Das Denken in Kräften

als Hilfsmittel beim Entwerfen von Teleskopstrukturen

Thinking in Forces

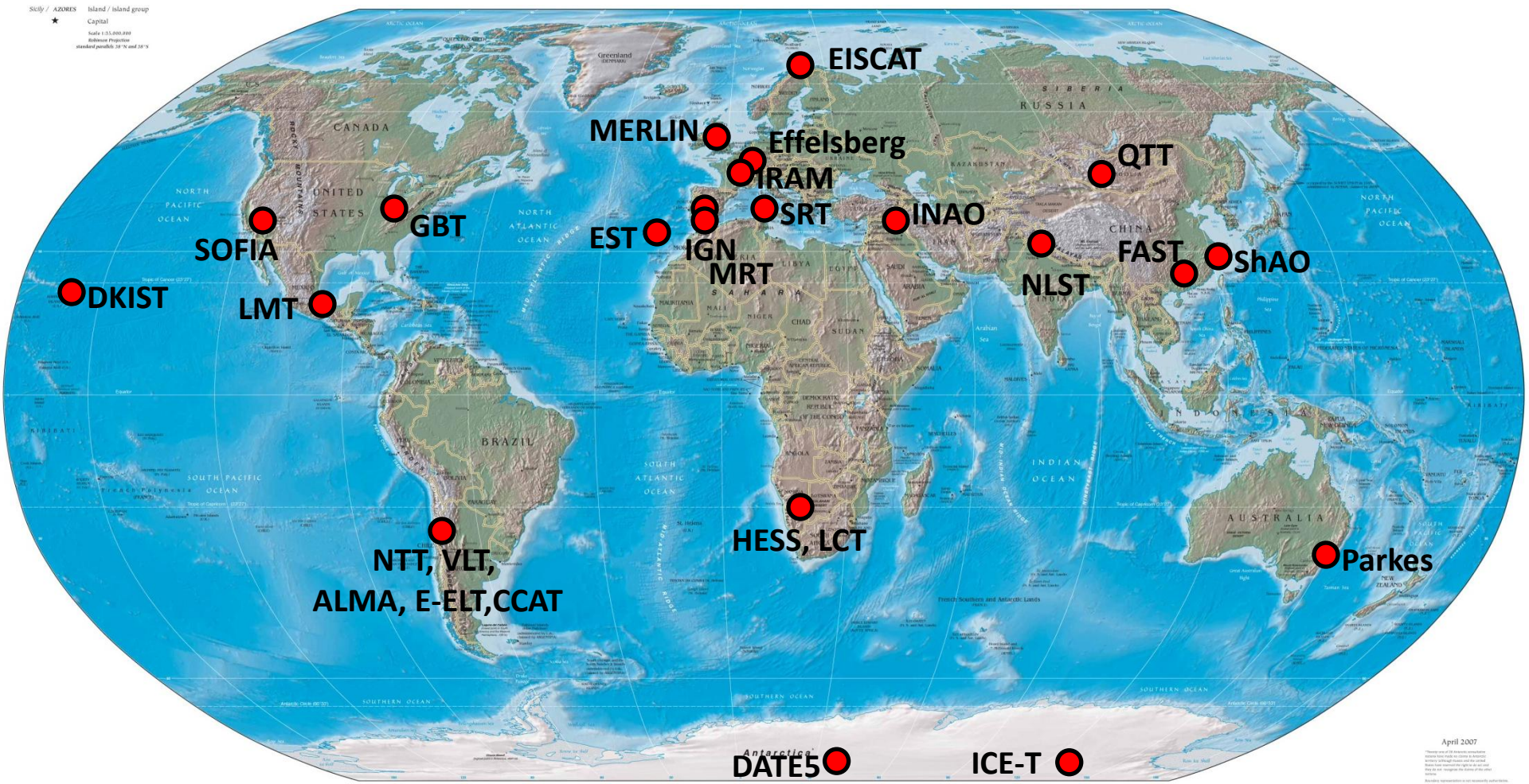
as a tool for the design of telescope structures

Hans Jürgen Kärcher
Kirchgasse 4, 61184 Karben
Tel: 06039 485277 Mob: 0152 2196 2380

Hans Jürgen Kärcher

Telescope sites - worldwide

Personal involvement



Some “own” Telescopes

Developed together with the MT Mechatronics engineering team in Mainz

SOFIA 2002

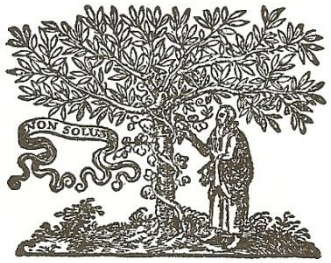
LMT 2006

DKIST 2014

Galilei 1638

(28 years after the Sidereus Nuncius)

DISCORSI
E
DIMOSTRAZIONI
MATEMATICHE,
intorno à due nuoue ſcienze
Attenenti alla
MECANICA & i MOVIMENTI LOCALI;
del Signor
GALILEO GALILEI LINCEO,
Filoſofo e Matematico primario del Sereniſſimo
Grand Duca di Toſcana.
Con vna Appendice del centro di grauità d'alcuni Solidi.



IN LEIDA,
Appreſſo gli Elſeuirii. M. D. C. XXXVIII.

One of the „two new sciences"

Statics

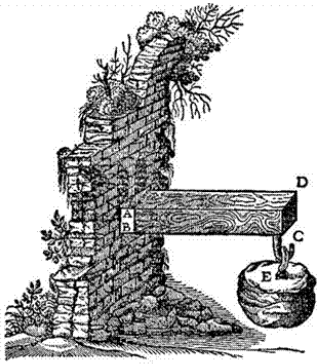


Fig. 17

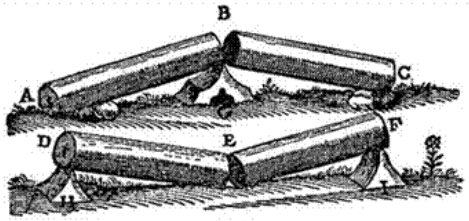


Fig. 29

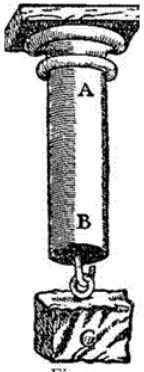


Fig. 1

Fig. 21

telescopemechanics@hjkaercher.de

Newton 1686 – Equilibrium!

AXIOMS, OR LAWS OF MOTION[1]

LAW I

Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.

PROJECTILES continue in their motions, so far as they are not retarded by the resistance of the air, or impelled downwards by the force of gravity. A top, whose parts by their cohesion are continually drawn aside from rectilinear motions, does not cease its rotation, otherwise than as it is retarded by the air. The greater bodies of the planets and comets, meeting with less resistance in freer spaces, preserve their motions both progressive and circular for a much longer time.

LAW II[2]

The change of motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.

If any force generates a motion, a double force will generate double the motion, a triple force triple the motion, whether that force be impressed altogether and at once, or gradually and successively. And this motion (being always directed the same way with the generating force), if the body moved before, is added to or subtracted from the former motion, according as they directly conspire with or are directly contrary to each other; or obliquely joined, when they are oblique, so as to produce a new motion compounded from the determination of both.

LAW III

To every action there is always opposed an equal reaction: or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.

Whatever draws or presses another is as much drawn or pressed by that other. If you press a stone with your finger, the finger is also pressed by the

[1 Appendix, Note 14.] [2 Appendix, Note 15.]

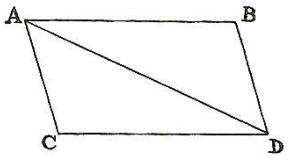
[13]

stone. If a horse draws a stone tied to a rope, the horse (if I may so say) will be equally drawn back towards the stone; for the distended rope, by the same endeavor to relax or unbend itself, will draw the horse as much towards the stone as it does the stone towards the horse, and will obstruct the progress of the one as much as it advances that of the other. If a body impinge upon another, and by its force change the motion of the other, that body also (because of the equality of the mutual pressure) will undergo an equal change, in its own motion, towards the contrary part. The changes made by these actions are equal, not in the velocities but in the motions of bodies; that is to say, if the bodies are not hindered by any other impediments. For, because the motions are equally changed, the changes of the velocities made towards contrary parts are inversely proportional to the bodies. This law takes place also in attractions, as will be proved in the next Scholium.

COROLLARY I

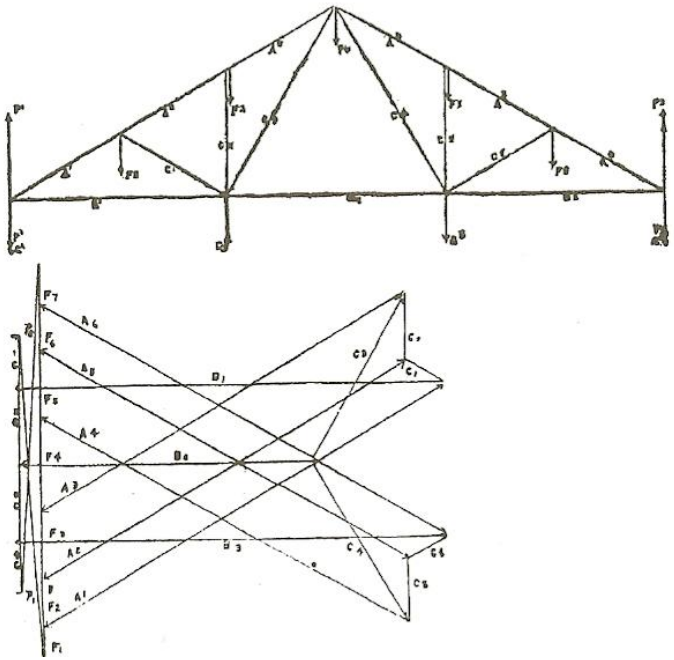
A body, acted on by two forces simultaneously, will describe the diagonal of a parallelogram in the same time as it would describe the sides by those forces separately.

If a body in a given time, by the force M impressed apart in the place A, should with an uniform motion be carried from A to B, and by the force N impressed apart in the same place, should be carried from A to C, let the parallelogram ABCD be completed, and, by both forces acting together, it will in the same time be carried in the diagonal from A to D. For since the force N acts in the direction of the line AC, parallel to BD, this force (by the second Law) will not at all alter the velocity generated by the other force M, by which the body is carried towards the line BD. The body therefore will arrive at the line BD in the same time, whether the force N be impressed or not; and therefore at the end of that time it will be found somewhere in the line BD. By the same argument, at the end of the same time it will be found somewhere in the line CD. Therefore it will be found in the point D, where both lines meet. But it will move in a right line from A to D, by Law 1.

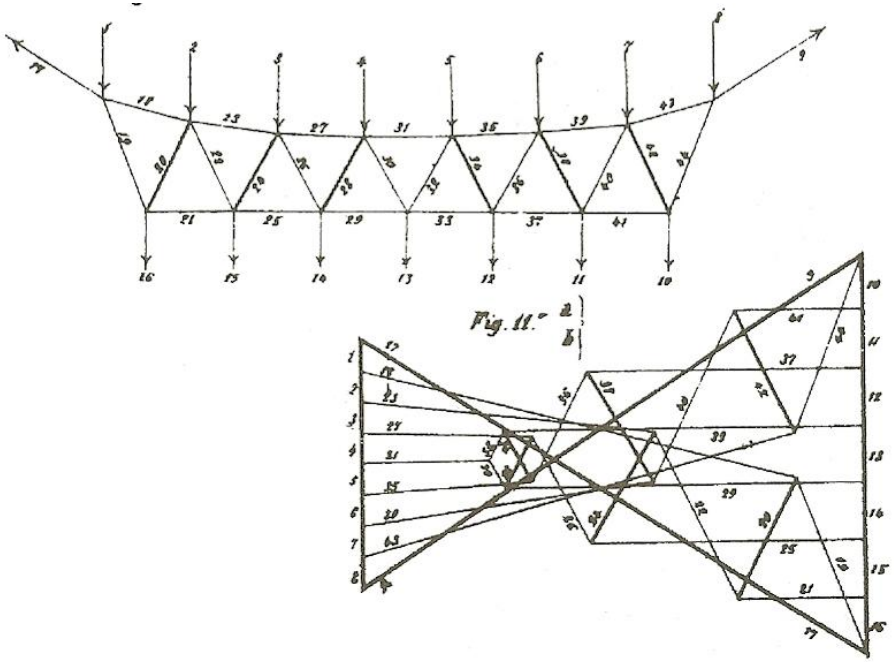


Graphical Statics – Karl Culmann 1864

James Clerk Maxwell 1867



Luigi Cremona 1872



B. Maurer, „Karl Culmann und die graphische Statik“, GNT Verlag, Stuttgart 1998

What is a Force?

