SXT Calibration Note 42

DARK CURRENT VARIATION of the SXT CCD

Barry LaBonte

REPORT ON SXT CCD DARK CURRENT VARIATION
Barry LaBonte
July 19, 1994

TABLE OF CONTENTS:

I) INTRODUCTION

The decline in solar X-ray flux levels has caused us to take longer exposures to observe fainter structures on the Sun. We are now finding that the SXT CCD dark current varies in ways that are not completely defined. This uncertainty limits our ability to measure accurate solar fluxes. In this report I will describe an effort to characterize the dark variation.

The variation of the dark current level is well known, and is the reason for the weekly Dark Calibrations and the online SDC dark current image database. The SDC database includes images at Full-, Half-, and Quarter-resolution, with several different exposure times (DPE). There is a single image at a given resolution and DPE.

Recently, Acton (re)discovered variation of the dark current within each orbit. The online database cannot deal with variations on times less than 1 week, so exploration of the timescales of dark variation has become important.

II) DARK CURRENT ERRORS

It is important to understand that the errors caused by incorrect dark subtraction are not small. Normal dark subtraction uses a single dark image, with shot noise (1 DN?) and digitization error (0.5 DN). Taking a median of many dark images removes the shot noise but keeps the digitization; it is necessary to take an average to get the most accurate value.

We now are taking 30 sec (DPE 30) exposures. We know there is a variation of the dark current of 1.5 DN for this exposure time. Averaging does not remove this.

The leak subtraction causes more error. The terminator images have 5 sec exposures, so the orbital variation is about 0.3 DN. But the terminators all happen at the end of the orbit, so this error is systematic - there is no terminator which is correctly dark subtracted. Then we multiply the terminator image * 6 to leak subtract the 30 sec exposures. So this adds another 1.5 DN of dark error to the data. (It also adds 6 x the terminator image noise, photon plus digitization, but that is another issue.)

In the coronal holes we have levels of about 10 DN after subtracting dark, leak, and scattered light, in the last round of reductions that I did. So there is as much as 50% error (1.5 + 1.5. + 1.5 DN) just from the darks. Accurate temperature measurements are not possible with this situation.

III) DARK CURRENT VARIATION MEASUREMENT ###########################

The histograms of all Full Frame Image darks are stored in the SDL database. This database was used to study the variation of the dark current. The parameters for the data search were:

TIME INTERVAL:	15-NOV-92 to 11-JUN-94	
PERCENT_D:	100%	(Complete images)
DATA.HIST(0):	0	(No 0 DN pixels)
SAA:	0	(Exclude SAA images)
TEMP_CCD:	< -20	(CCD cold)
FILTER:	AlMg	(Present default)

There are a number of dark images which are listed as 100% complete but have 1 row of pixels with values of 0 DN. This appears to be true mostly for Full-res images starting at pixel (0,0). There should be no zero DN pixels; the Bias level should always be present.

The dark current level was chosen to be the mean DN value for the image. This was computed from the histogram by multiplying the numbers of pixels by the decompressed DN values, totaling, and dividing by the total number of pixels in the image. Plots of the integral distribution function show that the dark spikes do not affect the image total DN, and thus the image mean DN, at a significant level.

REGRESS is used to fit for a quadratic time variation plus a linear trend during the orbit:

(1) DN = A + B * year + C * year^2 + D * TIM2FMS

The year is set to 0.0 at 1-JAN-93. TIM2FMS is the Time to First Minute of Sun, in minutes, from the procedure TIM2ORBIT. To perform the regression, images with TIM2FMS < 10. are excluded because it is known that the dark current is unusually high early in the orbit.

The actual variation of the dark within an orbit is not linear. The recent workd of Lemen and Handy show that there is a rapid decline for TIM2FMS < 8., followed by a slow decline that stops and reverses at about TIM2FMS = 60. In the SLD database, there are few images with TIM2FMS > 60., so the late reversal is not clearly observed. Because the

FFI darks in normal calibration sequences are taken at long intervals, the SLD data do not show the rapid decline at early times, but rather exhibit 2 levels, normal and High. In the plots, both states overlap in TIM2FMS, but there may be confusion because of the secular variation, which spreads the dark values over a range.

To perform the regression, data with TIM2FMS < 10. are excluded. The histograms show that the High darks are just brighter than the normal ones. There is no anomalous intensity distribution. Scatterplots of the pixel values in high vs low darks show that the effect is multiplicative; the points lie on a line of zero intercept but with slope different from unity.

IV) ODD-EVEN A/D EFFECT ##

The SDL histograms show there is a strong odd-even difference in the A/D. The number of even pixels is about 1.5 x the number of odd pixels. This effect is smeared out above DN=64 by the compression scheme. The odd-even effect has little effect on the measurements here, but does represent a problem with the CCD camera electronics chain. The presence of odd-even A/D error increases the digitization error above 0.5 DN at low intensities.

V) DARK CURRENT AVERAGE ##

The quadratic time fits are adequate for removing the gross change over time. The constants A then represent an average dark current. The dark current (A) was modelled as

```
(2) A = BIAS + RATE * (Texp + Tread) * BINNING  + SPURIOUS * SHIFTS
```

with:

```
BIAS  =  the electronic zero offset (DN)
RATE  =  dark current  (DN/second/Full-res pixel)
Texp  =  exposure time (seconds)
Tread =  readout time for an average pixel (seconds)
SHIFTS = number of parallel and serial shifts per pixel minus 2
SPURIOUS = spurious charge induced by binning (DN/full-res pixel).
```

The average readout time is half of the image readout time, given by

```
Tread  =  ((NX * NY)/131,072 pxl/sec)/2.  (seconds).
```

The lengthy readout time implies that the imtegration time for dark current varies by less than a factor of 30 between DPE 2 and DPE30, NOT factors of 10^4. Only in PFI images is the readout time very short.

The SPURIOUS charge induced by binning is not separable from BIAS for the case of 1 x 1 binning, thus the definition. With this definition, SHIFTS takes the values:

Resolution	SHIFTS
Full	0
Half	2
Quarter	6

A regression to the measured values was performed. The coefficients found were:

```
RATE        =  0.2155  DN/second/Full-res pixel
SPURIOUS    = 14.832   DN/Shift
BIAS        = 12.300   DN
```

Table 1 summarizes the result.

TABLE 1

Resolution	DPE	A (DN)	Fit (DN)	Error (DN)	Dark (DN)	Spurious (DN)
Full	30	21.89	19.24	2.7	6.9	0.0
Full	2	14.67	12.73	1.9	0.4	0.0
Half	30	68.17	68.86	-0.7	26.9	29.7
Half	23	41.91	45.12	-3.2	3.2	29.7
Half	2	38.84	42.83	-3.0	0.9	29.7
Quarter	26	128.6	128.2	0.4	26.9	89.0
Quarter	2	104.1	102.2	1.9	0.9	89.0

VI) ORBITAL DARK VARIATION ##

A) The linear estimate of the dark current variation during an orbit is represented as:

(3) DN = A + D * TIM2FMS.

The slope D is derived from the least-squares fits to the data presented in the Appendix.

We know that the orbital effect is actually multiplicative, not additive. Therefore we know that neither the BIAS nor the SPURIOUS properties of the CCD are varying; they are a constant for all pixels To confirm this, a regression identical to that of Section V was done for the slopes D. The result is:

```
(4) D = 1.209e-4                                        ("bias")
      - 3.347e-4 * (Texp + Tread) * BINNING             ("dark")
      - 8.498e-4 * SHIFTS                               ("spurious")
```

The correlation coefficients of the various terms show that 99% of the variance is explained by the "dark" term, confirming the dark as the source of the orbital variation.

Note that formally, a scatterplot of pixel values should not have exactly zero intercept. The intercept should be of order (BIAS + spurious)*D/A. Tis is too small to notice on the plot itself.

B) A global least-squares solution for the orbital variation in terms of the circumstances of observation can be found. A single parameter least-squares fit of the form:

(5) D = (A - BIAS - SPURIOUS * SHIFTS) * F

was made for the fractional variation F. The result is:

F = -0.001639 per minute

The correction of a dark image for orbital variation is then made as:

```
(6) OUT = (IN - BIAS - SPURIOUS * SHIFTS) * (1 + F * TIM2FMS)
          + BIAS + SPURIOUS * SHIFTS
```

or

```
(6') OUT = IN * (1 + F * TIM2FMS)
           - (BIAS + SPURIOUS * SHIFTS) * F * TIM2FMS
```

with IN the input dark image, OUT the corrected output dark image, BIAS and SPURIOUS the constants found in Section V, and SHIFTS the value appropriate to the input image.

The Table 2 summarizes the results single parameter fit.

TABLE 2

Resolution	DPE	D (SLOPE) (x 1.e-3)	Fit (x 1.e-3)	Error (x 1.e-3)
Full	30	-9.3468	-15.72	6.4
Full	2	-0.2150	-3.89	3.7
Half	30	-46.704	-42.95	-3.8
Half	23	-6.0835	0.08	-6.2
Half	2	-2.4412	3.47	-5.9
Quarter	26	-43.717	-44.70	1.0
Quarter	2	-8.5149	-4.54	-4.0

C) The actual variation of the dark within an orbit is not linear. The recent workd of Lemen and Handy show that there is a rapid decline for TIM2FMS < 8., followed by a slow decline that stops and reverses at about TIM2FMS = 60.

In the SLD database, there are few images with TIM2FMS > 60., so the late reversal is not clearly observed. Because the FFI darks in normal calibration sequences are taken at long intervals, the SLD data do not show the rapid decline at early times, but rather exhibit 2 levels, normal and High. In the plots, both states overlap in TIM2FMS, but there may be confusion because of the secular variation, which spreads the dark values over a range.

The histograms show that the High darks are just brighter than the normal ones. There is no anomalous intensity distribution.

VII) RESIDUAL DARK VARIATION ###

A) The slow trend and orbital variation account for much of the variation of the dark current, but not all. The residuals from the fits listed in the Appendix show variation on many timescales. The most noticeable changes are discontinuous drops in the dark current. There are also discontinuities in the rate of dark current change over time.

B) The dates on which the dark current level drops discontinuously are listed here. The list is biased; there are other changes of comparable magnitude, but with shorter durations.
There are also sudden changes in the slope of the dark level with time that are not listed.

(Dates and times are those of the first Half-res DPE2 dark image after the change.)

4-JAN-93	20:34:15
9-JAN-93	20:50:42
23-JAN-93	01:41:34
14-APR-93	08:55:11
21-MAY-93	17:17:18
4-AUG-93	07:06:50
11-AUG-93	04:52:49
8-NOV-93	05:30:59
23-FEB-94	06:26:36
6-JUN-94	07:00:51

These may be compared with other significant dates in the operation of the CCD.

