Intelligent Number Crunching for the ELT?

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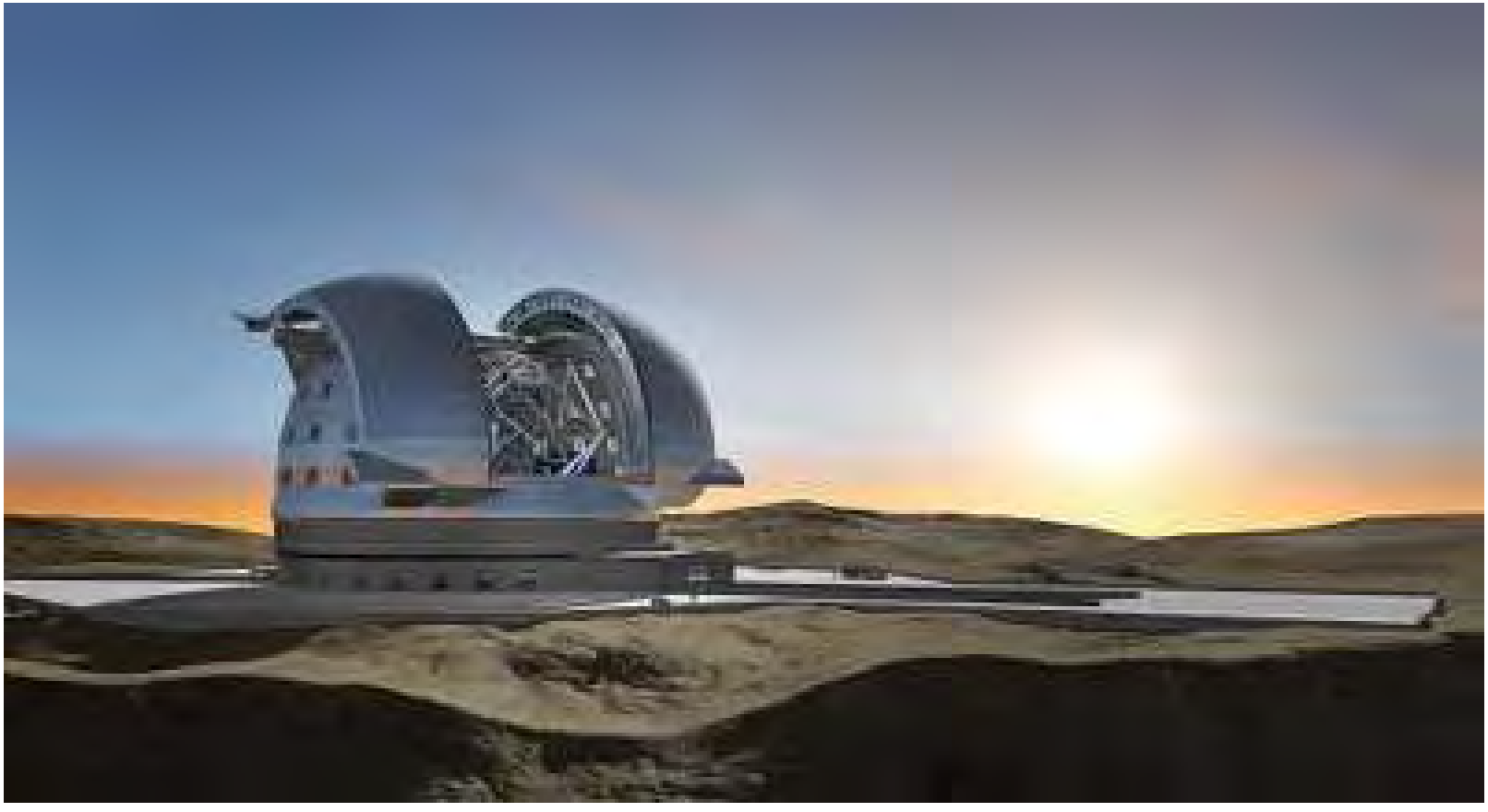
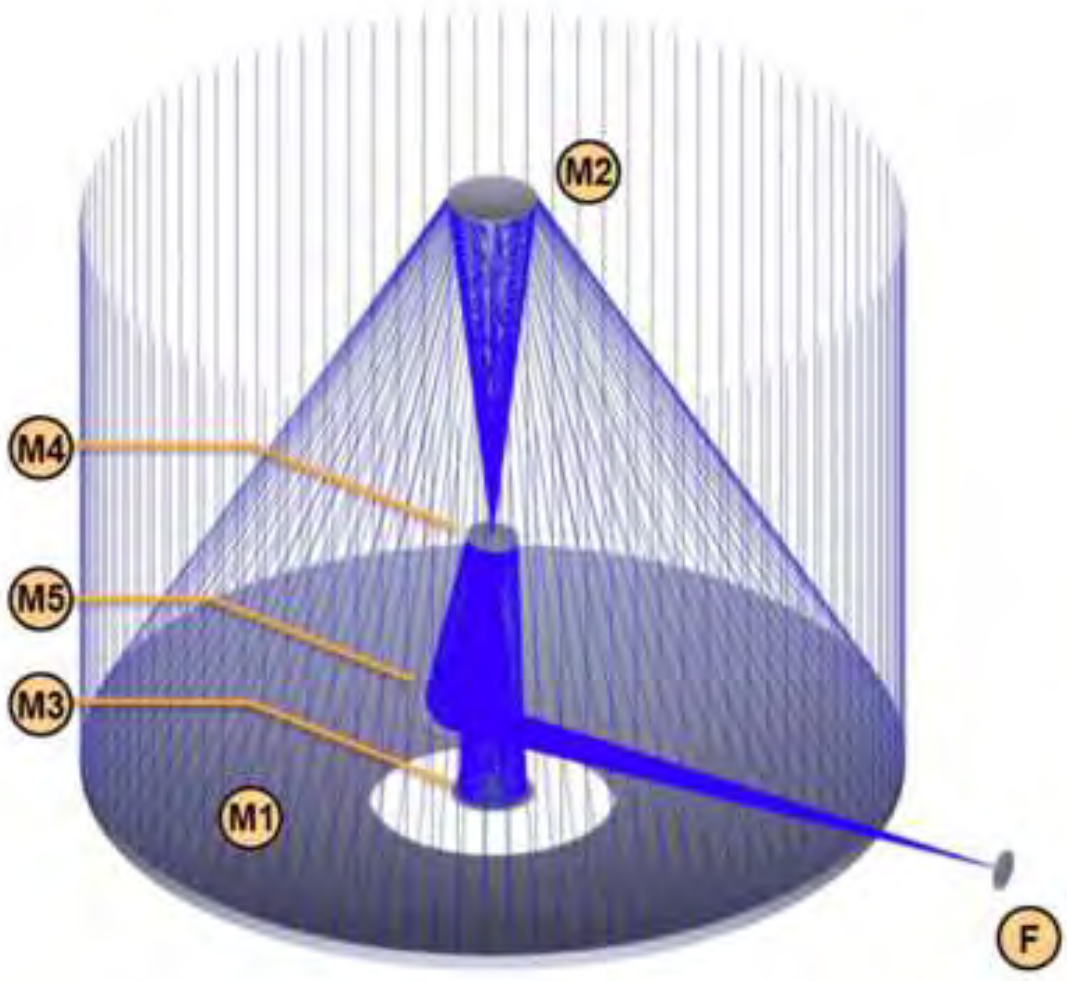
Outline

