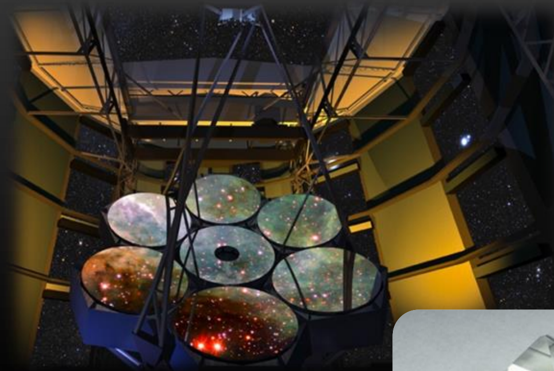
GIANT MAGELLAN TELESCOPE



LABORATORIO NAZIONALE ADONI OTTICA ADATTIVA

PYRAMID PROTOTYPING FOR THE GMT

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INAF – Osservatorio Astrofisico di Arcetri, L.go E. Fermi 5, 50125 Firenze, Italia
ADONI – Laboratorio Nazionale di Ottiche Adattive
INAF – Osservatorio Astronomico di Teramo, via Mentore Maggini, 64100 Teramo, Italia
GMTO Corp., 251 S. Lake Ave., Pasadena, CA, USA 91101.

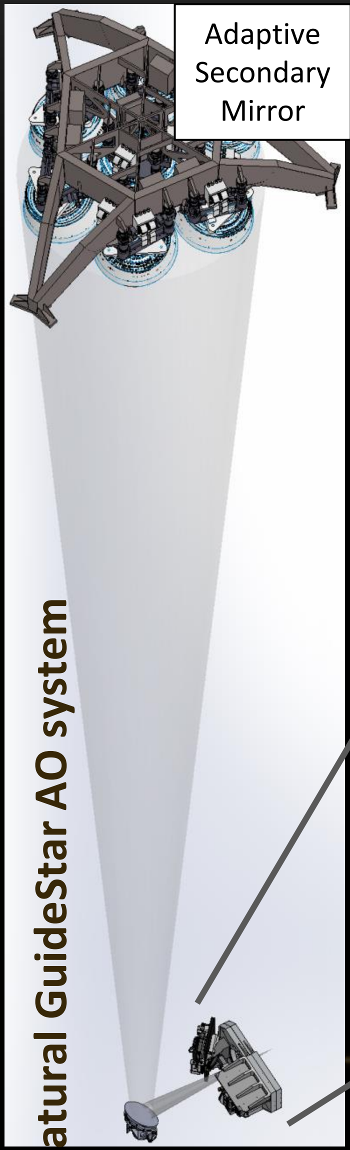
WFSensing in the VLT era II

WFSensing in the VLT and ELT era II - Padova 02 Oct. 2017

OUTLINE

- Introduction to GMT NGWS
- Specifications for the pyramid
- Procurement
- Laboratory test
- Next steps

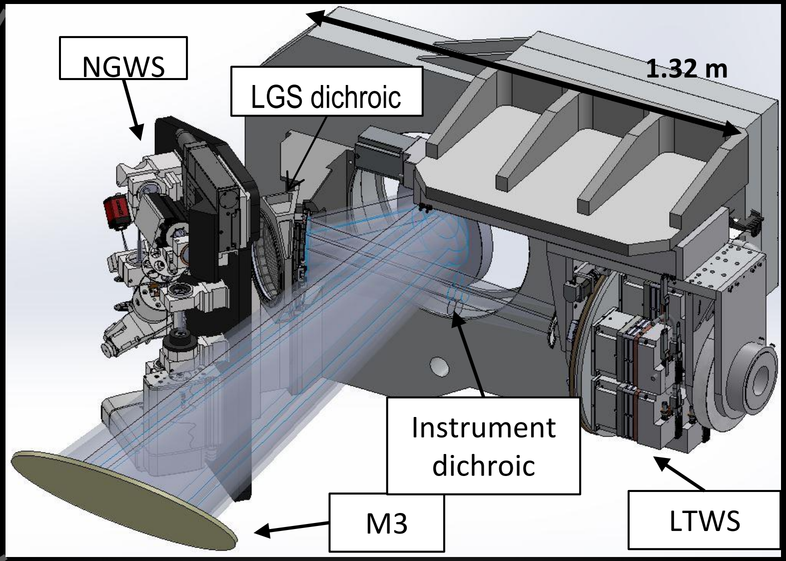
GMT'S NGSAO SYSTEM



Natural GuideStar Adaptive Optics:

- the GMT NGS SCAO system (high SR, high contrast in the NIR)
- composed by Adaptive Secondary Mirror + **Natural Guidestar WFS (NGWS)**
- feeding: GMTIFS + GMTNIRS + 2nd generation instrument

