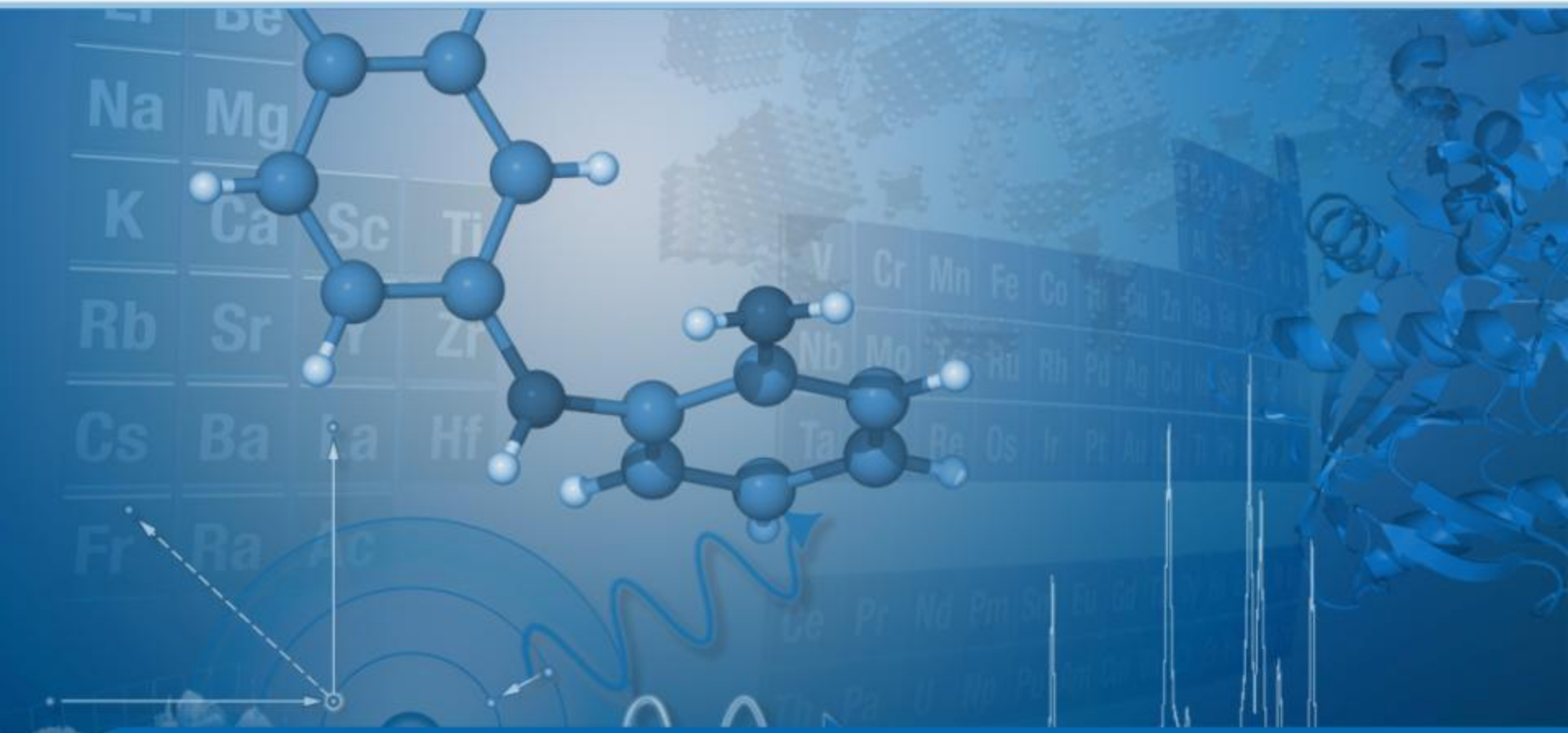
The PHOTON 100: The First CMOS Active Pixel Sensor for X-ray Crystallography

Bruker AXS
Madison, WI



Welcome

Today's Topics

- Image Sensors
  - CMOS vs CCD
  - Scientific applications
- Introducing the new PHOTON 100
- D8 Crystallography Solutions
  - D8 QUEST
  - D8 VENTURE
  - PHOTON 100 data

Speakers

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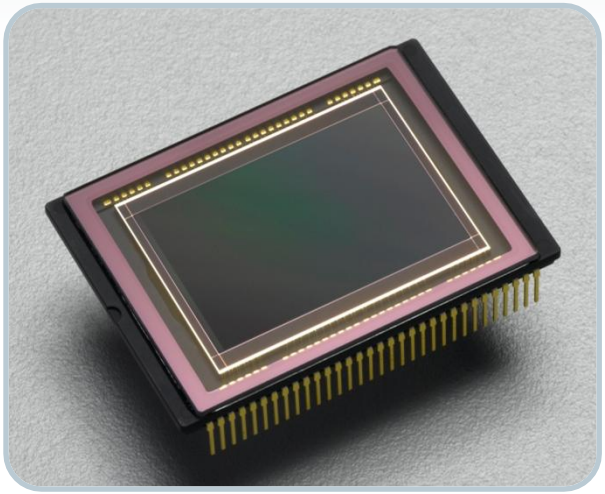
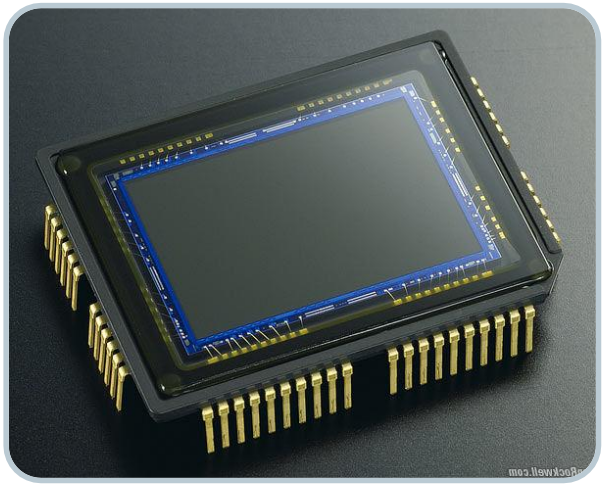
Image sensors
http://en.wikipedia.org/wiki/Image_sensor

