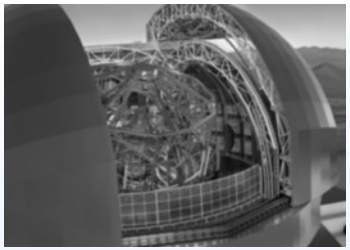
Optische Technologien für das "European Extremely Large Telescope" der ESO

Wolfgang Gaessler
Max-Planck Institut für Astronomie

Bild: ESO

Ein Blick in die Kuppel



10’ Bildfeld
0.006” Auflösung
~ 11m auf Mond

Primärspiegel:
- **798 Segmente**
- **Ø = 39m**

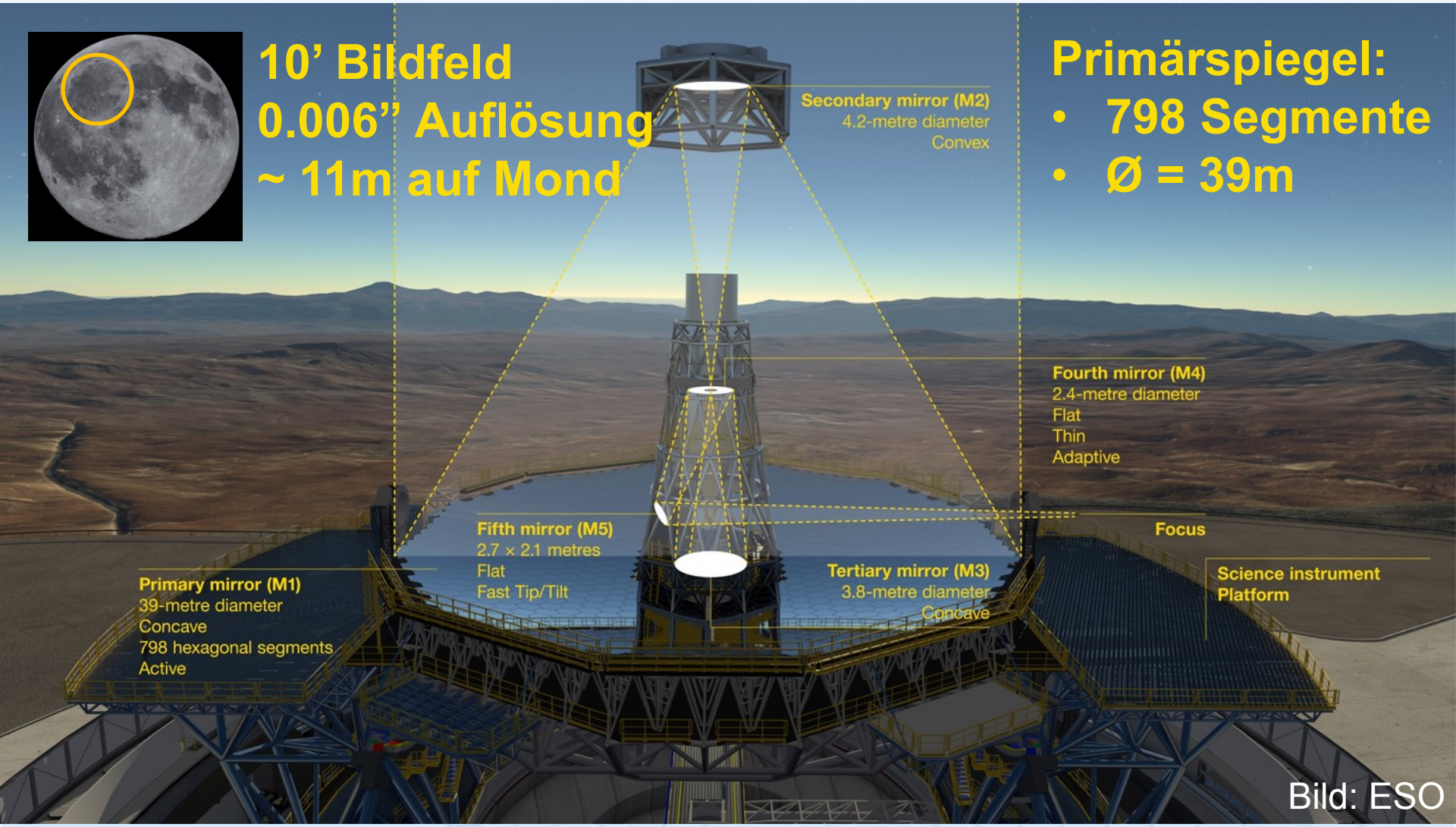
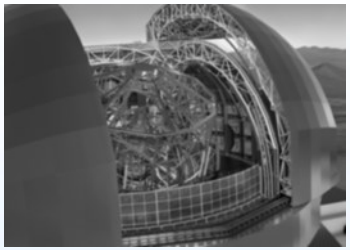


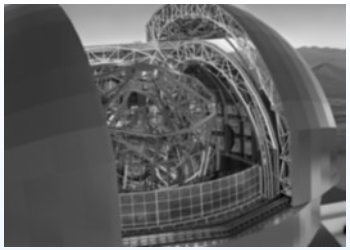
Bild: ESO

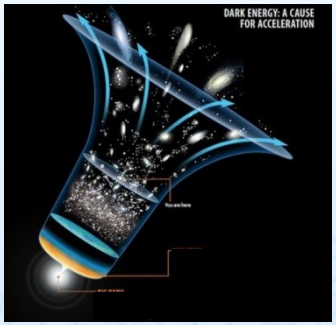
Grössenrelation



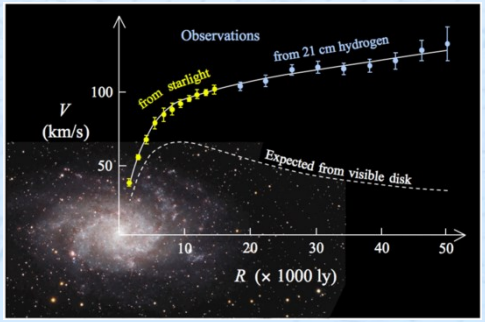
Mainzer Dom Ostfassade: Wikipedia/Moguntiner

Offene Fragen der Astronomie

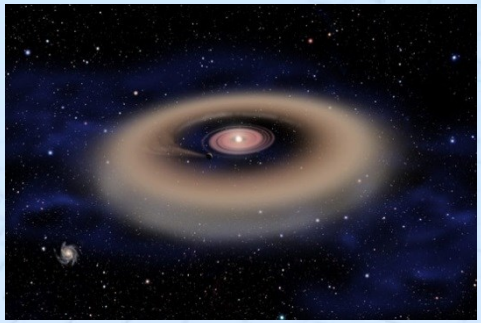




- ***Dunkle Energie***
  - Entwicklung des Kosmos



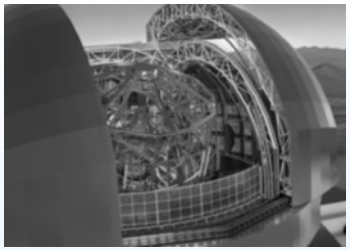
- ***Dunkle Materie***
  - Entwicklung der Galaxien

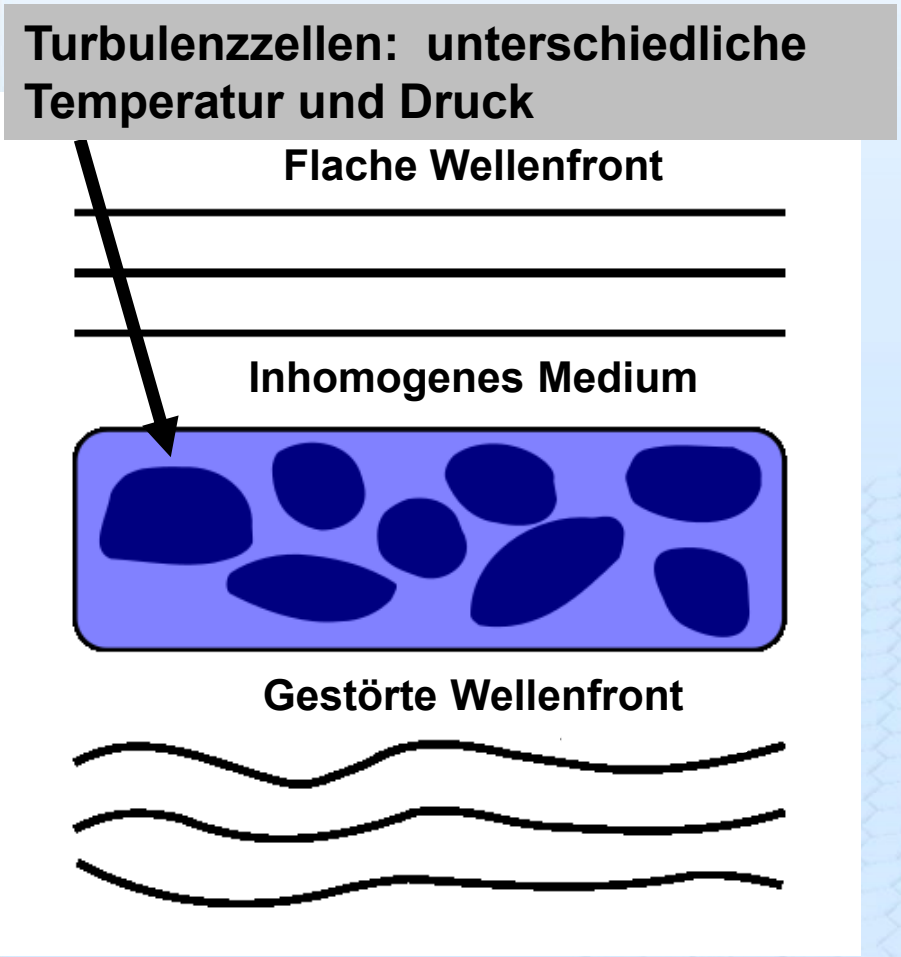


- ***Planeten und Sterne***
  - Entstehung und Aufbau

Objekte liegen im ∞
Durchmesser = Auflösung
Fläche = Lichtmenge
Credit:ESO

Atmosphärenturbulenzen





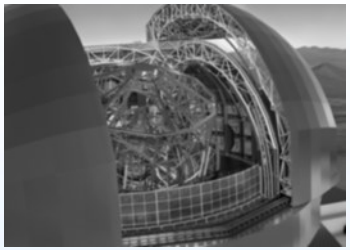
- ❖ Ständige Änderungen des Brechungsindex
- ❖ Wellenlängenabhängig