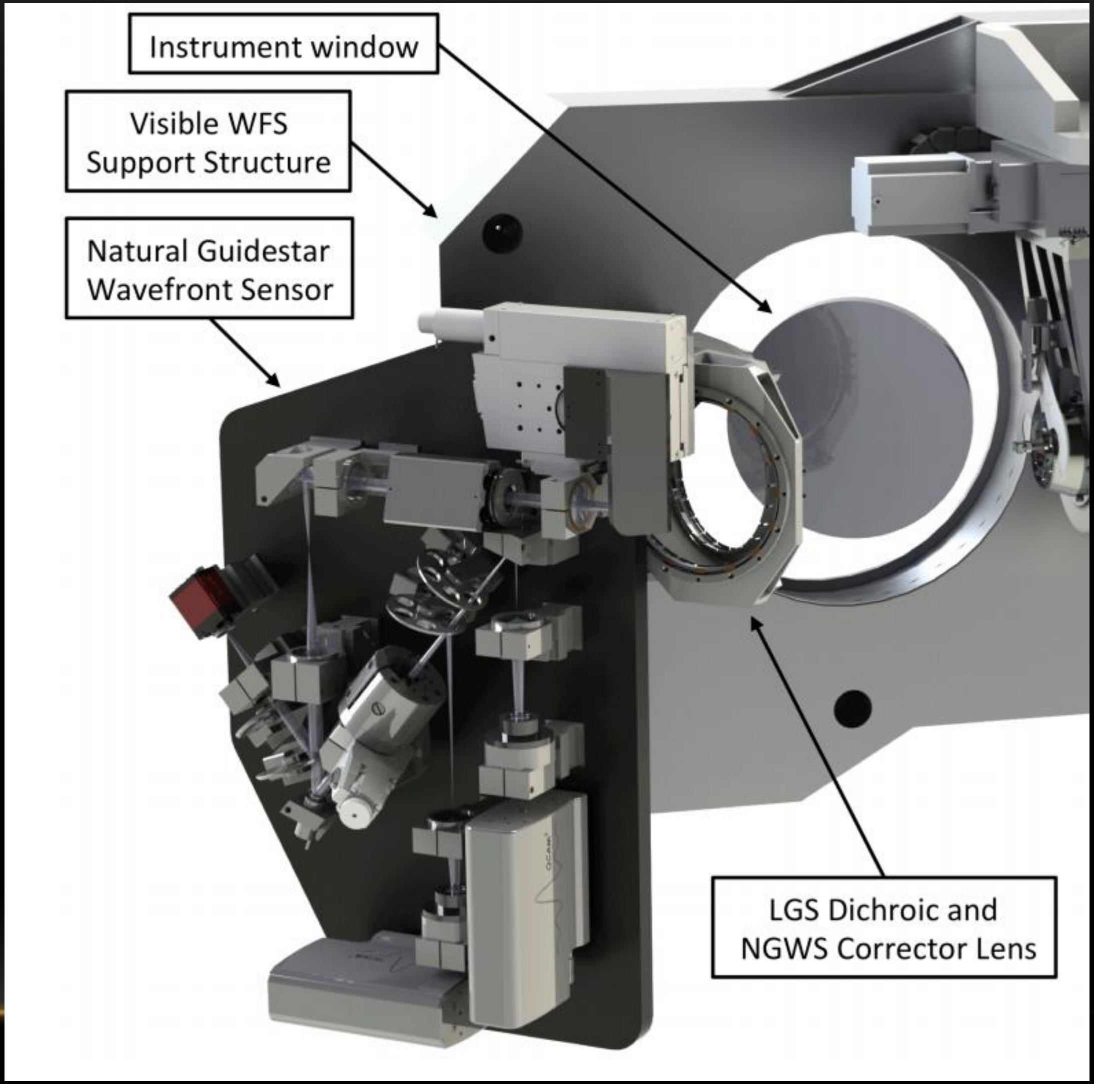
Same architecture of the LBT SCAO systems:
WFS with small FoV (small optics) + stages to move the WFS in the patrol field



NGS WAVEFRONT SENSOR

- The NGWS design successfully passed the GMT-AO Preliminary Design Review in July 2013

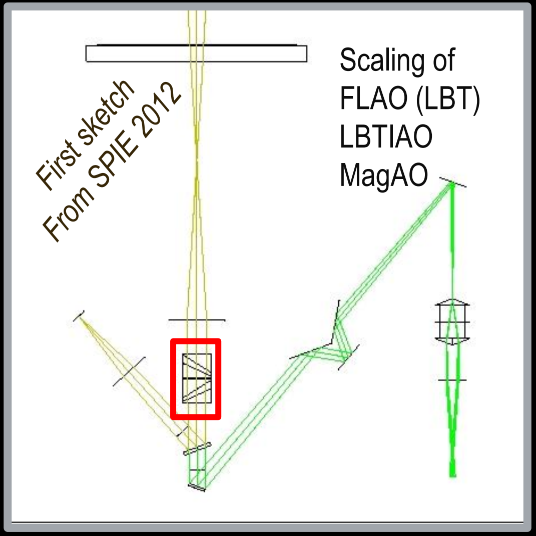
- NGS WFS Prototyping pahse:
  - modulation tip-tilt mirror @2kHz
  - refractive double pyramid



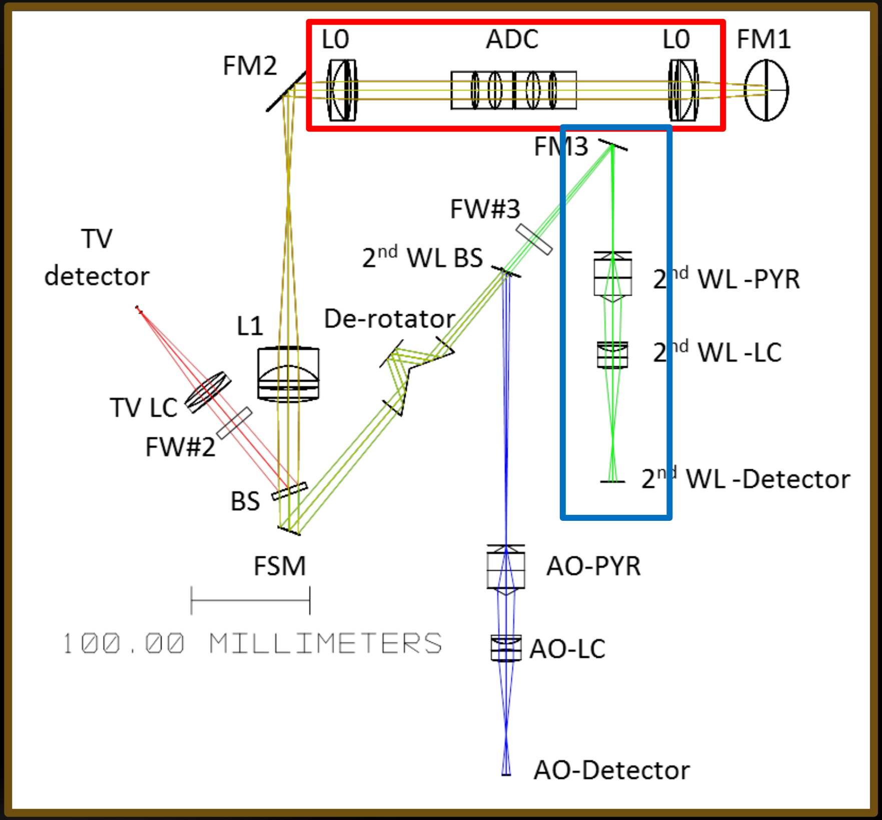
FROM FLAO-LBT TO NGWS-GMT

Main design requirements:

- Modulated pyramid WFS
- Sub-apertures > 90
- segment differential piston



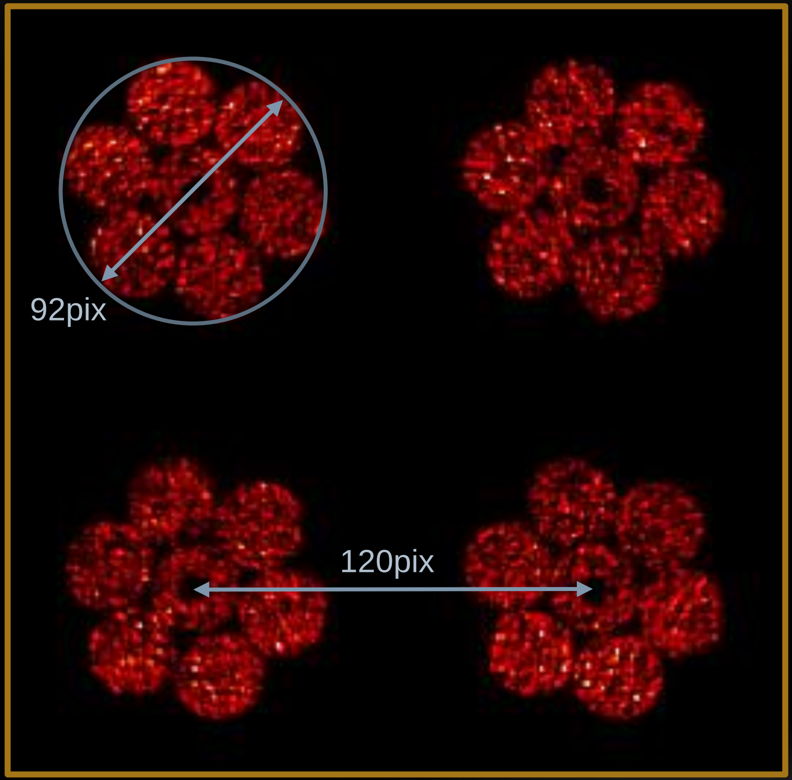
Preliminary Design Review



PUPIL ARRANGEMENT

25m pupil with 27cm sampling -> 92SA on the diameter

CCD220 frame 240pix X 240pix



The positioning requirement

- 0.1SA per axis
- 0.11% of the puil size
- <u>0.08% of pupil distance</u>

PYRAMID DESIGN

Transmitted FoV
2.5” diam. (25m telescope)

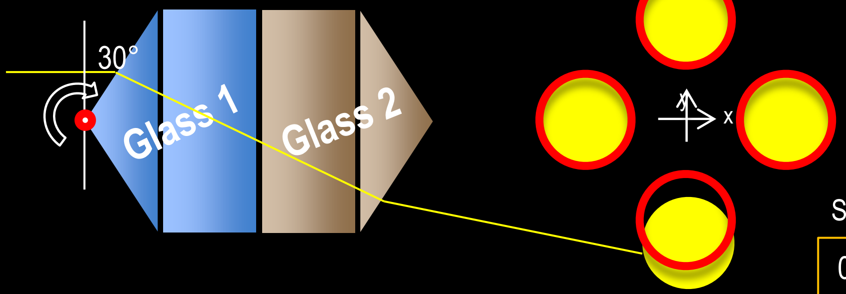
Pyramid side
LBT 10mm -> GMT 22mm

Single pyramid height
LBT 9mm -> GMT 26mm

Pupil arrangement
LBT 0.1pix / 36pix
GMT 0.1pix / 120pix

FRONT PYR | LATERAL VIEW | REAR PYR

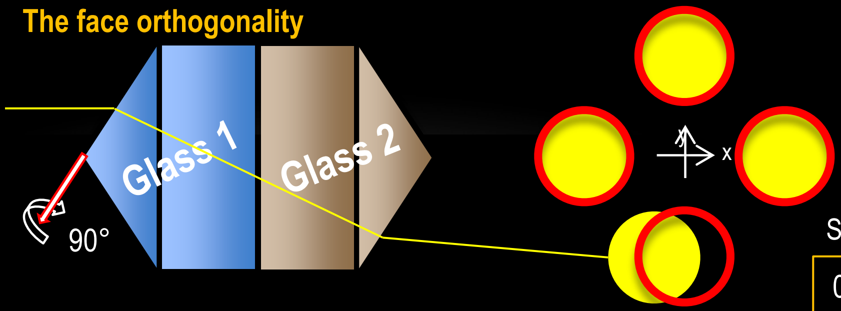
The vertex angle



Sensitivity

0.24 µm/asec

The face orthogonality

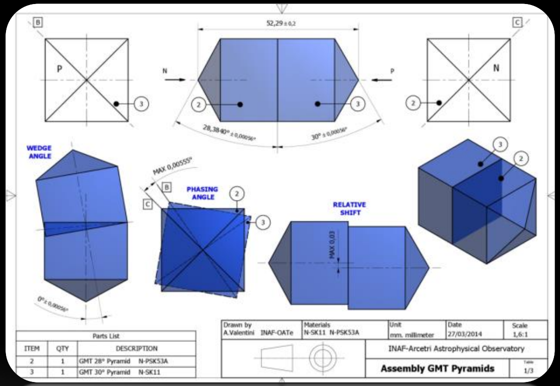


Sensitivity

0.24 µm/asec

BUDGET FOR PUPIL POSITION

Error	Sensitivity	Impact on the error (worst -worst)	tolerance	Max error per axis [μm]
Vertex angle	0.24 μm/asec	0.96 μm/asec	**2 asec**	0 – 0.96 – 1.92
Face hortogonality	0.24 μm/asec	0.96 μm/asec	**2 asec**	1.92 – 0.96 - 0
Relative shift	0.0154	0.0154	**30 μm**	0.4
Relative wedge	0.074 μm/asec	0.074 μm/asec	**2 asec**	0.15
TOTAL				***2.47 (1SA = 24μm)***



PYRAMID SPECIFICATIONS

Front

ID	Requirement description	Specification
REQ01	Material	N-SK11 or equal Refraction index nd = 1.56384 ±0.0002 Abbe number vd = 60.80 ±0.3%
REQ02	Physical Dimension	Square pyramid with base side (35±0.1)mm
REQ03	Clear Apertures	Top: Circular >18mm diameter Base: Circular >18mm diameter
REQ04	Central Thickness	(26.35±0.1) mm
REQ05	Vertex angle for each of the 4 pyramid faces	(30.±0.00056)°
REQ06	Face orthogonality for each of the 4 pyramid faces	(0.±0.0008)° Baseline (0.±0.00056)° Goal
REQ07	Roof on the pyramid tip*	< 0.020mm Baseline < 0.010mm Goal
REQ08	Scratch edge (of the 4 pyramid faces)	< 0.005mm
REQ09	Surface shape	
REQ10	Surface flatness	
REQ11	Coating on the four roof surfa	
REQ12	Scratches and digs in the Clear A	

