

Bringing The High Energy Universe Into Focus

NUSTAR
Nuclear Spectroscopic Telescope Array

NuSTAR

“First mission to bring the High Energy Universe into Focus”

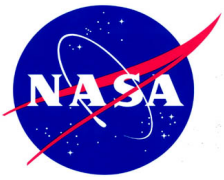
Kristin Kruse Madsen

Fiona Harrison

Brian Grefenstette

Karl Forster

Caltech, Pasadena



NuSTAR specifications



1 Ms Sensitivity

3.0×10^{-15} erg/cm²/s (6 – 10 keV)
 1.2×10^{-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

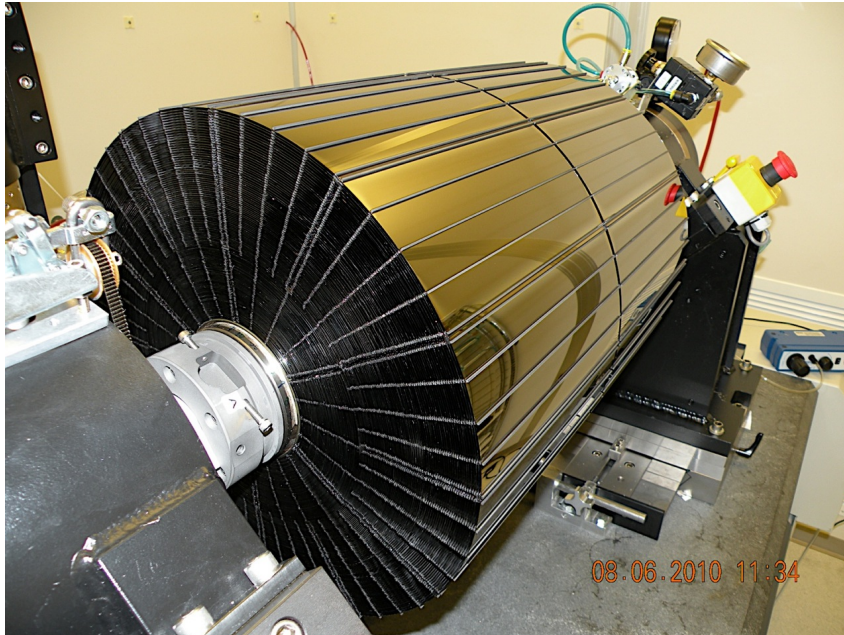
relative 100 microsec
absolute 30 msec

Spectral response

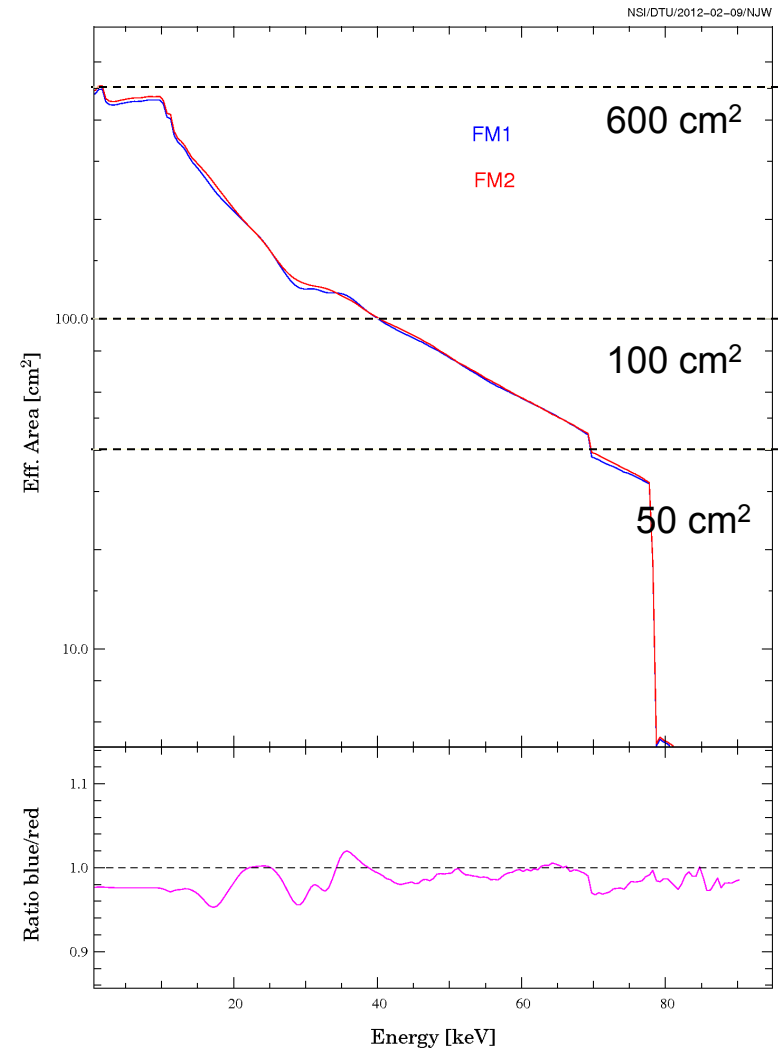
threshold 2.5 keV
 ΔE @ 6 keV 0.6 keV FWHM
 ΔE @ 60 keV 1.0 keV FWHM

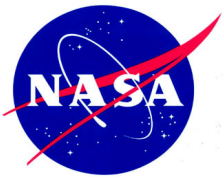
Target of Opportunity

response <24 hr (reqmt)
typical 6-8 hours
85% sky accessibility

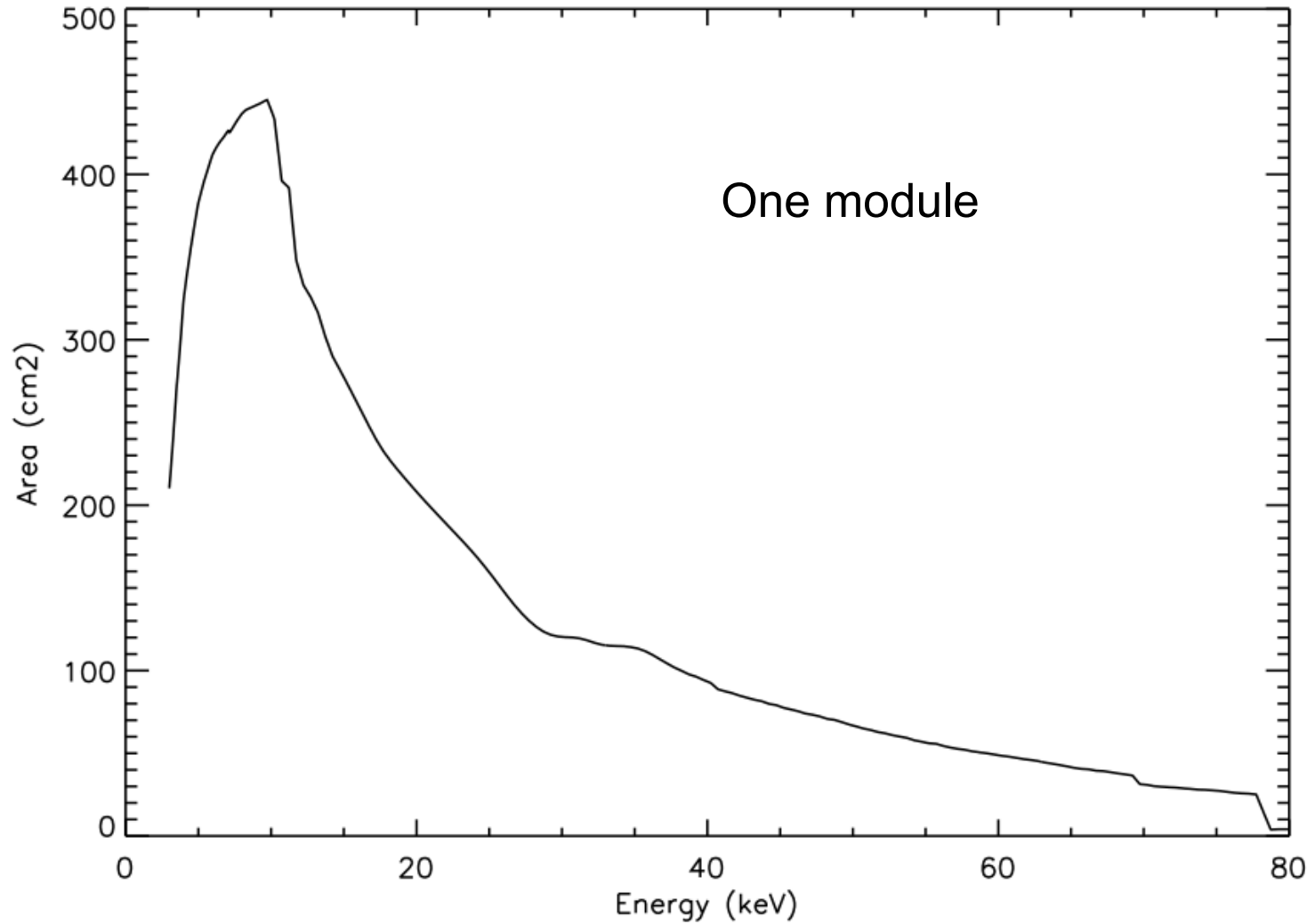


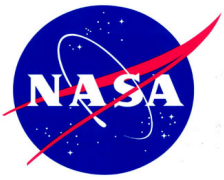
- Wolter-I conical approximation
- Focal length = 1015 cm
- 133 shells
- Multilayers (Pt/C, W/Si)



