FINAL REPORT

COOMET.L-K3
Key comparisons of national standards of the unit of plane angle

Authors

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1. Introduction

The metrological equivalence of national measurement standards and calibration certificates issued by national metrology institutes is established by a set of key comparisons chosen and organised by the Consultative Committees of the CIPM or by the regional metrology organisations in collaboration with the Consultative Committees.

At the meeting of TC 1.5 “Length and angle” in 2009 it was decided to do comparison of national standards of the unit of plane angle. VNIIM was chosen as a pilot-laboratory. The result of this international comparison contributes to the Mutual Recognition Arrangement (MRA) between the national metrology institutes of the Metre Convention. This CIPM key comparison is linked with regional comparisons (RMO key comparisons) following exactly the same protocol. Laboratories participating in both the CIPM and the RMO comparisons establish the link between these and ensure equivalence of national metrology institutes according to the MRA between NMIs.

2. Participants

Table 1. Participants of comparisons

NMI	Address	Contact person	Contacts
VNIIM	190005 Moskovsky pr. 19, St. Petersburg, Russia	Konstantin Chekirda	Tel.: + 7 812 323 96 86 E-mail: K.V.Chekirda@vniim.ru
BelGIM	93, Starovilensky trakt, 220053 Minsk, Belarus	Vladimir Makarevich	Tel.: +375 17 239 23 38 Fax: +375 17 288 09 38 E-mail: makarevich@belgim.by
Ukrmetrteststandart	03680, Metrologicheskaya St., 4/122, Kiev, Ukraine	Anna Fursa	Tel.: +380445263626

3. Organisation

3.1. Schedule

The comparison has been carried out in a circulation form.
The circulation schedule is in table 2.

Table 2. The circulation schedule

NMI	Country	Date
VNIIM	Russia	2012
Ukrmetrteststandart	Ukraine	2013
BelGYM	Belarus	2015
VNIIM	Russia	2016
Report	Russia	2017

3.2. Artefact

The artifact is the glass ceramics polygon with 24 faces, № 13.

A gauging face is 18x25 mm. The polygon has a hole about 30 mm in diameter. Views of the polygon is on figure 1.

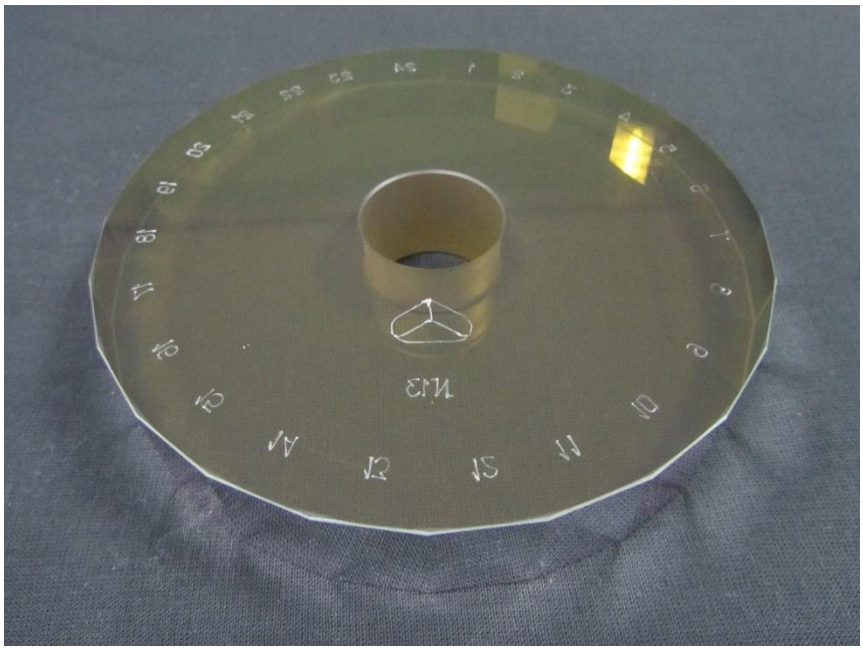

Figure 1 – View of the polygon

Schematic illustration is on figure 2. $\frac{360^{\circ}}{n}$ is nominal angle of polygon; $\Delta\alpha_i$ – deviation from nominal angle of polygon.

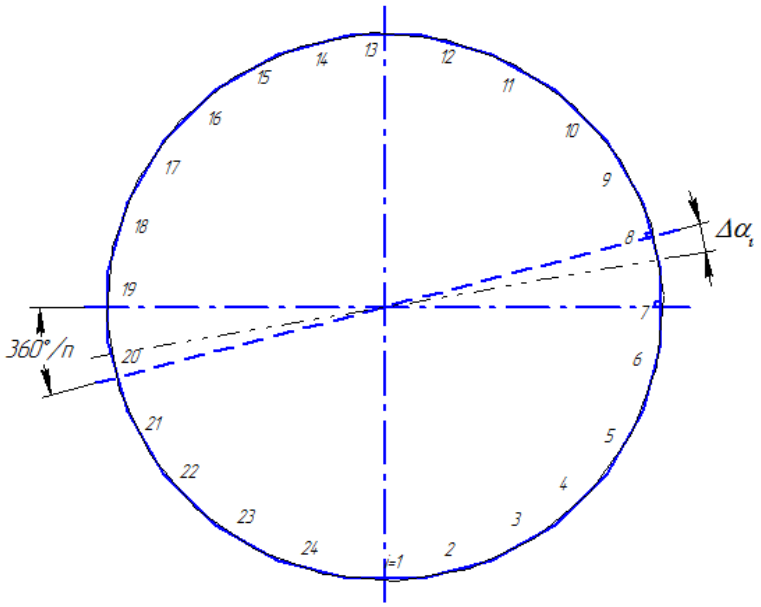

Figure 2 – Schematic illustration of the polygon

3.3. Technical and metrological characteristics

Technical and metrological characteristics of the polygon are given in the table 3.

Table 3. Technical and metrological characteristics of the polygon

Parameter	Value
Range of values of plane angle	from 0° to 360°
Nominal angle	15°
Deviation from nominal angle	±3"
Perpendicularity tolerance of measuring face to reference surface	±6"
Overall dimensions, mm	140x25
Mass, kg	1 kg

4. Measurement instructions and reporting of results

Conditions of comparisons:
- air temperature, °C 20±1;
- air humidity, % 60±20.

It is necessary to perform inspection of artefact before measurements. Information about surface irregularities should be transferred to the pilot laboratory.

The polygon must be established the marked surface upwards.

It is not allowed to clamp the polygon in mandrels.

Uncertainty of measurement has to be expressed according to ISO Guide 98-1:2009. Uncertainty of measurement.

5. The results

5.1. The results by VNIIM, Russia

The polygon was measured by The State Primary Standard of the unit of the plane angle GET 22 and the measuring system of temperature, pressure and humidity.

Measurements conditions:
- air temperature – (20,1±0,2) ^{0}C;
- air humidity – (55±5) %;
- air pressure – (101,2±3) kPa.

Measurements of the polygon in VNIIM were twice, because of VNIIM is the pilot laboratory. The results of the polygon's measuring in 2012 are given in the table 4. The results of the polygon's measuring in 2016 are given in the table 5.

Table 4. The results of the polygon's measuring in 2012

Faces	Nominal central angle from reference face	Deviation from nominal central angle from reference face	Faces	Deviation from nominal central angle of adjacent faces
1-1	0° 00' 00,000"	0,000"		
1-2	15° 00' 00,000"	-0,799"	1-2	-0,799"
1-3	30° 00' 00,000"	+0,188"	2-3	+0,987"
1-4	45° 00' 00,000"	-1,162"	3-4	-1,310"
1-5	60° 00' 00,000"	-0,601"	4-5	+0,561"

1-6	75° 00' 00,000"	+0,696"	5-6	+1,257"
1-7	90° 00' 00,000"	-1,921"	6-7	-2,649"
1-8	105° 00' 00,000"	+2,054"	7-8	+3,973"
1-9	120° 00' 00,000"	+0,922"	8-9	-1,132"
1-10	135° 00' 00,000"	+0,664"	9-10	-0,258"
1-11	150° 00' 00,000"	-1,727"	10-11	-2,391"
1-12	165° 00' 00,000"	-2,194"	11-12	-0,467"
1-13	180° 00' 00,000"	-1,622"	12-13	+0,572"
1-14	195° 00' 00,000"	+1,907"	13-14	+3,529"
1-15	210° 00' 00,000"	-3,304"	14-15	-5,121"
1-16	225° 00' 00,000"	-0,735"	15-16	+2,586"
1-17	240° 00' 00,000"	-0,921"	16-17	-0,186"
1-18	255° 00' 00,000"	+0,191"	17-18	+1,112"
1-19	270° 00' 00,000"	-0,213"	18-19	-0,405"
1-20	285° 00' 00,000"	-0,074"	19-20	+0,140"
1-21	300° 00' 00,000"	+0,626"	20-21	+0,700"
1-22	315° 00' 00,000"	-0,407"	21-22	-1,033"
1-23	330° 00' 00,000"	+0,791"	22-23	+1,198"
1-24	345° 00' 00,000"	-0,589"	23-24	-1,381"
			24-1	+0,589"

Table 5. The results of the polygon's measuring in 2016

Faces	Nominal central angle from reference face	Deviation from nominal central angle from reference face	Faces	Deviation from nominal central angle of adjacent faces
1-1	0° 00' 00,000"	0,000"		
1-2	15° 00' 00,000"	-0,707"	1-2	-0,707"
1-3	30° 00' 00,000"	+0,410"	2-3	+1,117"
1-4	45° 00' 00,000"	-1,066"	3-4	-1,476"
1-5	60° 00' 00,000"	-0,552"	4-5	+0,513"
1-6	75° 00' 00,000"	+0,543"	5-6	+1,096"
1-7	90° 00' 00,000"	-2,070"	6-7	-2,632"

1-8	105° 00' 00,000"	+1,693"	7-8	+3,758"
1-9	120° 00' 00,000"	+0,479"	8-9	-1,223"
1-10	135° 00' 00,000"	+0,290"	9-10	-0,189"
1-11	150° 00' 00,000"	-2,146"	10-11	-2,436"
1-12	165° 00' 00,000"	-2,550"	11-12	-0,404"
1-13	180° 00' 00,000"	-1,728"	12-13	+0,822"
1-14	195° 00' 00,000"	+1,709"	13-14	+3,443"
1-15	210° 00' 00,000"	-3,300"	14-15	-5,009"
1-16	225° 00' 00,000"	-0,762"	15-16	+2,538"
1-17	240° 00' 00,000"	-0,936"	16-17	-0,174"
1-18	255° 00' 00,000"	+0,115"	17-18	+1,051"
1-19	270° 00' 00,000"	-0,358"	18-19	-0,473"
1-20	285° 00' 00,000"	-0,274"	19-20	+0,085"
1-21	300° 00' 00,000"	+0,450"	20-21	+0,723"
1-22	315° 00' 00,000"	-0,635"	21-22	-1,084"
1-23	330° 00' 00,000"	+0,679"	22-23	+1,313"
1-24	345° 00' 00,000"	-0,656"	23-24	-1,335"
			24-1	+0,656"

Expanded uncertainty Up at the confidence coefficient of 0,95 for a coverage factor of of k=2 is 0,032".

5.2. The results by BelGIM, Belarus

The polygon was measured in 2015 by The National Standard of the unit of the plane angle. The National Standard is consists of goniometer GS-1L with ring laser № 114, set of polygons (8 faces, № 018; 24 faces, № 118; 36 faces, № 19); PC.

Measurement of angles between polygon's faces is based on formation of electric impulses out of autocollimator at rotation of a polygon when surface is normal to faces of a polygon coincide with an optical axis of the autocollimator and at the account of number of the periods of a signal of the transducer of an angle. The account of number of the periods is carried out for the time intervals corresponding to turn of a polygon on the angles equal to angles between surfaces are normal to faces. At rotation of the platform one reception of measurement is carried out for five turns of the platform clockwise and five turns counterclockwise.

Measurements conditions:

- air temperature – (20±2) °C;
- air humidity – (60±20) %.

The results are given in the table 6.

Table 6. The results

Faces	Nominal central angle from reference face	Deviation from nominal central angle from reference face	Faces	Deviation from nominal central angle of adjacent faces
1-1	0° 00' 00,000"	0,000		
1-2	15° 00' 00,000"	-0,686"	1-2	-0,686"
1-3	30° 00' 00,000"	+0,418"	2-3	+1,104"
1-4	45° 00' 00,000"	-1,101"	3-4	-1,519"
1-5	60° 00' 00,000"	-0,445"	4-5	+0,656"
1-6	75° 00' 00,000"	+0,716"	5-6	+1,161"
1-7	90° 00' 00,000"	-1,859"	6-7	-2,575"
1-8	105° 00' 00,000"	+1,841"	7-8	+3,700"
1-9	120° 00' 00,000"	+0,734"	8-9	-1,107"
1-10	135° 00' 00,000"	+0,517"	9-10	-0,217"
1-11	150° 00' 00,000"	-1,855"	10-11	-2,373"
1-12	165° 00' 00,000"	-2,375"	11-12	-0,520"
1-13	180° 00' 00,000"	-1,629"	12-13	+0,746"
1-14	195° 00' 00,000"	+1,934"	13-14	+3,563"
1-15	210° 00' 00,000"	-3,163"	14-15	-5,097"
1-16	225° 00' 00,000"	-0,680"	15-16	+2,483"
1-17	240° 00' 00,000"	-0,818"	16-17	-0,138"
1-18	255° 00' 00,000"	+0,175"	17-18	+0,993"
1-19	270° 00' 00,000"	-0,275"	18-19	-0,450"
1-20	285° 00' 00,000"	-0,177"	19-20	+0,098"
1-21	300° 00' 00,000"	+0,518"	20-21	+0,695"
1-22	315° 00' 00,000"	-0,534"	21-22	-1,052"
1-23	330° 00' 00,000"	+0,747"	22-23	+1,281"
1-24	345° 00' 00,000"	-0,547"	23-24	-1,294"
			24-1	+0,547"

Expanded uncertainty Up at the confidence coefficient of 0,95 for a coverage factor of of k=2 is 0,14".

5.3. The results by Ukrmetrteststandart, Ukraine

The polygon was measured in 2012 with the angle-measuring system GS-1L from The Ukraine State Primary Standard of the unit of the plane angle – DETU 01-05-10 by direct gaging. The angle-measuring system works according to a transformation of angle of rotation rotary table to impulse signal which is generated by ring laser.

Measurements conditions:

- air temperature – 18,2 °C;
- air humidity – 23 %;
- air pressure – 100,4 kPa.

The results are given in the table 7.

Table 7. The results

Faces	Nominal central angle from reference face	Deviation from nominal central angle from reference face	Faces	Deviation from nominal value of central angle of adjacent faces
1-1	0° 00' 00,000"	0,000"		
1-2	15° 00' 00,000"	-0,770"	1-2	-0,770"
1-3	30° 00' 00,000"	+0,250"	2-3	+1,020"
1-4	45° 00' 00,000"	-1,040"	3-4	-1,290"
1-5	60° 00' 00,000"	-0,560"	4-5	+0,480"
1-6	75° 00' 00,000"	+0,700"	5-6	+1,260"
1-7	90° 00' 00,000"	-2,050"	6-7	-2,750"
1-8	105° 00' 00,000"	+1,920"	7-8	+3,970"
1-9	120° 00' 00,000"	+0,640"	8-9	-1,280"
1-10	135° 00' 00,000"	+0,400"	9-10	-0,240"
1-11	150° 00' 00,000"	-1,930"	10-11	-2,330"
1-12	165° 00' 00,000"	-2,390"	11-12	-0,460"
1-13	180° 00' 00,000"	-1,770"	12-13	+0,620"
1-14	195° 00' 00,000"	+1,810"	13-14	+3,580"
1-15	210° 00' 00,000"	-3,340"	14-15	-5,150"
1-16	225° 00' 00,000"	-0,670"	15-16	+2,670"
1-17	240° 00' 00,000"	-0,860"	16-17	-0,190"
1-18	255° 00' 00,000"	+0,220"	17-18	+1,080"

1-19	270° 00' 00,000"	-0,310"	18-19	-0,530"
1-20	285° 00' 00,000"	-0,180"	19-20	+0,130"
1-21	300° 00' 00,000"	+0,490"	20-21	+0,670"
1-22	315° 00' 00,000"	-0,600"	21-22	-1,090"
1-23	330° 00' 00,000"	+0,650"	22-23	+1,250"
1-24	345° 00' 00,000"	-0,630"	23-24	-1,280"
			24-1	+0,630"

Expanded uncertainty U_P at the confidence coefficient of 0,95 for a coverage factor of of k=2 is 0,11".

6. Calculations

6.1. Stability of the artefact

The polygon as the artefact was measured twice at the beginning and at the end of comparisons.

The results of analysis of stability are in tables 8-9. The results show that the polygon was not stable during the comparison, with differences in measured angles being greater than measurement uncertainty. Due to the fact that a lot of time has passed between the first and second measurements of the polygon, a significant instability of the comparison measure was obtained during the measurements, which cannot be excluded. Thus, it is expected that for the faces that were most affected by the instability of the polygon, E_n will be more than 1. The drift exceeded the pilot's estimated uncertainty on almost all faces, with the exception of 1-15, 1-16, 1-17, 6-7, 13-14, 15-16, 16-17, 20-21, 23-24.

Table 8. The results of analysis of polygon's stability at measurements of central angle from the reference face

Faces	Nominal central angle from reference face	Measured central angle from reference face at the beginning of comparison x_1	Measured central angle from reference face at the end of comparison x_2	Standard deviation at the beginning of comparison S_{x_1}	Standard deviation at the end of comparison S_{x_2}	$x_2 - x_1$	$U(x_2 - x_1)$
1-1	0°	0°00'00,000"	0°00'00,000"	0,000"	0,000"	0,000"	0,000"
1-2	15°	14°59'59,201"	14°59'59,293"	0,017"	0,016"	0,092"	0,047"
1-3	30°	30°00'00,188"	30°00'00,410"	0,018"	0,016"	0,222"	0,048"
1-4	45°	44°59'58,838"	44°59'58,934"	0,014"	0,014"	0,096"	0,040"
1-5	60°	59°59'59,399"	59°59'59,448"	0,015"	0,017"	0,049"	0,045"
1-6	75°	75°00'00,656"	75°00'00,543"	0,019"	0,016"	-0,113"	0,050"
1-7	90°	89°59'58,022"	89°59'57,930"	0,017"	0,017"	-0,092"	0,048"

1-8	105°	105°00'02,054"	105°00'01,693"	0,016"	0,017"	-0,361"	0,047"
1-9	120°	120°00'00,922"	120°00'00,479"	0,018"	0,018"	-0,443"	0,051"
1-10	135°	135°00'00,664"	135°00'00,290"	0,019"	0,019"	-0,374"	0,054"
1-11	150°	149°59'58,273"	149°59'57,854"	0,018"	0,017"	-0,419"	0,050"
1-12	165°	164°59'57,806"	164°59'57,450"	0,016"	0,021"	-0,356"	0,053"
1-13	180°	179°59'58,378"	179°59'58,272"	0,018"	0,017"	-0,106"	0,050"
1-14	195°	195°00'01,807"	195°00'01,709"	0,016"	0,021"	-0,098"	0,053"
1-15	210°	209°59'56,686"	209°59'56,700"	0,017"	0,020"	0,014"	0,052"
1-16	225°	224°59'59,265"	224°59'59,238"	0,018"	0,017"	-0,027"	0,050"
1-17	240°	239°59'59,079"	239°59'59,064"	0,017"	0,023"	-0,015"	0,057"
1-18	255°	255°00'00,191"	255°00'00,115"	0,016"	0,016"	-0,076"	0,045"
1-19	270°	269°59'59,787"	269°59'59,642"	0,018"	0,021"	-0,145"	0,055"
1-20	285°	284°59'59,926"	284°59'59,726"	0,018"	0,018"	-0,200"	0,051"
1-21	300°	300°00'00,626"	300°00'00,450"	0,016"	0,018"	-0,176"	0,048"
1-22	315°	314°59'59,593"	314°59'59,365"	0,015"	0,020"	-0,228"	0,047"
1-23	330°	330°00'00,791"	330°00'00,679"	0,016"	0,016"	-0,112"	0,051"
1-24	345°	344°59'59,411"	344°59'59,344"	0,018"	0,018"	-0,067"	0,051"

Table 9. The results of analysis of polygon's stability at measurements of central angle of adjacent faces

Faces	Nominal central angle of adjacent faces	Measured central angle of adjacent faces at the beginning of comparison x_1	Measured central angle of adjacent faces at the end of comparison x_2	Standard deviation at the beginning of comparison S_{x_1}	Standard deviation at the end of comparison S_{x_2}	$x_2 - x_1$	$U(x_2 - x_1)$
1-2	15°	14°59'59,201"	14°59'59,293"	0,017"	0,016"	0,092"	0,047"
2-3	15°	15°00'00,987"	15°00'01,117"	0,018"	0,014"	0,130"	0,046"
3-4	15°	14°59'58,650"	14°59'58,524"	0,017"	0,015"	-0,126"	0,045"
4-5	15°	15°00'00,561"	15°00'00,513"	0,017"	0,014"	-0,048"	0,044"
5-6	15°	15°00'01,257"	15°00'01,096"	0,017"	0,014"	-0,161"	0,044"
6-7	15°	14°59'57,366"	14°59'57,387"	0,019"	0,014"	0,021"	0,047"

7-8	15°	15°00'04,032"	15°00'03,763"	0,018"	0,015"	-0,269"	0,047"
8-9	15°	14°59'58,868"	14°59'58,786"	0,019"	0,015"	-0,082"	0,048"
9-10	15°	14°59'59,742"	14°59'59,811"	0,019"	0,016"	0,069"	0,050"
10-11	15°	14°59'57,609"	14°59'57,564"	0,020"	0,015"	-0,045"	0,050"
11-12	15°	14°59'59,533"	14°59'59,596"	0,019"	0,017"	0,063"	0,051"
12-13	15°	15°00'00,572"	15°00'00,822"	0,017"	0,017"	0,250"	0,048"
13-14	15°	15°00'03,429"	15°00'03,434"	0,018"	0,017"	0,008"	0,050"
14-15	15°	14°59'54,879"	14°59'54,991"	0,018"	0,020"	0,112"	0,054"
15-16	15°	15°00'02,579"	15°00'02,538"	0,018"	0,015"	-0,041"	0,047"
16-17	15°	14°59'59,814"	14°59'59,826"	0,017"	0,018"	0,012"	0,050"
17-18	15°	15°00'01,112"	15°00'01,051"	0,018"	0,018"	-0,061"	0,051"
18-19	15°	14°59'59,595"	14°59'59,527"	0,020"	0,016"	-0,068"	0,051"
19-20	15°	15°00'00,140"	15°00'00,085"	0,018"	0,020"	-0,055"	0,054"
20-21	15°	15°00'00,700"	15°00'00,723"	0,017"	0,018"	0,023"	0,050"
21-22	15°	14°59'58,967"	14°59'58,916"	0,018"	0,020"	-0,055"	0,054"
22-23	15°	15°00'01,198"	15°00'01,313"	0,018"	0,020"	0,115"	0,054"
23-24	15°	14°59'58,619"	14°59'58,665"	0,018"	0,016"	0,046"	0,048"
24-1	15°	15°00'00,589"	15°00'00,656"	0,016"	0,018"	0,067"	0,048"

6.2. Calculation of comparison's data

6.2.1. Determination of the Key Comparison Reference value

The reference value is calculated according to (1) and (2)

$$x_{ref} = \frac{\sum_1^n \frac{1}{u_i^2} \cdot x_i}{\sum_1^n \frac{1}{u_i^2}}; \qquad (1)$$

$$u_{ref}^2 = \frac{1}{\sum_1^n \frac{1}{u_i^2}}. \qquad (2)$$

6.2.2. Analysis of the results

The E_n value is calculated according to (3)

$$E_n = \frac{x_i - x_{ref}}{2\sqrt{u_i^2 - u_{ref}^2}}. \quad (3)$$

If $|E_n| < 1$ and confidence coefficient is 0,95, the value of uncertainty are confirmed.

