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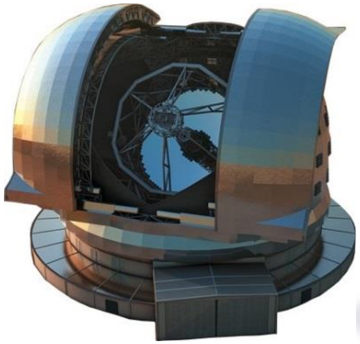

# Disturbance Feedforward Control for Vibration Suppression in Adaptive Optics of Large Telescopes

Martin Glück, Jörg-Uwe Pott, Oliver Sawodny

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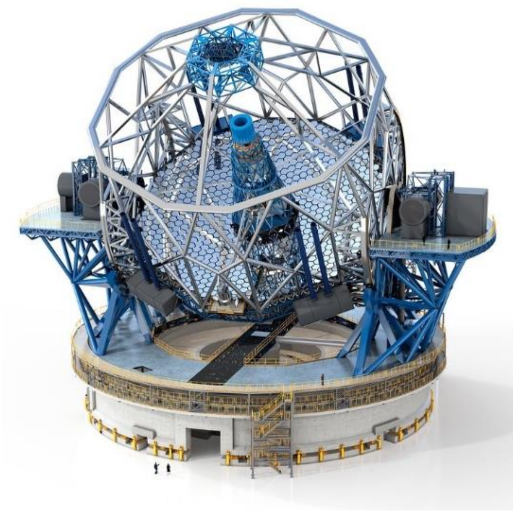
Institute for System Dynamics

**Disturbances affecting the Telescope Resolution**

- Atmospheric Turbulences
- Structural Vibrations

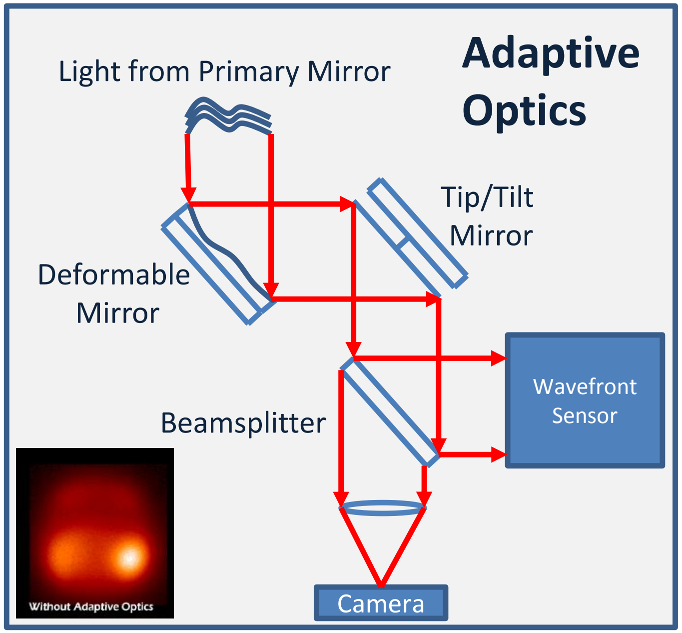
⇨ Adaptive Optics



**Observations with Faint Guide Stars**

- Long exposure for better Signal-to-Noise-Ratio
- Adaptive Optics (AO) loop speed is reduced
- High frequency Vibrations are seen at the Telescope Mirror (> 5 Hz)
- Classical AO loop is to slow

⇨ Accelerometer-based Disturbance Feedforward



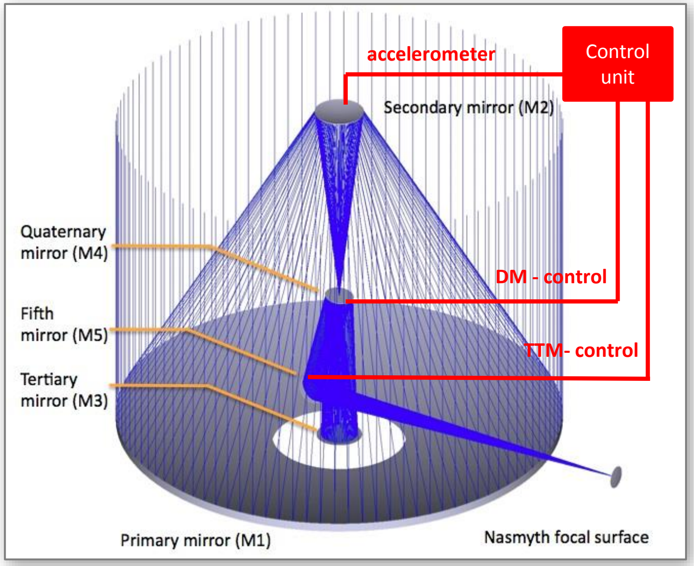
# Accelerometer-based Disturbance Feedforward Control

