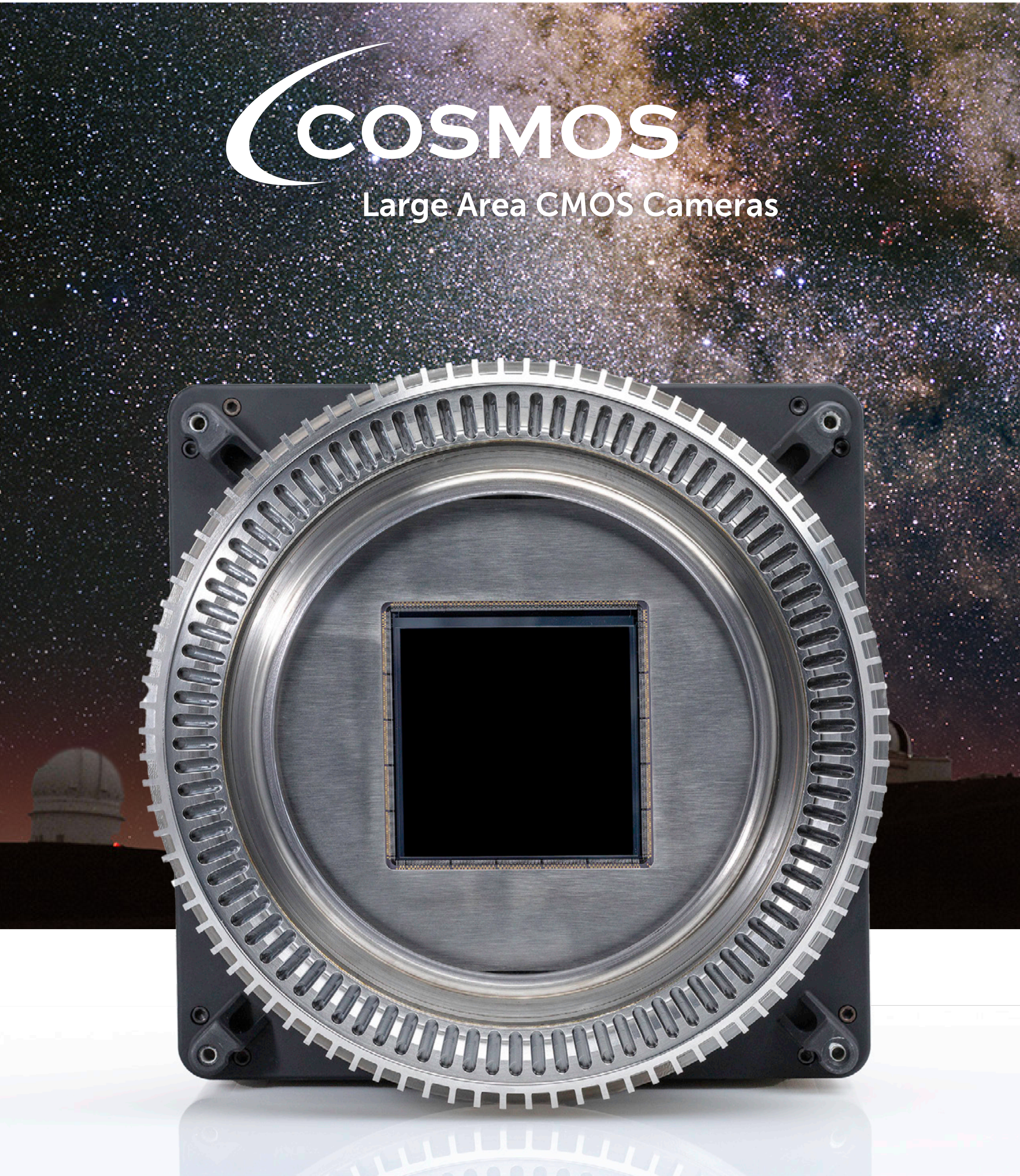
TELEDYNE

The next generation of high-performance, large array cameras for astronomy

COSMOS

Large Area CMOS Cameras



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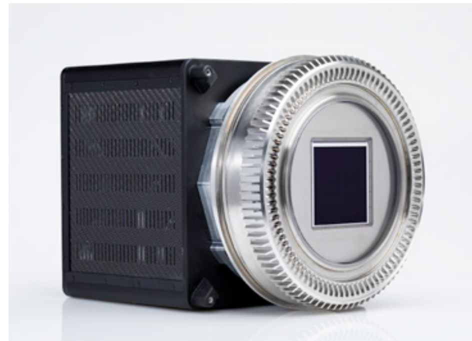
Introducing COSMOS: Merging CCD and CMOS –The Best of Both Worlds

The COSMOS camera meets the increasing demand for higher performing sensor technology by combining the essential elements of both CCD and CMOS technology to create a new generation of devices that is distinctly different from anything currently available on the market. COSMOS is the optimal combination of resolution, pixel size, sensitivity, and speed. It is the only large format, high performance CMOS camera designed and manufactured entirely within a single source.



