Towards XMM-Newton's first Enhanced Stacked Catalogue

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The “classical” approach

emldetect, edetect_stack

- counts above background from PSF maximum likelihood fitting
- developed for single observations
- observations with overlapping sky areas can be “stacked” (fitted together)

✓ state-of-the-art! (Traulsen+19, Traulsen+20)
multi-level source characterisation (images → observation → stack)
good compromise between depth, accuracy, variability information

The downside

Large number of degrees-of-freedom during fitting

Can we do better than “classical” emldetect?

New “enhanced” approach: *spectral*

XMM2ATHENA: let’s find out. . .

- constancy between epochs while fitting for spectral shape and intensity

What to expect?

- reduction on the number of d.o.f., independently of the size of the stack
- better handling of the detection likelihood controling spurious sources
- ✓ sensitivity boost + spectral parameters directly from source detection

WP4: Enhanced stacked catalogue

- how? re-designed software: emldetect_esc
- testing and validation; two pilot catalogues (D4.3+D4.4), documentation

Two pilot catalogues from 4XMM-DR13(s) pool (13k+)

XMM2ATHENA

D4.3: ESC (2023-03)

- 300 stacks, sizes 2–18
- all cameras active, (e)full-frame
- low background
- minimum 12 arcmin overlap
- random de-selection of small-size stacks (sizes 2, 3)

➠ emldetect_esc-0.3

✓ 63 990 unique sources

D4.4: Combined ESC (2023-11)

- D4.3 stacks + 300 “singles”
- all cameras active, (e)full-frame
- low background
- minimum exposure 10 ks
- random selection
- screening (veto on “problematic”)

➠ emldetect_esc-0.4

✓ 95 222 = 64 247 + 30 975

SIXTE simulations of the CDF-S

https://www.sternwarte.uni-erlangen.de/sixte

XMM2ATHENA

Ready-to-use SIMPUT catalogues

- ∼700 point sources, power-law
- 50 extended, APEC
- large-scale diffuse, power-law

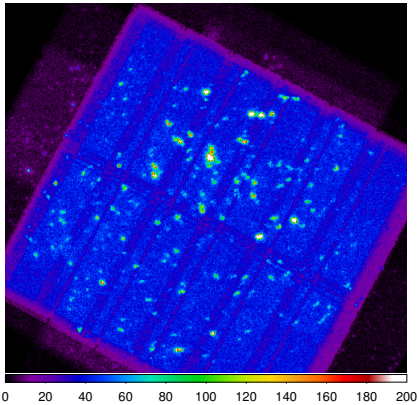
Pointing, duration, setup

- XMM LP 2008-2010, PI: Comastri
- 23 EPIC observations with >100 ks

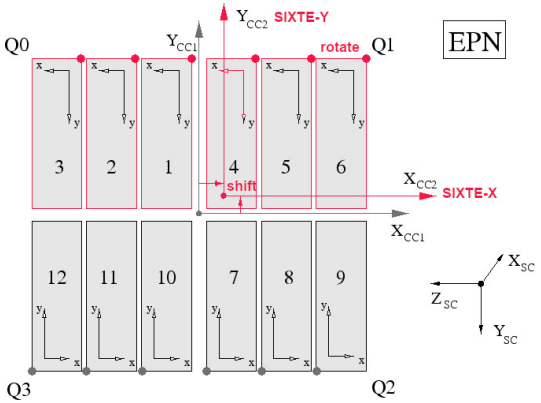
EPIC simulations

- 10 stacks (size 1–10; 55 simulations)

