X-shooter

Detector Report

CCD Readout Modes Characterization

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CHANGE RECORD

ISSUE	DATE	SECTION/PAGE AFFECTED	REASON/INITIATION DOCUMENTS/REMARKS
0.2	21.08.08	§3.2	Dummy pixels removed before the prescan of the VIS arm detector on request of Joel Vernet.
0.3	01.05.2009	§4	Video board gain resistors R50 and R54 increased from 36ohm to 44ohm to compensate for change in timing files to fix spectral linearity problem.
1.0	28.05.2009	All	First release

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1 INTRODUCTION

1.1 Purpose and Scope of this Document

X-shooter is a wide band (300-1900nm), intermediate resolution (4500-7000), high efficiency spectrograph designed for the Cassegrain focus of a VLT UT. X-shooter is a fast-track instrument built from currently available technology. X-shooter consists of a central structure (the backbone) which supports three prism-cross dispersed echelle spectrographs optimized for the UV-Blue (UVB), Visible (VIS) and Near-IR (NIR) wavelength ranges.

This document reports on the testing and commissioning of X-shooter detectors, e2v Pisces Australis II and MIT/LL Catherine when read out using the final read out modes, [AD 01]. Pisces Australis II, an e2v CCD44-82 serial number 02395-04-01, is the UVB arm detector. Catherine, serial number 14-4-6, is the VIS arm detector. It is a phase 3 thick high resistivity (40 µm) BIV MIT/LL CCID-20.

1.2 Applicable and Reference Documents

The following documents, of the exact issue shown, form a part of this document to the extent specified herein.

Reference	Document Number	Issue	Date	Title
[AD 01]		1.0	04.08.06	X-shooter CCD readout modes V.1, Hans Dekker.
[AD 02]	XSH-TRE-ESO-6000-0105	3.0	22.05.09	X-shooter CCD Detector and Acquisition System Final Design Report
[AD 03]	XSH-VER-ESO-9000-0156	1.0	06.12.06	PAE1 – Verification Matrix of Subsystems

The following documents are not applicable, but are referred to in this document.

Reference	Document Number	Issue	Date	Title
[RD 01]	Internal ODT Technical Note		24/5/2004	Connecting more than one preamplifier to one video board of FIERA, Javier Reyes
[RD 02]	PSF measurement report			
[RD 03]	TO3-0500/prj	1.0	08/05/2000	Design Information for CCD44-82 Devices for the European Southern Observatory, May 2000, Marconi Applied Technologies
[RD 04]		1.0		2048x4096 CCD Imager for the U. of Hawaii Consortium, Barry Burke MIT/LL
[RD 05]	10683C	1.0	10/11/00	Pisces Australis II e2v Test Report, serial number 02395-04-01.

1.3 Abbreviations And Acronyms

AC	Alternating Current
AFC	Automatic Flexure Correction
BFD	Back Focal Distance
BIV	Blue Indigo Voilet
BFD	Back Focal Distance
BOB	Broker for Observation Blocks (OB)
CAS	Central Alarm System
CCC	Closed Cycle Cooler
CCD	Charge Coupled Device
DC	Direct Current
DCS	Detector Control Software
DFE	Detector Front-End Electronics
DH	Detector Head
DMA	Direct Memory Access
EMC	Electromagnetic Compatibility
ESD	ElectroStatic Discharge
E2V,e2v,E2v	e2v Technologies (CCD manufacturer http://e2vtechnologies.com)
FDR	Final Design Review
FIERA	Name of a VLT Optical Detector Controller
FITS	Flexible Image Transport System
FWHM	Full Width at Half Maximum
GUI	Graphical User Interface
ICD	Interface Control Document
IWS	Instrument WorkStation
HW	Hardware
ICS	Instrument Control Software
I^2C	Inter-IC BUS (http://www.semiconductors.philips.com/markets/mms/protocols/i2c)
IfA	Institute for Astronomy (http://www.ifa.hawaii.edu)
IWS	Instrument Workstation
LAN	Local Area Network
LBNL	Lawrence Berkeley National Laboratory (http://www.lbl.gov)
LCD	Liquid Crystal Display
LCU	Local Control Unit
LED	Light Emitting Diode
Lick	University of California Observatories/Lick Observatory (http://www.ucolick.org)
LRU	Line Replaceable Unit
LN2	Liquid Nitrogen
MIT/LL	Massachusetts Institute of Technology's Lincoln Laboratory (http://www.ll.mit.edu)
MMB	Mirror Maintenance Building
NGC	New General detector Controller
MS	Maintenance Software
N/A	Not Applicable
ODT	Optical Detector Team
OS	Observation Software
OFDR	Optical final Design review
PAE	Preliminary Acceptance Europe
PCI	Peripheral Component Interconnect (Computer BUS)
PDR	Preliminary Design Review
PID	Proportional Derivative Integral
PRNU	Photon Response Non-Uniformity
p.i.n	"p" Intrinsic "n"
PSF	Point Spread Function (system response to an infinitely narrow stimulus)
QA	Quality Assurance
QE	Quantum Efficiency
r.o.n	Read Out Noise
RMS	Root Mean Squared

RRM	Rapid Response Mode
RTD	Real Time Display
SCP	Service Connection Point
SLCU	Sparc Local Control Unit
SLED	Stabilized LED
SW	Software
TBC	To Be Clarified
TBD	To Be Defined
TDI	Time Domain Integration
UPS	Uninterruptible Power Supply
UVB	Ultra Violet-Blue (300 - 550 nm)
VIS	VISible (550 - 1020 nm)
VLT	Very Large Telescope
VME	Versa Module Eurocard
WS	Workstation

2 Verification Matrix

To confirm PAE (see [AD 03]), the following verification matrixes are provided.

2.1 UVB ARM DETECTOR: Pisces Australis II

Table 1: Verification matrix of measured performance of CCD44-82 Pisces Australis II versus detector requirements of UVB arm. Measurements performed on ODT Test Bench.

Detector Characteristics	Required Performance	Pisces Australis II	Compliance	Refn.	Comments
UVB -DR1 Number of Pixels	2048 x 4096	2048 x 4102	✓	**[RD 03]**	See manufacturer data sheet
UVB -DR2 Pixel size	15 um	15 µm	✓	**[RD 03]**	See manufacturer data sheet
UVB -DR3 Q.E. @ nm (may be 5% below spec if spec exceeded at other wavelengths)	>70% @ 300 >75% @ 320 >77% @ 350 >78% @ 370 >80% @ 400 >85% @ 450 >85% @ 500 >80% @ 550	54% @ 300 79% @ 320 82% @ 350 82% @ 370 88% @ 400 86% @ 450 83% @ 500 81% @ 550	✗	**§6.1**	300nm not meet due to difficulty of measuring. At 500nm, QE 2% low however within measurement tolerance.
UVB -DR4 Operating Temperature	150-160 K	155K	✓	**§5.1**	Standard operating temperature of CCD44-82 chosen.
UVB -DR5 Dark Current	<2e/px/h	< 0.5 e^-/pix/h (at 155K)	✓	**§11**	Dark current measurements are normally dominated by background radiation.
UVB -DR6 Read Out Modes	Slow (50 – 100 kpix/sec, tbc) Fast, (600 kpix, sec tbc) Binning 1x1, 1x2, 2x2	Slow: 100 kpix/sec Fast: 400 kpix/sec Binning 1x1, 1x2, 2x2	✓	**§3**	400 kpix/sec read out speed meets UVB -DR15 Read Time + Overheads spec.
UVB -DR7 R.O.N	Slow: < 3 e Fast: < 8 e	Slow: <2.6e Fast: <4.7e	✓	**§11**	
UVB -DR8 Pixel Saturation	> 120000 e	> 200,000 e^-	✓	**§9**	
UVB -DR9 Linearity	<1% 10-100000 e From best linear fit	< ±0.5 % 100 – 120,000 e^-	✗	**§10**	Lower range 10-100e too difficult to measure.
UVB -DR10 Cosmetic Defects	Max 1 bad column <0.01% hot or dead pixels	2 bad columns 2 Hot pixels 8 dead pixles	✗	**§8**	Exceeds bad column specification.
UVB -DR11 Radiation Events	<120/cm^2/h larger than 30 e	<120/cm^2/h	✓	**§5.1.3**	
UVB -DR12 PSF	>42% in 1 pixel >88% in 2x2 pixels (point source at f/3)	> 45% in 1 x 1 pixel > 93% in 2x2 pixels	✓	**§12.1**	Measured down to 400nm.
UVB -DR13 Number of detectors amplifiers	2	2	✓	**[RD 03]**	See manufacturer data sheet
UVB -DR14 Controller	One Fiera/ two pulpo	One Fiera/ two pulpo	✓	**[AD 02]**	
UVB -DR15 Read Time + Overheads	<90 sec (CCD slow,1x1, hg) <20 sec (CCD slow,2x2, lg) <20 sec (CCD fast,1x1, l.g) <10 sec (CCD fast,2x2, l.g)	70 sec (CCD slow,1x1, hg) 22 sec (CCD slow,2x2, lg) 19 sec (CCD fast,1x1, l.g) 8 sec (CCD fast,2x2, l.g)	✗	**§3.2**	Reported times do not include software overheads. Times slightly out of spec. due to request to read out through one amplifier.

2.2 VIS ARM DETECTOR: MIT/LL Catherine

Table 2: Verification matrix of measured performance of high resistivity (40 µm) BIV MIT/LL CCID-20 Catherine versus detector requirements of VIS arm. Measurements performed on ODT Test Bench.

Detector Characteristics	Required Performance	Catherine	Compliance	Refn.	Comments
VIS -DR1 Number of Pixels	2048 x 4096	2048 x 4102	✓	[RD 04]	
VIS -DR2 Pixel size	15 um	15 µm	✓	[RD 04]	
VIS -DR3 Q.E. @ nm (may be 5% below spec if spec exceeded at other wavelengths)	>70% @ 500 >75% @ 550 >80% @ 600 >80% @ 650 >85% @ 700 >85% @ 750 >85% @ 800 >85% @ 850 >75% @ 900 >50% @ 950 >30% @ 1000	73% @ 500 77% @ 550 82% @ 600 87% @ 650 90% @ 700 93% @ 750 92% @ 800 85% @ 850 75% @ 900 51% @ 950 24% @ 1000	×	§6.2	Exceeds specs except for 1000 nm.
VIS -DR4 Operating Temperature	150-160 K	135K	×	§5.2	Operating temperature chosen to reduce "hot pixels". This is the standard operating temperature for this type of CCD.
VIS -DR5 Dark Current	<2e/px/h	< 0.4 e^-/pix/h (at 135K)	✓	§5.2.3	Dark current measurements are normally dominated by background radiation.
VIS -DR6 Read Out Modes	Slow (50 – 100 kpix/sec, tbc) Fast, (600 kpix, sec tbc) Binning options 1x1, 1x2, 2x2	Slow: 100 kpix/sec Fast: 400 kpix/sec Binning 1x1, 1x2, 2x2	✓	§3.2	
VIS -DR7 R.O.N	Slow: (50–100 kpix/sec) < 3.5 e Fast (600 kpix/sec) < 8 e	Slow (100kpix/s): <3.2e Fast (400kpix/s): <5.3e	✓	§11	
VIS -DR8 Pixel Saturation	> 90000 e	> 90,000 e^-	✓	§9	
VIS -DR9 Linearity	<1% 10-100000 e From best linear fit	< 1 % 100 – 90,000 e^-	×	§10	Lower range 10-200e too difficult to measure. Typical linearity range for this type of device.
VIS -DR10 Cosmetic Defects	Max 1 bad column <0.01% hot or dead pixels	2 bad columns 246 Hot pixels 249 dead pixles	×	§8	Exceeds bad column specification.
VIS -DR11 Radiation Events	<120/cm2/h larger than 30 e	<120/cm2/h	✓	§5.2.3	
VIS -DR12 PSF	>42% in 1 pixel >88% in 2x2 pixels (point source at f/3)	> 65% in 1 x 1 pixel > 97% in 2x2 pixels (Note 1 below)	✓	§12.2	
VIS -DR13 Number of detectors amplifiers/channels	2	2	✓	[RD 04]	
VIS -DR14 Controller	One Fiera/ two pulpo	One Fiera/ two pulpo	✓	[AD 02]	
VIS -DR15 Read Time + Overheads	<90 sec (CCD slow,1x1, hg) <20 sec (CCD slow,2x2, lg) <20 sec (CCD fast,1x1, l.g) <10 sec (CCD fast,2x2, l.g)	92 sec (CCD slow,1x1, hg) 27 sec (CCD slow,2x2, lg) 24 sec (CCD fast,1x1, l.g) 9 sec (CCD fast,2x2, l.g)	×	§3.2	Reported times do not include software overheads. Times out of spec. due to request to read out through one amplifier. This simplifies the data pipeline.

1. Values for PSF of Catherine inferred from tests on similar CCDs.

3 Readout Modes

3.1 Requested Readout Modes

The detailed read out modes as defined in technical note **[AD 01]** are:

#	Mode	Speed (kpix/sec)	Gain e^-/ADU	Binning (X.Y)	Window	RON (e)	Read + wipe time (s)	P
1	1pt/100kHz/hg	100	0.7	1x1	B: 2K X 3K V: 2K X 4K	< 3 <3.5	67 87	
2	1pt/100kHz/hg	100	0.7	1x2	B: 2K X 3K V: 2K X 4K	< 3 <3.5	37 47	P
3	1pt/100kHz/hg	100	0.7	2x2	B: 2K X 3K V: 2K X 4K	< 3 <3.5	22 27	P
4	1pt/400kHz/lg	400	1.7	1x1	B: 2K X 3K V: 2K X 4K	< 8	22 27	P
5	1pt/400kHz/lg	400	1.7	1x2	B: 2K X 3K V: 2K X 4K	< 8	14 17	
6	1pt/400kHz/lg	400	1.7	2x2	B: 2K X 3K V: 2K X 4K	< 8	11 12	
7	1pt/400kHz/lg_AFC	400	1.7	1x1	B: 1K X 1K V: 1K X 1K	< 8	2.5 2.5	

Notes:
1. Modes most likely to be offered to users (pending commissioning results) are marked with P (priority).
2. Low noise is most important for the UVB arm detector, because of low sky background in UVB.

3.2 Implemented Readout Modes

The read out modes as implemented in X-shooter are defined in Table 3.

Table 3: X-shooter implemented read out modes.

#	Mode Name	Speed (kpix/ sec)	Sequence File (.seq)	Bin (X.Y)	Window: (prescan+X+Overscan) · Y pixels	Read Time [# Note 1,2] (s)
1	100k/1pt/hg	100	B: shdetb_100_r_1x1 V: shdetv_100_a_1x1	1x1	B: 48+2048+48 · 3000 V: 10+2048+48 · 4000	70 92
			B: shdetb_100_r_1x2 V: shdetv_100_a_1x2	1x2	B: 48+2048+48 · 1500 V: 10+2048+48 · 2000	38 48
			B: shdetb_100_r_2x2 V: shdetv_100_a_2x2	2x2	B: 24+1024+24 · 1500 V: 5+1024+24 · 2000	22 27
4	400k/1pt/lg	400	B: shdetb_400_r_1x1 V: shdetv_400_a_1x1	1x1	B: 48+2048+48 · 3000 V: 10+2048+48 · 4000	19 24
			B: shdetb_400_r_1x2 V: shdetv_400_a_1x2	1x2	B: 48+2048+48 · 1500 V: 10+2048+48 · 2000	12 14
			B: shdetb_400_r_2x2 V: shdetv_400_a_2x2	2x2	B: 24+1024+24 · 1500 V: 5+1024+24 · 2000	8 9
7	400k/1pt/lg_AFC	400	B: shdetb_400_r_1x1 V: shdetv_400_a_1x1	1x1	B: 1000 · 1000 V: 1000 · 1000	4.5 4.5

1. Read out times as reported by FIERA software.
2. Includes wipe time of 2.5 sec, but not time to finalize saving of file at end of read out (~ 5s TBC).

Note the following:

1. The amplifiers of both CCDs have very similar good performance. The right "_r_" amplifier of e2v Pisces Australis II and the left "_a_" amplifier of MIT/LL Catherine were chosen as they had slightly better noise performance, however, the performance of the other amplifiers are very acceptable.
2. The read out time of the AFC mode (#7) is 4.5 sec compared to the requested 2.5 sec. The time is longer due to the need to do pre-clocking to exercise the video chain before read out. This is done to reduce the slope of the bias image in the first 100 or so lines. In addition, as only one amplifier is used for the read out, a substantial amount of time is spent skipping unused pixels in the lines that are read out. This mode can be sped up by reading out through two amplifiers or placing the window in the left or right half only of the CCD so that the whole window is read out through one amplifier.

4 System Setup

4.1 Video Board

Video board setup is shown in Table 4.