- ❖ Kohärenzlänge
  - ~20cm@V, 1m@IR
- ❖ Zeitliche Entwicklung
  - Wind dominiert
  - 1 ~ 50ms -> 20 ~ 1000Hz

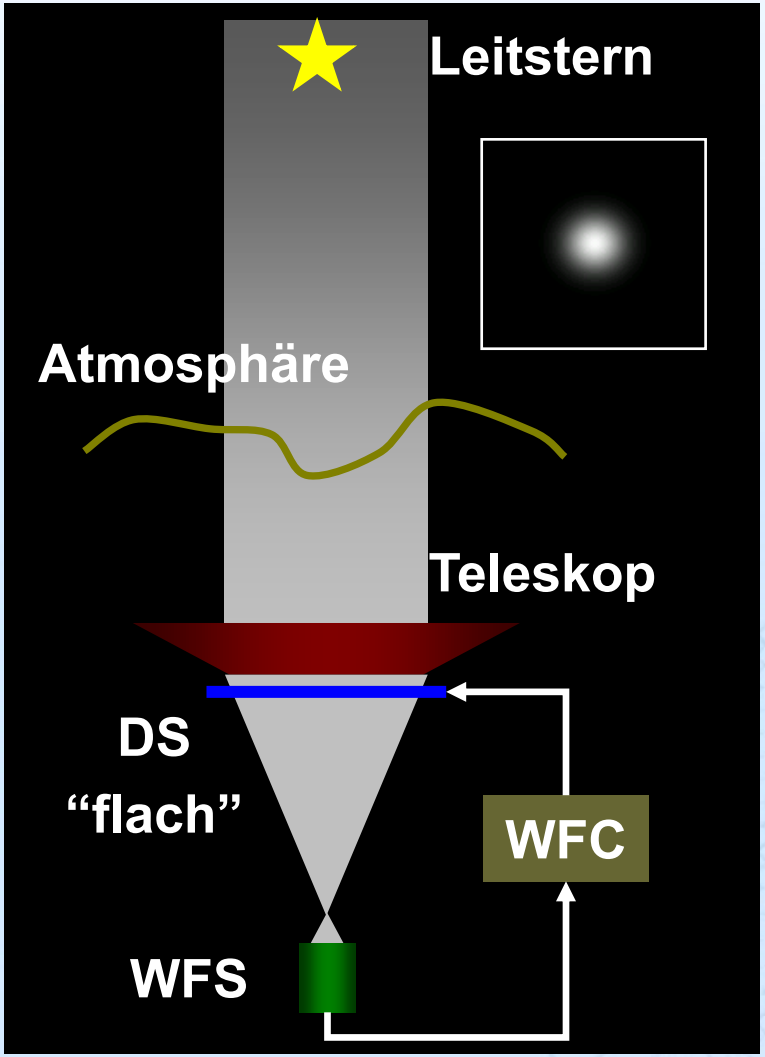
Korrektursystem

= Adaptive Optik

Babcock 1953



Prinzip der Adaptiven Optik



- 1 Leitstern (LS)
- 1 Deformierbarer Spiegel (DS)
- 1 Wellenfrontsensor (WFS)
- 1 Wellenfrontcomputer (WFC)

❖ Durchmesser ~ zu korrigierende Freiheitsgrade (Moden)

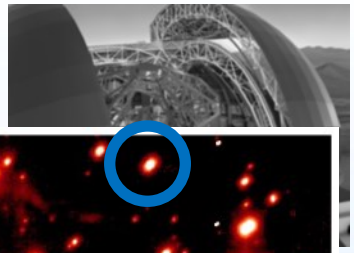
❖ Erreicht >70% Strehl* @ IR

❖ Beobachtungsfeld ~1’

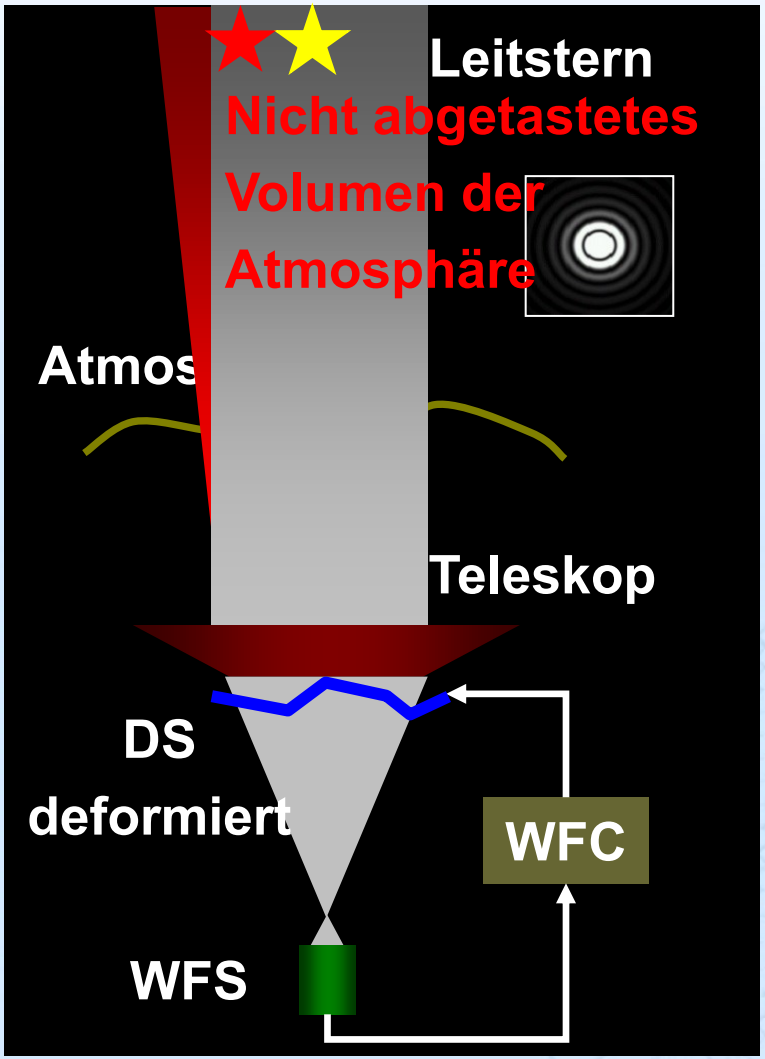
❖ Himmelsabdeckung von ~ 5% für natürliche LS @ V

