NASA SBIR Success Story:-
Active Edge-Control in Polishing of Mirror Segments and Other Applications

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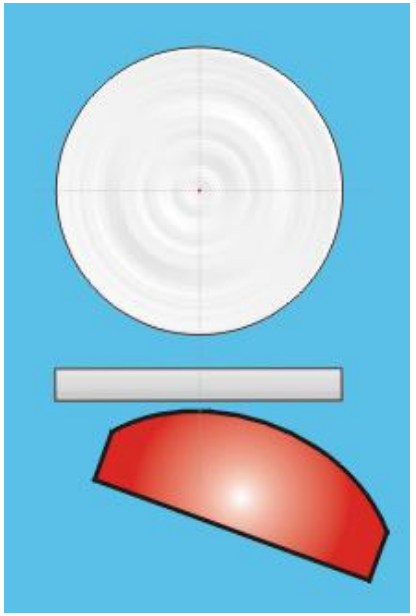
This talk

- Starting-point – NASA SBIR grant
- E-ELT and prototype segments
- Another application of edge-control
- Acknowledgements

NASA SBIR grant

- "Edge Control in Large Segmented Optics Using Zeeko Polishing Technology", Proposal S4.04-9574



- Demonstrated the basic method
  - Compressible spherical bonnet
  - Rotated and axis precessed
  - Tool compressed against the part
  - Delivers variable spot-size

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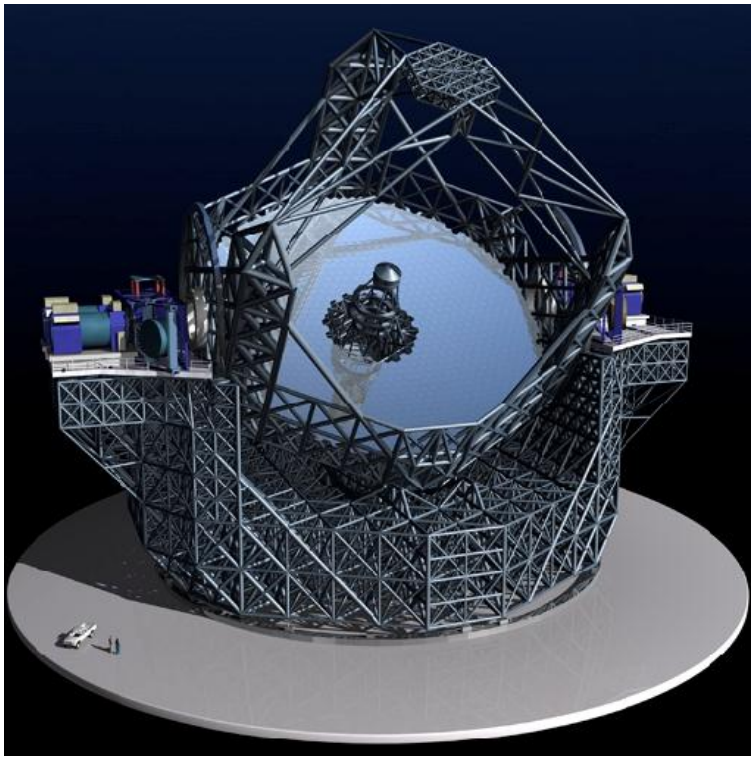
The 39.3m aperture European Extremely Large Telescope

- Segmented primary mirror
  - 798 hexagonal segments +133 spares
  - Each 1.4m a/corners
  - Irregular hexagons
  - 50mm thick
  - ~ 200 microns max asphericity



Prototype segments near edge of primary. Reflect the earlier 42m telescope design with 84m ROC segments.

