solar telescopes

Solar Physics course lecture 2

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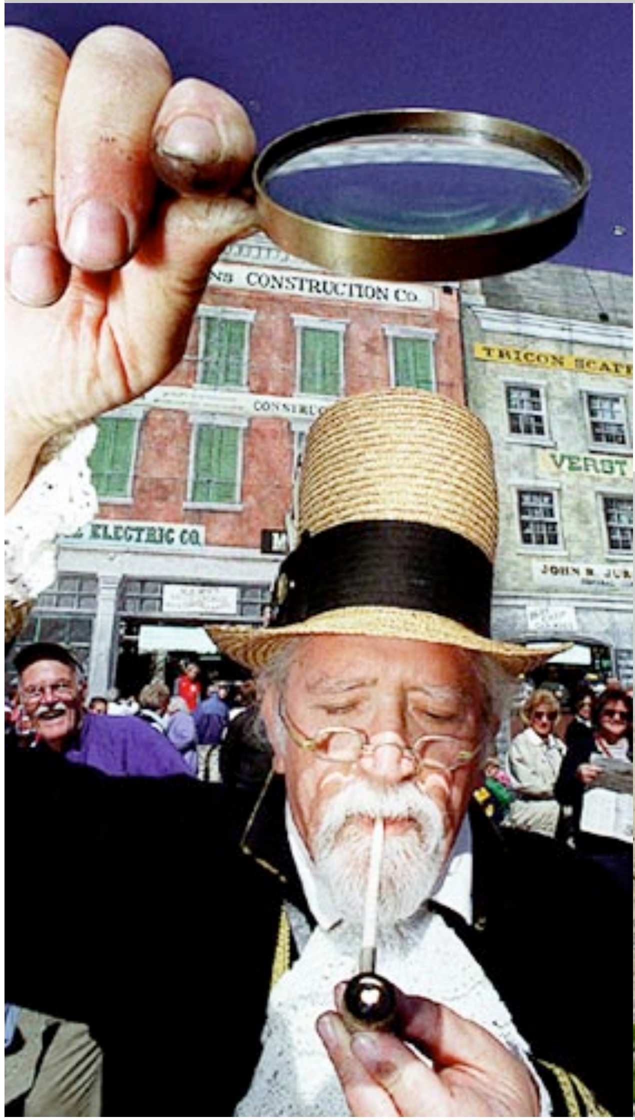
solar telescopes

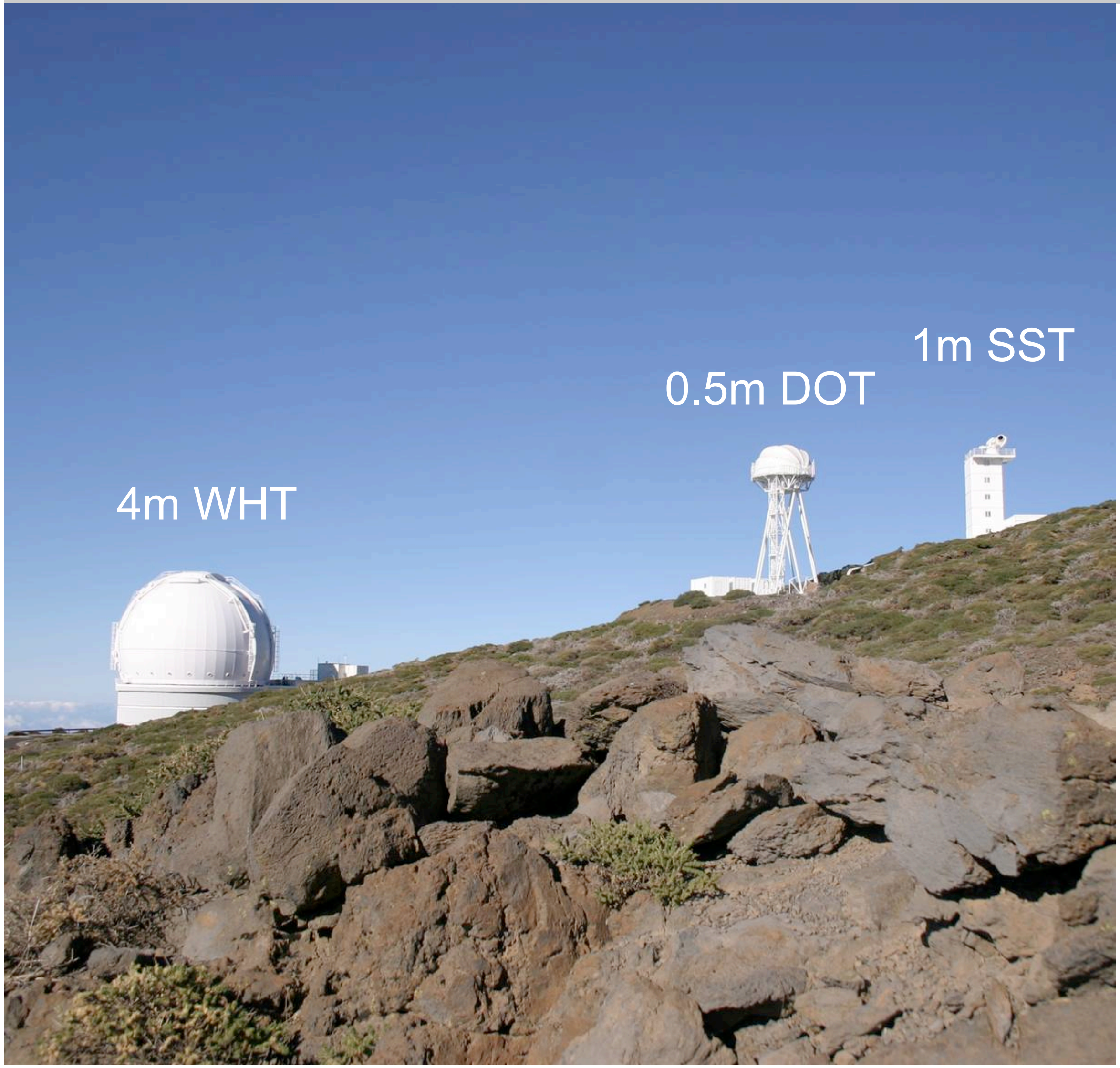
solar vs. nighttime telescopes



solar constant: 1.37 kW/m^2

- destroys optics
- creates seeing

solar vs. nighttime telescopes



nighttime telescopes:

4-10 m

solar telescopes:

0.5-1.5 m

solar telescopes

fighting local seeing (3.1.3)

vacuum telescope

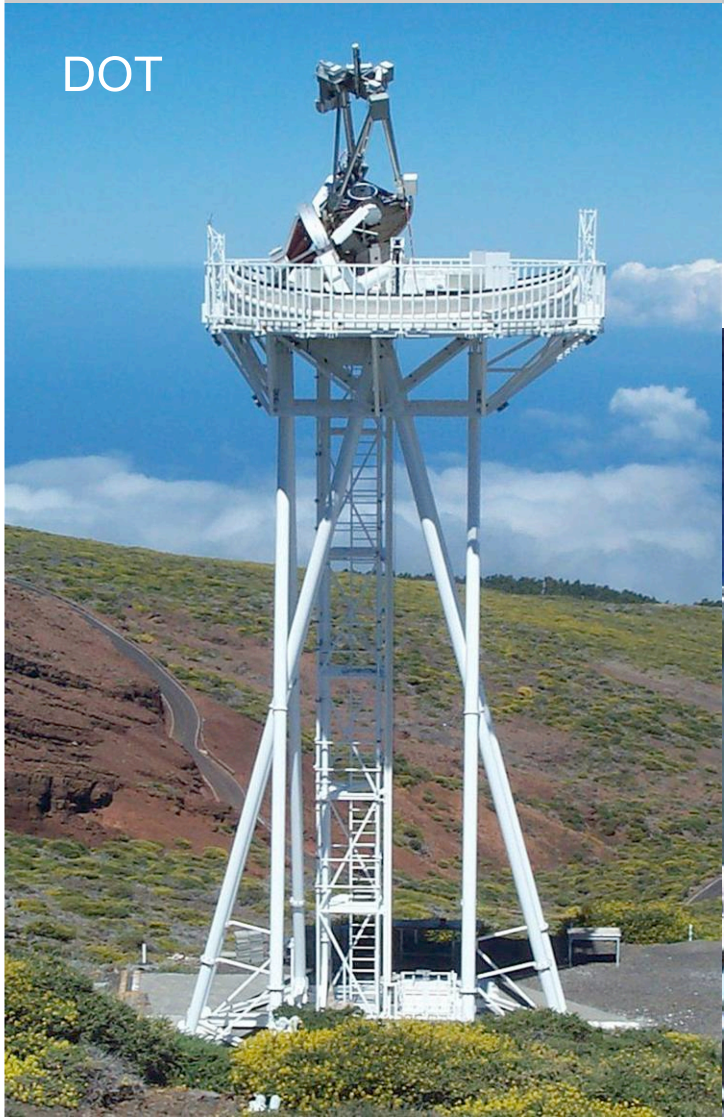
solar telescopes

fighting local seeing

Helium-filled telescope

solar telescopes

fighting local seeing



open telescope

solar telescopes

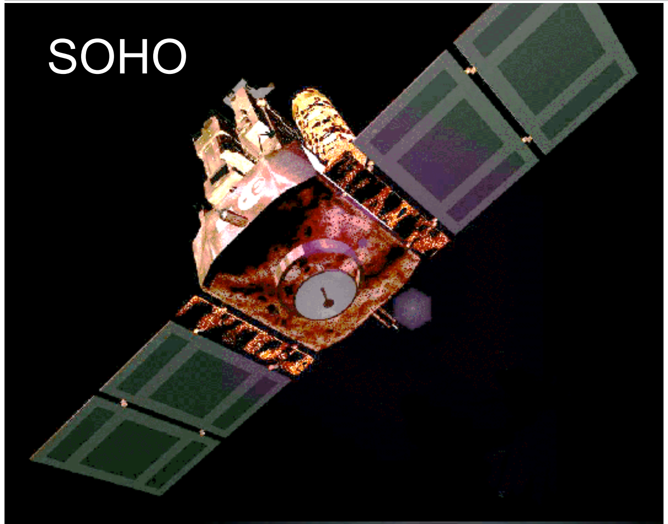
fighting local seeing

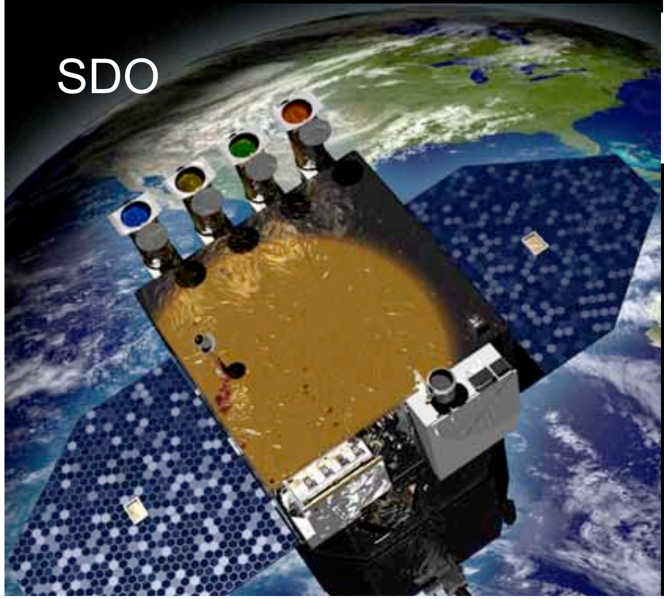
active cooling

- mirror cooling
- heat stop reflecting unwanted light out (+cooling)
- light path cooling

