MIT CSR

ACIS FLIGHT SOFTWARE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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CAMBRIDGE, MASSACHUSETTS 02139

TO: Chandra Scientists and ACIS Engineers

FROM: Peter Ford, ACIS SI Team, NE-80 6071

DATE: May 7, 2001

SUBJECT: Anomalous ACIS Pixel Values

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1. INTRODUCTION

This memo attempts to characterize several classes of anomalous ACIS pixel values that have been received from the flight unit. The occurrence of unphysically low pixel values was first noticed in February, 2000, when it was the subject of several memoranda between the Chandra Science Operations Team (SOT) and the ACIS Science Instrument Team. It has been monitored since then and became particularly severe during a recent period of increased solar activity. The fear is that radiation damage may have exacerbated the problem.

2. APPLICABLE DOCUMENTS

	Reference	Title	URL*
1	MIT 36–02205, Rev. C	DPA/DEA Interface Control Document	*axaf/deadpaicd*
2	MIT 36-02104, Rev. C	DPA Hardware Specification & System Description	*axaf/dpa*
3	MIT 36-01103, Rev. I	ACIS Software Requirements Specification	*acis/sreqi*
4	MIT 36-53200, Rev. A	ACIS Software Detailed Design Specification	*acis/sdetail*
5	MIT 36-53204.0204, Rev. N	ACIS Instrument Procedures and Command Language	*acis/ipcl*

* Prefixed with “http://acis.mit.edu/”.

3. HISTORY

The first person to report anomalous pixel values was the ACIS P.I., Gordon Garmire:

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From: Gordon Garmire <garmire@astro.psu.edu>
To: plucinsk@head-cfa.harvard.edu
Date: Fri, 11 Feb 2000 17:47:27 -0500 (EST)
Subject: Re:CCD9 Problem

I just received the grb0210 data and noticed that CCD9 is showing
a strange behavior. There are large peaks in the PHA data between
1-2 keV. The other CCDs appear fine, so it is not something to do
with backgrounds or anything.
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I replied as follows

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From: “Peter G. Ford” <pgf>
To: garmire@astro.psu.edu
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Date: Fri, 11 Feb 2000 23:34:18 -0500 (EST)
Subject: Re:CCD9 Problem

I've looked at the data from S5 for this run (OBSID 602). The
anomaly is caused by 4 super-low bias values, all from output node
C...
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Beverly Lamarr then examined all bias files downlinked between launch and February 12, 2000,

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From: Beverly LaMarr <fergason>
To: brm@head-cfa.harvard.edu
Date: Thu, 17 Feb 2000 14:26:16 -0500 (EST)
Subject: bias files to look out for

I just wanted to let you know about some files that we recently
found with bias values below the event threshold. The reason that
you will want to know about these files is because they show up in
the data as hot pixels, but they really aren't. So, I would recom-
mend against using any eventlists processed with the following
biases to hunt for hot pixels.
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She subsequently listed 71 OBSIDs with a total of 355 anomalously low bias values, all but 10 of them from S5 (295) and S2 (50).

There the matter sat until an especially large number of background events was reported from an ACIS science run on March 31, 2001. The message from Paul Plucinsky read as follows:

```
From: “Paul P. Plucinsky” <plucinsk@head-cfa.harvard.edu>
To: sot@head-cfa.harvard.edu
Date: Mon, 02 Apr 2001 10:15:00 -0400
Subject: URGENT  !! NEW BAD PIXELS  ?!?!

There appear to be ~15 new hot pixels in the first quadrant of S2.
I am looking at a partial events list from OBSID 2093 and an image
in detector coordinates shows a some pixels with between 1000 and
4000 cts out of a total of 4200 frames. Would someone at MIT
please check.
```

So we did. The anomalous “events” were centered at 77 locations on two CCDs, S2 and S5. This was a time of high solar radiation flux and “hot” pixels were anticipated, but these particular pixels displayed no aberrant behavior in subsequent science runs. Instead, the problem was traced to the bias maps for these CCDs, which contained values at these 77 locations that were far below the average overclock values for their respective quadrants. The reports from February 2000 were dusted off and a new investigation began.

4. BIAS DETERMINATION

The ACIS front end processors (FEPs, see Applicable Document #2) distinguish x-ray events from background by searching for local maxima in the two-dimensional charge distribution that is reported from each CCD. Even in the absence of x-ray or background event, the voltage reported from each pixel is seen to vary with row and column location on the CCD, with temperature, and with the detailed pixel clocking waveform. Each FEP must therefore create a bias map, an array of baseline pixel values against which to compare subsequent values in the hunt for x-ray events.

The bias map is created by running the CCDs and examining a series of readout values of each pixel. Their distribution typically exhibits a low energy peak with a width of 2-4 pixel units

(ADU), a medium-energy exponential tail with width ~10 ADU, and discrete higher energy values representing real x-ray and charged particle background events. The desired bias value lies at the low-energy peak of the distribution, and this would be a trivial matter to compute if it were possible to store within the FEPs many samples of each of the 10 million pixels. Since sufficient memory isn't available, the FEP flight software (see Applicable Document #3) allows the user to choose between two classes of bias map creation algorithm, described fully in Applicable Document #4.

In the "strip" method, only a limited number of rows is read from each CCD at any one time. A series of samples of each pixel is then assembled. Since most of the samples will cluster about the "true" bias value, anomalously high- and low-energy outliers can be identified and removed before selecting the mean or median as the bias value. Strip algorithms are slow since, to assemble N samples of each pixel, N^2 frames must be processed. Also, since the mean bias value will slowly vary as the CCDs and video boards warm up, successive strips of bias values may be systematically higher or lower, introducing a subtle row-dependent bias in quantum efficiency. For these reasons, the strip-mode have not yet been used in orbit.

The "full-frame" method proceeds in two stages. In the first, a series of M "conditioning" frames are examined, and the minimum value of each CCD pixel, p_0, is chosen as the zeroth approximation, b_0, of that pixel's true bias. In the second, "accumulating" stage, a series of N frames is examined. A pixel that is more than a certain value above its corresponding approximate bias value is deemed an x-ray or background event and it, and its 8 neighbor pixels, are ignored. The remainder are used to improve the bias value itself. For example, if at the nth accumulation frame, the pixel p_i is less than a fixed threshold value above the approximate bias value b_i, and if p_i's neighbors are similarly constrained with respect to their own bias values, the new "better" bias value is approximated by

$$b_{i+1} = [p_i + (n-1)\, b_i] / n \qquad n = 1, N. \tag{1}$$

The full-frame algorithm is fast since only M+N frames need to be taken. However, its results are sensitive to the medium-energy tail of the pixel distribution and the conditioning phase can be ruined by a single very low pixel value which will become the initial approximate bias value for that pixel and will then cause subsequent, reasonable values to be identified as x-rays or background, and hence rejected. The anomalously low pixel values will therefore show up in the final bias map. This possibility was recognized when the algorithm was first proposed and a simple fix was developed in the form of a median filter that can be applied between the conditioning and accumulating stages. The filter examines each value in the approximate bias map. Any that are lower than 7 of their 8 neighbors by more than a specified value are replaced by the median of those neighbors. Since this would occur *before* the accumulating stage, the replaced bias value will be modified by subsequent pixel values which will most probably not be rejected. Thus far, however, the median filter step (invoked by a non-zero value of the *biasArg2* parameter, as described in Applicable Document #5) has not been used in orbit.

5. DATA ANALYSIS

I have written a simple program (see *~pgf/acis/pixanom1*) that examines *all* bias maps and event data telemetered from ACIS since launch. It reports the number of anomalously low values in each quadrant of each bias map, namely those values that are more than 10 ADU below the average overclock values for that quadrant. It also reports the number of anomalously low and saturated values in all event data, *i.e.*, the 3x3 and 5x5 pixel arrays reported in faint- and very-faint mode timed-exposure and continuous-clocking runs. Again, the criterion for an anomalously low value is that it is more than 10 ADU lower than its quadrant's average overclock, after compensating for overclock drift. Saturated values are those with a reported value of 4095 ADU. Pixels whose corresponding bias values are 4095 are excluded from these statistics since this indicates that the pixel is a member of the current "bad pixel" or "bad column" list.

As detailed in item (d) below, anomalously low corner-pixel values frequently follow saturated pixels in quadrant readout order, *i.e.*, an anomalously low pixel value at row *r*, column *c*, is likely to be associated with a 4095 ADU valued pixel at row *r*, column *c*+*i* of the same exposure frame, where *i*=-1 when the pixel is in quadrant A or C and *i*=+1 when in quadrant B or D. The analysis program was therefore altered to report this class of anomalies separately.[1]

In addition, histograms were made of the number of low and saturated values in each row and column of each CCD. The various distributions are shown in the appendix. To compare the results over the past 18 months, the saturated pixel counts have been normalized by the total static exposure times of their science runs, compensating for dropped frames, sub-array readout, etc. This follows the reasonable assumption that almost every saturated pixel will be reported as an event. The same is not true for anomalously low values. They will only be reported if they lie close to an event, so their distributions have been scaled by the number of pixels whose values were reported in that run.

