



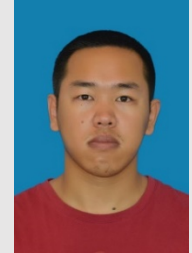
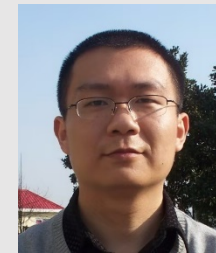
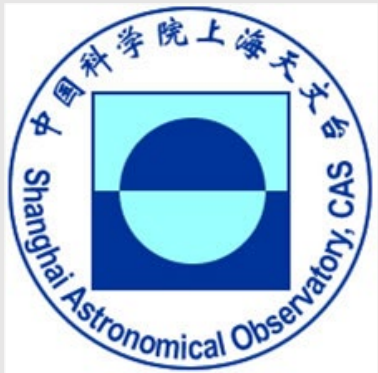
Simulation the observation of hot gas and cold gas in ISM and CGM

富坚

fujian@shao.ac.cn

2023-06-23, 苏州

Collaborators: 钟文心、刘磊、王左磊



IGM

IGM

Diffuse gas

CGM

CGM

Recycling gas

ISM

Accreting gas

15 kpc

ISM

ISM

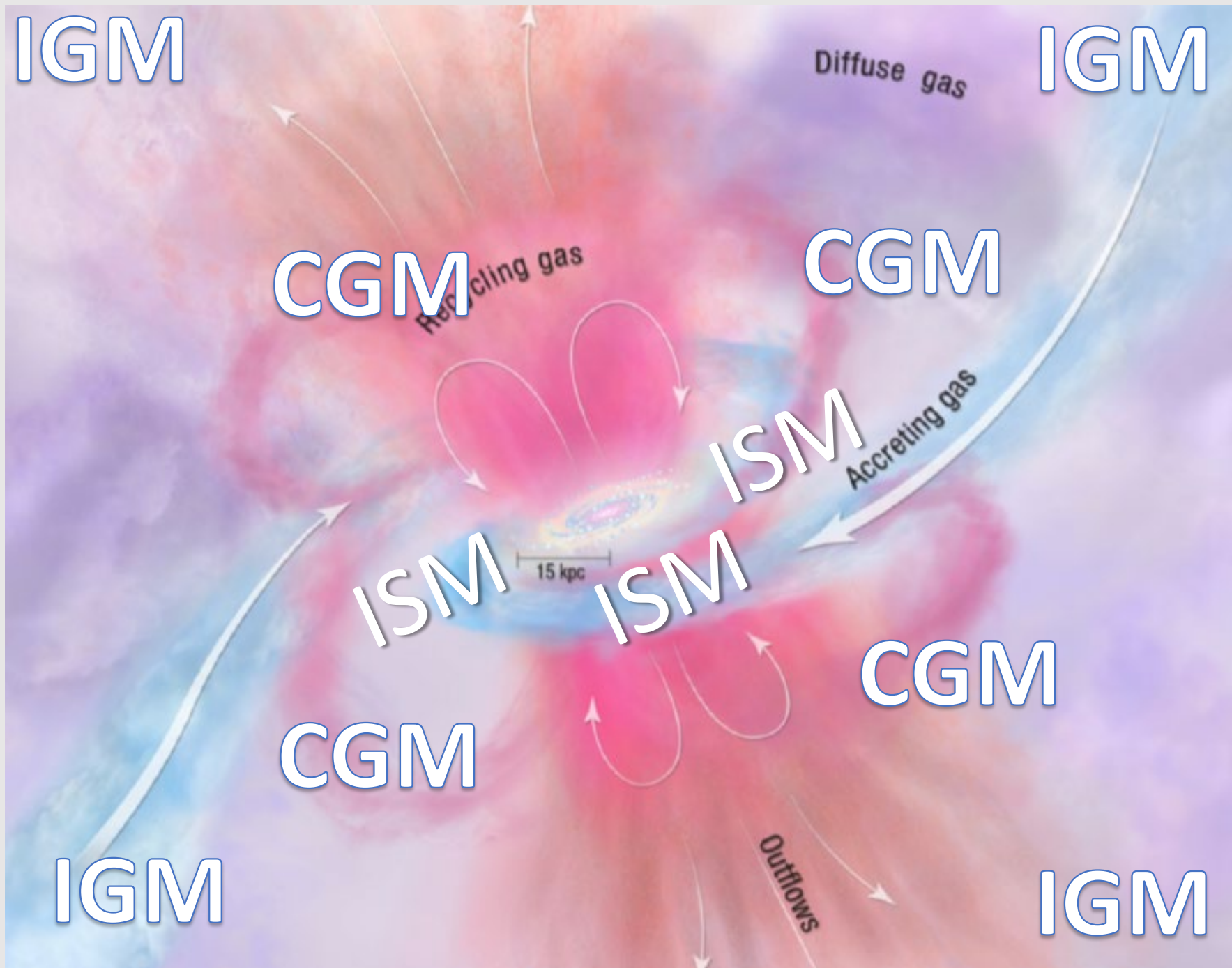
CGM

CGM

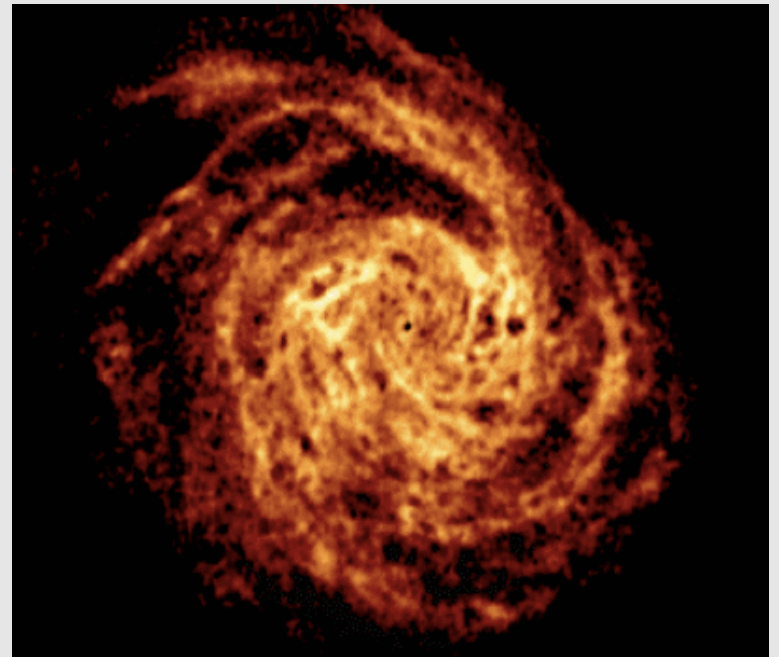
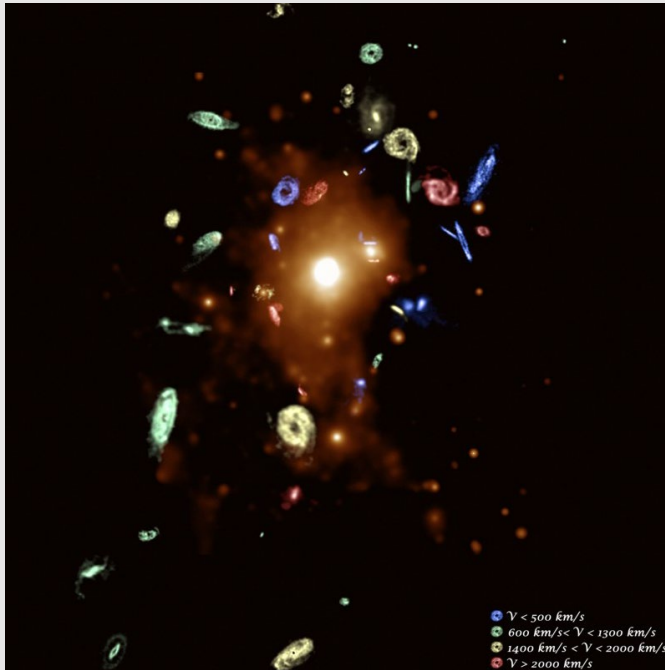
IGM