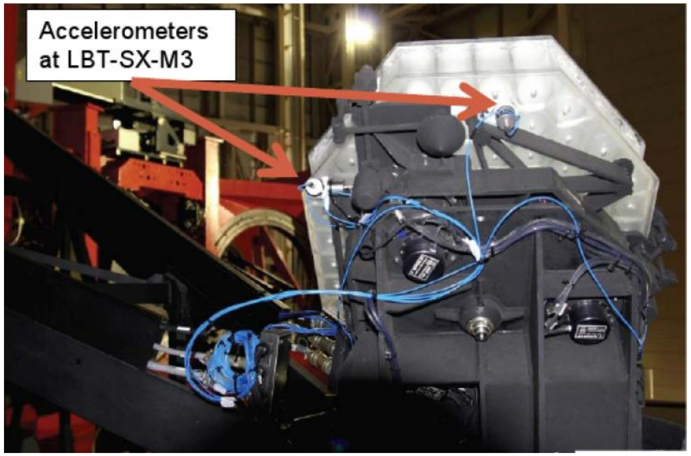
## Compensation of the Telescope Vibrations

- Measuring vibrations at relevant telescope mirrors with additional accelerometers
- Reconstruction of the Optical Modes influenced by Vibrations (Piston, Tip, Tilt Zernike Modes)
- Compensating by the Tip-Tilt mirror and Deformable Mirror

➡ Independent of the Wavefront Exposure Time

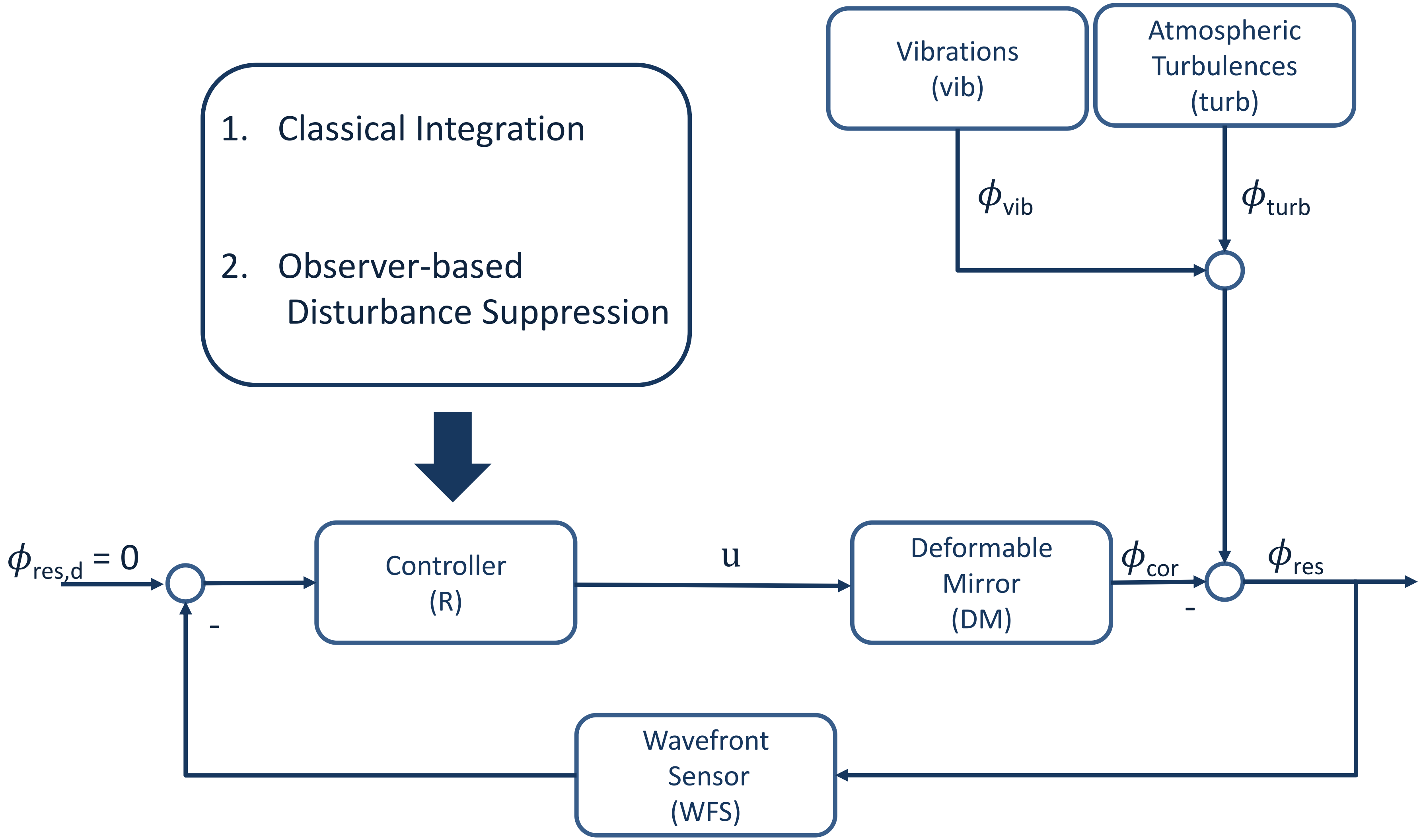
➡ Suppression of high frequency Vibrations

