Spatial gain calibration of MOS & pn: relevance to extended sources study

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Calibration

- Spatial gain calibration for the EPIC MOS and pn is good to about 5, 10 eV respectively.
- This is a very high quality cal., opens up interesting possibilities for extended source studies.

Application for extended sources

In the case of GC we have INDIRECT evidence of subsonic gas motions with typical velocities

of the order of 1/4 to 1/2 of the sound speed (few 100 km/s). 5eV precision implies that the

Fe K line at 6.7 keV can be used to detect

velocity differences down to ~250 km/s, provided of-course sufficient statistics is available in the line.

Good, but if we could only improve the calibration by a factor of 2-3 we would really be in business

Can we do it?

How to improve Calibration

Phenomenological approach

Assume I am totally ignorant of the way events are corrected for gain.

Can the temporal and spatial dependence of the gain be decoupled?

$$\mathcal{E}(x,y,t) = \mathcal{E}(x_o,y_o,t) \times Gain(x,y)$$

Question can be recast in the form: Can we produce a gain map?

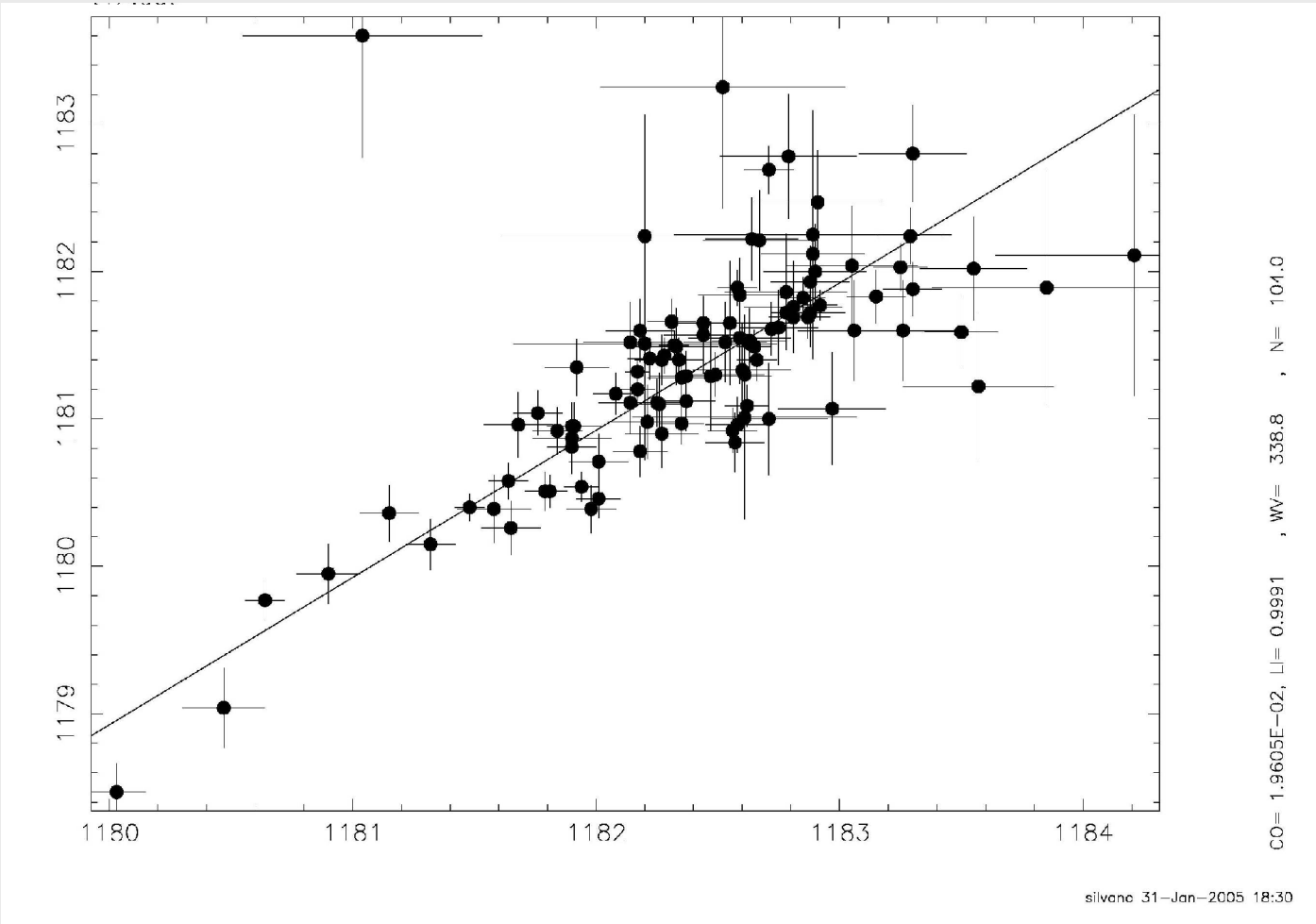
Analysis

- Take calibrated event files of long cal closed observations
- Divide FOV in different regions (sectors of annuli) extract spectra using 5eV binning
- Fit the MnKa line at 5.9 keV in channel space (no rmf) deriving centroids

Correlation!

