Temperature-Dependent ACIS Response

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ACIS and CTI

Chandra ACIS CCD response width: Radiation damage very early in the mission

- BI CCDs (S3, S1): little or no apparent change
- FI CCDs (I0 .. I3, S0, S2, S4, S5):
  - imaging area: greatly increased CTI
  - frame store: protected by a cover (Al, Au)
- response width broadening $\propto$ distance from readout
  - chipy-dependence
  - broadening $\propto$ CTI
- increased focal plane $T_{FP} \longrightarrow$ increased CTI
- response width increase $\propto$ overall T_{FP}-dependent CTI increase

CALDB detgain and p2_resp Structure

CALDB:

- detgain: PHA(chipx,chipy,EGrid,[CCD_ID])
  - fixed grid of 30 energies: 0.1 .. 12.0 keV ($\sim$ log-spacing)
- p2_resp: detector response width vs PHA
  - RMF generation factored into:
    - ideal (undamaged) CCD response
    - CTI broadening: convolve ideal with “scatter matrix”
  - five HDUs
    - 1 (FI) & 2 (BI) ideal response
    - 3 (FI) & 4 (BI) scatter matrices [CTI broadening]
    - 5 “gain tweaks”
  - Scatter Matrix
    - scatmtx(chipx,chipy,PHAGrid) (per CCD_ID);
      40 .. 3100 ADU ($\sim$ log-spacing);
      fixed grid of PHAs: 16 (FI), 20 (BI)

Merge ECS data; split into Temperature Bins

- Merge External Calibration Source (ECS) data;
- Fit to merged epochs 40 to 91
- split into Focal Plane Temperature (T_{FP}) bins (C):
  - -109.19 C to -107.19 C [2 deg C]
  - -111.19 C to -109.19 C [2 deg C]
  - -113.19 C to -111.19 C [2 deg C]
  - -115.19 C to -113.19 C [2 deg C]
  - -117.19 C to -115.19 C [2 deg C]
  - -119.19 C to -117.19 C [2 deg C]
  - -120.19 C to -119.19 C [1 deg C] [cold] [current CALDB]
- Later: examine smaller ECS epoch ranges
  - check for any time variation
  - not feasible for all T_{FP} bands

Extract & Fit Spectra on “Tiles”: [Δ chipx, Δ chipy]

- Extract spectra from ECS data on “tiles” (chipx,chipy)
  - I0..I3, S2: Δ`chipx`=64, Δ`chipy`=64
    fit lines: [ECS:] Al-Kα, Ti-Kα, β, Mn-Kα, β, [BGD:] Au-L_{a1}
- Fitting: use RMF with no CTI broadening
- line profile (Xspec local model `2kfz`):

$$\left(1 + x^2\right)^{-\alpha}, \quad \alpha = \alpha_1 \; [x < 0], \quad \alpha = \alpha_2 \; [x > 0]$$

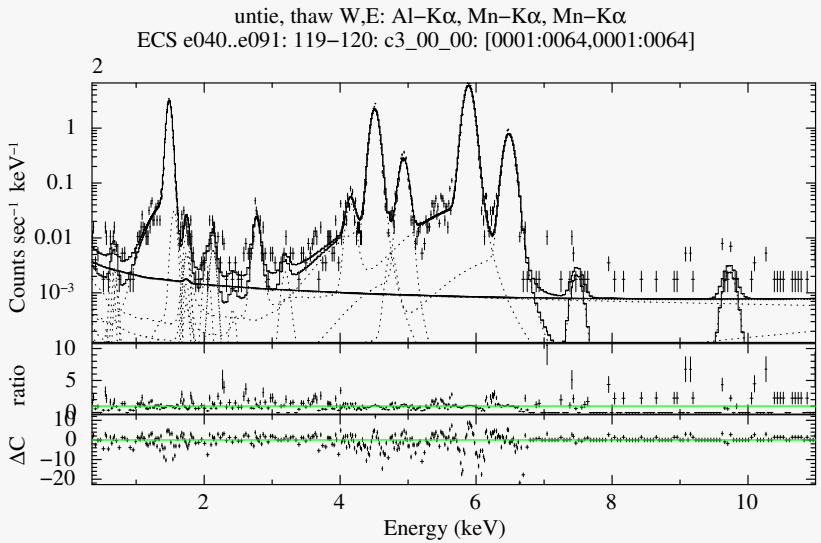
  - $x = (E - E_0)/\Delta$
  - $2\Delta \sim \mathrm{FWHM}$
  - $\Delta \Rightarrow$ `LI_WIDTH` in FI scatter matrix
  - header keywords: $\alpha_1 \Rightarrow$ `L1ALPH1` = 3.7; $\alpha_2 \Rightarrow$ `L1ALPH2` = 1.9

