pnCCDs for Adaptive Optics

Sebastian Ihle

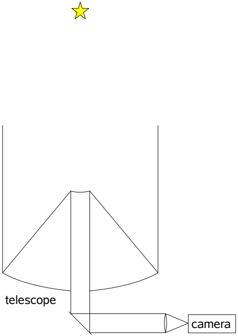
PNSensor GmbH

MPI Halbleiterlabor

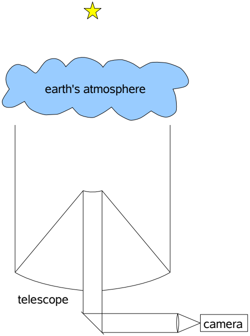
May 7, 2007

Outline

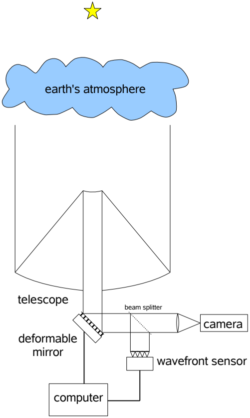
AO principle



AO principle



AO principle



Wavefront sensors

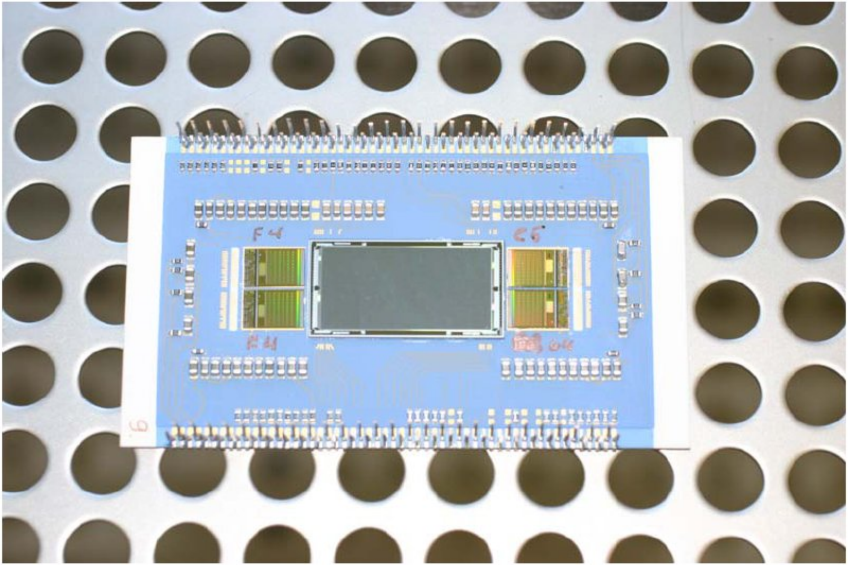
Parameters of Shack-Hartmann wavefront sensors (WFS) used nowadays at large telescopes:

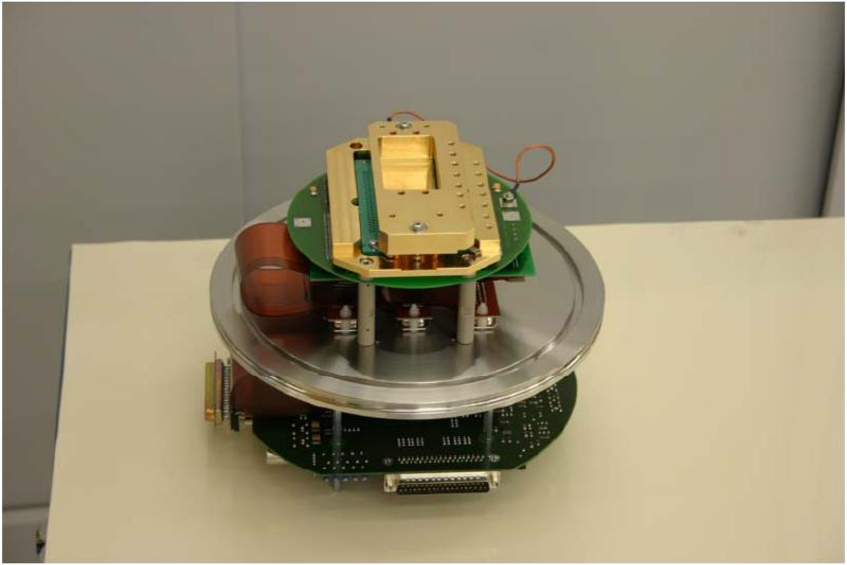
# WFS	1
sensing wavelength	450-950 nm
frame rates	80-1000 Hz
# pixels	up to 128*128
readout noise	3-7 e^- rms
quantum efficiency	20-90 %