Table 4: Setup of X-shooter video board.

Arm	**VIS**		**UVB**	
Camera	**shdetv**		**shdetb**	
CCD	**Catherine MIT/LL CCID-20**		**Pisces Australis II e2v CCD44-82**	
Video board 0	**Channel 0**	**Channel 1**	**Channel 2**	**Channel 3**
CCD Amplifier	**Left "a" Amplifier**	**Right "b" Amplifier**	**Left "l" Amplifier**	**Right "r" Amplifier**
Nominal Gains:				
Low Gain (Gain0)	1.5 e^-/ADU	1.5 e^-/ADU	1.7 e^-/ADU	1.7 e^-/ADU
High Gain (Gain1)	0.6 e^-/ADU	0.6 e^-/ADU	0.6 e^-/ADU	0.6 e^-/ADU
Common gain resistor	R 44 = 620R	R 48 = 620R	R 52 = 620R	R 56 = 620R
Resistors for low gain	R 43 = 180R	R 47 = 180R	R 51= 120R	R 55 = 120R
Resistors for high gain	R 42 = 120R	R 46 = 120R	R 50 = 44R	R 54 = 44R
Video Offset Range:	-10 to 0 Volts	-10 to 0 Volts	-5 to 0 Volts	-5 to 0 Volts
Clamp/Sample Time Constants:				
Filter 0	C21=100pF (τ = 150ns)	C25=100pF (τ = 150ns)	C29=100pF (τ = 150ns)	C33=100pF (τ = 150ns)
Filter 1	C22= 220pF (τ = 500ns)	C26= 220pF (τ = 500ns)	C30= 220pF (τ = 500ns)	C34= 220pF (τ = 500ns)
Filter 2	C23= 1nF (τ = 1500ns)	C27= 1nF (τ = 1500ns)	C31= 1nF (τ = 1500ns)	C35= 1nF (τ = 1500ns)
Filter 3	C24 = C374 = 1nF (τ = 3000ns)	C28 = C375 = 1nF (τ = 3000ns)	C32 = C376 = 1nF (τ = 3000ns)	C36 = C377 = 1nF (τ = 3000ns)

- Low gain of MIT/LL Catherine was set to 1.5 e^-/ADU to fully utilize the dynamic range of the 16 bit ADC. Maximum well depth of 90 ke^- is best sampled by the 65535 levels of the ADC at a gain 1.5 e^-/ADU (90 ke^-/65535).

4.2 Preamplifier

The setup of the two X-shooter preamplifiers is shown in Table 5.

Table 5: Setup of X-shooter preamplifiers.

Arm	**VIS**		**UVB**	
Camera	**shdetv**		**shdetb**	
CCD	**Catherine MIT/LL CCID-20**		**Pisces Australis II e2v CCD44-82**	
Preamplifier ID	**VIS**		**UVB**	
I^{2}C bus address	**3D # Note 2**		**3C**	
Channel	**Channel 0**	**Channel 1**	**Channel 0**	**Channel 1**
Amplifier	**Left “a” Amplifier**	**Right “b” Amplifier**	**Left “l” Amplifier**	**Right “r” Amplifier**
CCD Output Amplifier Load	3k resistor	3k resistor	J511 (4.7mA)	J511 (4.7mA)
Gains:				
Low Gain setting	Gain3=1.5 # Note 1	Gain3=1.5 # Note 1	Gain1=2.25	Gain1=2.25
High Gain setting	Gain3=2.25	Gain3=2.25	Gain1=2.25	Gain1=2.25

1. The output amplifier responsitivity of the MIT/LL CCID-20 is 20uV/e. At well depth of 100ke, the output voltage range of the CCD amplifier is ~ 2.2V (110ke x 20 uV/e /10^6) plus reset feedthrough spike. As the op-amps (supplied by 5V) in the preamplifier saturate at preamplifier gain of 2.25, the gain in the low gain mode was reduced to 1.5 to avoid saturation.
2. VIS Preamplifier has been modified (**[RD 01]**) to respond to address ‘3D’.

4.3 Bias Board

The following bias voltage settings were selected to provide low noise while at the same time good linearity (< ±0.5%)

Table 6: Bias voltage setting, assignment and setting of hardwired protection limits of connector A on bias board 0, BRD_ANABIAS0, which provides the biases for the e2v CCD, Pisces Australis, of X-shooter UVB arm.

PERIPH_ID	**Bias No.**	**Bias Name**	**Low Limit (V)**	**High Limit (V)**	**Voltage (V)**
ANA_PRESET_VOLT_A	0	OG1-R	-8	+8	-3.5
ANA_PRESET_VOLT_B	1	OG2-R	-8	+8	-2.5
ANA_PRESET_VOLT_C	2	OD-R	GND	+30	23
ANA_PRESET_VOLT_D	3	RD-R	GND	+15	11.25
ANA_PRESET_VOLT_E	4	JD-R	GND	+30	25
ANA_PRESET_VOLT_F	5	Not used	GND	+8	0
ANA_PRESET_VOLT_G	6	Not used	GND	+8	0
ANA_PRESET_VOLT_H	7	Not used	GND	+8	0
ANA_PRESET_VOLT_I	8	OG1-L	-8	+8	-3.5
ANA_PRESET_VOLT_J	9	OG2-L	-8	+8	-2.5
ANA_PRESET_VOLT_K	10	OD-L	GND	+30	23
ANA_PRESET_VOLT_L	11	RD-L	GND	+15	11.25
ANA_PRESET_VOLT_M	12	JD-L	GND	+30	25
ANA_PRESET_VOLT_N	13	Not used	GND	+8	0
ANA_PRESET_VOLT_O	14	DD-LR	GND	+30	18
ANA_PRESET_VOLT_P	15	Not used	GND	+8	0

- L” = e2v left amplifier, “R” = e2v right amplifier.

Table 7: Bias voltage setting, assignment and setting of hardwired protection limits of connector B on bias board 0, BRD_ANABIAS0, which provides the biases for MIT/LL CCD, Catherine, of X-shooter VIS arm.

PERIPH_ID	Bias No.	Bias Name	Low Limit	High Limit	Voltage
ANA_PRESET_VOLT_AA	16	OD-A	GND	+30	19
ANA_PRESET_VOLT_AB	17	OG-A	-8	+8	0
ANA_PRESET_VOLT_AC	18	RD-A	GND	+15	12.5
ANA_PRESET_VOLT_AD	19	SCP-A	GND	+15	10
ANA_PRESET_VOLT_AE	20	Not used	GND	+8	0
ANA_PRESET_VOLT_AF	21	Not used	GND	+8	0
ANA_PRESET_VOLT_AG	22	Not used	GND	+8	0
ANA_PRESET_VOLT_AH	23	Not used	GND	+8	0
ANA_PRESET_VOLT_AI	24	OD-B	GND	+30	19
ANA_PRESET_VOLT_AJ	25	OG-B	-8	+8	0
ANA_PRESET_VOLT_AK	26	RD-B	GND	+15	12.5
ANA_PRESET_VOLT_AL	27	SCP-B	GND	+15	10
ANA_PRESET_VOLT_AM	28	Not used	GND	+8	0
ANA_PRESET_VOLT_AN	29	Not used	GND	+8	0
ANA_PRESET_VOLT_AO	30	Not used	GND	+8	0
ANA_PRESET_VOLT_AP	31	Not used	GND	+8	0

- “A” = MIT/LL left amplifier, “B” = MIT/LL right amplifier.

4.4 Clock Boards

The following clock voltage settings and SIMM output resistors were selected for best performance.

Table 8: Clock Board SIMM output resistors and voltage settings.

Camera:		**UVB**				**VIS**			
CCD		**Pisces Australis II e2v CCD44-82**				**Catherine MIT/LL CCID-20**			
Board ID		**BRD_CLKDRV0**				**BRD_CLKDRV1**			
Board BUS address #note 3		**0**				**1**			
SIMM/ Clock No.	**DAC ID CLKDRV_**	**Name # Note 1,2**	**Output Resistor**	**High Level (V)**	**Low Level (V)**	**Names # Note 1,2**	**Output Resistor**	**High Level (V)**	**Low Level (V)**
0	DAC0	SWL	50R	-5	+5	SWA	50R	-5	+5
1	DAC1	SWR	50R	-5	+5	SWB	50R	-5	+5
2	DAC2	RF3	50R	-5	+5	S3	50R	-3	+6
3	DAC3	RF2L	50R	-5	+5	S2A	50R	-3	+6
4	DAC4	RF1L	50R	-5	+5	S1A	50R	-3	+6
5	DAC5	RF2R	50R	-5	+5	S2B	50R	-3	+6
6	DAC6	RF1R	50R	-5	+5	S1B	50R	-3	+6
7	DAC7	DG	50R	-6	+6	empty # Note 4	-	-	-
8	DAC8	IF1	10R	-8	+2	P1	10R	-6	+2
9	DAC9	IF2	10R	-8	+2	P2	10R	-6	+2
10	DAC10	IF3	10R	-8	+2	P3	10R	-6	+2
11	DAC11	Empty # Note 4	10R	0	0	empty # Note 4	-	-	-
12	DAC12	FRL	10R	-6	+6	RGA	10R	0	+10
13	DAC13	FRR	10R	-6	+6	RGB	10R	0	+10

1. “L” = e2v left amplifier, “R” = e2v right amplifier, “A” = MIT left amplifier, and “B” = MIT right amplifier.
2. The clock phase names shown here are the ones used by the waveform generation program, WES.
3. Addresses are selected by changing jumpers on the clock board.
4. To reduce power dissipation, only clocks used are populated with SIMMs.

5 Detectors Operating Temperature

5.1 UVB Arm Detector Operating Temperature

Standard operating temperature of 155K which has been used on other CCD44-82 CCDs at La Silla Paranal was chosen. Operating Pisces Australis II at this temperature meets all X-shooter requirements.

5.1.1 Bias Images at 155K

Good uniformity of bias is shown in the row plot (left graph where bias has been collapsed in column direction) and column plot (right graph where bias has been collapsed in row direction) of Figure 1 for temperatures of 155K. The kink at pixel 1000 is a common feature and is due to discontinuity in the FIERA timing as a maximum of 1024 pixels can be read out before reloading the micro-sequencer.

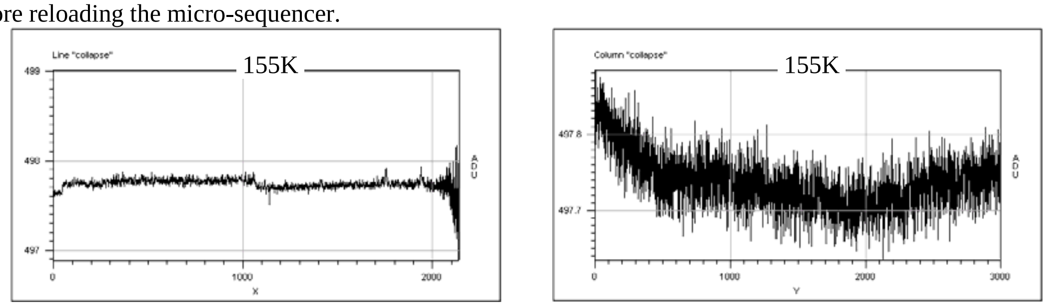

Figure 1: Pisces Australis II: Left: Row plot of Bias Image (100kps/1pt/1x1/hg) collapsed in column direction at temperatures of 155K. Right: Column plot of Bias Image (100kps/1pt/1x1/hg) collapsed in row direction at temperature of 155K.

5.1.2 Dark Images at 155K

Good uniformity of 3600s Dark images is shown in the row plot (left graph where bias has been collapsed in column direction) and column plot (right graph where bias has been collapsed in row direction) of Figure 2 for temperature of 155K.

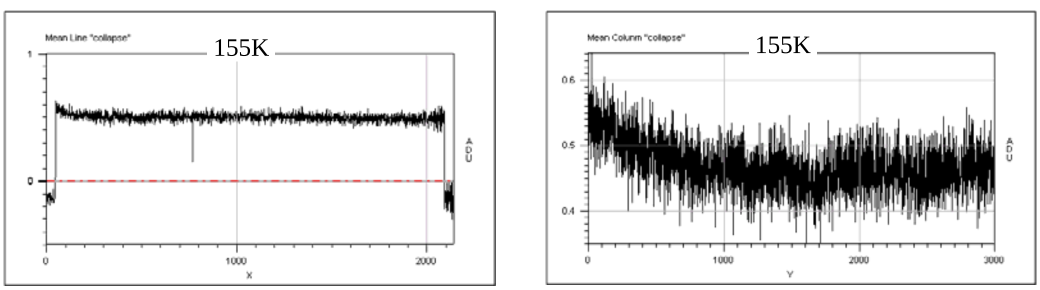

Figure 2: Pisces Australis II: Left: Row plot of biased subtracted median filtered 3600s Dark image (100kps/1pt/1x1/hg) collapsed in column direction at temperature of 155K. Right: Column plot of biased subtracted median filtered 3600s Dark Image (100kps/1pt/1x1/hg) collapsed in row direction at temperature of 155K.

5.1.3 Summary and Conclusion

Table 14 contains a summary of bias and dark measurements (dark current, cosmic event rate and hot pixels) of the UVB arm detector Pisces Australis II at temperature of 155K.

Table 9: Summary of Bias and Dark measurements (100kps/1pt/1x1/hg) at temperature of 155K on ODT Tets Bench.

Temperature	Bias	1 Hour Dark			
	Number of Pixels outside 5σ	Dark Current (e/px/hr)	Cosmic Event Rate (events/cm²/hr)	Hot Pixels (>60 e/px/hr)	Very Hot Pixels (>2x10^5 e/px/hr)
155K	0	0.45	84	0	0

Table 10: Summary of Bias and Dark measurements (100kps/1pt/1x1/hg) at temperature of 155K during commissioning in the MMB (Mirror Maintenance Building) at Paranal

Temperature	Bias	1 Hour Dark			
	Number of Pixels outside 5σ	Dark Current (e/px/hr)	Cosmic Event Rate (events/cm²/hr)	Hot Pixels (>60 e/px/hr)	Very Hot Pixels (>2x10^5 e/px/hr)
155K	0	0.6	132	0	0

Operating Pisces Australis II at temperature of 155K meets X-shooter requirements of dark current < 2e/px/hr, cosmetics of <0.01% hot or dead pixels (i.e. 615 pixels for 2Kx3K regions) and cosmetic event rate of <120 events/cm²/hr. However, when installed in the instrument at Paranal, the cosmetic event rate is slightly above specification (132 versus the required of 120 events/cm²/hr).

5.2 VIS Arm Detector Operating Temperature

The operating temperature of Catherine, VIS arm detector, was varied to determine its optimum operating temperature.

5.2.1 Bias Images Versus Temperature

The uniformity of bias is shown in the row plots of Figure 3 (bias collapsed in column direction) and column plot of Figure 4 (bias collapsed in row direction) for temperatures of 135K, 155K, and 165K.

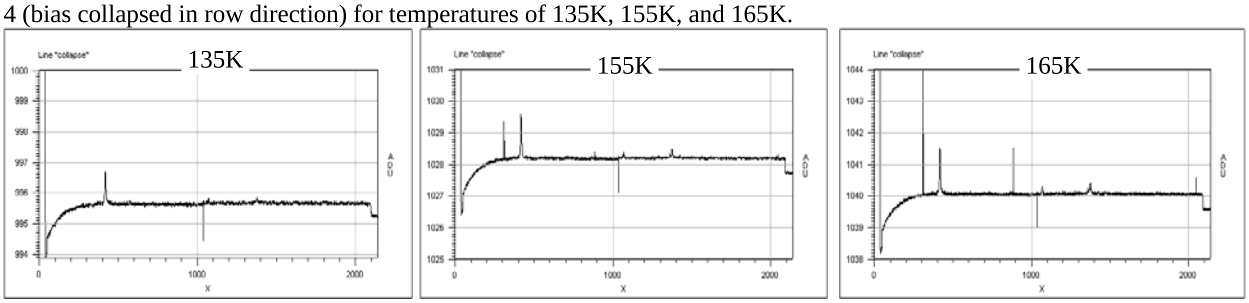

Figure 3: Catherine: Row plot of Bias image (100kps/1pt/1x1/hg) collapsed in column direction at temperatures of 135K, 155K, and 165K.

