

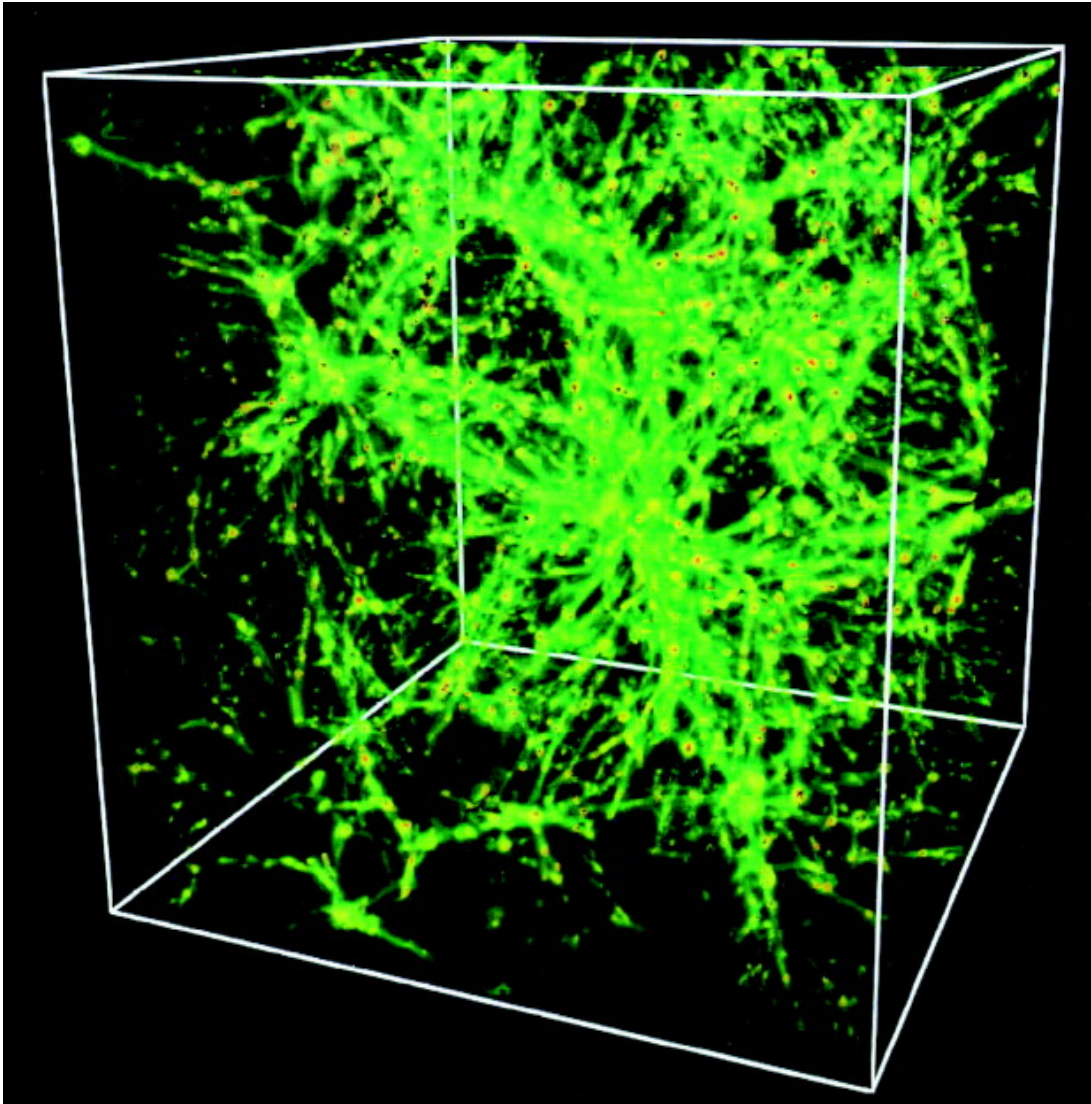
The missing baryons and the warm-hot intergalactic medium

Jelle Kaastra

Alexis Finoguenov

Fabrizio Nicastro, Enzo Branchini, Joop Schaye, Nico Cappelluti, Jukka Nevalainen, Xavier Barcons, Joel Bregman, Klaus Dolag, Massimiliano Galeazzi, Takaya Ohashi, Luigi Piro, Mauro Roncarelli, Yoh Takei, Eugenio Ursino

WHIM: $10^5 < T < 10^7$ gas



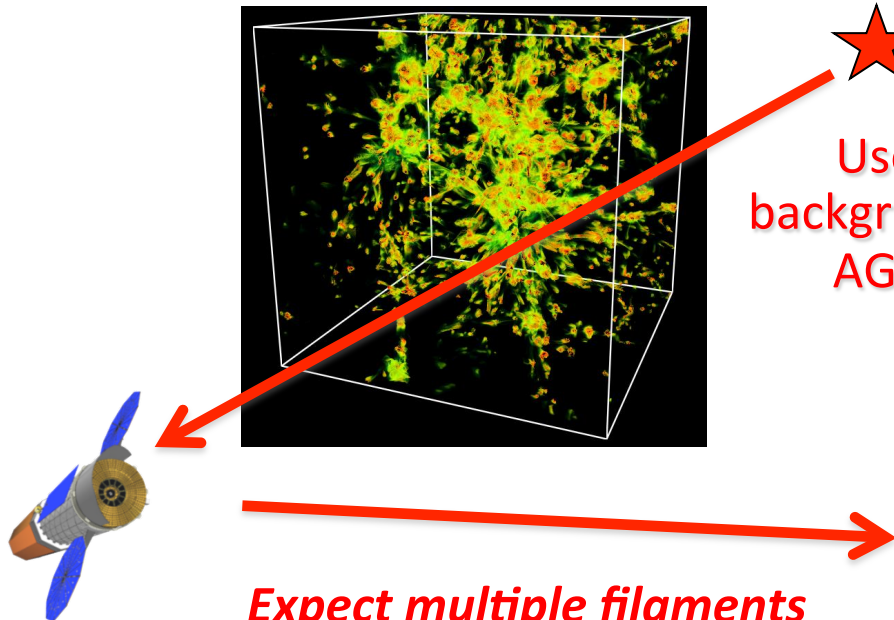
50Mpc/h Λ CDM
simulation
(Cen & Ostriker 1999)

Key questions

- **Where are the baryons** still missing from the cosmic budget at $z \sim 0$? Do they really trace the **filaments** of the cosmic web, as the theory predicts? What is their physical **state & composition**?
- Where have the **missing baryons in galactic haloes**, including our own Galaxy, gone? Do we see them in the circumgalactic space?
- What is the **role of feedback** by galactic winds and active galactic nuclei in the process of galaxy formation?
- What happens with the **gas**: how much gas **accretes**, how much is **blown out**, and what fraction **is locked-up** temporarily in stars?
- What are the contributions from accretion versus outflows in **structure formation**?
- *Observations with Athena: → location, chemical composition, physical state & dynamics of roaming population of baryons.*

