
# Advances in the PCA energy calibration - nearing the statistics limit

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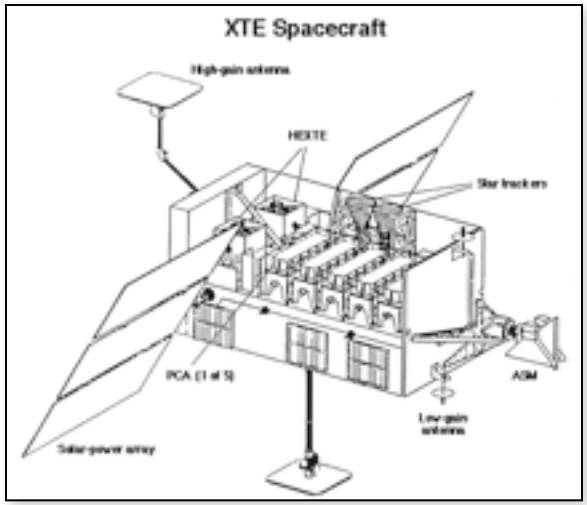
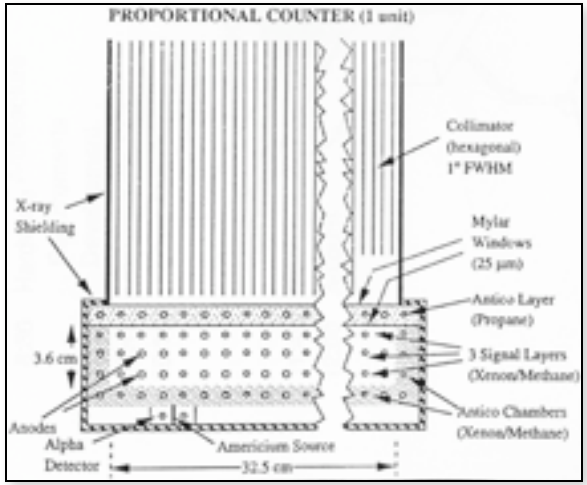
# RXTE Proportional Counter Array




- PCA is a primary instrument on board RXTE
- 5 Proportional Counter Units (PCU)
- Effective PCU area ~ 1500 $cm^2$
- 3 – 50 keV effective energy range
- Microsecond time resolution
- Main instrument for study spectral evolution and fast timing phenomena in galactic compact sources for almost 14 years. Flux and energy scale

# PCA Response Calibration

- Implemented as PCARMF and XPCAARF FTOOLS
- Based on the physical model (Jahoda et al. 2006, ApJS, 163, 2, 401)
  - energy-to-channel (E2C) relationship
  - quantum efficiency
  - redistribution
- 256 instrument channels
- E2C information
  - on board calibration source $Am_{241}$ 6 lines 13 to 60 keV
  - Cas-A iron line at ~6.4 keV (v11.1)
  - Xe L-edge in Crab spectra (v11.7)
- Flux calibration
  - Crab
  - Power law spectral distribution is assumed
  - $\Gamma$=2.11, Norm (1 kev) = 11.0, $N_H = 0.34 \times 10^{22}$ $cm^{-2}$
- Current version v11.7 presents a major change in minimization method

# PCA Response Components

## Energy-to-channel relationship

$$ch(E,T) = A + BE_p + C_0 E_p^2$$

$$A = A_0 + A_1 \Delta T + A_2 (\Delta T)^2$$

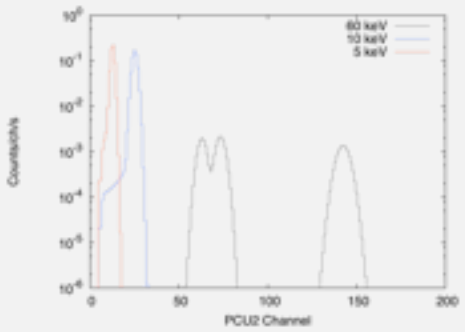
$$B = B_0 + B_1 \Delta T + B_2 (\Delta T)^2$$

## Quantum efficiency

- Amounts (and daily change) of xenon and propane in PCU layers and thickness of mylar and aluminum windows