MOS1, MOS2

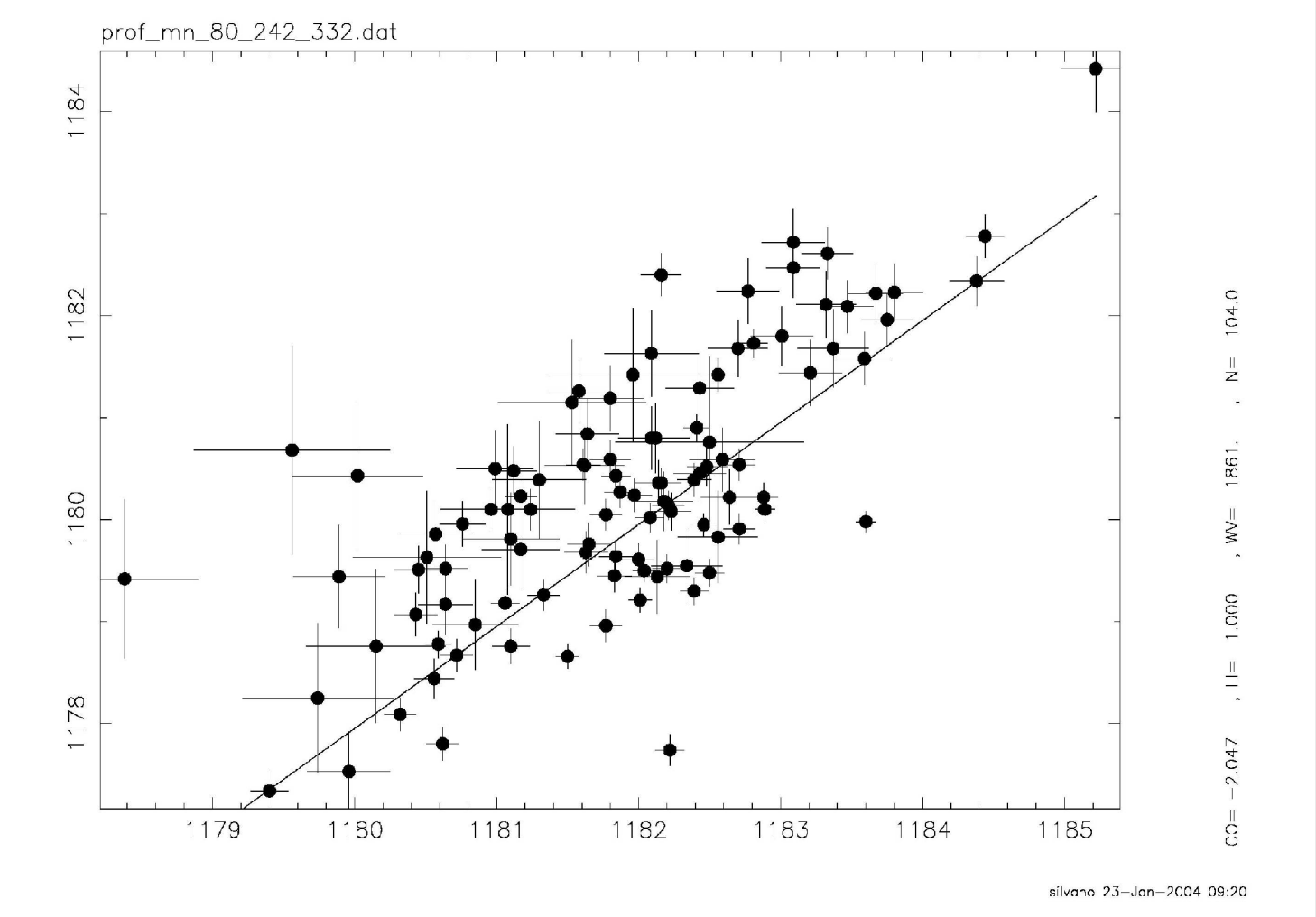
Plot E_{obs1} vs E_{obs2}



Correlation!

pn

Plot $\mathcal{E}_{obs1}$ *vs* $\mathcal{E}_{obs2}$



Correlation!

MOS1 and MOS2 show good correlation with little scatter, the same is not true for pn

Standard Calibration

Distribution of $\mathcal{E}_{MOS1}$ and $\mathcal{E}_{MOS2}$

Rev.	Det.	Date dd-mm-yy	Exp. Ks	E^1 channel	σ_{int} channel
142	M1	16-09-00	101.5	2.38 ± 0.03	0.28 ± 0.02
172	M1	15-11-00	47.2	1.30 ± 0.05	0.66 ± 0.04
242	M1	04-04-01	76.8	1.33 ± 0.06	0.75 ± 0.04
142	M2	16-09-00	69.8	1.14 ± 0.04	0.50 ± 0.03
172	M2	15-11-00	31.3	1.41 ± 0.04	0.49 ± 0.03
242	M2	04-04-01	64.0	3.90 ± 0.04	0.53 ± 0.03

$\mathcal{E}^1 = \langle\mathcal{E}\rangle - 1180$

standard deviation associated to the intrinsic dispersion can be quantified in 0.3-0.7 channels

How tight?

We build distributions of the differences between the centroids for the same region in two different observations.

