MDI Calibration Issues

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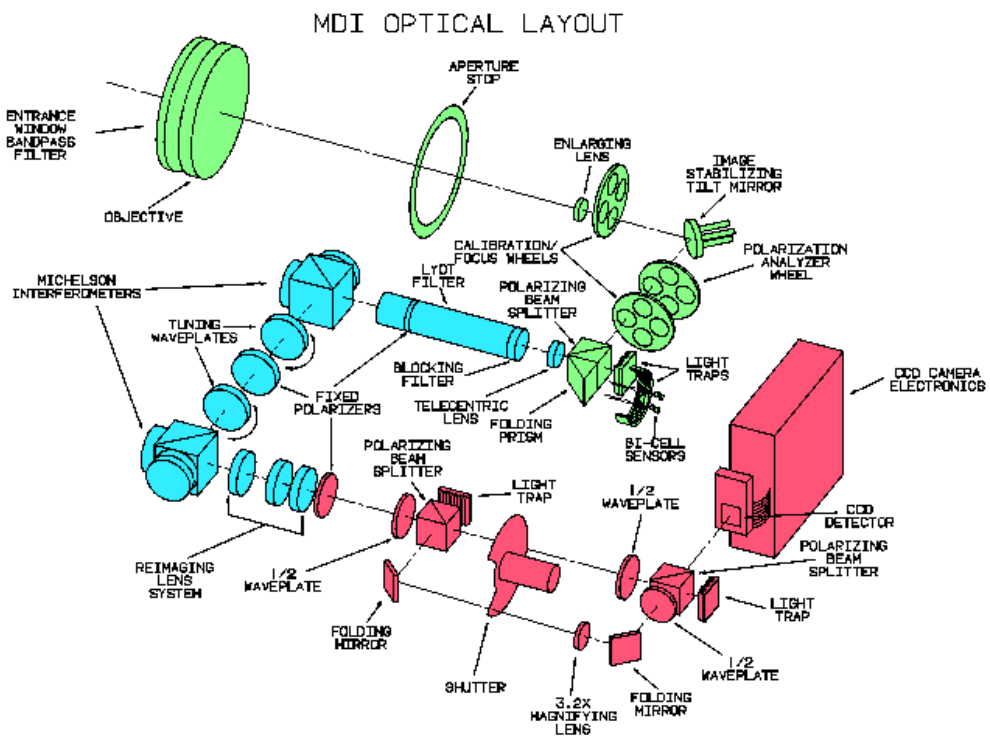
Contents:

General MDI Overview

Specific Issues

MDI Overview

MDI is a camera with a tunable narrow band filter.
It makes a repeating sequence of images in sets of tuning positions and polarizations



MDI has several “Observing Programs” which are designed to optimize the return from the various telemetry opportunities. All programs operate in a basic 60-second cadence. The first half of each minute is the same sequence in all observing modes to obtain data for the basic continuous structure program.

In medium rate times or when SOHO is out of contact MDI operates the “structure program” for both halves of each minute averaging the results to obtain 60-second average quantities. In all cases the center of the 30 or 60 second structure program is on the TAI minute “tick”.

In short high rate times which occur at the end of the SOHO Solid State Recorder memory dumps MDI operates the “Magnetic Program” In this mode any stored magnetograms (obtained on a 96-minute (15/day) cadence) are downlinked and some standard reference images are obtained and downlinked. These include a full disk continuum proxy image.

In longer high rate telemetry intervals lasting from 8-12 hours or 60-90 days MDI operates its “Campaign” or “Dynamics” programs respectively. In these times the second 30-second intervals are used for observables not included in the structure program sequences. These may be in either full disk or high resolution (a 3.2 times magnified fixed region centered just north of disk center) and may collect magnetograms, Doppler velocity, line depth, continuum tuned filtergrams. If the collecting area is less than the full disk or full high resolution field of view several observables may be obtained.

Observables – See 1995 Solar Physics paper for details.

The line scanned in five wavelengths, I0, I1, I2, I3, I4 where I0 is nearly continuum and I1, I2 are on the blue wing and I3 and I4 on the red wing. I1,I2, I3, and I4 are equally spaced by 75mA

The polarization analyzer wheel can be set at LCP, RCP, or linear. The Structure program is observed in linear polarization. The Magnetic and usually Campaing and Dynamics are in LCP/RCP pairs.

Each filtergram takes 3 seconds allowing sequences of 10 per 30-second basic interval.
Sa = (I1 – I3); Sc = (I2 – I4); Sall = (I1 + I2 + I3 + I4); Ssum = Sa + Sc;

V = OnBoardTable[(Ssum) / (if Ssum > 0 then Sa else -Sc)]]

M = Vrcp – Vlcp

Ld = Sqrt(2 *(Sa^2 + Sc^2))

Ic = 2*I0 + Ld/2 + Sall/4

MDI Data Access

MDI data may be obtained via the Web via:

http://soi.stanford.edu/data

The first text link on that page is for

Automated Data Search and Export Requests

This is the normal way to get the data. On that page ***MOST*** data users will choose the links:

Calibrated Data Products for Structure Program or Magnetic Program data, or

Calibrated Campaign Data for Campaign or Dynamics Program data

The second text link in the data page is:

Calibration Notes and Problems

Which contains at least some information about calibration issues that the data user should be aware of.

MDI data header keywords lev1.4 and above are described in:

http://soi.stanford.edu/cgi-bin/keyword.pl

MDI Dataset Names

MDI data products are specified via a multipart naming scheme. The names are of the form Program,Level,Series. The parts are formatted as:

prog:{progname},level:{levelname}[version],series:{seriesname}[seriesnumber]

Where “version” defaults to the most recent version. “progname” will be “mdi” for calibrated MDI data. Level names most often used are:

lev0	Raw telemetry data as FITS files, Series are onboard codes
lev1	lev0 format but calibrated to physical units.
lev1.5	lev1 with meaningful series names and expanded headers
lev1.8	lev1.5 with corrected calibration information
lev2	higher processing levels.

Lev1.4 and 1.7 are like lev1.5 and lev1.8 but stored in cropped form vs images.

Lev1.4 and above have series names constructed as:

{mode}_{observable}_[{cadence}_]{blocking}

MOST data users should want lev1.8 or lev2 data

The seriesnumber interpretation is governed by the blocking. It is usually the block count since the standard MDI reference epoch of 1993.01.01_00UT

Seriesname format is usually: {mode}_{observable}_[{cadence}_]{blocking} where:

mode is:

fd	full disk 2” pixels
hr	high resolution 0.6” pixels
vw	vector weighted averages, 10” pixels
loi	LOI style bins, 180 bins can be summed to mimic LOI pixels
rwbin	rectangular weighted binning 16” pixels only option used
limb	limb annulus of about 5 pixel thickness, 2” pixels

observable is:

V	Doppler line-of-sight velocity, linear polarization
M	Magnetic field as difference Vrcp and Vlcp
Vm	Doppler as average of Vrcp and Vlcp
Ic	Continuum proxy
Ld	Line depth
I0	Brightness in tuning position 0

cadence – optional sampling cadence

96m	15-per day magnetograms
6h	3 per day continuum proxy

blocking – duration of each dataset in the series

01h	1 hour blocking. Series number is hour number since 1993.01.01
06h	6-hour blocking Series number is 6-hour number
01d	1 day blocking, series number is day number
72d	72-day blocking, series number is 72-day number, GONG phase

For the ISSI Irradiance Workshop the MDI dataseries of most interest are:

prog:mdi,level:lev1.8,series:fd_M_96m_01h

prog:mdi,level:lev1.8,series:fd_Ic_6h_01h

prog:mdi,level:lev2,series:fd_Ic_6h_01h

The following discussion of “Calibration Issues” introduces some of the “quirks” and “features” of these dataseries.

- Things that affect all data products:
  - Image Geometry
    - Focus and plate scale changes with time, few pixels
    - Cubic distortion, 2/3 pixel
    - “as if” CCD is tilted in camera header, Rmajor – Rminor ~ ½ pixel
    - Image center not solar center, < 0.5 pixel
    - MTF not symmetrical, astigmatism
    - Image plane not flat, focus varies across image
  - Shutter exposure variation – affects all data products
  - Michelson passband
    - Uniformity affects calibration uniformity
    - Variation effects linearity for large B and V conditions
  - Ni677nm line contaminated in strong fields – umbral fields
- Things that affect brightness data
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  - Different LCP and RCP distortion allows granulation to leak as noise
  - “saturation” in umbra due to onboard arithmetic precision
- Things that affect velocity data
  - Beat between SOHO major frame pulse and 15-seconds

