Simulating X-ray Observations with Python and yt

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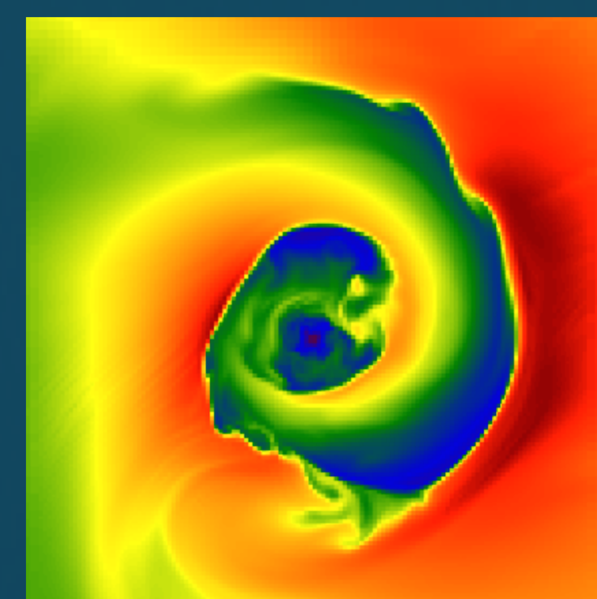
Mocking the High-Energy Universe

- X-ray astronomy probes the high energy universe, from hot thermal plasmas (galaxy clusters, solar corona, supernova remnants) to relativistic particles (inverse-Compton scattering of the CMB, AGN)
- X-ray astronomy deals in small-number statistics—must simulate the actual photon events
- Biffi et al. 2012 developed a novel technique for simulating X-ray observations: PHOX
- We have implemented the PHOX algorithm in yt (http://yt-project.org), a software package for the analysis of astrophysical simulation data

