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The results of the Telescope Analyses for 23 yrs of the Subaru Telescope (1999 – 2022)

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Abstract:

We analyze the effect on the telescope status from the changes in the telescope coefficients obtained from pointing analysis observations from the beginning of the Subaru Telescope operations to the recent primary mirror coating work (1999 -2022.9) . We checked the long-term variation of the coefficients. We found that the origin of the azimuth(Az) was -0.023 $\pm$ 0.004 degrees shifted after the M6.7 earthquake on Oct. 15th ,2006, and –0.003 $\pm$ 0.001 degrees slightly changed after recoating and reinstallation of the IR-M2, IR-M3, and ImR of NsIR focus on 2009. Since then, Az origin has been stabled at 0.313 $\pm$ 0.001 degrees. The elevation (El) origins also changed in 2006 and 2009 but it depends on the focus. The verticality of the Az axis (N-S component) shows continuous tilting with a change rate of 0.334"/yr. It may be interpreted as a geological problem of the base of the telescope: "uneven subsidence." even though it is not a significant problem.

- In this report, we examine main six focal configurations of Cassegrain Optical and IR (CSOP, CSIR), Primary focus (POpt2(S-CAM), POpt2(HSC)), Nasmyth Optical (NSOP), and Nasmyth IR (NSIR) among the 31 focal configurations.

CSOP= Cs(CsOpt), CSIR=Cs(IR).
POpt2(S-CAM)=POpt2 w/ S-CAM,
POpt2(HSC)=POpt2 w/ HSC,
NSOP=NsOpt(NsOpt),
NSIR=NsIR(IR) before 2013, NsIR(IR+AO) since 2013

Telescope Coefficients

- The formula used in the pointing analysis of the telescope is as follows for all focal points. The unit of coefficient is degrees (°) .
- $\Delta A = a_0 + (-a_2 \cos A + a_3 \sin A) \tan h + a_4 \tan h + a_5 \sec h$
- $\Delta h = a_1 + a_2 \sin A + a_3 \cos A + a_6 \cos h$

A: Azimuth angle , h : Elevation angle

a_0: Azimuth angle origin correction

a_1: Elevation angle origin correction

a_2: Verticality of azimuth axis (east–west component)

a_3: Verticality of azimuth axis (north–south component)

a_4: Orthogonality between azimuth axis and elevation axis

a_5: Orthogonality of elevation axis and sight axis

a_6: Rigid body displacement (deflection) component of the telescope barrel

(ref: Consideration of JNLT pointing analysis (Tanaka done) [#N5-9506]

Pyo et al., 1998, National Astronomical Observatory of Japan , 3, 99-115

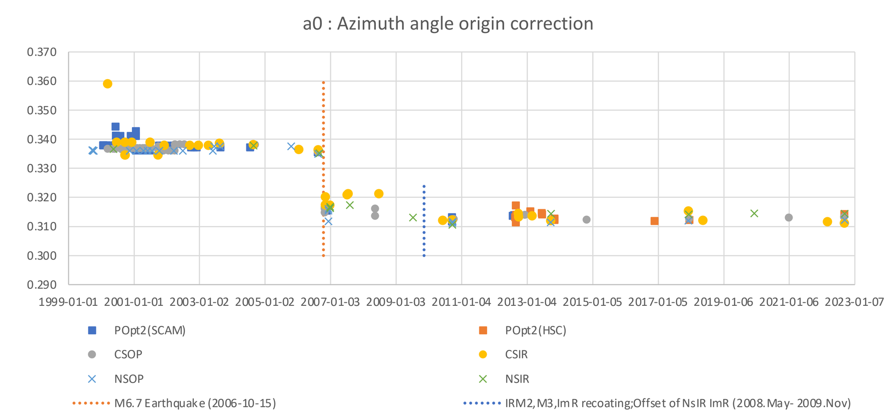
TED Wiki http://teldiv.subaru.nao.ac.jp/dokuwiki/doku.php?id=system:pama:pa

cf : a_2, a_3: The directions of the east–west and north–south have been swapped as the result of the Okita-san's analysis of the formula, . Note that the formula itself has not changed.

