The
Kiepenheuer-Institute AO System

KAOS

– a flexible control system for AO and MCAO –

Thomas Berkefeld and Dirk Schmidt

Real Time Control for Adaptive Optics Workshop
ESO Garching, December 2012

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Applications of KAOS

from Tenerife via Arctic to California

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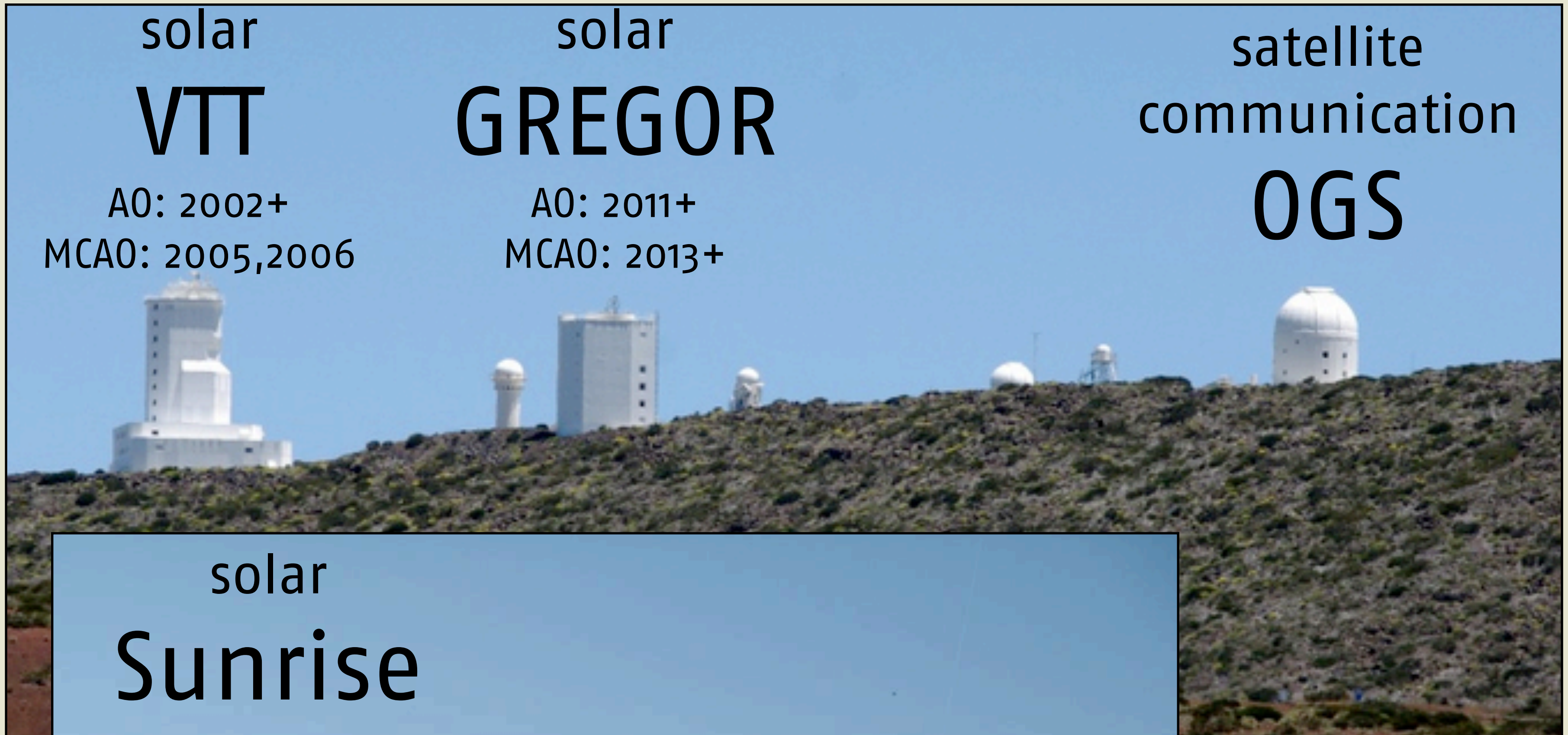

solar
VTT
AO: 2002+
MCAO: 2005,2006

solar
GREGOR
AO: 2011+
MCAO: 2013+

satellite communication
OGS

solar
Sunrise
2009,2013
image stabilization
active optics

solar
Big Bear
AO: last week, first test
MCAO: 2013+ (714–1071 act.)