The major findings are as follows:

a. The few instances in which large numbers (> 10^2) of low bias values are reported are all due to known anomalies, *e.g.*, a bad uplink parameter block, a failure to recompute bias maps after an ACIS mode change, and the infamous FEP_0 bias thresholding problem that appeared mysteriously in October 1999, and just as mysteriously vanished again 12 days later.
b. Node A of CCD_S2 and node C of CCD_S5 continue to report anomalously low bias values at approximately the same rate as found by Beverly Lamarr last year.
c. The frequency of low bias values is correlated, run-for-run, CCD-for-CCD, and node-for-node, with the frequency of anomalously low corner-pixel values in the following science run.
d. Many anomalously low corner-pixel values are immediately preceded by a saturated pixel (value 4095) from the same output node of that CCD. This is particularly true for node A of CCD_S2 and node C of CCD_S5 which together are responsible for ~80% of all low values.
e. The large numbers of saturated pixel counts from particular rows and columns of CCD_I1 (*i.e.*, columns 340 and 715 and rows 165, 426, and 717) are due to sporadic "flickering" pixels.
f. The incidence of saturated pixels peaked shortly after launch, during the on-orbit checkout phase, and then dropped to maintain a relatively constant value ever since. This may be correlated with the drop in focal plane temperature from -100C to -110C on 9/11/99.
g. The number of saturated pixels per kilosecond varies from CCD to CCD, and from output

1. It is to be expected that low values and saturated values will be correlated sicne the latter are likely to be reported as events, but the correlation is much stronger when the low value *follows* the saturated value in node readout order, and when both pixels are in the *same* row.

node to output node, but not significantly with orbital phase or SIM position. The variation is strongest (±30%) between the nodes of CCD_S1 and for node B of CCD_S2 and node D of CCD_I2, which are both anomalously low by 50%. On average, front- and back-illuminated CCDs generate the same number of saturated pixels.

h. Those anomalously low values that immediately follow saturated values from the same node are now restricted to certain nodes of particular CCDs, especially Node A of CCD_I1, nodes A and C of CCD_S2, and node C of CCD_S5, although the condition was observed in all nodes of all CCDs, except possibly S3, at the start of OAC.

i. Many low pixel values were reported from a group of 14 science runs on 5/23/00 and 5/24/00. They come only from node A of CCD_I0, CCD_I1, and CCD_S2, and were always preceded by saturated pixels. The runs comprised OBSIDs 1716-1729 inclusive and observed the standard calibration source G21.5-0.9 off-axis with SIM movements between runs. A second such cluster came from OBSIDs 1874-7 on 1/5/01, a series of observations of the Rosette Molecular Cloud, an extended source.

j. A third statistically significant cluster occurred between 6/21/00 and 6/28/00 when all nodes of some CCDs reported anomalously low values during one or more science runs, as detailed in the following table. The cells show the number of the FEP that is processing that CCD. Those with an anomalously large number of low values are shadowed.

OBSID	Date	I0	I1	I2	I3	S0	S1	S2	S3	S4	S5
26019	6/21/00	1									
1740	6/21/00					0	2	3	1	4	5
659	6/27/00					0	2	3	1	4	5
861	6/27/00		0	5	3			2	1	4	
795	6/27/00				4		2	3	1	5	
62011	6/28/00					4	2	3	1	5	0

k. The incidence of anomalously low bias values is strongly correlated with those CCDs and output nodes whose anomalously low pixel values follow saturated values.

l. All nodes of all CCDs also report anomalously low pixel values that are *not* associated with saturation. The rate was about 1 in 10^5 pixels during early OAC, and then fell to the current value of about 1 in 10^6 pixels. Since OAC, it has not been strongly correlated with node, row, column, date, radiation environment, etc., etc.

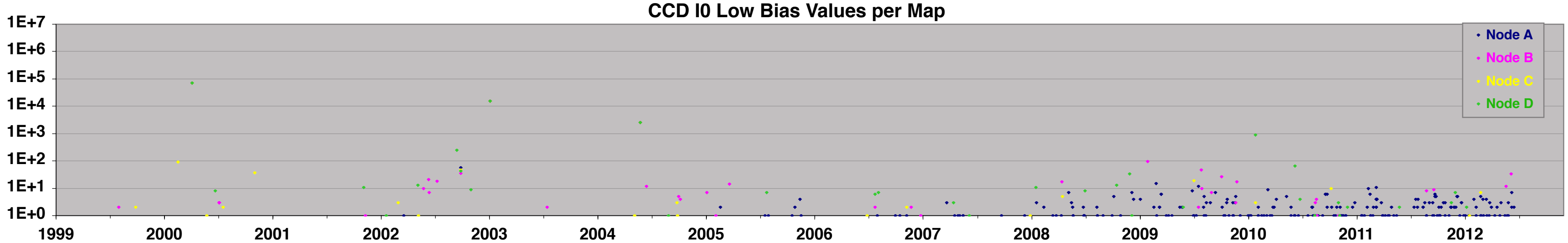
6. CONCLUSIONS

- The anomalies are coming from within ACIS, not from corrupted telemetry. They are uncorrelated with particular FEP boards. The most likely sources are (1) the CCD readout nodes, (2) the conductors that carry the signals to the DEA boards, and (3) the DEA circuits that amplify and convert the analog signals to 12-bit integers.
- The apparent correlation between anomalous values and focal plane temperature tends to rule out the DEA circuits as the *sole* cause since their temperature has remained within close limits throughout the mission.
- There are two classes of anomalously low pixel values: those that immediately follow a saturated pixel and those that don't.
- When the low values occur during the "conditioning" phase of bias map computation, they

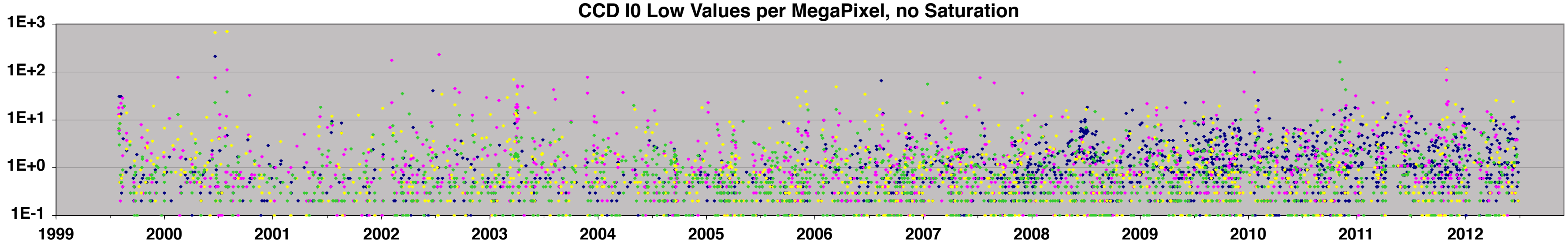
lead to low bias map pixels and hence to an increase in background events reported.

- A low value that follows a saturated value may be a feature of the DEA amplifiers or A/D converters, although this doesn’t explain why *every* saturated pixel isn’t followed by a low value. Perhaps it depends on the degree of over-saturation. This could be investigated in the laboratory using flight-spare CCDs and DEA boards.
- The origin of low pixel values not associated with saturated pixels remains mysterious, as does their prevalence in clusters of science runs, as described in item (i), above.
- More work will be needed to determine whether the probability of low and saturated pixels is correlated with solar or cosmic background.
- Low pixel values will continue to appear in timed-exposure bias maps, unless the median filtering feature is used. This entails setting *biasArg2 = n* in all timed-exposure parameter blocks. From evidence collected to date, an *n* value of 20 is appropriate.

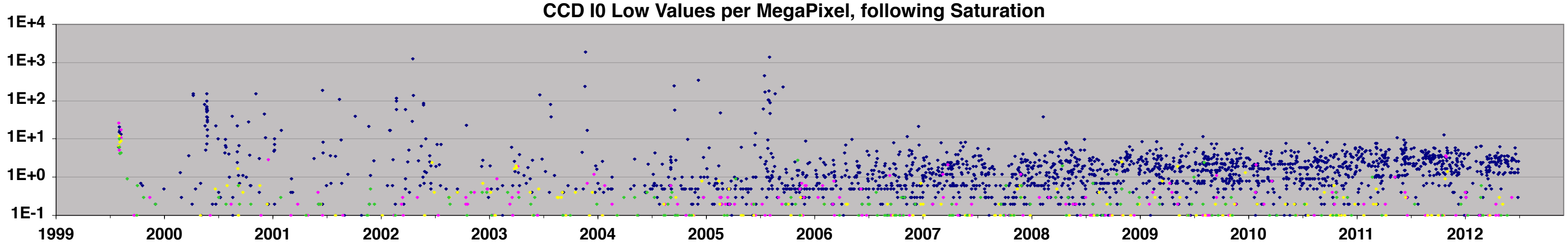
CCD I0 Low Bias Values per Map



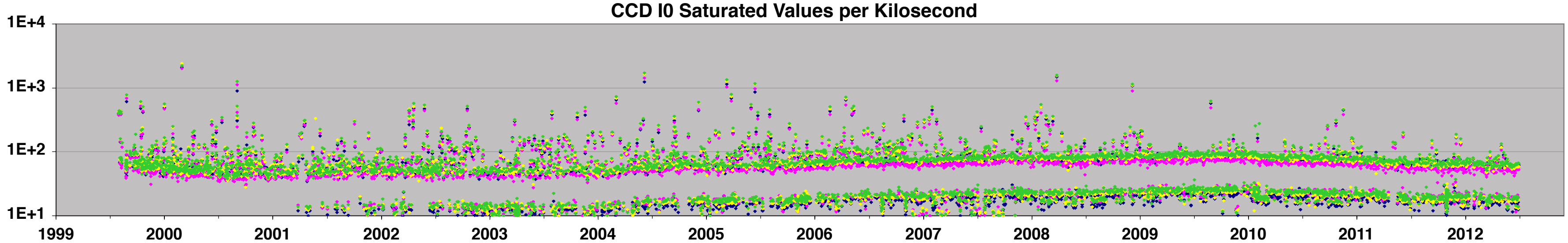
CCD I0 Low Values per MegaPixel, no Saturation