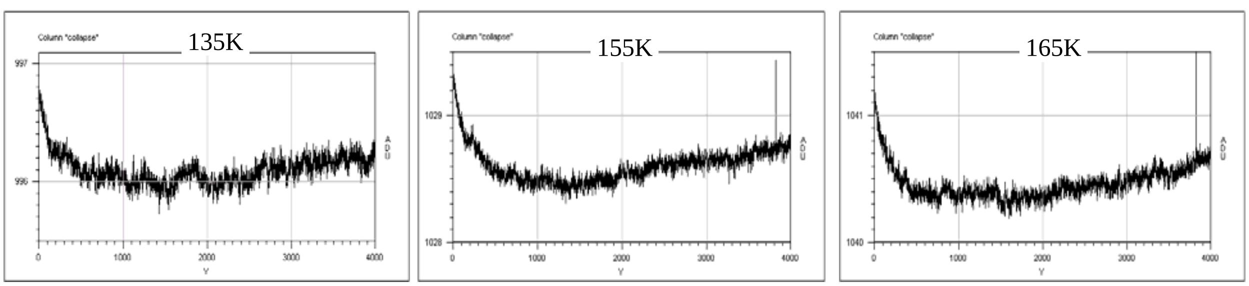

Figure 4: Catherine: Column plot of Bias image (100kps/1pt/1x1/hg) collapsed in row direction at temperatures of 135K, 155K, and 165K.

5.2.2 Dark Images Versus Temperature

The uniformity of 3600s Dark image is shown in the row plot of Figure 5 (collapsed in column direction) and column plot of Figure 6 (collapsed in row direction) for temperatures 135K, 155K, and 165K. Note the initial ramp up of the image and kink seen in the bias in Figure 3 (in first 400 columns) and Figure 4 (in first 800 rows) are fully subtracted in the row direction and almost in the column direction. Master bias was generated by median stacking. No overscan subtraction was performed.

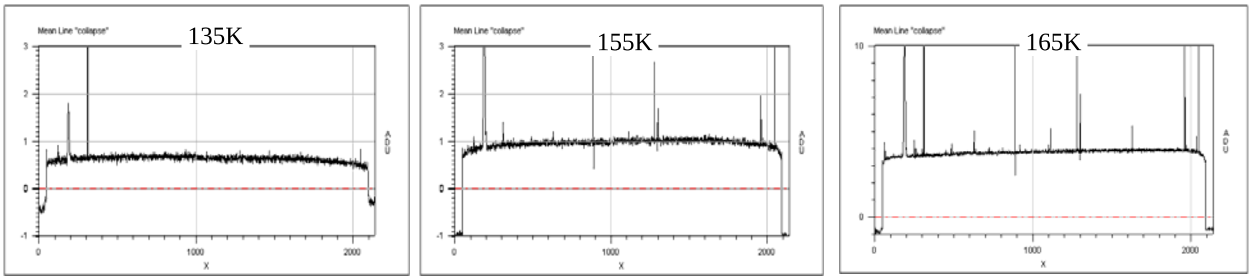

Figure 5: Catherine: Row plot of biased subtracted median filtered 3600s Dark image (100kps/1pt/1x1/hg) collapsed in column direction at temperatures of 135K, 155K, and 165K.

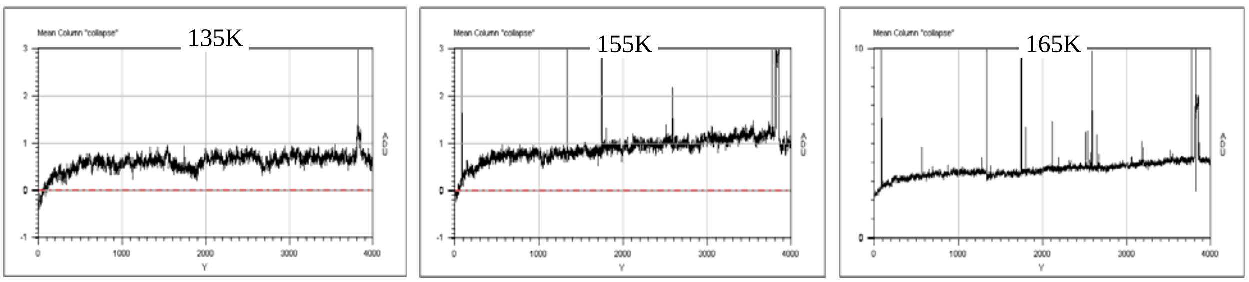

Figure 6: Catherine: Column plot of biased subtracted median filtered 3600s Dark image (100kps/1pt/1x1/hg) collapsed in row direction at temperatures of 135K, 155K, and 165K.

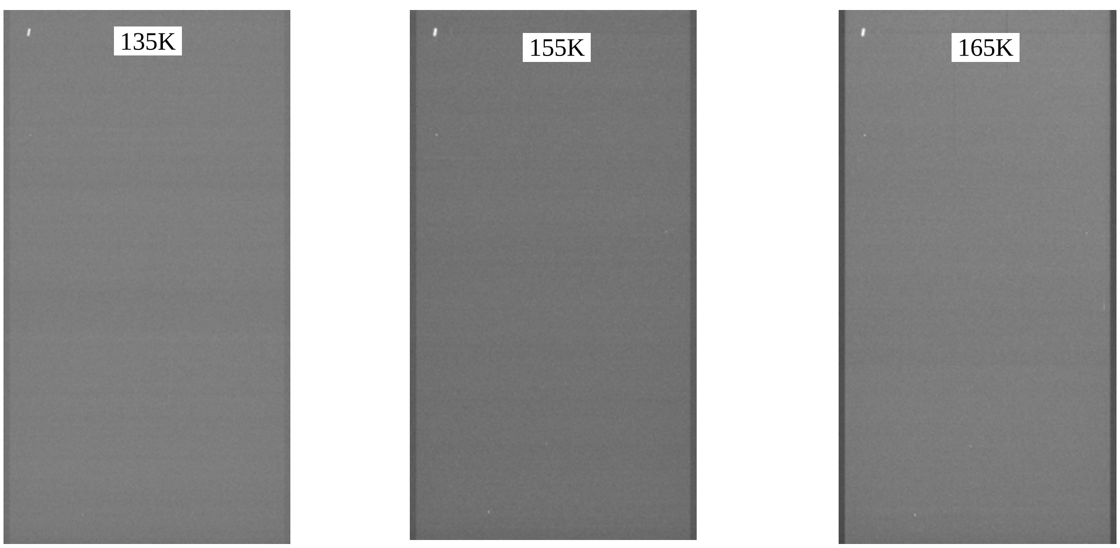

Figure 7: Catherine: Image of biased subtracted median filtered 3600s Dark image (100kps/1pt/1x1/hg) at temperatures of 135K, 155K, and 165K.

Table 11: Hot pixel (> 60 e/px/hr) map of Catherine at 135K.

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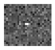
(X,Y)</th><th>Image</th><th>Histogram around the hot pixels</th><th>Comment</th></tr>
<tr><td>1281, 88</td><td></td><td>
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<tr><td>88</td><td>2</td><td>-1</td><td>629</td><td>17</td><td>5</td></tr>
<tr><td>87</td><td>0</td><td>-4</td><td>-2</td><td>5</td><td>4</td></tr>
<tr><td>86</td><td>-2</td><td>0</td><td>4</td><td>0</td><td>-1</td></tr>
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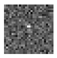
<tr><td>887, 1338</td><td></td><td>
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<tr><td>1338</td><td>-1</td><td>1</td><td>577</td><td>17</td><td>1</td></tr>
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<tr><td>1336</td><td>3</td><td>-1</td><td>3</td><td>6</td><td>2</td></tr>
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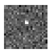
<tr><td>2050, 1750</td><td></td><td>
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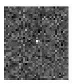
<tr><td>1298, 3548</td><td></td><td>
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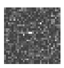
<tr><td>311,3824</td><td></td><td>
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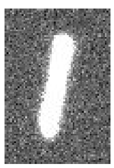
3858</td><td></td><td>
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Table 12: Hot pixel (> 60 e/px/hr) map of Catherine at 155K.

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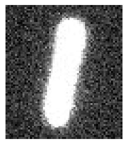
<tr><td>[186:195, 3807:3860]</td><td></td><td>
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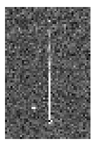
<tr><td>[311,3823:3828]</td><td></td><td>
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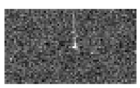
<tr><td>[2049: 2050,1750:1751</td><td></td><td>
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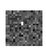
<tr><td>[630,2517:2518]</td><td></td><td>
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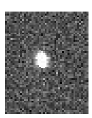
<tr><td>[200:202,3058:3063</td><td></td><td>
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<tr><th></th><th>197</th><th>198</th><th>199</th><th>200</th><th>201</th><th>202</th><th>203</th></tr>
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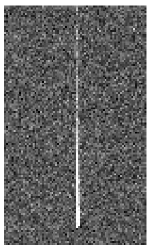
</table>
</td><td>Cluster of hot pixels</td></tr>
</table>

Table 13: Hot pixel (> 60 e/px/hr) map of Catherine at 165K.

<table>
<tr><th>Position
(X,Y)</th><th>Image</th><th>Histogram around the hot pixels</th><th>Comment</th></tr>
<tr><td colspan="3">[1281,88], [953,159], [124,165], [53,294], [253,569], [1750,603], [888,698], [1456,735], [1975,875], [2059,987], [299,1126], [917,1280], [887,1338], [1506,2000], [1630,2121], [65,2538], [266,2569], [77,2576], [1301,2593], [2036,2649], [1103,3200], [1973,3525], [1298,3548], [1962,3773], [272,3790], [1418,3957], [1647,3968]</td><td>Single hot pixel</td></tr>
<tr><td>[590:591,213:215]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[1159:1160,1389]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[2049: 2050,1749: 1758]</td><td></td><td>
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<tr><td>1752</td><td>5</td><td>365</td><td>132</td><td>2</td></tr>
<tr><td>1751</td><td>3</td><td>618</td><td>1175</td><td>2</td></tr>
<tr><td>1750</td><td>3</td><td>7534</td><td>31680</td><td>-2</td></tr>
<tr><td>1749</td><td>2</td><td>2626</td><td>4</td><td>-4</td></tr>
<tr><td>1748</td><td>3</td><td>-1</td><td>5</td><td>5</td></tr>
<tr><td>1747</td><td>4</td><td>5</td><td>4</td><td>5</td></tr>
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</td><td>Cluster of hot pixels</td></tr>
<tr><td>[1115,1804:1805]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[451:452,2195]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[811:812,2339:2340]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[630,2517: 2518]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[723:724,2669]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[487:488,3181]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[185:199,3807:3865]</td><td></td><td>
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<tr><td>3843</td><td>392</td><td>636</td><td>870</td><td>1019</td><td>890</td><td>832</td><td>665</td><td>358</td></tr>
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<tr><td>3840</td><td>447</td><td>811</td><td>885</td><td>954</td><td>894</td><td>751</td><td>403</td><td>258</td></tr>
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<tr><td>3838</td><td>626</td><td>861</td><td>965</td><td>899</td><td>870</td><td>564</td><td>330</td><td>174</td></tr>
<tr><td>3837</td><td>710</td><td>950</td><td>940</td><td>899</td><td>876</td><td>553</td><td>295</td><td>151</td></tr>
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<tr><td>3835</td><td>821</td><td>923</td><td>938</td><td>998</td><td>806</td><td>391</td><td>201</td><td>108</td></tr>
<tr><td>3834</td><td>838</td><td>1005</td><td>969</td><td>898</td><td>660</td><td>351</td><td>176</td><td>105</td></tr>
<tr><td>3833</td><td>910</td><td>1001</td><td>1049</td><td>953</td><td>680</td><td>303</td><td>188</td><td>87</td></tr>
<tr><td>3832</td><td>911</td><td>1047</td><td>952</td><td>934</td><td>571</td><td>296</td><td>137</td><td>79</td></tr>
<tr><td>3831</td><td>973</td><td>1000</td><td>1032</td><td>869</td><td>460</td><td>240</td><td>120</td><td>76</td></tr>
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</td><td>Cluster of hot pixels</td></tr>
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<tr><td>3829</td><td>-1</td><td>144</td><td>7</td><td>5</td></tr>
<tr><td>3828</td><td>6</td><td>204</td><td>3</td><td>4</td></tr>
<tr><td>3827</td><td>4</td><td>355</td><td>5</td><td>10</td></tr>
<tr><td>3826</td><td>6</td><td>615</td><td>6</td><td>5</td></tr>
<tr><td>3825</td><td>5</td><td>31624</td><td>-2</td><td>4</td></tr>
<tr><td>3824</td><td>1</td><td>-8220</td><td>153</td><td>4</td></tr>
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<tr><td>3822</td><td>2</td><td>9</td><td>3</td><td>1</td></tr>
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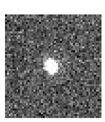
</table>
</td><td>Cluster of hot pixels</td></tr>
<tr><td>[633:634,3865]</td><td></td><td></td><td>Cluster of hot pixels</td></tr>
<tr><td>[200:202,3058:3064]</td><td></td><td>
<table>
<tr><th></th><th>197</th><th>198</th><th>199</th><th>200</th><th>201</th><th>202</th><th>203</th></tr>
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</table>
</td><td>Cluster of hot pixels</td></tr>
</table>

5.2.3 Summary and Conclusion

Table 14 contains a summary of bias and dark measurements (dark current, cosmic event rate and hot pixels) of the VIS arm detector Catherine at temperatures of 135K, 155K, and 165K.

Table 14: Summary of Bias and Dark measurements (100kps/1pt/1x1/hg) of the VIS arm detector Catherine at temperatures of 135K, 155K, and 165K.

Temperature	Bias	1 Hour Dark			
	Number of Pixels outside 5σ	Dark Current (e/px/hr)	Cosmic Event Rate (events/cm²/hr)	Hot Pixels (>60 e/px/hr)	Very Hot Pixels (>$2x10^5$ e/px/hr)
135K	17 (threshold 9.4 ADU)	0.36 ± 0.3	114 ±6	246	0
155K	201 (threshold 7.5ADU)	0.49 ± 0.3	120 ±6	524	0
165K	204 (threshold 7.8 ADU)	3.4 ± 1.0	114 ±36	636	0

To meet X-shooter requirements of dark current of < 2e/px/hr and cosmetics of <0.01% hot or dead pixels (i.e. 800pixels for 2Kx4K regions) and cosmetic event rate of <120 events/cm²/hr, the operating temperature of 135K was chosen. This temperature is the standard operating temperature used with other MIT/LL CCID-20 detectors at La Silla Paranal.

Table 15: Summary of Bias and Dark measurements (100kps/1pt/1x1/hg) of the VIS arm detector Catherine at temperatures of 135K measured during commissioning in the MMB at Paranal.

Temperature	Bias	1 Hour Dark			
	Number of Pixels outside 5σ	Dark Current (e/px/hr)	Cosmic Event Rate (events/cm²/hr)	Hot Pixels (>60 e/px/hr)	Very Hot Pixels (>$2x10^5$ e/px/hr)
135K	11 (threshold 48 ADU)	0.9	198 ±5		0

6 Quantum Efficiency (QE)

6.1 QE UVB Arm Detector: Pisces Australis II

Table 16 contains measured value of QE and Photon Response Non-Uniformity (PRNU) of Pisces Australis II.

Table 16: Measured quantum efficiency and PRNU of Pisces Australis II.

Wavelength	QE%	PRNU rms%	Wavelength	QE%	PRNU rms%
300	54.7	1.7	660	75.7	1.03
310	82.9	1.37	680	73.7	1.04
320	79.7	1.19	700	70.8	1.05
330	82.1	1.16	720	67.4	1.1
340	83.5	1.17	740	63.8	1.09
350	83.3	1.18	750	61.2	1.1
360	81.8	1.18	760	59.3	1.12
370	82.7	1.14	780	54.6	1.21
380	85.5	1.1	800	50.3	1.25
390	87.3	1.06	820	45.7	1.79
400	88.4	1.04	840	41.3	2.05
420	88.3	1.03	850	38.7	2.2
440	87.6	1.01	860	36.3	2.25
460	86.3	1.01	880	31.5	2.94
450	86.1	1.0	900	25.9	2.98
480	84.9	0.999	920	20.4	2.66
500	83.4	1	940	15.4	2.17
520	82.4	0.995	950	13.2	2.0
540	81.4	0.997	960	10.9	1.74
550	80.5	1.0	980	7.21	1.4
560	80.8	0.994	1000	4.19	2.1
580	80.3	0.995	1020	2.01	3.06
600	79.5	1	1040	0.71	3.74
620	78.6	1	1060	0.34	3.84
640	77.4	1.02	1080	0.2	4.5
650	75.9	1.0	1100	0.1	5.8

A safe process of cleaning the surfaces of CCDs of moisture contamination has been developed at ESO. The process involves baking the CCD at 60°C in the presence of dry synthetic air while at the same time illuminating the imaging surface with a UV lamp. This process was applied to Pisces Australis II in the anticipation of a QE improvement in the blue. However no significant improvement was observed (Figure 8). The conclusion is that CCDs with already high QE do not suffer from moisture contamination thus little improvement can be gained.