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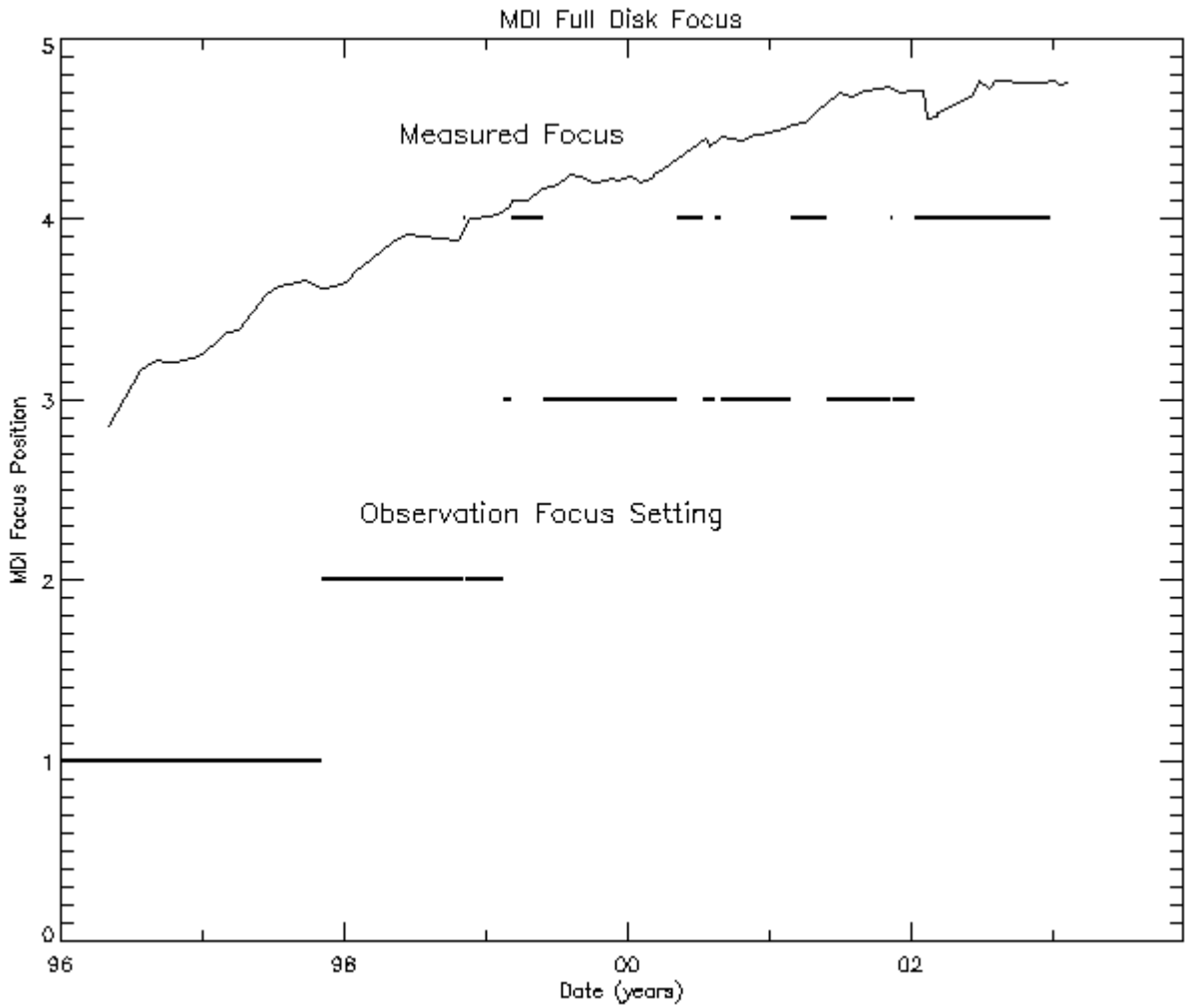
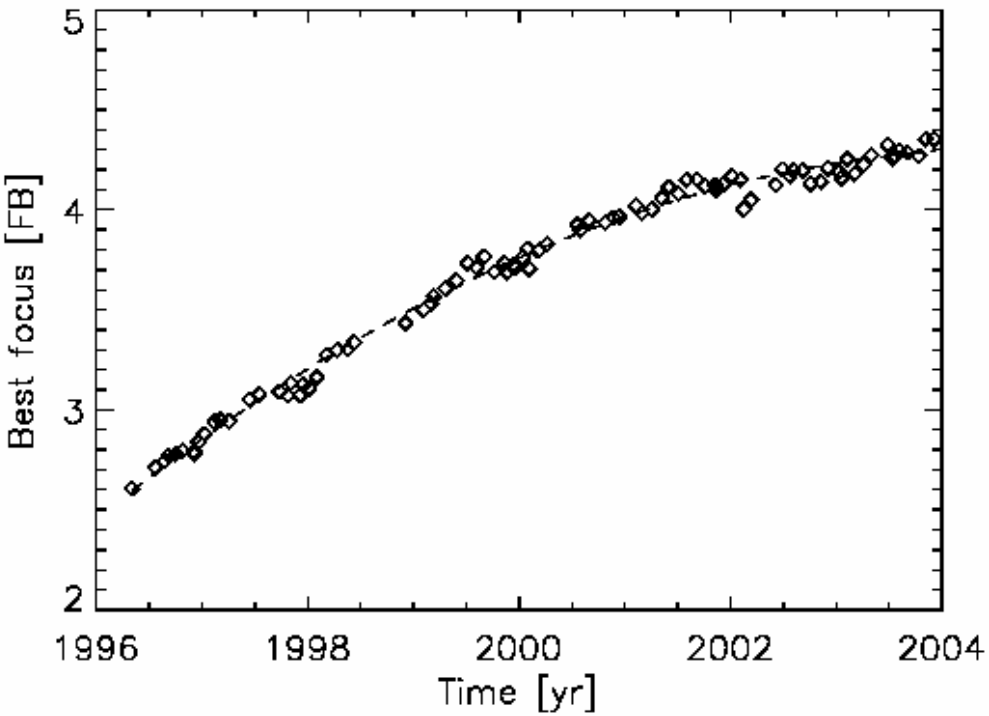


MDI fd best focus (curve) and commanded focus setting. The hr focus is 2 stops higher than the fd focus. Normal setting has the hr image In good focus and fd somewhat out of focus – by design. Starting in 1999 Best fd focus is used during the Dynamics Program.

Plate Scale Depends on Focus

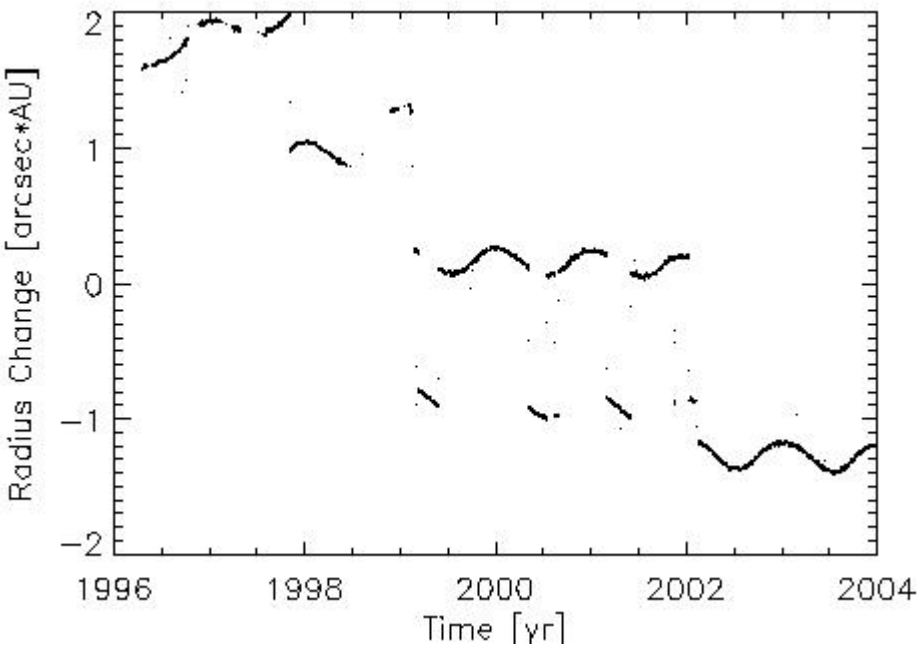


The plate scale depends on the current focus setting and the current optimum focus. The discreet focus changes are the cause of the largest jumps in image size.

MDI Events

1996 Feb 13 & front door closed
1996 Feb 16 & front door opened
1997 Nov 03 & focus from 1 to 2
1997 Nov 05 & focus from 2 to 4
1998 Nov 11 & focus from 4 to 2
1998 Nov 15 & front door closed
1998 Nov 16 & heater 1 turned on
1998 Nov 20 & front door opened
1999 Feb 18 & focus from 2 to 3
1999 Mar 11 & focus from 3 to 4
1999 Apr 12 & focus from 4 to 6
1999 Apr 14 & focus from 6 to 4
1999 May 28 & focus from 4 to 3
2000 May 08 & focus from 3 to 4
2000 Jul 14 & focus from 4 to 3
2000 Aug 14 & focus from 3 to 4
2000 Aug 29 & focus from 4 to 3
2001 Jan 19 & exposure increase
2001 Feb 28 & focus from 3 to 4
2001 Jun 01 & focus from 4 to 3
2001 Nov 12 & focus from 3 to 4
2001 Nov 16 & focus from 4 to 3
2002 Jan 11 & focus from 3 to 4
2002 Feb 12 & heater 1 turned off
2003 Jan 17 & exposure increase

Apparent Radius Variability



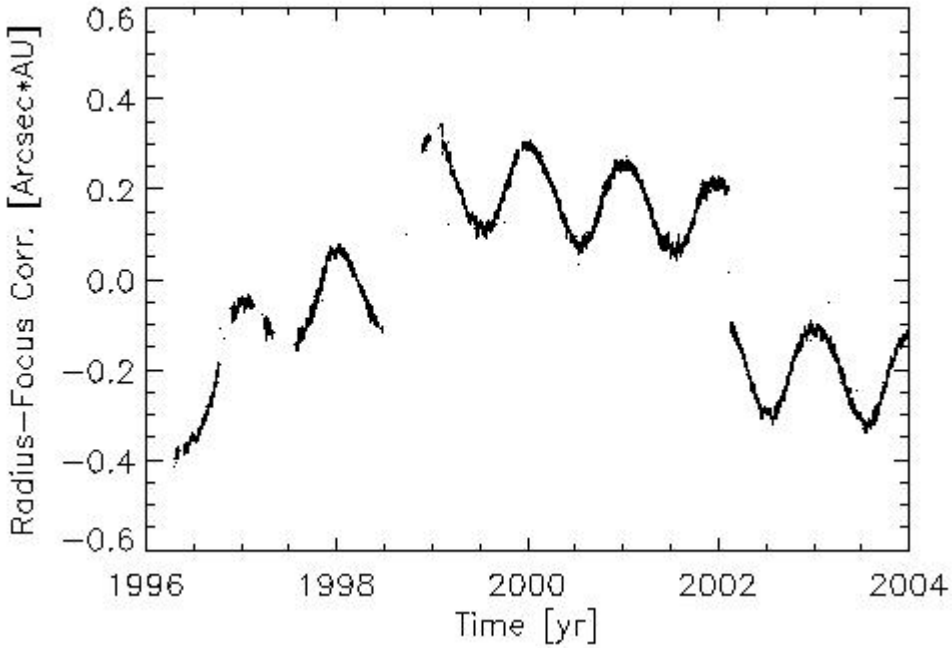


Image size or apparent radius jumps (left) can be removed (right) by knowing the offset between the current best focus and current selected setting. The corrected best estimate of the plate scale is included in the image headers for all lev1.8 data products.

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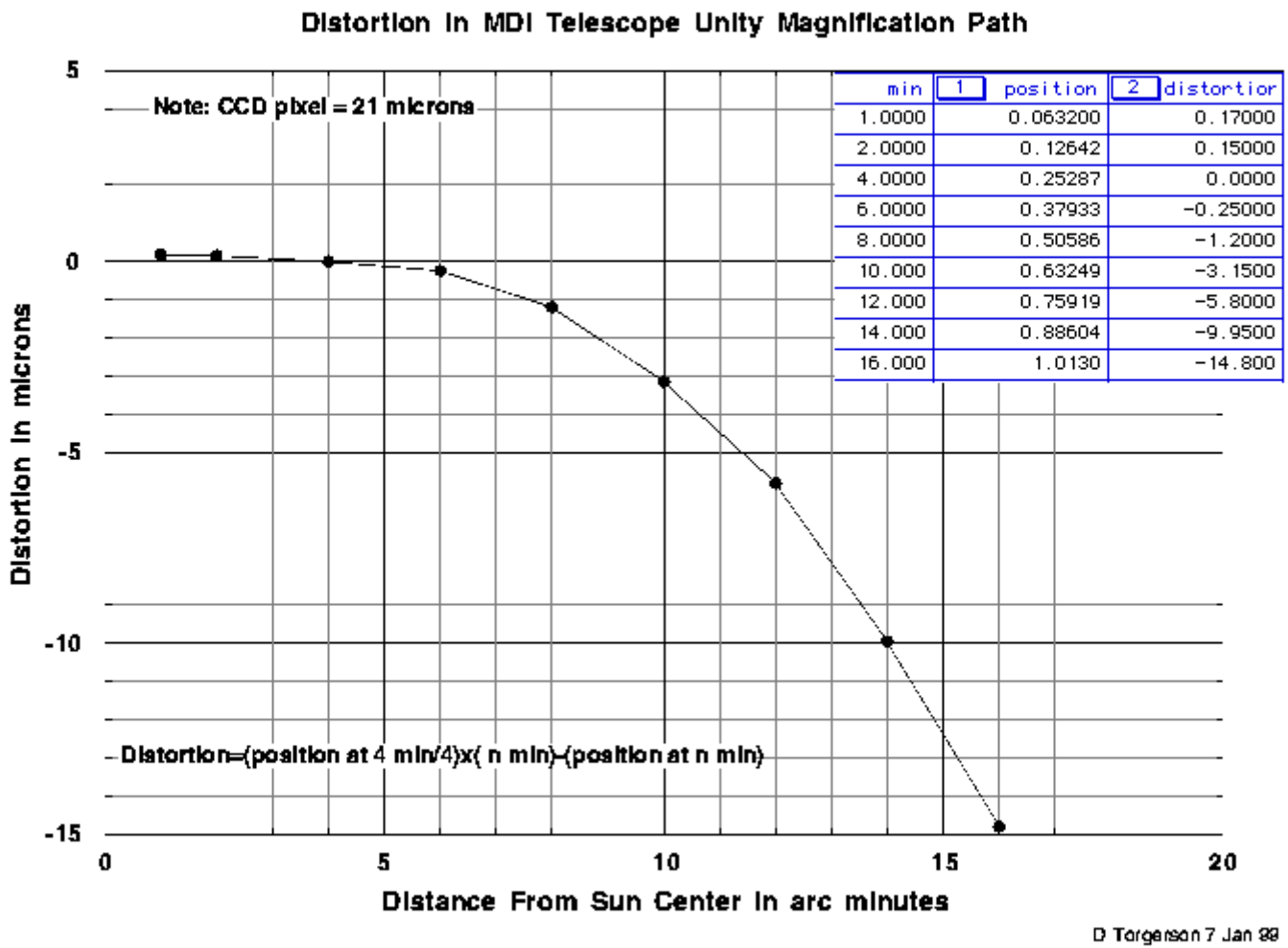

