CYGNO

A quick comparison of specs between CMOS cameras:
Orca Fusion *vs* **Orca Quest**
CoaxPress *vs* **USB**

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March 2024

Orca Fusion *vs* Orca Quest

		Fusion	Quest
Product Number		C14440-20UP	C15550-20UP
Imaging Device		Gen III sCMOS image sensor	qCMOS image sensor
Effective nº of pixels		2304 x 2304 (5.3 Mpixels)	4096(H) x 2304(V) (9.4 Mpixels)
Pixel size	µm	6.5 x 6.5	4.6 x 4.6
Effective Area	mm	14.9 x 14.9	18.8(H) x 10.5(V)
Quantum Efficiency (typ)	%	80 (peak)	85 (peak)
Readout speed *	frames/s	89 (Coaxpress), 31 (USB)	120 (Coaxpress), 17.6 (USB)
Readout noise **	e (RMS)	0.70	0.27
Exposure Time		17us to 10s (Fast scan)	7.2us to 1800s (Std scan)

* Best numbers, depend on the operation (scan) mode.
** Ultra quiet scan mode.

Orca Fusion

ORCA®-Fusion

Camera
ORCA®-Fusion
Digital CMOS camera

Product Number
C14440-20UP

Pixel Size
6.5 μm (H) × 6.5 μm (V)

Effective number of pixels
2304 (H) × 2304 (V)

Effective Area
14.976 mm (H) × 14.976 mm (V)

[1] Typical value

[2] In Ultra quiet scan

[3] Calculated from the ratio of the full well capacity and the readout noise

[4] The water temperature is +20 °C and the ambient temperature is +20 °C

[5] Dark current depends on cooling temperature

[6] Valid to 4 digits and rounded up to 5th digit

[7] USB 3.1 Gen 1 compatible

[8] The value with AC 240 V. (Approx. 70 VA with AC 100 V)

Readout noise [1]	
Fast scan	1.4 electrons, rms
Standard scan	1.0 electrons, rms
Ultra quiet scan	0.7 electrons, rms
Quantum efficiency [1]	
@ 400 nm	65 %
@ 550 nm	80 %
@ 700 nm	70 %
@ 800 nm	50 %
Full well capacity [1]	15 000 electrons
Dynamic range [1]	21 400:1 [3]
Conversion factor [1]	0.24 electrons / count
Cooling Temperature	
Forced-air cooled	-5 °C (Ambient temperature: +25 °C)
Water cooled	-5 °C (Water temperature: +25 °C)
Water cooled (Max cooling)	Less than -15 °C [1], [4]
Dark current [1], [5]	
Cooling temperature: -5 °C	0.5 electrons/pixel/s
Cooling temperature: -15 °C	0.2 electrons/pixel/s
Dark offset	100 counts
Dark signal non-uniformity (DSNU) [1], [2]	0.06 electrons
Photo response non-uniformity (PRNU) [1]	
At 7500 electrons	0.06 %
Linearity error [1] (EMVA 1288 standard)	0.5 %
Readout modes	Full resolution, Digital binning (2x2, 4x4), Sub-array, Lightsheet
Readout times at full resolution [6]	
Fast scan	11.22 ms (89.1 frames/s with CoaXPress or 31.6 frames/s with USB 3.0)
Standard scan	42.99 ms (23.2 frames/s with CoaXPress or USB 3.0)
Ultra quiet scan	184.4 ms (5.4 frames/s with CoaXPress or USB 3.0)
Lightsheet Readout Mode (Fast scan)	
Row interval time	4.868 μs to 963.8 μs [6]
Readout time at full resolution	11.22 ms to 2.221 s [6]
Readout modes	Full resolution, Sub-array
Readout directions	Top to bottom readout / Bottom to top readout
Exposure times	
Fast scan	17 μs to 10 s (4.87 μs step)
Standard scan	65 μs to 10 s (18.65 μs step)
Ultra quiet scan	280 μs to 10 s (80.00 μs step)

|	
Trigger modes	Edge, Level, Sync readout, Start, Global reset edge, Global reset level
Trigger delay function	0 s to 10 s in 1 μs steps
Trigger output	3 programmable timing, Global exposure timing, trigger ready, low, high
Trigger input connector	SMA
Trigger output connectors	SMA
Master pulse mode	Free running / start trigger / burst
Digital output	16 bit / 12 bit / 8 bit
Interface	CoaXPress (Dual CXP-6) and USB 3.0 [7]
Lens mount	C-mount
Power consumption	Approx. 150 VA [8]
Ambient operating temperature	0 °C to + 40 °C
Ambient operating humidity	30 % to 80 %, with no condensation

