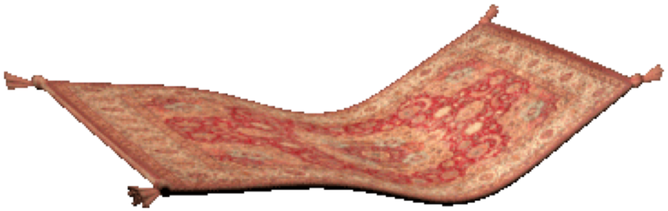
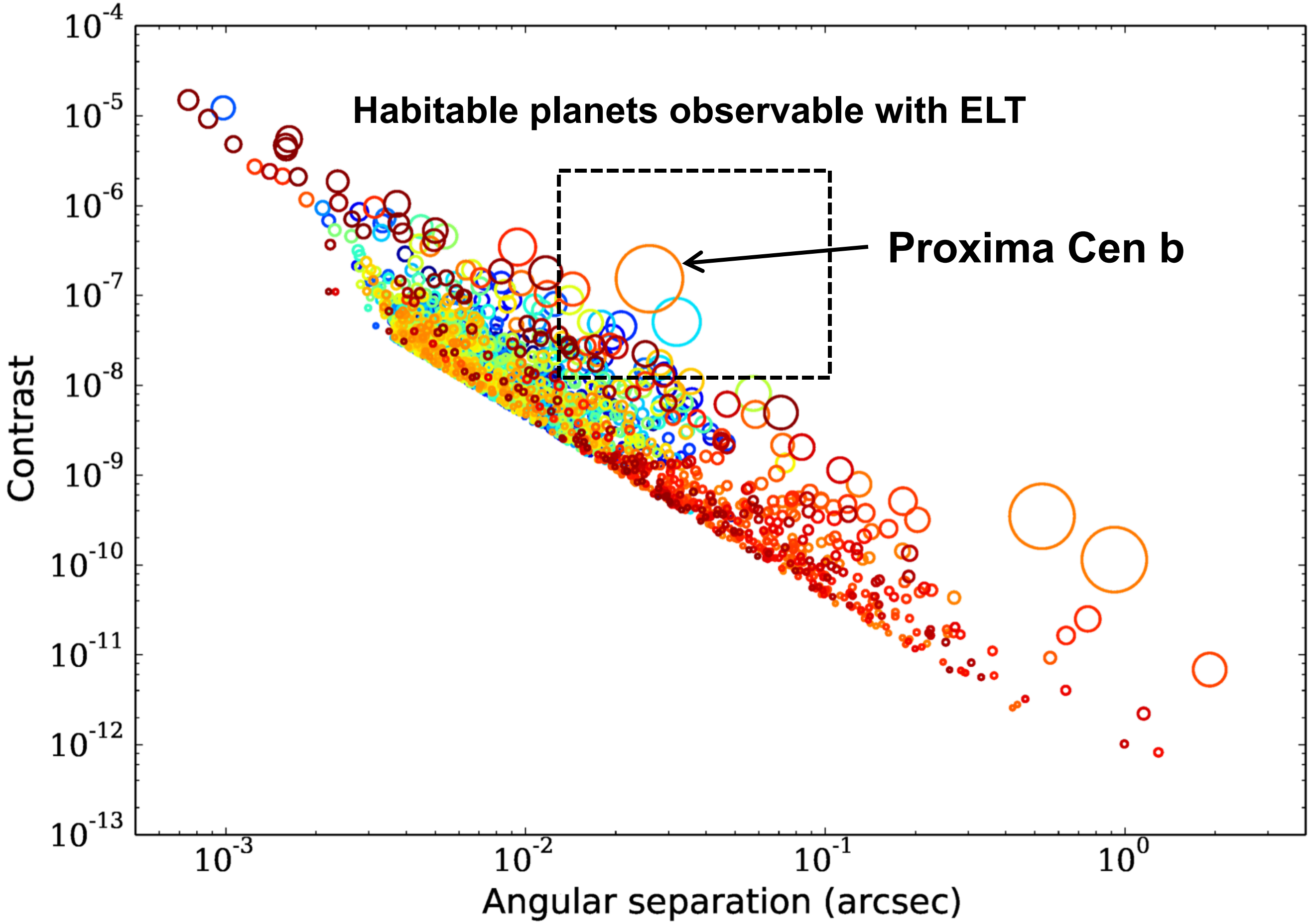
A Shack-Hartmann based setup to study deformable mirrors dynamics at very high framerates



Prashant Pathak, Stefan Ströbele, Nelly Cerpa, Markus Kasper

Habitable planets within the reach of ELT

ELT is well suited for imaging habitable exoplanets around M-type stars using the reflected light.