Back

ID	Requirement description	Specification
REQ13	Material	N-PSK53A or equal Refraction index nd = 1.61800 ±0.0002 Abbe number vd = 63.39 ±0.3%
REQ14	Physical Dimension	Square pyramid: (35±0.1)mm
REQ15	Clear Apertures	Top: Circular >26mm diameter Base: Circular >18mm diameter
REQ16	Central Thickness	(25.94±0.1) mm
REQ17	Vertex angle for each of the 4 pyramid faces	(28.38400±0.00056)°
REQ18	Face orthogonality for each of the 4 pyramid faces	(0.±0.0008)° Baseline (0. ±0.00056)° Goal
REQ19	Roof on the pyramid tip*	< 0.02mm
REQ20	Scratch edge (on the 4 pyramid faces)	< 0.03mm
REQ21	Surface shape	Flat
		PV λ/10 @632nm
		AR 600-1000nm R<1%, AOI 30°
	ture	< 0.04 Baseline < 0.01 Goal

Assembly

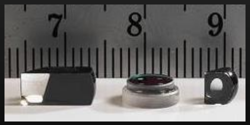
ID	Requirement description	Specification
REQ25	Central thickness	(52.29±0.20) mm
REQ26	Relative shift	Max. 0.03mm
REQ27	Wedge angle	(0.00000±0.00056)°
REQ28	Phasing angle	(0.00000±0.00139)°

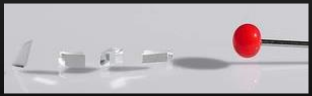
A.A.A. PYRAMID PROVIDERS WANTED

After a preliminary screaning, the short-list:

- THALES SESO
- BERLINER GLAS
- WZWOPTICAG
- Winlight Optics
- SÜSS MicroTec
- KIWISTAR OPTICS
- valley design corp.
- BERN
- OPCO LABORATORY, INC.
- swissoptic

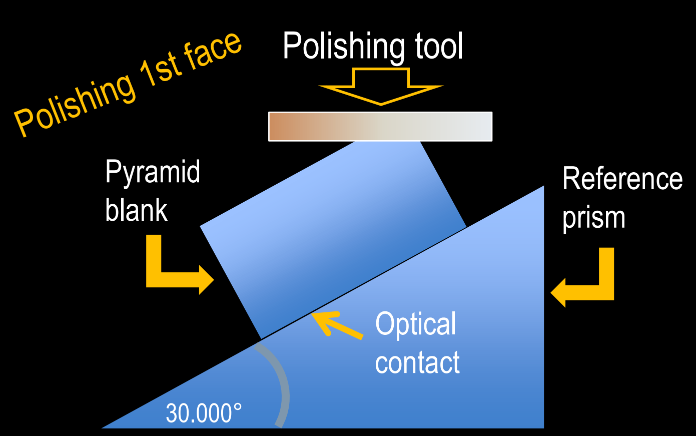
WZW - OPTICAL CONTACT STRATEGY

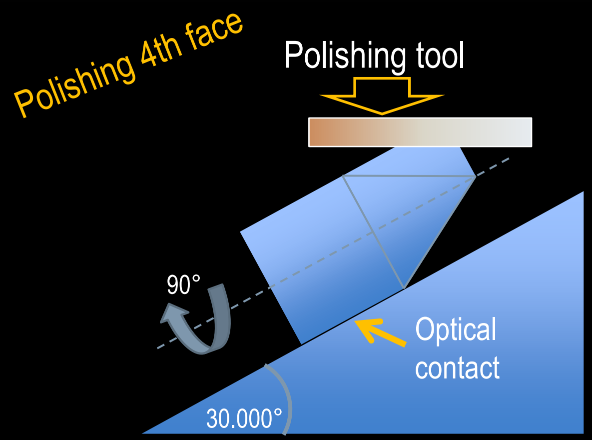


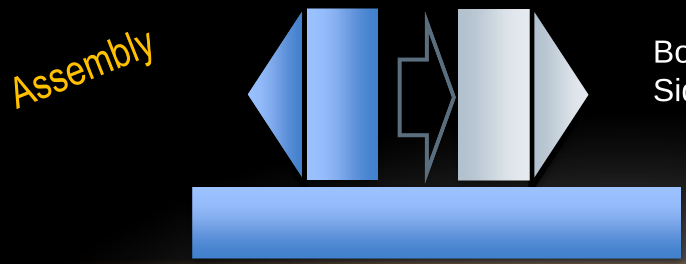


Credits: WZWOpticAG

New polishing strategy: accurate parallelepiped + reference prism + optical contact



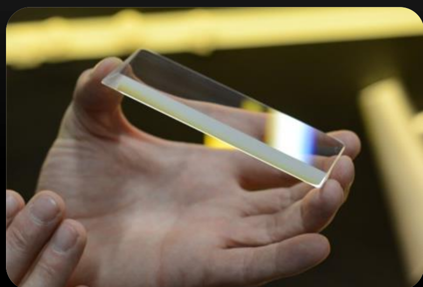




Bottom flat reference: wedge, clock
Side flat reference: cenetring

SINGLE PYRAMIDS (FRONT AND BACK)

