



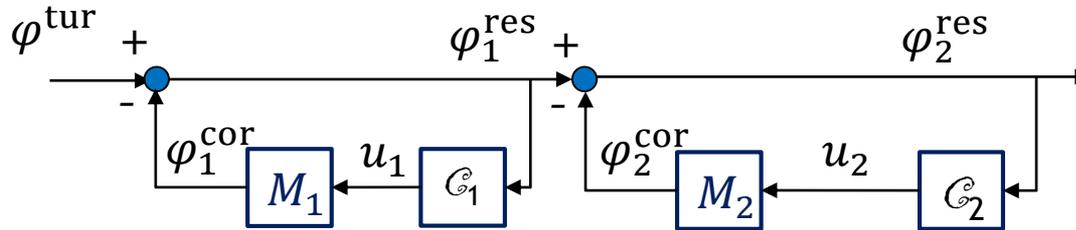
# Cascade Adaptive Optics with two stages for XAO: how disentangled control can improve performance

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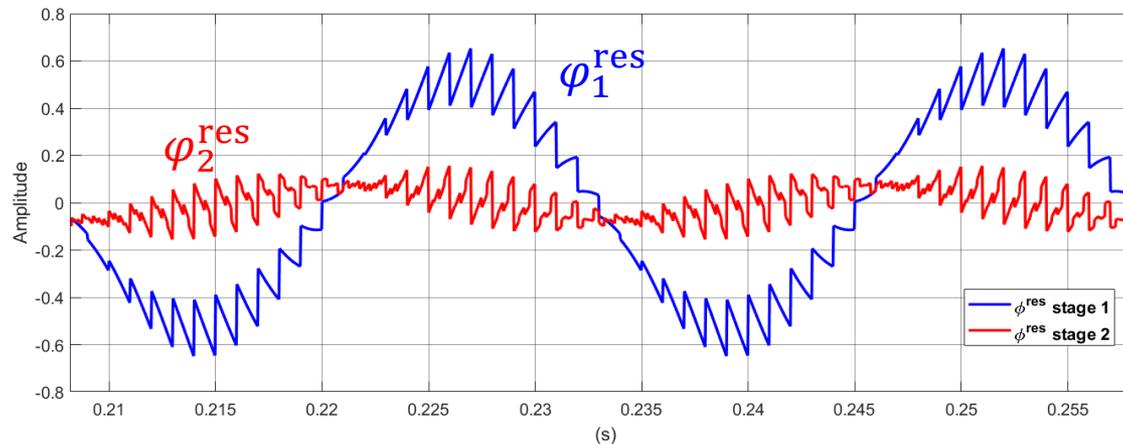


$F_1 < F_2$   
 $M_1, M_2$ : DMs + delays  
 $G_1, G_2$ : WFSs + controllers

- 1<sup>st</sup> stage residual  $\varphi_1^{res}$  fed into 2<sup>nd</sup> stage
- Smaller 2<sup>nd</sup> stage signals
  - ⇒ High-sensitivity WFS (e.g., pyramid)
  - ⇒ Higher bandwidth DM
- Faster 2<sup>nd</sup> stage
  - ⇒ Improved correction, especially for low spatial frequencies
  - ⇒ Improved rejection transfer function

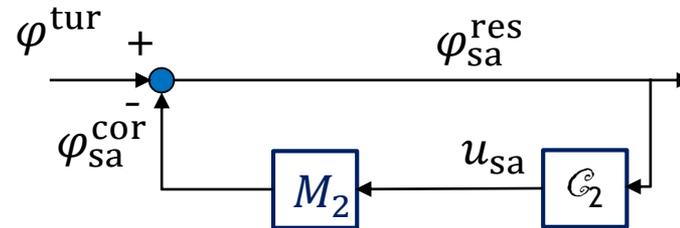
- Simple 2-stage simulation:  $F_1 = 1$  kHz,  $F_2 = 4$  kHz  
 $\varphi^{\text{tur}}$  = sinusoidal signal, amplitude 1, 40 Hz

cf. talk on CAO yesterday



- High-frequency see-saw component of  $\varphi_1^{\text{res}}$ 
  - ⇒ non-stationary process
  - ⇒ no efficient compensation by linear time-invariant controller

# 1. Disentangled CAO (dCAO)

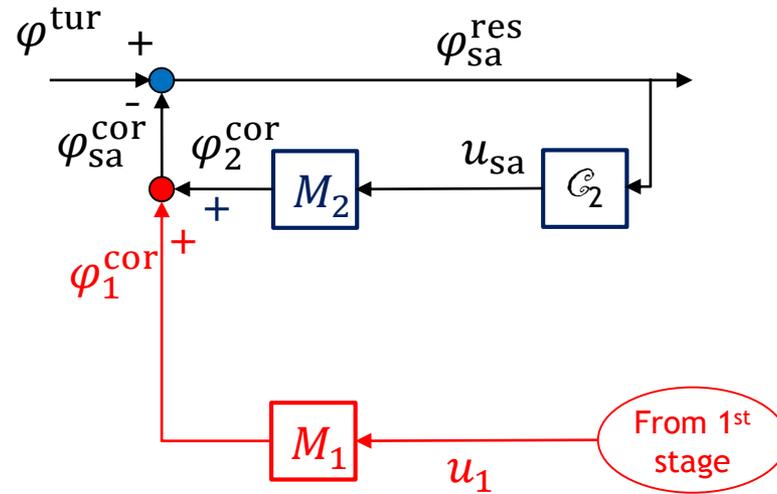


Stand-alone fast LTI 2<sup>nd</sup> stage to  
 efficiently correct for the turbulence?

