Building an Affordable 4m Class Optical-NIR Telescope

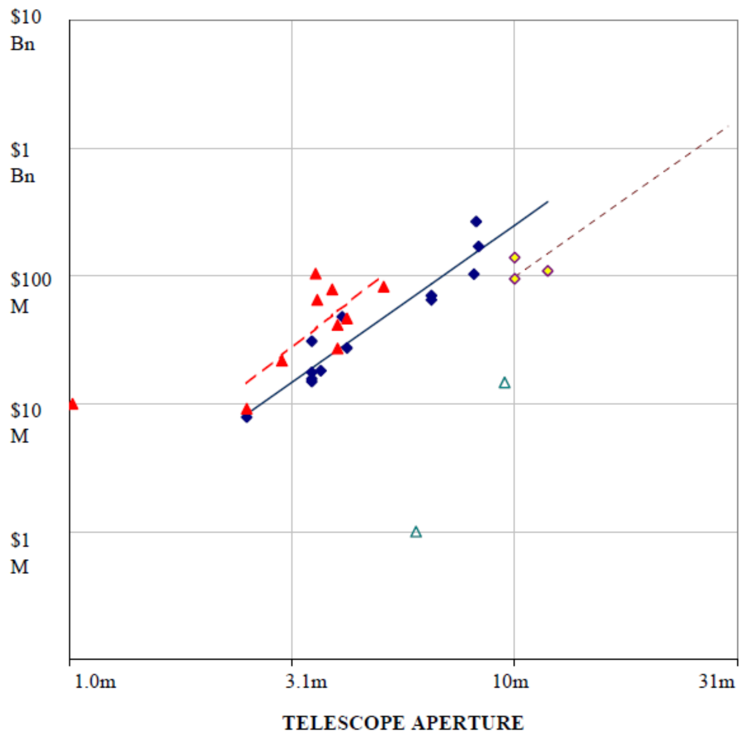
Padmakar Parihar

Indian Institute of Astrophysics, Bangalore India

6th Madanak User Meeting: 01-03 November 2021

Outline

- Cost of large telescopes
- Segmented Mirror Technology
- Conceptual Opto-Mechanical Design of 4m telescope
- Cost drivers and way to reduce the cost
- A Four meter class telescope for MAO



Costing ground based telescopes

Cost Scaling laws:

Cost $= K D^{2.8}$ (for classical telescopes)

Cost $= K D^{1.7}$ (for segmented telescopes)

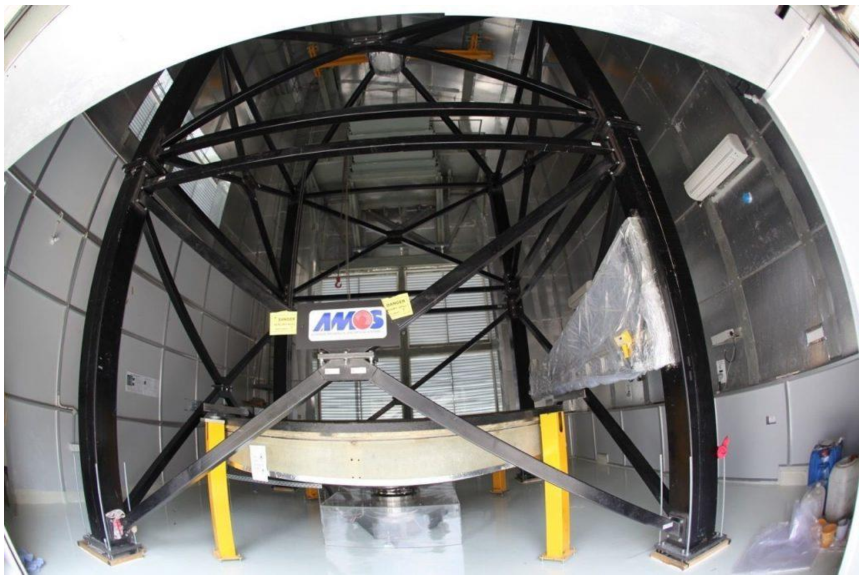
Cost $= K M^{3}$

$$C = C_P n^{-1} L^{0.5} + C_F n^{-0.32} L^{2} + C_M n^{-0.1} L^{3}$$

Telescope	Organization	Size(m)	Cost ($m)	Year	Cost (2000)	Mass
AAT	AAO	3.9	22.8	1973	78.8	-
ESO 3.6m	ESO	3.6	41.7	1977	104.3	240
CFHT	CFHT Cons	3.6	30.0	1979	65.1	-
WHT	Obs. Cons	4.2	21.5	1979	46.6	210
NTT	ESS	3.5	13.0	1988	17.6	110
ARC	Apache Point Obs.	3.5	11.0	1988	14.9	-
WIYN	WIYN Cons	3.5	14.0	1994	15.7	-
AEOS	USAF	3.7	18.2	2000	18.2	75
SOAR	CTIO	4.2	28.0	2001	27.4	-
DOT	ARIES	3.6	18.0	2016	18.0	150
SEIMEI	Kyoto Univ	3.8	15.0	2018	15.0	18

Kaler et al (1997), Belle et al (2004), Jeffrey et al (2008)

Costing ground based telescopes



Costing the Ground based Telescopes

Many segments and few dollars:

SALT solutions for ELTs ?

D. A. H. Buckley[1a], J. G. Meiring[2a], J. Swiegers[3a] and G. Swart[4a],

Southern African Large Telescope Foundation, Observatory, Cape Town, South Africa

ABSTRACT

The Southern African Large Telescope (SALT) is a little over 18 months away from completion (in early 2005). It is based on the innovative tilted-Arecibo optical analog, first pioneered by the Hobby-Eberly Telecope (HET). By the end of 2003, all major subsystems, including the verification instrument, will be in place and the commissioning of them begun. Tests of a 7-segment subset of the mirror array, including the Shack-Hartmann alignment instrument, the mirror actuators, capacitive edge sensors and active control system has recently started. The first engineering on-sky tests involving the complete light path, from object to detector, have begun.

System	Budgeted amount	Cost at Completion	Over/under spend
Facility building	$2.340M	$1.944M	-16.92%
Telescope structure	$1.040M	$0.574M	-44.81%
Dome	$0.868M	$0.590M	-32.03%
Tracker and payload	$2.391M	$3.018M	+30.14%
Primary mirror system	$5.927M	$6.006M	+1.34%
Telescope control system	$0.589M	$0.505M	-14.22%
Engineering	$0.360M	$0.388M	+7.78%
Science instruments*	$1.349M	$1.553M	+15.12%
Project Management	$3.290M	$3.896M	+18.42%
Contingency risk**	$1.647M	$1.501M	-8.86%
Foreign exchange losses	$0.000M	$0.465M	
SALT Total	*$19.728M*	*$20.440M*	*+3.60%*

N.B. * cash only component of instrument budget, not including in-kind/non-cash components
** amount used to date. Expect to use more before completion of project.

Table 4: Costs of SALT systems compared to originally budgeted amounts

Fast Development & Lesser cost

We should aim to have inexpensive telescope without compromising with the performances.

GTC was 160m USD whereas SLAT/HET are just 25m USD telescope

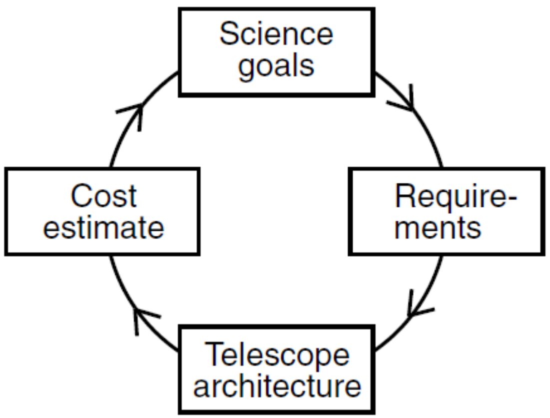
As much as possible we should use existing technology /design/facilities , which will not only reduce the cost but also save lot of construction time.

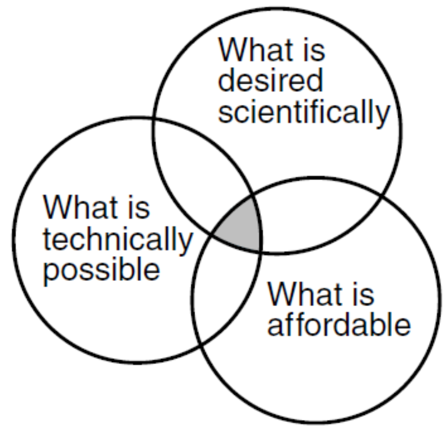
We should aim to have telescope of 4m class by 5-6m USD and 10m class within 50m USD.

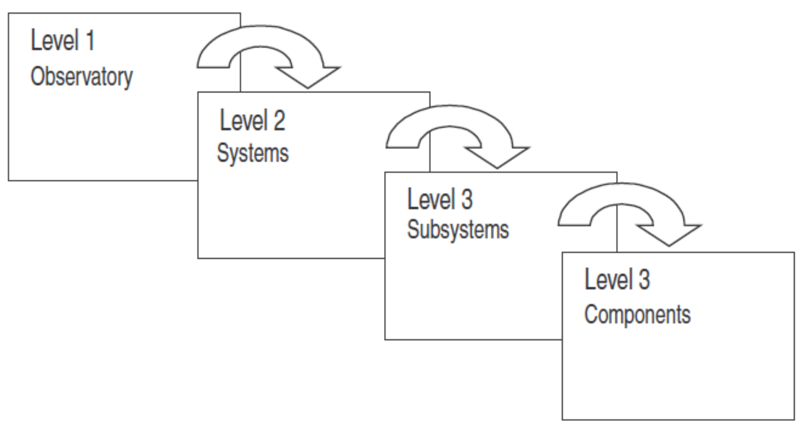
Requirement and Design

Based on top level science requirement one need to design telescope opto-mechanical system, control and the instruments.

It’s an iterative process and takes quite a lot of time to come up with the base line design of the telescope





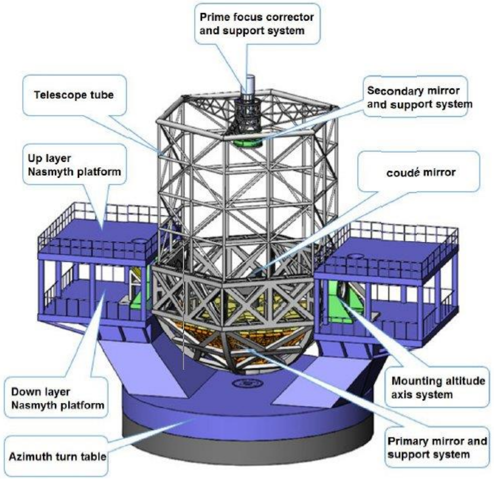


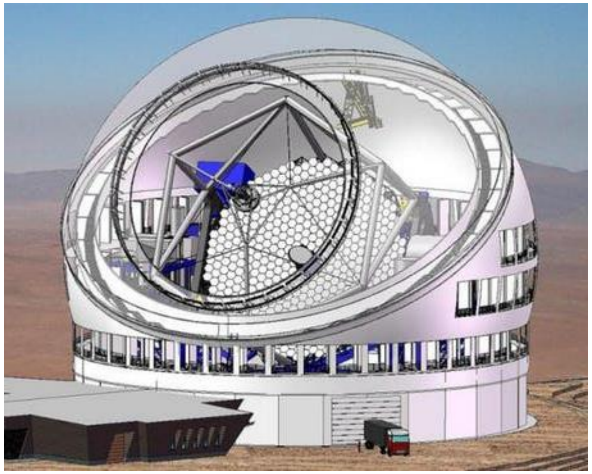
Segmented Mirror: A technology for large telescopes

