DARK ENERGY SURVEY

Two Image Based Methods for Measuring the Flatness of the MultiCCD Focal Plane

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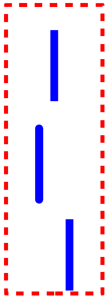
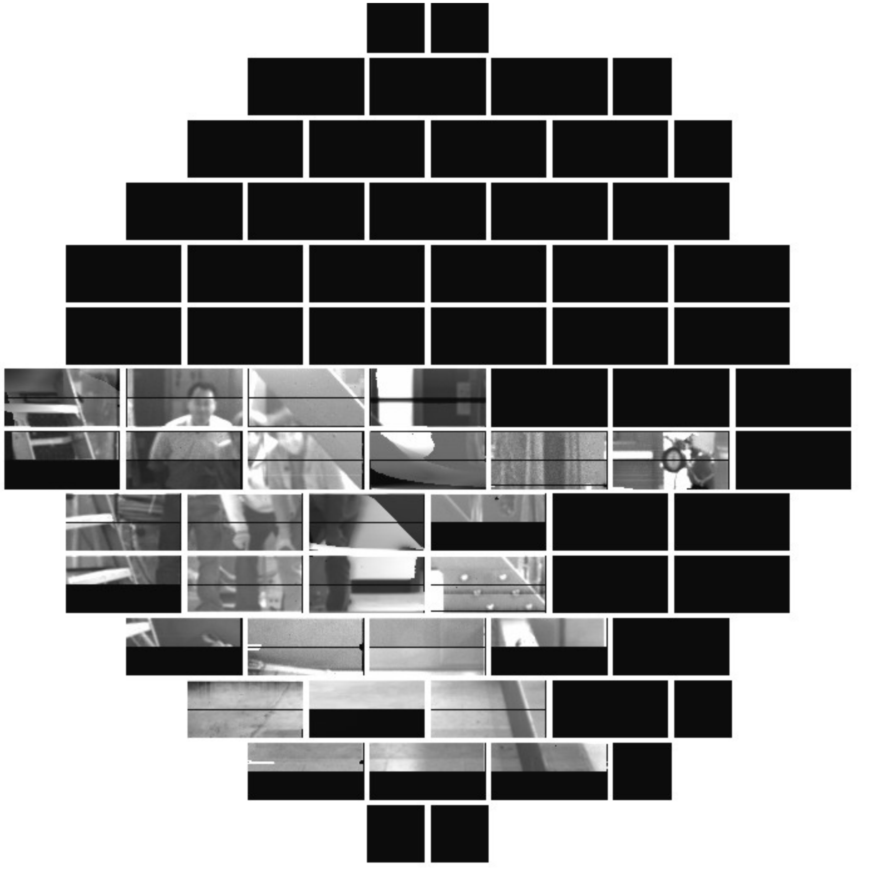
Flatness of the MCCD focal plane

- All CCD detectors need to be on the same plane so that they are all correctly focused.
- The DES specification for the flatness is all detectors are within a 60 microns envelope.



60 microns



Mosaic image taken from MCCDTV

Methods for measuring flatness

- Optics Based Method

  Using optical method to measure the flatness of the CCD detectors. See the method using opto-NCDT by Tom Diehl

- Image Based Method

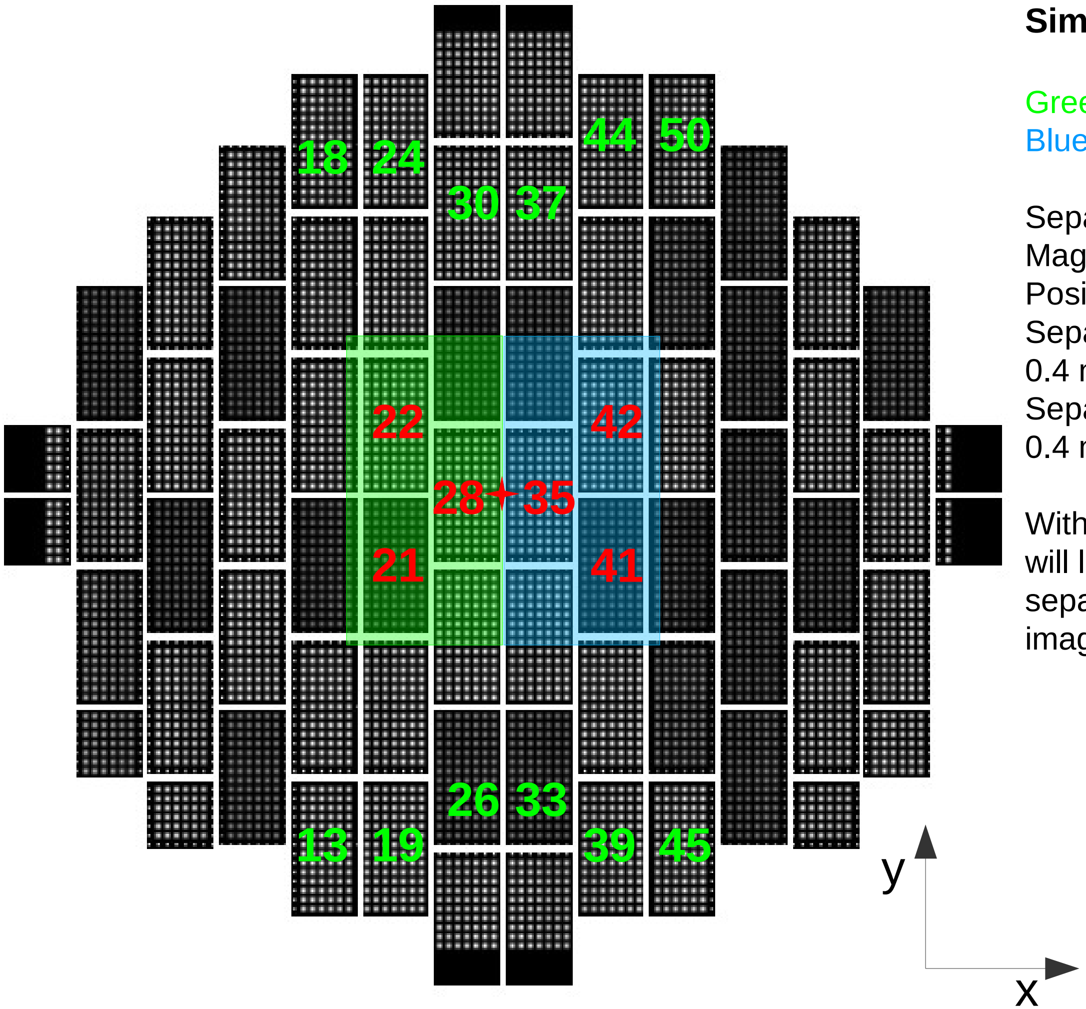
  Imaging some pattern on the CCDs and then measure the flatness of the CCDs by deformation of the patterns measured from the images.