IGM

Outflows

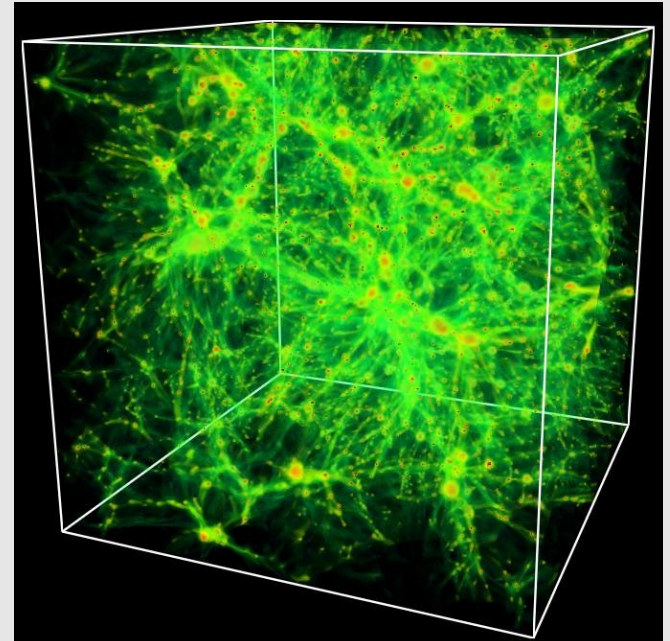
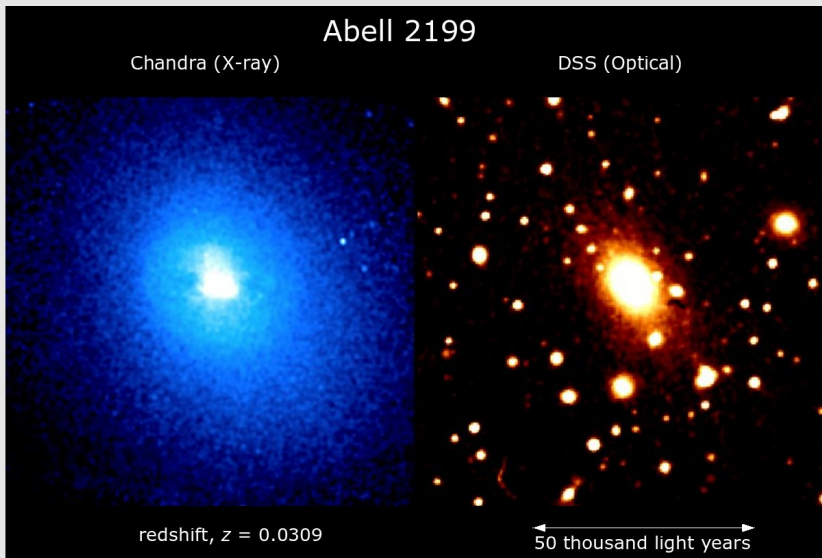


HI gas in ISM: 21cm



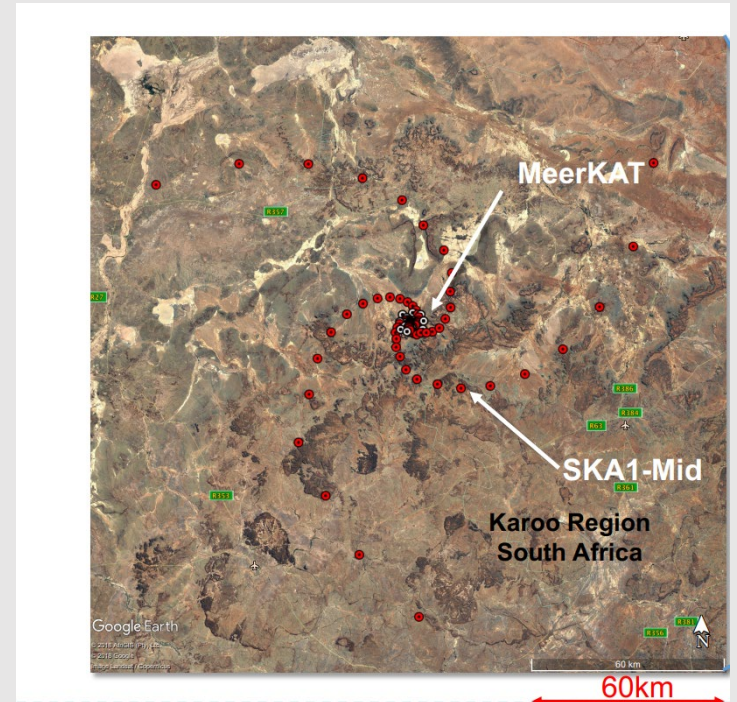
Hot gas in CGM and ICM

- $T > 10^6 \text{K}$, X-ray emission, fully ionized gas
- Missing baryon problem

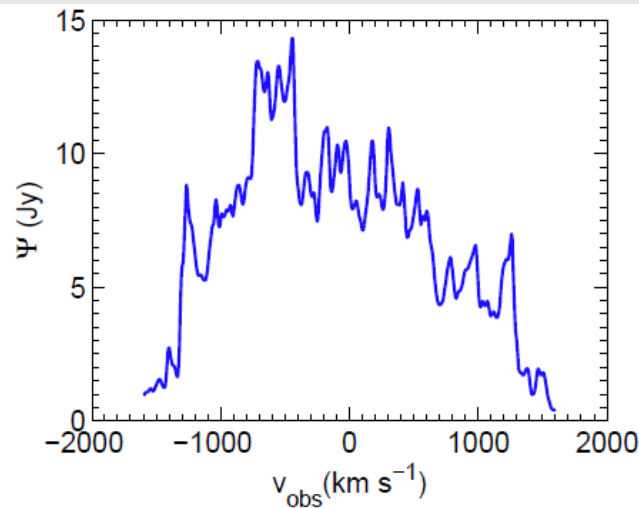
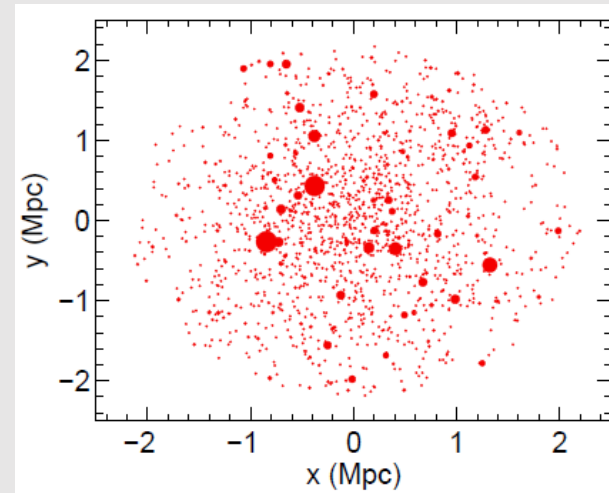
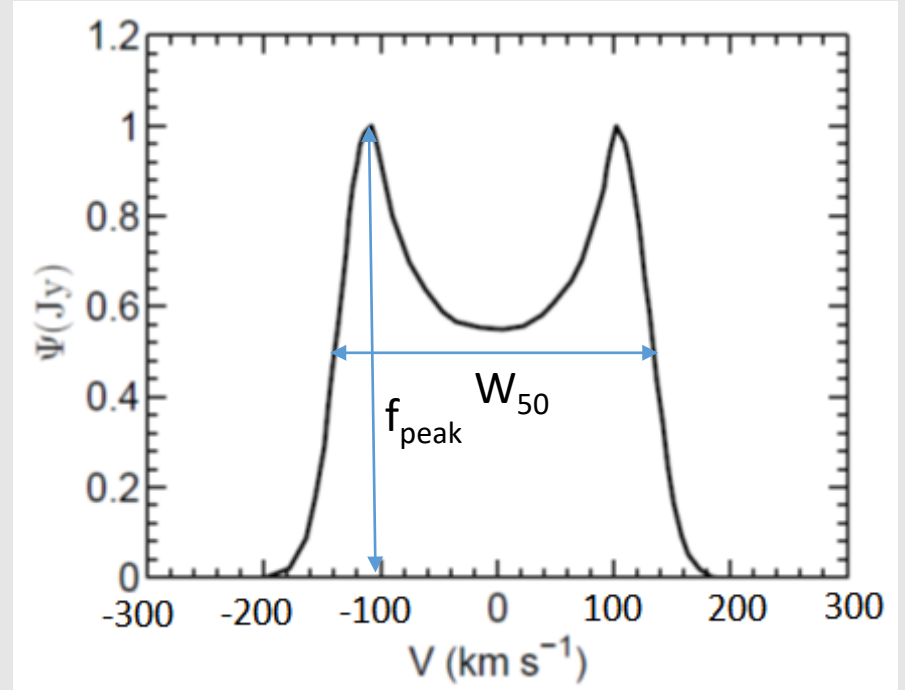
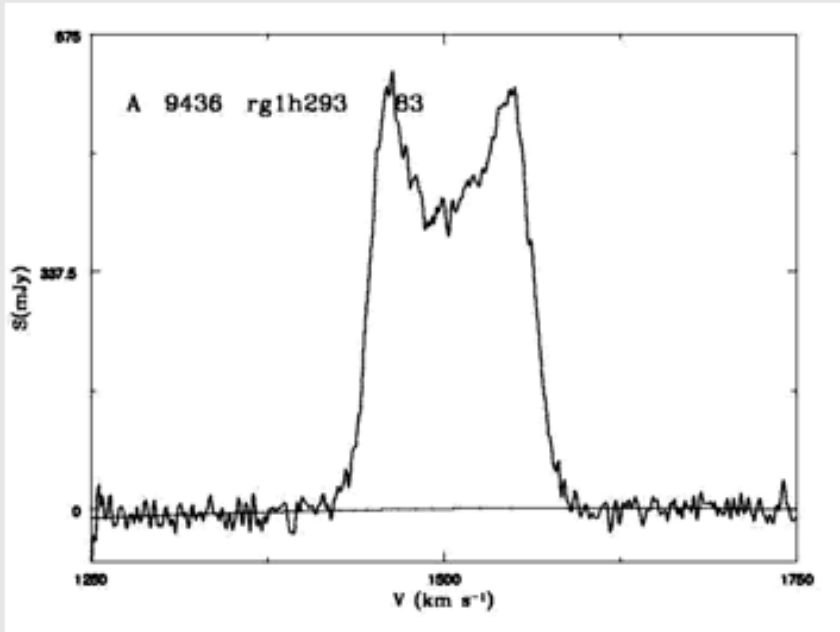