- **High-angular resolution:**
  H-band: ~ 11 mas
- **High performance Coronagraphy:**
  - Raw Contrast: ~ $\mathbf{10^{-5}}$
  - Inner Working Angle: **2 λ/D**

Potential habitable Earth-size exoplanets within 20 pc

DM Related HCI Challenges

1. Fitting error:

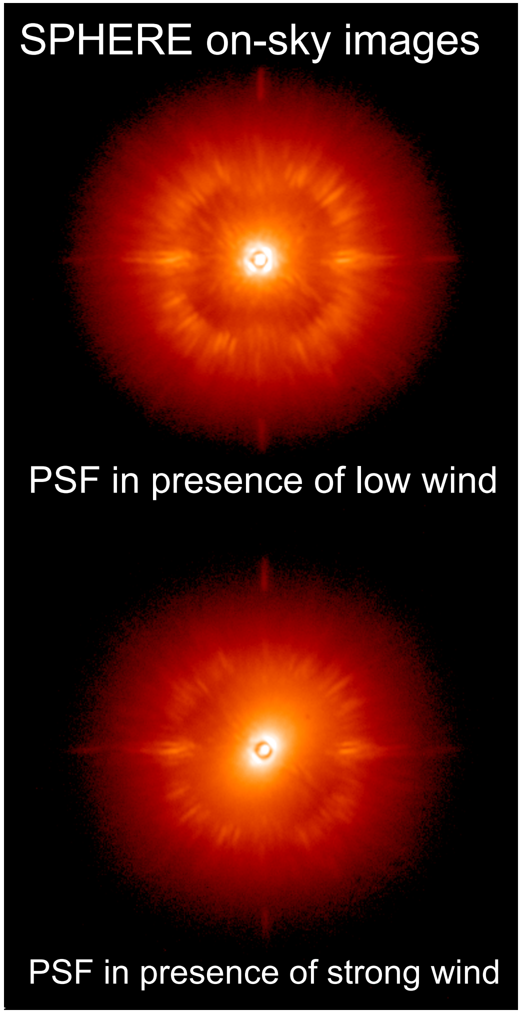
$$\sigma^2_{fitting} = k\,\left({}^{D}/_{r_0}\right)^{5/3} N^{-5/6}$$

- Residual speckles
- Speckle control (static, quasi-static, atmospheric). Promising for improving contrast at small inner working angle

2. Temporal Error (servo lag):

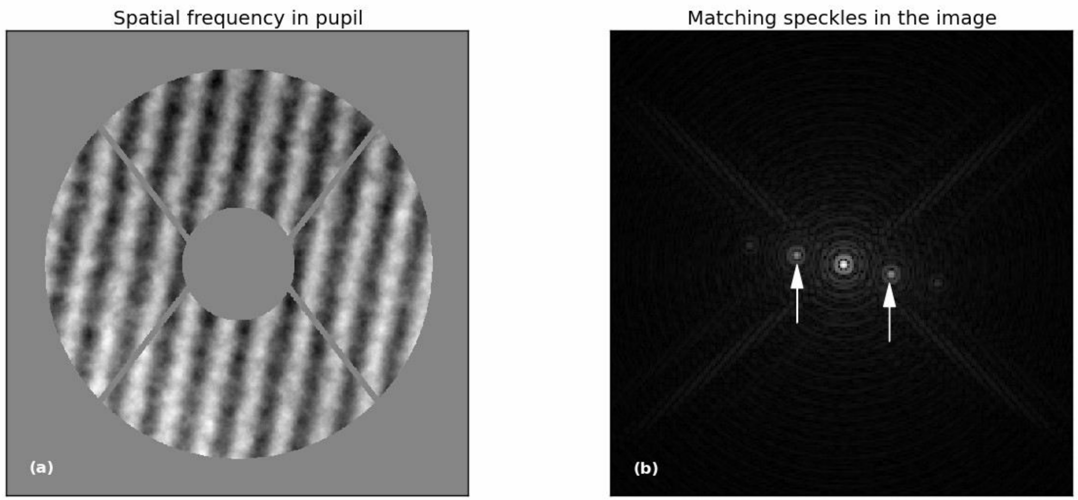
$$\sigma^2_{temporal} = \left({}^{\tau}/_{\tau_0}\right)^{5/3}$$

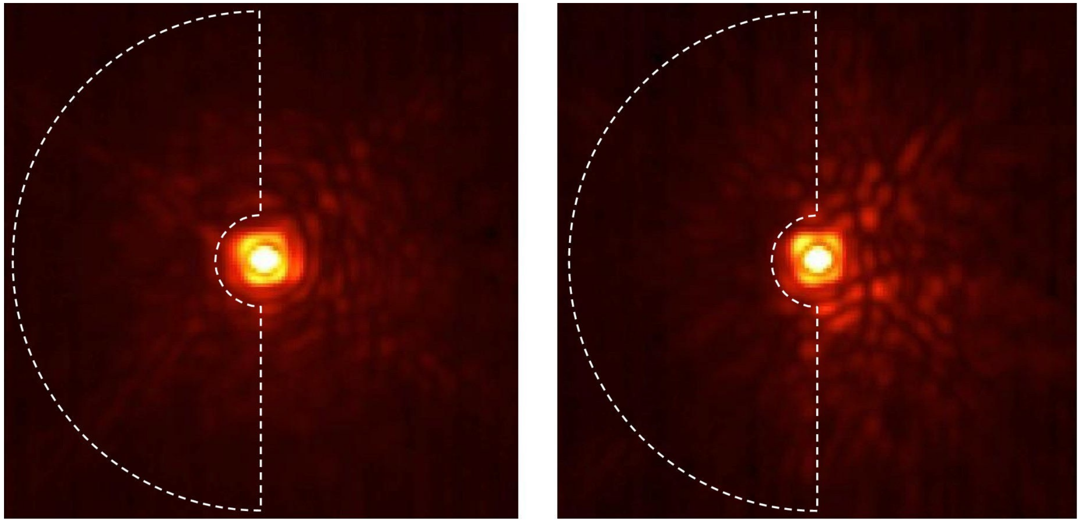
- Butterfly effect
- Higher control frequency
- Predictive control



