Cascade Adaptive Optics with non-modulated Pyramid WFS

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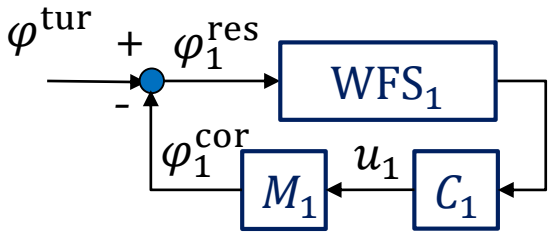
This work has received funding from the European Union Horizon 2020 research and innovation program, ORP Pilot, grant agreement No 101004719

1. Two-stage Cascade AO



$F_1 = 1\ \mathrm{k\,Hz}$

M_1: Deformable mirror

C_1: Integrator controller

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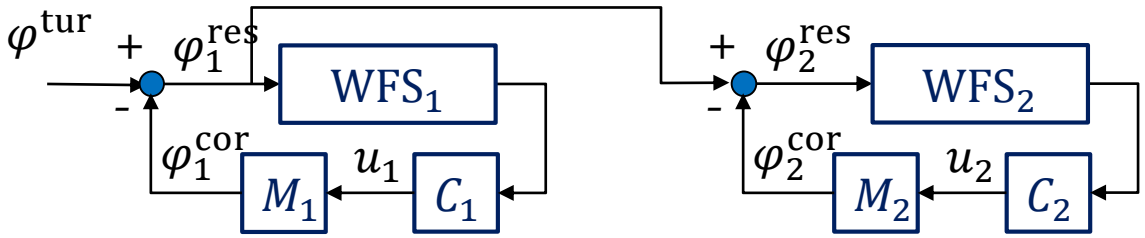

$F_1 = 1$ k Hz
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$F_2 = 4$ k Hz
M_2: Deformable mirror
C_2: Integrator controller

- 1st stage residual φ_1^{res} fed into 2nd stage

[Cerpa *et al.* JATIS 2022]

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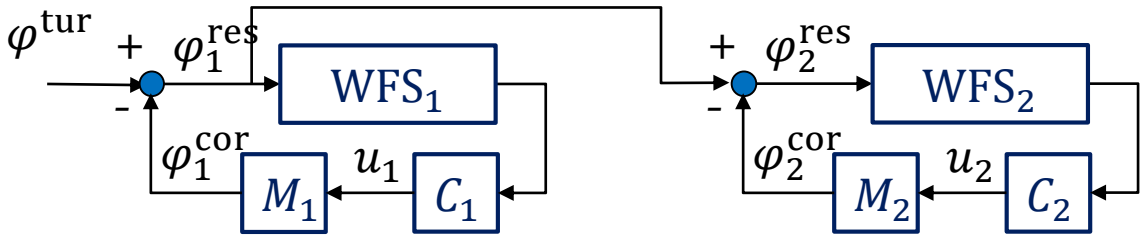

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- 1st stage residual φ_1^{res} fed into 2nd stage

- Smaller 2nd stage signals
  - ⇨ High-sensitivity WFS (e.g., pyramid)
  - ⇨ Higher bandwidth DM

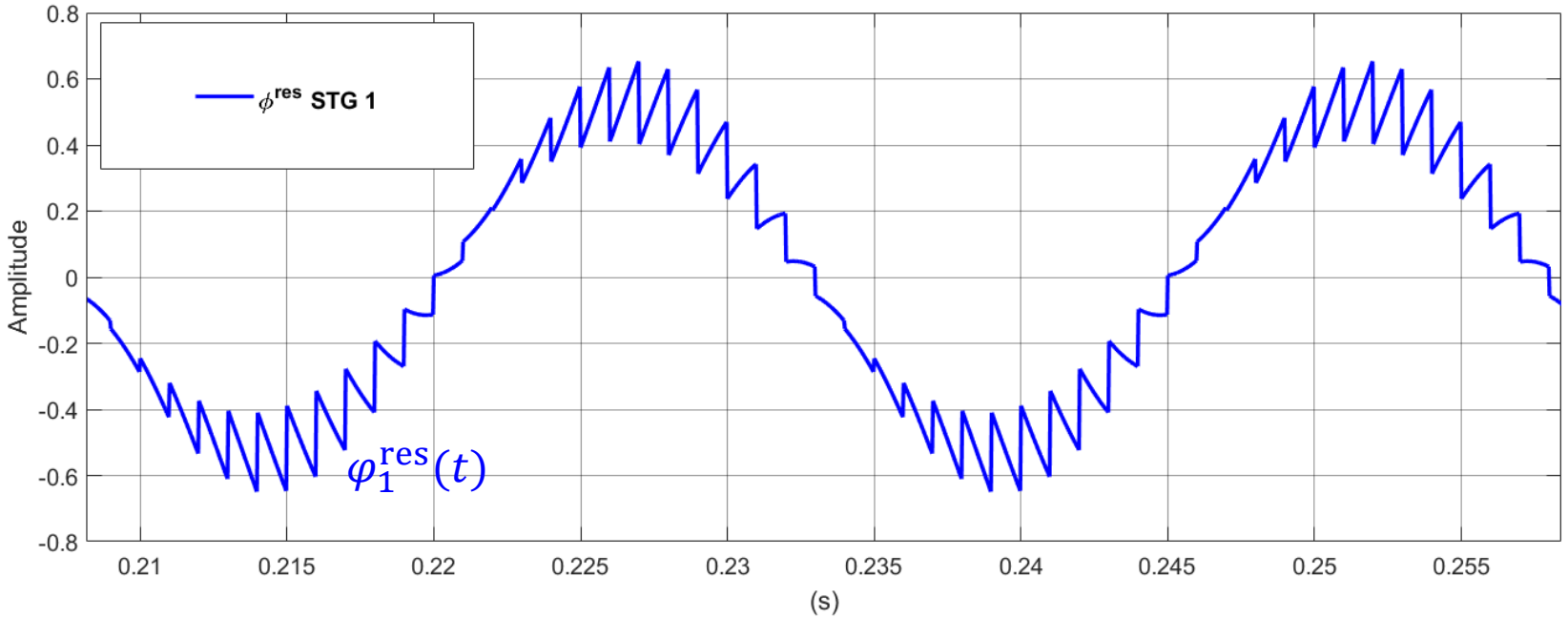
- Faster 2nd stage
  - ⇨ Improved correction, especially for low spatial frequencies
  - ⇨ Improved rejection transfer function

