A NOVEL VIRTUAL X-RAY TELESCOPE FOR HYDRODYNAMICAL SIMULATIONS

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"Observing simulated galaxy clusters with PHOX: a novel X-ray photon simulator"
V. Biffi, K. Dolag, H. Böhringer, G. Lemson 2012, MNRAS

CLUES meeting - Lyon - 20.6.2012

OUTLINE

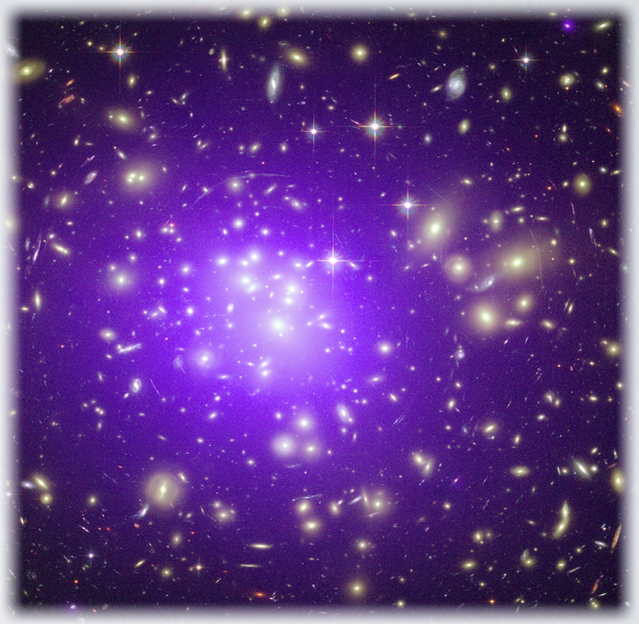
- Motivation: study of galaxy clusters
- PHOX: structure of the simulator code
- Advantages & perspectives

CLUSTERS OF GALAXIES:
AT THE TOP OF THE COSMIC HIERARCHY

- Crossroads of cosmology and astrophysics

→ <u>total gravitating mass</u>

- Hot diffuse plasma (**ICM**), T~10^7-10^8 K: **X-rays**



Use X-ray observations of the ICM to trace intrinsic structure & total mass

Hydrostatic Equilibrium

$$\frac{1}{\rho}\frac{dP}{dr} = -\frac{GM}{r^2}$$

+

- Spherical symmetry
- Gas <u>pressure support</u> only due to <u>thermal</u> motions

X-RAY MASS:

$$\mathbf{M(<r) = -\frac{k_B T_{gas}}{G\mu m_p} r \left(\frac{d \ln \rho_{gas}}{d \ln r} + \frac{d \ln T_{gas}}{d \ln r} \right)}$$

Are assumptions reliable?
Effects of thermal structure?
What about non-thermal motions?

✳ Details of ICM thermal structure:

Also current telescopes (e.g. Suzaku): hydrosims allow for comparison to intrinsic cluster structure
[e.g. Peterson et al. 2003; Kaastra et al. 2004; **Biffi**, Dolag, Böhringer, Lemson I 2]

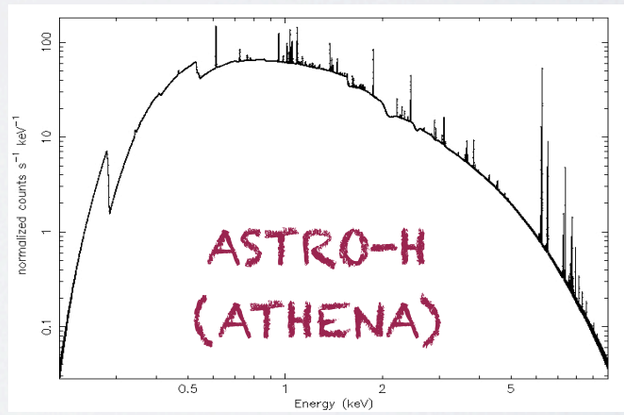
✳ Mass determination and validity of hydrostatic equilibrium:

$$P = P_{thermal} + P_{non-thermal}$$

e.g. turbulence, bulk motions (straming, rotation)[Fang et al. 09; Lau et al. 09; Zhuravleva et al. 10; **Biffi**, Dolag, Böhringer 11]

✓ possible to constrain directly with hydro-simulations!

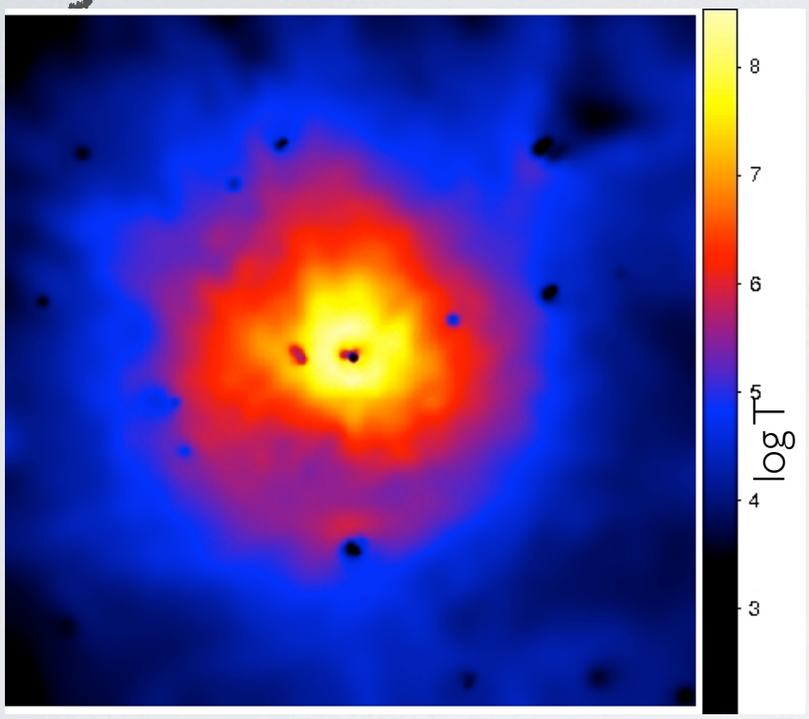
(possibly) detectable spectral signatures: velocity broadening of emission lines



Required faithful comparison between hydro-simulations and X-ray observations

A NEW X-RAY PHOTON SIMULATOR

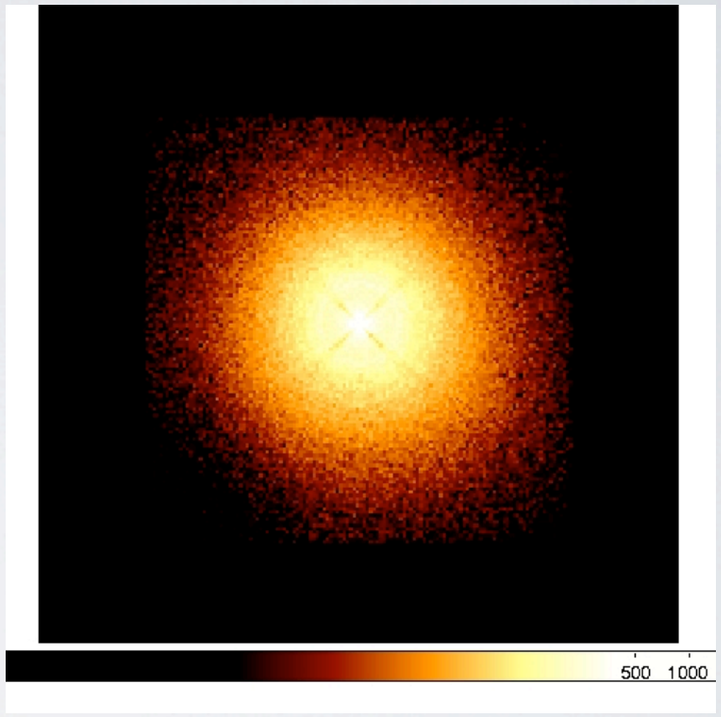
hydro-simulation



Gas element ~ single-temperature emitting plasma

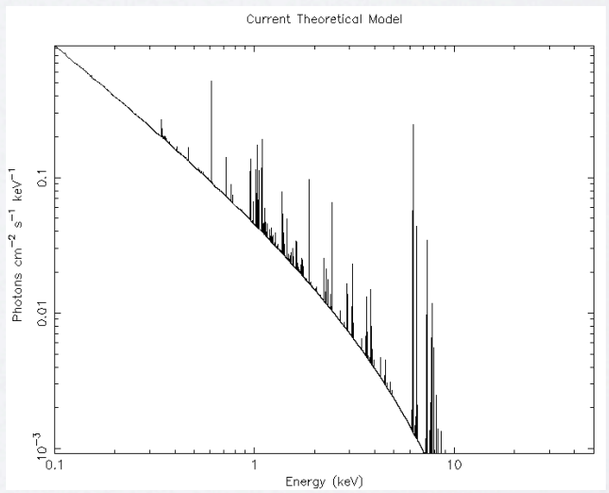
Emission in the X rays: spectrum → photons

