Purchasing a Back-illuminated sCMOS for Astronomy & Physical Sciences?

Seven Reasons To Choose Marana

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Technical Note

Considering a Back-illuminated sCMOS for **Astronomy and Physical Sciences**: 7 Reasons to Choose Andor **Marana**

Introduction

The Marana sCMOS camera platform has been designed to deliver the ultimate in performance, longevity and experimental adaptability, pushing the absolute best out of high-end sCMOS sensors. Marana has also been designed with the solution needs of Astronomers, Physicists and Chemists firmly in mind, offering features and functionality that are particularly relevant within these fields.

Back-illuminated sCMOS sensors are growing in popularity, primarily due to the best-in-class Quantum Efficiency (QE) performance that they offer. It therefore makes sense to combine these high-end sensors with best-in-class performance across all other key parameters. For those who have made the decision to purchase a back-illuminated sCMOS camera, here we offer seven key reasons that the Andor Marana should be your back-illuminated sCMOS of choice for Astronomy and Physical Sciences applications.

Marana is currently available in two models:

Model Option	Array	Pixel Size	Frame Rate (16-bit)	Description
Marana 4.2B-11	2048 x 2048	11 µm	24	*Superior Field of View*
Marana 4.2B-6	2048 x 2048	6.5 µm	74	*Fastest Speed*

1. The Most Sensitive Back-illuminated sCMOS Available

Both back-illuminated Marana models feature **95% Quantum Efficiency (QE)** with **market-leading vacuum cooling to -45 °C**. Benefiting from a unique vacuum design, Marana thermoelectrically cools to -25 °C using only the internal fan for heat dissipation, pushing down to a hugely competitive -45 °C utilizing liquid assisted cooling. The darkcurrent of the back-illuminated sCMOS sensors is a significant contributor to overall system noise, so effective cooling becomes essential. For example, with air cooling, Marana 4.2B-11 has almost 5x lower darkcurrent than the nearest physical science competing camera that utilizes the

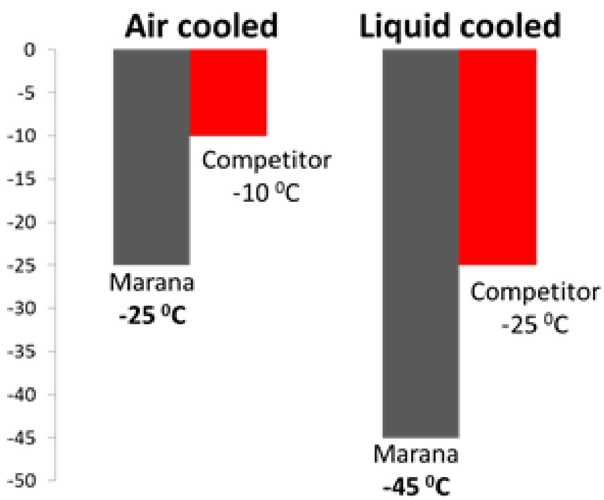

Figure 1: Air (fan) cooled and Liquid cooled performance of Marana 4.2B-11, versus the nearest competitive back-illuminated sCMOS camera for physical sciences.

Marana 4.2B-6 Low Noise mode: Furthermore, the Marana 4.2B-6 model offers a specific 'Low Noise mode', that further reduces readout noise from 1.6 e- down to only 1.2 e- (typical). The primary trade-off of this mode is pixel well depth, reducing down to 1800 e-. Maximum frame rate, while still fast for many applications, also reduces from 74 fps down to 44 fps in Low Noise mode. However, the mode is ideal when highest possible sensitivity is a priority, for example when performing fluorescence Quantum Gas measurements of low atom numbers.

Having the most sensitive Back-illuminated sCMOS camera carries a host of practical advantages within Astronomy and Physical Sciences, for example:

- ✓ Detect smaller objects - more successful Space Debris and NEO tracking
- ✓ Lower laser powers/doses - preserve photosensitive samples
- ✓ Lower detection limits - detect and quantify trace concentrations, e.g. spectroscopy
- ✓ Lower exposure times - follow faster events with high SNR, e.g. Pulsars and fast BEC dynamics
- ✓ Narrowband filters – such as use of ultra-narrowband Solar imaging of specific emission lines
- ✓ Detect fluorescence from discrete atoms - more successful Quantum Gas/BEC experiments

Back-illuminated sensors are valued specifically for their enhanced sensitivity. It makes sense to choose the most sensitive camera adaption of this high-end technology.