[Cerpa *et al.* JATIS 2022]

2. Rejection of 1st stage residuals

- Simple 2-stage simulation: F_1 = 1 kHz, F_2 = 4 kHz

  φ^{tur} = sinusoidal signal, amplitude 1, 40 Hz



- High-frequency see-saw component of φ_1^{res} = non-stationary process

[Cerpa *et al.* JATIS 2022]

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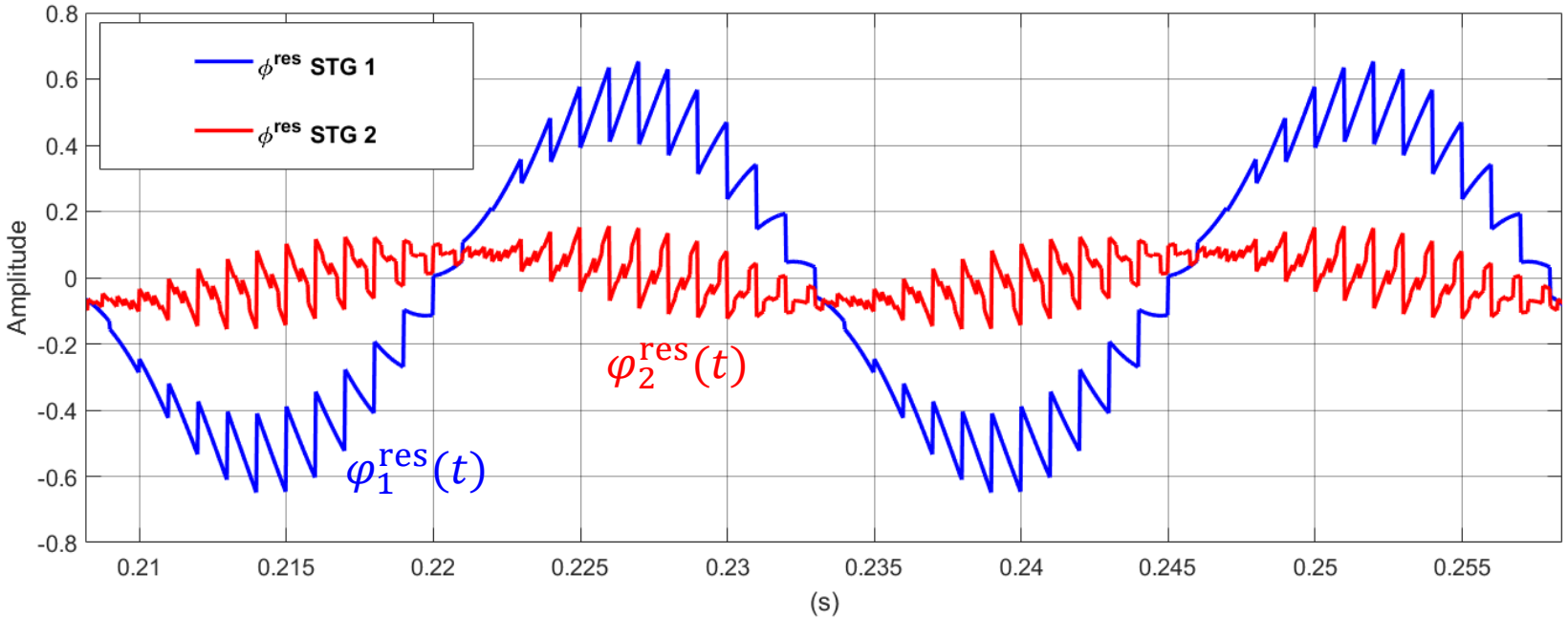

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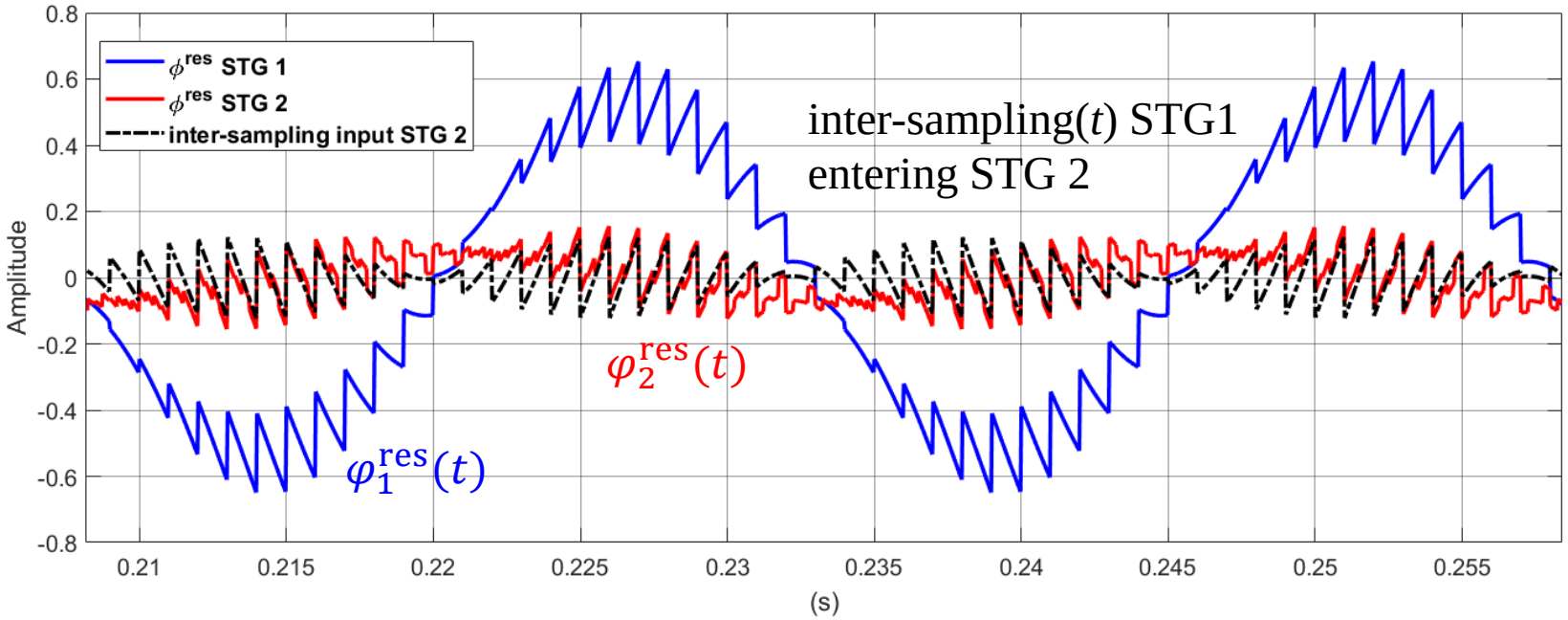