mock observation

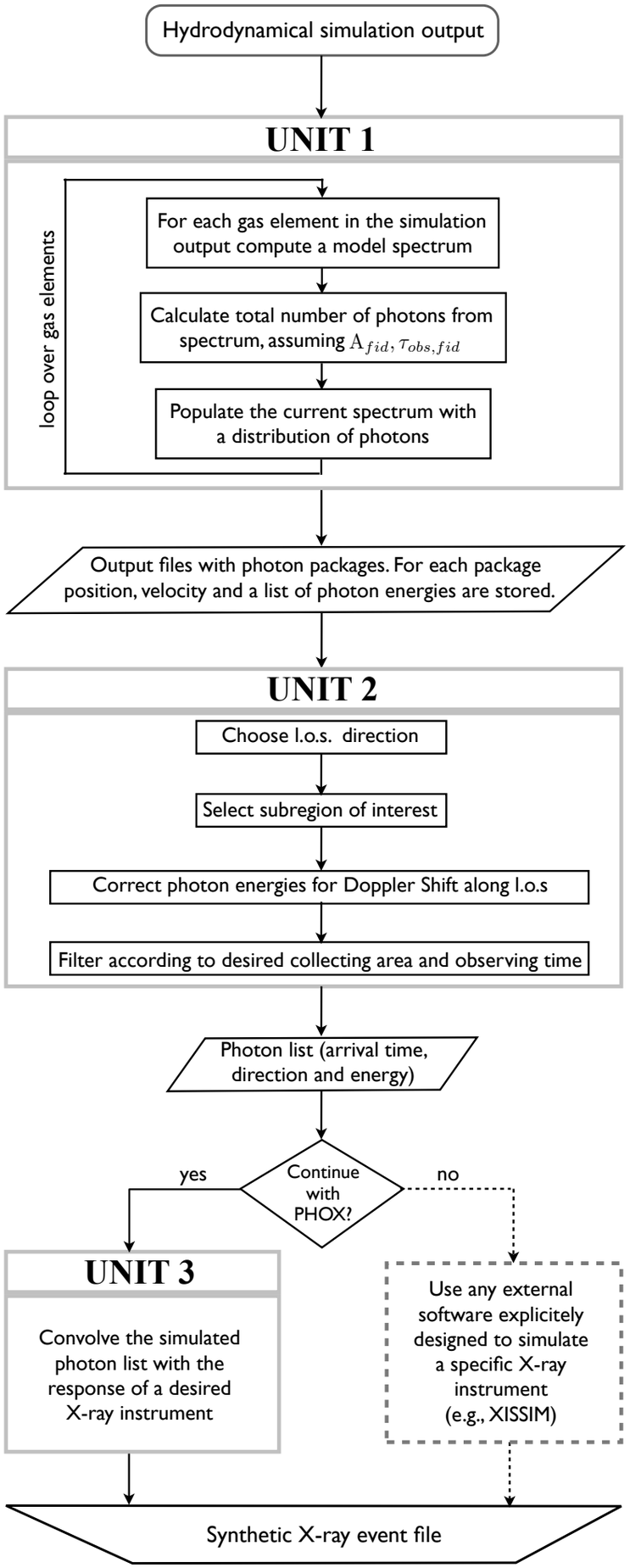


$\mathbf{x}_i, \mathbf{v}_i$

$(n,T,Z)_i$



PHOX



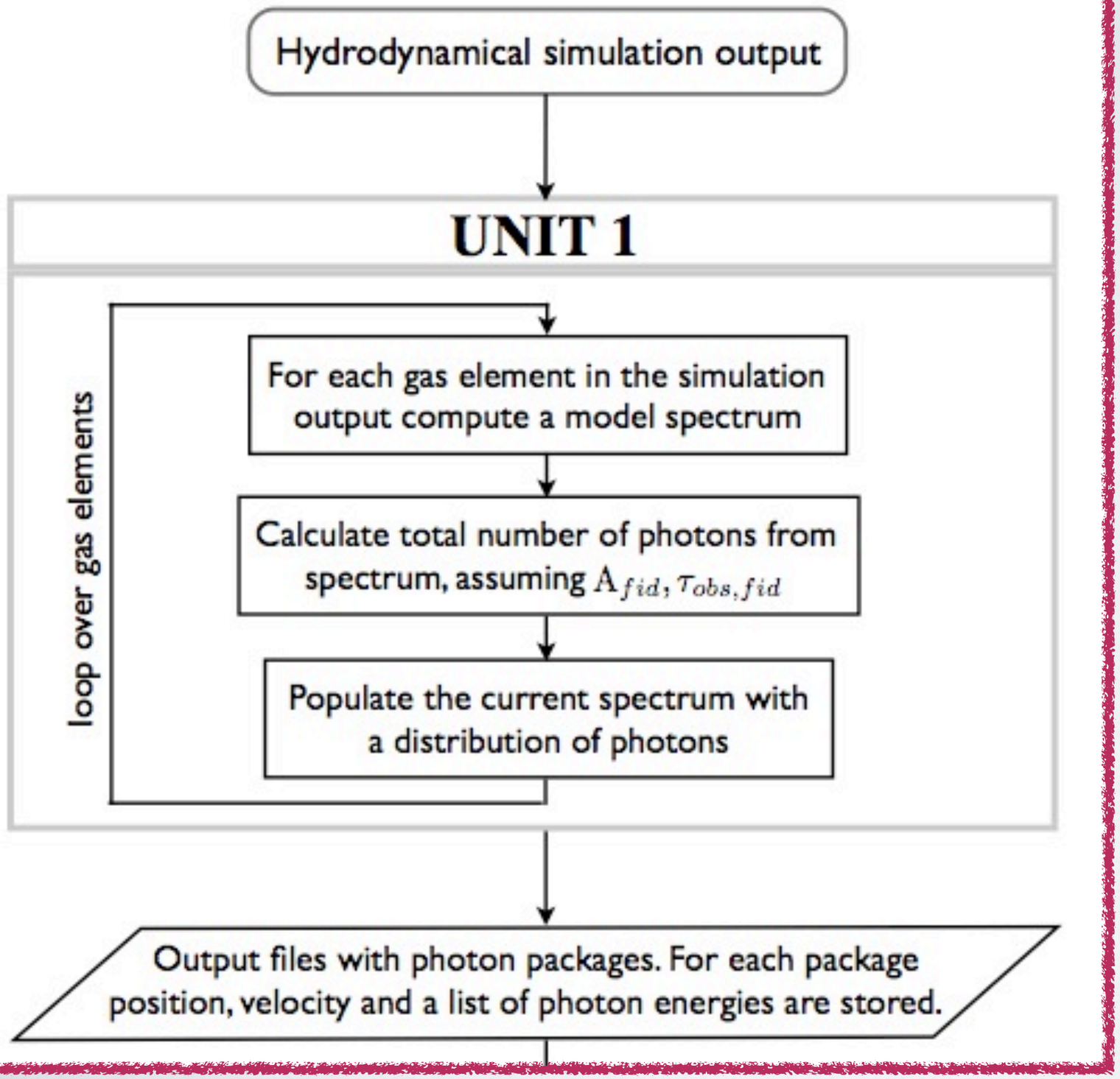
VB, Dolag, Böhringer, Lemson 2012, MNRAS