# 1. Disentangled CAO (dCAO)

$$\varphi_{sa}^{cor} = \varphi_1^{cor} + \varphi_2^{cor}$$

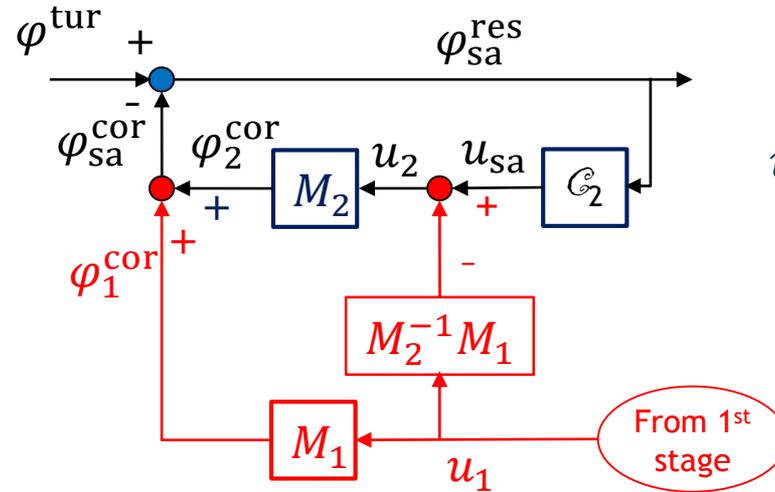
What you want



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What you want



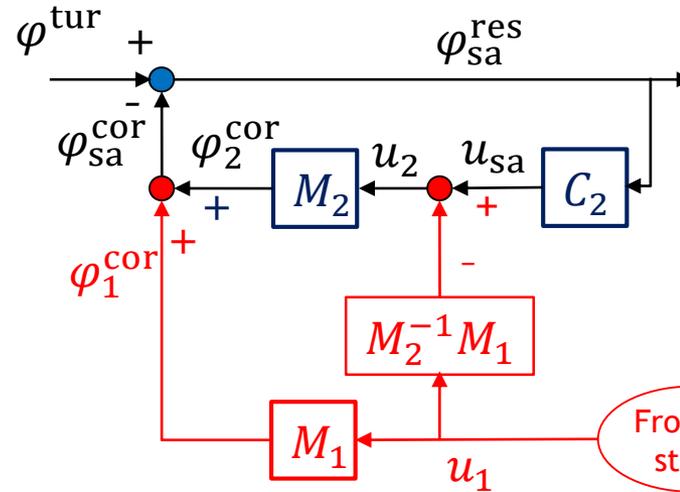
$$u_2 = u_{sa} - M_2^{-1}M_1 u_1$$

From 1<sup>st</sup> stage

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What you want



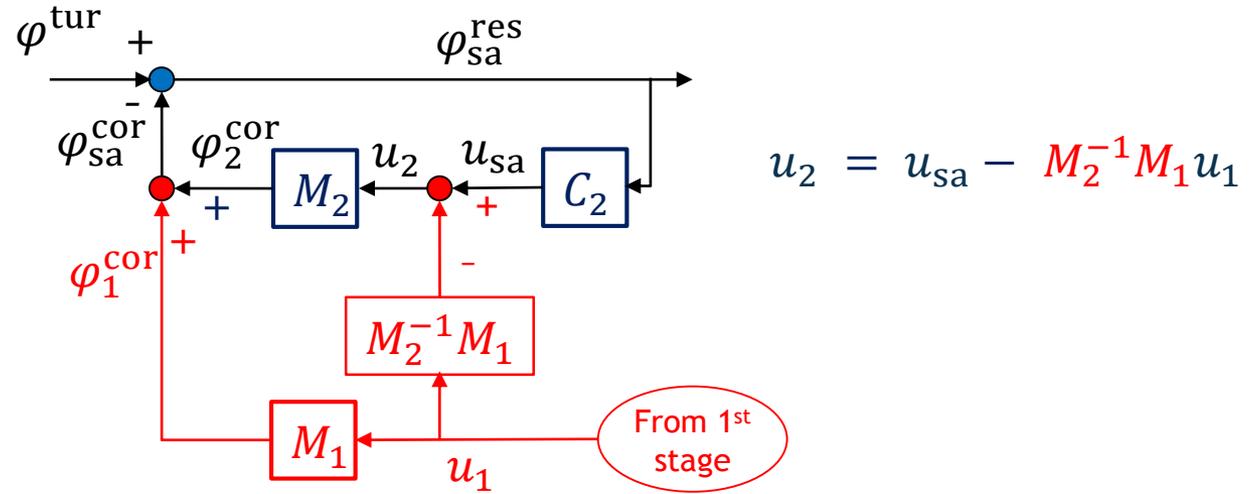
$$u_2 = u_{sa} - M_2^{-1} M_1 u_1$$

⇒ Total control effort split between  $u_1$  and  $u_2$  (like a woofer-tweeter!)

