Outliers in minute trends for H1:ASQ-LSC-AS_Q and suggested vetoed times

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1 Introduction

I collected the minute trends for all six interferometer channels, and sensitivity and noise indicators in the web page `http://www.phys.lsu.edu/faculty/gonzalez/S2Trends/H1/`. The interferometer channels are H1:LSC-AS_Q ("gravity wave" channel, error signal of the differential arm length loop); H1:LSC-AS_I; H1:LSC-POB_I (error signal of recycling cavity length loop); H1:LSC-POB_Q (error signal of Michelson loop); H1:LSC-REFL_I (error signal of sum of arm lengths loop), and H1:LSC-REFL_I. The information in channel H1:LSC-AS_I is not well understood, except that is known to be very sensitive to alignment fluctuations; it is however used in a servo loop that feeds back to the electronic signal (not to mirror positions). The channel H1:LSC-REFL_Q has in principle only information on residual Michelson length, but again it is not well understood and observed to be sensitive to alignment fluctuations. This channel is not used as an error signal, so the mean value is not close to zero.

The other channels included are H1:LSC-LA_PTRT_NORM, H1:LSC-LA_PTRR_NORM (proportional to arm powers in the X and Y arms, respectively), H1:LSC-LA_SPOB_NORM (proportional to sideband power in the recycling cavity), and H1:LSC-AS_DC (proportional to DC power in the antisymmetric photodiode). The signal of the gravitational wave is in principle proportional to $\sqrt{(PTRT + PTRR) * SPOB}$; the shot noise in the gravitational wave signal is proportional to AS_DC. It is not clear that the SPOB signal in H1 is a faithful follower of the sideband power in the recycling cavity over time scales of hours (due to the drift of the beam on the photodiode); however the fluctuations with shorter time scales are probably good indicators of the changes in the sideband power.

Each of these channels (and of all DAQ channels in general) is "minute trended", which means that for every minute, the mean value and the maximum and minimum values during that minute are stored on disk, labeled by the GPS time of the beginning of the trended minute. The analysis presented here is based on the minute trends of these channels, considered only at times when the interferometer was in "science mode", as indicated by the minimum value of H1:IFO-SV_STATE_VECTOR during that minute being 65534. The minute trends were retrieved using DataViewer.

Finally, two other time series were retrieved, produced by SenseMon: H1:LSC-Range_kpc, indicating the range of the interferometer to binary neutron systems with average orientation; and H1:LSC-CalLine_Ampl_ASQcounts, indicating the amplitude of the calibration line at 9XX Hz. These quantities are calculated once per minute, and saved in frame files that can also be retrieved with DataViewer.

The time series and histograms of the interferometer channels are presented in Figs. 1-5.

2 Outliers in H1:LSC-AS_Q

The histogram of the peak to peak values in H1:LSC-AS_Q minute trends is shown in Fig. 6. The median value is 46 counts; the largest and smallest values are 769 counts and 32 counts, respectively. I fitted a straight line to the log-log plot of the histogram between 60 and 100 counts. If we assume the distribution of large values would follow this straight line, then values above 160 are "outliers", as shown in the lower panel of Fig. 6. There are 71 such points in the minutes trended. It is apparent, however, that there is an excess of minutes with peak-to-peak ASQ values larger than 140 counts. We define as "ASQ outliers" the minutes when the ASQ peak to peak value is larger than 140.

There were 60,239 points (minutes) in the times series trended, or a total of a 1004 hours. This does not include some science mode times in S2 for which the trend was unavailable; and in general does not include