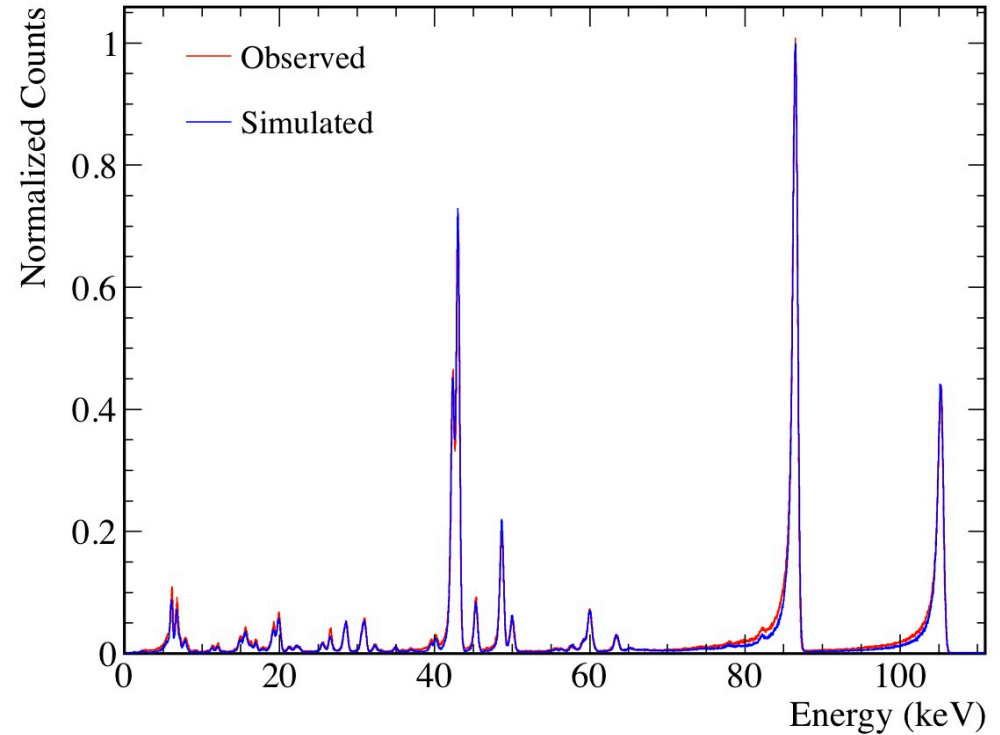
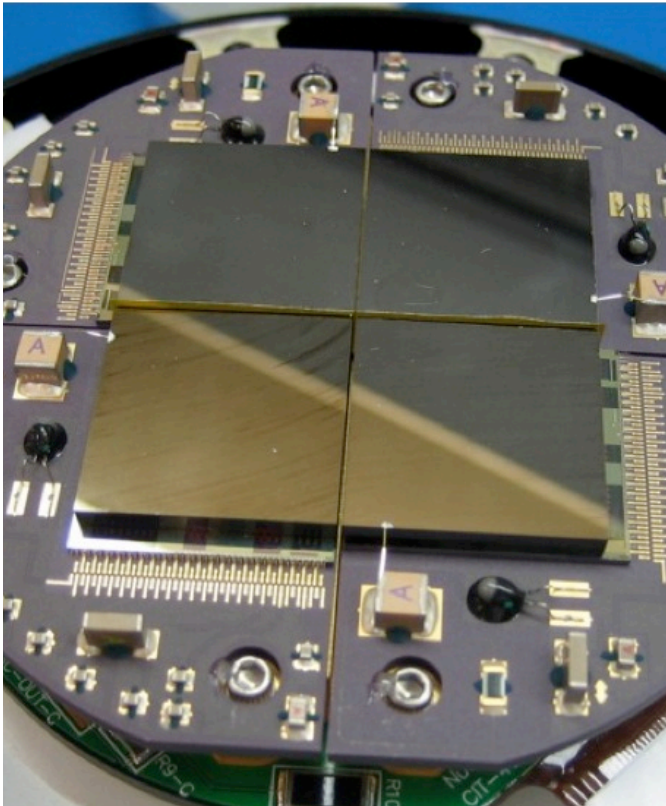


Effective Area

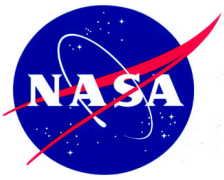




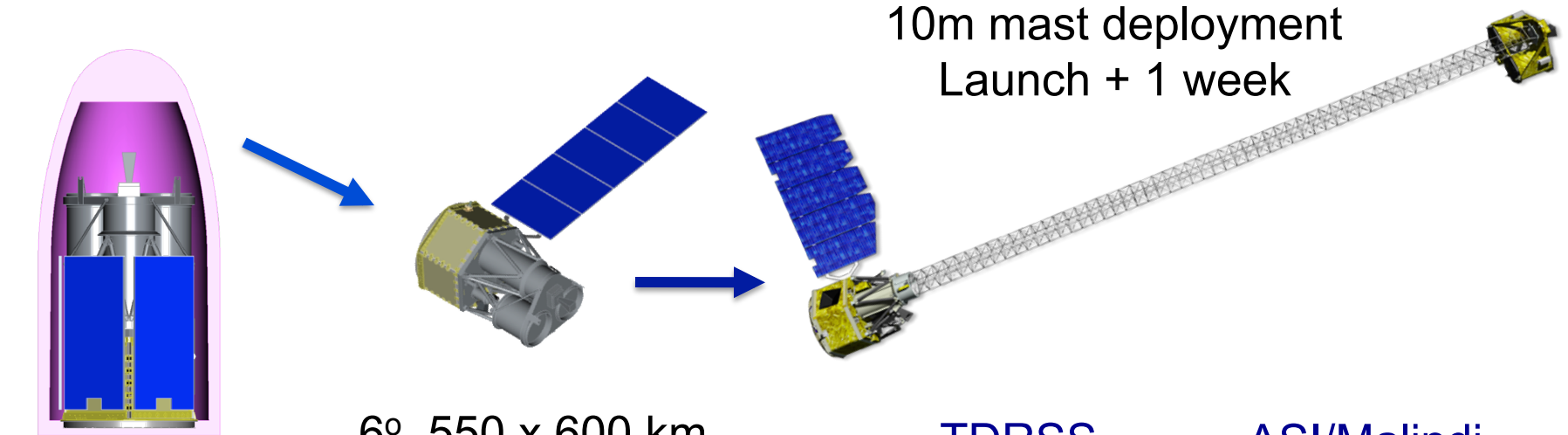
Focal Plane



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



Mission Overview

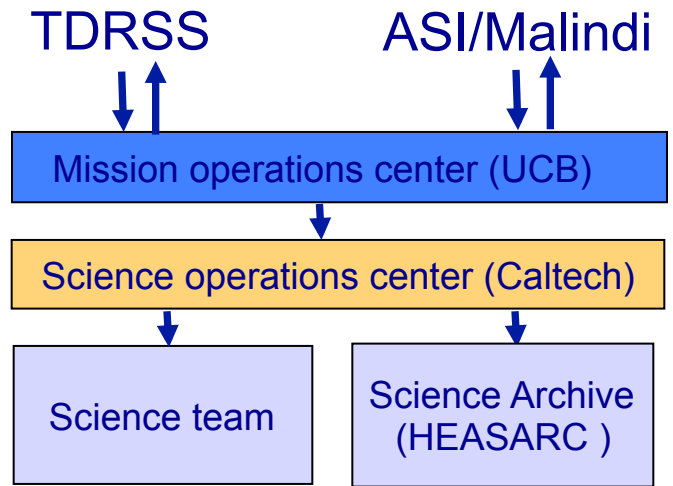


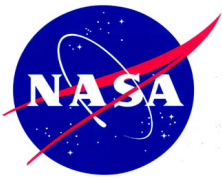
10m mast deployment
Launch + 1 week

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



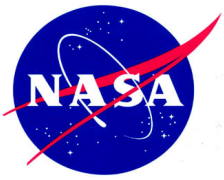


Planned Observations/ exposures



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

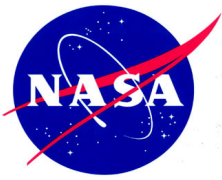
Total 316 days



Other Science Targets



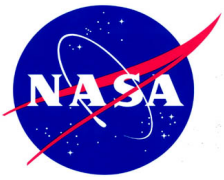
Science	Target/ #pointings	Science	Target/ #pointings
Star cluster	1	ULIRGs	15
X-ray binaries	17	Compton-thick AGN	31
Supernova remnants	9	Radio galaxies	9
Magnetars	9	BAL QSOs	2
Gamma-ray binaries	4	WISE AGN	5
Pulsars	4	Other transients	TBD
Ultraluminous X-ray (ULX) sources	8	Starburst galaxies	2
Blazars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