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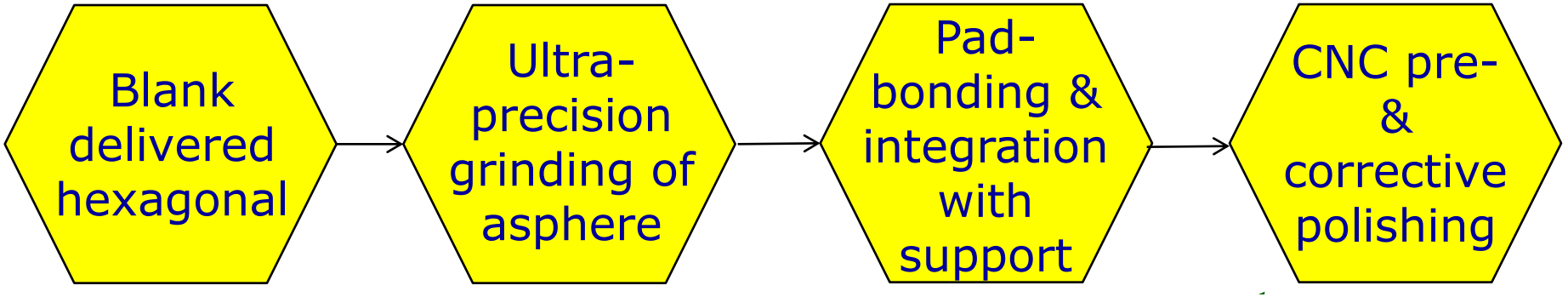
Segment production-rate & quality

- Construction schedule:- 2-3 segments per week
- Segment warping harness in the telescope will remove most of the low-order aberrations

ESO specification (abridged!)	**Average**	**Maximum**
RMS surface form (excluding 10mm edge-zone)	**25nm**	**50nm**
RMS surface form (ESO Zernike allowances removed)	**7.5nm**	**15nm**
PVq (95%) edge mis-figure (surface) in edge-zone	**100nm**	**200nm**

- RMS surface form *includes* errors in *matching* segment base-radii and conic-constants

Process-chain and metrology



In-situ metrology

National Facility for Ultra Precision Surfaces

Hosted by OpTIC in North Wales
Operated by Glyndŵr University

On-machine deployment of pentaprism profilometer

Zeeko IRP1600 under test-tower On-axis optical test

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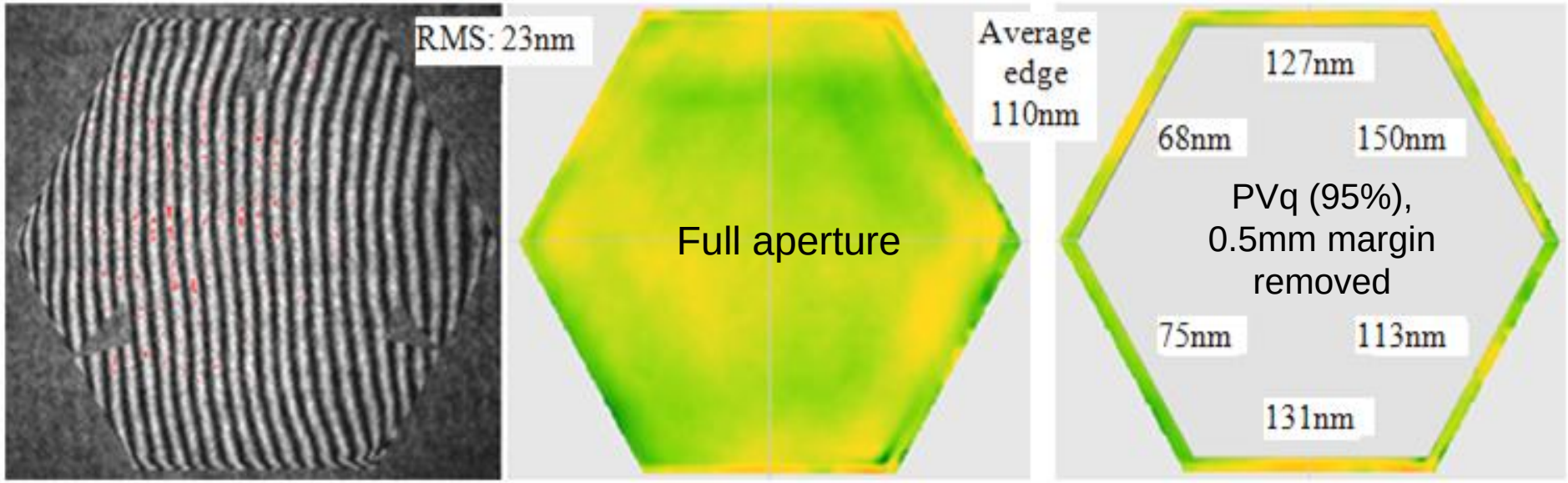
Edge-polishing strategy

