NuSTAR

"First mission to bring the High Energy Universe into Focus"

Kristin Kruse Madsen

Fiona Harrison

Brian Grefenstette

Karl Forster

Caltech, Pasadena

NuSTAR specifications

1 Ms Sensitivity

3.0 x 10^{-15} erg/cm^2/s (6 – 10 keV)
1.2 x 10^{-14} (10 – 30 keV)

Imaging

HPD	~50”
FWHM	10”
Localization	2” (1-sigma)

Field of View

FWZI	12.5’ x 12.5’
FWHI	10’ @ 10 keV
	8’ @ 40 keV
	6’ @ 68 keV

Timing

relative	100 microsec
absolute	30 msec

Spectral response

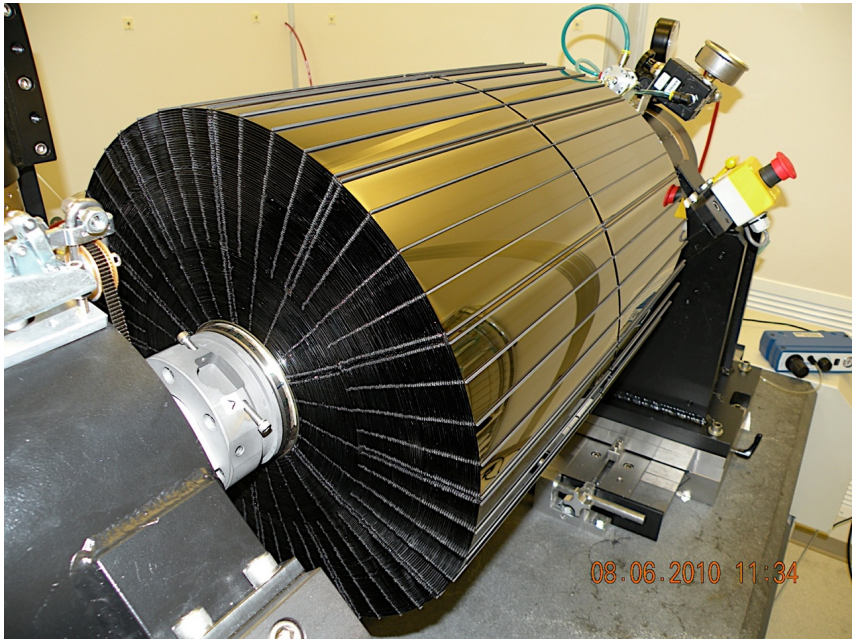
threshold	2.5 keV
ΔE @ 6 keV	0.6 keV FWHM
ΔE @ 60 keV	1.0 keV FWHM

