Wave optics simulator for precision surface analysis for reflective nano focusing optics coupled to "At Wavelength metrology"

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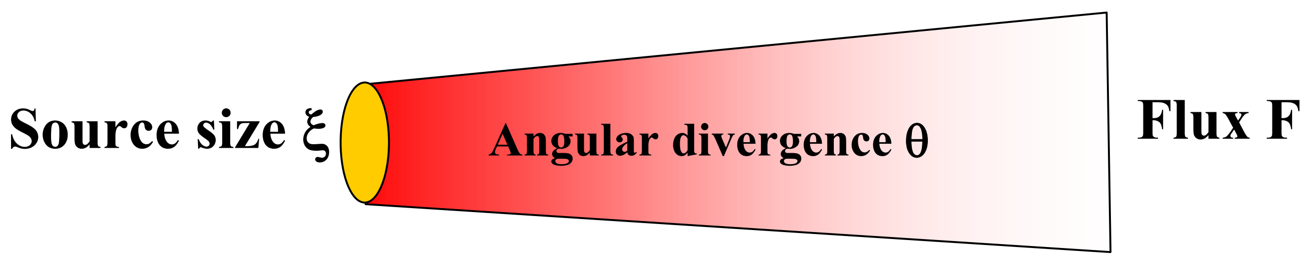
- ⇨ **Background**
- ⇨ **Developmental activities**
- ⇨ **Research Activities**
- ⇨ **Future plan**

New generation sources and optics

- New synchrotron sources have a high degree of spatial coherence
- Source size 10-50μm
- Long source to object distance 50-1000m
- Undulator sources are highly collimated < 20 μrad vertical divergence



Coherent imaging technique
Nano beam applications

$$Brightness = K * \frac{Flux}{\xi \times \theta}$$

Challenges to optical components

High spatial coherence has given rise new kind of challenges that were never encountered in 2nd generation sources

Any spatial and compositional homogeneity in

- Beryllium windows
- Reflection mirrors

Generates interference fringes!!!!

↓

Need of wave optics simulations

Nano focusing application

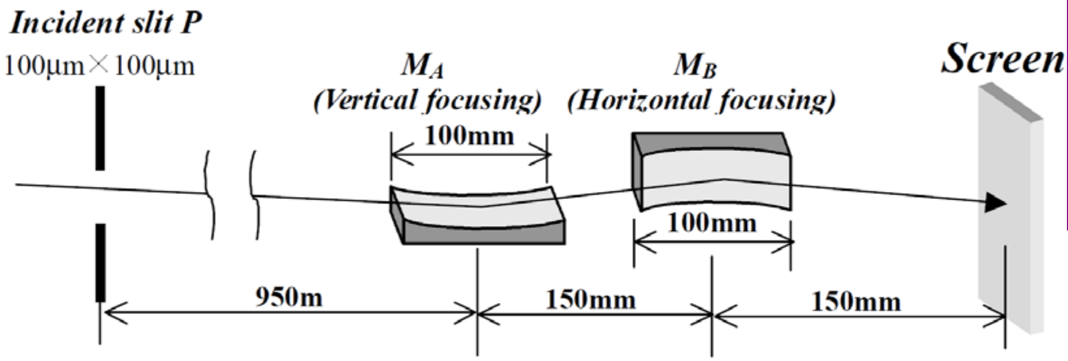
Wide range of scientific applications need a nanometer beam → a challenge for optics people

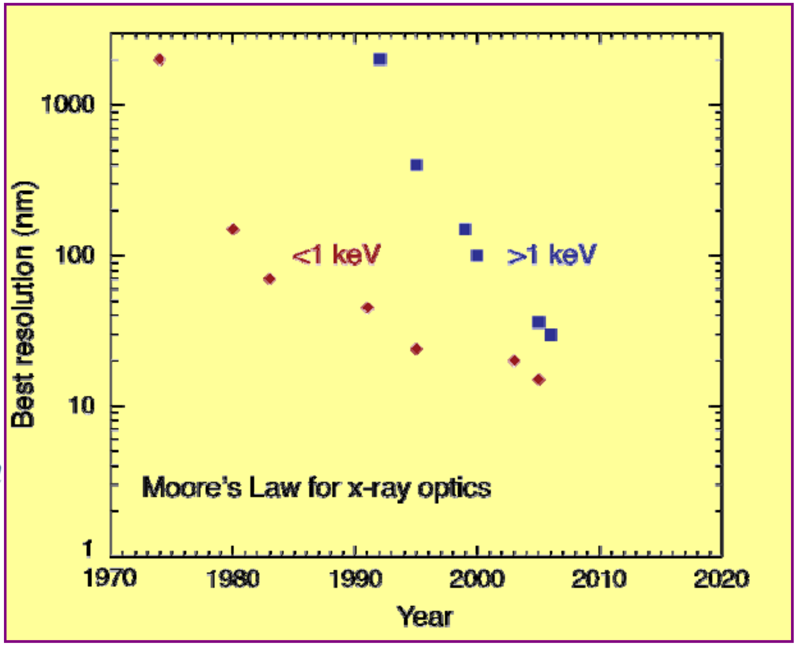
NEED to generate diffraction limited focusing optics

- **Beam Size:** **<10 nm**
- **Energy:** **Hard X-rays (2- 30 keV)**

$$d = 2.0 * \lambda * \frac{f}{D}$$

d – beam size
f - focal distance
D - mirror aperture





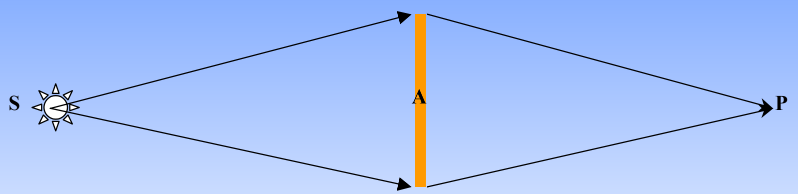
Challenges

- Minimize intensity fluctuation
- Minimize wave front phase errors

- Metrology is a key: optics cannot be made if it cannot be measured
- Measuring elliptical surfaces with slope errors << 0.1 μrad:

Wave optics simulator

At wavelength metrology



Huygen's principle

- Amplitude at aperture due to source S is $E_A = E_o \frac{e^{ikr'}}{r'}$
- Now suppose each element of area dA gives rise to a spherical wavelet with amplitude $dE = E_A dA$
- Then at P, $dE_P = E_A dA \frac{e^{ikr}}{r}$
- The total disturbance at P is just proportional to the sum of all the wavelets weighted by the obliquity factor F(θ)
- This is just a mathematical statement of Huygen's principle.

