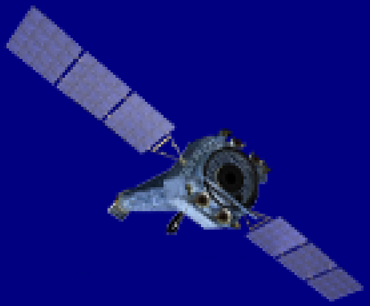
# *ACIS Gain Challenges*

# *Warm Focal Plane Temperatures*
# *&*
# *Lorentzians*



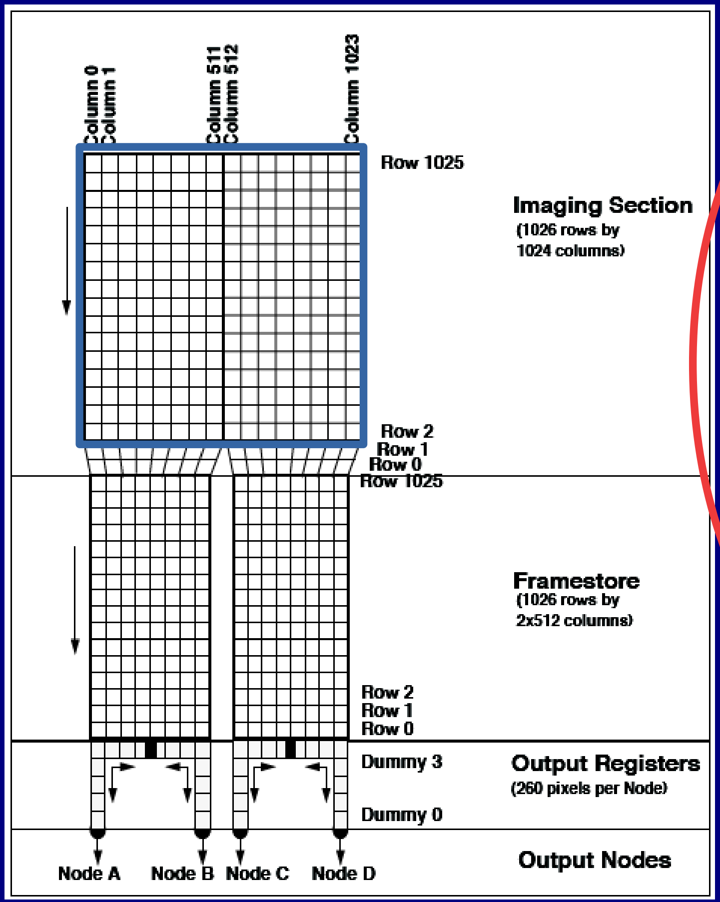
**1. ACIS Gain Challenges**
- **Cause of Gain decline.**
- **How Chandra ACIS detector time-dependent gain is calibrated.**
- **Calibration Challenges & Solutions.**

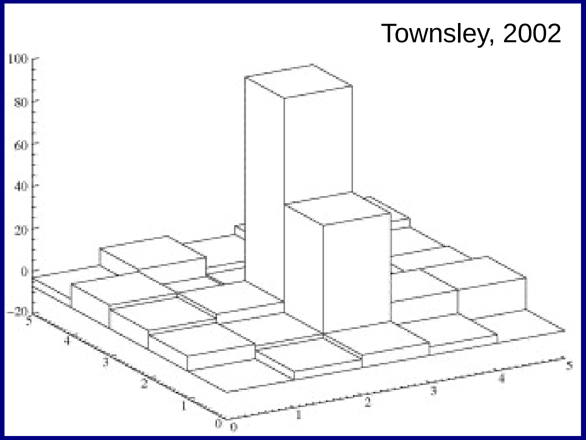
**2. ACIS Warm Focal Plane Temperature Calibration**
- **Analyses of 2017-2018 ECS observations of Al-Kα, Ti-Kα, Mn-Kα lines.**
- **Lorentzian vs. Gaussian natural line emission profile.**
- **FWHM vs FP_TEMP**

Nick Durham
CXC Calibration Group

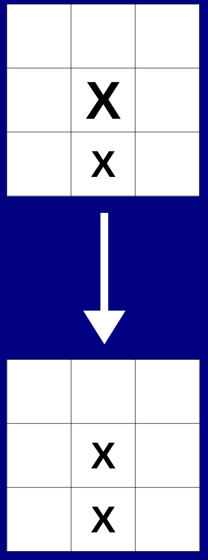
# Charge Transfer Inefficiency

ACIS CCD architecture



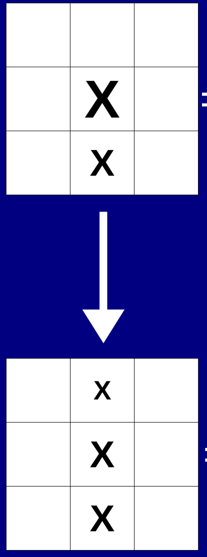

1) Charge Loss




PHA = **X+x**

PHA = **x+x**

2) Grade Migration




= Flight Grade 2
GOOD

= Flight Grade 66
REJECTED

CTI manifests two modes:

1) Gain decline

Charge loss: Portion of charge packet is trapped, reducing overall PHA

2) QE decline

Grade migration: Trapped event charge is re-emitted into a trailing event island pixel during readout.

# How ACIS Gain is Calibrated

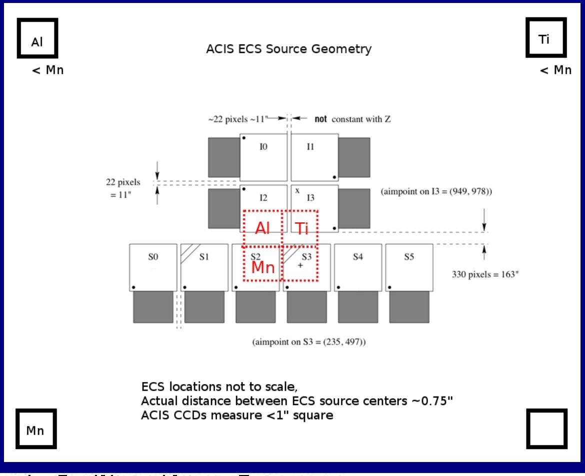
**External Calibration Source (ECS)**

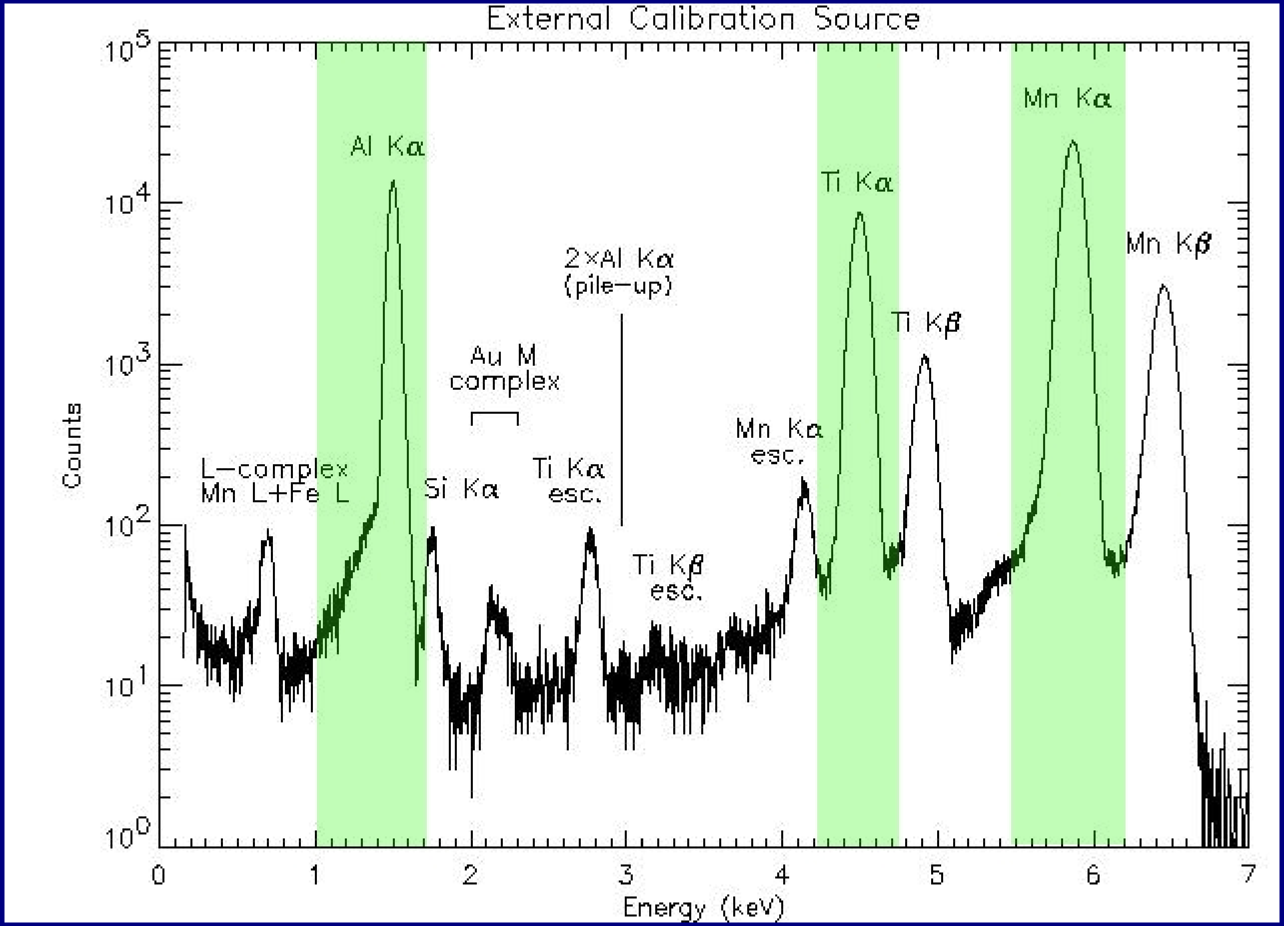
ACIS exposed when HRC is in the focal plane

Fe55 sources, $T_{1/2}$ = 2.7 years

Bright ECS lines:

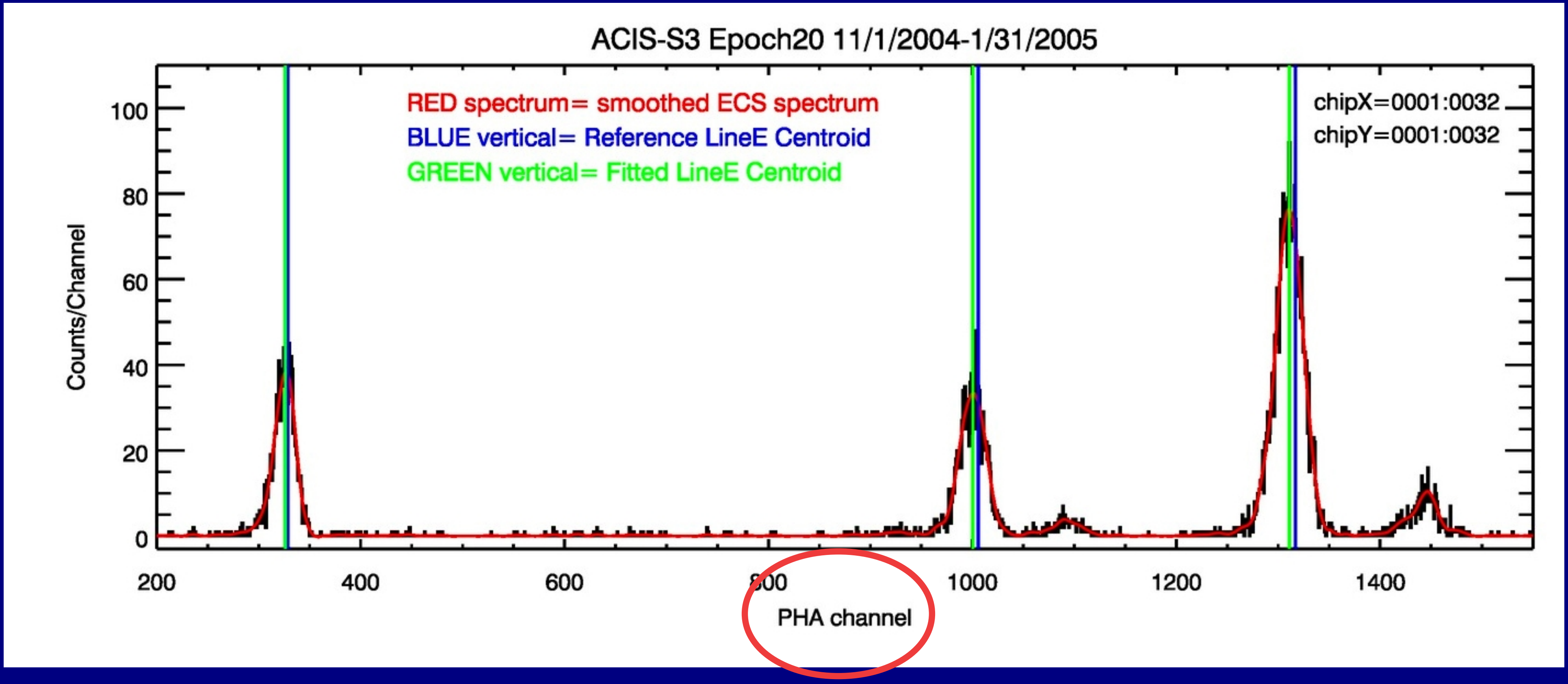
| | |
|---|---|
| Al-Kα | 1.49 keV |
| Ti-Kα | 4.51 keV |
| Mn-Kα | 5.89 keV |