1. The "mastermind" of the ELT
   - The ELT M4 DM for AO
2. The Principle of Adaptive Optics
   - Cartoon-type of Explanation
3. Control Challenges

The ELT Artist View

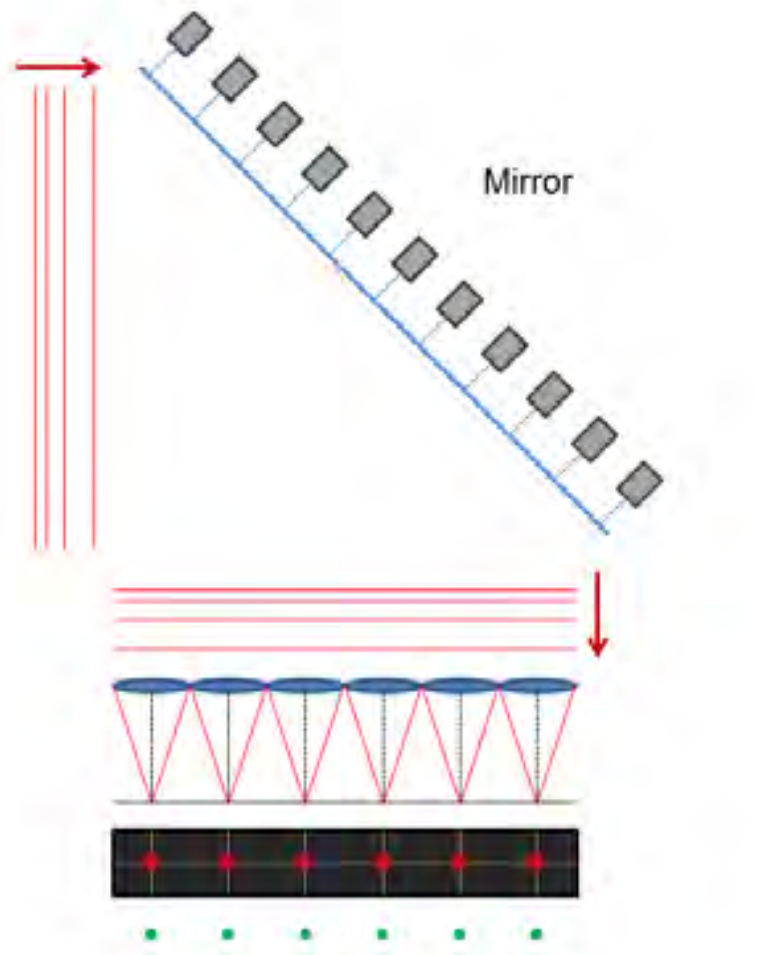


The ELT Schematic: Focus on M4



Courtesy: http://www.wikiwand.com/fr/Telescope_gant_europen

The ideal medium and the ideal optical system



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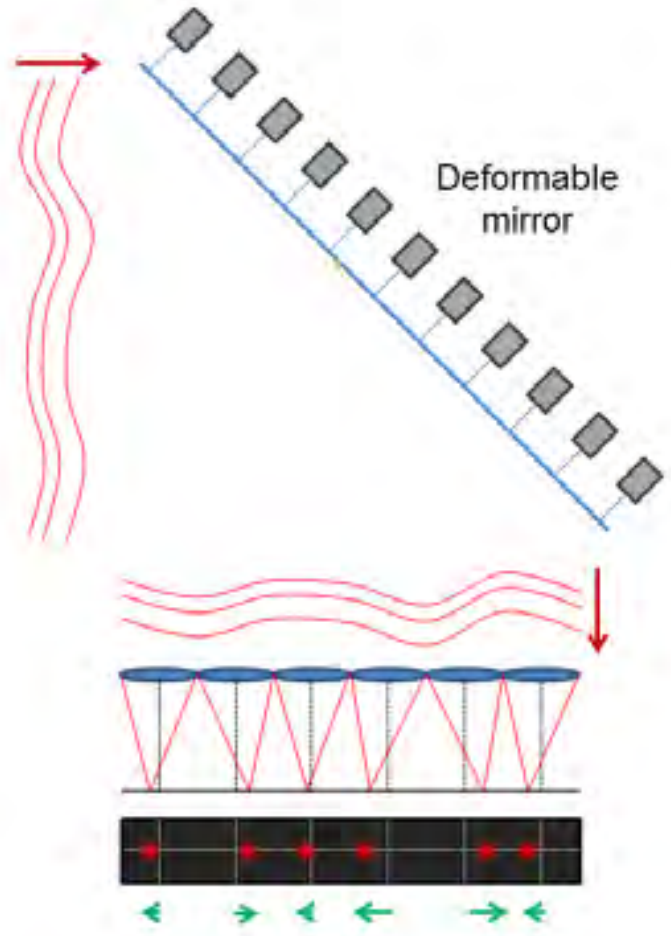
The non-ideal scenario and Wavefront Sensor



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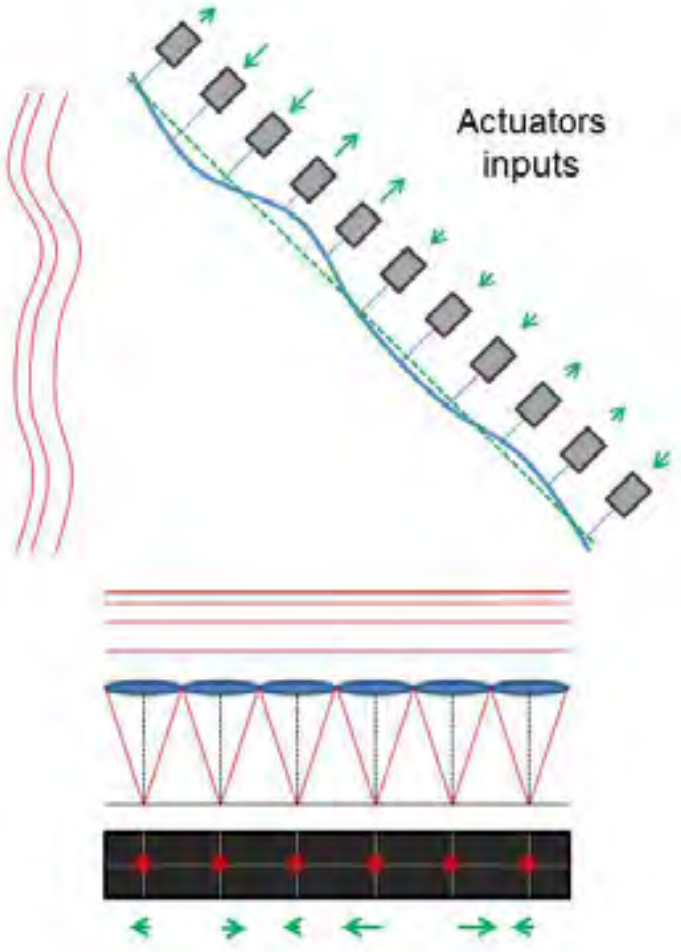
The non-ideal scenario and “Freeform” optics



