



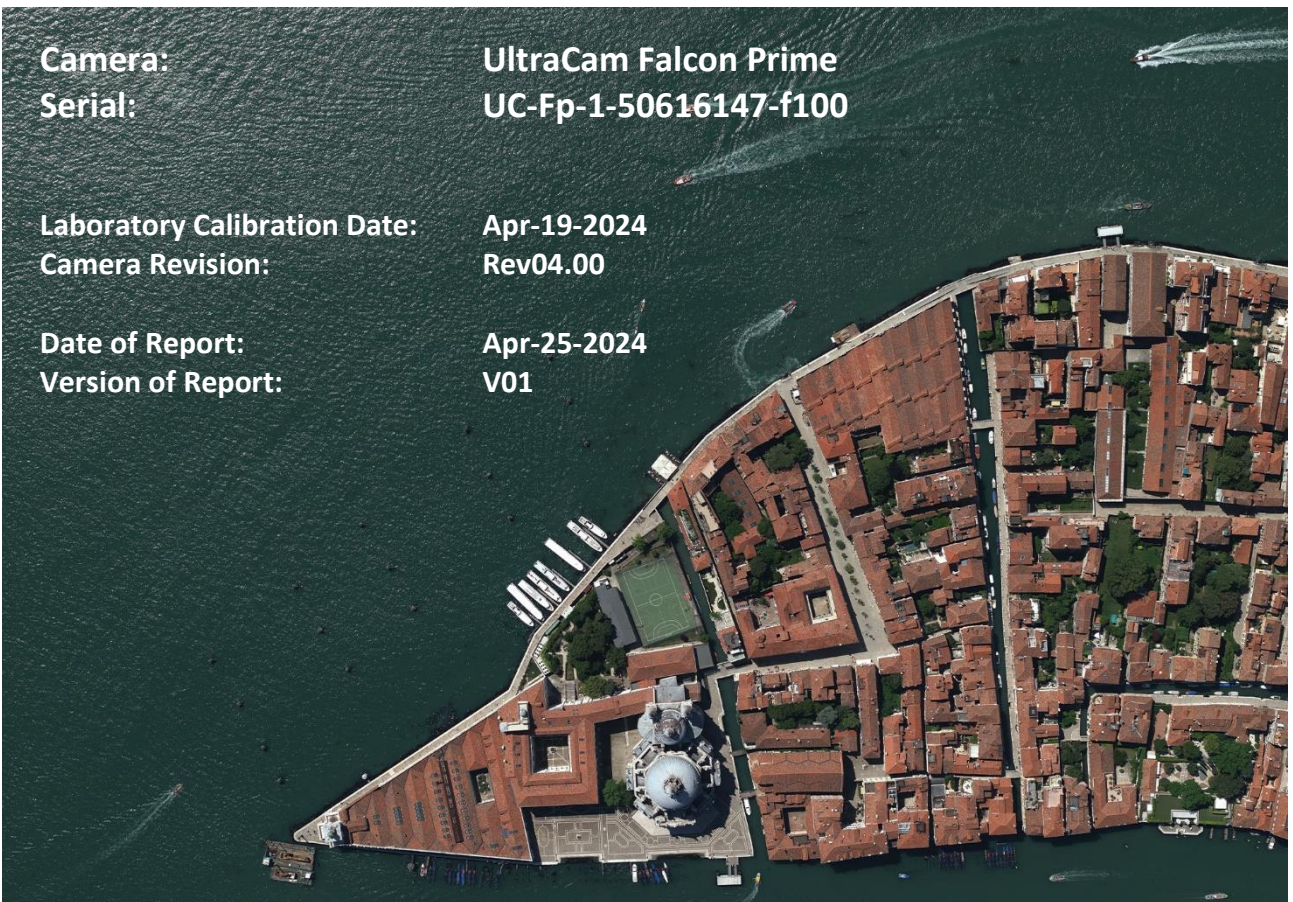
# ULTRACAM

## Calibration Report

**Camera:** UltraCam Falcon Prime  
**Serial:** UC-Fp-1-50616147-f100

**Laboratory Calibration Date:** Apr-19-2024  
**Camera Revision:** Rev04.00

**Date of Report:** Apr-25-2024  
**Version of Report:** V01



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Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH



# **ULTRACAM**

## Geometric Calibration

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**Camera:** UltraCam Falcon Prime  
**Serial:** UC-Fp-1-50616147-f100

**Panchromatic Camera:** ck = 100.500 mm  
**Multispectral Camera:** ck = 100.500 mm

**PPA Information:** X: 0.000mm  
Y: 0.000mm



## Panchromatic Camera

### Large Format Panchromatic Output Image

<b>Image Format</b>	long track cross track	67.860mm 103.860mm	11310pixel 17310pixel
<b>Image Extent</b>		(-33.930, -51.930)mm	(33.930, 51.930)mm
<b>Pixel Size</b>		6.000µm*6.000µm	
<b>Focal Length</b>	ck	100.500mm	± 0.002mm
<b>Principal Point (Level 2)</b>	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
<b>Lens Distortion</b>	Remaining Distortion less than 0.002mm		