- Image based methods directly measure the “flatness” that we will see from the real observation.
- They are complementary methods to the Optics Based Method

Method 1: “polka” dots projector

- We image a grid of dots on the full CCD focal plane and then extract the positions of the dots using sextractor.
- If there are offset among the detectors, the spacing of the grid dots will change.
- Looking at the distribution of the spacing among the nearest dots, we can see how much it is offset from the focal plane.

Realistic Simulation



Simulation parameters:

Green box: FP back by 4 pix
Blue box : FP forward by 4 pix

Separation between PH to FP: 150 mm
Magnification: 10.5
Position precision on image: 1 micron
Separation between neighboring dots on source: 0.4 mm
Separation between neighboring dots on image: 0.4 mm x 10.5 = 4.2 mm ~ 280 piexls

With this configuration, 4 pixel (60 microns) offset will lead to 0.106 pixel increase/decrease for the separations of neighboring pairs of dots on the image.

Thanks Huan and Nikolay for creating the simulated image

Distribution of separations

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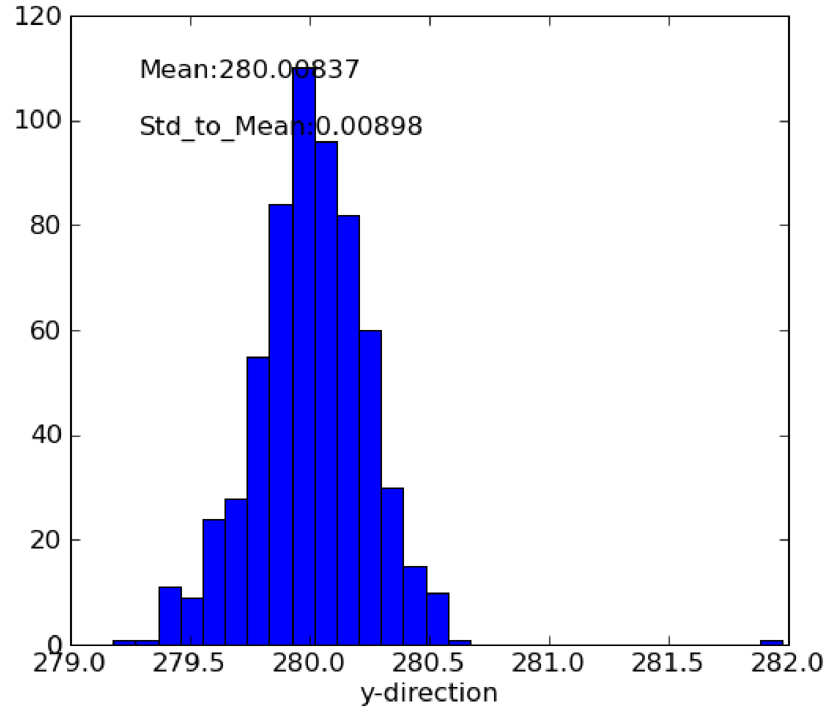
