PIR/corrector+Echidna Engineering Summary

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- Ver.1.0 : 2008/06/05 : Updated 2007/12 report with 2008/01,2008/05 engineering results
- Ver.-1.1 : 2008/01/18 : Bug fixed, the FPI coordinate of the distortion center is updated to be (2.4mm, 4.0mm) after applying the SKY and SPINE camera offset. Updated result is consistent with the offset between the CMM center and the rotator axis. The target was M38 (not M37).
- Ver.-1.0 : 2008/01/17 : Previous report circulated AAO/Kyoto/Subaru.

This is a summary of the Echidna engineering observations for the telesocpe model construction.

1 Converting the SKY CCD coordinate to the FPI XY coordinate

The relation between the SKY camera coordinate and the FPI XY coordinates is determined with stars taken with the SKY camera at multiple FPI XY positions (i.e. stars in the overwrapping regions). The CCD camera coordinate (local) can be converted to the FPI XY coordinate (global) with

$$
\begin{aligned}
X(\mathrm{FPI}) &= A \times X(\mathrm{CCD}) + B \times Y(\mathrm{CCD}) + C, \\
Y(\mathrm{FPI}) &= D \times X(\mathrm{CCD}) + E \times Y(\mathrm{CCD}) + F \\
C &= (\text{FPI encoder x coordinate} \\
&\quad +\text{X correction for the offset between the SKY and SPINE cameras}) \\
F &= (\text{FPI encoder y coordinate} \\
&\quad +\text{Y correction for the offset between the SKY and SPINE cameras})
\end{aligned} \tag{1}
$$

We use the SKY coordinate definition measured on the FITS images.

The XY offset between SKY and SPINE cameras are determined by aligning a guide fibre to a bright star. Two measurements were performed with the same guide fiber to different stars. There results are shown as parameters C and F in Table 1. Using these values as the offset between the SKY and SPINE cameras in relation (1), the coordinates measured with the SKY camera can be converted to the spine positions measured with the SPINE camera. (In order to align a star to guide spine No.168, we need to move telescope by $+878.48''$, $-243.09''$ (or $+901.76''$, $-258.28''$).

The FPI XY directions and the celestial coordinates NE directions are aligned well. The relation is summarized in Figure 1.