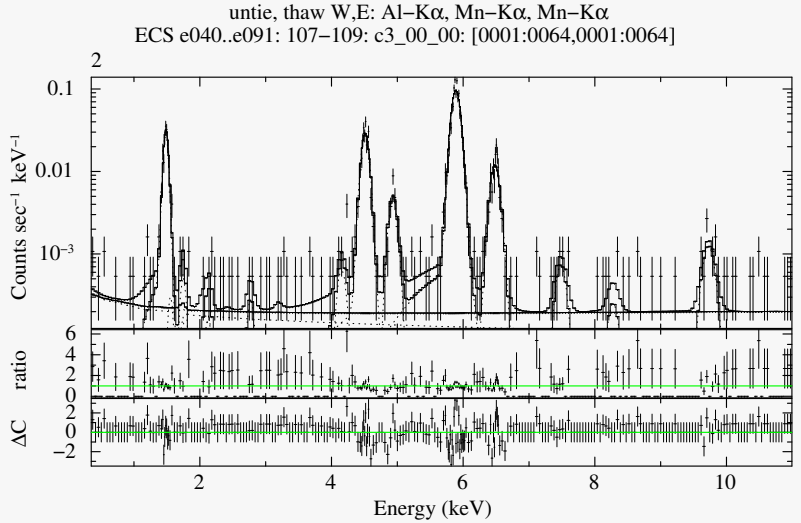
ECS Line Fits

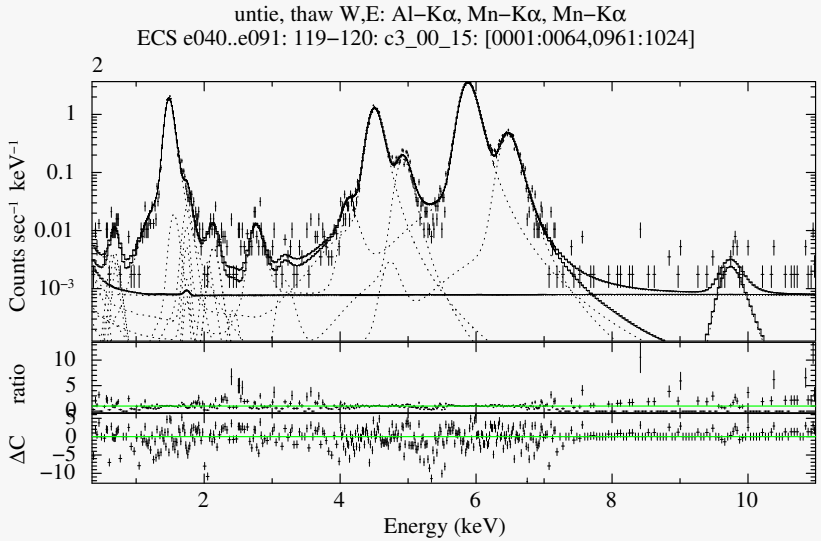
- These fits:
  - Width Scaling with Energy: width $\propto E^{0.12} + 0.3E \sim E^{0.44}$
  - only Al-Kα width allowed to vary
  - Ti-Kα, Mn-Kα, Au-L$_{a,1}$ scaled to Al-Kα width
  - Ti-Kβ scaled and tied to Ti-Kα width
  - Mn-Kβ scaled and tied to Mn-Kα width
  - BG line Au-L$_{a,1}$: weak
  - may be ok at lower T_{FP}

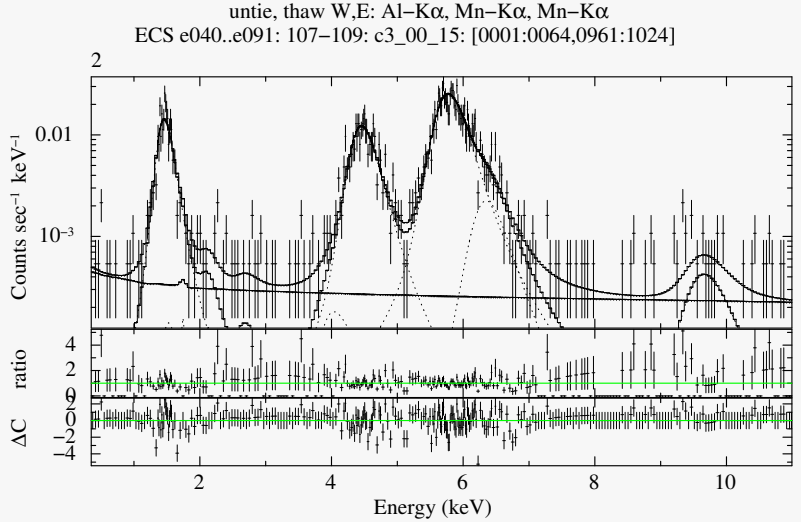
Merged Epochs 40 to 91 ($\sim$ 2010 to $\sim$ 2022)