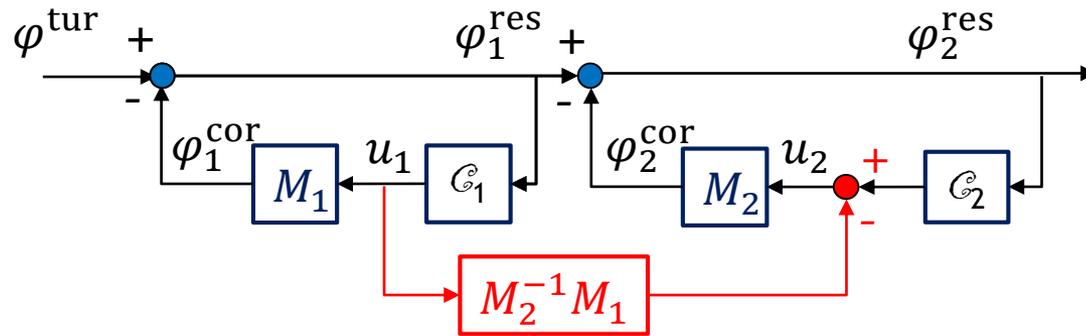
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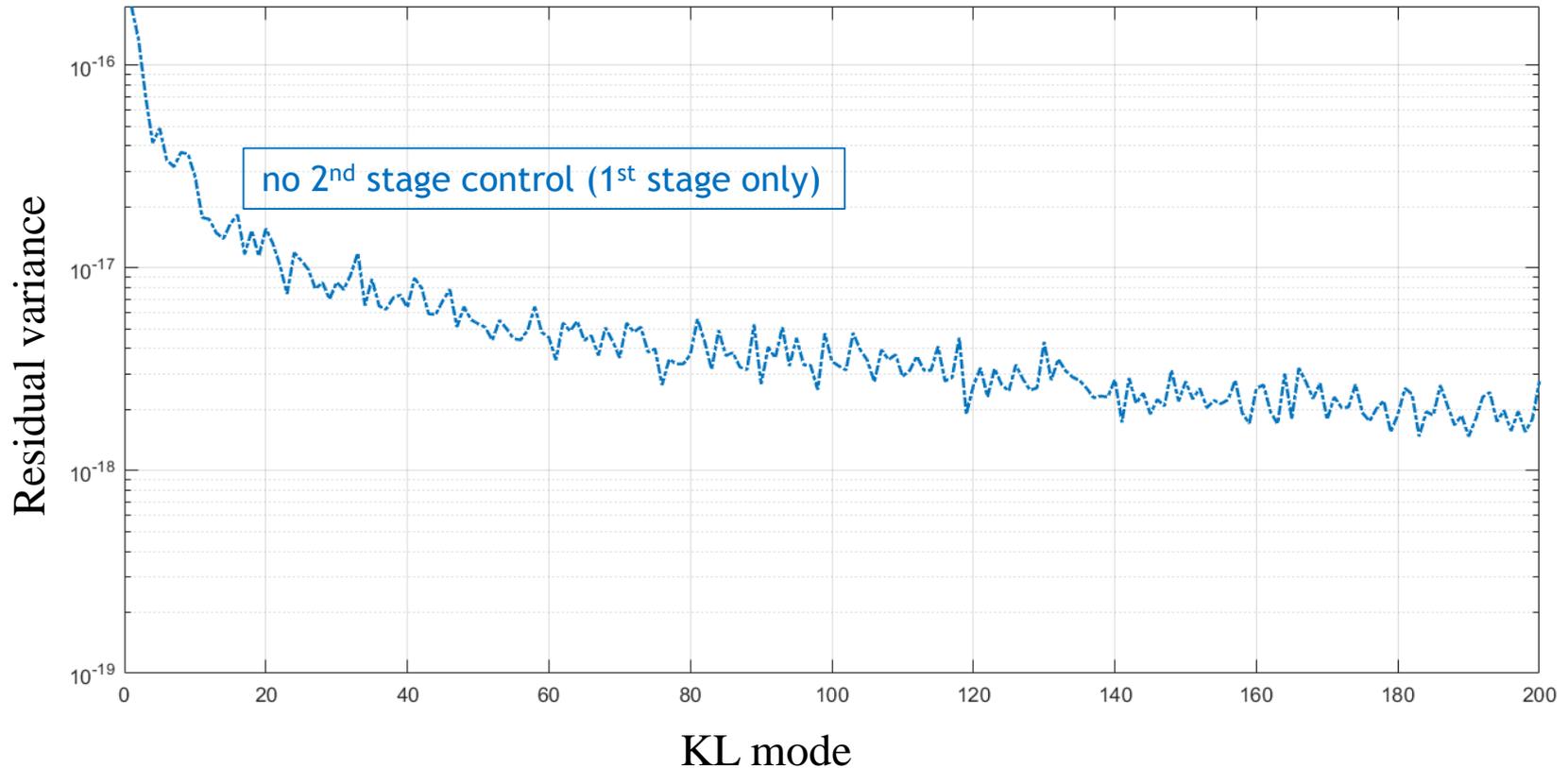