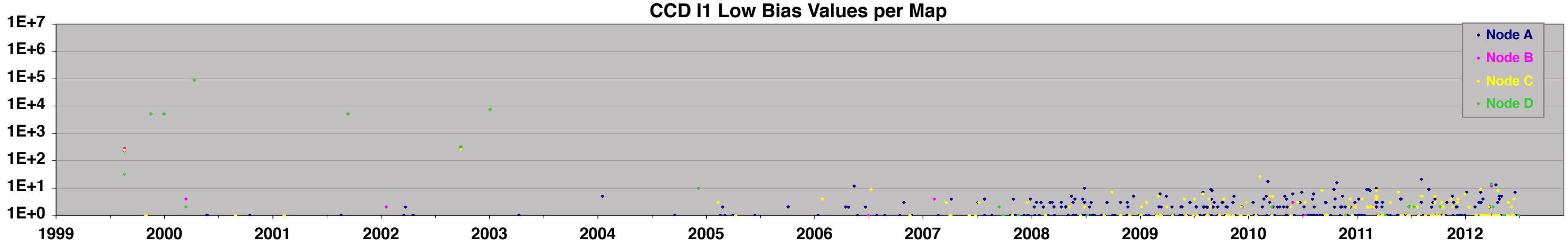
CCD I0 Low Values per MegaPixel, following Saturation



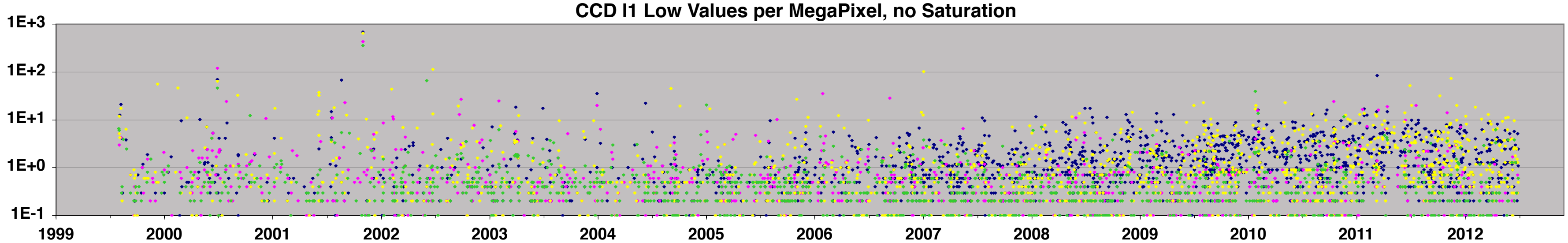
CCD I0 Saturated Values per Kilosecond



CCD I1 Low Bias Values per Map



CCD I1 Low Values per MegaPixel, no Saturation



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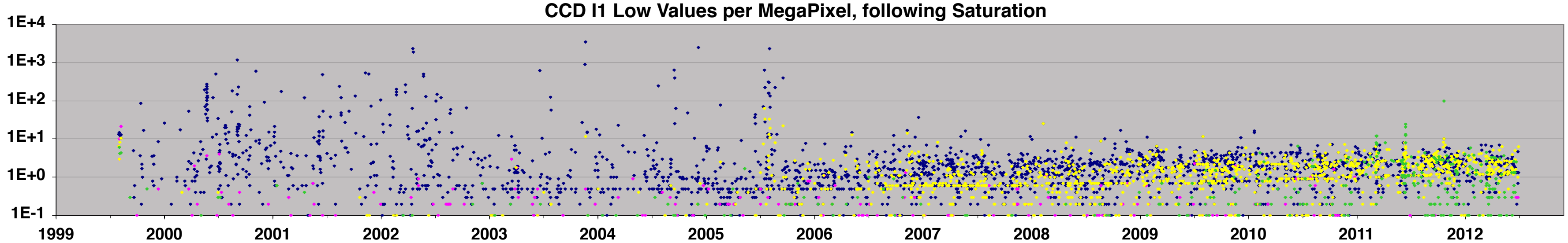
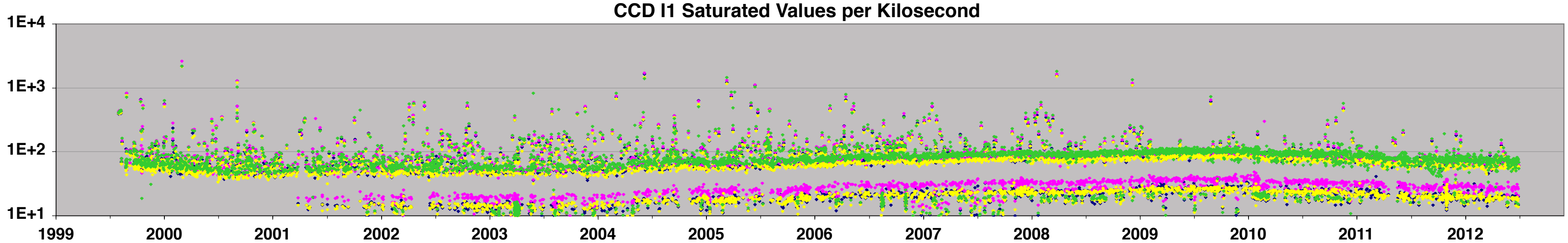
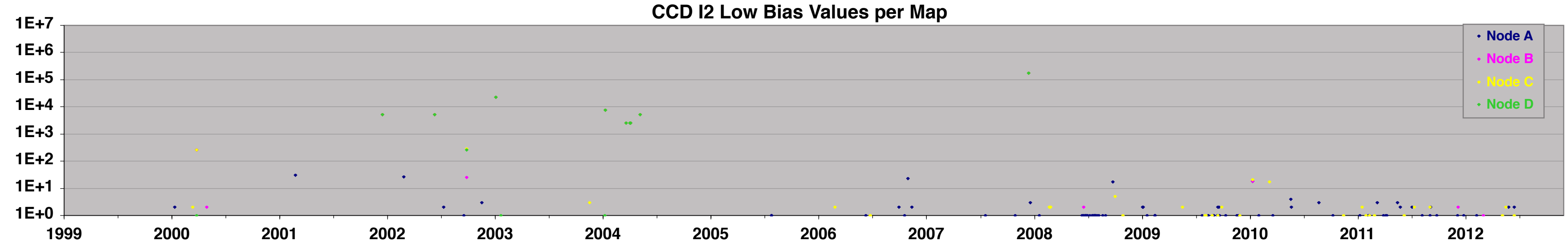
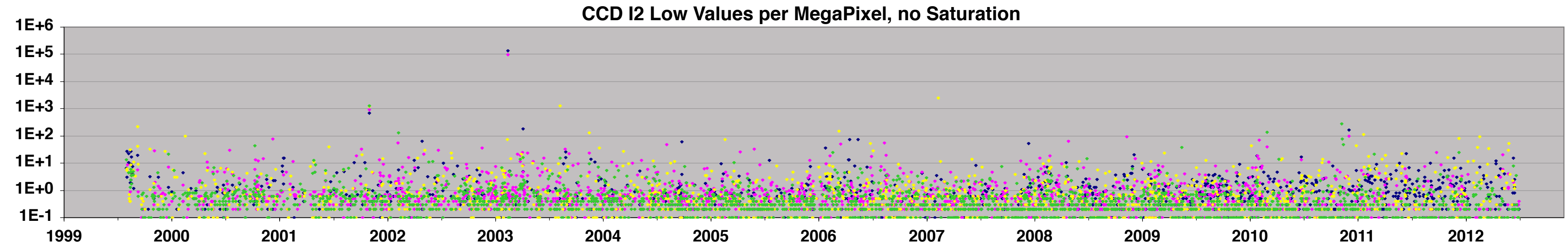
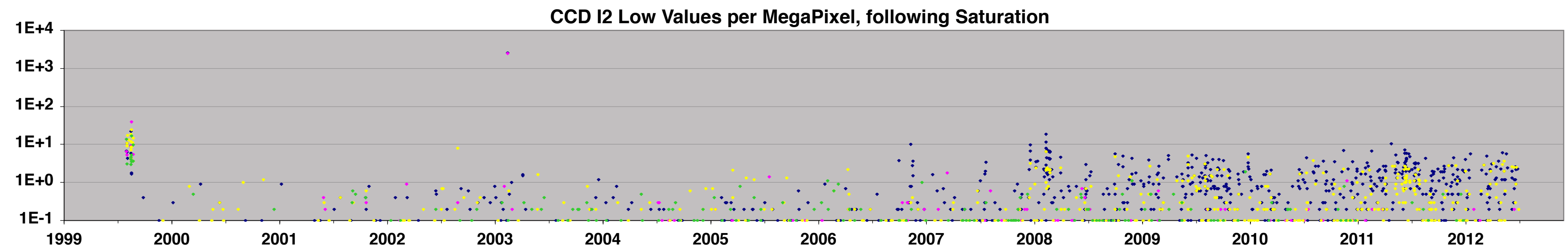


