5.3.1.1 WAC FM GEOMETRIC DISTORTION CALIBRATION RESULTS

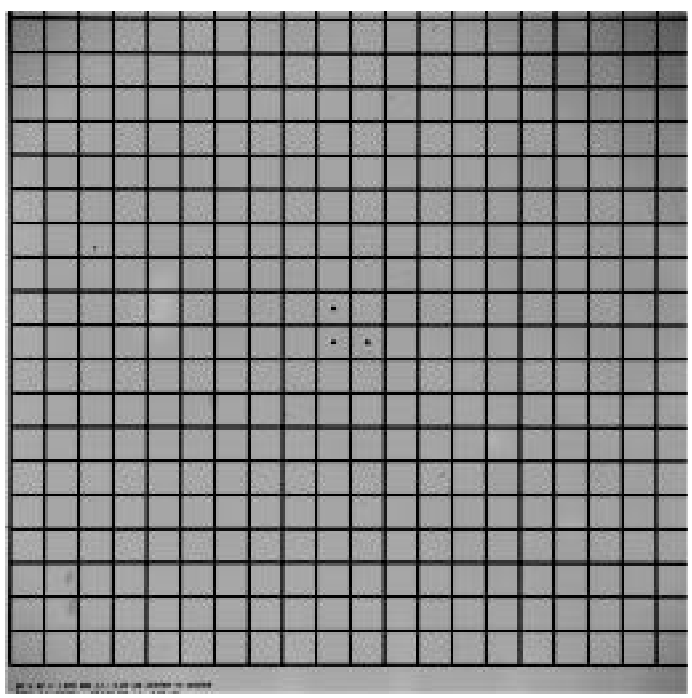
As reported in Reference 5.3.1.1-1

Reference 5.3.1.1-1 - IOM 388-PAG-CCA98-3, "WAC FM Calibration Results: Geometric Distortion", C. Avis, January 15, 1998

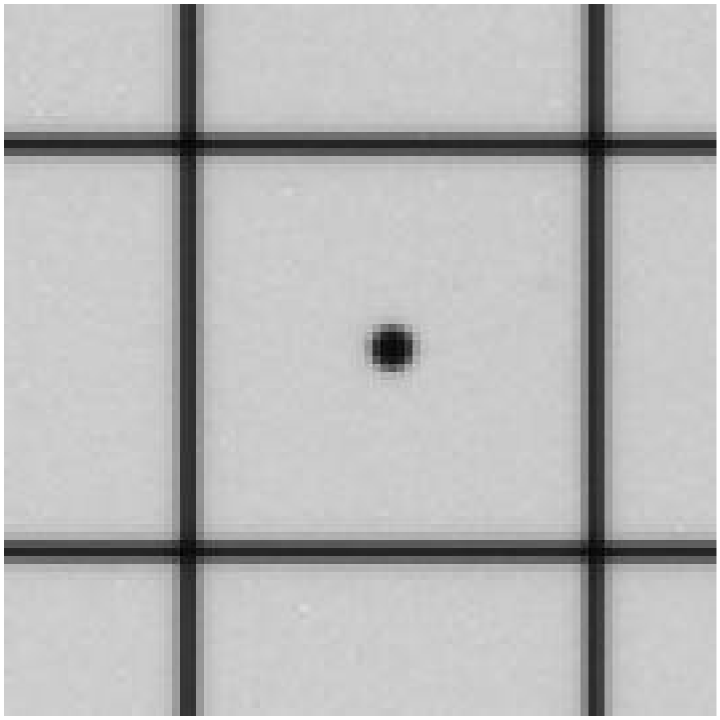
5.3.1.1.1 INTRODUCTION

The Wide-angle Flight Model thermal/vacuum testing included the acquisition of a set of images for analysis of geometric distortion. The image data were taken at a temperatures of +25° C, +10° C and -5° C. The instrument imaged a grid target with 19 horizontal and 19 vertical rulings about 2 pixels wide. Exposures were taken in the CL1/HAL and CL1/CL2 filters at a fixed target position with the target being translated up and down occasionally. In addition, the target position was varied while imaging with the CL1/BL1 filters.

The image below is one of the input image frames.