- < 1 e^- read noise for detection of faint objects
- Up to 8k x 8k sensor sizes for maximum field of view
- > 90% peak quantum efficiency for high sensitivity
- High duty cycle and more than 50 fps for capturing dynamic events
- Large dynamic range to prevent sensor saturation
- Rolling and global shutter

Teledyne's Imaging Heritage

Built upon decades of detector design and fabrication, Teledyne has provided solutions for a wide range of world changing projects, including the JWST, Mars Rover missions and various observatory instruments such as the European Southern Observatory Very Large Telescope (MICADO, HARMONI, METIS, and MUSE). Teledyne has also participated in numerous surveys, including the Javalambre Physics of the Accelerating Universe Astrophysical Survey.

Teledyne's imaging portfolio includes sensors, cameras, and imaging systems that cater to a broad spectrum of imaging needs. These applications range from airborne and space-based platforms to defense and security applications.

Ground Astronomy	Earth Observation	Space Science	Planetary Exploration	Space Astronomy
30+ Telescopes	80 Flown Missions	50 Flown Missions	12 Flown Missions	10 Flown Missions
10 Under Construction	20 Planned Missions	10 Planned Missions	2 Planned Missions	2 Planned Missions
500+ Sensors Delivered	2000+ Years in Orbit	600+ Years in Space	300+ Years Space Exploration	2200+ Years in Space

LACera Technology: Only from Teledyne

Exclusively developed and owned by Teledyne, LACera marks the beginning of a new era in CMOS technology. LACera is a monumental step forward in CMOS capabilities for advanced imaging, enabling the next generation of discovery. The challenge of CMOS sensors has been maintaining performance when scaling to larger formats.

LACera
Large Area CMOS

LACera addresses this challenge by combining high-speed and low-noise architecture. It delivers deep-cooled, low-noise performance on a multi-megapixel scale with a global shutter, 18-bit readout, and glow reduction technology.

LACera is a critical component of advanced imaging solutions and is only possible due to the nature and scale of Teledyne. From pixel, sensor, and ROIC design, through low noise electronics, to deep cooling, and system interface, Teledyne is the only company capable of delivering this 100% organic solution in large-format CMOS.

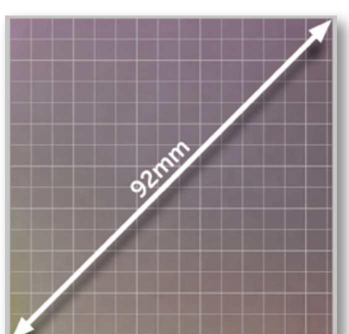
COSMOS: Harnessing LACera Technology

Utilizing the powerful technology of LACera, COSMOS also combines low-noise electronics and novel sensor cooling and packaging to deliver unprecedented performance. Typical CMOS limitations, such as "glow", limited dynamic range, and compromised global shutter, have also been improved to provide a turnkey product that answers the demands of many applications.