Testbed of GREGOR's MCAO

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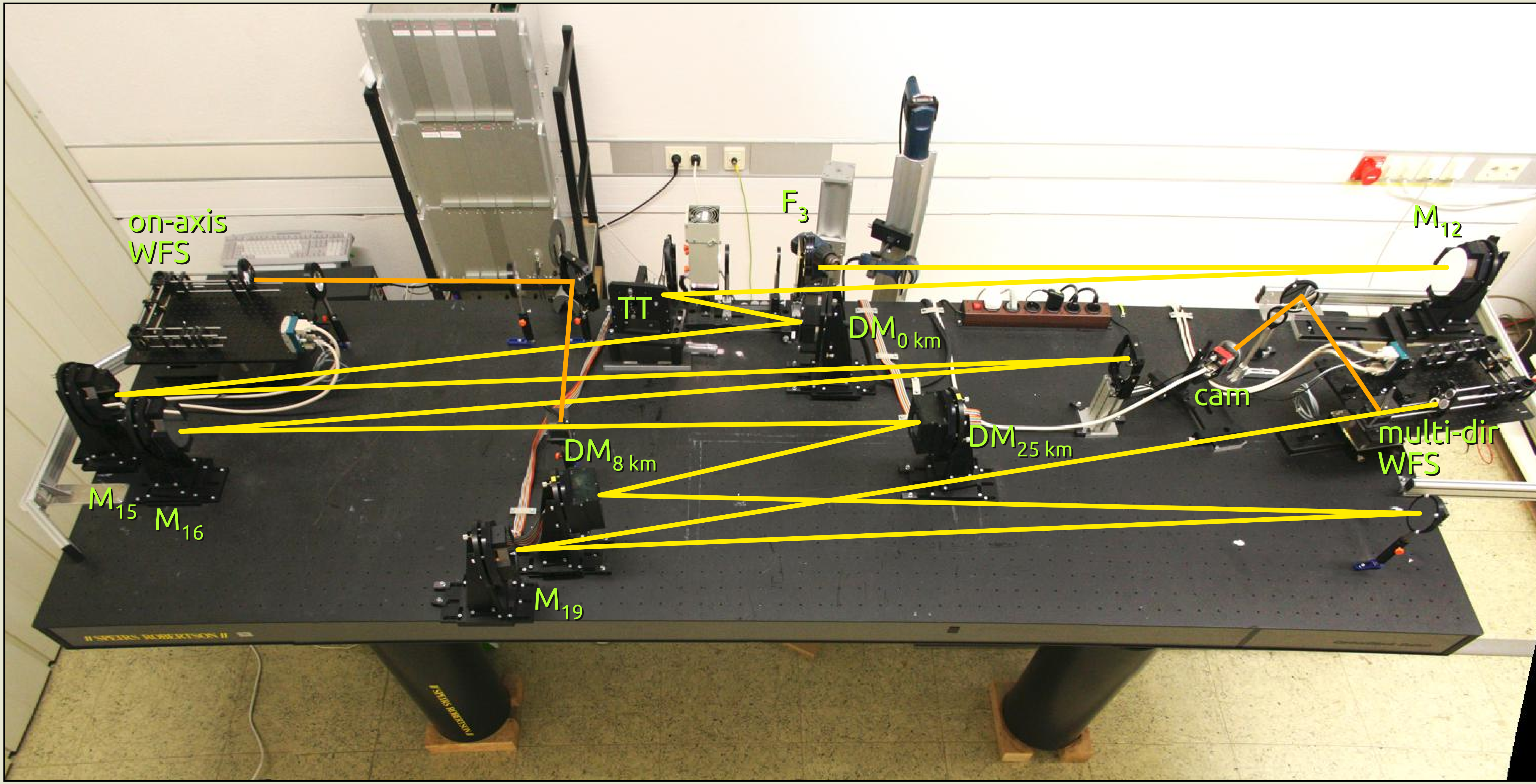