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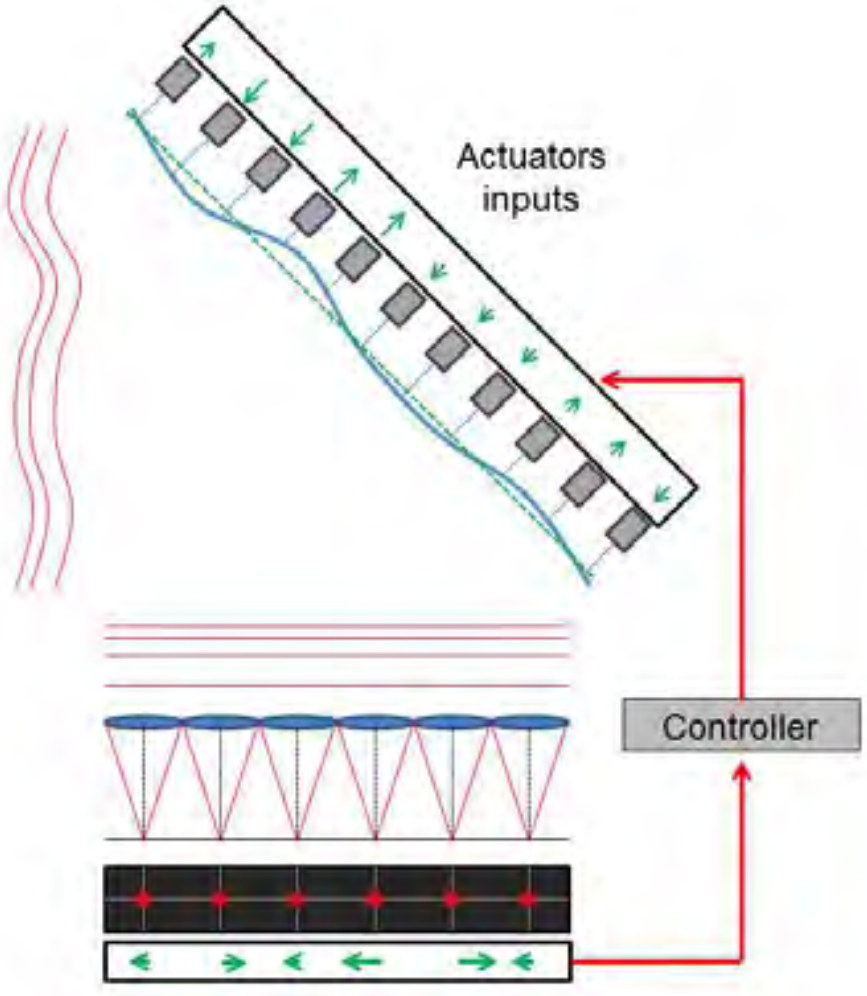
Control 4 Spatially-temporally varying Aberrations



