Grid distortion on D2am CCD cameras.

J.-F. Bérar, D2am-CRG/F, ESRF

Contents

Introduction.

This document present the distortions of the CCD-FO cameras used at the BM2-ESRF beamline. It explains the method used to correct images from them using *bm2img* (2) and also how to build new sets of correction parameters (3.1). The detailled explainations in section (1) refer to the first camera in use on the beamline. However the characteristic on the 1340×1300 pixels camera can be found in section (**??**).

1 D2am 1242x1152 camera : Fiber Optic Coupled CCD.

SAXS users have noticed that distorsions on D2am CCD camera were significant and lead to some troubles when data have been collected both at high and at low Q with separate settings. Using a copper grid (holes diameter .3mm on a 3mm square lattice) etched by electronic board technics by Cyrile Rochas (LSP, Grenoble), these distorsions have been characterised and a correction procedure deduced.

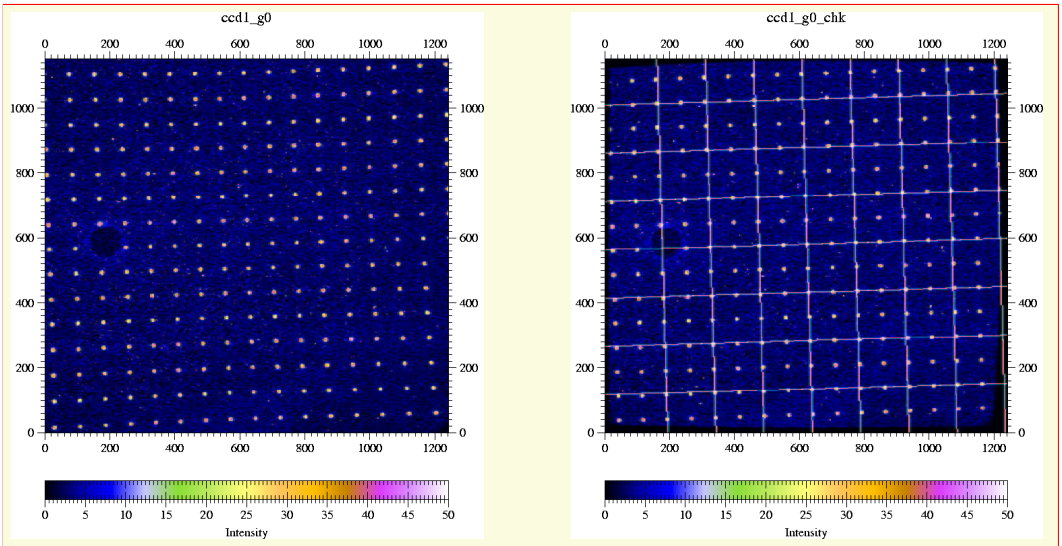

Figure 1: Uncorrected grid image and corrected one.

The added lines on the right image have been drawn to figure a perfect grid located around the "central" node.

1.1 The distortions

As distorsions seem very weak near the center, they have been expressed by a polynomial function using the center as origin : $X = f(X - X_o) = f(x)$. The adjustement lead to a grid size of 74.9 pixels corresponding to $40.1 \mu m/pixel$ in the horizontal direction.

Following table contain the coefficients of X and Y expansions :
$X = X_o + A_x x + A_y y + A_{x^2} x^2 + A_{xy} xy + A_{y^2} y^2 + ...$

	X					Y				
scale	x^0y^0					x^0y^0				
factor	x^1y^0	x^0y^1				x^1y^0	x^0y^1			
on	x^2y^0	x^1y^1	x^0y^2			x^2y^0	x^1y^1	x^0y^2		
$A_{x^iy^j}$	x^3y^0	x^2y^1	x^1y^2	x^0y^3		x^3y^0	x^2y^1	x^1y^2	x^0y^3	
	x^4y^0	x^3y^1	x^2y^2	x^1y^3	x^0y^4	x^4y^0	x^3y^1	x^2y^2	x^1y^3	x^0y^4
1	621					576				
10^3	1000	0.00				4.70	1003			
10^5	-1.92	0.59	-1.62			-0.13	0.17	2.66		
10^8	-7.34	1.92	-5.20	-0.32		-0.01	-5.01	-0.02	-6.50	
10^{11}	1.63	-0.66	-0.19	2.39	-0.50	-0.44	2.38	-1.83	1.53	-3.60

The A_y value, 1.003 shows that the lattice is nearly a perfect square. The maximum deviation is observed in X (bottom right) is near 30 pixels, in Y (bottom left) near 24 pixels.

The 246 nodes located on the grid are then adjusted with a standard error of 1.5 pixels to be compared with an error of 8.9 pixels before correction. Following pictures show the distorsions on each nodes and the remaining values after correction of the image.