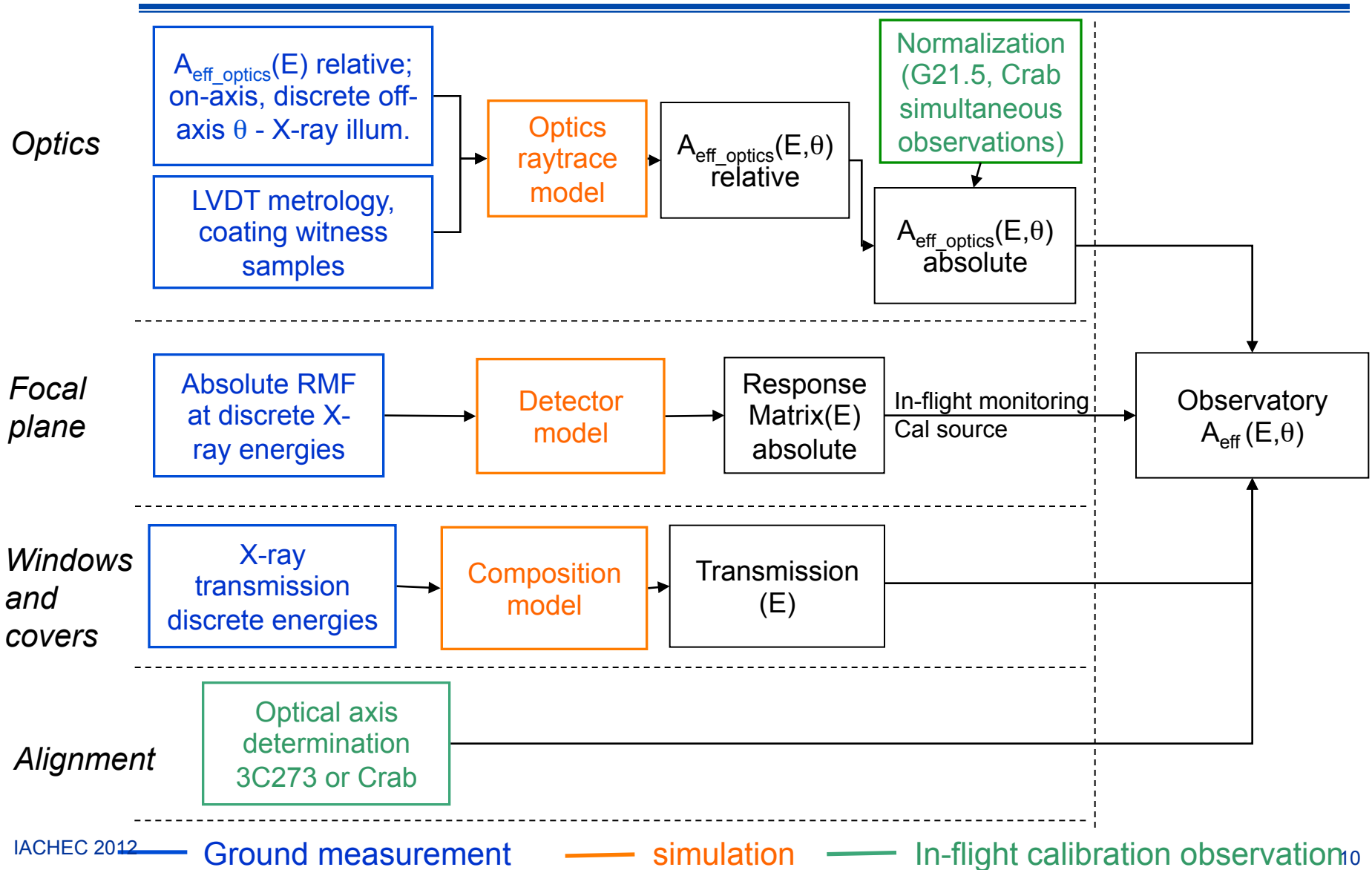
Joint Science Programs

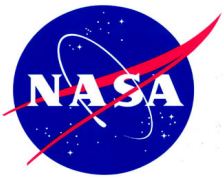


- 30% of first year observations are joint with other missions
 - Cross calibrations are **essential**
- Joint science programs:
 - Chandra
 - SGR A* (XVP)
 - NGC 253
 - XMM (1.4 Msec)
 - Black hole spin
 - ULXs
 - Swift
 - BAT AGN
 - Magnetars
 - Suzaku
 - Cyg X-1, Her X-1 & HMXB ToO
 - NGC 4151/IC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

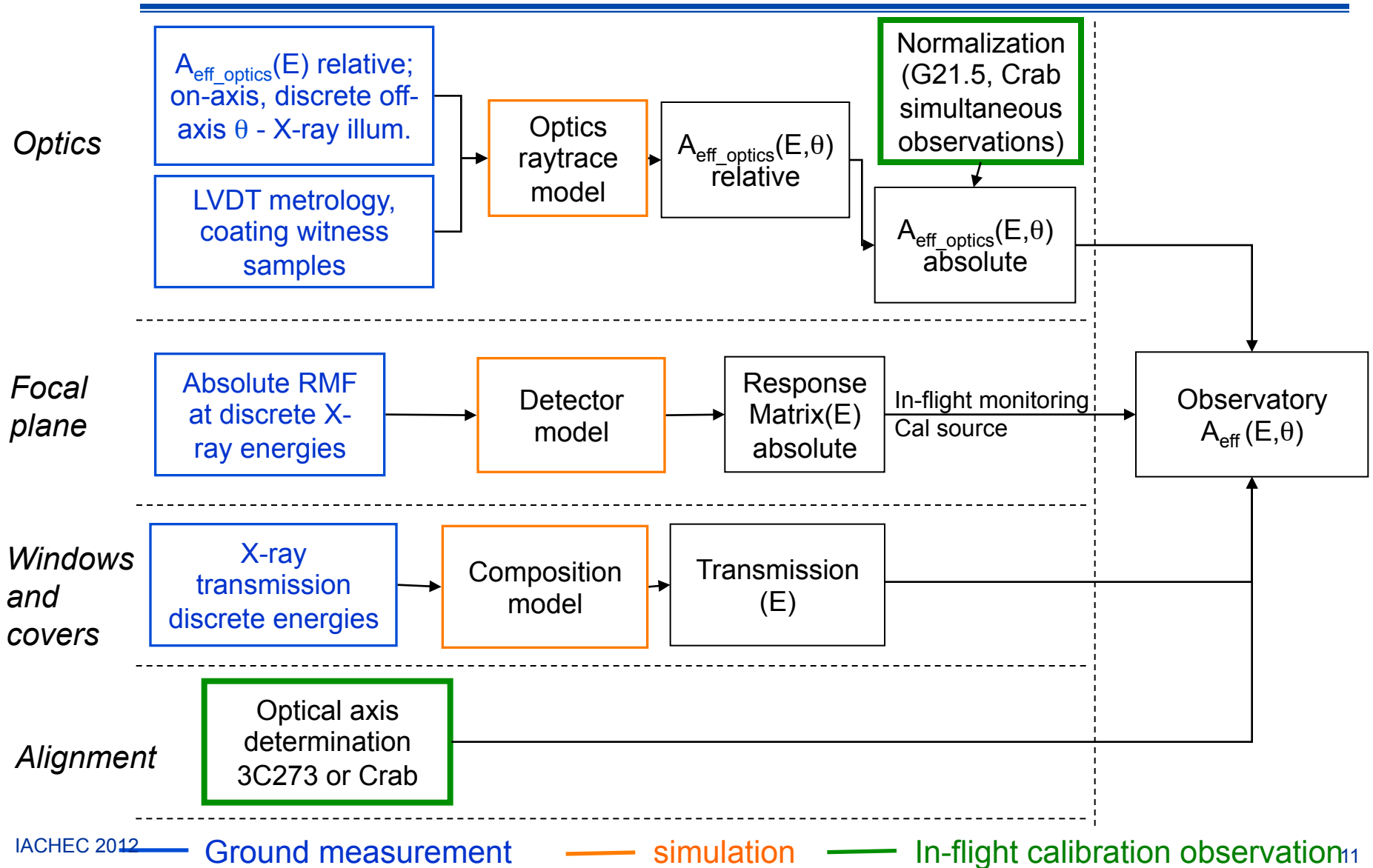


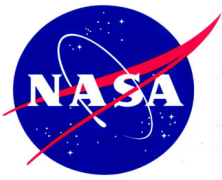
Calibration Approach Effective Area - $A_{eff}(E, \theta)$



