Durham University

CfAI
Centre for Advanced Instrumentation

CHOUGH, the **C**anary **Ho**sted-**U**p**g**rade for **H**igh-order adaptive optics

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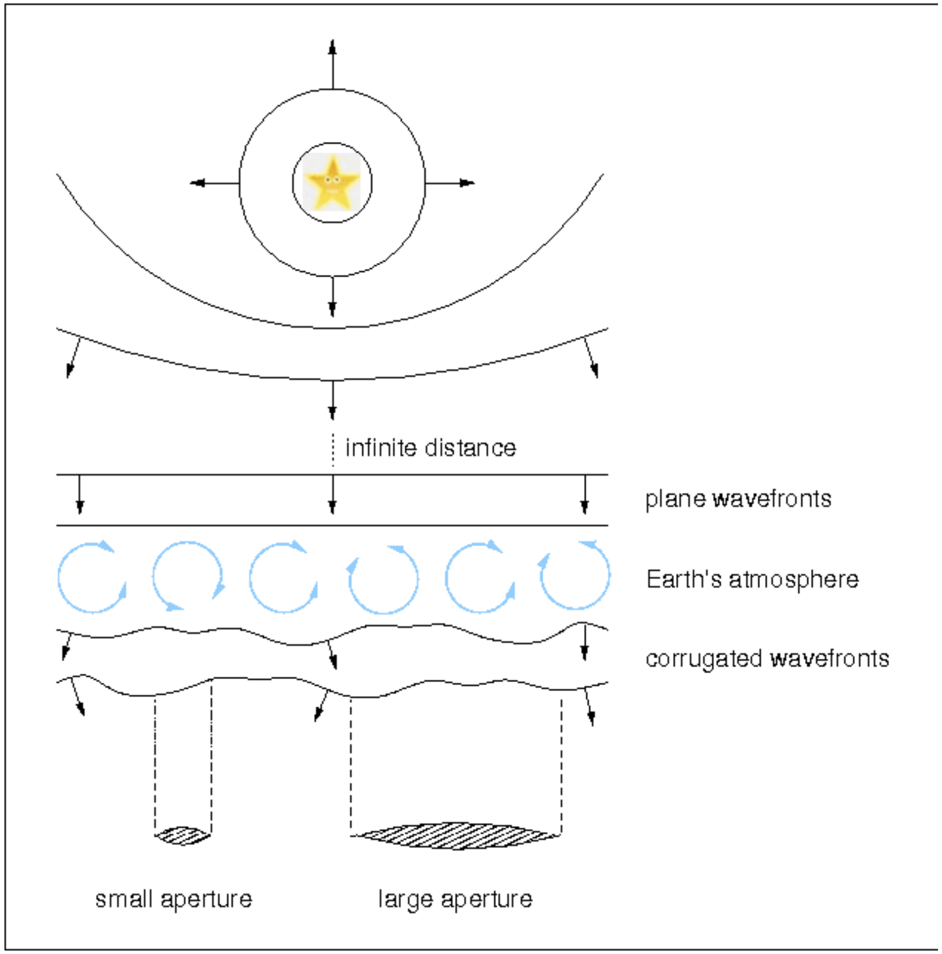
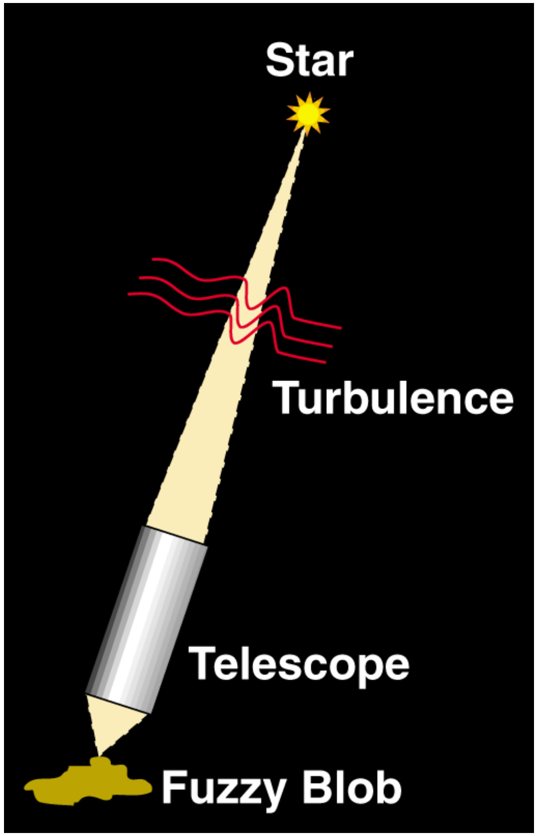
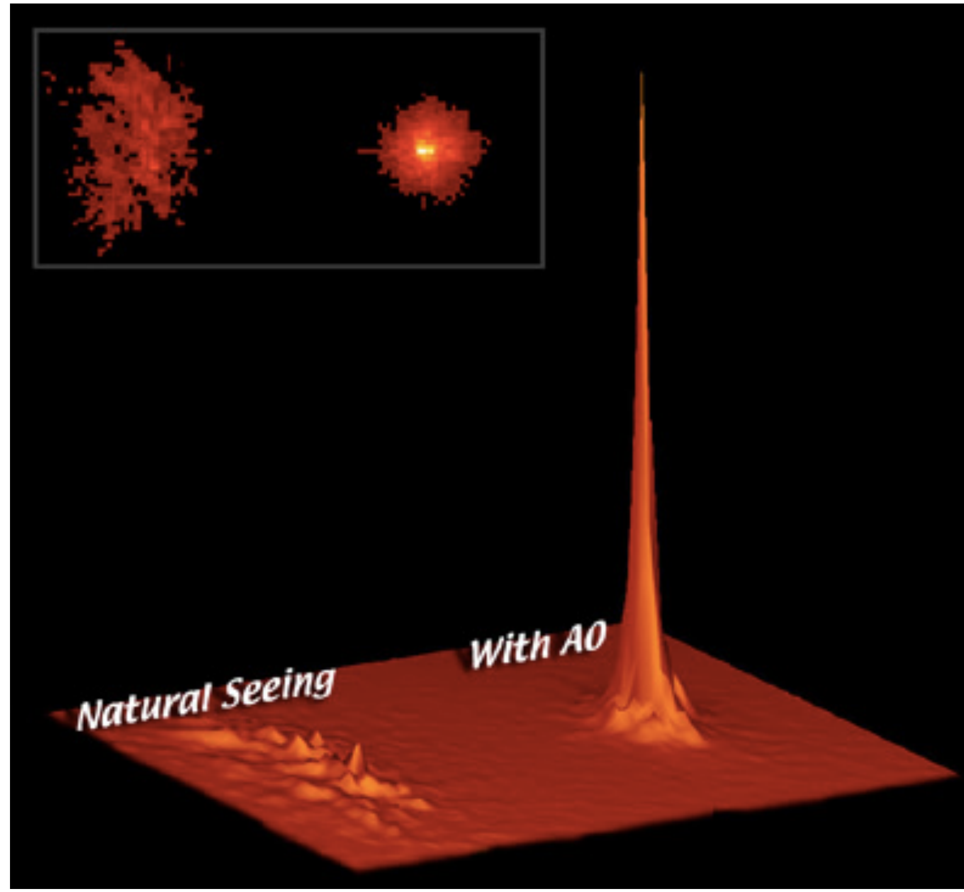
Atmospheric perturbations cause distorted wavefronts