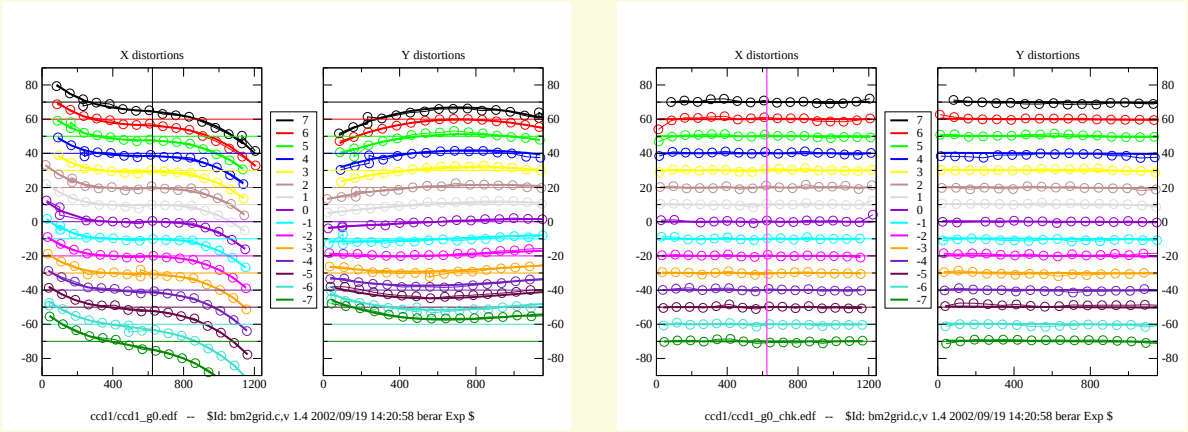

Figure 2: Relative position of nodes before and after correction.

1.2 Camera distortions.

The difference between the image after and before correction allows to visualise easily the effect of the correction. The following zoom on the grid corners (top, right) and (bottom, left) proof that the correction improve greatly the image quality. The relative size of the pixels is represented in the image. It can be noticed on the figure, the size far from the center is reduced by more than 10%.

The relative size of the pixels is represented in the image. It can be noticed on the figure, the size far from the center is reduced by about 20%.

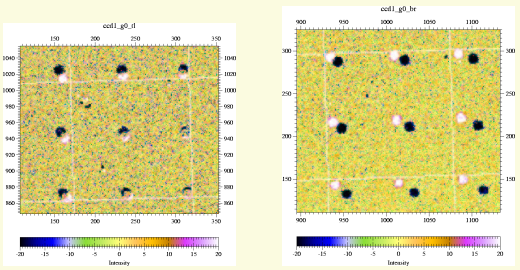

Figure 4: Details of the corrected image.

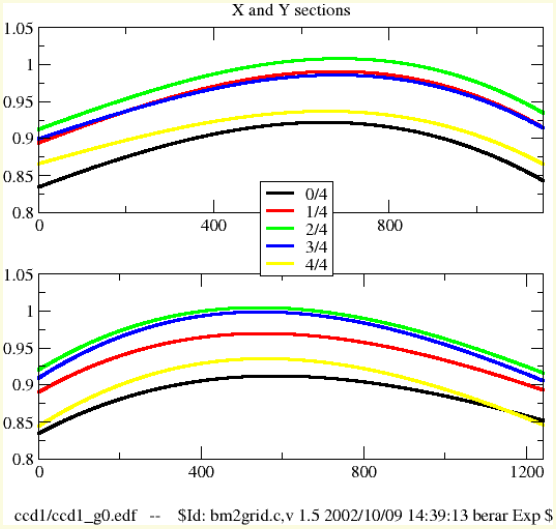

Figure 3: .

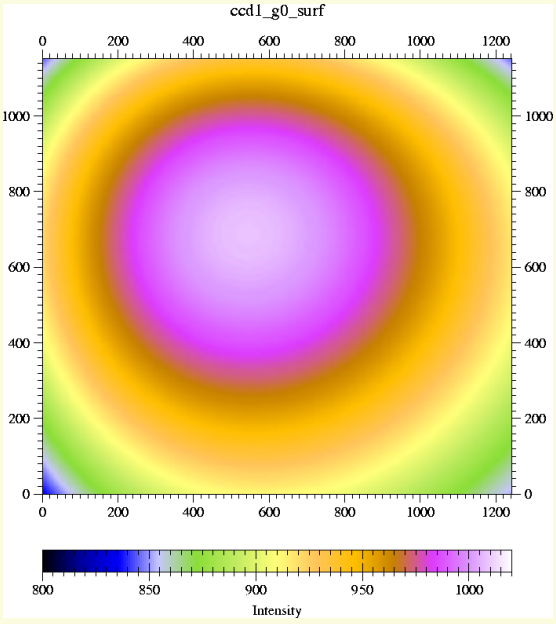

Figure 5: .

