The 2nd Shanghai Assembly on
Cosmology and Structure Formation

The hot gas distribution and mock X-ray observations in SAMs

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Zhong, Fu*, Sharma, Yates et al. 2023, MNRAS, 519, 4344
Zhong, Fu*, Shen, et al. 2023, RAA, 23, 5004

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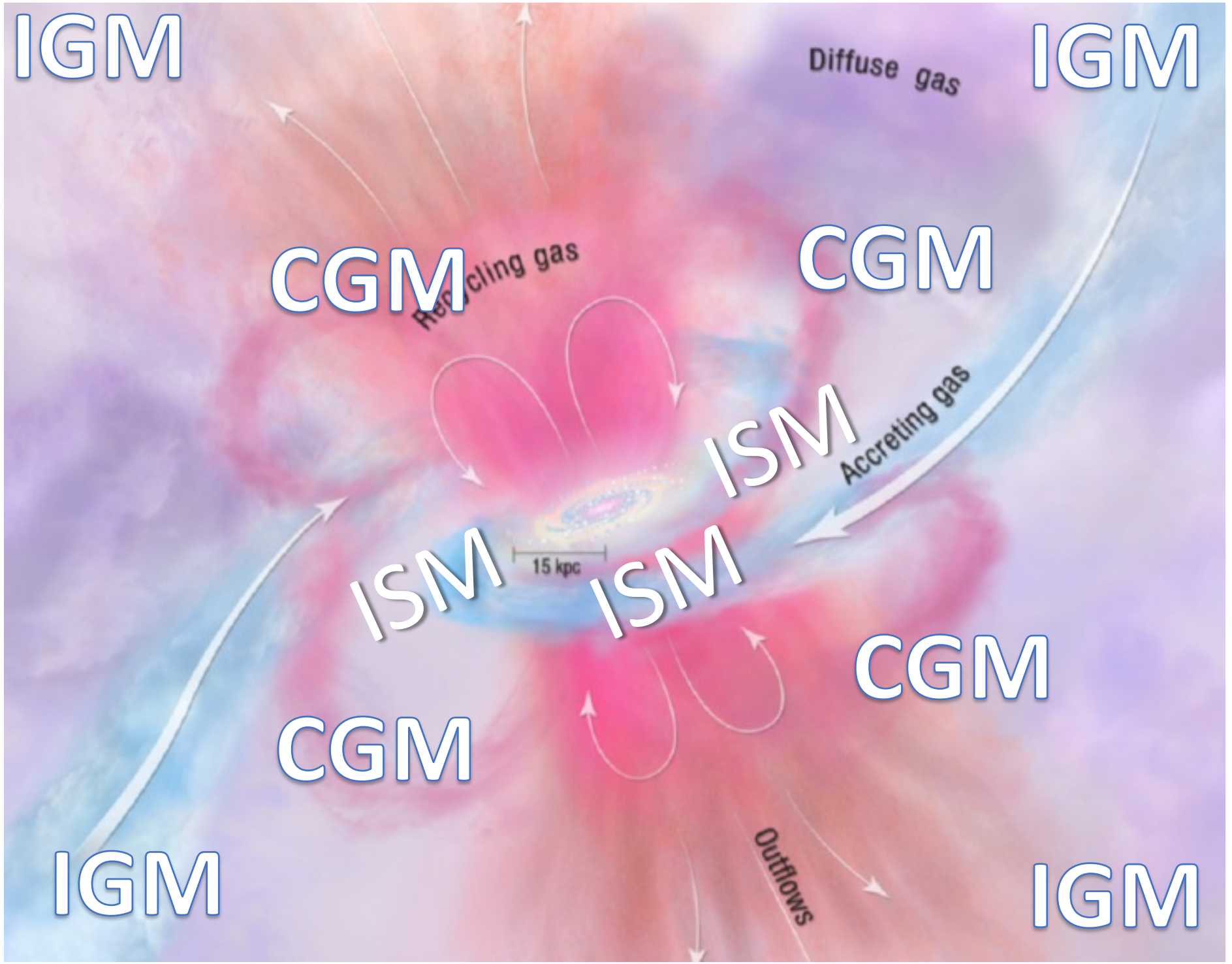
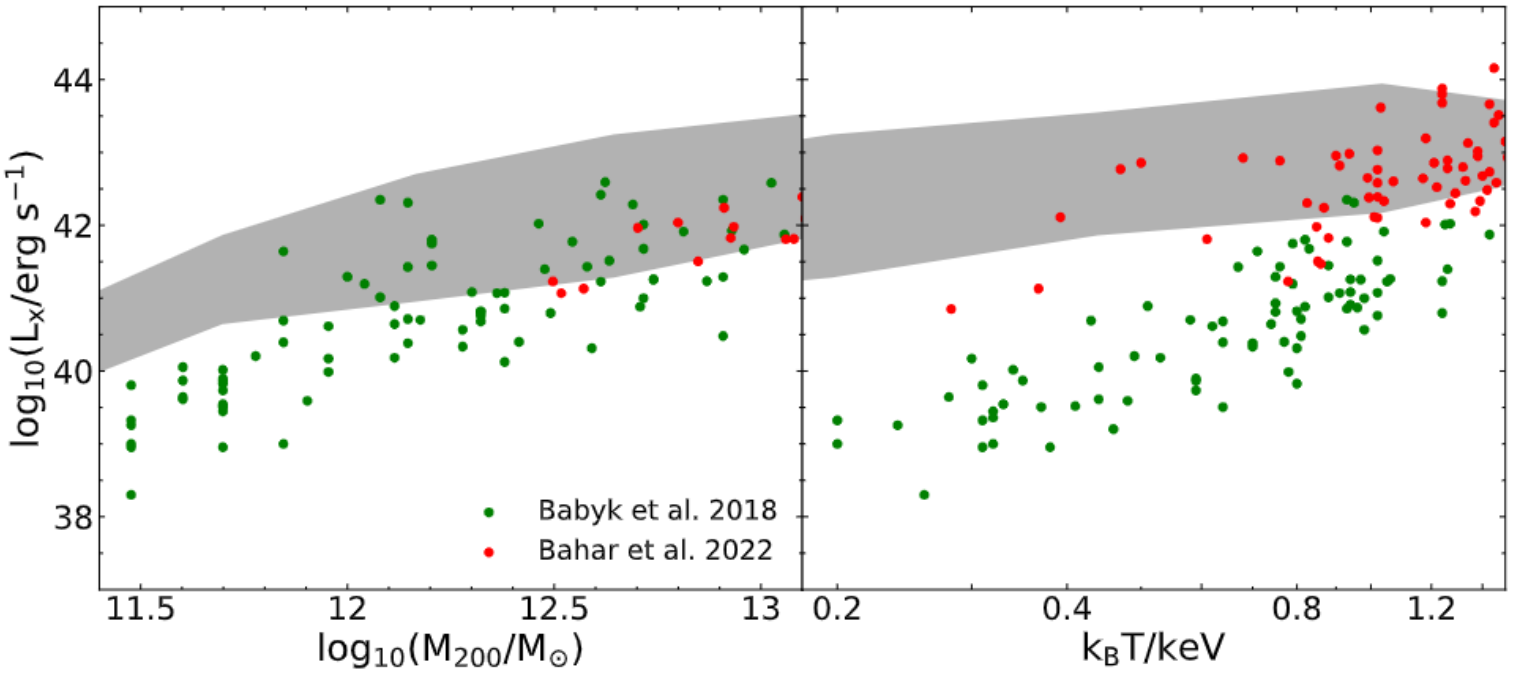

IGM
IGM
Diffuse gas
CGM
Recycling gas
CGM
ISM
Accreting gas
ISM
15 kpc
ISM
CGM
CGM
IGM
Outflows
IGM

motivation: prediction X-ray luminosity in L-Galaxies



- isothermal sphere ($\rho \propto r^{-2}$) too high at the inner region (β model or else)
- constant T_{gas} profile