Courtesy Markus Kasper

Speckle Control





Martinache, et. al., PASP, 126, 565M (2014).

- Sine waves are applied on the DM to create speckles.
- The amplitudes and phases of the sine waves are adjusted to cancel stellar speckles.

✓ Works with higher amplitude speckles

❖ Smaller amplitude speckles?

❖ Requires DM drive electronics with better resolution.

XAO DM Key – requirement

- Actuators count: 10800-20000
- DM Ø : 150mm to 450mm
- Small stroke settling time: 50nm to ±10% within <150µs, goal <100µs
- Stroke: > 3µm
- Resolution 0.1nm goal 0.06nm! ~15Bit
- Hysteresis <5%
- Few non functioning actuators

DM Technologies

- Stacked array DMs, CILAS
- Bimorph DMs
- Voice-coil actuator DMs, ex- DSM/ASM
- Micro Electro-Mechanical System (BMM), XAO systems- SPHERE, GPI, SCExAO
- Micro voice coil (ALPAO), ex- compact DM-64x64

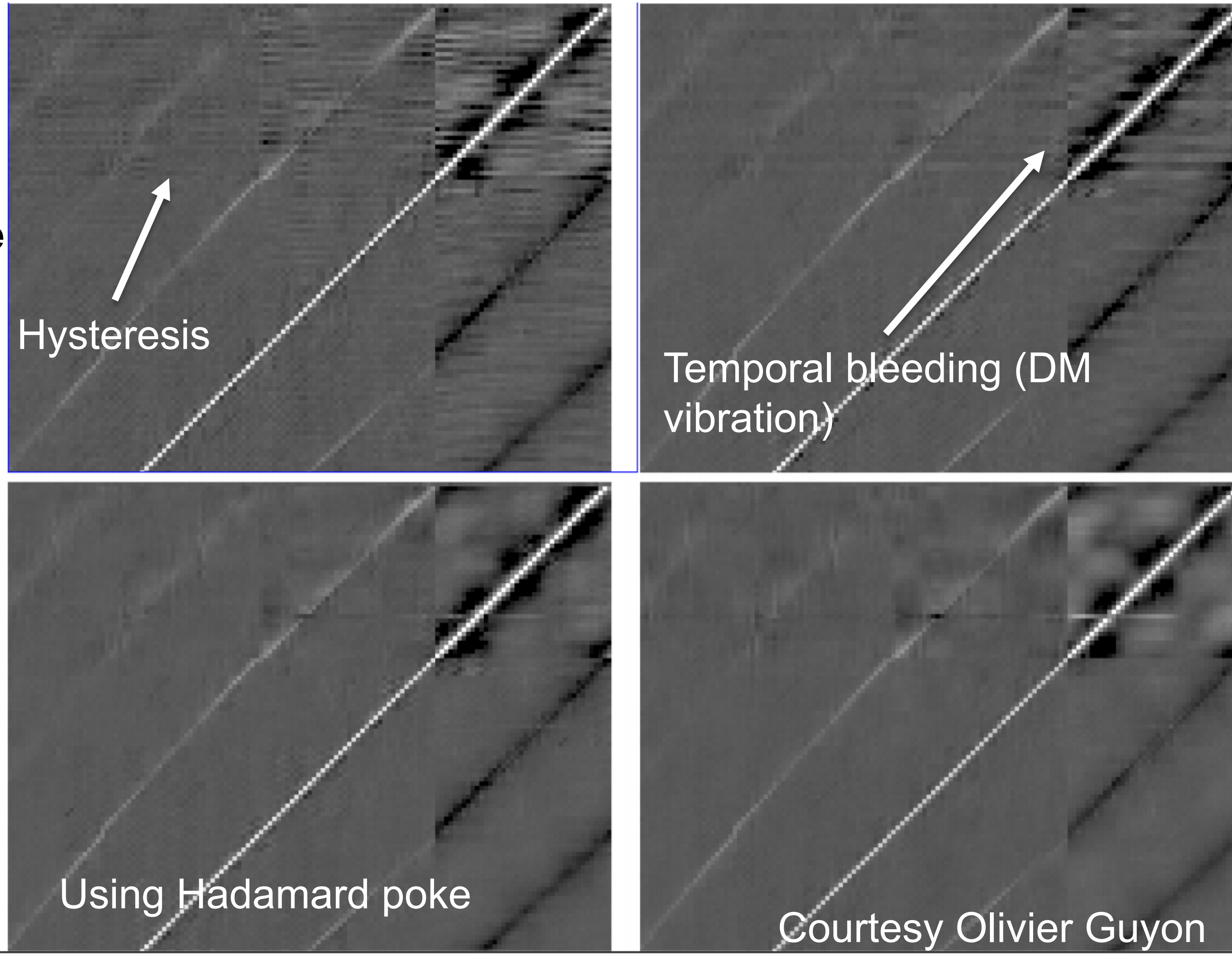
XAO compatible

- Higher control frequency
- Large number of actuators
- Low latency

CILAS Bimorph DM

AO188 DM
Subaru Telescope

RM recorded at high speed



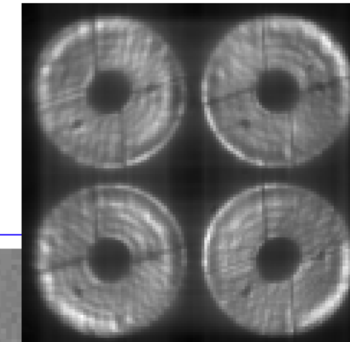
Boston MEMS DM

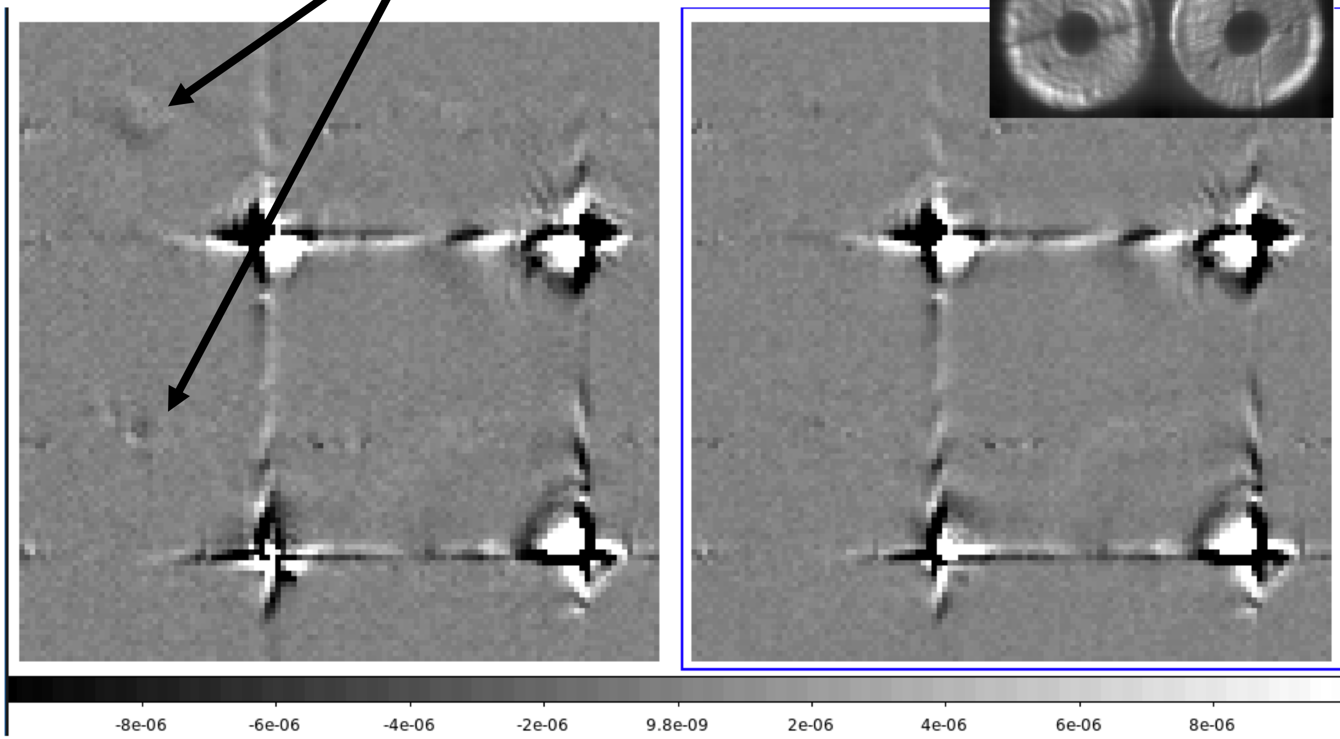
Temporal bleeding from previous poke pattern

Temporal response:

Preliminary results show, at high speed some parts of the DM seem to respond faster than others (more characterization required).