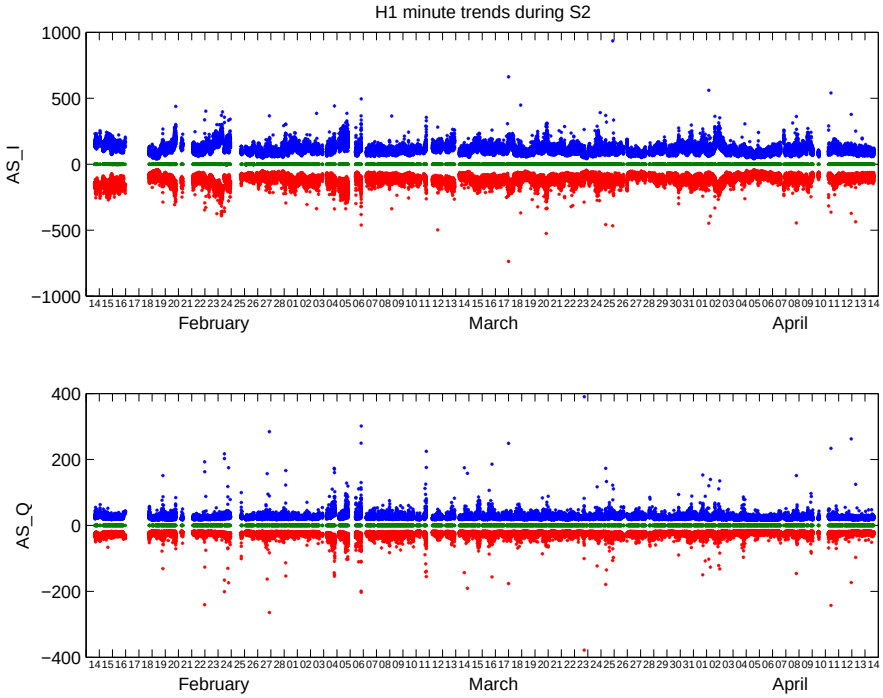

Figure 1: Minute trends of H1:LSC-AS_I and H1:LSC-AS_Q in science segments during S2.

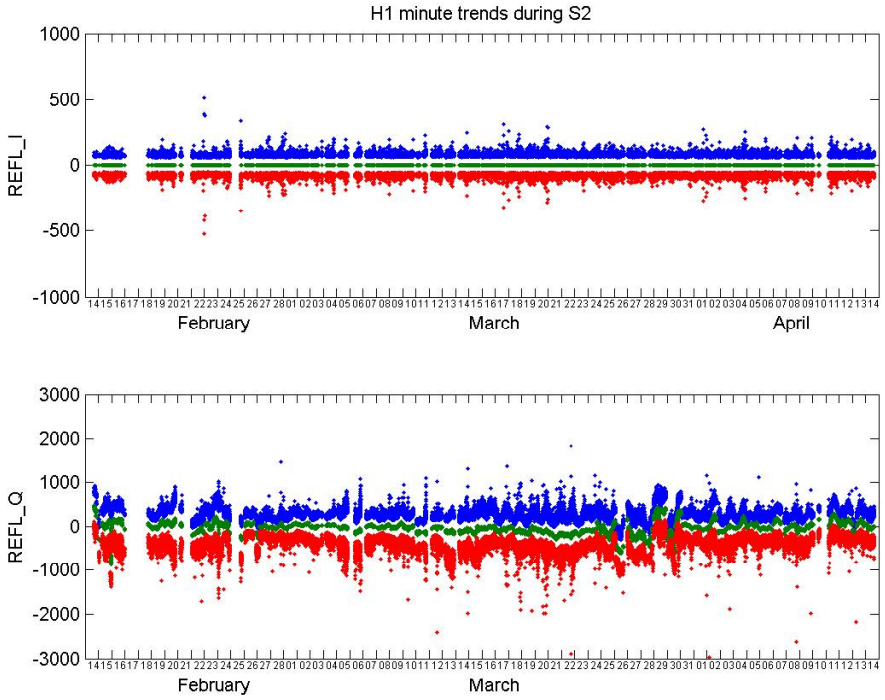

Figure 2: Minute trends of H1:LSC-REFL_I and H1:LSC-REFL_Q in science segments during S2.

