The Cool Portion of the WHIM

&

The Cold/Warm Milky Way CGM

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Outline

- *Chandra Detection of the Cool Portion of the WHIM Mass Distribution*

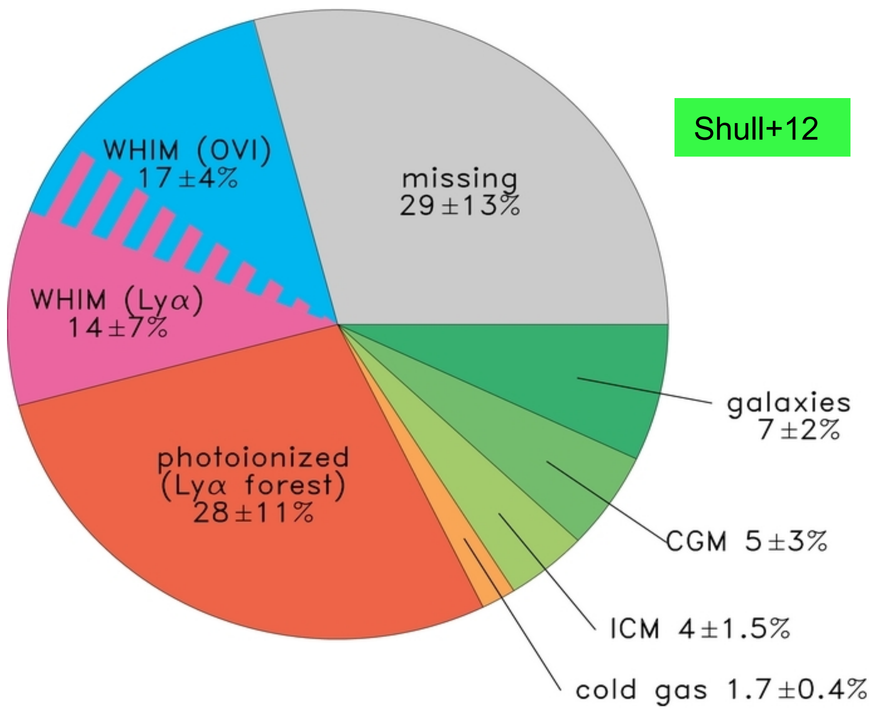
- *Cold and Warm Baryons in-and-around the Galaxy*
  - Ubiquitous presence of z=0 OII absorption (OII Kβ) casts doubts on z=0.03 WHIM discoveries