Orca Quest

Product number		C15550-20UP
Imaging device		qCMOS® image sensor
Effective number of pixels		4096 (H) × 2304 (V)
Pixel size		4.6 µm (H) × 4.6 µm (V)
Effective area		18.841 mm (H) × 10.598 mm (V)
Quantum efficiency (typ.)		85 % (peak QE)
Full well capacity (typ.)		7000 electrons
Readout noise (typ.)	Standard scan	0.43 electrons rms
	Ultra quiet scan	0.27 electrons rms
Dynamic range (typ.) *1		26 000: 1 (rms)
Dark signal non-uniformity (DSNU) (typ.) *2		0.06 electrons
Photoresponse non-uniformity (PRNU) (typ.) *2*3		0.1 %
Linearity error	EMVA 1288 standard (typ.)	0.5 %

Cooling	Sensor temperature	Dark current (typ.)
Forced-air cooled (Ambient temperature: +25 °C)	−20 °C	0.016 electrons/pixels/s
Water cooled (Water temperature: +25 °C) *4	−20 °C	0.016 electrons/pixels/s
Water cooled [max cooling (Water temperature: +20 °C, Ambient temperature: +20 °C)] *4	−35 °C (typ.)	0.006 electrons/pixels/s

| At Normal area readout and Photon number resolving (PNR)		
Readout mode		Full resolution, Digital binning (2×2, 4×4), Sub-array
Frame rate at full resolution	Standard scan *5	120 frames/s (CoaXPress), 17.6 frames/s (USB)
	Ultra quiet scan	5 frames/s (CoaXPress, USB)
Exposure time	Standard scan *5	7.2 µs to 1800 s
	Ultra quiet scan	199.9 ms*6 to 1800 s (internal, edge, level, start) 200.2 ms*6 to 1800 s (sync readout) 172.8 µs to 1800 s (global reset edge, global reset level)
Trigger input	External trigger input mode	Edge / Global reset edge / Level / Global reset level / Sync readout / Start
	Software trigger	Edge / Global reset edge / Start
	Trigger delay function	0 s to 10 s in 1 µs steps
At Lightsheet readout (Patented) *7*8		
Readout mode		Full resolution, Sub-array
Readout direction		Forward readout / Backward readout / Bidirectional readout / Reverse bidirectional readout
Row interval time		7.2 µs to 237.6 µs
Exposure time		7.2 µs to 273.7 ms
Trigger input	External trigger input mode	Edge / Start
	Software trigger	Edge / Start
	Trigger delay function	0 s to 10 s in 1 µs steps

Trigger output		Global exposure timing output / Any-row exposure timing output / Trigger ready output / 3 programmable timing outputs / High output / Low output
Master pulse	Pulse mode	Free running / Start trigger / Burst
	Pulse interval	5 µs to 10 s in 1 µs step
	Burst count	1 to 65 535
Digital output		16 bit / 12 bit / 8 bit
Image processing function		Defect pixel correction (ON or OFF, hot pixel correction 3 steps)
Emulation mode		Available (ORCA®-Fusion)
Interface		USB 3.1 Gen 1, CoaXPress (Quad CXP-6)
Trigger input connector		SMA
Trigger output connector		SMA
Lens mount		C-mount *9
Power supply		AC100 V to AC240 V, 50 Hz/60 Hz
Power consumption		Approx. 155 VA
Ambient operating temperature		0 °C to +40 °C
Ambient operating humidity		30 % to 80 % (With no condensation)
Ambient storage temperature		−10 °C to +50 °C
Ambient storage humidity		90 % Max. (With no condensation)

