Telescope Structure and Kinematics

(Presented by E. Brunetto, F. Koch)

TELESCOPE STRUCTURE

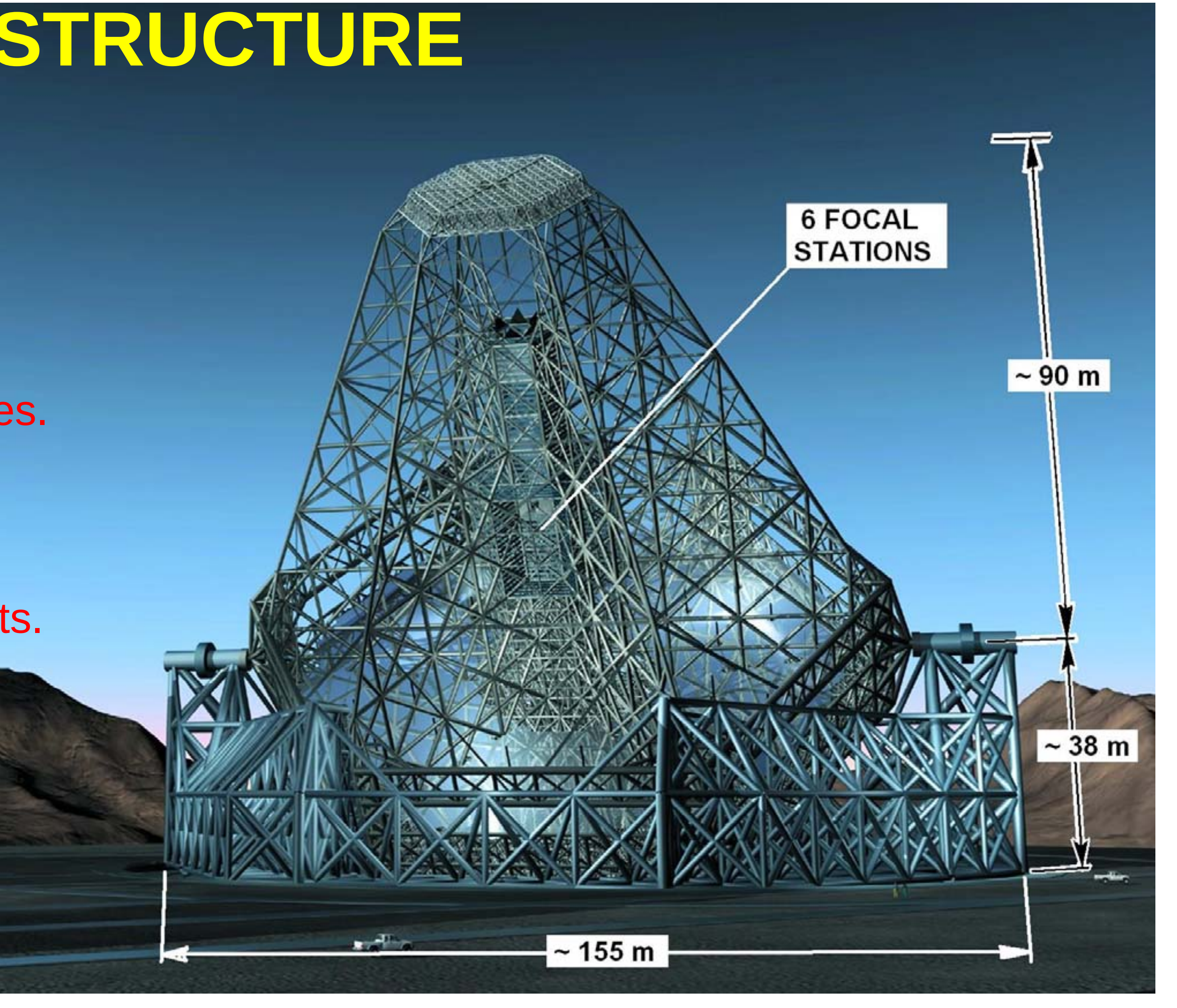
and

KINEMATICS

- Assumption and Principles.
- Evolution.
- Base Line Design.
- Sub-Systems.
- Technology developments.
- Verifications.

- Structural Analyses.

- Conclusions.



From System analysis to conceptual design.

DESIGN ASSUMPTIONS.

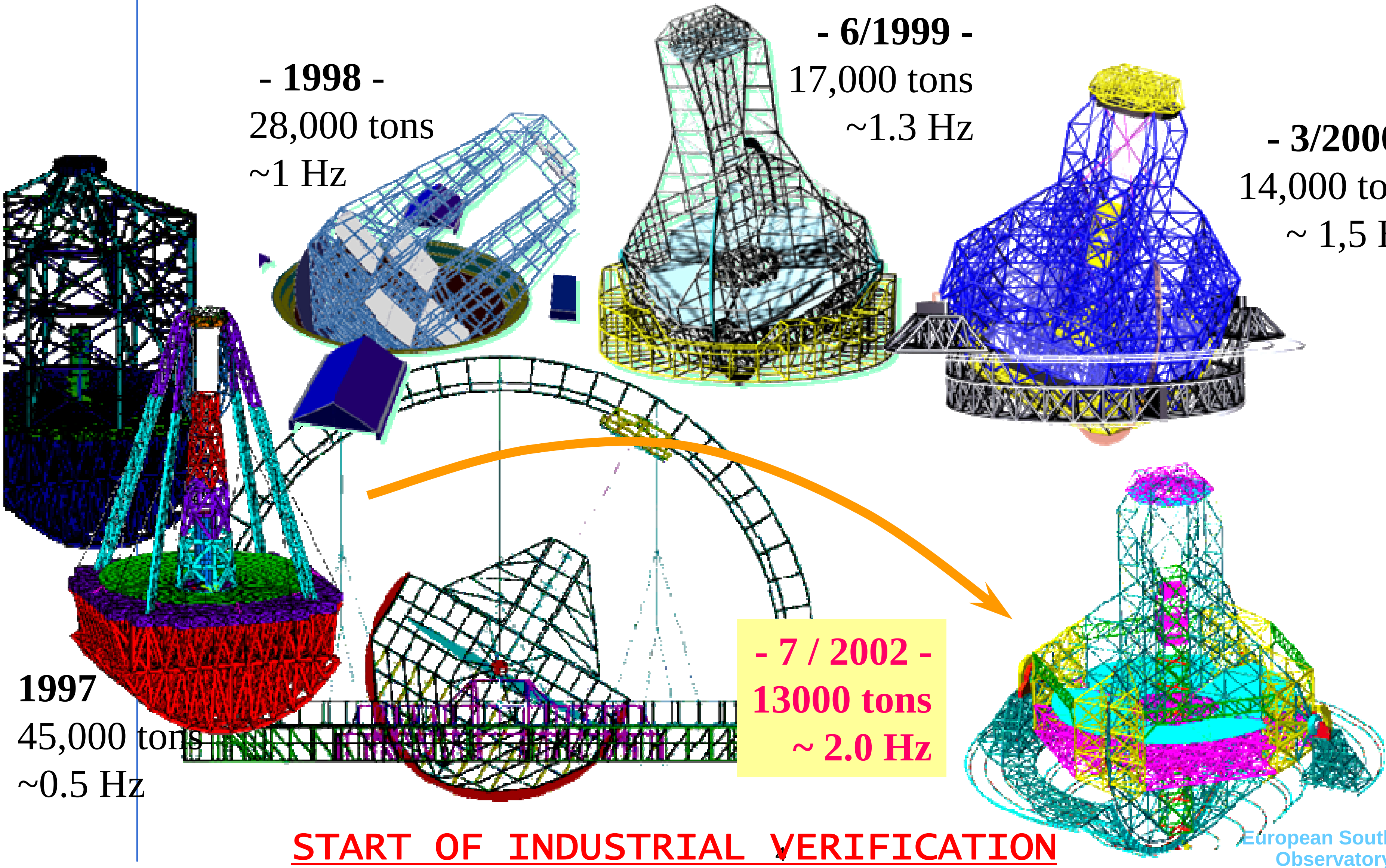
- Soil characteristic.
  - Paranal 50000 MPa.
  - La Palma 5000 MPa.
- Existing infrastructures.
  - Harbor.
  - Roads.
- Seismicity.
  - Paranal 0,34 g
  - La Palma 0,06 g.
- Wind.
  - 10 m/s.

- COSTS
- SAFETY
- VERIFICATION
  - what
  - who
  - when
  - How

DESIGN PRINCIPLES.

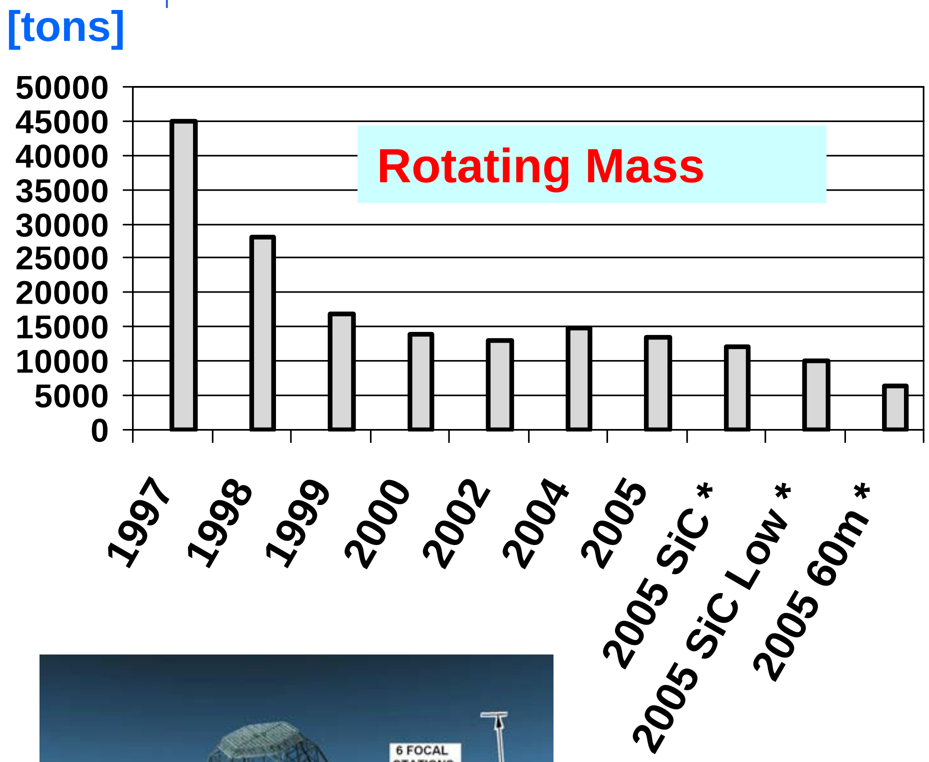
- Maximize dynamic and static performance.
  - Minimize mass.
  - Embedded configuration (low CoG).
- Manufacturing.
  - Existing technology, availability.
  - Mass produced modular system.
- Assembly, Integration and Verification.
  - Transport (maximum size).
  - Assembly (Self standing).
  - Instrument.
  - Metrology.
- Operations.
  - Low thermal inertia.
  - Wind disturbance.
- Maintenance.
  - Segment re-coating
  - Access to sub-systems.

