Looking for Missing Baryons in the Local Universe

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OAT-DAUT
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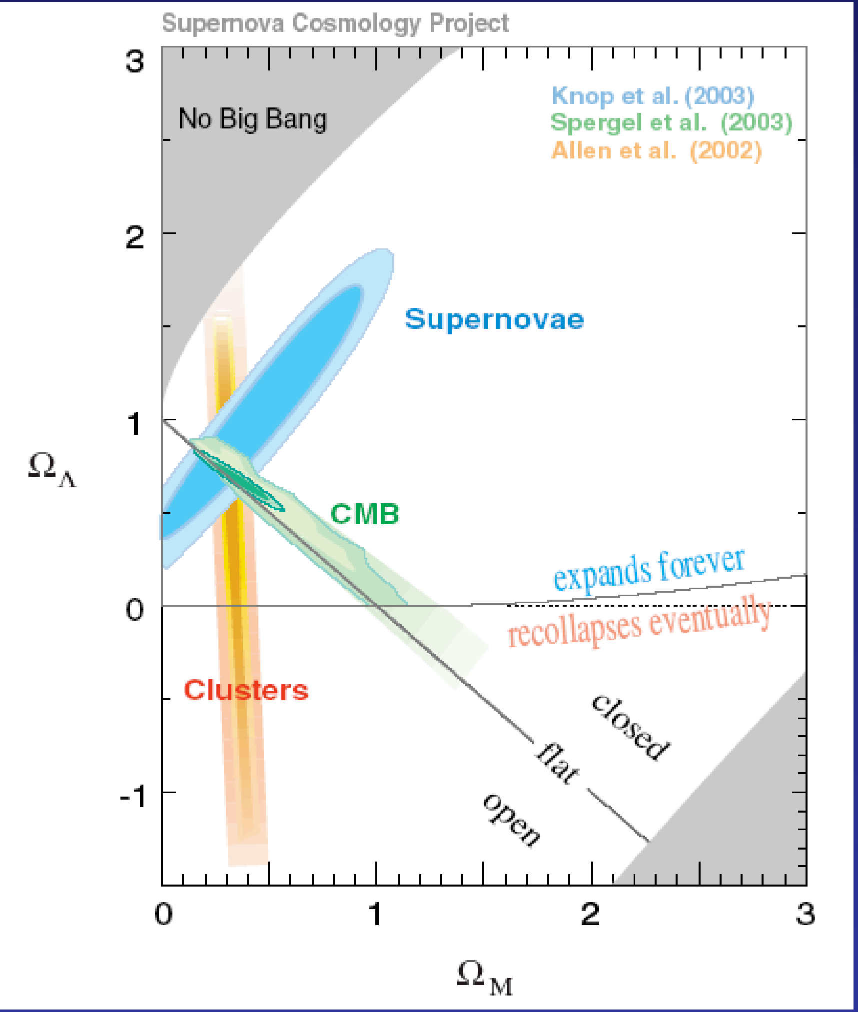
Cosmological Concordance Model