The results of measurements with standard uncertainty of all countries are in tables 10-13.

The results of VNIIM are presented as results of measuring at the beginning of comparisons. The E_n values given in tables 11 and 13 include acontribution to u_{ref} coming from the instability of the artefact.

Table 10. The results of measurements of central angle from reference face with standard uncertainty

Faces	Nominal central angle from reference face	VNIIM		BelGIM		Ukrmetrteststandart	
		x_i	$u(x_i)$	x_i	$u(x_i)$	x_i	$u(x_i)$
1-1	0°	0°00'00,000"	0,016"	0°00'00,000"	0,070"	0°00'00,000"	0,055"
1-2	15°	14°59'59,201"	0,016"	14°59'59,314"	0,070"	14°59'59,230"	0,055"
1-3	30°	30°00'00,188"	0,016"	30°00'00,418"	0,070"	30°00'00,250"	0,055"
1-4	45°	44°59'58,838"	0,016"	44°59'58,899"	0,070"	44°59'58,960"	0,055"
1-5	60°	59°59'59,399"	0,016"	59°59'59,555"	0,070"	59°59'59,440"	0,055"
1-6	75°	75°00'00,656"	0,016"	75°00'00,716"	0,070"	75°00'00,700"	0,055"
1-7	90°	89°59'58,022"	0,016"	89°59'58,141"	0,070"	89°59'57,950"	0,055"
1-8	105°	105°00'02,054"	0,016"	105°00'01,841"	0,070"	105°00'01,920"	0,055"
1-9	120°	120°00'00,922"	0,016"	120°00'00,734"	0,070"	120°00'00,640"	0,055"
1-10	135°	135°00'00,664"	0,016"	135°00'00,517"	0,070"	135°00'00,400"	0,055"
1-11	150°	149°59'58,273"	0,016"	149°59'58,145"	0,070"	149°59'58,070"	0,055"
1-12	165°	164°59'57,806"	0,016"	164°59'57,625"	0,070"	164°59'57,610"	0,055"
1-13	180°	179°59'58,378"	0,016"	179°59'58,371"	0,070"	179°59'58,230"	0,055"
1-14	195°	195°00'01,807"	0,016"	195°00'01,934"	0,070"	195°00'01,810"	0,055"
1-15	210°	209°59'56,686"	0,016"	209°59'56,837"	0,070"	209°59'56,660"	0,055"
1-16	225°	224°59'59,265"	0,016"	224°59'59,320"	0,070"	224°59'59,330"	0,055"
1-17	240°	239°59'59,079"	0,016"	239°59'59,182"	0,070"	239°59'59,140"	0,055"

1-18	255°	255°00'00,191"	0,016"	255°00'00,175"	0,070"	255°00'00,220"	0,055"
1-19	270°	269°59'59,787"	0,016"	269°59'59,725"	0,070"	269°59'59,690"	0,055"
1-20	285°	284°59'59,926"	0,016"	284°59'59,823"	0,070"	284°59'59,820"	0,055"
1-21	300°	300°00'00,626"	0,016"	300°00'00,518"	0,070"	300°00'00,490"	0,055"
1-22	315°	314°59'59,593"	0,016"	314°59'59,466"	0,070"	314°59'59,400"	0,055"
1-23	330°	330°00'00,791"	0,016"	330°00'00,747"	0,070"	330°00'00,650"	0,055"
1-24	345°	344°59'59,411"	0,016"	344°59'59,453"	0,070"	344°59'59,370"	0,055"

Table 11. E_n - values

x_{ref}	u^2_{ref}	E_n		
		VNIIM	BelGIM	Ukrmetrteststandart
0,000"	0,0000"	0,000	0,000	0,000
14°59'59,208"	0,0117"	-0,034	+2,330	+0,102
30°00'00,203"	0,0564"	-0,032	+1,061	+0,101
44°59'58,850"	0,0125"	-0,054	+0,244	+2,680
59°59'59,409"	0,0043"	-0,080	+0,560	+0,265
75°00'00,662"	0,0098"	-0,031	+0,324	+0,207
89°59'58,022"	0,0062"	-0,001	+0,665	-1,168
105°00'02,034"	0,1199"	+0,029	-0,336	-0,175
120°00'00,892"	0,1834"	+0,035	-0,199	-0,365
135°00'00,638"	0,1291"	+0,037	-0,178	-0,441
149°59'58,252"	0,1634"	+0,026	-0,137	-0,252
164°59'57,783"	0,1165"	+0,034	-0,261	-0,294
179°59'58,367"	0,0085"	+0,062	+0,024	-0,678
195°00'01,813"	0,0071"	-0,037	+0,698	-0,018
209°59'56,691"	0,0011"	-0,088	+0,513	-1,511
224°59'59,272"	0,0004"	-0,346	+0,546	+0,530
239°59'59,088"	0,0002"	-0,835	+0,507	+0,522
255°00'00,192"	0,0039"	-0,012	-0,144	+0,244

269°59'59,777"	0,0171"	+0,039	-0,216	-0,444
284°59'59,913"	0,0344"	+0,034	-0,279	-0,291
300°00'00,611"	0,0261"	+0,047	-0,351	-0,563
314°59'59,573"	0,0456"	+0,047	-0,289	-0,689
330°00'00,778"	0,0096"	+0,065	-0,169	-0,775
344°59'59,410"	0,0029"	+0,011	+0,659	-0,545

Table 12. The results of measurements of central angle of adjacent faces with standard uncertainty

Faces	Nominal central angle of adjacent faces	VNIIM		BelGIM		Ukrmetrteststandart	
		x_i	$u(x_i)$	x_i	$u(x_i)$	x_i	$u(x_i)$
1-2	15°	14°59'59,201"	0,016"	14°59'59,314"	0,070"	14°59'59,230"	0,055"
2-3	15°	15°00'00,987"	0,016"	15°00'01,104"	0,070"	15°00'01,020"	0,055"
3-4	15°	14°59'58,650"	0,016"	14°59'58,481"	0,070"	14°59'58,710"	0,055"
4-5	15°	15°00'00,561"	0,016"	15°00'00,656"	0,070"	15°00'00,480"	0,055"
5-6	15°	15°00'01,257"	0,016"	15°00'01,161"	0,070"	15°00'01,260"	0,055"
6-7	15°	14°59'57,366"	0,016"	14°59'57,425"	0,070"	14°59'57,250"	0,055"
7-8	15°	15°00'04,032"	0,016"	15°00'03,700"	0,070"	15°00'03,970"	0,055"
8-9	15°	14°59'58,868"	0,016"	14°59'58,893"	0,070"	14°59'58,720"	0,055"
9-10	15°	14°59'59,742"	0,016"	14°59'59,783"	0,070"	14°59'59,760"	0,055"
10-11	15°	14°59'57,609"	0,016"	14°59'57,627"	0,070"	14°59'57,670"	0,055"
11-12	15°	14°59'59,533"	0,016"	14°59'59,480"	0,070"	14°59'59,540"	0,055"
12-13	15°	15°00'00,572"	0,016"	15°00'00,746"	0,070"	15°00'00,620"	0,055"
13-14	15°	15°00'03,429"	0,016"	15°00'03,563"	0,070"	15°00'03,580"	0,055"
14-15	15°	14°59'54,879"	0,016"	14°59'54,903"	0,070"	14°59'54,850"	0,055"
15-16	15°	15°00'02,579"	0,016"	15°00'02,483"	0,070"	15°00'02,670"	0,055"
16-17	15°	14°59'59,814"	0,016"	14°59'59,862"	0,070"	14°59'59,810"	0,055"
17-18	15°	15°00'01,112"	0,016"	15°00'01,993"	0,070"	15°00'01,080"	0,055"
18-19	15°	14°59'59,595"	0,016"	14°59'59,550"	0,070"	14°59'59,470"	0,055"

19-20	15°	15°00'00,140"	0,016"	15°00'00,098"	0,070"	15°00'00,130"	0,055"
20-21	15°	15°00'00,700"	0,016"	15°00'00,695"	0,070"	15°00'00,670"	0,055"
21-22	15°	14°59'58,967"	0,016"	14°59'58,948"	0,070"	14°59'58,910"	0,055"
22-23	15°	15°00'01,198"	0,016"	15°00'01,281"	0,070"	15°00'01,250"	0,055"
23-24	15°	14°59'58,619"	0,016"	14°59'58,706"	0,070"	14°59'58,720"	0,055"
24-1	15°	15°00'00,589"	0,016"	15°00'00,547"	0,070"	15°00'00,630"	0,055"

Table 13. E_n - values

x_{ref}	u^2_{ref}	E_n		
		VNIIM	BelGIM	Ukrmetrteststandart
14°59'59,208"	0,0087"	-0,040	+0,858	+0,144
15°00'00,995"	0,0171"	-0,030	+0,494	+0,106
14°59'58,647"	0,0278"	+0,010	-0,548	+0,201
15°00'00,559"	0,0025"	+0,017	+0,993	-1,781
15°00'01,253"	0,0261"	+0,013	-0,315	+0,024
14°59'57,360"	0,0015"	+0,083	+0,558	-1,419
15°00'04,012"	0,0443"	+0,047	-0,786	-0,104
14°59'58,858"	0,0069"	+0,060	+0,385	-1,103
14°59'59,745"	0,0050"	-0,023	+2,035	+0,167
14°59'57,614"	0,0023"	-0,060	+0,123	+0,999
14°59'59,531"	0,0042"	+0,015	-0,961	+0,130
15°00'00,584"	0,0627"	-0,023	+0,338	+0,075
15°00'03,446"	0,0087"	-0,095	+0,947	+0,888
14°59'54,878"	0,0128"	+0,005	+0,141	-0,142
15°00'02,581"	0,0025"	-0,025	-1,010	+1,990
14°59'59,816"	0,0004"	-0,090	+0,342	-0,057
15°00'01,104"	0,0039"	+0,065	-1,799	-0,398
14°59'59,584"	0,0048"	+0,084	-2,359	-1,330
15°00'00,137"	0,0033"	+0,024	-0,484	-0,244

15°00'00,698"	0,0008"	+0,055	-0,020	-0,289
14°59'58,962"	0,0033"	+0,046	-0,173	-1,581
15°00'01,206"	0,0135"	-0,033	+0,407	+0,217
14°59'58,631"	0,0023"	-0,126	+0,746	+1,711
15°00'00,590"	0,0195"	-0,004	-0,178	+0,155