2 Correcting image with *bm2img* procedure.

The correction of the position of the pixels is obvious when the grid is known but some problems may occur with the intensity.

2.1 Method of correction

In a constant flux, due to the pixel size the counts in each pixel are proportional to the pixel surface as represented on the figure of a distorded camera.

In the natural view, the intensity are shown on a regular non corrected grid and the surface distortion appear like an intensity change.

The easiest way to correct the grid is to split the intensity of the real pixel in proportion of the surface common to the new pixel.

Applying this calculation, this image is obtained. There is no problem for all the inner pixel, for very sharp signal a small convolu- tion may occurs, for the case in which the detector resolution is very important, local fit of intensity may allow a better splitting of the intensity on the new array. But pixels in the border lines may are affected by this remapping.

A solution is to extend the intensity of these pixels, if the surface concerned is not too tiny. After this operation the excluded pixel have to be redefined by generating a new mask including the effect of the distortion. change

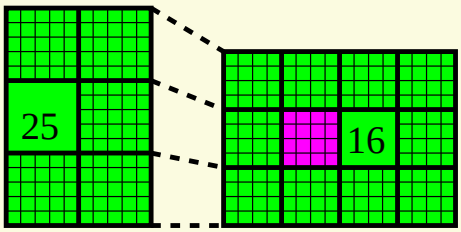

Figure 6:

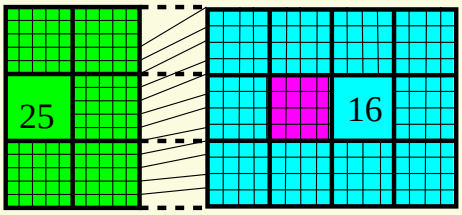

Figure 7:

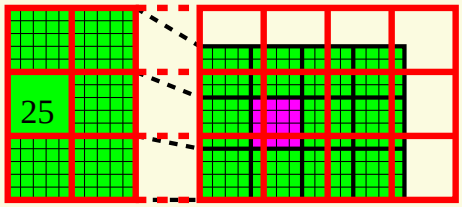

Figure 8:

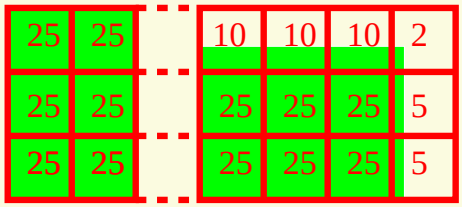

Figure 9:

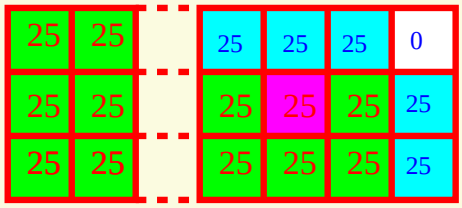

Figure 10:

2.2 Interaction with the flatfield correction.

When a flatfield correction is applied be- fore the grid correction, the content of pixels changes.

Applying the normal correction lead to overestimate the pixel with small size. However the normal result can be achieved if a surface correction is applied.

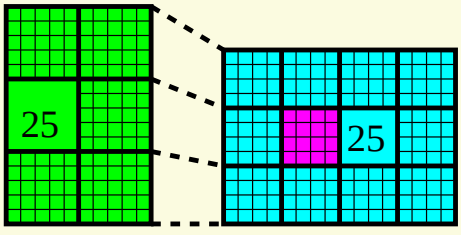

Figure 11:

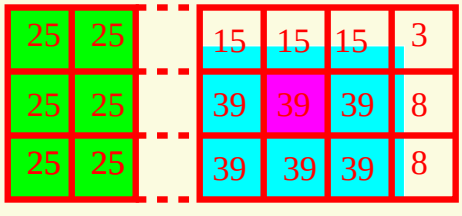

Figure 12:

2.3 Practical correction of images with *bm2img* .

2.3.1 Geometrical grid parameters.

The coefficient calculated by bm2grid can be used to correct images in bm2img, this is done by writing the following tags and lines in bm2img.ini.

GRID_DCOR=	15			number of coefs
GRID_XCOR=	621		1 2.71678e-07	...
GRID_YCOR=	576	0.00424391	1.00337	...

The following lines can be used, the values inside may be more readable.

GRID DCOR=	15				number of coefs
GRID XTAB=	0	1	621		
GRID XTAB=	1	2	1	2.10727e-07	
GRID XTAB=	3	3	-1.9238e-05	5.95292e-06	-1.61841e-05
GRID XTAB=	...				
GRID YCOR=	576	0.00424391	1.00337	...	

