The MICADO derotator and its test stand at MPIA

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precision mechanical workshop MPIA

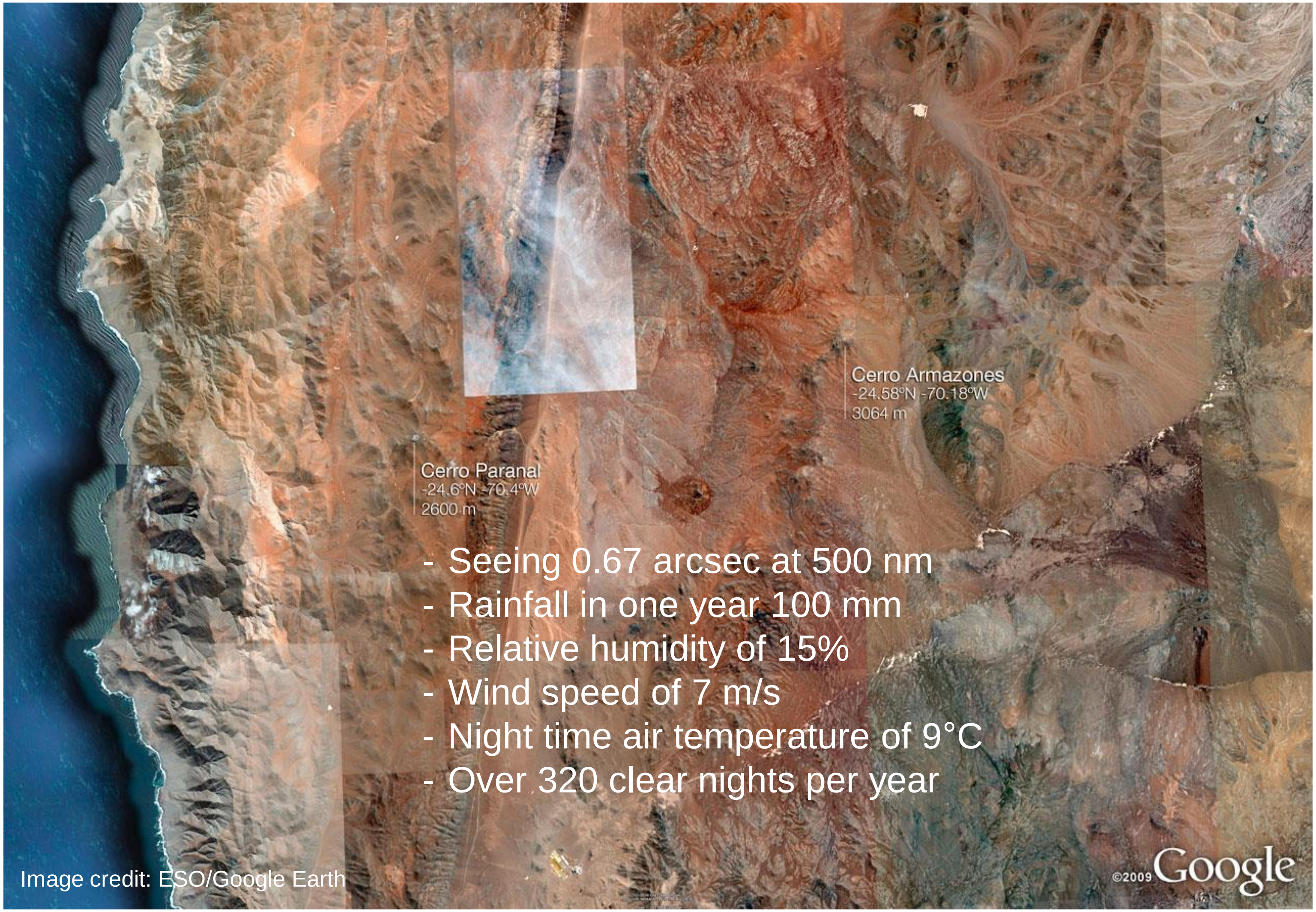
Astro Tech Talk
MPIA, 28 October 2016

Outline

- European Extremely Large Telescope (E-ELT)
- MICADO
- Why a Derotator is needed
- The Derotator concept
- Test stand and the integration process
- Integration status and missing components
- Goals of the experiment (kick-off)
- Planning for the test campaign
- Implementation schedule of the test campaign
- Tests already performed

E-ELT

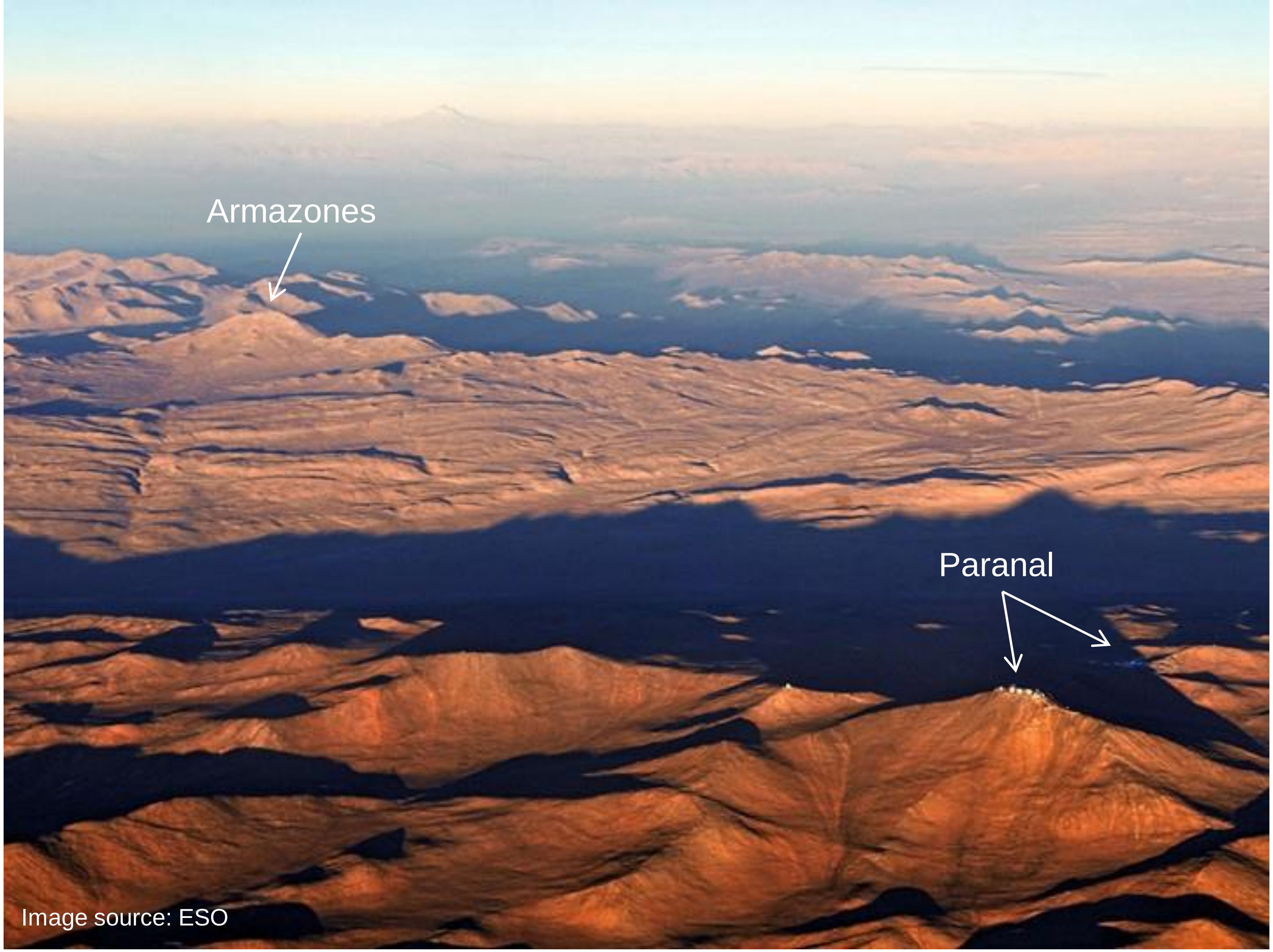
- Location



Atacama Desert, Chile

E-ELT

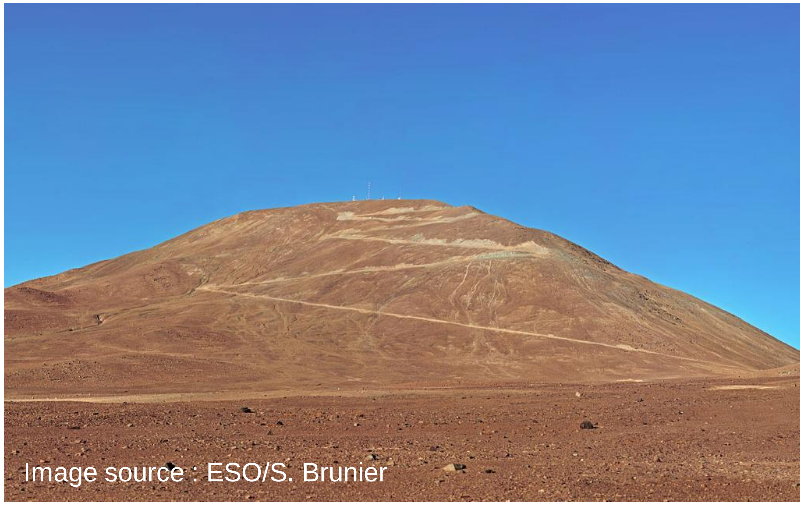
- Location

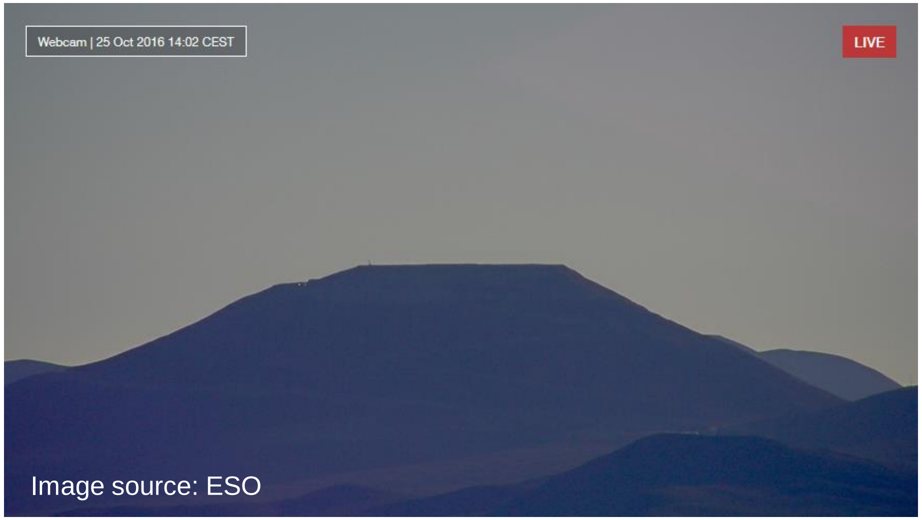


Atacama Desert, Chile

E-ELT

- Location

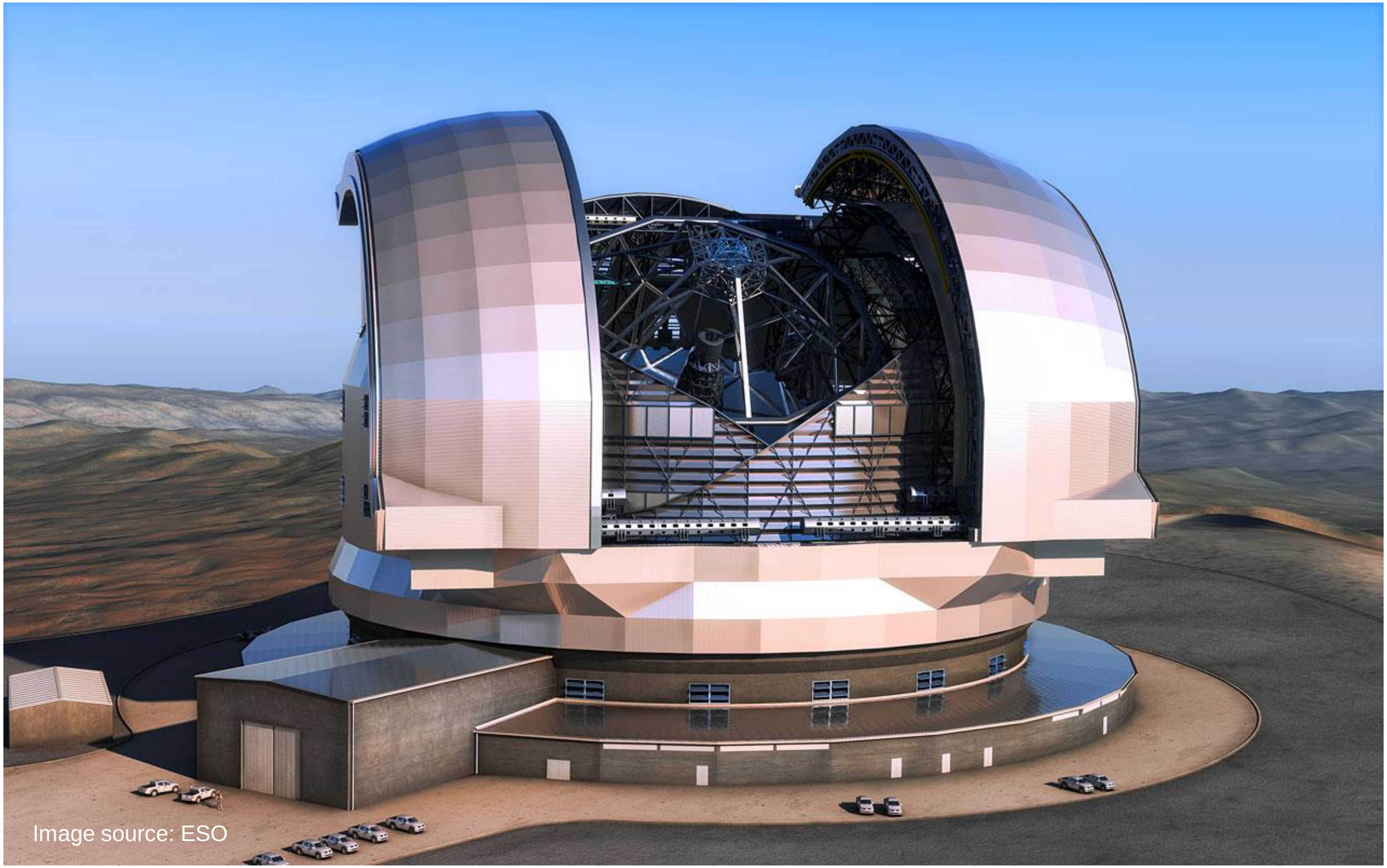




Atacama Desert, Chile

E-ELT

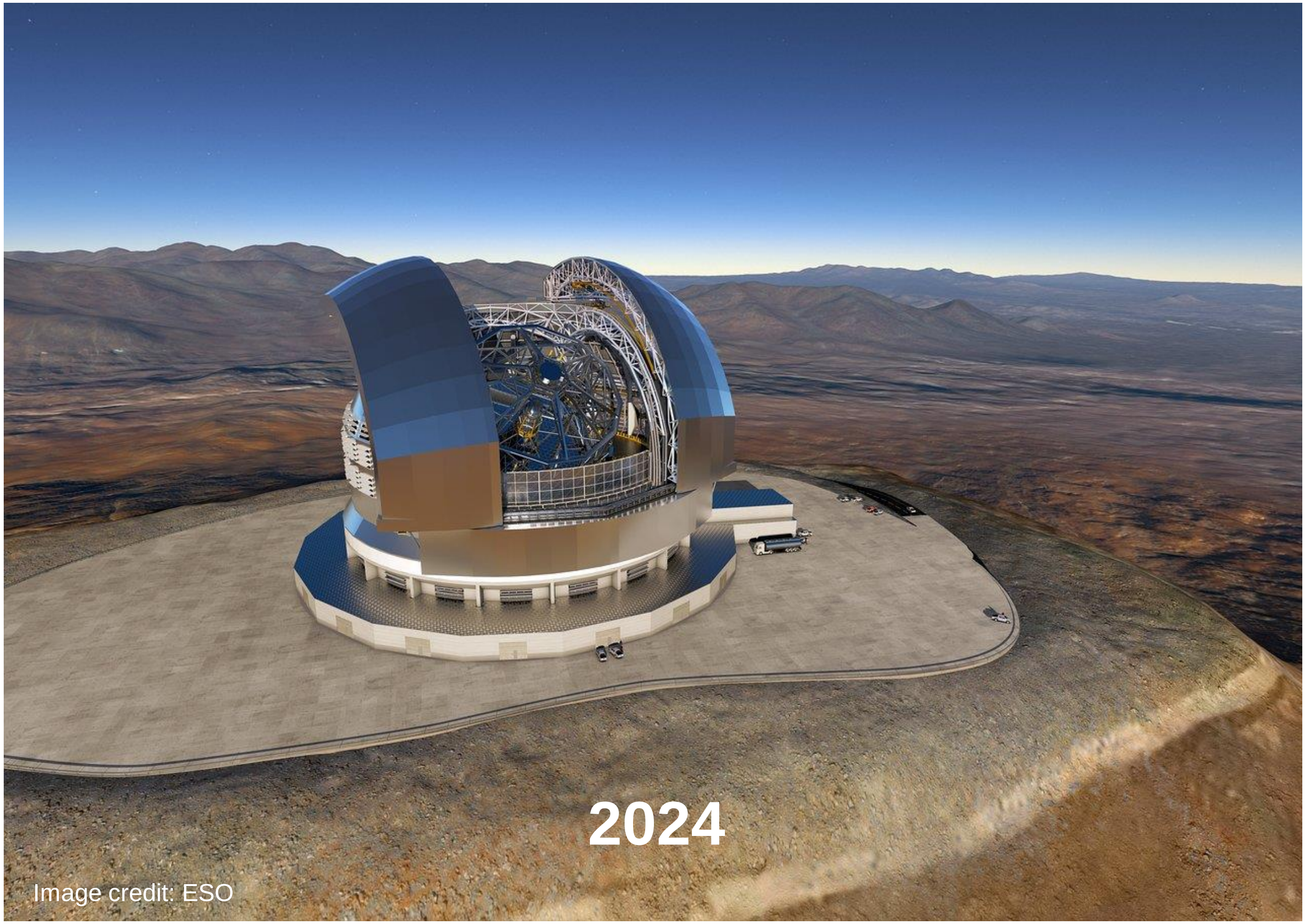
- Green light for E-ELT construction “Phase 1”
  (see organization release eso1440 - The Messenger 158, December 2014)



