Soft X-ray synchrotron cameras based on Back Side Illuminated CMOS sensor at SOLEIL

IN2P3 instrumentation networks, juin 2024

K. Desjardins – SOLEIL synchrotron

Genesis

CCD BSI to CMOS BSI

Genesis

Back Side Illuminated (BSI) CCD
e2v CCD42-40

1 Hz with **noise 31.5 e-**

down to **0.01 Hz** lower **noise 3 e-**

Upgrade of camera for the UV beamline

Needs :

High dynamic rage, ***Quantum Efficacy @ 280 nm > 50%***
& low noise

→ *Efficiency for UV =* ***Back Side Illuminated sensor (BSI)***

→ ***Scientific*** *grade sensor (High capacity and low electronic noise)*

+ Small pixel size < 11 µm
+ Large sensor size
+ Frame rate > 10 fps
+ No mechanical shutter

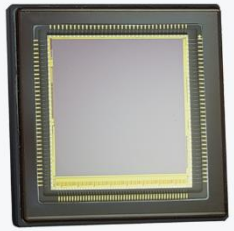
→ ***CMOS*** *technology*

In 2015, **GPIXEL** team published "A 4MP high-dynamic–range, low-noise CMOS image sensor" *(SPIE electronic imaging, San Francisco, US)*

doi:10.1117/12.2083085

First large production
CMOS BSI 2k × 2k pixels

GSENSE400-TVISB

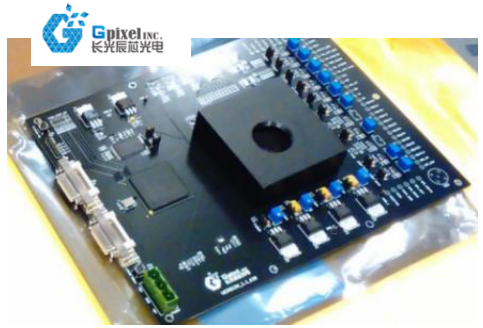


Gpixel INC. 长光辰芯光电

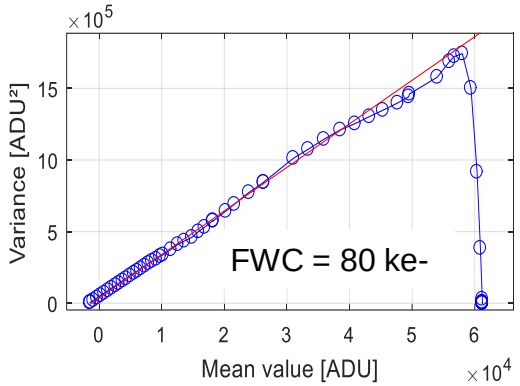
Resolution	**2048 x 2048 pixels**
Pixel size	**11 µm**
Photon sensitive area	22.5 mm x 22.5mm
Shutter type	Rolling shutter
Dark noise	**1.2 e-**
Dynamic range	**>97dB**
Full well charge	**91 ke-**
Frame rate	**48fps@STD, 24fps@HDR**
Dark current	0.2 e-/s/pix@-50°C

Genesis

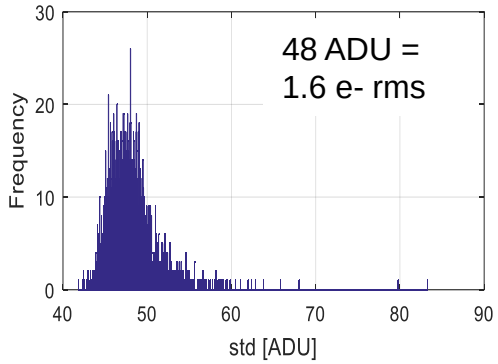
GSENSE400BSI sensor evaluated in 2016 at SOLEIL in det. Lab.



Photon transfer Curve



Readout noise



And this sensor has been integrated firstly by TUCSEN

With the Dhyana 95 camera

- Quick supply
- Relatively low cost (< 10 k€)
- Cooling (-25 deg.C)
- USB3 speed limit (25 fps)

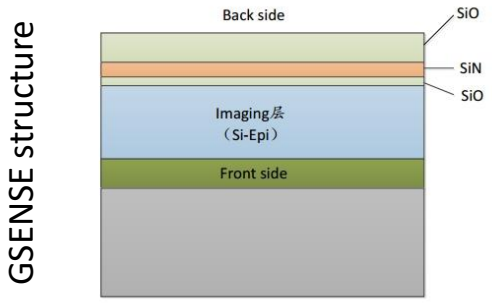
Andor : Marana

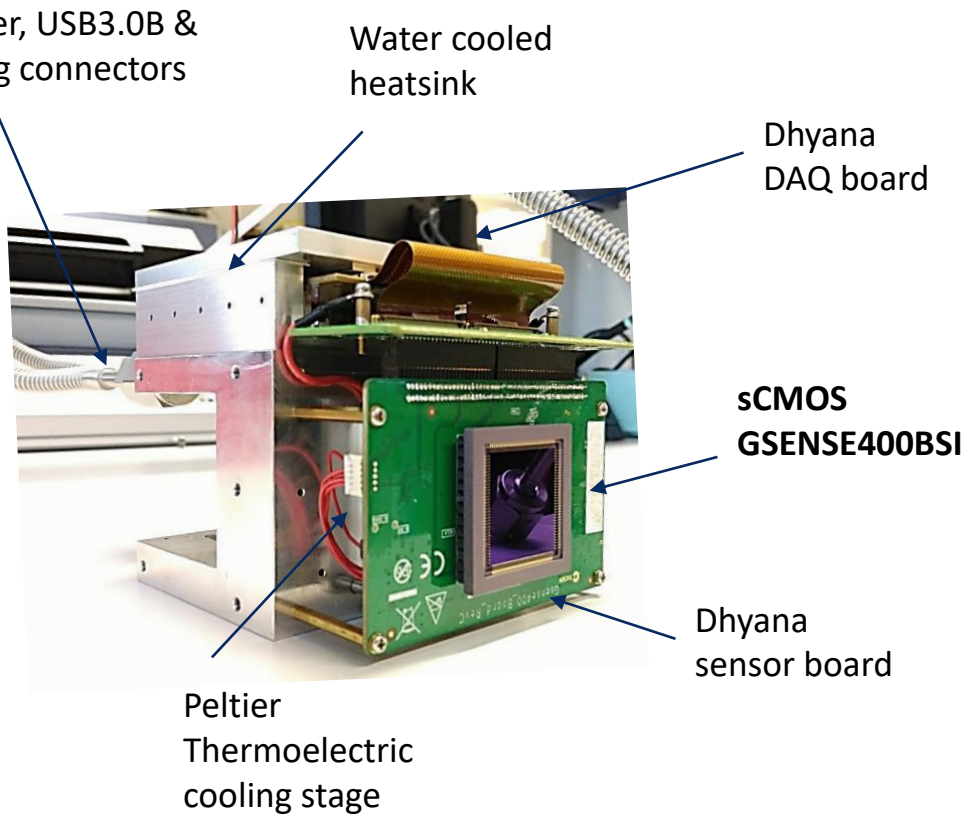
Genesis

Ok for UV, Why not use it for soft X-ray applications?

TUCSEN Dhyana 95 TO the DhyanaX project

GSENSE400-TVISB in Dhyana95
Back illuminated without micro lens
=
Thin thickness epi Si < 10 µm
+
Passivation layer (SiO2) < 10 nm
& visible anti-reflective coating (SiN) < 100 nm.