solar telescopes

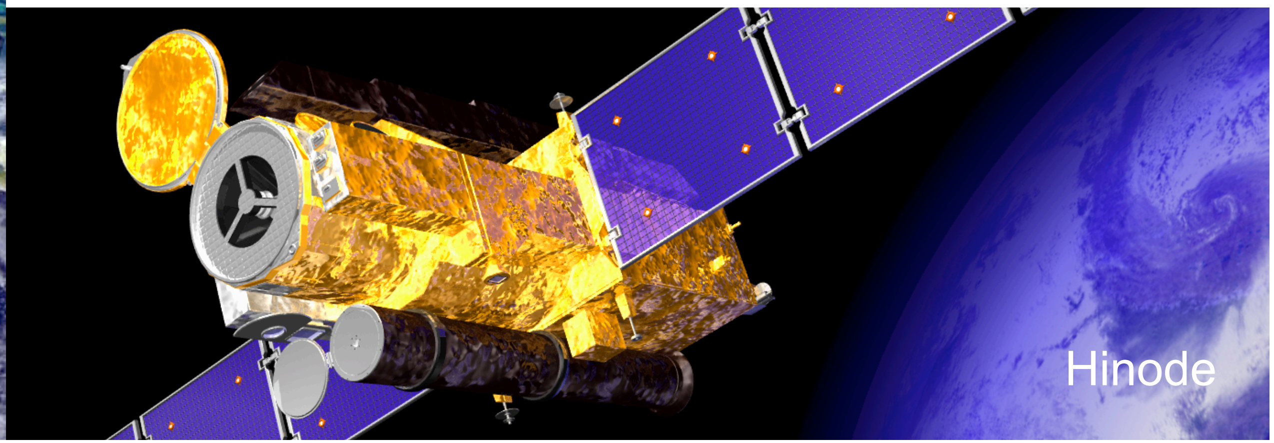
fighting local seeing (3.1.1)





space /rocket telescope

- also UV, X-ray
- no atmospheric scattering
  $\rightarrow$ coronagraph
- *in situ* solar wind measurements



focal length (3.2.3, 3.2.4)

high resolution:

$$d = 2f \cdot r_{sol} / AU \qquad (3.21)$$

large f → large telescope building to accommodate
>50 m of beam length

or large f_{eff} → re-imaging + field stop
steerable telescope

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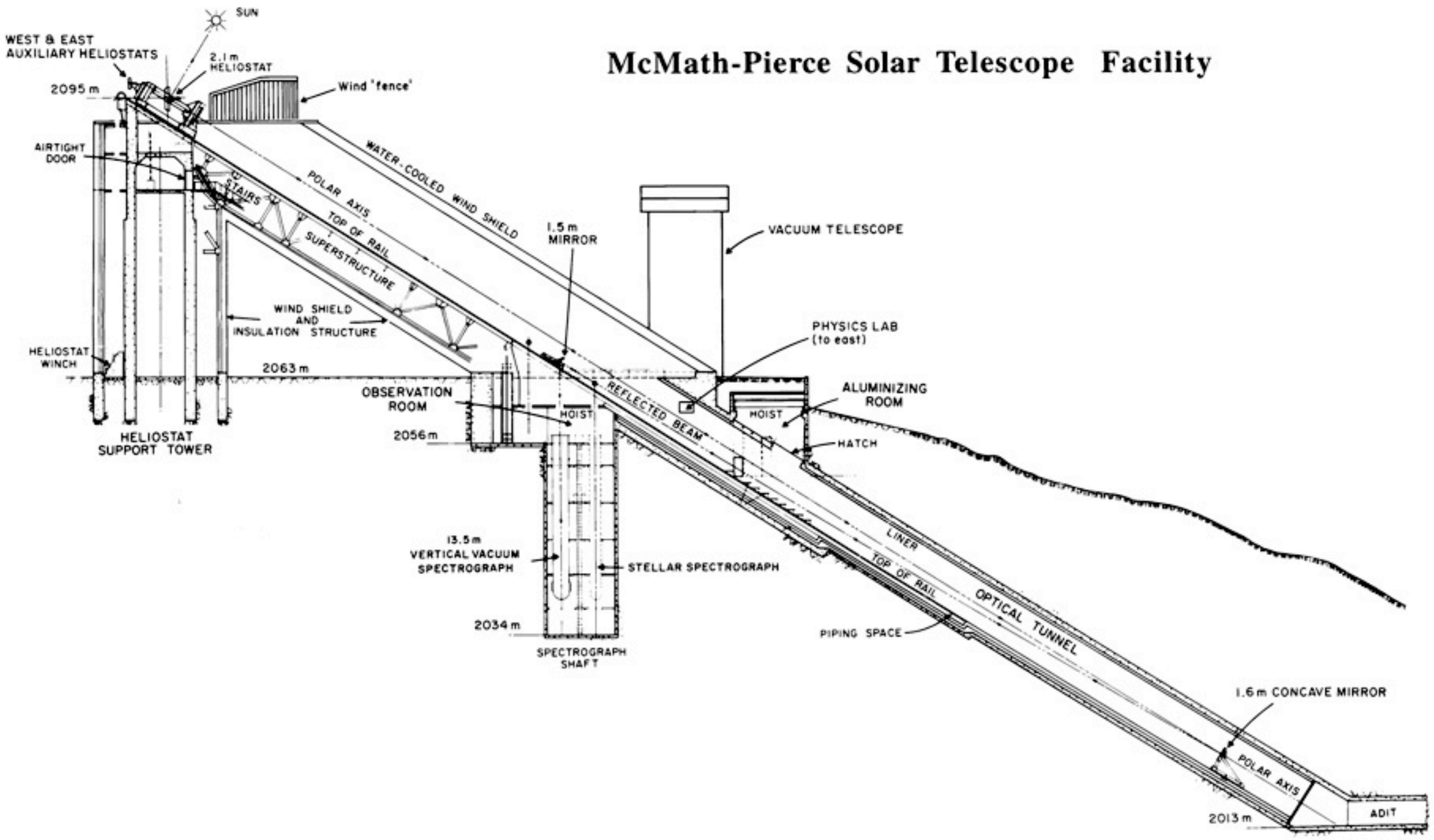
telescope types (3.2.2-4)

- heliostat



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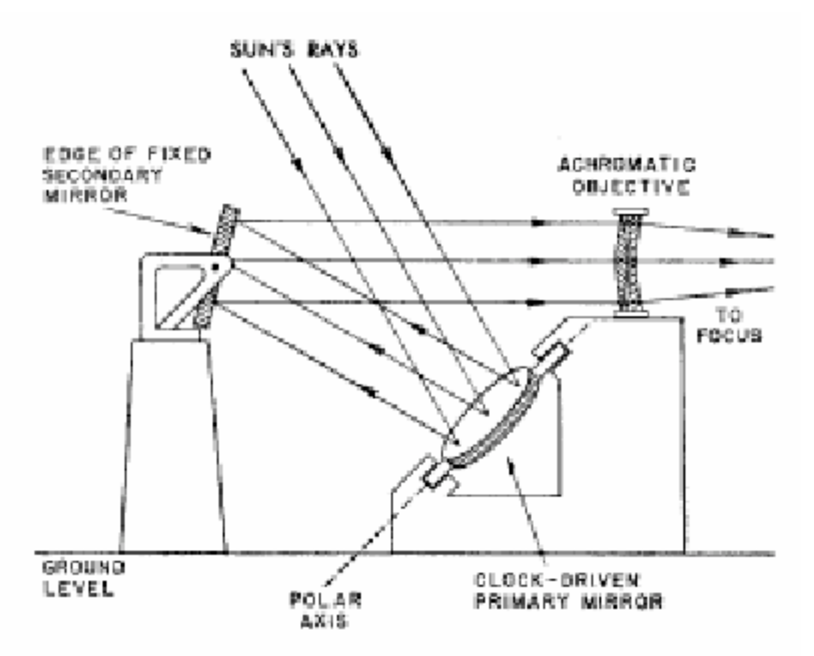
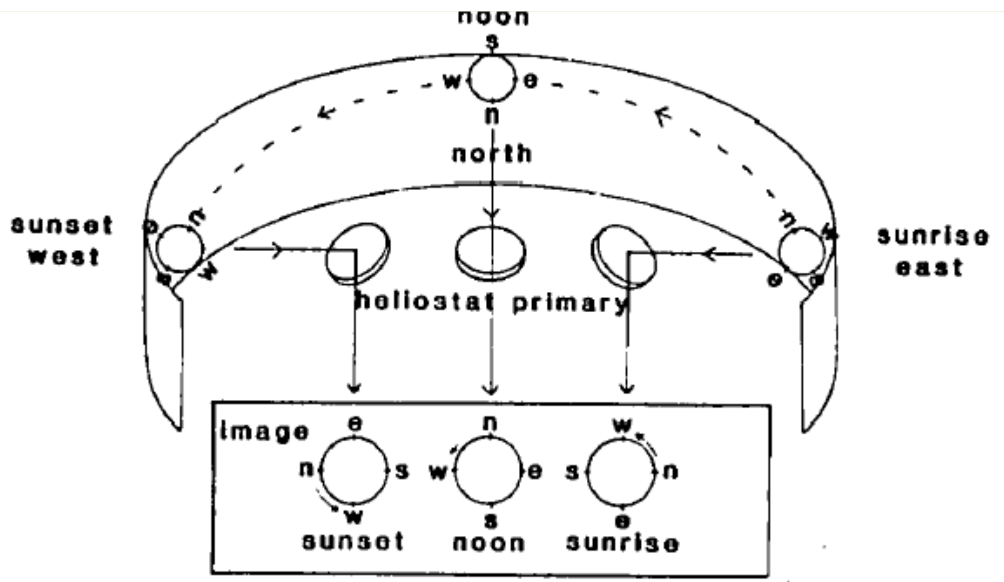
telescope types

