PIR/corrector+Echidna Engineering Summary

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- Ver.2.1 : 2008/08/11 : Bug fixed.
- Ver.2.0 : 2008/08/10 : Updated with 2008/06 engineering results (200805eng/200806eng.tex)
- Ver.1.0 : 2008/06/05 : Updated 2007/12 report with 2008/01,2008/05 engineering results (200805eng/200805eng.tex)
- 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 (positioner/ECH_test/200801eng.tex). 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 by taking stars with moving SKY camera in FPI X and Y directions. The determined relation between CCD camera coordinate (local) and the FPI XY coordinate (global) is described 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, i.e. (0,0) at the bottom left of the 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

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	
200808							Need to be checked

Table 1: The measured sky-camera to FPI coordinate converstion factors. The sky-camera was re-installed between 200712 and 200805 and between 200805 and 200808.

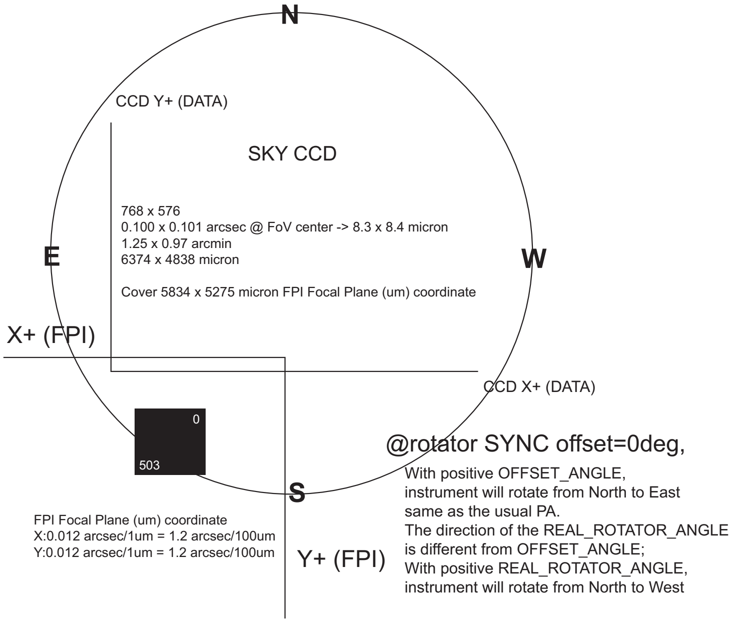

Figure 1: The relation between the sky camera CCD coordinate, the FPI XY coordinate, and the cerestial coordinate. It should be noted that the SKY camera Y coordinate is flipped on the data and the Echidna GUI window.

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.

2 Rotator axis on the FPI coordinate

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 $(-124,+15)$

Date	EL		Note
20071208	∼80	(−702, −727)	
20080125	85	(−826, −712)	
20080125	27	(−826, −712)	No significant shift from El=85deg.
20080513	∼80	(−754, −567)	
20080617	∼80	(−739, −577)	This value used
20080617		(−666, −597)	
200808			Need to be checked

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.

(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 movement of the center of the distortion pattern (1)

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 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. The center of the circle of the distortion pattern movement is consistent with the rotator axis described in Section 2.

4 Measuring the center of the distortion pattern (2)

The movement of the distortion pattern is further examined with the sky-camera mapping. In order to reduce the error caused by the tracking error etc, we only observed 10 stars at the edge of the field of view with a few stars at the center on the nights of 20080617. The results are summarized in Figure 4. As we expect, the radius of the circle of the distortion pattern movement changes as we change the position of the CMM. The radius of the circle and the center of the distortion pattern at ROTATOR_REAL_ANGLE=0deg is determined by fitting circle to the data points. The center of the circle is fixed at the measured rotator axis. The resulting best fit circles are shown in the figure. The residual of the fitting is 514mum rms. for the $(4700, -4200)$ dataset taken on 20080617.

