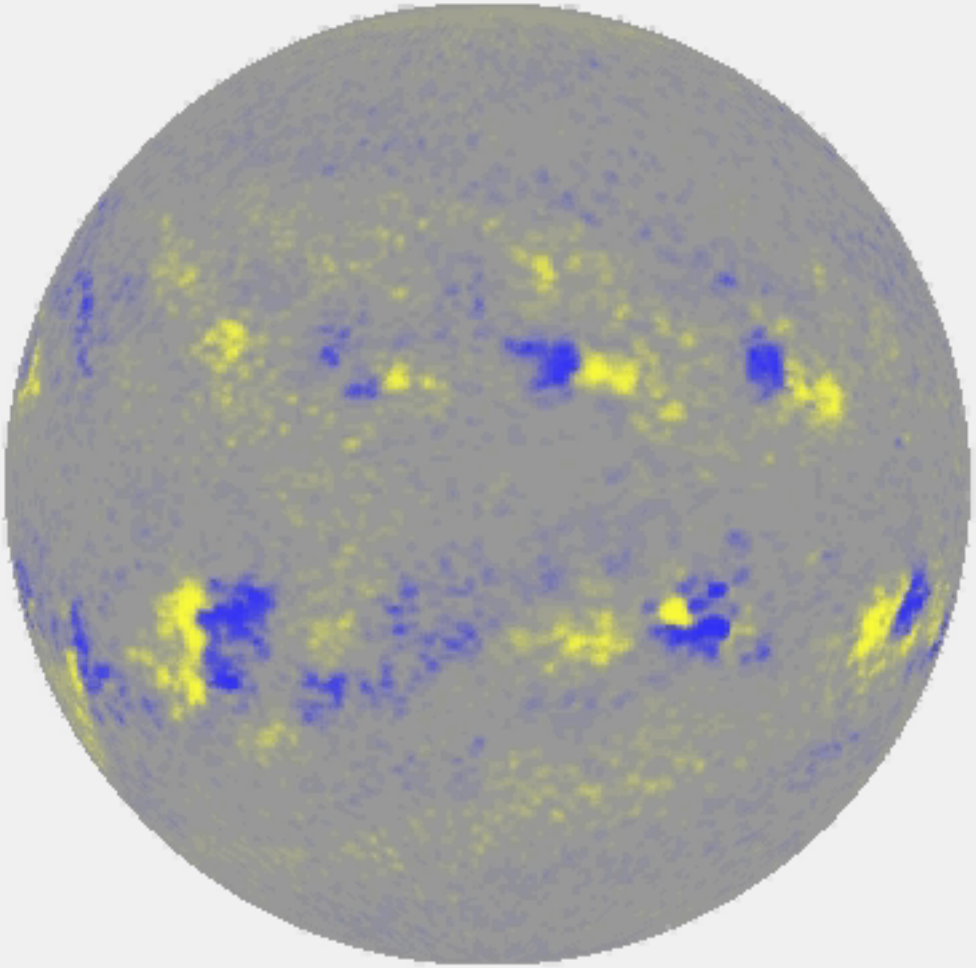


Chromospheric activity

Photospheric Activity

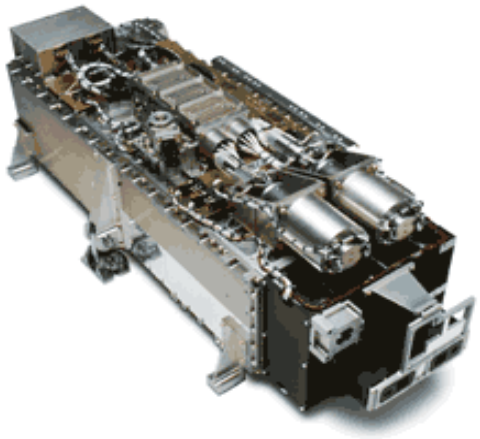


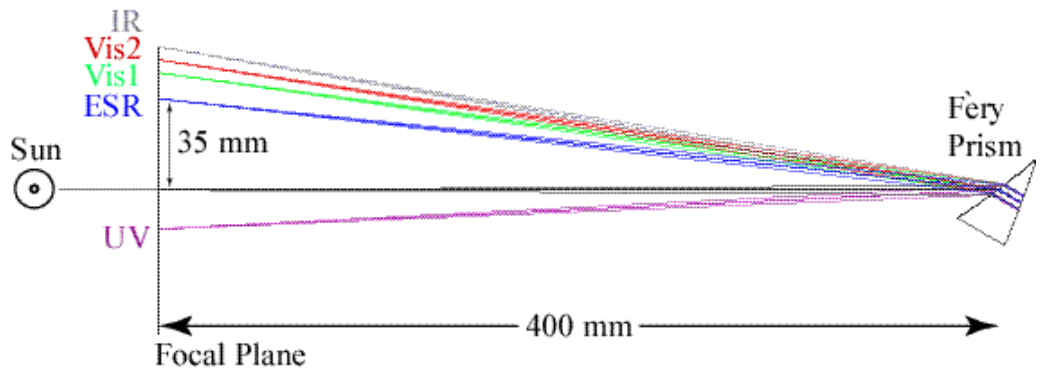

11 Aug 1980
14 Aug 1981
23 Aug 1982
11 Aug 1983
14 Aug 1984
Sunspot Groups
Wolf Sunspot Number
+ + + + + Aurorae (Krivsky/Legrand)
150
100
50
0
Year A.D.→
1600
1700
1800
1900
2000
10 Jul 1985
15 Aug 1986
24 Jul 1987
29 Jul 1988
18 Aug 1989
Source: NOAA+Zürich+RDC (D.V. Hoyt)+CNRS/INSU (J.-P. Legrand)+Ondrejov Obs. (K. Krivsky)
HAO A-017



SIM Instrument

SIM measures top-of-atmosphere (TOA) Solar Spectral Irradiance (SSI) necessary to interpret atmospheric and oceanic radiative processes





SIM Optical Layout

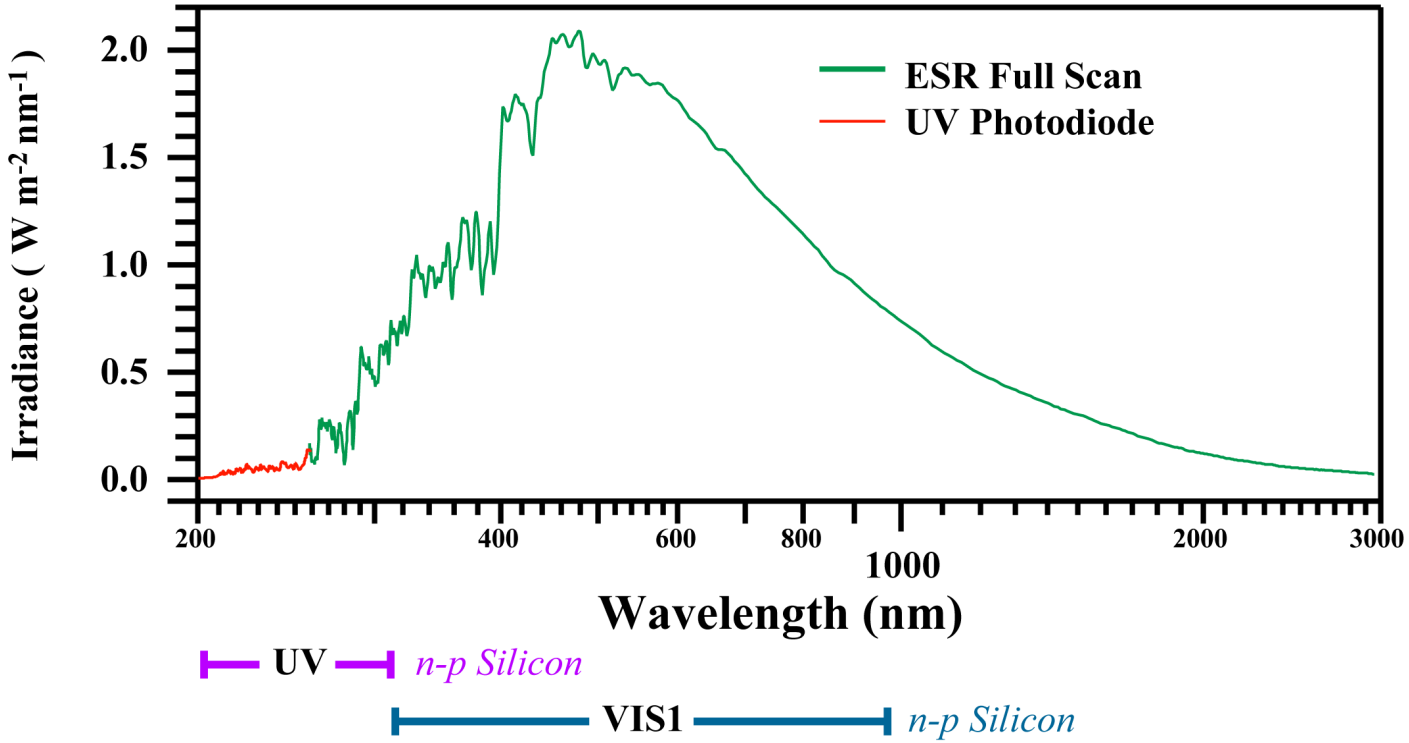
- *Instrument Type: Fèry Prism Spectrometer*
- *Wavelength Range: 200 - 2400 nm*
- *Wavelength Resolution: 0.24 - 34 nm*
- *Absolute Accuracy: 2-8%*
- *Long-term Stability: 0.015% /yr*
- *Mass: 21.9 kg*
- *Orbit Average Power: 25.3 W*
- *Orbit Average Data Rate: 1.5 kbits/s*
- *Redundancy: Dual channels*

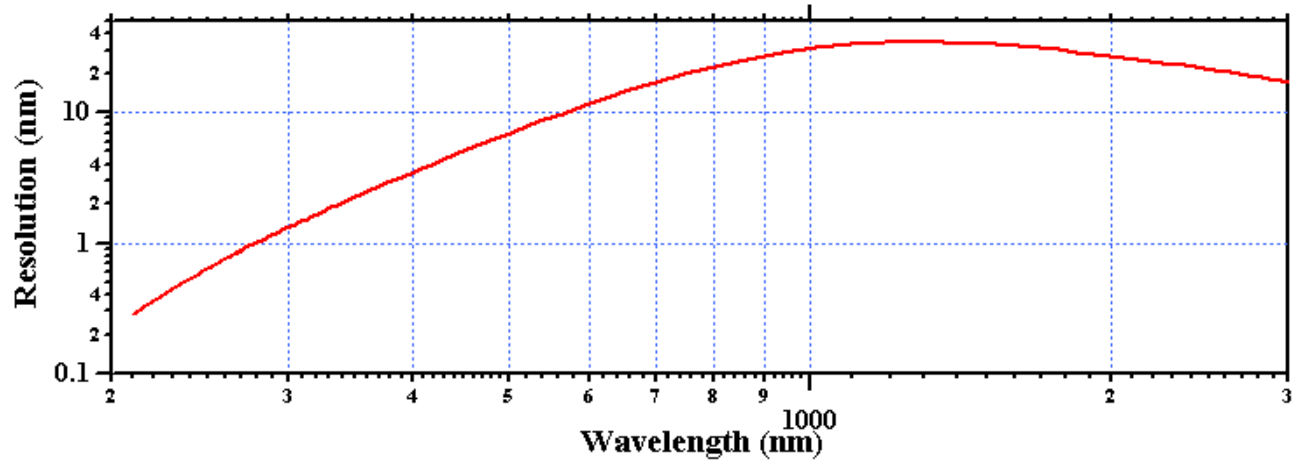
Key Technologies

- *Miniature ESR with Féry prism*
- *Prism rotation angle (wavelength) measured in focal plane.*
- *Coupled SIM channels*

Harder, J., et al., Solar Physics, 2005

SIM Irradiance Spectrum April 21, 2004





SIM Spectral Resolution

WHY?

The Earth’s atmosphere processes solar radiation in a wavelength dependent way, so it is impossible to fully understand the Sun’s effects on Earth’s atmosphere without a thorough understanding of all wavelengths in the spectrum.

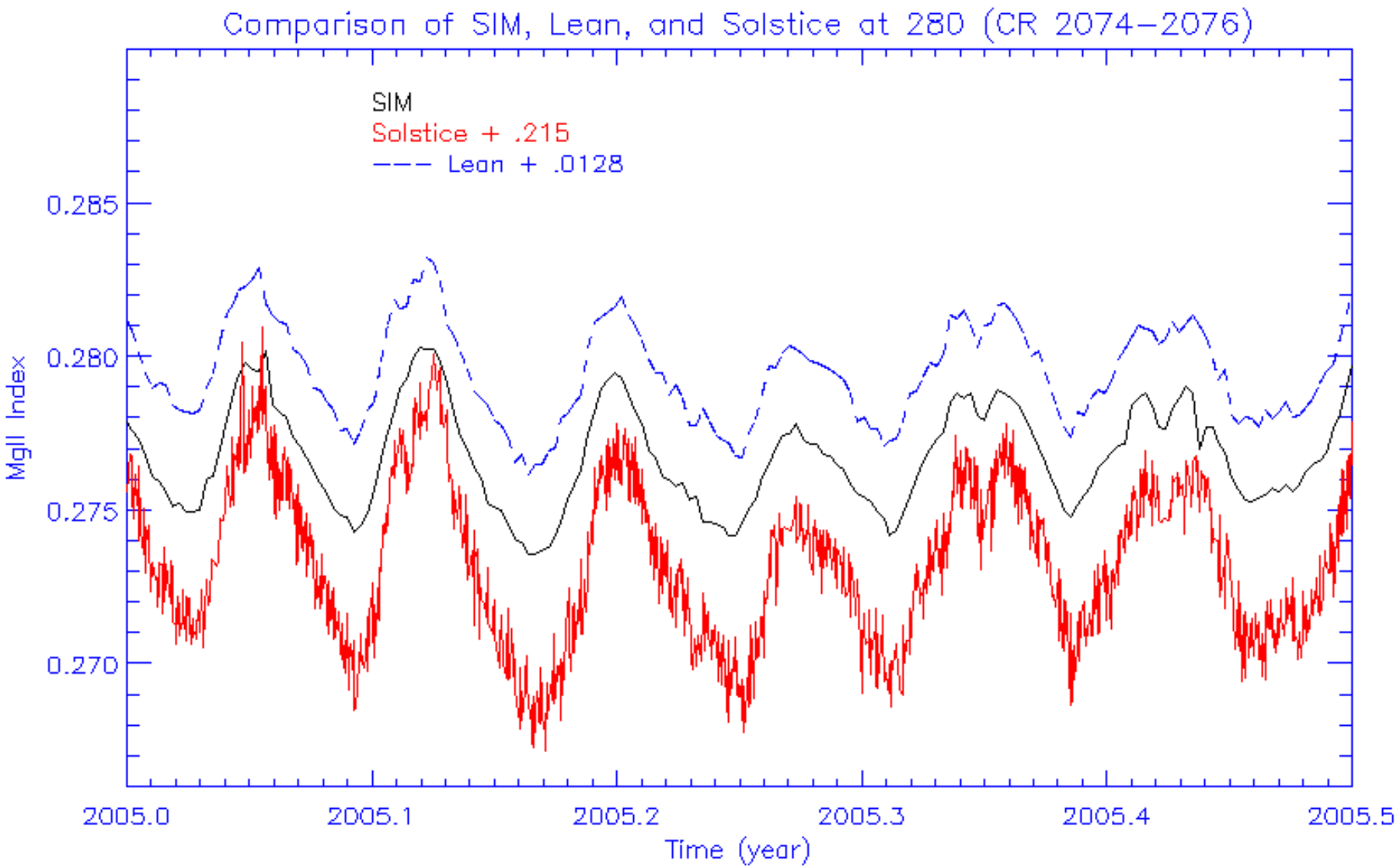
Mg II Index:

$$MgII_{SIM} = \frac{4[I_{279.8} + I_{280.0} + I_{280.2}]}{3[I_{276.6} + I_{276.8} + I_{283.2} + I_{283.4}]}$$

