Model-based Systems Engineering
Telescope Modelling Challenge Team

Robert Karban

30 January 2011

About Robert

Agenda

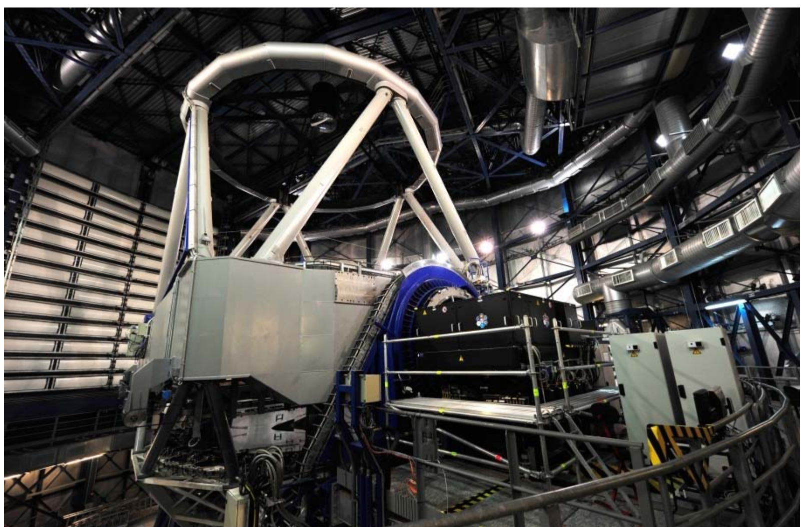
- Challenge team for Telescope Modeling
  - About
  - Achievements
- Early adopters at the European Southern Observatory
  - About ESO
  - The European Extremely Large Telescope (E-ELT) Project
  - Modeling in the E-ELT project
  - Status
- Live Demo of the Models

Challenge team for Telescope Modeling

About SE^2

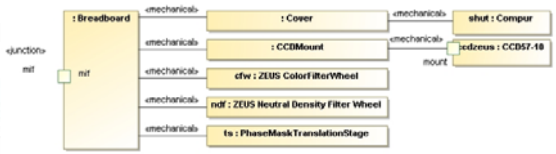
- Collaboration between European Southern Observatory (ESO) and German Chapter of INCOSE (GfSE) since 2007
- Access to high-tech project, the Active Phasing Experiment (APE).
- The team members are:
  - Robert Karban (ESO)
  - Tim Weilkiens (oose GmbH)
  - Rudolf Hauber (HOOD Group)
  - Rainer Diekmann
  - Michele Zamparelli (ESO)
  - Andreas Hein (TU Munich)
- Former members: Andreas Peukert (TU Munich)

What is the challenge project about?



- System case study
  - APE technology demonstrator for future Extremely Large Telescope (ELT)
  - High-Tech interdisciplinary opto-mechatronical system in operation at Paranal observatory
- Goals
  - Create modeling guidelines and conventions for all system aspects, hierarchy levels, and views
  - Create fully fledged SysML model
  - **Documented at http://mbse.gfse.de**


MAPS
Internal
Calib.
Metrology
ZEUS
Pupil Cam
DIPSI
Pupil Cam
GCAM
PYPS
SHAPS
ICAM
Derot
Parabola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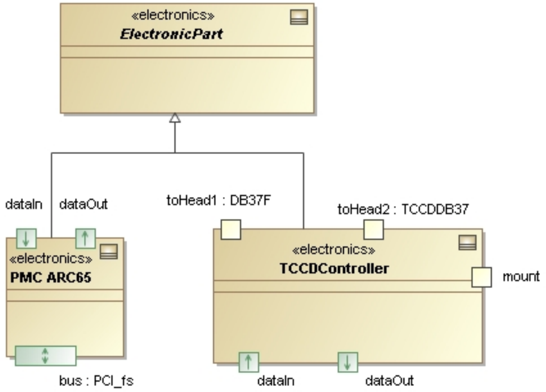
mif
: Breadboard
mif
«mechanical»
: Cover
«mechanical»
shut : Compur
«mechanical»
: CCDMount
«mechanical»
ccdzeus : CCD57-10
mount
«mechanical»
cfw : ZEUS ColorFilterWheel
«mechanical»
ndf : ZEUS Neutral Density Filter Wheel
«mechanical»
ts : PhaseMaskTranslationStage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ElectronicPart
dataIn
dataOut
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TCCDController
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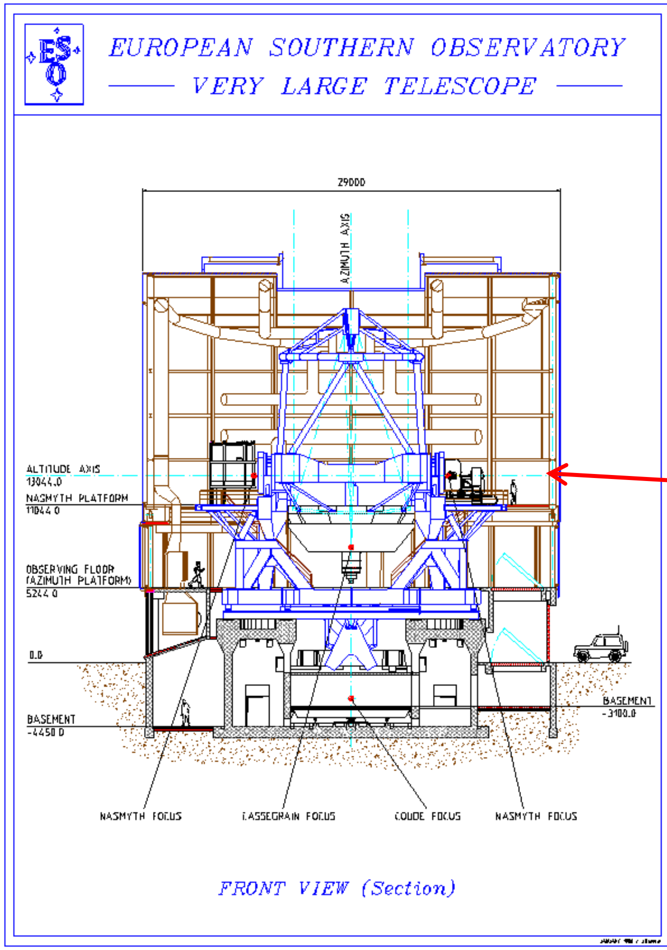
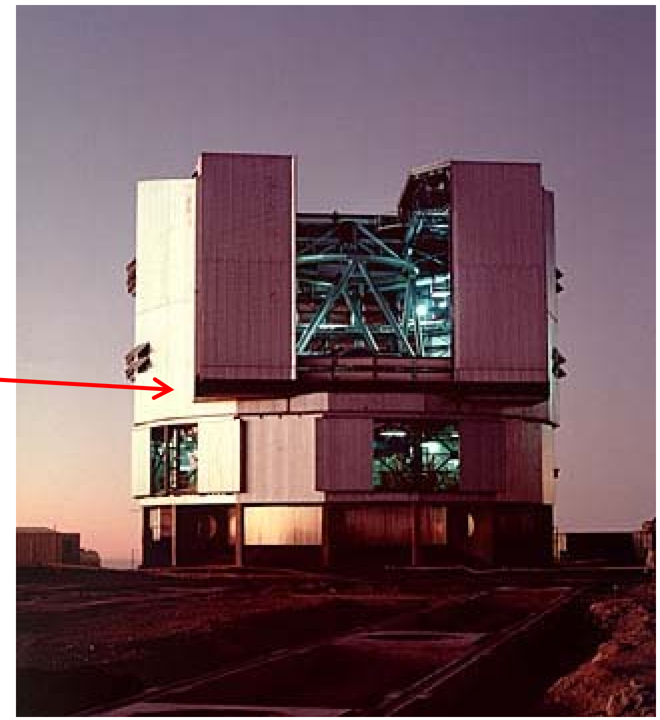




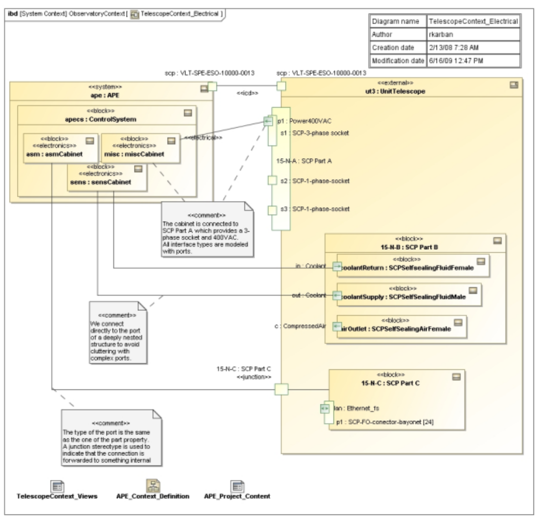
APE was installed at telescope in Atacama desert, Chile.