- High-frequency see-saw component of φ_1^{res} = non-stationary process

  ⇨ no efficient compensation by linear time-invariant controller

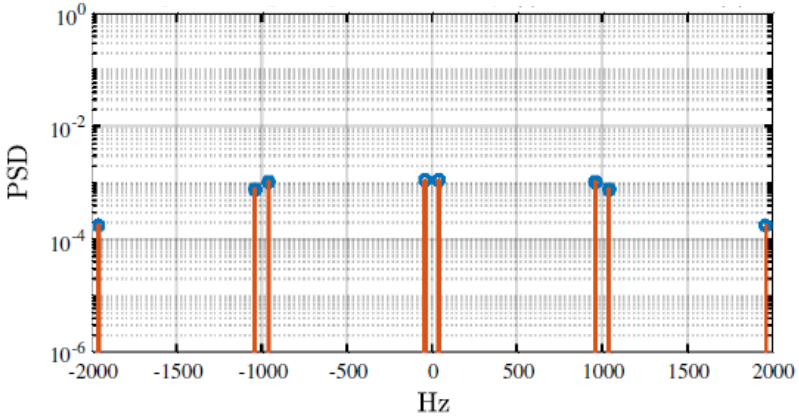
[Cerpa *et al.* JATIS 2022]

2. Rejection of 1st stage residuals

- Simple 2-stage simulation: F_1 = 1 kHz, F_2 = 4 kHz

φ^{tur} = pure sinusoidal signal 40 Hz

Spectrum at the output of STG2



⇨ Low-frequency signals generate high-frequency components because of oversampling

[Cerpa *et al.* JATIS 2022]

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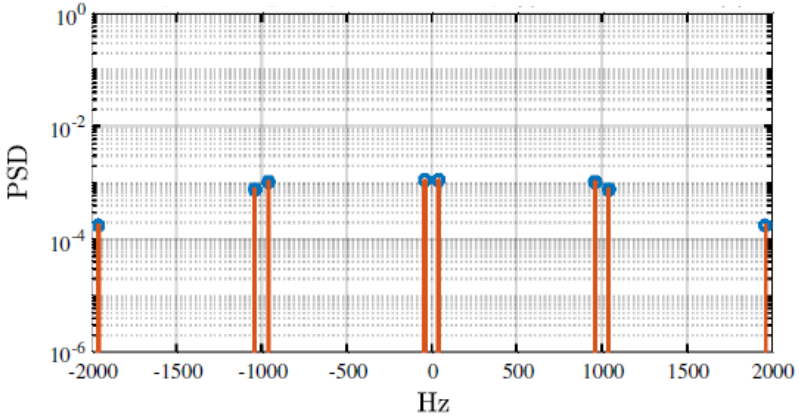
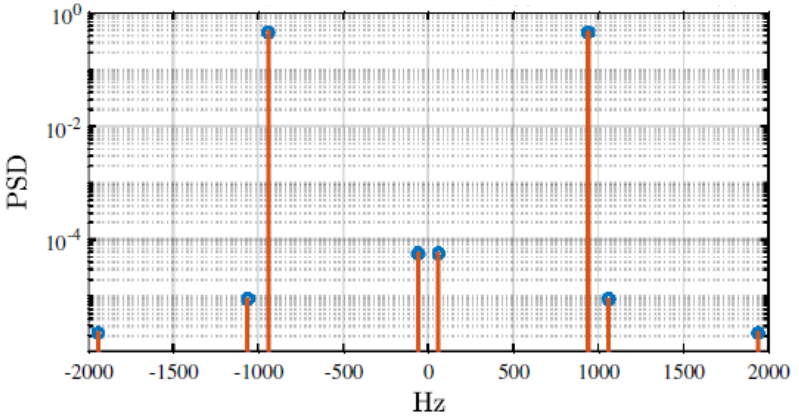


φ^{tur} = pure sinusoidal signal 940 Hz

Spectrum at the output of STG2



⇨ Low-frequency signals generate high-frequency components because of oversampling

⇨ Higher frequency signals are aliased in STG1 and badly attenuated by STG2

[Cerpa *et al.* JATIS 2022]