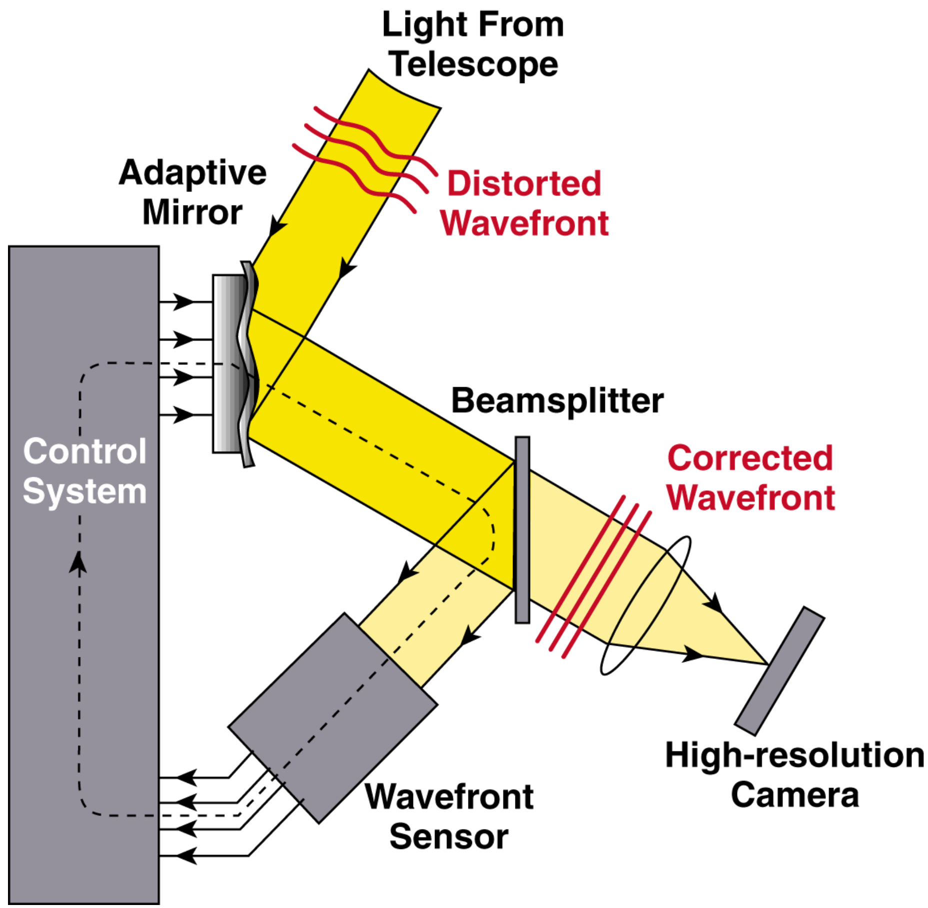


Adaptive Optics(AO)

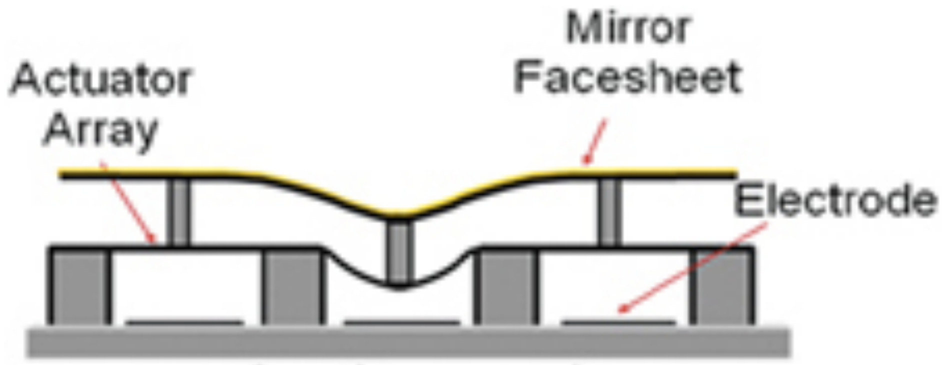
AO is a technology used to improve the performance of optical systems by reducing the effect of wavefront distortion.