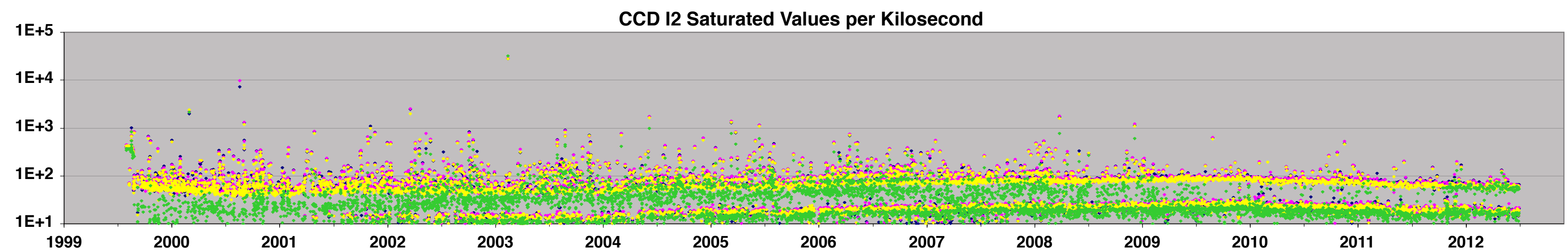
CCD I1 Saturated Values per Kilosecond



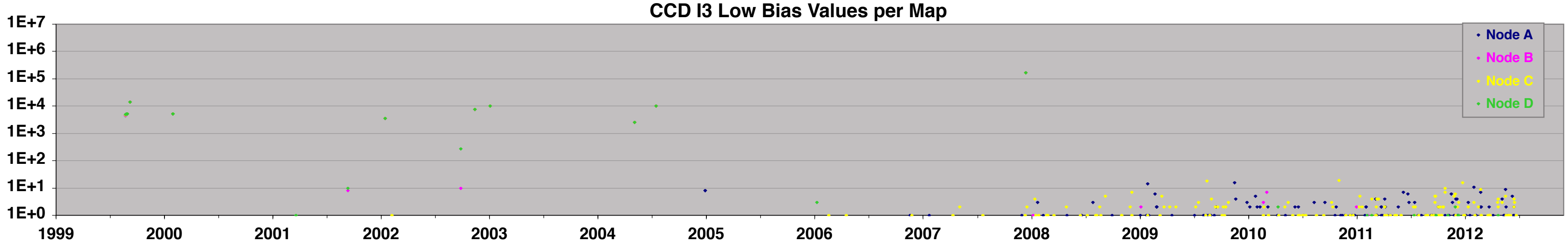

CCD I2 Low Bias Values per Map
1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Node A
Node B
Node C
Node D


CCD I2 Low Values per MegaPixel, no Saturation
1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


CCD I2 Low Values per MegaPixel, following Saturation
1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


CCD I2 Saturated Values per Kilosecond
1E+5
1E+4
1E+3
1E+2
1E+1
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

CCD I3 Low Bias Values per Map



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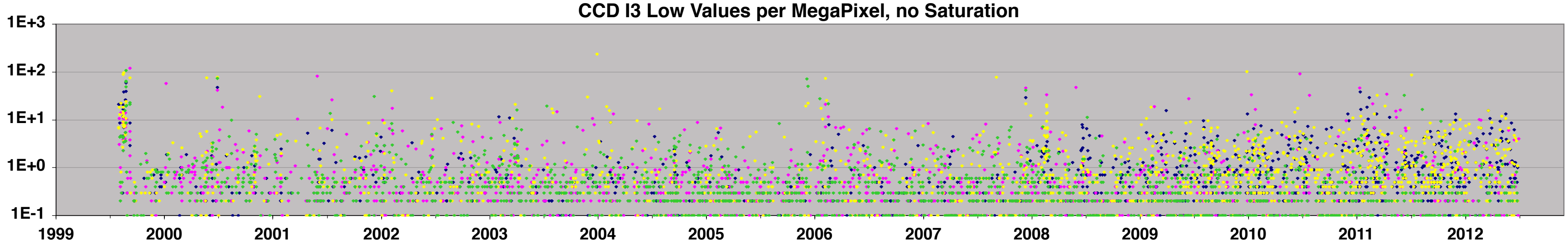

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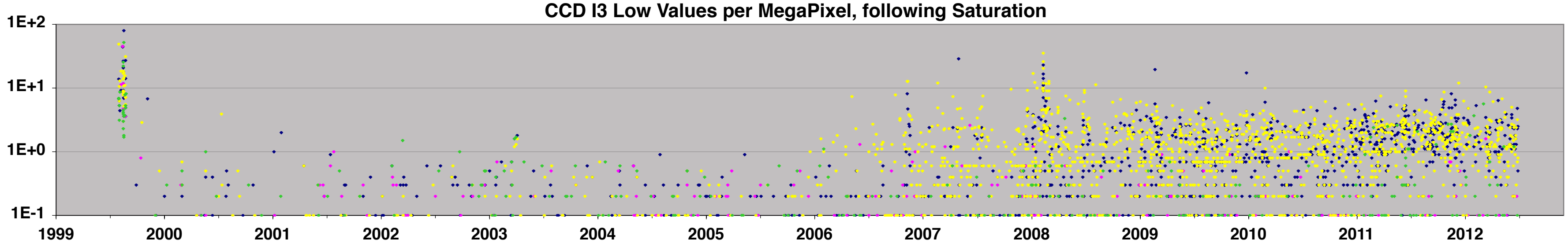
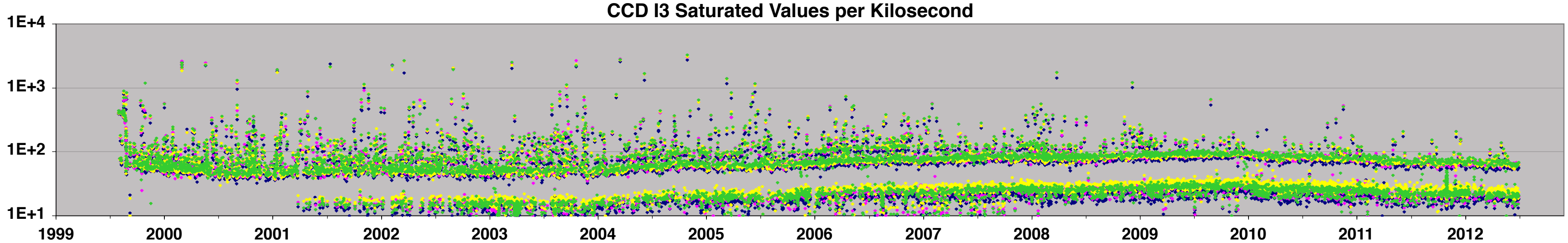
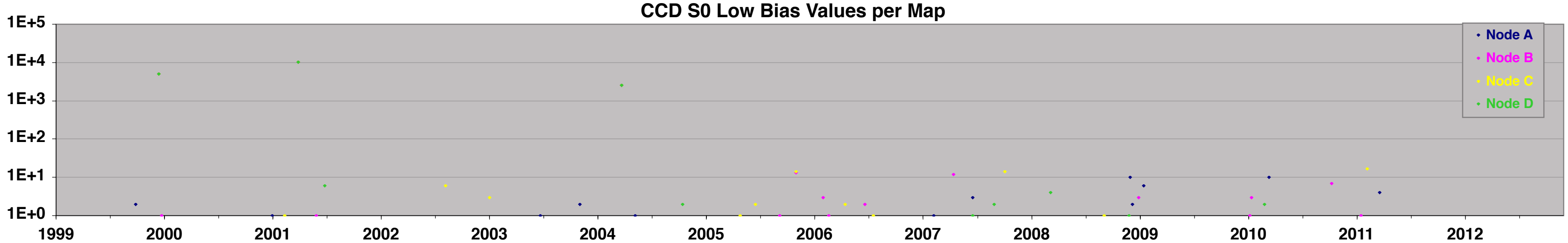


CCD I3 Saturated Values per Kilosecond



CCD S0 Low Bias Values per Map



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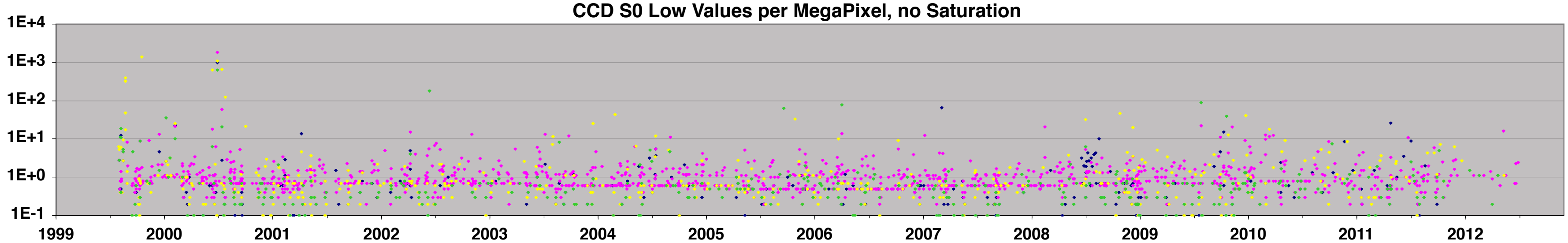