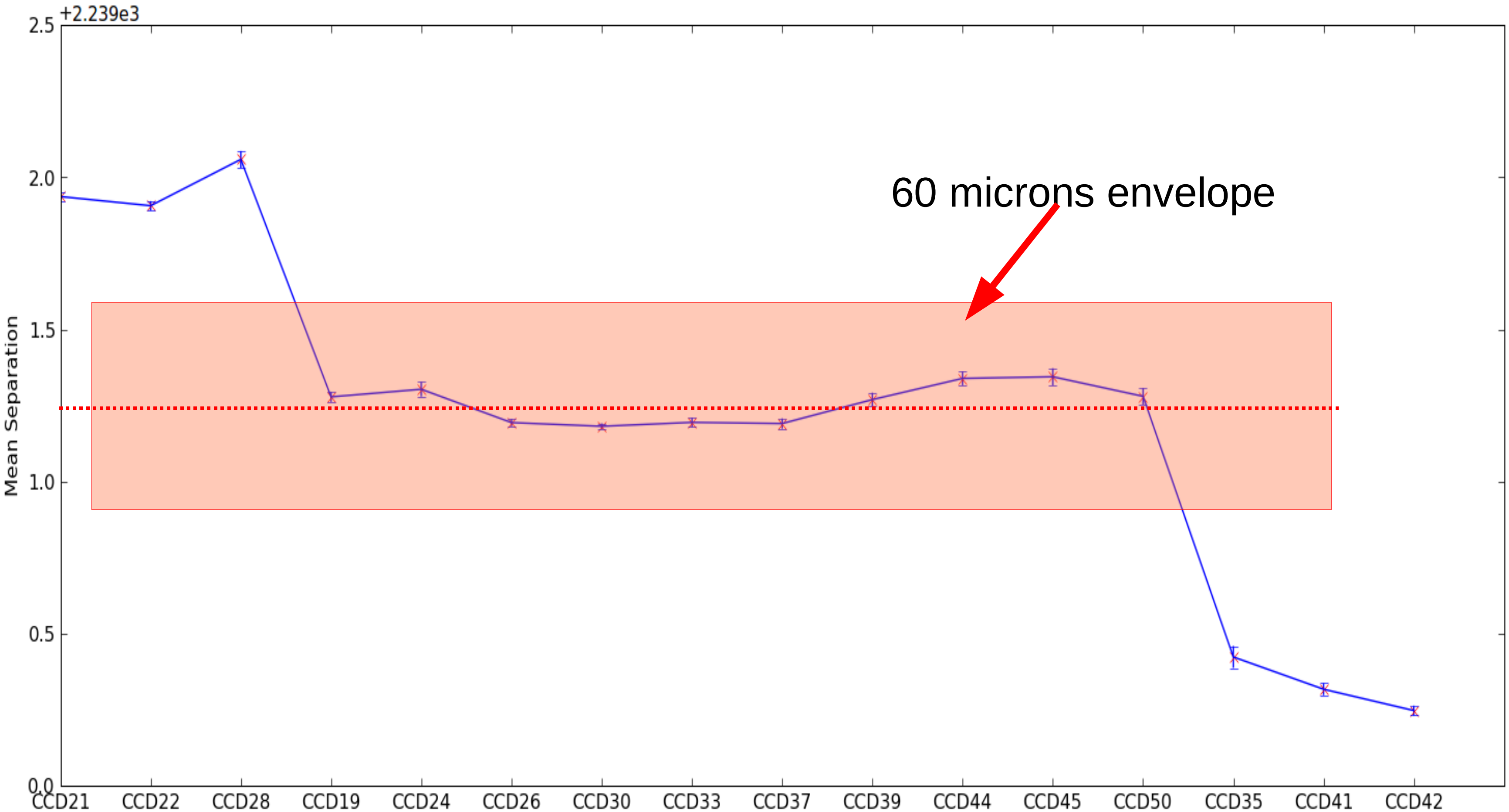
- We use Sextractor to extract the objects on the simulated images.
- For a given Channel, the distribution of the separations between neighboring dots along y direction follow a distribution as show by the right figure.



Flatness Results for Simulated Image



We look at the separations between 8th nearest dots. That means 4 pixels offset is converted to 0.106 x 8 = 0.848 pixels difference in separations.

Challenge of the polka method

- The analysis from “polka” dots are very straightforward. However, it requires high precision on the positions of the source. i.e., the position on the source plate need to be ~0.1 micron for our setup to achieve the quality of the measurement.
- We therefore have the method 2
- But the tools we developed here can be use to test the stability of the image when the imager is moved with the telescope simulator. This does not require high precision of the positions of the dots because we just measure the relative changes before and after it is moved.(I will introduce this at the last part)

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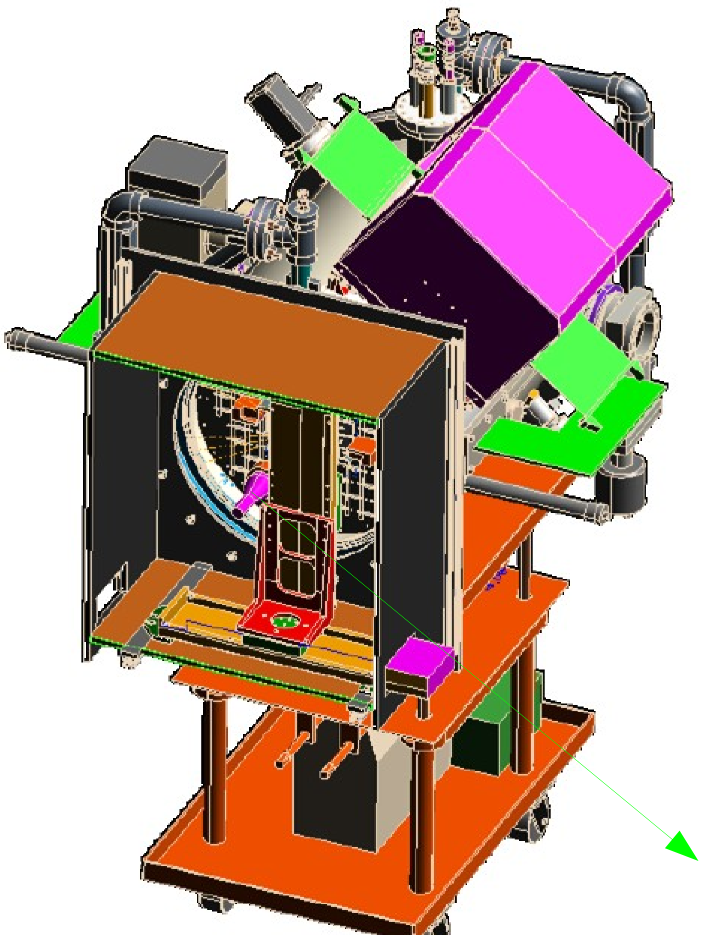
Method 2: Moving star projector by xy-stage