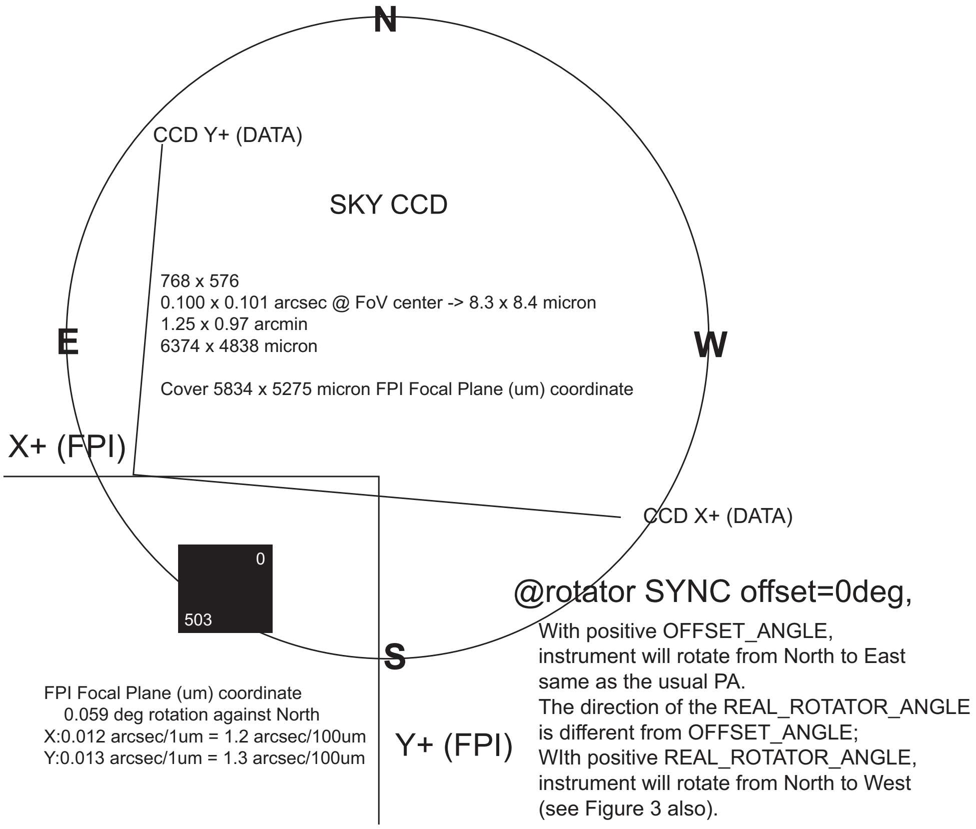

Figure 1: The relation between the sky camera CCD coordinate, the FPI XY coordinate, and the cerestial coordinate. It should be noted that the SKY camera Y coordinate is flipped on the data and the Echidna GUI window).

Date	A	B	C	D	E	F	Note
200712	-8.103	$+0.677$	$+3445$	-0.668	-8.268	$+2876$	175.3deg rotation
200712			$+3556$			$+2821$	
200805	-8.082	-0.251	$+3556$	$+0.388$	-8.673	$+2641$	
200805			$+3550$			$+2639$	

Table 1: The measured sky-camera to FPI coordinate converstion factors. Between 200712 and 200805, the sky-camera was re-installed.

Date	EL		Note
20071208	$\sim$80	$(-702,\ -727)$	
20080125	85	$(-826,\ -712)$	
20080125	27	$(-826,\ -712)$	No significant shift from El=85deg.
20080513	$\sim$80	$(-754,\ -567)$	

Table 2: The measured FPI coordinates of the rotator axis. Echidna re-installations happen between 200712 and 200801 and between 200805 and 200801. The shifts of the FPI coordinates reflect the shift of the Echidna against the rotator axis.

2 Rotator axis on the FPI coordinate

The FPI coordinates of the rotator axis correspond to the pointing center of the FoV, because the pointing center of the telescope is set at the rotator axis of the telescope. The axis of the rotator is measured by taking stars with the sky-camera with rotating the instrument. The measured CCD coordinate were converted to FPI coordinate using the relation (1). On 20080125, the rotation axis was measured at EL=85deg and at EL=27deg (At EL=27deg, the position of the FPI was keeped at $(0, 0)$ referring the FPI encoder values, otherwise the recorded star track is not on a circle due to the flexure of the FPI gantry. The movement of the FPI was $\pm 200\mu$m at most at EL=27deg). No shift was observed. The difference of the FPI coordinate of the pointing center between 20071208 and 20080125 measurements is $(-124, +15)$ (in μm), which represents the accuracy of the installation of Echidna unit to PIR enclosure (we remove Echidna 20080110 and re-install 20080117, it should be noted that this is not related to the accuracy of the PIR mounting accuracy).

3 Measuring the center of the distortion pattern

We observed open cluster fields with tiling the SKY camera FoVs in vertical and horizontal strips on the FPI coordinate. The data are taken with the instrument rotator with SYNC status, i.e. the instrument is rotated against the corrector - primary mirror system. The measured coordinates of the stars on the SKY camera were at first converted to the FPI XY coordinate using the above relation. Then the FPI XY catalog was cross matched with the RA-DEC catalog of the stars in the FoVs. Using the (X, Y, RA, DEC) file, the distortion pattern of the field is determined by ccmap command in IRAF. One measurement of the distortion pattern is shown in Figure 2. The offset from the plate scale at the center of FoV is shown as the optical distortion pattern. The distortions are determined by ccmap command in IRAF. The measured distortion is consistent with the ray trace result shown with green lines and dots. The FPI XY coordinate