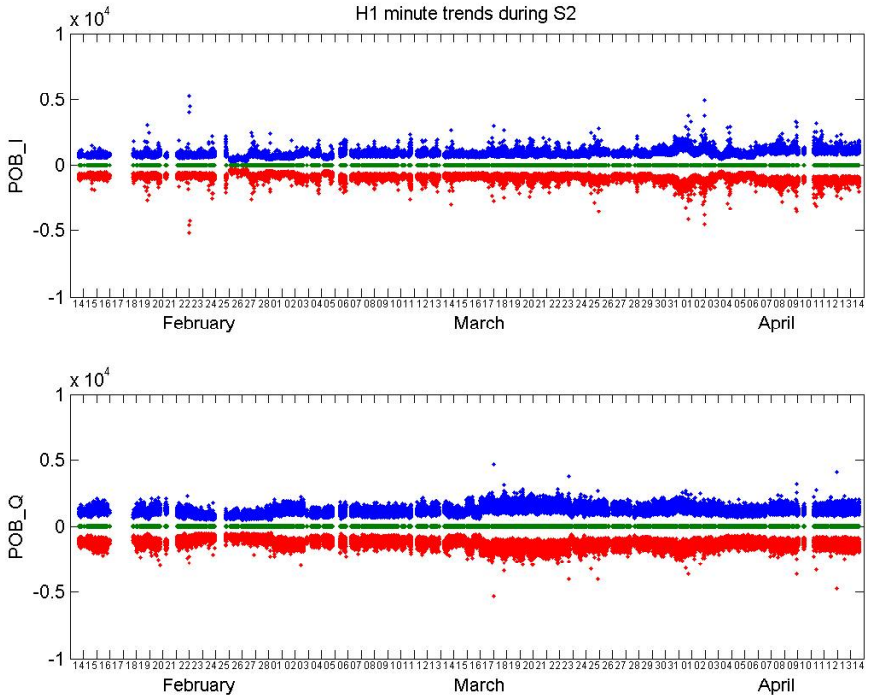

Figure 3: Minute trends of H1:LSC-POB_I and H1:LSC-POB_Q in science segments during S2.

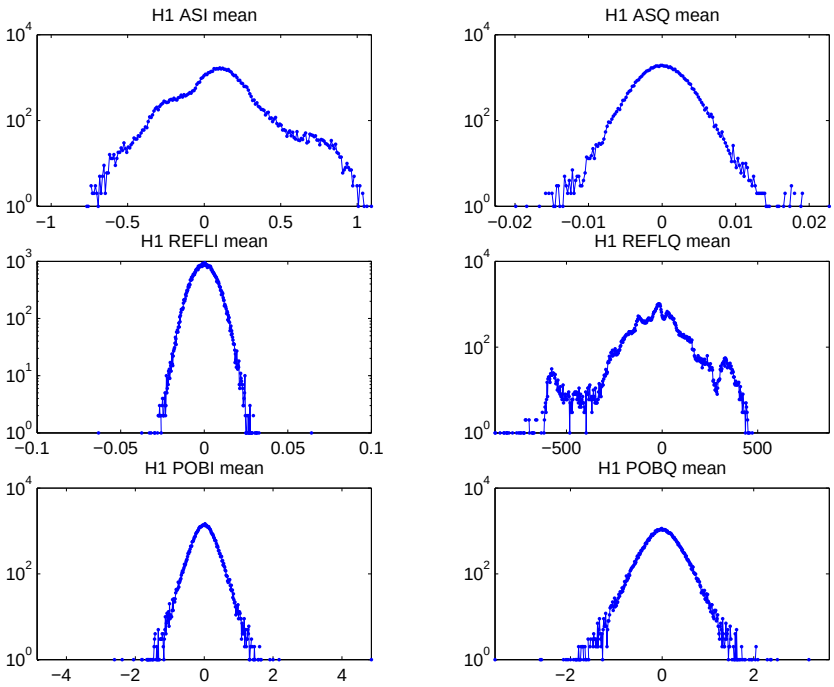

Figure 4: Histogram of mean values of minute trends of H1:LSC-(AS_I, AS_Q, POB_I, POB_Q, REFL_I, REFL_Q) during S2 science segments.