PA/MA at present (2022.9)

(1) Mandatory focus for PA/MA: 15 foci						(HST)	
Focus ID	Configuration (P)	TU	Priority	Instrument	Status	PA	MA
30	POpt2	POpt2	1	HSC	OK	9/10/2022	9/10/2022
31	PFS		1	PFS	n/a	n/a	n/a
Focus ID	Configuration (NsIR)						
6	NsIR (IR+AO)	IR-M2	1	IRCS, SCExAO, AO188, etc	OK	9/15/2022	9/23/2013
Focus ID	Configuration (NsOpt)						
15	NsOpt (IR+ADC)	IR-M2	1	HDS	OK	9/16/2022	9/16/2022
14	NsOpt (IR)		2		OK	9/16/2022	9/16/2022
23	NsOpt (CsOpt+ADC)	CsOpt-M2	1		OK	9/8/2022	9/7/2022
26	NsOpt (CsOpt+ImR_Blue)		2		OK	9/8/2022	9/7/2022
25	NsOpt (CsOpt+ImR_Red+ADC)		3		OK	9/8/2022	9/7/2022
22	NsOpt (CsOpt)		4		OK	9/7/2022	9/7/2022
8	NsOpt (NsOpt+ADC)	NsOpt-M2	1		OK	9/12/2022	9/12/2022
12	NsOpt (NsOpt+ImR_Blue)		2		OK	9/13/2022	9/13/2022
5	NsOpt (NsOpt)		3		OK	9/13/2022	9/13/2022
Focus ID	Configuration (Cs)						
4	Cs (IR)	IR-M2	1	MOIRCS	OK	9/15/2022	9/16/2022
3	Cs (CsOpt)	CsOpt-M2	1	FOCAS	OK	9/6/2022	9/6/2022
7	Cs (CsOpt+ADC)		2		OK	9/5/2022	9/5/2022

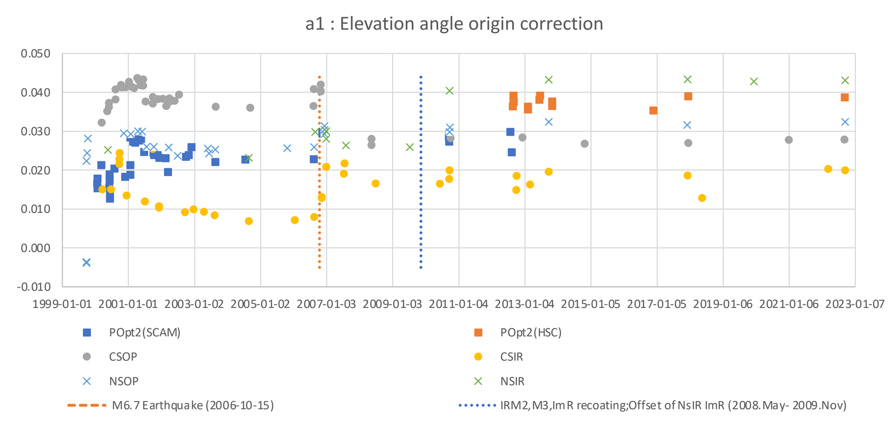
a_0: Azimuth angle origin correction



Period	Mean	Std
Befiore 2006/10/15	0.337	0.003
After 2006/10/15	0.314	0.002
(Difference)	-0.023	0.004
OP: 2006.10.20-2008.6	0.315	0.002
OP: 2009-present	0.312	0.001
IR: 2006.10.20-2008.6	0.319	0.002
IR: 2009-present	0.313	0.001

The misalignment of the azimuth origin was due to the M6.7 earthquake that occurred on October 15 , 2006. In average, there is a deviation of 0.023 degrees from 0.337 degrees to 0.315 degrees. It shows that it was moved clockwise direction (westward) from due south point when viewed from the zenith.
After November 2006, there is a more offset of 0.01 degrees in the focus related to the infrared secondary mirror before and after 2009. It may relate to the recoating and reinstallation of the IR–M2, IR–M3, ImR of NsIR during 2008–2009.

