pnCCD
First Test Results

Mark Downing, Robert Hartmann, Sebastian Ihle
European Southern Observatory ESO (http://www.eso.org)
Max-Plank-Institut Semiconductor Laboratory (http://www.hll.mpg.de/)

7 Nov 2007

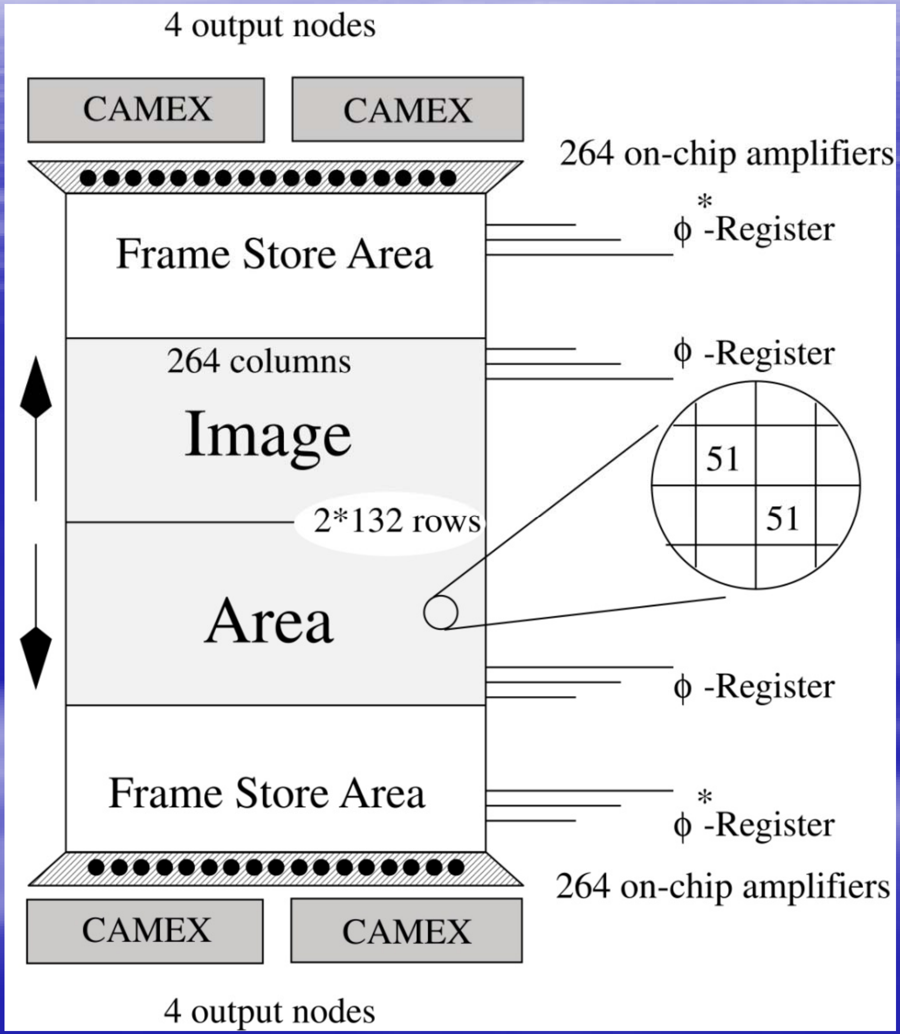
Talk Overview

- Background
- Setup
- Dark Measurement Results
  - ⇨ Bias stability
  - ⇨ Dark Current
  - ⇨ Bright Defects
- Light Measurements
  - ⇨ Photon Transfer Curve
  - ⇨ QE
  - ⇨ PRNU
  - ⇨ Cosmetics
  - ⇨ PSF
- Conclusions

Background

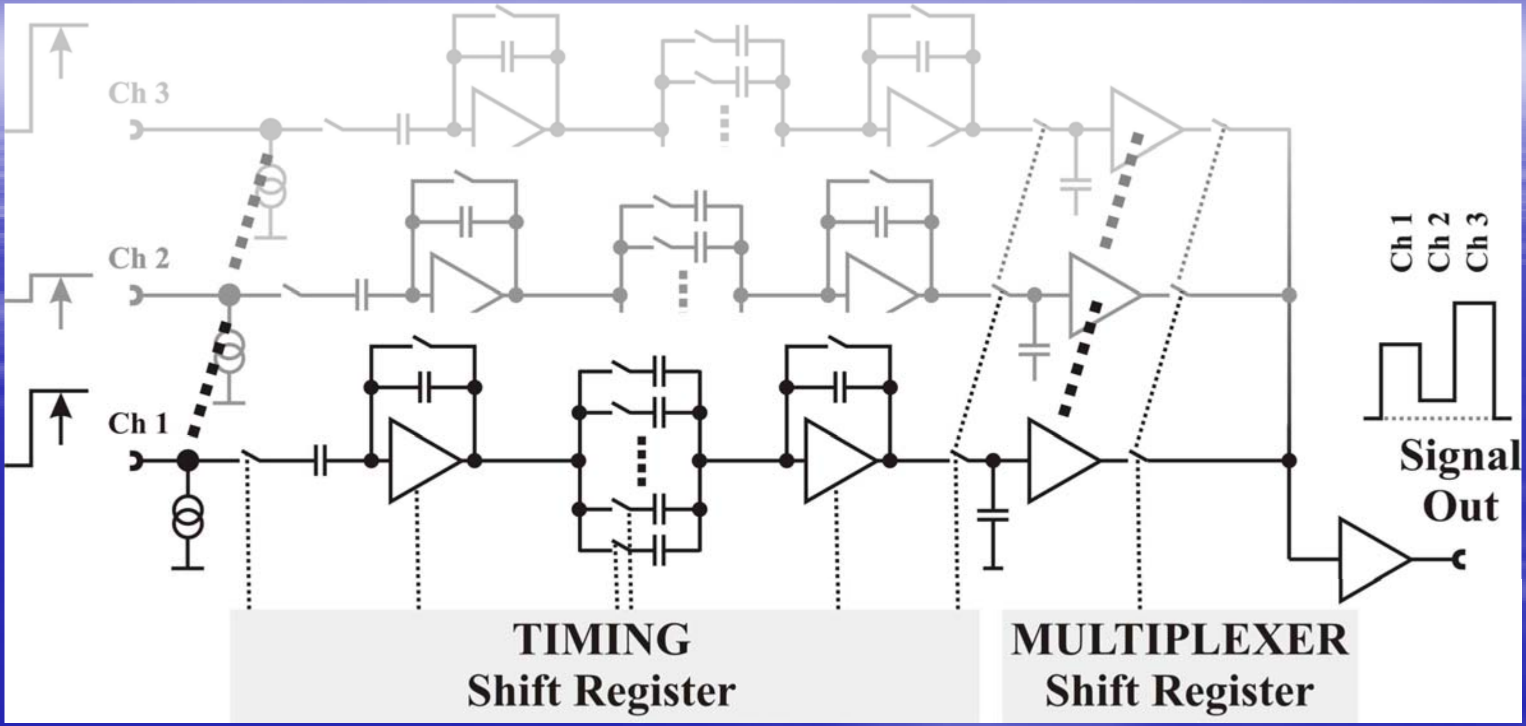
- Contract between ESO and MPE/HLL (pnSensor) for:
  - ⇨ Three Test Runs
  - ⇨ Delivery of engineering and science device
- Report on first Test Run.
- MPE/HLL is a common research facility of the Max-Planck-Institut für Physik in Muenchen and the Max-Planck-Institut für extraterrestrische Physik in Garching
- Produce pnCCDs for particle physics and X-ray astronomy
  - ⇨ Large pixel size 36-300um
  - ⇨ Thick 300-500um => >80% QE over 450-950nm
  - ⇨ Low ron of 3e
  - ⇨ Fast read out 1000fps
  - ⇨ High speed clocking – non-overlapping aluminum clock lines
- Developed 264x264 51µm square pixel size by 450µm thick pnCCD that is interesting for AO WFS for VLT and ELT.

264x264 pnCCD



- 264x264 51um pixel
- 450um thick
- Split frame transfer
- One output amplifier per column
- Total 528 amplifiers
- 1000fps
- RON < 3e
- Integrated with CAMEX
  - Gain
  - Analog DCS signal processing
  - Multiplexing of 132 channel to 1 output