stack of $N = 6$ CDF-S simulations



SIXTE customisation and corrections

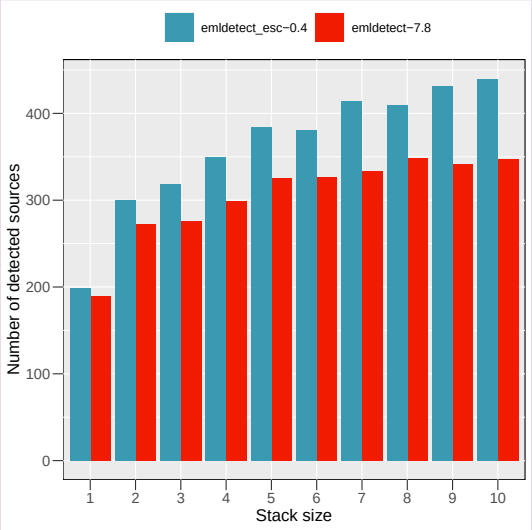


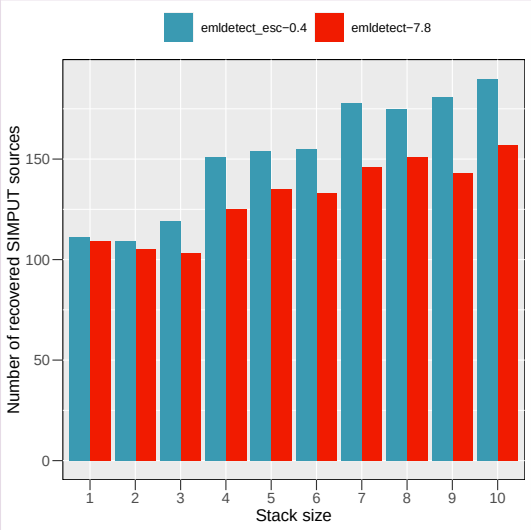
- chip geometry, orientation (XML)
- vignetting; RMF, ARF (FF/thin)
- background model
  (drawn from blank-sky spectra)
- correction of RAWX, RAWY shifts
- SAS compliance:
  header keywords, data types
- boresight correction
- detector and sky coords
- improved astrometry

🙏 much input and shortcuts from Angel Ruiz@NOA https://github.com/ruizca/sixtexmm

CDF-S: total detected and recovered SIMPUT sources

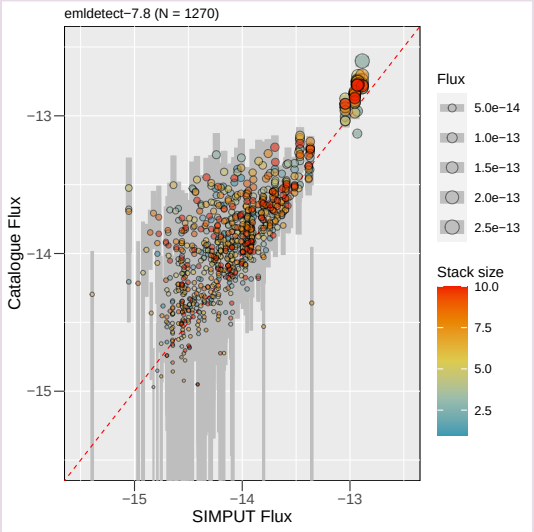
SIMPUT fluxes: median 2×10^{-15} cgs; range: $(0.2 - 130) \times 10^{-15}$ cgs