Low vs high chipy: Left: -120 to -119C, Right: -109 to -107C









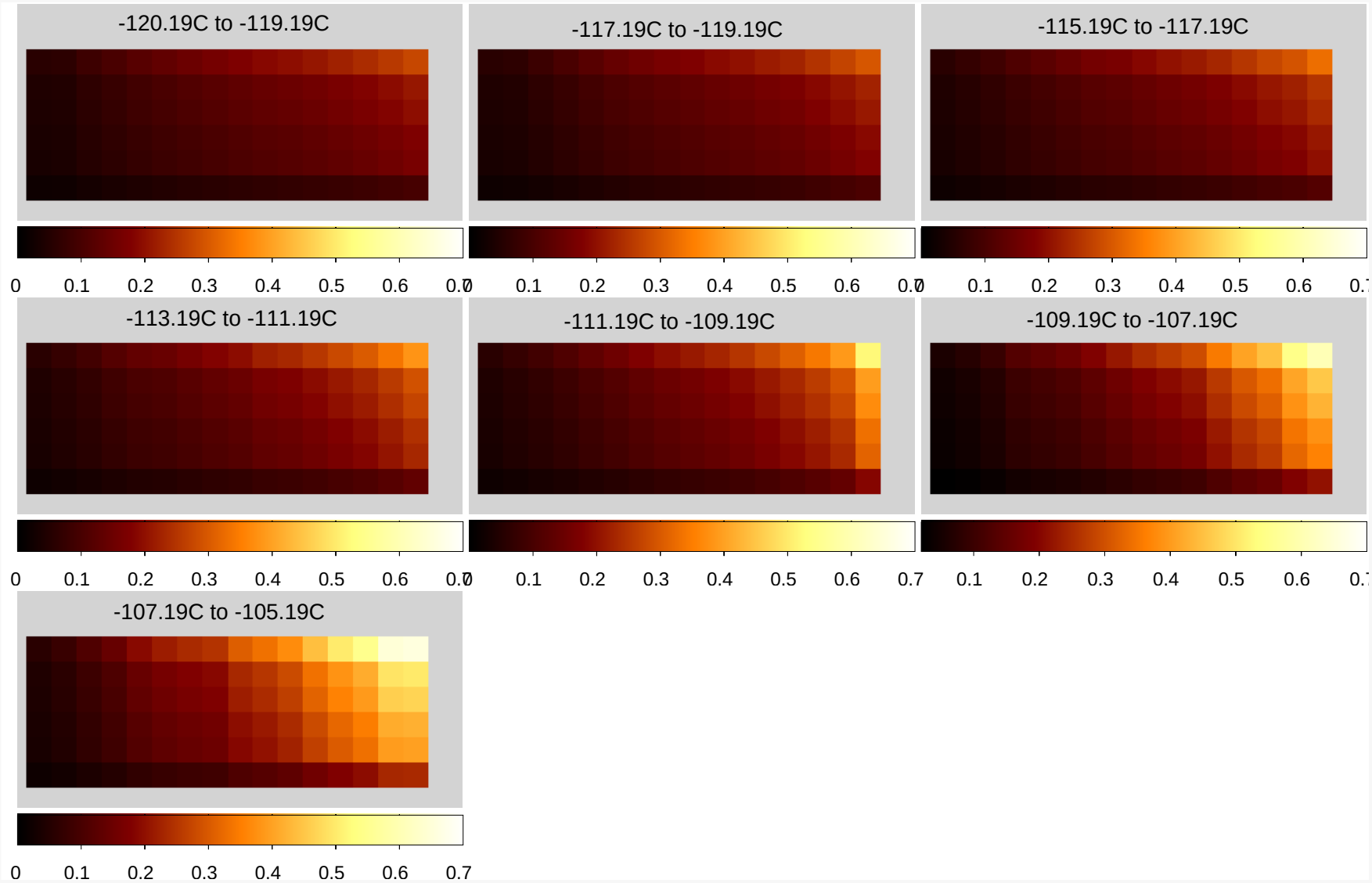
Approach

For each ccd and focal plane temperature bin:

- Use detgain to interpolate p2_resp:
  - fixed PHAGrid $\Rightarrow$ to fixed detgain EGrid:
  - $[32 \times 32 \times 16] \Rightarrow [32 \times 32 \times 30]$
- Interpolate p2_resp to ECSGrid (6 line energies)
  - l1_width[chipx,chipy,EGrid] $\Rightarrow$ l1_width[chipx,chipy,ECSGrid]
  - $[32 \times 32 \times 30] \Rightarrow [32 \times 32 \times 6]$
- scale l1_width[chipx,chipy,ECSrid] ($[32 \times 32 \times 6]$
  Currently: overall scale and linear in chipy:
  - $a_0(1 + a_1 chipy)$
  - may need to add quadratic: $a_0 + a_1 chipy + a_2(chipy - chipy_0)^2$
- Least Absolute Difference estimate of ECS line widths vs.CALDB line widths.