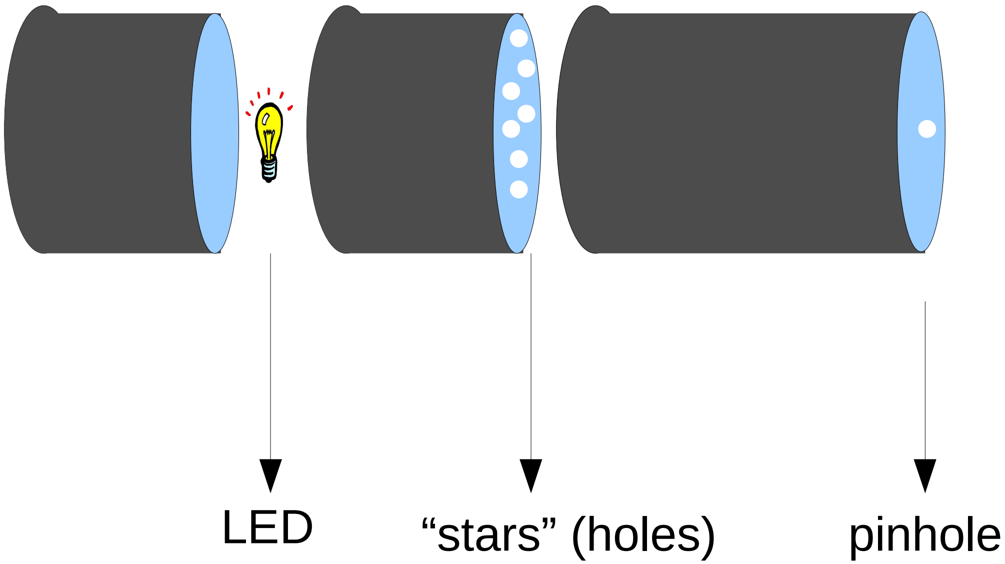
- Using the existing instruments (see left figure)
- Using “star-projector”, we can project many “stars” on CCD. Record the image as image1 and extract the positions of the “stars”.
- Move the star-projector along y(or x) direction for distance “d” and get another image2 for “stars”, recording their positions too.
- On image1, calculate the difference of y (or x) coordinates of every star with respect to one star.
- On image2, cross matching the objects and calculate the difference of y (or x) coordinates in a similar way.
- The change of separations will be turned into an estimator of the tilt of the plane.
- Repeat to get image3, … and we will have many measurements on the tangent of the angle.

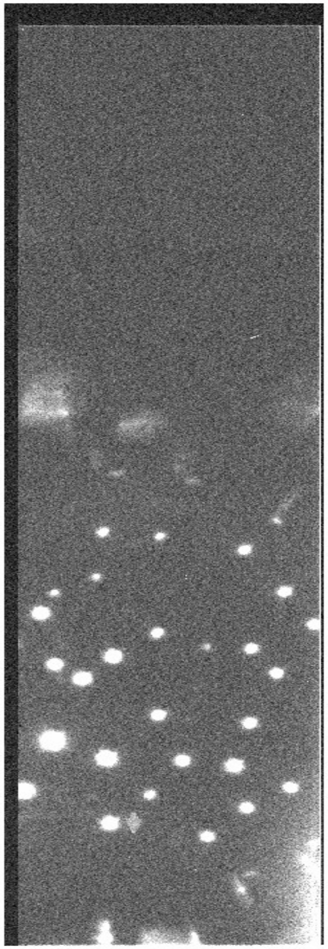


From doc: 3862 (Tom Diehl)