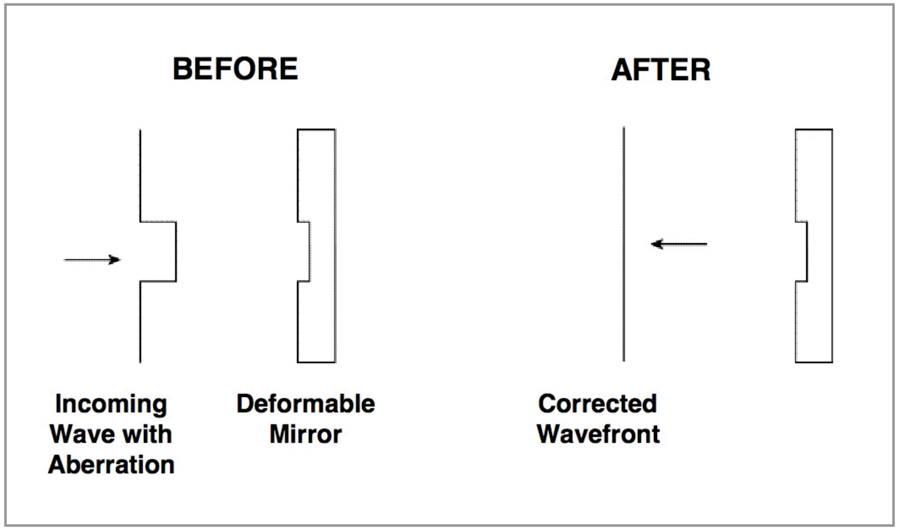


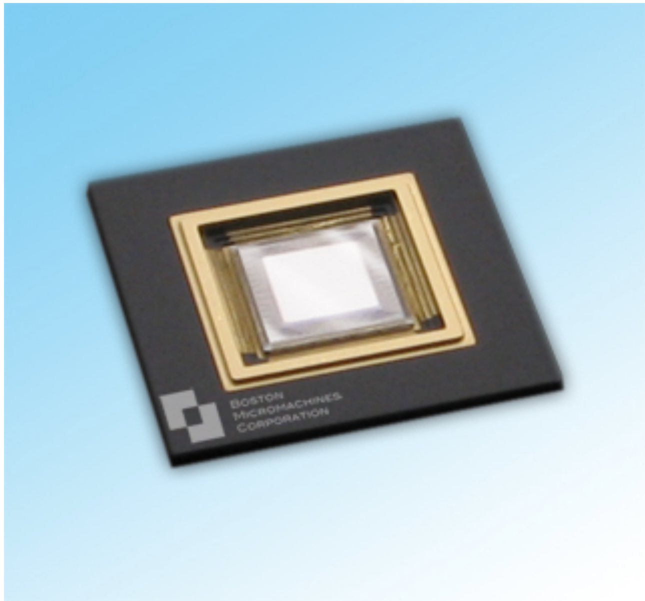
Optical Schematic of an AO system



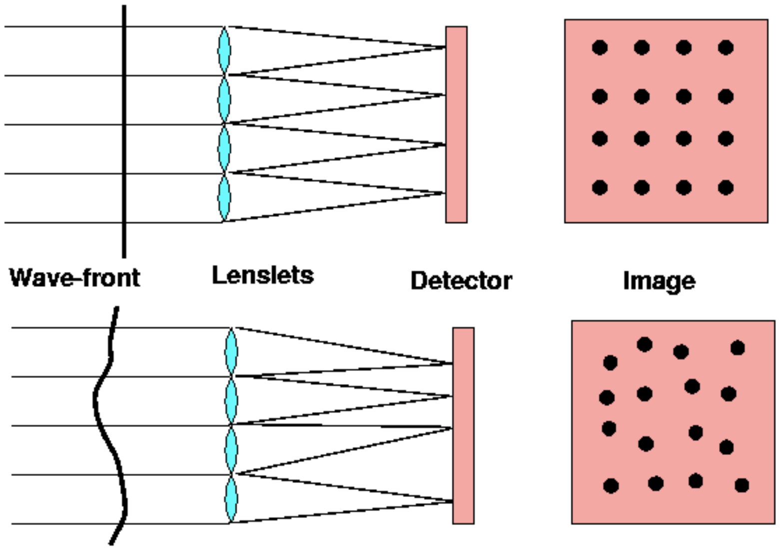
Deformable Mirror(DM)

