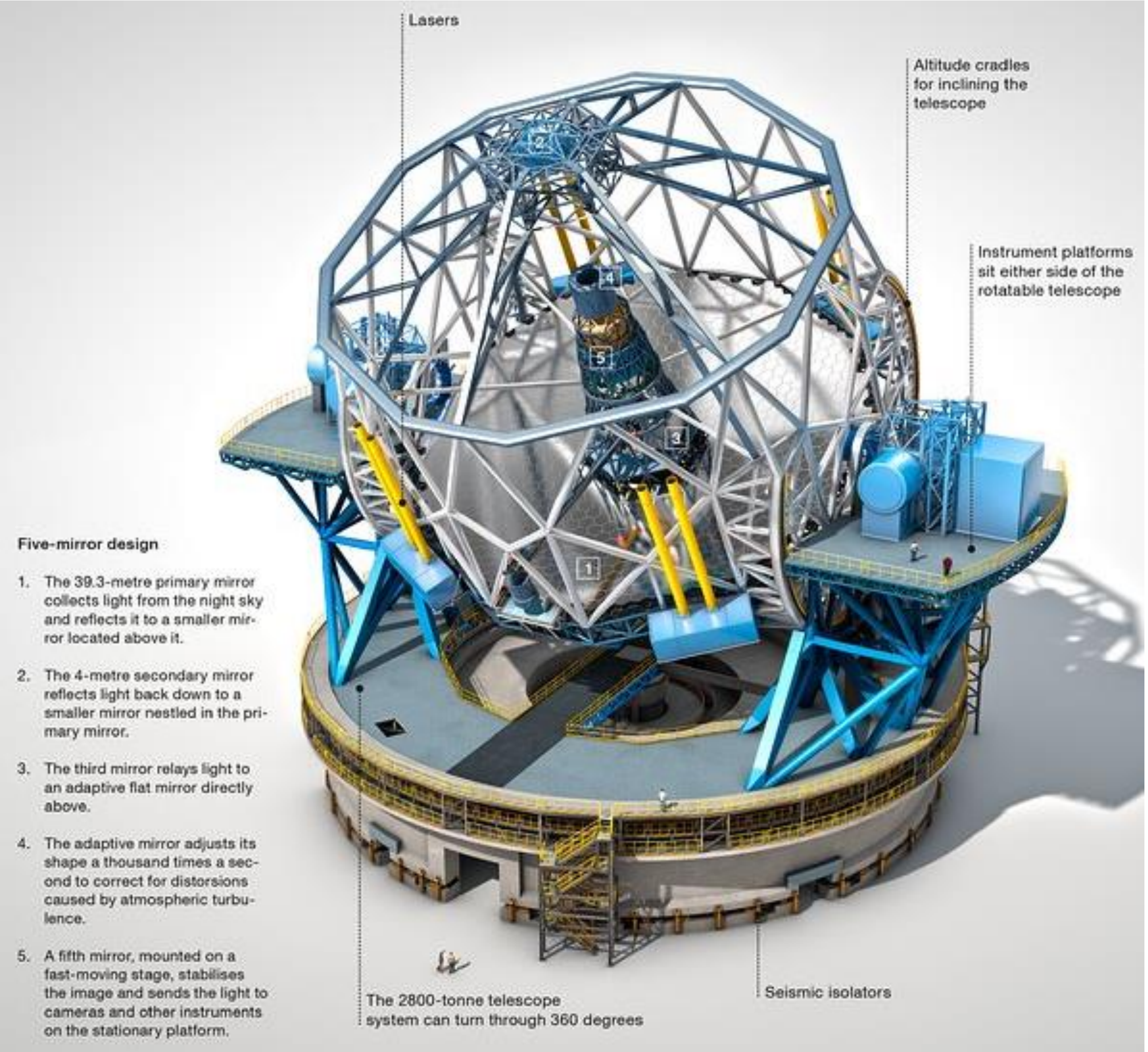
M1/M2 Ray Tracer

for High-Speed Mirror Metrology in the E-ELT

Ron Holzlöhner, 21 Sep 2016
European Southern Observatory (ESO)