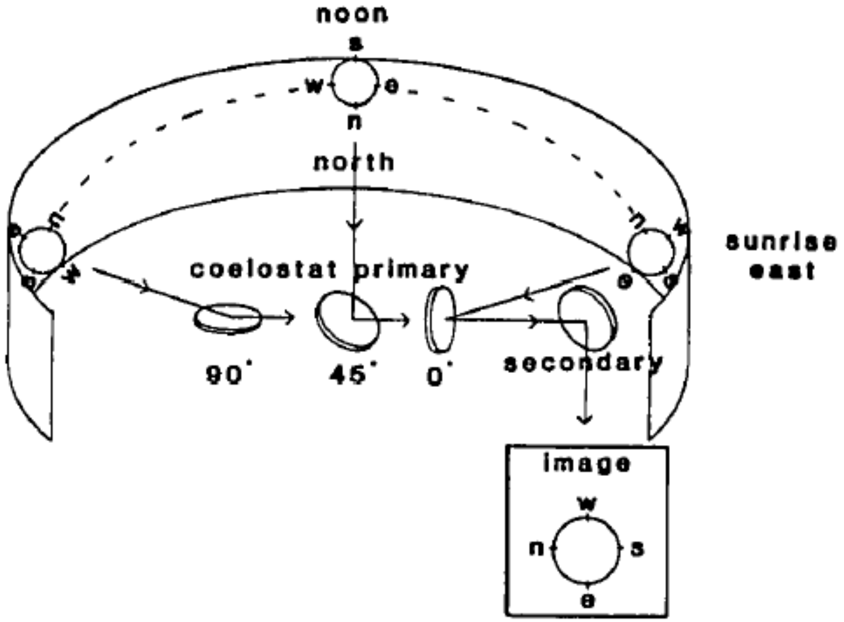
- coelostat



telescope types

image rotation





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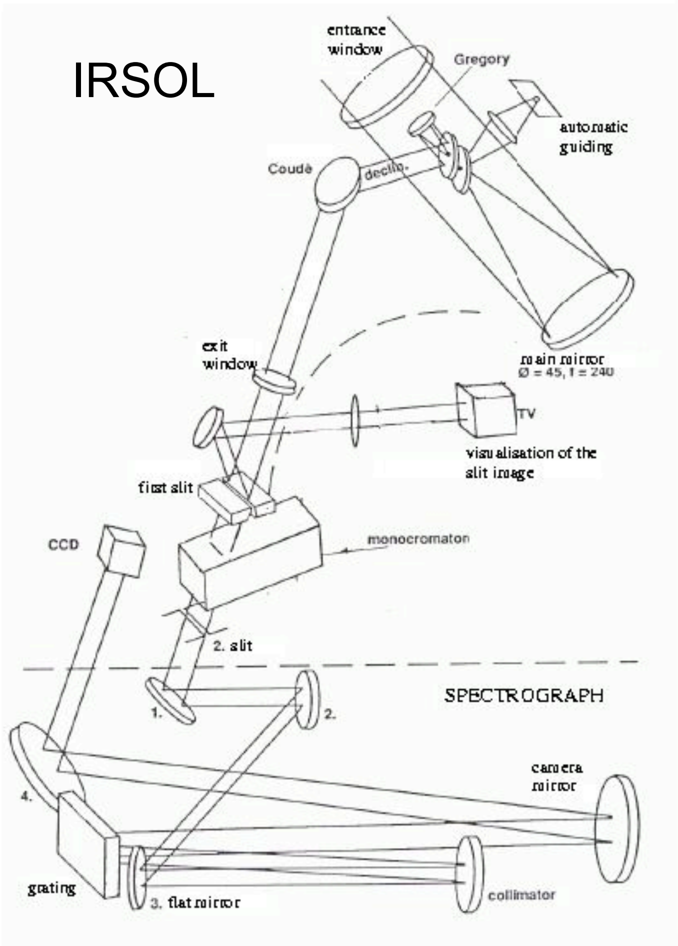
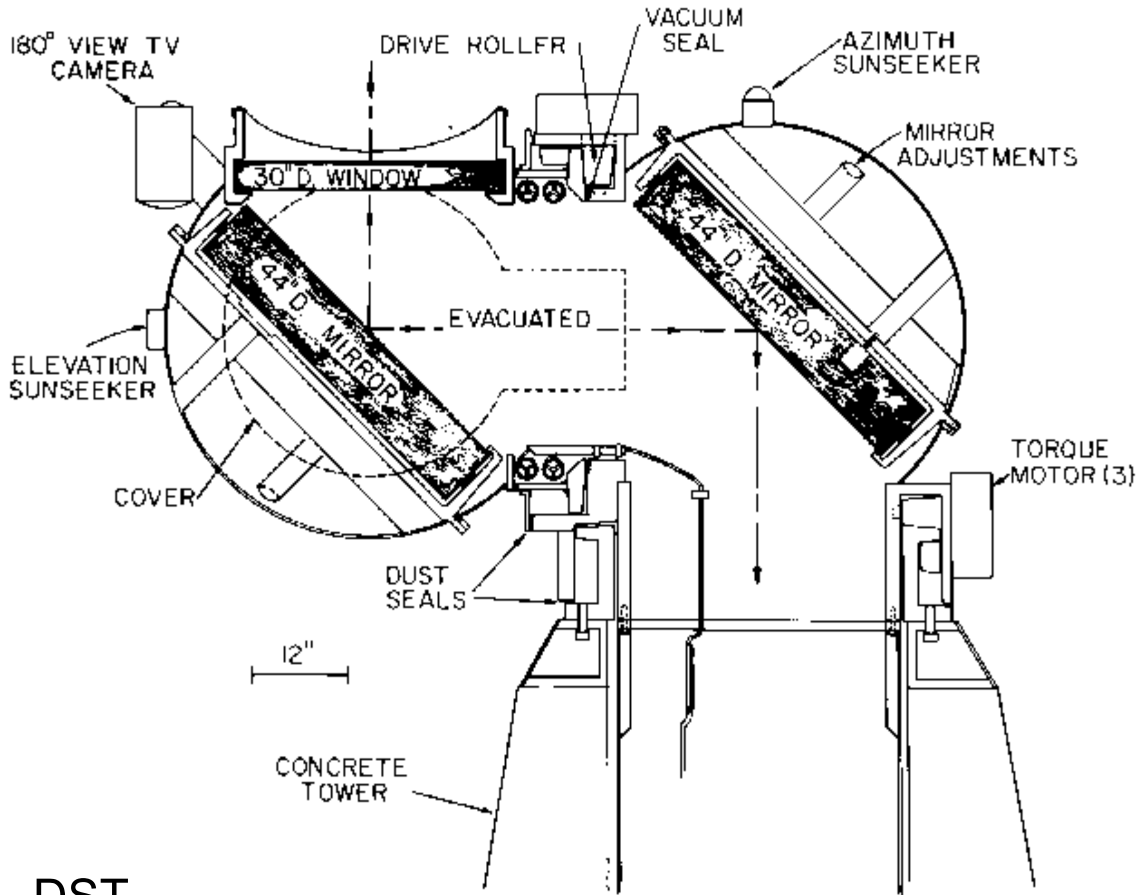
telescope types

- equatorial (RA-dec)



telescope types

- altazimuth



DST

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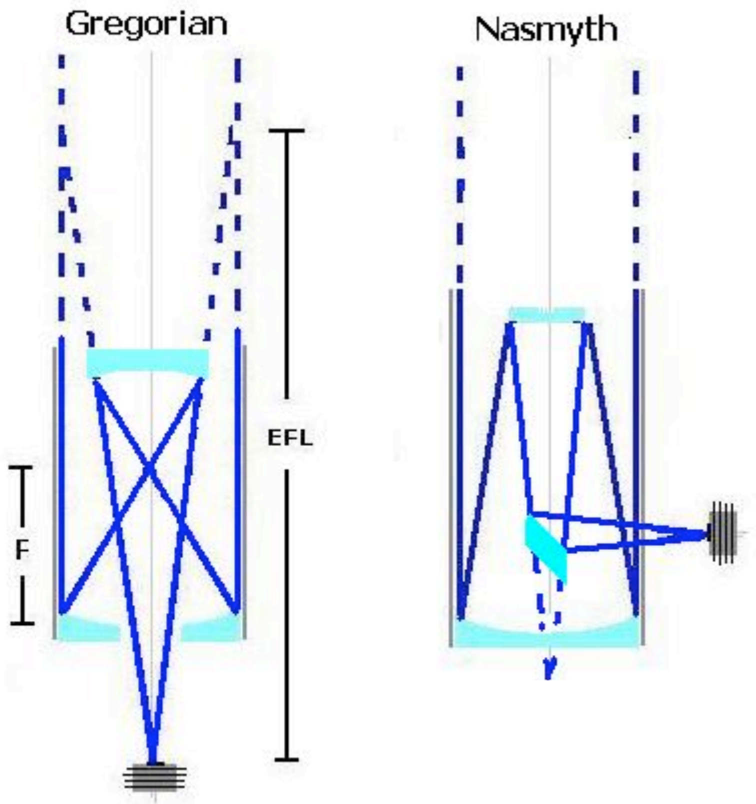
focus positions

- prime focus (heat stop)
- (Cassegrain)
- Gregorian
- Nasmyth
- Coudé



→image rotation

& (constant) instrumental polarization?