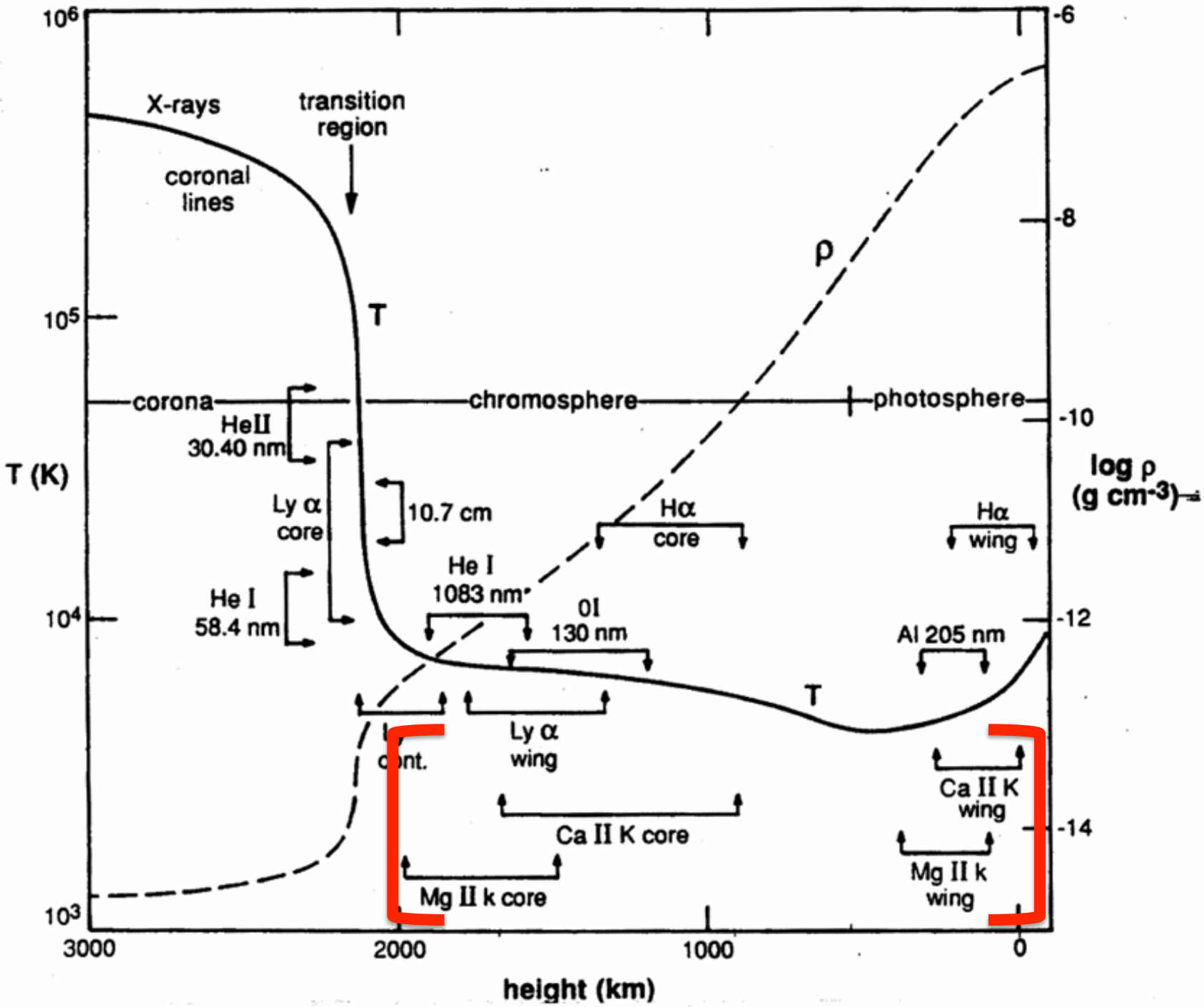
Fractional Difference

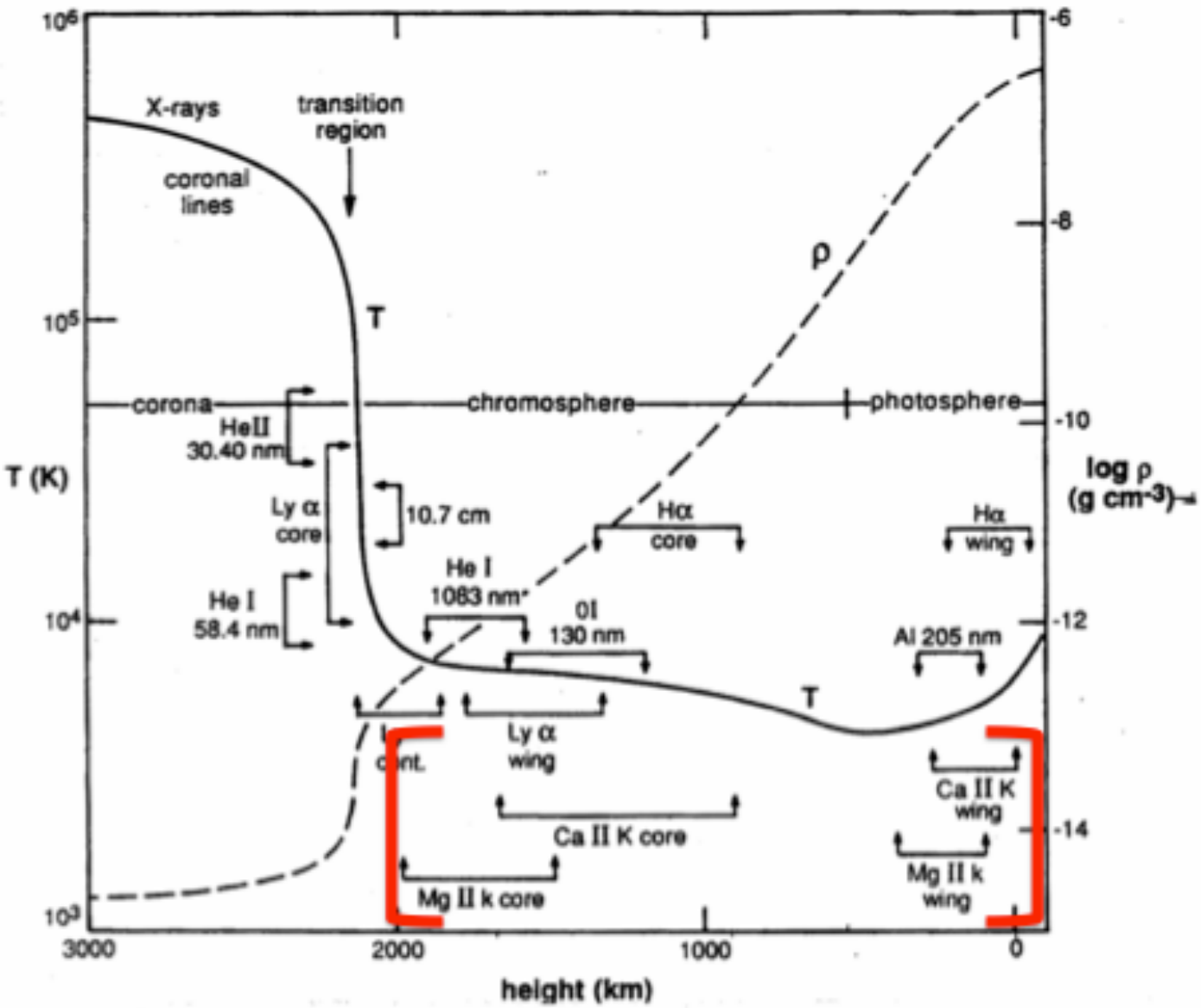
for solar rotation variability:

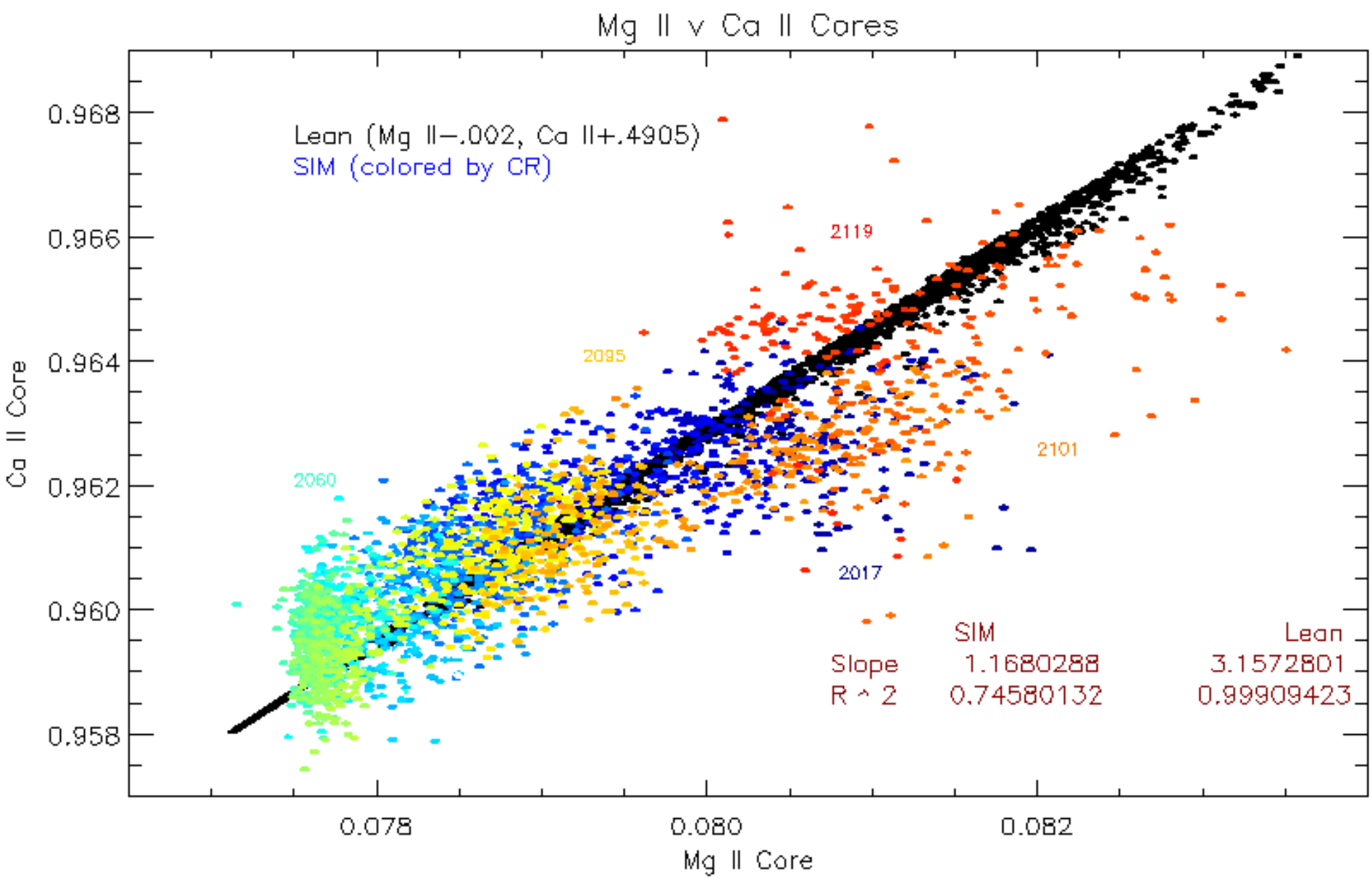
$$\frac{Max}{Min} - 1$$

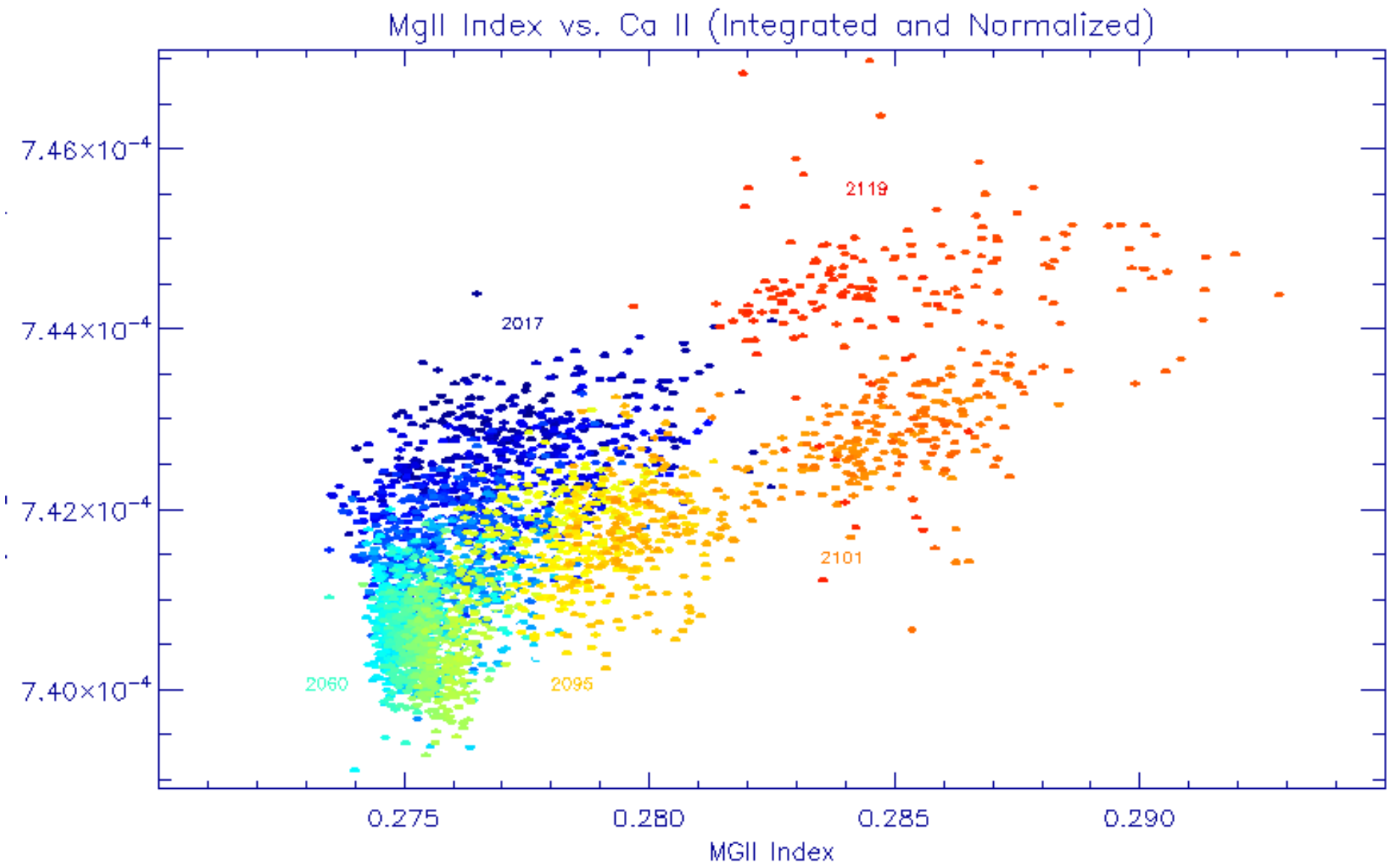


**The Lean model used is often called the NRL SSI model

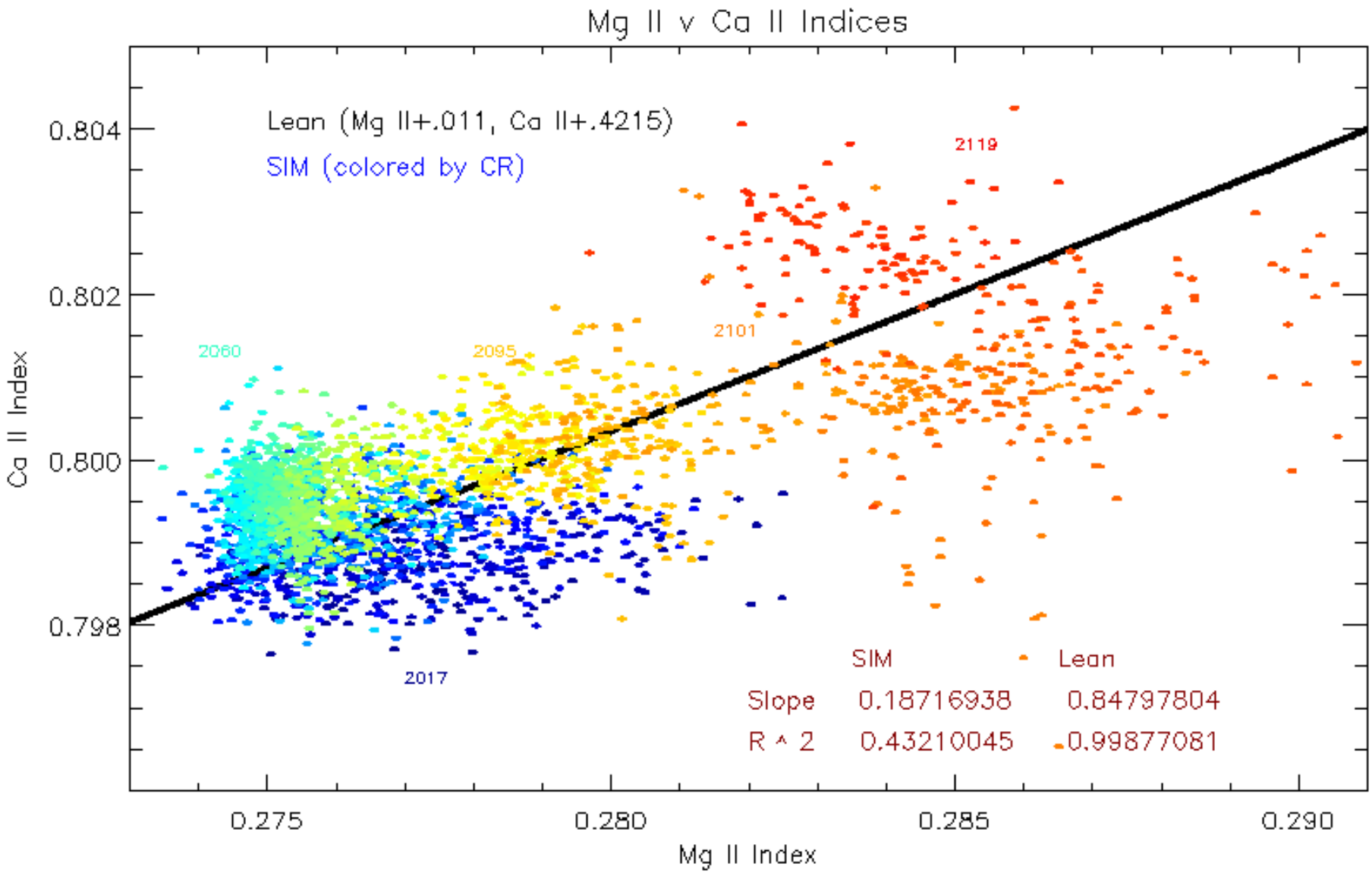

X-rays
transition region
coronal lines
T
ρ
corona
chromosphere
photosphere
HeII 30.40 nm
Ly α core
10.7 cm
He I 58.4 nm
He I 1083 nm
Hα core
Hα wing
OI 130 nm
Al 205 nm
T
Ly α wing
Ca II K wing
Ca II K core
Mg II k core
Mg II k wing
T (K)
log ρ (g cm-3)
height (km)
10^6
10^5
10^4
10^3
3000
2000
1000
0
-6
-8
-10
-12
-14


X-rays
transition region
coronal lines
T
ρ
corona
chromosphere
photosphere
HeII 30.40 nm
Ly α core
10.7 cm
He I 58.4 nm
He I 1083 nm
OI 130 nm
Hα core
Hα wing
Al 205 nm
T
Ly α wing
Ca II K wing
Ca II K core
Mg II k wing
Mg II k core
T (K)
log ρ (g cm-3)
height (km)
3000
2000
1000
0
10^6
10^5
10^4
10^3
-6
-8
-10
-12
-14

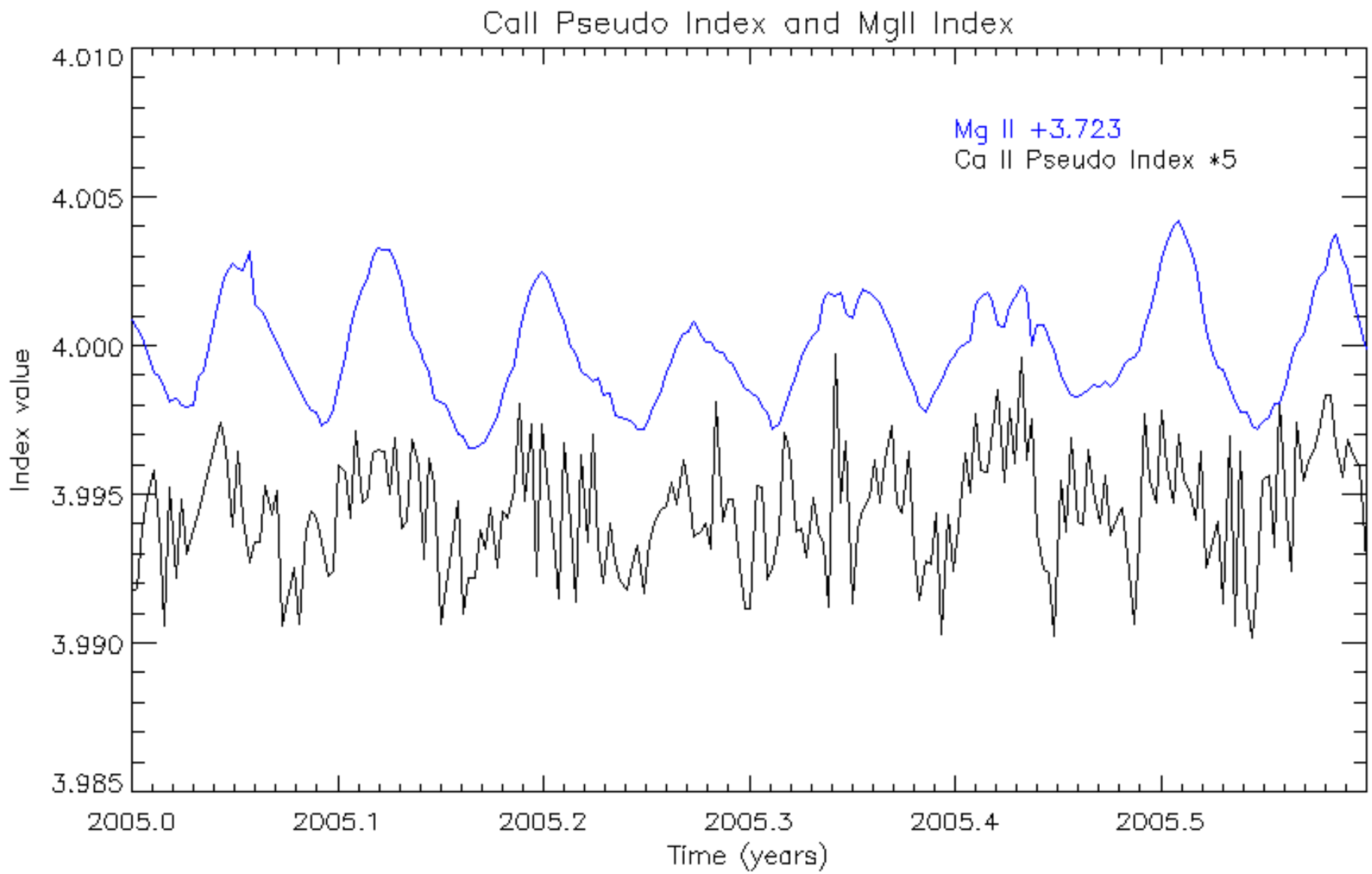

Mg II v Ca II Cores
Lean (Mg II−.002, Ca II+.4905)
SIM (colored by CR)
2119
2095
2101
2060
2017
SIM
Lean
Slope
1.1680288
3.1572801
R ^ 2
0.74580132
0.99909423
0.968
0.966
0.964
0.962
0.960
0.958
Ca II Core
0.078
0.080
0.082
Mg II Core