Books of Max Jammer:

Dover Science Books, Mineola, New York 1961

1. **Concepts of Space –**
   The History of Theories of Space in Physics
2. **Concepts of Mass**
   in Classical and Modern Physics
3. **Concepts of Force**

Books of Karl-Eugen Kurrer:

Ernst & Sohn, Berlin, 2016

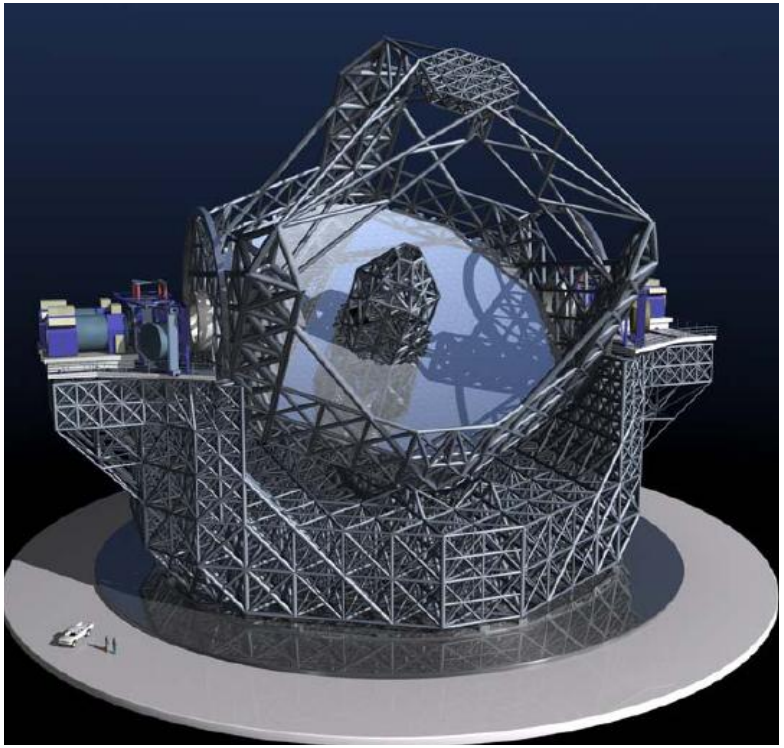
1. **The History of Theory of Structures**
   From Arch Analysis to Computational Mechanics
2. **Geschichte der Baustatik**
   Auf der Suche nach dem Gleichgewicht

Hier strotzt die Backe voller Saft,
Da hängt die Hand gefüllt mit Kraft;
Die Kraft infolge der Erregung
Verwandelt sich in Schwungbewegung;
Bewegung, die mit schnellem Blitze
Zur Backe eilt, wird hier zu Hitze.
Die Hitze aber durch Entzündung
Der Nerven brennt als Schmerzempfindung
Bis auf den tiefsten Seelenkern,
Und dies Gefühl hat keiner gern.
Ohrfeige nennt man diese Handlung
Der Forscher nennt es Kraftverwandlung.

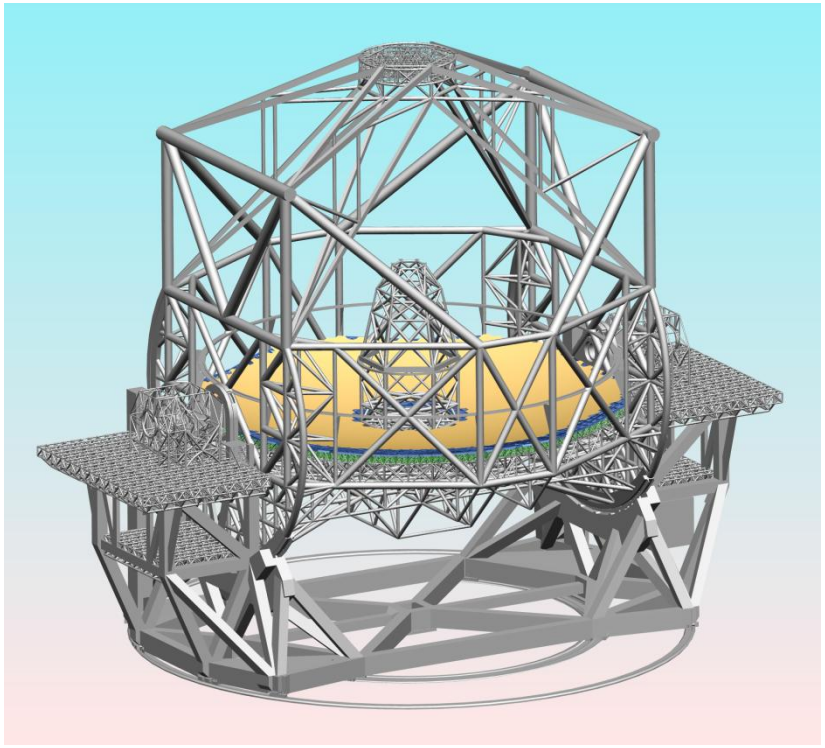
Wilhelm Busch, Balduin Bählamm, Bassermann, 1883

European Extreme Large Telescope E-ELT

ESO Reference Design 2007



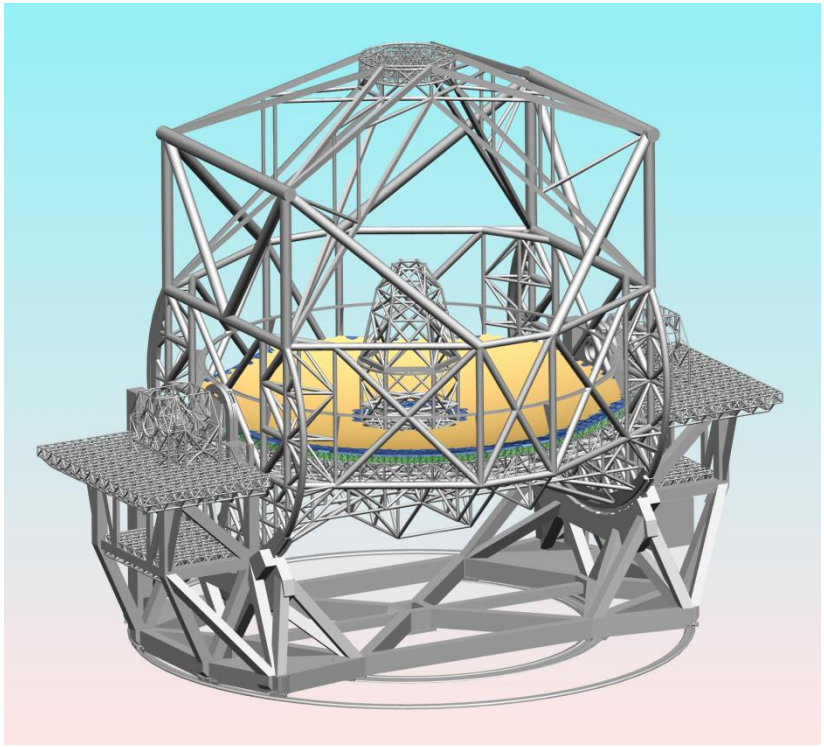
MTM Design Study 2008



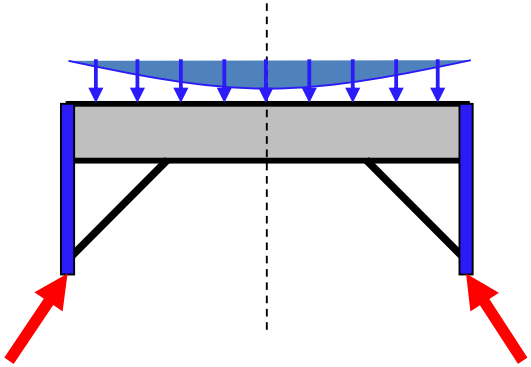
Outcome of „Structural Mechanics“ =>> 2000 tons of weight and related cost reduction

The Telescope and the Bridge

E-ELT Design Study 2008



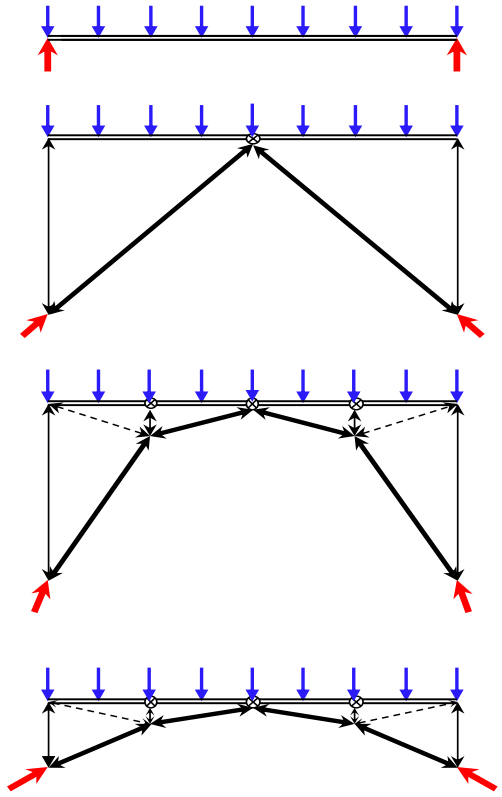
Railway Bridge Mainz 1864



H. J. Kärcher, „Das Teleskop und die Brücke“, Sterne und Weltraum 11, 2010, S. 44-55

Thinking in forces – understanding the "bridge"

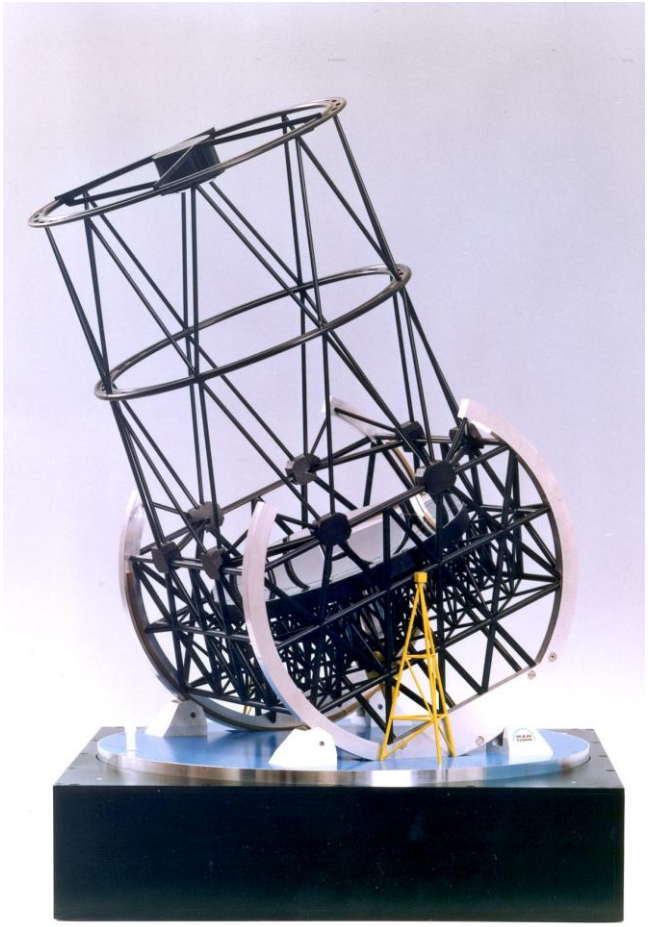
Tilted bearings activate the arch thrust!

