ANL-LBNL Fast CCD:
Current Status and Future Developments

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Acknowledgements

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  - Especially John Weizeorick and Tim Madden
- Lawrence Berkeley National Lab (LBNL)
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- Northern Illinois University
  - Larry Lurio, Janae DeBartolo (APS), Nuwan Karunaratne, Sambhunath Bera
- Larry Lurio, Nuwan Karunaratne, Peter Denes and John Weizeorick for slides

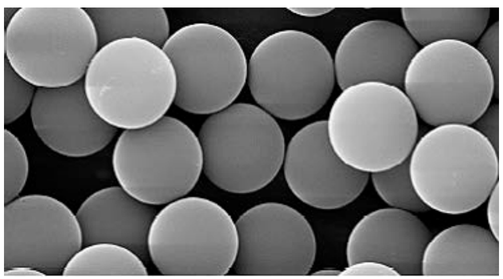
Outline

- Motivation
- Background
- Design
- Development and characterization
- Applications
- Future prospects
- Summary

Motivation

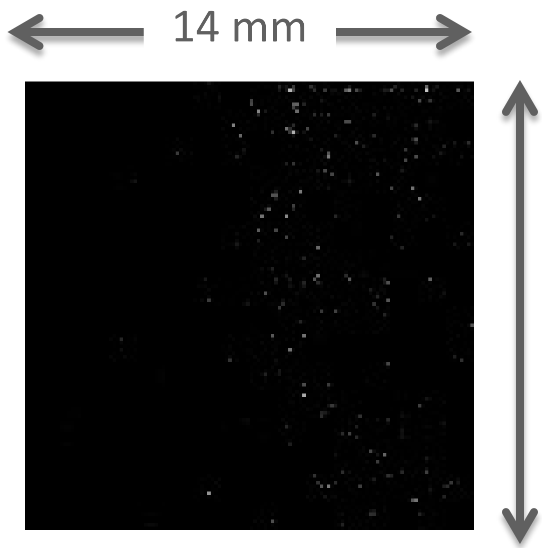
- Scientific need for fast high-resolution photon sensitive detectors:
  - I.e., dynamics in a dense colloid solution with temperature-sensitive inter-particle interactions

1. Illuminate sample with a partially-coherent x-ray beam



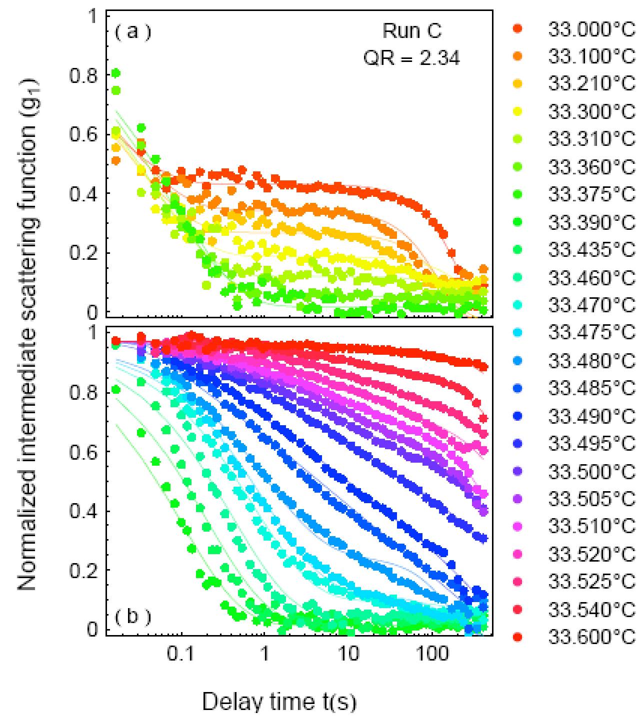
200 nm radius silica spheres

2. Record speckle pattern versus time with an XPCS-suitable detector



$$g_2(Q,\Delta t) = \frac{\langle I(Q,t)I(Q,t+\Delta t)\rangle}{\langle I(Q,t)\rangle^2}$$

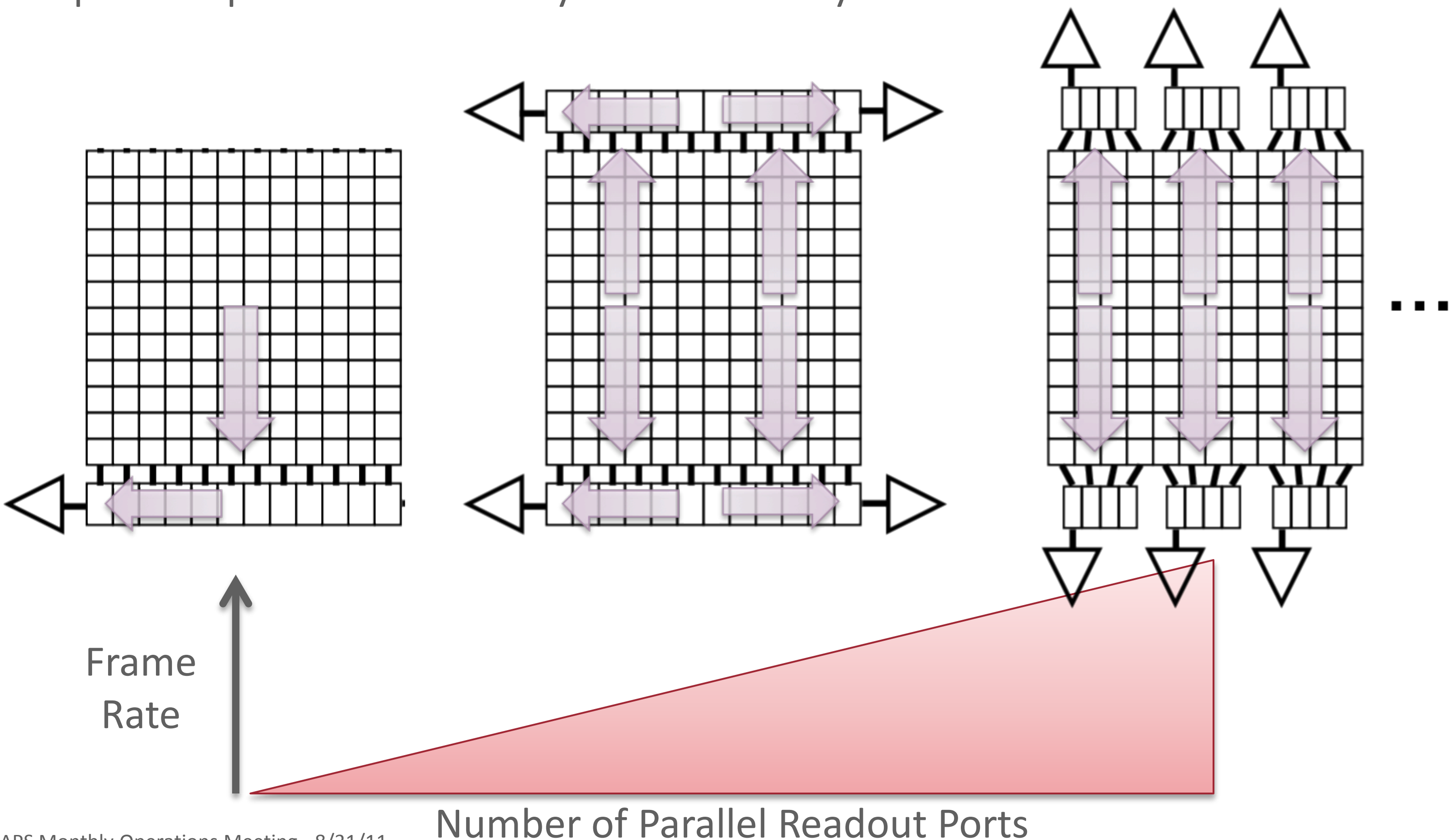
3. Time autocorrelate speckle patterns to reveal sample dynamics