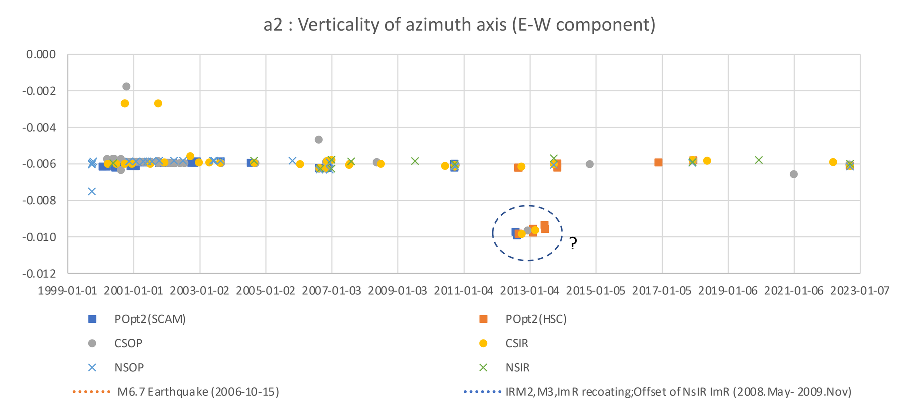
a_1: Elevation angle origin correction



	before 2006.10.15		After 2006.10.15		
	Mean	Std	Mean	Std	
POpt2(SCAM)	0.0218	0.0044	0.0283	0.0017	
POpt2(HSC)			0.0376	0.0013	after 2012.Aug
CsOP	0.0392	0.0028	0.0312	0.0062	
CsIR	0.0135	0.0063	0.0176	0.0029	
NsOP	0.0230	0.0100	0.0310	0.0011	
NsIR	0.0261	0.0034	0.0276	0.0018	until 2009.July
			0.0426	0.0012	from 2010.Sep

The deviation of the origin of the elevation angle differs depending on the focal point (see the table on the left). Correction values are different before and after the 2006 earthquake, but the NsIR focus more fluctuates around 2010 , For POpt2 , there is a difference of 0.0093 degrees (33") between S–Cam and HSC . Since 2013, the deviation of the elevation angle origin is in the order of : CsIR (63.5") < CsOP (112.4") < NsOP (111.8") < POpt2(HSC; 135.3") < NsIR (153.3").

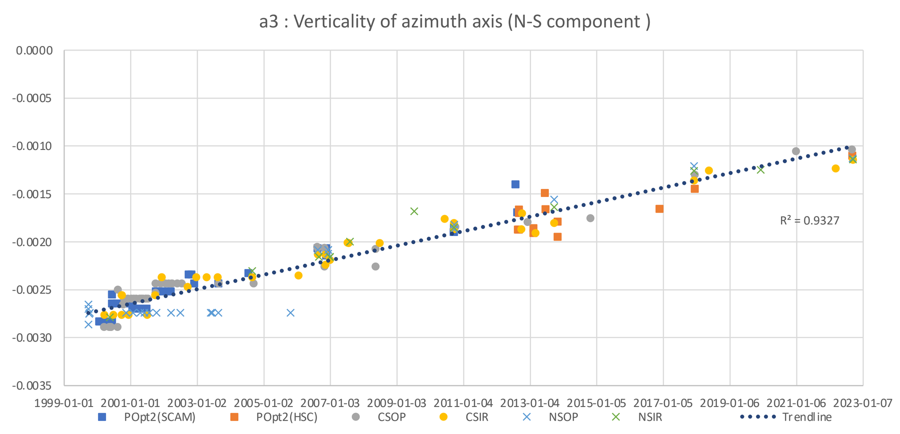
a_2: Verticality of azimuth axis (E–W component)