1. CNC-grind the off-axis asphere
2. Apply 0.5mm of the final 1mm bevel
3. Bonnet polishing programmed to leave turned-up edge at every stage
4. Up-turn progressively narrowed and lowered
5. Hard pitch tool to remove residual up-stand
6. Final 0.5mm bevel applied at end

Repeated edge-trials on 400mm borosilicate spherical parts

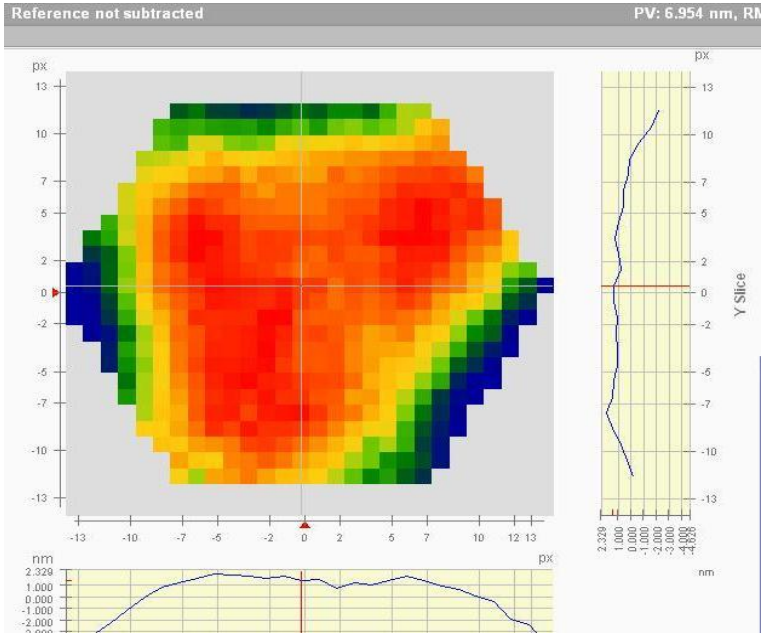


In 10mm wide edge zone (to start of bevel):-

110nm PVq surface edge-misfigure (average over 6 edges)

Grinding 1st aspheric segment SPN01 (Zerodur)

- Cranfield University BoX™ m/c
- Built by Cranfield Precision Ltd
  - **6.5µm PV** measured on grinding platen (Cranfield Univ. CMM)
  - **~ 150nm** mid-spatials



