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Observing simulated clusters: a novel virtual X-ray observatory

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X-ray observations continue to provide us with an increasingly detailed picture of galaxy clusters, for which a clear interpretation of the underlying physical processes is very challenging. While hydrodynamical simulations can currently address many of the questions about the dynamics of galaxy clusters, it is vital to find a faithful way to directly compare the outputs from such simulations to X-ray observations. This can be achieved through virtual observatories dedicated to obtain X-ray mock images from simulated galaxy clusters, which can be analyzed with the same tools and methods used for the real ones. I present here a ***novel X-ray photon simulator*** based on an original approach which reverses the procedure commonly adopted so far in the implementation of virtual observatories, allowing to ***significantly gain in spatial and spectral resolution*** and ***computational cost***. The simulator is therefore optimal to process large simulations on reasonably feasible time scales, although keeping the high resolution. Ultimately, the promising goal is the possibility to anticipate the results that the up-coming generation of X-ray instruments, like ASTRO-H or IXO, is expected to reach. With particular concern for galaxy clusters, such high-precision spectroscopy will eventually allow to detect ICM non-thermal motions (e.g. bulk, ordered motions, see [2]) via the broadening diagnostics of emission lines from heavy ions (e.g. the iron line at 6.7 keV).

THE CODE

UNIT 1: generating the cube of photons

- Read the data from an hydro-simulation output as input;
- Read input parameter file with:
  - switch for XSPEC emission model: MEKAL/APEC;
  - energy binning: E_{min}, E_{max}, n_{chans};
  - fiducial observing time;
- For each gas particle in the hydrosim compute model spectrum with XSPEC;
- Calculate total number of photons, N_{ph}, from spectrum assuming fiducial collecting area and observing time;
- Populate on-the-fly the spectrum of each gas particle with a distribution of N_{ph} photons: to each emitting gas particle corresponds a "package" of photons;
- Store photon energies, with position and velocity, of all emitting particles.

UNIT 2: geometrical selection and projection

- Input: output from Unit 1;
- Accept parameter file with user-specified geometrical parameters for the region to select, desired detector physical area and observing time;
- Correct for Relativistic Doppler Shift: $E_{ph}^{obs} = E_{ph}^{em}\sqrt{\frac{1+v_{los}/c}{1-v_{los}/c}}$
- Reduce photons according to:
  - geometrical selection;
  - specified collecting area and exposure time;
- Create a photon list to be convolved afterwards with instrumental response.

UNIT 3: convolution with instrument response

- The photon list is read and convolved with the response of the desired instrument, as defined by the ancillary response file (ARF) and by the redistribution matrix file (RMF);
- The final spectrum has also to be stored in a fits format best-suited to be then analyzed with the standard observational tools (e.g. spectral fitting with XSPEC).

([1], *in preparation*)

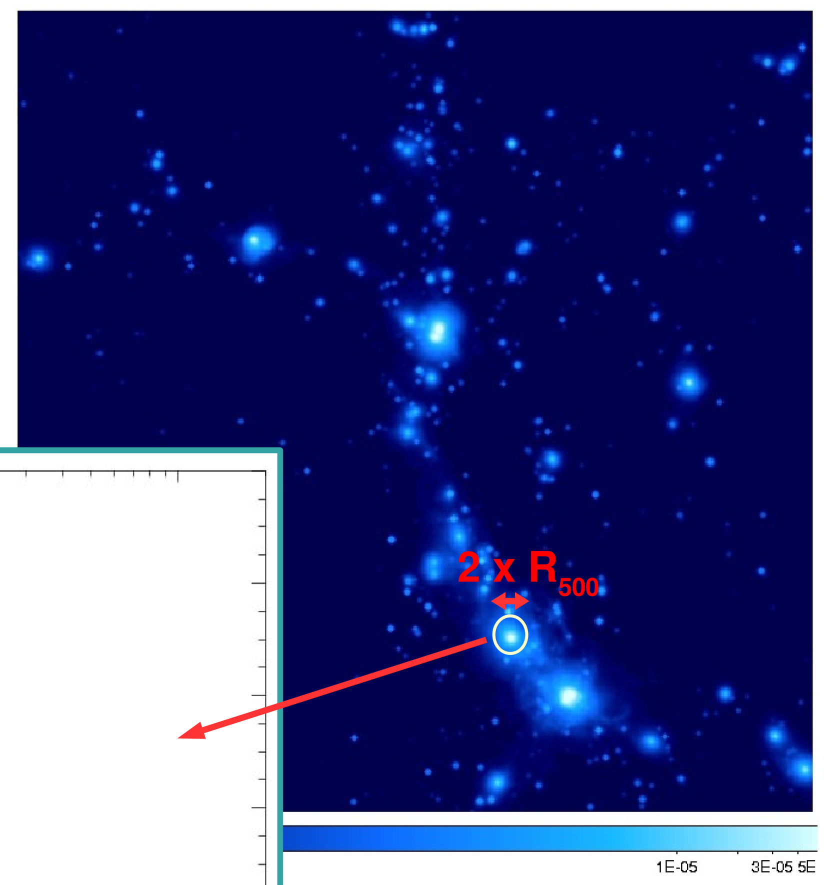
References: [1] V. Biffi, K. Dolag, H. Böhringer & G. Lemson 2011, "Observing simulated clusters with PHOTON-X: a novel X-ray photon simulator", *in preparation*
[2] V. Biffi, K. Dolag & H. Böhringer 2010, MNRAS *in press* (arXiv1012.1606B)