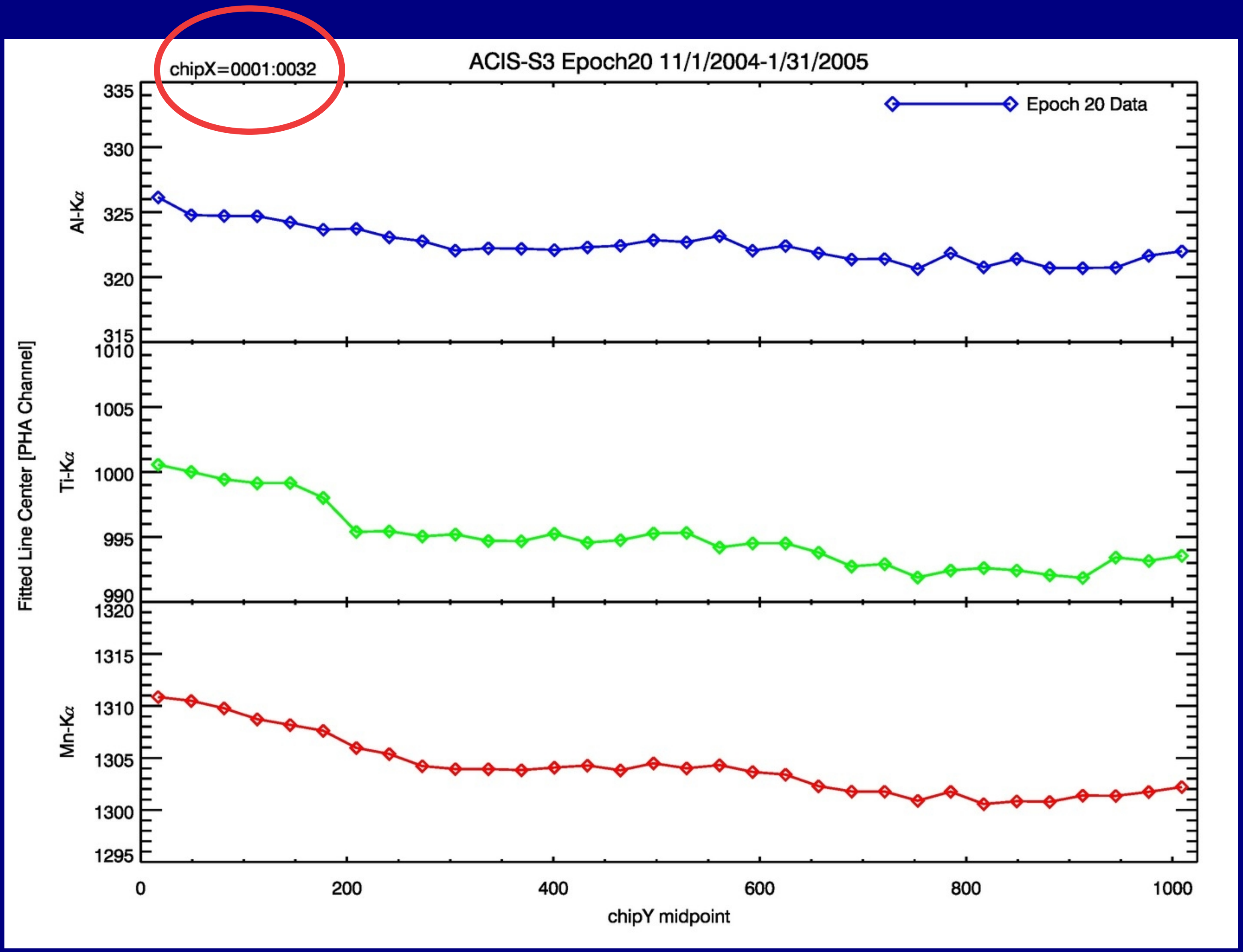
# Line Energy Centroid Fit
# PHA Channel Spectrum

Simple Calculation to find Line Centroids
Fit at each 32x32 pixel location across the ACIS CCDs

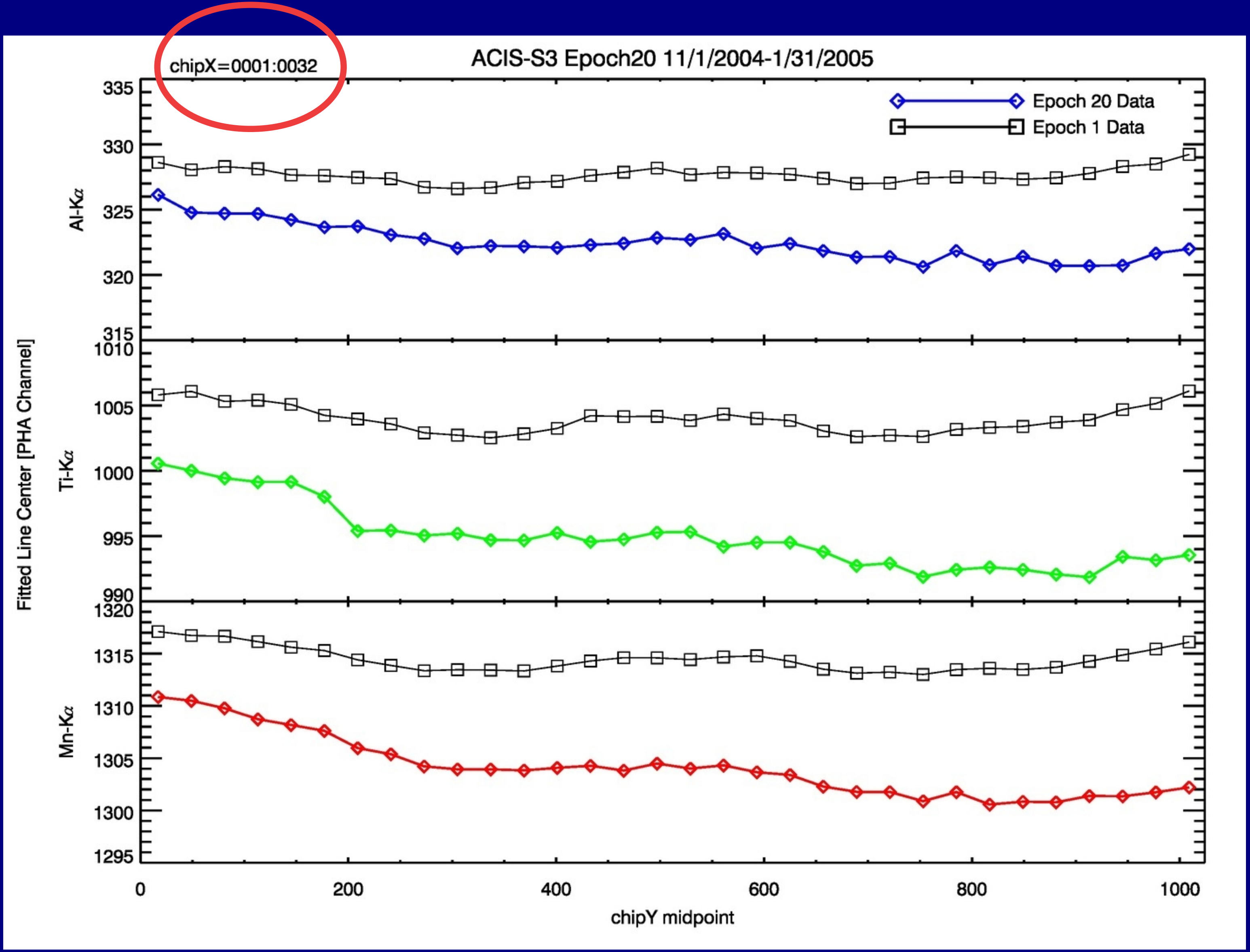



PHA channel space histogram
NO gain correction applied during data reprocessing
1 channel ≈ 4.5 eV

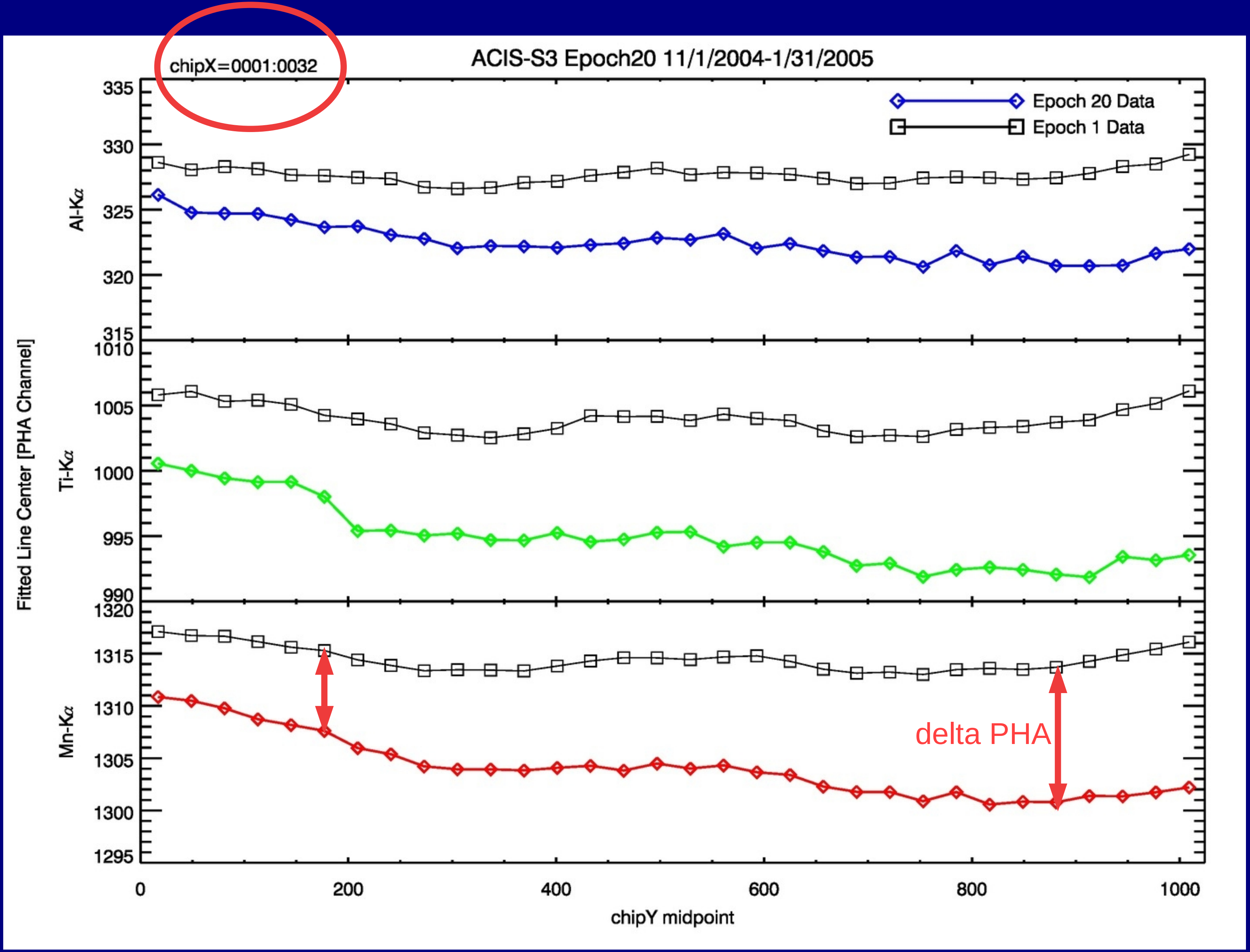
# Line Energy Centroid Fit vs ChipY



# Line Energy Centroid Fit vs ChipY



# Line Energy Centroid Fit vs ChipY



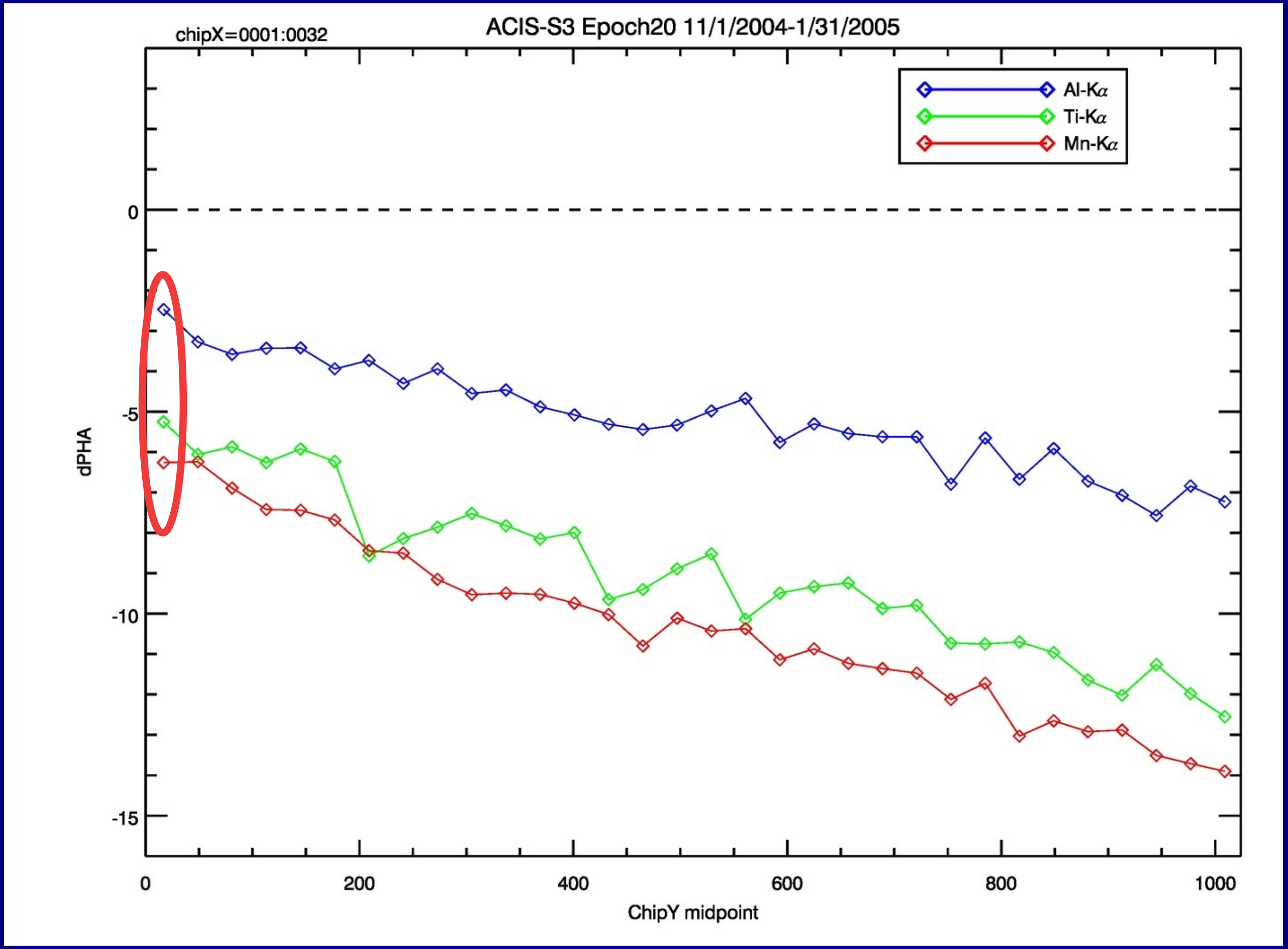
# dPHA vs ChipY

Gain correction = dPHA[x,y,E]

Each location fit Al, Ti, Mn dPHA to energy scaling equation:

$$dPHA = A\sqrt{E} + BE$$

Solve for “A” and “B” coefficients. Unique for each chip(x,y) location.