$$\Omega_{\mathrm{TOT}} = \sum \Omega_i = 1.02 \pm 0.03$$ WMAP

$\Omega_\Lambda \sim 73\%$ - $\Omega_{DM} \sim 23\%$ WMAP+Sn1a+LSS

$\Omega_\gamma \sim \Omega_\nu \sim 10^{-5}$ CMB+Big Bang Model

$$\Omega_b^{Nucl} \sim 4\%$$ WMAP Light Elements

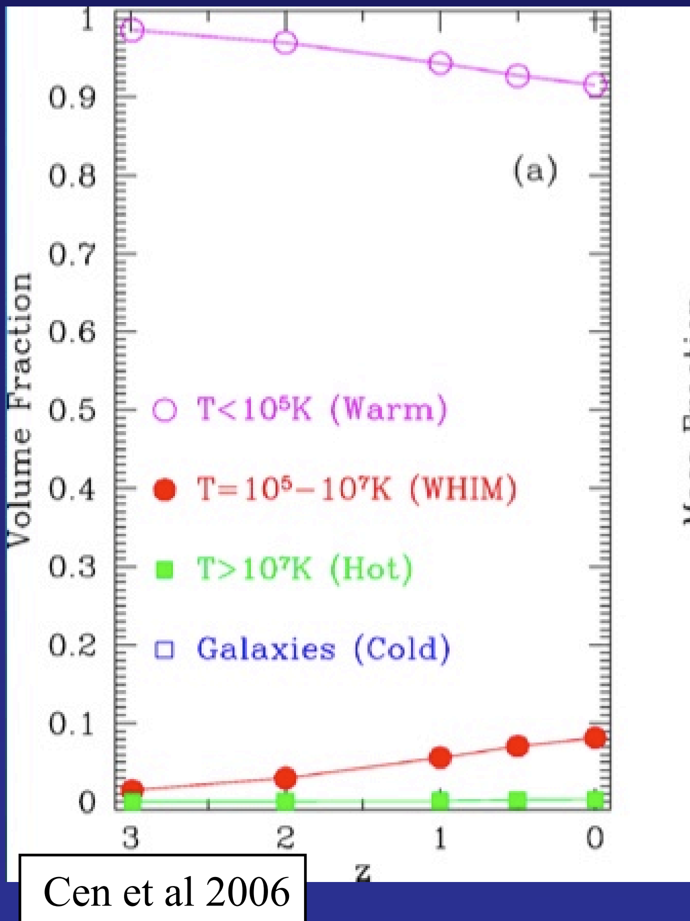
Fukugita, Hogan & Peebles 1998, Fukugita 2003 and subsequent estimates

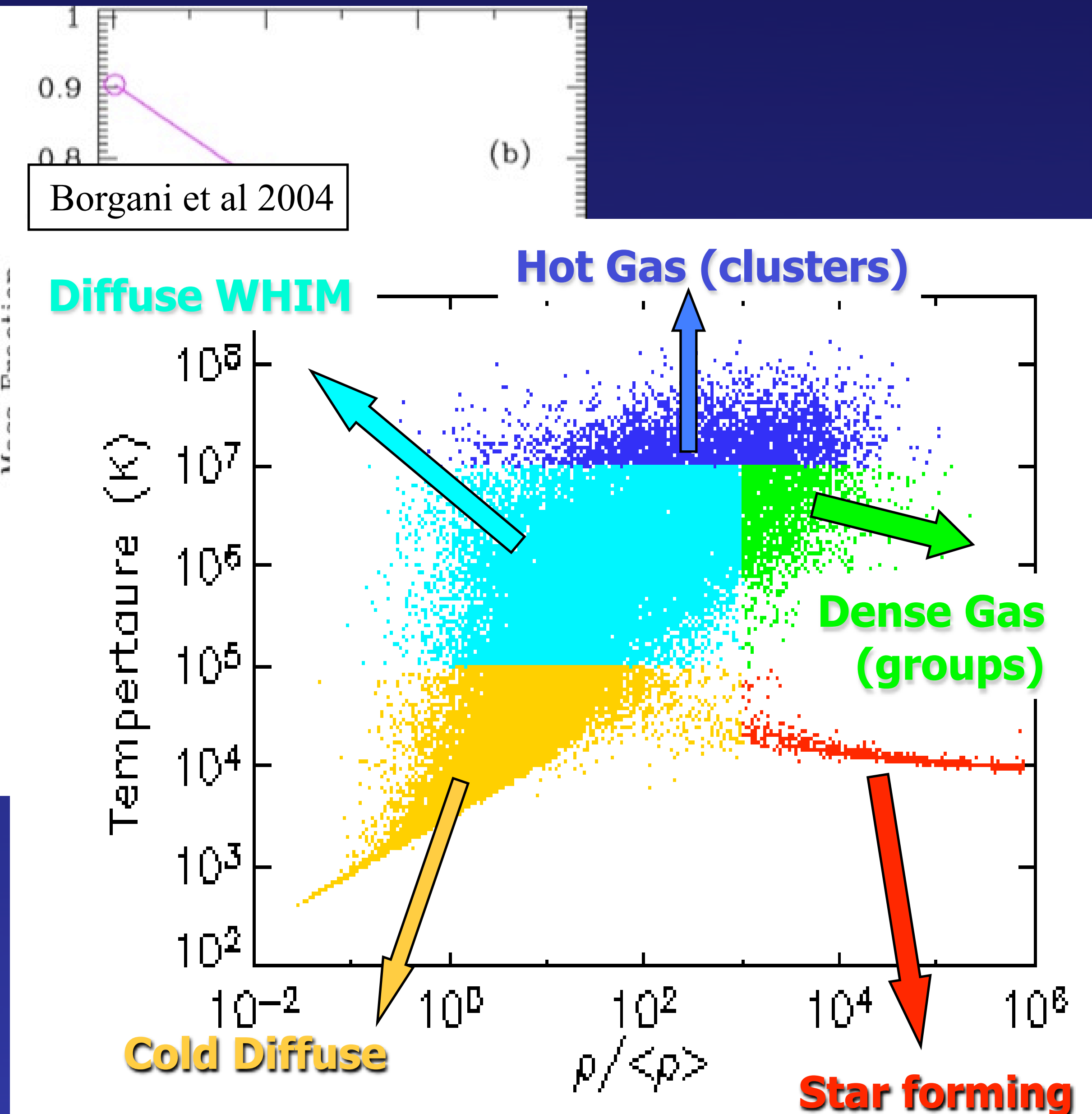
Table 1 **Census of baryons in the high-and low-redshift Universe**