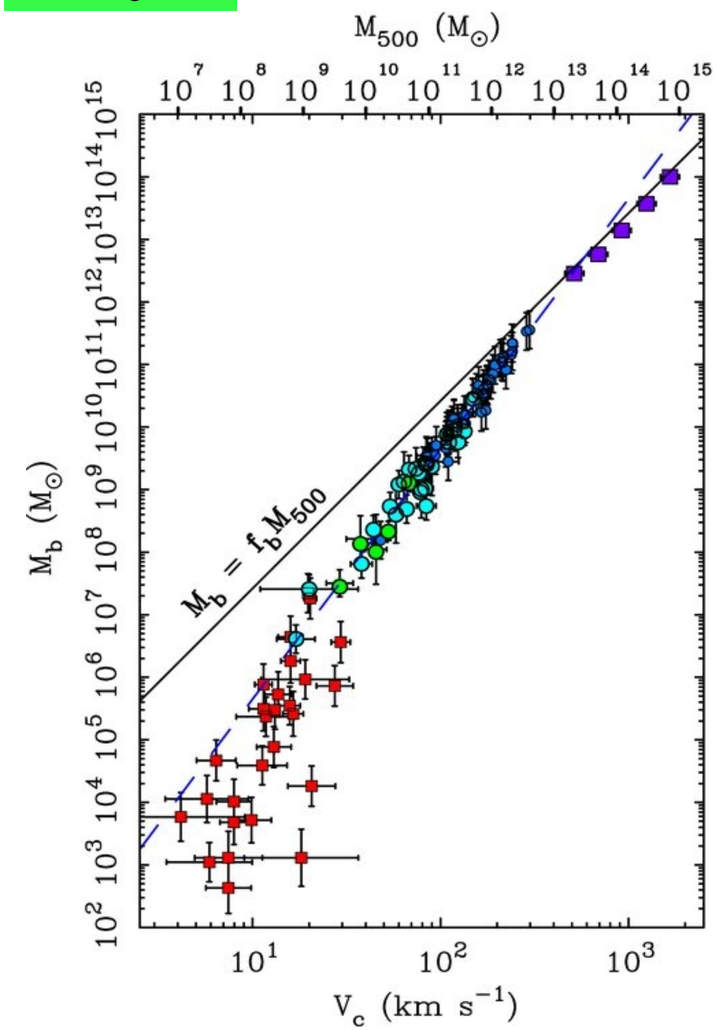
The Missing Baryons Problems

McGaugh+10

$\Omega_b^{WMAP} h^{-2} = 0.0226\ h^{-2} = 0.0456 \sim 5\%$

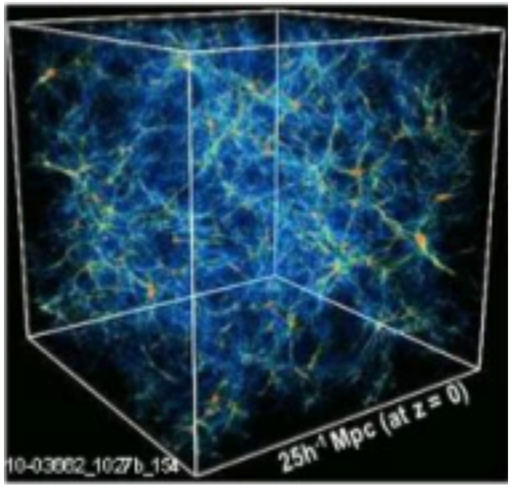
Shull+12



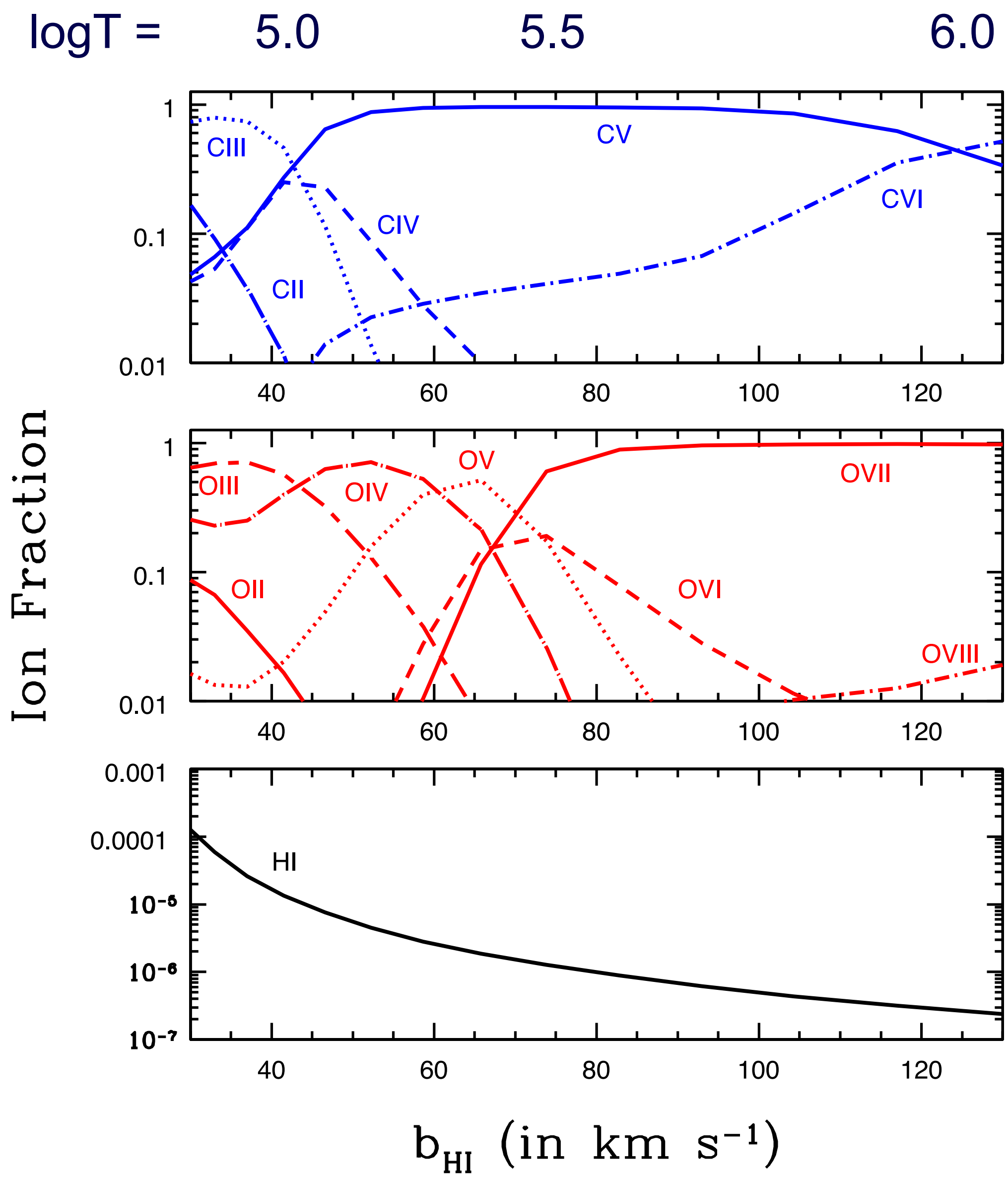


~ 30-40% (or more) of Baryons
Still Missing at z~0

Cosmological Baryon Fraction f_b = 0.17



The WHIM Solution

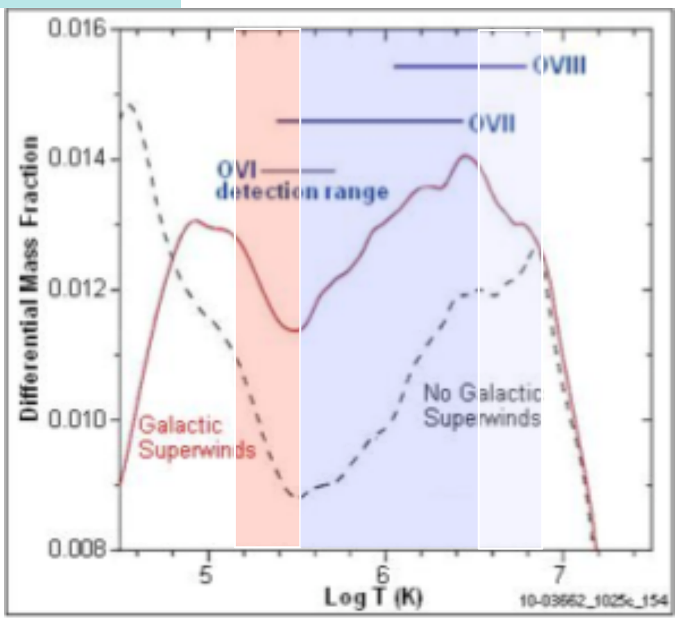


Cool-Phase: ~20%

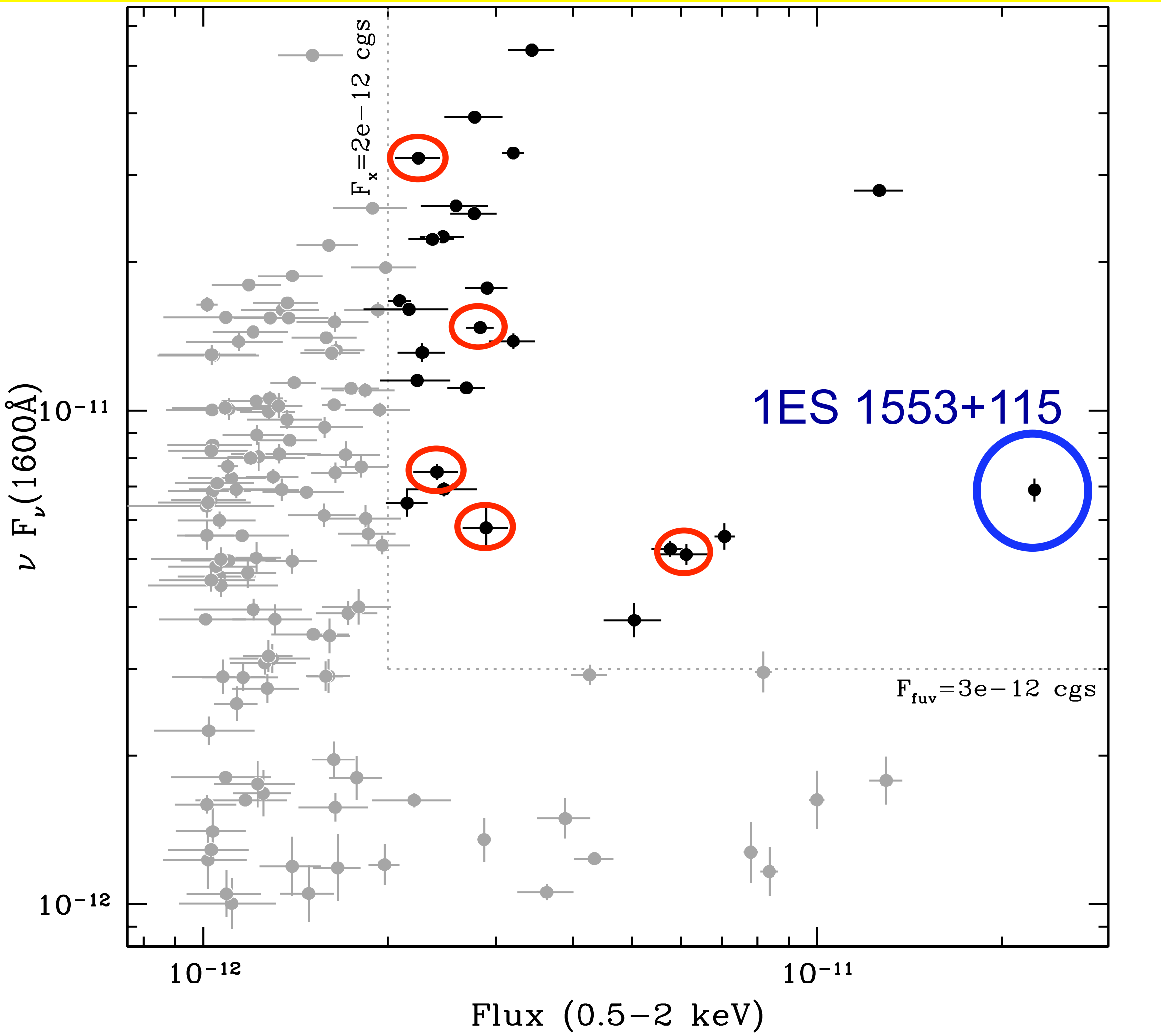
Warm-Phase: ~60%

Hot-Phase: ~20%

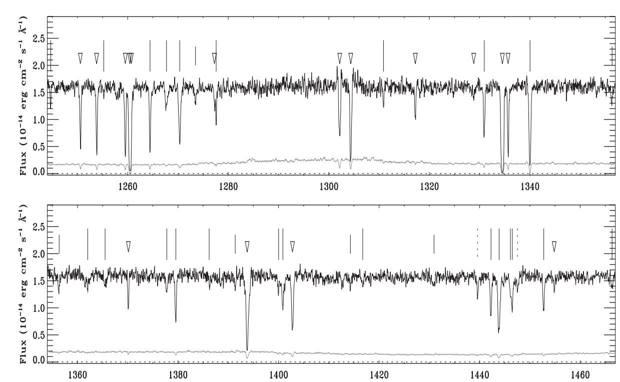
Britton+12



Best WHIM Target in the Universe: 1ES 1553+113

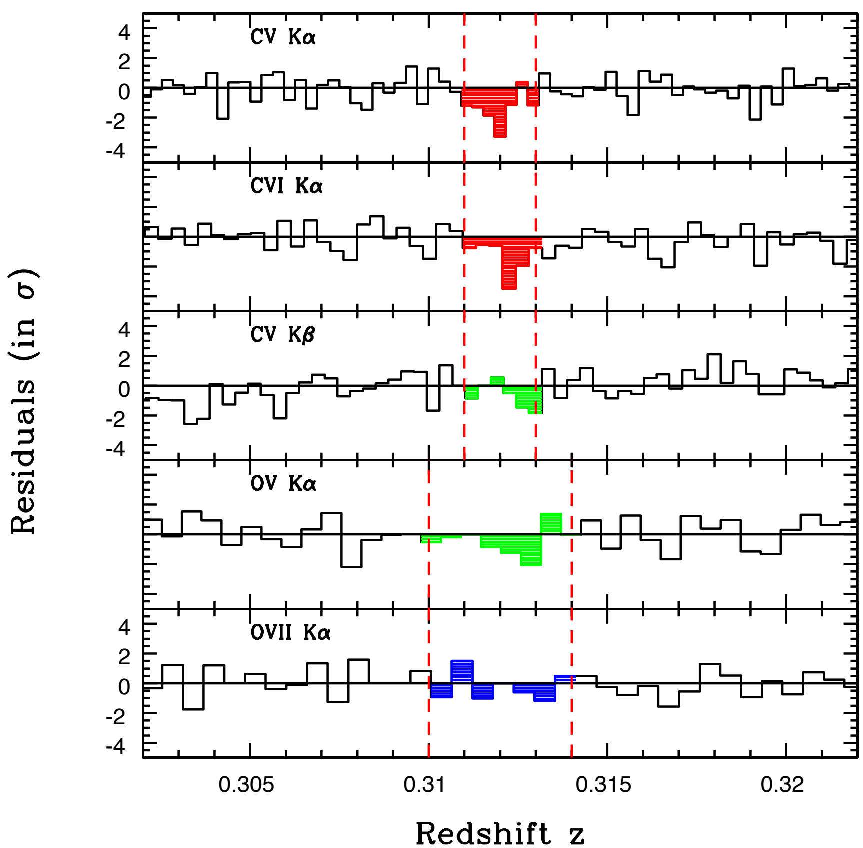


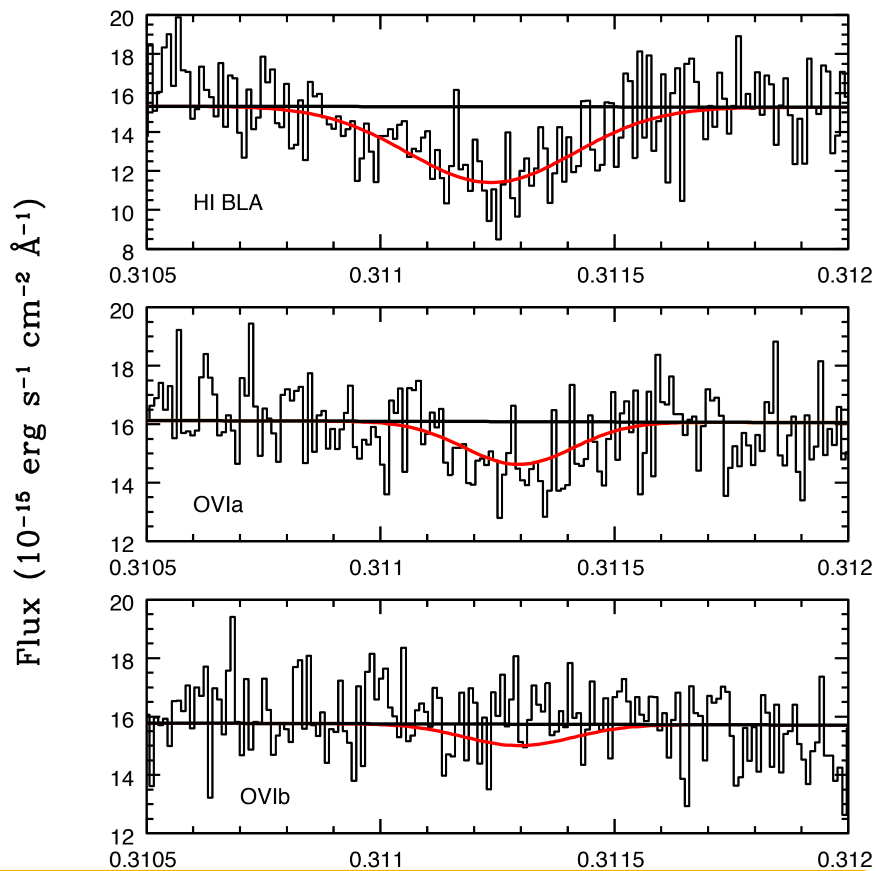
- z > 0.4
- F_X ~ 1-2 mCrab