$M_1, M_2$ : DMs + delays  
 $C_1, C_2$ : WFSs + controllers

# 2. Simulation results: XAO system

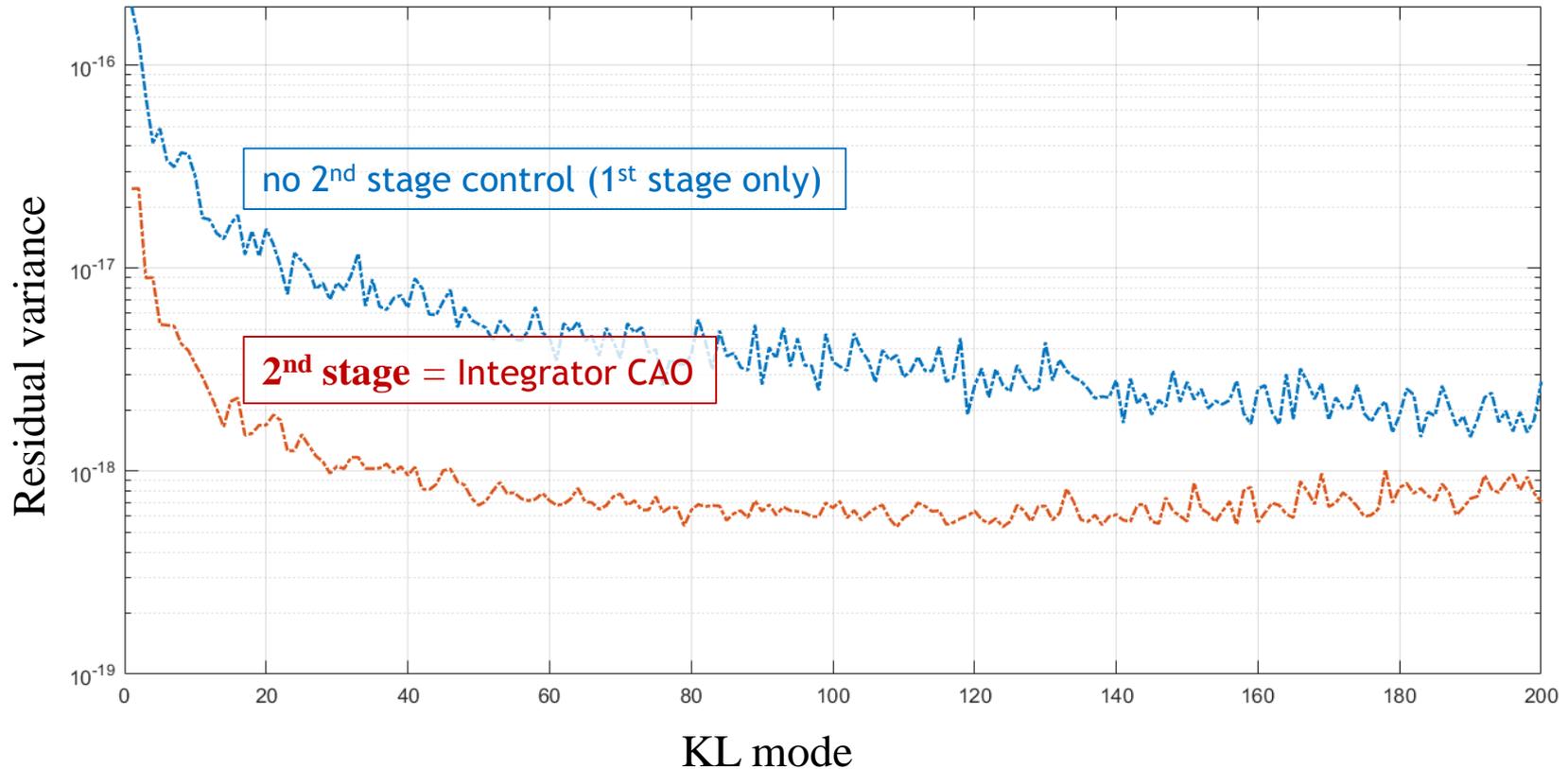
- 2-stage XAO system, 8-meter telescope,  $F_1 = 1$  kHz,  $F_2 = 4$  kHz
- 1<sup>st</sup> stage controller = integrator

