alphadot
High-impact Innovation

Why Systems Engineering?

Western Cape Chapter Meeting

19 February 2015

Alphadot
Why SE works...
SALT

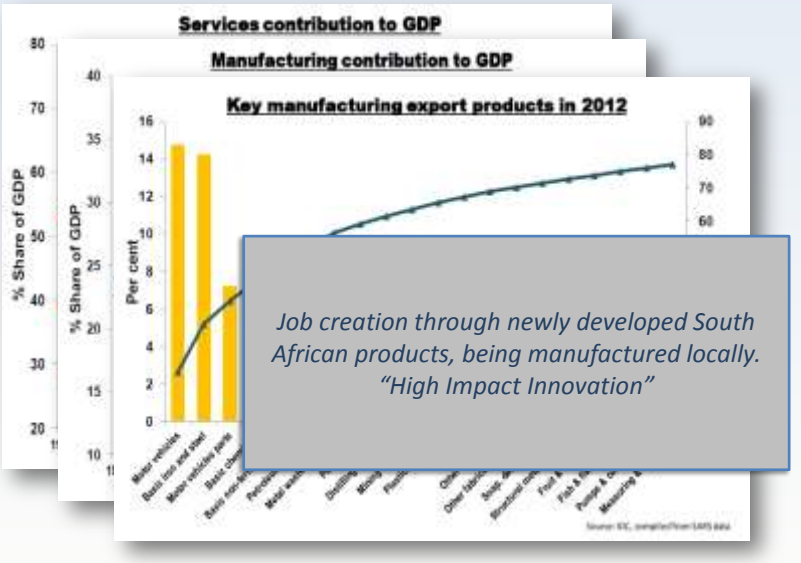
Gerhard Swart

INCOSE South Africa

alphadot
High-impact Innovation

alphadot
High-impact Innovation

Our passion



Job creation through newly developed South African products, being manufactured locally. "High Impact Innovation"

3

alphadot
High-impact Innovation

Supporting our customers…

We help our customers achieve the benefits of new technology innovation through strategic advice and support in research, development and commercialisation.

In areas where it has high impact…

- Renewable Energy
- Complex products
- Electric Mobility
- Data security
- Manufacture
- Energy efficiency

Resulting in…

- Reduced risk
- Increased performance
- Lower cost
- Greater profitability
- Socio-economic benefit

4

alphadot
High-impact Innovation

Why SE works…

(pre-school explanation)

5

alphadot
High-impact Innovation

Software Engineering institute

- Stan Rifkin, USA SEI survey
- Cost to write 200 000 lines of SW

Table 6 Relationship between Maturity Level, Effort, and Total Cost

Maturity Level	Effort (man-months)	Total Cost (US$)
Initial	595	5,5 million
Repeatable	143	1,3 million
Defined	80	730,000
Managed	43	392,000
Optimised	16	146,000

Most companies by far

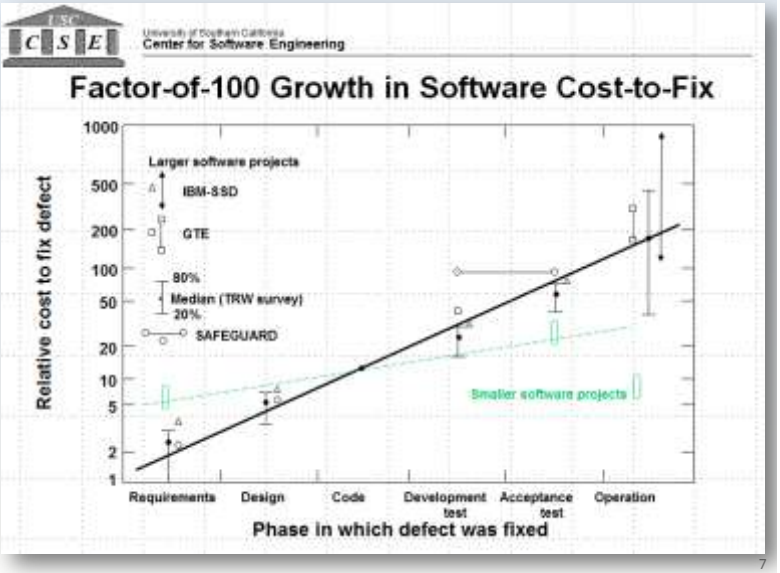
Top-down Process

6

alphadot
High-impact Innovation

Boehm – Economics of Software

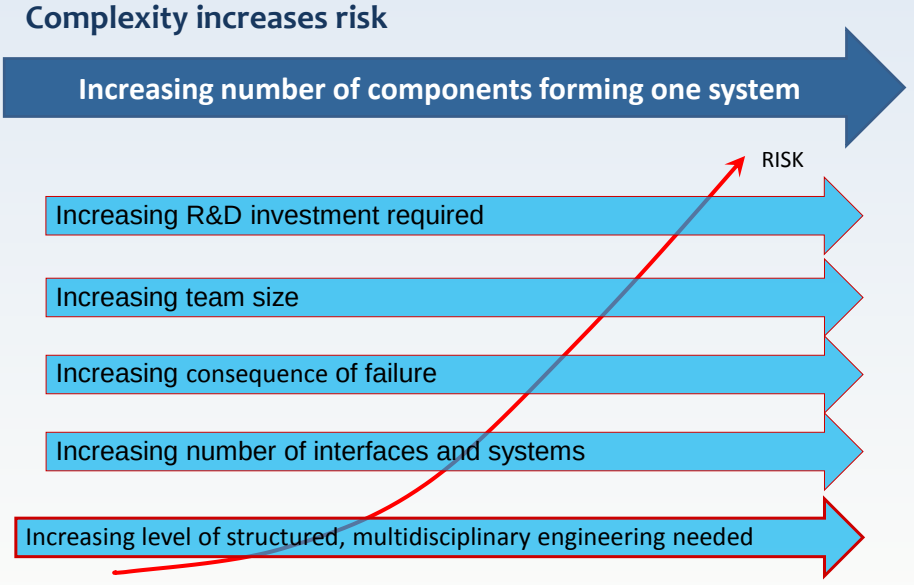
- Real projects
- Mostly poor requirements



7

alphadot
High-impact Innovation

Complexity increases risk



alphadot
High-impact Innovation

SOUTHERN AFRICAN LARGE TELESCOPE

Southern African Large Telescope

Construction 2000 - 2005

SALT concept and complexity
SALT Systems Engineering highlights

Co-authors: Dr David Buckley, Kobus Meiring, Hendrik Schalekamp, Janus Brink

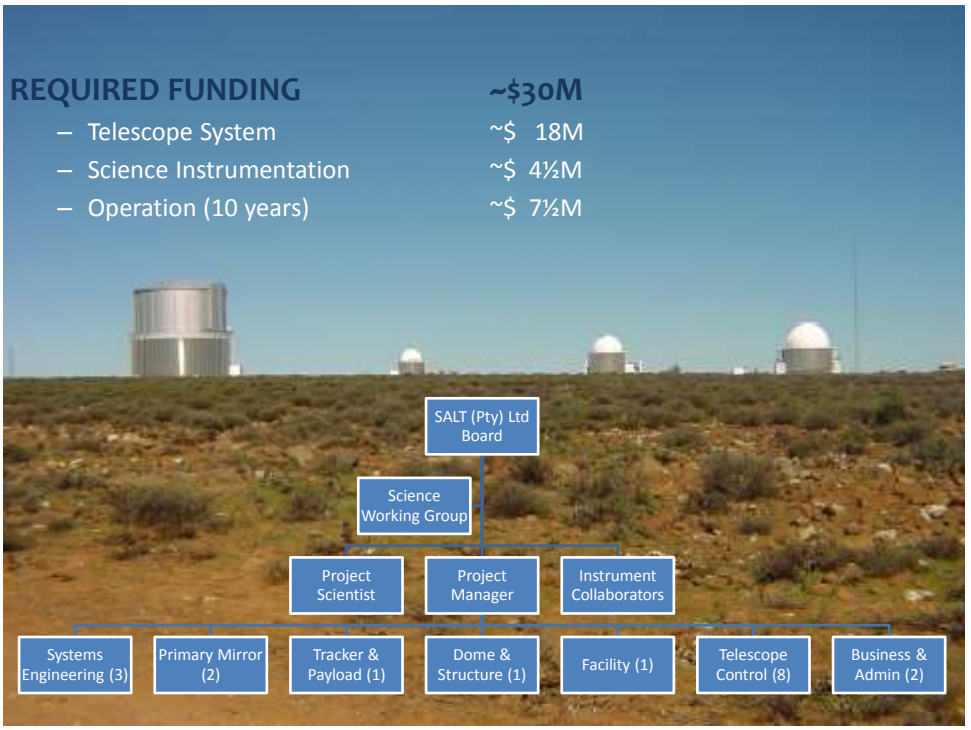
9

alphadot
High-impact Innovation

SALT Partners (today)