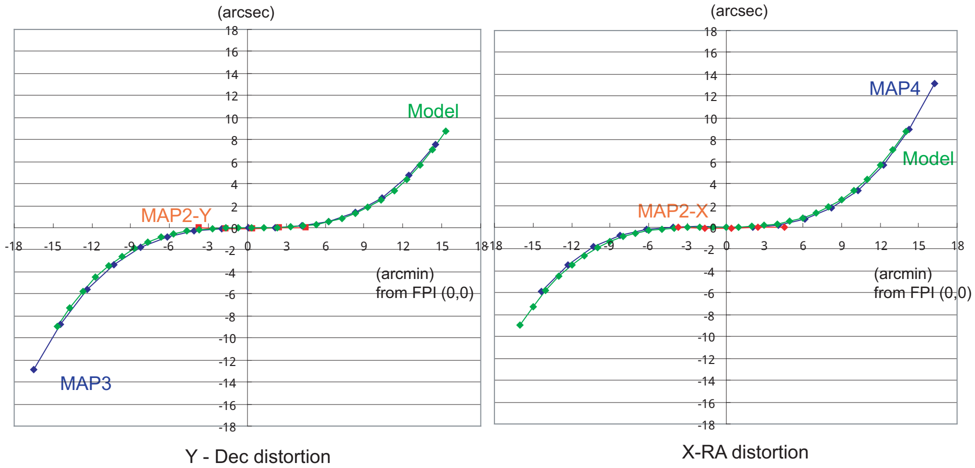

Figure 2: The measured distortion of the corrector lens in 20071224 with rotator angle of −97deg. Horizontal axis is the distance from the FPI (0,0) position in arcmin. Vertical axis is the offset from the 0.01240 (or 0.01237) arcsec/μm in arcsec. Left) in Y (or Dec) direction, MAP2-Y and MAP3 results 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).

Date	EL	Rotator	CMM(mm)	FAM	Distortion Cnt. (μm)	Scale (″/mm)
20071224	45	−97	(+4.0, −4.0)	+0.60	(−4600, −1940)	(12.398, 12.401)
20080124	30	+0	(+3.7, −3.8)	+0.55	(+980, −4630)	(12.405, 12.409)
	30	−90	(+3.7, −3.8)	+0.55	(−4540, −2720)	(12.411, 12.401)
	30	+90	(+3.7, −3.8)	+0.55	(+3180, +970)	(12.409, 12.401)
	30	+180	(+3.7, −3.8)	+0.55	(−2740, +3260)	(12.420, 12.416)
20080125	85	+6	(+3.7, −3.8)	+0.60	(+1680, −4260)	(12.405, 12.405)
	85	−84	(+3.7, −3.8)	+0.60	(−4670, −3720)	(12.400, 12.403)
	85	−174	(+3.7, −3.8)	+0.60	(−3350, +3130)	(12.404, 12.402)
	85	+96	(+3.7, −3.8)	+0.60	(+3000, +1650)	(12.404, 12.408)
20080513			(+4.7, −4.2)	−5.00		

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

	CMM position	Dist.Shift.Rot0	Fitted Dist.Shift.Rot0
20080125	(3700, −3800)	(1230, −4652)	(1455, −4752)
20080617	(4700, −4200)	(2465, −5390)	(2409, −5445)
20080617	(3200, −4000)	(1121, −4260)	(1074, −4301)
20080617	(3700, −4500)	(1743, −4769)	(1623, −4570)

Table 4: The best-fit distortion pattern center at ROTATOR_REAL_ANGLE=0.0 compared with the CMM positions. Fitted Dist.Shift.Rot0 shows Dist.Shift.Rot0 determined with equation shown in Sect.4. All values are in μm.