CCD BAKEOUT

Date Warm	Date Cold	Approx # days warm	High Temp
9-JAN-92	10-JAN-92	2 days at	-0.6 C
8-APR-92	11-APR-92	4 days at	23.8 C
9-JUN-92	11-JUN-92	3 days at	-2.5 C
4-SEP-92	6-SEP-92	3 days at	-1.2 C
8-JAN-93	9-JAN-93	2 days at	23.8 C
21-JAN-93	22-JAN-93	2 days at	23.8 C
5-APR-93	6-APR-93	2 days at	23.8 C
4-JUL-93	5-JUL-93	2 days at	22.5 C
22-AUG-93	24-AUG-93	3 days at	25.2 C
8-NOV-93	10-NOV-93	3 days at	23.8 C
10-JAN-94	11-JAN-94	2 days at	22.5 C
6-APR-94	8-APR-94	3 days at	25.2 C

UV FLOOD LONG-TERM CHANGES

19-JAN-93	00:05:00	To 128 seconds from 256 seconds
18-AUG-93	00:24:00	To 256 seconds from 128 seconds
15-FEB-94	10:34:00	To 128 seconds from 256 seconds

There appears to be some correlation of the Dark discontinuities with the CCD Bakeout. The correlation is not perfect, however.

VIII) RECOMMENDATIONS ##

A) The procedure DARK_SUB should have a new keyword added, /PRECISION. This keyword would imply the already implemented keywords /INTERPOLATE and /FLOATING as well as adjusting the dark images for the orbital dark current variation to the TIM2FMS of the data image.

B) A procedure to describe the orbital dark current variation should be written. The dependence on SPE and binning for Full Frame images is known from this report. The procedure should account for the more precise form of the orbital variation being determined by Lemen and Handy. NOTE: The dark calibration images are Full Frame, and they are the images that need to be matched to the data.

C) The SDC database should be upgraded, or a new precision dark database constructed by using floating point average dark images in place of the byte simgle dark images. One issue in building such a database is choosing the image times so that conventional procedures give a correct description of the dark image, in terms of SAA and TIM2FMS. I am writing a procedure to comstruct average darks with valid times and will place it online when it is tested.

D) Dark variation on timescales between 1 orbit and 1 week is poorly known. The SDL data show large discontinuous jumps in dark current. It may be desireable to implement a standard dark observation on a cadence of once per orbit(day?), and place the mean dark current value found into a new database to provide complete time variation information. The SXT CCD dark current would then be described by the weekly image, the Lemen/Handy orbital function, and the level in a given orbit(day).

IX) APPENDIX ##

RESULTS FOR INDIVIDUAL BINNING, EXPOSURE TIMES

A) Full-res DPE 30 -------------------------

There are 231 valid darks between:

```
31-MAR-93  09:46:32  QT/H  Open /AlMg  Full Dark C  30 30208.0 1024x512
07-JUN-94  02:19:25  QT/H  Open /AlMg  Full Dark C  30 30208.0 1024x512
```

Fit values are:

```
        A       21.8909
        B        2.90207
        C       -0.418459
        D       -0.00934677

        Std. Dev of residuals:  0.159887
```

There are 16 High value darks of 26 cases. The latest is at 7.7 minutes. The earliest low value dark is at 3.6 minutes. The Higk Value darks are scattered through the interval. The difference High - Low = 0.8 DN.

The data from a single day are usually within 0.05 DN, but over weeks or months the variation is +/- 0.6 DN.

B) Full-res DPE 2 -------------------------

There are 236 valid darks between:

```
12-FEB-93  14:44:28  QT/H  Open /AlMg  Full Dark C  2       1.0 1024x512
13-JUN-94  14:29:27  QT/H  Open /AlMg  Full Dark C  2       1.0 1024x512
```

Fit values are:

```
        A        14.6692
        B        1.00758
        C        -0.489595
        D        -0.000215003
```

Std. Dev. of residuals: 0.0658612

It is difficult to identify High Value darks. At best, they are only about 0.2 DN above the normal.

The requirement that DATA.HIST(0) NE 0 eliminates all dark images that start at pixel (0,0). A check of the values of those darks compared to the images starting at (0,512) shows that the values are not different. This occurs because the parallel shift is rapid, so the effective image size is 1024 x 512, not 1024 x 1024 for accounting for the Tread average time to readout a pixel.

C) Half-res DPE 30 -------------------------

There are 776 valid darks between:

```
9-DEC-92  02:01:47  QT/H  Open /AlMg  Half Dark C  30 30208.0  512x512
7-JUN-94  01:16:41  QT/H  Open /AlMg  Half Dark C  30 30208.0  512x512
```

There are 5 anomalous darks that are further ejected, with MEAN DNk > 90:

```
23-JAN-93  01:38:28  QT/H  Open /AlMg  Half Dark C  30 30208.0  512x512
 5-JUL-93  19:32:48  QT/H  Open /AlMg  Half Dark C  30 30208.0  512x512
24-AUG-93  20:06:24  QT/H  Open /AlMg  Half Dark C  30 30208.0  512x512
```

or MEAN DN < 60

```
29-SEP-93  00:32:31  QT/H  Open /AlMg  Half Dark C  30 30208.0  512x512
 8-MAR-94  11:44:53  QT/H  Open /AlMg  Half Dark C  30 30208.0  512x512
```

The fit values are:

```
        A        68.1661
        B        12.9001
        C        -1.70467
        D        -0.0467043
```

Std. Dev of residuals: 0.940628

There are about 21 High Value darks out of 151 total with TIM2FMS < 10. The high variance makes the distinction less clear. The difference High - Low = 2.5 DN.

Data from withina day range +/- 0.25 DN, but the total range is +/- 2 DN over longer times.

D) Half-res DPE 23 ----------------------

There are 542 valid darks between:

```
 8-JAN-93  06:31:28  QT/H  Open /AlMg  Half Dark C  23  2668.0  512x512
 7-JUN-94  01:22:59  QT/H  Open /AlMg  Half Dark C  23  2668.0  512x512
```

There 3 anomalous darks that are further ejected, with MEAN DN > 49:

```
10-NOV-93  04:29:27  QT/H  Open /AlMg  Half Dark C  23  2668.0  512x512
12-JAN-94  00:34:43  QT/H  Open /AlMg  Half Dark C  23  2668.0  512x512
 8-APR-94  08:00:03  QT/H  Open /AlMg  Half Dark C  23  2668.0  512x512
```

The fit values are:

```
        A       41.9126
        B       5.87832
        C       -2.01142
        D       -0.00608350

        Std. Dev of the residuals  0.432323

There are 43 High Value darks out of 87 total with TIM2FMS < 10.
The difference High - Low = 1.0 DN.


E) Half-res DPE 2 ------------------------

There are 784 valid darks between:
 8-DEC-92  20:55:23  QT/H  Open /AlMg  Half Dark C   2      1.0  512x512
 7-JUN-94  01:14:29  QT/H  Open /AlMg  Half Dark C   2      1.0  512x512

The fit values are:
        A       39.8446
        B       4.04577
        C       -1.41146
        D       -0.00244116

        Std Dev. of the residuals  0.32832

There are about 47 High Value darks out of 135 with TIM2FMS < 10.
The difference High - Low = 0.7 DN.


F) Quarter-res DPE 26 -----------------------

There are 330 valid darks between:
31-MAR-93  09:51:42  QT/H  Open /AlMg  Qrtr Dark C  26  7548.0  256x256
 7-JUN-94  00:57:39  QT/H  Open /AlMg  Qrtr Dark C  26  7548.0  256x256

The fit values are:
        A       128.563
        B        28.9613
        C       -9.33287
        D       -0.0437169

        Std. Dev. of residuals  1.22137

There are 7 High Value darks out of 32 with TIM2FMS < 10.
The difference High - Low = 6 DN.

The range internal to a day is +/-0.25 DN, but over longer times is +/-2 DN.


G) Quarter-res DPE 2 ------------------------

There are 707 valid darks between:
 8-DEC-92  20:54:03  QT/H  Open /AlMg  Qrtr Dark C   2      1.0  256x256
 7-JUN-94  00:56:19  QT/H  Open /AlMg  Qrtr Dark C   2      1.0  256x256

The fit coefficients are:
        A       104.063
        B       9.20920
        C       -2.87157
        D       -0.00851493

        Std. Dev of residuals  1.22033
```

The resiudals show tight correlation
on short times, but large variation over weeks to months, by +/- 2 DN.