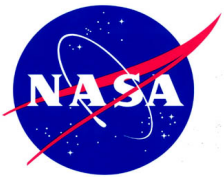


Calibration Approach Effective Area - $A_{eff}(E, \theta)$

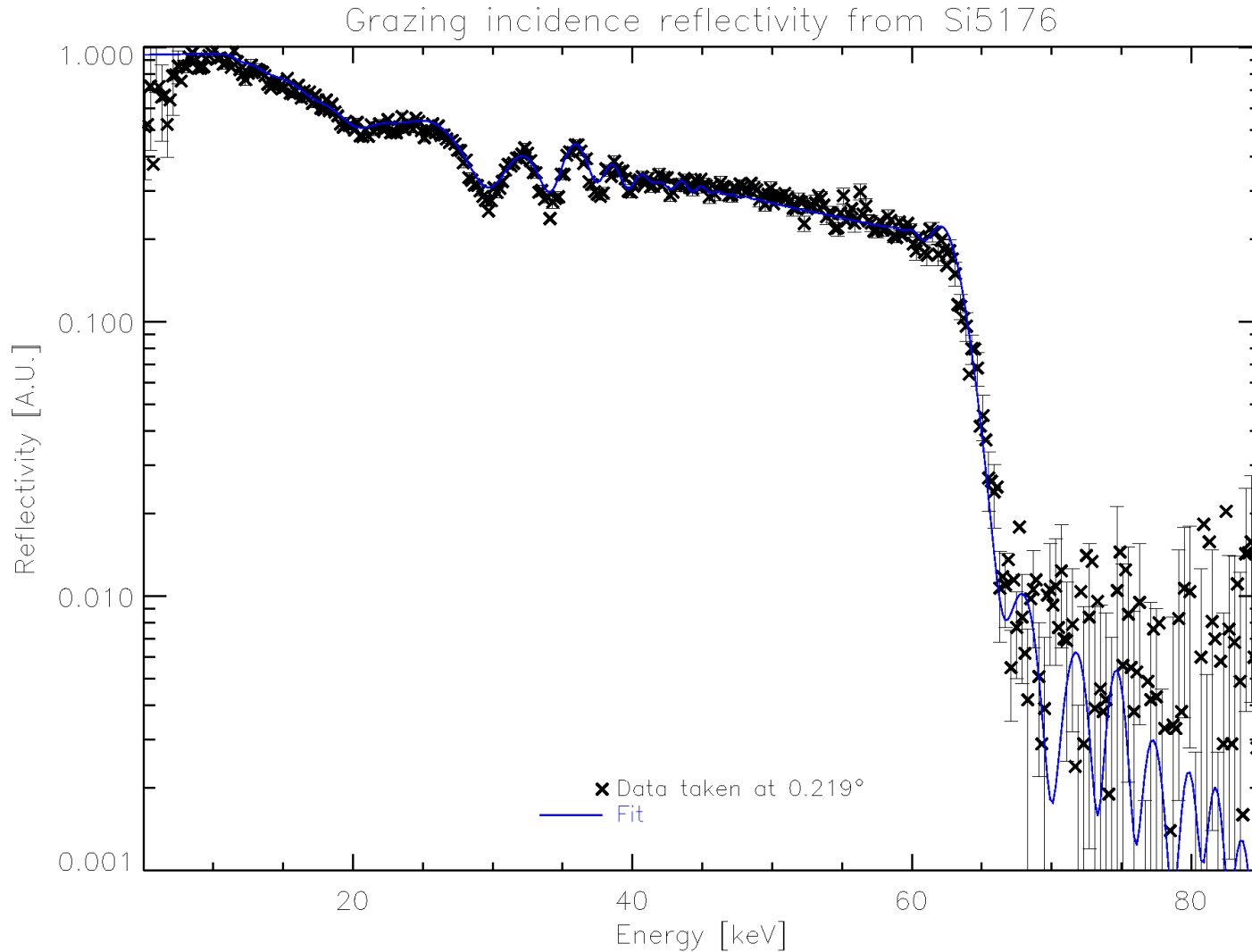


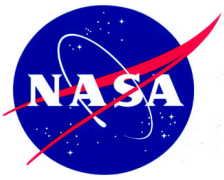


- MTRayor (Niels-Jorgen Westergaard, DTU) has been validated against other raytraces (ctrace, IRT, Marshall)
- Includes components
 - LVDT (Linear Variable Differential Transformer) scans on the backside of every single mirror on mm scales
 - Multilayer witness samples (every coating run has a witness 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

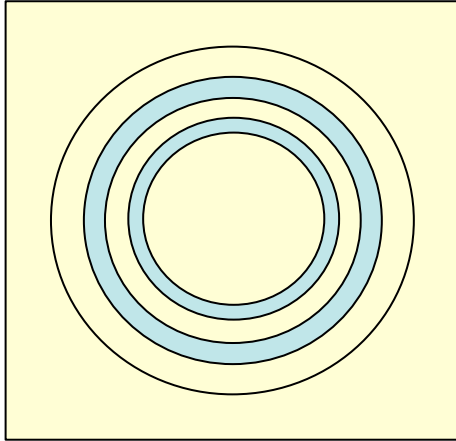




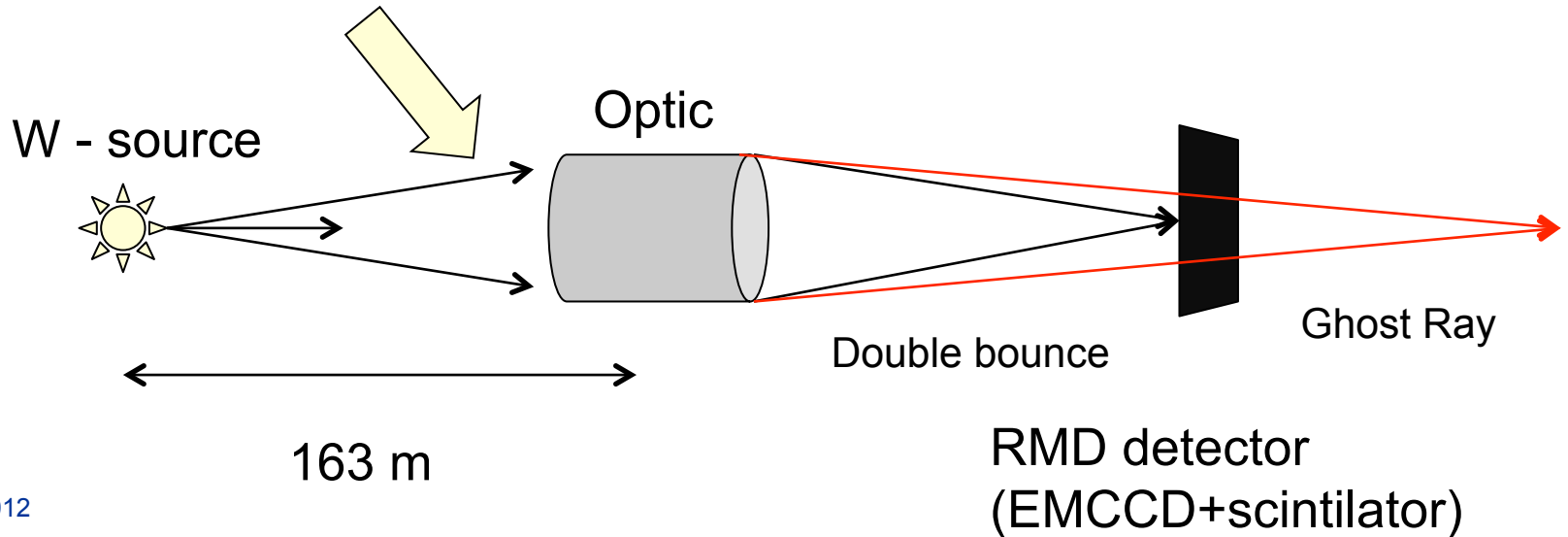
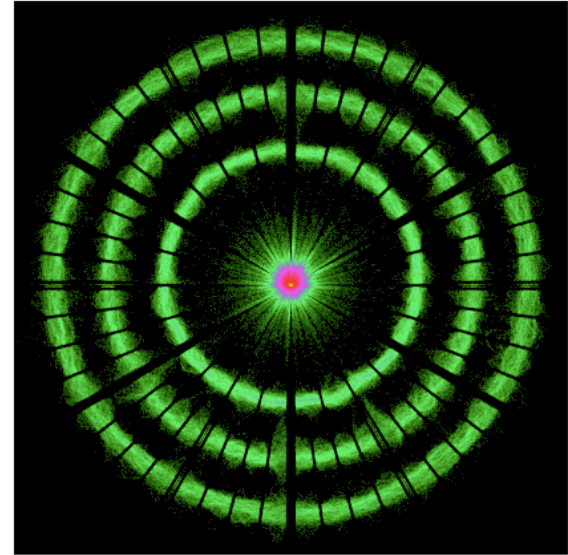
The Nevis facility