SCExAO's 2k DM





RM assembled from single poke sequence:
+- +- +- +-

RM assembled from average of two poke sequences:
+- +- +- +-
+- -+ +- -+

Courtesy Oliver Guyon

Characterization of DM

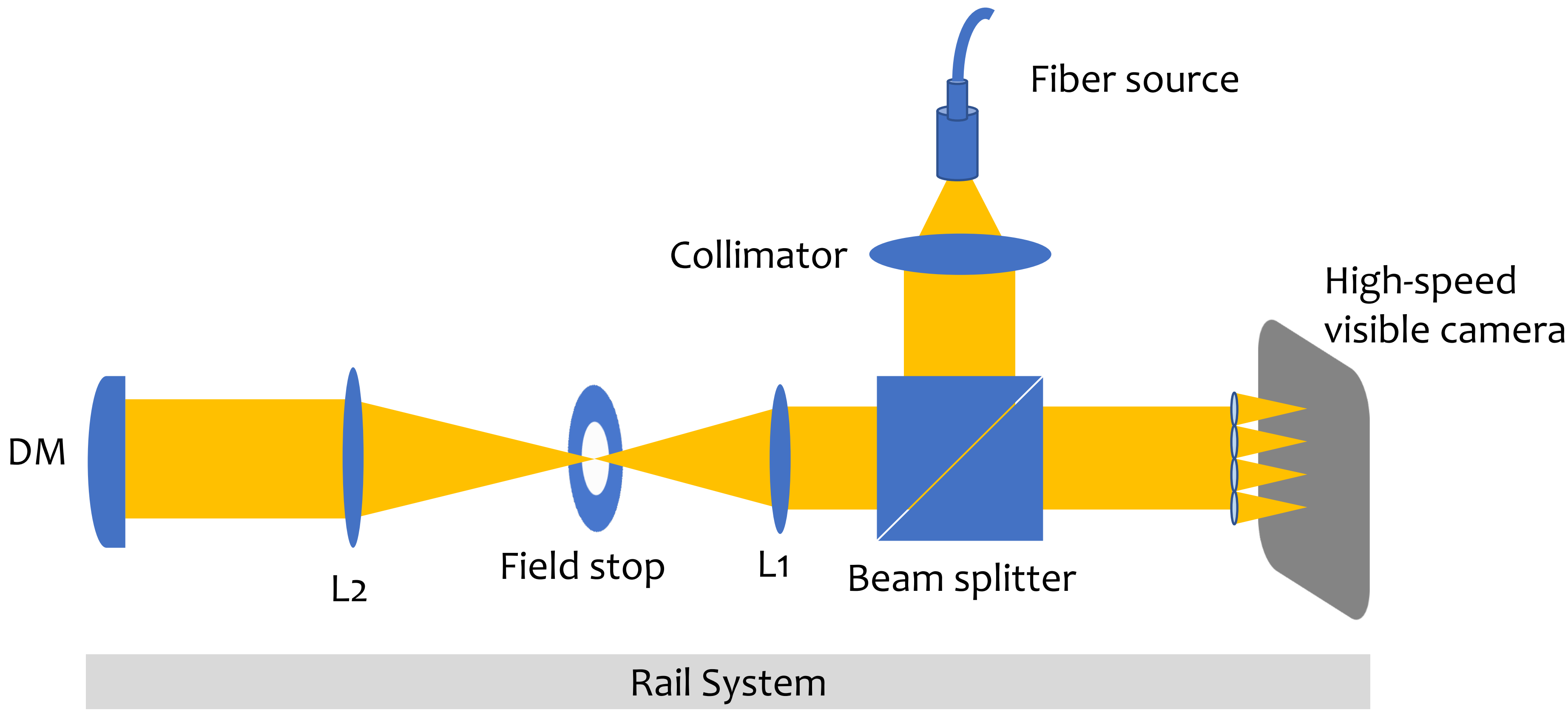
- DM dynamics: mostly characterized by single point transfer function combined with a measured influence function.
- Dynamic actuators coupling generally ignored.
- The approach is valid if the update / control frequency and the actuators resonance is sufficiently separated and in presence of some level of damping.

