Proposed Adaptive Optics system for Vainu Bappu Telescope

Essential requirements of an adaptive optics system

Adaptive Optics is a real time wave front error measurement and correction system

The essential subsystems of an adaptive optics system are

- Wave-front sensing (WFS)
- Wave-front error computation
- Control of adaptive mirrors to compensate the measured wave front errors

Wave front sensing

The essential subsystems of a wave front sensor are:

Lenslet array or Shearing Interferometer to sample wave front (WF) at very short intervals dictated by ‘**seeing**’

Very fast image acquisition system to capture the WF

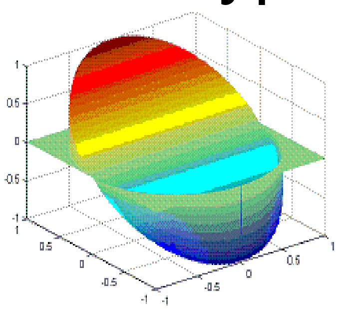
Computer system to do image processing and to calculate errors in the wave front

Wavefront errors can be classified into two broad categories

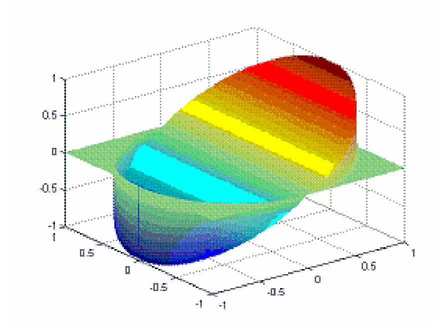
Tilt in the wave front

High frequency corrugation in the wavefront

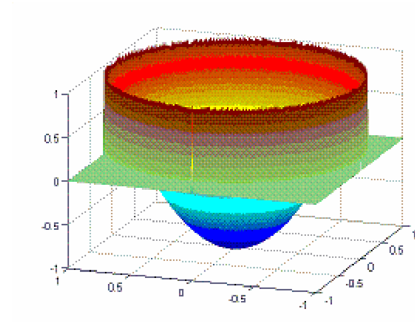
Typical aberration in the wavefront



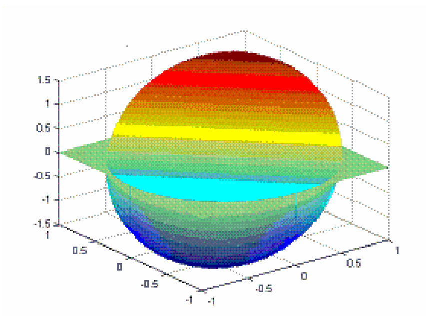