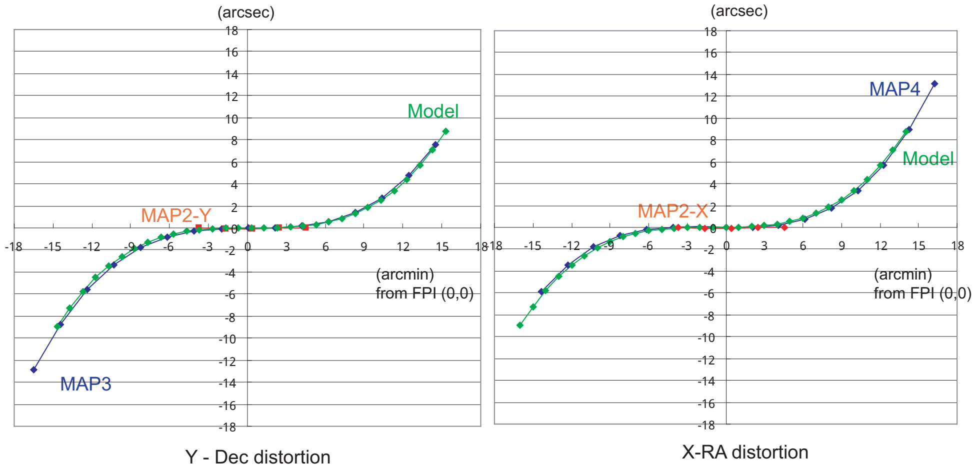

Figure 2: The measured distortion of the corrector lens in 20071224 with rotator angle of −97deg. Horizontal axis is the distance from the FPI (0,0) position in arcmin. Vertical axis is the offset from the 0.01240 (or 0.01237) arcsec/μm in arcsec. Left) in Y (or Dec) direction, MAP2-Y and MAP3 results are shown in red and blue, respectively. Ray trace model is shown in green. The model is offsetted by −0.39arcmin (−1.9mm) to match the observed distortion curve. Right) in X (or RA) direction, MAP2-X and MAP4 results are shown in red and blue, respectively. Ray trace model is shown in green. The model is offsetted by −0.95 arcmin (−4.6mm).

of the distortion center was estimated to be (−4.6mm,−1.9mm) for this measurement.

In the nights of 20080124 and 20080125, the same measurements are done with changing the rotator angle. The results are summarized in Table 1 and Figure 3. Using the data, the center of the rotation axis is estimated to be (−0.7mm, −0.7mm) on the FPI coordinate. The position is consistent with the sky camera measurements as shown in Section 2. The distance between the rotation axis and the distortion center are summarized in the 7th column in the table.

The estimated positions of the distortion center and the rotator axis, and the relation between the CMM coordinate and the FPI XY coordinate are shown in Figure 4.

4 Summary of 1st pass telescope model with sky camera

In order to refine the telescope model further, several 10s stars scattered in FoV are observed with the sky-camera (Item 6.9: 1st pass telescope model with sky camera). The offset between the predicted position using a telescope model and the observed position were measured for each star. Using the measured offsets, the telescope models were refined further by multiple parameter fitting. The obtained data were fitted with the telescope model with the rotation, the distortion parameters (1st, 3rd, 5th orders), and offset of the distortion as free parameters.

The first observations were performed on 20080127 with M35. 69 11th magnitude stars were observed. The first refined telescope model was determined with $0.67''$ RMS

On the night of 20080513 and 20080514, multile fields were observed. The telescope model fitting results are summarized in Table 4. The observed offsets and the residual of the fitting for the offsets were shown in the top left and right panels, respectively, of Figure 5 for field5. The observed offsets for field5, 6, and 7 were similar, and the fitted results were sufficiently consistent. The residuals of the fitting were $0.43''$ RMS and there remains systematic pattern