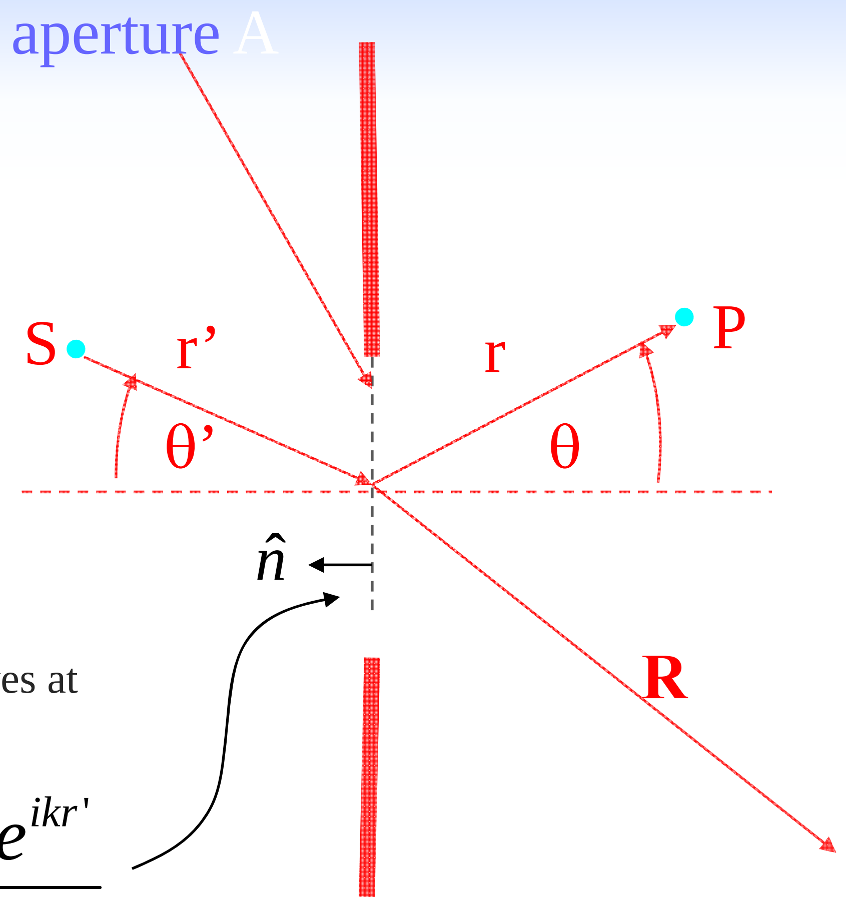
H. Yumoto, H. Mimura, S. Matsuyama, et al., **2006** *Rev. Sci. Instrum*. **77** 063712.
C. Kewish et al Applied optics vol 46, 2010-2021

This relation is known as Fresnel-Kirchoff Formula

$$E_P = -\frac{iE_o}{\lambda}\int_{aperture}\frac{e^{ik(r+r')}}{rr'}F(\theta)dS$$