2. Largest Field of View Available: Marana 4.2B-11

Marana 4.2B-11 offers the largest field of view solution, combined with a long exposure capability, compared with competitive cameras that also use the same back-illuminated sensor type from GPixel. The GSENSE400BSI sensor of Marana has an impressive 32 mm diagonal. However, camera companies to date have not been able to utilize it without severe restrictions, the reason being that the native operation of the sensor exhibits edge glow! The approach so far has either been to (a) live with the full unsuppressed glow; (b) only use the middle of the sensor; or (c) firmware restrict exposure times to much less than 100 ms in order to contain the impact of glow on experiments. Marana 4.2B-11 features a unique real time approach to suppress the effects of glow and unlock the full sensor array, presenting an exclusive solution for capturing a large field of view across a wider range of exposure conditions.

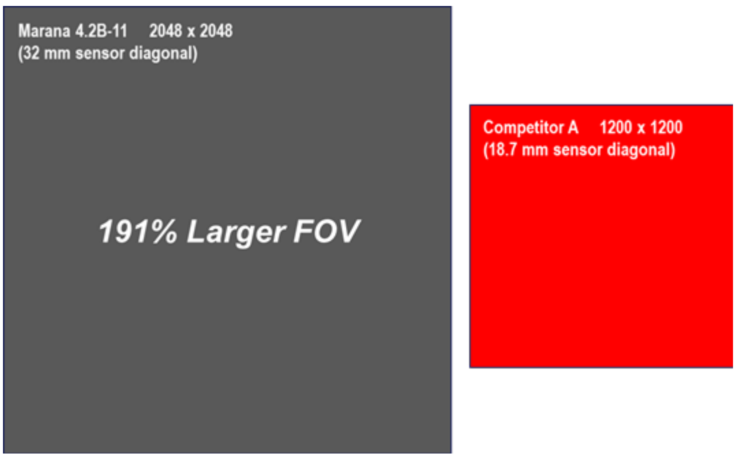

Figure 2: Scale representation of Field of View difference between Marana 4.2B-11 and a competitor physical science camera utilizing the same GSENSE400BSI back-illuminated sCMOS sensor, restricted to 1200 x 1200 max. resolution.

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The Marana 4.2B-11 is native F-mount and can be compared against "Competitor A" above, a camera using the same sensor but cropped down to 1200 x 1200 pixel format. By cropping the sensor down, this camera can avoid sensor glow issues that affect the edges of this sensor. However, Marana 4.2B-11 enables the full native 2048 x 2048 of the array to be harnessed. Figure 2 shows the 191% larger field of view advantage offered by Marana 4.2B-11.

Furthermore, the Marana 4.2-11 allows use of the full 2048 x 2048 array with exposures up to several seconds. This is significantly enabling, as the nearest competing physical science camera platform that has opened the full sensor array has addressed the sensor glow effect through imposing a severe restriction on the maximum exposure time, limiting to only 30 milliseconds.

Maximizing field of view with Back-illuminated sCMOS cameras is highly beneficial for a range of physical science applications, for example:

- ✓ Space Debris and NEO tracking – detect and track objects across greater area of sky
- ✓ Solar Astronomy – image sun spots and solar flares, maintaining structural detail
- ✓ Tomography – 3D reconstruct larger objects without sacrificing resolution
- ✓ Wafer inspection - detect greater wafer area with high resolution
- ✓ Hyperspectral imaging - Extended high density multi-fiber input, or push broom hyperspectral over wide spatial and spectral ranges.

