

# Synthetic Observations with pyXSIM and SOXS for XRISM

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ASTROPHYSICS

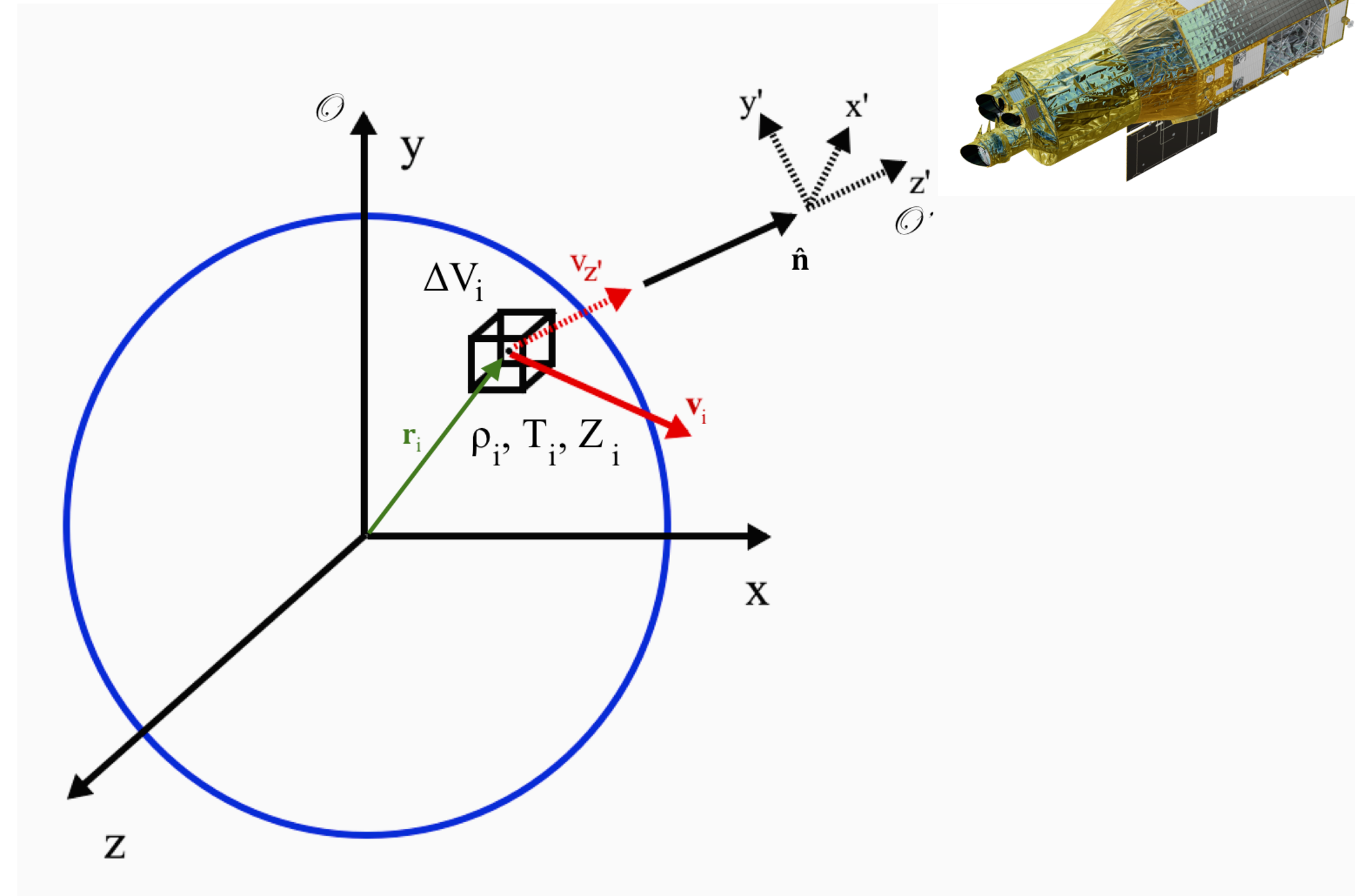
HARVARD & SMITHSONIAN

# Two Python Packages

- SOXS: <http://hea-www.cfa.harvard.edu/soxs>
  - Simple spectral models and 2D spatial models → SIMPUT
  - Instrument simulation (supports XRISM similar to SIMX, not as good as SIXTE, HEASIM)
- pyXSIM: <http://hea-www.cfa.harvard.edu/~jzuhone/pyxsim>
  - Simulated X-ray emission from 3D sources → SIMPUT
  - Most of the spectral machinery is outsourced to SOXS, then used in pyXSIM
- Both open-source, Python-based
- pip and conda-installable

# pyXSIM

- Built on top of the yt package so that many different simulation dataset types can be used (FLASH, Enzo, Gadget, Arepo, RAMSES, etc.)
- Take material properties of source from 3D model, construct X-ray emission field, generate simulated X-ray photons
- Project photons to sky, Doppler and cosmologically shift their energies, apply galactic foreground absorption
- Save the pre-detected "events" to disk

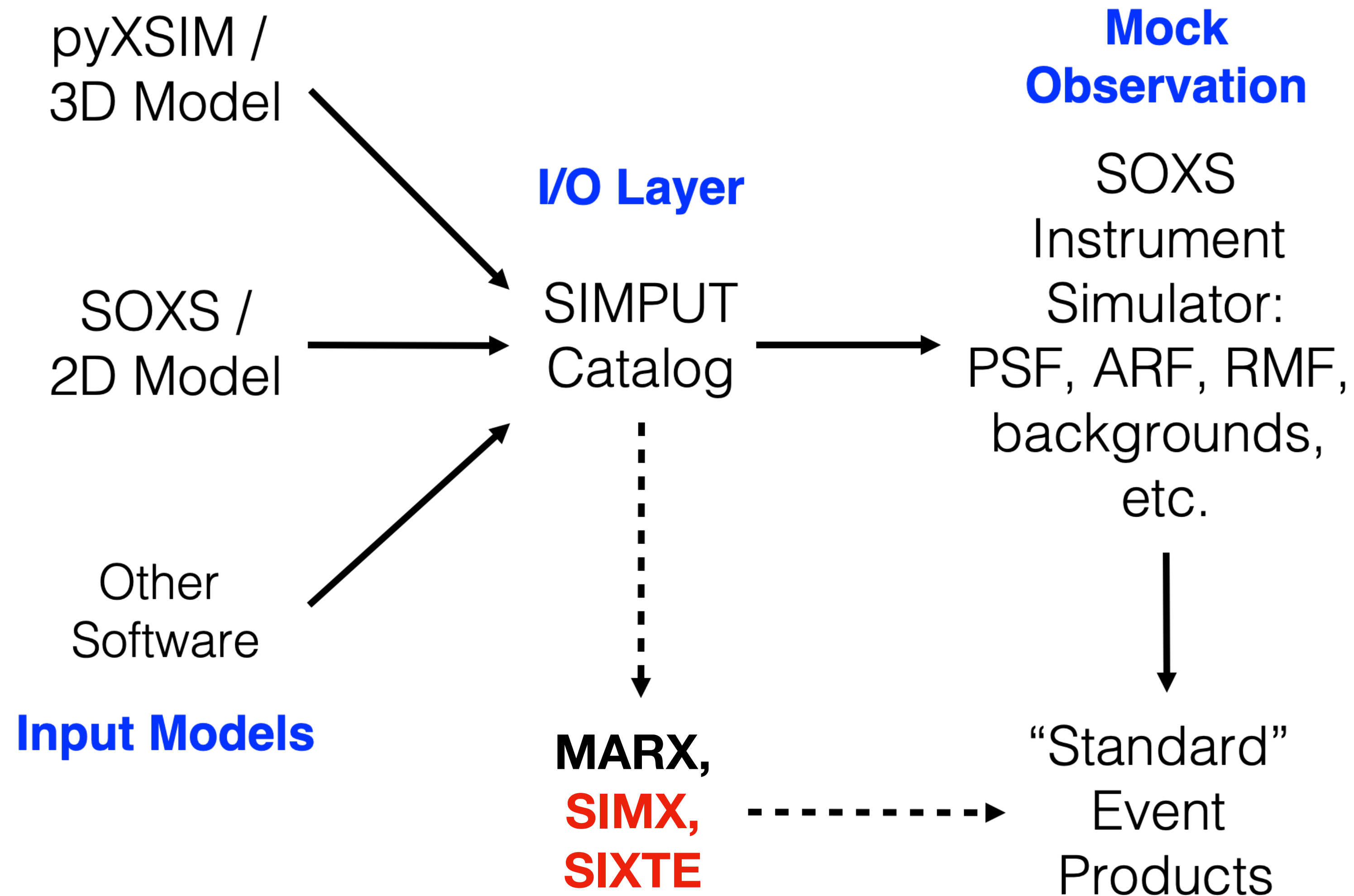


<https://hea-www.cfa.harvard.edu/~jzuhone/pyxsim/>

# Source Models in pyXSIM

- Thermal Sources (hot plasma of many kinds)
  - APEC (CIE/NEI)
  - SPEX (CIE only currently)
  - Cloudy-based photoionization model (with optional resonant scattering off the CXB)
  - Cloudy-based CIE model
  - Want to add: XSTAR models, SPEX PIE, CX, etc.
- Power-law Sources (emission from BHs, XRBs, etc.)
- Emission Line Sources (...)
- Everything is currently under the assumption of an optically thin plasma, but we can try something else if you would like!