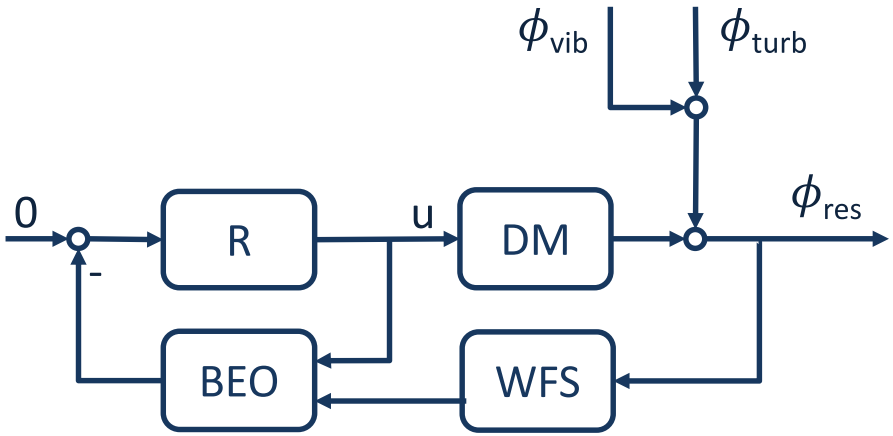


# Agenda

# Overview Adaptive Optics






**Assumptions**

- DM ≈ 1 (fast position control)
- 2 sample delay of the WFS

**Disturbance Modelling**

- Atmosphere
  - Approximation of the temporal power spectral density by a second order AR model

$$X_t = a_1 X_{t-1} + a_2 X_{t-2} + \epsilon_t$$

- Vibrations
  - Modal representation of the mechanical system (considering dominant natural frequencies) $\ddot{x} + 2d\omega_0\dot{x} + \omega_0^2 x = u$