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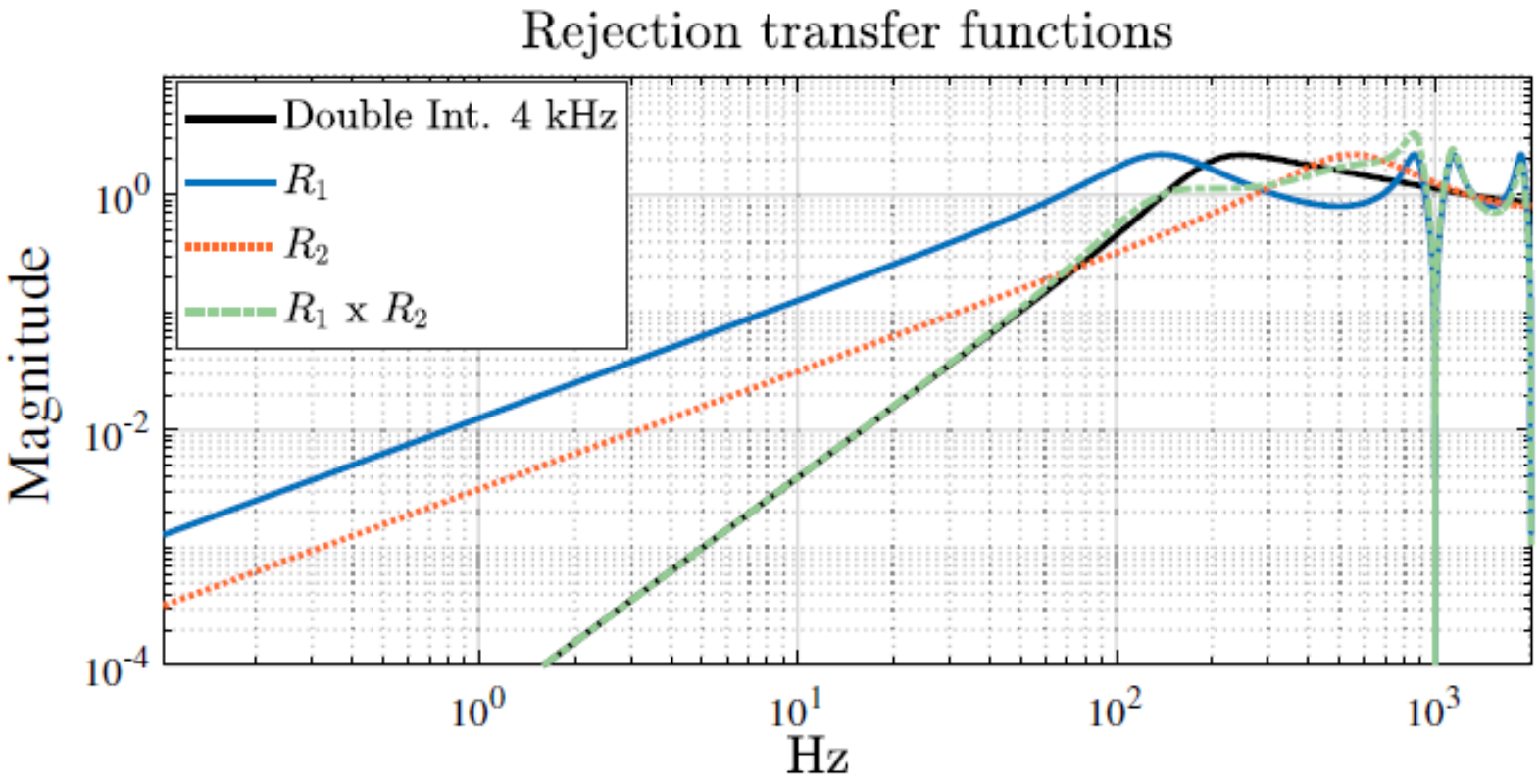

⇨ Rejection of low frequency components similar to double integrator

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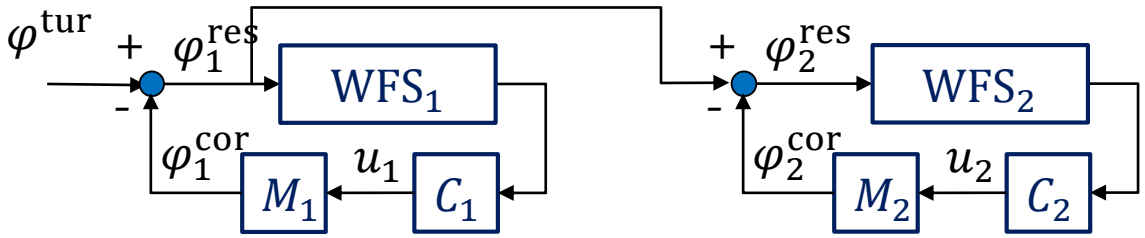
3. Simulation parameters



$F_1 = 1$ k Hz

M_1: Deformable mirror 37x37

WFS_1: Shack-Hartmann 36x36

J-band (1215 nm) or I-band (790 nm)

C_1: Integrator controller, best tuning

$F_2 = 4$ k Hz

M_2: Deformable mirror 19x19

WFS_2: non-modulated Pyramid 18x18

I-band

C_2: Integrator controller, best tuning

- Telescope diameter 8 m
- Secondary diameter 1.16 m
- Split ratio
  - 80 % on 1st stage
  - 20 % on 2nd stage