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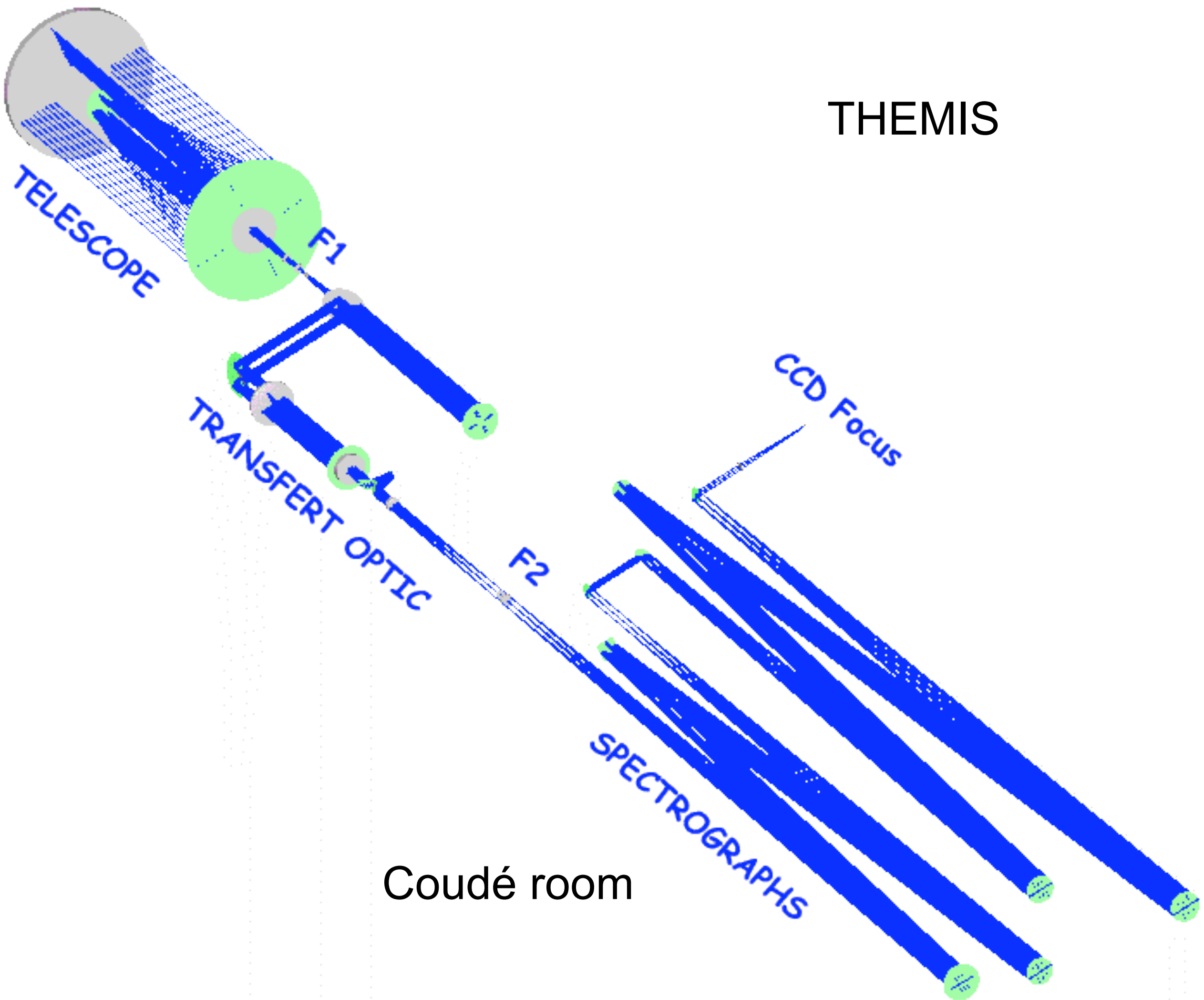
focus positions



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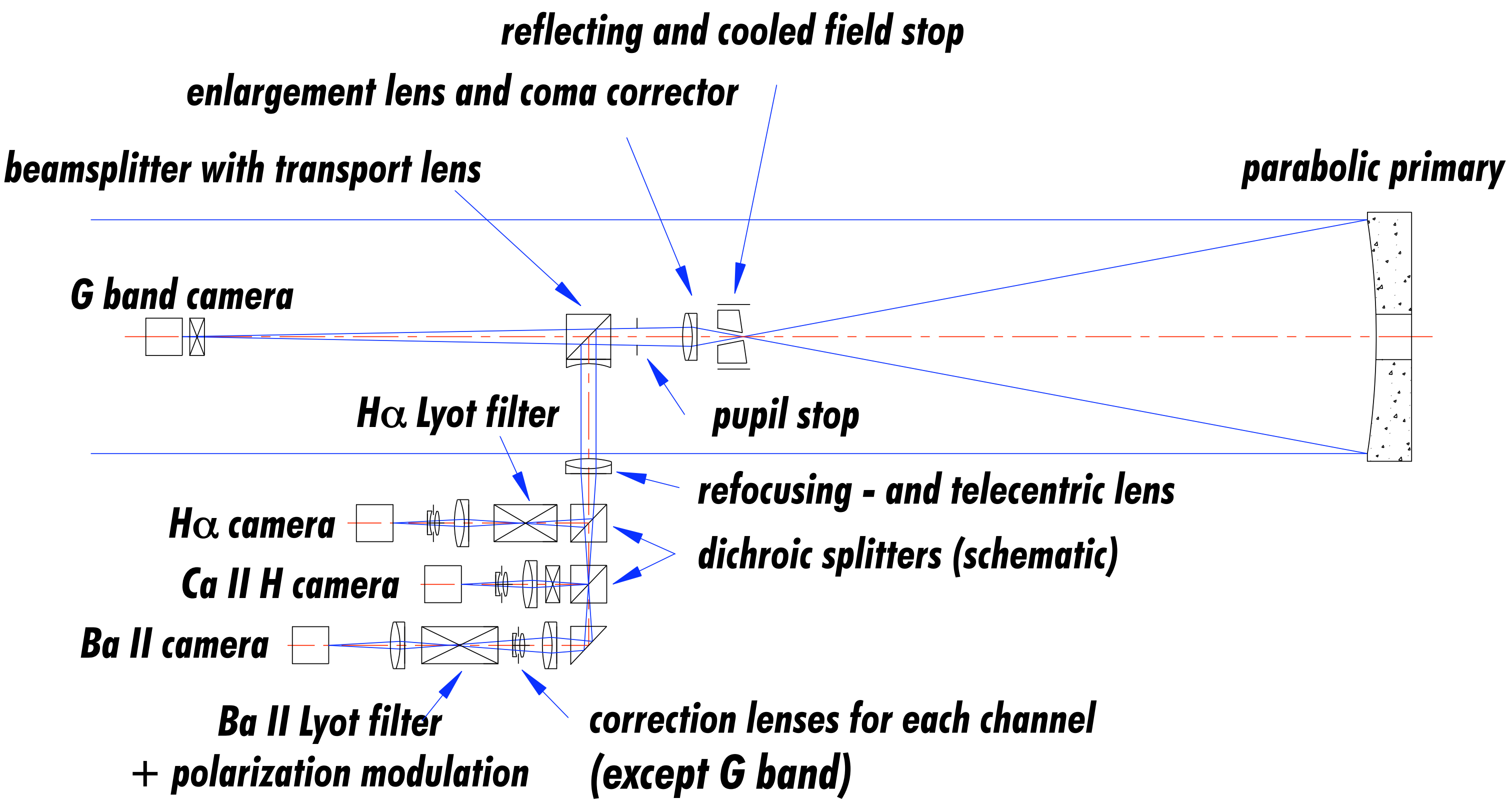
focus positions



DOT

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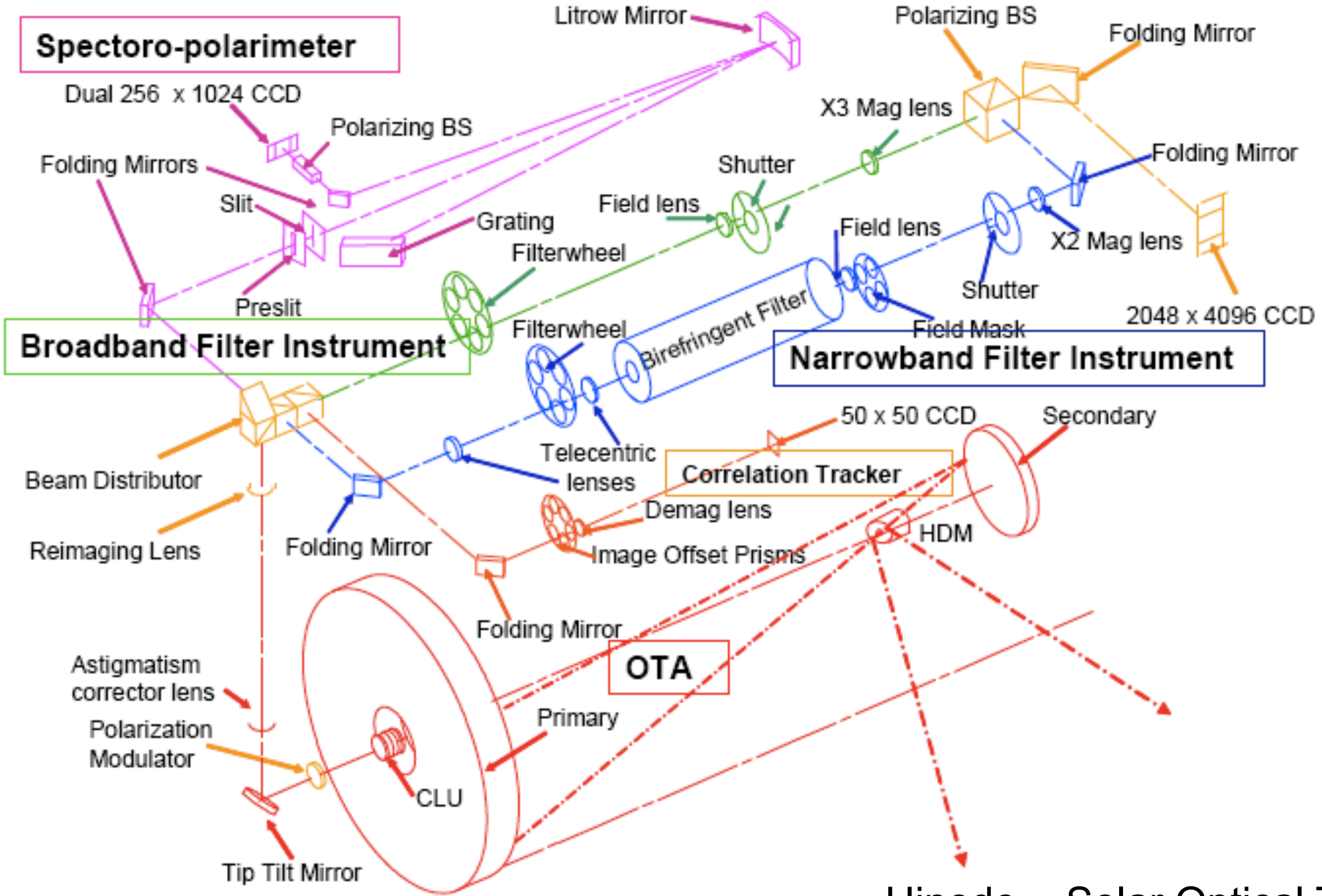
focus positions