1<sup>st</sup> stage WFS J-band (GS Mag 7.35), 2<sup>nd</sup> stage WFS I-band (GS Mag 7.41),  $r_0 = 0.157$  (I-band)



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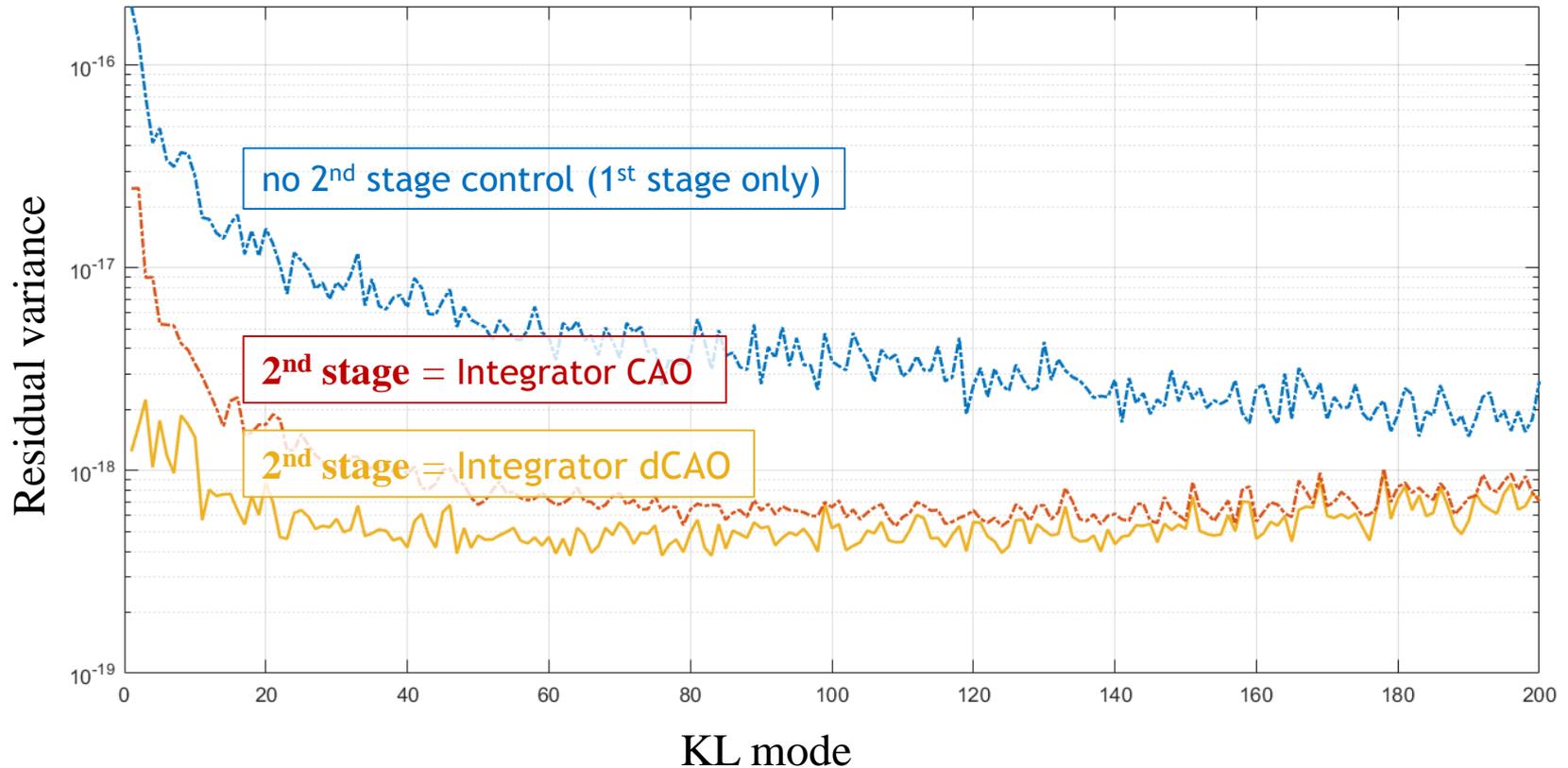
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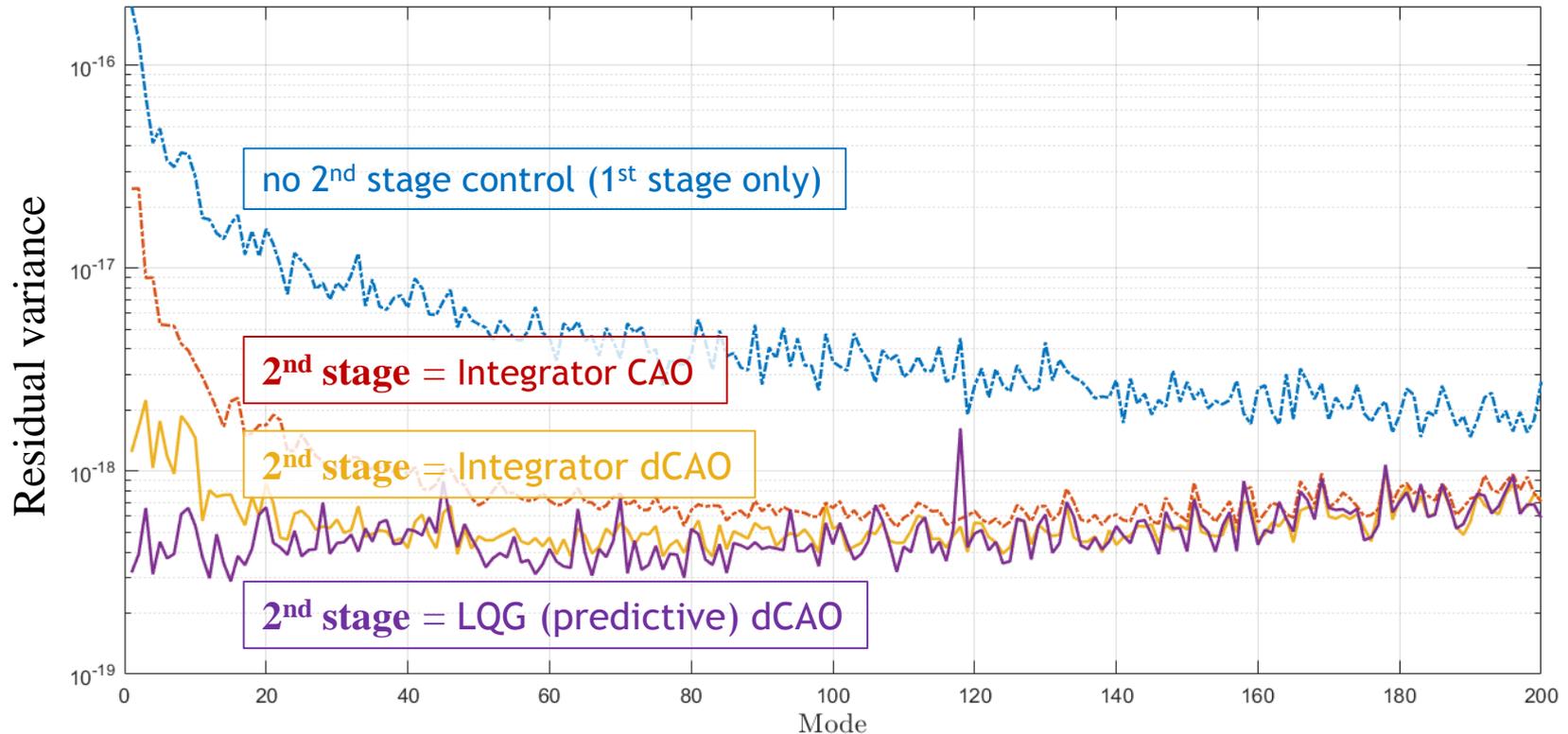