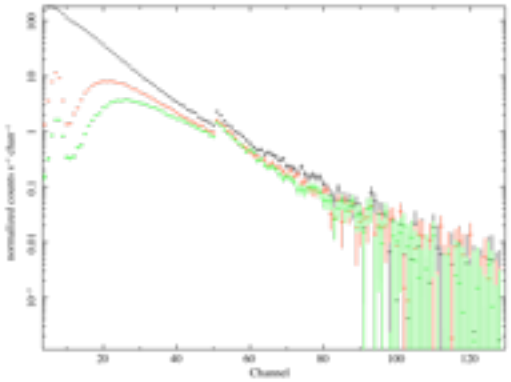
## Redistribution

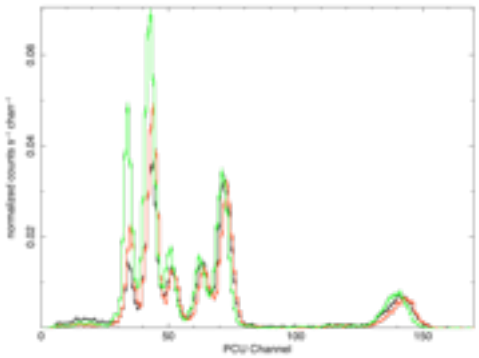
- $\Delta ch = B\sqrt{aE + b}$

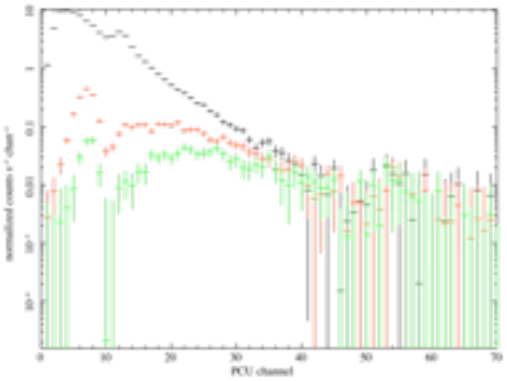



Overall we need 43 parameters to describe response for a particular detector layer