- High S/N COS spectrum with 5 a-priori BLA signposts



Cool WHIM at z=0.312:
(6.3σ X-ray only)

Nicastro+13



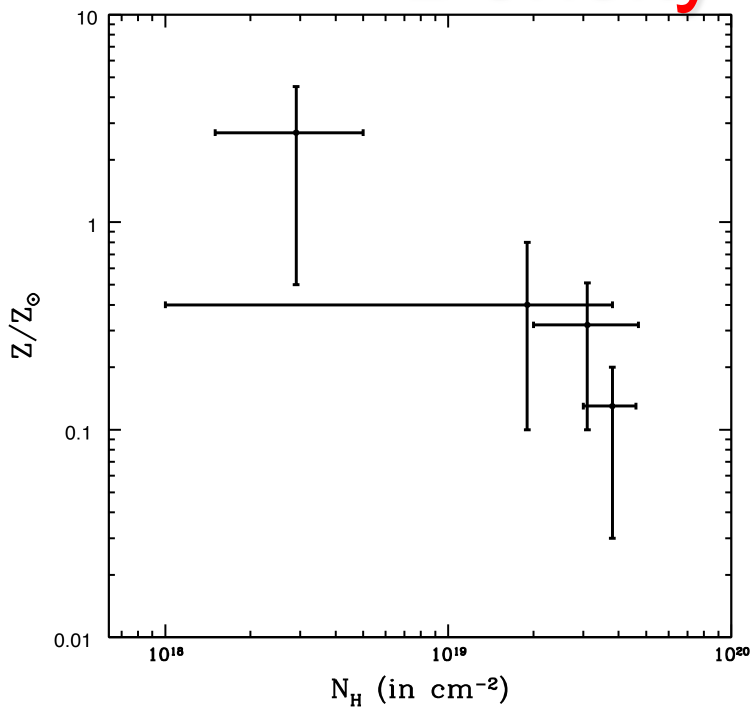


From COS BLA and OVI b:

➔ b_{th} = 52 ± 7 km s^{-1} (b_{turb} = 30 ± 14 km s^{-1}) ➔ logT = 5.2 ± 0.1

Fully Consistent with presence of CV, CVI, OV

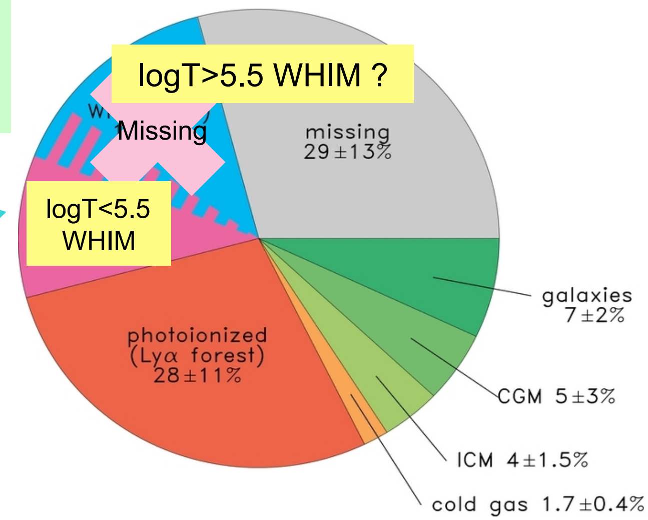
Metallicities and Cosmological Mass Density of the Cool WHIM



$$\Omega_b = \frac{1}{\rho_{cr,0}} \frac{\mu m_p \sum_i N_H^i}{\Delta l_{comoving}}$$

$$dl_{comoving} = {}^{c}\!/_{H(z)}\, dz$$

$$\sigma_{\Omega_b} = \frac{1}{[1-1/K]^{1/2}} \frac{1}{\rho_{cr,0}} \frac{\mu m_p \sqrt{\sum_{i=1}^{K} [N_H^i - \langle N_H^i \rangle]^2}}{\Delta l_{comoving}}$$



