Instrument and Testing 3i Award 2021
Outstanding new product
Winner

Innovation Award 2022
Biophotonics & Medical Engineering category
Category Winner

Prism Awards 2022
Quantum category
Finalist

ORCA®-Quest

qCMOS® camera C15550-20UP

Photon number resolving

HAMAMATSU
PHOTON IS OUR BUSINESS

The dawn of a new era in scientific

camera evolution

Introducing the new ORCA®-Quest – a camera that achieves the ultimate in quantitative imaging.

Since the 1980s, Hamamatsu Photonics has continued to develop high-sensitivity, low-noise cameras using its unique camera design technology and has always contributed to the development of cutting-edge scientific and technological research.
With over 40 years of experience, in 2021, Hamamatsu Photonics are proud to have released the ORCA®-Quest with ultimate performance.

Evolution from single photon counting to photon number resolving

What is qCMOS®?

The qCMOS® (Quantitative CMOS) is a CMOS image sensor that has the ability to detect and identify the number of both single and multiple photoelectrons.
ORCA®-Quest is the world's first camera to incorporate the qCMOS® image sensor and to be able to resolve the number of photoelectrons using a newly developed dedicated technology. (See page 6)

The world's first qCMOS® camera

ORCA®-Quest

1980s

Electron multiplication type
With advances in electron multiplication technology, scientific cameras move from single photon counting toward high QE/resolution imaging

PIAS
World's first photon counting camera

1990s

Low noise type
With advances in sensor technology, scientific cameras move toward high speed/resolution

High-level cooled CCD camera
C3140, C3640
Readout noise
15 electrons

ICCD camera
C2400 series

2000s

Low-noise cooled CCD camera
C4742 series
Readout noise
8 electrons

EB-CCD camera
C7190 series

EM-CCD camera
C9100 series

2010s

sCMOS camera
C11440 series
Readout noise
1.5 electrons

2020s

ORCA®-Quest
Readout noise
0.27 electrons

*Readout noise is rms value.

Four key features
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1. Extreme low-noise performance
2. Realization of photon number resolving (PNR) output
3. Back-illuminated structure and high resolution
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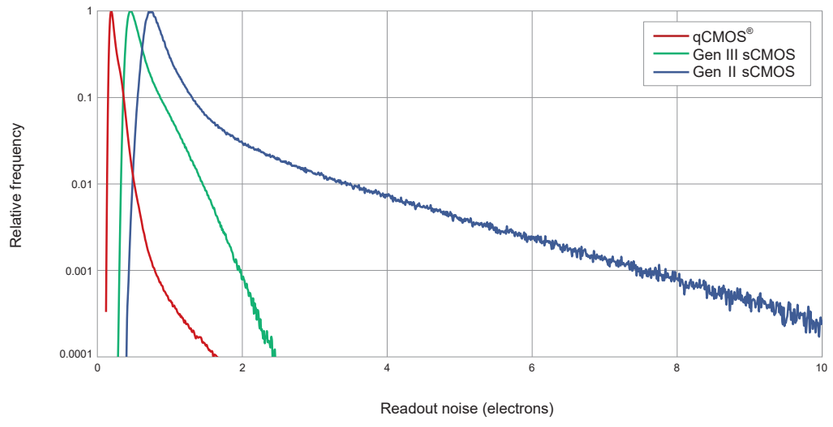
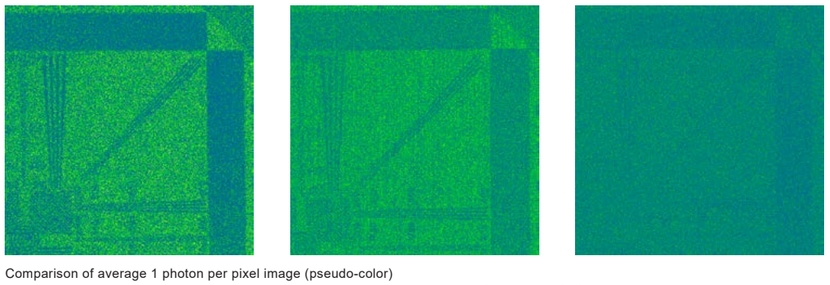
1. Extreme low-noise performance

Ultra-low readout noise 0.27 electrons rms
at Ultra quiet scan

In order to detect weak light with high signal-to-noise, ORCA®-Quest has been designed and optimized to every aspect of the sensor from its structure to its electronics. Not only the camera development but also the custom sensor development has been done with latest CMOS technology, an extremely low noise performance of 0.27 electrons has been achieved.