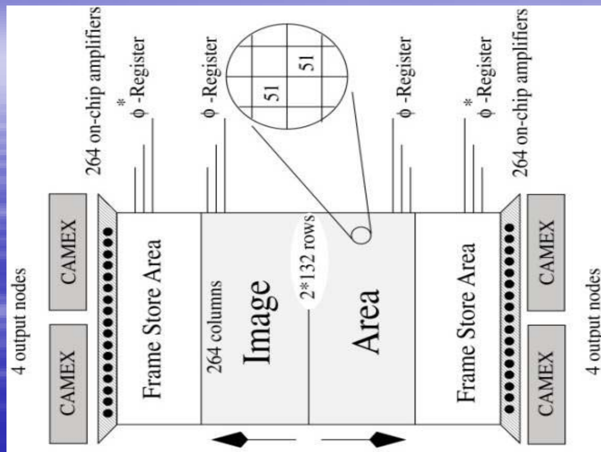
CAMEX

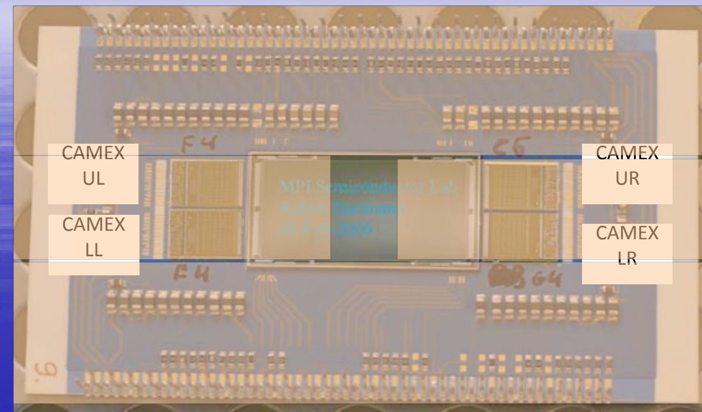


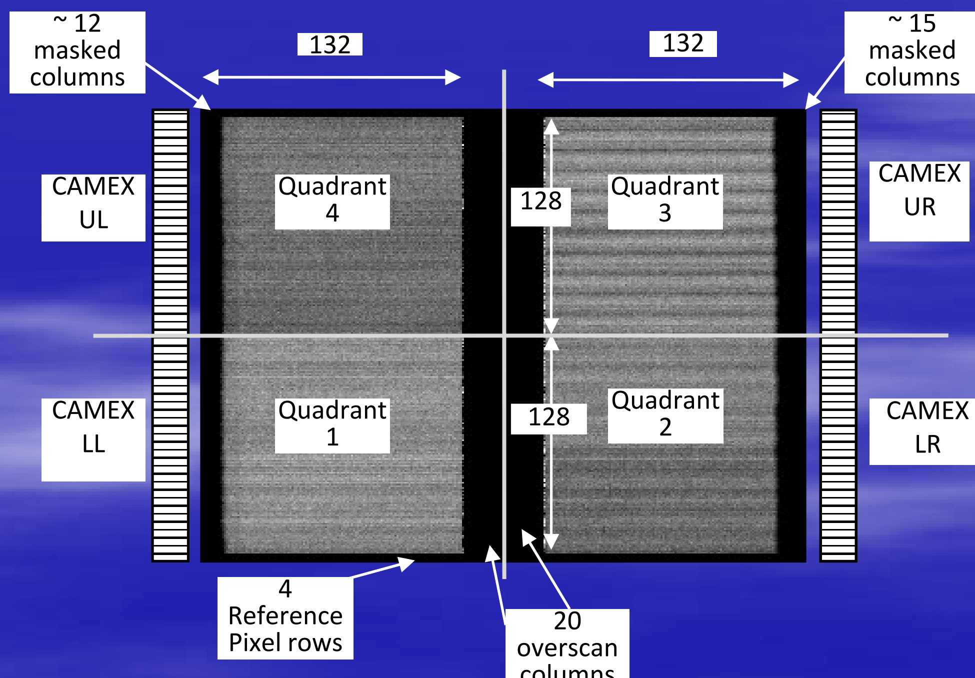
Provides

- ⇨ Load for CCD output amplifier
- ⇨ Gain stages
- ⇨ Analog DCS that average over several samples
- ⇨ Multiplexer 132column amplifiers to 1 output

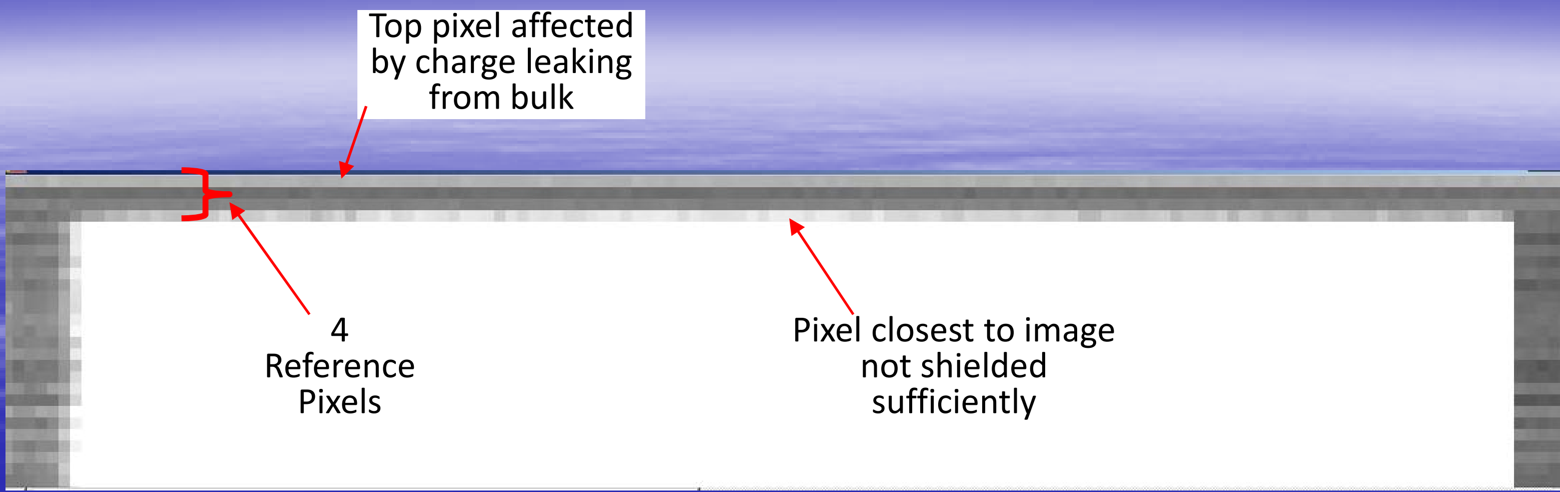
Image Format

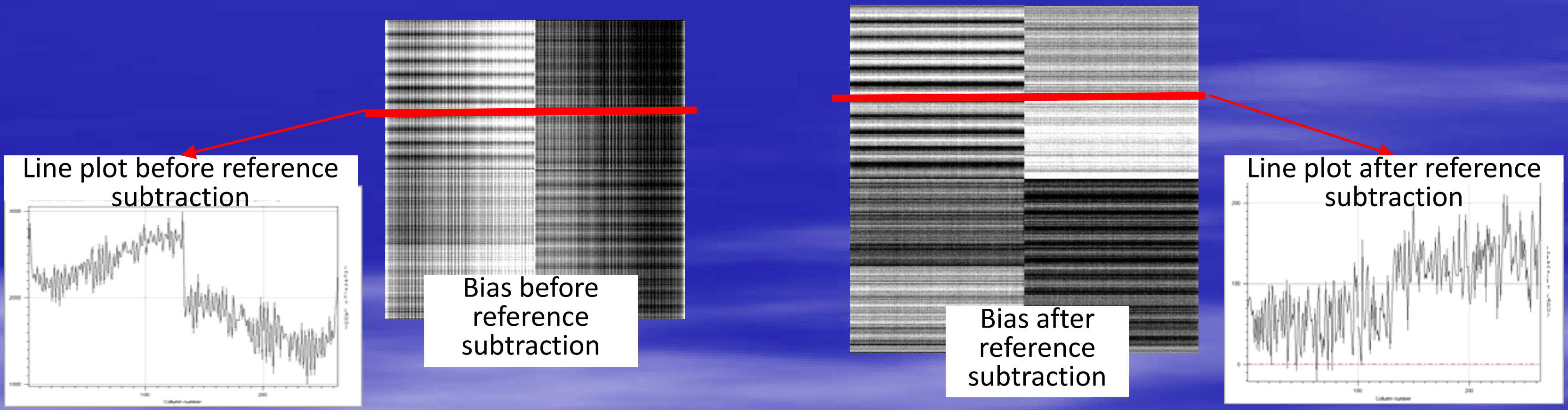






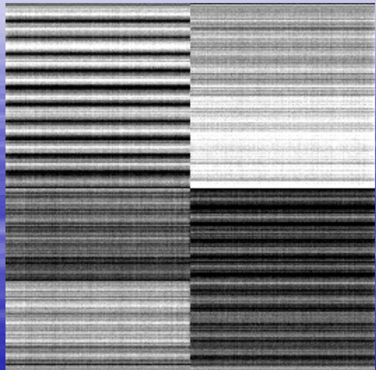
Reference Pixels





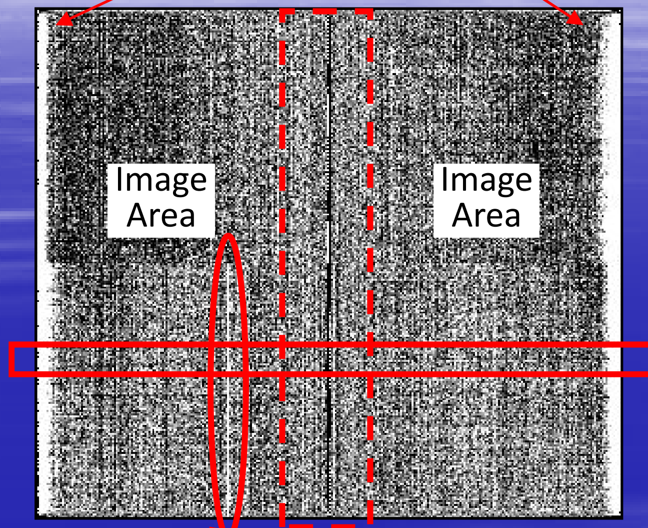
- Purpose to subtract column to column variations
- Out of four only two are usable

Overscan Subtraction



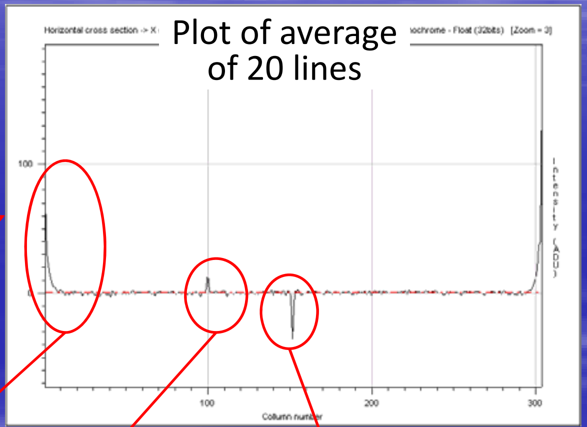
Bias before overscan subtraction

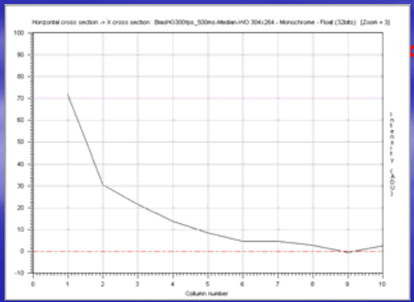
Prescan pixels made by light mask



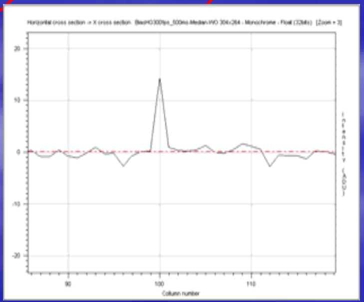
Hot reference pixel [3,100]

Overscan

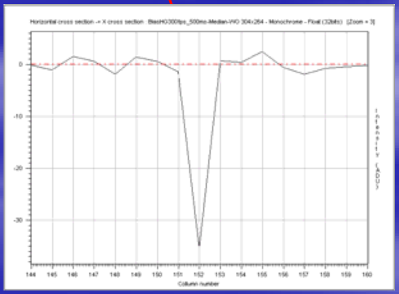




Ramp on bias image during first few columns



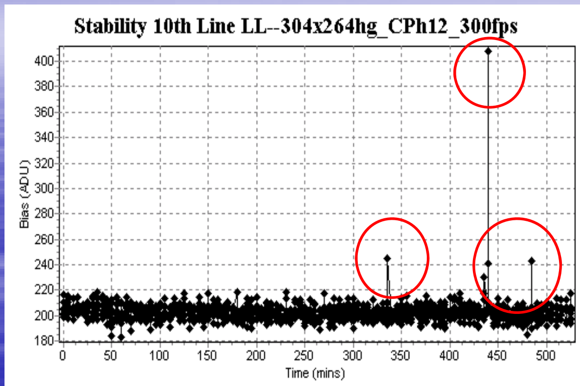
Hot reference pixel [3,100] causes column fault