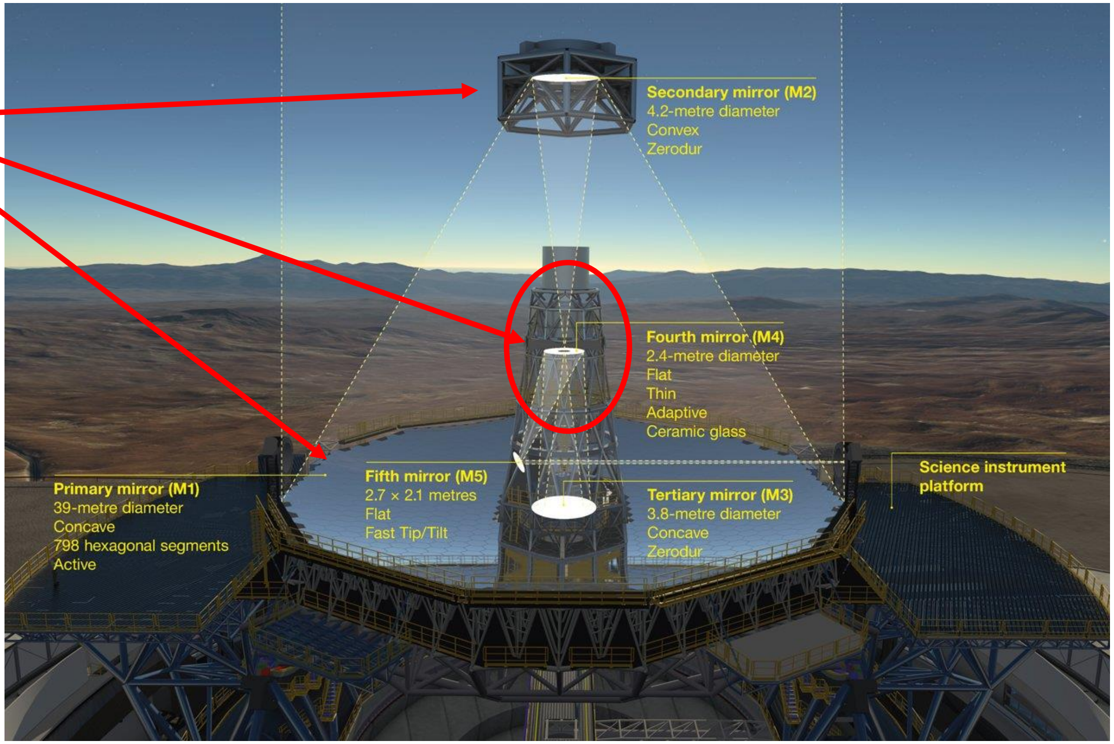
# Accelerometer-based Disturbance Feedforward Control

**Concept**

- Measuring Vibrations with Accelerometers at Telescope structure

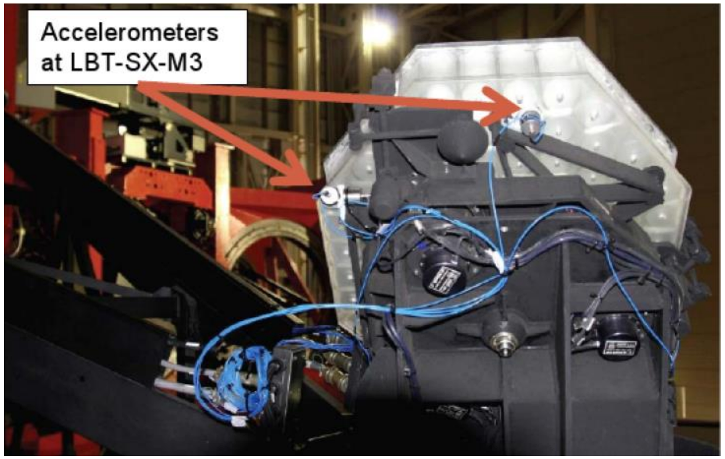
- Reconstructing Optical Modes (Piston, Tip, Tilt, Defocus)
  - Different Tip-Tilt Sensitivity of each Mirror

- Adding to the Control Input of the Adaptive Mirrors (M4, M5)
  - Considering time delay



## Challenges

- Online Double Integration of Accelerometer Signals
  - Unstable
- Time Delay




## Reconstruction Methods

- Approximation of a Double Integrator by a Bandpass Filter, Böhm[2]
- Disturbance Observer
  - Modal Model of the Mechanics
  - Luenberger Observer Design
- Adaptive Resonator , Keck[1]
  - Using Online Fourier Analysis

$$\dot{x} = \begin{bmatrix} 0 & 1 \\ -\omega_0^2 & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u \qquad y = \begin{bmatrix} -\omega_0^2 & 0 \end{bmatrix} x$$

$$\dot{\hat{x}} = A\hat{x} + L\,(y - \hat{y}), \qquad \hat{y} = C\hat{x}$$

$$\ddot{\varphi}_{AR,i} = A\,cos(\omega_1 \mathrm{t}) + \mathrm{B}\sin(\omega_1 t)$$

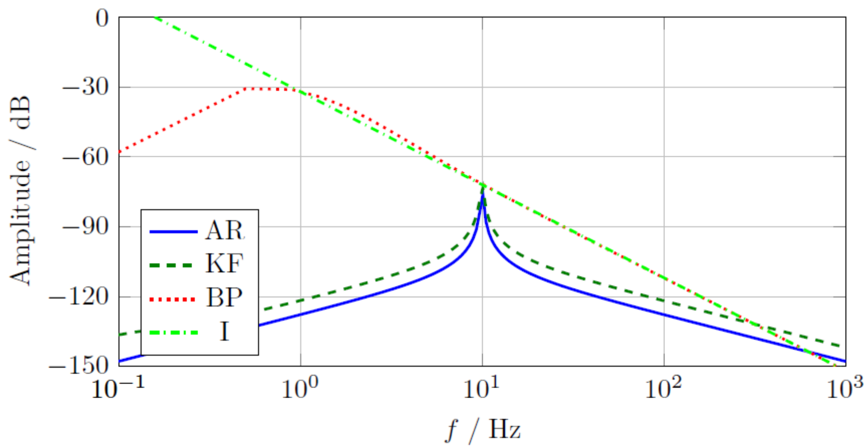
$$\varphi_{AR,i} = -\frac{1}{\omega_1^2}\,\ddot{\varphi}_{AR,i}$$