Date	EL	Rotater	CMM	FAM	Distortion Cnt.	Dist	Scale (″/mm)
20071224	45	−97	(+4.0, −4.0)	+0.60	(−4.60, −1.94)	4082	(12.398, 12.401)
20080124	30	+0	(+3.7, −3.8)	+0.55	(+0.98, −4.63)	4314	(12.405, 12.409)
	30	−90	(+3.7, −3.8)	+0.55	(−4.54, −2.72)	4222	(12.411, 12.401)
	30	+90	(+3.7, −3.8)	+0.55	(+3.18, +0.97)	4344	(12.409, 12.401)
	30	+180	(+3.7, −3.8)	+0.55	(−2.74, +3.26)	4409	(12.420, 12.416)
20080125	85	+6	(+3.7, −3.8)	+0.60	(+1.68, −4.26)	4344	(12.405, 12.405)
	85	−84	(+3.7, −3.8)	+0.60	(−4.67, −3.72)	4881	(12.400, 12.403)
	85	−174	(+3.7, −3.8)	+0.60	(−3.35, +3.13)	4597	(12.404, 12.402)
	85	+96	(+3.7, −3.8)	+0.60	(+3.00, +1.65)	4496	(12.404, 12.408)
20080513			(+4.7, −4.2)	−5.00			

Table 3: Summary of the results of the distortion center measurements.

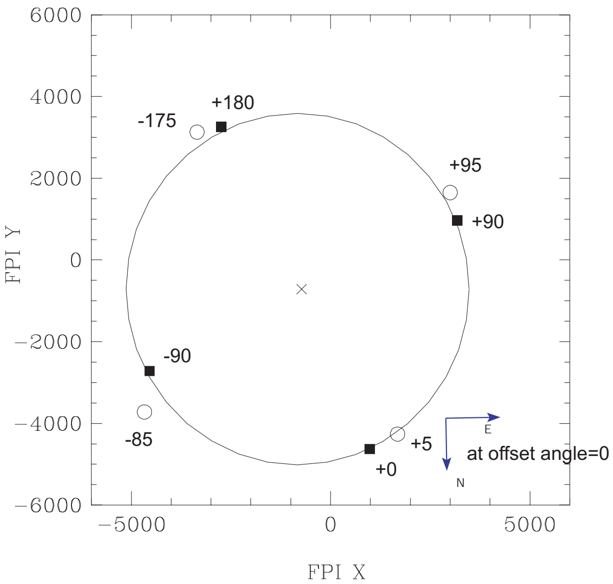

Figure 3: Summary of the results of the distortion center measurements. The numbers in the figure indicate the ROTATOR_REAL_ANGLE during the measurements. The cross mark indicates the measured position of the rotator center. The measured distortion centers circles arount the rotator center with radius of 4.3mm. The direction of the ROTATOR_REAL_ANGLE is different from the OFFSET_ANGLE.

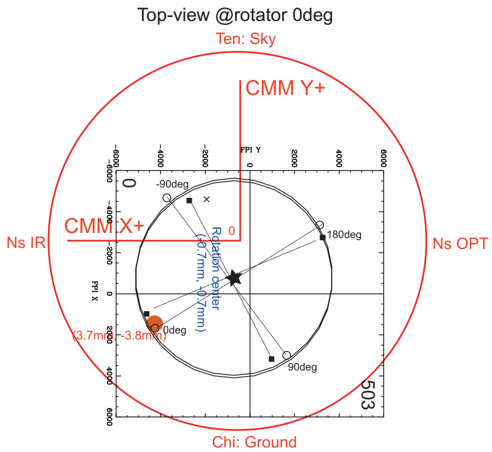

Figure 4: The position of the distortion center and the rotator axis, and the relation between the CMM coordinate and the FPI XY coordinate, evaluated based on the CMM position (($+3.7$mm, -3.8mm) in the CMM coordinate) of the measurements, the rotator angle ($\sim$ 0deg), and the distortion center results. The zeropoint of the CMM coordinate is estimated to be (-2.1mm, -0.6mm) on the FPI XY coordinate, thus the offset between the CMM center and the rotation center is (-1.4mm, $+0.1$mm), which is roughly consistent with the measured offset between the CMM center and the rotation center ($\sim$1mm, $\sim$1mm). (!!! It need to be confirmed that the CMM coordinate is aligned with FPI coordinate !!!).

in the middle of the field.

