



Competitiveness Operational Programme (COP)
Extreme Light Infrastructure - Nuclear Physics (ELI-NP) – Phase II

Young Researcher Competition Award 2020

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Qualification measurements of 4th order helical mirror

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Contents

- What is a helical wavefront?
- Why optical vortices matter?
- Helical mirror development
- Qualification procedure
- Preliminary results
- Perspectives

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- What is a helical wavefront?
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What is a helical wavefront?

Orbital angular momentum of a wave's phase dislocation:
due to azimuthal component of local k-vectors

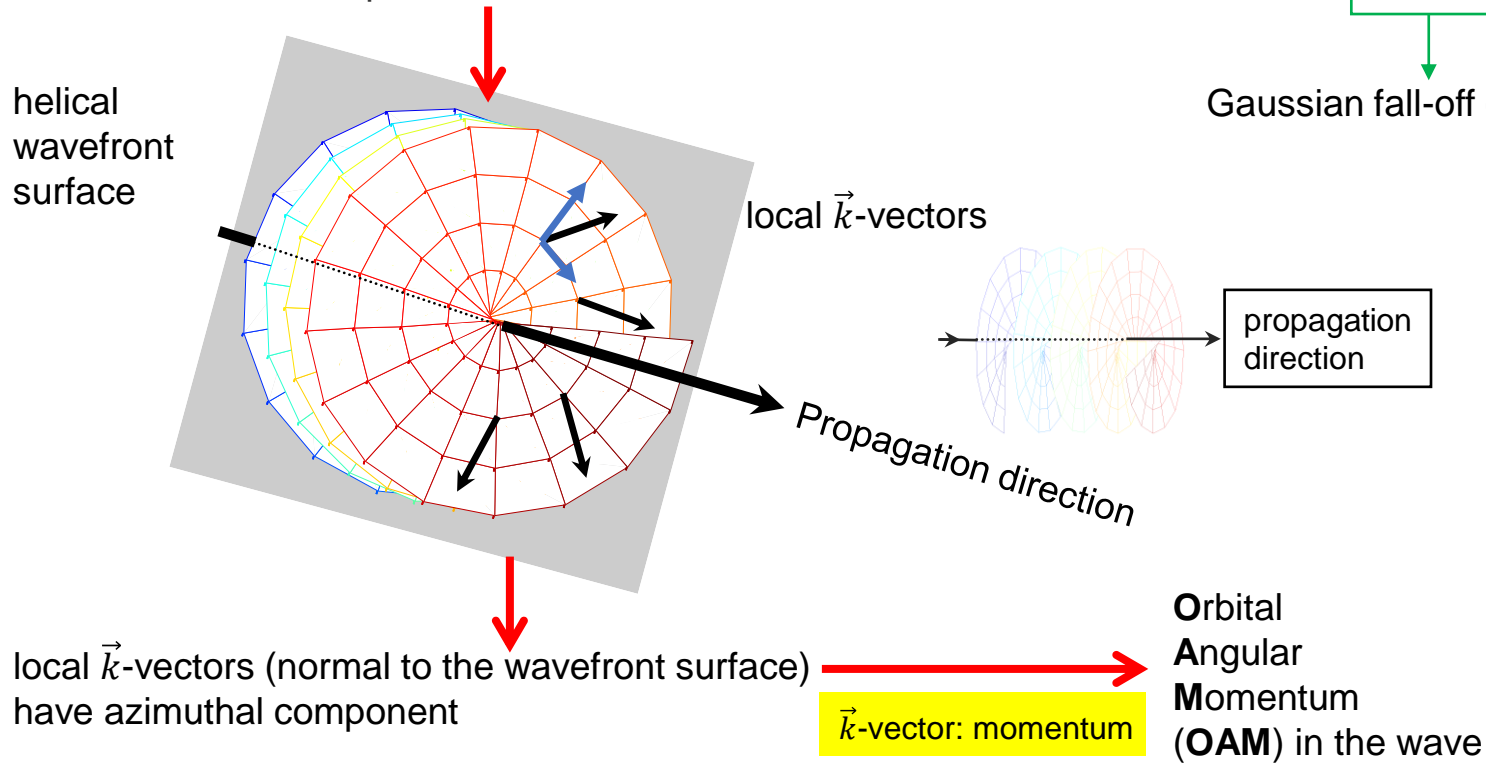


Fig. 1. Phase dislocated wavefront

Eq. 1. Solutions of the paraxial wave equation in cylindrical coordinates.
Amplitude that depends on three terms.

$$E(r) \propto r^l \exp\left(-\frac{r^2}{w^2}\right) L_p^l\left(\frac{2r^2}{w^2}\right)$$

→ Laguerre polynomial for coordinate r

Gaussian fall-off of amplitude

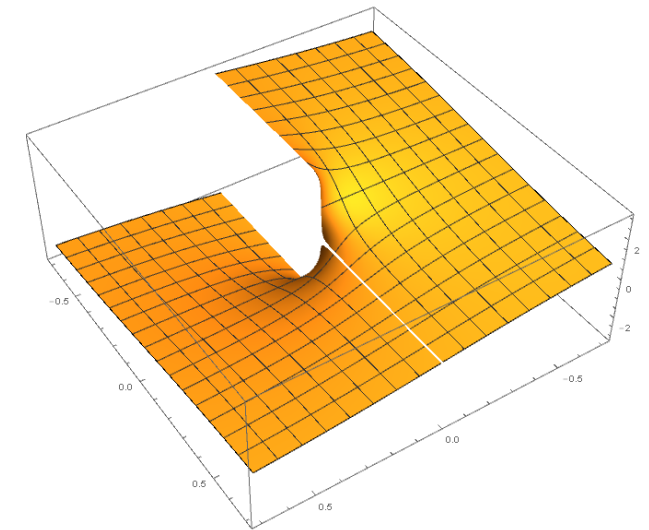


Fig. 2. Ideal helical wavefront structure (phase jump with continuous regular step along the radial direction)

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Why optical vortices matter?

Motivation

- OAM coupling effects within plasma systems

Possible Applications

- Plasma generation by variable topological charge helical beams
 - Plasma dynamics and parametric instabilities modification
- Particle acceleration *via* variable topological charge laser beams

Phys. Rev. Lett. 112, 215001 (2014), DOI: 10.1103/PhysRevLett.112.215001
Phys. Rev. A 45, 8185 (1992), DOI: 10.1103/PhysRevA.45.8185
Phys. Rev. Lett. 105, 035001 (2010), DOI: 10.1103/PhysRevLett.105.035001
Phys. Rev. Lett. 118, 094801 (2017), DOI: 10.1103/PhysRevLett.118.094801

OAM leads to increased energy transfer from the laser to accelerating electrons inside the plasma.