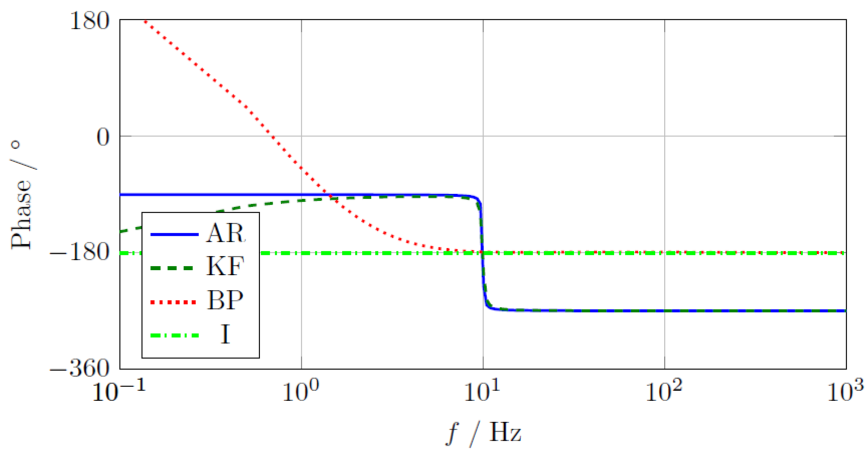
$$\Rightarrow$$

$$A = \int_0^t g(\ddot{z}_i - \ddot{z}_{AR,i})\cos(\omega_1\tau)\,d\tau$$

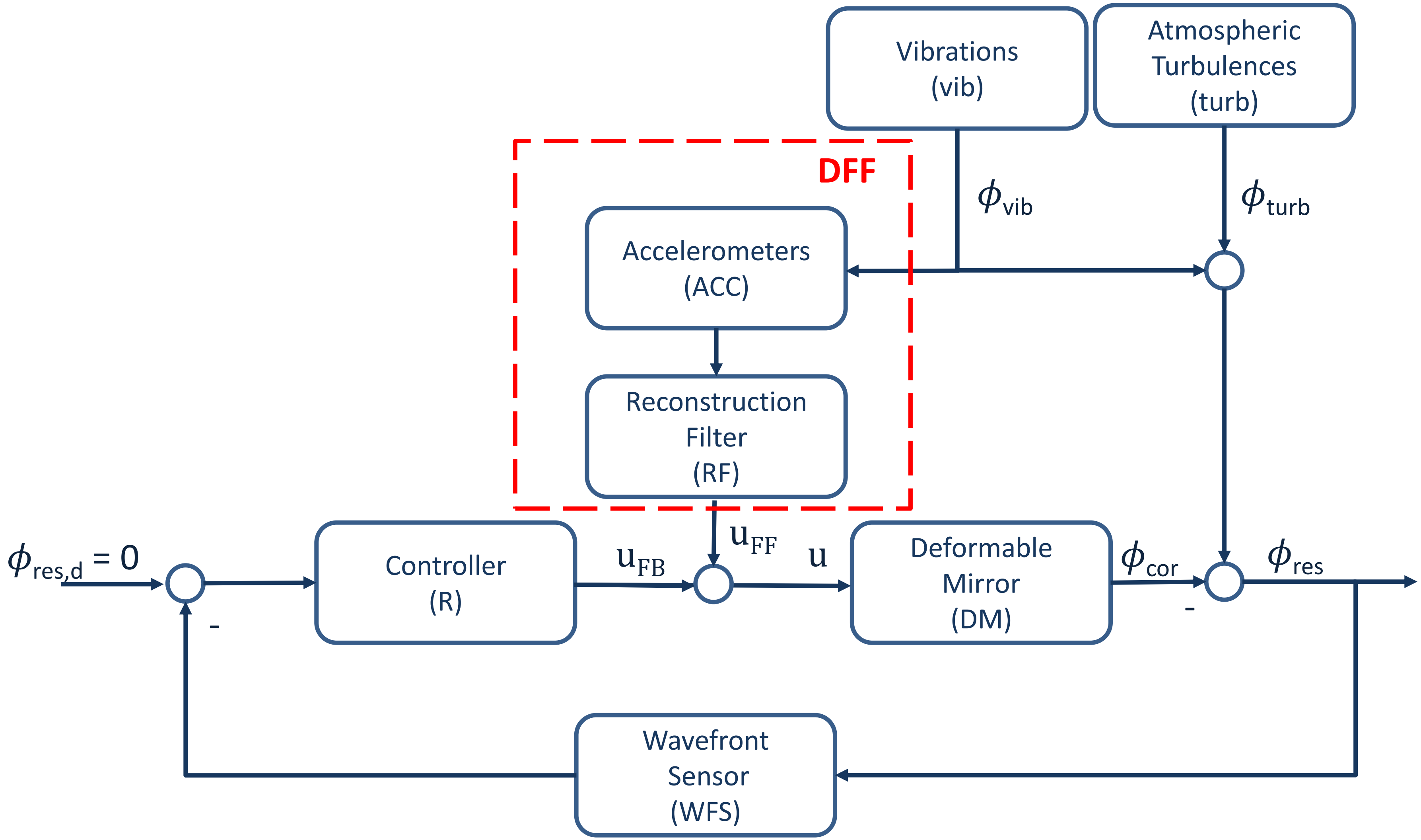
$$B = \int_0^t g(\ddot{z}_i - \ddot{z}_{AR,i})\sin(\omega_1\tau)\,d\tau$$