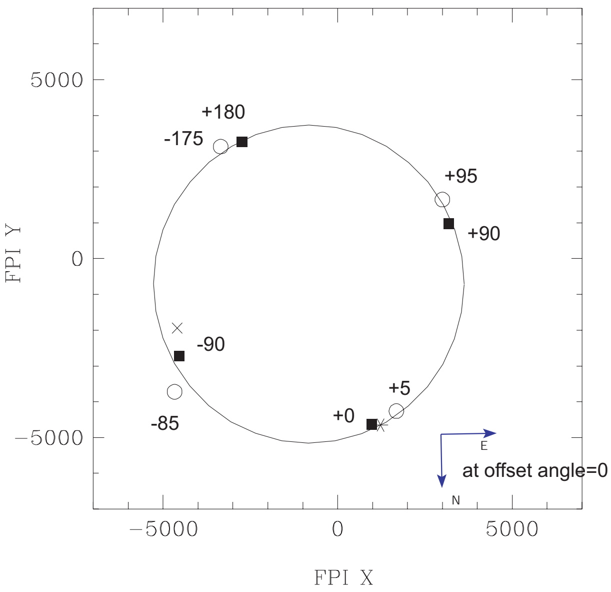

Figure 3: The measured positions of the distortion pattern center on the FPI coordinate from 200801 engineering observations. The numbers in the figure indicate the ROTATOR_REAL_ANGLE during the measurements. The measured distortion centers locate on a circle around the rotator center with radius of 4.444mm (shown with the large circle). The asterisk indicate the best fit position of the distortion center at ROTATOR_REAL_ANGLE=0.0. (The direction of the ROTATOR_REAL_ANGLE is different from the OFFSET_ANGLE.)

The center of the distortion pattern at ROTATOR_REAL_ANGLE=0.0degree is summarized in Table 4. The conversions between the centers and the CMM positions are determined assuming coordinate conversion with shift, scale, and rotation. The conversion is,

$$\begin{aligned} \mathrm{DISTCEN\_FPIX\_0} &= A \times \mathrm{CMMX}(\mu\mathrm{m}) + B \times \mathrm{CMMY}(\mu\mathrm{m}) + C, \\ \mathrm{DISTCEN\_FPIY\_0} &= D \times \mathrm{CMMX}(\mu\mathrm{m}) + E \times \mathrm{CMMY}(\mu\mathrm{m}) + F \\ A &= 0.644 \\ B &= -0.807 \\ C &= -4152.4 \\ D &= -0.807 \\ E &= -0.644 \\ F &= -4334.2 \end{aligned} \tag{2}$$

The best-fit scale is 1.033. The CMM coordinate is 51 degree rotated against the FPI coordinate. The rms is 141μm and 243μm in FPIX and FPIY coordinates. The origin of the CMM is at (4152, 4334) on the FPI coordinate. This looks inconsistent with the measured offset between the CMM center and the rotator center (~1mm, ~1mm).

Using the center of the distortion pattern as described above, we fit the sky-camera mapping results again in order to refine the distortion model parameters. The results are shown in Table 5. The distrotion model parameters are not consistent each other yet, the measurements can be affected by telescope tracking error during measurements. Further refinement need to be done.

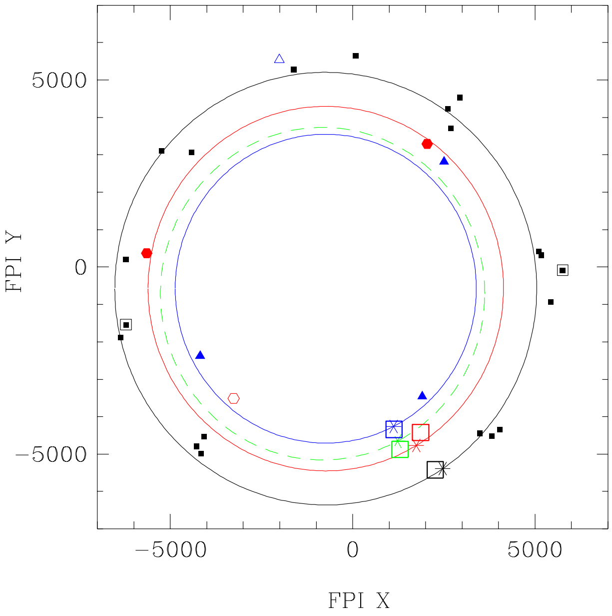

Figure 4: The measured positions of the distortion pattern center on the FPI coordinate from 200805 (only two points marked with filled square with large open square) and 200806 engineering observations. 200806 results shown with filled symbols are used for determine the best fit circle. Black, blue, and red symbols represents results with CMM at (4700,-4200), (3200, -4000), and (3700, -4500). The asterisk indicate the best fit position of the distortion center at ROTATOR_REAL_ANGLE=0.0. The results of 200801 (shown in the previous figure) are shown with green symbols.