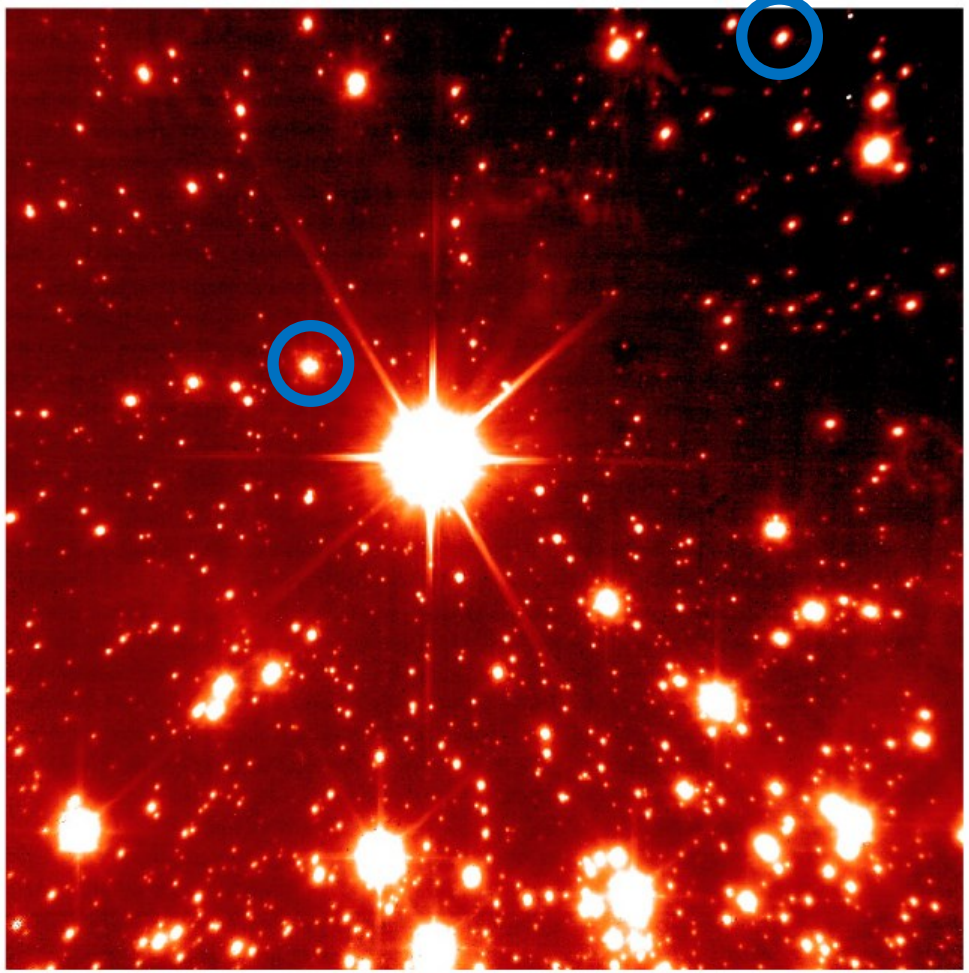
* Verhältnis max. zur theo. Intensität

Babcock 1953



Prinzip der Adaptiven Optik



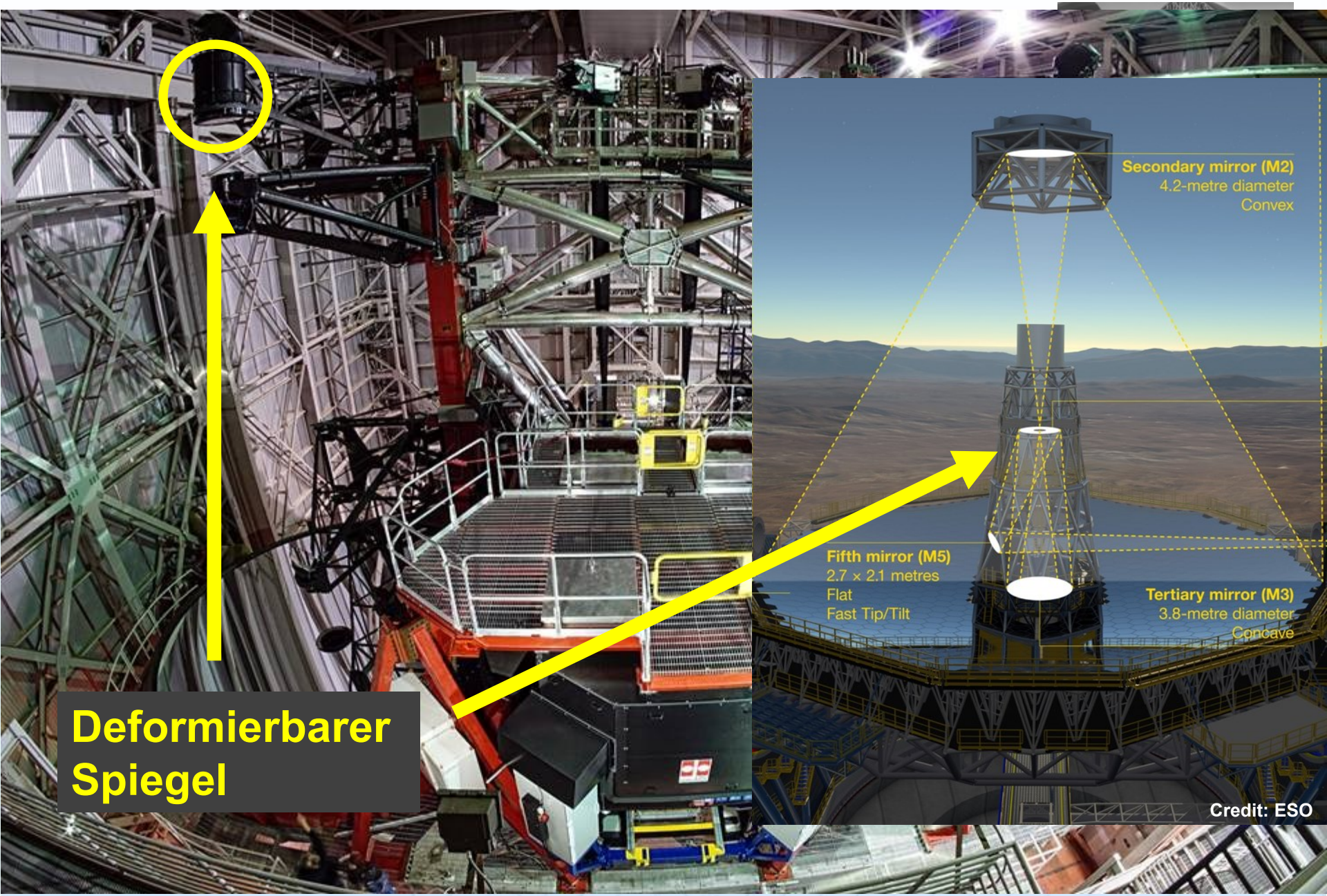


Area Near Centre of NGC 3603
(VLT YEPUN + NAOS-CONICA)

ESO PR Photo 33c/01 (3 December 2001)