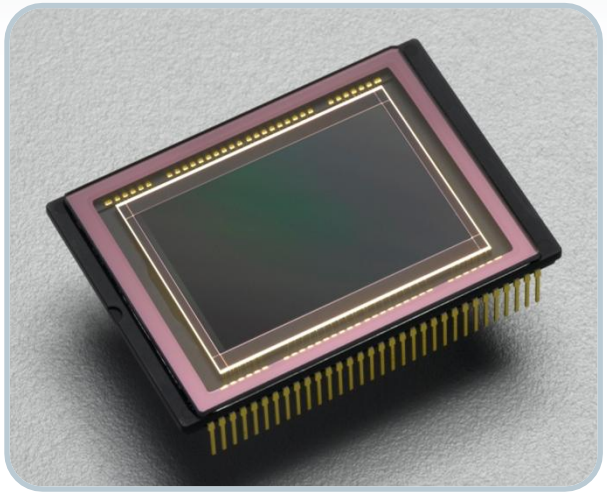
- An image sensor is a device that converts an optical image into an electronic signal
- A modern sensor is typically a charge-coupled device (CCD) or a complementary metal–oxide–semiconductor (CMOS) active pixel sensor
- Both types of sensor accomplish the same task of capturing light and converting it into electrical signals
- Both types of sensor are silicon devices

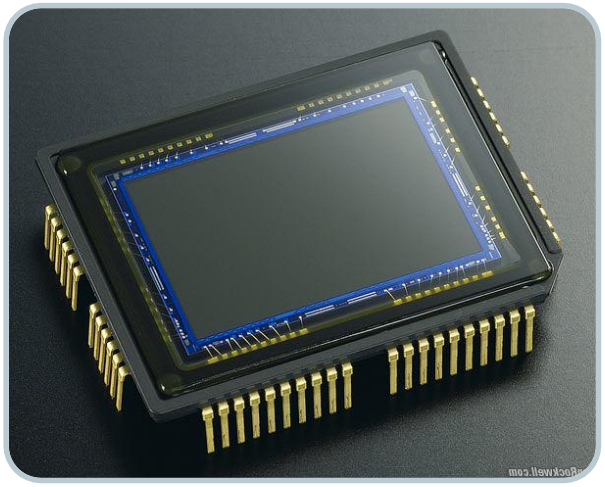




CMOS versus CCD

- CMOS detector technology has begun to rapidly displace CCDs in most high-end applications
- CMOS technology provides many advantageous features and is quickly developing
- CCD technology has matured and has reached its performance limit "as good as it gets"





CMOS Sensor Technology in professional photography

- Google:
  "Best professional digital SLR cameras review"

- All major manufacturers' flagship professional digital SLR cameras use large format CMOS sensors

  - **Nikon**'s D3X uses Nikon's FX-format CMOS sensor
  - **Canon**'s EOS-1D Mark III/IV uses Canon's full frame CMOS sensor
  - **Olympus**' E-3 uses the 4/3 type Hi-Speed Live MOS sensor
  - **Sony** Alpha DSLR-A900
  - **Pentax** K-7

CMOS Sensor Technology in professional photography

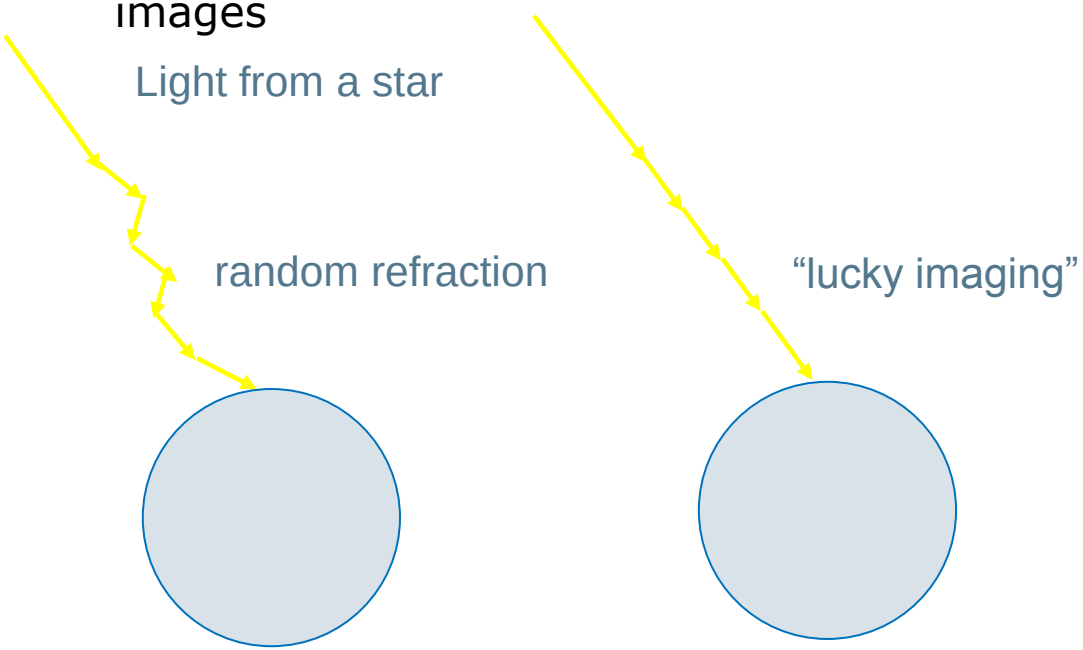
- Current good quality sensors in digital cameras are photon noise limited (counting statistics)
- The foremost factor distinguishing high-end sensors for professional use from other image sensors is
  - The larger pixel size, which allows it to collect more light
  - Larger sensor size
- Larger pixels have higher signal-to-noise ratio at all levels, but especially at low signal levels

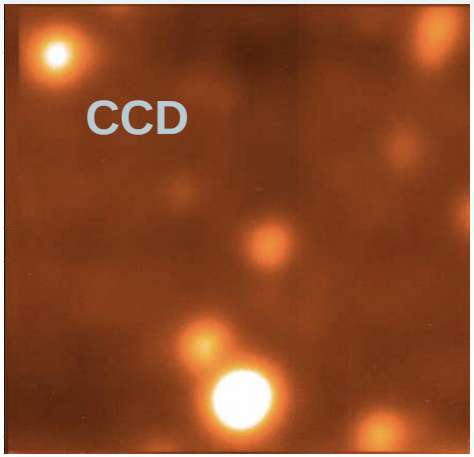
- The Nikon FX-format sensor has a size of 36 mm × 24 mm with a pixel size of 8.45 µm × 8.45 µm

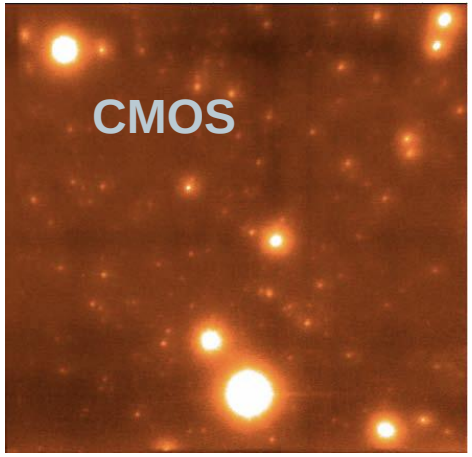
- **Bruker's CMOS sensor is 11.5 times larger and its pixels have a 130 times larger area!**