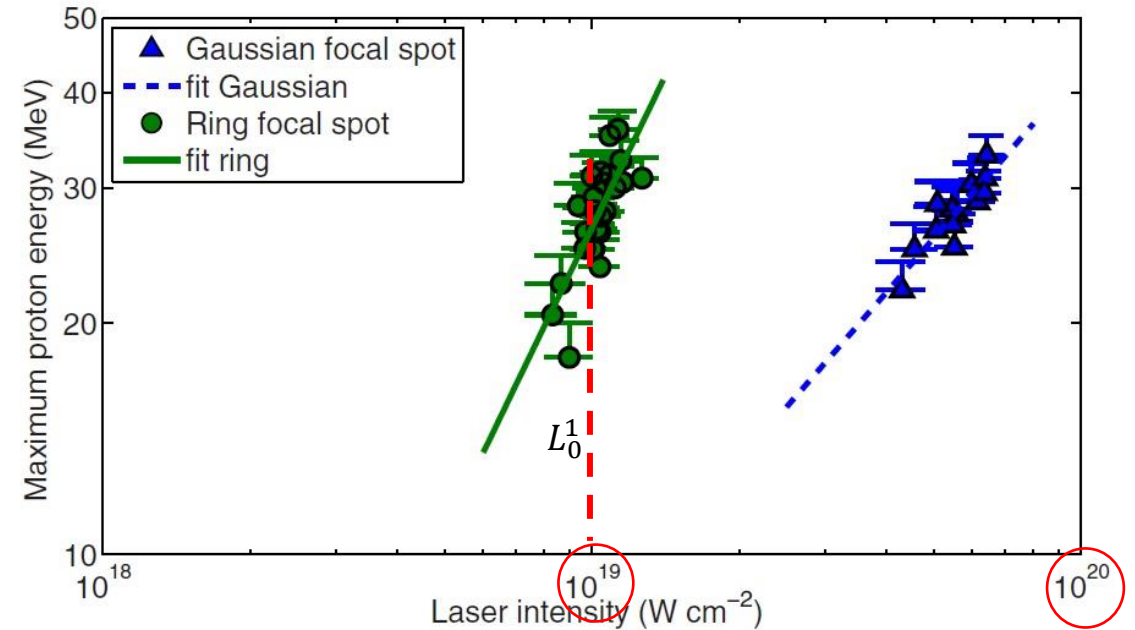


Fig. 3. Experiment with varied topological charge laser beams in TNSA regime.

Note: L_0^1 phase mask laser beams (green circles) and Gaussian focal spots (blue triangles)

Phys. Plasmas 22, 013105 (2015), DOI: 10.1063/1.4905638

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Helical mirror development

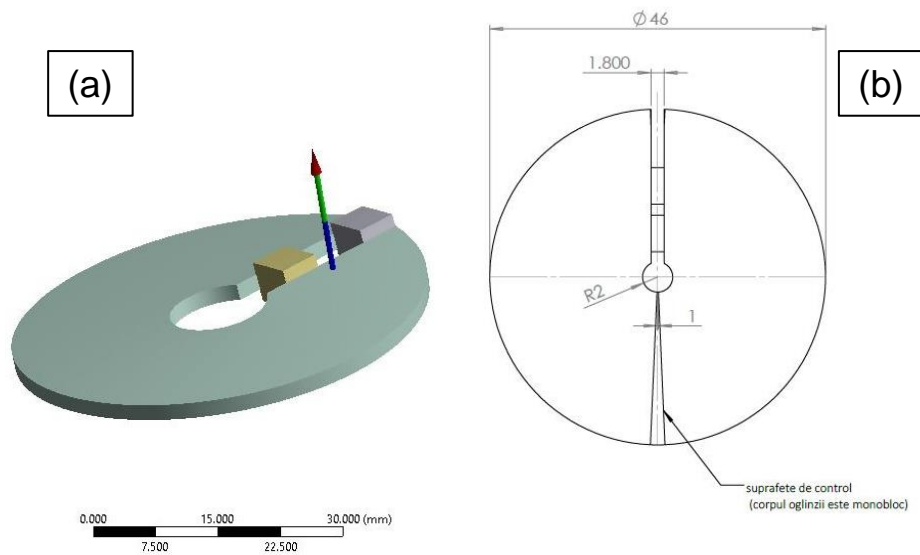


Fig. 4. CAD design of the 2" helical mirror design. Piezo-elements mounted allows continuous surface displacement.

(a) piezo-actuators location

(b) CAD design

CAD & ANSYS courtesy of L. Caratas

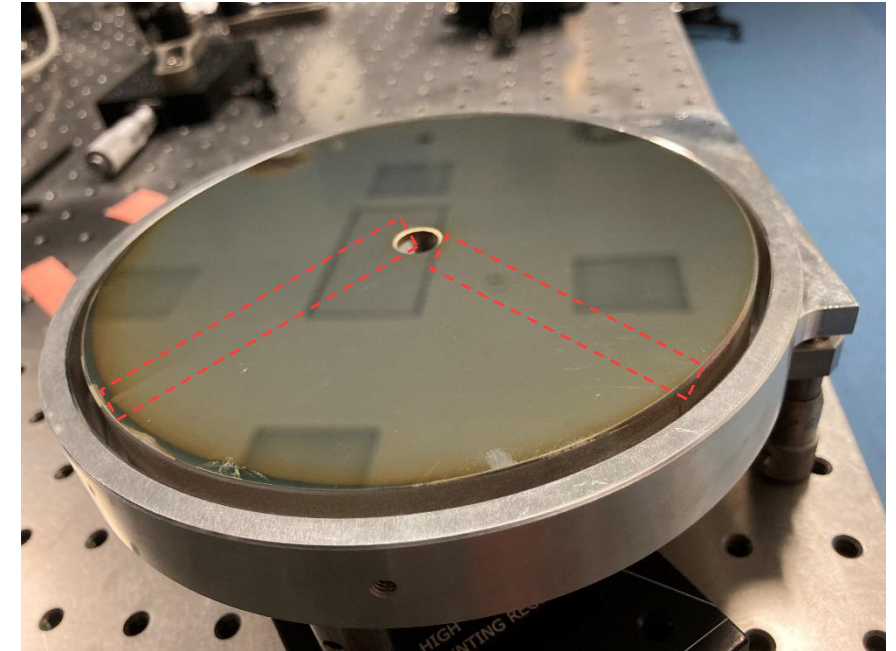


Fig. 5. 6" helical mirror implementation.

How to qualify wavefront phase jumps?



High spatial resolution methods!