Orca Fusion *vs* **Orca Quest**: Dark Read Noise
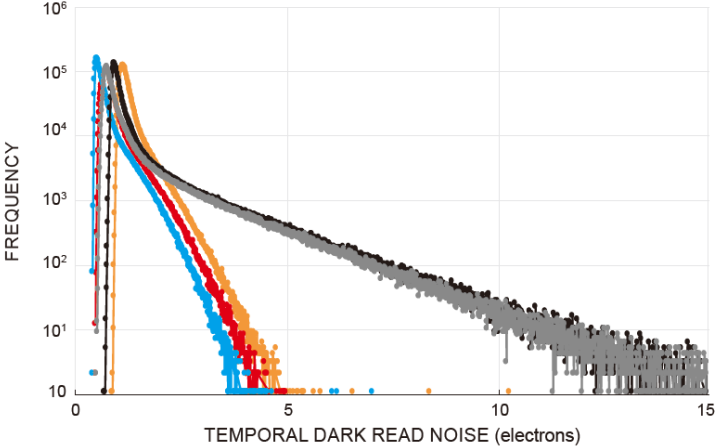
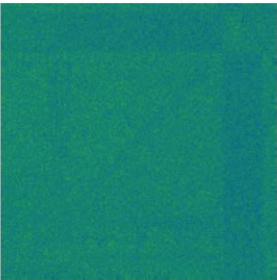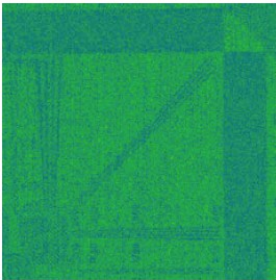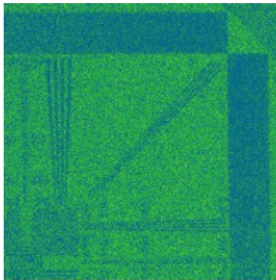|	RMS	Median	Mean
ORCA®-Fusion Ultra quiet Scan	0.73 e-	0.57 e-	0.67 e-
ORCA®-Fusion Standard Scan	0.91 e-	0.77 e-	0.85 e-
ORCA®-Fusion Fast Scan	1.28 e-	1.16 e-	1.25 e-
ORCA®-Flash4.0 V3 Standard Scan	1.63 e-	0.99 e-	1.30 e-
ORCA®-Flash4.0 V3 Slow Scan	1.22 e-	0.82 e-	1.13 e-

* e- refers to the electrons.