- **UNIT 1:** generation of the virtual cube of photons

- **UNIT 2:** geometrical selection and projection

- **UNIT 3:** convolution with the instrumental response

UNIT 1: GENERATION OF THE VIRTUAL CUBE OF PHOTONS

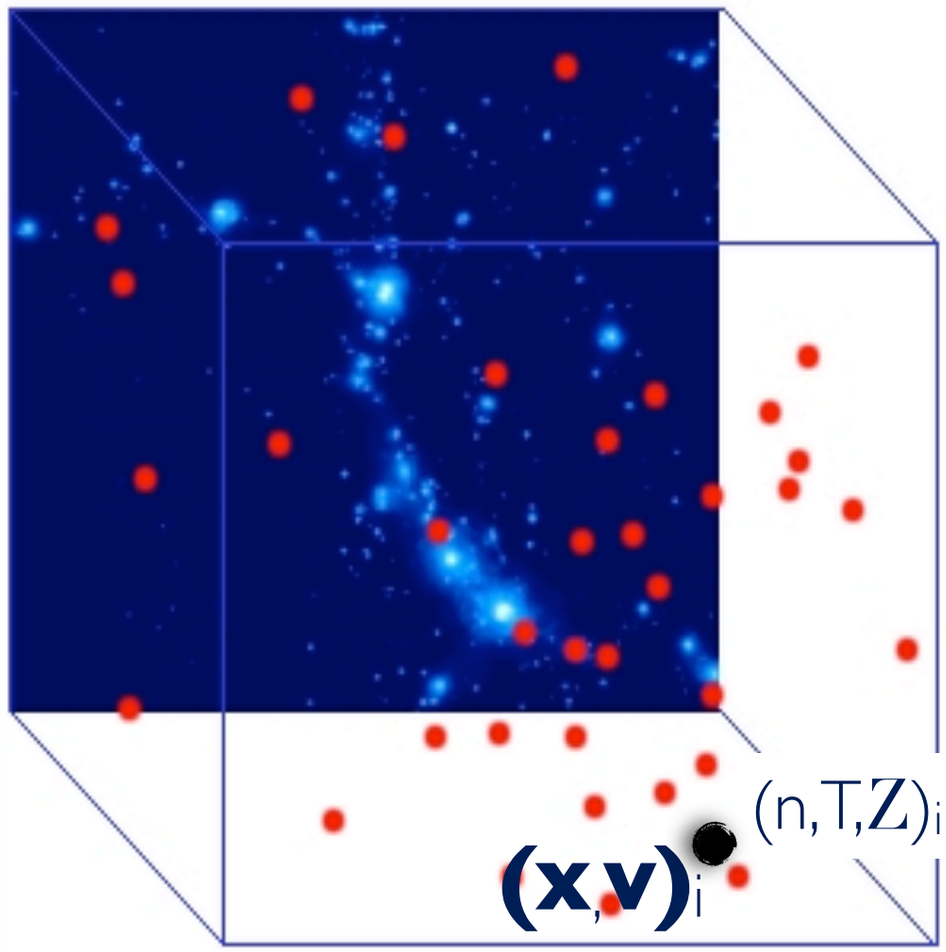


Advantages:

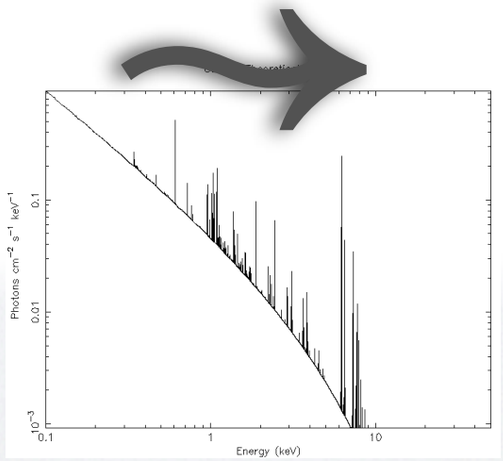
- Reduce all the computational effort to this first unit;
- No need for library of model spectra: easily increase # of gas parameters;
- Generality: no specifications about the mock observation or instrument.

Unit 1: from the simulation to the cube of photons

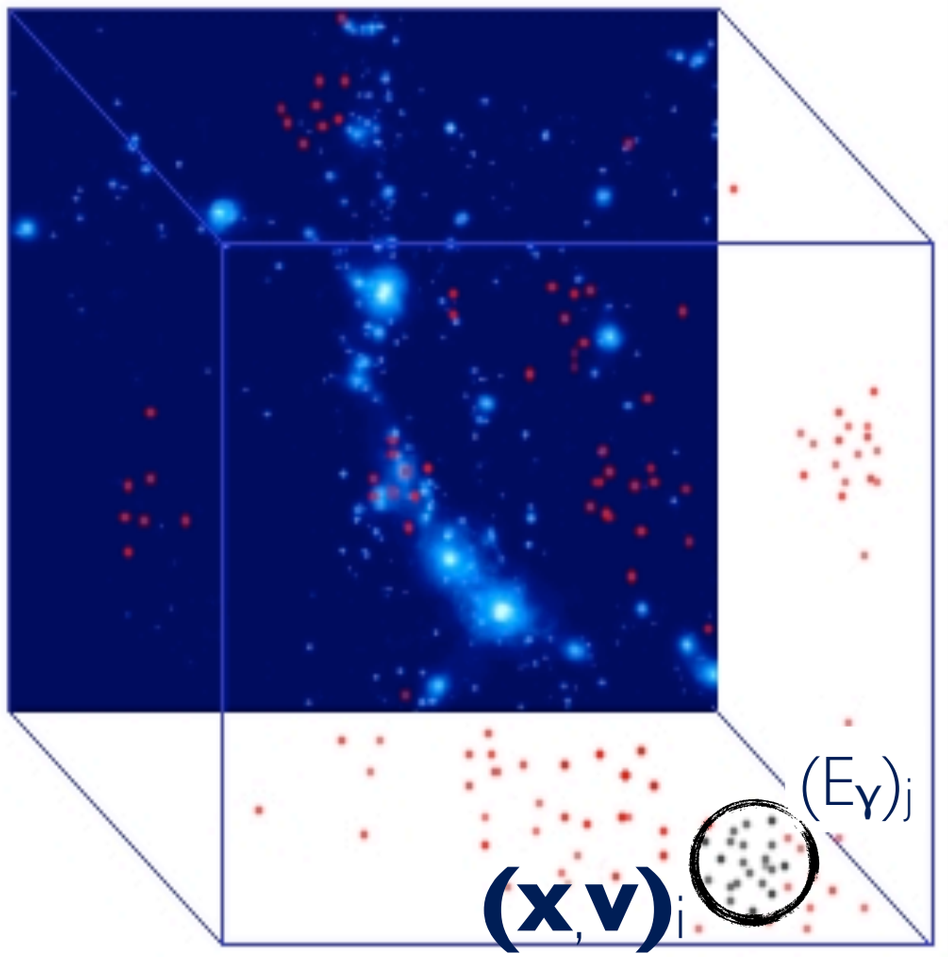
Hydrosimulation snapshot: cube of gas particles