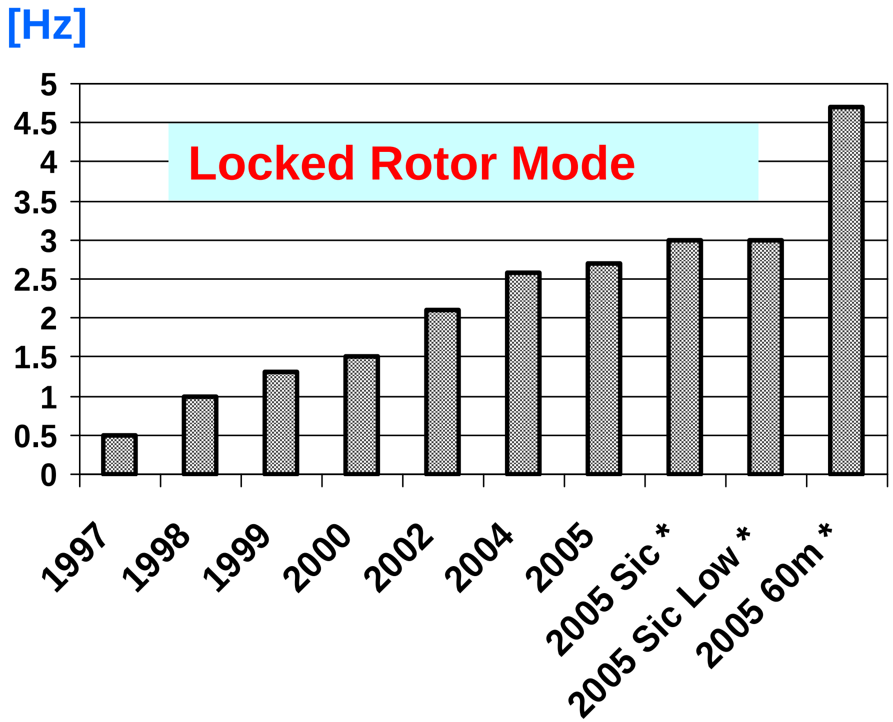
Design evolution (I)

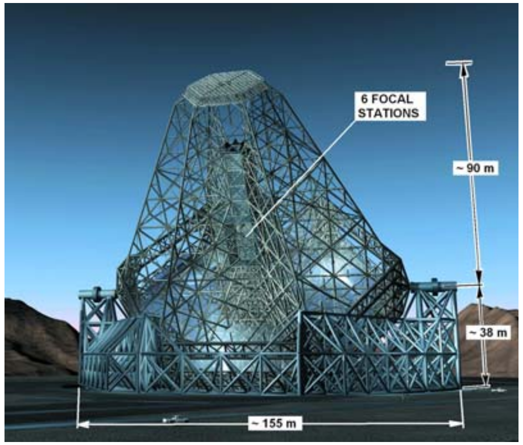


START OF INDUSTRIAL VERIFICATION

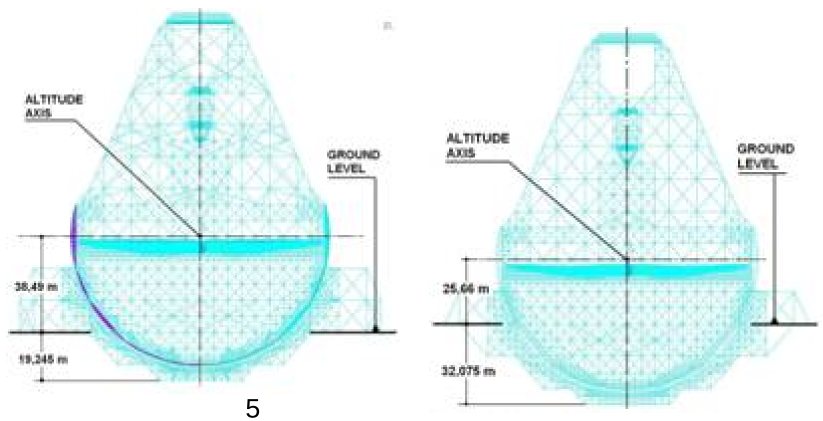
Design evolution (II)







2004 (2,6 Hz)
2005 (2,7 Hz)

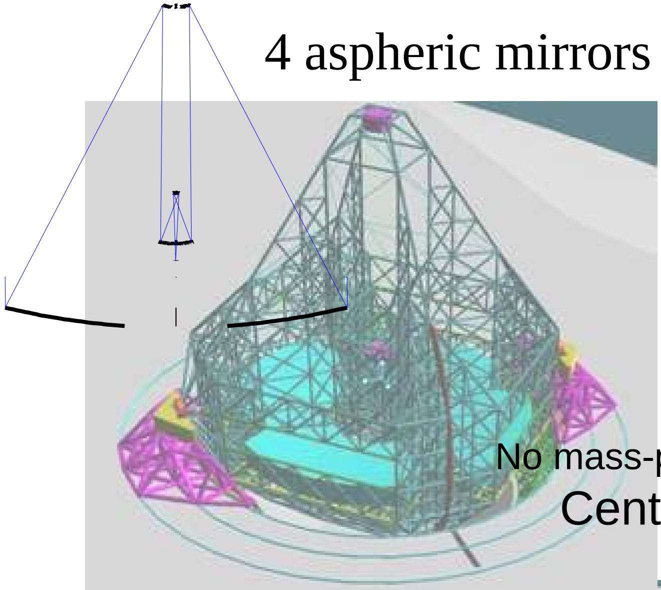


* Coarse Design

Opto-mechanical options.

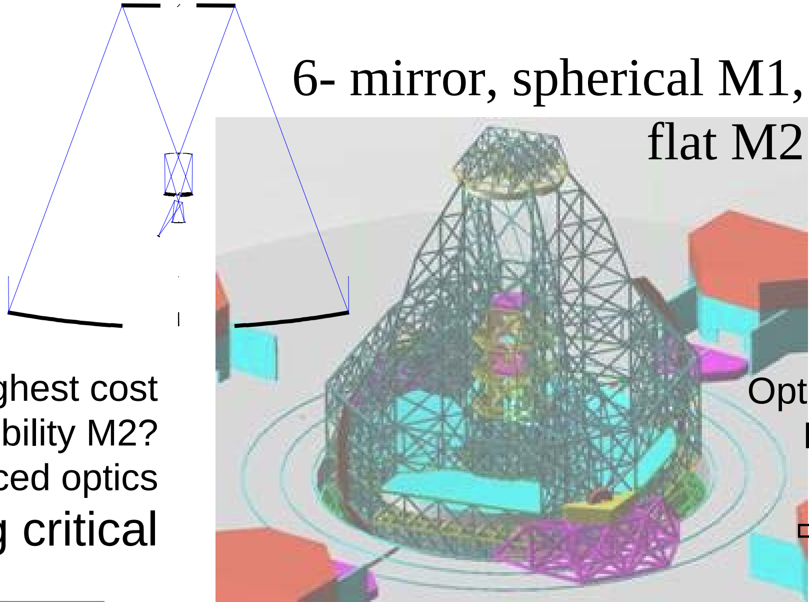
2002

4 aspheric mirrors



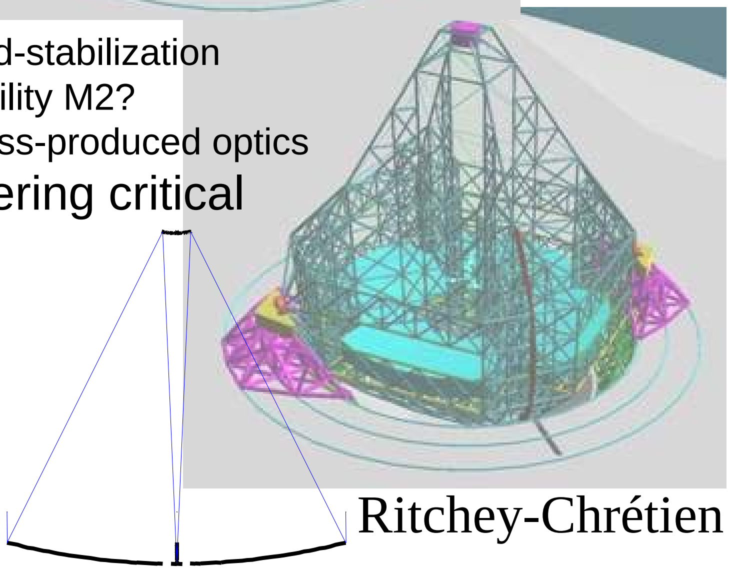
Highest cost
Feasibility M2?
No mass-produced optics
Centering critical

6- mirror, spherical M1, flat M2



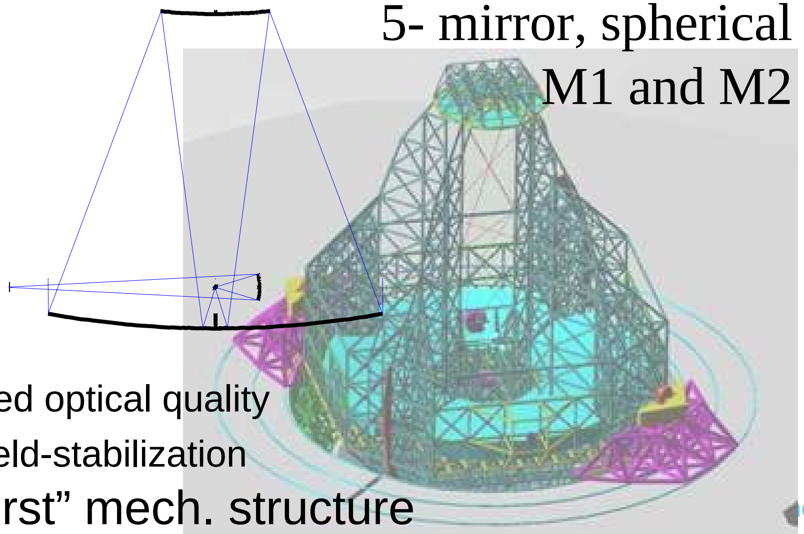
Optical quality (field)
Best functionality
Lowest cost
⇨ BASELINE