The following image is an enlargement of several intersections.



The imaging data has distortion contributions from the camera, the collimator, and the chamber window. Yet the optical model of this system should be able to derive the distortion contributed by the camera alone. The purpose of the analysis presented here is to confirm the optical model of the camera-collimator-window system based upon image data. If the optical model is confirmed, then its model of the camera alone can be confidently used to define of the geometric distortion.

5.3.1.1.2 METHOD

According to Hiroshi Katagawa, the optical model for the system yields a distortion function which is proportional to the cube of the distance from the image center:

$$R_{obs} - R_{actual} = C \; R_{obs}^3$$

where R_{obs} is the observed radial distance of a point from the center and,

R_{actual} is the correct radial distance for that point,

C is the coefficient.

The intersections are located using a multi-step process which results in knowledge of the locations to sub-pixel accuracy. These may be checked visually, allowing individual intersections to be deleted from the analysis (perhaps due to nearby blemishes, etc.)

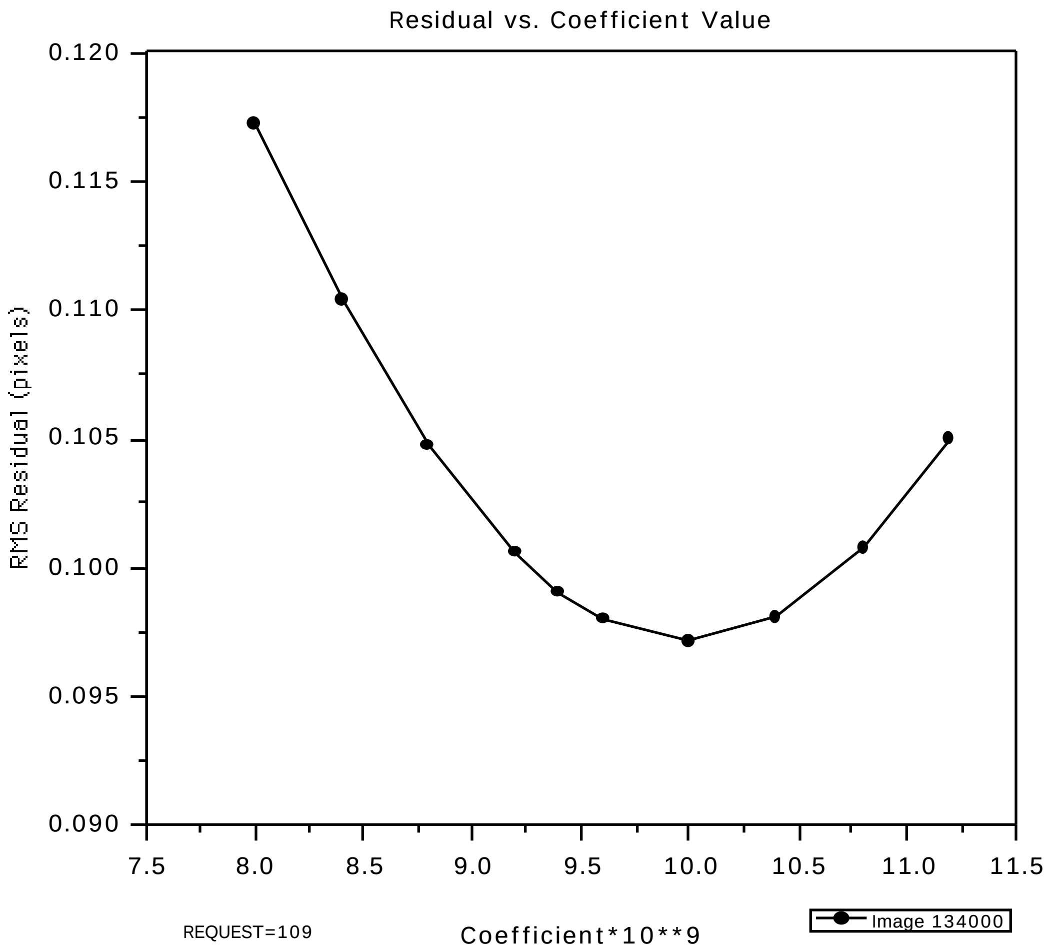
The processing then attempts to fit the set of measured intersections to a perfectly rectilinear set which has been transformed by the above equation into a set which defines the optical distortion model. Without exact knowledge of the location of the optical axis in the image, all radial distances were measured from (512,512).