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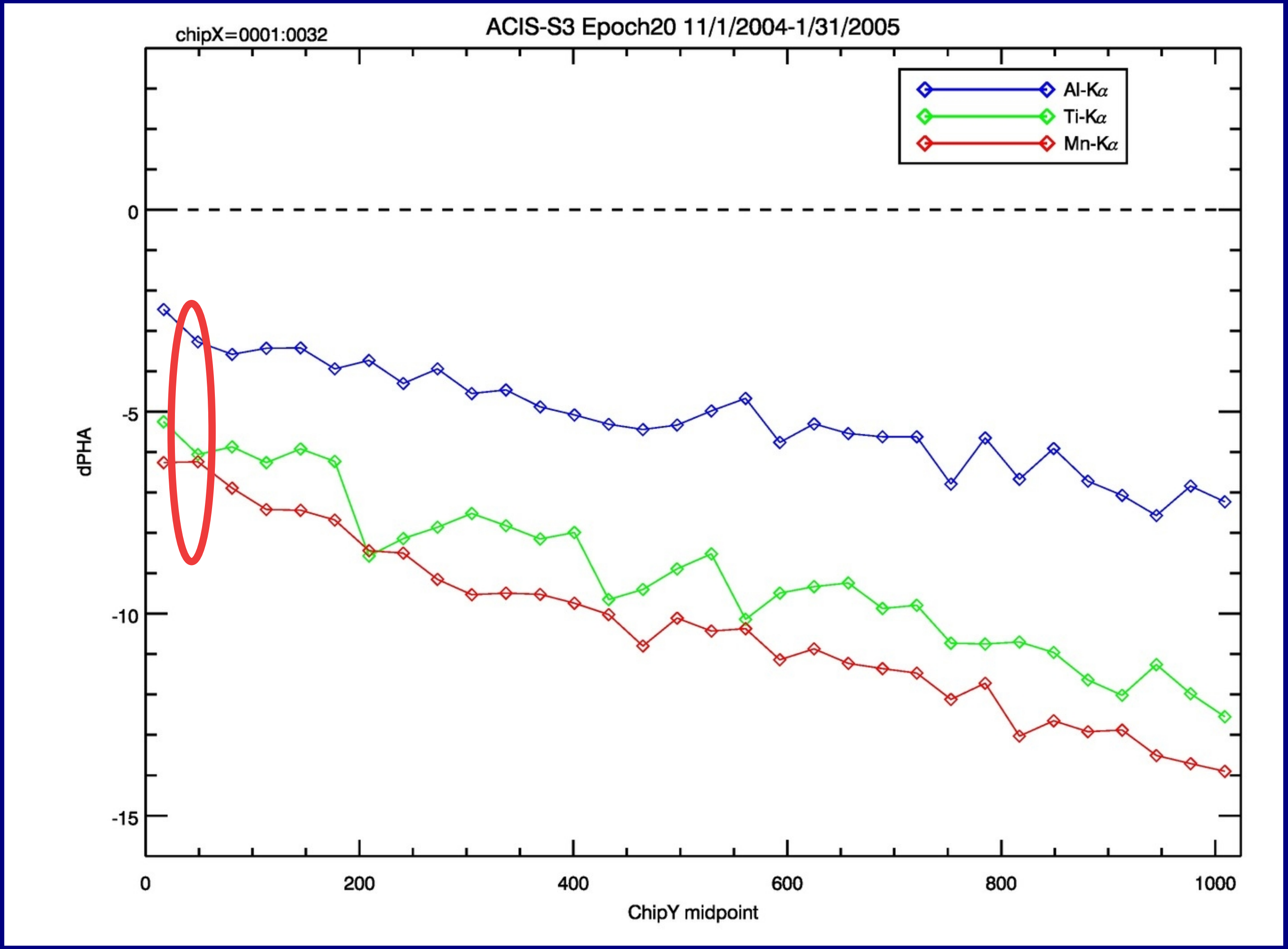

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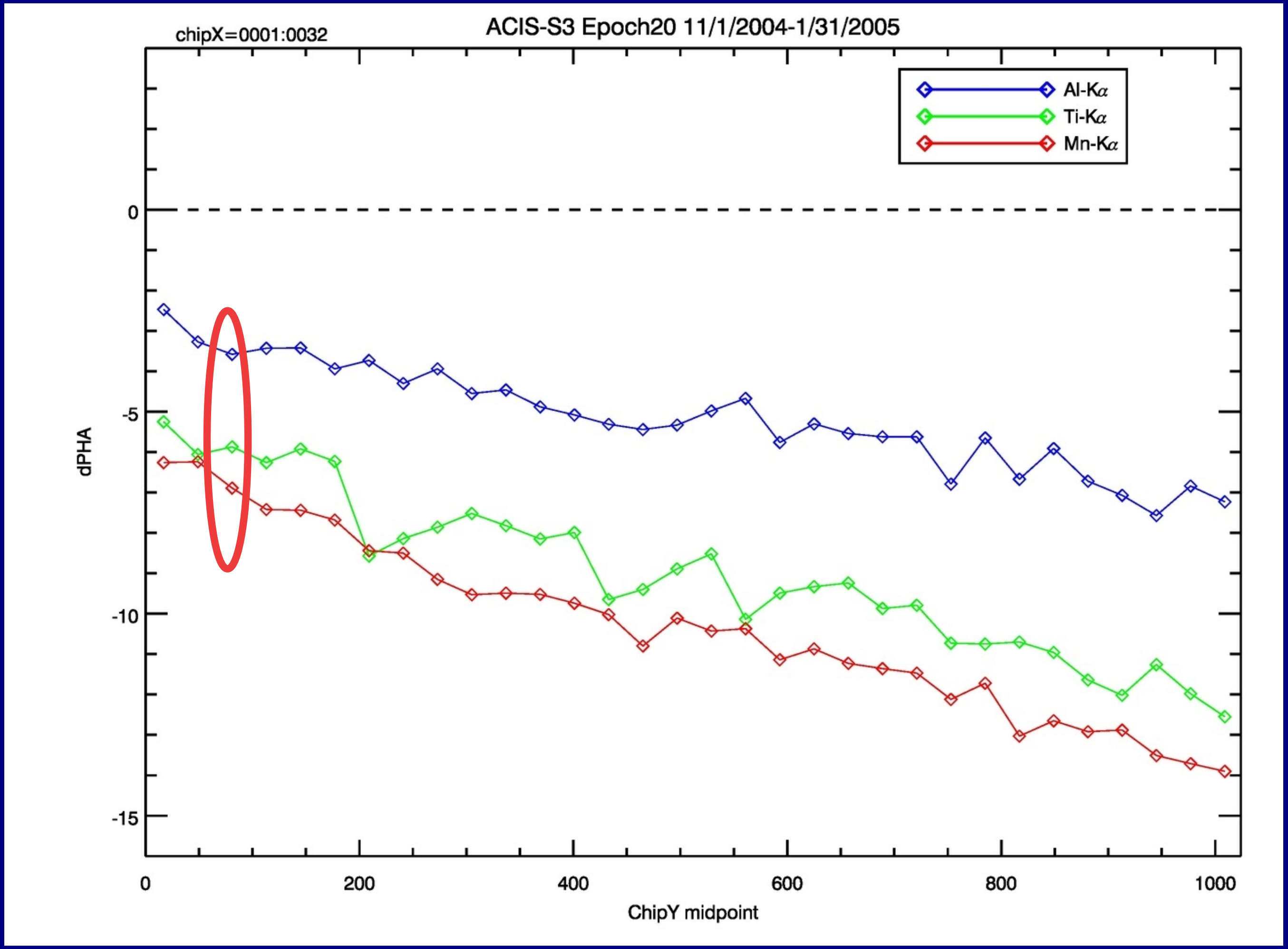