x-tilt



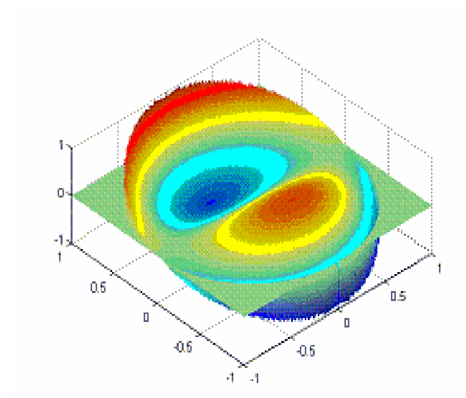
Y tilt



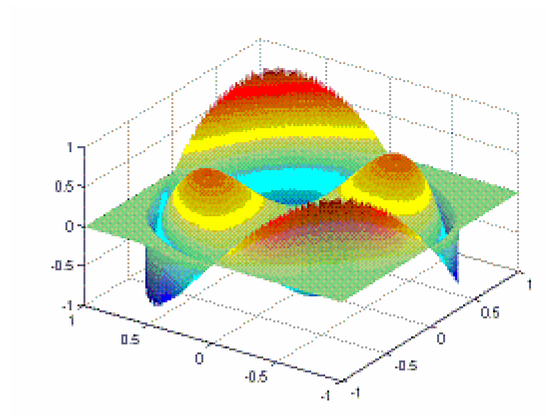
Defocus



X and Y tilt combined

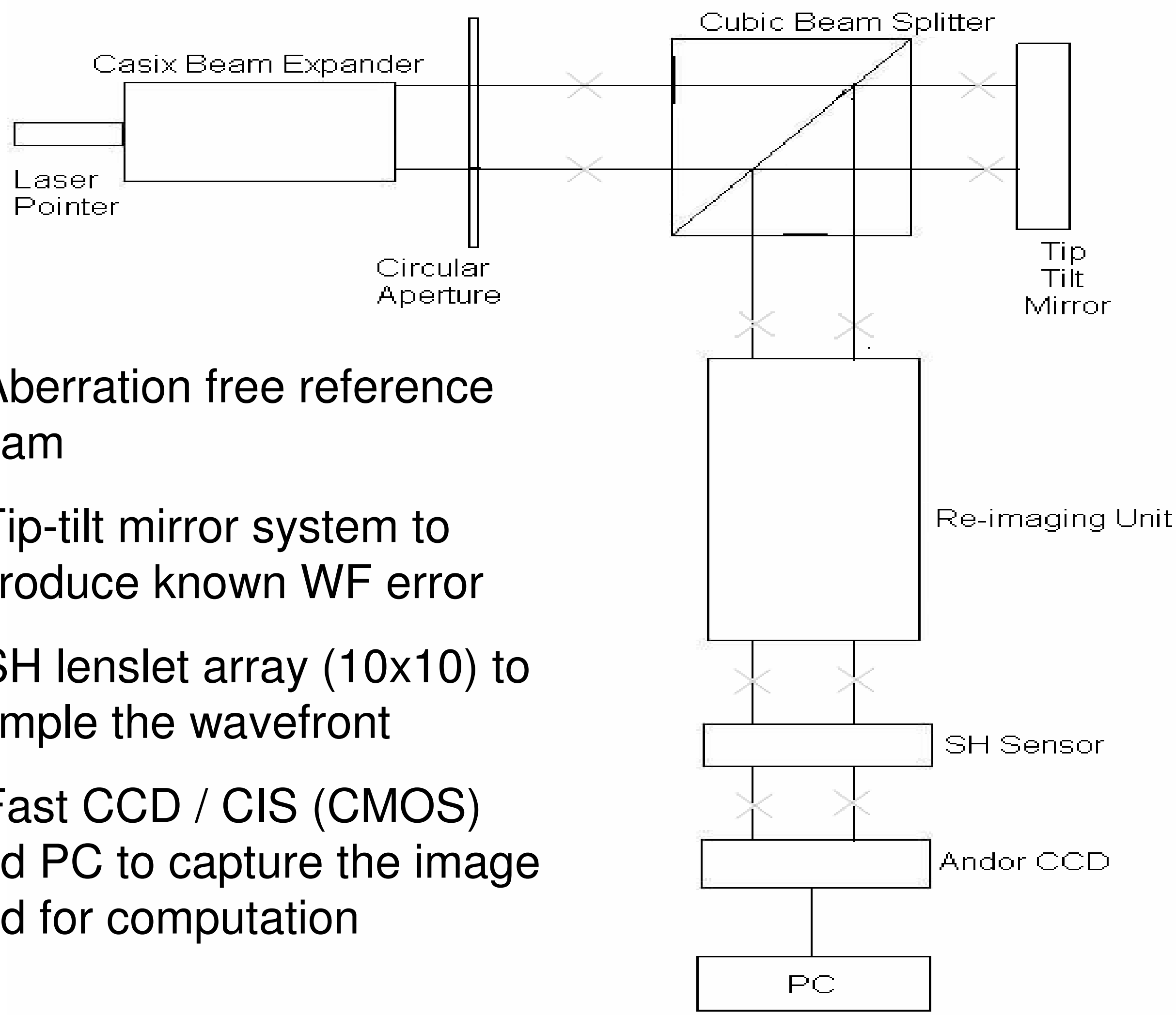


Coma along x axis



5th order Astigmatism

Lab Implementation and testing of SHWS



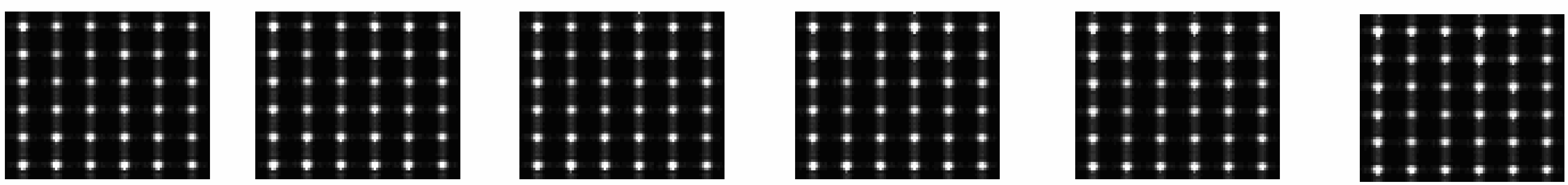
- Aberration free reference beam
- Tip-tilt mirror system to introduce known WF error
- SH lenslet array (10x10) to sample the wavefront
- Fast CCD / CIS (CMOS) and PC to capture the image and for computation

Shack Hartmann WF sensor implementation and results

Shack-Hartmann lenslet images with tilted wave fronts produced by a piezo-electric actuator based tip-tilt mirror

6 x 6 lenslet images (Lenslet size 300 μm)
Images captured by cooled EMCCD

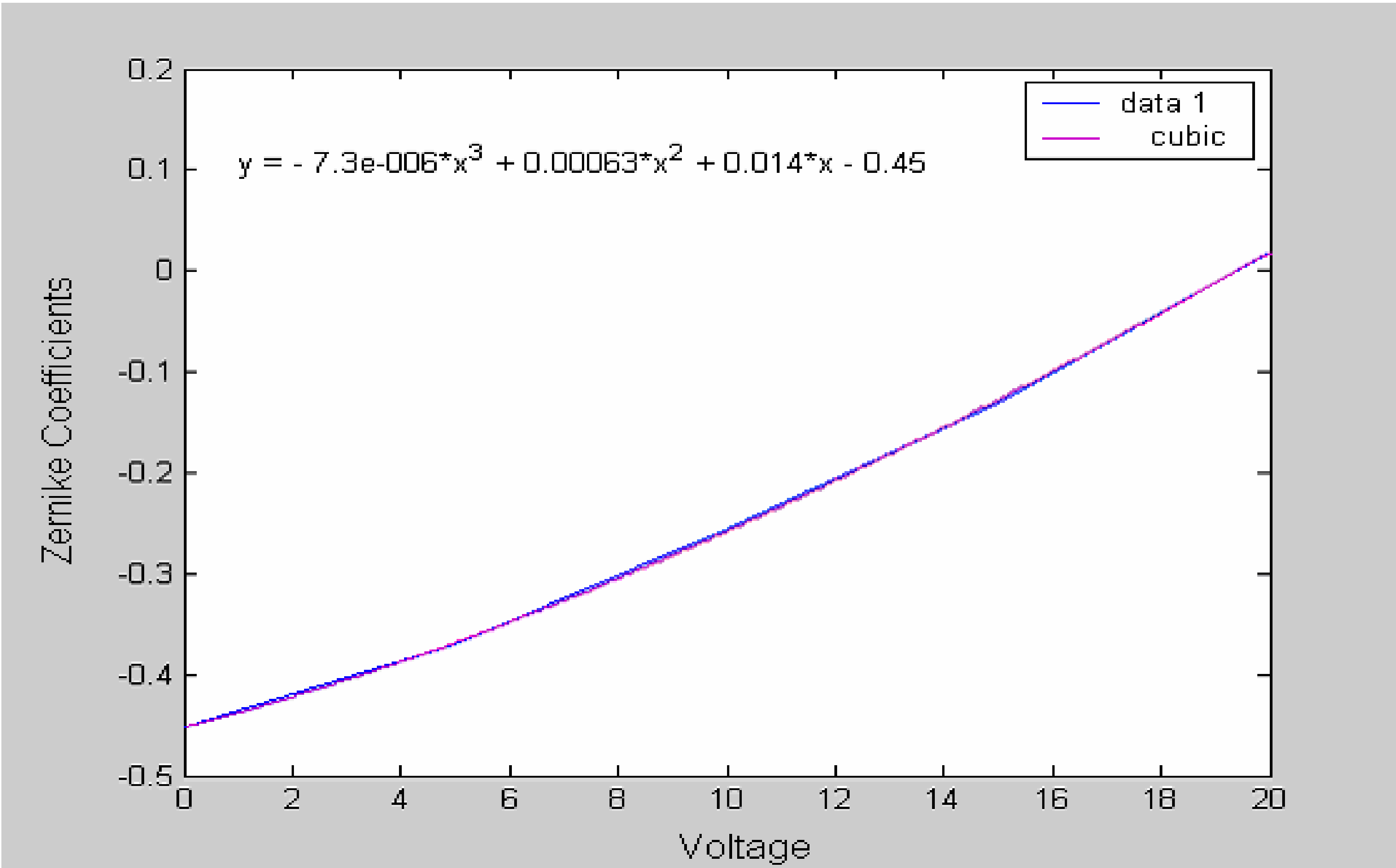
abc are three actuators of tip-tilt mirror
a0b0c0 is a reference image (plane wave front without errors) when 0 v is applied to all actuators
a0b1c1 is a tilted wavefront by applying 1 volt to b and c actuator