FREQUENCY

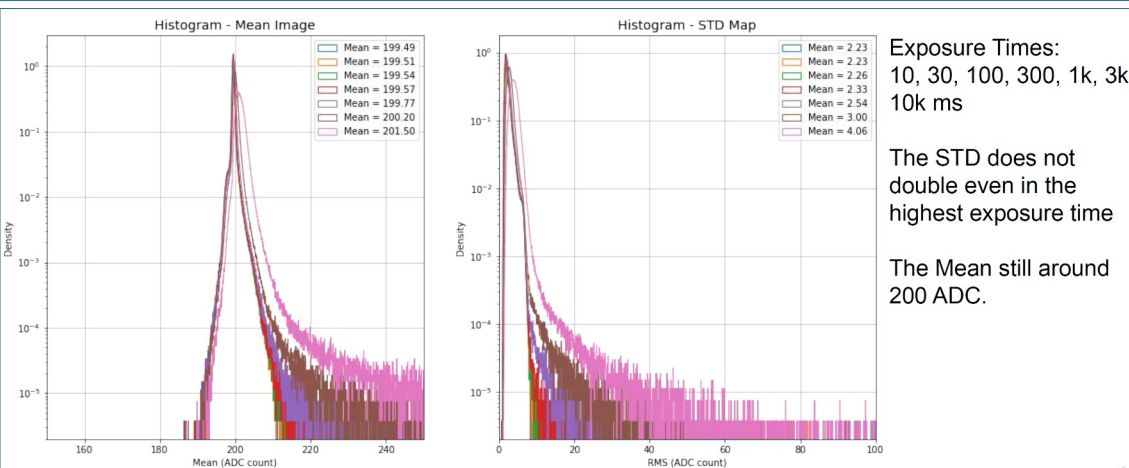TEMPORAL DARK READ NOISE (electrons)
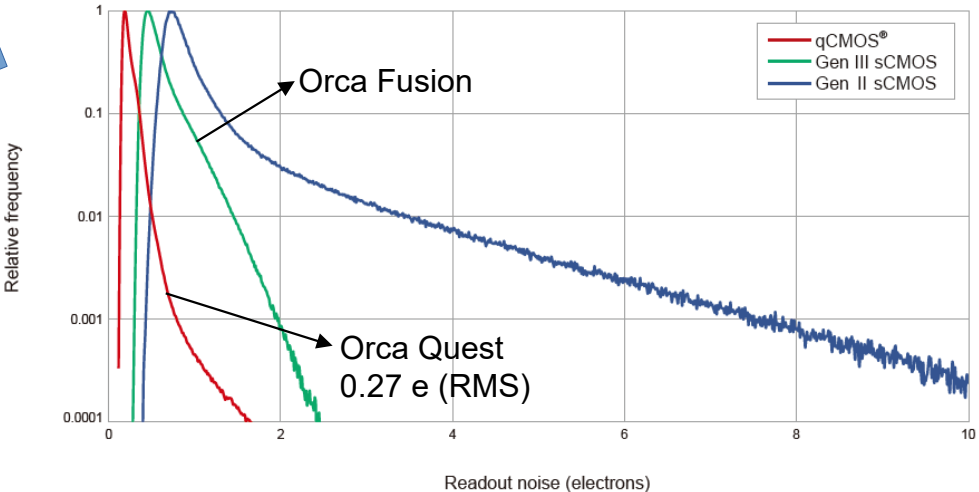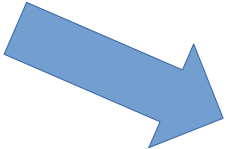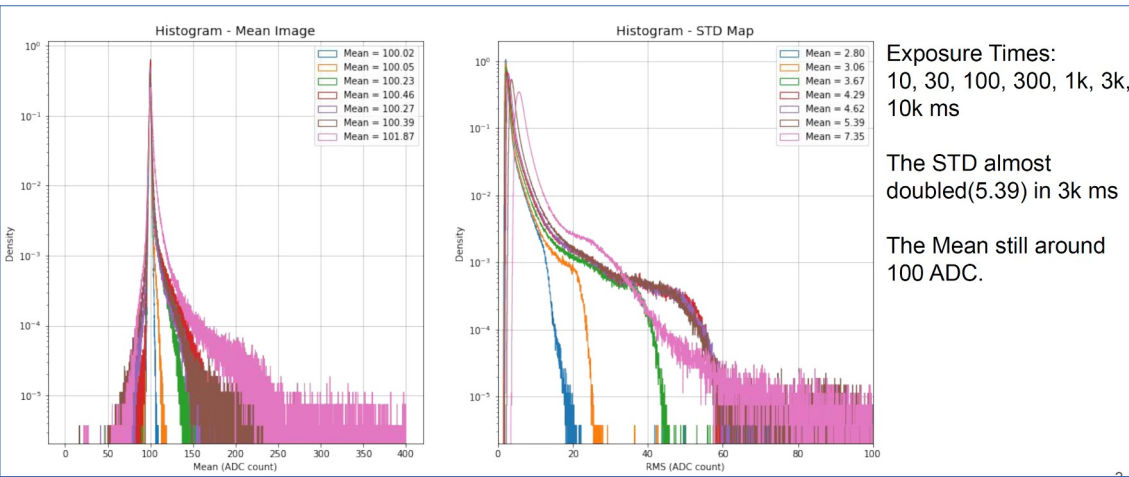
qCMOS® (ORCA®-Quest)   Gen III sCMOS   Gen II sCMOS

Comparison of average 1 photon per pixel image (pseudo-color)
Exposure time: 200 ms   LUT: minimum to maximum value   Comparison area: 512 pixels × 512 pixels

Relative frequency

Readout noise (electrons)

qCMOS®
Gen III sCMOS
Gen II sCMOS

Orca Fusion

Orca Quest
0.27 e (RMS)

Orca Fusion *vs* **Orca Quest**: Pedestal*

Exposure Times: 10, 30, 100, 300, 1k, 3k, 10k ms

The STD almost doubled(5.39) in 3k ms

The Mean still around 100 ADC.

Exposure Times: 10, 30, 100, 300, 1k, 3k, 10k ms

The STD does not double even in the highest exposure time

The Mean still around 200 ADC.

- **Orca Fusion BT** had good performance in pedestal images, but its STD doubled at 3k ms and reached 3x the initial value for the maximum exposure time. It also had border effect and the Energy Resolution is 12.9%.

- **Orca Quest** had best performance in pedestal images. It has no border effect and the STD did not increase too much even increasing the exposure time. The Energy resolution is 10.11%.

 * Results presented by B. D. Almeida (UFJF/Brazil) in a CYGNO meeting, March/2022.