X. Lu *et al.*, PRL **100**, 045701 (2008)

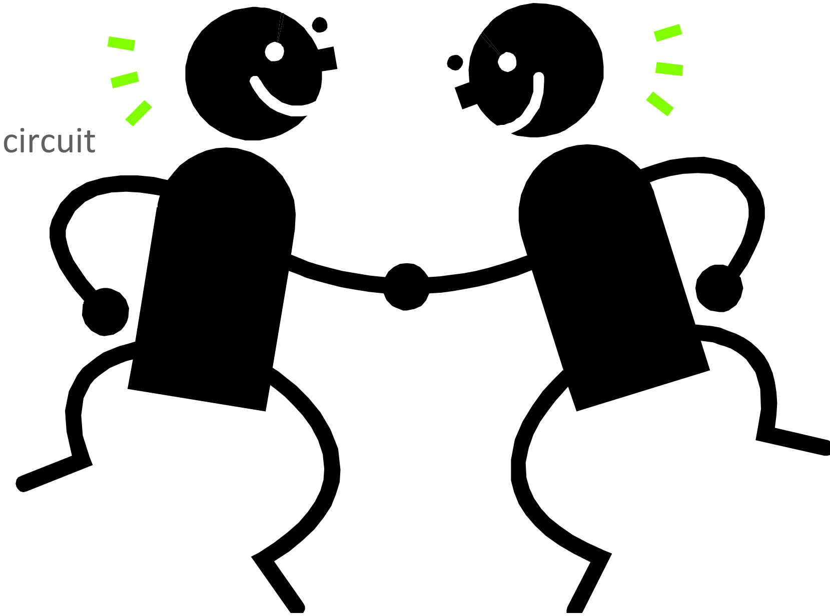
Background

- CCD's are tried and true pixelated x-ray detectors with many applications … but slow
- Improved speed and efficiency will make x-ray CCD's more useful



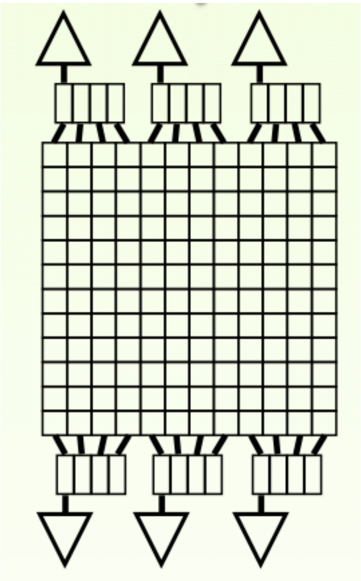
Background

- History and technical opportunity
  - IR astronomy CCD sensors developed at LBNL should also be useful for x-ray detection
    - Envisaged applications:
      - LCLS (but not an official LCLS detector)
      - Time-resolved diffraction and energy-resolved Laue diffraction
      - CDI
      - XPCS
  - S. Ross (DET) and H. Padmore (LBNL) explore collaboration to leverage LBNL astronomy sensors for x-ray applications (2005)
    - LBNL: sensor and application-specific integrated circuit (ASIC) design expertise
    - ANL: data-acquisition electronics and opto-mechanical expertise

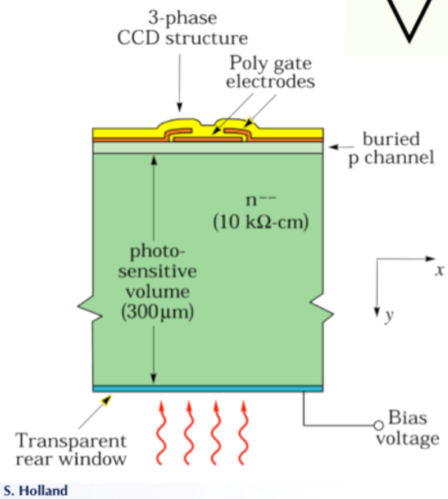


Design

- Based on Supernova Acceleration Probe (SNAP) sensor and readout designs
  - 494 × 480 30 µm pixels (≈ 14 × 14 mm^2)
  - Thick (200–300 µm) fully-depleted back-illuminated CCD
  - Direct detection or phosphor/fiber coupling
  - Parallel readouts (96) for speed
    - Split top and bottom and one output per 10 columns
    - Readout time of 2.4 msec / frame or 416 frame readouts/sec
  - Cooled sensor for low noise



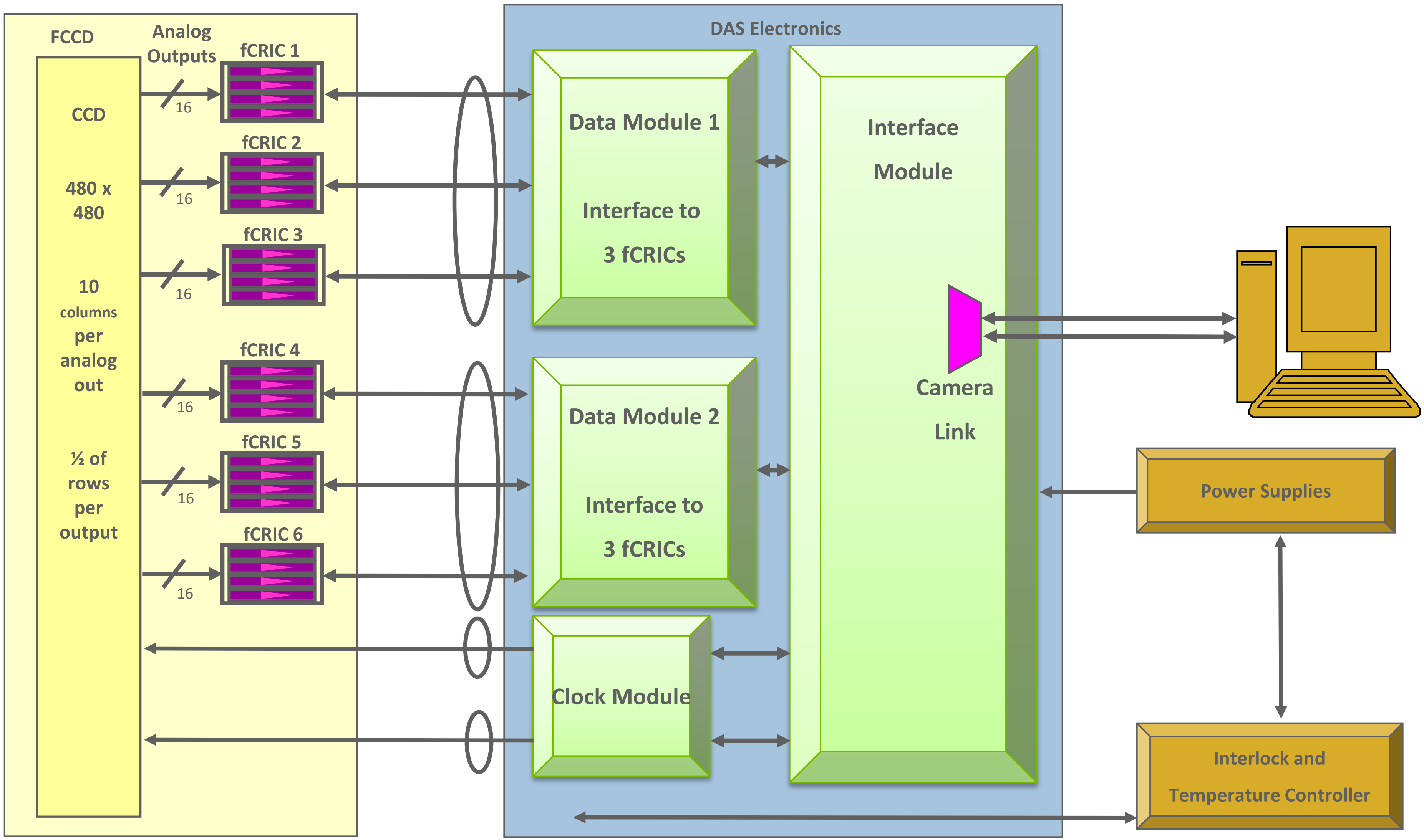
- Custom readout IC's to perform analog-to-digital conversion of input
  - 14-bit output
  - Conversion rate of 1 µsec/pixel
  - 4 serial LVDS outputs