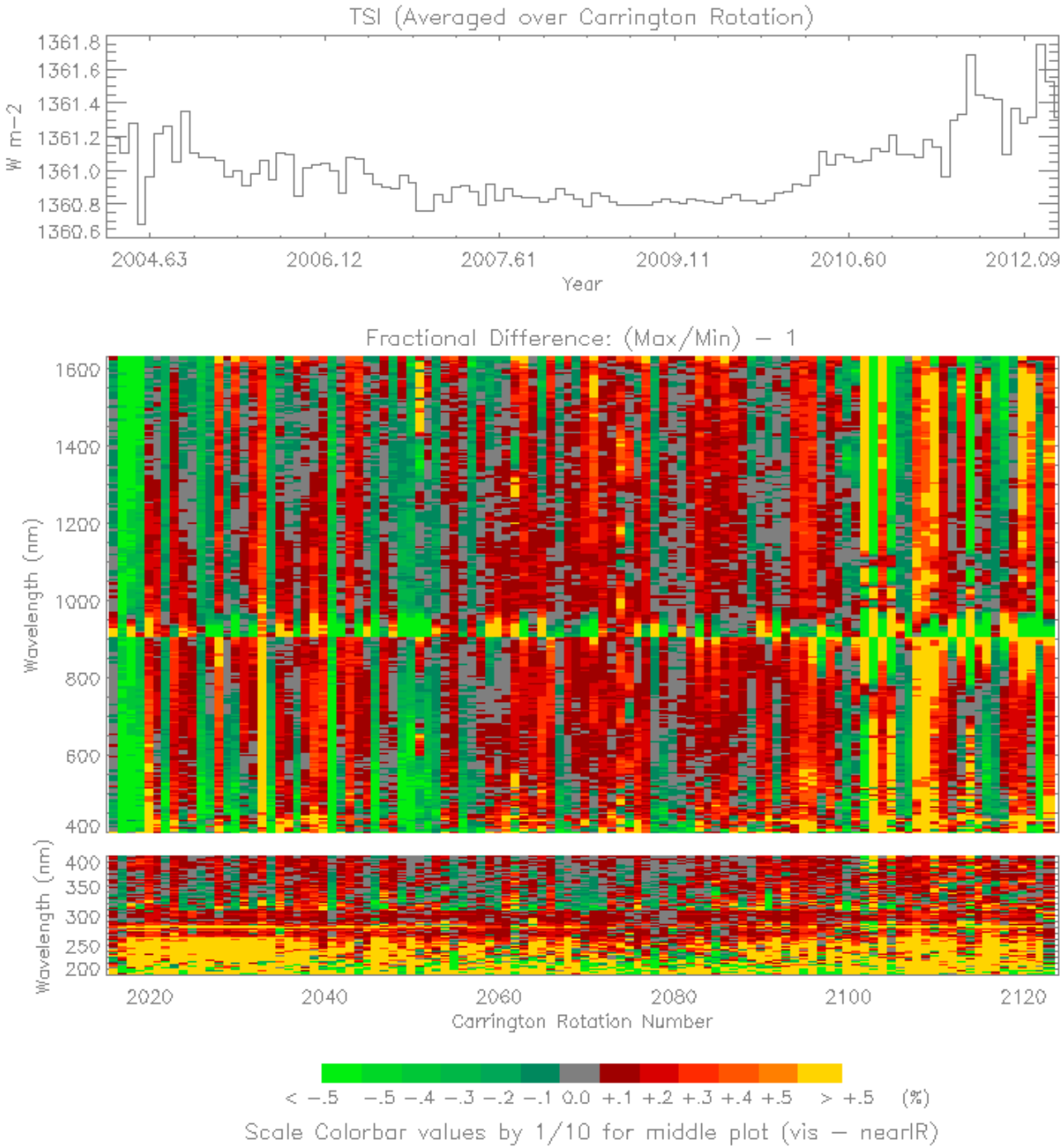


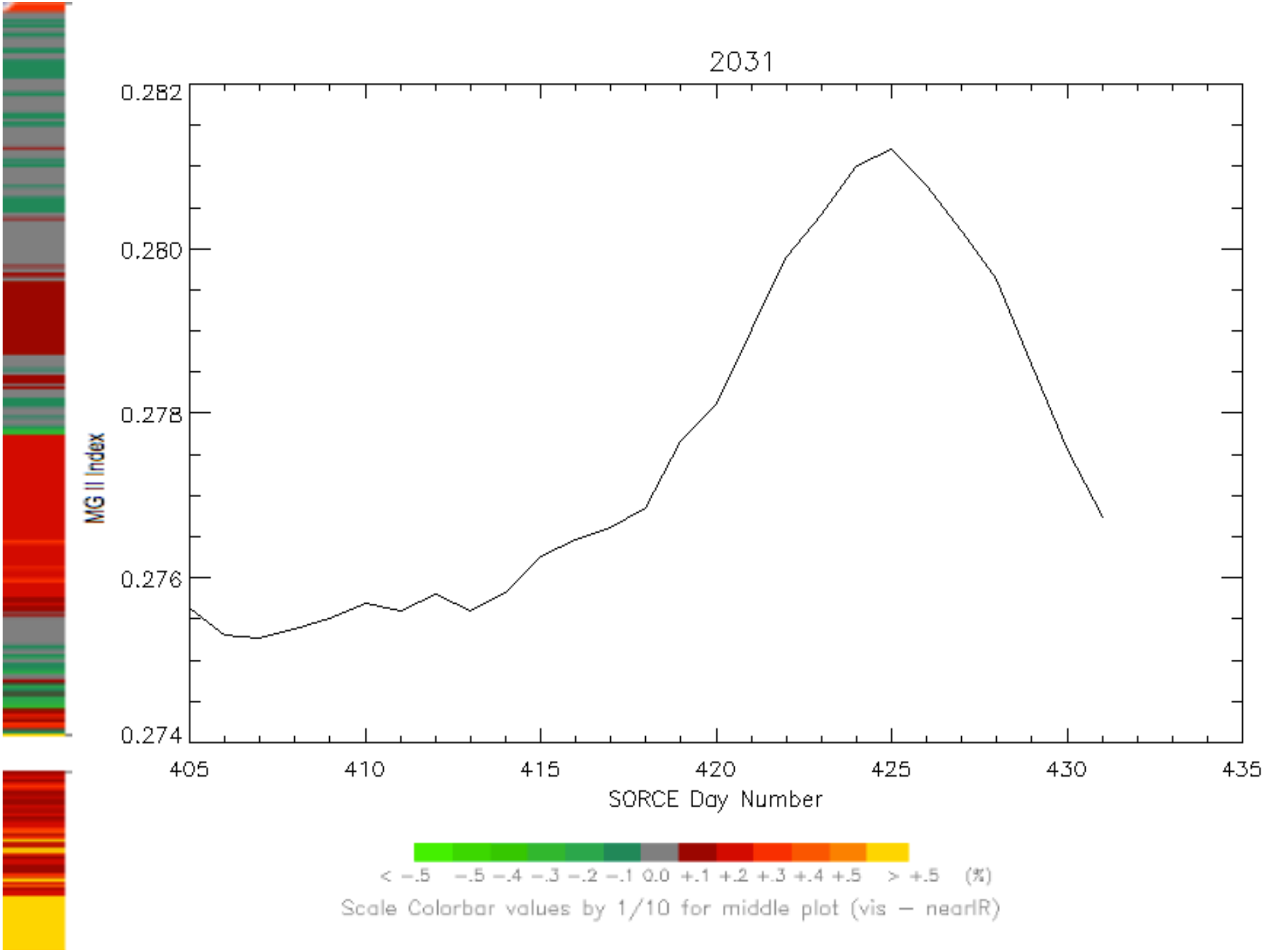
Ca II Integrated from wavelength 392 to 394

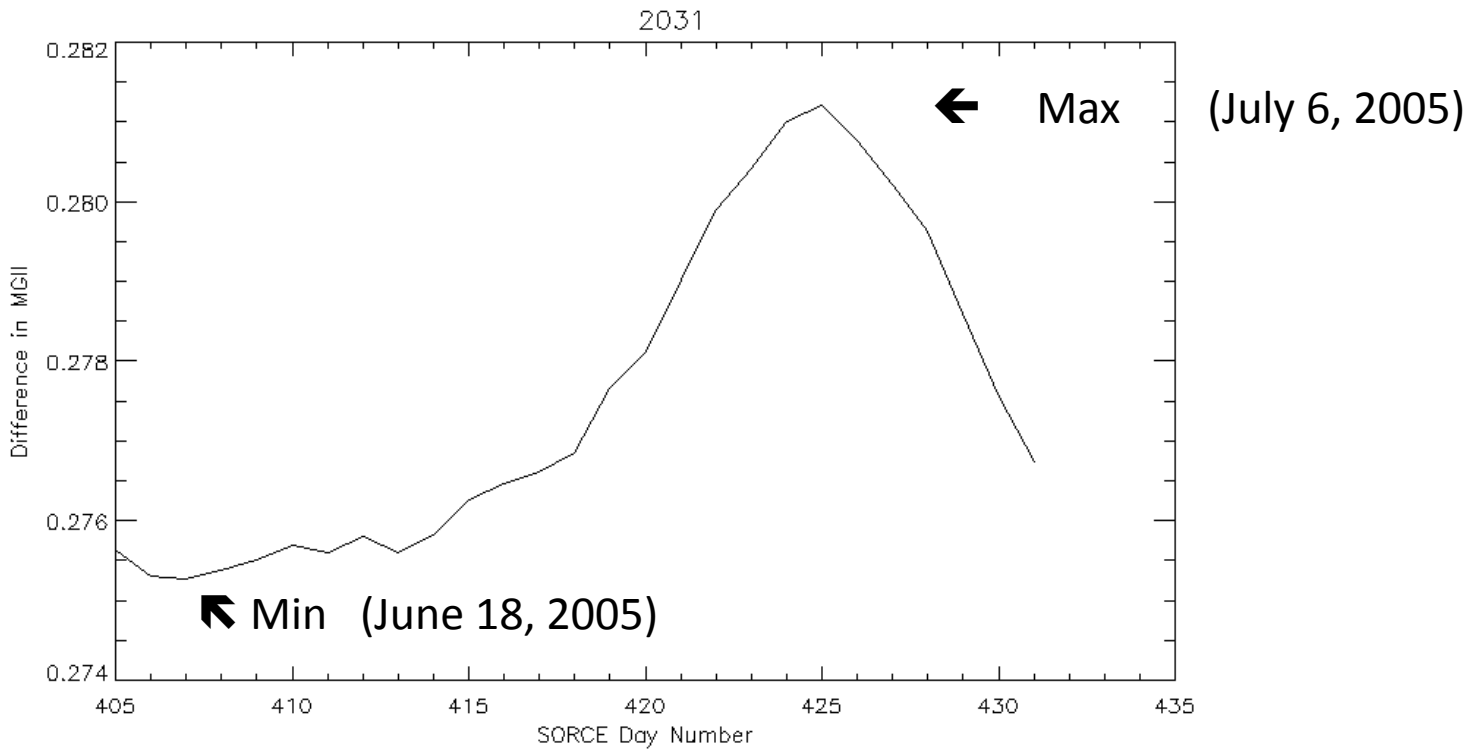


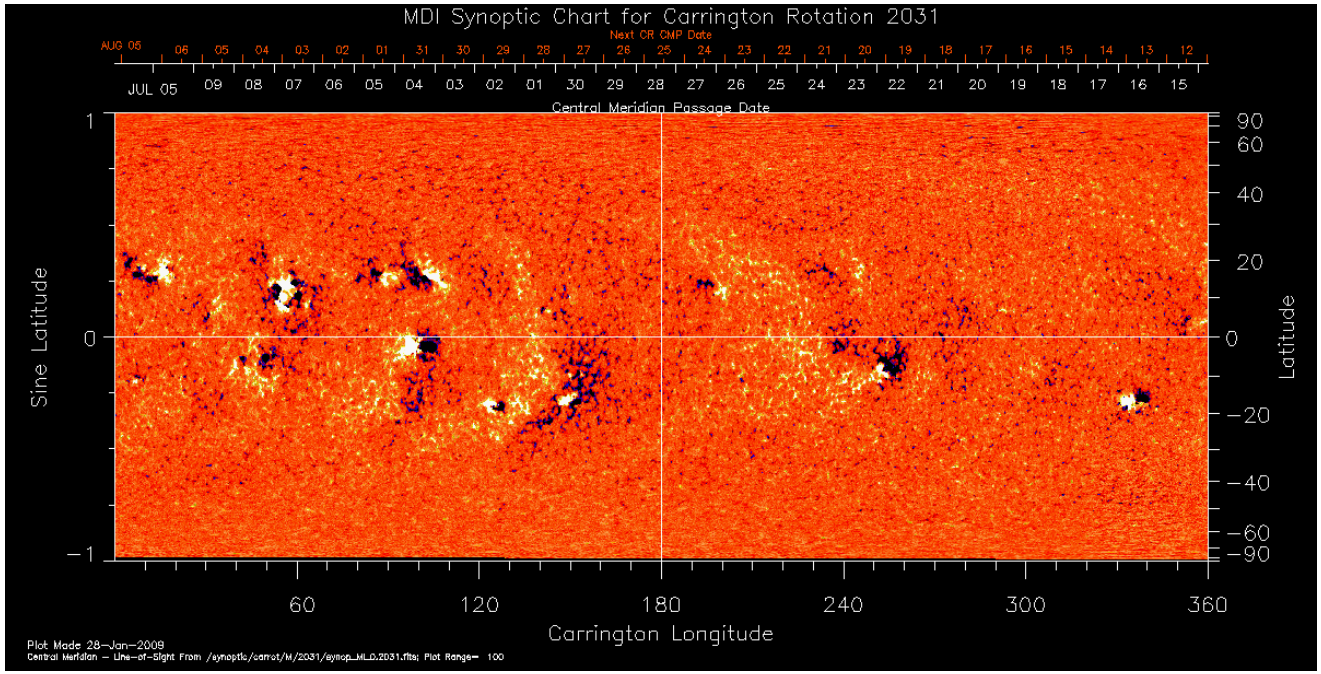
$$CaII_{Pseudo} = \frac{I_{393.36}}{I_{390.27}}$$

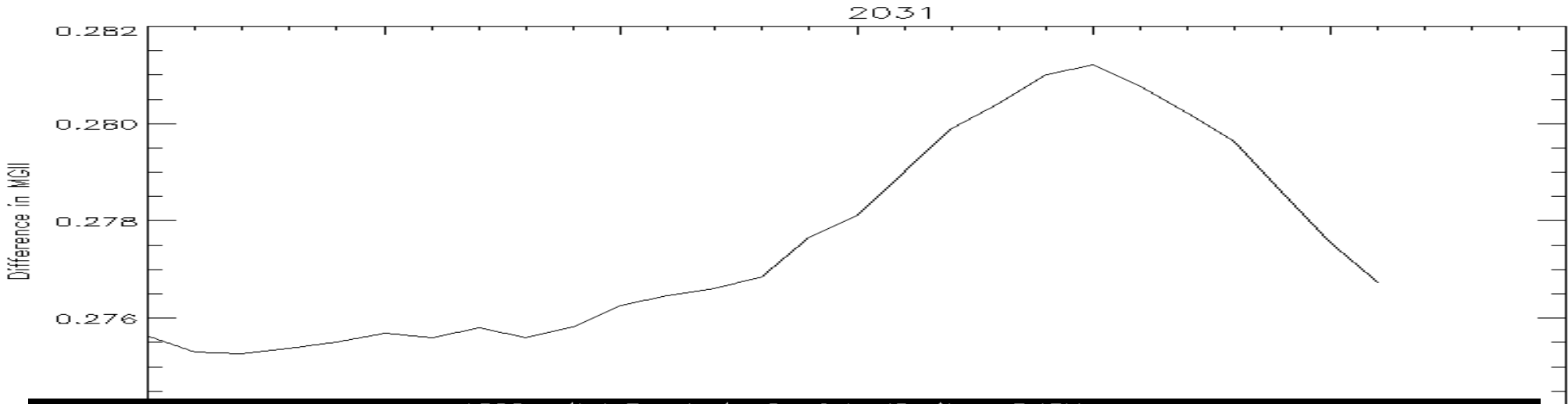

CaII Pseudo Index and MgII Index
Mg II +3.723
Ca II Pseudo Index *5
Index value
4.010
4.005
4.000
3.995
3.990
3.985
2005.0
2005.1
2005.2
2005.3
2005.4
2005.5
Time (years)