Orca Fusion *vs* Orca Quest: QE
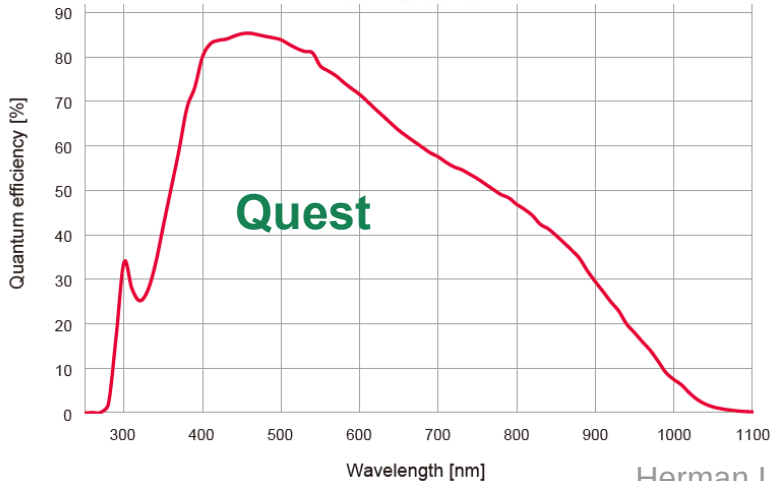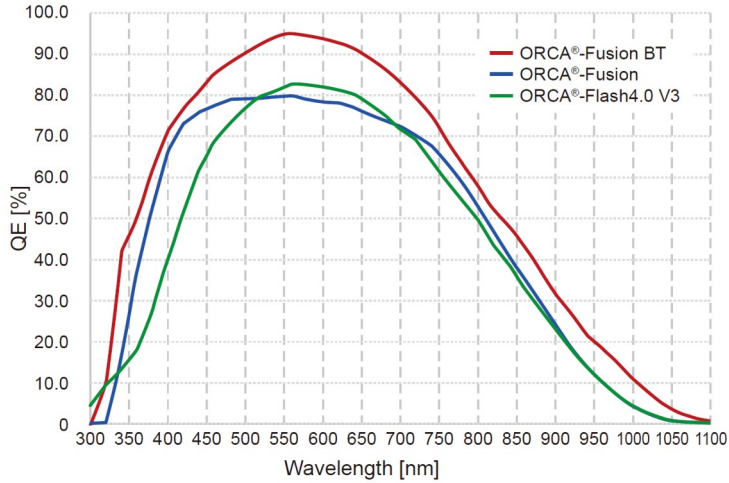
λ (nm)	Fusion	Quest
300 - 320	0	Q > 25%
320 - 400	30% < Q < 70%	30% < Q < 80%
400 - 500	70% < Q < 80%	**Q ~ 85%**
500 - 600	**Q ~ 80%**	70% < Q < 85%
600 - 1000	5% < Q < 80%	5% < Q < 70%

Fusion QE is more uniform between 400nm and 700nm (>70%)

Quest QE is higher between 400nm and 550nm (reaching 85%)

CoaxPress *vs* USB: cameras

		Orca Fusion	Orca Quest
Product Number		C14440-20UP	C15550-20UP
Readout Interface [1]		Coaxpress (**Dual** CXP-6), USB 3.0	Coaxpress (**Quad** CXP-6), USB 3.1
Readout Speed (**Coaxpress**)	frames/s	23.2 (Standard scan) 5.4 (Ultra quiet scan) **89.1 (Fast scan)**	**120 (Standard scan)** 5 (Ultra quiet scan)
Readout Speed (**USB**)	frames/s	23.2 (Standard scan) 5.4 (Ultra quiet scan) **31.6 (Fast scan)**	**17.6 (Standard scan)** 5 (Ultra quiet scan)

1) For both cameras Hamamatsu suggests the Frame Grabber from *Active Silicon*, but with different numbers of CoaxPress inputs for each camera.

2) **Fusion:** Coaxpress solution only reaches higher readout speed (2.8x) in the <u>Fast scan</u> mode.

3) **Quest:** Coaxpress solution achieves **6x higher** readout speed than USB in the <u>Standard scan</u> mode.