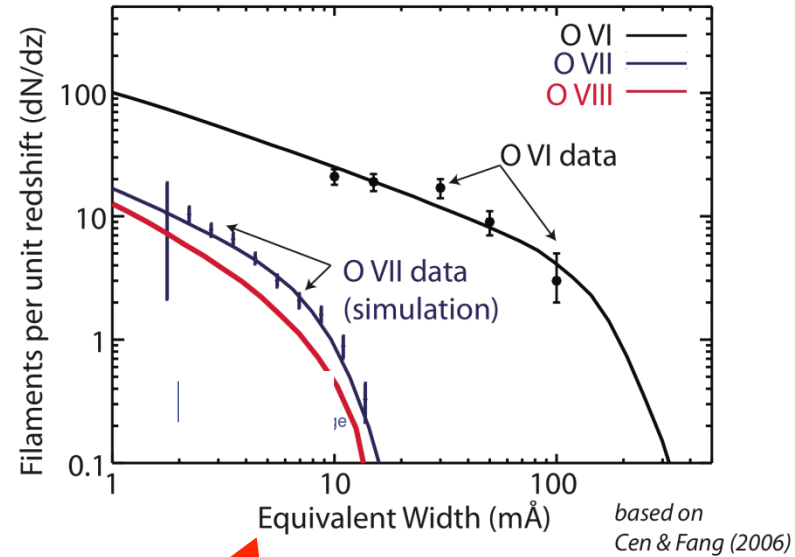
Find and Characterize the Missing Baryons

- *Where is the hot gas relative to the galaxies?*
- *How do filaments connect to groups and clusters?*

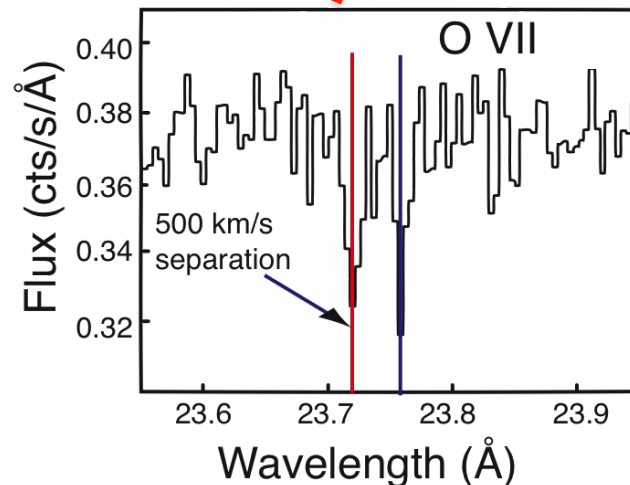


Use background AGN

Expect multiple filaments in each line of sight



Compare distribution of filaments to models

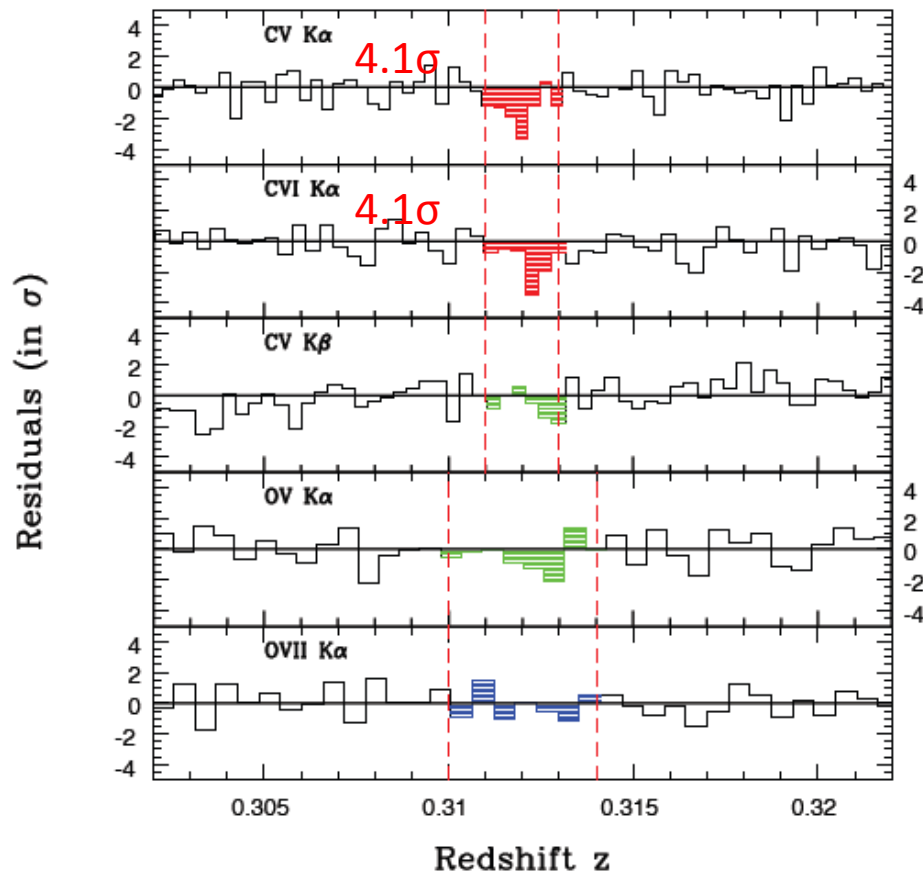


Best we can do now...