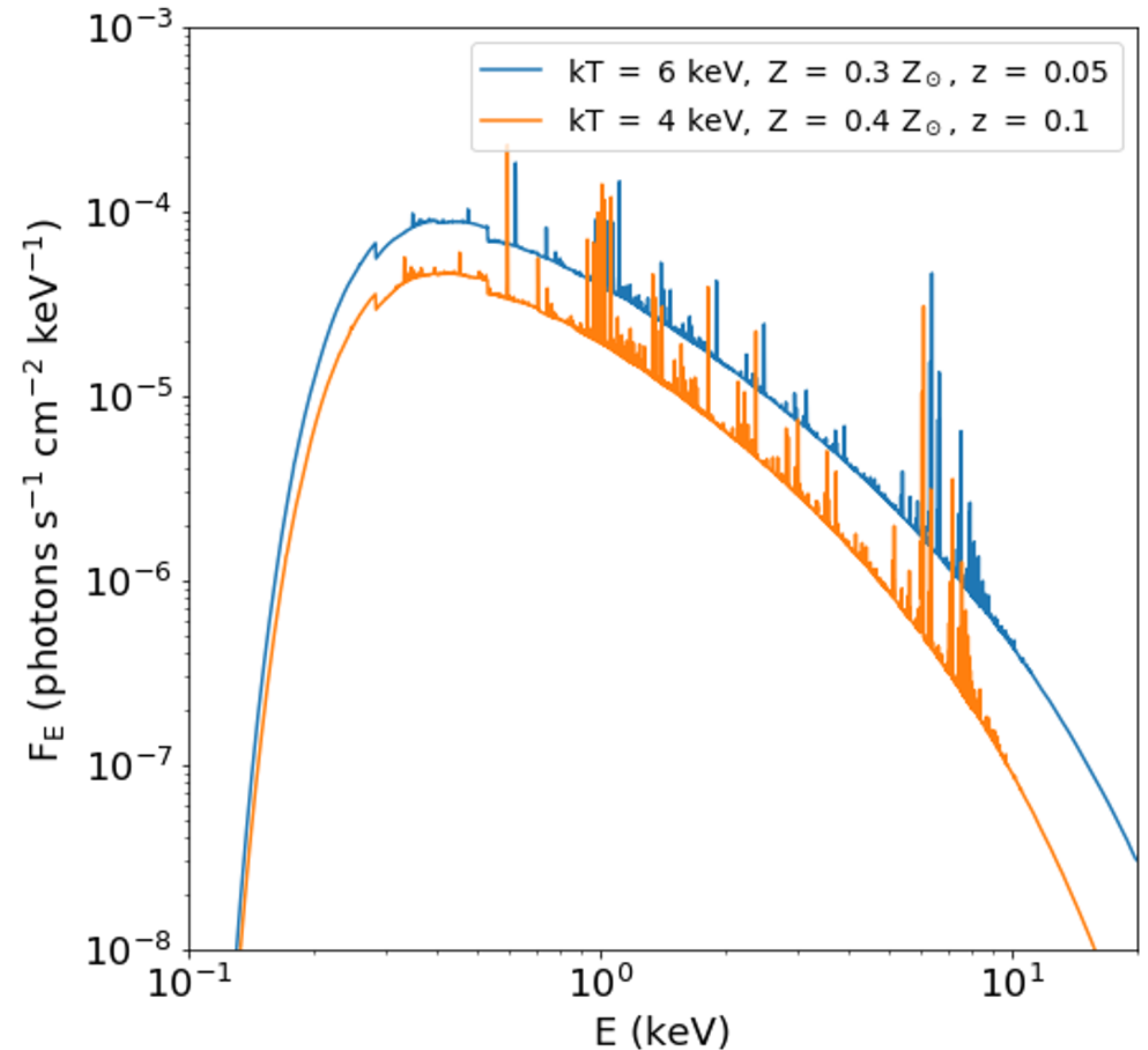
# SOXS Overview



<https://hea-www.cfa.harvard.edu/soxs/>

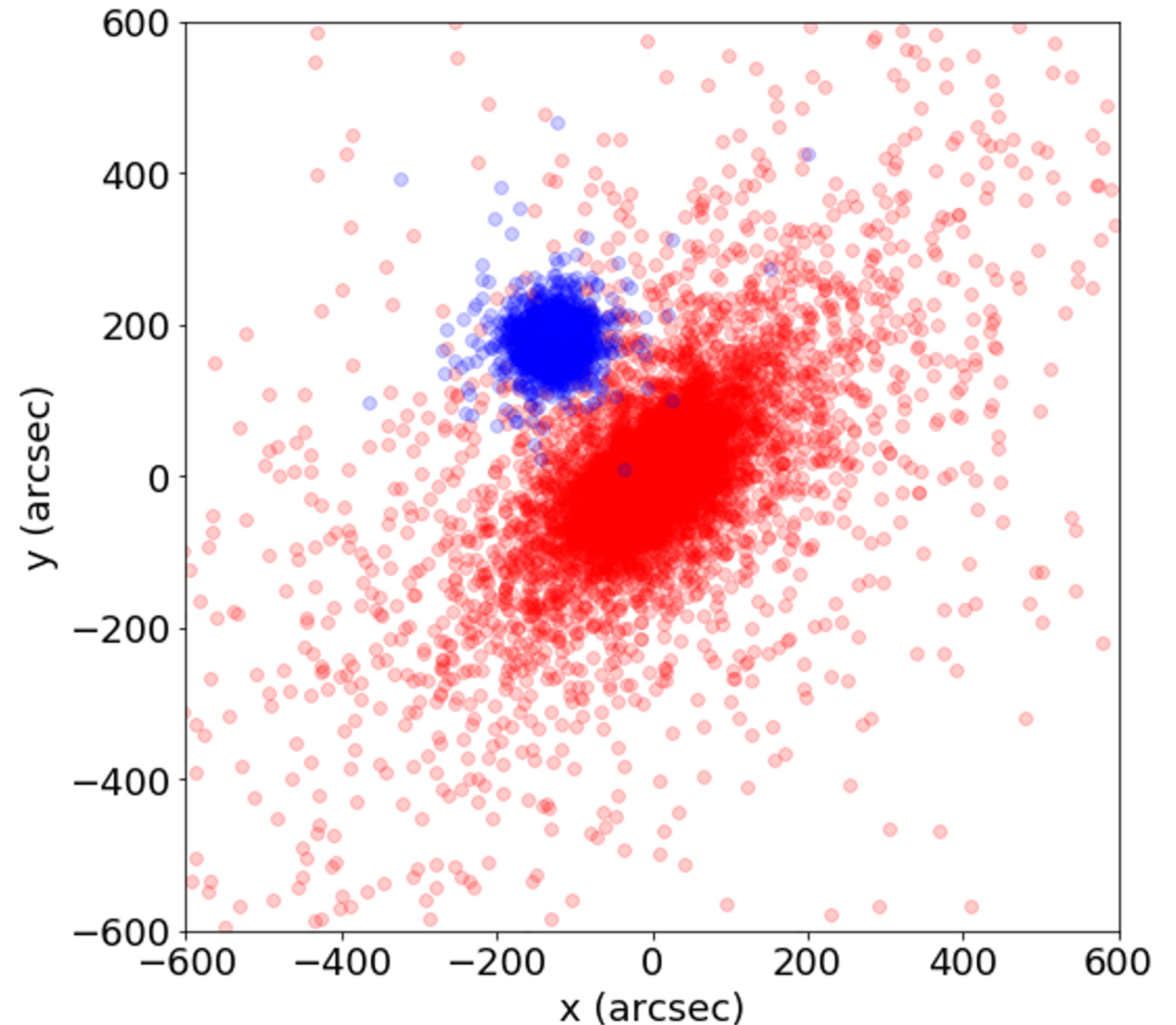
# Spectral Models

- Spectral models:
  - Thermal (APEC CIE/NEI, SPEX CIE, Cloudy CIE/PIE)
  - Power-law
  - From an XSPEC model or script
  - From a file
  - Want to add: XSTAR models, SPEX PIE, CX, etc.
- Operations:
  - Arithmetic with spectra (add spectra, multiply by a constant, etc.)
  - Foreground absorption (wabs, tbabs)
  - Add emission and absorption lines by hand



