Adaptive optics design

In most cases the performance of an optical telescope is limited not by the telescope's optical properties but by the turbulence in the atmosphere above. The temperature fluctuations in the atmosphere lead to fluctuations of the index of refraction which by themselves lead to degradation of the image quality.

Strehl Ratio: The image quality can be characterized by a single number the so called Strehl ratio. The Strehl ratio (often simply called Strehl) is defined as the ratio of the peak intensity of the system's point spread function (PSF) to the peak intensity of the corresponding diffraction limited system.

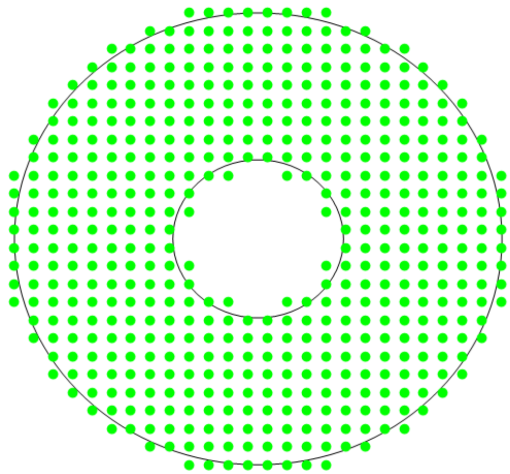
Fried's parameter r_0: When the fluctuation of the index of refraction as a function of height is known, a single number can be calculated which characterizes the atmosphere as a whole. This number is the Fried parameter r_0 and is interpreted as the statistical coherence length of the index of refraction in the atmosphere. It can be imagined as the size of an average turbulence cell (eddy) in the atmosphere. Preliminary results seem to show that r_0 is greater than 8 cm for a significant fraction of time during the day at Merak.

Atmospheric time constant: Atmospheric turbulence can be seen as an ensemble of eddies which are driven by the wind across the line of sight. So the change in rate of seeing is related to the wind speed *v*. In order to characterize the effect integrated over all heights one can introduce a *typical* time constant which is given by the typical cell size r_0 divided by the typical wind speed *v*.

The number of sub-apertures and the number of actuators: The number of sub-apertures determines the number of degrees of freedom and therefore the maximum correction that can be achieved. So a maximum number of sub-apertures is desirable. As a rule of thumb the size of a sub-aperture should be equal or smaller than Fried's parameter r_0. But for a solar telescope there is a lower limit for the size of the sub-aperture: The sub-aperture must be large enough to resolve the solar granulation. Solar granulation is the structure the AO has to lock on. It has a typical spatial scale of 2 arcsec; therefore the sub-aperture diameter has to be at least 63 mm. 25 sub-apertures across the telescope (i.e. 26 actuators) corresponds to a sub-aperture diameter of 80 mm.

The Wavefront Sensor Camera: The wavefront sensor camera has to be fast enough to allow for an approx. 3 kHz frame rate which roughly gives a 100 Hz 3db system bandwidth. The optimum number of pixels per sub-aperture depends on the speed of the camera (less pixels to read out increases the system bandwidth, but more pixels increases the accuracy) 24 x 24 pixels / subaperture provide a good balance. The region of interest on the camera follows as 25 sub-apertures x 24 pixel/sub-aperture plus a 10% margin for gaps between the sub-apertures, in total, 660 x 660 pixels.

This results in a very high pixel rate of 1.3 Gpixel/s, which is three times higher than what today's (2009) cameras provide. However, in the past, advancements in CMOS technology and computer technology have always been fast enough to provide the COTS cameras needed for solar AO.



Actuator pattern with 496 actuators for a mirror used under 22.5°.

The following table summarizes the specifications:

Frame rate	≥	3 kHz
Region of interest	:	660 x 660 pixels
Full well capacity	≥	50000 e^-
Digitization	:	8 bits/pixel
Quantum efficiency x fill factor (500nm)	≥	25%
Read noise	<	70 e^-

Automated Alignment: Since the proposed NLST AO is a high order system, an automatic alignment system that removes static aberrations and takes care of the pupil alignment is mandatory (active optics). The solid line to the DM and TT mirror resembles the fast (3 kHz) AO control loop frequency, whereas the other devices are driven a few times per minute or even only once per observation.