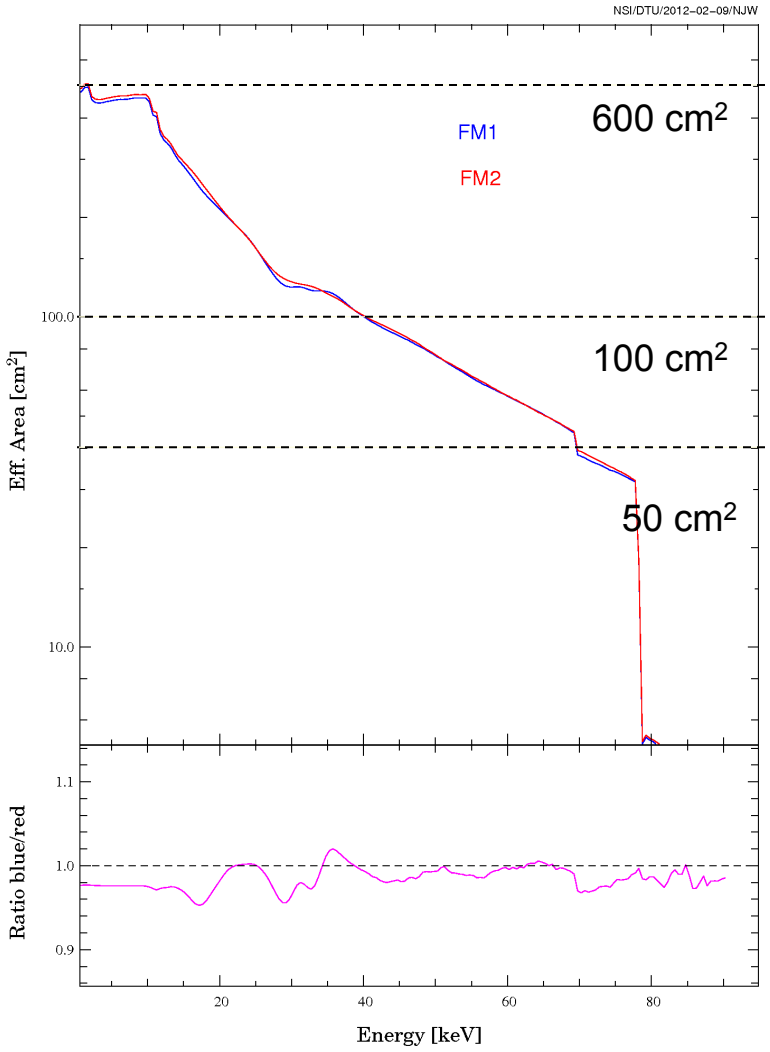
Target of Opportunity

response	<24 hr (reqmt)
typical	6-8 hours

85% sky accessibility

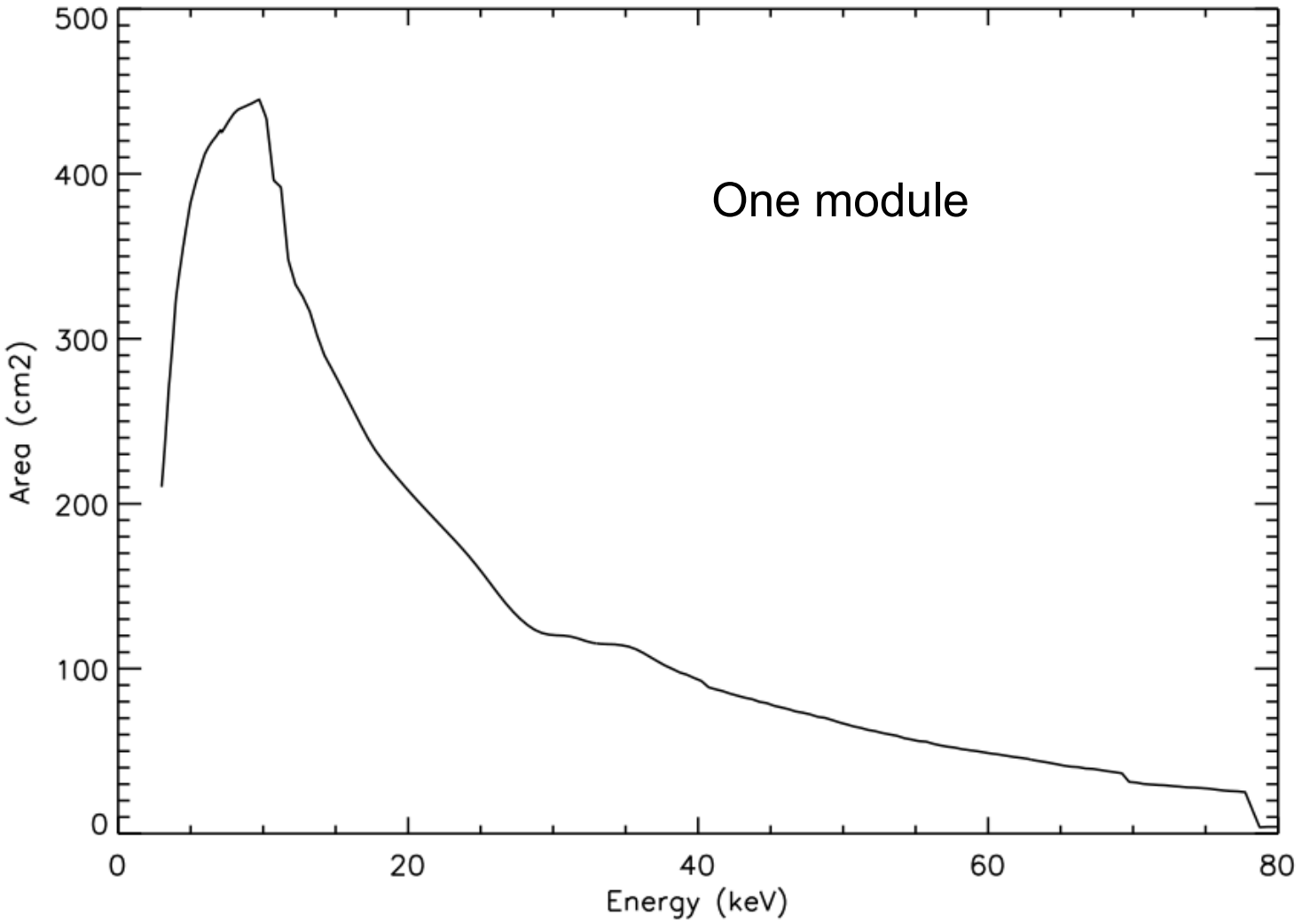
Optics



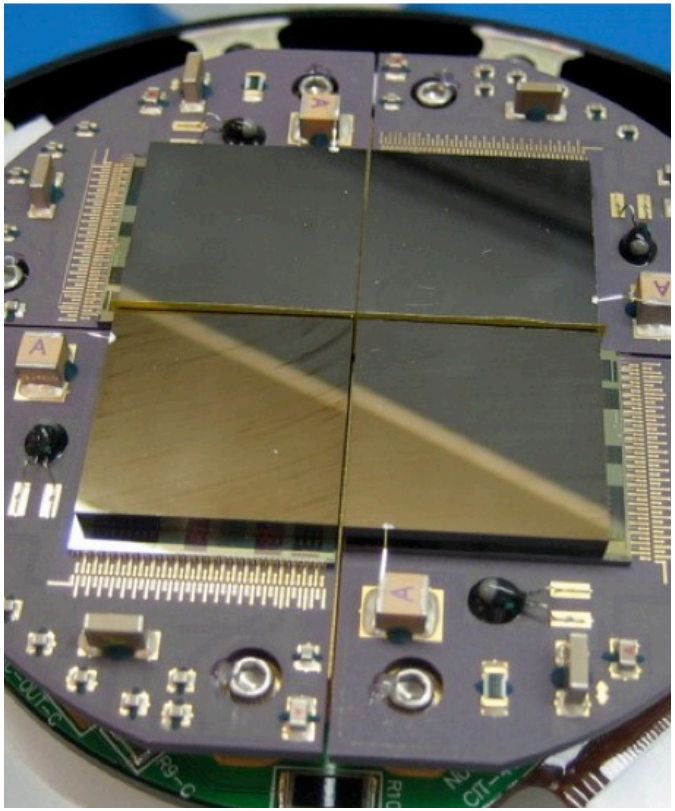


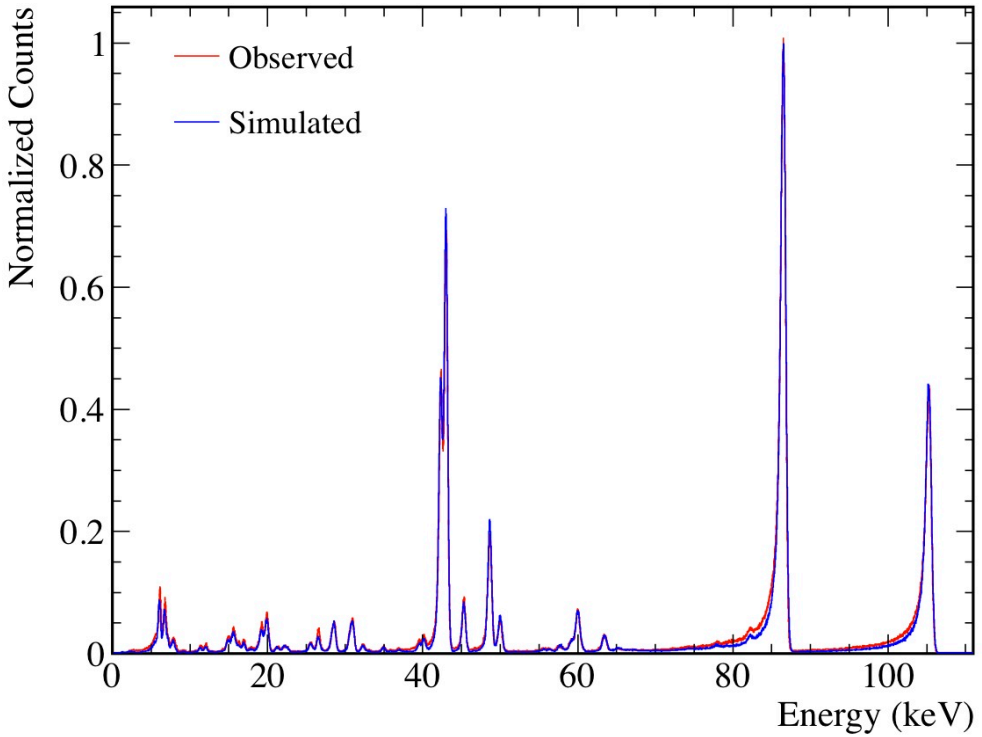
- Wolter-I conical approximation
- Focal length = 1015 cm
- 133 shells
- Multilayers (Pt/C, W/Si)

Effective Area



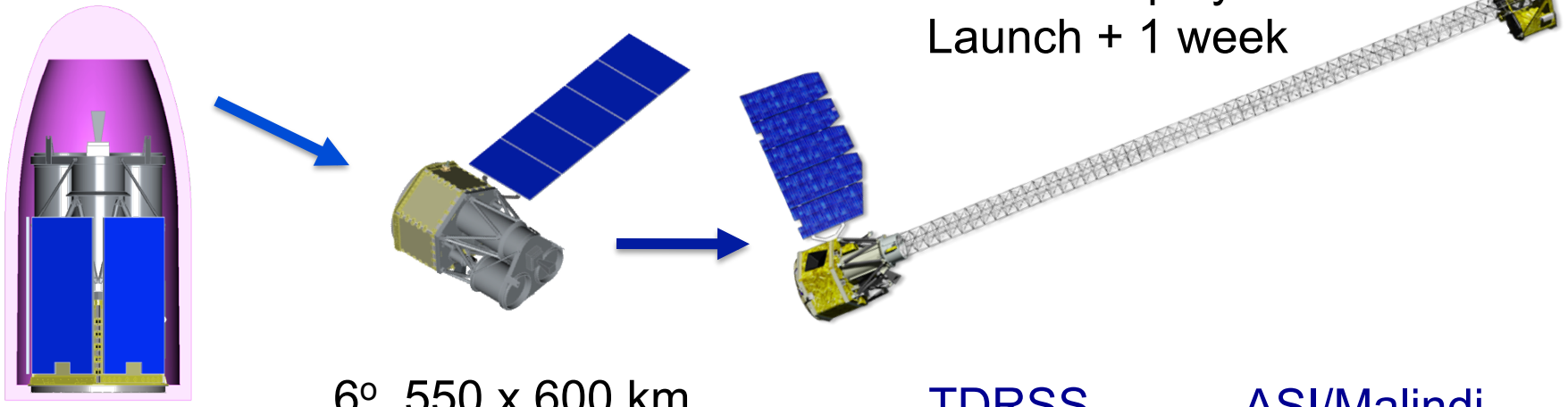
Focal Plane





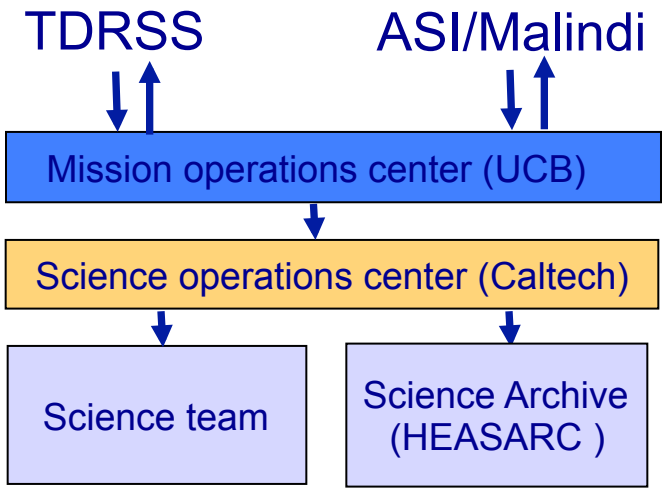
- CdZnTe, one module = 4 detectors
- One detector
  - 2mm thick, 2cm x 2cm
  - 32 x 32 pixels, pitch 604.8 μm, 12”

Mission Overview



Pegasus XL
Late May/early June 2012

6° 550 x 600 km
Low background
55% observing efficiency



30-day IOC
2-year baseline science mission
Observations planned by science team

Planned Observations/ exposures

Key science goal	Target	Exposure (elapsed time)
Locate massive black holes	COSMOS (3600 sq arcmin)	88 days/64 fields
	ECDF-S (900 sq arcmin)	88 days/16 fields
	BAT AGN (4 sq deg)	16 days/100 fields
Locate remnants of collapsed stars	0.8 deg x 2 deg centered on Sgr A*	28 days
^{44}Ti in young remnants	Cas A map	28 days
	SN1987A	28 days
VHE gamma ray sources	Mkn 421	10 days
	PKS 2155-304	10 days
	3C 454.3	10 days
	3C 279	10 days
Supernovae – core collapse and 1a	TBD	TBD