We applied the telescope model determined from field5 and observed field8 and field9. The observed offsets are shown in the bottom panels of Figure 5 for field9. The observed offsets still show a systematic pattern, but the residuals after fitting the observed offsets look sufficiently random as shown in the right panel. It need to be noted that the OffsetX and OffsetY parameters were significantly different from those determined in field5(field6,field7) and field9(field8). We still need to carefully watch these parameters during the further observations. The RMS of the residuals is $0.32''$. We should use the telescope.model refined based on the field9 observation.

5 Acquiring guide stars with guide bandles

After the determination of the telescope model, we tried to acquire guide stars with the guide bandles. The required telescope offset to acquire the guide stars are summarized in Table 5. For these observations XERR=+2355 and YERR=+2231 are used. We need to update these values using the observed systematic offsets.

6 Appendix

FieldID	Date	PA(OFF)	Angle	Dist1	Dist2	Dist3	OffsetX	OffsetY	RMS	No.
field5	20080514	0(0.52)	0.0094	0.29055	0.04205	0.06522	8284.24	−1031.67	0.43	70
field6	20080514	180(−118.1)	0.0047	0.29062	0.03769	0.12886	7966.91	−365.99	0.44	69
field7	20080514	90(−25.76)	0.0120	0.29055	0.04287	0.04349	6558.55	−3925.39	0.44	39
field2	20080514	0(−51.7)	0.0046	0.29055F	0.04205F	0.06522F	8284.24F	−1031.67F	0.34	17
field3	20080514	−90(43.8)	−0.0001	0.29055F	0.04205F	0.06522F	8284.24F	−1031.67F	0.55	16
field4	20080514	−180(136.6)	−0.0095	0.29055F	0.04205F	0.06522F	8284.24F	−1031.67F	0.53	17
field8	20080514	0(70.3)	−0.0157	0.29043	0.04558	0.01920	3355.42	2601.85	0.45	47
field9	20080514	0(71.2)	−0.0190	0.29065	0.03667	0.11354	2749.29	2877.59	0.32	79

Table 4: The results of the 1st pass telescope model with the sky-camera. Angle, Dist1, Dist2, Dist3, OffsetX, and OffsetY are the fitting results. For field2, field3, and field4, the distortion parameters were fixed because the number of available stars were small. The field7 and field8 were observed after appling the telescope model determined in field5. The resulting RMS values and the number of the stars are shown in the last two columns. OffsetX and OffsetY are offsets of the distortion pattern from the center of the pointing (the axis of the rotator). The best OffsetX,Y for field5-7 look not consistent with the measured offset shown in Figure 3. The results for field8,9 are roughly consistent (it shold be noted that the CMM positions were $(+4.7, -4.2)$ for 20080514).