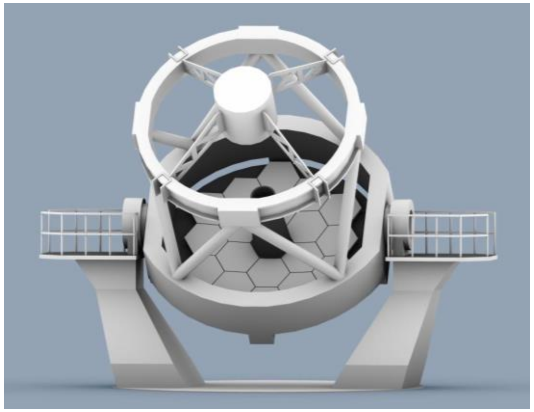
Mid size (4-5m)

Large size (10-12m)

Mega size (30-40m)



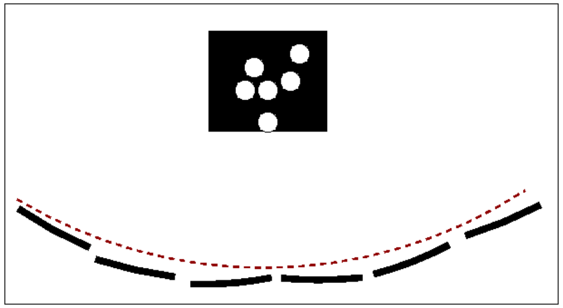




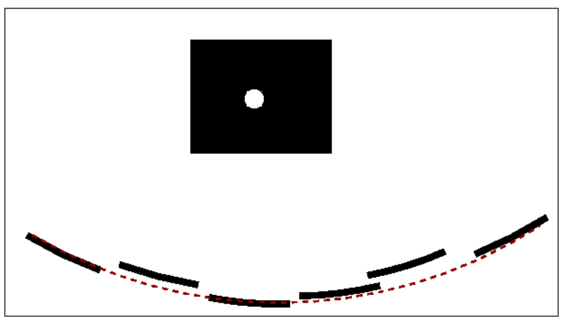
Segmented Mirror: A technology for large telescopes

Seeing limited telescope requires only alignment.
To achieve diffraction limited image one need to phase the mirror segments.

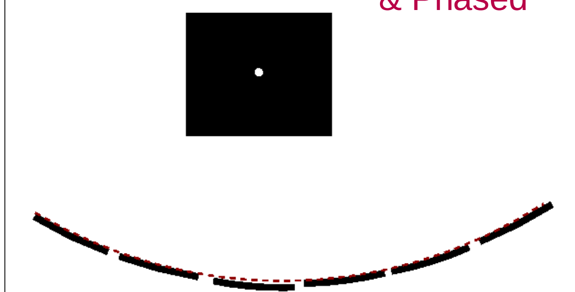
No alignment & Phased

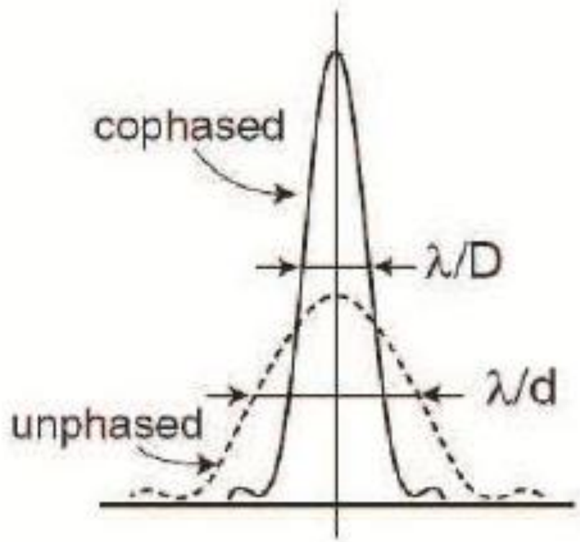


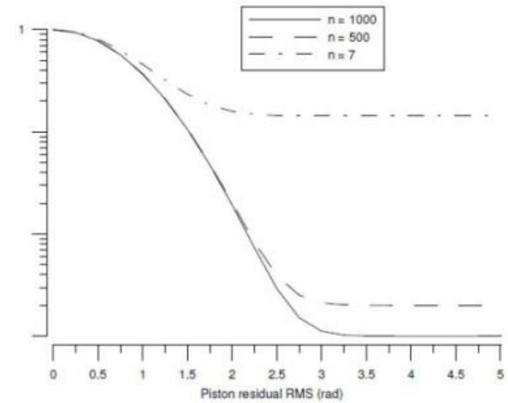
Aligned but not Phased



Aligned & Phased





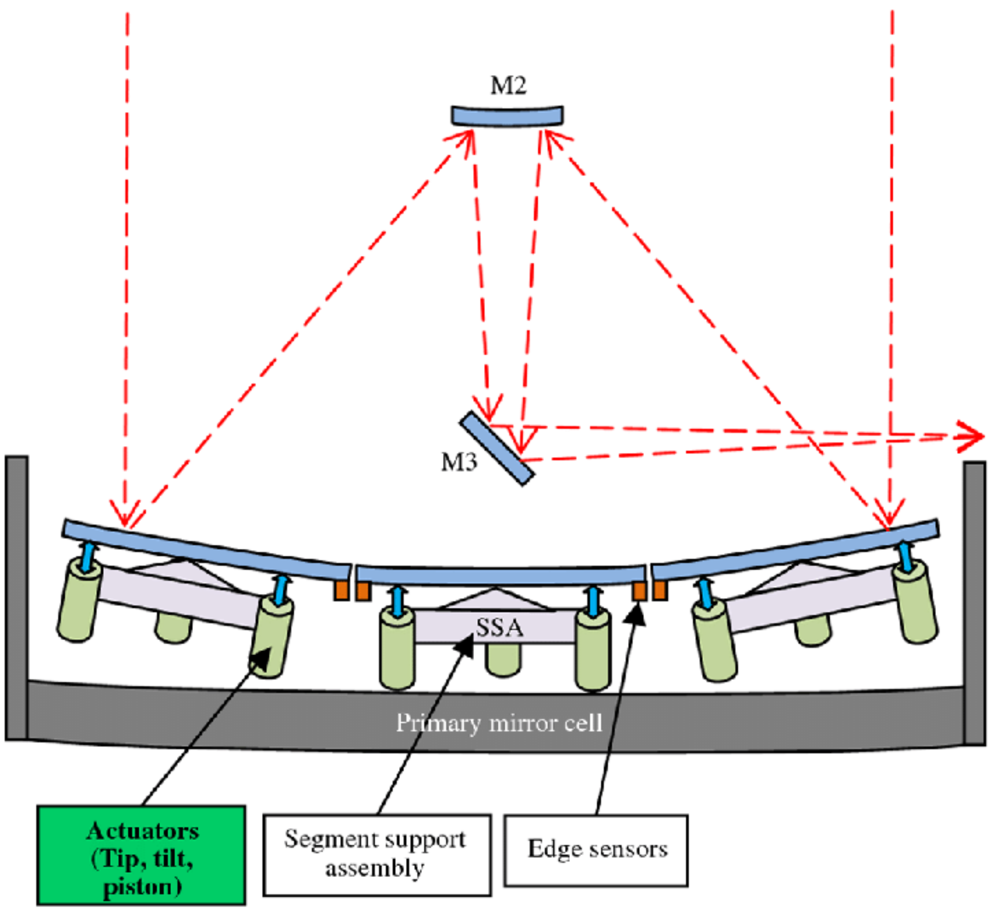


$$SR = \frac{1 + e^{-\sigma^2}(n-1)}{n}$$

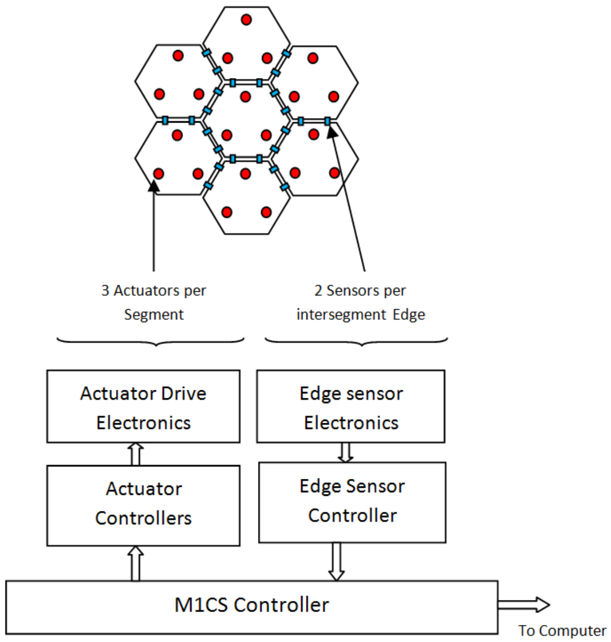
Alignment: Primarily done using Shak-Hartman

Phasing: SH, Pyramid Sensor, Interferometers

Primary Mirror Control



M1CS Architecture

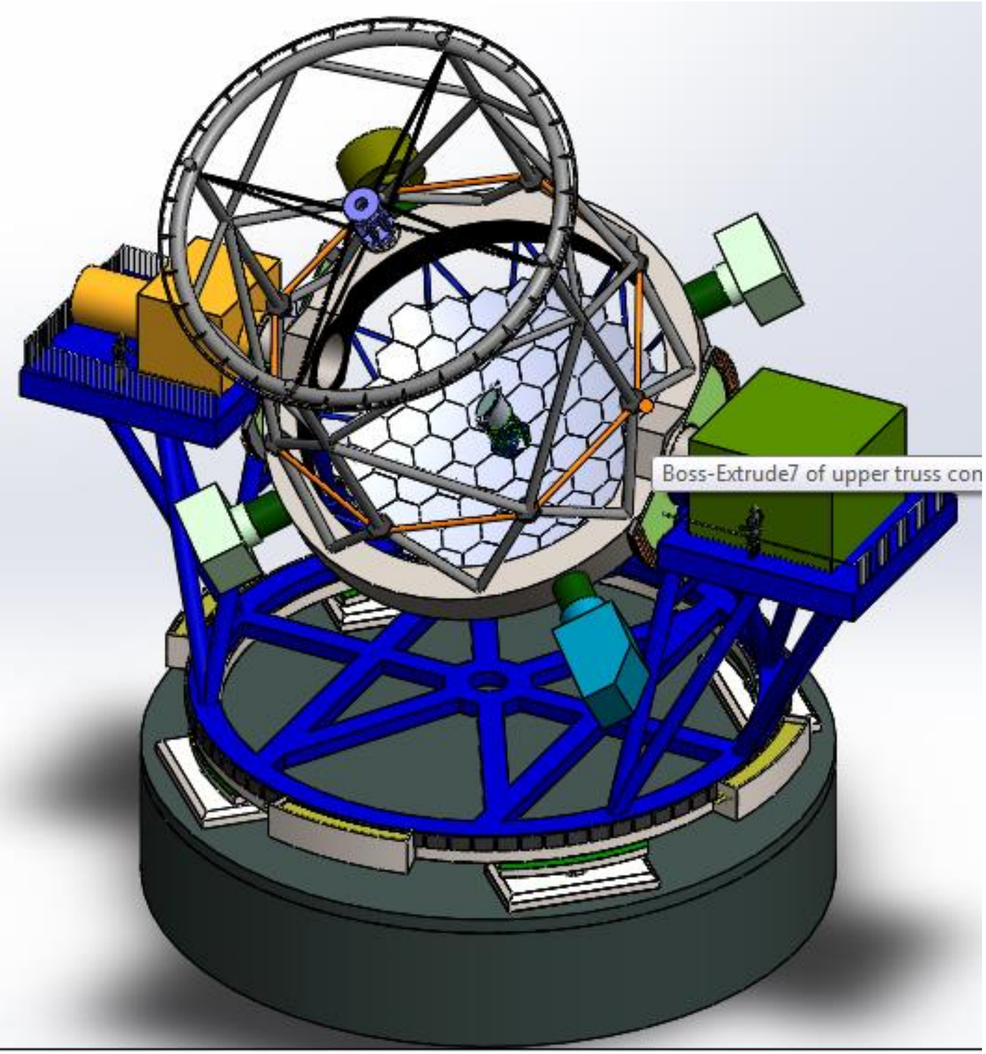


$$Az = s$$

$$z = A^{-1} s$$

Where **A** is control matrix, **S** is sensor reading, and **z** is actuator displacement. **A** depends only on geometry and usually not a square matrix