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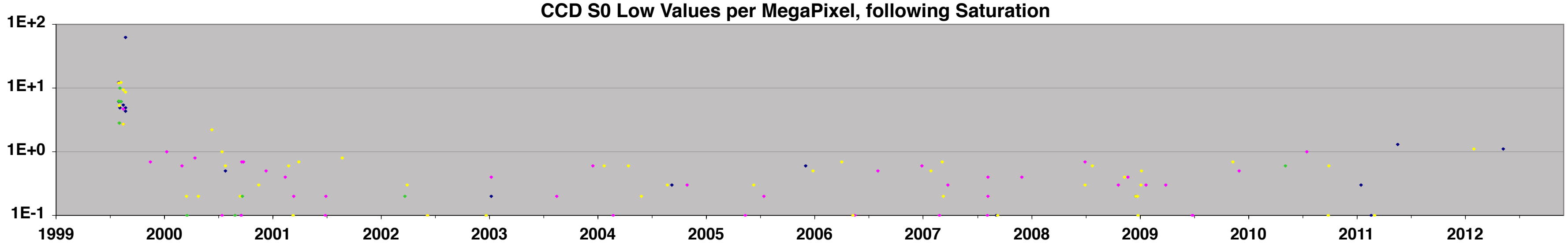
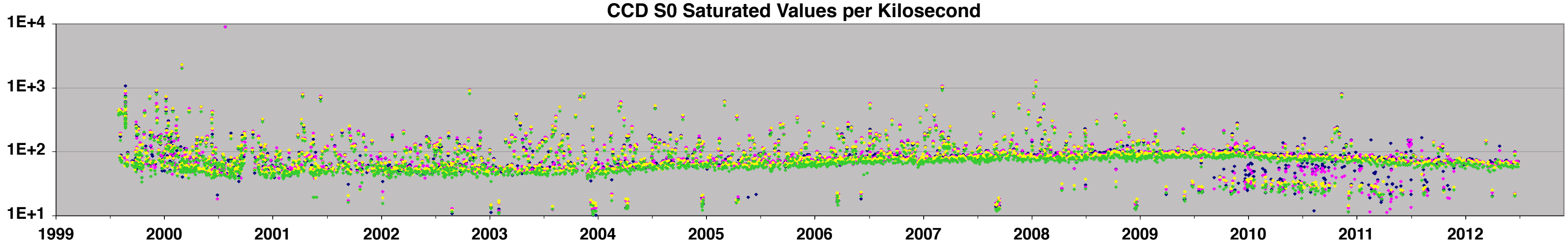
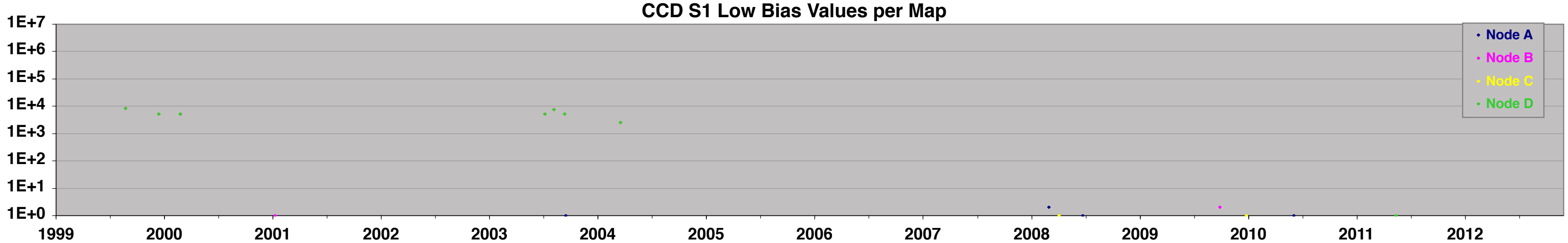


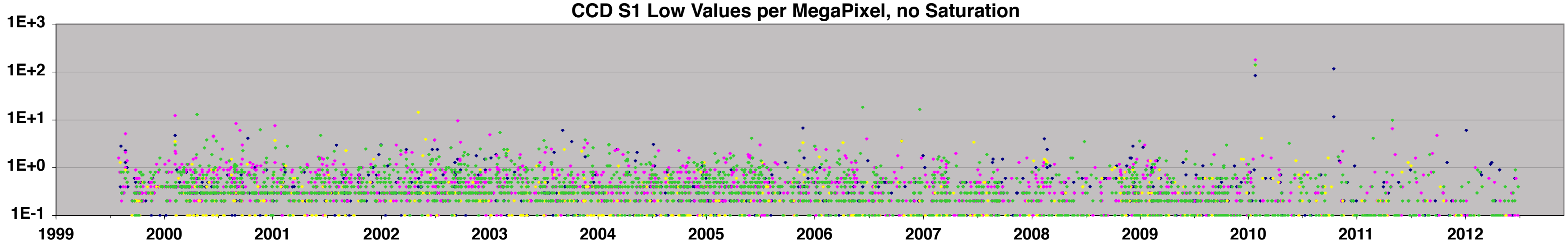
CCD S0 Saturated Values per Kilosecond



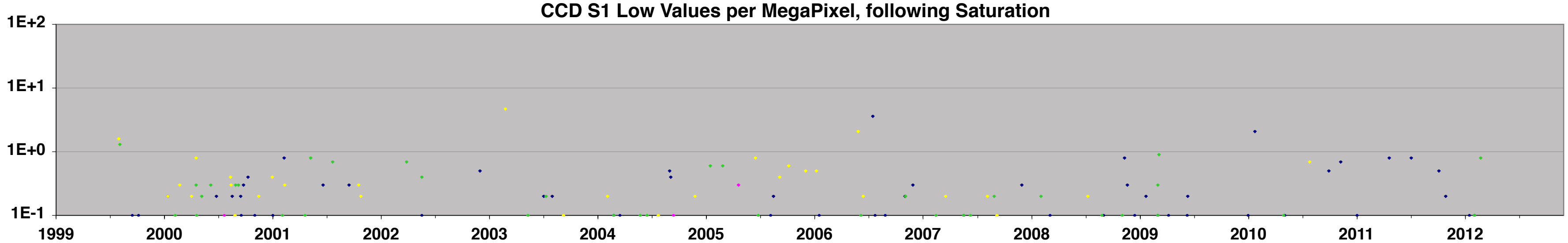
CCD S1 Low Bias Values per Map



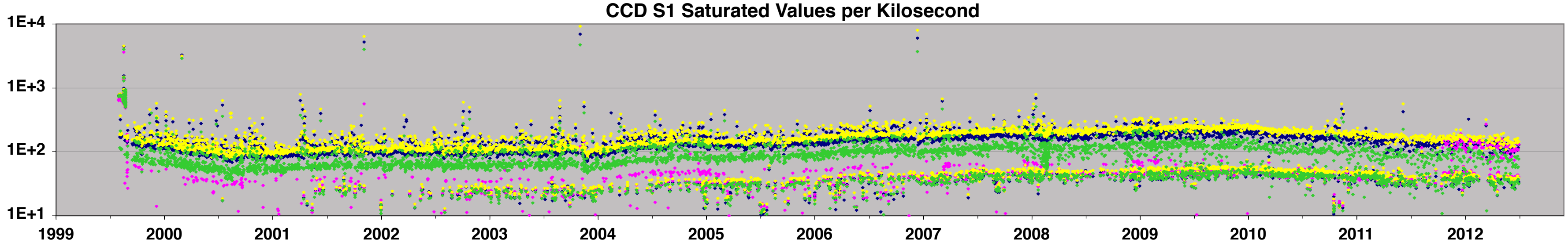
CCD S1 Low Values per MegaPixel, no Saturation



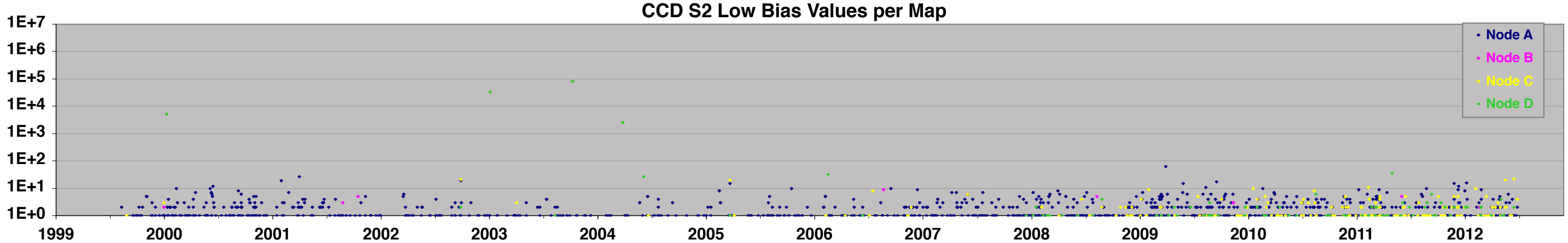
CCD S1 Low Values per MegaPixel, following Saturation