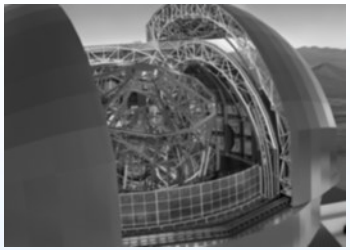
© European Southern Observatory

* V

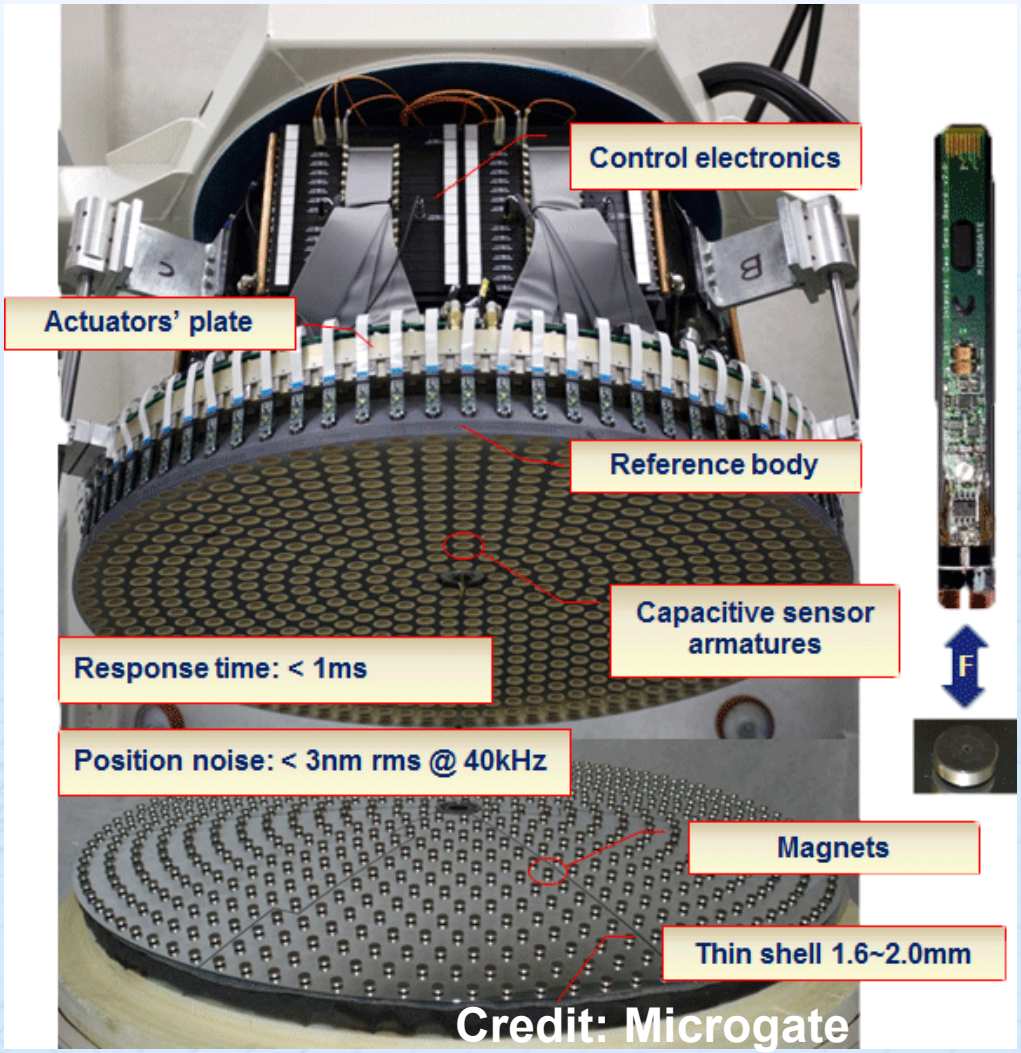


Deformierbarer Spiegel

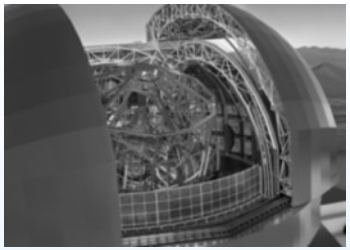
Aufbau



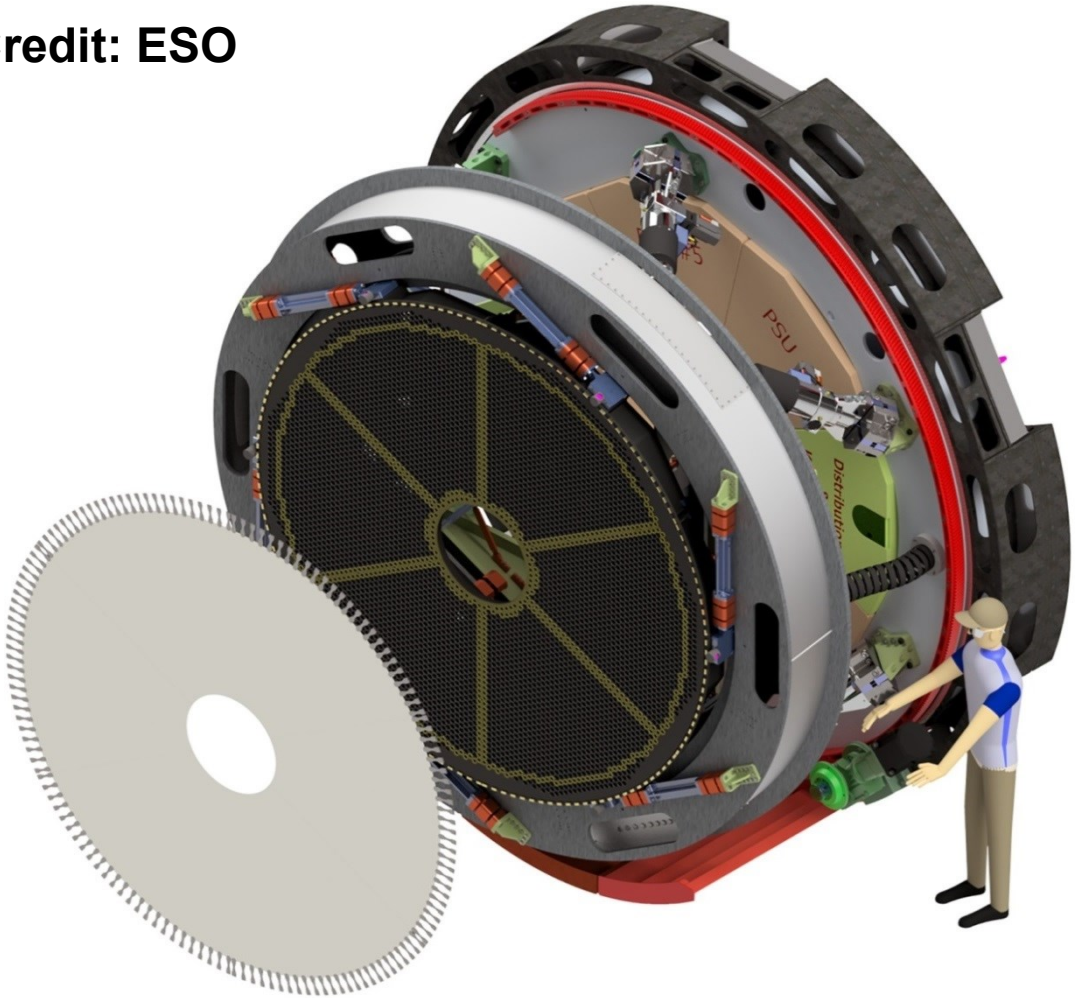
- ❖ Hexapot (nicht im Bild)
  - zur Ausrichtung
- ❖ Kontrollelektronik
  - gekühlt
- ❖ Aktuatoren
  - ~ 50µm Hub
  - < 1ms Reaktion
- ❖ Reference body
  - < 65nm Ebenheit
  - Abstand Shell ~ 40-50µm
- ❖ Shell sehr fragil
  - dicke < 2mm
  - Ø ~ 1m



E-ELT M4



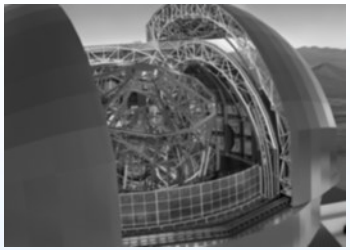
Credit: ESO

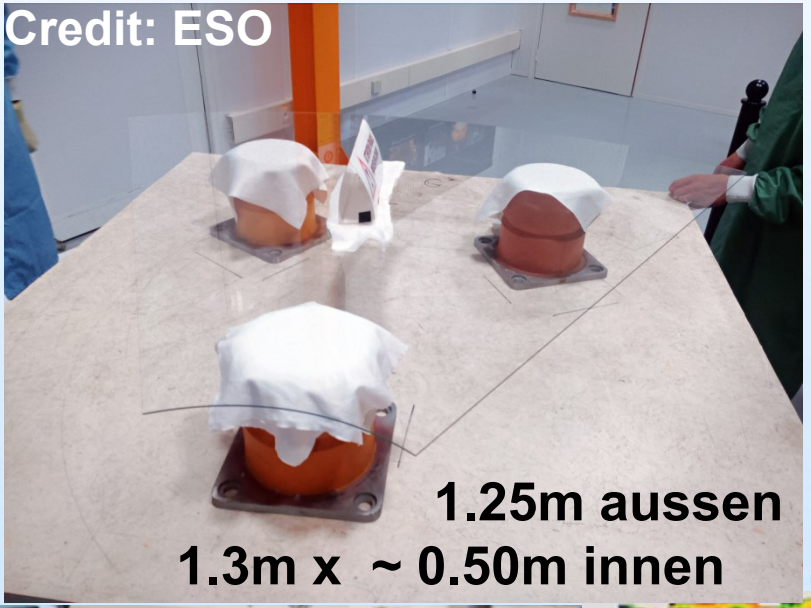


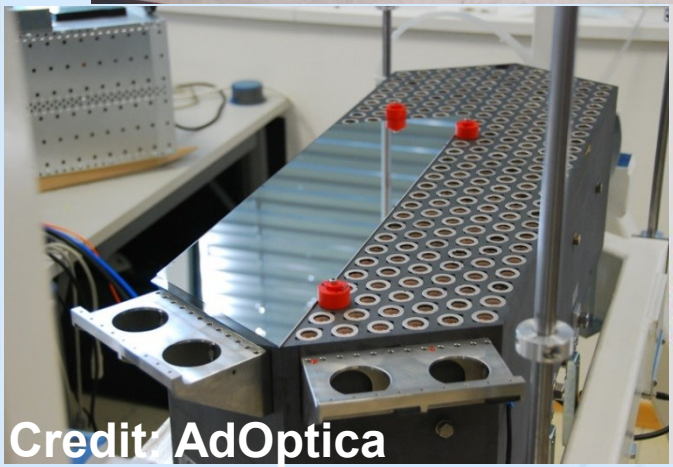
- ❖ Durchmesser
  ≤ 1m >> 2.4m
- ➢ Segmentierung

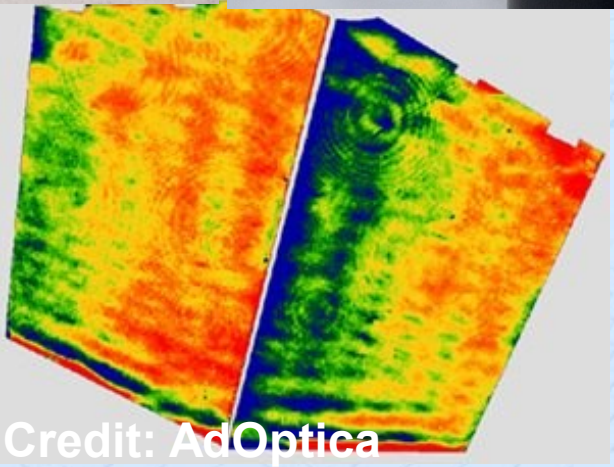
- ❖ Aktuatoren
  ≤1000 >> 5316
  - !Lebenszeit!
  - ➢ Wartbarkeit

M4 Segmente



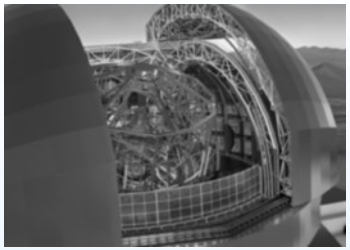


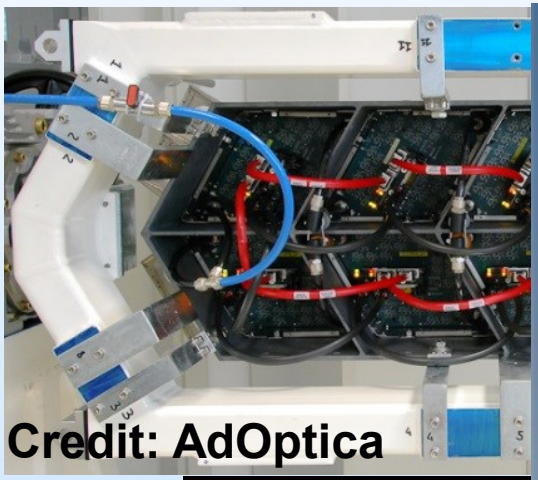




- 17 nm Ebenheit
- Thermische Einflüsse durch Elektronik!