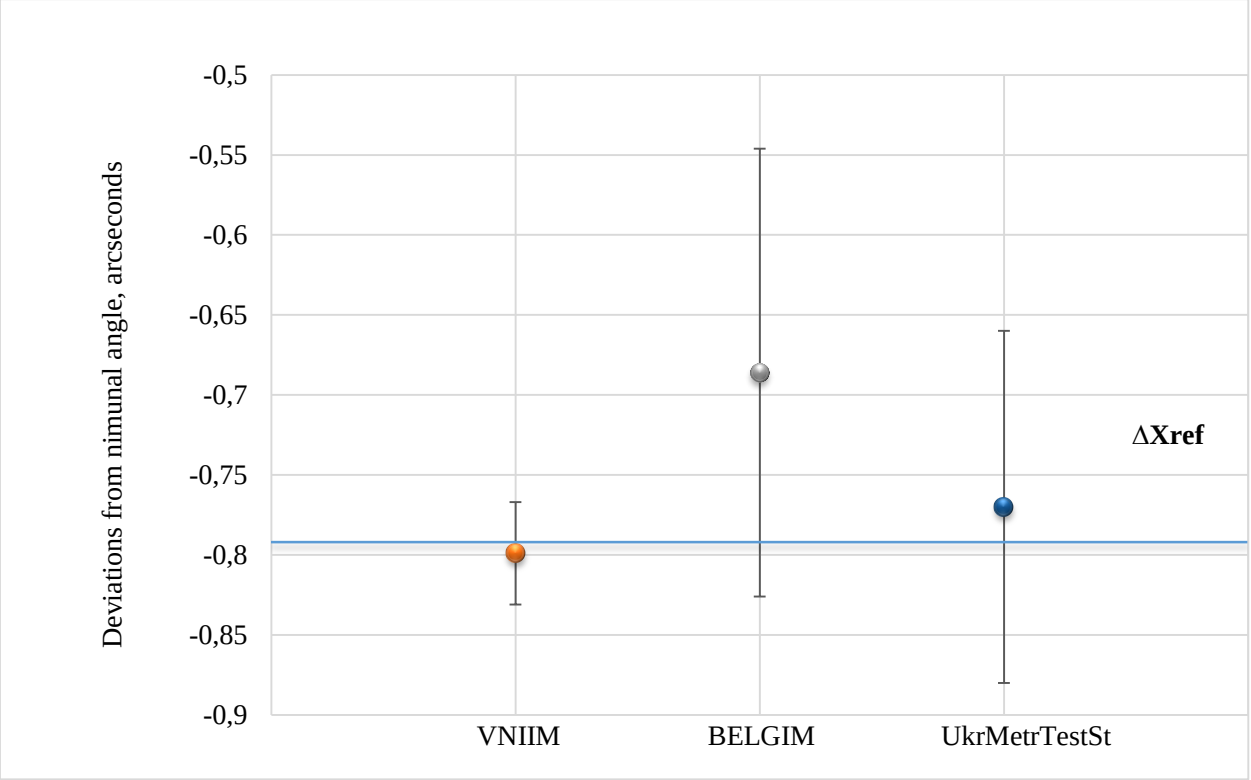

Figure 3 – Deviations from nominal angle between faces 1-2

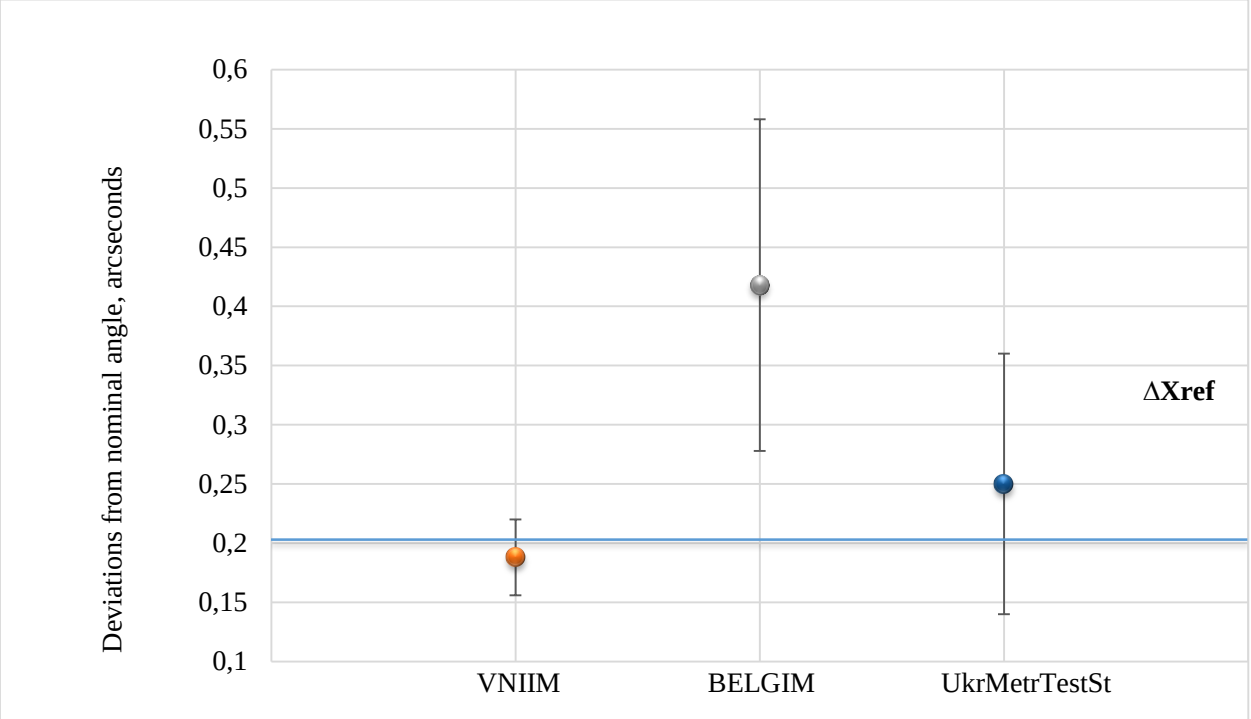

Figure 4 – Deviations from nominal angle between faces 1-3

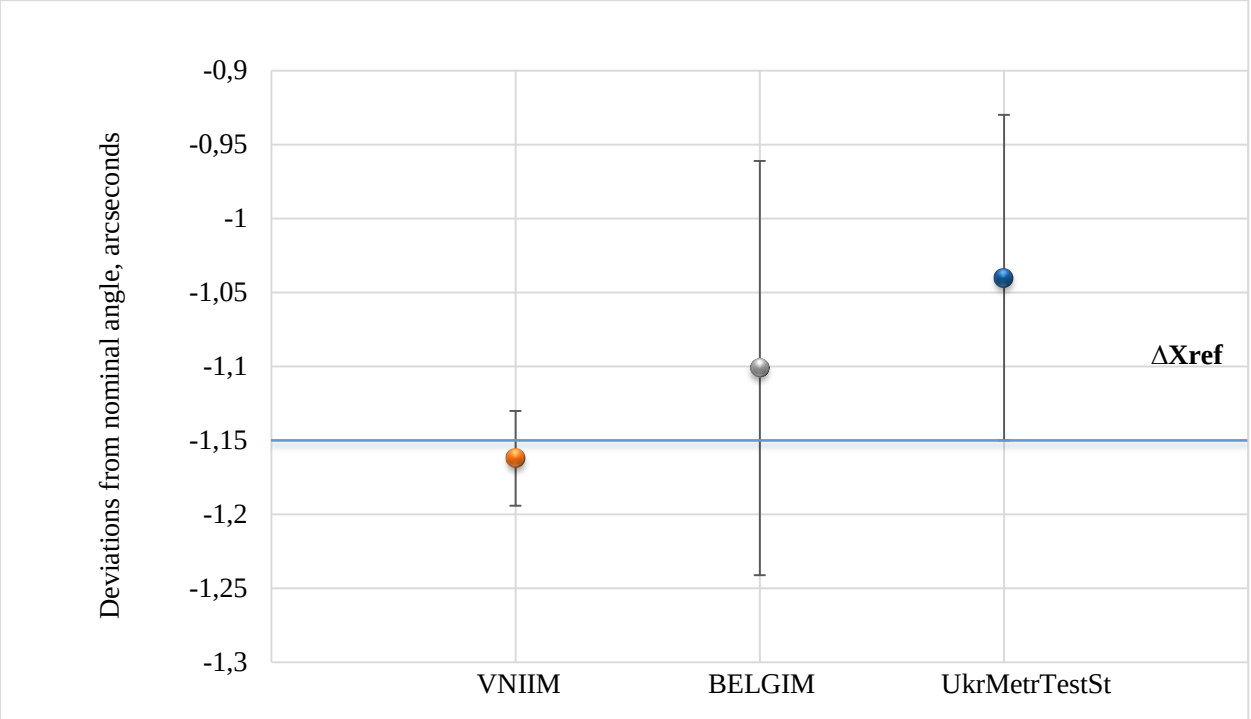

Figure 5 – Deviations from nominal angle between faces 1-4

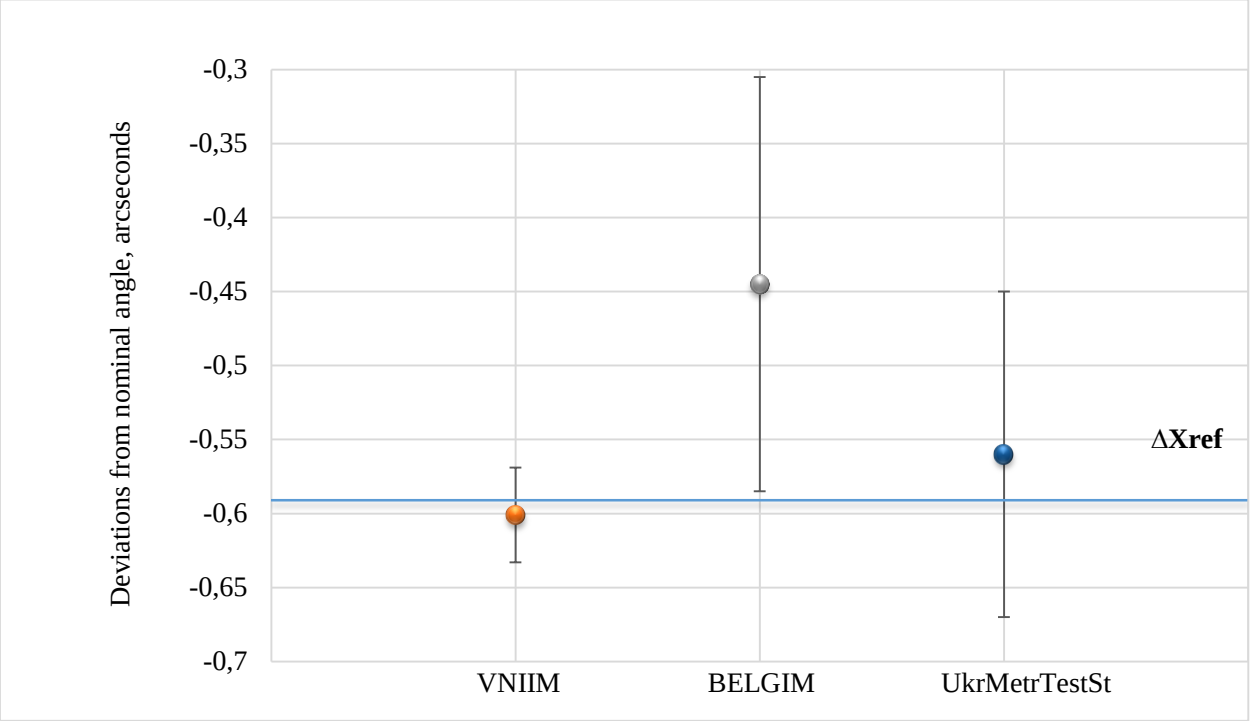

Figure 6 – Deviations from nominal angle between faces 1-5

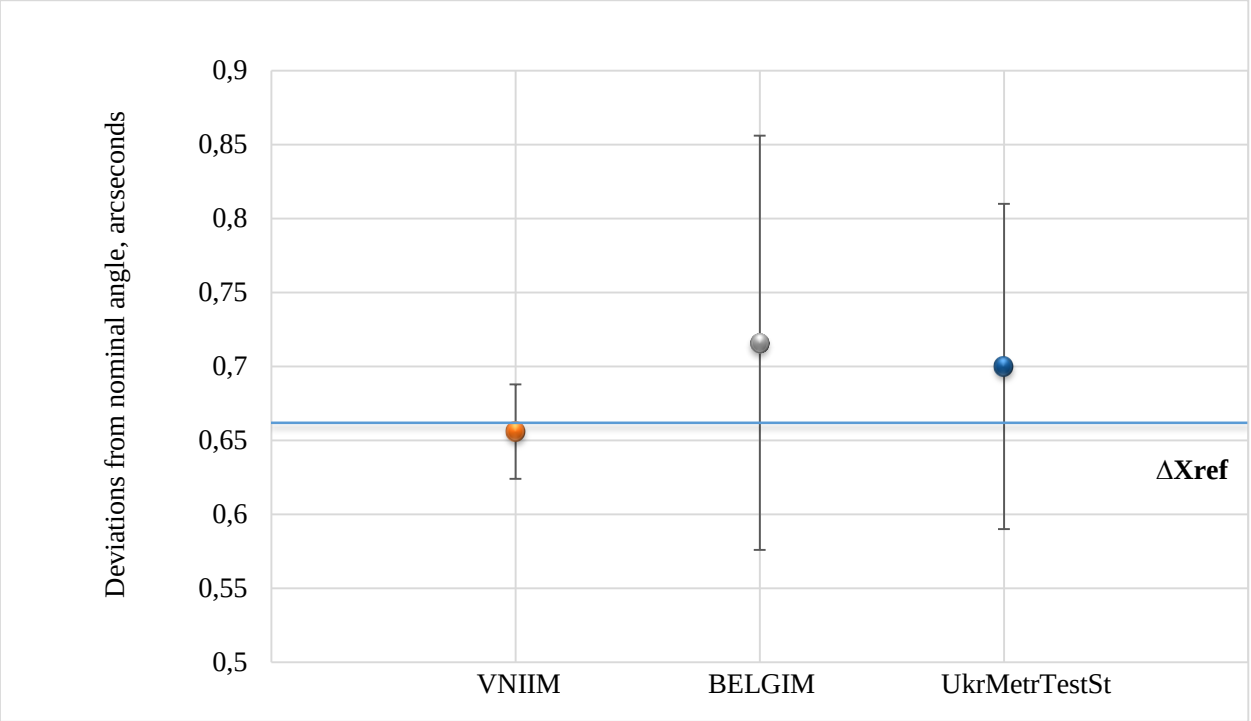

Figure 7 – Deviations from nominal angle between faces 1-6

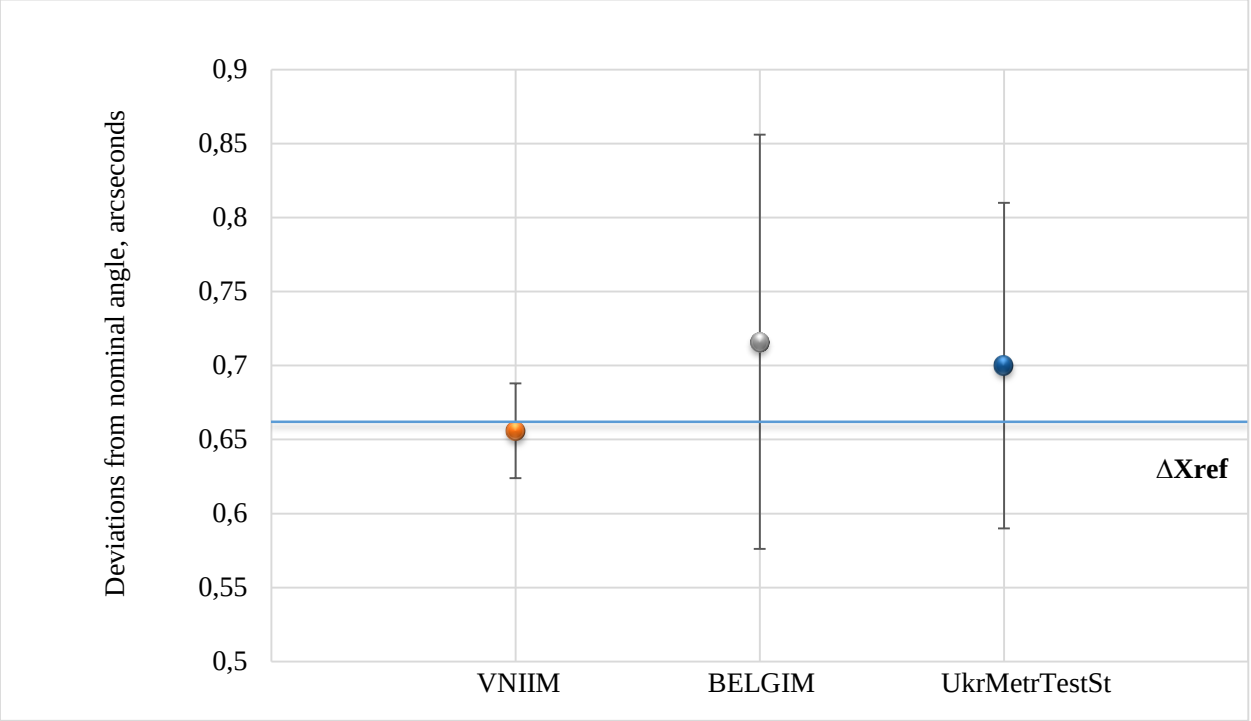

Figure 8 – Deviations from nominal angle between faces 1-7

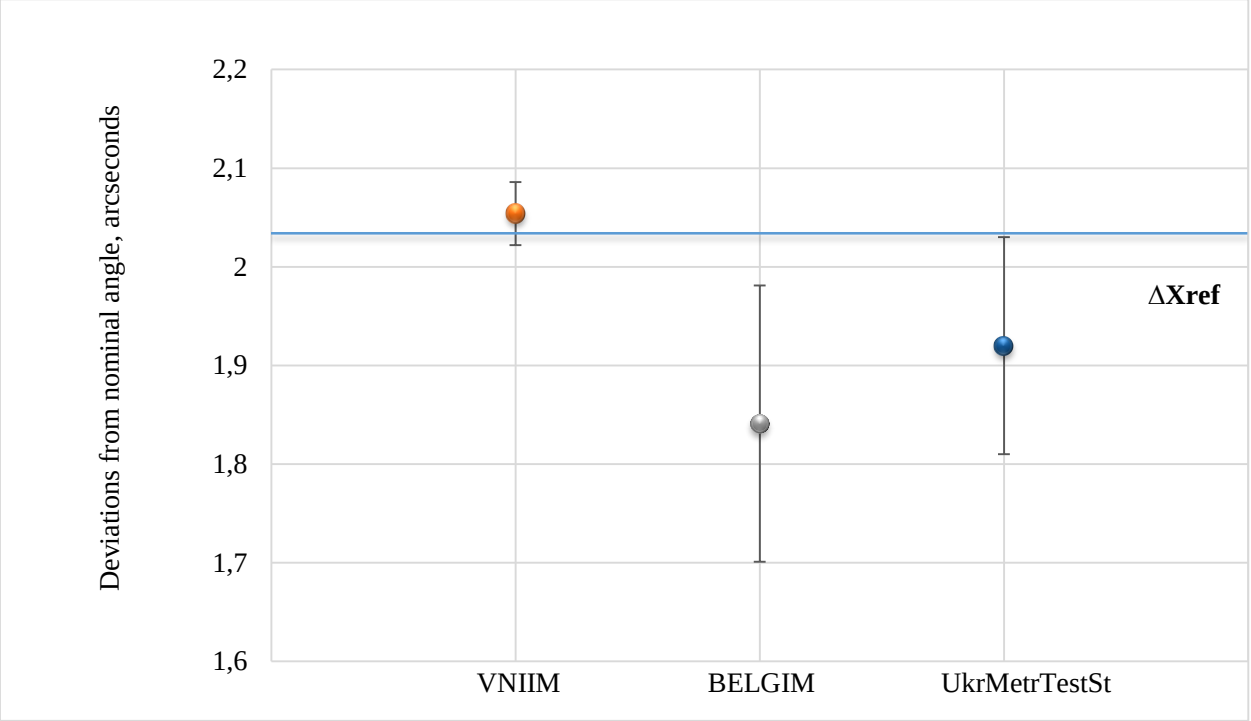

Figure 9 – Deviations from nominal angle between faces 1-8

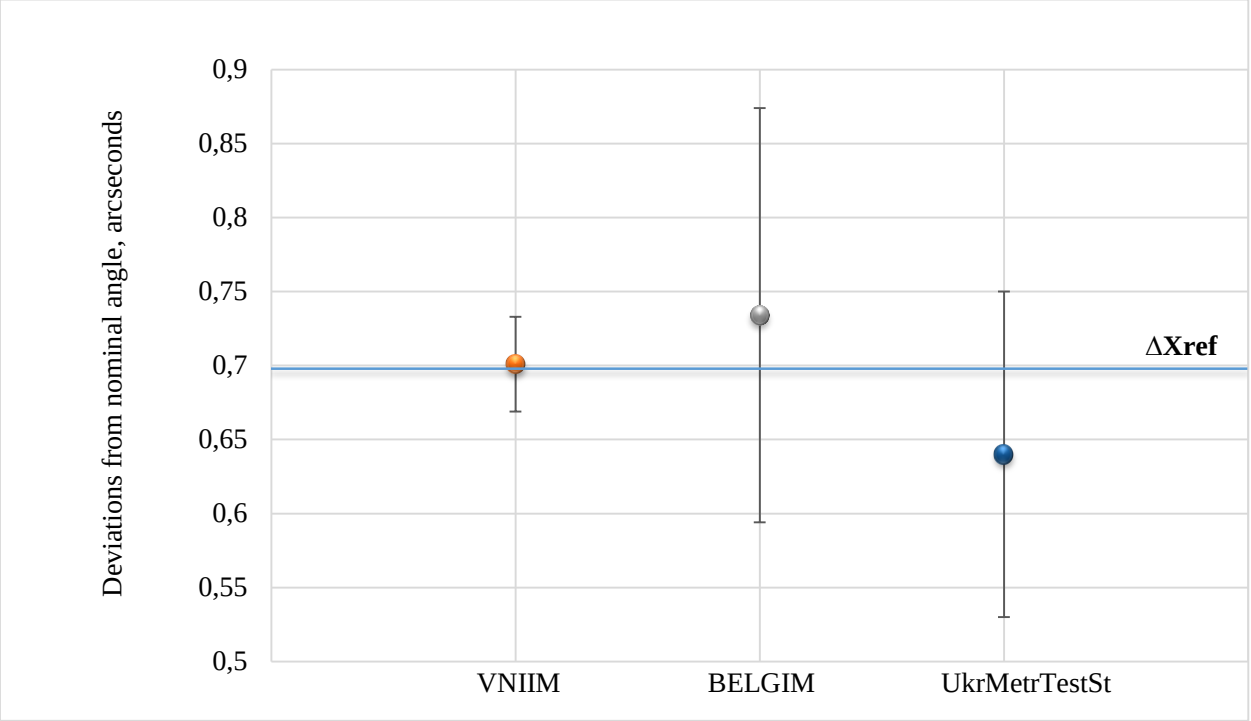

Figure 10 – Deviations from nominal angle between faces 1-9

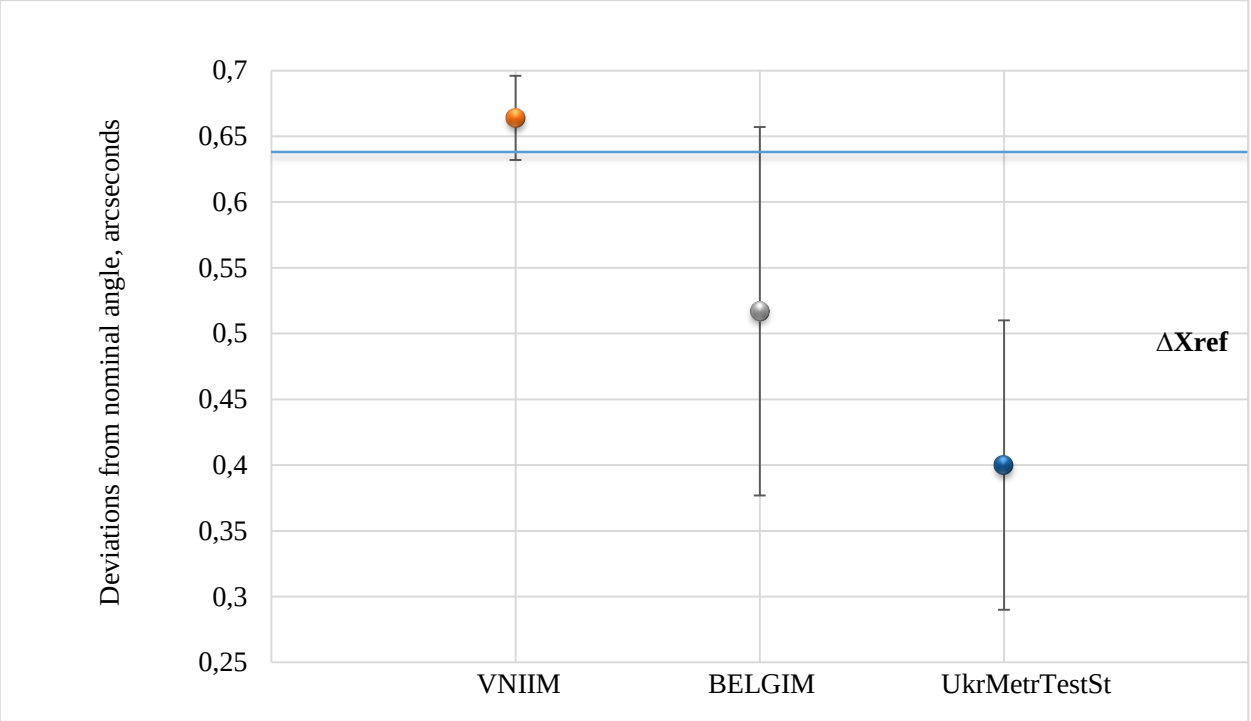

Figure 11 – Deviations from nominal angle between faces 1-10

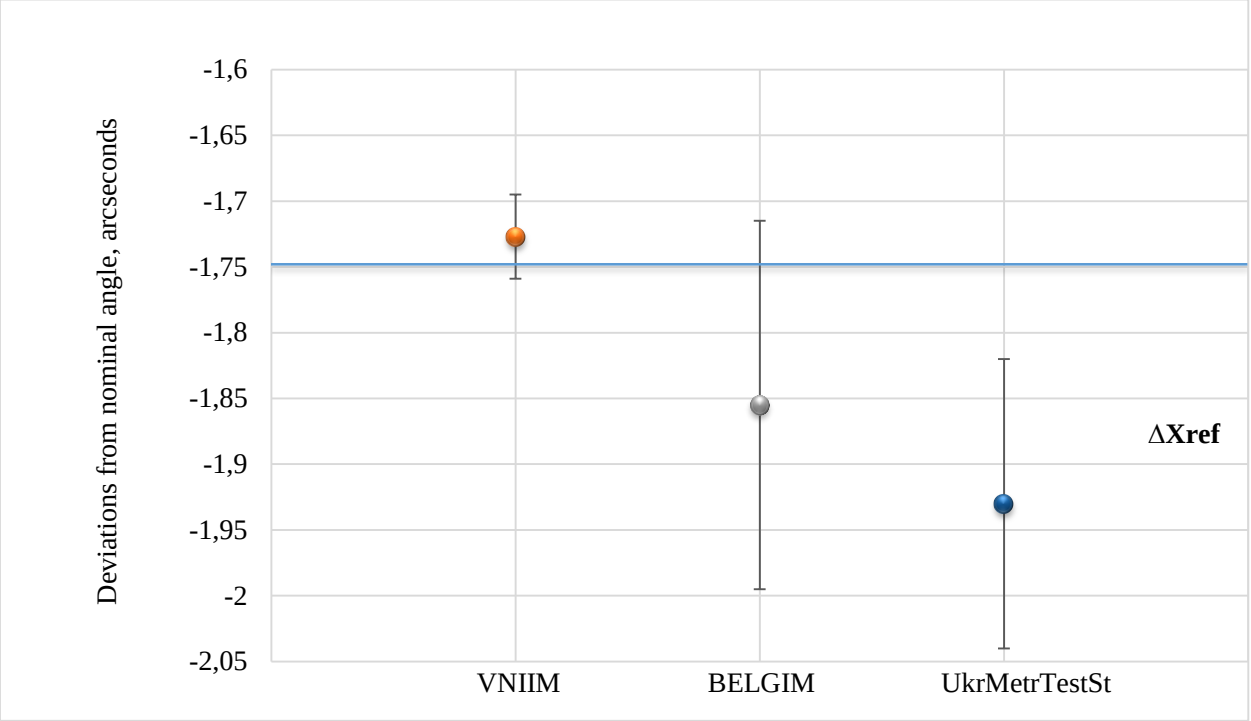