ELT rendering Atacama Desert, Chile

E-ELT

- In May 2016 ESO signed the contract for E-ELT Dome and Telescope Structure (see organization release eso1617)



Atacama Desert, Chile

E-ELT

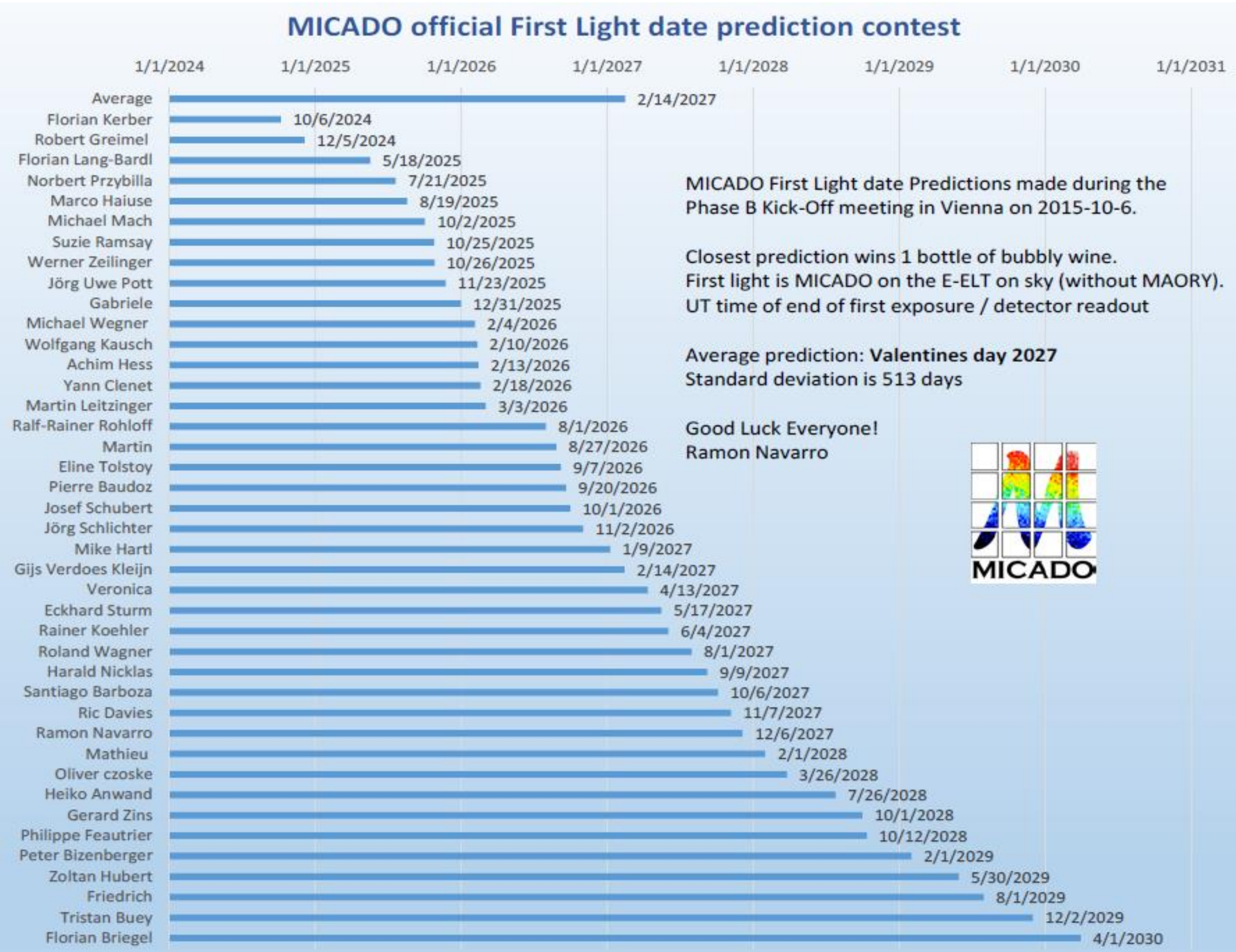
- Instruments and adaptive optics modules

Name	Instrument Type	Wavelength Range	Field of View
CODEX	High Resolution, High Stability Visual Spectrograph	0.37 – 0.71µm	0.82"
EAGLE	AO-assisted Multi-integral Field NIR Spectrometer	0.8 – 2.45µm	IFU: 1.65" x 1.65"
EPICS	Planet Imager, Spectrograph and Imaging Polarimeter with Extreme Adaptive Optics	0.6 – 1.65µm	IFU: 0.8" x 0.8"
HARMONI	Single Field Integral-field Spectrograph	0.47 – 2.45µm	10" x 5" with the coarsest pixel scale
METIS	Mid-infrared Imager and Spectrograph with AO	2.9 – 14µm	17.6" x 17.6" (imager)
MICADO	Imager and Slit Spectrograph	0.8 – 2.5µm	up to 53"
OPTIMOS-DIORAMAS	Wide-Field Imager & Low-Medium Resolution Slit Spectrograph	0.37 – 1.6µm	6.78' x 6.78'
OPTIMOS-EVE	Optical-NIR Fibre-based MOS	0.37 – 1.7µm	Large field IFU: 7.8" x 13.5"
SIMPLE	Cross-dispersed Echelle Spectrograph, Long-slit Option	0.8 – 2.5µm	up to ~4" patrol field for slit viewer
ATLAS	Laser Tomography AO Module	0.35 – 13.5µm	60"
MAORY	Multi Conjugate AO Module	0.8 – 2.4µm	2'

MICADO Kick-Off

Image of the consortium taken at the MICADO kick-off meeting in Vienna, 7 October 2015

- Preliminary Design Review, October 2018
- Final Design Review, 2020
- Preliminary Acceptance Europe, 2023
- First Light, 2024


MICADO official First Light date prediction contest
1/1/2024
1/1/2025
1/1/2026
1/1/2027
1/1/2028
1/1/2029
1/1/2030
1/1/2031
Average 2/14/2027
Florian Kerber 10/6/2024
Robert Greimel 12/5/2024
Florian Lang-Bardl 5/18/2025
Norbert Przybilla 7/21/2025
Marco Haiuse 8/19/2025
Michael Mach 10/2/2025
Suzie Ramsay 10/25/2025
Werner Zeilinger 10/26/2025
Jörg Uwe Pott 11/23/2025
Gabriele 12/31/2025
Michael Wegner 2/4/2026
Wolfgang Kausch 2/10/2026
Achim Hess 2/13/2026
Yann Clenet 2/18/2026
Martin Leitzinger 3/3/2026
Ralf-Rainer Rohloff 8/1/2026
Martin 8/27/2026
Eline Tolstoy 9/7/2026
Pierre Baudoz 9/20/2026
Josef Schubert 10/1/2026
Jörg Schlichter 11/2/2026
Mike Hartl 1/9/2027
Gijs Verdoes Kleijn 2/14/2027
Veronica 4/13/2027
Eckhard Sturm 5/17/2027
Rainer Koehler 6/4/2027
Roland Wagner 8/1/2027
Harald Nicklas 9/9/2027
Santiago Barboza 10/6/2027
Ric Davies 11/7/2027
Ramon Navarro 12/6/2027
Mathieu 2/1/2028
Oliver czoske 3/26/2028
Heiko Anwand 7/26/2028
Gerard Zins 10/1/2028
Philippe Feautrier 10/12/2028
Peter Bizenberger 2/1/2029
Zoltan Hubert 5/30/2029
Friedrich 8/1/2029
Tristan Buey 12/2/2029
Florian Briegel 4/1/2030
MICADO First Light date Predictions made during the Phase B Kick-Off meeting in Vienna on 2015-10-6.
Closest prediction wins 1 bottle of bubbly wine.
First light is MICADO on the E-ELT on sky (without MAORY).
UT time of end of first exposure / detector readout
Average prediction: Valentines day 2027
Standard deviation is 513 days
Good Luck Everyone!
Ramon Navarro
MICADO

MICADO

- Located in the straight focal station on the Nasmyth platform

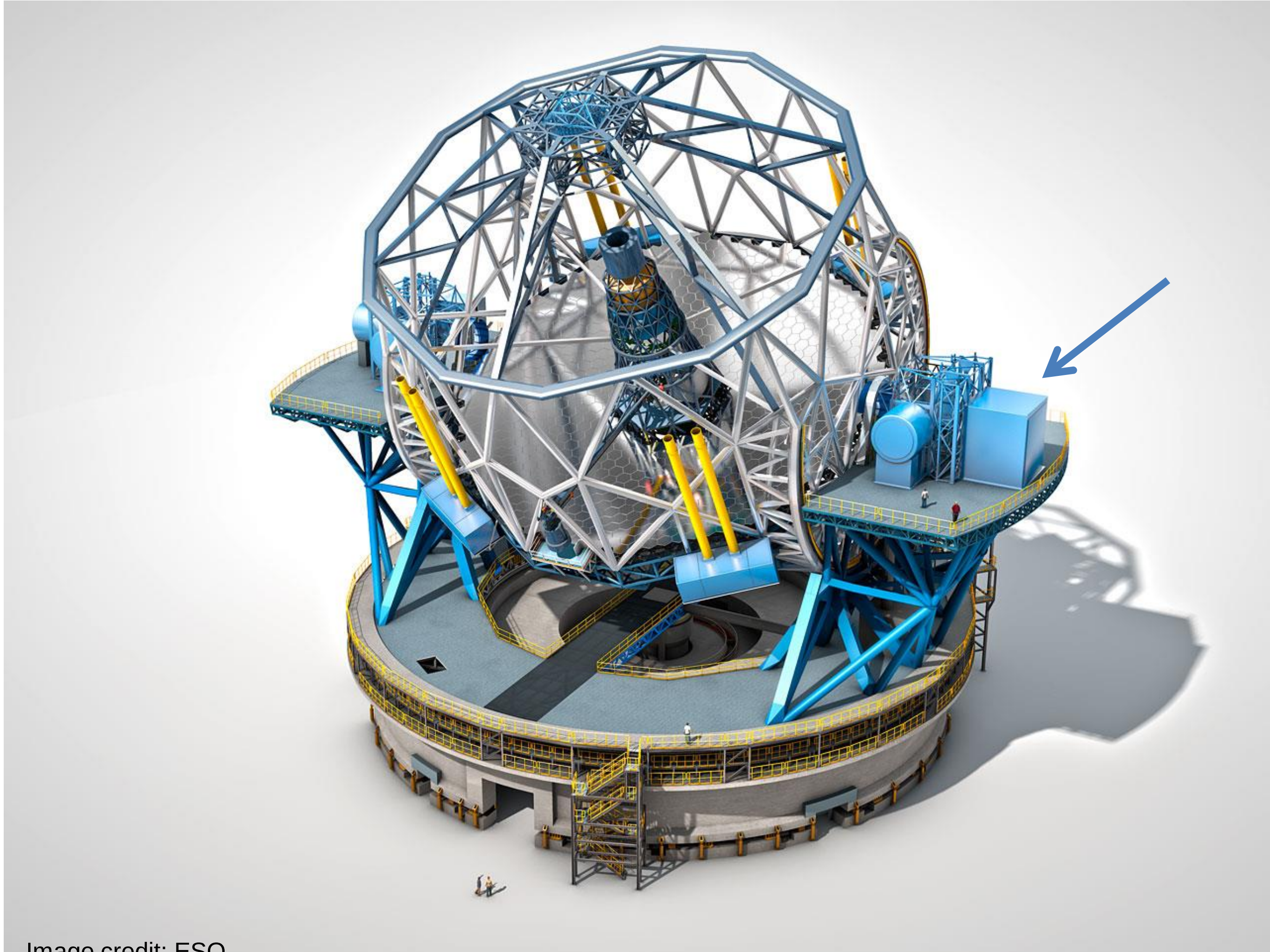


Image credit: ESO

MICADO

- The Multi-AO Imaging CAmera for Deep Observations

- Key Capabilities
  - Sensitivity and resolution
  - Precision astrometry
  - Spectroscopy
  - Simple and robust

- The instrument design has been optimized for MCAO (MAORY)

- Large 53 arcsec field of view at the diffraction limit of the E-ELT

- The early operational phase will used SCAO
(if MAORY is no ready)

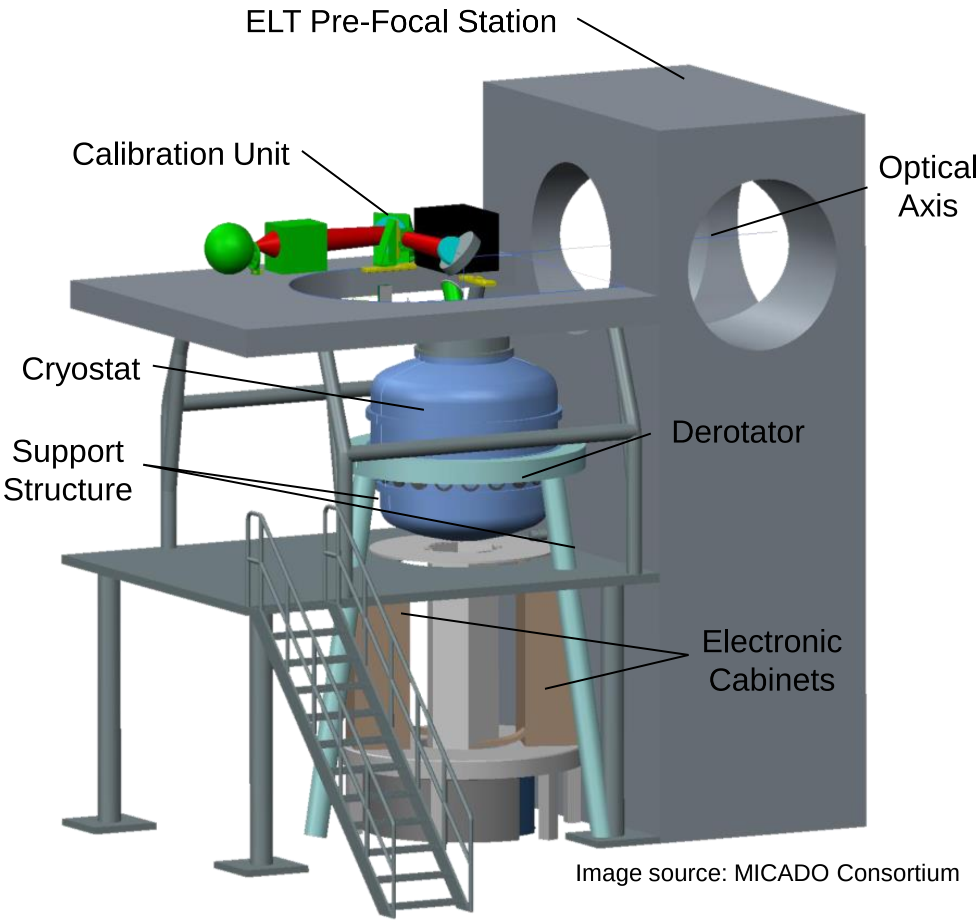


Image source: MICADO Consortium

MICADO- MAORY

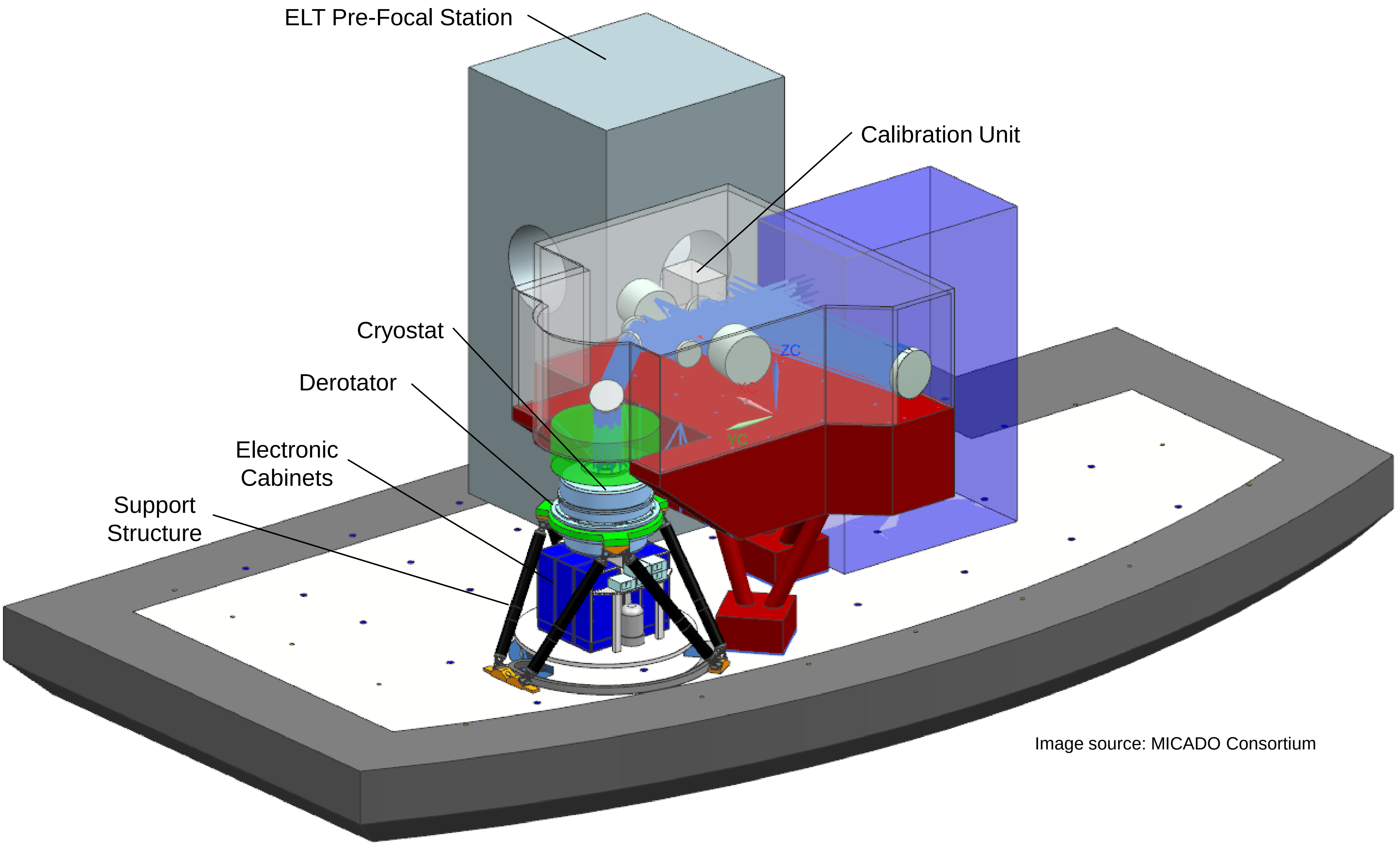


Image source: MICADO Consortium

Why a Derotator is needed?