# PCA Calibration Data



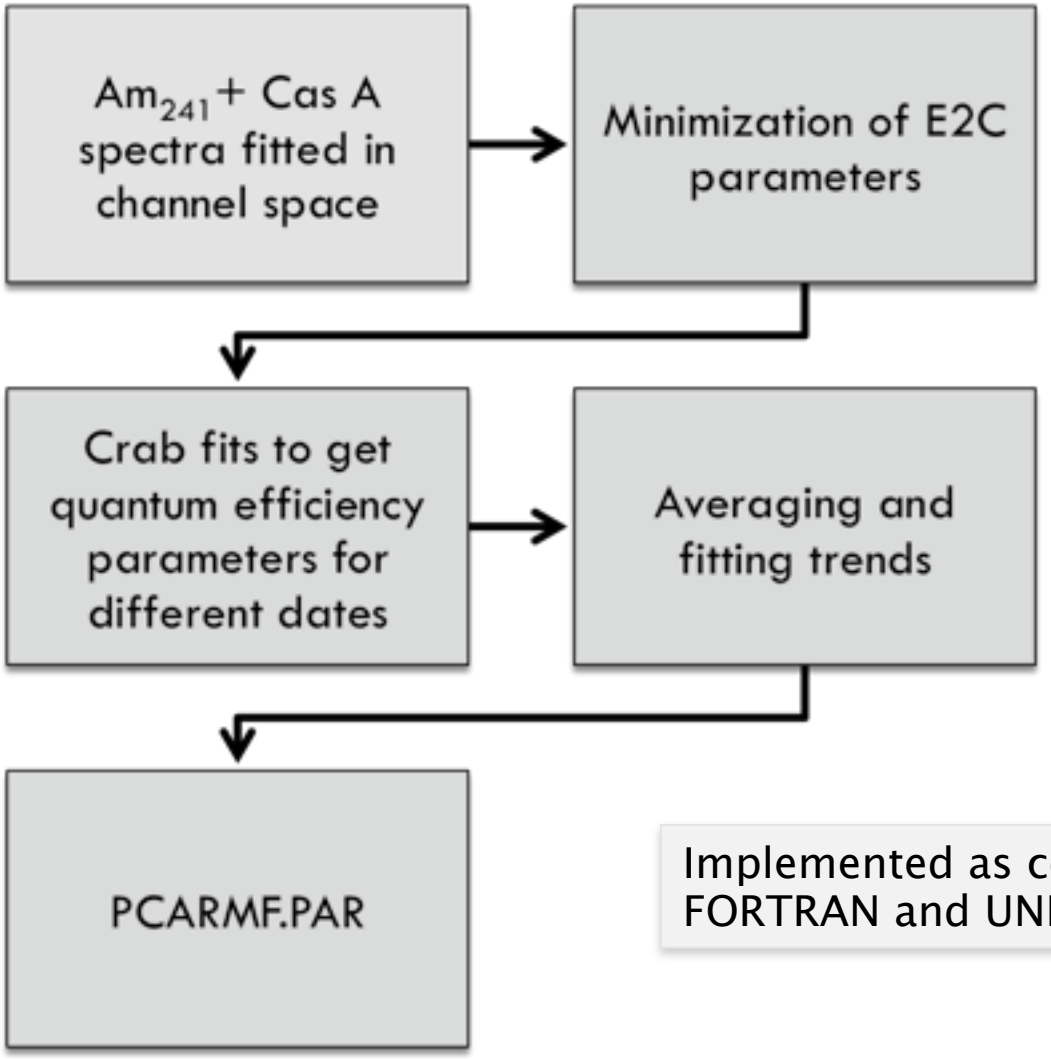




| Crab | Am 241 | Cas A |
|---|---|---|
| • Flux calibration<br>• Quantum efficiency parameters | • E2C calibration<br>• 6 Lines from 13 to 60 keV<br>• Resolution