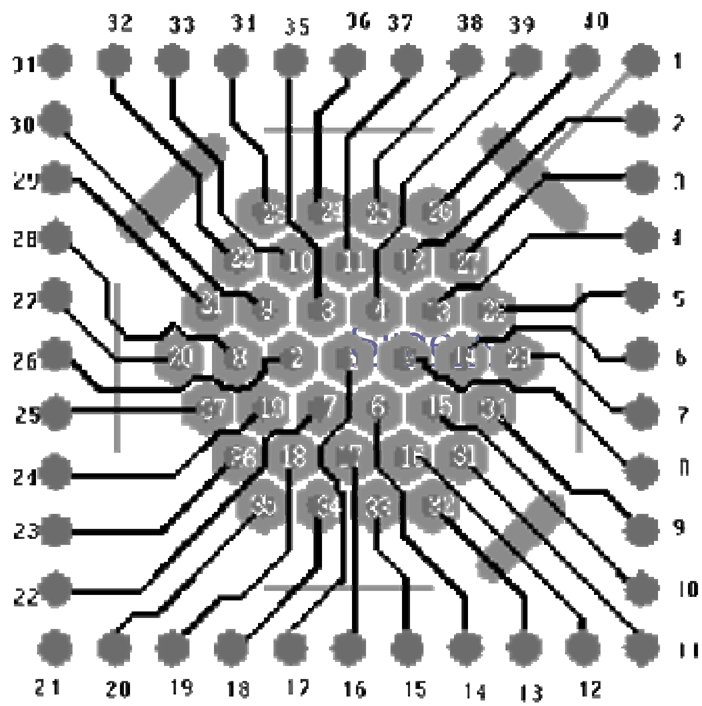
a0b0c0 a0b1c1 a0b5c5 a0b10c10 a0b15c15 a0b20c20

Zernike Coefficient	a0b5c5	a0b10c10	a0b15c15	a0b20c20
1 Tilt about X axis	-0.01948	-0.061855	-0.08133	-0.08879
2 Tilt about Y axis	-0.09832	-0.16985	-0.24516	-0.35071
3 Astigmat. +/-45deg	-0.00905	-0.02567	0.0085664	0.026946
4 Defocus	-0.01587	-0.035064	-0.024667	-0.04001
5 Astigmat. 0,90 deg	0.011256	-0.016897	-0.028187	0.015153
6 Trefoil x axis	-0.00383	-0.01878	-0.026595	-0.00912
7 3rd order Coma x	0.002477	-0.002104	0.00436	0.007624
8 3rd order Coma y	-0.0069	-0.013929	-0.012244	-0.01787