Figure 12 – Deviations from nominal angle between faces 1-11

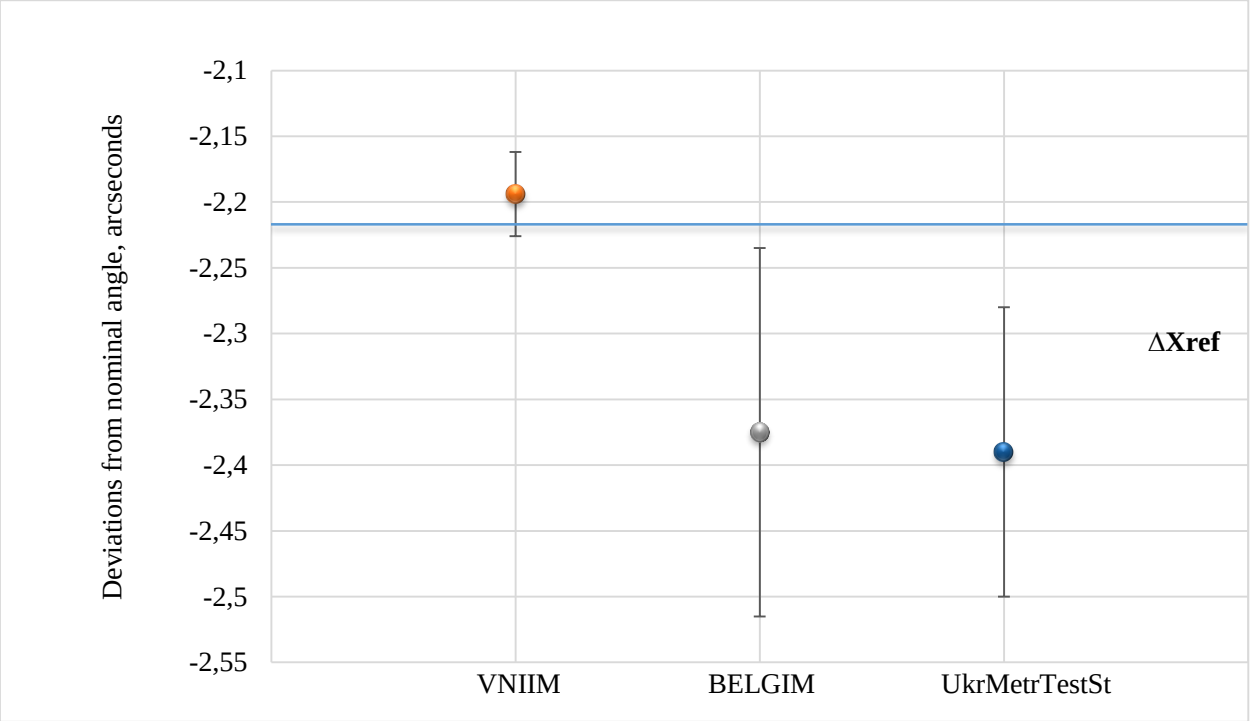

Figure 13 – Deviations from nominal angle between faces 1-12

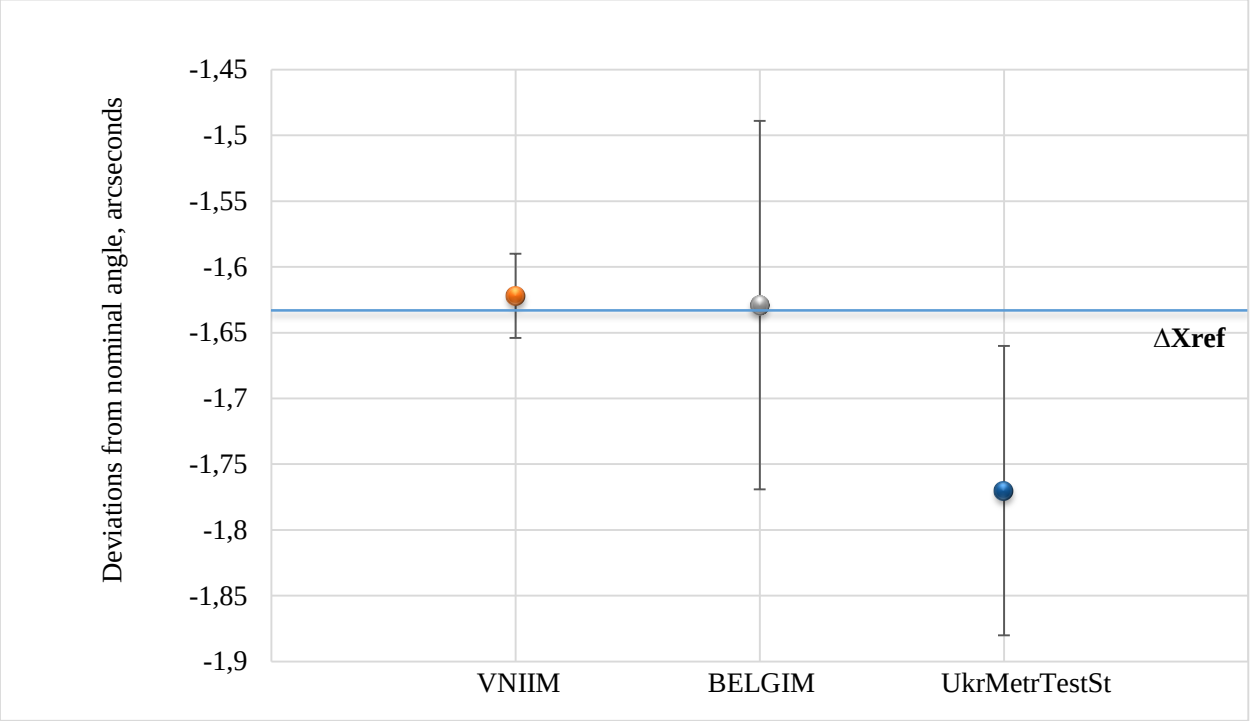

Figure 14 – Deviations from nominal angle between faces 1-13

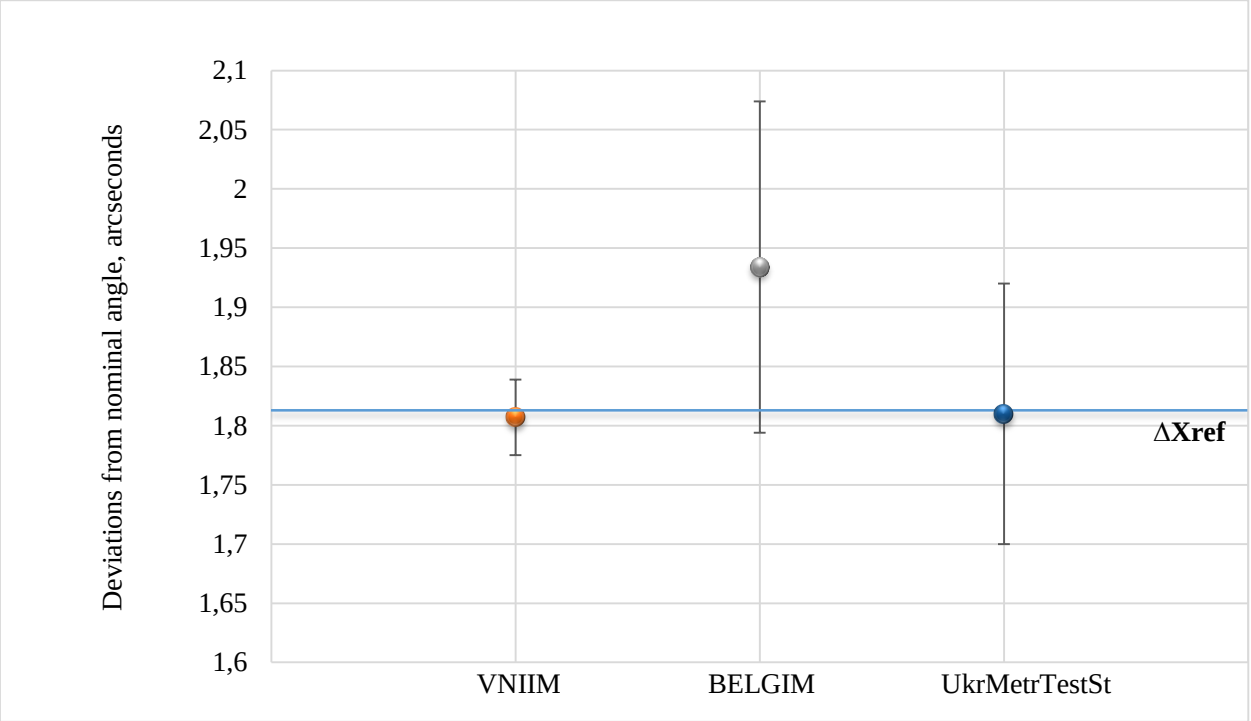

Figure 15 – Deviations from nominal angle between faces 1-14

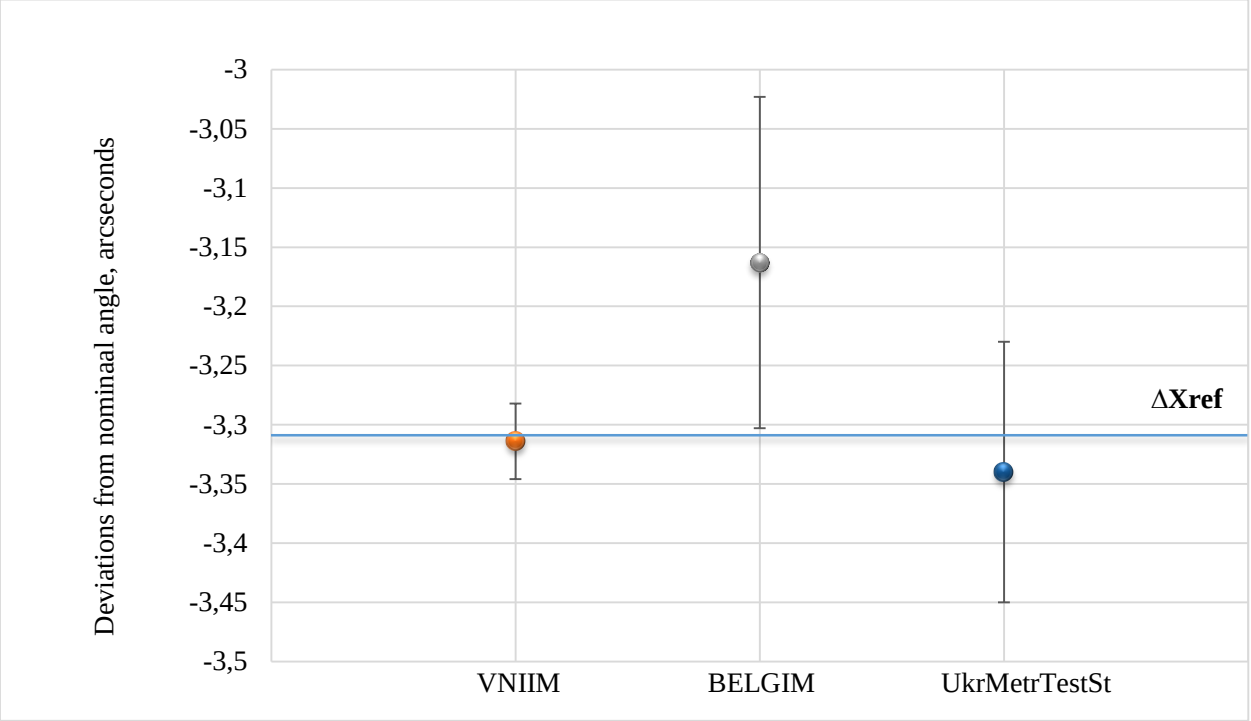

Figure 16 – Deviations from nominal angle between faces 1-15

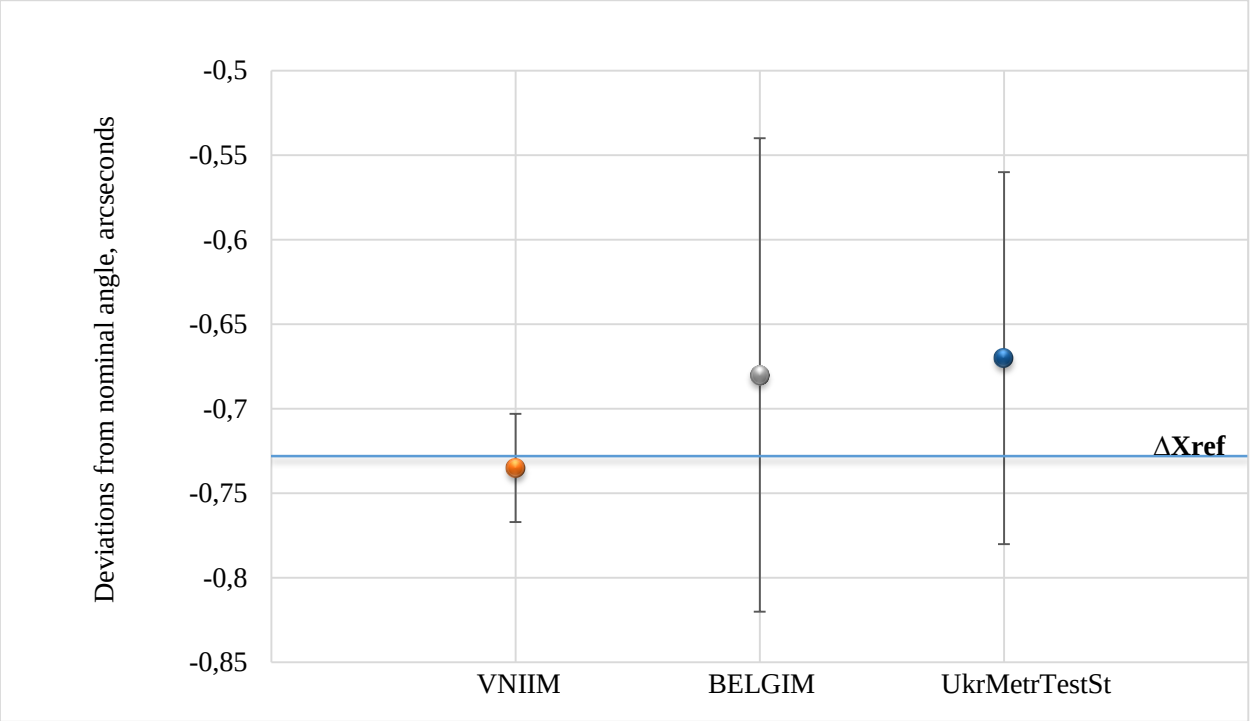

Figure 17 – Deviations from nominal angle between faces 1-16

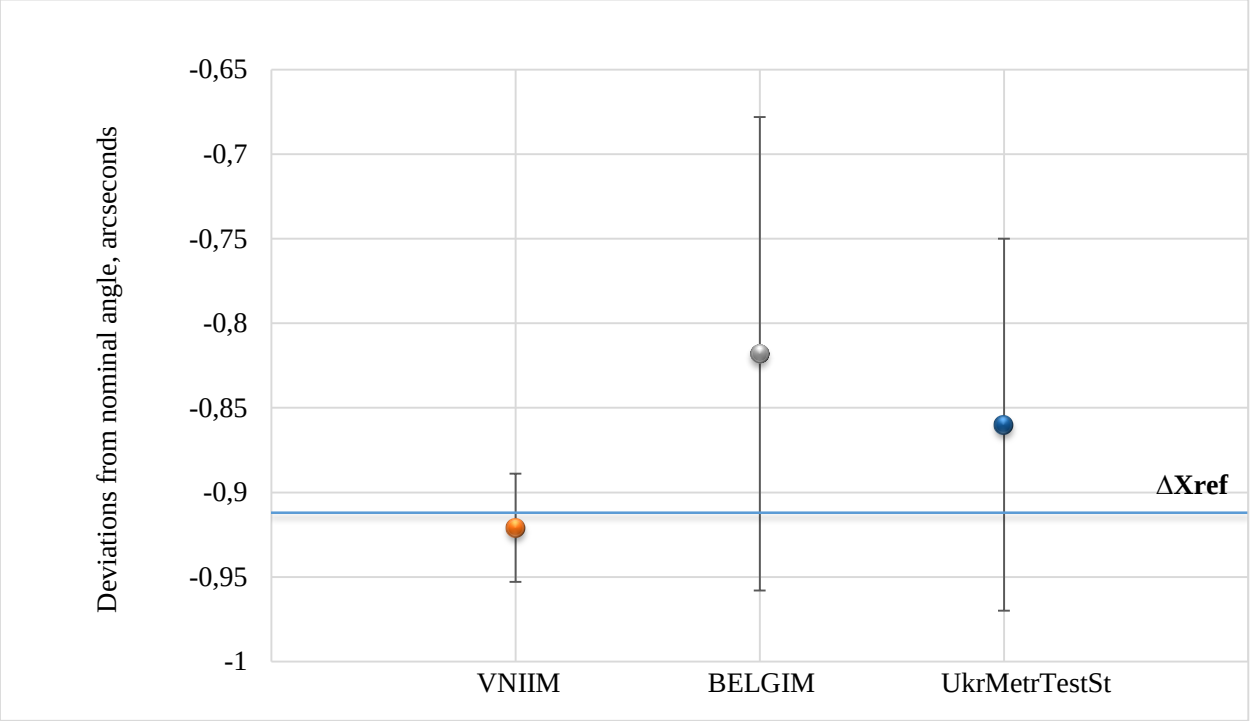

Figure 18 – Deviations from nominal angle between faces 1-17

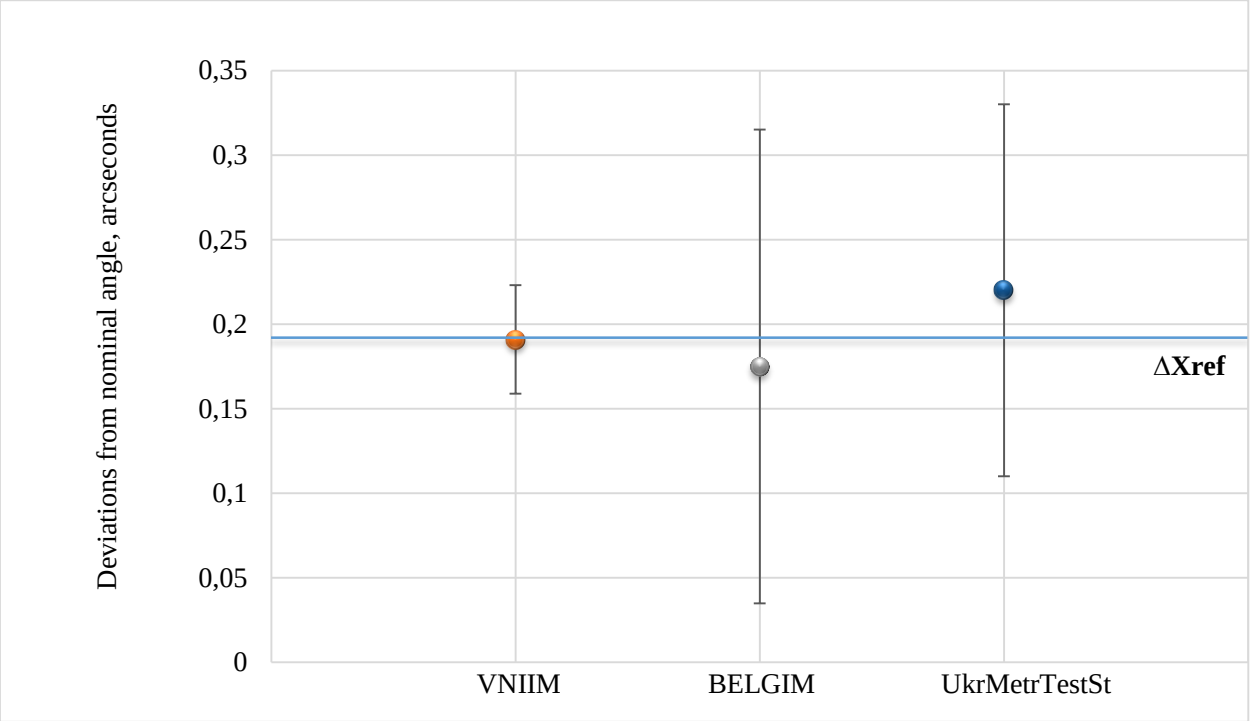

Figure 19 – Deviations from nominal angle between faces 1-18

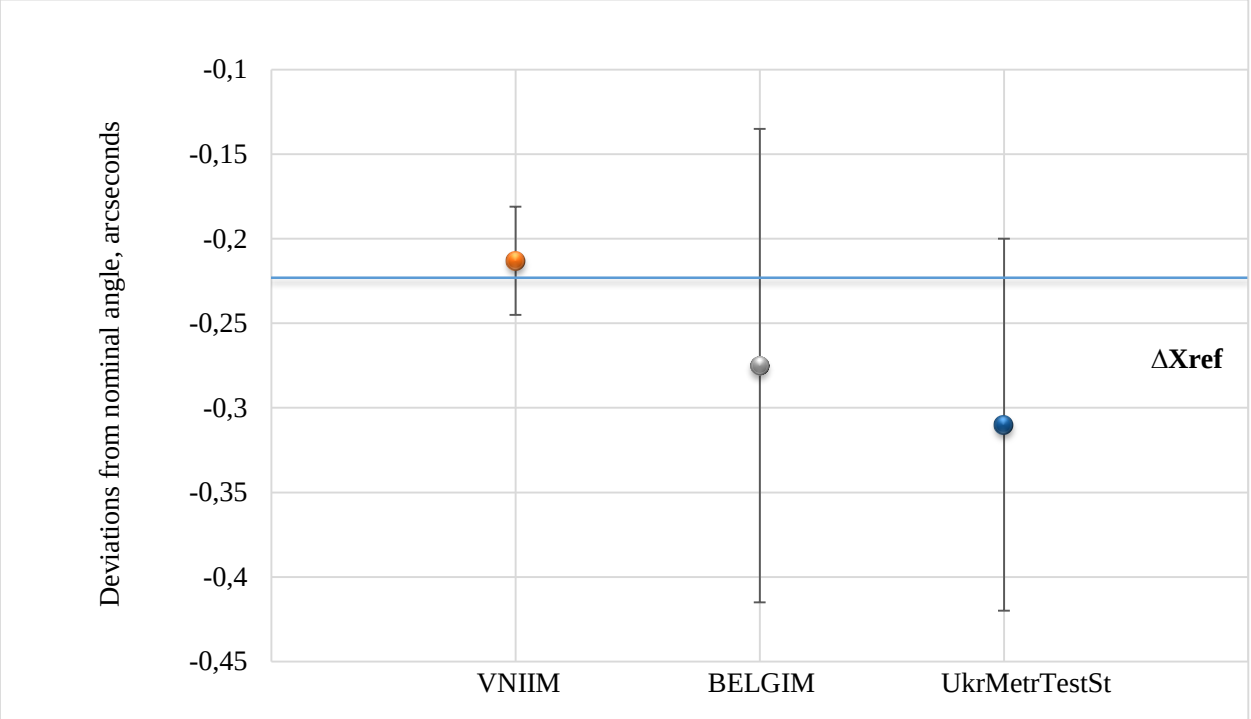

Figure 20 – Deviations from nominal angle between faces 1-19

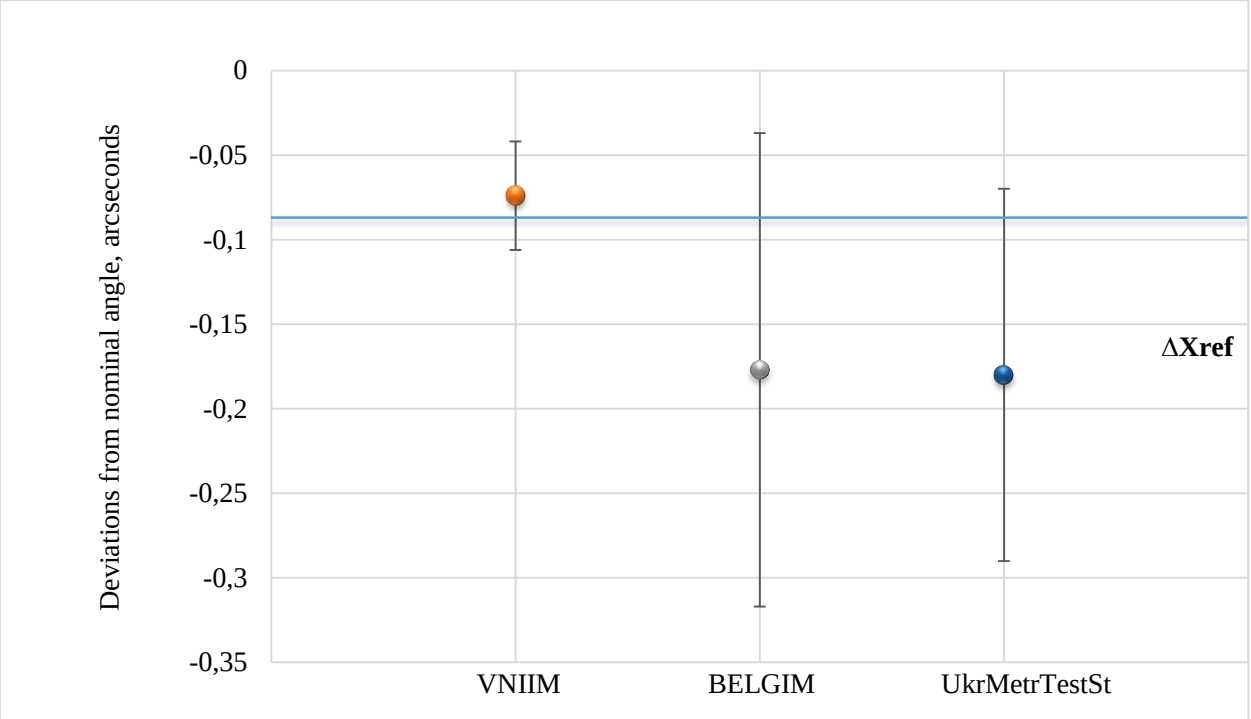

Figure 21 – Deviations from nominal angle between faces 1-20

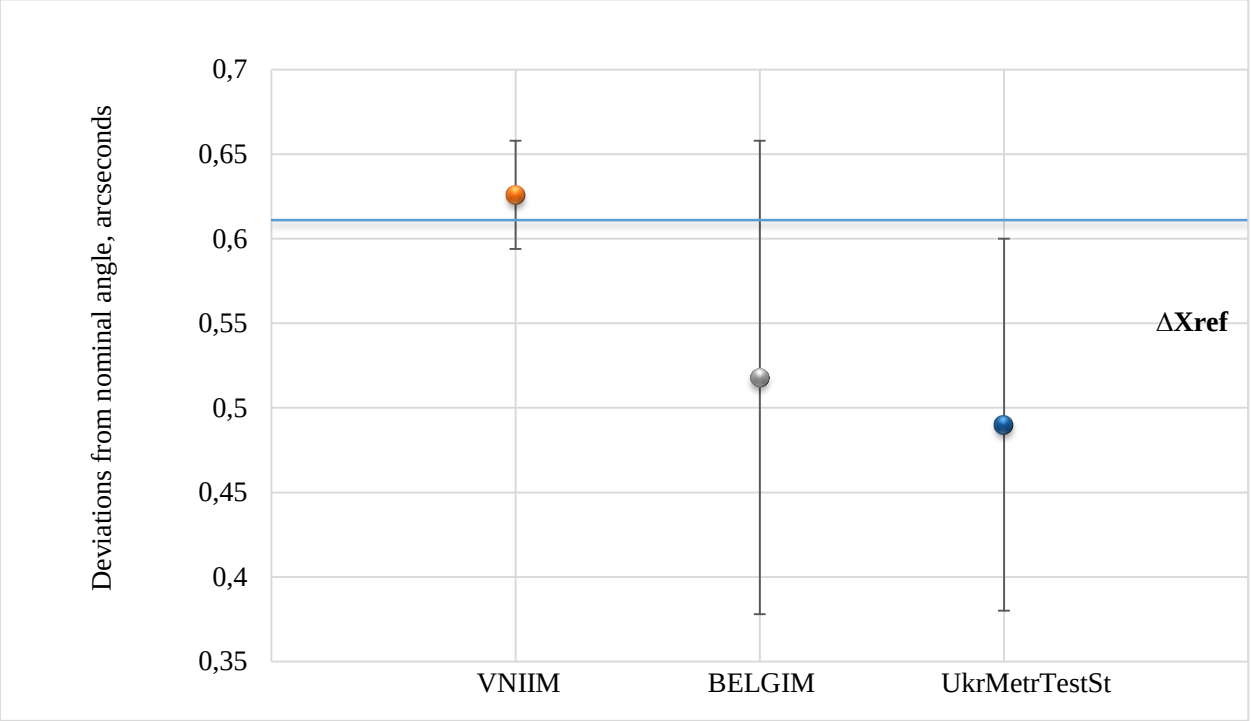