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

Low-dark current 0.006 electrons/pixel/s
at −35 °C

In the field of single photon counting and photon number resolving, even dark currents as low as 0.5 electrons/pixel/s can affect photon detection. The 0.006 electrons/pixel/s @−35 °C value achieved by ORCA®-Quest is an extremely low probabilistic value of only 1 electron of dark current generated in approximately 167 pixels when exposed for 1 second.
Thus, the ORCA®-Quest, which is less affected by dark current, is ideal for quantitative imaging and analysis.

ORCA®-Quest **Gen II sCMOS camera**

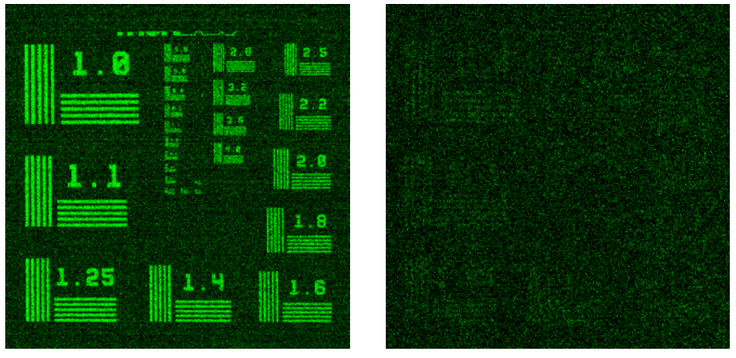


Image quality comparison at long exposure time (pseudo-color)
Incident light intensity: 0.05 photons/pixel/s Exposure time: 15 min (10 s × 90 times integration)

When performing long-time exposure, conventional EM-CCD cameras are easily affected by cosmic rays, and the resulting white spots have become a problem. ORCA®-Quest is not easily affected by cosmic rays and can suppress the deterioration of image quality due to white spots during long-time exposure.

ORCA®-Quest **EM-CCD camera**

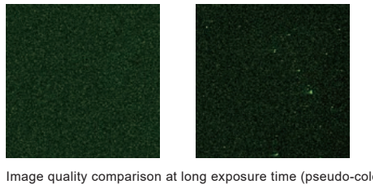


Image quality comparison at long exposure time (pseudo-color)
No incident light Exposure time: 30 min

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2. Realization of photon number resolving (PNR) output

Realization of photon number resolving by low-readout noise

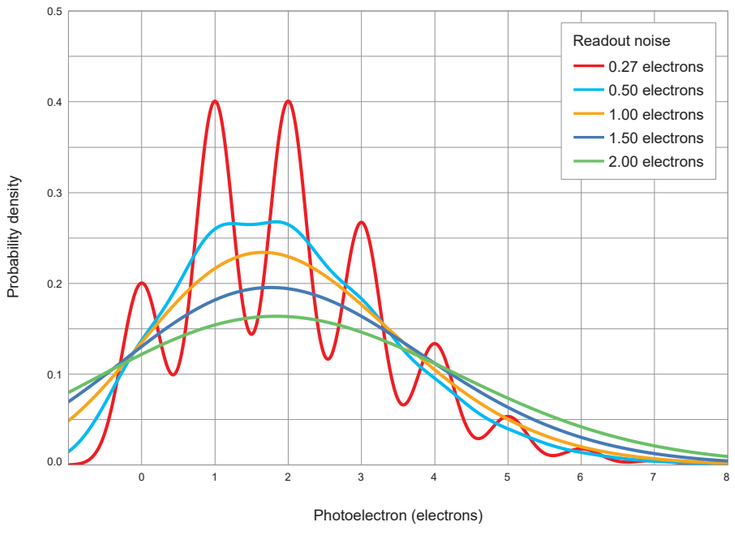
Light is a collection of many photons. Photons are converted into electrons on the sensor, and these electrons are called photoelectrons. “Photon number resolving” is a method of accurately measuring light by counting photoelectrons.*

In order to count these photoelectrons, camera noise must be sufficiently smaller than the amount of photoelectron signal. Conventional sCMOS cameras achieve a small readout noise, but still larger than photoelectron signal, making it difficult to count photoelectrons.