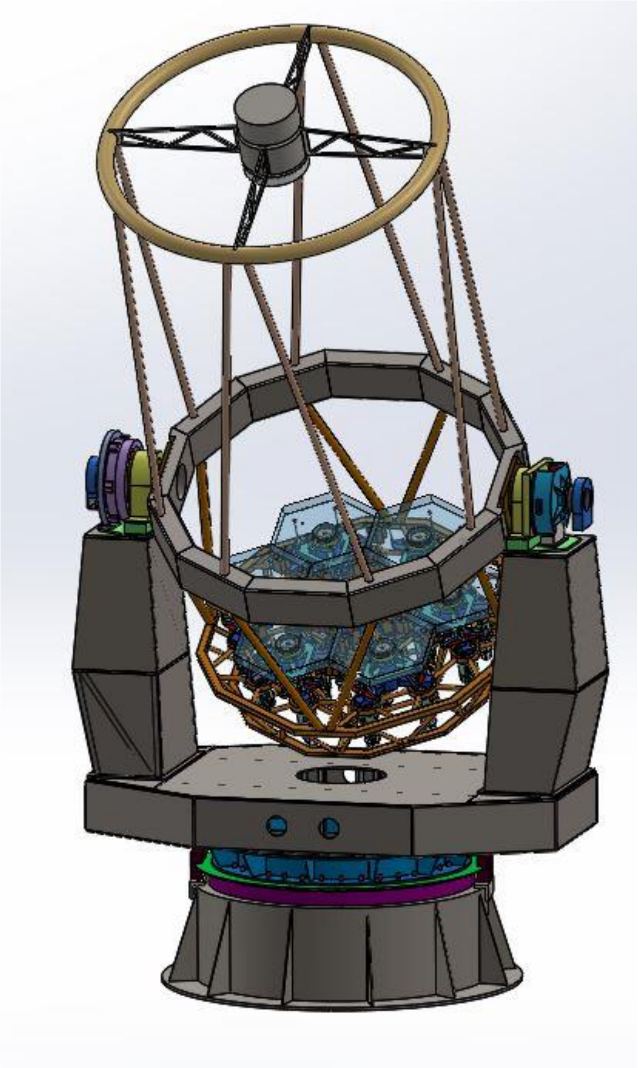
Building 10m class Segmented Mirror Telescope in Ind



- 10-12m size segmented mirror telescope
- RC Optics
- Fully steerable Alt/AZ Telescope
- Undersized Secondary for the NIR
- Removable/Retractable Tertiary
- 2 Nasmyth Focus for large instruments
- Cassegrain Focus
- 4 Bent Cassegrain for small instrument and APS
- Driven by Direct drive motors
- Hydro-static bearing for both Azimuth and Elevation

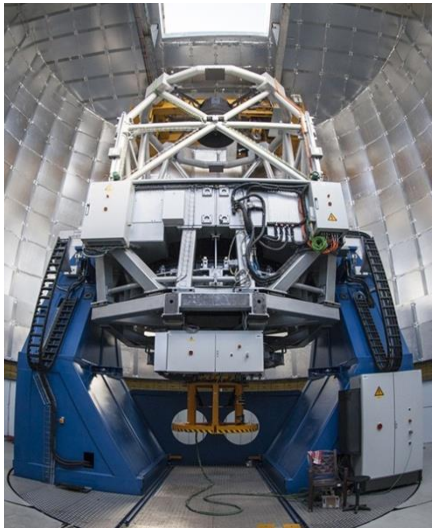
A pilot project for Technological Exploration

1.3m dia PSMT



- Segmented mirror Technology is not yet standardized.
- Require experimentation on primary mirror control and alignment/phasing.
- It is good to understand complication prior to embarking to large telescope project and avoid the risk linked with the performance (HET, SALT examples).
- A prototype telescope made of 7 spherical mirror segment is developed in IIA.
- Telescope will have all complexities as one can expect in a large segmented mirror telescope.

4m class telescopes in Asia



3.6m Indian Telescope

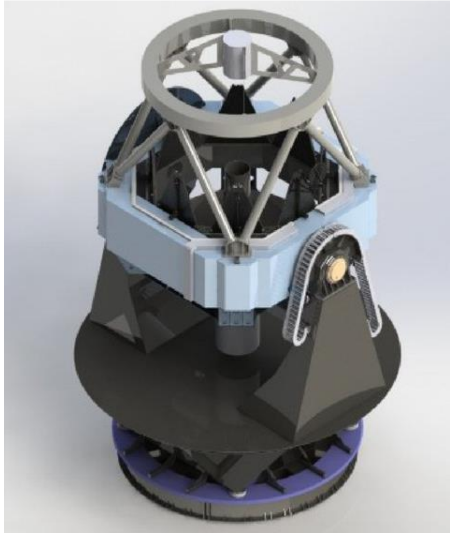
❖0.5-2.0 m size telescopes have now become very small observing tool and mostly evolved in time series studies of relatively bright objects.

❖In the era of mega telescope of 30-40m size, 4m class telescope becomes a necessary requirement to any astronomical community desire to make meaningful contribution to the science.

❖There are at least half dozen telescope projects at various state of realization within Asia.

3.8m Japanese

4m DAG Turkish



Iranian 3.4m INO

3.8m Indonesian

Base-line requirement for the 4m telescope

i. Fully steerable telescope 4m class telescope.

ii. Telescope should cove both optical and NIR observing window (0.35 to 5 micron)

iii. 5' (Diffraction limited) 20' (degraded) performance.

iv. Telescope optics should not degrade site seeing by more than 10%

v. Possibility of hosting 3-4 large instruments (Nasmyth or Cassegrain focus)

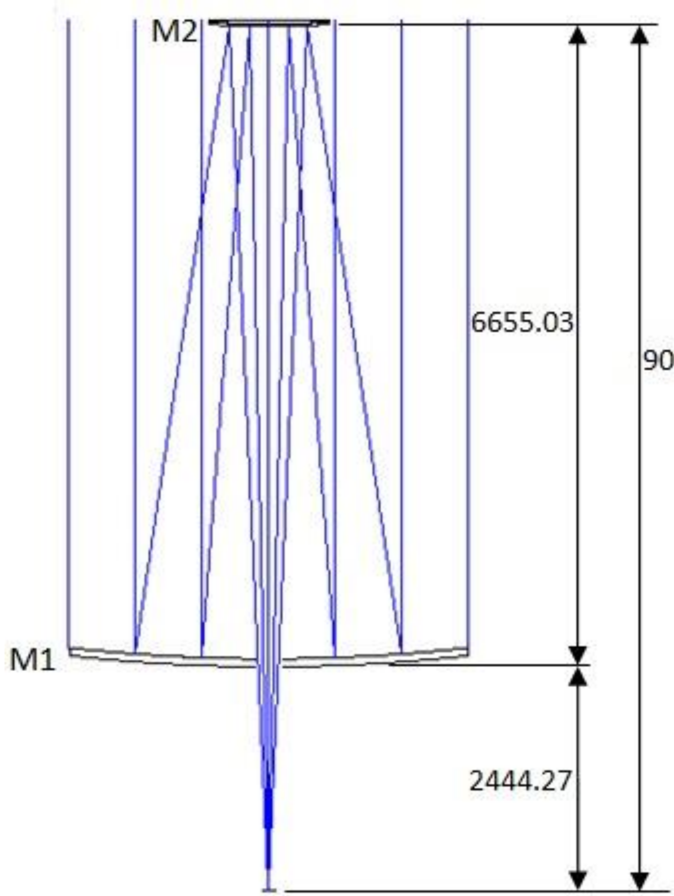
vi. Light weight and structerlly stiff

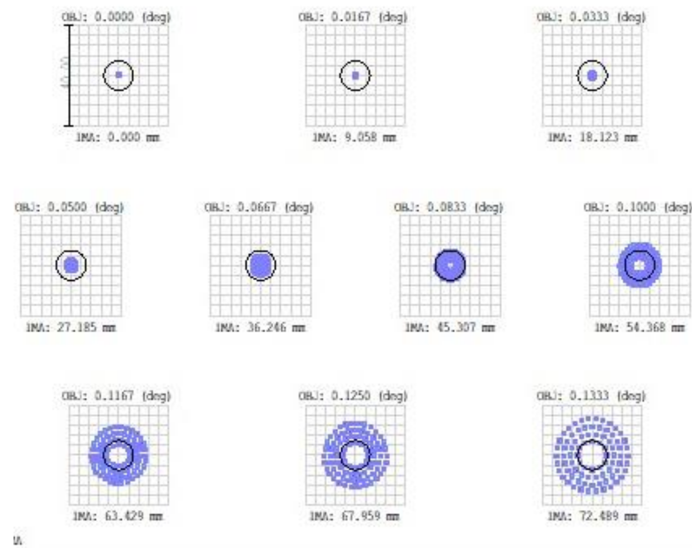
vii. Should be make use of segmented mirror technology

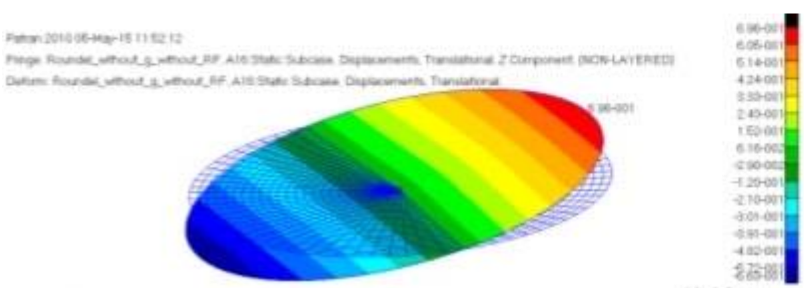
viii. Aim to have low cost telescope (within 5-6 million USD)

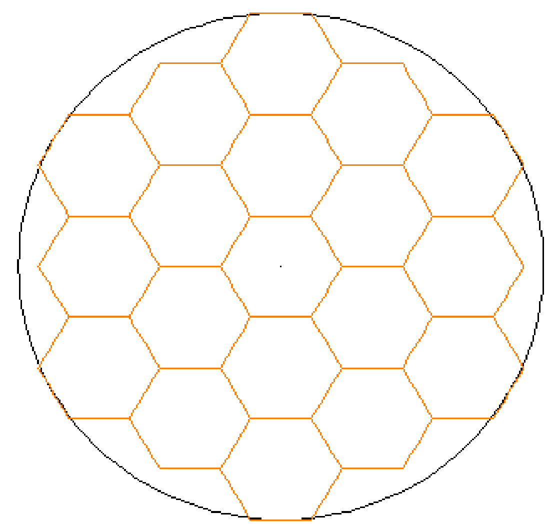
ix. Should be developed, using local design and manufacturing capabilities

Option with RC Optics







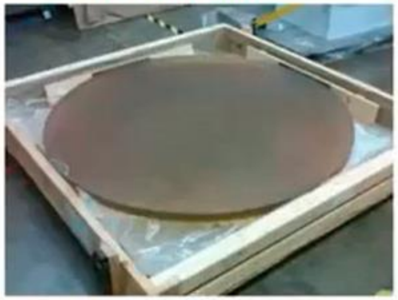


Option with RC Optics

The Primary Mirror:

- Most difficult and complex tasks involved.
- Journey has just begun, there are miles to go