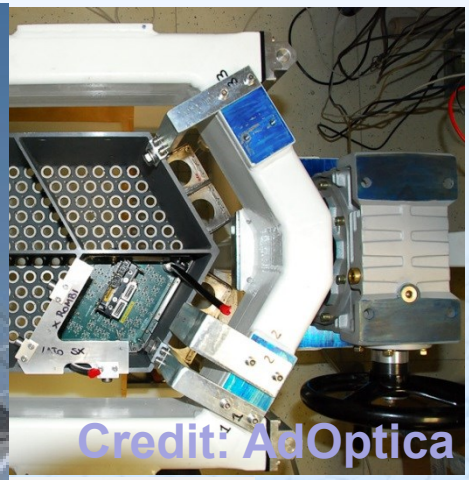
M4 Aktuatormodule



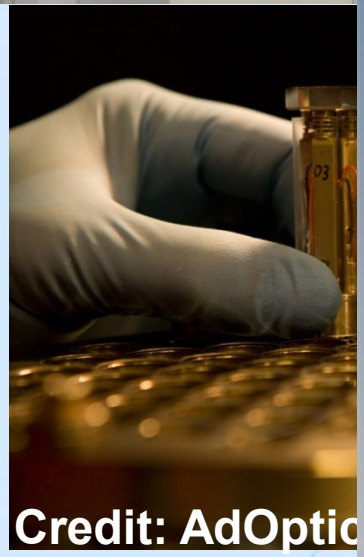


Credit: AdOptica

Credit: ESO



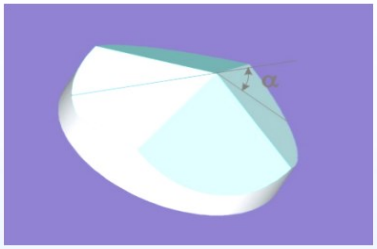
Credit: AdOptica



Credit: AdOptic

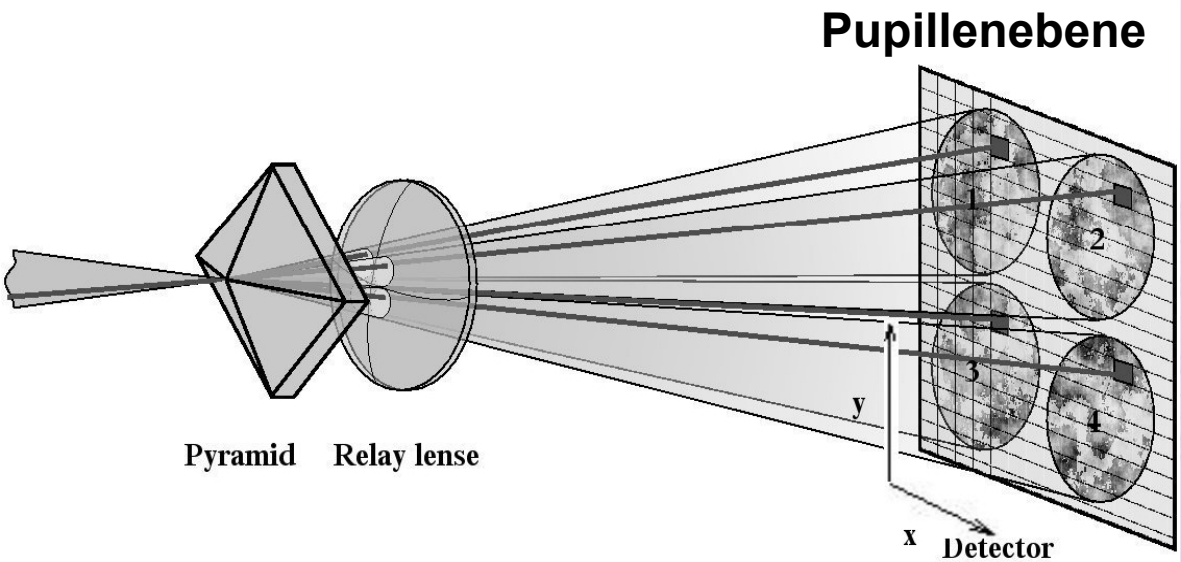
: AdOptica

Ragazzoni 1996



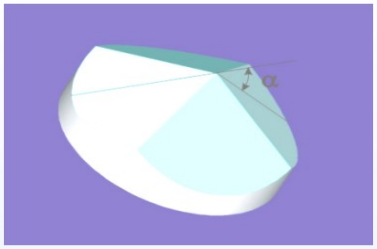
Pyramiden Wellenfrontsensor

Bild: S. Egner

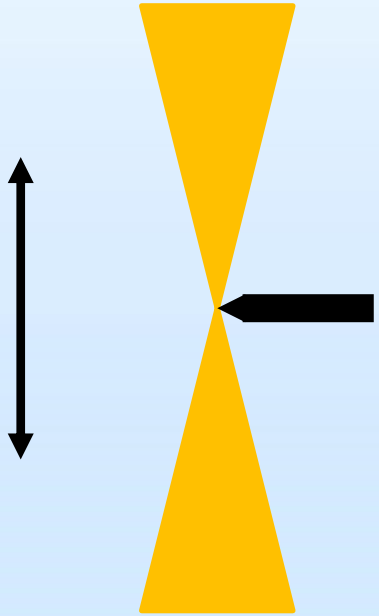


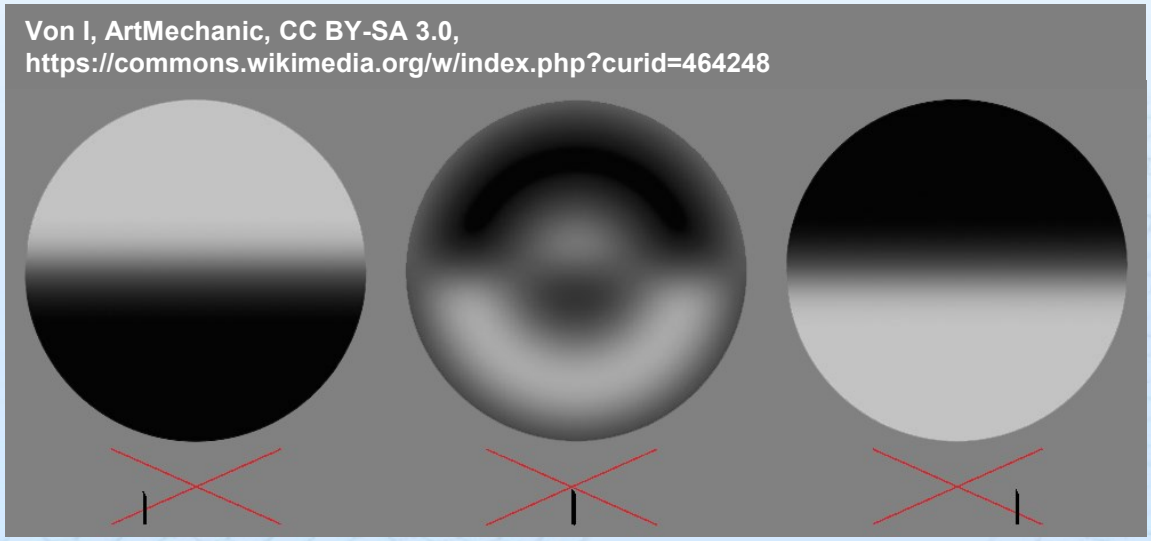
❖ Foucaultsche Schneidenprüfung in 2-dim