Under ESO's Technology development program

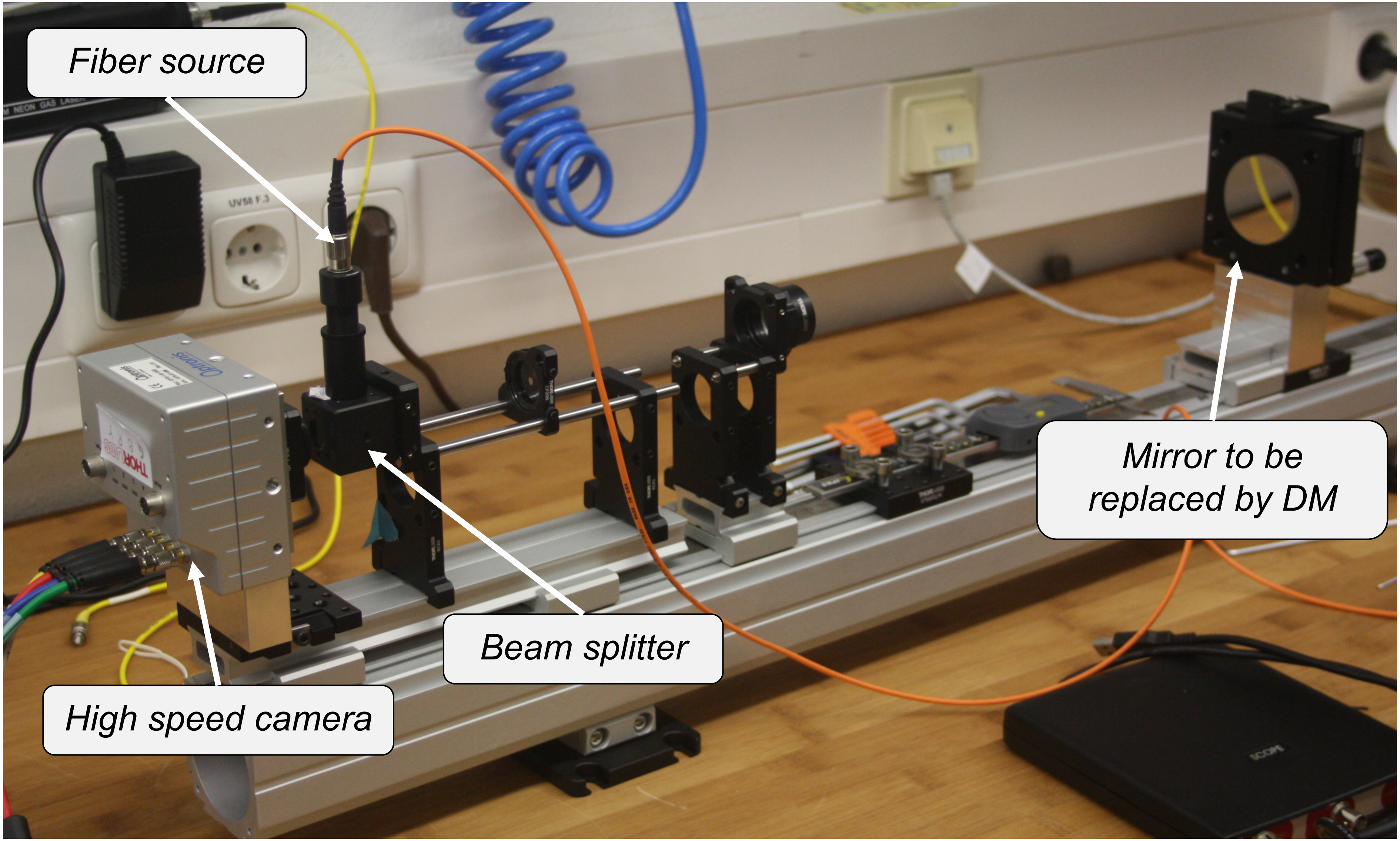
- For XAO the update frequency gets higher and some technologies have only little actuators inherent damping.
- To address this we want to measure the DM surface dynamics with sufficient framerates to sample the actuators resonance frequencies.