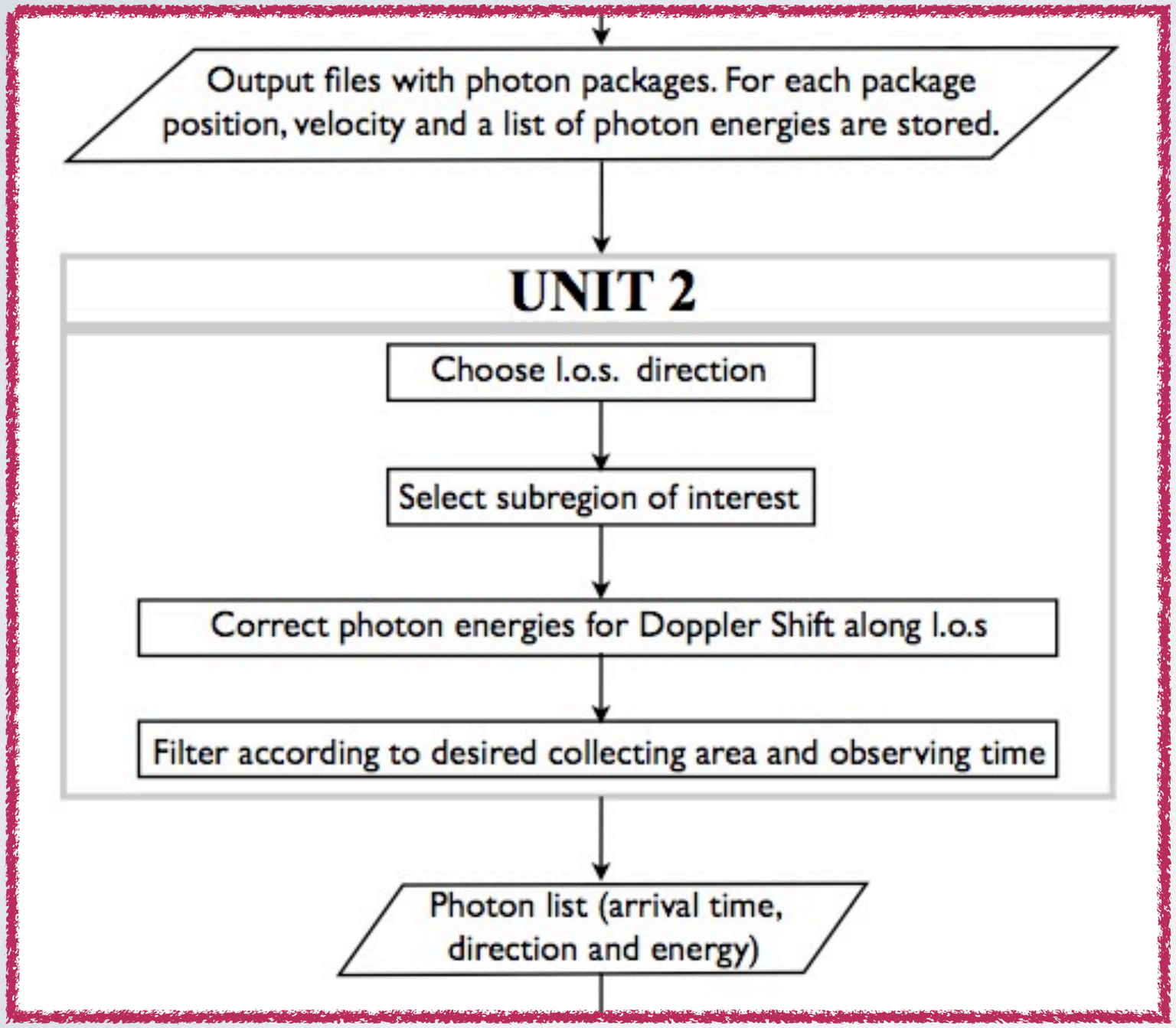
assume plasma emission model



Cube of virtual photons (1 photon-package per gas-particle)