coeff. (v11.7) | • Fe K $\alpha$ Line at ~6.6 keV<br>• Calibration source for v11.1 and earlier<br>• Test Source for v11.7 |

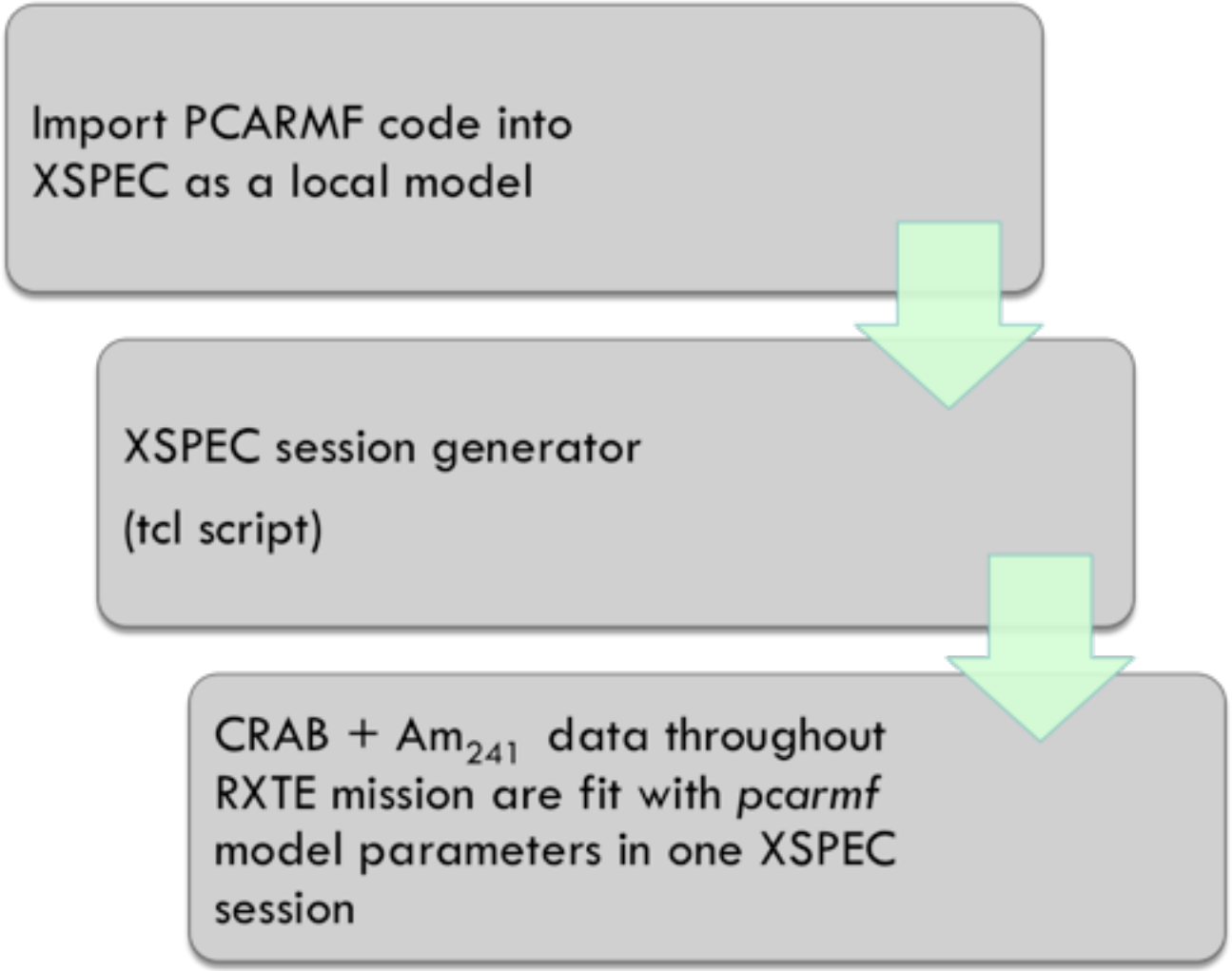
BNL ground calibration data on resolution: $\Delta E$=1 keV @ 6keV & 2 keV @ 22keV