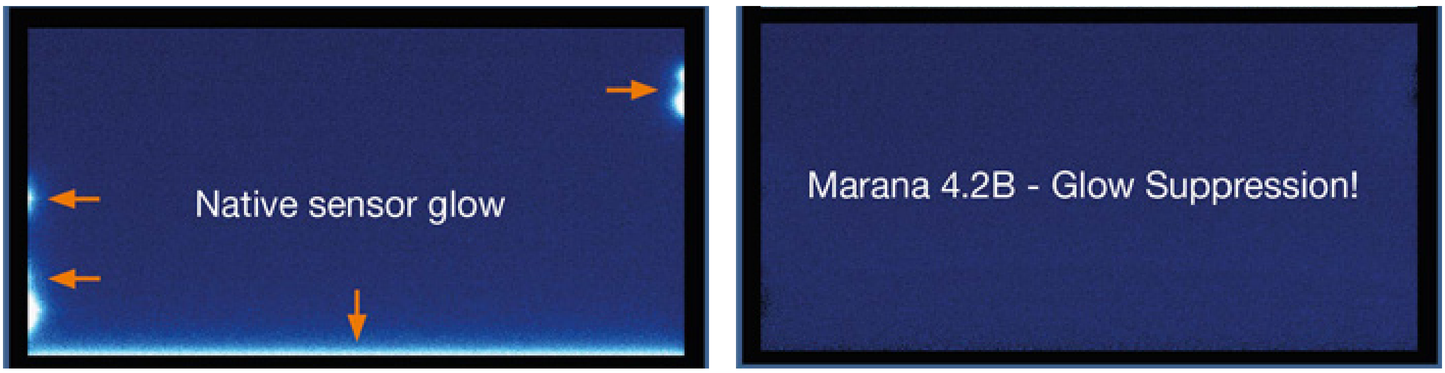

Figure 3: Dark exposure (1 sec), using a 1024 x 2048 region of the GSENSE400 BSI sensor. Images are compared: left - without, and right - with the Anti-Glow Technology of Marana 4.2B-11, employing the exact same intensity scaling.

3. Superior Quality & Longevity – UltraVac™

Why Vacuum Technology? As well as affording superior minimization of the noise floor, the **performance longevity** benefits of Andor's vacuum sensor enclosure are considerable.

REASON 1: **Sensor Protection** - Unless protected, back-illuminated silicon sensors are susceptible to attack from moisture, hydrocarbons and other gas contaminants, resulting in gradual performance decline, including QE decline. Ultravac™, Andor's proprietary approach to vacuum enclosures, with minimized out-gassing, offers the ultimate level of sensor protection.

REASON 2: **No re-backfilling of sensor enclosure required** - Cameras that do not use vacuum enclosures instead use a method called back-filling, whereby the sensor enclosure contains a positive pressure of dry gas, separated from the external atmosphere by only O-ring seals. Over time, moisture and gas from the atmosphere will ingress into the sensor enclosure and compromise the system, resulting in loss of cooling capability and often moisture appearing on the sensor. The cameras then have to be sent back to the factory for repair, re-backfilling and resealing, often outside of the warranty period. The UltraVac™ uses a **hermetic vacuum seal**, completely preventing any gas ingress from the outside environment. The vast majority of cameras hold their cooling performance **indefinitely**.

Marana is the **ONLY** physical sciences back-illuminated sCMOS camera on the market that benefits from a vacuum sensor enclosure. Vacuum sensor technology is one of Andor's core technology strengths, and we have a fantastic track record of vacuum integrity and associated camera longevity, stretching back more than 25 years.

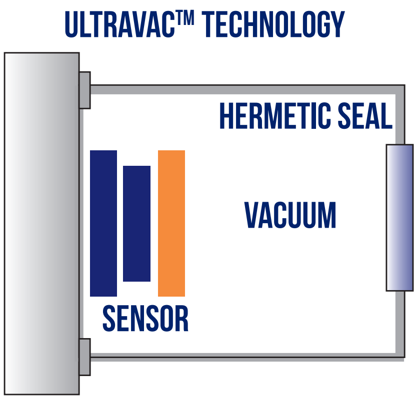

Figure 4: Andor's UltraVac™ provides superior sensor protection and performance longevity.