But to avoid typing mistakes lines the most efficient is to redirect the reading of this line to the file writen by bm2grid using tag like FILE=/grid/ccd2 g1.res in the bm2img.ini file; on BM2/ESRF beamline original files are located in the www/onsite only/tables/grid folder.

2.3.2 Interaction image size and mode.

The grid correction is defined on a whole oriented image. If the image to be corrected has been flipped (this is the case when CCD data are read using another amplifier mode), the image can be flipped before using the grid correction with the tag XY ORIEN=-X,Y.

But it seems better to preserve image orientation, then you have to use the tags GRID XMIN=... or GRID YMIN=.... This which allow to define position and orientation of the image with respect to the grid. These tags allow to use binded part of an image as it can be seen with the following part of a grid. The GRID XMIN has to take into account the real shift which can be associated with em bm2img X MIN tag or with otherwise defined ROI.

In the case of a binding obtained either by X BIND, Y BIND or tby reading binded pixel through hardware, the tags GRID XBIND=2,GRID YBIND=... have to be specified. As the value -1 is allowed for GRID XBIND this is another way to correct a flipped image.

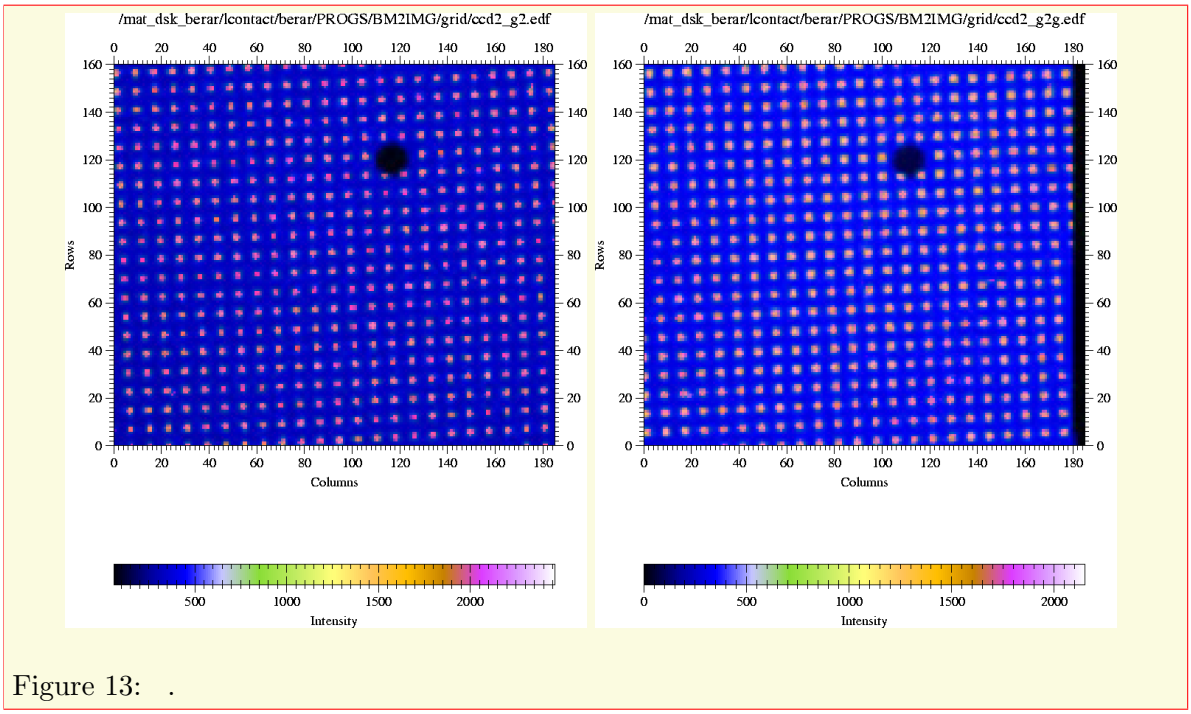

Figure 13: .

The upper image was measured in "Low Noise" mode while the grid was recorded in the "High Capacity" mode : both are flipped. This binded part was corrected using the follwing bm2img.ini

```
## bm2grid reference, orientation -X,Y

FILE=ccd2/ccd2_g1.res
GRID_XBIND=-4
GRID_YBIND=4
GRID_XMIN=200
GRID_YMIN=200
```

2.3.3 Interaction with excluded pixels.

Excluded pixels are often defined on the uncorrected image. As grid correction modify the position of excluded pixels, it interacts with some standard parameters in bm2img and the following extensions have been implemented : %g=filename will produce a excluded pixels file named filename to be read using the *F_EXCLUDED=filename* in *bm2img.ini* .

2.3.4 Other grid related parameters.

GRID AUTO= use grid correction always or on input request

NONE grid correction is performed only on the %G command AUTO the grid correction is done automaticaly after flat correction, no %G required.