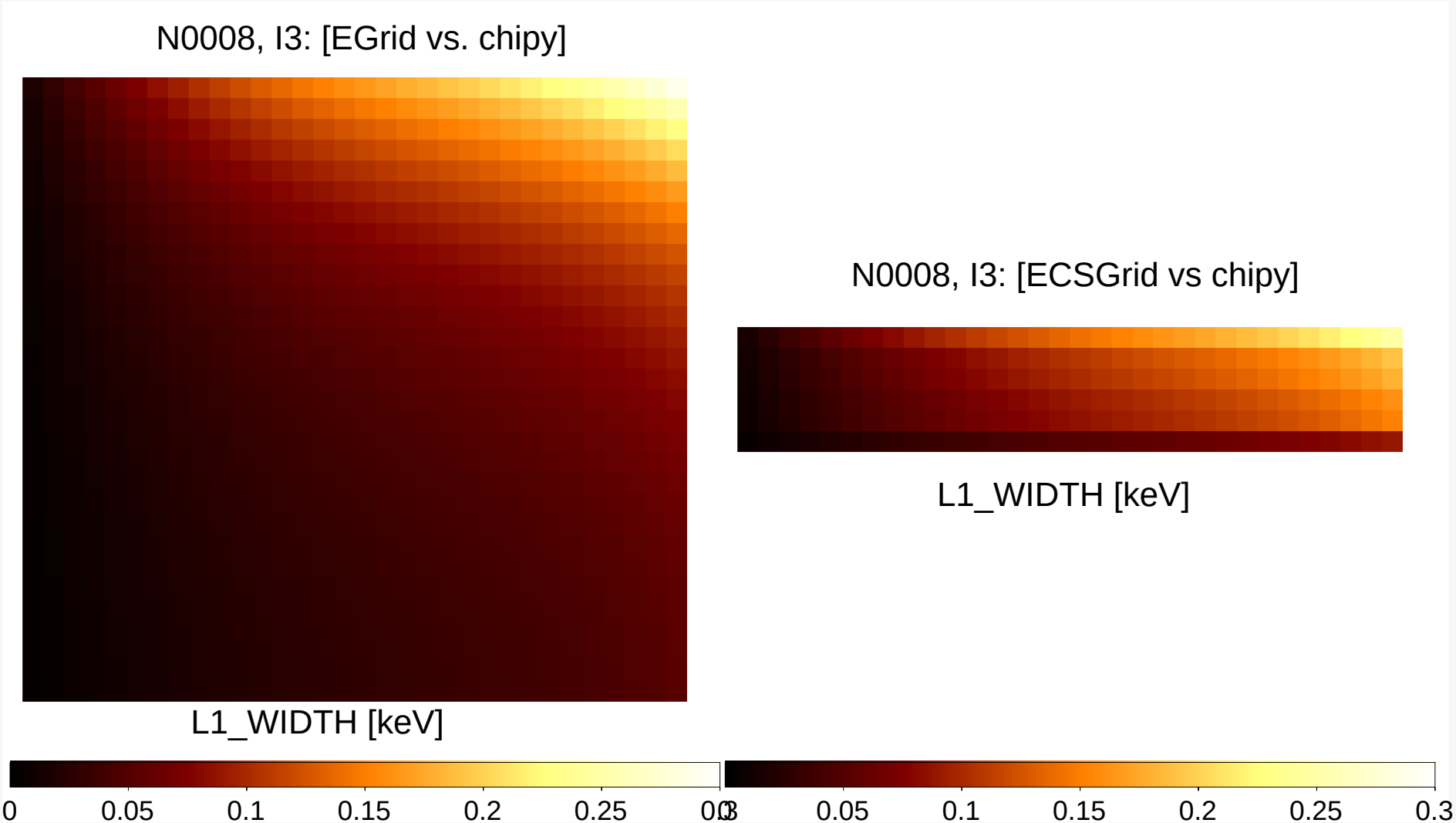
ECS line fits vs. *T_FP*; tiles 64 × 64 (chipx,chipy)