- Field rotation on telescopes with Alt-Azimuth mounts

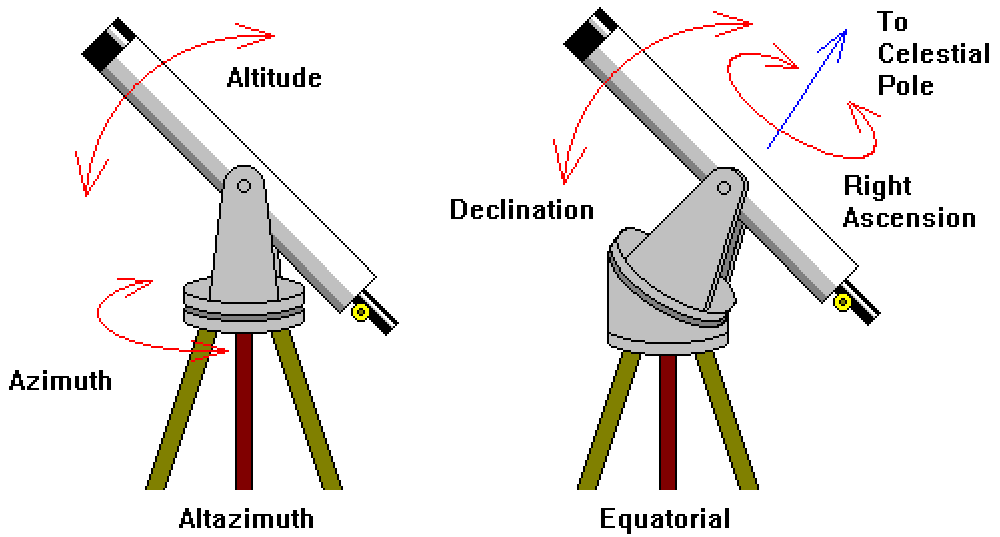


Image source: www.oasi.org.uk

Images with short-exposure time

Why a Derotator is needed?

- Field rotation on telescopes with Alt-Azimuth mounts

Images with long-exposure time

Why a Derotator is needed?

- Field rotation on telescopes with Alt-Azimuth mounts

Images with long-exposure time

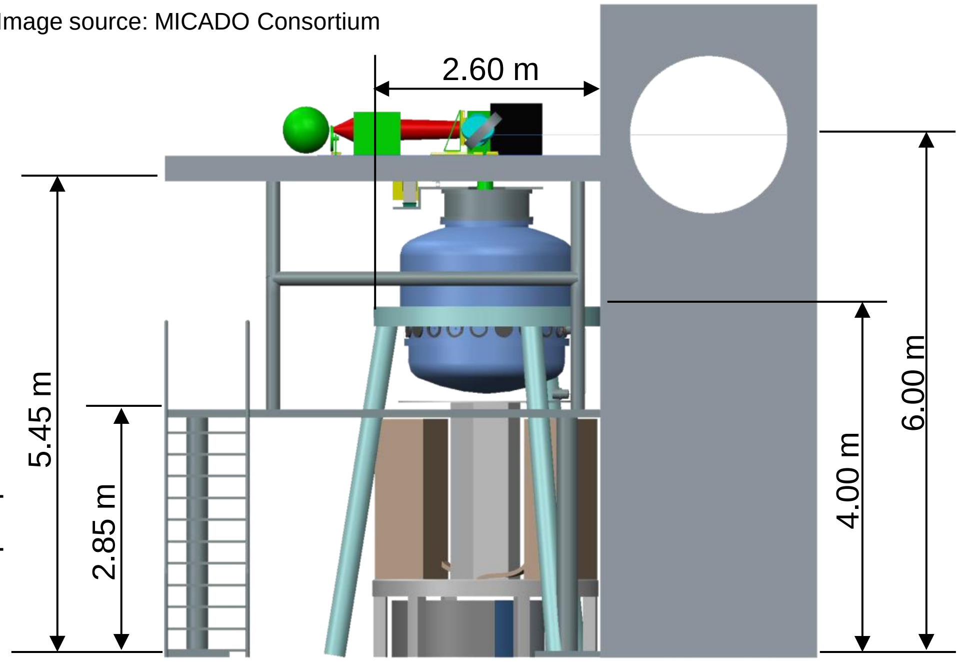
The Derotator

- Bearing, drivers, motors, encoders and mechanical interfaces
- High precision requirements
- How to achieve (if possible) 1 arcsec of rotational positioning accuracy ?

Parameter	Value
Inner diameter	> 2100 mm
Thickness	≤ 230 mm
Moving mass	≤ 4 ton
Axial runout	< 50 µm
Radial runout	< 100 µm
Wobble	< 10 arcsec
Operating temperature	−10°C to 20°C
Rotation speed	360° in ≤ 2 min
Relative angular positioning accuracy	<10 arcsec (rms)

Derotator preliminary requirements

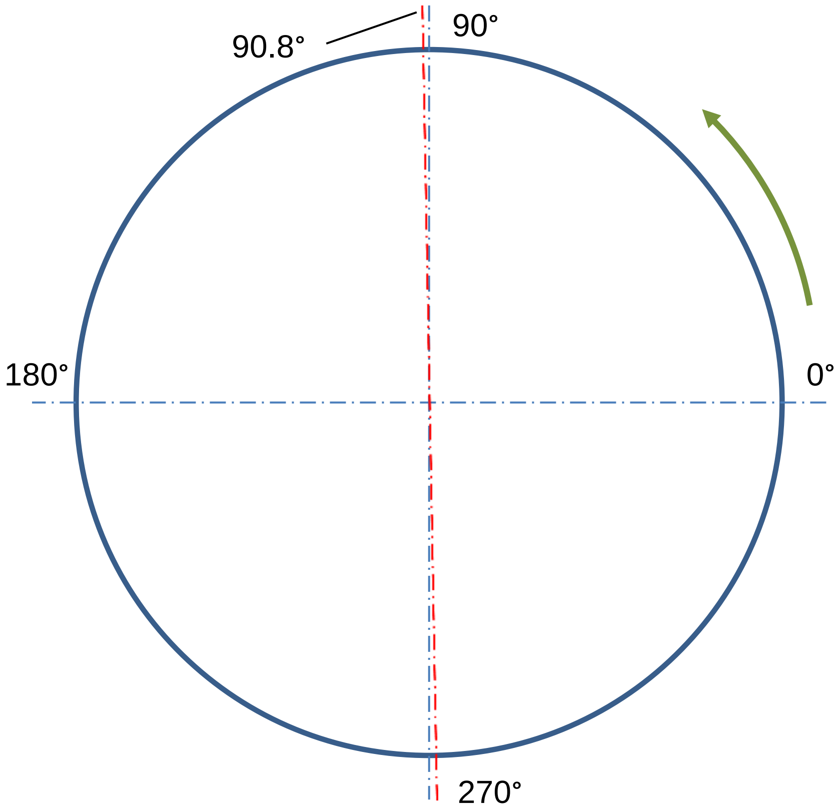
Image source: MICADO Consortium

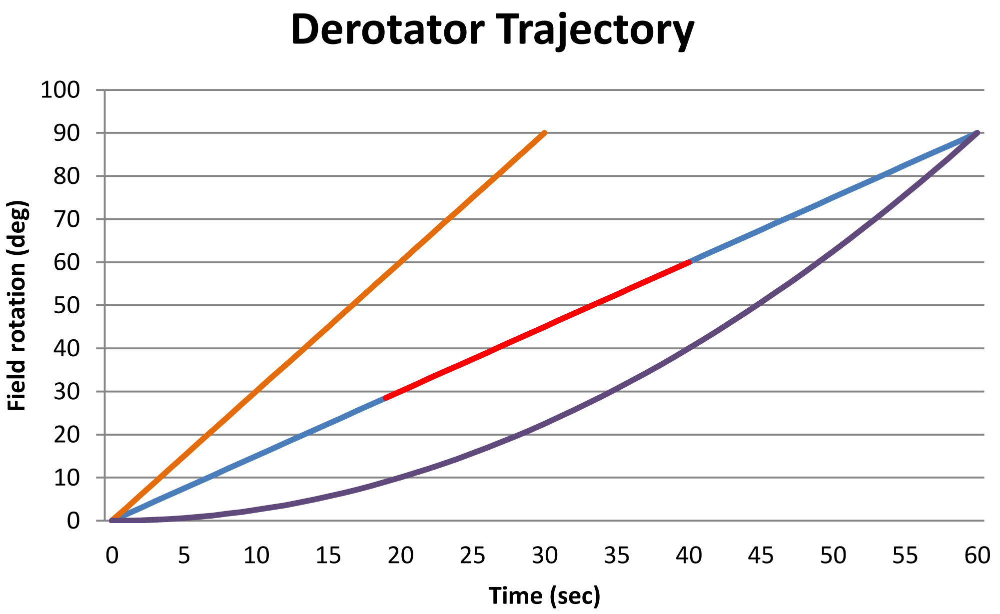


- Possible bearing technologies
  - Slewing bearings
  - Hydrostatic bearings
  - Air bearings
  - Magnetic bearings

How accurate must be the Derotator?

- What does relative angular positioning accuracy mean?
- How much is 10 arcsec (rms)?

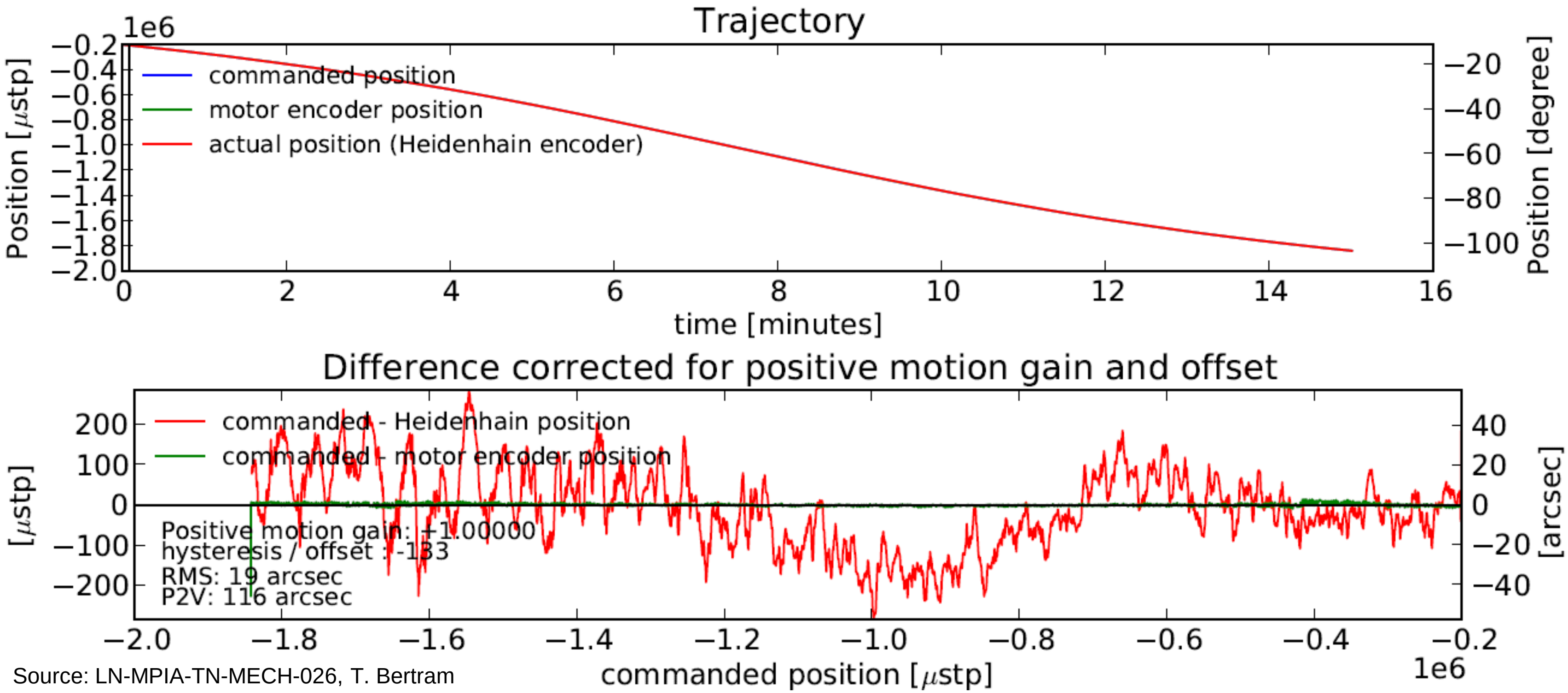




- Input = 90° → Output = 90.8° or 89.2° (measured position)
  - Absolute accuracy < 1° (Input – Output)
- 1 arcsec = 1°/3600 = 0.000287° → 10 arcsec = 0.00278°