Using advanced camera technology, the ORCA®-Quest counts photoelectrons and delivers an ultra-low readout noise of 0.27 electrons rms (@Ultra quiet scan), stability over temperature and time, individual calibration and real-time correction of each pixel value.

For more information about the qCMOS® image sensor, please refer to the ORCA®-Quest white paper.

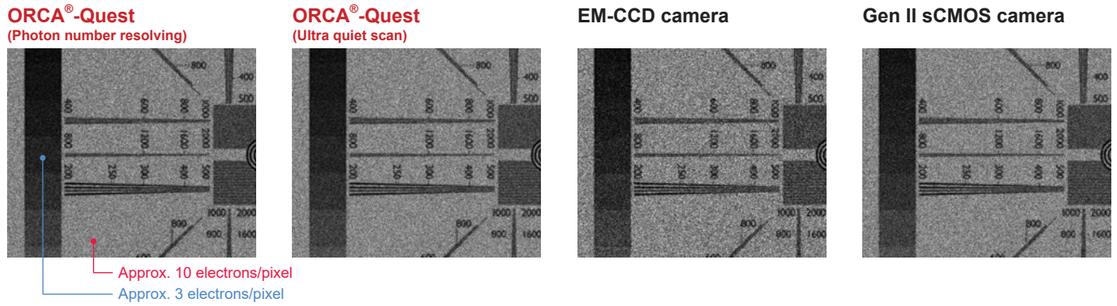
Simulation data of photoelectron probability distribution (Average number of photoelectrons generated per pixel: 2 electrons)



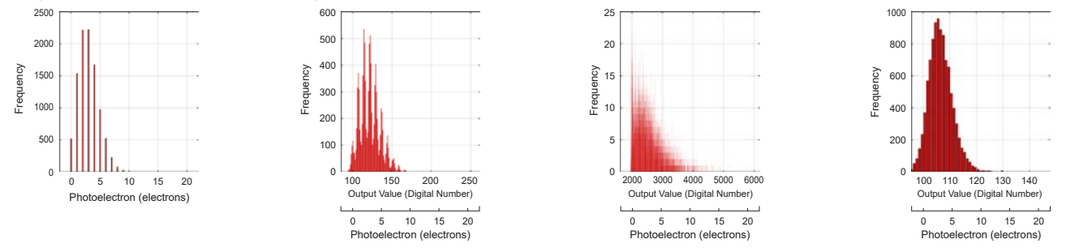
* Photon number resolving is unique and quite different from photon counting (More precisely the method resolves the number of photoelectrons. However, since single photon counting instead of single photoelectron counting has been used for a comparable method in this field, we will use the term “photon number resolving” in this brochure).

Spatial photon number resolving capability

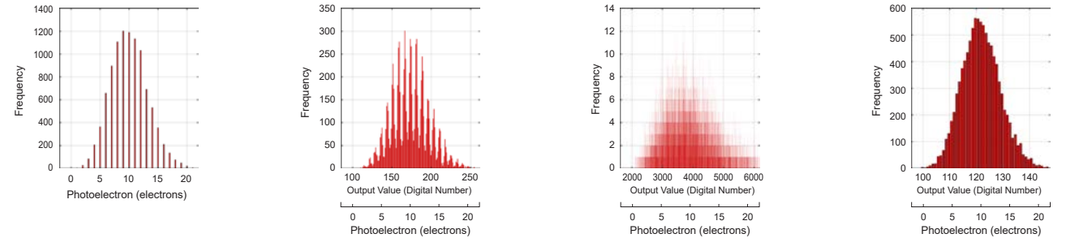
The graphs show simulated histograms when averaged photoelectrons are 3 and 10 electrons/pixel.
While the EM-CCD and Gen II sCMOS cameras cannot realize the photon number resolving due to multiplication noise or higher readout noise, the ORCA®-Quest realizes spatial photon number resolving in addition to temporal photon number resolving.
Furthermore, it follows Poisson distributions corresponding with averaged photoelectrons of 3 and 10 electrons/pixel.