No field-stabilization
Feasibility M2?
No mass-produced optics
Centering critical



Ritchey-Chrétien

5- mirror, spherical M1 and M2



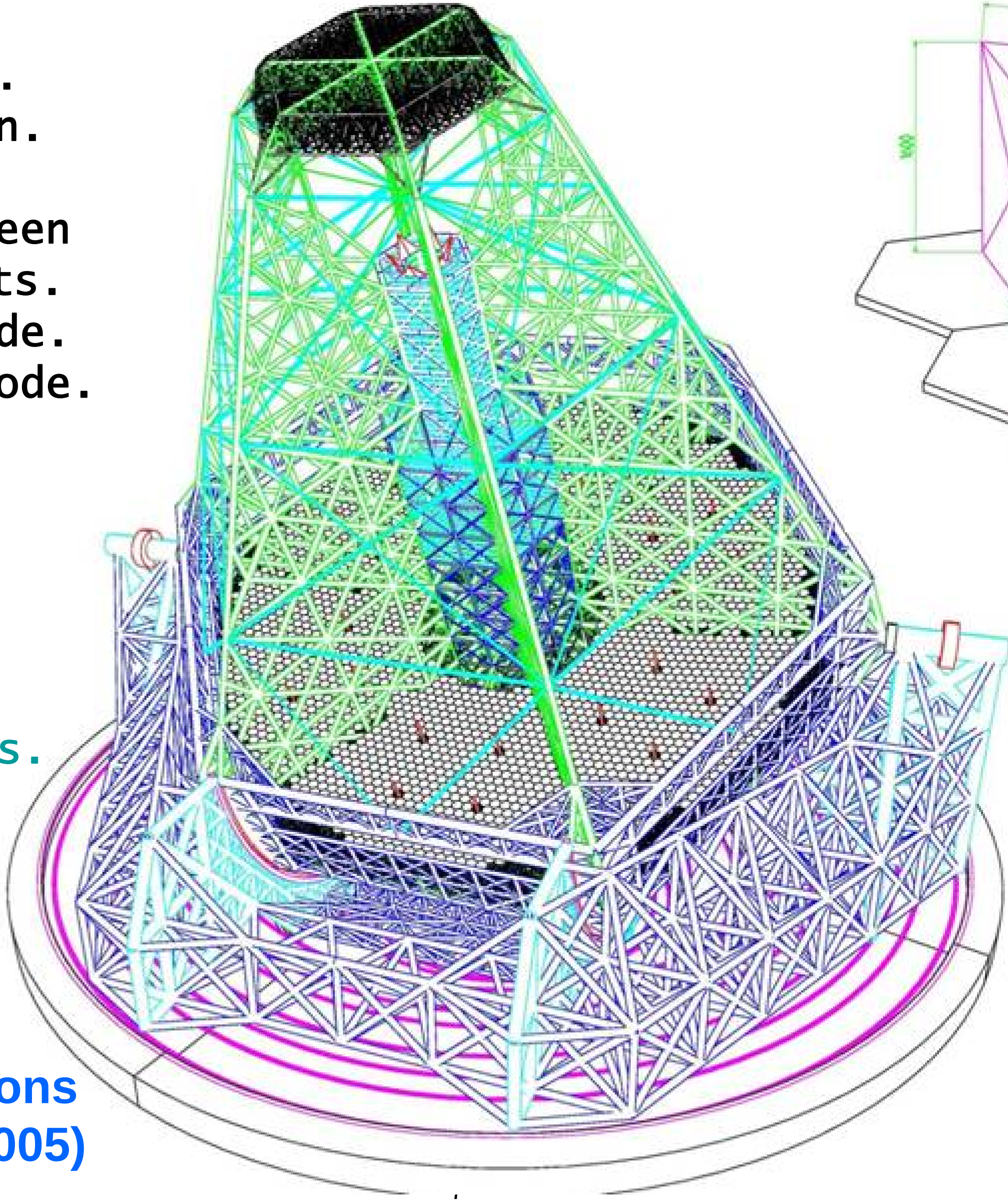
Limited optical quality
No field-stabilization
"Worst" mech. structure

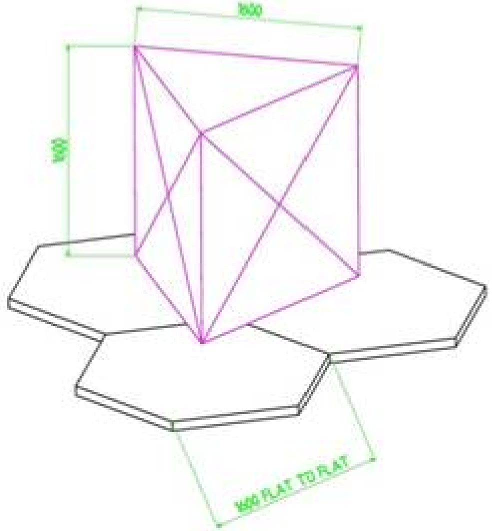
Optics & mechanics design baseline.

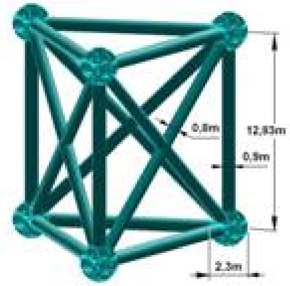
- Six fold symmetry.
- Six focal stations.
- Diffraction pattern.
- Near-circular M1.
- Perfect match between structure and segments.
- 60º observation mode.
- ±90º maintenance mode.
- Segment size 1.6-m
  - M1 3048 segments.
  - M2 216 segments.

BASELINE
- Steel structure.
- Kevlar tension ropes.
- Glass ceramic.

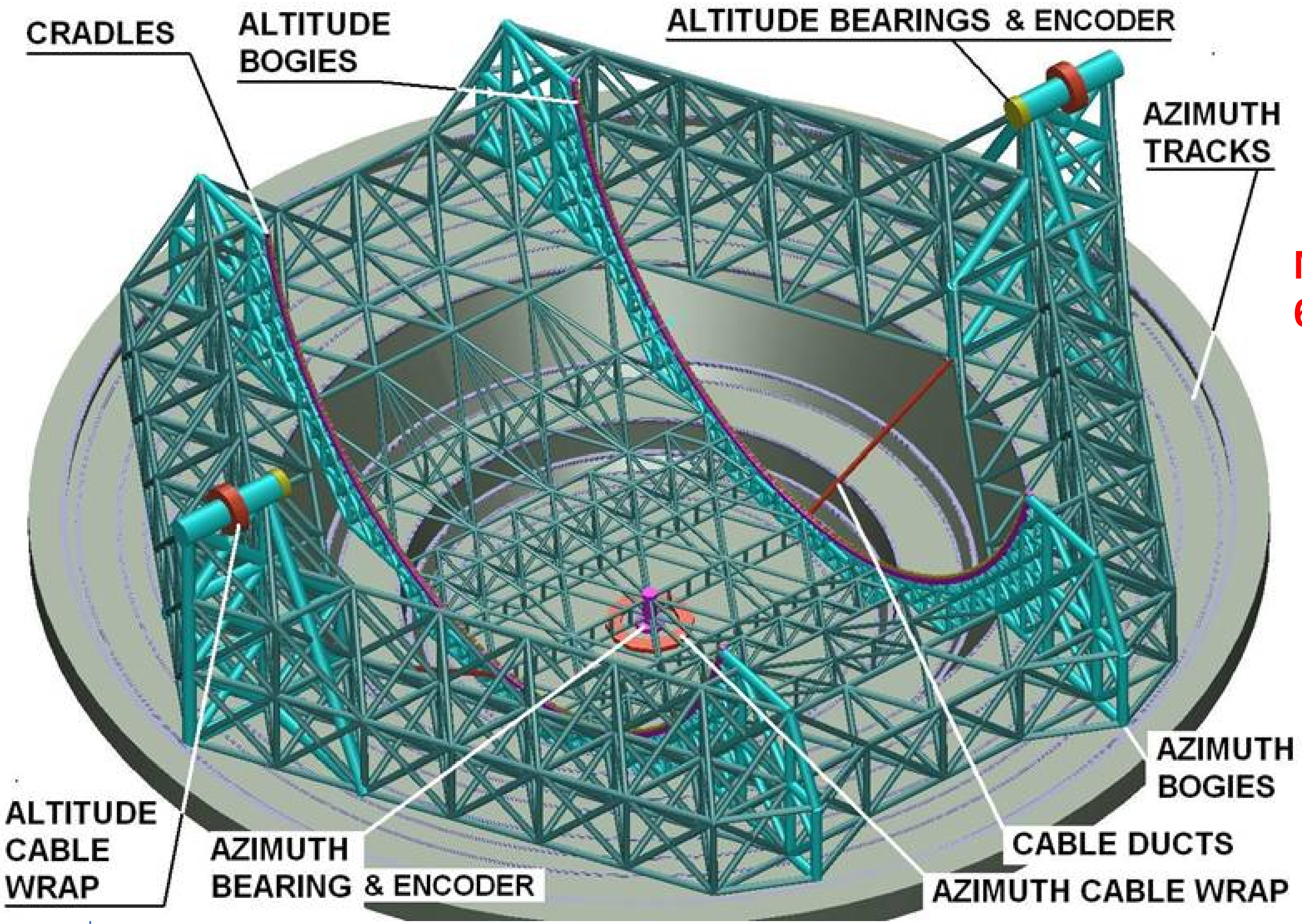
Rotating Mass 13350 tons
Locked rotor 2,7 Hz (2005)