Characterization of a back-illuminated CMOS camera for soft x-ray coherent scattering

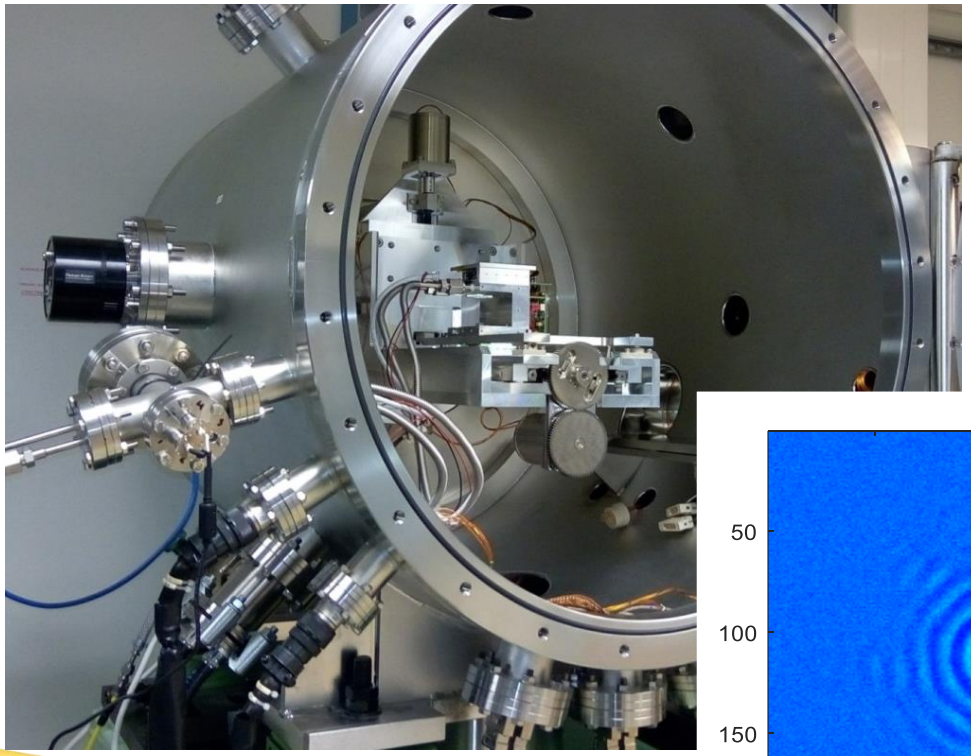
Desjardins et al, 2019 https://doi.org/10.1063/1.5084697

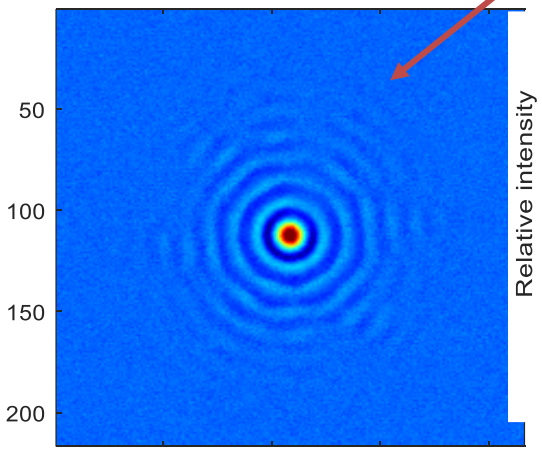
DhyanaX

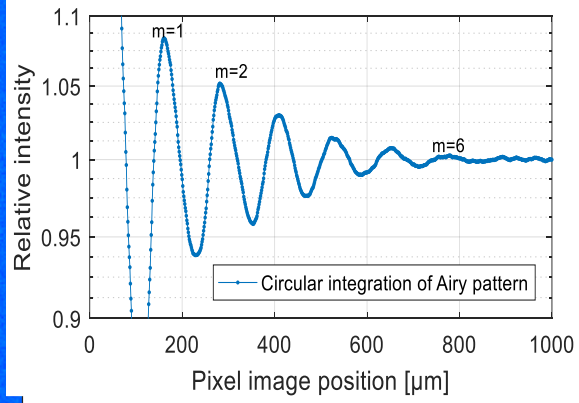
GSENSE400BSI CMOS BSI for soft X-ray

First soft X-ray demonstrations

Airy diffraction pattern of a 5 µm pinhole at 186 eV recorded by the BSI-sCMOS camera at METROLOGIE Beamline

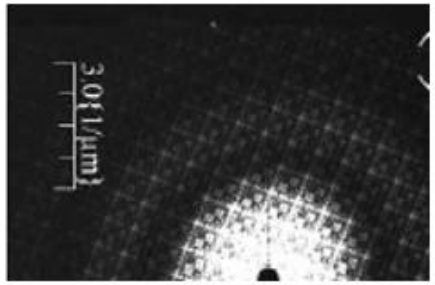




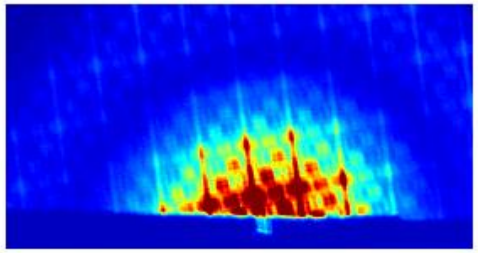


X-ray beam of 60 eV to 2000 eV

Irradiation (700eV) response of test mask consisting of eleven 200 nm diameter holes and comparison with the PI-MTE CCD Camera.



PI-MTE
CCD BSI [2]

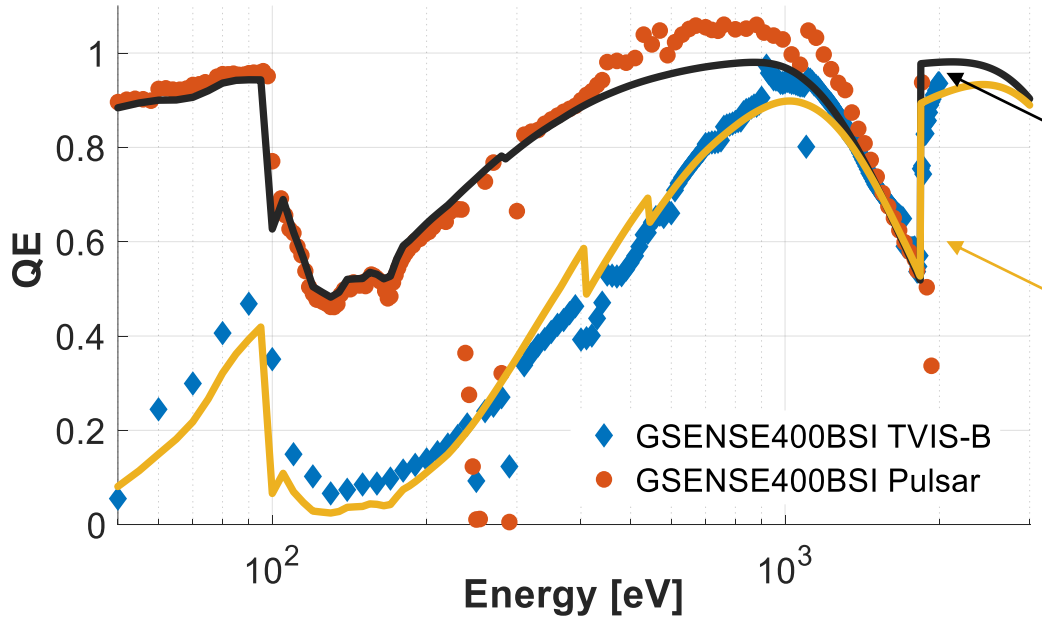


sCMOS
GSENSE400BSI

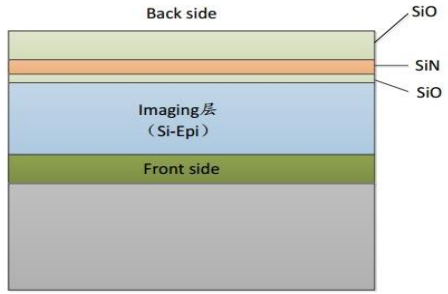
Quantum efficiency (QE)

Standard version GSENSE400BSI “**TVIS-B“** & XUV optimized version so called “**Pulsar”**

Ratio between image signal versus flux measured (dots).
Comparaison with an estimated model (solid curves).