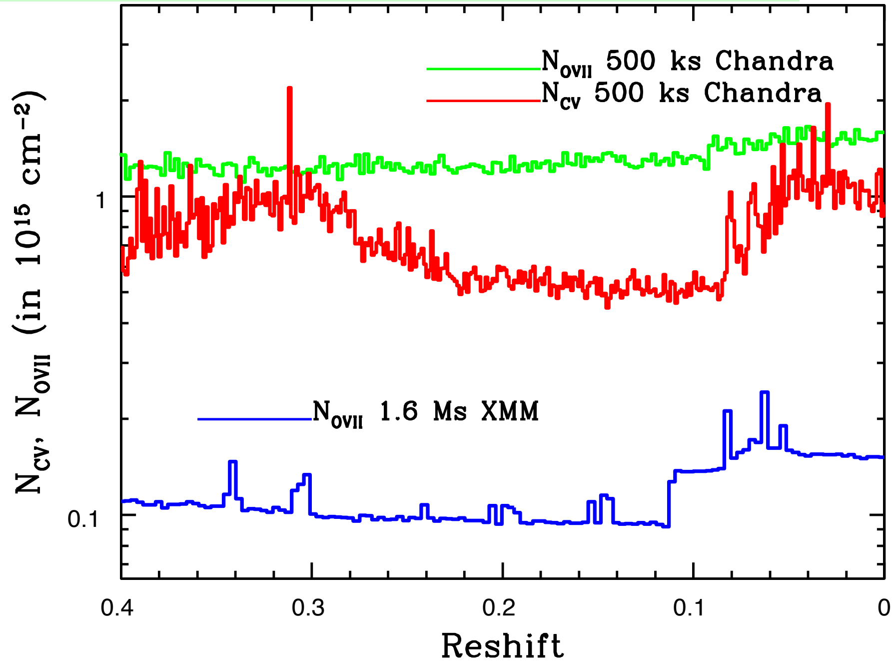
$$\Omega_b(5.0 < \log T < 5.5; EW_{CV,OVII} > 10\ m\overset{o}{A}) = 0.0055 \pm 0.0018 = (12 \pm 4)\%\ \Omega_b$$

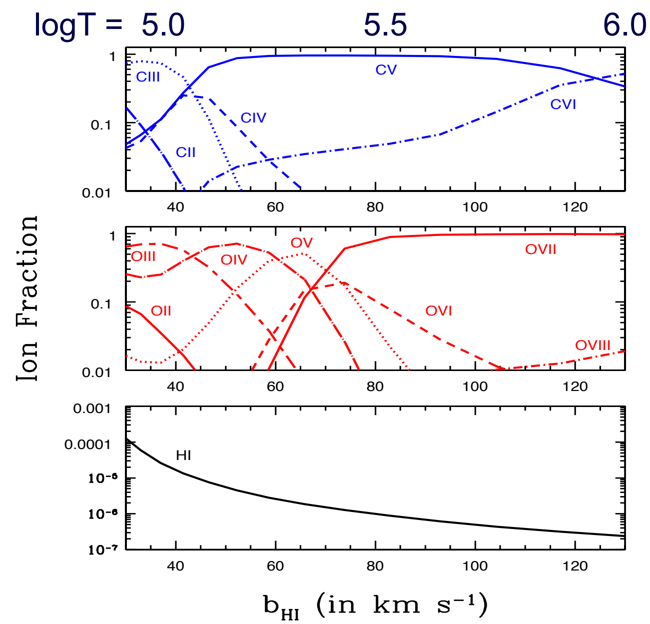
$$\Omega_b(5.0 < \log T < 5.5; EW_{CV,OVII} > 10\ m\overset{o}{A}) = 0.0069 \pm 0.0018 = (15 \pm 4)\%\ \Omega_b$$

Bound to Detect the Cool WHIM (CV)

$$N_{Ion} \geq 1.1 \times 10^{20} \frac{N_{\sigma} \Delta\lambda}{S/N} f_i^{-1} \lambda_i^{-2} (1+z)^{-1}$$

3σ Column Density Threshold





With the sensitivity of the current 500 ks *Chandra* bound to detect only the cool WHIM in CV.

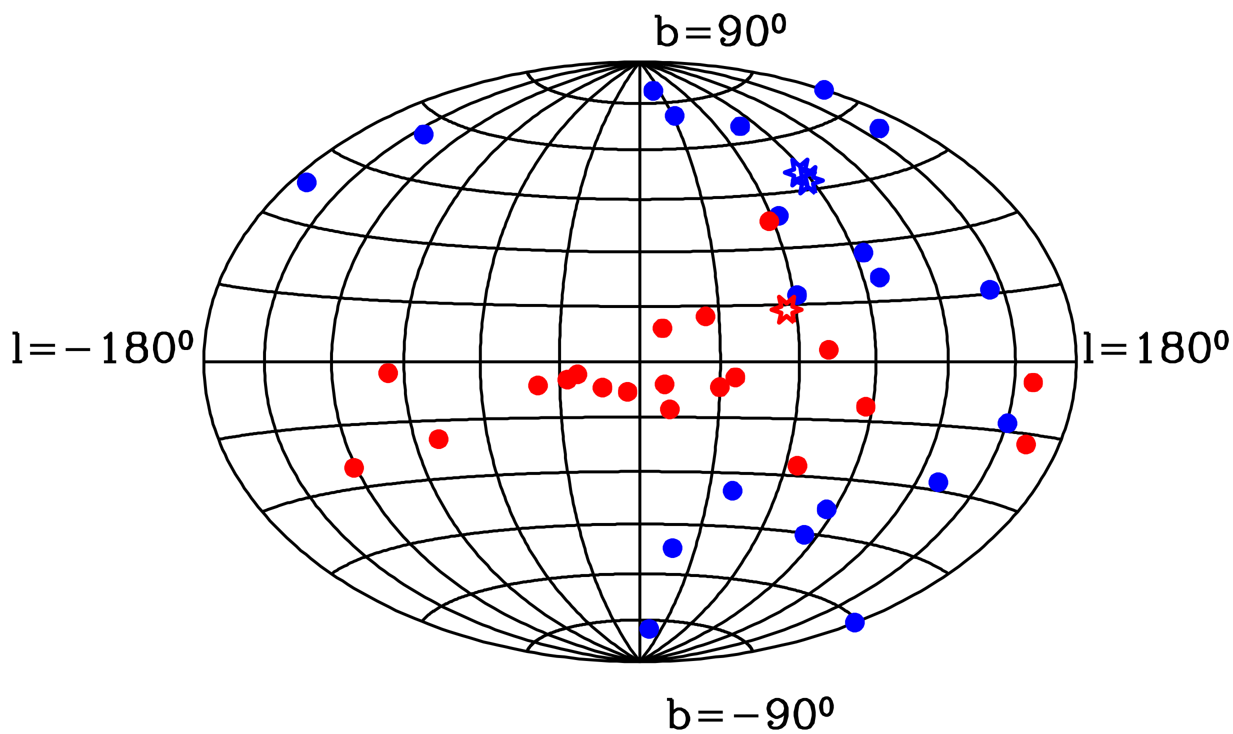
~3x exposure with XMM ➔ 10x S/N in OVII ➔ $N_{OVII} > 10^{14}$ cm^{-2} ➔ ~50 systems sampling the hot WHIM