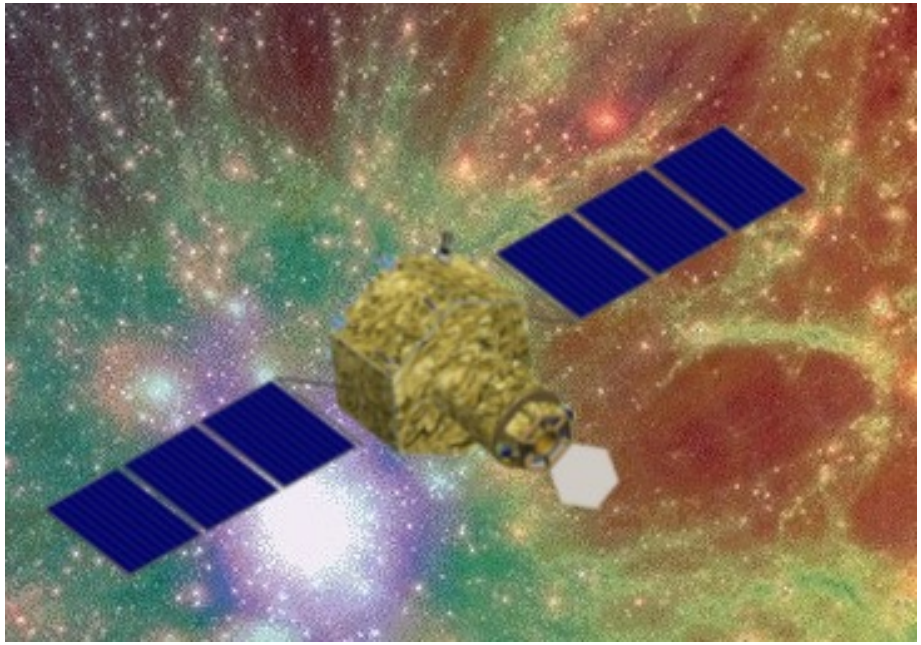
$$L_X \propto \dot{m}_{cool} v_{vir}^2$$

cooling and feedback decoupled: hard to make precise prediction for L_x

Mock X-ray observations for hot gas components

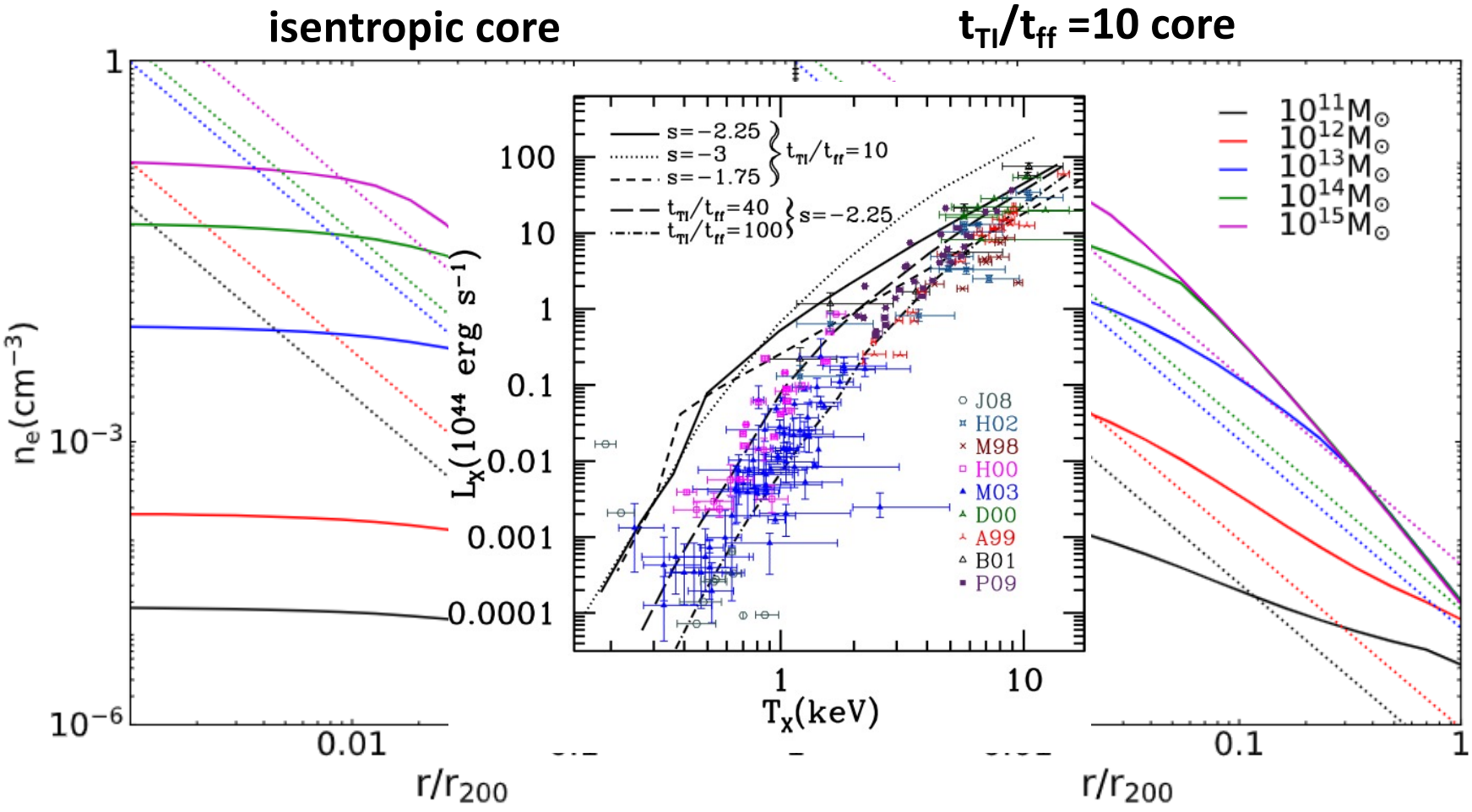
- Hot Universe Baryon Surveyor (**HUBS**)
  - soft X-ray band telescope (for hot CGM/IGM)
  - launched time: ~ 2030.
  - Main science target: missing baryons in hot gaseous halo

Key parameters	
Energy range	0.1-2 keV
Field of View	1° × 1°
Agular resolution	1′
Number of pixels	60×60
Effective area	500 cm^2
Spectral resolution	2 ev (main array) 0.6 ev (central)



Radial density profiles of hot ionized gas in CGM /IGM

- thermal instability models by Sharma et al. (2012)
- 1D radial distribution of hot gas profiles



Model parameters: M_{200}, f_b, c, f_d, redshift

Sharma12 profiles into L-Galaxies

M_{vir}, f_b, λ , z from L-Galaxies

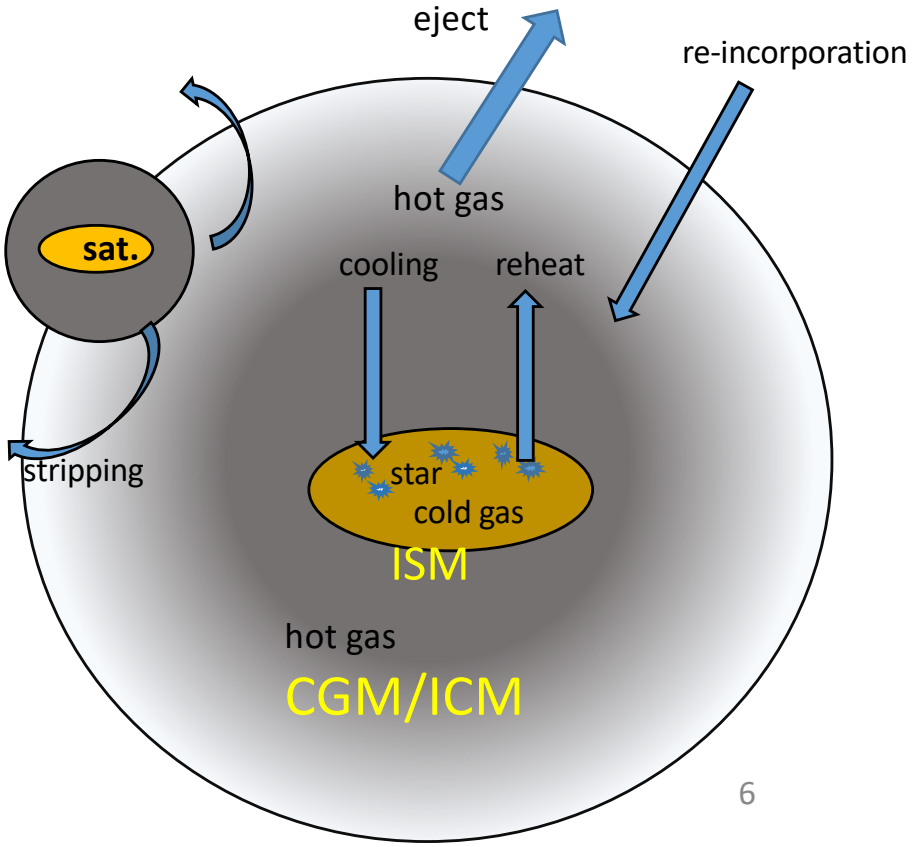
M_{200}, f_b, c, f_d, redshift

1D model code Sharma12+ → $\rho_{gas}(r)$, T(r)