Characterization setup

A low cost setup, capable of running at multiple KHz



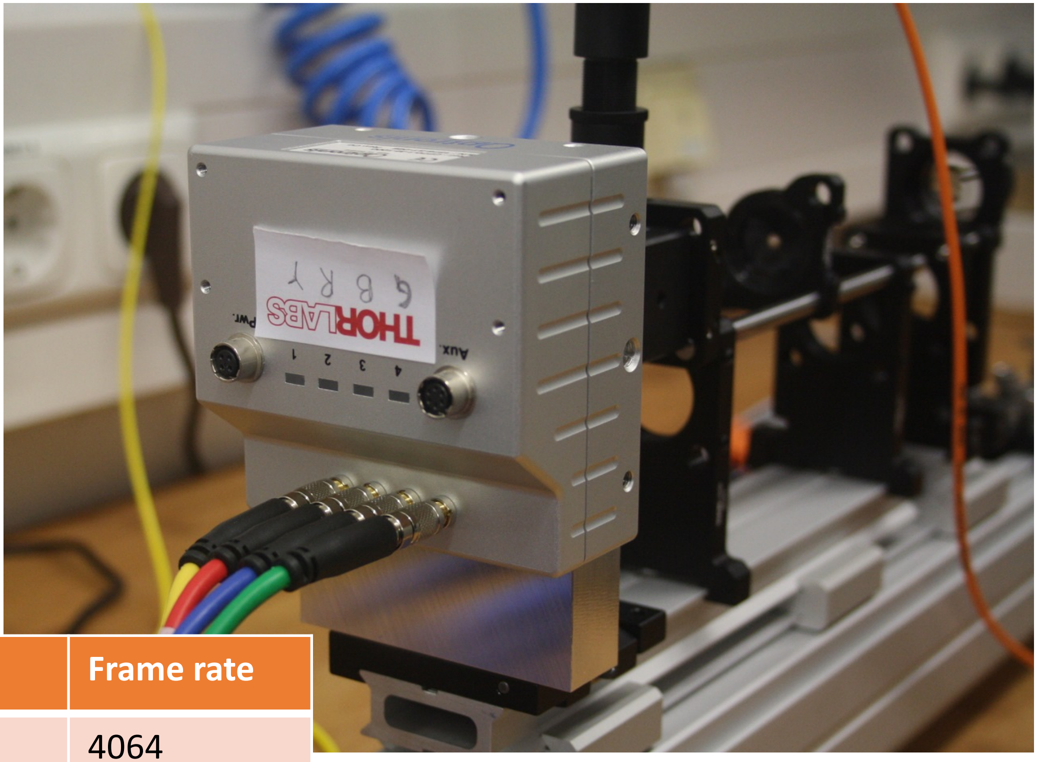
Lab Setup



Fiber source
Mirror to be replaced by DM
Beam splitter
High speed camera

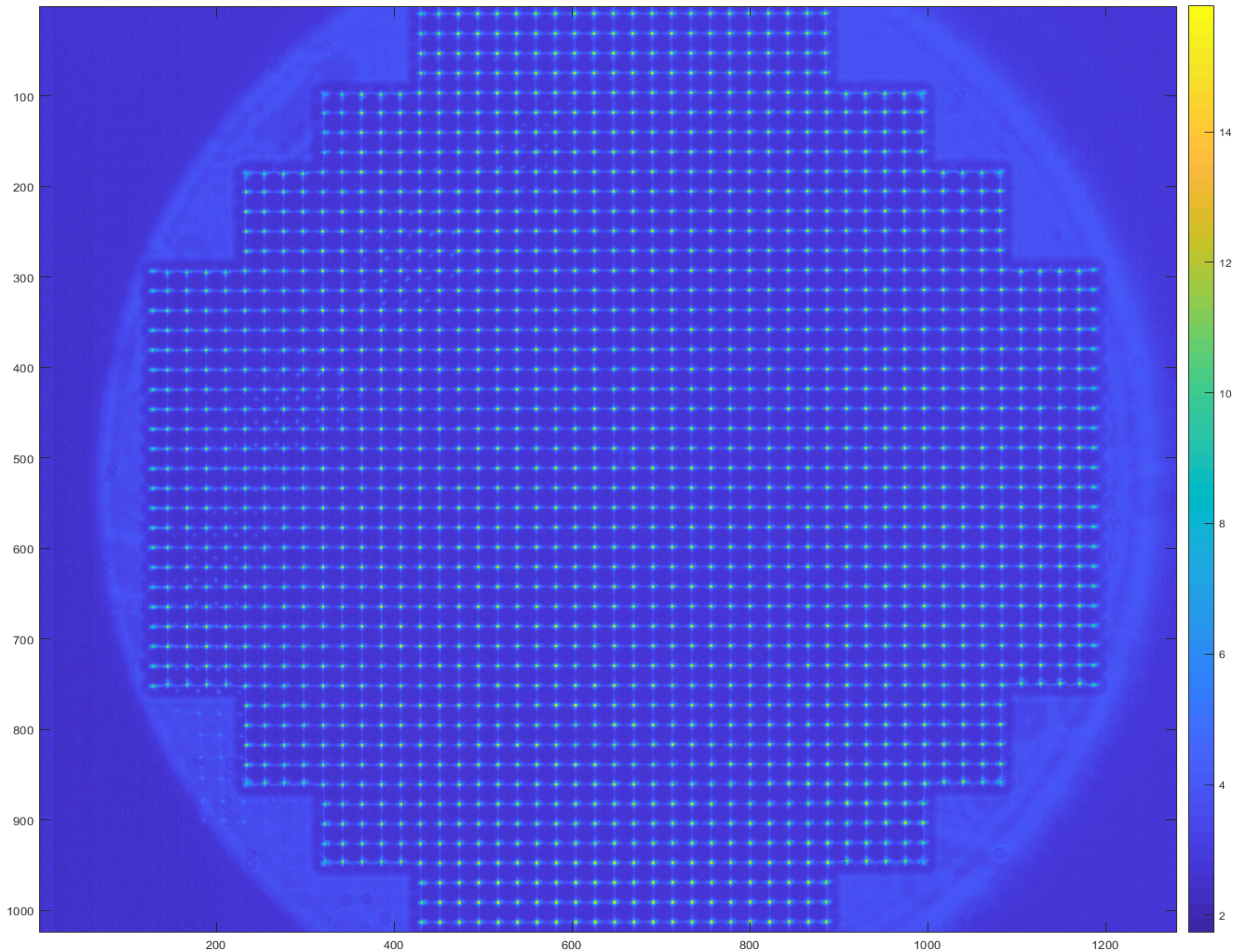
Main component (visible camera)

- CMOS, global shutter, 8 & 12 Bit
- Pixel size; 6.6 µm
- Gain analog; 1x – 16x
- Exposure time; 2 µs-1/Framerate
- External trigger
- Micro-second precision timing