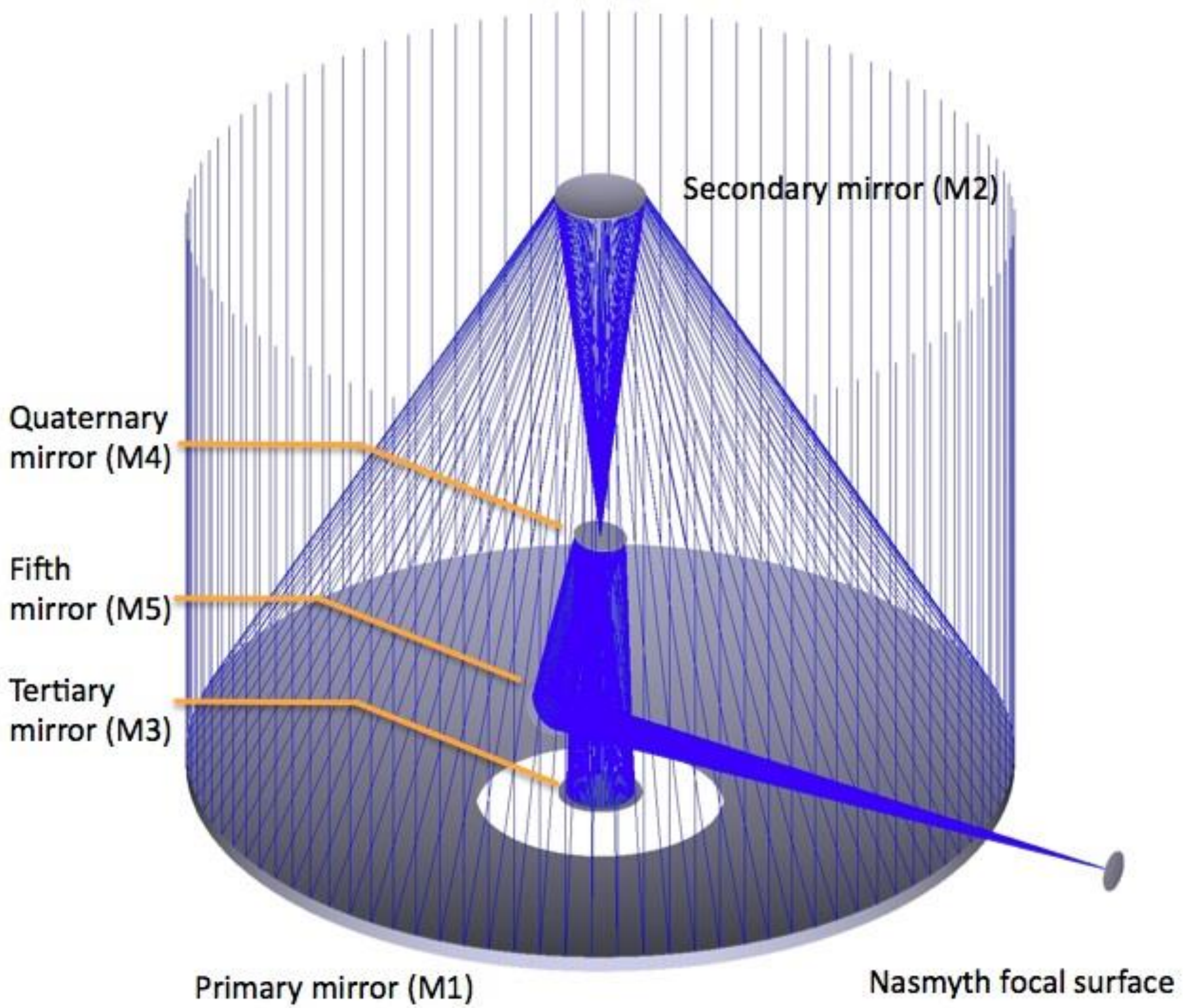
The E-ELT: 39m visible+IR Telescope

- ESO: Intergovernmental Organization, 15 member states
- EELT: 39 m visible+IR project
- Construction phase, first light 2024
- Segmented primary (~800 hexagons)
- 10 arcmin FoV
- Diffraction-limited through adaptive optics + LGS