GRID MODE= this parameter uses NONE as default value.

NONE it provides standart correction as shown in Fig.2-5, border effect are corrected for surface higher than 1/2. STRICT it provides standart correction as shown in Fig.2-4, no border effects are taken into ac- count.. FLAT the result is surface corrected to avoid effect shown in Fig.2-7.

GRID ORIG= : this parameter has to be used by users who calculate directly radial distribution from the original image file : with value CONVERT, it allows the coordinates of the distribution center to be converted on the fly from orinal space to grid corrected space.

2.4 Example : radial distribution.

When extracting a radial distribution using bm2img , it is possible to operate as usual with a single pass. In this case, the center is defined by its position on the uncorrected image and its position is modified on the fly if a grid correction is done. As it can be seen on the following example, the correction of the grid distortion increase the contrast at high angles and allows the very weak outer ring which can be noticed only in the corner to be taken in consideration. The radial distribution obtained after correction is drawn in red and can be compared to the raw one in black. The peaks become sharper but the integrate counts in the peak remain constant : in case of the second peak we obtain 7070 before correction and 7080 after; for the 7th the digits are 403 before and 398 after. In both case the difference is lower than 1% and seem mostly related to the base line definition before integrating. On a construted uniform image we proof that on the whole detector the integration remain stable within 2/14300.

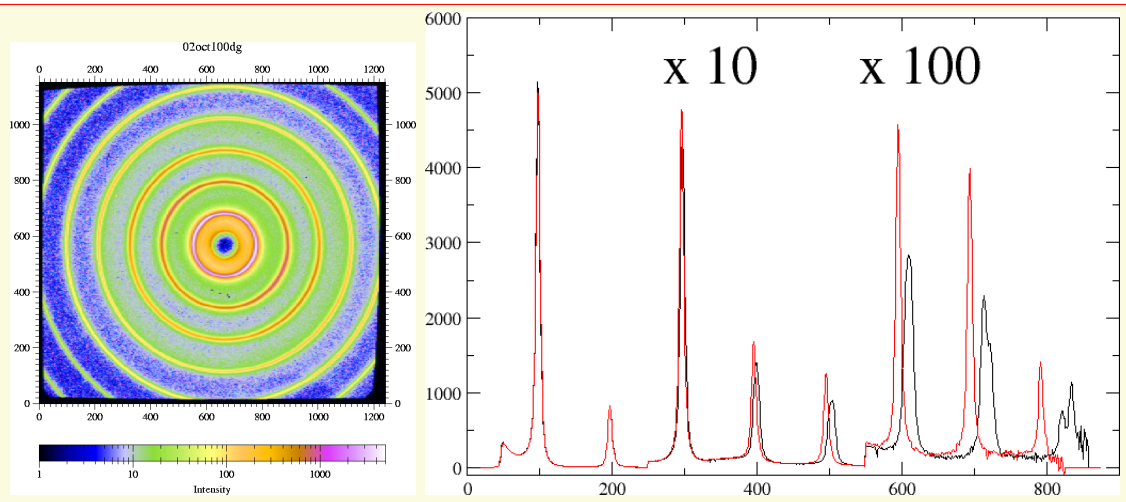

Figure 14:

3 Grid determination : *bm2grid* procedure

3.1 *bm2grid* program method

The program is divided into internal modules which are responsable of specific operation, these modules are called by the initialisation file which can be quite simple as in the case of this CCD in which the grid is easy to extract and fit. After assigning coordinates to grid nodes, the program try to fit some polynomial grid function in order to minimise the residual distortions. When the grid correction is important it is mandatory to reach some convergency to process by step :

· first ensure that the grid is well recognise, if not it may be usefull to force the grid parameters defining an origin node and the related translation.

· process the grid localy around the center on few nodes, from -5 to 5 by example, using only a low degree expansion. This will ensure that row and column will be well understood and we do not try to mix rows to draw lines.

· enlarge the area on which the grid is processed and the expansion degree

· when a valuable grid has been reached, save it and check if the corrected image is no more distorded.

3.2 Correction parameters.

The grid coefficients have been calculated using bm2grid. No special care have been necessary to extract the grid, the following parameters were given :

GRID LEVEL=20 minimum count on pixel used in grid nodes
GRID COUNT=10 minimum pixels number in grid nodes
GRID ERROR=0.2 tolerance around translation for nodes extraction
GRID SIZE=0.2 used to calculate the pixel size from grid spacing
GRID START= xo yo txx txy can be used if the grid recognition fails (origin, vector)

3.3 Command keys.

- **@GRID_IMAGE=** this key is used to specify the file containing the grid image. After reading the image a search is done to extract the node and assign them to a reasonable lasuare lattice.
- **@GRID_OUT NODES=** optional key used to print out in the specified file all the nodes with their counts and assignement. The node references of this file can be used to cancel some of them during anaysing procedure.