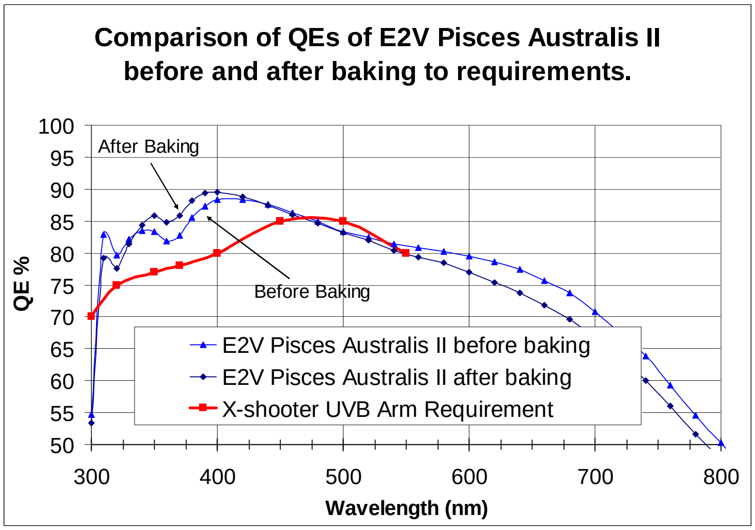


Figure 8: Comparison of measured QEs of E2V Pisces Australis II before and after treatment to that required for the UVB Arm.

The measured PRNU (Plot Figure 9) of E2V Pisces Australis II is typical of standard silicon CCD44-82 CCDs. The PRNU peaks at 1.9% at 300nm (due to the laser annealing of the back-side surface), drops to 1.2% by 340nm and progressively gets better until 750nm where the uniformity degrades due to fringing in the red. Experience has shown that this non-uniformity flat fields out.

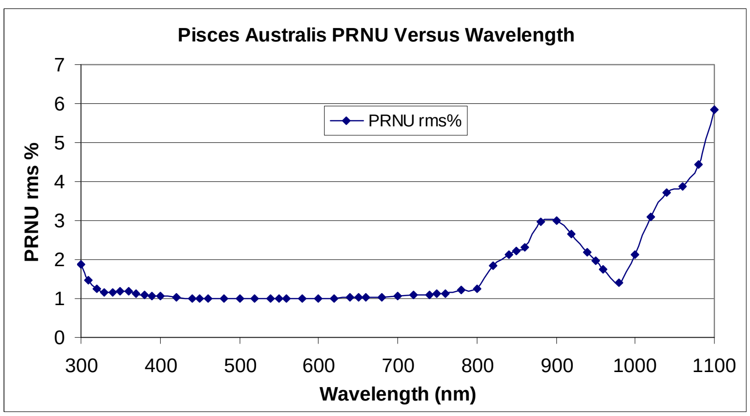


Figure 9: Measured PRNU of E2V Pisces Australis II.

6.2 QE VIS Arm Detector: Catherine

Table 17 contains measured value of QE and Photon Response Non-Uniformity (PRNU) of Catherine.

Table 17: Measured quantum efficiency and PRNU of Catherine.

Wavelength	QE%	PRNU rms%	Wavelength	QE%	PRNU rms%
310	13.0	6.7	680	89.4	2.0
320	13.5	6.5	700	90.8	1.9
330	15.2	6.4	720	92.0	1.8
340	16.8	6.4	740	93.0	1.7
350	17.7	6.4	750	93.2	1.7
360	18.2	6.4	760	93.4	1.6
370	22.7	5.9	780	92.6	1.5
380	35.3	4.4	800	91.9	1.4
390	47.4	3.4	820	90.8	1.3
400	55.5	2.9	840	87.5	1.3
420	63.8	2.6	850	85.5	1.2
440	67.7	2.4	860	83.4	1.2
450	68.9	2.4	880	80.1	1.2
460	70.1	2.4	900	75.1	1.1
480	71.5	2.3	920	65.0	1.1
500	73.0	2.3	940	55.3	1.1
520	74.8	2.3	950	50.9	1.1
540	76.5	2.3	960	46.4	1.1
550	77.5	2.3	980	35.3	1.1
560	78.4	2.3	1000	23.6	1.2
580	80.5	2.2	1020	12.8	1.2
600	82.3	2.2	1040	5.4	1.1
620	84.4	2.2	1060	3.0	1.1
640	86.3	2.1	1080	1.5	1.4
650	87.1	2.1	1100	0.7	1.6
660	87.9	2.0			

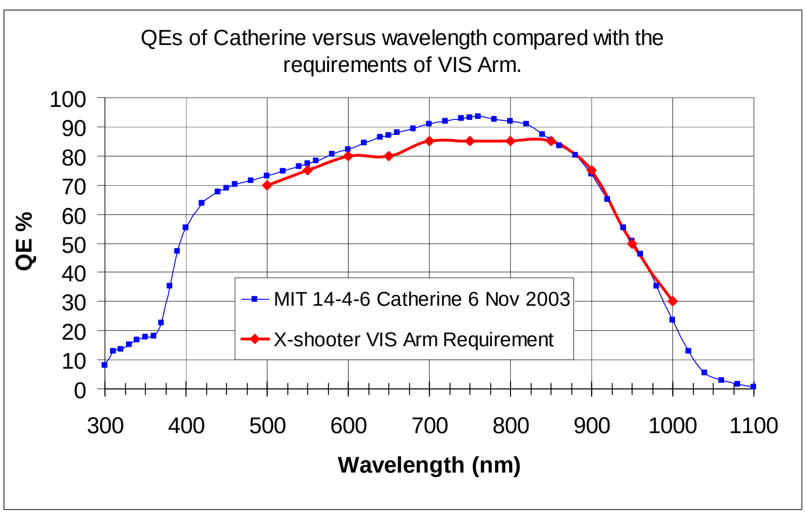


Figure 10: Plot of measured QEs versus wavelength of Catherine compared to the requirements of the VIS Arm.

The measured PRNU (Plot Figure 11) of Catherine is typical of MIT/LL phase 3 CCID-20 40µm thick CCD. The PRNU peaks at 7 % at 300nm (due to the laser annealing of the back-side surface, the brick-wall pattern), drops to 2.5 % by 420nm and progressively gets better. In the red (>750nm), the uniformity remains good (in fact improves at this measured bandwidth of 7nm) due to much less "fringing in the red" of a 40µm thick device. Experience has shown that this non-uniformity flat fields out.

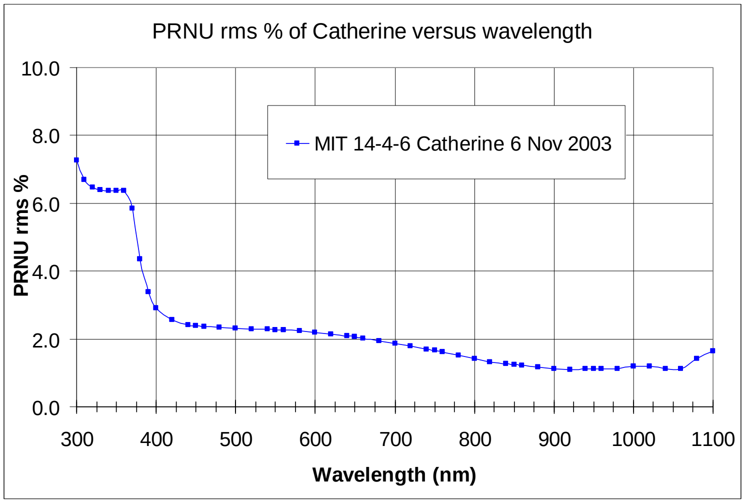


Figure 11: Plot of measured PRNU versus wavelength of Catherine.

7 CTE

Charge transfer efficiency (CTE) was measured (results Table 18) by Extended Pixel Edge Response (EPER) in both the serial and parallel transfer direction. Both devices, Pisces Australis II and Catherine, exhibit excellent CTEs.

Table 18: Results of serial and parallel CTE measurements for 400k/1pt/lg/1x1 read out mode.

Arm	Device	Serial CTE	Parallel CTE	Comment
UVB	Pisces Australis II E2v CCD44-82	0.9999997 (Signal Level 100,000e)	0.9999995 (Signal Level 100,000e)	
VIS	Catherine MIT/LL CCID-20	0.999997 (Signal Level 80,000e)	0.9999998 (Signal Level 80,000e)	

8 Cosmetic

Following definitions were used for hot pixels, very bright pixels, dark pixels, traps very large traps, and bad columns.

Table 19: Definition of defective pixels.

Defect	Definition	Read out Mode	Comment
Hot pixel	generates charge at > 60 e/px/hr	100kps/1pt/1x1/hg	
Very bright pixel	generates charge at > $2x10^5$ e/px/hr	100kps/1pt/1x1/hg	
Dark pixel	< 50% sensitivity w.r.t. average measured with uniform illumination of 50e.	100kps/1pt/1x1/hg	
Trap	pixel that captures more than 10 electrons, measured with uniform illumination of 500e.	100kps/1pt/1x1/hg	
Very large trap	pixel that captures more than 10,000 electrons, measured with uniform illumination of 90%.	400kps/1pt/1x1/lg	
Bad column	20 or more contiguous hot or dark pixels in a single column or a very bright pixel or a very large trap	100kps/1pt/1x1/hg or 400kps/1pt/1x1/lg	

Table 20: Defective pixels of X-shooter CCDs.

Camera	CCD	Hot pixel	Dark pixel	Very bright pixel (a)	Trap	Very large trap (b)	20 Continuous Pixels (c)	Bad Columns
UVB	**Pisces Australis II e2v CCD44-82**	0	8	0	2	2 Columns 721& 722	0	2
VIS	**Catherine MIT/LL CCID-20**	246	249	0	26	2 Columns 843 & 844)	0	2

The X-shooter cosmetic requirement is < 0.01% hot or dead pixels and 1 bad column per CCD. From Table 20, Pisces Australis II has 12 bad pixels and 2 bad columns and Catherine has 525 bad pixels and 2 bad columns. Both CCDs do not meet the bad column requirement.

9 Pixel Saturation/Residual Image

The requirement on pixel saturation is > 120ke.

Test report on previous measurements of pixel saturation/residual image can be found at

a) http://odt12.hq.eso.org/Testbench/EEV/residual/testreport.html for e2v CCD44-82
b) http://odt12.hq.eso.org/Testbench/MIT/Residual-image-effect/testreport.html for MIT/LL CCID-20.

Report a) shows that the e2v CCD44-82 has no problem with residual images even when overexposed. The e2v data sheet shows measured pixel saturation level of image area >200ke.

Report b) shows that the MIT/LL CCID-20 has no problem with residual images up to pixel saturation level of 200ke. Beyond saturation, residual images take 3 hours to decrease to 1e/pix/hr.

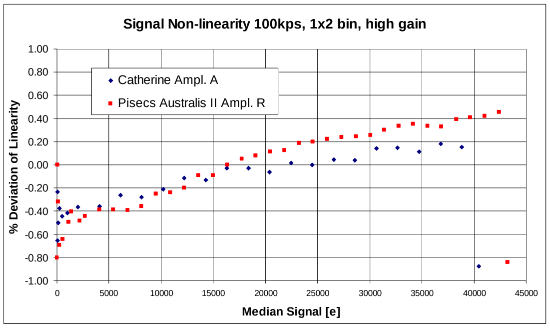
Quick measurements on Pisces Australis II and Catherine confirmed these results.

During Active Flexure Compensation (AFC), there is chance that the CCDs may be over-illuminated. This will not cause a problem with Pisces Australis II, however Catherine may suffer from residual image. To mitigate this risk, a special wipe mode has been implemented whereby the CCD is first wiped with the parallel clocks taken heavily into inversion (-10V to +2V) and then wiped a second time with normal wipe clock voltages (-6V to +2V). The first inversion wipe gets rid of the residual image and the second one cleans up the spurious charge left behind from taking the CCD into inversion.

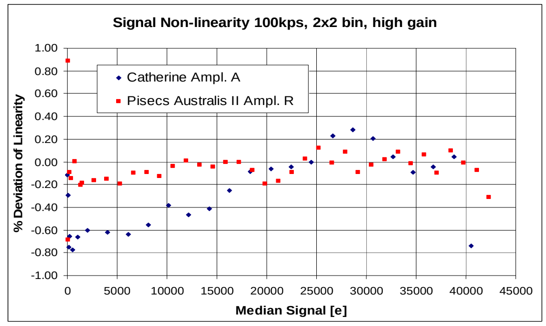
10 Linearity

The X-shooter requirement on linearity is <1% 10-100000 e from best linear fit. The difficult with verifying this requirement is to measure linearity over a wide dynamic range and down to 10e. The main source of errors is shutter uncertainty and stability of illumination source.

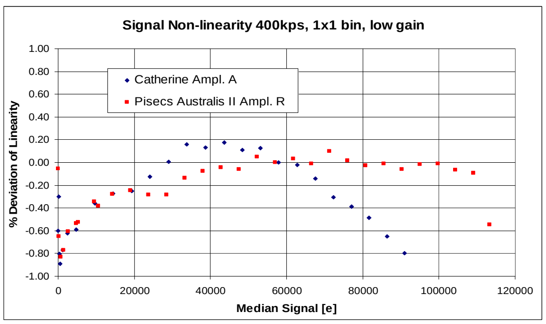
Figure 12 contains residual linearity results of accurate signal measurement of flats versus exposure time. For Pisces Australis II, linearity of < 1% over 100-110,000e is measured. For Catherine, linearity of < 1% over 100-90,000e is observed.



100k/1pt/hg 1x2 bin



100k/1pt/hg 2x2 bin



400k/1pt/lg 1x2 bin

Figure 12: Plot of residual Linearity for the main read out modes of MIT Catherine and Pisces Australis II.

11 Read Modes Performances

This section reports on the performance of the CCDs for the different read out modes.

11.1 UVB Arm Detector: Pisces Australis II

11.1.1 Measured on ODT Test Bench

The following measurements were performed on the ODT test bench at the end of characterization.

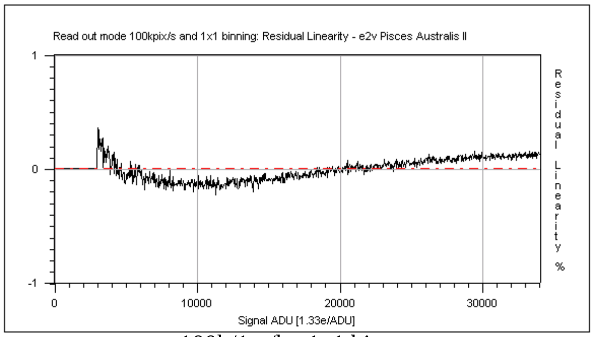
Table 21: Performance of the UVB arm detector, e2v Pisces Australis II, when read out through its right "r" amplifier.

#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr) See note #1	Bias Level (ADU)
1	100k/1pt/hg	1x1	0.67	2.6	0.6	0.45	1000
		1x2	0.67	2.6	0.6	0.73	1000
		2x2	0.67	2.6	0.7	1.3	1000
4	400k/1pt/lg	1x1	1.76	4.5	0.8	0.17	1000
		1x2	1.75	4.6	0.7	0.3	1000
		2x2	1.75	4.73	0.7	0.5	1000
7	400k/1pt/lg_AFC	1x1	1.76	4.5	0.7	-	1000

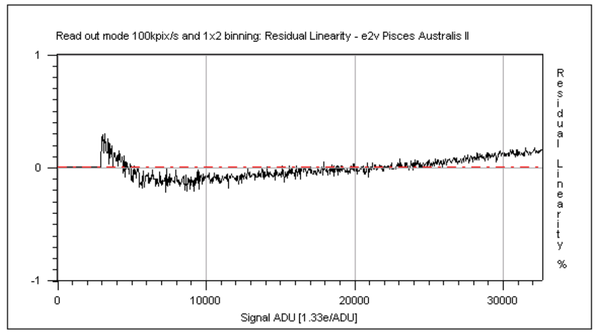
1. At temperature of 155K, Dark Current (DC) measurement is limited by background radiation, luminescence of surrounding material, and to a much lesser extent stabilization and low level persistence in the CCD than intrinsic

DC of the detector. DC decreases the longer the CCD and surrounding materials are keep in the dark. The DC measurements were recorded in the order they appear in the column and thus the reason why dark current per pixel (division of DC column by binning factor) becomes less as one moves down the column.

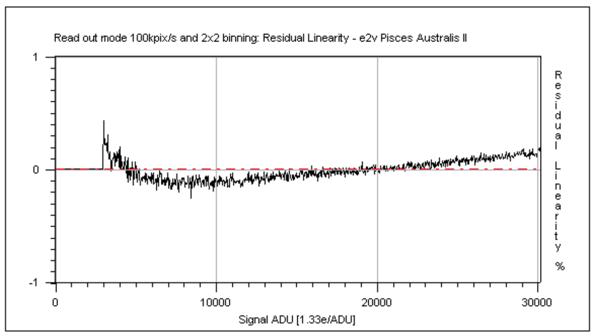
The following linearity curves for different read modes of Pisces Australis II were taken using Time Domain Integration (TDI) method.