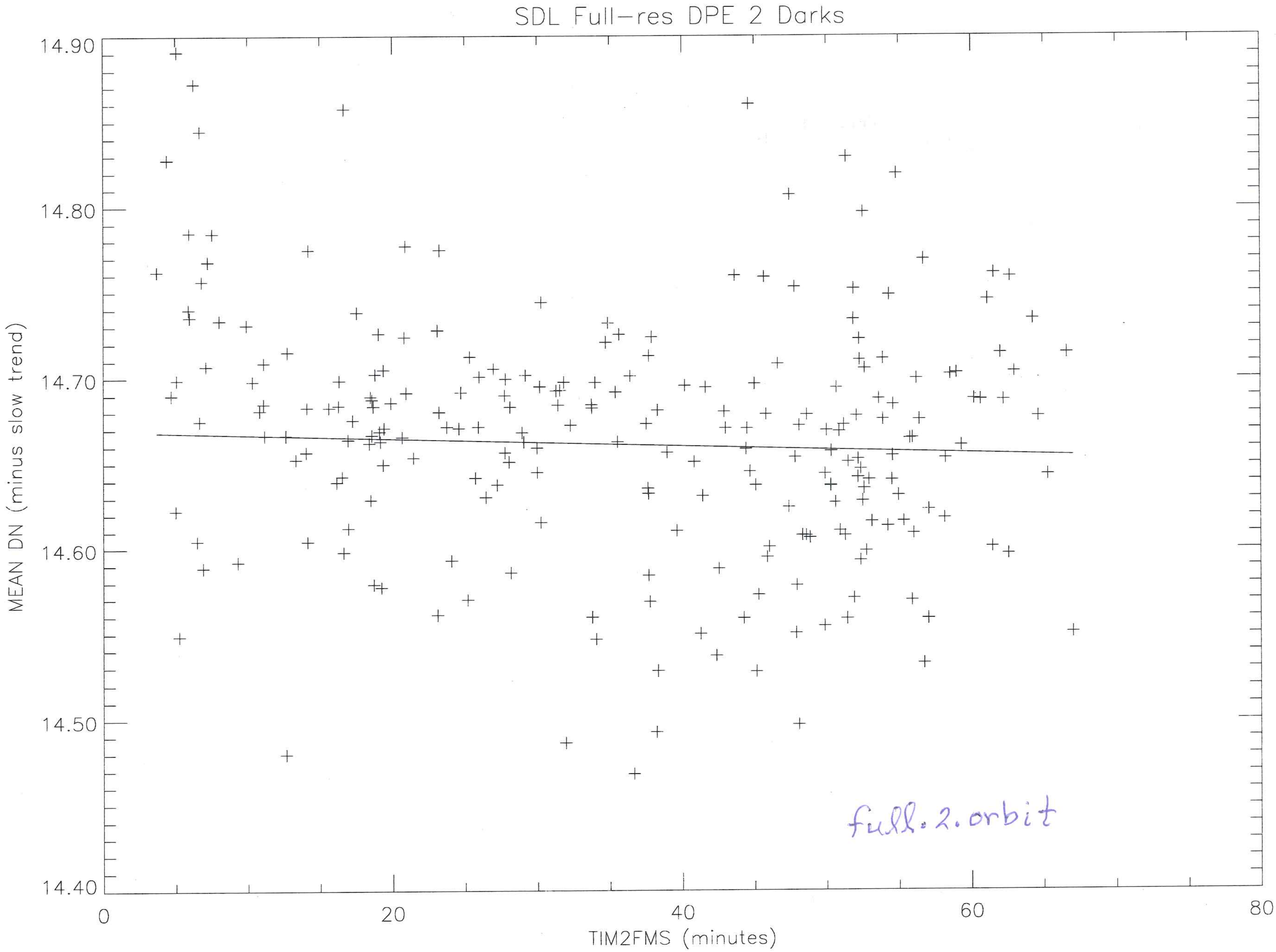
X) FIGURES ##

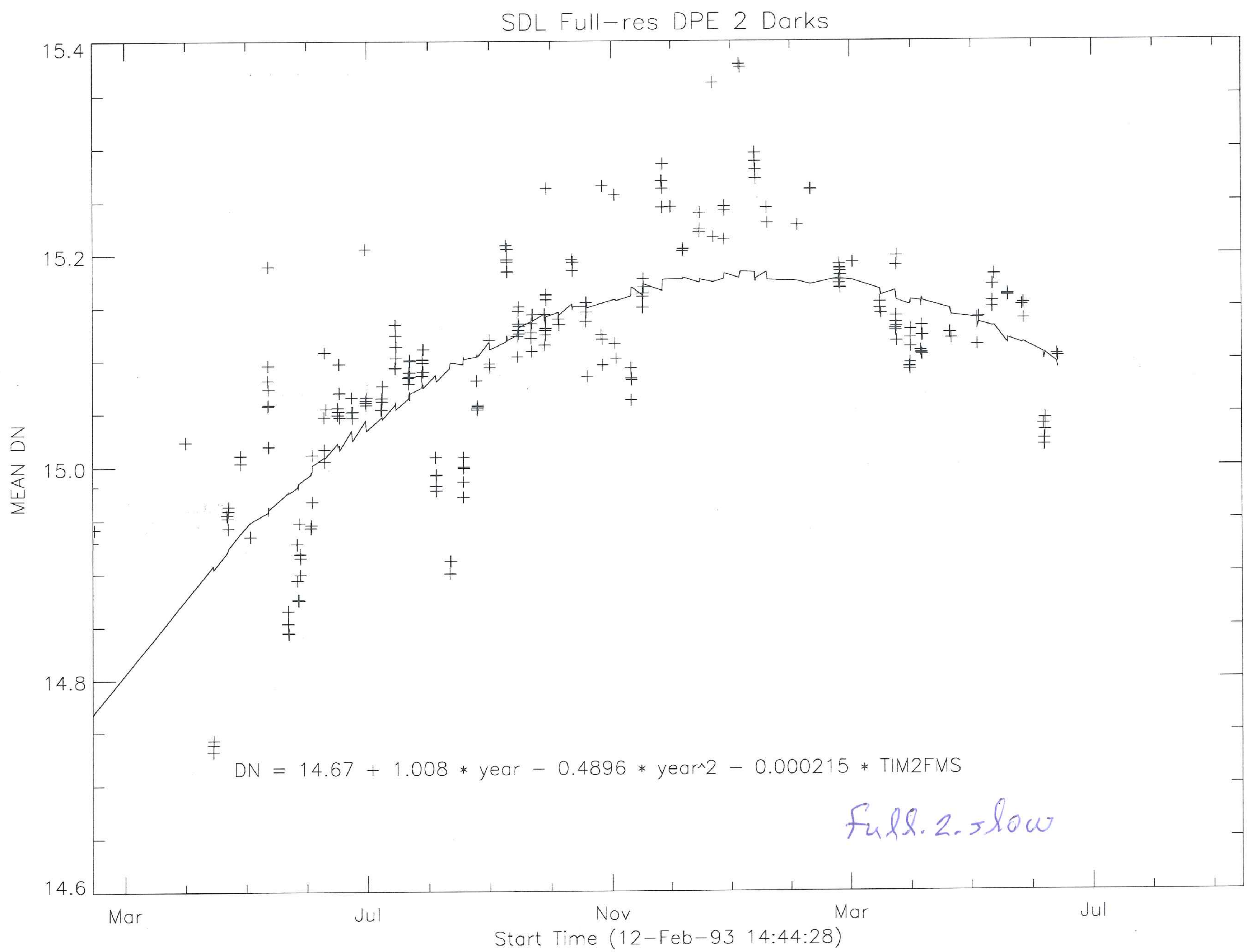
Postscript files with figures for this report are in the directory

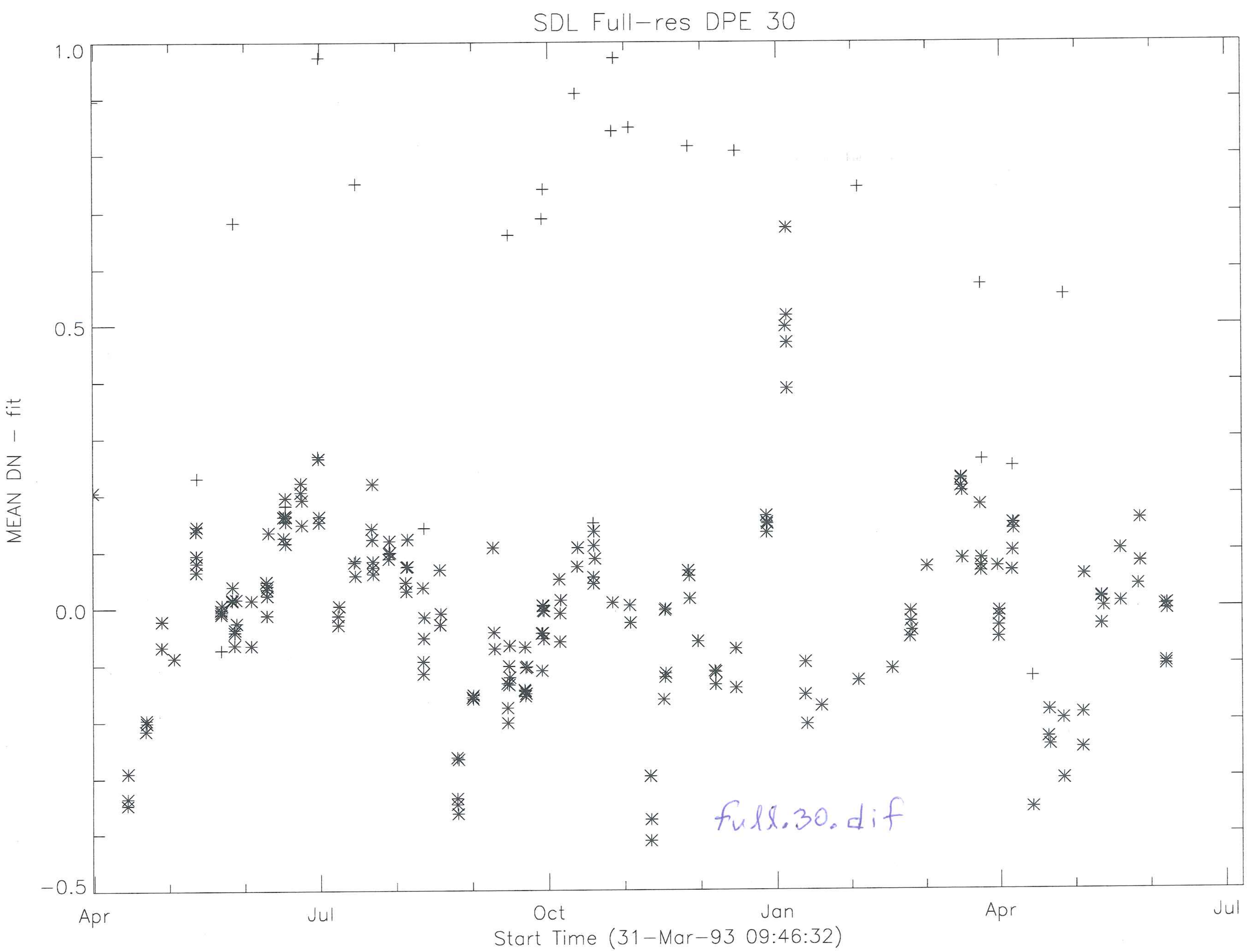
/4p/labonte/sxtdark

Files are labeled by resolution and DPE. File suffixes are:

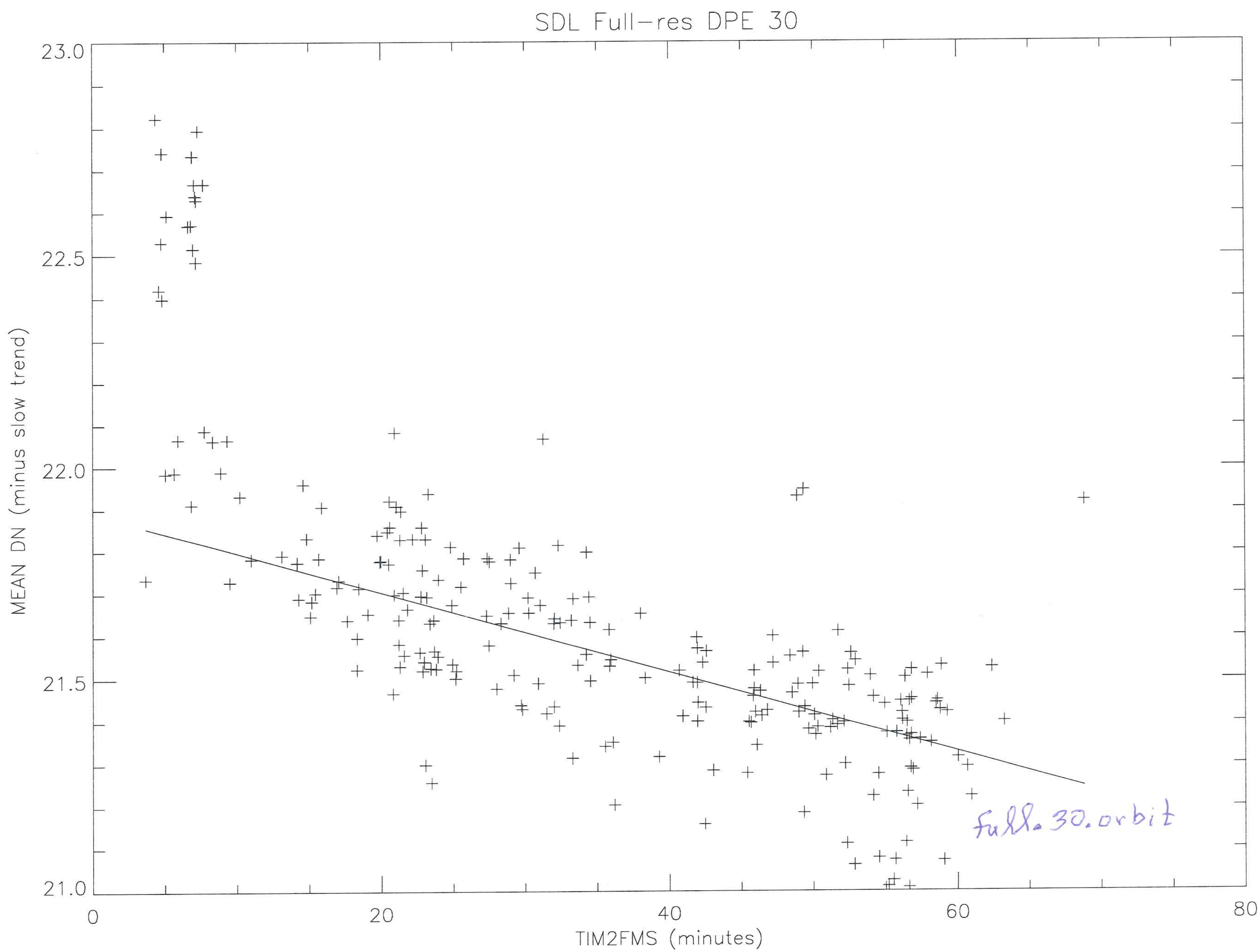
.slow	Raw data and least-squares fit.
.orbit	Orbital variation, slow trend removed.
.dif	Residuals, data - fit.
.dates	Raw data and special dates marked.