Figure 22 – Deviations from nominal angle between faces 1-21

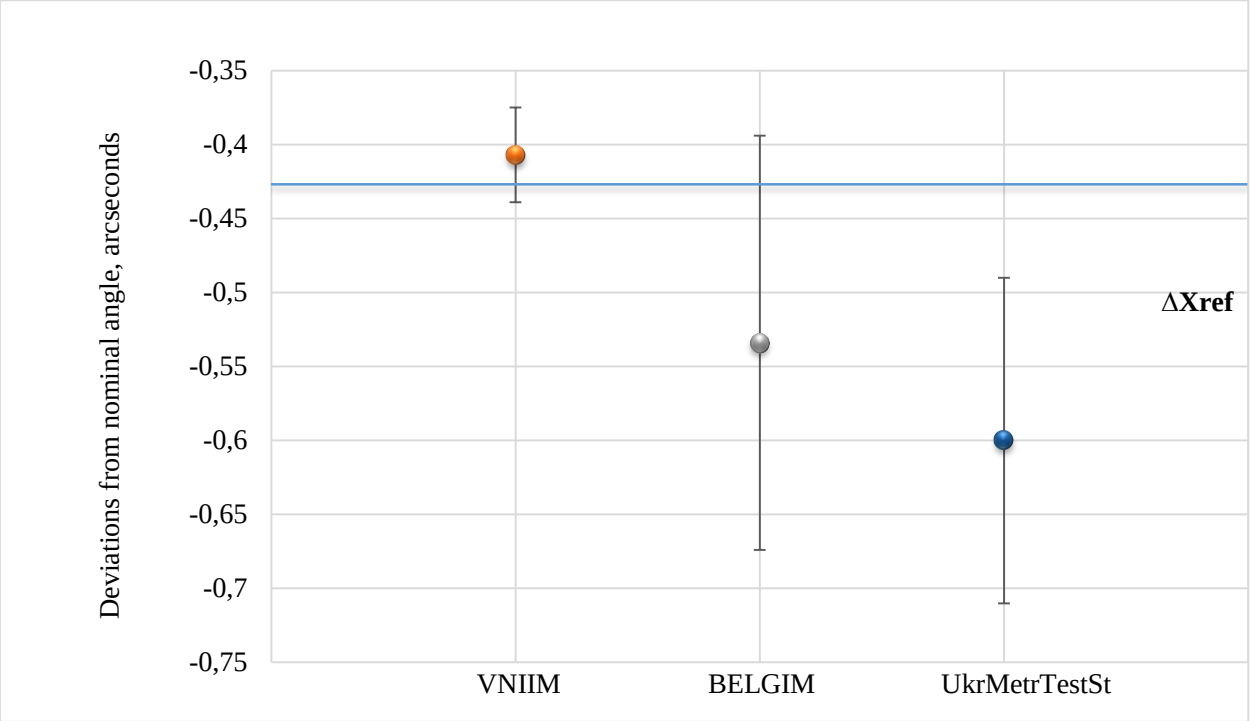

Figure 23 – Deviations from nominal angle between faces 1-22

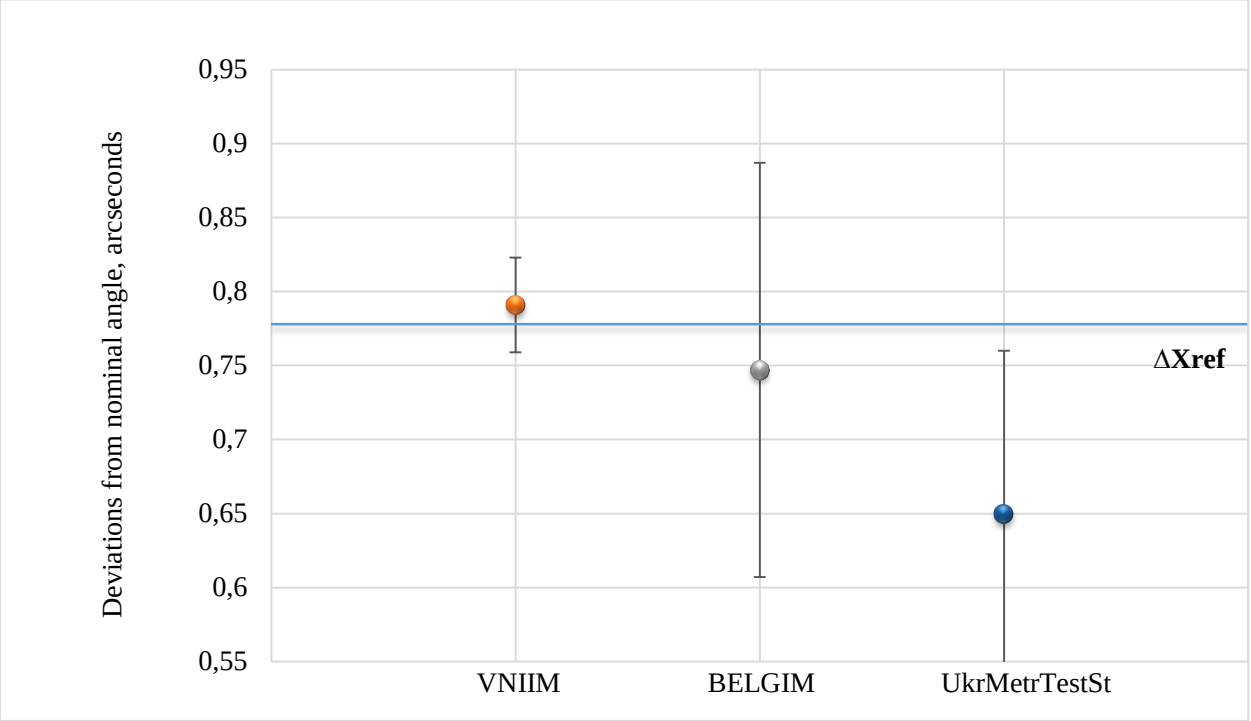

Figure 24 – Deviations from nominal angle between faces 1-23

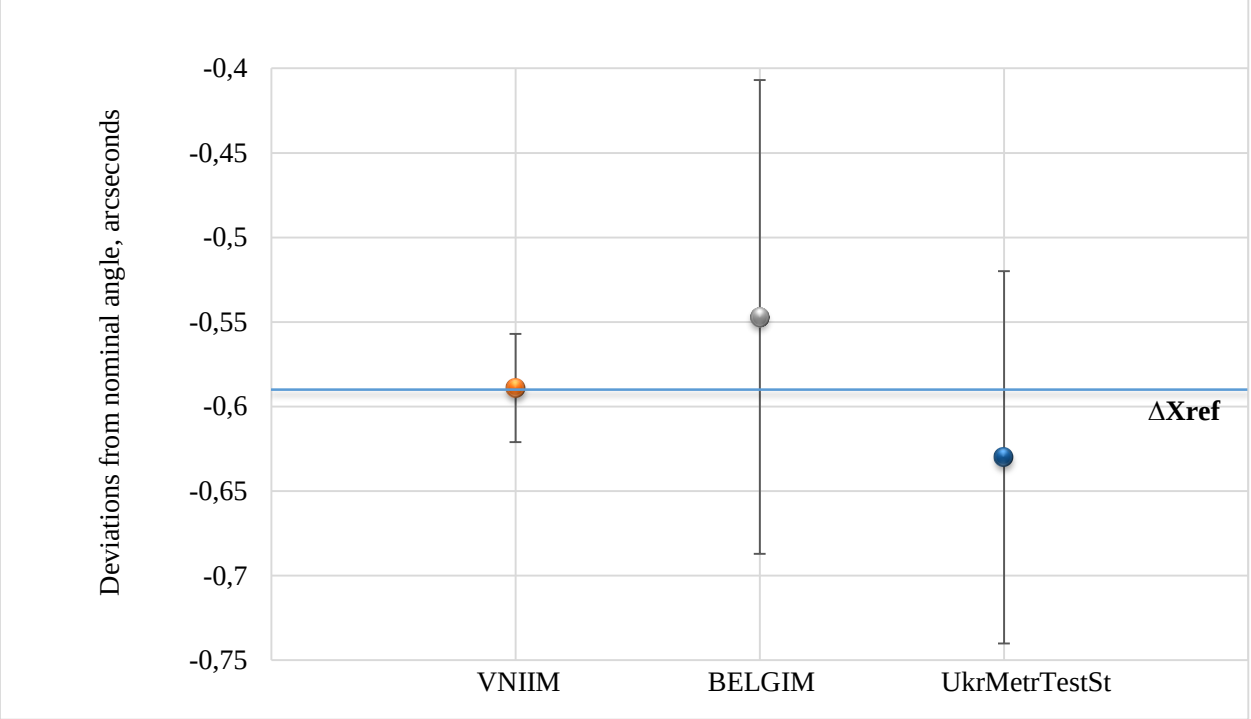

Figure 25 – Deviations from nominal angle between faces 1-24

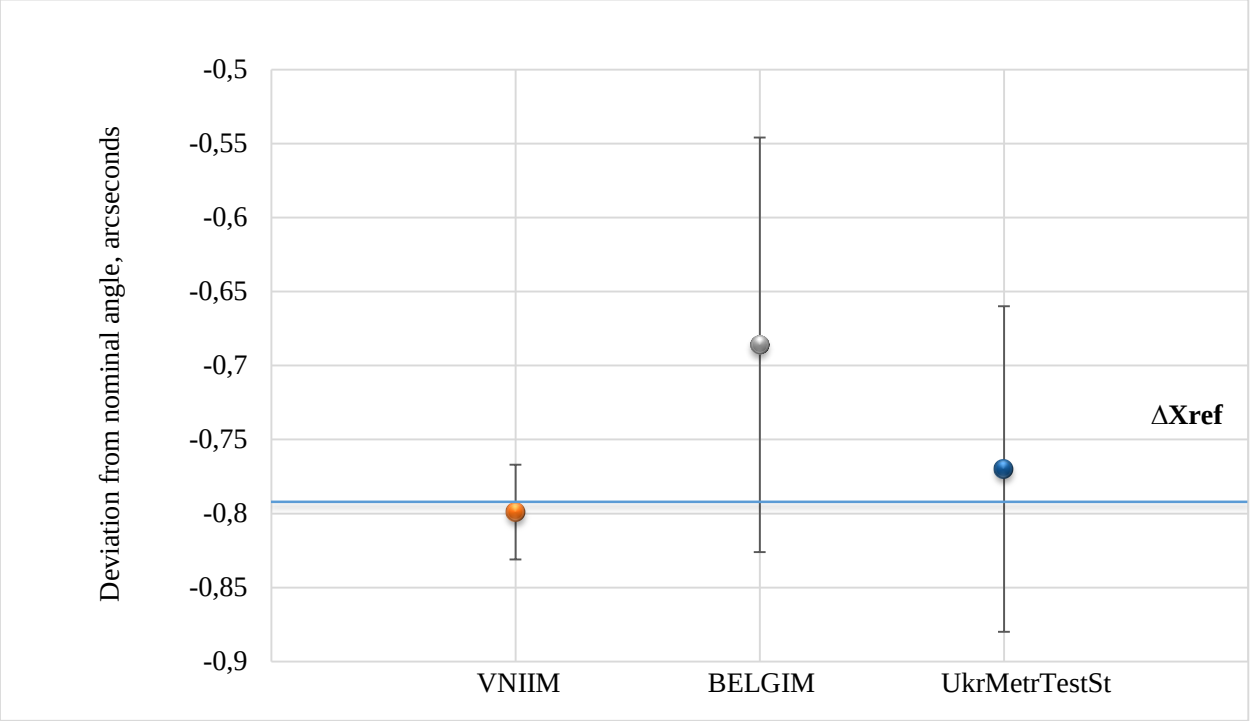

Figure 26 – Deviations from nominal angle between faces 1-2

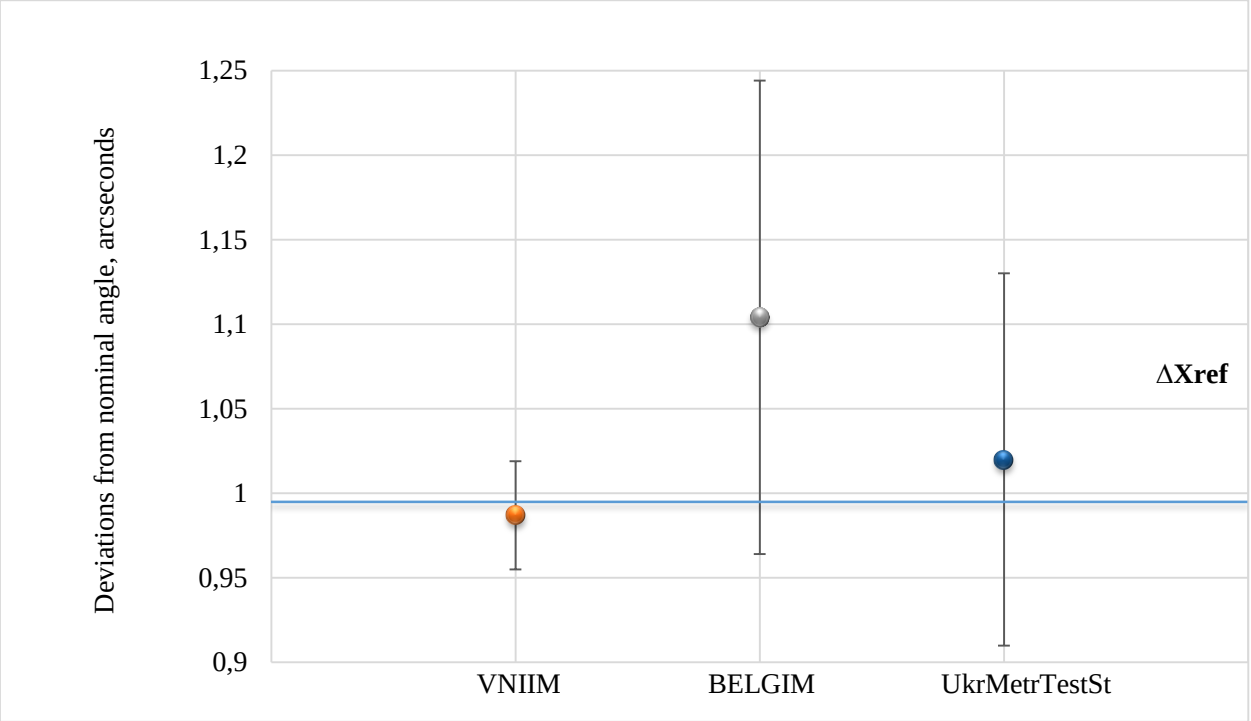

Figure 27 – Deviations from nominal angle between faces 2-3

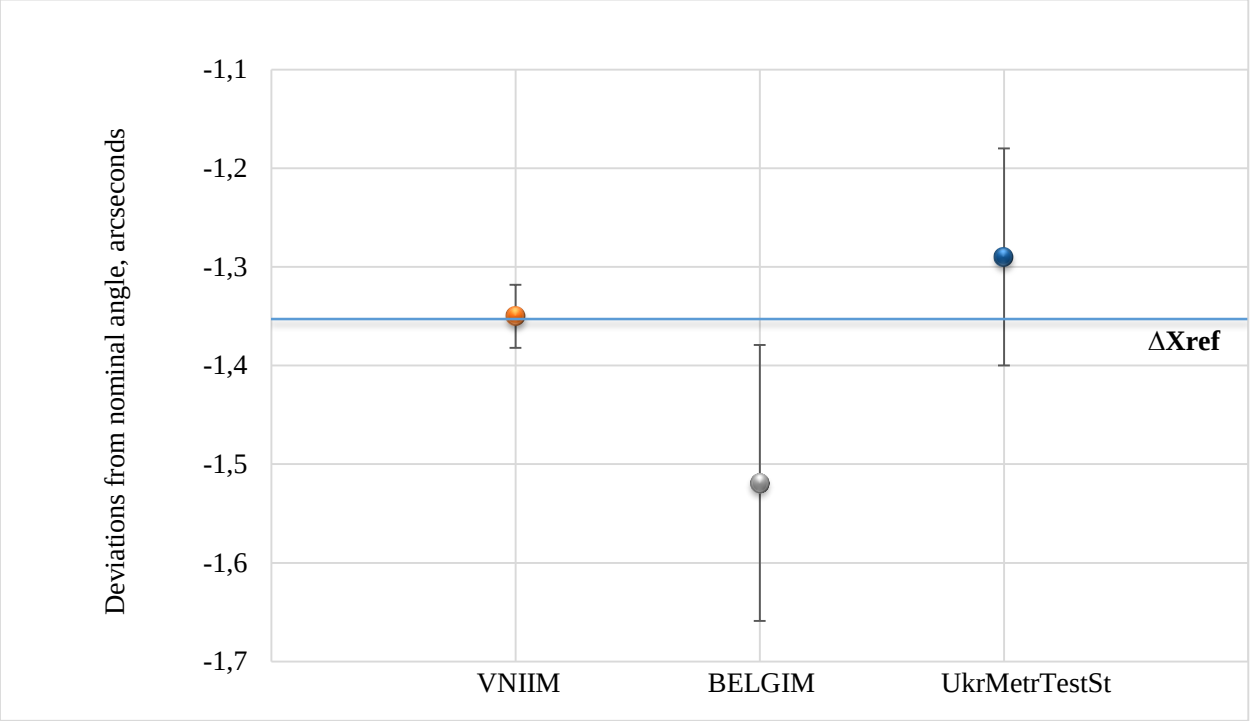

Figure 28 – Deviations from nominal angle between faces 3-4

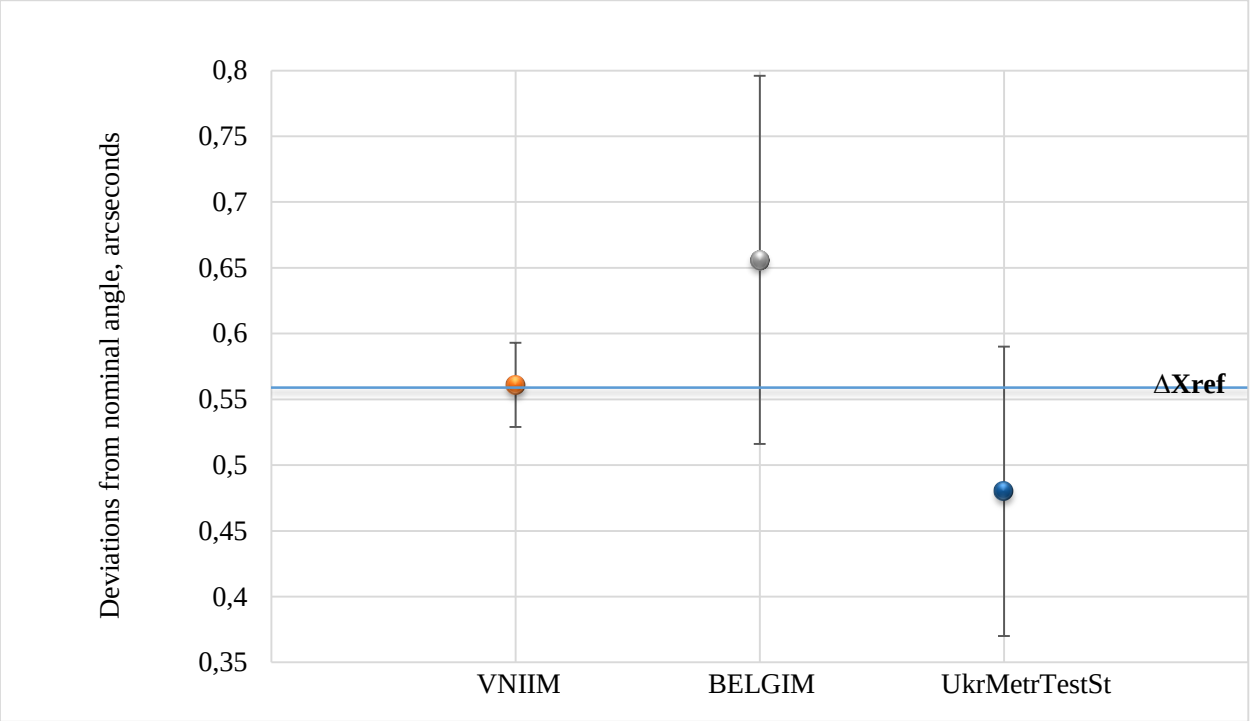

Figure 29 – Deviations from nominal angle between faces 4-5

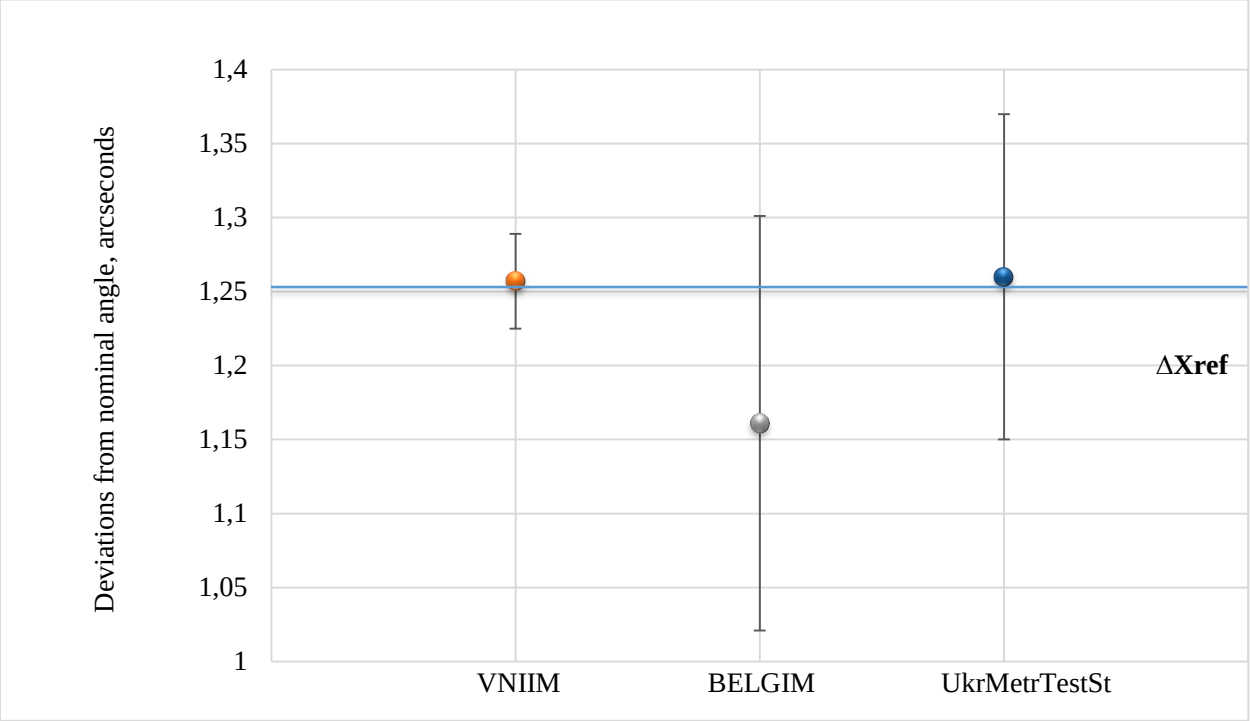

Figure 30 – Deviations from nominal angle between faces 5-6

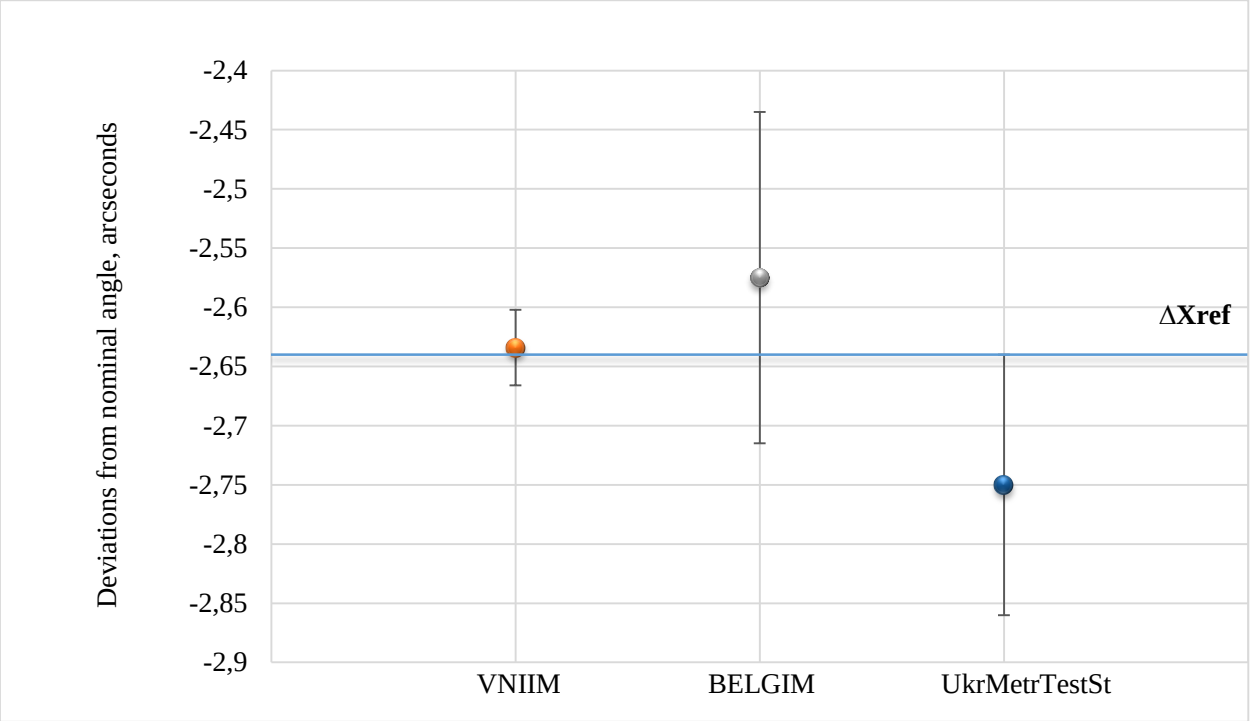

Figure 31 – Deviations from nominal angle between faces 6-7

