

New EPICS Support for Low-Cost High-Performance Devices:

**Measurement Computing USB-CTR08
Counter/Timer
and
Point Grey Grasshopper3 Camera**

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Measurement Computing Devices

- I gave a TWG talk in 2011 on EPICS devices for the small laboratory, that included 2 USB devices from Measurement Computing
- Original motivation was need for an non-VME scaler for the x-ray lab at University of Chicago
 - Only other solution I knew of was the Ortec 974, NIM module, only 2 channels, expensive. USB-4303 seemed like a possible solution.
- Also talked about EPICS support for USB-1608GX-2A0, which provides high-speed 16-bit analog input and output.

USB-1608GX-2A0 (\$799)

- 16-bit analog inputs
 - 16 single-ended channels or 8 differential channels, 500 kHz total maximum input rate
- 16-bit analog outputs
 - 2 channels, fixed $\pm 10V$ range , 500 kHz total maximum output rate
- Digital inputs/outputs
 - 8 signals, individually programmable as inputs or outputs
- Pulse generator
 - 1 output, 64MHz clock, programmable period, width, number of pulses, polarity
- Counters
 - 2 inputs, 20 MHz maximum rate, 32-bit registers
- Less expensive model (no analog outputs) is being used at APS for the vibration monitoring and logging system

USB-4303 (\$349)

- Architecture
 - 2 C9513 counter/timer chips, 5 16-bit counter timers
 - Programmable on-chip interconnects between them
 - 8 digital input
 - 8 digital output
 - I wrote support for EPICS scaler record
- No longer available, 9513 chips obsolete
- USB-CTR08, new model just recently released provides significantly enhanced capabilities

USB-CTR04/08 (\$429)

- 8 counters (USB-CTR08) or 4 counters (USB-CTR04)
 - 48 MHz maximum count rate
 - Up to 64-bit counter depth
 - Counters can be read synchronously on-the-fly
 - 4 modes:
 - Totalize (count number of pulses)
 - Period (measure time between rising or falling edge of successive pulses)
 - Pulse width (measure time between rising and falling edge of a single pulse)
 - Timing mode (measure time between edges of two different input signals)
- 4 pulse generators
 - 48 MHz clock
 - Programmable period, width, number of pulses, polarity
- Digital inputs/outputs
 - 8 signals, individually programmable as inputs or outputs



USB-CTR08 vs SIS3820

	USB-CTR08	SIS3280
# Counters	8	32
Interface	USB 2.0	VME
Maximum count rate	48 MHz (TTL)	100 MHz (TTL) 250 MHz (ECL, NIM)
Minimum dwell time	250 ns per active counter	220 ns for 8 active counters
Pulse generators	4	0
Digital I/O bits	8	1
Price	\$429	\$4,350

USB-CTR08 Main medm screen

USBCTR.adl

USB-CTR08 USBCTR:

Digital I/O

	0	1	2	3	4	5	6	7	
Inputs	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	0x0
Outputs	Low High	Low High	Low High	Low High	Low High	Low High	Low High	Low High	0x0
Direction	In Out	In Out	In Out	In Out	In Out	In Out	In Out	In Out	

Pulse generators

	1	2	3	4
Frequency	1.9200e+07	1.0000e+07	2.0000e+06	4.0000e+06
Period	5.2083e-08	1.0000e-07	5.0000e-07	2.5000e-07
Width	2.0833e-08	5.0000e-08	5.2083e-08	1.0417e-07
Initial delay	0.0000	0.0000	0.0000	0.0000
# pulses	0	0	0	0
Idle state	Low	Low	Low	Low
	Running	Done	Running	Running
	Start	Start	Start	Start
	Stop	Stop	Stop	Stop

Scaler

MCS

Trigger Mode

USB-CTR08 EPICS Control

scaler_full.adl

Done	OneShot	time	Count time	Elapsed time	Counts
Count	AutoCount	1.00	2.000	2.000	Cts/sec
#	Description	Gate?	Preset count	Actual count	Calc result
1		N Y	2000000	2000000	2000000.000
2		N Y	0	1000000	1000000.000
3		N Y	0	0	0.000
4		N Y	0	0	0.000
5		N Y	0	0	0.000
6		N Y	0	0	0.000
7		N Y	0	0	0.000
8		N Y	0	0	0.000

Delay 0.000 (s) Clock 1.000e+06 Hz DisplayFreq 10.00 Hz

AutoCount: Delay 0.000 (s) DisplayFreq 0.000 Hz

Calculations ENABLE SYNC WITH SCALER: Less More

Scaler record

USB-CTR08 Multi-channel scaler (MCS) mode control

USBCTR_MCS.adl

USB-CTR08 MCS Control USBCTR:MCS:

Acquire

Acquiring Status

1.90 Elapsed time

Preset time

Dwell time

Ext. prescale

Channel advance source

First counter

Last counter

Prescale counter

Read rate

Combined Plots

Individual Plots 1-8

Individual Plots 9-16

Individual Plots 17-24

Individual Plots 25-32

Max. # of channels

channels to use

Current channel

Wait for client

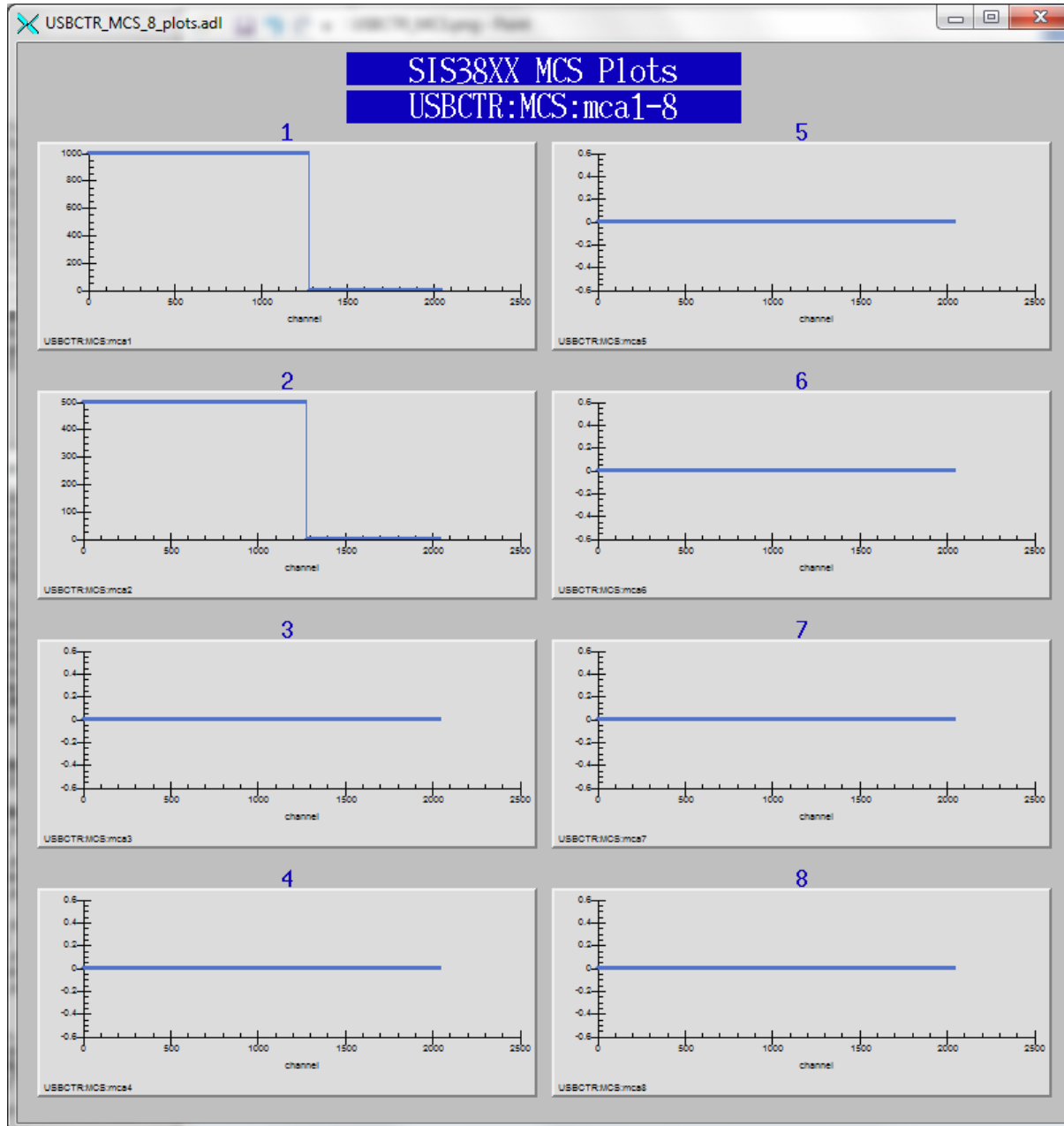
Client Wait

Asyn record

Connected SNL Status

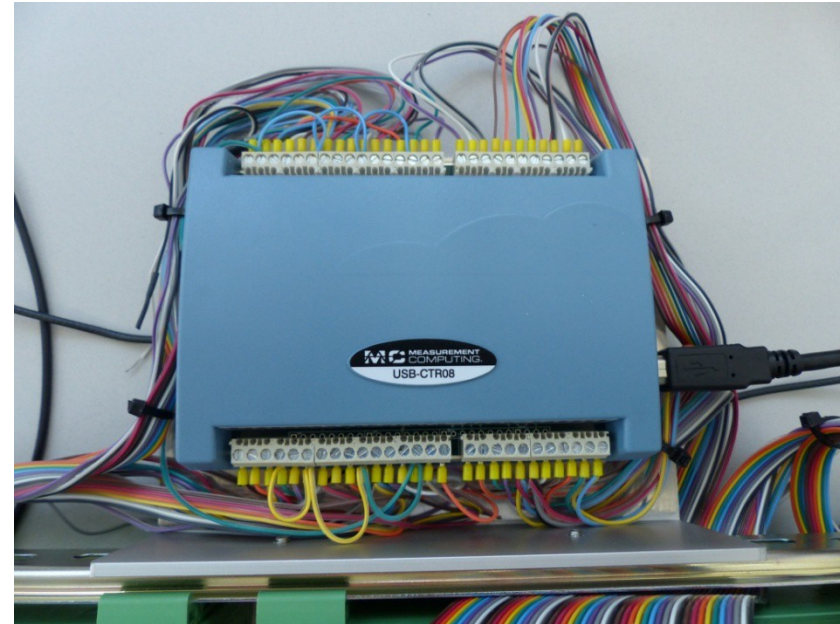
USB-CTR08 Model

USB-CTR08 Multi-channel scaler (MCS) mode plots



USB-CTR08 Cabling

- Using standard BCDA BC-020 LEMO breakout
- 50-pin ribbon cable with ground on all even pins
- Currently using wire-wrap.
- Kurt Goetze is designing new daughter card to replace wire-wrap.
 - 25 LEMOs plus grounds on even lines



USB-CTR08 Restrictions

- The EPICS driver only works on Windows, because it requires the Measurement Computing Universal Library which is only available for Windows.
- The EPICS scaler record support has true preset on Counter 0. It will stop all of the other counters instantly. The other counters can also have presets, but they stop the counter in software, with 0.01 second worst-case latency.
- The EPICS driver only uses the Totalize mode of the counters. With the scaler record it does a one-shot totalize, while in the MCS mode it totalizes into time-bins. The USB-CTR08 is also capable of running in 3 other modes.
 - In Period mode it measures the time between the rising or falling edges of successive input pulses.
 - In Pulse Width measurement mode it measures the time between the rising and falling edges of a each pulse.
 - In Timing Mode it measures the time between an event on the counter input and another event on the counter gate.
- None of these modes are currently supported by the EPICS driver, but they could be added in a future release.

USB-CTR08 Restrictions

- In Totalize mode each counter has many options in how it works: count up/down, gate clears counter, gate controls counter direction, preset counts where the output signal goes high/low, polarity of the output, etc. These options are not currently exposed in the EPICS driver.
- The EPICS driver only works in 32-bit counter depth mode. The USB-CTR08 can count with a 64-bit counter depth.