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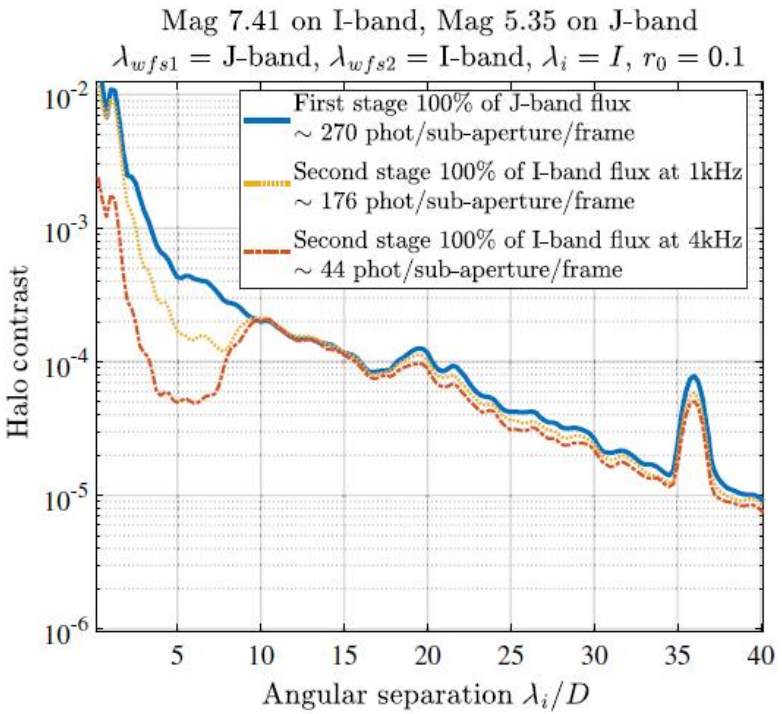
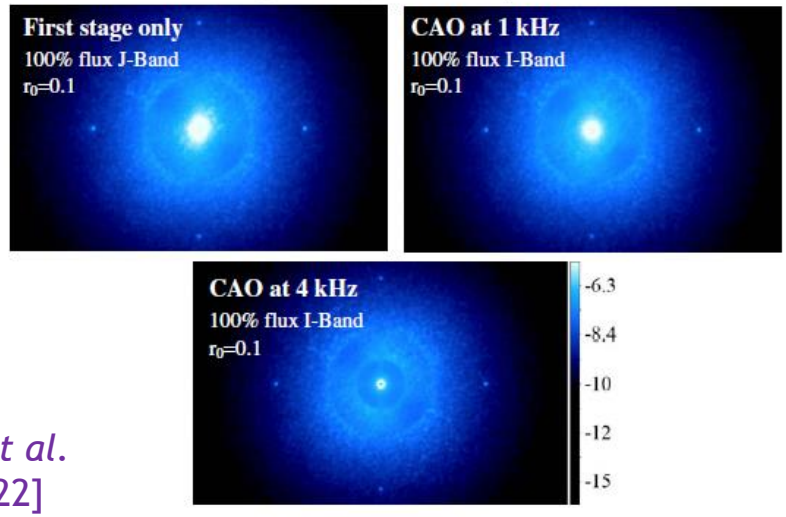
4. Contrast





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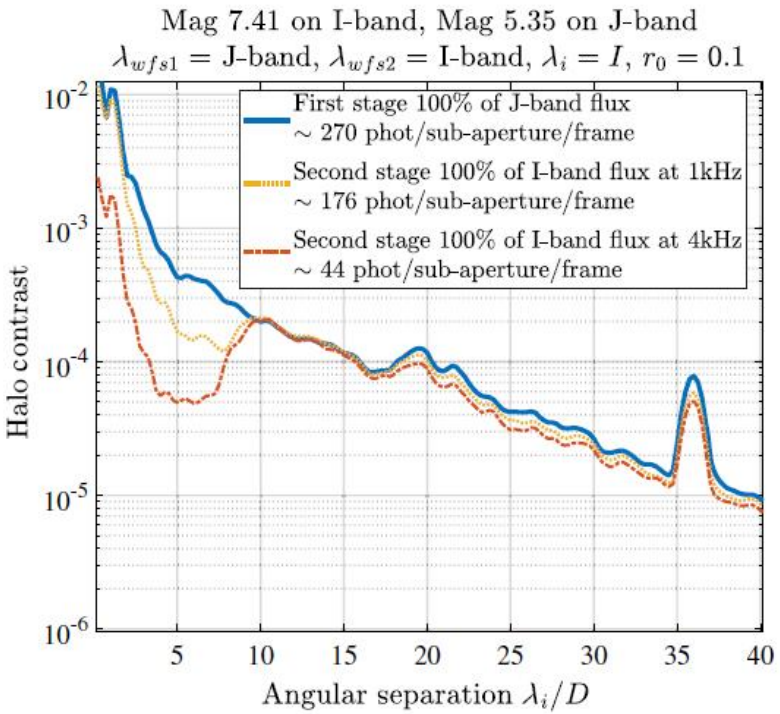