COSMOS-3k

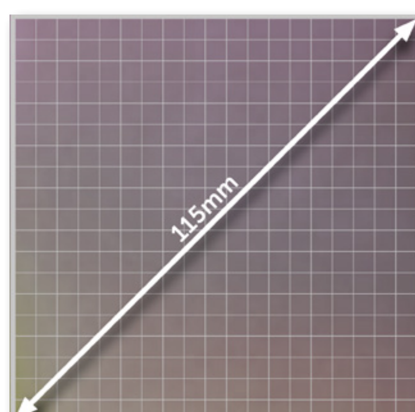
3260 x 3260
10 micron

COSMOS-6k



6500 x 6500
10 micron

COSMOS-8k



8120 x 8120
10 micron

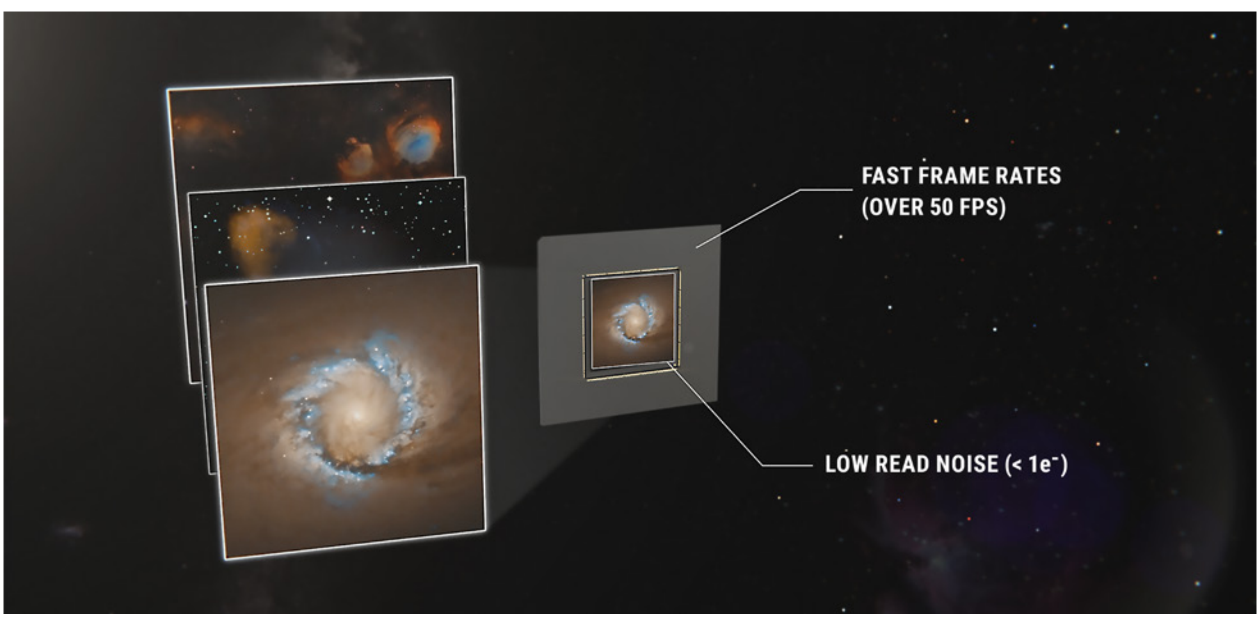
Specifications

Camera Specifications

SPECIFICATIONS	CAMERA PERFORMANCE
CMOS image sensor	Back illuminated; grade 1; 100% fill factor
Dark current @ -25°C (with ambient air @ +20°C)	< 0.05 e^-/p/s (typical)
Quantum efficiency	> 90% Peak QE, See QE curves on page 6
Pixel format	10 µm
Resolution	Up to 8120 x 8120 pixels
Sensor Cooling temperature	< -25°C (typical)
Full well	Single pixel: > 100 ke^- (typical)
ADC settings	14, 16, and 18 bit
System read noise	< 1.5 e^-rms[1], < 1 e^- rms[2]
Shutter	rolling and global
Nonlinearity	< 1%
Binning[3]	2 x 2; 4 x 4
Data interface	CoaXPress®
Operating environment	-30°C to +30°C non-condensing
ROI	Multiple regions of interest
Certification	CE

Specifications are subject to change.

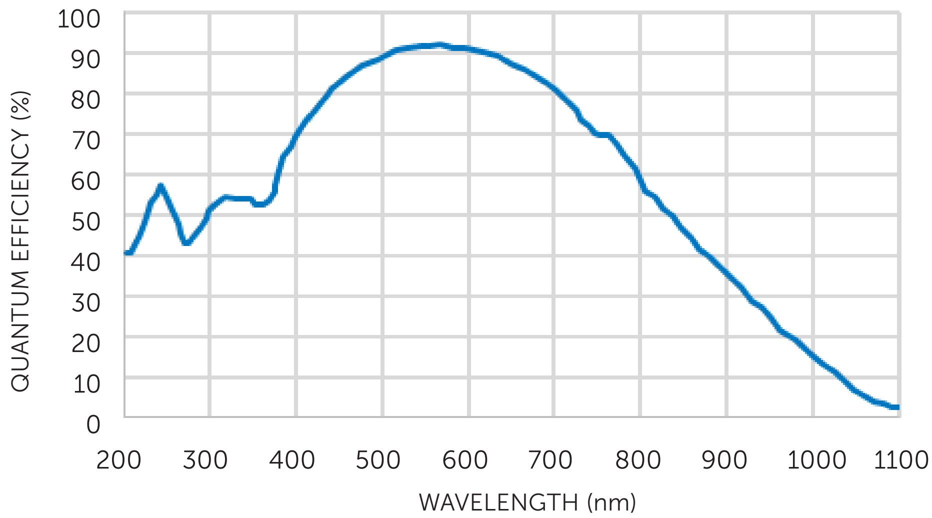
1. Rolling shutter and high gain. Global shutter and high gain < 3 e^- rms
2. With Correlated Multiple sampling and high gain
3. FPGA binning



Key Features Explored

Unbeatable Sensitivity

COSMOS achieves near-perfect light collection thanks to back-illumination, with quantum efficiency peaking at over 90%. What's more, with minimal < 1e⁻ read noise and less than 0.05e⁻/p/s dark current, the COSMOS surpasses both CCD and EMCCD technology in its ability to detect weak signals.



Multiple Readout Modes

The COSMOS sensor can support a wide range of operating modes, utilizing rolling and global shutter modes, high and low gain modes and various bit depth. So COSMOS adapts to your experiment or observation with an optimized configuration.

Data	Gain Setting[1]	Shutter Mode[2]	Read Noise (e^-)	Frame Rate (fps)
16-bit	High – CMS (8x)	Rolling	< 1	0.8
14-bit	High	Rolling	1.4	18.3
14-bit	High	Global	2	18.3
16-bit	Low	Rolling	6	7.4
16-bit	Low	Global	11	6.3
18-bit	HDR	Rolling	1.2	2.9