Design

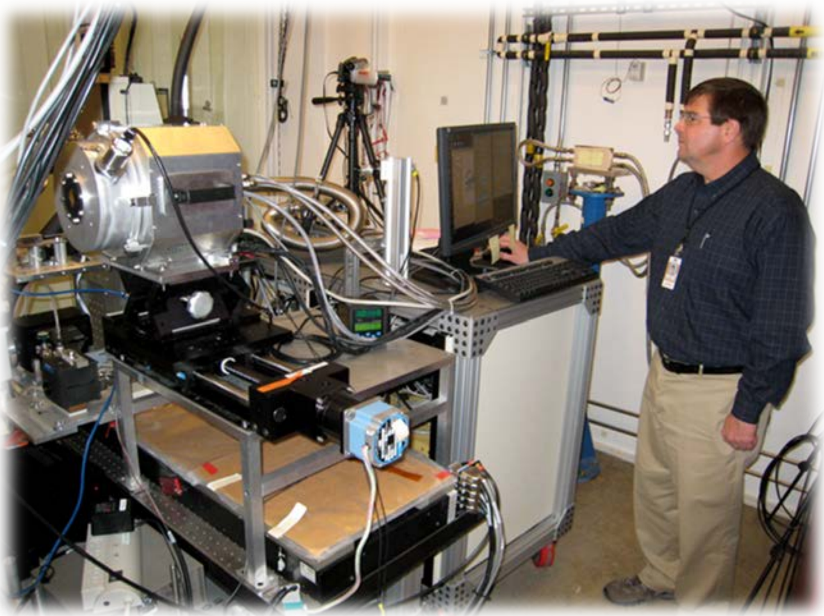
Front End Electronics – LBNL

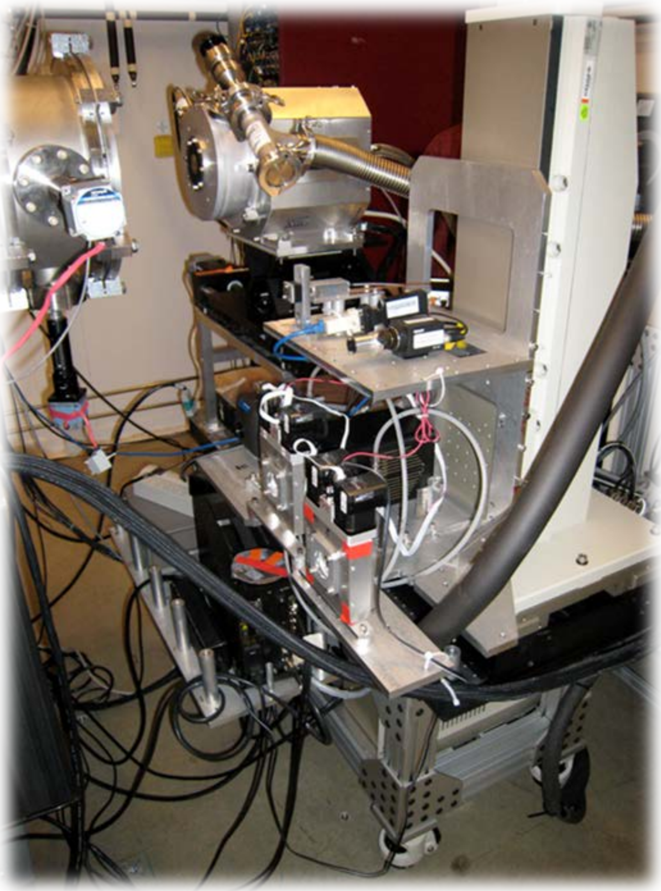
Back End Electronics – ANL



Development and Characterization

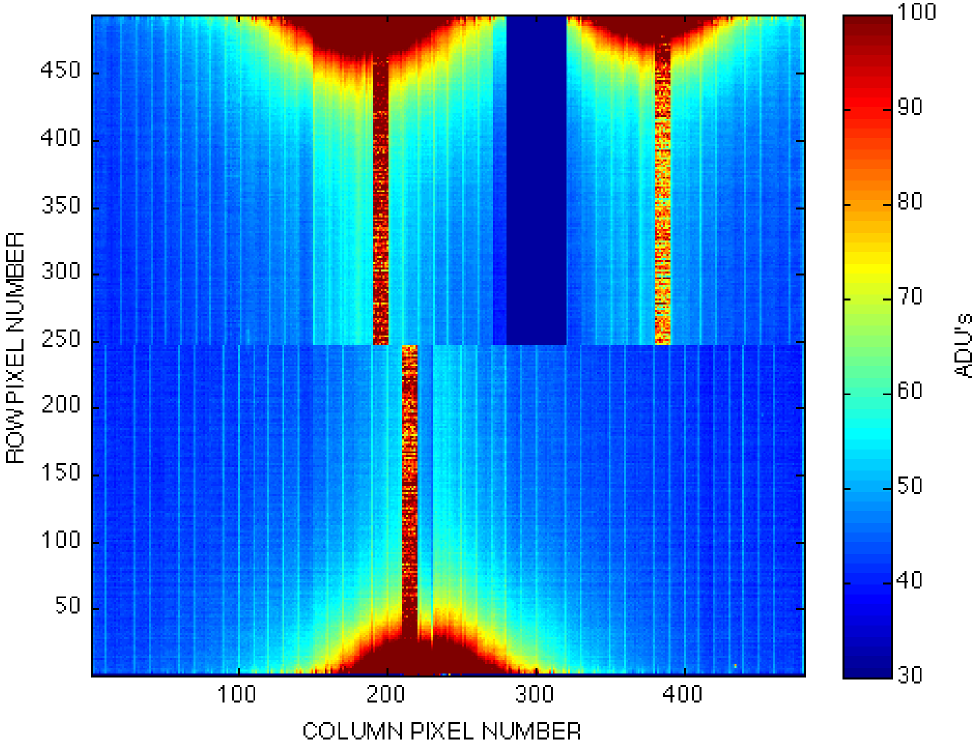
- APS instance 1 of version 1.0 released for testing ~ 2 years ago
  - Flat field response
  - Point-spread function (PSF)
  - Efficiency and energy resolution
  - Usability, robustness
  - Applications