Mirror Blank

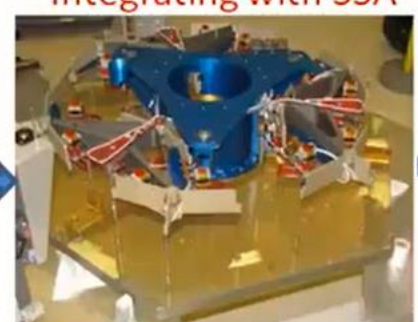


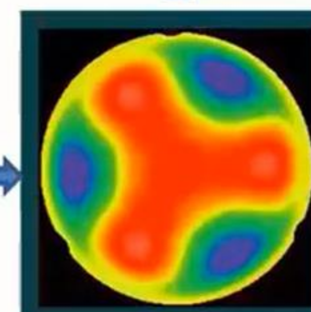
SMP

Hex Cutting

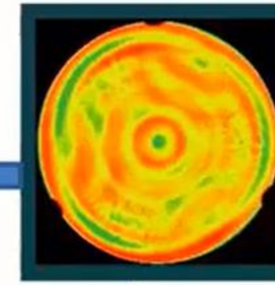
Pocketing

Integrating with SSA

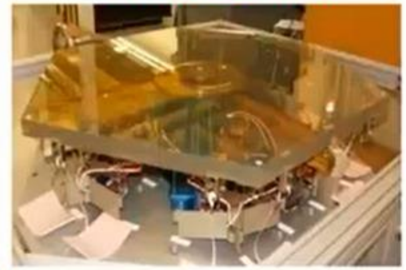




IBF



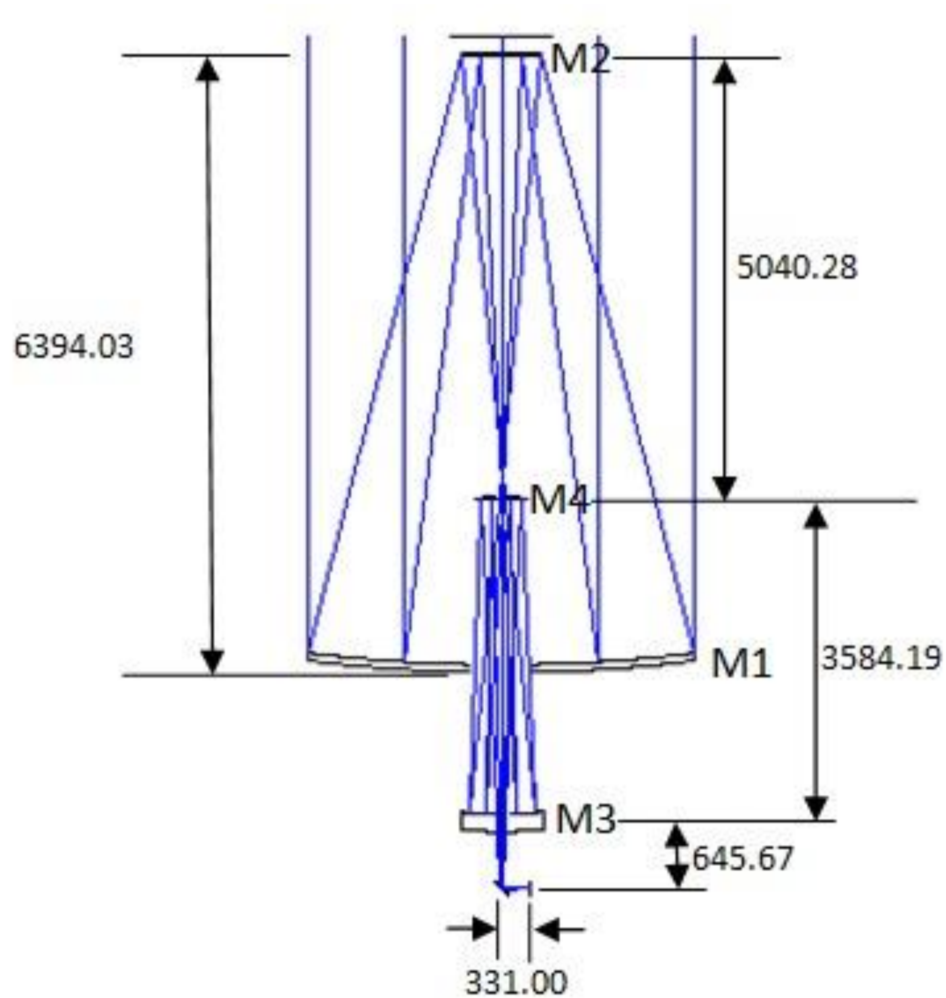
Finished PMA



ITOFF, CREST Hosakote

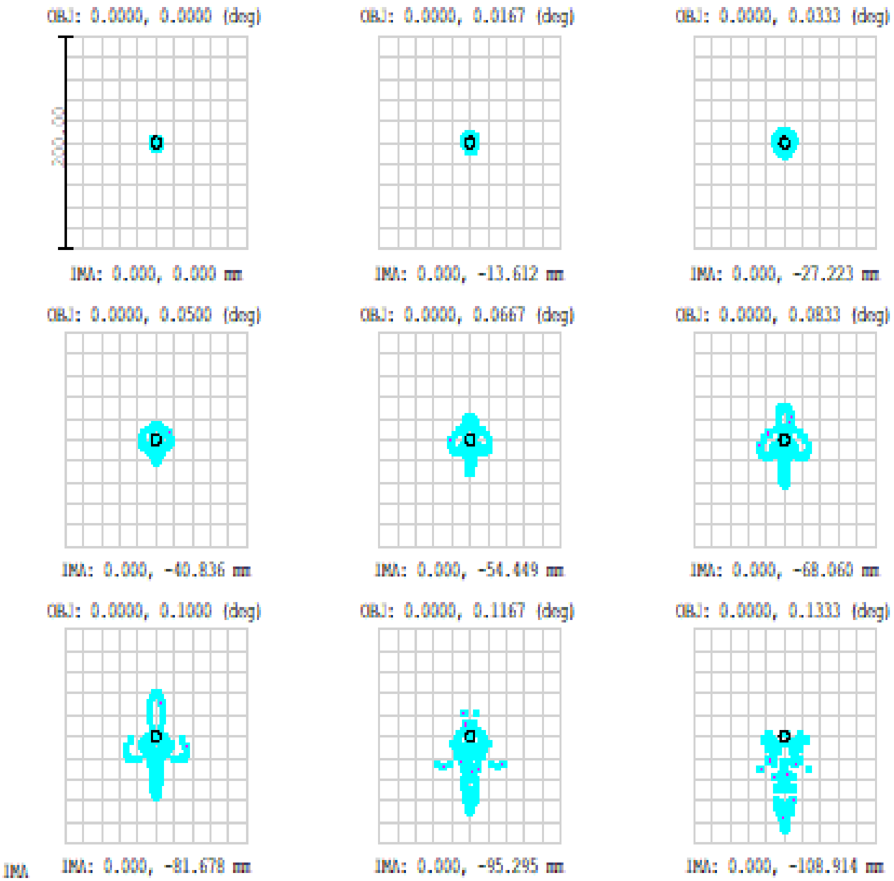
Option with 4 Mirror Spherical   Optics

Primary Mirror (M1):	
ROC	-17.48m
Diameter	4.4m
Hole radius	350mm
Secondary	
Mirror(M2):	5.593m
ROC	0.9069m
Diameter	
Tertiary Mirror(M3):	
ROC	-5.4974m
Diameter	0.8461m
Hole radius	118.860mm
Aspheric	
Mirror(M4):	41.90m
ROC	0.4522m
Diameter	74.0960mm
Hole radius	3.6336e-5
2^{nd} order term	-1.656e-10
4^{th} order term	-3.331e-17
6^{th} order term	
System Fno.	10.6387

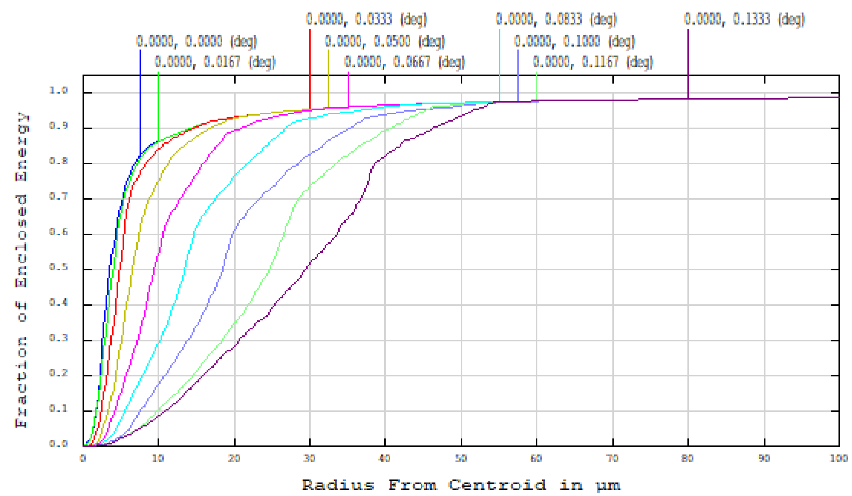


Design: Inspired by   R.N. Wilsons many papers & book, and Mikio Kurita (2017)