min	1 position	2 distortior
1.0000	0.063200	0.17000
2.0000	0.12642	0.15000
4.0000	0.25287	0.0000
6.0000	0.37933	-0.25000
8.0000	0.50586	-1.2000
10.000	0.63249	-3.1500
12.000	0.75919	-5.8000
14.000	0.88604	-9.9500
16.000	1.0130	-14.800

Compared to the plate scale at disk center the image it too big by about ¾ pixel at the limb. Pixels are 21 microns. This error is not described in the ≤ lev1.8 image headers.

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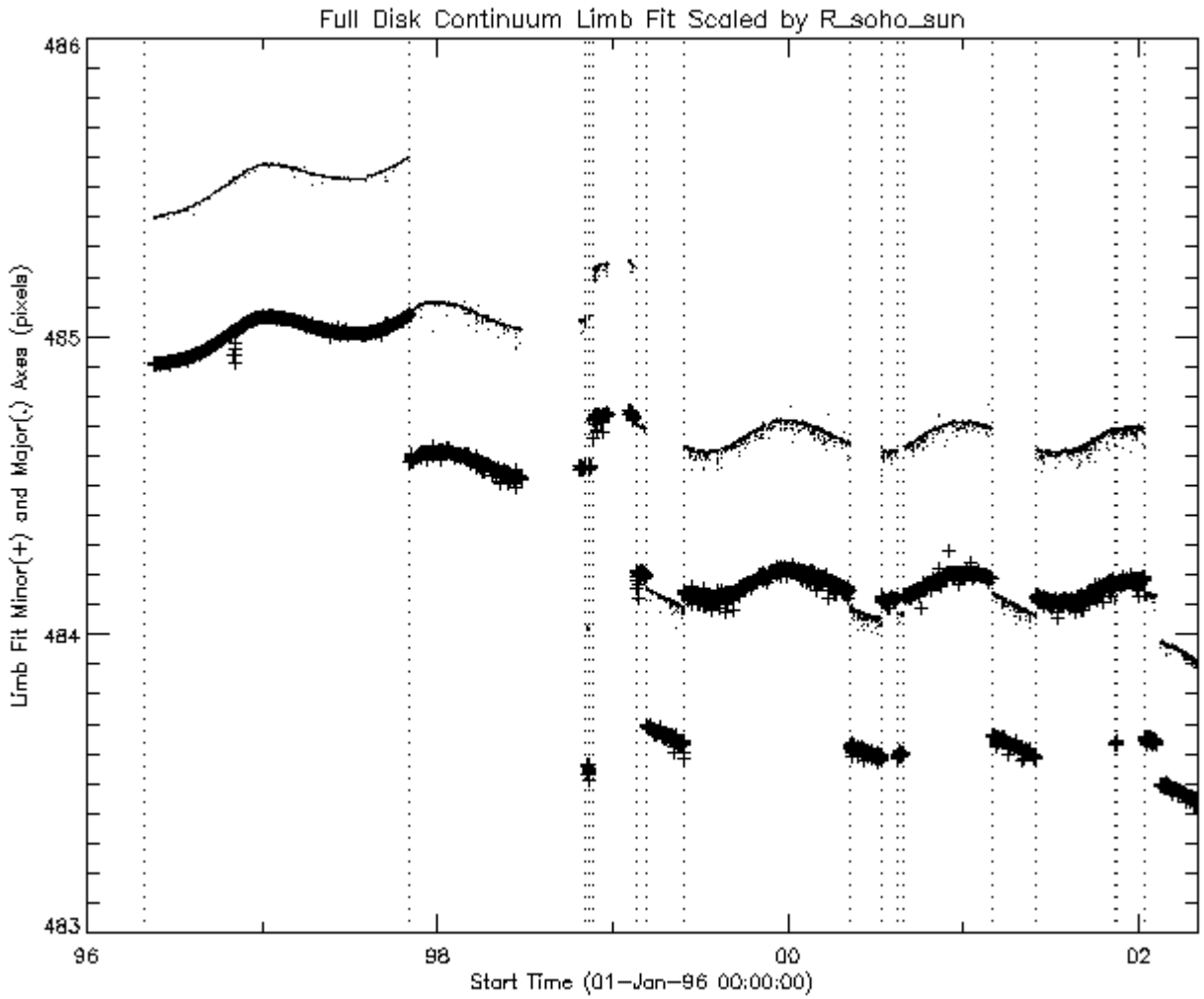

The image is an ellipse with the semi-major axis about 15 degrees clockwise from East-West. The Rmajor is about a half pixel larger than Rminor. This is consistent with a tip of about 2.5 degrees in the CCD wrt the optic axis. The resulting distortion was absent before the BDS beamsplitter and CCD were changed in the spring of 1994. Lev1.8 presently does **NOT** make this correction.

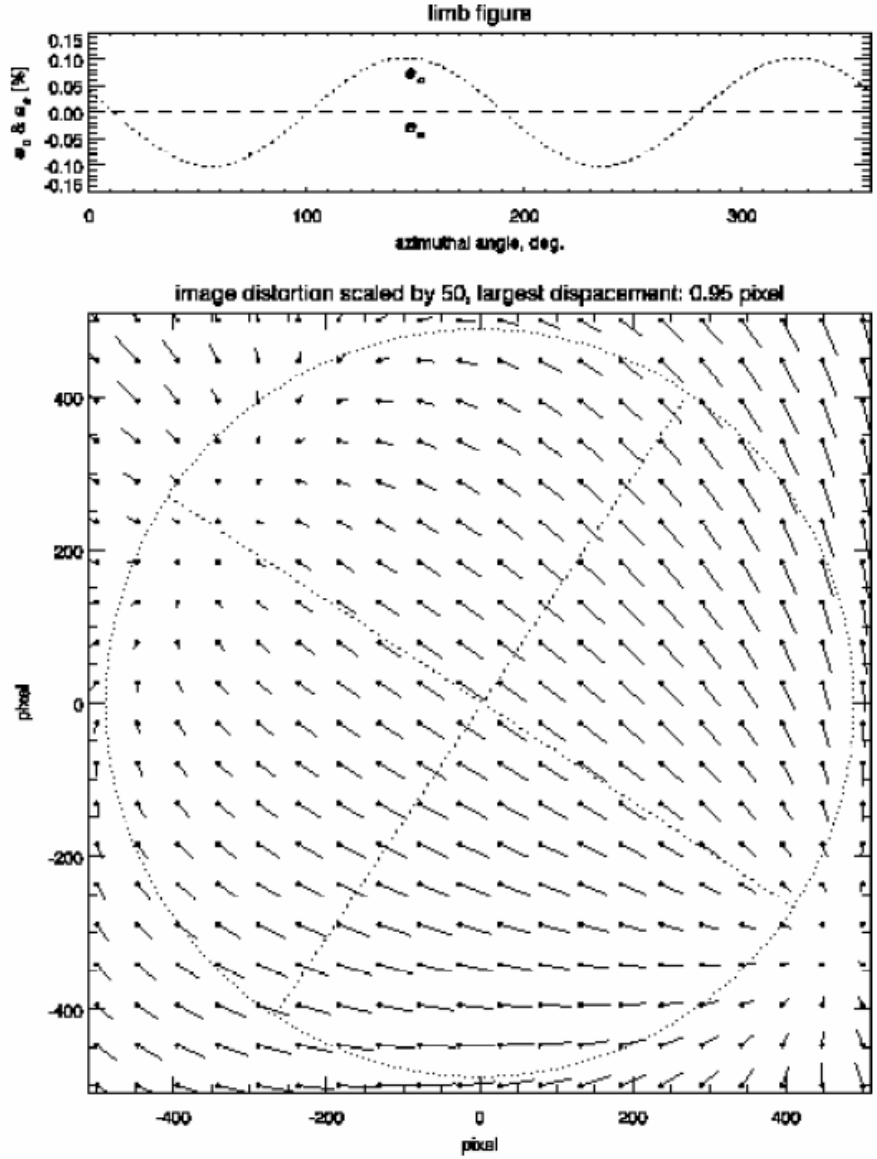

Fig. 38.— Map of the image distortion in the plane of the CCD. The distortion has been multiplied by a factor 50 to make it visible. The largest displacement inside the solar limb is 0.95 pixel. The top panel illustrates how the distorted departs from a circle (*i.e.*, $e_c = (x/r)^2 + (y/r)^2 - 1$) and how well it fits an ellipse (*i.e.*, $e_e = (x/a)^2 + (y/b)^2 - 1$).