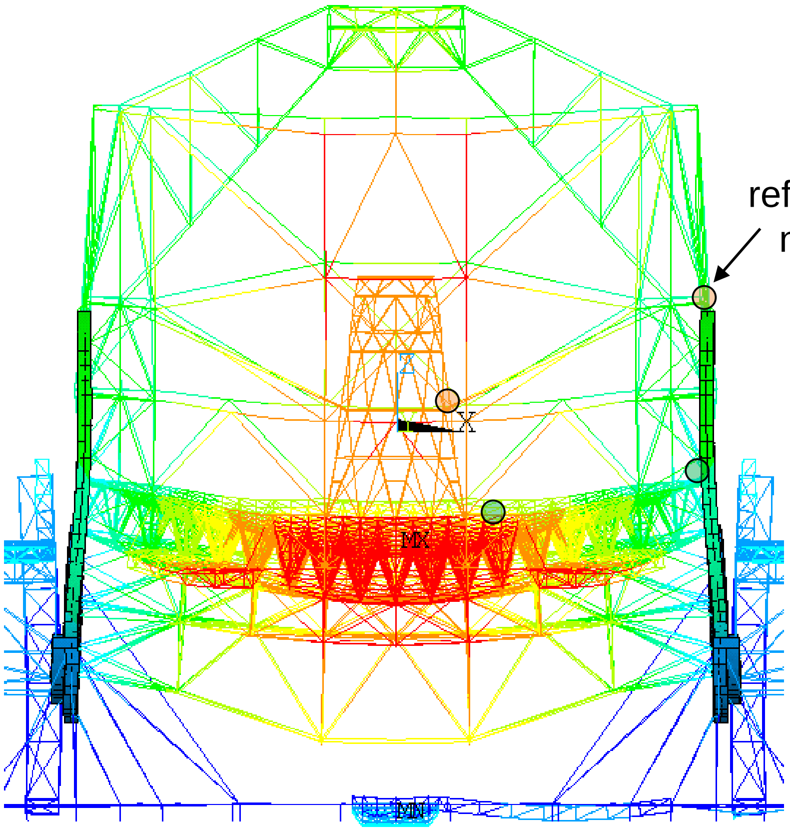
E-ELT Optical Design

- 3-mirror anastigmat
- M1–M3 powered, M4: adaptive optics, M5: fast tip/tilt
- Intermediate focus (hole in M4)
- Active optics baseline: 3 WFS around focal plane
- No online mirror position metrology in baseline