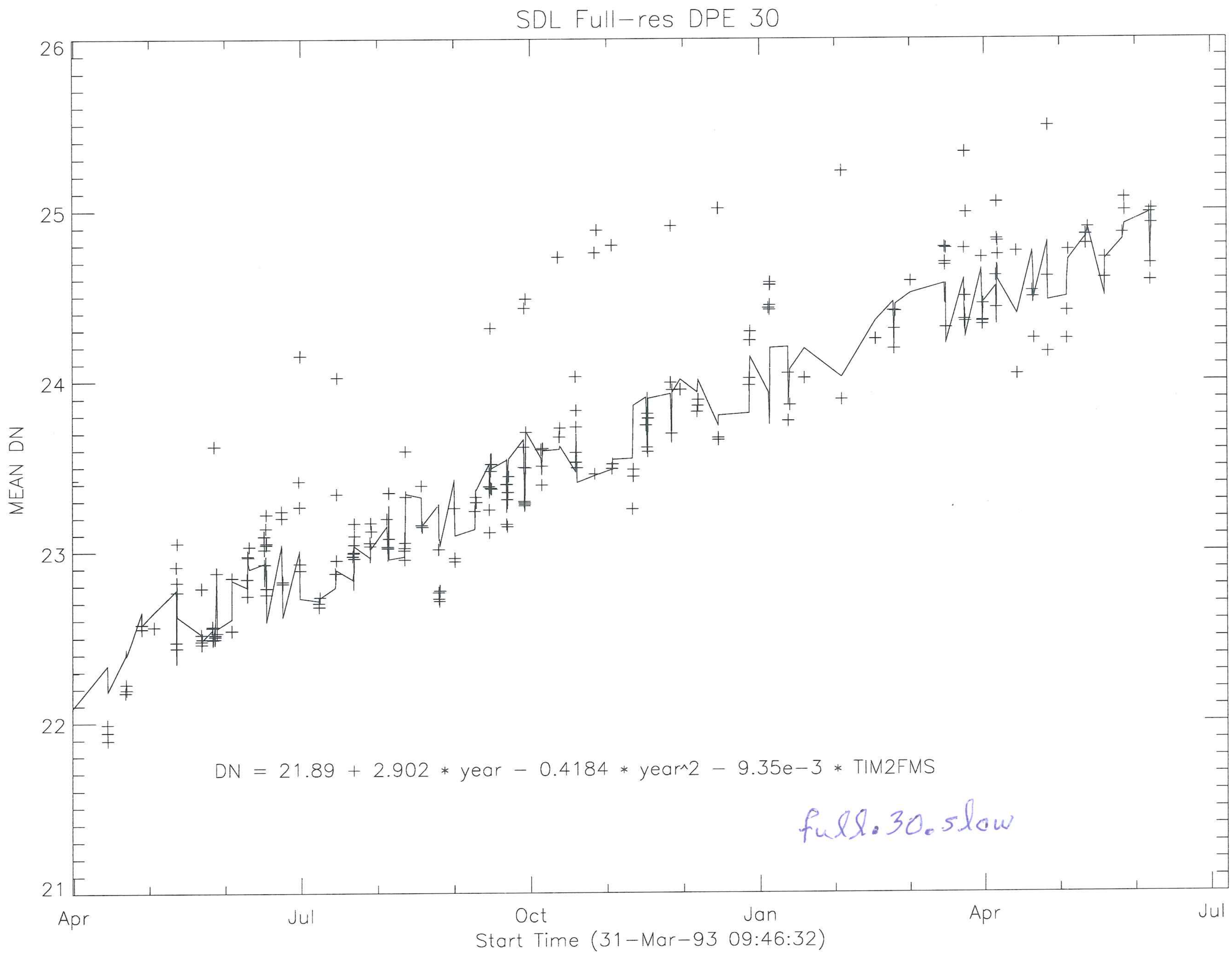

SDL Full-res DPE 2 Darks
14.90
14.80
14.70
14.60
14.50
14.40
MEAN DN (minus slow trend)
0
20
40
60
80
TIM2FMS (minutes)
full.2.orbit

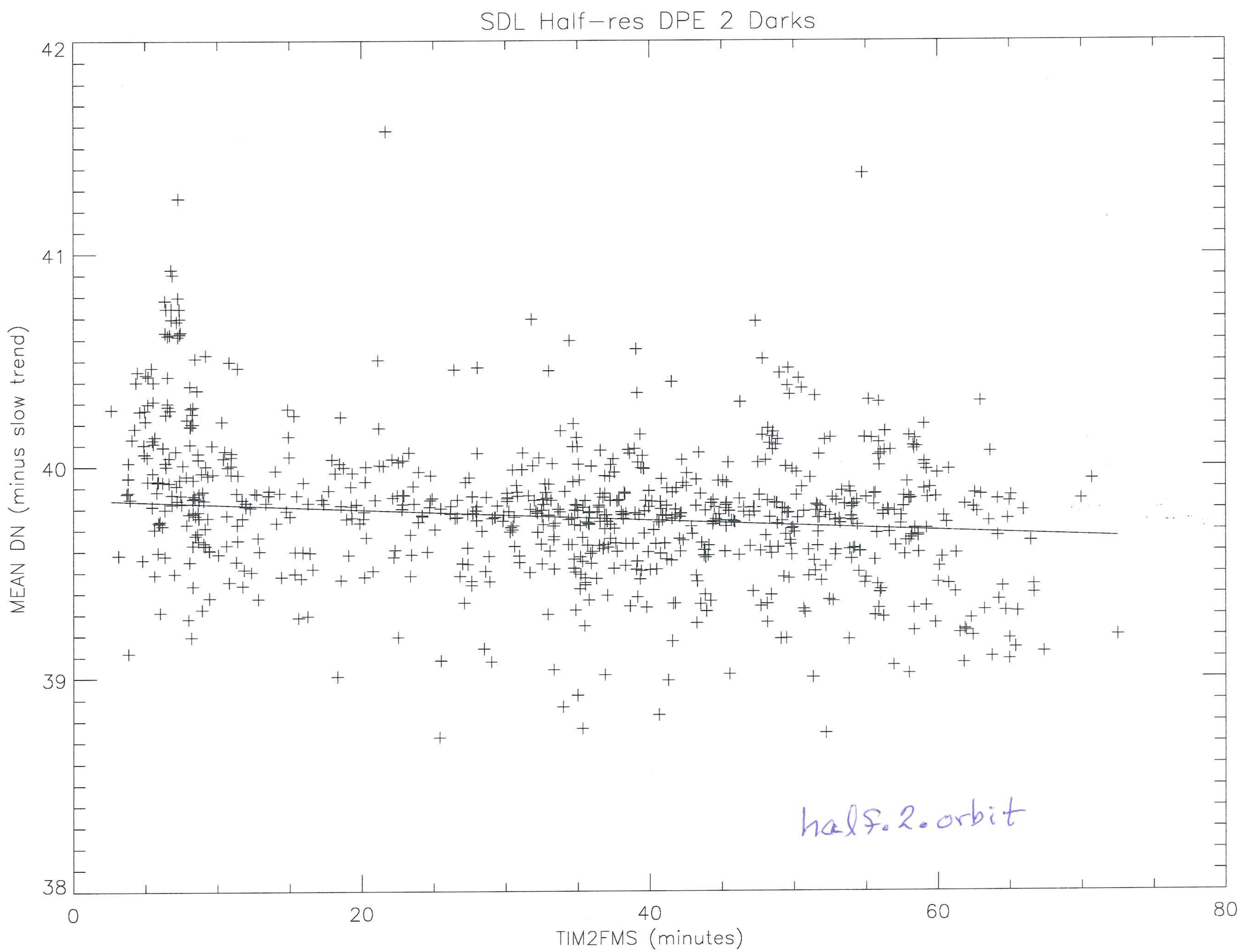

SDL Full-res DPE 2 Darks
15.4
15.2
15.0
14.8
14.6
MEAN DN
DN = 14.67 + 1.008 * year - 0.4896 * year^2 - 0.000215 * TIM2FMS
Full.2.slow
Mar
Jul
Nov
Mar
Jul
Start Time (12-Feb-93 14:44:28)