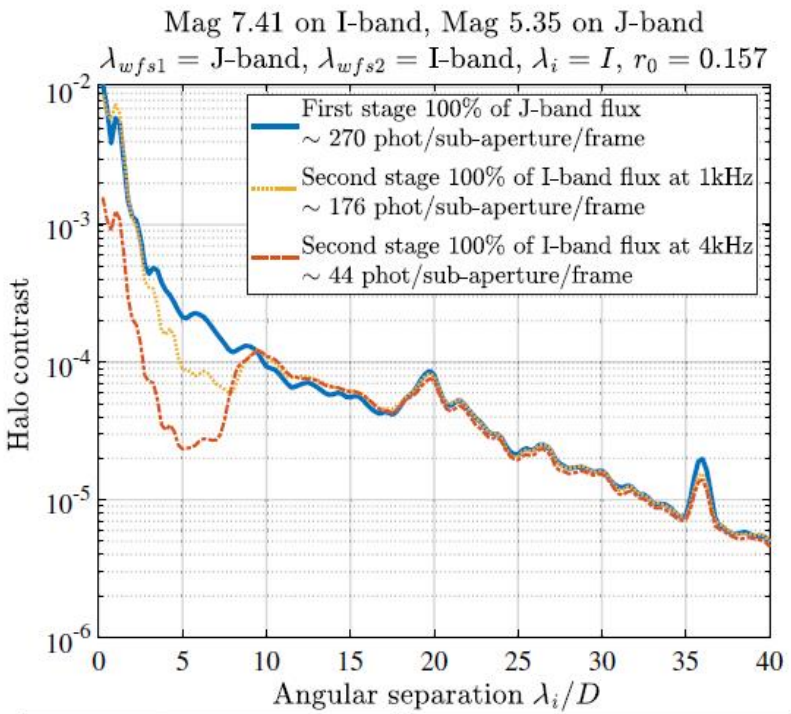

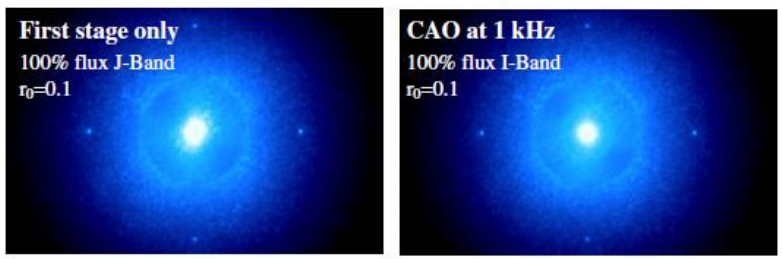

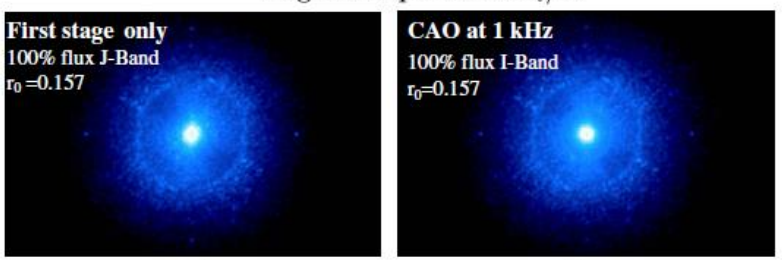

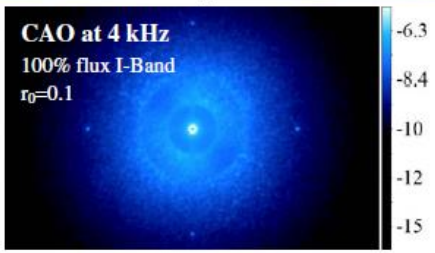

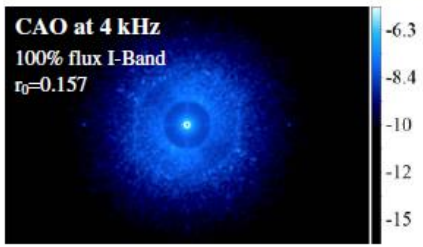

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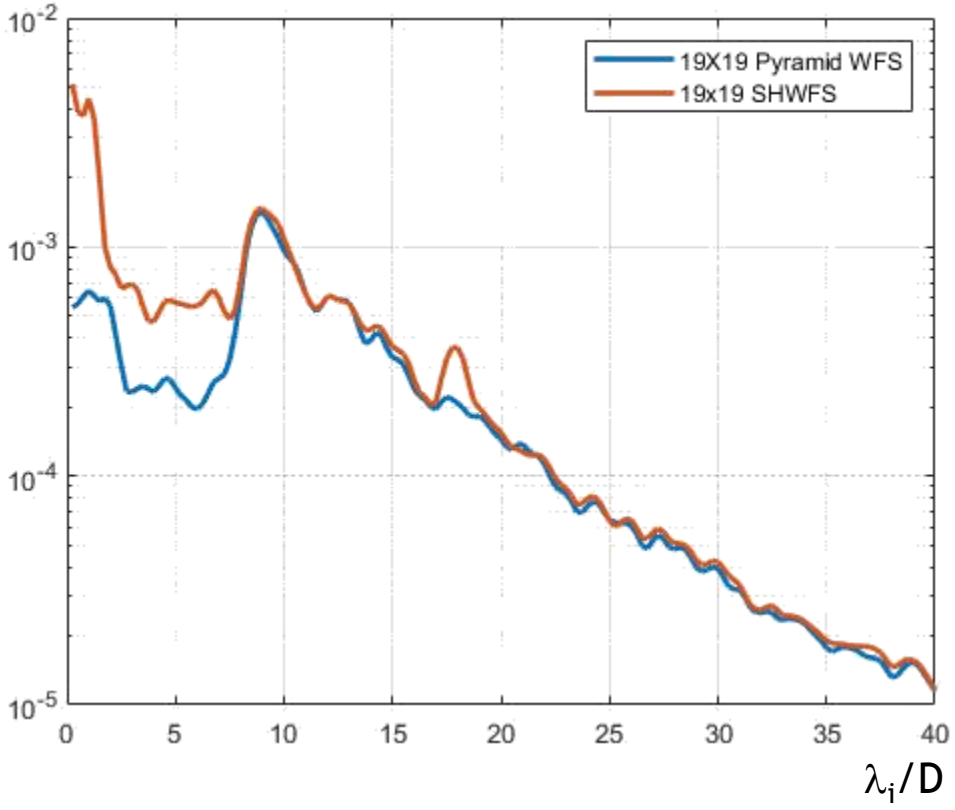
4. Contrast

2nd stage: Shack-Hartmann vs Pyramid



⇨ The Pyramid WFS better improves contrast (it's not just the loop frequency)