Model comparison :

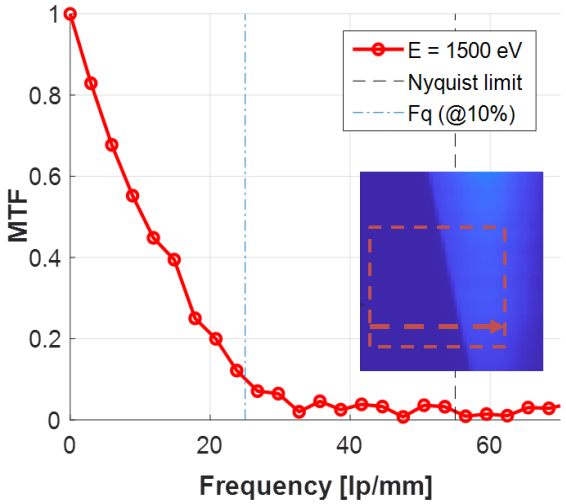


- **TVISB** [30 nm of SiO_2 + 63 nm of SiN_4 & 11 µm for the Epi-Si]

- **Pulsar** [21 nm of SiO_2, without AR coating & 10.5 µm for Epi-Si]

Backside-illuminated scientific CMOS detector for soft X-ray resonant scattering and ptychography *Desjardins et al 2020, https://doi.org/10.1107/S160057752001262X*

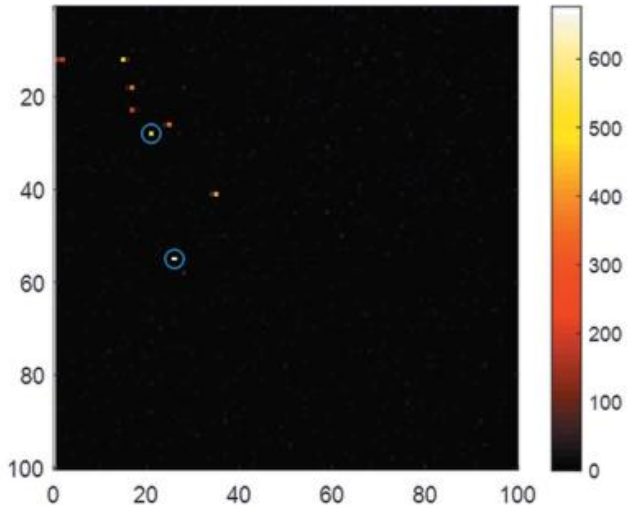
Resolution



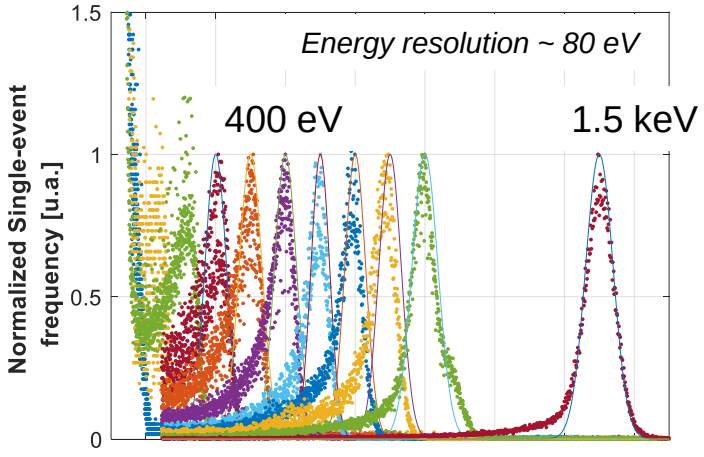
24 line-pairs/mm @ 10%
~ 21 µm

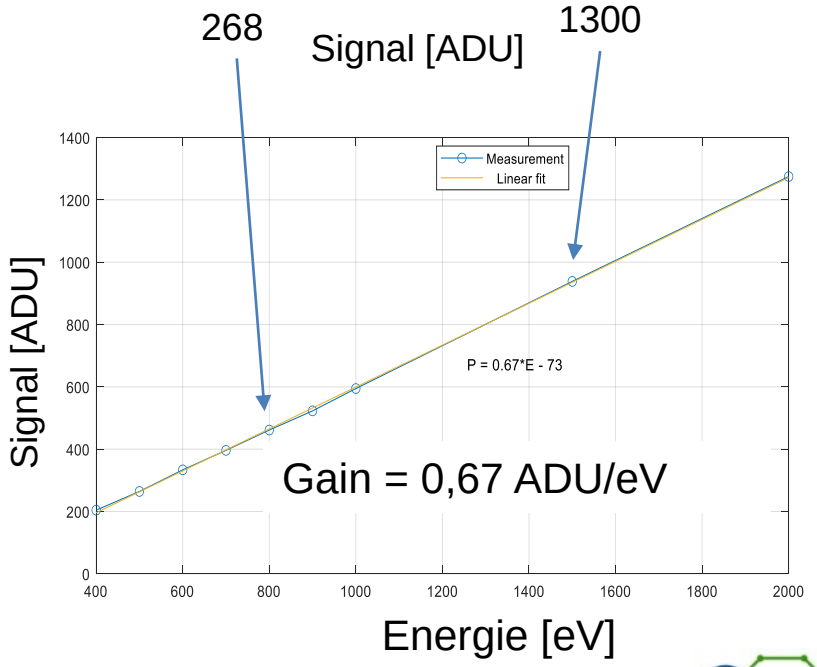
Spectroscopy

Monochromatic beam



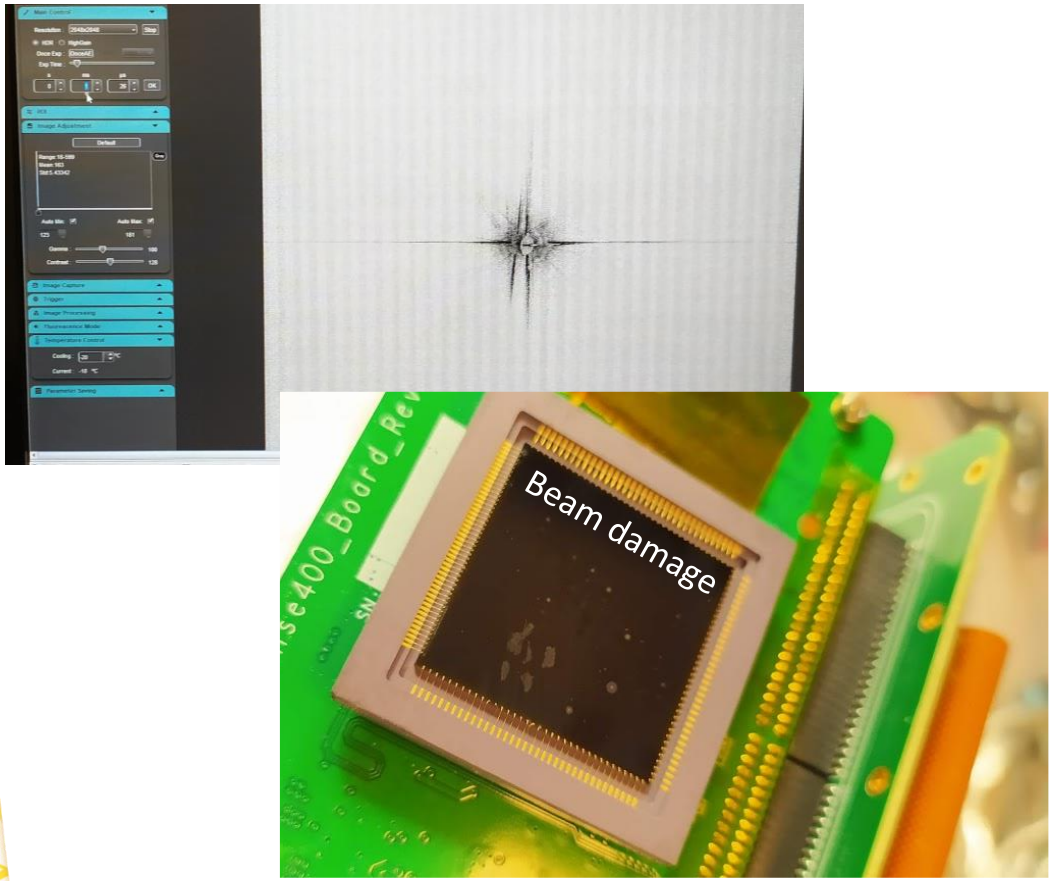
Region of interest of image
Beam photon at 1000 eV