Average number of photoelectrons generated per pixel: 3 electrons



Average number of photoelectrons generated per pixel: 10 electrons



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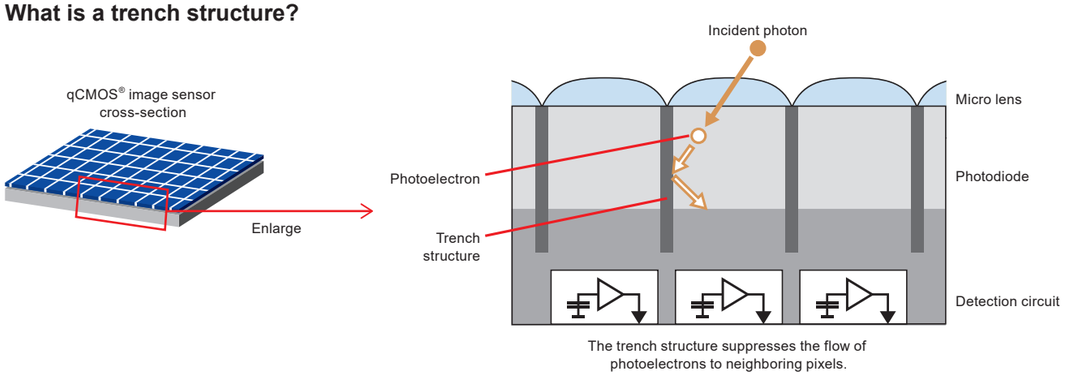
3. Back-illuminated structure and high resolution

Trench structure to suppress crosstalk

High QE is essential for high efficiency of detecting photons and achieved by back-illuminated structure.

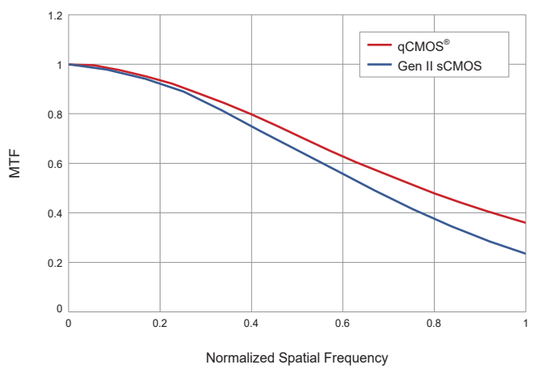
In conventional back-illuminated sensors, crosstalks occur between pixels due to no pixel separation, and resolutions are usually inferior to those of front-illuminated sensors. The ORCA®-Quest qCMOS®'s sensor has back-illuminated structure for achieving high quantum efficiency, and trench structure in one-by-one pixel for reducing crosstalk.

What is a trench structure?



The trench structure suppresses the flow of photoelectrons to neighboring pixels.

Measurement result of MTF

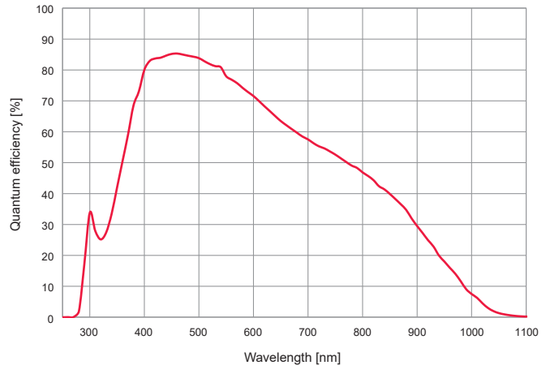


Modulation Transfer Function (MTF) is a type of resolution evaluation. It is the value of how accurately the contrast of an object can be reproduced.

High QE 85 % at 460 nm 30 % at 900 nm

It also has high quantum efficiency in the near-infrared region because of its thicker layer of the charge detection region.

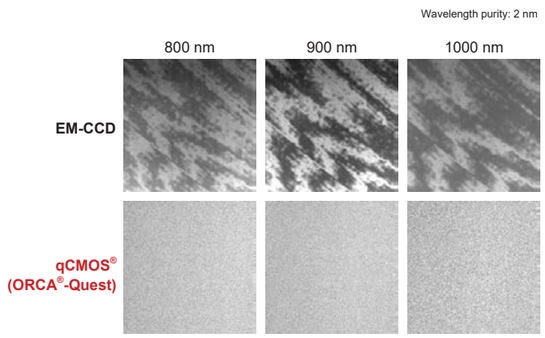
Normally, there is a trade-off between the thickness of the layer of the photon detection region and the resolution, but the trench structure suppresses the degradation of the resolution.