Inferred from*	Ω_b (%) for $h_{70} = 1$
BBN + D/H	(4.4 ± 0.4)
CMB anisotropy	(4.6 ± 0.2)
Observed at $z > 2$ in†	
Lyman-α forest	>3.5
Observed at $z < 2$ in‡	
Stars	(0.26 ± 0.08)
H I + He I + H_2	(0.080 ± 0.016)
X-ray gas in clusters	(0.21 ± 0.06)
Lyman-α forest	(1.34 ± 0.23)
Warm + warm–hot O VI	(0.22 ± 0.03)
Total (at $z < 2$)§	(2.1 ± 0.3)
Missing baryons (at $z < 2$)§	(2.5 ± 0.4)

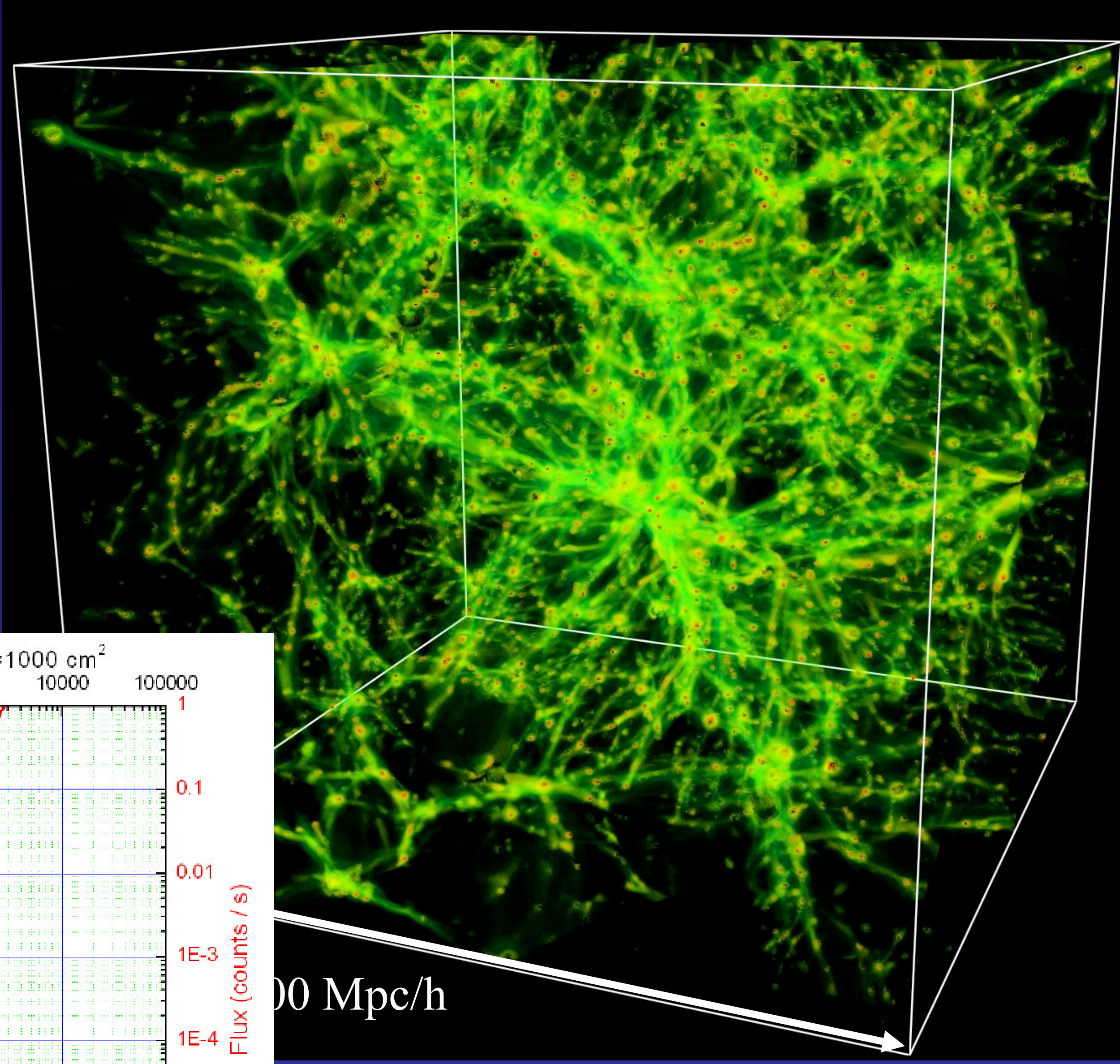
~50% of baryons in the local Universe are missing !

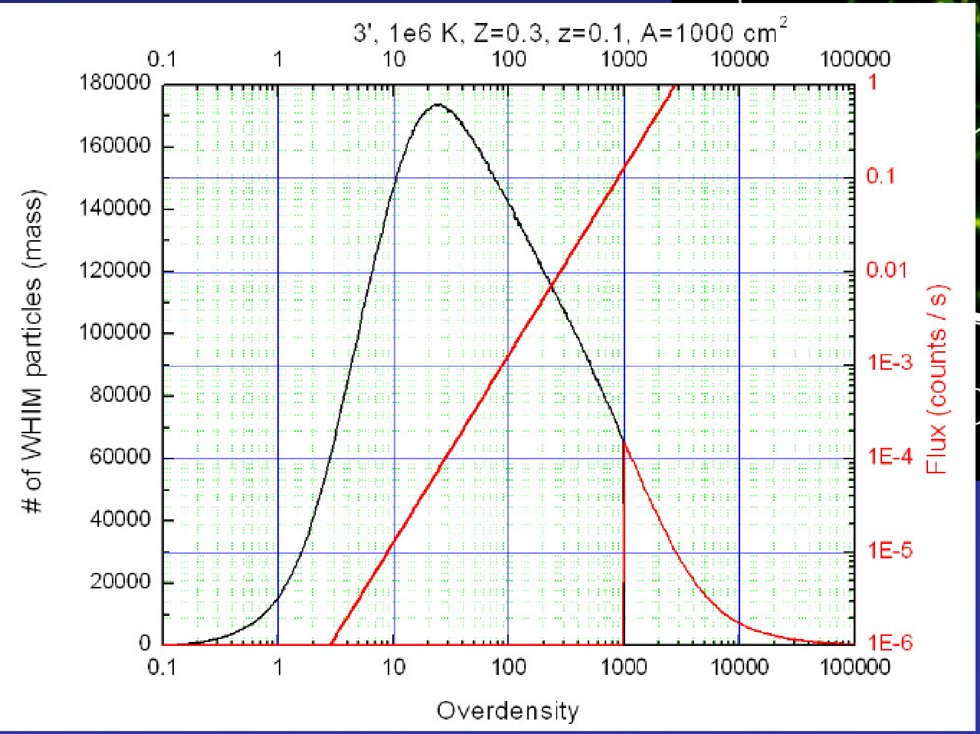
Hydro-simulations: they're in a Warm-Hot form (WHIM)