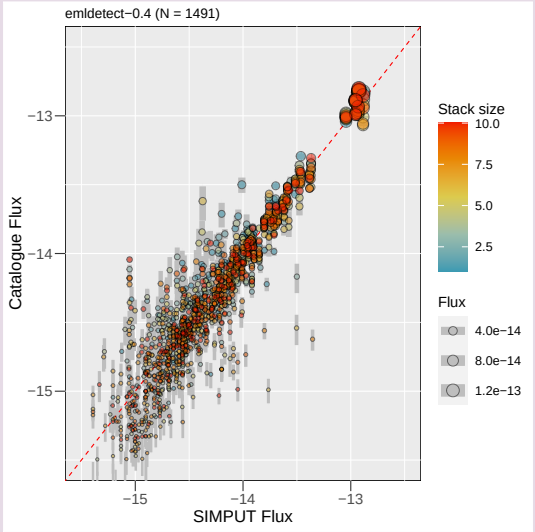




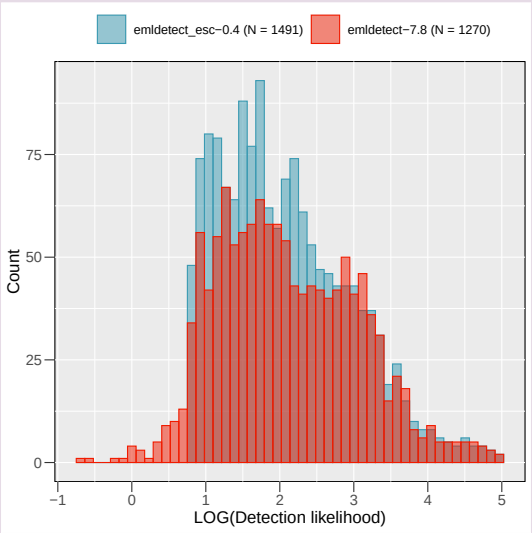
CDF-S: flux of recovered SIMPUT sources

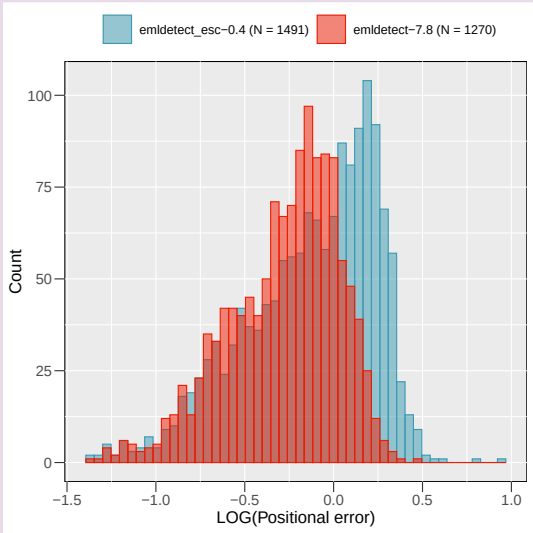
emldetect ECF: $N_H = 3 \times 10^{20}\,\mathrm{cm}^{-2}$, $\Gamma = 1.7$; SIMPUT parameters: $N_H = 4.78(15) \times 10^{21}\,\mathrm{cm}^{-2}$, $\Gamma = 2.28 \pm 0.06$



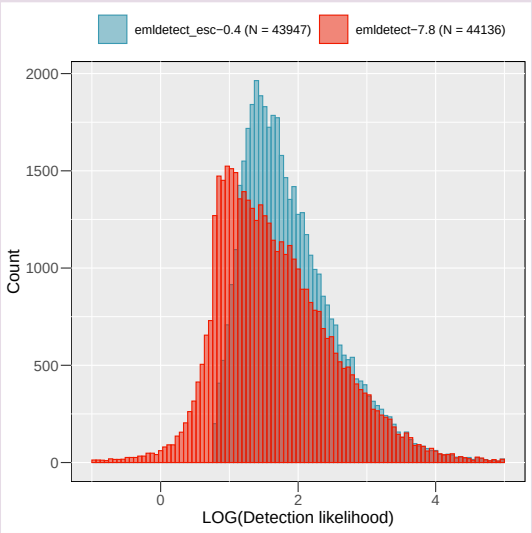


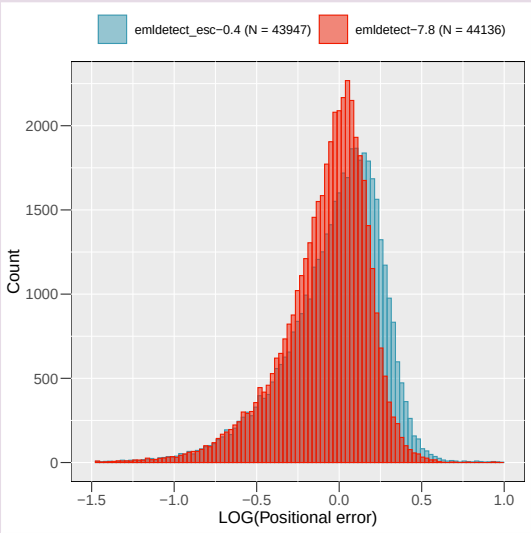
CDF-S: detection likelihood, positional errors





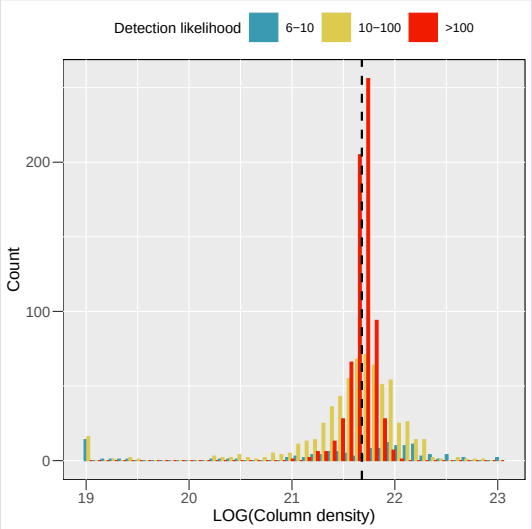
D4.3/D4.4: detection likelihood, positional errors