$$F(\theta) = \frac{1}{2}[\cos\theta - \cos\theta']$$

Where F(θ) is obliquity factor

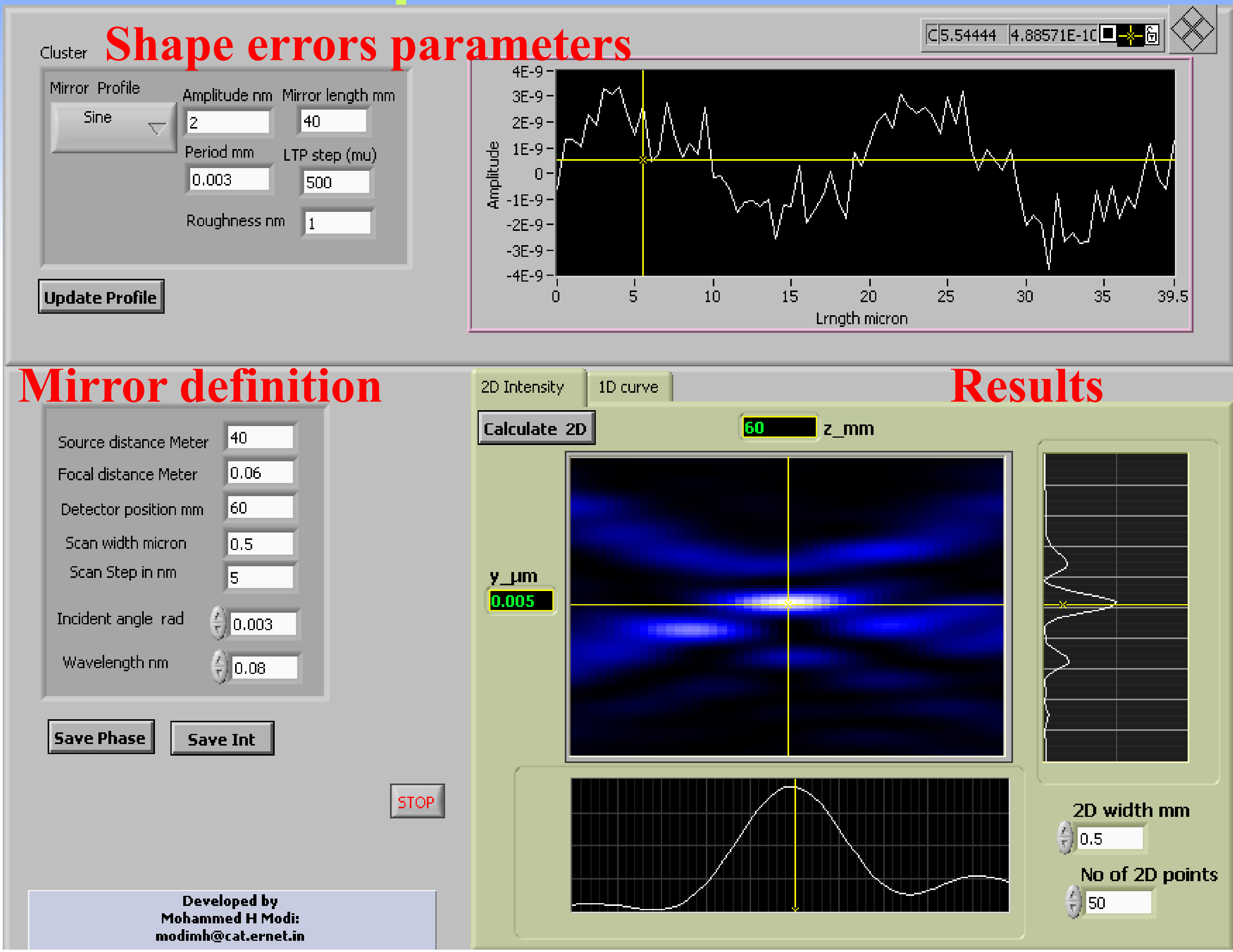


Radiation from source, S, arrives at aperture with amplitude

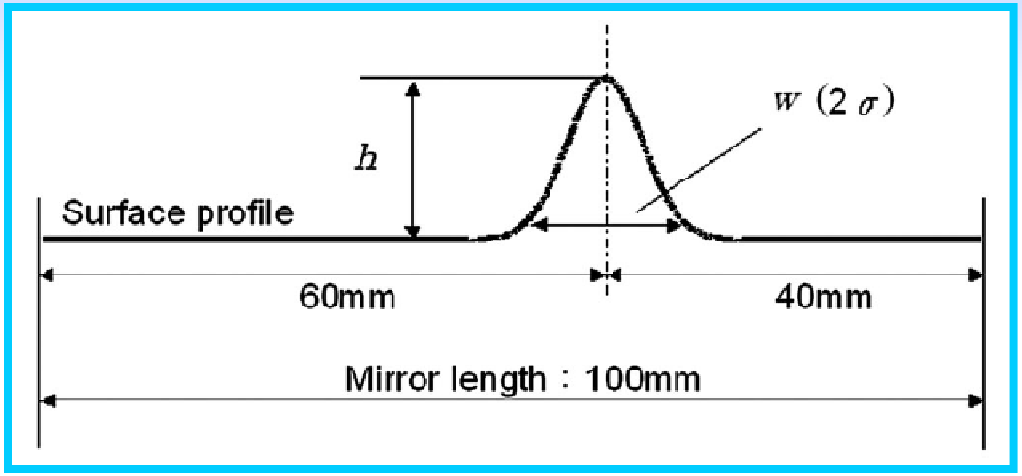
$$E = E_o\frac{e^{ikr'}}{r'}$$

Wave Optics calculator

SMEXOS 2009

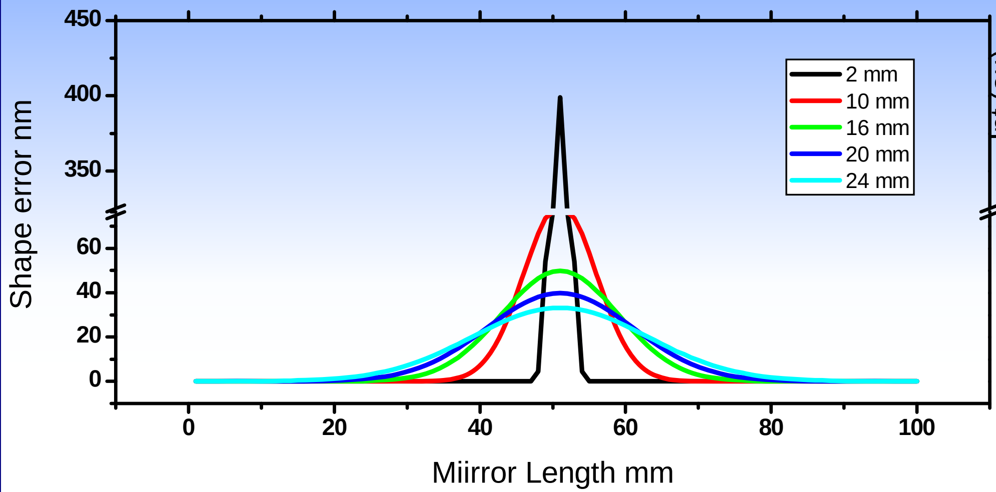


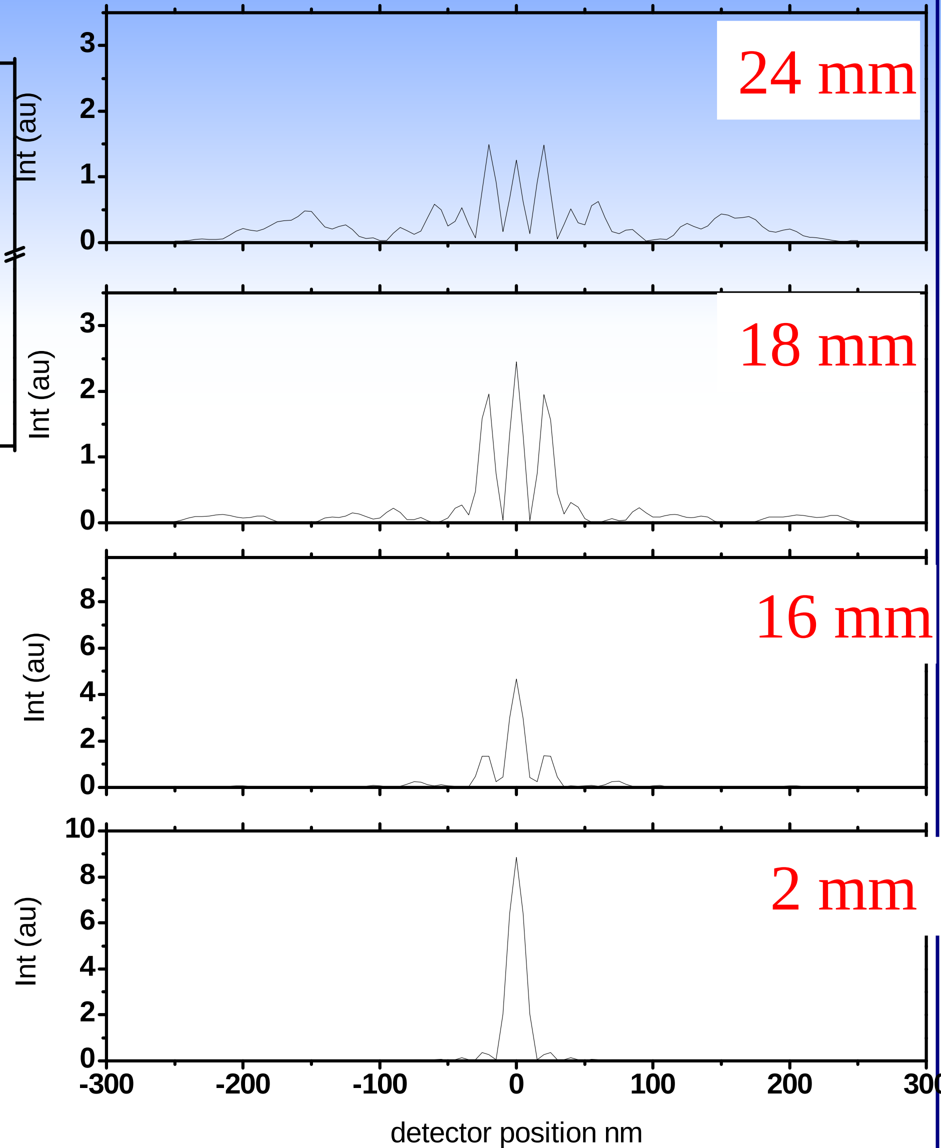
Bump Effect



In high heat load environment, surface deformation on optical elements create a Bump on the optical surface