– 3 DMs (209 act.), 2 WFSs and cameras (192 correlation fields), 2 kHz

The GUI of KAOS Evo 2 for GREGOR's MCAO

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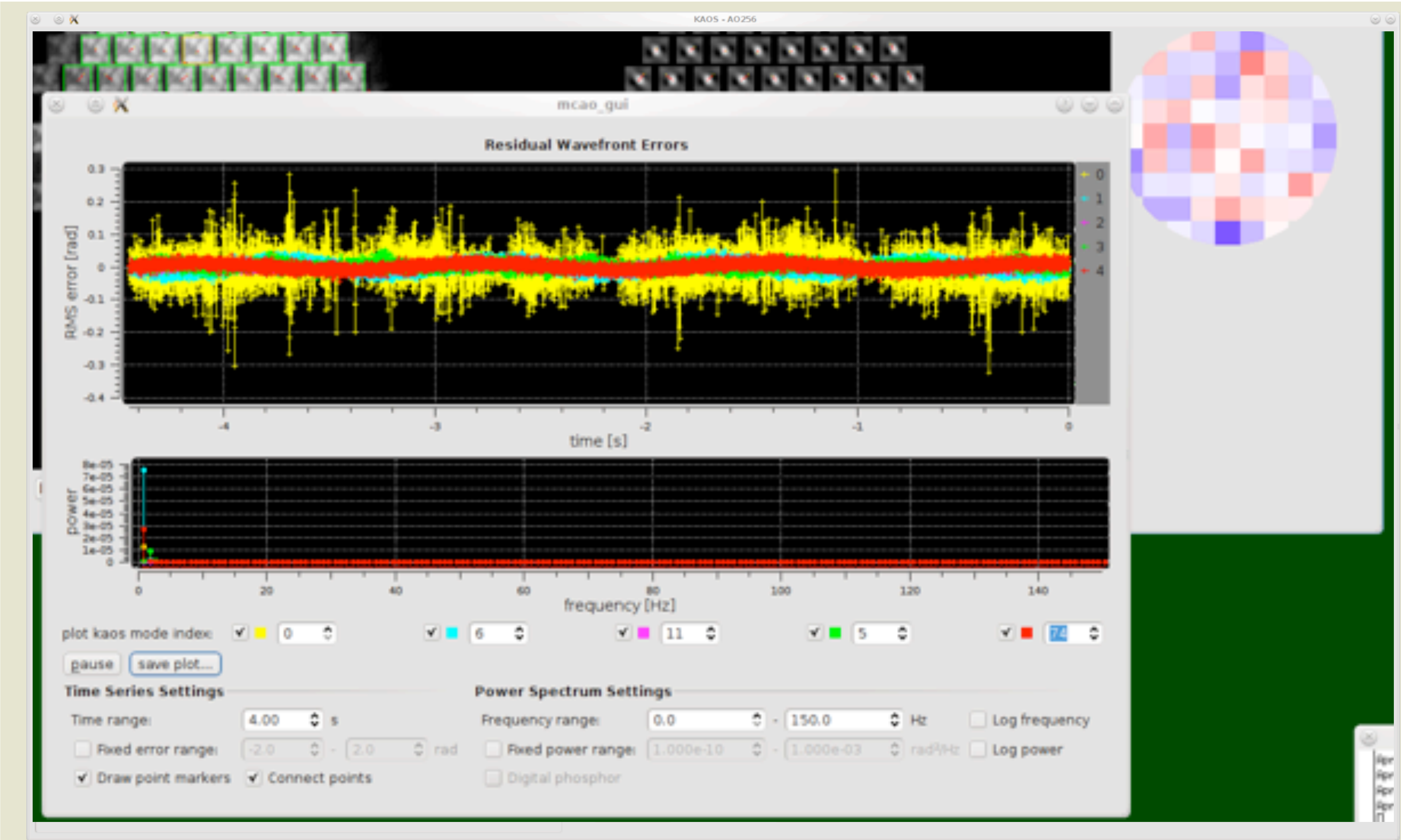

Primary design goals for KAOS

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- ease of use
  - $\Longrightarrow$ scientists can use it on their own
- high performance
  - $\Longrightarrow$ scientists want to use it
- robustness
  - $\Longrightarrow$ scientists cannot destroy it
  - $\Longrightarrow$ remote serviceability just in case... (naive promise)
- high flexibility
  - $\Longrightarrow$ easy trailing of new things (control schemes etc.)
- high portability to other platforms (hard-/software, telescopes)
  - $\Longrightarrow$ quick adaption to new demands and possibilities

Solar AO Properties

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- extended targets
  - Shack Hartmann crosscorrelation
    typically 24x24 pixels / subaperture
  - 35-40 kflops / subaperture
- observations at 500nm -> typically 2kHz loop frequency
- largest system so far: AO at 1.6m Big Bear Solar Telescope (308 subaperturs, 357 actuators)
  -> no extreme AO, data fits into (multiple) CPU caches