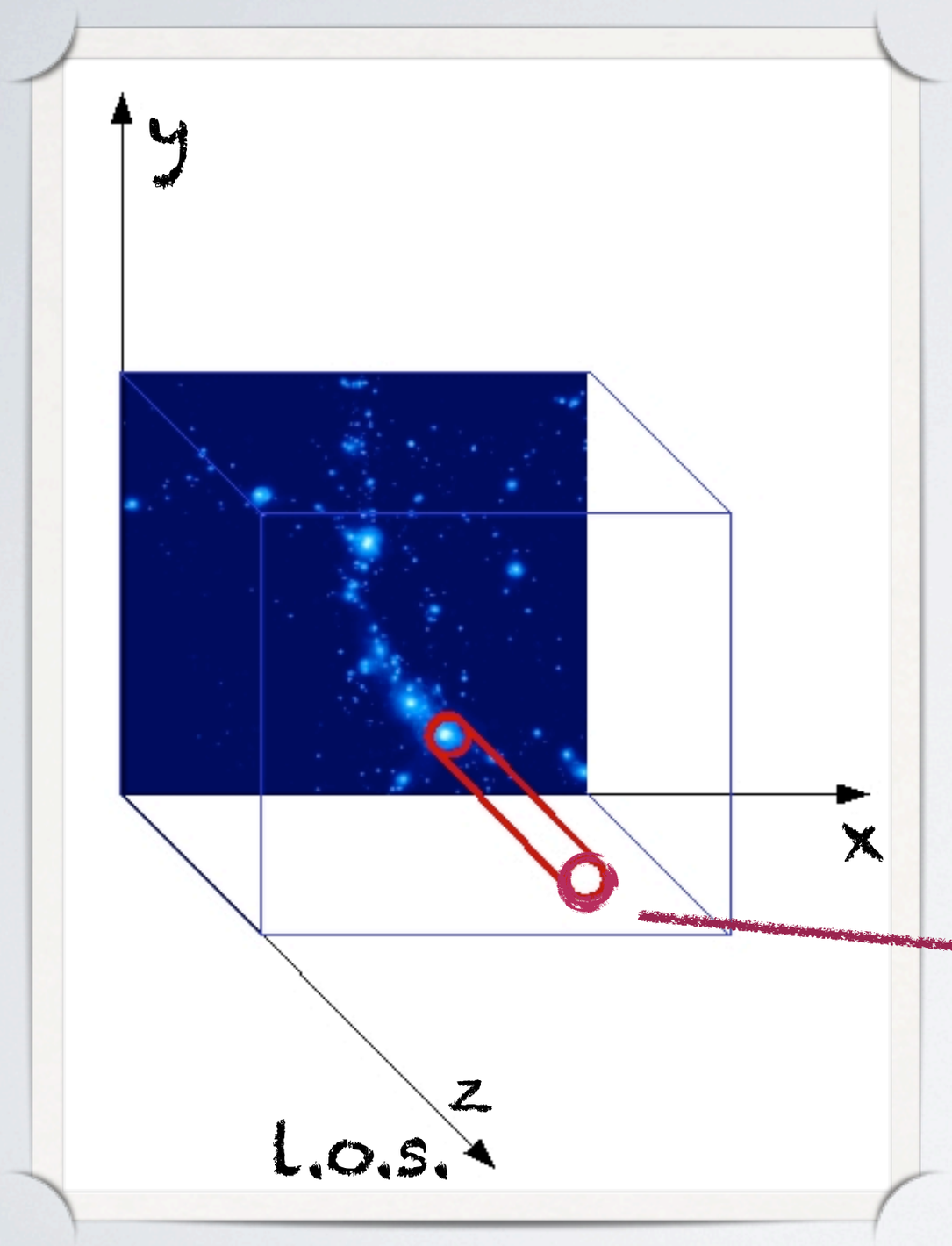


UNIT 2: GEOMETRICAL SELECTION AND PROJECTION

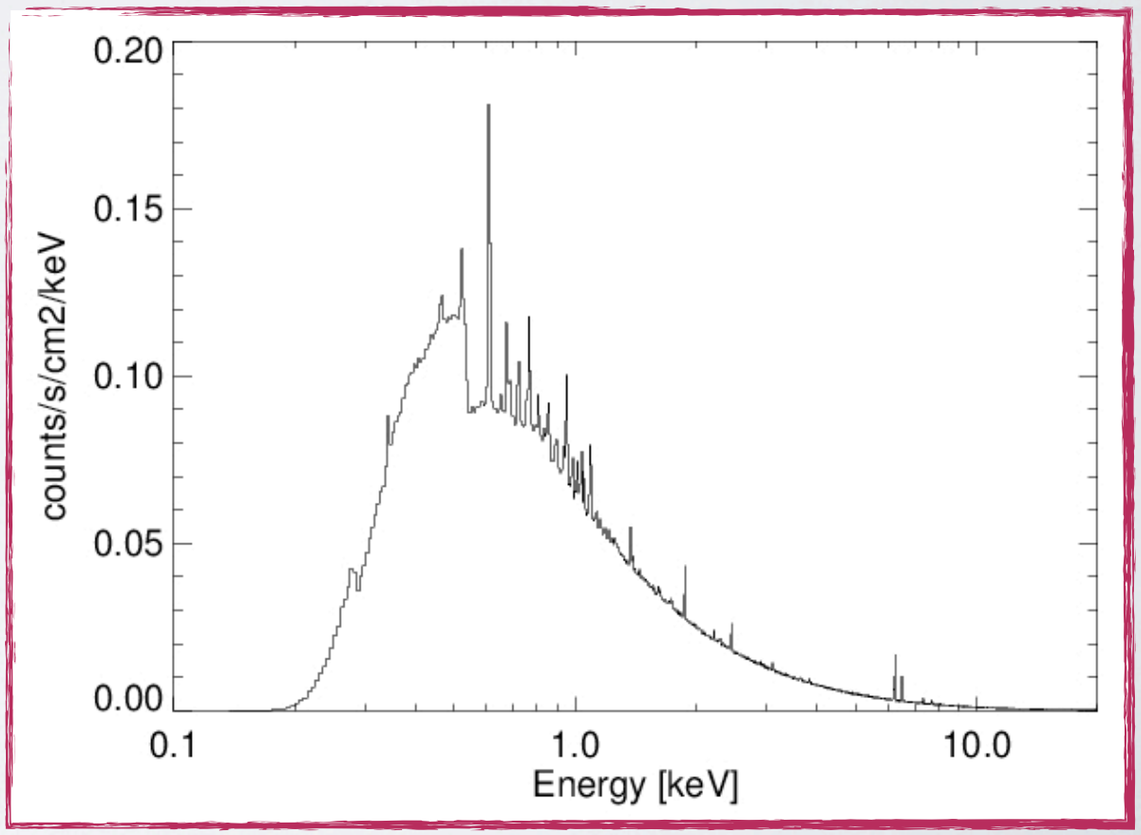


- Original simulation no longer required
- Extremely fast and computationally trivial
- Change very efficiently parameters (e.g. sub-region, l.o.s.)

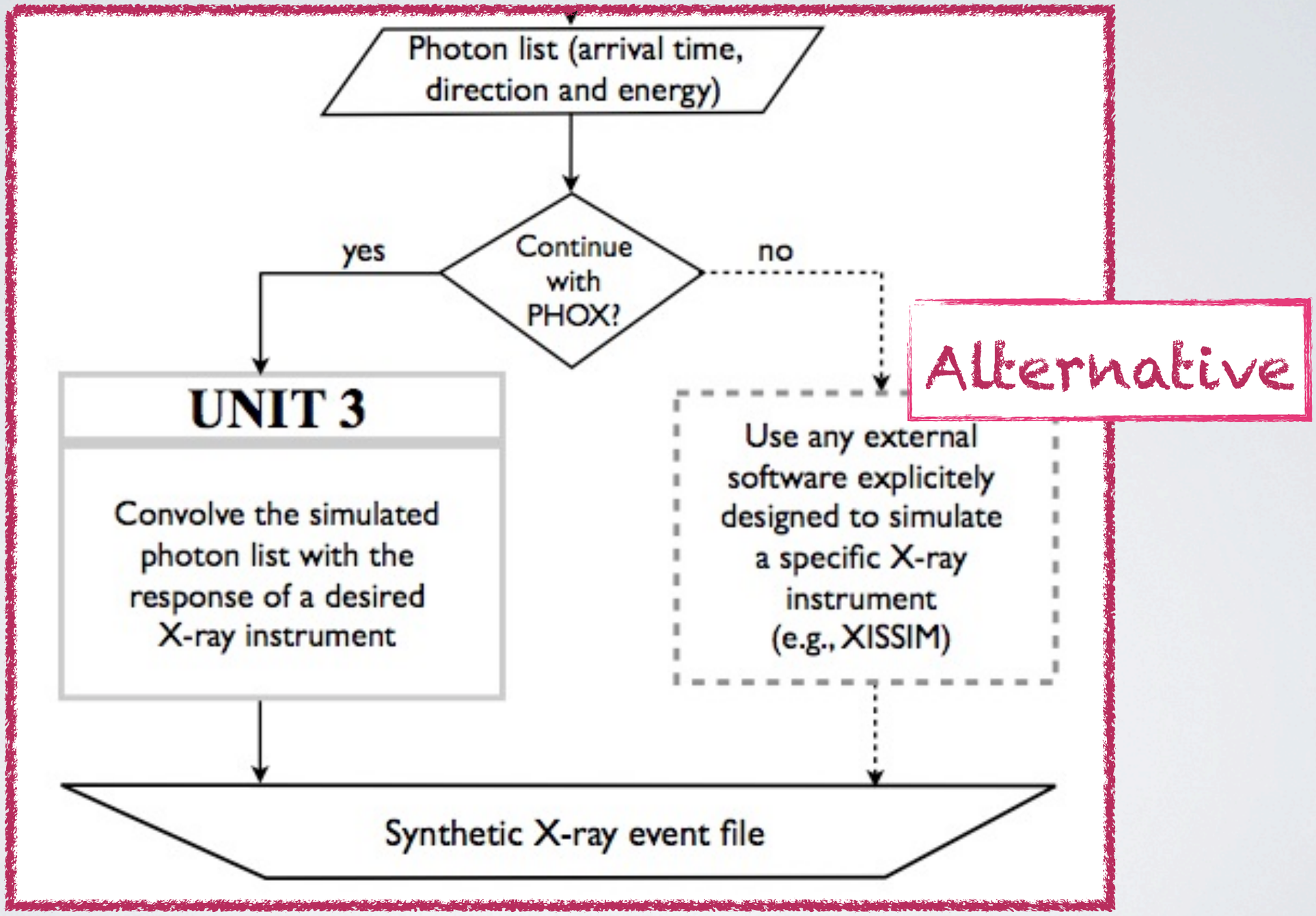
Unit 2: geometrical selection and projection



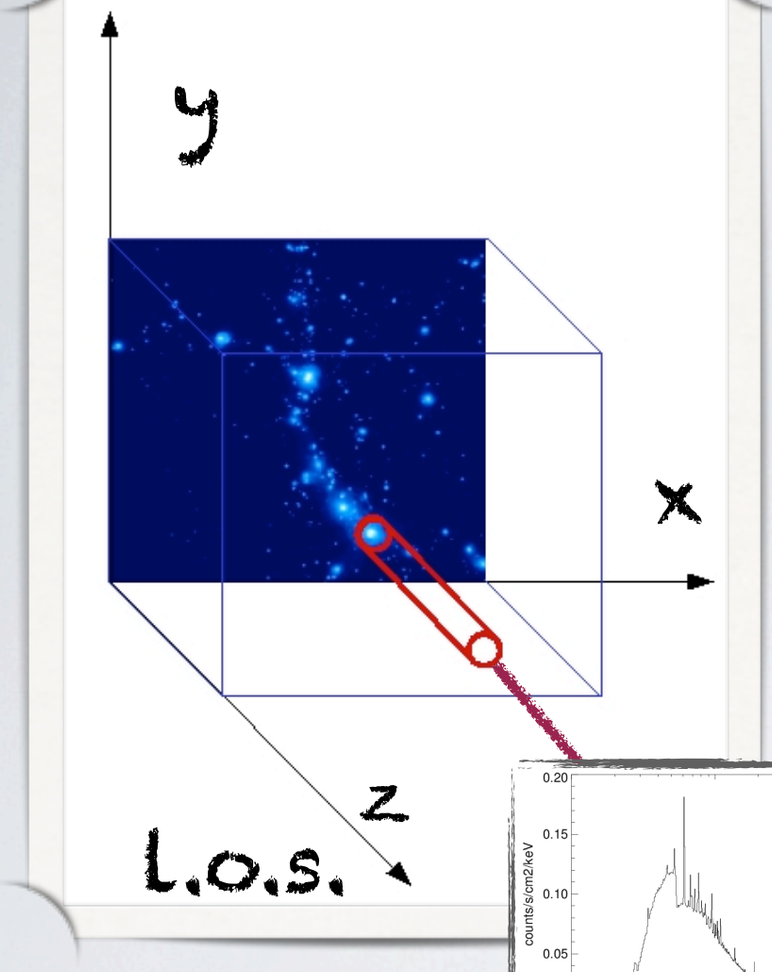
- Select a region containing cluster
- Correct ph energies for Doppler shift
- Rescale for specific observing time and collecting area
- Create ideal photon list