# PCA Calibration Data Flow (PCARMF v11.1 and earlier)

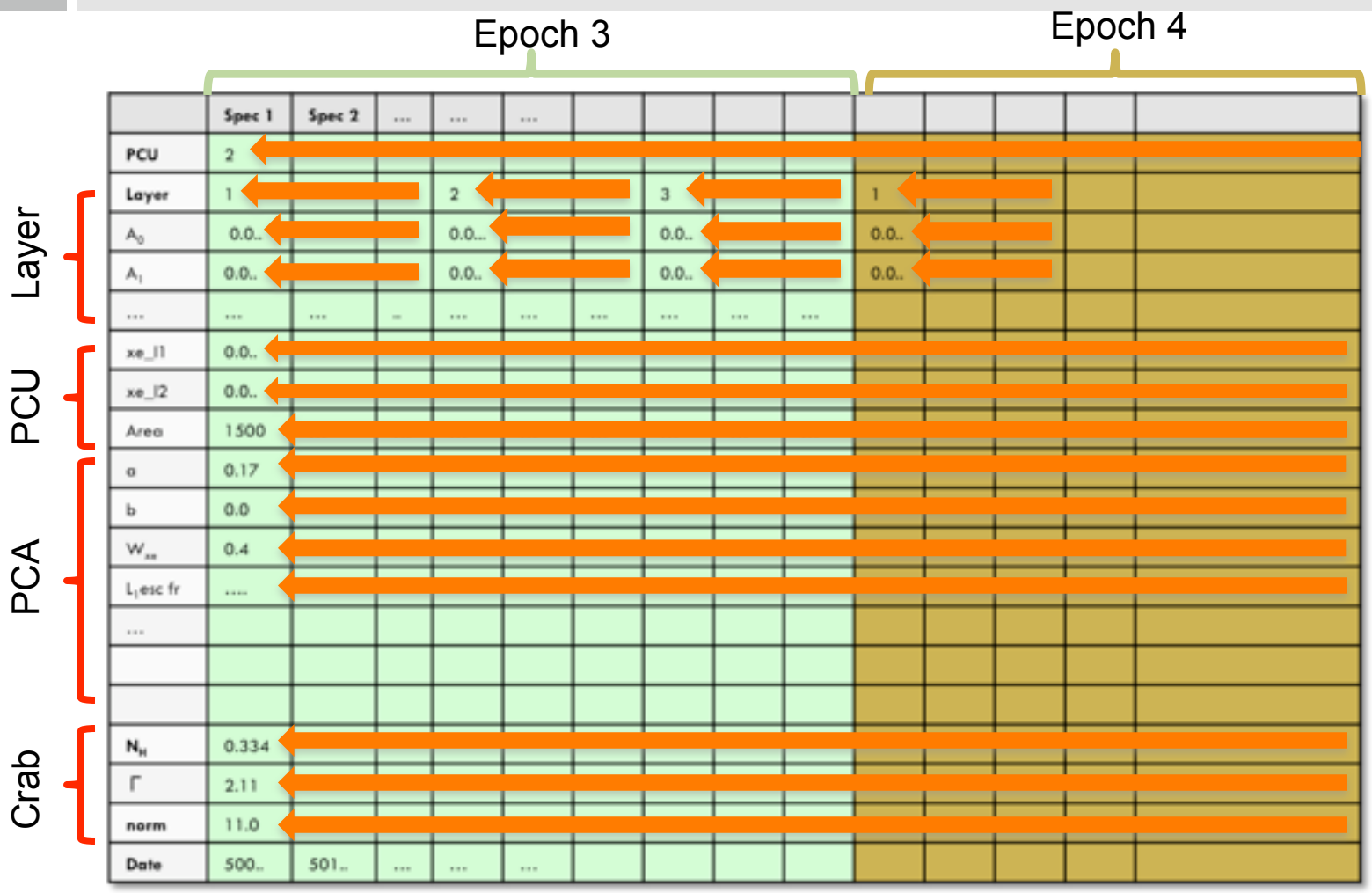



Implemented as combination of FORTRAN and UNIX shell scripts