CMM data on 50mm grid, by courtesy Cranfield University

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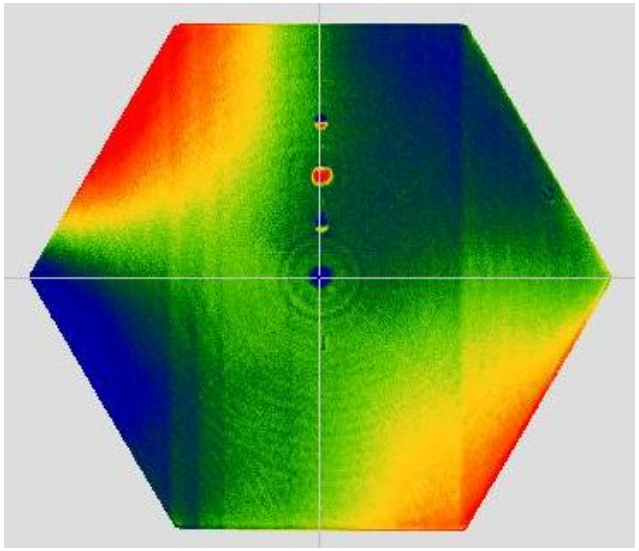
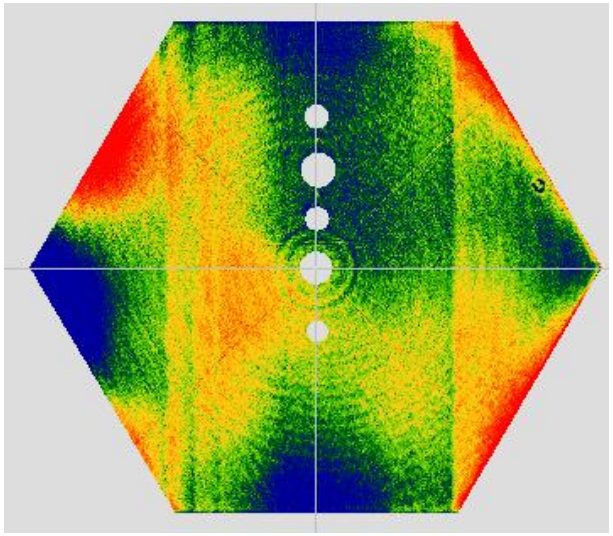
Zeeko polishing SPN01

- Used extensively for equipment / process / metrology / software de-bugging and qualification