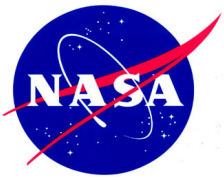


Aperture Plate



One sub-group ring exposes
~5 shells

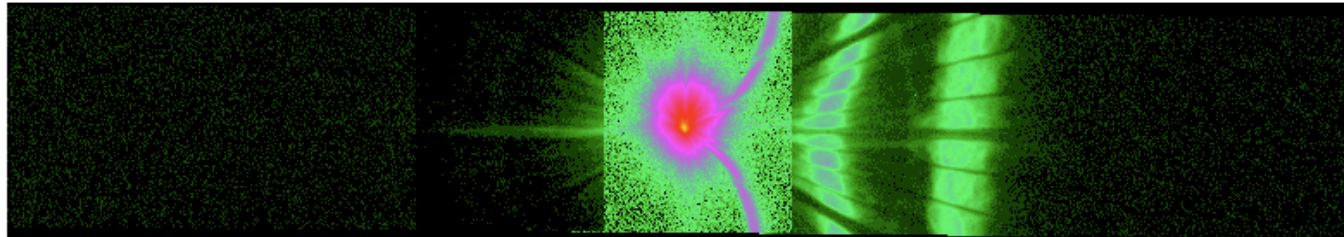




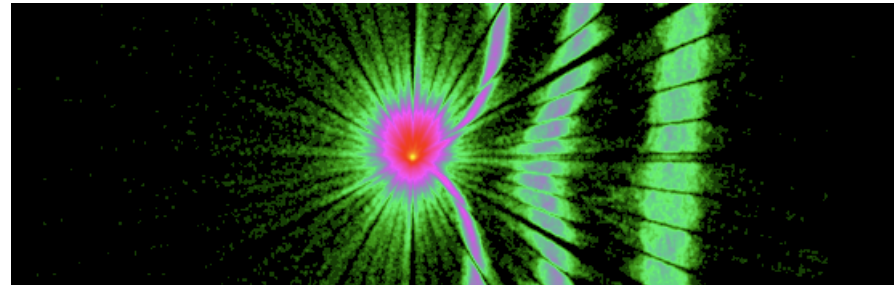
Simulations versus data



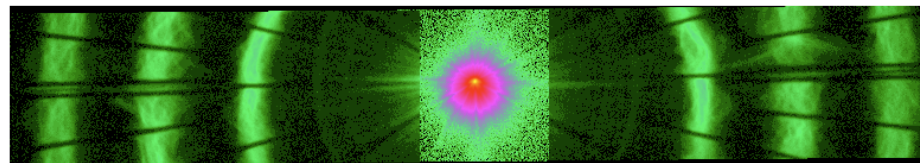
RMD data



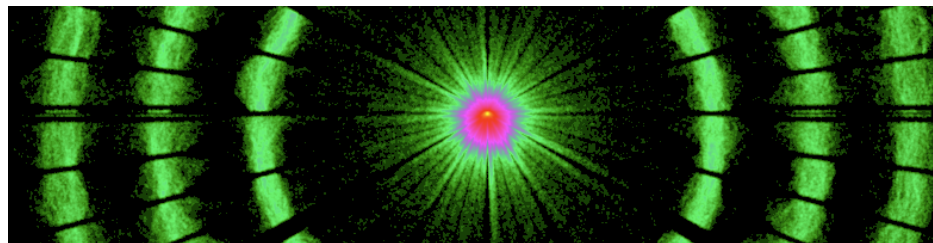
Simulated data

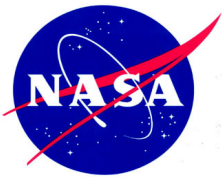


RMD data

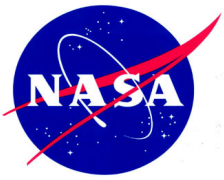


Simulated data





-
- 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

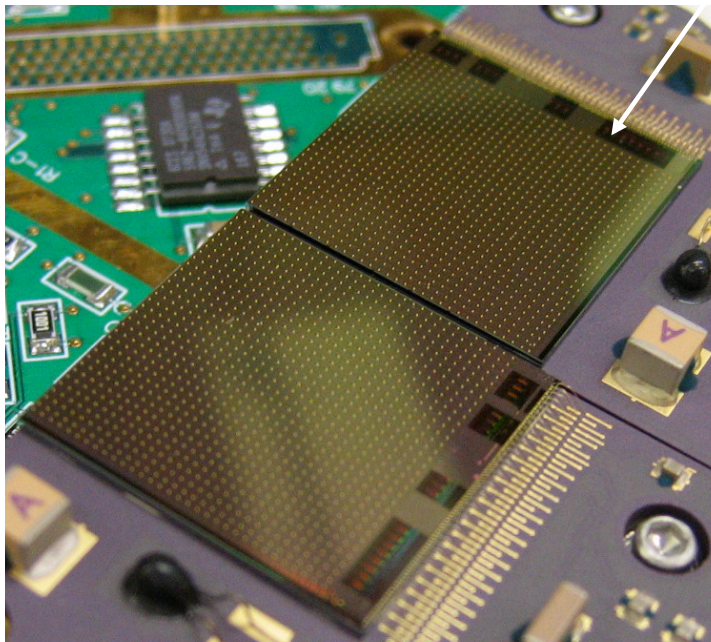
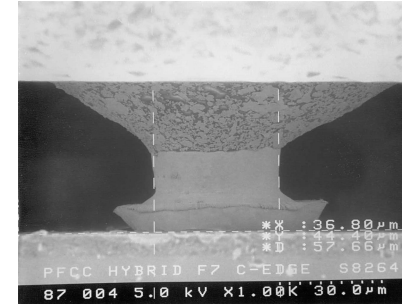


Hybrid Detector Design

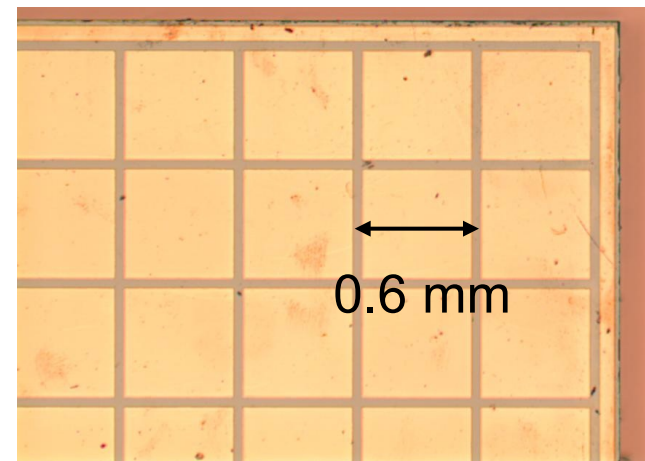


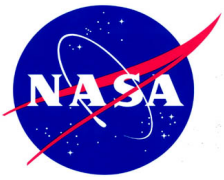
*Custom Low-noise, Low-power ASIC:
32 x 32 array of amplifier, discriminator,
sample and hold circuits on 0.6 mm
pitch with on-chip ADC.
Read noise on ASIC is ~ 250 eV
FWHM*