 - EPICS does not currently have support for 64-bit integer data types, so this cannot be supported.
- To work with the scaler record the Counter 0 Output must be wired to the Gate Inputs of Counters 1-7. This allows Counter 0 to be the preset counter and stop all of the other counters. This is most easily done on the screw terminals, not on the LEMO breakout.

areaDetector R2-0 Release

- areaDetector was getting too big.
 - New releases being held up waiting for testing on one detector types, etc.
- Hard to collaborate with other sites using APS Subversion repository
 - git and github provide much better tools for multi-site collaborations

R2-0 Organization

areaDetector

Top-level module
RELEASE files, documentation, Makefile

ADCore

Core module
Base classes, plugins,
simDetector, documentation

ADB binaries

Binary libraries for
Windows (HDF5,
GraphicsMagick)

ADProsilica

Prosilica driver

ADPilatus

Pilatus driver

...

- Each box above is a separate git repository
- Can be released independently
- Hosted at <http://github.com/areaDetector> project
- Each repository is a submodule under areaDetector/areaDetector

R2-0: Point Grey driver

- New driver for all cameras from Point Grey using their FlyCap2 SDK.
- Firewire, GigE and USB 3.0
- High performance, low cost



Mono
Sensor



R2-0: Point Grey driver

pointGrey.adl

Point Grey Area Detector Control - 13PG1:cam1:

Setup

asyn port **PG1**
EPICS name **13PG1:cam1:**
Manufacturer **Point Grey Research**
Model **Blackfly BFLY-PGE-20**
Serial Number **13481965**
Firmware Vers. **1.27.3.0**
Software Vers. **2.6.3**
Debugging

Shutter

Shutter mode **None**
Status: Det. **Closed** EPICS **Closed**
Open/Close **Open** **Close**
Delay: Open **0.000** Close **0.000**
EPICS shutter setup

Status

Status rate **1 second**
Dropped frames **0**
Corrupt frames **0**
Driver dropped **0**
Transmit failed **0**
Temperature **42.8**

Attributes

File

Trigger

Internal
Trigger mode **Internal**
Trigger source **GPIO_0** **GPIO_0**
Trigger polarity **High** **High**
Trigger delay **0.000** **0.000**
Skip frames **0** **0**
Software trigger **Trigger**

Strobe

Strobe source **GPIO_1** **GPIO_1**
Strobe enable **Enable** **Enable**
Strobe polarity **Low** **Low**
Strobe delay **0.001** **0.001**
Strobe duration **0.020** **0.020**