# Comparison of the Reconstruction Methods



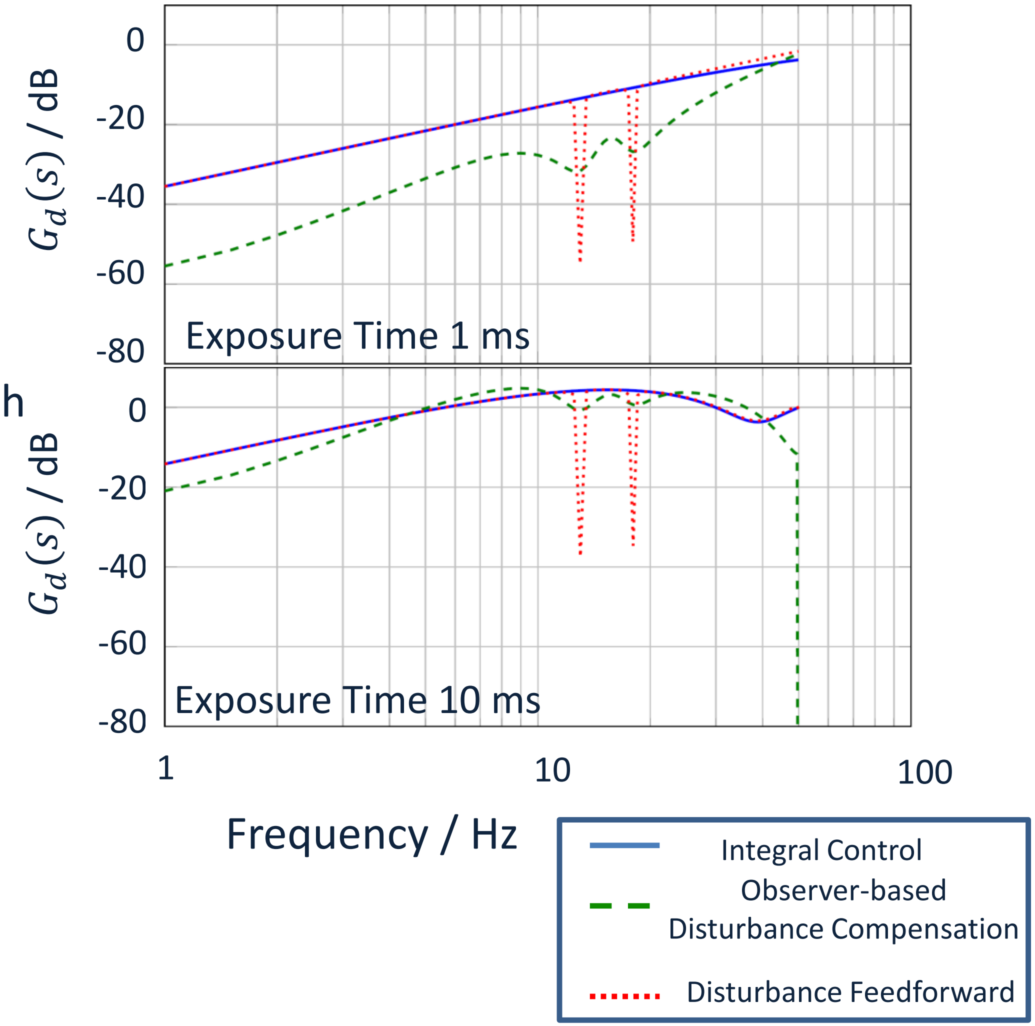
# Schematic View of an Adaptive Optics with an additional DFF