Date	FieldID	PA(OFF)	Angle	Dist1(θ)	Dist2(θ^3)	Dist3(θ^5)	Dist4(θ/λ)	residual($''$)
Design	value			0.291950	0.0445	0.0364	−0.197	
Required	accuracy			0.000032	0.000540	0.00842		
20080514	field5	0(0.52)	0.00214	0.290461	0.046430	0.001194	−0.197F	0.16
20080514	field6	180(−118.1)	-0.00071	0.290559	0.042003	0.049526	−0.197F	0.19
20080514	field9	0(71.2)	0.00115	0.290434	0.051681	0.001150	−0.197F	0.16
20080617	field50	90(108.1)	0.00157	0.290539	0.042683	0.049064	−0.197F	0.17

Table 5: The distortion model parameters determined for each field. Distortion parameter change which will make 0.1$''$ difference at the edge of FoV shown as “Required accuracy”.

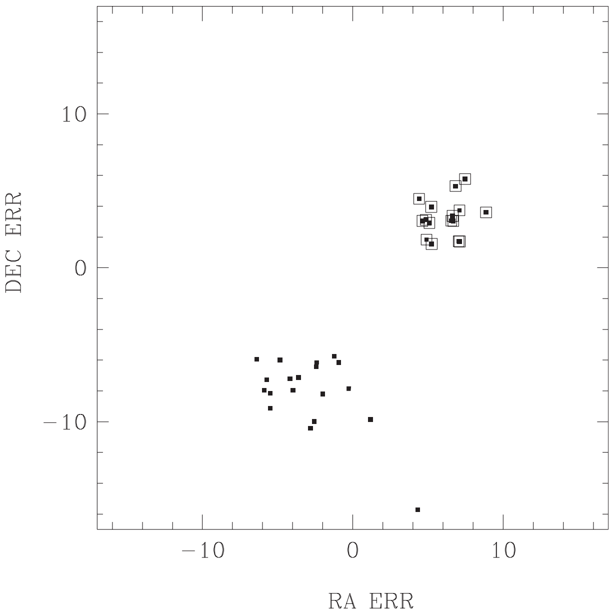

Figure 5: Measured pointing error for various field, the difference of the RA-DEC coordinate of the rotation center from the target RA-DEC coordinate. Data taken before meridian are marked with open squares.

5 Pointing center

Currently, the rotator axis is refered as the pointing center of the telescope, but the rotator axis does not match the origin of the FPI coordinate as described in Section 2. The configuration of the fiber is caluculated from the origin of the FPI coordinate, and the RA-DEC coordinate of the origin need to be supplied to the fiber configuration software. The difference between the pointing center of the telescope and the origin of the FPI coordinate is handled with the environmental variables, POINTING_ERR_RA and POINTING_ERR_DEC (the naming sounds not appropriate, needs to be changed...).

We evaluate the pointing errors with the current telescope pointing model (determined by PA) by checking RA-DEC coordinate of the rotator axis with the sky-camera mapping data. The resuling offsets between the target coordinate and the RA-DEC coordinate of the rotator axis is shown in Figure 5. There is a large offset between the data points taken before and after meridian. Need to be checked..

6 Appendix: calibration items summary

IF WE RE-INSTALL SKY-CAMERA, then we need to determine the relation between SKY-camera coordinate and FPI coordinate as described in Section 1 and Table1. SKYC_ environmental variables need to be updated.
IF WE RE-INSTALL ECHIDNA TO PIR, the position of the rotator axis on the FPI coordinate can be changed. We need to determine the rotator center on the FPI coordinate as described in Section 2 and Table 2. ROTATOR_AXIS_X and ROTATOR_AXIS_Y, and POINTING_ERR_RA and POINTING_ERR_DEC environmental variables need to be updated.