Hinode - Solar Optical Telescope

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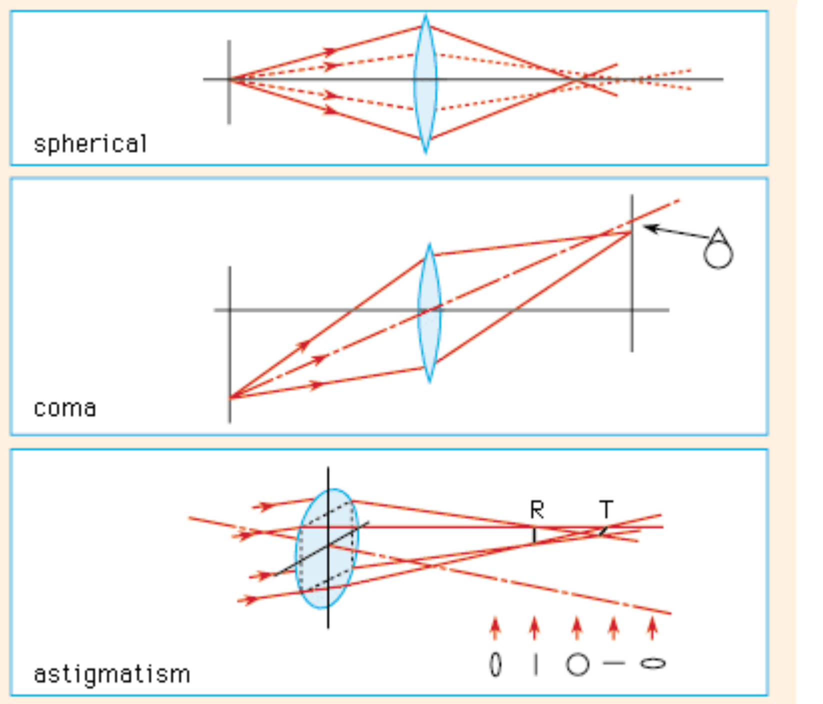
aberrations (3.2.3)

- spherical
  →use parabolae, high F/#
- coma
  →meniscus lenses, small field
- astigmatism
  →cylindrical optics, bend
- chromatic
  →use mirrors, achromats



coronagraph (3.6.3)

corona is 10^4-10^6x fainter than the disk
→ scattered/diffracted light is a huge issue

- coronographic mask
- Lyot stop in pupil plane to kill diffracted light
- off-axis design
- clean optics

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options

- fixed vs. steerable
- open vs. closed tube
- reflective vs. refractive
- on-axis vs. off-axis
- field size (aberrations)
- focus position
- image rotation
- instrumental polarization
- mechanical difficulty

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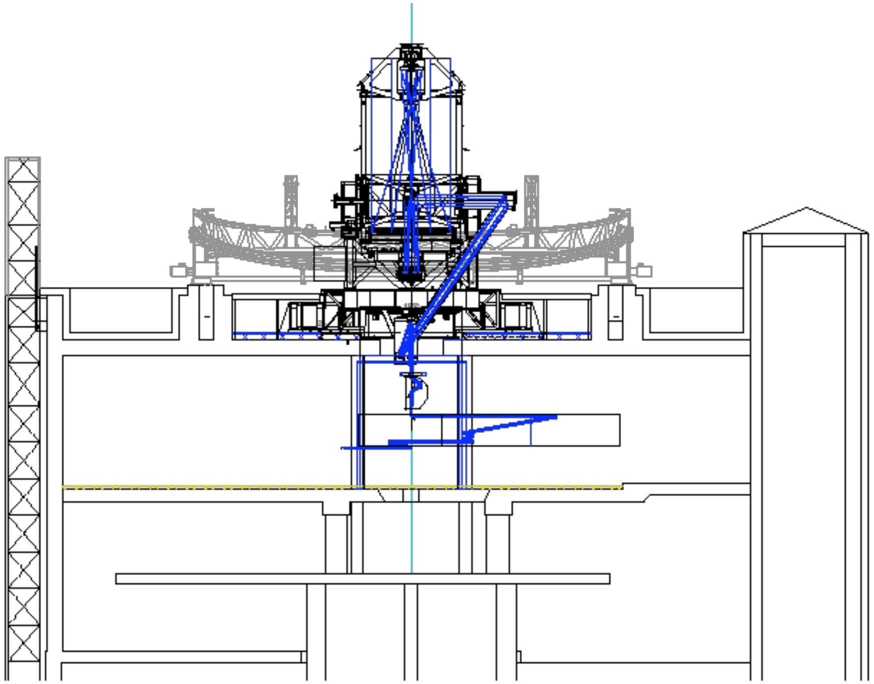
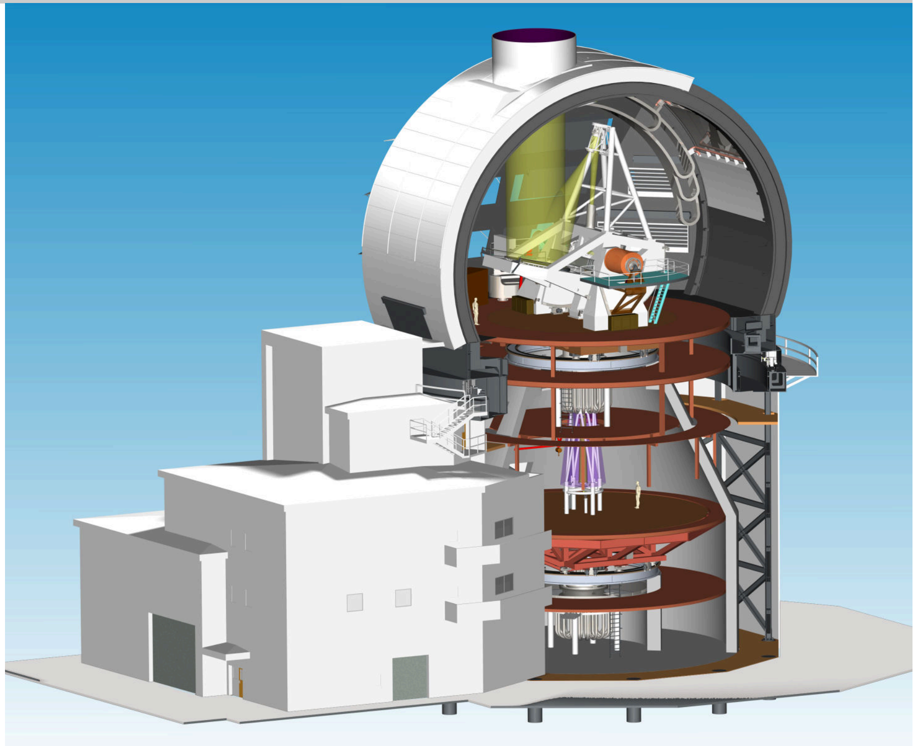
new designs





Gregor (1.5 m)

ATST (4 m)

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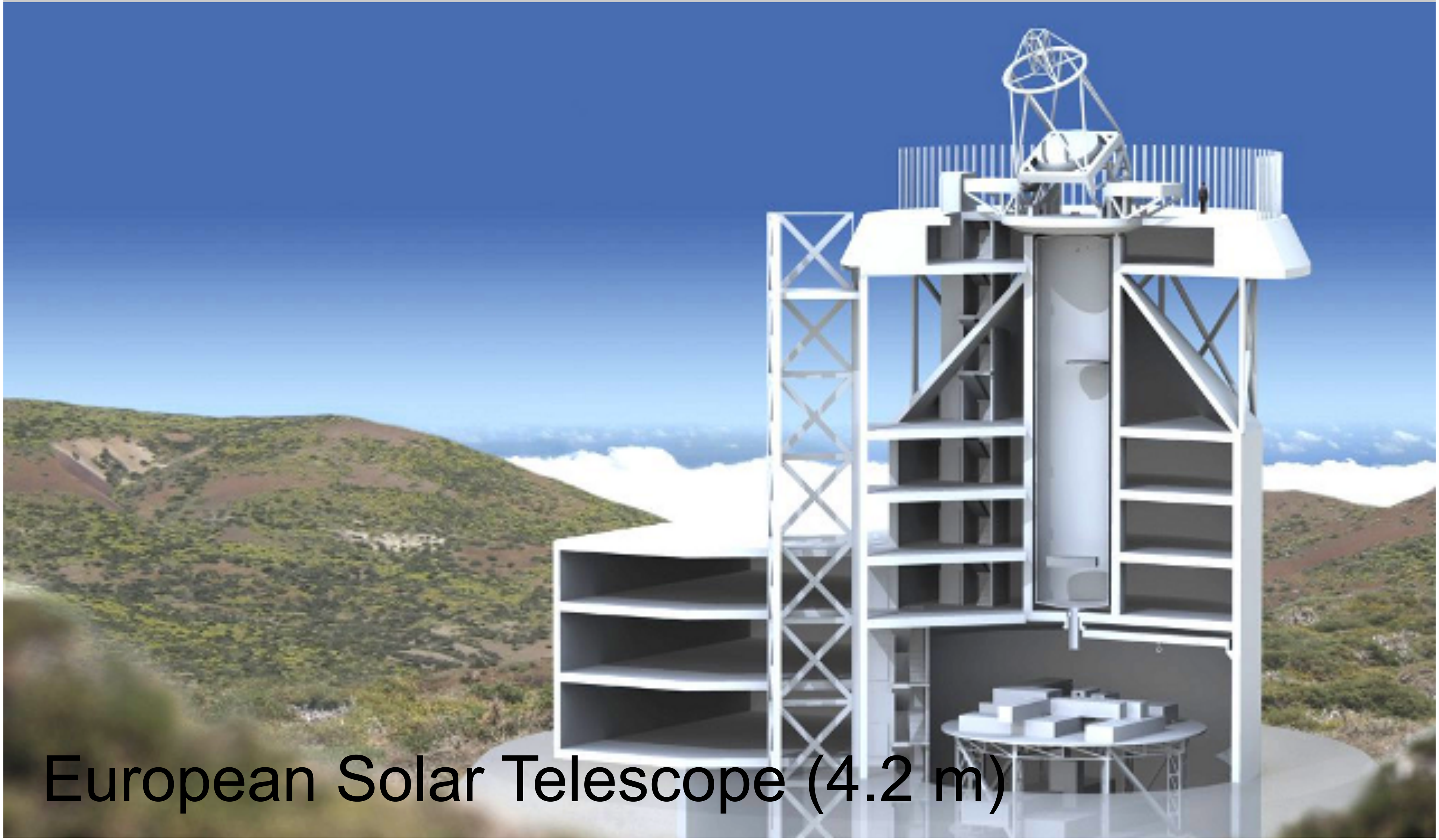
new designs