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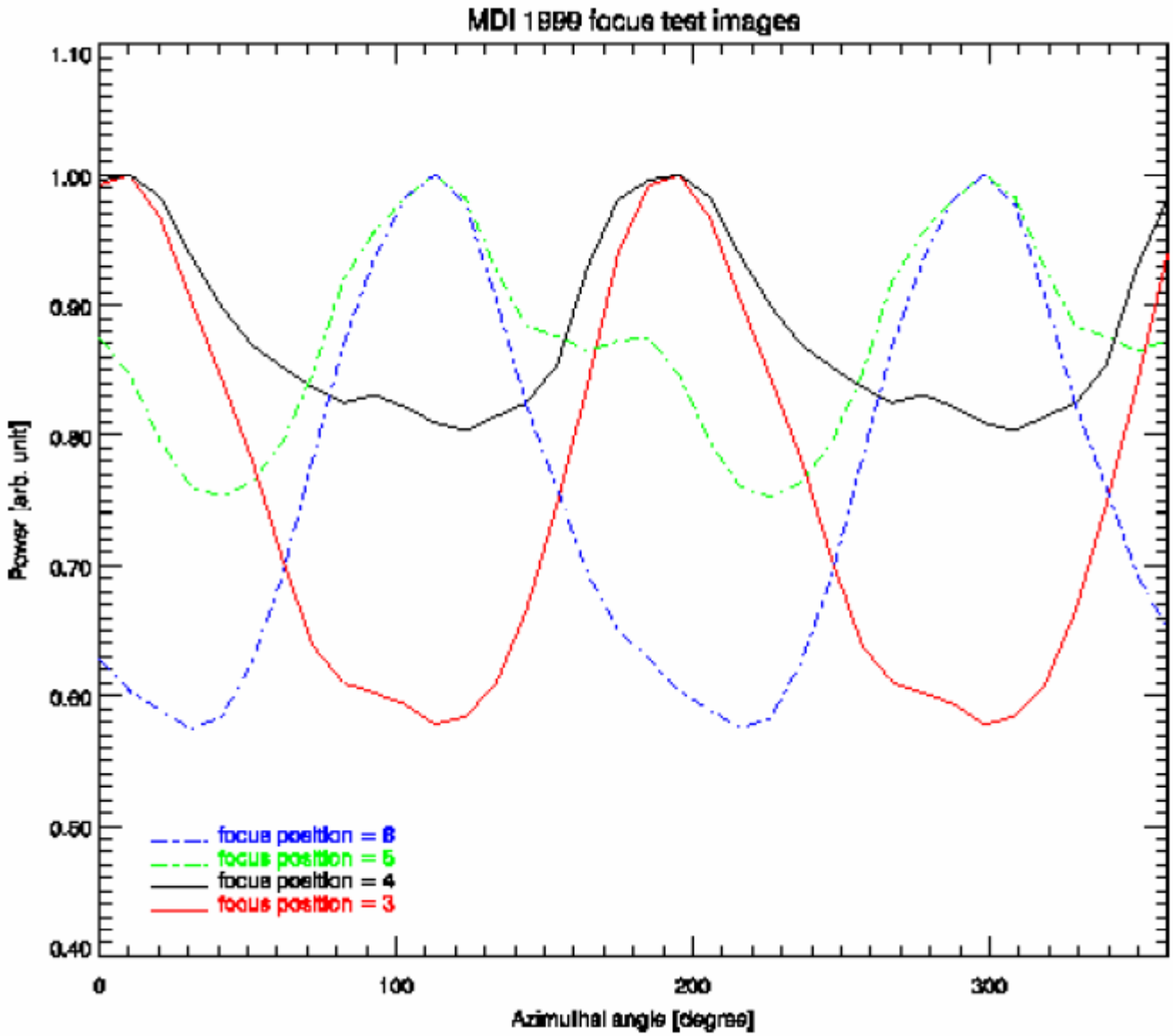

Observed accoustic wave power in different directions for different focus settings. Usually fd observed with focus set less than best focus so more power EW than NS

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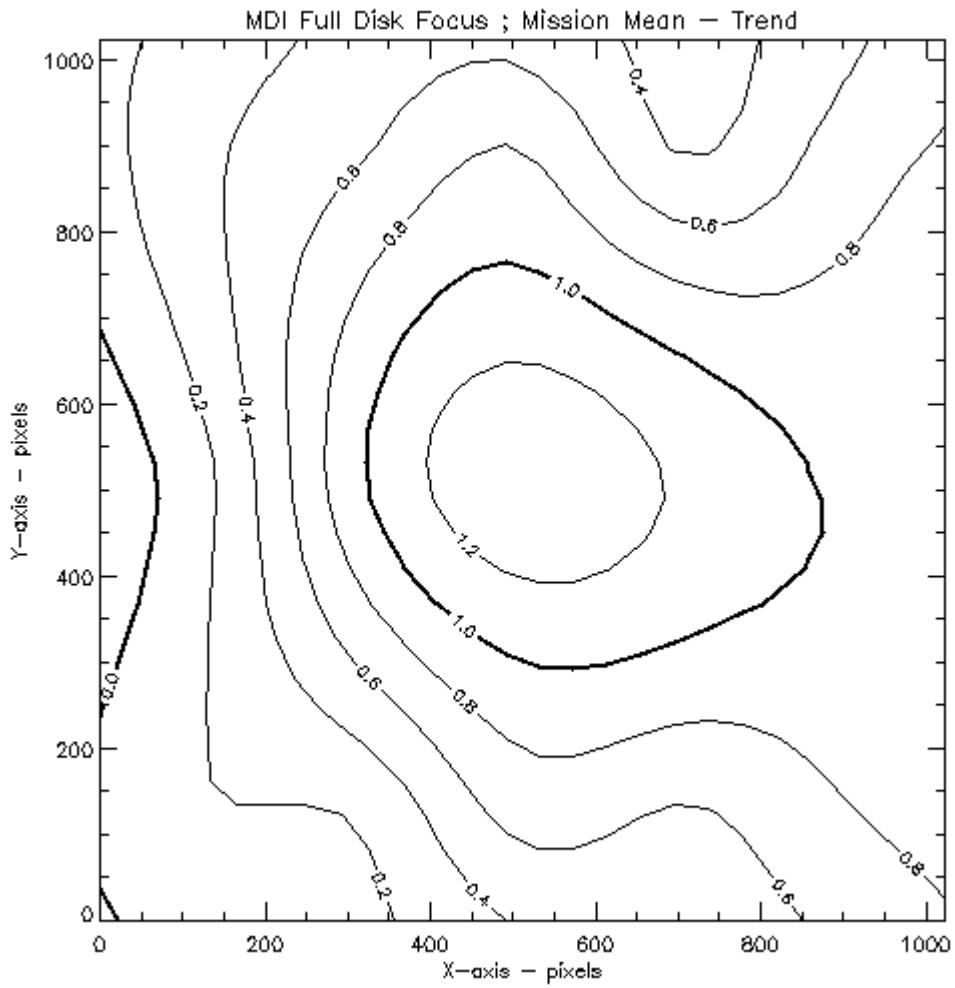

MDI image is not flat. About 1 focus block, 0.5mm, difference between center and limb. Center is usually in focus beyond the CCD.

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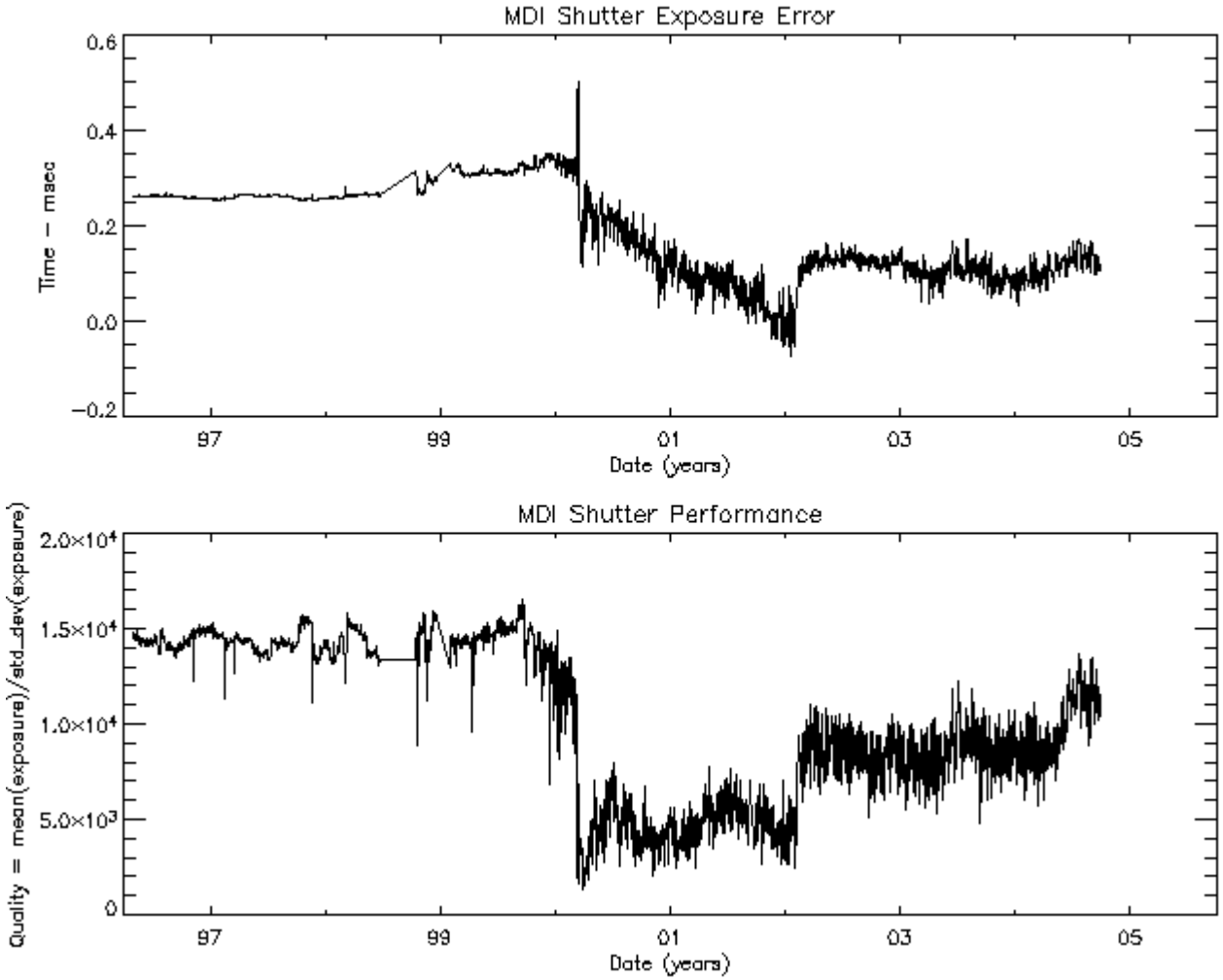

Since early 2000 the MDI shutter motion is not so smooth as before. Causes noise in full disk quantities such as magnetogram zero level and Doppler for $l \leq 3$ with $l+m$ even ("GOLF modes"). Magnetogram correction offsets are computed and put into header keyword BFITZERO but are **NOT** subtracted from the data. That action is left to the user. (this should be done as part of lev1.8 but is not at present)