Ragazzoni 1996



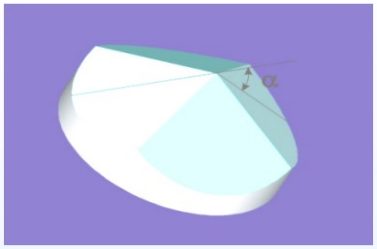
Pyramiden Wellenfrontsensor



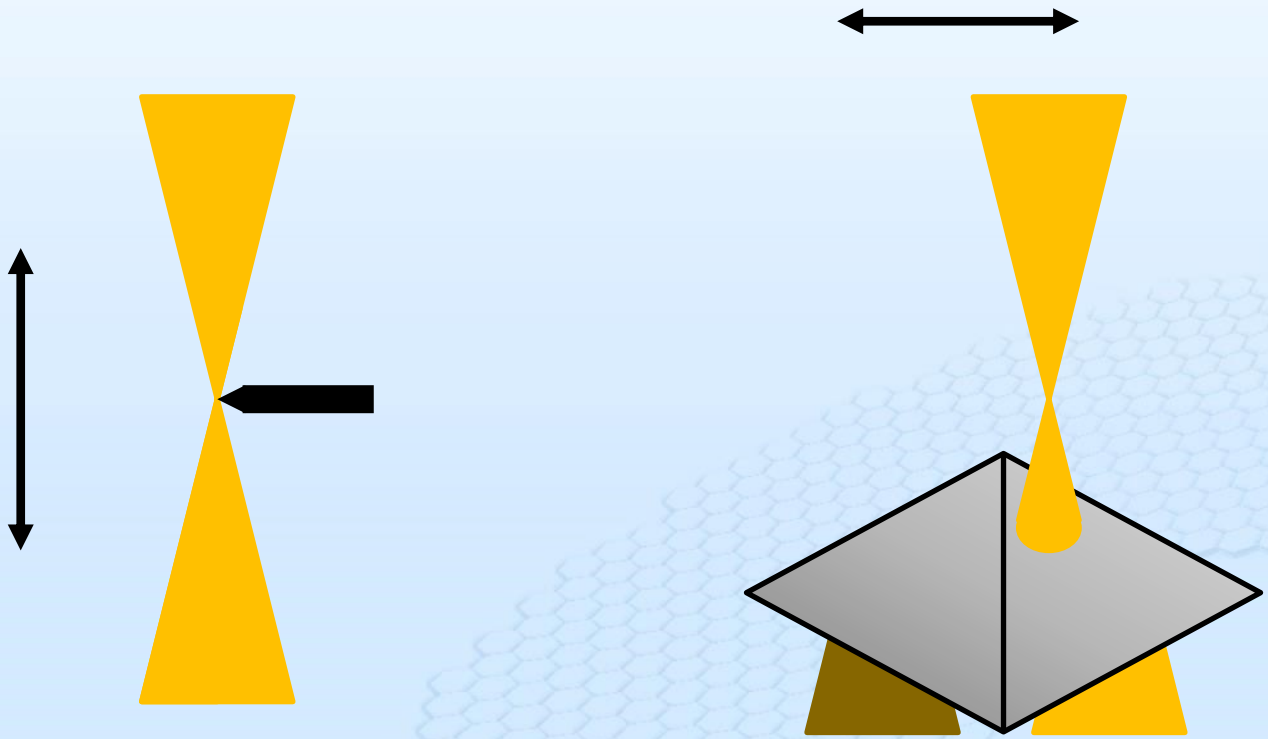


❖ **Foucaultsche Schneidenprüfung in 2-dim**

Ragazzoni 1996

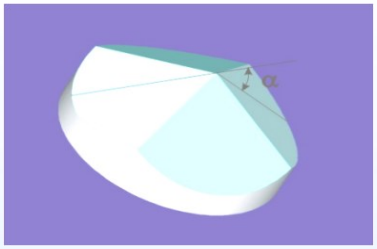


Pyramiden Wellenfrontsensor

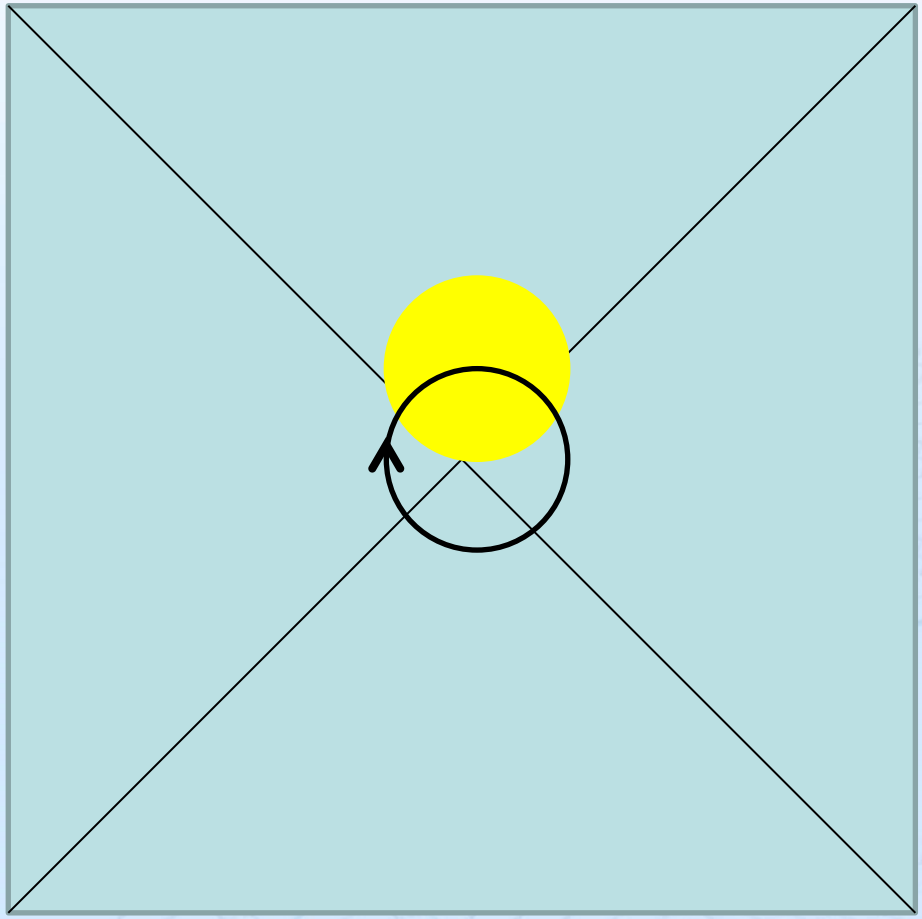


- Foucaultsche Schneidenprüfung in 2-dim
- Pro Aufnahme Spot über alle Kanten “modulieren”

Ragazzoni 1996



Pyramiden Wellenfrontsensor



- Foucaultsche Schneidenprüfung in 2-dim
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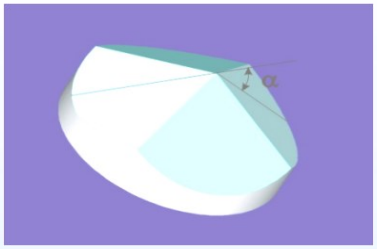


Pyramiden Wellenfrontsensor

- ❖ Rasterung in Subaperturen (= Anzahl Moden) durch Pixel
- ❖ A+B Abbild Foucaultsche Schneidenprüfung in x Achse
- ❖ C+D inverses Abbild in x Achse
- ❖ Berechnung der Gradienten in x und y

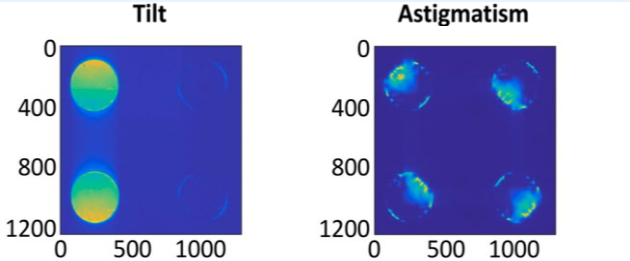
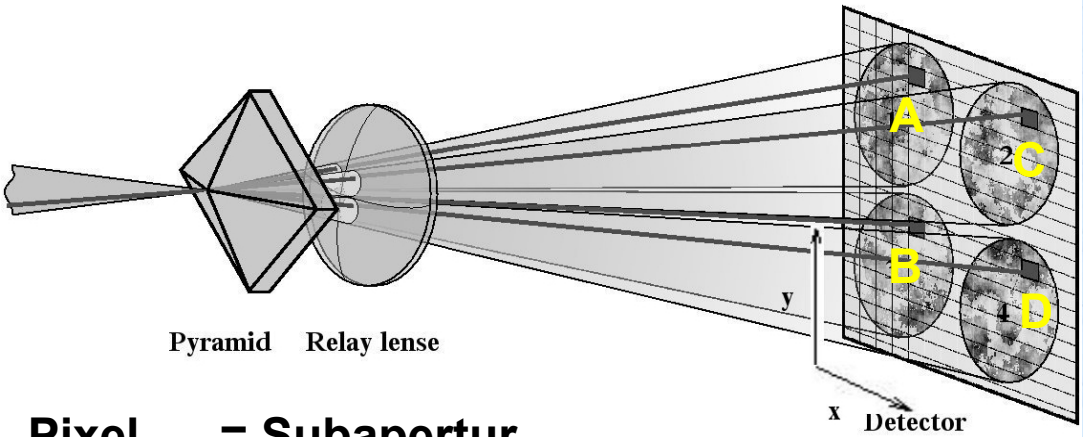


Bild: S. Egner

- $x = \frac{(A+B)-(C+D)}{\sum pix}$
- $y = \frac{(A+C)-(B+D)}{\sum pix}$

Pupillenebene

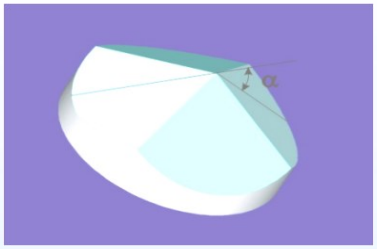


- ❖ Helligkeitsanpassung durch Pixelbinning
- ➢ schwächer Leitsterne bei geringere Korrektur
- ❖ intrinsisch höhere Messgenauigkeit!