CoaxPress *vs* USB: Frame Grabber

FireBird Dual CXP-6

FIREBIRD COAXPRESS

Orca Fusion →
Orca Quest →

Dual CXP-6 Frame Grabber
Quad

- CoaXPress Frame Grabber
- CoaXPress links, each at 6.25 Gbps
- RISC based ActiveDMA engine technology
- 8-lane Gen2 PCI Express interface

Active Silicon
COMPUTER IMAGING PRODUCTS

CoaXPress   USB 3.0

USB 3.1 Gen 1   CoaXPress

FEATURES

- CoaXPress gives high speed data, power, and camera control all over a single cable.
- High performance with 12.5 Gigabits per second input rate.
- Fast PCI Express 8-lane Gen2 interface.
- ActiveDMA engine – acquisition with zero CPU usage.
- Comprehensive I/O.
- Supports PoCXP (Power over CoaXPress).
- Standard half-length PCI form-factor.
- Full GenICam support (including GenTL Producer).
- Supported by the proven ActiveSDK.
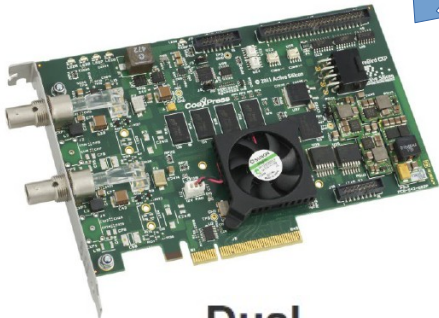
Dual
AS-FBD-2XCXP6-2PE8

Quad
AS-FBD-4XCXP6-2PE8

CoaxPress *vs* USB: Speed x ROI size

Orca Fusion

Maximum frame rates (frames/s)					
ROI	Scan mode	CoaXPress	USB 3.0		
		16 bit	8 bit	12 bit	16 bit
2304 × 2304	Fast	89.1	63.3	42.2	31.6
	Standard	23.2	23.2		
	Ultra-quiet	5.4	5.4		
2048 × 2048	Fast	100	80.1	53.4	40.0
	Standard	26.1	26.1		
	Ultra-quiet	6.1	6.1		
256 × 256	Fast	799	799		
	Standard	208	208		
	Ultra-quiet	48.6	48.6		

Table 5. Maximum frame rates of ORCA®-Fusion / ORCA®-Fusion BT through CoaXPress and USB 3.0.

Orca Quest

Table 3-1.   Maximum frame rates with sub-array (fps)

ROI	Scan modes	CoaXPress	USB		
		16 bit	8 bit	12 bit	16 bit
4096 × 2304	Standard	120	35.3	23.5	17.6
	Ultra quiet	5.0	5.0	5.0	5.0

Table 4-1.   Maximum frame rates of CoaXPress and USB at standard scan mode (fps)

Number of pixels in vertical direction	CoaXPress	USB			
	Number of pixels in horizontal direction				
	4096	512	1024	2048	4096
2304	120	120	70.7	35.3	17.6
2048	134	134	79.5	39.8	19.9
1024	268	268	158	79.3	39.9
512	532	532	315	157	78.9
256	1044	1044	622	312	156
128	2012	2012	1218	609	304
4	19 841	19 841	19 841	8169	4084

CoaxPress *vs* **USB**: Speed x ROI size

3-1-3. CoaXPress interface

When connecting with the CoaXPress interface, images of 9.4 megapixel and 16 bit each can be transferred to a computer in 120 frames/s (full frame). The interface speed is even higher than the sensor readout speed and it means there is no compromise in speed with the CoaXPress interface.

3-1-4. USB 3.1 Gen 1 interface

The USB 3.1 Gen 1 interface is a general-purpose interface with a maximum speed of 500 MB/sec. It comes as standard with many computers and is equipped in many notebook computers. The maximum frame rate in USB is 17.7 frame/s with full frame. However, the ORCA®-Quest offers user-controllable Look Up Tables (LUT) for 8 bit or 12 bit data in order to record only the necessary range of digital output. With this capability, users can not only reduce image data volume but also improve the camera frame rates by eliminating the need to record unnecessary image data.