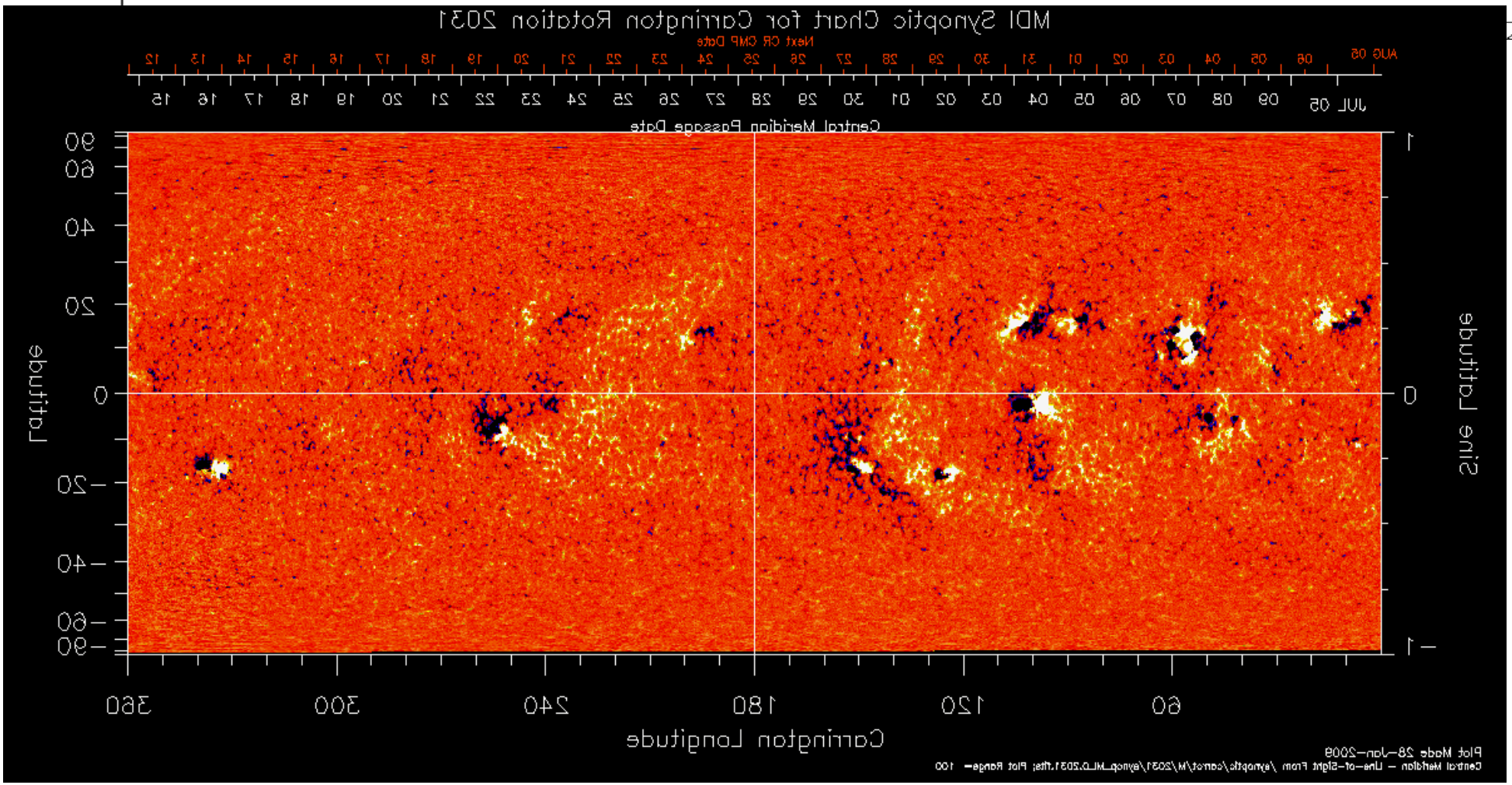

TSI (Averaged over Carrington Rotation)
W m−2
1361.8
1361.6
1361.4
1361.2
1361.0
1360.8
1360.6
2004.63
2006.12
2007.61
2009.11
2010.60
2012.09
Year
Fractional Difference: (Max/Min) − 1
Wavelength (nm)
1600
1400
1200
1000
800
600
400
Wavelength (nm)
400
350
300
250
200
2020
2040
2060
2080
2100
2120
Carrington Rotation Number
< −.5 −.5 −.4 −.3 −.2 −.1 0.0 +.1 +.2 +.3 +.4 +.5 > +.5 (%)
Scale Colorbar values by 1/10 for middle plot (vis − nearIR)

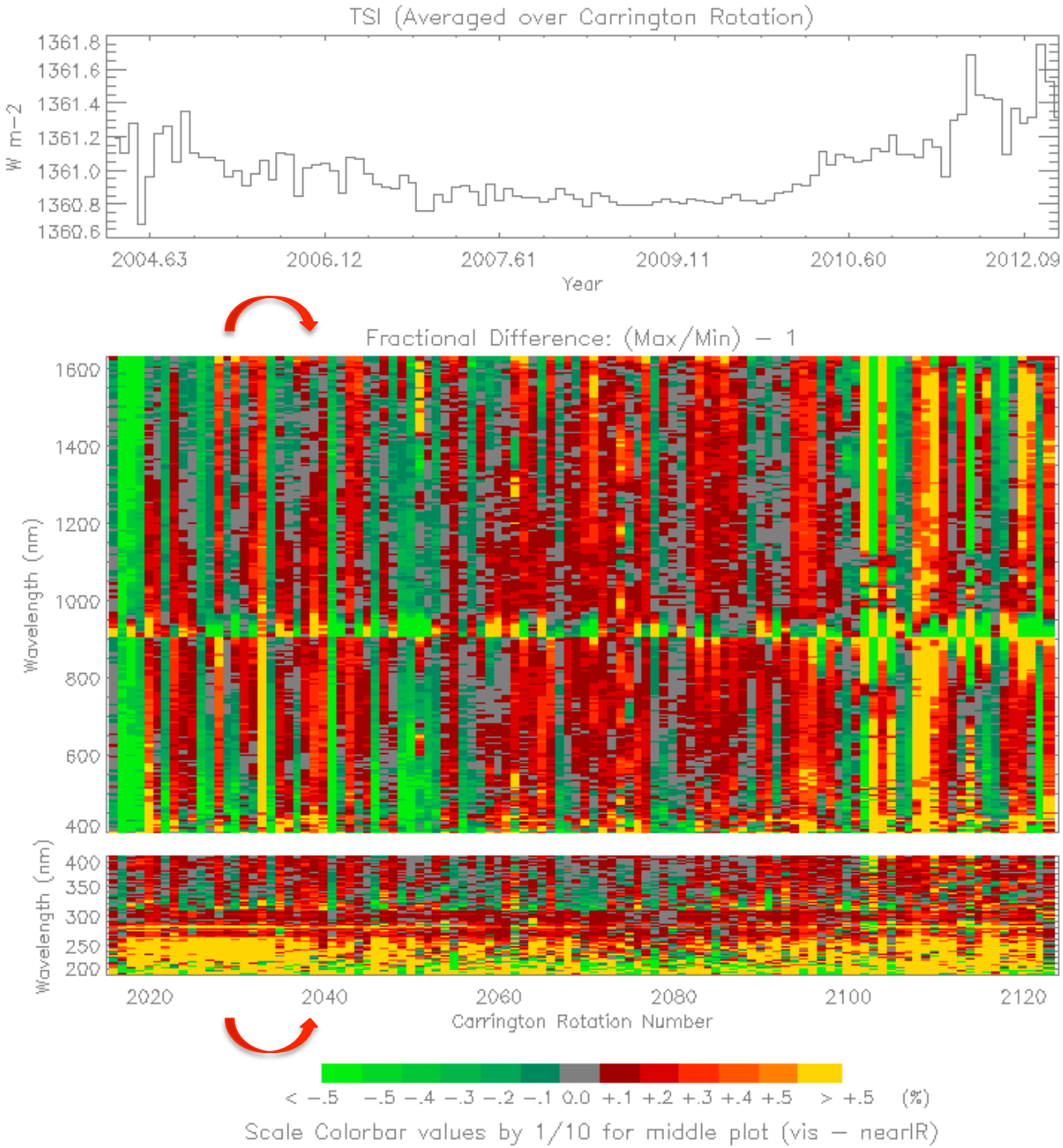

2031
0.282
0.280
0.278
0.276
0.274
MG II Index
405
410
415
420
425
430
435
SORCE Day Number
< −.5 −.5 −.4 −.3 −.2 −.1 0.0 +.1 +.2 +.3 +.4 +.5 > +.5 (%)
Scale Colorbar values by 1/10 for middle plot (vis − nearIR)

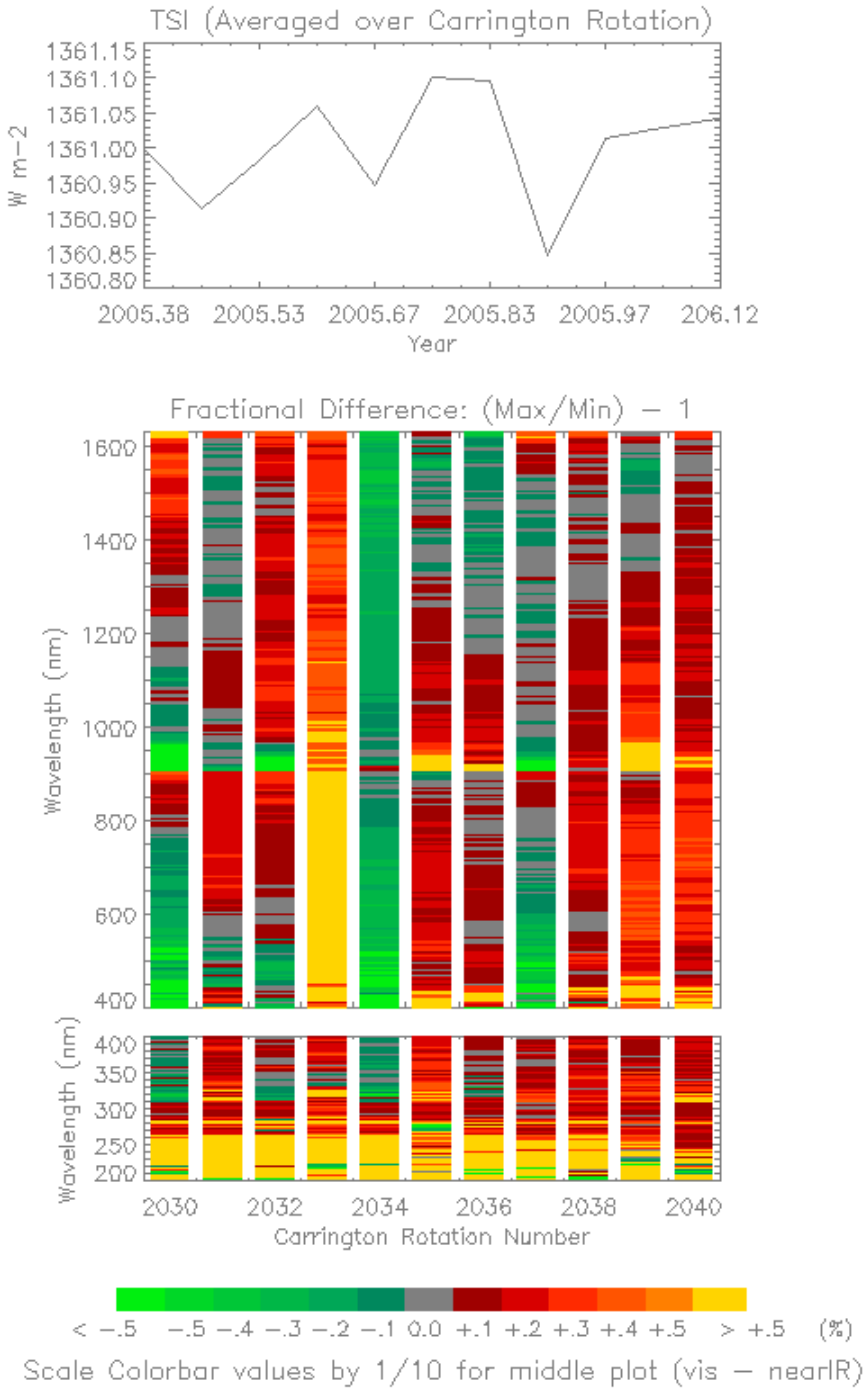

2031
Max
(July 6, 2005)
Min (June 18, 2005)
Difference in MGII
SORCE Day Number
0.282
0.280
0.278
0.276
0.274
405
410
415
420
425
430
435

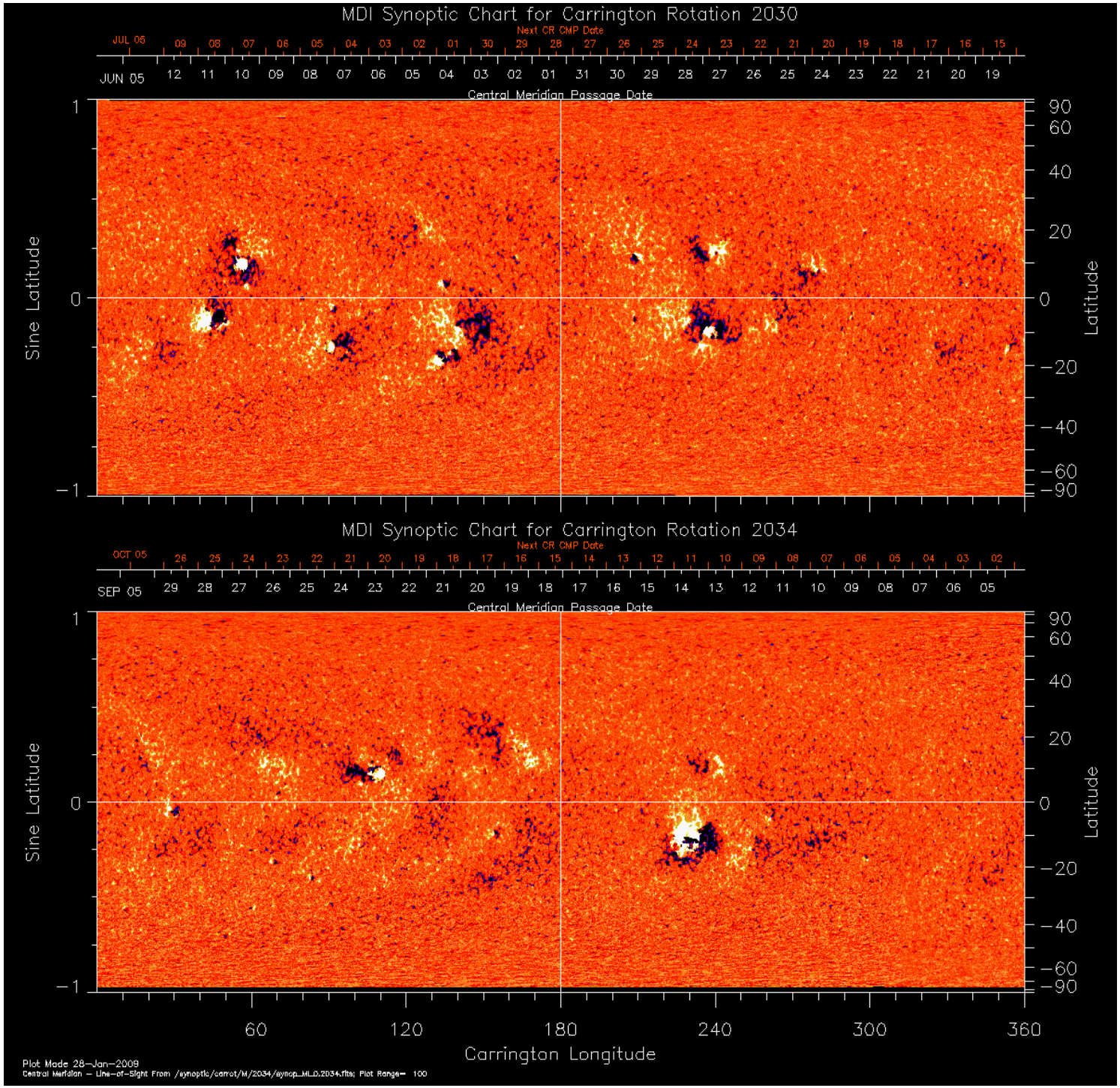

MDI Synoptic Chart for Carrington Rotation 2031
Next CR CMP Date
Central Meridian Passage Date
Sine Latitude
Latitude
Carrington Longitude
Plot Made 28-Jan-2009