100k/1pt/hg 1x1 bin

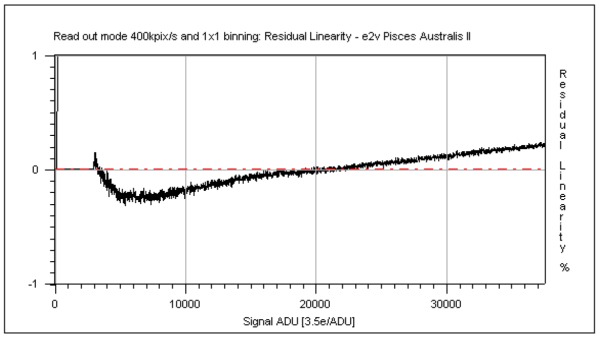


100k/1pt/hg 1x2 bin

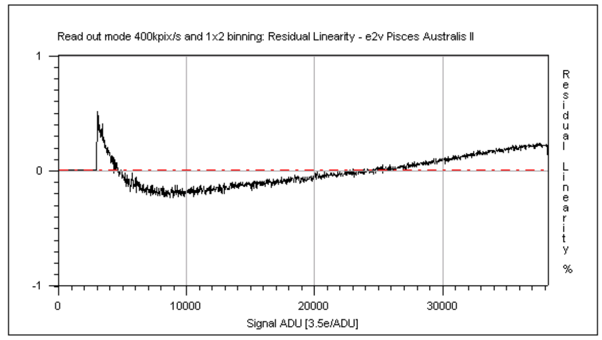


100k/1pt/hg 2x2 bin

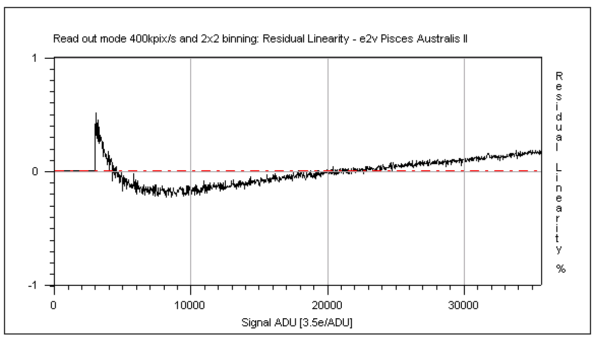
Figure 13: e2v Pisces Australis II TDI Residual Linearity plots for different binning factors of 100k/1pt/hg read out mode.



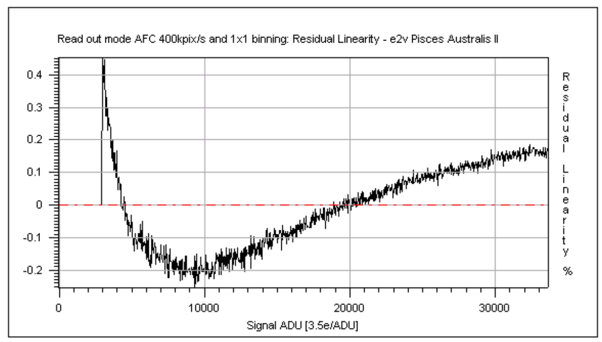
400k/1pt/lg 1x1 bin



400k/1pt/lg 1x2 bin



400k/1pt/lg 2x2 bin



AFC 400k/1pt/lg 1x1 bin

Figure 14: e2v Pisces Australis II TDI Residual Linearity plots for different binning factors of 400k/1pt/lg read out mode.

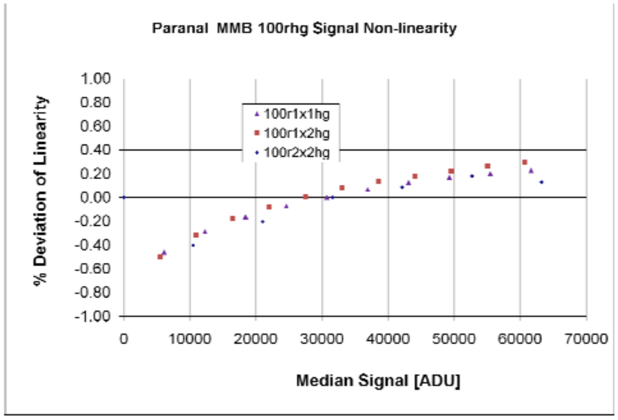
11.1.2 Measurements at Paranal in MMB (Mirror Maintenance Building)

Confirmation of noise, gain, linearity, and dark current was performed during commissioning in the MMB at Paranal. Measurements were performed by taking a sequence of double flats with increasing exposure time using the Stabilized LED.

The gain is normally determined by taking a progressive increasing time series of two flats at constant illumination and calculating the slope (the measured gain) of the variance versus signal level. It has been shown previously ("CCD riddle: a) signal vs time: linear; b) signal vs variance: non-linear", M Downing et al, SPIE2006) that e2v CCDs do not have a linear relationship between variance and signal level and thus the gain calculated by this method is dependent on the signal levels used. The true gain is where the gain curve crosses the Y-axis.

Table 22: Performance confirmed in the MMB at Paranal during commissioning of the UVB arm detector, e2v Pisces Australis II, when read out through its right "r" amplifier.

#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr)	Nominal Bias Level (ADU)
1	100k/1pt/hg	1x1	0.66	2.2-2.3	0.7	< 0.6	1000
		1x2	0.66	2.2-2.3	0.7		1000
		2x2	0.66	2.2-2.3	0.7		1000
4	400k/1pt/lg	1x1	1.73	4.2	0.8		1000
		1x2	1.73	4.2	0.8		1000
		2x2	1.73	4.2	0.8		1000
7	400k/1pt/lg_AFC	1x1	1.73	4.2	0.8		1000



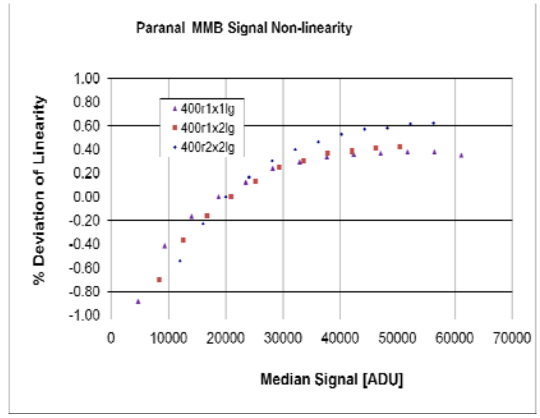
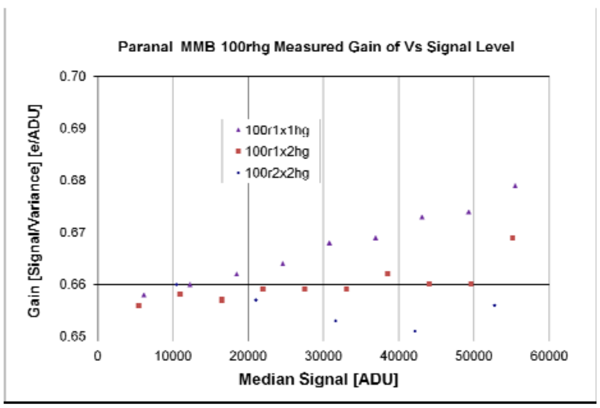


Figure 15: e2v Pisces Australis II Residual Linearity plots at MMB Paranal for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), r is amplifier (r=right, l=left), XxY is the binning factor, and gg is the gain (hg=high gain and lg=lowgain. Plot generated by taking exposures of increasing exposure time with the Stabilized LED.



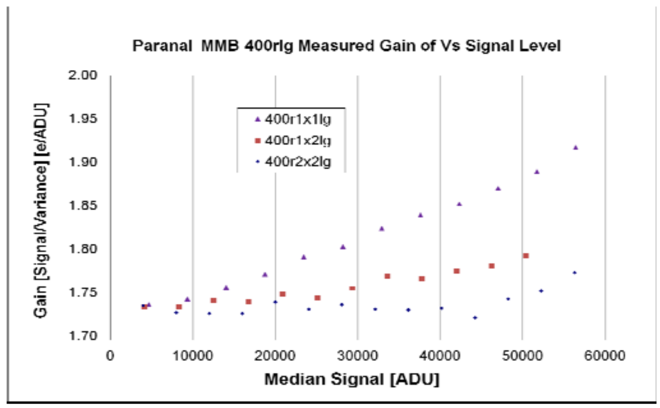


Figure 16: e2v Pisces Australis II Calculated Gain Vs Signal plots at MMB Paranal for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), r is amplifier (r=right, l=left), XxY is the binning factor, and gg is the gain (hg=high gain and lg=lowgain.

11.1.3 Measurements at Paranal During Telescope Commissioning

Confirmation of noise was performed during Telescope commissioning at Paranal. A set of biases in each read out mode was taken.

Table 23: Performance confirmed during Telescope commissioning of the UVB arm detector, e2v Pisces Australis II, when read out through its right "r" amplifier.

#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr)	Nominal Bias Level (ADU)
1	100k/1pt/hg	1x1	0.66	2.3-2.4	-	-	987
		1x2	0.66	2.3-2.4	-	-	987
		2x2	0.66	2.3-2.4	-	-	987
4	400k/1pt/lg	1x1	1.73	4.2	-	-	987
		1x2	1.73	4.2	-	-	986
		2x2	1.73	4.2	-	-	989
7	400k/1pt/lg_AFC	1x1	1.73	4.2	-	-	987

11.2 VIS Arm Detector: Catherine

11.2.1 Measured on ODT Test Bench

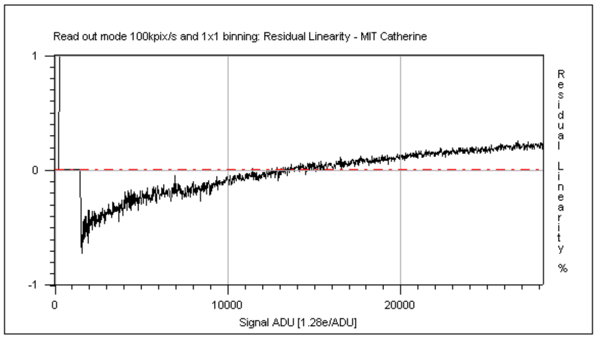
The following measurements were performed on the ODT test bench at the end of characterization.

Table 24: Performance of the VIS arm detector, MIT/LL Catherine, read out through its left "a" amplifier. Measurements performed on ODT Test Bench.

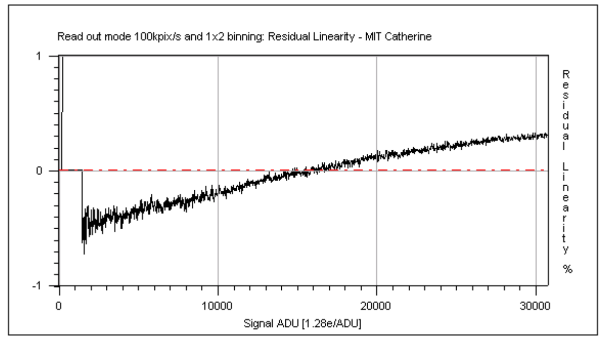
#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr) See note #1	Bias Level (ADU)
1	100k/1pt/hg	1x1	0.64	3.2	0.8	0.7	1000
		1x2	0.64	3.2	0.8	0.5	1000
		2x2	0.63	3.2	0.7	1.1	1000
4	400k/1pt/lg	1x1	1.5	5.3	0.8	0.3	1000
		1x2	1.49	5.3	0.8	-	1000
		2x2	1.49	5.3	0.7	-	1000
7	400k/1pt/lg_AFC	1x1	1.5	5.4	0.7	-	1000

1. At temperature of 135K, Dark Current (DC) measurement is limited by background radiation, luminescence of surrounding material, and to a much lesser extent stabilization and low level persistence in the CCD than intrinsic DC. DC decreases the longer the CCD and surrounding materials are keep in the dark. The DC measurements were recorded in the order they appear in the column and thus the reason why dark current per pixel (division of DC column by binning factor) becomes less as one moves down the column.

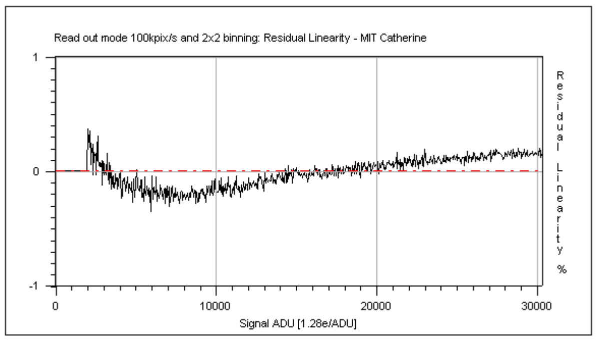
The following linearity curves of MIT Catherine read out modes were taken using Time Domain Integration (TDI) method.



100k/1pt/hg 1x1 bin

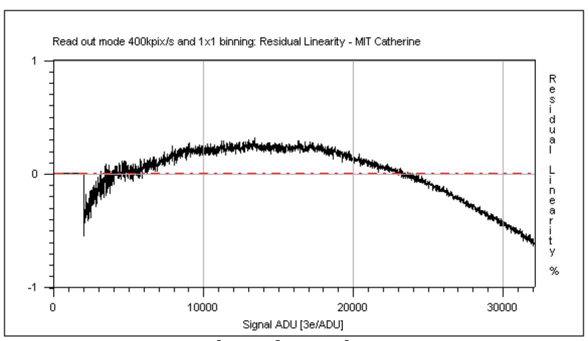


100k/1pt/hg 1x2 bin

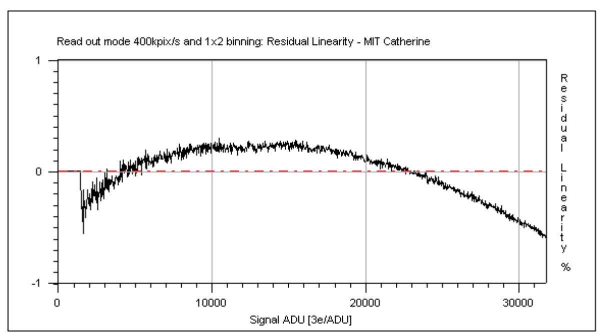


100k/1pt/hg 2x2 bin

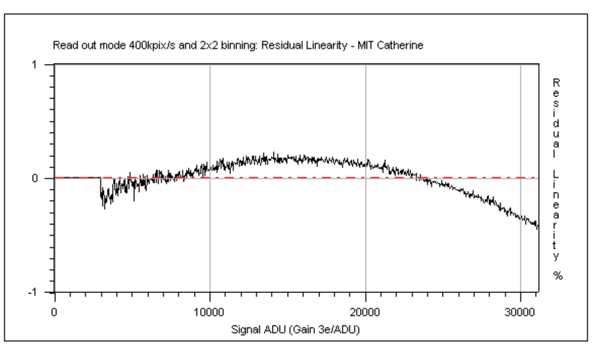
Figure 17: MIT Catherine TDI Residual Linearity plots for different binning factors of 100k/1pt/hg read out mode.



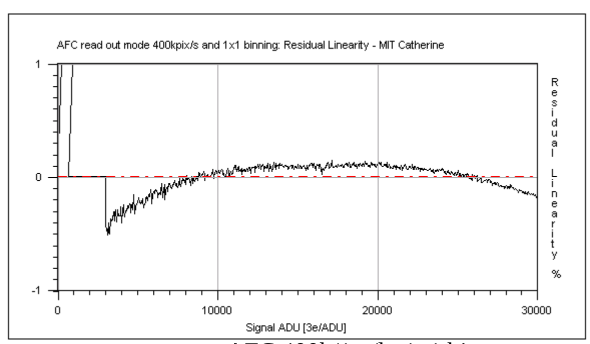
400k/1pt/lg 1x1 bin



400k/1pt/lg 1x2 bin



400k/1pt/lg 2x2 bin



AFC 400k/1pt/lg 1x1 bin

Figure 18: MIT Catherine TDI Residual Linearity plots for different binning factors of 400k/1pt/lg read out mode.

11.2.2 Measurements at Paranal in MMB

Confirmation of noise, gain, linearity, and dark current was performed during commissioning in the MMB at Paranal. Measurements were performed by taking a sequence of double flats with increasing exposure time using the Stabilized LED.

Table 25: Performance confirmed in the MMB at Paranal during commissioning of the VIS arm detector, MIT/LL Catherine, read out through its left "a" amplifier.

