pnCCDs for Adaptive Optics

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Outline



Adaptive Optics (AO)

- Principle of AO
- Requirements for AO wavefront sensors

2 pnCCDs

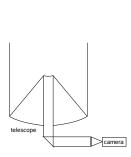
- Features of pnCCDs for optical applications
- pnCCDs as WFS?

Measurements

- Measurements at ESO
- Measurements at Skinakas Observatory (crete)

Principle of AO Requirements for AO wavefront sensors

AO principle



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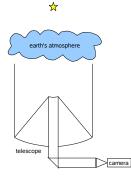
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Principle of AO Requirements for AO wavefront sensors

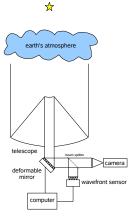
AO principle



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Principle of AO Requirements for AO wavefront sensors

AO principle



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Requirements for AO wavefront sensors

Wavefront sensors

Parameters of Shack-Hartmann wavefront sensors (WFS) used nowadays at large telescopes:			
 # WFS sensing wavelength frame rates # pixels readout noise quantum efficiency 	1 450-950 nm 80-1000 Hz up to 128*128 3-7 e ⁻ rms 20-90 %		

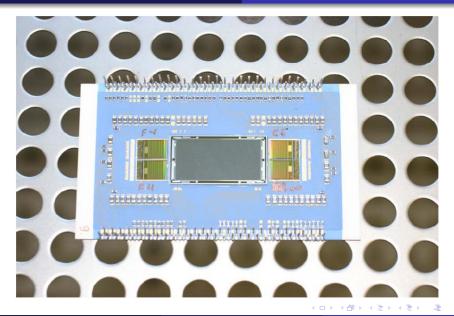
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Principle of AO Requirements for AO wavefront sensors

Wavefront sensors

Parameters necessary for future AO applications (KPAO, MCAO, ELT-AO,):			
 # WFS sensing wavelength frame rates # pixels readout noise quantum efficiency 	up to 9 450-1000 nm 800-1000 Hz ≥ 128*128 1-3 e ⁻ rms ≥ 85 %		

Features of pnCCDs for optical applications pnCCDs as WFS?

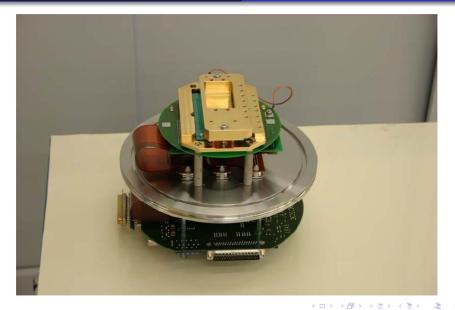


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May 7, 2007 8 / 19

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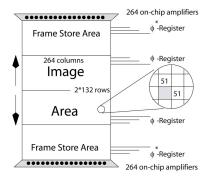


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May 7, 2007 8 / 19

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pnCCD for optical applications

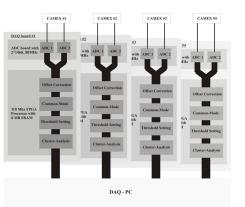


- 264*264 pixels each in image area and in frame store area
- readout two both sides
- frame rate up to 1000 fps
- 100 % fill factor
- frame transfer time = 30 μ s \Rightarrow Out of time probability = 3% (1000 fps)
- charge transfer loss CTI ≈ 10⁻⁵
 ⇒ total charge loss < 0.3%
 (264 shifts)

Image: Image:

Features of pnCCDs for optical applications pnCCDs as WFS?

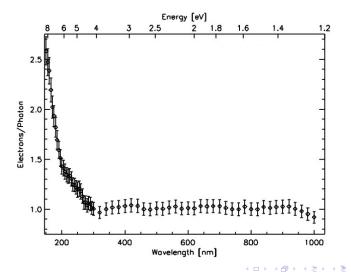
Data Aquisition



- 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 1^{st} CCD line is available with a latency time $< 40 \mu s$

Features of pnCCDs for optical applications pnCCDs as WFS?