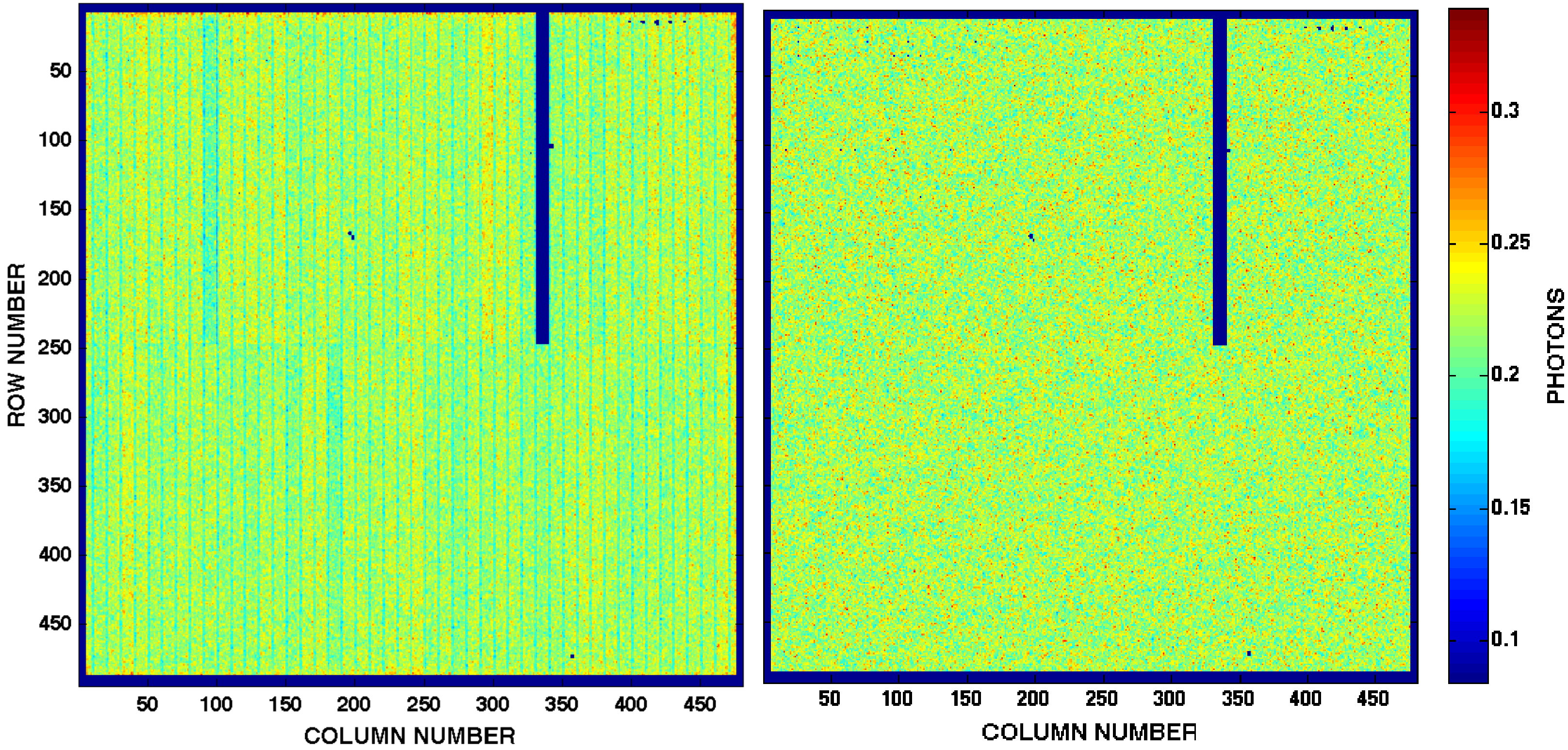
Development and Characterization

- APS instance 1 of version 1.0
  - Demonstrated big-picture suitability for XPCS
    - Higher frame rate than almost all x-ray CCD’s
    - High gain response to photons via direct detection
    - High efficiency
  - Enabled development of robust control and compression algorithms
  - Operational challenges
    - Heat leaks from readout electronics limit exposure times and exposure areas
    - Sensor or electronics with significant dead or high noise regions
    - Transient noise spikes
    - Bulky and heavy