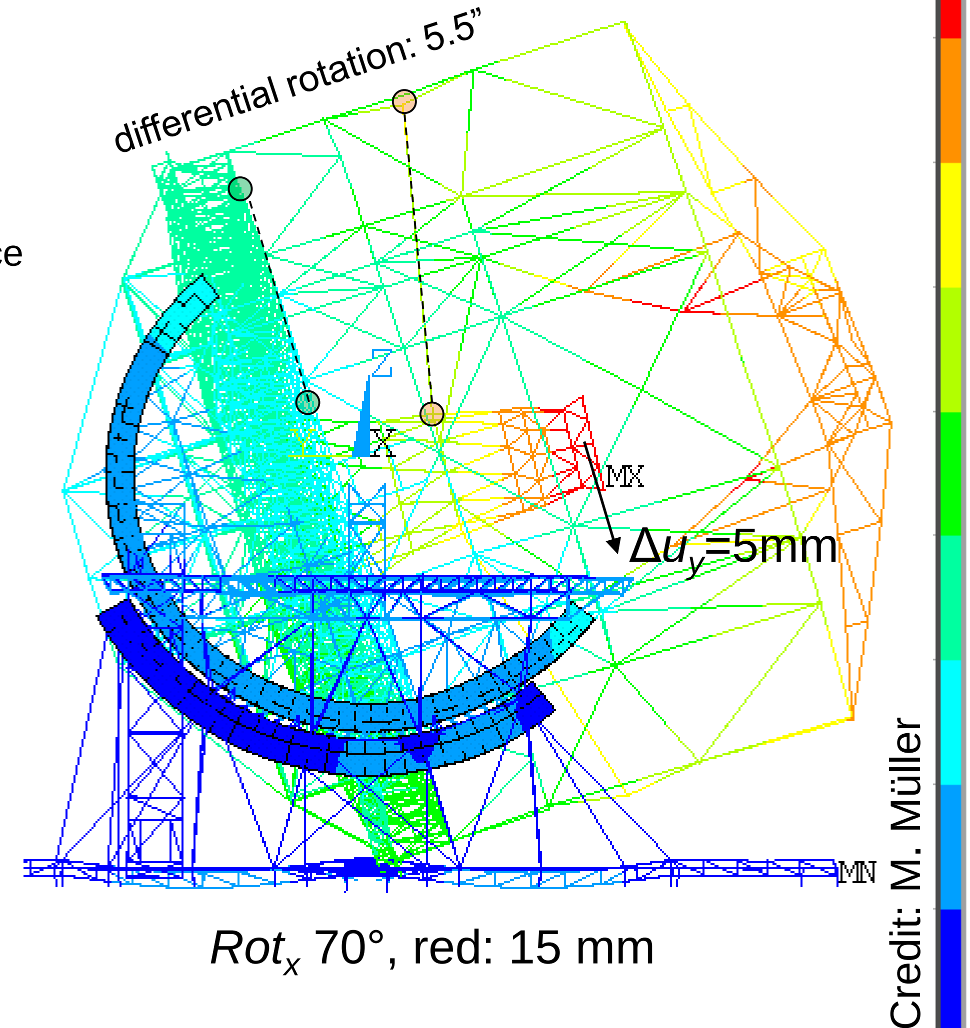


Structure Gravity Flexure

Absolute gravity flexures



zenith, red: 11 mm total *xyz*



Rot_x 70°, red: 15 mm

Credit: M. Müller

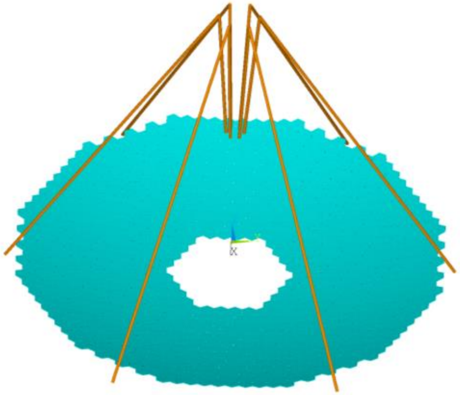
How to do precision mirror metrology with such flexures?