Images on this slide were produced by ESO

Installation on the platform of the telescope

City of Phoenix

What have we achieved?



- APE model, guidelines and best practices:
  - Model Organization
  - Style, Layout Naming Conventions
  - System Views
  - Requirements and Use Case Modeling
  - Structure, Interface, and Behavior Modeling
  - Non-functional Aspects Ontologies, Part Catalogs
  - Variant Modeling
  - Integration with other Disciplines
  - Cross-cutting the model and Traceability
  - Domain Specific Model Extensions
- Model, Model library and SE Profile
- Plug-in for modeling tool
- Input for tool vendor and SysML RTF

Cookbook for MBSE with SysML

Early Adopters at ESO

ESO

Non-profit Intergovernmental European Organisation for Astronomical Research in the Southern Hemisphere

http://www.eso.org

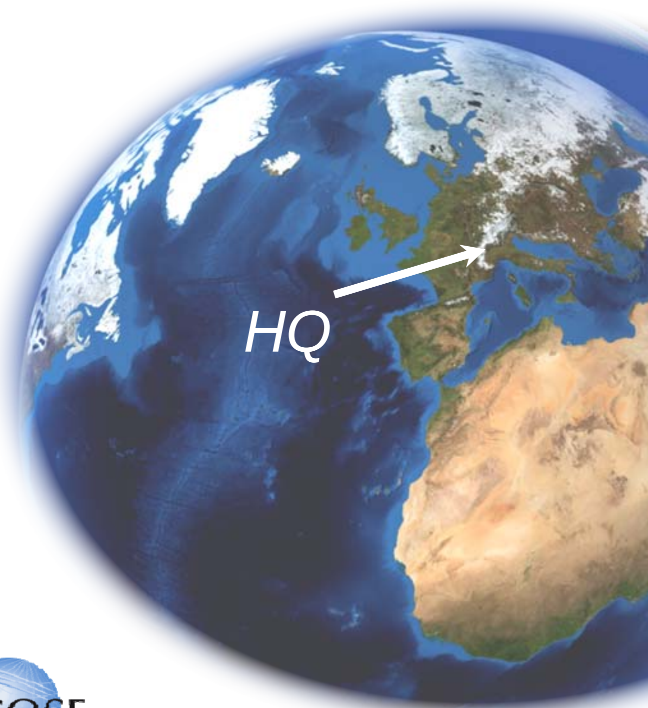
Headquarters in Munich, Germany, 3 Observatories in Chile

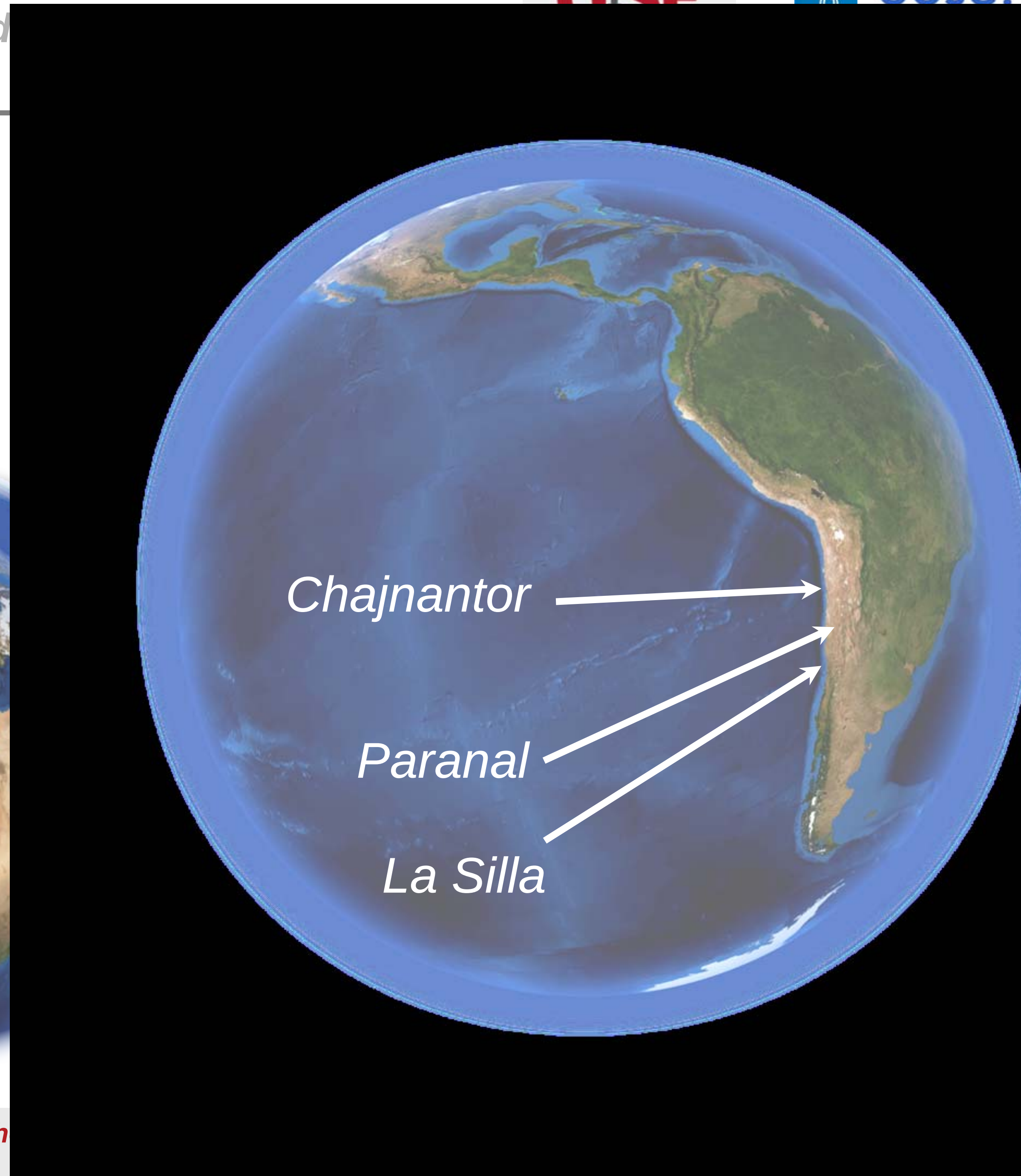
Mission statement

Build and operate world class ground based astronomical facilities

ESO’s sites

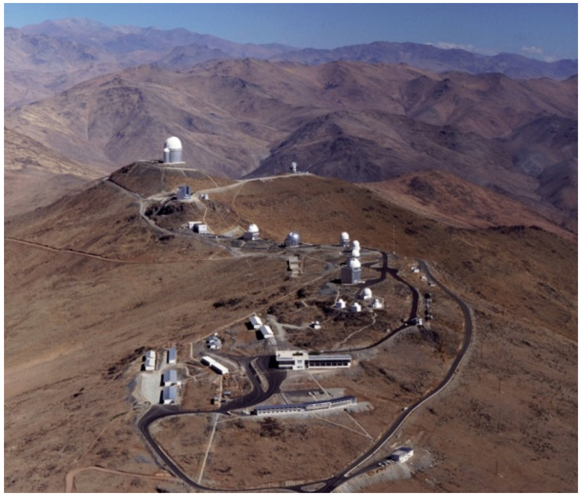
- Paranal (2600 m)
- La Silla (2400 m)
- Chajnantor (5000 m)