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Qualification procedure

Surface topology measurement

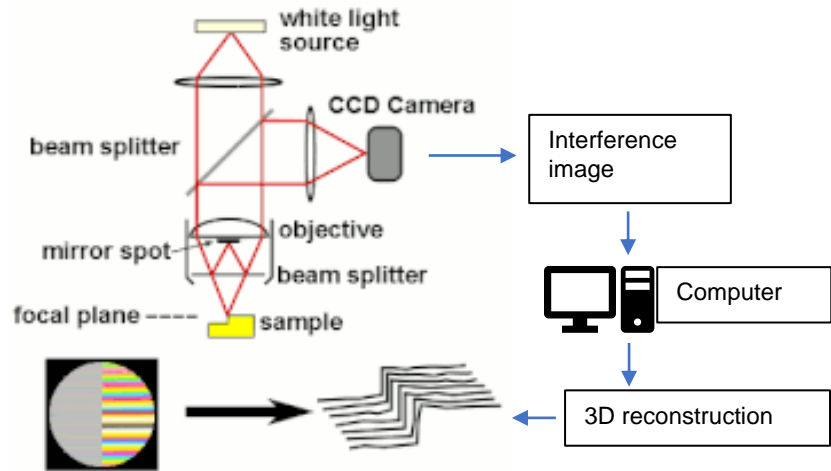
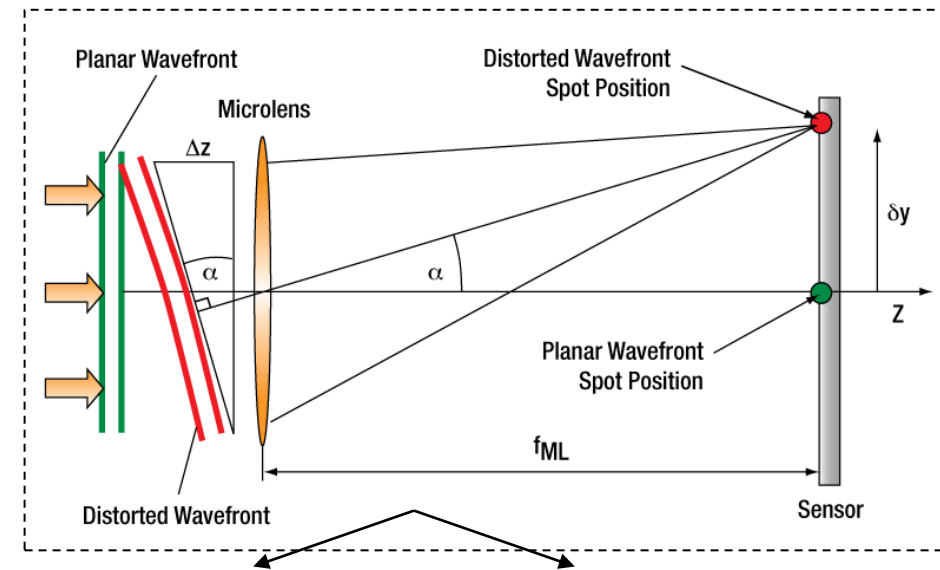


Fig. 6. Scanning optical profilometer operation principle.

Applied Optics 26 (1987) 2810

J Refract Surg. 2001, 17(5):S573-7. PMID: 11583233

Wavefront sensor measurements



**Quadri - Wave
Lateral
Shearing
Interferometry
(QWLSI)**

SID4-HR/PHASICS

LIFT

HASO4_126/IMAGINE OPTICS

Fig. 7. Standard Shack-Hartmann wavefront sensor operation principle

Qualification procedure

Wavefront sensor measurements

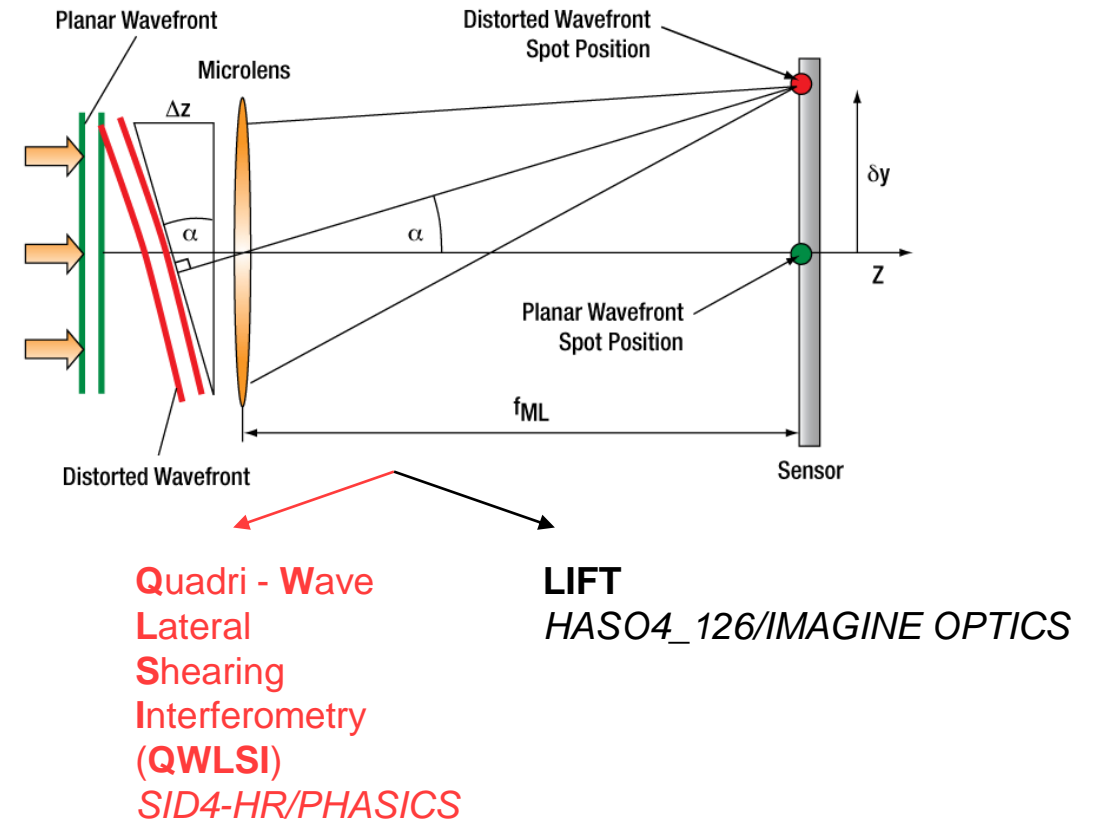
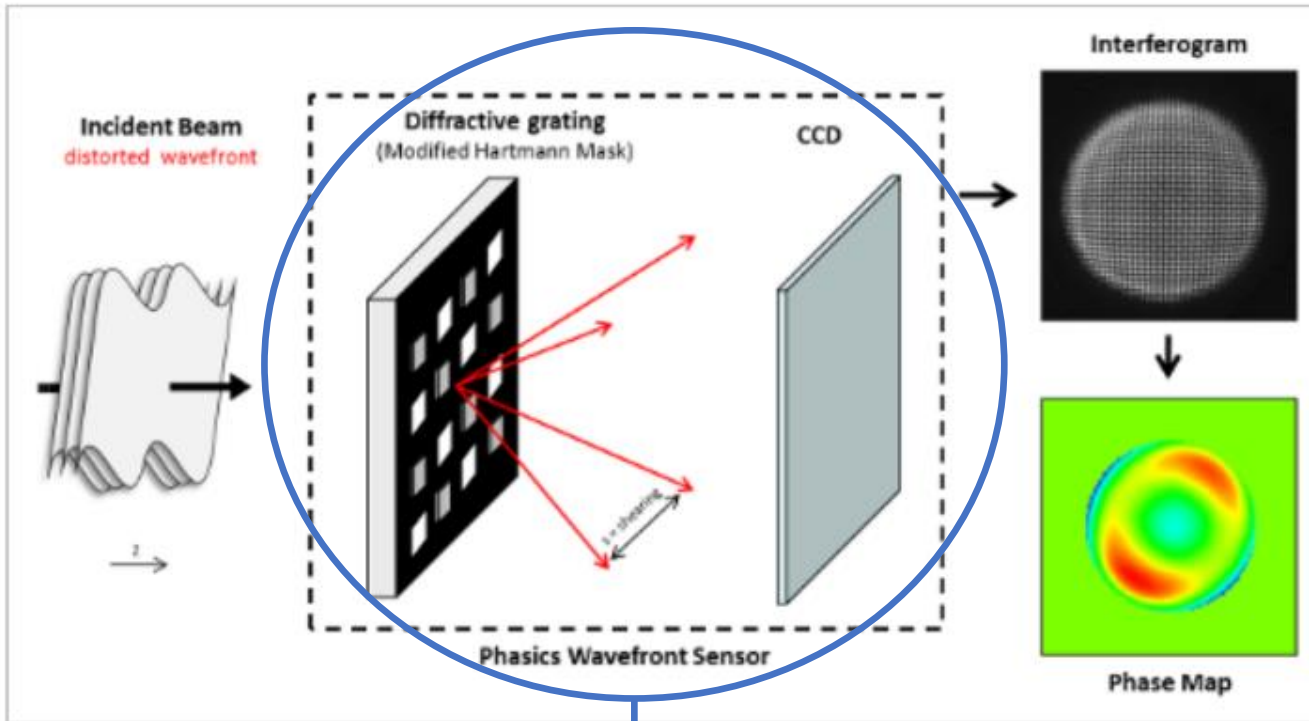