CMOS Sensor Technology in scientific applications

- Astronomy - Stellar scintillation
  - the light of the star is refracted many times and in random directions when it hits a change in density in earth's atmosphere
  - Sensitive, low-noise, high-speed CMOS sensors are used to selectively assemble undistorted images



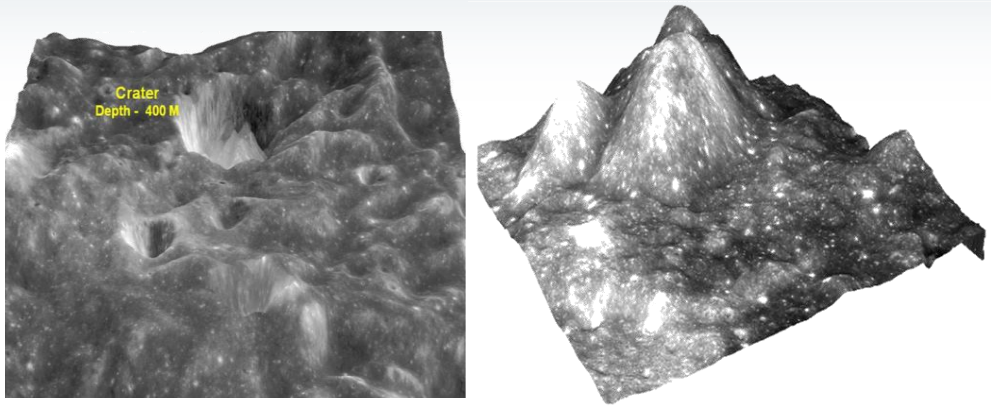




Astronomy: Palomar 5m "Lucky Imaging"

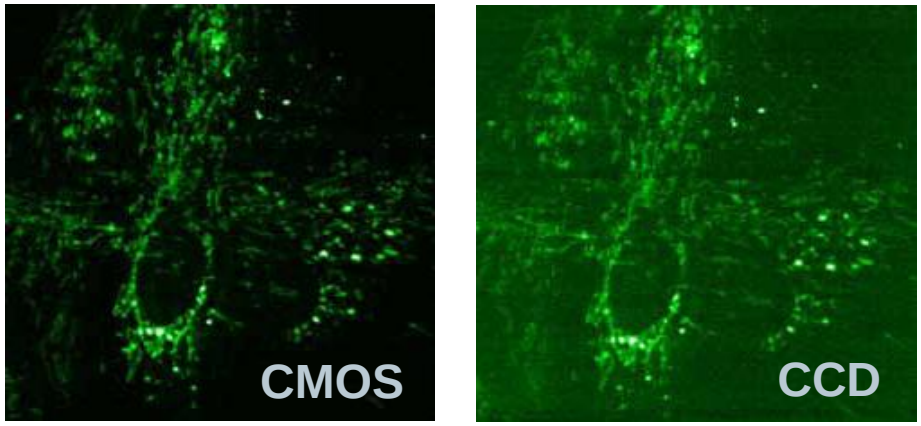
CMOS Sensor Technology in scientific applications

- Terrain Mapping Cameras
  - CMOS Hyper Spectral mapping of lunar surface in visible and near infrared spectral regions
  - …Very high dynamic range of the sensor helps in taking excellent features of dark polar sections of moon surface…



Satellite Imaging: TMC

- Light microscopy
  - …CMOS is unique in its ability to simultaneously offer ultra-low noise, extremely fast frame rates, wide dynamic range, high resolution and a large field of view…

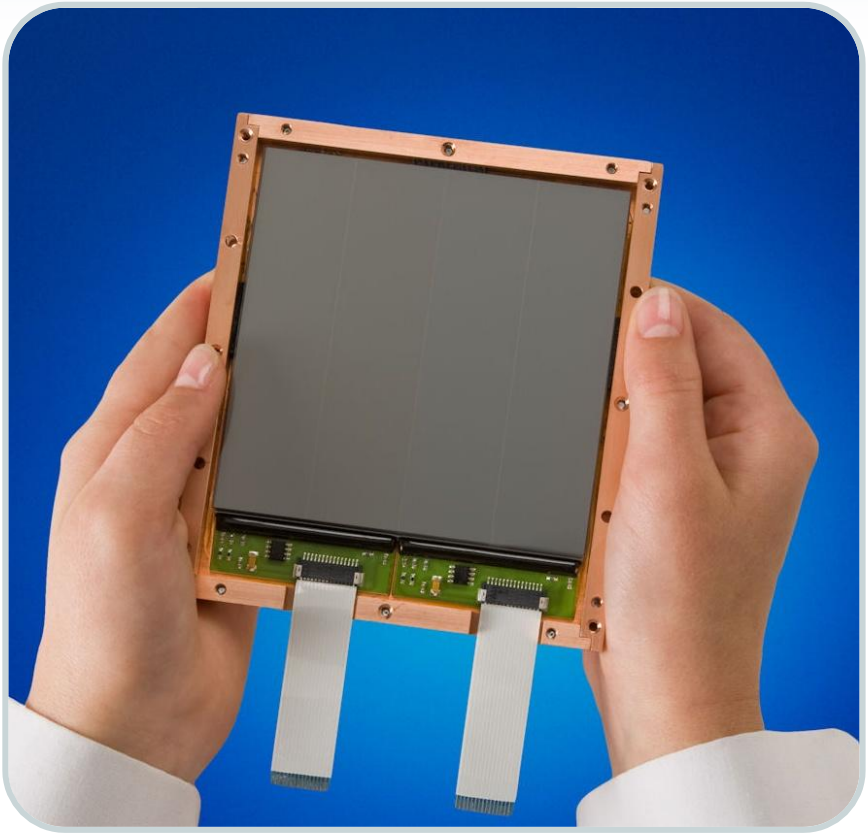


Microscopy: Fluorescently labeled fixed cell (x60 oil objective)

New PHOTON 100 Detector for X-ray crystallography

- Large 100 cm^2 sensor for fast and efficient data collection
- Low-power consumption sensor for high-reliability
- Air-cooled for low maintenance
- High sensitivity
- No glass fiber taper for superior spatial accuracy
- Optimized pixel size and point spread function for superior signal
- Large pixel volumes for best light conversion