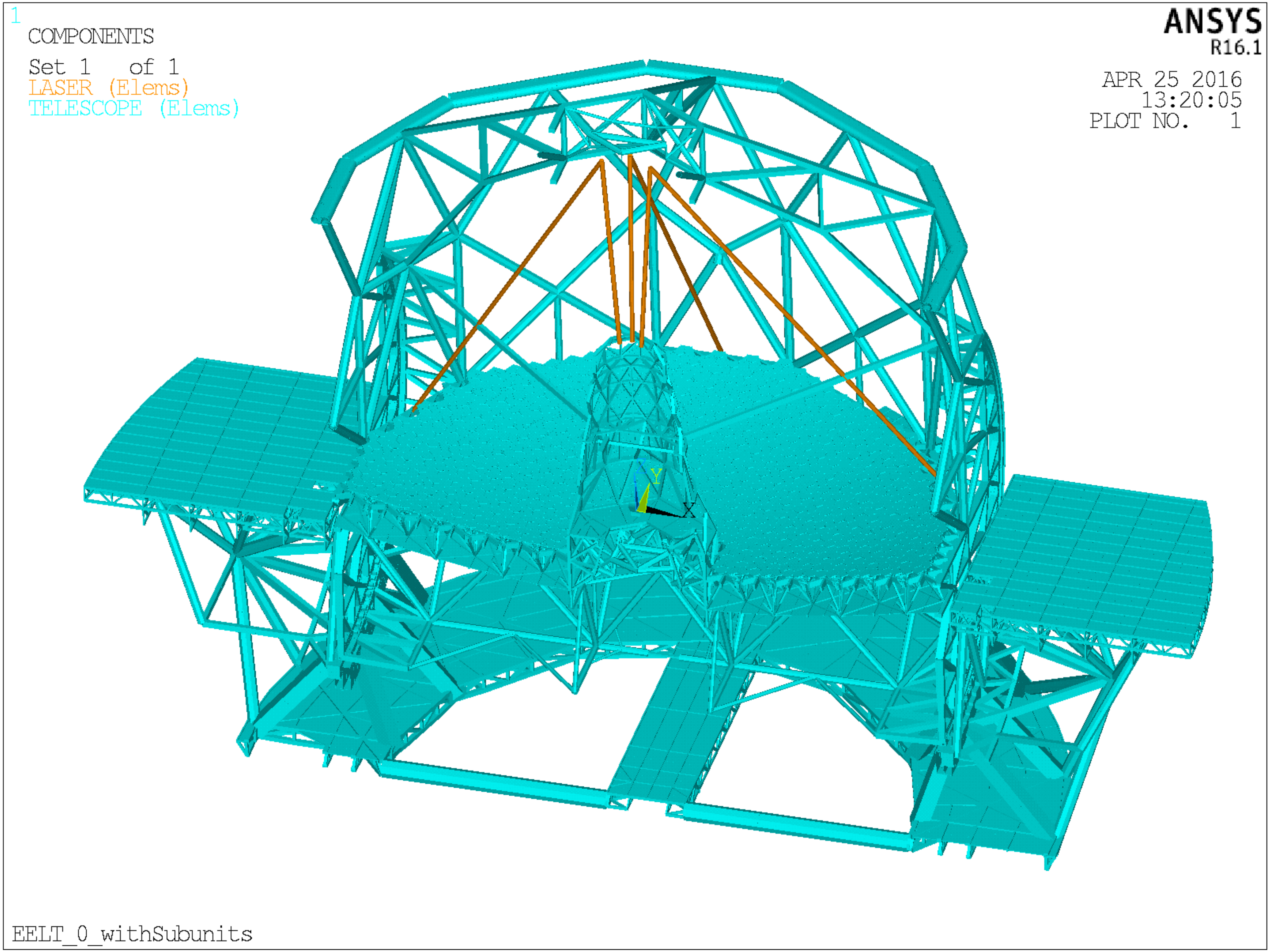
Global Mirror Metrology

- What is global mirror metrology useful for?
  - Global mirror position + figure: AIT, Commissioning
  - Applications: Blind pointing
  - Scalloping, plate scale, wind shake metrology
- Sub-micron/arcsecond accuracy over tens of meters requires lasers
- Candidate: *Etalon Multiline* (24-channel laser interferometer) extended to 30+ meters. Challenges:
  - Measurements compromised by main structure flexure
  - Local turbulence → opt. path length jitter, beam wander
  - Light pollution of science and/or WFS

Goals & Concept

- Would be nice to…
  - Measure global M1/M2 position+figure *all the time*
  - Launch/receive beams in low-flex positions
  - Be transparent to science: Operate at 589nm or 1450nm?
  - Propagate (near-)parallel to science light: beat turbulence
- Concept: Laser "Ray Tracer"
  - Launched from outer M1 segment edges…
  - …reflected on M2…
  - …and received near intermediate focus
  - Launched 13.5' off-axis (outward)
  - 70 mm beam, 100 µW (eye safe)