Low Maintenance Astronomy: The vacuum-protected longevity benefits of Marana are particularly relevant to the needs of astronomers, where cameras are often in remote unmanned observing locations and need to operate without service intervention, over long durations of time. Furthermore, observing time is often tightly scheduled and we need to know the camera is not going to suffer from a cooling compromise or moisture build up, either on the sensor or on the outside of the window. All of this ultimately translates not only into a higher experimental throughout, but also into a lower cost of ownership.

4. Extended Dynamic Range & Higher Quantitative Accuracy

Marana 4.2B-11 and Marana 4.2B-6 each offer **Extended Dynamic Range** functionality, supported by a 16-bit data range. Harnessing an innovative 'dual amplifier' sensor architecture, we can access the **maximum pixel well depth AND the lowest noise simultaneously**, ensuring that we can quantify extremely weak and relatively bright signal regions in one exposure. This functionality is useful for accurately visualizing and quantifying many challenging scenes that have both weak and bright regions, such as Space Debris, NEOs, Solar signals and spectroscopic materials characterisations.

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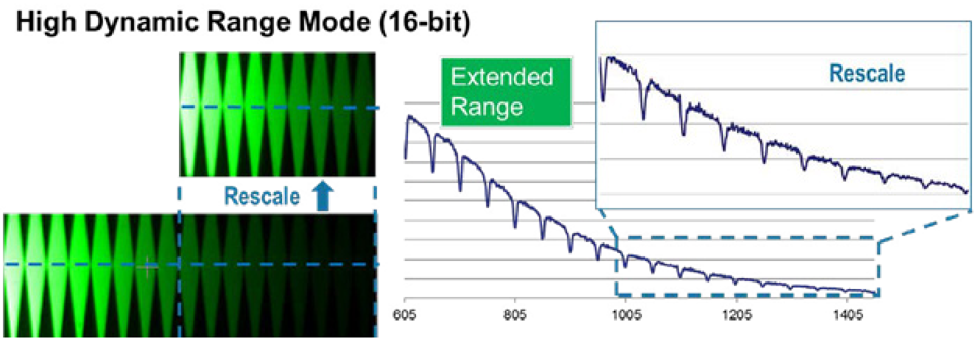

Figure 5: Measurements taken of a high dynamic range test chart using Marana 4.2B-11 in Extended Dynamic Range Mode, which enables accurate quantification of signal intensities that range from the noise floor detection limit to the full pixel well depth.

Market Leading Linearity: To achieve best in class quantification accuracy, Andor have implemented enhanced real time on- head intelligence to deliver linearity of > 99.7%.

Many applications in physical sciences require accurate quantitative information rather than simply structural detail, for example Astro-Photometry, Solar measurements and quantitative Spectroscopic characterisations.

Further Extending Dynamic Range through Fast Image Stacking: The fast, low noise readout of Marana sCMOS is ideal for massively extending dynamic range through rapid stacking (accumulation) of multiple frames. For example, the plot below shows Dynamic Range and Effective Well Depth as a function of the number of stacked (accumulated) frames, plotted for Marana 4.2B-6. A Dynamic Range of 188,280:1, and a corresponding Effective Well Depth of 1,650,000 electrons can be reached with only 30 stacked frames. At maximum frame rate, this number of accumulated frames takes only 0.4 secs to acquire, achieving > 2 fps. This capability is significant for a range of challenges across imaging and spectroscopic characterisations.