LINC-NIRVANA GWS

- Bearing Ø 852 mm
- System working in open loop

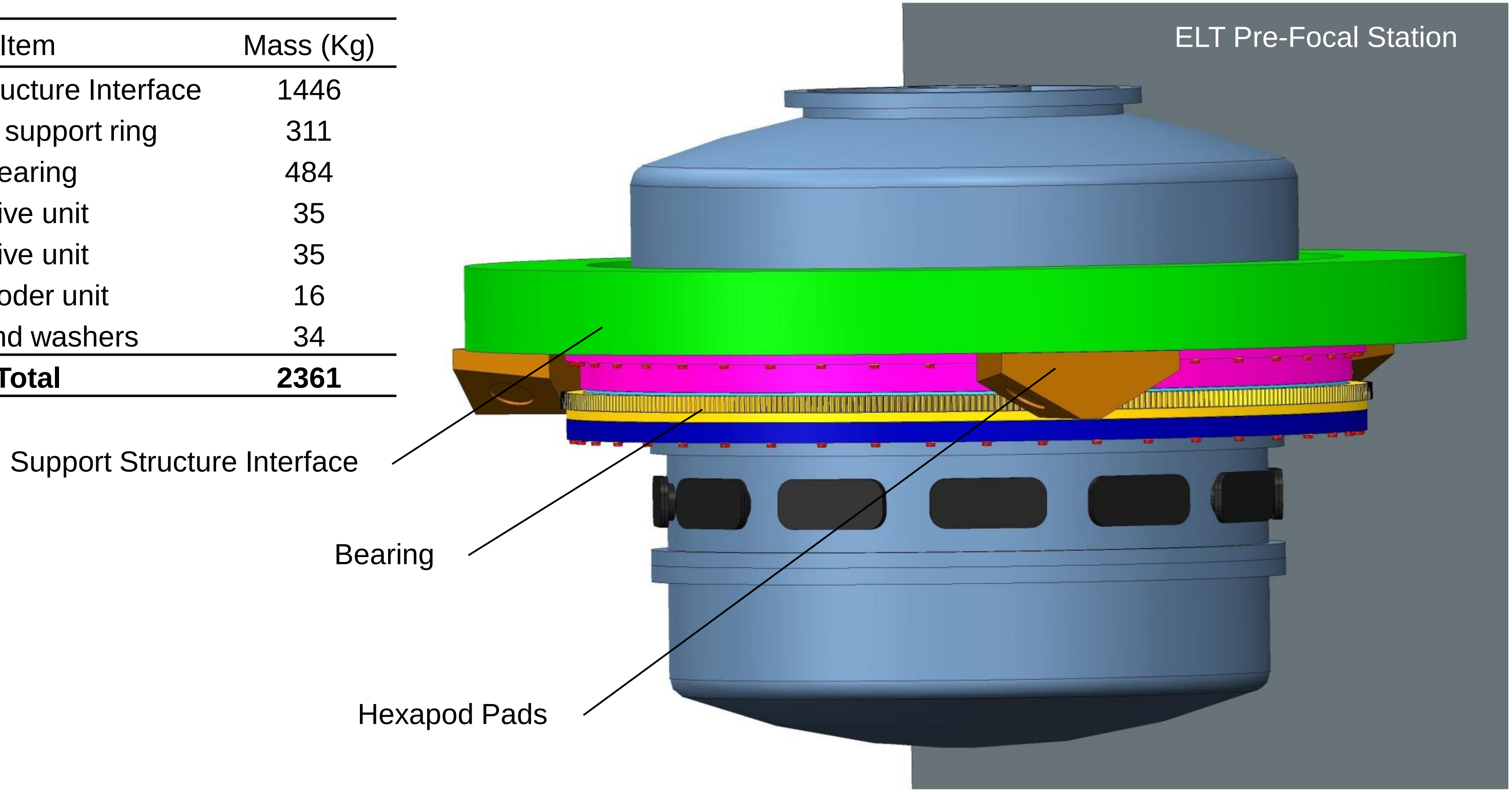


Source: LN-MPIA-TN-MECH-026, T. Bertram

The Derotator Concept

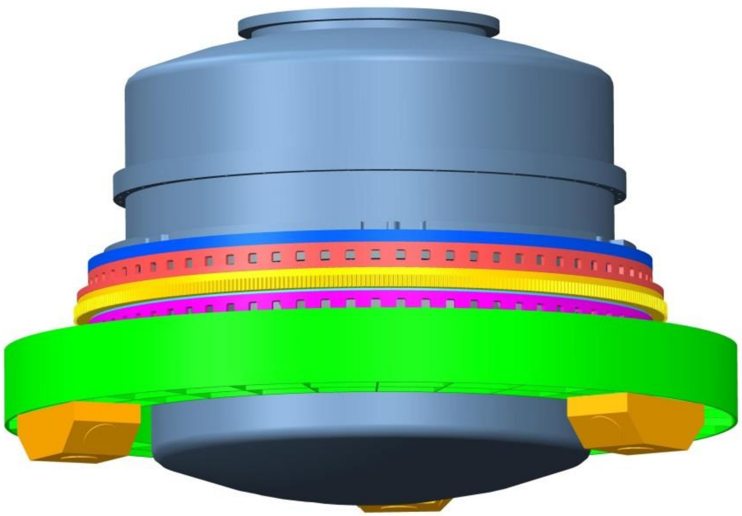
- Using Rhothe Erde Ball Bearing 83244820 (Gear Module 6)
  - Radial/Axial runout < 30 µm (requirement 100 µm / 50 µm)
- Based on a three points interface to the instrument support structure

Item	Mass (Kg)
Support Structure Interface	1446
Bearing support ring	311
Bearing	484
Drive unit	35
Drive unit	35
Encoder unit	16
Bolt and washers	34
Total	**2361**

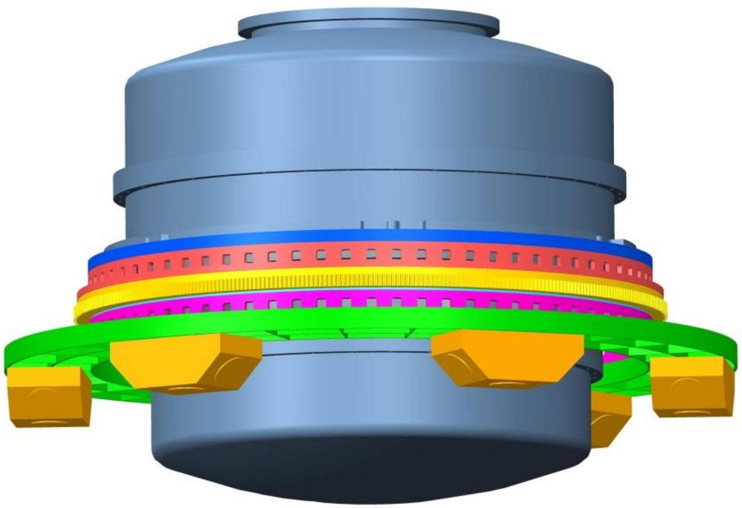


MICADO Derotator concept (support structure and motors not shown)

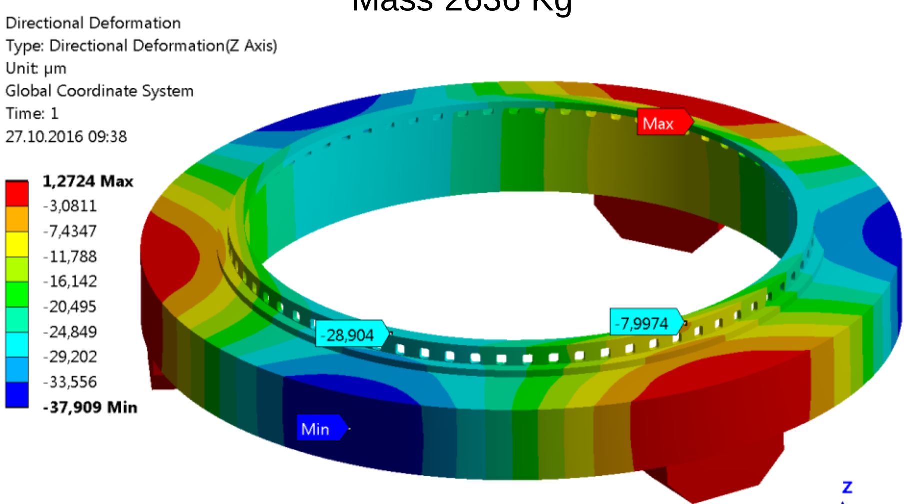
The Derotator Concept



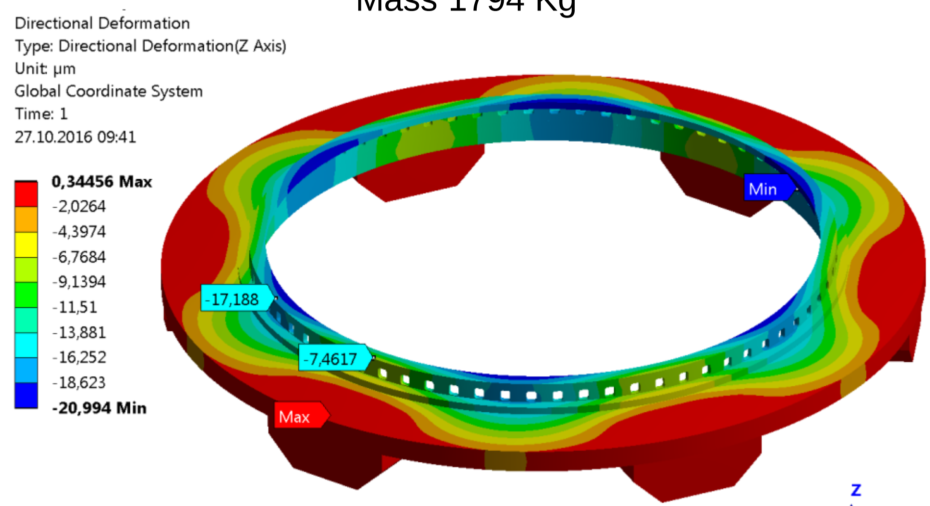
Mass 2636 Kg



Mass 1794 Kg



Deformation on the bearing 21 µm

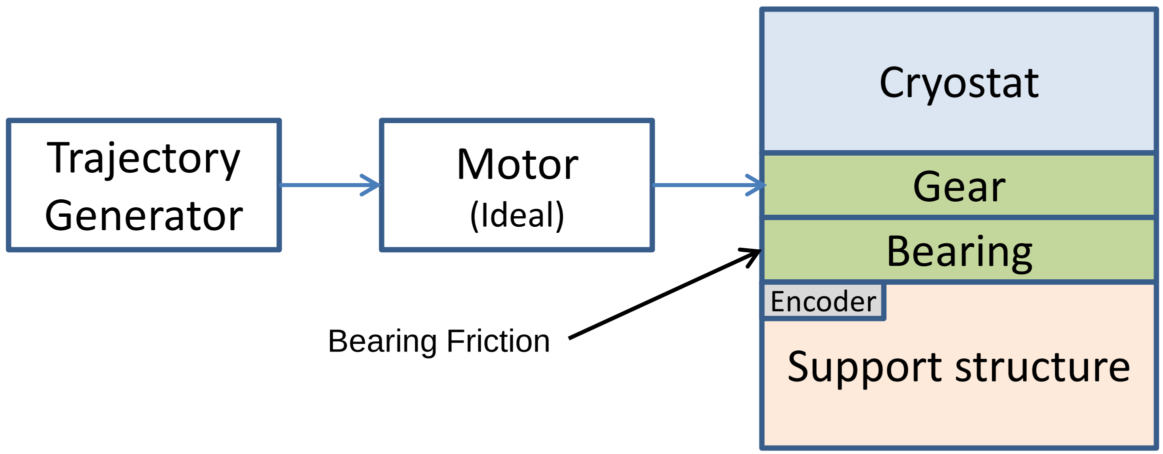


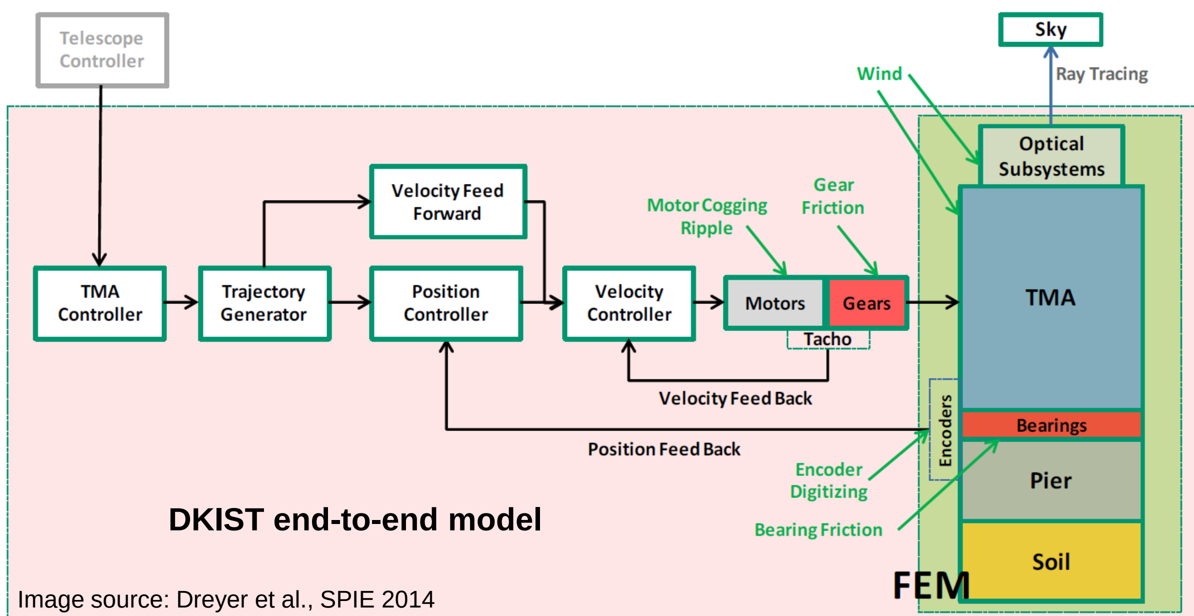
Deformation on the bearing 10 µm

MICADO Derotator concept (support structure and motors not shown)

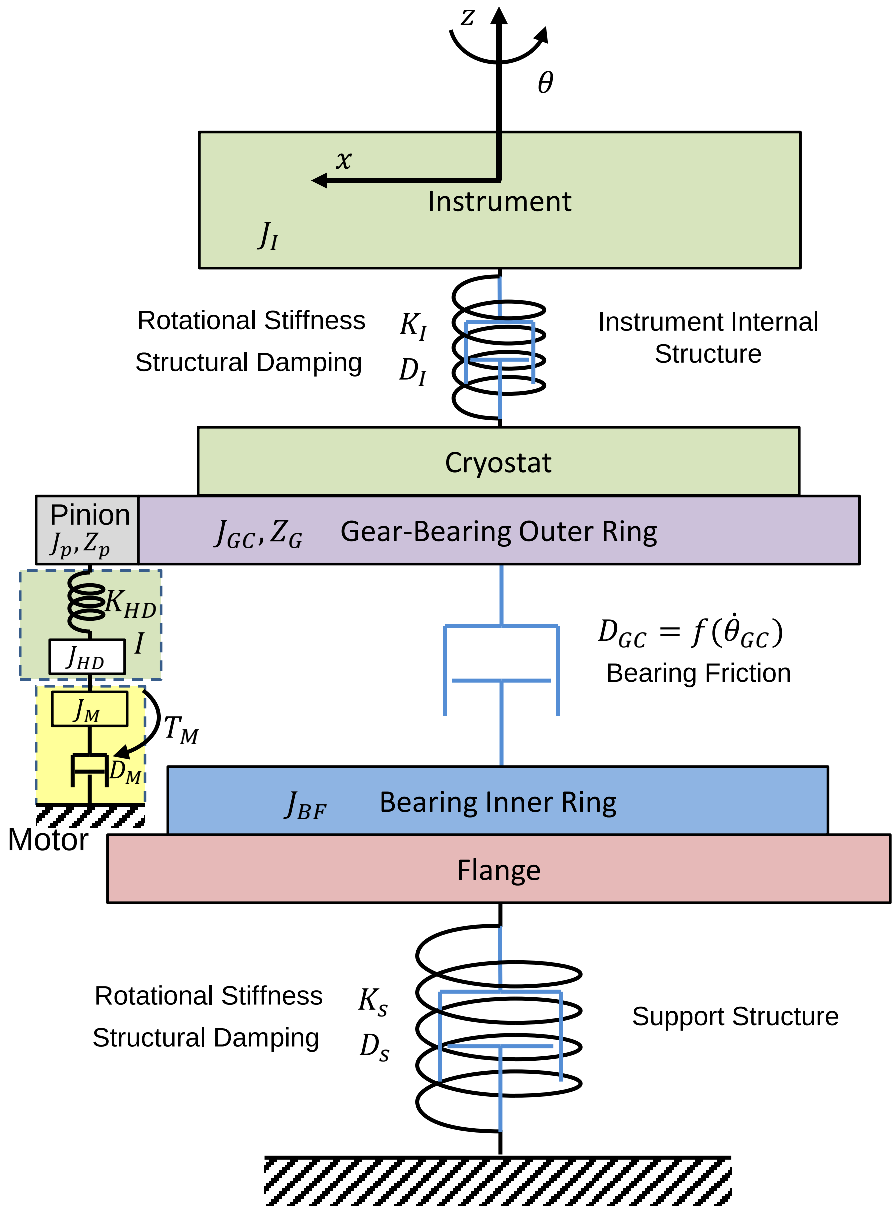
End to End Simulation

- From a simple to a complex end to end model





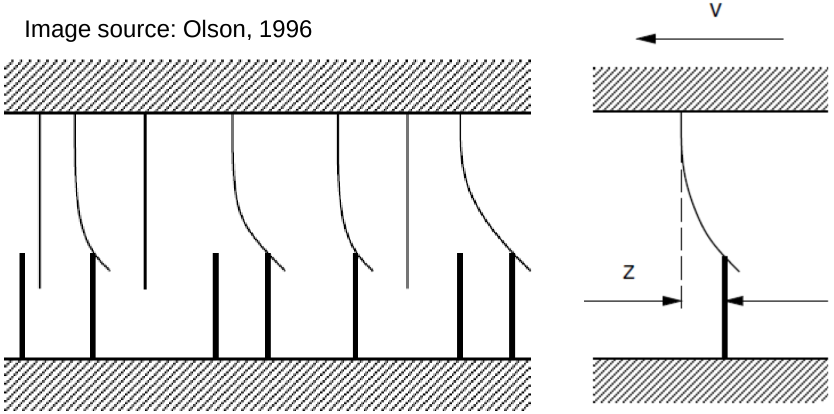
MICADO Mechanical System



Bearing Friction

- The LuGre Model (Olson, 1996)
  - The model is related to the bristle interpretation of friction
  - Friction is modelled as the average deflection force of the bristles (elastic springs)

Image source: Olson, 1996



Bristle model and deflection

- Parameters which have influence on the friction
  - Rolling friction coefficient
  - The rolling elements
  - Cages or spacers
  - Seals
  - Load distribution
  - The out-of-flatness of the support structure
  - The grease filling
  - The type of grease
  - The lubrication of the lip seals
  - The seal preload
  - The variation in the bearing‘s clearance resulting from installation