Fig. 7. Standard Shack-Hartmann wavefront sensor operation principle

Qualification procedure

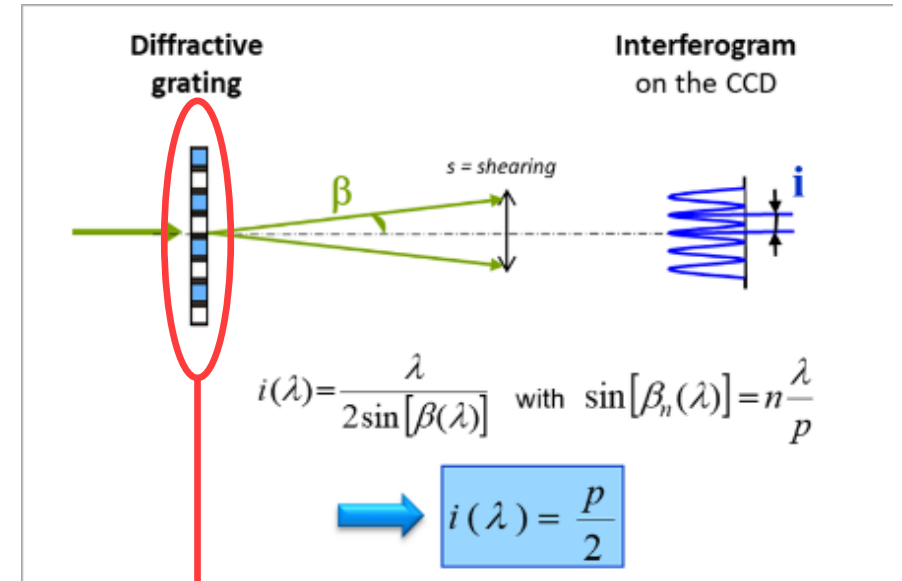
Wavefront sensor measurement: QWLSI



One measurement point per interferogram fringe

Fig. 7.1. Quasi-wave lateral shearing interferometry (QLSI) operation principle.

Note: Images courtesy of Prof. T. Jitsuno and PHASICS CORP.

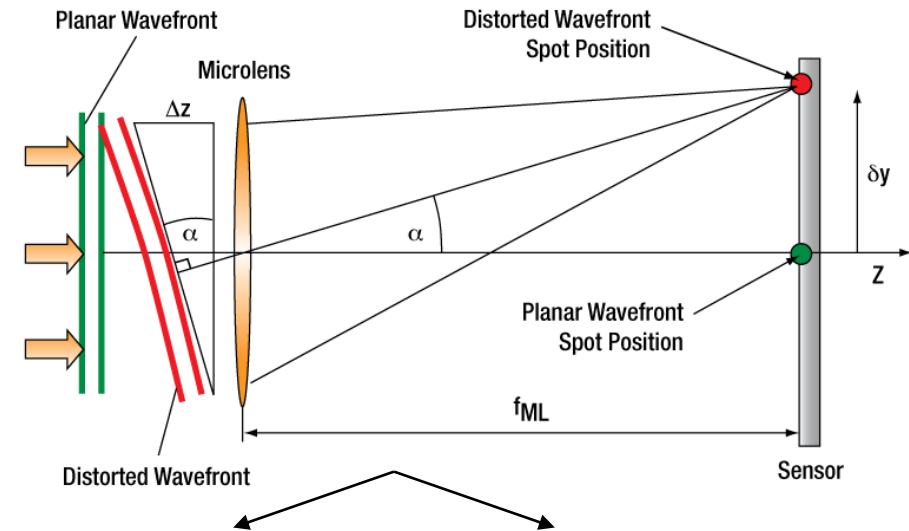


Achromatic nature

Appl. Opt. 44, 9 (2005), DOI: 10.1364/ao.44.007261

Qualification procedure

Wavefront sensor measurements



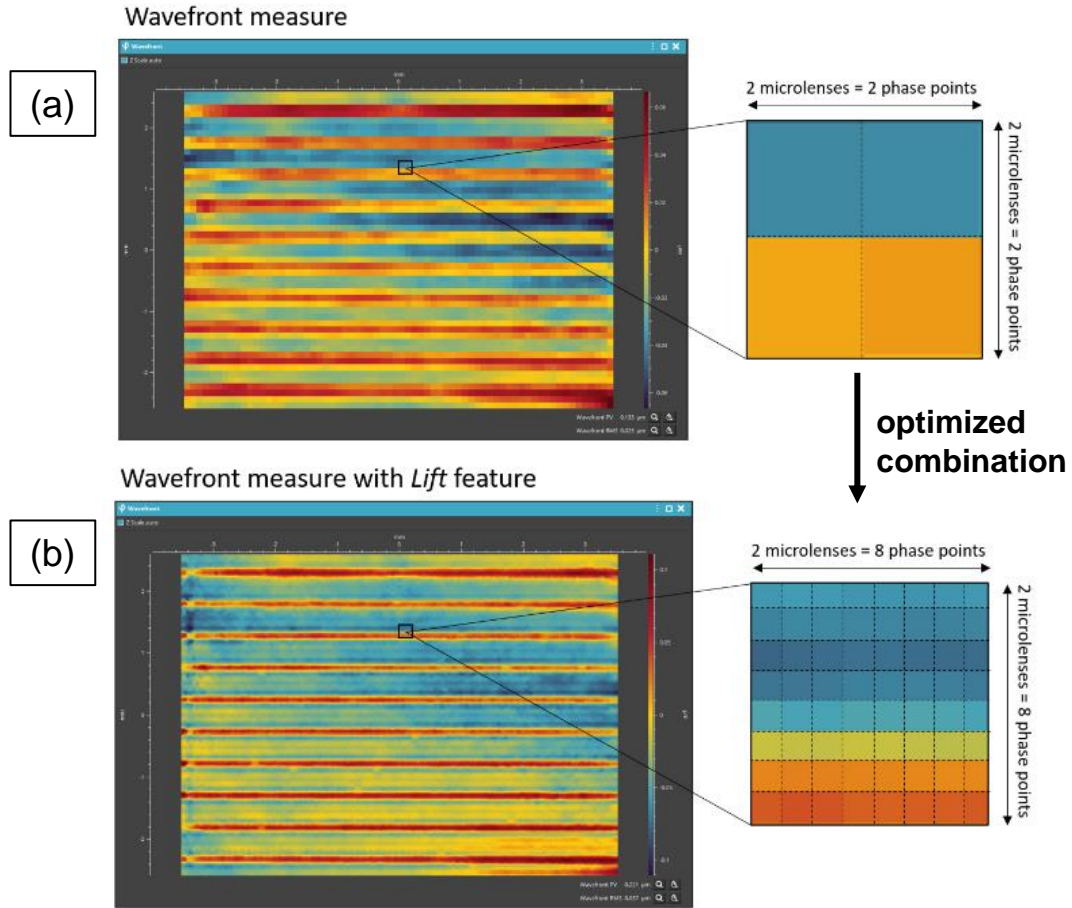
**Quadri - Wave
Lateral
Shearing
Interferometry
(QWLSI)
SID4-HR/PHASICS**