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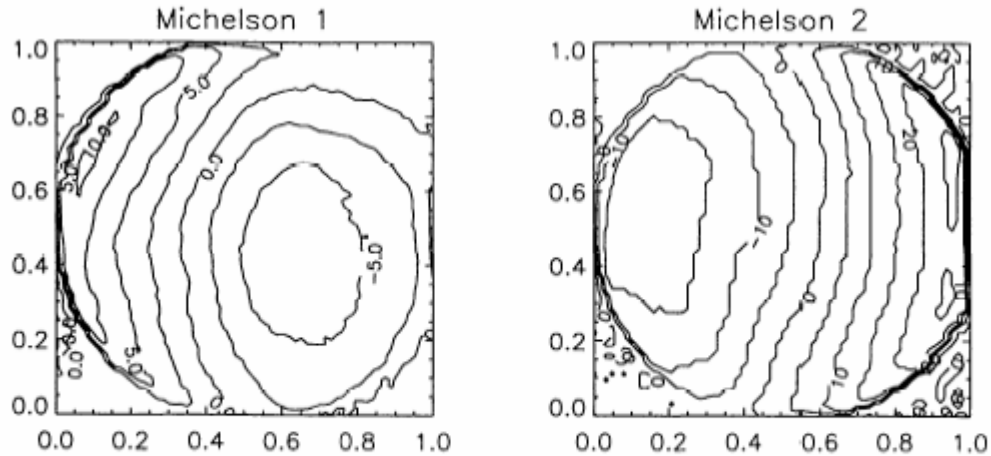
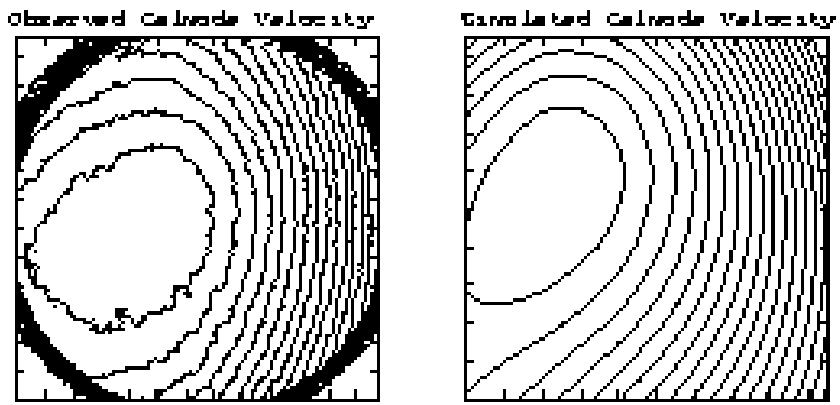
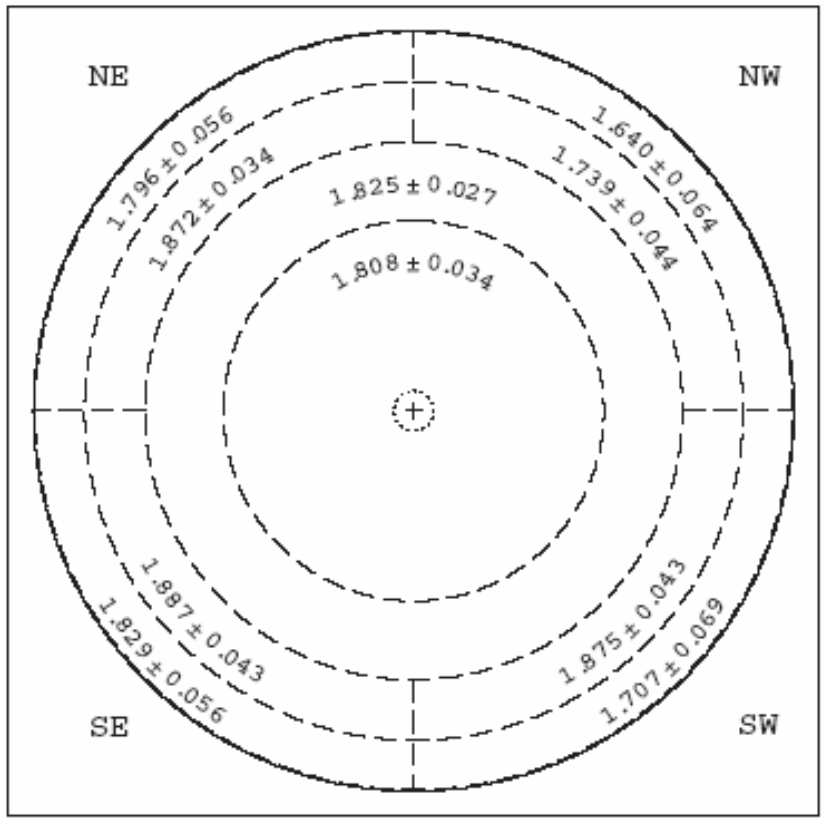


Fig. 9. Michelson central wavelength maps: spatial variation of the peak transmission wavelength for each Michelson from solar measurements in mÅ. M1 is the narrower interferometer.





Ratio of MDI fd_M data with MtWilson magnetograms. The absolute scale is not so important as the variation across the disk. We believe this is a result of the calibration errors in the onboard V table which does not vary with disk position. Present work indicates a similar pattern results from applying the on-ground velocity recalibration to the magnetic data. This figure is from an as yet unpublished paper by Ulrich et al.

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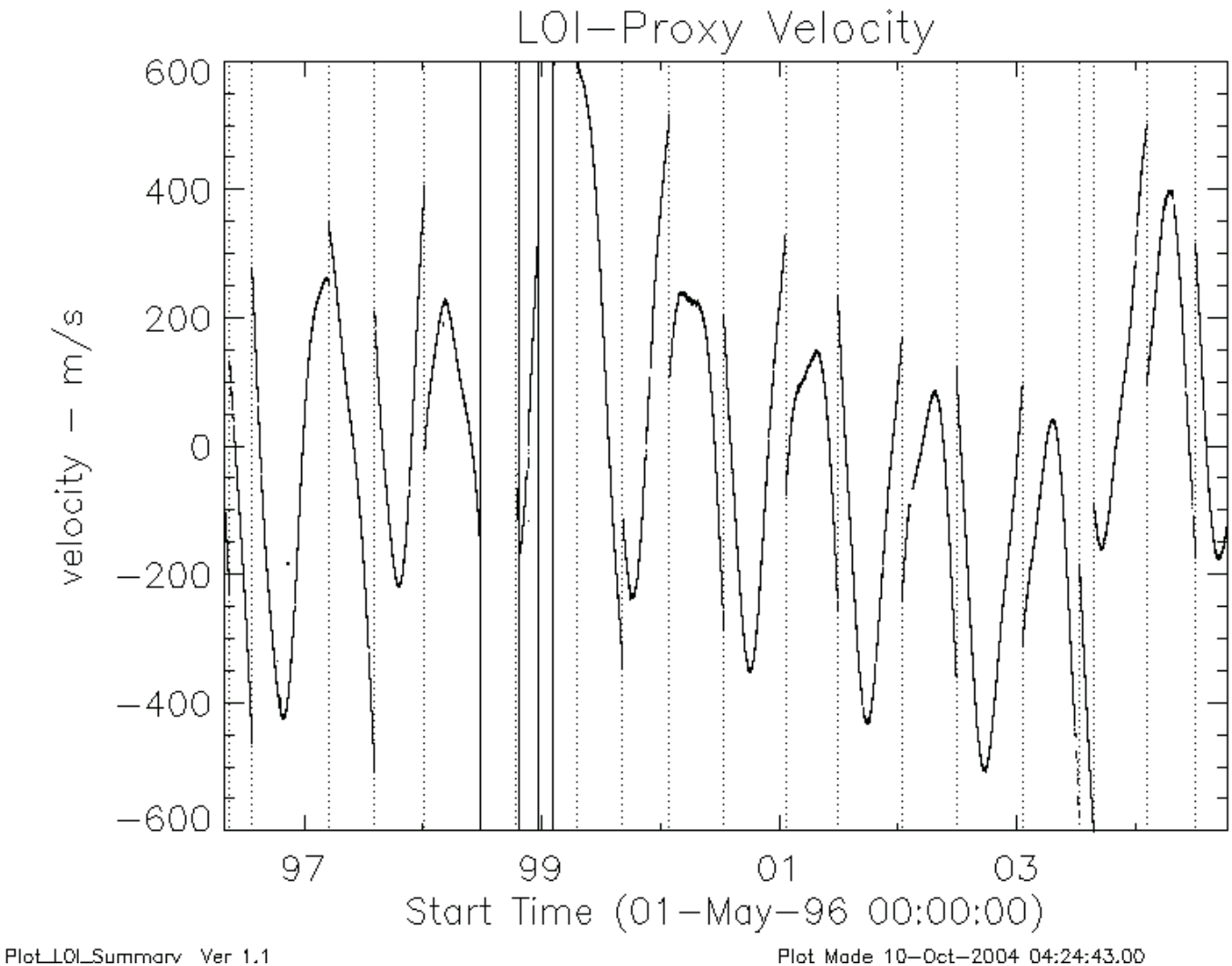

Michelson passband drifts about 1 m/s per day. SOHO orbit variations cause 500 m/s annual term leading to semi-annual changes in the waveplate angles to keep the observed velocity zero near disk center.

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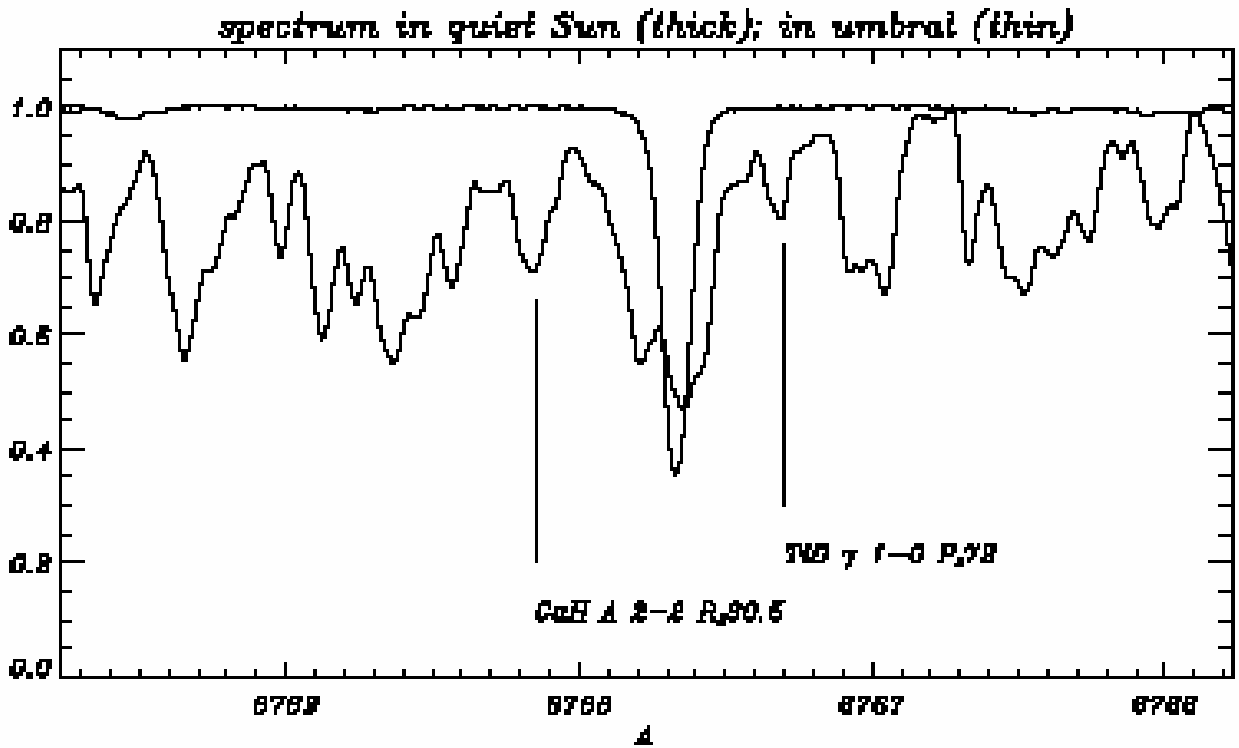

Line profiles for Ni6768A inside and outside spot umbra. This along with The dark pixel large field saturation renders umbra measurements suspect.