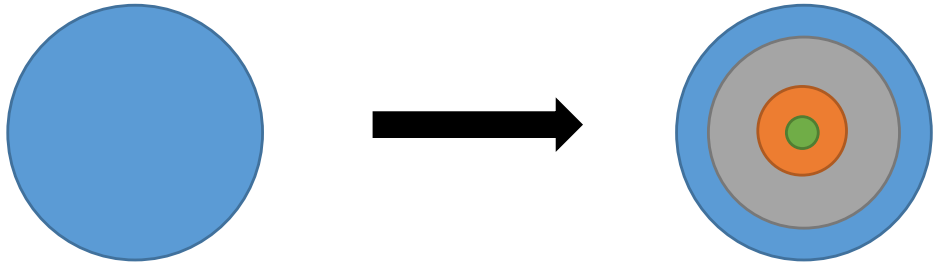
Baryonic processes in L-Galaxies 2015 → Model outputs

Prescriptions related to hot gas

- Cooling and infall
- Stripping: ram pressure & tidal
- Feedback: SN & AGN



Radial concentric shells in the halo



- Get the radial profiles of the hot gas
- Update the profiles in each time step, do not trace profiles between time steps
- Assume homogeneous metallicity in hot gaseous halo

Gas infall and cooling

Quasi-static cooling

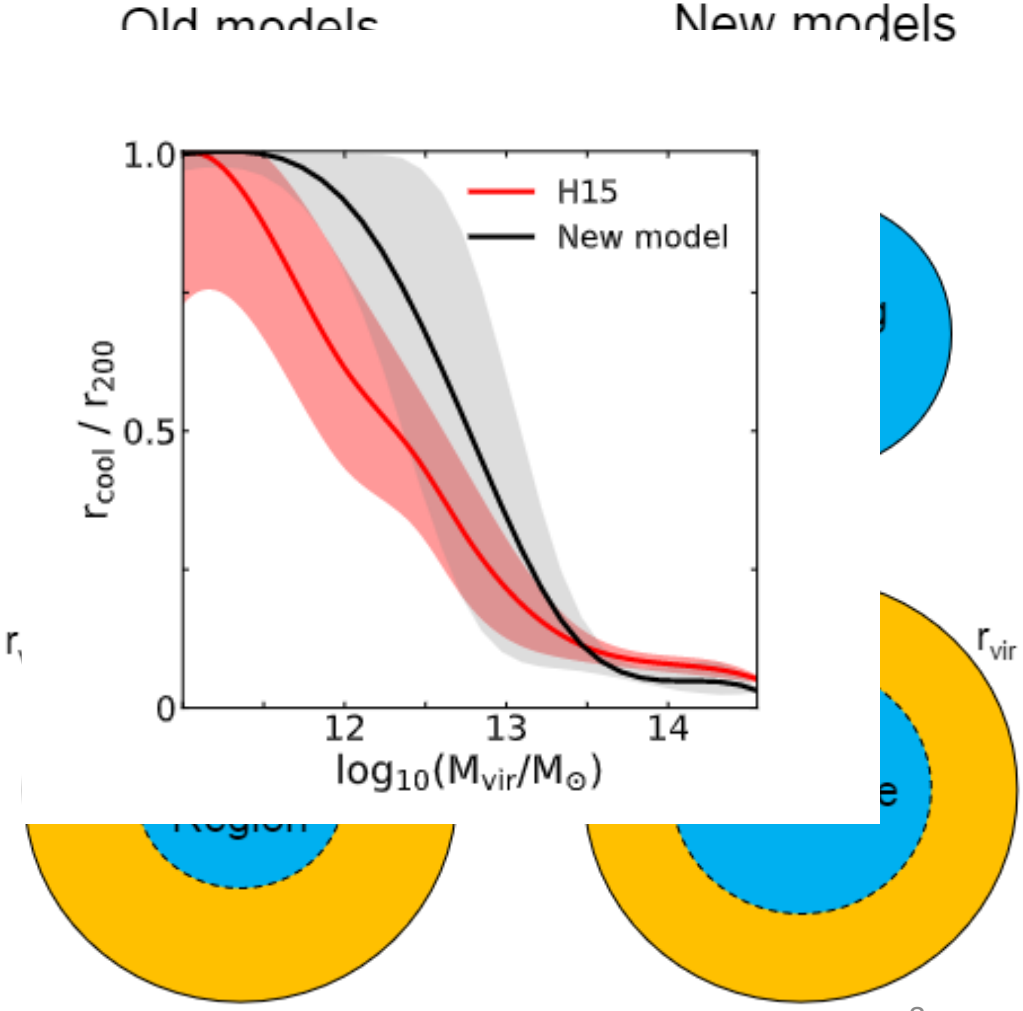
- old: cooling region ($t_{cool}<t_{dyn}$)
- new: cool core ($t_{TI}/t_{ff}<10$)

Rapid cooling

- old: $r_{cool}=r_{vir}$
- new: $t_{TI}/t_{ff}<10$ at r_{vir}

Cooling time scale

- old: t_{dyn}
- new: $t_{infall}=r_{core}/v_{vir}$



Prescriptions of ram pressure & tidal stripping

- tidal stripping

old: $\frac{m_{\rm hot,infall}}{m_{\rm DM,infall}} = \frac{m_{\rm hot}\left(r_{\rm tidal}\right)}{m_{\rm DM,tidal}}$

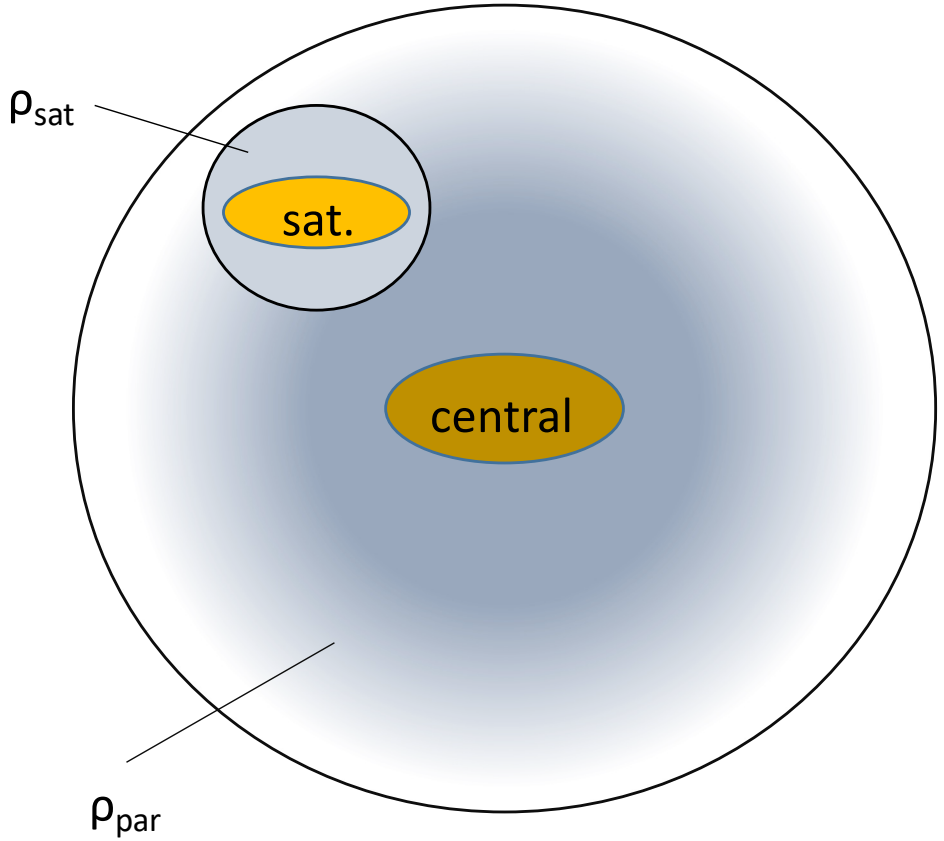
new:

$m_{\rm DM,tidal} = m_{\rm DM,infall}\left(r < r_{\rm tidal}\right)$

- ram pressure

$\rho_{\rm hot,sat}(r_{\rm rp})v_{\rm sat}^2 = \rho_{\rm hot,cen}(r)v_{\rm orbit}^2$

$r_{\rm strip} = \min\left(r_{\rm tidal}, r_{\rm rp}\right)$



Feedback prescriptions

SN reheating and ejection

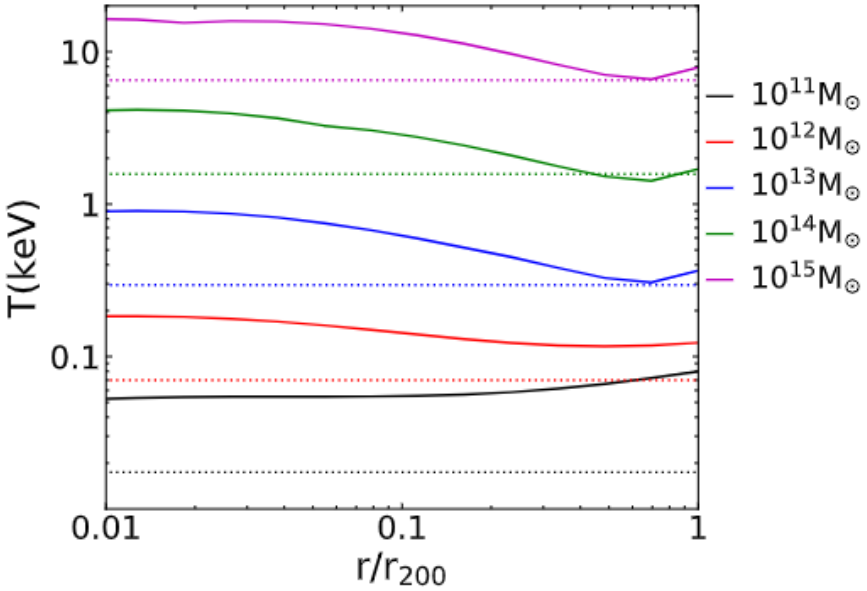
$$\text{old: } \Delta E_{\text{reheat}} = \frac{1}{2}\Delta m_{\text{reheat}} v_{\text{vir}}^2$$

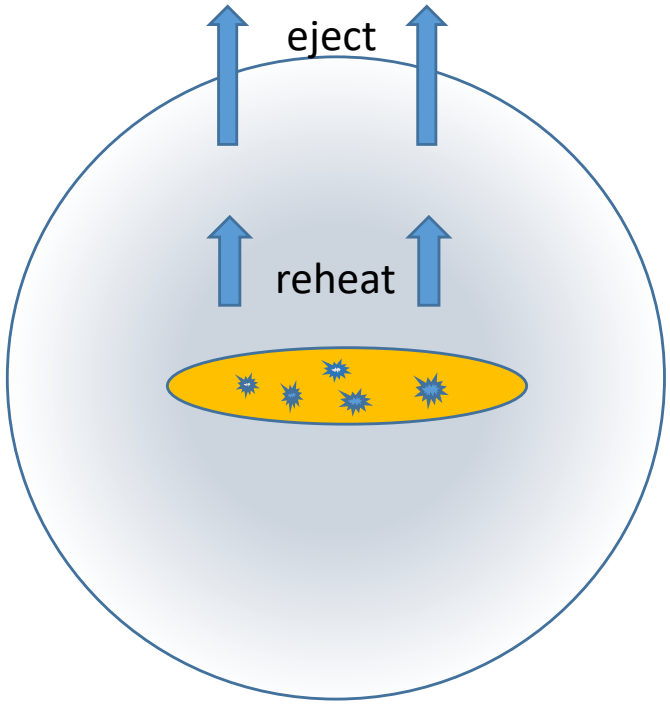
$$\text{new: } \Delta E_{\text{reheat}} = \frac{3k_{\text{B}}}{2\bar{\mu} m_{\text{H}}}\left[m_{\text{hot}}^{+}\bar{T}_{\text{hot}}^{+} - \bar{T}_{\text{hot}}^{-} m_{\text{hot}}^{-} \right]$$

$\bar{T}_{\text{hot}}$: mass-weighted mean temperature

mass of SN ejection $\left(\Delta E_{\text{SN}} > \Delta E_{\text{reheat}}\right)$:

$$\Delta m_{\text{eject}} = \frac{\Delta E_{\text{SN}} - \Delta E_{\text{reheat}}}{v_{\text{vir}}^2 / 2}$$



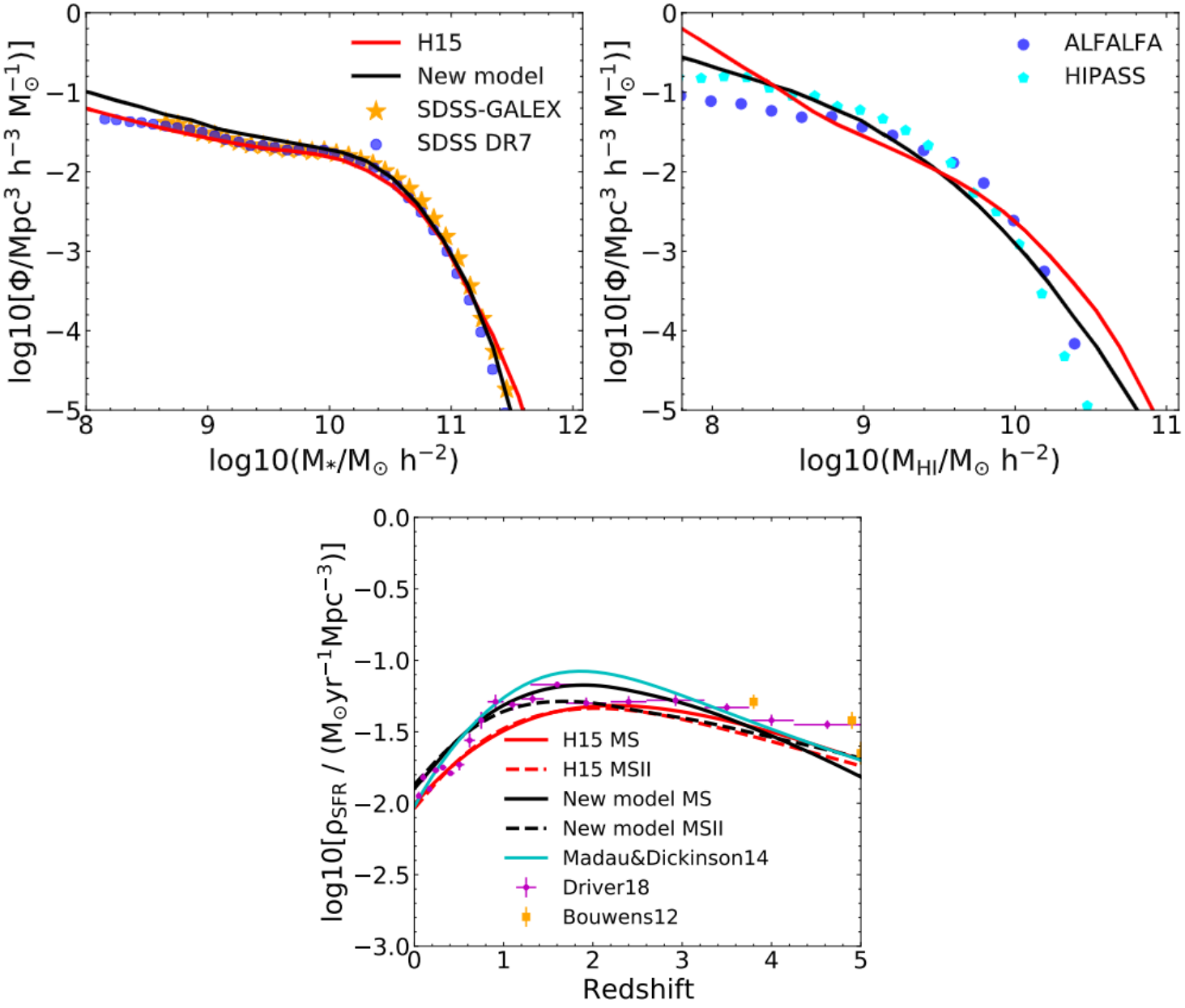


AGN feedback (radio mode)