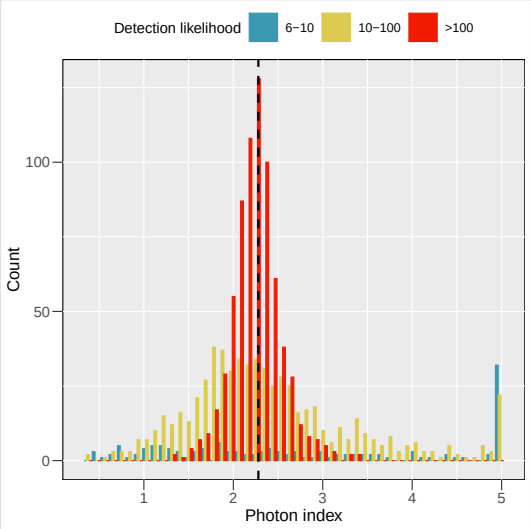




CDF-S: spectral parameters by detection likelihood

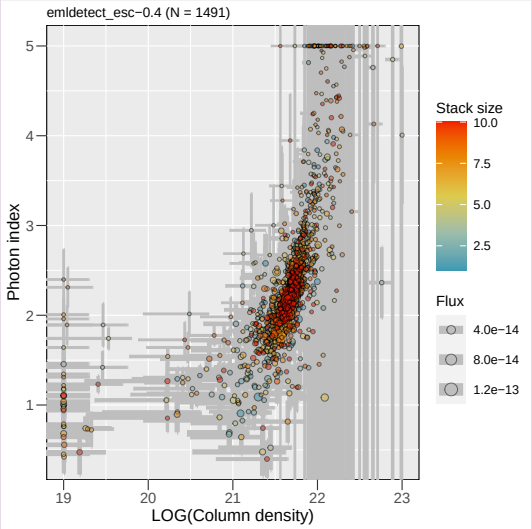
SIMPUT parameters: $N_H = 4.78(15) \times 10^{21}\,\mathrm{cm}^{-2}$, $\Gamma = 2.28 \pm 0.06$

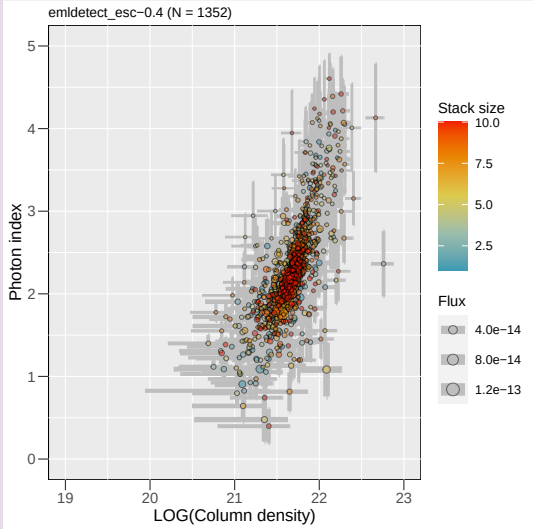




Spectral parameters; “pegging”

SIMPUT parameters: $N_{\rm H} = 4.78(15) \times 10^{21}\,{\rm cm}^{-2}$, $\Gamma = 2.28 \pm 0.06$





Pegging percentage

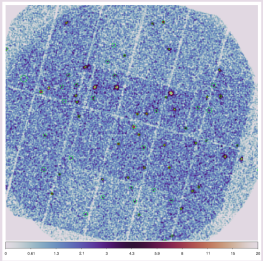
D4.3/D4.4: about one-third

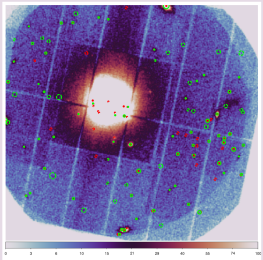
Quantile	$6 \leq \mathcal{L} < 13$	$13 \leq \mathcal{L} < 30$	$30 \leq \mathcal{L} < 100$	$\mathcal{L} \geq 100$
% pegged (D4.3)	50	37	27	20
% pegged (D4.4)	36	28	22	19