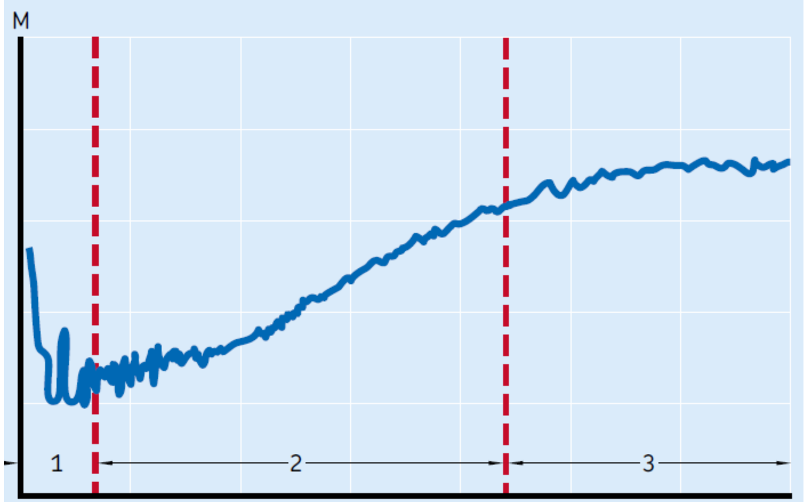


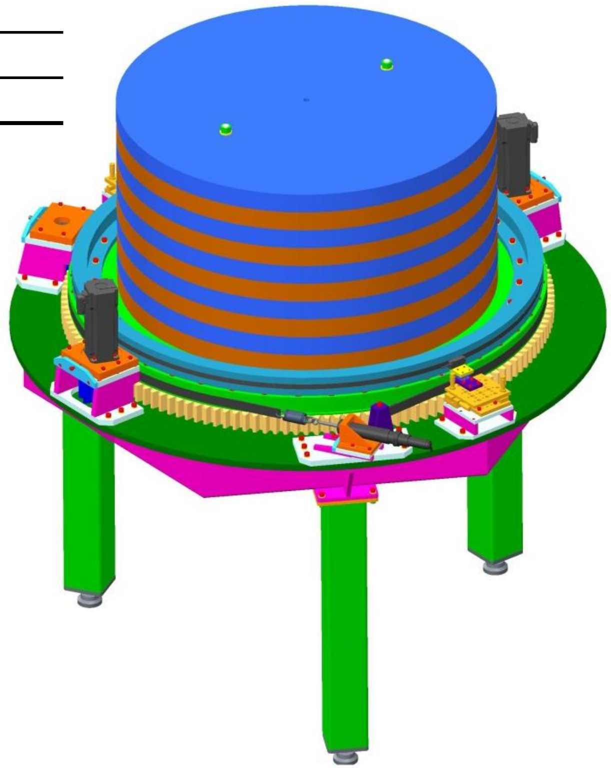
Image source: SKF rolling bearing Catalog

Test Stand Kick-off Meeting (February 2016)

- Design of the experiment using an standard bearing

Parameter	Test Stand Bearing	Derotator Bearing
Race way diameter	1094 mm	2290 mm
Axial runout	≤ 300 µm	≤ 30 µm
Radial runout	≤ 260 µm	≤ 30 µm
Gear module	8 mm	6 mm
Number of teeth	148	403
Starting friction torque (0 rpm)	1000 Nm	1800 Nm
Running friction torque (1 rpm)	900 Nm	1350 Nm

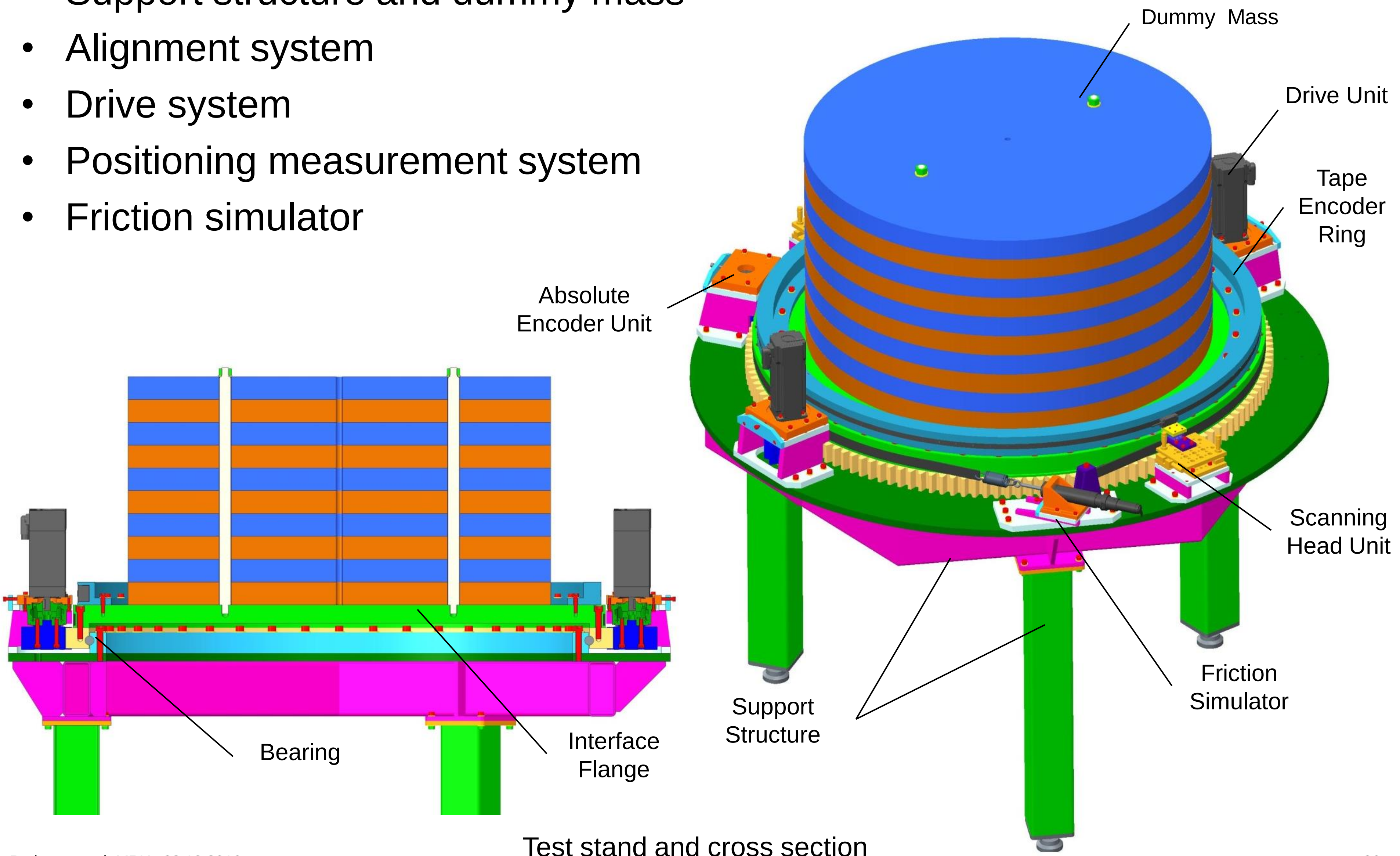
- Goals of the experiment
  - Learn about the implementation and performance of the tape encoder
  - Proof the alignment procedure between the interface flange and the bearing
  - Test backlash suppression system
  - Understand the effects of the friction over the positioning accuracy
  - Calibrate the parameters of the end-to-end model
  - Compare the results of the model with the performance of the real prototype
  - Validate the FEM of the bearing



Test stand

Test Stand Components and subsystems

- Support structure and dummy mass
- Alignment system
- Drive system
- Positioning measurement system
- Friction simulator



Test stand and cross section

Drive system

- Servo motor Beckhoff AM8532D (rated torque: 2.2 Nm)
- Harmonic Drive (gear ratio: 160)
- Pinion with 12 teeth (gear ration: 12.33)

$$T_{TM} = K_S T_M = \mathbf{2.02\ Nm}$$

$$K_S = 1.2$$

$$T_M = \frac{T_{HD\ input}}{\eta_{HD}} = 1.68\ Nm$$

$$\eta_{HD} = 57\ \%$$

$$T_{HD\ output} = T_F + T_a = 0.96\ Nm$$

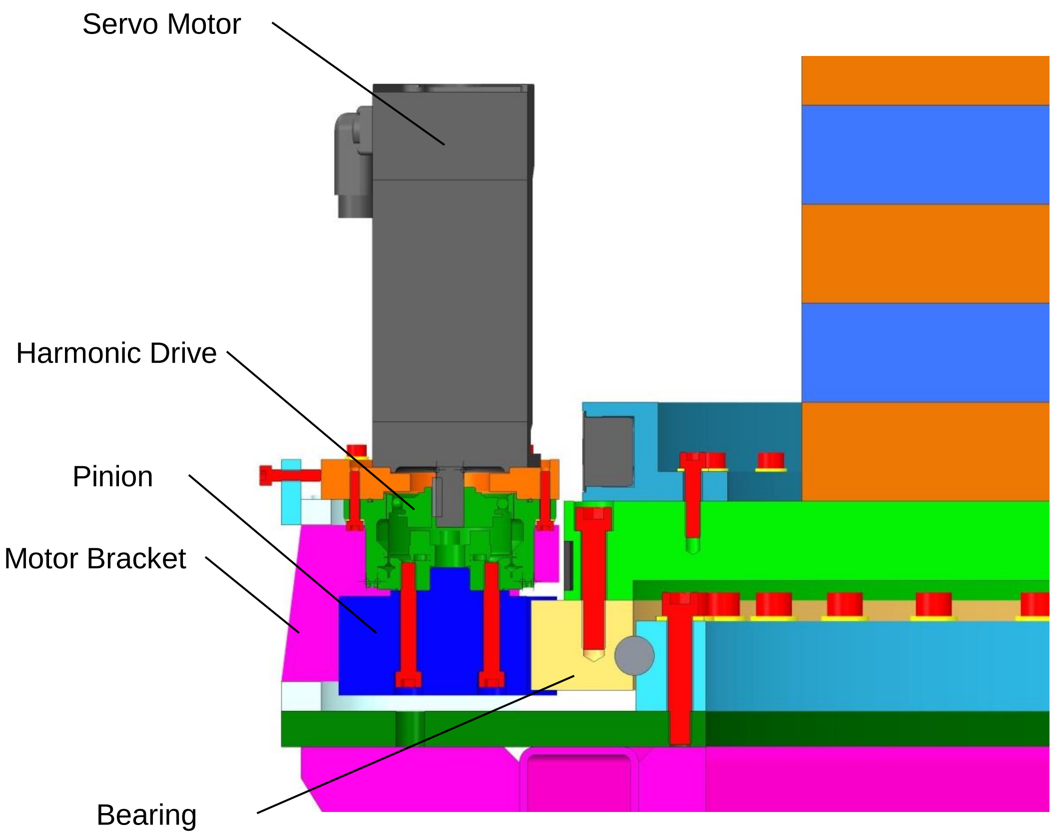
$$\boldsymbol{T_F = \frac{T_{FG}}{I_G I_{HD}} = 0.917\ Nm}$$

$$T_{FG} = 1800\ Nm\ \text{(Rothe Erde)}$$

$$I_G = \frac{Z_P}{Z_G} = 12.33$$

$$Z_P = 12,\ Z_G = 148,\ I_{HD} = 160$$

$$\boldsymbol{T_a = J_T\ \alpha = 0.05\ Nm}$$



Drive system components cross section

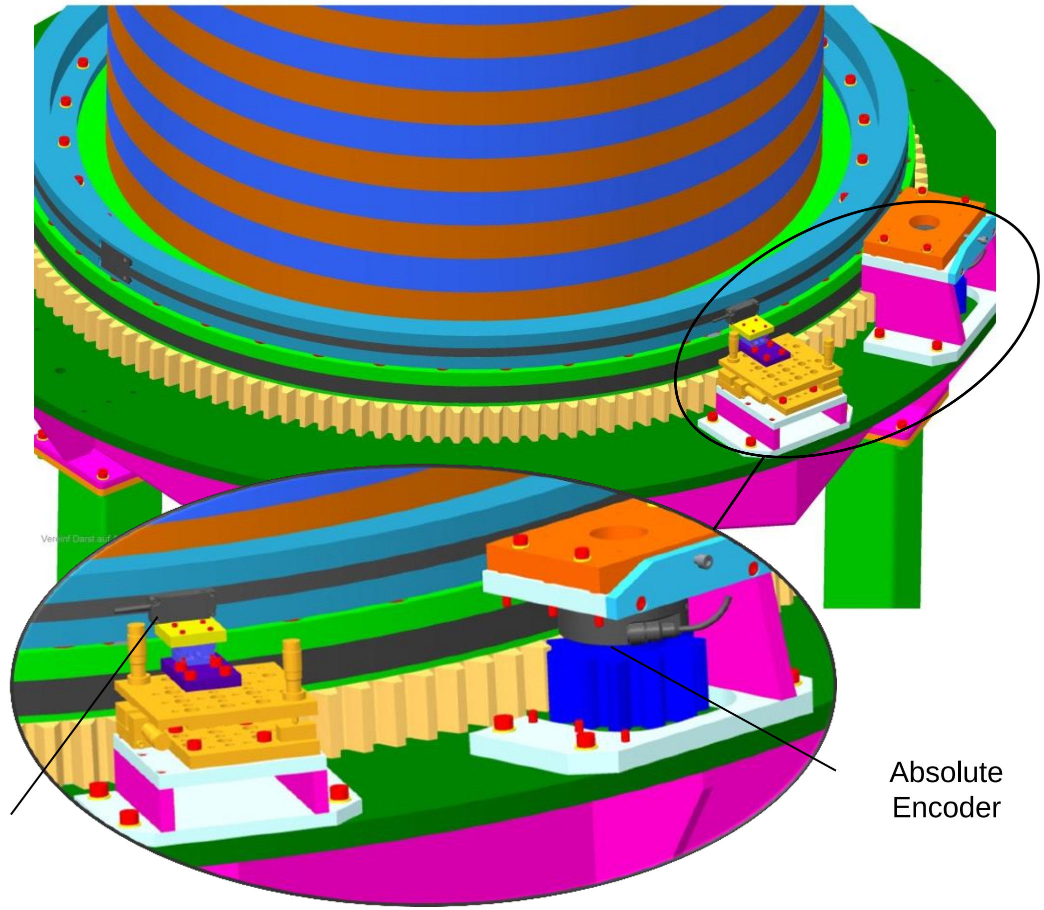
Positioning measurement system

- Integrated stator coupling absolute angle encoder (accuracy ±2.5”)
- Steel scale tape incremental angle encoder (accuracy ± 1.9”) plus Scanning head