Bandwidth Control

Max packet size **9000**
Packet size **1440** **1440**
Packet size **1440**
GigE packet delay **400** **400**
Bandwidth (MB/s) **54.9**

Readout

	X	Y
Sensor size	1600	1200
	0	0
Region start	0	0
	1600	1200
Region size	1600	1200
GigE binning	1x1	1x1
Image size	1600	1200
Image size (bytes)	1920000	
Gain	0.000	0.000
Data type	UInt8	
Color mode	Mono	
Video mode	Format7	Format7
	0 (1600x1200)	
Format7 mode	0 (1600x1200)	
Properties	<input type="checkbox"/>	
Frame rate	<input type="checkbox"/> More	Undefined1
Pixel format	<input type="checkbox"/> More	Raw8
Convert raw	None	None
Timestamp	Camera	Camera

Collect

Exposure time **0.040** **0.033**
Acquire period **0.250** **0.033**
Frame rate **43.716** **30.000**
Images **1000** **1000**
Images complete **189**
Exp./image **1** **1**
Image mode **Multiple** **Multiple**
Collecting
Acquire **Start** **Stop**
Detector state **Waiting**
Status **Waiting**
Image counter **0** **189**
Image rate **30.0**
Array callbacks **Enable** **Enable**

Plugins

All File ROI
Stats Other

Buffers

Buffers max/used	0	1
Buffers alloc/free	2	1
Memory max/used (MB)	0.0	3.7
Buffer & memory polling	1 second	

Point Grey GigE Camera BlackFly PGE-20E4C

- e2v EV76C570 CMOS sensor
- Global shutter
- 29 x 29 x 30 mm
- Power Over Ethernet
- 4.5 micron pixels
- 1600 x 1200 pixels, color (mono)
- 47 frames/s
- \$595
 - 5X cheaper than comparable Prosilica cameras we bought in the past



Point Grey USB-3.0 Camera Grasshopper3 GS3-U3-23S6M

- 1920 x 1200 global shutter CMOS
- Sony IMX174 1/1.2
- No smear • Distortion-free
- Dynamic range of 73 dB
- Peak QE of 76%
- Read noise of 7e-
- Max frame rate of 162 fps
 - ~356 MB/S, >3X faster than GigE
- USB 3.0 interface
- \$1,295



Comparison to Other Cameras

	Grasshopper3	Photometrics CoolSnap HQ ²	Andor Zyla	Andor Neo
Format	1920 x 1200	1392 x 1040	2560 x 2160	2560 x 2160
Interface	USB 3.0	PCI Proprietary	CameraLink 10-tap	CameraLink 3-tap
Maximum frame/s	162 (8-bits) 80 (12-bits)	10 (12-bits)	100 (Rolling, 12-bit) 75 (Rolling, 16-bit) 50 (Global 12/16-bit)	30 (Rolling or Global) 79 (1920x1080)
Cooled	No	-30°C	0°C	-30°C
Full-well e ⁻	32,513	16,000	30,000	30,000
Read noise e ⁻	7	5.5	1.2 (Rolling) 2.5 (Global)	1.0 (Rolling) 2.3 (Global)
Price	\$1,295	~\$15,000	\$19,500	~\$15,000