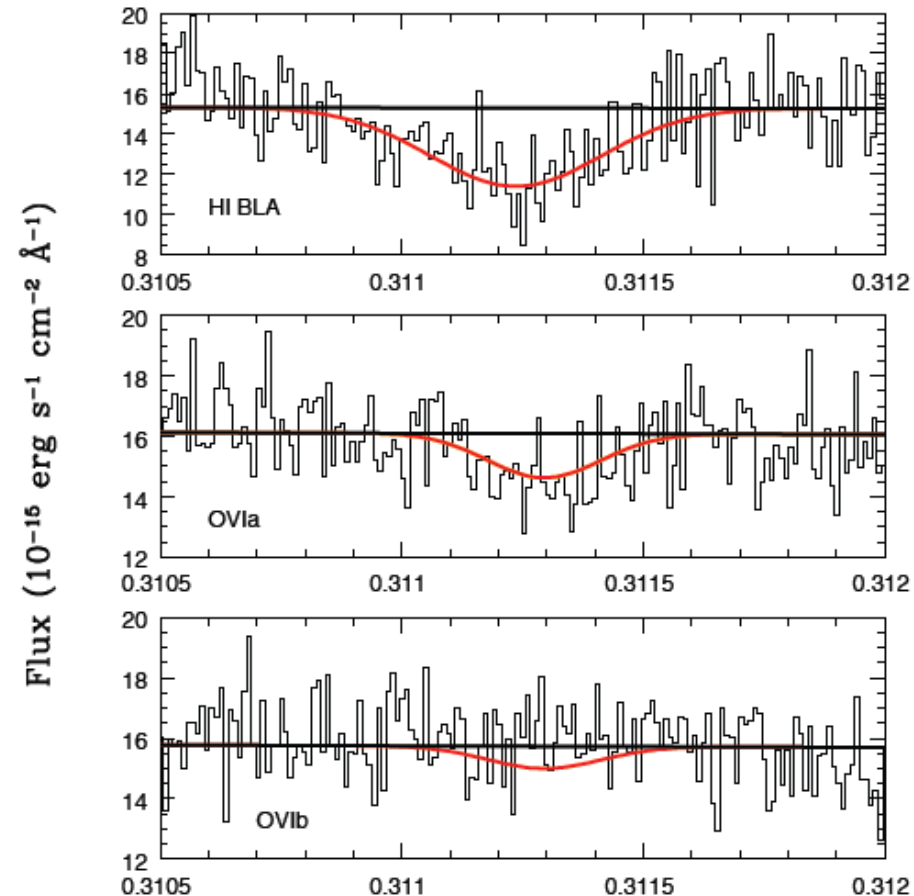
1ES 1553+113, Nicastro et al. 2013

500 ks Chandra LETGS

Chandra detections @ COS redshift

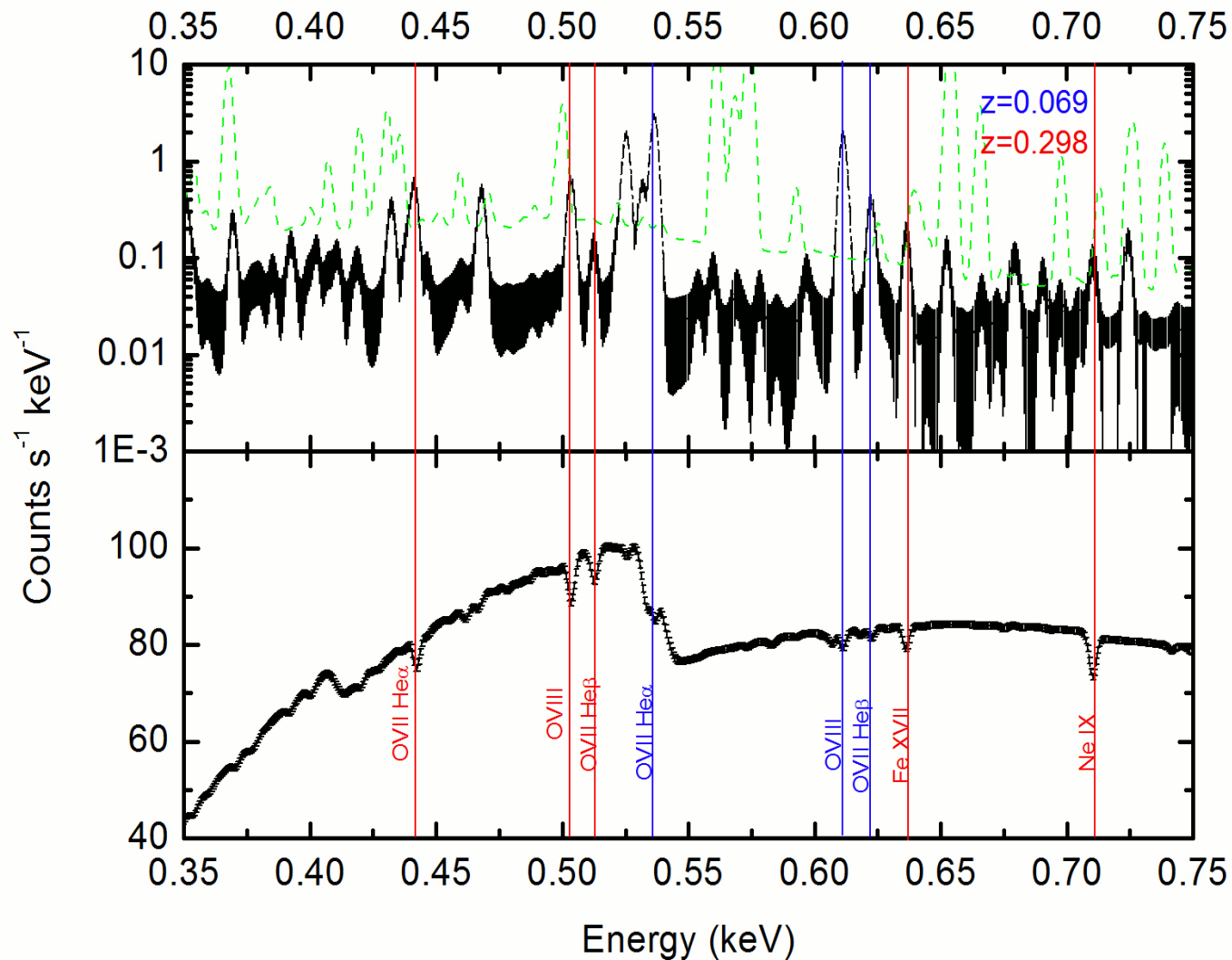


HST/COS detections @ $z=0.312$

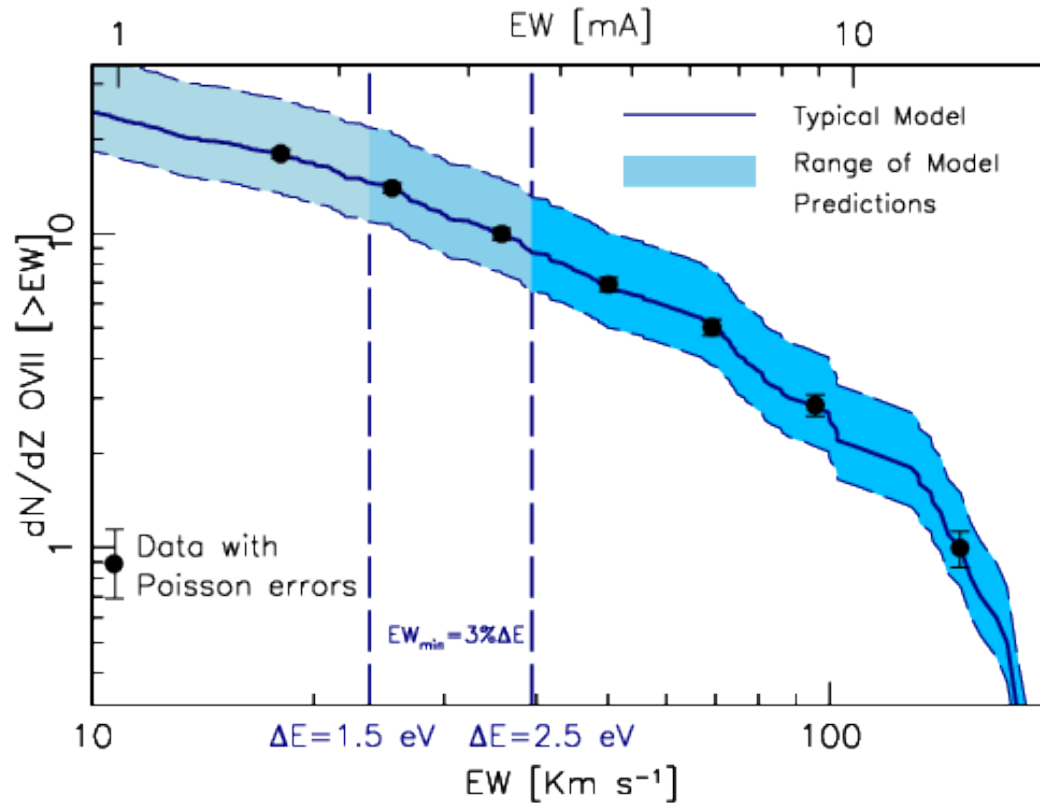


XIFU observation of bright object

$$3 \times 10^{-6} \text{ erg cm}^{-2} = 3 \times 10^{-9} \text{ J m}^{-2}$$



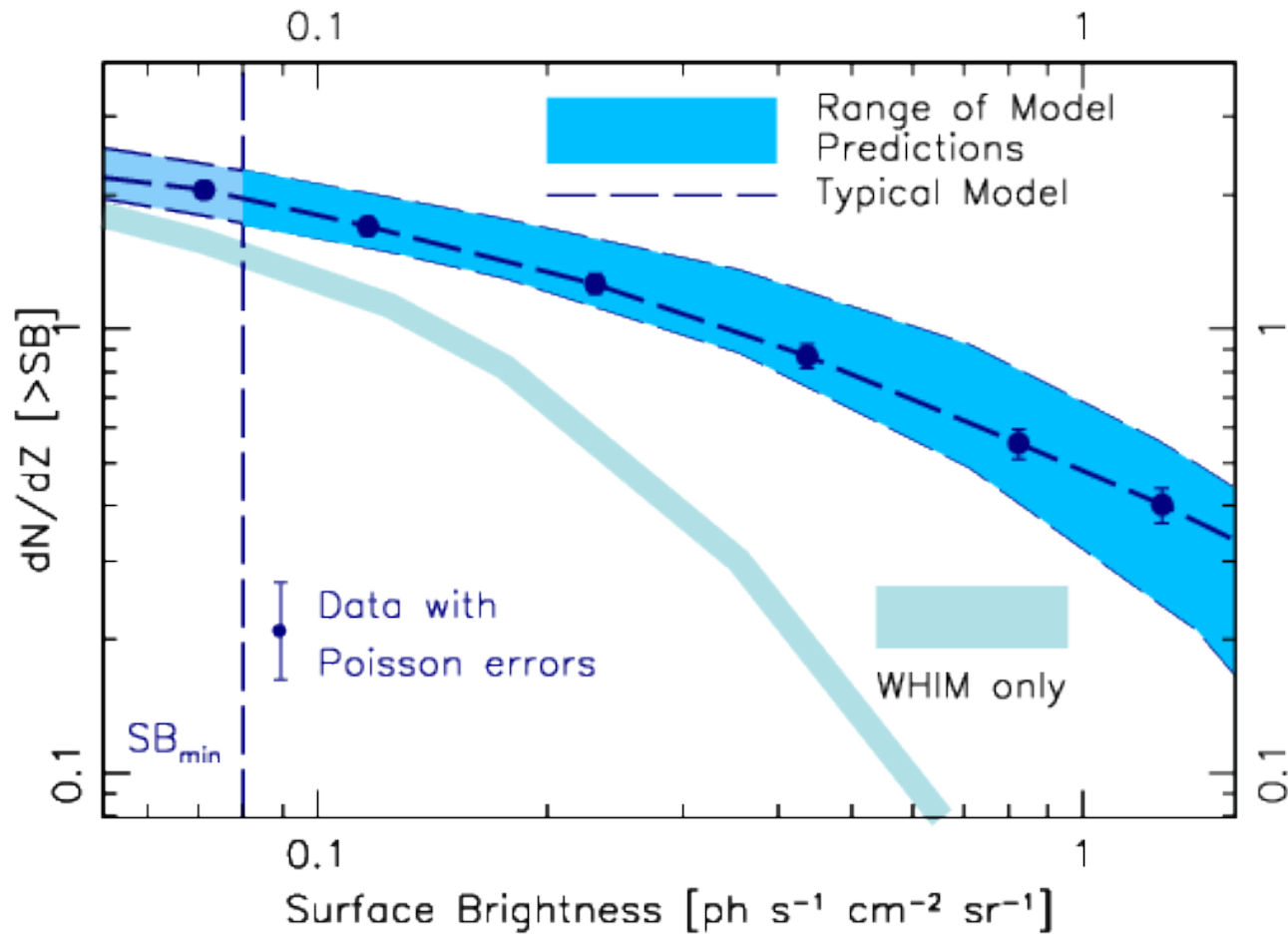
Athena+ OVII dn/dz: Absorption



24 AGNs with $dz \sim 0.3$