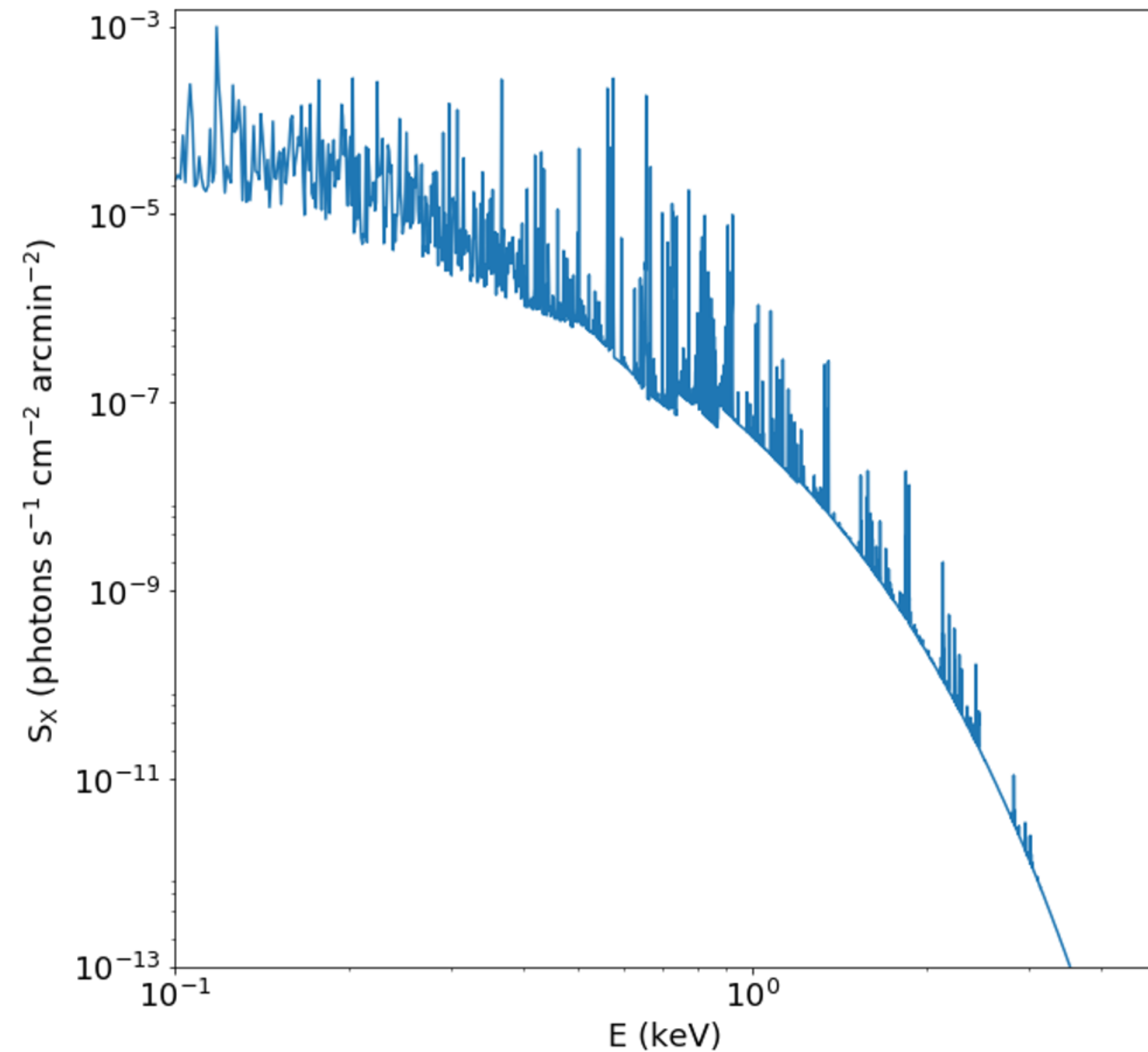
# 2D Spatial Models

- These models generate images and photon coordinates for SIMPUT catalogs
  - Point sources
  - $\beta$ -models
  - Annuli and disks
- Generic models from Python functions, files, arrays