2031
Difference in MGII
0.282
0.280
0.278
0.276


MDI Synoptic Chart for Carrington Rotation 2031
Next CR CMP Date
AUG 05
06 05 04 03 02 01 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12
Central Meridian Passage Date
JUL 05
09 08 07 06 05 04 03 02 01 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15
Latitude
90
60
40
20
0
−20
−40
−60
−90
Sine Latitude
1
0
−1
Carrington Longitude
60
120
180
240
300
360
Plot Made 28-Jan-2009
Central Meridian – Line-of-Sight from /synoptic/carrot/M/2031/synop_MLO.2031.fts; Plot Range= 100


TSI (Averaged over Carrington Rotation)
W m−2
1361.8
1361.6
1361.4
1361.2
1361.0
1360.8
1360.6
2004.63
2006.12
2007.61
2009.11
2010.60
2012.09
Year
Fractional Difference: (Max/Min) − 1
Wavelength (nm)
1600
1400
1200
1000
800
600
400
Wavelength (nm)
400
350
300
250
200
2020
2040
2060
2080
2100
2120
Carrington Rotation Number
< −.5 −.5 −.4 −.3 −.2 −.1 0.0 +.1 +.2 +.3 +.4 +.5 > +.5 (%)
Scale Colorbar values by 1/10 for middle plot (vis − nearIR)

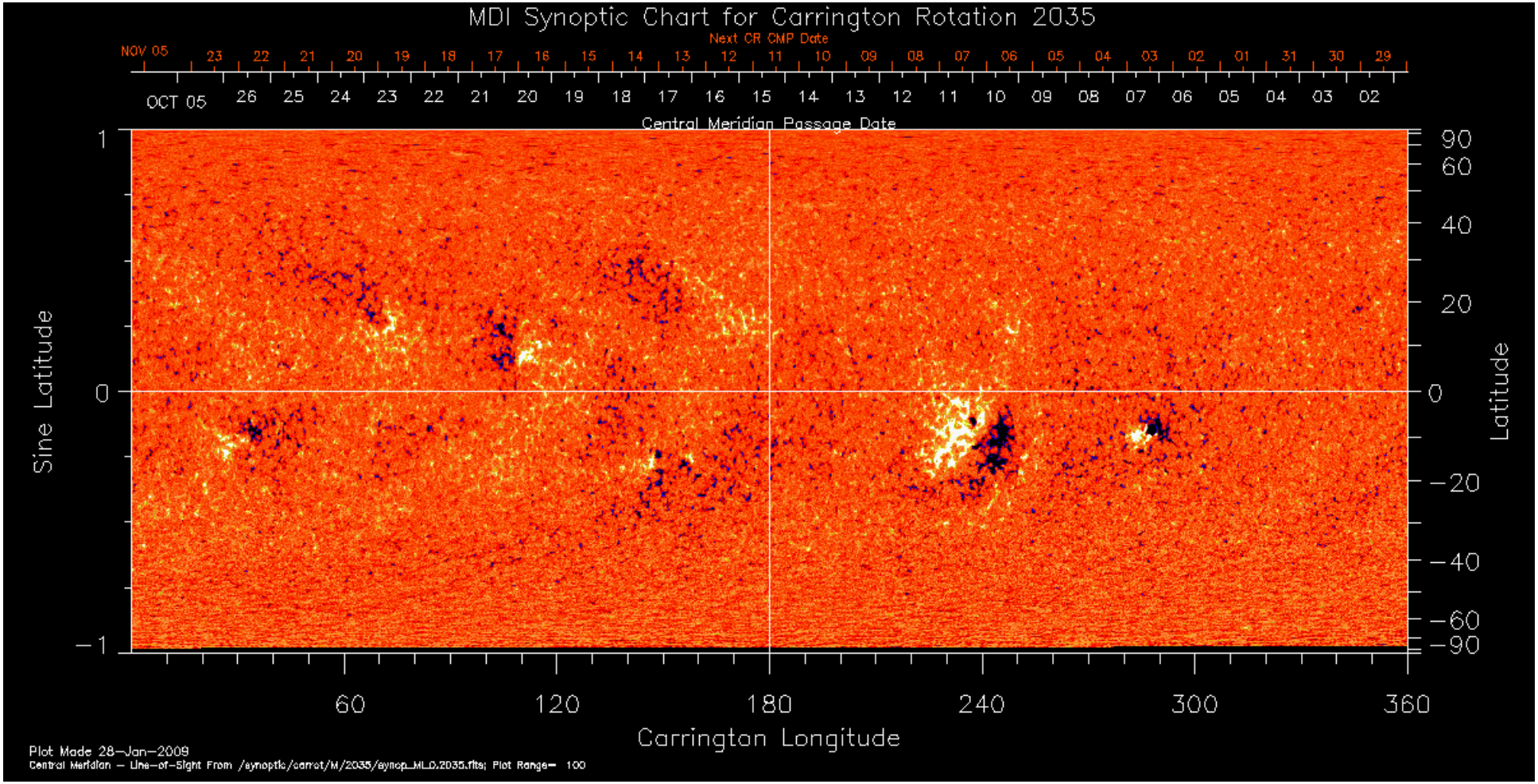

TSI (Averaged over Carrington Rotation)
W m−2
1361.15
1361.10
1361.05
1361.00
1360.95
1360.90
1360.85
1360.80
2005.38
2005.53
2005.67
2005.83
2005.97
206.12
Year
Fractional Difference: (Max/Min) − 1
Wavelength (nm)
1600
1400
1200
1000
800
600
400
350
300
250
200
2030
2032
2034
2036
2038
2040
Carrington Rotation Number
< −.5 −.5 −.4 −.3 −.2 −.1 0.0 +.1 +.2 +.3 +.4 +.5 > +.5 (%)
Scale Colorbar values by 1/10 for middle plot (vis − nearIR)