SKA1-mid

- SKA-mid :350 MHz-15.4 GHz
- HI gas in low redshift galaxies~1.42GHz ~0.5'' resolution



Synthetic observation for signals of single dish



$$\frac{F_{\text{HI}}}{\text{Jy km/s}} = \frac{1}{2.36 \times 10^5 D^2} \frac{M_{\text{HI}}}{M_{\odot}}$$

Simulations softwares for radio interferometer arrays

- OSKAR
- RASCIL
- CASA
- ◦ ◦
- SKA1-mid/FASTA等未来设备要考虑类似VLBI模式的观测

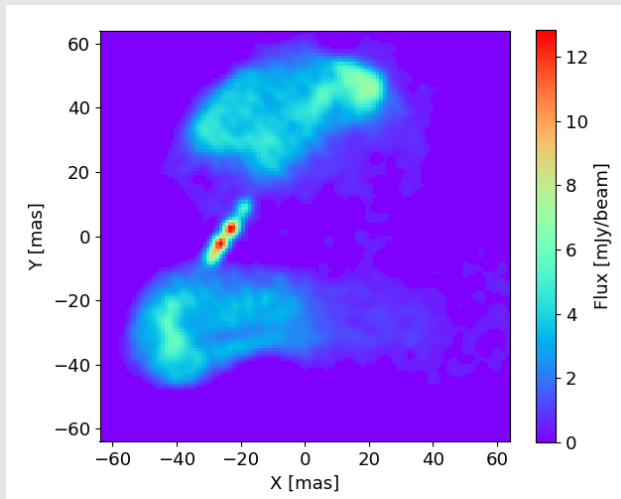
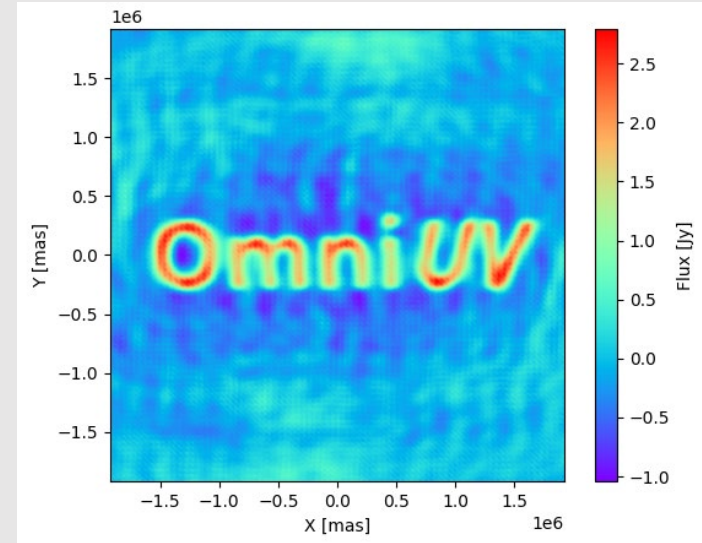


- 仿真程序局限：
- 只能模拟较短基线
- 共视
- 振子天线/碟形天线
- GPU



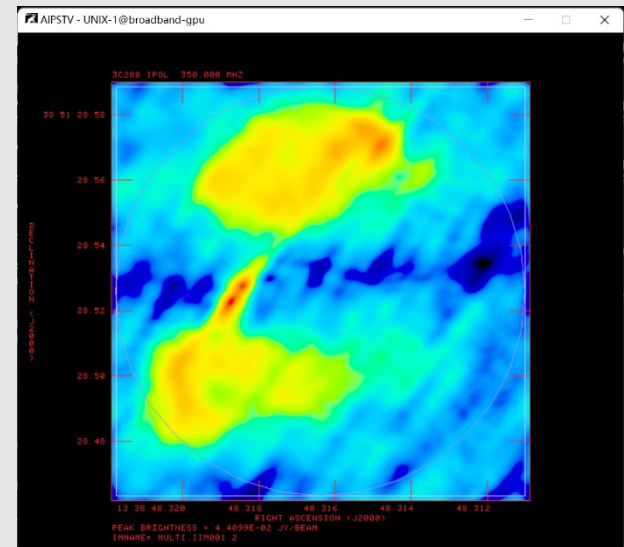
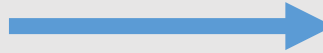
OmniUV: Omnipotent UV

- Station trajectory calculation
- UVW calculation
- Visibility simulation
- Image/beam reconstruction



Source

OmniUV



Simulated

OmniUV

- Available on GitHub
- **Codes**, documents, examples
- **Smearing effect**
- **FIT-IDI output**
- **DRO/Halo orbit support**
- **Aperture array beam pattern**
- <https://github.com/liulei/omniuv>

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<https://doi.org/10.3847/1538-3881/ac77f0>



OmniUV: A Multipurpose Simulation Toolkit for VLBI Observation

Lei Liu^{1,2,3} , Weimin Zheng^{1,2,3}, Jian Fu⁴, and Zhijun Xu¹ 

¹ Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, People's Republic of China; liulei@shao.ac.cn

² National Basic Science Data Center, Beijing 100190, People's Republic of China

³ Shanghai Key Laboratory of Space Navigation and Positioning Techniques, Shanghai 200030, People's Republic of China

⁴ Key Laboratory for Research in Galaxies and Cosmology, Shanghai Astronomical Observatory, Chinese Academy of Sciences, 80 Nandan Rd., Shanghai, 200030, People's Republic of China

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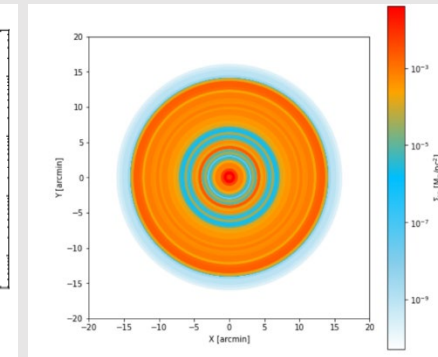
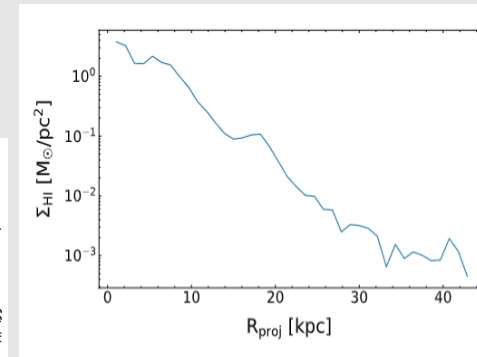
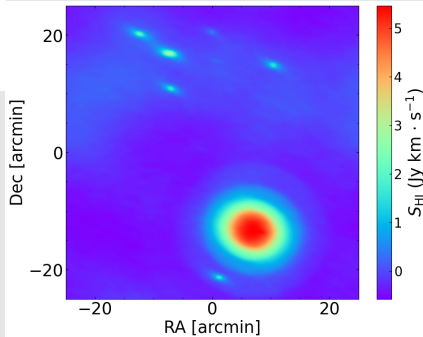
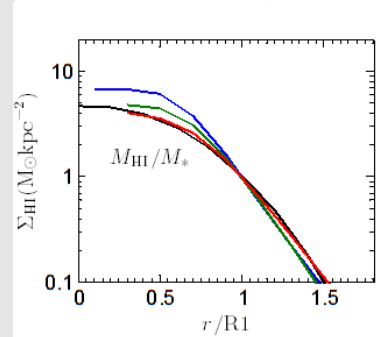
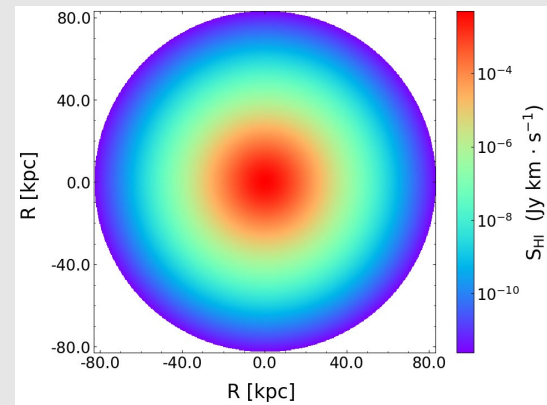
HI gas components in simulated galaxies