Wavefront sensors

Parameters necessary for future AO applications (KPAO, MCAO, ELT-AO, ...):

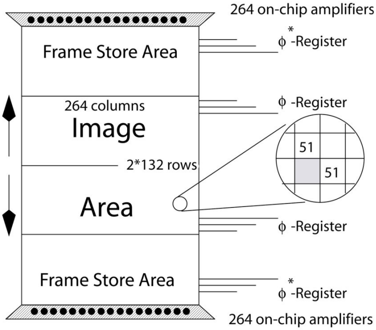
# WFS	up to 9
sensing wavelength	450-1000 nm
frame rates	800-1000 Hz
# pixels	$\geq$ 128*128
readout noise	1-3 e^- rms
quantum efficiency	$\geq$ 85 %





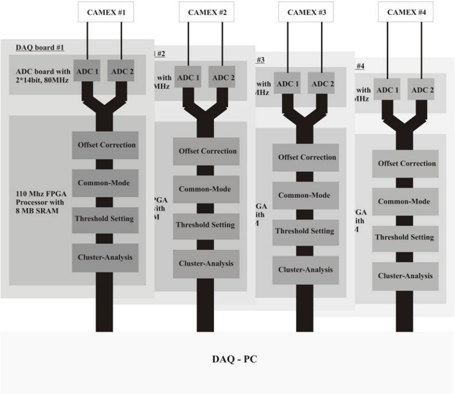

CompactPCI
ECH 338 M - K

pnCCD for optical applications



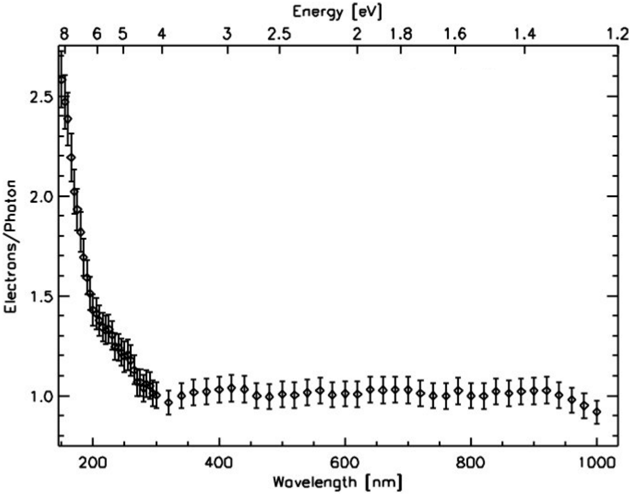
- 264*264 pixels each in image area and in frame store area
- readout two both sides
- frame rate up to 1000 fps
- 100 % fill factor
- frame transfer time = 30 μs
  $\Rightarrow$ Out of time probability = 3% (1000 fps)
- charge transfer loss CTI $\approx 10^{-5}$
  $\Rightarrow$ total charge loss < 0.3% (264 shifts)

Data Aquisition

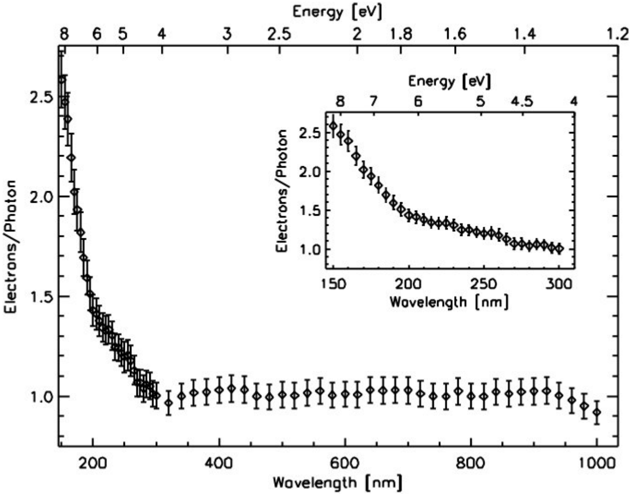


- High data rate:
  - 1000 frames/s
  - 264 lines/frame
  - 1000 frames/s
    $\Rightarrow$ 70 Mpixel/s
    $\Rightarrow$ 140 MB/s
- split on 4 DAQ boards with 2x14 bit flash-ADC each
- pipelined data processing in fast FPGA processor for real-time data correction and reduction
- output of 1st CCD line is available with a latency time $< 40\mu s$