European Solar Telescope (4.2 m)

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new designs

S^{5}T (0.05 m)

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site selection (3.1.3)

- no jet streams → tropics
- high volcano in ocean → stable trade winds and atmospheric stratification (low inversion layer)
- in a lake → less ground layer seeing

still need high tower to decrease influence of ground layer seeing

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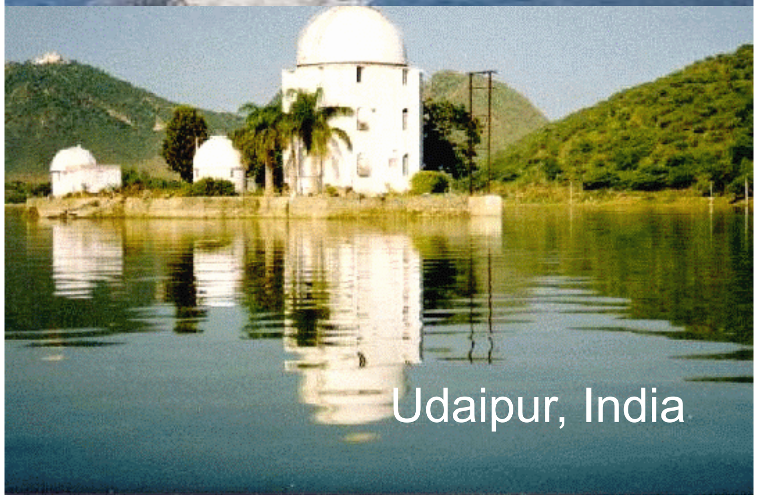
site selection



seeing (3.1.2)

- blurring
- image motion
- image distortion

due to atmospheric pressure/temperature fluctuations

$$n - 1 \propto \frac{P / P_0}{T / T_0} \qquad (3.1)$$

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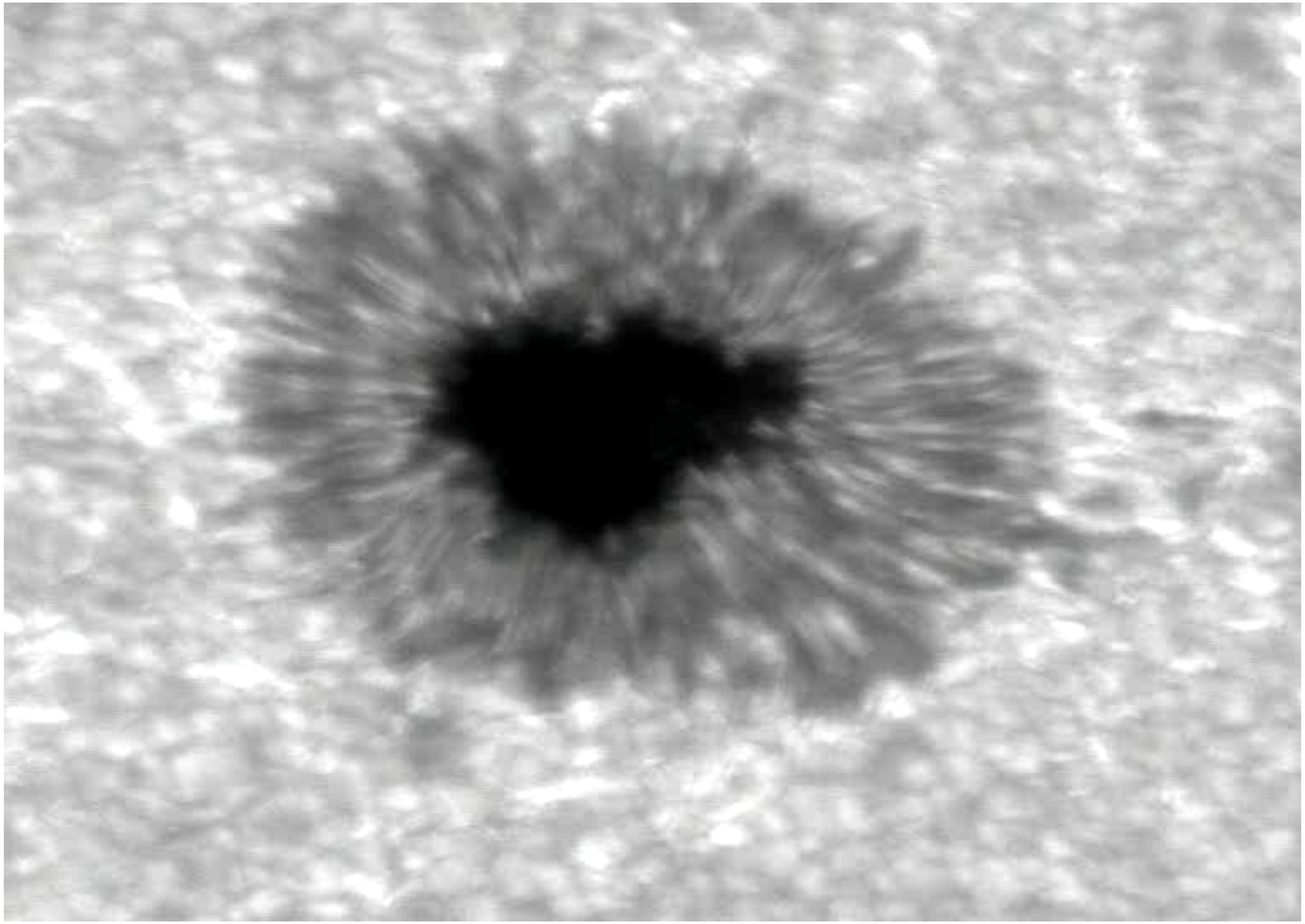
seeing (3.1.2)



PSFs and MTFs

$$I(x,y) = I_0(x',y') \otimes PSF \qquad (3.2)$$

PSF: point spread function

$\otimes$: convolution

= multiplication in Fourier space

MTF: modulation transfer function = |F(PSF)|

$$MTF_{total} = MTF_{telescope} \cdot MTF_{seeing} \qquad (3.4)$$

PSFs and MTFs

diffraction limited:

$PSF_{telescope}$= Airy function (3.6)

fully sampled seeing:

PSF_{seeing}=Gaussian(s_0) (3.9)

s_0: ~angular resolution

good seeing: s_0<1”

Fried parameter

Kolmogorov turbulence spectrum of *n*:

→r_0 (Fried parameter):

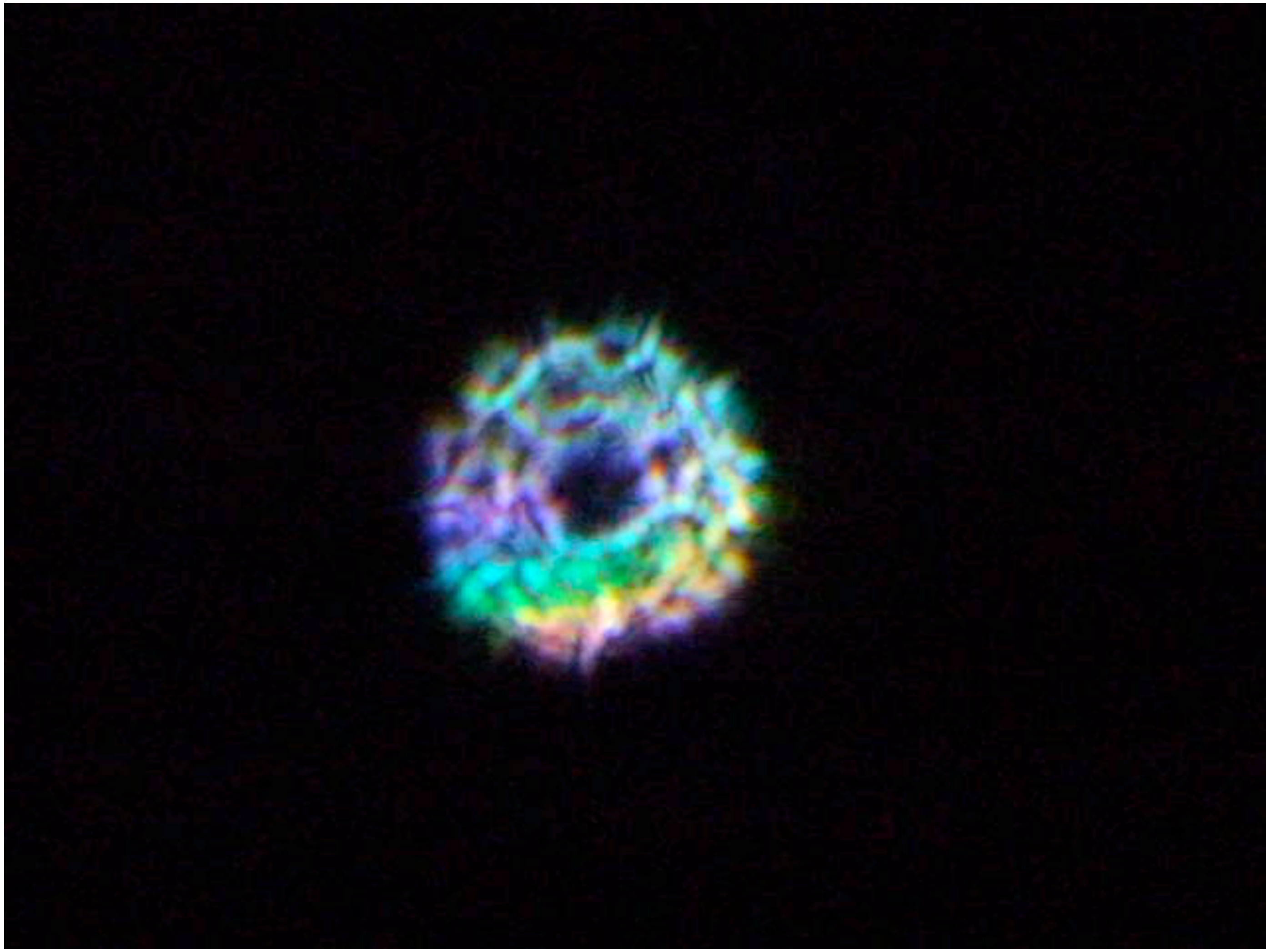
characteristic coherence scale of turbulent air pockets in the light path

PSF_{total} is seeing-dominated for $D>r_0$

$$\tau_0 \approx 0.31 \cdot \frac{r_0}{V_{wind}}$$

→~10 ms

Fried parameter



courtesy: ik ter Horst

seeing monitors

- scintillation

(ζ=zenith angle)

→ground layer seeing

$$\sigma_I \propto \left(\frac{\cos^{1/5}\zeta < h^{-1/5} >}{r_0} \right)^{5/6}$$

