Summary of the Recent Update to the *Chandra* HRMA Calibration

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Calibration Review 2009

Overview

- A_{eff} updated to version N0008;
  2009-01-21; part of CALDB 4.1.1
- overview: calibration approach
- previous model (N0007)
- cross-calibration (and *internal*!) discrepancies
  $\Rightarrow$ prompted reevaluation of A_{eff}
- evidence leading to model N0008
- testing the new model

Introduction

Impractical to calibrate vs E, $(\theta, \phi), \ldots$ directly:
Sparse datasets (energies, off-axis angles, aperture sizes)

- The *Chandra* mirror A_{eff} is a semi-analytic model:
- Physics-based where possible
- Raytrace + Ground Calibration Data

Introduction

Impractical to calibrate vs E, $(\theta, \phi), \ldots$ directly:
Sparse datasets (energies, off-axis angles, aperture sizes)

- based on detailed raytrace model
  - figure, geometry, misalignments
  - surface properties: shape (deformations) and microroughness (scattering)
  - measured reflectivity properties (Ir optical constants)
  - as-measured as-built where possible
  - raytrace model (and calibration) is per-shell
    add up four shells to get full HRMA

Introduction

Impractical to calibrate vs E, $(\theta, \phi), \ldots$ directly:
Sparse datasets (energies, off-axis angles, aperture sizes)

- Ground Calibration Data
  - sparse datasets (energies, off-axis angles, pinhole sizes)
  - not enough to fully constrain A_{eff}
  - used to verify raytrace models.
- Ground calibrations measured A_{eff} with two detectors
  - FPC:flow proportional counter
    - ★ various pinholes up to 35mm diameter
  - SSD:solid state detector, 2mm diameter pinhole
    - ★ mainly 2mm diameter pinhole
  - FPC and SSD: line and continuum sources

Introduction

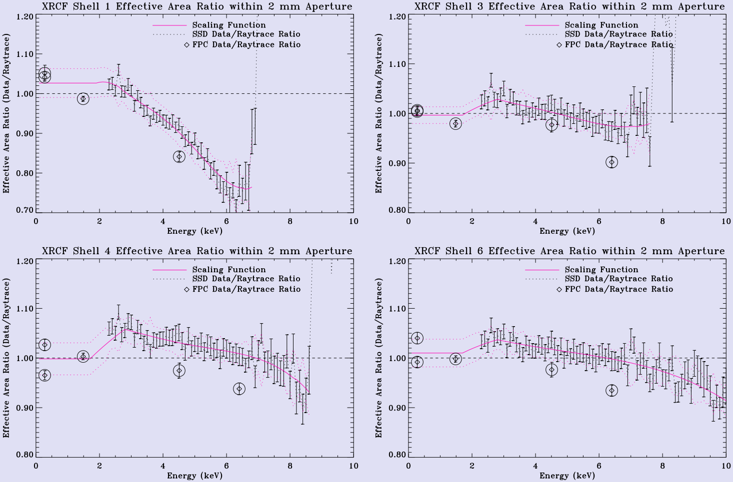
Impractical to calibrate vs E, $(\theta, \phi), \ldots$ directly:
Sparse datasets (energies, off-axis angles, aperture sizes)

- Ground calibration models did not reproduce the detailed shape of raytrace A_{eff}.
  - discrepancies between detectors; not well understood
  - generated energy dependent correction factor for raytrace
    applied to on-orbit models only

XRCF Model Underlying the Previous CALDB Version

Individual shells - polynomial correction factor

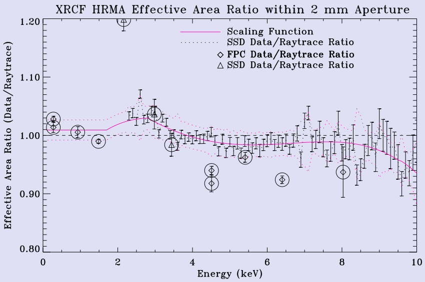
Correct individual shells



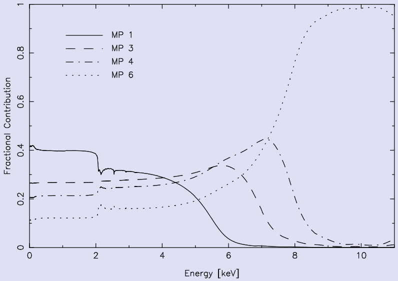
XRCF Model Underlying the Previous CALDB Version