Etaloning-desensitized

Etaloning is a phenomenon that occurs when the incident light interferes with the reflected light from the back surface of the silicon and causes varying sensitivity - dependent both on the spatial and the spectral position. In the case of an EM-CCD camera, it appears as a fringe pattern even with uniform monochrome light input, mostly in the IR.

The qCMOS® camera shows minimal etaloning compared to EM-CCD cameras.



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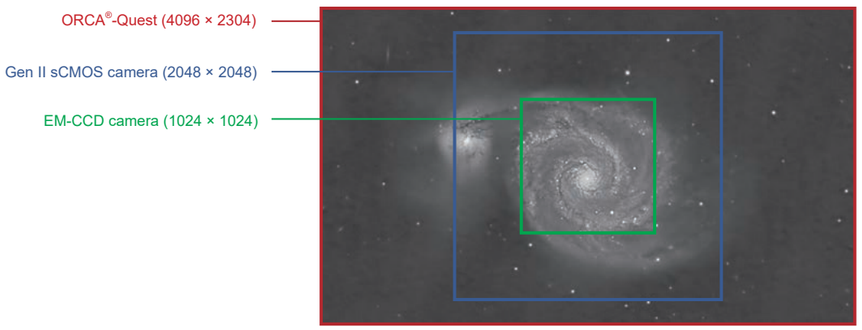
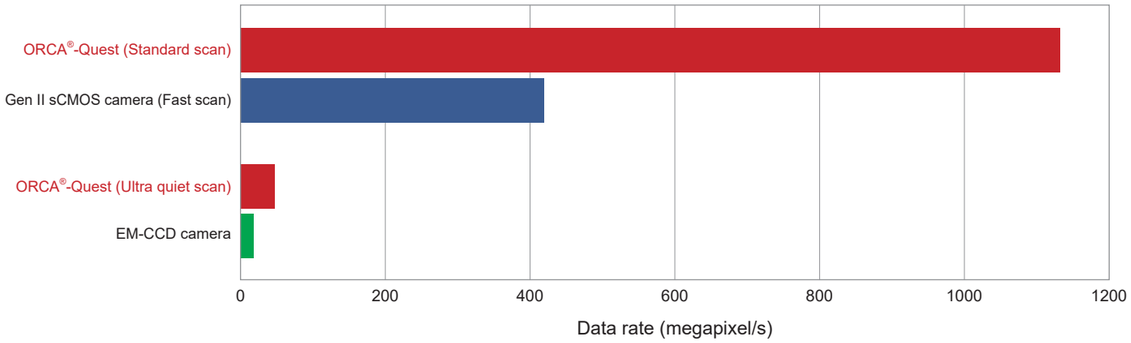
Coexistence of quantitative imaging, many pixels, and high speed

ORCA®-Quest realizes ultra-low noise with 9.4 megapixels (4096 (H) × 2304 (V)). ORCA®-Quest is capable of capturing a larger number of objects, compared to conventional scientific cameras like Gen II sCMOS and EM-CCD camera.

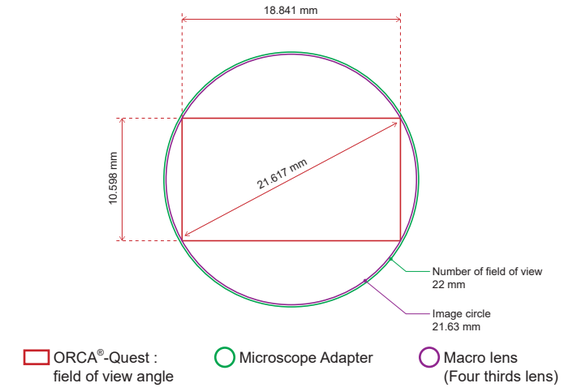


In addition, ORCA®-Quest has outstanding performance in terms of its readout speed. Here, we refer to “data rate (number of pixels × frame rate)” , which represents how many pixels a camera read out in 1 second, for comparison among scientific cameras. ORCA®-Quest with Standard scan realizes higher data rate even with lower readout noise than conventional sCMOS cameras. Also, ORCA®-Quest with Ultraquiet scan realizes photon number resolving imaging with faster data rate than single photon counting imaging by EM-CCD cameras.