#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr) See note #1	Bias Level (ADU)
1	100k/1pt/hg	1x1	0.62	3.0	0.8	< 0.5	1000
		1x2	0.62	3.0	0.8		1000
		2x2	0.62	3.0	0.8		1000
4	400k/1pt/lg	1x1	1.45	4.8	1.0		1000
		1x2	1.45	4.9	1.0	-	1000
		2x2	1.45	4.9	1.0	-	1000
7	400k/1pt/lg_AFC	1x1	1.45	4.9	1.0	-	1000

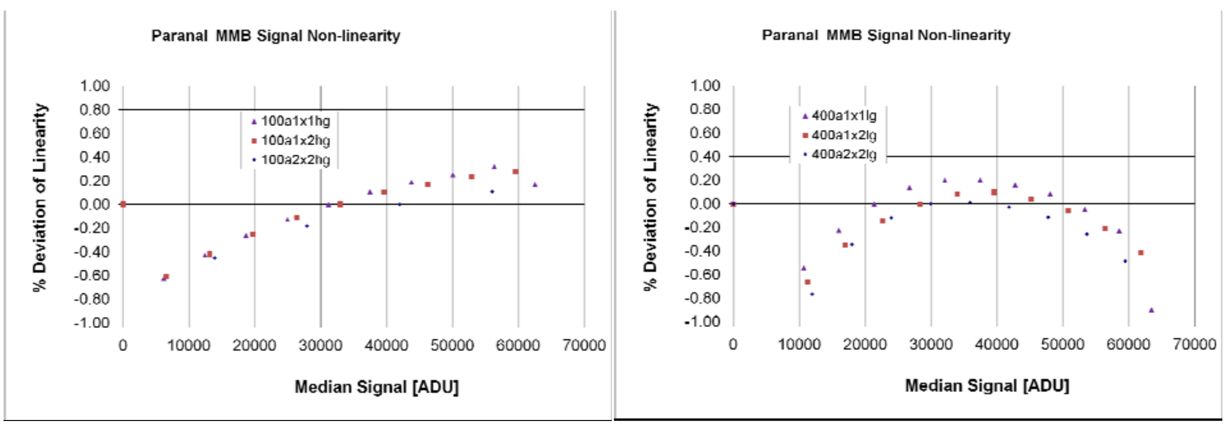
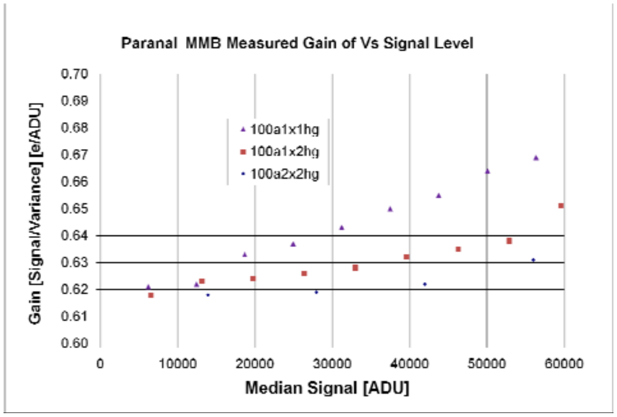


Figure 19: MIT Catherine Residual Linearity plots at MMB Paranal for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), a is amplifier (a=right, b=left), and gg is the gain (hg=high gain and lg=lowgain). Plot generated by taking exposures of increasing exposure time with the Stabilized LED.



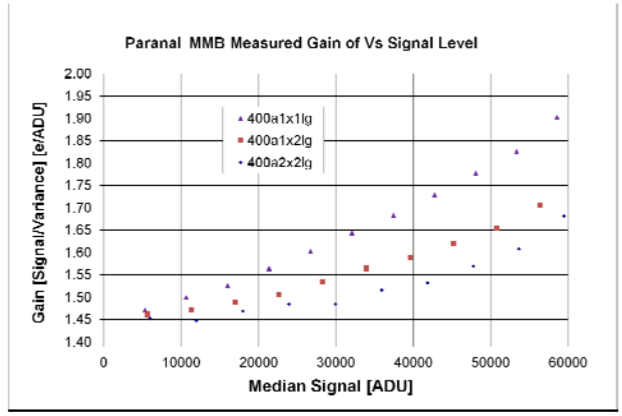


Figure 20: MIT Catherine Calculated Gain Vs Signal plots at MMB Paranal for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), a is amplifier (a=right, b=left), and gg is the gain (hg=high gain and lg=lowgain).

11.2.3 Measurements at Paranal During Telescope Commissioning

Confirmation of noise was performed during Telescope commissioning at Paranal. A set of biases in each read out mode was taken.

Table 26: Performance confirmed during Telescope commissioning of the VIS arm detector, MIT/LL Catherine, read out through its left "a" amplifier.

#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr) See note #1	Bias Level (ADU)
1	100k/1pt/hg	1x1	0.62	3.1	-	-	-
		1x2	0.62	3.1	-	-	-
		2x2	0.62	3.1	-	-	-
4	400k/1pt/lg	1x1	1.45	5.0	-	-	-
		1x2	1.45	5.0	-	-	-
		2x2	1.45	5.0	-	-	-
7	400k/1pt/lg_AFC	1x1	1.45	5.0	-	-	-

12 PSF

Requirements are > 42% of electrons is collected in the adjacent pixel and > 88% within 2x2 pixels (point source at f/3).

12.1 UV Arm Detector: Pisces Australis II

The results of scanning a spot across a pixel (details [RD 02]) of same technology (standard silicon CCD44-82) CCD as Pisces Australis II are shown in Figure 21 (left plot: Gauss fit to PSF profile and right plot: % of charge collected within central pixel) and Figure 22 (% of charge collected within central one and two lines). Right plot of Figure 21 shows that > 45% of electrons is collected in the central pixel. Right plot of Figure 22 shows that > 93% of electrons is collected within two lines when the spot is positioned at a common boundary between the lines.

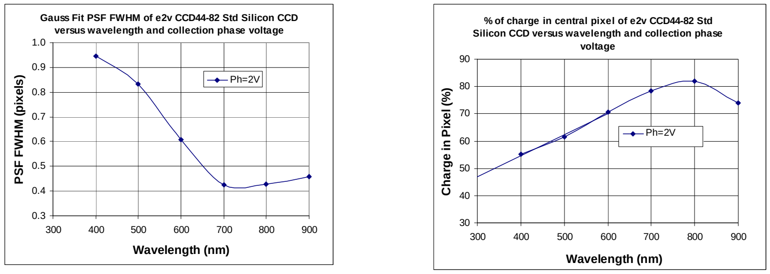


Figure 21: PSF measurement results of same technology CCD as Pisces Australis II. Left: Plot of PSF FWHM in units of pixels versus wavelength. Right: Plots of percentage of charge collected in the central pixel versus wavelength.

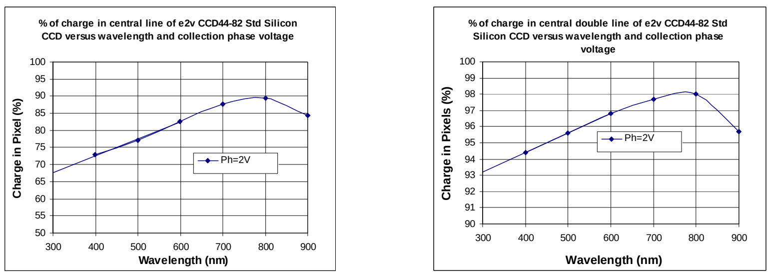


Figure 22: Plots of percentage of charge collected in central lines versus wavelength of same technology CCD as Pisces Australis II. Left: Percentage in central line. Right: Percentage in central two lines.

12.2 VIS Arm Detector: Catherine

The results of scanning a spot across a pixel (details [RD 02]) of same technology (CCID-20 40µm thick Deep Depletion) CCD as Catherine are shown in Figure 23 (left plot: Gauss fit to PSF profile and right plot: % of charge collected within central pixel) and Figure 24 (% of charge collected within central one and two lines). For operating wavelengths (500nm to 960nhm), the right plot of Figure 23 shows that > 65% of electrons is collected in the central pixel. Right plot of Figure 24 shows that > 97% of electrons is collected within two lines when the spot is positioned at a common boundary between the lines.

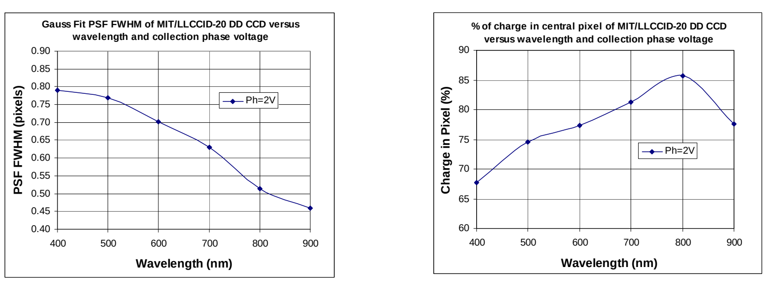


Figure 23: PSF measurement results of same technology CCD as MIT/LL CCID-20 CCD Catherine. Left: Plot of PSF FWHM in units of pixels versus wavelength. Right: Plots of percentage of charge collected in the central pixel versus wavelength.

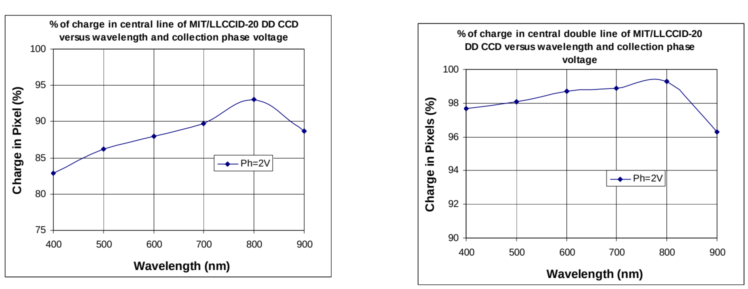


Figure 24: Plots of percentage of charge collected in central lines versus wavelength of same technology CCD as Catherine. Left: Percentage in central line. Right: Percentage in central two lines.

13 Overscan Offset Variation with Signal Level

It has been reported that the offset level of images taken with FIERA varies with signal intensity and progressively get worse at higher read out speeds. This affect was investigated by taking flat field images which are considered worse case for this affect. The following sections contain column plots for both Catherine and Pisces Australis II that clearly show that the FIERA of X-shooter exhibits this behavior.

For 100kpix/sec read out speed, the affect is very small and at a uniform flat field intensity of ~ 50,000ADU over the whole image area is less than 2 times the read noise at ~ 10 ADU. This will cause a negligible error of < 0.02%.

For 400kpix/sec read out speed, the affect is larger but still very small and is 60-70 ADU for a flat field intensity of ~ 50,000ADU. This will cause an error of < 0.14%.

Normal scientific images will not fill all pixels with signal (in fact much less than 50% of pixels will contain signal) and thus the offset level of the FIERA video chain will have time to settle back to its no signal level and the affect will be much less.

Note also that offset variation is observed in strong point sources.

If greater accuracy is required for the Flat Fields and strong point source type images then the overscan pixels can be subtracted to correct for this affect.

13.1 Plots of overscan of e2v Pisces Australis II: Read out Mode 100kpix/s and 2x2 binning

Figure 25 to Figure 27 contain column plots of image area and overscan region of flat fields of e2v Pisces Australis II at increasing intensity levels for read out mode of 100kpix/s and 2x2 binning. The overscan plots show that the offset level varies with the intensity of the flat field in ratio of ~ 0.016%.

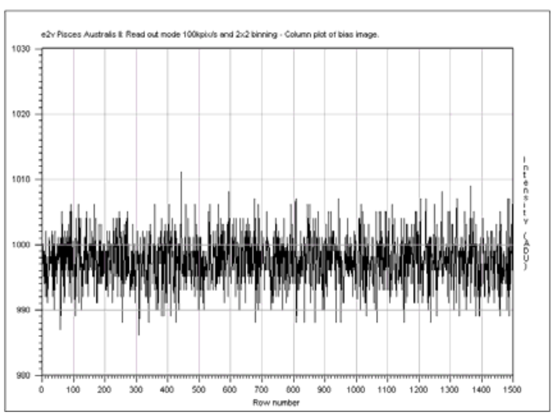


Figure 25: Column plot of bias image of e2v Pisces Australis II when read out at 100kpix/s and 2x2 binning.

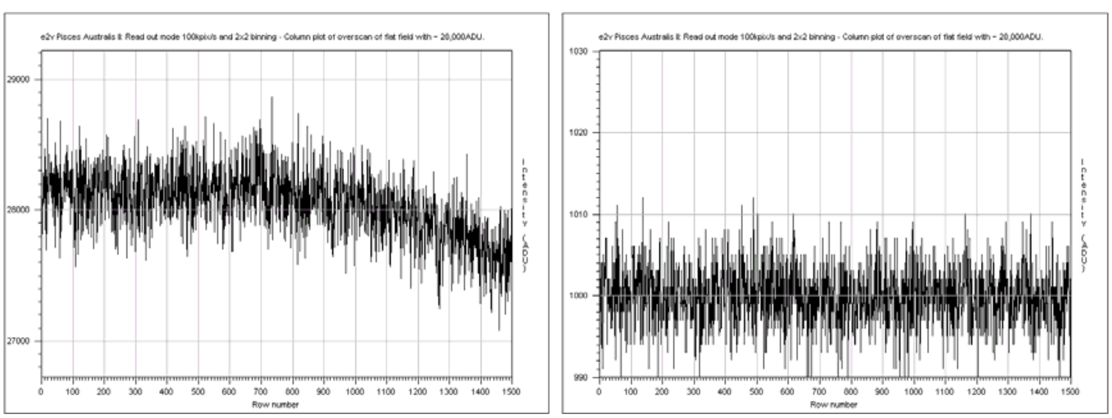


Figure 26: Column plots of flat field with intensity level of ~ 28,000ADU of e2v Pisces Australis II when read out at 100kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

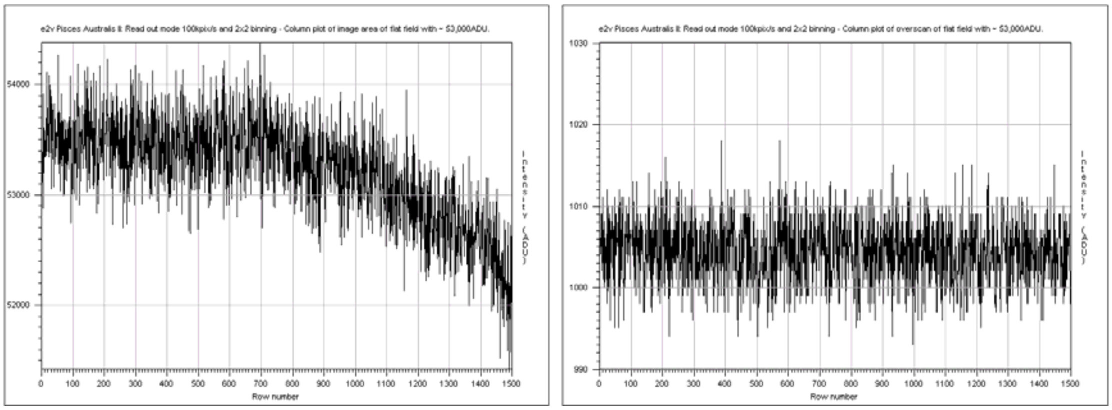


Figure 27: Column plots of flat field with intensity level of ~ 53,000ADU of e2v Pisces Australis II when read out at 100kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

13.2 Plots of overscan of e2v Pisces Australis II: Read out Mode 400kpix/s and 2x2 binning

Figure 28 to Figure 31 contain column plots of image area and overscan region of flat fields of e2v Pisces Australis II at increasing intensity levels for read out mode of 400kpix/s and 2x2 binning. The overscan plots show that the offset level varies with the intensity of the flat field in ratio of ~ 0.12%.

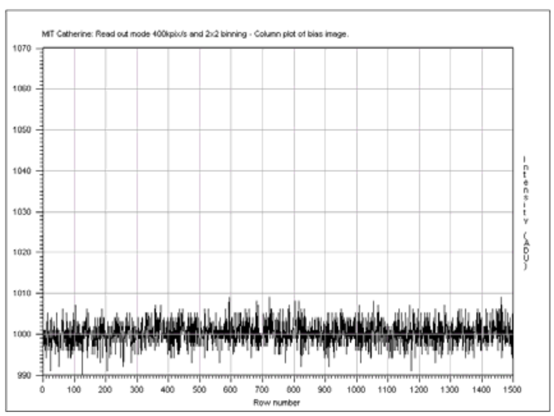


Figure 28: Column plot of bias image of e2v Pisces Australis II when read out at 400kpix/s and 2x2 binning.