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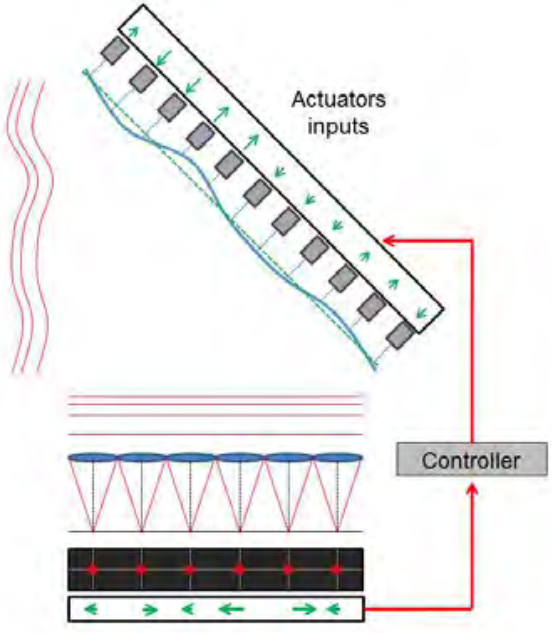
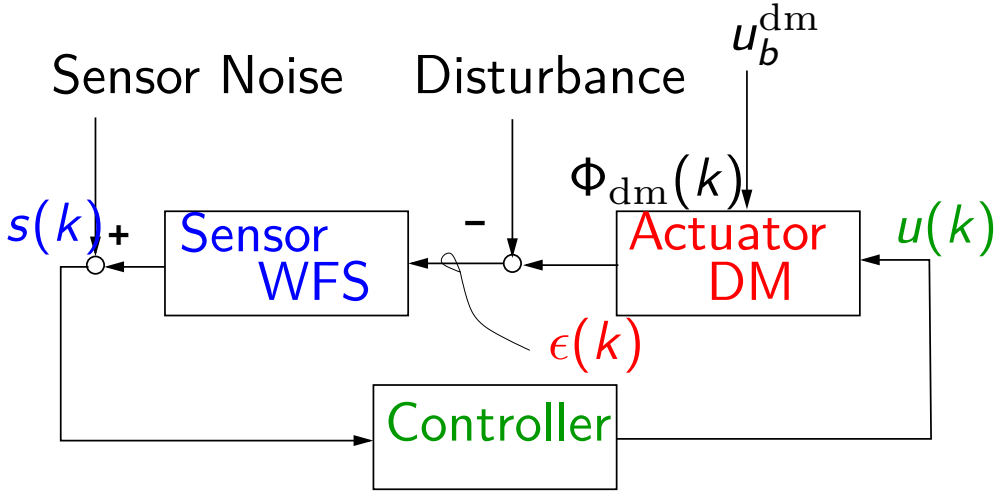
Control Challenges





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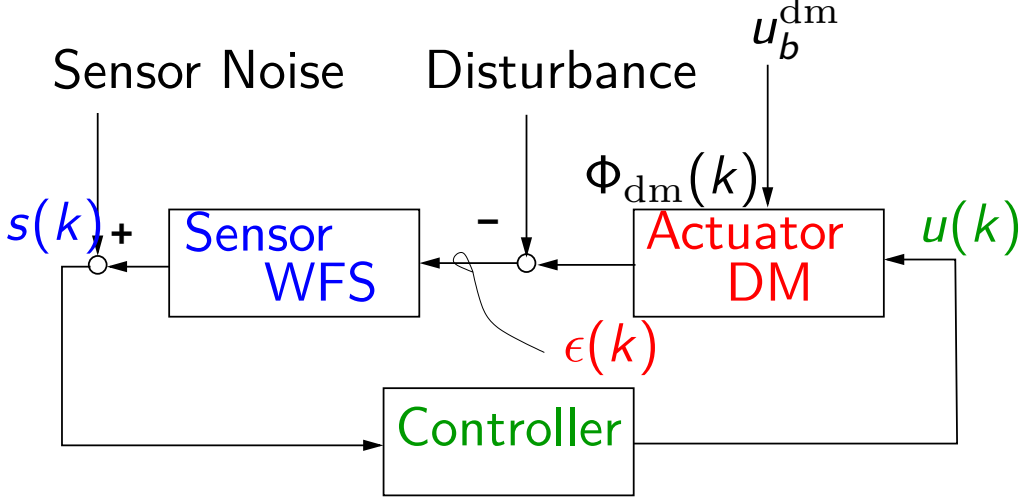
Control Scientific Instruments