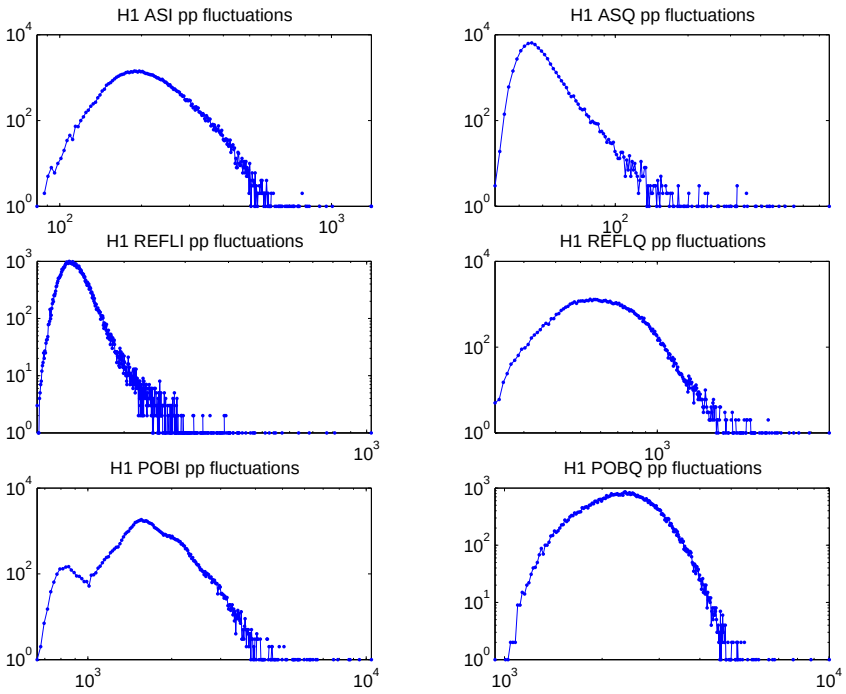

Figure 5: Histogram of peak-to-peak (max-min) values of minute trends of H1:LSC-(AS_I, AS_Q, POB_I, POB_Q, REFL_I, REFL_Q) during S2 science segments.

as much as 59 seconds at the beginning or the end of a science segment, since the trends are produced at 60 second intervals not necessarily coincident with the start or end of science segments. The 102 outliers defined above constitute 0.17 % of the time analyzed.

I have made plots of science segments containing ASQ peak to peak values larger than 140 in `http://www.phys.lsu.edu/fa` ordered y the magnitude of the outlier. The time of the outlier is indicated in all of the trend of the interferometer channels. From these plots, one can classify the outliers in the following categories:

- Clustered outliers: several outliers in consecutive minutes; or one minute apart.
- Correlated outliers: outliers simultaneous (within the one minute correlation) with glitches in other channels. A "glitch" is loosely defined as a value in the peak-to-peak minute trend which is significantly higher than the few previous and following minutes, and/or significantly higher than the average in that segment. **We propose to veto the minute containing the outlier in the ASQ minute trend, when a glitch is seen in the same minute in at least another interferometer channels, not being ASI**.
- ASQ-only outliers: a large, outlier, peak-peak value in ASQ, not coincident with glitches in the minute trends of any other of the channels investigated.

We describe in the following sections each of these categories, and propose associated vetoed times for S2.

3 Clustered outliers

If the outliers were randomly distributed in time, we expect a mean interval of 590 minutes, or 9.8 hours, between outliers. We are thus suspicious of outliers happening in the same locked segment, although we have not made a detailed study of the expected statistics. However, there are some obvious clusters observed in the times analyzed, that lead us to propose the following vetoed times:

3.1 Science Segment #96

Twelve of the 102 minute trends when ASQ peak-to-peak exceeded 140 counts were in the last 27 minutes of this segment, shown in Figs 7 and 8. There is obvious deterioration of the sensitivity, probably due to a drift in alignment. A note in the elog (Mar 6, 13:56, by Vorvick) notices the deterioration and eventually loss of lock due to increasing winds. All the power indicators (PTRR, PTRT, SPOB and ASDC) grow increasingly worse starting at the time of outlier #80, 731015100. The increased noise is also obvious in ASI, and also (but less so) in POBI, POBQ, and REFLQ.

We propose to veto the times 731015100 - 731016696, from the beginning of the minute outlier #80 until the end of the segment.

3.2 Science Segment #95

In segment #95, 730892713-730931930, there are 11 outliers, all in the 5 hours making the second half of the segment. Four (#69,90,83,70) are clustered in 12 mins; two (#88,91) are 4min apart, the rest are at least 18min apart. SPOB is significantly worse in the second half of the segment. ASI is noisier in this segment than normal.

The earlier cluster of outliers (#69,90,83,70), happening between 730913940 and 730914720, are coincident with increased peak-peak minute trends in POBI, REFLQ, SPOB and ASDC. These outliers are also coincident with glitches in ASI. After this cluster, the statistics of the ASQ trends is qualitatively different from the earlier time in the segment, as shown in Fig. 9.