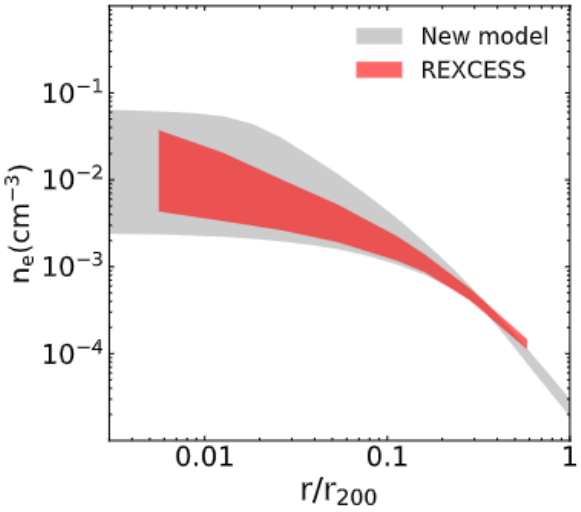
$$\text{old : } \dot{m}'_{\text{cool}} = \dot{m}_{\text{cool}} - \frac{L_{\text{BH}}}{v_{\text{vir}}^2 / 2}$$

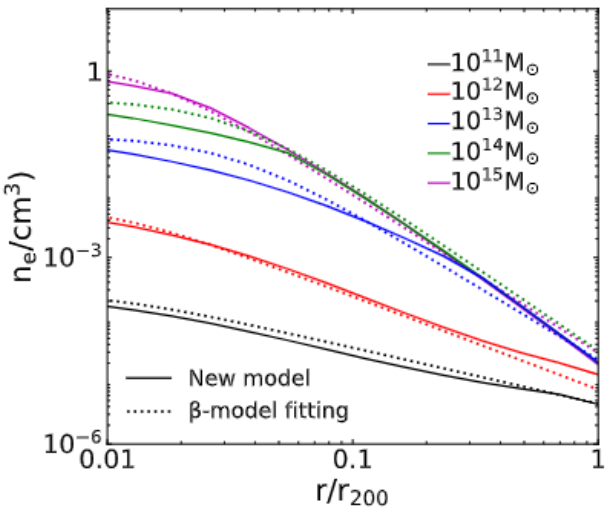
$$\text{new: } \dot{m}'_{\text{cool}} = \dot{m}_{\text{cool}} - \frac{L_{\text{BH}}}{3k_B \bar{T}_{\text{hot}} / 2\bar{\mu} m_{\text{H}}}$$

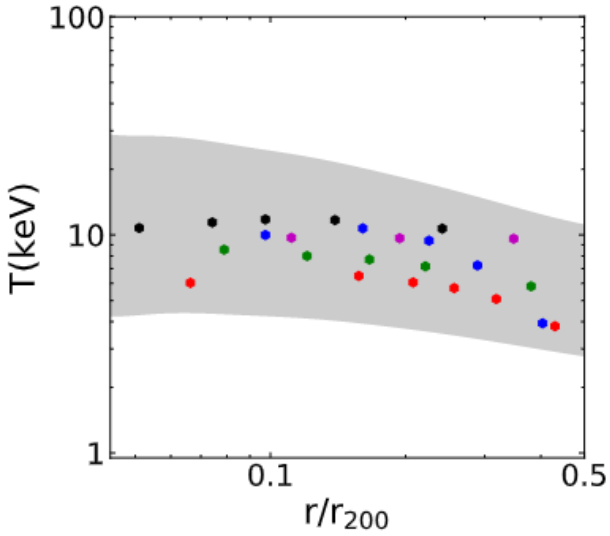
Model calibrations



Gas Density & Temperature profiles





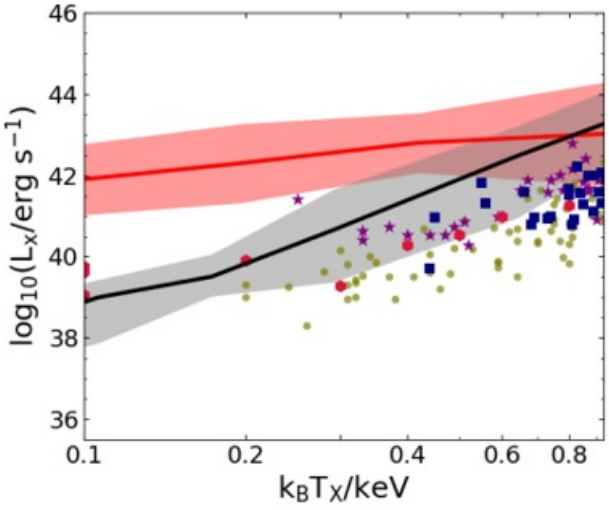


Results: scaling relations of soft X-ray emission from hot gas

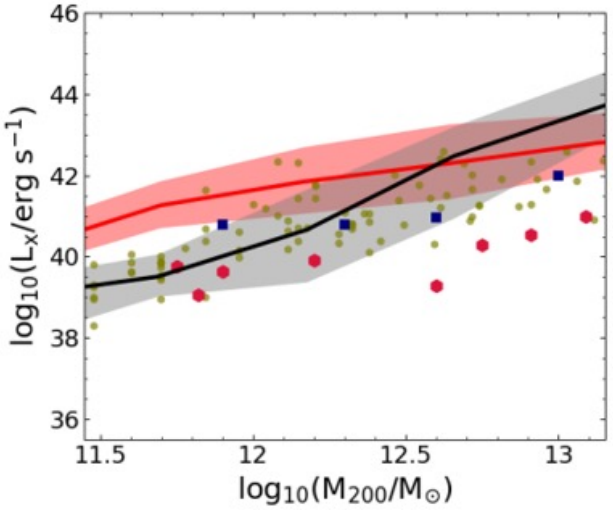
$$L_X = 4\pi \int n_e(r) n_i(r) \Lambda(T(r), Z) r^2 dr$$