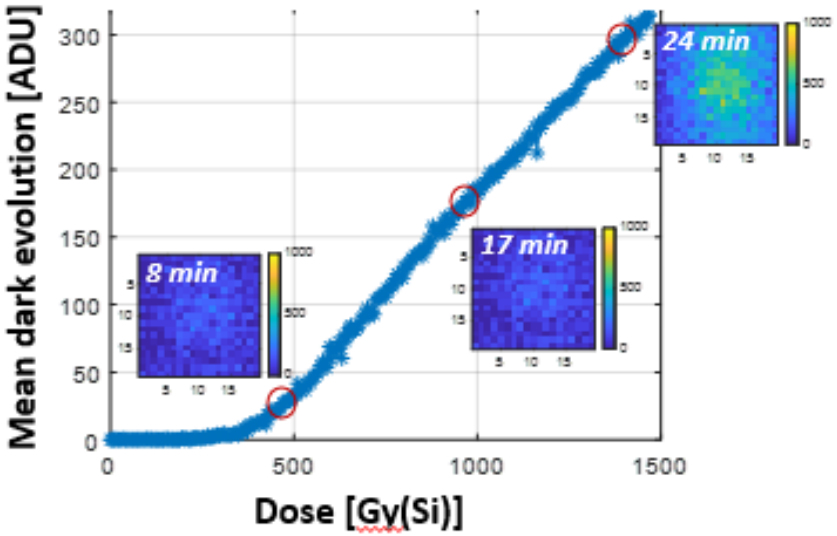
Radiation damage

Example of dark image
After 1 year



Radiation damage of **Pulsar** sensor

Dark level evolution with focus beam of 1000 eV &
Flux ~ 5 x 10^7 ph/s/0.2 x 0.2 mm^2 (mode LG)



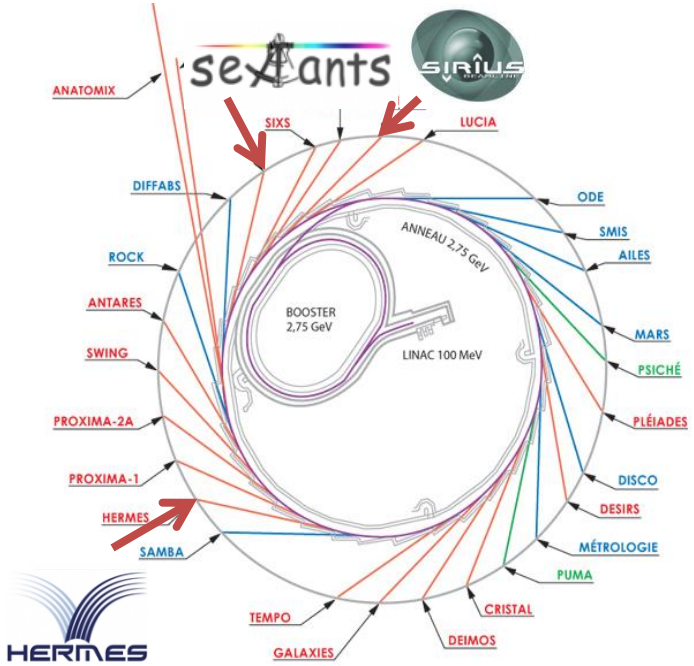
The estimated dose limit is **~ 600 Gy** on dielectric layer, as already estimated with GSENSE400-TVISB [2]

Production

GSENSE400BSI soft X-ray detector in production

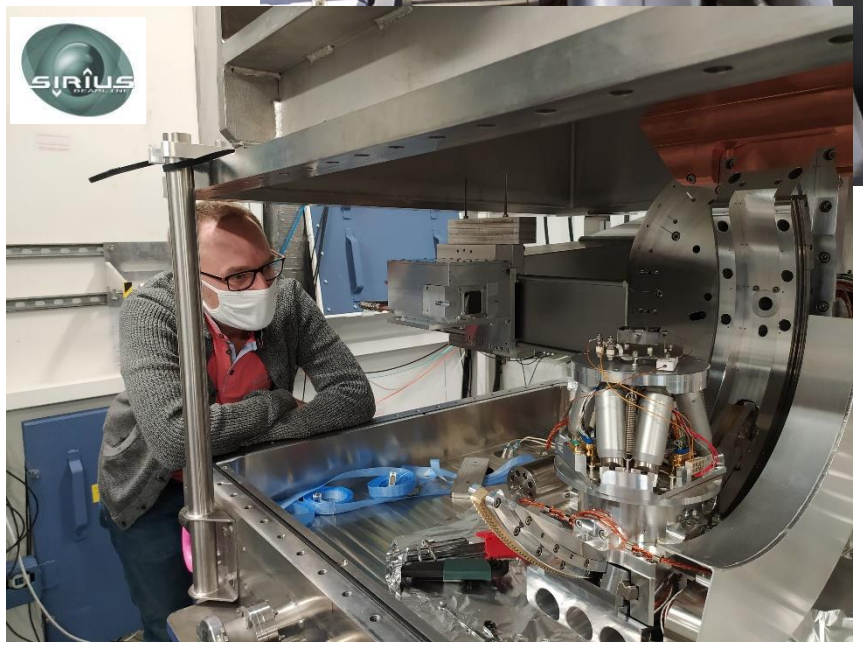
CMOS BSI in operation

3 soft X-ray beamlines at SOLEIL



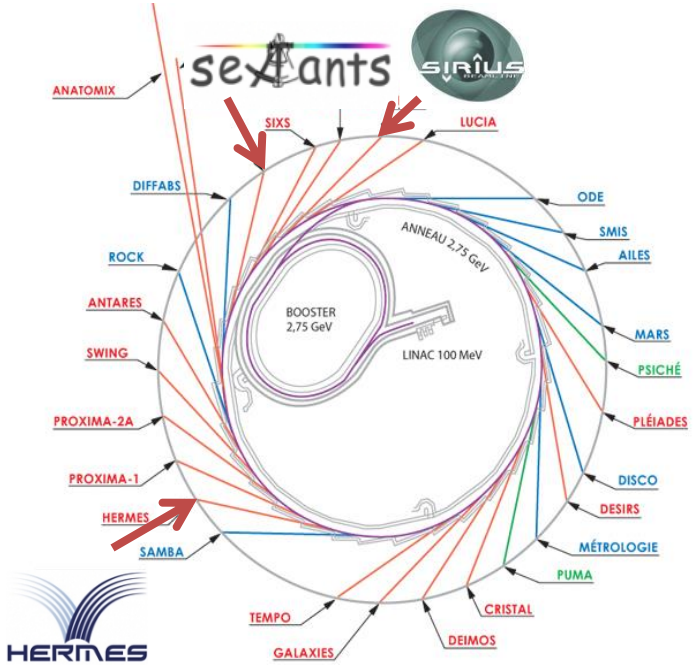
And other beamlines over the world (ESRF, MAXIV, DESY, Fermi, …)