- increases among faint sources
- larger in “complex” fields
  (eg. bright diffuse background emission, crowded fields)

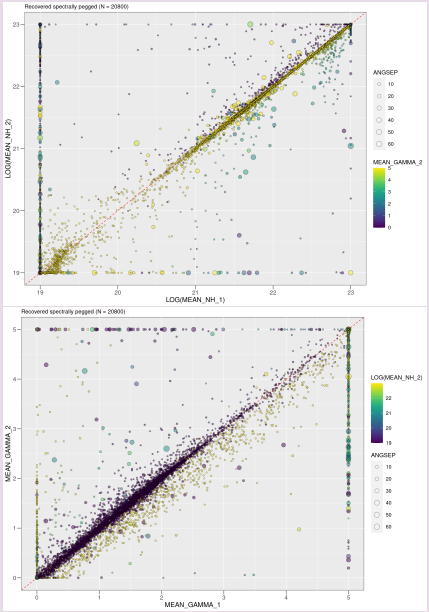
  least molecular cloud MBM16: 15%
  worst SNR W49B: 74%

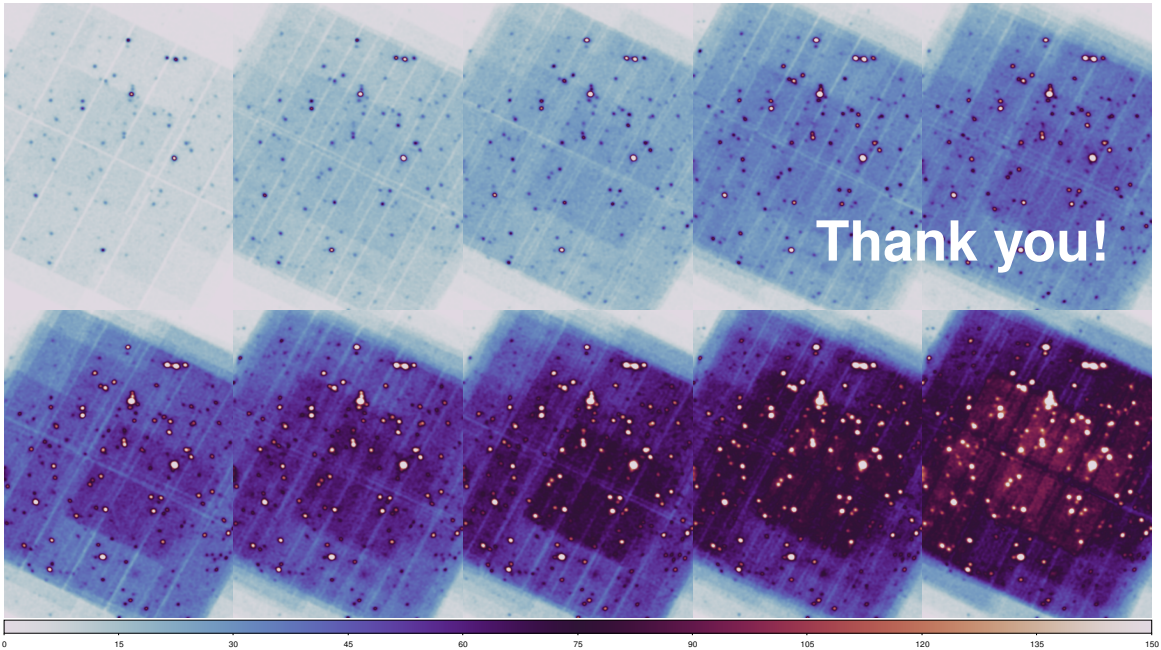
CDF-S: about 4%–8%, no trend on stack size





- ✓ ESC performance (mainly based on CDF-S)
  - sensitivity;
    count rate of faintest non-spurious source
  - reliability and robustness:
    parameters and errors
  - runtime as a function of stack size
- To quantify
  - contamination *vs.* detection likelihood
  - stacking “saturation”
  - theoretical agreement
    (statistical framework)
- ➠ To understand/address
  - larger positional errors in spectral mode
  - spectral pegging: workarounds




Thank you!
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