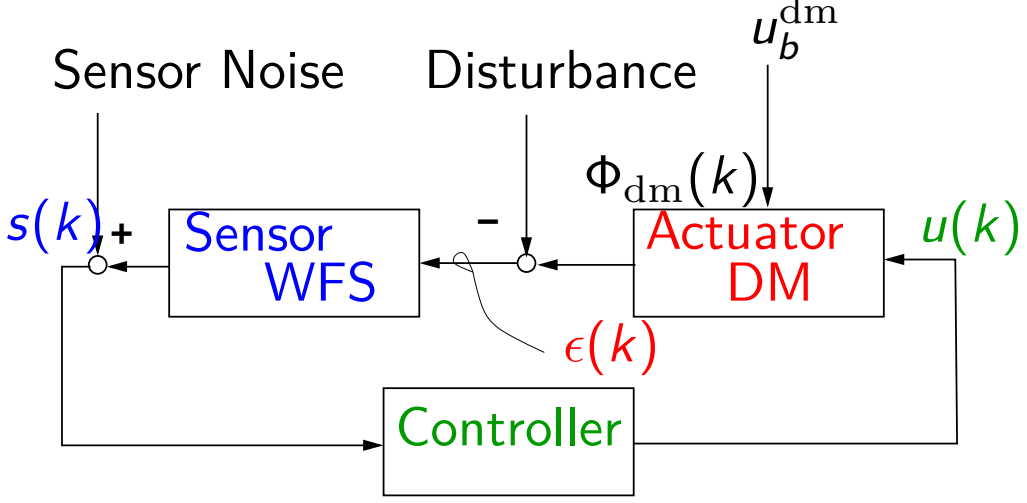


Sensor Challenges

- WFS measures "slopes" (spatial derivatives)
- Measurements are "contaminated"
- Wavefront varies "randomly" in space **and** time
- Control loop contains delays ("dynamics")
- E-ELT large scale $> 400 \times 400$

Actuator Challenges

- Fitting Error $\sigma^2_{\mathrm{fit}} =_A \kappa_f \left(\frac{d_t}{r_0}\right)^{\frac{5}{3}}$ with
  - d_t — interactuator spacing
  - r_0 — Fried Parameter
  - κ_f — 1.26 (segmented), 0.28 (membrane)



Sensor Challenges

- WFS measures "slopes" (spatial derivatives)
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- Wavefront varies "randomly" in space **and** time
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- E-ELT large scale $> 400 \times 400$

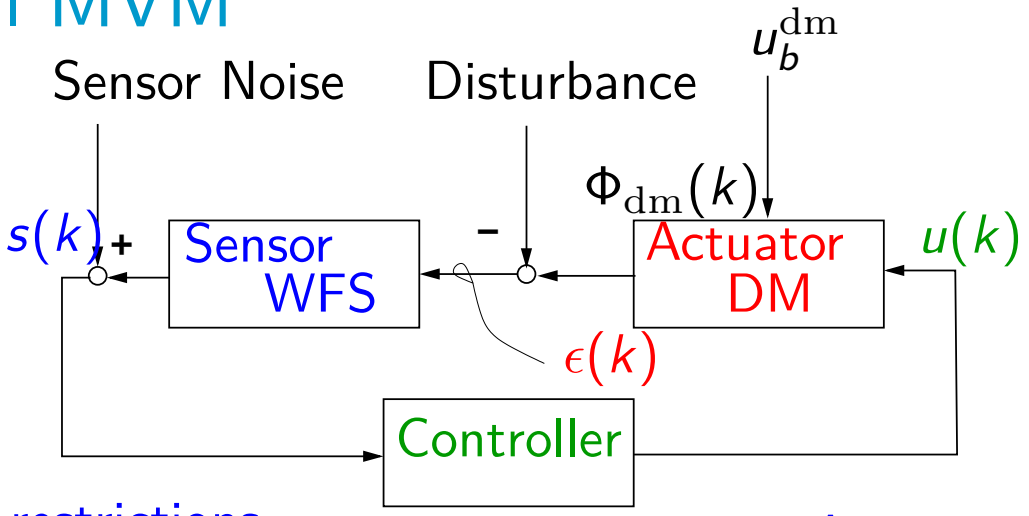
Actuator Challenges

- Fitting Error
- Nonlinearity (Hysteresis, creep, ...)
- Temporal and spatial dynamics
- E-ELT large scale $> 200 \times 200$

Controller Challenges

- (E-ELT large scale) Dimensionality

The Classical MVM



MVM restrictions

- WFS measures "slopes" (spatial derivatives)
- Measurements are "contaminated"
- Wavefront varies "randomly" in space
- Control loop contains delays
- VLT $20 \cdot 10^3$