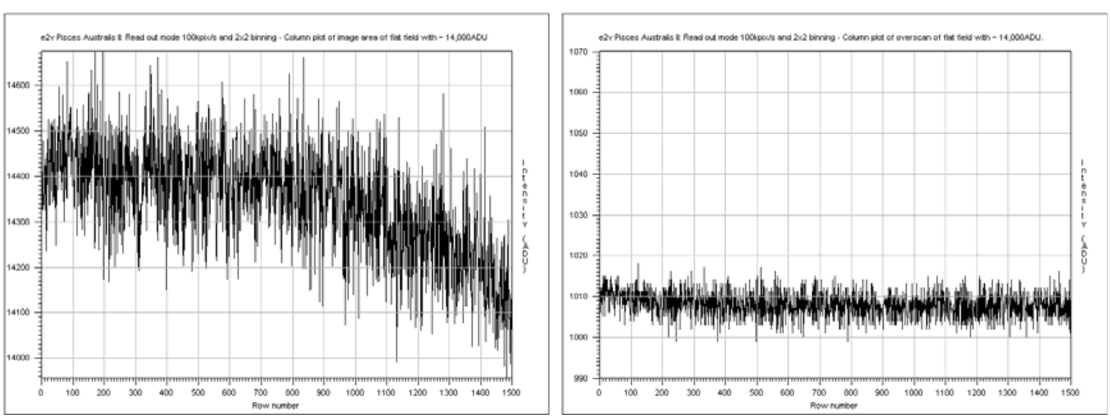


Figure 29: Column plots of flat field with intensity level of ~ 14,000ADU of e2v Pisces Australis II when read out at 400kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

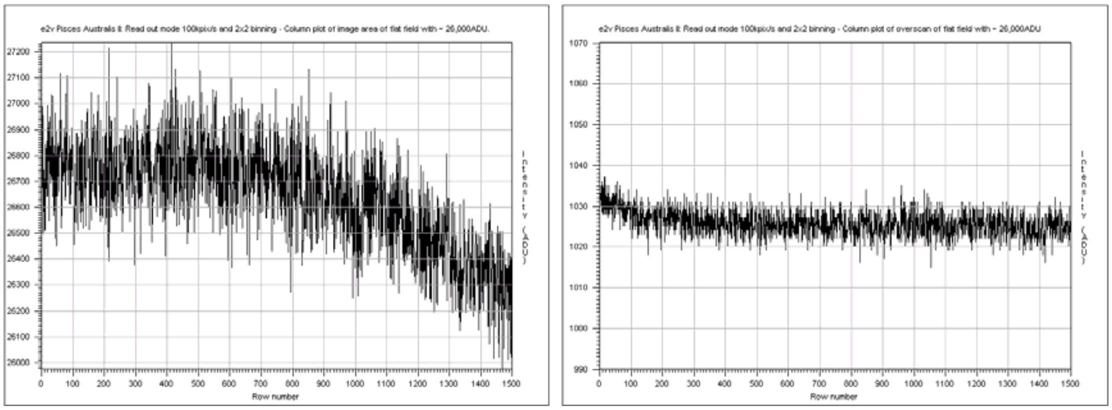


Figure 30: Column plots of flat field with intensity level of ~ 26,000ADU of e2v Pisces Australis II when read out at 400kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

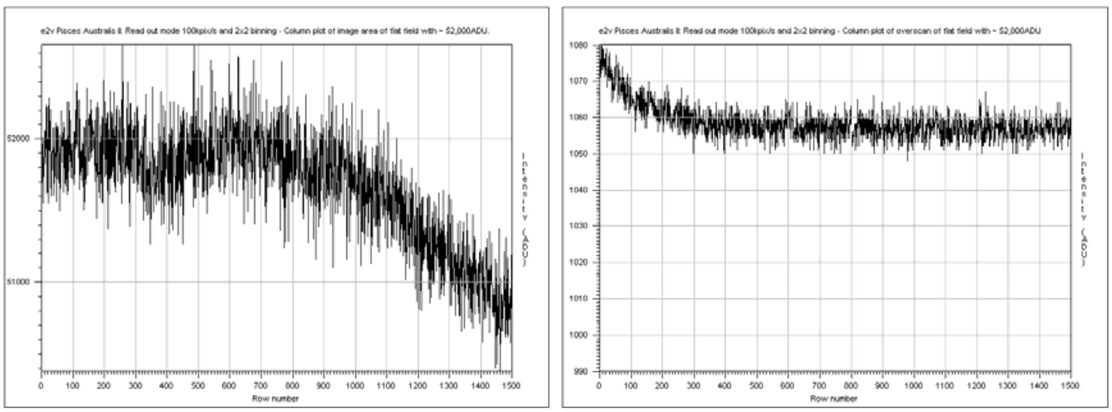


Figure 31: Column plots of flat field with intensity level of ~ 52,000ADU of e2v Pisces Australis II when read out at 400kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

13.3 Plots of overscan of MIT Catherine: Read out Mode 100kpix/s and 2x2 binning

Figure 32 to Figure 34 contain column plots of image area and overscan region of flat fields of MIT Catherine at increasing intensity levels for read out mode of 100kpix/s and 2x2 binning. The overscan plots show that the offset level varies with the intensity of the flat field in ratio of ~ 0.02%.

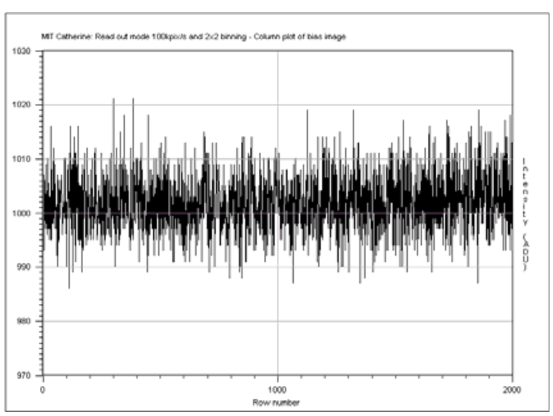


Figure 32: Column plot of bias image of MIT Catherine when read out at 100kpix/s and 2x2 binning.

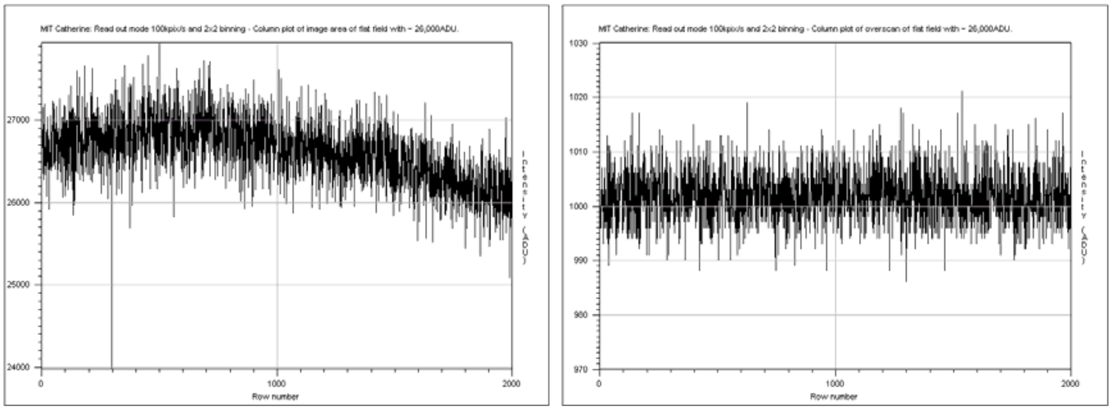


Figure 33: Column plots of flat field with intensity level of ~ 26,000ADU of MIT Catherine when read out at 100kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

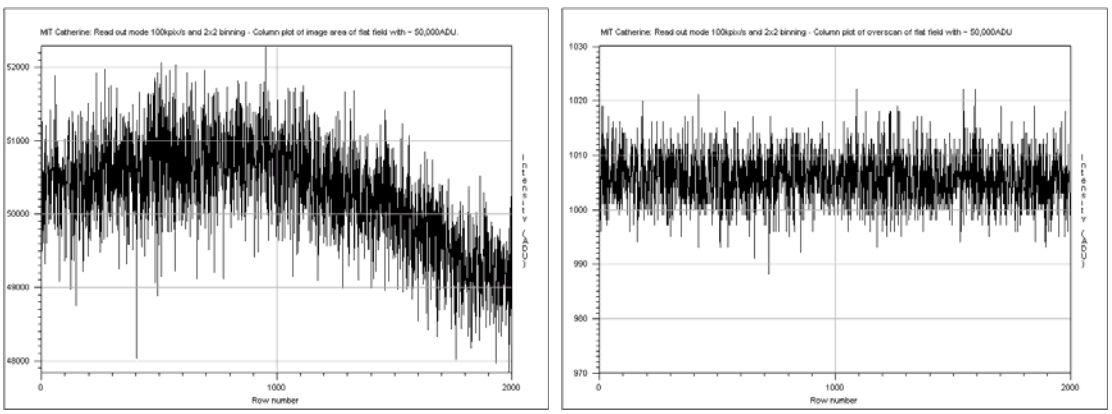


Figure 34: Column plots of flat field with intensity level of ~ 50,000ADU of MIT Catherine when read out at 100kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

13.3.1 Plots of overscan of MIT Catherine: Read out Mode 400kpix/s and 2x2 binning

Figure 36 to Figure 38 contain column plots of image area and overscan region of flat fields of MIT Catherine at increasing intensity levels for read out mode of 400kpix/s and 2x2 binning. The overscan plots show that the offset level varies with the intensity of the flat field in ratio of ~ 0.14%.

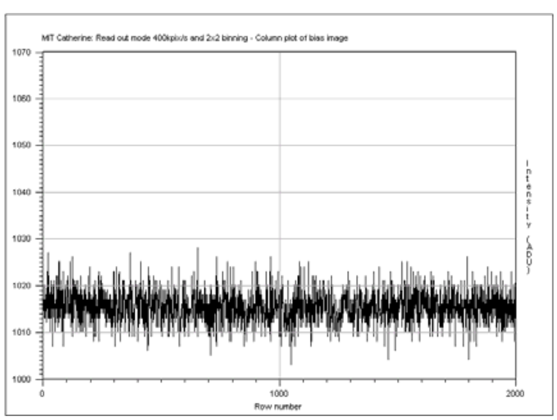


Figure 35: Column plot of overscan region of bias image (0 ADU) of MIT Catherine when read out at 400kpix/s and 2x2 binning.

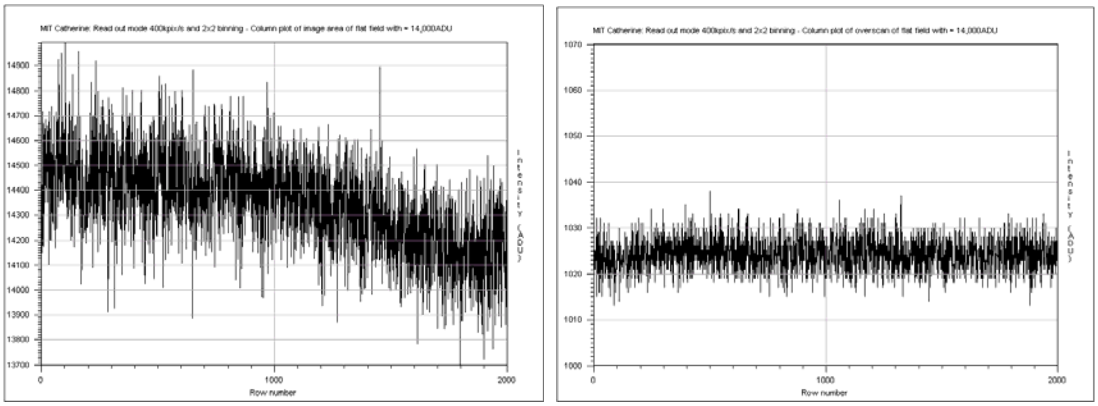


Figure 36: Column plots of flat field with intensity level of ~ 14,000ADU of MIT Catherine when read out at 400kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

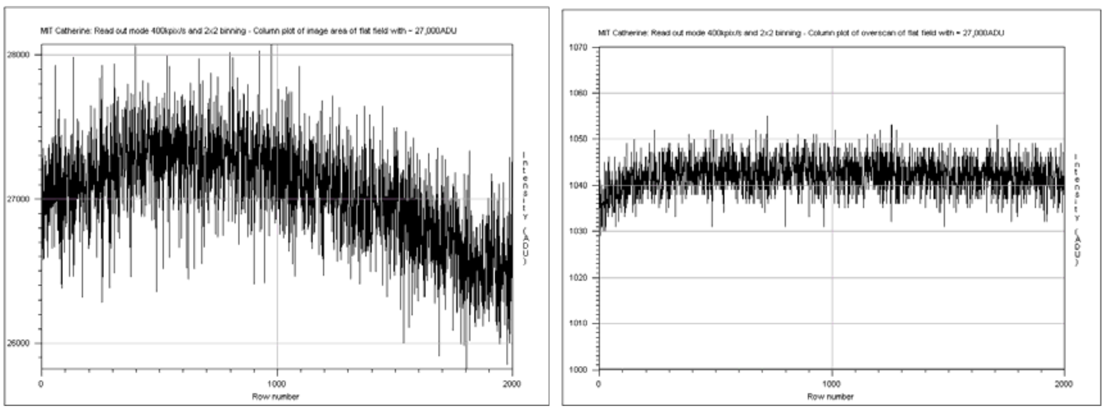


Figure 37: Column plots of flat field with intensity level of ~ 27,000ADU of MIT Catherine when read out at 400kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

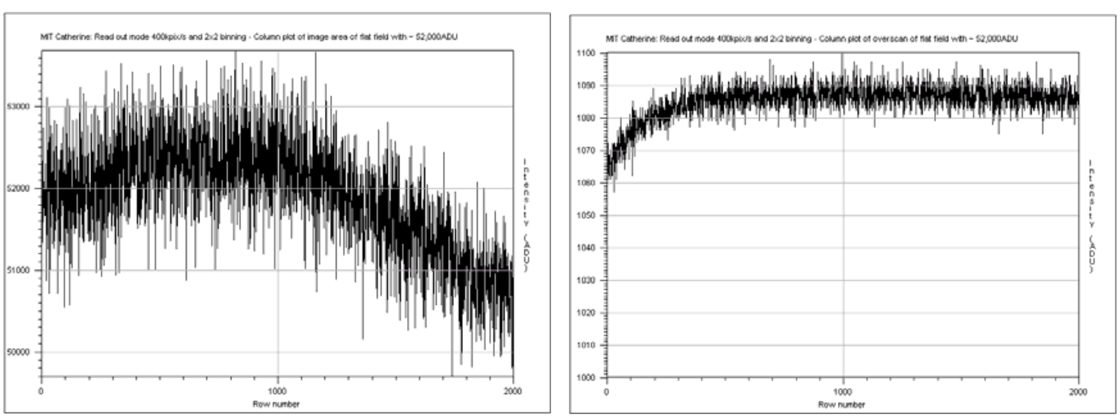


Figure 38: Column plots of flat field with intensity level of ~ 52,000ADU of MIT Catherine when read out at 400kpix/s and 2x2 binning. Left: Column plot of image area; Right Column plot of overscan region.

14 Problem of Spectral Non-linearity with UVB arm 100kps Mode

Linearity with flat-fields on the ODT test bench and SLED at Paranal was measured to be very good and within specifications. However with Spectral images, a flattening of the peaks was observed above 50 kADU (see **Figure 39**).

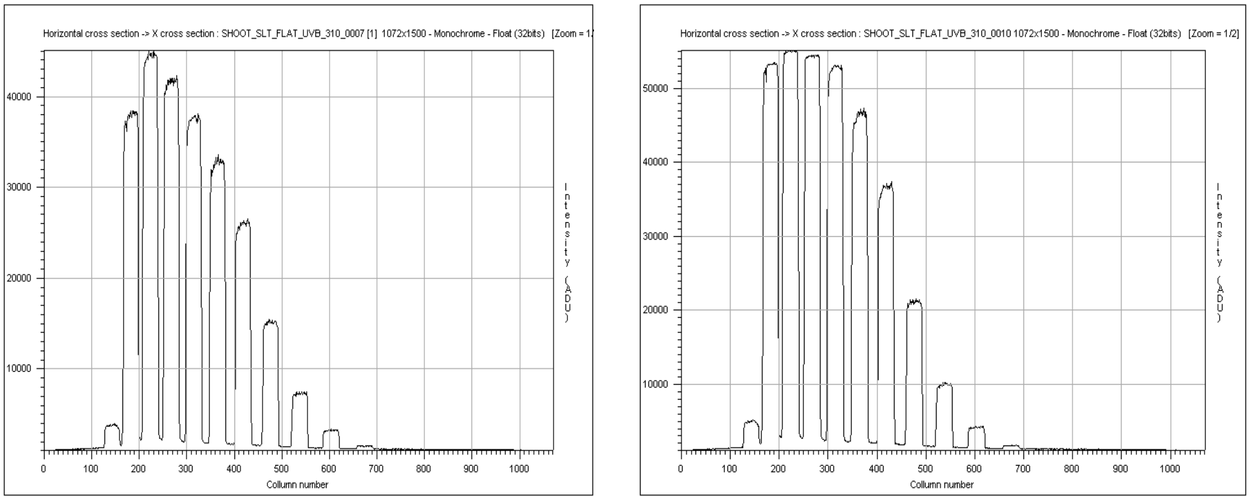


Figure 39: Line plots at Y=1166 showing flattening of peaks of spectra above 50 kADU. Left: Spectral below 50 kADU. Right: Spectral above 50 kADU.