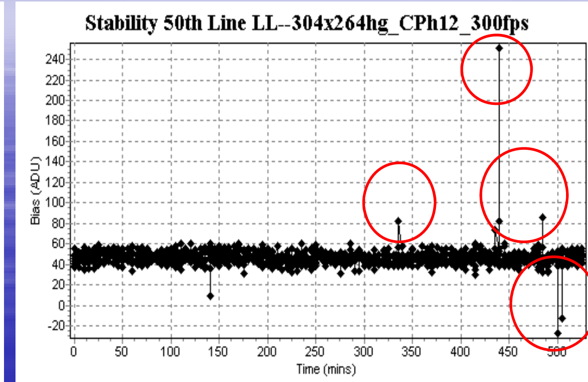


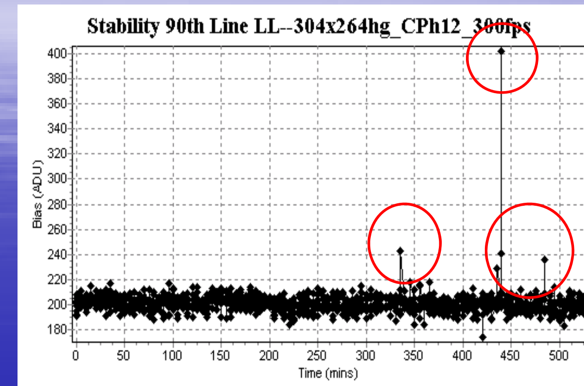
Artifact on center two overscan columns

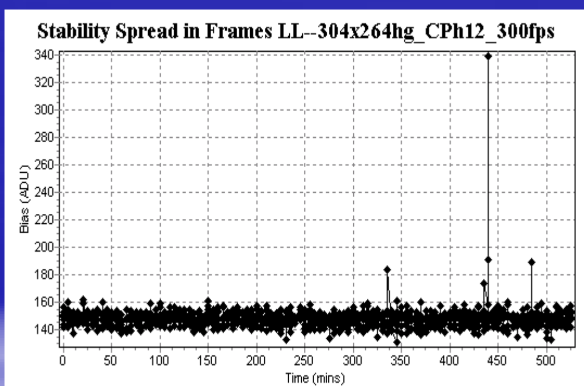
DARK Measurement Results

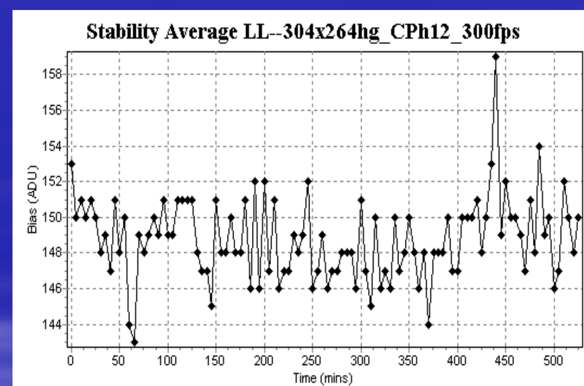
Bias Stability





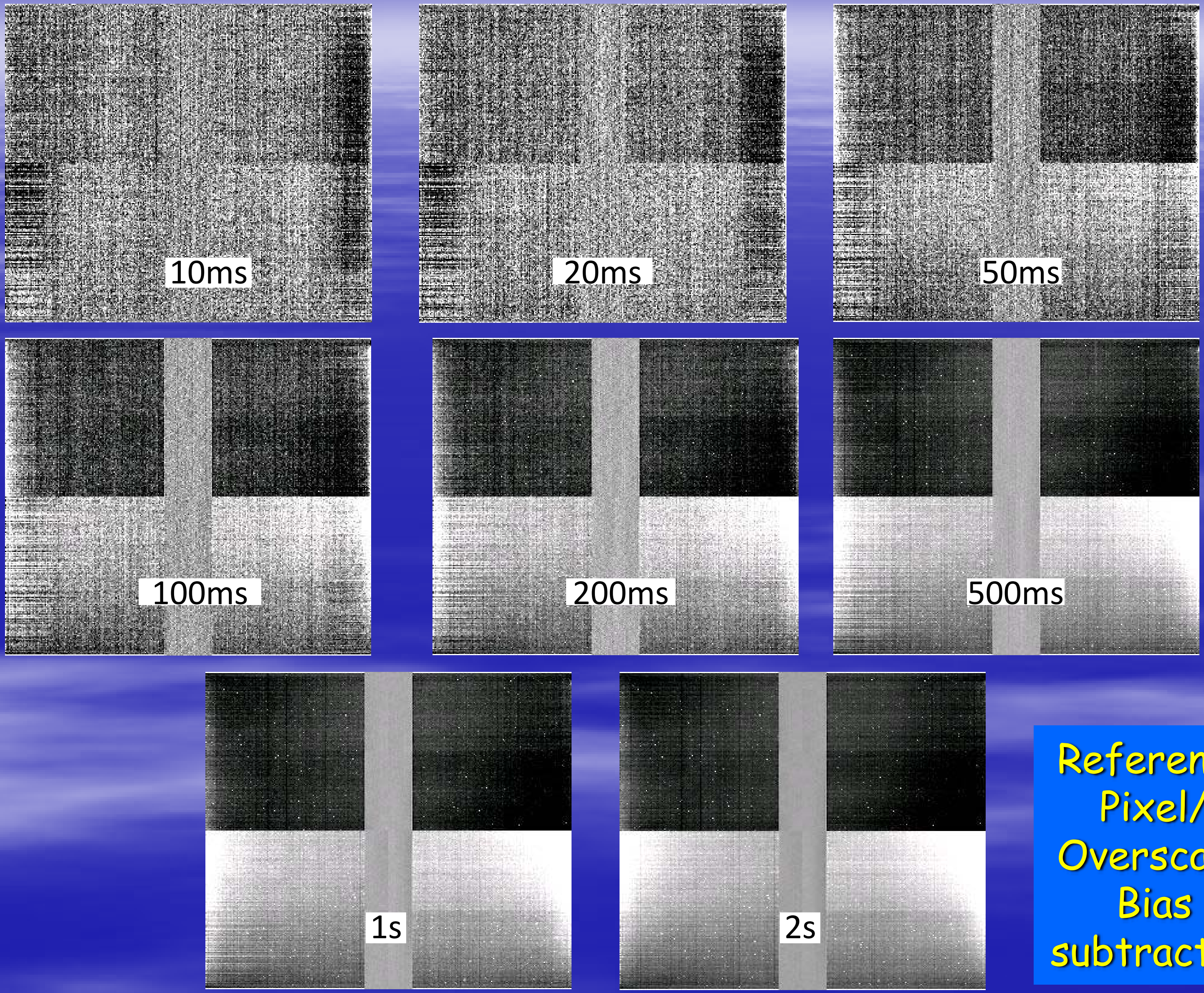






- 10 biases taken every 10 minutes for several hours.
- Good long term stability
- Poor short term stability – up to 200ADU (20e) between successive images.
- Can be improved by overscan subtraction but cause should be investigated.

Dark Images



Reference Pixel/ Overscan/ Bias subtracted

Dark Current

Amplifier	Frame Rate (Hz)	Dark Current e-/pix/sec	Dark Level e-	Bias Level e-
Amp Left Lower	100	-4.3287	-0.048	-0.005
	50	-4.9552	-0.079	0.021
	20	-1.4866	-0.081	-0.007
	10	-1.1484	-0.094	0.021
	5	-1.1994	-0.253	-0.013
	2	-0.5187	-0.276	-0.017
	1	-0.3032	-0.316	-0.013
	0.5	0.0358	0.062	-0.01
Amp Left Upper	100	-11.2398	-0.238	-0.126
	50	-10.5436	-0.297	-0.087
	20	-7.0603	-0.511	-0.158
	10	-8.8803	-1.013	-0.125
	5	-10.5697	-2.242	-0.128
	2	-11.8431	-6.045	-0.123
	1	-11.7472	-11.875	-0.127
	0.5	-11.6421	-23.42	-0.135

- Darks are dominated by drift in the image area at different exposure times thus dark current is difficult to calculate, but for > 50fps, dark current is very low < 1e/pixel.

Bright Defects

Number of Hot Pixels

Frame Rate (Hz)	Hot Pixels > 20e	Hot Pixels > 10e	Hot Pixels > 5e
100	0	0	0
50	0	0	0
20	0	0	0
10	0	0	1
5	0	3	18
2	5	29	638
1	30	879	5204
0.5	1258	6312	11967

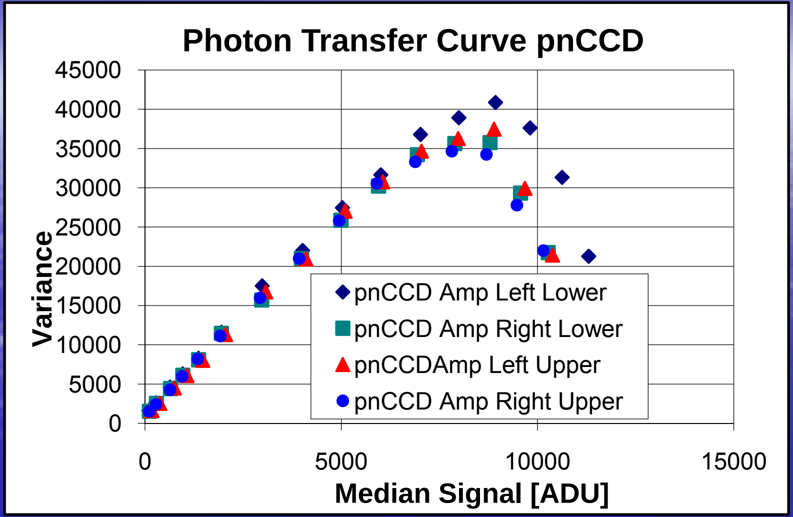
Brightest Hot Pixels versus frame rate

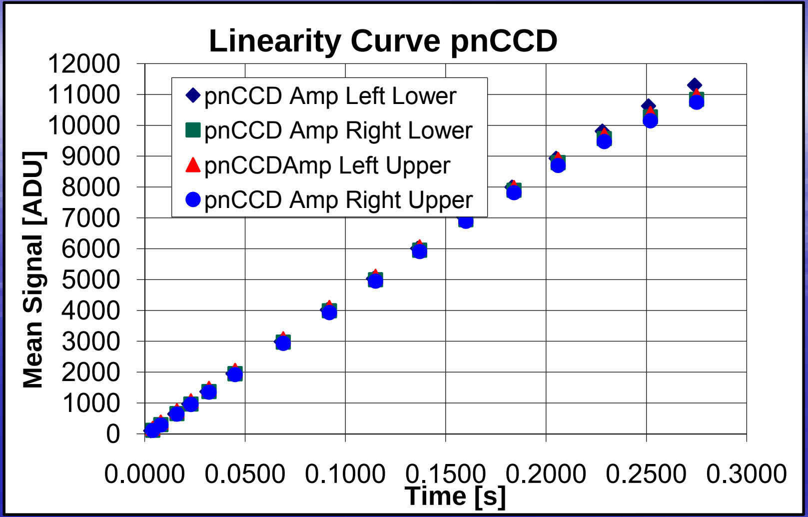
Frame Rate (Hz)	Hot Pixel [153,91] e-	Hot Pixel [79,124] e-	Hot Pixel [99,179] e-	Hot Pixel [3,100] e-
100	0.12	0.6	0.18	2.0
50	1.2	0.85	1.2	4.2
20	2.9	2.3	3	11.1
10	5	4	3.5	24
5	10	10.2	11	47.9
2	25	23	23	121.5
1	51	44	48	243
0.5	103	90	110	478