American Museum of Natural History
Armagh Observatory
Nicolaus Copernicus Astronomical Center
Dartmouth
HET
Keele University
NRF National Research Foundation
The Open University
UC University of Canterbury
uclan
The University of Nottingham
University of Southampton
WISCONSIN

10



alphadot
High-impact Innovation

Contracting network

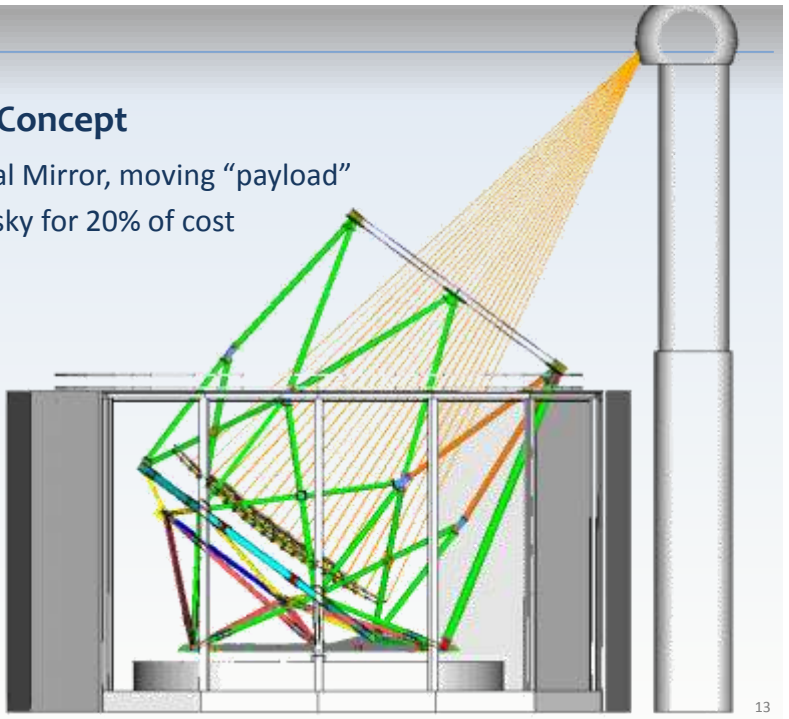
- System Analysis and Design: in-house
- Industry contracts
  - Buildings: Ninham Shands, HBO, Atlantis Panel, TF Design, Johardine and Associates + many more
  - Mirror glass: LZOS (Russia)
  - Mirror figuring: Kodak (USA)
  - Spherical Aberration Corrector: SAGEM (France)
  - Structure and Dome: BKS Advantec (Pretoria)
  - Tracker: Reutech Radar Systems (Stellenbosch)
  - Mirror edges sensors: Fogale Nanotech (France)
- Academic collaborating suppliers
  - PFIS: University of Wisconsin-Madison (USA)
  - HRS: University of Canterbury (New Zealand)
  - SALTICAM: South African Astronomical Observatory
- Integration and Testing: in-house

12

alphadot
High-impact Innovation

Optical Concept

- Spherical Mirror, moving “payload”
- 70% of sky for 20% of cost



13

System Overview

alphadot
High-impact Innovation

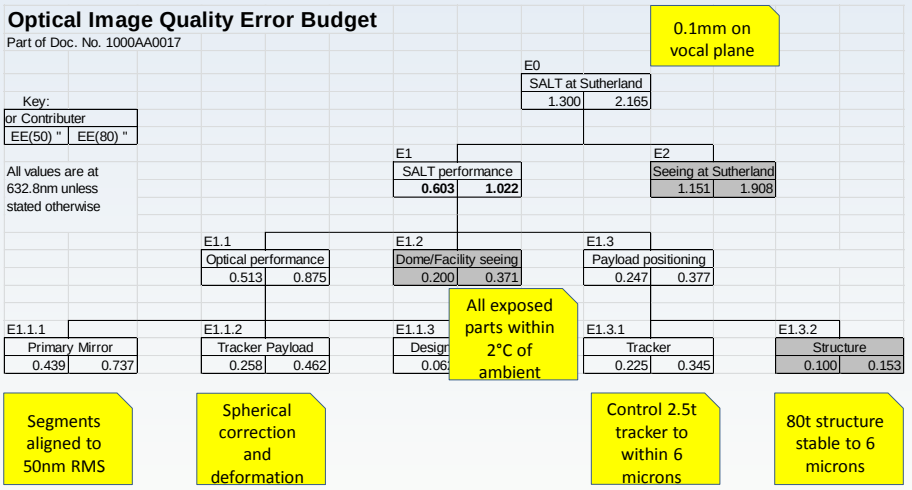
Challenge: Image Quality

- Required to concentrate images onto single points
- Primary Mirror comprises 91 Segments (Area 77m^2)
  - Figure quality ~30nm RMS
  - Radius-of-Curvature variation <0.5mm on 26.5m
- Each segment aligned to within 0.06" (0.3mm over 1 km)
  - Mounted on steel truss
  - Wind
  - CCAS Tower and sensor
  - Edge Sensors measure control to 50nm
  - Actuators provide continuous control for each segment
- Dome Seeing
  - No heat sources (passive or active)
  - Louvres and air-conditioning
  - Air flow design and modelling

16

alphadot
High-impact Innovation

Achieving required Image Quality



alphadot
High-impact Innovation

Challenge: Telescope efficiency

	Step 1	Step 2	Step 3	Step 4	Step 5		Step 6	
Tracker		Slew to destination (120s)			Open-loop tracking of object and implementation of tracking offsets (within 60s).		Closed-loop tracking of guide object	
Structure		Lift up (20s)	Rotate (130s)	Lower (30s)	Stay in the same place			
Dome		Rotate (180s)			Stay in the same place			
Operator actions	Select Objects from list (30s)				Acquire object (30s)	Activate guidance (30s)	Fine-tune position (90s)	Observe object (1s to 90 min)

alphadot
High-impact Innovation

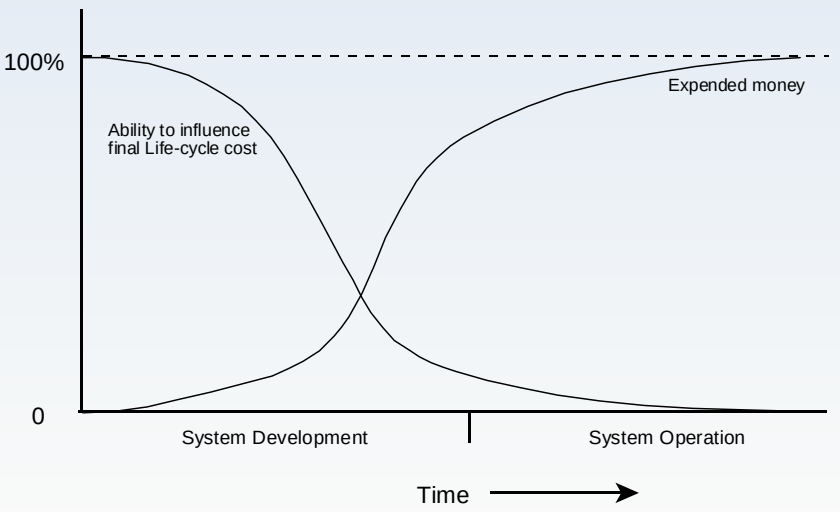
Challenge: Systems Engineering

- Unfamiliar territory for customer
- Team has never built a telescope before
- Pushing the limits of Physics
- Multiple contracts across the Globe
- Large software component
- Fixed Budget and Schedule before engineering is done
- High system reliability required (operates 365 nights/year)
- High operational efficiency required
- Requires good development process