Synthesize full HRMA model - add up the shells

HRMA = combined shells



relative weighting



On-Orbit

Discrepancies

A_{eff} Discrepancy at the Ir edge

- HETG data showed a discrepancy at the Ir edge
- consistent with ∼20Å hydrocarbon contamination layer
- Contamination added to on-orbit models
- CALDB 3.2.1 (2005-12-15): new HRMA A_{eff} hrmaD1996-12-20axeffaN0007.fits

Cross-calibration (& internal discrepencies)

- Fits for high-T clusters: *Chandra* and *XMM-Newton* discrepant
- *Chandra* fits showed internal discrepancies for the same clusters
  - Fe Kα line vs. continuum
  - prompted reexamination of on-axis A_{eff}

A_{eff} Reexamination
Initial analysis:

Initial analysis:

- "XRCF Correction" doesn't account for Ir edges;
  adding $\sim$ 20Å contamination layer made Ir edge look better,
- "XRCF Correction" qualitatively has same effect as contamination (away from the edges).
- Did "correction" partially account for contamination already existing on ground?

If so... contamination layer effect $\sim$doubled away from Ir edges.

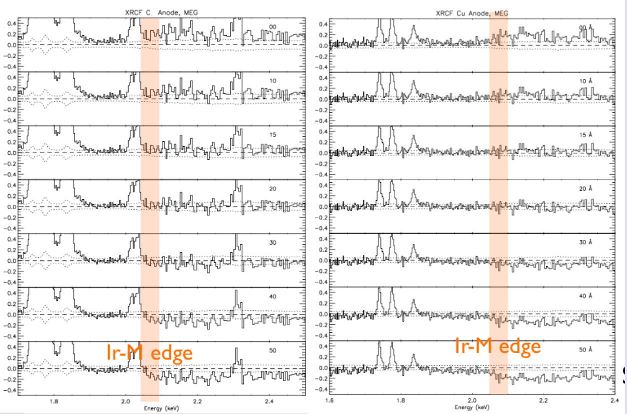
- Removing the "XRCF Correction" while retaining an $\sim$ 20Å contamination layer *seemed* to address the inconsistencies within the *Chandra* fits.
- Does *not* completely resolve differences between observatories.

Stability on-orbit

- Flux Contamination Monitor (contamination cover at front of HRMA). ACIS+FCM measurements:
  - just before leaving XRCF
  - before opening contamination cover on-orbit
  - change in effective thickness of hydrocarbon layer $\leq$ 10Å (Elsner et al., SPIE 4138, 2000)
- analysis of HZ 43 data (Nov 1999 – Jan 2002); upper limit on C contamination thickness change: $\sim$ 50Å (if at normal incidence) $\Rightarrow \sim$ 1Å (at grazing incidence); i.e., no significant change since at least shortly after launch. (J. Drake memo).

Contamination on the ground - HETG evidence

HETG continuum measurements; C Anode, Cu Anode (MEG) (from H. Marshall talk)



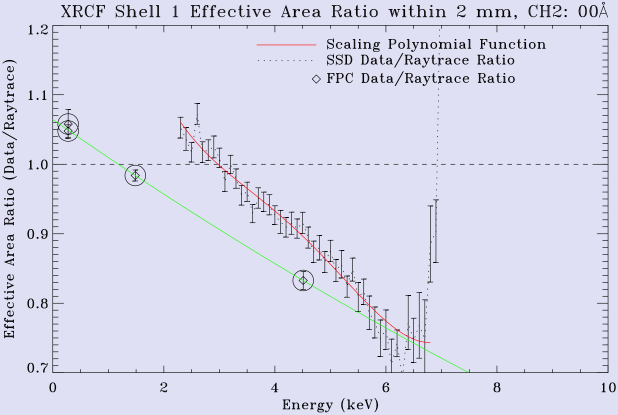
Consistent with $\sim$ 20Å overlayer

If contamination layer was also present in ground testing, how is final final on-orbit A_{eff} affected?