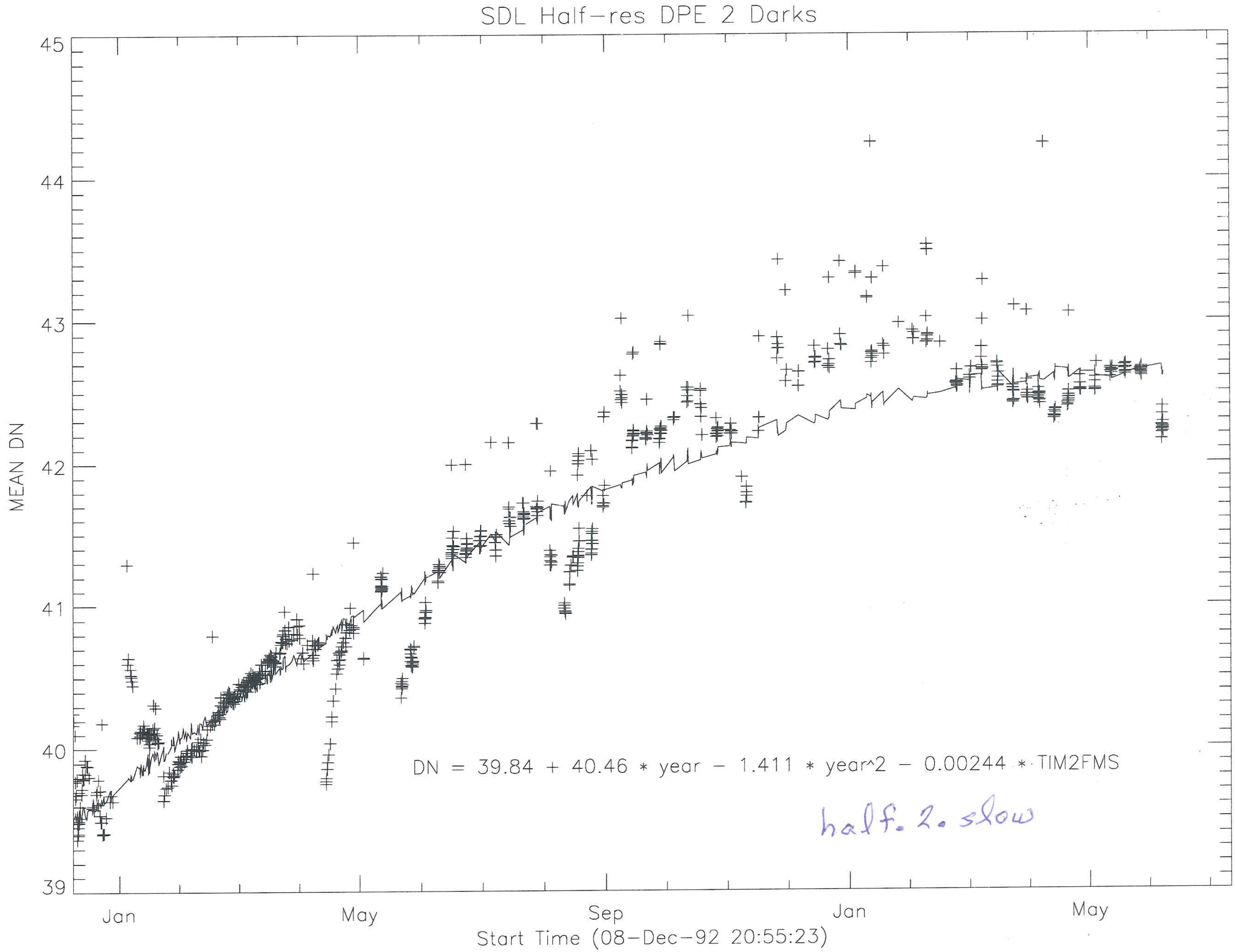


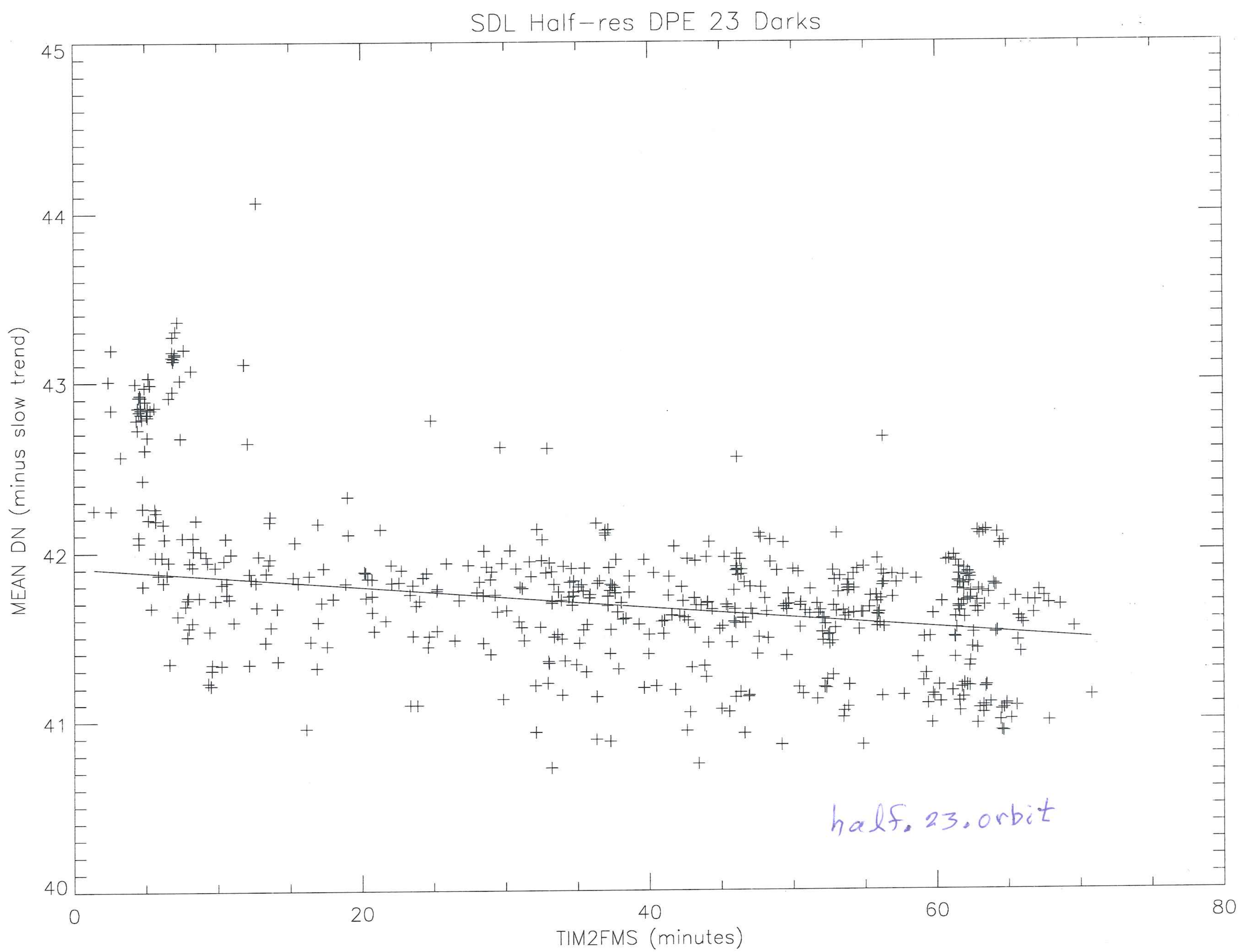
SDL Full-res DPE 30
MEAN DN - fit
1.0
0.5
0.0
-0.5
Apr
Jul
Oct
Jan
Apr
Jul
Start Time (31-Mar-93 09:46:32)
full.30.dif

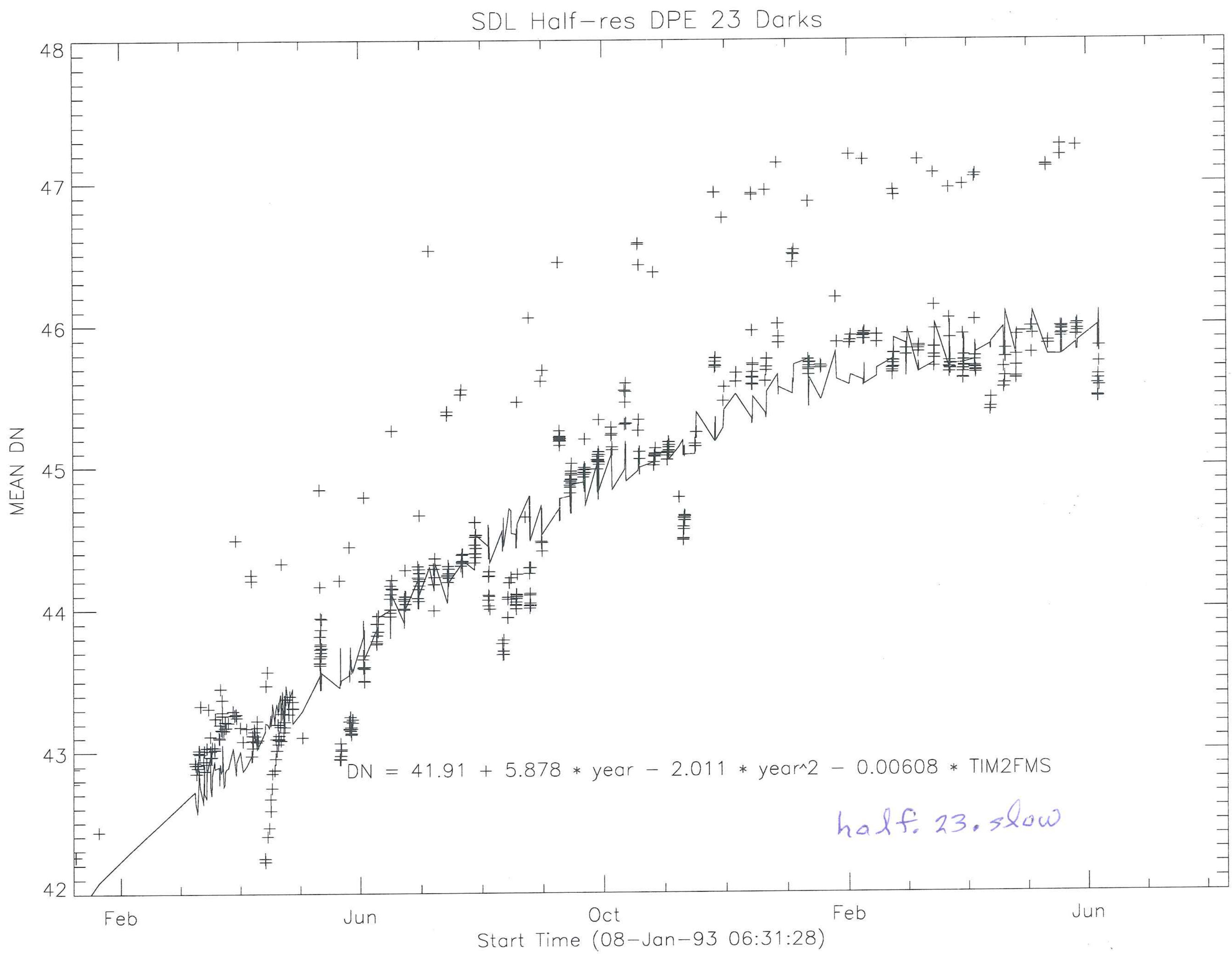

SDL Full-res DPE 30
MEAN DN (minus slow trend)
23.0
22.5
22.0
21.5
21.0
0
20
40
60
80
TIM2FMS (minutes)
full.30.orbit