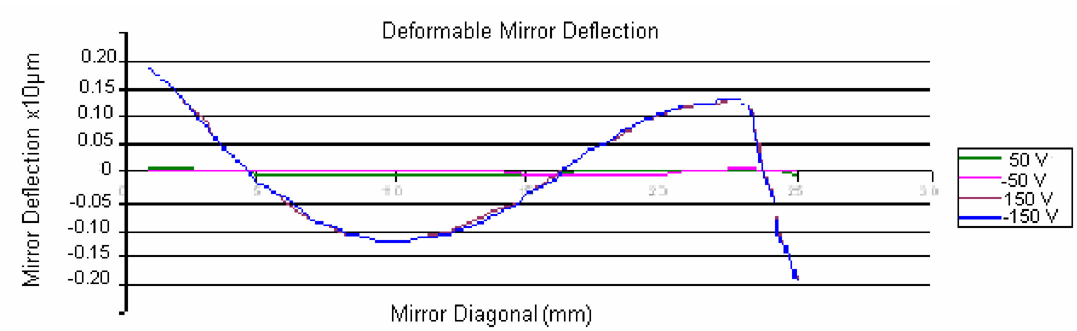
Measured tilt Vs Voltage

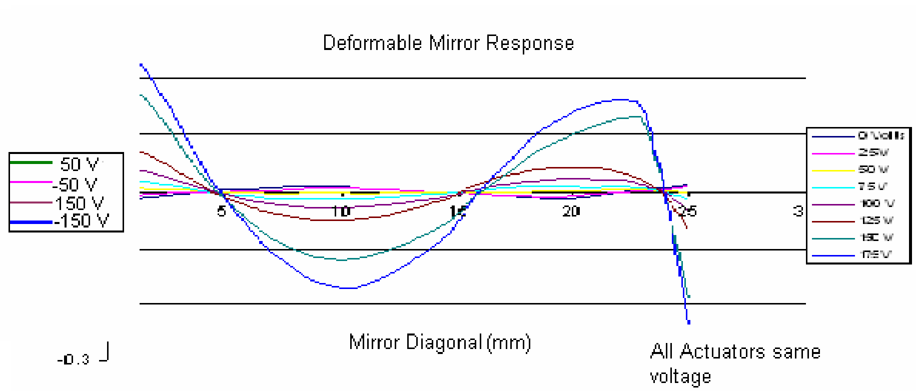


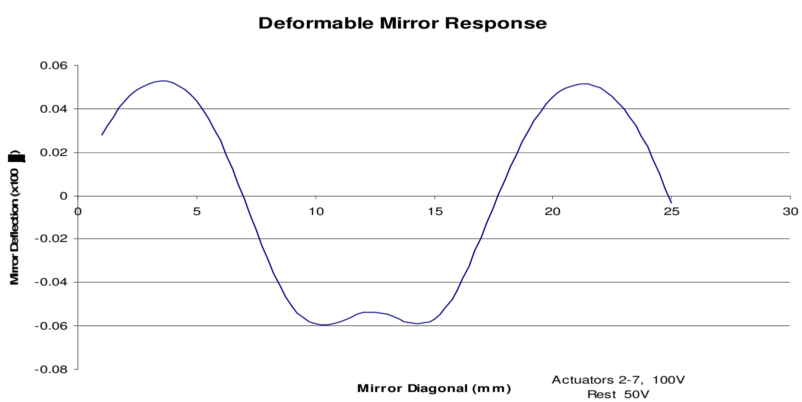
Layout of 37 actuator deformable mirror



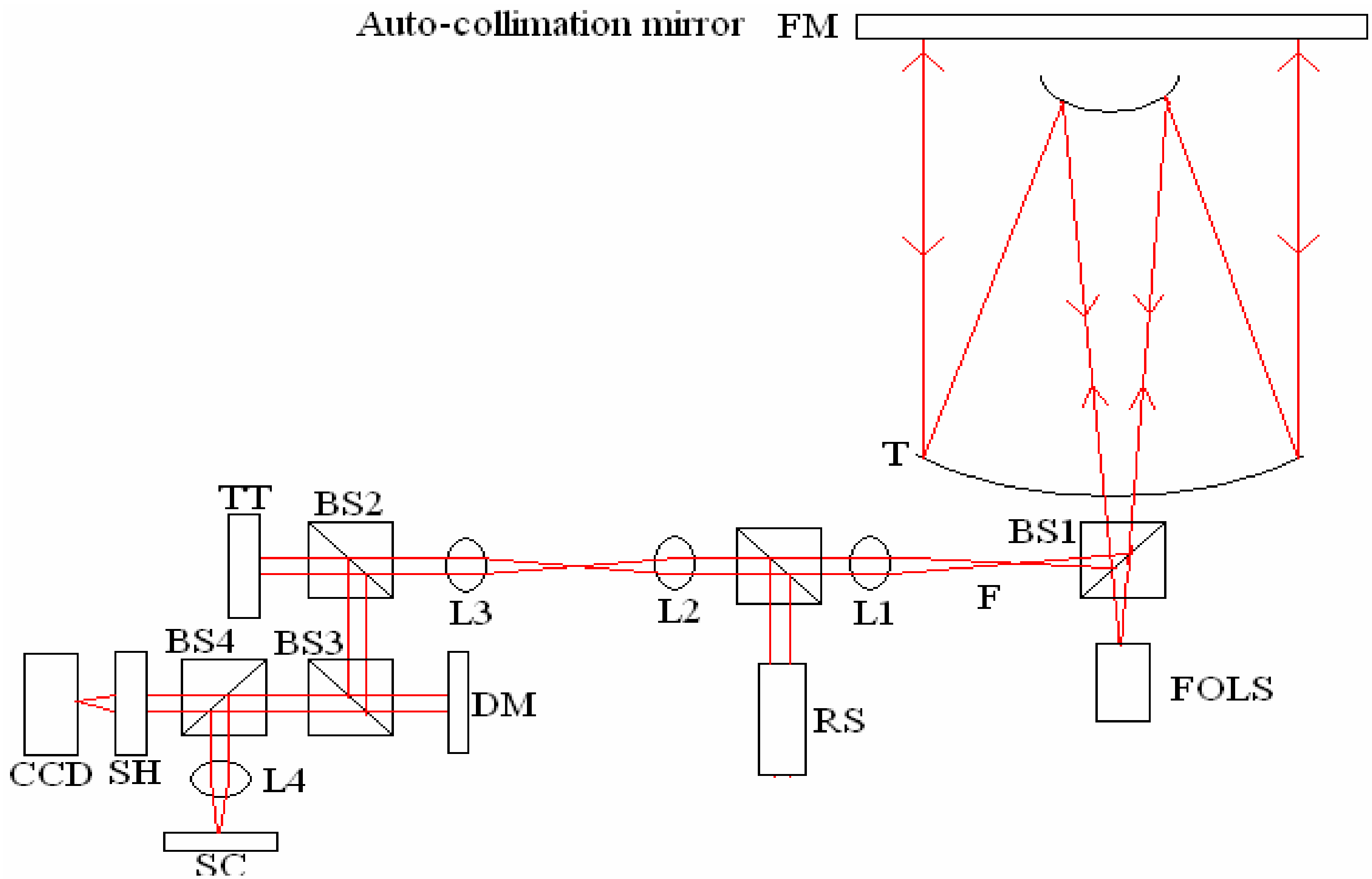
MEMS Based Adaptive Mirror characterization with Long Trace Profilometer