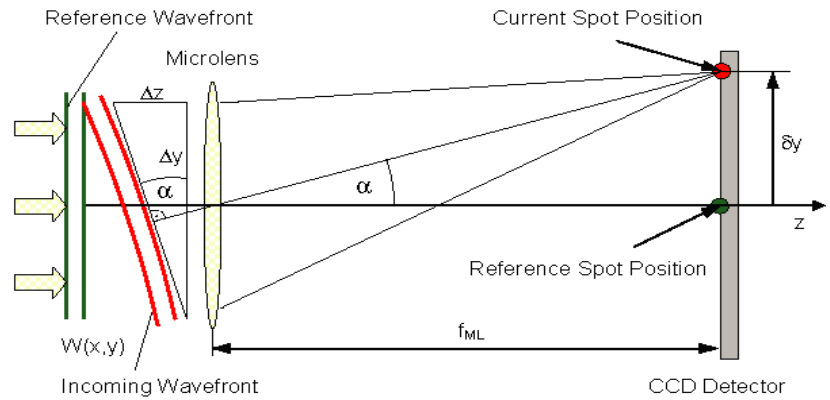


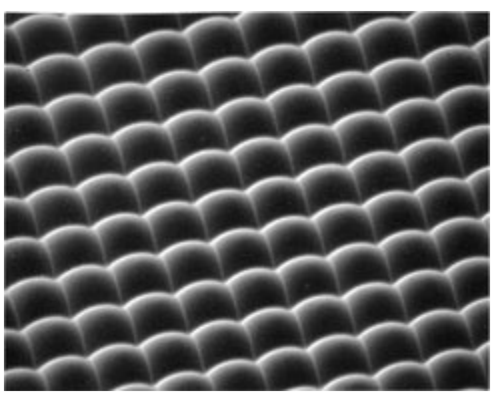




Shack-Hartmann Wavefront Sensor

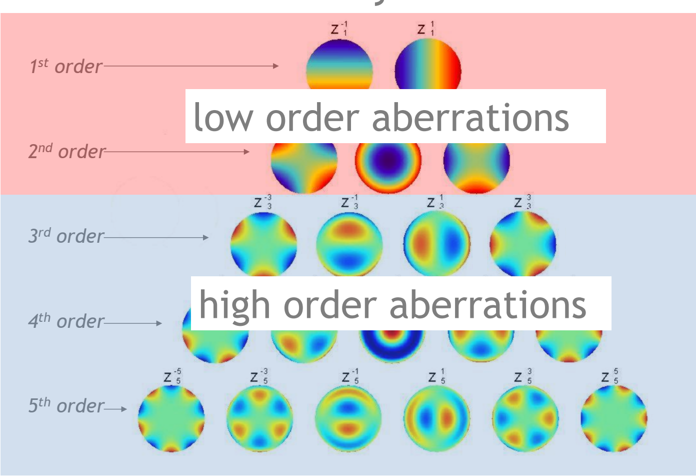




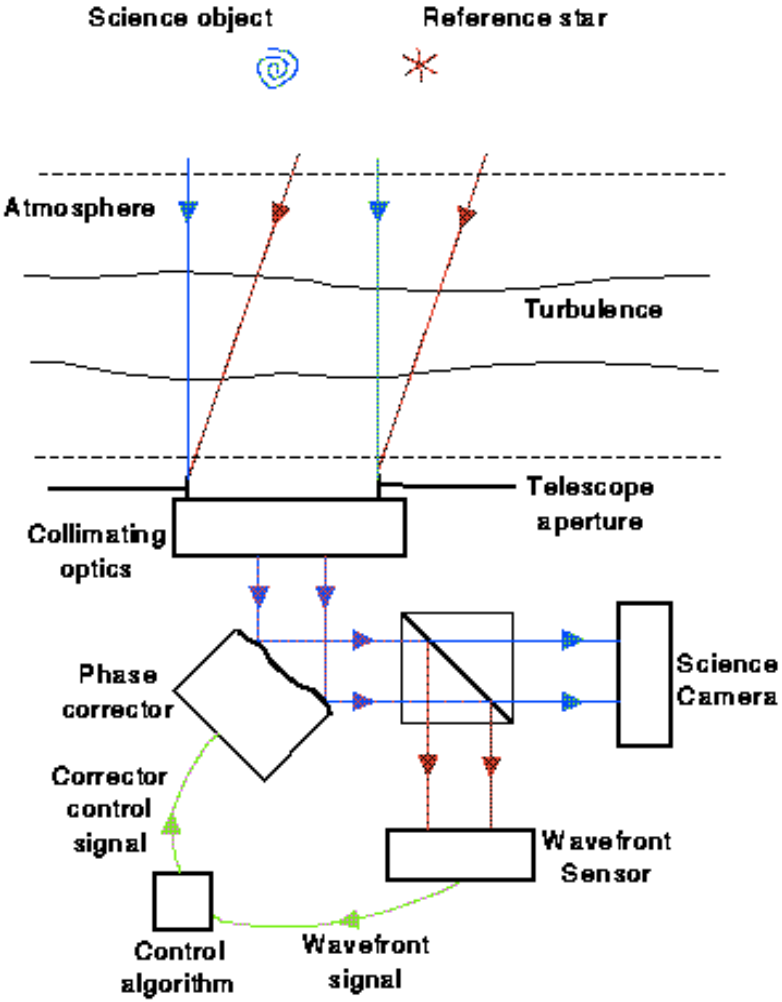


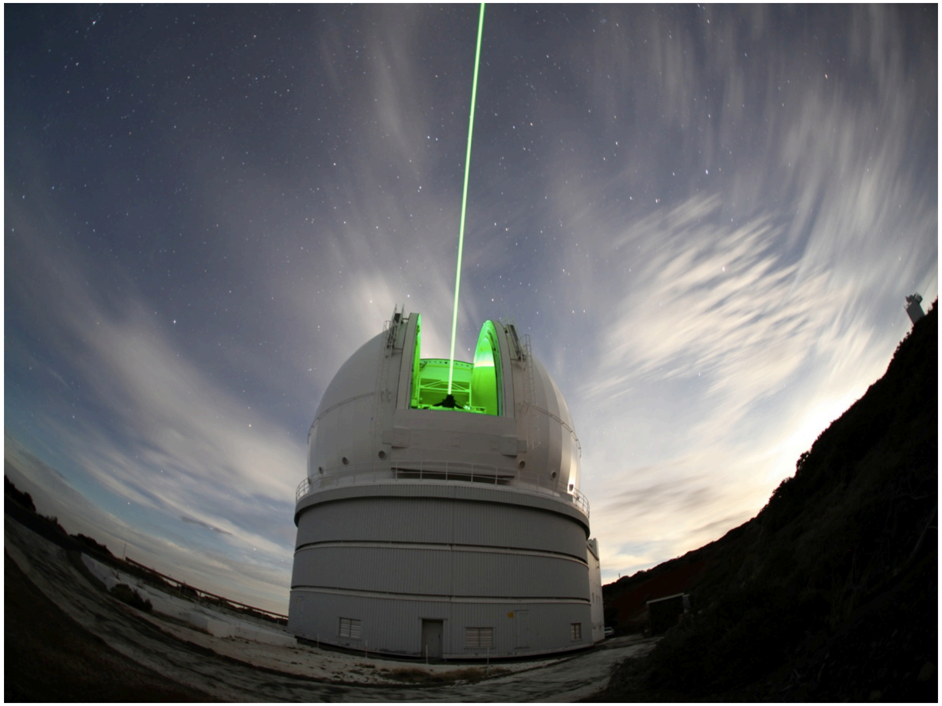
http://www.rpcphotonics.com

Zernike Polynomials



Guide Stars

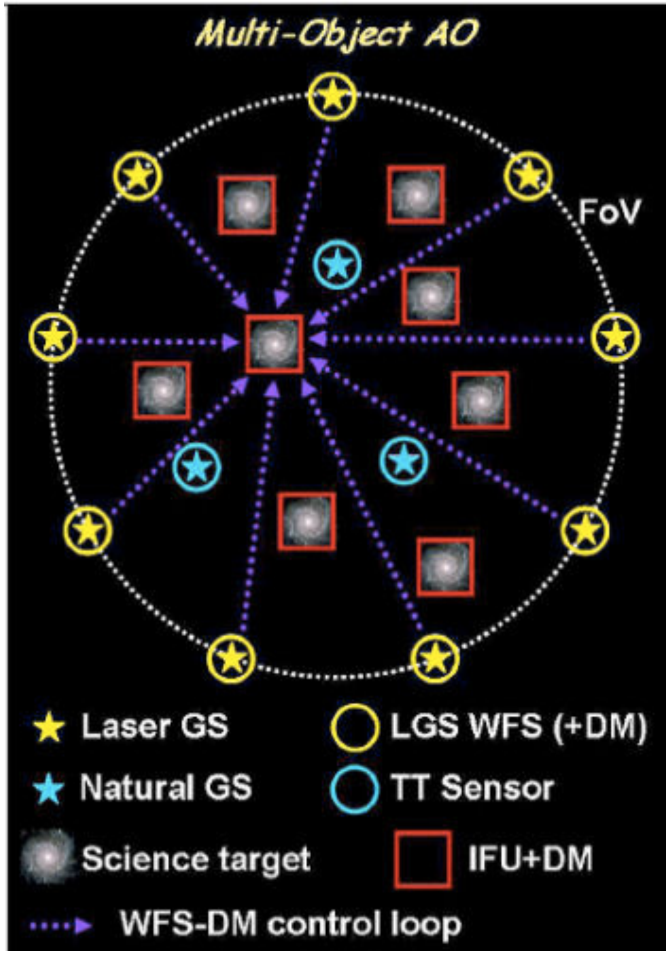

Science object
Reference star
Atmosphere
Turbulence
Telescope aperture
Collimating optics
Phase corrector
Science Camera
Corrector control signal
Wavefront Sensor
Control algorithm
Wavefront signal



Questions?

CANARY

- 4.2m William Herschel Telescope
- EAGLE is a multi-object 3D spectroscopy instrument currently under design for the 42m E-ELT
- Multi-Object Adaptive Optics (MOAO)
- Emulate a single channel of the proposed E-ELT MOAO instrument, EAGLE



CHOUGH

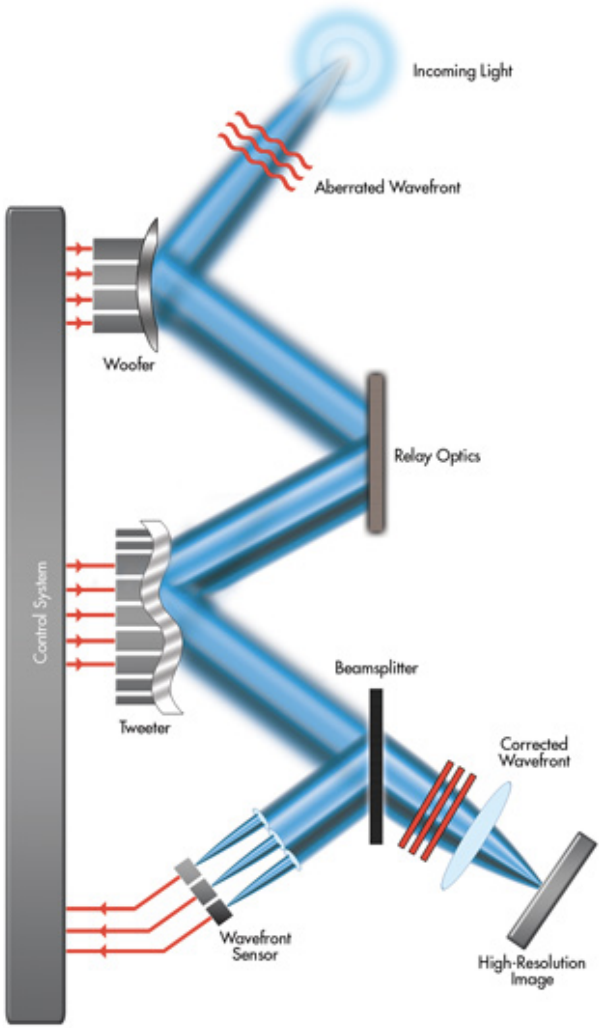
- The choughs are medium-sized **corvids**; the red-billed chough is 39–40 centimetres (15–16 in) in length with a 73–90 centimetres (29–35 in) wingspan