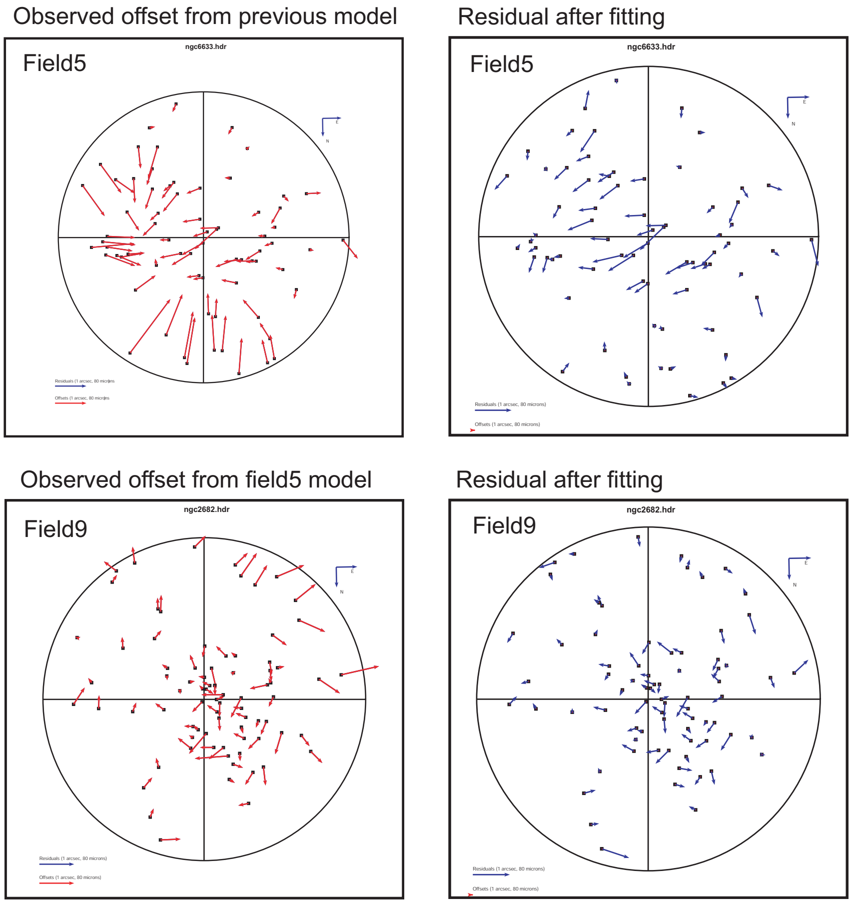

Figure 5: The measured offsets (left panels) and the residuals after fit for the measured offsets (right panels). The top panels are for field5 and the bottm panels are for field9. The measurements for field9 were done after appling the telescope model determined in the field5. FPI X+ is to the right, and FPI Y+ is to the top.

ID	RAoffset	DECoffset
field5	$-7.0''$	$+16.5''$
field9	$-4.5''$	$+14.8''$
field10	$-5.3''$	$+16.6''$
field11	$-3.0''$	$+14.2''$
field12	$-13.8''$	$+7.0''$
average	$-5.0''$	$+15.5''$
	$-416(\mu\mathrm{m})$	$-1292(\mu\mathrm{m})$

Table 5: Summary of the required offsets to acquire guide stars in several fields. After slewing telescope, the telescope needed to be moved in the above amount in order to acquire guide stars. The last line indicates the required corrections for the XERR and YERR, i.e. XERR and YERR needs to be 1939 and 939, respectively (NEED TO BE CHECKED!)

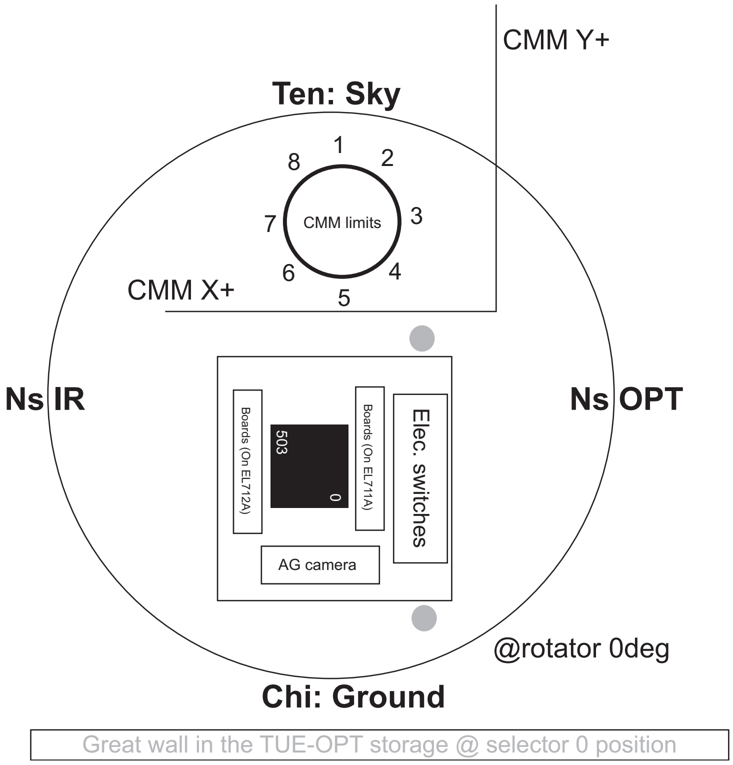

Figure 6: The relation between the Echidna unit and the PIR/CMM unit at rotator angle of 0 degree. !!! INCONSISTENT WITH FIGURE 3, NEED TO BE CHECKED FURTHER !!!