Epoxy-gold stud interconnect

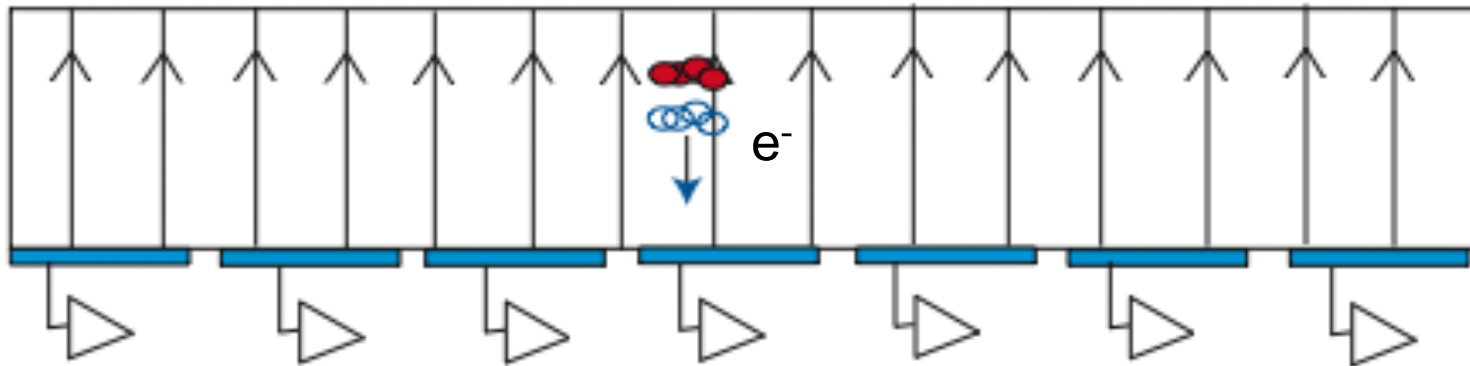


*2mm thick CdZnTe - segmented
anode*

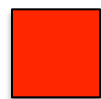




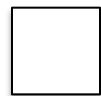
ASIC readouts bipolar signal, so collects signal from both electrons and holes.



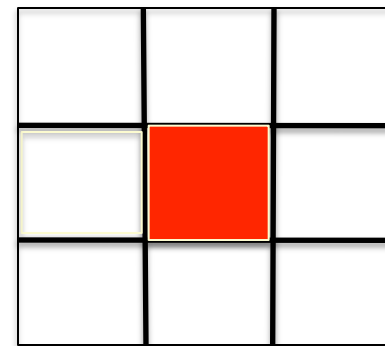
When triggered, reads out a 3x3 grid



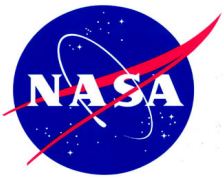
- Largest pulse height



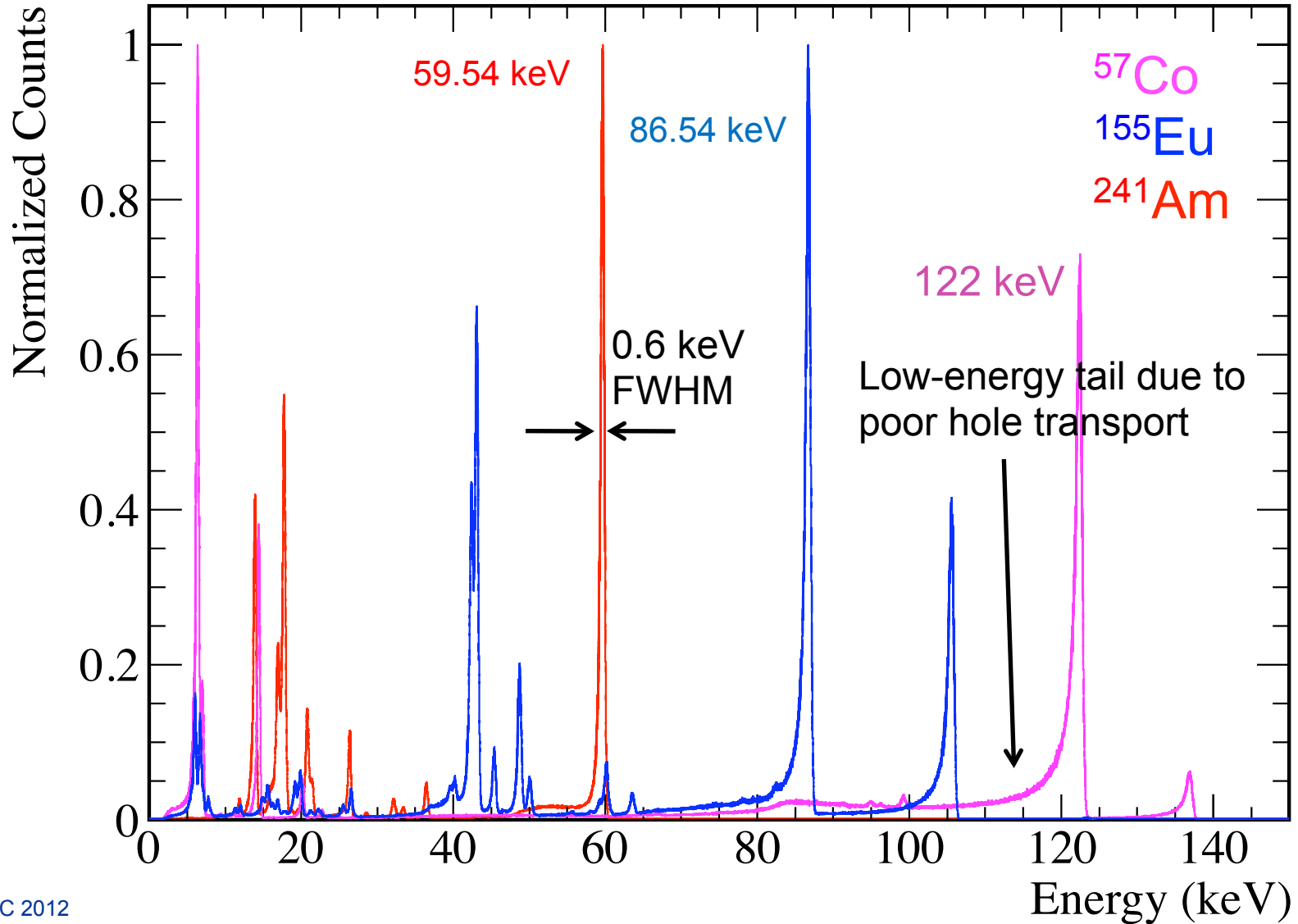
- non-triggered (Hole signal)

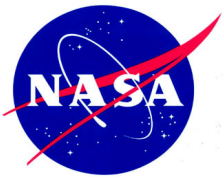


9-pixel read out



Observed CdZnTe Spectra





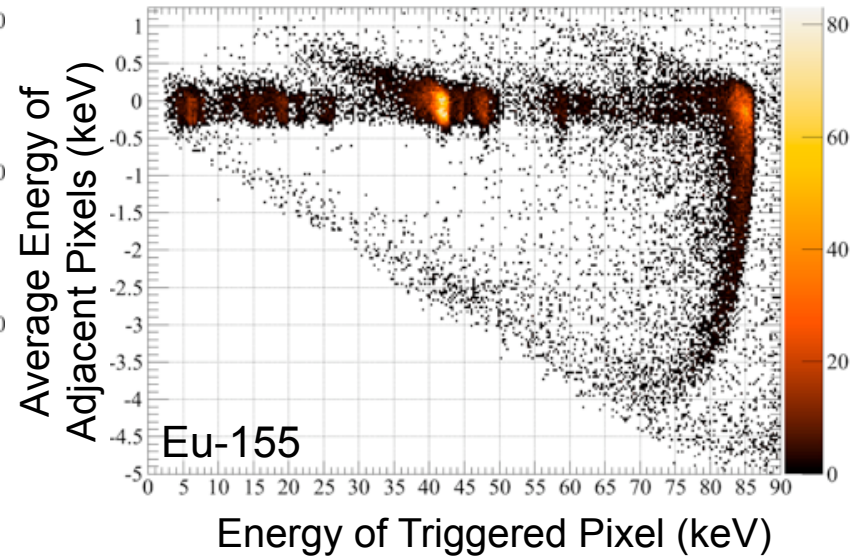
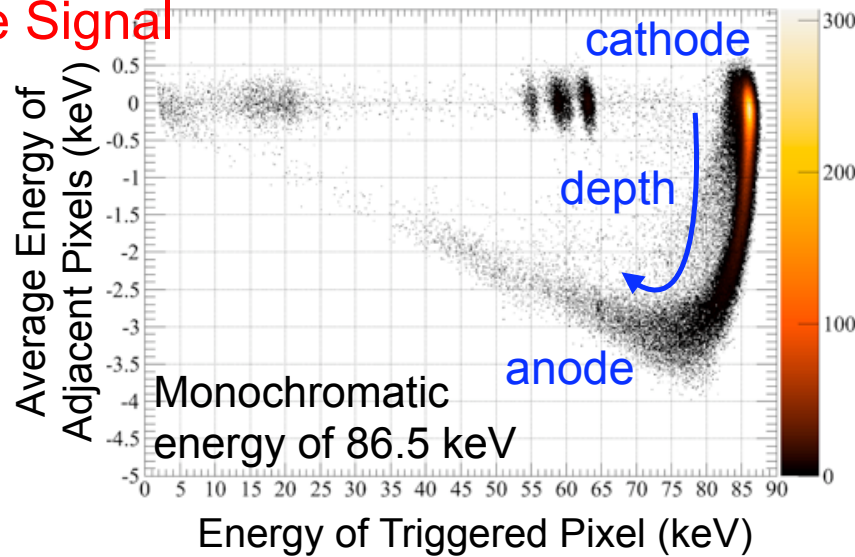
Model Results