**Simulation Parameters**

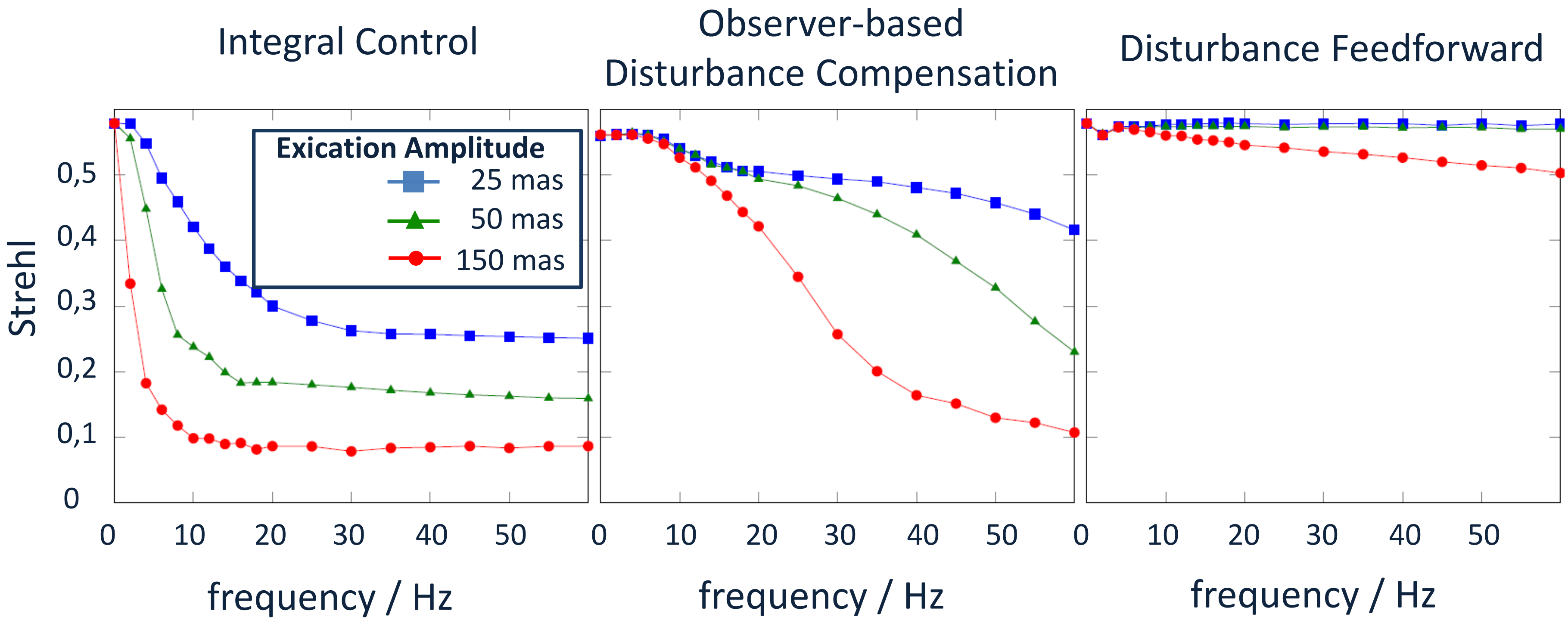
- Wind velocity 10 m/s
- Natural frequenies at 10 Hz and 13Hz
- Sample Rate Accelerometers 1 kHz
- Disturbance Feedforward Control with a Kalman Reconstructor