- These birds are mountain specialists, although red-billed chough also uses coastal sea cliffs in Ireland, **great Britain**, and Brittany, feeding on adjacent short grazed grassland or machair;[17] the small population on **La Palma**,

CHOUGH Goals

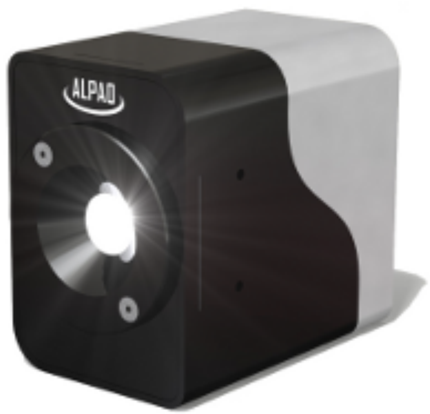
- Investigate high-quality PSF correction with Strehl ratios ≥ 0.5
- Optimize the AO system so that the best Strehl ratios can be achieved in the visible part of the spectrum (≥ 600-900 nm)

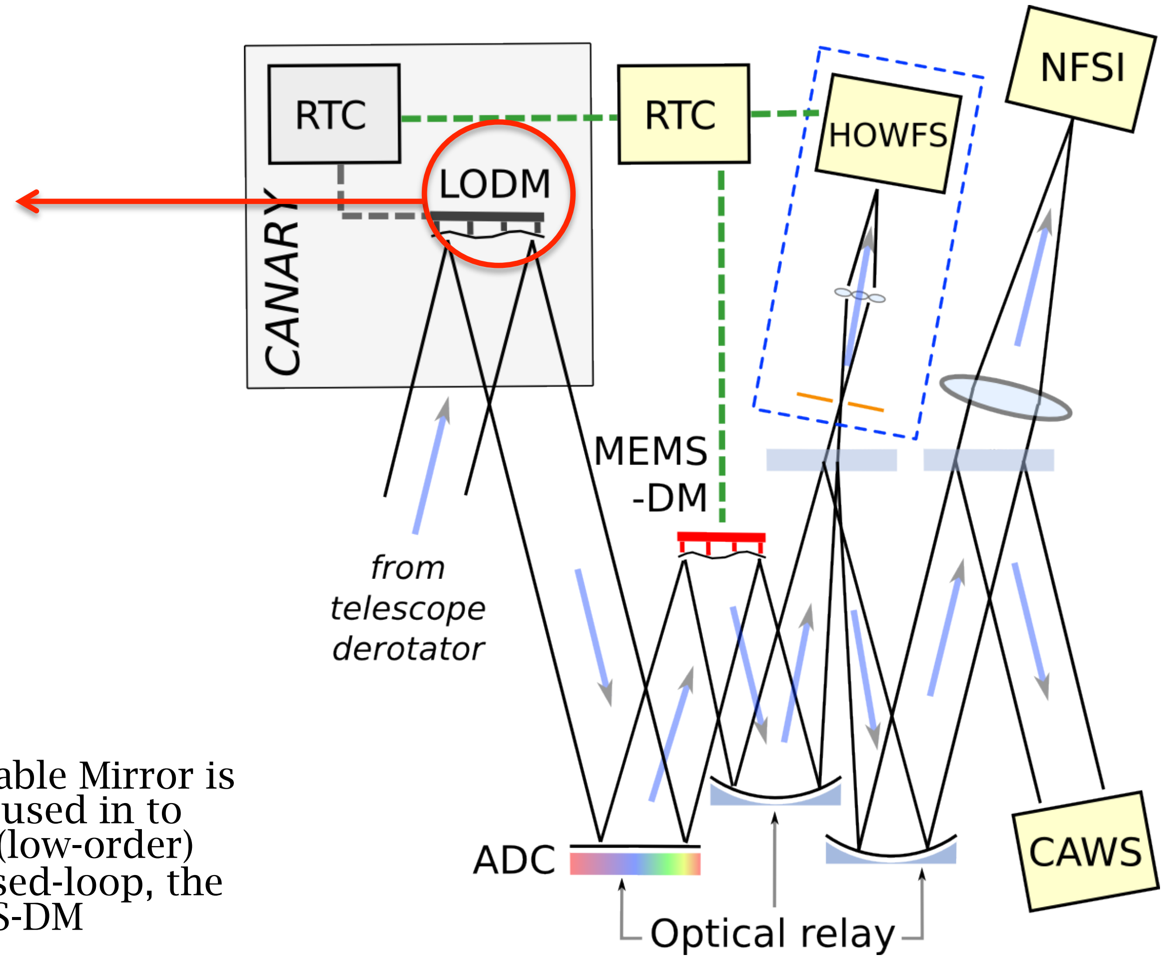
Dual-Mirror AO System



- Low-order optical aberrations are the most common and are corrected using a high-stroke, low-resolution mirror
- High-order aberrations are corrected using a low-stroke mirror