LIFT
HASO4_126/IMAGINE OPTICS

Fig. 7. Standard Shack-Hartmann wavefront sensor operation principle

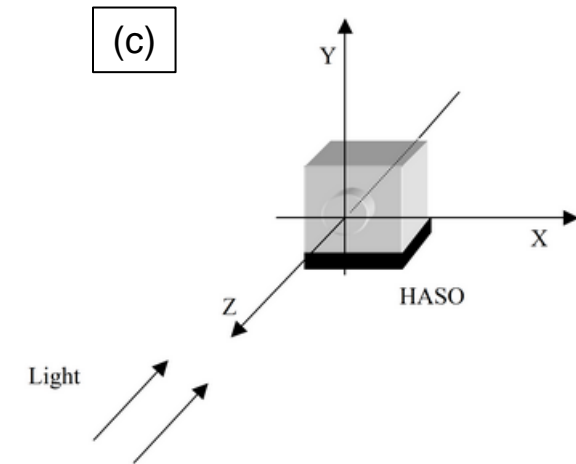
Qualification procedure

Wavefront sensor measurement: LIFT



Hartmanngram provides a single phase value

- Microlenses design
- Algorithmic process



Webinar: "THE BIG LIFT, a wavefront sensing revolution - session 1"
Wed, Mar 24, 2021 11:00 AM - 12:00 PM EET
Contact: : digital@imagine-optic.com

Fig. 7.2. (a) Standard Hartmanngram, (b) LIFT algorithm for wavefront reconstruction and (c) HASO4 sensor diagram.

Qualification procedure

Experimental Set-Up

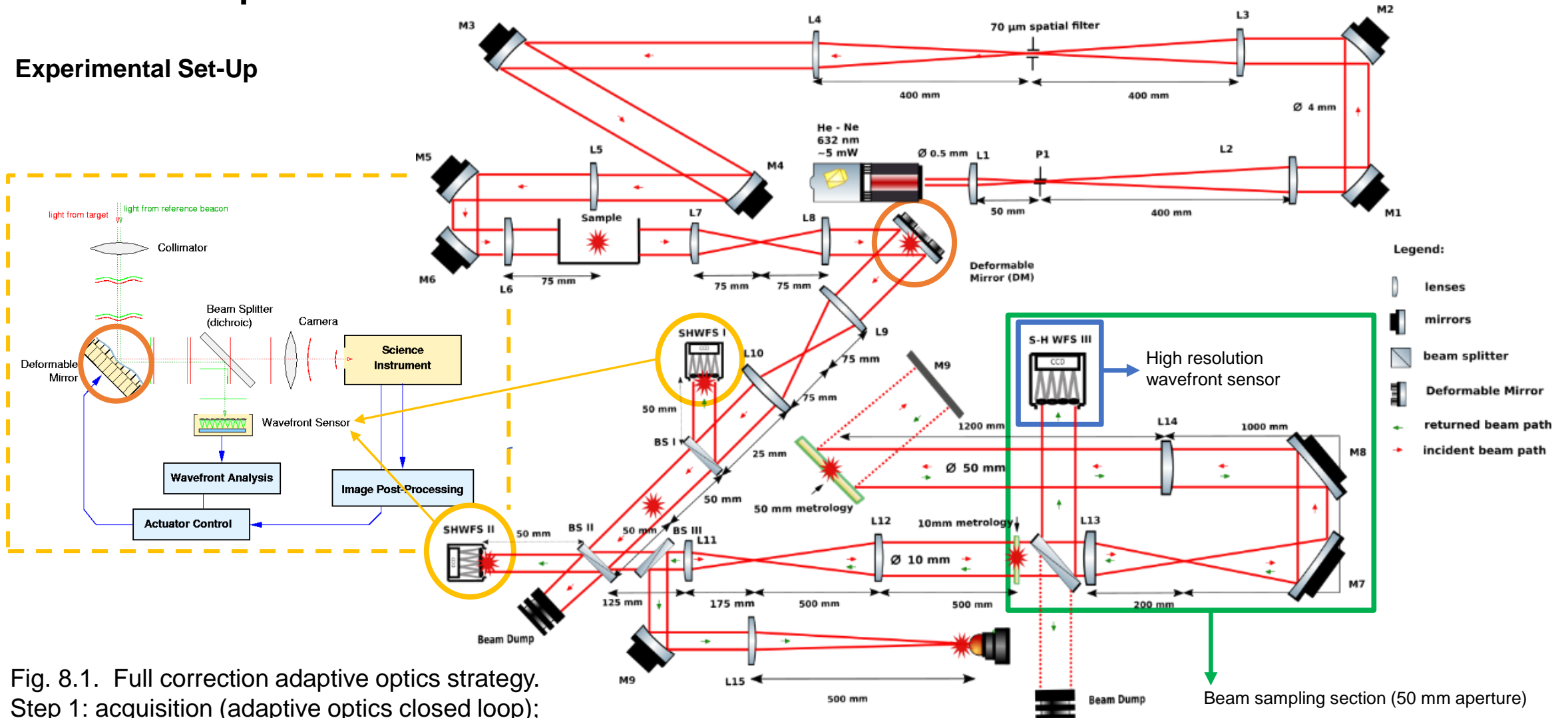
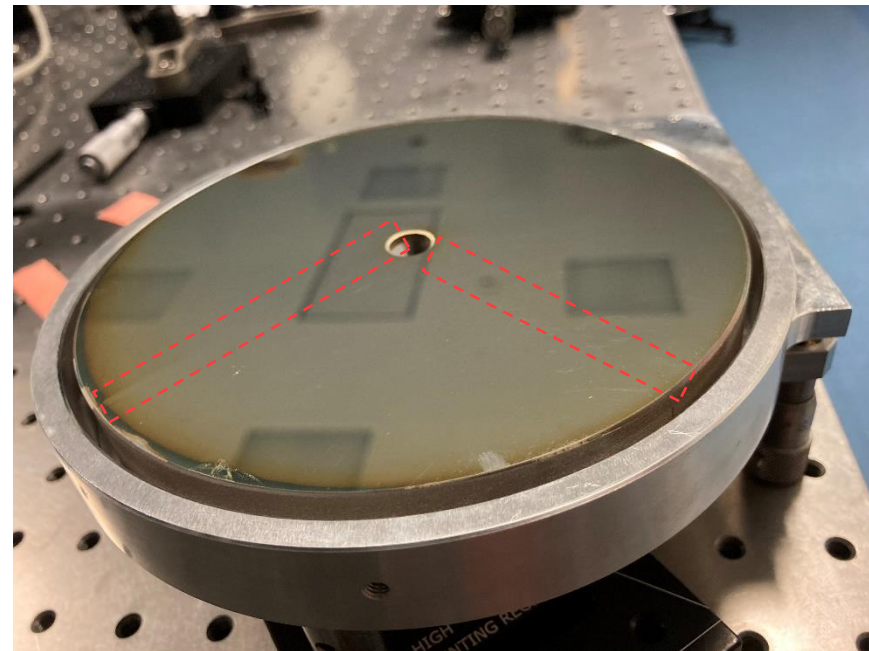


Fig. 8.1. Full correction adaptive optics strategy.
 Step 1: acquisition (adaptive optics closed loop);
 Step 2: calculation (acquired images → phase retrieval
 → estimating spot aberrations as Zernike coefficients);
 Step 3: correction by deformable mirror.