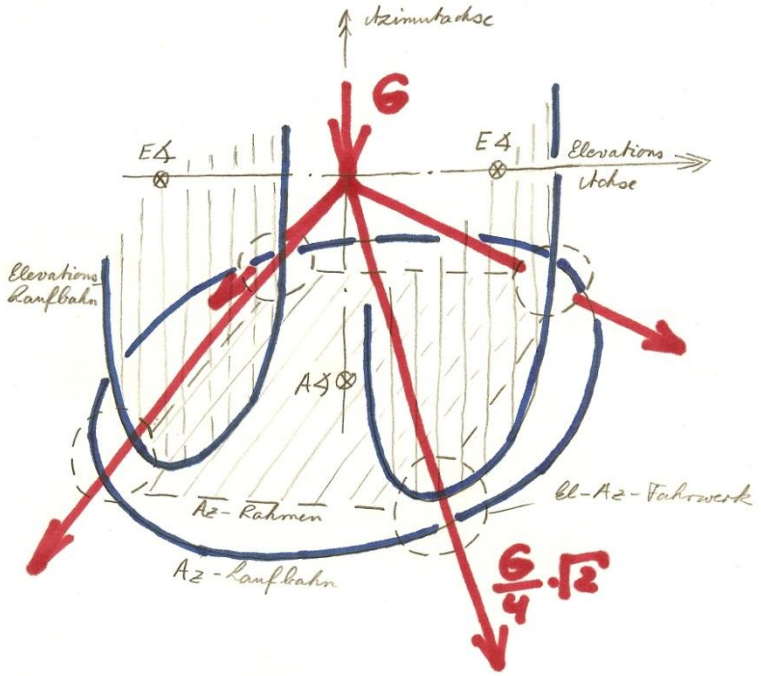


H. J. Kärcher, „Das Teleskop und die Brücke", Sterne und Weltraum 11, 2010, S. 44-55

The beginning of the rocking chair mount

Deutsches Groß-Teleskop 1988



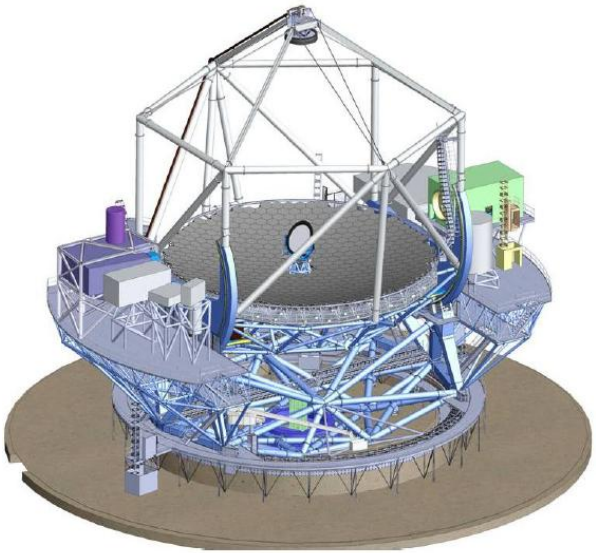


H. J. Kärcher, J. Kühn, H. Nicklas
„An alternative concept to current alt-azimuthal mountings …“,
ESOC…30, 1988, S. 157-167

Actual ELT's use all rocking chair mounts

39m E-ELT

30m TMT

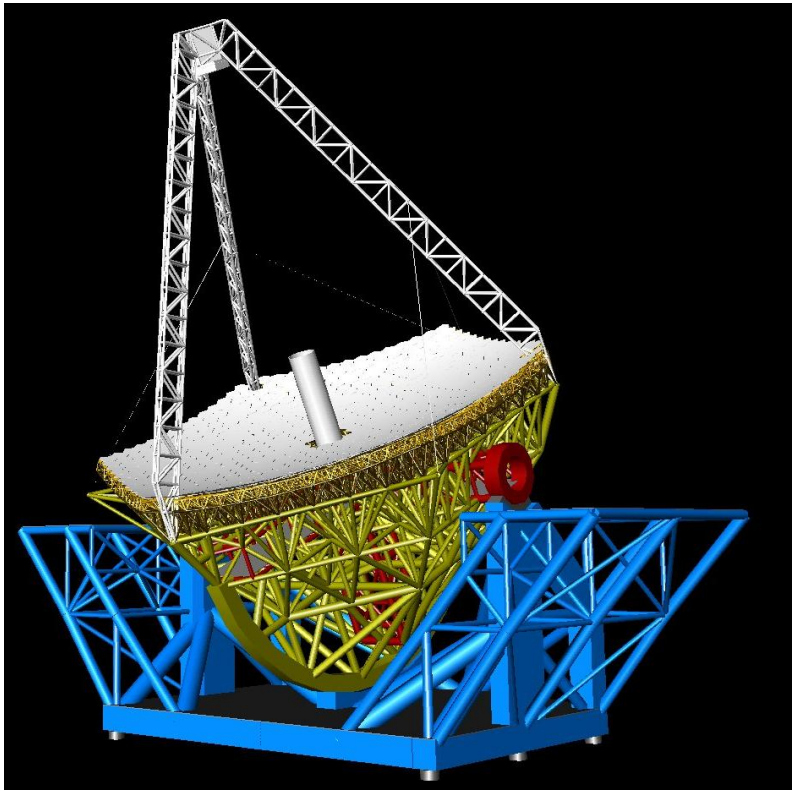


24.5m GMT

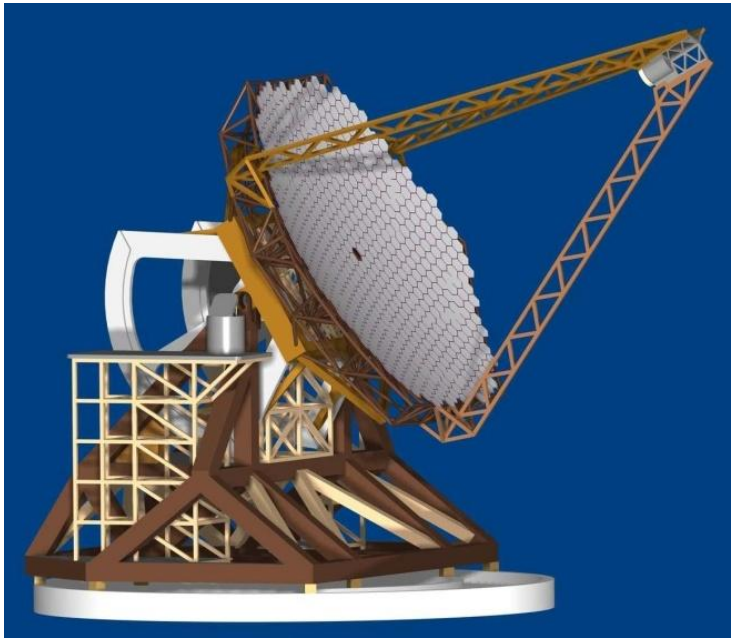
ELT projects other than rocking chair mounts

Not realized!

50m Euro50 – University Lund 2003



30m GSMT – Aura Tucson 2005



Hans Jürgen Kärcher

Large radio telescopes – the story of "homology"

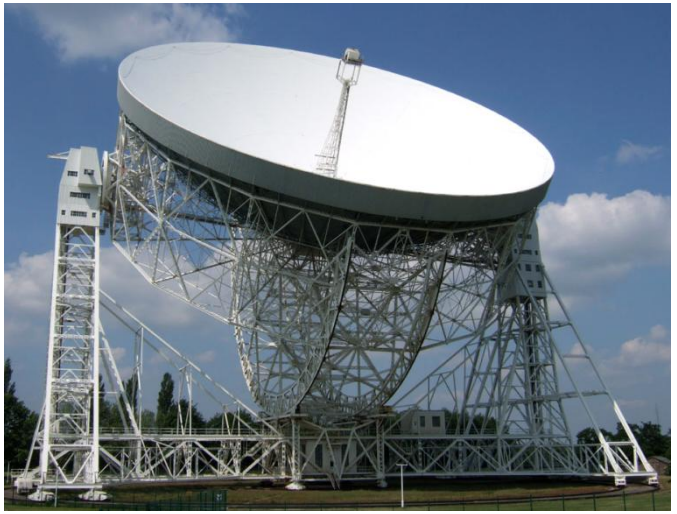
74m Lovell Telescope Jodrell Bank UK

The first large radio telescope

Design Concept 1951

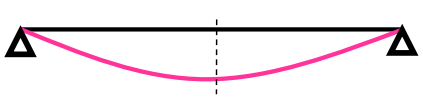
As built 1956

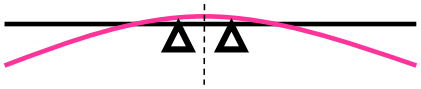
Today

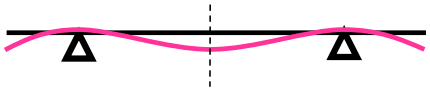


Large radio telescopes – the story of "homology"