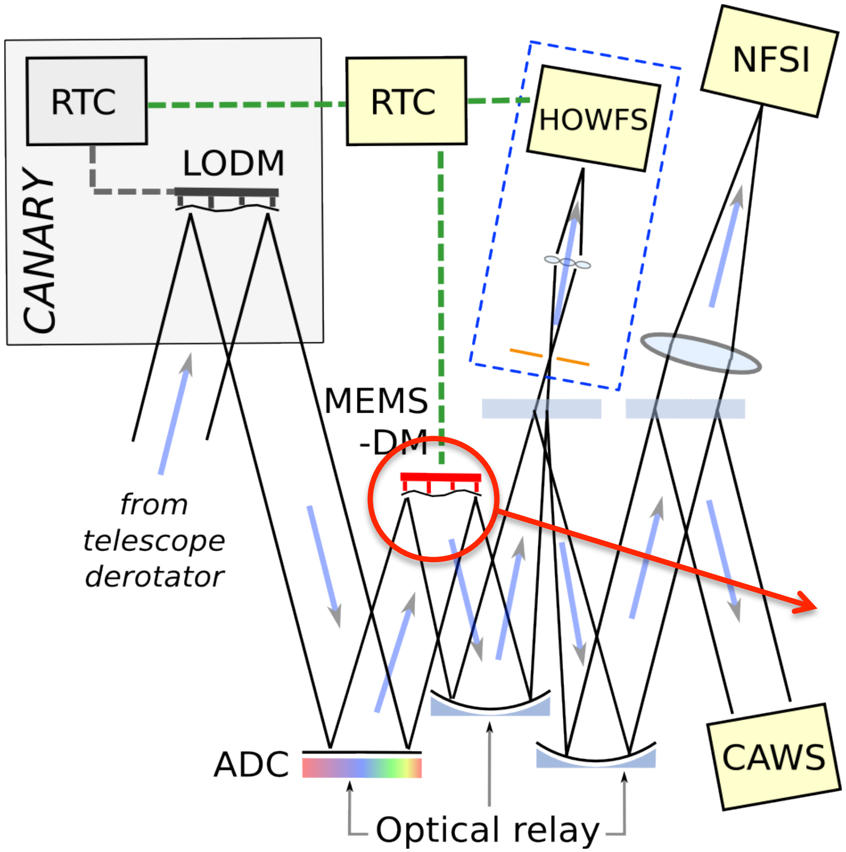
Low-order DM



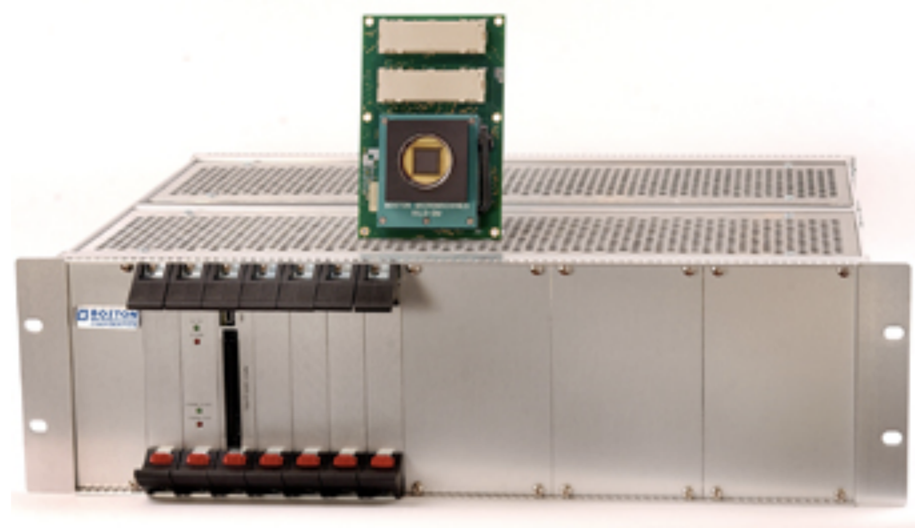


- The Low-Order Deformable Mirror is part of CANARY and is used in to correct all large-stroke (low-order) aberration terms in closed-loop, the remainder via the MEMS-DM

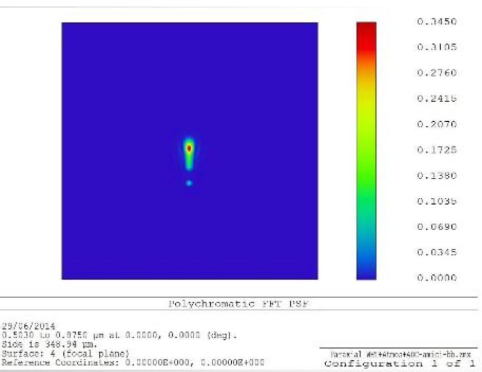
High-order DM

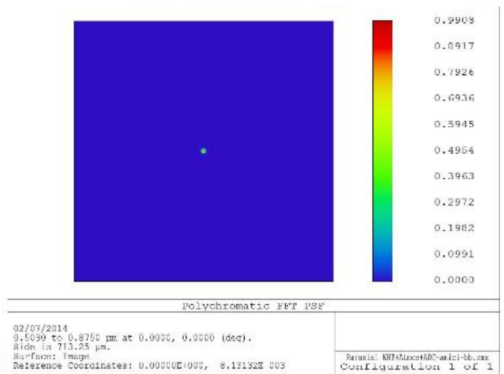


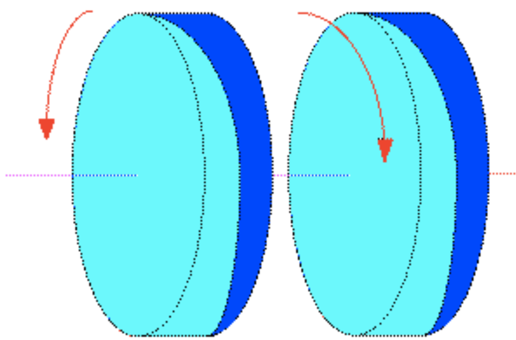
- The MEMS-DM is used to correct high-order (low-stroke) aberrations.
- It is the restricted stroke of this DM that requires operation with the LODM

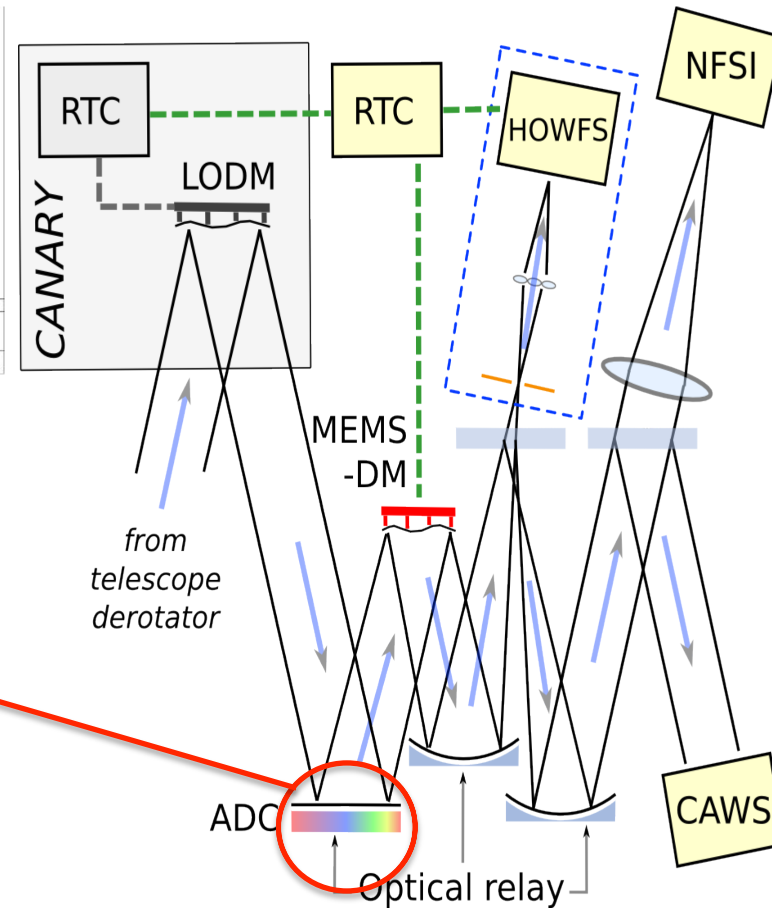


Atmospheric Dispersion Compensator(ADC)