PHOTON 100 CMOS Sensor for X-ray crystallography



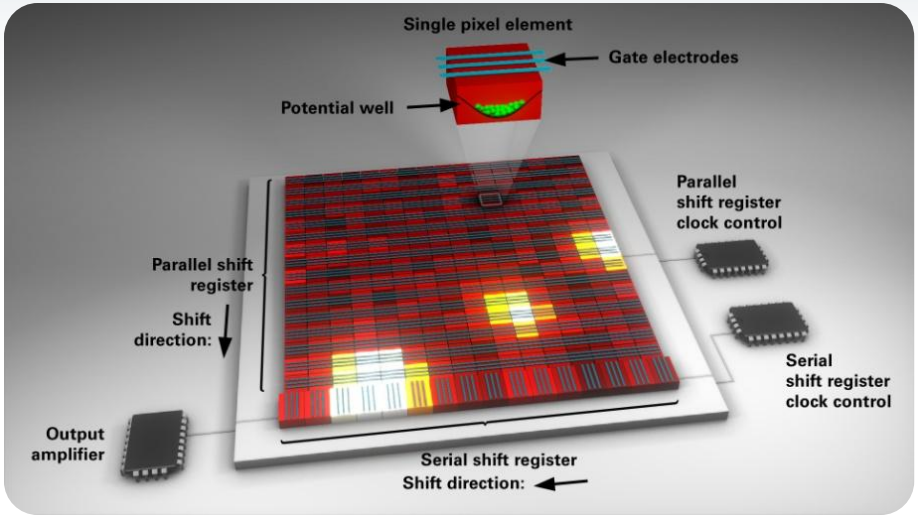
- First CMOS active pixel sensor for X-ray diffraction
- Large 10 x 10 cm^2 active area
- Seamless, no gaps or dead areas
- 96 micrometer pixels
- High sensitivity, near quantum limited
- Fast 0.5 sec readout for fast data collection
- Real-time hardware data correction
- No frame correlation needed
- No blooming or streaking for best data quality

- *Capable of continuous scan mode – shutter-less operation*

Introducing the PHOTON 100

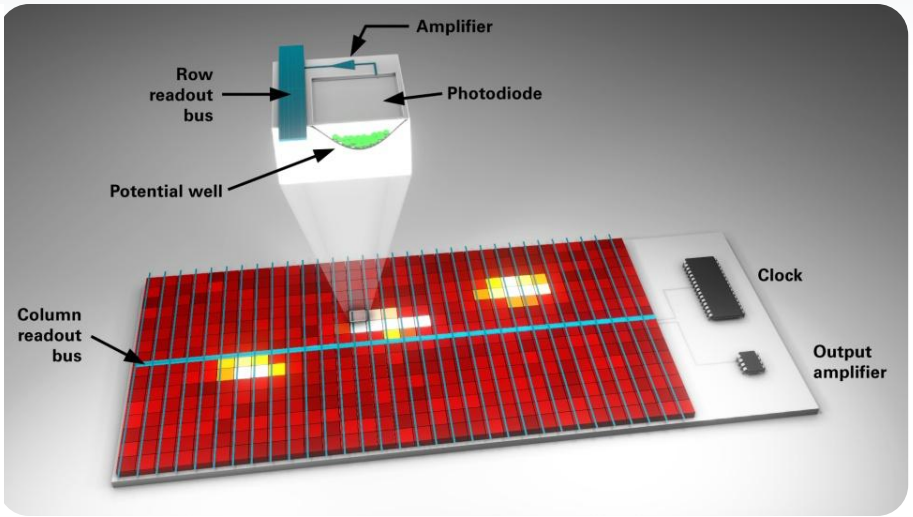
- The first CMOS active pixel sensor (APS) detector for crystallography
- 100 x 100 mm^2 active area
- Taper-free: no demagnification
- Air-cooled
- Cu/Mo/Ag
- High sensitivity
- High reliability
  - 3-year detector warranty
- Fast readout
  - *Zero readout dead time mode*

CCD



- CCD: charge is shifted from one pixel to the next until it reaches the readout amplifier
  - Similar to a shift register