Reflector deformation principles







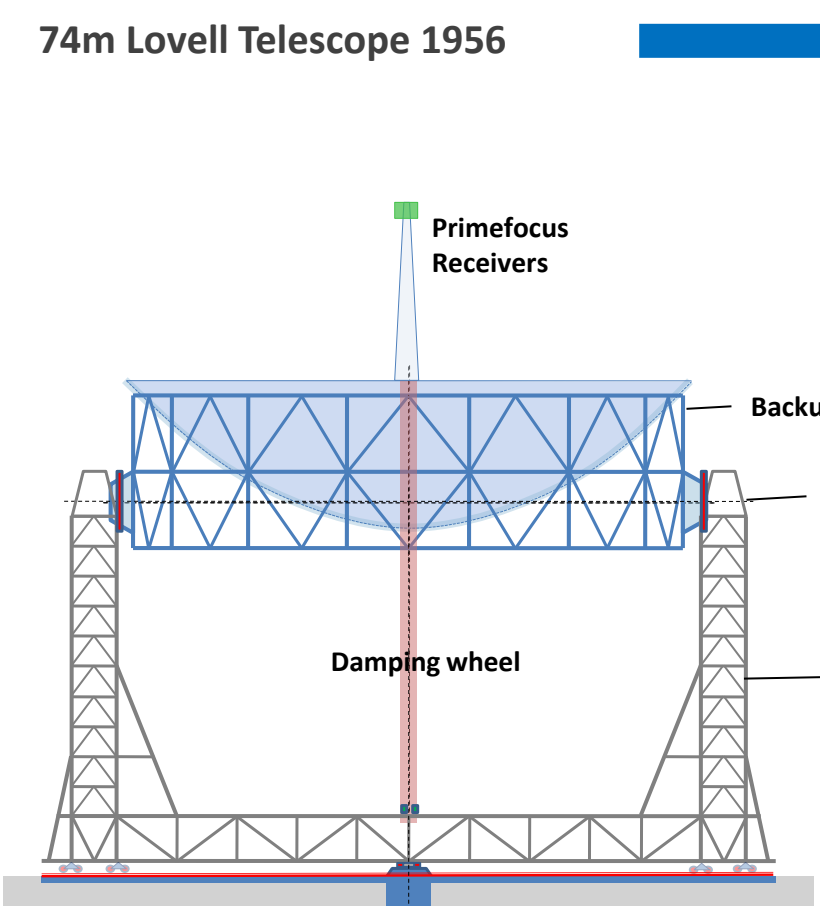
Jodrell Bank 1956

Parkes 1957

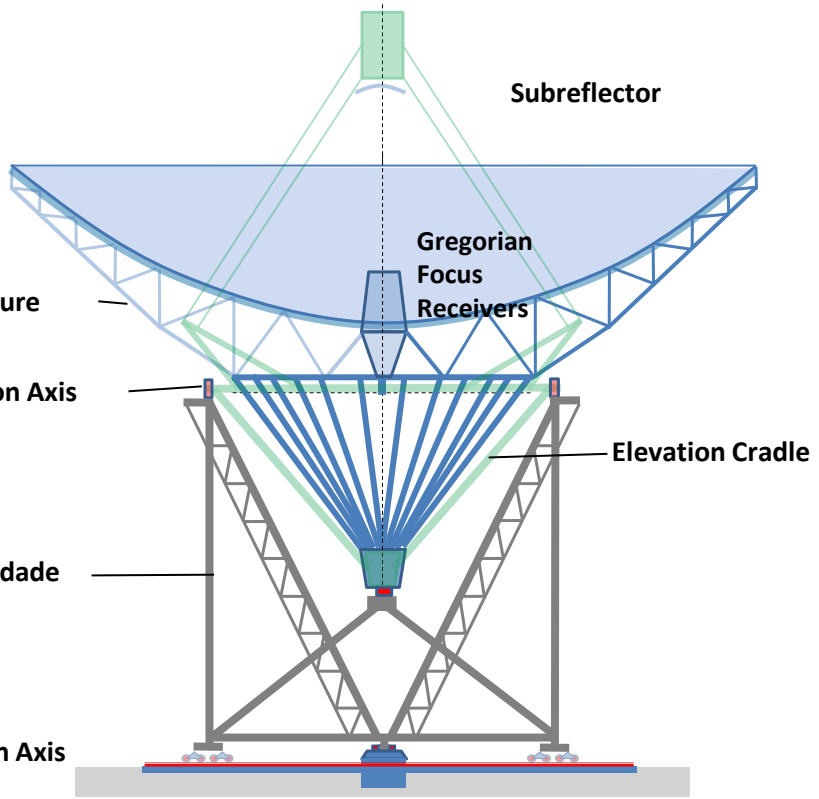
Effelsberg 1972

Homology – Historical Development

74m Lovell Telescope 1956

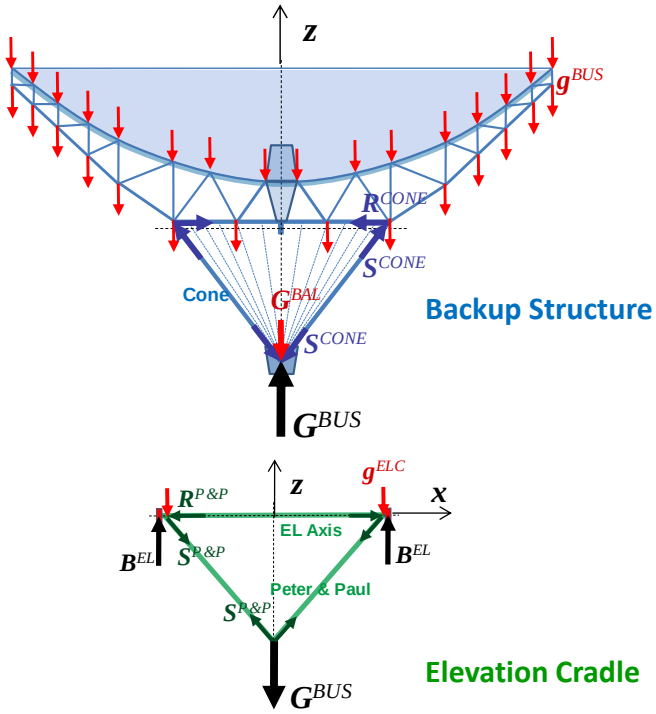


100m Telescope Effelsberg 1972

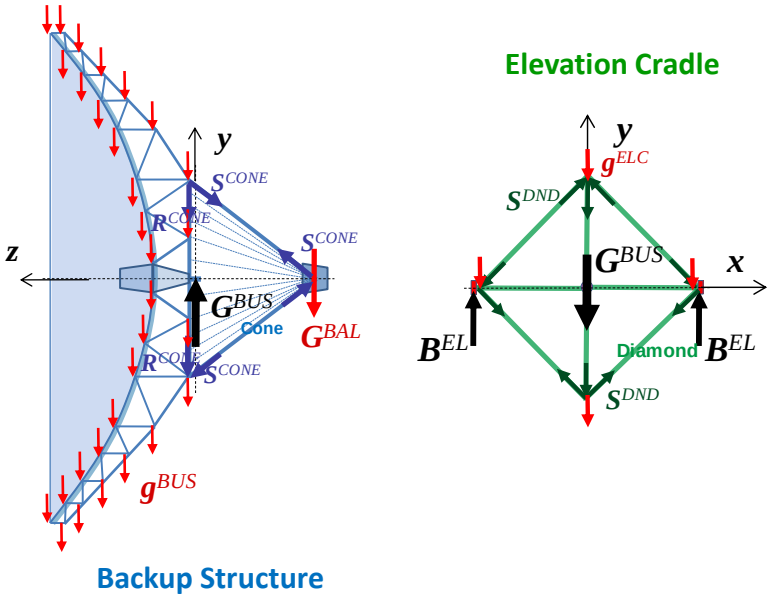


Effelsberg – structural design principle

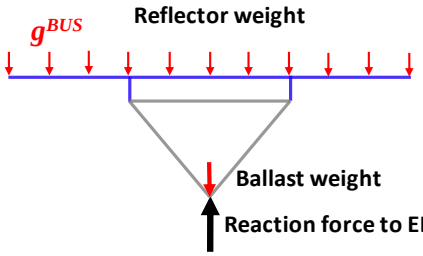
Load paths zenith



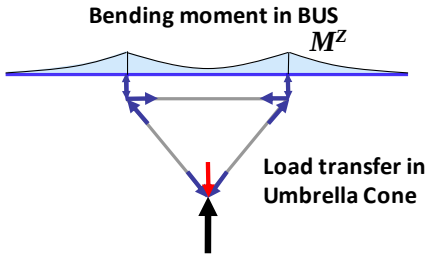
Load paths horizon



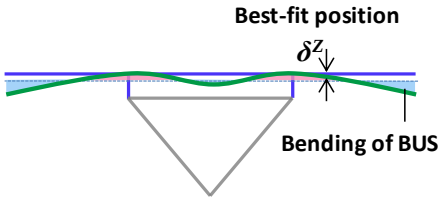
Effelsberg – interpretation of deformation patterns



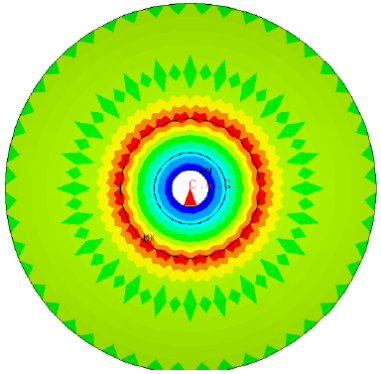
External Loads



Internal Load paths



Deformation Pattern

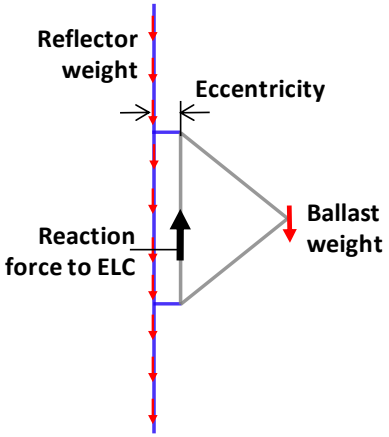


324 µm rms

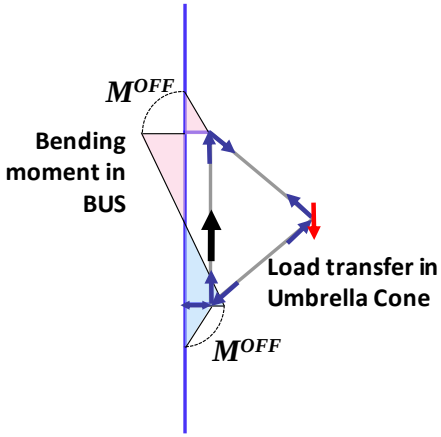
Zenith

Horizon

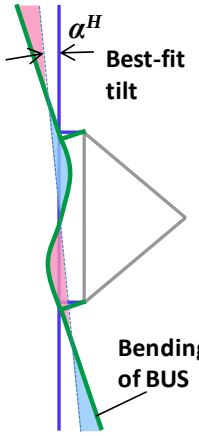
External Loads

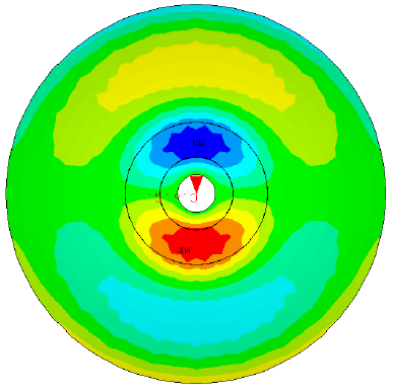


Internal Load paths



Deformation Pattern

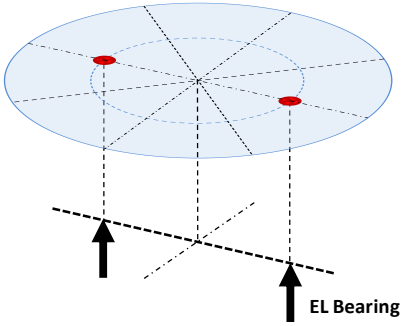


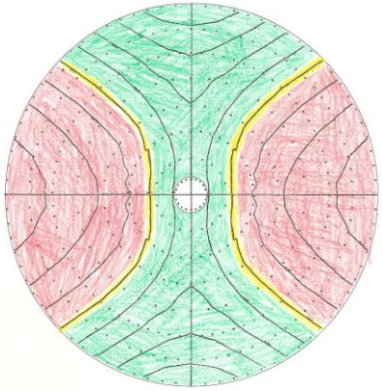


2048 µm rms

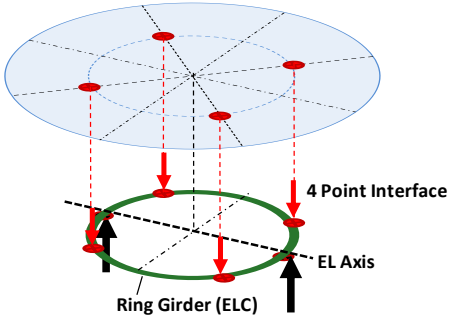
4-point supports – MERLIN

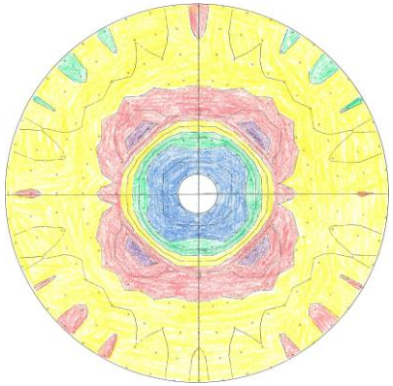
32m radio reflector in Cambridge UK





σ^Z = 4,117µm rms





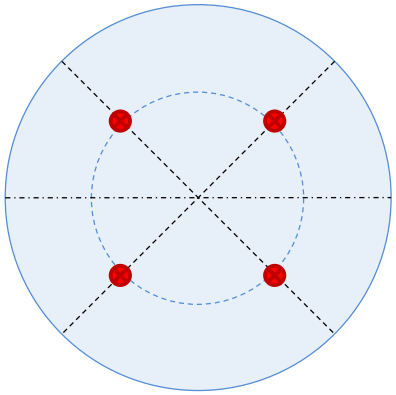
σ^Z = 467µm rms

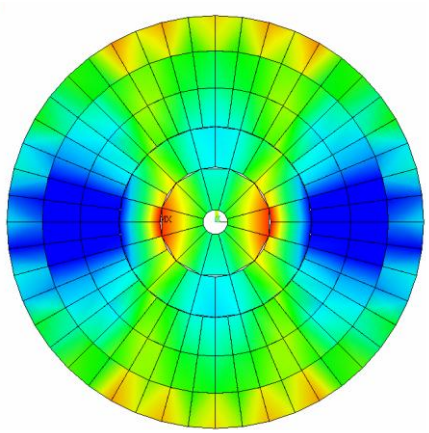
50-m Large Millimeter Telescope LMT/GTM

Largest millimeter telescope worldwide – surface accuracy 70µm rms

Cerro la Negra, Puebla, Mexico – 4600 m

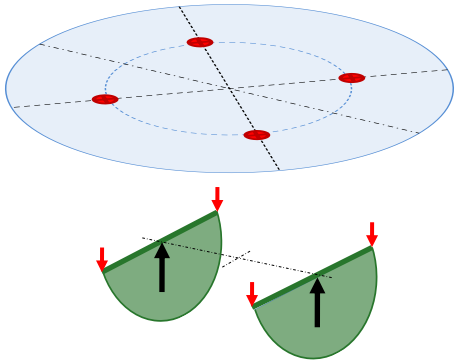
4-point support and contour plots of the LMT