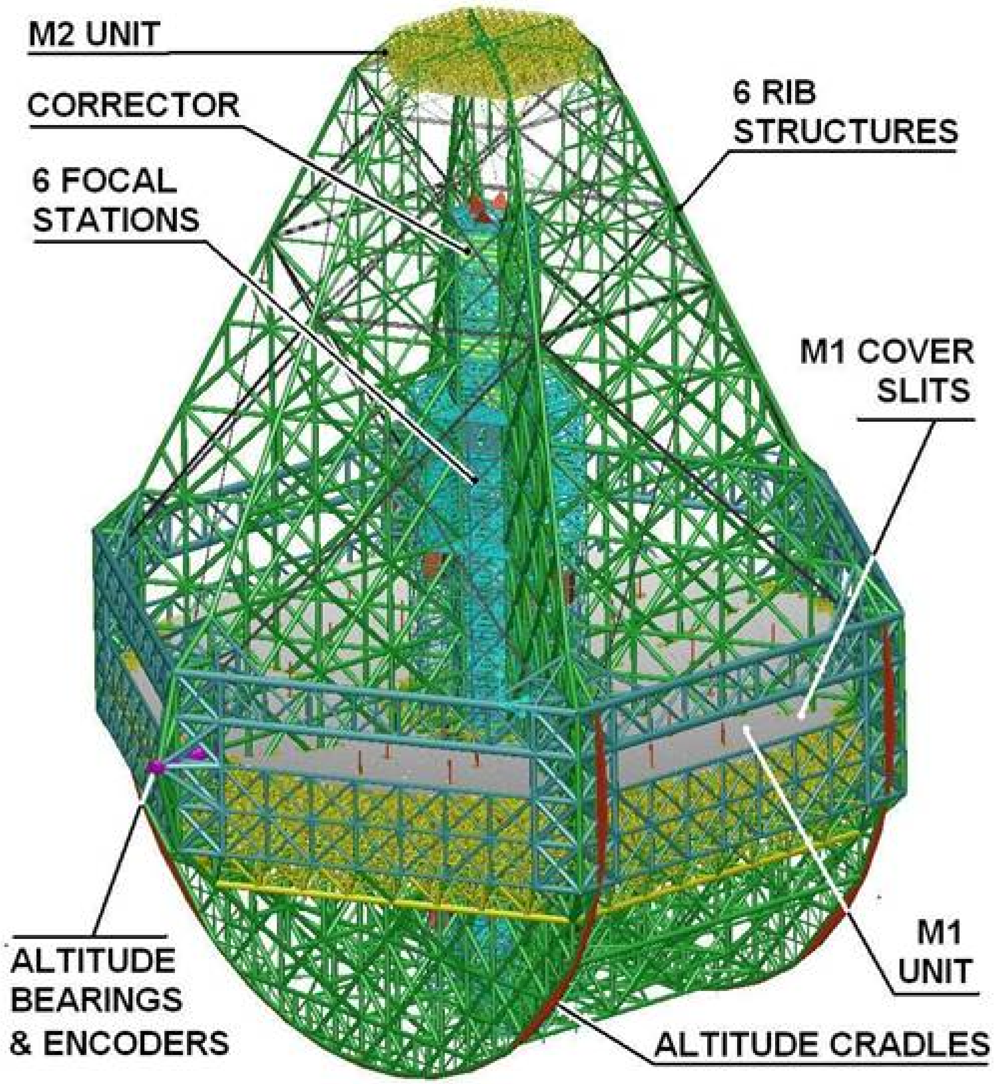


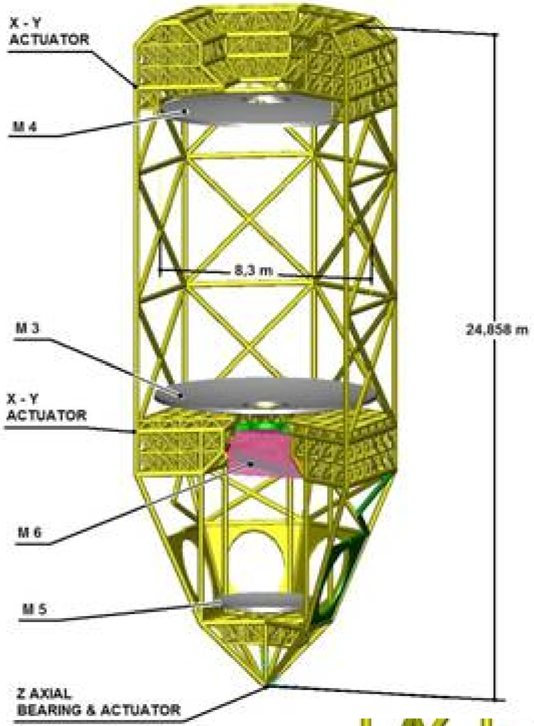
AZIMUTH STRUCTURE

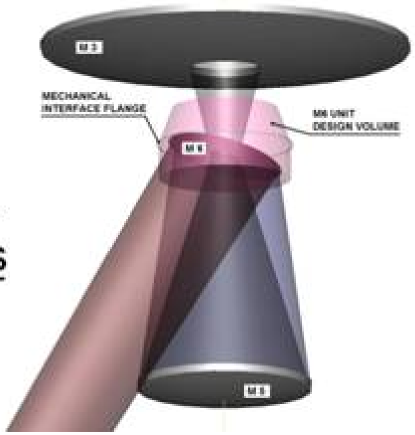


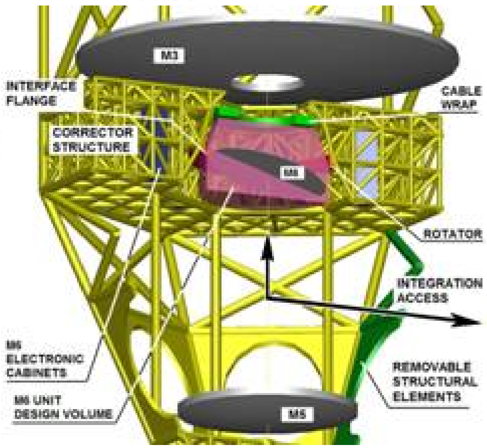
Mass
6180 tons

ALTITUDE STRUCTURE and CORRECTOR









Mass 7170 tons

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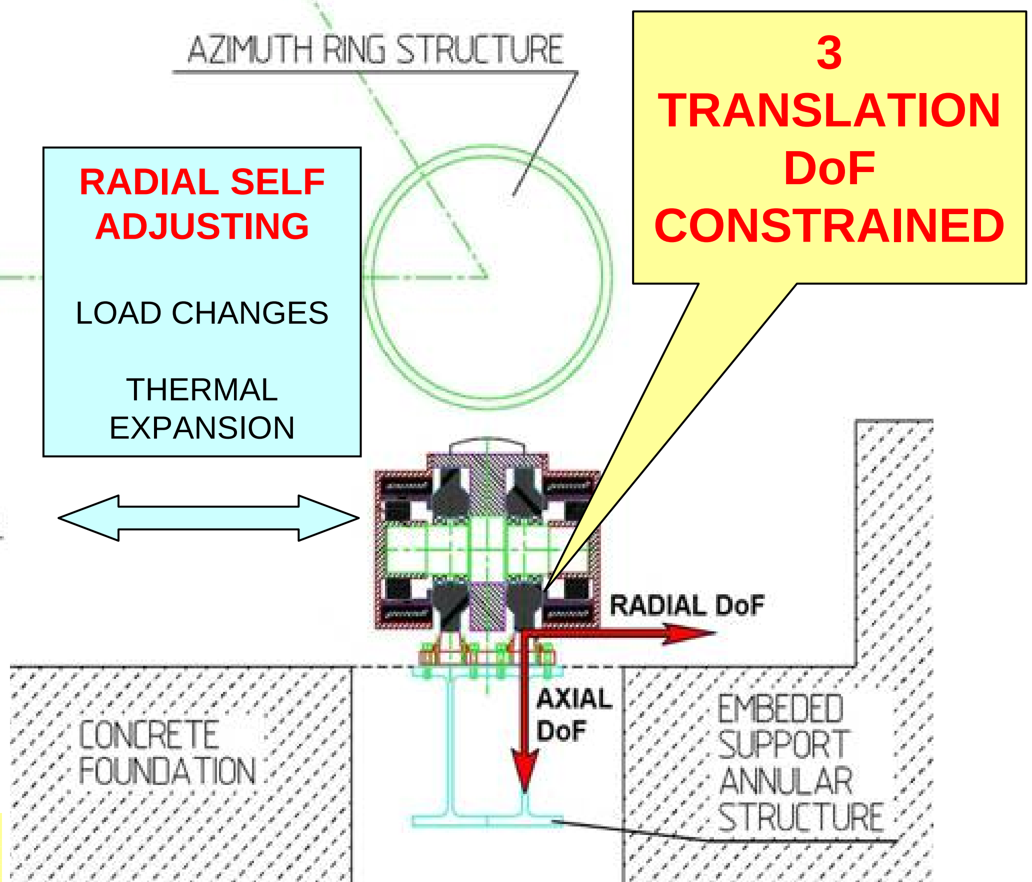
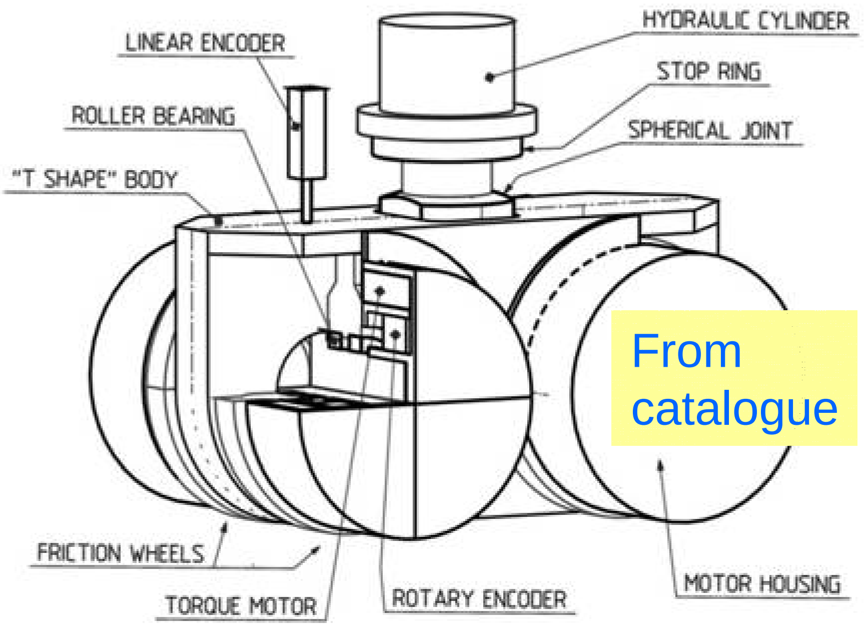
Main Axes Kinematics