Sensor sizes that can be used with general-purpose optical systems

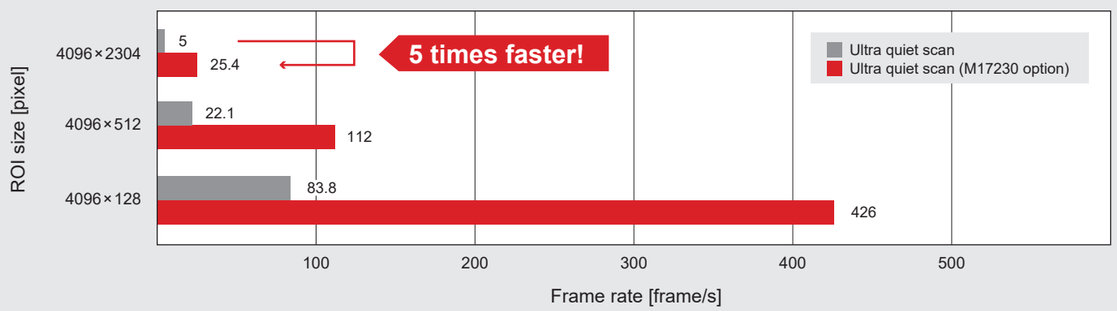
As the number of pixels increases, the size of the sensor also increases, resulting in cases where the peripheral field of view is missing when using optics such as under a microscope. The ORCA®-Quest has 18.841 mm (H) × 10.598 mm (V) by 9.4 megapixels, 4.6 µm px size, that fits in a C-mount of dia. 25.4 mm, making it suitable for use with general-purpose optics.
* An F-mount option is also available.



Enhance speed of Ultra quiest scan mode

Frame rate option M17230

ORCA®-Quest has realized photon number resolving owing to ultra-low noise characteristic, but the availability is limited for users because only the ultra quiet scan, whose speed is 5 frames per second in full resolution (4096x2304), make the resolving possible.
M17230 option offers you a faster ultra quiet scan with 25.4 frames per second in full resolution with a similar ultra-low noise characteristic.



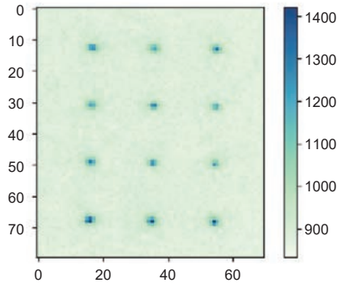
Application and Measurement Examples

Quantum technology

Neutral atom, Trapped ion

Neutral atoms and ions are aligned one by one in an array to be utilized as Qubits for Quantum computing. The qubit states can be determined by observing the fluorescence from each of them. The measurement of the fluorescence needs to be done in short time and then photodetectors with very low noise and high speed are needed. ORCA®-Quest can do both of diagnosis of the whole qubit array and state detection of each qubit with very low noise characteristics and high speed readout.

Fluorescence imaging of Rb atom array with ORCA®-Quest



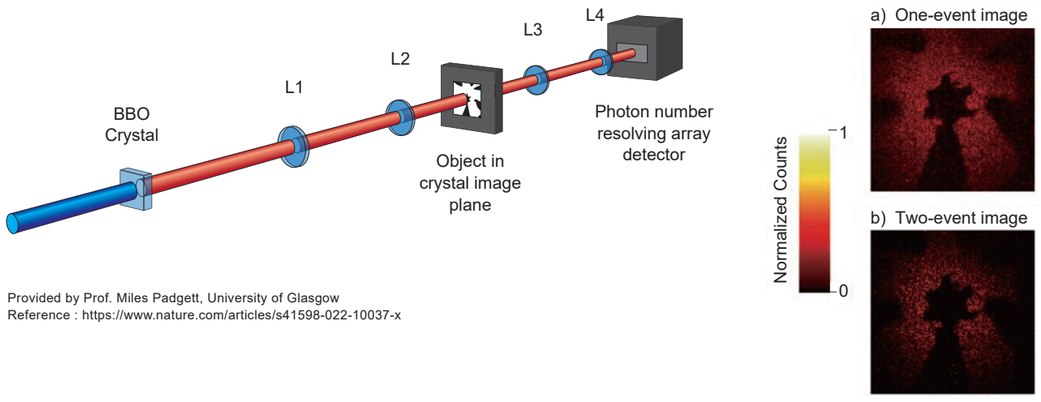
Provided by Prof. Takashi Yamamoto and Asst. Prof. Toshiki Kobayashi, Osaka University

Reference :
https://camera.hamamatsu.com/us/en/application_and_case_study/quantum_technology/Imaging_single_atom_array_by_orca_quest.html

Quantum optics

Quantum optics uses single photon sources to make use of the Quantum nature of the single photon.
The quantum optics research also uses single photon counting detectors, and now there are emerging needs of photon number resolving detectors to distinguish photon numbers coming into the detectors.
A photon counting camera, a new concept in camera technologies, is expected to make a new discovery in this field.