	Mean	Stdev
a2	-0.006	0.001

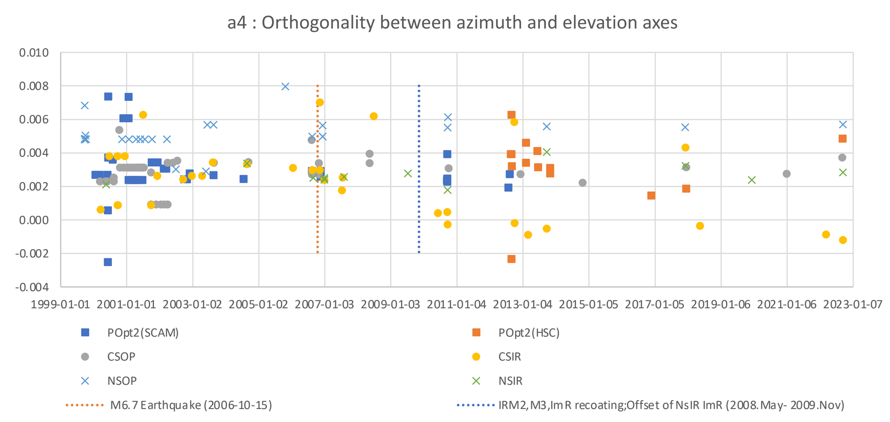
The east-west component of the verticality of the azimuth axis shows a generally stable value (-0.006 degrees). This coefficient is caused by the tilt of the azimuth rail or the base of telescope. For the east-west component, the slope to the west is positive. Therefore, it indicates that the azimuth rail or the base of telescope is tilted to the east by 0.006 degrees (22").

a_3 : Verticality of azimuth axis (N–S component)



It can be seen that the north-south component of the verticality of the azimuth axis has been tilted since the beginning of the Subaru Telescope to the present. The rate of change is 3.34" in 10 years. The verticality of the azimuth axis is the component caused by the tilt of the azimuth rail or the base of telescope. The north-south component is positive for the tilt to the south. The continuous tilting can be interpreted as a geological problem of the base of the telescope . There is a possibility of " uneven subsidence". There is no necessary countermeasure because the amount of change is very small. Thus it can be considered that there is no substantial problem.

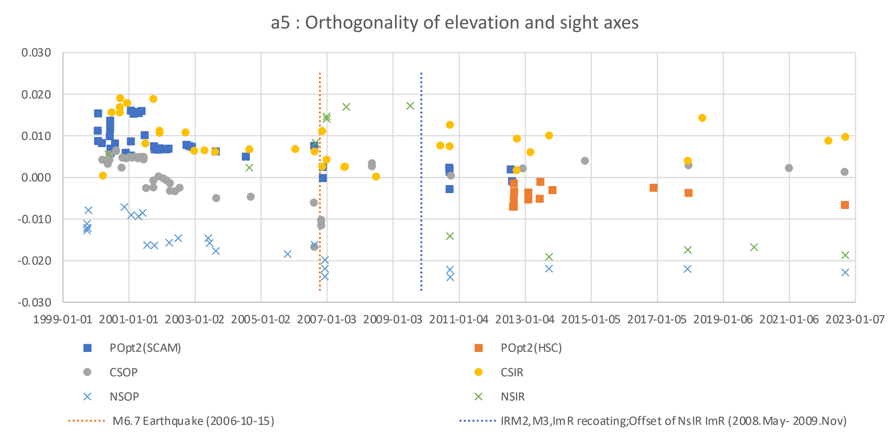
a_4: Orthogonality between azimuth and elevation axes



	before 2006.10.15		After 2006.10.15		
	Mean	Std	Mean	Std	
POpt2(SCAM)	0.0031	0.0018	0.0026	0.0006	
POpt2(HSC)			0.0032	0.0020	after 2012.Aug
CsOP	0.0028	0.0010	0.0031	0.0005	
CsIR	0.0027	0.0014	0.0017	0.0027	
NsOP	0.0050	0.0011	0.0055	0.0004	
NsIR	0.0027	0.0006	0.0026	0.0002	until 2009.July
			0.0029	0.0009	from 2010.Sep

The orthogonality between the elevation axis and the azimuth axis shows no systematic change before and after the 2006 earthquake. Average values by each focus since 2010 is as follows: CSIR(0.0017°) < NSIR(0.0029°) < CSOP(0.0031°) < POpt2(HSC; 0.0032°)< NsOP (0.0055°) . This coefficient is positive when the elevation angle is moved clockwise direction viewing the telescope from due south point. Since it is a component of ΔA = a4·tan(h) , the pointing error increases as the elevation angle increases. Therefore , The pointing error is 3 times higher at the NsOpt focus than the CsIR focus when the elevation angle is going to be high.