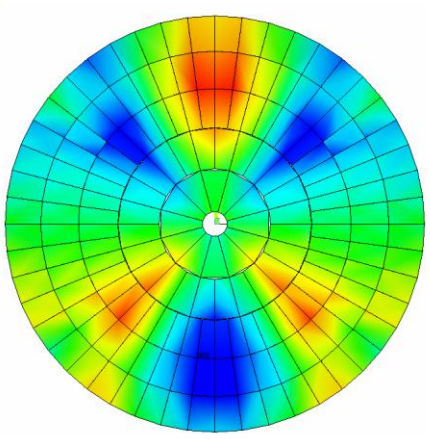




Zenith position

σ^Z = 316µm rms

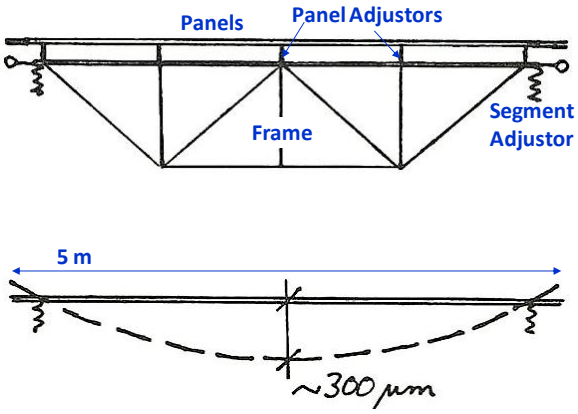


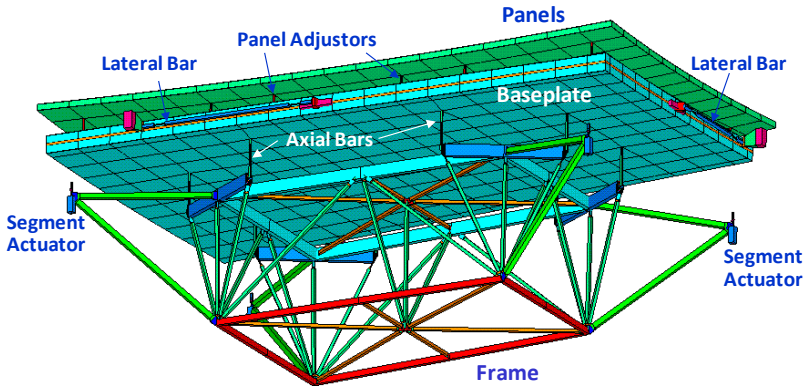


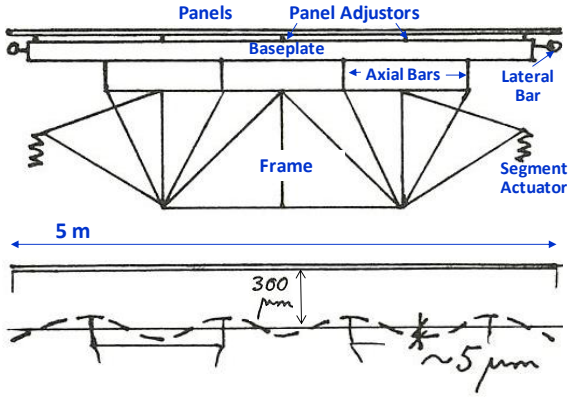
Horizontal position

σ^H = 415µm rms

Iso-static subframes of the LMT reflector





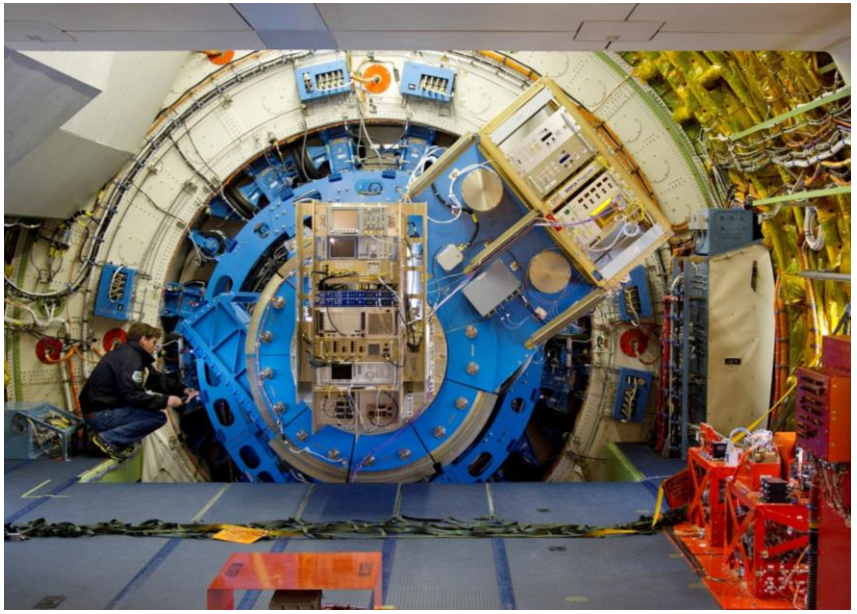


Hans Jürgen Kärcher

Above the Mojave Desert

SOFIA

Stratospheric Observatory For Infrared Astronomy



German Instrument GREAT

SOFIA

Some impressions of the suspension assembly

telescopemechanics@hjkaercher.de

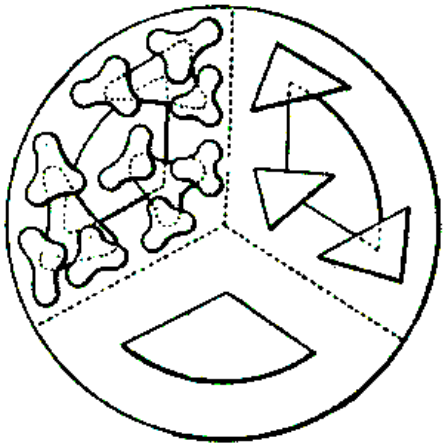
The SOFIA Mirror

2.7m diameter

telescopemechanics@hjkaercher.de

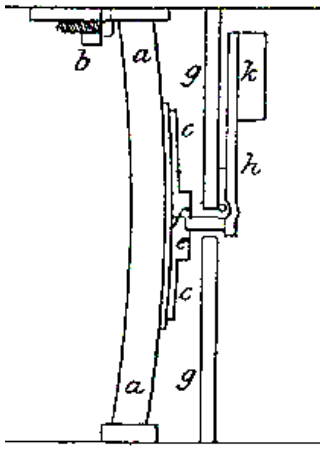
Design history of mirror supports

Whiffle Tree



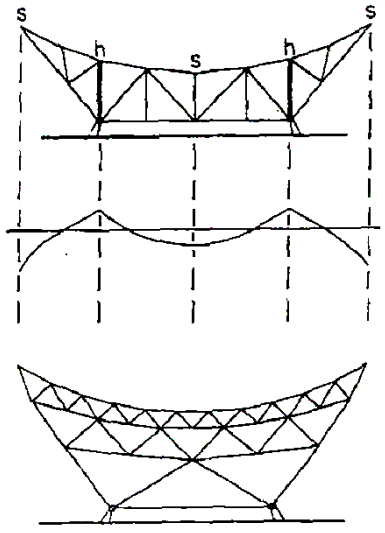
Thomas Grubb 1845

A-static Levers



William Lassell 1842

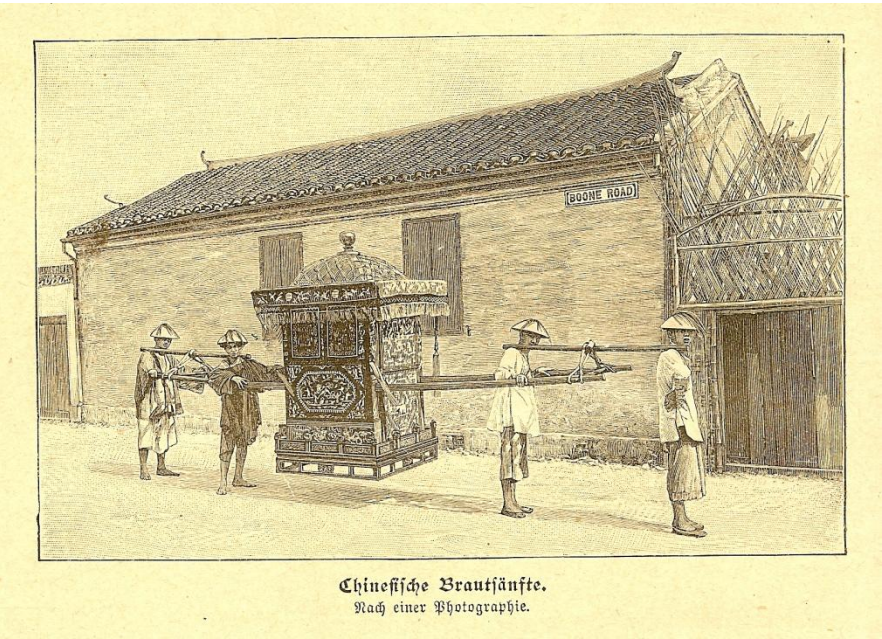
Homology

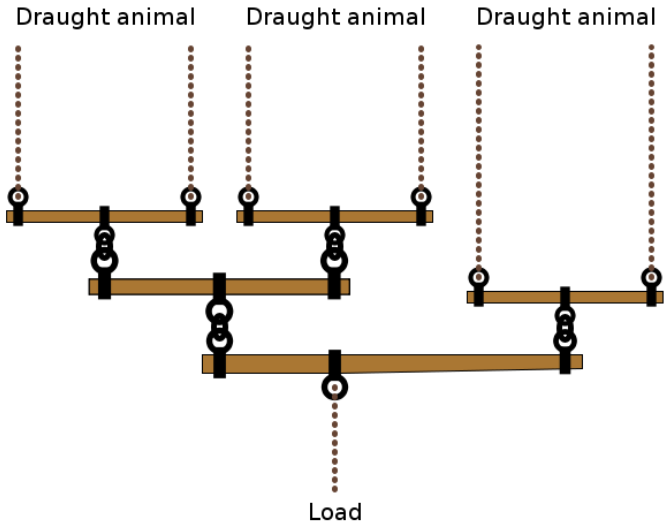


Sebastian von Hoerner 1967

What is a whiffle tree?