This segment was separated from #96, described in the previous section as containing many clustered outliers, by 12 hours of non-locking time due to high winds.

We propose to veto the times 730913940 - 730931930, from the beginning of the minute outlier #69 until the end of the segment.

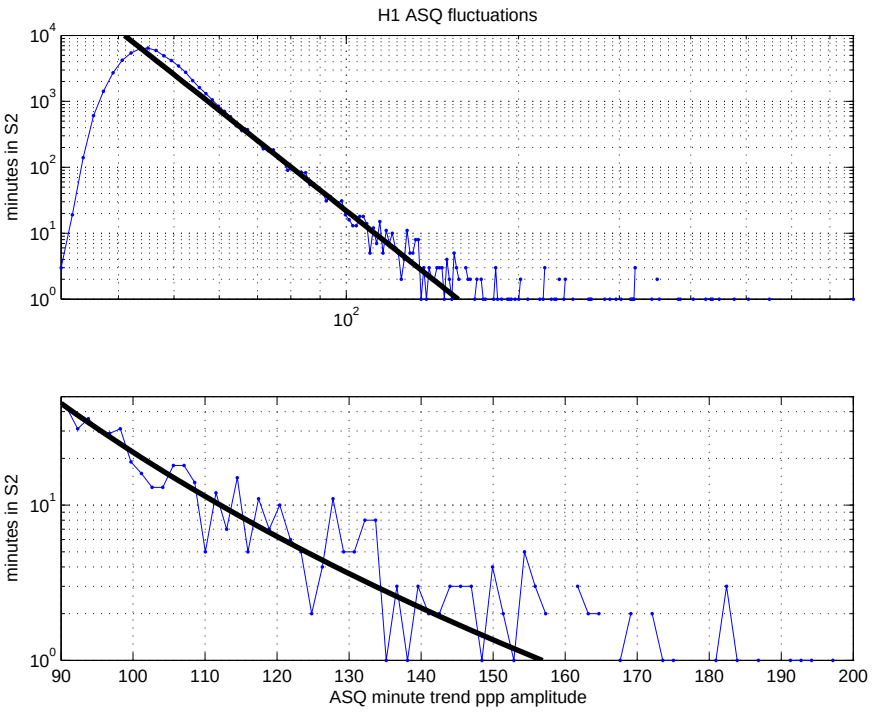

Figure 6: Histogram of peak-to-peak (max-min) values of minute trends of H1:LSC-AS_Q during S2 science segments. A log-log fit with a linear function for the histogram between 60 and 100 counts is also shown.

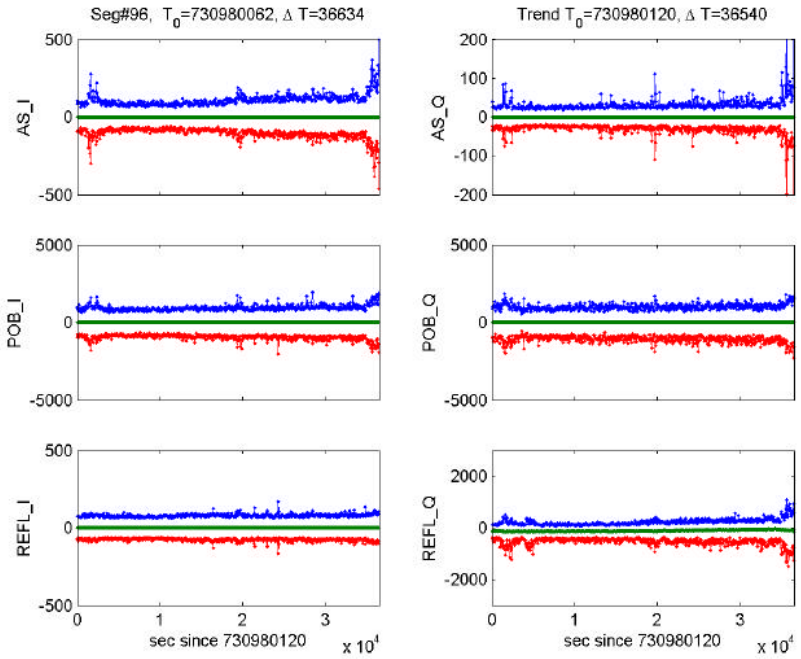

Figure 7: Minute trends for the interferometer channels in Science segment #96, containing 12 ASQ outliers in the last 27 minutes.