Fig. 8.2. Qualification setup.

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Preliminary results

Profilometer

4th order helical mirror

Area: $350.889 \mu\text{m} \times 264.19 \mu\text{m}$
Pixel Size: $0.26 \mu\text{m} / \text{pixel}$

(a)

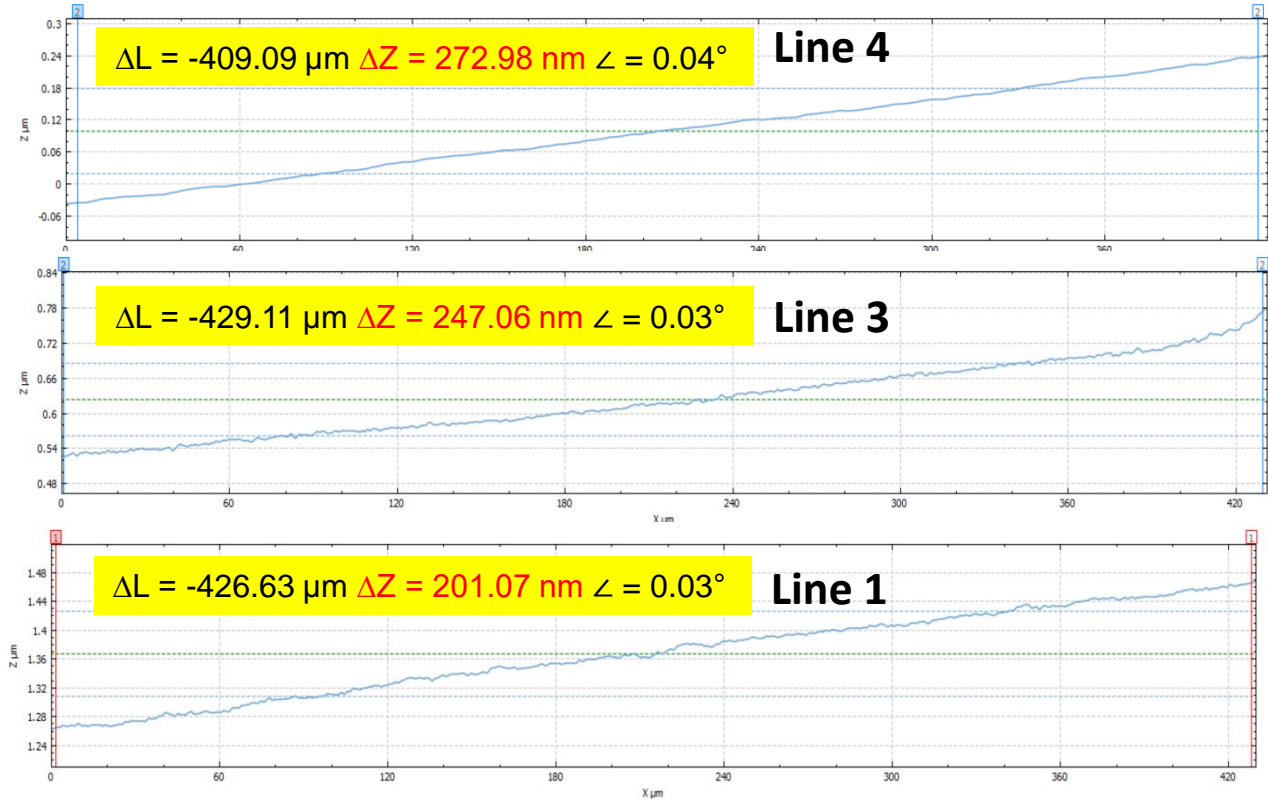
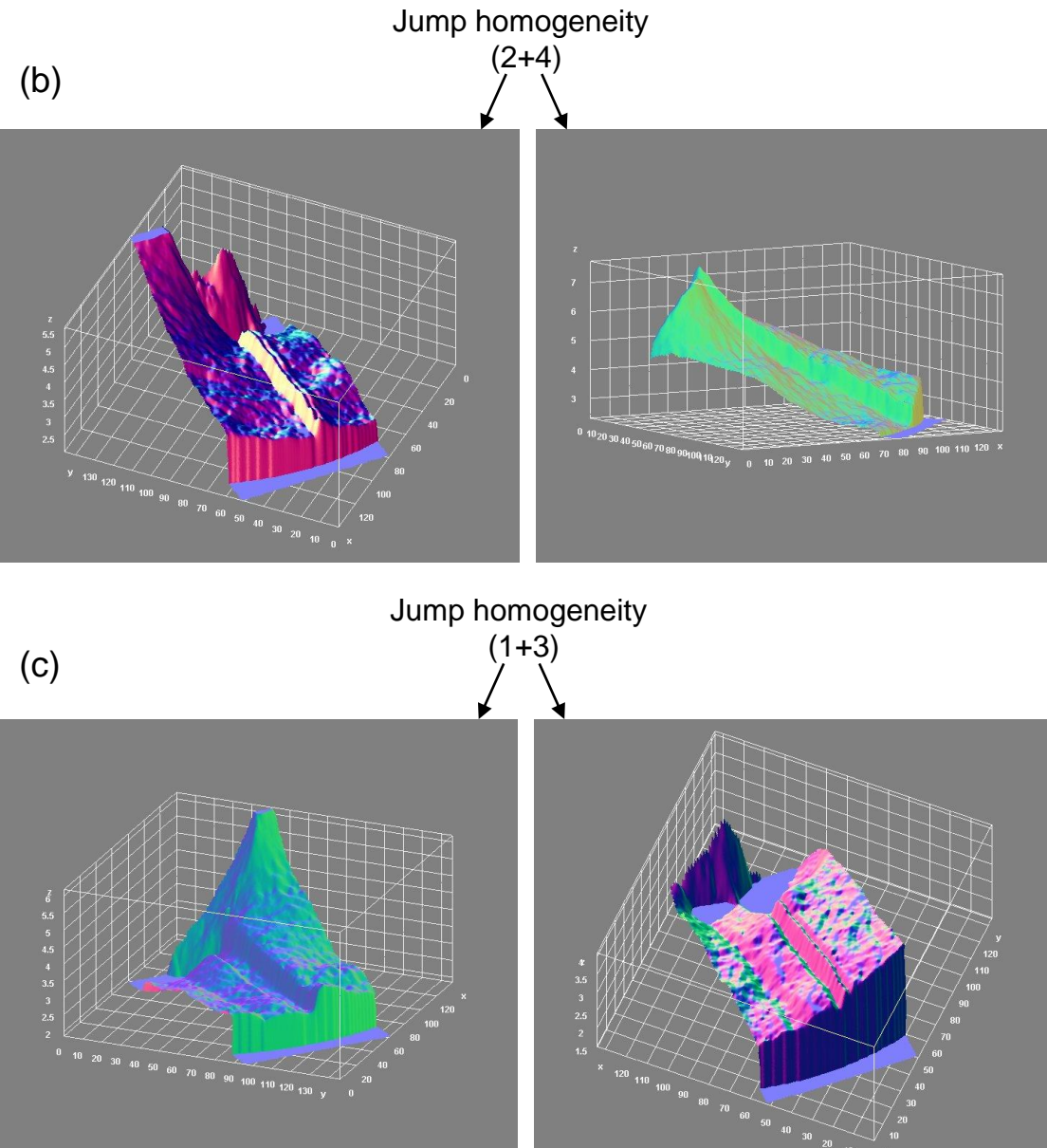