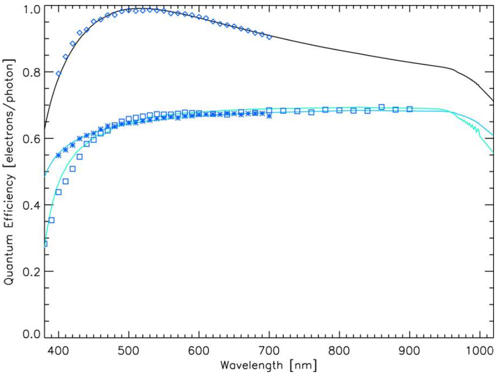
Internal quantum efficiency



Internal quantum efficiency



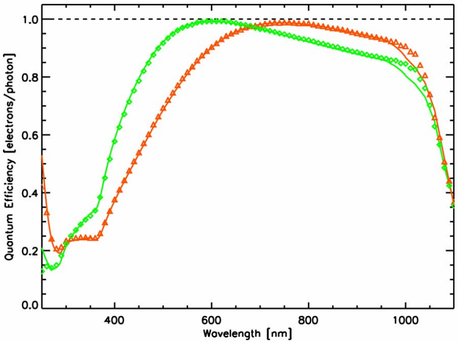
Total quantum efficiency



Quantum efficency of pnCCD:

- uncoated Si/SiO_2:
  QE < 70 %
- AR coating optimized for laser guide stars:
  QE > 85 % for λ = 450-950 nm
  (max @ 580 nm)
- AR coating optimized for red part of spectrum:
  QE > 85 % for λ = 680-1020 nm

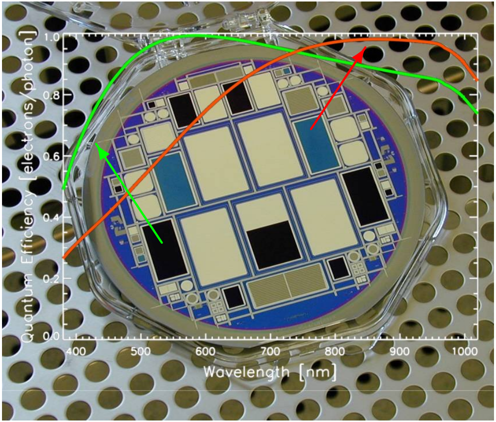
Total quantum efficiency



Quantum efficency of pnCCD:

- uncoated Si/SiO_2:
  QE $<$ 70 %
- AR coating optimized for laser guide stars:
  QE $>$ 85 % for λ = 450-950 nm
  (max @ 580 nm)
- AR coating optimized for red part of spectrum:
  QE $>$ 85 % for λ = 680-1020 nm

Total quantum efficiency

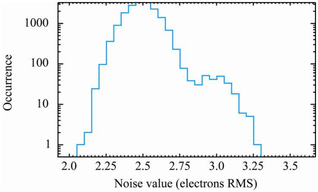


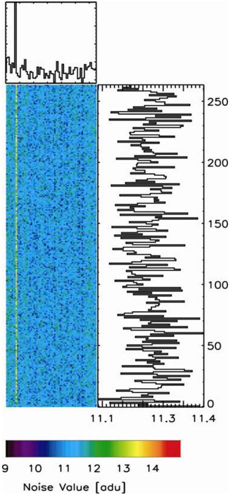
Quantum efficency of pnCCD:

- uncoated Si/SiO_2:
  QE $<$ 70 %
- AR coating optimized for laser guide stars:
  QE $>$ 85 % for λ = 450-950 nm
  (max @ 580 nm)
- AR coating optimized for red part of spectrum:
  QE $>$ 85 % for λ = 680-1020 nm

Noise performance

- 1 quadrant of pnCCD
- operating temperature = -55°C
- 1000fps - timing scheme
- Mean noise = 2.5 electrons (rms)
- 98.8% of all pixel exhibit less than 2.9 e- noise





May pnCCDs be used as WFS?