- **@GRID_PROCESS=** try to fit the polynomial grid function. This command may be repeated if the number of nodes to take into account change.

@GRID OUT XMGR= optional key used to print out in the specified xmgrace pro ject file a figure showing the distorsions along X and Y on the surface detector

@GRID OUT RES= optional key used to print out in the specified file the parameters of the polynomial distorsion function. This file can be used as entry for other applications. specified xmgrace pro ject file a figure showing the distorsions along X and Y on the surface detector

@GRID OUT SURF= optional key used to print out in the specified file an image showing the surface variation on the detector.

@GRID INPUT= this key is used to read the result produced by @GRID OUT RES

@GRID CHECK= similar to @GRID IMAGE but apply on the image the known grid correction. A corrected image will be output by adding " chk" to the input name. This module allows to see the consistency of previously obtained polynomial distorsion function.

@GRID LIM NODES= optional key to restrict the node indices used. It allow to used only a part of the detector and to increase its surface in some PROCESS pass. The arguments are xmin xmax ymin ymax in which xy are the minimum or the maximum values allowed for the nides indices. The limits are applied at each time this command is found. Join with @GRID PROCESS it allows to enlarge the fitted surface.

@GRID DEL NODES this command delete the nodes which references number are given. It uses the reference given by @GRID OUT NODES.

```
GRID_DCOR=15
GRID_XCOR=          621         1     2.10727e-07               ....
GRID_YCOR=          576 0.00470413   1.0034 -1.31391e-06       ....
```

3.4 Example of initialisation files

3.4.1 File used for the 1242x1152 CCD

No special care have been necessary to extract the
grid, the following parameters were given :

```
# bm2grid.ini : grid calibration
# C Rochas grid, 1242x1152 CCD
GRID_LEVEL=20
GRID_ERROR=0.2
GRID_COUNT=10
GRID_SIZE=3.00
```

Then the following inputs define the operations.

```
@GRID_IMAGE=ccd1/ccd1_g0.edf

@GRID_OUT_NODES=ccd1/ccd1_g0.nod

@GRID_PROCESS=

@GRID_OUT_XMGR=ccd1/ccd1_g0.agr

@GRID_OUT_SURF=ccd1/ccd1_g0_surf.edf

@GRID_OUT_RES=ccd1/ccd1_g0.res
```

```
@GRID_INPUT=ccd1/ccd1_g0.res

@GRID_CHECK=ccd1/ccd1_g0.edf,1000,2

@GRID_PROCESS=

@GRID_OUT_NODES=ccd1/ccd1_g0_chk.nod

@GRID_OUT_XMGR=ccd1/ccd1_g0_chk.agr
```

3.4.2 1340x1300 CCD, High dynamic mode

This CCD camera is more distorded and it was necessary to define the grid locally around the center before increasing the grid corrected area.

```
\# bm2grid.ini : grid calibration
PRINT=3
\# C Rochas grid, 1340x1300 CCD, high dynamic
GRID_LEVEL=100
GRID_ERROR=0.35
GRID_COUNT=50
GRID_SIZE=1.50

@GRID_IMAGE=ccd2/ccd2_g1.edf
@GRID_LIM_NODES=-10 10 -10 10
@GRID_PROCESS=4

@GRID_LIM_NODES=-16 16 -16 16

@GRID_PROCESS=5

@GRID_LIM_NODES=-26 26 -26 26

@GRID_PROCESS=6

@GRID_OUT_NODES=ccd2/ccd2_g1.nod

@GRID_OUT_XMGR=ccd2/ccd2_g1.agr

@GRID_OUT_SURF=ccd2/ccd2_g1_surf.edf

@GRID_OUT_RES=ccd2/ccd2_g1.res

@GRID_INPUT=ccd2/ccd2_g1.res

@GRID_CHECK=ccd2/ccd2_g1.edf,500,2

@GRID_PROCESS=
@GRID_OUT_NODES=ccd2/ccd2_g1_chk.nod
@GRID_OUT_XMGR=ccd2/ccd2_g1_chk.agr
```

4 D2am 1340x1300 camera : Fib er Optic Coupled CCD.

These preliminary result have been obtained with the grid image provided by Roper Scientific (about 0.6mm) in the file "flm-4-1.SPE" (August 14th, 2002). The very high contrast om this grid image shows it has been realised with visible light and not X-ray. But ths step used in this grid was too small and it was very difficult to achieve some reliable result. A new grid has then been prepared by Cyrile Rochas (LSP, Grenoble), using a copper grid (holes diameter .3mm on a 1.5mm square lattice) etched by electronic board technics. This grid has been illuminated by X-rays suing fluorescence at Sr edge. Then distorsions have been characterised. The following grid ccd2 g1 have been recorded in "High Capacity" mode, the images obtained in the "Low Noise" mode have a different orientation. The following grid can be used by bm2img with the tag GRID XBIND=-1 in case of image recorded in "Low Noise" as shown in section.2.3.2.