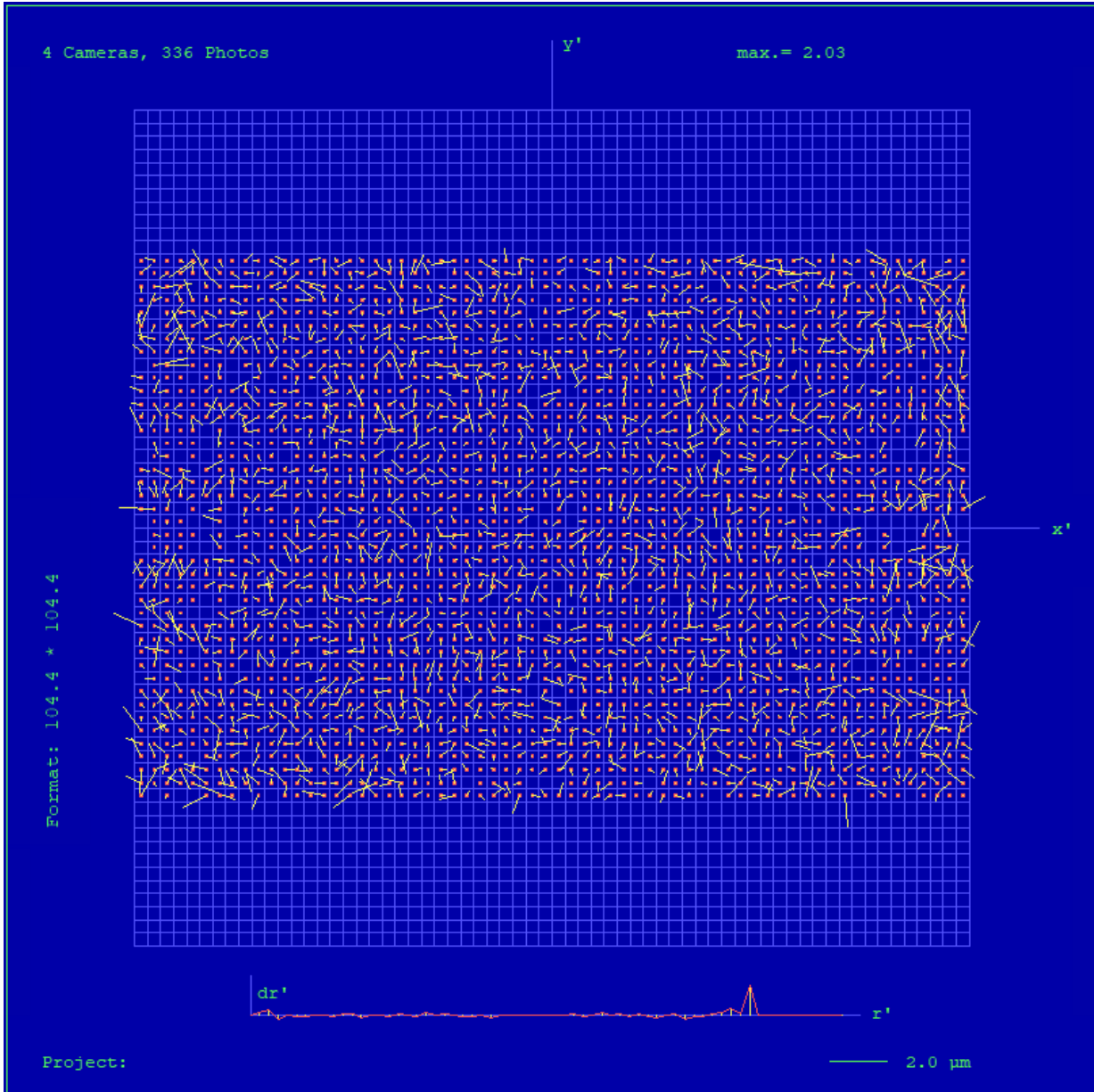
## Multispectral Camera

### Medium Format Multispectral Output Image (Upscaled to panchromatic image format)

<b>Image Format</b>	long track cross track	67.860mm 103.860mm	3770pixel 5770pixel
<b>Image Extent</b>		(-33.930, -51.930)mm	(33.930, 51.930)mm
<b>Pixel Size</b>		18.000µm*18.000µm	
<b>Focal Length</b>	ck	100.500mm	± 0.002mm
<b>Principal Point (Level 2)</b>	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
<b>Lens Distortion</b>	Remaining Distortion less than 0.002mm		



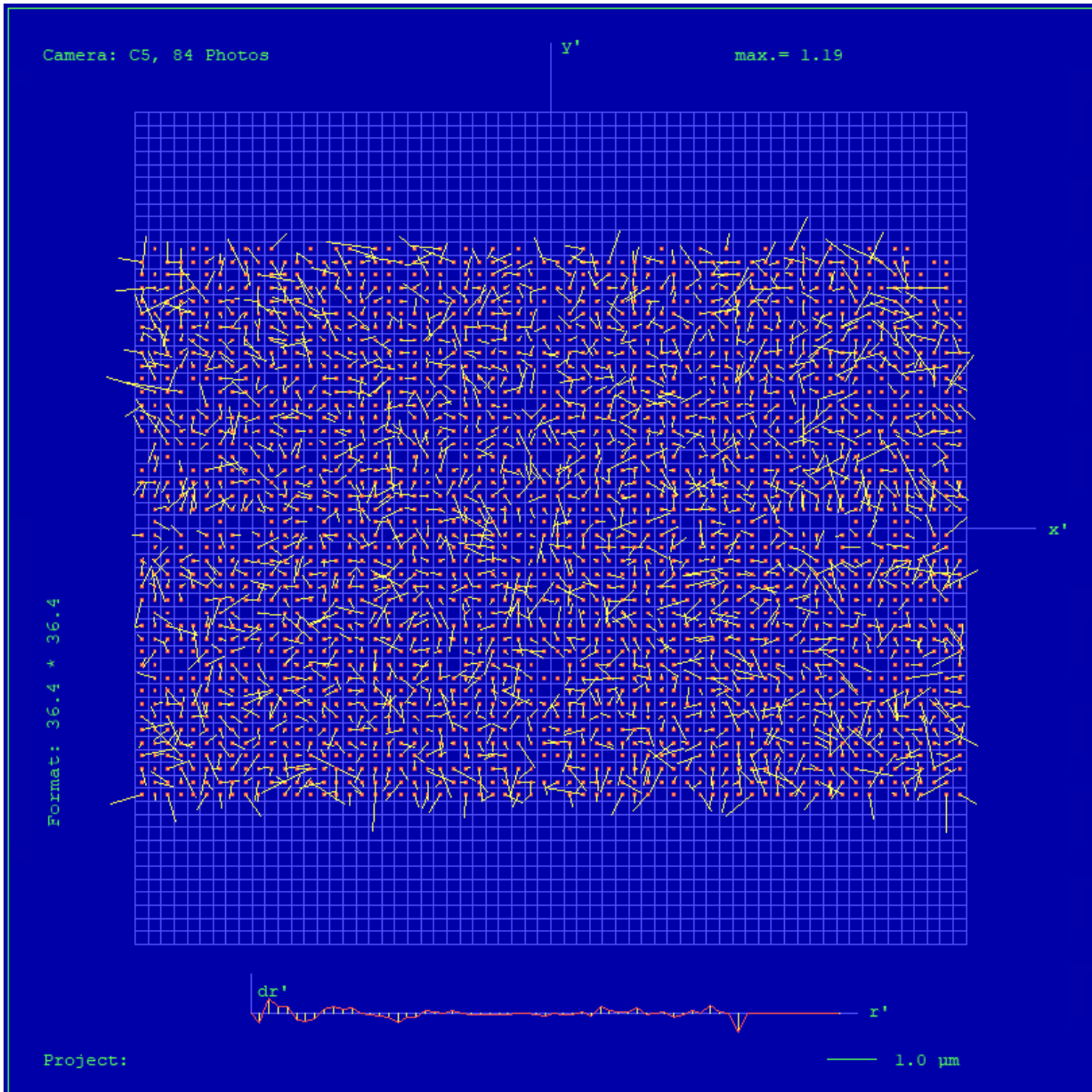
# Full Panchromatic Image, Residual Error Diagram