Dataset



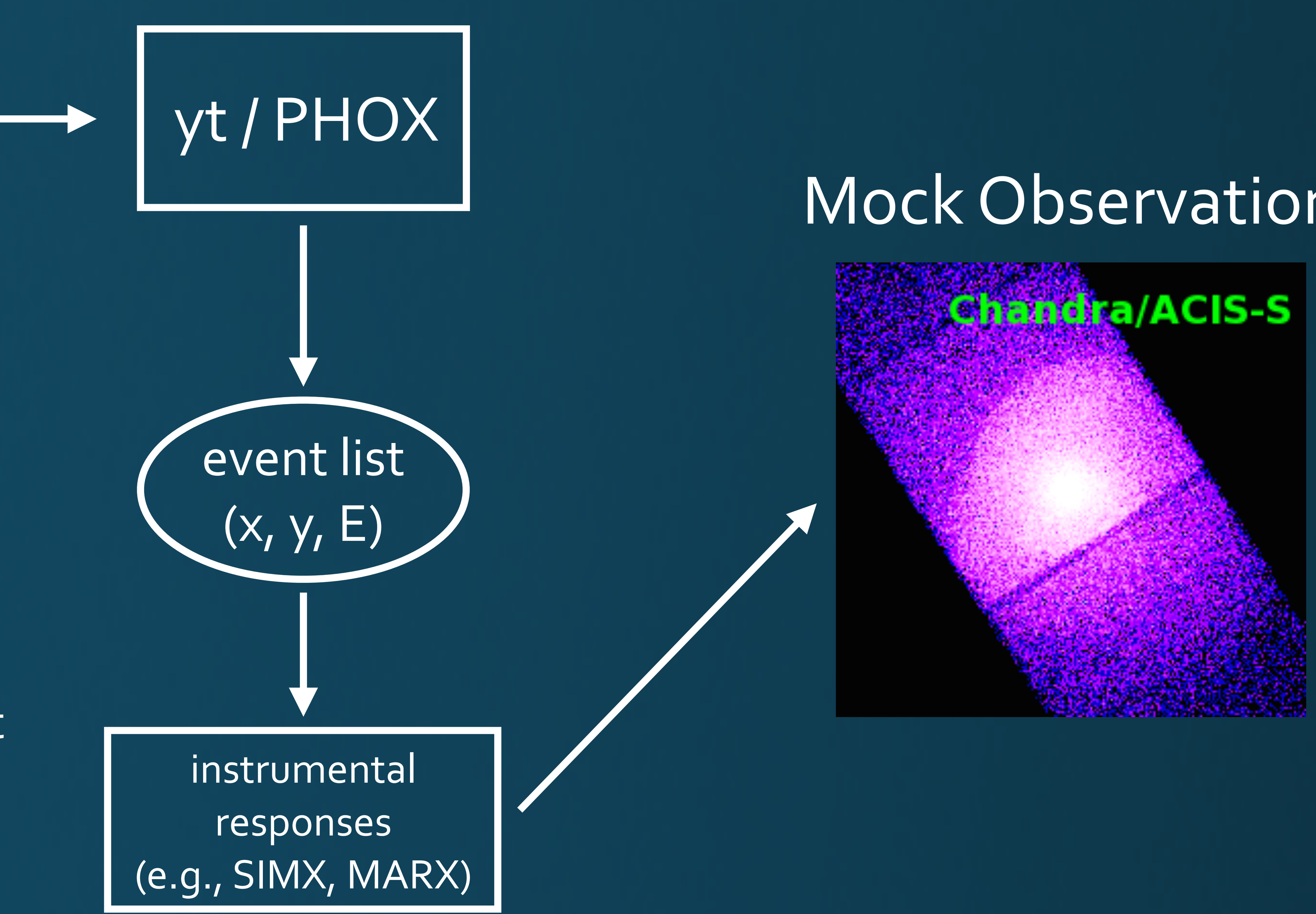


Figure 1: Taking a dataset such as a hydro simulation, we pass it through our pipeline to create event lists, which may then be convolved with instrumental responses to produce mock observations.

The PHOX Approach

- **Step 1**: Using an appropriate spectral model (APEC, MeKaL, power-law, etc.) and a 3D dataset, generate a large number of photons in 3D space, assuming large values for exposure time and telescope collecting area. Save to disk if necessary for re-use.
- **Step 2**: Using more realistic values for exposure time and collecting area, select a subset of photons for observation. Project these photons along a chosen line of sight, applying the local Doppler shift to the photons. Cosmologically redshift for distant sources. Apply Galactic foreground absorption.
- **Step 3**: Convolve with instrumental responses, create images and spectra from event lists.