The fit algorithm allows the measured coordinates to be transformed six different ways to account for target alignment errors. Let (x,y) represent an observed point, and let (u,v) represent the corresponding point in a model grid. The transformation used to compensate for alignment errors is a linear mapping from the plane of the given coordinate set into the plane of the model grid and is of the form:

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix}$$

The transformation coefficients $a,b,c,d,e,$ and f are computed by fitting the observed points in the given coordinate set and the model grid to this linear equation via the method of least squares. The resulting RMS error is due to effects not allowed by the transformation (i.e., non-linear effects - actual distortions or measurement errors).

Various values of the optical model coefficient were used so that the coefficient value could be plotted vs. RMS residual. An example plot is shown below.



The coefficient with the minimum residual is the value of interest. So, a 2nd order polynomial is fit to the points and its derivative set to zero. This gives the value of the best coefficient.

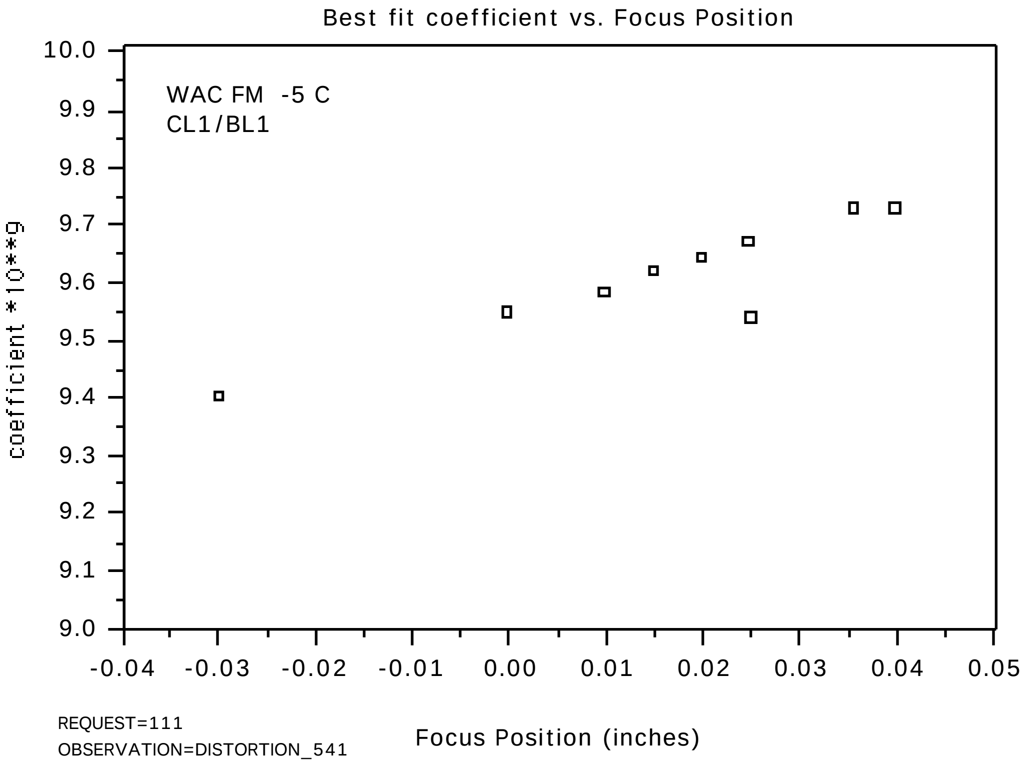
5.3.1.1.3 RESULTS

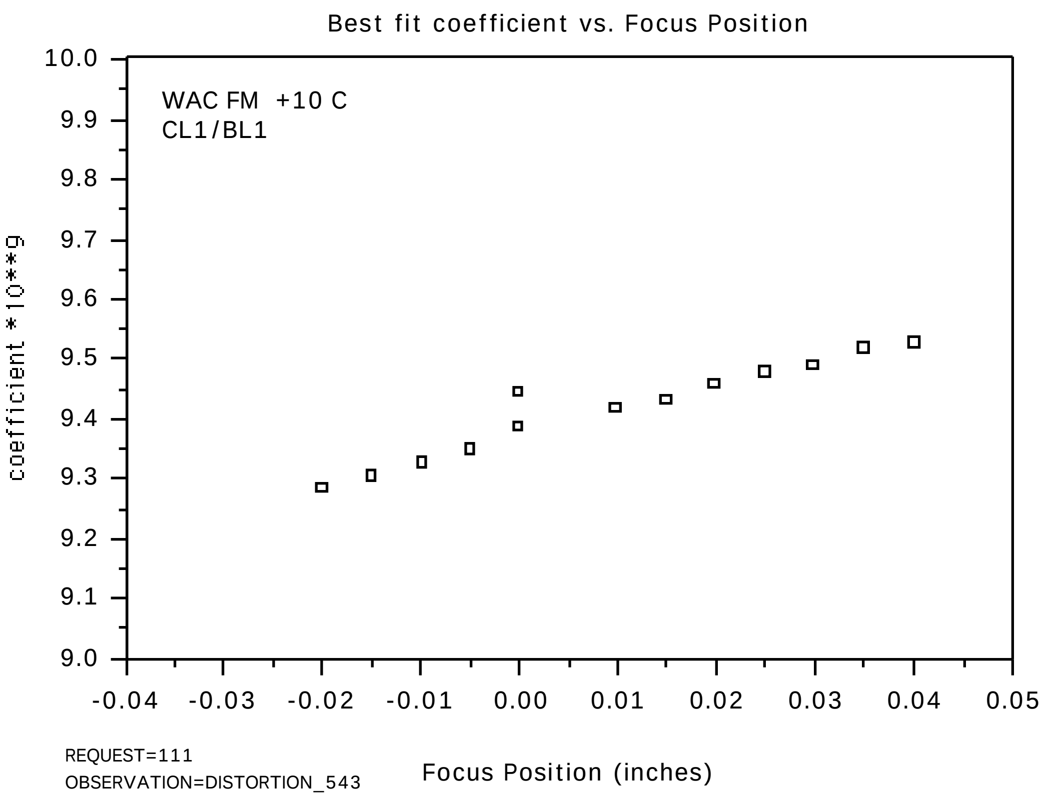
The following table gives the best fit coefficient and the associated RMS residual for each image analyzed.