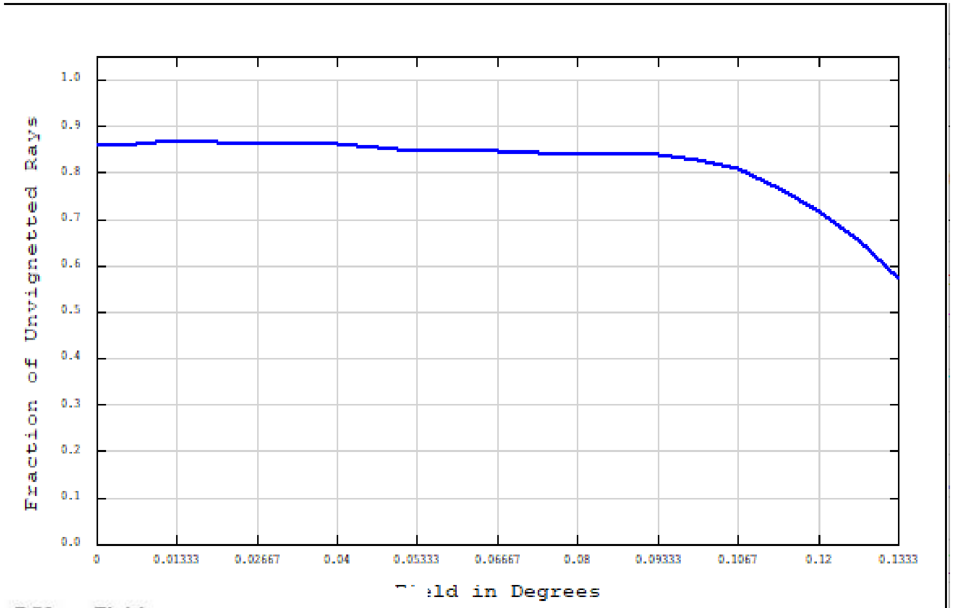
Option with 4 Mirror Spherical   Optics

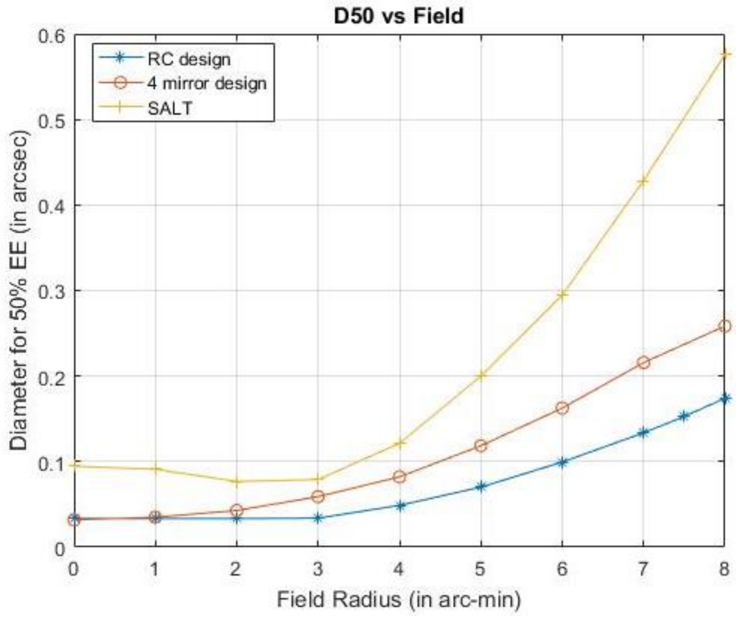


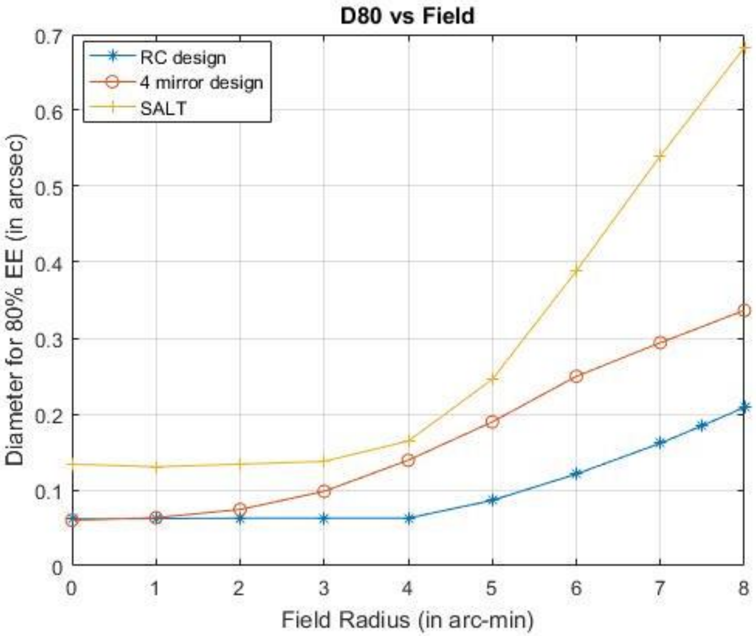
Field Value (Diameter)	50% EE in arc-sec	80% EE in arc-sec
0	0.03181	0.05995
2’	0.03499	0.06327
4’	0.04288	0.07415
6’	0.05906	0.09810
8’	0.08214	0.13899
10’	0.11855	0.18959
12’	0.16253	0.24952
14’	0.21577	0.29395
16’	0.25843	0.33652



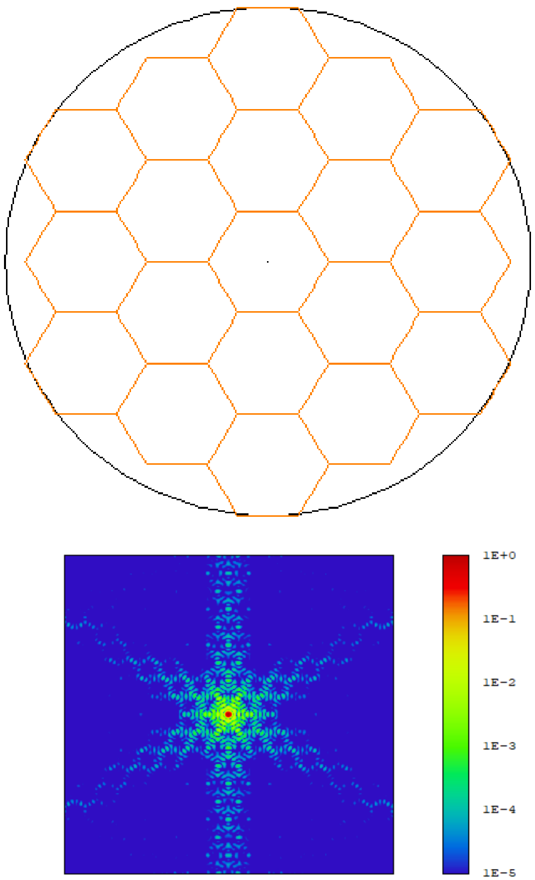
Option with 4 Mirror Spherical Optics

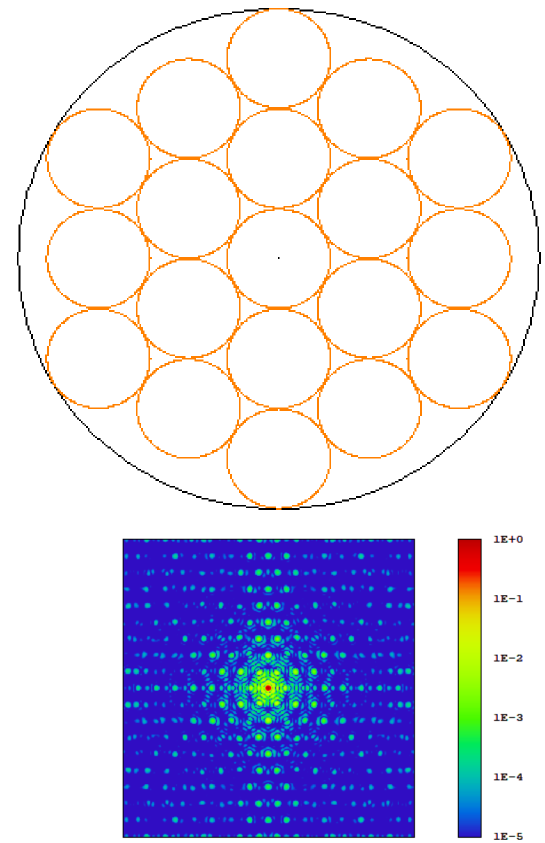






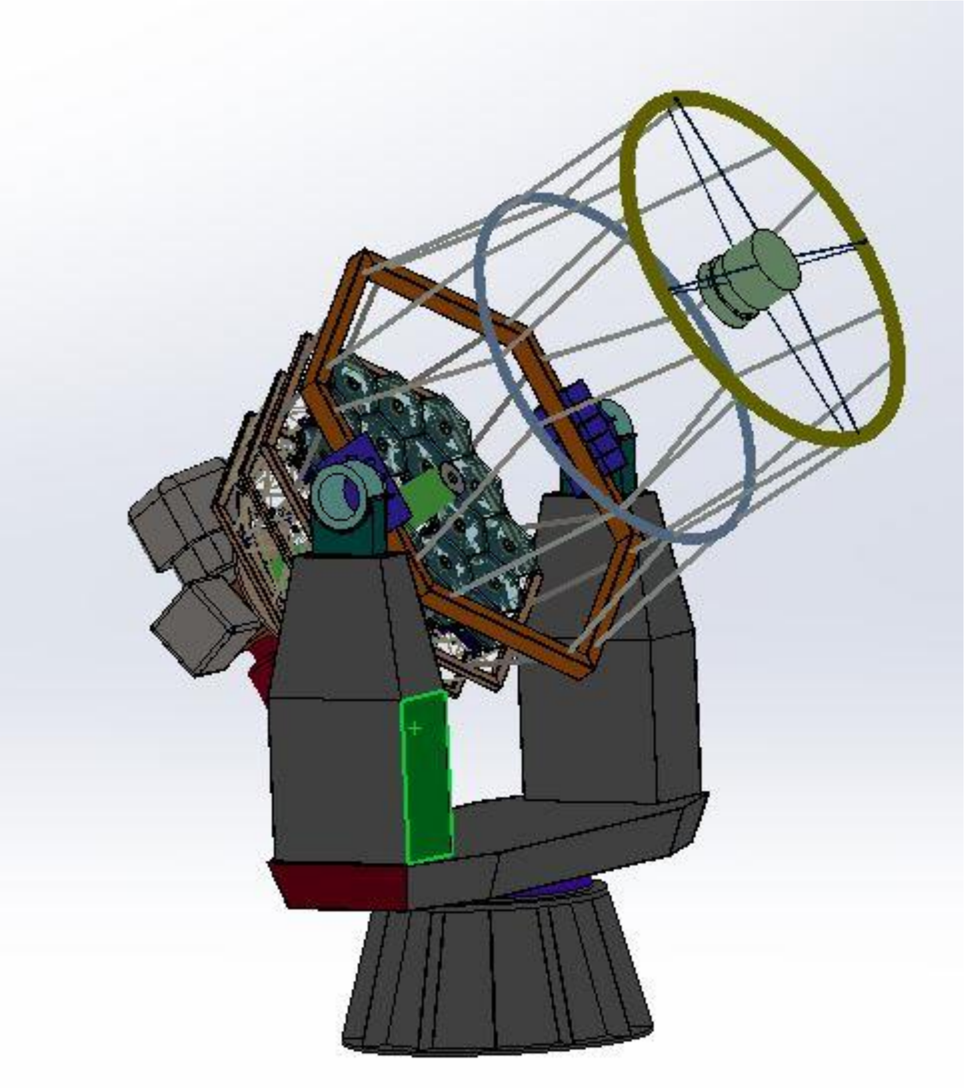
Geometry of the Segments





Wavelength (in micron)	Diffraction limited spot diameter	FWHM for hexagonal segments	FWHM for circular segments
0.32	0.03777”	0.01719”	0.01719”
0.55	0.06492”	0.02954”	0.02955”
0.65	0.07672”	0.03491”	0.03491”
1.6	0.18885”	0.08591”	0.08591”
2.4	0.28325”	0.12890”	0.12890”