Internal quantum efficiency

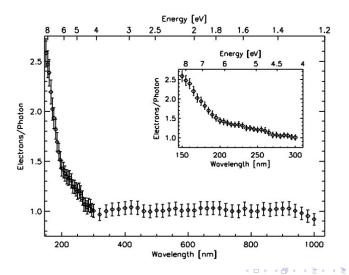


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May 7, 2007 11 / 19

Features of pnCCDs for optical applications pnCCDs as WFS?

Internal quantum efficiency

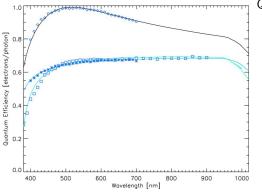


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Features of pnCCDs for optical applications pnCCDs as WFS?

Total quantum efficiency



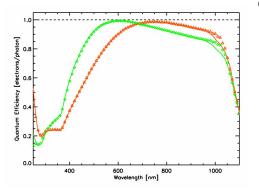
Quantum efficency of pnCCD:

- uncoated Si/SiO₂: 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:

 $\mathsf{QE}>85$ % for $\lambda=680\text{--}1020~\mathsf{nm}$

Features of pnCCDs for optical applications pnCCDs as WFS?

Total quantum efficiency



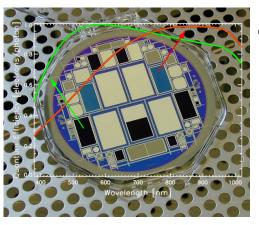
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Total quantum efficiency



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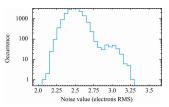
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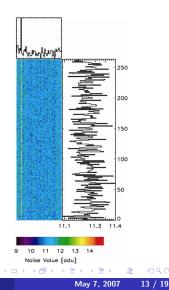
QE > 85 % for $\lambda =$ 680-1020 nm

Features of pnCCDs for optical applications pnCCDs as WFS?

Noise performance

- 1 quadrant of pnCCD
- operating temperature = $-55^{\circ}C$
- 1000fps timing scheme
- Mean noise = 2.5 electrons (rms)
- 98.8% of all pixel exhibit less than 2.9 enoise





pnCCDs for Adaptive Optics

Features of pnCCDs for optical applications pnCCDs as WFS?

May pn	CCDs	be us	sed as	WFS?
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# pixels	264*264
sensing wavelength range	400-1000 nm
frame rate	1000 fps
readout noise	2-3 e ⁻ rms
quantum efficiency	85-100 %

Features of pnCCDs for optical applications pnCCDs as WFS?

May pnCCDs be used as WFS?			
# pixels	264*264	V	
sensing wavelength range	400-1000 nm		
frame rate	1000 fps		
readout noise	$2\text{-}3 e^- rms$		
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May 7, 2007 14 / 19

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Features of pnCCDs for optical applications pnCCDs as WFS?

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Features of pnCCDs for optical applications pnCCDs as WFS?

May pnCCDs be used as WFS?			
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May 7, 2007 14 / 19

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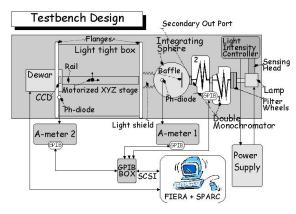
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Measurements at ESO Measurements at Skinakas Observatory (crete)

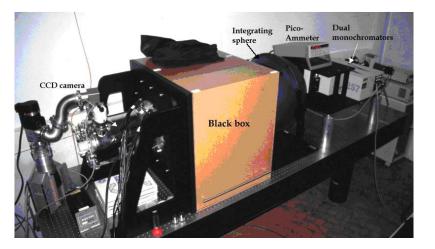
Measurement setup



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

Measurements at ESO Measurements at Skinakas Observatory (crete)

Measurement setup



Measurements at ESO Measurements at Skinakas Observatory (crete)

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

Measurements at ESO Measurements at Skinakas Observatory (crete)

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