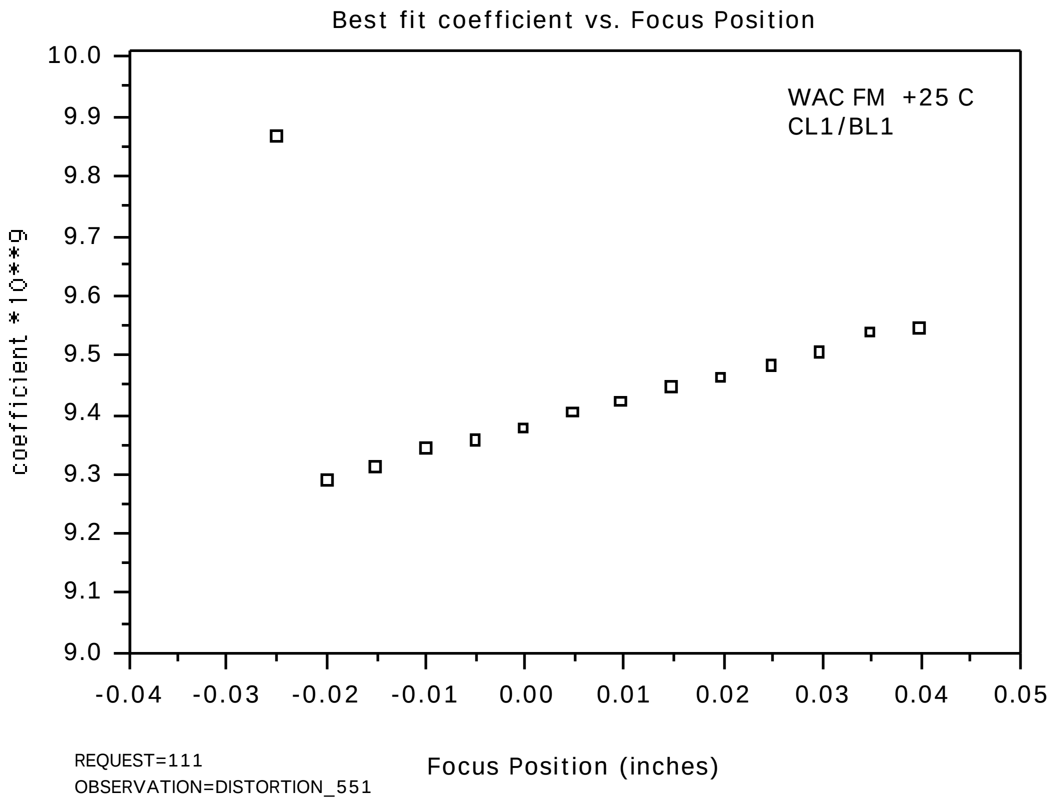
image	filters	optics temp	target position (inches)	translated from previous?	10^9 * best coefficient	lowest residual (pixels)
132491	CL1/HAL	-5 C	0.0	-	9.413	0.052
132493	CL1/HAL	-5 C	0.0	up	9.546	0.104
132496	CL1/BL1	-5 C	+0.0400	no	9.728	0.112
132497	CL1/BL1	-5 C	+0.0357	no	9.728	0.112
132498	CL1/BL1	-5 C	+0.0247	no	9.671	0.111
132499	CL1/BL1	-5 C	+0.0200	no	9.644	0.110
132500	CL1/BL1	-5 C	+0.0150	no	9.618	0.110
132501	CL1/BL1	-5 C	+0.0100	no	9.581	0.110
132502	CL1/BL1	-5 C	0.0	no	9.549	0.108
132503	CL1/BL1	-5 C	-0.0298	no	9.401	0.104
132504	CL1/BL1	-5 C	+0.0250	down	9.537	0.065
133251	CL1/HAL	+10 C	0.0	-	9.373	0.058
133253	CL1/HAL	+10 C	0.0	up	9.517	0.041
133258	CL1/BL1	+10 C	0.0	down	9.387	0.059
133259	CL1/BL1	+10 C	+0.0099	no	9.415	0.060
133260	CL1/BL1	+10 C	+0.0149	no	9.431	0.060
133261	CL1/BL1	+10 C	+0.0199	no	9.458	0.062
133262	CL1/BL1	+10 C	+0.0250	no	9.476	0.062
133263	CL1/BL1	+10 C	+0.0299	no	9.489	0.062
133264	CL1/BL1	+10 C	+0.0350	no	9.519	0.062
133265	CL1/BL1	+10 C	+0.0400	no	9.525	0.062
133266	CL1/BL1	+10 C	-0.0199	no	9.284	0.058