# PCA Response Minimization Method



# XSPEC session for PCARMF model fit



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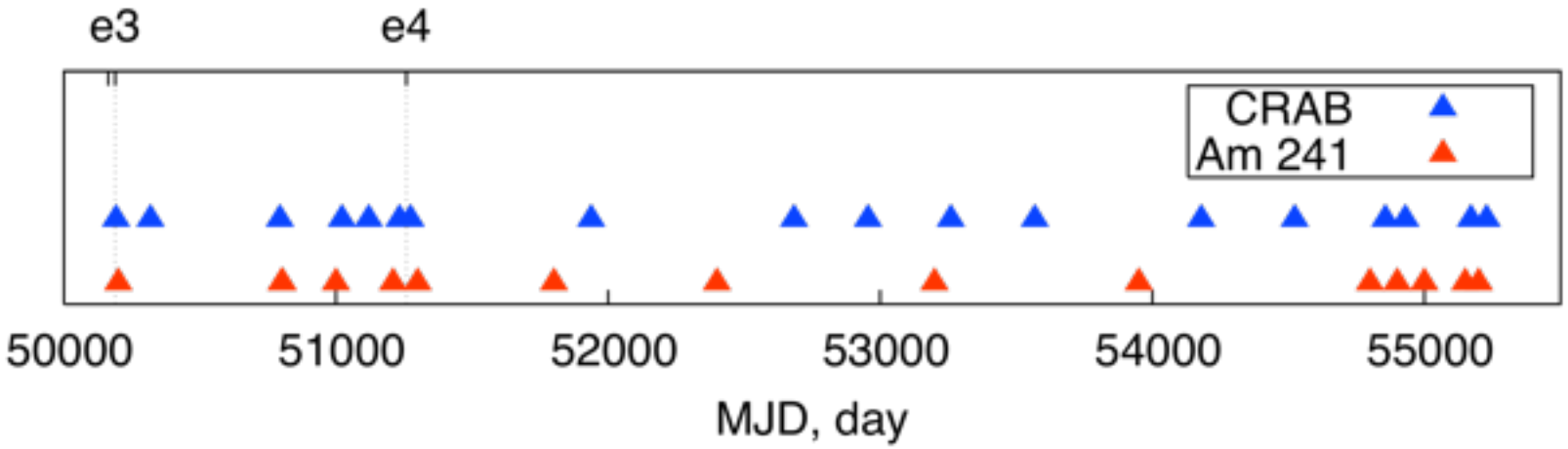
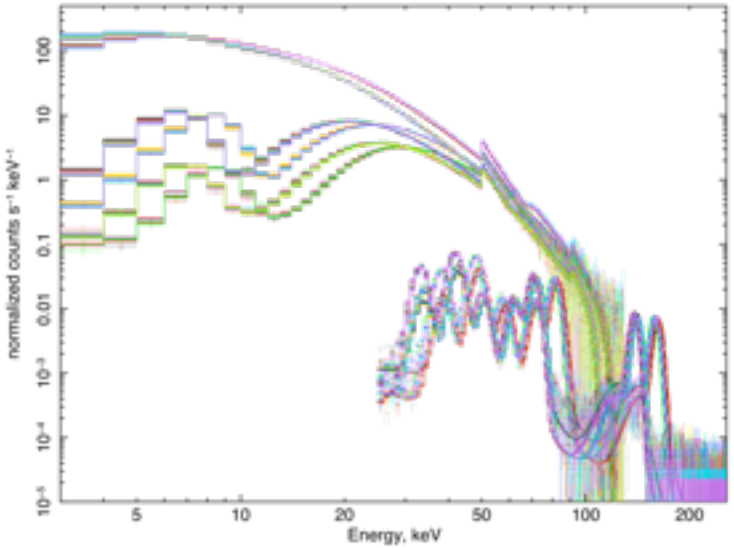