Fits to I3 ECS line widths; each panel: T_{FP} up, CHIPY right

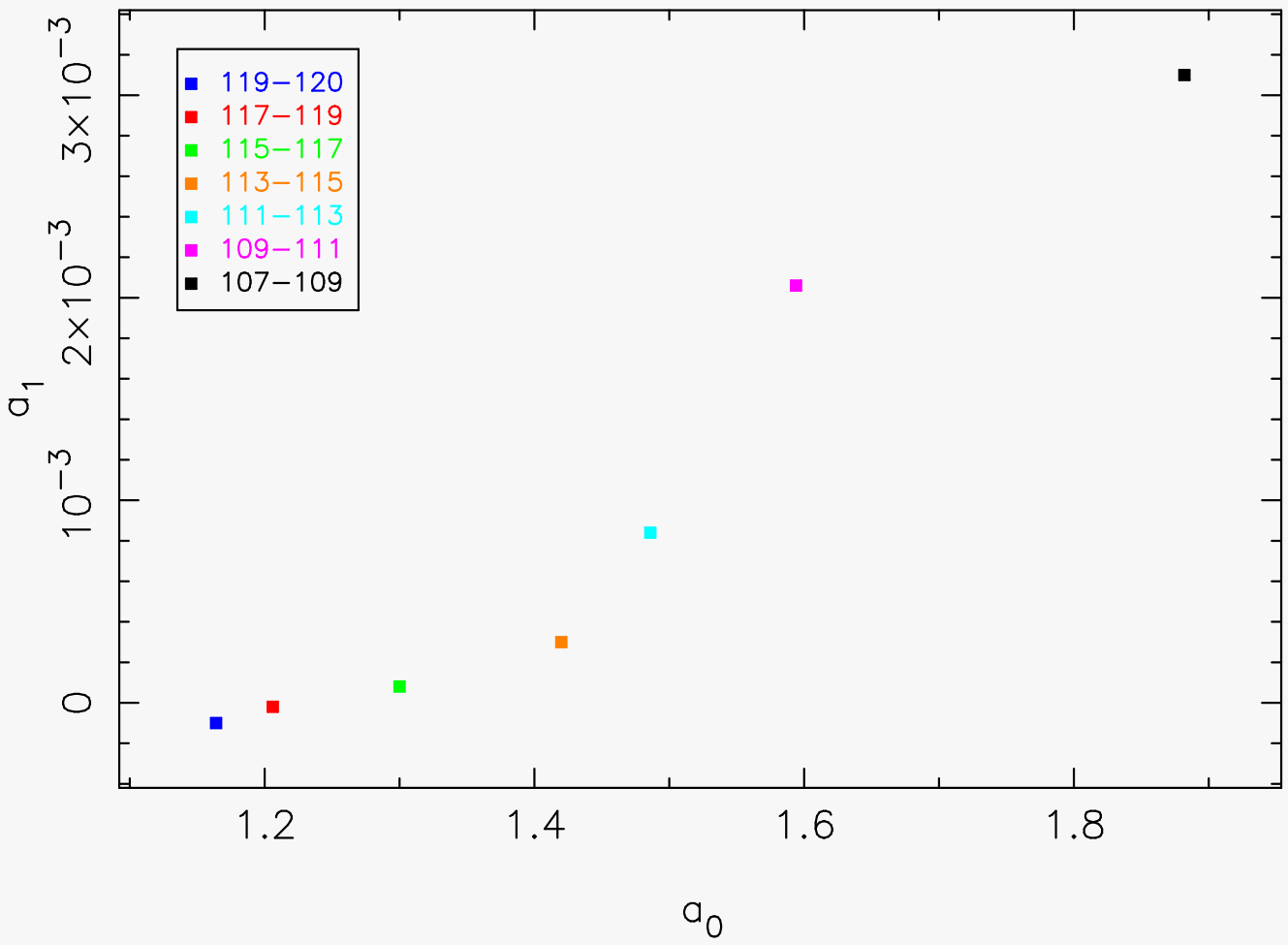


CALDB p2_resp: L1_WIDTH: energy vs chipy

Left: mapped PHAGrid to EGrid. Right: ECSGrid (ECS/BG line energies)