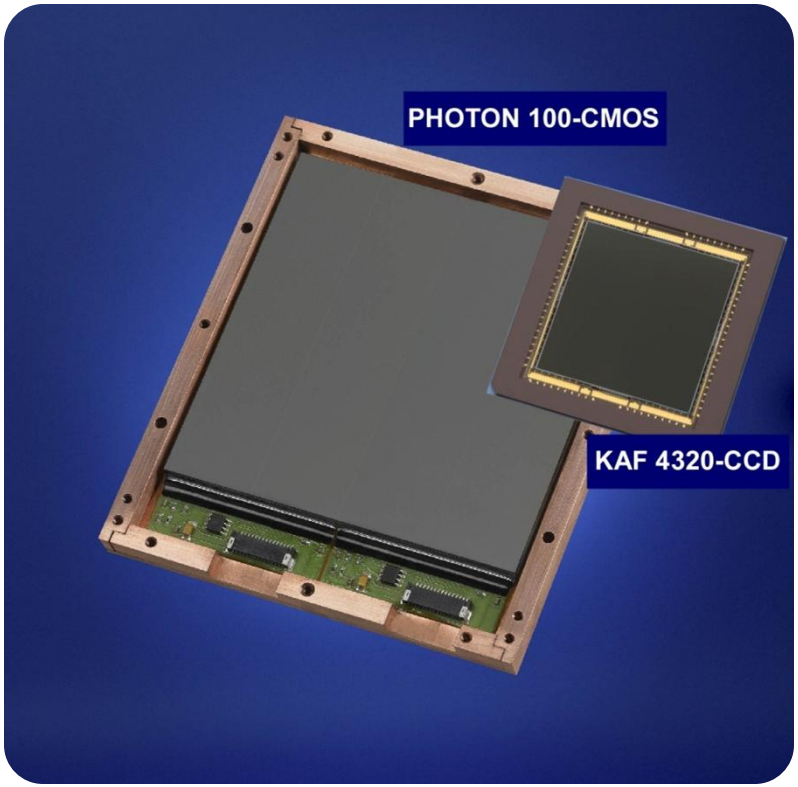
CMOS active pixel sensor



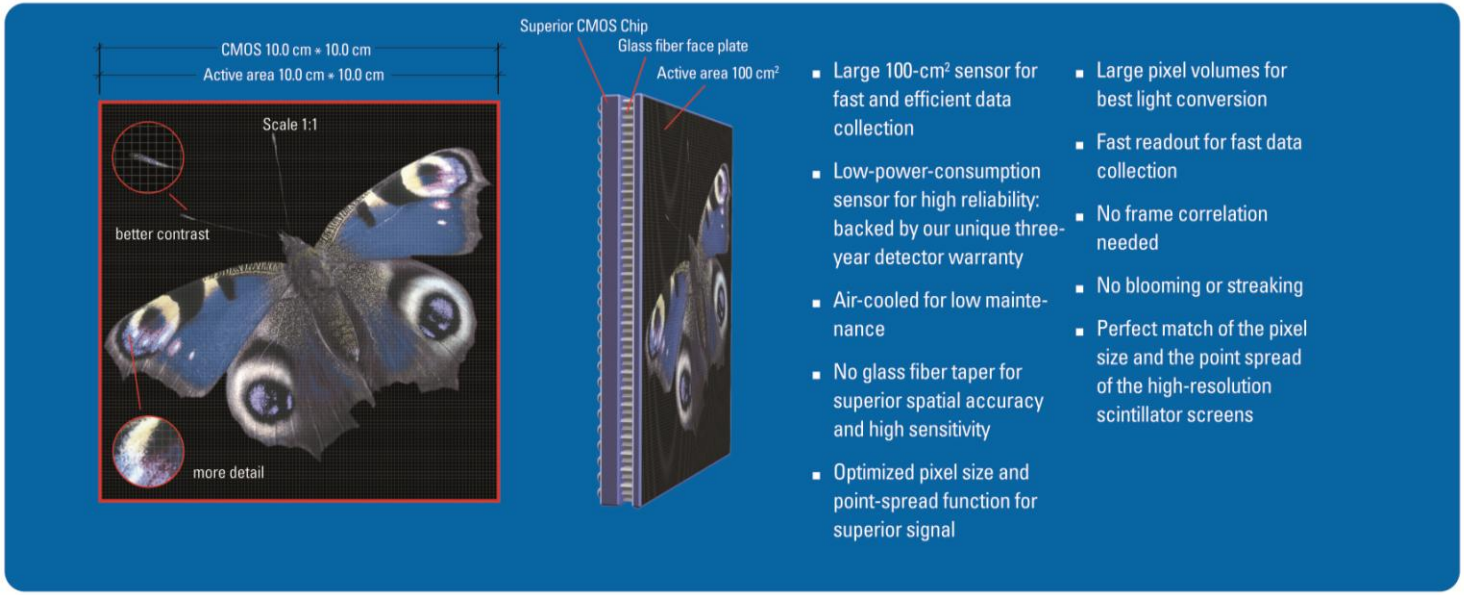
- CMOS: charge is readout from each pixel through a readout bus
  - Similar to a random access memory
- X-rays converted in phosphor screen (like CCD)

PHOTON 100 CMOS imager

- The world's largest production sensor for X-ray imaging
  - 100 x 100 mm^2
  - 1024 x 1024 pixels
  - Exclusive to Bruker
- 4 times larger than the KAF 4320 CCD used in many detectors



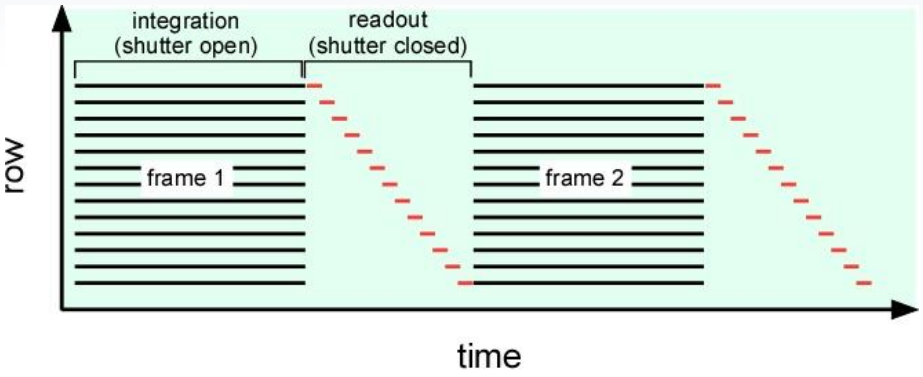
PHOTON 100: taper-free design



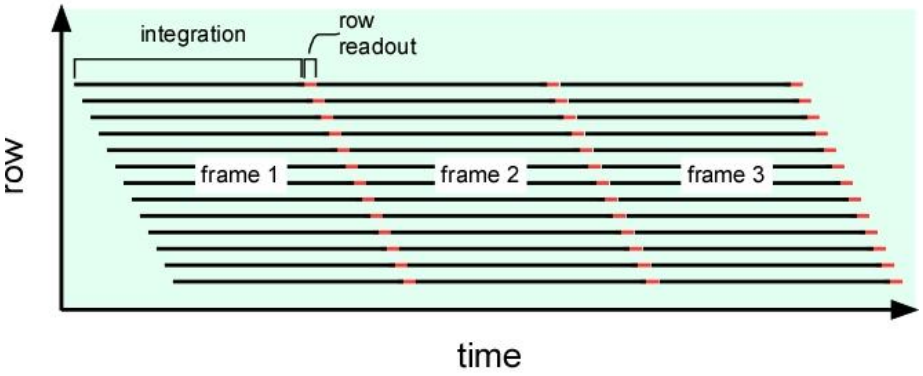
- Like the APEX II, the PHOTON 100 does not require a fiber optic taper
  - Better sensitivity
  - Better spatial resolution
  - No distortion (better unit cells)
  - No zingers!

CMOS continuous scans: “shutter free”

- Unlike a CCD, a CMOS detector can be readout without closing the X-ray shutter
  - This eliminates the dead time between frames
    - Significantly decreases “wall time”, especially for short exposures
  - Also eliminates timing jitter (which for short frames can be the dominant error)
    - 0.5 sec jitter error 2%!



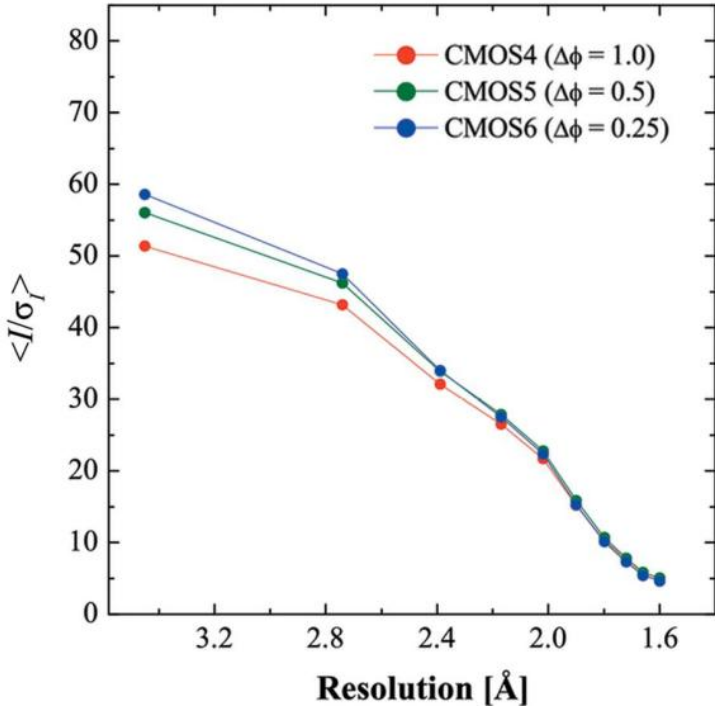
a) Conventional (CCD) readout with mechanical shutter



b) CMOS readout with electronic (rolling) shutter

How do continuous scans improve data?