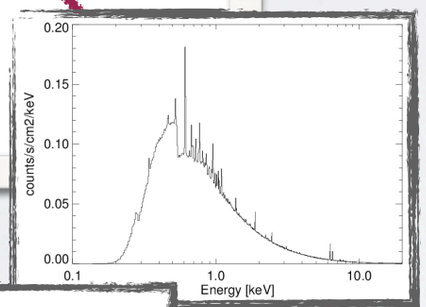


UNIT 3: CONVOLUTION WITH INSTRUMENTAL RESPONSE



Unit 3: convolution with instrumental response





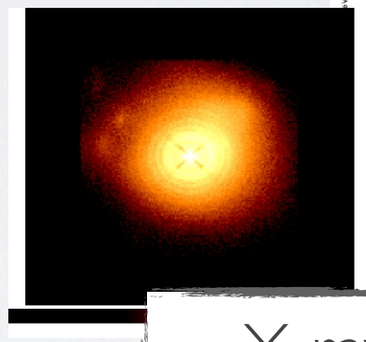
ideal photon list by Unit 2

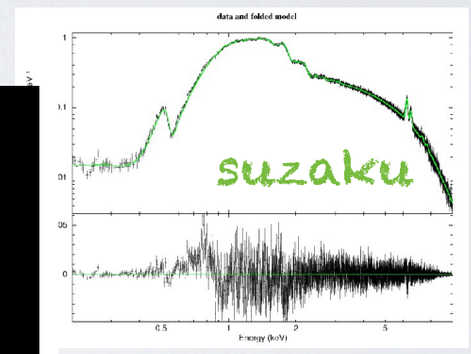
- Very fast and computationally trivial;
- Possibility to perform mock of same cluster with various X-ray instruments;
- Possibility to replace **Unit 3** with external, specifically-designed softwares like **XISSIM** simulator for Suzaku:

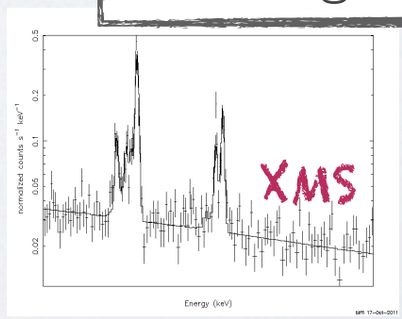
XISSIM

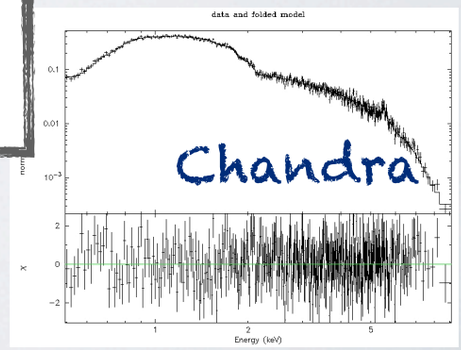
PHOX U3

X-ray spectrum & image









PHOX: ADVANTAGES & PERSPECTIVES

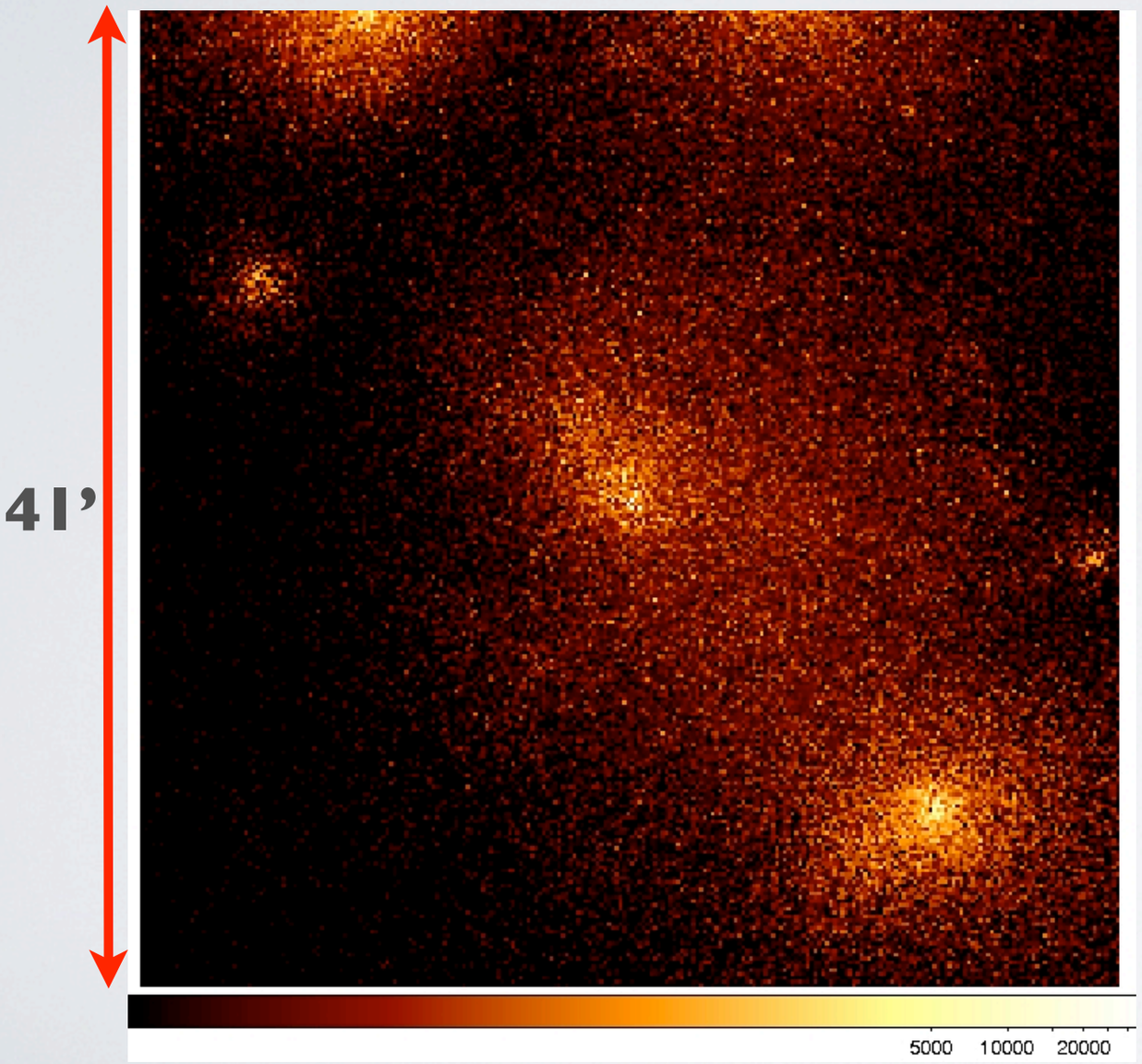
- **PHOX:** new photon simulator to obtain mock X-ray obs from hydrodynamical simulations.
  Original approach: **modular design** (3 independent units), **significant gain in computational time and effort.**