The relation between the CMM coordinate and the FPI coordinate can be changed (param-

Parameter	Value	Note
SKYC_AKIYAMA_A	-8.082	see Sec.1. TBC.
SKYC_AKIYAMA_B	-0.251	see Sec.1. TBC.
SKYC_AKIYAMA_C	3550.0	see Sec.1. TBC.
SKYC_AKIYAMA_D	0.388	see Sec.1. TBC.
SKYC_AKIYAMA_E	-8.673	see Sec.1. TBC.
SKYC_AKIYAMA_F	2639.0	see Sec.1. TBC.
SKYC_CENTRE_X_OFFSET	1081	
SKYC_CENTRE_Y_OFFSET	-776	
ROTATOR_AXIS_X	−739	Currently explicitly coded in echTelMdl.cc
ROTATOR_AXIS_Y	−577	Currently explicitly coded in echTelMdl.cc
POINTING_ERR_RA	−9.12	At PA=0, for FPI(0,0), this needs to be **subtracted** from commanded RA
POINTING_ERR_DEC	+7.20	At PA=0, for FPI(0,0), this needs to be **subtracted** from commanded DEC
telescope.model No.10	0.290549	see Tab.5 need to be refined
telescope.model No.11	0.042343	see Tab.5 need to be refined
telescope.model No.12	0.049295	see Tab.5 need to be refined
telescope.model No.13	−0.197	need to be checked with tel.rastering.
telescope.model No.23	−2465	depends on CMM position, see Sec.4,Tab.5, **sign is inverted from Tab.4,Fig.4 by definition**
telescope.model No.24	5390	depends on CMM position, see Sec.4,Tab.5, **sign is inverted from Tab.4,Fig.4 by definition**
telescope.model No.25	Not used	echTelMdl.cc revised such that No.23,24 refer to ROTATOR_REAL_ANGLE=0deg
telescope.model No.26	Not used	echTelMdl.cc revised such that No.23,24 refer to ROTATOR_REAL_ANGLE=0deg
telescope.model No.27	Not used	echTelMdl.cc revised such that No.23,24 refer to ROTATOR_REAL_ANGLE=0deg
telescope.model No.28	Not used	echTelMdl.cc revised such that No.23,24 refer to ROTATOR_REAL_ANGLE=0deg

Table 6: Summary of the best estimate environmental variables for ICS and telescope model parameters related to the distortion pattern modeling. It should be noted that POINTING_ERR does not relate to the pointing error of the telescope, relate to the offset between the rotator axis and the FPI origin.

eters shown in Section 4). The shift of the relation can be checked by measuring the center of the distortion pattern at ROTATOR_REAL_ANGLE=0.0. If the center is measured at ROTATOR_REAL_ANGLE=0.0 additionally, the matching between the rotator axis and the center of the circle of the distortion pattern movement can be checked.
IF WE RE-INSTALL PIR TO TELESCOPE, the coma-free CMM position can be changed. No.23 and No.24 telescope.model parameters need to be changed using the updated CMM position and the equation shown in Section 4. It should be noted that the equation may be changed if we re-install Echidna to PIR. (The radius of the circle of the distortion pattern movement can be changed).

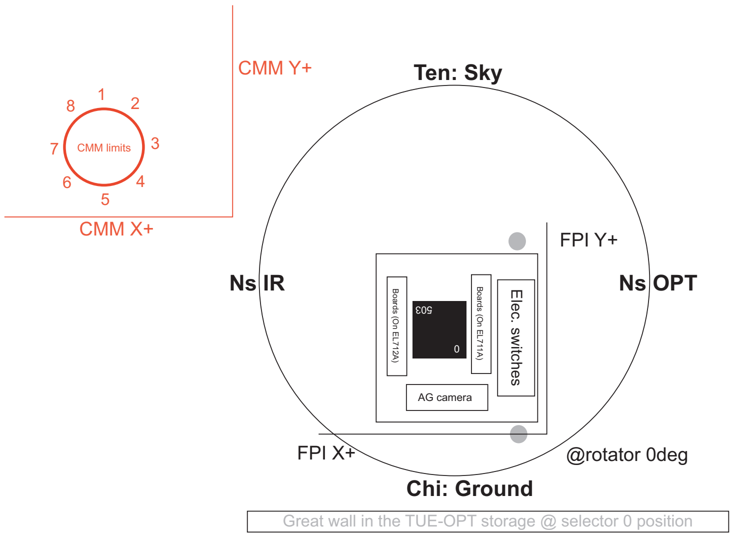

Figure 6: The relation between the Echidna unit and the PIR/CMM unit at rotator angle of 0 degree. ??? THE CONFIGURATION NEED TO BE CHECKED !!!