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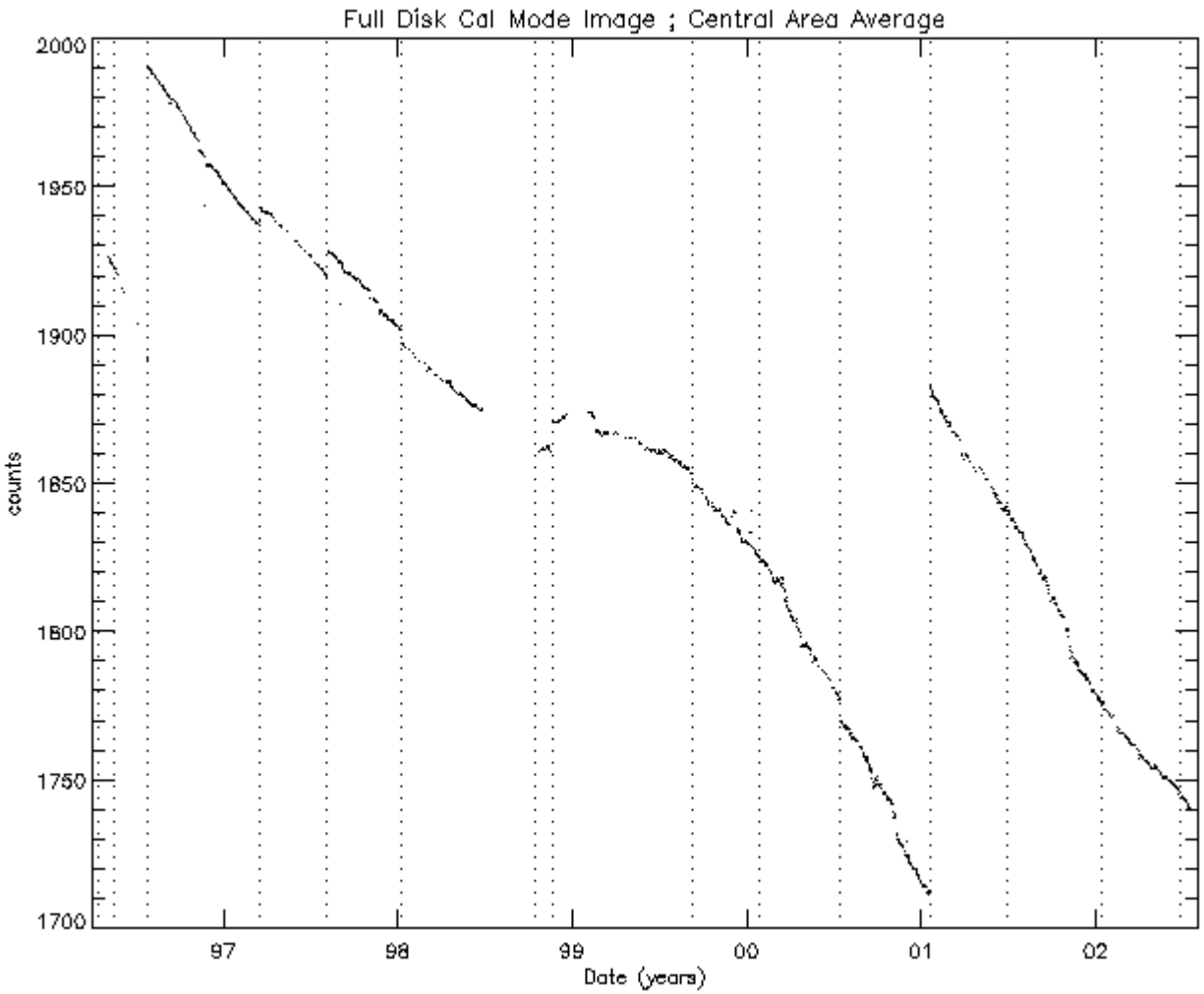

MDI light throughput has decreased during the mission. The normal fd exposure has been changed from 150 to 165 to 180 ms at present.

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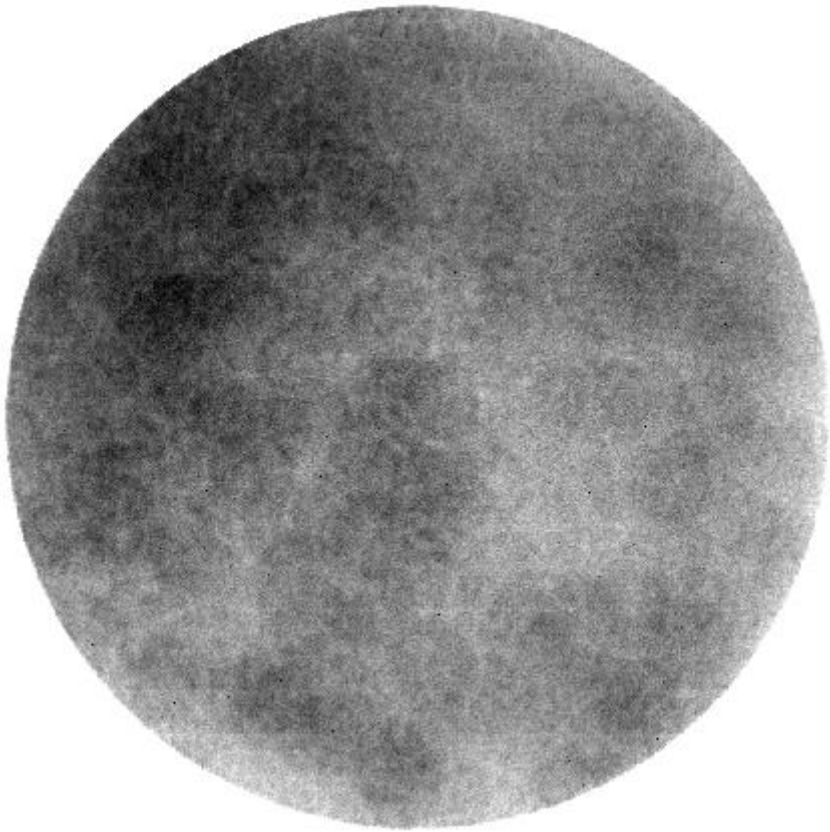
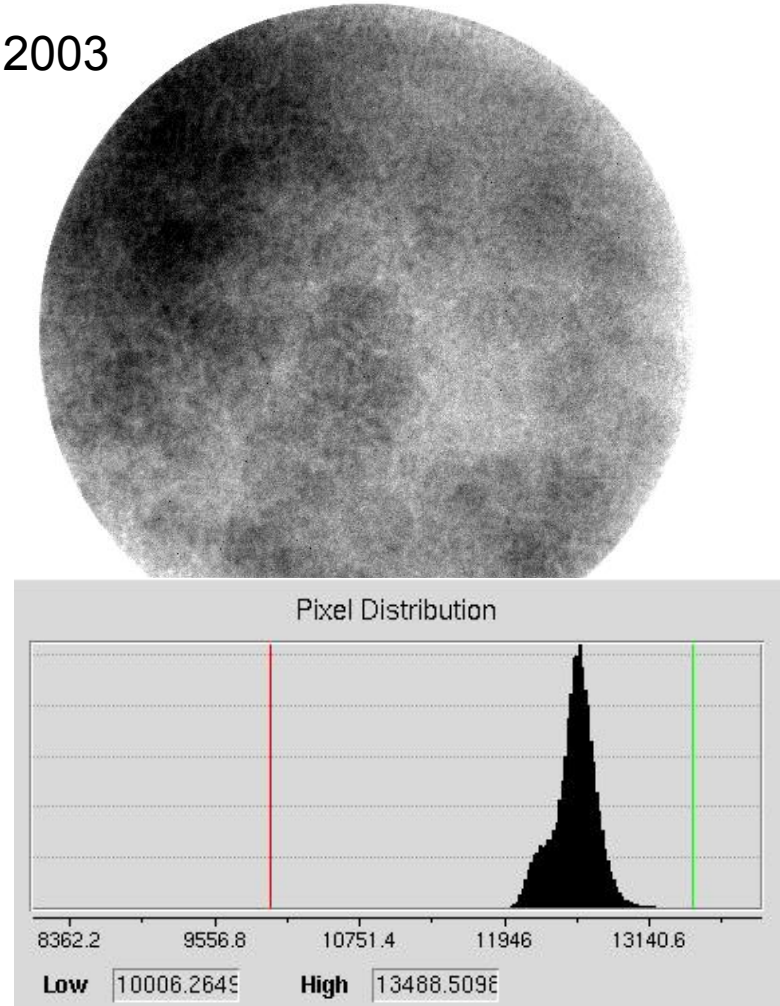
    - Focus and plate scale changes with time, few pixels
    - Cubic distortion, 2/3 pixel
    - “as if” CCD is tilted in camera header, Rmajor – Rminor ~ ½ pixel
    - Image center not solar center, < 0.5 pixel
    - MTF not symmetrical, astigmatism
    - Image plane not flat, focus varies across image
  - **Shutter exposure variation – affects all data products**
  - **Michelson passband**
    - Uniformity affects calibration uniformity
    - Variation effects linearity for large B and V conditions
  - Ni677nm line contaminated in strong fields – umbral fields
- **Things that affect brightness data**
  - Optics tranparency degrades with time
  - **Onboard and standard ground flat field poor, varies with focus**
- Things that effect Magnetograms
  - Different LCP and RCP distortion allows granulation to leak as noise
  - “saturation” in umbra due to onboard arithmetic precision
- Things that affect velocity data