133267	CL1/BL1	+10 C	-0.0149	no	9.303	0.058
133269	CL1/BL1	+10 C	-0.0099	no	9.325	0.059
133270	CL1/BL1	+10 C	-0.0049	no	9.347	0.061
133271	CL1/BL1	+10 C	0.0	up	9.443	0.038
133994	CL1/CL2	+25 C	0.0	-	9.267	0.065
133995	CL1/CL2	+25 C	0.0	up	9.919	0.104
133999	CL1/HAL	+25 C	0.0	down	9.377	0.064
134000	CL1/HAL	+25 C	0.0	up	9.985	0.097
134007	CL1/BL1	+25 C	0.0	down	9.375	0.065
134009	CL1/BL1	+25 C	+0.0049	no	9.402	0.066
134010	CL1/BL1	+25 C	+0.0099	no	9.421	0.066
134011	CL1/BL1	+25 C	+0.0149	no	9.443	0.069
134012	CL1/BL1	+25 C	+0.0199	no	9.462	0.067
134014	CL1/BL1	+25 C	+0.0250	no	9.480	0.068
134015	CL1/BL1	+25 C	+0.0299	no	9.502	0.068
134016	CL1/BL1	+25 C	+0.0350	no	9.537	0.069
134017	CL1/BL1	+25 C	+0.0399	no	9.543	0.069
134018	CL1/BL1	+25 C	-0.0199	no	9.287	0.064
134019	CL1/BL1	+25 C	-0.0149	no	9.311	0.064
134020	CL1/BL1	+25 C	-0.0099	no	9.340	0.065
134021	CL1/BL1	+25 C	-0.0049	no	9.356	0.065
134022	CL1/BL1	+25 C	-0.0250	up	9.867	0.073

5.3.1.1.3.1 COEFFICIENT SENSITIVITY TO TARGET POSITION

The following plots show the stability of the distortion as a function of the target position.