To investigate the degree of non-linearity, Spectra at increasing exposure times was analyzed. The results (**Figure 40**) show good linearity below 50kADU and rapid degradation above.

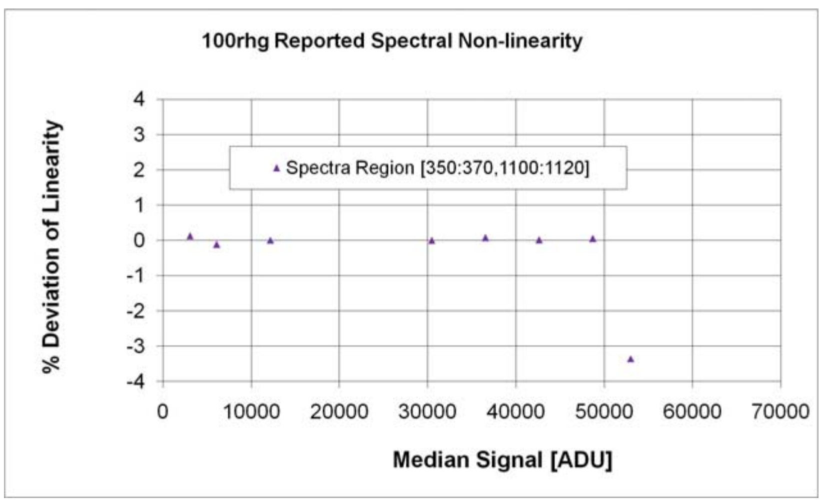


Figure 40: Linearity plot of spectra data taken in sub-region [350:370,1100:1120].

The problem was diagnosed to inadequate settling time in the FIERA video chain. FIERA video board settling time constant was decreased from 1.5us to 500us. This fixed the problem (see linearity plot in Figure 41 and spectral line plot in Figure 42).

See §14.1 for results of performance measurements after the change and after the spare video board was inserted.

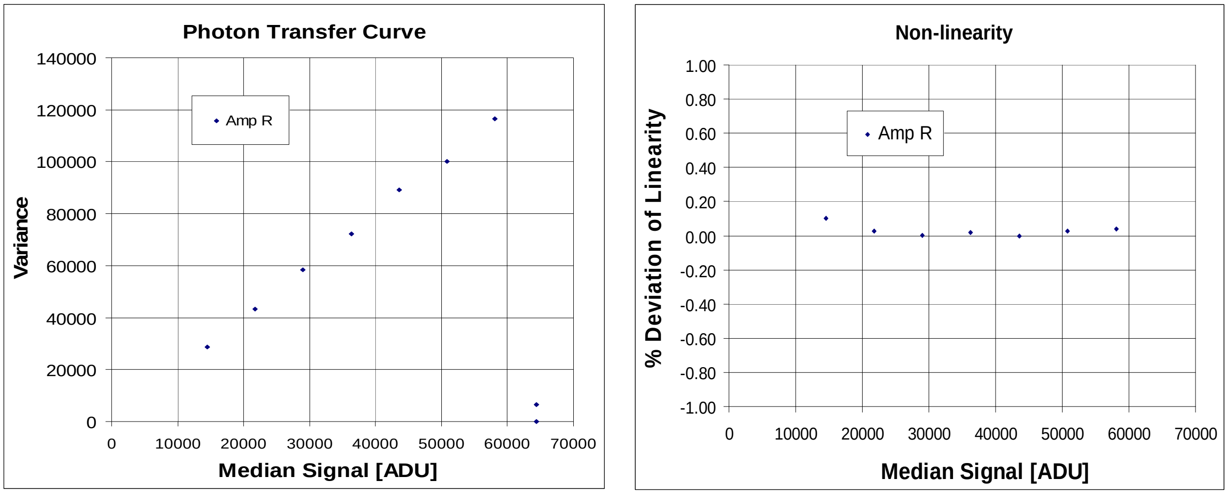


Figure 41: Photon transfer curve (left) and linearity (right) plot of spectra data taken in sub-region [390:418,550:750] after changing time constants. Good linearity behavior is observed.

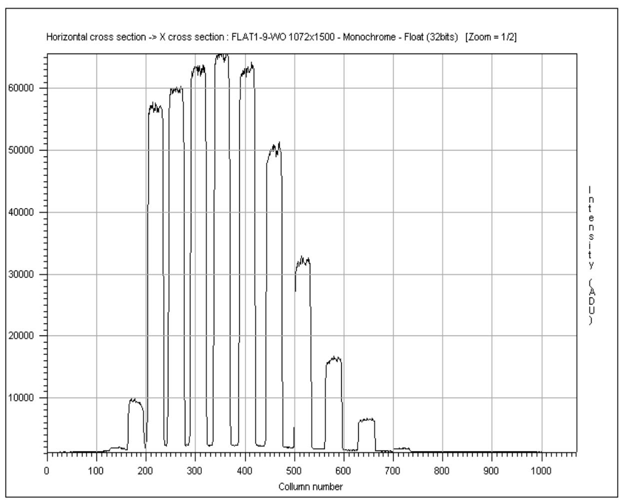


Figure 42: Line plots showing no flattening of peaks of spectra up to ADC saturation (65 kADU) after changing time constants.

14.1 Performance of Spare Video Board (serial number 67) During Commission (date - 30th April 2009)

Due to observed bias jumps in the detector of the VIS arm (§15) and the fact that one of the unused channels was faulty, the video board used during commissioning (serial number 71) was replaced by the spare video board (serial number 67). The performance of noise, gain, and linearity of the Spare Video Board (serial number 67) was measured by taking a sequence of double flats with increasing exposure time using the Stabilized LED. The results are summarized in the following tables and figures.

Table 27: Performance with spare video board (serial number 67) of the UVB arm detector, e2v Pisces Australis II, when read out through its right "r" amplifier.

#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr)	Nominal Bias Level (ADU)
1	100k/1pt/hg	1x1	0.62	2.5	0.4	-	1000
		1x2	0.62	2.5	0.4	-	1000
		2x2	0.62	2.5	0.4	-	1000
4	400k/1pt/lg	1x1	1.75	4.5	1.0	-	1000
		1x2	1.75	4.5	1.0	-	1000
		2x2	1.75	4.5	1.0	-	1000
7	400k/1pt/lg_AFC	1x1	1.75	4.5	1.0	-	1000

Table 28: Performance with spare video board (serial number 67) of the VIS arm detector, MIT/LL Catherine, read out through its left "a" amplifier.

#	Mode Name	Bin (X.Y)	Gain (e^-/ADU)	RON (e^-)	Linearity Peak-to-peak (%)	Dark Current (e^-/binnedpix/hr) See note #1	Bias Level (ADU)
1	100k/1pt/hg	1x1	0.595	3.1	0.8	-	1000
		1x2	0.595	3.1	0.8	-	1000
		2x2	0.595	3.1	0.8	-	1000
4	400k/1pt/lg	1x1	1.4	5.2	0.8	-	1000
		1x2	1.4	5.2	0.8	-	1000
		2x2	1.4	5.2	0.8	-	1000
7	400k/1pt/lg_AFC	1x1	1.4	5.2	0.8	-	1000

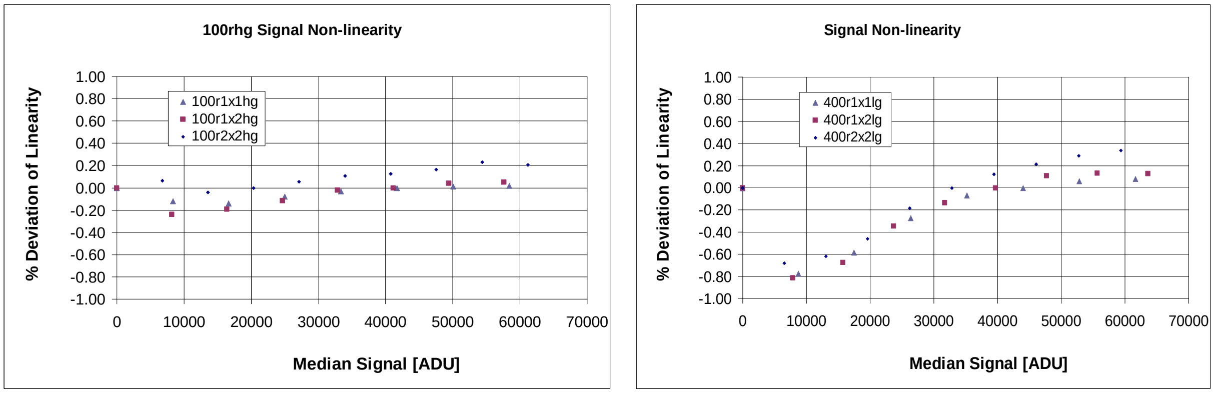


Figure 43: e2v Pisces Australis II Residual Linearity plots of the spare video board for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), r is amplifier (r=right, l=left), and gg is the gain (hg=high gain and lg=lowgain. Plot generated by taking exposures of increasing exposure time with the Stabilized LED.

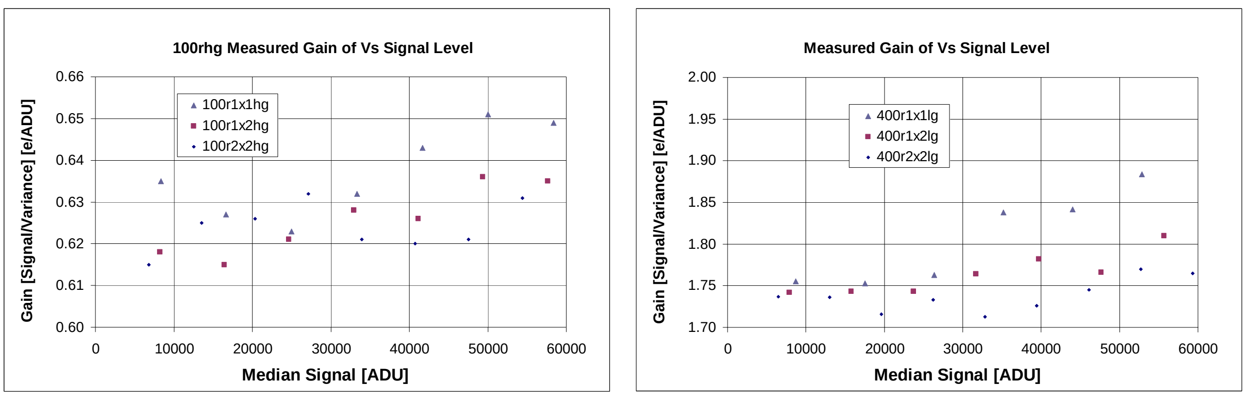


Figure 44: e2v Pisces Australis II Calculated Gain Vs Signal plots of the spare video board for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), r is amplifier (r=right, l=left), and gg is the gain (hg=high gain and lg=lowgain.

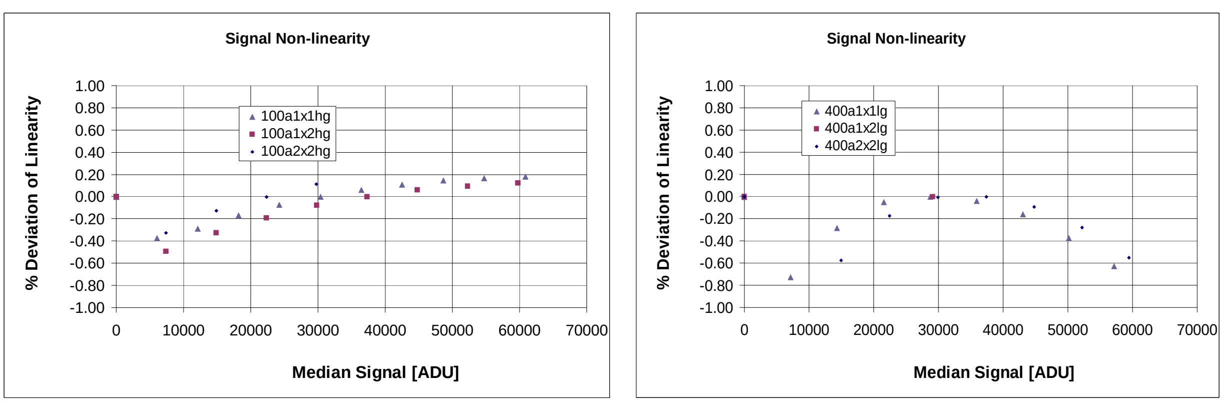
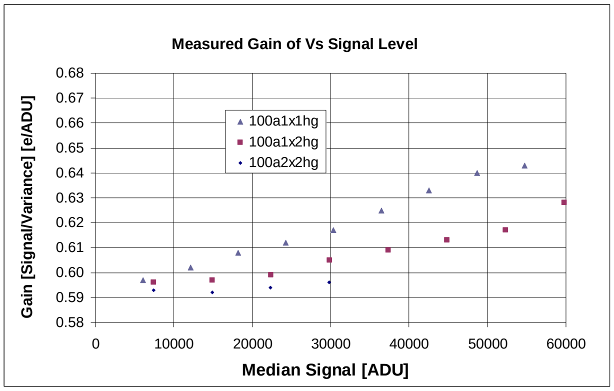


Figure 45: MIT Catherine Residual Linearity plots of the spare video board for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), a is amplifier (a=right, b=left), and gg is the gain (hg=high gain and lg=lowgain). Plot generated by taking exposures of increasing exposure time with the Stabilized LED.



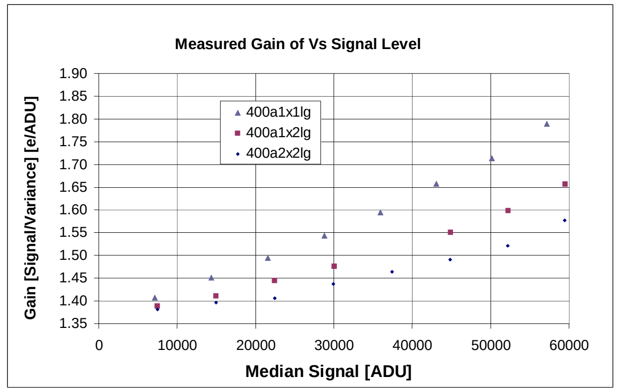


Figure 46: MIT Catherine Calculated Gain Vs Signal plots of the spare video board for the various read out modes. Note legend is defined as SSSrXxYgg, where SSS is read out speed (100kps and 400kps), a is amplifier (a=right, b=left), and gg is the gain (hg=high gain and lg=lowgain).

15 Investigation of Reported Bias Jump on VIS Arm

Table 29 and Table 30 contain measurements of one (date 16 Jan 2009) of several bias jumps observed during commissioning 1 to 3 on the VIS arm. To fix the problem, the video board (serial number 71) was replaced with the spare one (serial number 67). See §14.1 for results of performance measurements after the swap.

Table 29: Gain, RON, and bias level before and after bias jump during Telescope second commissioning run of the VIS arm detector, MIT/LL Catherine, read out through its left "a" amplifier.

#	Mode Name	Gain Ratio	Bias Ratio	Bin (X.Y)	Before Bias Jump			After Bias Jump		
					Gain (e^-/ADU)	RON (e^-)	Bias Level (ADU)	Gain (e^-/ADU)	RON (e^-)	Bias Level (ADU)
3	100k/1pt/hg	1.068		2x2	0.62	3.1	1044	0.58	3.0	1370
6	400k/1pt/lg	1.058		2x2	1.45	5.0	1012	1.37	5.0	1124

Table 30: Gain, RON, and bias level before and after bias jump in VIS arm during Telescope second commissioning run of the UVB arm detector, e2v Pisces Australis II, when read out through its right "r" amplifier.

#	Mode Name	Gain Ratio	Bias Ratio	Bin (X.Y)	Before Bias Jump			After Bias Jump		
					Gain (e^-/ADU)	RON (e^-)	Bias Level (ADU)	Gain (e^-/ADU)	RON (e^-)	Bias Level (ADU)
3	100k/1pt/hg			2x2	0.66	2.4	987	0.65	2.4	994
6	400k/1pt/lg			2x2	1.73	4.2	989	1.7	4.3	992