19

alphadot
High-impact Innovation

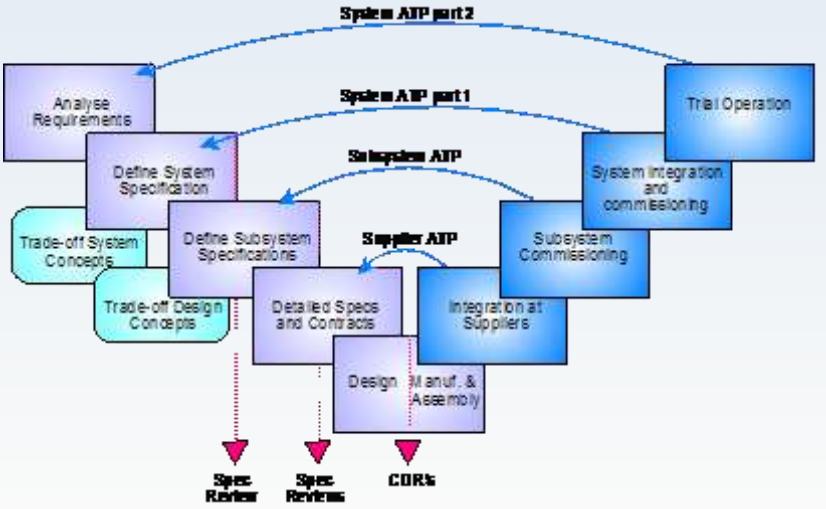
Define requirements first



20

alphadot
High-impact Innovation

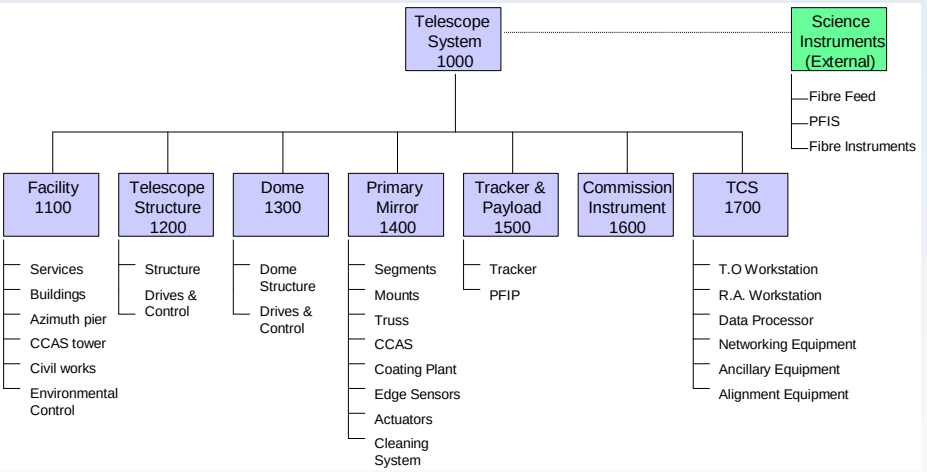
Development Process



21

alphadot
High-impact Innovation

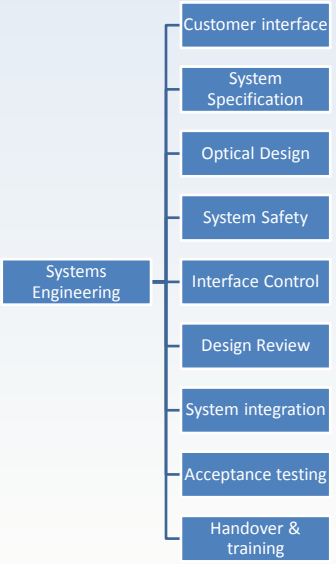
System Breakdown Structure



22

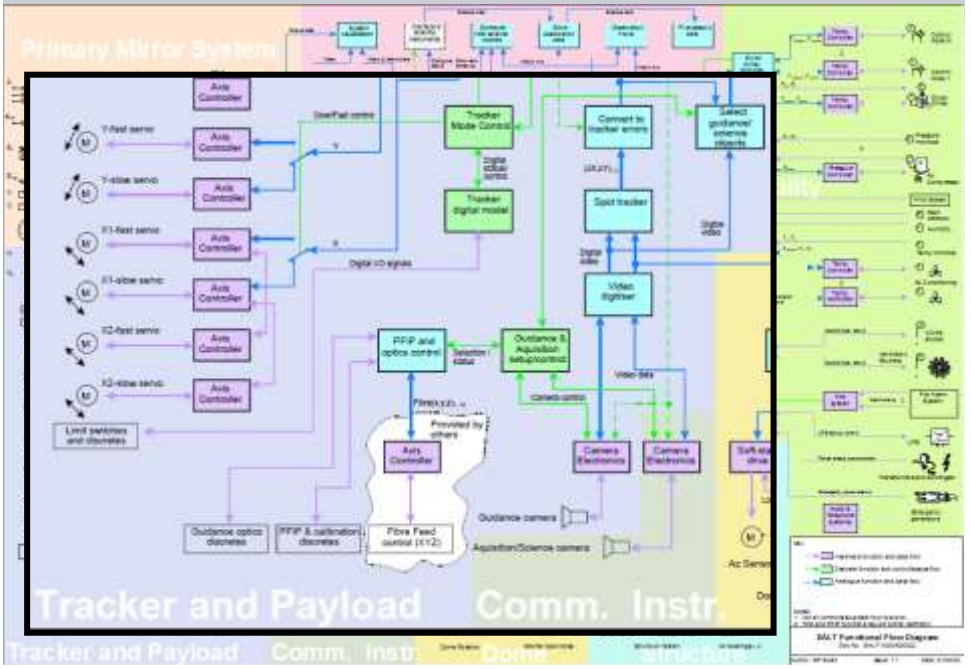
alphadot
High-impact Innovation

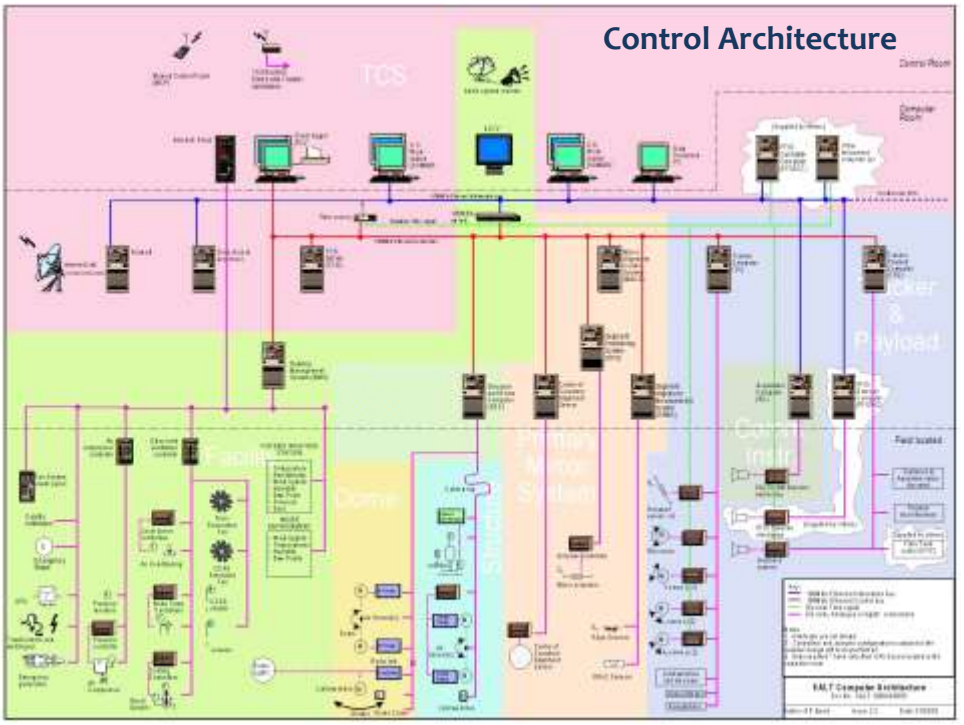
Systems Engineering activities

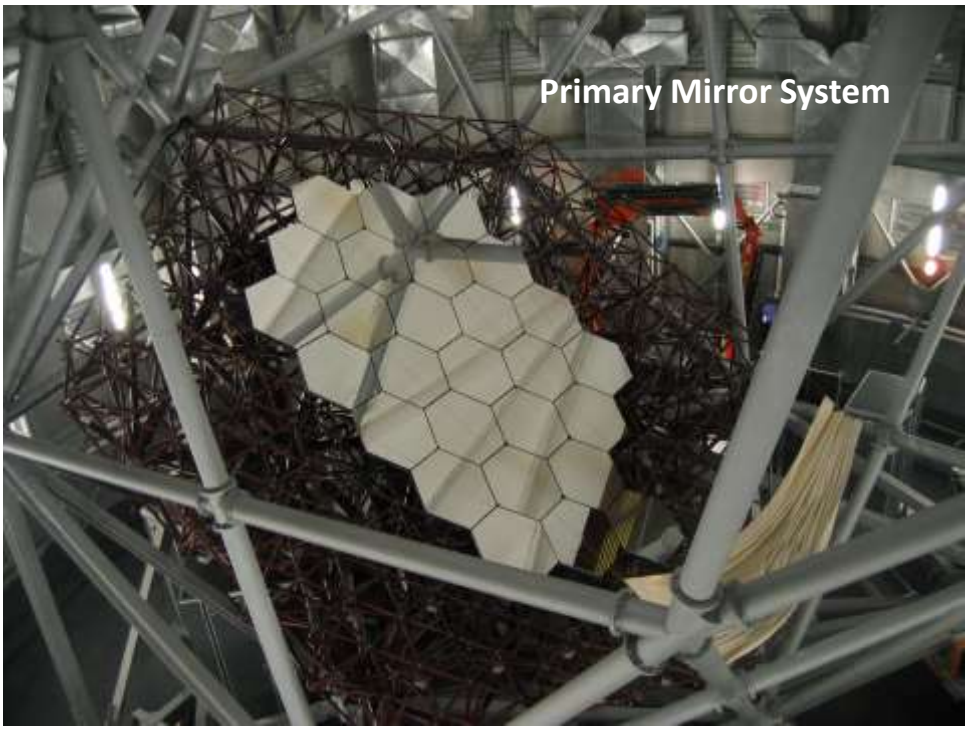


23

Functional Flow Block Diagram to optimise function allocation

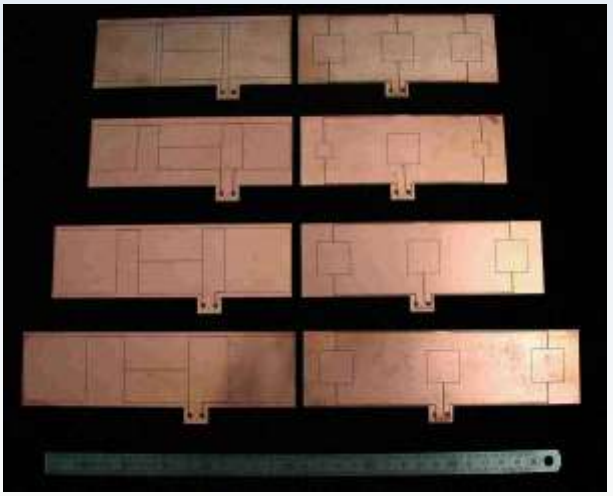



Control Architecture
TCS
Primary Mirror System
Dome


Primary Mirror System

alphadot
High-impact Innovation

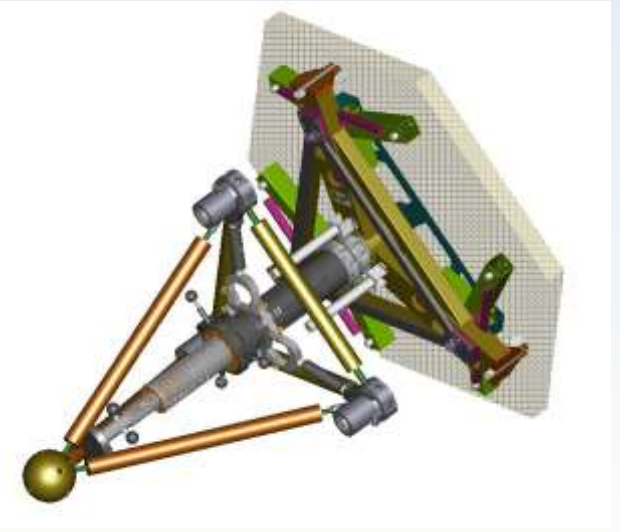