Historical examples

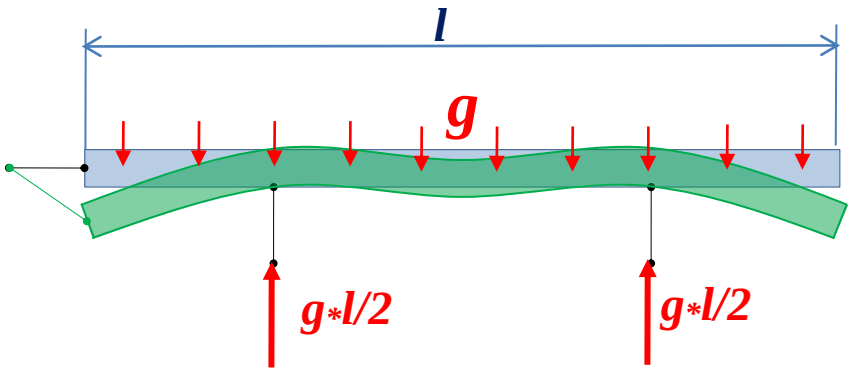




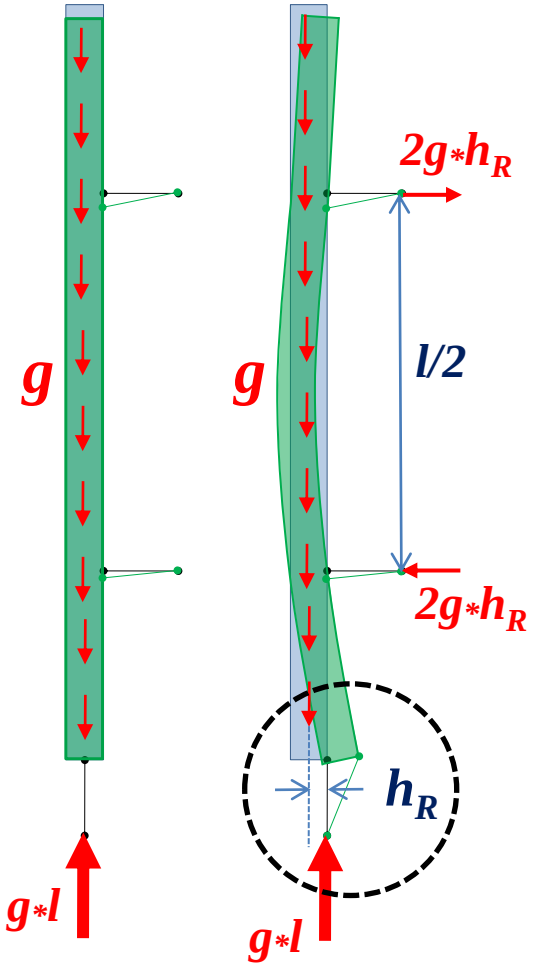
Explanation of the bending behavior

Historical examples

Zenith position



Horizontal position



H. J. Kärcher, „Die Kunst Linsen und Spiegel zu halten“
Sterne und Weltraum 3, 2012, S. 52-63

Examples of different types of mirror supports

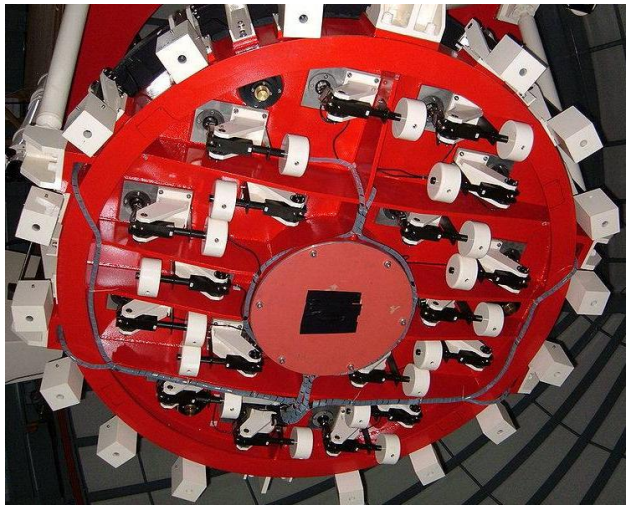
2.7m Sandwich Meniscus
(SOFIA 2004)

Axial supports: structural whiffle tree
Lateral supports: 3-point flexures

3.6m Thick Meniscus
(Calar Alto 1982)

Axial supports: hydraulic whiffle tree
Lateral supports: a-static levers

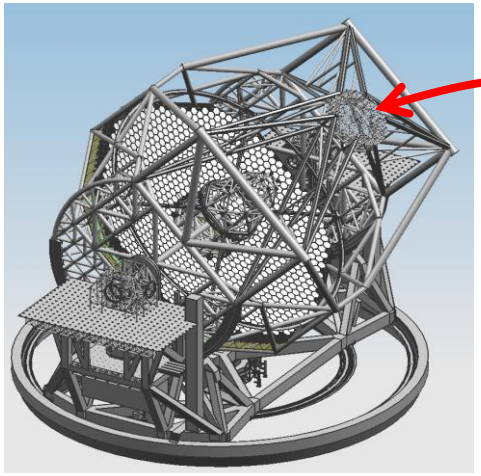
1.8m Meniscus
(MOA Telescope NZ 2002)

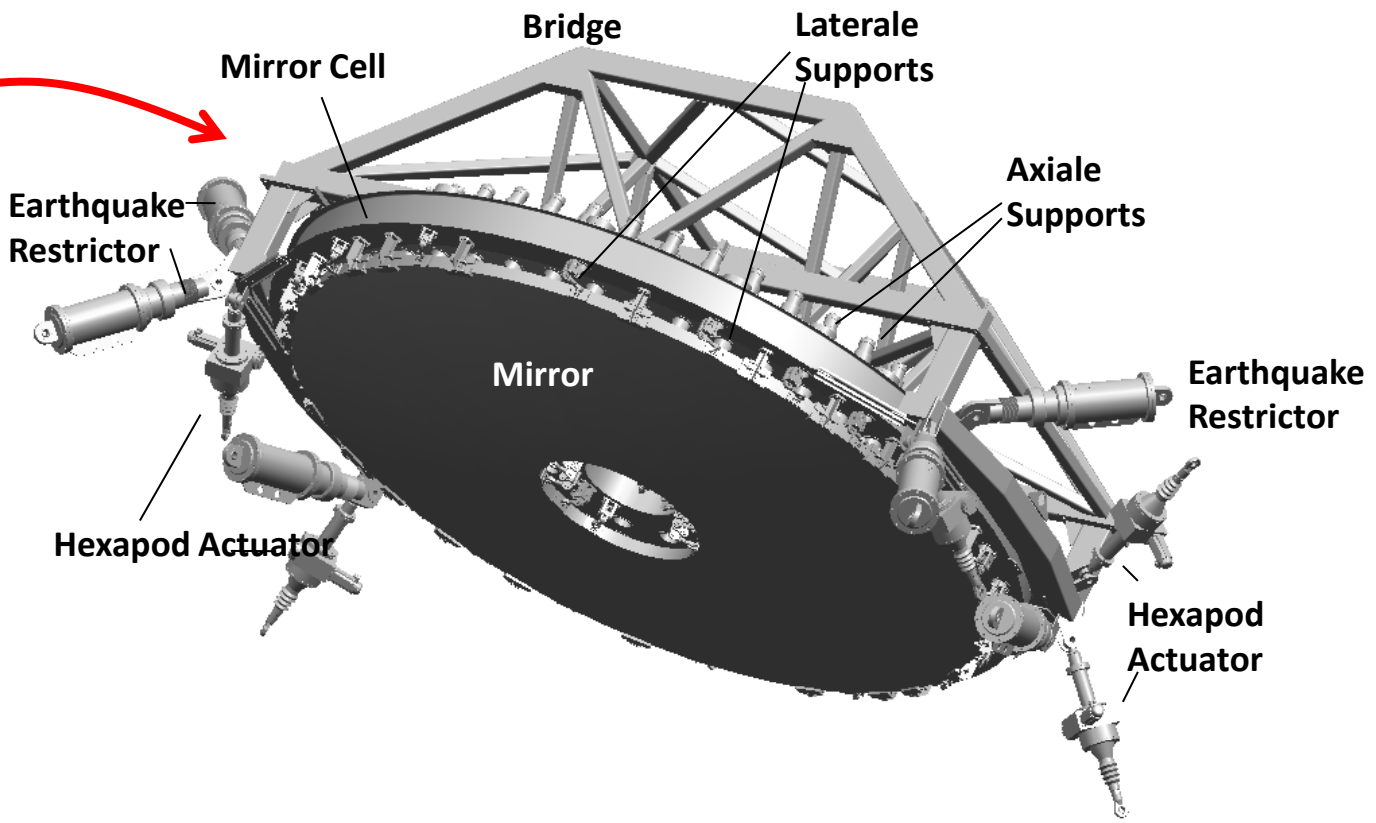


Axial supports: a-static levers
Lateral supports: a-static levers

E-ELT M2 Unit

Design status 2009 – mirror diameter 6.2m





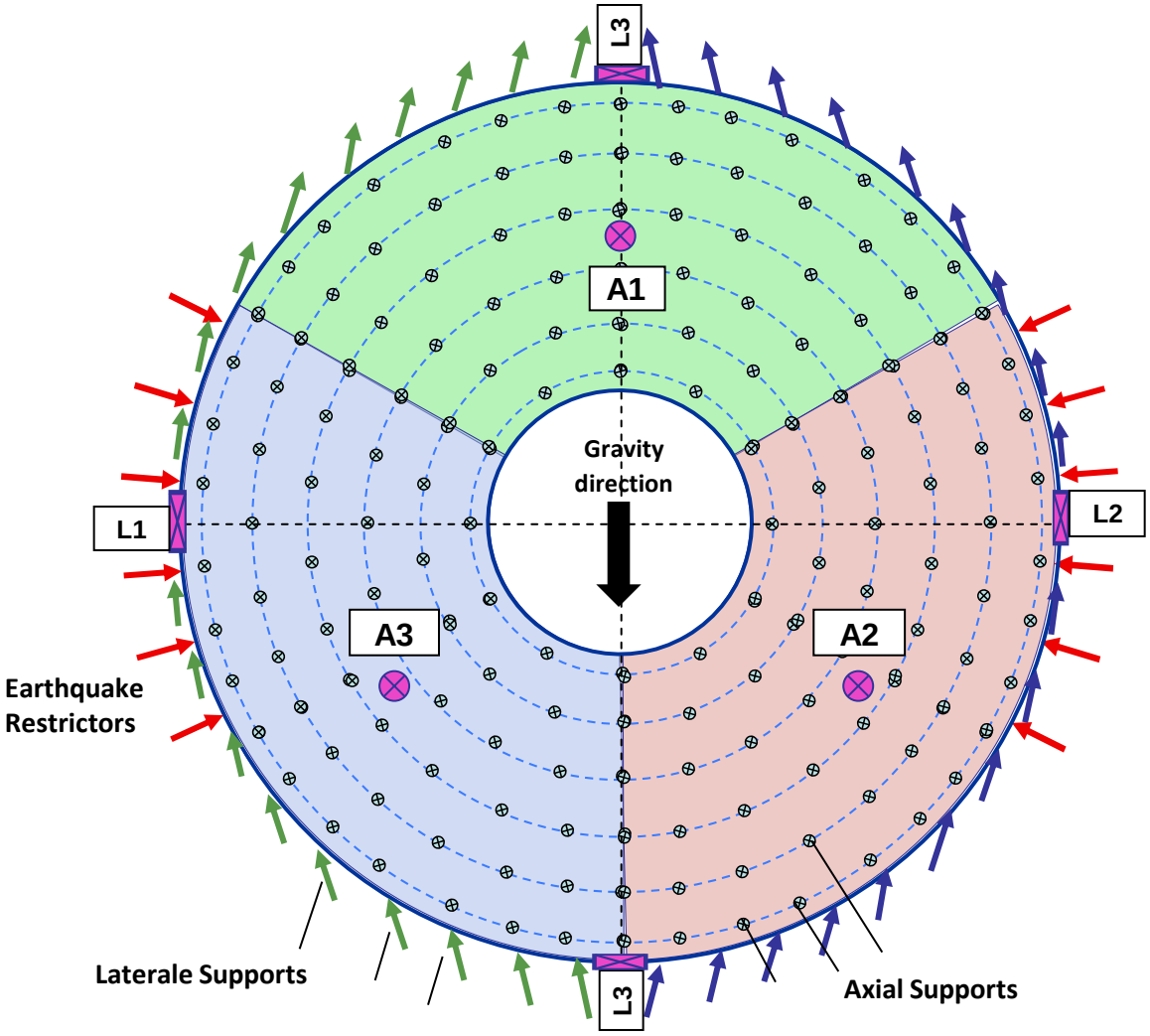
H. J. Kärcher, „Die Kunst Linsen und Spiegel zu halten“, Sterne und Weltraum 3, 2012, S. 52-63