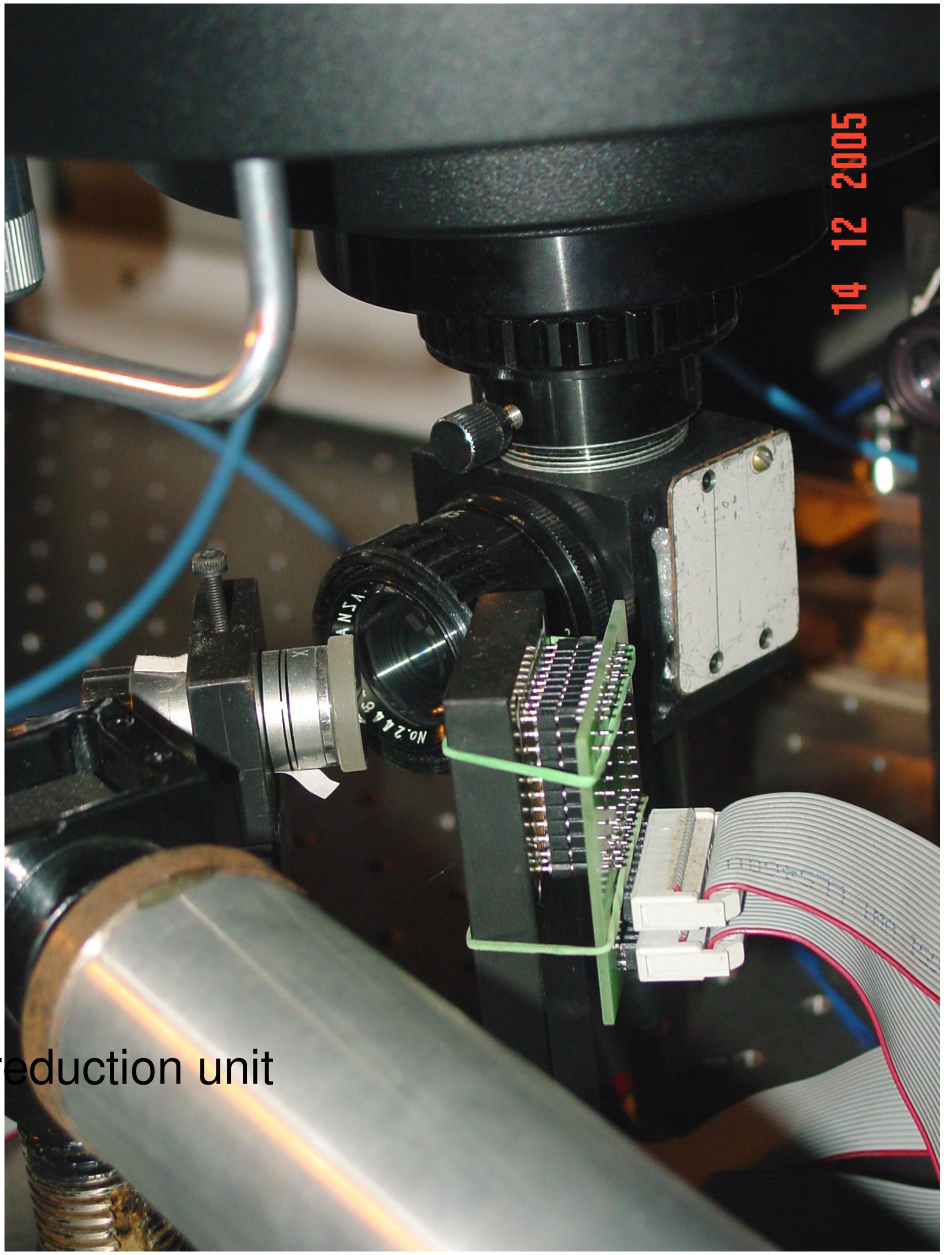




Optical layout of wave front measurement and correction system



Photograph of experimental setup in the lab



Telescope in autocollimation mode

Fibre optic light source with pin-hole

Tip-tilt mirror

Adaptive mirror

Beam reduction unit

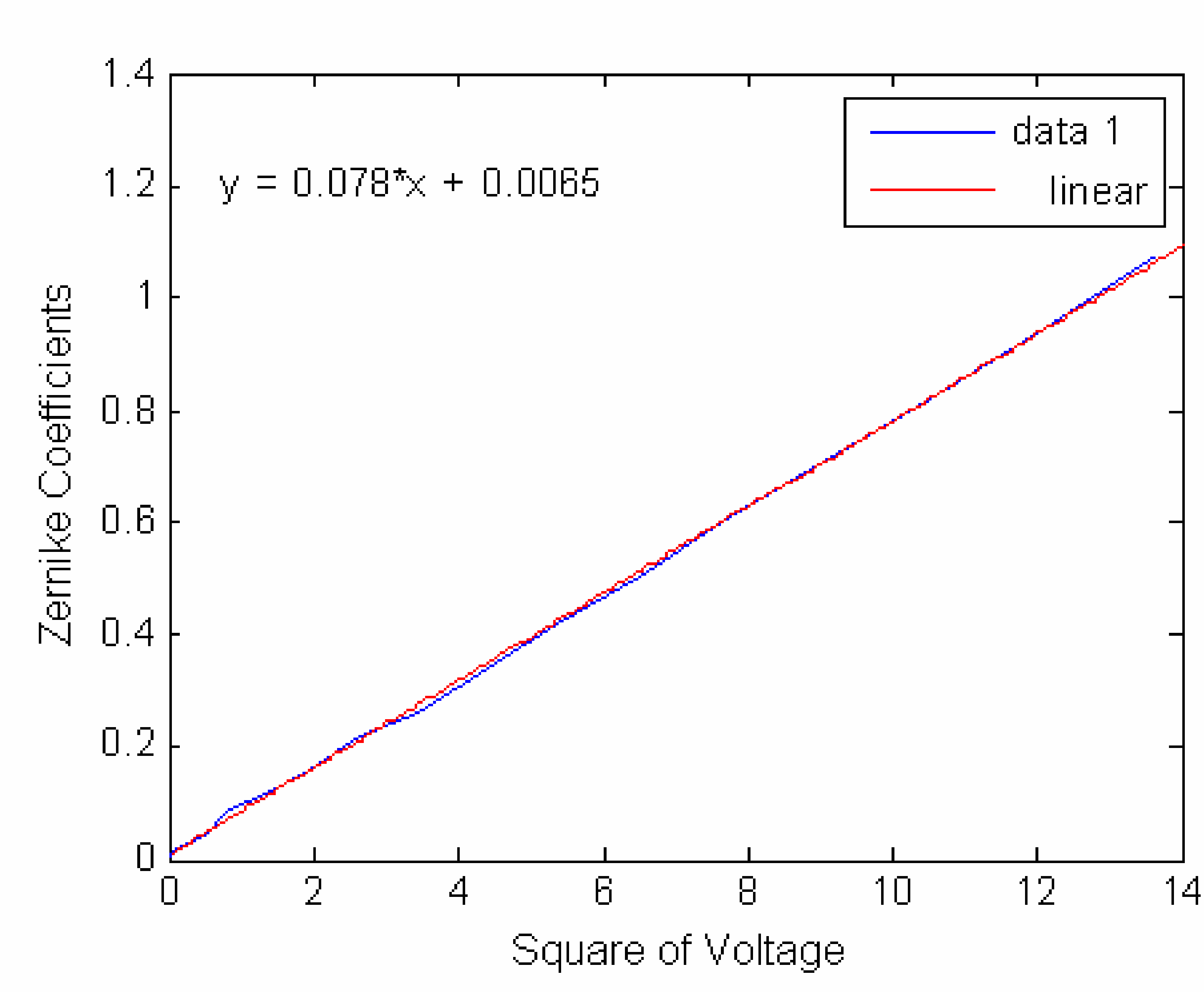
Lenslet with CCD

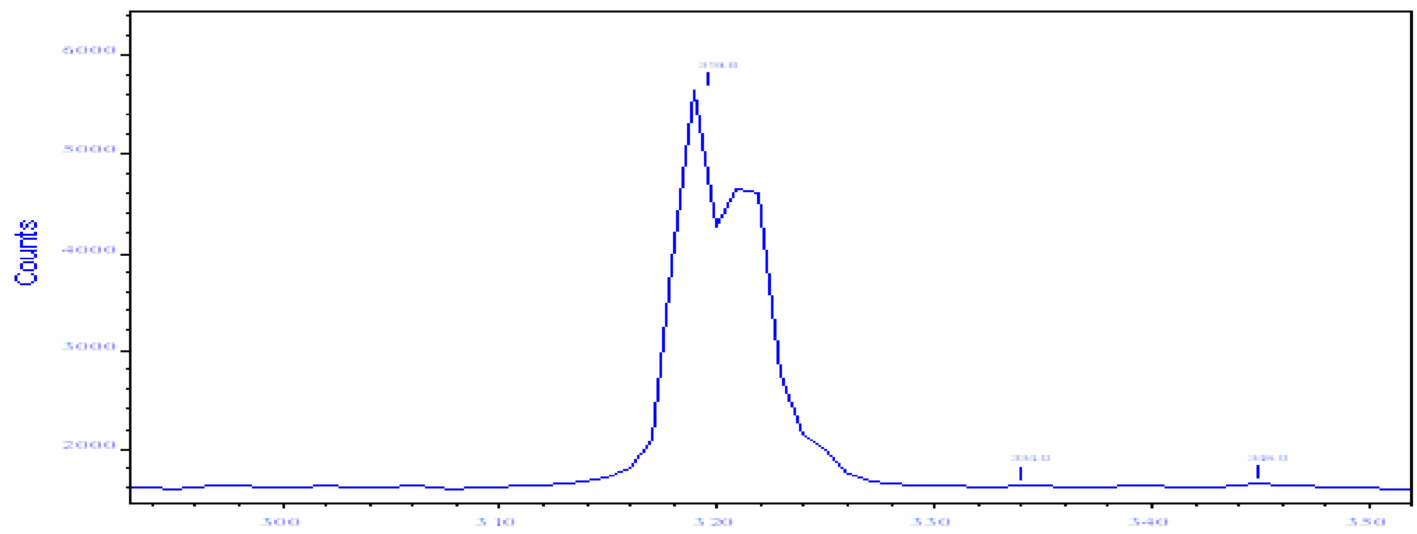
Lab Experiments with AO Mirror

DAC V	Z1 Y tilt	Z2 X tilt	Z3 Astigmat	Z4 Defocus	Z5 Astig (90)
0.237	-0.0707	0.0775	0.0021	-0.0016	0.0045
0.469	-0.0699	0.0648	0.0060	0.00057	0.0044
0.932	-0.0912		0.0026	0.0085	0.0055
1.005				0.0131	
1.164				0.0191	
1.236				0.0205	
1.395				0.0281	
1.858				0.0531	
2.321				0.0816	
2.785				0.1257	
3.248				0.1277	
3.697				0.1301	