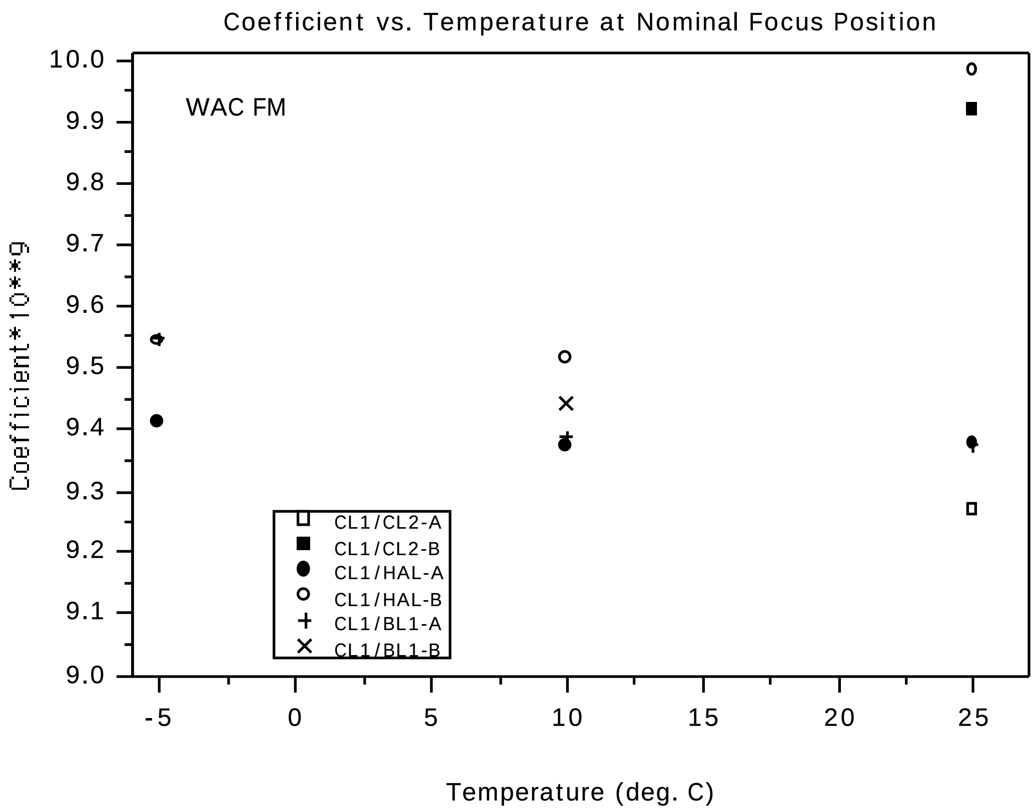


Note:

1. The lower point of the two at -5° C at target position +0.025 probably belongs at -0.025 (due to a typo), but no confirmation is available. No other positions had duplicates other that 0.0.
2. The point at coefficient value of 9.87 at +25° C is inconsistent, but no cause has been found.

5.3.1.1.3.2 COEFFICIENT SENSITIVITY TO TEMPERATURE

The following plot shows the value of the coefficient over the available temperatures with the system at the nominal target position. In addition, all three filter combinations are shown. The '-A' and '-B' in the legend refer to separate images with the same conditions.



5.3.1.1.4 CONCLUSIONS

1. The best coefficient value changes only slowly with target position.
2. The mean coefficient value for all images at nominal target position is $9.51\text{x}10^{-9} \pm 0.21\text{x}10^{-9}$. This corresponds to 3.61 ±0.08 pixels of distortion at the corner pixels.
3. The coefficient shows no consistent variation with filter.
4. The coefficient for the nominal target position is consistent at -5° C and +10° C, but shows considerable scatter at +25° C. However, the +25° C data with changing target position showed little scatter.