Vary contamination thickness - shell by shell

Example: (Data/Raytrace) for Shell 1

Example: (Data/Raytrace) for Shell 1 0 Å

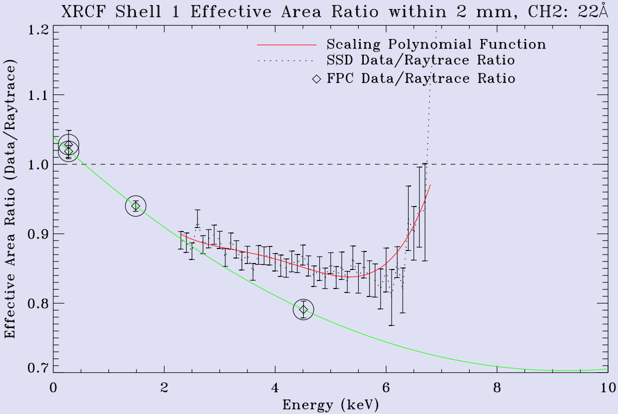


[turnup at high E: residual pileup effect]

Vary contamination thickness - shell by shell

Example: (Data/Raytrace) for Shell 1

Example: (Data/Raytrace) for Shell 1 22 Å

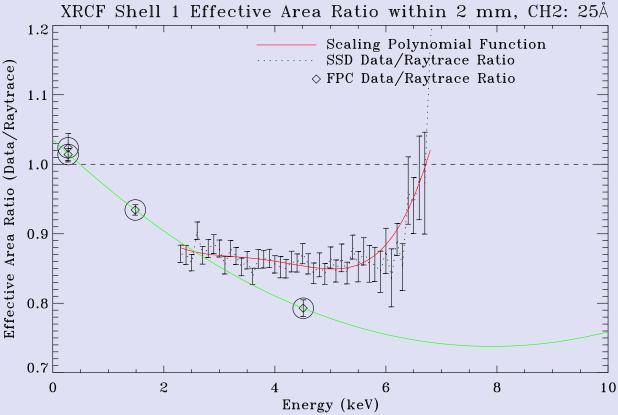


[turnup at high E: residual pileup effect]

Vary contamination thickness - shell by shell

Example: (Data/Raytrace) for Shell 1

Example: (Data/Raytrace) for Shell 1 25 Å

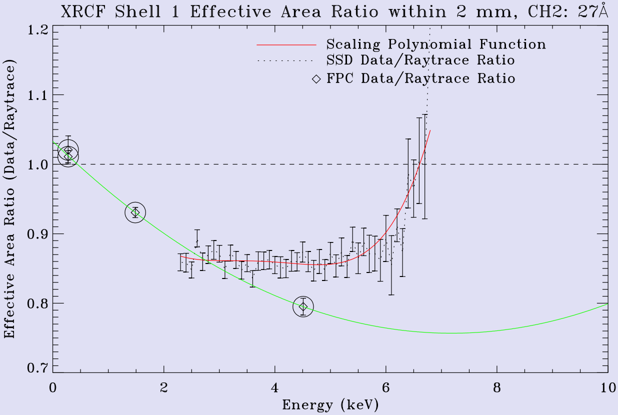


[turnup at high E: residual pileup effect]

Vary contamination thickness - shell by shell

Example: (Data/Raytrace) for Shell 1

Example: (Data/Raytrace) for Shell 1 27 Å

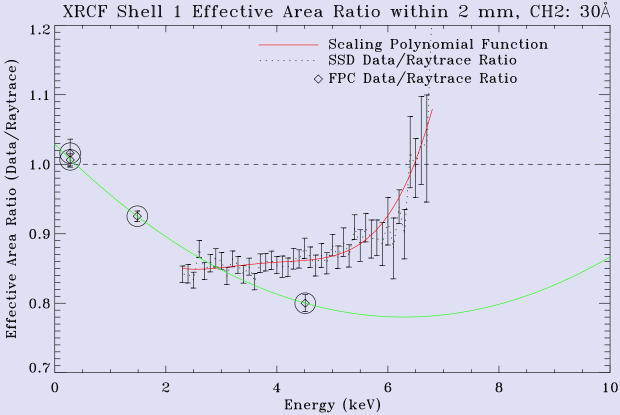


[turnup at high E: residual pileup effect]

Vary contamination thickness - shell by shell

Example: (Data/Raytrace) for Shell 1

Example: (Data/Raytrace) for Shell 1 30 Å



[turnup at high E: residual pileup effect]

Vary contamination thickness - shell by shell

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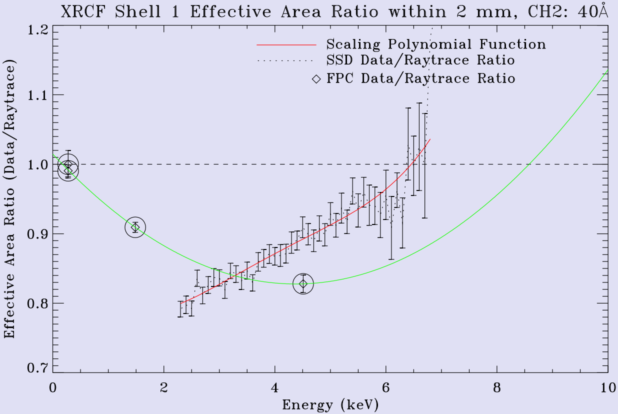
Example: (Data/Raytrace) for Shell 1 40 Å