Error - Transfer Function $G_d(s) = \frac{\phi_{res}}{\varphi_{vib}}$



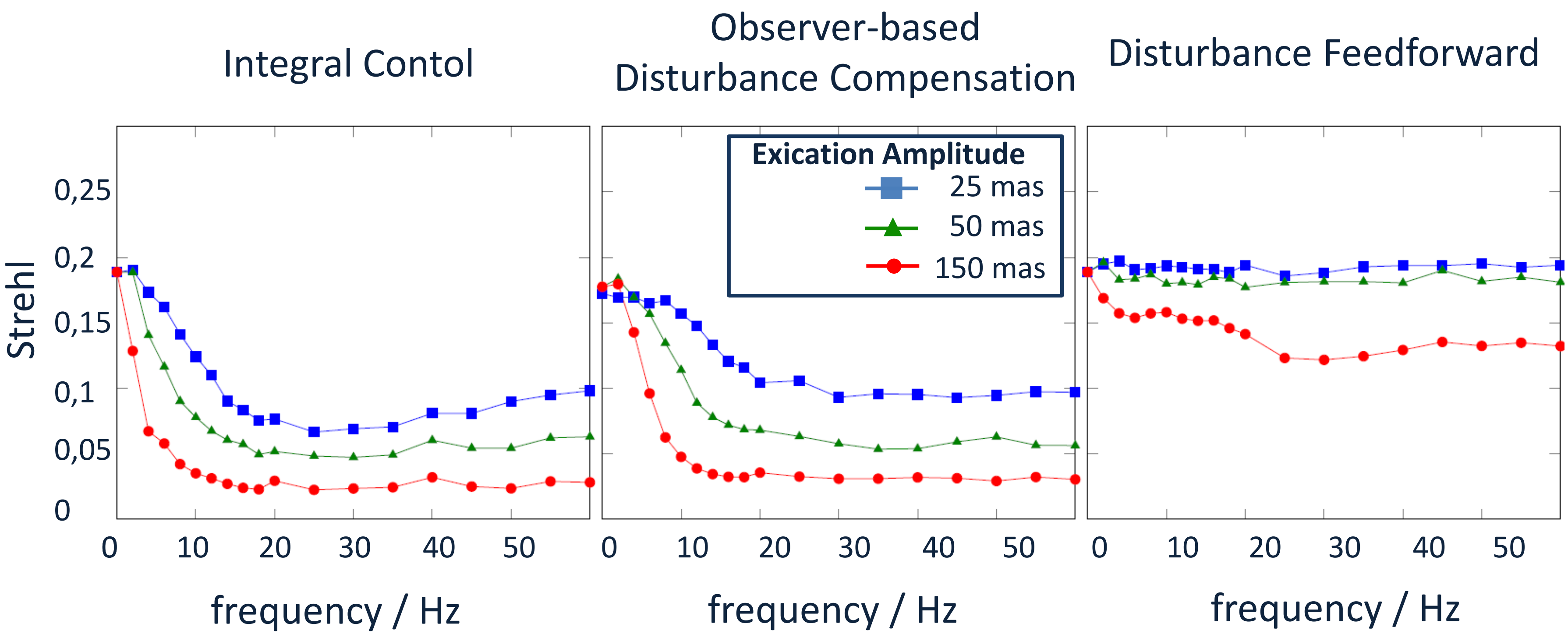
# Agenda

# Simulation Results for a bright Guide Star




- Bright guide star 10 mag und exposure time  800 Hz
- Typical atmospheric condition 0.8 arcsec
- Exciting the system by varying the natural frequency 0 Hz … 50 Hz

# Simulation Results for a faint Guide Star




- Faint guide star with 14.6 mag and exposure rate 200 Hz
- Exciting the system by varying the natural frequency 0 Hz … 50 Hz

# Agenda

1. Methods for Vibration Suppression
2. Simulation Results
3. Conclusion and Outlook

### Conclusion

- High frequency vibrations worsen the performance for observations with faint guide stars
- Improving the performance with an Accelerometer-based Disturbance Feedforward control

Bild:ESO

### Outlook

- Considering the influence of the actuator dynamics (M4, M5)
- Testing Disturbance Feedforward at the LBT

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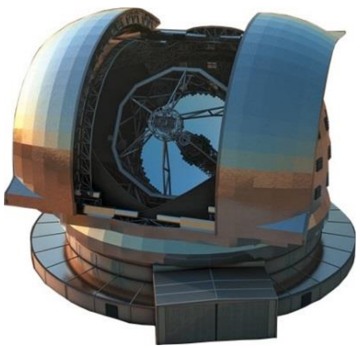
# Thank You! Questions ?



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