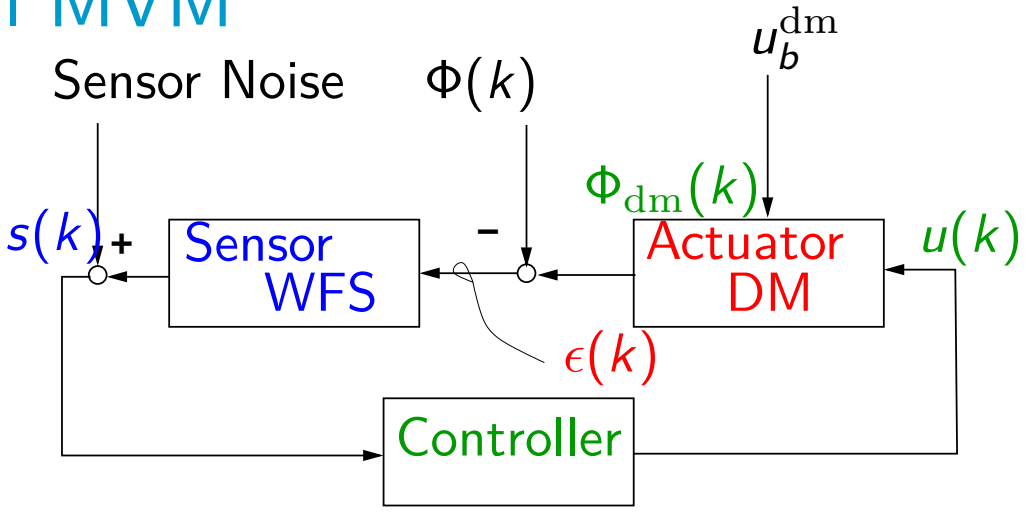
Actuator Challenges

- Fitting Error
-
- spatial dynamics
- VLT $9 \cdot 10^3$

Controller Challenges

- Dimensionality

The Classical MVM



Controller Challenges based on *Model:*

$$\left.\begin{aligned} s(k) &= W\underbrace{\left(\Phi(k)-\Phi_{\mathrm{dm}}(k)\right)}_{\epsilon(k)}+n(k)\\ \Phi_{\mathrm{dm}}(k) &= Du(k)\\ u(k) &= Cs(k)\end{aligned}\right\} \Rightarrow \epsilon(k) = (I-\mathcal{Q}W)\Phi(k)+\mathcal{Q}n(k)$$

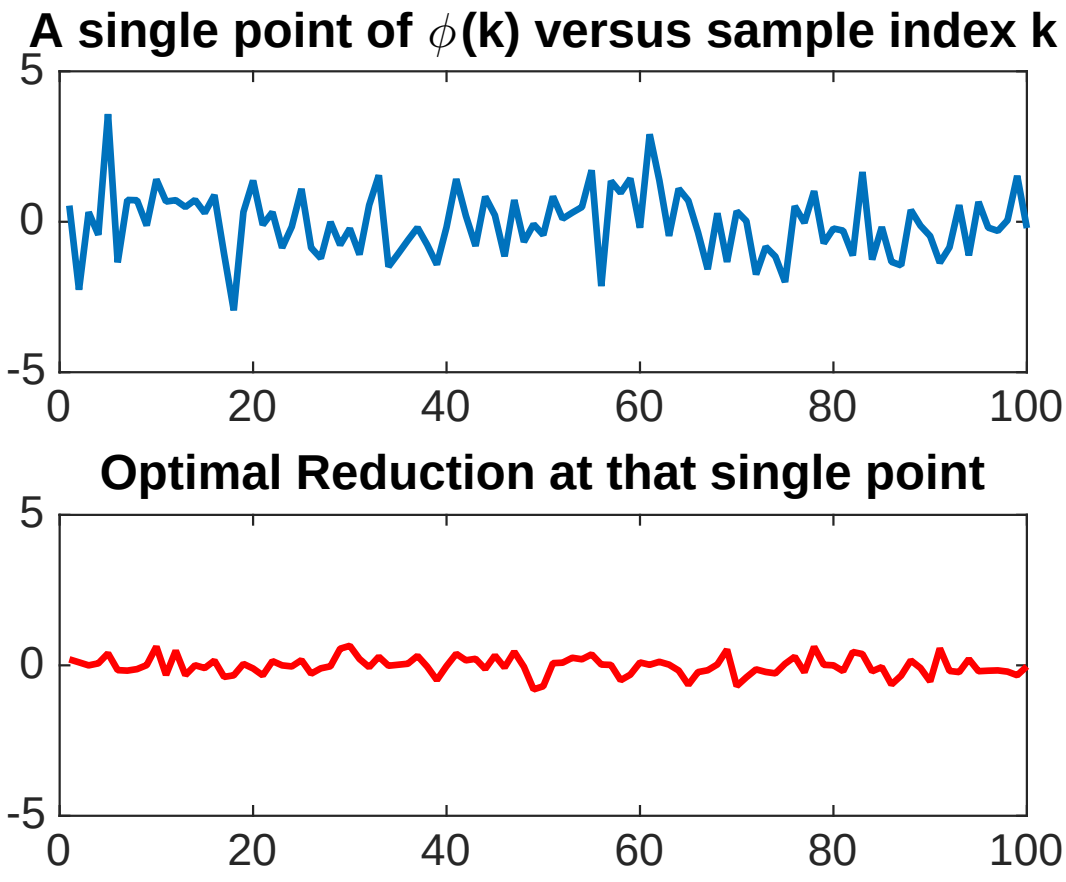
Control Design Problem

$$\underset{\text{Controller } \mathcal{Q}}{\text{Minimize}} \quad \text{Covariance}\left(\epsilon(k)\right) \text{ given Covariance}\left(\Phi(k)\right) \text{ and the Model:}$$