- differential image motion of limb

Longintudinal and Transverse between two apertures

$$\Sigma_L^2, \Sigma_T^2 \propto \lambda^2 r_0^{-5/3}$$

Beckers (2001)

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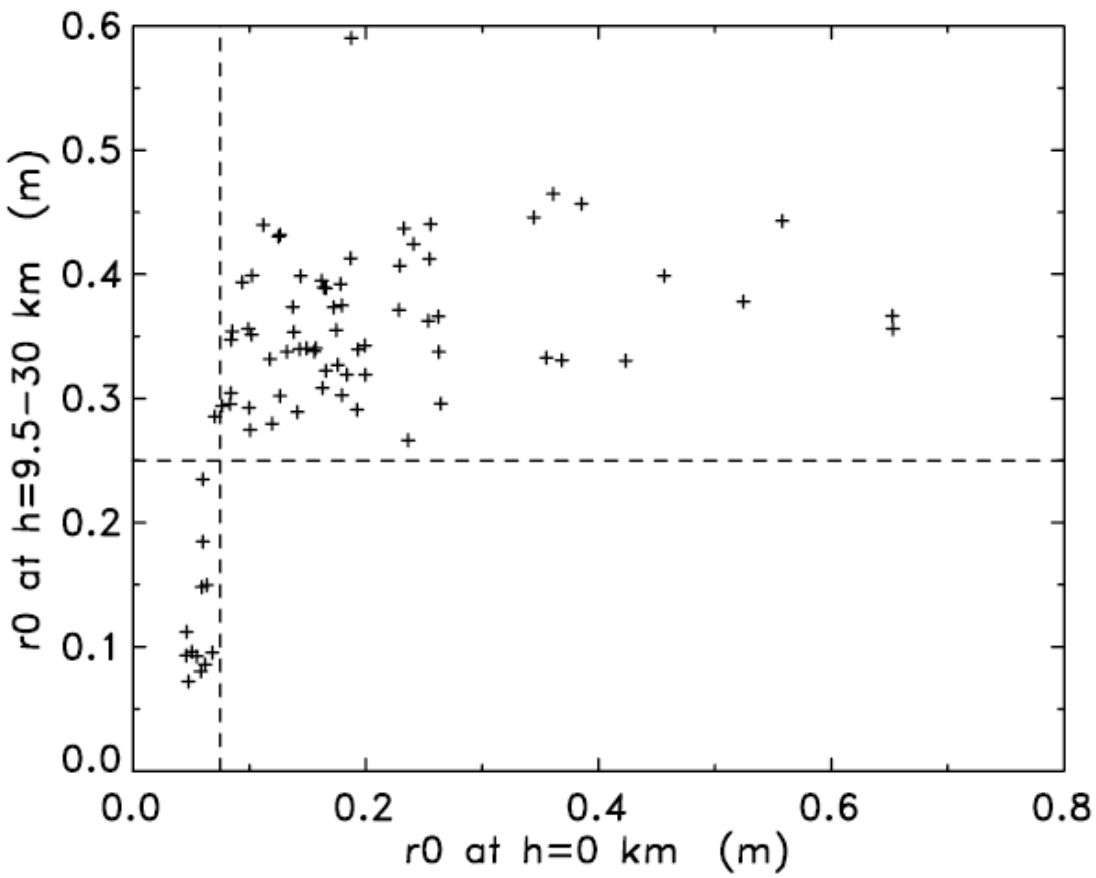
seeing monitors



Scharmer & van Werkhoven (2010)

compensating seeing

- adaptive optics
- post processing

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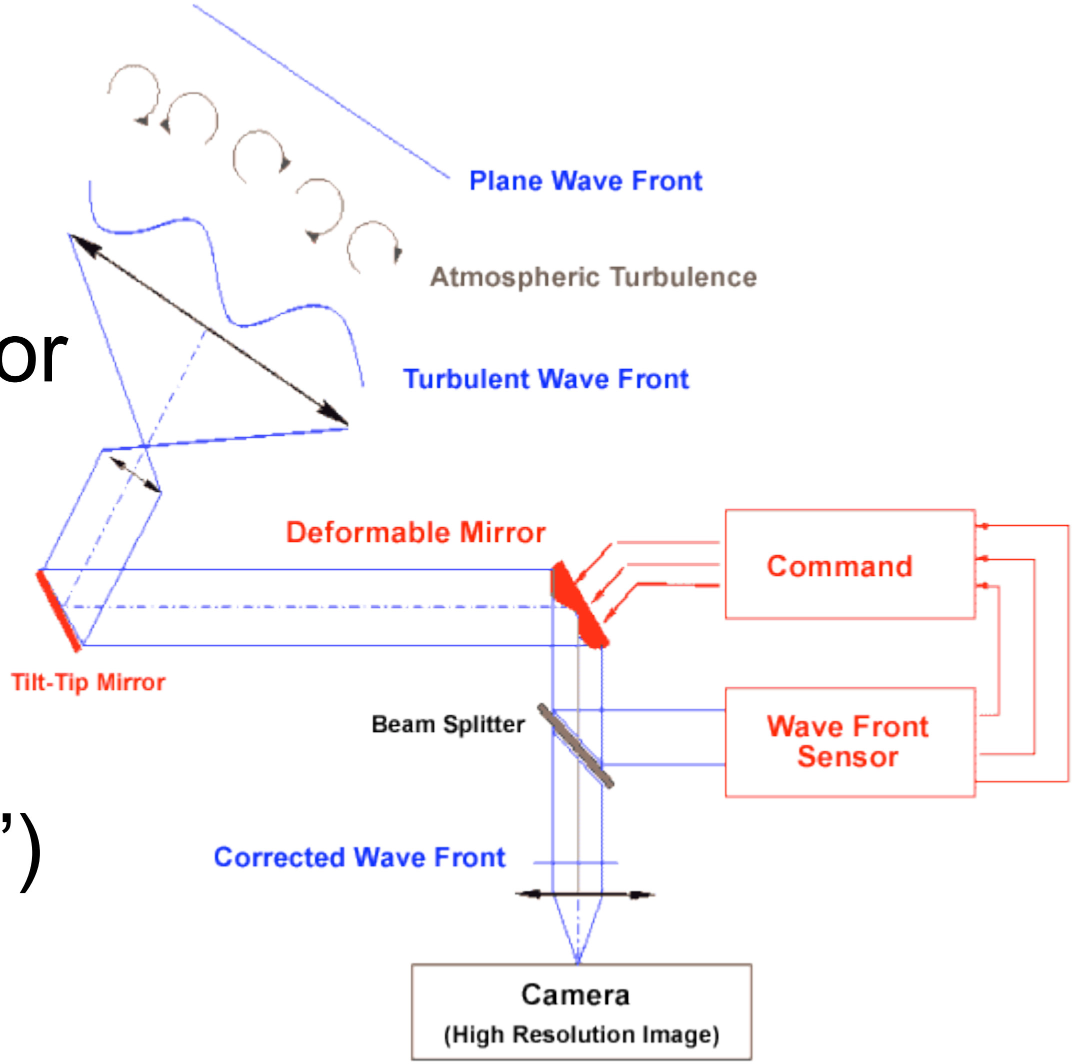
adaptive optics (3.1.4)

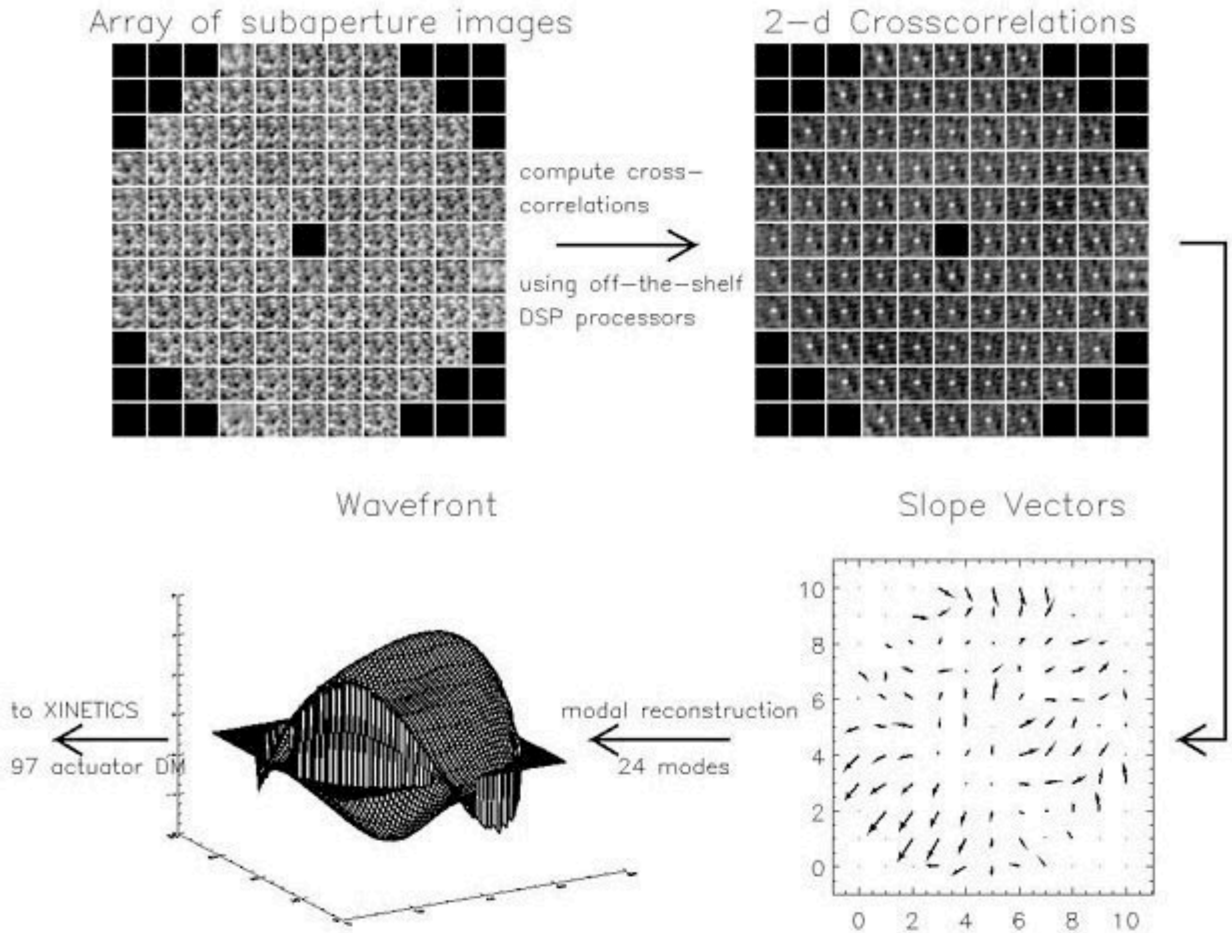
- focusing
- tip-tilt
- deformable mirror

(only works for "isoplanatic patch")



adaptive optics

- Shack-Hartmann wavefront sensor



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post processing (3.1.5)

- frame selection (“lucky imaging”)
- rubbersheeting
- speckle reconstruction
- phase diversity
- (MO)MFBD

speckle reconstruction

$$|O|^2 = \frac{\langle |I_t|^2 \rangle}{\langle |S_t|^2 \rangle}$$

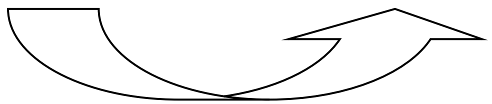
$\langle|S_n|^2\rangle$ needs to be determined

=speckle transfer function in Fourier space

=f(r_0 (t), $PSF_{telescope}$) (3.16)

also need Fourier phase from cross-spectrum

$$\langle I(f) \cdot I^*(f+\Delta f) \rangle = \langle O(f) \cdot O^*(f+\Delta f) \rangle \bullet \langle S(f) \cdot S^*(f+\Delta f) \rangle$$



real!