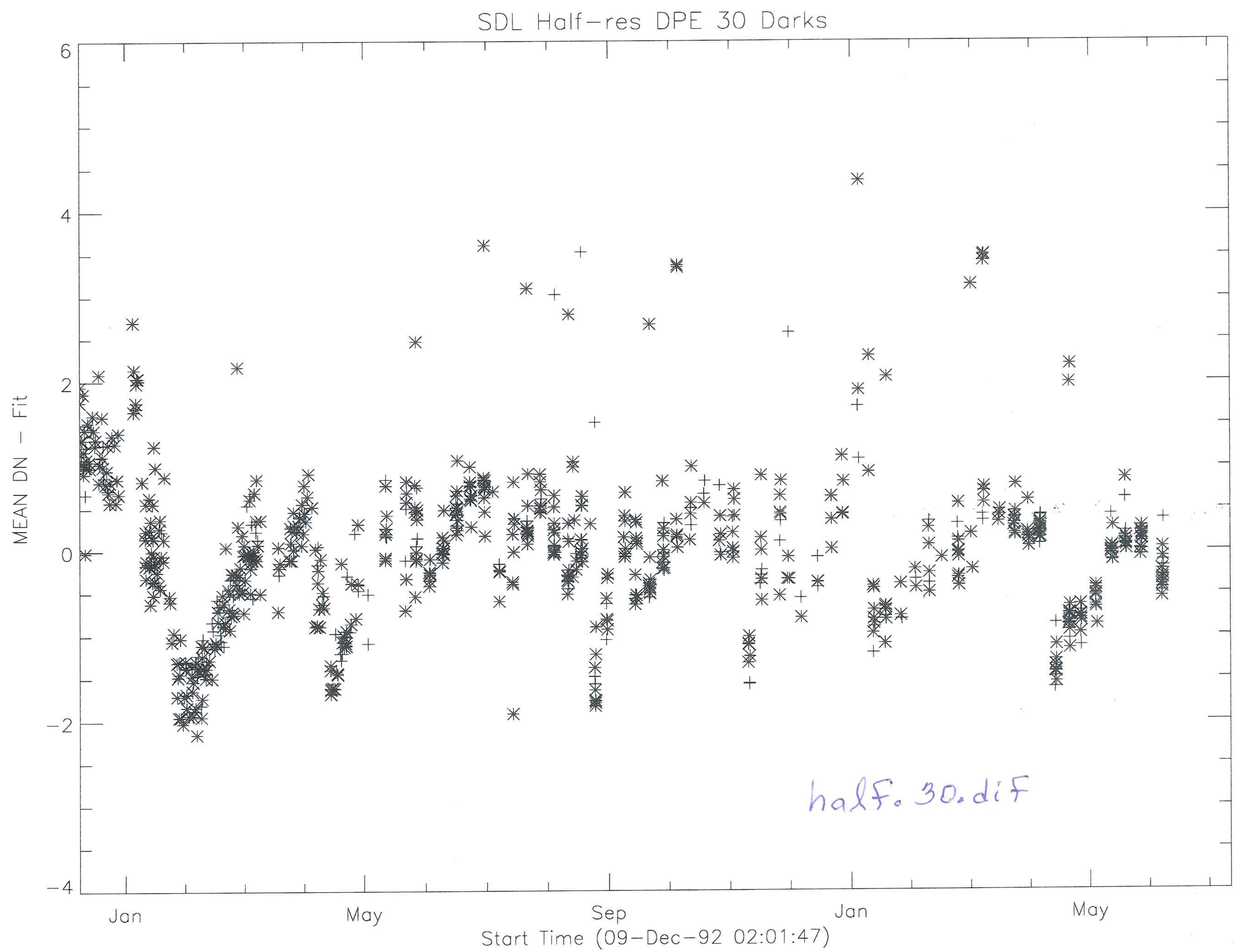

SDL Full-res DPE 30
MEAN DN
26
25
24
23
22
21
Apr
Jul
Oct
Jan
Apr
Jul
Start Time (31-Mar-93 09:46:32)
DN = 21.89 + 2.902 * year - 0.4184 * year^2 - 9.35e-3 * TIM2FMS
full.30.slow

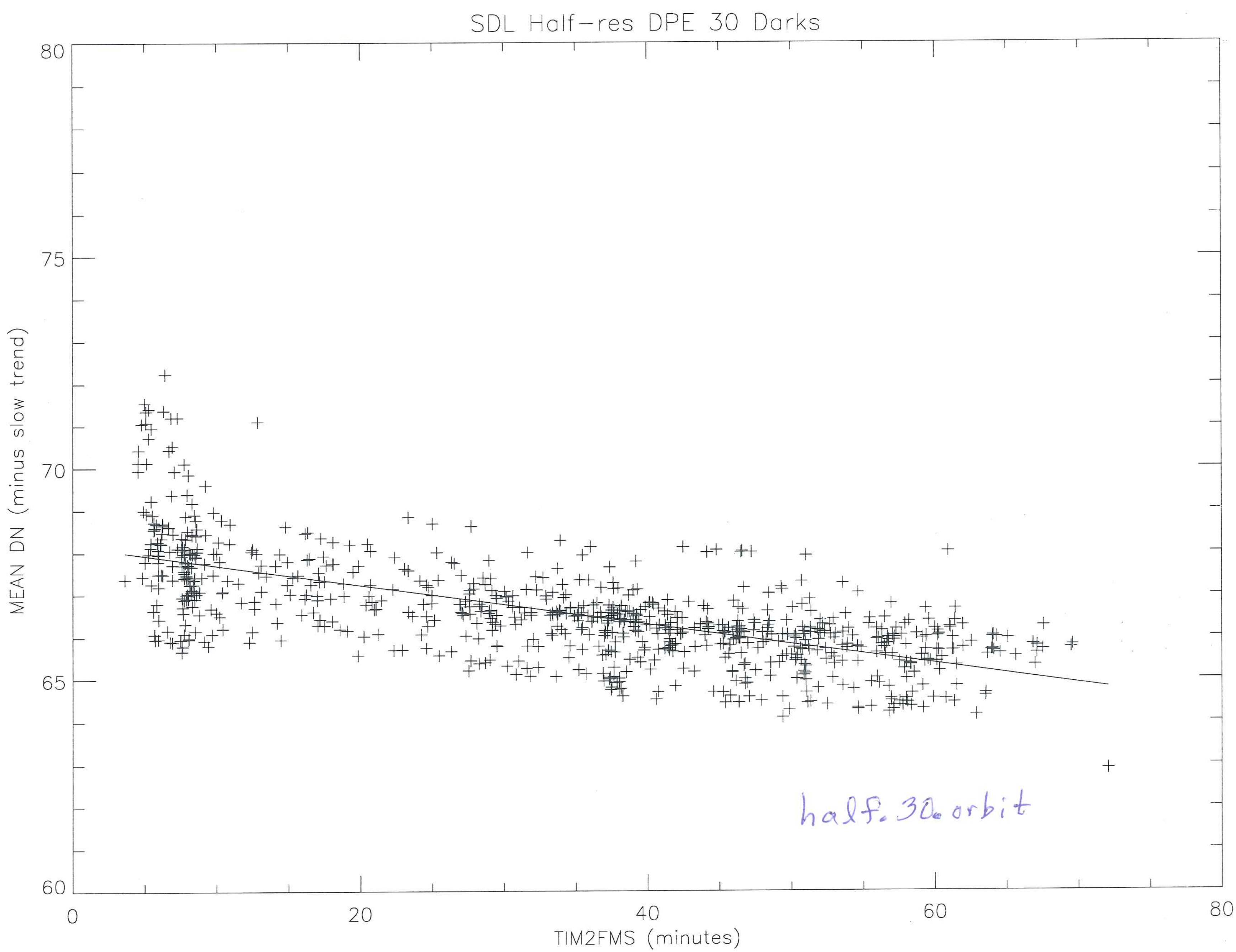

SDL Half-res DPE 2 Darks
42
41
40
39
38
MEAN DN (minus slow trend)
0
20
40
60
80
TIM2FMS (minutes)
half.2.orbit

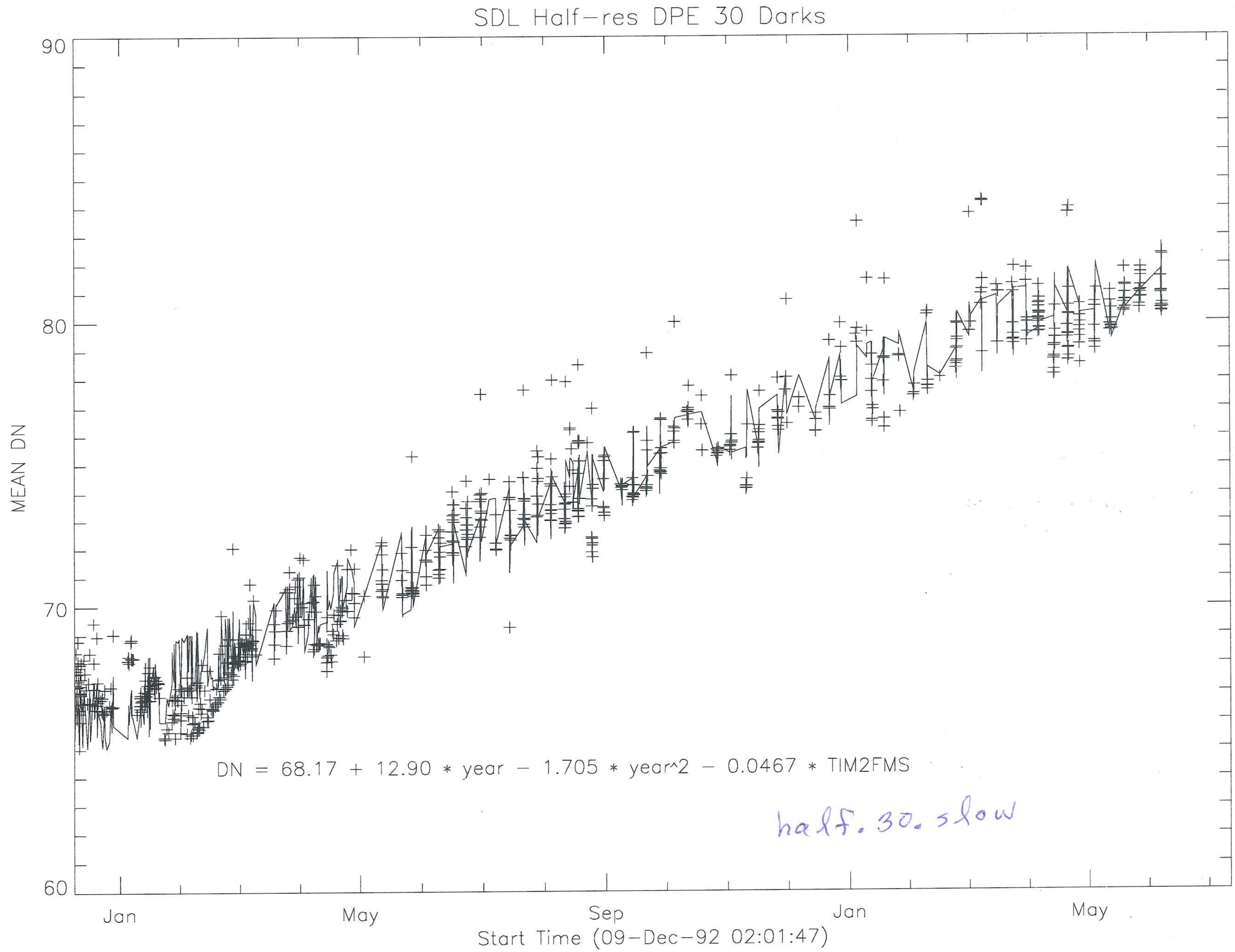

SDL Half-res DPE 2 Darks
MEAN DN
45
44
43
42
41
40
39
Jan
May
Sep
Jan
May
Start Time (08-Dec-92 20:55:23)
DN = 39.84 + 40.46 * year - 1.411 * year^2 - 0.00244 * TIM2FMS
half. 2. slow