1
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TELESCOPE (Elems)
ANSYS
R16.1
APR 25 2016
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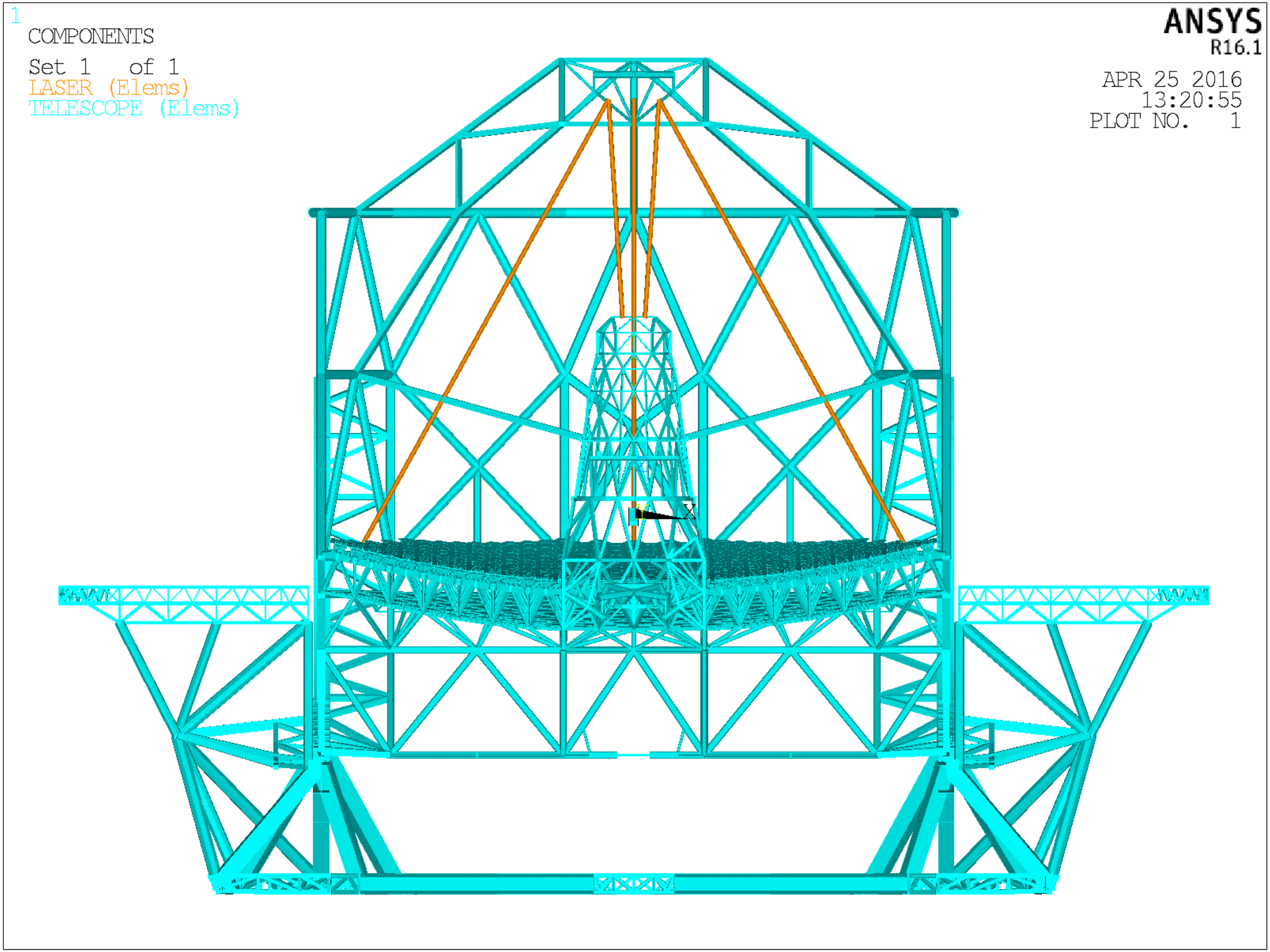
PLOT NO. 1
Y
X
EELT_0_withSubunits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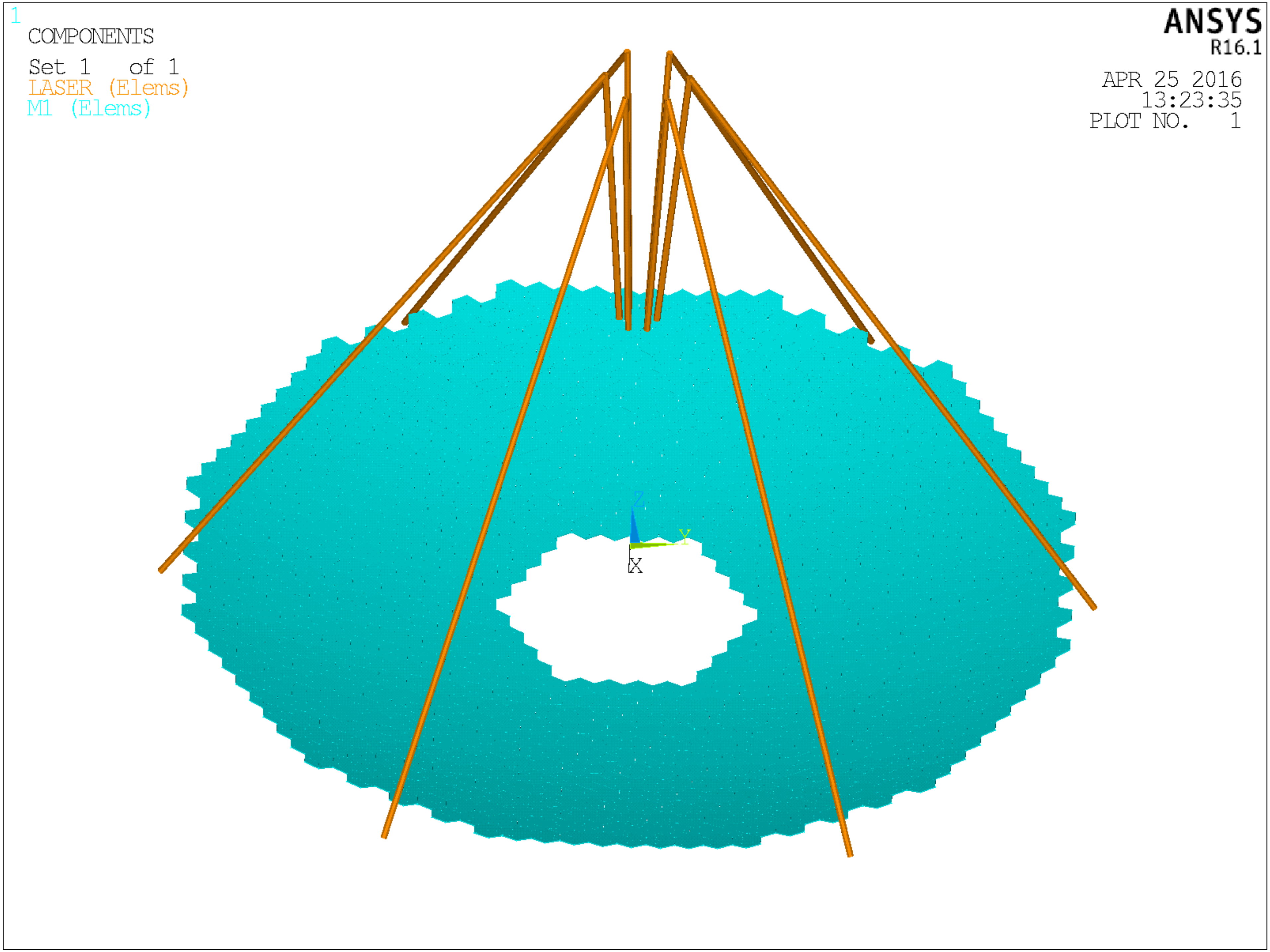