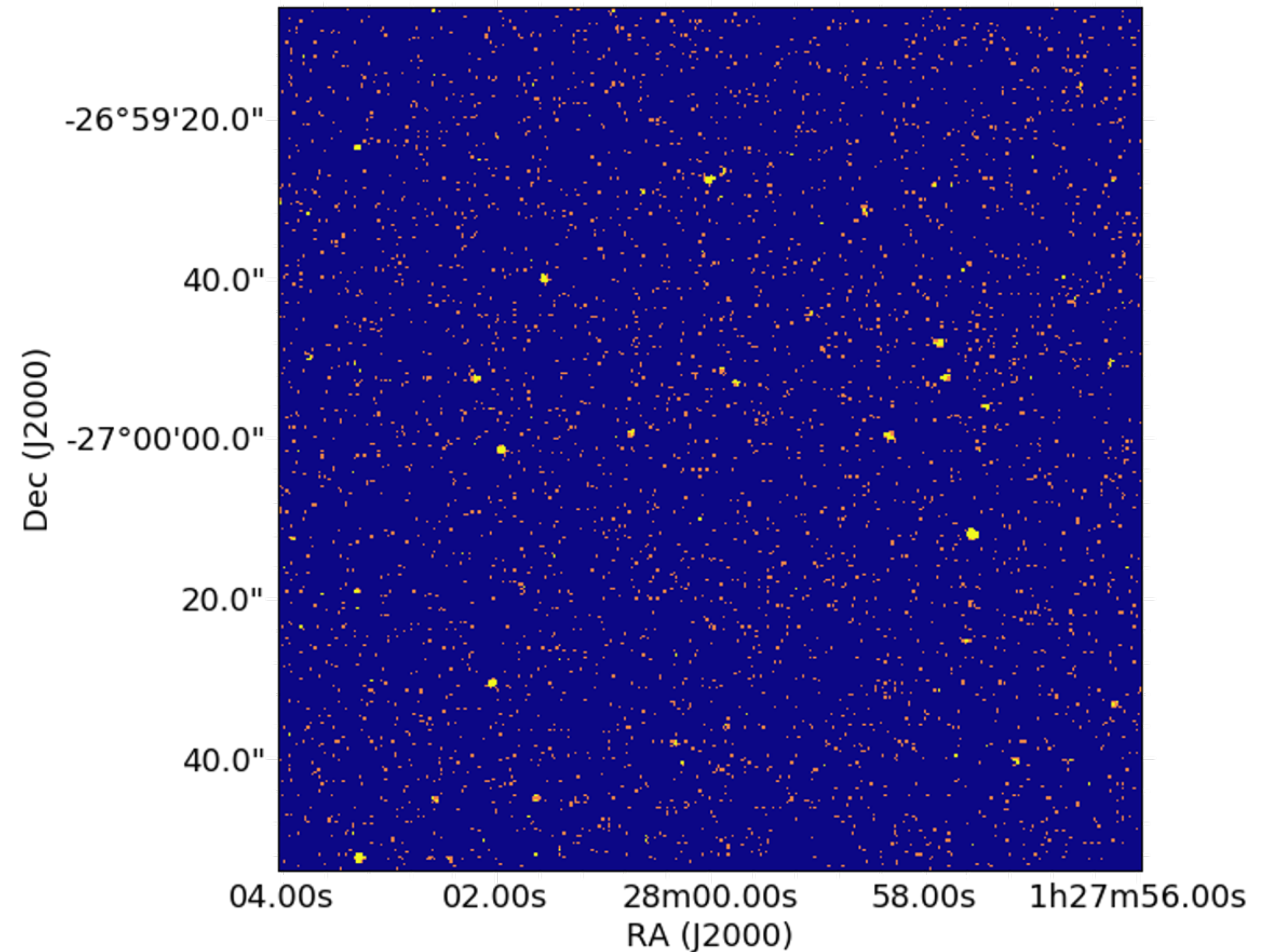


# Backgrounds/Foregrounds

## Milky Way Foreground



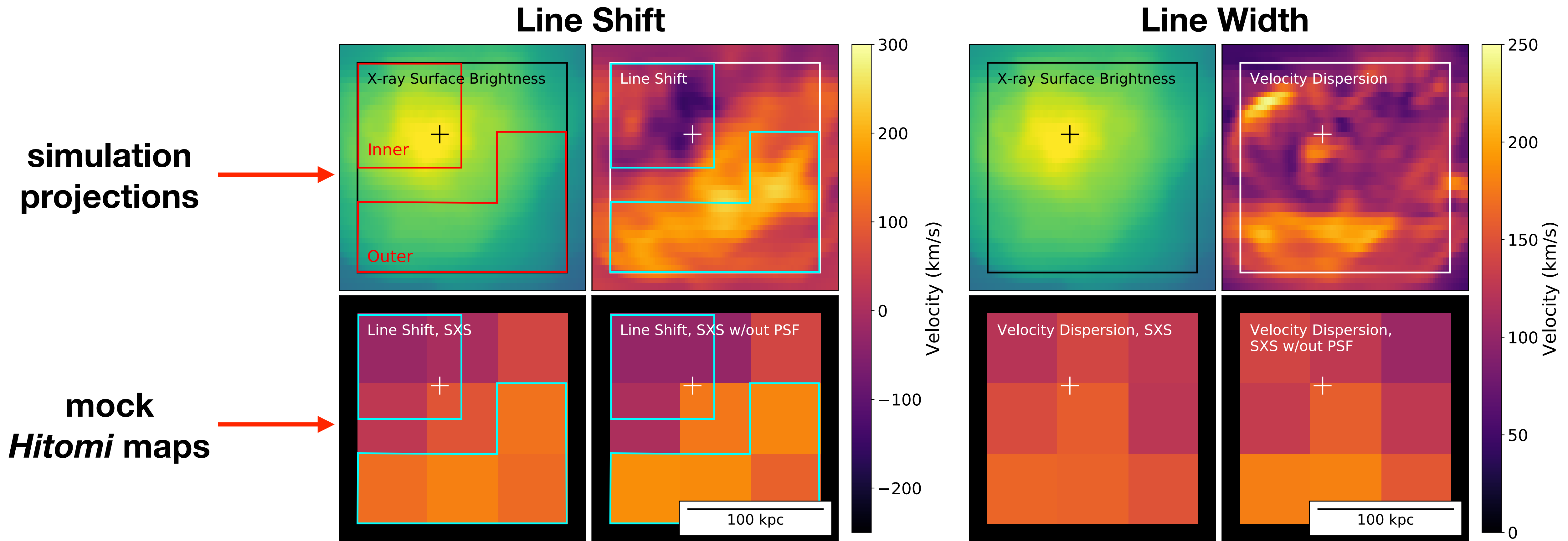
## Cosmic X-ray Background



**These can be