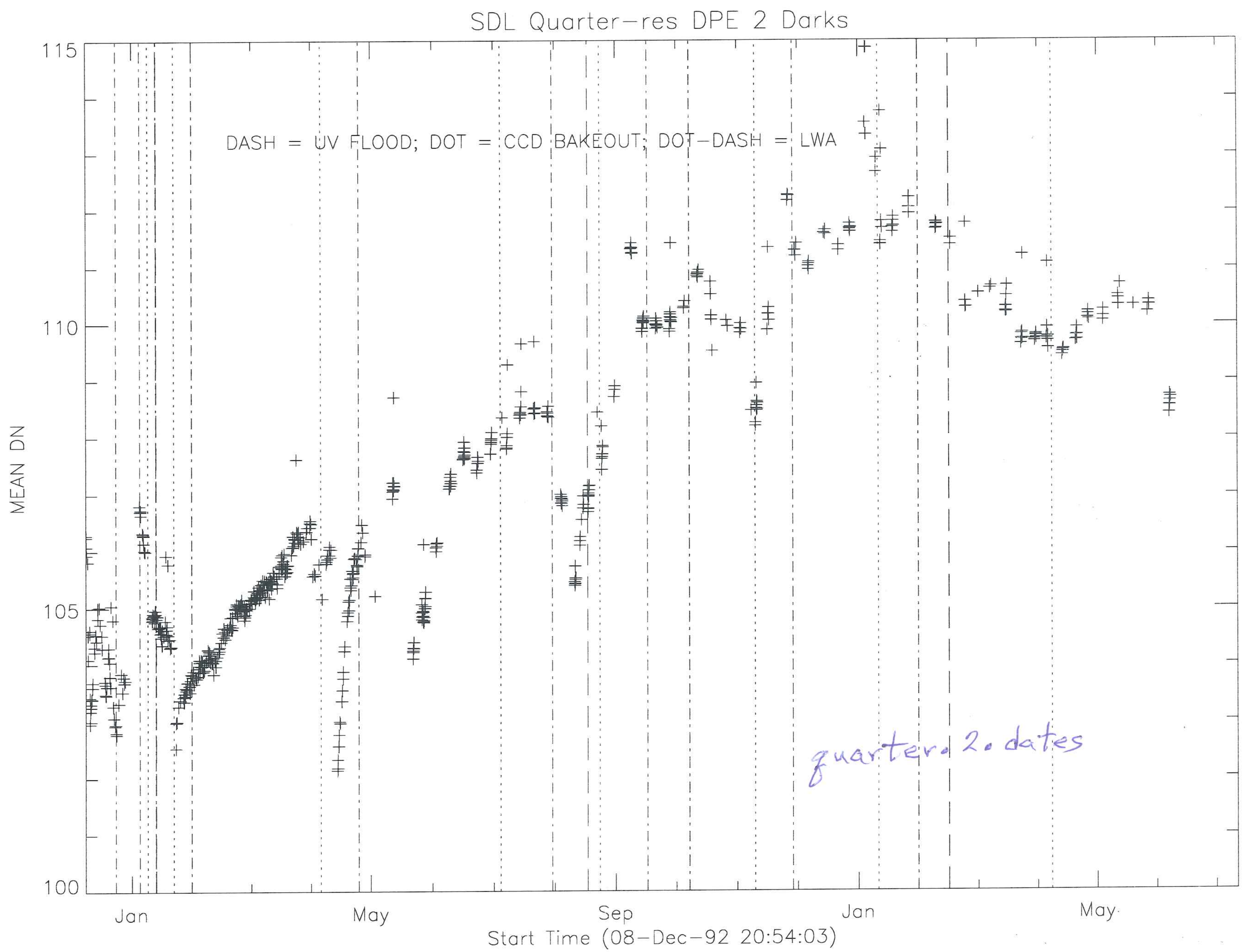

SDL Half-res DPE 23 Darks
MEAN DN (minus slow trend)
45
44
43
42
41
40
0
20
40
60
80
TIM2FMS (minutes)
half. 23. orbit

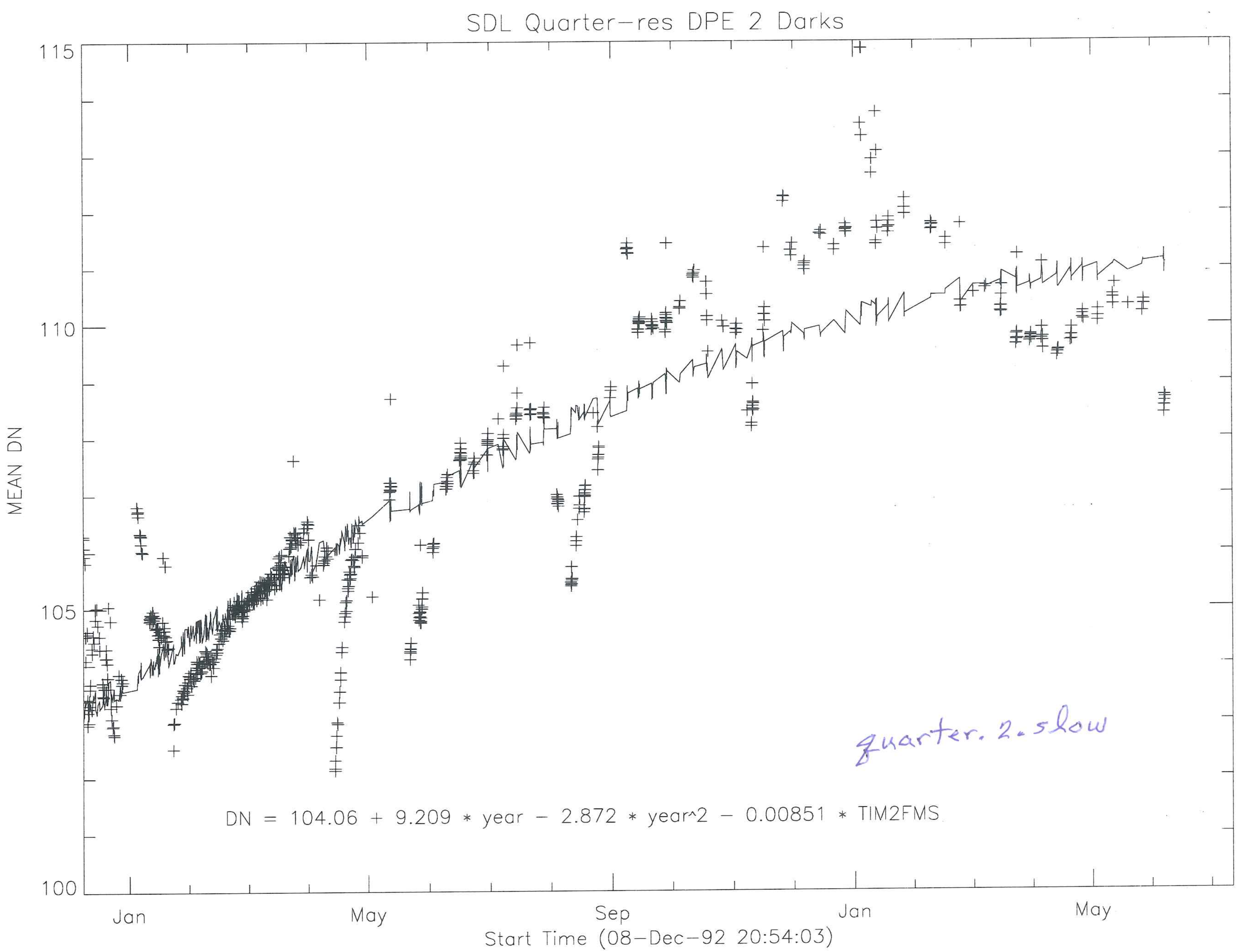

SDL Half-res DPE 23 Darks
MEAN DN
48
47
46
45
44
43
42
Feb
Jun
Oct
Feb
Jun
Start Time (08-Jan-93 06:31:28)
DN = 41.91 + 5.878 * year - 2.011 * year^2 - 0.00608 * TIM2FMS
half. 23. slow

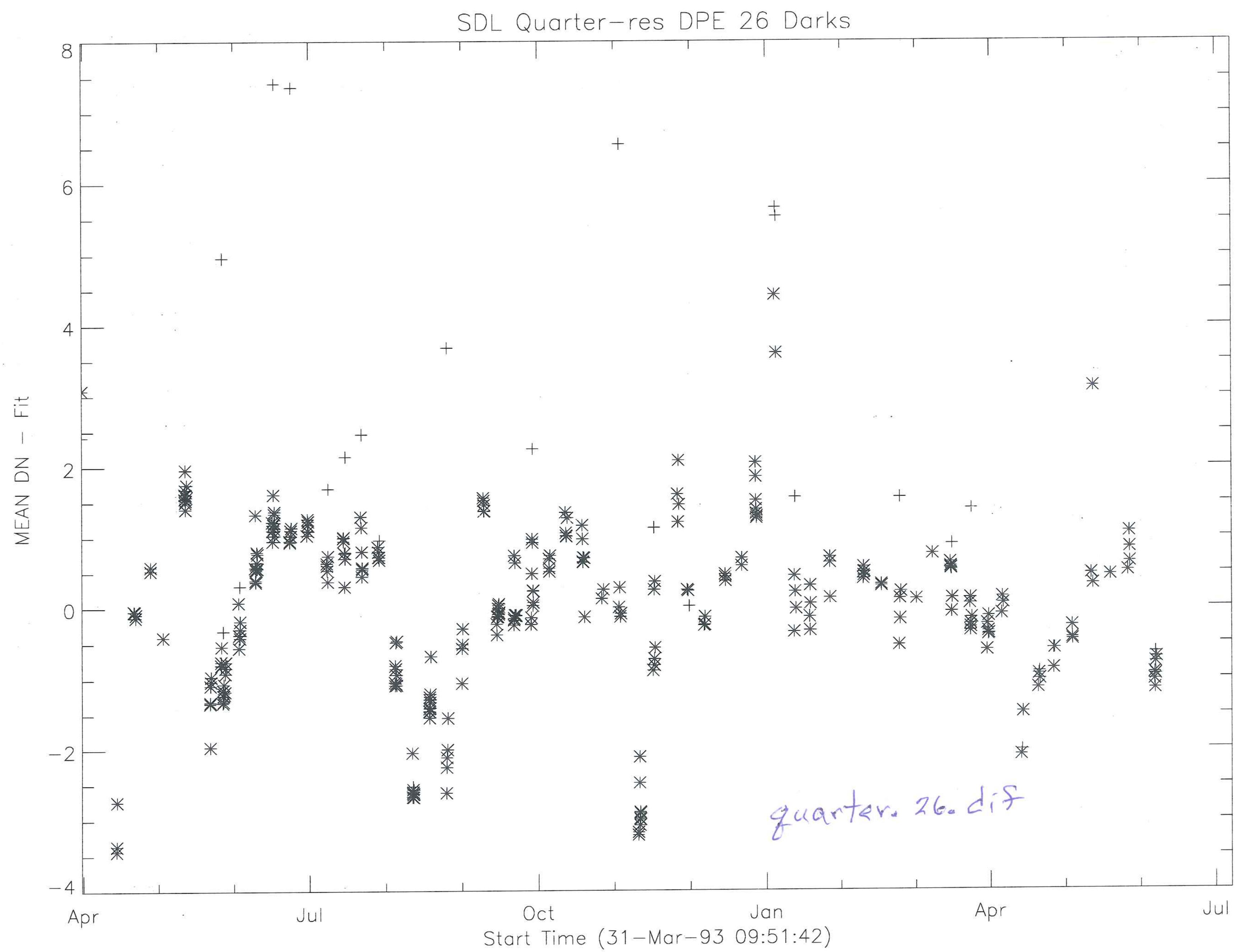

SDL Half-res DPE 30 Darks
6
4
2
0
-2
-4
MEAN DN - Fit
Jan
May
Sep
Jan
May
Start Time (09-Dec-92 02:01:47)
half.30.dif