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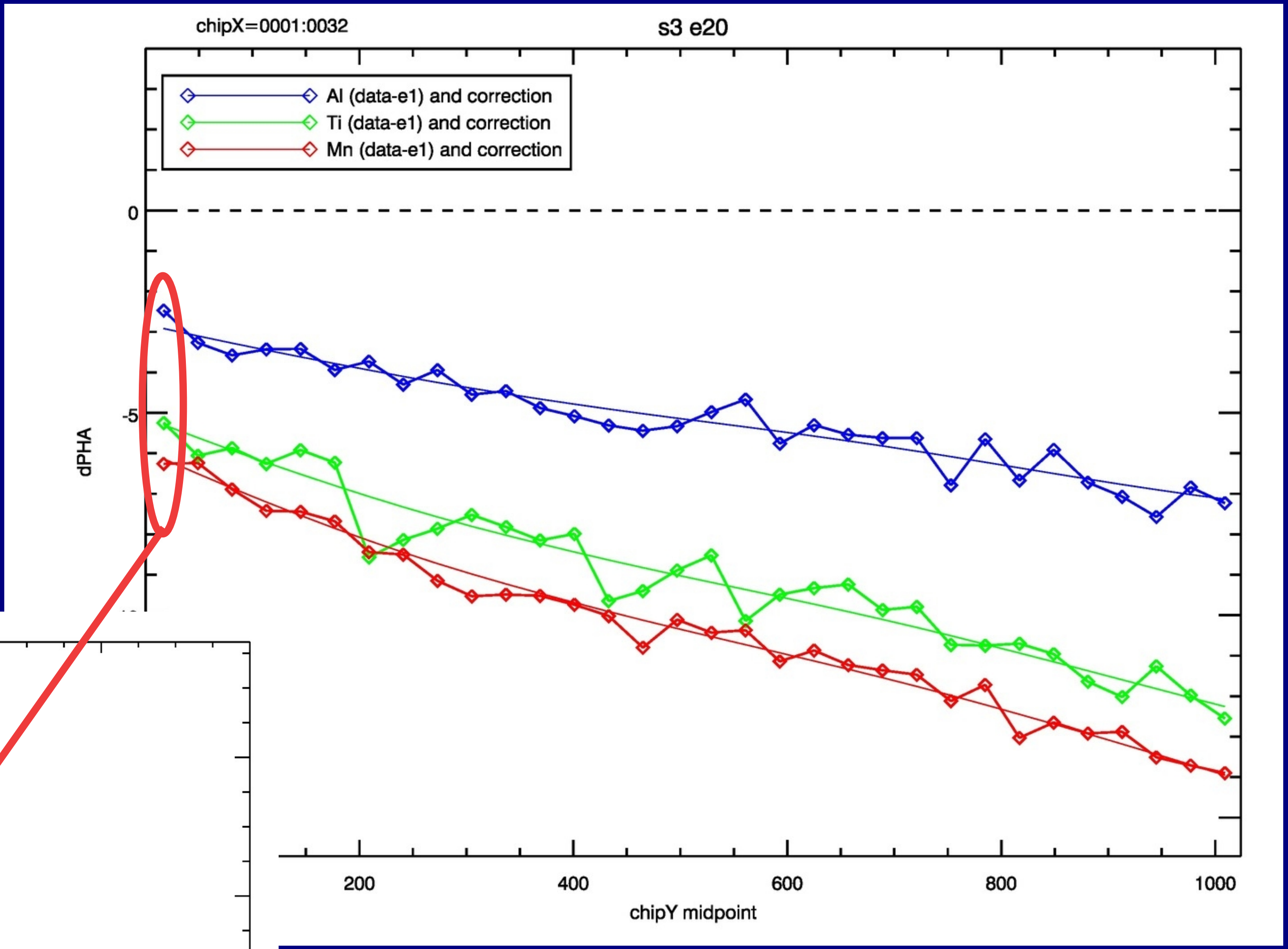
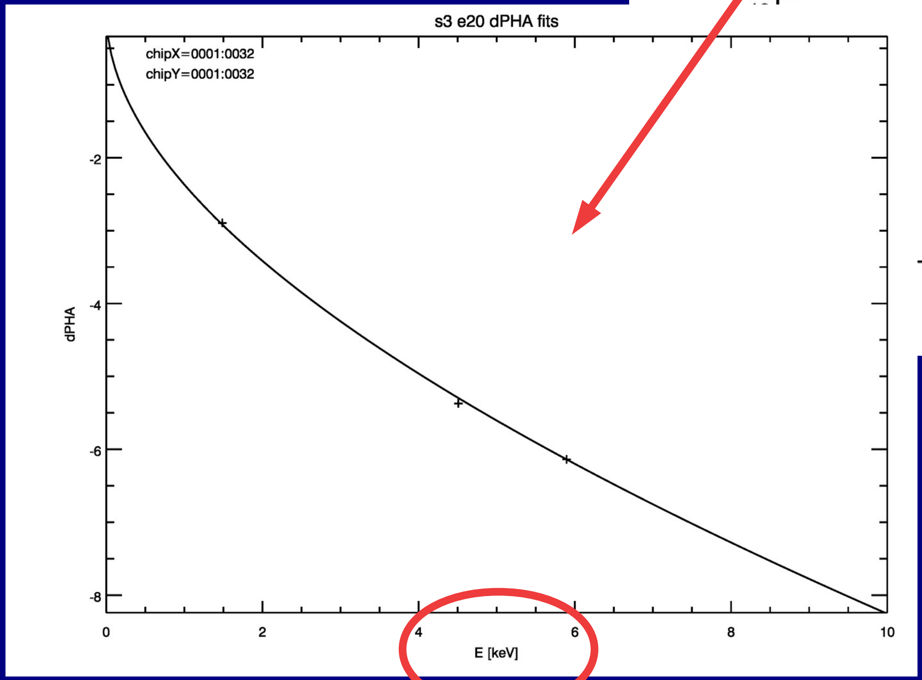
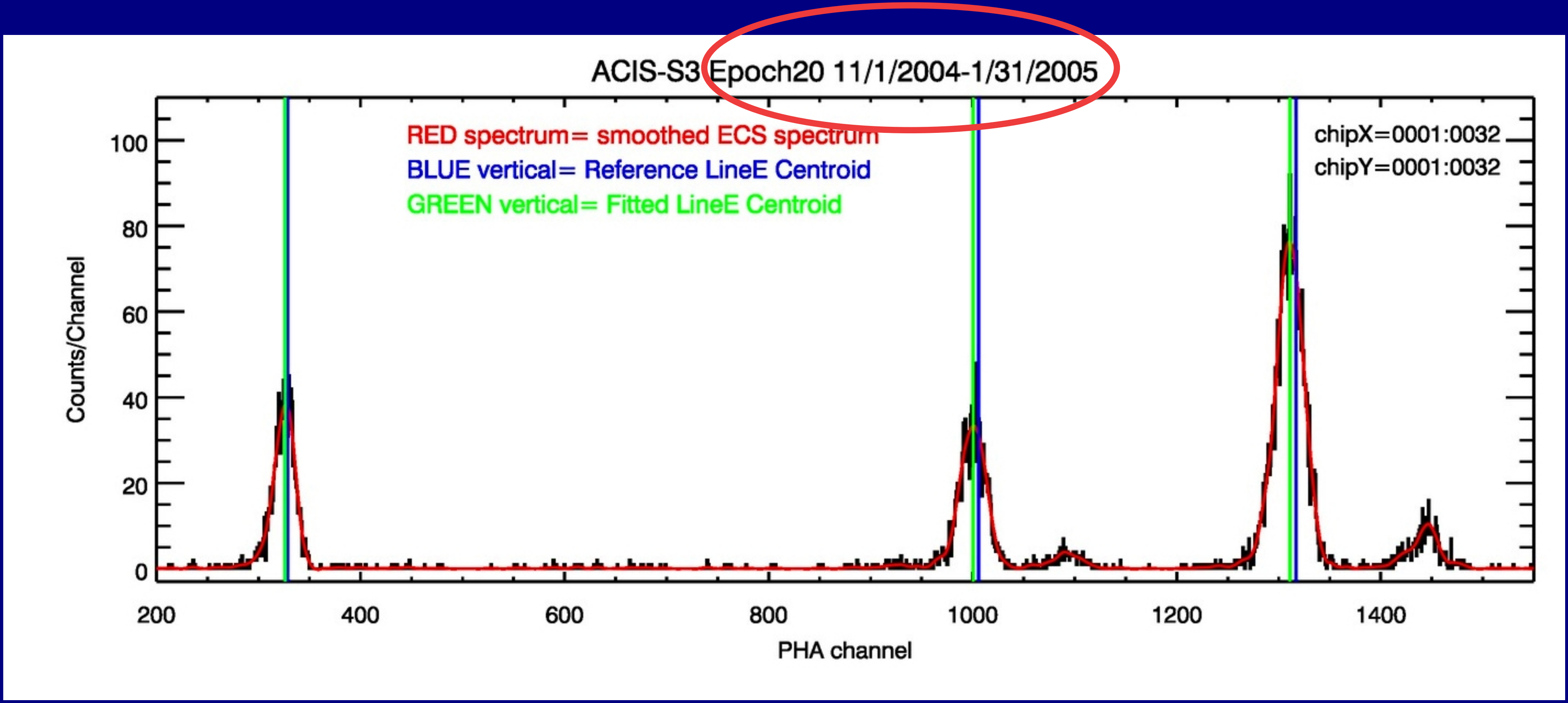
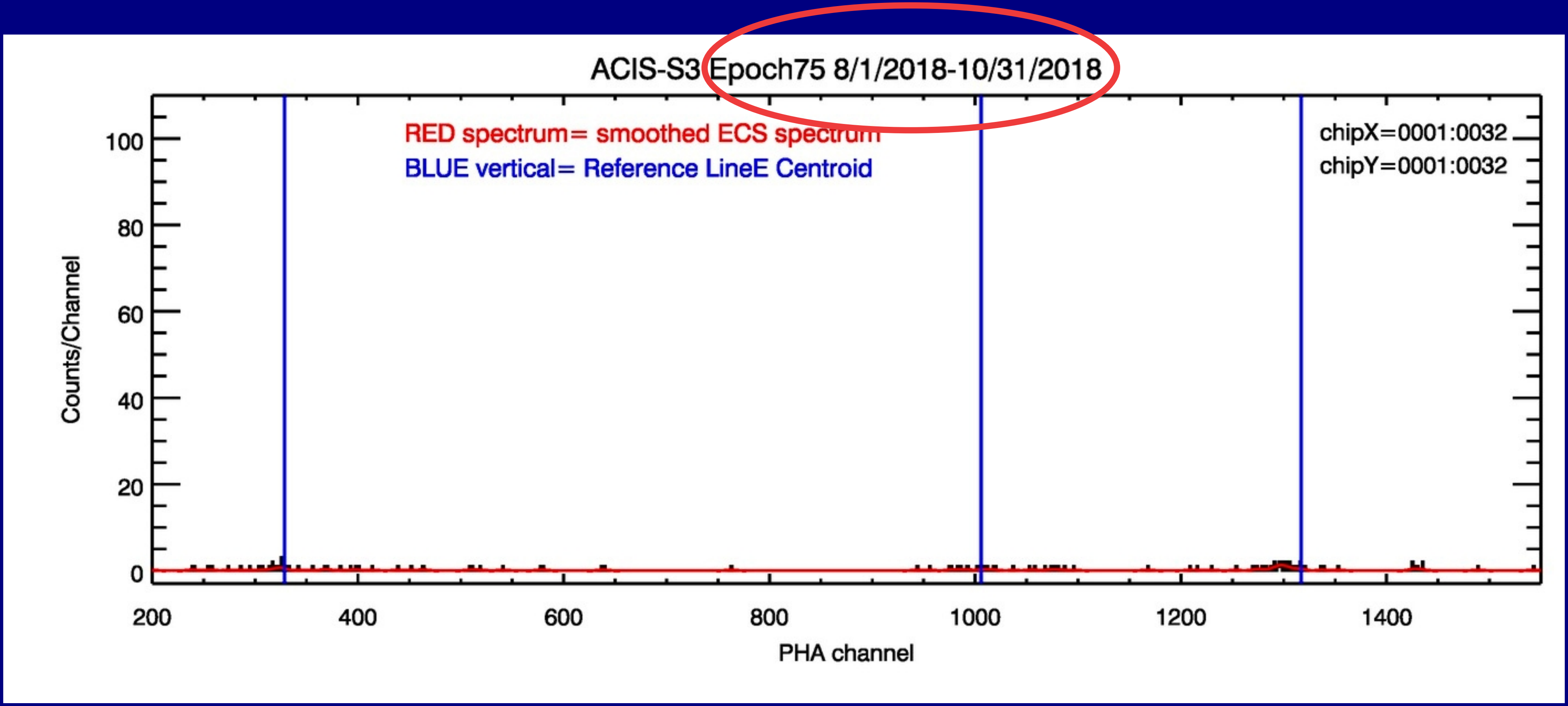


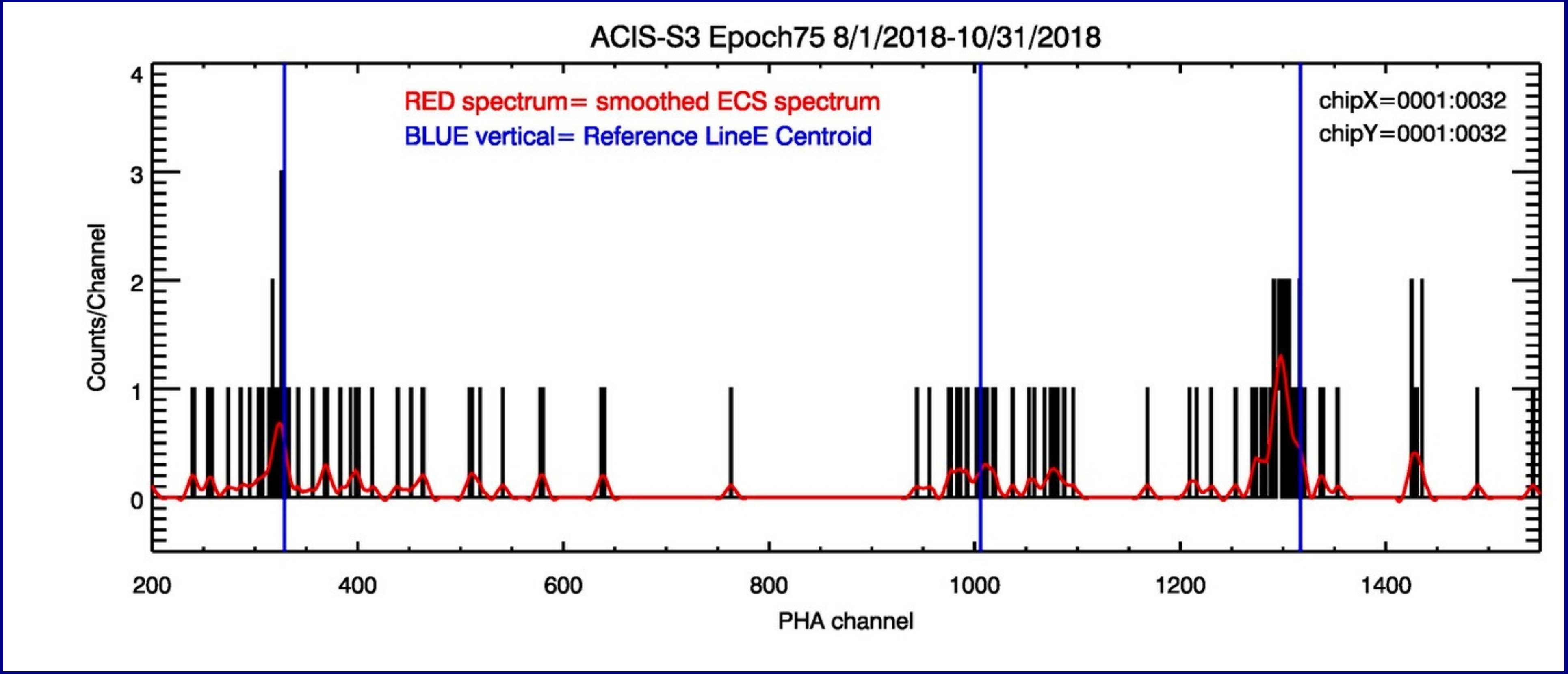
# ECS Evolution



# ECS Evolution



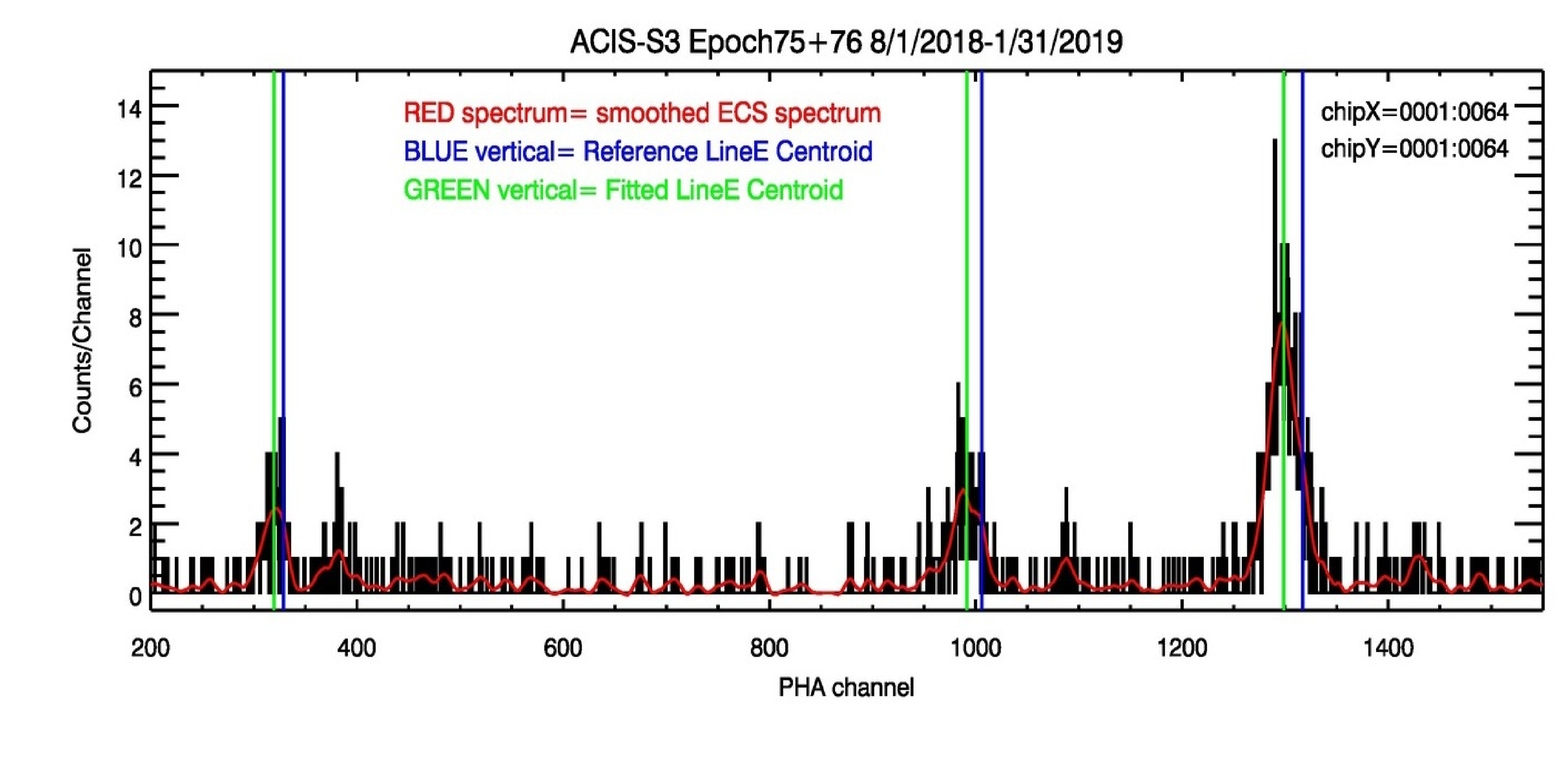
# ECS Evolution



# *ECS Evolution*

6 months of ECS
64x64 pixel regions

= 8x more counts



# No More Simple Line Centroid Fitting

Physical model does not exist.
Approximate the expected line profile using the shape of the response.