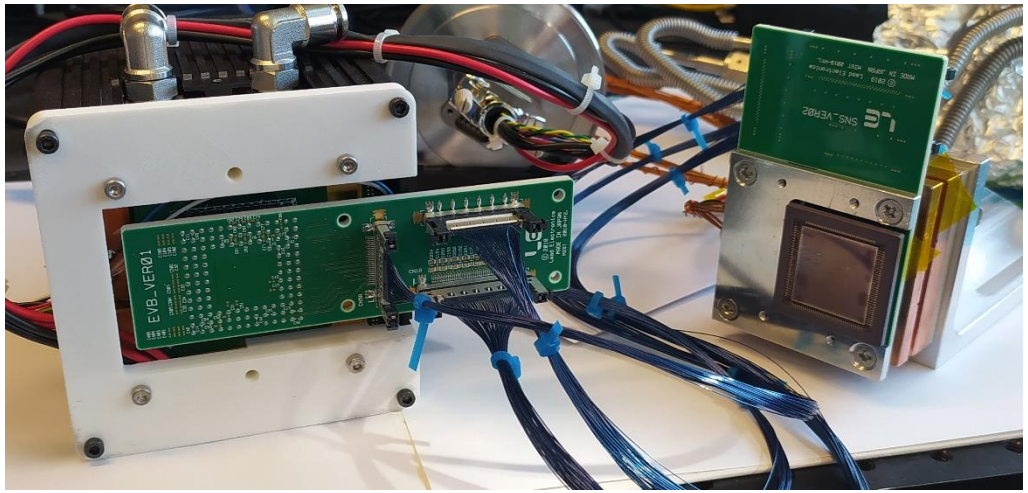
2 detectors based on DhyanaX concept supplied by AXIS Photonique (Canada) – **AXIS-SXR**

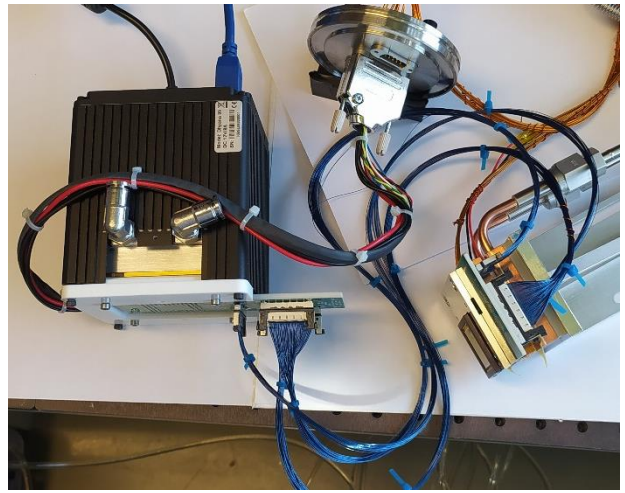


CMOS BSI in operation

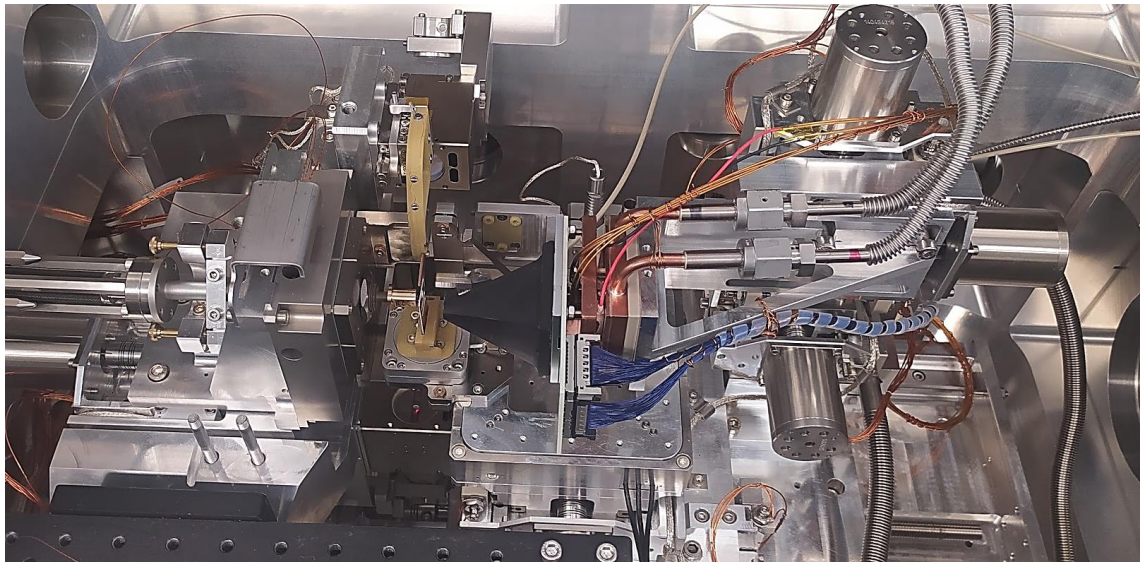
3 soft X-ray beamlines at SOLEIL







1 compact detector based on DhyanaX concept with a completely “head & Electronic” deportation

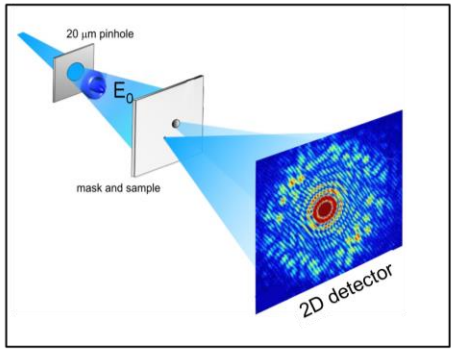


HERMES

And other beamlines over the world (ESRF, MAXIV, DESY, Fermi, …)

CMOS BSI in operation

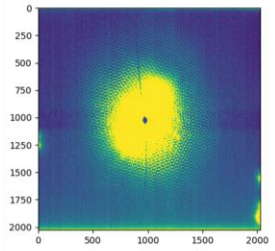
Fourier Transform Holography



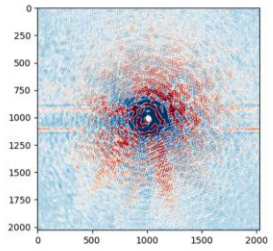
Two accumulations of images are recorded for each soft X-ray beam polarization (Circular Left & Right) at **777.4 e**V. Comparison with data acquired by a CCD (still in operation) allowed to validate the new setup.

The CMOS camera recorded 1000 x 500 ms images (total exposure of 500 s) without dead time (total acquisition time of 8 min.) which is significantly less than CCD (50 min).