**Residual Error (RMS):**            **0.86 μm**



## Green Cone (Cone 5), Residual Error Diagram



**Residual Error (RMS):**            **0.63 μm**





## Explanations

### Calibration Method:

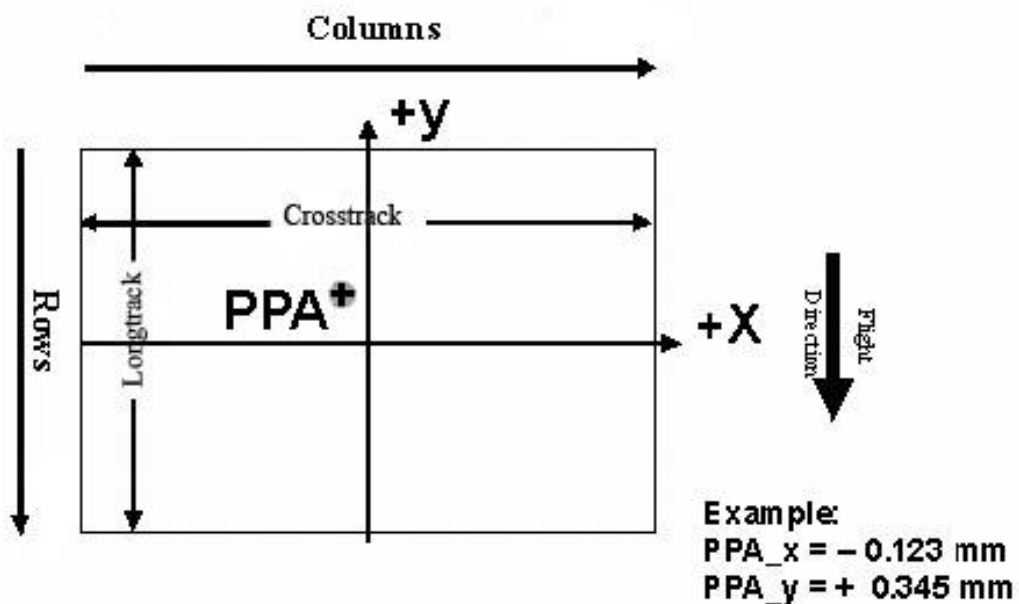
The geometric calibration is based on a set of 84 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera : >16000  
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.  
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

### Level 2 Image Coordinate System:

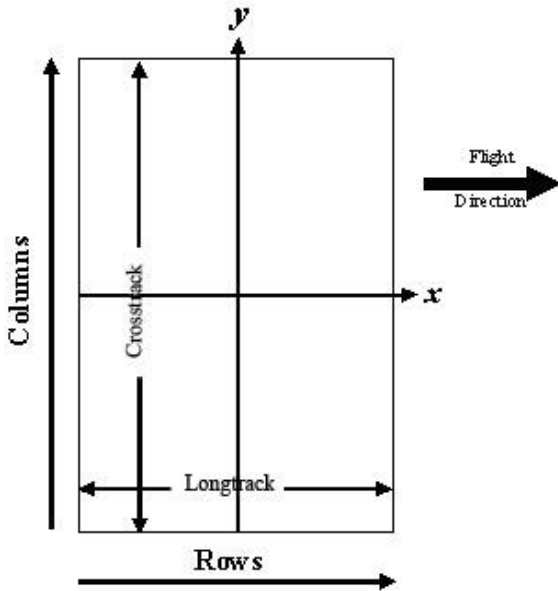
## Lvl2, Camera prop. Orientation



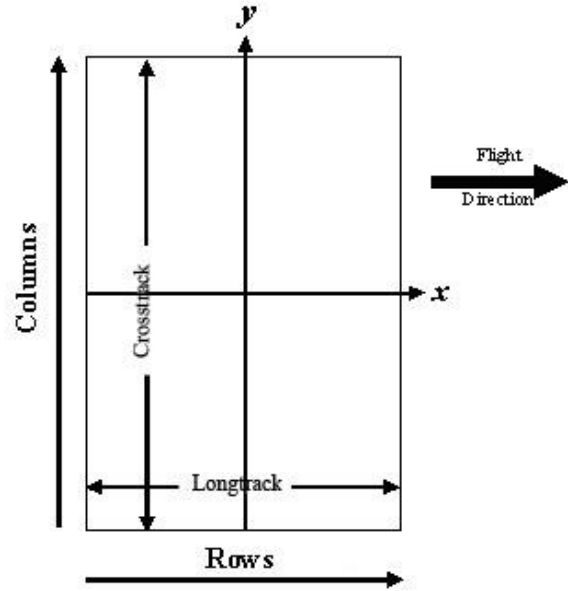
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



**Level 3 Image Coordinate System:**  
(after rotation of 270° CW)



Panchromatic Image Format



Multispectral Image Format

**Position of Principal Point in Level 3 Image**

The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 4 for high- and low resolution images.