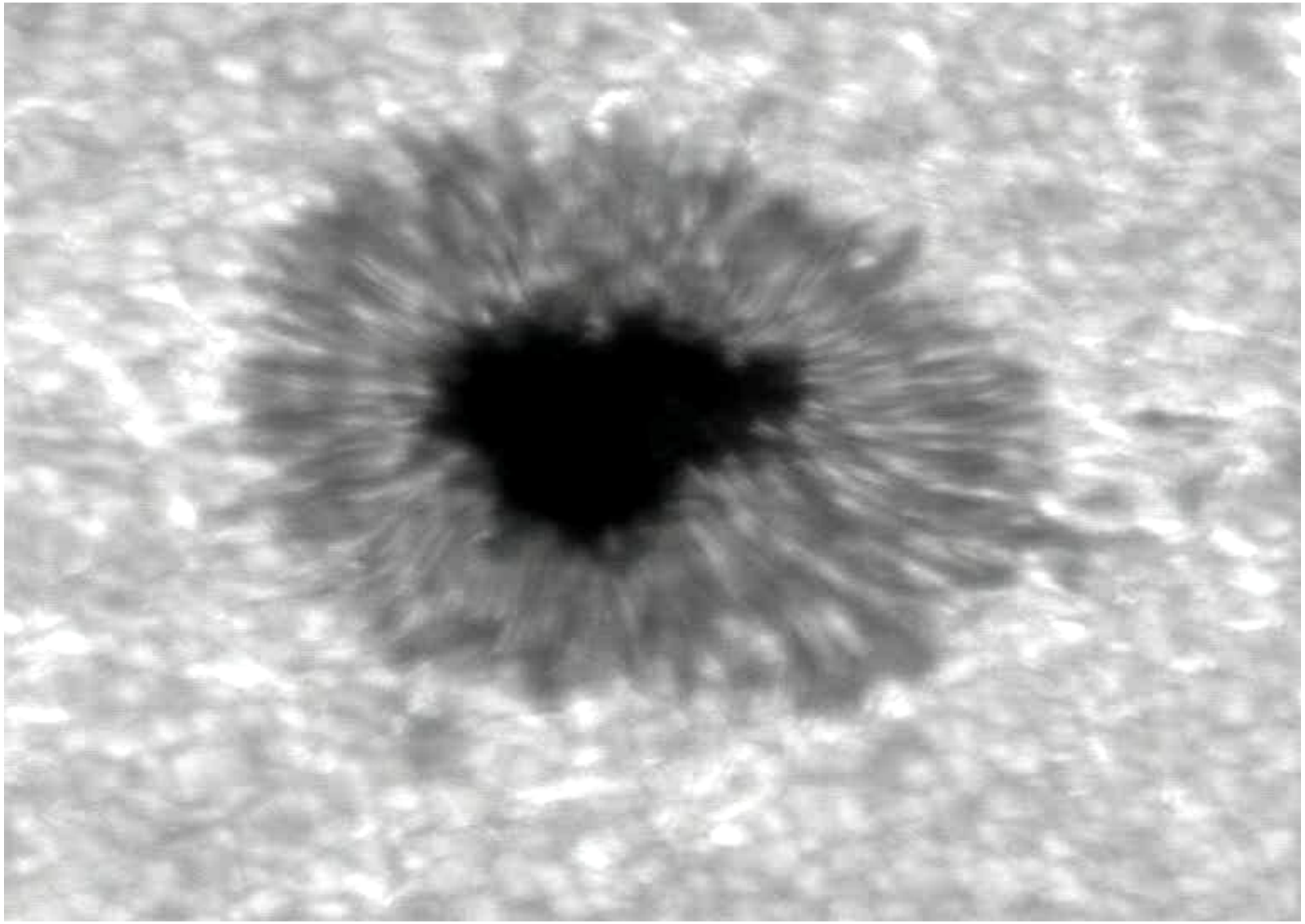
(3.17)

speckle reconstruction

100 samplings of max. 20 ms within solar change time (20 s @ 0.2”)

still need reasonable seeing

speckle reconstruction



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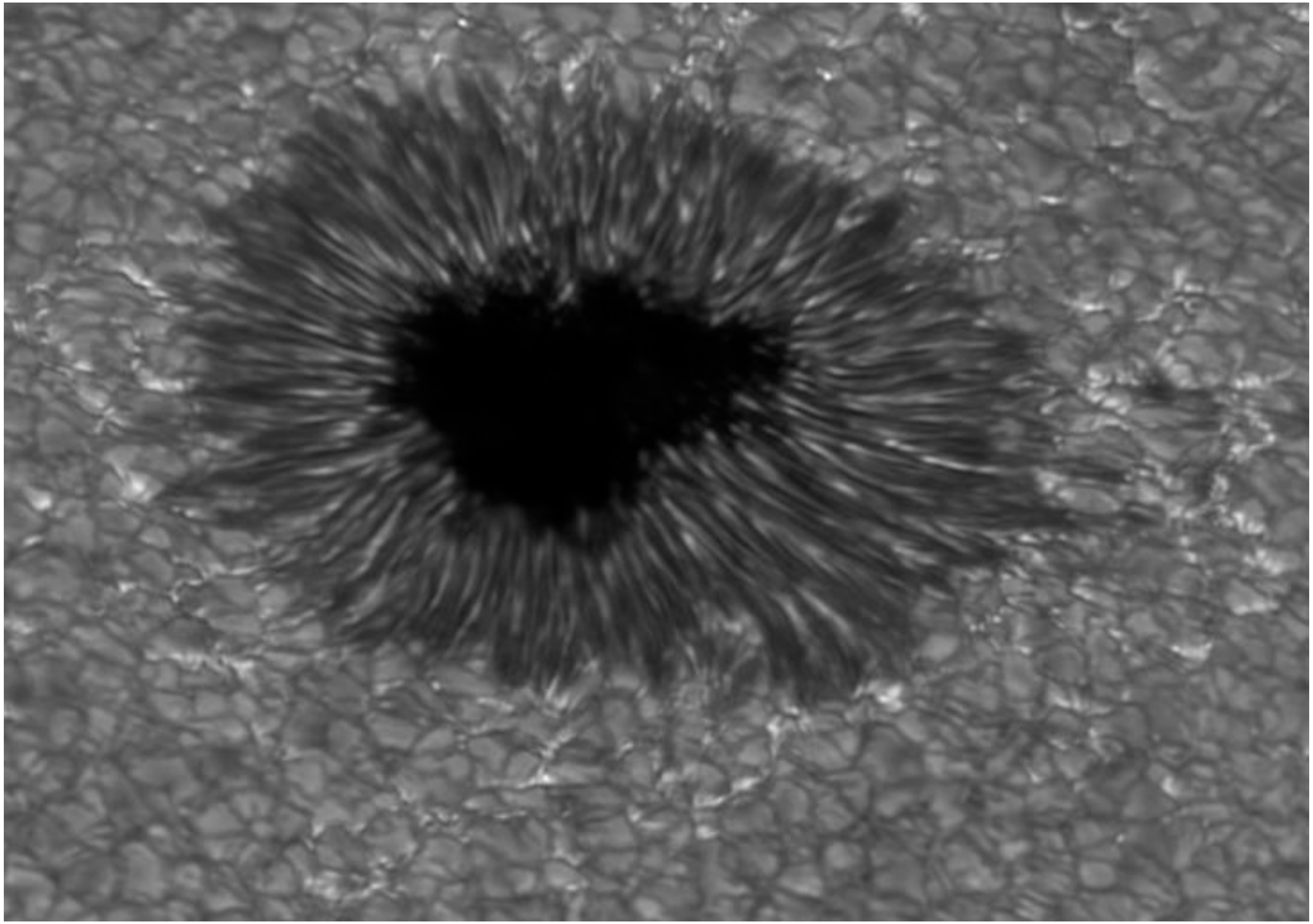
speckle reconstruction

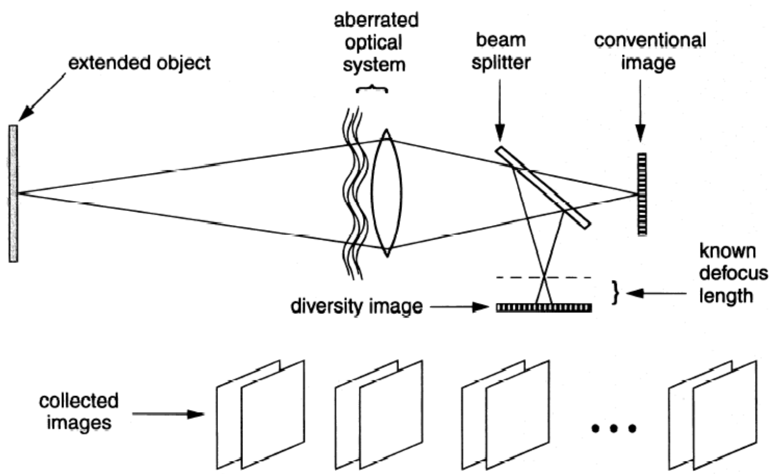


phase diversity

=wavefront measurement (3.19-20)

two images of same
- object at known
- different focal positions
- allow for two local
- samplings of the PSF

→object + aberrations



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exercises

- 3.1
- 3.4 (without the mathematical proof, use Fig. 3.1)