Observatories

La Silla



Paranal

Chajnantor

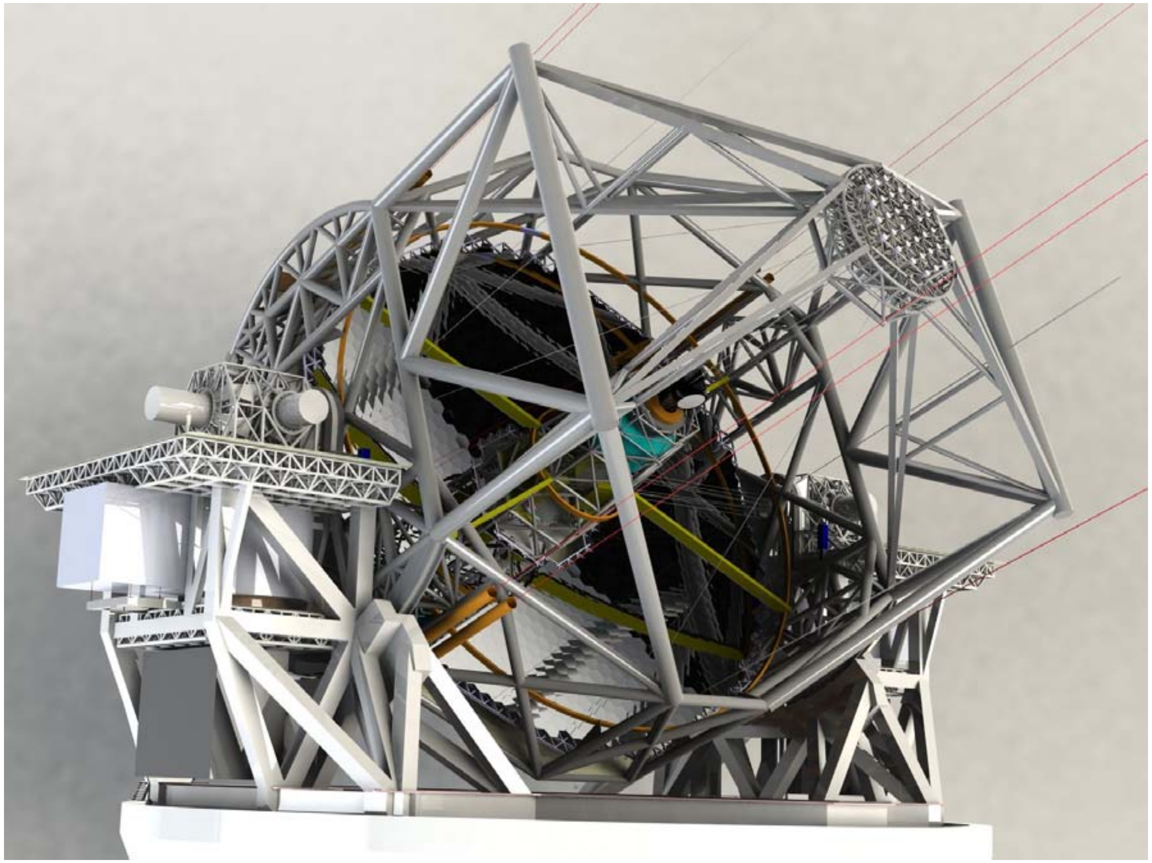
ESO major projects

Very Large Telescope (VLT)
Started 1988, in operation since 1999

Atacama Large Millimeter Array (ALMA)
Europe-US-Japan
Started 1998, installation starting now

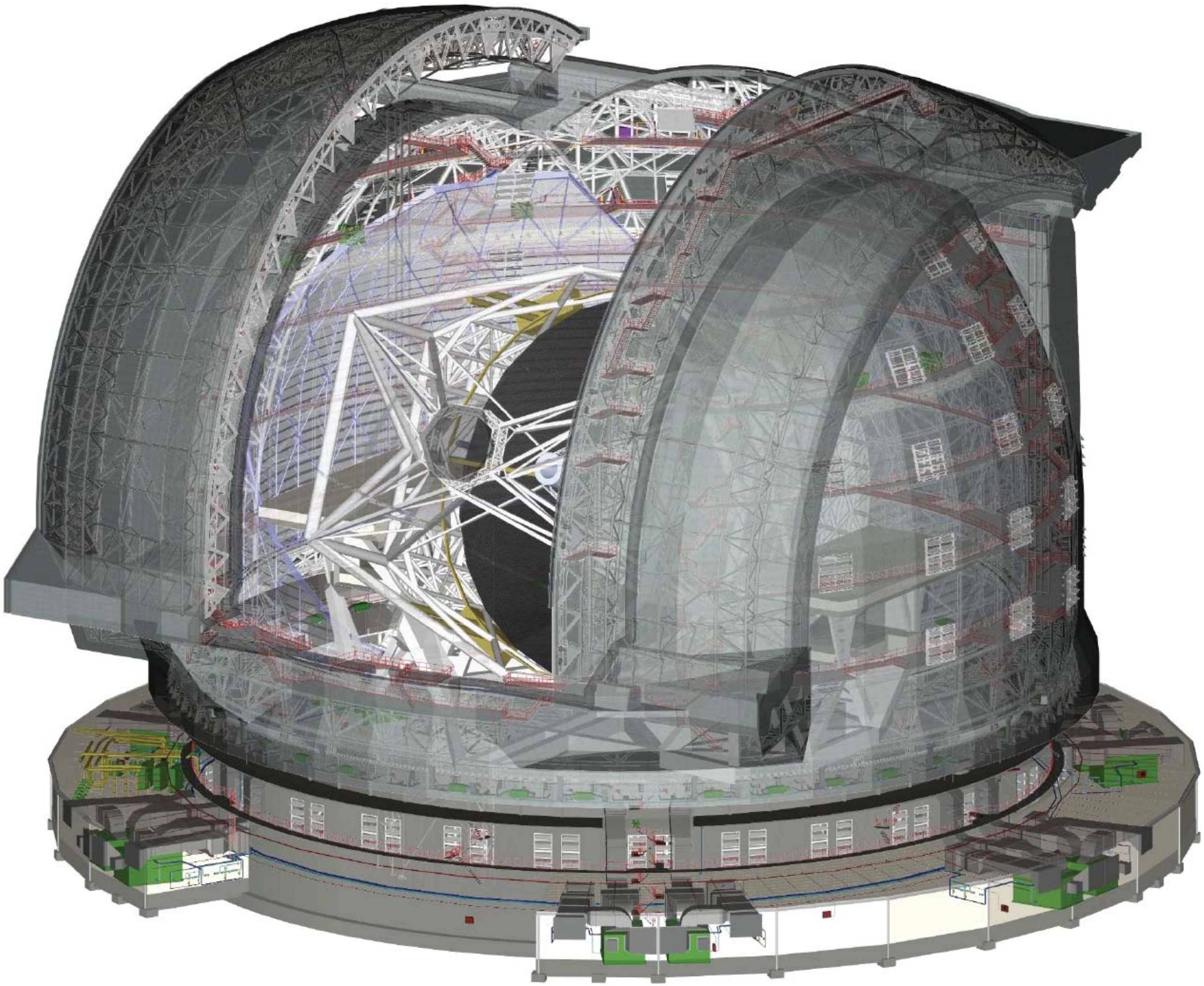
Images on this slide were produced by ESO