Architectural foundation of KAOS

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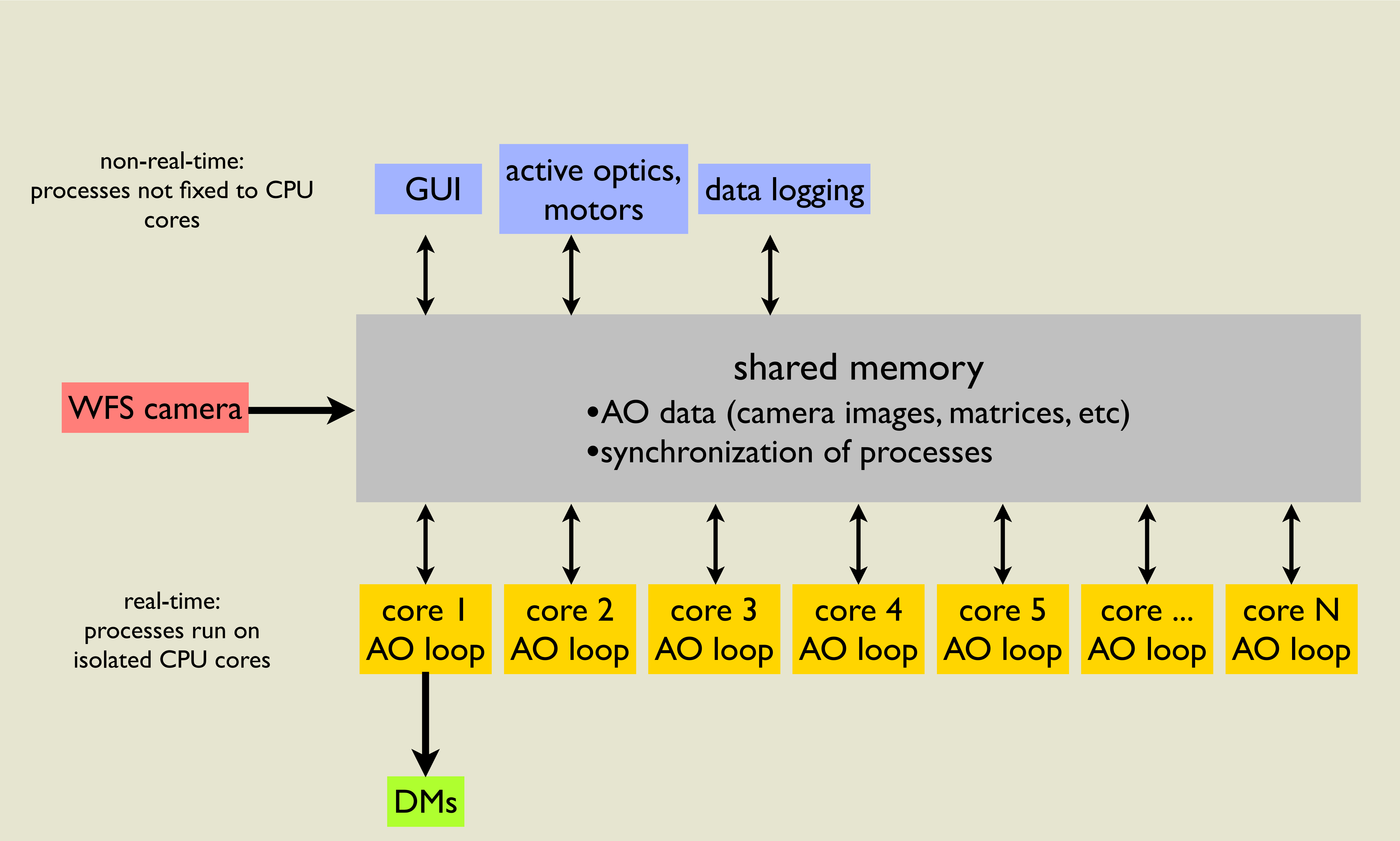
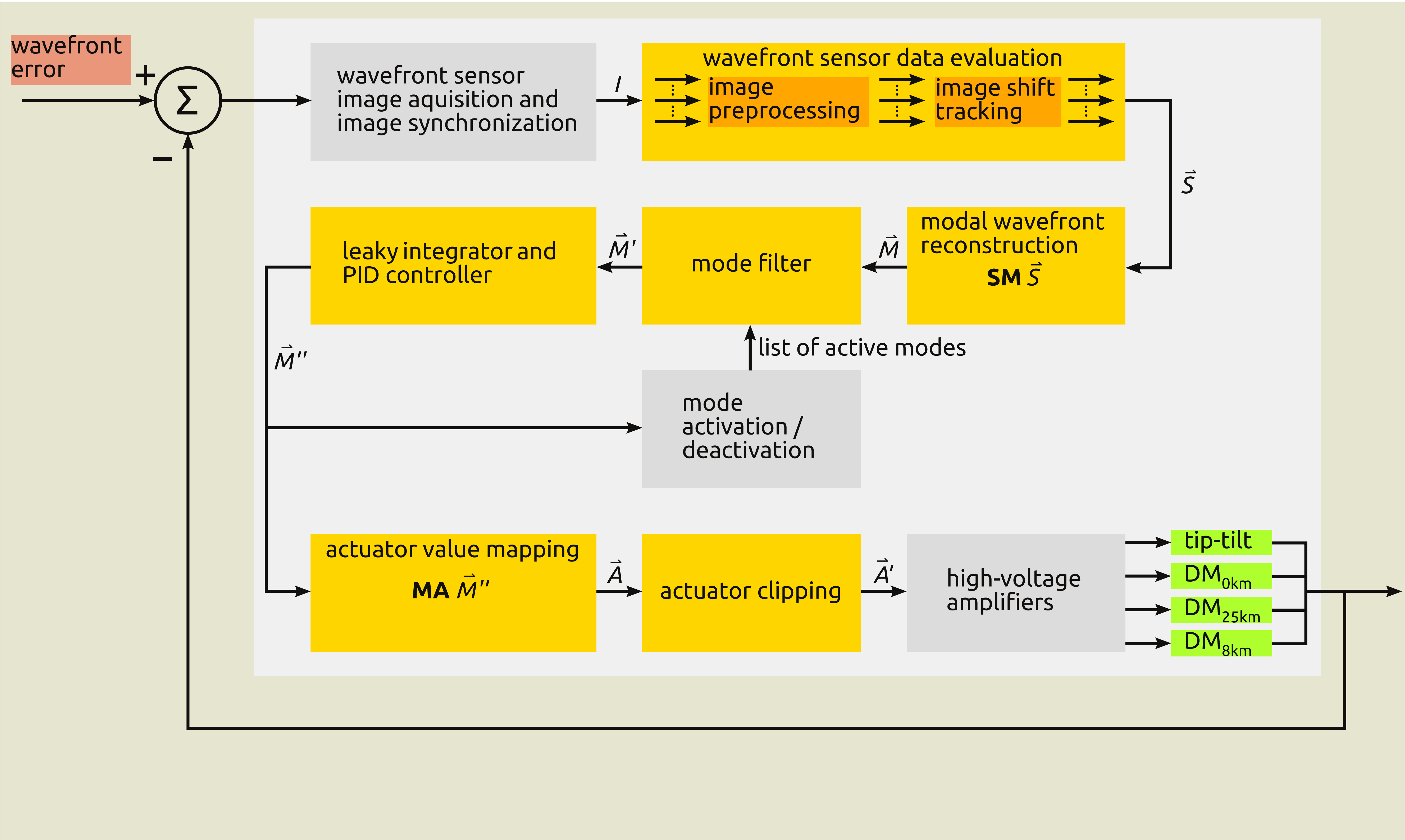
- C/C++, POSIX with little Linux specific code
- all computations performed on (x86-64) processors
- compiler tuned and handwritten vectorization (SIMD)
- parallel shared memory processes (POSIX, no threads), linear scaling up to at least 15 CPU cores
- modular design for camera, mirror and motor interfacing
- 3rd party libraries / APIs
  - FFTW for Fourier transforms
  - BLAS (ATLAS/GotoBLAS) for vector-matrix multiplication
  - LAPACK for singular-value decomposition
  - Qt / Qwt for GUI