Pixel = Subapertur
= typischer Koherenzlänge

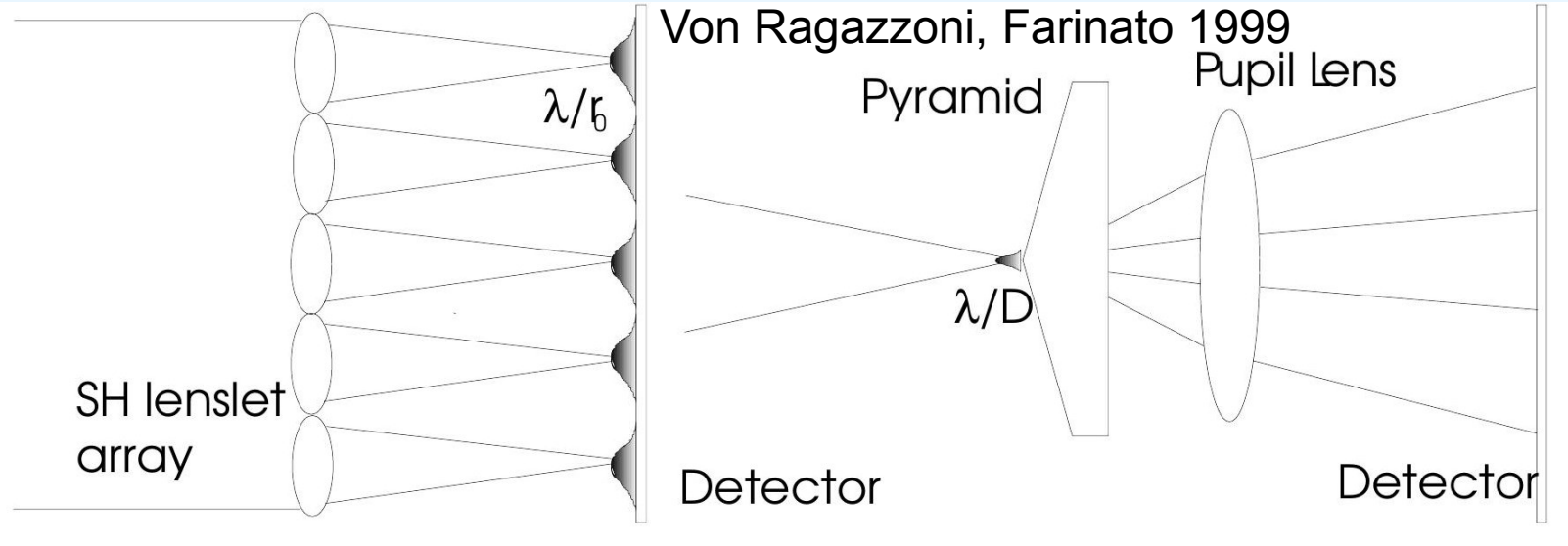
Mit äquivalenten Pixel Gradientenberechnung

Ragazzoni, Farinato 1999
Ghedina 2003



Vorteil der Pyramide

❖ **Closed Loop Bootstrap**

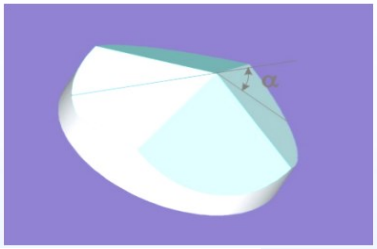


	Shack-Hartmann	Pyramide
Messgenauigkeit	r_0	D
Signal zu Rauschen	1/N	1/4

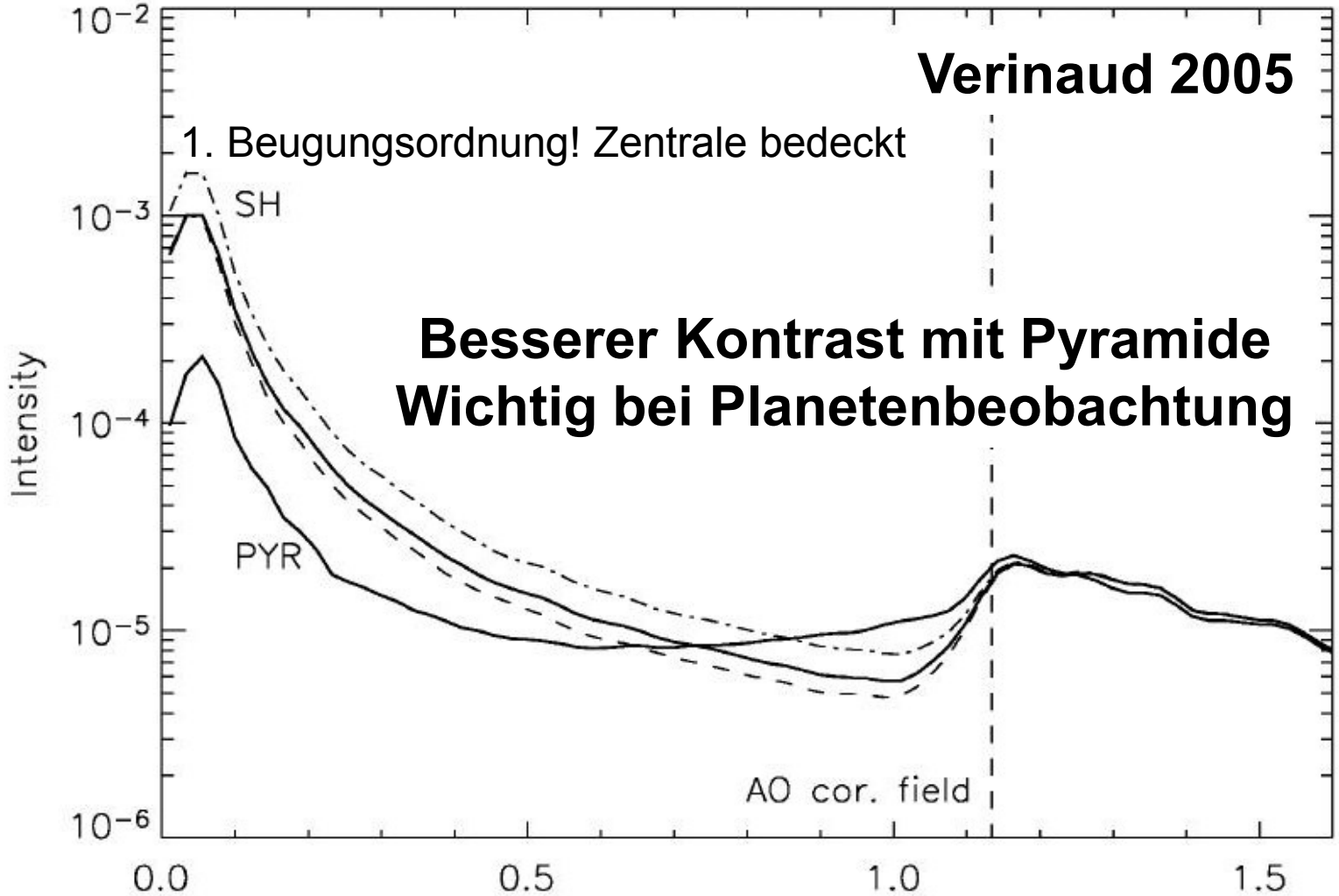
Subaperturgrösse r_0, Teleskopdurchmesser D
Anzahl Subaperturen N

Vorteil der Pyramide

Ragazzoni, Farinato 1999
Ghedina 2003



❖

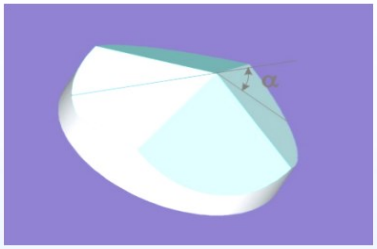


Besserer Kontrast mit Pyramide
Wichtig bei Planetenbeobachtung

Mess

Sign

Ragazzoni 2000



Optische co-addition

Layer 2

Layer 1

Reimaged Layers

Pyramid WFS based system easily complies with such an approach. Complexity scales mostly with the number of sensed layers rather than with the number of references.

Pyramids

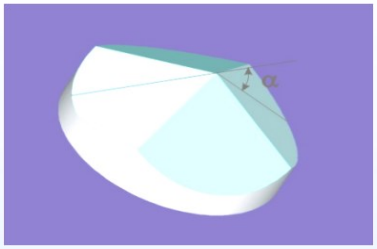
Reimaging Optics

Atmospheric 3D geometry is mapped in the WFS volume.