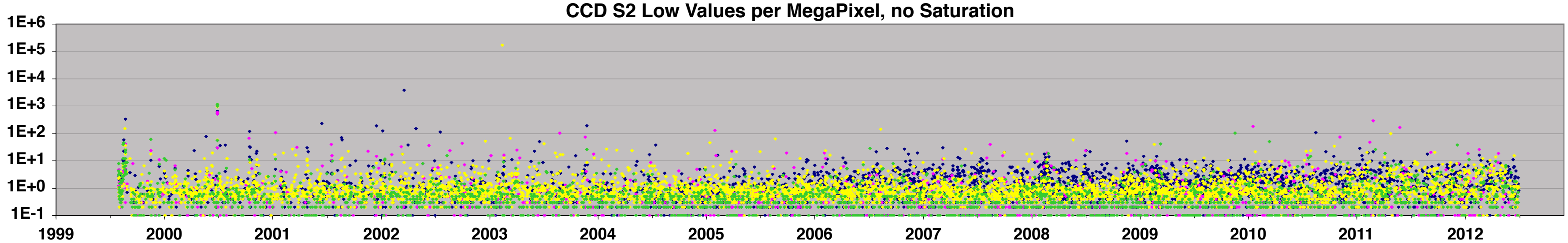
CCD S1 Saturated Values per Kilosecond



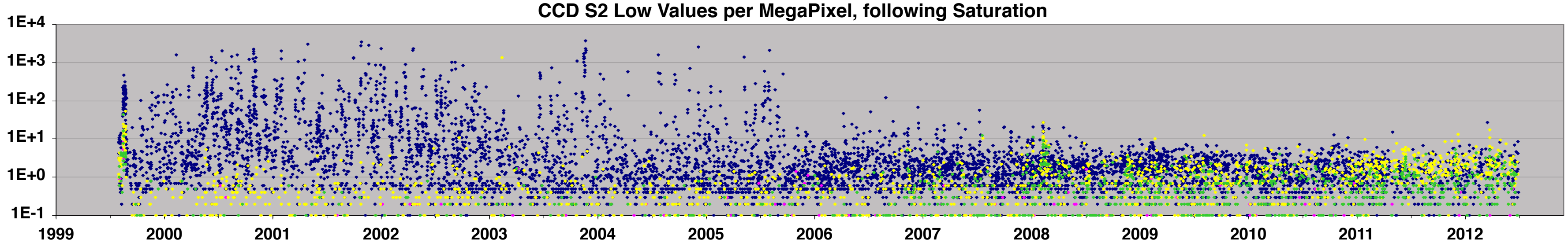
CCD S2 Low Bias Values per Map



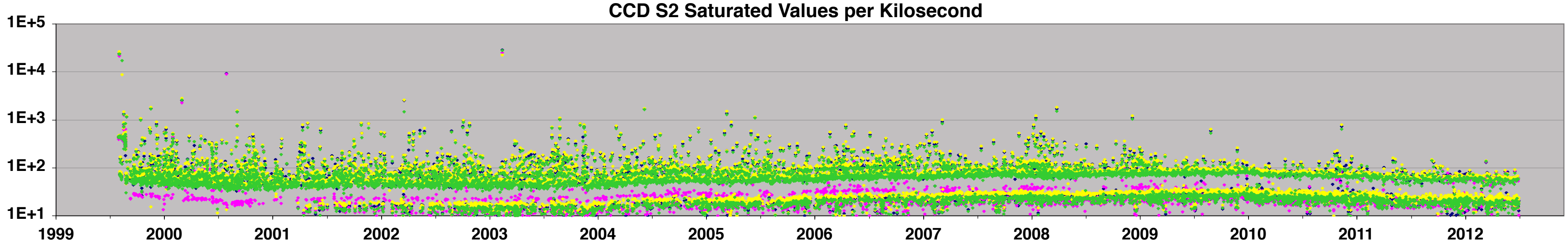
CCD S2 Low Values per MegaPixel, no Saturation

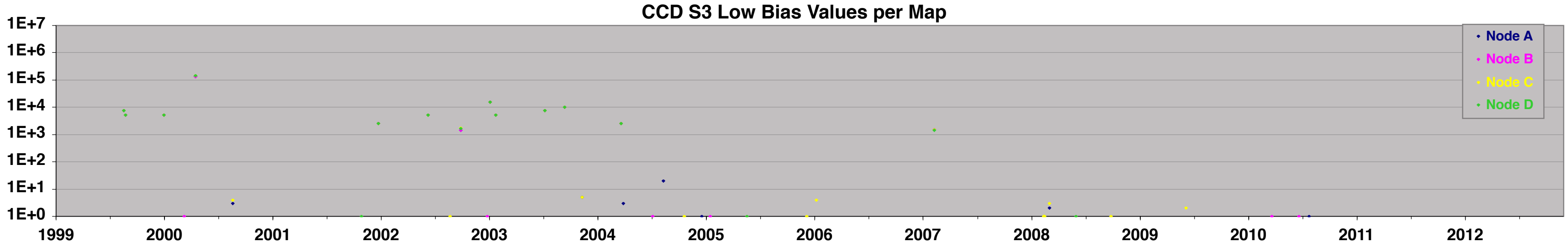


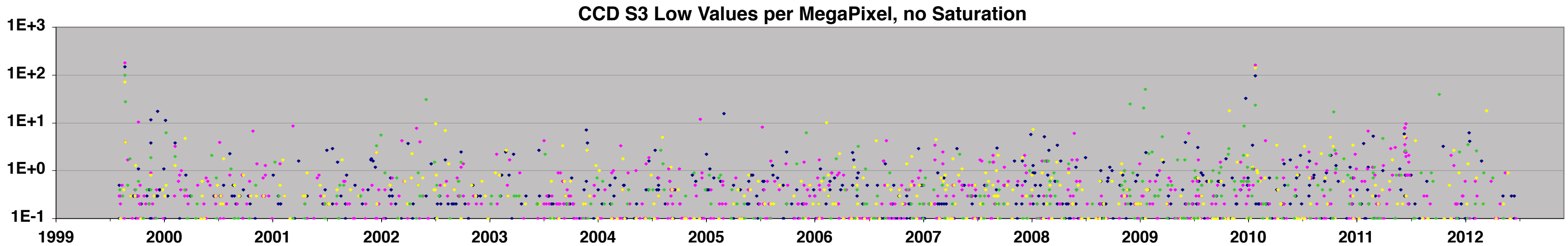
CCD S2 Low Values per MegaPixel, following Saturation

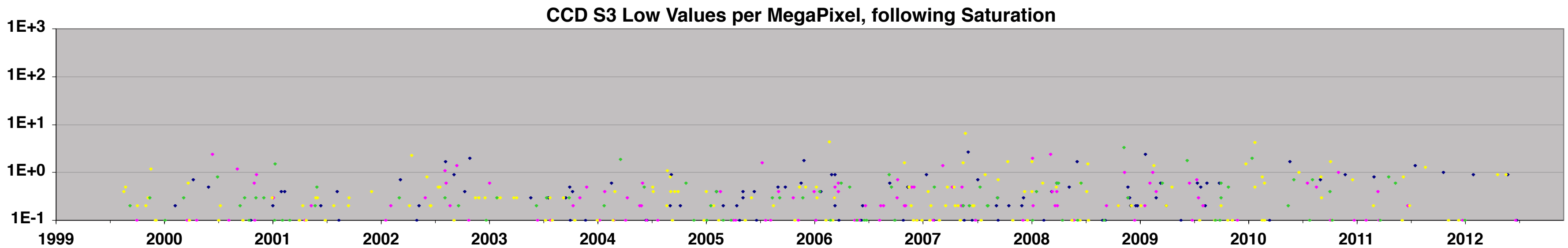


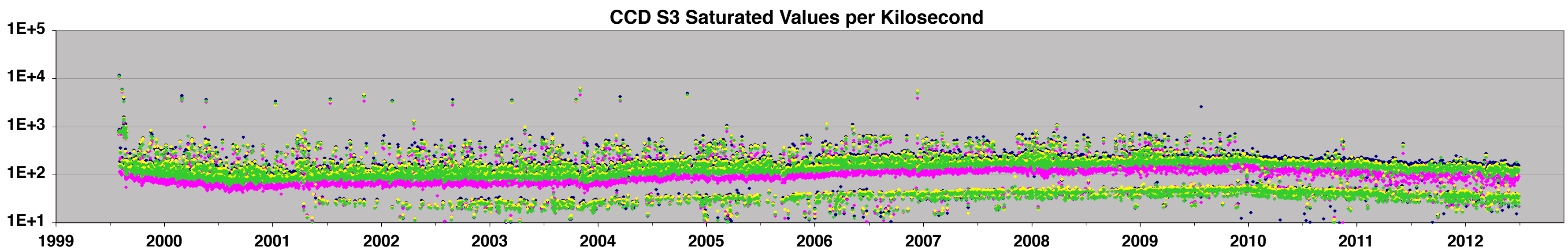
CCD S2 Saturated Values per Kilosecond



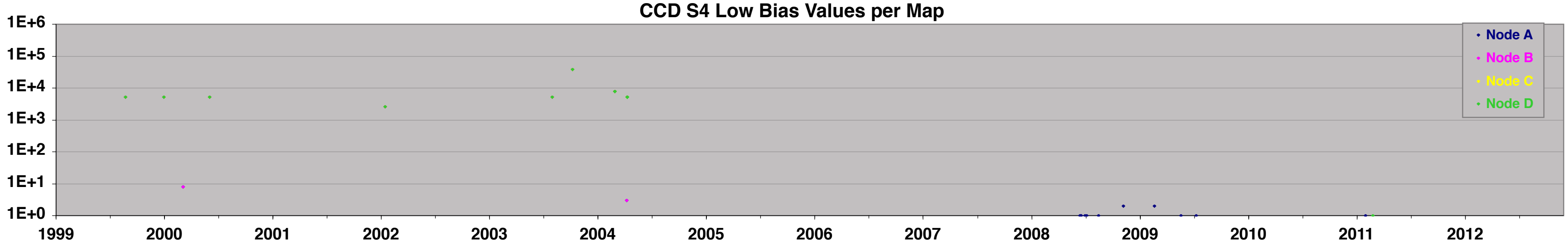

CCD S3 Low Bias Values per Map
1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
Node A
Node B
Node C
Node D
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