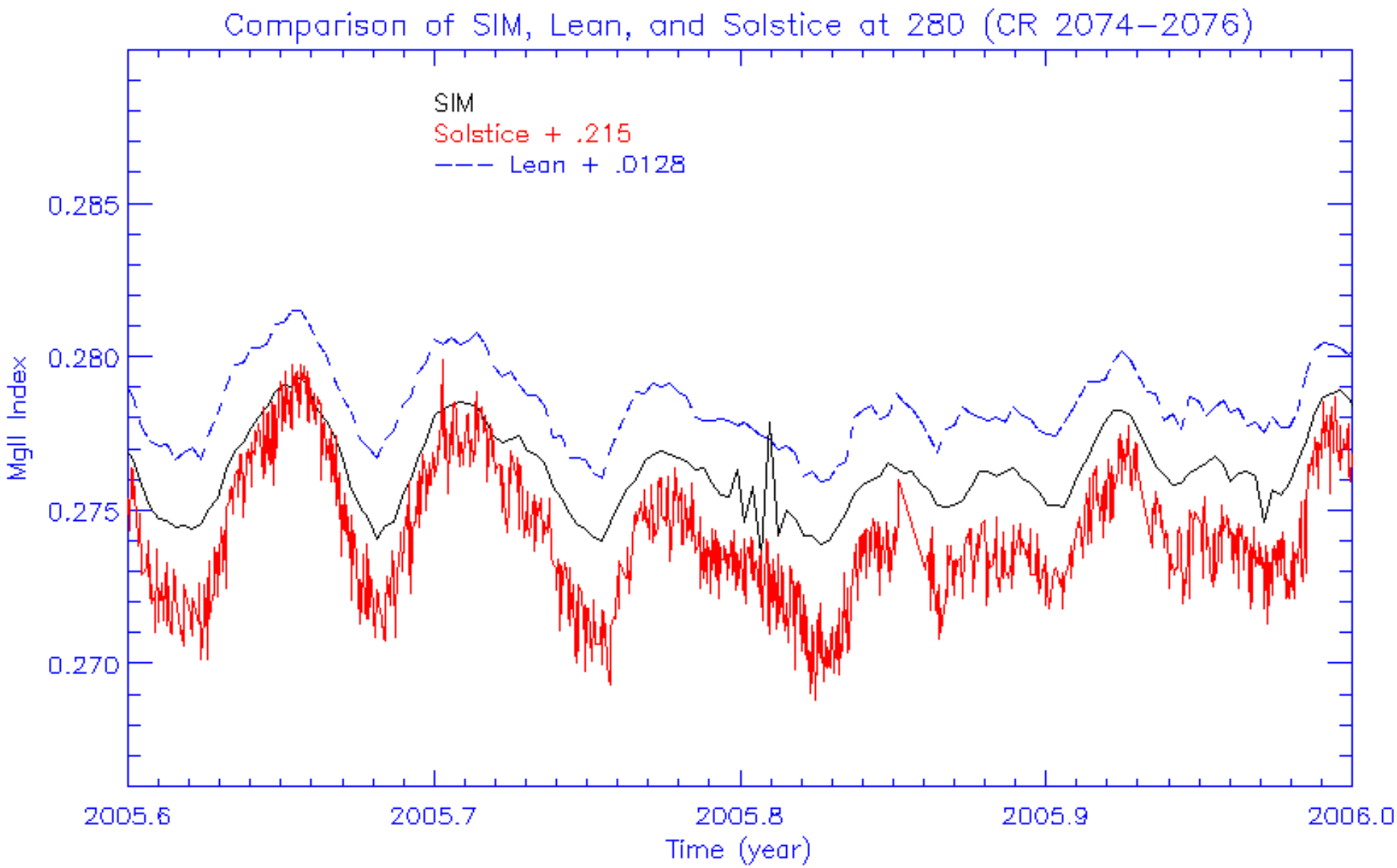


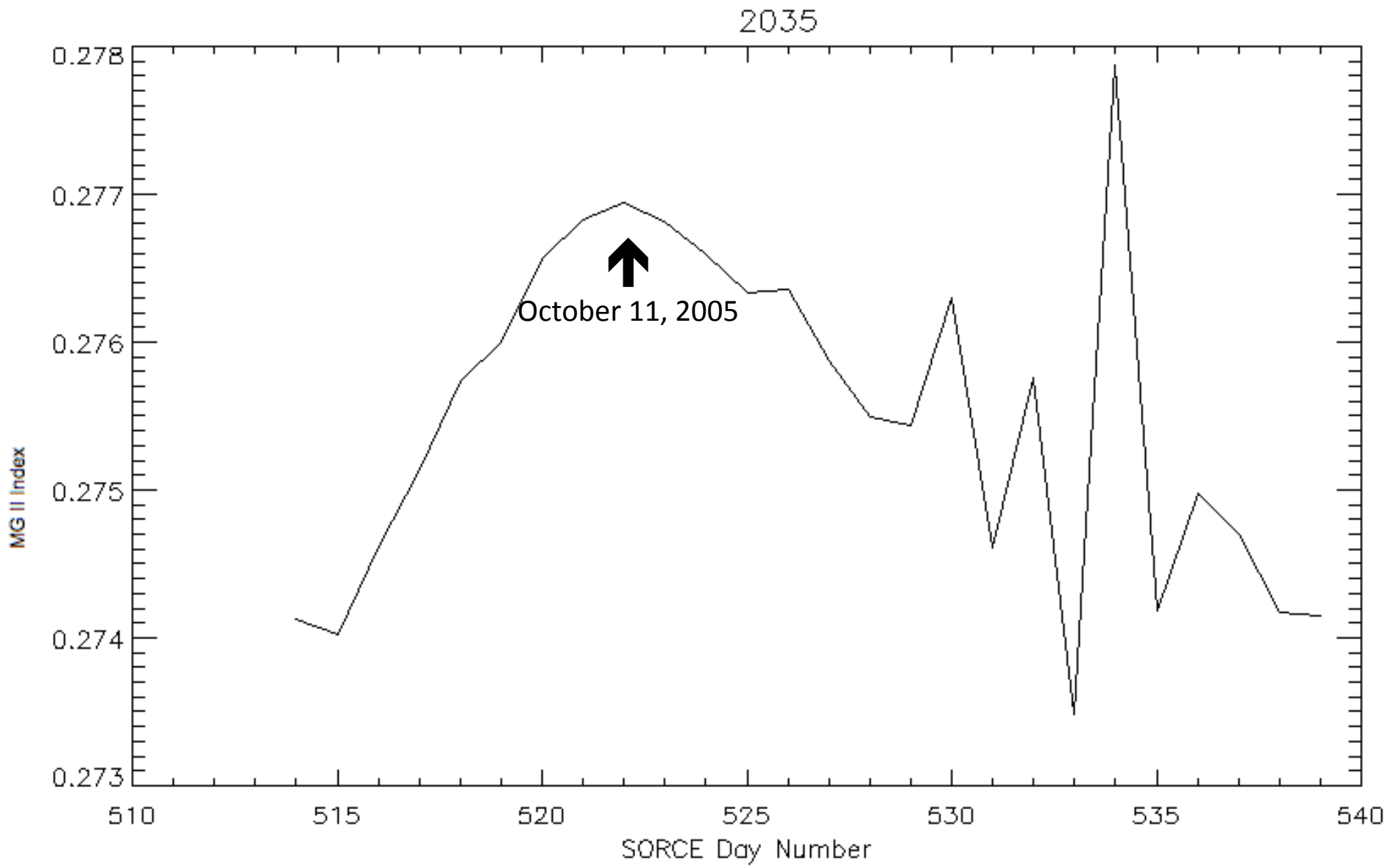
Plage brightening

Sunspot darkening

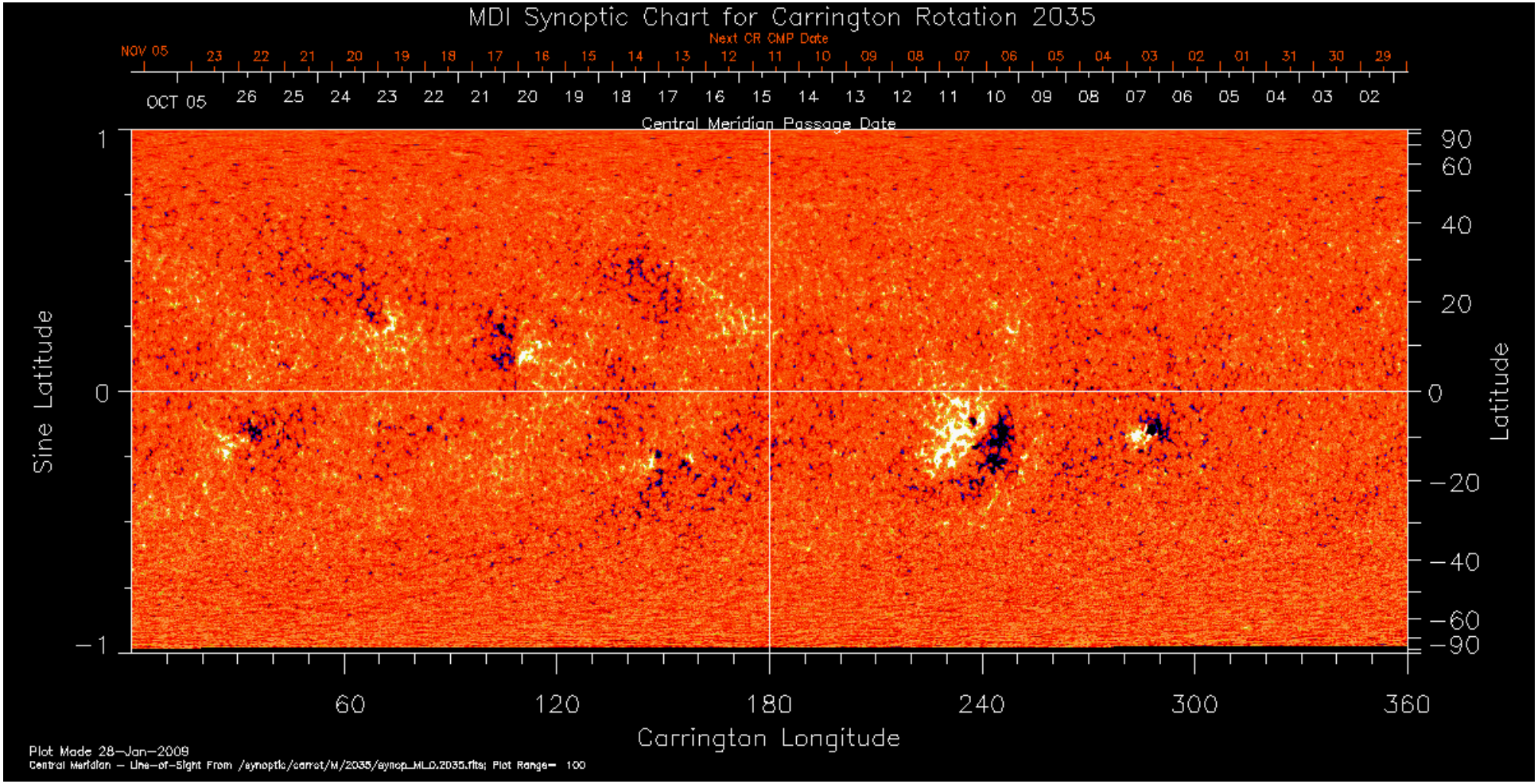
Max? ↘ ↙Min?

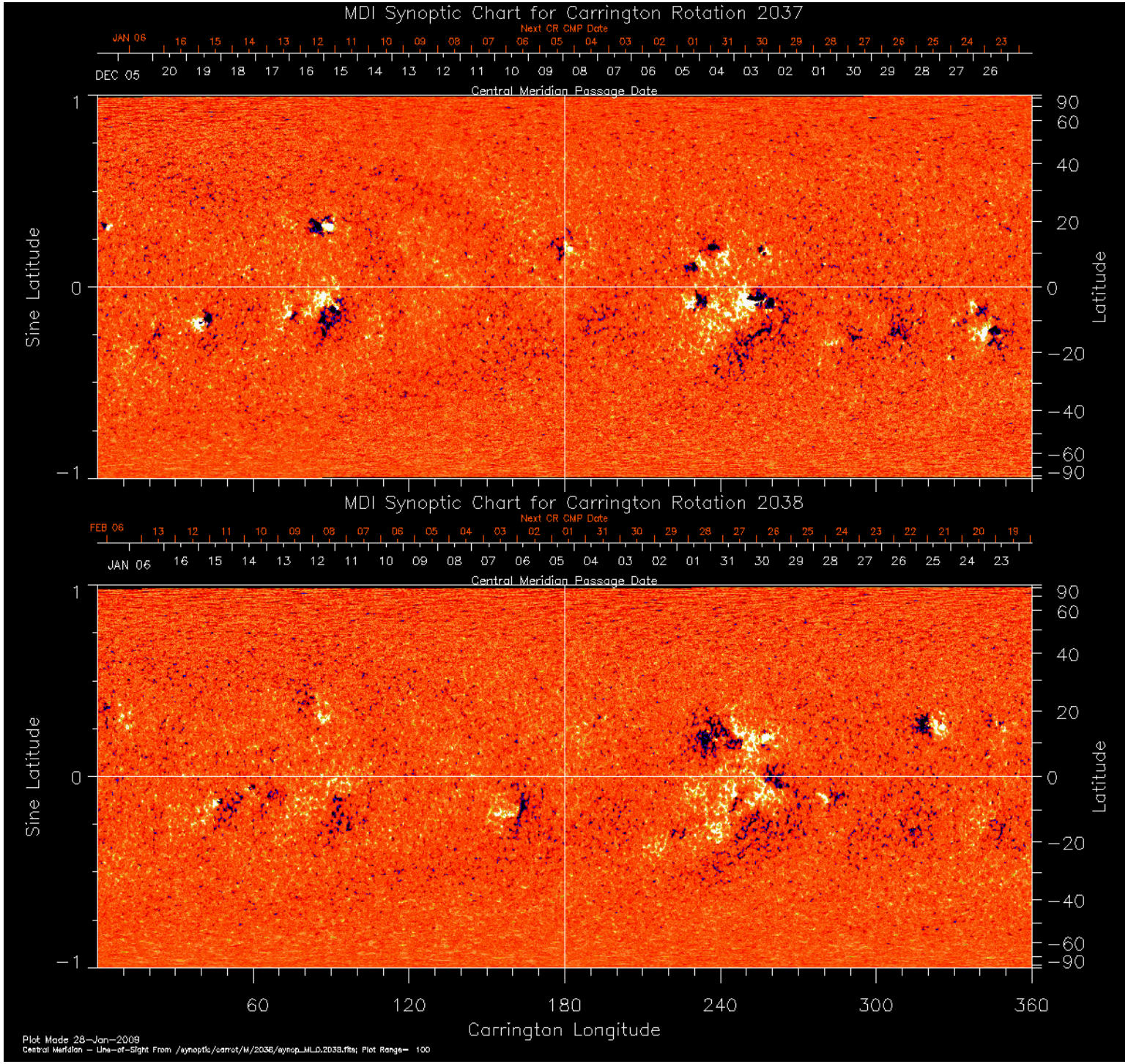

MDI Synoptic Chart for Carrington Rotation 2035
Next CR CMP Date
NOV 05
23 22 21 20 19 18 17 16 15 14 13 12 11 10 09 08 07 06 05 04 03 02 01 31 30 29
OCT 05
26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 09 08 07 06 05 04 03 02
Central Meridian Passage Date
Sine Latitude
1
0
−1
Latitude
90
60
40
20
0
−20
−40
−60
−90
60
120
180
240
300
360
Carrington Longitude
Plot Made 28−Jan−2009
Central Meridian − Line−of−Sight From /synoptic/carrot/M/2035/synop_MLO.2035.fits; Plot Range= 100

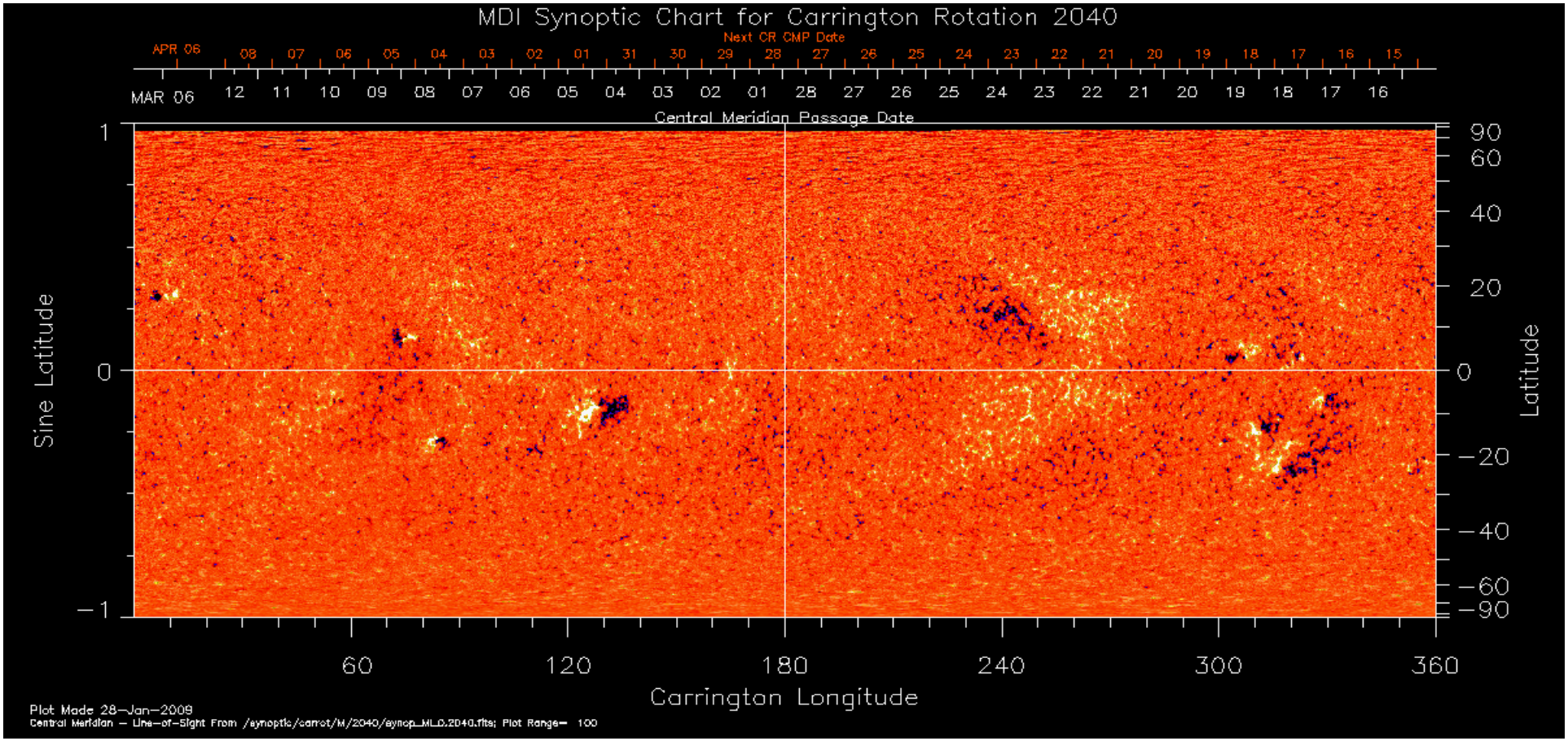

Comparison of SIM, Lean, and Solstice at 280 (CR 2074–2076)
SIM
Solstice + .215
--- Lean + .0128
0.285
0.280
0.275
0.270
MgII Index
2005.6
2005.7
2005.8
2005.9
2006.0
Time (year)


2035
0.278
0.277
0.276
0.275
0.274
0.273
MG II Index
October 11, 2005
510
515
520
525
530
535
540
SORCE Day Number

Max! ↓

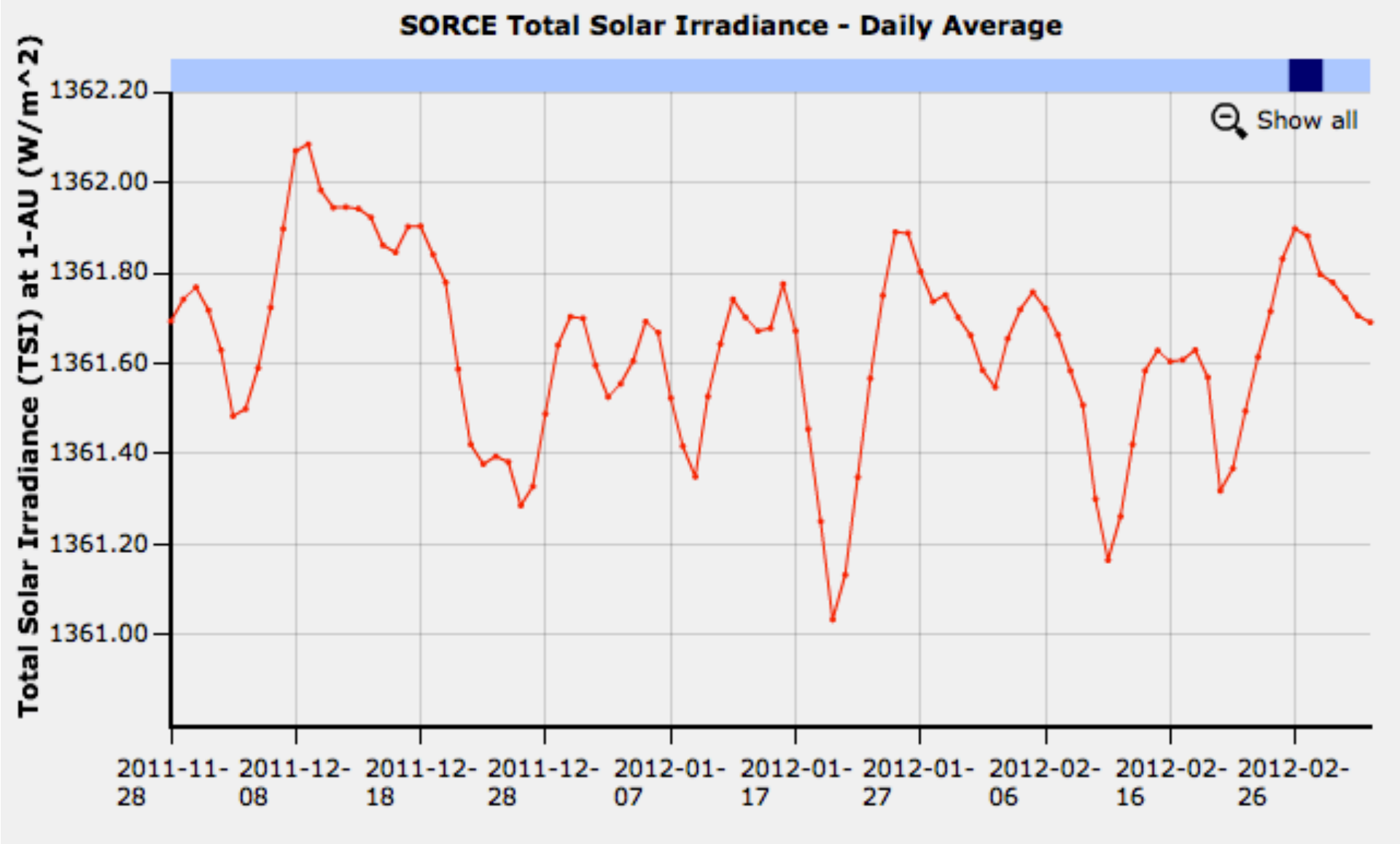

MDI Synoptic Chart for Carrington Rotation 2035
Next CR CMP Date
NOV 05
23 22 21 20 19 18 17 16 15 14 13 12 11 10 09 08 07 06 05 04 03 02 01 31 30 29
OCT 05
26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 09 08 07 06 05 04 03 02
Central Meridian Passage Date
Sine Latitude
1
0
−1
Latitude
90
60
40
20
0
−20
−40
−60
−90
60
120
180
240
300
360
Carrington Longitude
Plot Made 28−Jan−2009
Central Meridian − Line−of−Sight From /synoptic/carrot/M/2035/synop_MLO.2035.fits; Plot Range= 100