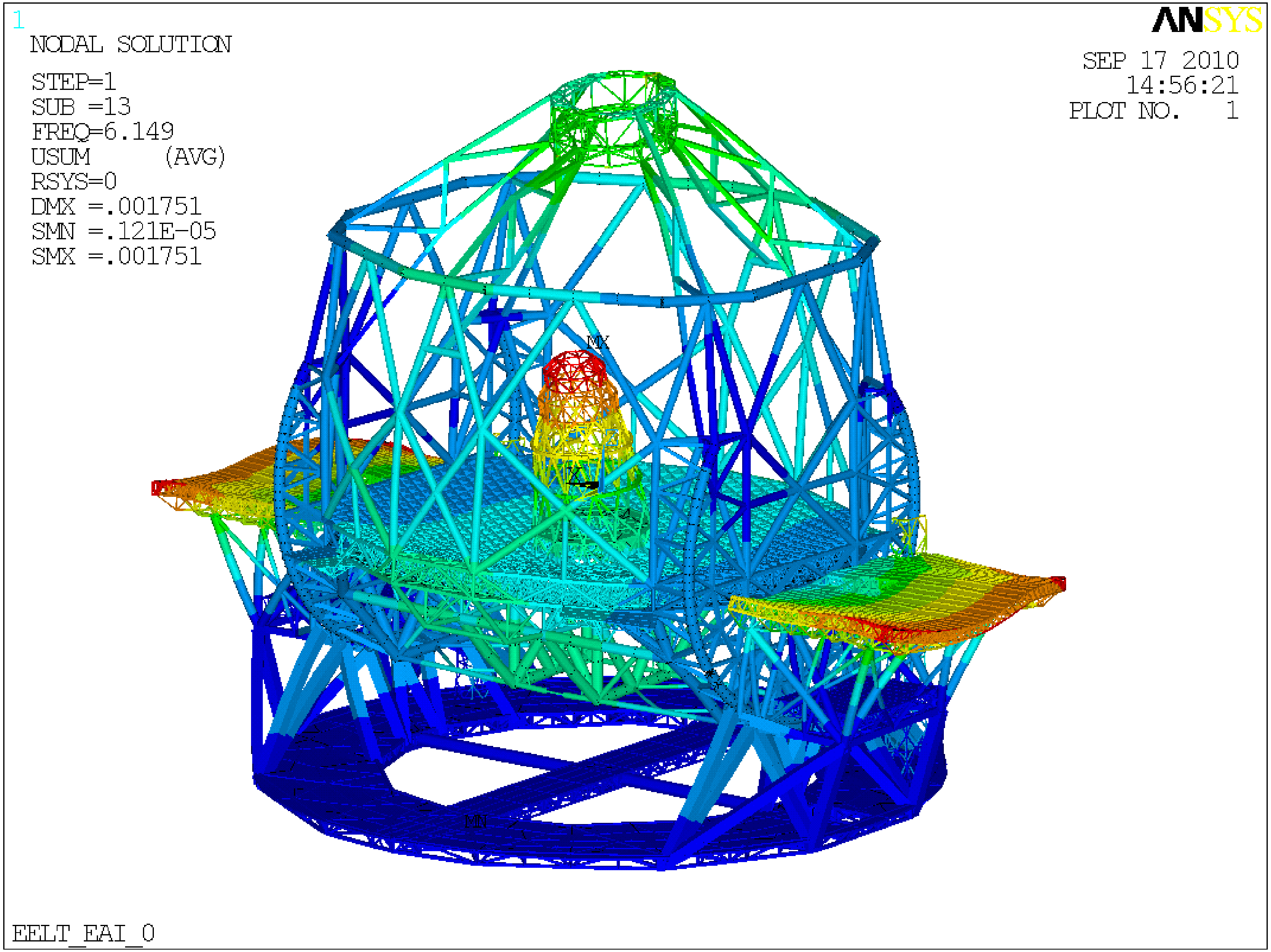
What we want to have: The E-ELT



- With its 42 m diameter mirror, the E-ELT will be the largest optical/near-infrared telescope in the world: “the biggest eye on the sky”.
- E-ELT will gather 15 times more light than any other telescope today.
- Exciting science: extra solar planets and discs, galaxy formation, dark energy/dark matter, and frontiers of physics.
- If approved construction could start in 2012 with beginning of operations 2020-2022

Images on this slide were produced by ESO

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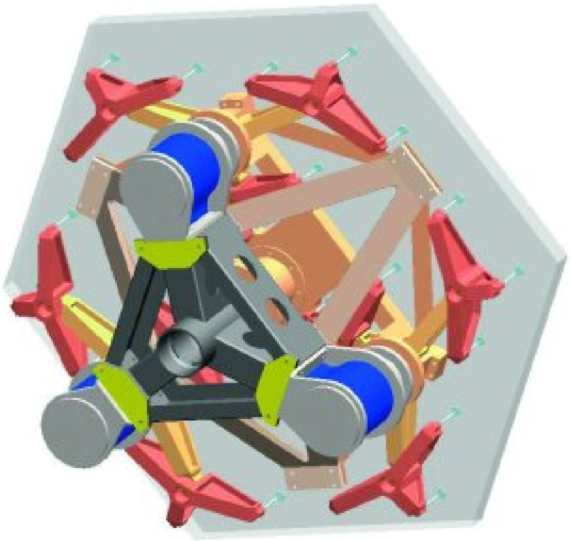
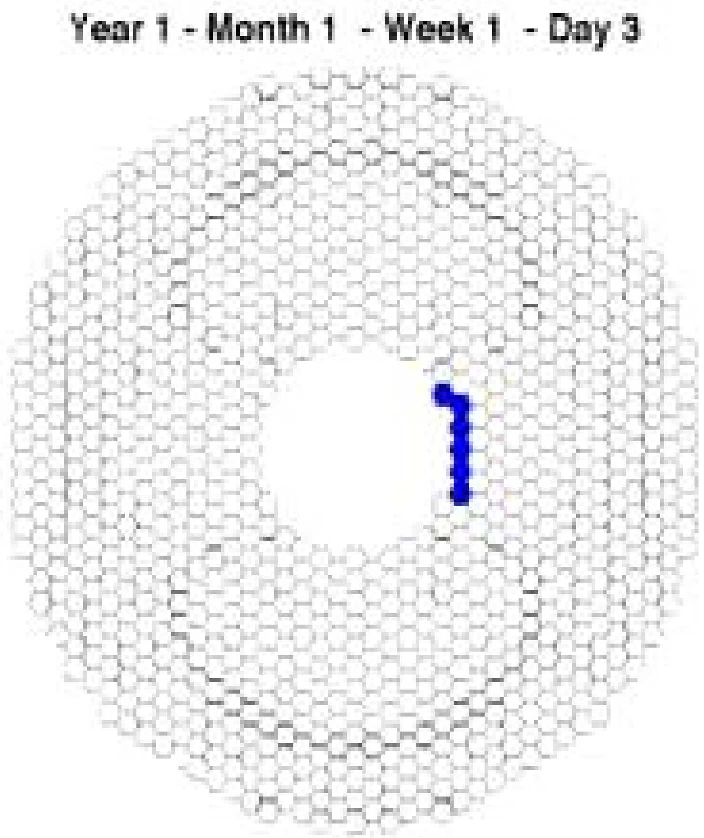
SMN =.121E-05
SMX =.001751
SEP 17 2010
14:56:21
PLOT NO. 1
MX
MN
EELT_EAI_0

E-ELT TCS (M1)