exported to SIMPUT files if you want to use them with SIXTE/SIMX**



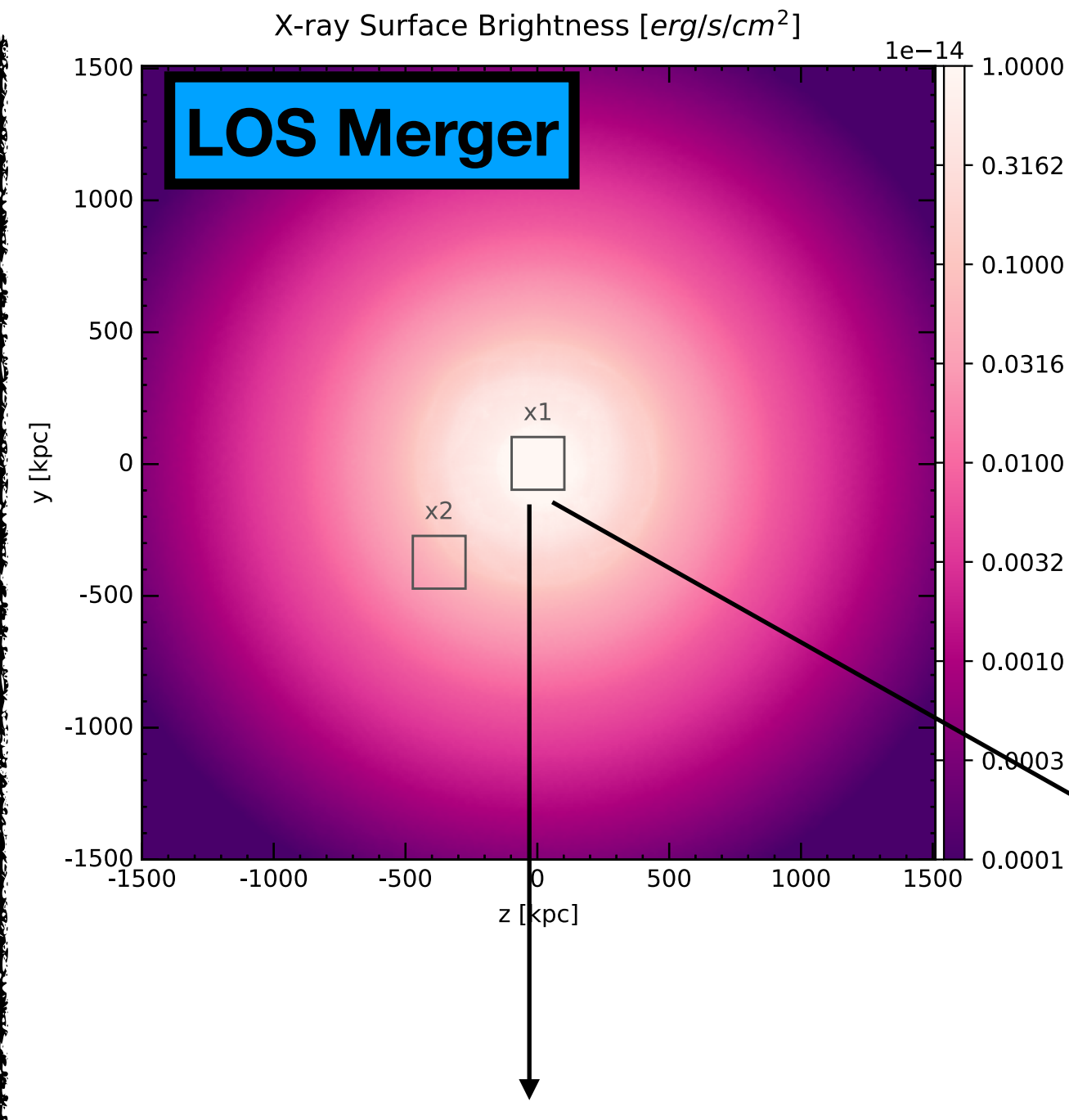
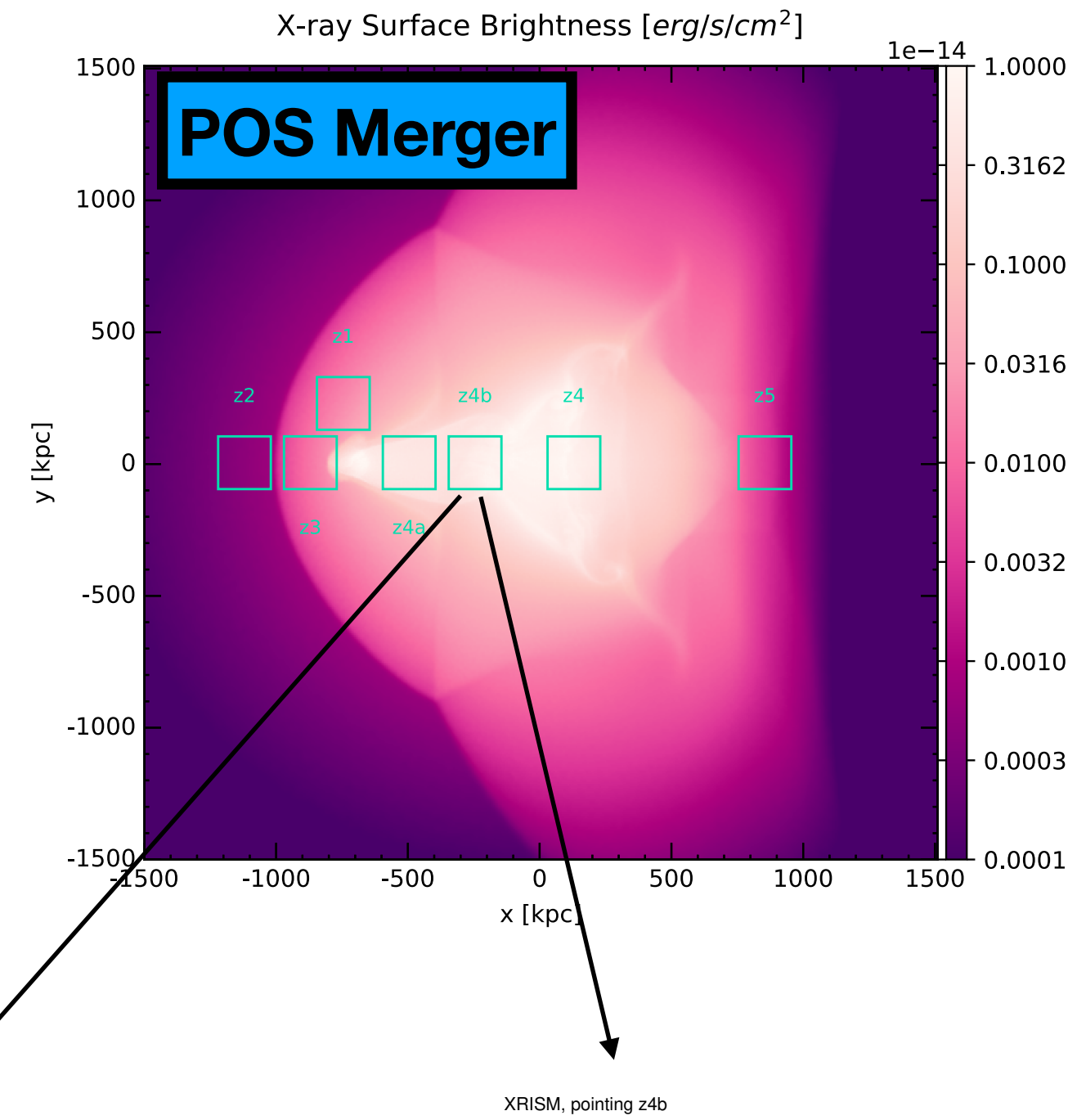
# *Hitomi* Mocks from FLASH Data