Total 316 days

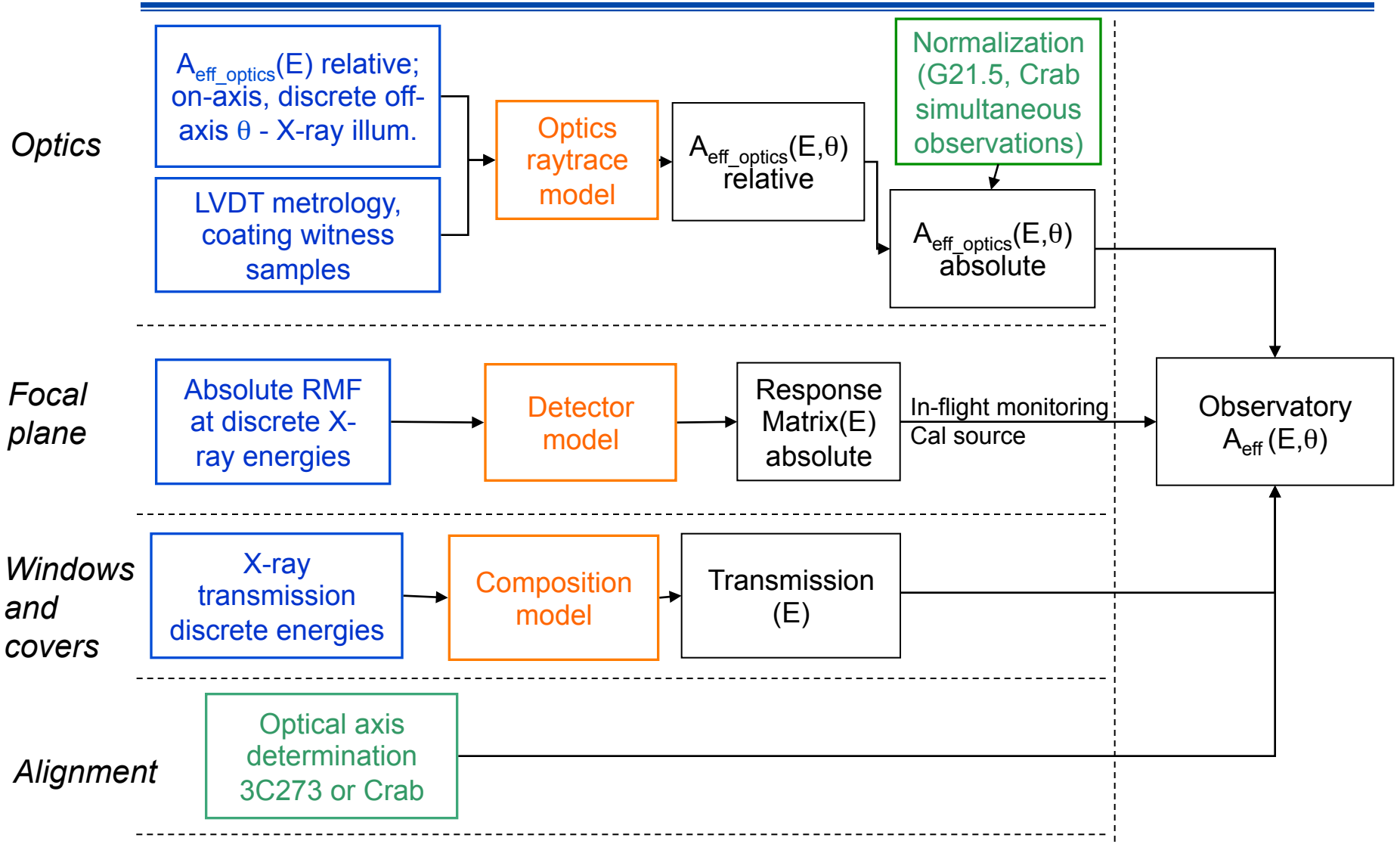
Other Science Targets

Science	Target/ #pointings	Science	Target/# pointings
Star cluster	1	ULIRGs	15
X-ray binaries	17	Compton-thick AGN	31
Supernova remnants	9	Radio galaxies	9
Magnetars	9	BAL QSOs	2
Gamma-ray binaries	4	WISE AGN	5
Pulsars	4	Other transients	TBD
Ultraluminous X-ray (ULX) sources	8	Starburst galaxies	2
Blazars	15	Galaxy clusters	12
AGN physics (black hole spin)	12	The Sun	6

Joint Science Programs

- 30% of first year observations are joint with other missions
  - Cross calibrations are ***essential***
- Joint science programs:
  - Chandra
    - SGR A* (XVP)
    - NGC 253
  - XMM (1.4 Msec)
    - Black hole spin
    - ULXs
  - Swift
    - BAT AGN
    - Magnetars
  - Suzaku
    - Cyg X-1, Her X-1 & HMXB ToO
    - NGC 4151/IC 4329A

Calibration Approach Effective Area - $A_{eff}(E,\theta)$



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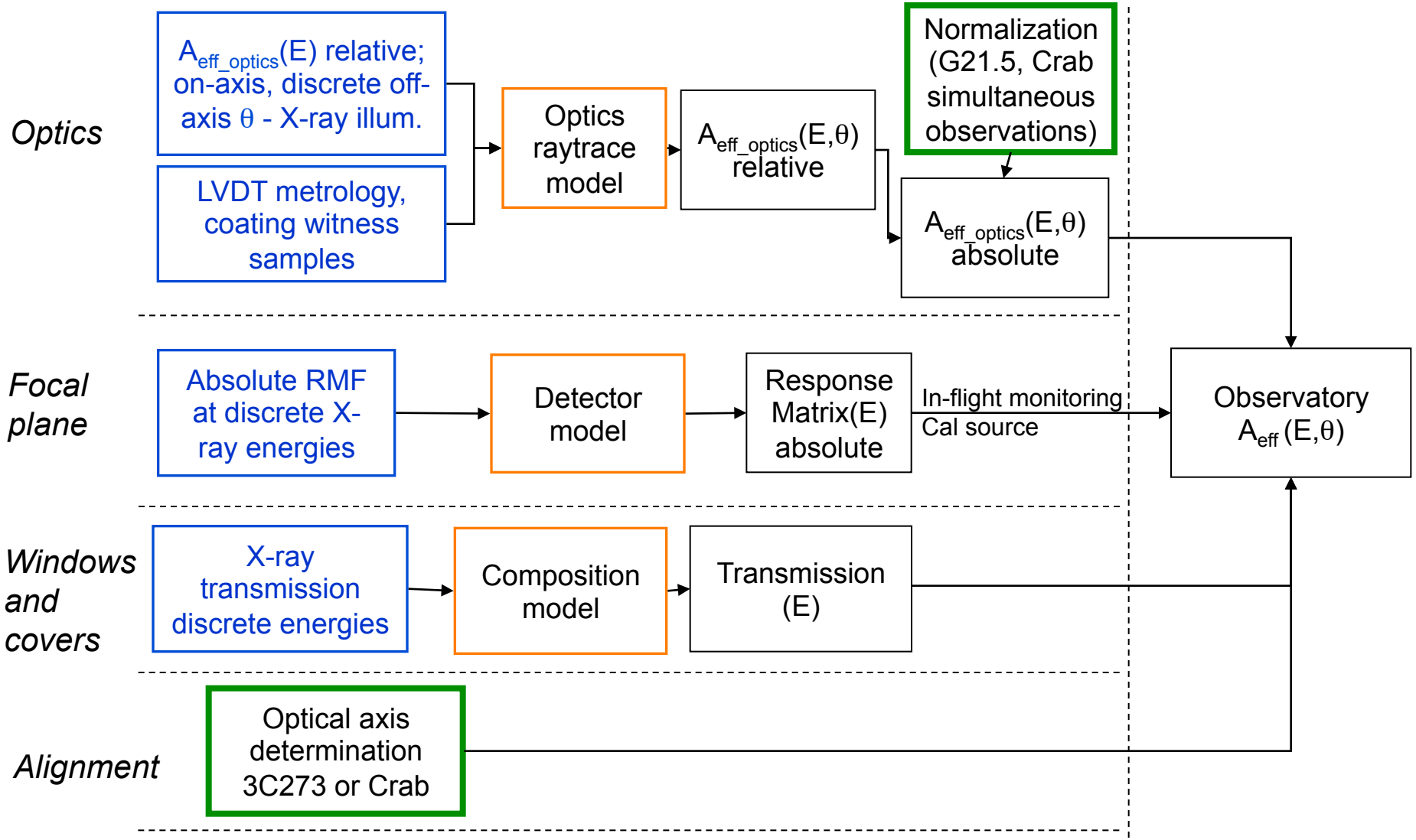
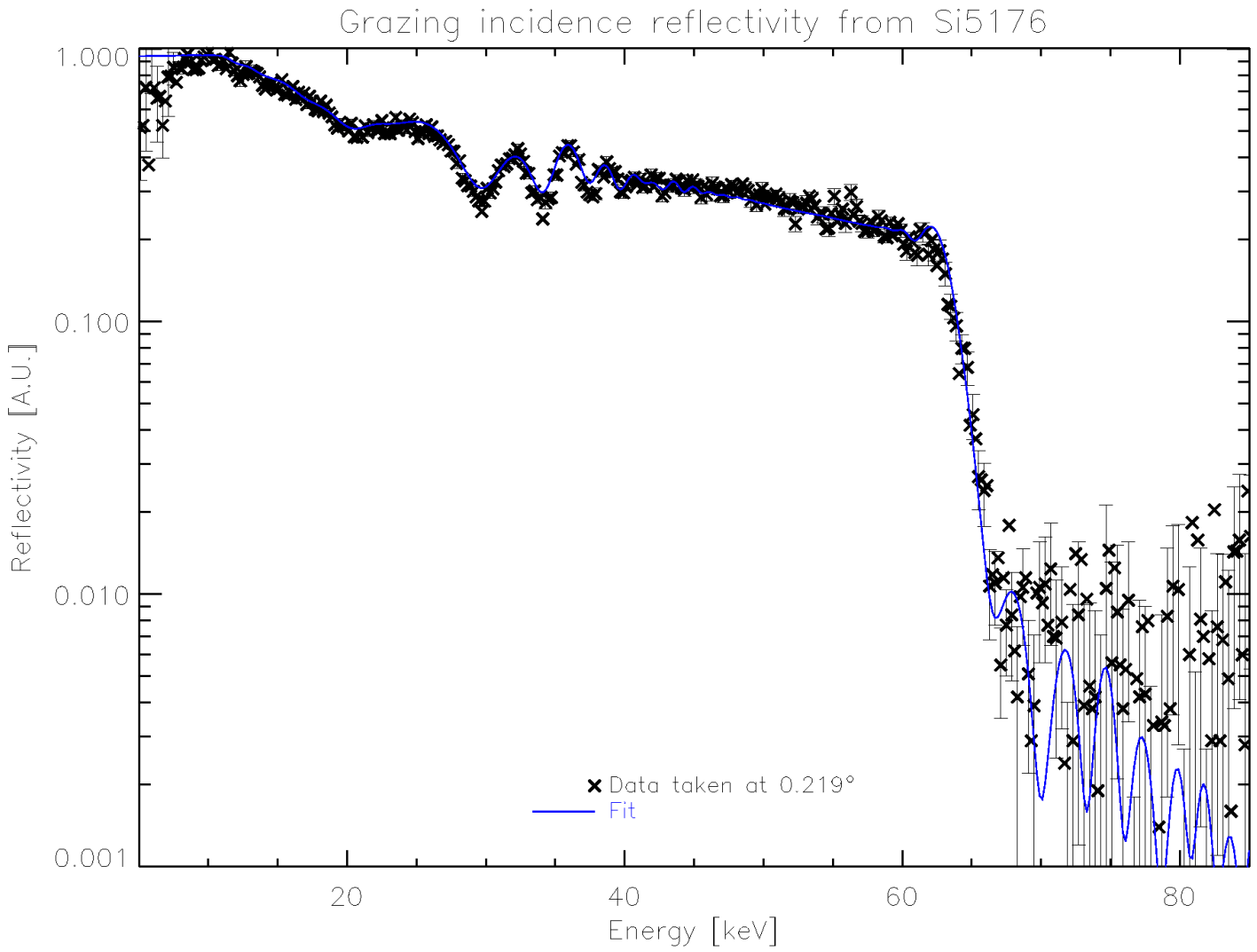