Orca Quest

Table 3-1.   Maximum frame rates with sub-array (fps)

ROI	Scan modes	CoaXPress	USB		
		16 bit	8 bit	12 bit	16 bit
4096 × 2304	Standard	120	35.3	23.5	17.6
	Ultra quiet	5.0	5.0	5.0	5.0

reading 8 bits doubles the speed in USB to 35 fps

CoaxPress *vs* **USB**: Speed x ROI size

4-4-1. Sub-array readout or Region of Interest (ROI)

Sub-array readout is a method of reading the sensor in which the output images are comprised of only the pixels in the user selectable region of interest (ROI). Since less data is being readout and transferred, this method can offer increased maximum frame rates with no increase in readout noise. Since CoaXPress speed is higher than the fastest sensor speed, the fastest frame rates are limited by sensor speeds that depend on both sub-array sizes and scan speeds. On the contrary, since USB speed is slower than the fastest sensor speed, frame rate with USB are limited by the interface speed and can be improved with sub-array sizes and scan speeds. Table 4-1 shows maximum frame rates of CoaXPress and USB at standard scan speed. When the horizontal pixel number is less than 512 pixels at USB, maximum frame rates are the same with those of CoaXPress. It indicates maximum frame rates are limited by the sensor speed when the horizontal pixel number of less than 512.

Orca Quest

Table 4-1. Maximum frame rates of CoaXPress and USB at standard scan mode (fps)

Number of pixels in vertical direction	CoaXPress	USB			
	Number of pixels in horizontal direction				
	4096	512	1024	2048	4096
2304	120	120	70.7	35.3	17.6
2048	134	134	79.5	39.8	19.9
1024	268	268	158	79.3	39.9
512	532	532	315	157	78.9
256	1044	1044	622	312	156
128	2012	2012	1218	609	304
4	19 841	19 841	19 841	8169	4084

for ROIs with 512 horizontal pixels the speed in USB equals CoaXPress

CoaxPress *vs* USB: single camera*

CoaxPress

Items	Recommended	
Camera	C15550-20UP (ORCA-Quest) C14120-20P (ORCA-Lightning)	C15440-20UP (ORCA-Fusion BT) C14440-20UP (ORCA-Fusion)
Model	Dell Precision™ 5820 Tower Workstation	
CPU	Intel Xeon W-2223	
OS	Windows 10 Professional 64-bit (Driver for 32-bit OS is not prepared)	
RAM	64 GB or more	32 GB or more
Frame Grabber	Active Silicon AS-FBD-4XCXP6-2PE8	Active Silicon AS-FBD-2XCXP6-2PE8
	installed in SLOT1_PCIe3x8 or SLOT4_PCIe3x16	
Drivers	DCAM-API v21.7 or later	

USB 3.1

Items	Recommended
Camera	C15550-20UP (ORCA-Quest) C15440-20UP (ORCA-Fusion BT) C14440-20UP (ORCA-Fusion)
Model	Dell Precision™ 5820 Tower Workstation
CPU	Intel Xeon W-2223
OS	Windows 10 Professional 64-bit
RAM	8 GB or more
Frame Grabber	Front-side USB 3.1 Gen1 interface connector
Drivers	DCAM-API v21.7 or later

- By using the frame bundle, it is possible to realize high-speed capture (Quest : 19,000 or more / Fusion : 41,000 or more) with a small area setting.

- Changing the following BIOS settings will help to achieve highest performance.
  - Disable (uncheck) SpeedStep and C-State under the Performance section.
  - Enable (check) Turbo Boost and Hyper-Threading under the Performance section.

* PC Recommendation for ORCA-Quest/Fusion/Fusion BT, Hamamatsu Photonics, July 2021 (20210714).

CoaxPress *vs* USB: single camera*

Recommended DIY PC configuration for Single Camera

HAMAMATSU
PHOTON IS OUR BUSINESS

Camera Interface	CoaXPress (Quad CXP-6)	CoaXPress (Dual CXP-6)	USB3.0 (USB 3.1 Gen1)	Note
CPU	Intel Xeon E5-1630 v4 or better			We recommend that you use at least a single 3.2Ghz Quad (or more) Core High End CPU with a CPU Mark equal or higher than the E5-1630 v4 from this benchmark table: High End CPU's - Intel vs AMD Frequency is more important than the number of CPU cores.
OS	Windows 10 Professional 64-bit			Regarding CoaXPress, 32-bit Edition is not prepared because of performance and memory size limitations
RAM	>= 64 GB	>= 32 GB	>= 8 GB for Fusion (>= 32 GB for Quest)	DDR4 2400MHz or higher-speed
Chipset	Intel C610 series or newer			e.g. C612, C236, C422, C624 If you are using Intel C620 series (e.g. C624) and CoaXPress board, Windows may BSoD when the drivers attempt to access the frame grabber. If this happens, contact your local Hamamatsu Support for assistance.
Free Slot	PCIe2(3) x8 wired		PCIe2(3)	PCIe Gen2 is mandatory but Gen3 should cover Gen2.
BIOS	Latest			PCIe slot performance sometimes is improved in the latest BIOS. We highly recommend to adjust the following BIOS settings: 1. Disable Processor C-state_control to force C0 state for all processors. 2. Enable Intel Turbo Boost. 3. Disable Intel SpeedStep if allowed with Turbo Boost Enabled. Enable Turbo Boost may mutually exclude disabling SpeedStep. 4. Enable Intel Hyper-Threading.