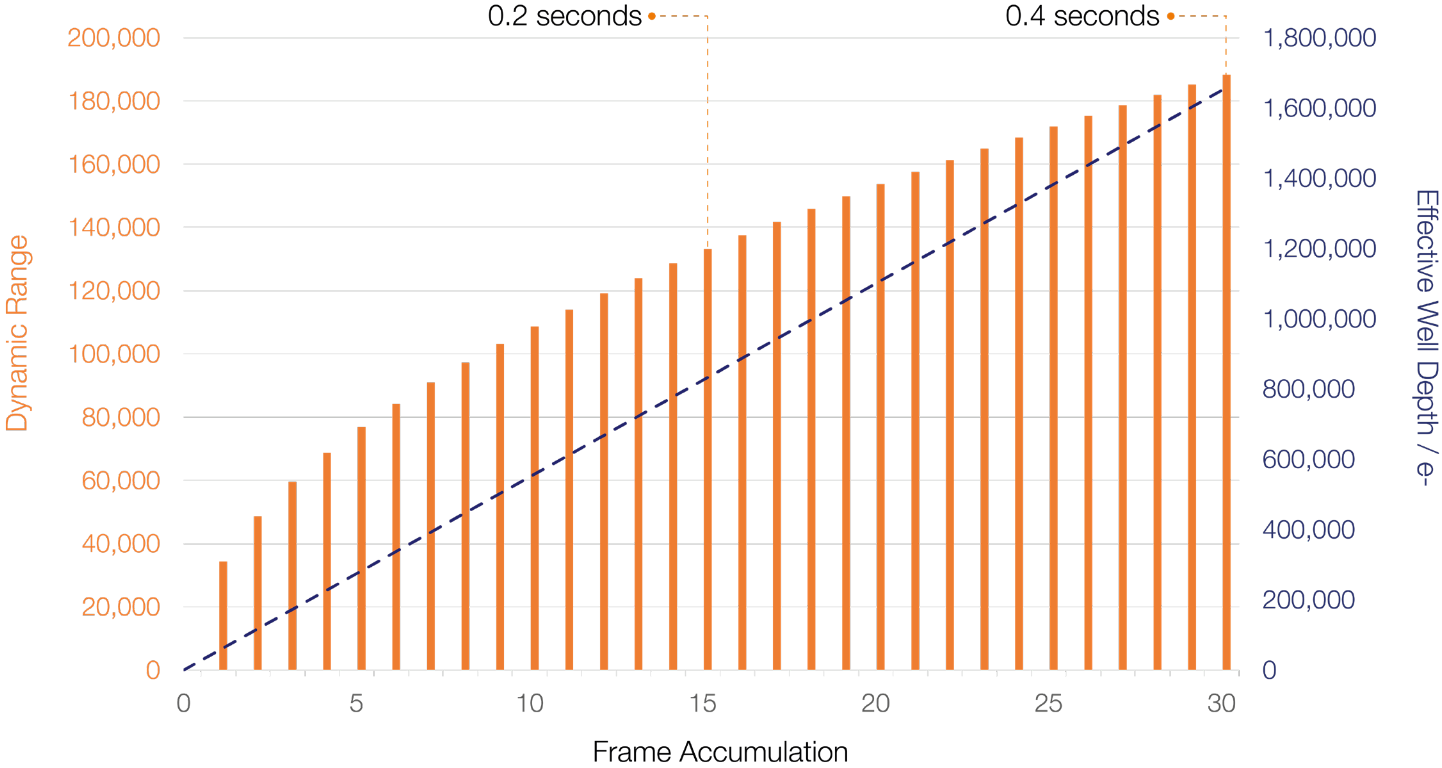

Figure 6: Dynamic Range and Effective Well Depth as a function of the number of stacked (accumulated) frames, plotted for Marana 4.2B-6.

5. Faster Frame Rates

Marana models offer fast frame rate capability, rendering them ideal for dynamic applications while avoiding motion smear, benefiting applications such as **Space debris and NEO tracking, Pulsar imaging, Solar flares, Sunspot flashes/waves, Lucky imaging/Speckle Interferometry, AO wavefront sensing and Quantum Gases/BEC dynamics.** Region of Interest (ROI) can be utilized to considerably boost frame rates further.

Marana 4.2B-6 **offers absolute fastest speeds, combined with high dynamic range**: Marana 4.2B-6 is the best model for achieving fast speeds under all imaging conditions. It offers up to 74 fps (full resolution array) without a sacrifice in dynamic range, i.e. in 'Fast High Dynamic Range mode'. Marana 4.2B is 72% faster than its nearest competitor (see below table)!

	Max Frame Rate (16-bit)	
ROI Size	**Marana** 4.2B-6	Competitor A
2048 x 2048	74 fps	43 fps
2048 x 1024	147 fps	87 fps

Table 1: Not all commercial cameras utilizing the GS2020BSI sensor achieve such fast frame rates. Maximum frame rates of Marana 4.2B-6 are shown here versus a competitive camera using the same sensor that does not offer such fast speeds.