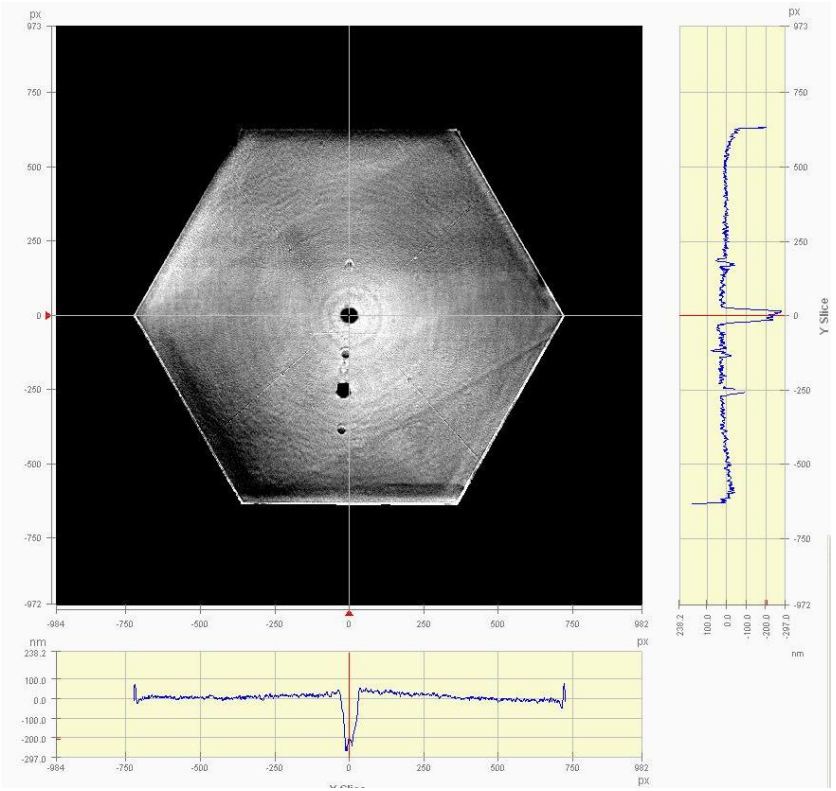


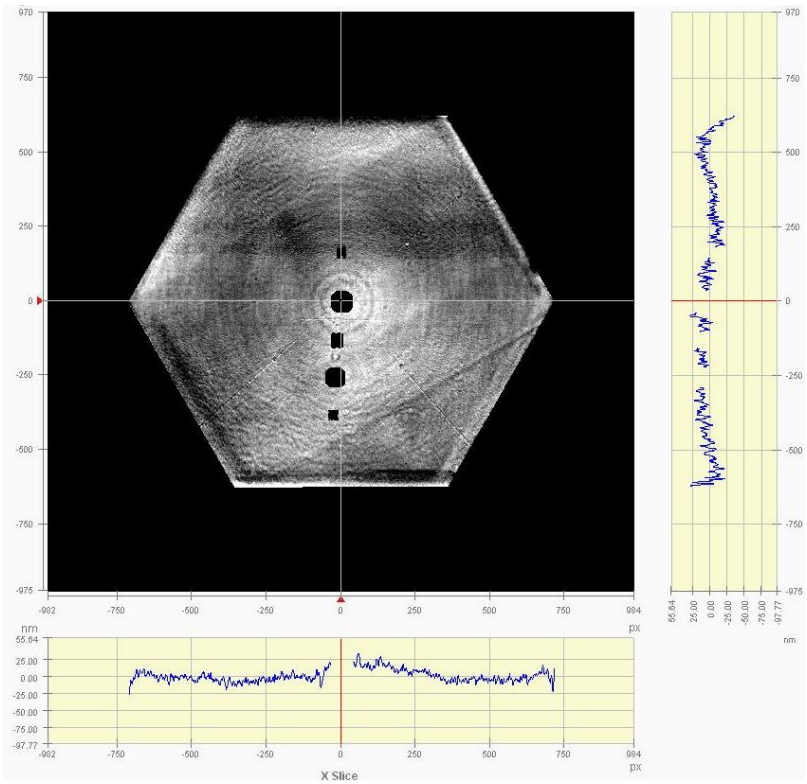
- SPN01 then held, due to Test Tower thermal issues
- Now rectified:- stable to ~ +/- 0.25 degs C

BoX grinding SPN04 Corning ULE

- Again, mounted on diamond-turned platen
- After grinding, ~ 2µm “flash pre-polish”
  - Measured on **27 point hydrostatic** support
  - Grinding form-error **> 40 µm PV** (4X expected)
    - grinding support ?
    - springing due to “Twyman effect” ?
- Needed to remove > 60µm DC material in polishing and retain quality of edges.

SPN04 under acceptance … this week!





Full Aperture to edge
Only tip/tilt removed
22.9nm RMS Surface

10mm edge zone cropped
ESO low-order allowances removed
CGH artifacts masked
10.3nm RMS Surface

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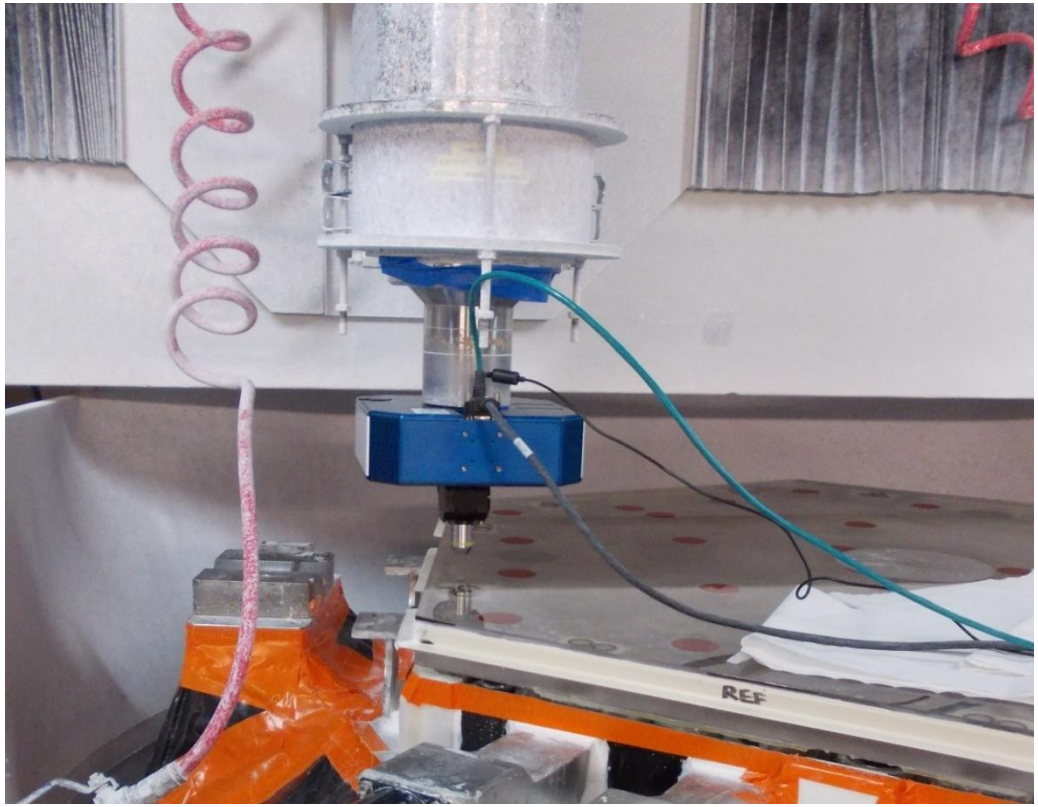
3D Surface-texture measurement