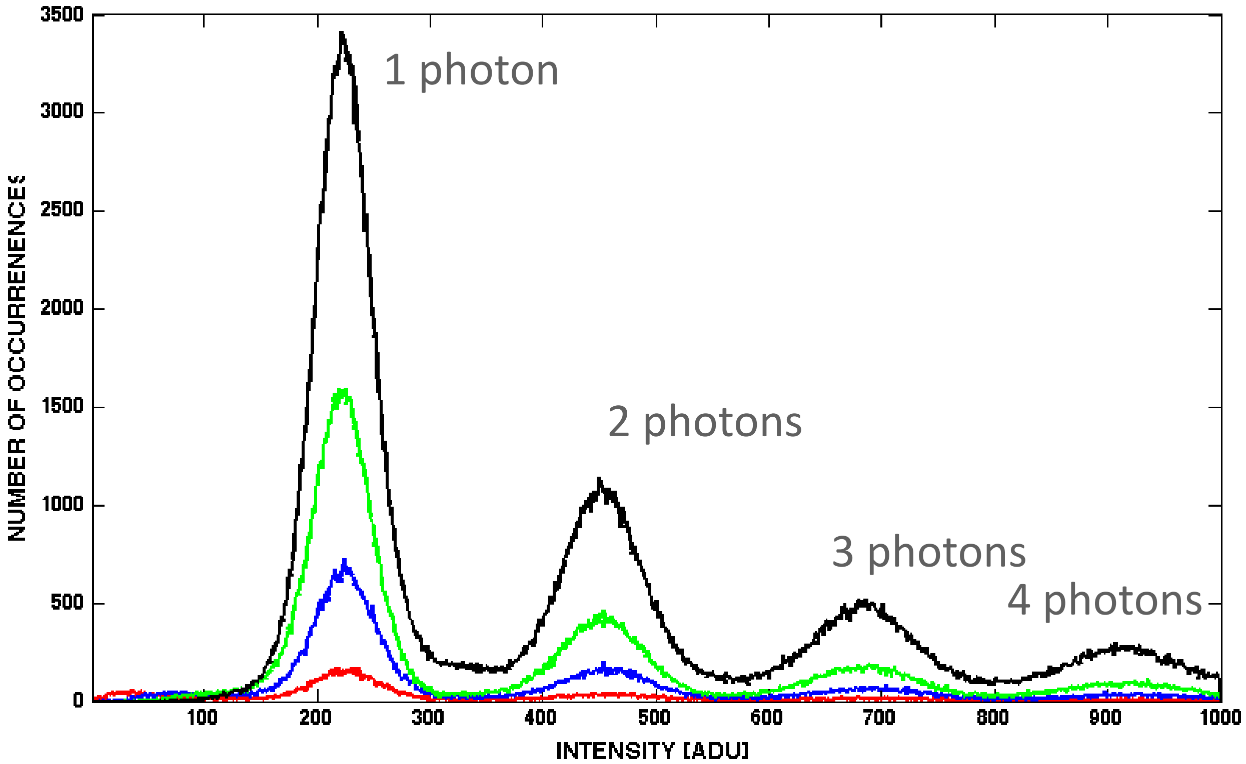
Development and Characterization

- APS instance 2 of version 1.0 deployed at 8-ID in February for testing
  - Much better!
    - Flat field



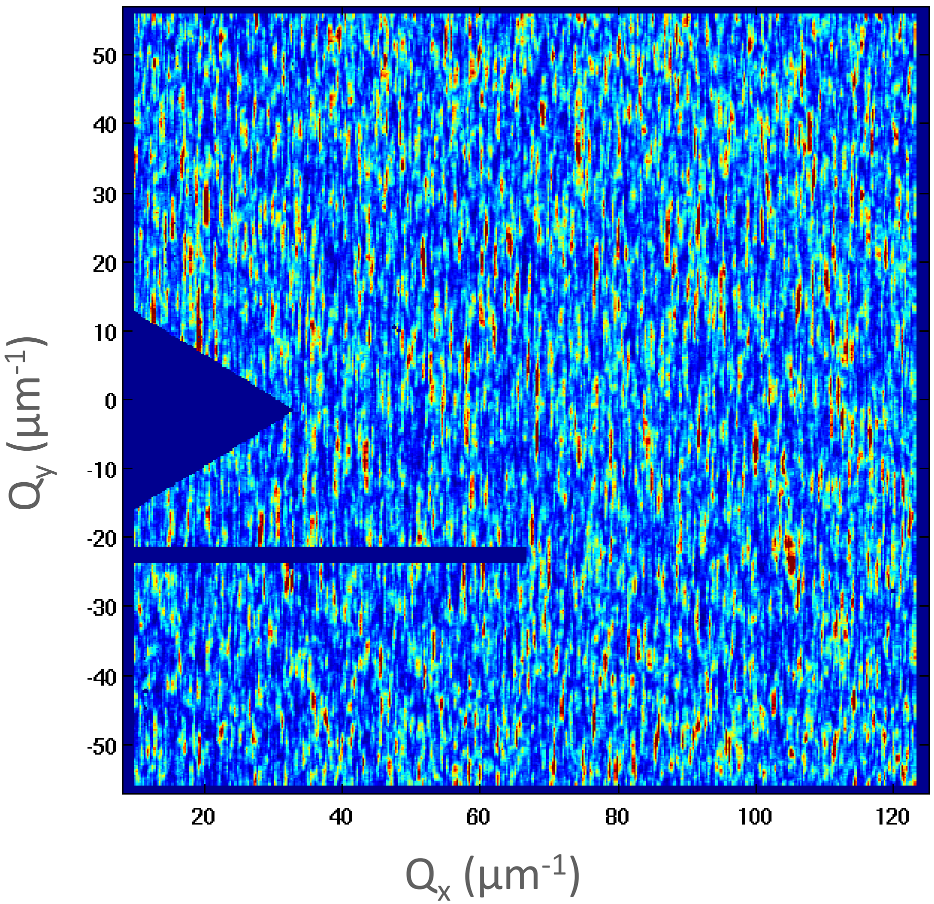
Development and Characterization

- Photon counting (or energy resolution for single photon counting)
  - Different color lines represent different (software) discriminator levels
  - Energy resolution ≈ 300 eV



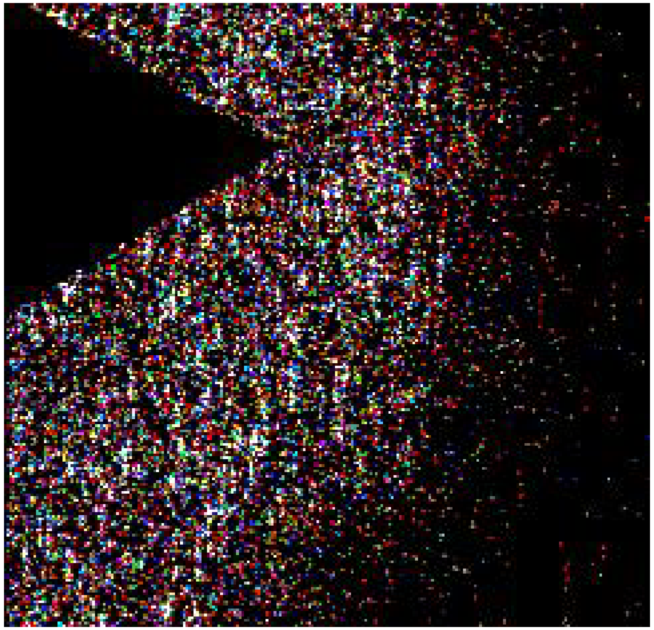
Development and Characterization

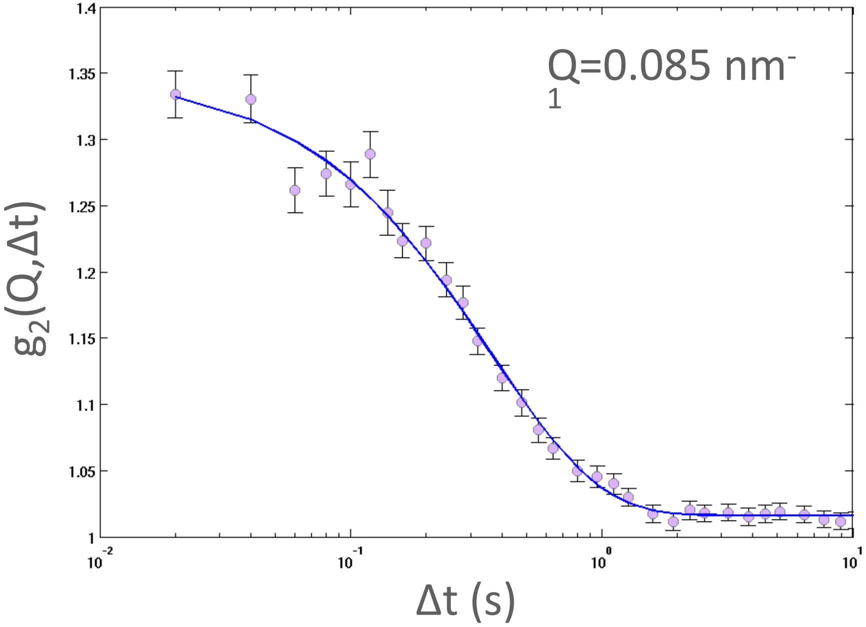
- X-ray speckle from a static reference sample