A science case: *SUZAKU* observation of a simulated galaxy cluster

We test the code by processing the photon list obtained from UNIT 1 + UNIT 2 with the public available *Suzaku* simulator, `XISSIM` (Ishisaki et al. 2007).

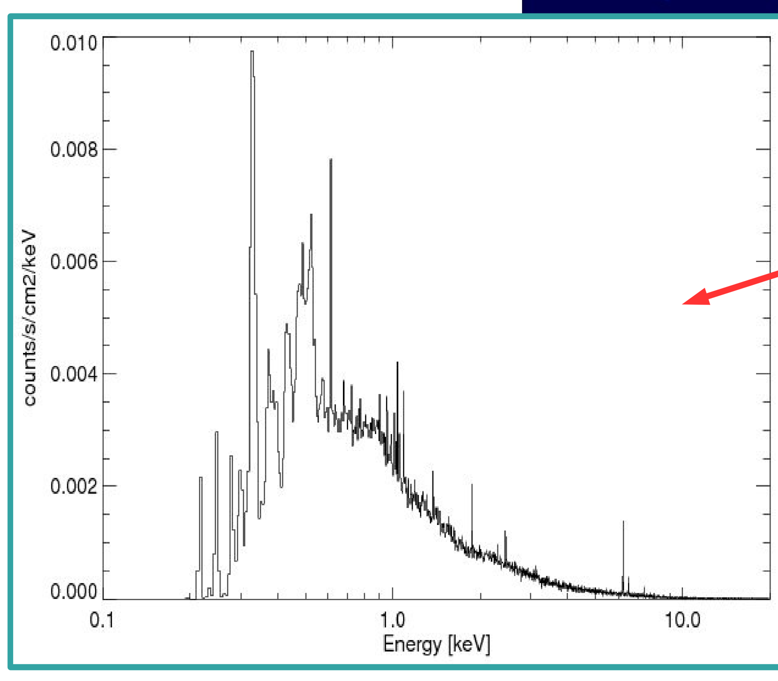
(1) Numerical input: hydro-simulation (including star formation, cooling and feedback from supernova winds, performed with GADGET-2) of a supercluster-like region with ~10^7 gas particles, at z=0.07.

Model spectrum *for each* gas particle: `WABS` x `APEC`;
A_{fid} = 2000 cm^2, $\tau_{fid} = 10^6$ s → N_{ph} ~ 1.9 x 10^9