3.3 Science segment #90

There are 12 outliers (#65,52,100,20,93,16,49,22,59,57,75,45) in this segment, 15 hrs long. Four of them (#16,49,22,59) are in a 9 min interval, 91 min before the end of the segment. Another cluster of three (#57,75,45) are in consecutive minutes, 20 minutes after the first cluster. Outlier #93 is 16min before the first cluster; and #20 is 18 minutes before #93. The rest of the outliers (#65, 52, 100) happen much earlier and far part. Outlier #16 is the largest and earliest of the 9min-cluster. All the outliers except the smallest in this cluster are also seen in ASI, POBI and REFLI. The outliers in the other cluster are not seen in other channels.

We propose to veto the times 730841760 - 730842300, corresponding to the 9-min cluster containing four outliers, also seen in ASI, POBI and REFLI.

3.4 Science Segment #104

Six outliers in this segment (#11, 21, 31, 35, 46, 84). Three outliers (#84, 11, 21) in the last 4 minutes of the segment. The rest (#46, 35, 31) happened more than 54min before the noisy end and more than 30 minutes apart; they are probably unrelated to the end glitches.

The end of the segment is obviously deteriorating, as seen not only in ASQ but in ASI, POBI, REFLQ and most visible in ASDC. It looks like the deterioration started previous to outlier#84, but the values in ASQ are not large enough to be in the defined set of outliers.

We propose to veto the times 731442360 - 731442641, from outlier #84 until the end of the segment.

4 List of outliers

The tables below has a complete list of the outliers, with the following color code:

- red are part of the clusters described above;

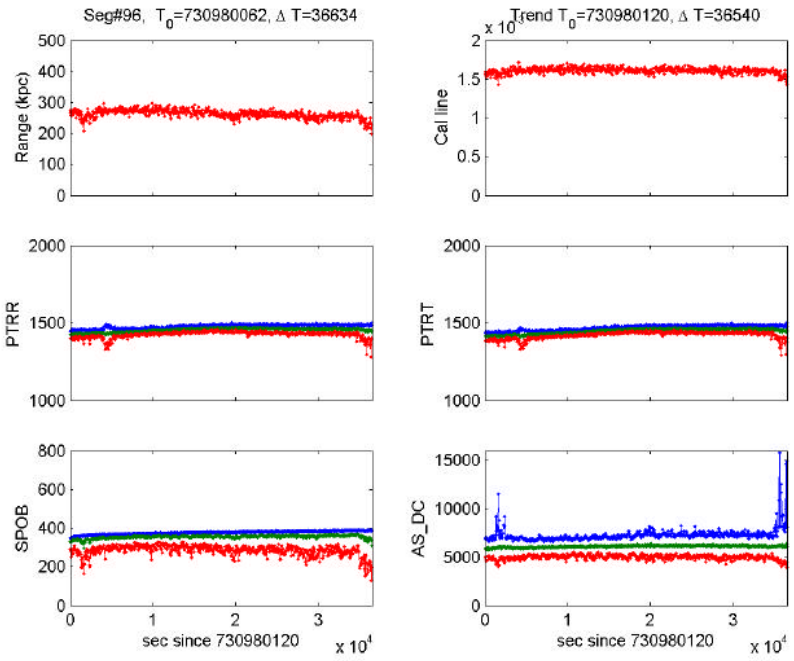

Figure 8: Minute trends for BNS range, calibration line, power in the arm cavities, sideband power in the recycling cavity and DC power in the antisymmetric photodiode for Science segment #96, containing 12 ASQ outliers in the last 27 minutes.