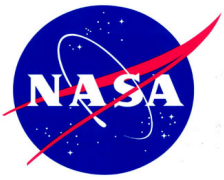
Simulation

Observation

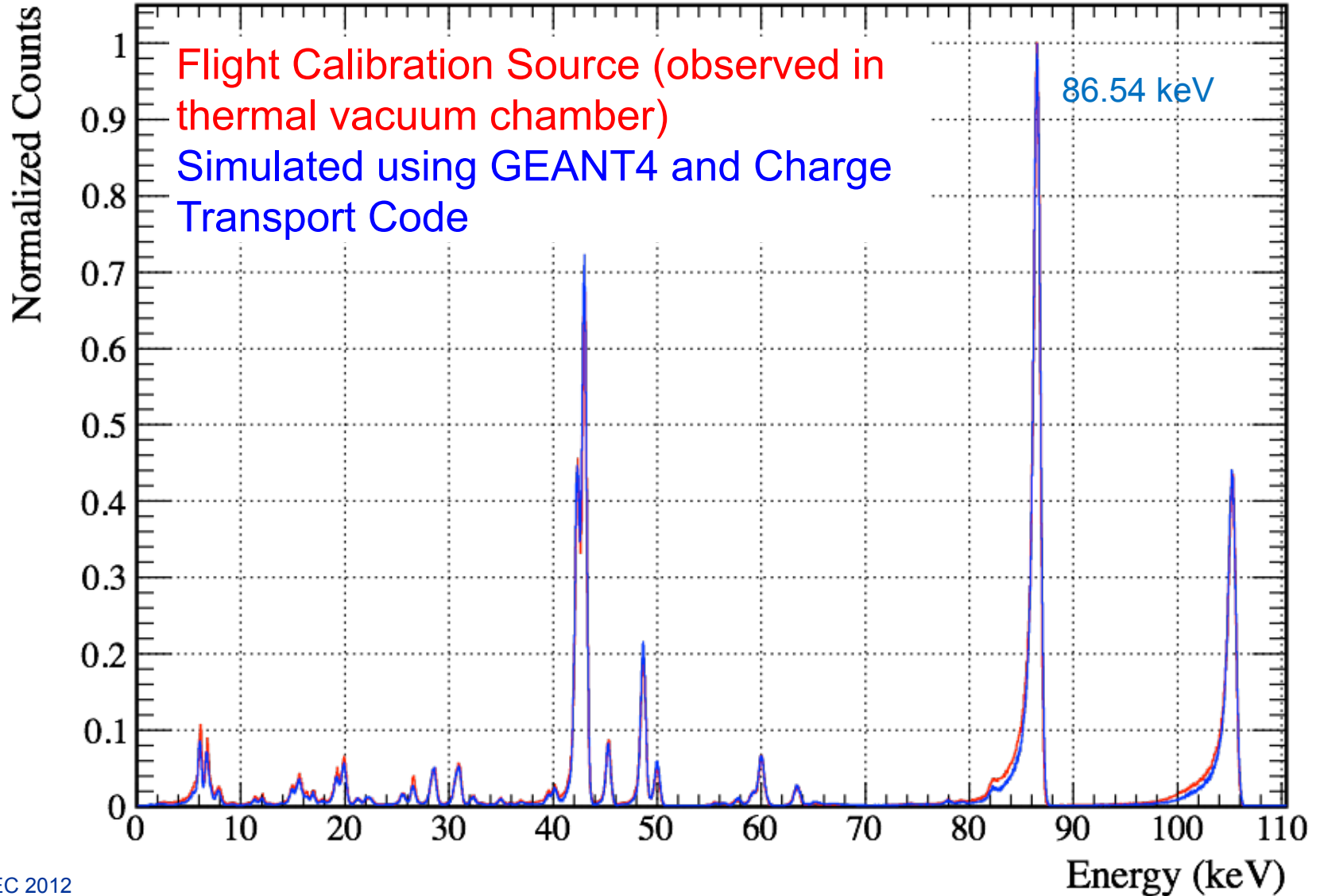
Hole Signal

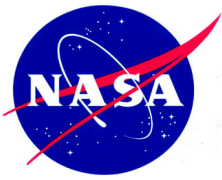


Electron Signal →

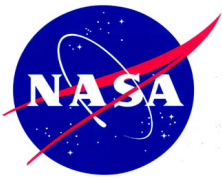


Comparison of ^{155}Eu Spectra

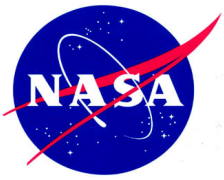




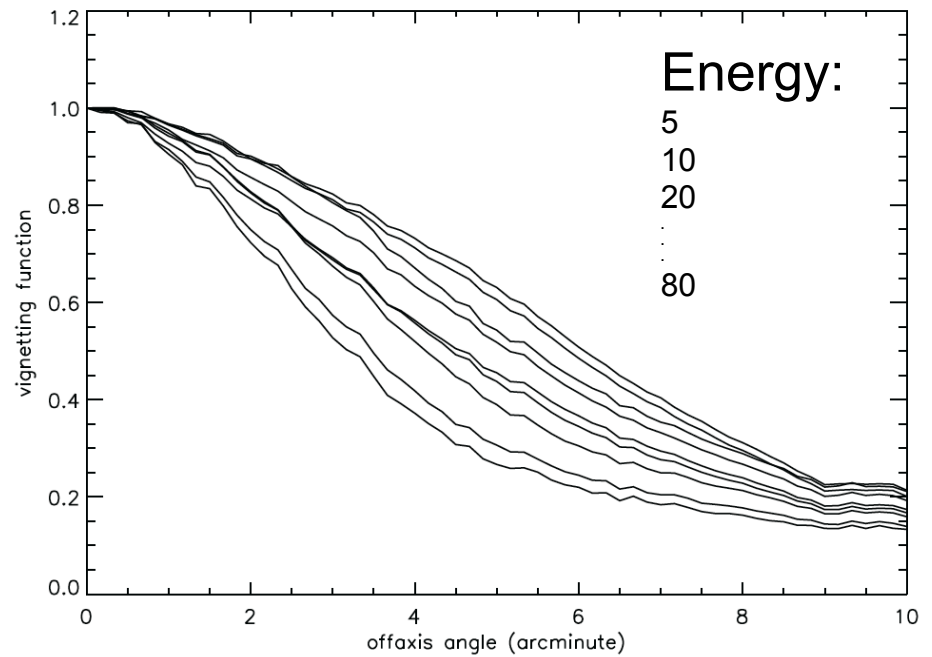
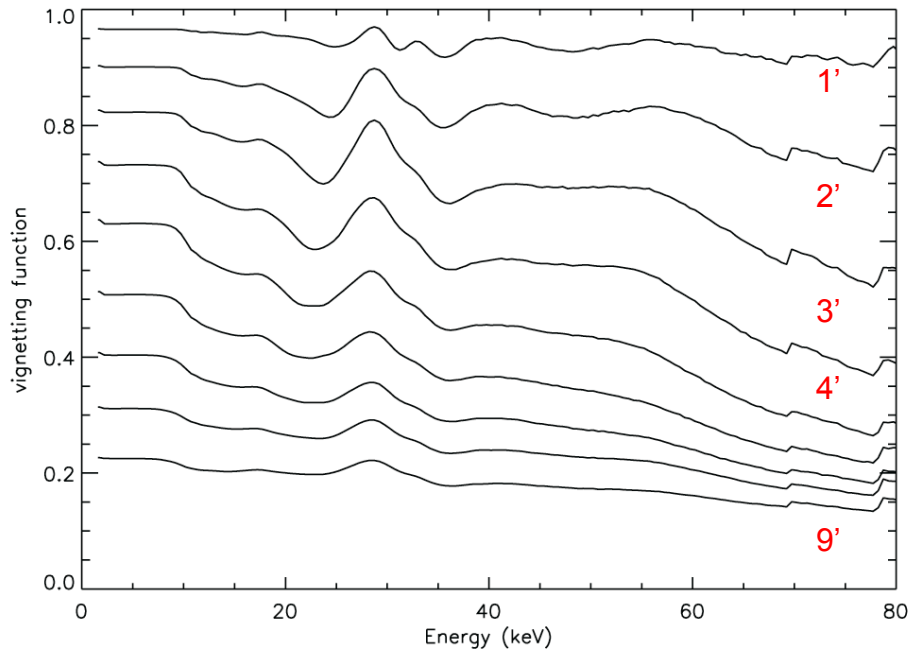
- **Complicated RMF**
 - Here mostly shown single-pixel reconstruction and RMFs.
 - Split pixels (high grades) contribute additional tailing
 - Reconstruction introduces additional non-Gaussian line structures
 - Ongoing analysis work to understand contribution to the RMF