1. Typical well depth: High gain ~14k e^- / Low gain ~ 100k e^-
2. Global shutter is true global reset and transfer

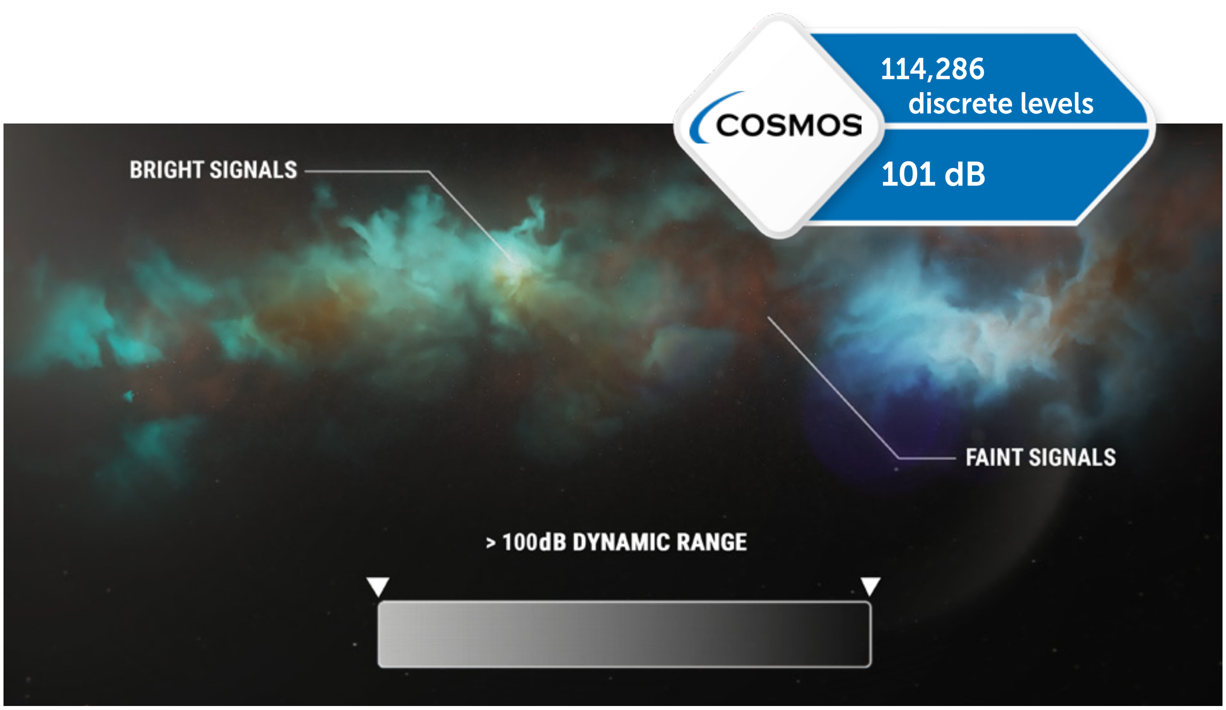
Dynamic Range

What is dynamic range?
Dynamic range is a measure of the total number of discernible signal levels, determined by the peak signal and the noise floor in the signal digitization process. In a CMOS sensor, we seek to find the ratio of the total number of photoelectrons a pixel can store prior to saturation and loss of linearity divided by the read noise. For example, a CMOS pixel with a 10,000 e^- full well (high gain) having a read noise of 3 e^- rms (high gain) has a dynamic range of 3333 or approximately 70 dB.

What dynamic range is not?
Dynamic range is not equivalent to the total number of digitization levels or analog to digital units (ADUs) – i.e., a camera with a 12-bit A/D converter does not necessarily have 12 bits of dynamic range because this does not take into account the noise floor. First, the intrinsic dynamic range of the pixel must be determined, and then enforce that the A/D converters have at least that in bit resolution, preferably higher.

Dynamic range is also not equal to the sum over all bit depths of the A/D converters in a mutli-conversion gain camera operating in high dynamic range (HDR) mode. For example, a camera with two or even three 12-bit sampled images does not have 24- or 36-bits dynamic range.

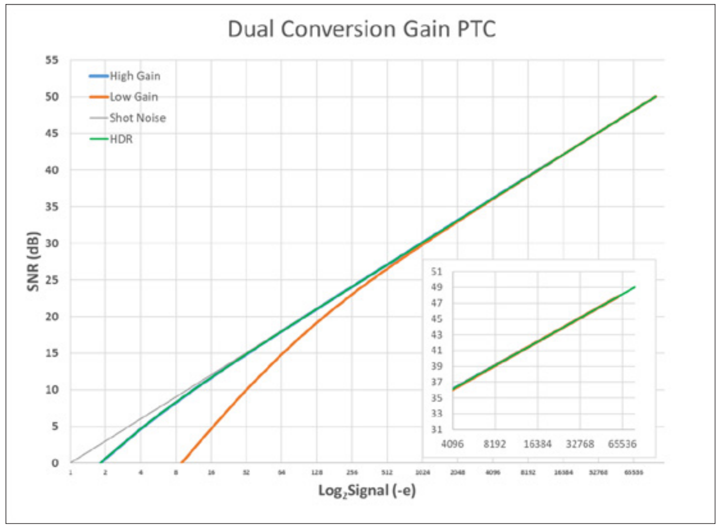
Dynamic range and COSMOS
The combined HDR signal in COSMOS is the merged result of two 16-bit measurements onto a larger 18-bit range. By combining the low read noise, along with the intrinsically low noise of the analog to digital converters (ADC), COSMOS enables accurate measurement of weaker signals and unlocks wider dynamic range. However, the dynamic range is still bounded by the read noise floor in high gain and the FWC in low gain. As such, the COSMOS has a dynamic range of 80,000 e^-/0.7 e^-rms, which is equivalent to 114,286 discrete levels or approximately 101 dB.



Shot Noise Limited HDR

It is common practice in sCMOS sensors to enhance dynamic range by combining two or even three conversion gains within a single CMOS pixel. This imaging modality is commonly referred to as high dynamic range or HDR. To understand how dynamic range is enhanced in HDR readout modes, one must first consider how read noise and full well capacity are affected by changing gain and how the final photon transfer curve (PTC) is established.