5.3.1.1.5 LIST OF IMAGES USED FOR DISTORTION ANALYSIS

image	observation	day	eventtime	filt1	filt2	temp
132491	DISTORTION_540	203	8:37:15.0	CL1	HAL	-5.41
132493	DISTORTION_540	203	8:41:13.0	CL1	HAL	-5.41
132496	DISTORTION_541	203	9:3:55.0	CL1	BL1	-5.33
132497	DISTORTION_541	203	9:11:4.0	CL1	BL1	-5.24
132498	DISTORTION_541	203	9:15:19.0	CL1	BL1	-5.33
132499	DISTORTION_541	203	9:18:7.0	CL1	BL1	-5.24
132500	DISTORTION_541	203	9:23:43.0	CL1	BL1	-5.24
132501	DISTORTION_541	203	9:27:27.0	CL1	BL1	-5.24
132502	DISTORTION_541	203	9:30:26.0	CL1	BL1	-5.24
132503	DISTORTION_541	203	9:47:47.0	CL1	BL1	-5.16
132504	DISTORTION_541	203	9:57:50.0	CL1	BL1	-5.24
133251	DISTORTION_542	205	15:10:4.0	CL1	HAL	9.50
133253	DISTORTION_542	205	15:29:3.0	CL1	HAL	9.50
133258	DISTORTION_543	205	15:51:27.0	CL1	BL1	9.50
133259	DISTORTION_543	205	15:54:45.0	CL1	BL1	9.42
133260	DISTORTION_543	205	15:59:32.0	CL1	BL1	9.50
133261	DISTORTION_543	205	16:2:24.0	CL1	BL1	9.50
133262	DISTORTION_543	205	16:4:58.0	CL1	BL1	9.50
133263	DISTORTION_543	205	16:7:57.0	CL1	BL1	9.50
133264	DISTORTION_543	205	16:9:33.0	CL1	BL1	9.50
133265	DISTORTION_543	205	16:11:52.0	CL1	BL1	9.50
133266	DISTORTION_543	205	16:16:33.0	CL1	BL1	9.50
133267	DISTORTION_543	205	16:18:51.0	CL1	BL1	9.42
133269	DISTORTION_543	205	16:22:34.0	CL1	BL1	9.50
133270	DISTORTION_543	205	16:24:32.0	CL1	BL1	9.50
133271	DISTORTION_543	205	16:27:44.0	CL1	BL1	9.50
133994	DISTORTION_552	207	11:57:54.0	CL1	CL2	27.95
133995	DISTORTION_552	207	12:1:17.0	CL1	CL2	27.86
133999	DISTORTION_550	207	12:9:54.0	CL1	HAL	27.86
134000	DISTORTION_550	207	12:11:44.0	CL1	HAL	27.86
134007	DISTORTION_551	207	12:24:9.0	CL1	BL1	27.86
134009	DISTORTION_551	207	12:28:17.0	CL1	BL1	27.86
134010	DISTORTION_551	207	12:29:51.0	CL1	BL1	27.86
134011	DISTORTION_551	207	12:31:18.0	CL1	BL1	27.86
134012	DISTORTION_551	207	12:32:52.0	CL1	BL1	27.86
134014	DISTORTION_551	207	12:35:28.0	CL1	BL1	27.86
134015	DISTORTION_551	207	12:36:44.0	CL1	BL1	27.86
134016	DISTORTION_551	207	12:37:56.0	CL1	BL1	27.86
134017	DISTORTION_551	207	12:39:17.0	CL1	BL1	27.86
134018	DISTORTION_551	207	12:41:22.0	CL1	BL1	27.86
134019	DISTORTION_551	207	12:42:37.0	CL1	BL1	27.86
134020	DISTORTION_551	207	12:43:52.0	CL1	BL1	27.86
134021	DISTORTION_551	207	12:45:24.0	CL1	BL1	27.86
134022	DISTORTION_551	207	12:47:30.0	CL1	BL1	27.86