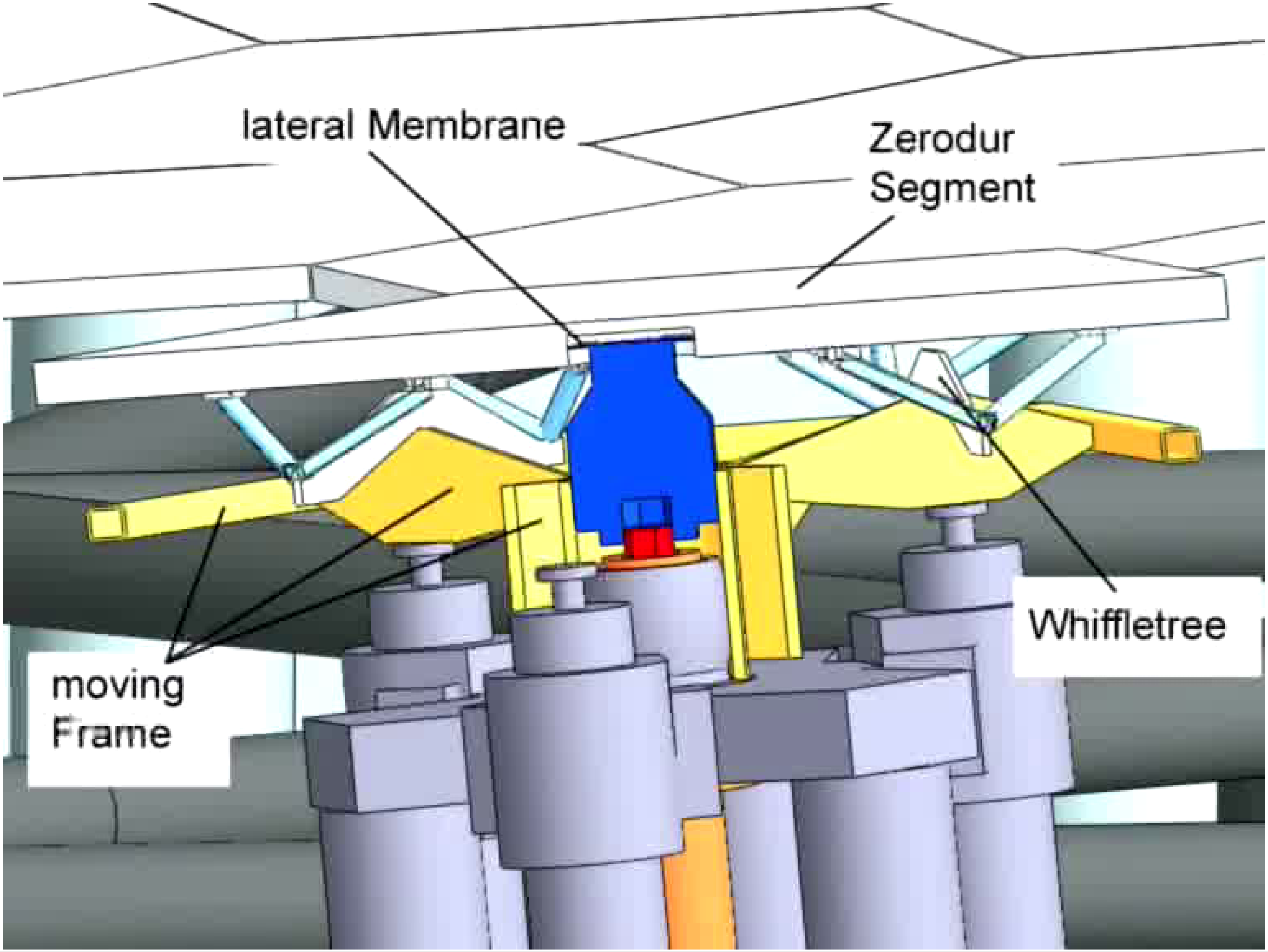


- The position of the 1000 mirrors must be coordinated to deliver a continuous surface with an error below 50nm across the 42m.
- 3000 actuators and 6000 sensors must work in a1Khz closed loop to meet this requirement.
- Moreover 12000 actuators (12 motors per segment, the warping harness) are responsible for deforming each individual segment in order to correct aberrations
- The control strategy must be flexible and adaptable to e.g. failure of sensors

M1 Evolution

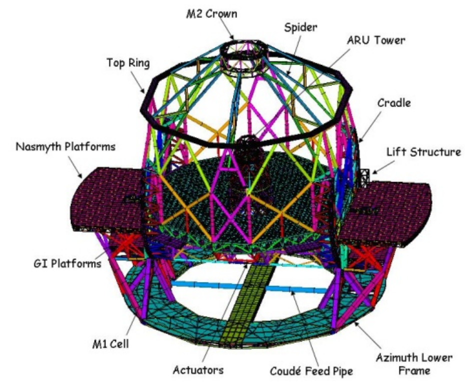


Not Phased	6	Missing	978	Not Usable	978	Mean Age	0
OK	0	Too Old	0	Broken	0	Max Age	0

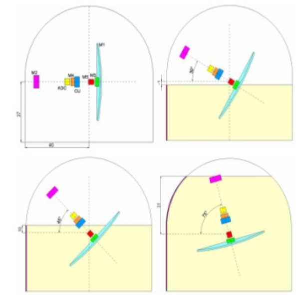

lateral Membrane
Zerodur
Segment
moving
Frame
Whiffletree

Models, Models, Models

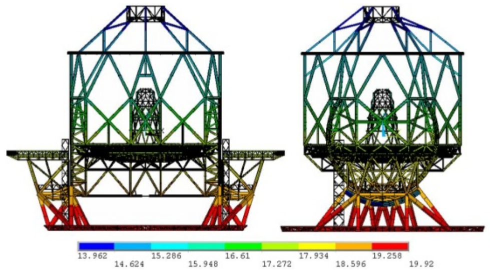
- Static and dynamic performance
  - The FE-model consists of about 19000 nodes and 38000 elements (beam, shell, mass and link).
  - Load cases analysed: gravity, buckling, wind, thermal gradients, earthquake



- Static Behavior under Wind-load
  - Wind Load on FE-model at different angles of elevation for maximum operational wind-speed

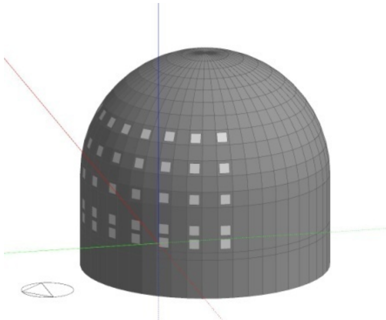


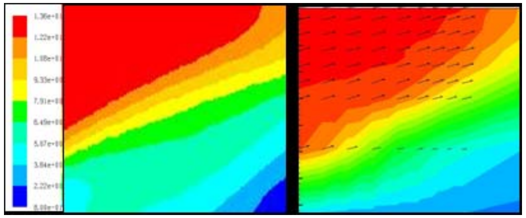
- Static Behavior under Thermal loads
  - Temperature Distribution [ºC] with a gradient along Z of 0.1ºC/m
  - Reference temperature is 20ºC

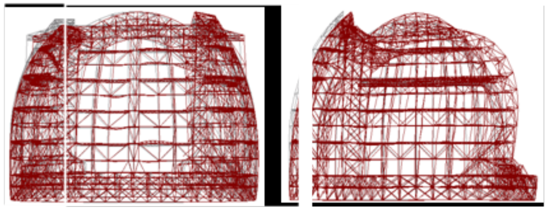


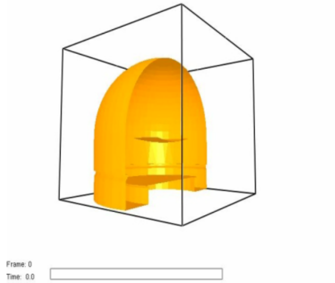
More Models

- Air Conditioning Performance
- Analyze Wind Buffeting and Dome Seeing
  - Analyse Air Velocity
  - CFD Analysis Models
  - Wind tunnel tests
  - Thermal Analysis Models
- Earthquake Analysis
  - Verify the structural behaviour during an earthquake
  - Analyze time history to obtain stresses and deflections.
- Fire Analysis
  - Determine Smoke-free layer



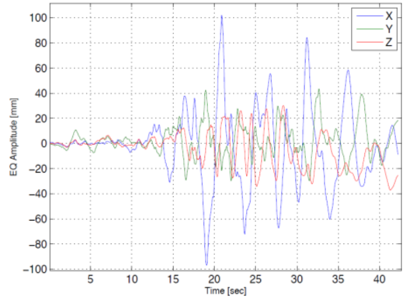




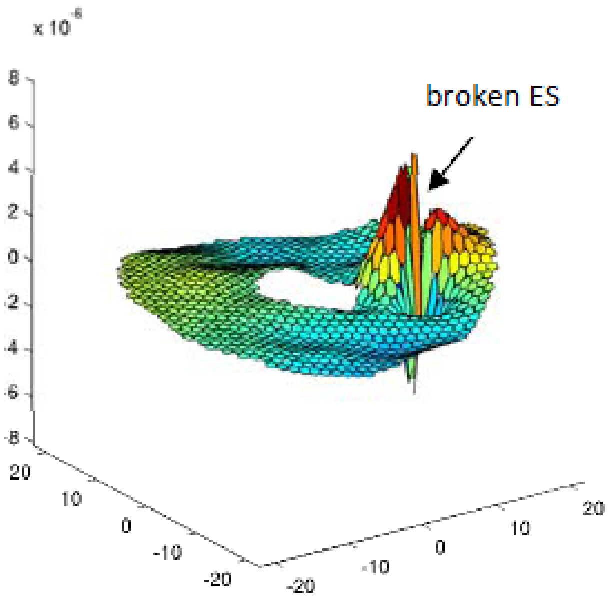


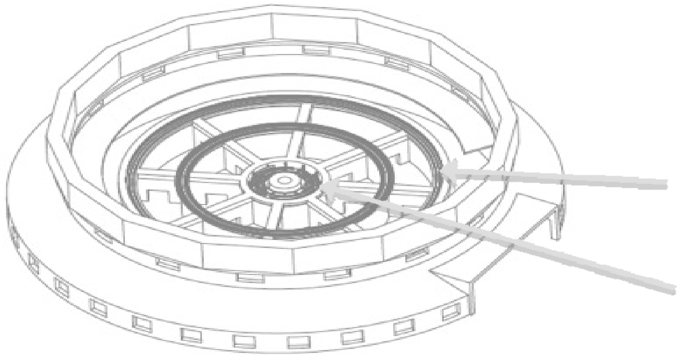
Need more Models?