Replaced with star projector

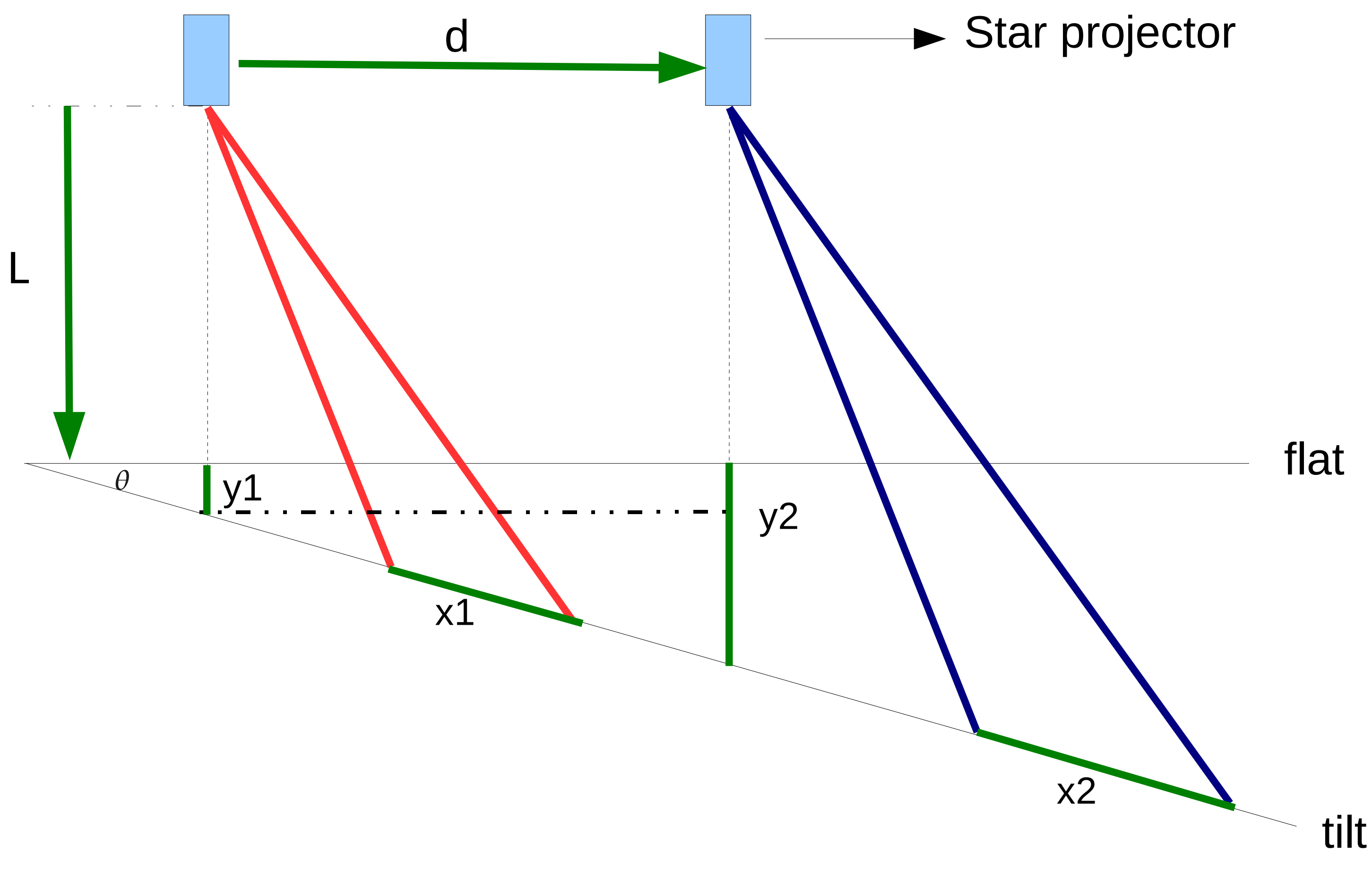
Star projector





CCD Image from star projector

Schematic



Geometric Relation

From the similarity of triangles

$$\frac{x1}{x2}=\frac{(L+y1)}{L+y2} \quad\Rightarrow\quad \frac{x2-x1}{x2}=\frac{(y2-y1)}{L+y2} \quad\Rightarrow\quad \frac{x2-x1}{x2}\times L\left(1+\frac{y2}{L}\right)=(y2-y1)$$

$$\tan(\theta)=\frac{y2-y1}{d}=\frac{(x2-x1)}{x2}\times\left(\frac{L}{d}\right)\times\left(1+\frac{y2}{L}\right)$$

$$y2 \ll L$$

Eq.1

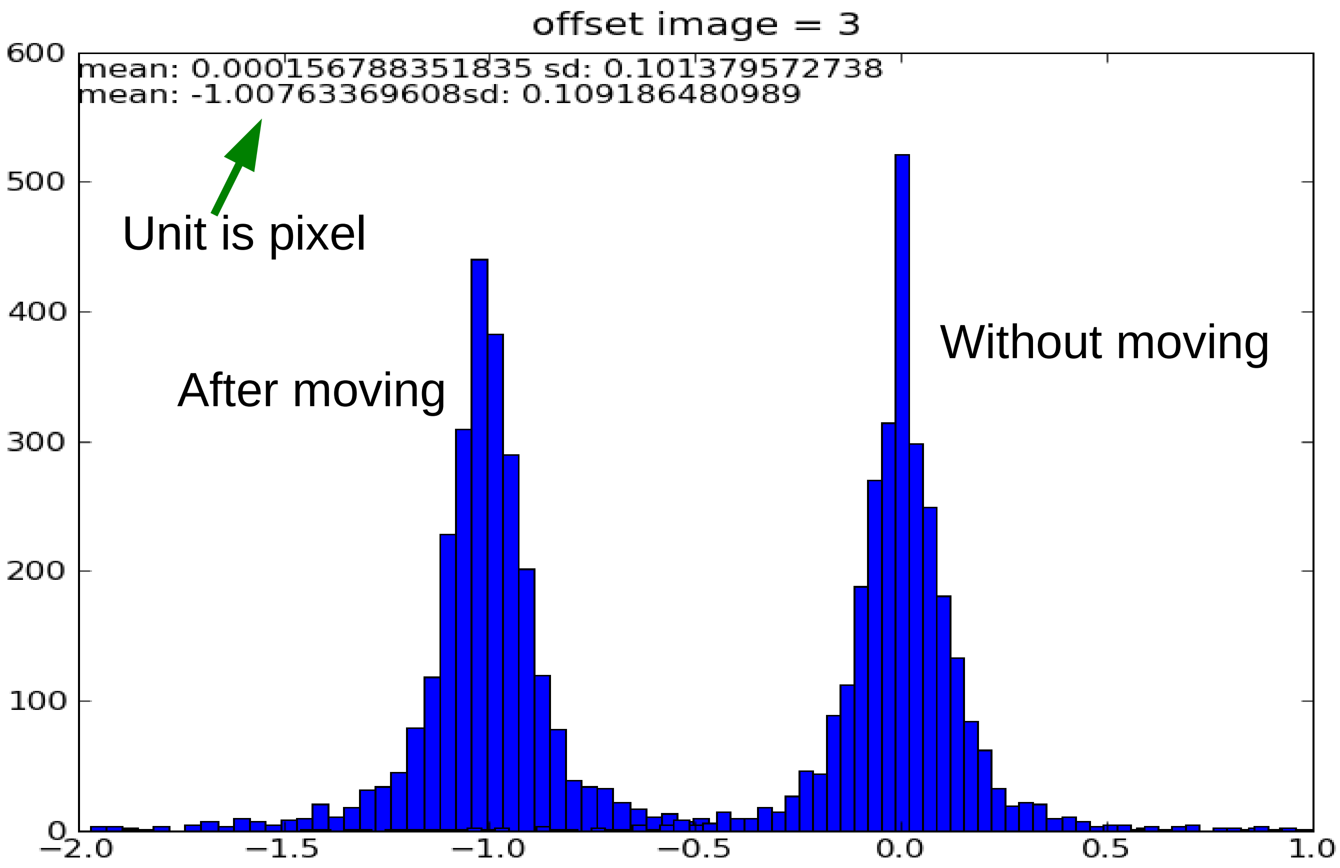
$$\boxed{\tan(\theta)=\frac{(x2-x1)}{x2}\times\left(\frac{L}{d}\right)}$$