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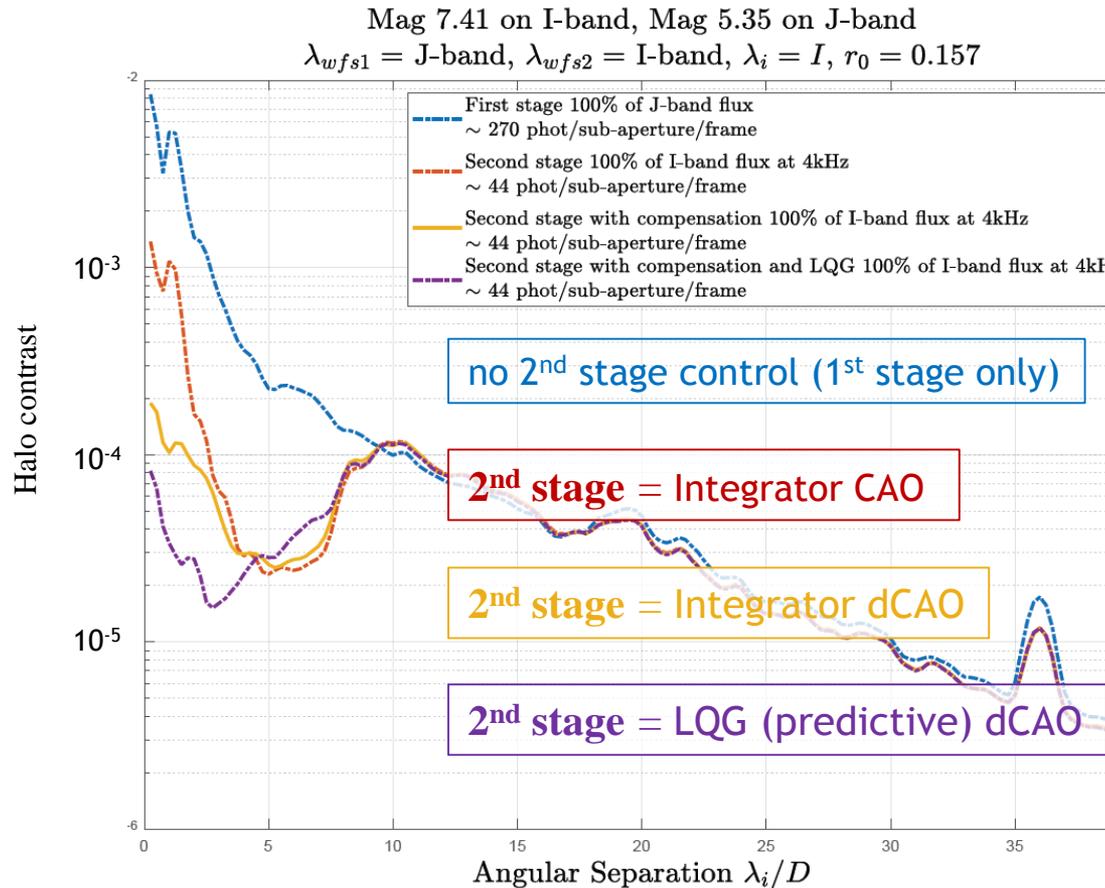
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- dCAO  $\Rightarrow$  significant improvement
- LQG (predictive)  $\Rightarrow$  further improvement especially for low-order modes (should be good for contrast...)