- Earthquake
  - Analyze displacement of actuators
- FDIR
  - Analyze impact of broken sensors
- Tradeoff analyses
  - Control Structure
  - Drive and sensor location

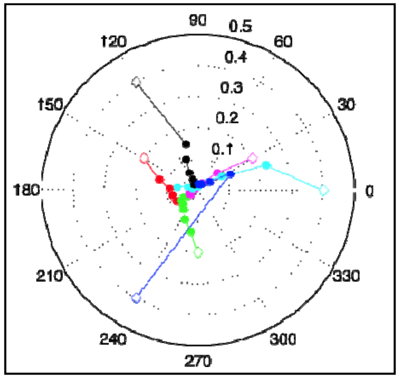


Mirror shape after 25.0 s with ES 239 failure

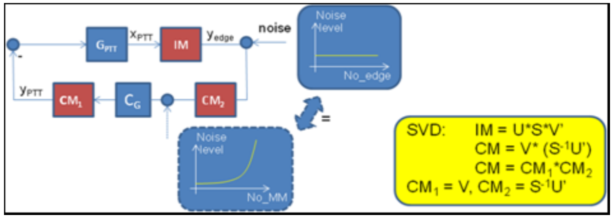




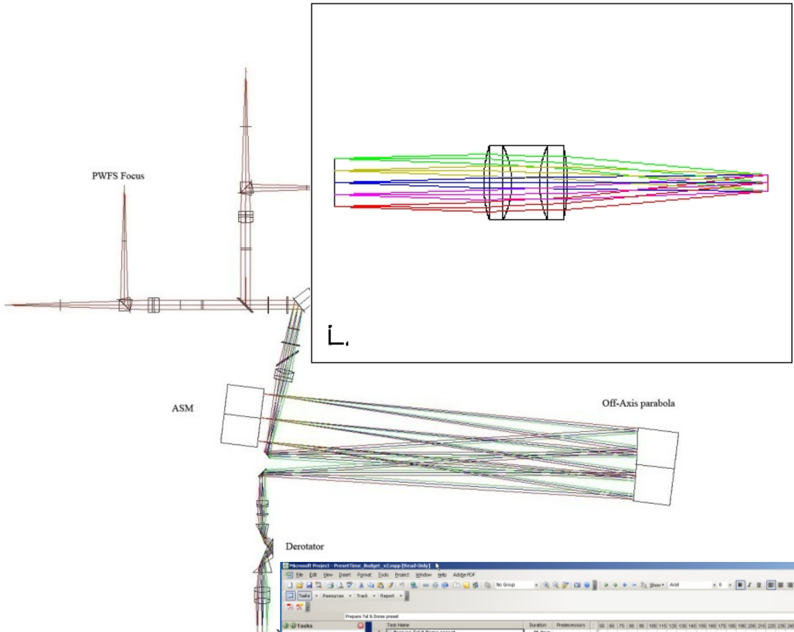
And more Models

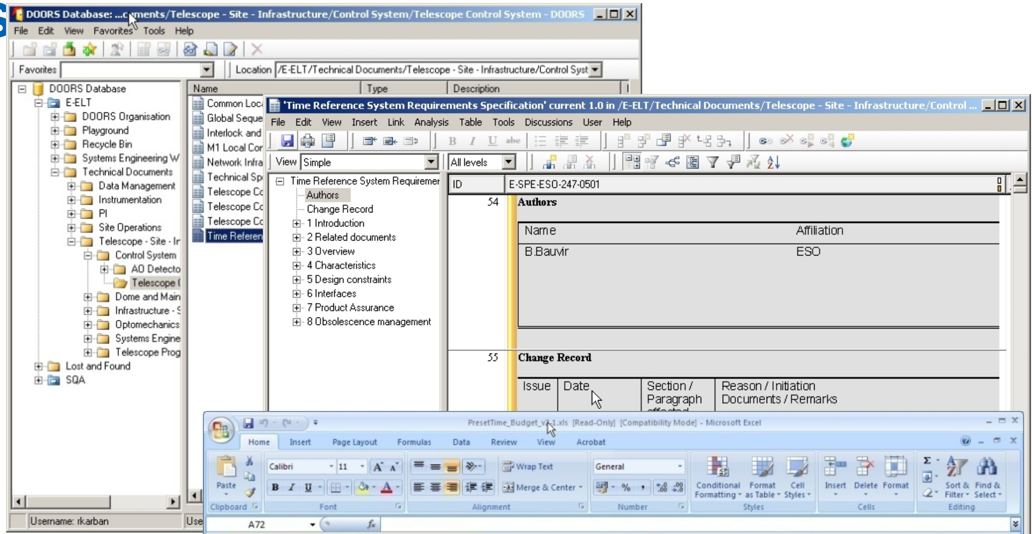


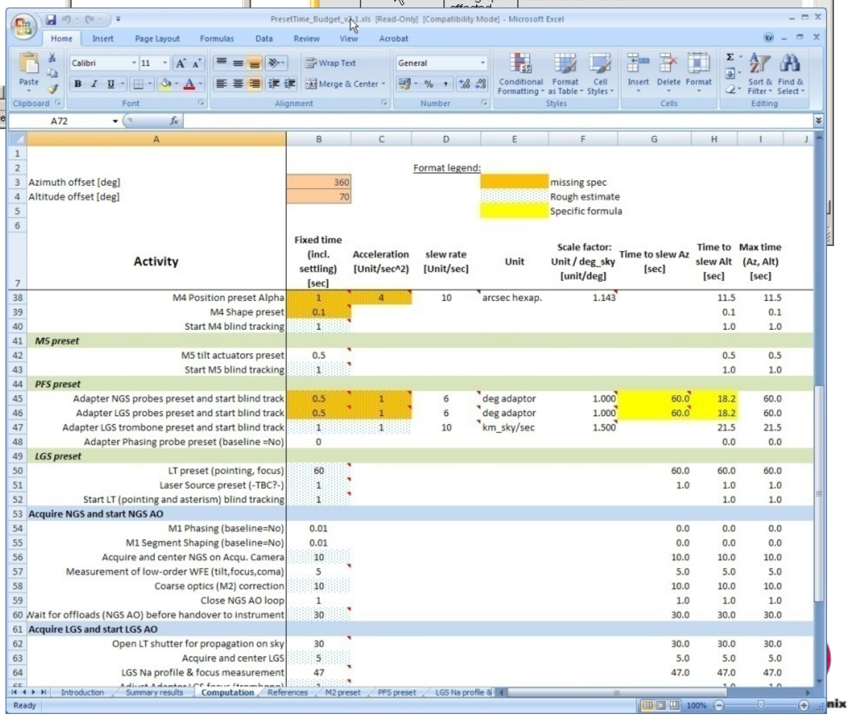
- Control strategy
  - Blind tracking
  - Low order optimization, stroke management
  - Numerical DM/WFS registration
  - AO controller
    - 500Hz, 2ms delay
    - Saturation management, anti wind-up
- Control engineering
    - Design trade-off analyses
    - Performance analysis
    - Requirements elicitation for actuators, sensors and control system
    - Failure and hazard analyses
    - Verification of contracted design