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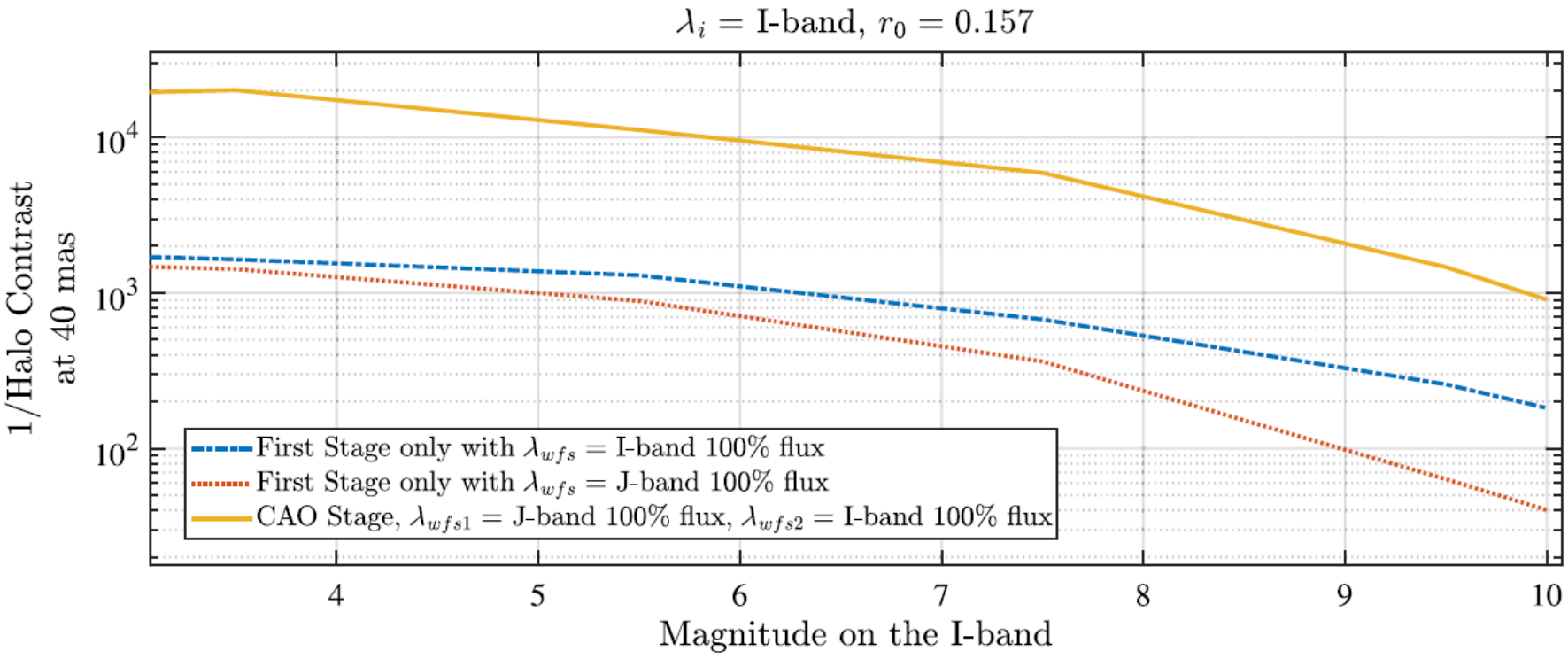

⇨ One order of magnitude better in contrast

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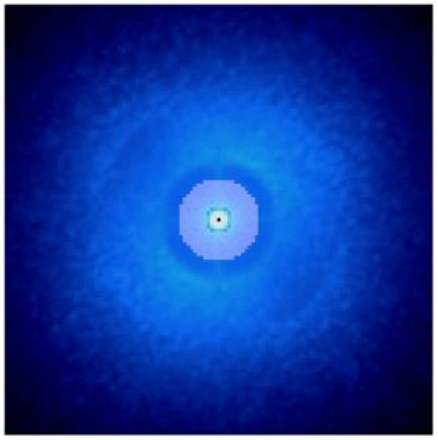
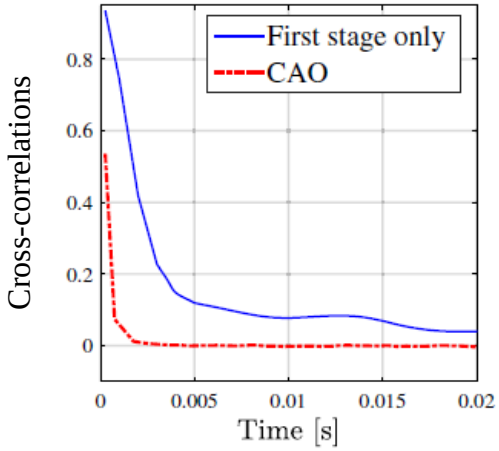
5. Speckle lifetime

2 – 5 λ/D





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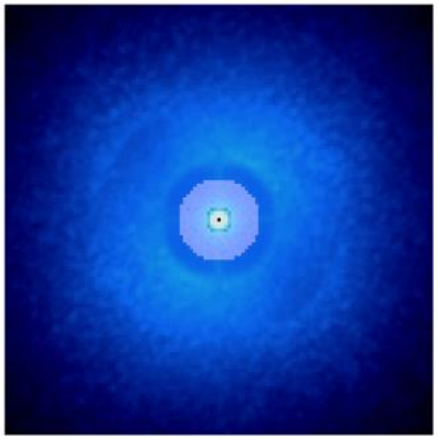
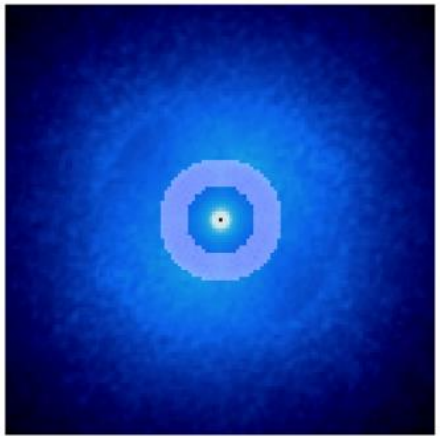
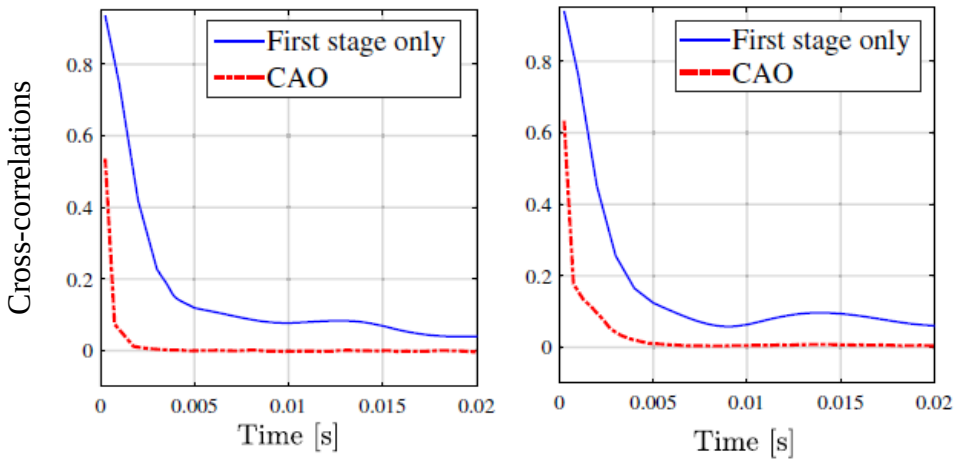