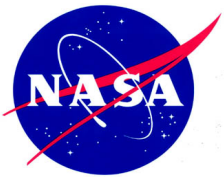


- Planned calibrations
 - PSF – Cygnus X-1
 - Instrument Axis Alignment
 - 3C 273
 - Response validation
 - 3C 273
 - G21.5-0.9
 - Crab
 - Simultaneous science cross calibrations (desired)
 - Chandra HETG (3C 273, MKN 421, PKS2155, G21.5-0.9)
 - XMM (3C273, PKS, MKN, G21)
 - Suzaku (3C 273, Her X-1,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



Vignetting Functions

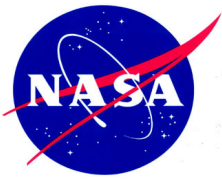




Onaxis

2' offaxis

4' offaxis

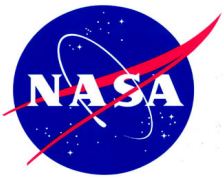


NuSIM simulator



The screenshot displays the NuSIM simulator interface. The main window, titled 'NuSim', features a central logo and version information: 'The NuSTAR science simulator (Version: 0.10.0, SVN revision 564)'. On the left, a vertical stack of modules is shown, including the Source engine (General source engine), Optics engine (NuSTAR default optics), Aperture engine (NuSTAR default aperture), and Detector interaction simulator (Detailed: Compton, Photo, Rayleigh). Below these are the Detector effects engine (SciSimCIE thread effects engine cal), Trigger/packaging engine (SciSim thread trigger engine), Detector data calibrator (SciSimCIE thread calibrator), Event selector (Standard selector), and Science analyzer (Backprojection imaging). On the right, a horizontal stack of modules includes the Background engine (The master background simulator), Star tracker engine (Trivial), and Metrology engine (NuSTAR default). Below these are the Star Tracker calibrator (Pass through - placeholder), Metrology calibrator (Trivial), and Observatory reconstructor (NuSTAR default). At the bottom, there are buttons for Supervisor, Switch to satellite modules, Toggle Diagnostics GUI, and Start Analysis. A 'Module options' dialog box is open on the right, titled 'Options for module "Source engine: General source engine":'. It shows settings for 'Crab-Nebula' and 'Crab-Pulsar'. The Name field is set to 'Crab-Nebula'. The Beam type is 'From FITS file (far field)'. The Beam options section includes a 'Choose a FITS file' field with a file path: '\$NUSIM/resource/examples/Crab/Crab.image.fits'. The Spectral type is 'Power law'. The Spectral options section includes Energy min [keV] (3), Energy max [keV] (82), and Photon index (2). The Light-curve type is 'Flat - no light curve'. The Light-curve options section shows 'No options required...'. The Flux (average over light curve) [ph/s/cm2] is set to 2.6643. At the bottom of the dialog are buttons for Pointing, Import from file, Add new source, Remove current source, Cancel, and OK.

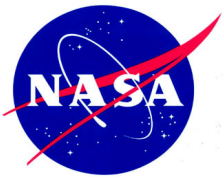
- Mast motion model
- Space craft stability model
- Monte Carlo raytrace
- Detector effects model
- Orbital model



Count rates



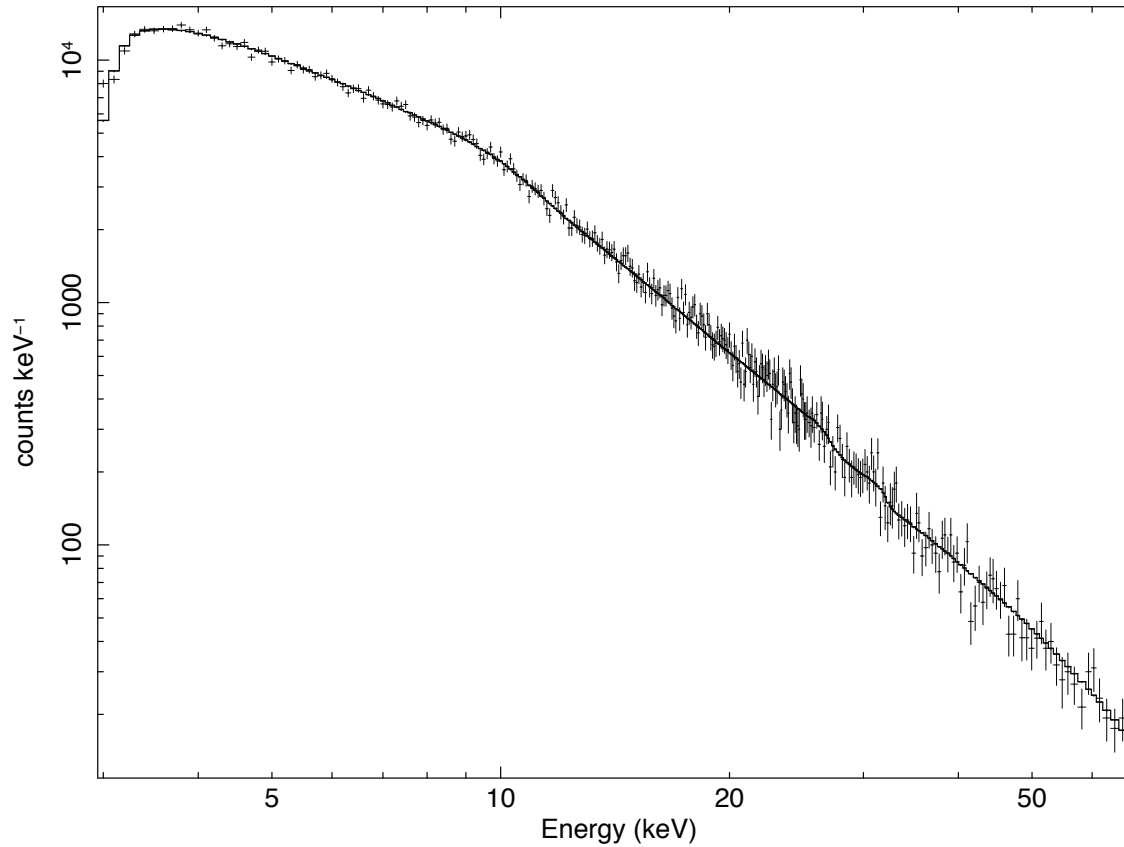
	5 - 10	10-20	20-60
G21.5-0.9	1.87 cts/s	0.81 cts/s	0.51 cts/s
3C 273	4.69 cts/s	2.38 cts/s	1.07 cts/s
PKS 2155-304	13.15 cts/s	4.45 cts/s	1.16 cts/s
MKN 421	25.6 cts/s	7.42 cts/s	2.42 cts/s
CRAB	218.8 cts/s	86.8 cts/s	26.7 cts/s



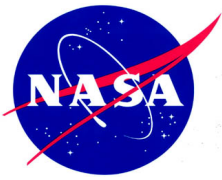
3C 273 – 50 ks



data and folded model



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)