Ground measurement — simulation — In-flight calibration observation

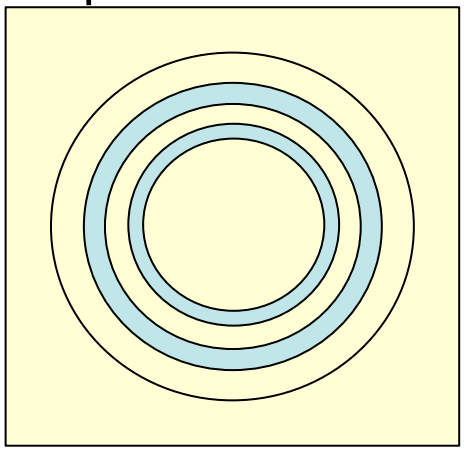
Raytrace Model

- MTRayor (Niels-Jorgen Westergaard, DTU) has been validated against other raytraces (ctrace, IRT, Marshall)
- Includes components
  - LVDT (Linear Variable Differential Transformer) scans on the backside of every single mirror on mm scales
  - Multilayer witness samples (every coating run has a witness sample measured at high energies)
  - Non-uniformity variations across mirrors (coating chamber variations).
  - Interfacial roughness measurements from selected curved glass pieces
  - High energy scatter measurements at BNL to tie down the mid-frequency roughness.
  - Validation by ground calibrations performed at NEVIS (Columbia University).

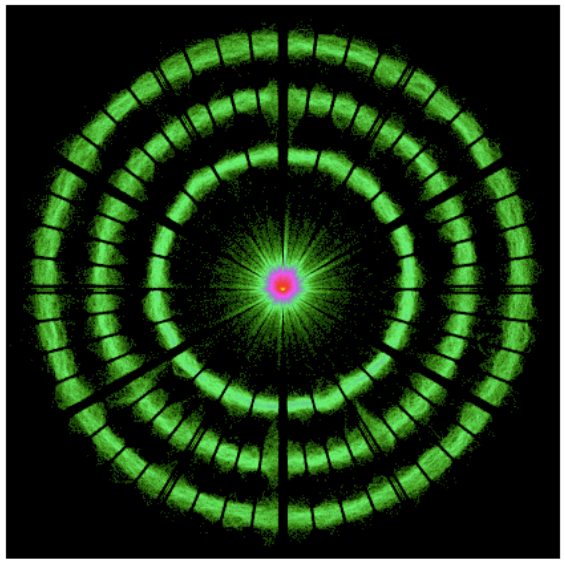
Example Multilayer (Pt/C) energy reflectivity curve

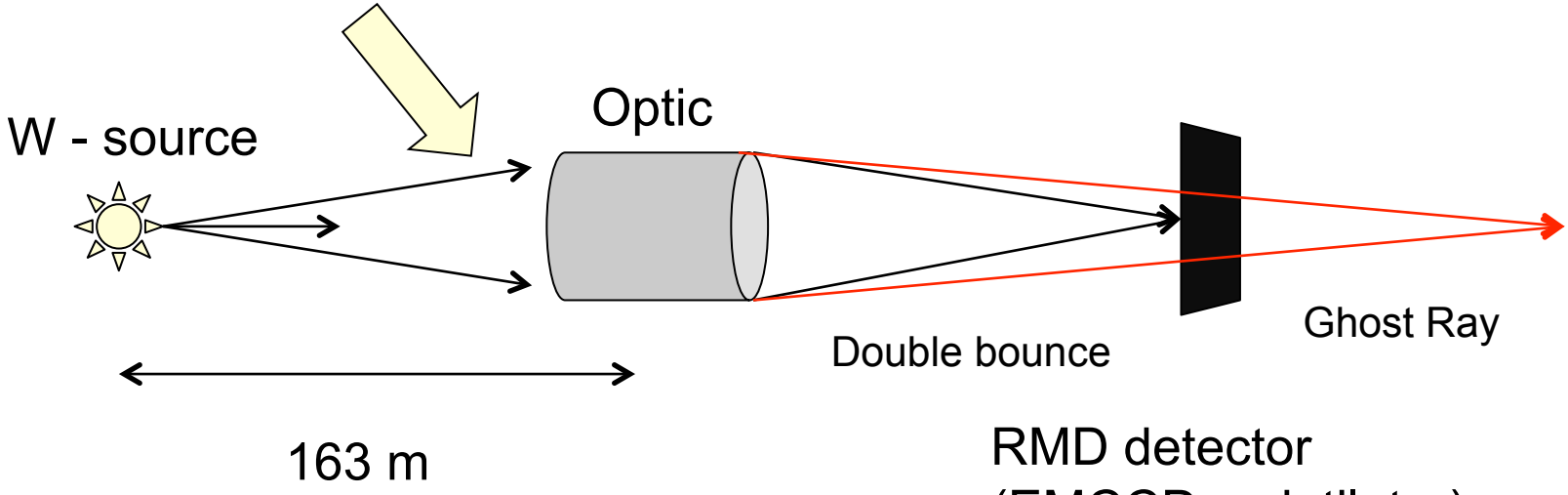


The Nevis facility



One sub-group ring exposes ~5 shells

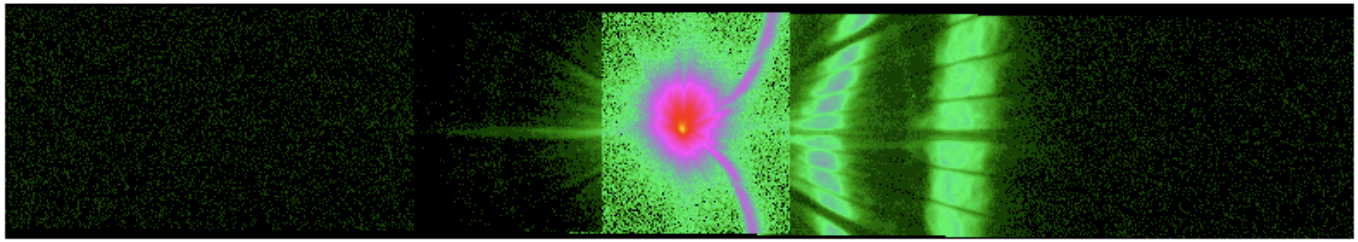




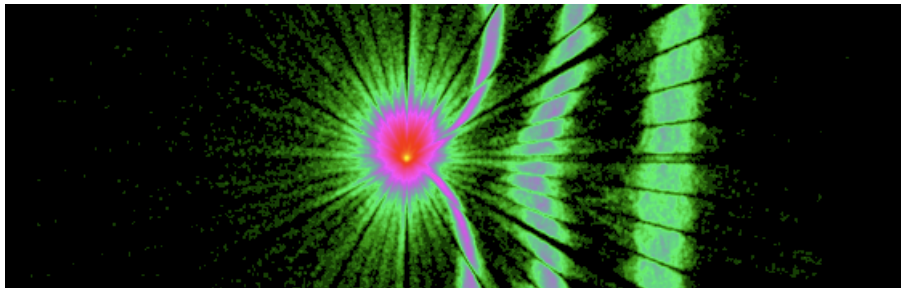
RMD detector (EMCCD+scintilator)