Capacitive edge sensors – 50nm accuracy



28

alphadot
High-impact Innovation

Mirror mount and insertion tool



29

alphadot
High-impact Innovation

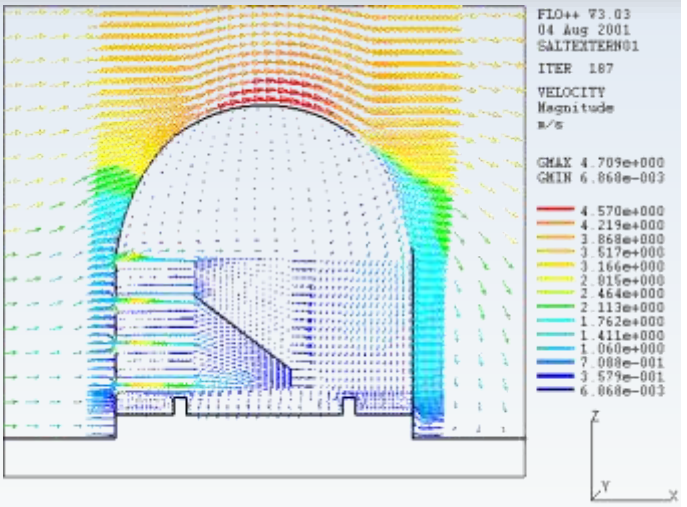
Facility

- Seismic stability
- Thermal properties
- Pier flatness

32

alphadot
High-impact Innovation

Air Flow Modeling

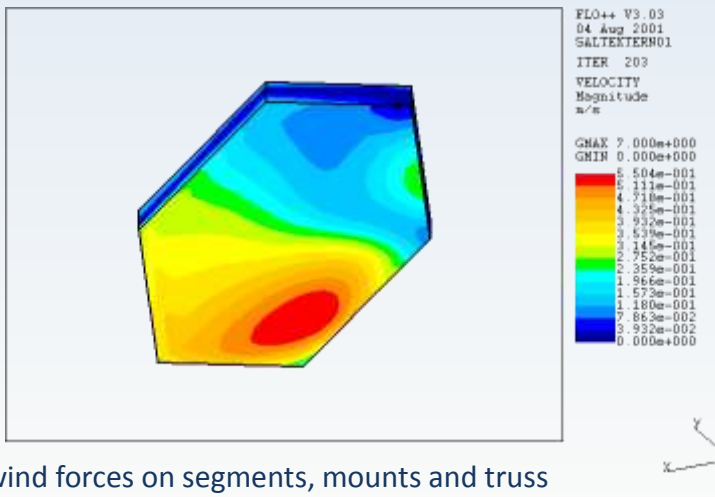


- Minimise Dome Seeing
- Determine wind forces on Mirror and Structure

33

alphadot
High-impact Innovation

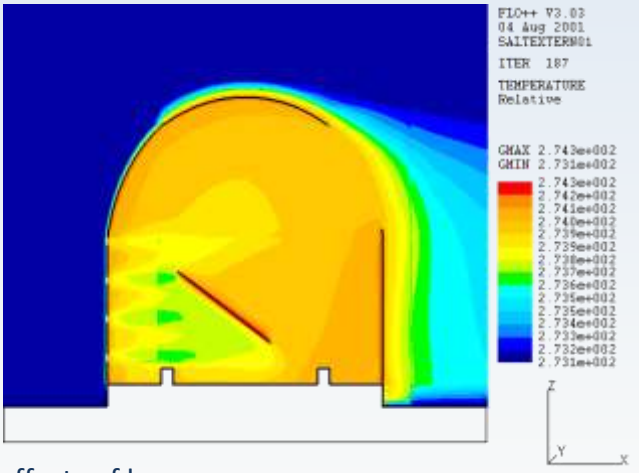
Wind on Mirror



- Confirm wind forces on segments, mounts and truss

alphadot
High-impact Innovation

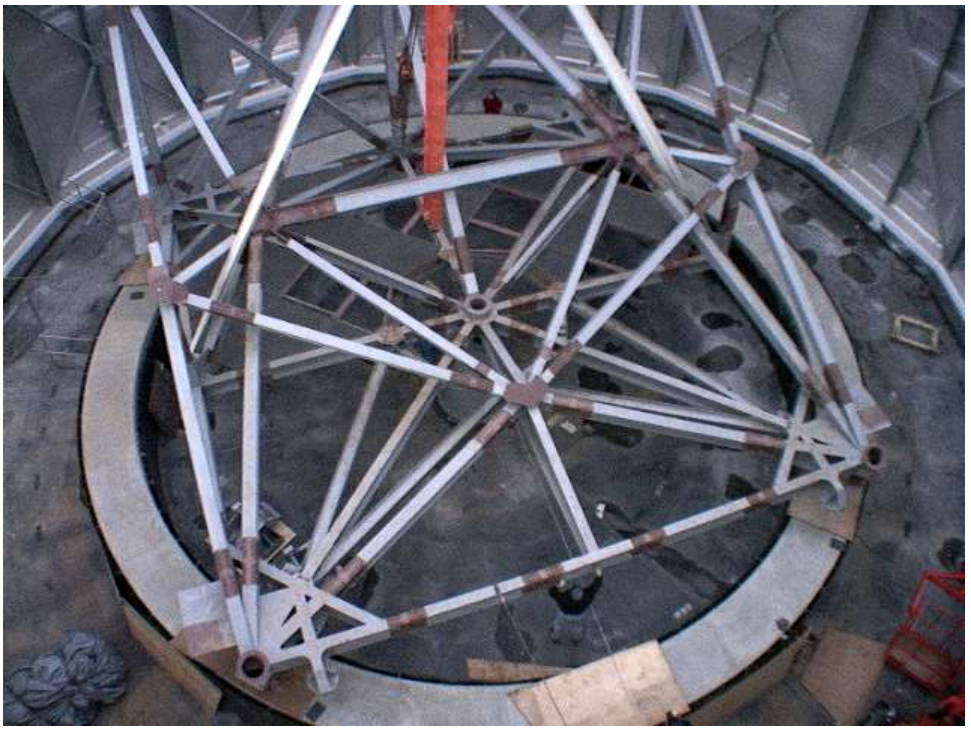
Thermal Modeling

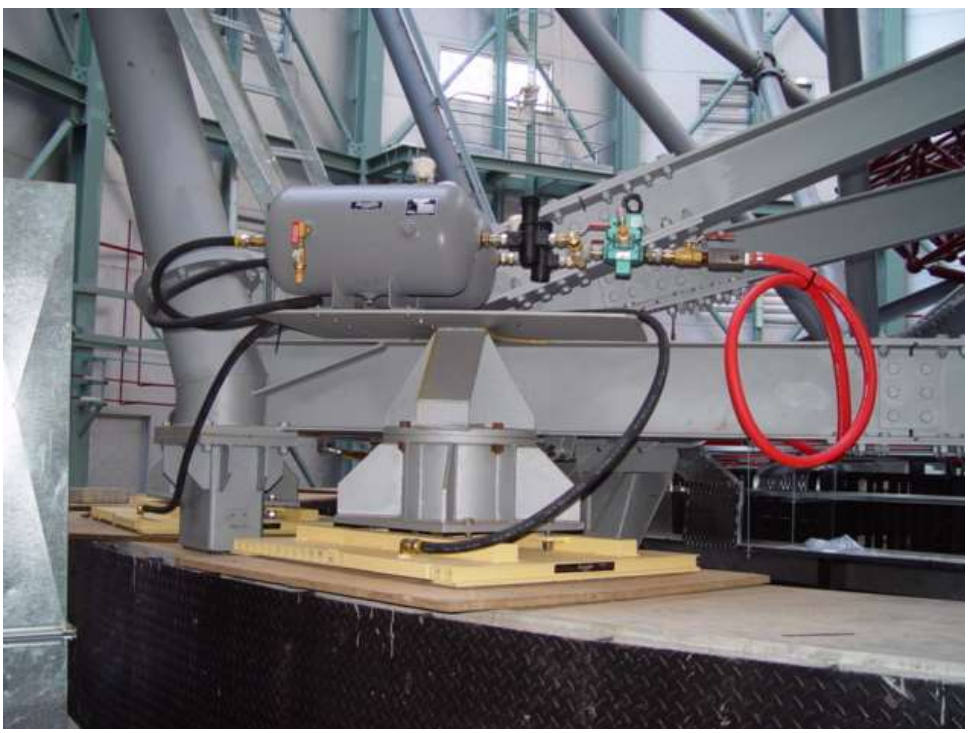


- Confirm ventilation effects of louvres
- Determine louvre control logic
- Confirm Temperature specs can be met

35


System Overview
Centre of Curvature Sensor
Dome
Optical Payload
Tracker
Primary Mirror
Structure
Visitor's gallery
Mirror Coating Room
Control room and workshop
Spectrometer Room






Telescope Dome

45

alphadot
High-impact Innovation

Challenges: Tracker

- Must follow star as it "moves" across the sky
  - For up to 3 hours without smudging of image
  - Keep light falling on the same CCD pixel
  - 750kg Payload mass
  - 15m up in the air (wind and thermal effects)
- Precision X, Y, Z,
  - Tracking to within 6 micron
  - 3.25 m total travel
- Φ,Θ and ρ positioning
  - Follow angle to within 1" (0.0003 degrees)
  - +/- 8.5 degrees total travel
- Motion is time synchronised to within 1 millisecond absolute