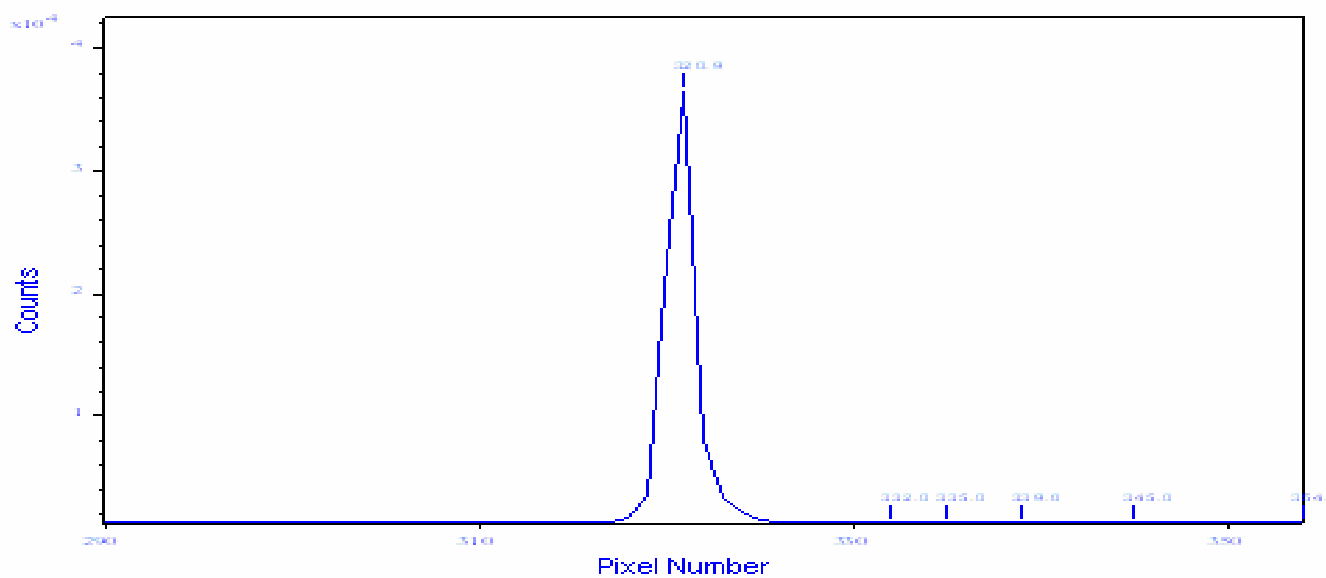
DAC V	Z6 Triang. Astig	Z7 3rd coma	Z8 Y Coma	Z9 Astig
0.237	0.000037	0.0012	0.0021	0.0001
0.469	0.000259	0.0013	0.0016	-0.0011
0.932	0.0017	0.0008	0.0021	0.00001

Relationship between Z4 and square of applied voltage





(a)



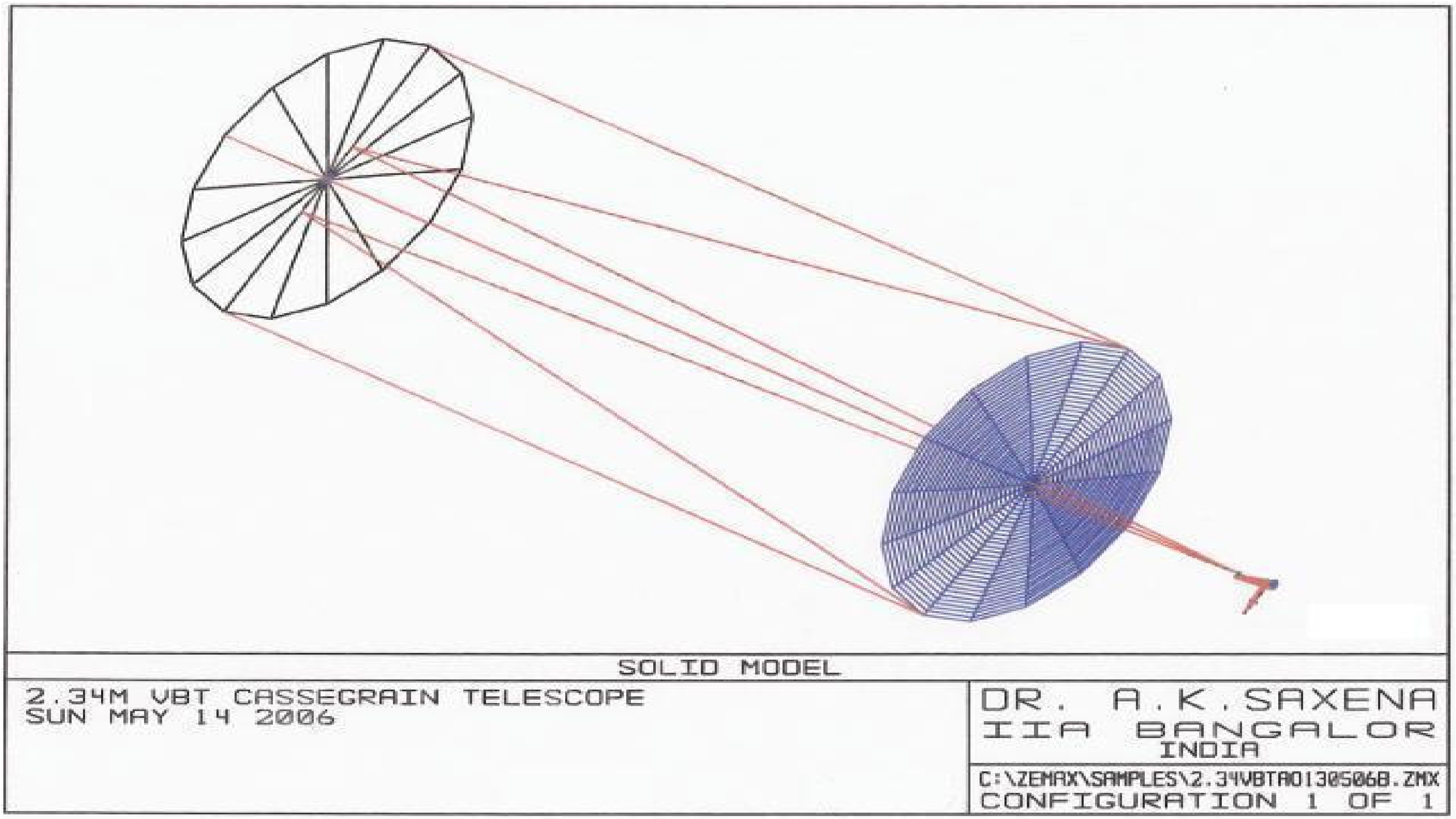
(b)