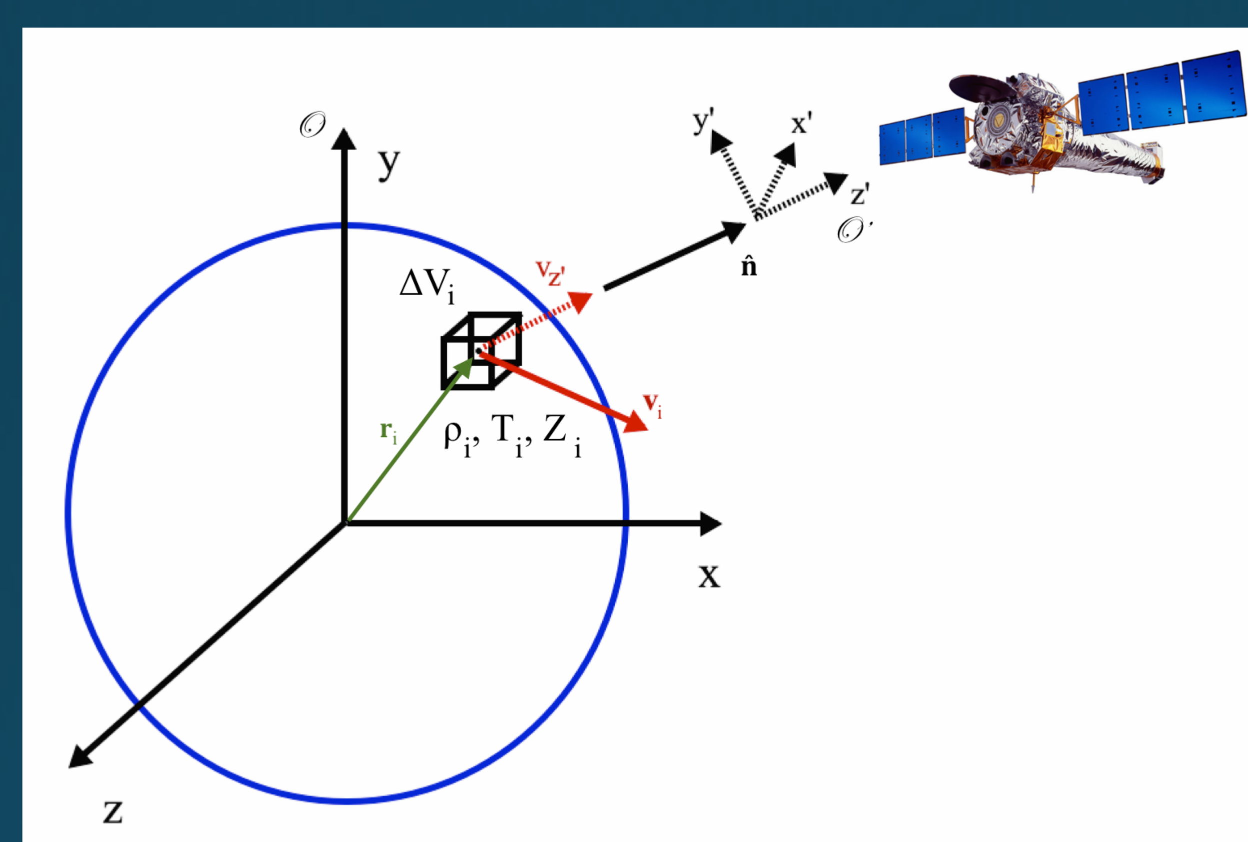


Figure 2: Schematic representation of a roughly spherical X-ray emitting object, such as a galaxy cluster. The volume element ΔV_i in the source has a velocity v_i. Photons emitted along the direction $\hat{n}$ will be received by the observer and will be Doppler-shifted by the line-of-sight velocity component $v_{z'}$. *Chandra* image credit: NASA/CXC.

Advantages

- Generating the photons in 3D first requires the most expensive step to be performed only once, and the same photon sample may be used to simulate events for a variety of exposure times, projections, and instruments
- Implementing the algorithm in yt allows the user to create synthetic observations from a wide variety of sources, from Enzo simulations to NumPy arrays, from arbitrary sub-volumes extracted from the simulation
- Our implementation allows us to take advantage of the scientific Python ecosystem, including AstroPy, SciPy, PyXspec, and Sherpa.

An Example: Detecting Bulk Motions in Cluster Cool Cores with *Astro-H*

- The "cold fronts" seen in *Chandra* images of cool-core clusters are associated with subsonic tangential "sloshing" motions.
- We examine hydrodynamic simulations of sloshing to show that these motions produce shifting and broadening that the upcoming *Astro-H* satellite will be able to observe in nearby systems (Figure 3).
- We use synthetic *Astro-H* spectra to constrain various spectral models (Figure 4), and we find that models that do not incorporate velocity broadening can be ruled out.
- We also find that it will be essential to account for the effects of PSF scattering (~1′) from the bright core for accurate determinations of the velocity shift, width, and gas temperature.

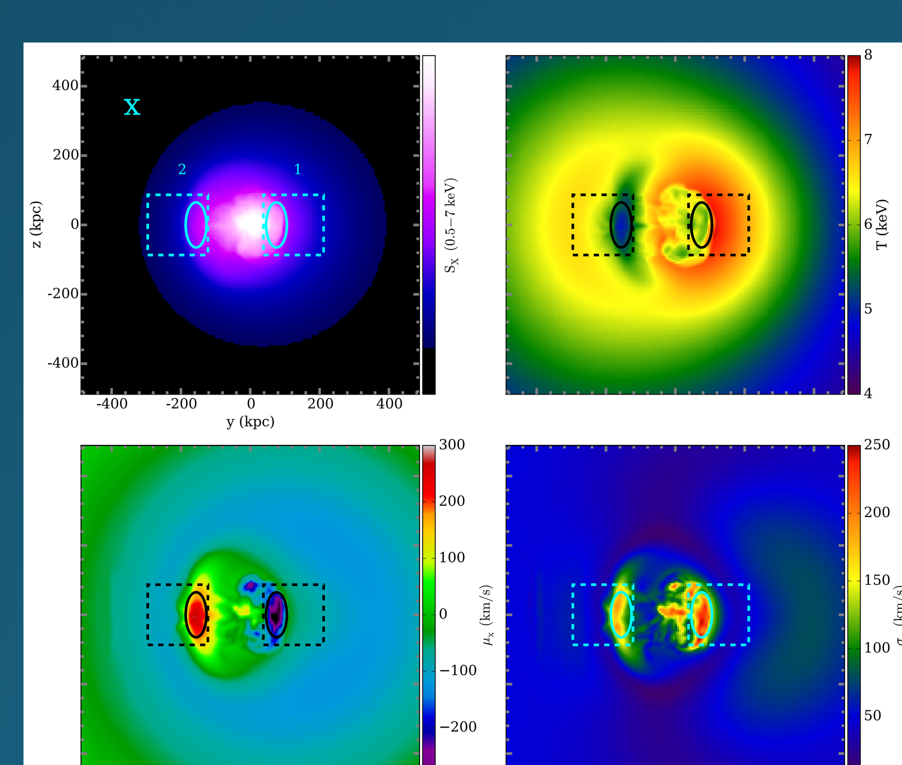


Figure 3: Projections of quantities along the simulation x-axis with spectral extraction regions indicated.