Summary

- *The cool portion of the WHIM has been detected in UV and X-rays*
- *High metallicity (~0.3 on average), consistent with feedback models*
- *CV-OVI-BLA dominated WHIM contains ~ 15% of Baryons*

➔ *40-50 % of Baryons still Missing and likely to reside in logT>5.5 WHIM:* *detectable with our 1.6 Ms XMM VLP*

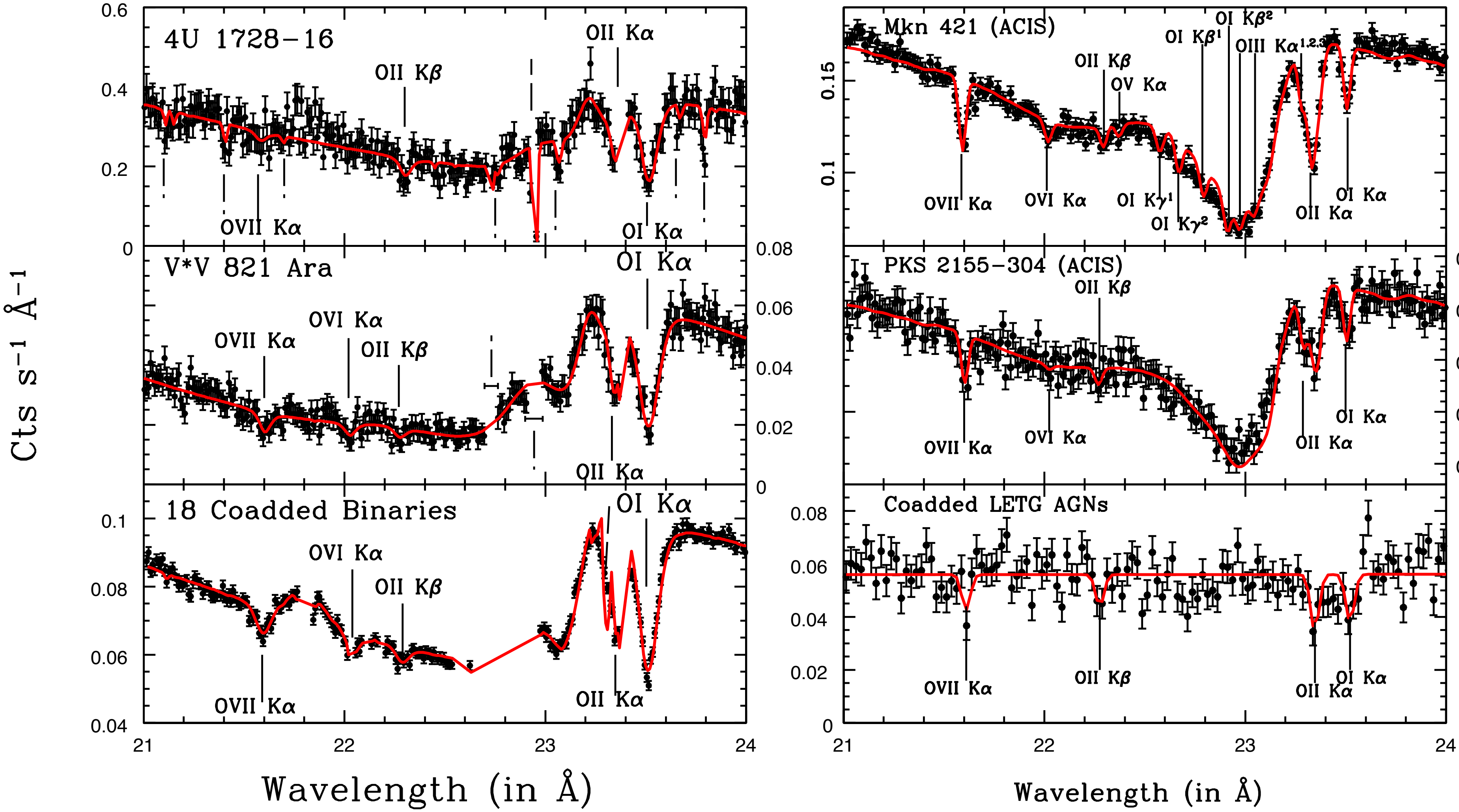
The Milky Way as Lab:
Internal and External Probes



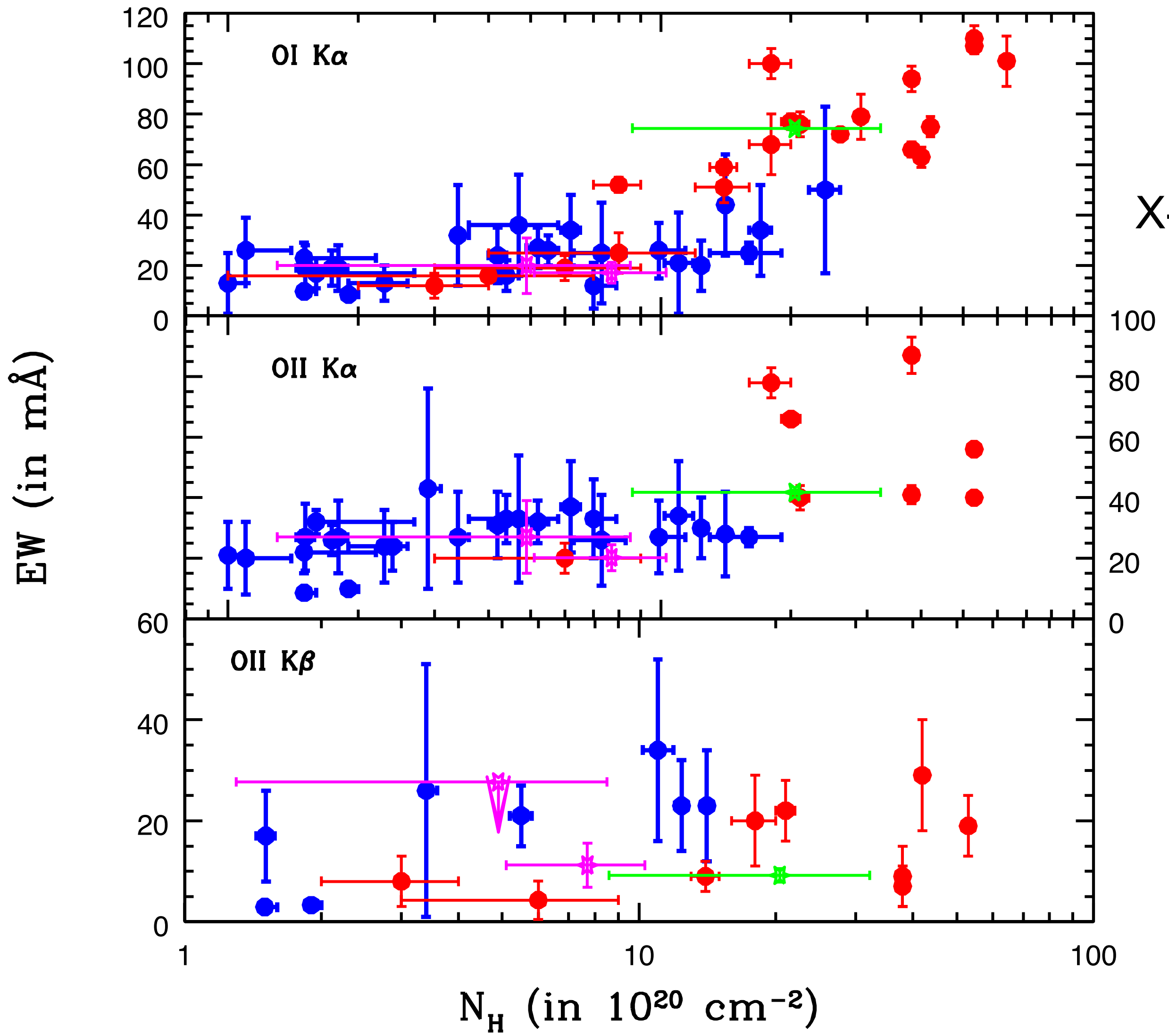
20 X-Ray Binaries wit RGS spectra with SNRE > 10 @ 22.2 A: probe the Disk
28 AGNs from Gupta+11: HETG/LETG spectra with low SNRE (1-8 @ 22.2 A) except Mkn 421 (100) and PKS 2155-304 (80): probe small portions of Disk and the Halo/CGM