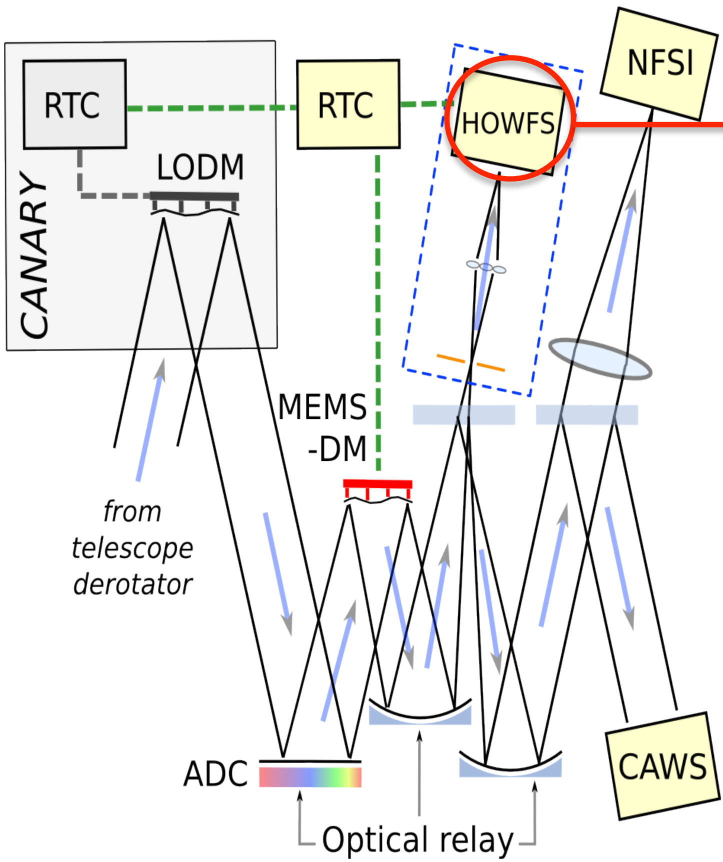


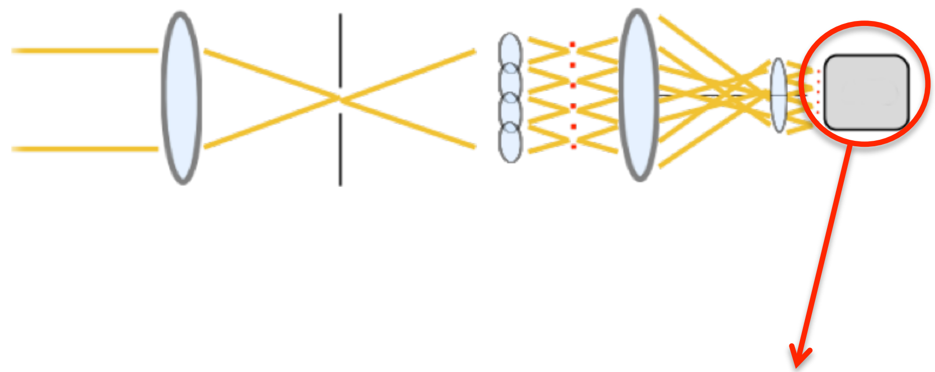


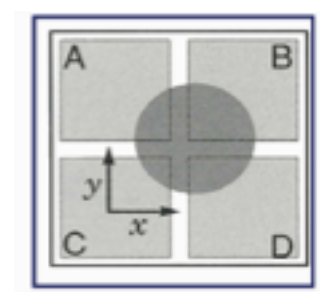




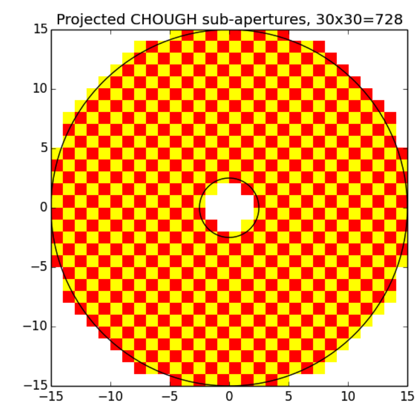
Shack-Hartman WFS



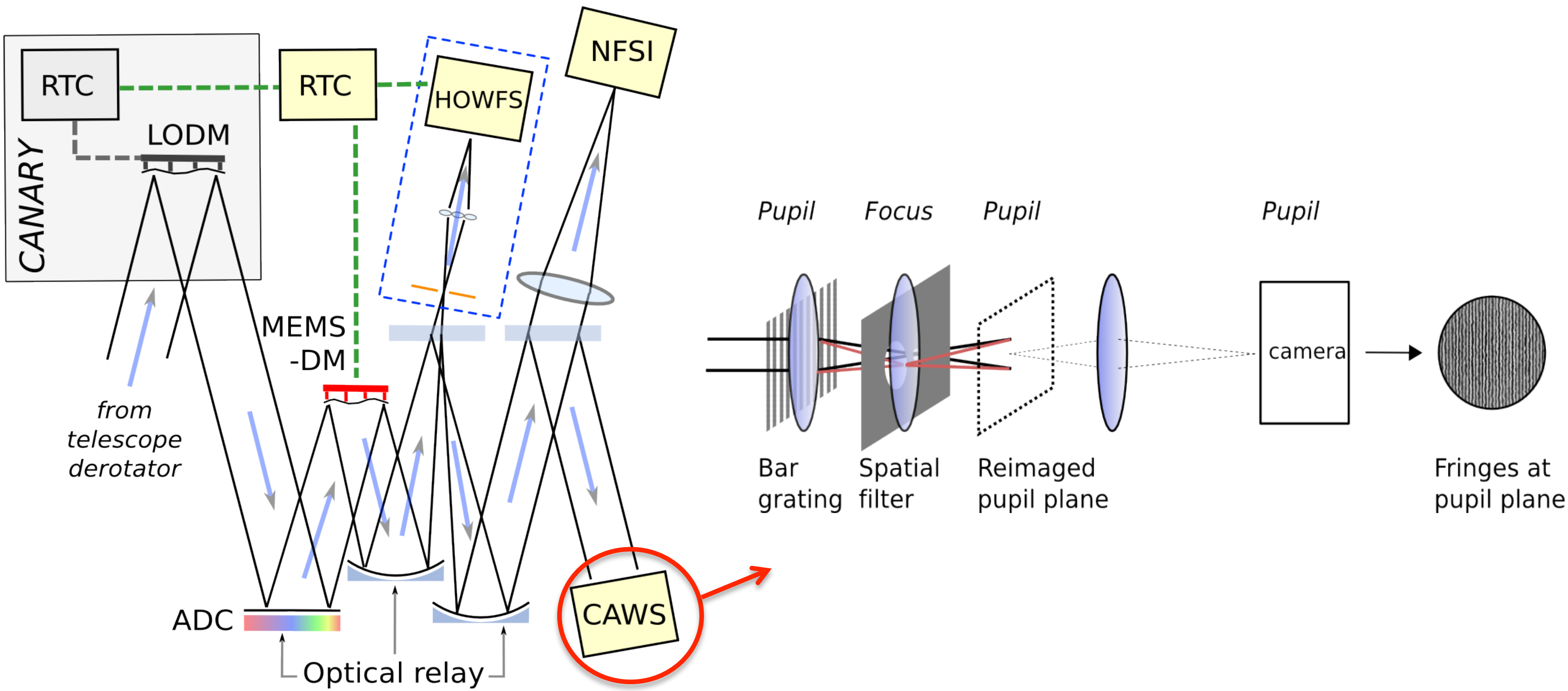




Quad-cell



Calibration and Alignment Wavefront Sensor (CAWS)