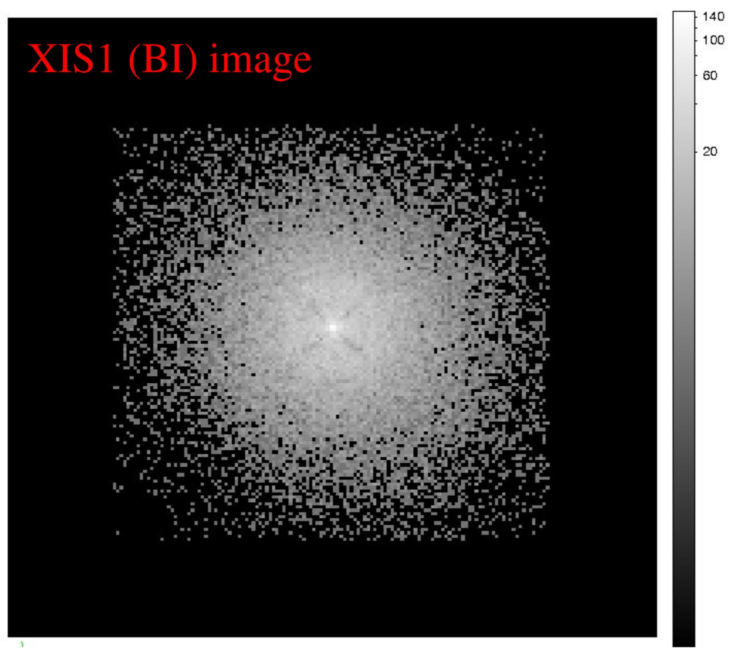


(2) Geometrical selection: cylindrical region along the z-axis, containing a galaxy cluster with M_{500}=2.78 x 10^{14} $h^{-1}M_{sun}$ and R_{500}=801.5 h^{-1}kpc.

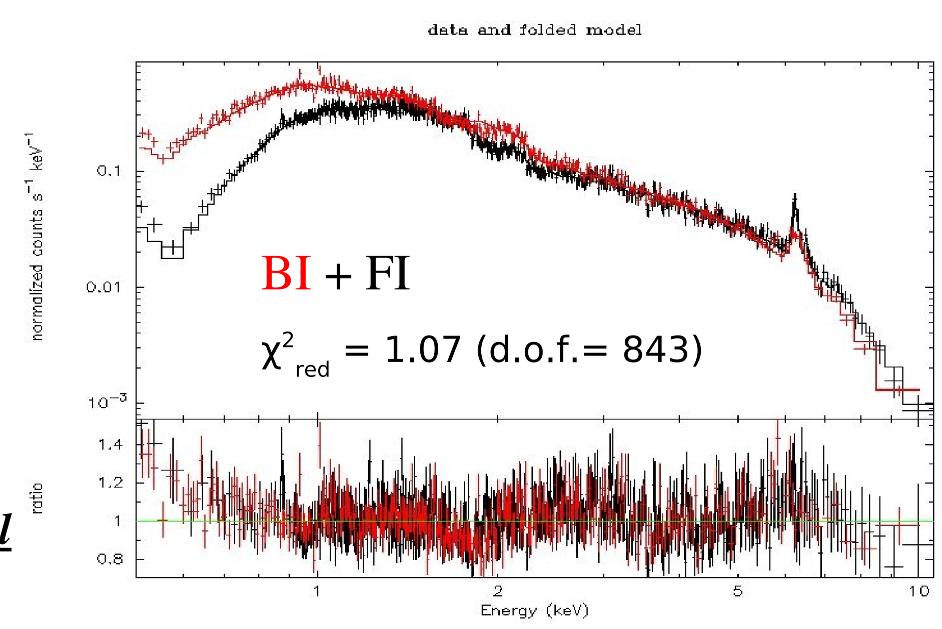
A_{XRT} = 1152.41 cm^2,
τ_{EXP} = 500 ks
→ N_{ph} ~ 3.1 x 10^6



Top: zoom [50x50x50 (h^{-1}kpc)^3] on the supercluster contained in a cosmological box of 479h^{-1}kpc a side.
Left: theoretical spectrum from the photons selected in phase (2).