All Measurable

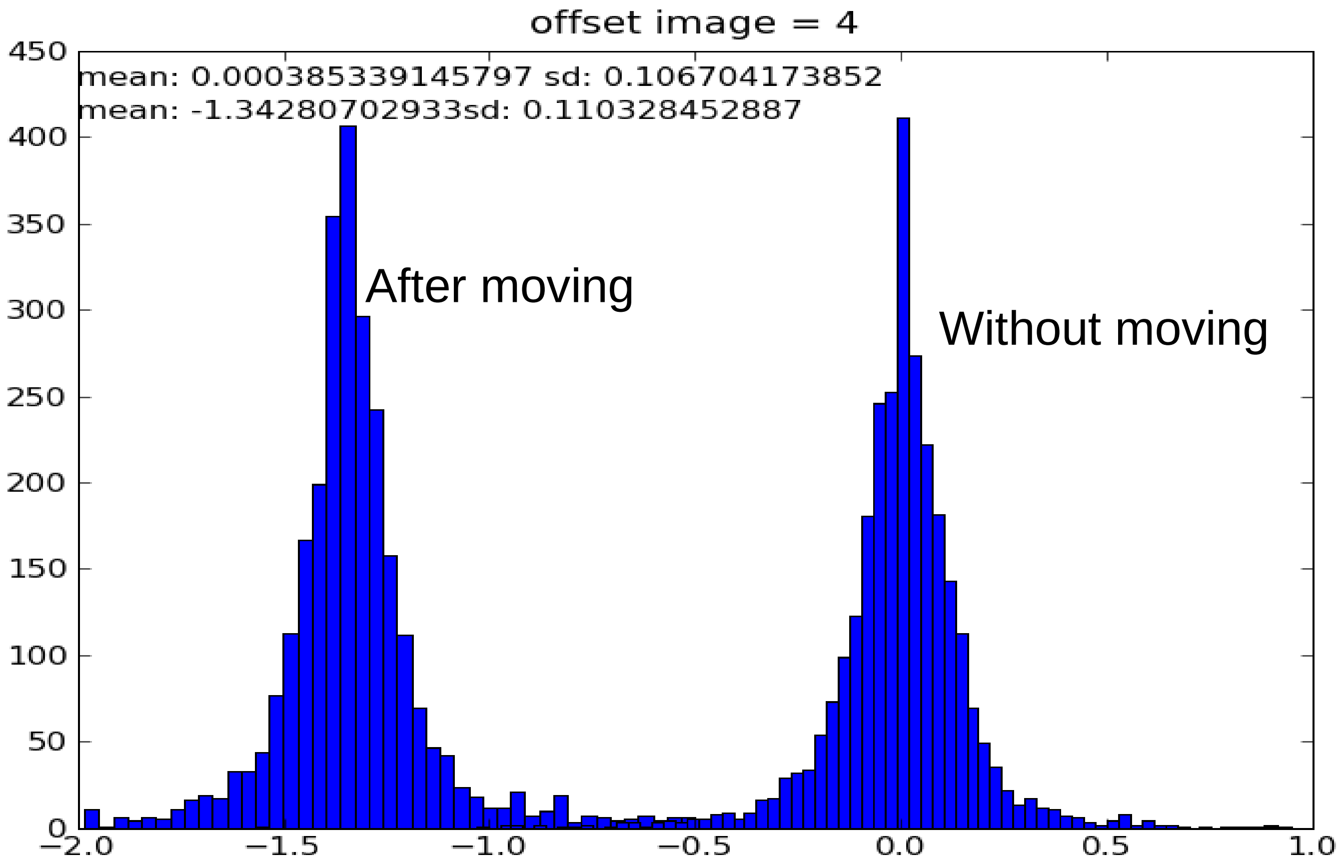
Calibrate the x-y stage

- Before we start our measurement, we need to be sure that the x-y stage can produce the precision displacement and we can recover this displacement from image measurement.
- First, we take an image as reference and extract the “star” positions as reference positions.
- Second, without moving the star projector, we take another image. We extract the positions of the “stars” and calculate the difference between them and the reference positions.
- Next, we move the star projector and take another image. Repeat the step 2.
- Then, we can compare the differences of the positions.