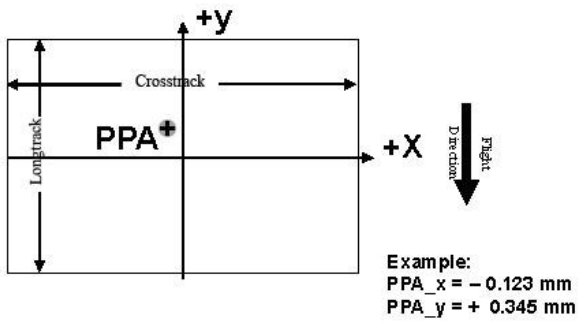
Image Format	Clockwise Rotation (Degree)	PPA	
		X	Y
Level 2	-	0.000	0.000
Level 3	0	0.000	0.000
Level 3	90	0.000	0.000
Level 3	180	0.000	0.000
Level 3	270	0.000	0.000



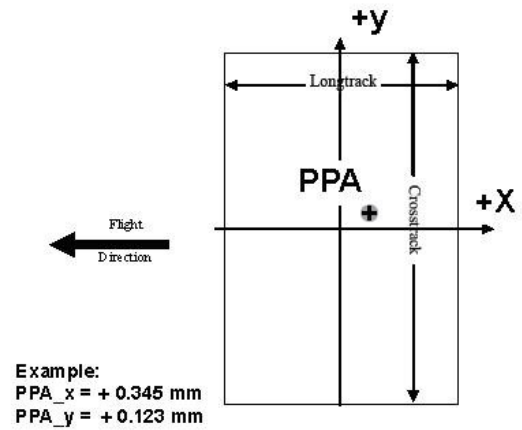


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

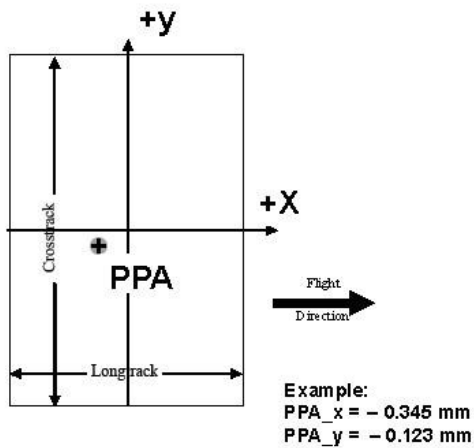
Lvl3, Rotation 0 deg clockwise



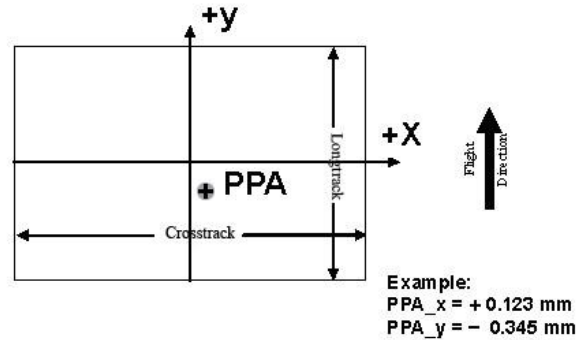
Lvl3, Rotation 90 deg clockwise



Lvl3, Rotation 270 deg clockwise



Lvl3, Rotation 180 deg clockwise





## Lens Resolving Power

The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones.

Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

The curves are given for the meridional (tangential) and sagital (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

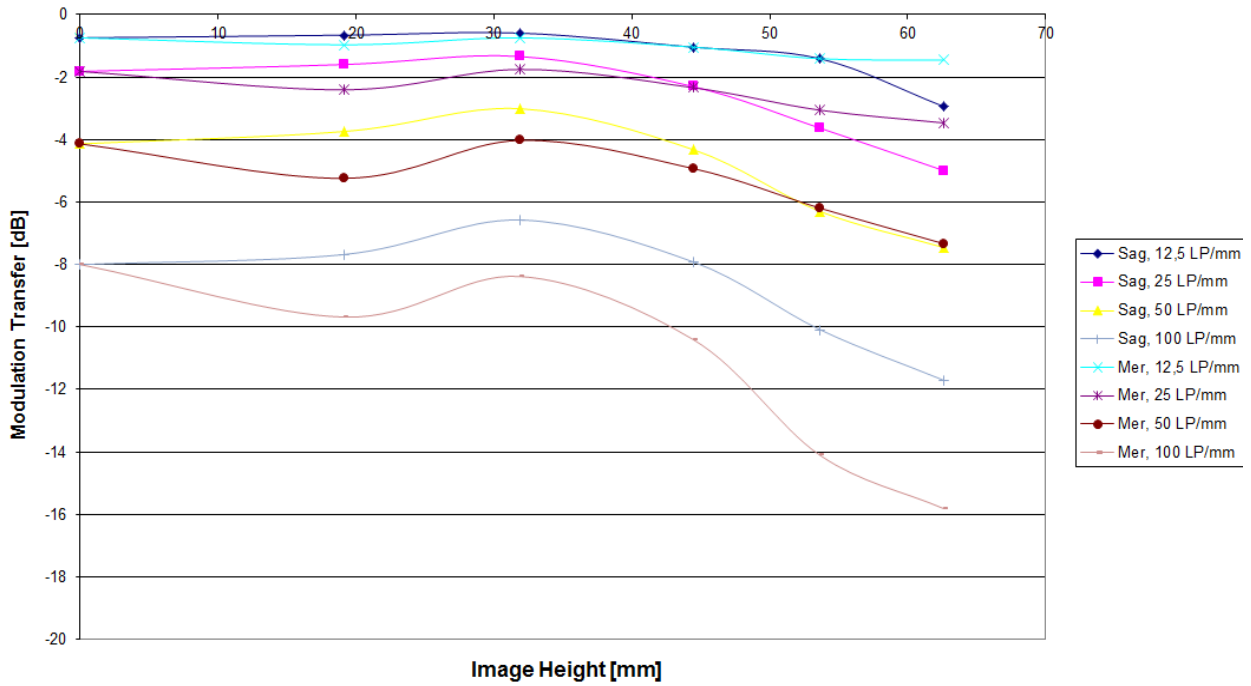
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