The Classical MVM approach: Illustrative Example

Conditions

- A single point of the wavefront $\Phi(k)$
- Uncontrolled
- Controlled with an ideal sensor ($W = I$) only sensor noise and an ideal DM ($D = I$)

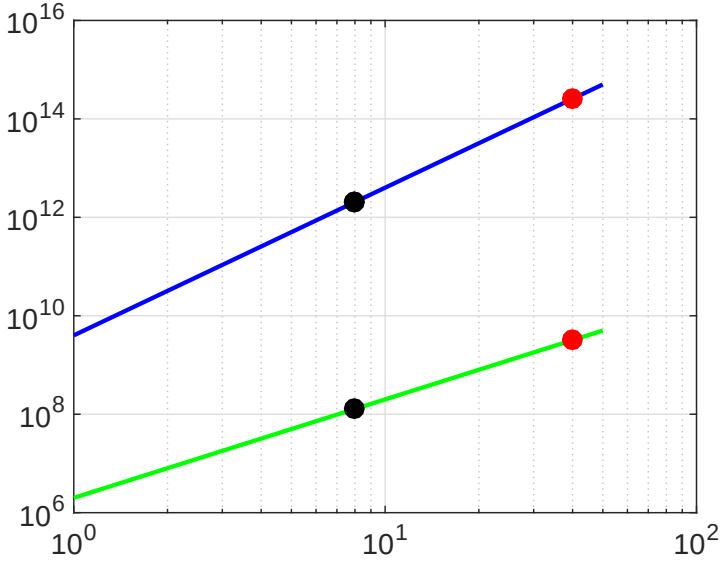


The Classical MVM approach

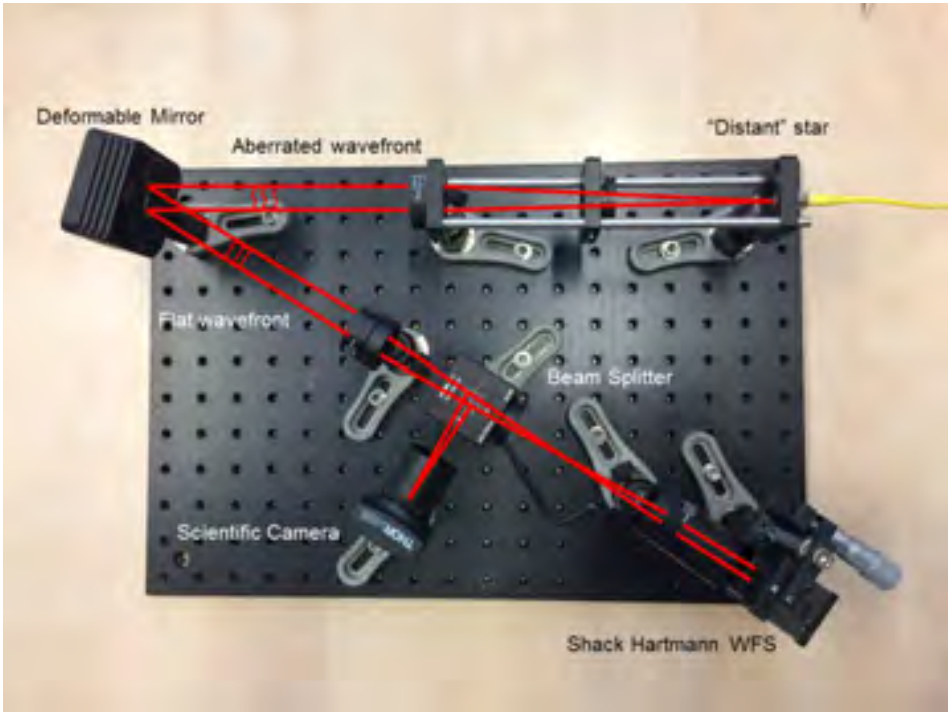
For the M1 segmented mirror of the VLT with 8 K actuators and 16K sensors (no structure in the model matrices)

Computational Complexity:

1. Off-line Solution of the least squares problem - $O(K^3)$
2. Real-time Calculation (MVM) - $O(K^2)$



Real-life Demo



Thanks to the people of The Smart Optics Lab and many others ...