- L-Galaxies 2020 SAMs

HI to H₂ prescription by Fu et al. 2013

- Illustris-TNG

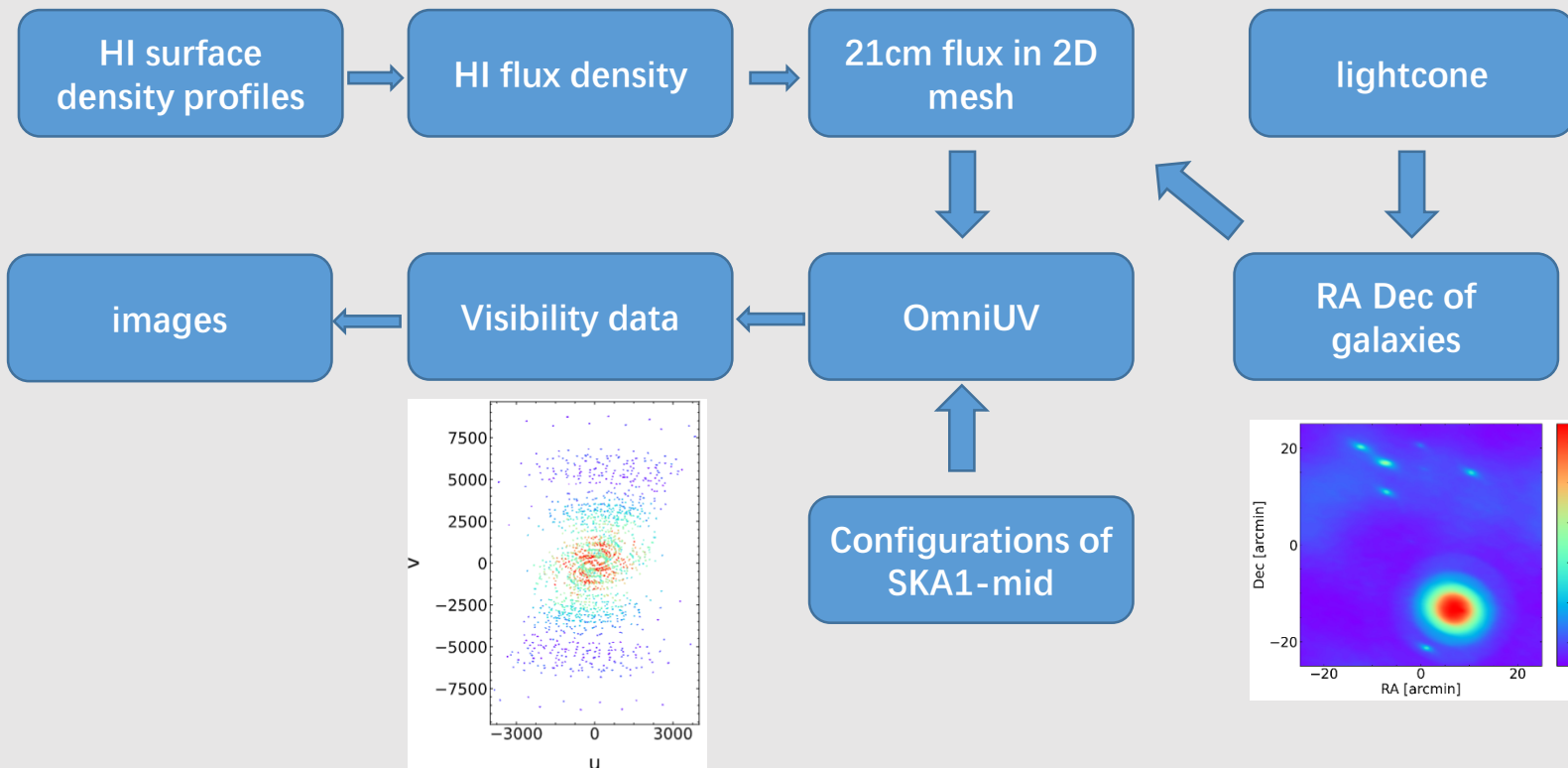
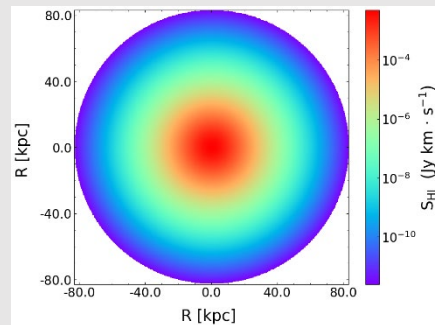
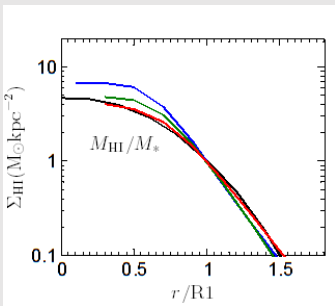
HI and H₂ post-processing catalogues by Diemer et al. 2018 in TNG100 box



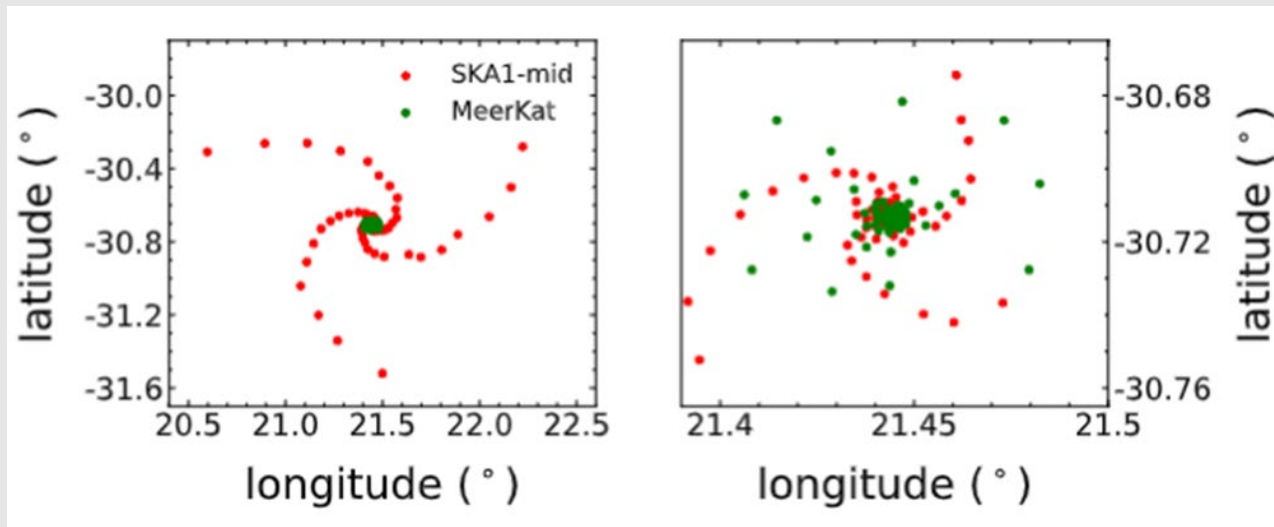
position, J , v_{HI} , r_{HI} , M_{HI} , Σ_{HI}

Wang, Fu et al. in preparation

模拟仿真步骤



SKA-1 mid configurations

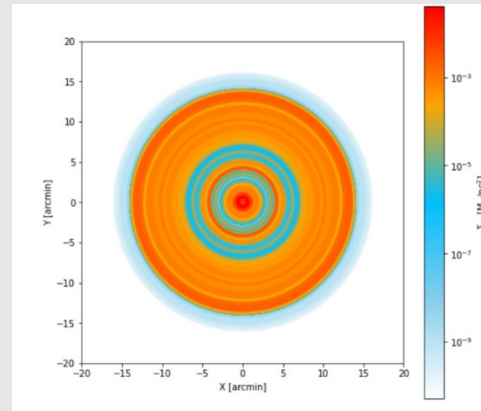


196 dishes:
133 15m SKA dishes + 64 13.5m MeerKAT dishes

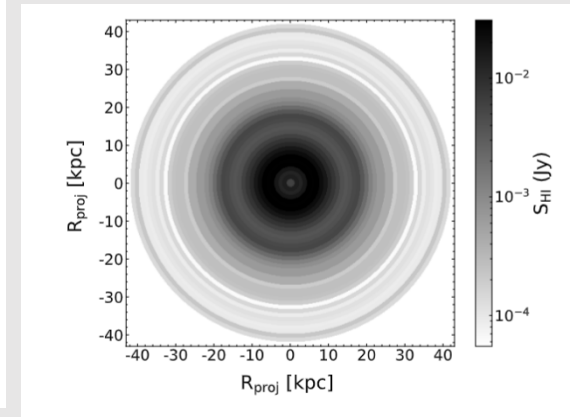
HI flux and image

$$\frac{S_{\text{HI}}}{\text{Jy}} = \frac{M_{\text{HI},2\text{d}}}{2.35 \times 10^5 M_{\odot}} \left(\frac{D}{\text{kpc}} \right)^{-2}$$