* PC Recommendation for ORCA-Quest/Fusion/Fusion BT, Hamamatsu Photonics, July 2021 (20210714).

Storage size *vs* Number of recorded images*

Orca Fusion

Free space	Number of Recorded Images[1]	Time in seconds[2] (Approx.)		
		Ultra Quiet (5.42 fps)[3]	Standard (23.2 fps)[3]	Fast (89.1 fps)[3]
8 GB	809	149 (~2 min)	34	9
16 GB	1,618	298 (~4 min)	69 (~1 min)	18
32 GB	3,236	597 (~9 min)	139 (~2 min)	36
64 GB	6,472	1,194 (~19 min)	278 (~4 min)	72 (~1 min)
128 GB	12,945	2,388 (~39 min)	557 (~9 min)	145 (~2 min)
256 GB	25,890	4,776 (~79 min)	1,115 (~18 min)	290 (~4 min)
512 GB	51,781	9,553 (~159 min)	2,231 (~37 min)	581 (~9 min)
1 TB	103,563	19,107 (~318 min)	4,463 (~74 min)	1,162 (~19 min)

Orca Quest

Free space	Number of Recorded Images[1]	Time in seconds[2] (Approx.)	
		Ultra Quiet (5.00 fps)[3]	Standard (120 fps)[3]
32 GB	1,820	364 (~6 min)	15
64 GB	3,640	728 (~12 min)	30
128 GB	7,281	1,456 (~24 min)	60 (~1 min)
256 GB	14,563	2,912 (~48 min)	121 (~2 min)
512 GB	29,127	5,825 (~97 min)	242 (~4 min)
1 TB	58,254	11,650 (~194 min)	485 (~8 min)
2 TB	116,508	23,301 (~388 min)	970 (~16 min)
4 TB	233,016	46,603 (~776 min)	1,941 (~32 min)

*PC Recommendation for ORCA-Quest/Fusion/Fusion BT, Hamamatsu Photonics, July 2021 (20210714).

Conclusions

- **ORCA Quest** is superior to Fusion:

➜ Readout noise: 0.27 e x 0.70 e (UltraQuiet mode)

➜ Readout speed: 120 fps x 23 fps (Std scan and CoaxPress)

➜ Resolution (pixel size): 4.6 μm x 6.5 μm

- Cameras are similar in terms of Quantum Efficiency, but Orca Quest peaks at 85% at 460 nm and Fusion QE is more uniform in the 400 nm-700 nm range.

- **CoaxPress** readout provides **6x higher readout speed** than USB for Orca Quest in <u>Std Scan mode</u>. In <u>Ultra Quiet mode</u> there is no difference.

- Hammatsu confirmed that to read the Orca Quest is mandatory to use the 4 CoaxPress inputs in the Quad *Firebird* Frame Grabber, which means that for 6 cameras (CYGNO-04), 6 Frame Grabbers are needed in the DAQ computer.

- On the other hand, CoaxPress is a more robust solution. It supports DMA engine - acquisition with zero CPU usage – and Power over CoaxPress (the camera can be powered with the same cable used for readout). If these features are not necessary, the CoaxPress solution does NOT seems so interesting.

Conclusions

- If 6 cameras are to be used in CYGNO-04, some considerations on transfer speed and load on the DAQ computer processor may arise with the USB solution. <mark>waiting answer from Hamamatsu</mark>

- If **readout speed** is NOT a critical issue, **USB is more suitable** for CYGNO-04, and also cheaper.

CoaxPress		USB	
Pros:	**Cons:**	**Pros:**	**Cons:**
Readout speed	Cost ($)	Cost ($)	Readout speed
DMA	More cables	Simplicity	
Zero CPU usage	More RAM	Less cables	
Power over Coax		Less RAM	