Simulations versus data

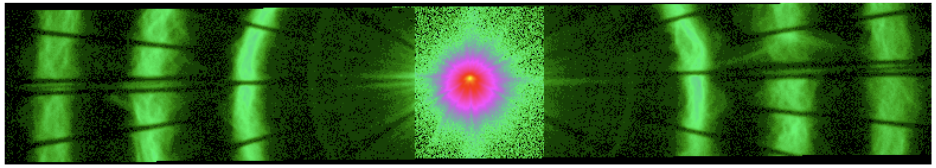
RMD data



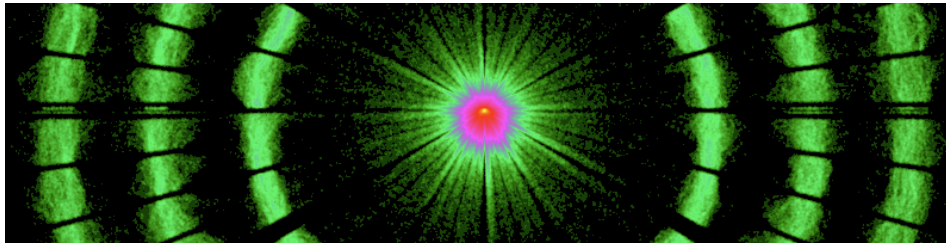
Simulated data



RMD data



Simulated data



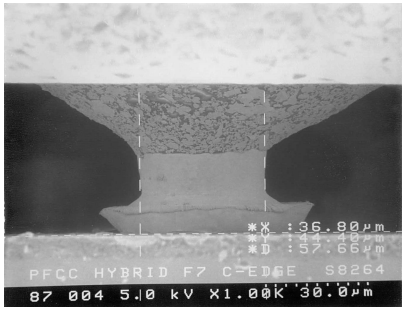
Detector Model

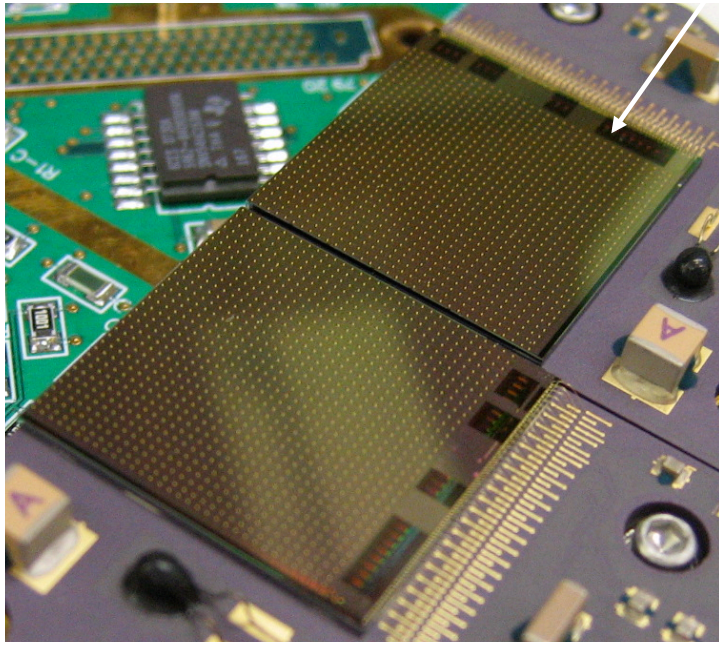
- Complicated RMF
- Precise Monte Carlo-based detector response model is required
  - Laboratory measurements of response at several energies
  - Detailed pixel-by-pixel charge transport properties derived
  - Laboratory measurements of absolute QE at several energies
- Detailed GEANT/charge transport model used for interpolation

Hybrid Detector Design

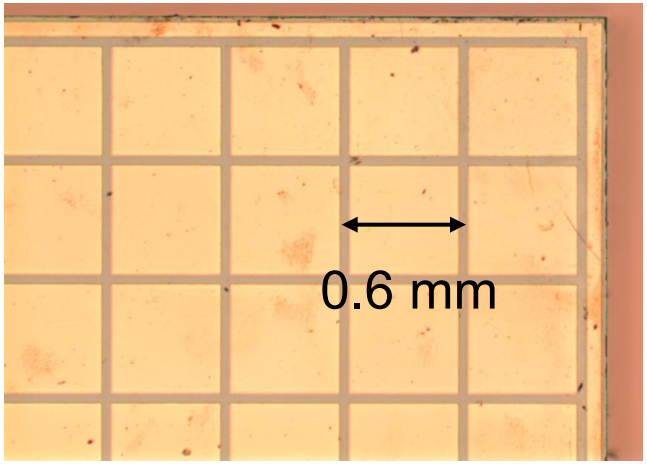
Custom Low-noise, Low-power ASIC: 32 x 32 array of amplifier, discriminator, sample and hold circuits on 0.6 mm pitch with on-chip ADC.
Read noise on ASIC is ~ 250 eV FWHM

Epoxy-gold stud interconnect



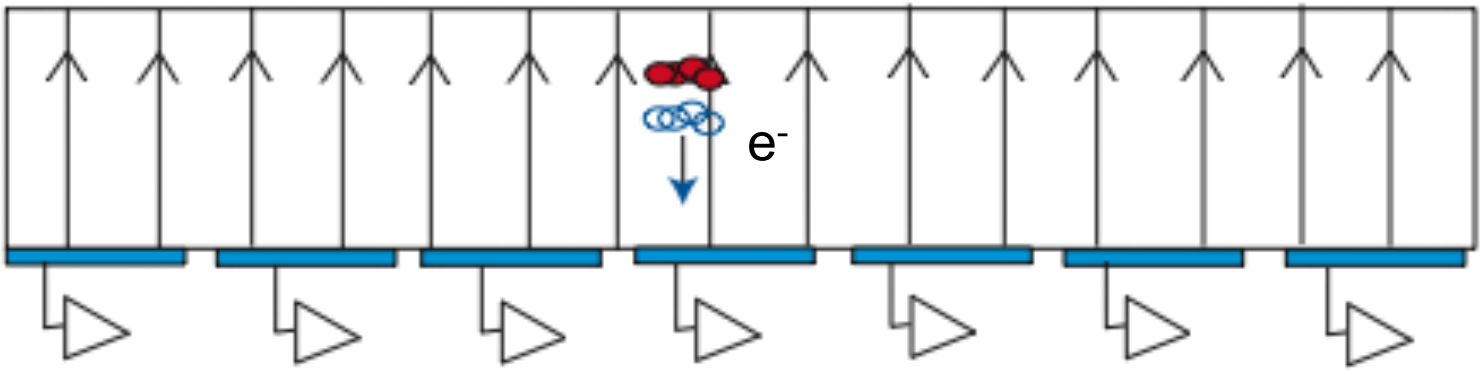


2mm thick CdZnTe - segmented anode



Hybrid Architecture

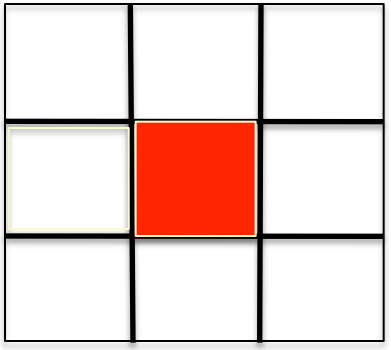
ASIC readouts bipolar signal, so collects signal from both electrons and holes.