- 1D HI profile \rightarrow 2D mesh image

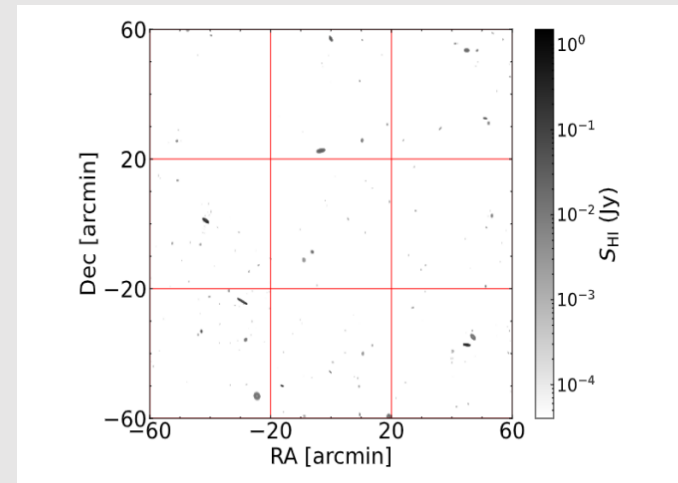


HI surface density



Flux of an HI disk

- $40' \times 40'$ grid with $0.5''$ angular resolution



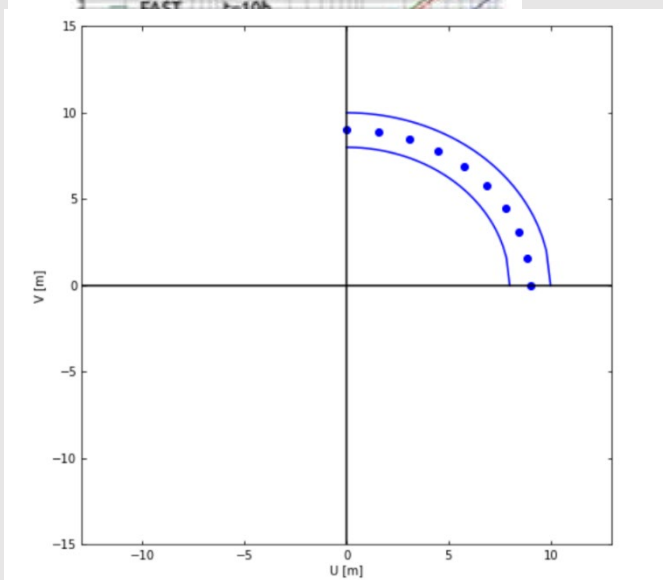
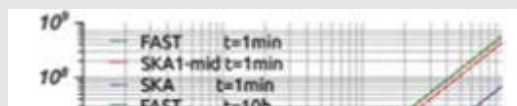
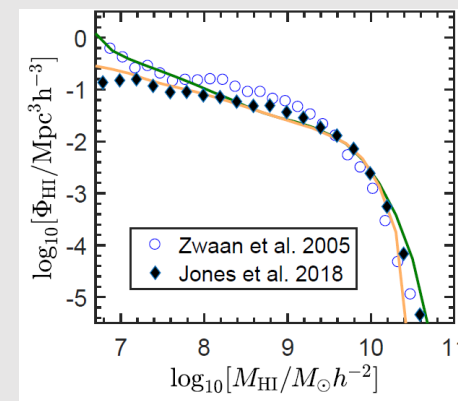
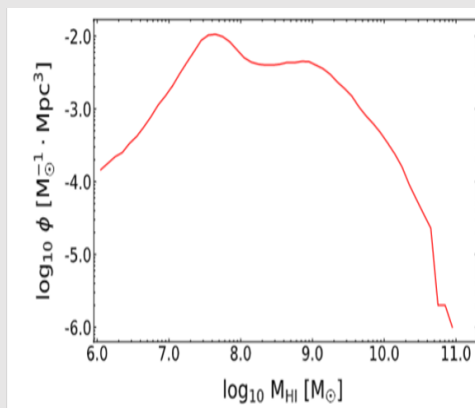
Simulations for SKA1-mid array

1. Simulation 1: $M_{\text{HI}} > 10^8 M_{\odot}$

Full box

2. Simulation 2: $M_{\text{HI}} > 10^6 M_{\odot}$

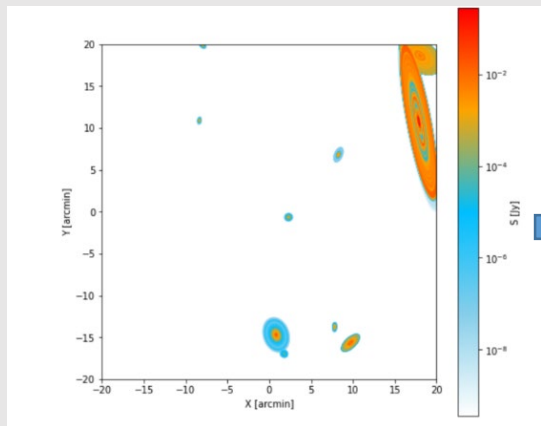
One area with most abundant low mass galaxies



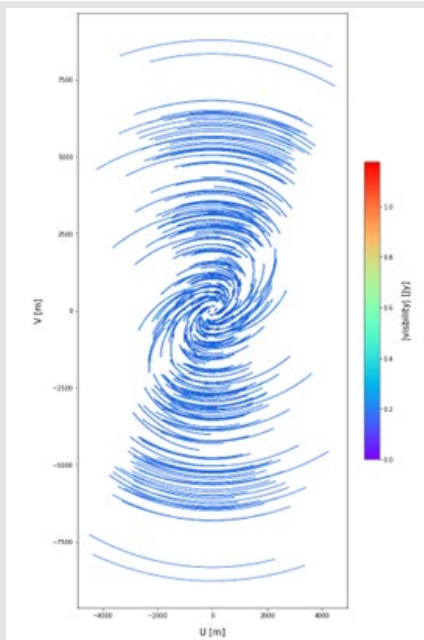
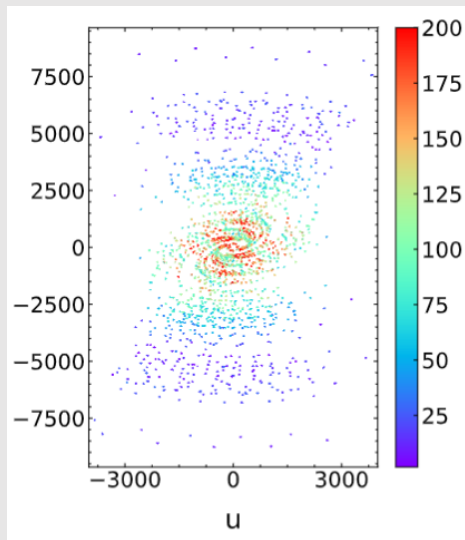
参数	仿真1	仿真2
观测时长/h	6	6
单次扫描时长/min	1	360
扫描次数	10	1
接收机带宽/GHz	1.36-1.42	
角分辨率	0.5''	
Dec	-30.7°	