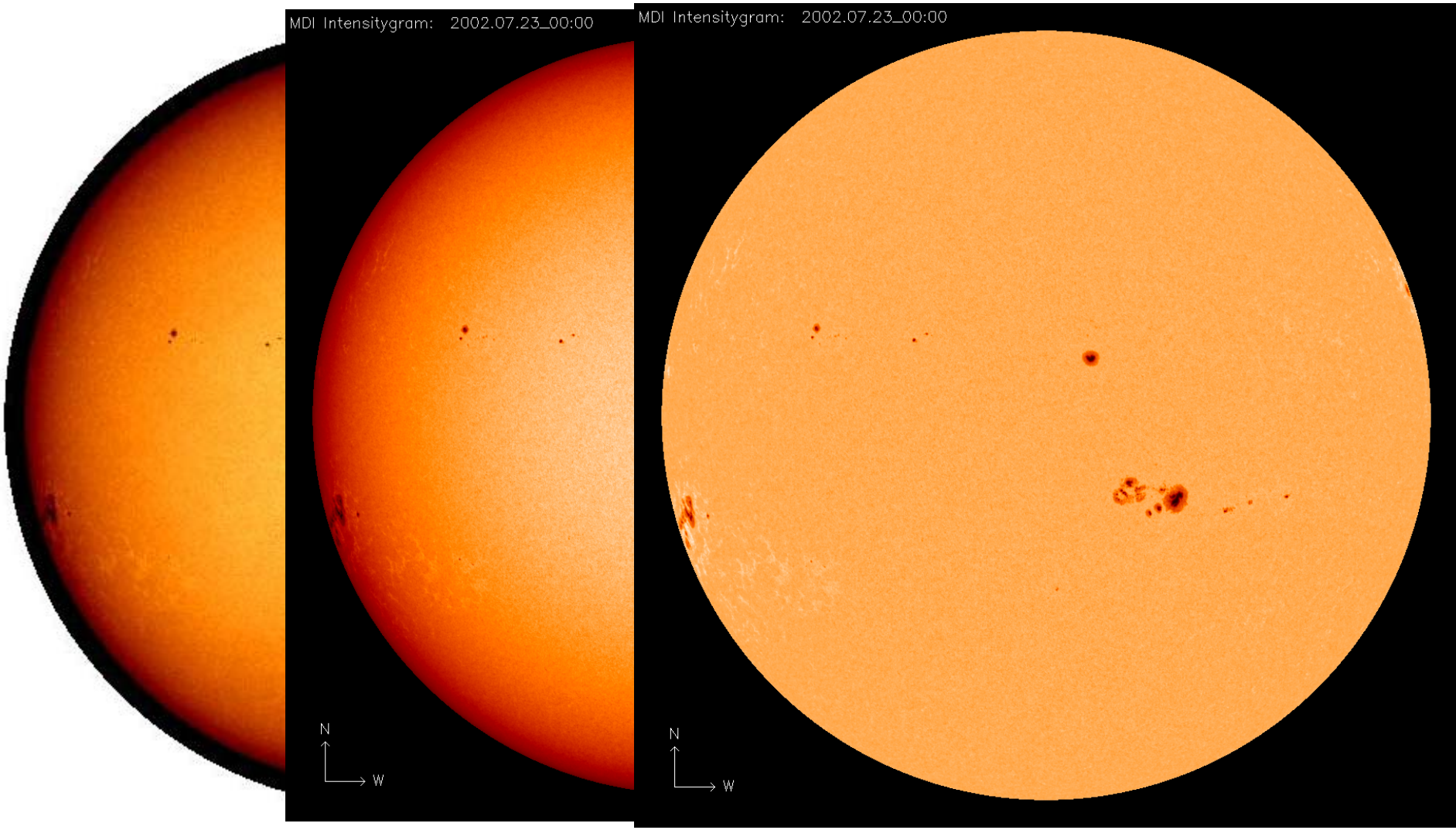
July 2002



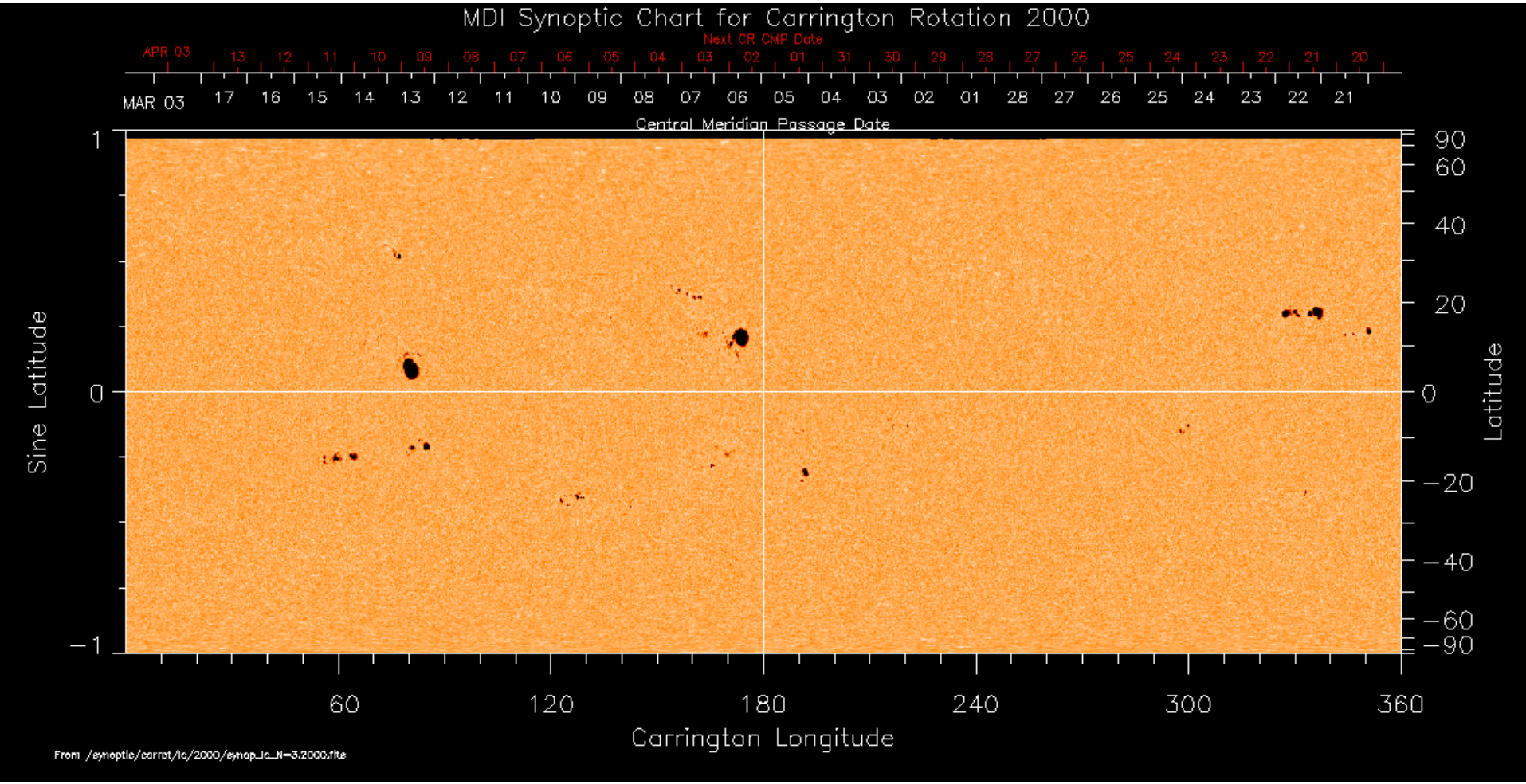
March 2003



Median of 27-day set of fd_Ic images. These images are computed for each Carrington rotation and are used to correct the flat field before making Ic synoptic charts. The corrected fd_Ic data is available as lev2 data. The range between light and dark is about 700 counts of 13000 or about 0.5%.



Fd_Ic data for a random day, 23 July 2002. From left to right the images are lev1.5, lev2 with limb darkening restored, and lev2. .gif files for all such lev2 images are available online.



Synoptic chart computed from lev2 fd_lc data. These are available as .gif and .fits.

- Things that affect all data products:
  - Image Geometry
    - Focus and plate scale changes with time, few pixels
    - Cubic distortion, 2/3 pixel
    - “as if” CCD is tilted in camera header, Rmajor – Rminor ~ ½ pixel
    - Image center not solar center, < 0.5 pixel
    - MTF not symmetrical, astigmatism
    - Image plane not flat, focus varies across image
  - **Shutter exposure variation – affects all data products**
  - **Michelson passband**
    - Uniformity affects calibration uniformity
    - Variation effects linearity for large B and V conditions
  - Ni677nm line contaminated in strong fields – umbral fields
- Things that affect brightness data
  - Optics tranparency degrades with time
  - Onboard and standard ground flat field poor, varies with focus
- **Things that effect Magnetograms**
  - **Different LCP and RCP distortion allows granulation to leak as noise**
  - “saturation” in umbra due to onboard arithmetic precision
- Things that affect velocity data
  - Beat between SOHO major frame pulse and 15 seconds

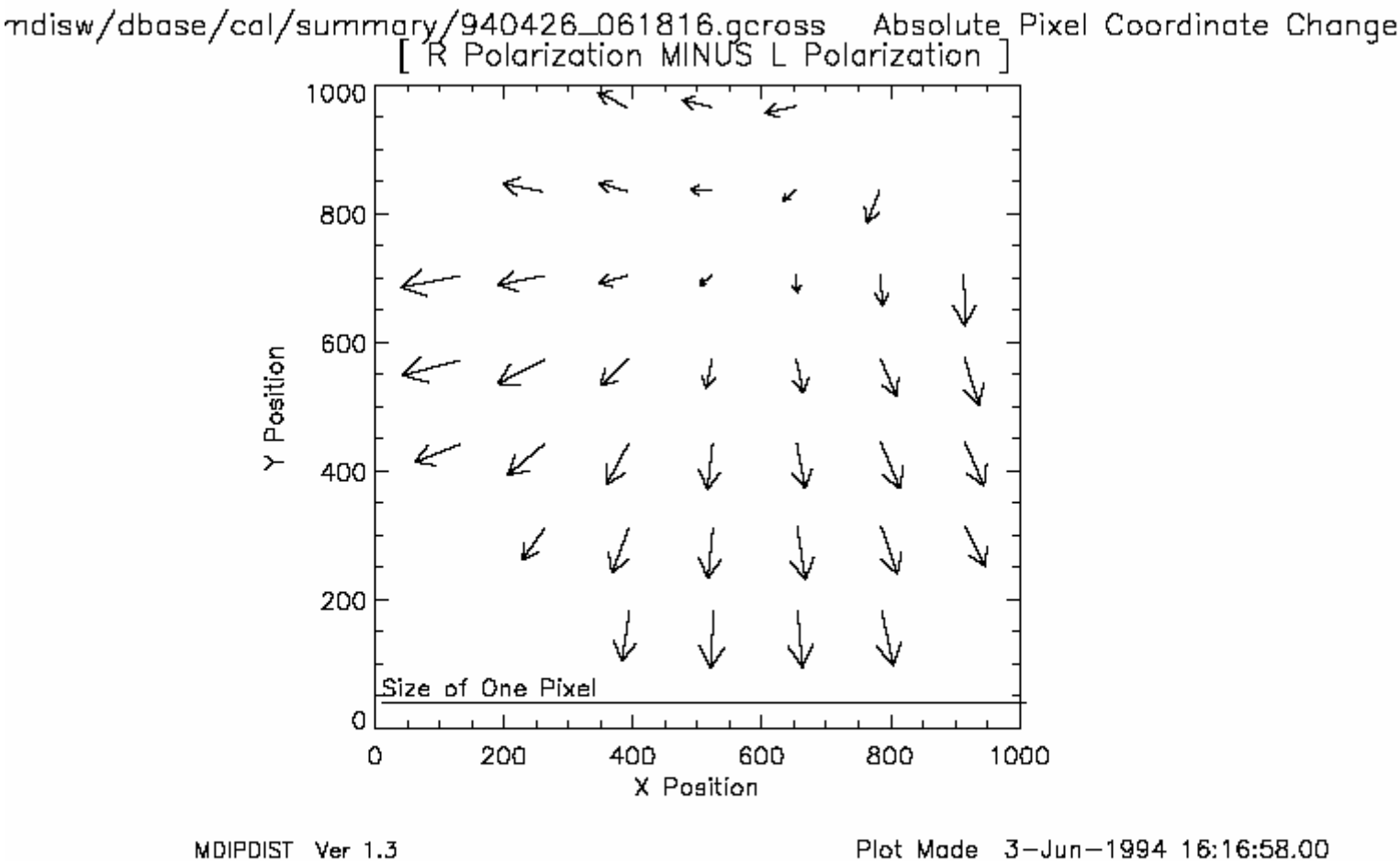


Figure 34: MDIPDIST Sample - Displacement Caused By Polarization

in the optical path (upstream from the ISS' feed-back limb sensors).