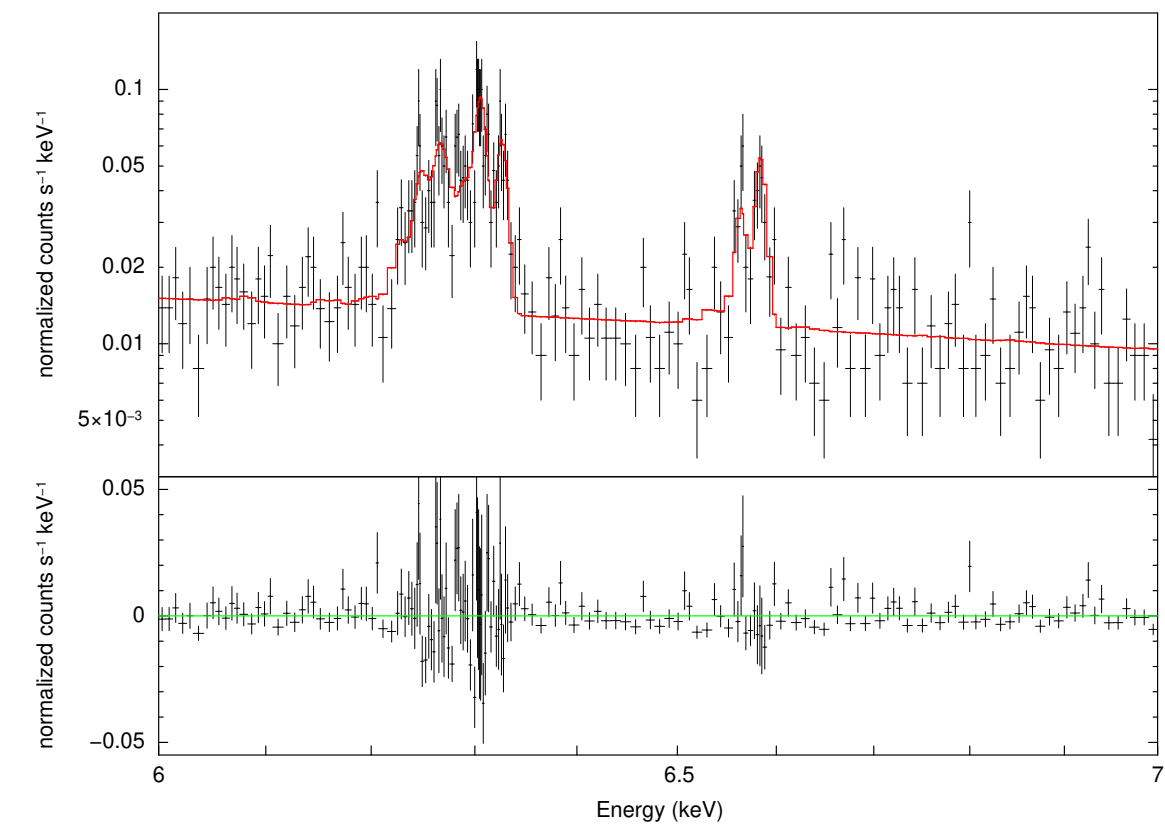
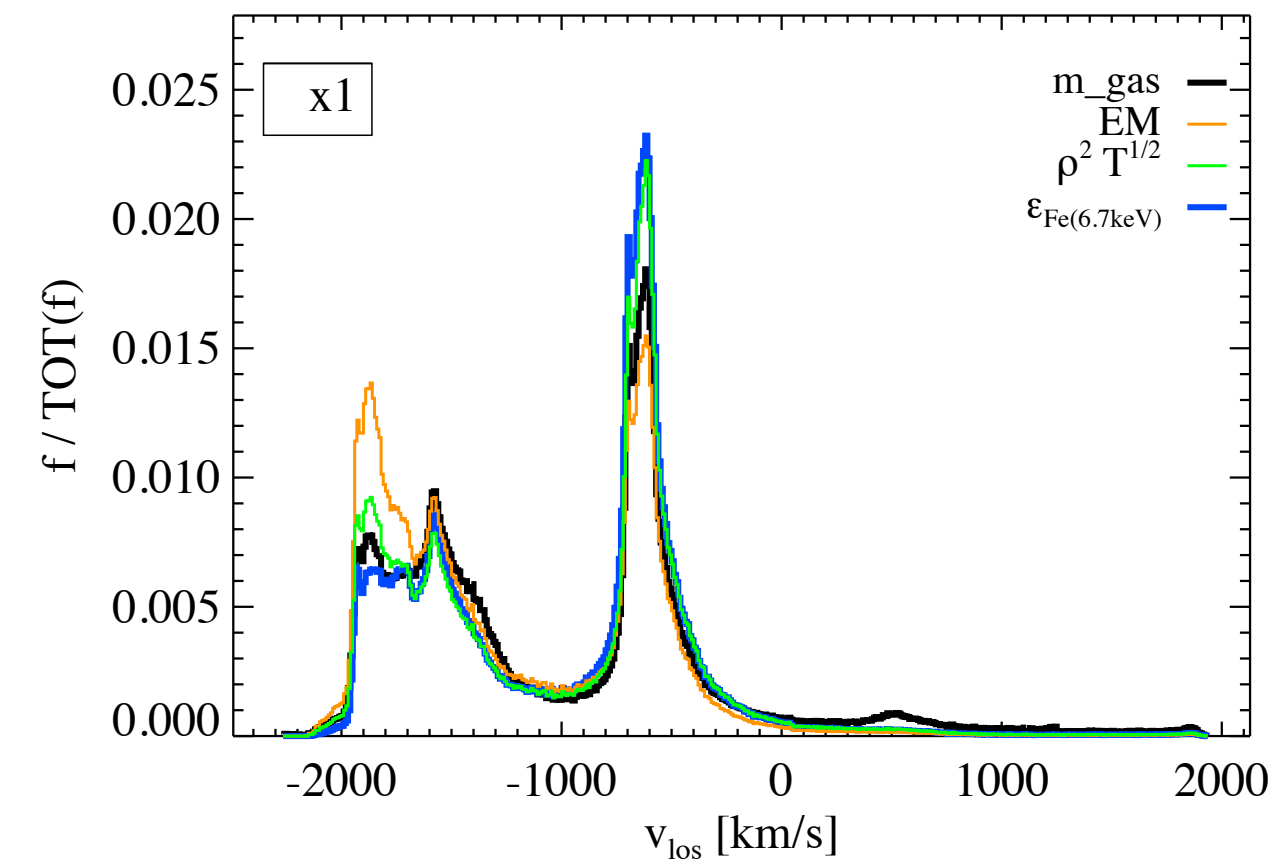
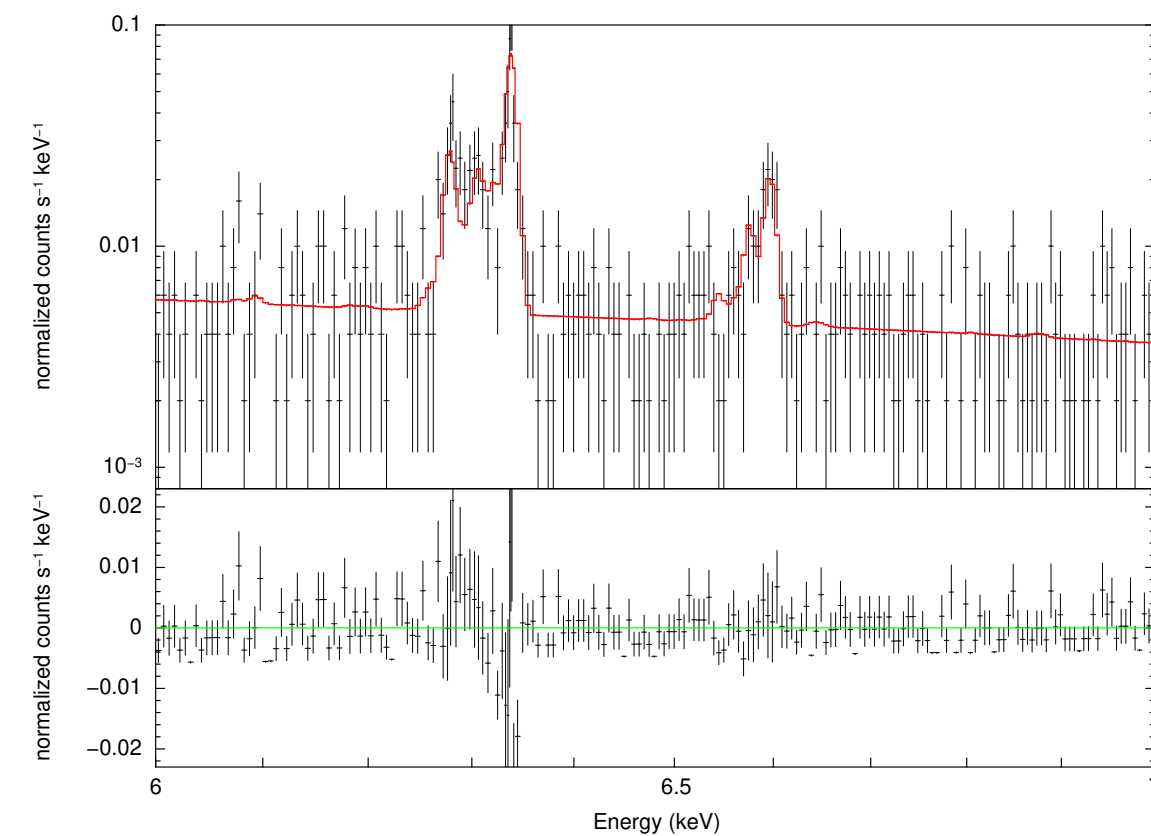
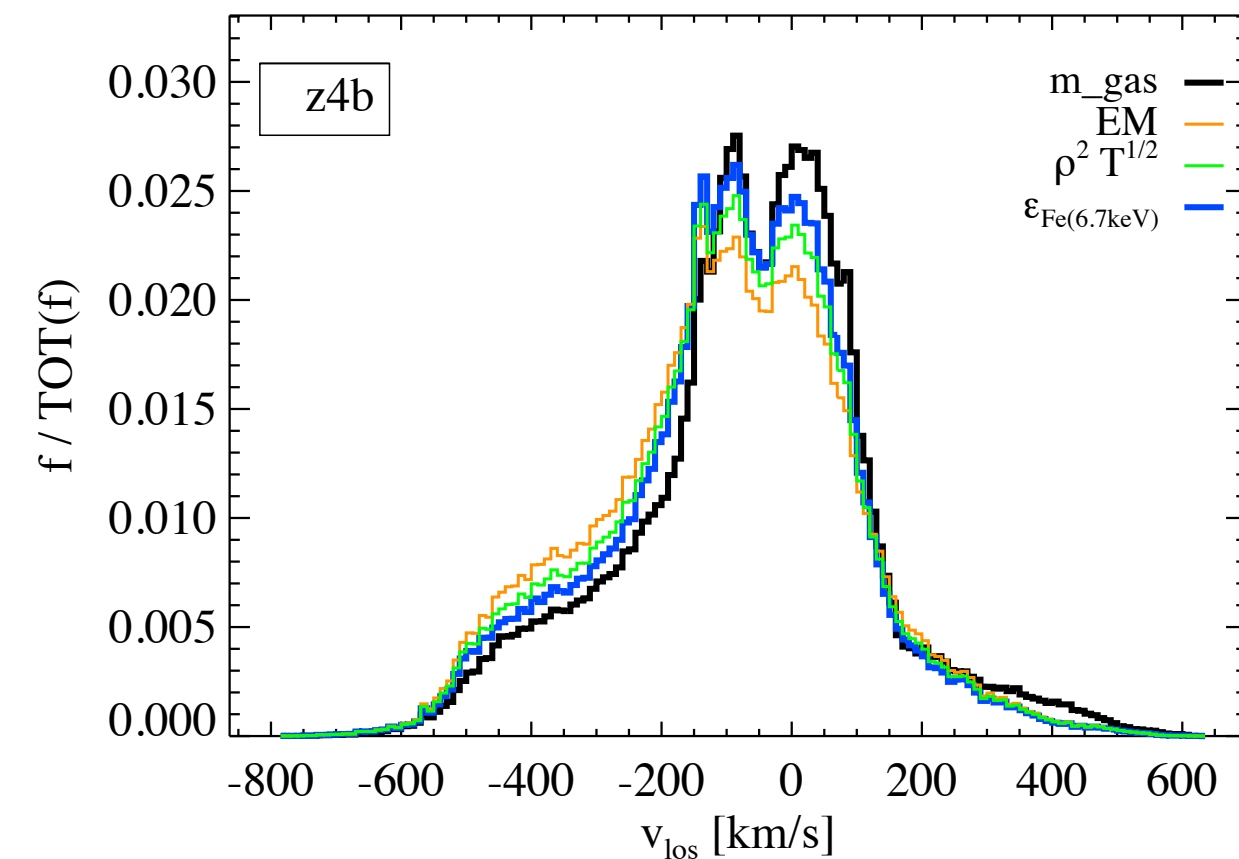
ZuHone et al. 2018