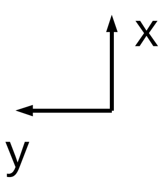
Move by 15 microns (1 pixel)



Move by 20 microns



Implementation



Move 1mm per step

d=1mm
L ~ 10 cm

We use an x-y stage to move the star projector along the y direction

One more cross-check with x direction

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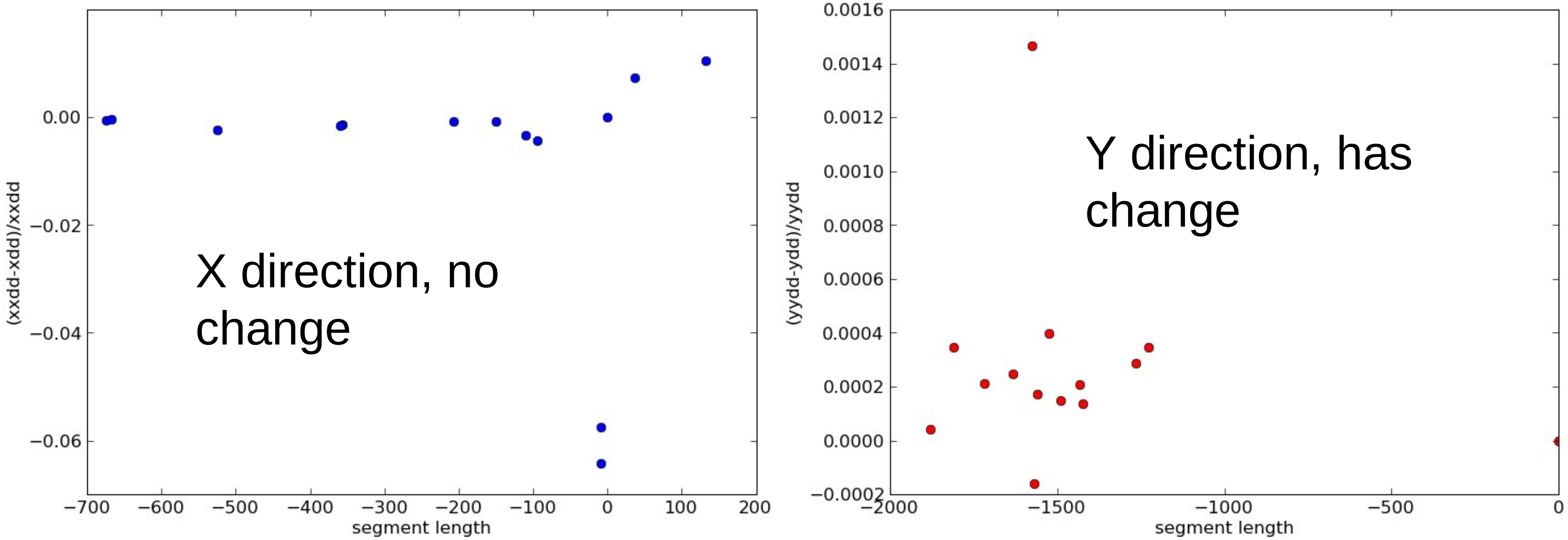
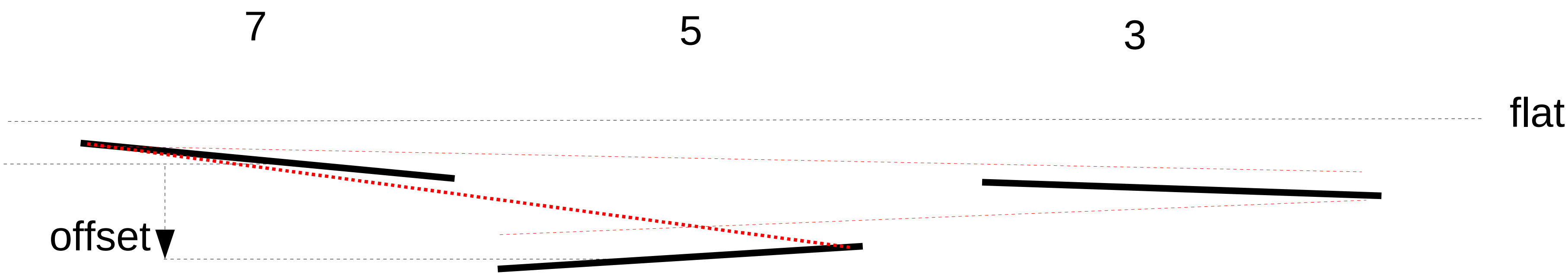
- If the above approach really works, then in x direction, we will not expect a change in the length of the separations among pairs of stars.
- Using extension 7, we check this. See the following plot



So, the method we are using do make sense.