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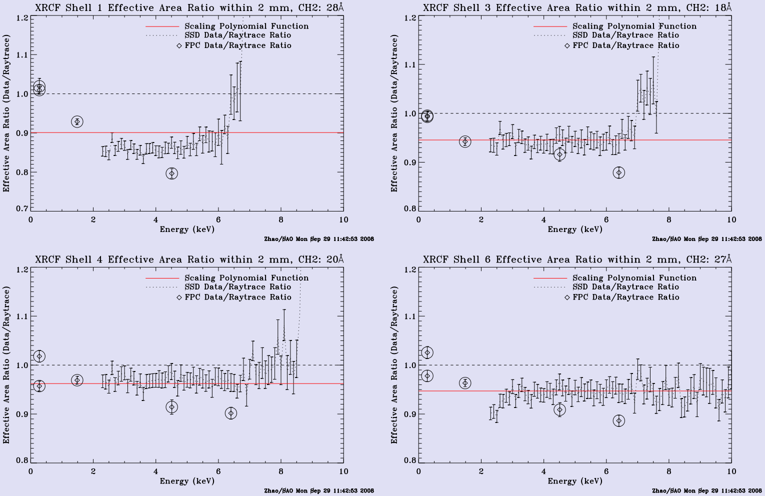
Contamination layer thicknesses: Final Results

Shell 1: 28Å, Shell 3: 18Å, Shell 4: 20Å, Shell 6: 27Å



grey offsets unexplained; largest for shell 1

Combining SSD and FPC data

A new correction factor

- Considered 10 algorithms for combining the FPC, SSD data:
  - none truly horrible
  - a few worse than the rest
  - most pretty comparable
- many tests and much debate ⇒ algorithm **f**
  Combines lowest order moments of the FPC, SSD data.
  For each *shell*:
  - mean of FPC data
  - mean SSD data
  - average the averages
- grey correction factors: larger for shell 1
- applied shell by shell to the on-orbit raytrace model
  - HRMA model $= \sum$ single shell models
    $\Rightarrow$ overall HRMA correction is not grey
    ($\approx$ grey for low E, nongrey for high E)

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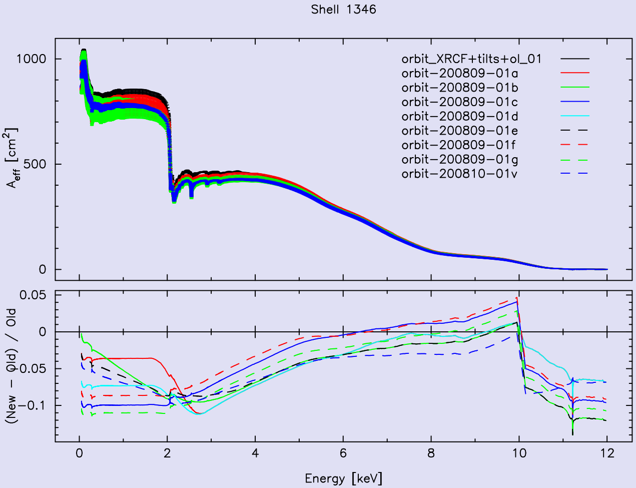
Comparison of Models

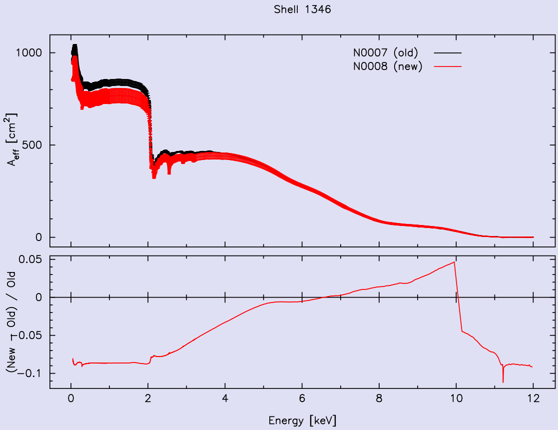


- lower panel: deviations from CALDB N0007 model ($\Rightarrow$ flat line)

New HRMA axial effective area (N0008)