examples

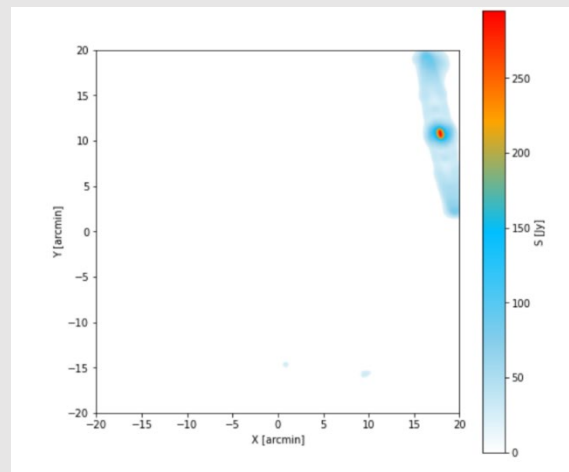
仿真1



输入



仿真2

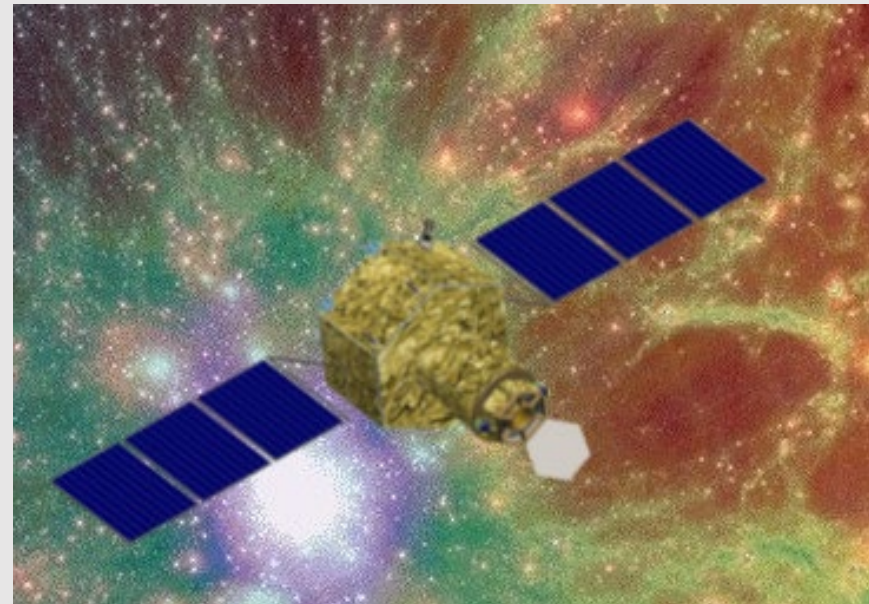


成图

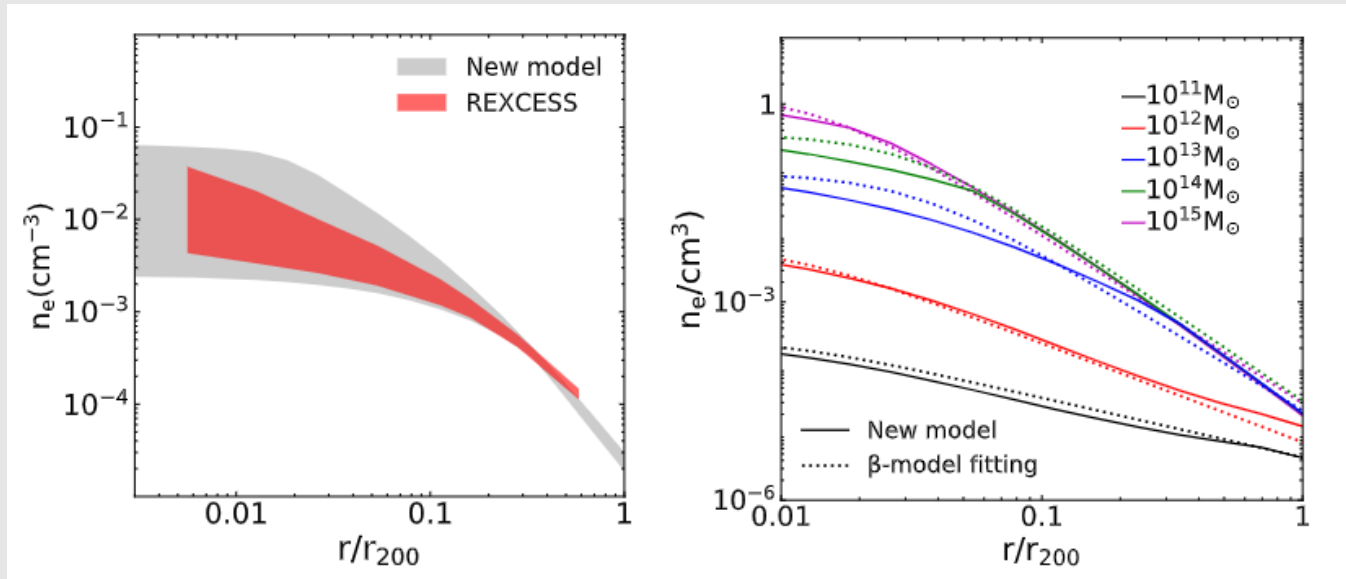
模拟热气体的X波段观测

- 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	$1^\circ \times 1^\circ$
Angular resolution	$1'$
Number of pixels	60×60
Effective area	500 cm^2
Spectral resolution	2 eV (main array) 0.6 eV (central)

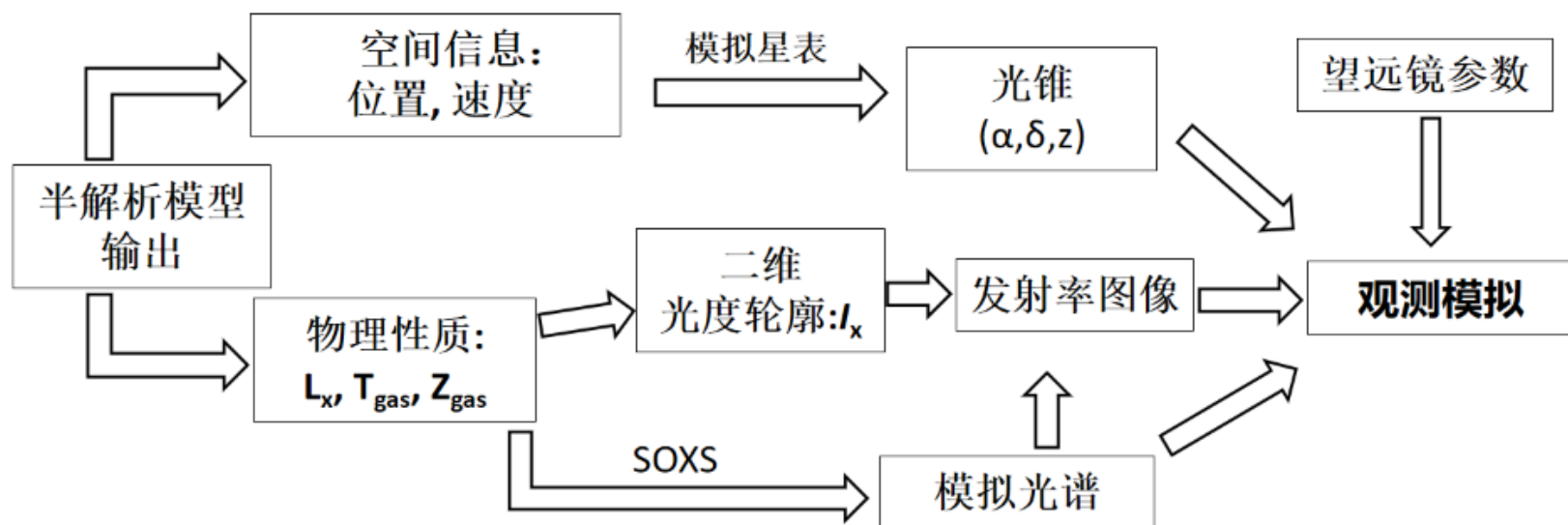


SAMs model for radial density profiles of hot ionized gas in CGM / IGM

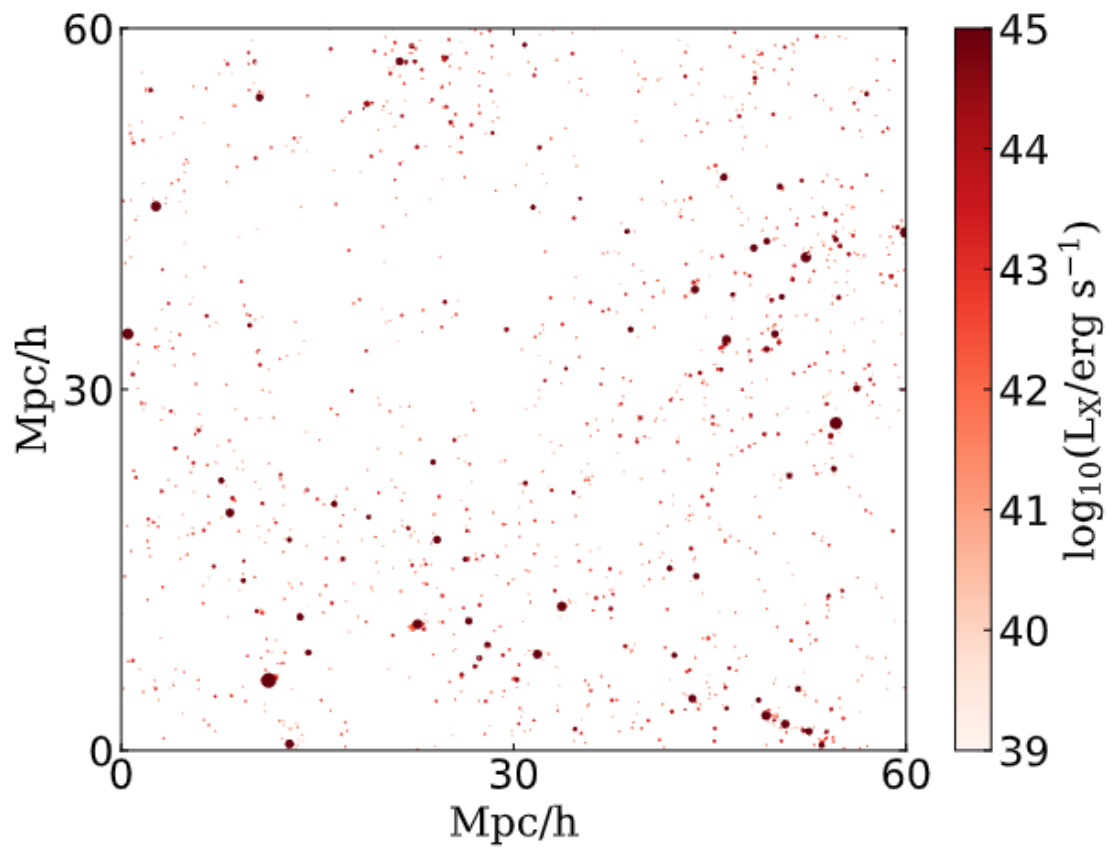


Zhong, Fu, Sharma et al. MNRAS, 2023

观测模拟



Zhong, Fu, Shen, Yuan, RAA, 2023



光谱构建

- 使用软件：SOXS (APEC模块构建等离子体光谱)