20-40 GRB with $dz \sim 1$

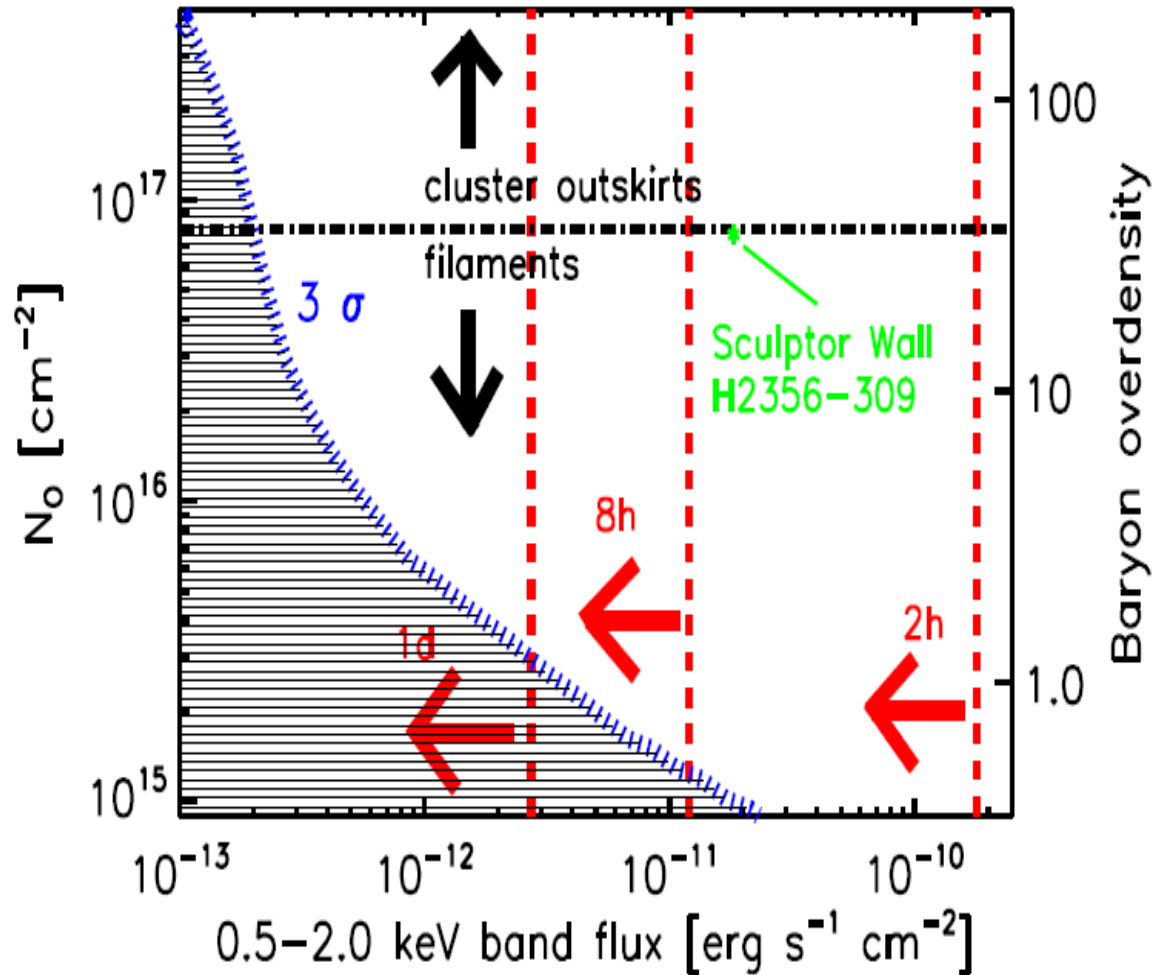
Athena+ OVII+OVIII dn/dz: Emission



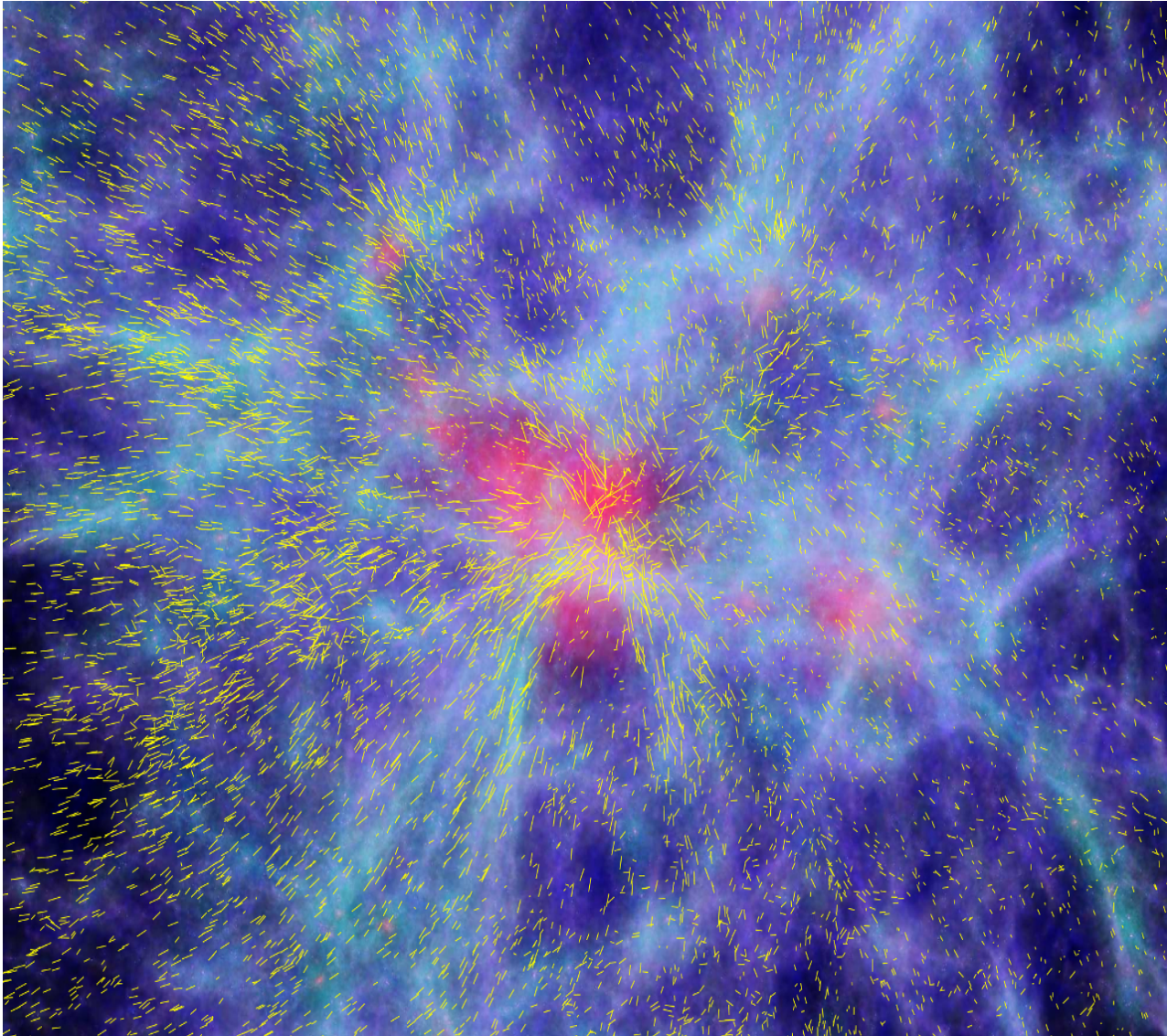
4 detections in each 100ks observation

GRB afterglow

ATHENA+ X-IFU 50ks simulation

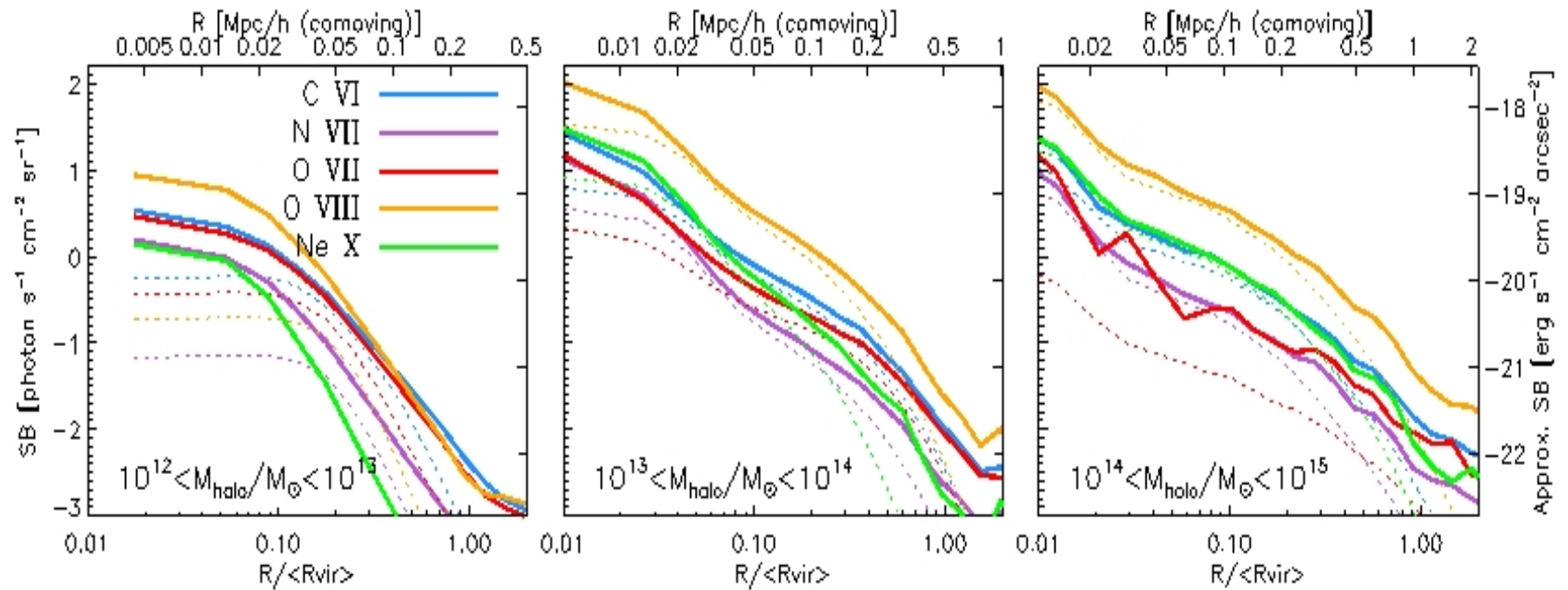


Kinematics of missing baryons



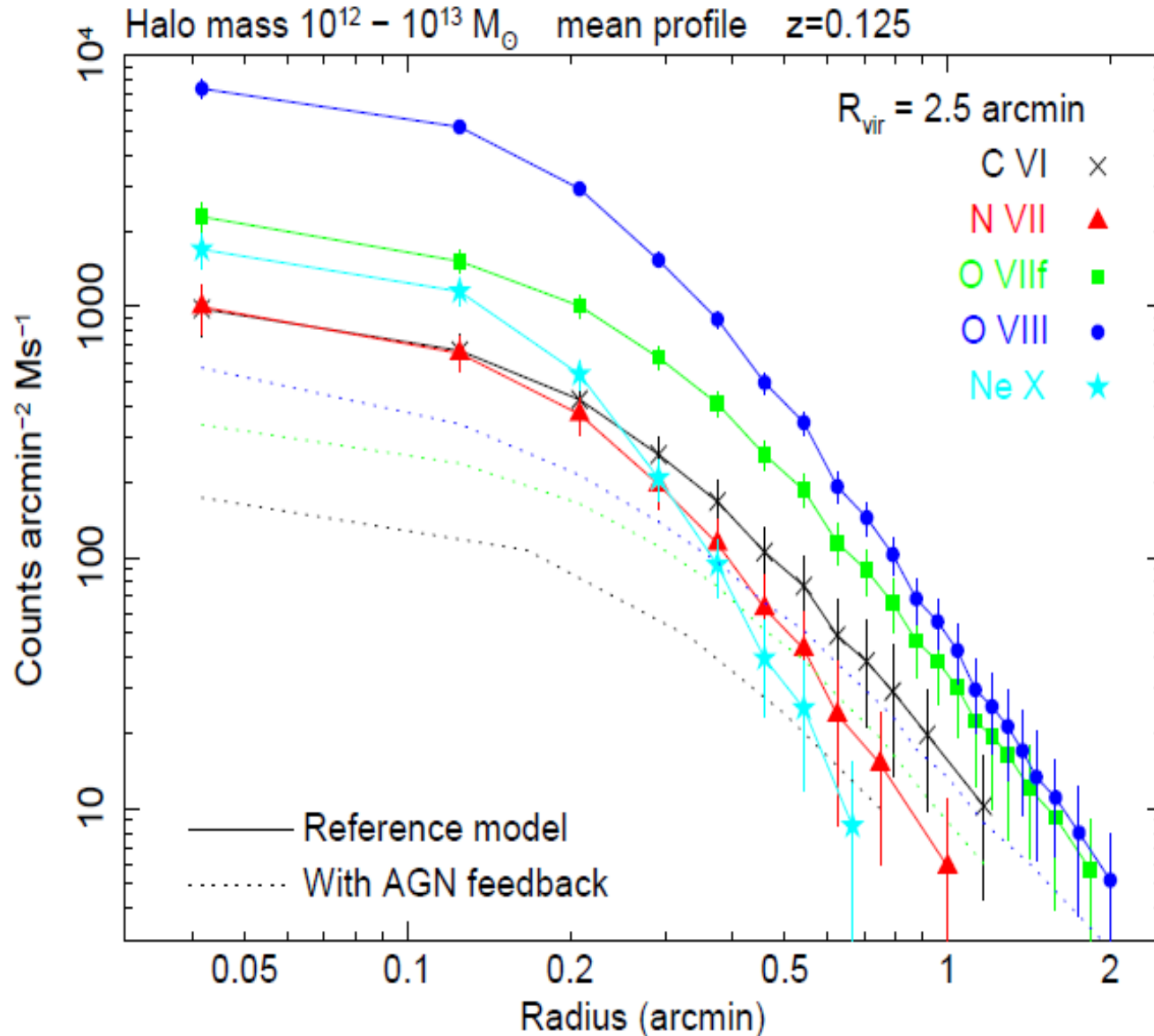
K.Dolag

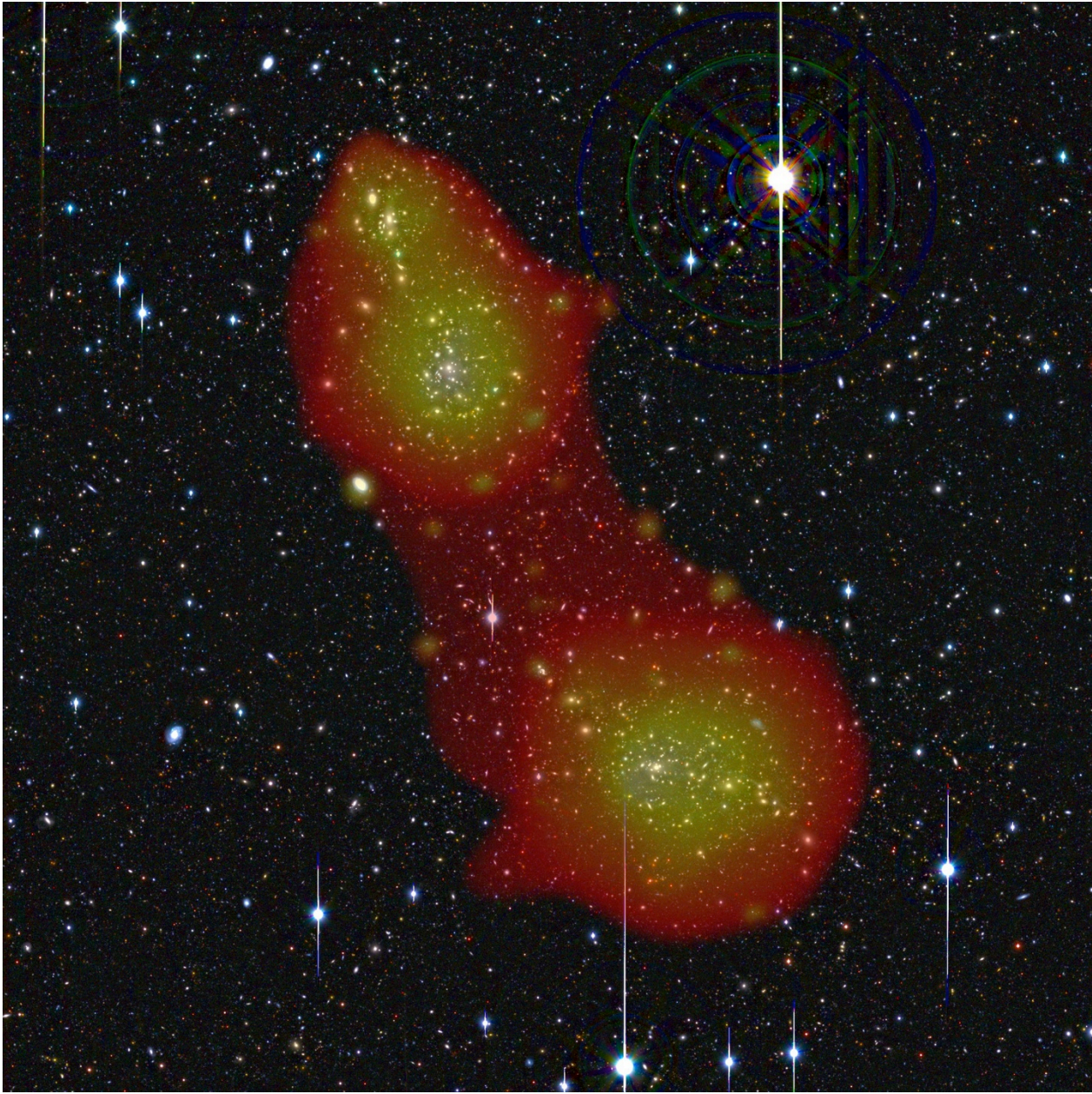
Element distribution in halos



Van de Voort & Schaye 2012