### Lens types

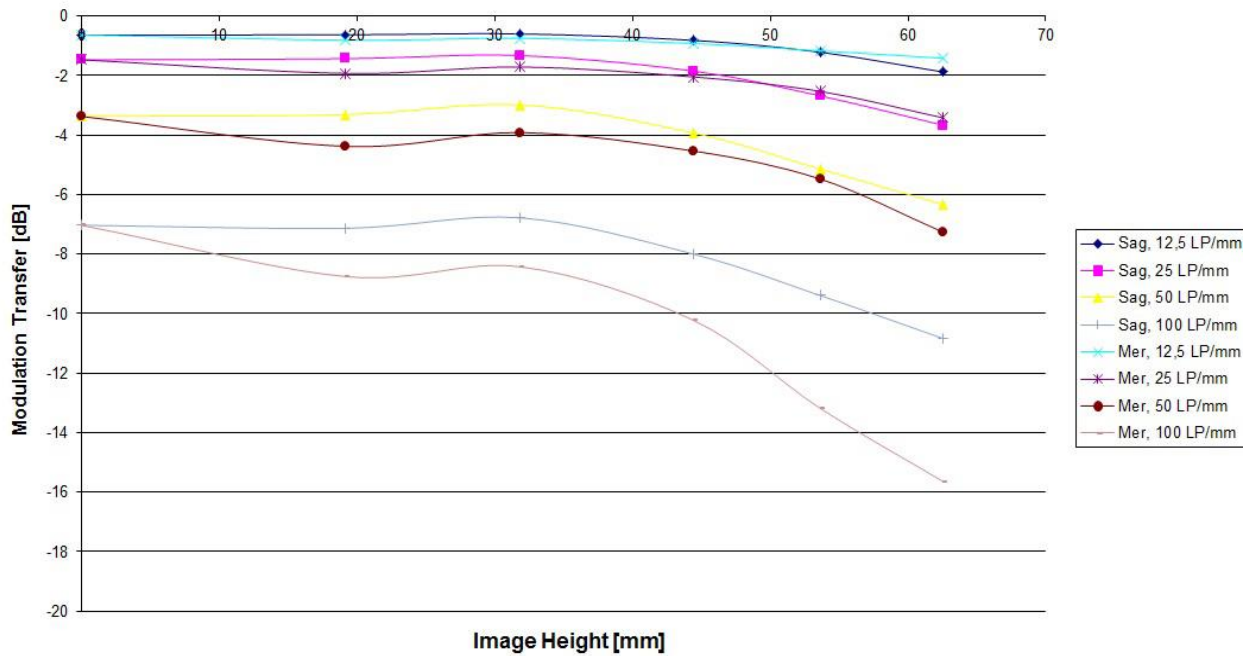
Cone	Lens
C0	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C1	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C2	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C3	Linos Vexcel Apo-Sironar Digital HR 1:5,6/100mm, Linos GmbH, Germany
C4 (RED)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C5 (GREEN)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C6 (BLUE)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany
C7 (NIR)	Linos Vexcel Apo-Sironar Digital HR 1:4/33mm, Linos GmbH, Germany