Resolution	Frame rate	2x2 binning	Frame rate
1280 x 1080	1051	640 x 512	4064
1280 x 720	1491	640 x 360	5711
640 x 480	4087	320 x 240	8396
256 x 256	7540	128 x 128	15394

Image SH-WFS setup



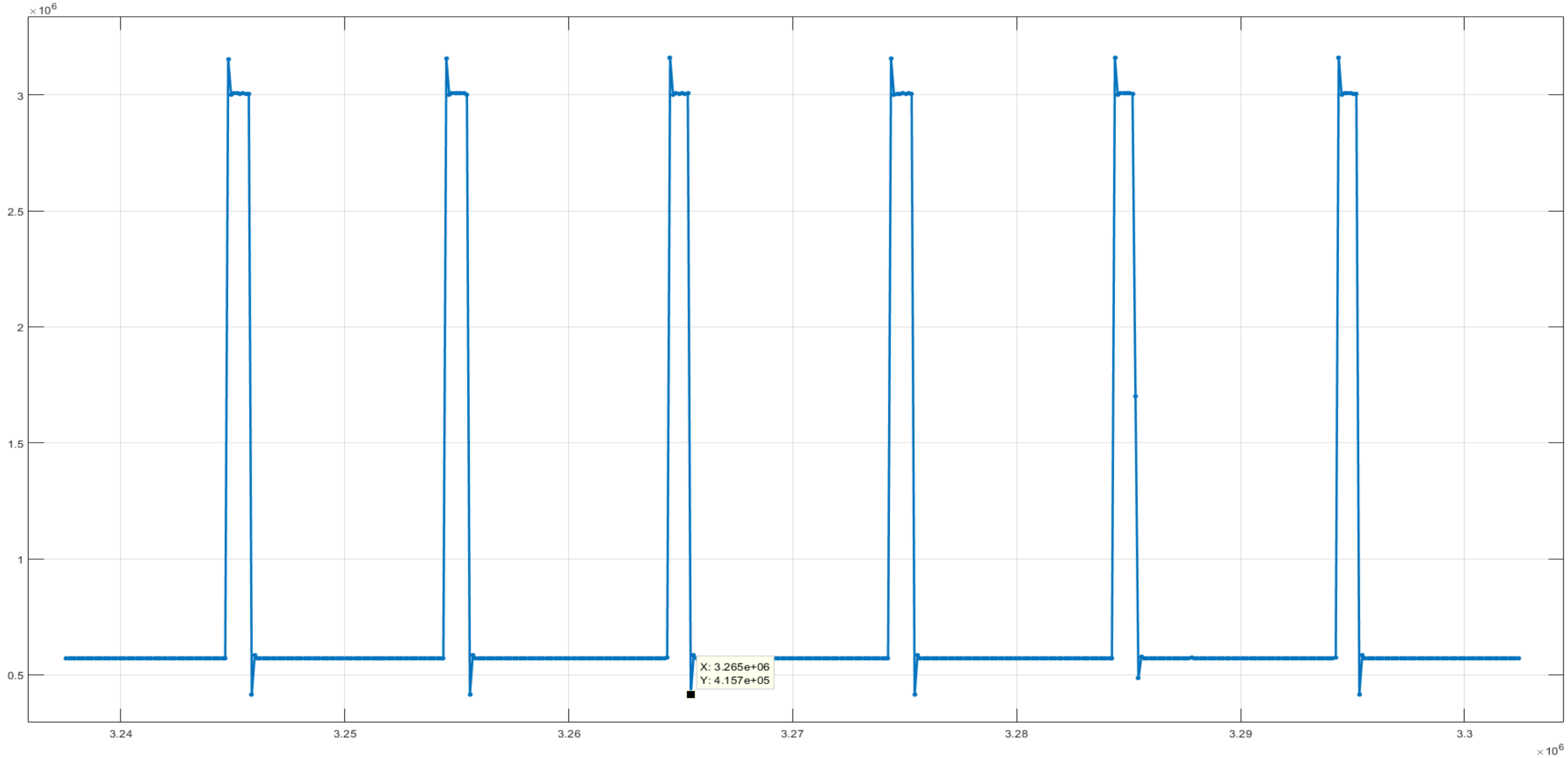
Timing Characterization

Blinking LED setup:

(1) 1 msec pulse width @100Hz,

(2) Camera running @7.5kHz, (256 x 256)

(3) Timing: microsecond precision



Summary

- ✓ Main challenge: to run camera at high-speed with microsecond timing information
- ✓ Software: MATLAB to drive the camera and DM
- ✓ Timing characterization using blinking LED
- Todo:
  - External trigger
  - Reconstructor: from slopes to phase

Characterization Goals

DM Calibration:

- Predictive control
- Sensor fusion: multi WFS
- Machine learning

- Measure DM surface motion over various areas and speeds.
- Optimal control: single and multi-step approach.
- The knowledge about the DM behavior will be included in the XAO modeling.

Thank You