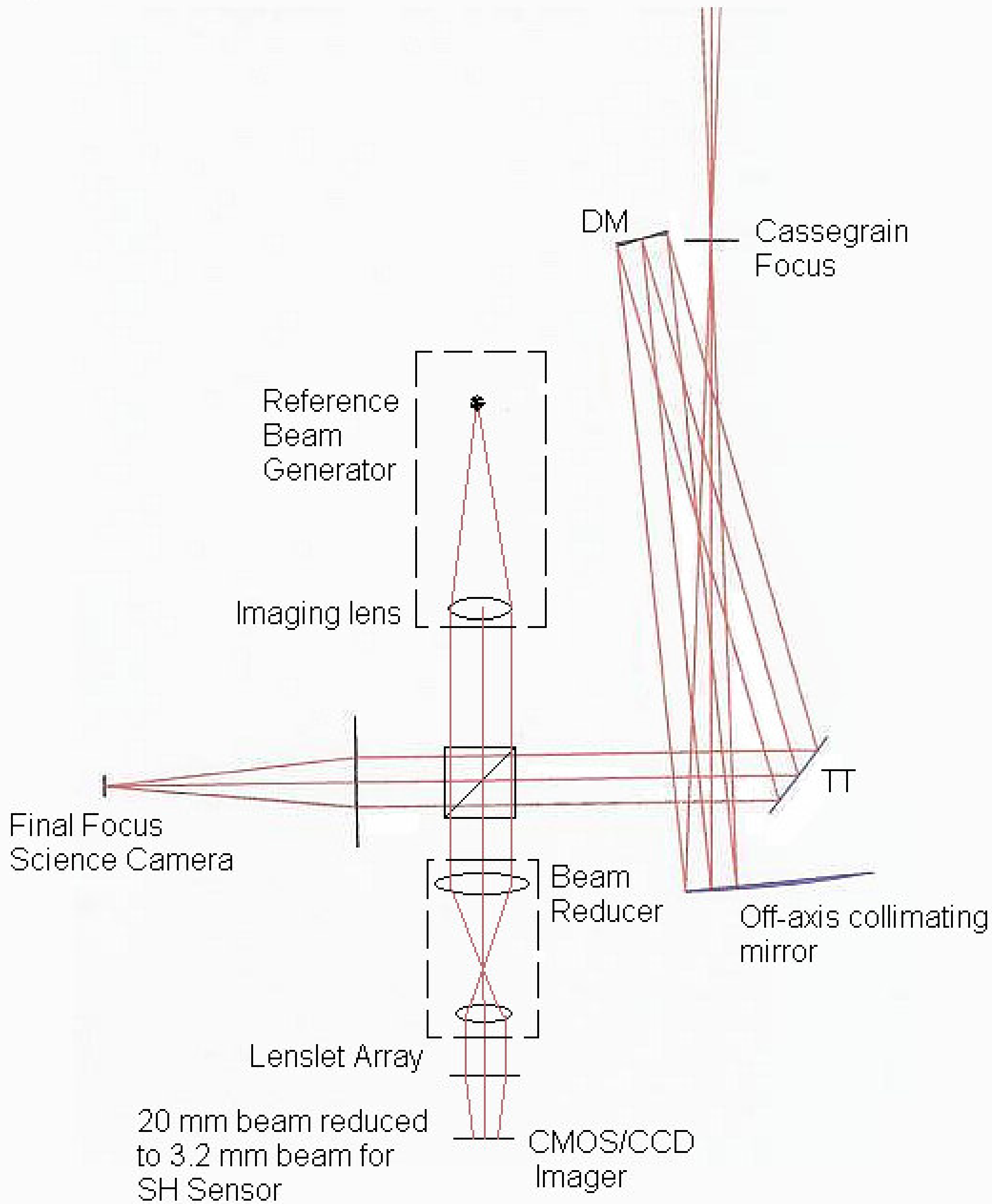
VBT Optical Parameters

The important parameters of 2.3 m VBT are given below

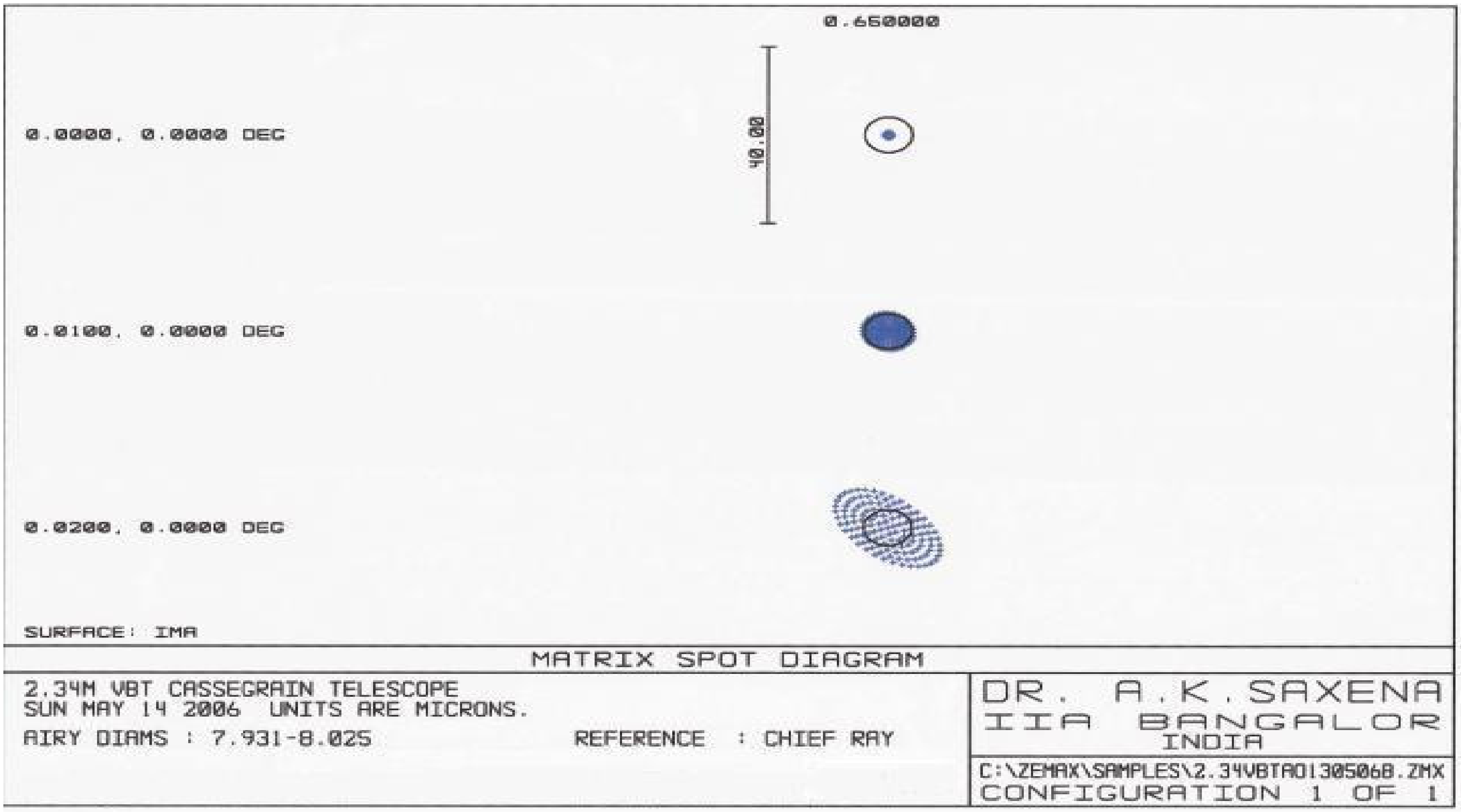
■ Diameter	:2360 mm
■ Clear aperture	: 2320 mm
■ Material	: Zerodur
■ Density	: 2.52 gm / cc
■ Cassegrain hole dia	: 720 mm
■ Central obscuration	:0.3
■ Prime focus F ratio	:3.237
■ Prime image scale	:27.463 “ / mm
■ Cassegarin focus F ratio	: 12.97
■ Aperture of Secondary mirror	: 630 mm
■ Cassegrain image scale	: 6.854 “ / mm