1. Extract RESPONSE vs PHA_Channel from RMF.
    - @ Energy corresponding to nominal Al-Kα, Ti-Kα, Mn-Kα
        - *(DET_GAIN Calibration Required for keV -to- PHA_Channel conversion)
    - @ Each spatial fitting region

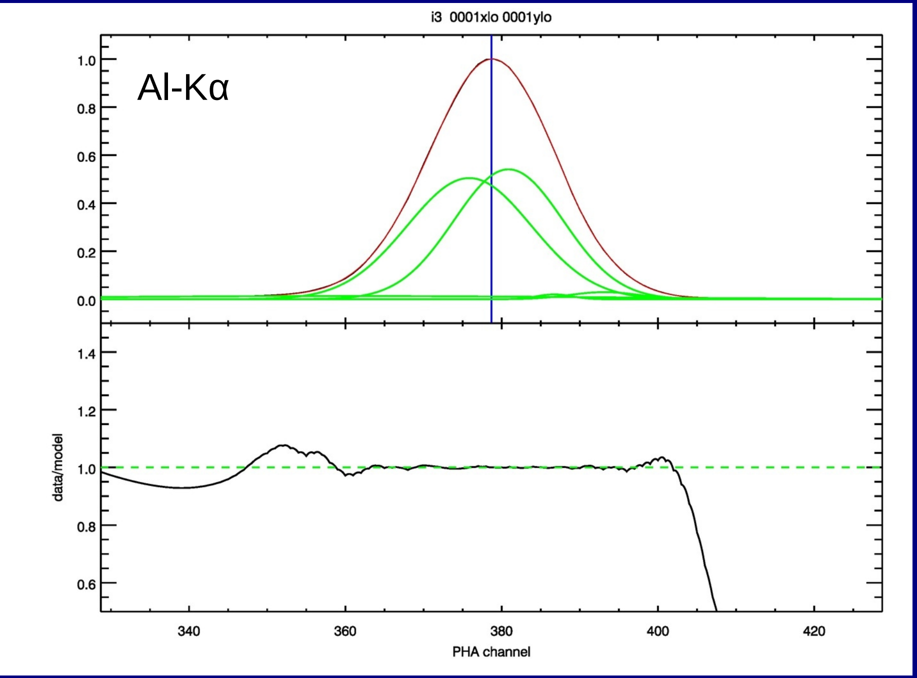
| | | |
|---|---|---|
| 32x32 pixels | I0/1/2/3, S2/3 | *Revised to 64x64 for TGAIN 3.0 |
| 64x64 pixels | S1 | |
| 256x32 pixels | S0/4/5 | |

2. Fit multiple gaussians to the response.

3. Stitch together the Model =

| | |
|---|---|
| GAUSS_1 | LineE thawed |
| GAUSS_1 | norm thawed |
| GAUSS_1 | sigma thawed |

Subsequent gaussians LineE tied to GAUSS_1
    *(offset relative to GAUSS_1)
Subsequent gaussians norm tied to GAUSS_1
Subsequent gaussians sigma tied to GAUSS_1



# 1. Line Energy Fitting Constraints

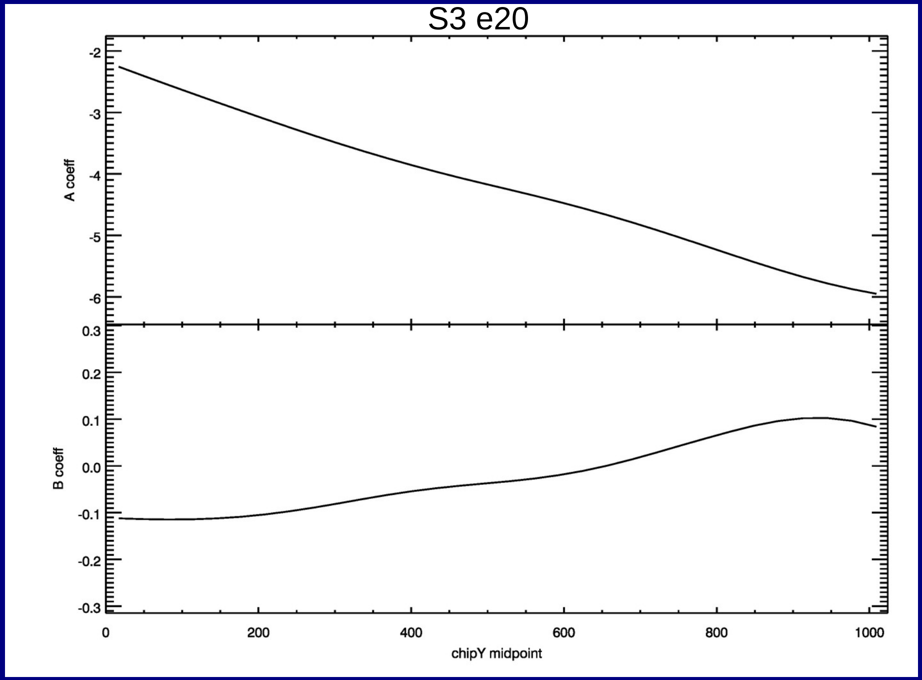
- PHA channel search windows relative to RMF PHA channel peak (includes DET_GAIN correction to PHA) calculated from nominal Al-Kα, Ti-Kα, and Mn-Kα line energies.
- Search windows tailored to expectations:
    - I0 and I2 windows RMF_PK-100 < PHA Search Window < RMF_PK+80
    - All other chips RMF_PK-100 < PHA Search Window < RMF_PK+15
    - FI chip node1/2 boundary region extends lower search channel to RMF_PK-120
- Initial line centroids = mean(channel @ 90% max counts), weighted by smoothed counts.
- Abort fit if total counts within response FWHM < 6 (Al, Ti), or < 8 (Mn).
- Fit multiple-gaussian model to each Al, Ti, Mn line.
    - Al model:
        - multiple gaussian, fixed to 1$^{st}$ gaussian
            - peak counts lower limit = 1.75
            - sigma lower limit = response sigma
            - initial_LineE - 15 > LineE > initial_LineE + 15
        - + mean_background
        - + multiple gaussian model of Si-Kα, frozen to: sigma= Al-Kα sigma, norm= max(smoothed counts within Si-Kα window), LineE= channel @ max_counts within Al-Kα initial centroid x [1.14, 1.2]
    - Ti/Mn models similar to above, Kβ components replace Si-Kα model.

# 2. Time-Dependent Gain Correction Fitting

- lowess, error weighted, smoothing LineE vs ChipY, for each ChipX column
    - Smoothing factor relaxed at FI node1/2 boundary
    - Missing data (LineE fitting did not converge) replaced with linear interpolation to nearby values
- Fit each ChipY set of dPHA values to energy scaling equation.

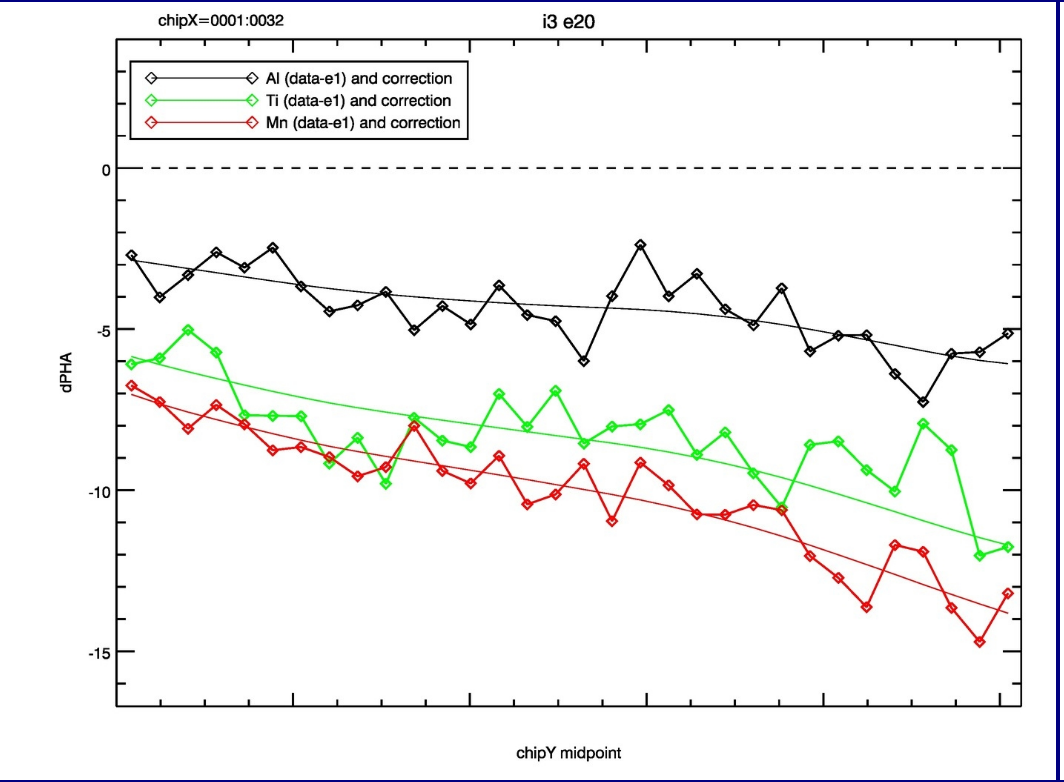
$$dPHA = A\sqrt{E} + BE$$

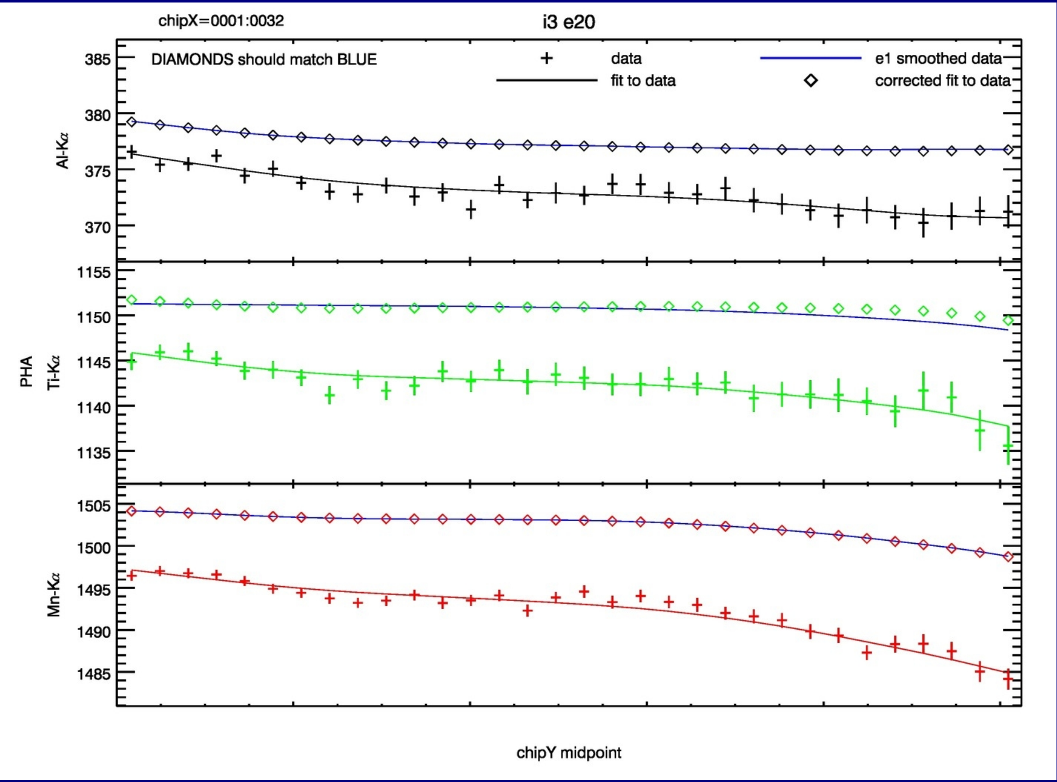
    - ”A” and “B” coefficients thawed for all chips, “B” coefficient limited to: 1 < B < 8
    - dPHA values for each line are weighted based on total line counts: Ti-Kα < Al-Kα < Mn-Kα
- Limit “B” coefficient for the column, and smooth versus ChipY:
    - mean(B) - stdev(B) < “B” < mean(B) + stdev(B)
    - lowess smooth “B”, error weighting = reverse(chipY)
- Fit again with “B” coefficient frozen.