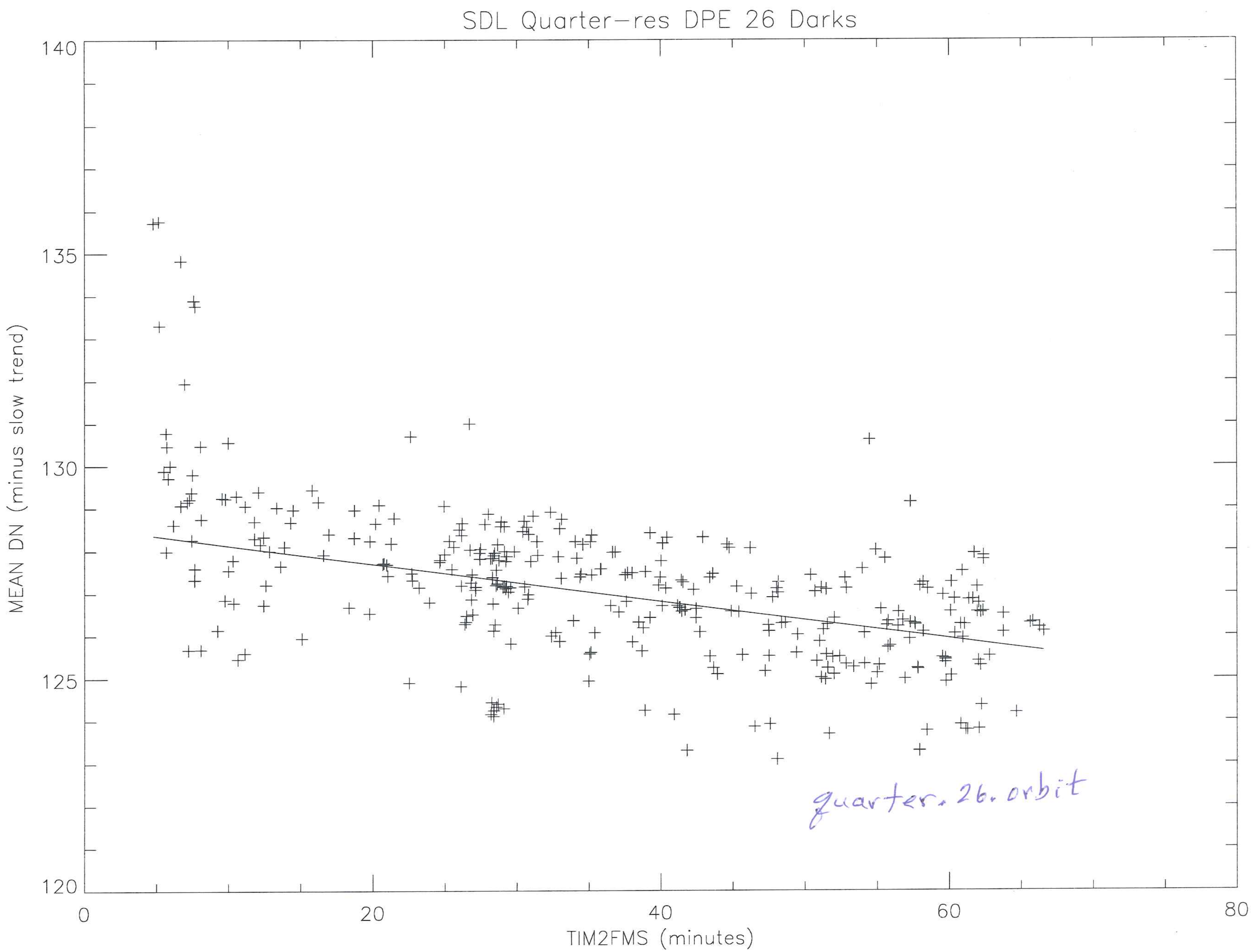

SDL Half-res DPE 30 Darks
MEAN DN (minus slow trend)
TIM2FMS (minutes)
80
75
70
65
60
0
20
40
60
80
half.30.orbit

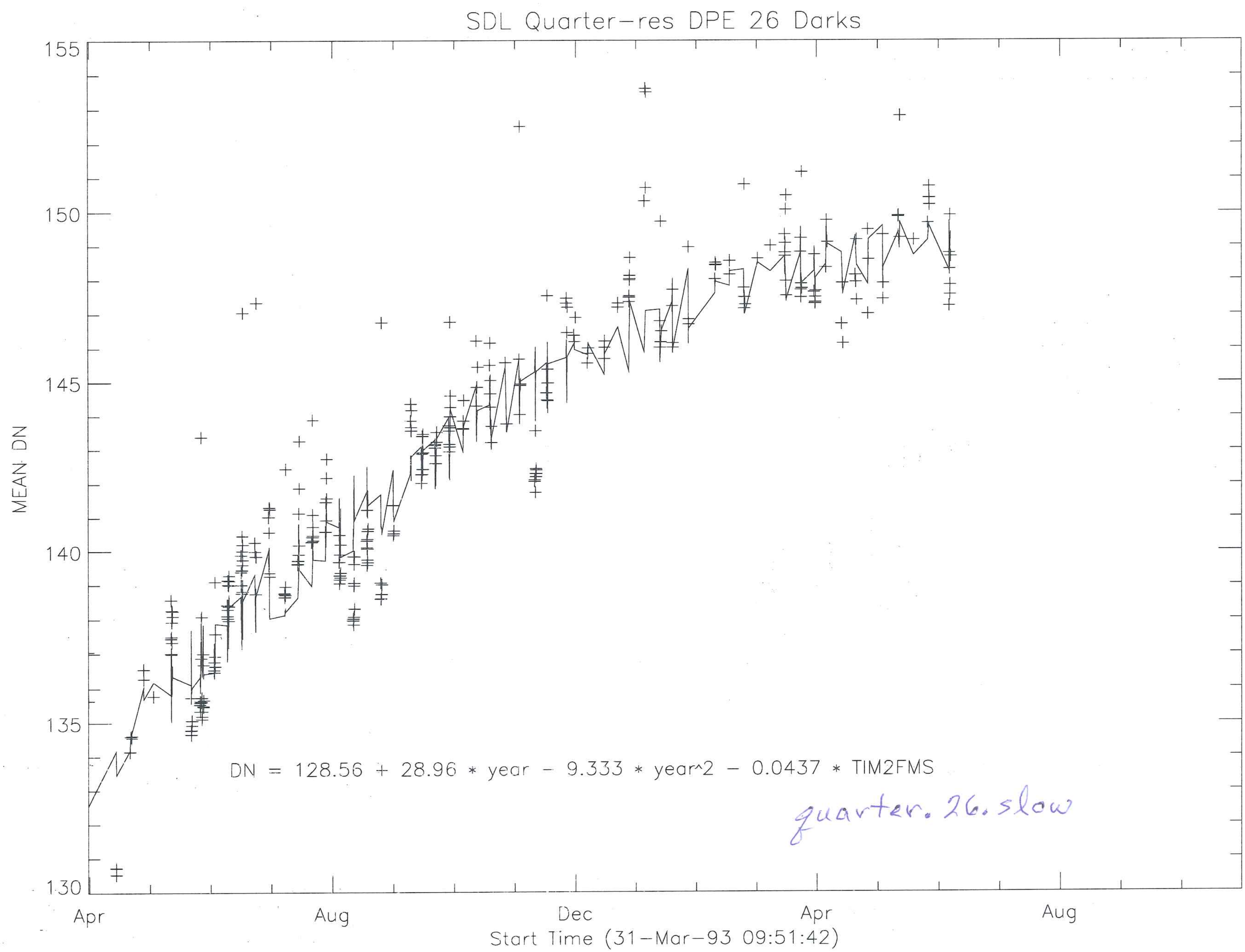

SDL Half-res DPE 30 Darks
90
80
70
60
MEAN DN
Jan
May
Sep
Jan
May
Start Time (09-Dec-92 02:01:47)
DN = 68.17 + 12.90 * year - 1.705 * year^2 - 0.0467 * TIM2FMS
half.30.slow


SDL Quarter-res DPE 2 Darks
DASH = UV FLOOD; DOT = CCD BAKEOUT; DOT-DASH = LWA
MEAN DN
115
110
105
100
Jan
May
Sep
Jan
May
Start Time (08-Dec-92 20:54:03)
quarter. 2. dates


SDL Quarter-res DPE 2 Darks
115
110
105
100
MEAN DN
Jan
May
Sep
Jan
May
Start Time (08-Dec-92 20:54:03)
DN = 104.06 + 9.209 * year - 2.872 * year^2 - 0.00851 * TIM2FMS
quarter. 2. slow


SDL Quarter-res DPE 26 Darks
MEAN DN - Fit
8
6
4
2
0
-2
-4
Apr
Jul
Oct
Jan
Apr
Jul
Start Time (31-Mar-93 09:51:42)
quarter.26.dif


SDL Quarter-res DPE 26 Darks
MEAN DN (minus slow trend)
TIM2FMS (minutes)
140
135
130
125
120
0
20
40
60
80
quarter.26.orbit


SDL Quarter-res DPE 26 Darks
155
150
145
140
135
130
MEAN DN
DN = 128.56 + 28.96 * year - 9.333 * year^2 - 0.0437 * TIM2FMS
quarter.26.slow
Apr
Aug
Dec
Apr
Aug
Start Time (31-Mar-93 09:51:42)