Clusters

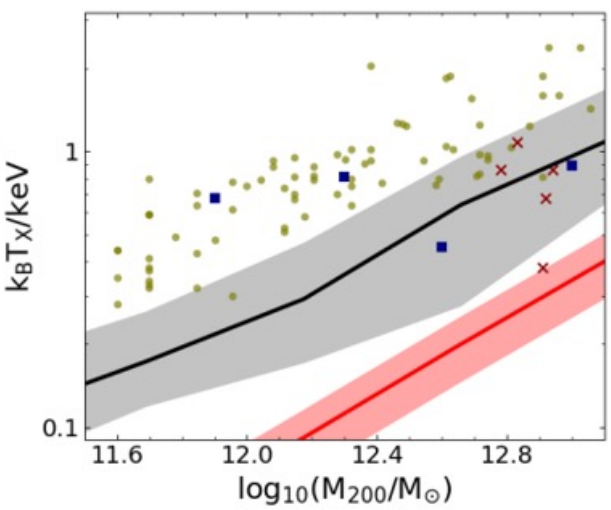
$L_X \sim T_X^{4.5}$



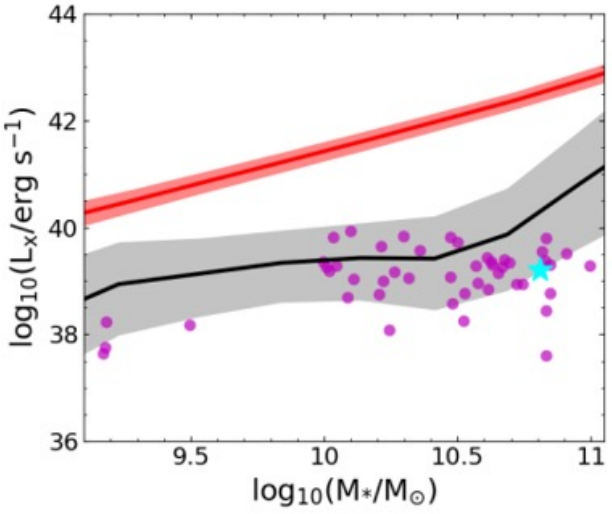
$L_X \sim M_{200}^{2.5}$

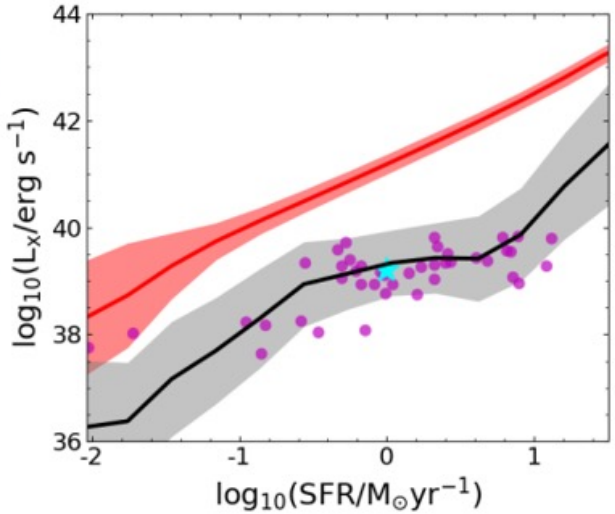


$M_{200} \sim T_X^{2.0}$

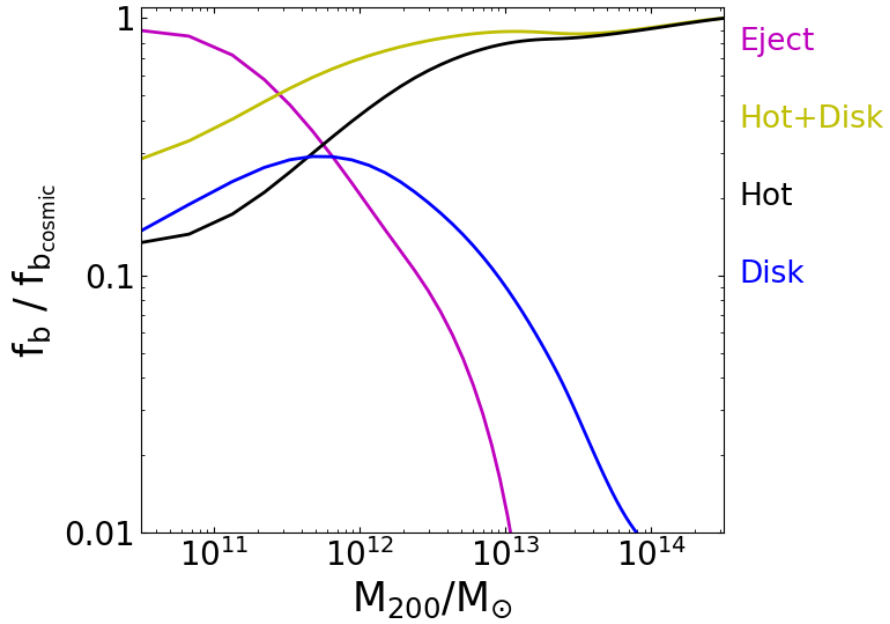


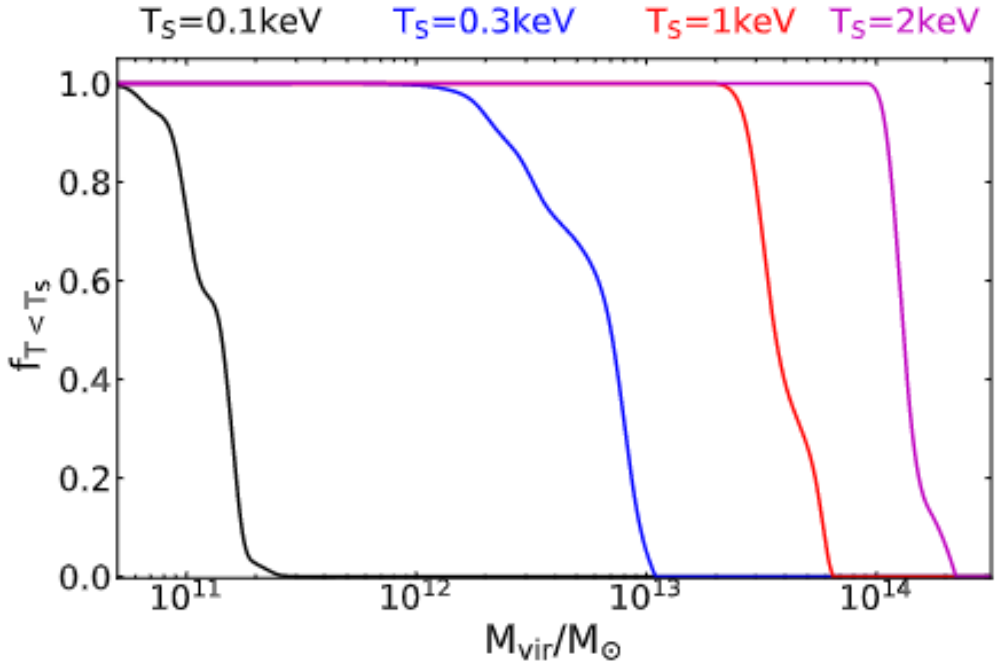
Galaxies





Baryon budgets and missing baryons





Unbounded reservoir out of halo potential

Hot gas in low mass haloes

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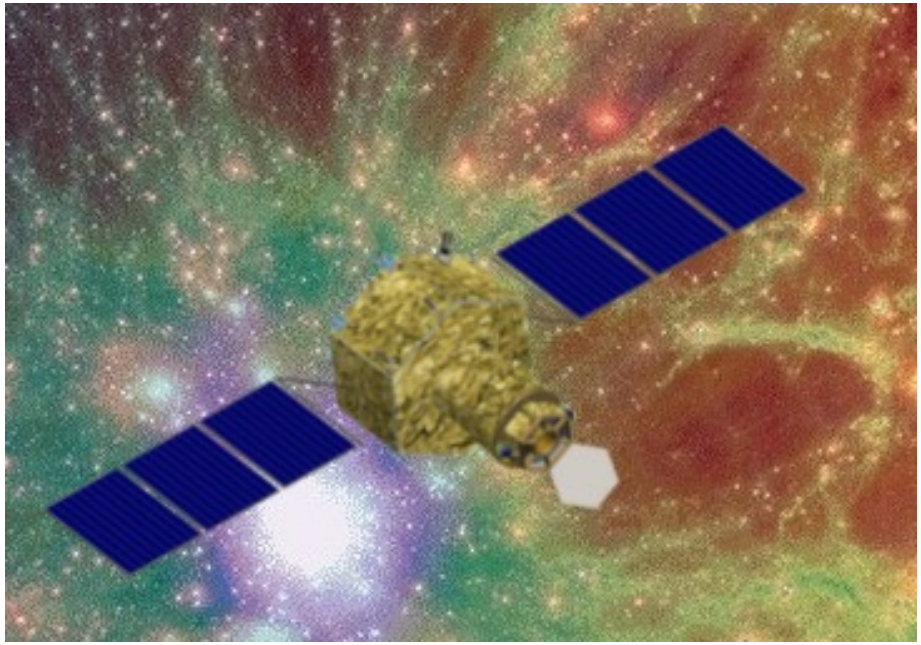
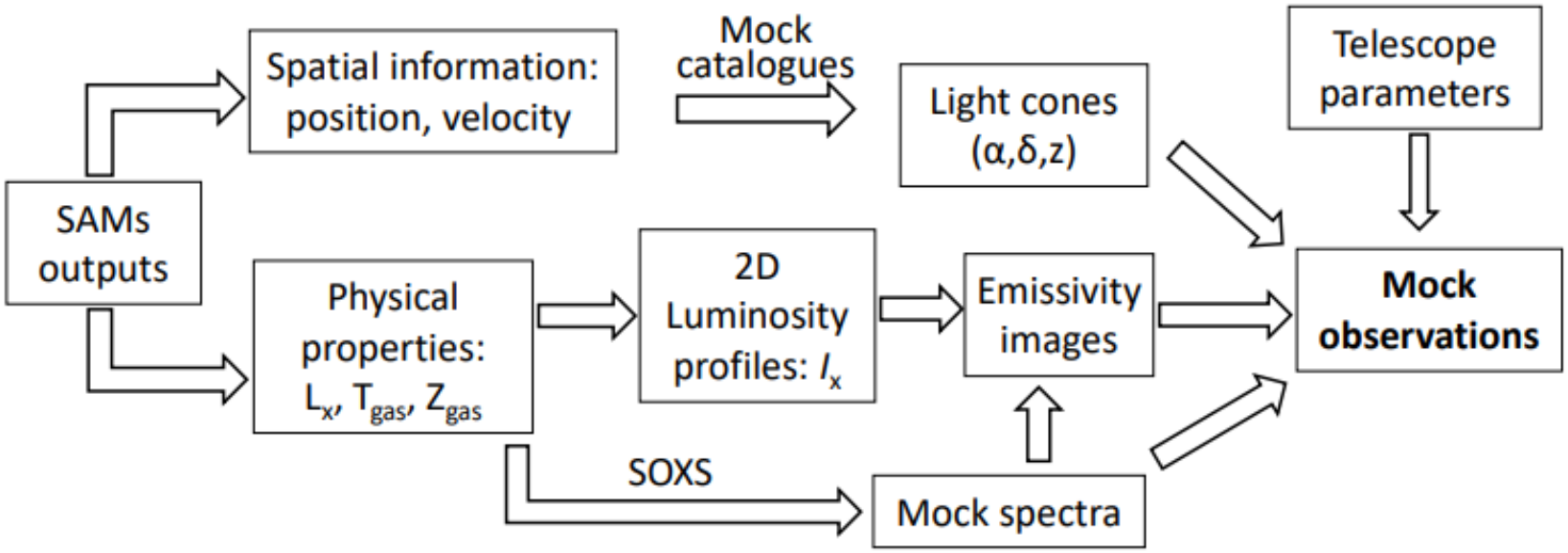