# I3 LineE Before / After TGAIN Correction

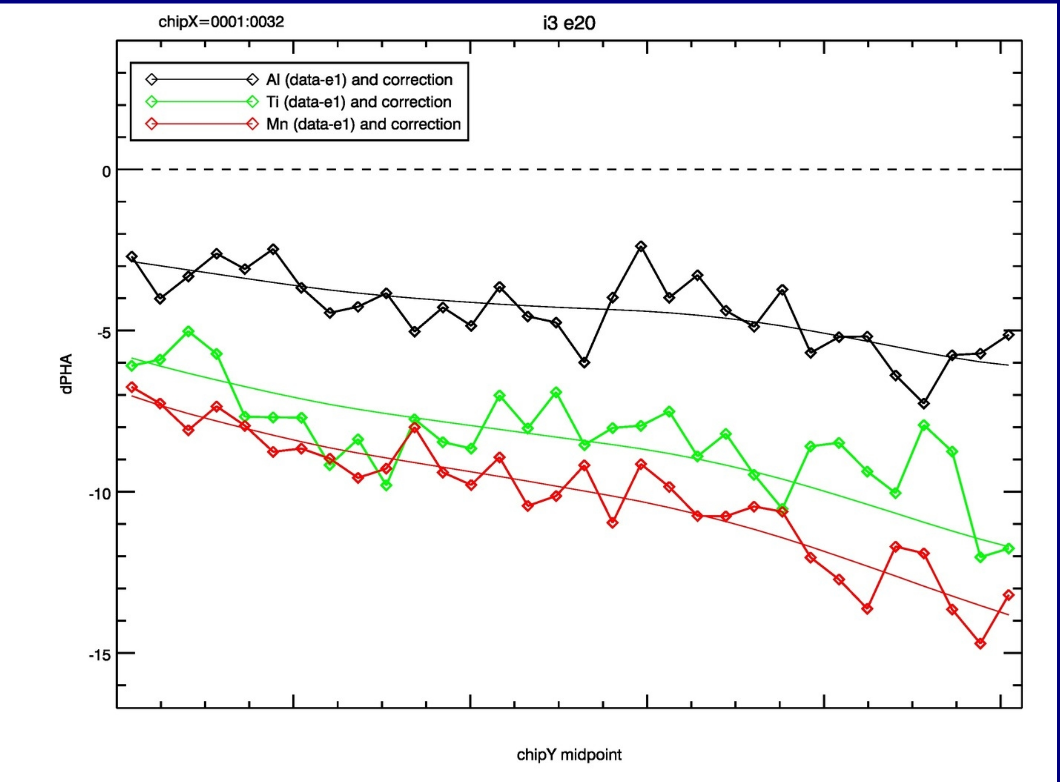
Epoch 20
I3
ChipX= 1:32

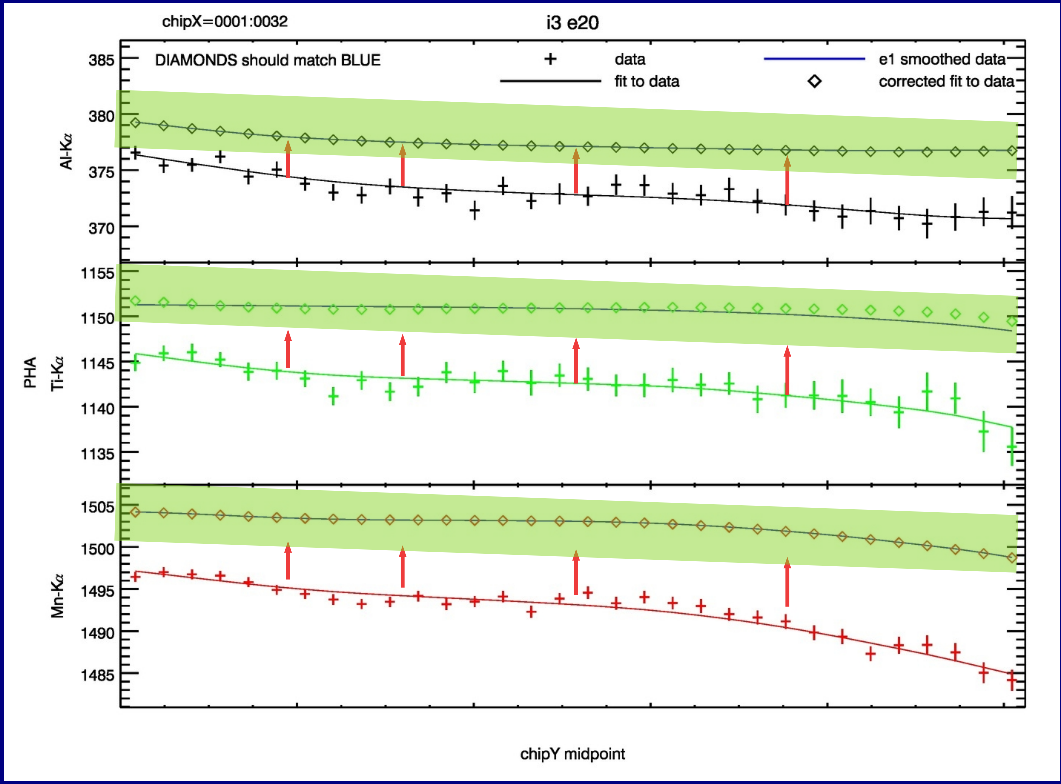


# I3 LineE Before / After TGAIN Correction

Epoch 20
I3
ChipX= 1:32

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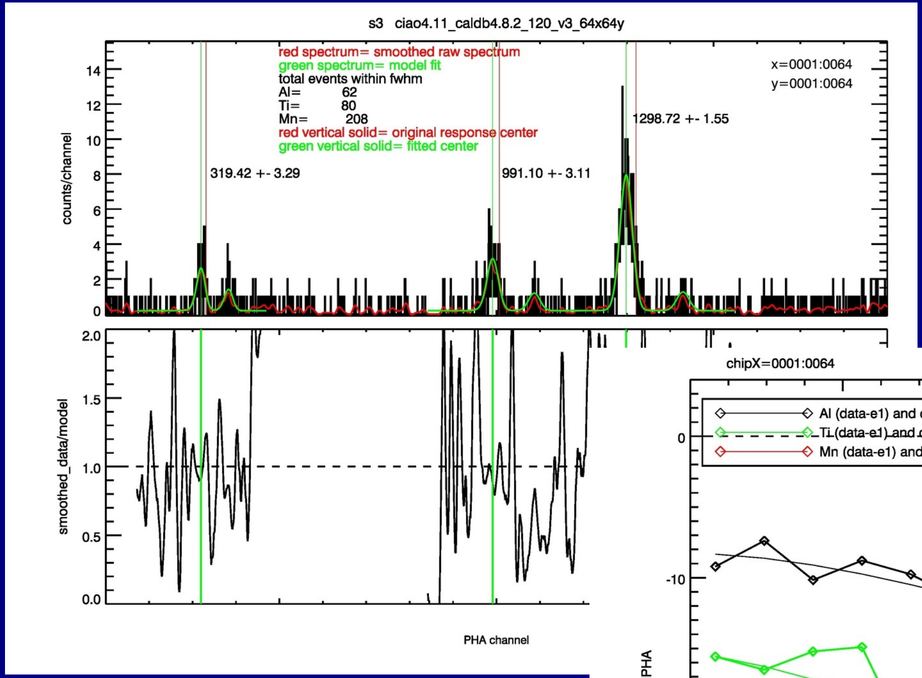
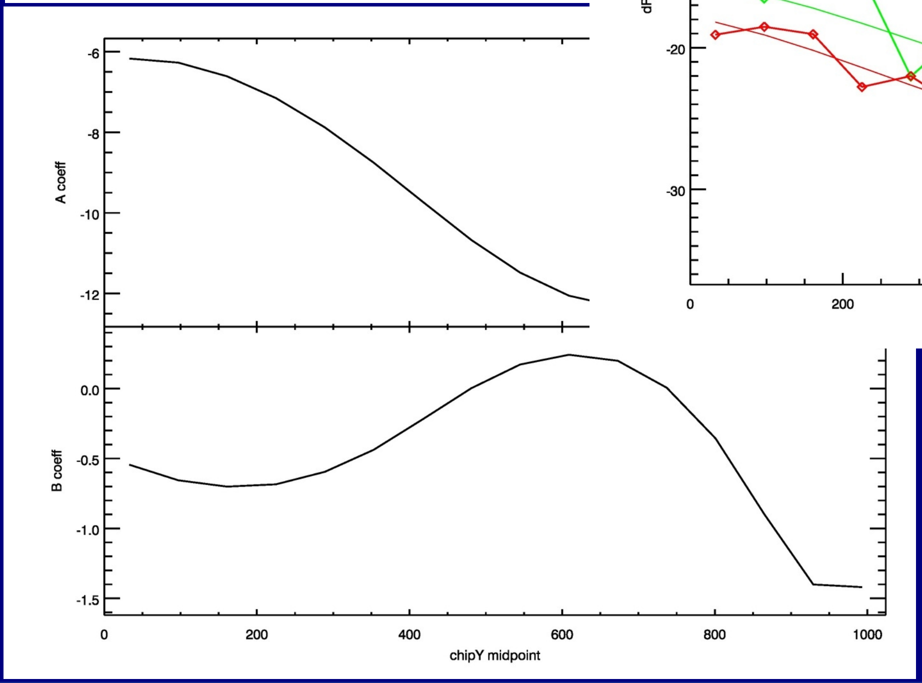
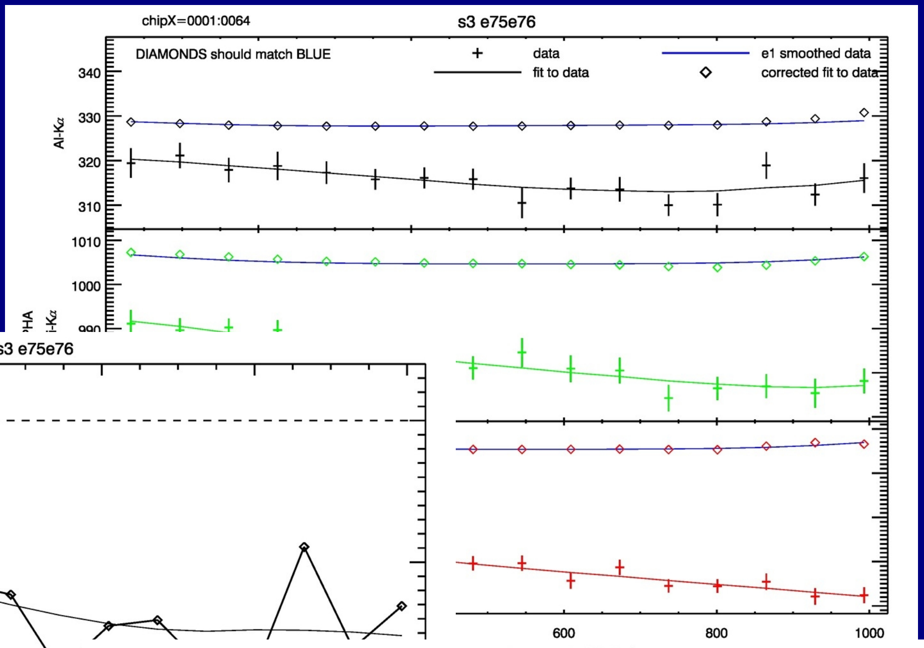
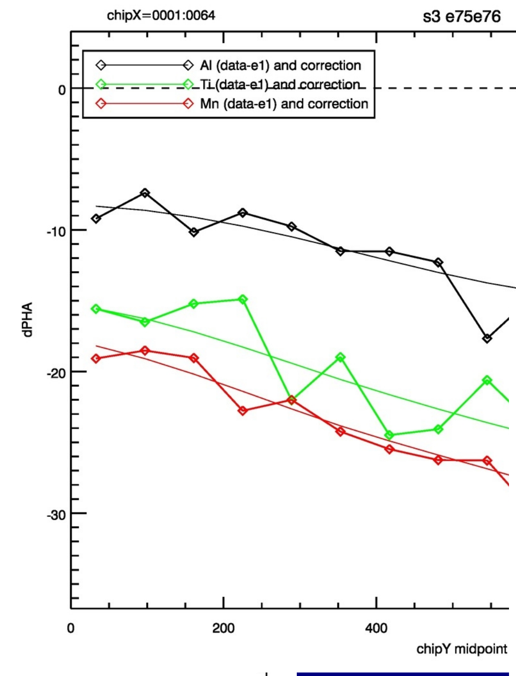
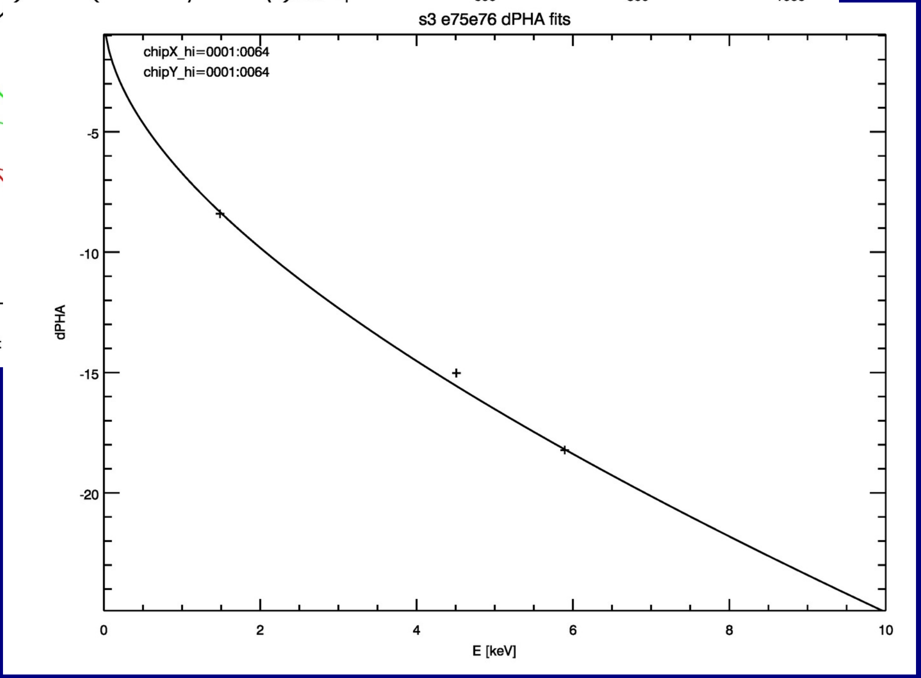
# Most Recent TGAIN Correction
# S3 x=1:64