Fig. 9. (a-c) Surface local topological measurements.

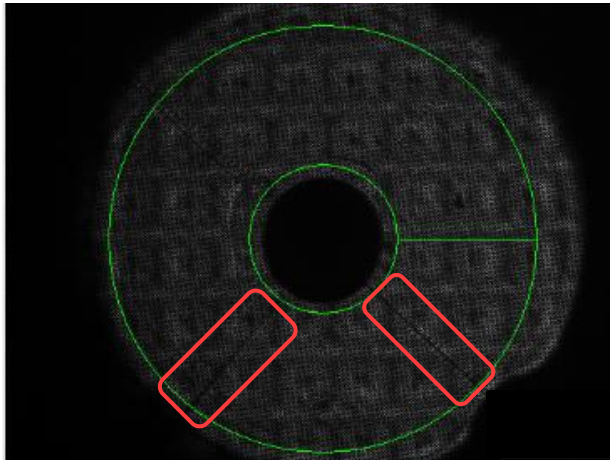
(Target Lab: L. Dinca, C. Gheorghe & A. Ionescu)



Preliminary results

SID4-HR PHASICS

4th order helical mirror



Phase retrieval
→

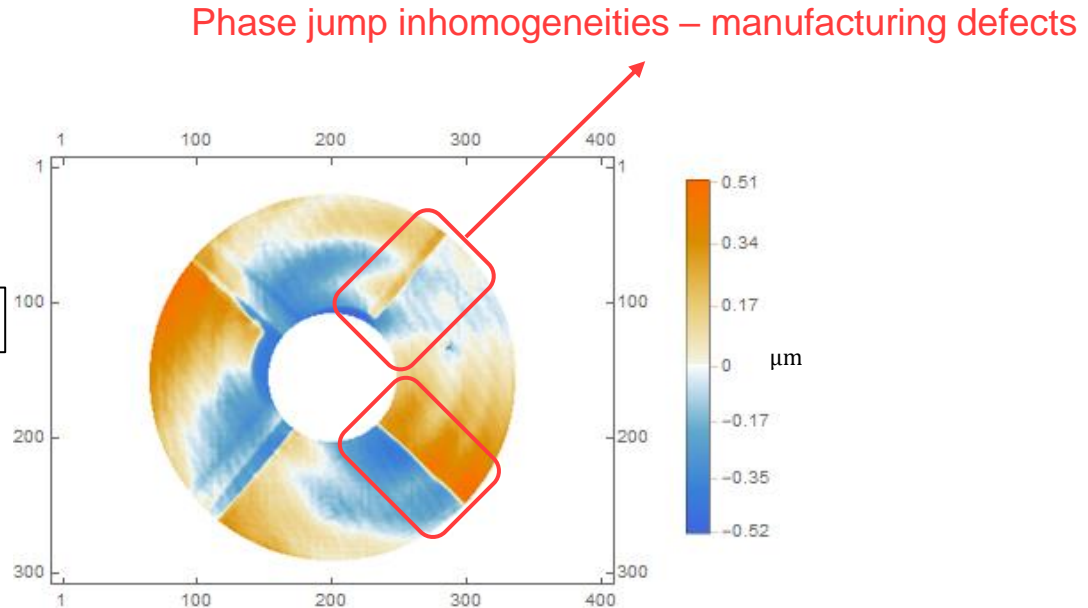


Fig. 14. 1. Sub-aperture phase mask

Fig. 14. Reconstructed wavefront.

Fig. 14. Wave front sub aperture measurements of the 4th order helical mirror.

Profilometer measurements → 200 nm – 270 nm

Note:

SID4 PHASICS measurements

Wavefront map at 0° incidence angle, (50 mm aperture, λ @ 633 nm)

Double path configuration → Surface Map = Wavefront Map / 2)

Phase jump on mirror → 253 nm

Preliminary results

IMAGINE OPTICS HASO4_126

4th order helical mirror

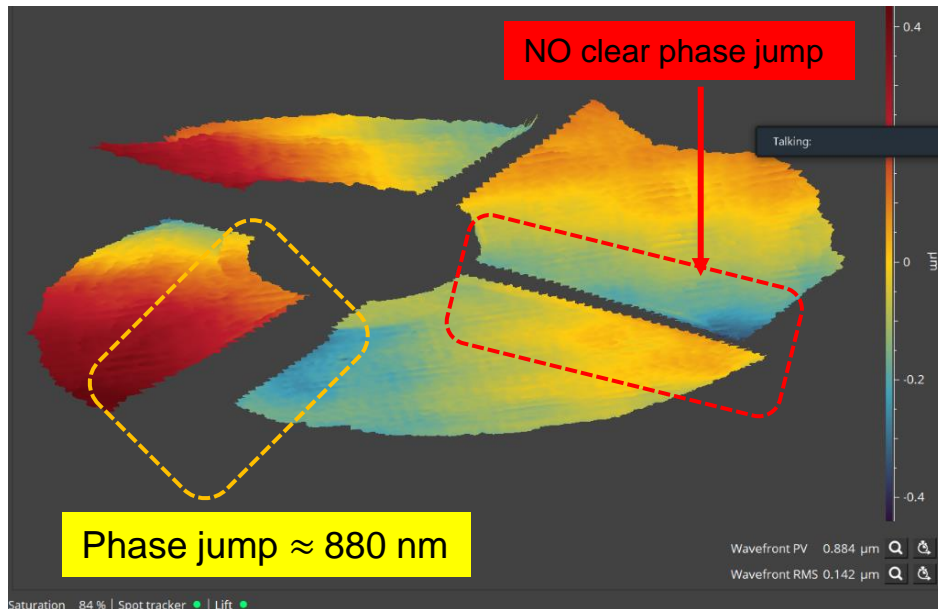


Fig. 15. Wave front sub aperture measurements of the 4th order helical mirror by the HASO4 sensor @ 632 nm.

Note: Wavefront recovered with LIFT algorithm.