Spectral Features:

OI OII Kα Ubituitous; OII Kβ >3σ in 6 spectra



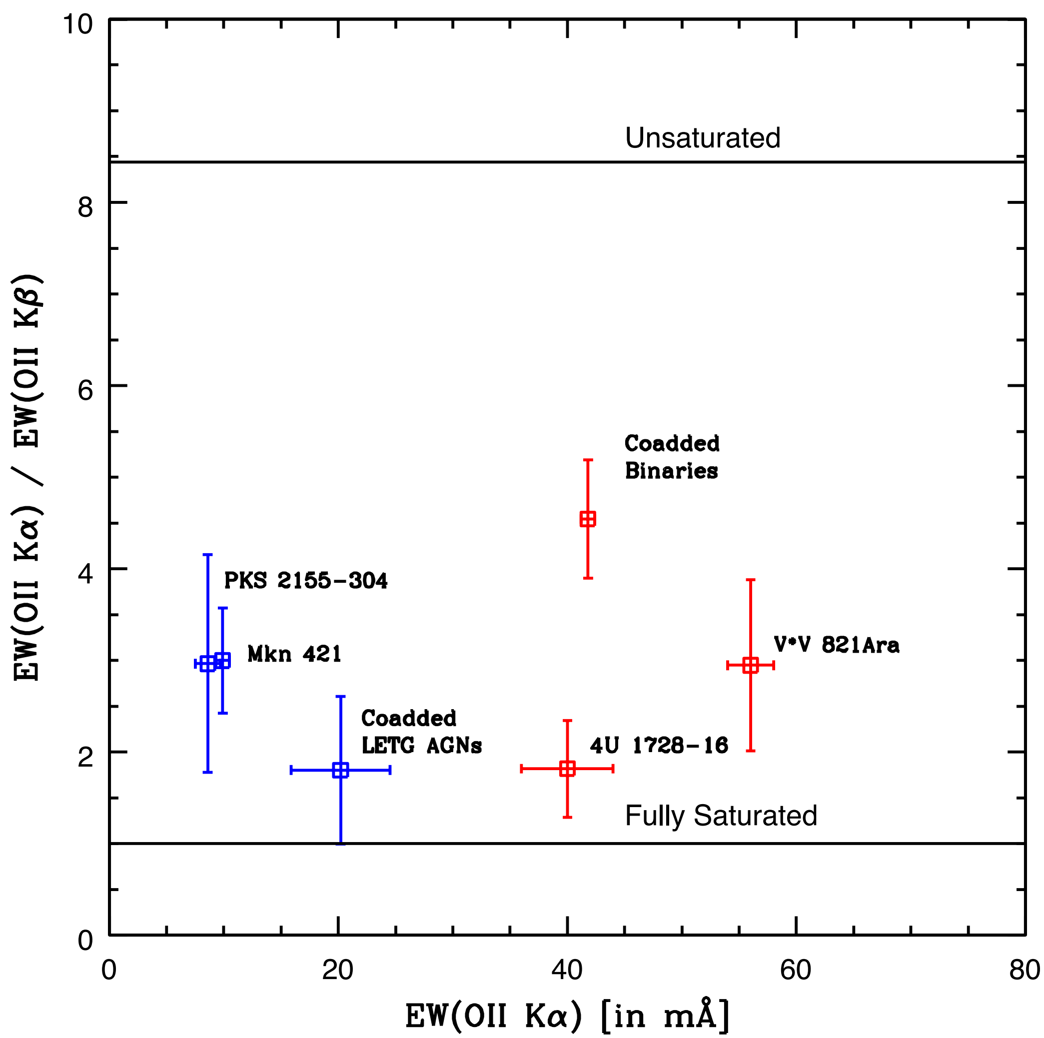
EWs and N_H^X



OI Kα correlates with N_H^X in X-Ray Binaries but not in AGNs

Saturation?
Different Absorbers?

Line Saturation



$<EW(OII\ K\alpha)>_{gal} = 46 \pm 8$ mA

$<EW(OII\ K\alpha)>_{exgal} = 13 \pm 6$ mA

OII is heavily saturated against both Galactic and extragalactic Lines of Sight.

However: stronger towards Galactic X-Ray Binaries

➔ b and/or N_{OII} must differ

Curves of Growth: b & N_{OII}

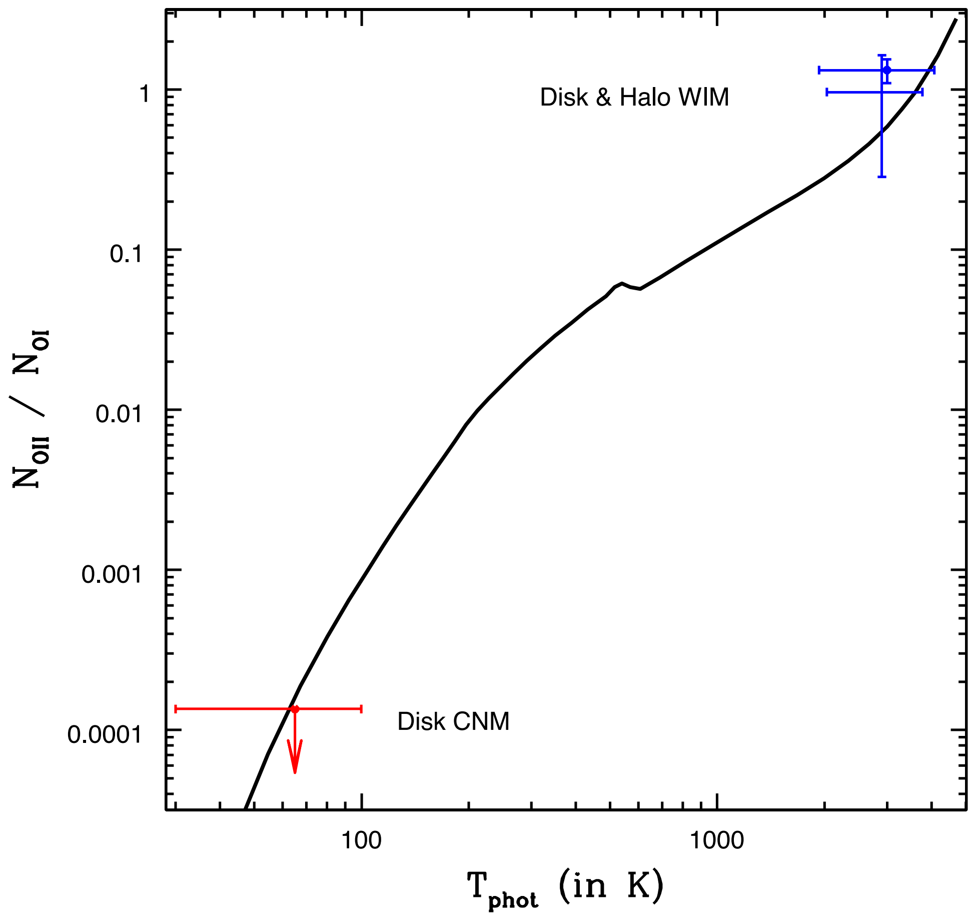
Line-of-Sight	N_{OII} in 10^{17} cm^{-2}	b in km s^{-1}
	Galactic Lines of Sight	
4U 1728-16	9^{+10}_{-4}	120^{+14}_{-17}
V*V 821 Ara	4.9 ± 0.8	200 ± 6
18CB	1.62 ± 0.08	182^{+7}_{-4}
	Extragalactic Lines of Sight	
Mkn 421	$0.42^{+0.11}_{-0.09}$	40^{+4}_{-3}
PKS 2155-304	$0.30^{+0.07}_{-0.11}$	40^{+4}_{-9}
8CLETG	4^{+9}_{-3}	60^{+16}_{-15}