E-ELT M2 Unit

Design status 2009

Mirror diameter 6.2m

Arrangement of axial and lateral Supports



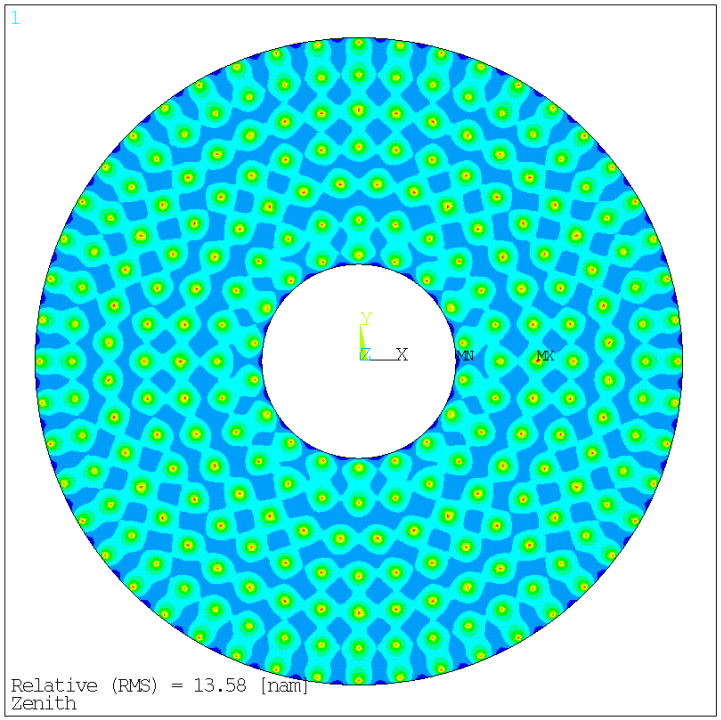
A1 – A3: axial position sensors
L1 – L4: lateral position sensors

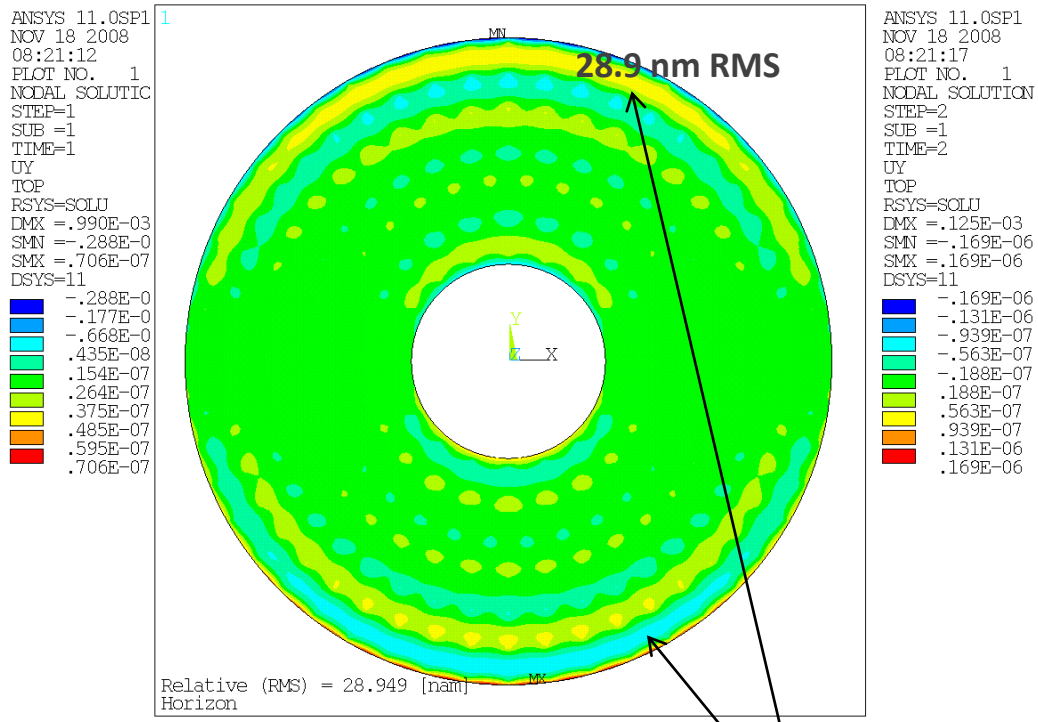
H. J. Kärcher,
„Die Kunst Linsen und Spiegel zu halten“,
Sterne und Weltraum 3, 2012, S. 52-63

E-ELT M2 Unit

Mirror deformations under gravity loads

Zenith position 13.6 nm RMS





Horizontal position

Design status 2009, mirror diameter 6.2m

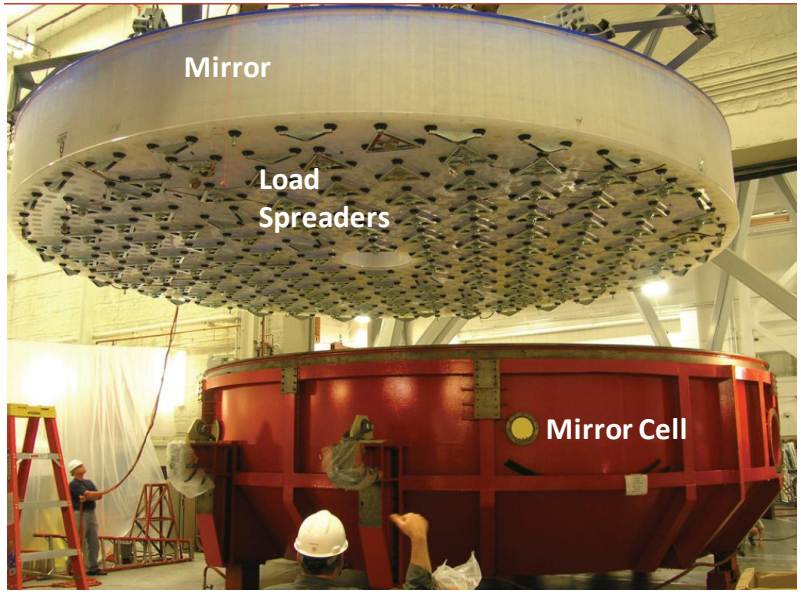
H. J. Kärcher, „Die Kunst Linsen und Spiegel zu halten“, Sterne und Weltraum 3, 2012, S. 52-63