# Mock XRISM Observations of a Major Cluster Merger in AREPO

- Major mergers can show some interesting velocity distributions along different sight lines
- Mock XRISM/Resolve observations and mock Athena/XIFU observations

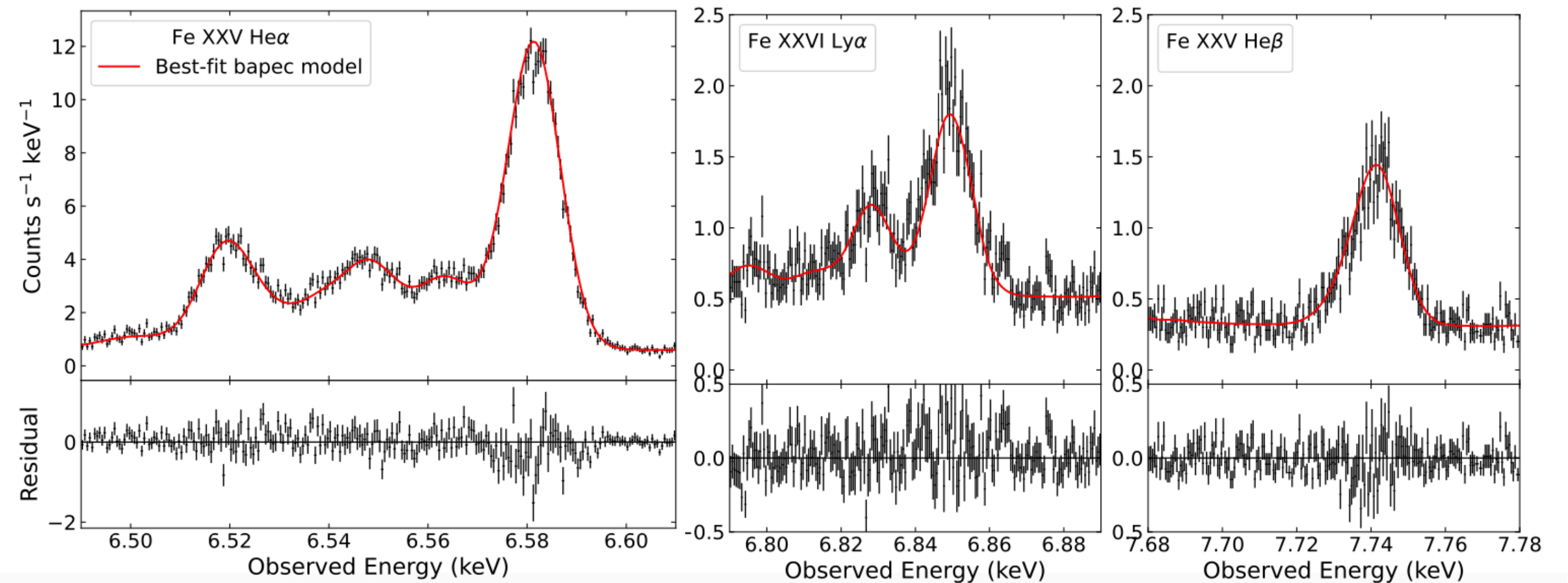
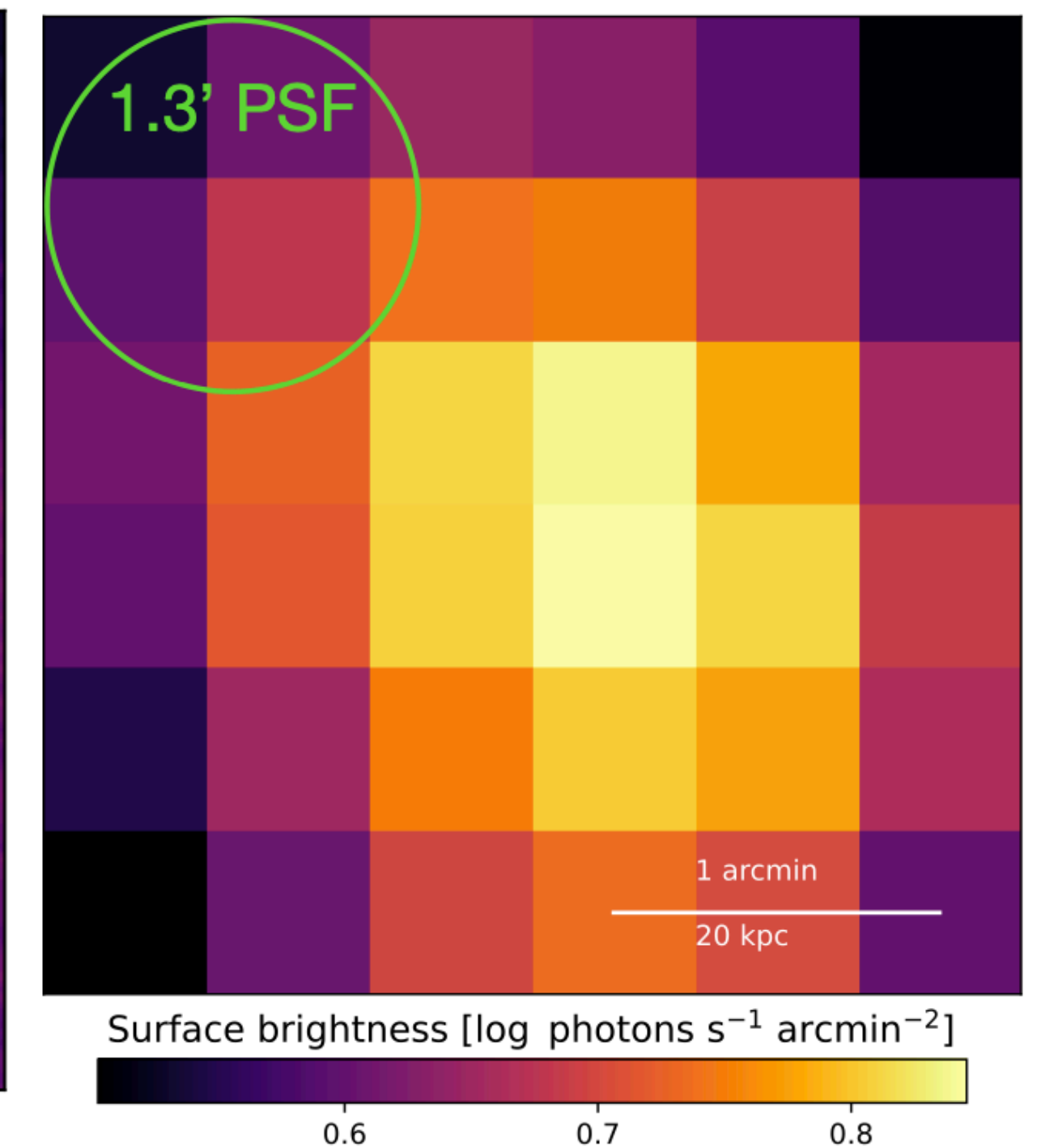
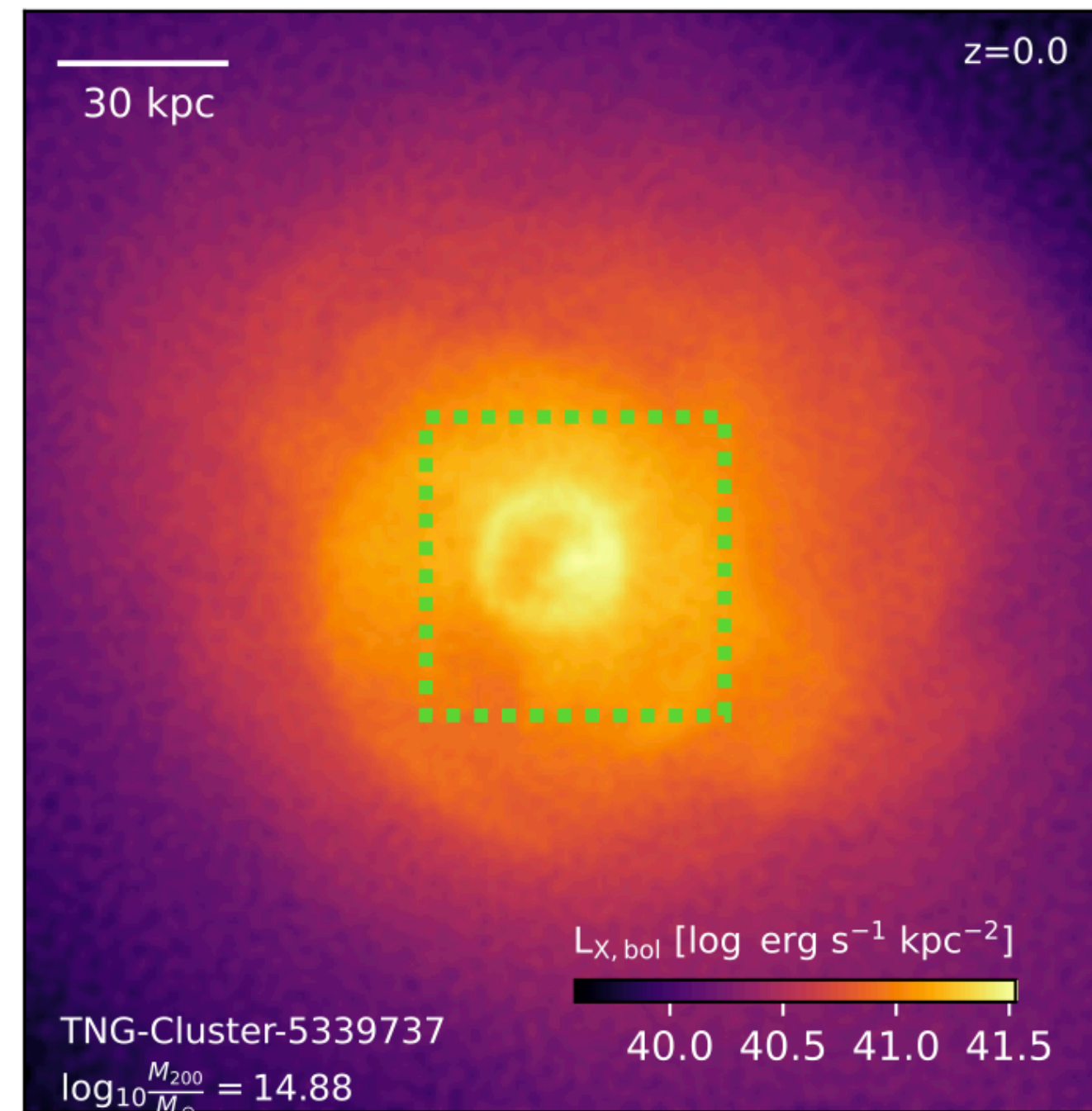