- Hasegawa et al. (SPRING-8) studied the effect of continuous scans on data quality
  - 2-sec exposures, lysozyme
  - Reported 10-20% improvement in I/σ depending on exposure time
  - Equivalent to 20-40% increase in intensity (or exposure time)



How does the PHOTON 100 compare to conventional detectors?

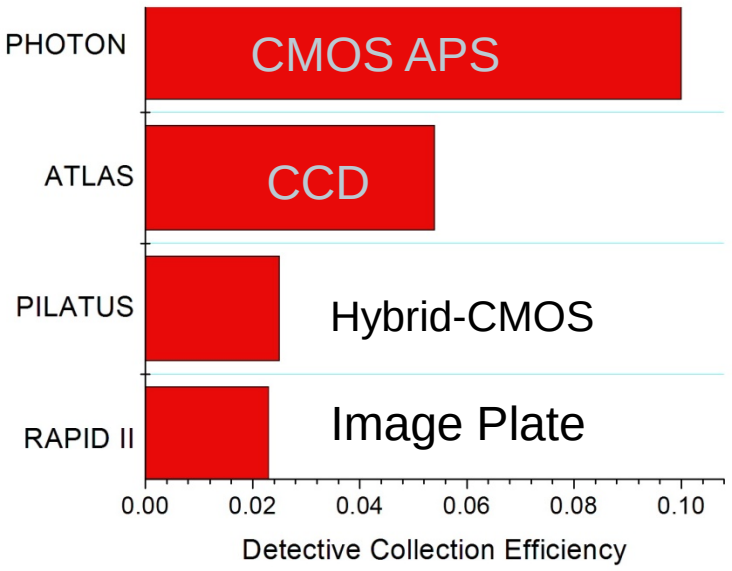
- Detective Collection Efficiency (DCE) quantifies the contribution of detector size, sensitivity, and readout speed on performance
- DCE is proportional to the "wall clock" time to achieve equivalent data statistics

$$DCE = \frac{\Omega}{4\pi} DQE \left(1 - f_{dead}\right)$$

size

sensitivity

speed



PHOTON 100: A "smart" camera

- In CCD detectors corrections (dark, flood, bad pixel, and spatial) are applied *after* readout in software
  - Slows down data acquisition and processing
- In the PHOTON 100, all corrections are applied *inside the camera,* in real time in a high performance pipeline processor
  - Data output from camera is *fully corrected*
    - No added dead time
  - Flood field and dark files stored *in the camera* non-volatile memory
    - New floods and darks can easily be collected and stored (in the camera) by the user
  - Up to 125,000 frames of data can be stored in the camera memory (250 GB)

Other CMOS advantages: Resistance to blooming

- CCDs suffer “blooming” of strong signals
  - Typically seen as a degradation in the quality of low resolution data
- CMOS is immune to blooming
  - Handles strong signals better, delivers superior low resolution data

PHOTON 100 comparison to CCDs: The details

	PHOTON 100	Agilent ATLAS
Active area (mm^2)	100 x 100	100 x 100
Sensor size (mm^2)	100 x 100	50 x 50
Gain (electrons)	450	80*
Detective Collection Efficiency	0.1	0.05
Dynamic range	16,000	14,000*
Taper	No	Yes
Spatial Distortion	No	Yes
Cooling	Air	Water
Anti-blooming	Yes	No
Real-time data correction	Yes	No
Continuous scans (shutter-free)	Yes	No
Warranty (years)	3	1

*Measured

Other PHOTON advantages: reliability

- CMOS detectors exhibit higher reliability (that is, a longer Mean Time Between Failures) due to lower operating voltage
    - CCD: 30 V
    - CMOS: 3 V
- ***We are passing this reliability advantage on in the form of the first (and only) 3-year factory warranty for the PHOTON 100***

Summary

- The PHOTON 100 is the next generation of X-ray detector technology
- Large active area
  - No fiber taper
  - No dead areas
  - No zingers
- Air-cooled
- High sensitivity
- Intrinsic anti-blooming
- Smart camera: built in processor, memory
  - Real time corrections
- Shutter-free operation
- High reliability: 3-year warranty

D8 Crystallography Solutions

D8 QUEST

D8 VENTURE

D8 QUEST Configurations

- Single-source sealed tube and IμS systems
- TRIUMPH optional
- FIXED-CHI
  - Manual track
  - Motorized track
- KAPPA
  - Motorized track
- PHOTON 100
- All air-cooled configurations
- Low-temperature device
  - KRYOFLEX II
  - Cryostream