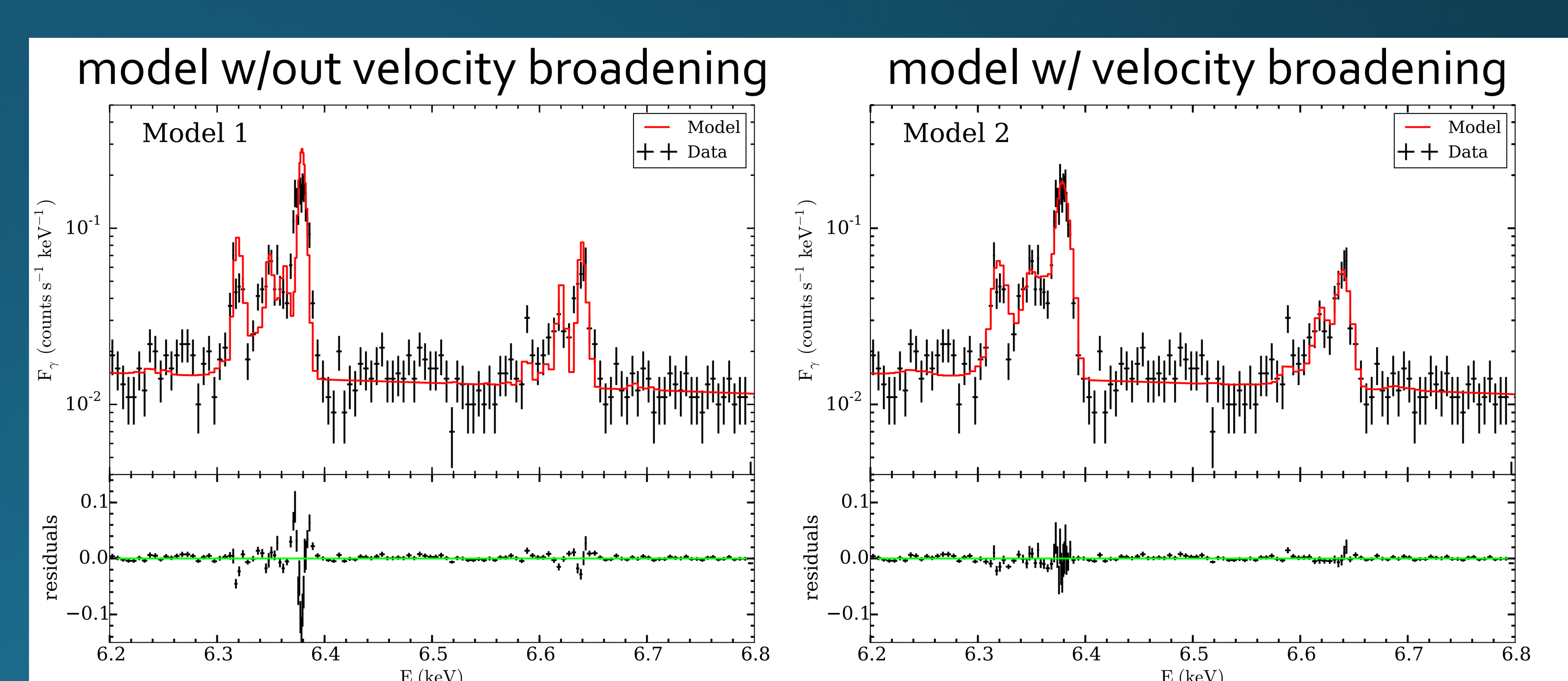


Figure 4: Synthetic *Astro-H* spectra and fitted models around the Fe-K lines.

arXiv: http://arxiv.org/abs/1407.1783

SciPy 2014 Talk: http://conference.scipy.org/proceedings/scipy2014/zuhone.html

yt docs: http://yt-project.org/doc/analyzing/analysis_modules/photon_simulator.html