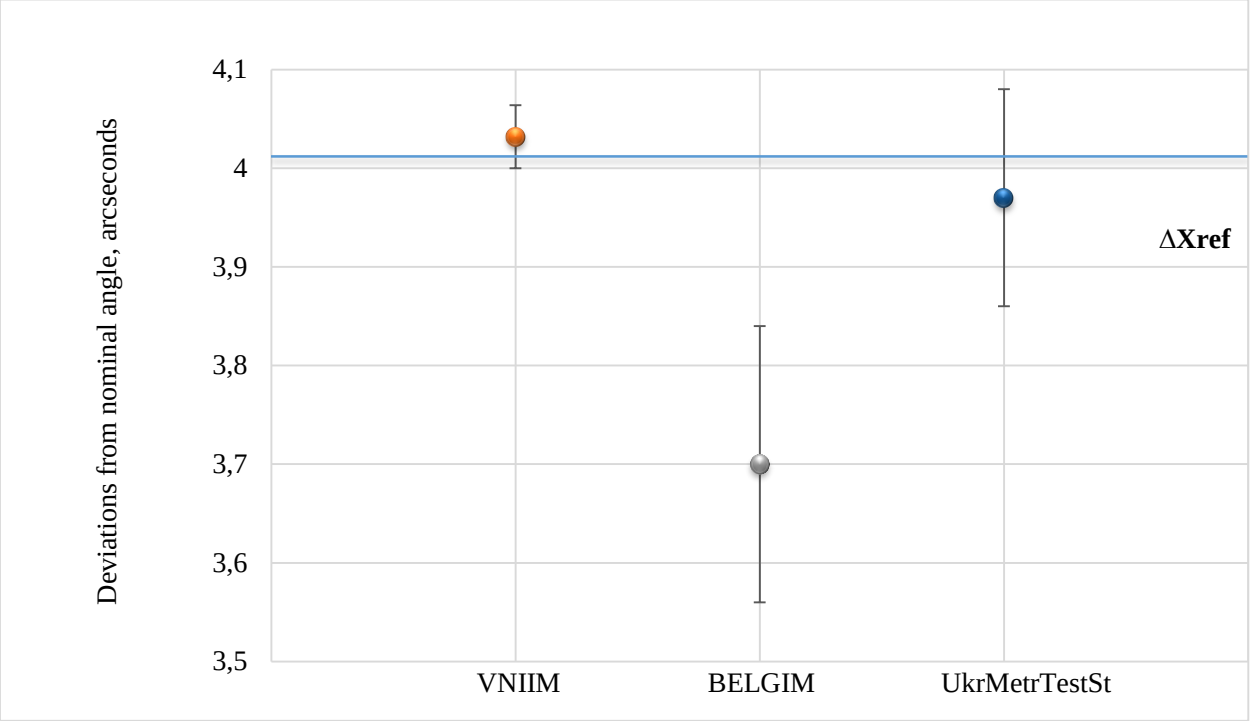

Figure 32 – Deviations from nominal angle between faces 7-8

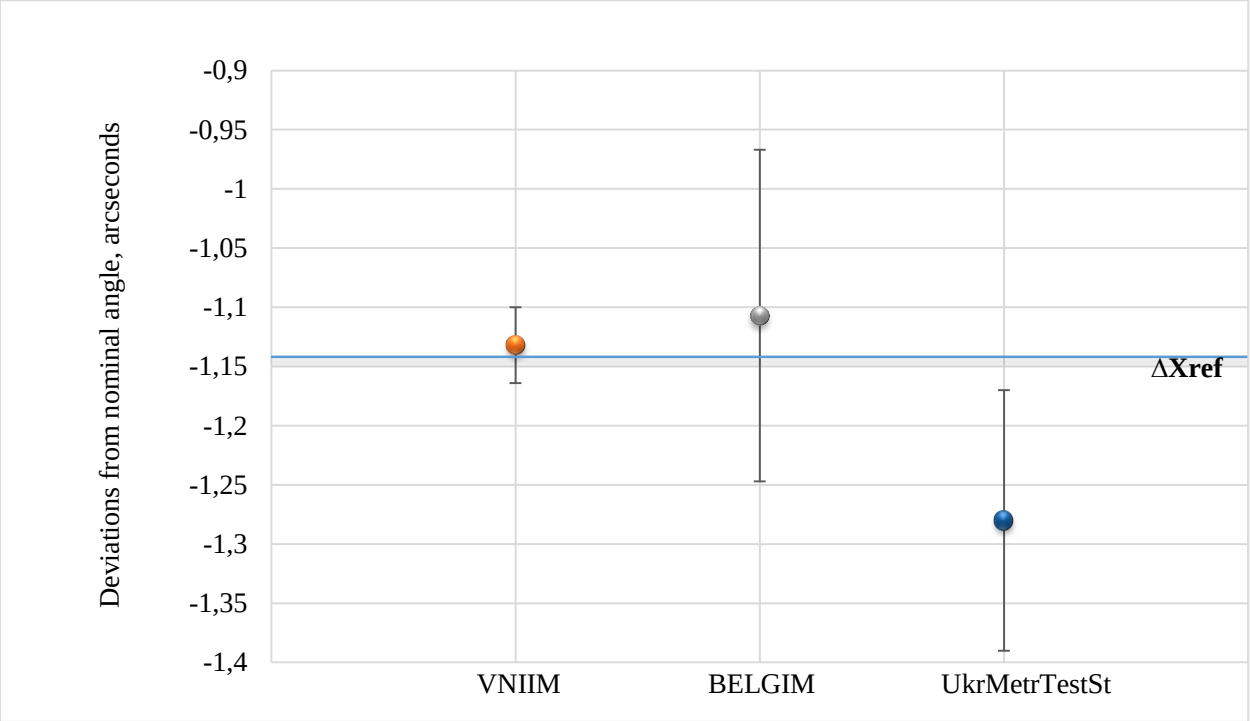

Figure 33 – Deviations from nominal angle between faces 8-9

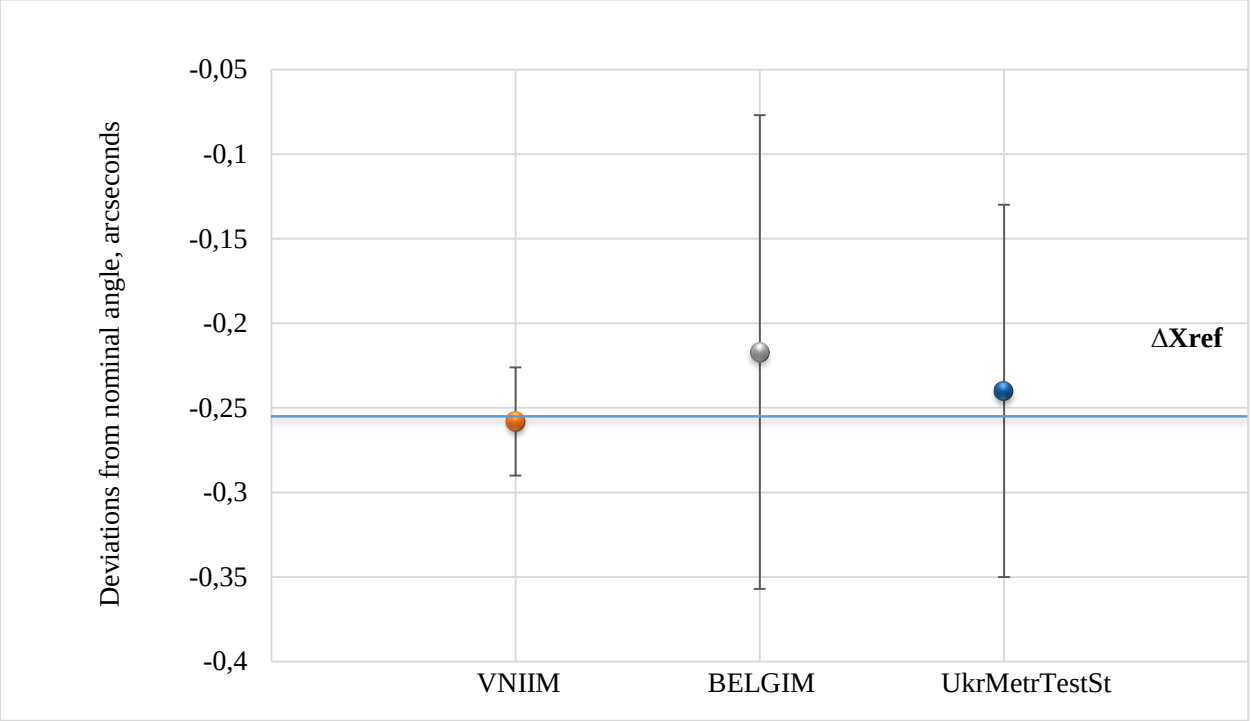

Figure 34 – Deviations from nominal angle between faces 9-10

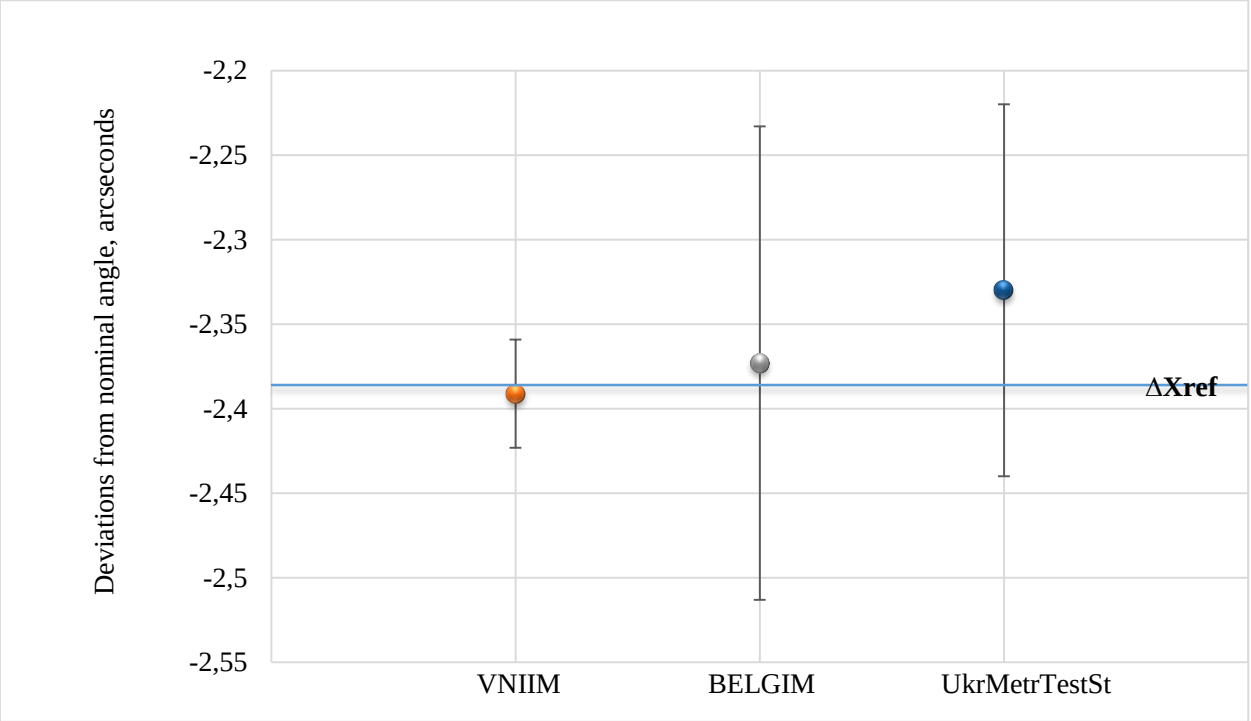

Figure 35 – Deviations from nominal angle between faces 10-11

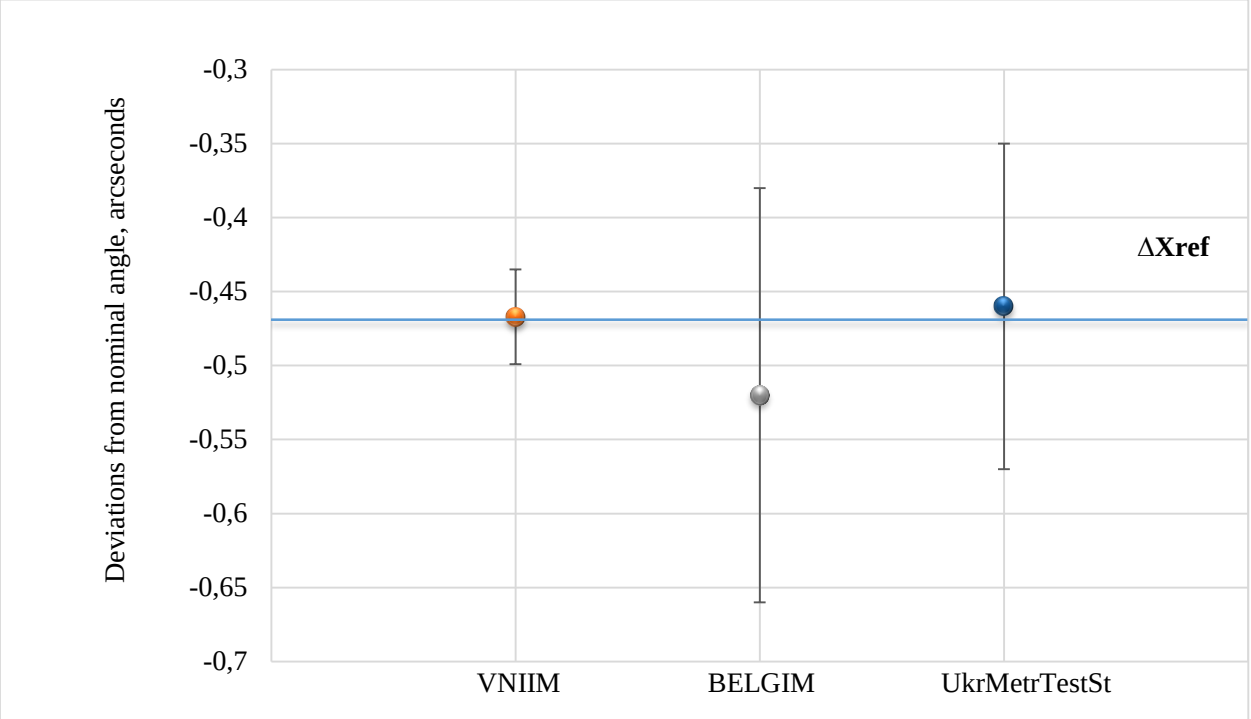

Figure 36 – Deviations from nominal angle between faces 11-12

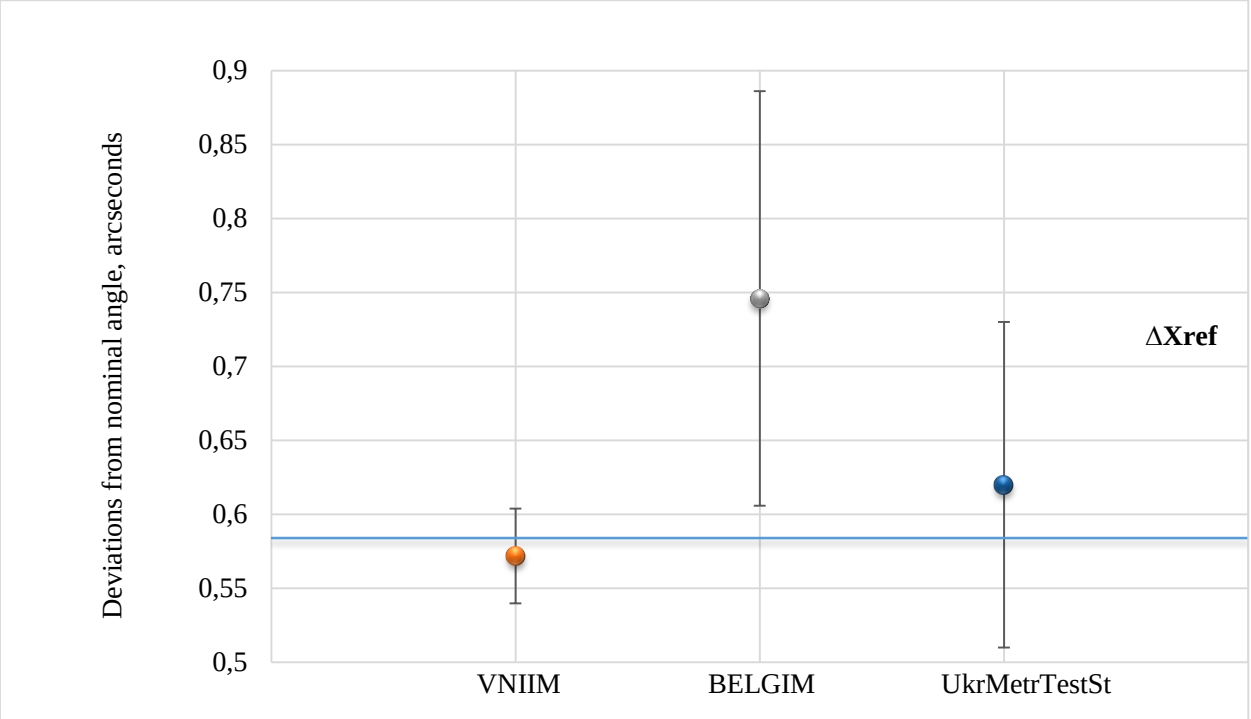

Figure 37 – Deviations from nominal angle between faces 12-13

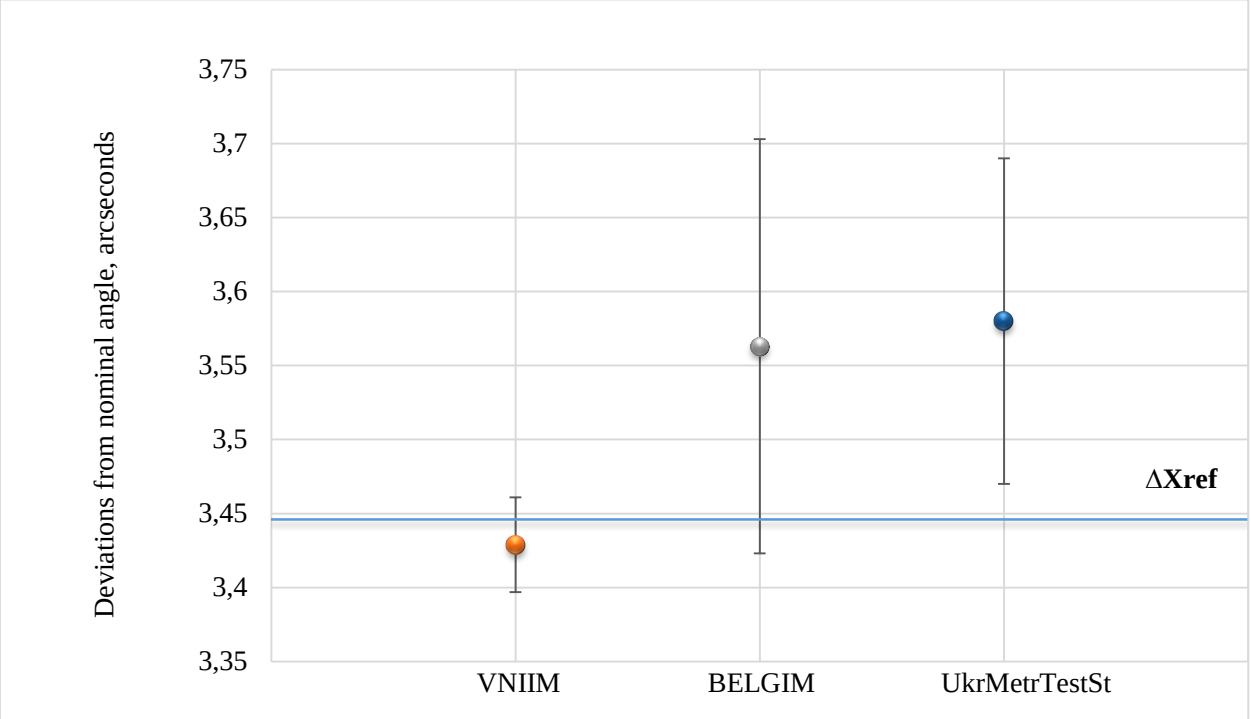

Figure 38 – Deviations from nominal angle between faces 13-14

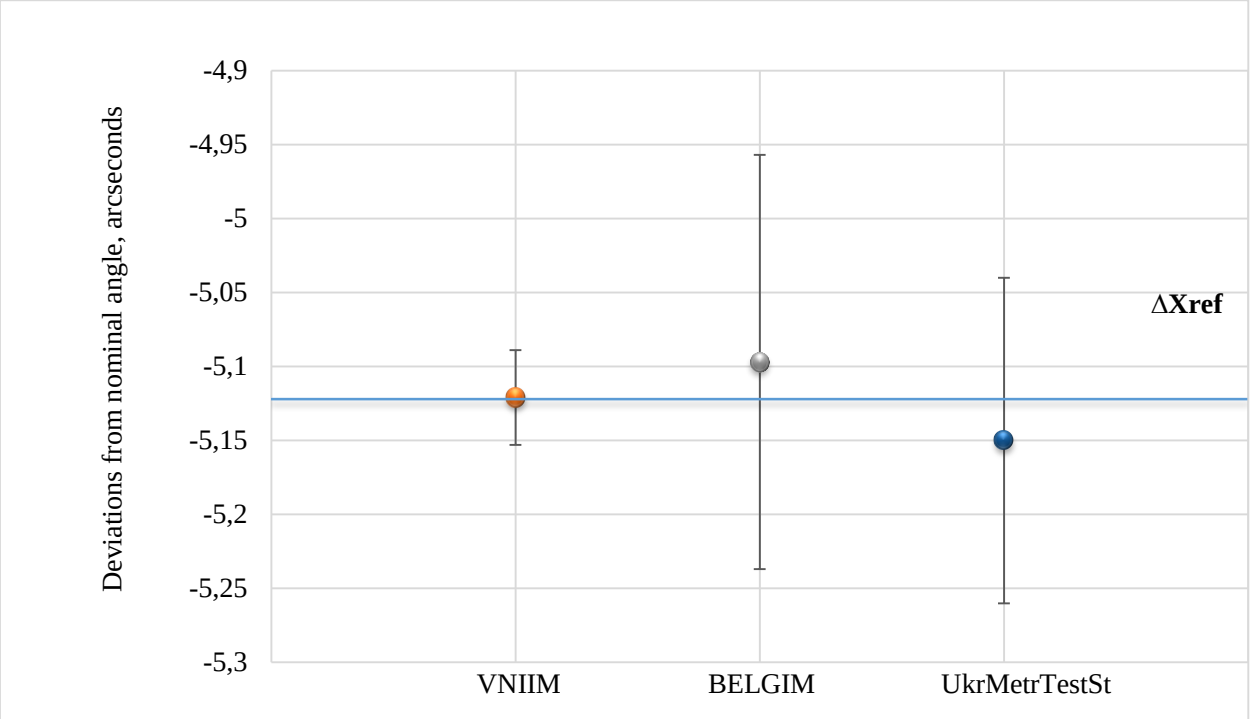

Figure 39 – Deviations from nominal angle between faces 14-15

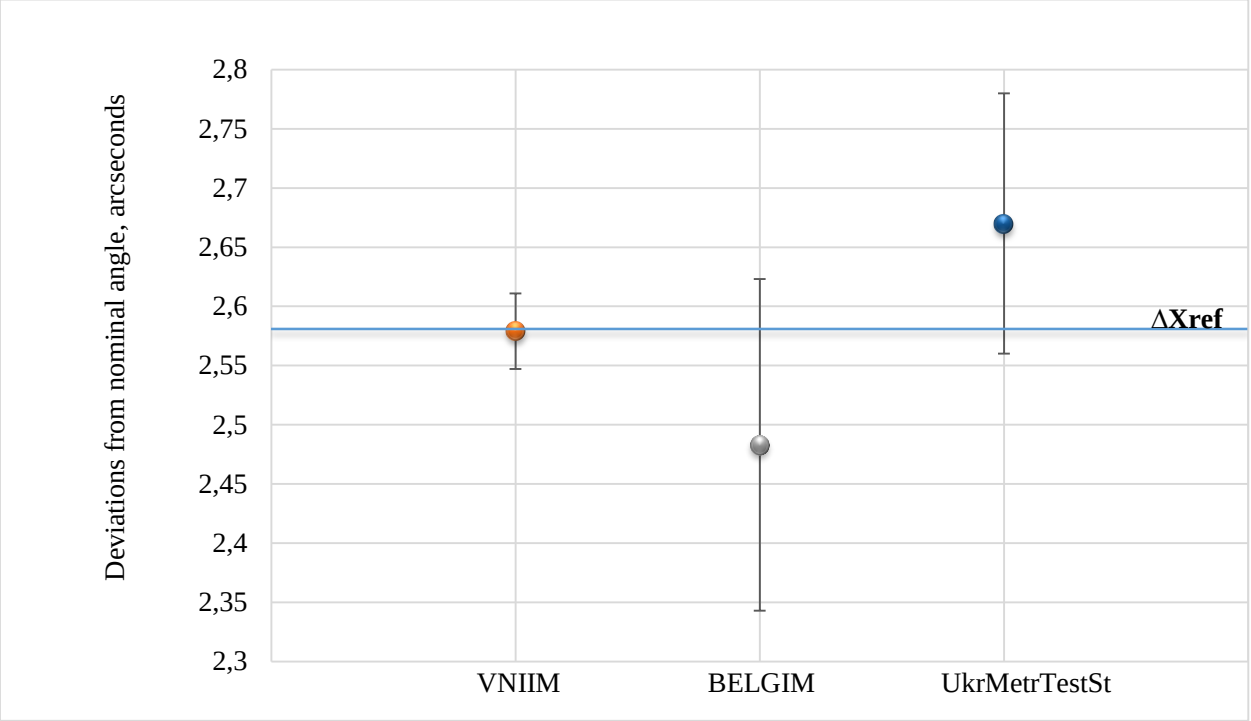

Figure 40 – Deviations from nominal angle between faces 15-16

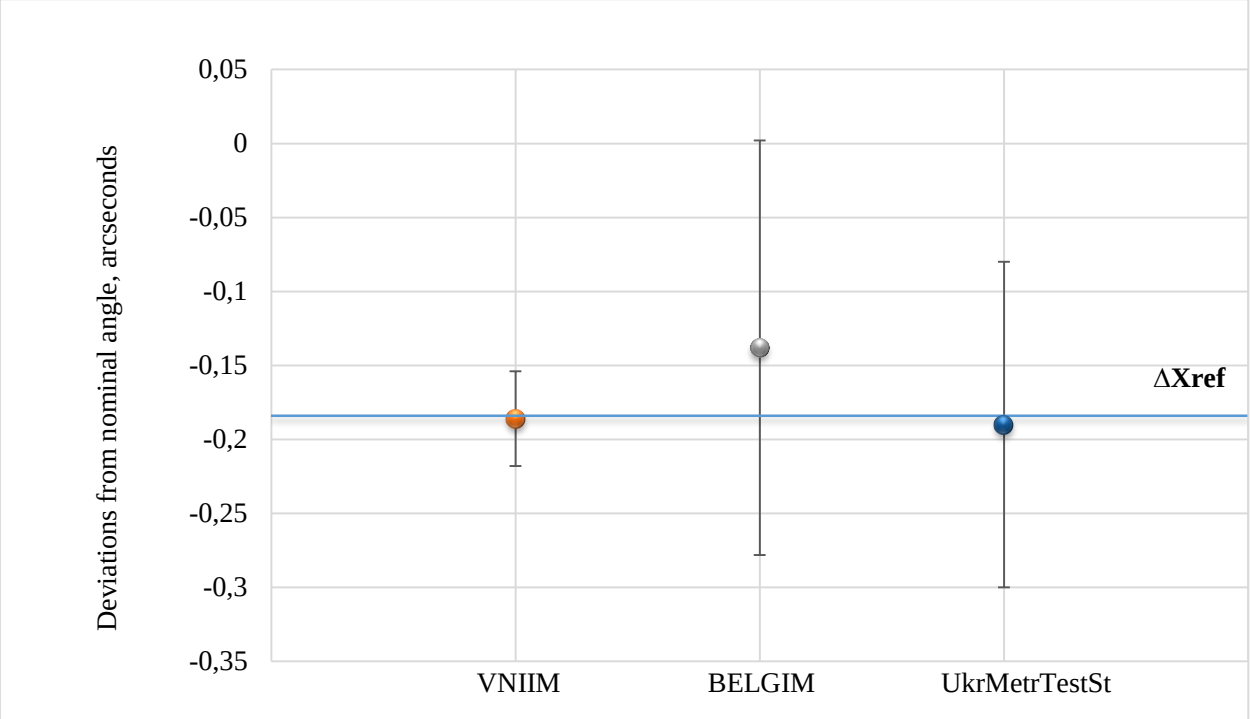