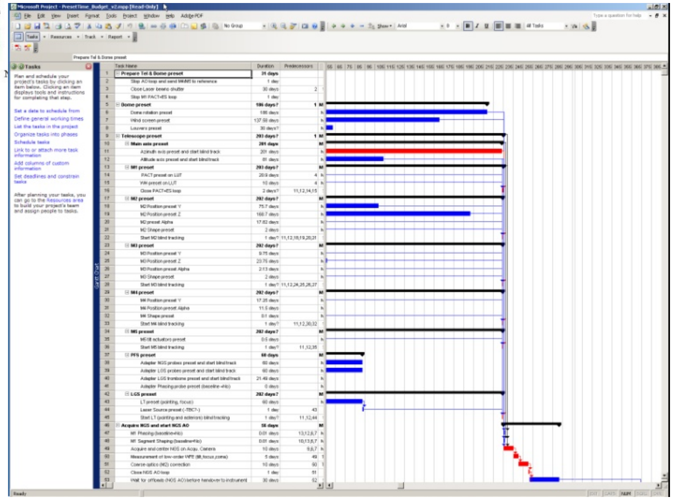


Artifacts, Artifacts, Artifacts

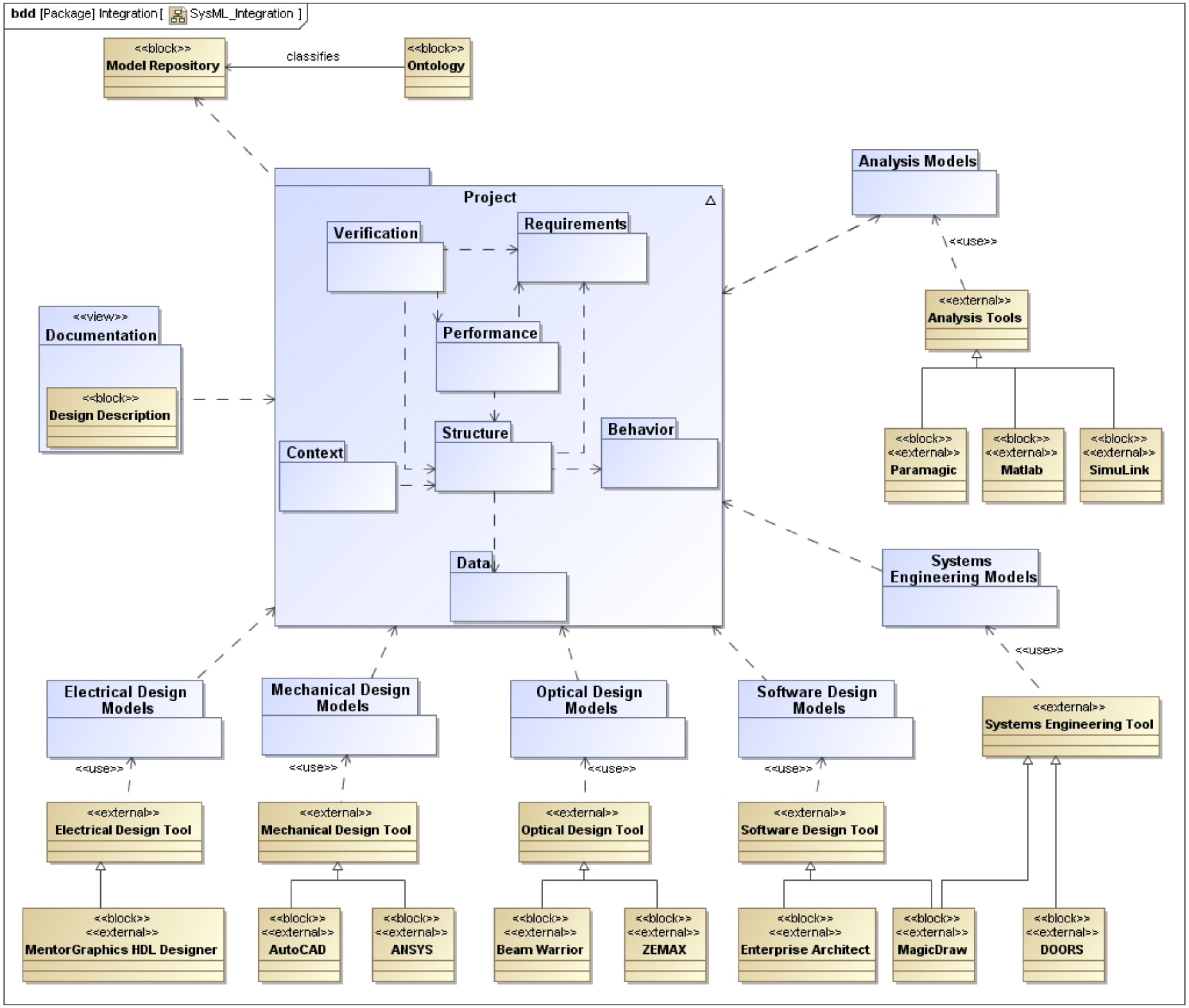








System Model

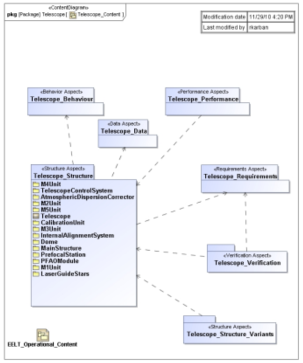


Modeling

- Integration of different disciplines at system level
- Integration of different discipline specific models and exchange information

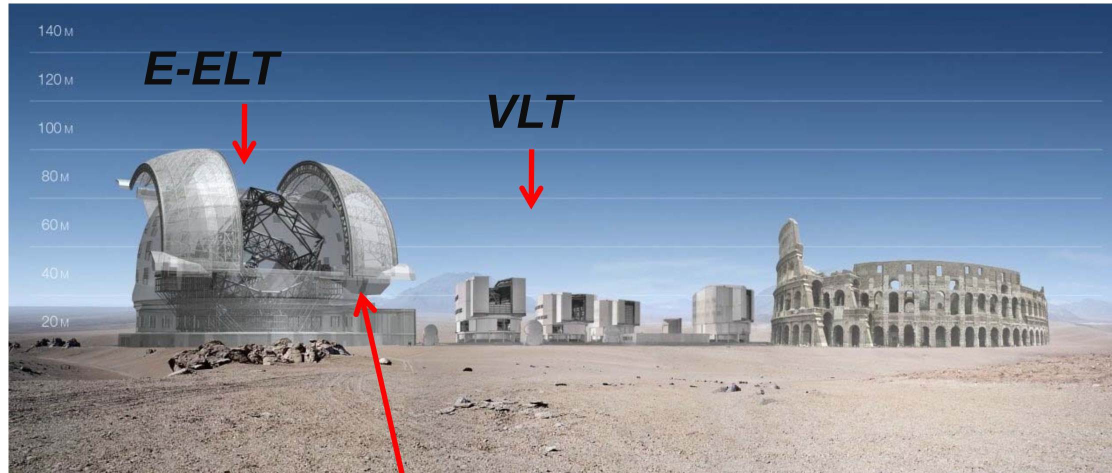
- Consistent terminology
- Consistent figures across technical disciplines
- Consistent requirements, analysis, design, integration, and verification
- Compatibility of functional and physical interfaces

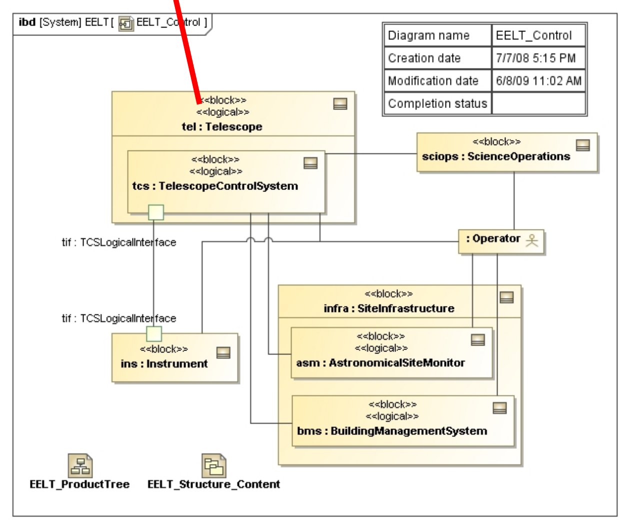
- A large part of the above can be enforced, supported, and checked with a Model, using
  - Ontologies
  - Methodology
  - System Modeling Language
  - Modeling recipes, best practices, and patterns
  - Tools



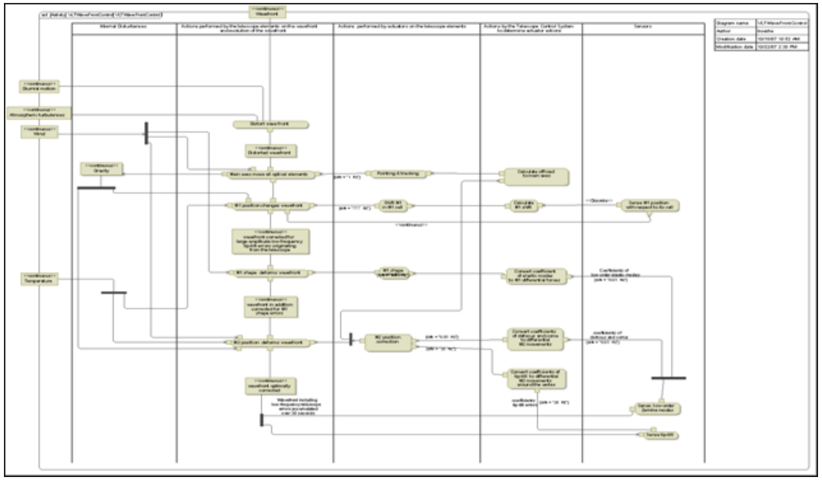
E-ELT Control System

- Includes all hardware, software and communication infrastructure required to control the System
- Provides access to the opto-mechanical components.
- Manages and coordinates system resources (subsystems, sensors, actuators, etc…)
- Performs fault detection and recovery
- The performance and functional control requirements of the entire system are assigned to the TCS.
- Interaction of Control Engineering, Software Engineering and Electrical Engineering