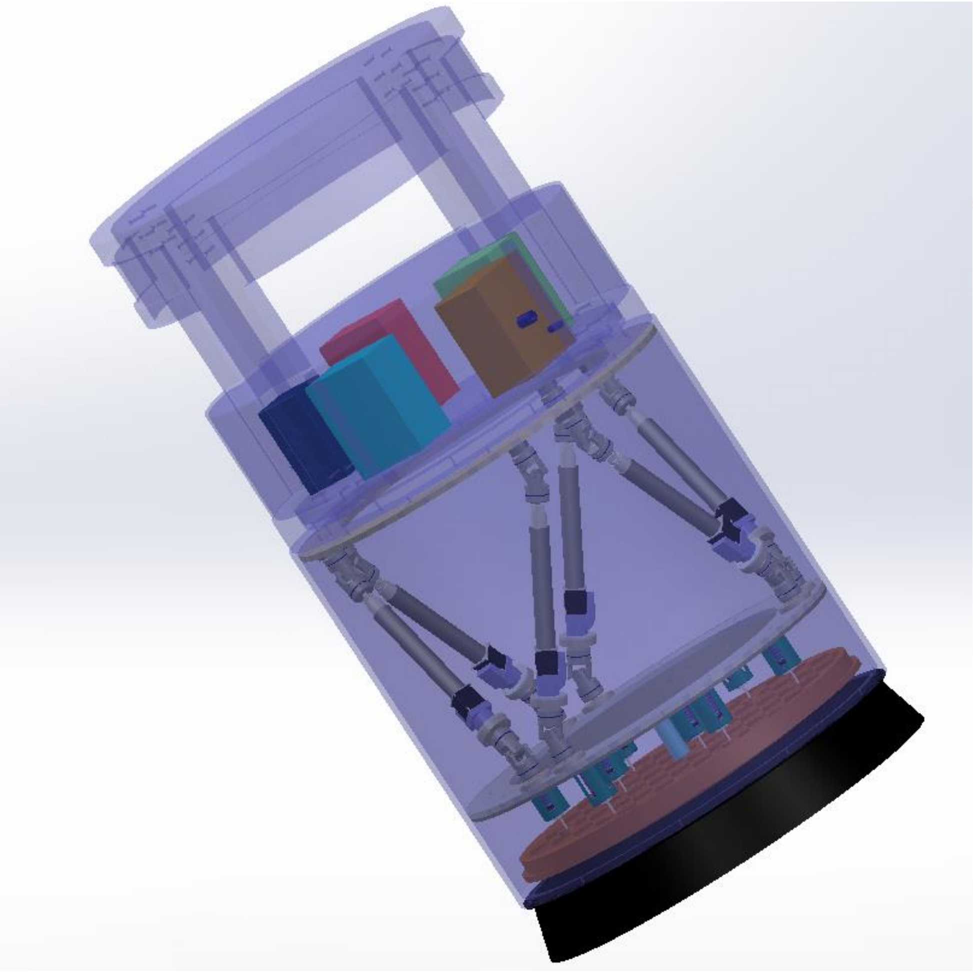
Option with 4 Mirror Spherical Optics



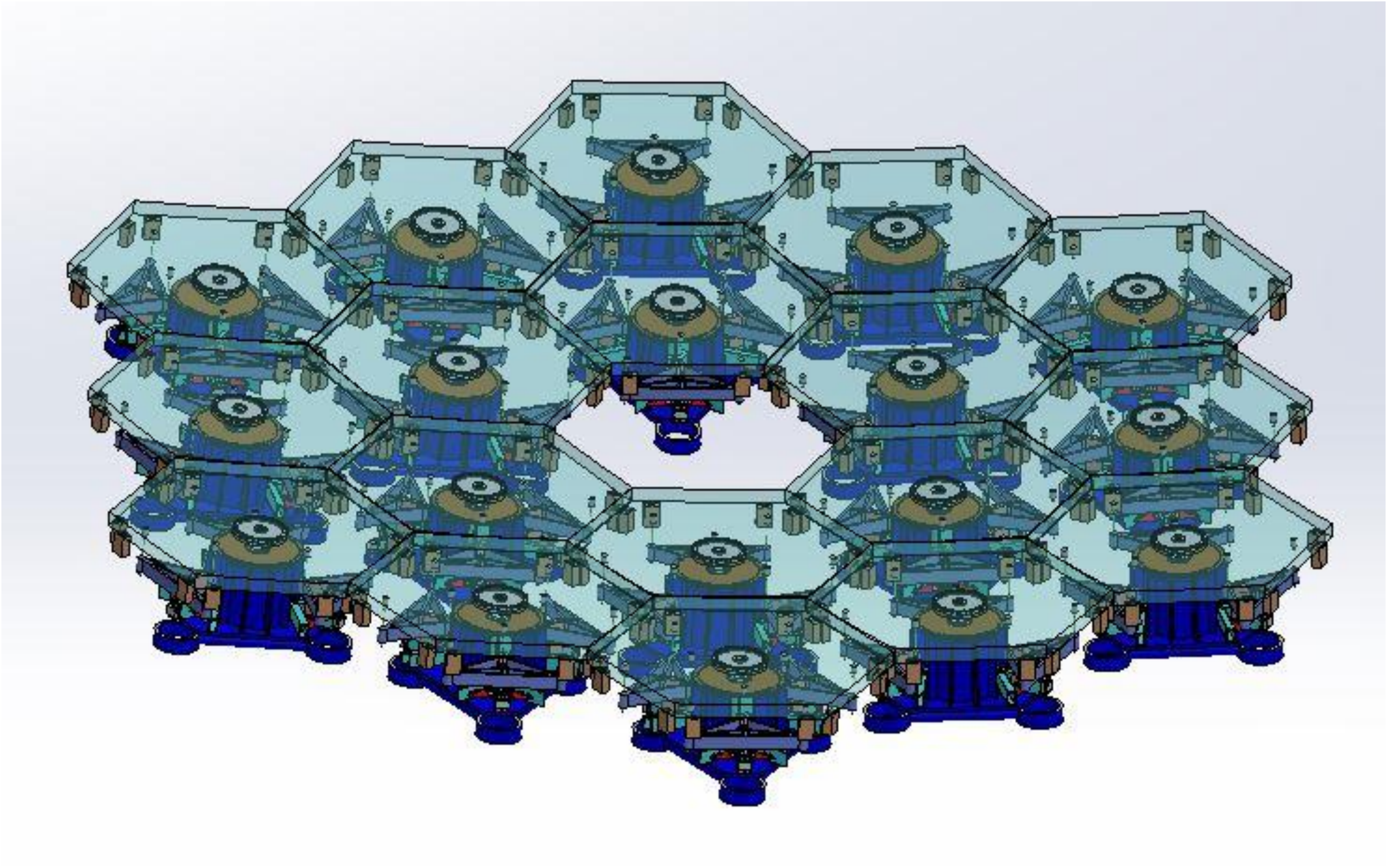
- ◆Alt/Az Telescope.
- ◆Uses 18 spherical Mirrors.
- ◆Cassegrain is preferred focus.
- ◆Driven by direct drive (no gear).
- ◆ Hexapod based secondary.
- ◆Concept of the telescope and its subsyster are continuously being improved.
- ◆Telescope will be light weight but very stiff, that it can work in windy environments.

Total Moving weight of the telescope 36.5 ton

Hexapod based Secondary Drive

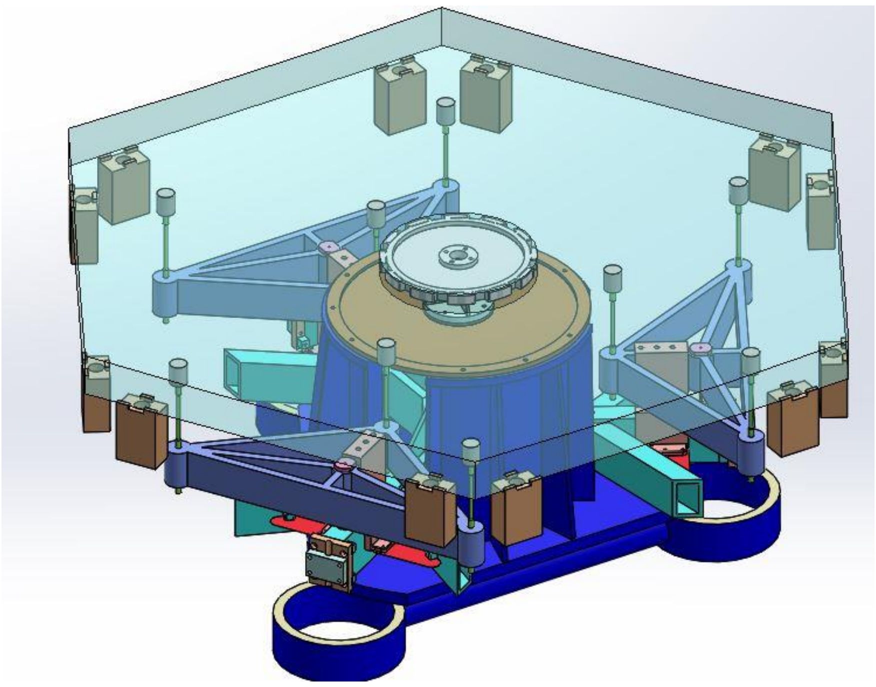


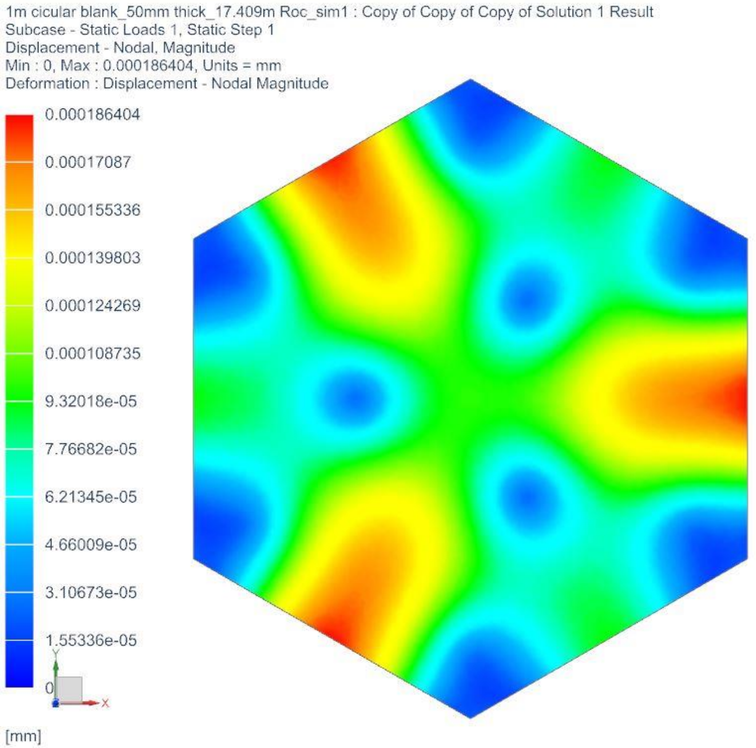
Segmented Primary Mirror



2.6 ton Primary mirror including mirror segments support

Segment Support

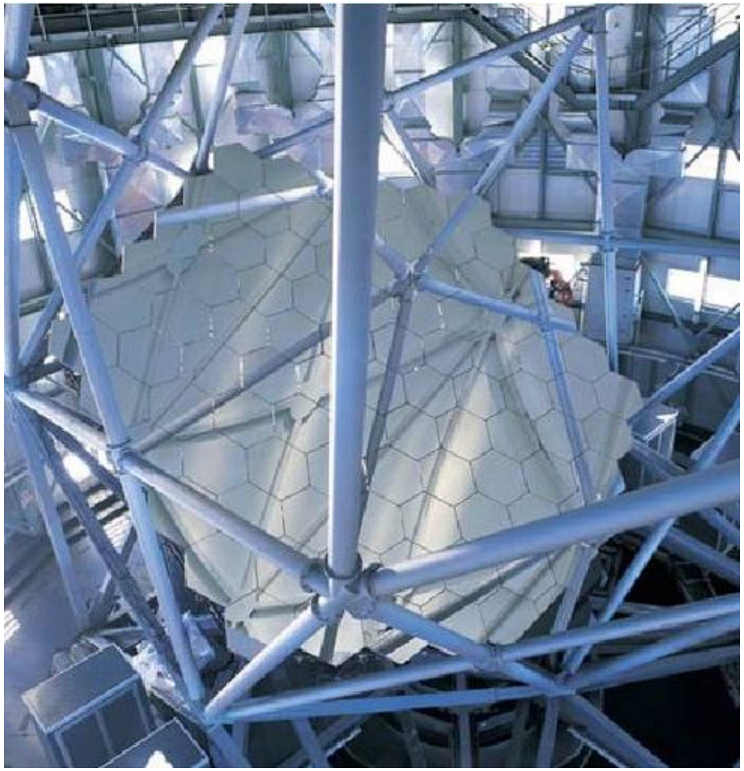


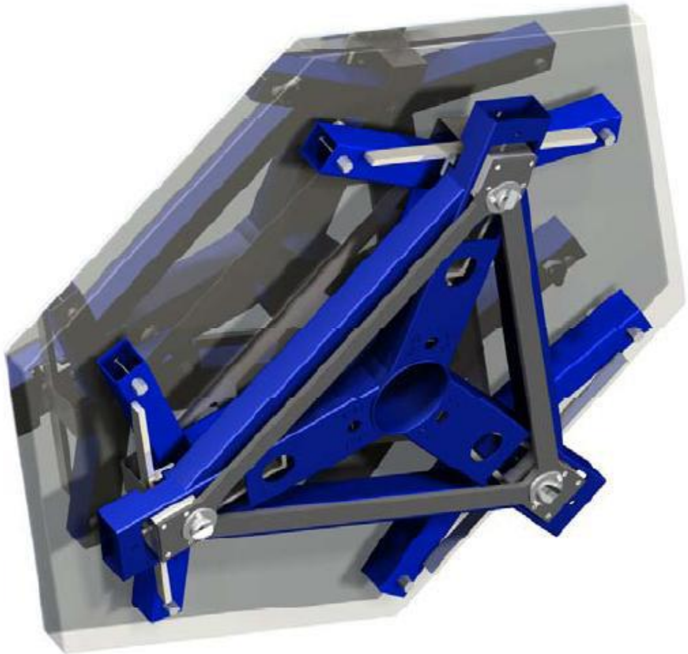


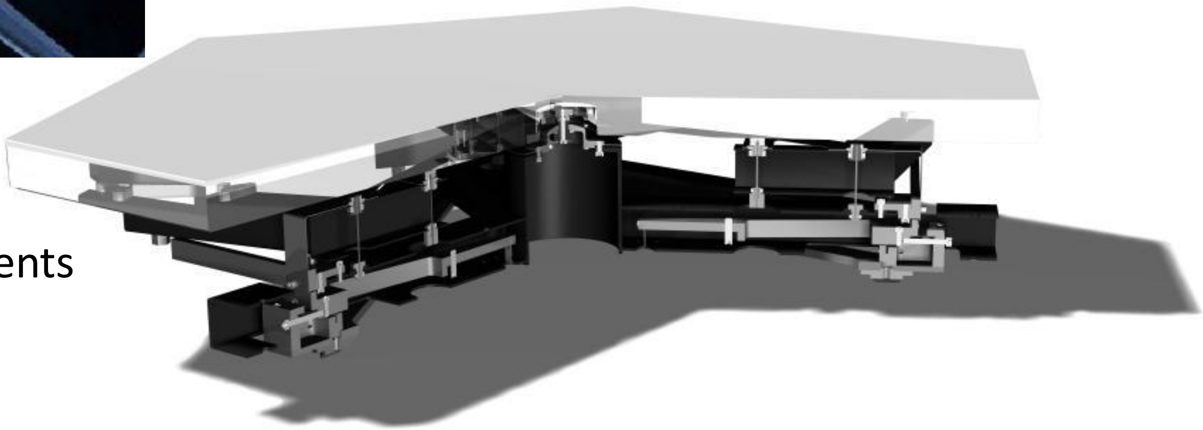
Maintain the shape of the mirror to λ/30
9 point wiffle tree axial support
Central radial support
Moving frame allows large tip/tilt/piston for segment alignment
Kinematic registration.
Minimized mass (145 Kg including segment)