- Merged drive and bearing
- Low-cost tracks and alignment.
- Maintenance-friendly, high redundancy.
- Highly reliable
- Optimal load distribution
  - (connected ⇨ hydraulic “whiffle tree”).
- Control of dimensional changes.
- High telescope dynamic performance.
- Self-aligning.
- Required tangential resolution ~ 0,1 mm.
  - Delivered tangential resolution µm

BOGIES CONCEPT



NUMBER OF BOGIES
Azimuth axis ~ 246
Altitude axis ~ 154

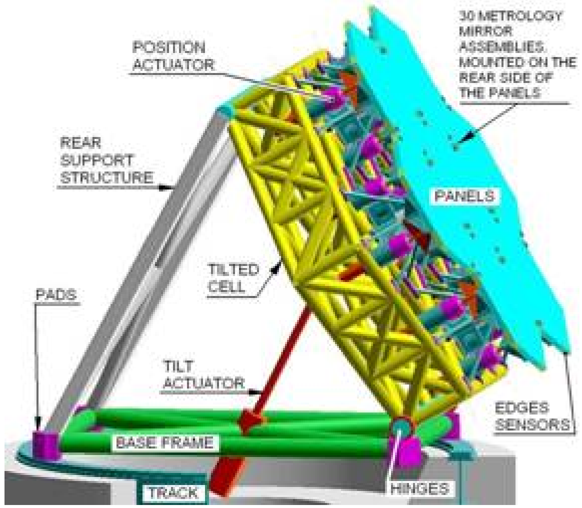


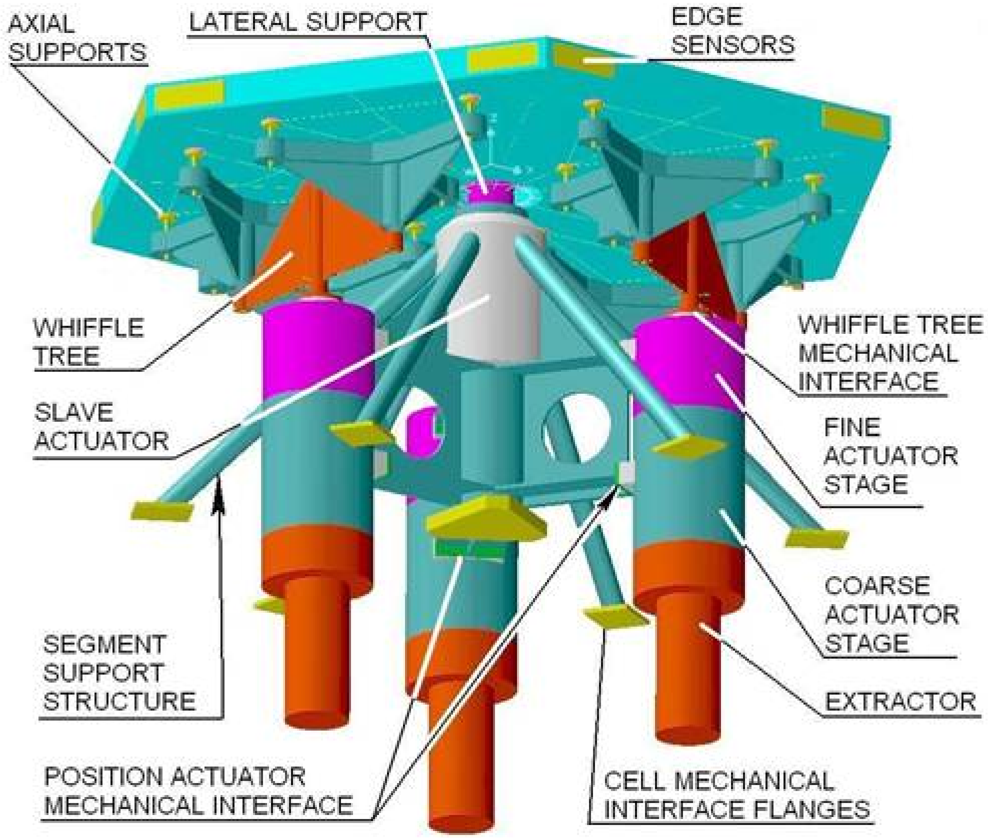
Segment assembly.

- **PHASING**
  - **Position Actuators**
  - **Edge Sensors**

Accuracy: ± 5 nm. Goal ± 2 nm
Stroke 15 mm

Control bandwidth goal 10 Hz



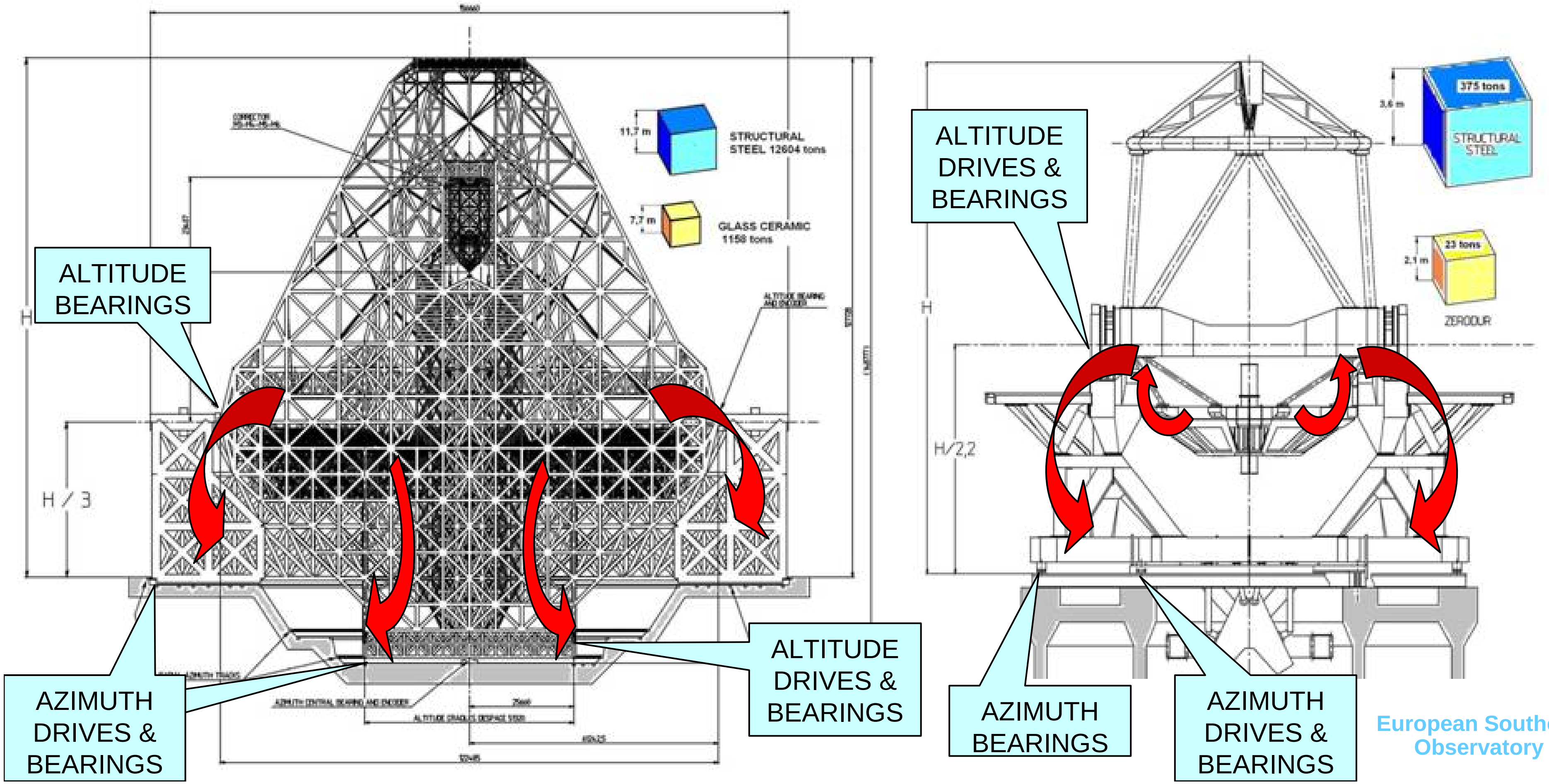


Wind
Evaluation
Breadboard

FP6 ELT

OWL and VLT

- Lightweight
  - OWL based on VLT design. Structural steel mass **679876** tons.
- Drive & Bearing location
  - Large radius
- Optics Load
  - Distribution
  - Path



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Mechanical structure verification.

FEASIBILITY, COSTS AND SAFETY:

- ✓ CCI (Sulzer): Feasibility study of Framework structure.
  - ✓ Manufacturing → availability, technologies, personnel, schedule,
  - ✓ Nuclear industry Quality Assurance for welded structure.
  - ✓ Costs analysis ex works (9,6 Euros/kg and 2 Euros/kg).
- ✓ IHF: Mechanical safety analysis.
  - ✓ Buckling (maximum stress, material choice).
  - ✓ Pretension of ropes.
  - ✓ Fatigue (wind buffeting).

CONTROL:

- ✓ TUM: Reduced model (40 to 1000 DoF).
- ✓ EPFL: Telescope Main axes Control study.
- ✓ Segment Control
- ✓ TUM: Impact of soil and foundation.

WIND DISTURBANCE:

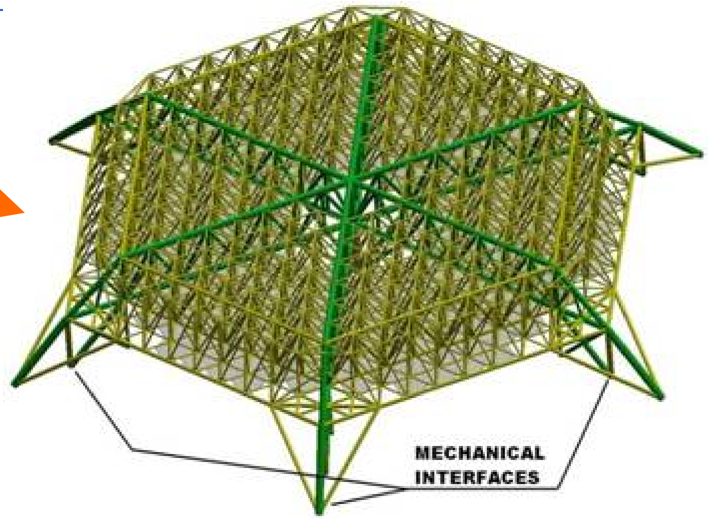
- ✓ CADFEM: Wind disturbance. Computational Fluid Dynamic study.
- PSP & Jodrell Bank: Wind on 76 m Lovell telescope.
- Wind tunnel tests.