Released 2009-01-21 as part of CALDB 4.1.1

Model **f** $\Longrightarrow$ HRMA effective area N0008.
Comparison: N0007 vs N0008



New HRMA axial effective area (N0008)

Tests

Numerous tests, including:

- galaxy clusters
- AGNs
- thermal SNR (E0102)
- synchrotron-dominated SNR (G21.5-0.9)
- soft thermal sources

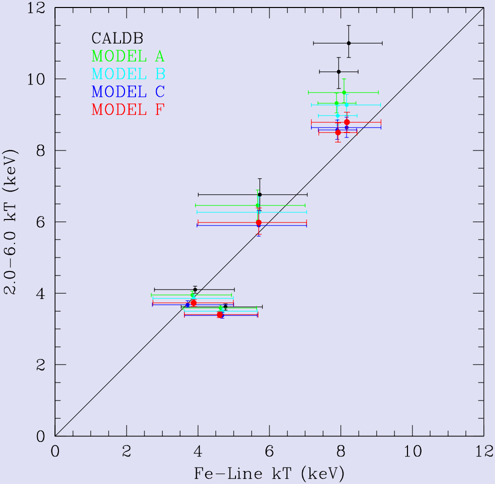
Differences between N0008 and N0007:

- Derived spectral parameters (e.g., kT, Γ) typically differ less than $\sim 3\%$
- However...
  - kT can be up to $\sim 10\%$ less for hot galaxy clusters
  - soft sources (0.5-2 keV band): derived fluxes can be up to $\sim 8\%$ higher.

New HRMA axial effective area (N0008)

Galaxy Clusters

ACIS: kT_e: Fe Kα vs continuum



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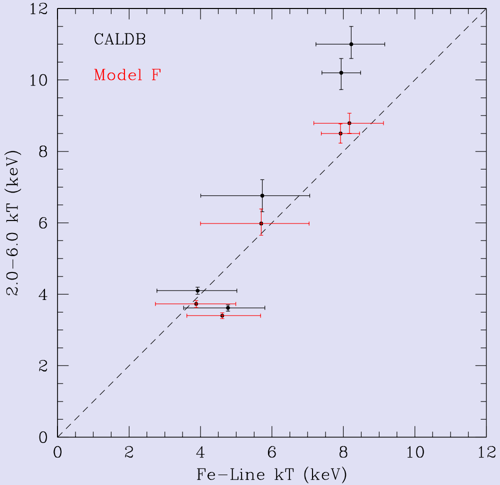
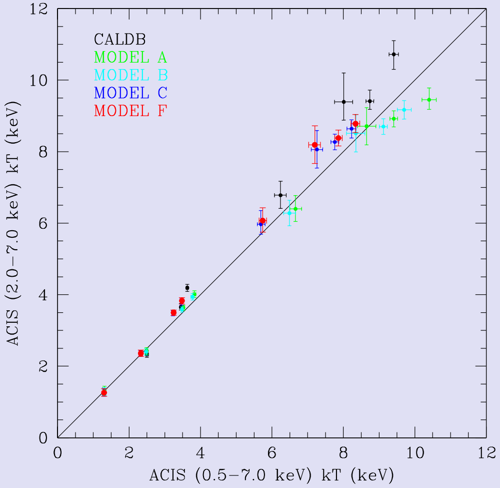


New HRMA axial effective area (N0008)

Galaxy Clusters

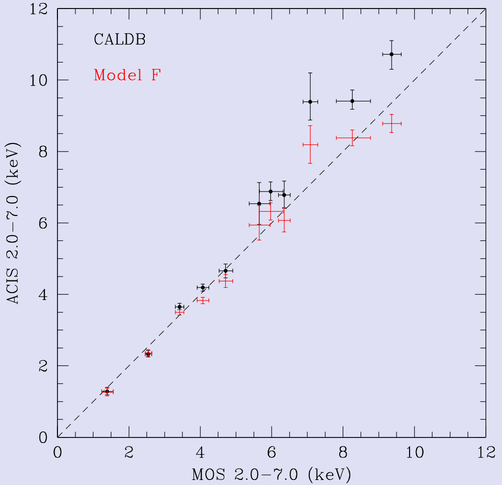
ACIS: Hard vs Broad band



New HRMA axial effective area (N0008)