D8 VENTURE Configurations

- Single-source sealed tube and IμS systems
- Dual-source systems
  - Sealed tube – IμS
  - TRIUMPH optional
  - IμS - IμS
- FIXED-CHI
  - Manual track
  - Motorized track
- KAPPA
  - Motorized track
- PHOTON 100
- All air-cooled configurations
- Low-temperature device
  - KRYOFLEX II
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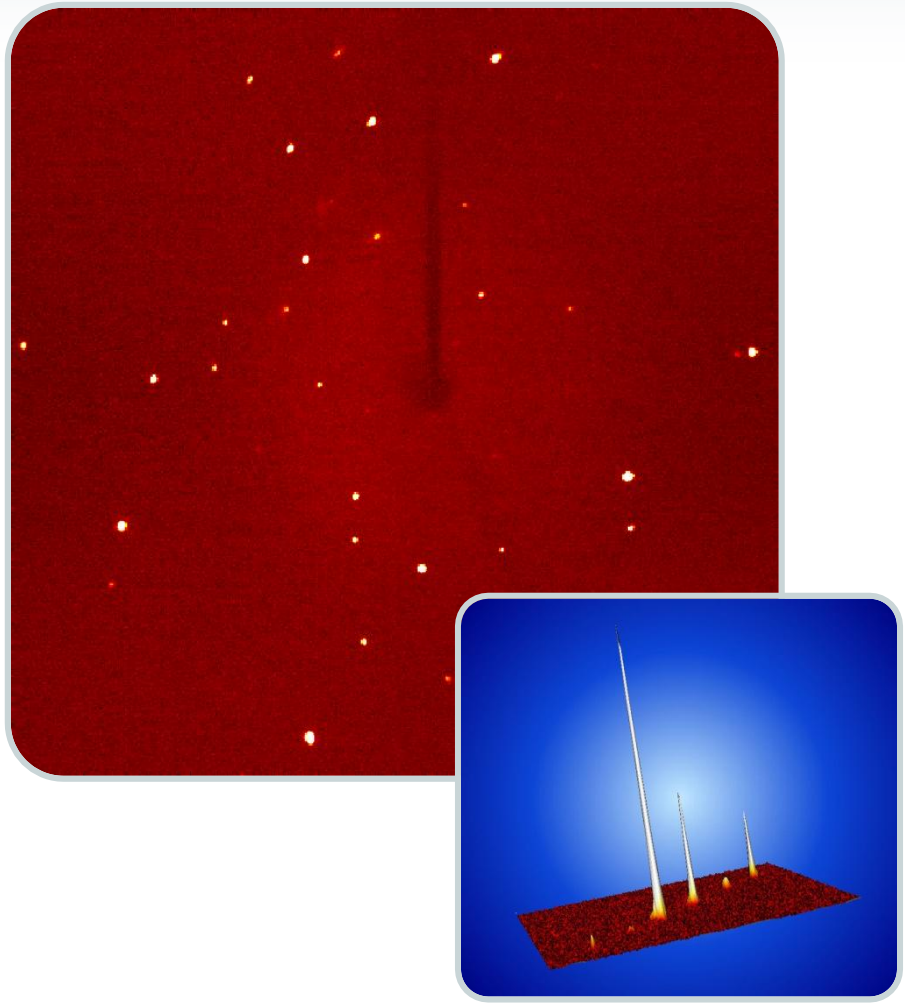
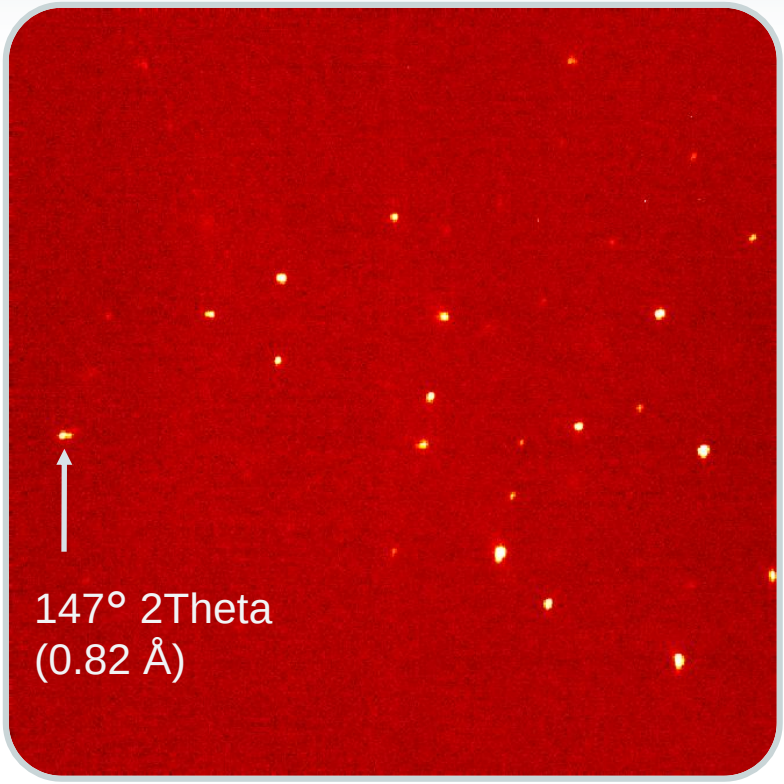
PHOTON 100 data



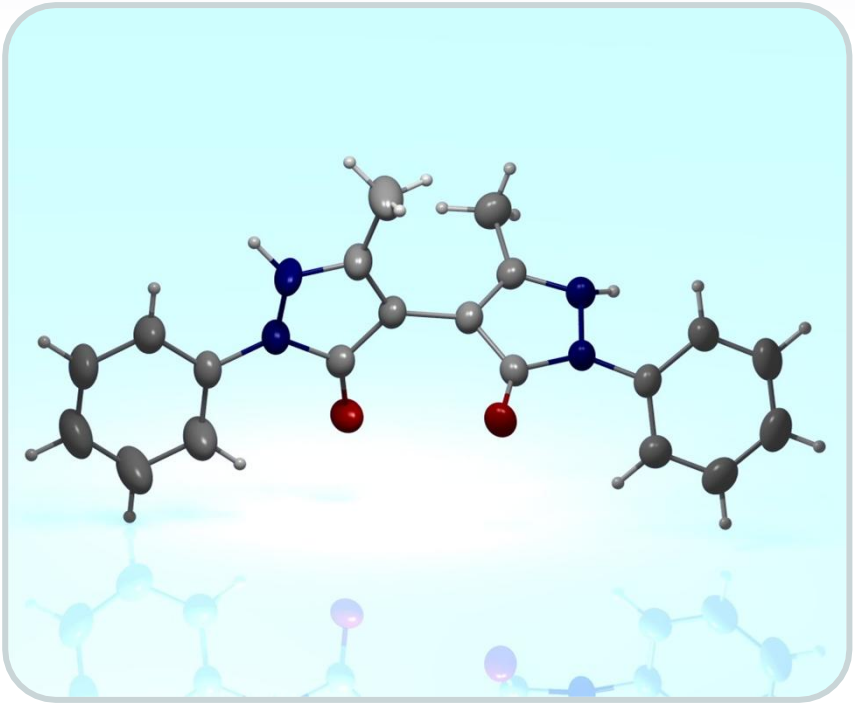
- Large field of view
  - 87° in 2Theta at 5 cm distance
  - 109° in 2Theta at 4 cm distance
- Homogenous background
- No gaps
- Low noise
  - Beamstop shadow and mount shadow are visible from a 10s exposure
- Large dynamic range
- Good spatial resolution

PHOTON 100 data
D8 VENTURE with IμS™ Cu MX



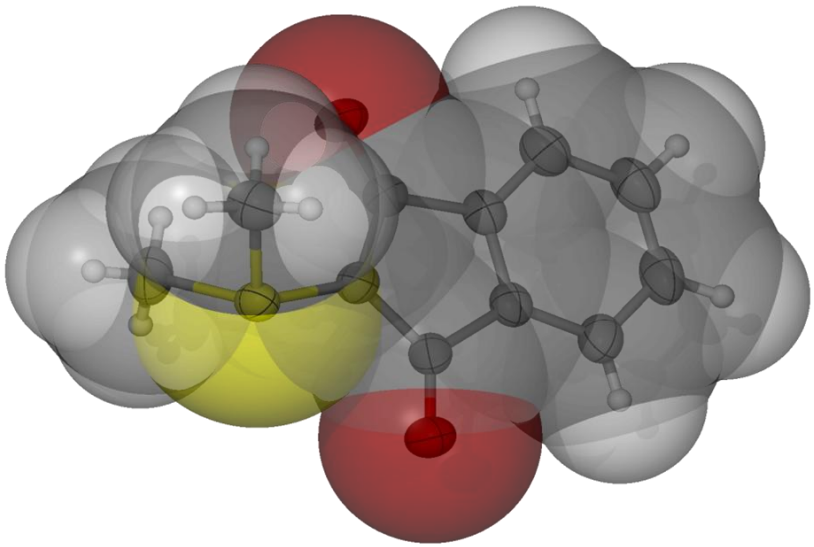
- Diffraction pattern of a Li-Phthalocyanine complex
- Strong diffraction spots at 147° 2Theta (0.82 Å) 30s exposure
- Detector edge at 152° 2Theta (0.80 Å)
- No spots detected on a customer Mo-sealed tube system