Modulation versus Image Height - Aperture f/ 5.6

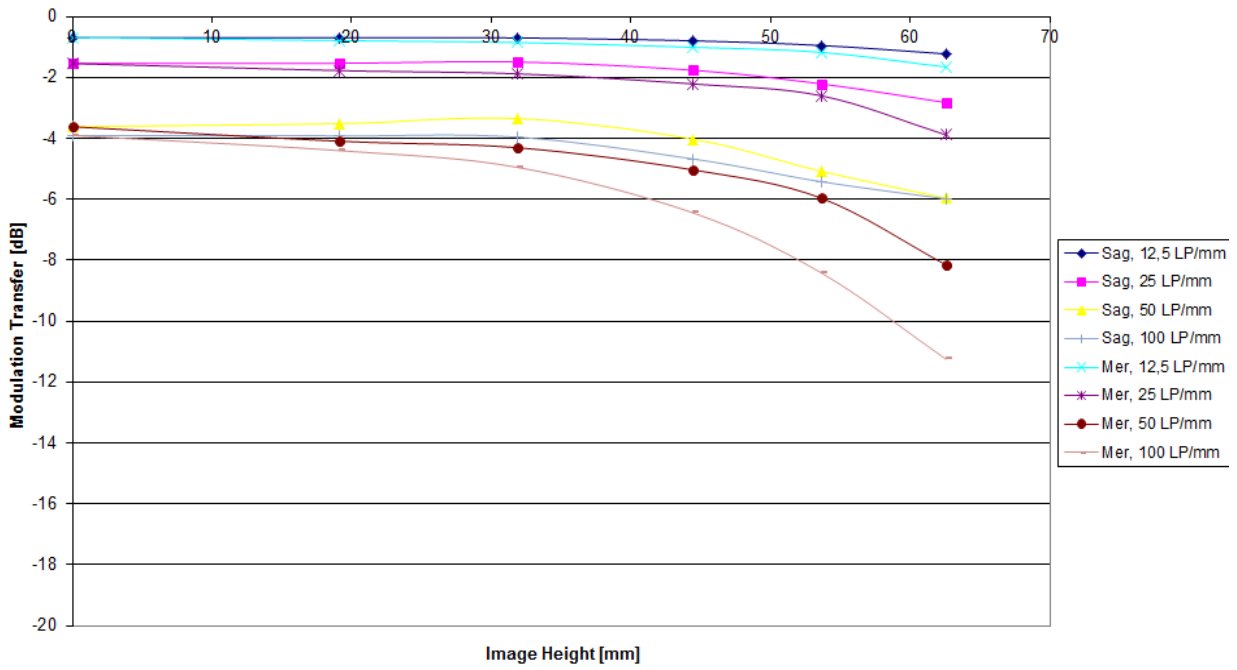


Modulation versus Image Height - Aperture f/ 6.7

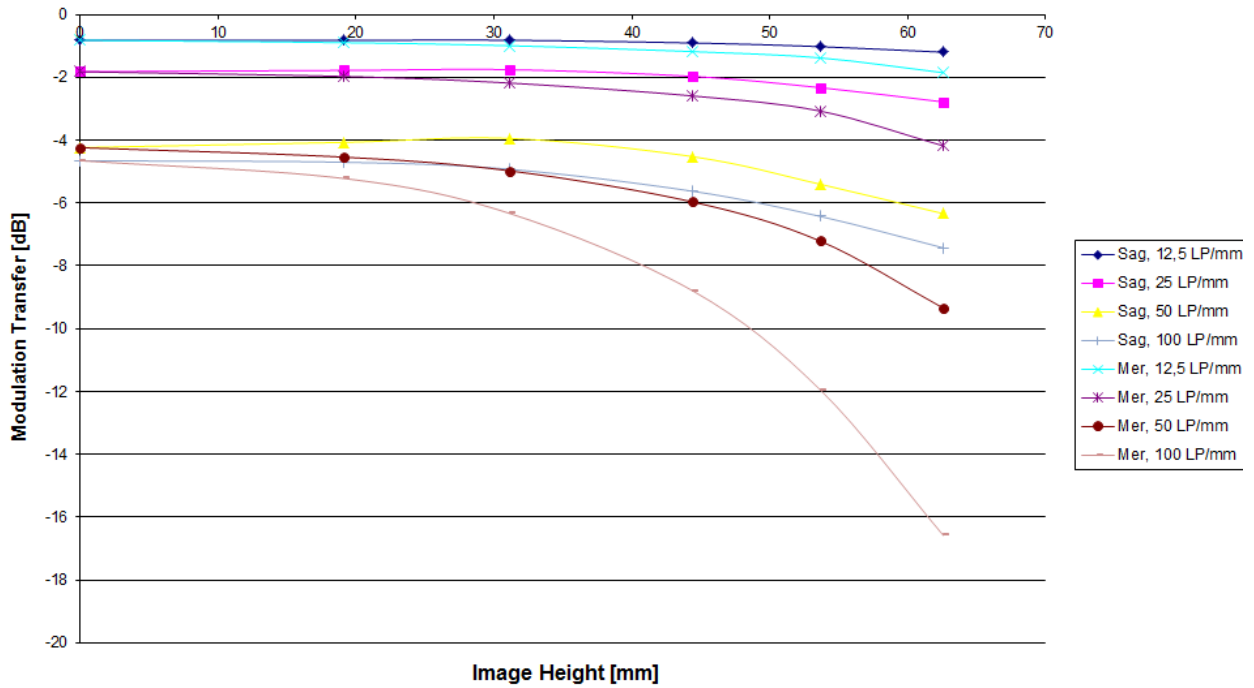




Modulation versus Image Height - Aperture f / 8



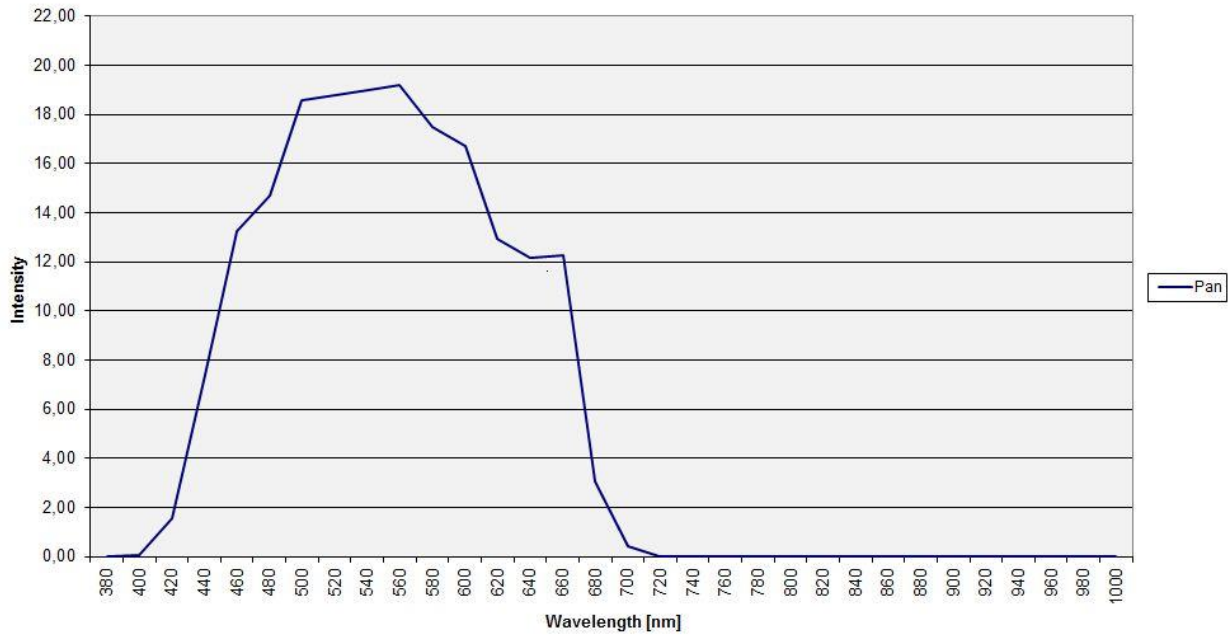
Modulation versus Image Height - Aperture f / 9.5