Heidenhain RCN 2000 Series

Heidenhain ERA 8000 Series

Image source: Heidenhain catalog

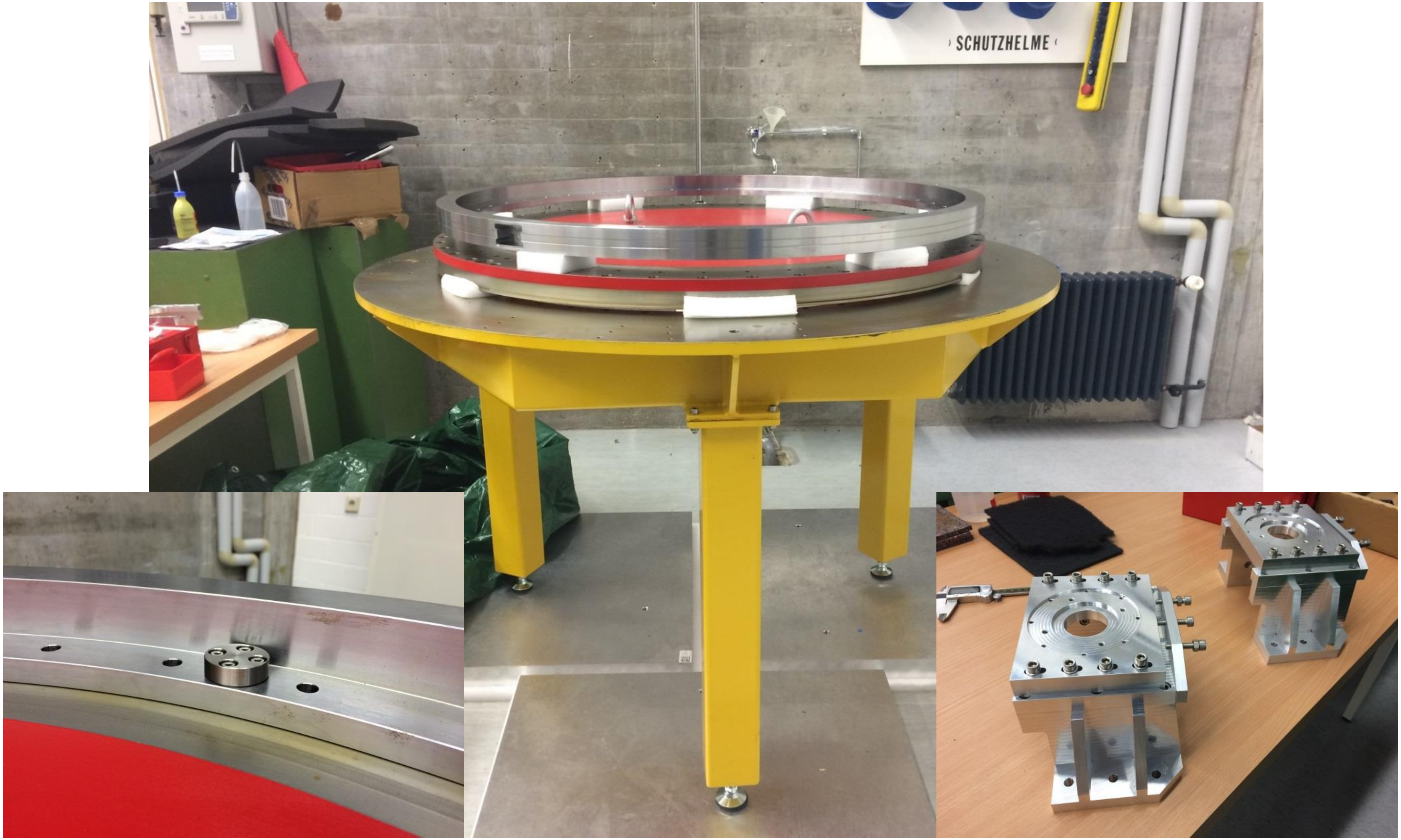


Encoders of the positioning measurement system

Test Stand Integration Process

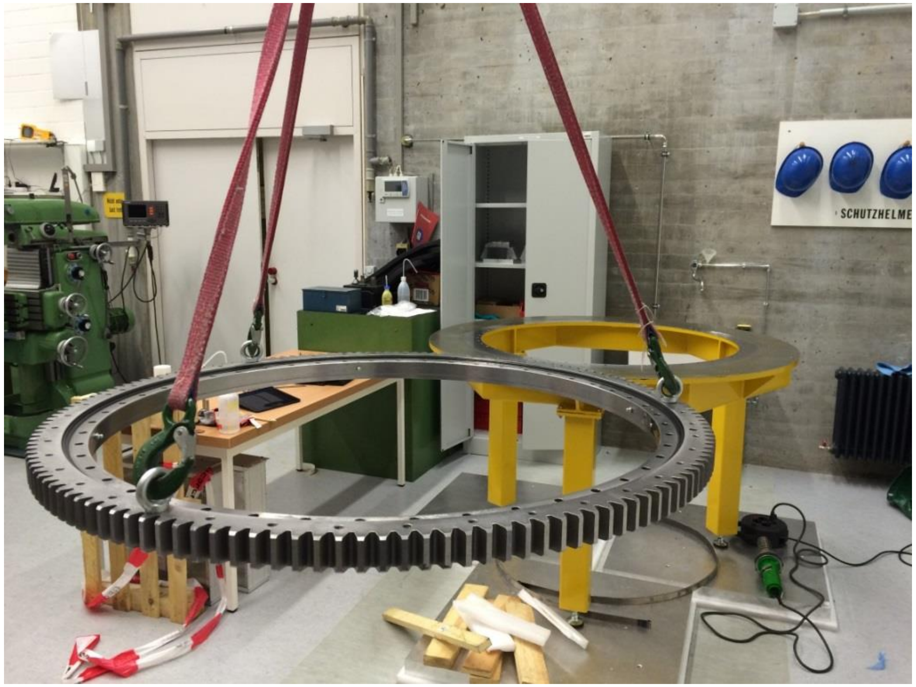
Test stand support structure and interface plate

Test Stand Integration Process



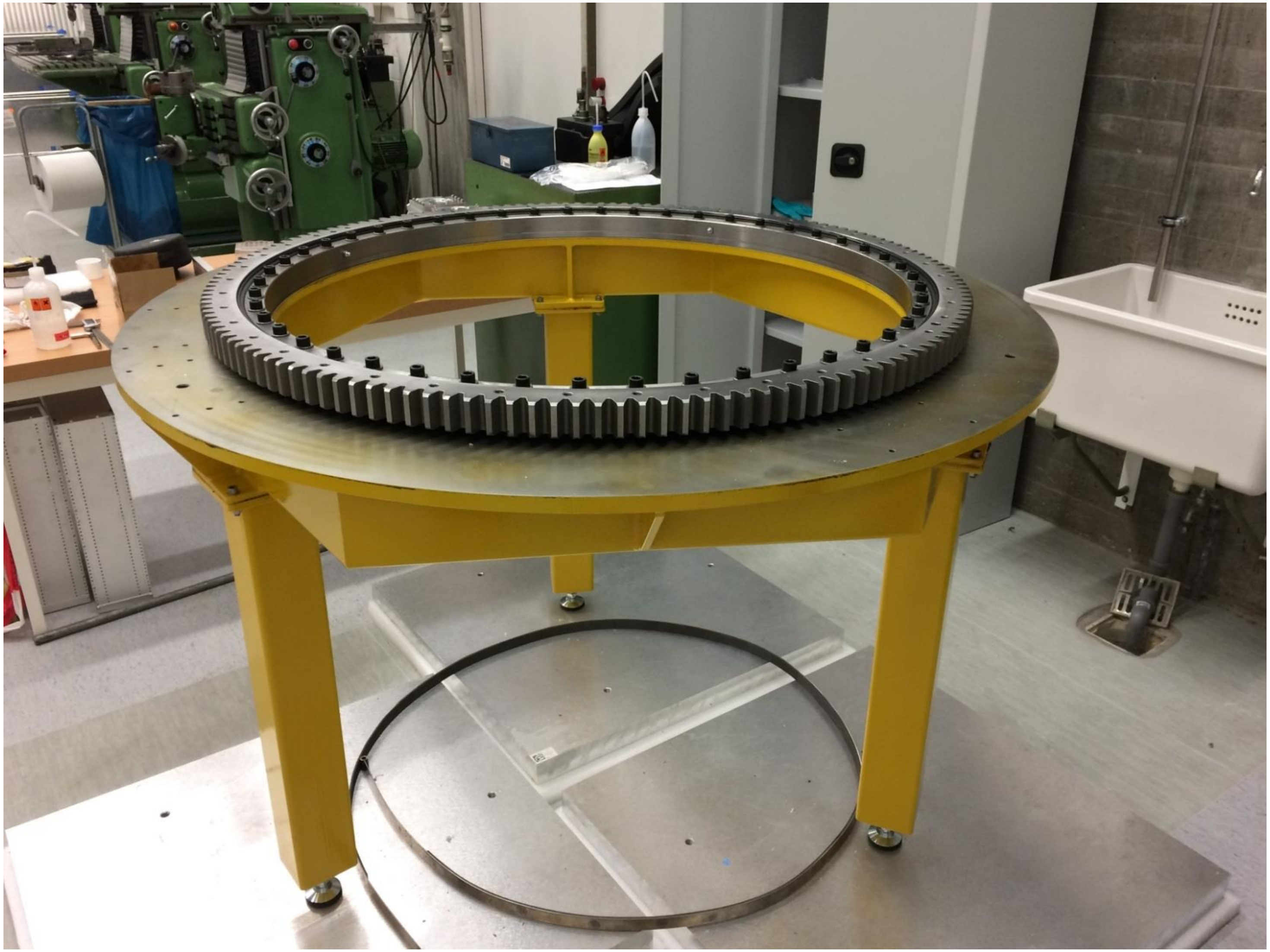
Encoder ring delivered by KINKELE, alignment pins and motor brackets by MPIA work shop

Test Stand Integration Process



Standard Ø1.2 m bearing delivered by Rothe Erde

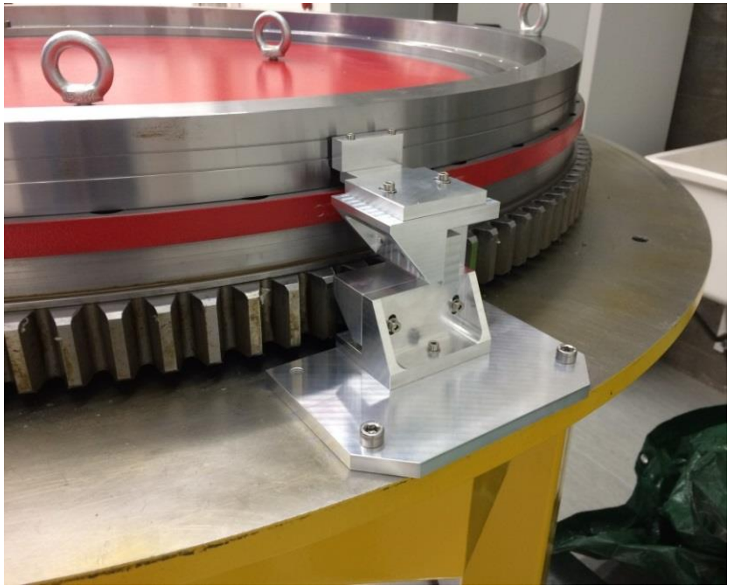
Test Stand Integration Process

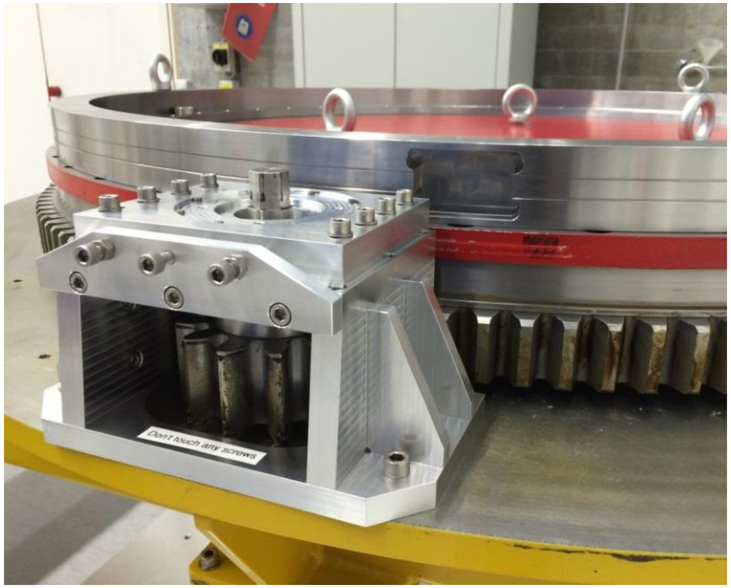


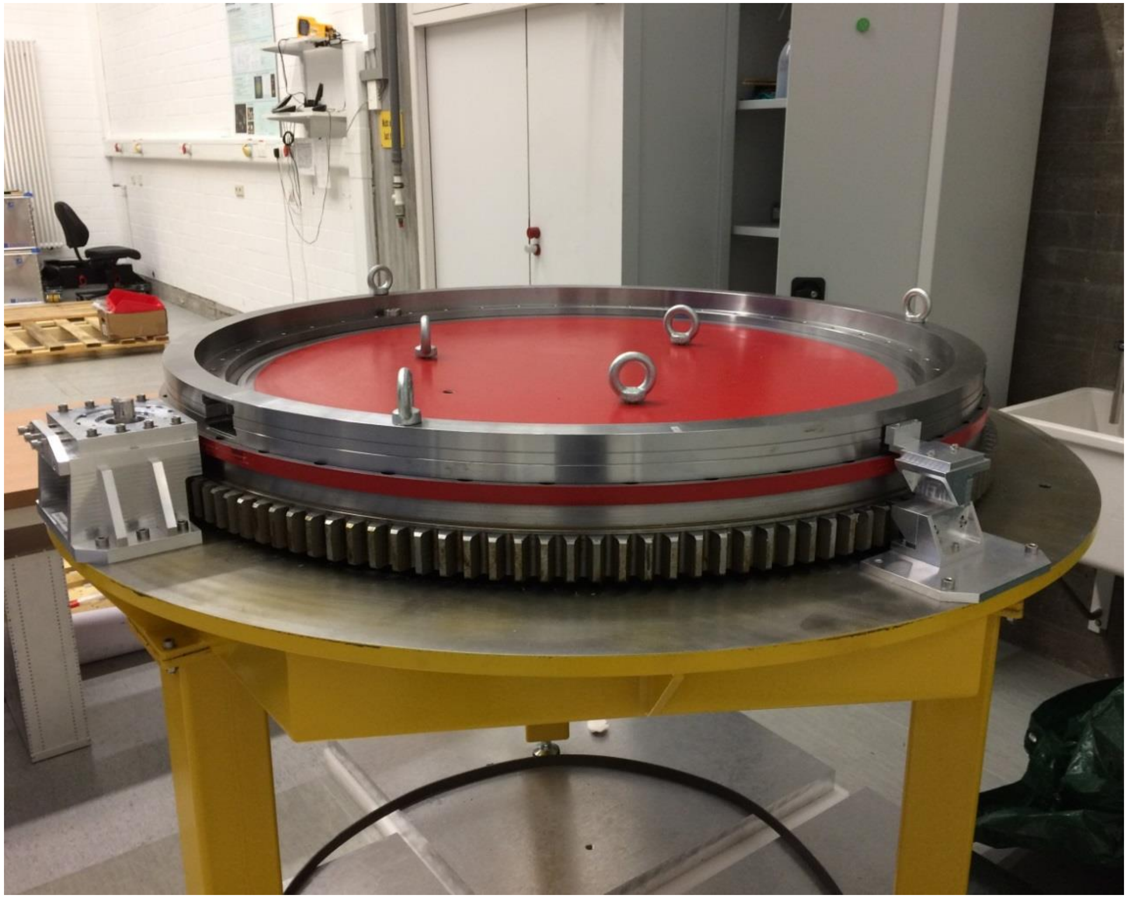
Bearing installed on the support structure