Results



Angles:	Tangent:
7: 0.053	0.00093
5: -0.063	-0.00110
3: 0.0126	0.00022
7-5: 0.0784	0.00137
7-3: 0.0126	0.00022
5-3: -0.052	-0.00091

Based on the angles, the above is the possible configuration of the CCDs.

Offset 7-5: 60000*0.00137 ~ 82 microns
Offset 7-3: 120000*0.00022 ~ 26 microns
Offset 5-3: 60000*(-0.00091) ~ -54.6 microns

Note the uncertainty on Tangents are ~ 0.0002, corresponding to 12 microns. We can improve this by projecting more "stars".

Summary of the two methods

- We here show two image based methods to measure the flatness of the focal plane. They are direct measurements of the image quality.
- We are going to use the method 2 to measure the flatness as an independent cross check of the optical method by Tom Diehl.

Testing image quality in telescope simulator using polka dots projector

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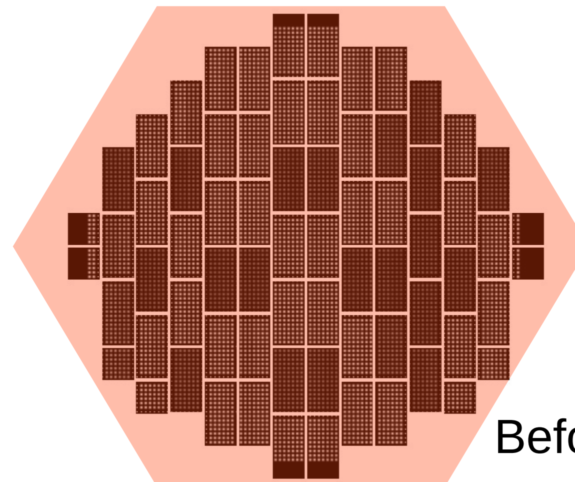
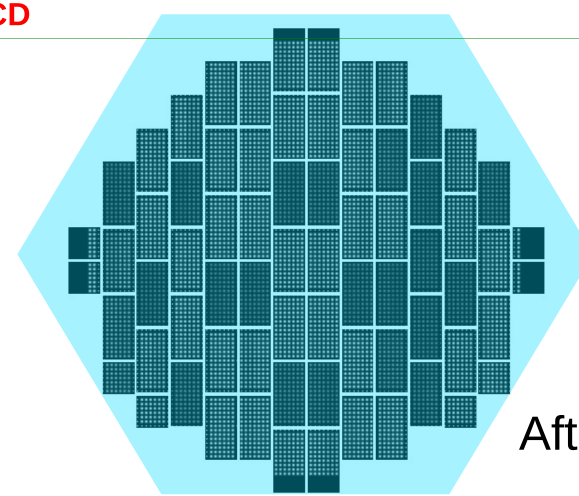
- The previous Method 1 can project a grid of polka dots on the full focal plane through pinhole.
- We can measure the relative changes of the polka dots positions when we move the imager
- We can measure the relative change of the photometry of the dots when the imager is moved.
- We have already developed the tools that can be used for this purpose.



Before move

Relative astrometric and photometric change can be measured using our existing tools CCD by CCD



After move

Our current plan for setup

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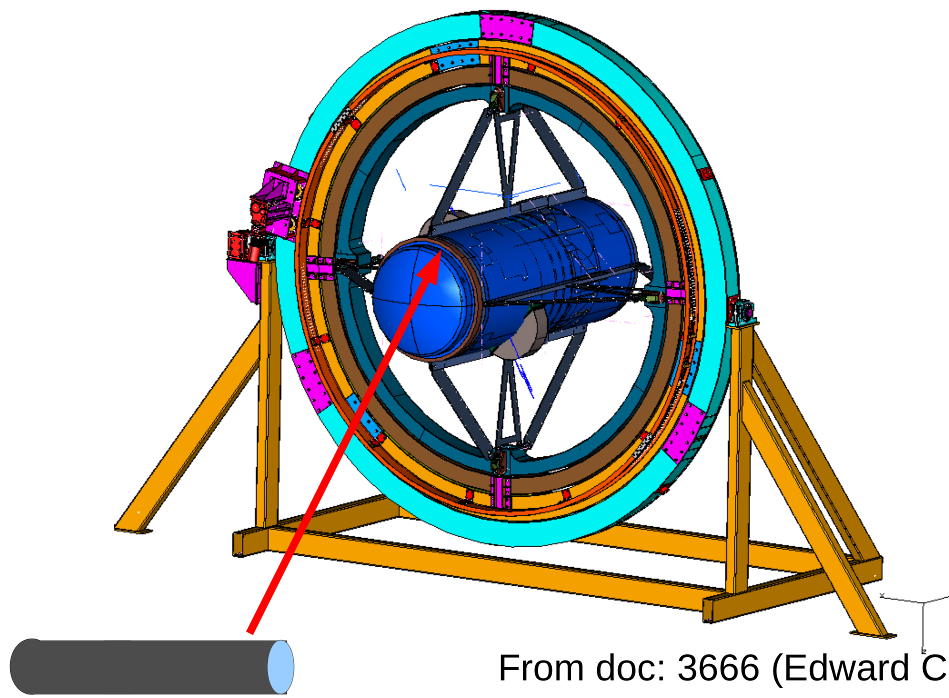
- Mount our polka dots projector on the cage (not the barrel)
- By this way, we will be able to measure the image stability and repeatability of the movements of the hexapod.



From doc: 3666 (Edward Chi)

Polka dot projector