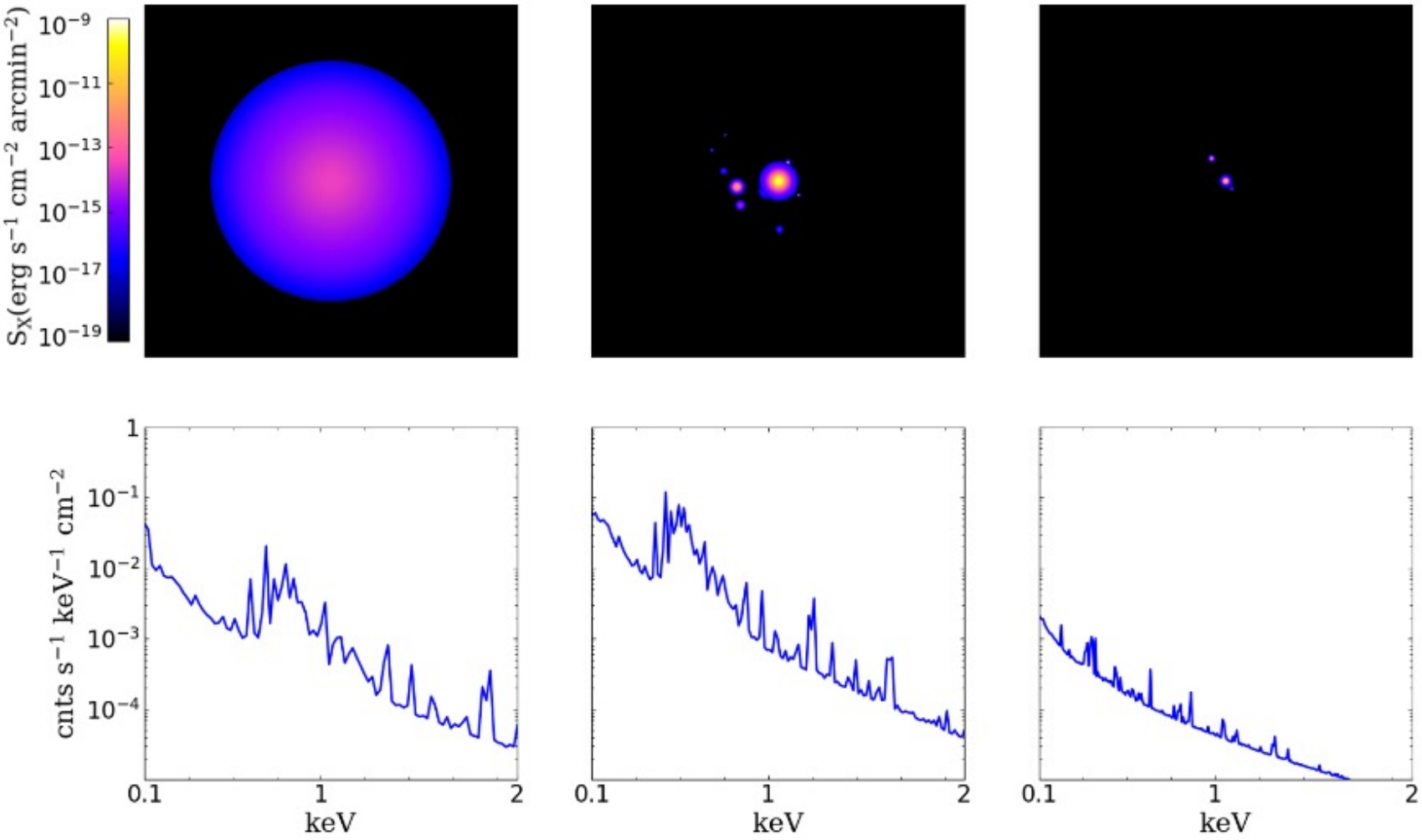
Procedures for Mock observations



z=0.03,
$M_{200}=10^{12.6}M_{\odot}$

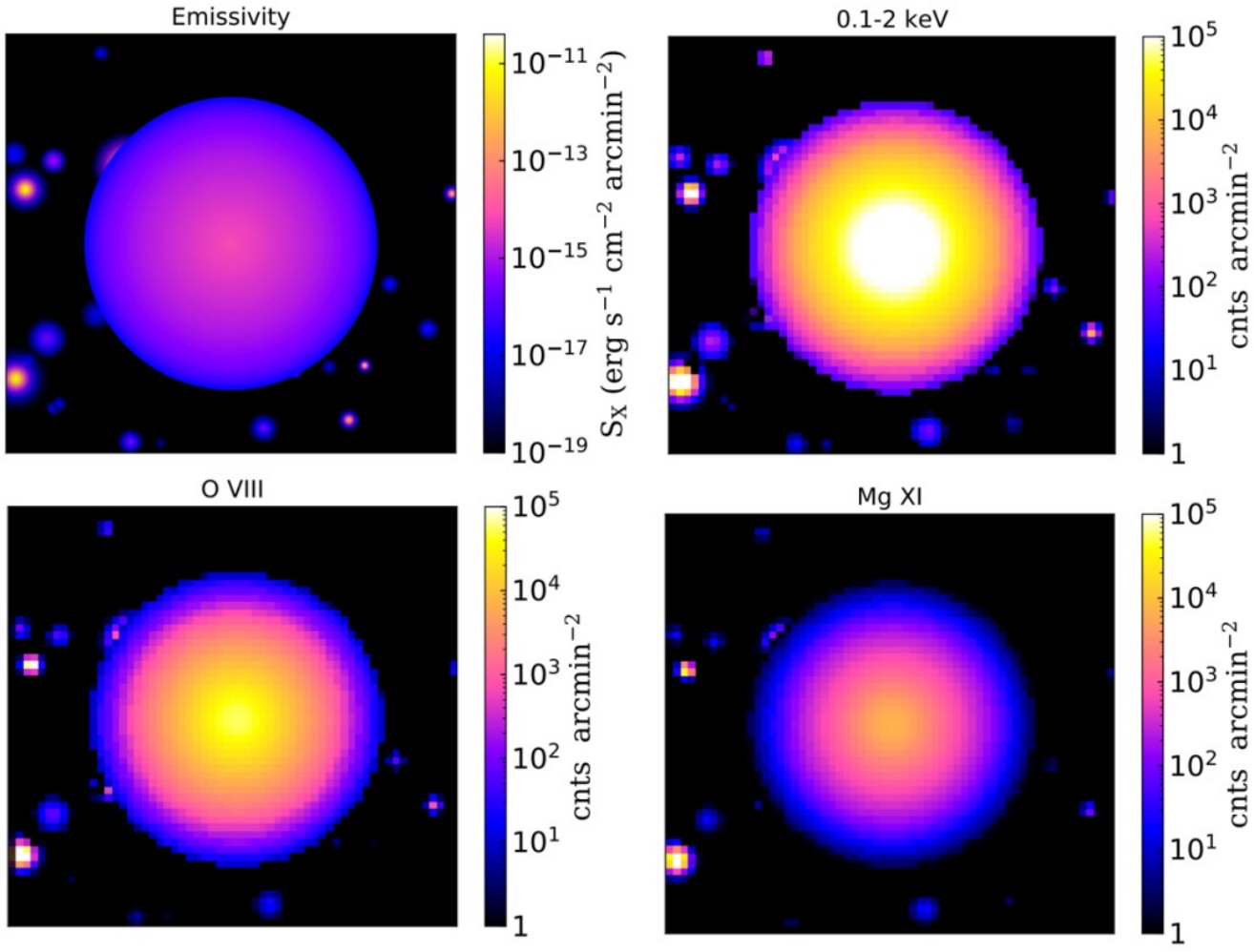
z=0.51,
$M_{200}=10^{14.6}M_{\odot}$

z=2.07,
$M_{200}=10^{14.2}M_{\odot}$



Mock images for HUBS

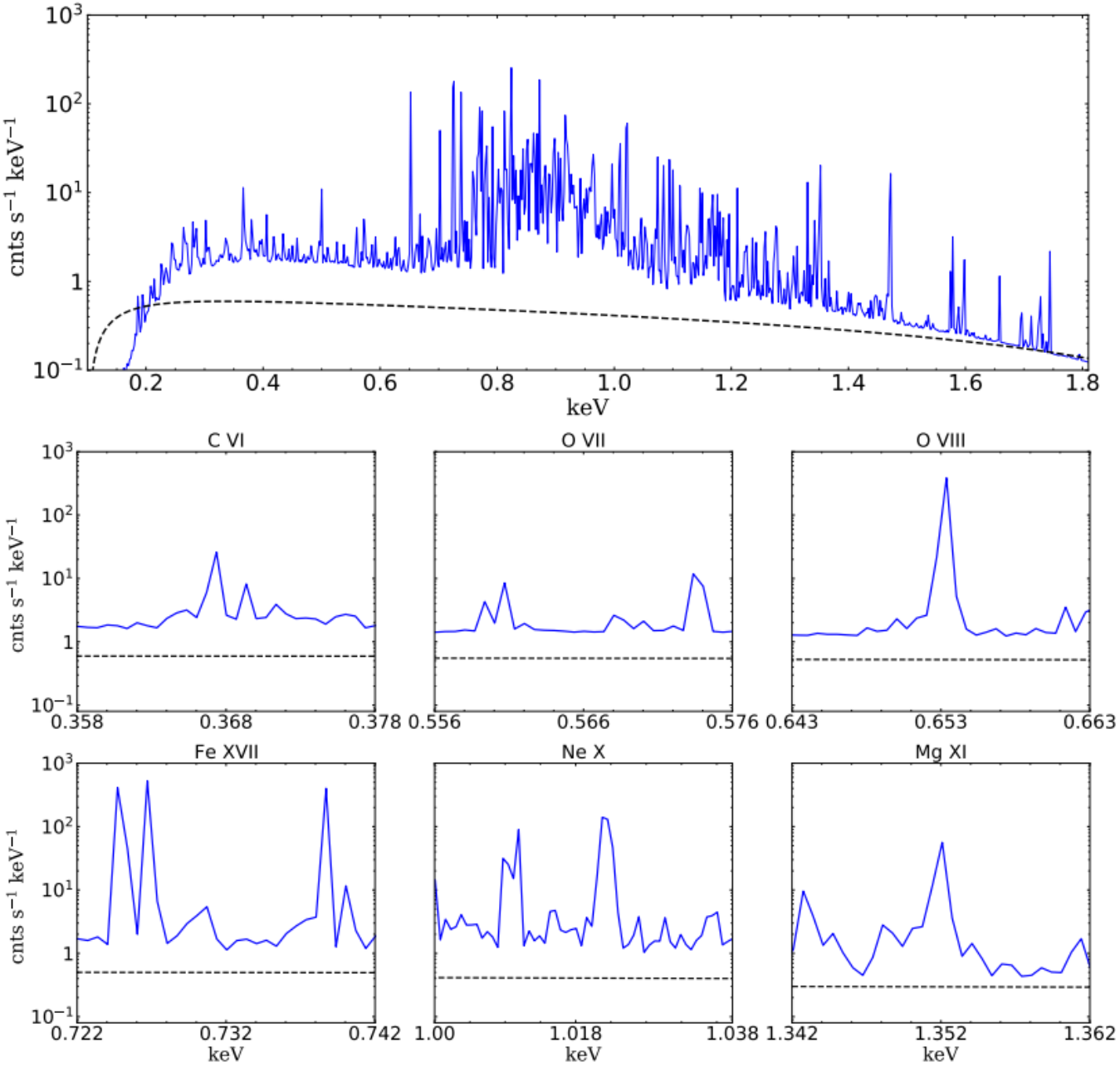
Mock images in different bands

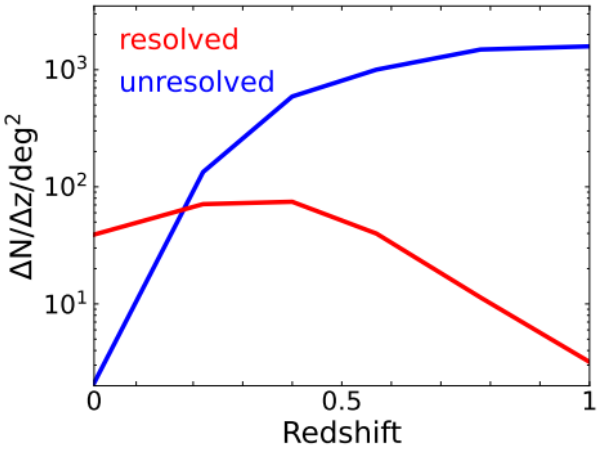


z=0.014,
$M_{200}=5\times10^{12}M_{\odot}$
FoV: $1^{\circ}\times1^{\circ}$

$t_{exposure}=10^6$s
(stacking)

Mock observations for HUBS





Summary

- Consistent with observations, flatter density profiles in halo centers produce lower X-ray emission than an isothermal sphere.
- Cool core regions prone to precipitation have higher gas temperature than the virial temperature, and a larger T_X/T_{vir} ratio in smaller haloes leads to a steeper slope in the L_X-T_X relation.
- The ionized gas in the unbounded reservoir and low temperature intergalactic gas in low mass haloes could be the main components of the halo ``missing baryons''.
- By taking the advantage of the large simulation box and flexibility in SAMs, our mock X-ray observations provides the opportunity to make target selection and observation strategies for forthcoming X-ray facilities.
- The survey of hot baryons in resolved clusters by HUBS is effective at $z<0.5$. HUBS has the ability to detect the emission lines of hot gas in clusters at $z>0.5$, and future observations of point-like sources will help us understand the hot baryons in the early universe.

Thank you!