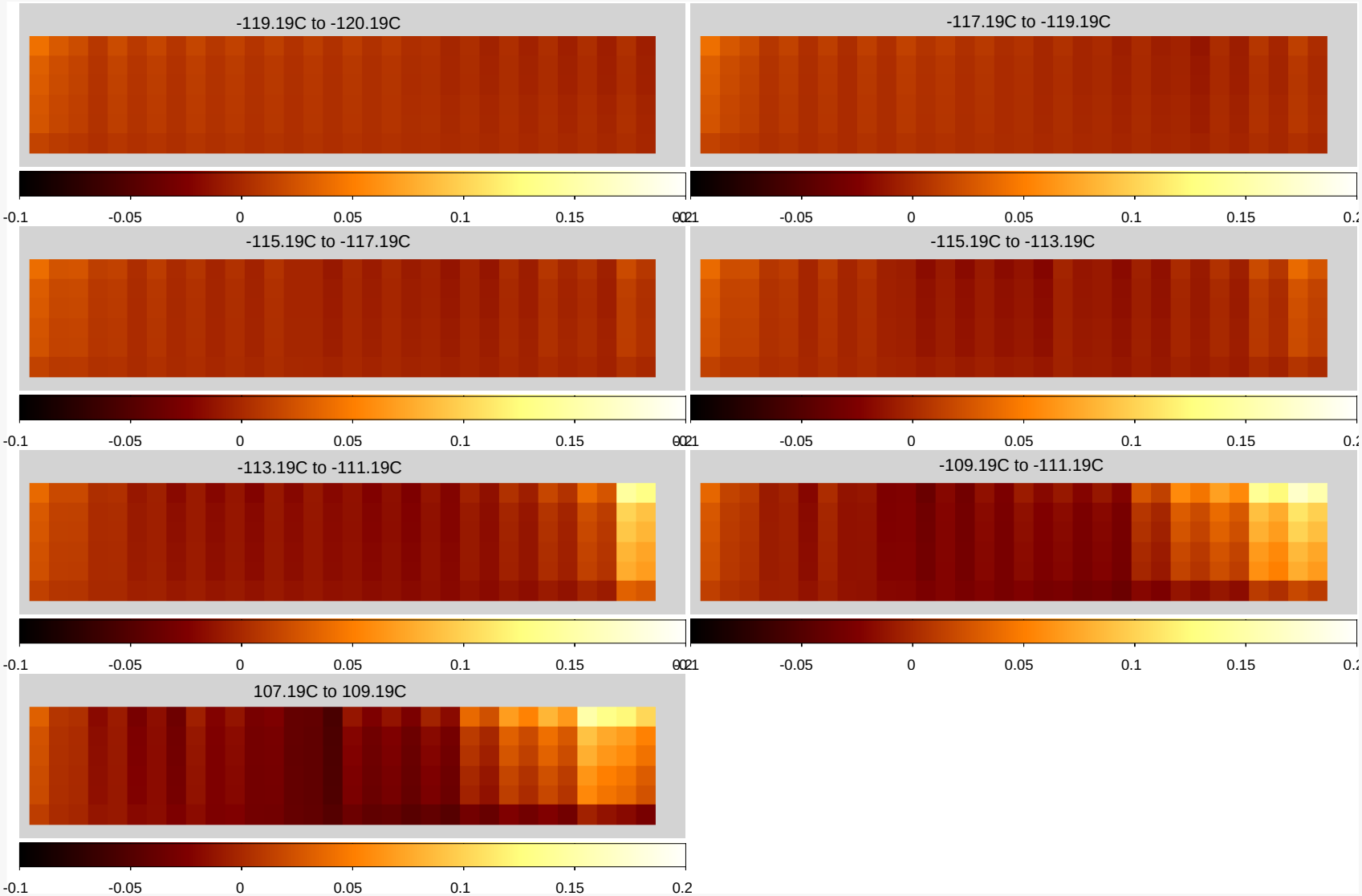


LAD Fit parameters (preliminary



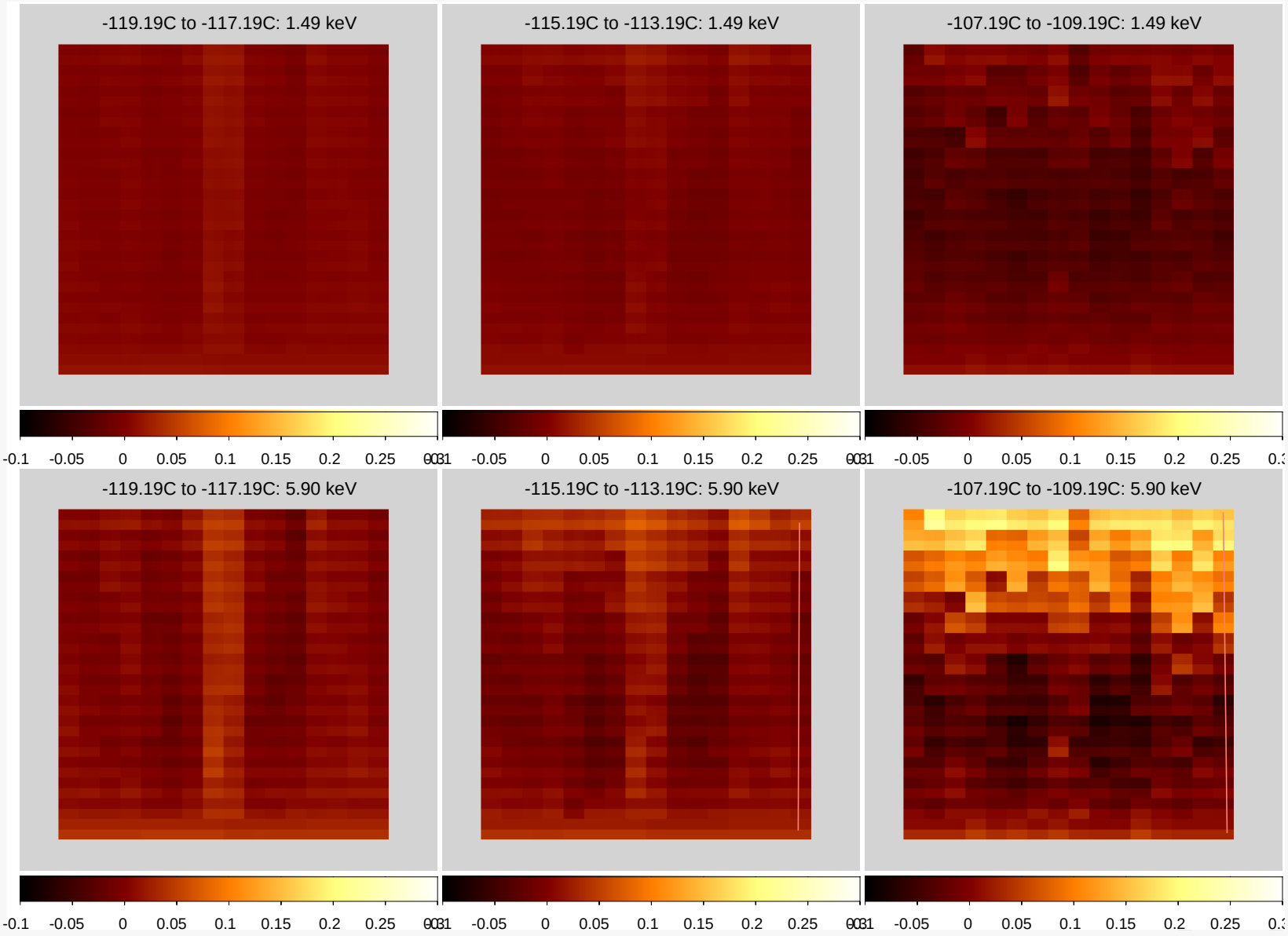
diffs: ECS linewidth - scaled CALDB linewidth