# pixels	264*264
sensing wavelength range	400-1000 nm
frame rate	1000 fps
readout noise	2-3 e^- rms
quantum efficiency	85-100 %

May pnCCDs be used as WFS?

# pixels	264*264	✓
sensing wavelength range	400-1000 nm	
frame rate	1000 fps	
readout noise	2-3 e^- rms	
quantum efficiency	85-100 %	

May pnCCDs be used as WFS?

# pixels	264*264	✔
sensing wavelength range	400-1000 nm	✔
frame rate	1000 fps	
readout noise	2-3 e^- rms	
quantum efficiency	85-100 %	

May pnCCDs be used as WFS?

# pixels	264*264	✔
sensing wavelength range	400-1000 nm	✔
frame rate	1000 fps	✔
readout noise	2-3 e^- rms	
quantum efficiency	85-100 %	

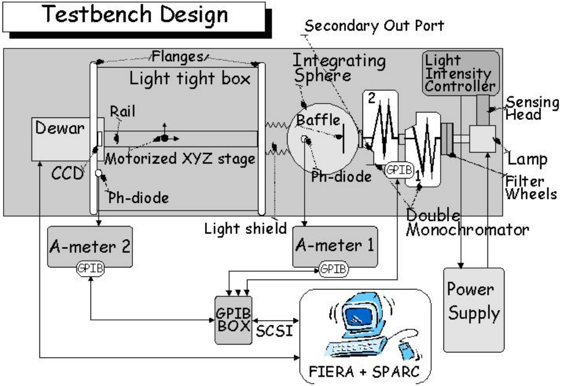
May pnCCDs be used as WFS?

# pixels	264*264	✔
sensing wavelength range	400-1000 nm	✔
frame rate	1000 fps	✔
readout noise	2-3 e^- rms	✔
quantum efficiency	85-100 %	

May pnCCDs be used as WFS?

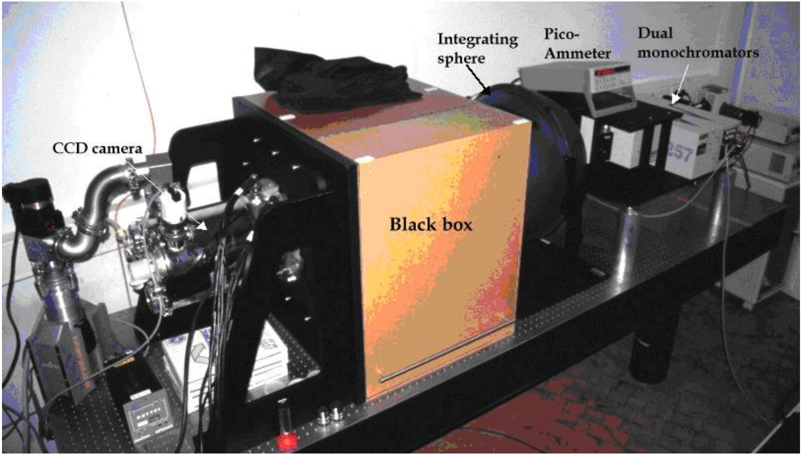
# pixels	264*264	✔
sensing wavelength range	400-1000 nm	✔
frame rate	1000 fps	✔
readout noise	2-3 e^- rms	✔
quantum efficiency	85-100 %	✔

Measurement setup



- white light source (400-1100nm)
- double monochromator for selection of wavelength
- integrating sphere to create uniform illumination
- calibrated photodiode to measure light intensity

Measurement setup



Measurement of important CCD parameters

By applying light at different luminosity levels and wavelengths several important CCD parameters will be measured:

- absolute quantum efficiency
- localization of traps
- bias stability
- dark current
- spatial resolution by PSF measurement

Measurement setup

- 1.3 m telescope
- pnCCD at telescope focus

Measurements at real objects

Observation of objects varying in brightness at timescales < 100 ms.

Test of several aspects at observation conditions:

- different read modes at high frame rates
- recording and processing of high amounts of data
- observation of faint objects (down to 10 photons/frame/pixel)
  - discrimination of object from detector noise and sky background
  - detection of brightness variation
- precision of differential photometry
- exploration of usable object brightness range