Segment Support

Using building block of the SALT Primary Mirror for the 4m telescope

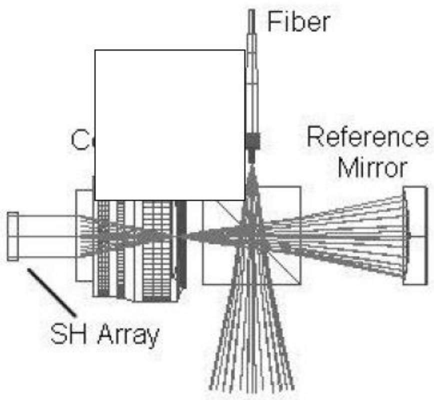


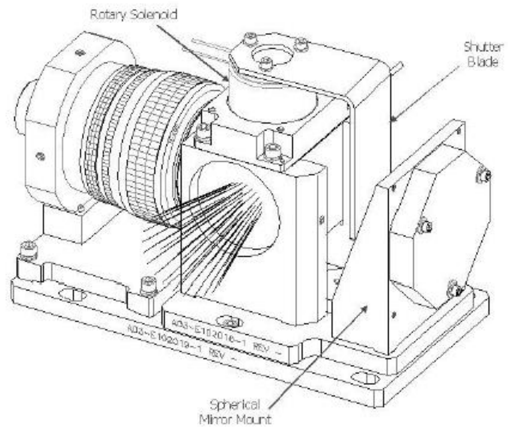


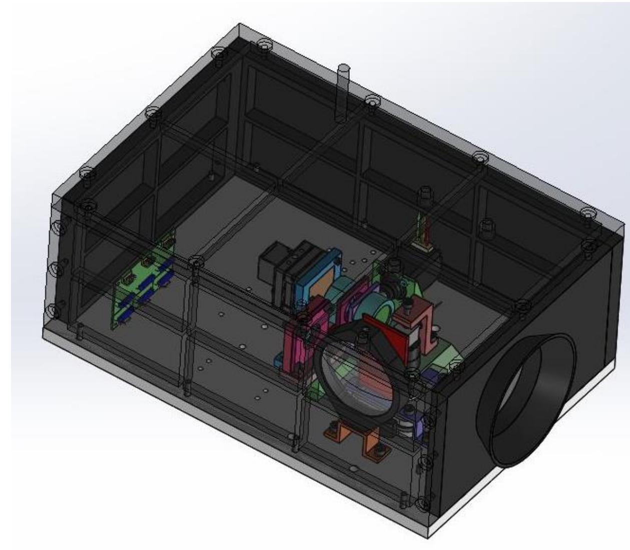


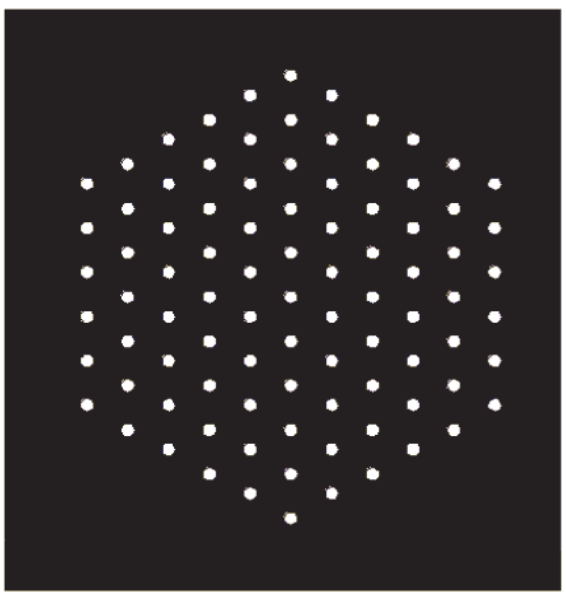
Requires only 18 SALT Segments

Segment Alignment and Phasing (APS):