PHOTON 100 data - Bispyrazolone
D8 VENTURE with IμS™ Cu MX



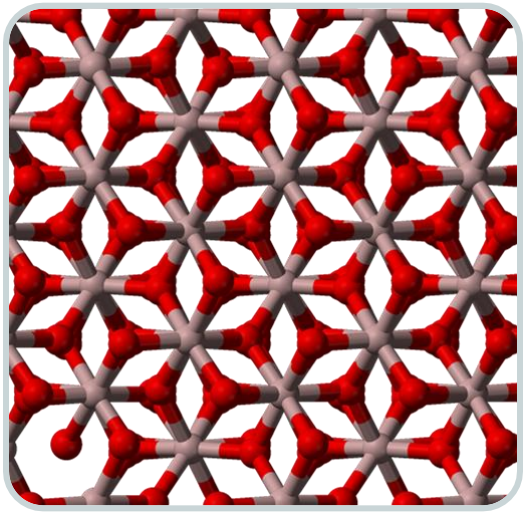
- Improved instrument design allows data to higher resolution
  - 0.81 Å D8 VENTURE
  - 0.84 Å X8 PROSPECTOR
- Good structure from small weakly diffracting organic sample
  - 0.06 mm x 0.11 mm x 0.14 mm
  - R1 = 4.45%

PHOTON 100 data – Ylid
D8 QUEST with Mo TRIUMPH



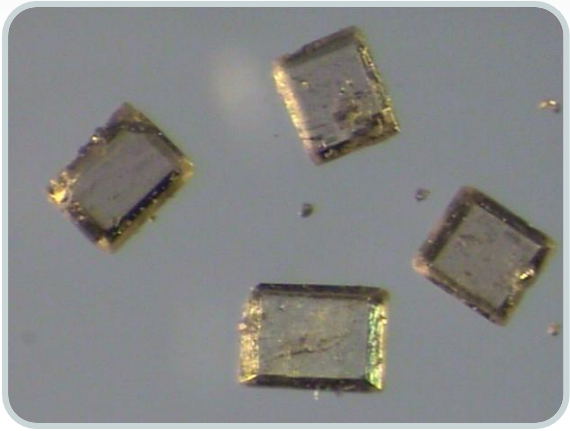
- Ylid is the best understood structure at Bruker and invaluable for judging instrument quality
- Ylid meets manufacturing specifications
- PHOTON 100 handles strong and weak reflections well
- R1 = 2.45%

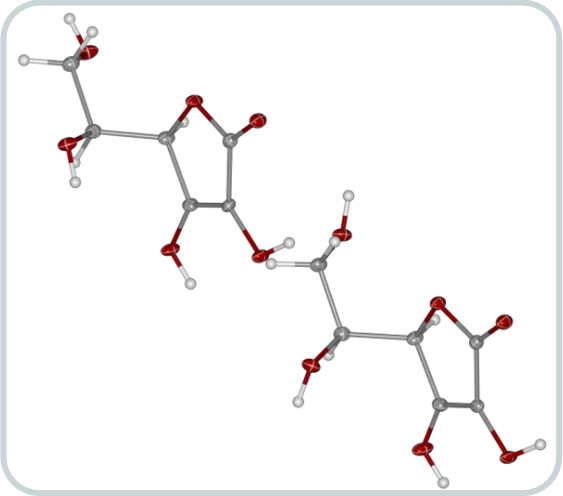
PHOTON 100 data– Ruby
D8 QUEST with Mo TRIUMPH



- D8 QUEST with PHOTON 100 delivers best unit cell data
- Ruby unit cell data is very accurate
  - Better than 1 in 1000
    or 0.1%
- Handles strong diffraction well
  - R(int) = 1.89% R(sigma) = 0.76%
  - R1 = 2.05% to 0.6 Å

PHOTON 100 data – Vitamin C
D8 VENTURE with IμS™ Cu MX





- D8 VENTURE handles well diffracting samples better
- Longer exposure times are possible without saturating the detector
- Weaker signals can be detected more accurately
- Better data than X8 PROSPECTOR (APEX II CCD)
  - D8 VENTURE: R1 = 2.39%
  - X8 PROSPECTOR: R1 = 2.60%

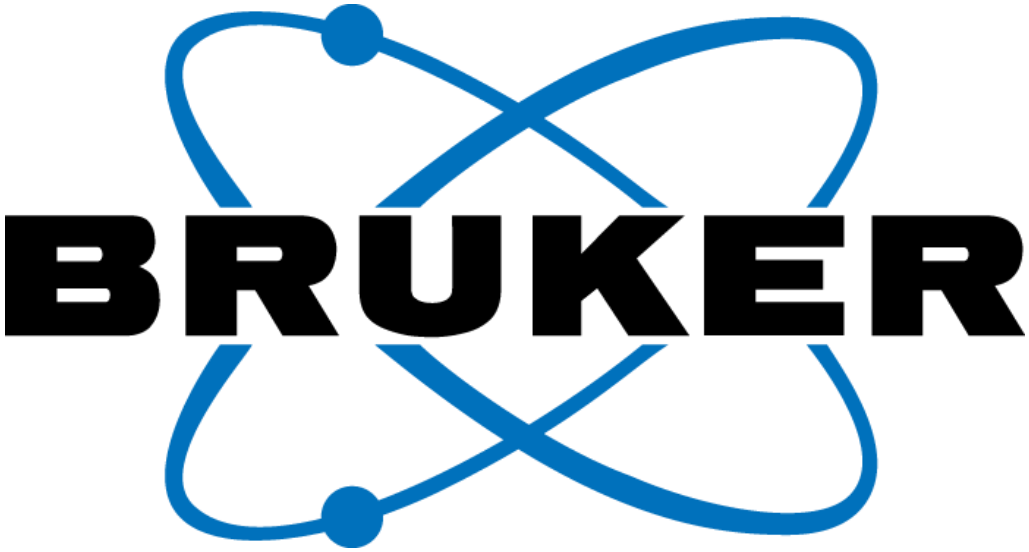
Small Environmental Footprint Systems

- For the first time completely air-cooled systems are available
- No compromise on performance
- Preservation of natural resources
  - 1,700 m^3 of water saved per year
  - 43,000 kWh of electrical energy per year
- Reduced carbon footprint
  - 26 metric tons of CO_2 per year
- Reduced noise
  - No recirculating chillers

Q & A

Any Questions?

Please **type** any questions you may have for our speakers in the **Q&A panel** and click **Send.**



Innovation with Integrity