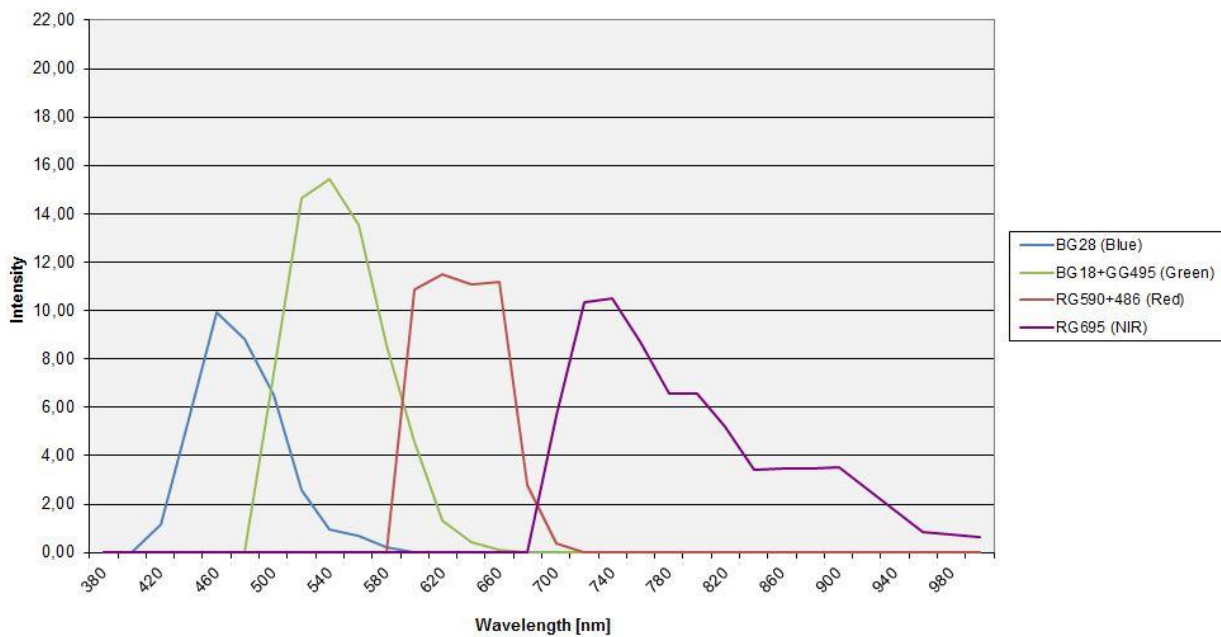


# Spectral Sensitivity

Spectral Sensitivity Vexcel UCX - Panchromatic with AR-106 Coating



Spektral Sensitivity Vexcel UCX - Multispectral with AR-106 Coating





# ULTRACAM

## Radiometric Calibration

Camera: UltraCam Falcon Prime  
Serial: UC-Fp-1-50616147-f100

	PAN	R, G, NIR	B
Used Apertures	F5.6	F4.8	F4.8
	F6.7	F5.6	F4.8
	F8	F6.7	F4.8
	F9.5	F8	F5.6
	F11	F9.5	F6.7
	F13	F11	F8
	F16	F13	F9.5
	F22	F19	F13

Dead Pixel Report: see Appendix I



### Calibration of Vignetting for working Aperture F6.7

	PAN	R, G, NIR	B
Aperture	F6.7	F5.6	F4.8

#### Graphical Overview of Pan Sensors:


#### Graphical Overview of Multispectral Sensors:






## Explanations

### Calibration Method:

The radiometric calibration is based on a series of 50 flat field images for each aperture size and sensor. The flat field is illuminated by eight normal light lamps with known spectral illumination curves.

These images are used to calculate the specific sensitivity of each pixel to compensate local as well as global variations in sensitivity. Sensitivity tables are calculated for each sensor and aperture setting, and applied during post processing from level 0 to level 1.

Outlier Pixels that do not have a linear behavior as described in the CCD specifications are marked as defective during the calibration procedure. These pixels are not used or only partially used during post processing and the information is restored by interpolation between the neighborhood pixels surrounding the defective pixels.

Certain pixels that are named Qmax pixels due to the fact that they can only store and transfer charge up to a certain maximum amount are detected in an additional calibration step. These pixels are treated differently during post processing, since their behavior can affect not only single pixel values but whole columns.



# **ULTRACAM**

## Shutter Calibration

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**Camera:** UltraCam Falcon Prime  
**Serial:** UC-Fp-1-50616147-f100

**Panchromatic Camera:** 4 \* Prontor Magnetic 0 HS  
Prontor-Werk Alfred Gauthier GmbH, Germany

**Multispectral Camera:** 4 \* Prontor Magnetic 0 HS  
Prontor-Werk Alfred Gauthier GmbH, Germany



### Calibration of Shutter Release Times:

The shutter release times measured during the calibration describe the time from the moment when the electrical current through the shutter is turned off by the electronics, until the shutter is mechanically closed.

This time is relevant for the exposure control and needs to be known before image recording can take place.

Currently used SRT values (operation values):

Cone Number	Lens Serial Number	SRT F5.6 [ms]	SRT F6.7 [ms]	SRT F8 [ms]	SRT F9.5 [ms]	SRT F11 [ms]	SRT F13 [ms]	SRT F16 [ms]	SRT F22 [ms]	Measurement Tolerance [ms]
C0 (Pan)	12 27 19 05	7.49	7.55	7.67	7.9	8.17	8.29	8.45	8.61	+/- 0.2
C1 (Pan)	12 27 19 06	6.65	6.69	6.88	7.14	7.34	7.53	7.67	7.68	+/- 0.2
C2 (Pan)	12 23 55 11	7	7.03	7.23	7.37	7.61	7.83	8.04	8.08	+/- 0.2
C3 (Pan)	12 23 55 07	6.76	6.83	6.97	7.22	7.32	7.54	7.63	7.76	+/- 0.2
C4 (Red)	12 23 11 66	5.92	6.06	6.24	6.42	6.51	6.63	6.69	6.77	+/- 0.2
C5 (Green)	12 24 50 24	7.35	7.5	7.72	8.1	8.18	8.25	8.35	8.35	+/- 0.2
C6 (Blue)	12 24 50 23	7.36	7.36	7.35	7.46	7.61	7.75	7.87	8.01	+/- 0.2
C7 (NIR)	12 23 11 83	8.39	8.47	8.71	8.71	8.9	8.95	9.33	9.33	+/- 0.2



# **ULTRACAM**

## Electronics and Sensor Calibration

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**Camera:** UltraCam Falcon Prime  
**Serial:** UC-Fp-1-50616147-f100

**Panchromatic Camera:** 9 \* FTF6040-M Area CCD Sensor by DALSA  
**Multispectral Camera:** 4 \* FTF6040-M Area CCD Sensor by DALSA



## Calibration of Negative Substrate Voltage (VNS):

For optimum performance of the DALSA CCD sensors, the negative substrate voltage is adjusted to a value specified by DALSA.

This voltage value is measured to achieve the best anti-blooming performance possible for each particular sensor.

Currently used VNS and VOG values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	VNS Voltage [V]
00_00	FTF6040-M	15 7701/020	22.50
00_01	FTF6040-M	15 7701/015	22.50
00_02	FTF6040-M	15 7701/032	22.50
00_03	FTF6040-M	15 5293/112	22.50
01_00	FTF6040-M	15 7701/026	22.50
01_01	FTF6040-M	16 5293/068	22.50
02_00	FTF6040-M	15 7701/019	22.60
02_01	FTF6040-M	15 5293/087	22.00
03_00	FTF6040-M	15 7701/022	22.50
04_00 (red)	FTF6040-M	15 7701/024	22.30
05_00 (green)	FTF6040-M	15 5293/110	22.30
06_00 (blue)	FTF6040-M	15 7701/021	22.50
07_00 (NIR)	FTF6040-M	15 7701/048	22.30



## Calibration of Intensity Threshold for Exposure Control:

Each CCD sensor and electronics module varies slightly in global sensitivity and intensity scale.