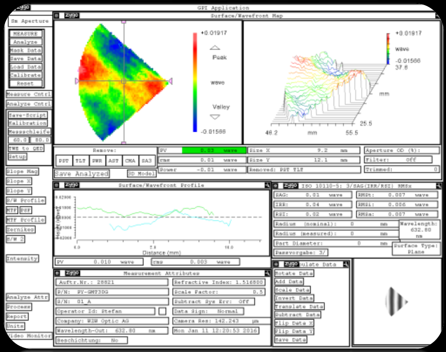
Reference prism



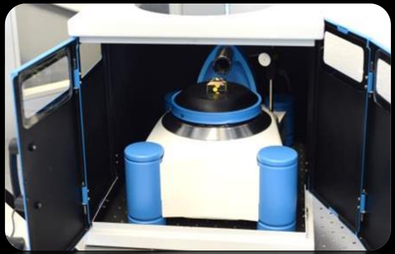
12 front + 5 back polished

WZW MEASUREMENTS: TOOLS

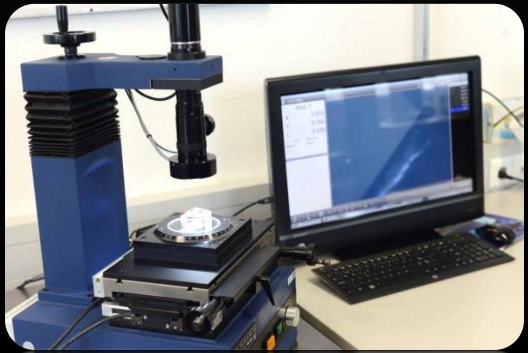
Interferometer -> Flatness

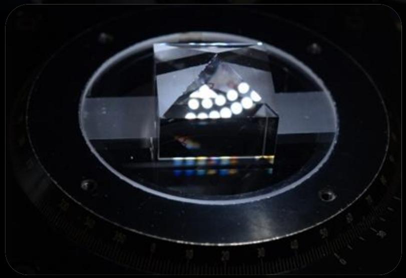


Goniometer -> Vertex angle

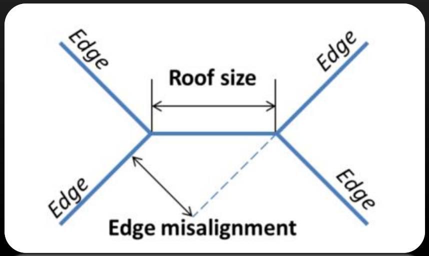


Microscope -> Edges, roof and centering

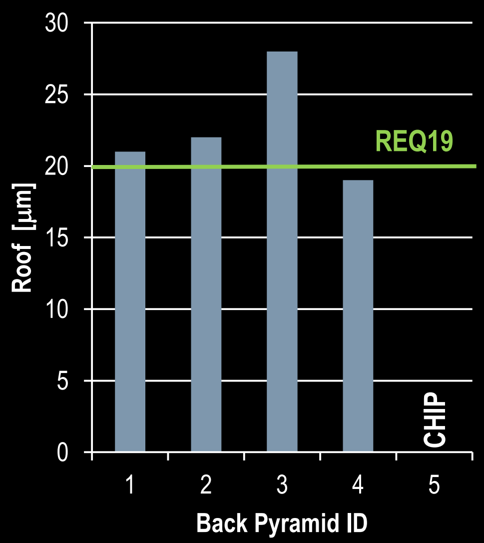




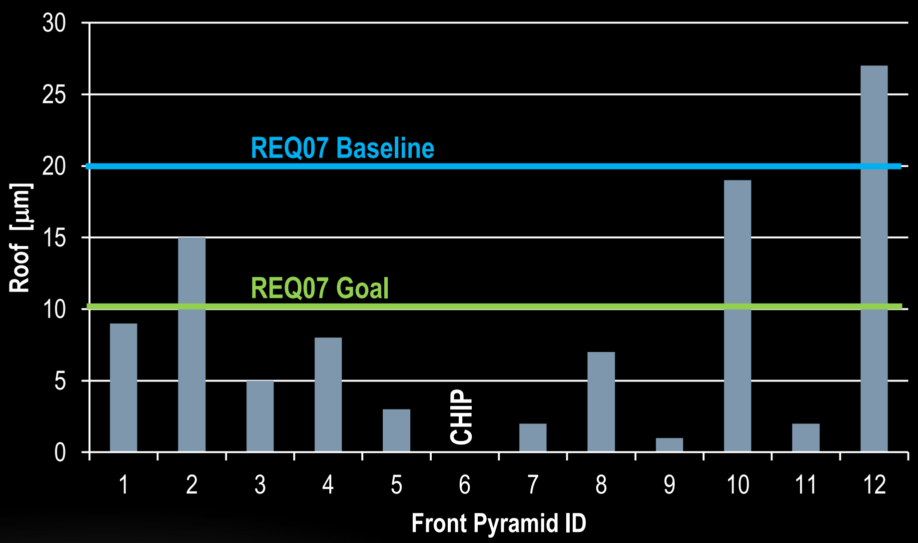
WZW MEASUREMENTS: ROOF



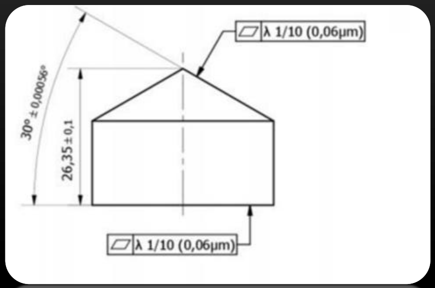
Back pyramids



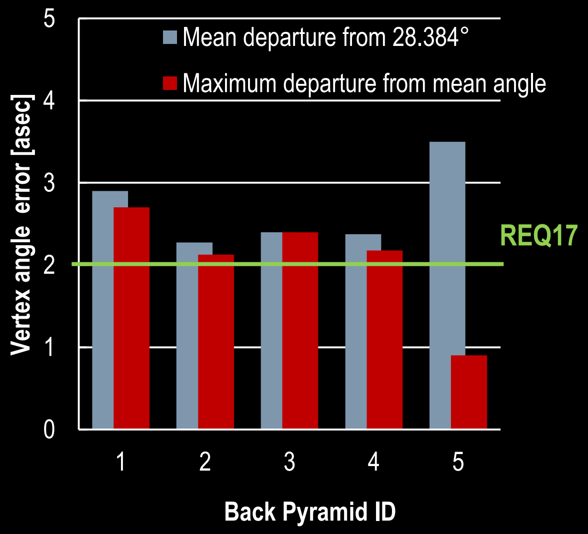
Front pyramids



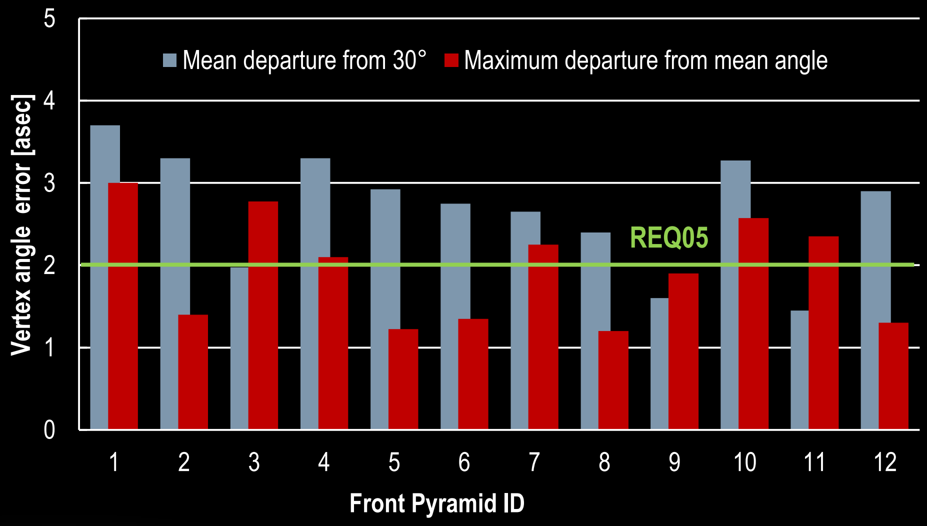
WZW MEASUREMENTS: VERTEX ANGLE



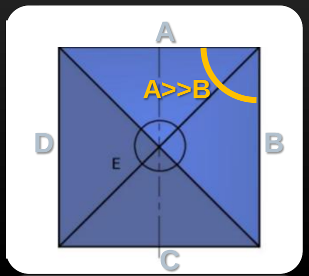
Back pyramids