- 4D Technologies STA1 white-light interferometer
- Mounted in Zeeko machine tool-holder
- Automated for multiple sample-areas
- SPN04 – uniform texture **~1nm Sq**

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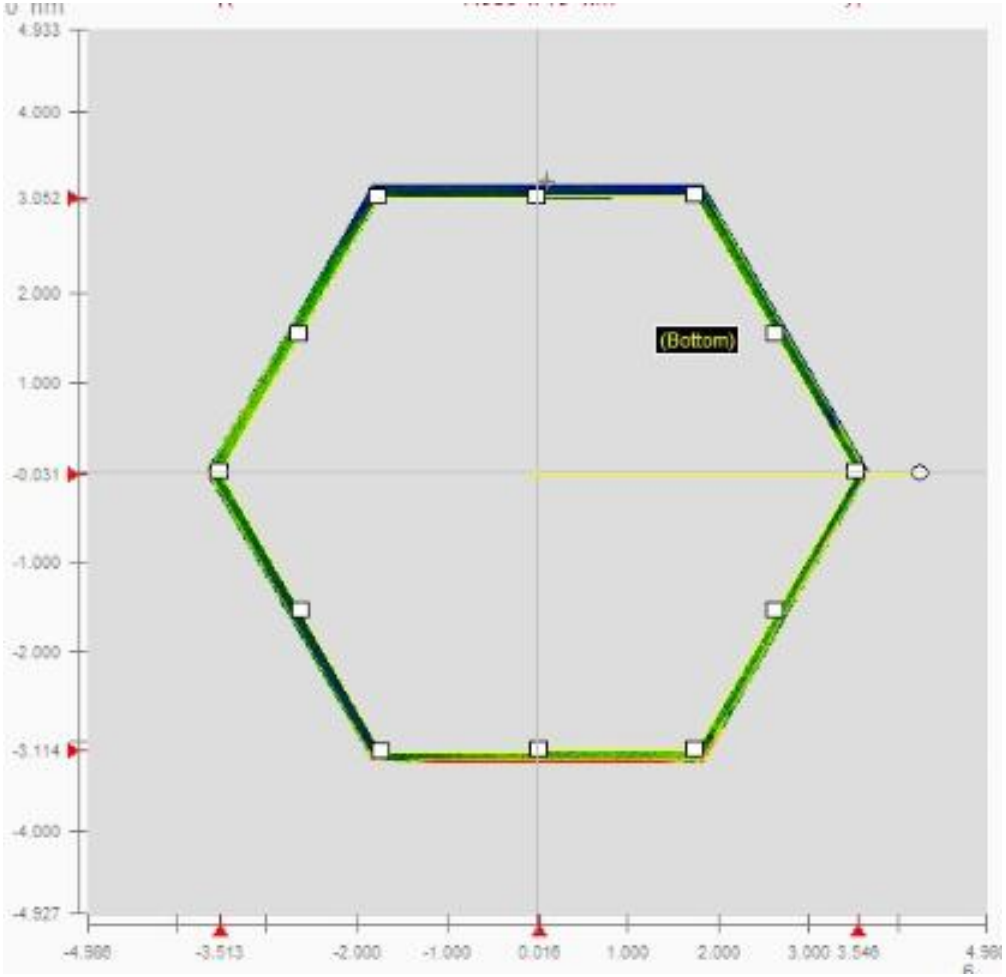
Edge result on SPN04