Bump effect





- Bump of small width < 2mm is tolerable
- Bump of large width having even small height error produce serious effects

Some examples : effect of shape error SMEXOS 2009

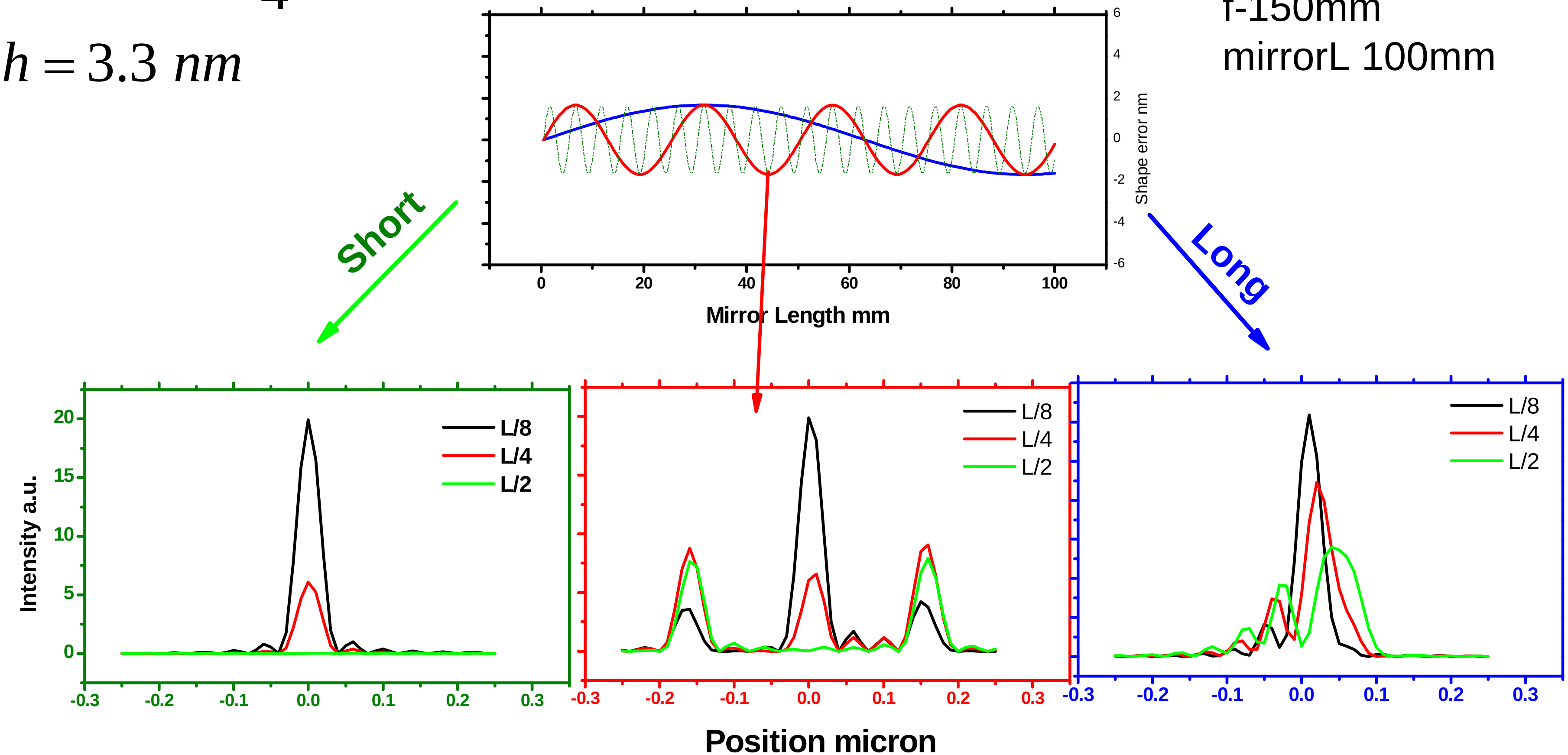
The wave optics tool is used to simulate the effect of long, mid and short frequency shape error components.

The PV height error h is rescaled in order to generate different intensity profile at the focal spot.