The PTC for the COSMOS sensor, in 16b high gain and 16b low gain HDR modes can be seen in the left-hand side graph. The PTC shows excellent stitching at the crossover point, with a combined HDR of 80,000 e⁻/0.7 e⁻, equating to 101 dB. This PTC curve is mapped onto an 18-bit output with a final gain of approximately 0.3 e⁻/ADU.



HDR Readout Mode

Teledyne's proprietary 18-bit HDR mode utilizes dual conversion gain to increase full well capacity (FWC) while maintaining ultra-low noise performance. In HDR mode, each pixel is sampled twice – once with high gain and once with low gain conversion.

The high gain readout provides ultra-low temporal noise, which is critical for sampling low light signals with reduced FWC. Low gain readout provides higher FWC for sampling intense signals dominated by photon shot noise where low temporal noise is less critical.

These two gain mode readouts are then combined into a single image, preserving the best of both worlds – ultra-low noise and high FWC. This approach provides an exceptional dynamic range, making it a critical component of advanced imaging solutions.

HIGH GAIN IMAGE

16 bit | 12k e^- FWC

0.7 e^- rms with CMS

LOW GAIN IMAGE

16 bit | 80k e^- FWC

< 9 e^- rms with CMS

HDR IMAGE

18 bit

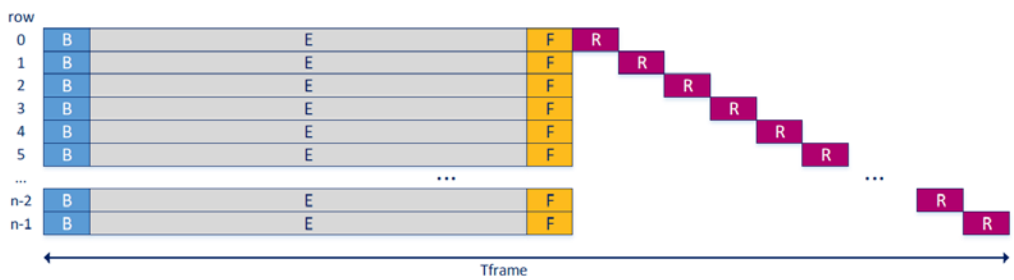
101dB dynamic range

Shutter Modes

CMOS sensor technology takes advantage of electronic shutters, removing the error, maintenance, and speed limitation associated with physical mechanical shutters. Although typically CMOS technology only provides rolling shutter modes, COSMOS implements both rolling and global shutter modes.

Global Shutter

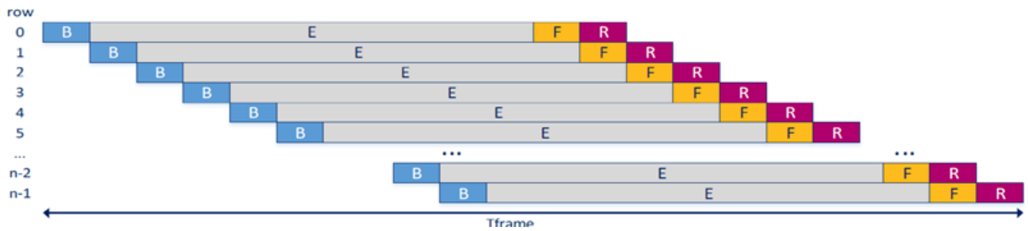
This is achieved on CMOS through the addition of a ‘storage area’ on each pixel, where the collected signal is stored at the end of an exposure, prior to being read out. Global shutter wasn’t previously possible on back-illuminated devices, as the storage area would be exposed to light by the back-illumination processes. This meant that ‘parasitic’ light could be detected while pixels were awaiting readout. COSMOS utilizes proprietary pixel design to store converted photoelectrons, without exposing the storage area to light.



Row-by-row readout after global F states in global shutter

Rolling Shutter

This mode yields low noise due to the cancellation of the reset noise due to on-chip “true” Correlated Double Sampling. Both the image acquisition and readout are performed in a row-by-row basis in rolling-shutter mode.



Rolling shutter row-by-row exposition and readout

Fast Frame Rates

With fast frame rates and high sensitivity, COSMOS is well suited to dynamic imaging applications. Further, the short readout times can enable quick decision making and analysis.

Frame rate at full resolution, High Speed Mode, Rolling Shutter		
	Resolution	Frame rate
COSMOS-8k	8120 x 8120	18
COSMOS-6k	6500 x 6500	22
COSMOS-4k	4800 x 4800	37
COSMOS-3k	3260 x 3260	56