5 - 8 λ/D





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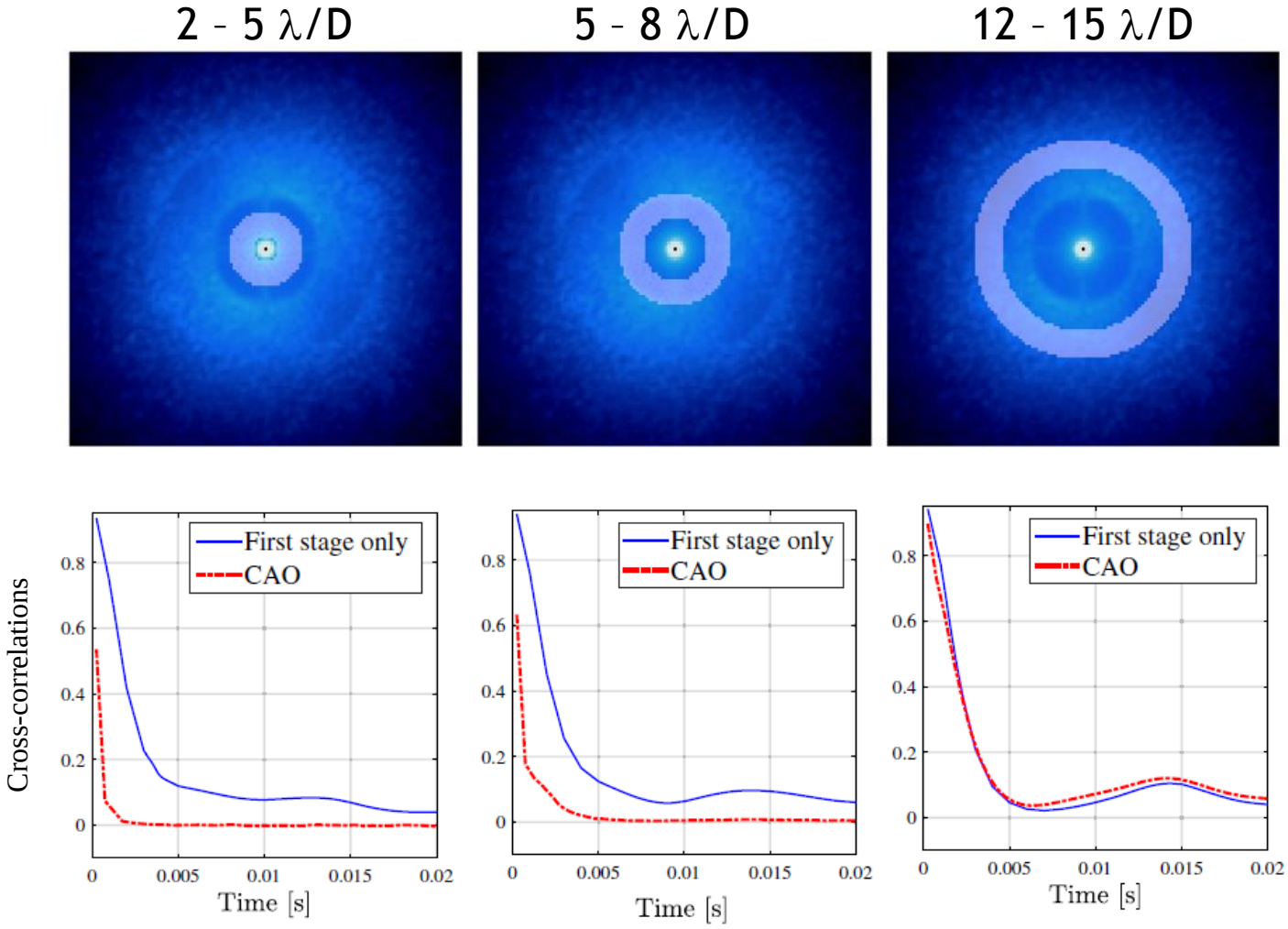

⇨ Speckle lifetime improvement linked to rejection

[Cerpa *et al.* JATIS 2022]

6. Conclusions and perspectives

- CAO
  - ⇨ 1st stage residuals: non-stationary processes
  - ⇨ Oversampling of 2nd stage: periodization induces high-frequency components
  - ⇨ Contrast and speckle lifetime improved

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  - ⇨ 1st stage residuals: non-stationary processes
  - ⇨ Oversampling of 2nd stage: periodization induces high-frequency components
  - ⇨ Contrast and speckle lifetime improved

Perspectives

- Modeling and control issues cf. Disentangled CAO talk on Friday
  - Modify the CAO structure to avoid see-saw behavior
  - Improve 2nd stage controller to limit amplification at high frequency
- Candidate XAO systems
  - SPHERE update (VLT) with SAXO+
  - PCS (ELT)

THANK YOU!