Δ Rev.	Det.	ΔE channel	σ_{int} channel
142-172	M1	1.08 ± 0.02	0.23 ± 0.02
142-242	M1	1.08 ± 0.03	0.30 ± 0.02
172-242	M1	0.00 ± 0.03	0.28 ± 0.02
142-172	M2	-0.26 ± 0.02	0.23 ± 0.02
142-242	M2	-2.75 ± 0.02	0.28 ± 0.02
172-242	M2	-2.49 ± 0.02	0.29 ± 0.02

standard deviation associated to the intrinsic dispersion can be quantified in 0.2-0.3 channels

How tight?

This corresponds to a fractional systematical error on the line centroid of

1.7×10^{-4} - 2.5×10^{-4},

which can be translated into a systematic

error on reconstructed velocities of the order of 50 km/s to 75 km/s.

Gain map

$$d\mathcal{E} \equiv \mathcal{E} - \overline{\mathcal{E}}$$

Where $\mathcal{E}$ is the centroid at a given position and $\overline{\mathcal{E}}$ is the mean centroid

Define correction map

$$\overline{d\mathcal{E}}$$

$$\overline{d\mathcal{E}} = \frac{\sum_{i=1}^{3} d\mathcal{E}_i/\sigma^2_{\mathcal{E}_i}}{\sum_{i=1}^{3} 1/\sigma^2_{\mathcal{E}_i}}$$