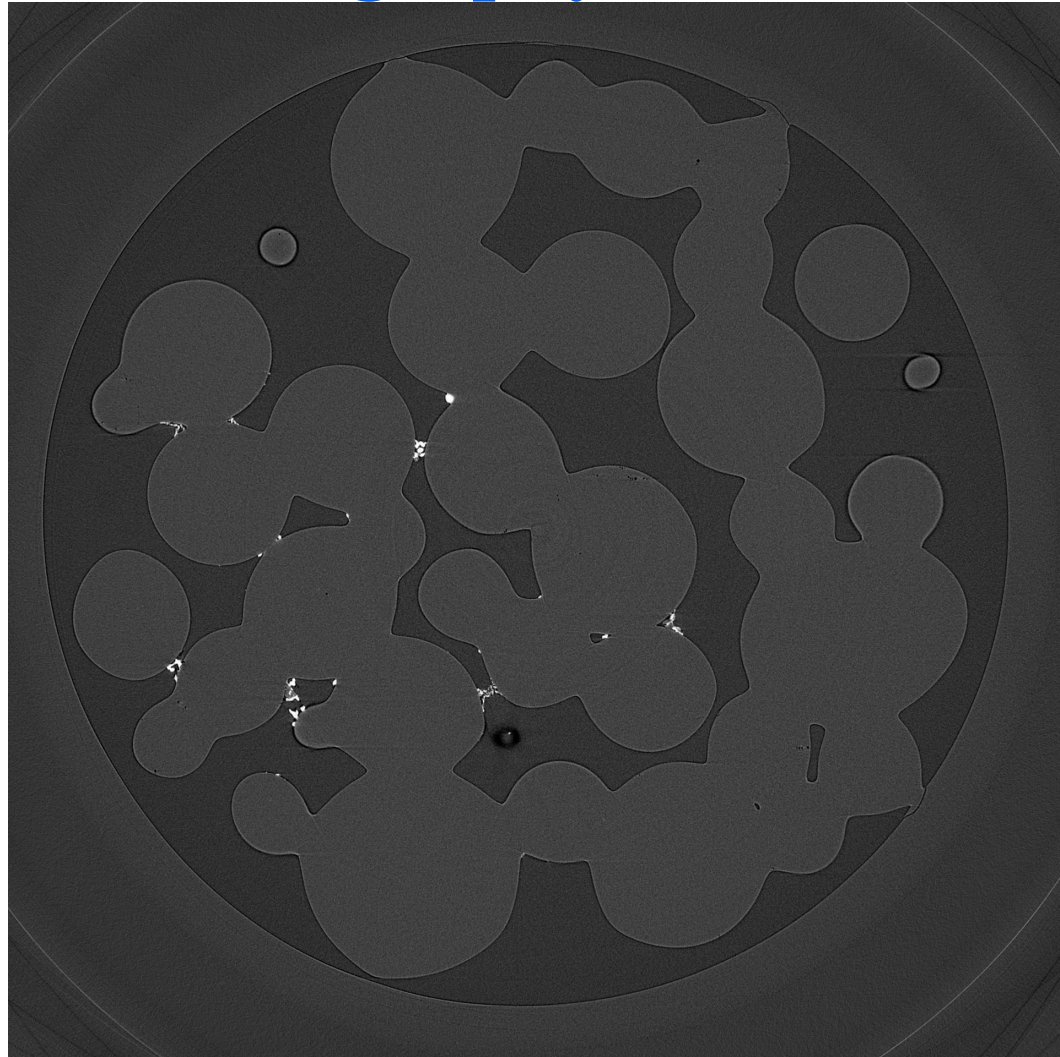
Grasshopper3 GS3-U3-23S6M

Applications

- I originally purchased the camera for planned fast pink-beam tomography
 - Not a full-time need, did not want to spend \$15K
 - Radiation damage worry. \$1,295 can be replaced frequently if needed
- Starting yesterday Grasshopper3 has replaced CoolSnap HQ2 as standard camera for regular tomography at 13-BM-D
 - 13 ms readout vs 100 ms in 12-bit mode, 6 ms in 8-bit mode
 - 2.5 more voxels in reconstruction
 - Equivalent quality
- Planning to do first pink-beam tomography this weekend, can do 900 projections in 11.25 seconds at 12-bit, 6.5 seconds in 8-bit