8m ∅ spin casted honeycomb sandwich mirrors

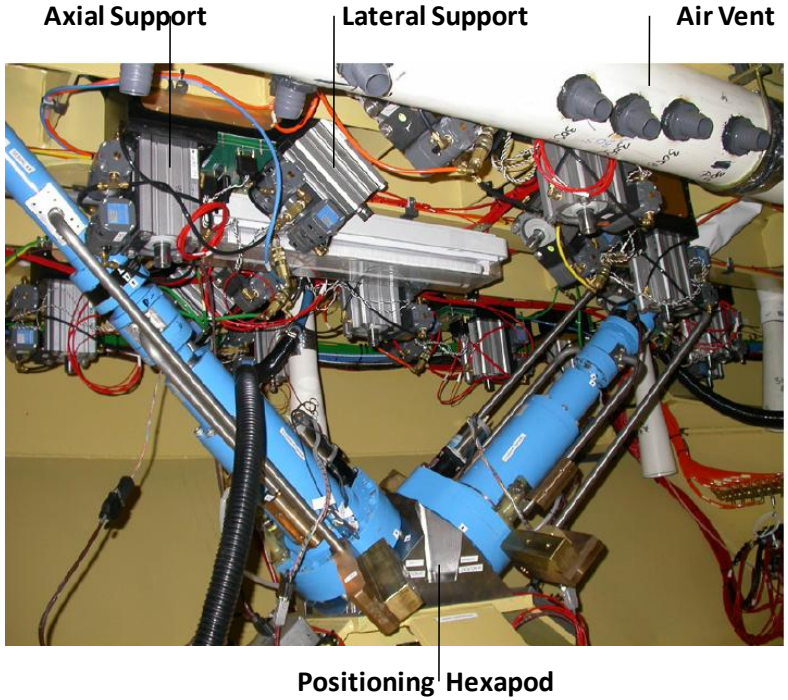
University of Arizona

LBT, GMT

The rear of the mirror during assembly

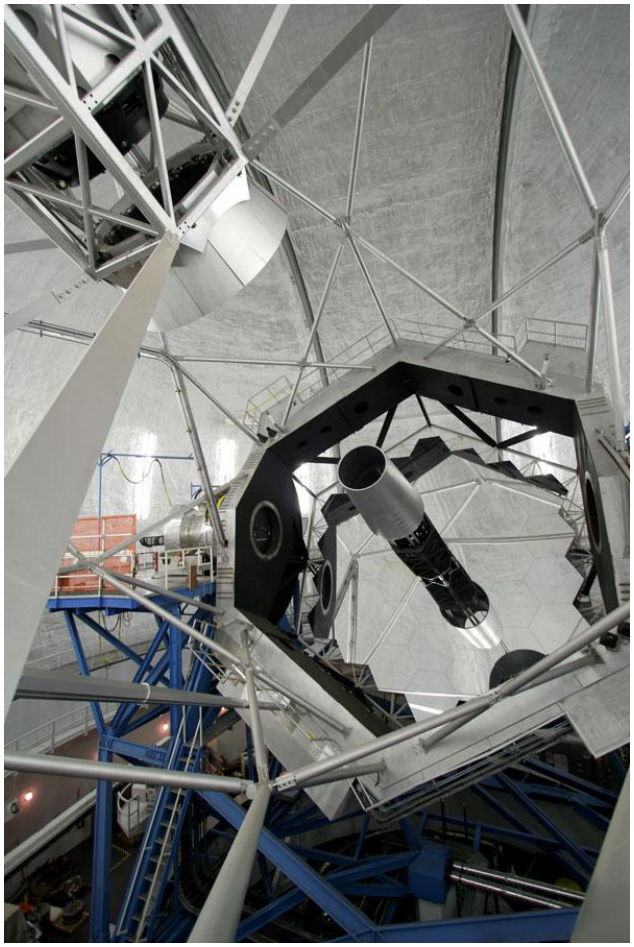


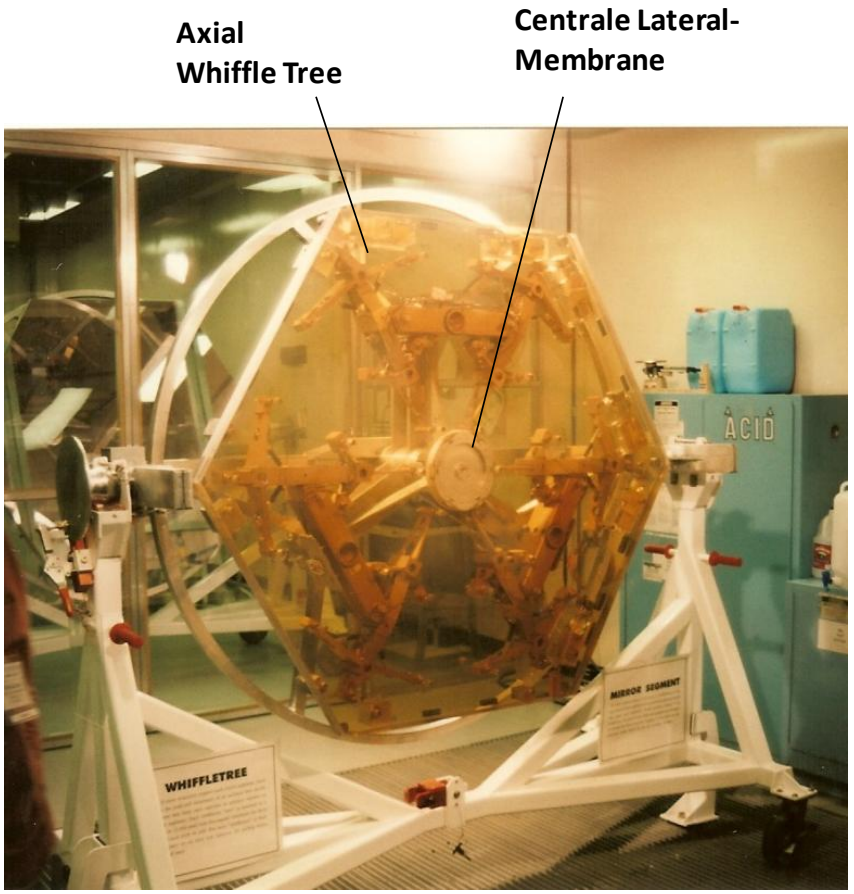
The interior of the mirror cell



Large segmented mirrors

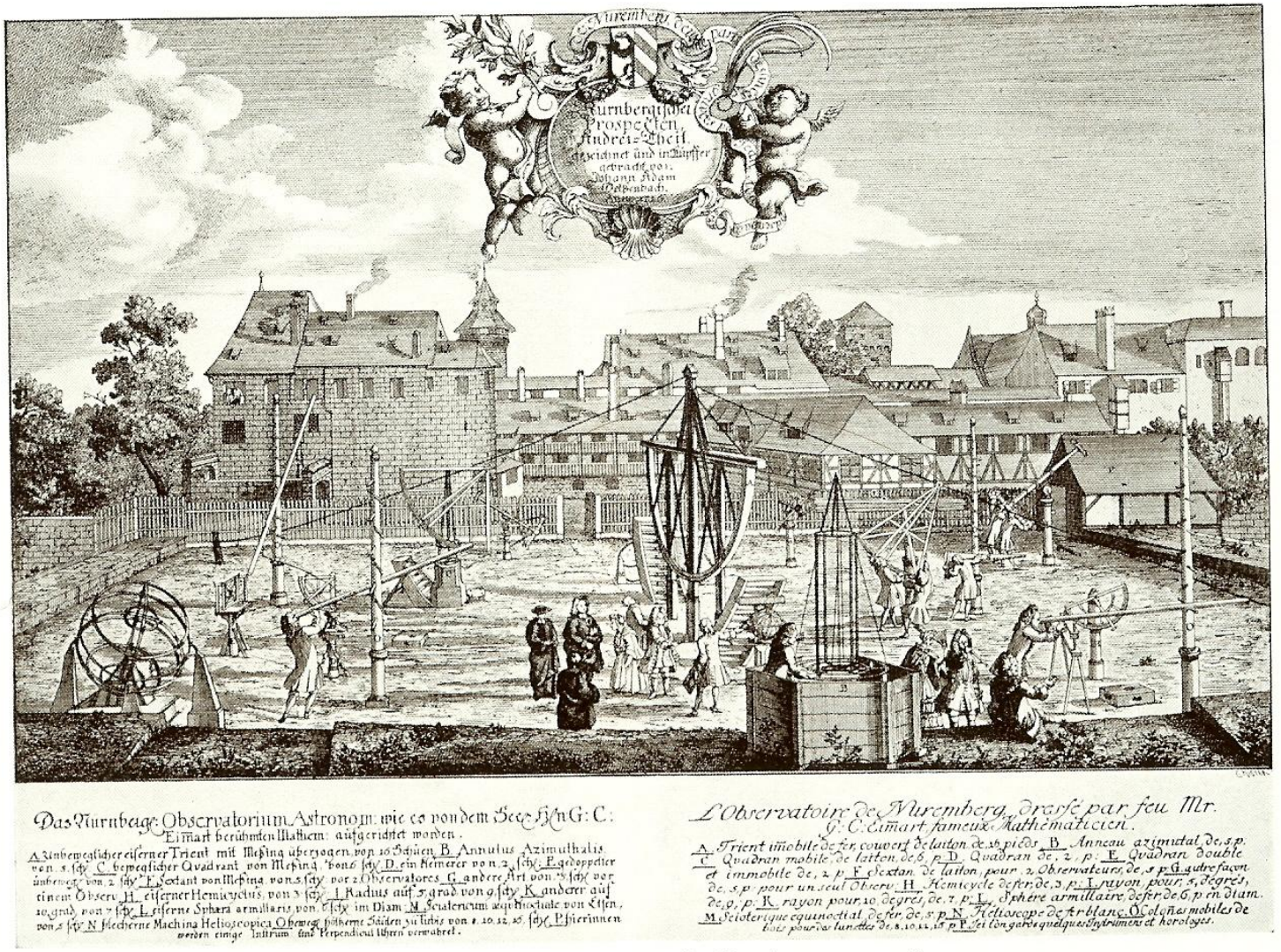
Keck, TMT, E-ELT





Hans Jürgen Kärcher

Telescope mechanics 300 years ago!



Das Nürnberg: Observatorium Astronom: wie es von dem Seel: Herrn G: C: Eimart berühmten Mathem: aufgerichtet worden.

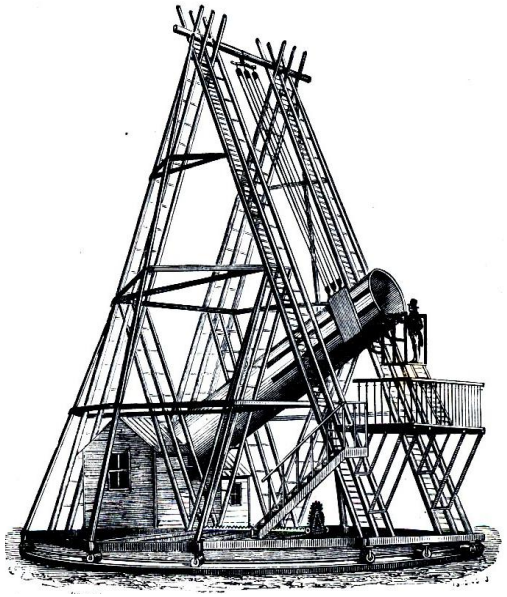
A Unbeweglicher eiserner Trient mit Meßing überzogen von 16 Schuhen. B Annulus Azimuthalis von 8 Schuh. C beweglicher Quadrant von Meßing 6 Schuh. D ein kleinerer von 2 Schuh. E gedoppelter unbeweglicher von 2 Schuh. F Sextant von Meßing von 3 Schuh vor 2 Observatores. G andere Art von 8 Schuh vor einen Observ. H eiserner Hemicyclus von 3 Schuh. I Radius auf 5 grad von 9 Schuh. K anderer auf 10 grad von 7 Schuh. L eiserne Sphæra armillaris von 6 Schuh im Diam. M Scutarium æquinoctiale von Eisen von 8 Schuh. N blecherne Machina Heliospica. Ohnweit hölzerne Säulen zu sehen von 8. 10. 12. 16. Schuh. Hierinnen werden einige Instrum: und Perpendicul Uhren verwahret.

L'Observatoire de Nuremberg dressé par feu Mr. G. C. Eimart fameux Mathématicien.

A Trient immobile de fer, couvert de laiton de 16 pieds. B Anneau azimutal de 8 p. C Quadran mobile de laiton de 6 p. D Quadran de 2 p. E Quadran double et immobile de 2 p. F Sextan de laiton pour 2 Observateurs de 3 p. G autre façon de 8 p. pour un seul Observ. H Hemicycle de fer de 3 p. I rayon pour 5 degrés de 9 p. K rayon pour 10 degrés de 7 p. L Sphère armillaire de fer de 6 p en diam. M Scioterique equinoctial de fer de 8 p. N Heliocospe de Arblanc. Colonnes mobiles de bois pour les lunettes de 8. 10. 12. 16 p. Et l'on garde quelques Instrumens et horloges.

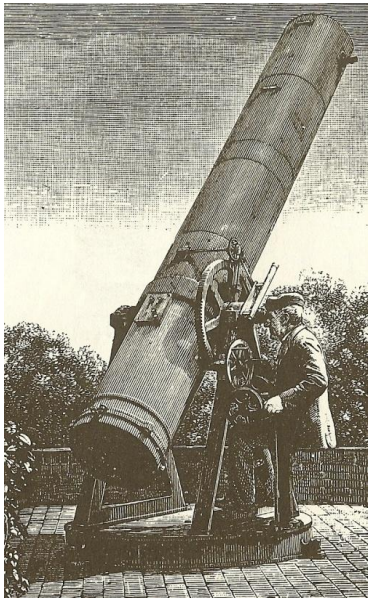
Sternwarte des G. C. Eimmart in Nürnberg von 1716

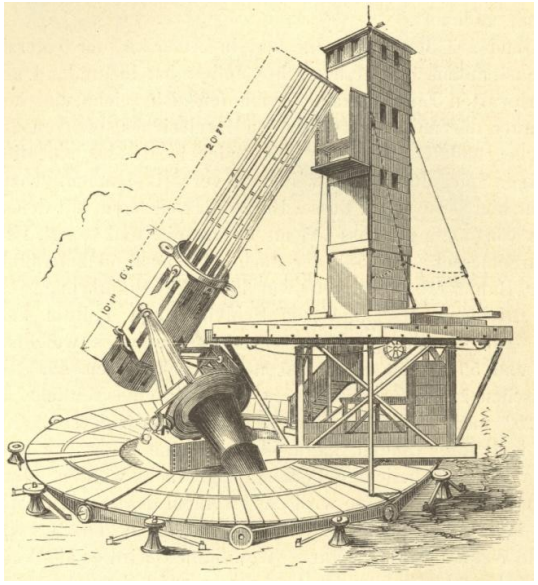
Hans Jürgen Kärcher

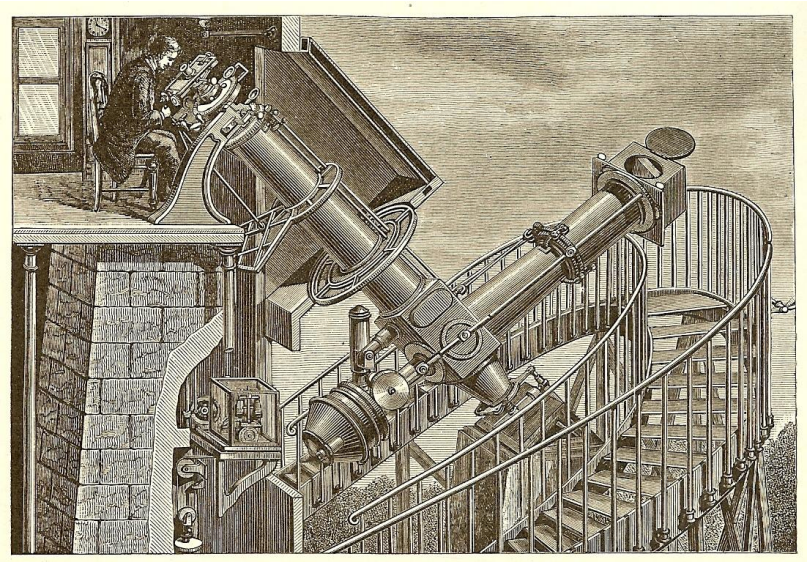


Telescope mechanics

200 years ago!







Telescope mechanics 100 years ago!

Telescope mechanics 50 years ago!