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## *Intermission...*

# ACIS Warm Focal Plane Temperature Effects on Data Quality

## Data

Epochs 70-75
1.5 years
5/1/2017 - 10/31/2018
128x 128y pixel regions
aimpoint chips

| I3 | |
|---|---|
| **FP_TEMP** | **ksec** |
| -120 : -119 | 600 |
| -119 : -118 | 178 |
| -118 : -117 | 141 |
| -117 : -116 | 168 |
| -116 : -115 | 161 |
| -115 : -114 | 219 |
| -114 : -113 | 199 |
| -113 : -112 | 112 |
| -112 : -111 | 69 |
| -109 : -108 | 94 |

| S3 | |
|---|---|
| **FP_TEMP** | **ksec** |
| -120 : -119 | 842 |
| -119 : -118 | 265 |
| -118 : -117 | 223 |
| -117 : -116 | 243 |
| -116 : -115 | 244 |
| -115 : -114 | 291 |
| -114 : -113 | 267 |
| -113 : -112 | 172 |
| -112 : -111 | 103 |
| -109 : -108 | 94 |

# ECS Model

PHYSICAL REVIEW A VOLUME 56, NUMBER 6 DECEMBER 1997

**$K\alpha_{1,2}$ and $K\beta_{1,3}$ x-ray emission lines of the 3$d$ transition metals**

G. Hölzer,[1] M. Fritsch,[1,2] M. Deutsch,[2] J. Härtwig,[3] and E. Förster[1]
[1]*X-ray Optics Group, Institute of Optics and Quantum Electronics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, D-07743 Jena, Germany*
[2]*Physics Department, Bar-Ilan University, Ramat-Gan 52900, Israel*
[3]*European Synchrotron Radiation Facility, Boîte Postale 220, F-38043 Grenoble, France*
(Received 14 May 1997)

PI Channel Space, DETGAIN & TGAIN Corrected

Al fit window= 0.9-2.1 keV
Ti & Mn fit window= 3.3-7.2 keV

$$Gauss(E) = K \frac{1}{\sigma\sqrt{2\pi}} \exp\frac{-(E-E_0)^2}{2\sigma^2}$$

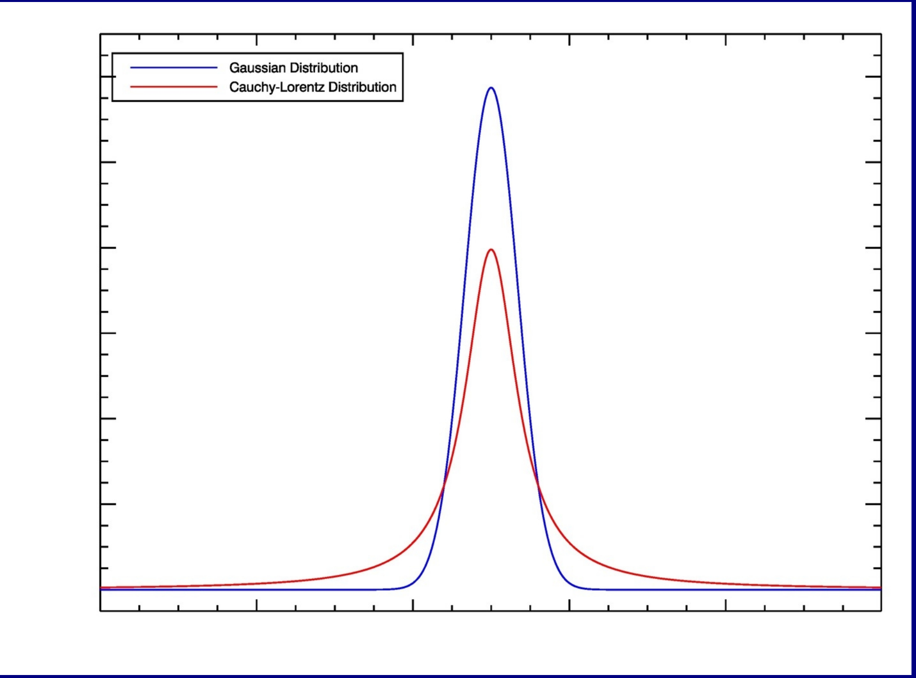
$$Lorentz(E) = K \frac{\Gamma}{2\pi} \cdot \frac{1}{(E-E_0)^2 + \left(\frac{\Gamma}{2}\right)^2}$$

ECS LINES

| | | |
|---|---|---|
| Al-Ka | lorentzian | FREE: norm, width=initial scaled to chipY, LineE |
| Al-Kb | lorentzian | norm=tied*Al-Ka, width=Al-Ka, LineE=tied*Al-Ka |
| Ti-Ka1 | lorentzian | FREE: norm, width=initial scaled to chipY, LineE |
| Ti-Ka2 | lorentzian | norm=tied*Ti-Ka1, width=Ti-Ka1, LineE=tied*Ti-Ka1 |
| Ti-Kb | lorentzian | norm=FREE, width=Ti-Ka1, LineE=FREE |
| Mn-Ka | lorentzians | FREE: norm, width=initial scaled to chipY, LineE |
| | +6 additional lorentzians | norm=tied, width=lorentz_0, LineE=tied |
| Mn-Kb | lorentzian | norm=FREE, width=Mn-Ka, LineE=FREE |
| | +4 additional lorentzians | norm=tied, width=lorentz_0, LineE=tied |

INSTRUMENTAL

| | | |
|---|---|---|
| Si-Ka | gaussian | fixed & chipY scaled for I-array |
| Au-Ma1 | gaussian | fixed & chipY scaled |
| Au-Ma2 | gaussian | tied to Au-Ma1 |
| Au-Mb | gaussian | tied to Au-Ma1 |
| Au-Mg | gaussian | tied to Au-Ma1 |
| Ni-Ka | gaussian | fixed |
| Au-La | gaussian | fixed |
| framestore Au-M | gaussian | fixed & chipY scaled |
| framestore Ni-Ka | gaussian | fixed |

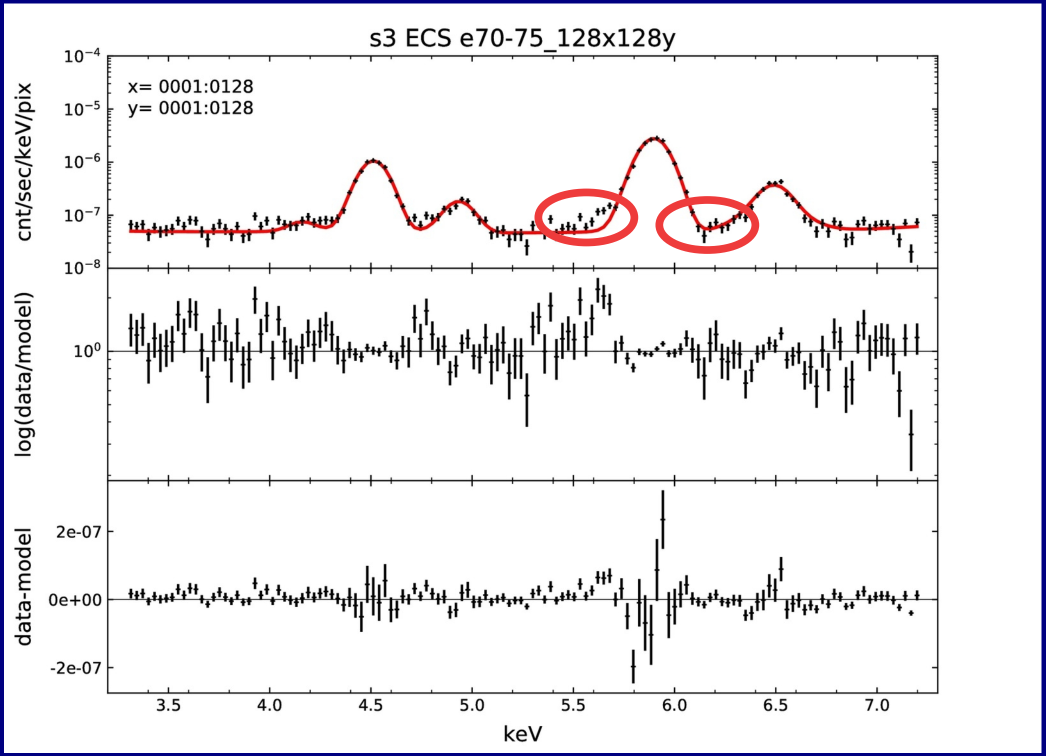



BACKGROUND Continuum, empirical model for 0.85-7.2 keV for I-array

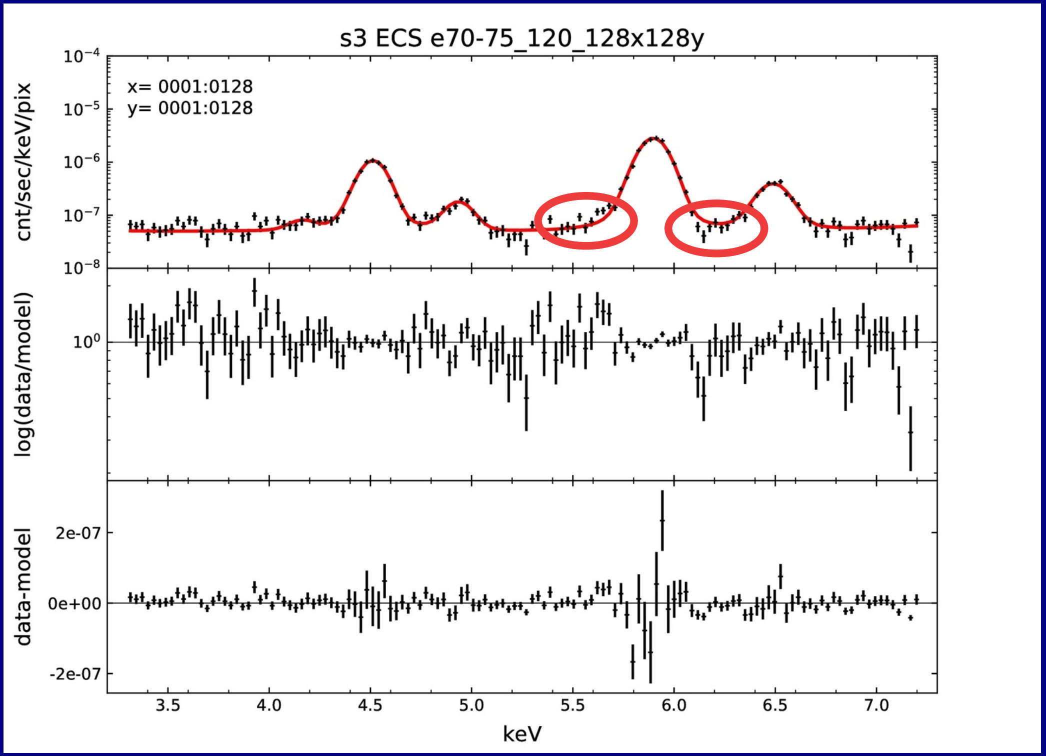
| | |
|---|---|
| powlaw | low energy component, PhoIndex>0 |
| powlaw | high energy component, PhoIndex<0 |
| gaussian | 0.85>E>1.0 low energy addition |