**Biffi et al. (2022)**

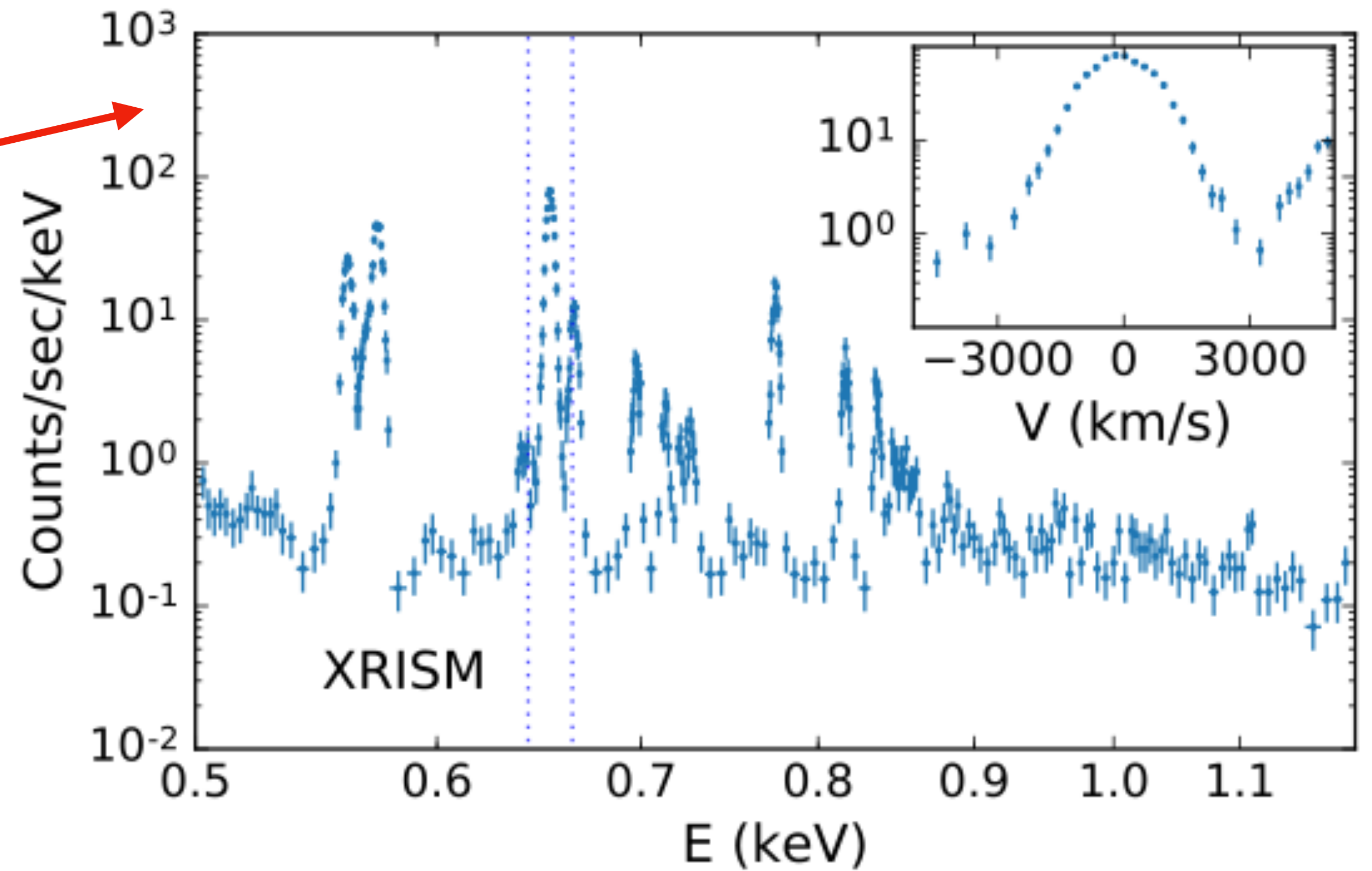
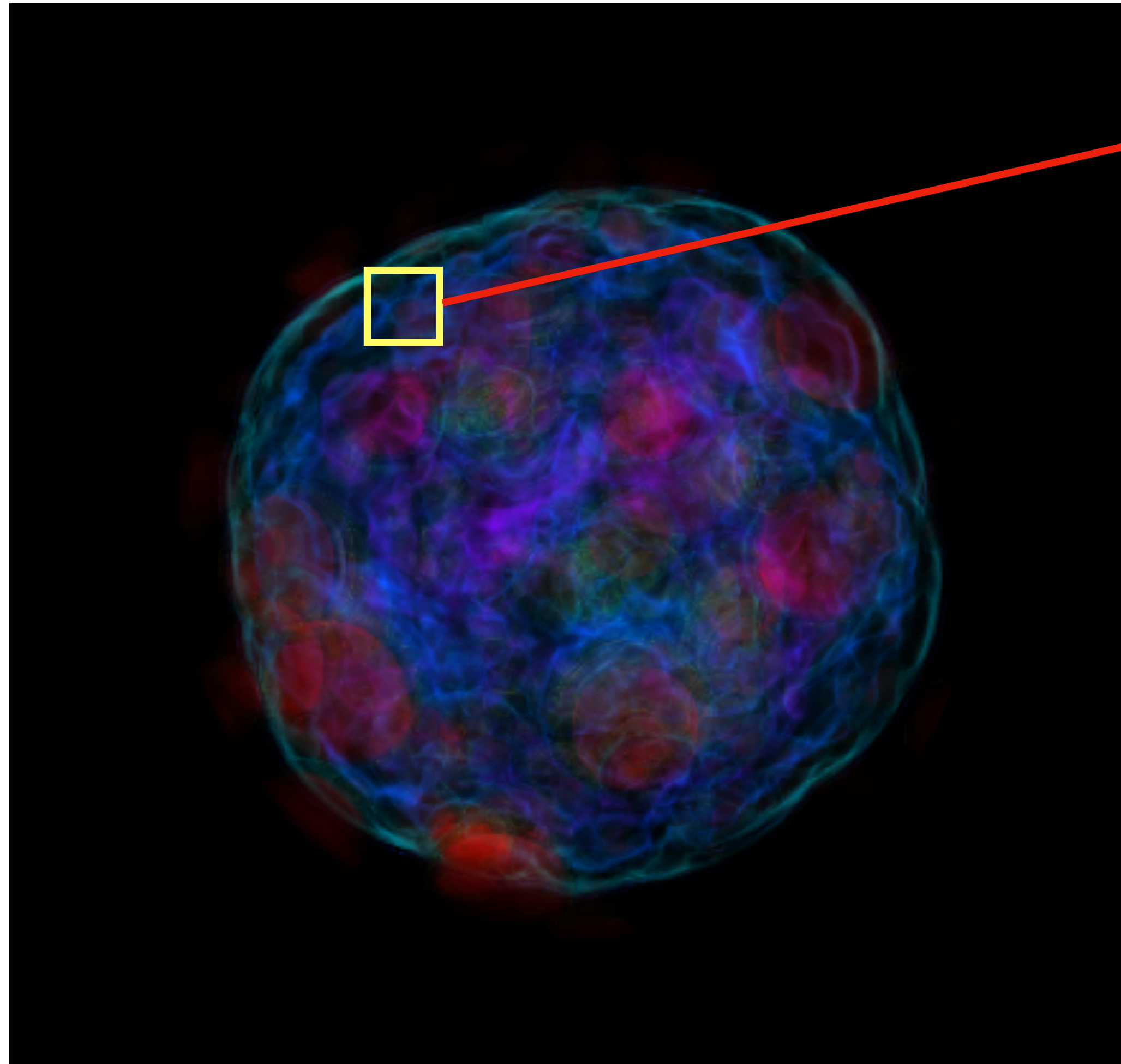


# Mock XRISM Observations of a galaxy cluster from TNG-Cluster

Truong et al. (2023)



# NEI Spectra from SNR



**Zhang et al. (2019)**