- 18 Crab observations
- 13 $Am_{241}$ observations
- Data sets
  (18+13)×3 = 93

- Model parameters
  (48×18+52×13) ×3 = 4620
- 74 free parameters

# PCARMF model fit results

Fit strongly suggested different resolution coefficients $\Delta ch = B\sqrt{(aE+b)}$

- v11.1 a=0.121 b=0.422
- v11.7 a=0.17 b=0.0 → $\Delta ch = B\sqrt{aE}$
- Consistent with Brookhaven data
- Requires broader redistribution function for high energies and narrower for low energies

Putting quadratic time dependence e2c coefficients to zero greatly improved the fit and simpified e2c model

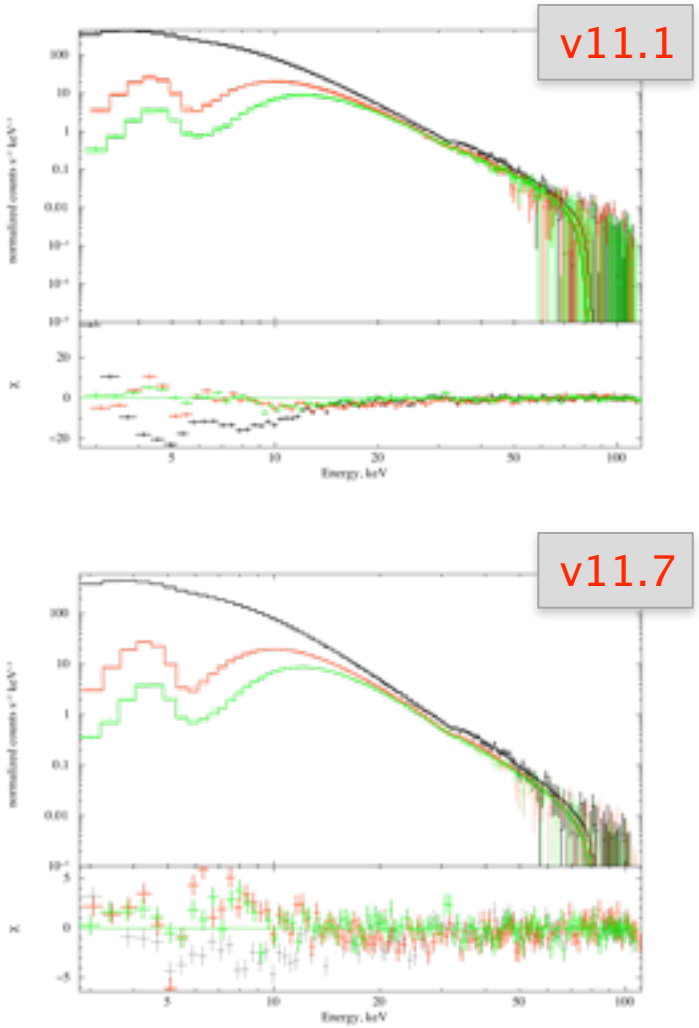
$ch = A + B \times E + C \times E^2$

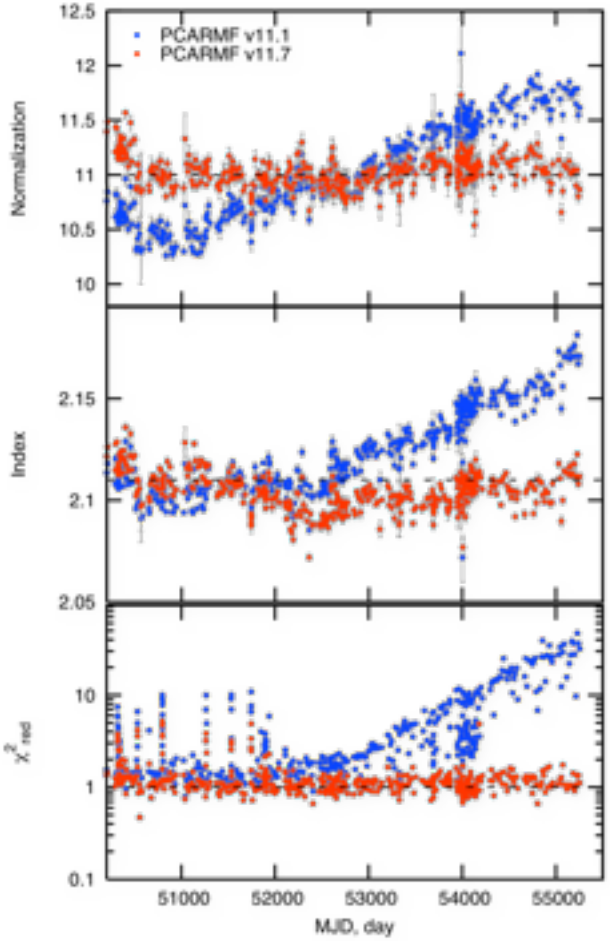
- v11.1 : $A = A_0 + A_1 \Delta T + A_2 (\Delta T)^2$
- v11.7 $A_2 = 0.0$ → $A = A_0 + A_1 \Delta T$
- Same story for B
- Makes sense physically

New e2c model renders 5th epoch for e2c relationship obsolete

- Epoch 5 remains for PCU 0 and PCU 1 due to loss of propane channel with the epoch start data at the event of propane loss