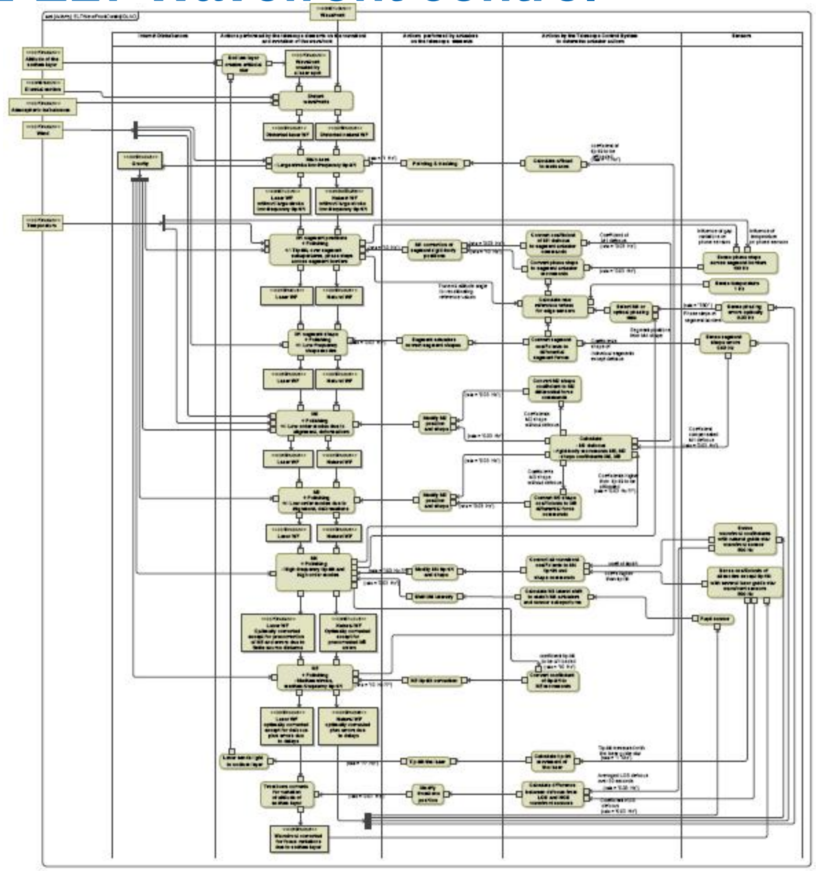




VLT Wavefront control

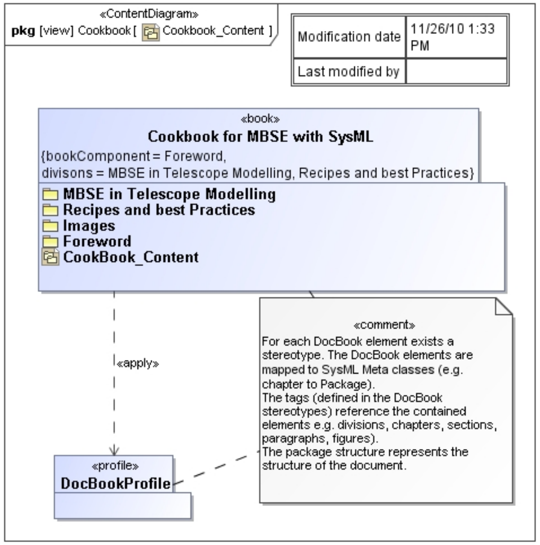


E-ELT Wavefront control



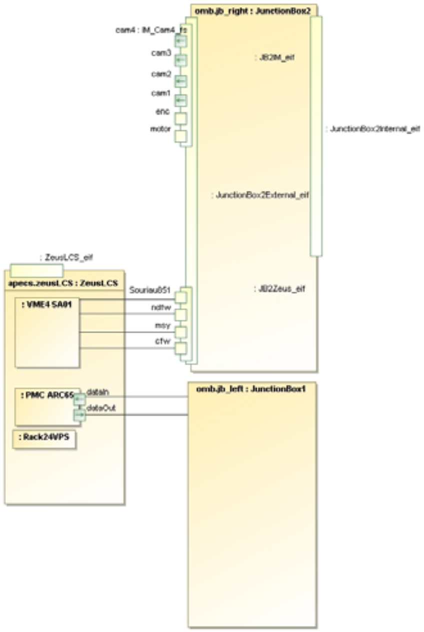
- 10000 tons of steel and glass
- 20000 actuators, 1000 mirrors
- 50000 I/O points, 700Gflops/s, 17Gbyte/s
- Many distributed control loops
- Use MBSE/SysML to model the control system since 2008

Challenges for the E-ELT CS



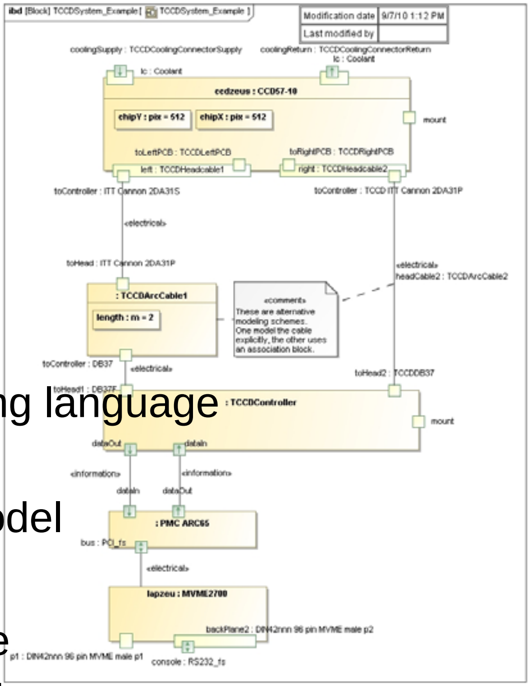
- Technical
  - Number of control points
  - Number of interfaces
  - Large data volume
  - Multitude of interacting control loops
  - Software intensive distributed control strategy
- Programmatic
  - Overall function and performance of the telescope is allocated to the control system
  - Long lag between contract set-up and development
  - Integration of heterogeneous distributed components

Why a system model for the E-ELT TCS?



- Define infrastructure (e.g. network)
- Derive power budget and cost estimate from equipment catalogue
- Enforce common standards through catalogue and design guidelines
- Define requirements for subsystems (e.g. data rates, data volume, latency)
- Consistent information model of TCS properties to manage its size
- Provide a design which satisfies telescope functions (e.g. wave front control strategies)
- Consistent design achieved through common system model
- Generate Documentation, Software, System Configuration, and Deployment

Status of MBSE at ESO



- E-ELT Phase B completed end of 2010
  - Preliminary design completed and PDR passed
  - Delivery of Construction Proposal
- E-ELT Control System
  - Enforce systematic architecture rules and formal modeling language
    - Correct-by-construction and verifiable system design
  - Consistent design achieved through common system model
    - Know what to do (and when to stop) with modeling …
  - Base-lined JPL's State Analysis Method and Architecture
    - Collaboration with JPL on a SysML profile for State Analysis
  - Adopted Concepts from OOSEM (Object Oriented Systems Engineering Method)
  - Setting up Model Based Document Generation
  - Field Testing at the Very Large Telescope (VLT)
    - Deploy and validate E-ELT CS technological choices
    - Applying State Analysis and OOSEM
- Infrastructure for Model execution (SCXML, fUML) and Code Generation

Break Out session topic

- MBSE Cookbook for SysML
  - Cookbook content
  - Experiences and strategies in setting up patterns, guidelines, and recipes
  - Educational aspects
  - Disseminating MBSE in an organization
  - Setting scope of modeling
  - Dynamic MBSE knowledge management in organization
- Model Based Document Generation

- How many of you would be interested?

Summary

- Challenge team activities concentrated in the past years on
  - Demonstrating usability of SysML in large, non-trivial applications
  - Compiling modeling pattern, guidelines, and practices
  - Providing a large amount of real-world examples
  - Providing feed-back to vendors and standardization bodies
- SysML as a language is mature enough to be used
  - Sufficient material is available to answer most modeling questions
- SysML and MBSE concepts are being applied to new projects
  - SysML, OOSEM, and State Analysis are applied within major ESO projects.
- Future Challenges are mainly in the areas of
  - Applying MBSE Methods with SysML
  - Model Execution
  - Usability issues for large scale models
  - Model Evolution
  - Integration with engineering disciplines (tool and standard wise)

Live demo of the APE, E-ELT, and VLT model

- Please standby - setting up the system…