Shared memory architecture of KAOS



Modal control loop



Control computers for KAOS

when will AO run on a tablet?

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VTT computer (2002–2010) 8 Ultra SparcIII (1 GHz) (replaced by 4-core Xeon 3 GHz) 	**GREGOR MCAO testbed** Dual Intel Xeon X5570 (4-core, 2.9 GHz) 	**AO/MCAO GREGOR + Big Bear** Dual Intel Xeon E5-2690 (8-core, 2.9 GHz) 
refrigerator size	4U 19" chasis	4U 19" chasis
36 subapertures @ 2.1 kHz (75 μs /CPU/subap)	200 subap @ 2 kHz (< 11 μs/CPU-core/subap)	500 subap @ 2 kHz (<9 μs /CPU-core/subap)
1500 W	500 W	500 W
100,000 € (2002) (132 € / subap / 100 Hz)	6,000 € (2009) (1.5 € / subap / 100 Hz)	5,500 € (2012) (0.55 € / subap / 100 Hz)

Real-time tweaks at (pre-)boot time

- standard Debian kernel (Squeeze, 2.6.32-amd64)
  - built with **`CONFIG_PREEMPT_VOLUNTARY=y`**, which is okay
  - **`CONFIG_PREEMPT_NONE=y`** is best (don't want any task switches at all)
- reserve cores for KAOS' real-time tasks
  - CPU shielding

    ```
    $ cset shield --cpu=1-14
    ```

  - IRQ masking

    ```
    CPU_AFFINITY_MASK="1"
    for i in /proc/irq/*/smp_affinity; do
      echo $CPU_AFFINITY_MASK > $i;
    done
    echo $CPU_AFFINITY_MASK > /proc/irq/default_smp_affinity
    ```

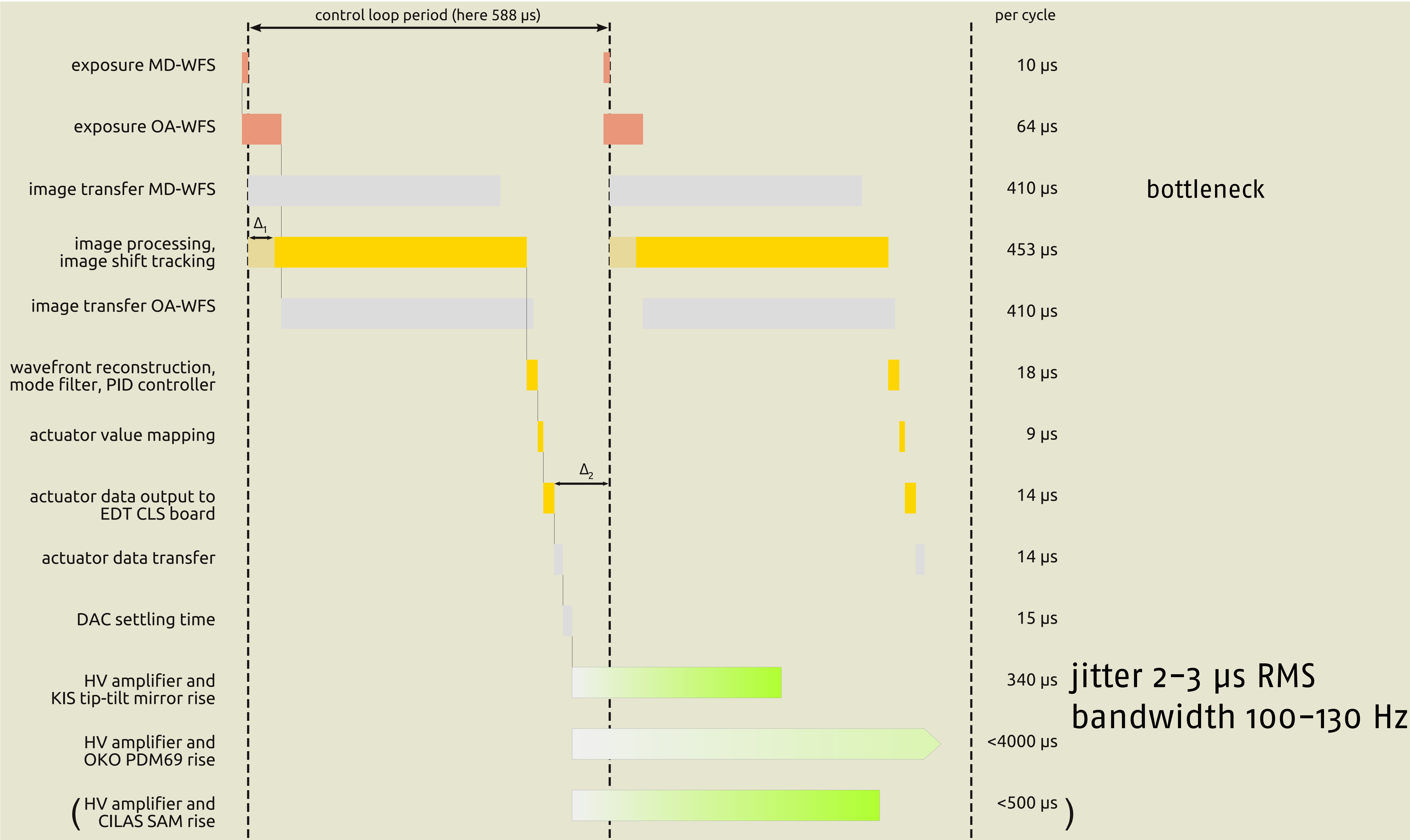
- disable nasty things
  - `$ hal-disable-polling --device /dev/dvd`