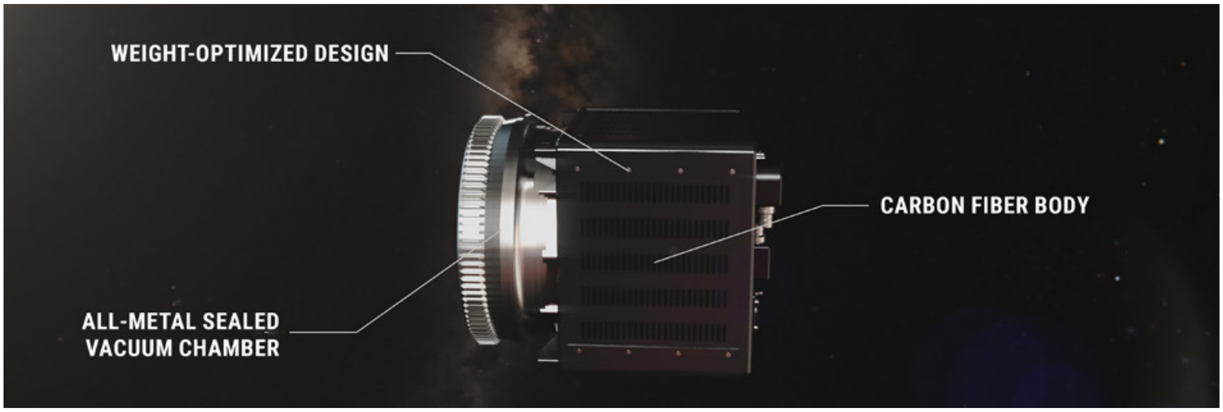
Frame rate at reduced frame size, (COSMOS-8k)			
Region of interest size (pixels)	14 bit rolling and global shutter	16 bit global shutter	18 bit HDR
8120 x 8120	18.3	6	2.9
4096 x 4096	36	12	6
2048 x 2048	73	24	11
1600 x 1600	93	31	15
1024 x 1024	144	48	23
512 x 512	288	96	45
256 x 256	572	189	88

Deep Cooling & Vacuum

For many astronomical observations, long exposure times are needed, thus deep camera cooling is necessary to reduce the thermal dark current noise. However, large CMOS sensors with high speed readout in fact generate a large amount of heat, even compared to CCD sensors.

The COSMOS builds on Teledyne's industry-leading cooling performance to overcome this challenge, achieving below -25°C cooling with low dark current, as shown by the test pixel data.

This is further improved by the long lifetime, all-metal, hermetically sealed vacuum enclosure, preventing the outgassing or degradation problems of other cameras.



Hardware Interface

The COSMOS camera utilizes the CoaXPress frame grabber for high-speed image transfer. It is specifically designed to work with Teledyne's high-performance Xtium™ CXP PX8, which ensures maximum throughput and ready-to-use image data.

The COSMOS camera is not compatible with all CoaXPress frame grabbers as GENICAM is not supported. However, it is specifically engineered to function seamlessly with the Xtium frame grabber. The necessary drivers and interfacing are provided through the PICam software drivers.

Key Parameters

CoaXPress 2.0 4-Lane CXP12

- 50 Gpbs of data bandwidth
- Full data rate with 15m cable length
- Host computer requires a PCIe Gen 3.0 x8 slot
- 75-ohm coaxial cables required (provided)

Software Interface

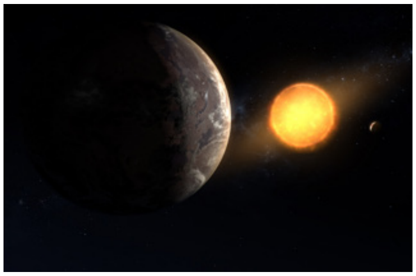
PICam API and SDK, from Teledyne Princeton Instruments offers complete control over all cameras. Available for all 64-bit Windows and Linux systems, PICam configures the identified hardware by adjusting parameters within its interface. PICam allows for the ultimate flexibility, providing developers, scientists and integrators the ability to build their own control and user interface directly on top of the driver.

For those who require a "plug-and-go" system, LightField® Software allows for complete control of COSMOS on an ease of use platform. LightField software also includes simple, image post-processing software and a built-in, smart math engine to obtain the most from acquired data.

Applications

Exoplanets

Exoplanet study is at the forefront of astronomy, with various techniques, such as transit imaging and direct imaging used for identification and characterization.These techniques often require tens of seconds of exposure time, therefore a camera with the lowest noise, (dark current), is imperative for best signal detection. Deep cooling and a read noise of < 1 e^-, 3x lower than our world-leading CCD sensors, empower COSMOS to detect faint objects over longer exposure times. Greater than 90% peak quantum efficiency is achieved with COMOS' back-illuminated sensor, allowing for detection of faint objects or even the slightest changes in brightness.



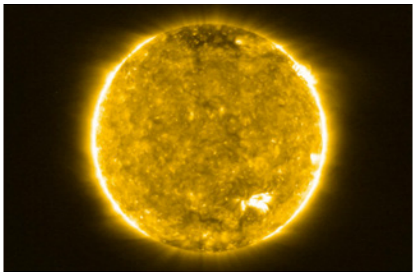
credit: NASA Ames Research Center
Daniel Rutter

Orbital Object Tracking

Orbital object tracking involves monitoring objects within Earth's orbit, such as asteroids, space debris, or satellites. Lower orbit objects move rapidly across the sky, requiring a large field of view to most accurately capture the object's position. The large field of view of the COSMOS allows low orbital objects to be captured over a longer period of time, resulting in minimal movement of the telescope tracking system. The high frame rate ensures accurate tracking throughout the entire movement of the object across the sky. Higher orbital objects are typically fainter and thus require higher sensitivity cameras. The >90% quantum efficiency achieved by COSMOS allows for detection of these fainter objects, with the low read noise allowing for fast image capture, without sacrificing sensitivity.