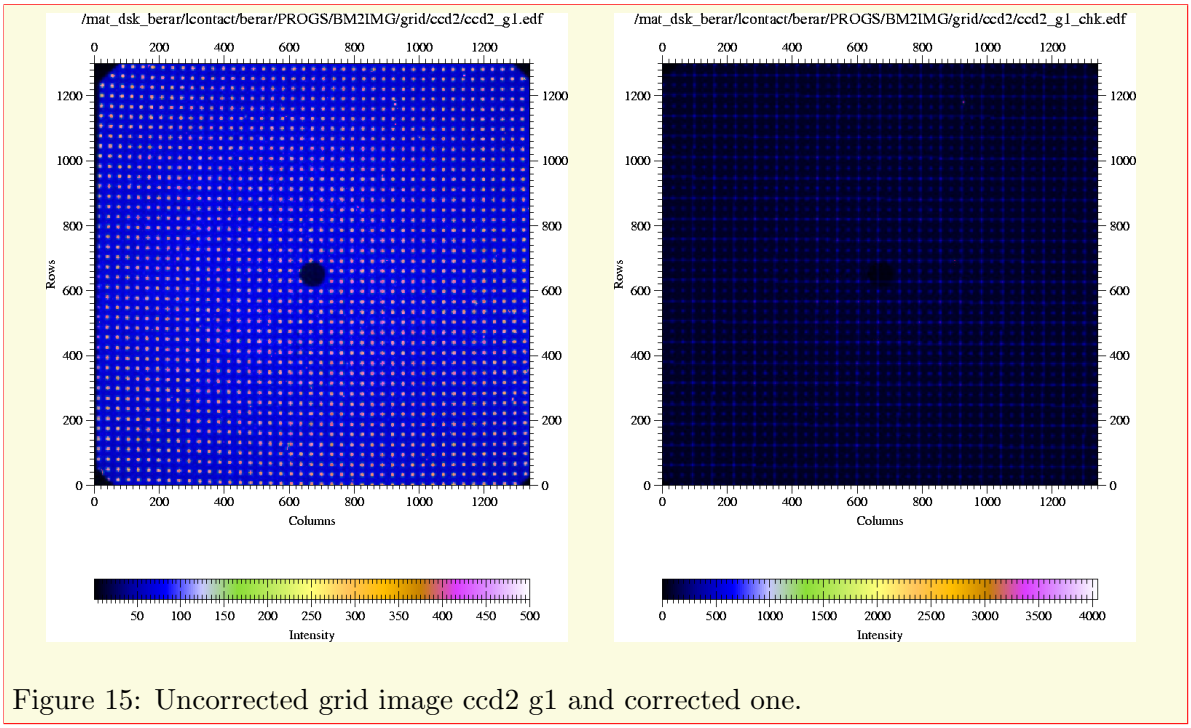

Figure 15: Uncorrected grid image ccd2 g1 and corrected one.

5 Characterization of distortions

On the corrected grid image a regular lattice has been reported. Due to the amplitude of the distortion, the correction parameters have been reached using a small loop. In the first step, only the 436 nodes near the center (-10 .. +10) have been considered and the correction function restricted to the 5th degree. Then the zone has been enlarged increasing the degree. In the last step 1758 nodes have been considered on the surface. Using the same expension, the coefficents are :

	X						Y					
scale factor on $A_{x^i y^j}$	x^0y^0					x^0y^0						
	x^1y^0	x^0y^1				x^1y^0	x^0y^1					
	x^2y^0	x^1y^1	x^0y^2			x^2y^0	x^1y^1	x^0y^2				
	x^3y^0	x^2y^1	x^1y^2	x^0y^3		x^3y^0	x^2y^1	x^1y^2	x^0y^3			
	x^4y^0	x^3y^1	x^2y^2	x^1y^3	x^0y^4	x^4y^0	x^3y^1	x^2y^2	x^1y^3	x^0y^4		
1	670						650					
10^3	1000	0.00					4.32	1004				
10^5	0.72	1.09	-1.45				-1.68	-1.56	0.67			
10^8	2.72	0.84	6.03	0.56			-0.09	4.42	0.42	1.40		
1011	-2.02	1.02	1.01	-0.13	0.23		-0.05	2.25	0.12	1.17	-0.17	
10^14	1.19	1.02	-7.06	-0.83	-2.82	-1.87	0.03	-4.16	0.13	-5.12	-0.70	2.06

After the correction process, the worst node is located in the corner with an error of about 2.5 pixels. The standard error remains weak : 0.4 pixels.