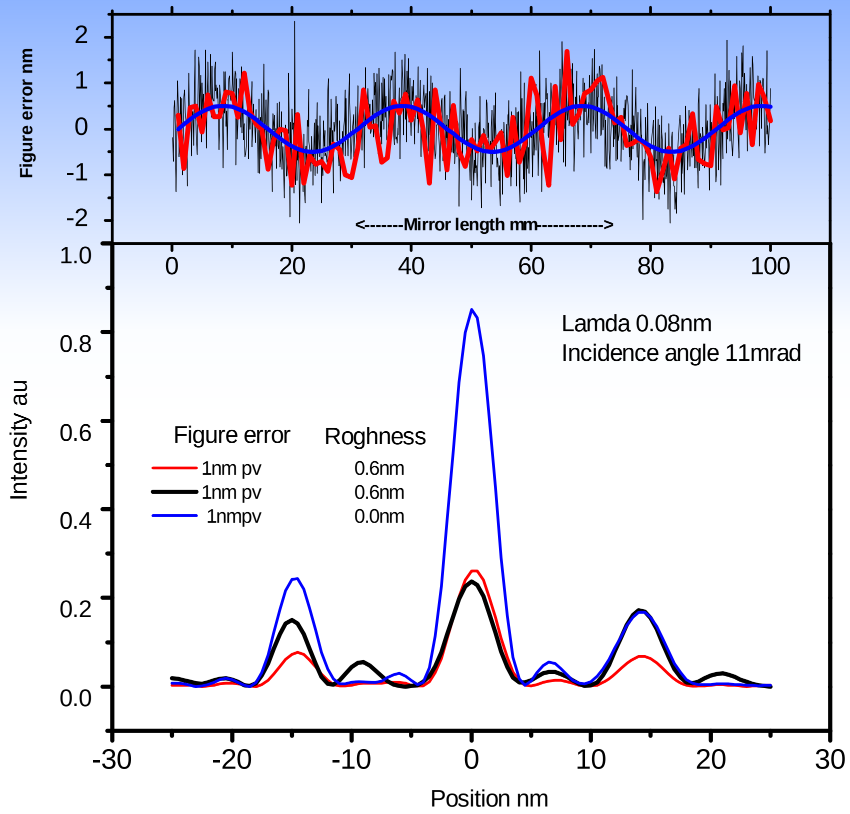
$$2h \cdot \sin\theta = \frac{\lambda}{4}$$