<b>$_{Gal}$ = 170 ± 40 km s^{-1}
<b>$_{Exgal}$ = 50 ±10 km s^{-1}

Either:
- Smaller Portion of Disk

Or:
- Two Distinct Absorbers

The Disk CNMM & The Disk+Halo/ CGM WIMM



Warm Ionized Metal Medium:

$<T^{Halo}>_{WIMM} = 2900 \pm 900$ K

$<Z^{Halo}>_{WIMM} = 0.3 \pm 0.2\ Z_\odot$

$<T^{Disk}>_{WIMM} = 3000 \pm 1000$ K

$<Z^{Disk}>_{WIMM} = 0.8 \pm 0.1\ Z_\odot$

Cold Neutral Metal Medium:

$<T^{disk}>_{CNMM} =$ 30 – 100 K

$<Z^{Disk}>_{CNMM} = 0.8 \pm 0.2\ Z_\odot$

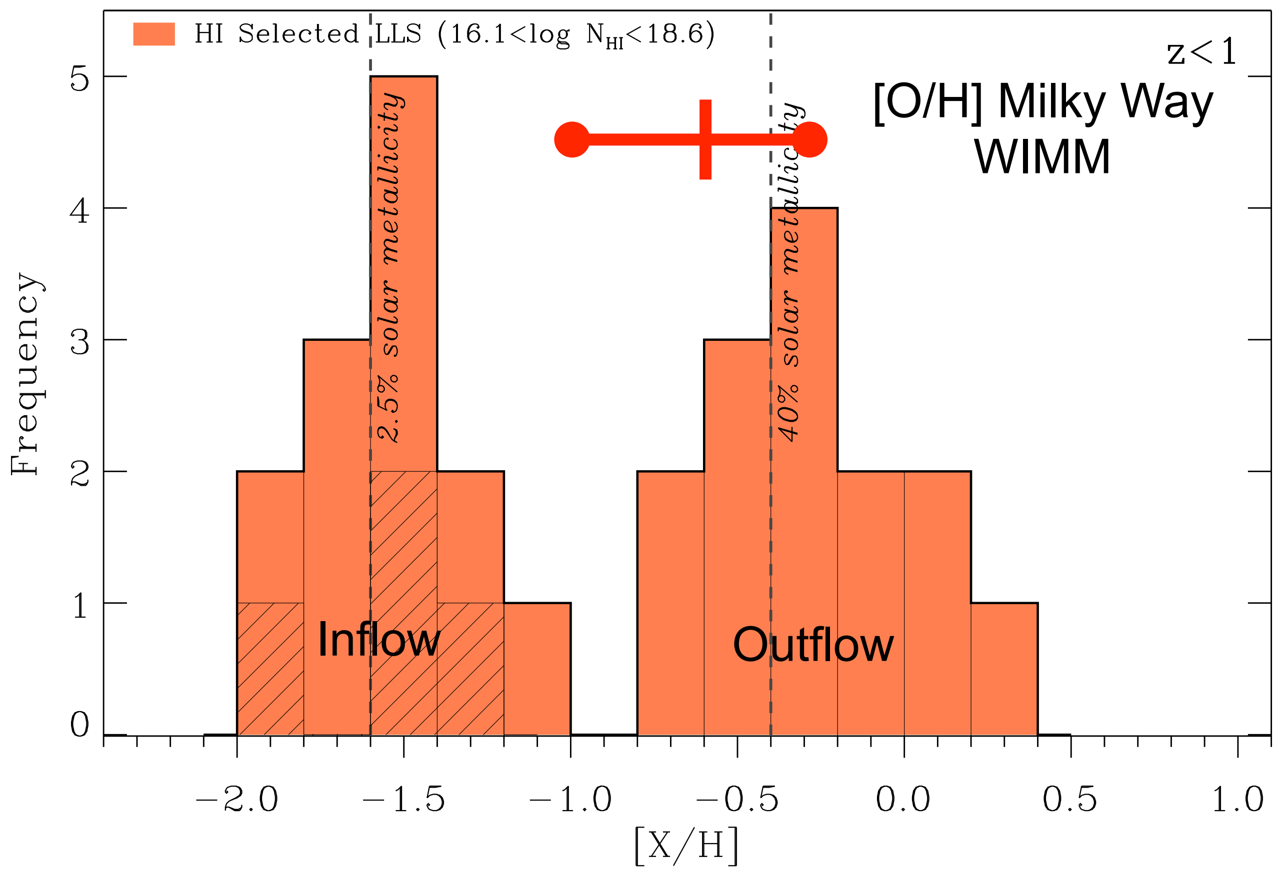
$<N_{OI}> = (1.0 \pm 0.4)\ 10^{18}$ cm^{-2}

$<b>_{CNMM} = 280 \pm 50$ km s^{-1}

➔ > 22 Clouds kpc^{-1} with D<50 pc and $n_H > 0.1$ cm^{-3}

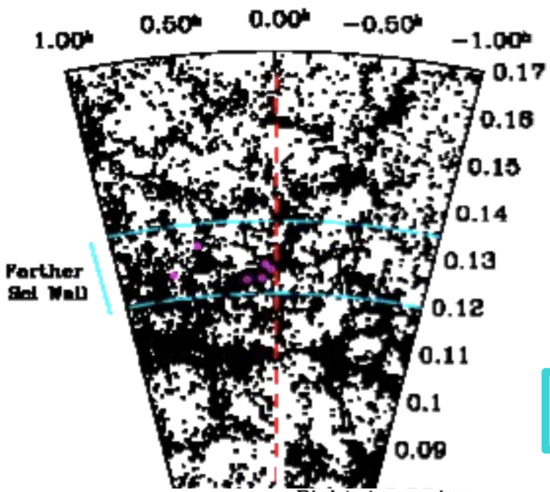
Metallicity of T<~10^4 K CGM at z<1

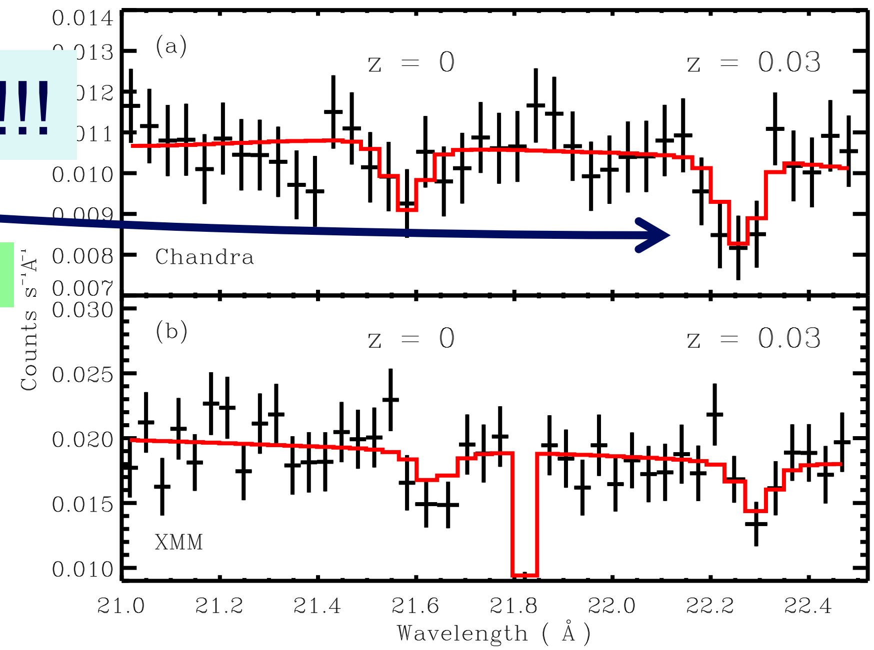
(Lehner+13)



Galaxy concentrations as WHIM tracers

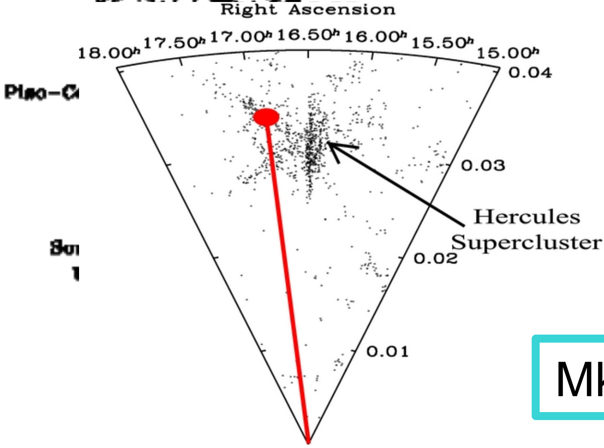
But: $N_{OVII} \sim 2 \times 10^{16}\ cm^{-2}$!!!