When triggered, reads out a 3x3 grid

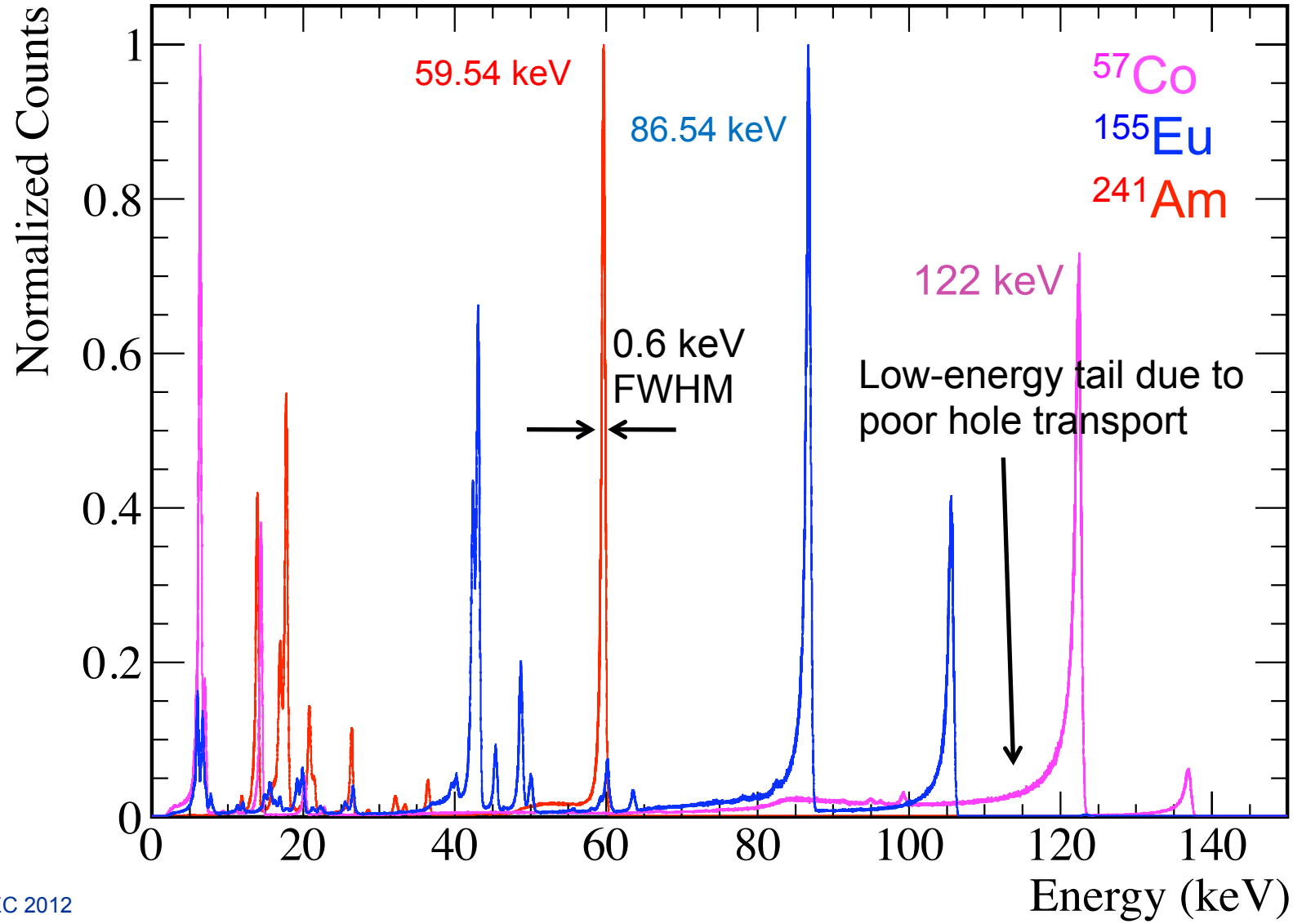
- Largest pulse height

- non-triggered (Hole signal)