# 3. What about contrast?

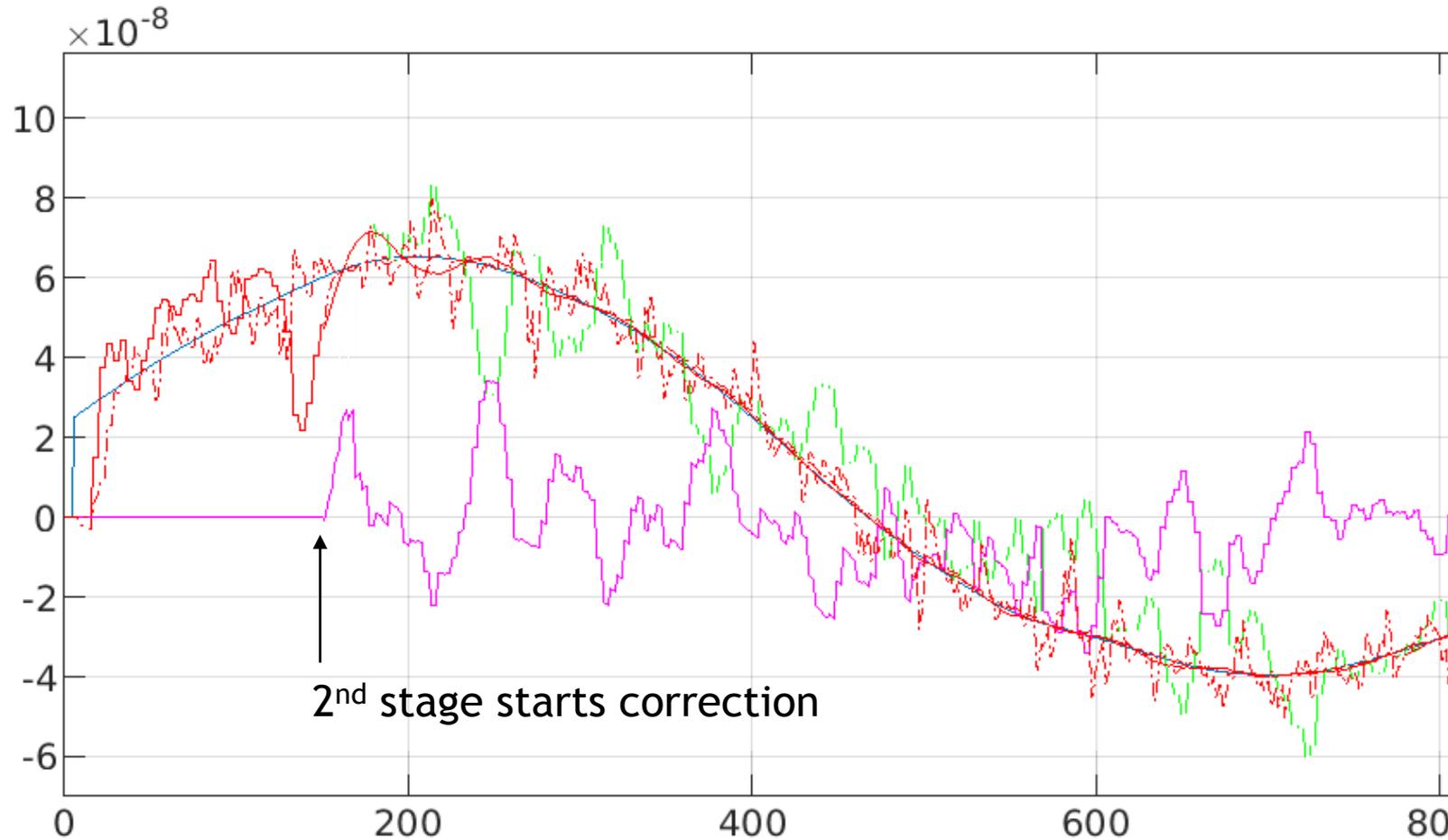


⇒ Greater contrast sensitivity at small angular separations

⇒ Improved imaging of faint exoplanets close to their host star

⇒ Puts proxima b at our reach

# 4. Switching adapter

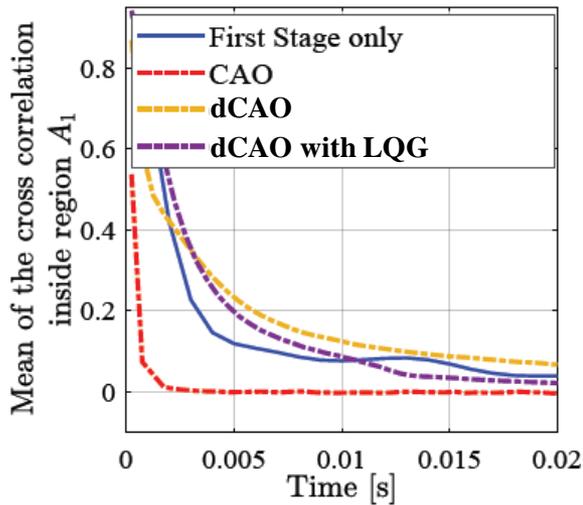


⇒ Allows to launch the 2<sup>nd</sup> stage without modulating the PWFS

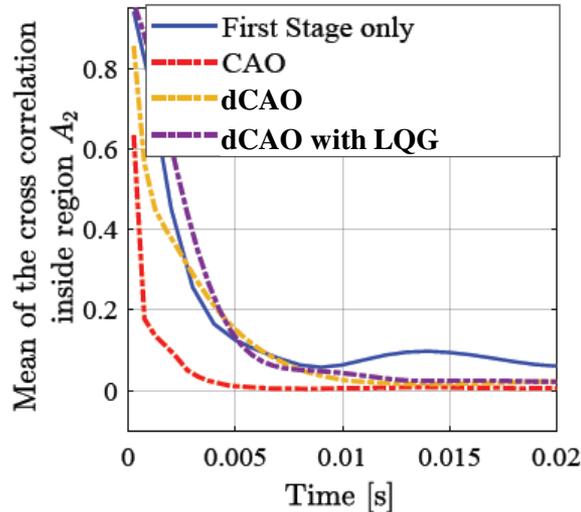
# 5. What about speckle lifetime?

Mean of the PSF cross-correlation inside rings of width

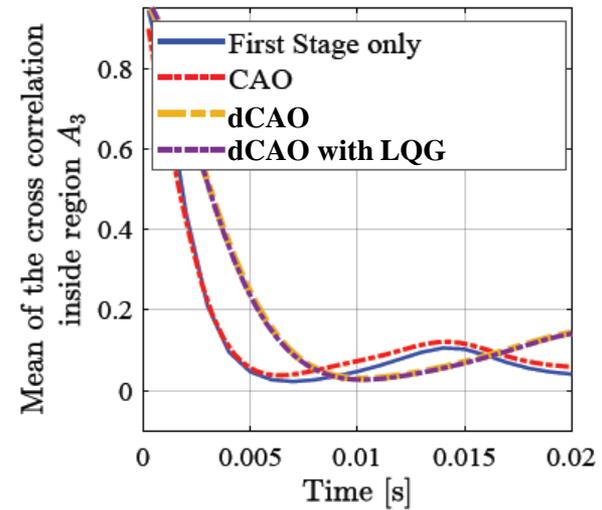
$2-5 \left[ \frac{\lambda}{D} \right]$



$5-8 \left[ \frac{\lambda}{D} \right]$



$12-15 \left[ \frac{\lambda}{D} \right]$



- ⇒ Speckle lifetime depends on rejection transfer function
- ⇒ Lifetime is degraded compared with CAO
- ⇒ Could be improved by increasing rejection at low temporal frequencies

- Disentangled CAO
  - ⇒ Significant improvement with 2<sup>nd</sup> stage integrator
  - ⇒ Requires adequate calibration & synchronization of 1<sup>st</sup> & 2<sup>nd</sup> stages
- 2<sup>nd</sup> stage LQG
  - ⇒ Lower residual, higher contrast, increased speckle lifetime
  - ⇒ Avoid transient control bumps when engaging 2nd stage

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## Perspectives

- Modeling and control issues
  - Good data-based turbulence model for LQG control (as always!)
  - Combine LQG control with an additional rejection at low temporal frequencies
- Candidate XAO systems
  - SPHERE update (VLT) with SAXO+
  - PCS (ELT)

# THANK YOU!