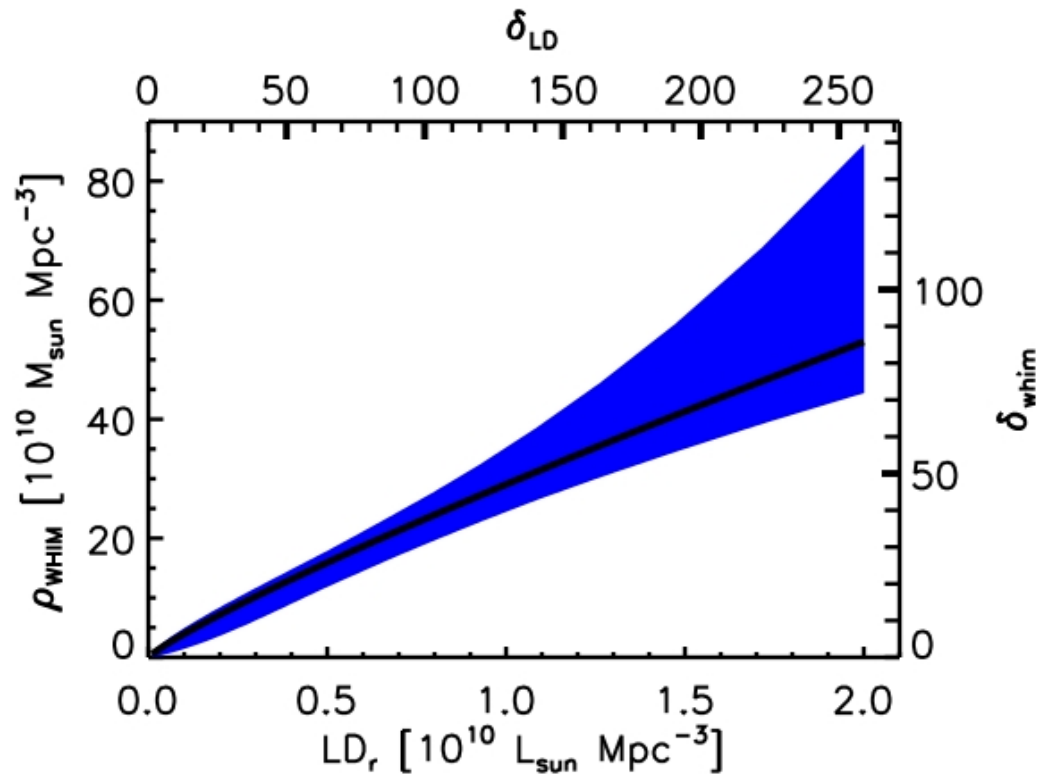
Athena simulation



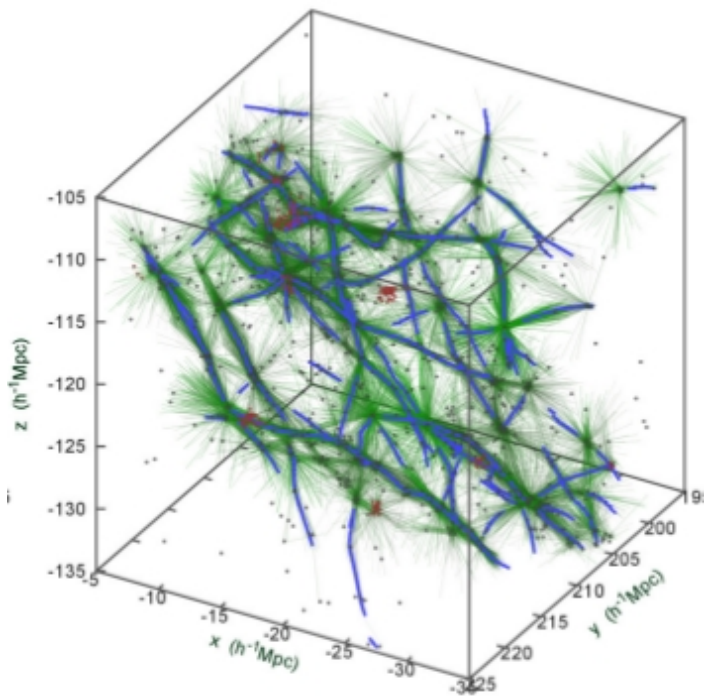


Mapping WHIM structures using galaxy luminosity density as a tracer

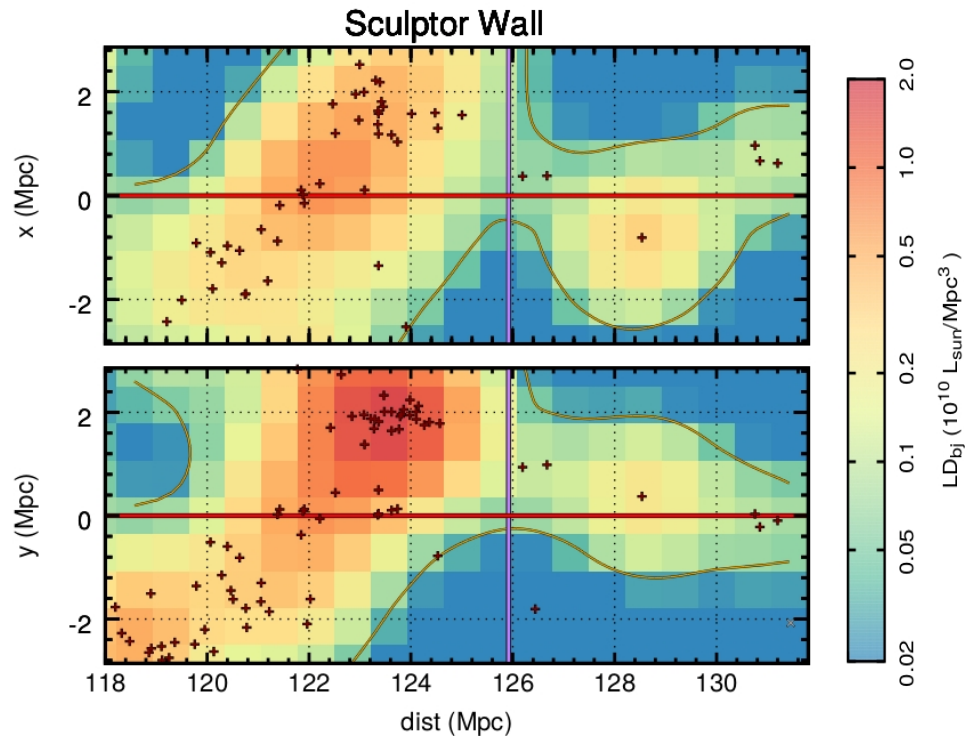
(Nevalainen et al., 2015, A&A, accepted, arXiv:1508.02310)



Large scale simulations (Cui et al. 2012):
WHIM density well correlated with galaxy luminosity density (LD) within cosmic filaments