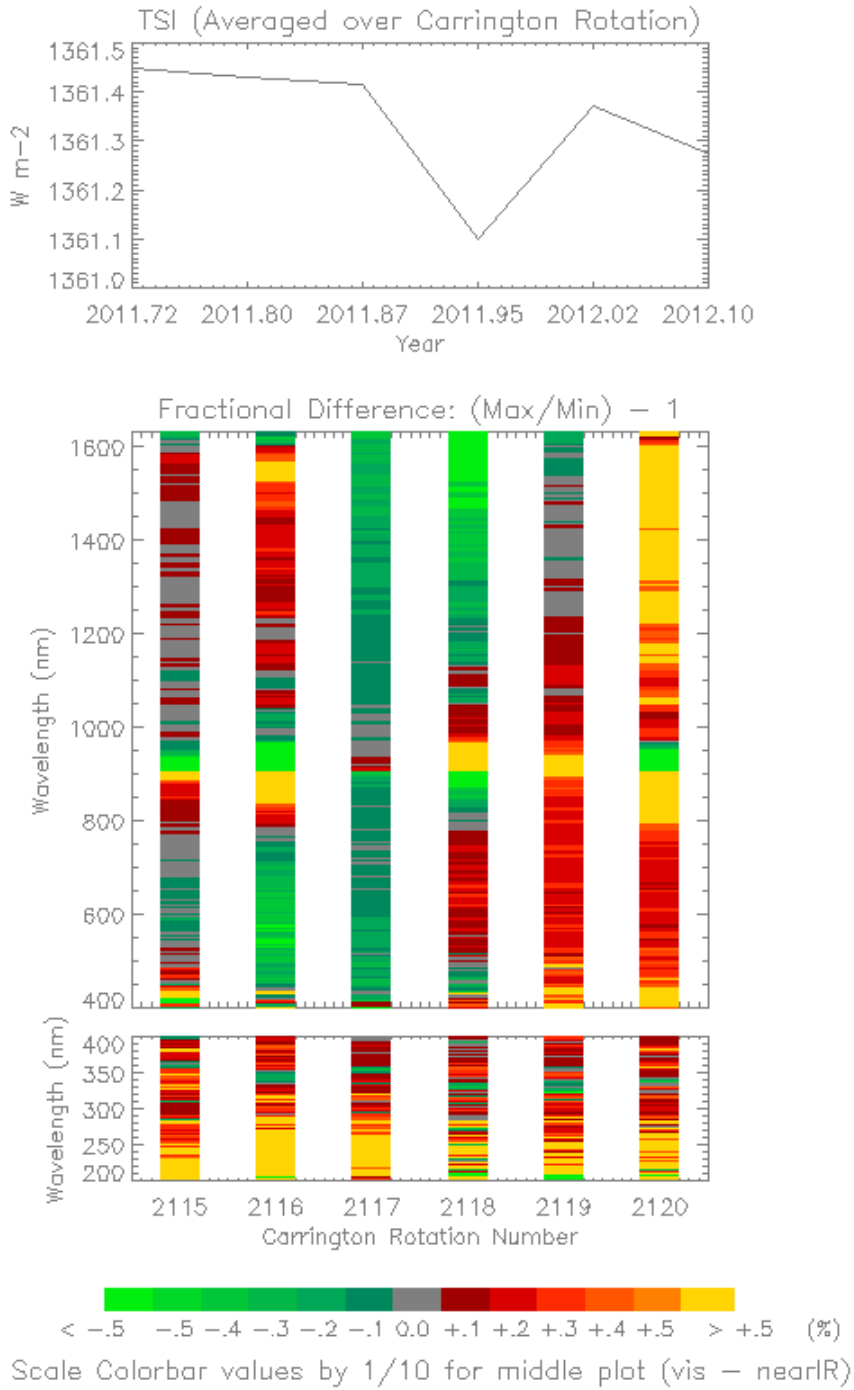

MDI Synoptic Chart for Carrington Rotation 2037
Next CR CMP Date
JAN 06 16 15 14 13 12 11 10 09 08 07 06 05 04 03 02 01 31 30 29 28 27 26 25 24 23
DEC 05 20 19 18 17 16 15 14 13 12 11 10 09 08 07 06 05 04 03 02 01 30 29 28 27 26
Central Meridian Passage Date
Sine Latitude
Latitude
1
0
−1
90
60
40
20
0
−20
−40
−60
−90
MDI Synoptic Chart for Carrington Rotation 2038
Next CR CMP Date
FEB 06 13 12 11 10 09 08 07 06 05 04 03 02 01 31 30 29 28 27 26 25 24 23 22 21 20 19
JAN 06 16 15 14 13 12 11 10 09 08 07 06 05 04 03 02 01 31 30 29 28 27 26 25 24 23
Central Meridian Passage Date
Sine Latitude
Latitude
1
0
−1
90
60
40
20
0
−20
−40
−60
−90
60
120
180
240
300
360
Carrington Longitude
Plot Made 28-Jan-2009
Central Meridian — Line-of-Sight From /synoptic/carrot/M/2038/synop_MLO.2038.fits; Plot Range= 100


MDI Synoptic Chart for Carrington Rotation 2040
Next CR CMP Date
APR 06 08 07 06 05 04 03 02 01 31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15
MAR 06 12 11 10 09 08 07 06 05 04 03 02 01 28 27 26 25 24 23 22 21 20 19 18 17 16
Central Meridian Passage Date
Sine Latitude
1
0
−1
Latitude
90
60
40
20
0
−20
−40
−60
−90
60 120 180 240 300 360
Carrington Longitude
Plot Made 28−Jan−2009
Central Meridian − Line−of−Sight From /synoptic/carrot/M/2040/synop_MLD.2040.fits; Plot Range= 100

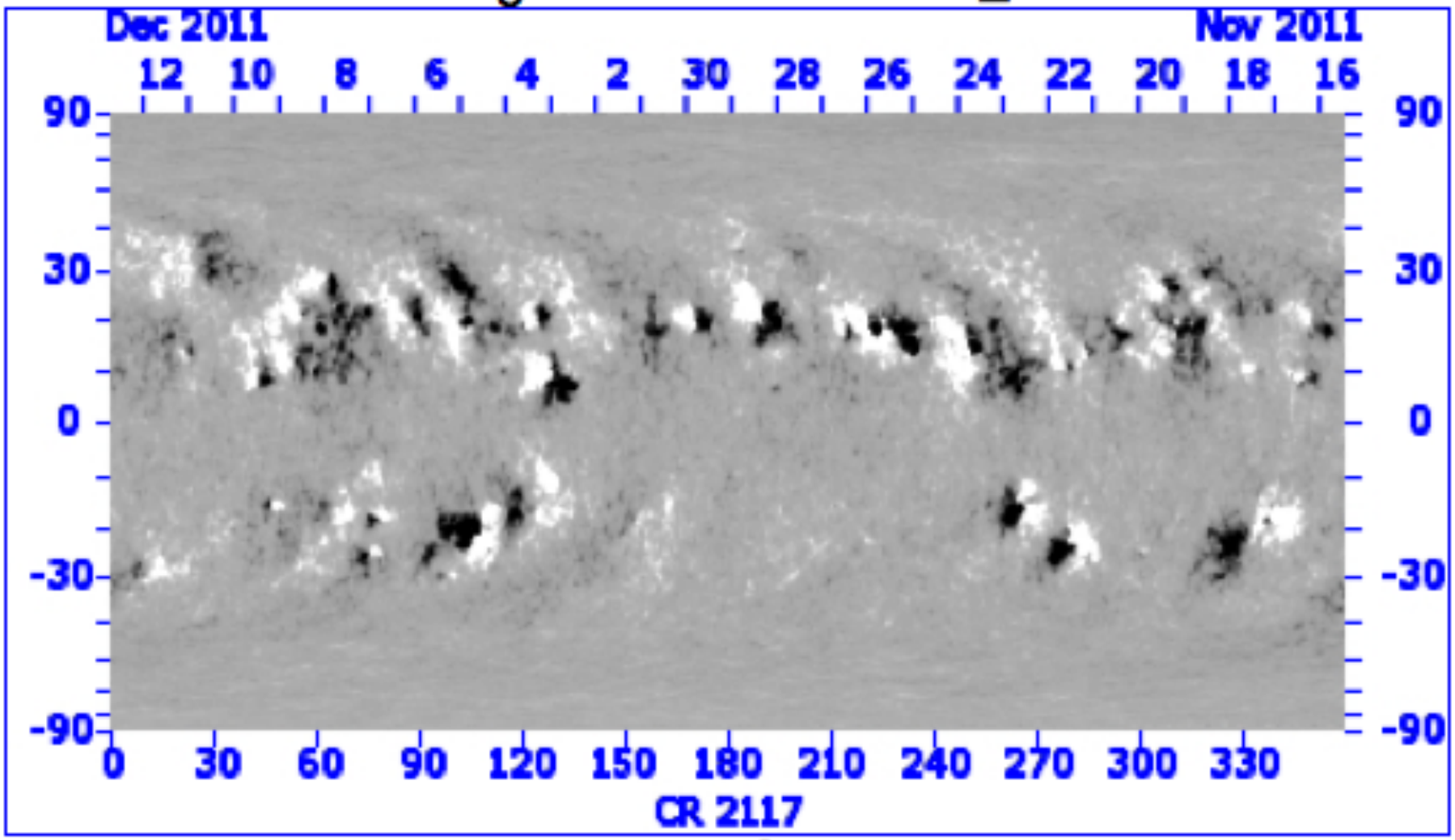
Conclusions

- The fractional differences in solar spectral irradiance between 250 nm and 400 nm are predominantly positive, indicating dominance by chromospheric plage brightening in the UV into the visible parts of the spectra. Between 400 and 1600 nm, the fractional differences ranged from negative to positive indicating a balance between chromospheric plage brightening and photospheric sunspot darkening in the visible to the near IR part of the spectra.
- The Total Solar Irradiance best correlates with the patterns in the visible part of the spectrum because the Sun primarily emits in the visible.
- The Calcium II and Magnesium II indices are not as linear as the solar spectral irradiance model predicted.


SORCE Total Solar Irradiance - Daily Average
Total Solar Irradiance (TSI) at 1-AU (W/m^2)
1362.20
1362.00
1361.80
1361.60
1361.40
1361.20
1361.00
Show all
2011-11-28
2011-12-08
2011-12-18
2011-12-28
2012-01-07
2012-01-17
2012-01-27
2012-02-06
2012-02-16
2012-02-26


TSI (Averaged over Carrington Rotation)
W m−2
1361.5
1361.4
1361.3
1361.2
1361.1
1361.0
2011.72
2011.80
2011.87
2011.95
2012.02
2012.10
Year
Fractional Difference: (Max/Min) − 1
Wavelength (nm)
1600
1400
1200
1000
800
600
400
350
300
250
200
2115
2116
2117
2118
2119
2120
Carrington Rotation Number
< −.5 −.5 −.4 −.3 −.2 −.1 0.0 +.1 +.2 +.3 +.4 +.5 > +.5 (%)
Scale Colorbar values by 1/10 for middle plot (vis − nearIR)

Carrington Rotation: 2117_000



Magnetogram Count: 6117

Future Studies

- Study other parts of the solar cycle, particularly higher latitude sunspots at solar maximum
- Find other examples of hemispheric switch
- Further research the relationship between the Mg II and Ca II indices from real data.

Acknowledgements

- My mentor, Odele Coddington, and co-mentors, Erik Richard and Marty Snow
- LASP and Colorado University-Boulder for providing us with the facilities to do this research
- SORCE mission for funding my research this summer

Works Cited

Data

Donnelly, R.,White, O., & Livingston, W., 1995, Solar Phys., 152, 69.

Lean, J., 2000, GRL, 27, 2425.

Lean, J. et al., 2005, Solar Phys., 230, 27.

Rottman, G., Woods, T., McClintock, W., 2005, Advances in Space Research, 37, 201.

Snow, M.. et al., 2005, Solar Phys., 230, 325.

Images

- http://www.astropa.unipa.it/~orlando/INTRO_SUN/slide17.html
- http://cbdakota.wordpress.com/2011/05/25/solar-cycle-24-and-the-sunspot-butterfly-diagram/
- http://www.djibnet.com/photo/solarflares/02-sun-structure-2819311727.html
- http://en.wikipedia.org/wiki/File:Solar_Spectrum.png
- http://www.sciencedaily.com/releases/2006/09/060914095559.htm