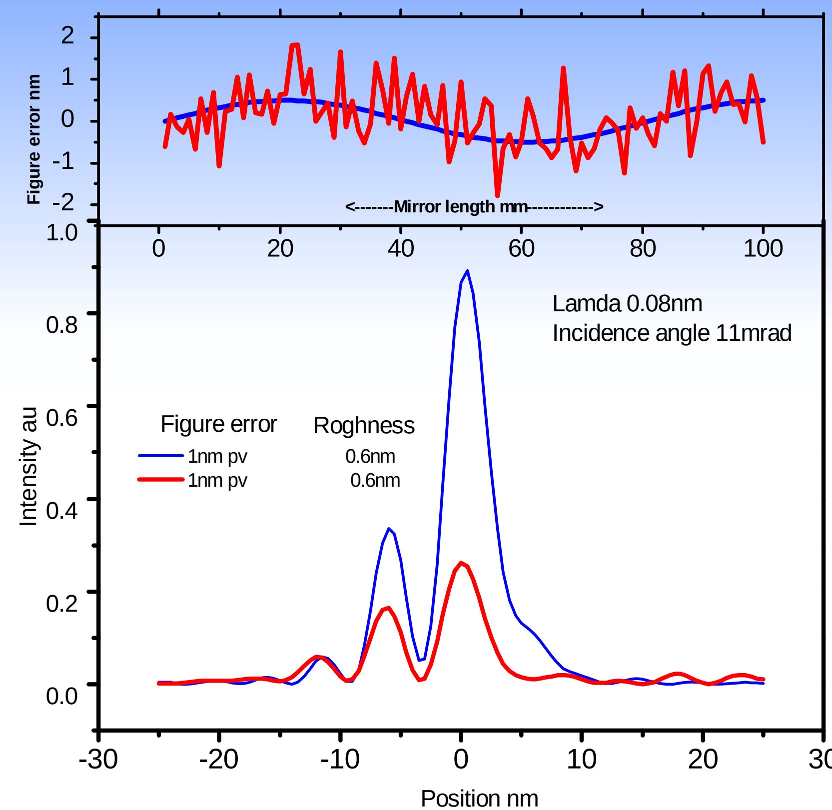
$$h = 3.3\ nm$$

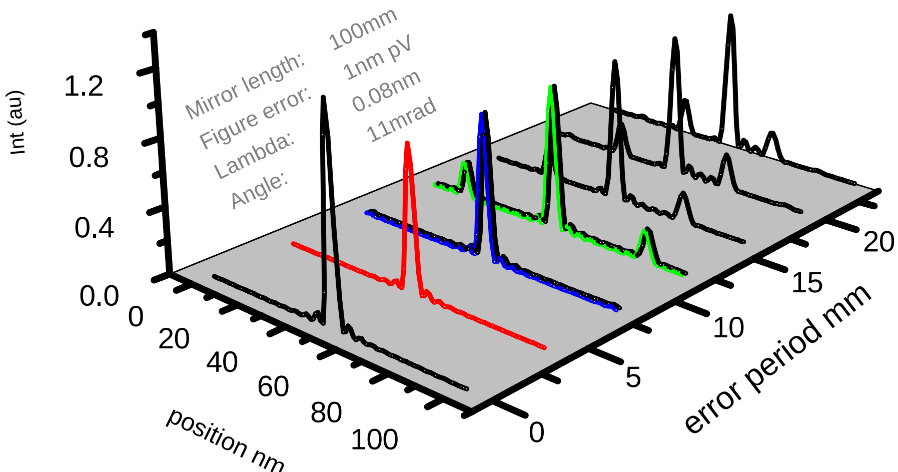
3mrad
0.08nm
f-150mm
mirrorL 100mm



Shape error







$$2h \cdot \sin\theta = \frac{\lambda}{4}$$

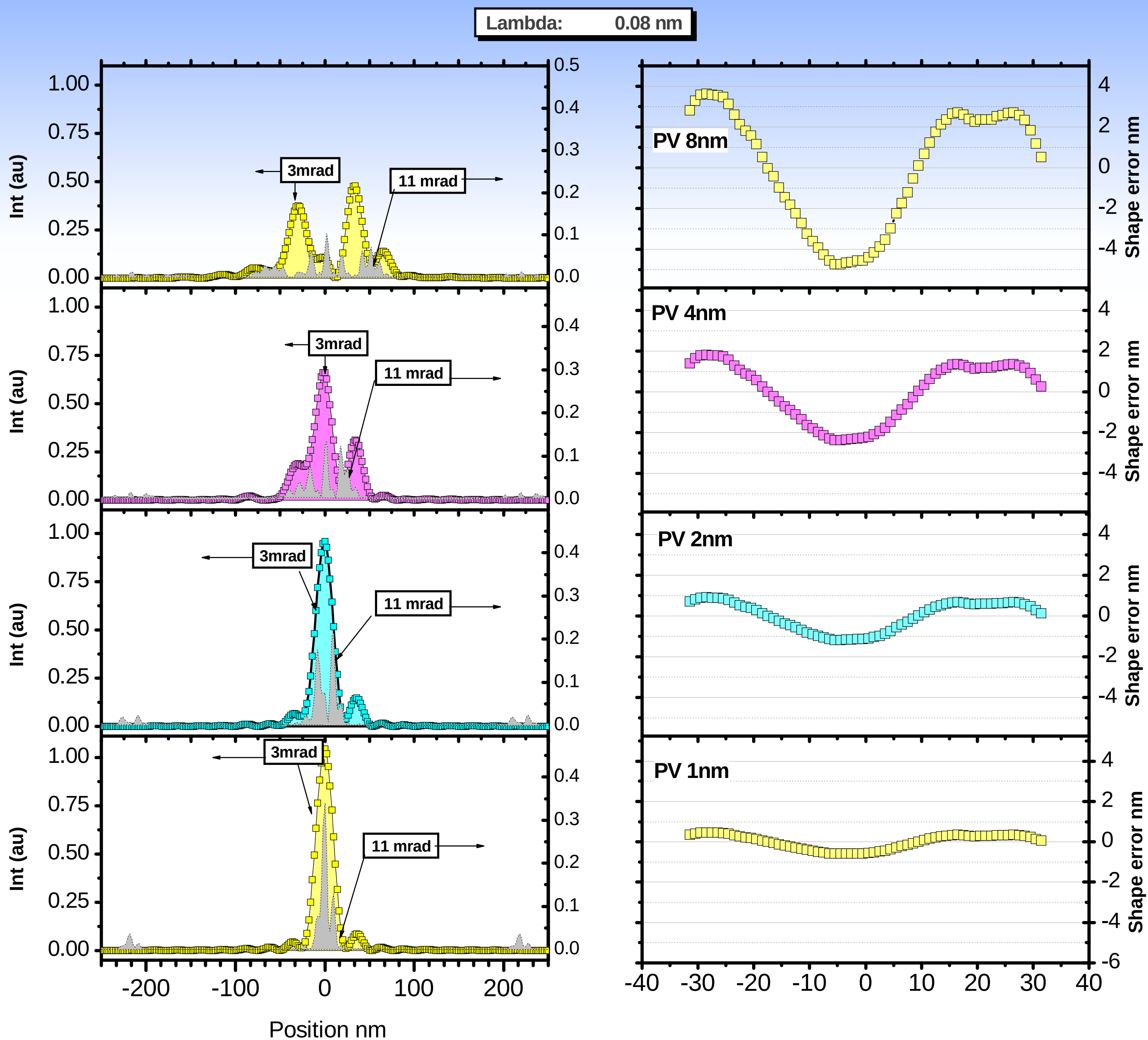
$$h = 0.9\ nm$$

Frequency component having period of 10mm or more are killing the mirror performances

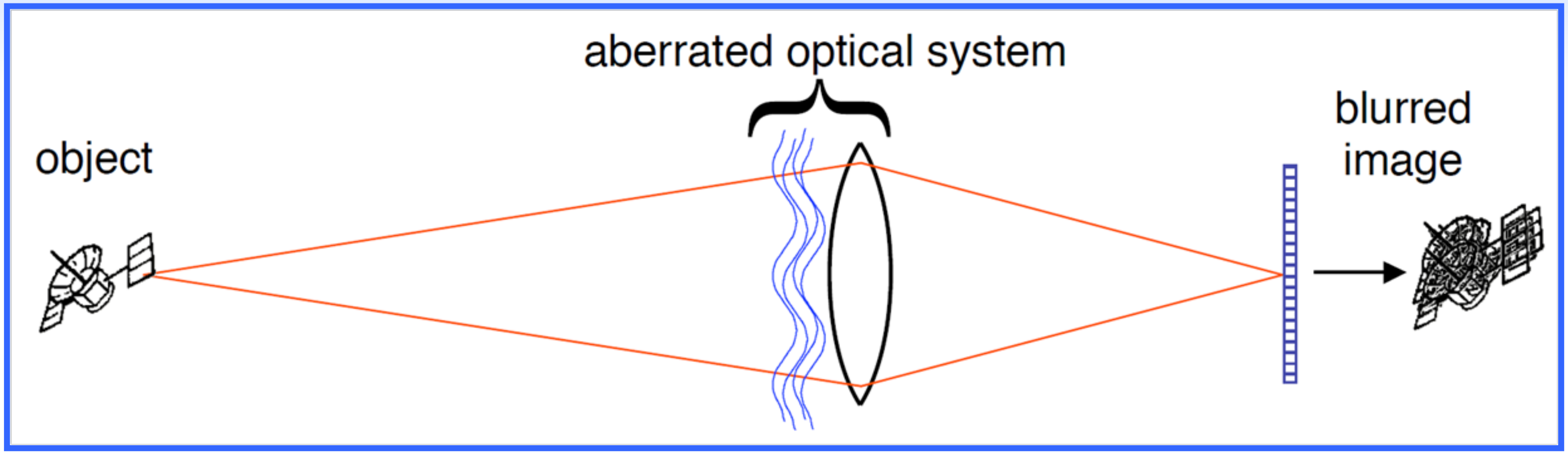
Mohammed H. Modi, Mourad Idir, *To be submitted Optics Communication (2009)*