Marana 4.2B-11 **12-bit mode for 2x speed boost**: Marana 4.2B-11 is architected to offer both 'High Dynamic Range (16-bit) mode' and 'Fast Speed (12-bit) mode'. The latter is selected specifically to accelerate frame rate of this model by 2x, for any ROI size, while sacrificing some dynamic range. The mode is useful for imaging fast phenomena that are exclusively low light, such as following dynamics on discrete numbers of fluorescent ultra-cold atoms.

	Max Frame Rate (12-bit)	
ROI Size	**Marana** 4.2B-11	Competitor B
2048 x 2048	48 fps	24 fps
1608 x 1608	60.5 fps	30 fps

Table 2: Not all commercial cameras utilizing the GS400BSI sensor offer this boosted speed capability. Maximum frame rates of Marana 4.2B-11 are shown here versus a competitive camera using the same sensor that does not offer this 12-bit fast speed mode.

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6. Enhanced Flexibility: Adapt to a Wide Range of Experimental Needs

The Marana platform has been designed to meet the needs and challenges of modern research, which often requires that the camera has inherent feature flexibility and experimental modes, to be adapted across multiple set-ups and experimental configurations. The following areas of flexibility are inherent to the Marana platform:

- ✓ **Air and Liquid Cooling** – Not only can the Marana be used in liquid cooled operation to maximize sensitivity in extreme low light conditions, use of liquid cooling rather than fan assisted cooling can also be beneficial in optical configurations that are particularly vibration sensitive.

- ✓ **Flexible Readout Modes**
  Marana 4.2B-6: The 'Fast High Dynamic Range (16-bit) mode' of Marana 4.2B-6 achieves maximum dynamic range of 34,000:1 while simultaneously achieving maximum frame rate of 74 fps. The 'Low Noise (12-bit) mode' of Marana 4.2B-6, described in Section 1, is used for achieving absolute maximum sensitivity under reduced dynamic range conditions.
  Marana 4.2B-11: The 'High Dynamic Range (16-bit) mode' of Marana 4.2B-11 is the Extended Dynamic Range mode, ideal for imaging samples that have both weak and bright signal regions. The 'Fast Speed (12-bit) mode' of Marana 4.2B-11, described in Section 5, can be utilized to double the available frame rate from any selected ROI size, superb for adapting to low light experiments that require excellent temporal resolution, such as Adaptive Optics wavefront sensing.

- ✓ **Flexible Pixel Binning** – The Marana models feature on-camera flexible pixel binning, user definable to 1 pixel granularity. Greater binning flexibility can be useful for some photon starved applications where resolution can be sacrificed in favour of enhanced photon collection area per pixel - e.g. extremely low light luminescence experiments.

- ✓ **Multiple Optical Mount Options** - Marana 4.2B-11 ships as default with standard F-mount optical coupling, however, the user can readily convert the camera for use with C-mount lenses, simply by selecting this additional optical mount accessories when ordering (or order separately at a later time if preferred). C-mount may be used with cropped sub-array sizes up to 1400 x 1400, yielding a 22mm sensor diagonal. The F-mount may also be readily detached to use Marana with a simple faceplate, for example on an optical table. Likewise, while the Marana 4.2B-6 model ships as a standard C-mount, it can be readily converted for use with F-mount lenses by selecting this additional optical mount accessories when ordering.

For attachment to various professional telescope configurations, the camera front end can be direct mounted. For The larger field of view Marana 4.2B-11 model, this provides up to **f/# 0.7** with 72° cone angle. Through engagement with Andor's **Customer Special Request** (CSR) service, **custom optical mounts** can be tailored to your specific optical needs.