CCD S3 Low Values per MegaPixel, no Saturation
1E+3
1E+2
1E+1
1E+0
1E-1
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

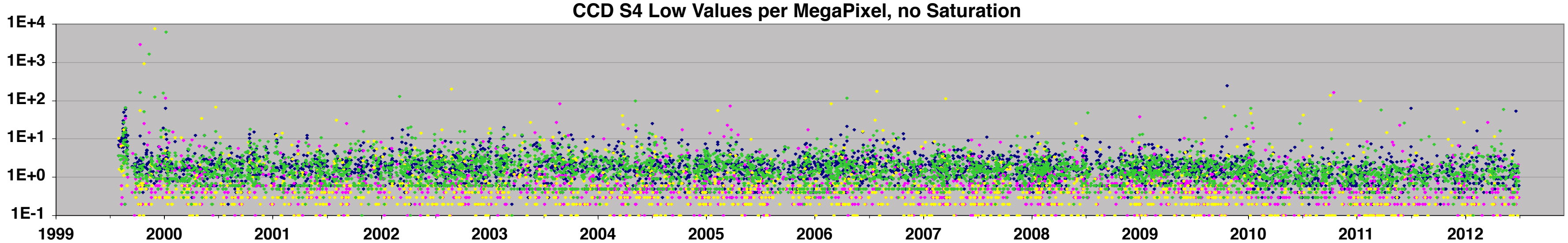

CCD S3 Low Values per MegaPixel, following Saturation
1E+3
1E+2
1E+1
1E+0
1E-1
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012


CCD S3 Saturated Values per Kilosecond
1E+5
1E+4
1E+3
1E+2
1E+1
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012

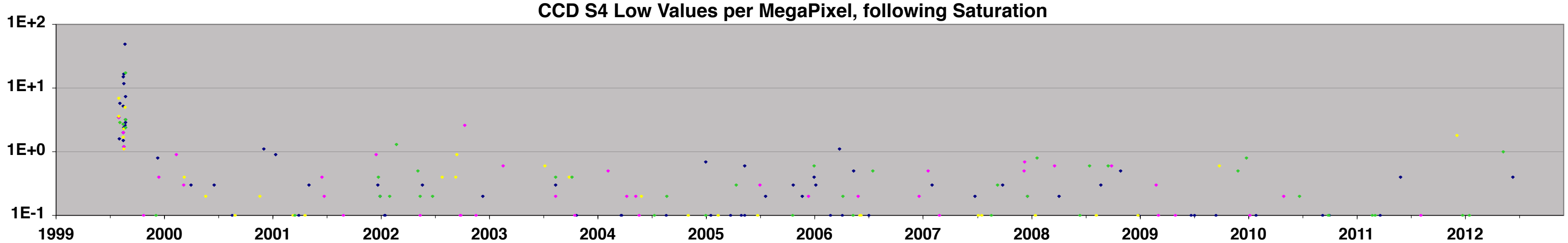
CCD S4 Low Bias Values per Map



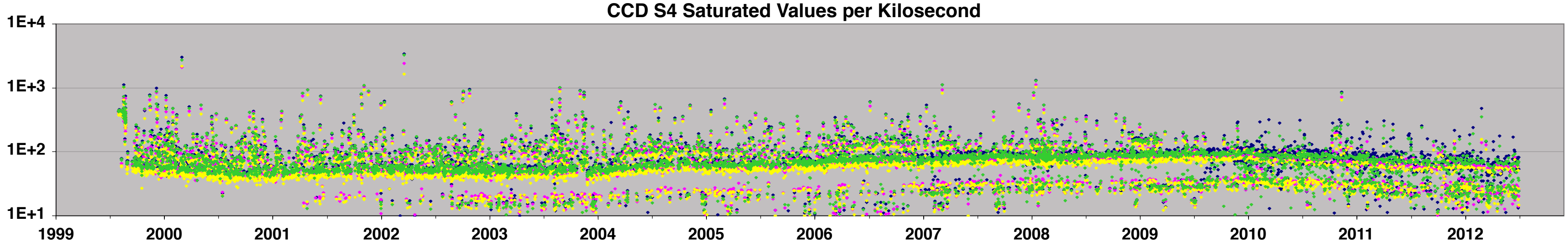
CCD S4 Low Values per MegaPixel, no Saturation



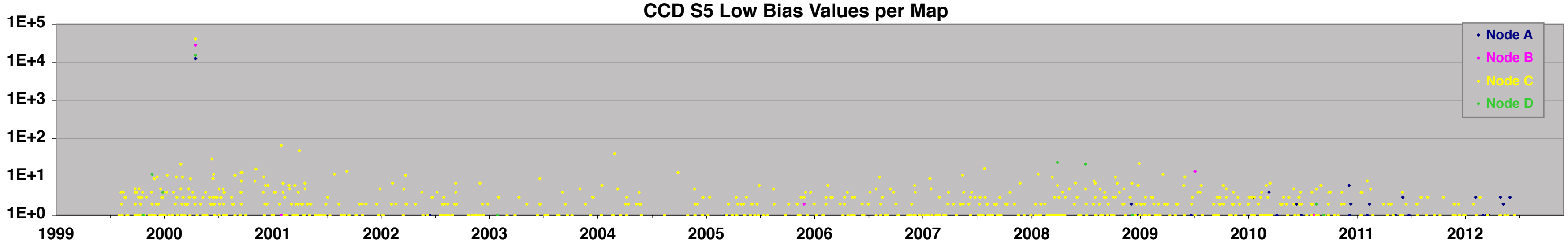
CCD S4 Low Values per MegaPixel, following Saturation



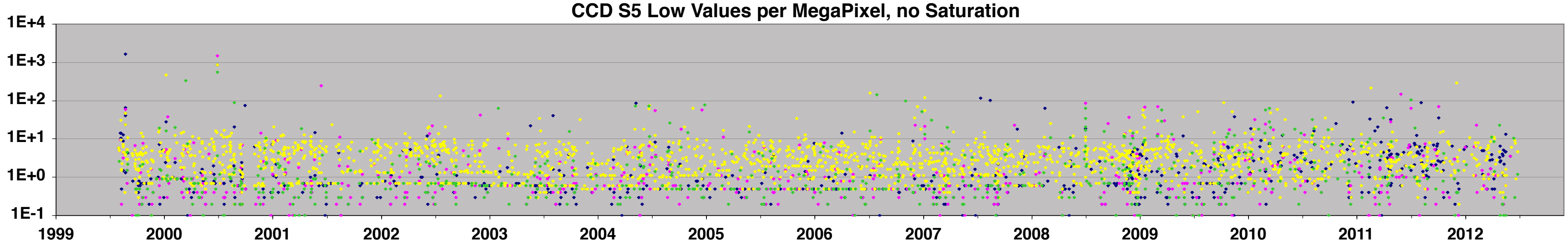
CCD S4 Saturated Values per Kilosecond



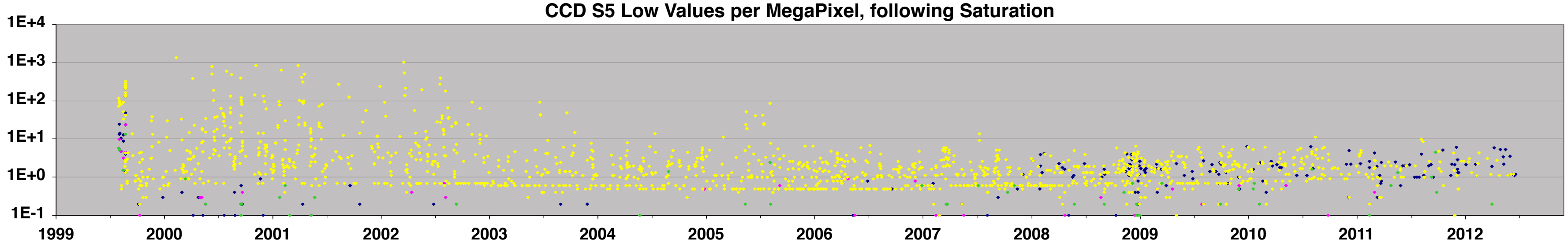
CCD S5 Low Bias Values per Map



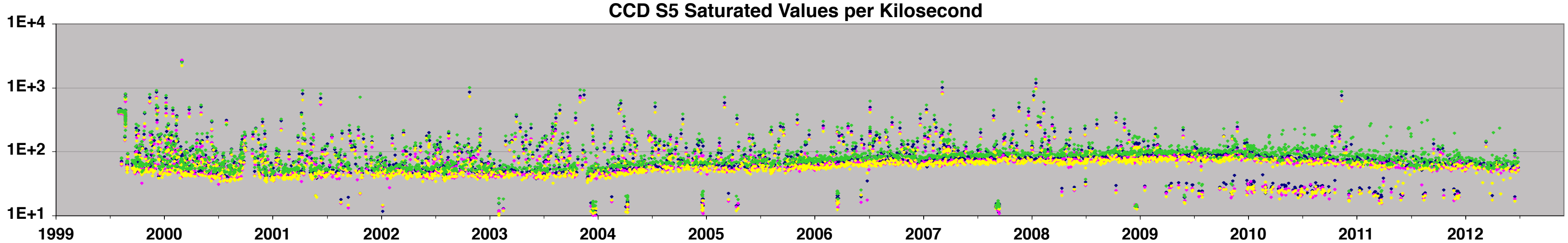
CCD S5 Low Values per MegaPixel, no Saturation