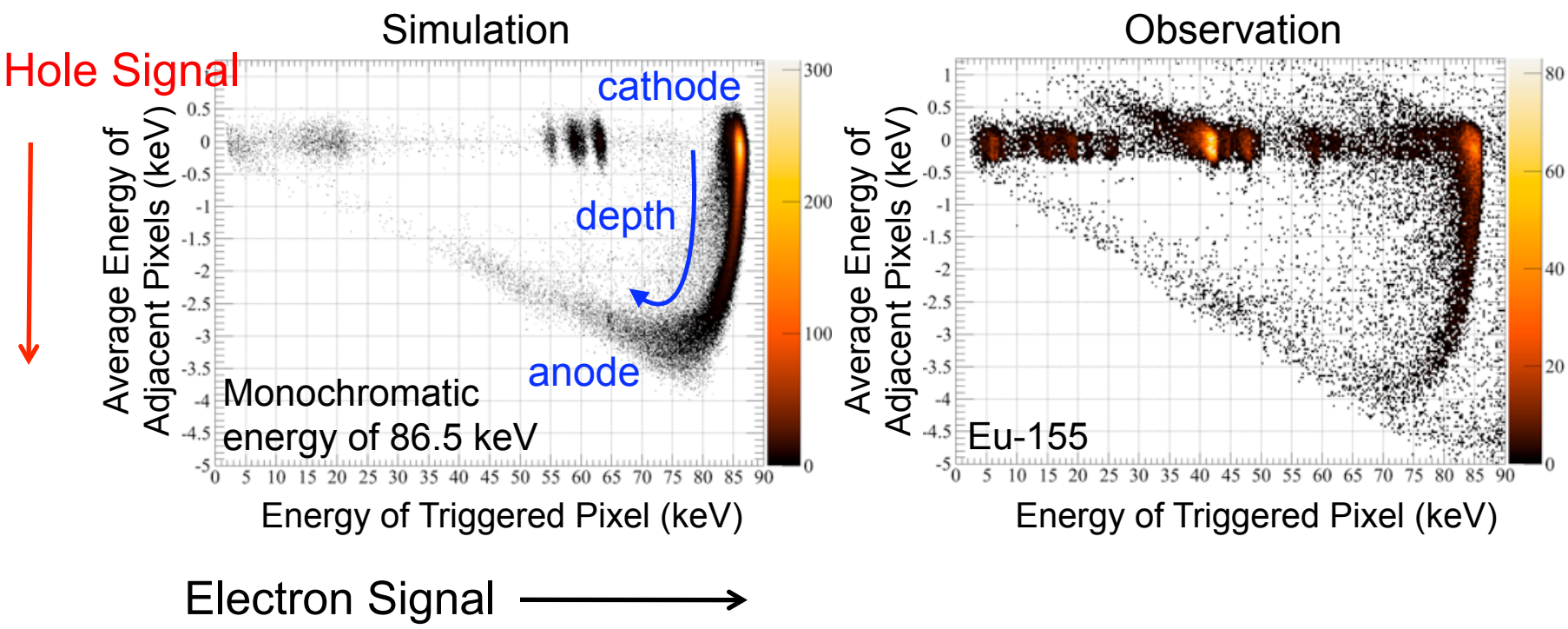


9-pixel read out

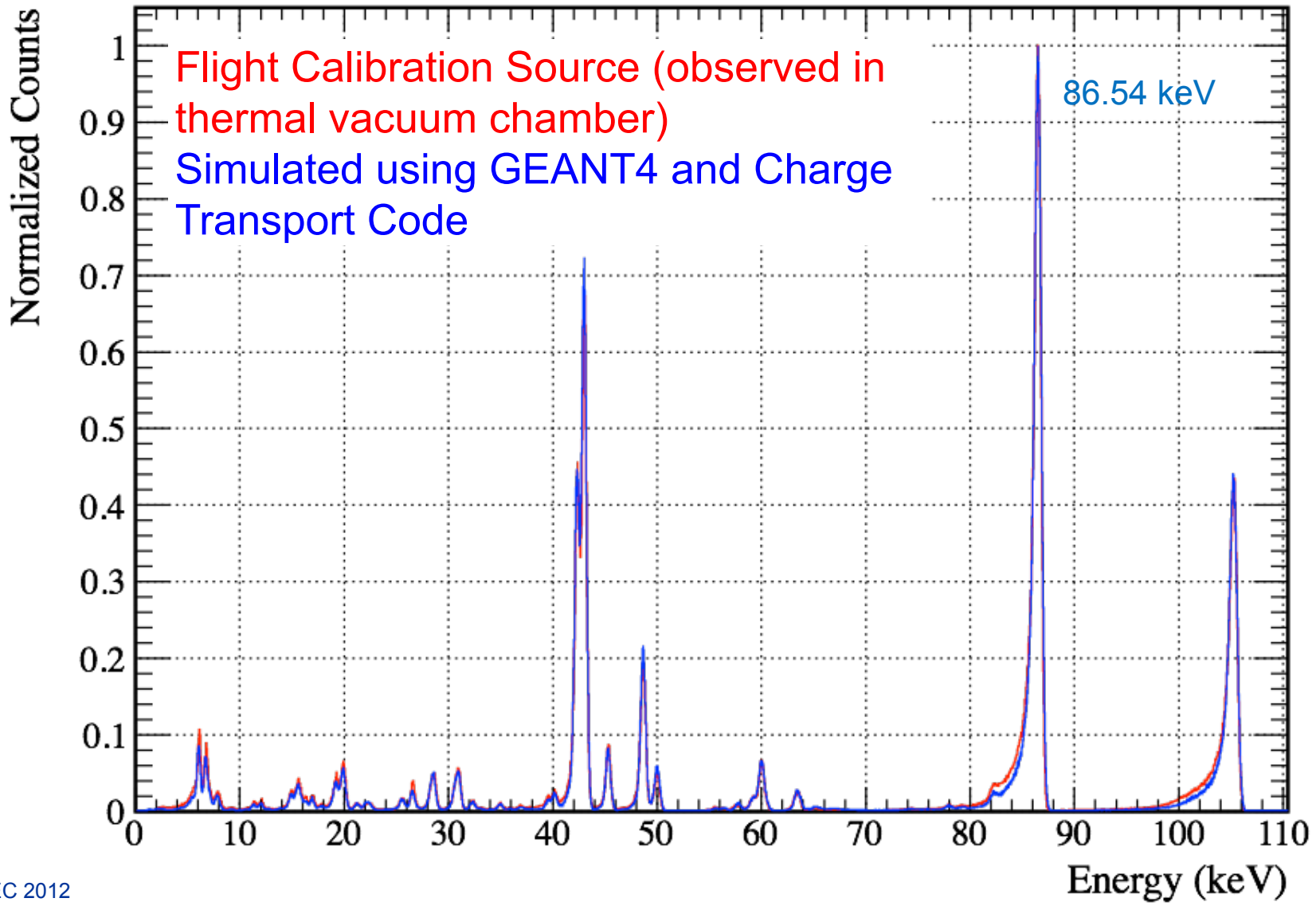
Observed CdZnTe Spectra



Model Results



Comparison of ^{155}Eu Spectra



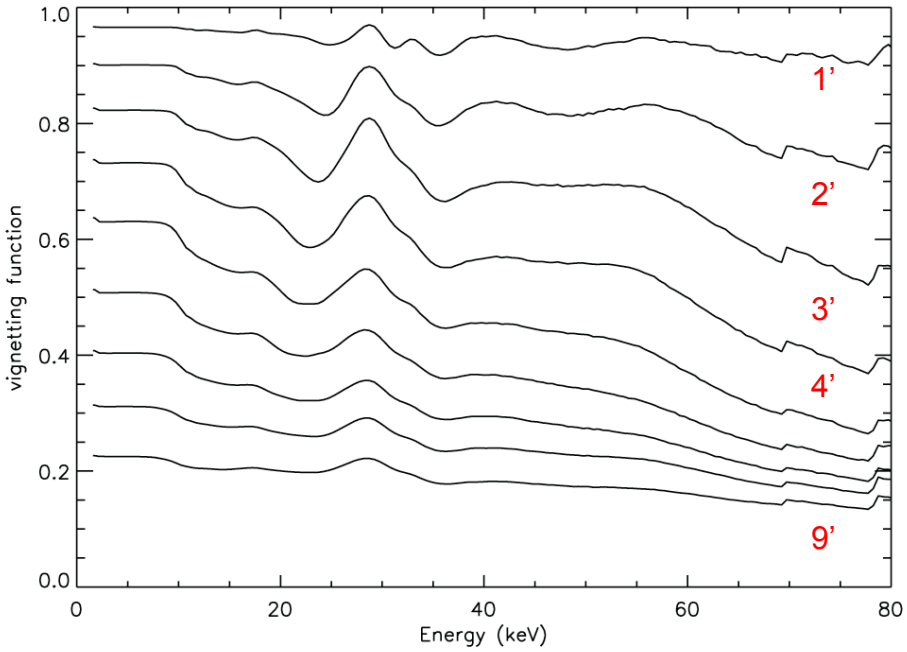
Detector Model

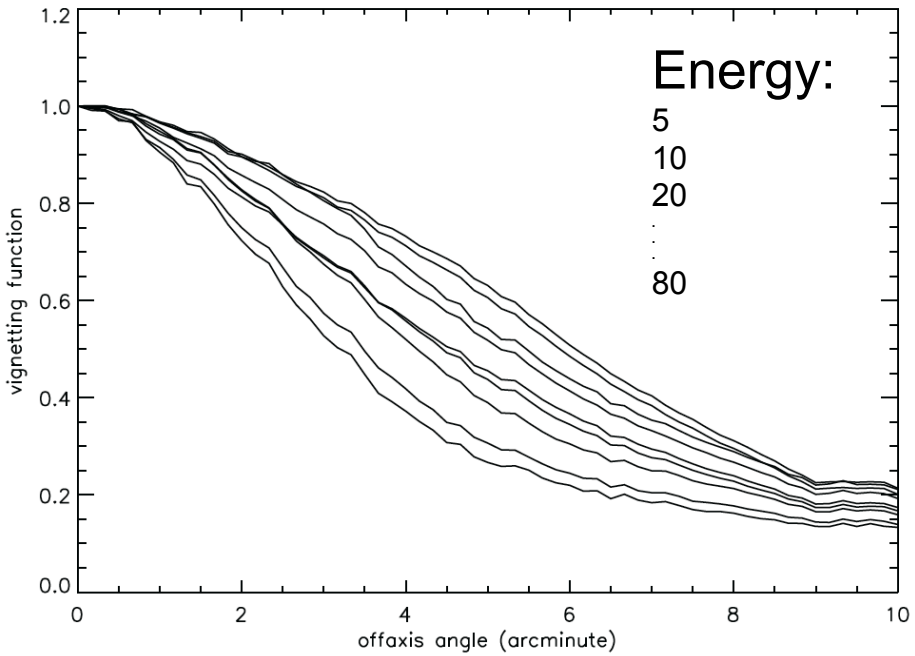
- Complicated RMF
  - Here mostly shown single-pixel reconstruction and RMFs.
  - Split pixels (high grades) contribute additional tailing
  - Reconstruction introduces additional non-Gaussian line structures
  - Ongoing analysis work to understand contribution to the RMF

Inflight Calibration Plan

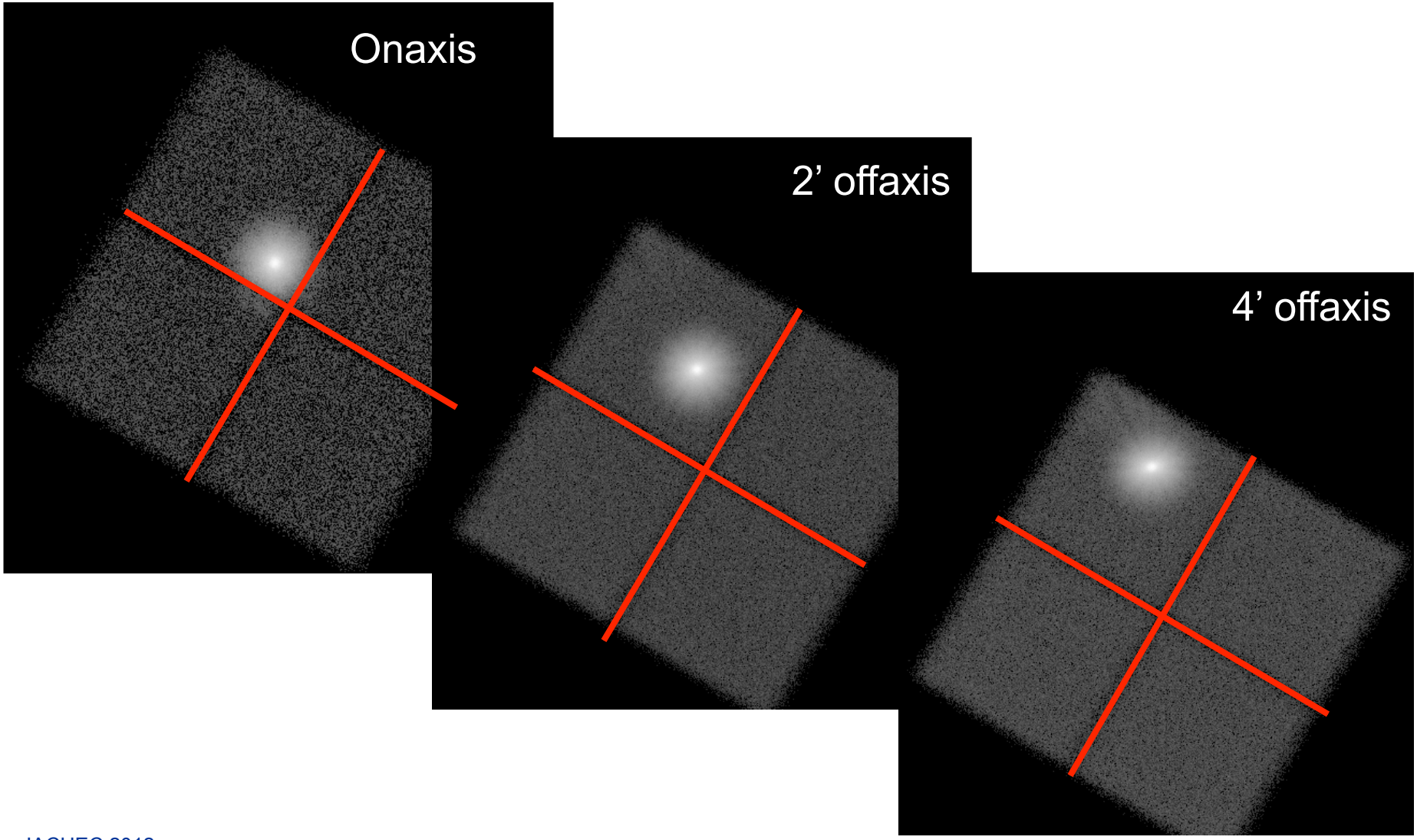
- Planned calibrations
  - PSF – Cygnus X-1
  - Instrument Axis Alignment
    - 3C 273
  - Response validation
    - 3C 273
    - G21.5-0.9
    - Crab
  - Simultaneous science cross calibrations (desired)
    - Chandra HETG (3C 273, MKN 421, PKS2155, G21.5-0.9)
    - XMM (3C273, PKS, MKN, G21)
    - Suzaku (3C 273, Her X-1, Cyg X-1)
    - Integral (3C 273, Cyg X-1, Her X-1)
    - Swift (3C 273)