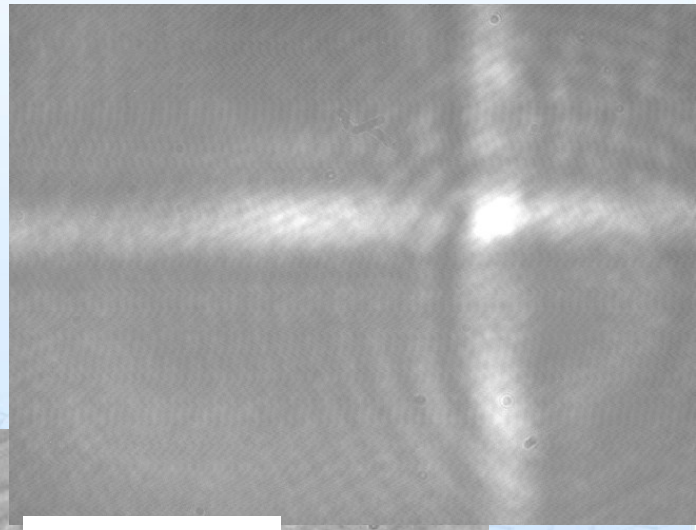
Detector 2

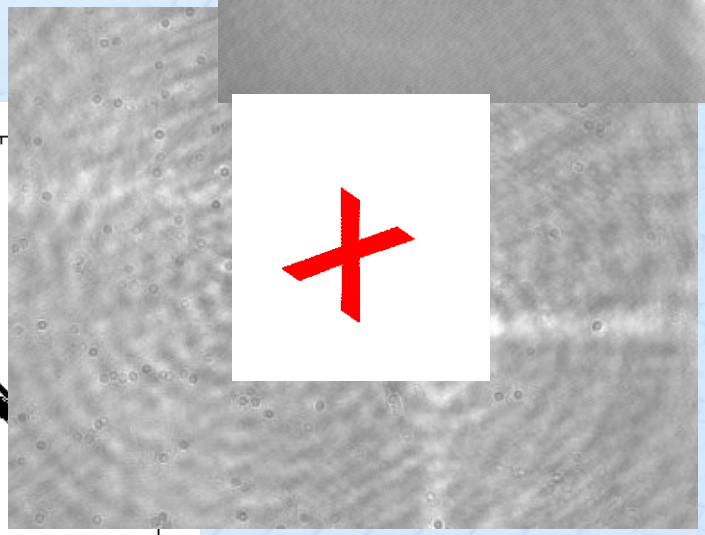
Detector 1

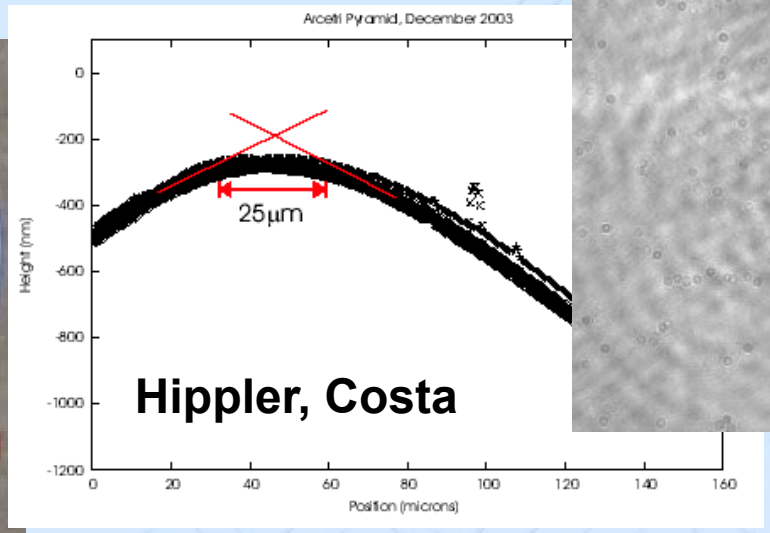
Fertigungsanforderungen



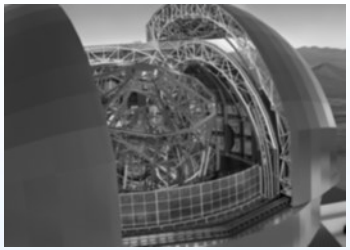
- Pyramide visuell/infrarot
  - Flachheit: ~30nm/100nm
  - Winkel: ~ 1°
  - Kanten: < 10µm/40µm

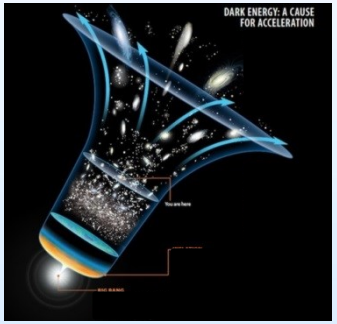




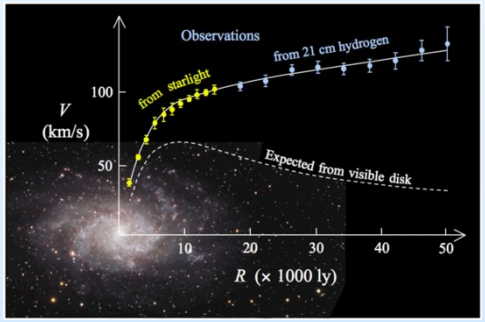


Zusammenfassung

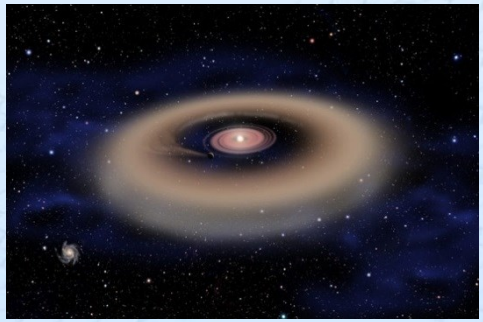




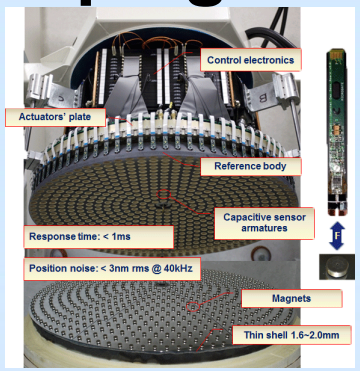
- Dunkle Energie
- Dunkle Materie
- Planeten und Sterne

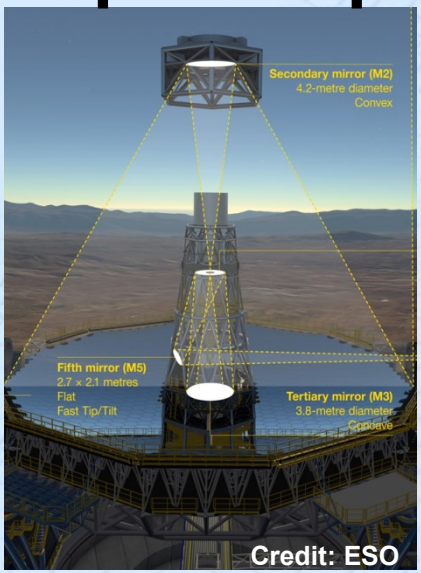


Grossteleskope
Adaptive Optik

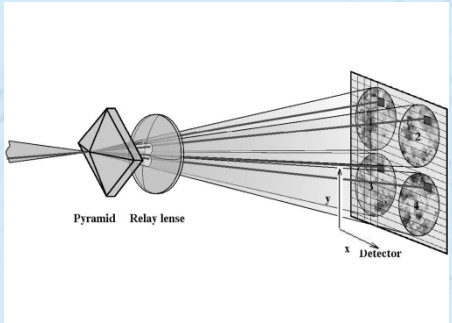


Deformierbare Spiegel





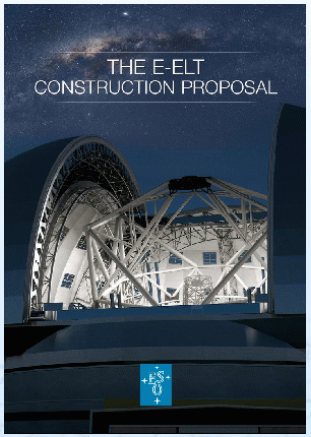
Wellenfrontsensoren



More information

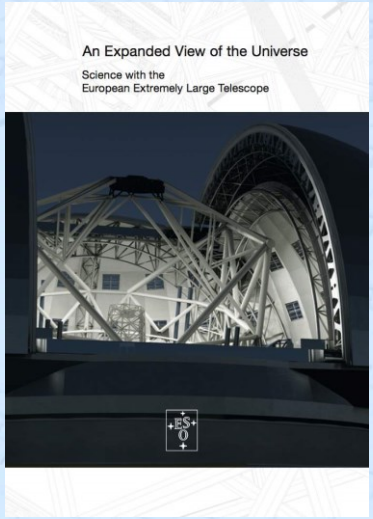
The science users web pages:
www.eso.org/sci/facilities/eelt

The E-ELT Construction Proposal:
www.eso.org/sci/facilities/eelt/docs/eelt_constrproposal.pdf



The E-ELT Science Case:
www.eso.org/sci/facilities/eelt/science/doc/eelt_sciencecase.pdf

The E-ELT Design Reference Mission:
www.eso.org/sci/facilities/eelt/science/doc/drm_report.pdf

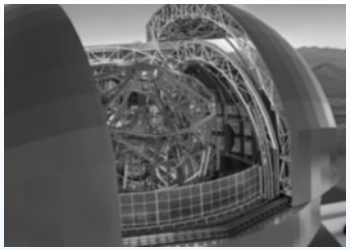


The public web pages:
www.eso.org/public/telesinstr/eelt.html

Brochures, Posters, etc:
www.eso.org/public/products/brochures/

Gallery:
www.eso.org/public/images/archive/category/eelt/

Referenzen



Referenzierte Publikationen können auf folgenden Seiten gefunden werden:

- https://ui.adsabs.harvard.edu/
- https://arxiv.org/archive/astro-ph
- https://www.researchgate.net/profile/Roberto_Ragazzoni2