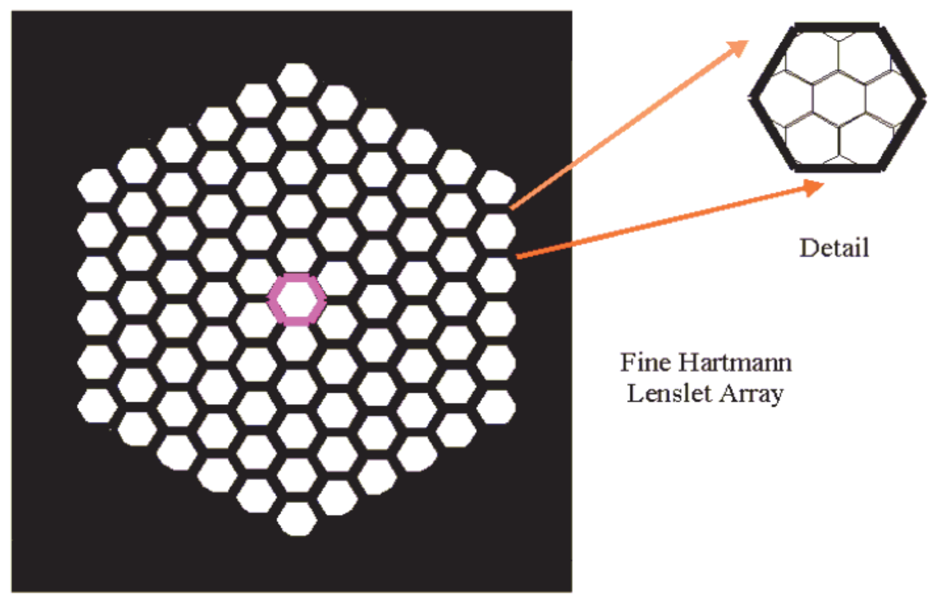








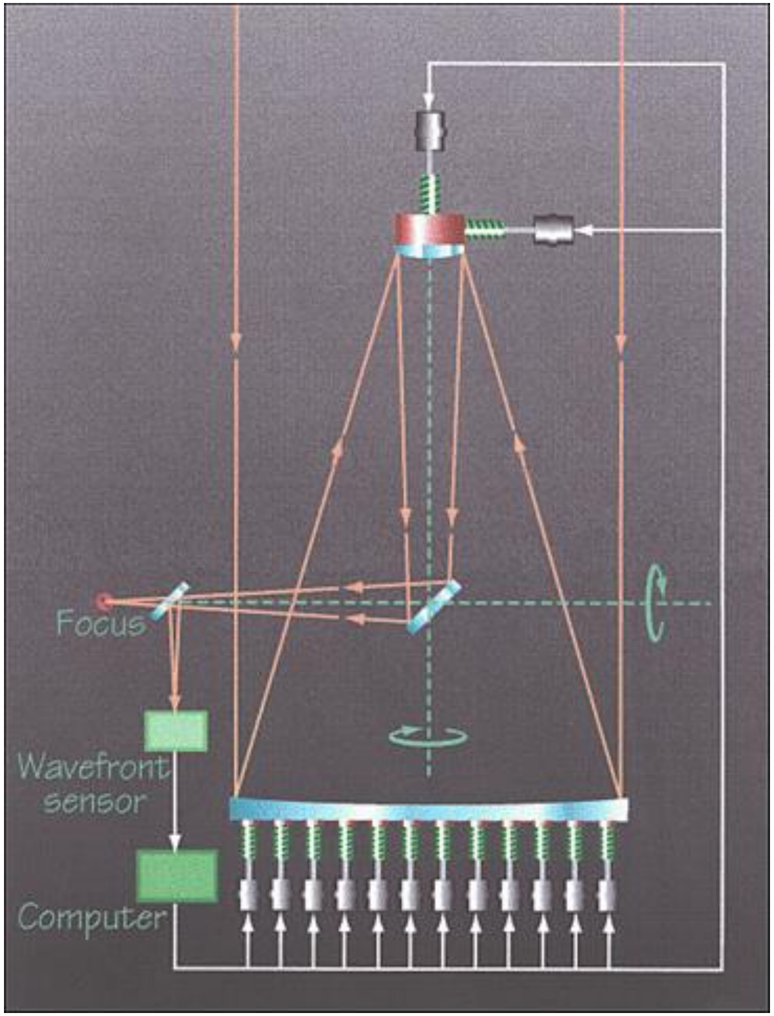
Coarse
Hartmann
Mask



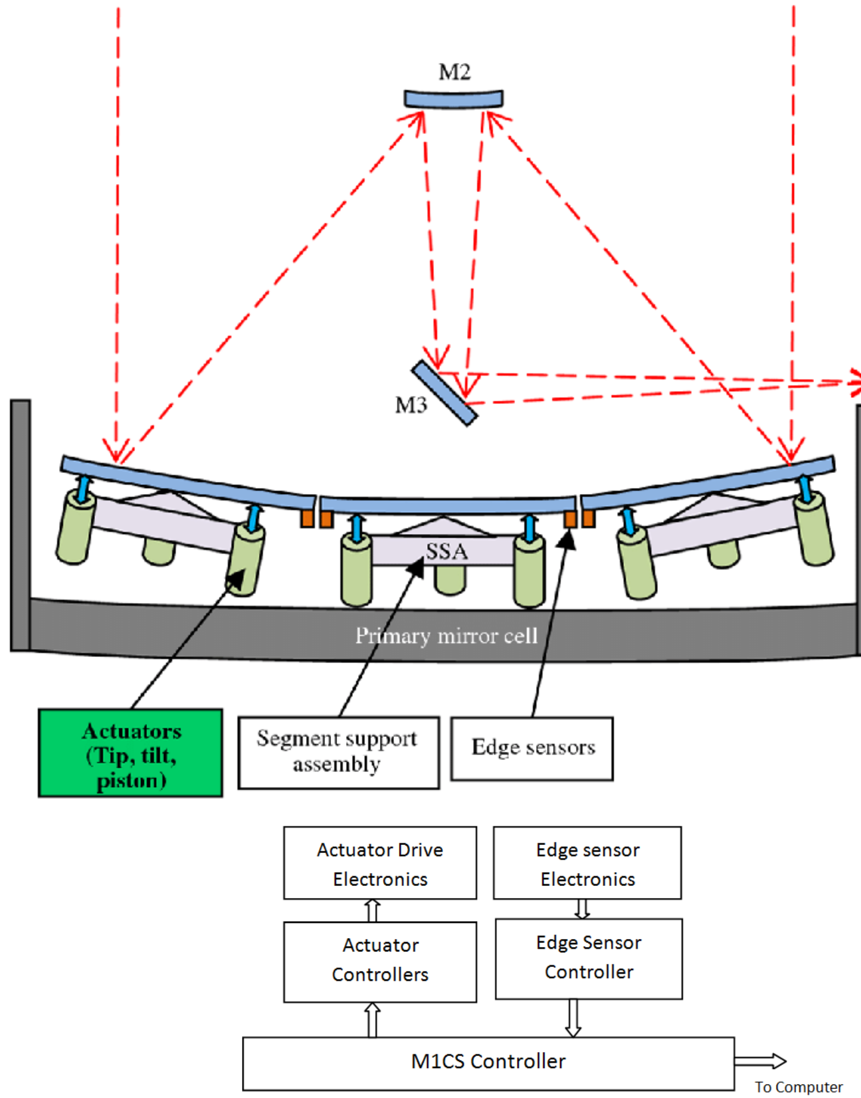
Fine Hartmann
Lenslet Array

Handling Segmented Primary Mirror

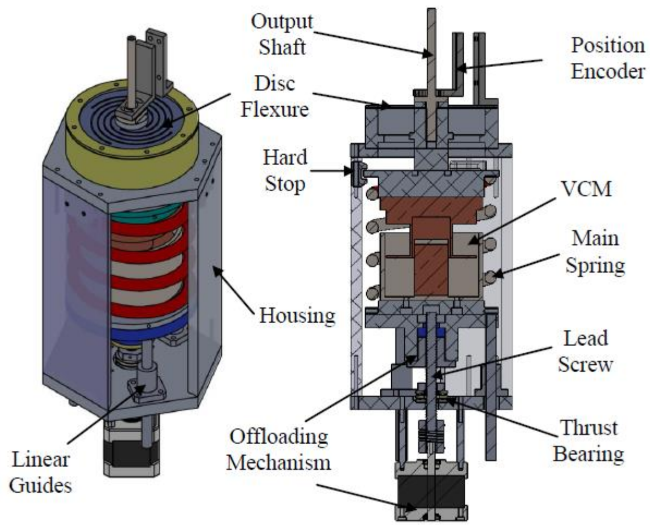
Close loop Control through Optical Feedback



Close loop Control through Edge Sensor Feedback



Actuator for the PSMT

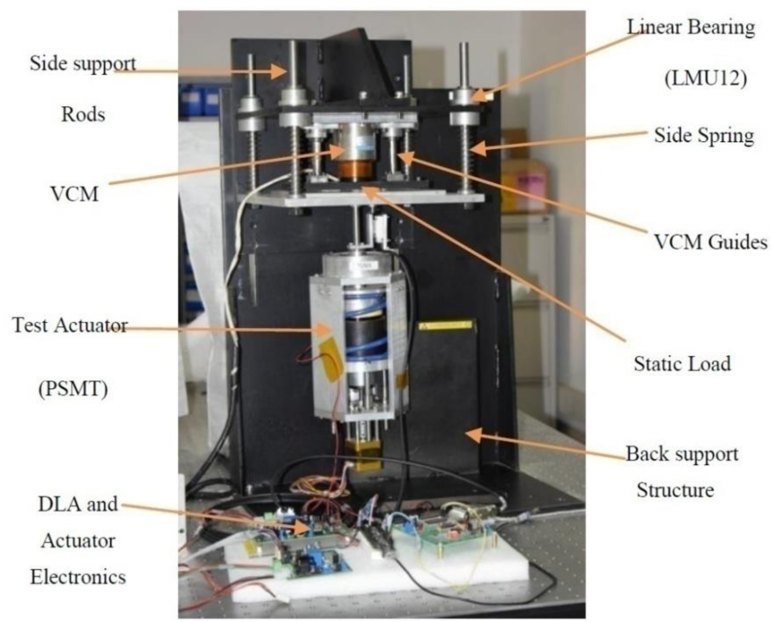


The Requirements

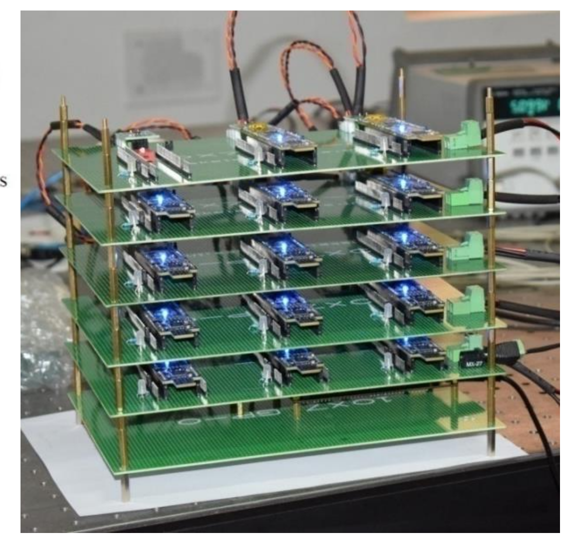
Parameter	Value
Stroke	±1.5mm
Position accuracy	<10 nm
Stifness	20,000 N/m
Weight	< 6 Kg
Power	< 1.5 W

Features:

- Uses VCM as prime movers
- Act as a force & position actuator
- Gravity offloading
- On axis mechanism
- Compact and lightweight



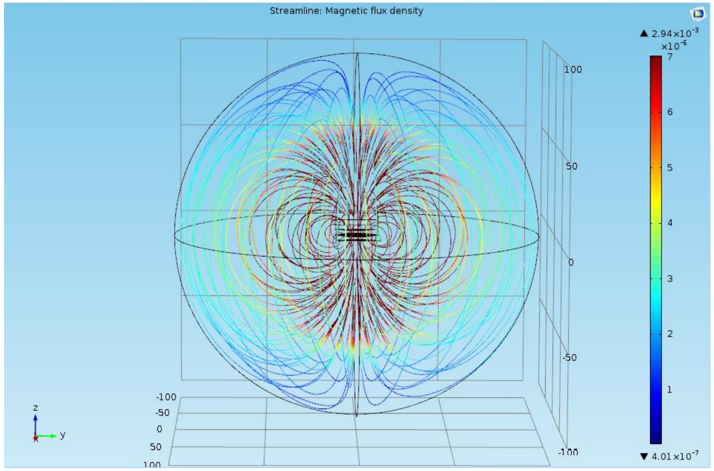
Prototype PSMT Actuator

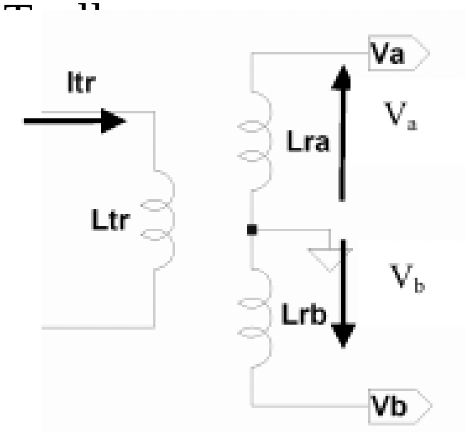


Actuator Controller

Development of Inductive Edge Sensor

- Sensor is based on the principle of mutual inductance measurement between two overlapping plane coils, which varies with the surfaces overlapping area and gap separation.
- ELT, SALT, LMOST, H...
other kind of Inductive se...
- Not affected by humidity...
- Sensor technology is pat...





Dimensions	Gap, height, dihedral angle
Piston range	± 1.5
Gap range	1- 5.0mm
Piston Noise	< 5 nm
Gap Noise	< 100nm
Temporal drift	< 2nm day

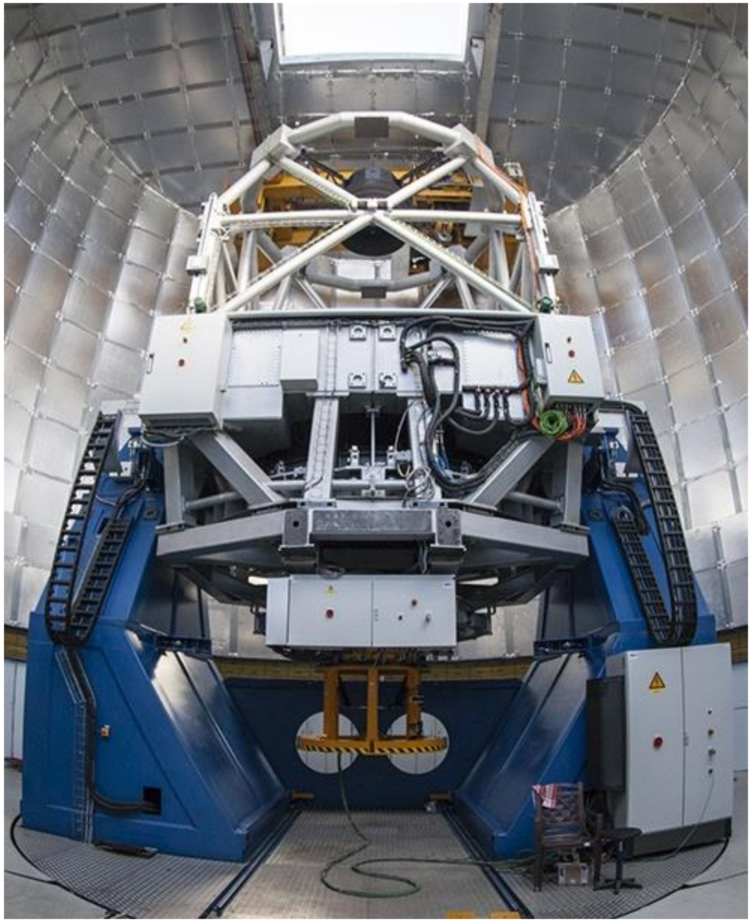
Inductive Sensor for PSMT

IUCAA is supporting in developing a precession sensor electronics.

Testing setup in ITCC

Mass Optimization

3.6m DOT Telescope (India)



Total Telescope Mass = 150 Ton

SEIMEI 3.8 Telescope (Japan)

Mass of the OTA = 8 ton (mirror 4 ton)

Total Moving Mass = 18 Ton (1/6 of a conventional telescope

Cost estimate for 4m Class Telescope (Rough)

Item	Cost ($k)	Note
Primary Mirror Segment	2000	Zerodur blanks (@30k USD, Grinding Polishing, Figuring, Pocketing and hex cutting costs are considered to be 3X of the blank cost.
M2, M3 & M4 Mirrors	1000	Just guess work. At present we have no reliable input
Secondary Drive	100	Hex pad based secondary drive . Price quote from Symmetrie France
Segment Support	126	Manufacturing cast of one segment support would be 7k$
M1CS (Actuators, edge sensor + controller)	400	54 actuator and … edge sensor . If use of the edge sensor is avoided then cost will reduce substantially
Primary Mirror Cell	50	Manufacturing cost of the primary mirror cell along with accessories required for the registration.
Manufacturing of Alt-Az Mount	200	Manufacturing Cost includes, lower & Upper truss, secondary mirror spider/housing, yoke, elevation ring, elevation, azimuth, drives etc.
Alt/Az drive + controller	100	Based on price quote obtained from ETEL motors, Renishaw Encoder and PAMAC controller.
Software (TCS + OCS)	300	2 FT for 2 years
Alignment and Co- focusing system (no phasing capability)	50	A customized Sack Hartman device. The main cost driver may be lenslet array and a small format CCD.
Opto-Mechanical design & Analysis	400	Assumed only critical design and analysis work will be out sourced rest of activities will be handled in-house
Total	~4730	

4m class telescope for MAO

I. MAO being one of the best site in Asia deserve to host large telescope.

II. At present, there are few 4m class telescope manufacture around the globe who can take project as a turnkey. However,this way ccost optimization may not be possible

III. .

IV. Building 4m telescope is very much possible by Uzjbeck astronomical community

V. itself, however, having international cooperation will make task simpler and faster.

VI. Building telescope at institution level require skiil manpower power with domain knowledge. UBI should put effort in capacity building exresize.

VII. Young scientists should be encourage to spend 30-40 % of their time in instruemntation related activities.

Acknowledgement

Radhika Dharmadhikari: For optical design and analysis

Abhishek Goudar: Mechanical Design:

Sandeep D S : Mechanical Analysis

Thank You for your Attention