(a) 2D wavefront representation

(b) sub-aperture mask

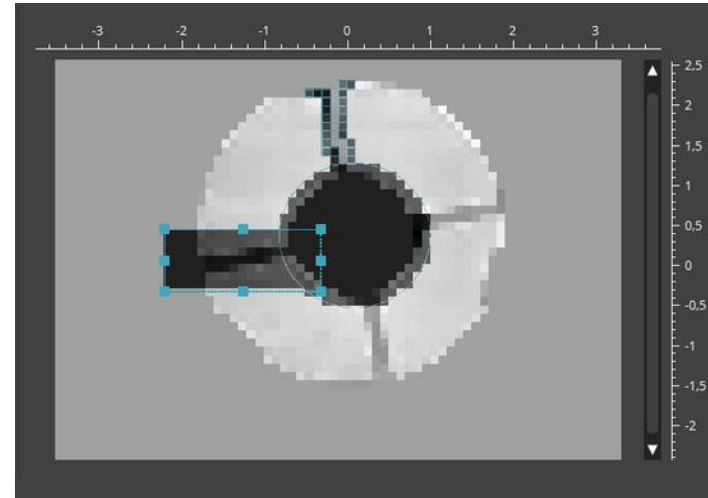


Fig. 16. Mask tool applied on the 4th order helical mirror.

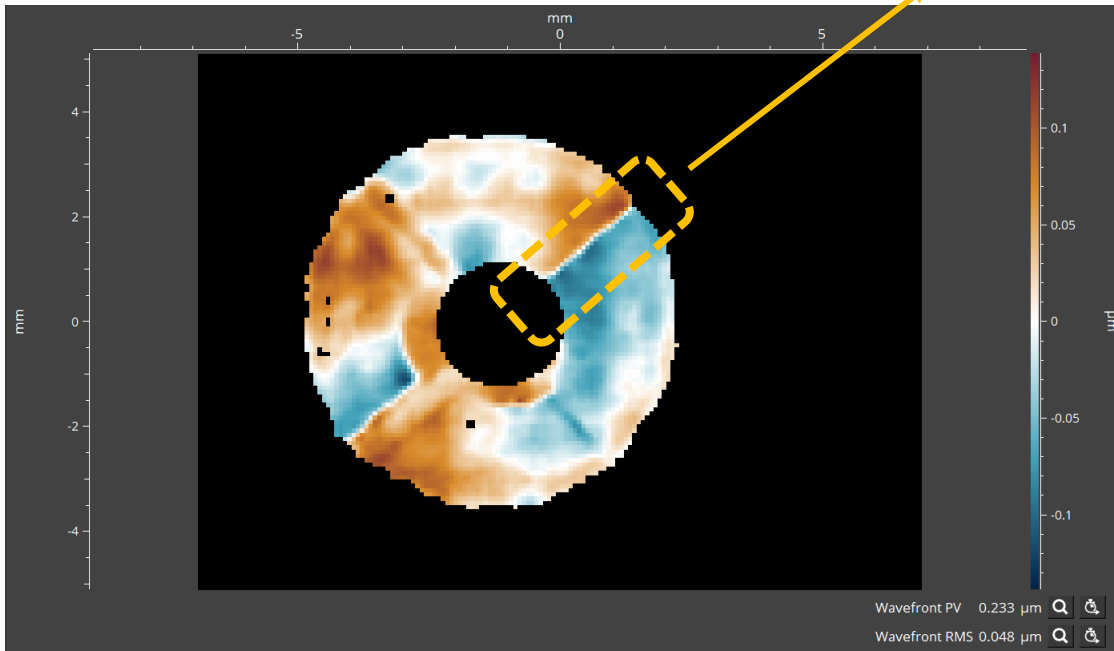
Preliminary results

IMAGINE OPTICS HASO4_126

4th order helical mirror

Phasics SID4
Phase jump ≈ 253 nm

phase jump ≈ 230 nm



Zernike RETREIVAL + LIFT \rightarrow Fails to account the phase jump

wavefront PV ≈ 150 nm

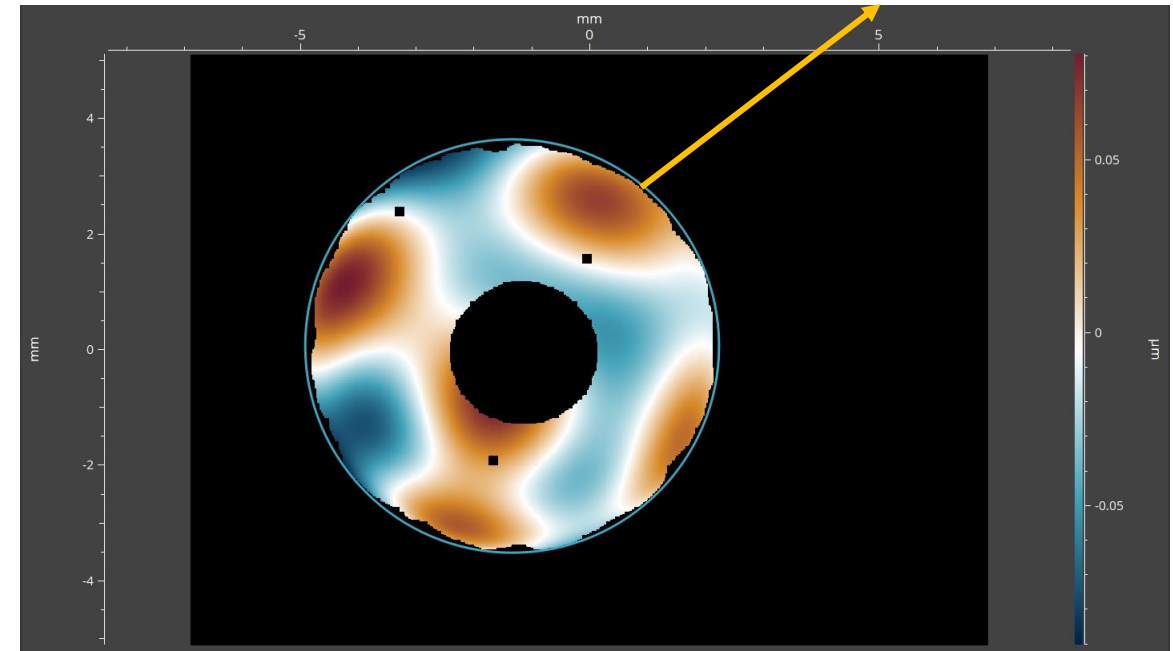


Fig. 17. 1. Sub-aperture wavefront reconstruction with iterative Zonal method and **LIFT** method.

Note for Fig. 17.1. & 17.2.

- Aberration filtering \rightarrow tilts (X & Y), focus and astigmatism (0^0 & 45^0)
- HASO4 sensor @ 632 nm in double path configuration

Fig. 17. 2. Sub-aperture wavefront reconstruction with Zernike polynomials and **LIFT** algorithm.

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Perspectives

- beam expander for full aperture wavefront measurements
- simulation of beam propagation with measured wavefront
- remanufacturing 4th order helical mirror coating
- implementation 4th order helical mirror in E4 experiments

References

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- <http://phasicscorp.com/cameras/sid4-hr/>
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- *Opt. Lett.* **41**, 3407-3410 (2016), DOI: 10.1364/OL.41.003407

Acknowledgments

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- ProOptica → interferometry measurements D. Ursu, M. Georgescu, I. Ghita

MGM Star Construct and A. Sobetskii → technological developments [www.mgmstar.ro]

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