Grasshopper3 GS3-U3-23S6M

First Tomography Data

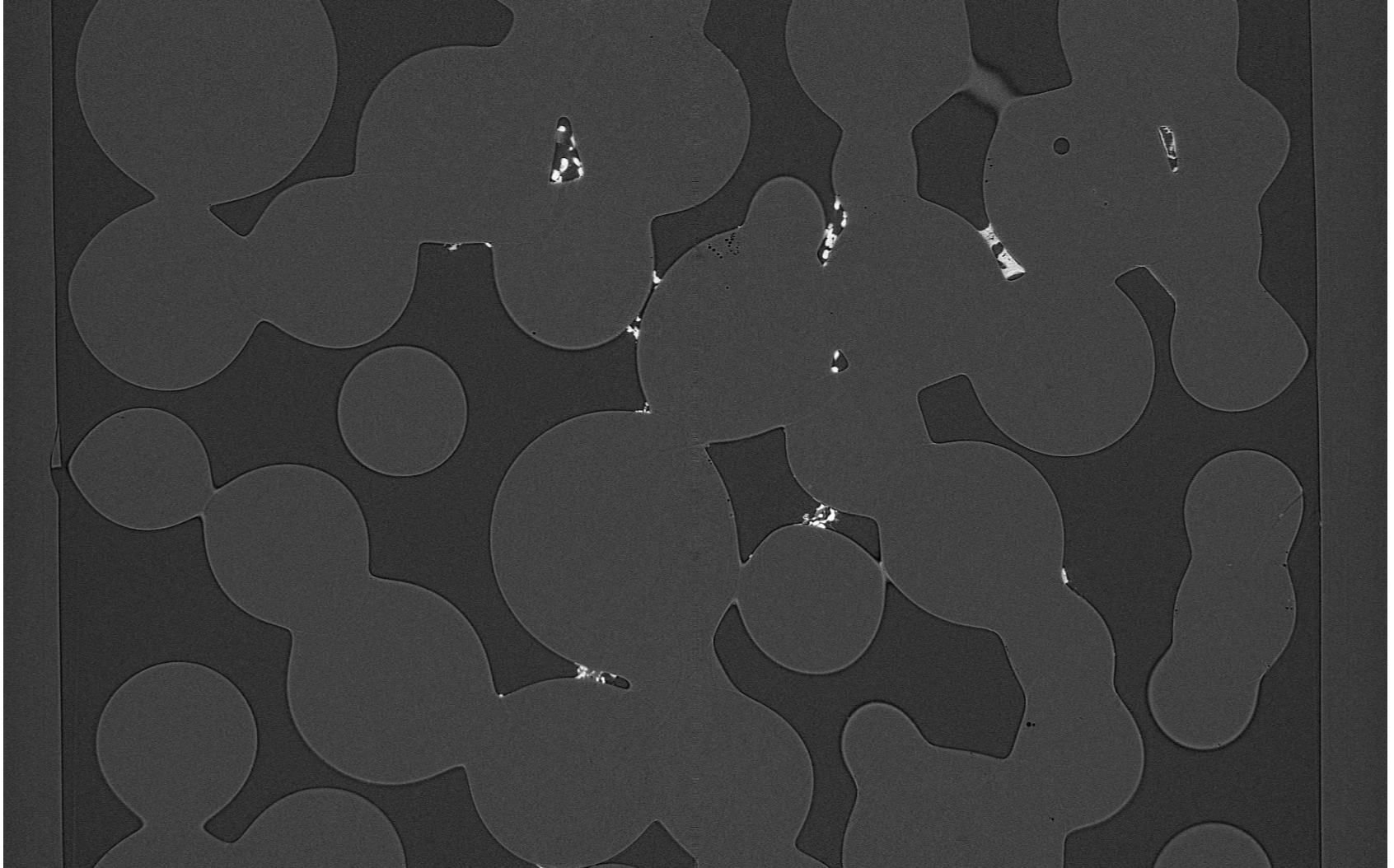


30 minutes total

Z slice for normal slow scan, 0.85 s exposure, 1800 projections

Grasshopper3 GS3-U3-23S6M

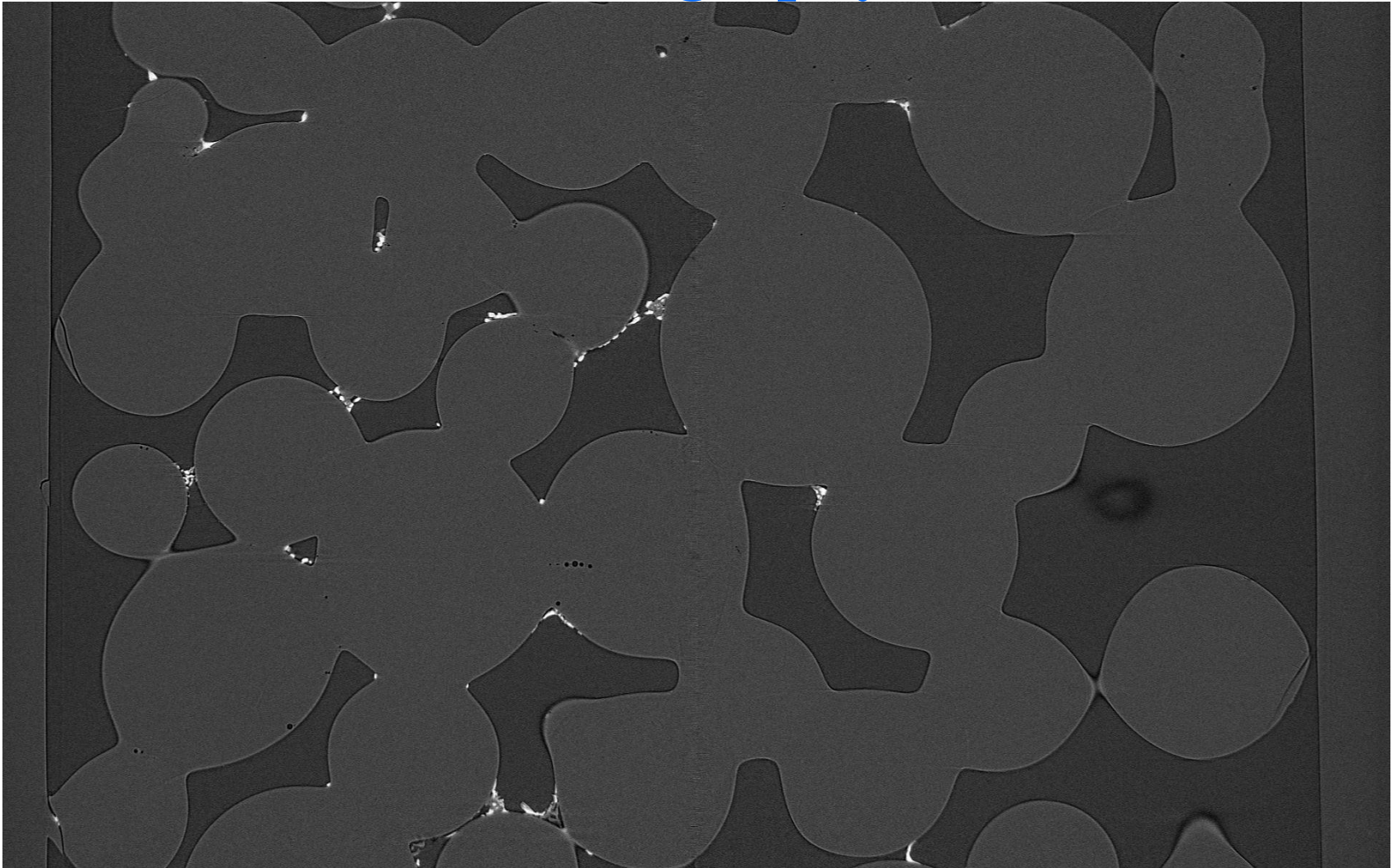
First Tomography Data



X slice for normal slow scan, 0.85 s exposure, 1800 projections

Grasshopper3 GS3-U3-23S6M

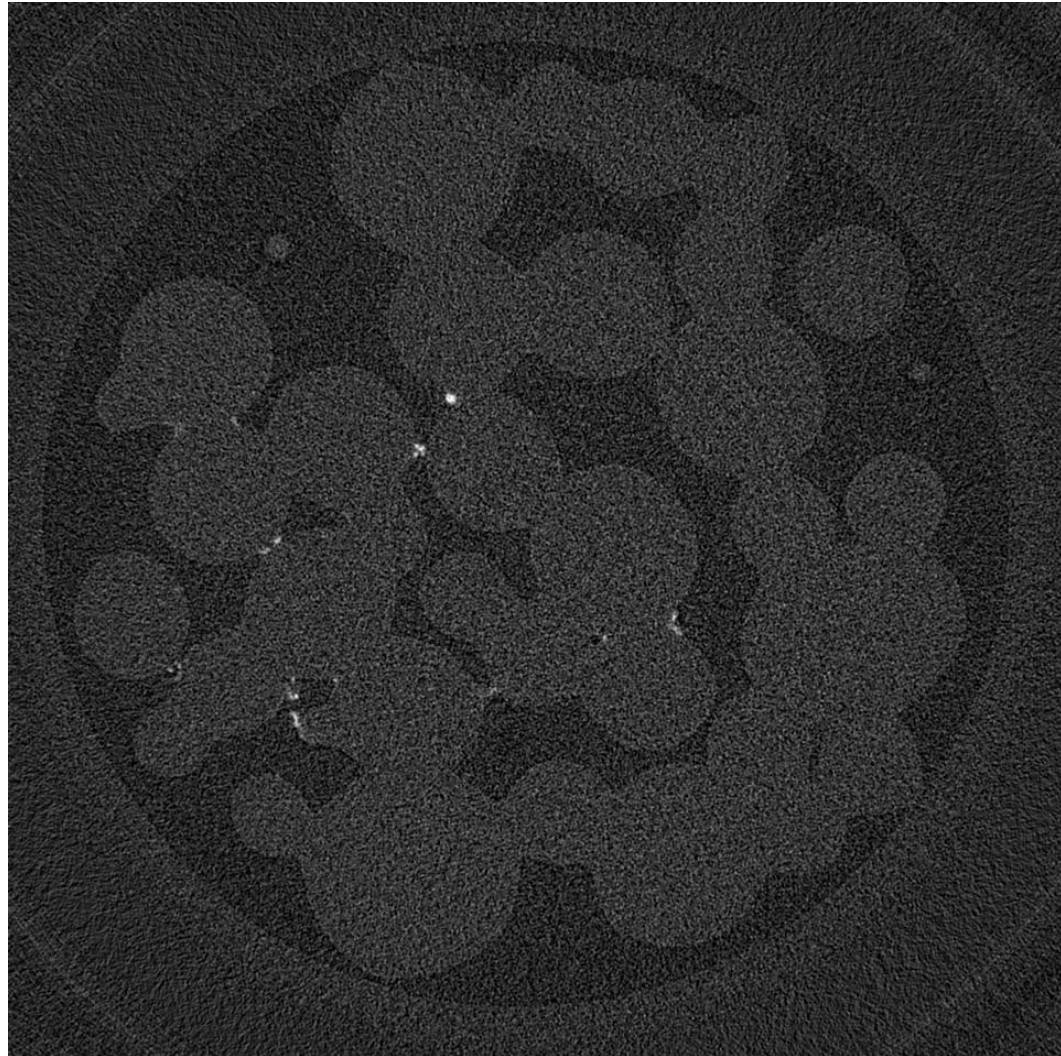
First Tomography Data



Y slice for normal slow scan, 0.85 s exposure, 1800 projections

Grasshopper3 GS3-U3-23S6M
First FastTomography Data
Si 111 mono beam

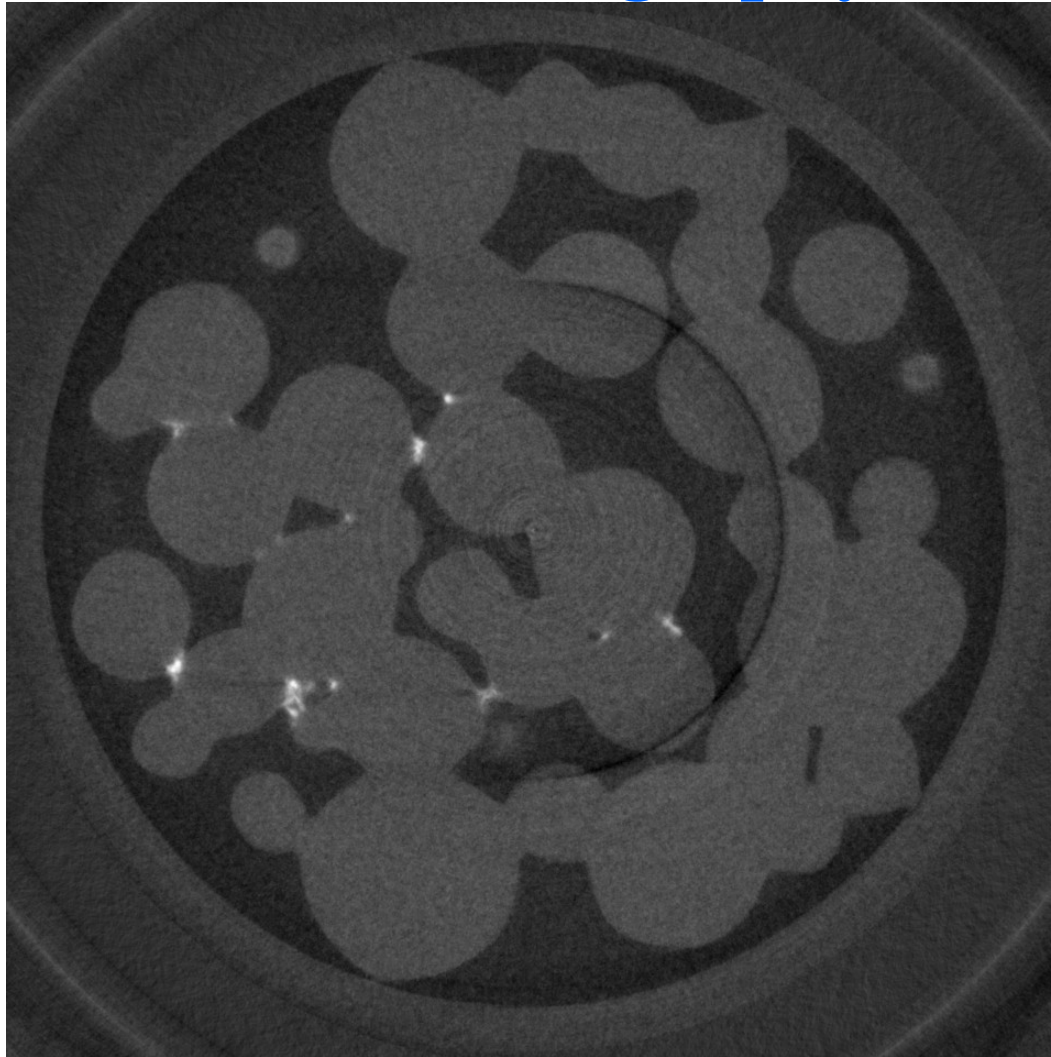
11.25 seconds total



Z slice for fast scan, 2x2 binned, 0.006 s exposure, 900 projections

Grasshopper3 GS3-U3-23S6M

First FastTomography Data