Figure 41 – Deviations from nominal angle between faces 16-17

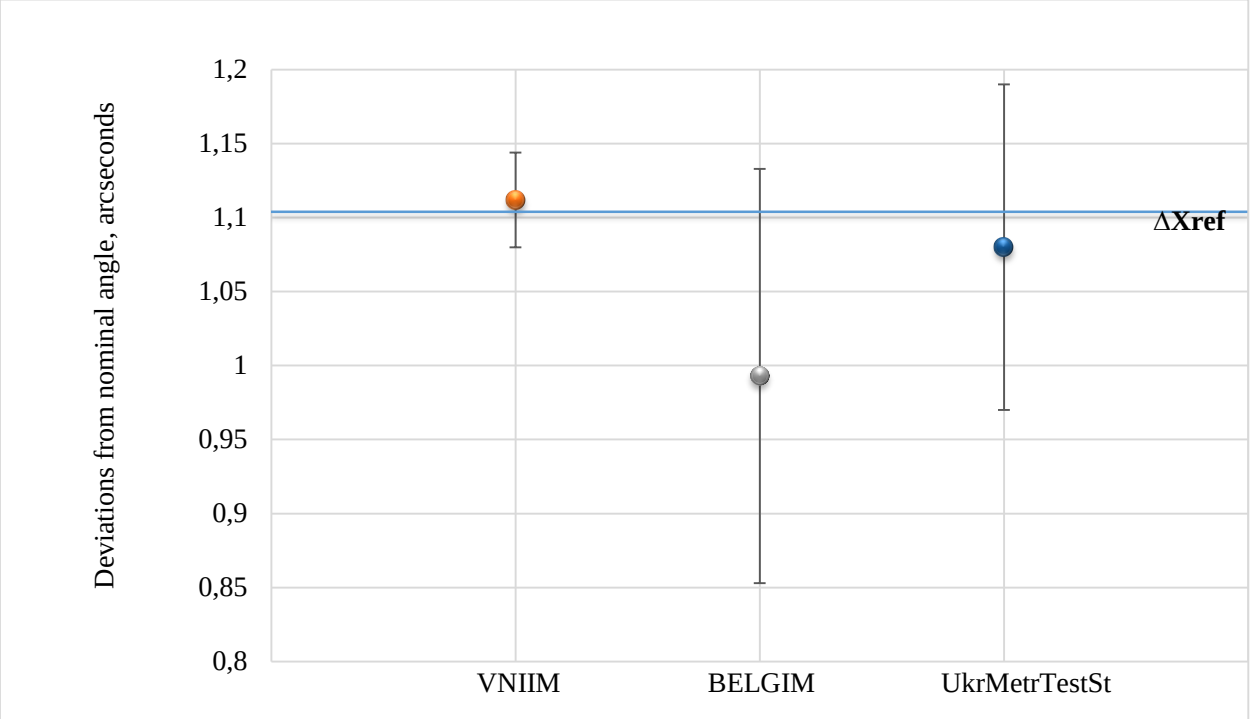

Figure 42 – Deviations from nominal angle between faces 17-18

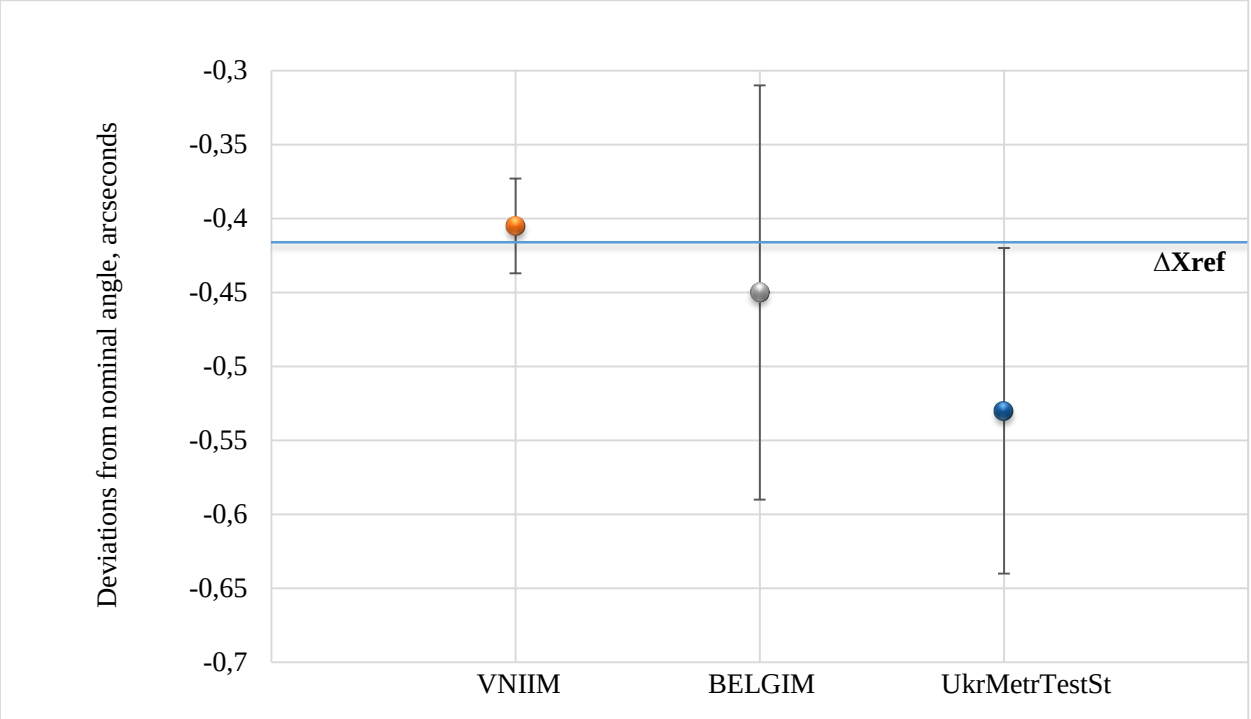

Figure 43 – Deviations from nominal angle between faces 18-19

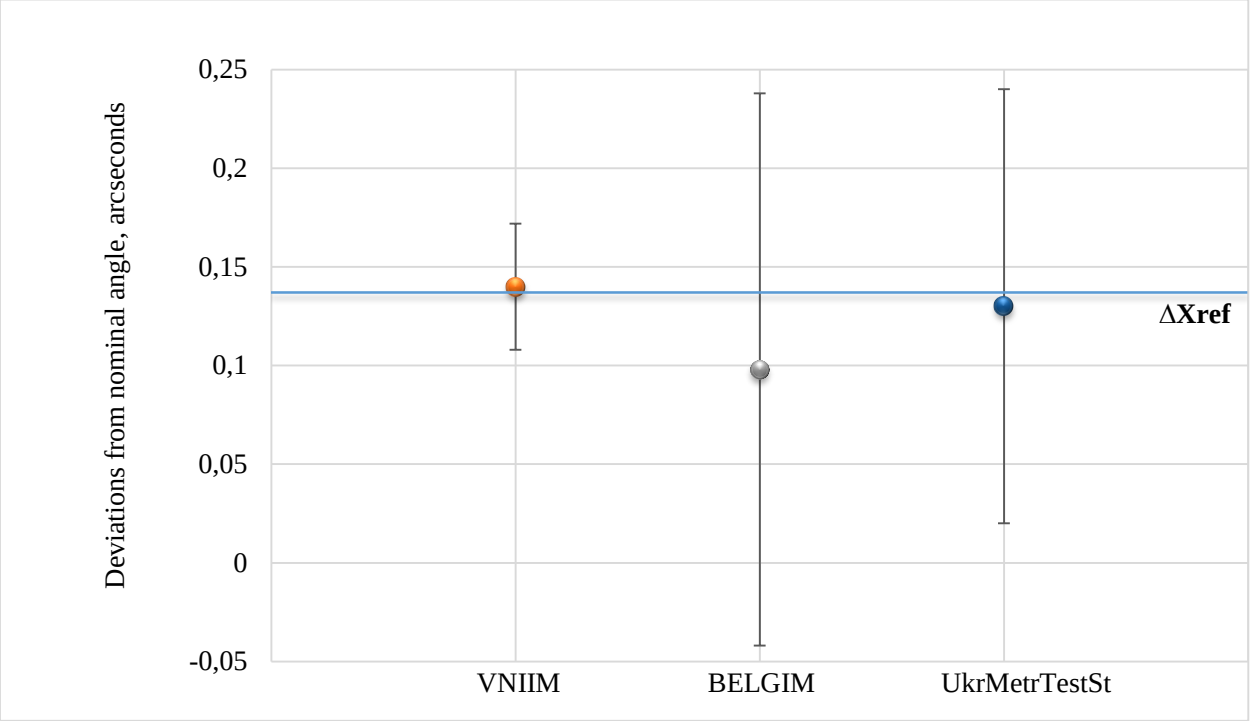

Figure 44 – Deviations from nominal angle between faces 19-20

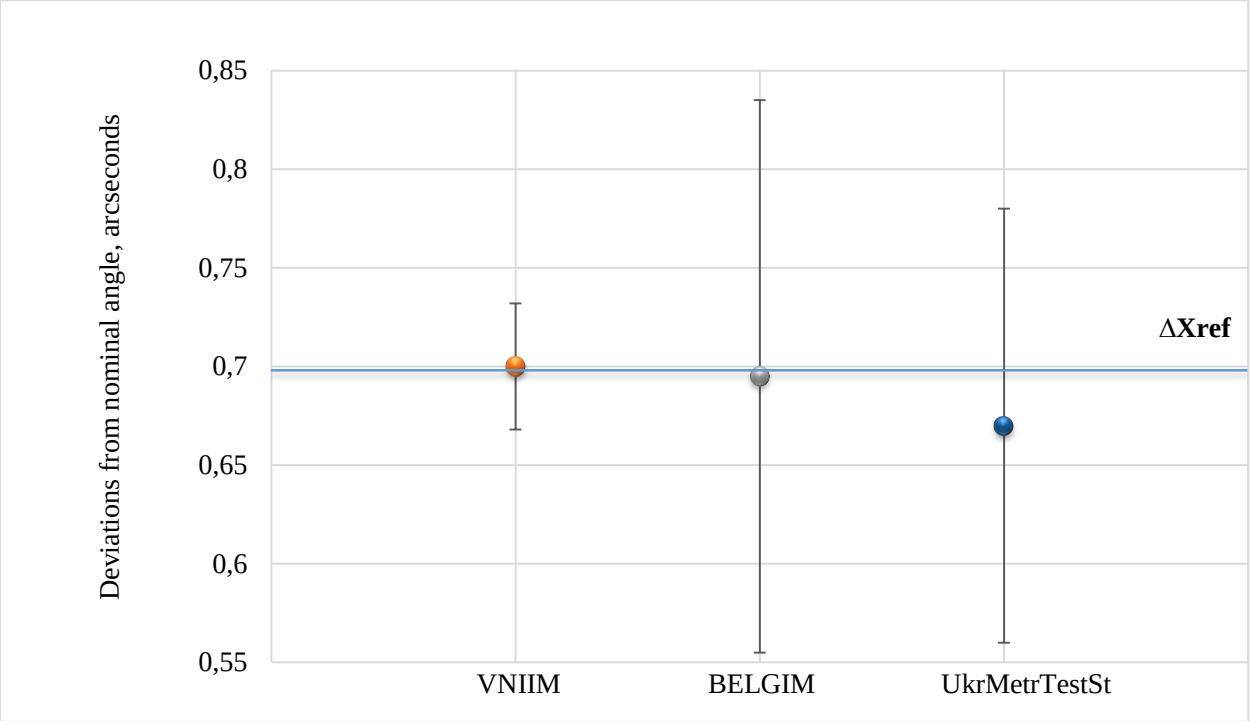

Figure 45 – Deviations from nominal angle between faces 20-21

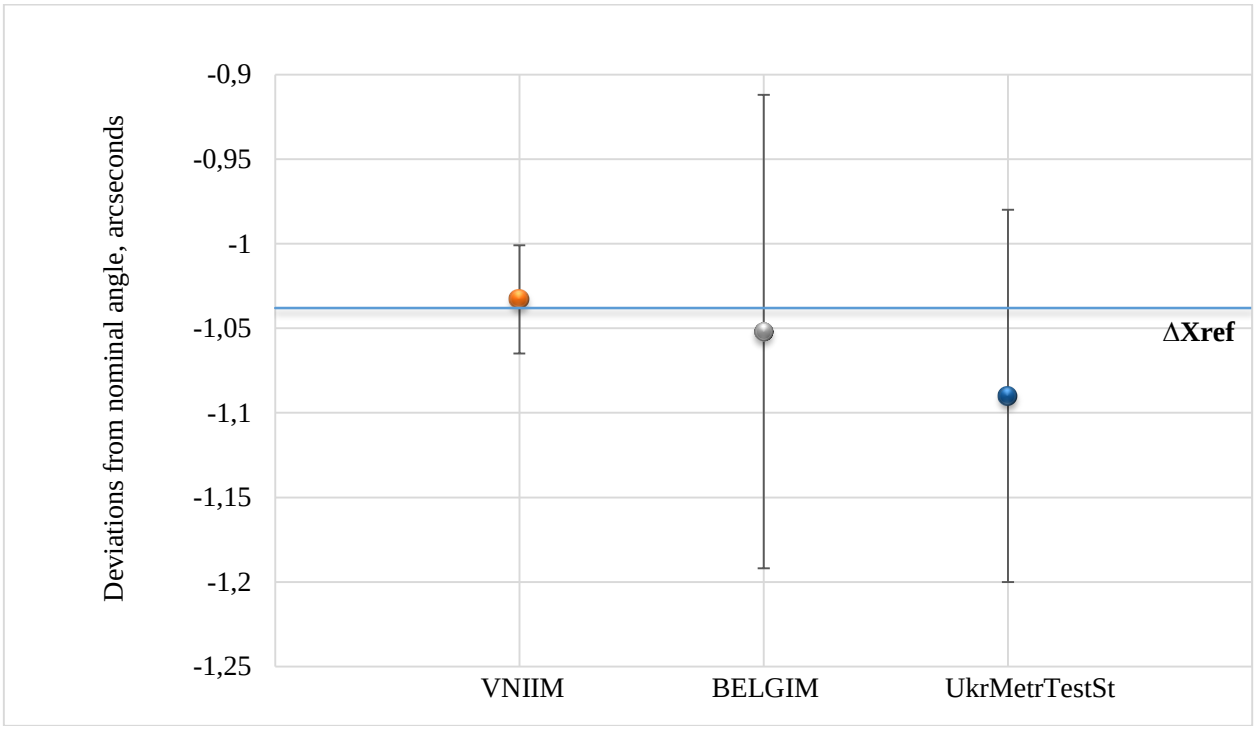

Figure 46 – Deviations from nominal angle between faces 21-22

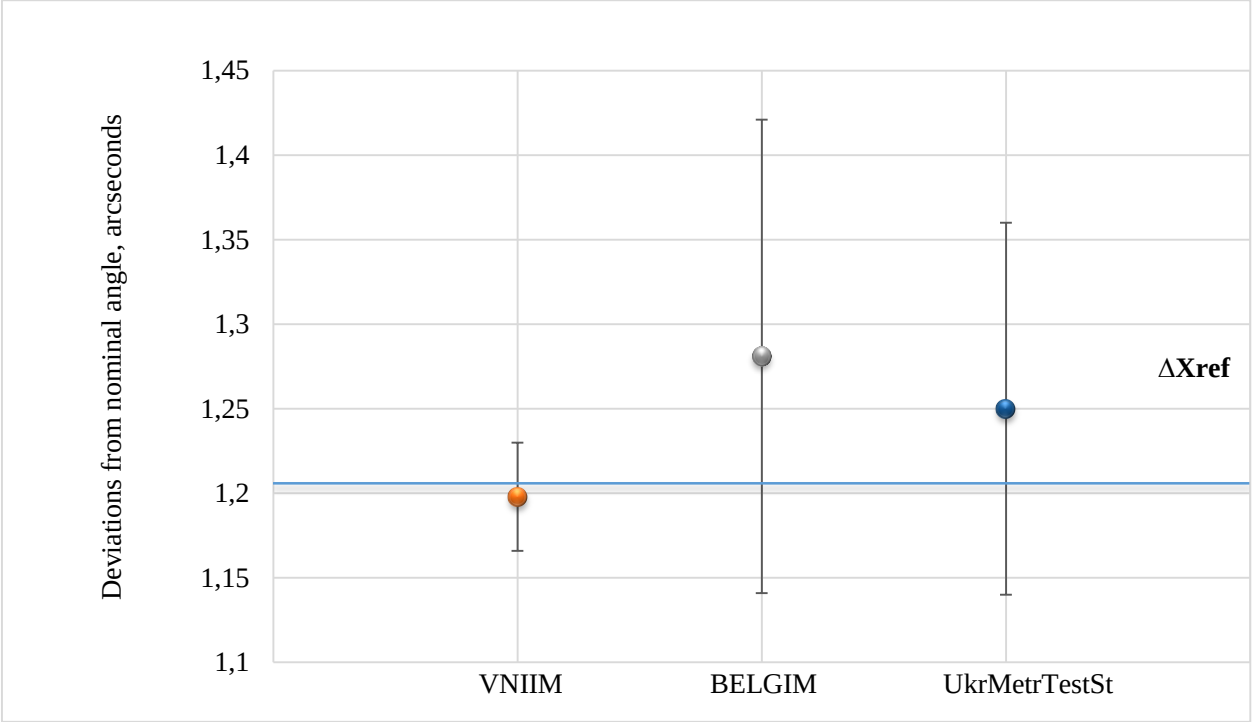

Figure 47 – Deviations from nominal angle between faces 22-23

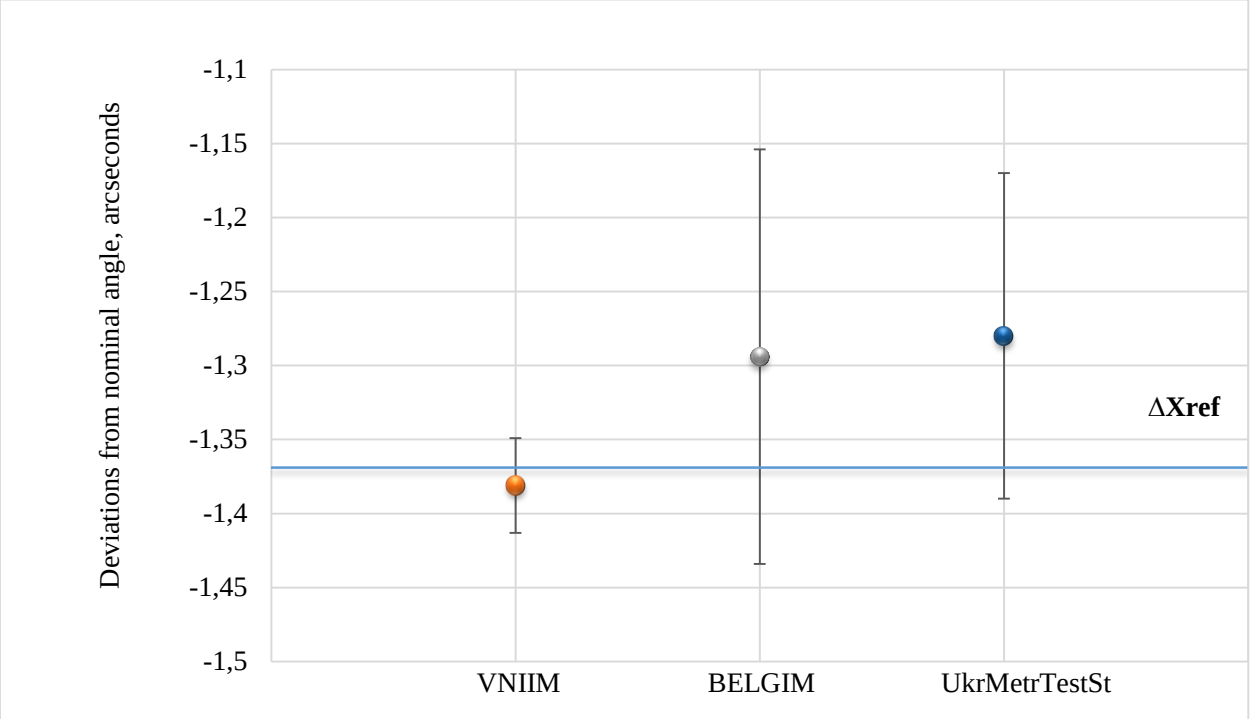

Figure 48 – Deviations from nominal angle between faces 23-24

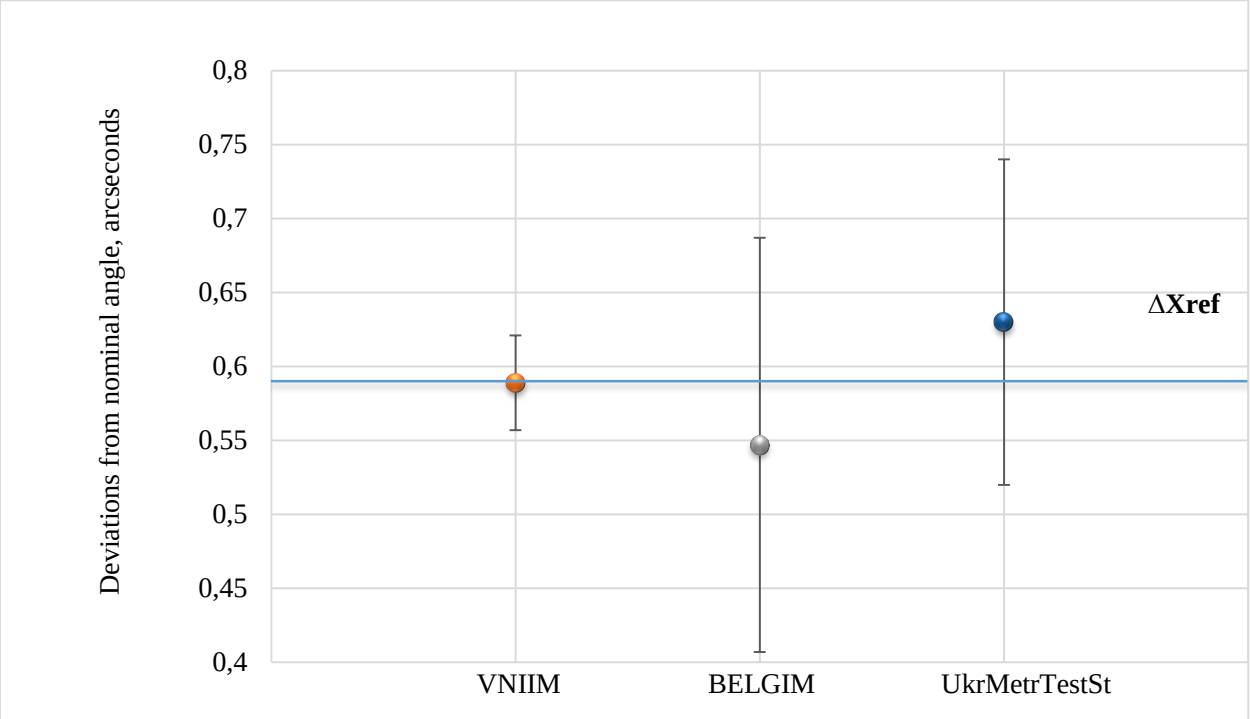

Figure 49 – Deviations from nominal angle between faces 24-1

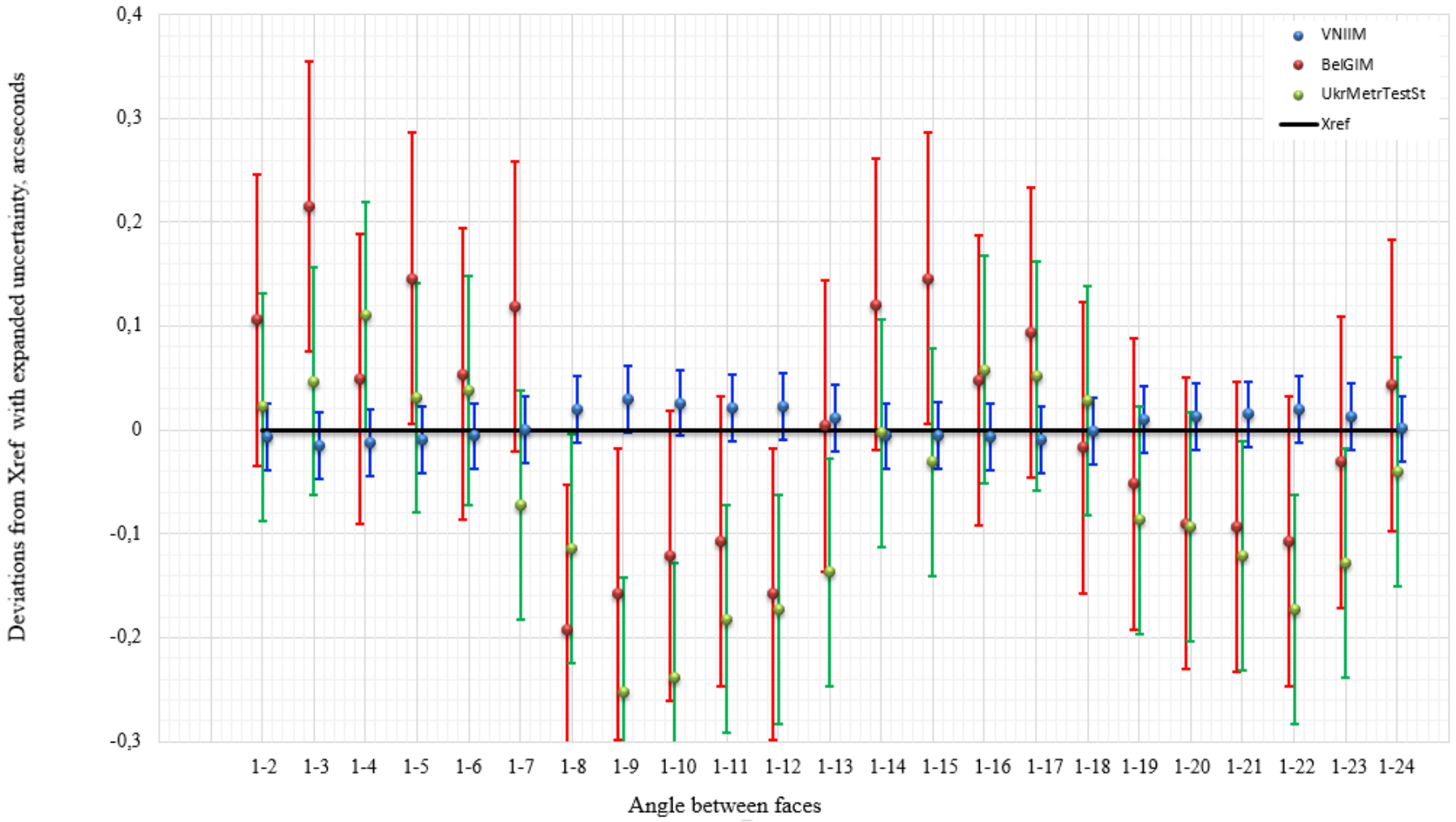