# *Lorentz vs Gauss*
# *S3 Ti & Mn*

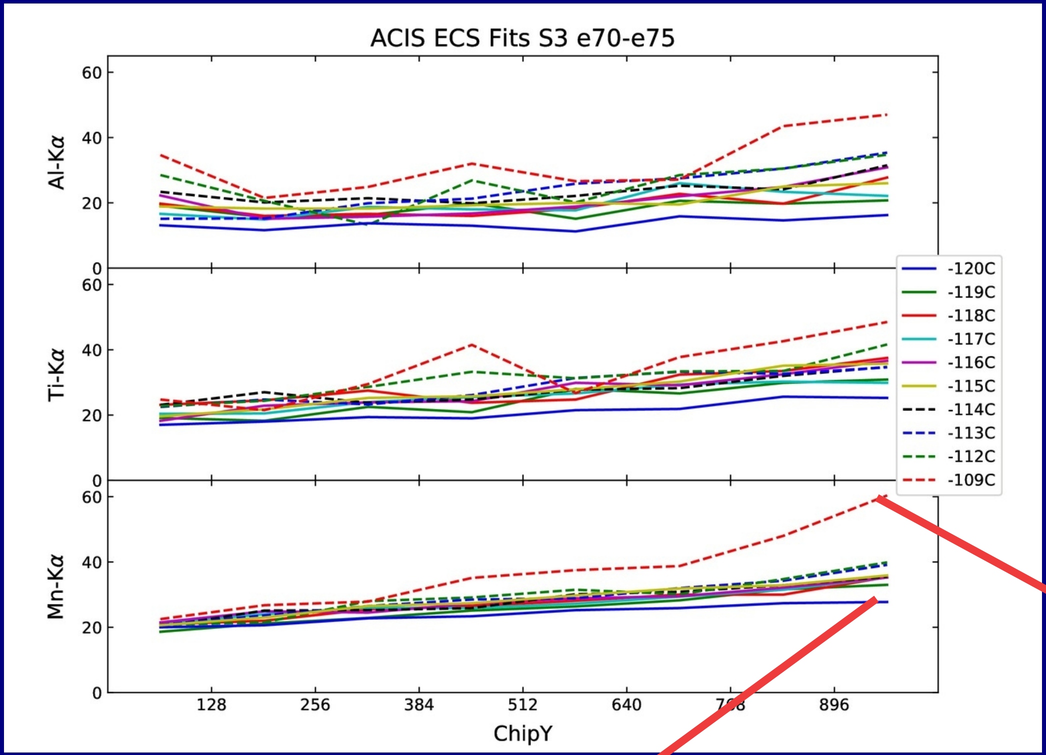
GAUSS



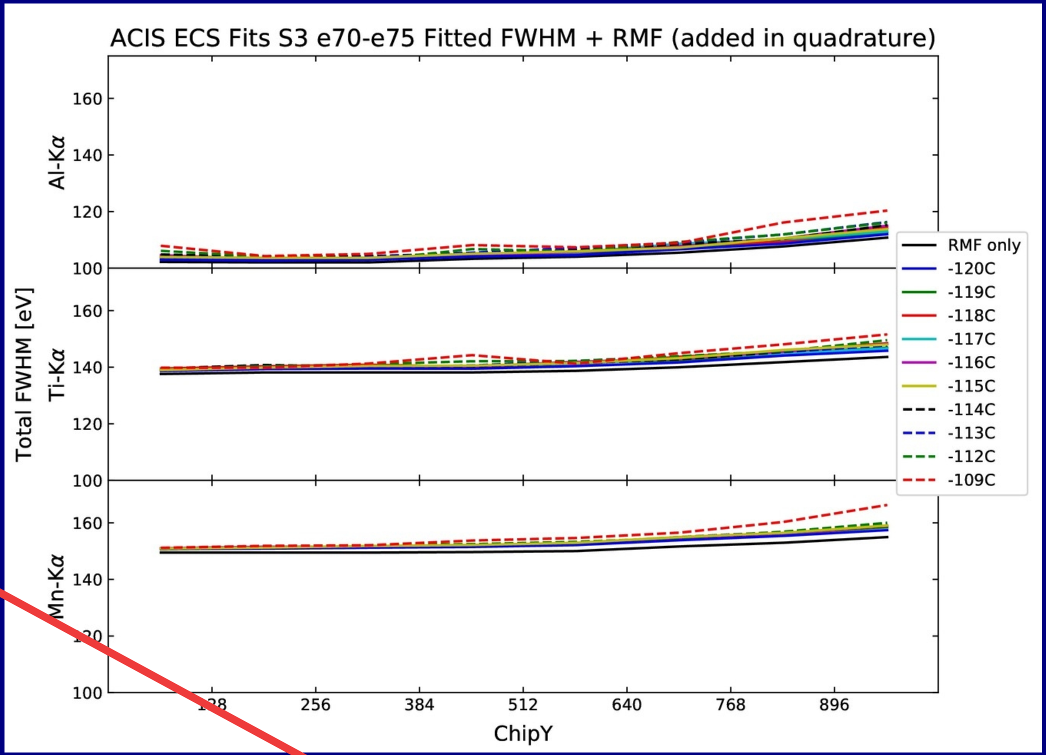

LORENTZ



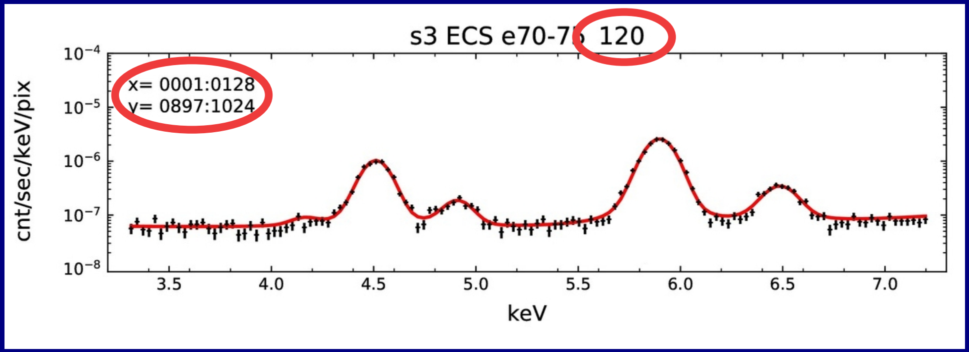
# *FWHM*
# *ACIS-S3*



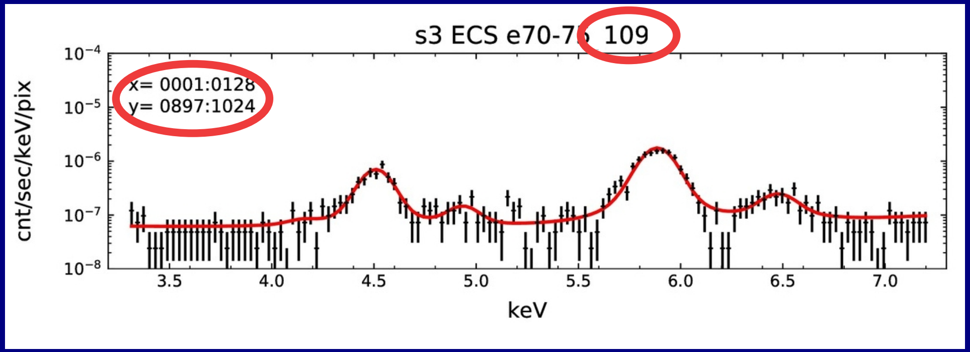
ACIS ECS Fits S3 e70-e75
Al-Kα
Ti-Kα
Mn-Kα
0
20
40
60
128
256
384
512
640
768
896
ChipY
-120C
-119C
-118C
-117C
-116C
-115C
-114C
-113C
-112C
-109C

ACIS ECS Fits S3 e70-e75 Fitted FWHM + RMF (added in quadrature)
Total FWHM [eV]
Al-Kα
Ti-Kα
Mn-Kα
100
120
140
160
128
256
384
512
640
768
896
ChipY
RMF only
-120C
-119C
-118C
-117C
-116C
-115C
-114C
-113C
-112C
-109C

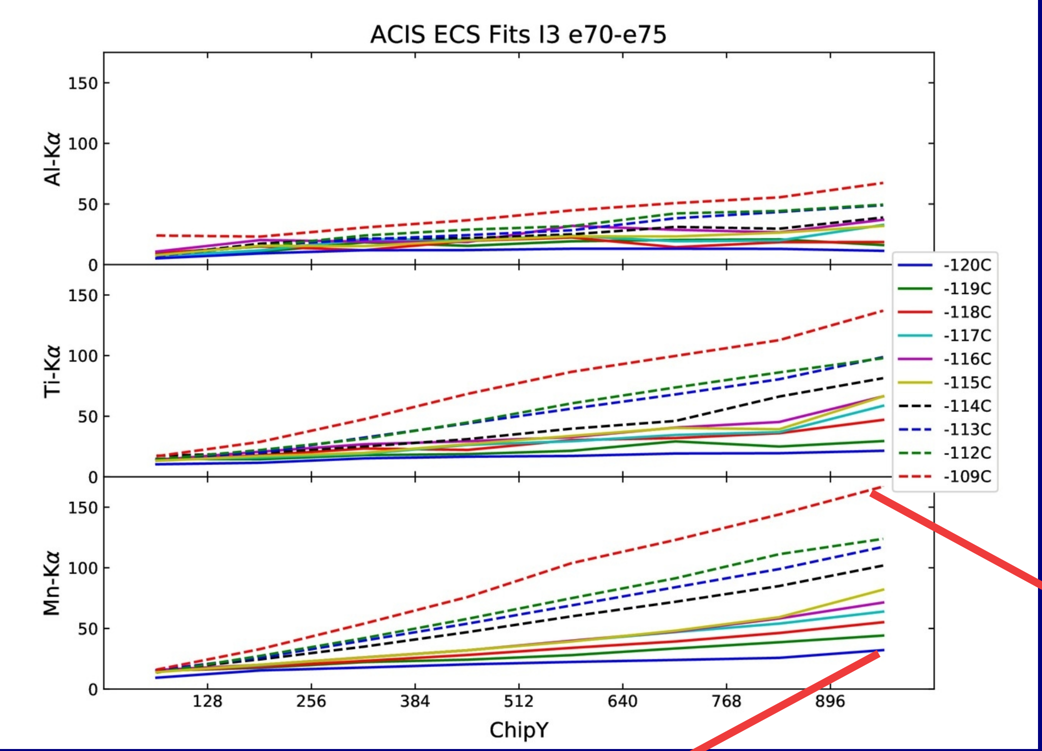



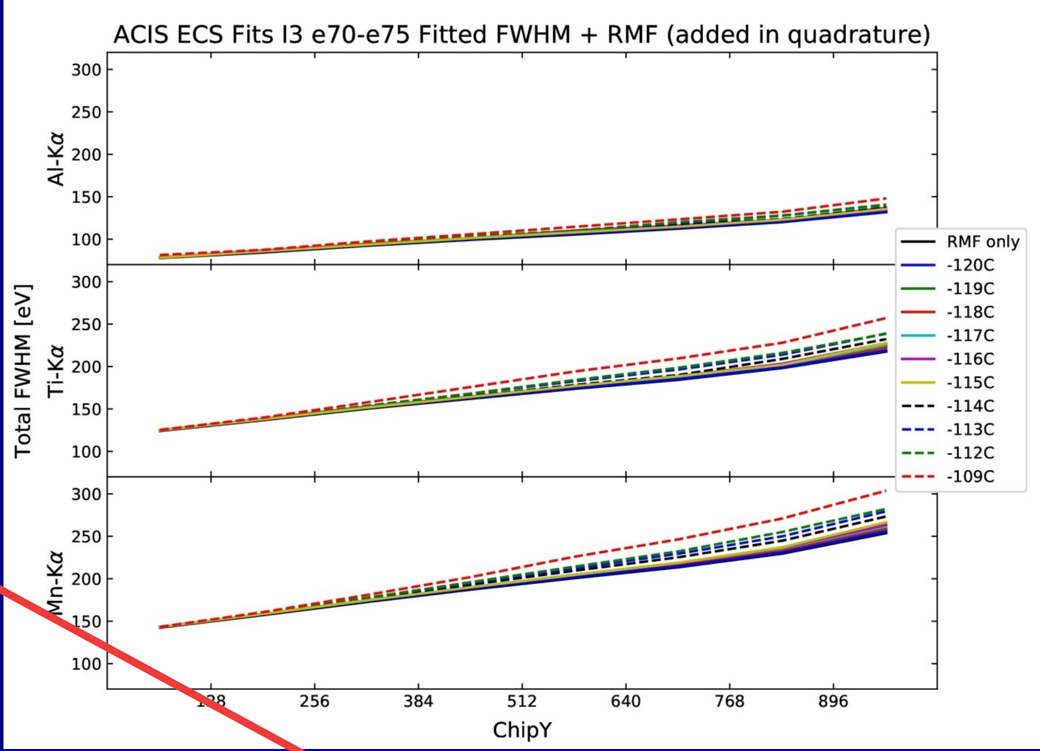
s3 ECS e70-75 120
x= 0001:0128
y= 0897:1024
cnt/sec/keV/pix
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
keV

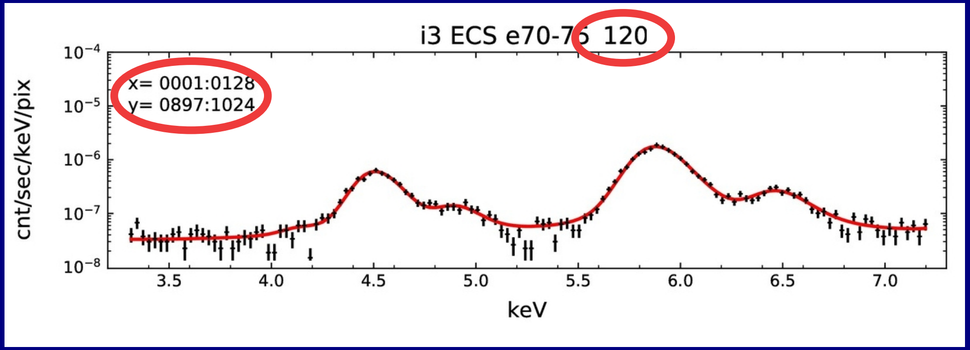



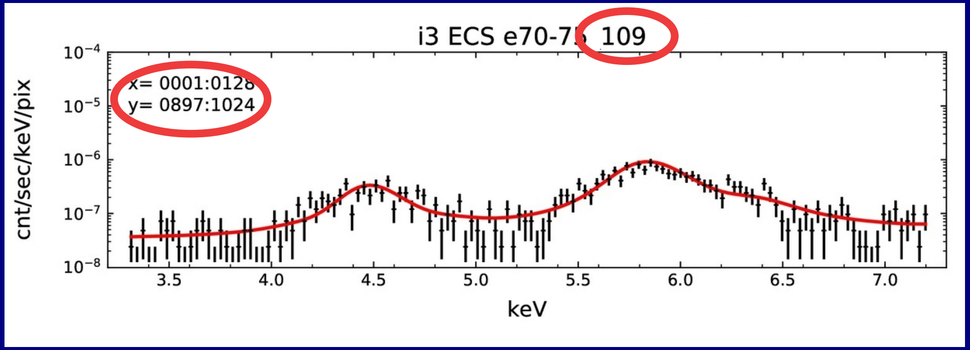
s3 ECS e70-75 109
x= 0001:0128
y= 0897:1024
cnt/sec/keV/pix
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
keV

# FWHM
# ACIS-I3


ACIS ECS Fits I3 e70-e75
Al-Kα
Ti-Kα
Mn-Kα
ChipY
-120C
-119C
-118C
-117C
-116C
-115C
-114C
-113C
-112C
-109C


ACIS ECS Fits I3 e70-e75 Fitted FWHM + RMF (added in quadrature)
Total FWHM [eV]
Al-Kα
Ti-Kα
Mn-Kα
ChipY
RMF only
-120C
-119C
-118C
-117C
-116C
-115C
-114C
-113C
-112C
-109C


i3 ECS e70-75 120
x= 0001:0128
y= 0897:1024
cnt/sec/keV/pix
keV


i3 ECS e70-75 109
x= 0001:0128
y= 0897:1024
cnt/sec/keV/pix
keV