Experimental setup and images of Quantum imaging with ORCA®-Quest



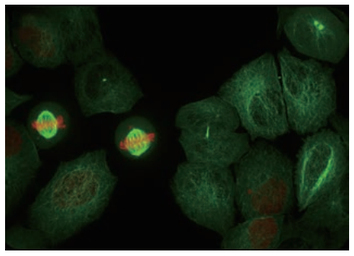
Provided by Prof. Miles Padgett, University of Glasgow
Reference : https://www.nature.com/articles/s41598-022-10037-x

Life science

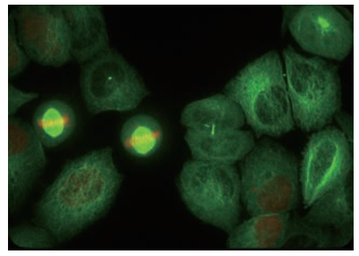
Super resolution microscopy

Super resolution microscopy refers to a collection of methods to get a microscope image with higher spatial resolution than diffraction limit.
The super resolution microscopy needs scientific cameras with combination of very low noise and small pixel size, resulting in a higher resolution.

Super resolution images from ORCA®-Quest and ORCA®-Fusion



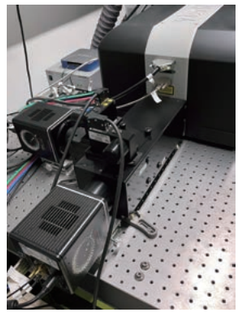
ORCA®-Quest
(qCMOS® camera, 4.6 µm pixel size)



ORCA®-Fusion
(Gen III sCMOS camera, 6.5 µm pixel size)

Provided by Steven Coleman at Visitech international with their VT-iSIM, high speed super resolution live cell imaging system.

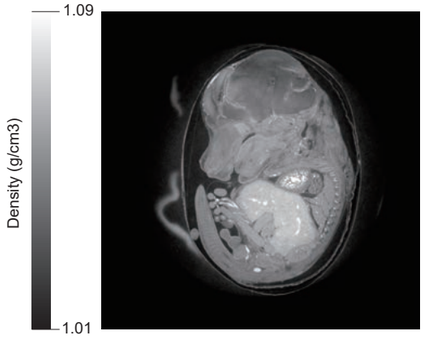
Experimental setup with ORCA®-Quest



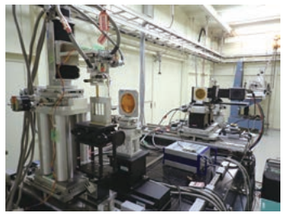
HEP / Synchrotron

For imaging of X-ray or other kinds of high energy particles, a scientific camera coupled with a scintillator is often used. Low noise and high speed are required in the imaging system to detect momentary phenomena.

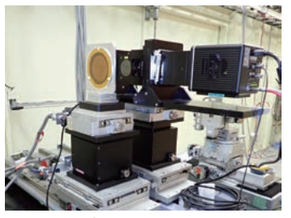
X-ray phase contrast CT image of mouse embryo



Experimental setup



Camera setup



- X-ray phase contrast CT image of mouse embryo from ORCA®-Quest combined with High resolution X-ray imaging system (Hamamstsu M11427)
- Exposure time: 15 ms, Total measurement time: 6.5 min
- Taken in SPring-8 BL20B2 beamline by Dr. Masato Hoshino, Senior researcher in Japan Synchrotron Radiation Research Institute (JASRI)

Case studies are now available on our website!