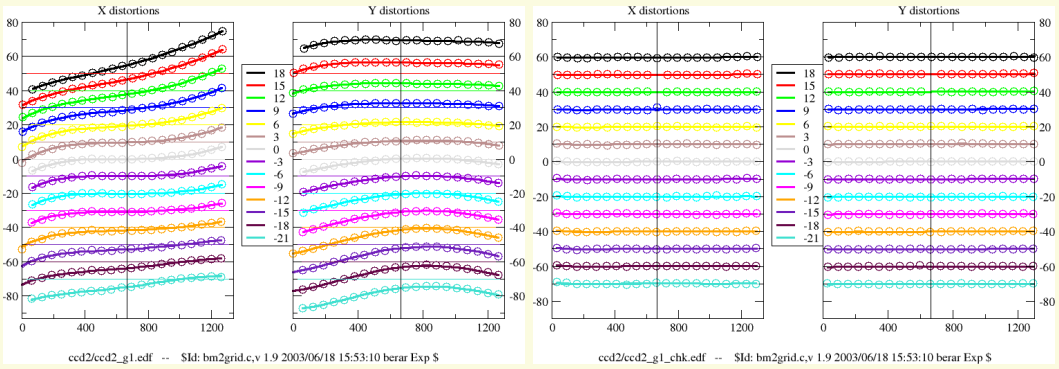

Figure 16: .

5.1 Camera distortions

The difference between the image after and before correction allows to visualise easily the ef- fect of the correction. The following zoom on the grid corners (top, right) and (bottom, left) proof that the correction improve greatly the image quality. The relative size of the pixels is represented in the image. It can be noticed on the figure, the size far from the center is reduced by more than 10%.

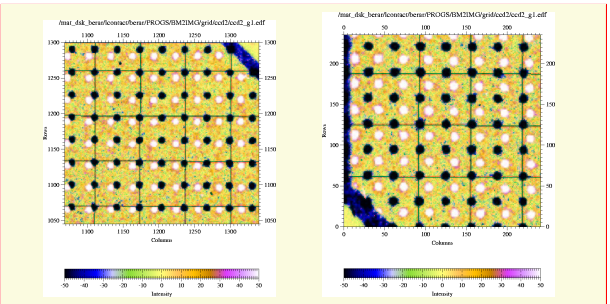

Figure 18: Details of the corrected image.

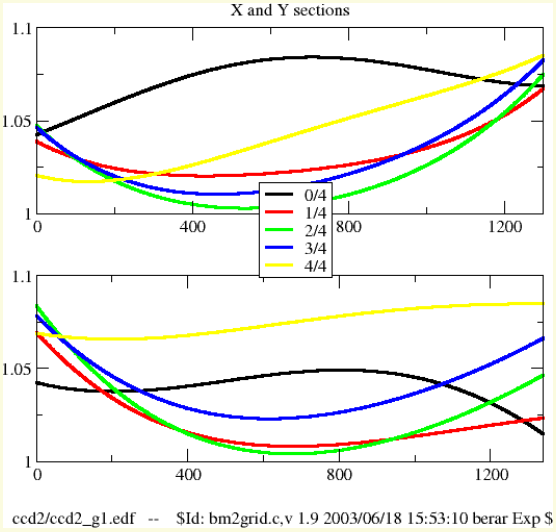

Figure 17: .

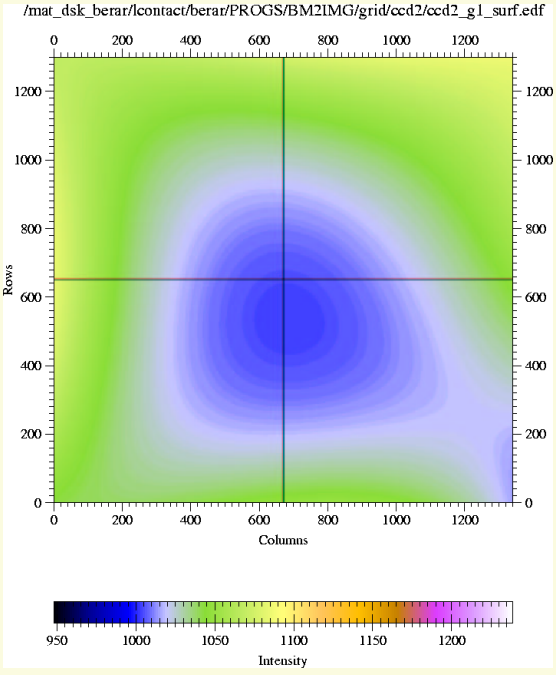

Figure 19: .