Therefore the maximum possible intensity of each sensor needs to be measured to evaluate the sensitivity behavior of the CCD and electronics.

This value is used as a threshold for the exposure control dialogue shown in the in-flight user interface of the Eagle.

Currently used Threshold values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]
00_00	FTF6040-M	15 7701/020	13650
00_01	FTF6040-M	15 7701/015	13790
00_02	FTF6040-M	15 7701/032	13830
00_03	FTF6040-M	15 5293/112	13570
01_00	FTF6040-M	15 7701/026	13800
01_01	FTF6040-M	16 5293/068	12720
02_00	FTF6040-M	15 7701/019	13450
02_01	FTF6040-M	15 5293/087	12850
03_00	FTF6040-M	15 7701/022	13760
04_00 (red)	FTF6040-M	15 7701/024	13330
05_00 (green)	FTF6040-M	15 5293/110	12930
06_00 (blue)	FTF6040-M	15 7701/021	14170
07_00 (NIR)	FTF6040-M	15 7701/048	13170



# ULTRACAM

## Summary

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<b>Camera:</b>	<b>UltraCam Falcon Prime</b>
<b>Serial:</b>	<b>UC-Fp-1-50616147-f100</b>
<b>Laboratory Calibration Date:</b>	<b>Apr-19-2024</b>
<b>Camera Revision:</b>	<b>Rev04.00</b>
<b>Date of Report:</b>	<b>Apr-25-2024</b>
<b>Version of Report:</b>	<b>V01</b>

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Radiometric Calibration
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber  
Chief Scientist, Photogrammetry  
Vexcel Imaging GmbH

Dipl. Ing. (FH) Helmut Jauk  
Senior Project Engineer R&D  
Vexcel Imaging GmbH





# Appendix I

## Dead Pixel Report:

Sensor number	Anomaly type	X-Coordinate	Y-Coordinate
C00-00	PIXEL: 876/ 157	PIXEL: 2141/3156	PIXEL: 2226/2723
	PIXEL: 4782/ 305	PIXEL: 4994/3003	PIXEL: 5031/3148
	PIXEL: 4284/2314	PIXEL: 4284/2315	PIXEL: 4285/2314
			PIXEL: 1591/1463
			PIXEL: 4285/2315
C00-01	PIXEL: 1225/1171	PIXEL: 4599/ 194	
	PIXEL: 4767/2638	PIXEL: 329/3832	PIXEL: 4740/3299
C00-02	PIXEL: 536/2665	PIXEL: 1831/ 347	PIXEL: 2023/ 918
C00-03	PIXEL: 1481/1299	PIXEL: 1573/ 693	
	PIXEL: 2220/1157	PIXEL: 2590/2777	PIXEL: 3897/2455
	PIXEL: 4583/3933	PIXEL: 5110/3668	PIXEL: 5442/3371
	PIXEL: 4728/1453	PIXEL: 4943/1444	PIXEL: 5104/1430
	PIXEL: 5108/1368	PIXEL: 5120/1370	PIXEL: 5129/1364
	PIXEL: 5142/1365	PIXEL: 5145/1365	PIXEL: 5155/1363
	PIXEL: 5165/1366	PIXEL: 5193/1369	PIXEL: 5193/1378
	PIXEL: 5275/1391	PIXEL: 5309/1399	PIXEL: 5378/1401
	PIXEL: 5413/1402	PIXEL: 5436/1381	PIXEL: 5482/1380
C01-00	PIXEL: 465/1062	PIXEL: 1039/ 571	
C01-01	PIXEL: 274/1597	PIXEL: 1375/ 468	
	PIXEL: 2054/3729	PIXEL: 3974/3534	
			C02-00
C02-01	PIXEL: 1057/2557	PIXEL: 3629/2184	
	PIXEL: 3898/2091	PIXEL: 4054/3350	PIXEL: 4521/3138
	PIXEL: 4859/1920	PIXEL: 5555/2250	PIXEL: 4521/3139



C03-00

C04-00

PIXEL: 2093/1984

PIXEL: 4874/1687

PIXEL: 3222/3816

PIXEL: 250/3937

PIXEL: 1674/1192

PIXEL: 2979/ 904

C05-00

PIXEL: 3466/ 973

PIXEL: 5244/1842

PIXEL: 3789/3972

PIXEL: 188/2186

PIXEL: 833/3640

C06-00

PIXEL: 119/ 863

PIXEL: 120/ 866

PIXEL: 119/ 864

PIXEL: 1433/ 911

PIXEL: 119/ 865

PIXEL: 2542/3173

PIXEL: 2543/3173

C07-00

PIXEL: 1509/2840

PIXEL: 2839/ 48

PIXEL: 1934/1643

PIXEL: 5970/3828



**Notes**

COLUMN anomaly: all pixels below the Qmax detector at location (X,Y) may be affected.

PIXEL anomaly: single detector at location (X,Y) is not functioning within normal range

The Level0 coordinates exclude the two leftmost pixels containing the line index: the corresponding pixel can therefore be located at column (X+2,Y).

**Appendix II**

**Calibration and Modification Dates**

Type of Calibration	Laboratory Calibration Date	Modification Date	Modification Reason
Geometric Calibration	19.Apr.2024		
Radiometric Calibration	19.Apr.2024		
Shutter Calibration	19.Apr.2024		
Electronics and Sensor Calibration	19.Apr.2024		



**Note:** The above-mentioned Laboratory Calibration Dates represent the dates the camera was calibrated in one of our calibration labs for a full Laboratory Calibration. The Modification date represents a date on which the calibration has been modified due to a calibration enhancement or part exchange. It is an additional information and does not replace the Laboratory Calibration date in any way. With the Modification Reason, always the last modification to the calibration is highlighted.