https://camera.hamamatsu.com/us/en/application_and_case_study.html

Specification

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

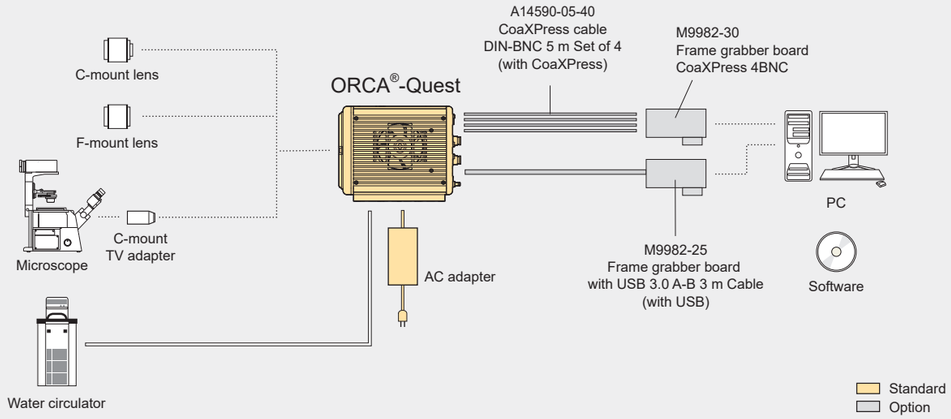
At Normal area readout and Photon number resolving (PNR)		
Readout mode		Full resolution, Digital binning (2×2, 4×4), Sub-array
Frame rate at full resolution	Standard scan *5	120 frames/s (CoaXPress), 17.6 frames/s (USB)
	Ultra quiet scan	5 frames/s (CoaXPress, USB)
Exposure time	Standard scan *5	7.2 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)

*1: Calculated from the ratio of the full well capacity and the readout noise in Ultra quiet scan
*2: In Ultra quiet scan
*3: At 3500 electrons, the center 1500 × 1500 area of the image sensor, 1000 times integration
*4: Water volume is 0.46 L/m.
*5: Normal area readout mode only
*6: If you need shorter exposure time, please contact your local Hamamatsu representative or distributor. The frame rate does not change even when setting the exposure time shorter.
*7: Software such as HCImage is required. For details, please contact your local Hamamatsu representative or distributor.
*8: For more patent information, please refer to our website. https://www.hamamatsu.com/all/en/product/cameras/cmos-cameras/lightsheet-readout-mode.html
*9: A product for F-mount (C15550-20UP01) is also available. If you wish, please contact your local Hamamatsu representative or distributor. F-mount has a light leakage due to its structure and it might affect your measurements especially with longer exposure time.

System Configuration



Option

Product number	Product name
A14590-05-40	CoaXPress cable DIN-BNC 5 m Set of 4
M9982-25	Frame grabber board with USB 3.0 A-B 3 m Cable
M9982-30	Frame grabber board CoaXPress 4BNC
A12106-05	External trigger cable SMA-BNC 5 m
A12107-05	External trigger cable SMA-SMA 5 m
M17230	Frame rate option for C15550-20UP *

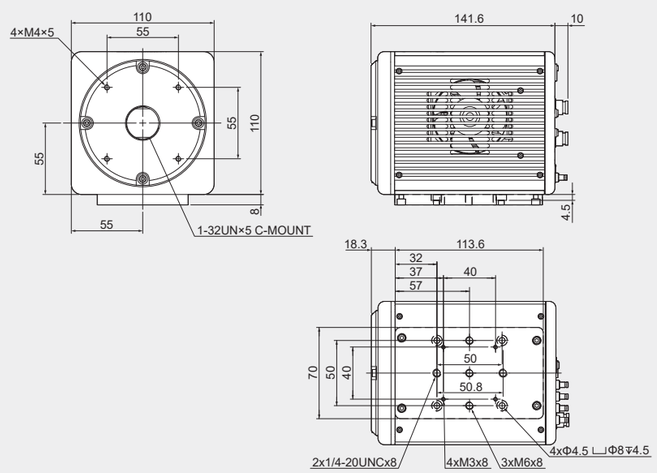
* You are able to add the option only at the time of purchase. It can not be added after shipping.

■ Specification comparison for M17230 option

	Ultra quiet scan / PNR mode	Ultra quiet scan / PNR mode (M17230 option)
Readout noise (typ.)	0.27 electrons rms	0.30 electrons rms
Frame rate at full resolution	5 frames/s (CoaXPress, USB)	25.4 frames/s (CoaXPress), 17.6 frames/s (USB)
Exposure time	199.9 ms to 1800 s (internal, edge, level, start) 200.2 ms to 1800 s (sync readout) 172.8 µs to 1800 s (global reset edge, global reset level)	33.9 µs to 1800 s (33.9 µs steps)

Dimensional Outlines (Unit: mm)

Camera (Approx. 3.8 kg)



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