Sum of 2 images (CR+CL)

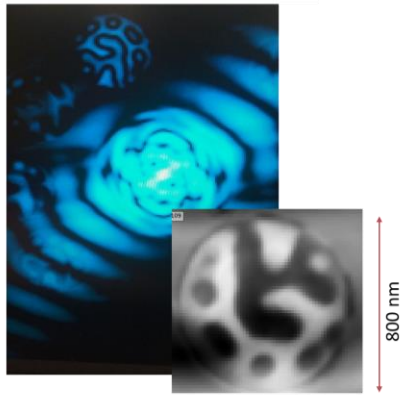


Diff. of 2 images (CR-CL)



"(…) an evident gain (8 min vs. 50 min) in efficiency for producing an image of equivalent quality (…)" [4]

Image obtained after FFT to reconstruct the sample

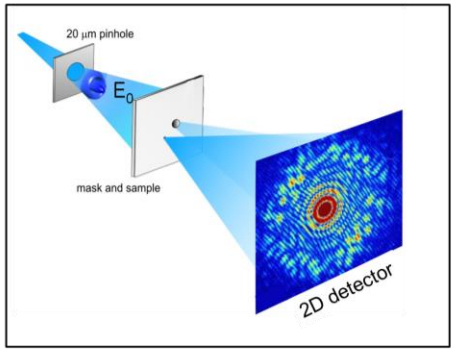


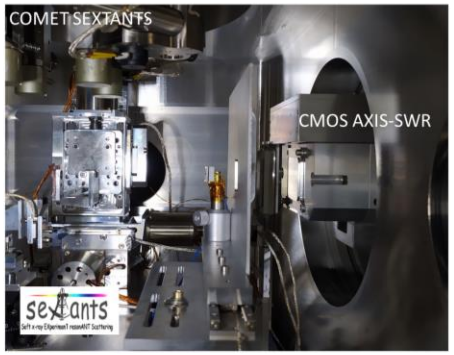
13 nm recons. pixel size

Applications of soft X-ray Synchrotron camera based on Back Side Illuminated CMOS sensor at SOLEIL. *Desjardins et al 2022, IWORID2022*

CMOS BSI in operation

Fourier Transform Holography





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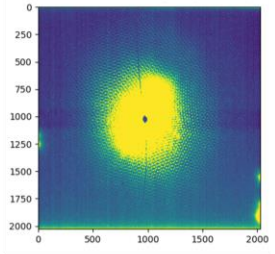

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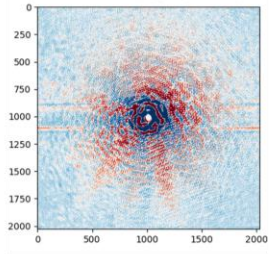

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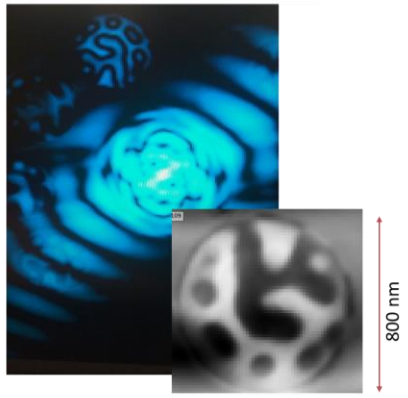
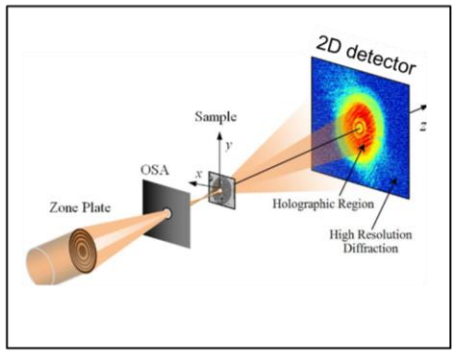


13 nm recons. pixel size

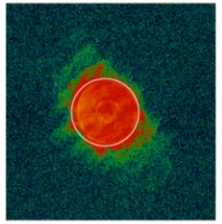
Soft X-ray Ptychography



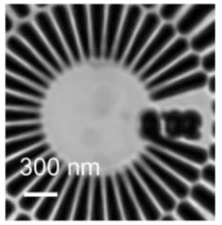
iffraction images have been recorded at **285.2 eV**. Demonstration has been done from Siemens star est pattern. The successfully images of Carbon nanotubes allowed to validate the new setup.

Siemens star reconstruction

(mean image, 100 x 50 ms)



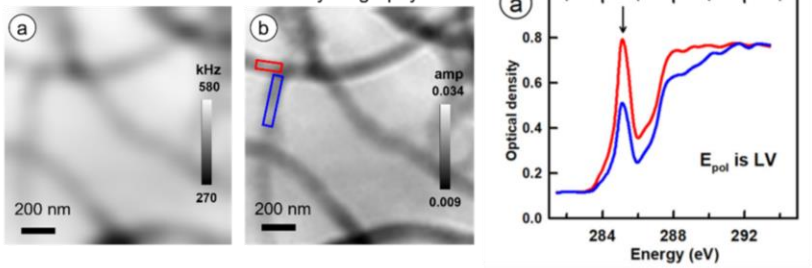
Ptycho. result



Ptychographic imaging obtained with defocus spot size of 1 µm compared to a classical STXM image (punctual PMT) performed using focused (FZP) 31 nm beam. Carbon edge spectra from images.

STXM

Ptychography



"(...) we performed, to the best of our knowledge, the first proof-of-principle ptychography at the carbon K-edge (...)" [5]

Applications of soft X-ray Synchrotron camera based on Back Side Illuminated CMOS sensor at SOLEIL. *Desjardins et al 2022, IWORID2022*

Other “fruits” of this work

Larger soft X-ray detector in production

Other “fruits” of this work

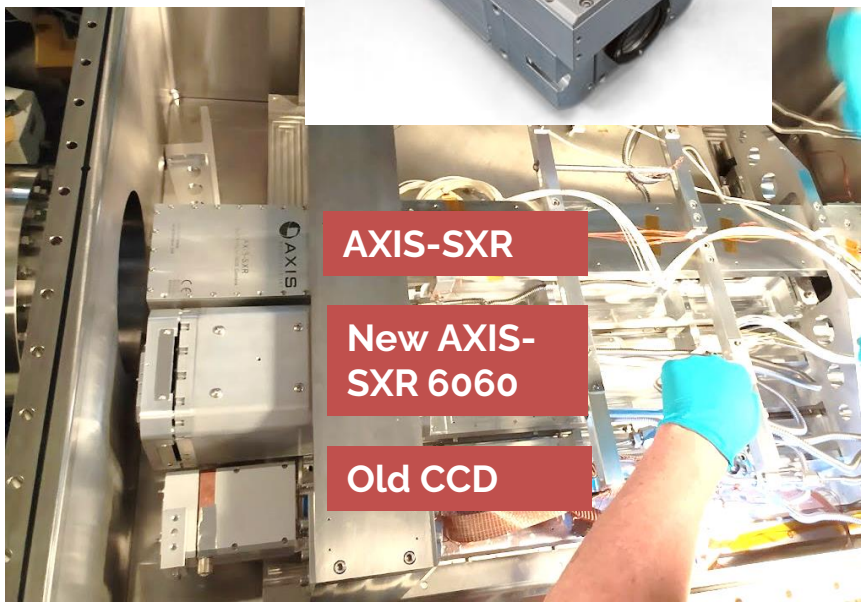
Upgrade of **SEXTANTS COMET** holographic experiment