- 输入量

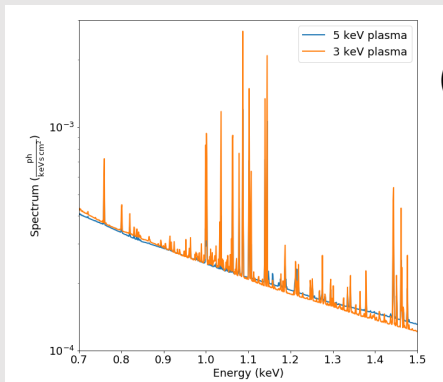
- $I_X = \frac{L_X}{4\pi d_c}$: 每个晕的 X 射线热光度 (bolometric luminosity) 流量

- Z_{gas} : 平均金属丰度

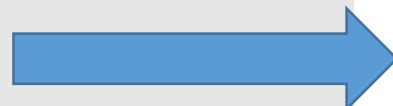
- T_X : X 射线光度加权平均温度

- 输出

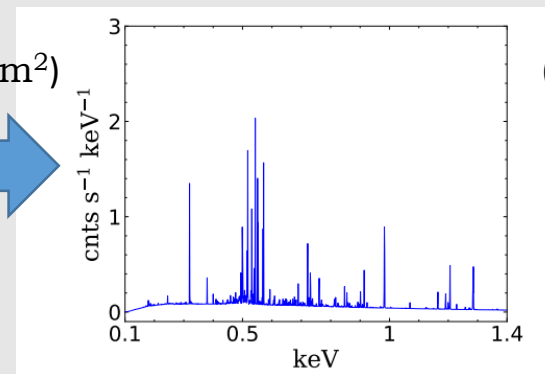
- 带有金属发射线的光谱



(单位: cnts/s/keV/cm²)



effective area

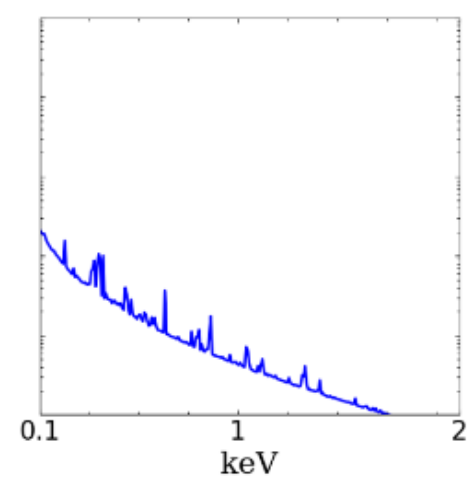
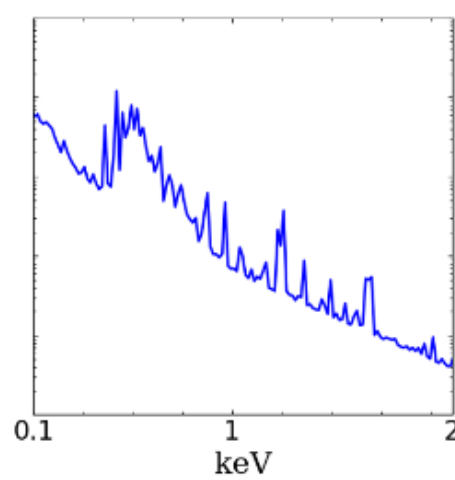
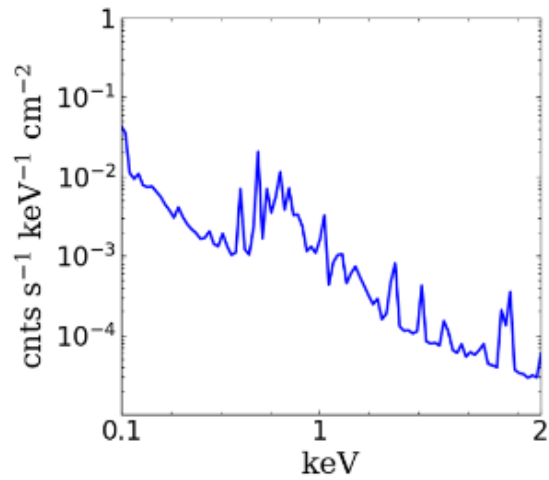
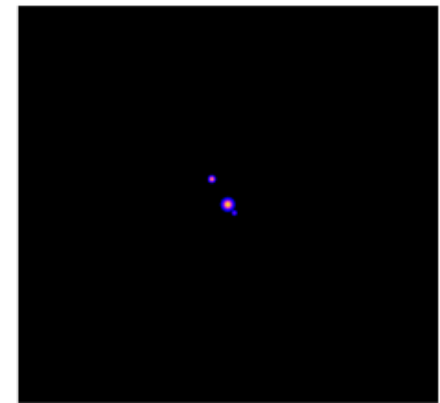
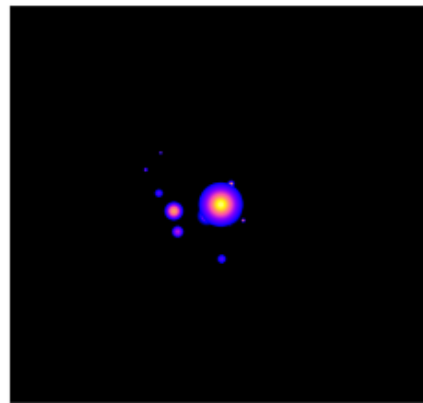
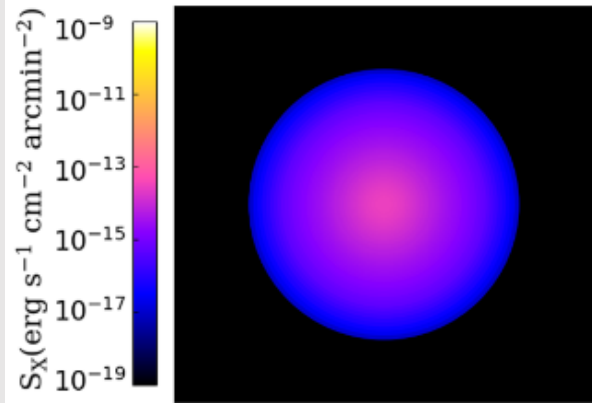


(单位: cnts/s/keV)