Real-time tweaks in main()

- move process to schielded cores
  - CPUSETS `sched_setaffinity(...);`
- nice level
  - `setpriority(PRIO_PROCESS, 0, -19);`
- round denormal (subnormal) number to zero
- `_MM_SET_FLUSH_ZERO_MODE( _MM_FLUSH_ZERO_ON );`
  `_MM_SET_DENORMALS_ZERO_MODE( _MM_DENORMALS_ZERO_ON );`

- no RT-scheduling policy (makes GUI, desktop unresponsive)
- no **`nanosleep`**, **`usleep`**, **`sleep`** etc. because not guaranteed
  - spin wait instead

Time diagram of GREGOR's MCAO



High-voltage electronics for DMs

- designed and built by Kiepenheuer-Institute (F. Heidecke)
- voltage driven amplifiers
- up to ± 500 Volts
- 14-bit digital-analog conversion
- 1.9 kHz cut-off frequency (-3 dB)
- remote diagnostics interface (ethernet)

- analog amplifier for tip-tilt mirror from manufacturer

KIS-M-Link

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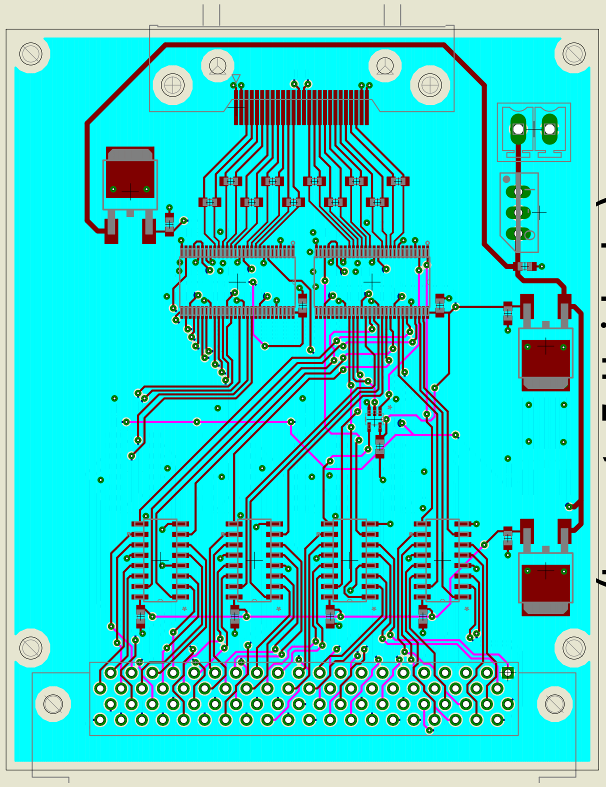
digital interface in control computer

- **very soon:** „KIS-Link“
  EDT PCIe8 DV CameraLink transmitter and
  KIS CameraLink to 32-bit parallel RS422
  converter (20 MHz)



(Layout: F. Heidecke)

- 40 µs latency for **sending** 256 actuators **and recieving** with 2nd CameraLink board in same computer (w/o transfer time)
- no latency increase observed for larger bursts
- good (x86-64 Linux) support
- standardized cables, EDT board about 2000 $ less expensive

2013 / 2014

- work on SUNRISE flight, GREGOR and BBSO AO/MCAO
- 12/2013 new project: correlating night time WFS for GREGOR (observation of solar system planets)
- 4m ATST AO (ca 1600 subapertures)
  - opted for FPGAs
  - but are still interested in a CPU solution if possible
    -> tests with KAOS in 2013