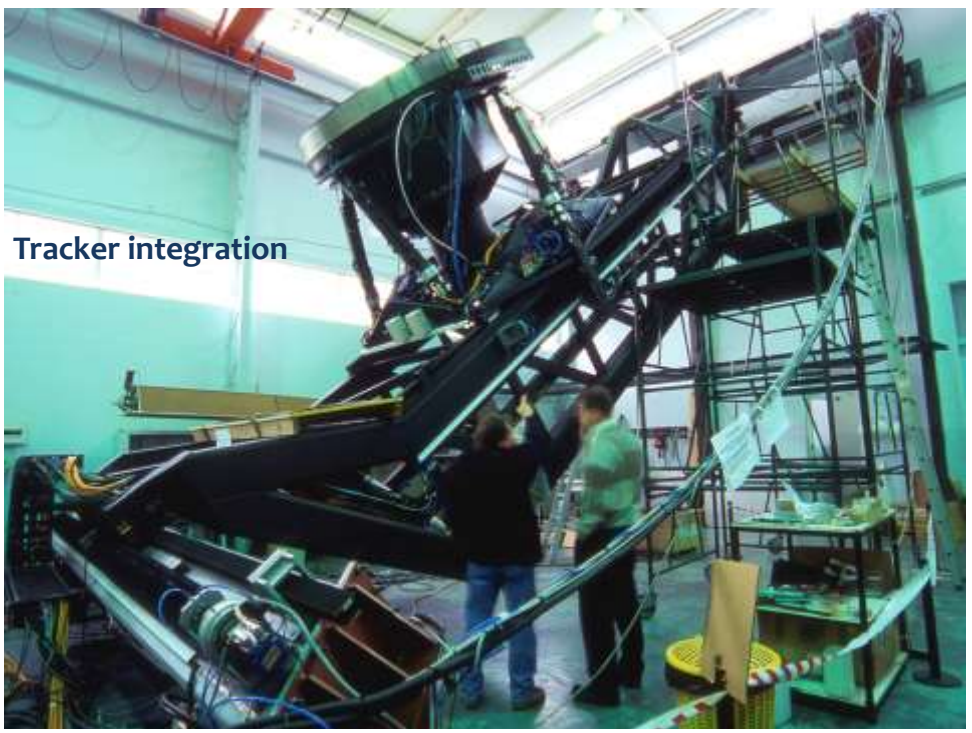
46

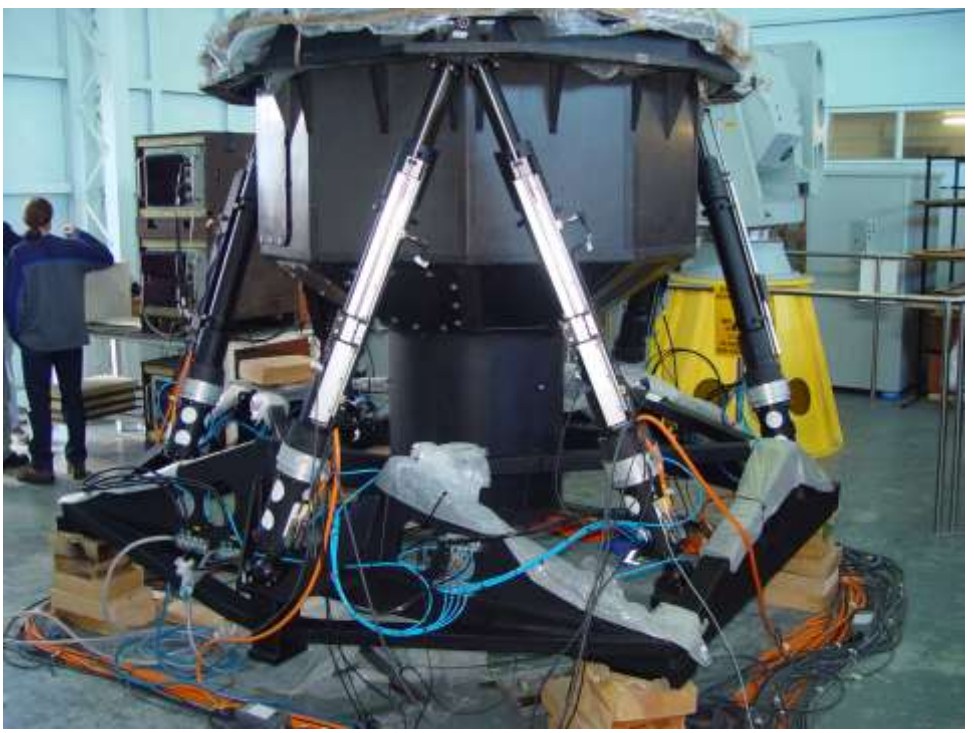
alphadot
High-impact Innovation

Challenge: Tracker (cont.)

- How is this achieved?
  - 10 axes of movement (13 actuator control loops)
  - High precision linear and rotary encoders
  - Separation of “hard” real-time and “soft” real-time SW
  - Thermal and positional compensation

47

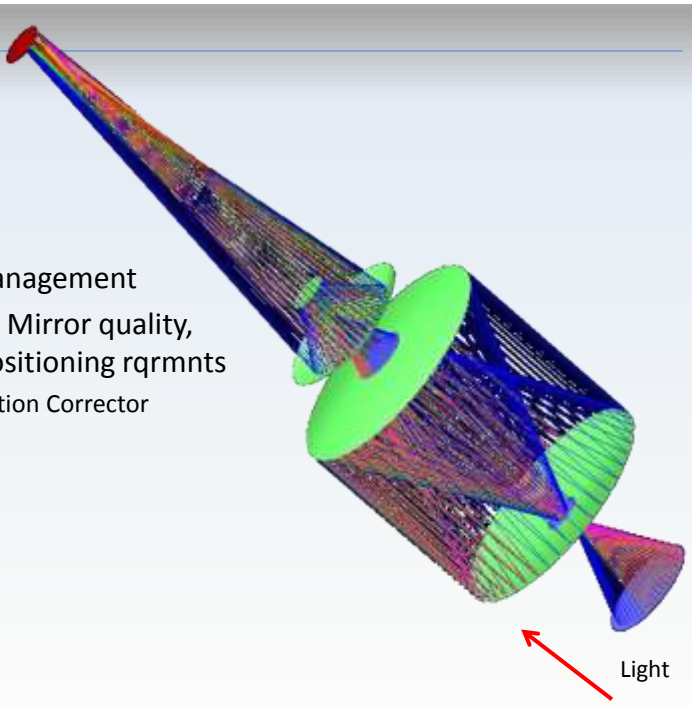


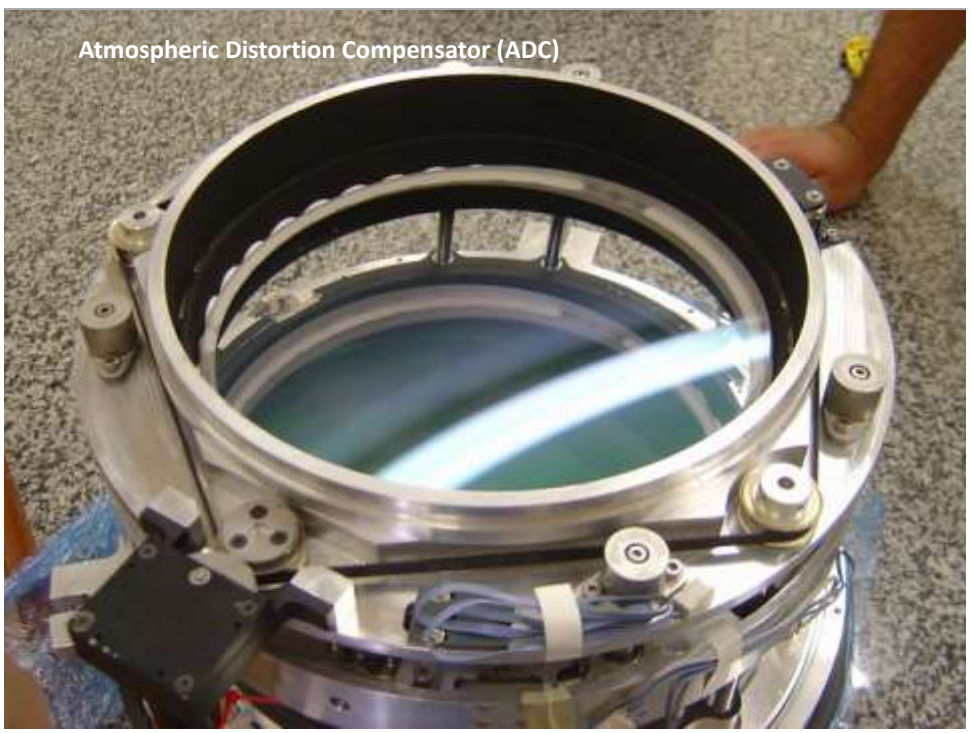


alphadot
High-impact Innovation

Optical Analysis

- Image Quality management
- Determination of Mirror quality, alignment and positioning rqrmnts
  - Spherical Aberration Corrector
  - Primary Mirror
  - Tracker



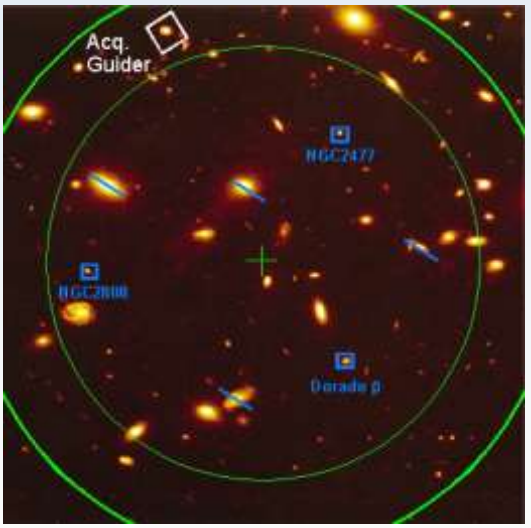



High Resolution Spectrograph (HRS)