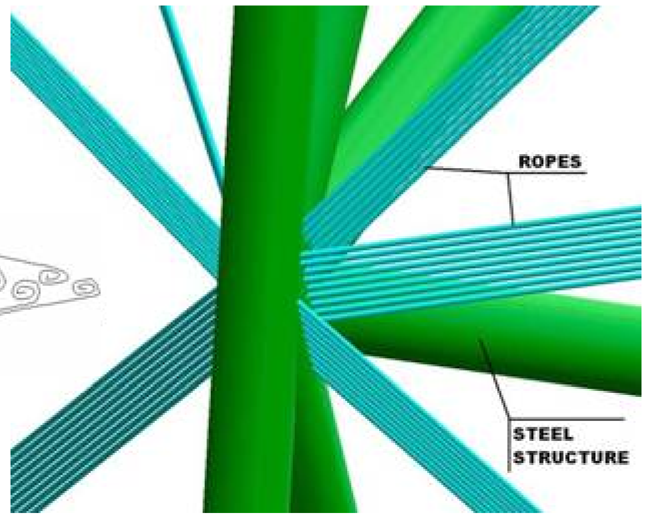
ESO:

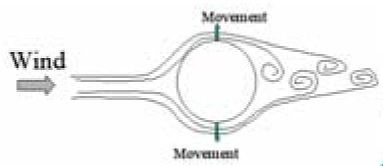
- Soil and Foundation.
- Thermal Analysis.
- Wind disturbance simulations.
- Segments Control simulations.

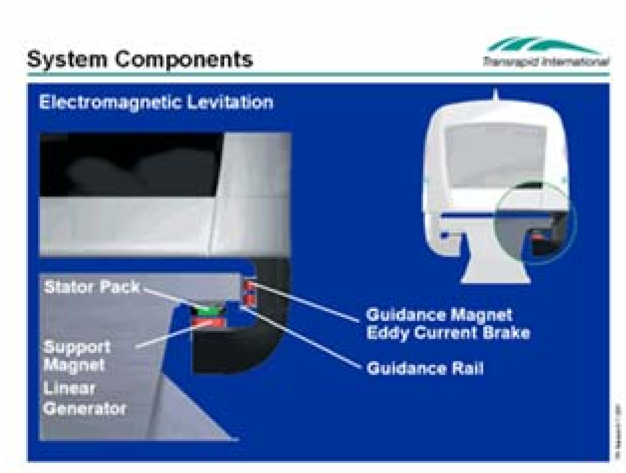
Technology Developments

- Composite material structural elements.
- Aramid fiber Tensioning ropes (Kevlar).
  - Thermal compensation.
  - Tension control.
  - Wind induced vibrations (Vortex Shedding).
- SiC segments substrate.
- Segments Durable Coating
- Magnetic Levitation. Main axes kinematics.
  - Frictionless.
  - Low track tolerance.
  - High stiffness and damping.

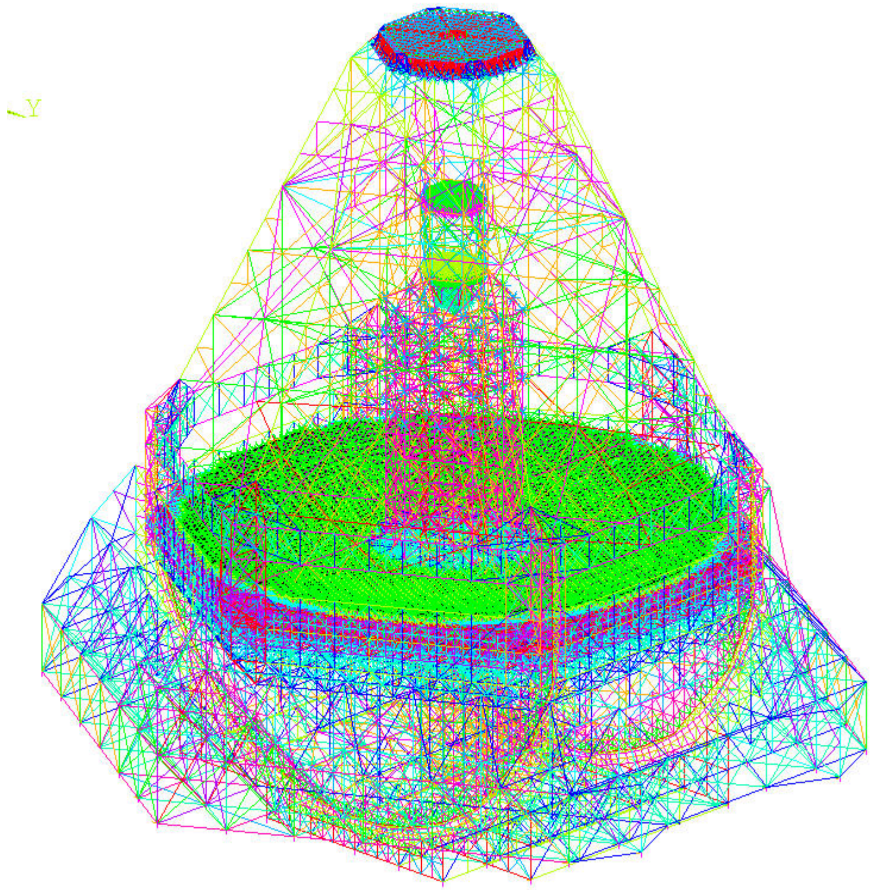








Structural Analyses

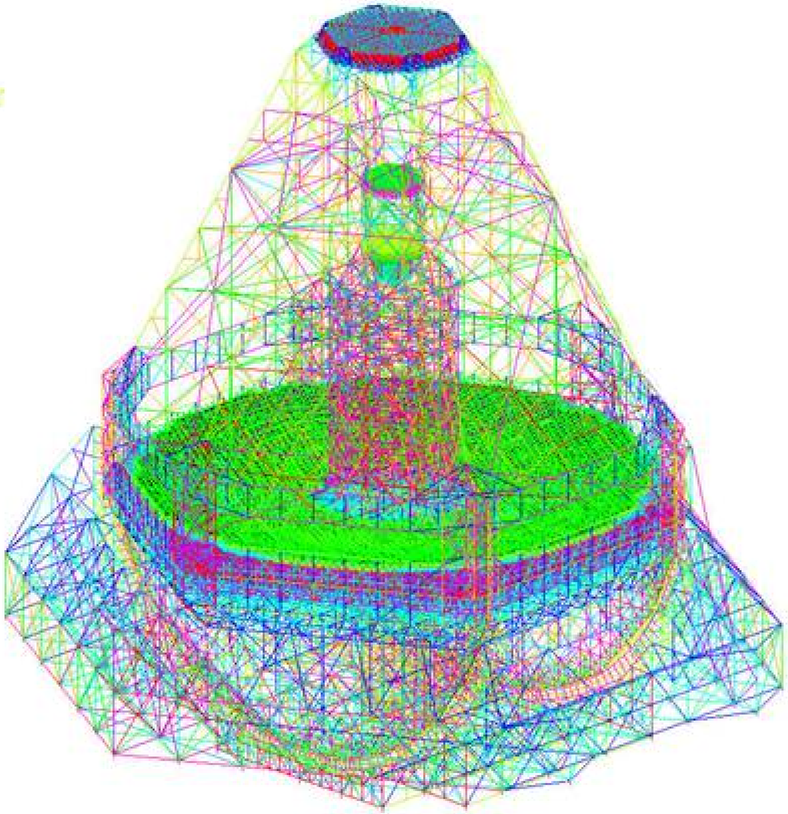


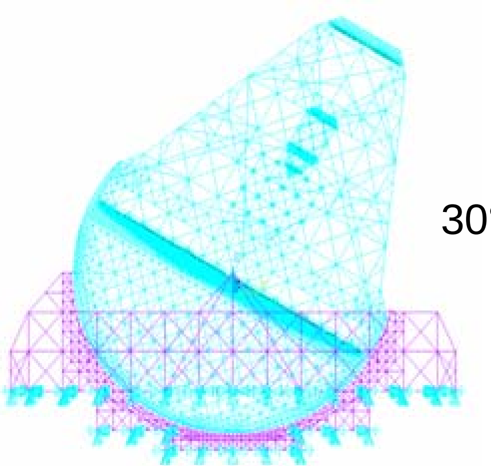
Structural Analysis - Objectives

- Assess structural feasibility of baseline design
- Predict static and dynamic behavior
  - Define actuator stroke
- Input to error budget
- Provide reduced control models for dedicated simulations
- Compare different configurations
- Pre-optimize mechanical structure
- Evaluate structural safety compliance

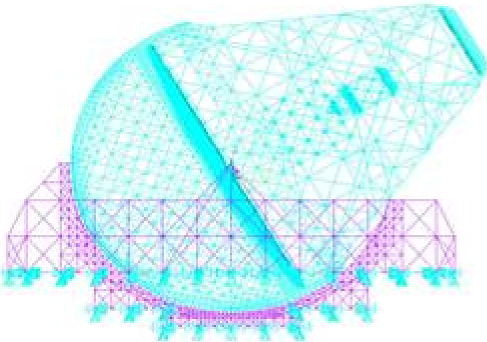
Finite Element Model

- Model Assumptions:
  - Representative stiffness and ma distribution
  - 40000 nodes
  - 146000 elements
  - Bogies coupling Alt and Az
  - Mirror segments rigid
  - Fixed at foundation interface





30°



60°

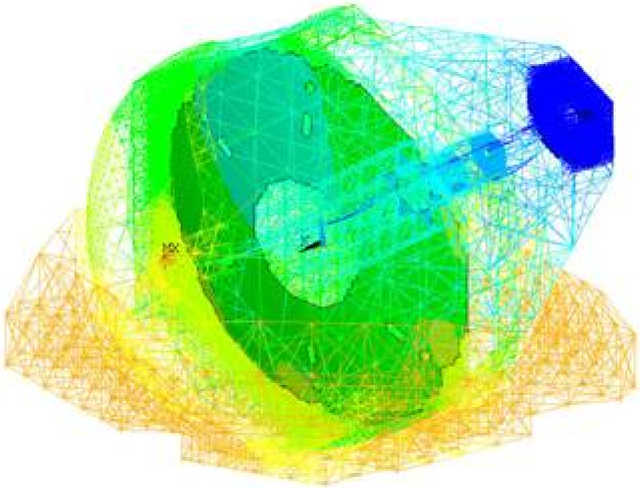
Gravity Analysis

- Differential displacements 0° to 60º
- Mean rigid body motions:

Mirror	Piston [mm]	Tilt [arcsec]	Decenter [mm]
M1	7.8	0.3	13.2
M2	11.2	13.4	(30.8)
Corrector	12.1	-44.9	23.0
M2 – M1	3.4	13.1	-13.2

  - Max. segments actuator stroke: 11 mm

- Stress level (max. 250 MPa)
  - Increase cross sectional areas
  - Modify topology
  - Higher strength material
  - Optimization analysis



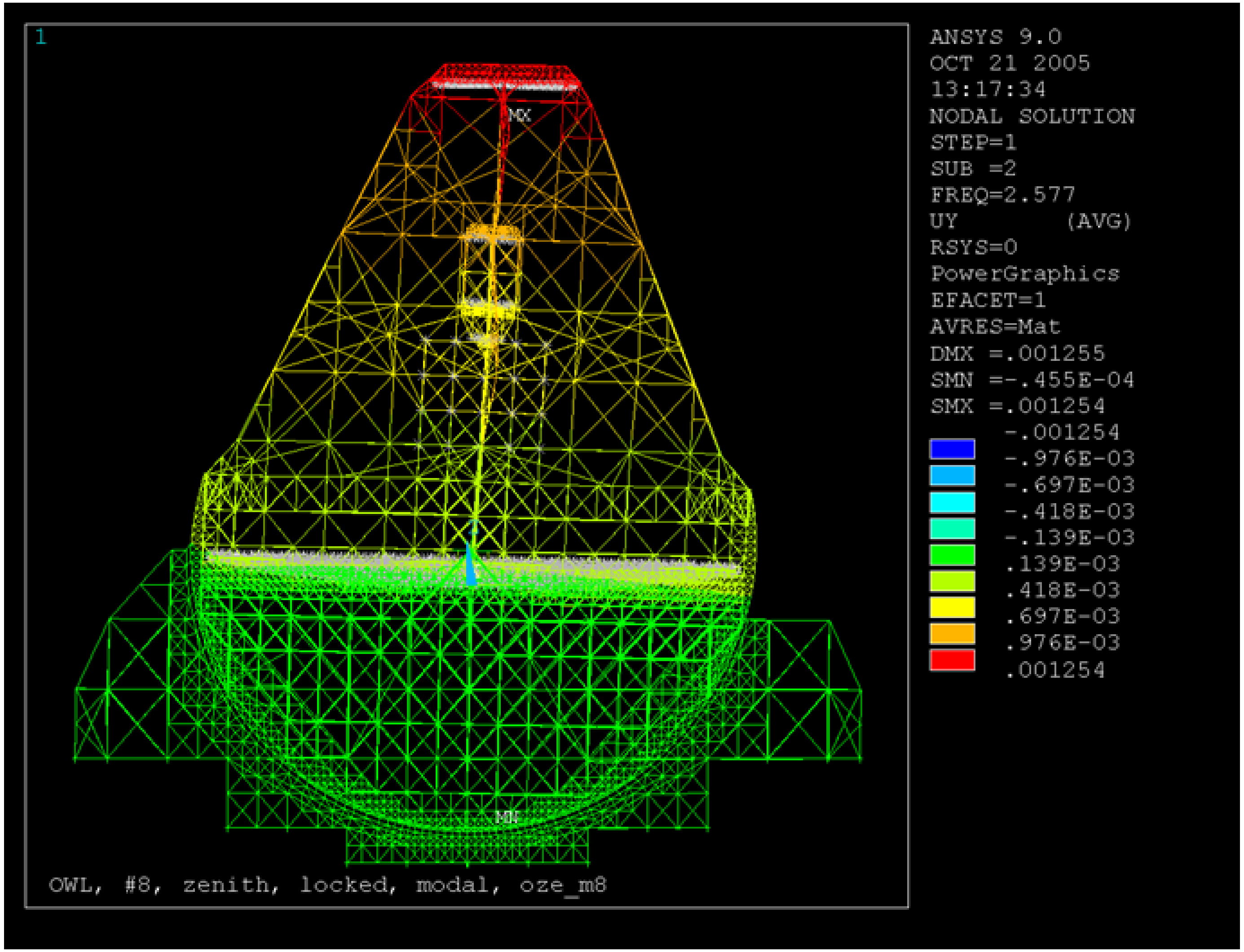
Modal Analysis

- Eigenfrequencies and mode shapes
- Effective masses
- Indication of specific stiffness
- Bandwidth of control systems

Mode	Frequency [Hz]	Effective mass in % of total						Mode
		MX	MY	MZ	IXX	IYY	IZZ	
1	1.59	67				2		Cross altitude
2	2.58		30		29			Altitude LR
3	2.86						44	Azimuth LR
9	4.03			46				Piston altitude
260	7.32			0.1				Piston M2 unit

Modal Analysis

- Locked rotor mode shape at 2.6 Hz



Dynamic Wind Analysis

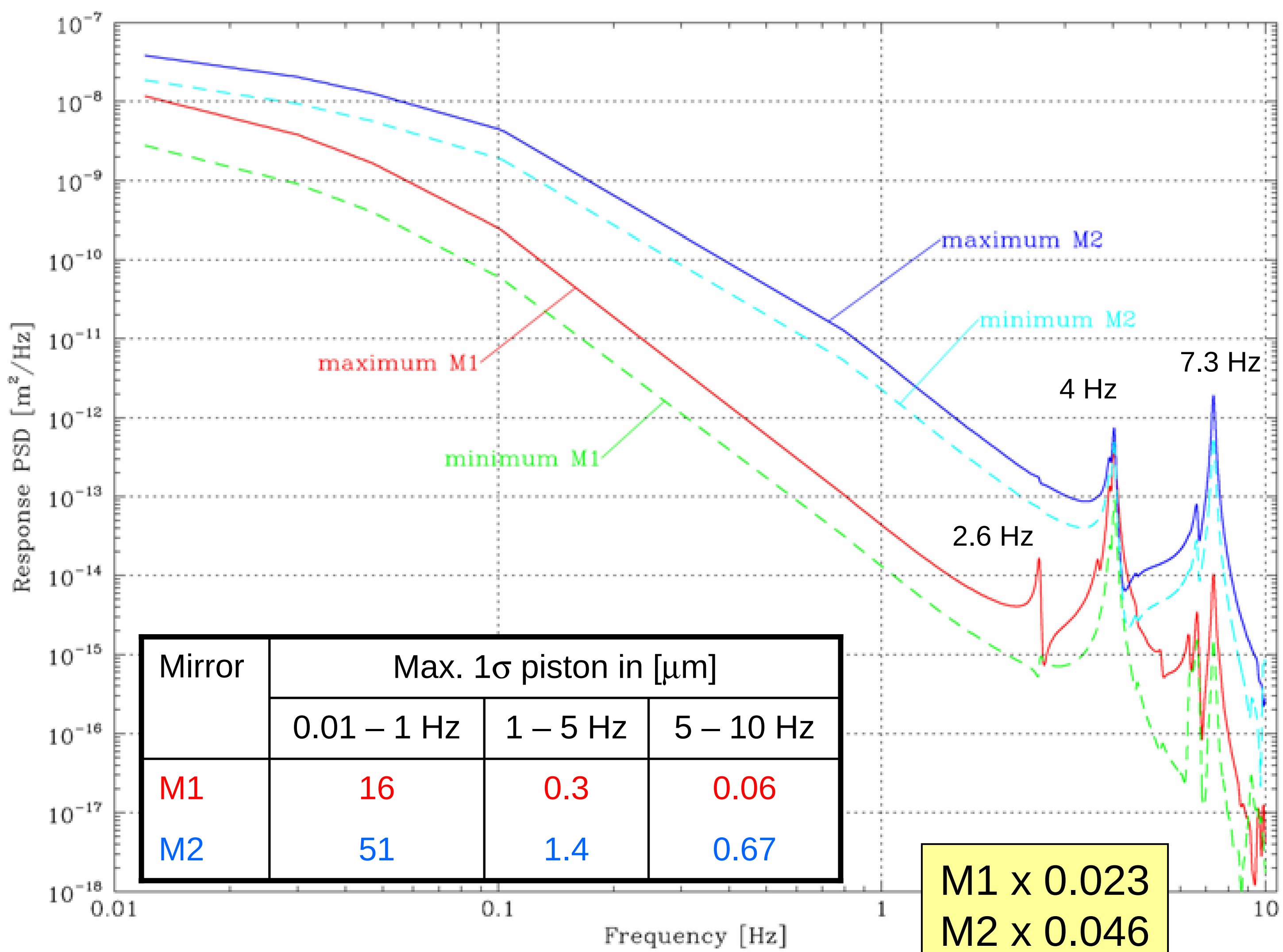
- Random vibration analysis (open loop)
  - Complete telescope FE Model
  - 400 modes (10 Hz) represented
  - PSD Wind load on M1 and M2 segments
    - M1 (10 m/s), M2 (14 m/s)

1. Macro scale wind effect on segmented mirrors
   - Wind load applied on entire segmented areas
     - Uniform and fully correlated

2. Micro scale wind effect on phasing error
   - Wind load applied on parts of M1 and M2 segments
     - Loaded area stepwise increasing (1 → all segments)