Solid Model of VBT




DM
Cassegrain Focus
Reference Beam Generator
Imaging lens
TT
Final Focus Science Camera
Beam Reducer
Off-axis collimating mirror
Lenslet Array
20 mm beam reduced to 3.2 mm beam for SH Sensor
CMOS/CCD Imager

Spot Diagram



Worst Case Requirement

- Seeing parameter (Fried's) measured at VBT using speckle interferometry = 75 mm to 125 mm
- Number of lenslet array required = $(2320 / 75)^2$ = 957
- Lenslet geometry = 31 * 31 = 961
- Number of actuators required for deformable mirror =957
- Bandwidth required of deformable mirror = 500 Hz
- Cycle time required for control = 10 msec

Typical AO system design

- No of actuators available in a low cost deformable mirror = 59
- No of lenslet array required = 100 (10 x 10) (60 % for mirror control)
- No. of pixels for subaperture = 10 x 10
- CMOS imager region of interest = 100 x 100 pixels
- No. of frames obtained for 128 by 128 pixel region = 50 frames / sec
- Minimum time required for one loop 20 msec. If this rate is too high, reduce the no.of lenslet points or go for high frame rate camera
- If 24 μm pixel is chose, CMOS pixel area covered = 3.2 mm x 3.2 mm
- In-coming collomated beam diameter = 20 mm
- Choose an adaptive mirror based on affordability and avilability
- Use a beam reduction unit 20 mm to 3.5 mm dia.

Typical Parameters of AO Mirror

- Membrane mirror : 5 0. µm silicon membrane coated with nitride and 0.2 µm Aluminum
- Dia. of mirror : 15 mm
- Usable dia. : 10 mm
- Actuator : Hexagon shaped PCB pad
- Spacing of actuator : 1.75 mm center to center
- Distribution : Actuators are in 3 concentric rings around a central
- Actuator with 6, 12 and 18 actuators in the rings
- Max. deflection : 5 µm

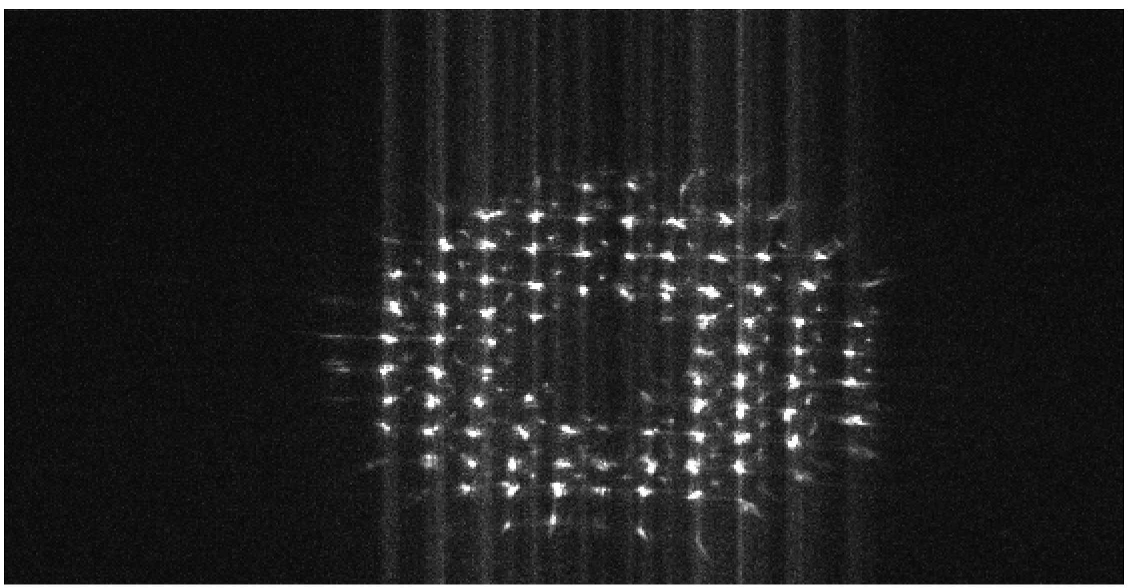
- **Piezo electric actuator based mirrors are available with large diameter with $2000 per actuator. For 37 actuators, cost is about $80000**
- Small size piezo mirrors are cheaper

MMDM of Boston Univ. Mirror

■ Membrane size	: 2 mm x 2 mm x 2 μm
■ Active mirror area	: 1 cm2
■ Number of actuators	: 100
■ Actuator size	: 300 μm x 300 μm
■ Actuation	: Integrated electrostatic
■ Package size	: 10 cm3
■ Power consumption	: 0.2 W / channel
■ Actuator spacing	: 0.3 mm
■ Actuator stroke	: 2 μm
■ Actuator repeatability	: 10 nm
■ Hysteresis	: 0%
■ Surface roughness	: 50 nm (root mean square)
■ Bandwidth in air	: 7 kHz
■ Maximum deflection	: 1.9 μm at 241 V

Current activities for AO implementation in VBT

- Shack Hartmann lenslet array images are captured using Andor EMCCD on 20 Feb. 2007
- The following points may be noted
- Image is rectangular, this is because of rectangular pixel of the CCD
- Spider positions distorts the lenslet images
- Better CCD camera, adaptive mirror and tip tilt mirror are being searched
- For fast processing of data and control, high speed multi core processors and related hardware is being probed



Current activities…

- A mechanical breadboard is fabricated to mount reference beam and other components at the cass focus of VBT
- The breadboard is being assembled and tested with the Cass focus simulator abricated earlier
- Next experiments will be conducted at VBT during May 07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