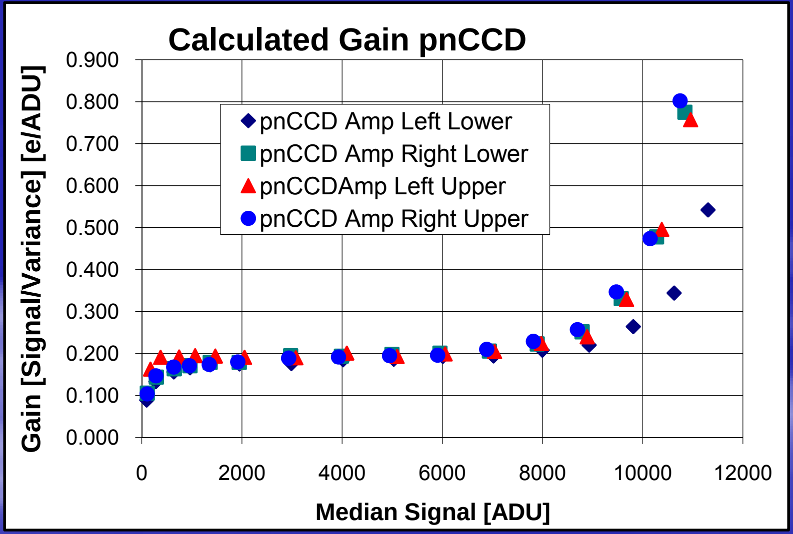
- Frame rate > 50Hz, no bright defect.
- Hot pixels scale with integration time as expected.

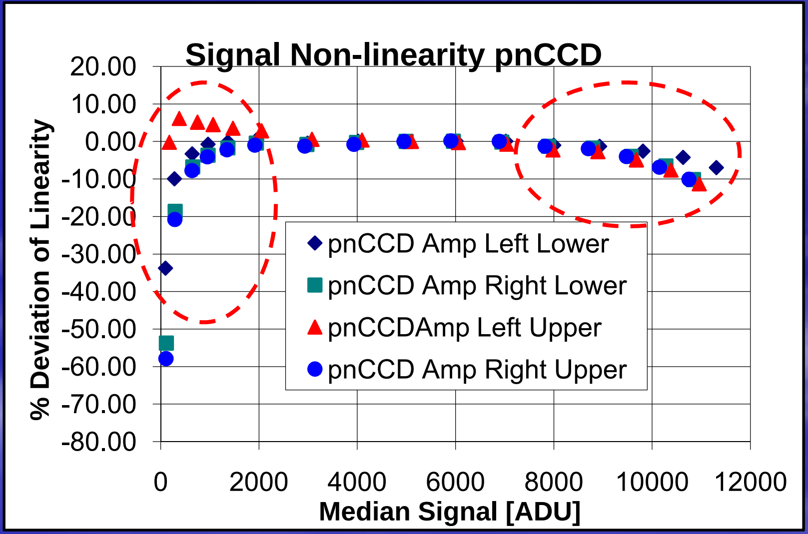
Light Measurement Results

Photon Transfer Curve





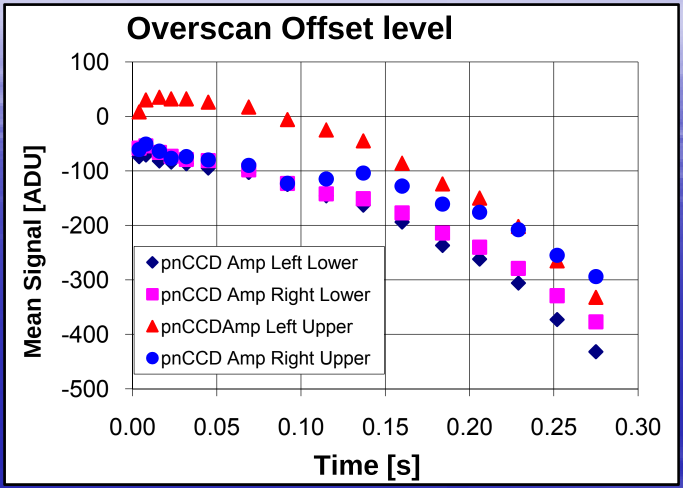


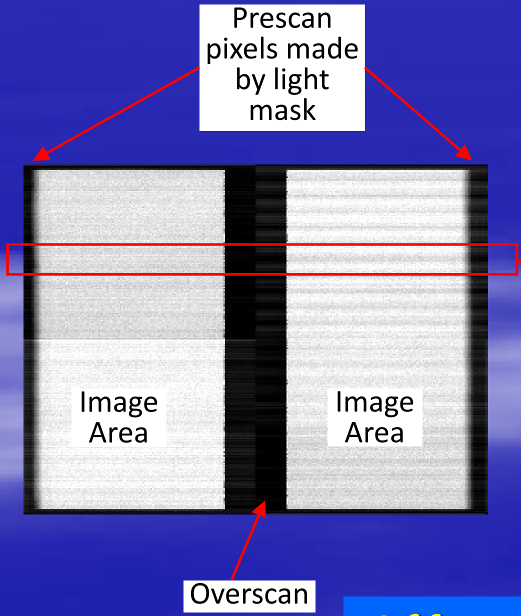


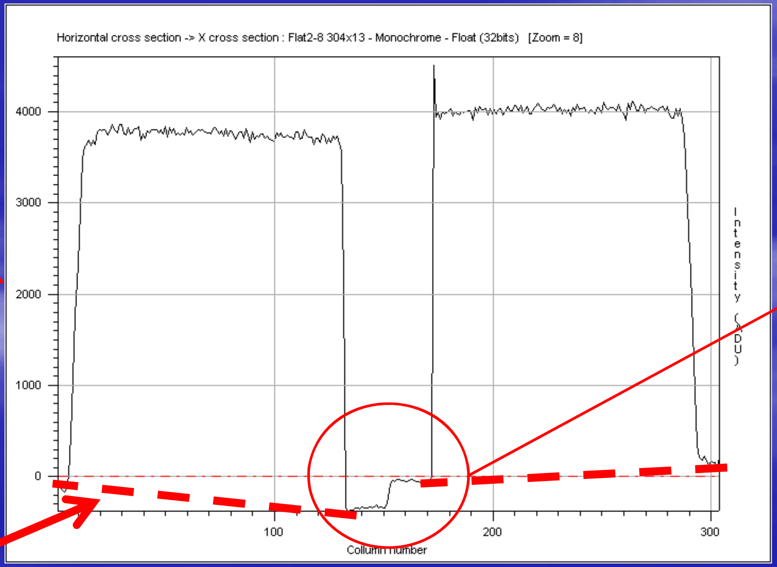
- Poor linearity < 200e and >700e

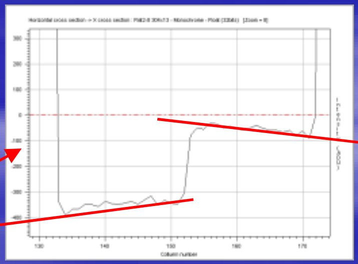
DC Level Varies with Illumination

- > 700e analog signal chain (CCD output amplifier) saturating
- < 200e the image DC offset level varies with signal and the need to correct