- Final 0.5mm of bevel still to be applied
- Phase-map cropped
  - Leaving 10mm wide edge-zone
  - Edges turned up
  - Average mis-figure over six edges is:-

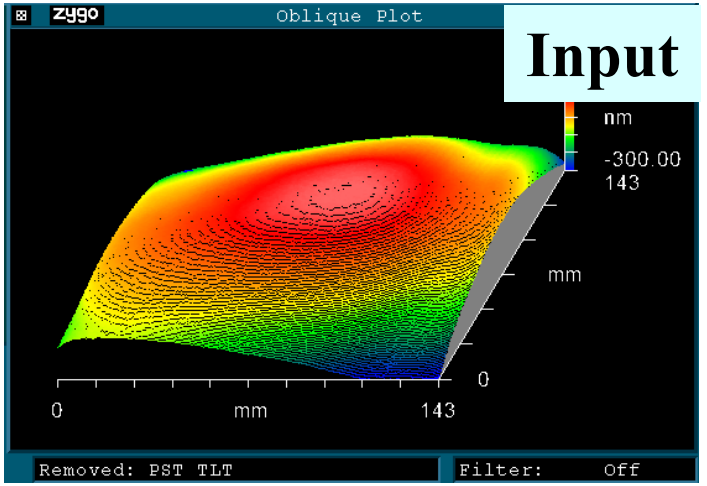
172nm PVq (95%) surface

EUV photolithography photomasks

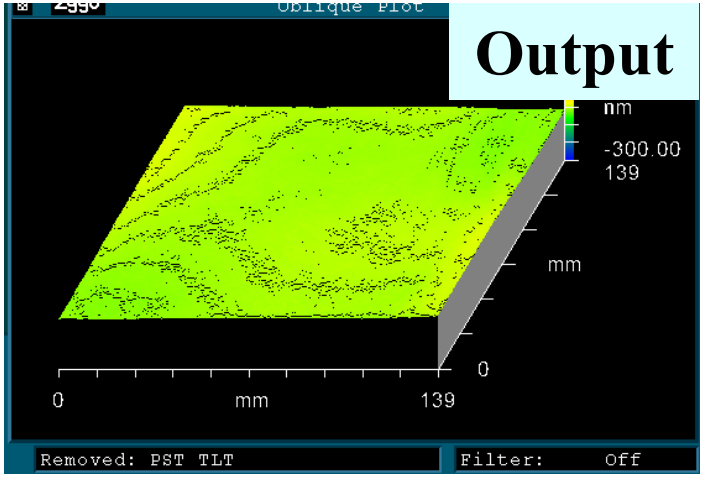
- Photomasks
  - Fused silica window + chrome pattern
  - One photomask needed for each layer in a wafer
- Next-generation EUV photomasks:-
  - 30-100nm PV form error
  - Edge dead-zone < 5mm wide
- With standard CMP on square blanks – tough!