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Set 1 of 1
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M1 (Elems)
ANSYS
R16.1
APR 25 2016
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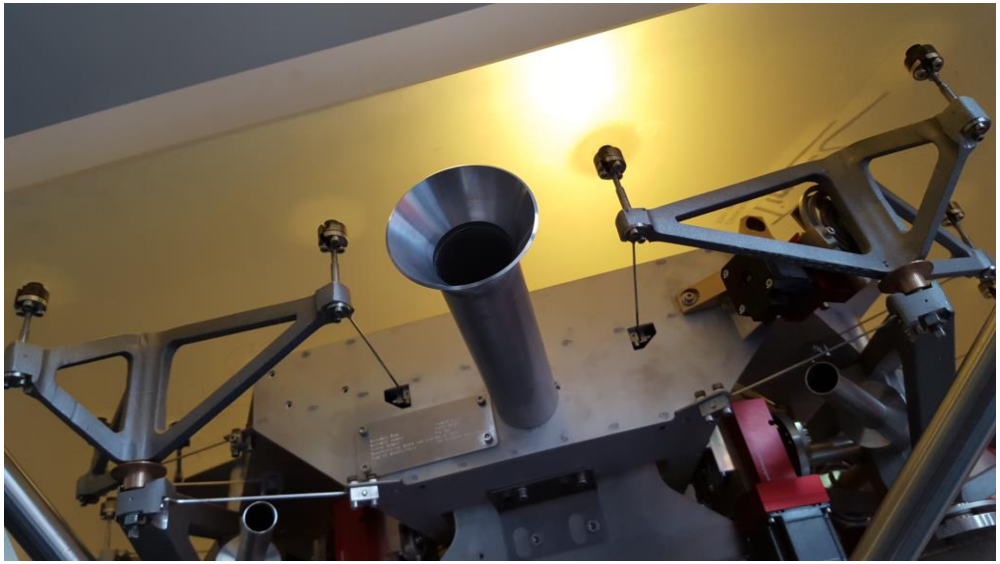
PLOT NO. 1
Z
Y
X