22.5 mm x 22.5 mm
with **GSENSE400BSI**

to

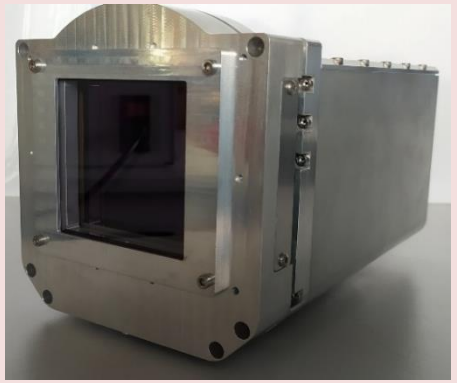
60 mm x 60 mm 36 Mpixels (10 µm)
with **GPIXEL GSENSE6060BSI**

Upgrade of COMET
SEXTANTS end station

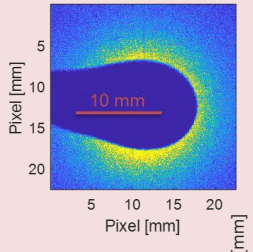


Recent upgrade : a very large CMOS Soft X-ray camera

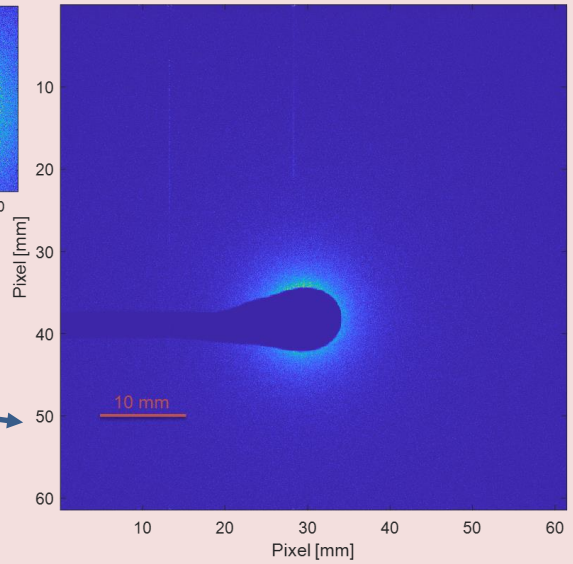
GSENSE 6060BSI



GSENSE 2020BSI



GSENSE 6060BSI

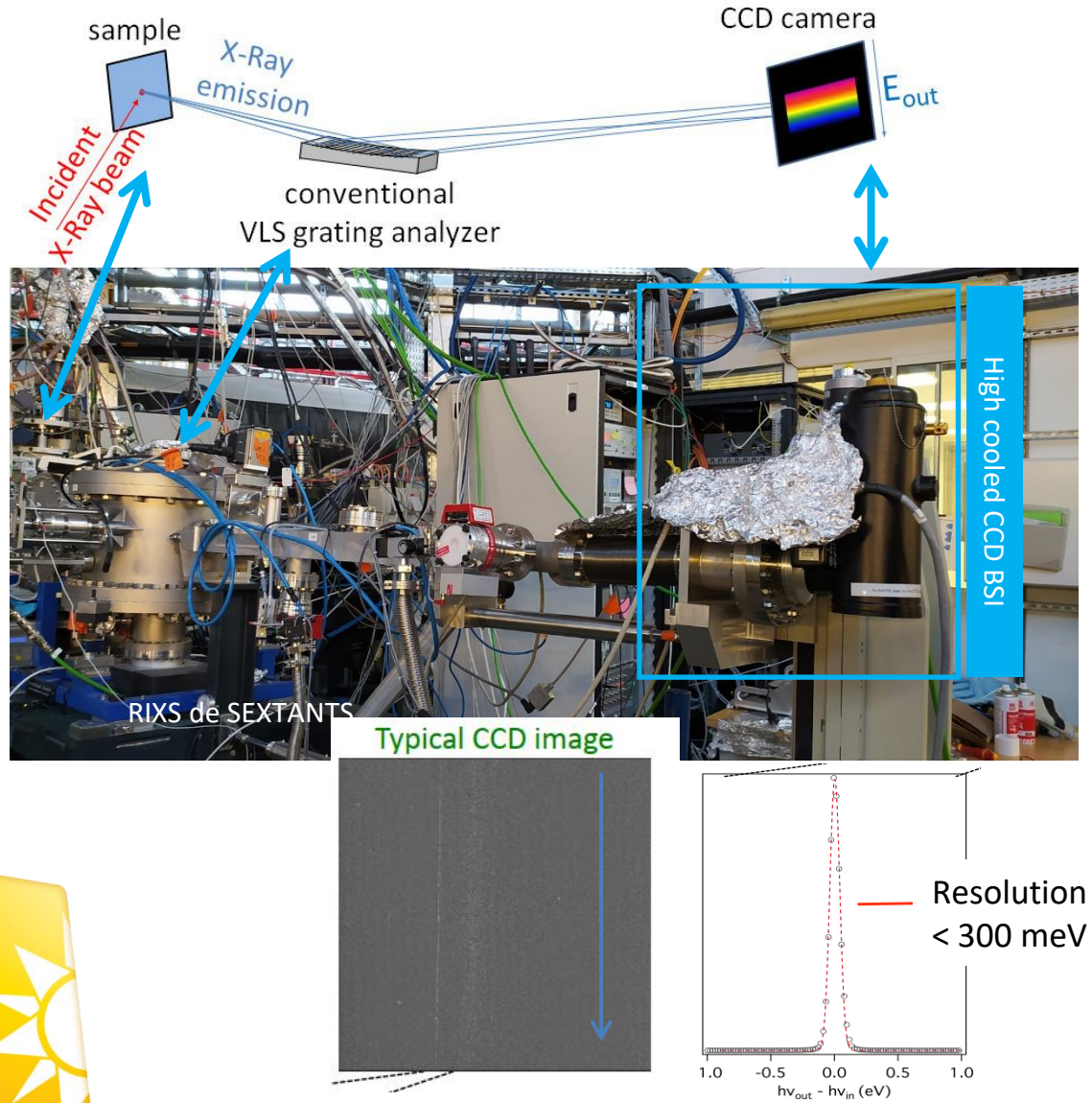


Improving the resolution of holographic reconstruction
down to 5 nm compare to 14 nm

*“Recent developments at the COMET instrument of the **SEXTANTS beamline at SOLEIL**” Popescu et al, SRI2022, https://doi.org/10.1088/1742-6596/2380/1/012046*

Other “fruits” of this work

Upgrade of **SEXTANTS RIXS** experiment

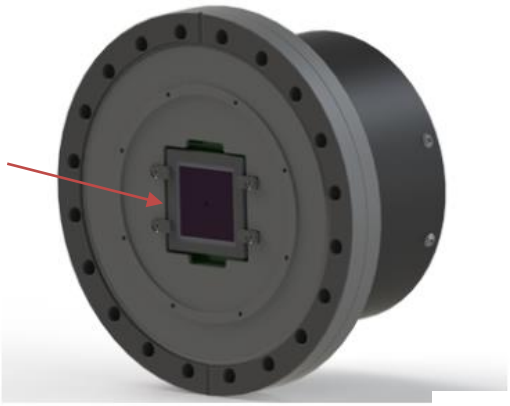


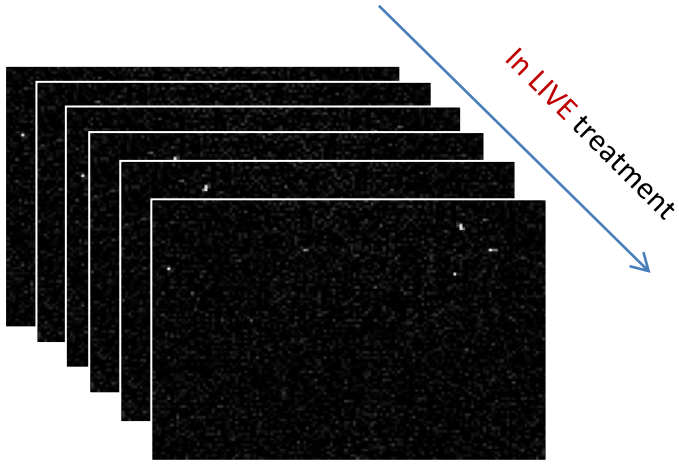
AXIS-SXRF-40 • 16 Mpix Large Format Soft X-ray sCMOS Camera on a Flange