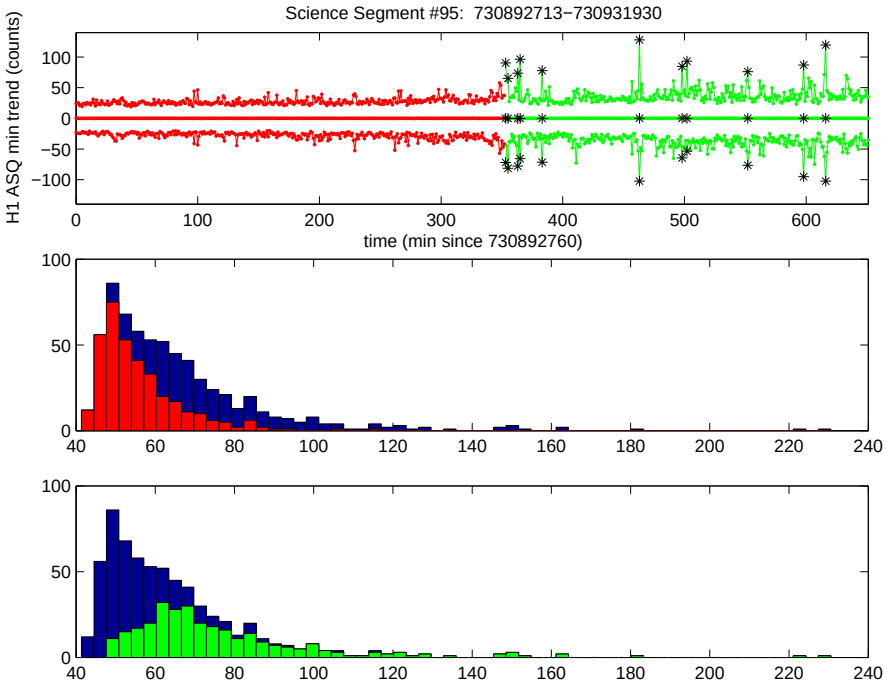

Figure 9: Upper panel: H1:LSC-AS_Q minute trends for Science Segment #95. The outliers (peak to peak values exceeding 140) are shown with stars. The histogram f the peak-to-peak values before the first outlier is shown in the second panel, and the histogram for the peak-to-peak values after the first outlier are shown in the lower panel. The background histogram in both lower panels is the histogram of the whole segment.

- gree are ASQ outliers which are not found coincident with glitches in other channels;
- black are the outliers that are coincident with glitches in other channels.

Red outliers would be vetoes in the cluster times defined in the previous section; we propose to veto the minute that includes the black outliers, and NOT to veto (at least yet, pending further investigation) the minutes containing green outliers. Some of the outliers are at the end of the segment, in these cases it may be wiser to veto a time from the beginning of the trended minute containing the outlier, until the end of the segment (rather than leaving a segment of a few seconds at the end). However, we hope there will a better tool to find out the noisy ends of deteriorating segments.

Outlier#	Science Seg#	GPS time	ASQ pp value	Other glitching channels
1	144	732475860	769	None (!)
2	68	730415400	548	ASI, POBI, POBQ, REFLI, REFLQ
3	96	731016600	504	Cluster at end of Seg#96
4	215	734090940	477	ASI, POBI, POBQ, REFLI
5	96	731015700	449	Cluster at end of Seg#96
6	217	734223660	436	ASI, POBI, POBQ, REFLI, REFLQ
7	50	729991680	433	ASI, POBI, POBQ, REFLI
8	130	731980860	425	ASI, POBI, POBQ, REFLI *last*
9	55	730121040	404	ASI, POBI, POBQ, REFLI, REFLQ
10	55	730121100	383	ASI, POBI, POBQ, REFLI, REFLQ
11	104	731442480	380	Cluster at the end of Seg#104
12	157	732616980	352	ASI, POBI, POBQ, REFLI, REFLQ * last*
13	57	730148460	349	ASI, POBI, POBQ, REFLI, REFLQ
14	112	731712060	349	POBI, REFLI
15	119	731872140	342	None
16	90	730841760	320	9min cluster in Seg#90
17	75	730522680	320	ASI, POBI, POBQ, REFLI
18	67	730401360	320	ASI, POBI, REFLI
19	111	731691300	318	ASI, POBI, REFLI
20	90	730839720	317	ASI, POBI, REFLI
21	104	731442540	315	cluster at end of Seg#104
22	90	730841940	314	9min cluster in Seg#90
23	185	733252020	303	ASI, POBI, POBQ, REFLI
24	207	733863840	297	ASI, REFLQ, PTRR, PTRT, SPOB, ASDC
25	50	729992760	289	ASI, POBI, POBQ, REFLI
26	36	729719280	282	ASI, POBI, REFLI
27	158	732621900	269	ASI (217sec segment,propose to veto)
28	189	733362840	267	ASI, POBI, ASDC
29	186	733301580	266	ASI, POBI, PTRR, PTRT, ASDC *last*
30	57	730143720	248	ASI, POBI, REFLI, SPOB
31	104	731439120	242	ASI
32	96	731015640	241	Cluster at end of Seg#96
33	149	732560220	240	ASI
34	75	730522620	236	ASI, POBI, POBQ, REFLI
35	104	731437320	236	POBI, REFLI
36	189	733355880	233	POBI
37	95	730920540	231	5 hrs cluster in Seg#95
38	161	732662220	228	ASI, POBI, POBQ, REFLQ, SPOB, ASDC
39	186	733290840	222	ASI, POBI, PTRR, PTRT, SPOB, ASDC
40	95	730929720	222	5 hrs cluster in Seg#95
41	218	734252160	222	ASI, POBI, POBQ, REFLQ * last*
42	96	730999800	221	ASI, POBI, POBQ, REFLI, REFLQ
43	96	731015820	219	Cluster at end of Seg#96
44	161	732666660	208	ASI, POBI, REFLI
45	90	730843560	202	None (3min cluster)
46	104	731433960	201	POBI
47	59	730231680	200	POBI, REFLI
48	186	733268520	196	ASI, POBI, REFLI, REFLQ
49	90	730841880	195	9min cluster in Seg#90
50	119	731853600	193	ASI
51	96	731015160	191	Cluster at end of Seg#96