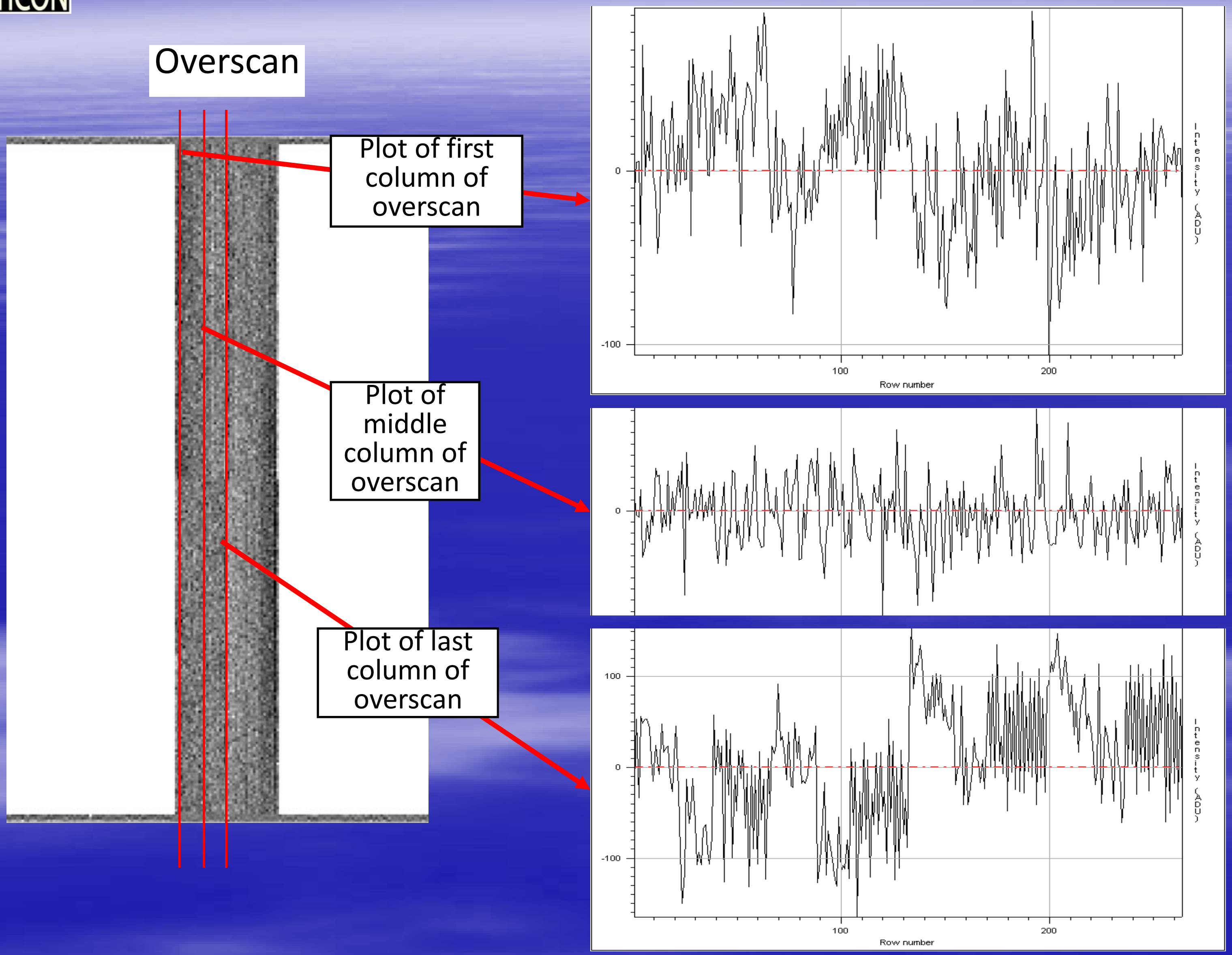




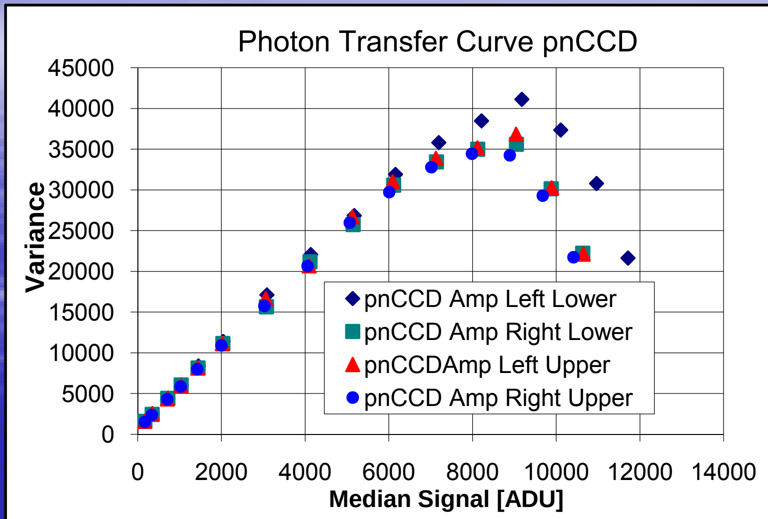


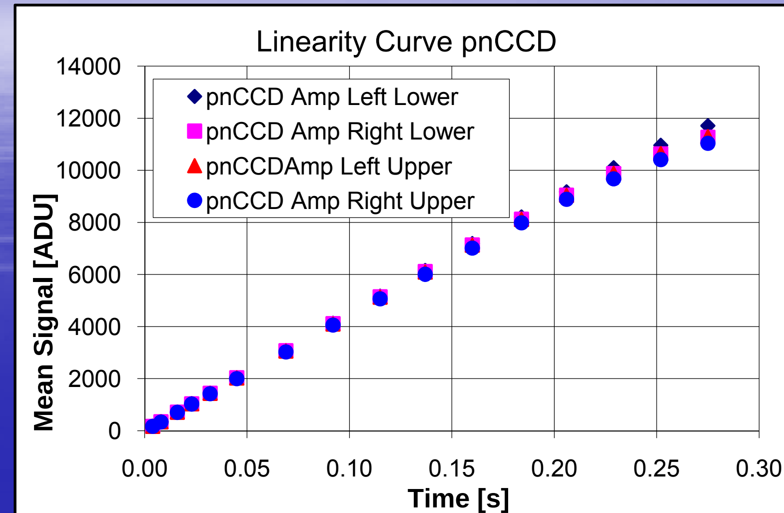
Offset level changes

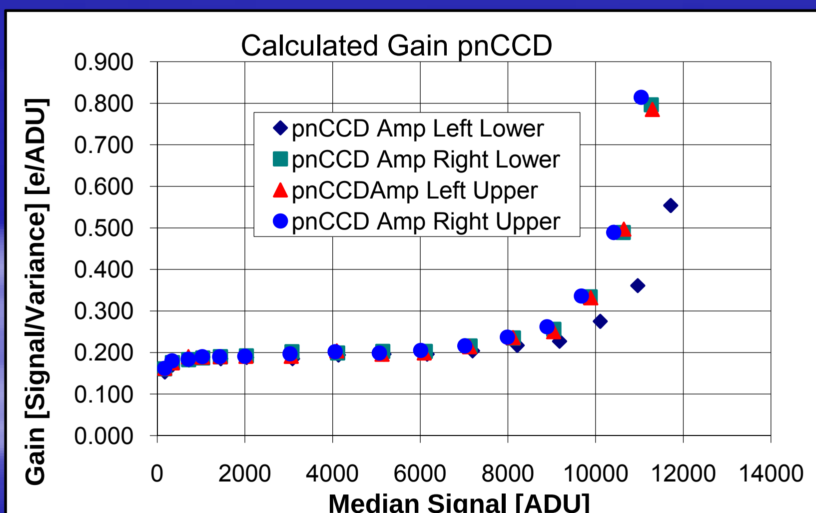
Care with use of Overscan

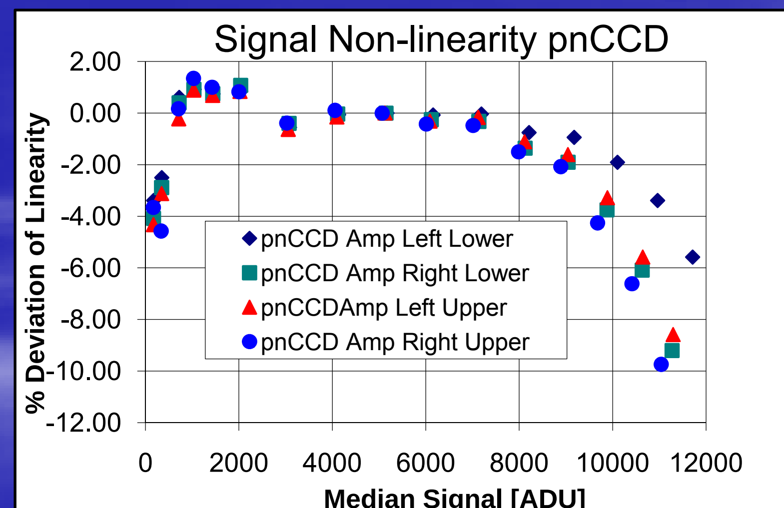


PTC Overscan Subtracted



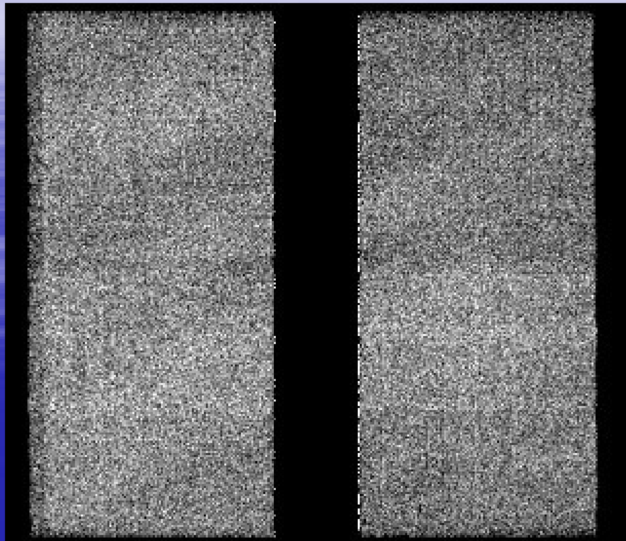


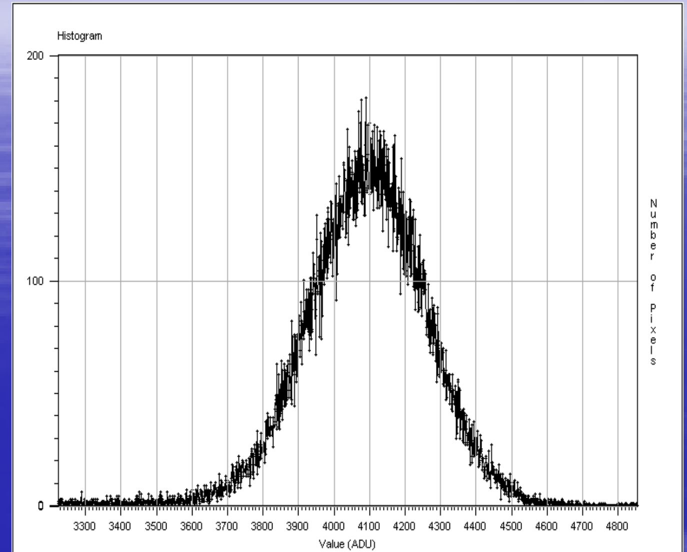




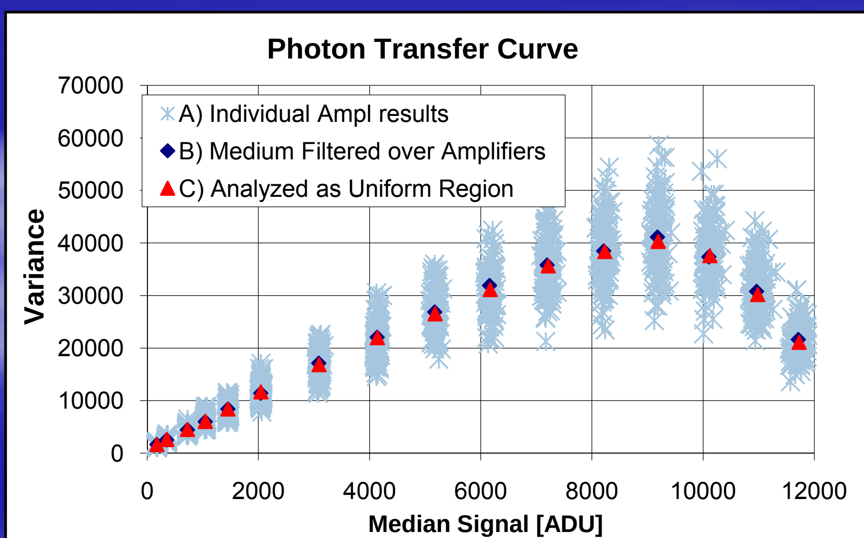