37 mm x 37 mm with **GSENSE4040BSI**

LARGER sensor size
SMALLER pixel

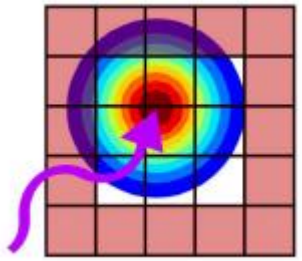
FPS = 16.5 fps





… in live treatment

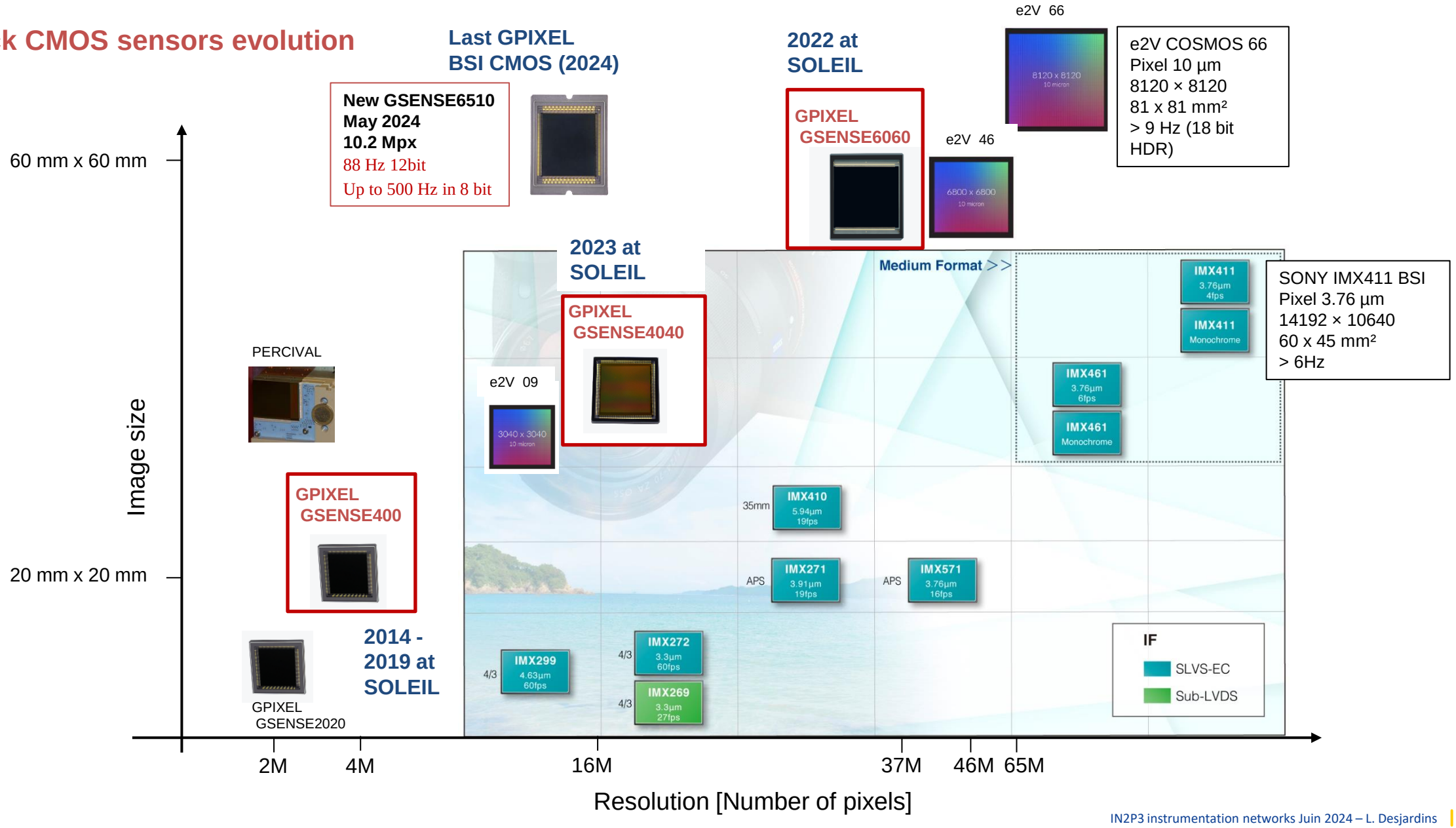
Centroid treatment of each photon detected = Live histogram reconstruction



Perspectives

Perspectives

Quick CMOS sensors evolution



Perspectives

Futur SOLEIL needs

Thick sensor + **radiation hardness** sensor

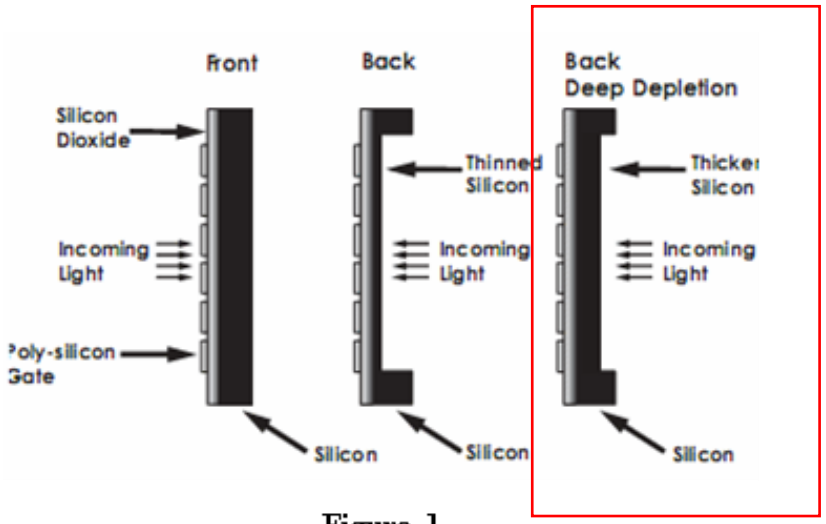


Figure 1

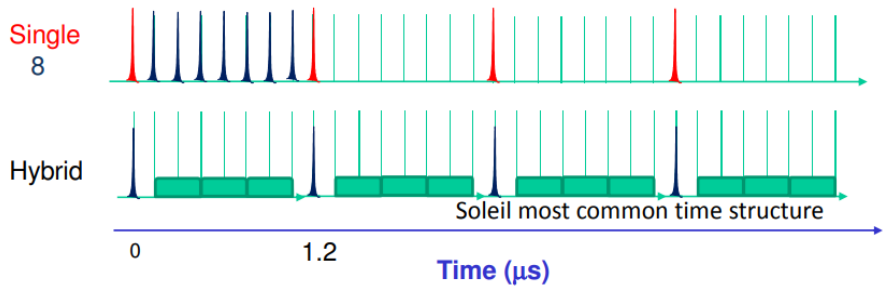
High capacity

The FULL WELL CAPACITY and FRAME RATE need to be increase

1 photon 1keV = 277 e-

High Frame rate

Filling patterns dedicated to temporal studies



Exemple of application = Pump -probe experiment with LASER pulse

Needs :

1kHz

Small size 20 mm x 1 mm

Thank you for your attention