Vignetting Functions

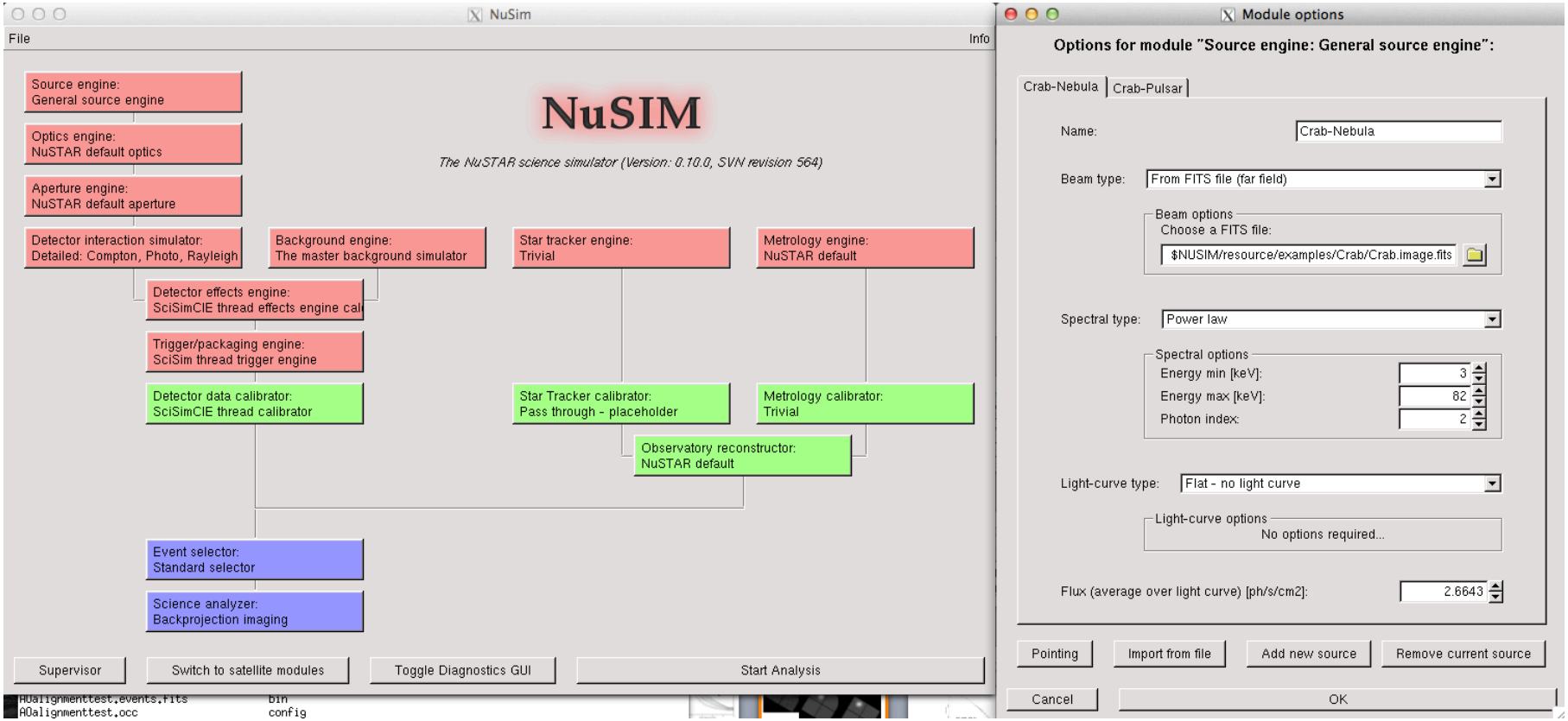




Imaging



NuSIM simulator

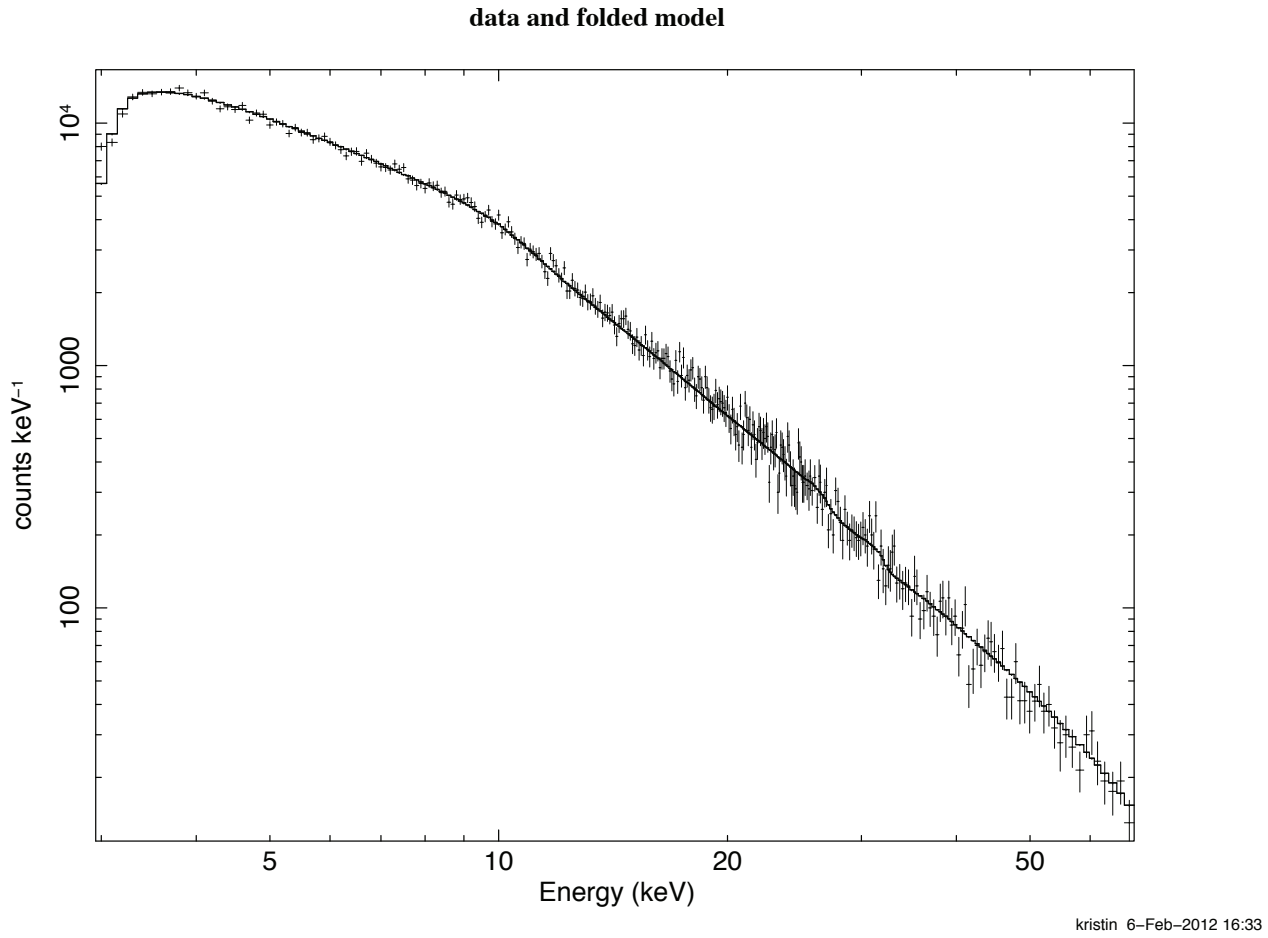


- Mast motion model
- Space craft stability model
- Monte Carlo raytrace
- Detector effects model
- Orbital model

Count rates

	5 - 10	10-20	20-60
G21.5-0.9	1.87 cts/s	0.81 cts/s	0.51 cts/s
3C 273	4.69 cts/s	2.38 cts/s	1.07 cts/s
PKS 2155-304	13.15 cts/s	4.45 cts/s	1.16 cts/s
MKN 421	25.6 cts/s	7.42 cts/s	2.42 cts/s
CRAB	218.8 cts/s	86.8 cts/s	26.7 cts/s

3C 273 – 50 ks


data and folded model
counts keV⁻¹
10⁴
1000
100
5
10
20
50
Energy (keV)
kristin 6–Feb–2012 16:33

Summary

- Launch late May/early June

- Simultaneous science cross calibrations (desired)
  - Chandra HETG (3C 273, MKN 421, PKS2155, G21.5-0.9)
  - XMM (3C273, PKS, MKN, G21)
  - Suzaku (3C 273, Her X-1, Cyg X-1, Crab)
  - Integral (3C 273, Cyg X-1, Her X-1, Crab)
  - Swift (3C 273, Crab)