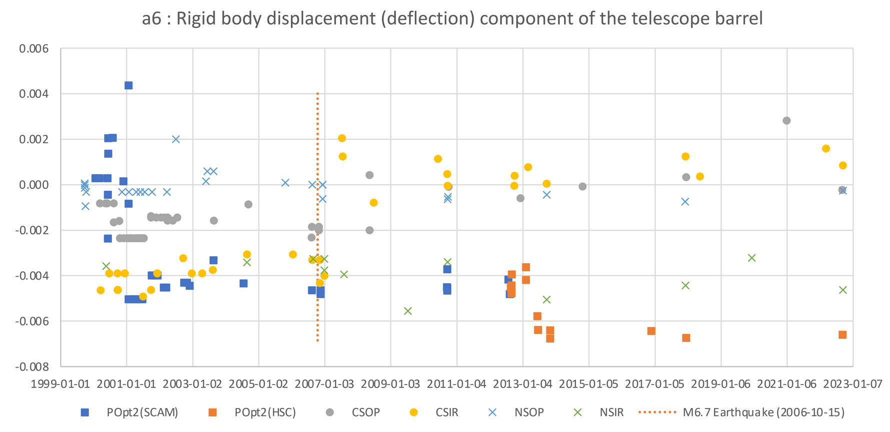
a_5: Orthogonality of elevation and sight axes



	before 2006.10.15		After 2006.10.15		
	Mean	Std	Mean	Std	
POpt2(SCAM)	0.0096	0.0037	0.0009	0.0018	
POpt2(HSC)			-0.0041	0.0020	after 2012.Aug
CsOP	0.0010	0.0051	0.0024	0.0012	
CsIR	0.0108	0.0056	0.0068	0.0042	
NsOP	-0.0131	0.0036	-0.0223	0.0013	
NsIR	0.0054	0.0030	0.0157	0.0016	until 2009.July
			-0.0172	0.0020	from 2010.Sep

The orthogonality between the sight axis and the elevation axis is the angle between the sight axis of the Cs focus and the elevation axis. It is the difference between the angle to form and the right angle. The coefficient is positive when the sight axis inclines clockwise viewing from due south at A=0, h = 90.
The order of the size are as follow: NSOP(-0.0223°) < NSIR(-0.0172°) < POpt2(HSC; -0.0041°) < CSOP(0.0024°) < CSIR (0.0068°) .

a_6: Rigid body displacement (deflection) component of the telescope barrel



	before 2006.10.15		After 2006.10.15		
	Mean	Std	Mean	Std	
POpt2(SCAM)	-0.0024	0.0028	-0.0044	0.0004	
POpt2(HSC)			-0.0064	0.0003	After 2013.June
CsOP	-0.0017	0.0006	-0.0005	0.0015	
CsIR	-0.0039	0.0006	-0.0001	0.0019	
NsOP	0.0000	0.0006	-0.0004	0.0003	
NsIR	-0.0034	0.0002	-0.0041	0.0010	until 2009.July
			-0.0041	0.0008	from 2010.Sep

The rigid body displacement of the barrel is the pointing error of elevation angle due to the gravitational deformation of the primary mirror, the secondary mirror, and the barrel. At present, CSOP, CSIR, and NSOP are close to 0° so the effect of the gravitational deformation is small. On the other hand, NSIR , POpt2(HSC) show -0.0041° , -0.0064°, relatively large coefficients. For POpt2(HSC), HSC and FEU are placed on the top of the telescope, so it can be susceptible. For NSIR, the same infrared secondary mirror (IRM2) is shared with CSIR , thus the influence of the third mirror (IRM3) can be considered .

Consideration

- a_0, a_2, a_3: The coefficients show very small differences between the respective focal points. On the other hand, a_1, a_4, a_5, a_6 show different values depending on the focus. Thus, it is important to apply the correct telescope coefficient setting for each focus. Especially a_1 , a_5 are 10 times larger, so they have a larger effect on the pointing accuracy.
- a_3: The coefficient increases by 0.0001 (~0.3") each year .
- Among other coefficients, a_4 shows scatter, but other coefficients show stable values after 2013 at each focus.