E_{ECS} vs chipy



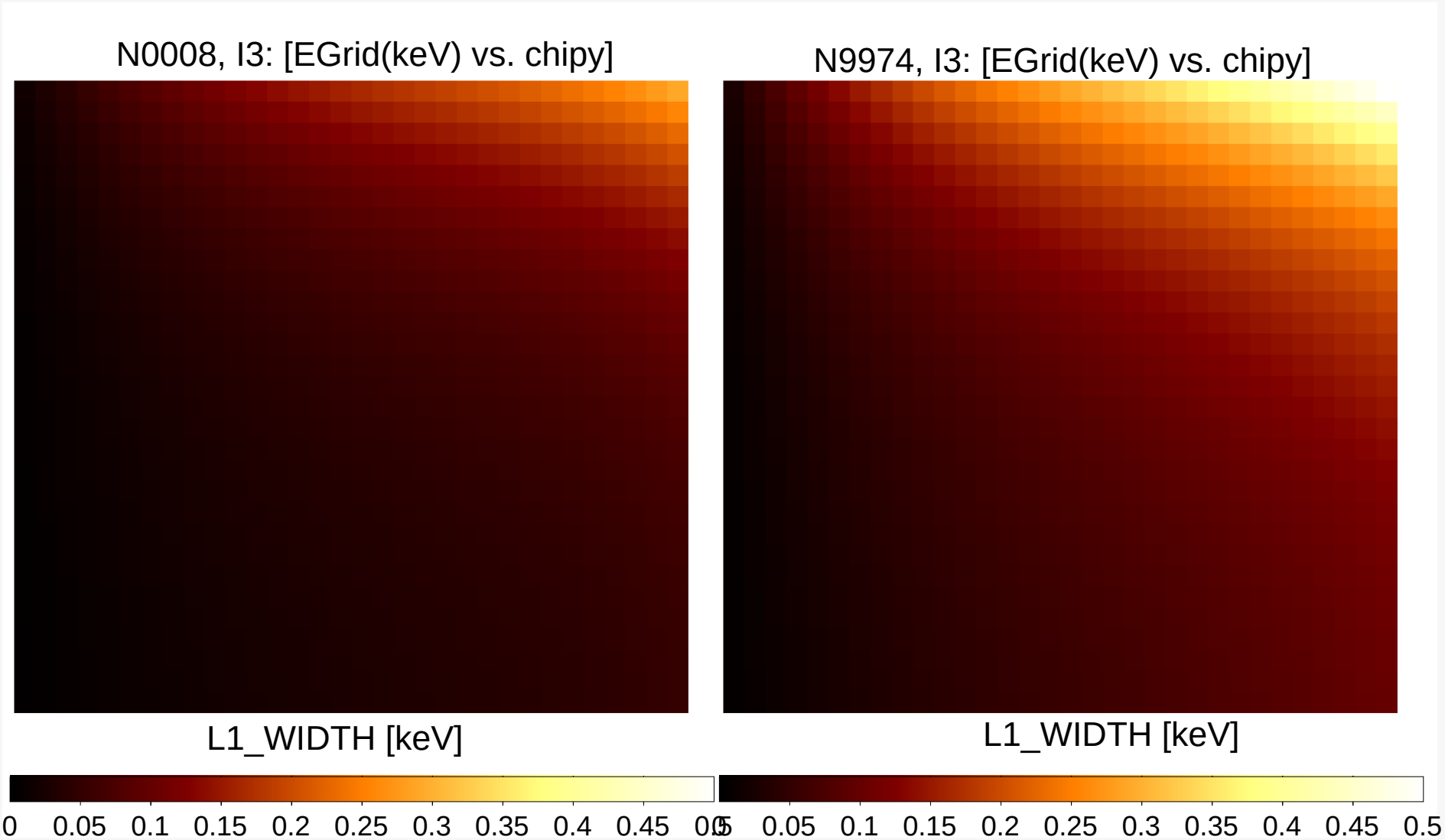
Spatial structure: chipy vs chipx; LAD differences