Solar Physics

The Sun is continually changing. Studying these dynamic events can provide valuable insight into the processes within a star. With high spatial and temporal resolution, the COSMOS allows for accurate investigation into the dynamic events of the solar atmosphere. The large pixel size and large pixel array of the COSMOS provides the most comprehensive field of view, allowing capture of the entire area of an event, such as a sunspot, to be imaged within one sensor.

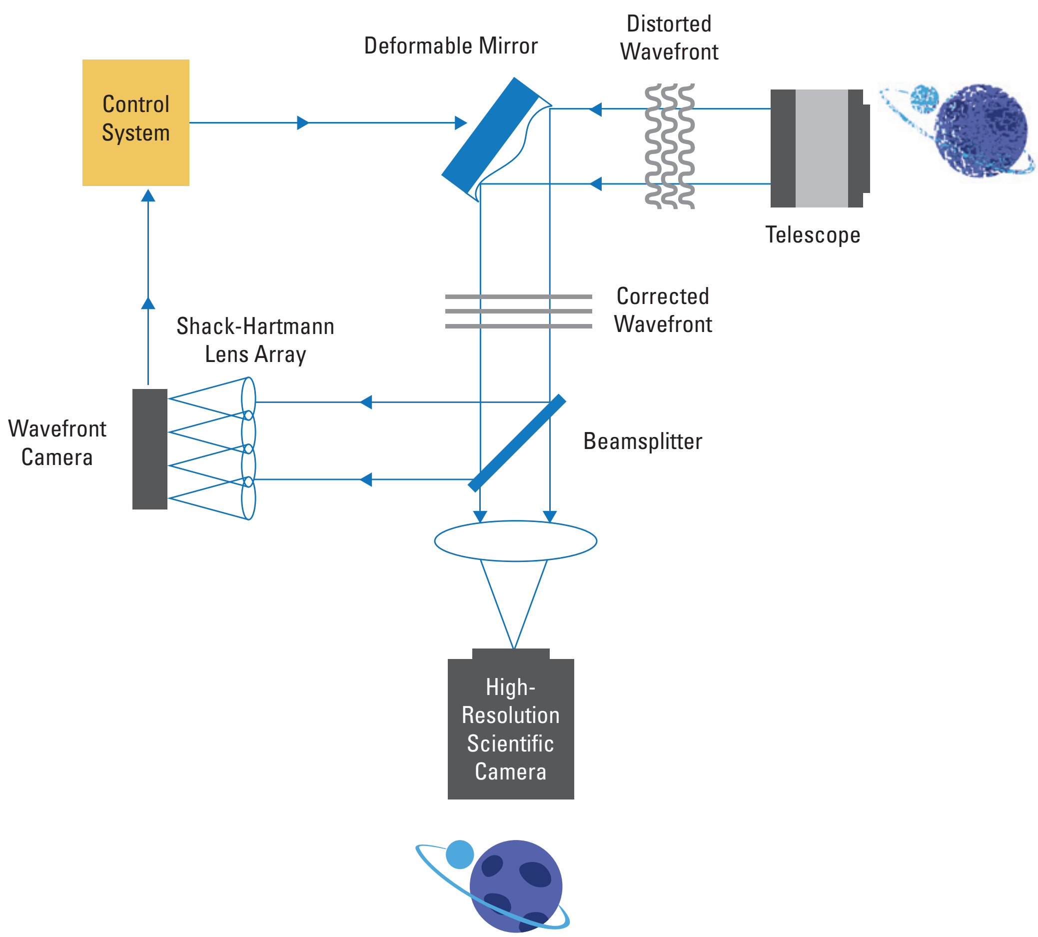


Techniques

Adaptive Optics

Adaptive optics is a technique that provides higher resolution images by counteracting the effects of atmospheric turbulence. In order to correct for these atmospheric changes, the adaptive optics system utilizes a camera with both fast frame rates and low read noise to feed back into the telescope system to make atmospheric adjustments.

With a read noise of < 1 e^-, the COSMOS is able to capture faint stars that are closer to the scientific object of interest. The COSMOS also provides fast frame rates without sacrificing sensitivity, with read noise remaining at X e^- rms which achieving frame rates of X. These frame rates combined with short frame times of the COSMOS allow for rapid system adjustments in the most turbulent of atmospheres.

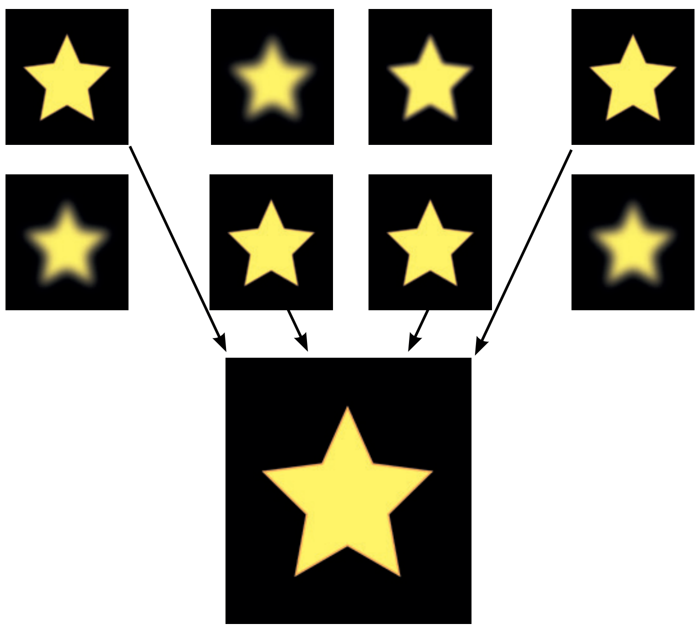


Speckle and Lucky Imaging

Speckle and lucky imaging are two alternative methods for counteracting atmospheric turbulence, which both utilize rapid image acquisition to "freeze" turbulence motion, overall improving image resolution. These techniques both require a camera with fast readout and low noise, not only to counteract the effects of turbulence, but to also detect the object of interest with much shorter exposure times.