Development and Characterization

- Fluctuating speckle from a dynamic reference sample

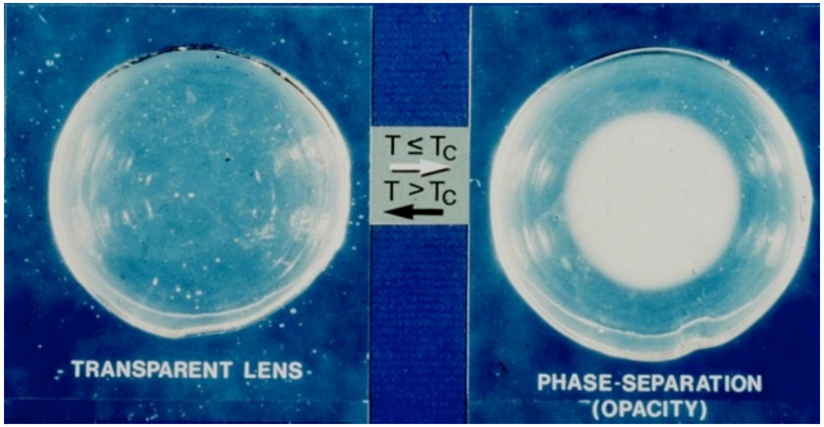




$$g_2(Q,\Delta t) = \frac{\langle I(Q,t) I(Q,t+\Delta t)\rangle}{\langle I(Q,t)\rangle^2}$$

Applications

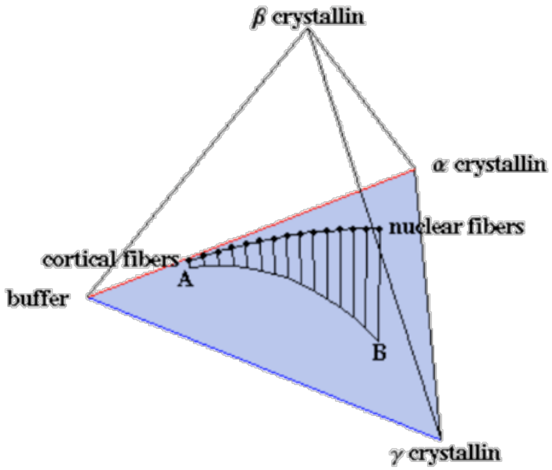
- XPCS to probe the dynamics of eye-lens-protein mixtures (L. Lurio, J. DeBartolo, G. Thurston, Nuwan K.)
  - Physiological motivation
    - Cold cataract is due to reversible liquid-liquid phase separation in young, mammalian eye lenses



    - Stiffening of eye-lens—presbyopia (far-sightedness)—possibly associated with liquid-glass transition in protein mixture
  - Dynamics measurements provide information on rate of phase separation, elasticity
  - X-rays provide information on local nanoscale diffusion and diffusion of clusters of proteins (cf. light scattering)

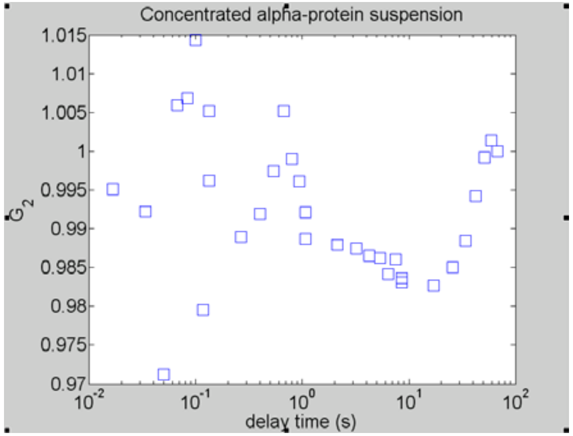
Applications

- XPCS to probe the dynamics of eye-lens proteins (L. Lurio, J. DeBartolo, G. Thurston, Nuwan K.)
  - Physics motivation
    - Dynamics of concentrated sticky “spheres”
  - Technical motivation
    - Extend XPCS to biological materials in aqueous solution
      - Faster time scales
      - Higher x-ray energies
    - Detector usability and robustness
      - Experienced and local user group
    - Intermittent trials over the years as test of state-of-the-art XPCS

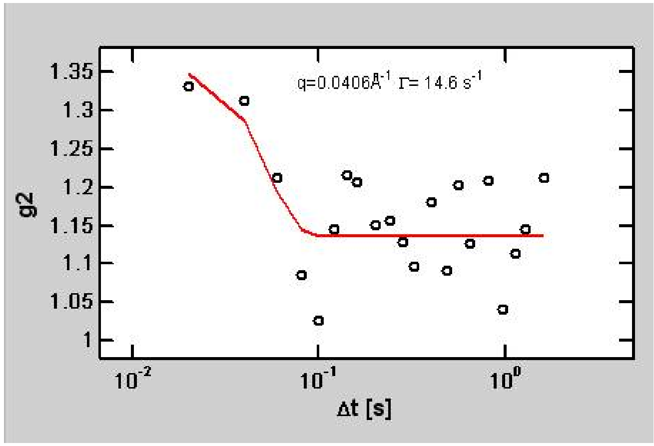


Applications

- Alpha crystallin suspension dynamics



July 2009:
- Fast CCD



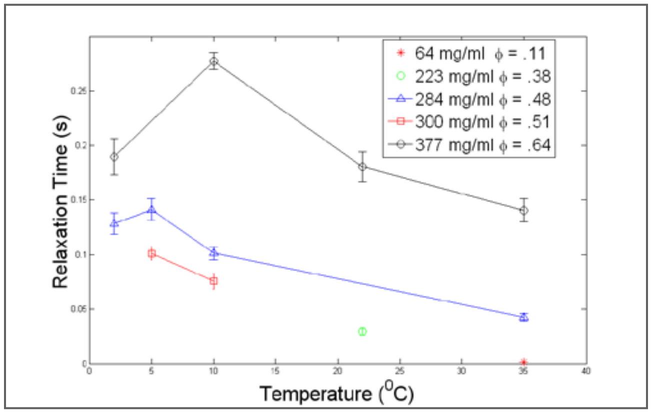
November 2009:
- Fast CCD
- Focusing

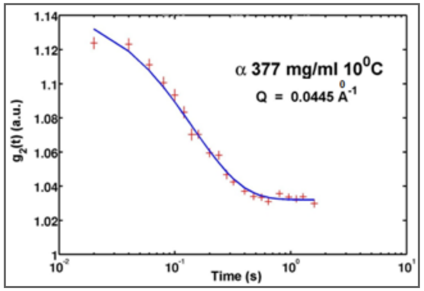
Applications

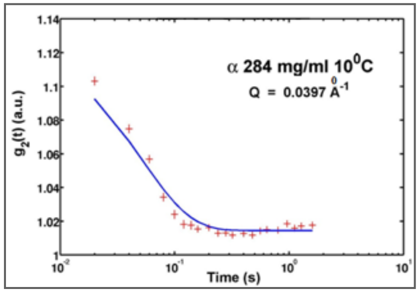
- Alpha crystallin suspension dynamics

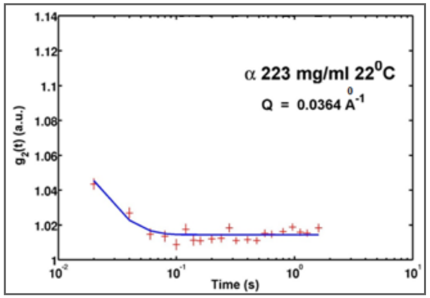
April 2010:

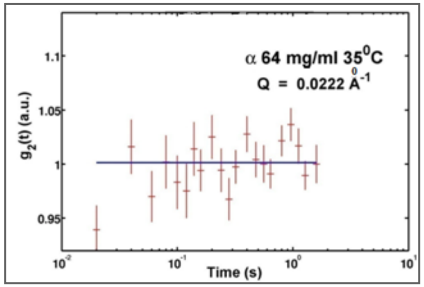
- Fast CCD
- Focusing











- August 2011:
  - Faster dynamics than observed previously so still a work in progress
  - Confidence gained in deploying detector for GU program

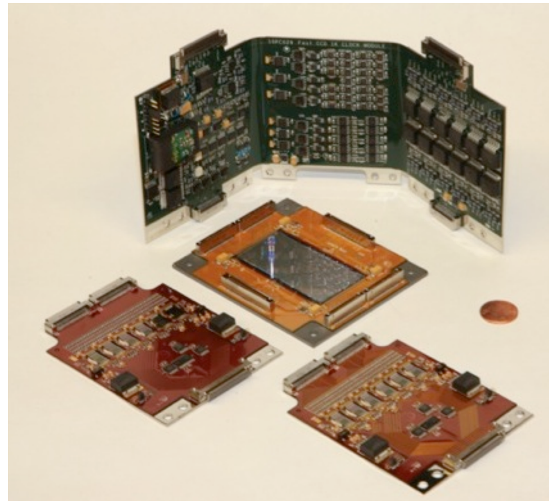
Future

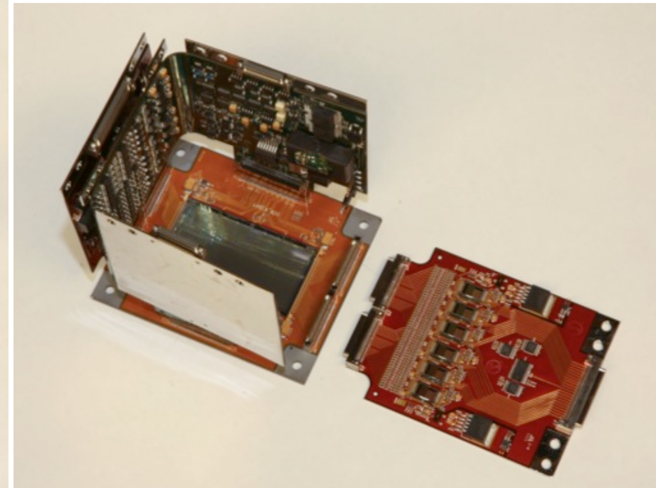
- Near term
  - ANL and LBNL ARRA-funded version 2.0 – Faster CCD
    - Prototype integration testing: Fall 2011
    - Production: Winter/Spring 2011/2012
    - Off-line testing: Summer 2012
    - Beamline deployment and testing: late Summer or Fall 2012

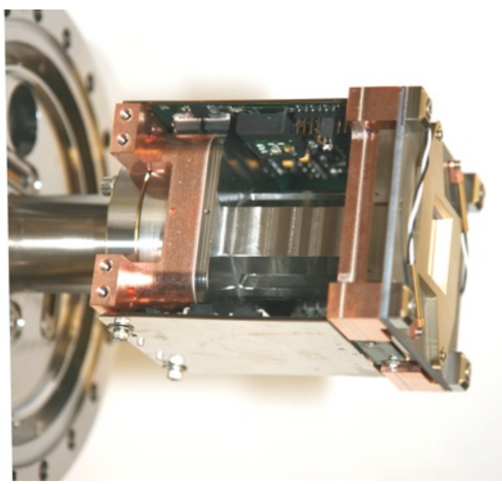
Item	1.0	2.0
Pixel size (µm^2)	30 × 30	30 × 30
Pixel thickness (µm)	250	250
Sensor size (pixels)	494 × 480	960 × 960
Bandwidth (Mpix/s)	38	160-200
Frame transfer (shutterless operation)	No	Yes
Area of interest	No	Yes
Kinetic/Streak mode	No	Yes
Weight (kg)	20	12

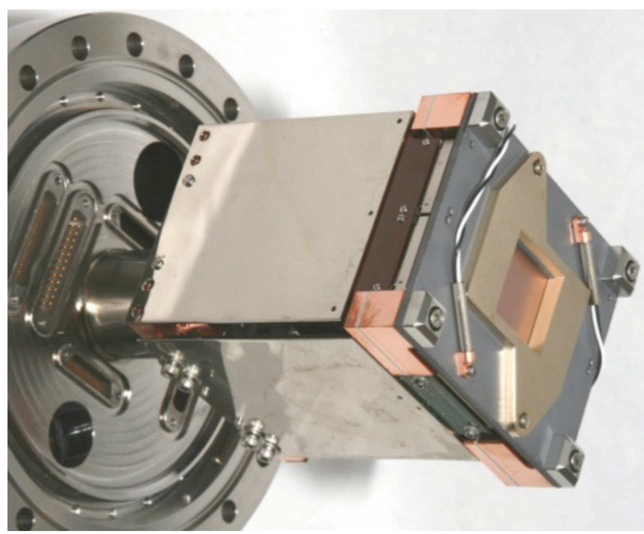
Future

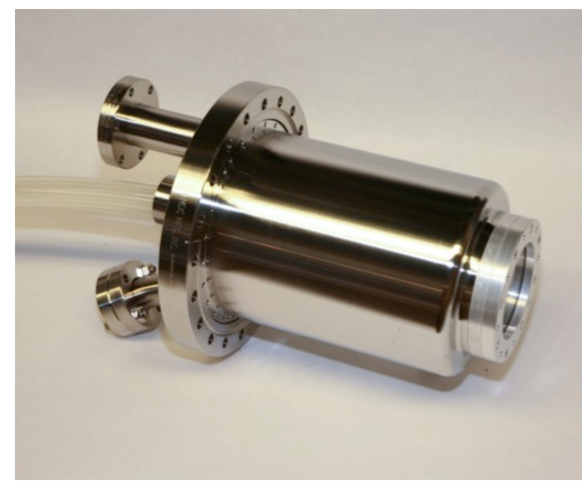
- Near term
  - Mechanical prototype assembly at LBNL