  - Unit 1: run only once per simulation, photon data cubes can be provided via databases accessible online (e.g. for MUSIC clusters);
  - Unit 2 & 3: computationally trivial

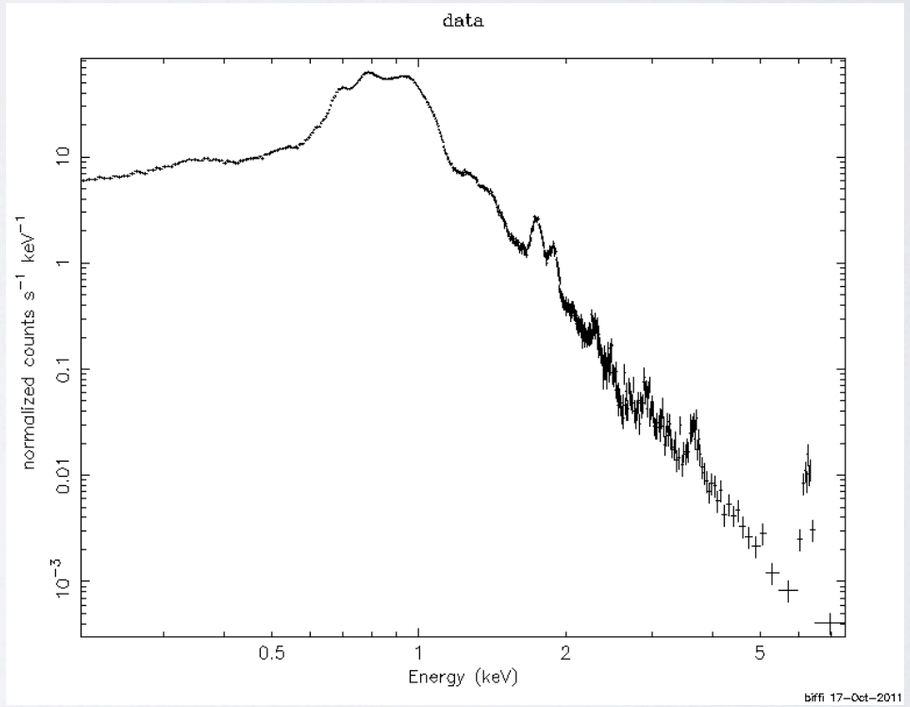
- **preserve high spatial and energy resolution**: simulate X-ray observational results from current and upcoming instruments (study of gas non-thermal velocity field from high-precision spectroscopic data; effect of thermal and velocity structure on global properties and **scaling relations**);
- perform, **very efficiently**, mock X-ray observations of large cosmic volumes;
- efficiently process and construct **vast catalogues of galaxy clusters**: **application to MUSIC clusters**.

PERSPECTIVES (I)

- Mock X-ray studies on large cosmological boxes and light-cones with feasible effort;

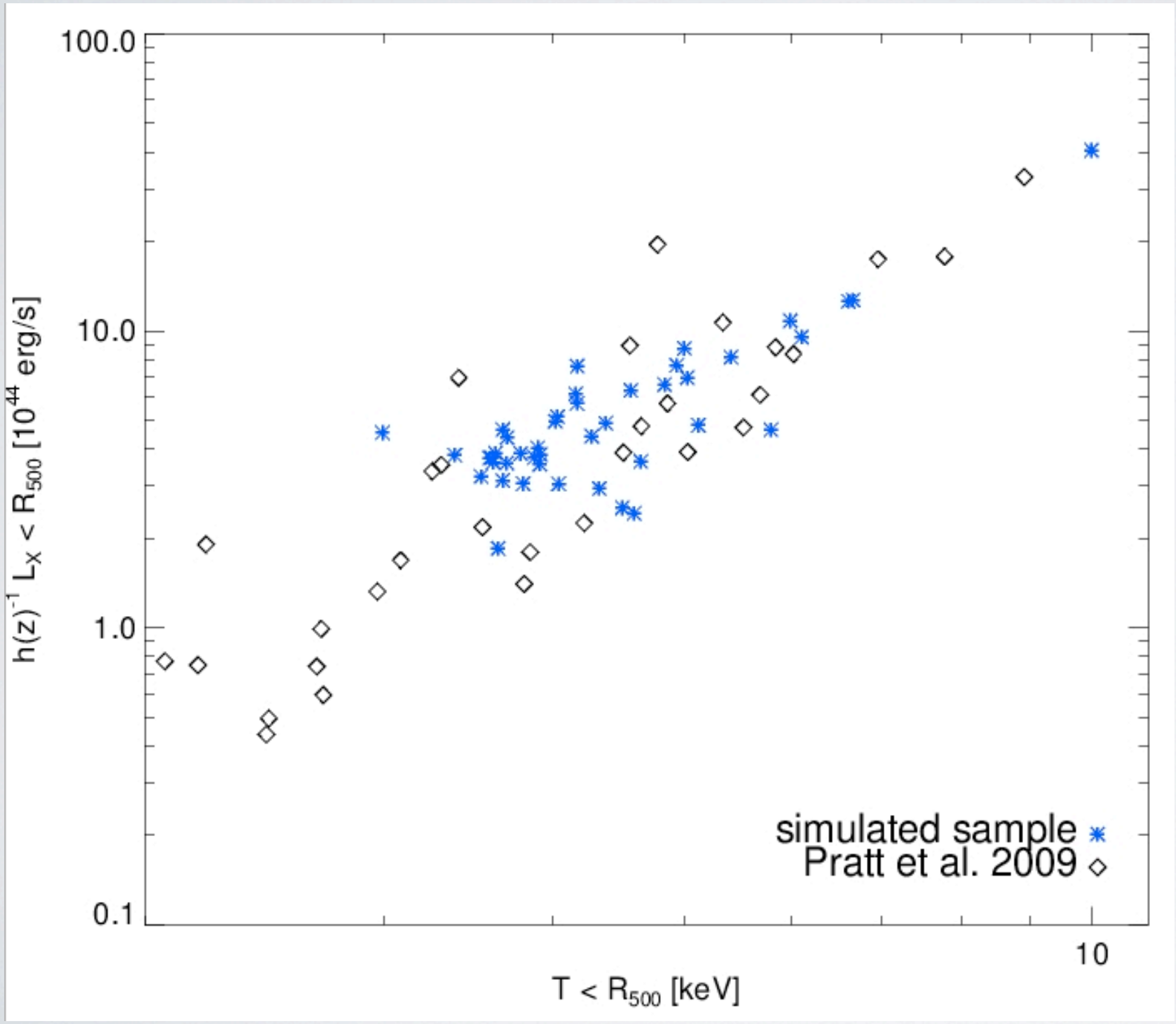


- predictions for large FoV surveys: e.g. **eRosita**



PERSPECTIVES (II)