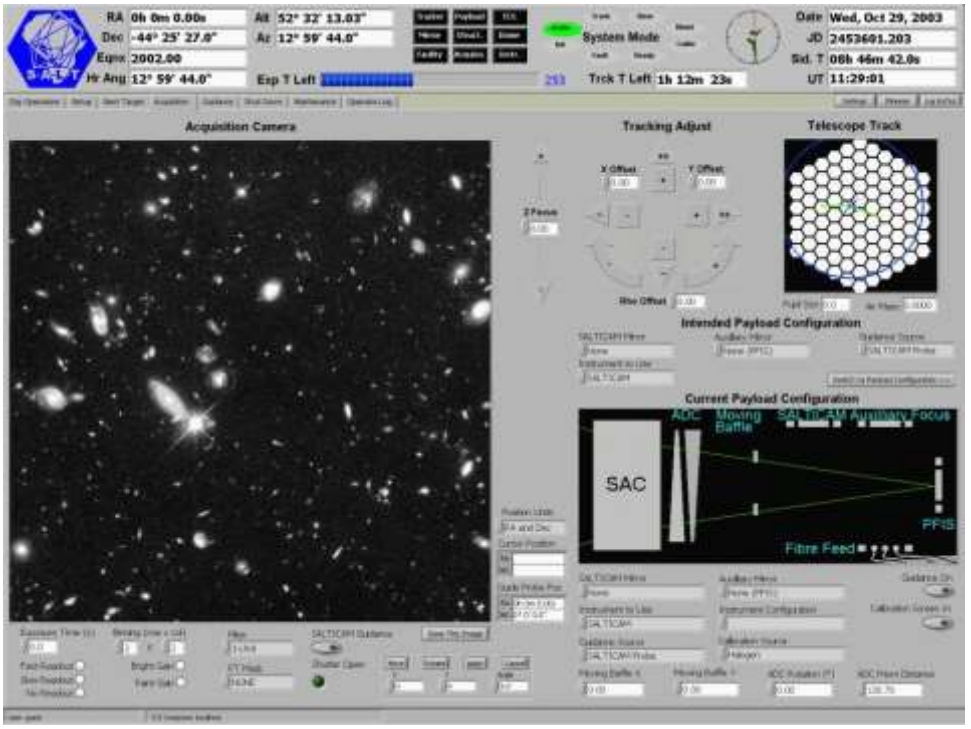
alphadot
High-impact Innovation

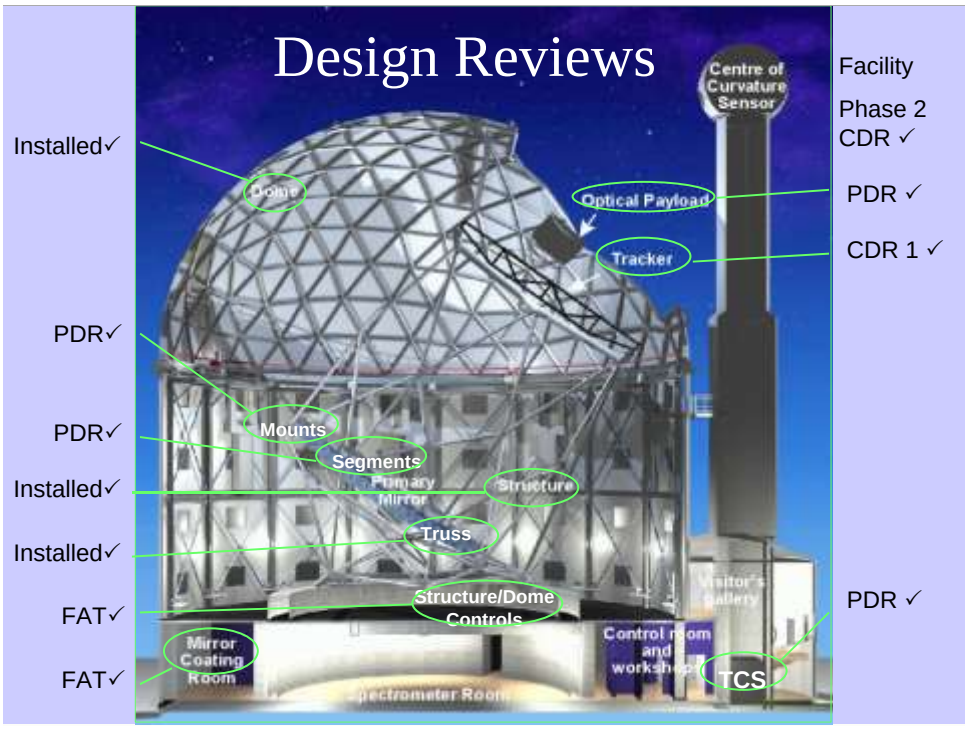
Telescope Control System

- Distributed control
- PC's (heavy maths)
- Labview
- 100 Mb/s Ethernet
- Central Node is TCS
  - SO and SA MMI
  - Astrometry
  - Observation scheduling
  - Pointing model
  - Subsystem co-ordination
  - Event/fault logging
  - Data storage



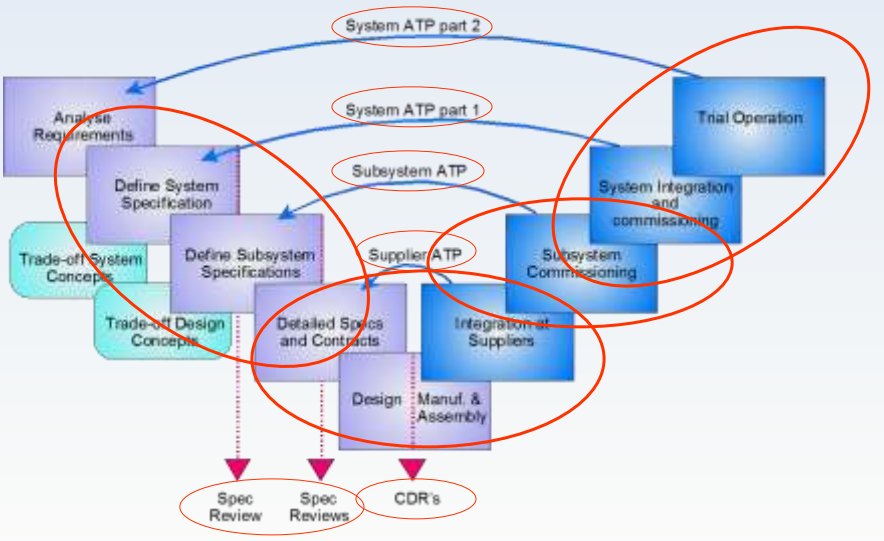
54


RA 0h 0m 0.00s
Dec -44° 25' 27.0"
Equinox 2002.00
Hr Ang 12° 59' 44.0"
Alt 52° 32' 13.03"
Az 12° 59' 44.0"
Exp T Left
System Mode
Trck T Left 1h 12m 23s
Date Wed, Oct 29, 2003
JD 2453601.203
Sid. T 08h 46m 42.0s
UT 11:29:01
Acquisition Camera
Tracking Adjust
Telescope Track
Intended Payload Configuration
Current Payload Configuration
SAC
PFIS
Fibre Feed