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

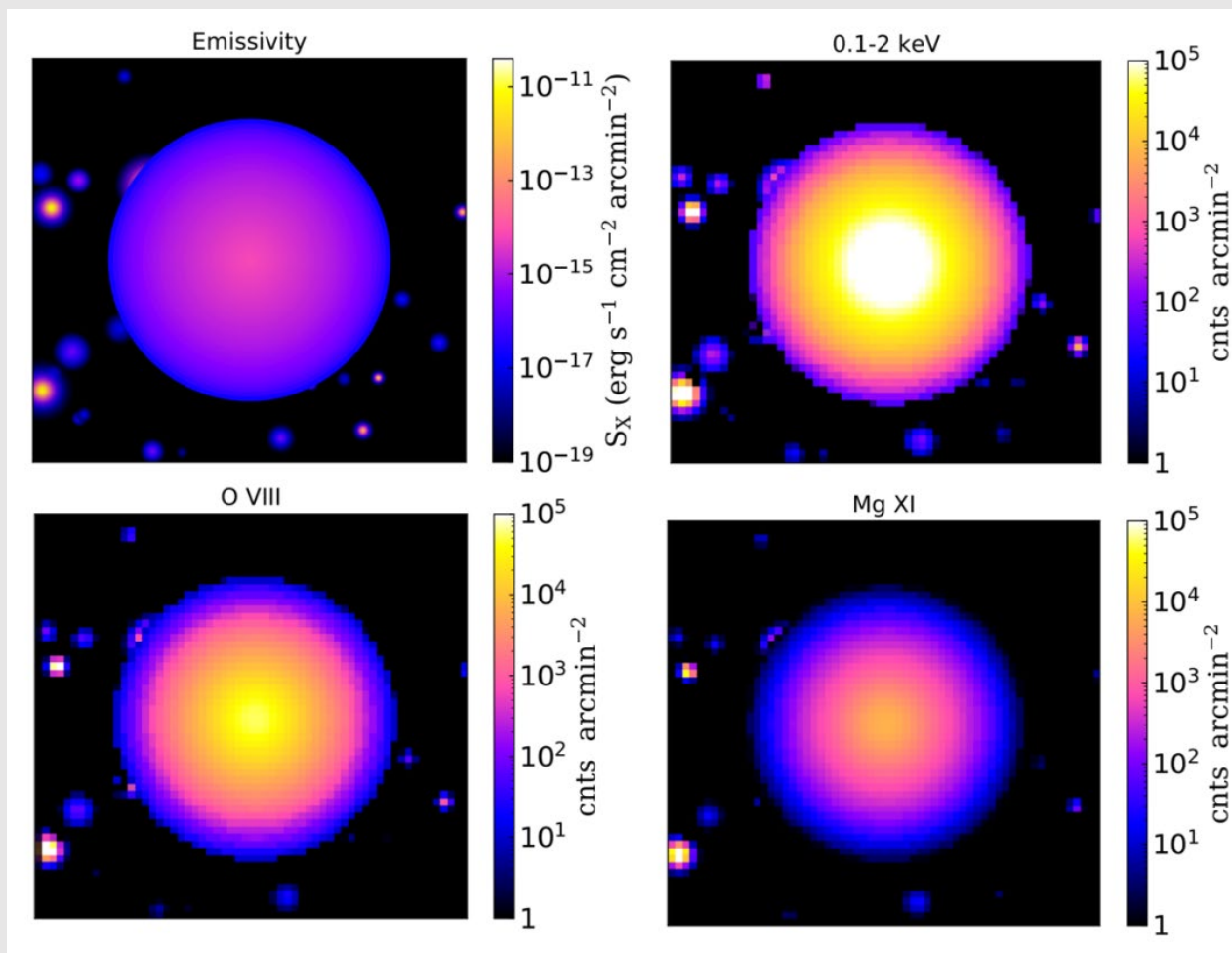
$z=0.51,$
 $M_{200}=10^{14.6}M_{\odot}$

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



HUBS观测模拟

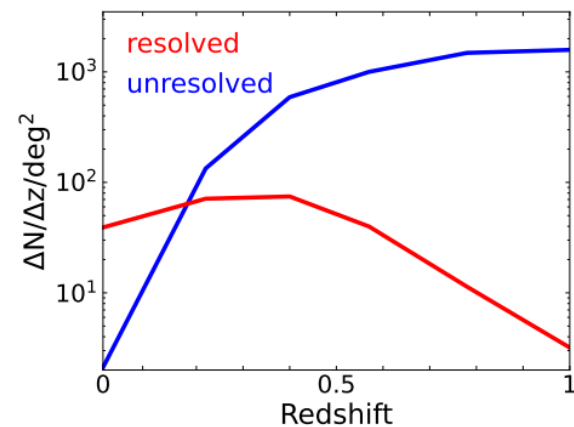
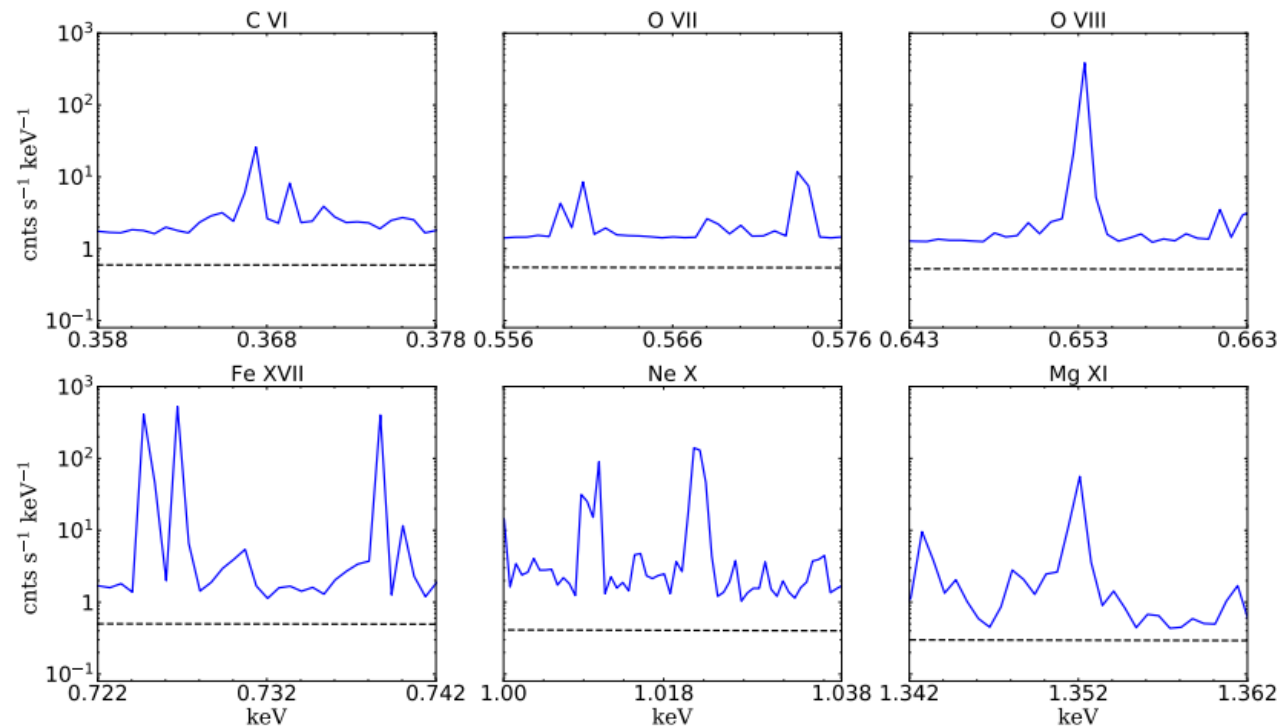
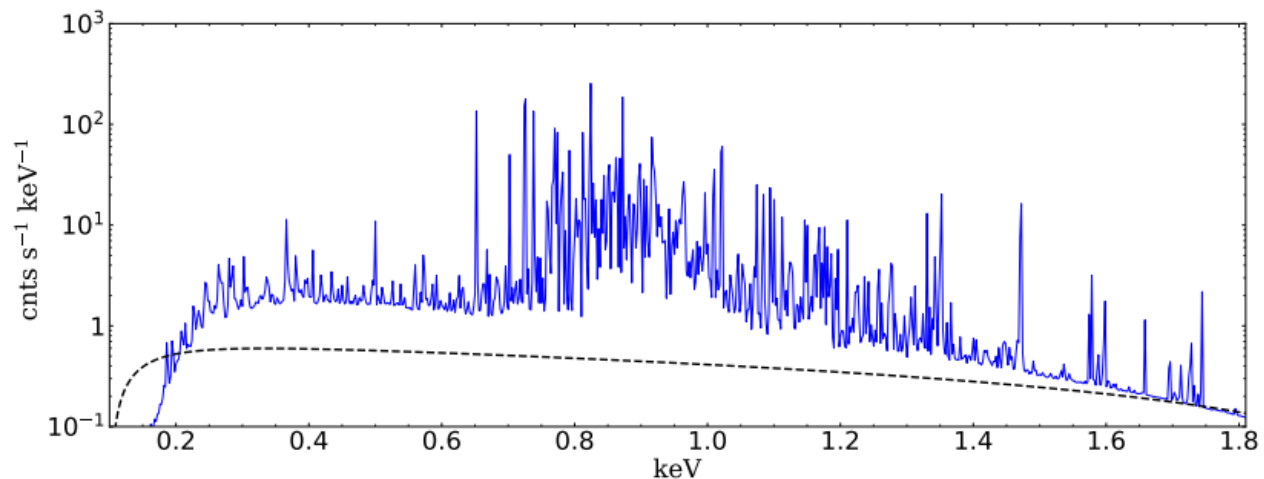
不同能段模拟图像



$z=0.014$,
 $M_{200}=5 \times 10^{12} M_{\odot}$
视场: $1^{\circ} \times 1^{\circ}$

曝光时间: 10^6s
(stacking)

HUBS观测模拟



Summary

- OmniUV can be used to simulated the interferometer signals for dish arrays with long base lines.
- We simulate the observation of 21cm interferometer signal for SKA1-mid for HI gas, which helps for future observation of HI in nearby universe.
- 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!