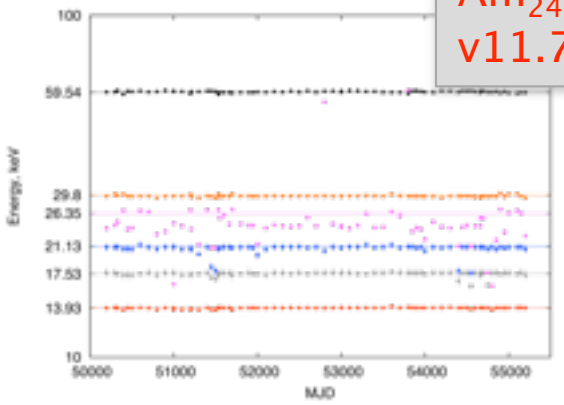
# PCARMF v11.1 vs v11.7: Crab Test



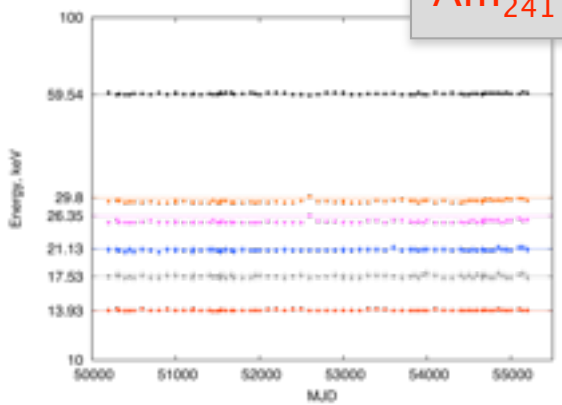



# Enenrgy-to-Channel Scale Test

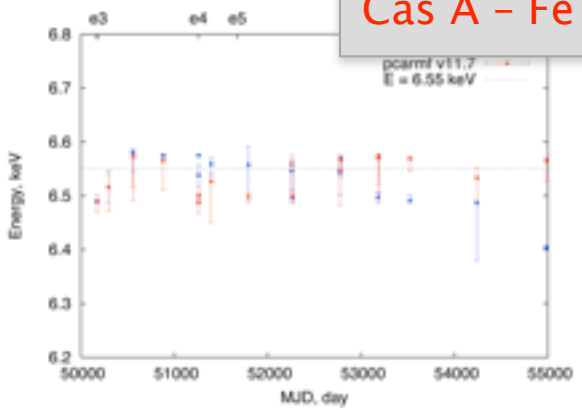
$Am_{241}$ v11.7



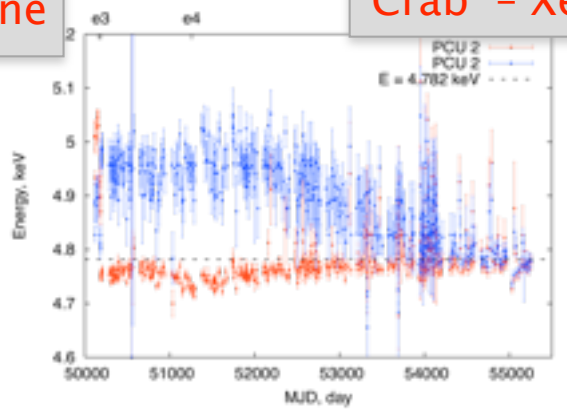

$Am_{241}$ v11.1




Cas A – Fe $K_\alpha$ Line

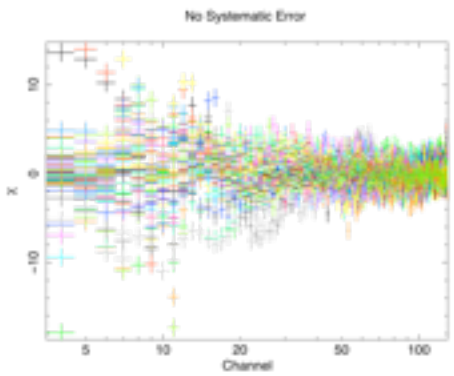



Crab – Xe L edge

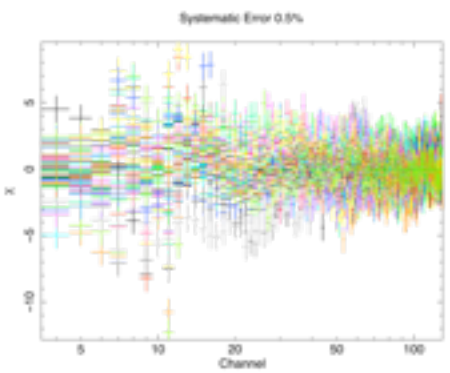


# Systematic Error

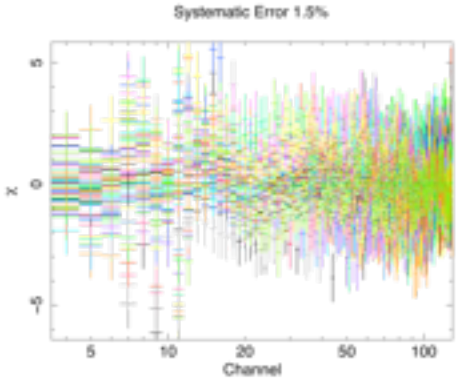
- PCU 2
- Crab data only
- Best fit parameters




$\chi^2_{red} = 3.2$




$\chi^2_{red} = 2.1$




$\chi^2_{red} = 1.2$

- systematic error is 0.5–0.8%
- very high statistic data – 1%, but not more 1.5%
- v11.1 response 1–2% sys. error

# PCARMF v11.1 vs v11.7

| | PCARMF v11.1 | PCARMF v11.7 |
|---|---|---|
| e2c relationship | •5 epochs<br>• 7 coefficients per epoch | • 4 epoch (except PCU 0,1)<br>•5 coeff./epoch |
| Resolution | •$\Delta ch = B\sqrt{(aE+b)}$<br>• a=0.121, b=0.422 | •$\Delta ch = B\sqrt{(aE)}$<br>• a = ~0.17 |
| Quantum efficiency | | Escape lines have different |
| Performance | •Show trends both in index and norm in Crab<br>• gradually worsening $\chi^2$<br>• PCUs 0 & 1 are unusable after propane loss<br>• e2c is not reliable esp. for | • Index and normalization is stable with only minor trends<br>• No signs of decline in $\chi^2$ quality<br>• e2c is stable and |

# SUMMARY

## Conclusion

- New response is a huge step up in RXTE/PCA calibration quality and instrument understanding
- PCA is healthy, performing well and can operate several more

## Future Plans

- To test theoretical Crab models (as per Weisskopf et al 2010)
- To work towards more universal calibration with other mission (Kirsch et al. 2005, XMM-Newton)
- Apply response minimization method for new instruments (ASTROSAT?)