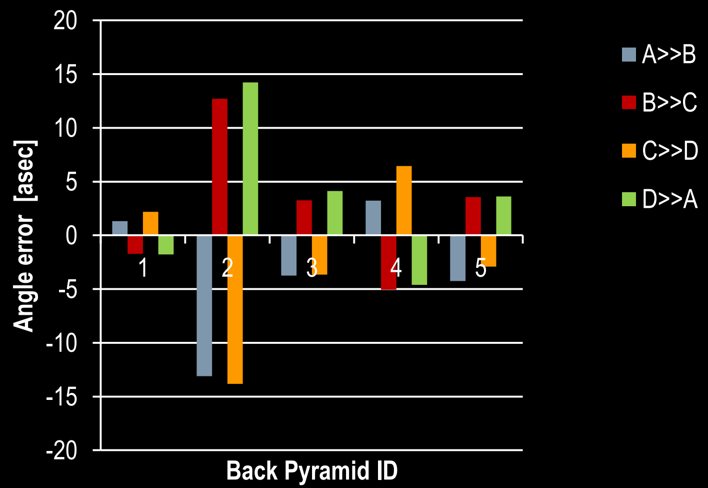


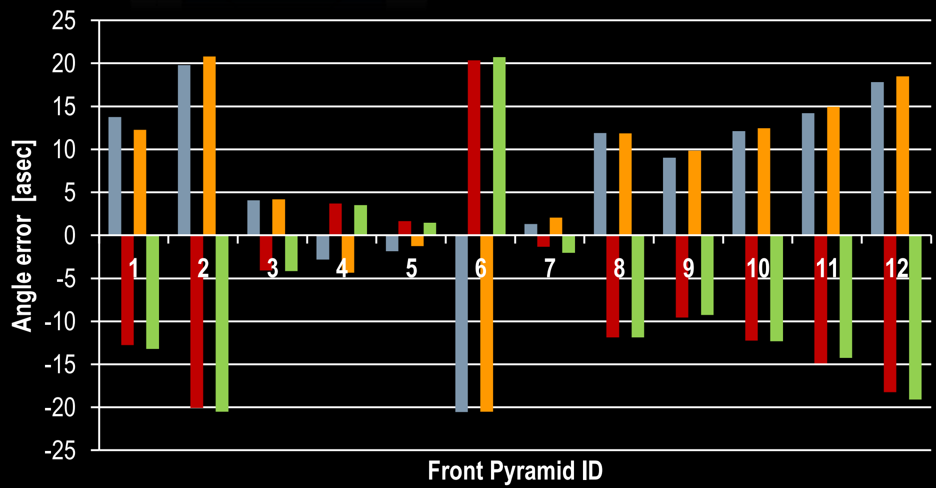
Front pyramids



WZW MEASUREMENTS: SQUARE ANGLES







BACK AND FRONT MATCHING

Using WZW measurement report

Pre-selection:
Front roof in the goal (<10um)

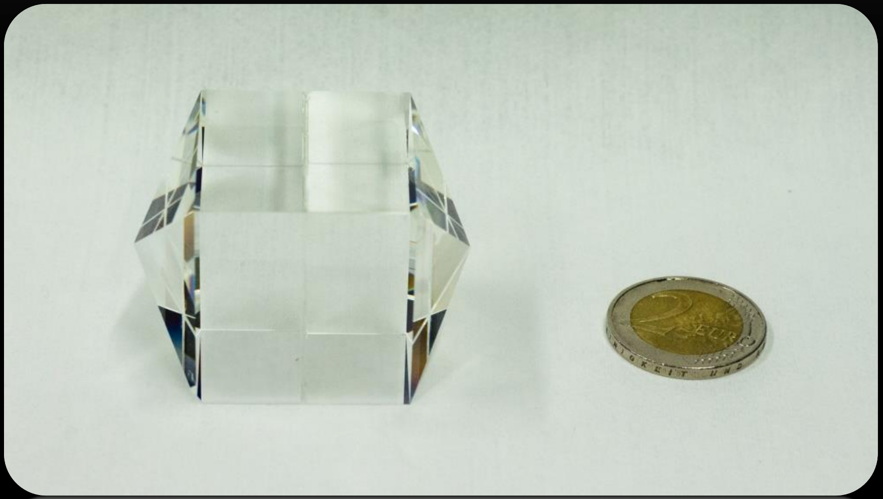
3 DoF:
- Front pyramid (8 elements)
- Back pyramid (5 elements)
- Relative clocking (4 positions)

Cost to be minimized:
Maximum (on the 4) departure from the average vertex angle

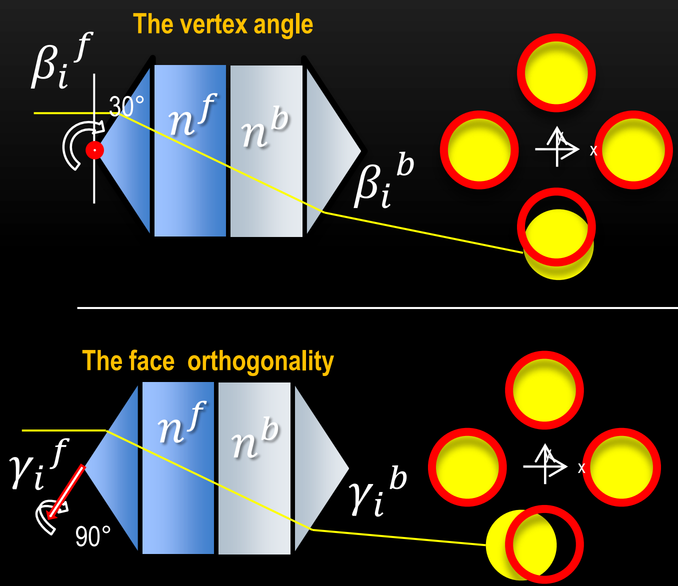
Very good matching, several combinations below 2asec of maximum departure

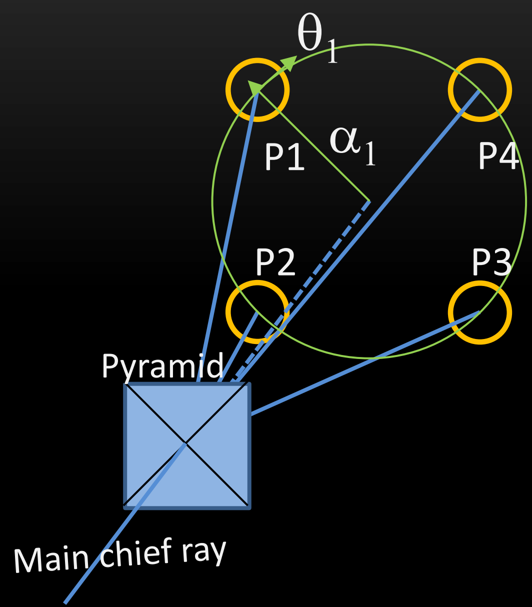
Post-selection:
Square angles below 5asec

Optical contact + glue in the chamfer



LAB TEST: HOW GOOD IS THE SQUARE?