Galaxy Clusters

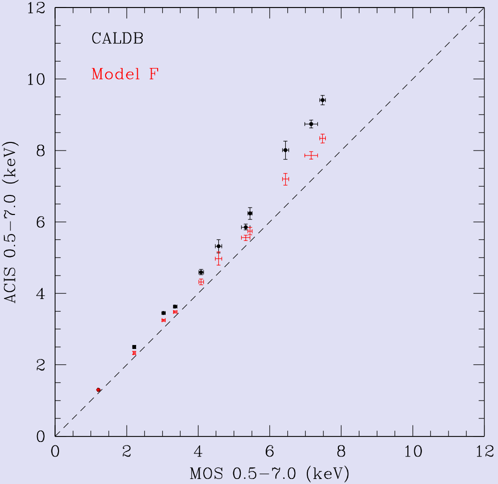
ACIS vs. MOS: hard band



New HRMA axial effective area (N0008)

Galaxy Clusters

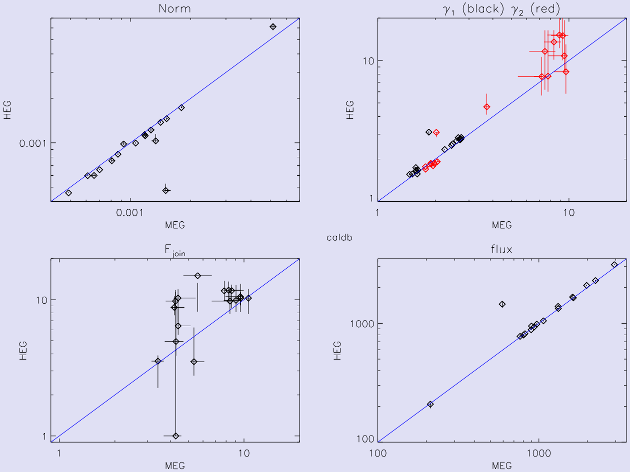
ACIS vs. MOS: broad band



New HRMA axial effective area (N0008)

AGN spectra; Powerlaw sources (fit 0.7-7.5 keV) N0007
(2nd order MEG/HEG correction not applied)

differences between variants statistically insignificant.



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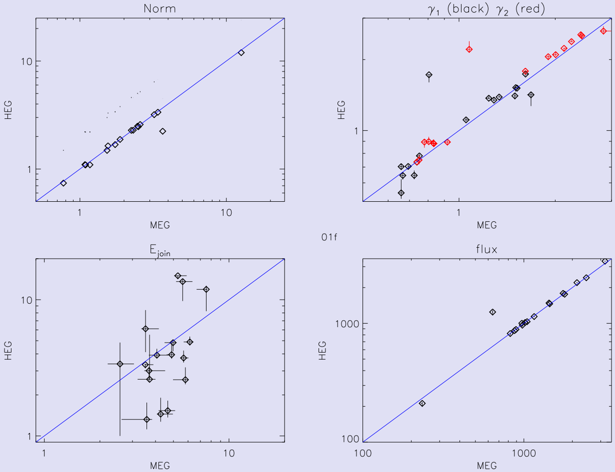
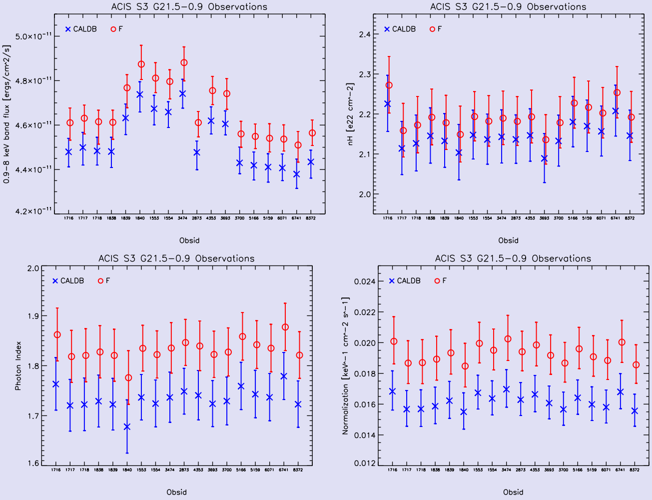


New HRMA axial effective area (N0008)

Synchrotron-dominated SNR (G21.5-0.9)



- modest systematic change for parameters; comparable χ^2_{red}

Summary

- Calibration based on detailed raytrace model plus ground tests
- Many tests, derived spectral parameters comparable ($\sim$ 3%) except for
  - hot galaxy clusters (kT $\lesssim$10% lower)
  - derived fluxes for soft source ($\sim$ 8% higher).
- New HRMA effective area (N0008) released