Top: 1.49keV; Bottom: 5.90keV



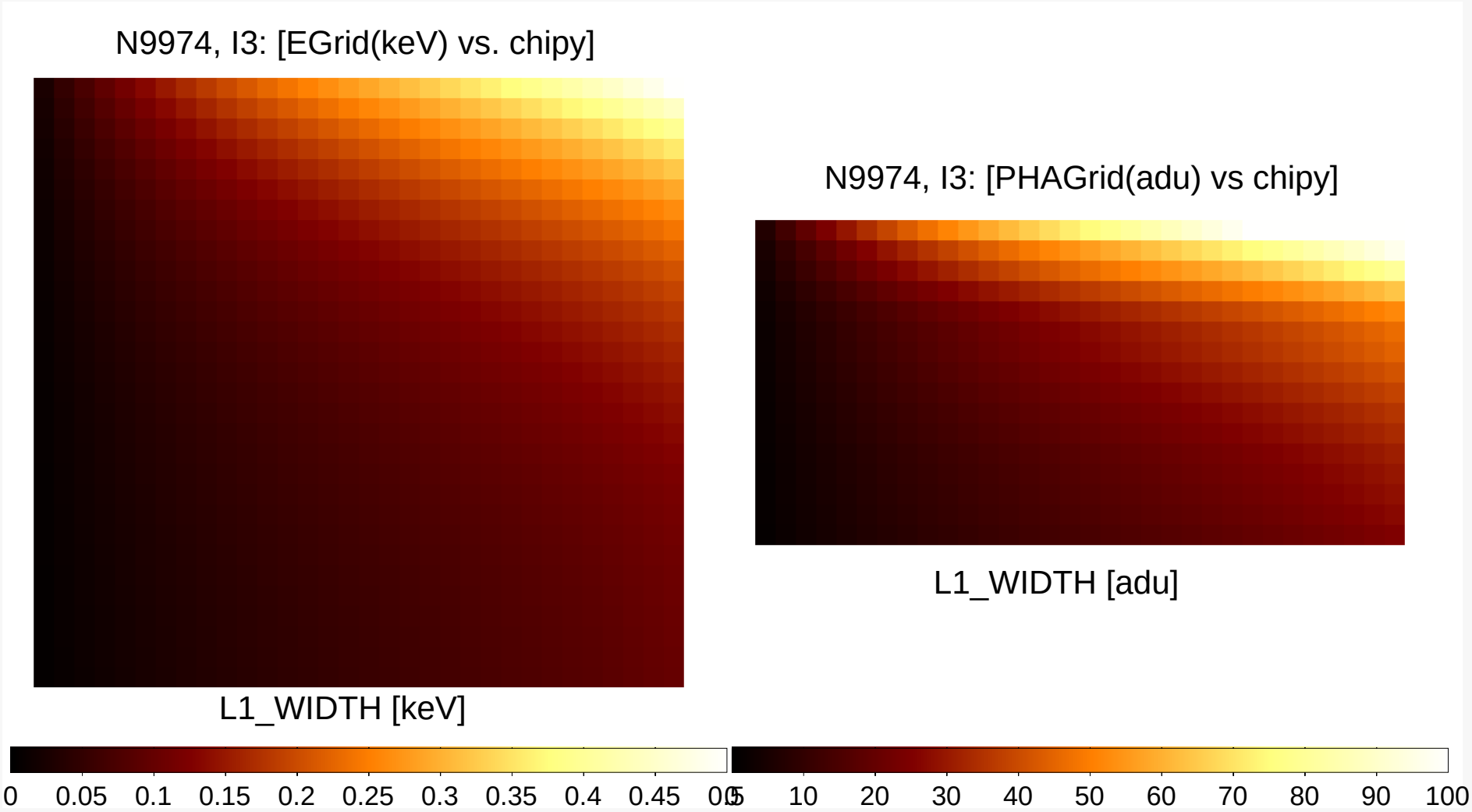
Apply Scale Parameters to l1_width[chipx,chipy,EGrid]

Left: L1_WIDTH (N0008); Right: L1_WIDTH (N9974) ($a_0 = 1.744$, a_1 =6e-5i)



Map EGrid to PHAGrid [32,32,30] $\Rightarrow$ [32,32,16]

Left: L1_WIDTH (N0008); Right: L1_WIDTH (N9974)



Summary

- fit ECS data:
  - 6 energies, tiles 64 $\times$ 64 (chipx, chipy)
  - interpolate to 32 $\times$ 32 tiles
- map CALDB I1_width data to [32,32,6] grid (ECSgrid: 6 lines)
- scale I1_width data: $a_0(1 + a_1 chipy)$, subtract (LAD minimization)
- linear scaling works pretty well, but ...
- Plan:
  - adjust scaling matrix for residual chipx structure
  - adjust scaling matrix for residual chipy quadratic structure
  - high T_{FP}: may need additional energy scaling
- Testing plan:
  - generate 32x32 scaling matrix; apply to full CALDB I1_width data;
  - convert back to I1_width[32,32,EGrid]; inject into p2_resp
  - refit ECS data with gaussian lines, allow line width to vary
  - check gaussian line width
  - iterate?