Outlier#	Science Seg#	GPS time	ASQ pp value	Other glitching channels
52	90	730827480	187	ASI
53	178	733093740	183	ASI
54	194	733517460	183	None
55	144	732475500	182	ASI, REFLQ
56	95	730928640	182	5 hrs cluster in Seg#95
57	90	730843440	181	None (3min cluster)
58	212	733960140	176	ASI, POBQ
59	90	730842240	174	9min cluster in Seg#90
60	68	730415760	172	POBI, REFLI
61	212	733961760	172	POBI, POBQ, REFLI
62	139	732202140	170	None
63	67	730405800	169	ASI, POBI, REFLI
64	96	731016120	168	Cluster at end of Seg#96
65	90	730808460	165	ASI
66	116	731784660	164	ASI
67	59	730232040	163	POBI, REFLI
68	52	729999840	163	ASI, POBI, REFLI
69	95	730913940	162	5 hrs cluster in Seg#95
70	95	730914660	162	5 hrs cluster in Seg#95
71	96	731016300	161	Cluster at end of Seg#96
72	101	731201520	158	ASI
73	57	730143780	157	ASI, POBI, REFLI, SPOB
74	194	733518840	156	None
75	90	730843500	156	None (3min cluster)
76	39	729803280	155	ASI
77	96	731016540	155	Cluster at end of Seg#96
78	35	729713280	154	None
79	140	732240480	154	ASI, POBI, REFLI
80	96	731015100	154	Cluster at end of Seg#96
81	96	731016060	154	Cluster at end of Seg#96
82	95	730925880	153	5 hrs cluster in Seg#95
83	95	730914540	152	5 hrs cluster in Seg#95
84	104	731442360	151	cluster at end of Seg#104
85	96	731016480	150	Cluster at end of Seg#96
86	96	731015520	150	Cluster at end of Seg#96
87	95	730915740	150	5 hrs cluster in Seg#95
88	95	730922640	150	5 hrs cluster in Seg#95
89	161	732663300	149	None
90	95	730914060	147	5 hrs cluster in Seg#95
91	95	730922880	147	5 hrs cluster in Seg#95
92	159	732640740	147	POBI, REFLI
93	90	730840800	146	ASI
94	96	730981740	146	ASI, POBI, POBQ and REFLQ
95	109	731626080	145	ASI, POBQ
96	96	731004360	145	POBI, REFLI
97	36	729719340	144	ASI, POBI, REFLI
98	170	732904680	143	None
99	171	732907080	143	None
100	90	730834500	143	None
101	115	731781180	141	ASI
102	189	733362900	140	ASI, POBI, ASDC