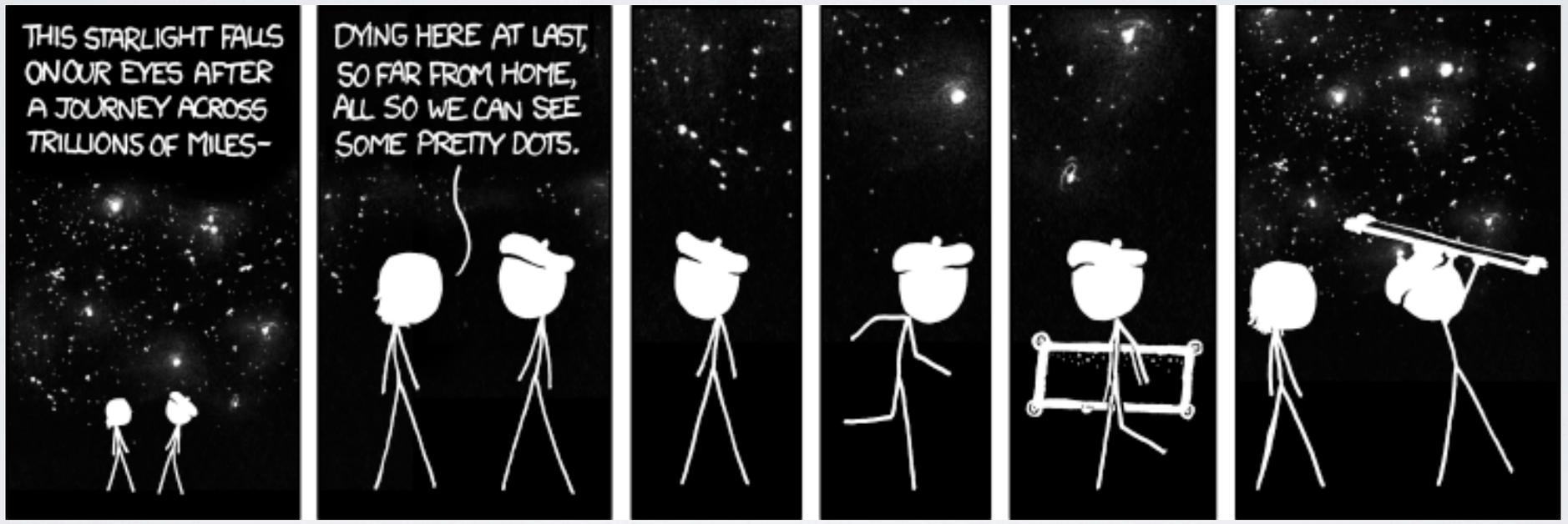
- Process **very efficiently large catalogues of clusters**, from the same photon cube obtained from a given simulation output;



sample of simulated clusters: **43 halos**

✓ mock Chandra observations obtained with PHOX

THANKS!


THIS STARLIGHT FALLS ON OUR EYES AFTER A JOURNEY ACROSS TRILLIONS OF MILES-
DYING HERE AT LAST, SO FAR FROM HOME, ALL SO WE CAN SEE SOME PRETTY DOTS.

SUZAKU observation of a simulated galaxy cluster

PHOX - unit 1

Application: Hydro-sim of a filament-like structure

performed with **GADGET-2**;

z~0.07; ~10^8 gas particles;

A_fid=2x10^3cm^2, **t_exp**=1 Ms → N_{ph} ~2x10^8

PHOX - unit 2

Application: selection of a cylinder containing the R500 region of a galaxy cluster

OBSERVATIONAL PARAMETERS:
A_xis = 1152.41 cm2
t_exp = 500 ks
-> XIS: ~1e6 ph

Suzaku FoV @ z=0.07 -> 1436.6 kpc
~ 0.51 R500

PHOX - unit 3 -> use XISSIM

Application: recover the ICM thermal structure from Suzaku spectrum.

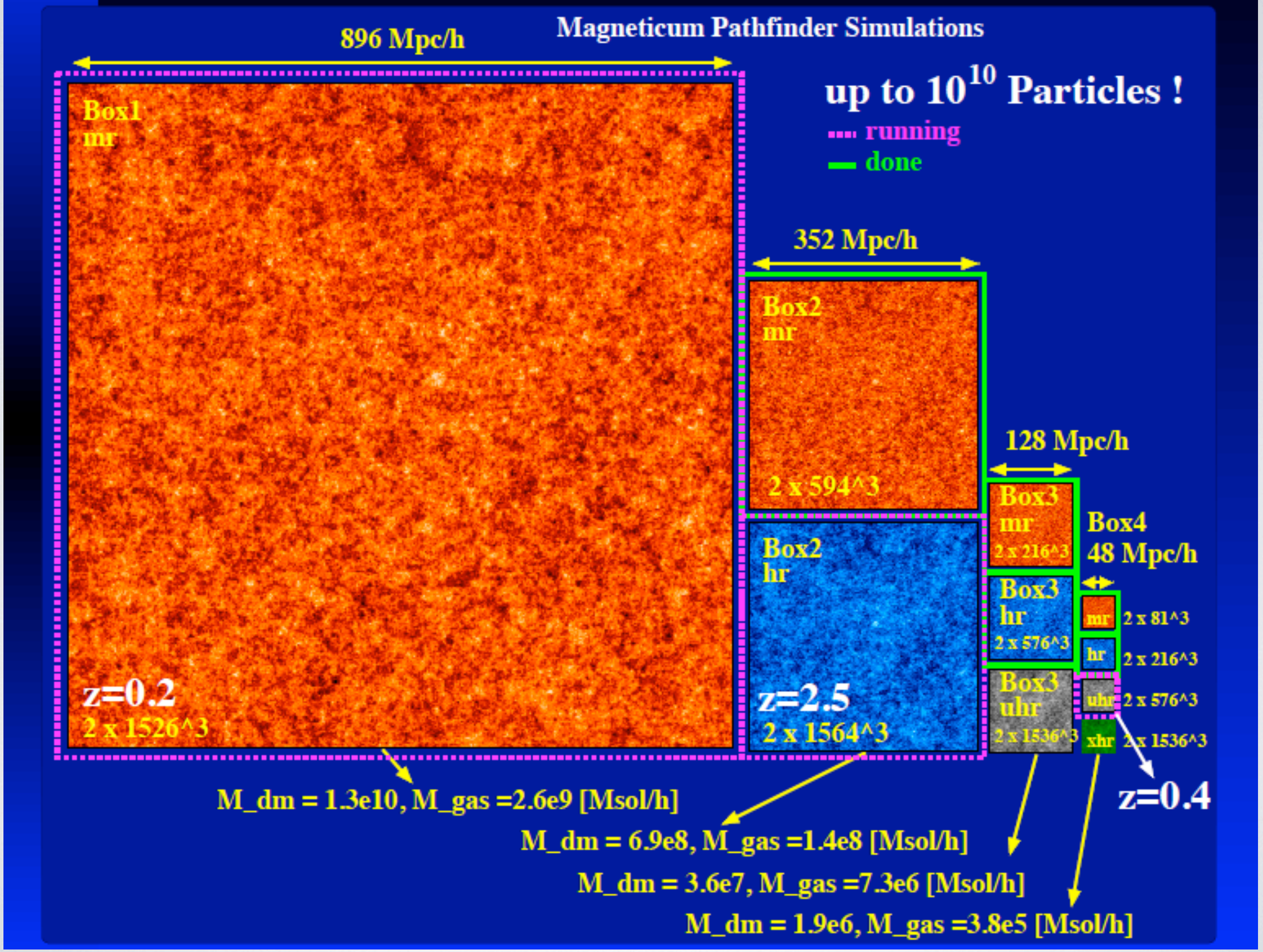
Model: 5-Temp APEC components

nH, Z_{abund}, z *frozen*

$kT_{1,2,3,4,5}$ = [0.69, 1.38, 2.75, **5.5**, 11] keV ,*frozen*

fit spectrum for: normalizations of the 5 models $K_{1,2,3,4,5}$

Magneticum Pathfinder



Magneticum Pathfinder

Physics to be included:

- cooling + star formation + winds Springel & Hernquist 2002/2003
- Metals, Stellar population and chemical enrichment, SN-Ia, SN-II, AGB Tornatore et al. 2003/2006
  + new cooling tables Wiersma et al. 2009
- BH and AGN feedback Springel & Di Matteo 2006, Fabjan et al. 2010
  + various modifications
- Low viscosity scheme to track turbulence Dolag et al. 2005
- Magnetic Fields (passive) Dolag & Stasyszyn 2009

Requirements:

- 16384 cores (BGP), ca. 1TB per snap, 40TB per sim.

Add ons:

- On the fly Sub-Find Springel et al. 2001/2010, Dolag et al. 2009
- Photometric code to assign optical/near-IR luminosities to galaxies (u,V,G,r,i,z,Y,J,H,K,L,M) Saro et al. 2006, Nuzza et al. 2010
- On the fly Cluster/Groups properties
- Novel sub-data access scheme allowing an efficient read-out of particles belonging to a galaxy cluster