Galaxy filaments detected from spectroscopic galaxy surveys like SDSS with Bisous model (Tempel et al., 2014)



Luminosity density fields created using galaxy positions and luminosities

- Luminosity density converted to WHIM density using the relation from simulations
- Application to SDSS & 2dF (in preparation) yields WHIM structures for 25% of the sky up to $z=0.1$
- Near future surveys → WHIM finding maps for ATHENA

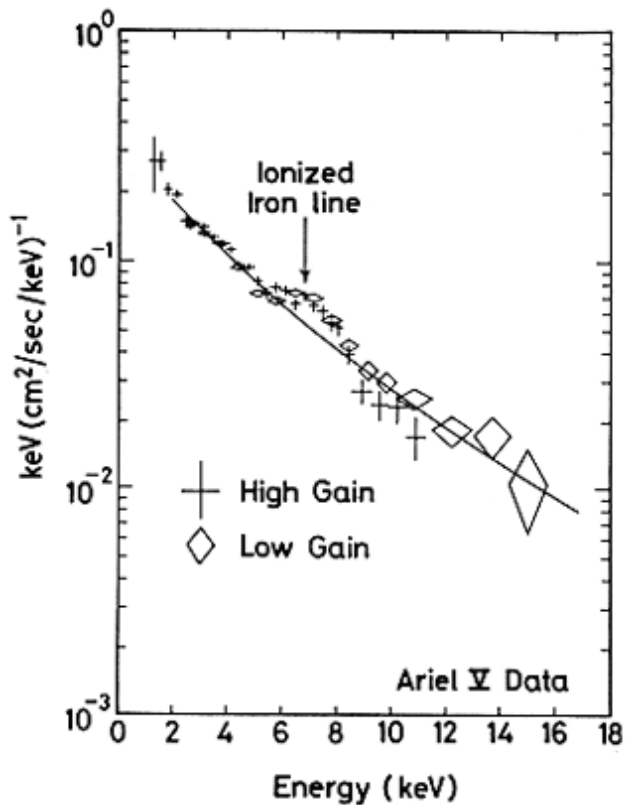
Observing strategies

- Detection 200 filaments in absorption (150 from blazars, 50 from GRB). 15 GRB fields follow-up for emission. Comparison to SDSS density fields.
- Serendipitous detection of WHIM emission in every >100 ks XIFU observation
- 100 ks depth XIFU survey of 1 deg^2 (10 Ms)
 - Line profiles of halos
 - Baryons in the calibrated LSS
 - Statistical studies of WHIM kinematics
 - Same strategy as in $z \sim 10$ QSO Fe-line tomography.
 - Identification of X-ray ghosts
- Missing metals at $z \sim 3$ in absorption (GRBs)

Clusters of galaxies and hot baryons

An international conference to celebrate the 40th anniversary of the discovery by Ariel 5 Exp. C spectrometer of X-ray emission lines from clusters of galaxies.

Mullard Space Science Laboratory, 6-8 October 2015



- Groups and clusters of galaxies
- Dark matter and large scale structure
- The intergalactic medium
- The large-scale influence of black holes

<http://www.ucl.ac.uk/astro/events/clusters2015>