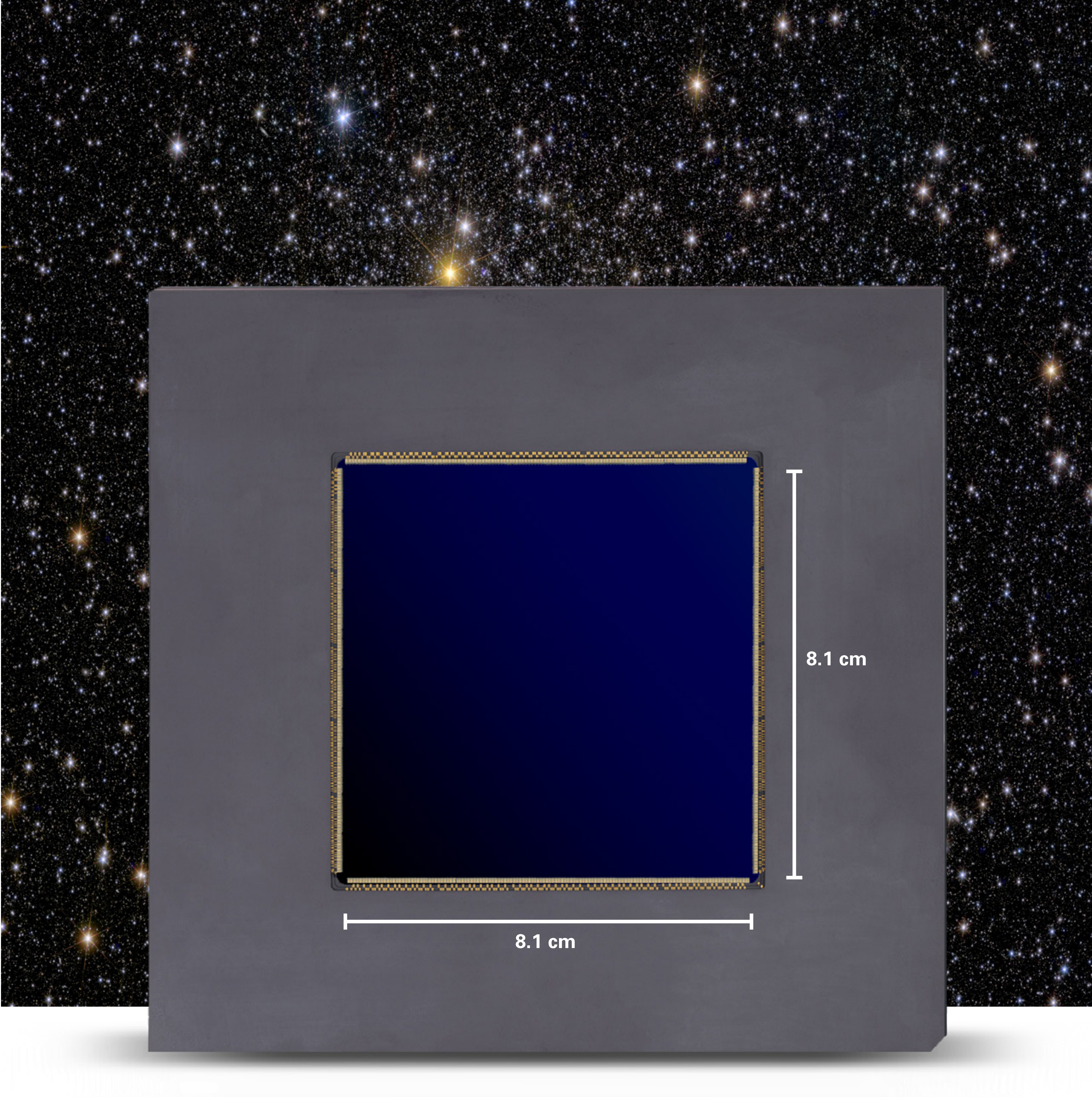
The COSMOS camera is able to combine short exposure time with fast frame rates of up to 50 fps, allowing for rapid image capture to deliver diffraction-limited imaging. COSMOS is also able to maintain low read noise at higher speeds without sacrificing sensitivity, allowing for fainter objects to be imaged using these techniques.

Multiple frames taken rapidly to "freeze" turbulence motion



Diffraction limited image

CMOS technology exclusively developed and owned by Teledyne



COSMOS-8k

actual size

TELEDYNE

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Specifications in this datasheet are subject to change. Refer to the Teledyne Princeton Instruments website for most current specifications.

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