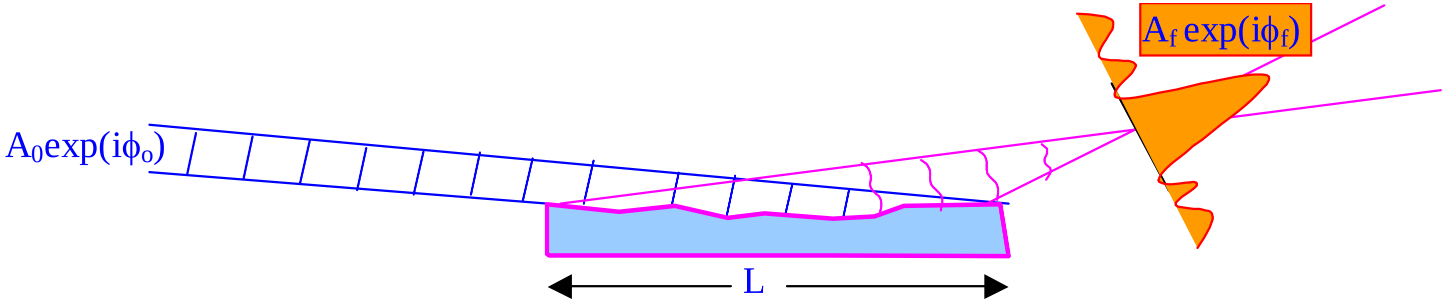
SMEXOS 2009

Simulation with LTP data



At wavelength metrology

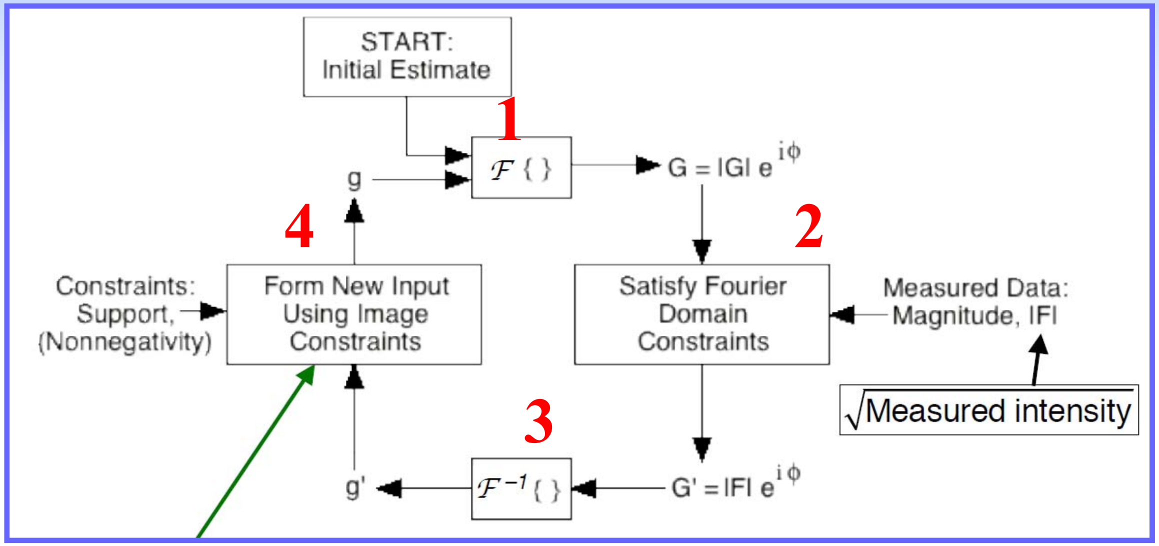




H. Yumoto, H. Mimura, S. Matsuyama, et al., **2006** *Rev. Sci. Instrum*. **77** 063712.
A Souvorov et al J. Synch. Radiation 9, 223-228, 2002
AG Peele et al , J. Elec. Spect. And Related Phenomena, 2005, vol 144-147, 1171-1173

Phase retrieval

J.R. Fienup, APPLIED OPTICS **21**, 2758 (1982).



The algorithm follows the four simple steps:

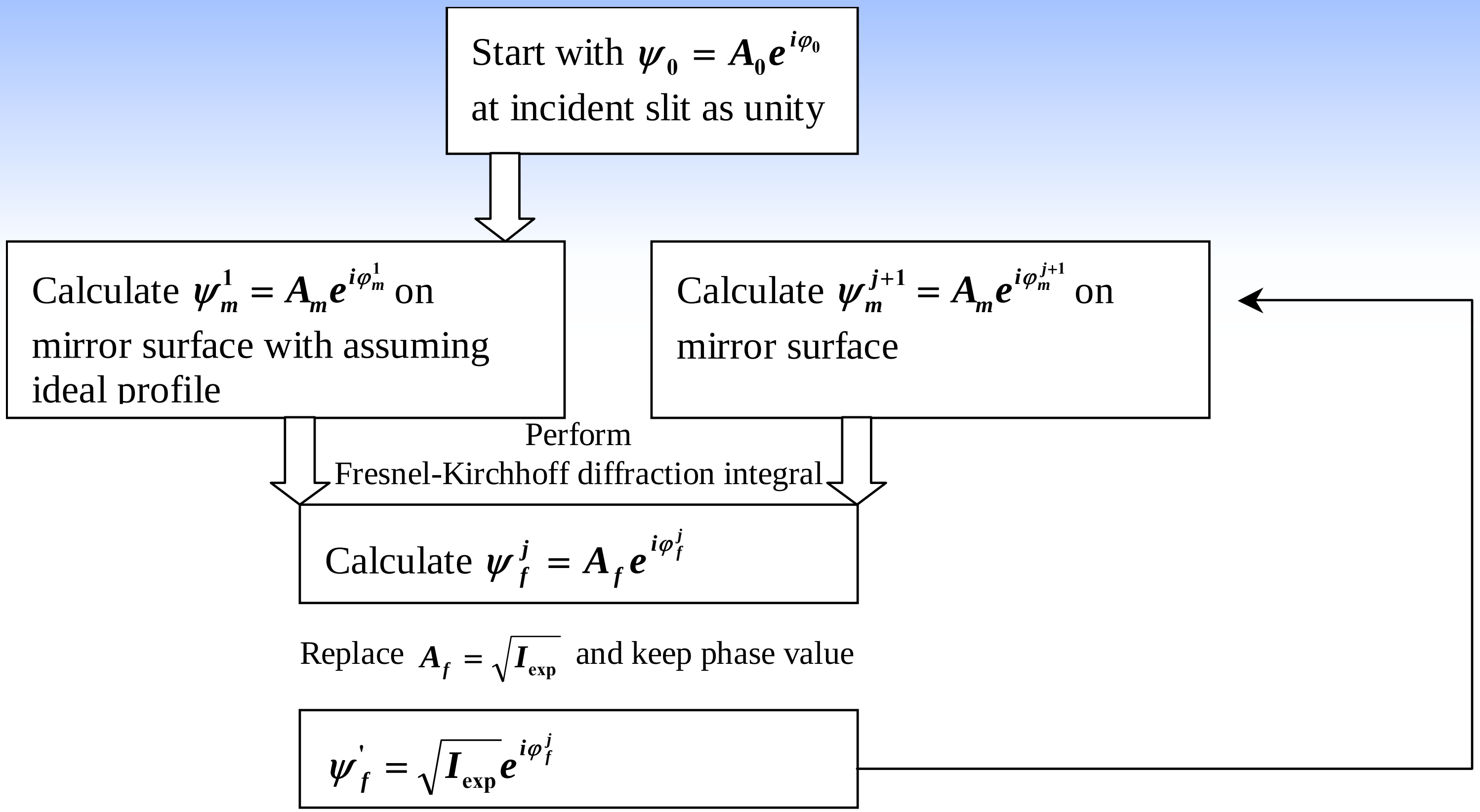
(1) Fourier transform an estimate of the object;