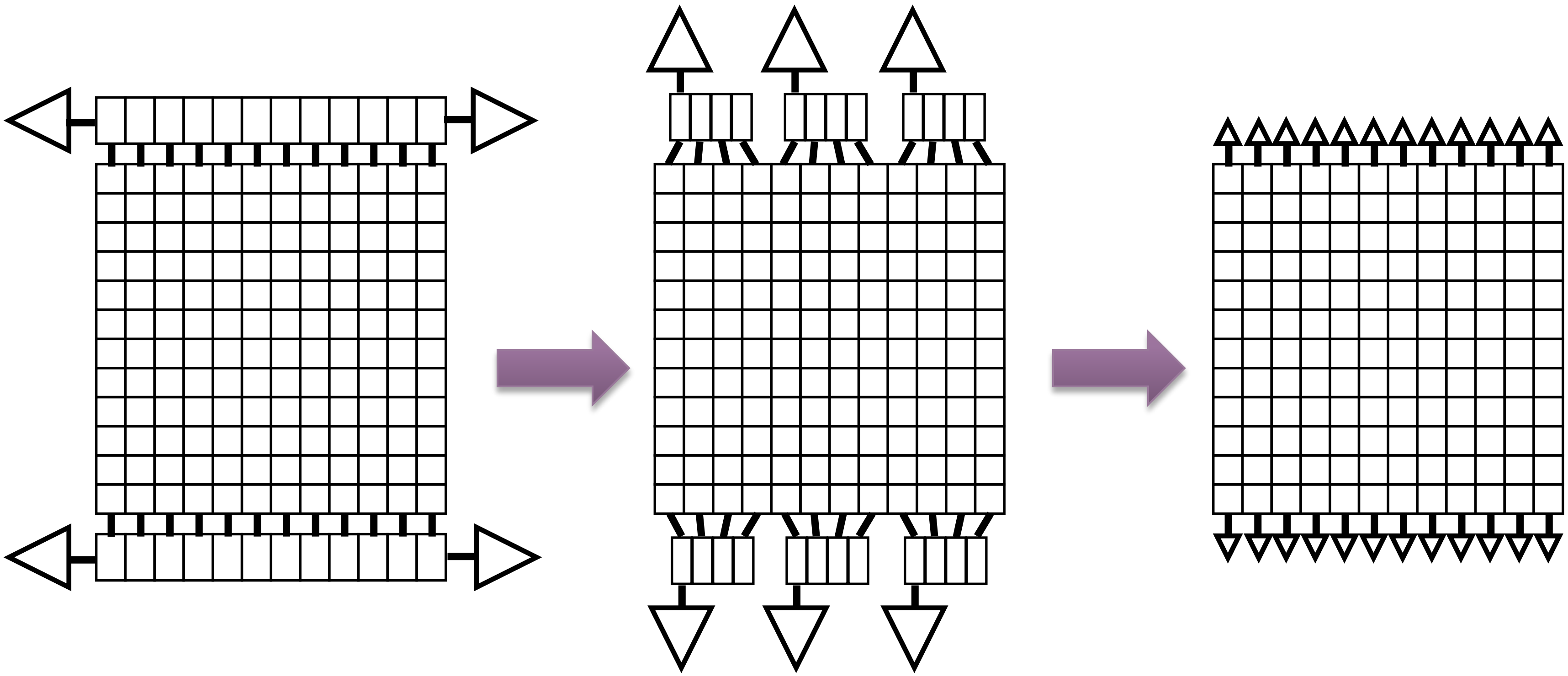






Future

- Further term
  - LBNL LDRD to develop a fully-column parallel CCD
    - Fastest CCD
      - ≈ 10X further increase in data bandwidth

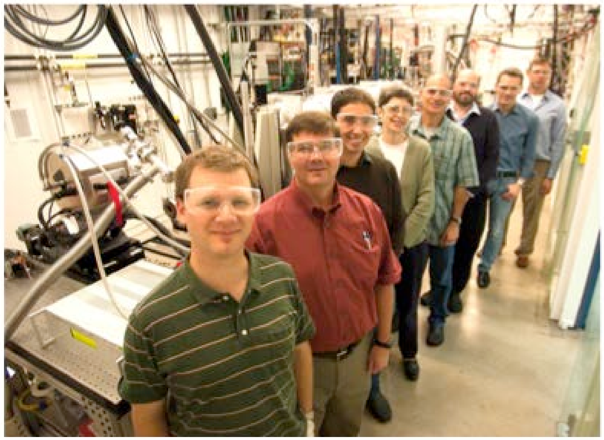


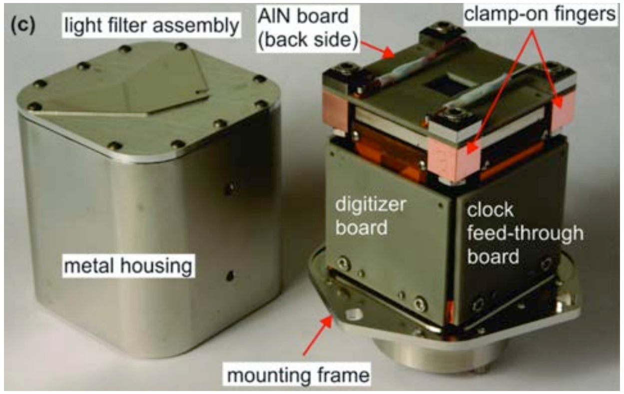
Summary

- Fast CCD developed and deployed for use at APS, ALS and LCLS
  - XPCS (APS)
  - Time- (and energy) resolved diffraction (ALS, LCLS)
  - Coherent diffraction imaging (ALS)

- Faster CCD nearing integration testing and production

- Productive and fruitful collaboration established with beamline staff, APS Detector Group and LBNL
  - Flexibility is one key benefit
    - Packaging, thresholding, timing, …





Further information:

- P. Denes *et al.*, Rev. Sci Instrum. **80**, 083302 (2009)
- D. Doering *et al.*, Rev. Sci. Instrum. **82**, 073303 (2011)
- T. Madden *et al.*, Rev. Sci. Instrum. **82**, 075109 (2011)

XPCS Detector Landscape

Item	PI LCX	FCCD 1.0	FCCD 2.0	FCCD 3.0	Maxipix	pnSensor CCD	Eiger	VIPIC
Pixel size (µm)	20	30	30	30	55	48	75	80
Thickness (µm)	~65	250	250	250	200	450		
Area (Mpix)	1.7	0.25	1	1	0.06	0.06	0.06*	0.005*
Bandwidth (Mpix/s)	2	38	160-200	1700	60	70	720*	400*
Frame transfer?	N	N	Y	Y	N	Y		
AOI?	Y	N	Y	Y				
Streak-mode?	Y	N	Y					
Counting?	N	N	N	N	Y	Y	Y	Y

- Pilatus: 172 µm pixels, 135 Hz (1M), 320 µm thick pixels, counting
- SMD/Dalsa: 14 µm pixels, 60 Hz (1M), 40 µm thick pixels, integrating, legacy device

* Specifications for (prototype) module. Parallel modules expected for production version.