Figure 50 – Deviations of central angle from reference face from Xref with expanded uncertainty

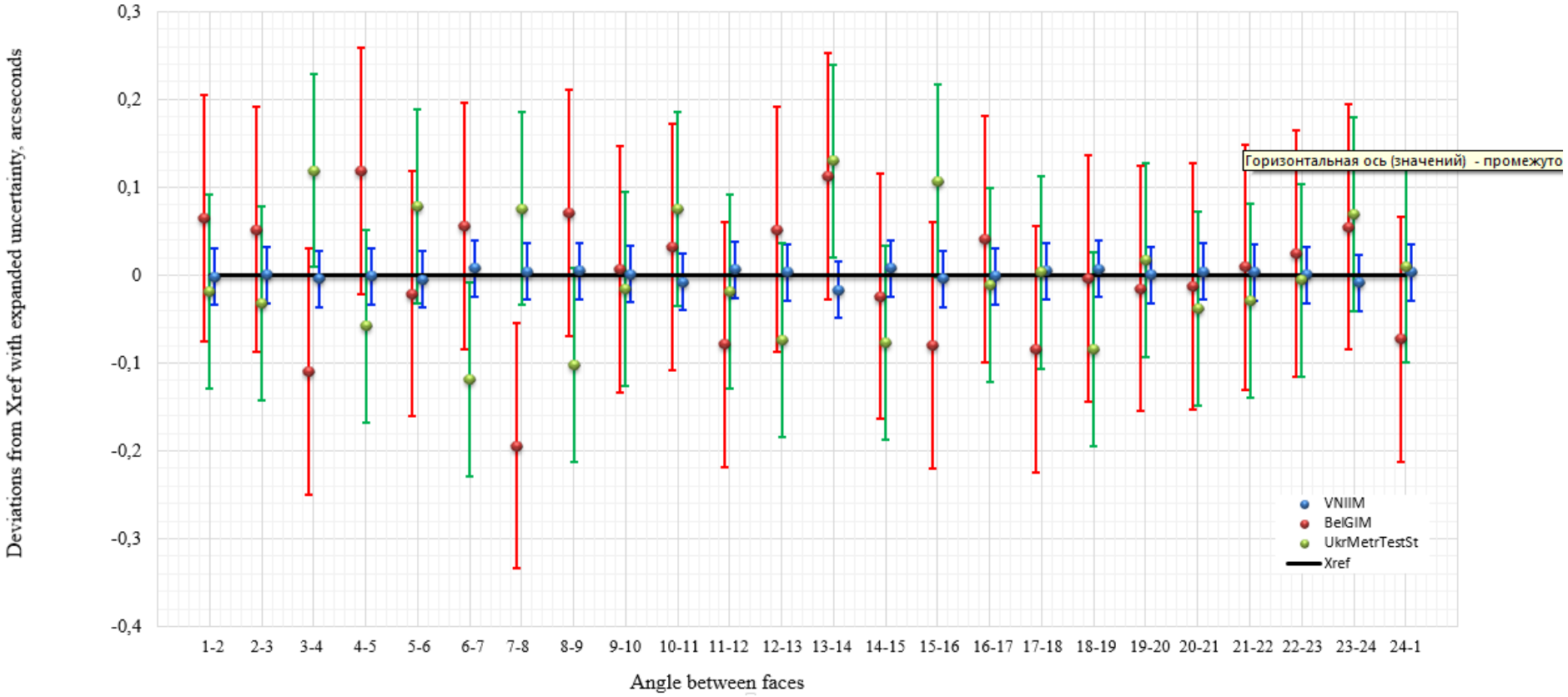

Figure 51 – Deviations of central angle of adjacent faces from Xref with expanded uncertainty

6.3. Conclusion

The comparison showed agreement between VNIIM, BelGIM and UkrMetrTestStandart. This is the confirmation of uncertainties of countries.

The non-conformity of data was revealed at measurement of angles between faces 1-2, 1-3, 1-4, 1-7, 1-15, 4-5, 6-7, 8-9, 9-10, 10-11, 15-16, 17-18, 18-19, 21-22, 23-24. The main reasons of non-conformity are connected with non-flatness of polygon's faces, surface tilt errors of the polygon and concentricity error and do not depend on measuring opportunities of State standards of unit of a flat angle of the countries, which took a part in comparisons. Additionally, the artefact was shown to be unstable during the comparison and the magnitude of the instability is sufficient to have been a significant contribution to the increased E_n values.