(2) replace the modulus of the resulting computed Fourier transform with the measured Fourier modulus to form an estimate of the Fourier transform

(3) inverse Fourier transform the estimate of the Fourier transform; and

(4) replace the modulus of the resulting computed image with the measured object modulus to form a new estimate of the object

Gerchberg-Saxton algorithm



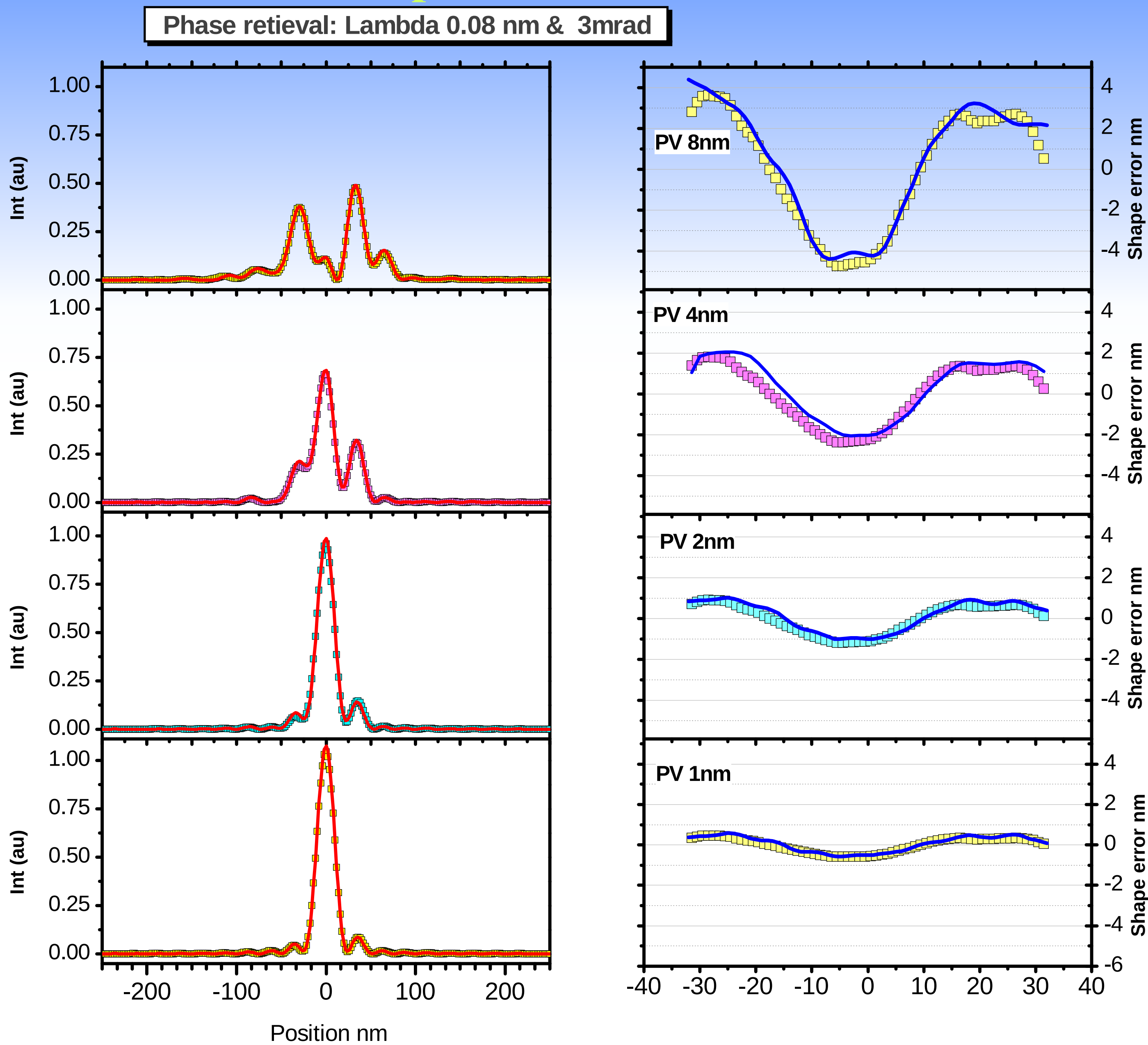
we start with some initial guess of mirror shape profile and calculate the intensity at focal plane using Fresnel-Kirchhoff integral method.

This calculated intensity is replaced by square root of the measured intensity data while keeping the calculated phase information.

This set of amplitude and phase value is used to back calculate the mirror profile by inverse calculation.

Performance of phase retrieval method

SMEXOS 2009



Mohammed H. Modi, Pascal Mercere, Mourad Idir, Conference Proceeding XRM 2008.

Summary

- A wave optics simulator using Fresnel-Kirchhoff diffraction integral has been developed.
- Both analytically calculated and measured surface topography data can be taken as an aberration source to outgoing wave field.
- Surface height fluctuations over wide frequency range in high, mid and low frequency band can be analyze to see their effect on focusing performances.
- The simulation results using real shape profile measured with LTP suggest that the shape error of $\lambda/4$ PV is tolerable to achieve diffraction limited performance
- With this tolerance limit it is desirable to remove shape error of very low frequency as 0.1 mm^{-1}, which otherwise will generate beam waist or satellite peaks.
- All other frequencies above this limit will not affect the focused beam profile but only caused a loss in intensity

Future

- **Implementation of 2D focusing system**
- **Implementation of other optical elements "and sources"**
  - **Zone Plate**
  - **Refractive lenses**
  - **Multilayer**
- **Looking for benchmarking calculations and collaborations**

Thank you