where i runs over analyzed calibration observations

Correction procedure

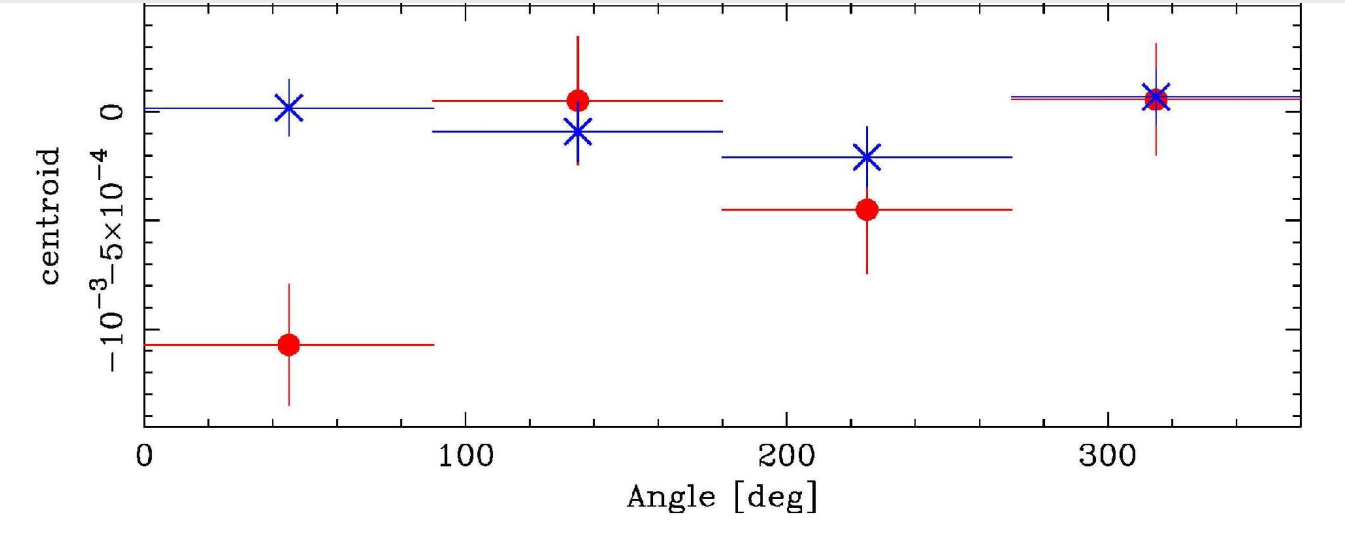
$$dE_{cor} = dE - \overline{d\mathcal{E}} * (\overline{E}/\mathcal{E}_{ref})$$

Where is dE rrected centroid shift with respect to mean centroid $\overline{E}$

$\mathcal{E}_{ref}$ reference energy of Mn K line

Applications

Annulus 2-6 arcmin, 4 sectors



Mn K line from a cal-closed obs,

Fe K line from archive Perseus observation

Systematic error of ~ 2×10^{-4}

Gas motion detected in Perseus at ~ 99% level

AstroE-2 & Chandra

ACIS CCDs apparently do not have the capability to carry out a centroid analysis similar to the one we have performed on EPIC (Sanders et al 2004).

Astro-E2 XRS has spectral resolution of 6 eV, more than an order of magnitude better than EPIC. However more than 50 pointing needed to cover the full EPIC MOS FOV.

Moreover shifts on scales of 1-2 arcmin will not be detectable with XRS because of its poor PSF (1.8 arcimn HPD).

The measurements that can be made with EPIC cannot be made with ANY other instrument flying or to be launched within the next decade.

Complementing AstroE-2

Astro-E2 XRS will detect broad lines, however because of its poor spatial resolution, we will not know if the broadening is in the source (turbulence) or due to the poor resolution bunching together regions with different ordered velocity fields.

In these cases EPIC may well be the ONLY instrument capable of braking the degeneracy.

GC and SNR

The technique requires lots of photons, can only be applied to a limited number of sources.

2. GC Fe K line, (approved 125 ks AO4 prop on Perseus to improve on archival observation).

3. SNR Fe K line (Cas A) , but also other lines, here velocities are a factor 10 higher, and statistics is better.

However, longer observations are easier to secure after a mission has been operating for a few years.

This would allow a totally new exploitation of EPIC data

Summary

2. EPIC MOS has the capability of performing velocity tomography on GC and SNR (the fact that I could not get things working for pn does not mean it cannot be done, see Konrad' s talk)

3. It would be very important to make this available to other observers, to do this more work is required possibly by people who understand gain calibration better than I do.