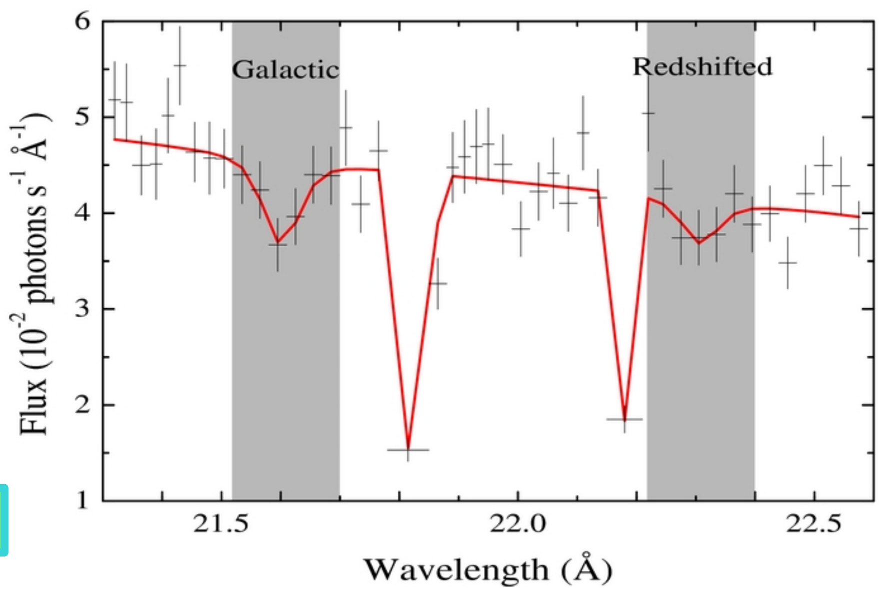




Buote+09, Fang+10

H 2356-309

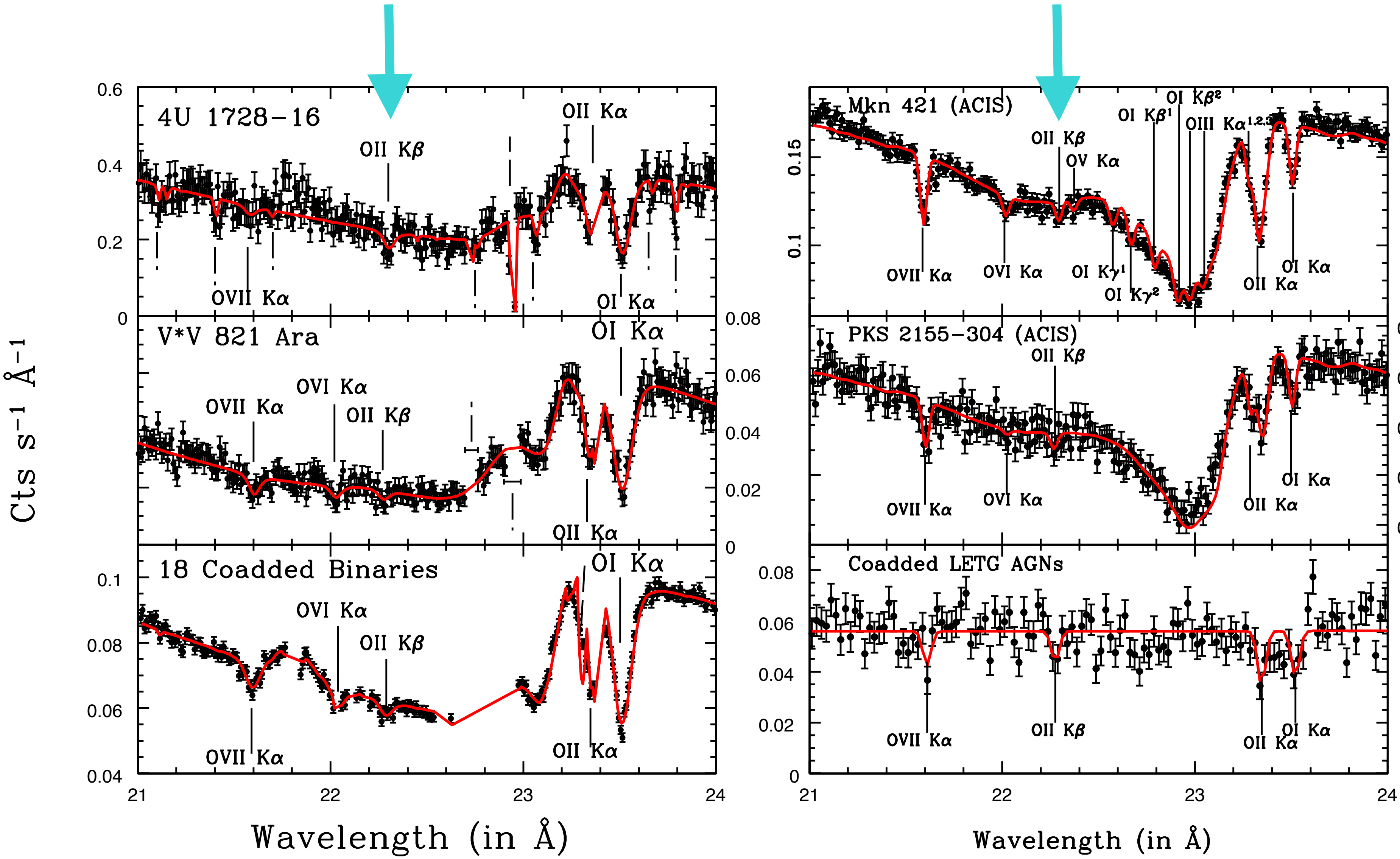




Mkn 501

Ren, Fang & Buote, 2014

OII Kβ @ z=0 Not OVII @ z=0.03



Conclusions

- Two distinct OI-OII components: the CNMM and the WIMM.
- The CNMM is confined in the disk of our Galaxy and has:

  $T_{CNMM} \simeq 30-100$ K, $<Z>_{CNMM} = 0.8 \pm 0.2\ Z_{\odot}$, $<b>_{CNMM} = 280 \pm 50$ km s^{-1}
- The CNMM must be patchy and made up of

  $>\sim 22$ clouds kpc^{-1}, with $D <\sim 50$ pc each.
- The WIMM has $<T>_{WIMM} = 3000 \pm 1000$ K and permeates the whole Galaxy.
  We find: $<Z^{Halo}>_{WIMM} = 0.3 \pm 0.2\ Z_{\odot}$, $<b^{Halo}>_{WIMM} = 48 \pm 6$ km s^{-1}

  $<Z^{Disk}>_{WIMM} = 0.8 \pm 0.1\ Z_{\odot}$, $<b^{Disk}>_{WIMM} = 100 \pm 10$ km s^{-1}
- We estimate:

  $M_{CNMM} < 8 \times 10^{8}\ M_{\odot}$

  $M_{WIMM} \sim 8.2 \times 10^{9}\ M_{\odot}$ (only 10% in the disk).
- OII Kβ from the WIMM invalidates OVII Kα WHIM detection at z=0.03