Design Reviews
Centre of Curvature Sensor
Dome
Optical Payload
Tracker
Mounts
Segments
Primary Mirror
Structure
Truss
Structure/Dome Controls
Mirror Coating Room
Control room and workshop
TCS
Visitor's gallery
Spectrometer Room
Installed✓
PDR✓
PDR✓
Installed✓
Installed✓
FAT✓
FAT✓
Facility
Phase 2 CDR ✓
PDR ✓
CDR 1 ✓
PDR ✓

alphadot
High-impact Innovation

SALT verification process



57

Subsystem factory testing

- PDR's and CDR's at suppliers (against subsystem spec)
- Software code reviews and testing (against SW standard and spec)
- Component-level inspections and tests
- Factory Acceptance Tests (FAT) (against subsystem spec)

alphadot
High-impact Innovation

System-level testing

- SW followed incremental development process
  - TCS builds integrated one subsystem at a time
  - Developmental tests
  - Dry-runs of acceptance tests
  - "As-built" image quality error budget
- Followed by formal verification
- Record results in VCRM
- "Concede" or "fix" failed items

alphadot
High-impact Innovation

VCRM

- System and subsystem specs
- Full spec in a spreadsheet format
- Records verification status (Pass, Fail, Concede, Info)

Spec Para.	Heading	Requirement	Test Level	Test Method	Ref.	Test Type	Status
5.3.1.5.3	Tracking rates	The tracker shall follow the motions of objects that deviate from sidereal track rate by as much as 4" per second , meeting the requirement in 5.3.1.5.2.	System	Test		Pointing and tracking tests	
		The tracker optical payload shall rotate to keep a constant image orientation during an entire observation (~230º).	System	Test		Pointing and tracking tests	
5.3.1.5.4	Tracking range	The tracker shall be able to follow any object along a 12° arc in Right Ascension anywhere in the required declination range, as per 5.3.1.4.8	System	Test		Pointing and tracking tests	

61

alphadot
High-impact Innovation

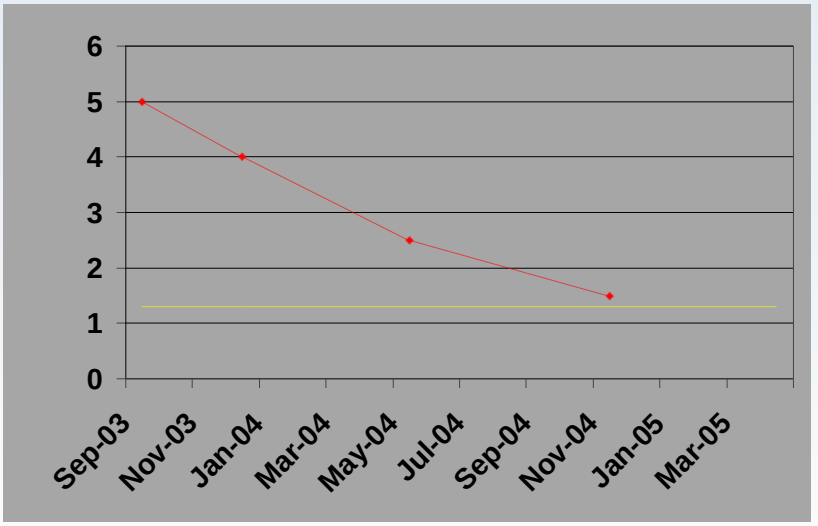
ATP Committee

- Represent the "SALT Board"
- Accept telescope on behalf of science community
- Comprise 5 members
  - Project Scientist (Chair)
  - Operations Manager
  - 3 Board members
- Must approve verification of System-level verification
  - Approve verification method and level
  - Approve test procedures
  - Review test results
  - Approve compliance evidence
- Involved in sub-system VRCM reviews where desired

62

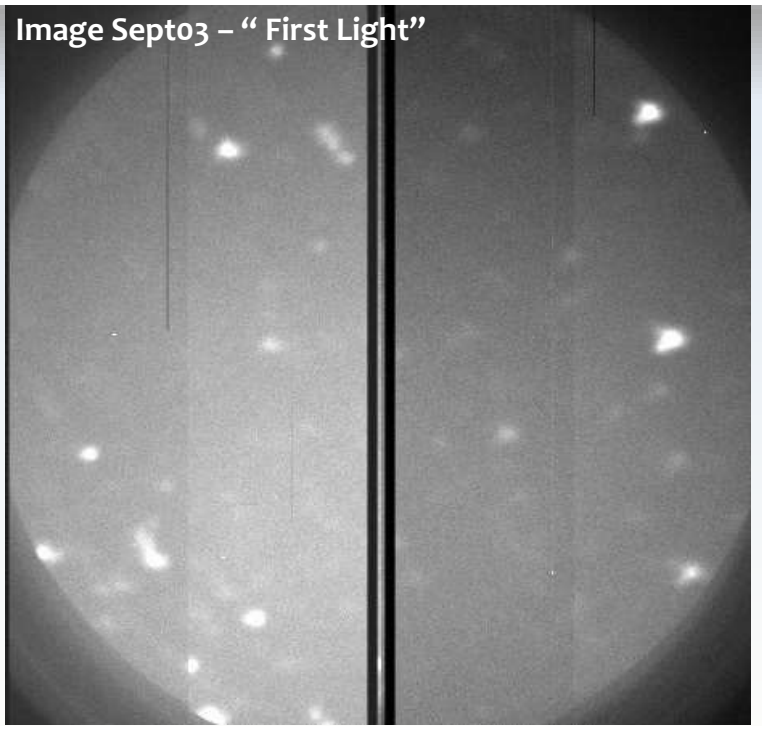
alphadot
High-impact Innovation

Image EE(50) on-sky [arcsec]



63

Image Sept03 – " First Light"



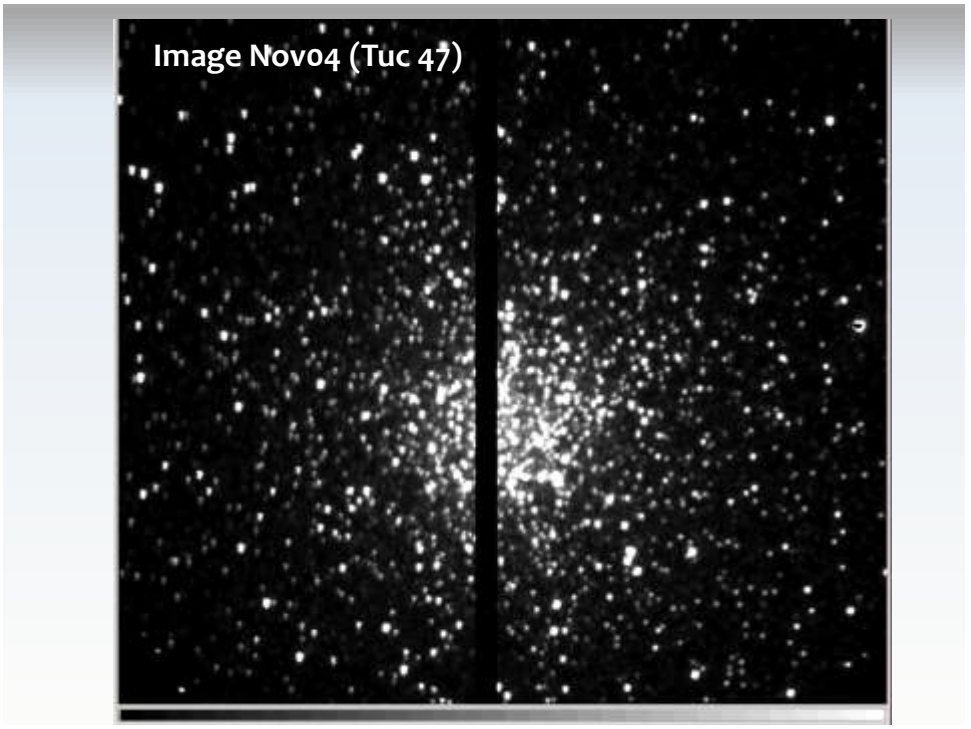


Image Nov04 (Tuc 47)


Image 2014 (Tuc47) – with artificial colour
http://www.salt.ac.za

66

alphadot
High-impact Innovation

Was SE worth it?

- Clear measurable targets per system – payment criteria
- Well orchestrated and understood process
- Problem resolution had baselines to refer to
- Technical visibility to the user/customer
- What seemed impossible, was achieved

- Not perfect
  - Residual 5% of issues carried over to Operation team
  - Two significant issues not resolved by handover
  - Operational staffing was underestimated

67

Development & Construction team – SALT Inauguration 2005