Narrow Field Science Imager(NFSI)

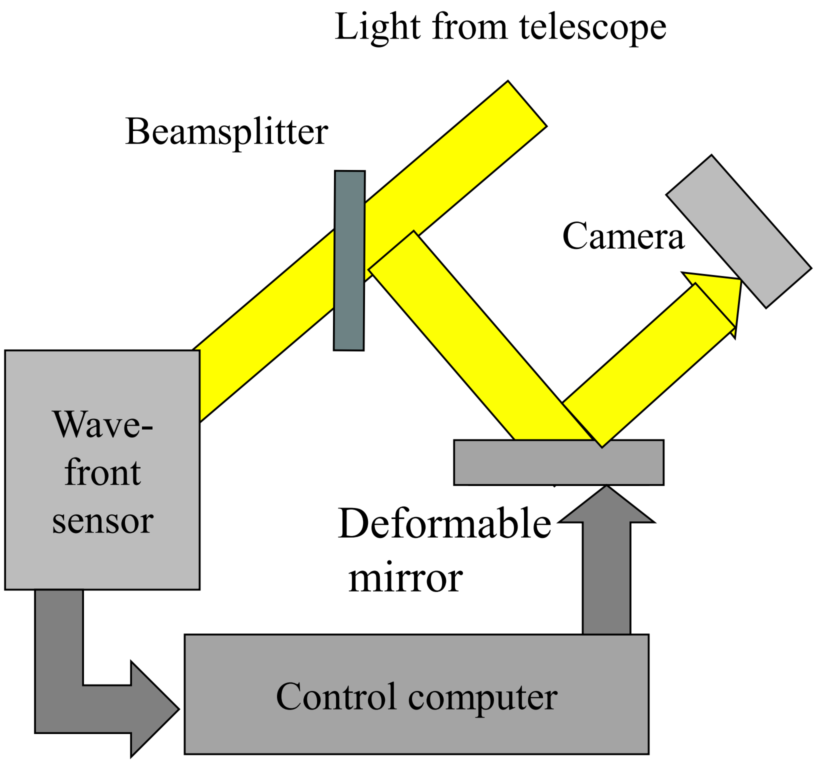
- The Narrow Field Science Imager is a conventional camera with integrated filter wheels (broad and narrow regions) and 7” FoV.

FIN

Requirement	**Value**	**Comment**
Science wavelength range (nm)	510-880	Silicon-based detector limit, V,R,I-bands
Residual WFE after correction (nm RMS)	< 100 (req.) < 70 (goal)	I-band, error corresponds to a Strehl ratio of > 0.5 / > 0.75.
Required contrast ratio (I-band)	> 1000:1	Based on non-coronographic imaging at a distance of 0.5''.
Field of view (arcsec)	4"	Determined by the maximum iso-planatic angle, covers the controlled frequencies of the MEMS-DM.
Limiting magnitude (m_V)	7.7	Based on initial simulation results for control of the PSF at a radius of 0.2''.
Tip-tilt correction stability (mas rms)	< 5	5% of the WHT theoretical PSF FWHM in I-band.
Pupil motion stability (% pupil diameter)	0.3	10% sub-aperture mis-registration.
Zenith angle limit	< 50°	To be finalized by ADC performance w.r.t. atmospheric air-mass.
CANARY static aberrations (nm rms)	< 300	Existing measurements suggest this is satisfied.
HOAO frame rate (Hz)	> 1000	Can be lower depending on conditions, but camera limit is 1.5kHz.

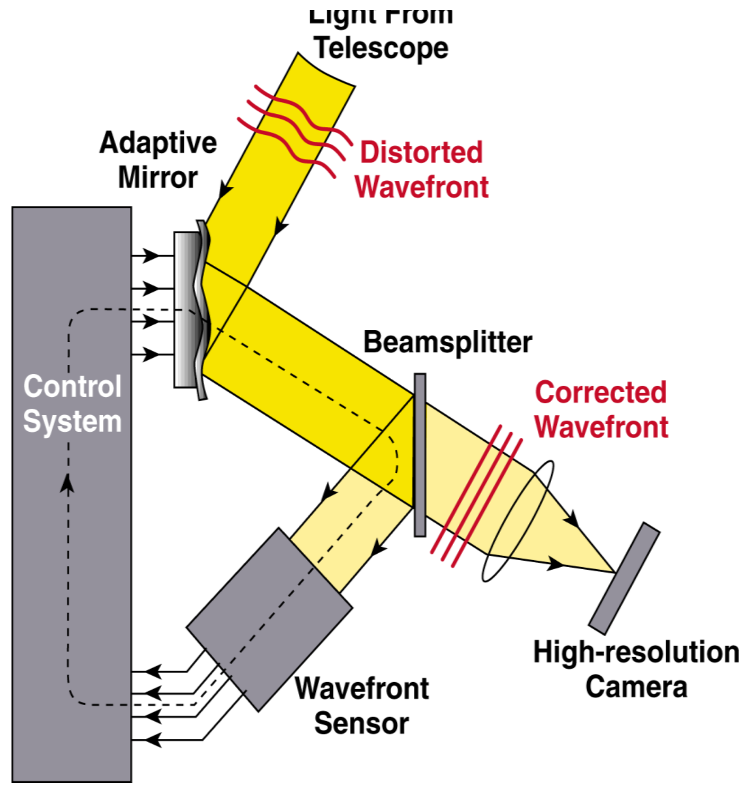
Parameters	**Values**	**Comments**
Telescope pupil (m)	4.2, 1.2 (primary, secondary)	Secondary mirror spiders irrelevant at the simulation resolution.
r0/L0 (m)	0.12/30	Realistic seeing at WHT.
Wind velocities (average, m/s)	21	3 Layers
Turbulent layers (km & fraction)	0(55%), 4(22%), 10(22%)	
WFS sampling	30×30	HOWFS sampling.
WFS camera format	128×128 pixels	2 pixel guard-band.
WFS read noise (e-)	0.1	EM-CCD detector.
WFS FoV	4”	DM-controlled frequencies.
WFS wavelength	R-band	
PSF wavelength	I-band	

AO systems



Open loop

Light hits sensor first



Closed loop

Light hits deformable mirror first

Open loop

Advantages:

1. Simpler because error need not be computed.
2. Can not go unstable.

Disadvantages:

1. Must be very accurately calibrated.
2. Any inaccuracy or disturbance can greatly affect control of the system.

Sthrel Ratio

- It is defined as the ratio of the PSF peak intensity to that of the “perfect” PSF

$$SR \approx e^{-\sigma_\varphi^2}$$

$$SR \equiv \frac{S(\vec{\alpha} = 0)}{S_P(\vec{\alpha} = 0)}$$