Dynamic Wind Analysis

- Macro scale wind effect

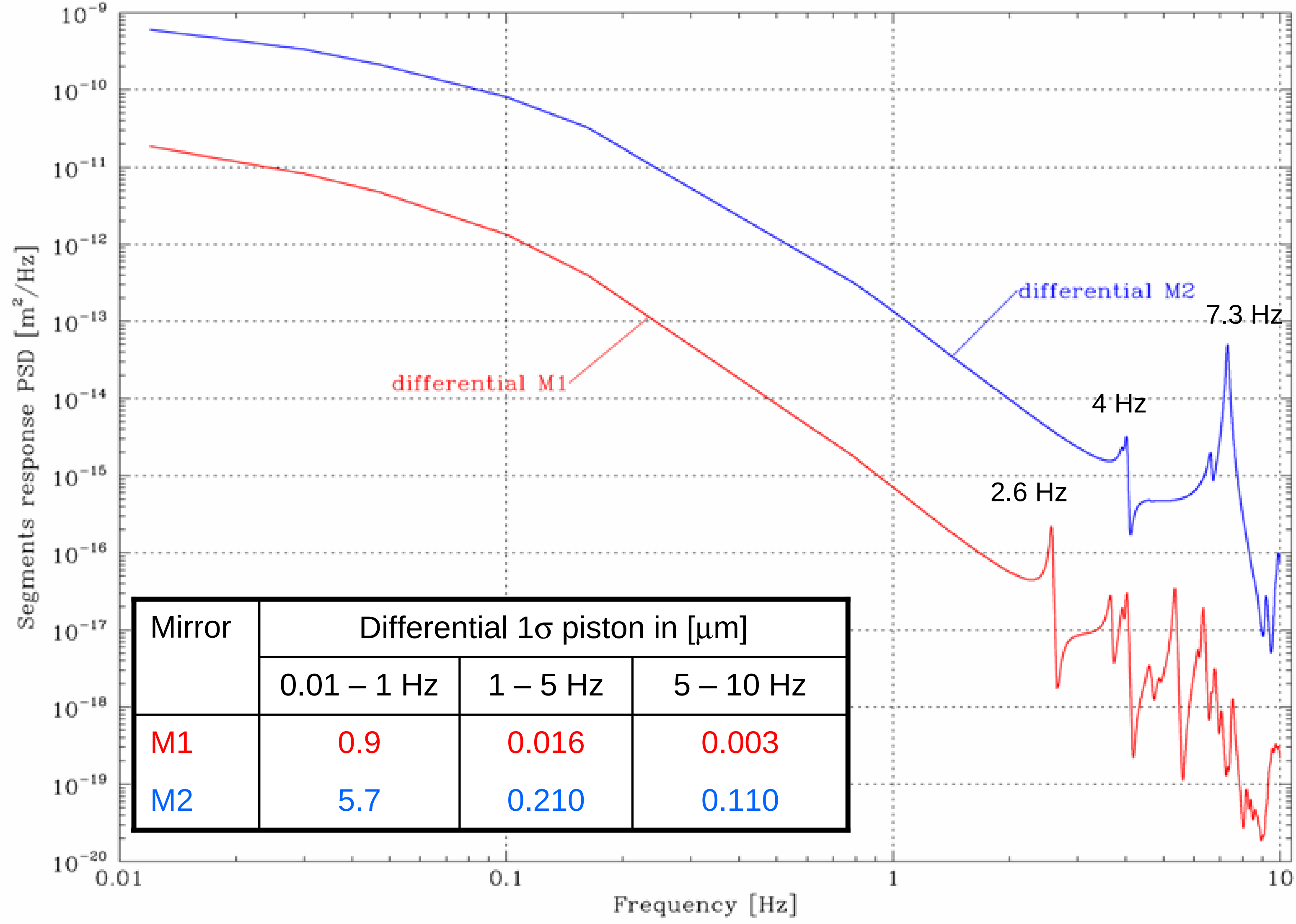


Mirror	Max. 1σ piston in [µm]		
	0.01 – 1 Hz	1 – 5 Hz	5 – 10 Hz
M1	16	0.3	0.06
M2	51	1.4	0.67

M1 x 0.023
M2 x 0.046

Dynamic Wind Analysis

- Micro scale wind effect (phasing error)



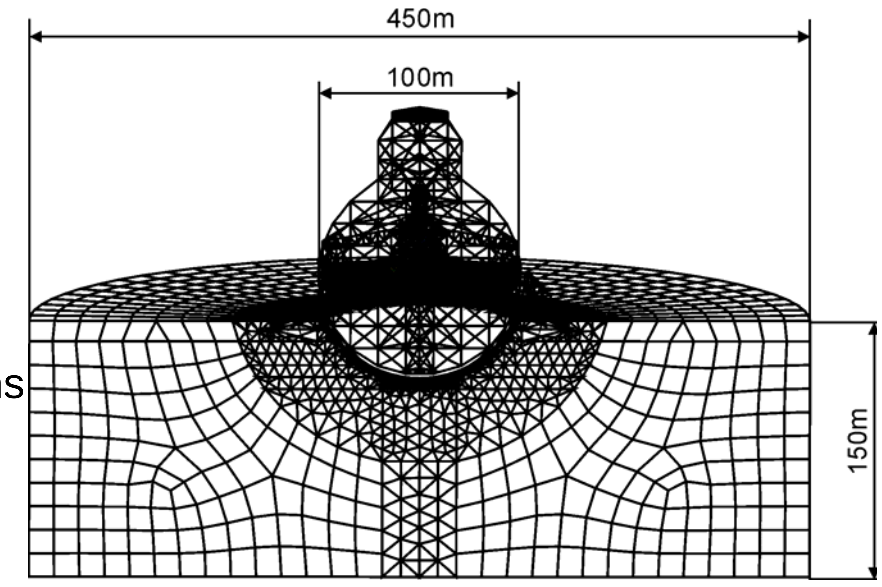
Mirror	Differential 1σ piston in [µm]		
	0.01 – 1 Hz	1 – 5 Hz	5 – 10 Hz
M1	0.9	0.016	0.003
M2	5.7	0.210	0.110

Effect of Soil and Foundation

- Soil-structure interaction
  - Influence on dynamic performance

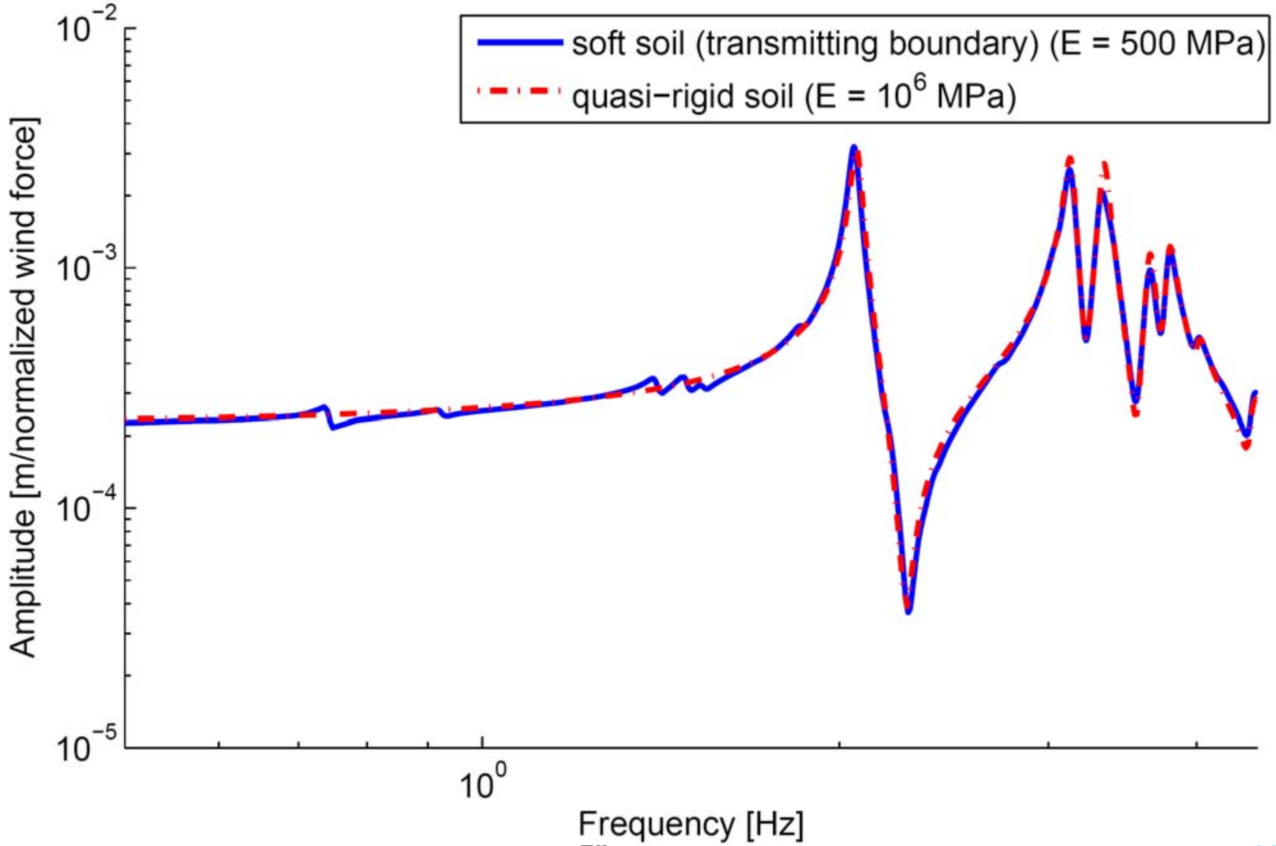
- Sensitivity study
  - FE Model of soil added
  - Variation of soil properties:

    E = 500 -1000000 MPa
    - La Palma 5000 MPa
    - Paranal 50000 MPa
  - Comparison of transfer functions under wind load



Effect of Soil and Foundation

- Results for weak soil (e.g. soft and light tuff):
  - Difference of peak amplitude: 10 %
  - Reduction of frequency: 4 %
  - Lightweight telescope supported on large area



Structural Safety Analyses

- Wind (30 m/s uncritical)
- Fatigue (uncritical, max. variable stress 17 MPa)
- Buckling
  - Moderate design modifications to fulfill safety requirements
- Pretension of ropes
  - Structure stress sensitive to pretension
  - Optimization of pretension process
    - → Minimize stress and maintain tension (gravity, temperature, etc.)
- Earthquake
  - Important design driver
  - 0.2 g horizontal ground acceleration
  - Allowable stress exceeded (20 %)
    - Higher steel quality
    - Changing beam cross-sections
  - Paranal-like conditions (0.34 g MLE)
    - Additional design modifications
    - Passive or active damping devices

Conclusions

- Mechanical structure feasible
  - Today standard and well-proven Technologies.
  - Stress level not negligible but within the limits of the applied technologies.
- Dynamic performance:
  - Compact and lightweight structure.
  - High eigenfrequencies.
  - Less sensitive to wind excitation.
  - Further improvements already investigated.
- Effect of soil on dynamic performance low
- Structural safety:
  - Wind and fatigue: uncritical.
  - Buckling: minor modifications required.
  - Earthquake: important design driver.

This design concept is one possible answer to OWL requirements. Other concepts can be envisaged. **BETTER FASTER CHEAPER**