Same fast scan, but reconstructed by Doga with phase retrieval rather than Gridrec
Very promising for doing fast tomography even with monochromatic beam!

How many bits do I really have/need?

Common misconceptions about required number of bits in a camera

- The ADC should be set so 1 LSB is \sim read noise.
- The number of bits required is then given by the ratio of the full-well capacity to the read noise. Example of Grasshopper3:
 - Full well = 32,513 e^-
 - Read noise = 7 e^-
 - Ratio = 4644 = 12.18 bits, so 12 bits required
- But this does NOT mean that the full-well is captured with 12 bit precision!
 - Noise in full-well measurement = $\text{sqrt}(30,000) = 173 e^-$
 - Signal to noise in full-well measurement = $30,000/173 = 173$. This is less than 8 bits!
 - So a 12-bit camera is not required to digitize the full-well with full precision.

How many bits do I really have/need?

- Example: Tomography where air/flat field use full-well (close to saturation) and maximum absorption is 80%.
- Darkest pixels have 20% transmission = $30000 * 0.2 = 6000 e^-$
- Noise in darkest pixels is $\text{sqrt}(6000) = 77 e^-$
- Brightest pixels are $30000 e^-$, so dynamic range is $30000/77 = 387$. This is 8.6 bits. So a 9 bits is all that is required for this application.
- Collecting 12 or 16 bits is completely overkill for a camera with $30000 e^-$ full-well UNLESS the range of the pixel intensities in a single image really covers the entire range from the read-noise to the full-well capacity. This applies to Andor and PCO Edge cameras.