Test Stand Integration Process

Status before the summer break…

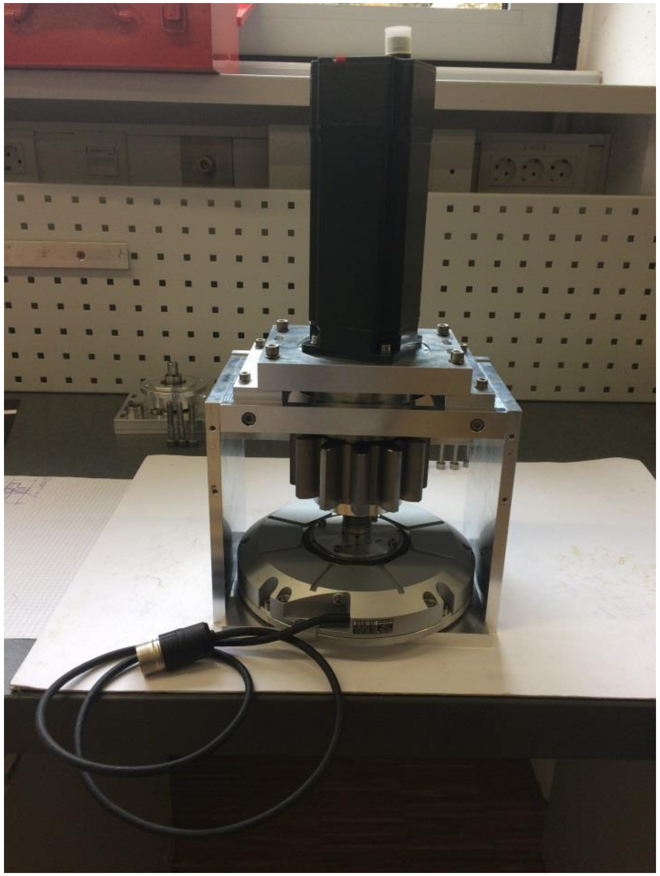


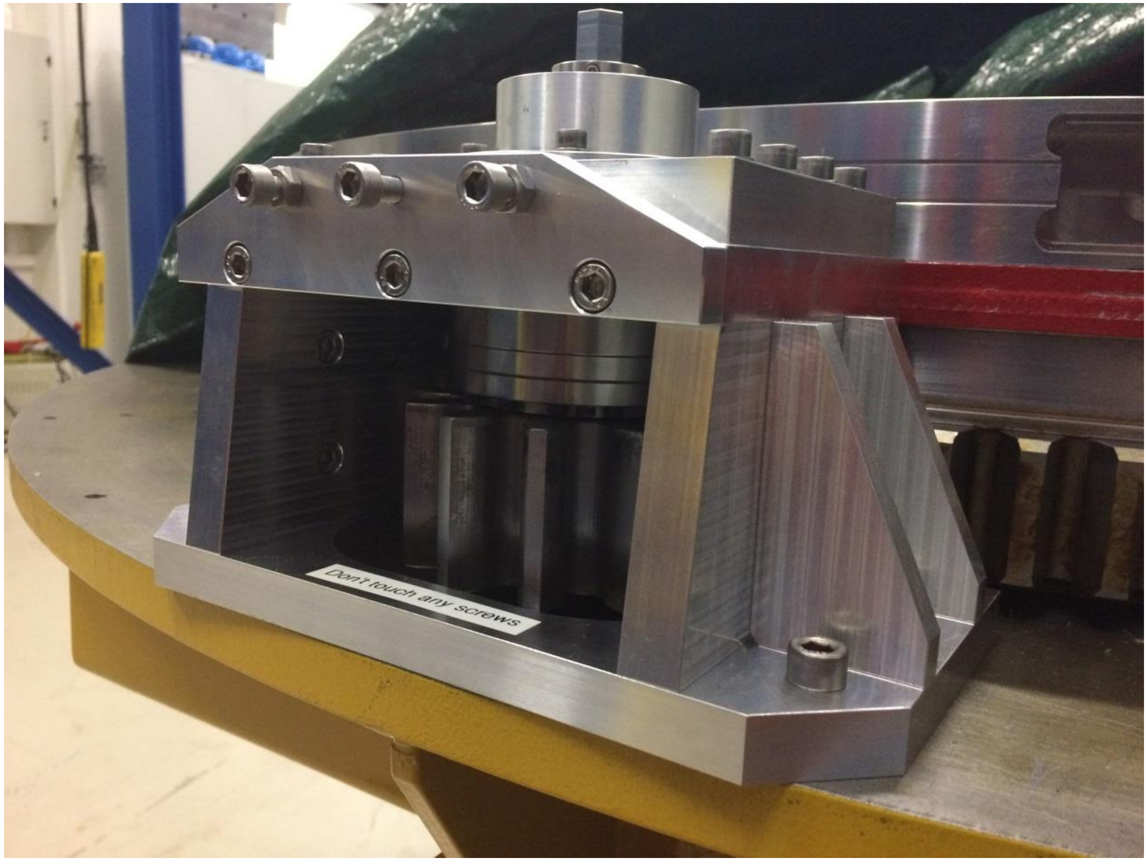




Manual drive unit and encoder scanning head support

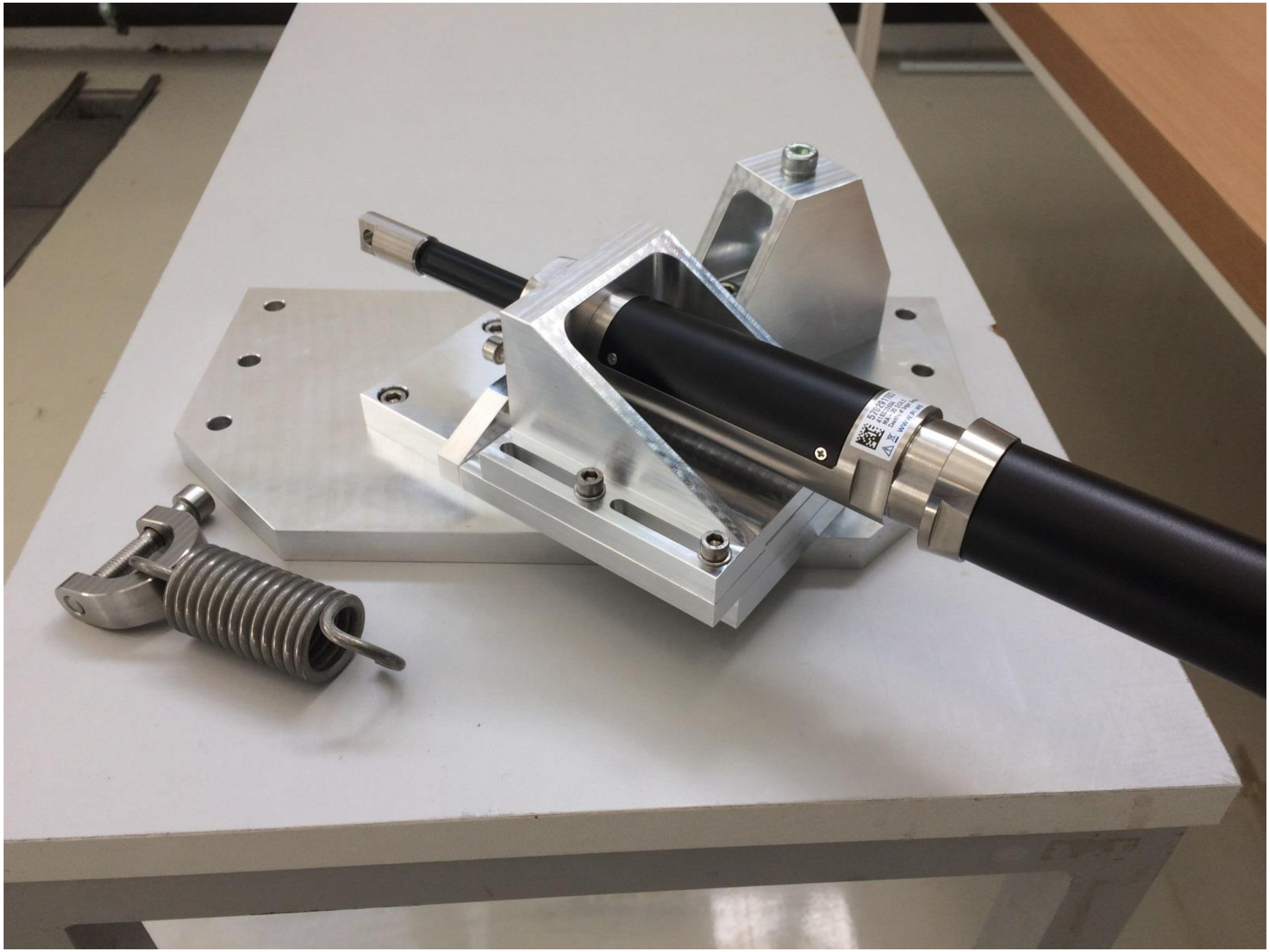
Test Stand Integration Process





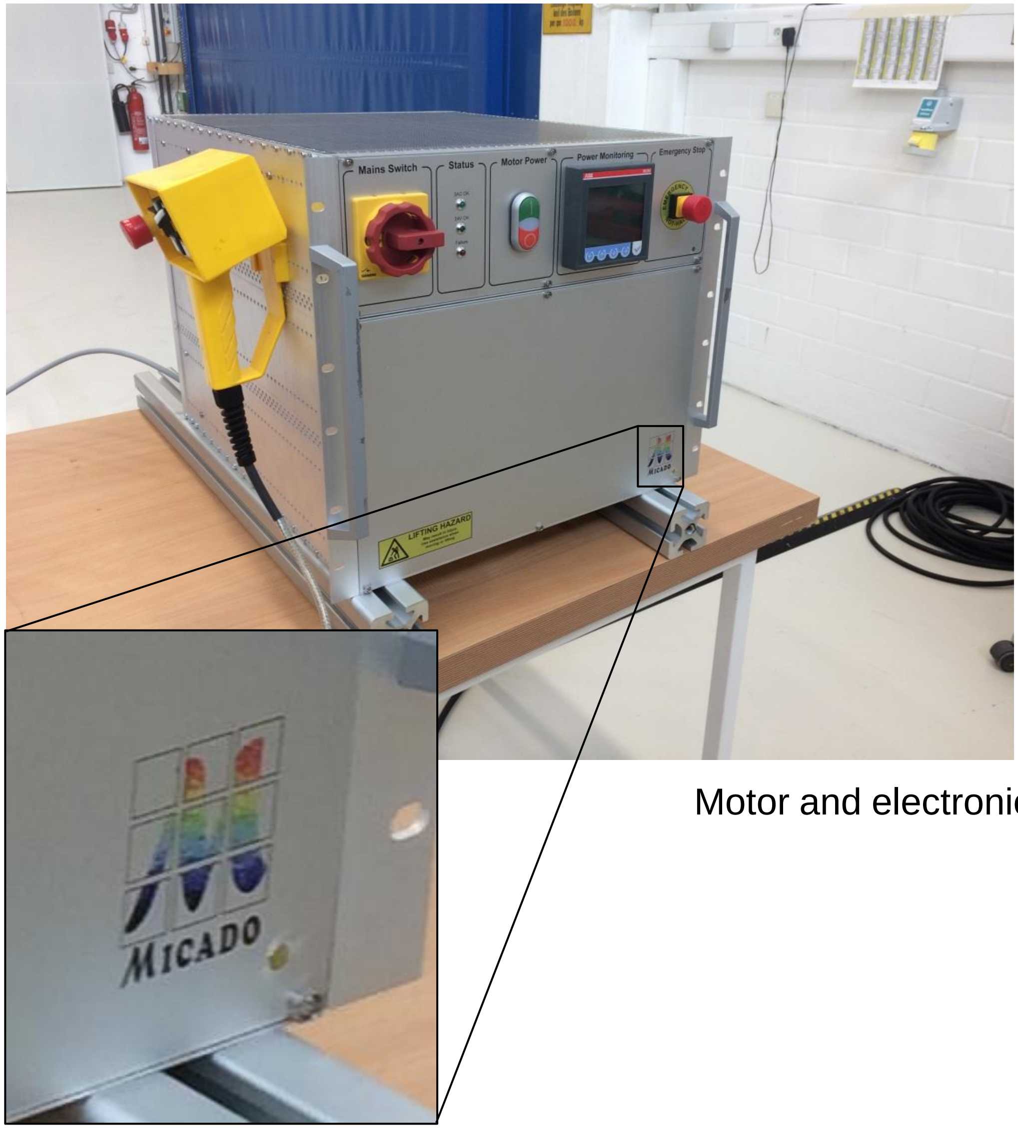
Drive unit test setup and manual drive unit with Harmonic Drive

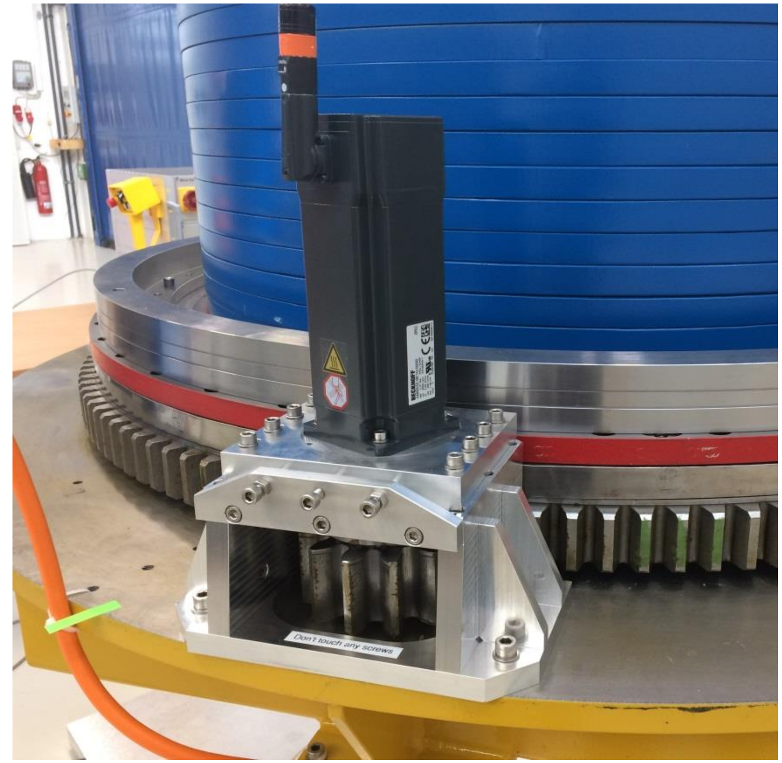
Test Stand Integration Process



Friction simulator

Test Stand Integration Process

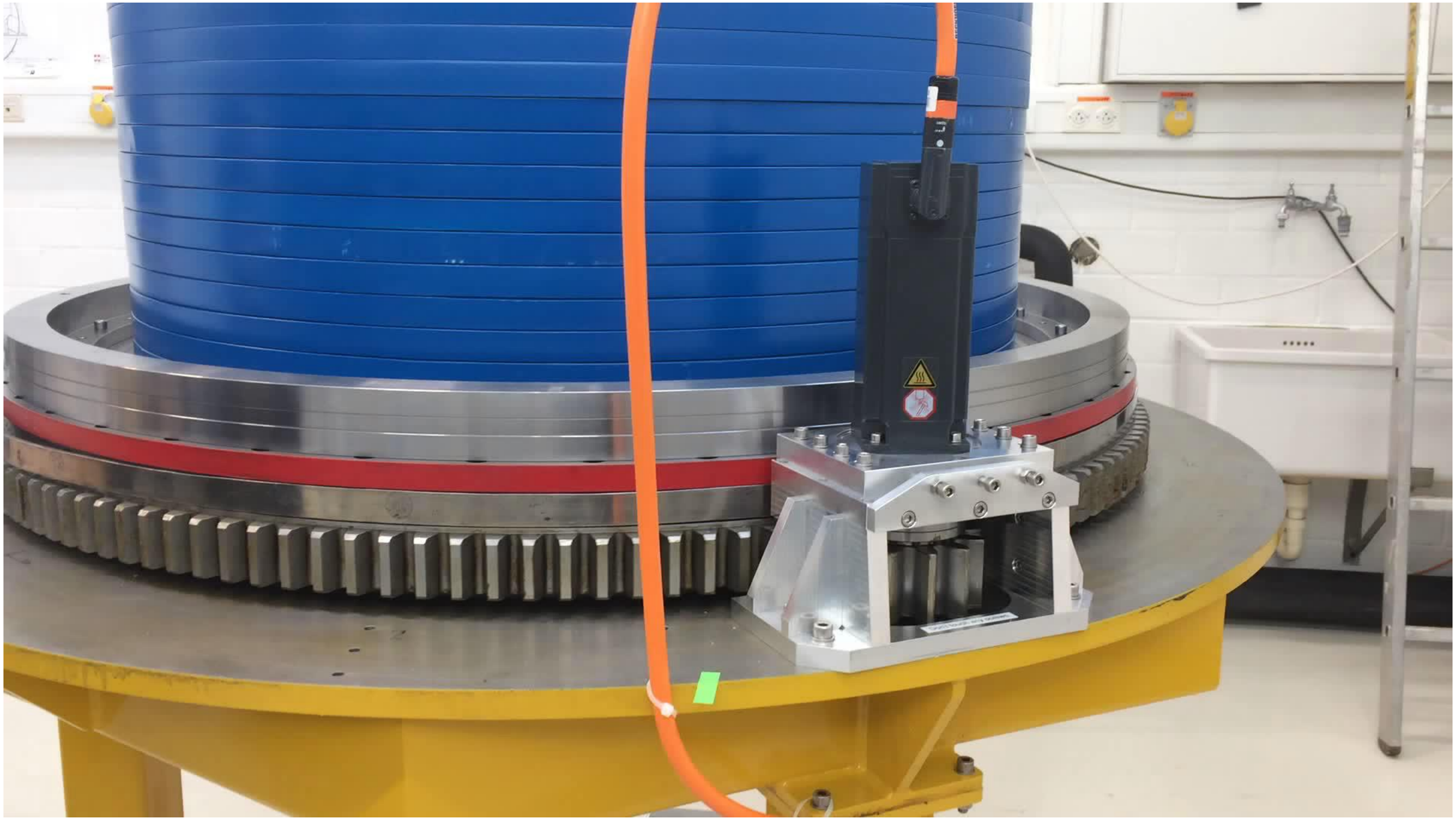




Motor and electronic cabinet

Test Stand Integration Process

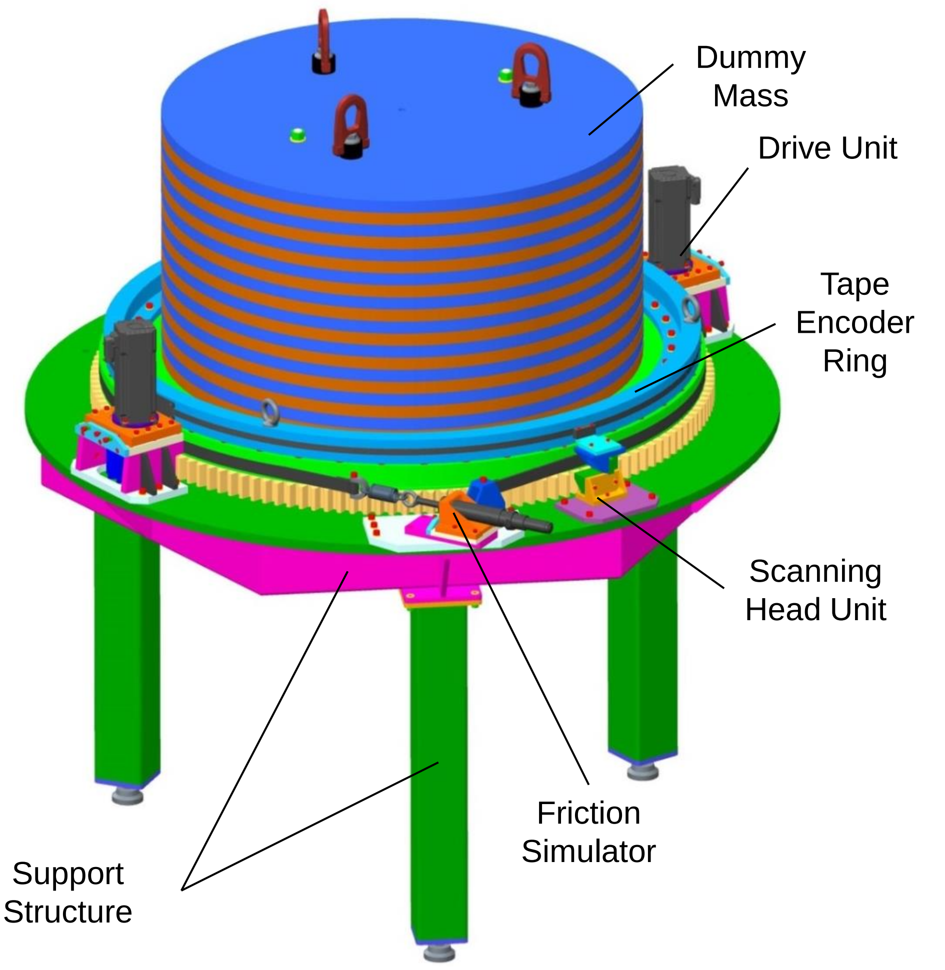
- The real motor @ 1800 rpm / bearing @ 0.9 rpm / 3 tons