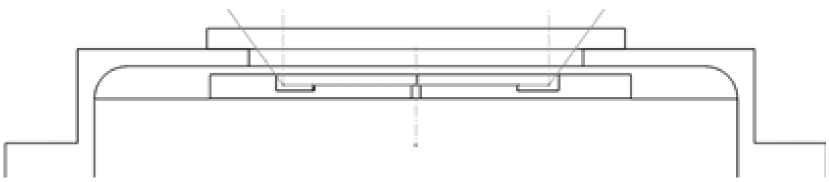
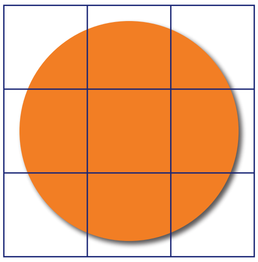


Figure 7: 'Direct mount' front end of Marana 4.2B-11, yielding f/# 0.7 and 72° Cone Angle. Discuss custom mounting flanges with Andor's CSR Service.

- ✓ **Marana 4.2B-6 Purchase Flexibility** – Don't want to commit to CoaXPress connectivity from the outset? If preferred, order the less expensive USB 3.0-only version and later avail of a simple in-field upgrade to CoaXPress capability, if and when you want to unlock the full speed potential of Marana 4.2B-6.

- ✓ **Timestamp** – The Marana platform can generate a timestamp for each image that is accurate to 25 nanoseconds. Accurate timestamps can be important where precise knowledge of frame time impacts temporal dynamic analysis. This is especially important for fast events, where computer and interface latencies need to be considered, for example in Pulsar or Solar studies.



- ✓ **Pixel Size Options** - The 11 µm or 6.5 µm pixel sizes of the available Marana models offer a solution to more closely resolution match the camera to the specific optical configuration. Pixel binning offers further usage flexibility.

- ✓ **Fast Spectroscopy Mode** – Marana 4.2B-6 and Marana 4.2B-11 can be readily adapted to the needs of fast spectroscopy, yielding up to greater than 25K spectra/sec. Such spectral rates are ideal for following fast reaction dynamics on sub-millisecond, stopped flow experiment timescales. Fast spectral kinetics capability can also be used for 'pseudo-gated' time-resolved functionality, whereby the first series of spectra from a fast series can be discarded to 'gate out' the effects of the initial exciting laser pulse.

	Max Frame Rate (fps)		ROI area (of sensor)	Example scenarios of use
ROI Size (W x H)	16-bit	12-bit		
2048 x 1200	41	81	22.5mm x 13.2mm	High density multitrack on Kymera/Shamrock
2048 x 8	5415	9747	22.5mm x 88µm	Single or dual track spectroscopy
2048 x 2	16244	24367	22.5mm x 22µm	Single track spectroscopy
2048 x 1	24367	24367	22.5mm x 11µm	Single track spectroscopy with ultrafast rates

Table 3: Selection of Marana 4.2B-11 Region of Interest (sub-array) configurations that can be readily harnessed for rapid spectroscopic applications. On-camera FPGA pixel binning for optimal photon collection is complimented by a bit depth of 32- bit for extended dynamic range.

- ✓ **Adaptive Optics Ready** – Marana readout is well suited to the needs of AO Wavefront Sensing, with ROI usage readily achieving several hundred frames/sec. Furthermore, it is highly important in AO to be able to react to information with minimal latency. Marana sends data from each row as soon as the row is read out, it does not wait until an entire image is captured and assembled on the camera before transmission through the interface. Thus AO researchers can begin processing and using the info, row at a time.

ROI Size (W x H)	Max Frame Rate (fps)	
	16-bit	12-bit (Low Noise)
1024 x 1024	148	87
512 x 512	295	174
256 x 256	587	346
128 x 128	1166	687

Table 4: Selection of Marana 4.2B-6 Region of Interest (sub-array) configurations that can be readily harnesses for Adaptive Optics Wavefront Sensing.

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7. UV Options

Marana 4.2B-11 comes with two sensor options, ‘BV’ and ‘BU’. Each offer a particular performance profile across the Blue/UV region, with the ‘BU’ sensor in particular showing greater optimization in the window between 260nm and 400nm range, offering high QE solutions for both 266 nm and 355 nm laser lines. Experiments that can benefit from enhanced UV sensitivity include Semiconductor Wafer Inspection (266nm), UV Raman and LIDAR. The ‘BU’ option is also well matched to some ultra-cold atom studies, e.g. Calcium and Magnesium.