- Linearity improved

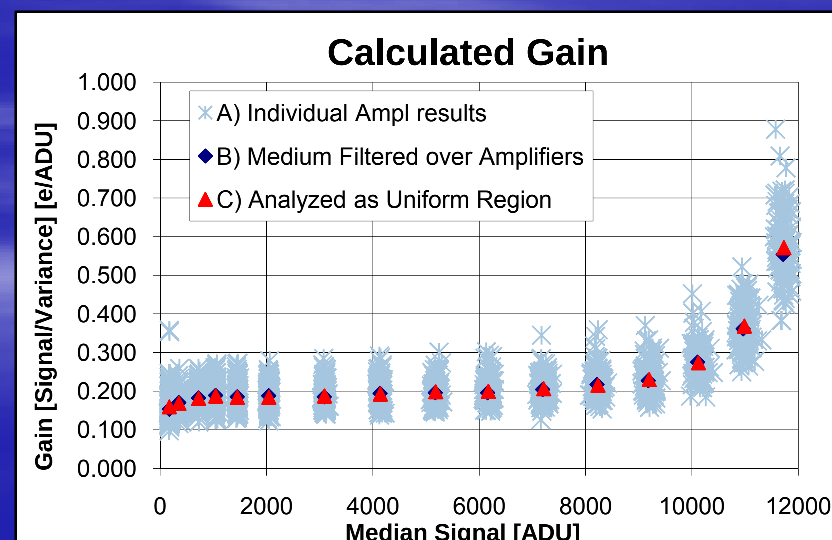
Good Gain Uniformity



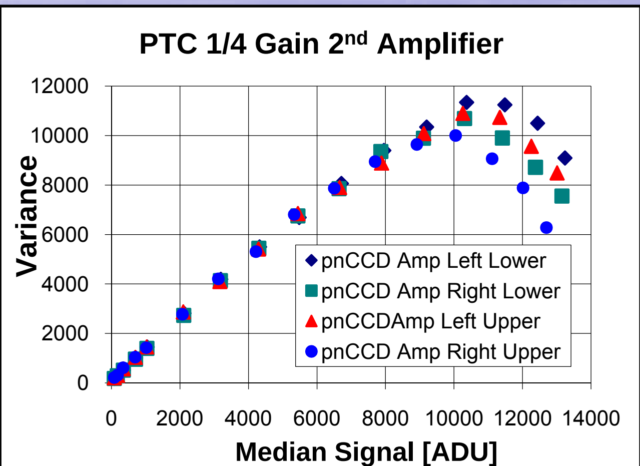


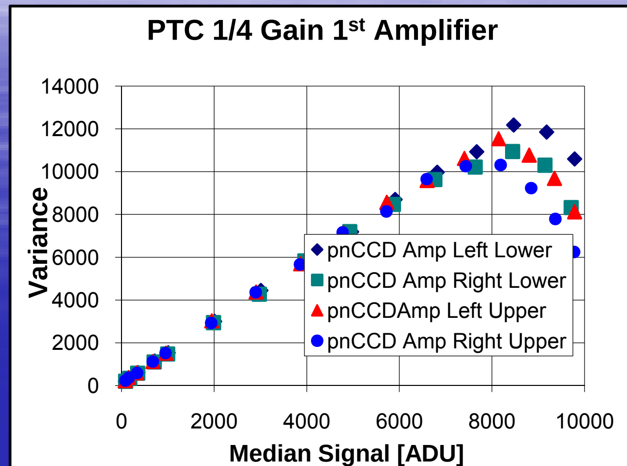
- Could do analysis without worrying about which amplifier pixel read from.

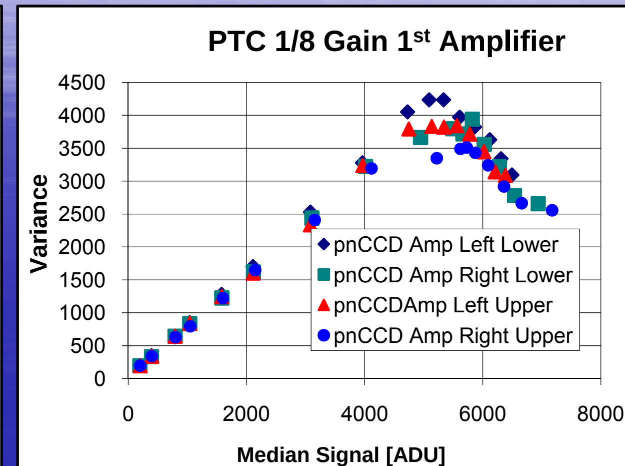


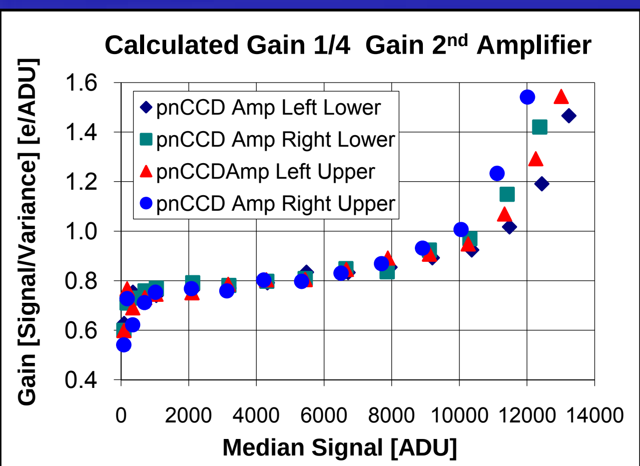


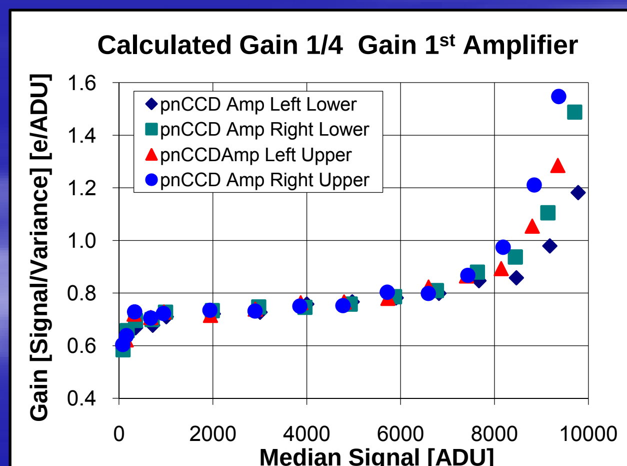
Lowering Gain, Full Well of 3200e possible