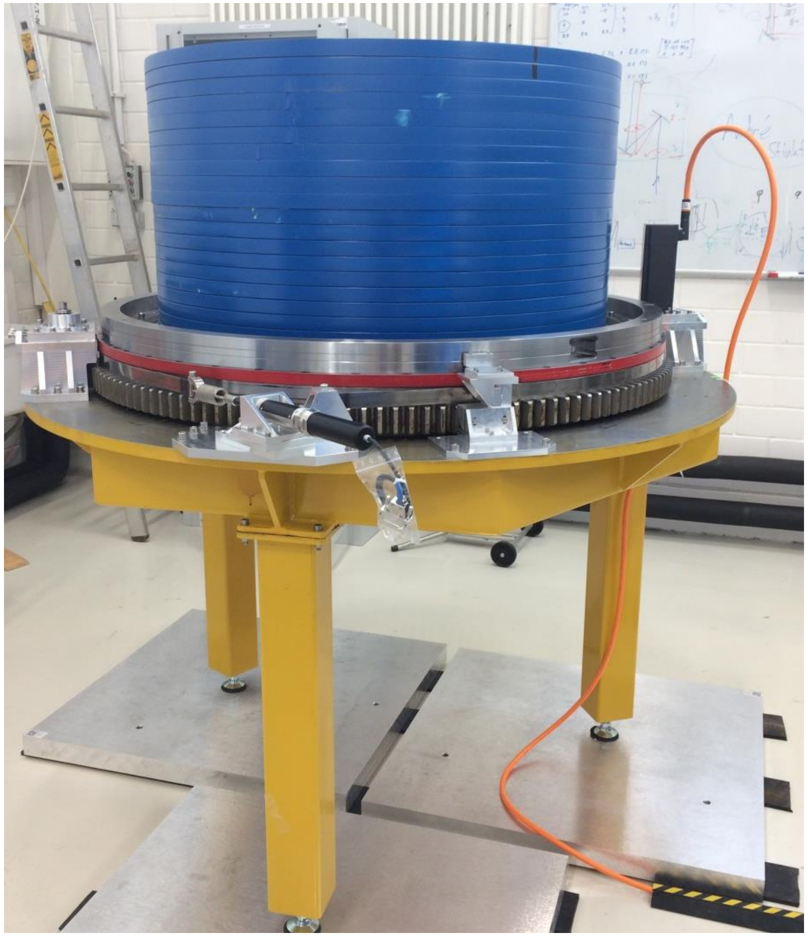


Motor and electronic cabinet

Integration status and missing components

- Procurement and manufacturing “75%” (99%) completed
- Assembly and integration “75%” (90%) completed





Test stand CAD model (Kick of meeting February 2016) and real hardware

Performance of the delivered bearing

Parameter	Offered Bearing	Delivered Bearing
Race way diameter	1094 mm	1094 mm
Axial runout	≤ 300 µm	≤ 50 µm
Radial runout	≤ 260 µm	≤ 60 µm
Wobble (calculated)	≤ 113 arcsec	≤ 23 arcsec
Starting friction torque (without mass)	780 Nm	300 Nm
Starting friction torque (with mass)	1000 Nm	730 Nm

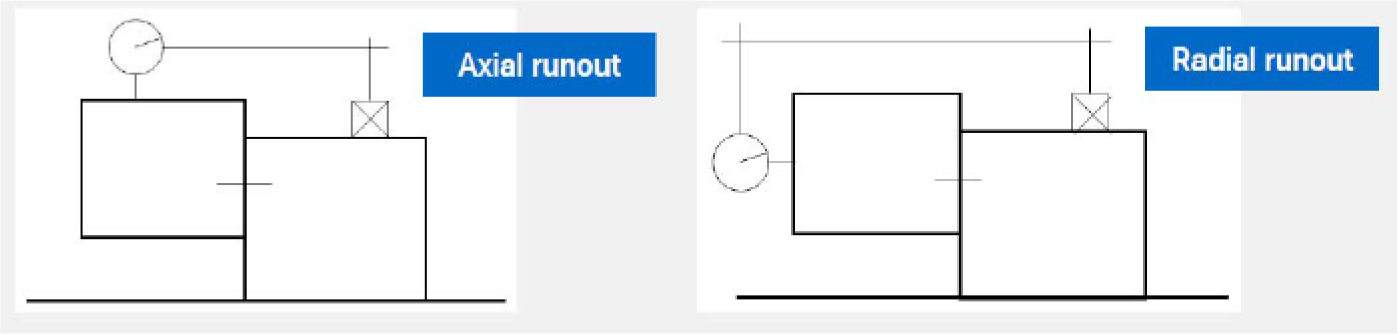


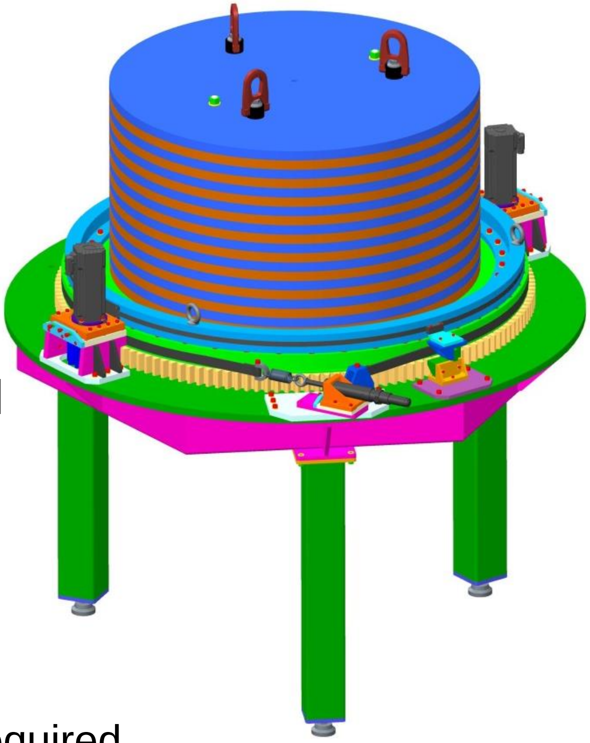
Image source: Rothe Erde

Measurement protocol performed by Rothe Erde

Planning for the test campaign

- Test alignment procedure
  - Repeatability of the radial runout of the bearing
  - Alignment of the interface plate and the encoder ring to the bearing axis
  - Repeatability of the alignment system (with mass)
- Measurement of the torque at the motor axis
  - Without mass
  - With mass (2990 Kg)
  - With mass and simulated **constant** friction of the real bearing (worst case)
- Validate the FEM of the bearing
  - Measurement of the differential deformation on key points with load and without load
- Test acceleration and speed
  - Time to rotate 360° with mass and friction

Motor required (not optimized?)



Test stand

Planning for the test campaign

- Test the angular positioning accuracy (open and closed loop)
  - Without mass
  - With mass (2990 Kg)
  - With mass and simulated friction of the real bearing
- Test of the backlash suppression system
  - Define torque values between the pinions
  - Control system optimization
  - Measurement of the positioning accuracy over a trajectory with change of direction
- Calibrate parameters of the end-to-end model
  - Parameter identification of the drive unit
  - Parameter identification of the friction model
- Performance of the real prototype vs end-to-end model
  - Drive unit end-to-end simulation
  - Derotator test stand end-to-end simulation

Test stand

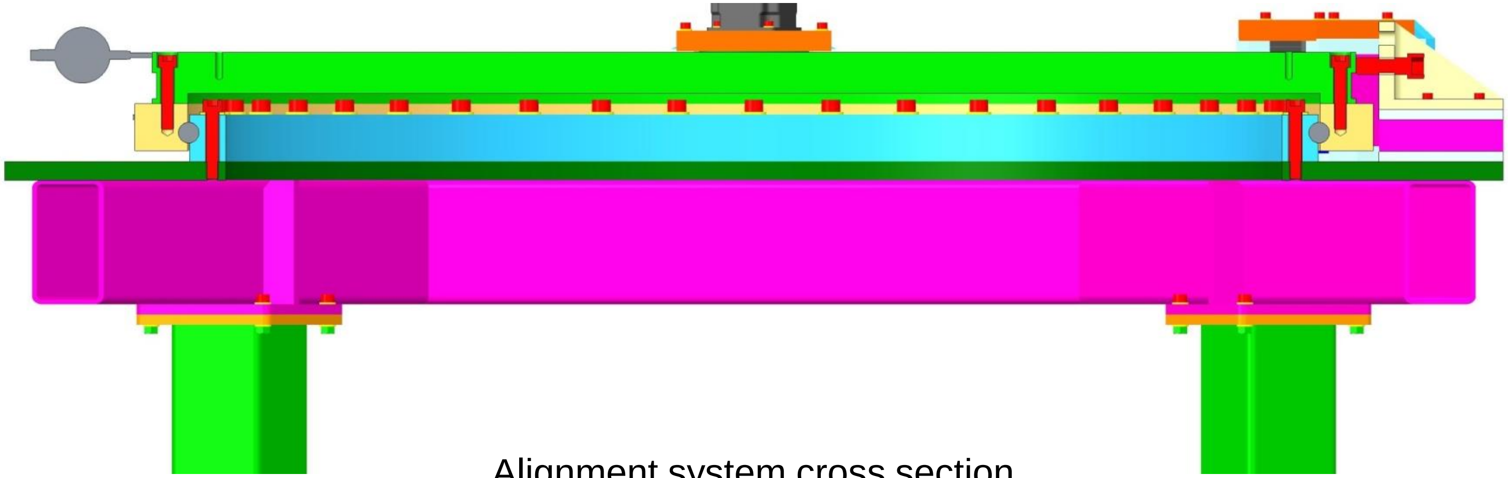
Implementation schedule of the test campaign

- What have to be tested before the SRR?
- What can be done after the SRR?

Items	October	November	December	January	February	March	April	May
Software development	?							
Test alignment procedure								
Measurement of the torque at the motor axis								
Test acceleration and speed								
Validate the FEM of the bearing								
Implementation of the encoder system								
Test the angular positioning accuracy (open and closed loop)								
Implementation of the friction system								
Implementation with 2 motors								→
Test of the backlash suppression system								→
Calibrate parameters of the end-to-end model								→

Tests already performed

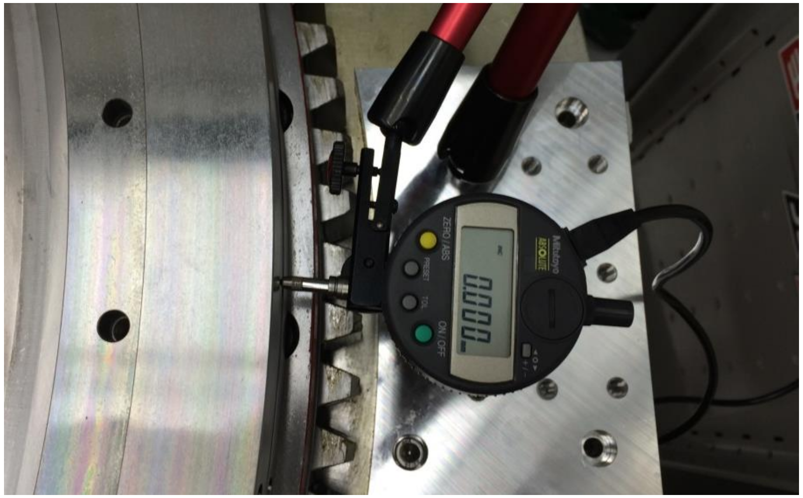
- Alignment procedure

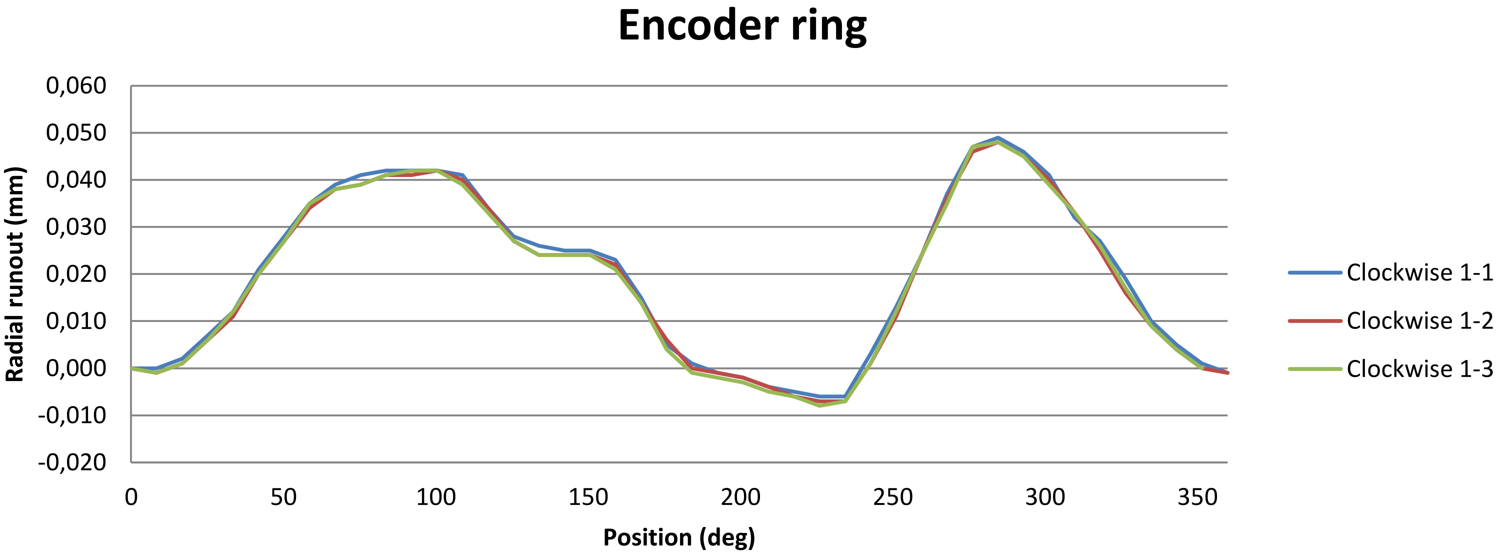


Alignment system cross section

Tests already performed

- Alignment procedure of the encoder ring (radial runout < 0,05 mm)

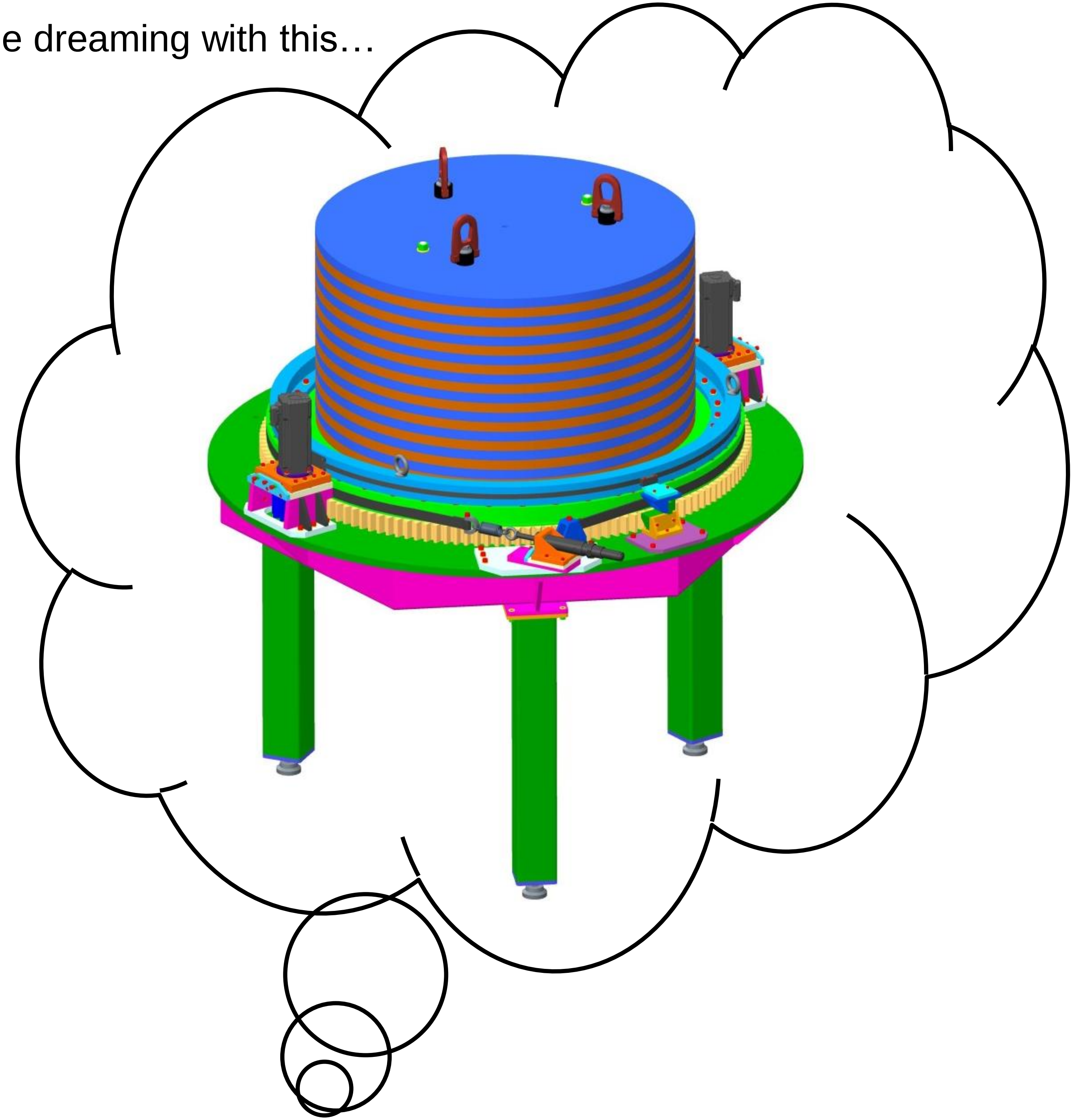




For inspiration…

Image source: ESO

Let's continue dreaming with this…



Let's continue dreaming with this…