Double pyramid

$$\begin{cases} \alpha_i = {\beta_i}^f (n^f - 1) - {\beta_i}^b (n^b - 1) \\ \theta_i = {\gamma_i}^f (n^f - 1) - {\gamma_i}^b (n^b - 1) \end{cases}$$

n = nominal +- 1/10000 relative err

β = nominal +- few asec abs err

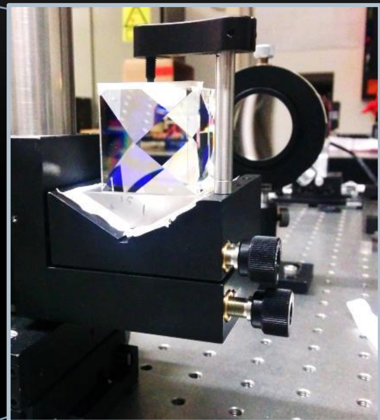
$\bar{\alpha}$ = nominal (~ 1°) +- 0.1%

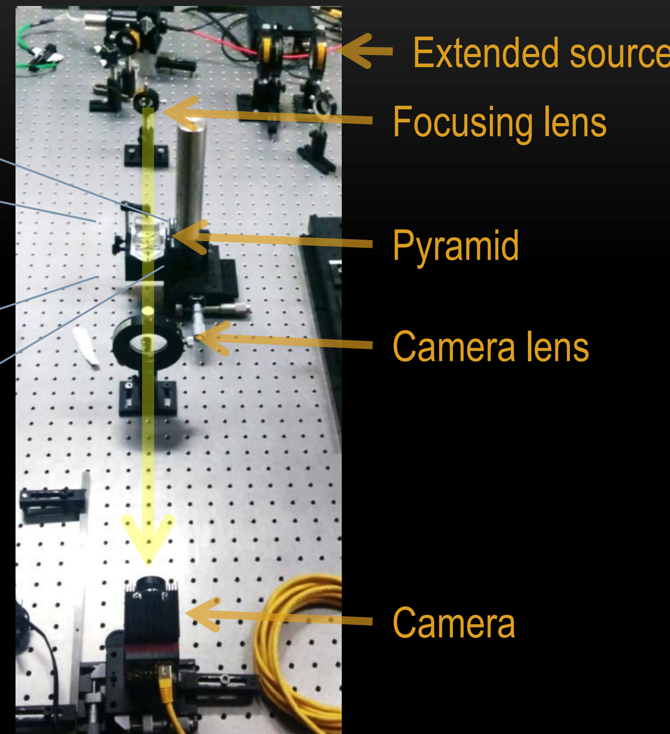
$\bar{\alpha}$ can be tuned aligning the WFS at the level of few %

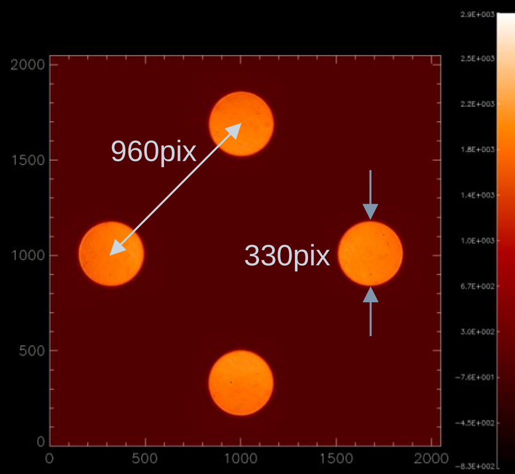
Lab meas. focus on differential errors $\alpha_i - \bar{\alpha}$ and $\theta_i - \theta_{i+1} - \pi$

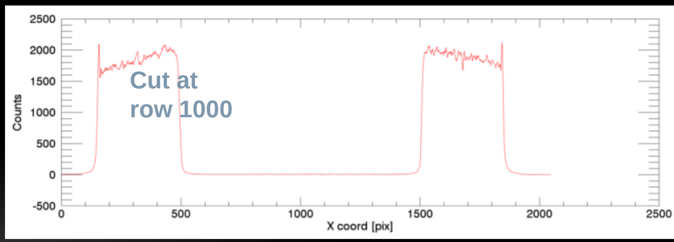
LAB TEST: SETUP

Double pyramid on 2 axis mount



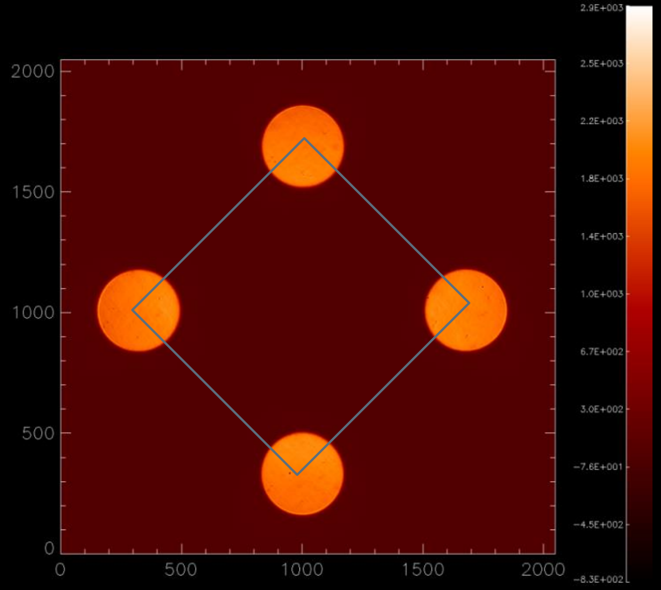






LAB TEST: HOW GOOD IS THE SQUARE?