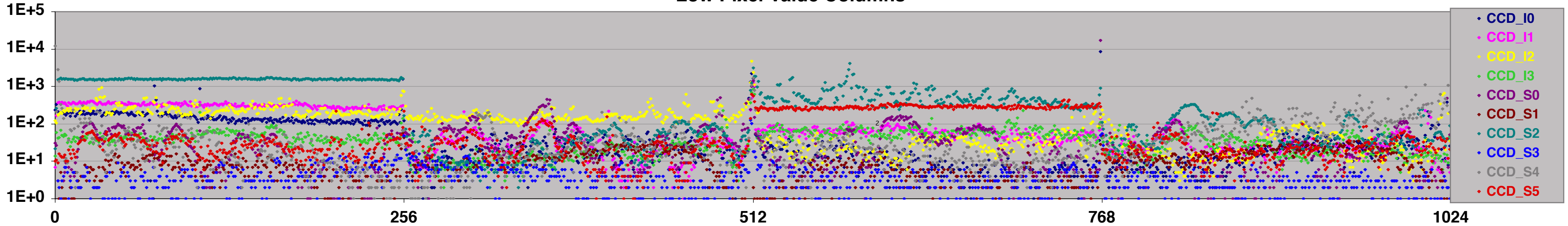
CCD S5 Low Values per MegaPixel, following Saturation



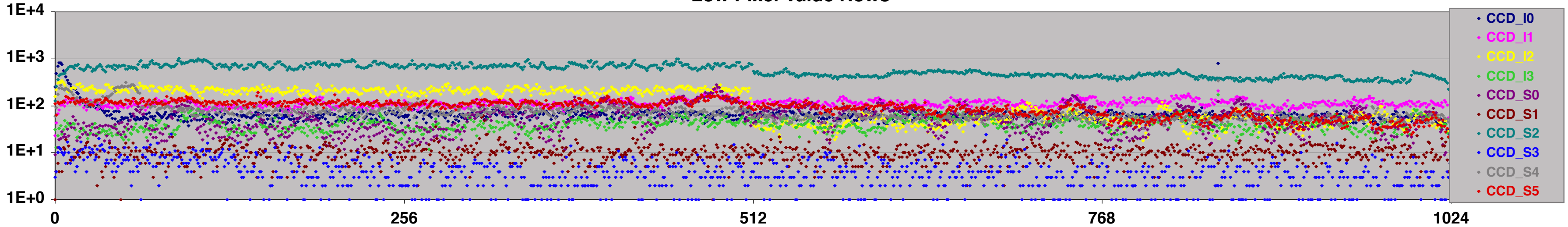
CCD S5 Saturated Values per Kilosecond



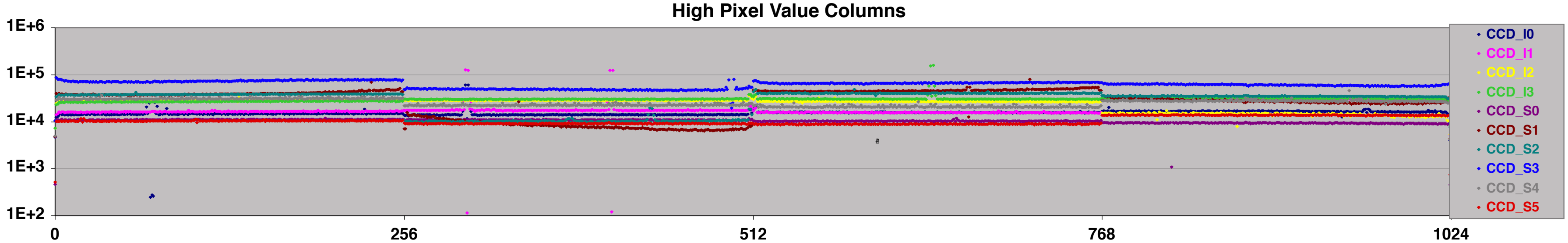
Low Pixel Value Columns



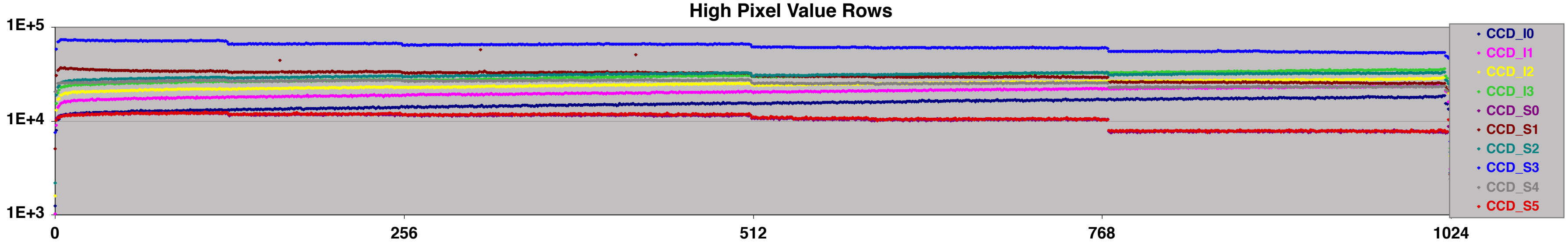
Low Pixel Value Rows

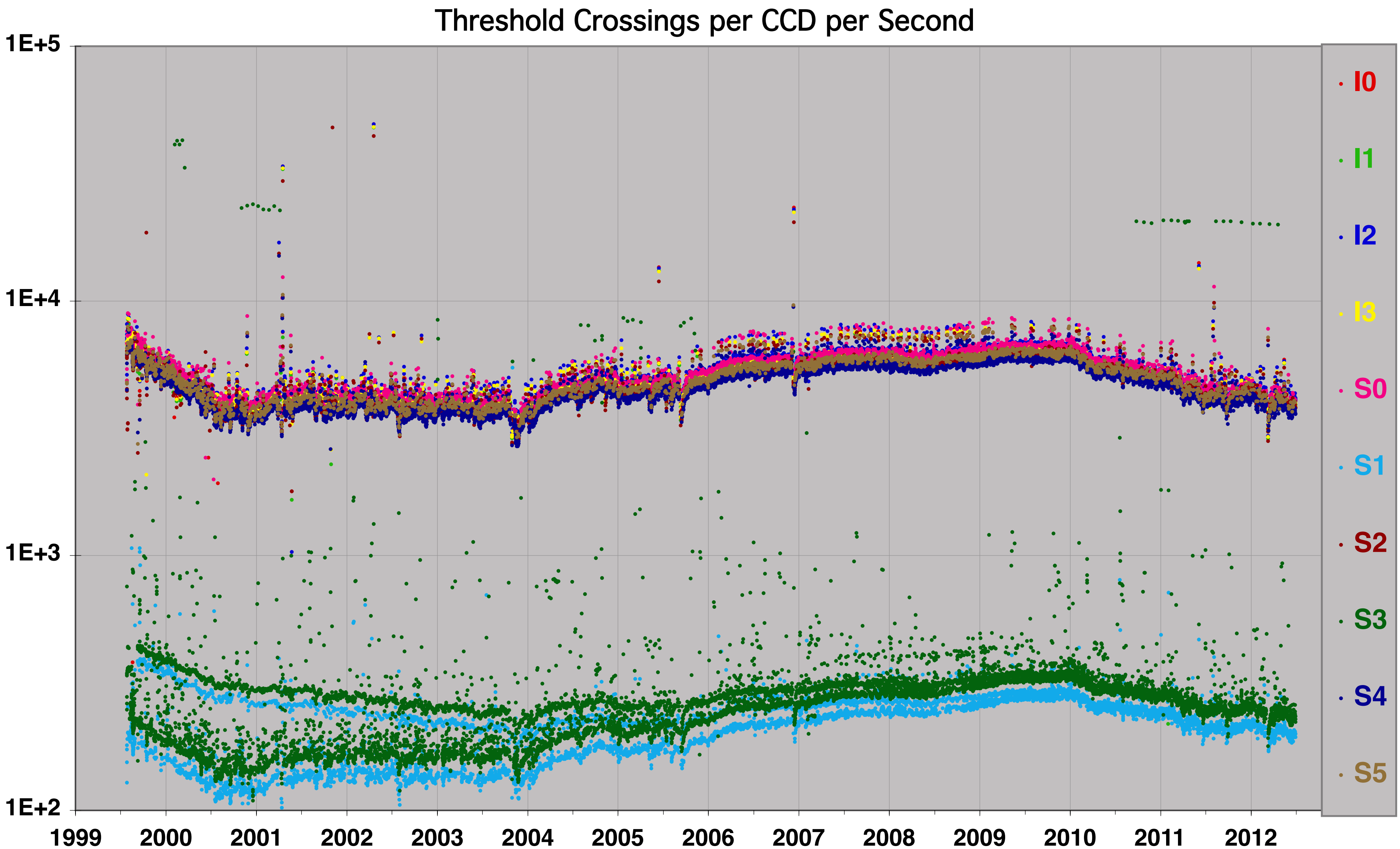


High Pixel Value Columns



High Pixel Value Rows




Threshold Crossings per CCD per Second
1E+5
1E+4
1E+3
1E+2
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
I0
I1
I2
I3
S0
S1
S2
S3
S4
S5