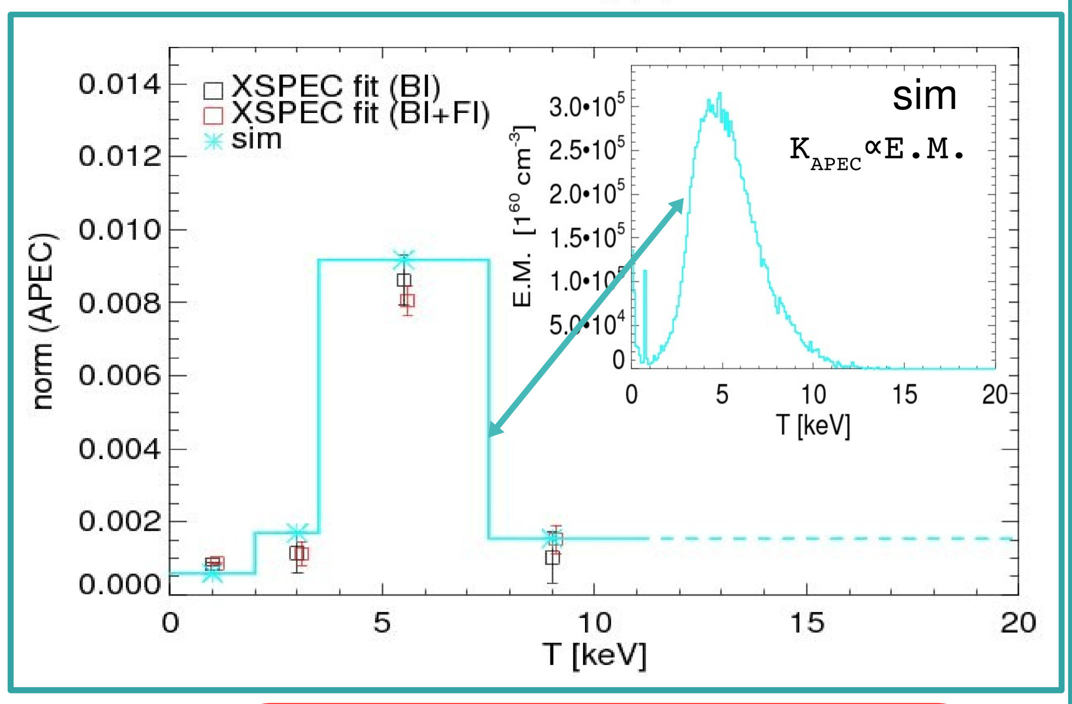


(3) Suzaku mock observation: simulation with the XIS back-illuminated CCD (XIS1, BI) and with two front-illuminated CCDs combined (XIS0+XIS3, FI) on board *Suzaku*.



GOAL: ***Is it possible to recover the theoretical emission distribution of the observed region?***

TEST:
the spectrum is fitted using `XSPECv12` with an absorbed, 4-temperature model:
`WABS(APEC`$_1$`+APEC`$_2$`+APEC`$_3$`+APEC`$_4$`)`
- $T_{[1,2,3,4]}$ = [1, 3, 5.5, 9] keV, fixed.
- N_H = 7 x 10^{22} cm^{-2}, Z = 0.3 Z_{sun}, z = 0.07, fixed.
- $K_{APEC[1,2,3,4]}$: free.



We compare (*right*) the best-fit values of the 4 K_{APEC} (*black squares: BI; red squares: BI+FI*) to the values computed directly from the theoretical emission distribution (*inset-panel*) of gas particles in the simulation (*light-blue asterisks and histogram*), as K_{APEC}∝E.M.

The multi-temperature fit recovers quite well the theoretical emission distribution!

CONCLUSIONS

Novelty: *firstly draw a distribution of photons* (`UNIT 1`) from gas particles of hydro-simulation and *secondly* (`UNIT 2`) *select them geometrically and project* along the l.o.s..

Advantages:
- *dramatically improves the spatial and spectral resolution achieved;*
- *reduce the computational effort* entirely to the first unit;
- `UNIT 1` is so general that can be ideally run only once per simulation output *independently* of the simulation sub-region to be observed and of the desired instrument;
- by initially turning the whole simulation box into a 'box of photons', we avoid the disadvantage of storing a library of model spectra.

Perspectives:
- anticipate results of future high-resolution spectrometers (as ASTRO-H and IXO);
- large simulations can be processed without losing in spatial/energy resolution;
- varying metallicities or even different chemical composition of individual gas particles can be considered;
- a number of different synthetic observations can be obtained without re-starting the calculations from the very beginning.

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