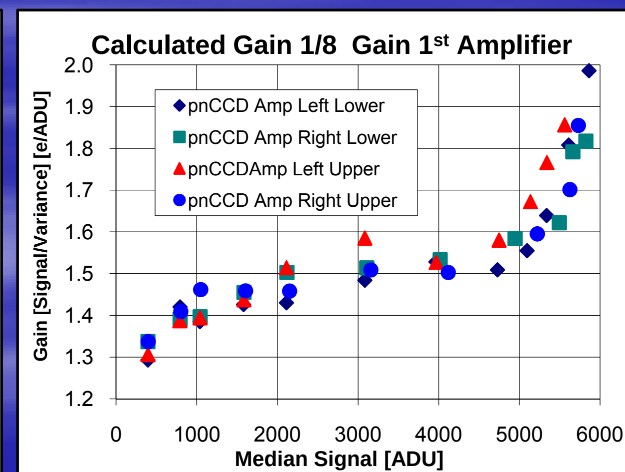




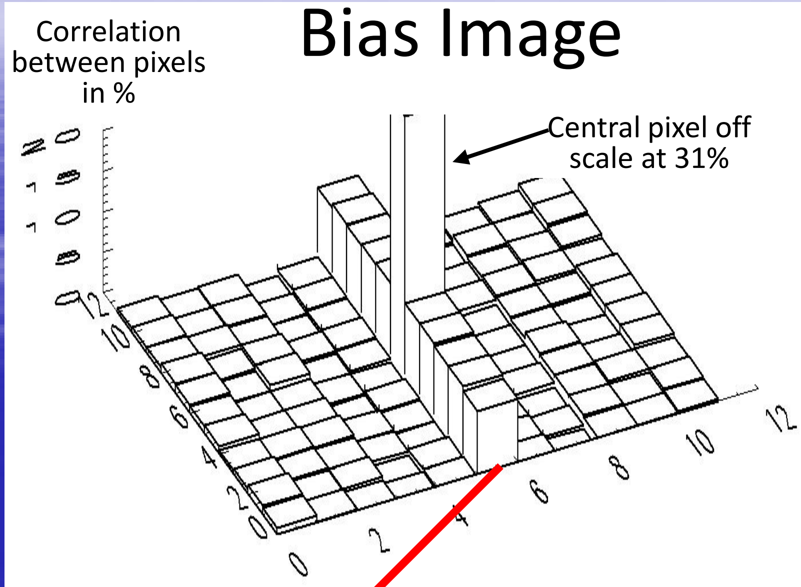


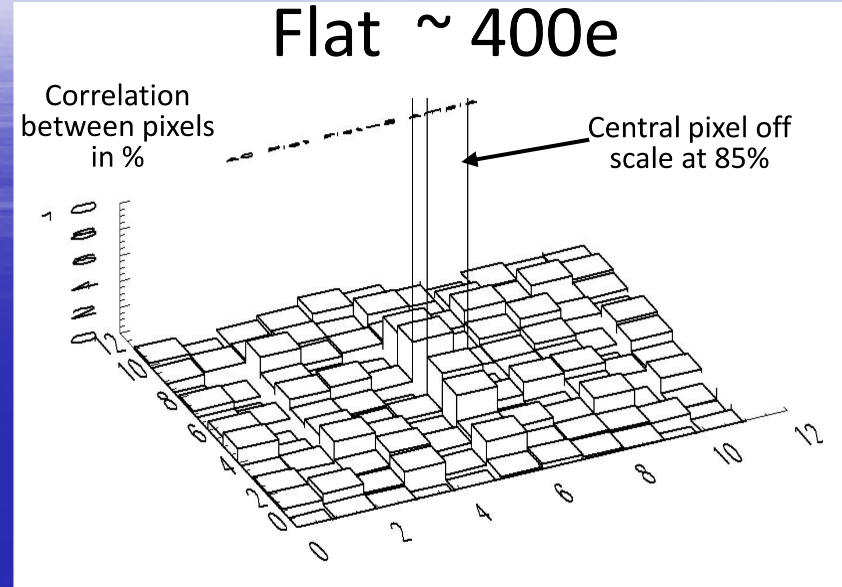


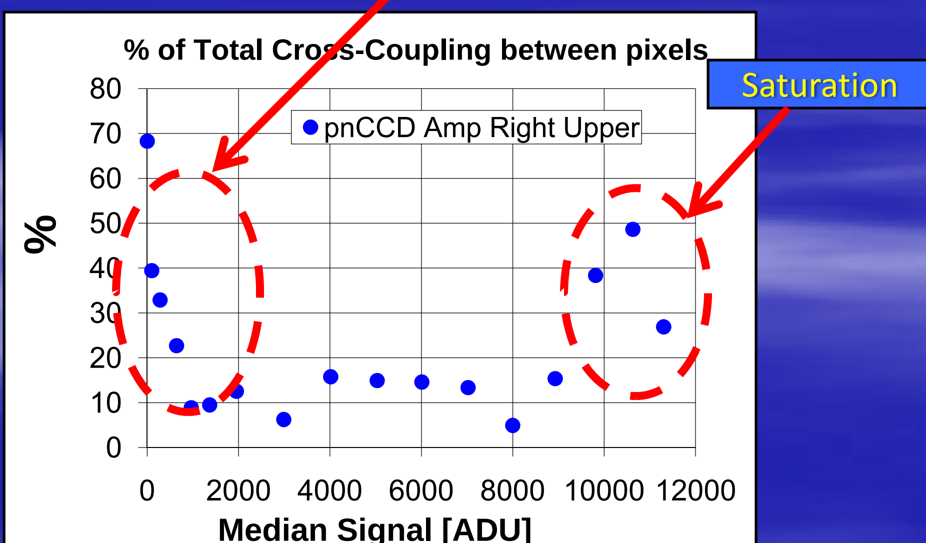




Spatial Autocorrelation Analysis

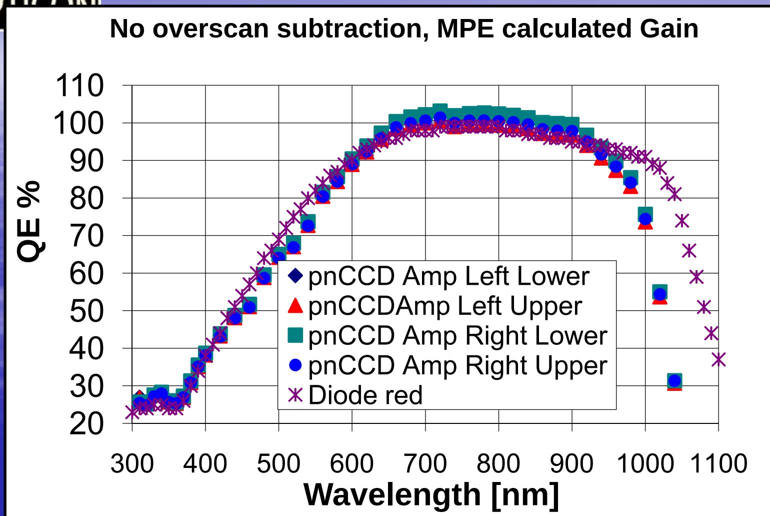


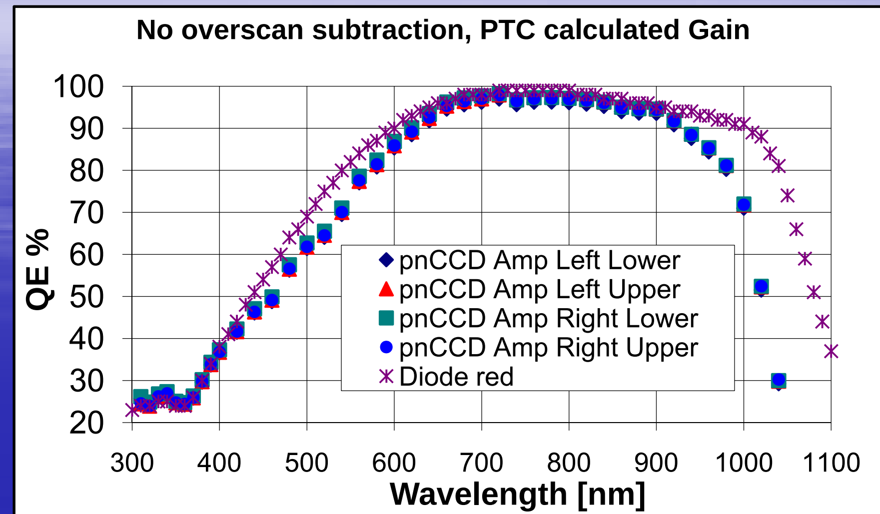


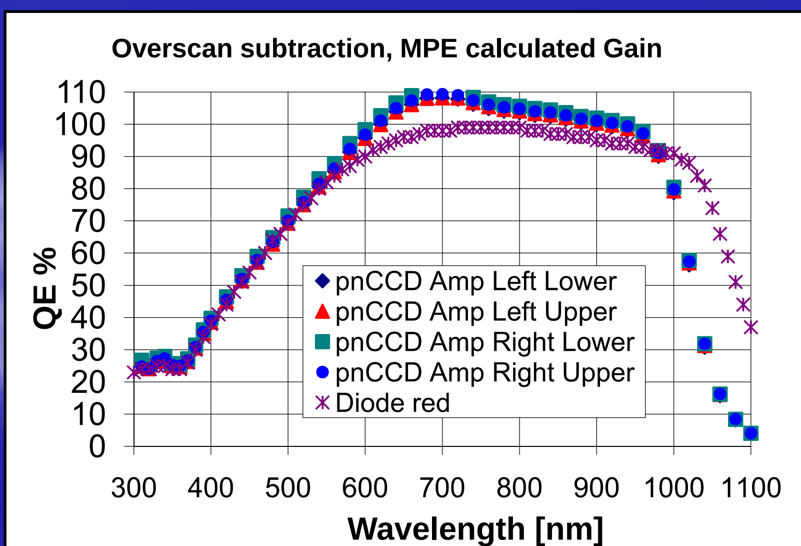


- Bias image shows high correlation (5-10%) between pixels in a column due to the subtraction of the reference pixels.
- This is less noticeable at higher illumination.

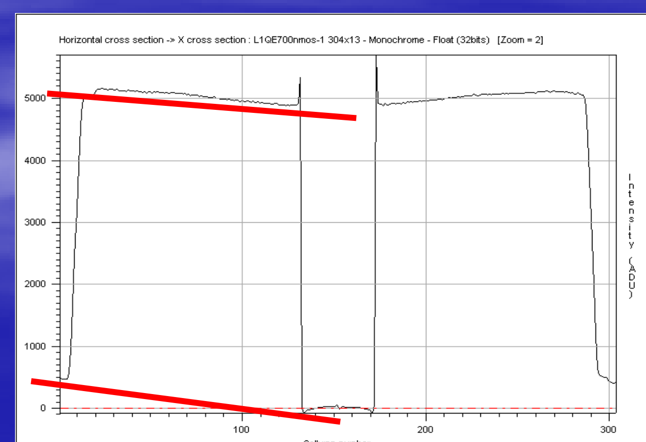
QE Excellent





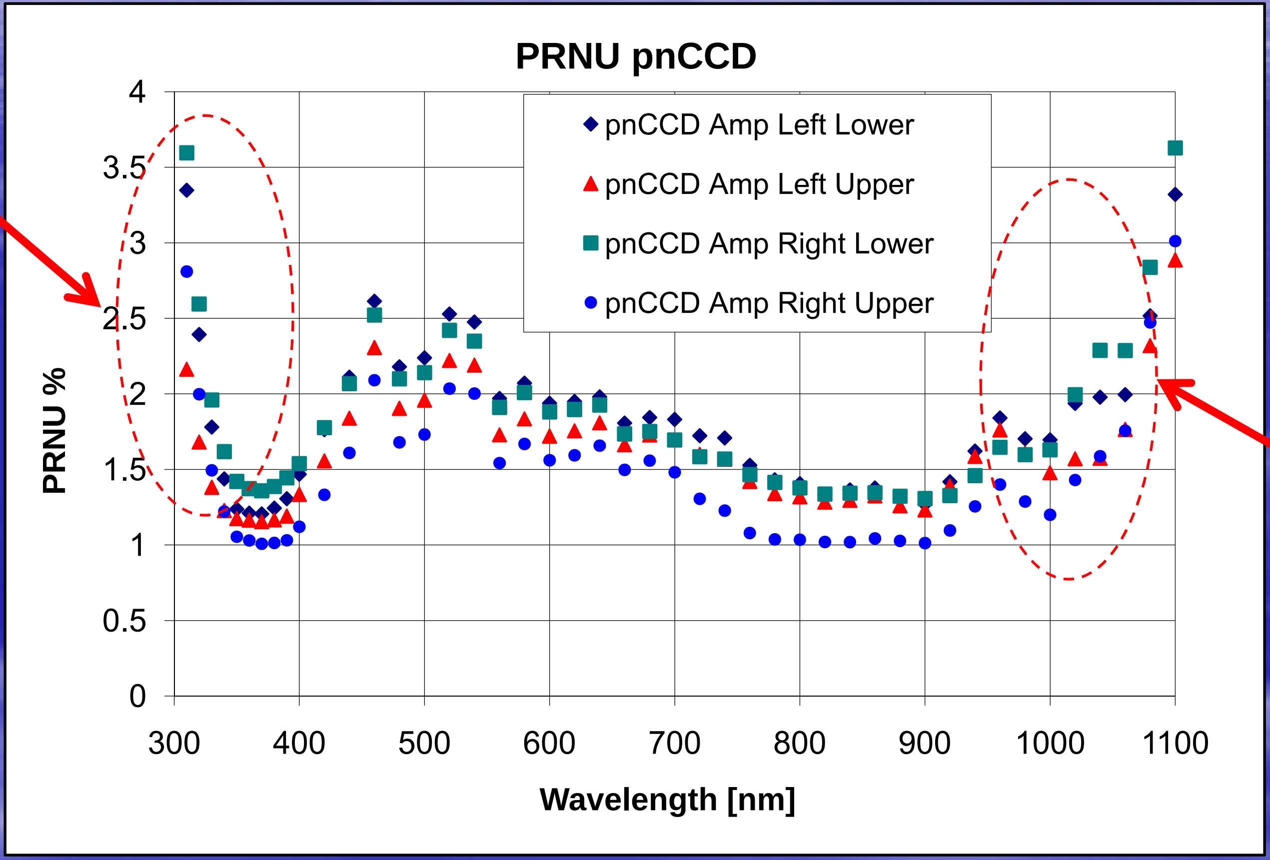


- Excellent QE into the "red".
- Accuracy of results depends on knowing gain and subtracting offset.