Photomasks

Photomask on Zeeko IRP200 machine



Corrective polishing within active area



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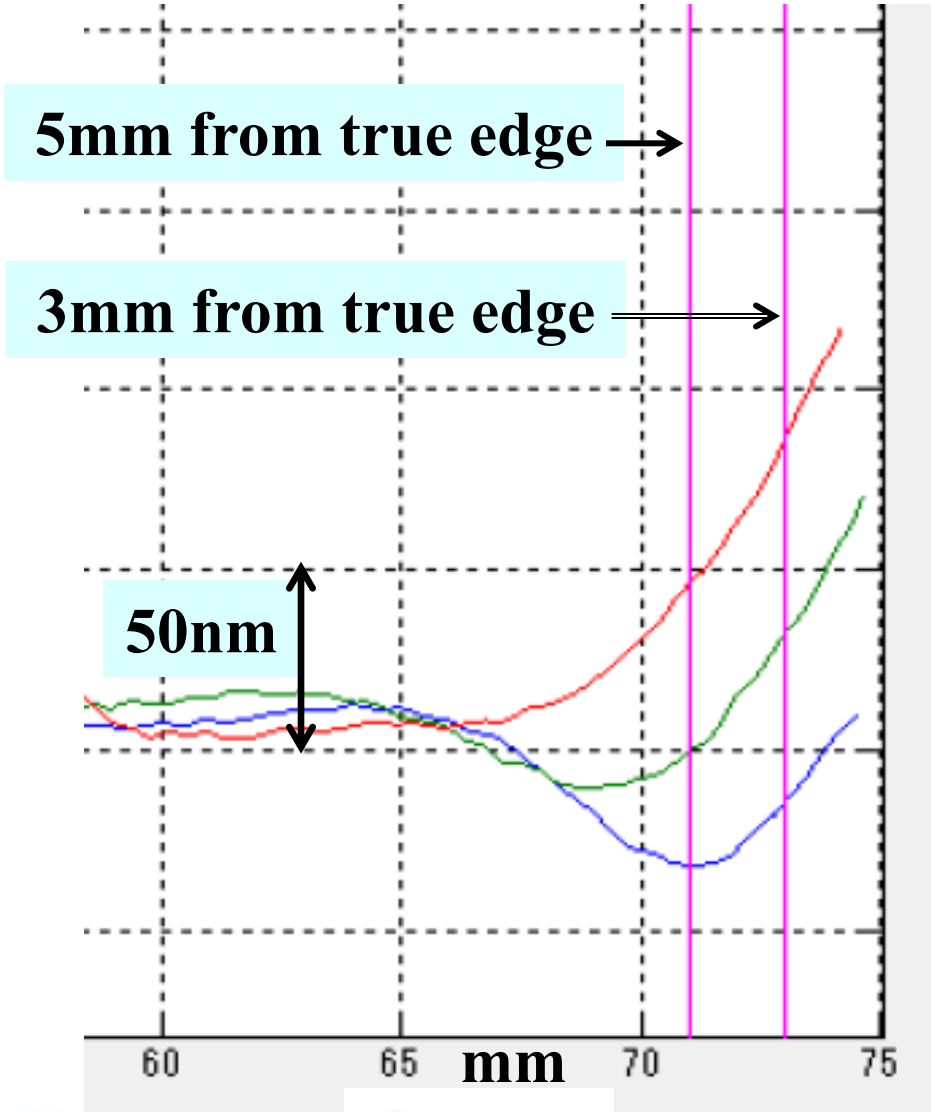
Results of three edge-lift regimes on a photomask



- Zeeko bonnet polishing alone exceeds edge-spec.
- Overall surface in active area:-
  - Input **611 nm PV**
  - Output **42nm PV**
  - Texture **< 0.5nm**

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Conclusions

- An end-to-end process chain
  - Part at final shape and size throughout
  - Well-suited to automated production-line
  - Edge control well understood
  - Applicable to various sectors …from segmented telescopes to photomasks!
- Next – finish SPN01
- Then polish SPN03 (has been BoX-ground)

Thank you!

Acknowledgements

- NASA SBIR grant proposal No. S4.04-9574
- ESO: segment prototype contract
- Substantial financial support from:-
  - Glyndŵr University
  - UK-EPSRC and STFC
  - Welsh Government:
- Zeeko Ltd: Build of IRP1600 machine and tech. support
- Cranfield University and Cranfield Precision Ltd: development of BoX grinder

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