- Fitting on the 4 pupil centers a perfect square with free side
- Residuals from pupil center and square vertex should be < 0.08% of the side to match the 0.1SA error on the GMT NGS WF
- Set of measurements with different pyramid tip/tilt

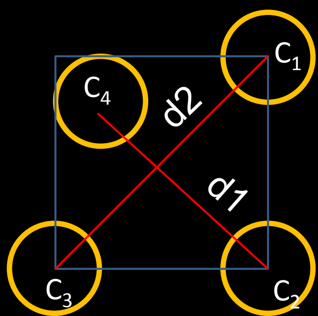


DATASET #	Fitted square side [pix]	Position mean error [% side]	Position max error [% side]
1	959.5	0.13	0.26
2	959.5	0.11	0.22
3	960.6	0.17	0.30
4	959.7	0.14	0.29
5	959.6	0.13	0.27
6	960.1	0.09	0.15
7	959.4	0.10	0.23
AVERAGE	959.8	0.12	0.25
STDDEV	0.4	0.03	0.05

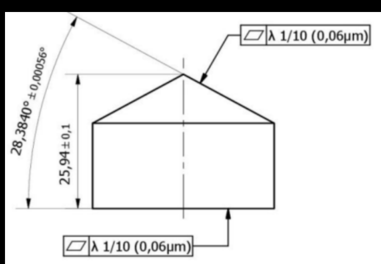
LAB TEST: DIAGONALS

- insensitivity to alignment errors on the test bench
- disentangle errors due to vertex and orthogonal errors

Diagonal error = d1-d2

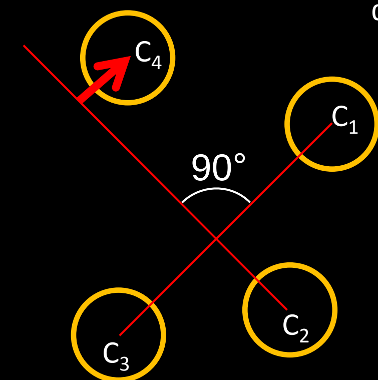


Differential vertex error

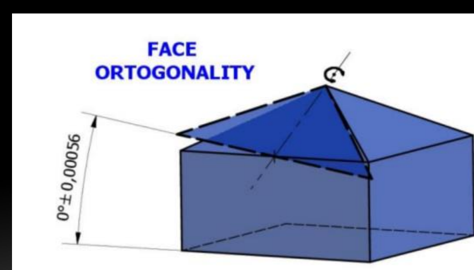


Off diagonal error = dist(c4,d1)

d1 normal to d2



Differential face orthogonality error

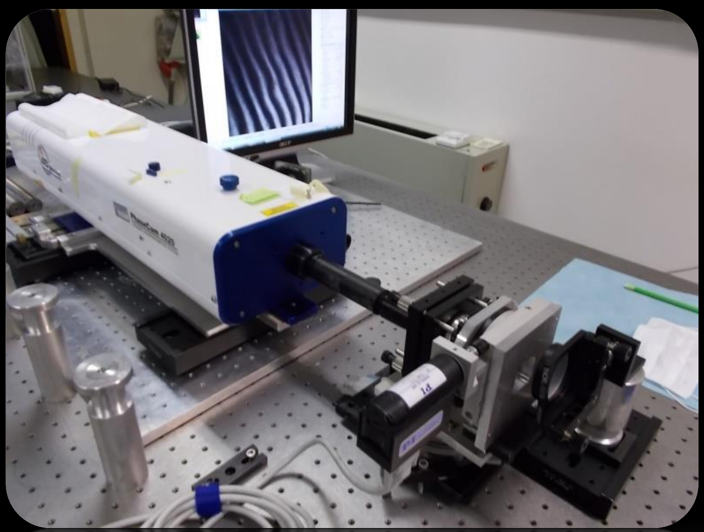


DATASET #	d1 d2 [pix]	d1 - d2 [% side]	Non-ortho error [% side]
1	1357.5 1356.5	**0.10**	**0.42**
2	1357.5 1356.5	**0.10**	**0.63**
3	1358.5 1358.5	**0.00**	**0.42**
4	1357.5 1357.0	**0.05**	**0.63**
5	1357.5 1356.5	**0.10**	**0.63**
6	1358.5 1357.0	**0.16**	**0.52**
7	1357.0 1356.5	**0.05**	**0.57**
AVERAGE	**0.8**	**0.08**	**0.54**
STDDEV	**0.5**	**0.05**	**0.09**

- Diagonal error in spec
- Non-ortho 6 times the spec

WORK STILL IN PROGRESS

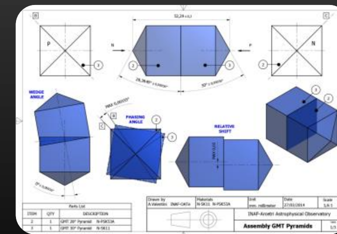
- Direct measurement of the orthogonal angle on front and back pyramid
- Second round in pyramidvmatching, vertex + orthogonal angle residuals in the cost



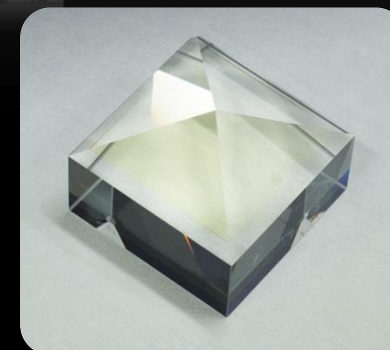
New measurement of pyramid face angles

- interferogram images
- self-correction of misalignment errors
- absolute accuracy (wrt to the basis) better to 0.5 arcsec

CONCLUSIONS



- GMT double refractive pyramid, specifications defined
- Market investigation, 1 company taking up the challenge
- New polishing and assembly techniques
  - ✓ Excellent edge quality (1um)
  - ✓ Roof <5um (down to 2um)
  - ✓ Assembly with optical contact:
    wedge, shift and centering down to polishing accuracy (<3asec)
  - ✓ Vertex angle accuracy of few asec + accurate metrology
  - ✓ Matching the vertex errors, residual differential errors of 1 to 2 asec
  - ✓ Lab measurement confirm vertex angles in specs
  - ✓ No direct measurement of orhogonal angles
  - ✓ Lab measurements suggest orthogonal angles out of specs
- Next steps
  - Direct measurement of orthogonal angle
  - New pyramid matching



THE DOUBLE REFRACTIVE PYRAMID FOR THE GMT IS NOT YET OFF THE SHELF, BUT IT IS ON THE ROAD