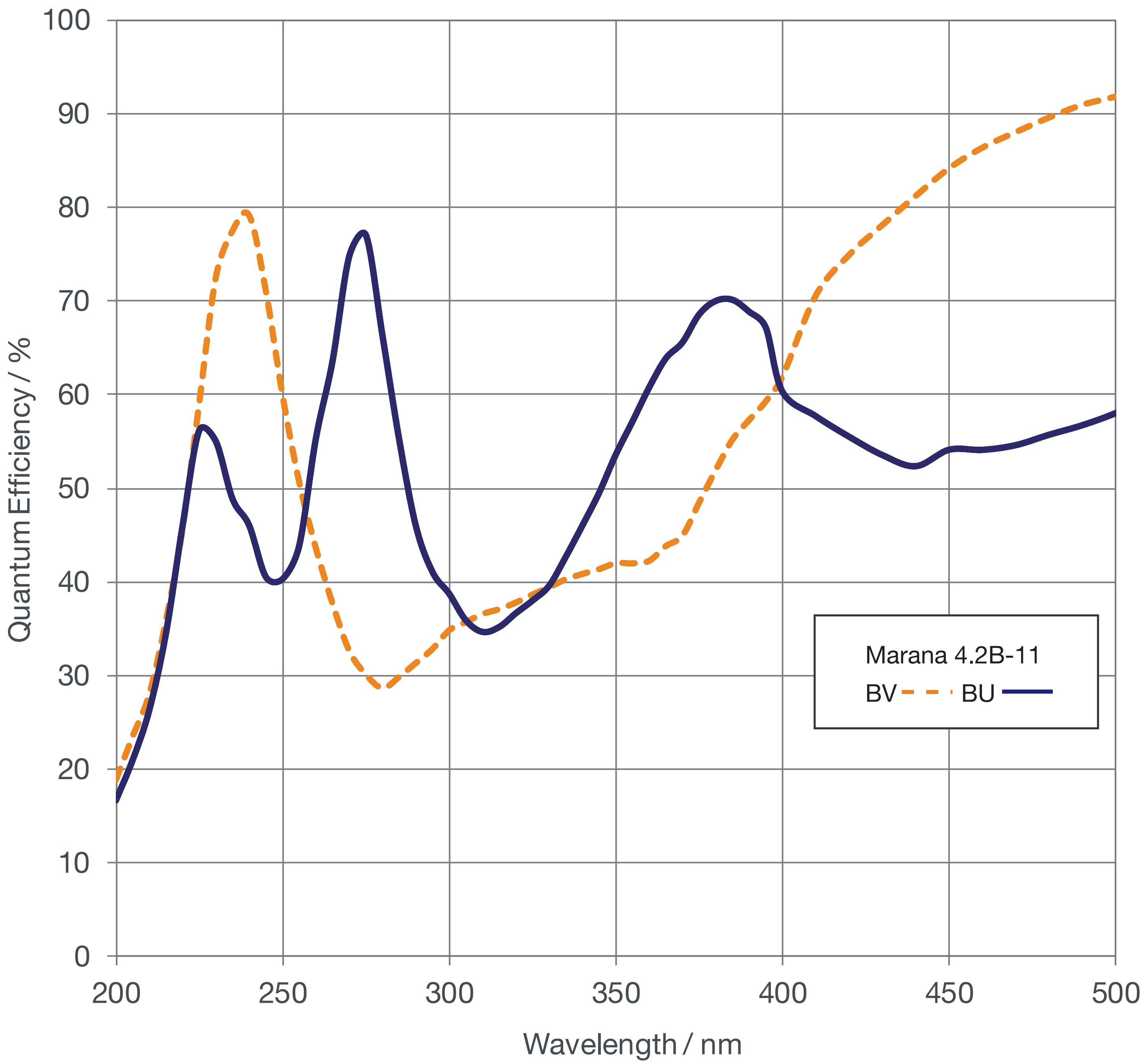

Figure 8: Marana 4.2B-11 QE options. The BU curve offers higher QE in the window between 260-400nm.