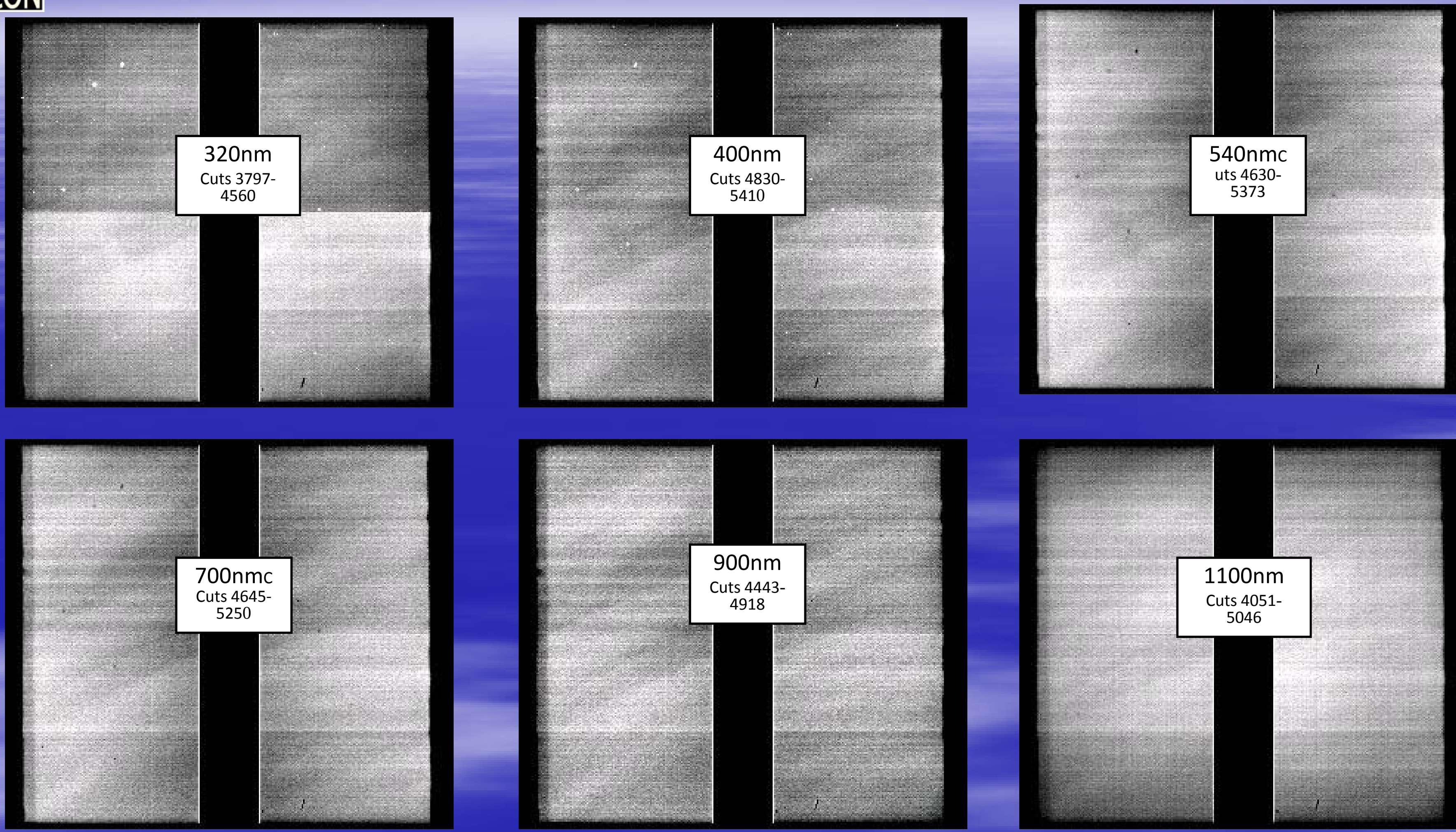
PRNU Good; little structure or fringing

Probably due to dark features - long exposure times



Not fringing but dome-ing of image

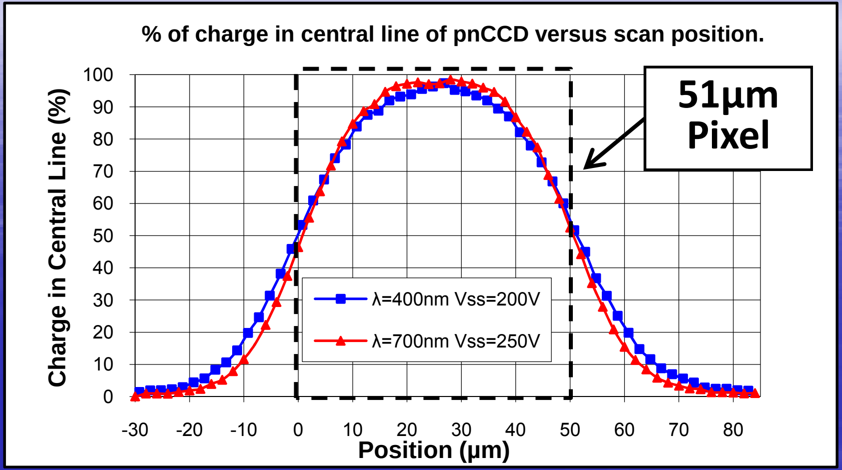
PRNU and Cosmetics Excellent

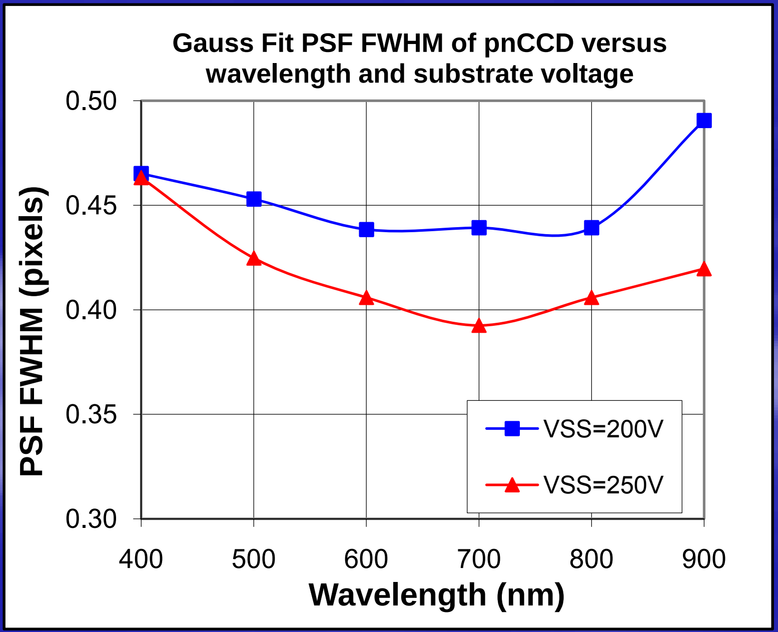


- No dark (< 50% sensitivity) pixels.

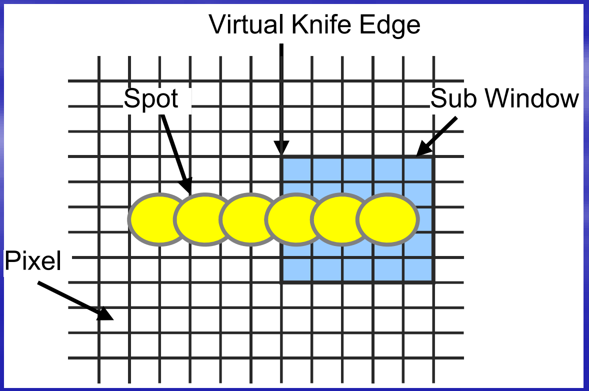
PSF is Excellent

234	24	22	22	20	23	19	20	27	20	25	22	22	21
233	12	17	12	10	13	12	17	15	15	19	15	13	11
232	-101	-96	-100	-93	-95	-96	-92	-92	-95	-99	-99	-97	-100
231	-57	-55	-55	-56	-57	-44	-2	-52	-54	-55	-51	-53	-60
230	-42	-40	-38	-36	-37	44	5235	-4	-36	-33	-36	-36	-37
229	71	70	73	75	77	88	203	84	72	73	73	73	70
228	-63	-62	-61	-59	-60	-59	-62	-56	-66	-58	-63	-63	-64
227	-184	-179	-177	-180	-177	-182	-181	-178	-182	-178	-181	-177	-180





- Requirements ~ < 0.8 pixel
- Pixels size could be reduced to a much smaller size and still meet requirements



Conclusion

- pnCCD has
  - ⇨ Good long term bias stability,
  - ⇨ Low dark current (<1e) and no hot pixels for > 50fps and -45DegC,
  - ⇨ Good gain uniformity between amplifiers and CAMEX,
  - ⇨ Good PRNU (< 2% peak-to-peak) - little structure or fringing,
  - ⇨ No dark (< 50% of surrounding) pixels,
  - ⇨ Excellent red QE > 90% over 600-900nm and > 80% 580-980nm,
  - ⇨ Excellent PSF of < 0.5pixel FWHM,
  - ⇨ Low read noise 2-3e at 300fps.
  - ⇨ Dynamic range of 3200e achievable by reducing CAMEX gain.
  - ⇨ Spatial Autocorrelation Analysis showed correlation due to reference pixel subtraction and little else up to saturation level.

Challenges

- Poor short term bias stability; bias level can vary > 20e from image to image. Possible to correct by overscan subtraction.
- Image offset level varies with illumination
  - ⇨ Problem of accurately determining the offset and correcting for it.
  - ⇨ For SH WFS maybe ok, need to be verified.
  - ⇨ For Pyramid (ELT XAO) WFS where most pixels are illuminated could be problem.
- Optical design would have to take into account the larger central pixels (where the split occurs).
- Cause of artifacts in overscan need further investigation.

Suggestions for Improvement/ Further Testing

- Increase reference pixels from 4 to 11. Only need 240 out of 264 rows.
- Test different illumination patterns (e.g. illuminate only a portion of the CCD) to better understand how the offset varies with the level and type (full/partial/spots) of illumination.
- Preclock and/or mask columns to obtain better estimation of prescan offset level. As only need 240 pixels, 11 columns could be masked and used for determining offset.
- Investigate more complicated offset correction techniques; e.g. fit curve between prescan and overscan to obtain better offset estimation of intervening pixels.

END