Launch from Segment Support

- Projectors mounted on M1 segment support
  - Mount onto Moving Frame (holds mirror)
  - Requires very stiff arm (< 1” flexure)
  - Removable for segment exchange
  - Launch beams just outside of pupil and field
  - …but close to both to emulate science light



Hardware

- Lasers:
  - Commercial narrow-band diode lasers
  - Single-mode fiber coupled, not mounted on arm

- Projectors:
  - Diffraction-limited refractive 70mm beam expanders
  - Monochromatic + on-axis (COTS item)
  - One-time manual alignment

20 ×
Newport

- Position Sensitive Detector (PSD):
  - COTS item, precision 10^{-5}
  - Four-cathode photodiode, analog
  - Frame rate 40 Hz and more
  - Automatic 2-mirror beam acquisition assembly

Sense & Sensitivities

- Gaussian beams
  - Beam path lengths: *M1* → 32.7 m → *M2* →13 m → det.
  - Example: Weakly convergent launch, $2w$ = 39 mm
    - ➔ Footprints: 4.5 mm (M2), 3.0 mm (detector)
  - $\mathrm{RoC}_{\mathrm{Launch}}$= 40m (~focus on M2)
  - Diameter far below r_0, thus low beam distortion
- Sense position (+angle) with Position Sensitive Det.
- Raw mechanical sensitivities:
  - 1” tip/tilt on M1: –0.6 mm, –7” (M2 amplified)
  - 1” tip/tilt on M2: 0.11 × –0.12mm, 1.8” × –1.9”
  - M1 RoC + 250 µm: –0.12 mm, –1.4”
  - Piston M2 by 100 µm : –0.2 mm, –2.1”

Pros & Cons

- Pros:
  - Independent of turbulence outside M1–M2–detector
  - Laser power can be tuned for sensor/frame rate
  - Does not require accurate M1 phasing, independent of AO
  - Can be used prior to M3–M6 commissioning
  - Can be used anytime (daytime, during science)
  - Fast enough to sense windshake
  - Eye safe, non-disruptive
  - Affordable (order 20k€ per laser/receiver)
- Challenges / ToDo:
  - Needs stiff launcher arm mounted to segment support
  - Light pollution to science instruments to be studied

What Can Be Sensed?

- Assume 6 lasers equally spaced around M1
  - Yields 6 *xy*-positions + 6 *xy*-angles: 24 scalars total
  - M1 defocus, global tip/tilt and astig, M2: 5 rigid-body DoF
  - Can sense 11 scalar aberration modes in total
  - Use Generalized Least Squares method to assess errors:

Aberration	σ	Related EELT Allocation (preliminary)
M1 defocus (Z4)	1.2 nm RMS	5 µm RMS defocus (blind acq.); 3.5 µm RMS (plate scale)
M1 astigmatism (Z5,Z6)	1.7 nm RMS	
M1 trefoil (Z9,Z10)	1.0 nm RMS	
M2 tip/tilt vs. M1	0.031 µrad	25 µrad (blind acquisition)
M2 lateral displacement vs. M1	310 nm	100 µm (blind acquisition)
ARU Tower tip/tilt at top	0.15 µrad	

  - The above values do not include projector jitter, turbulence, ARU Tower vibrations etc.

Conclusions

- Strength of the Ray Tracer lies in fast sensing of *relative* M1/M2 misalignment/misfigure/windshake
- Much smaller delay than laser interferometers like the *Etalon Multiline* (currently around 1s/target)
- Internal turbulence is sensed in a way relevant to the science PSF (real beam raytracing)
- Complements laser trackers which yield *absolute distances*, indispensable for AIV and coarse alignment after presets
- Cost estimate for six lasers/detectors: 110 k€

Seem like a good cost / benefit concept?