Distortion difference map for RCP and LCP images. From SOI_TN_95_124 Calibration Report. This differential distortion allows granulation and oscillations to leak into the magnetic signal as noise. It is larger on the west hemisphere. We do not have a good map but the effect is visible by inspection.

Hi Phil,

I estimated MDI mags (96 min) noise for east and west parts
using one month mags (Aug. 1999). Here is result (median values):

east portion: offset, error (one minute mags)	0.383755	14.9191
west portion: offset, error (one minute mags)	0.353955	17.4680

east portion: offset, error (five minute mags)	0.320656	8.95392
west portion: offset, error (five minute mags)	0.399118	10.4977

Regards, Yang

- Things that affect all data products:
  - Image Geometry
    - Focus and plate scale changes with time, few pixels
    - Cubic distortion, 2/3 pixel
    - “as if” CCD is tilted in camera header, Rmajor – Rminor ~ ½ pixel
    - Image center not solar center, < 0.5 pixel
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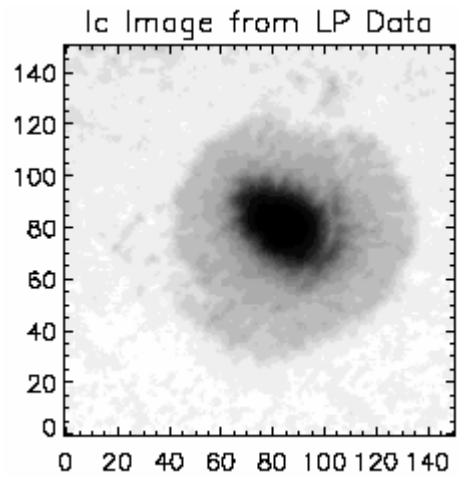
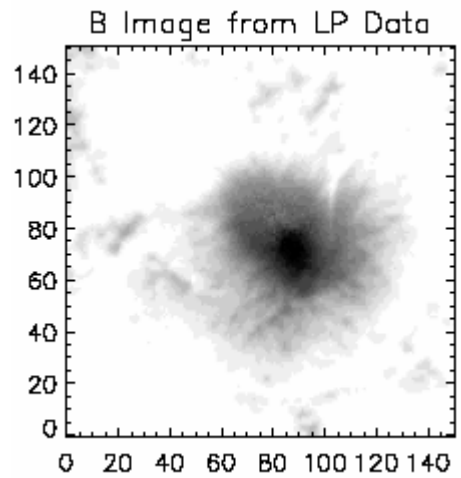
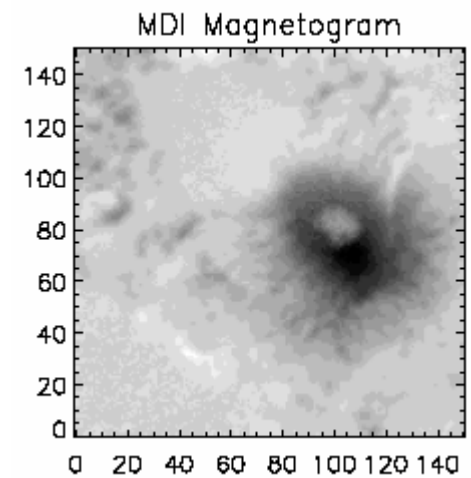
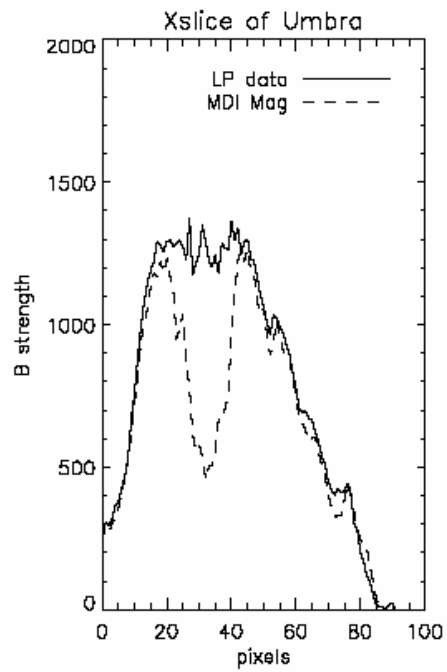
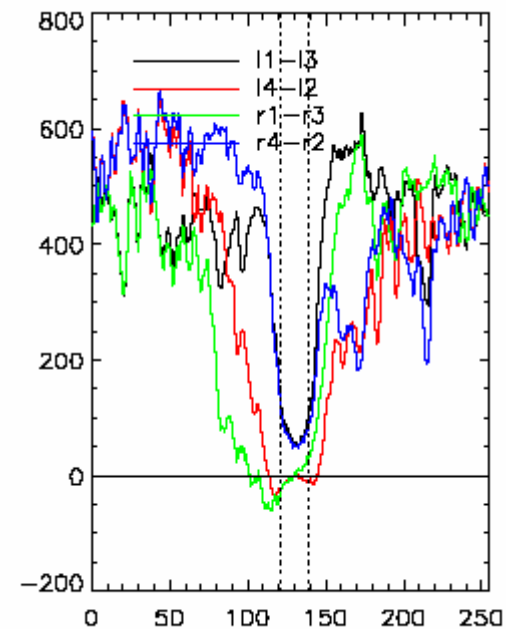
  - Optics tranparency degrades with time
  - Onboard and standard ground flat field poor, varies with focus
- **Things that effect Magnetograms**
  - Different LCP and RCP distortion allows granulation to leak as noise
  - **“saturation” in umbra due to onboard arithmetic precision**
- Things that affect velocity data











MDI magntic field saturates in umbra see SOI_TN_01_144, Liu & Norton

MDI papers and Tech Notes

Solar Physics 1995 paper:
http://soi.stanford.edu/sssc/doc/SP_paper_1995/MDI_SP_paper_1995.pdf

Velocity on board algorithm:
http://soi.stanford.edu/technotes/94.110.pdf

SOI_TN_95_124 Calibration Report
http://soi.stanford.edu/technotes/MDI_guide_calib.ps

Mag field tech note, Yang and Aimee
http://soi.stanford.edu/general/TechNotes/01.144/TN01-144.pdf

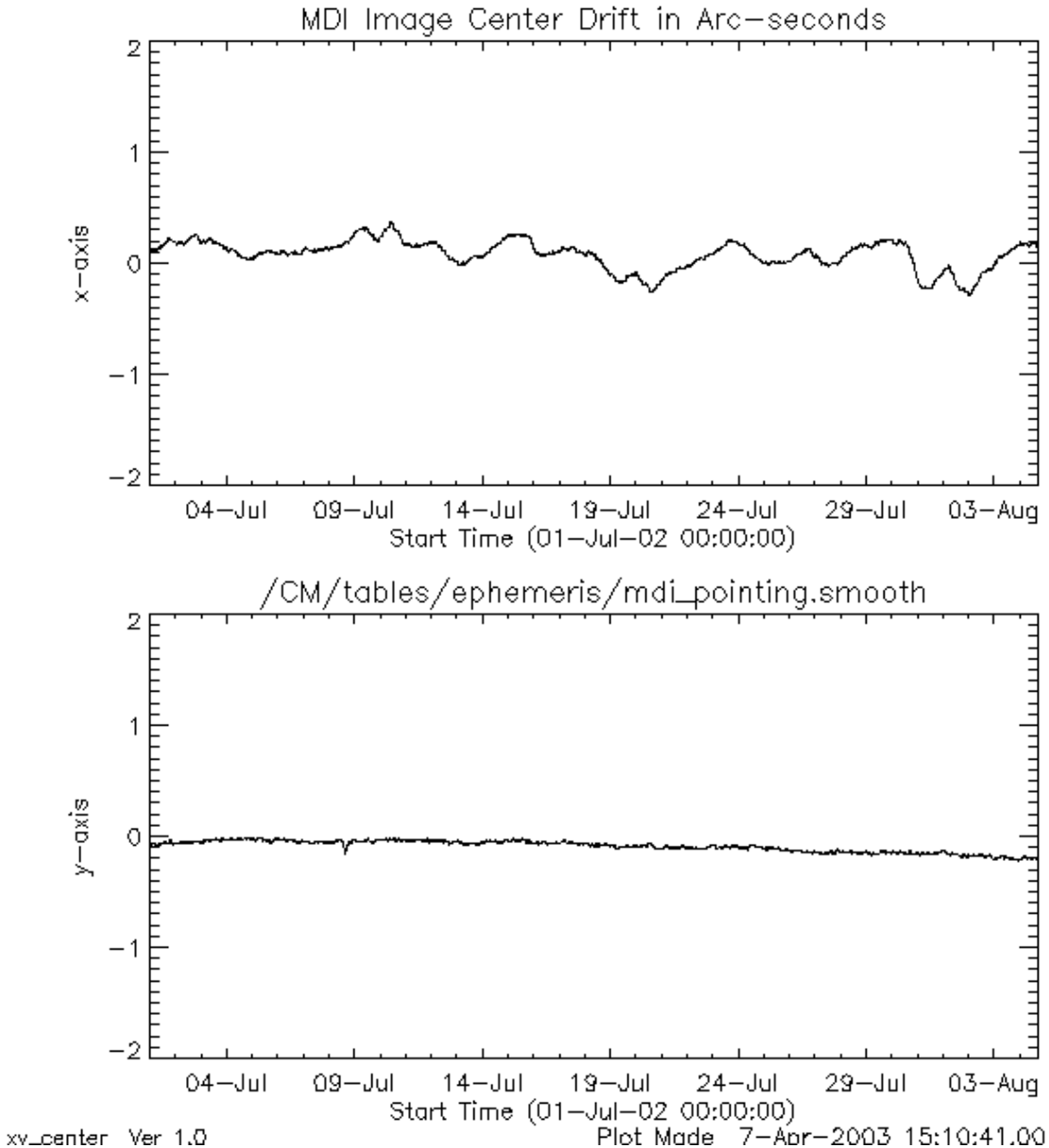
Some useful references:

On the Determination of Michelson Doppler Imager High-Degree Mode Frequencies, Korzennik, S. G.; Rabello-Soares, M. C.; Schou, J., ApJ, Volume 602, Issue 1, pp. 481-516.

Effect of spatial resolution on estimating the Sun's magnetic flux, N. A. Krivova and S. K. Solanki
http://www.edpsciences.org/articles/aa/pdf/2004/15/aah4754.pdf

Correction of Offset in MDI/SOHO Magnetograms, Yang Liu , Xuepu Zhao , J. Todd Hoeksema
http://www.kluweronline.com/oasis.htm/5256299

Weak-Field Magnetogram Calibration using Advanced Stokes Polarimeter Flux Density Maps – II. SOHO/MDI Full-Disk Mode Calibration, T.E. Berger, B.W. Lites.
http://www.kluweronline.com/oasis.htm/5114853



Sample month of X0,Y0 disk center correction. If you ignore these keywords This shows the centering error you will have.