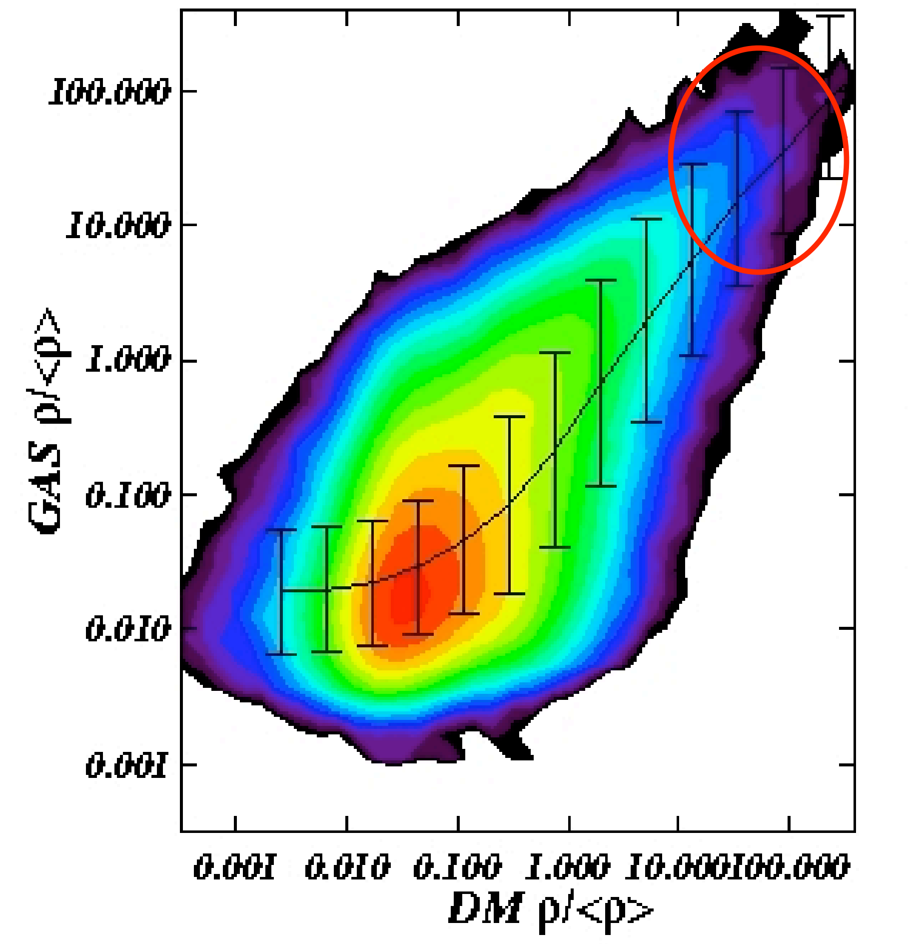
Cen et al. 1999

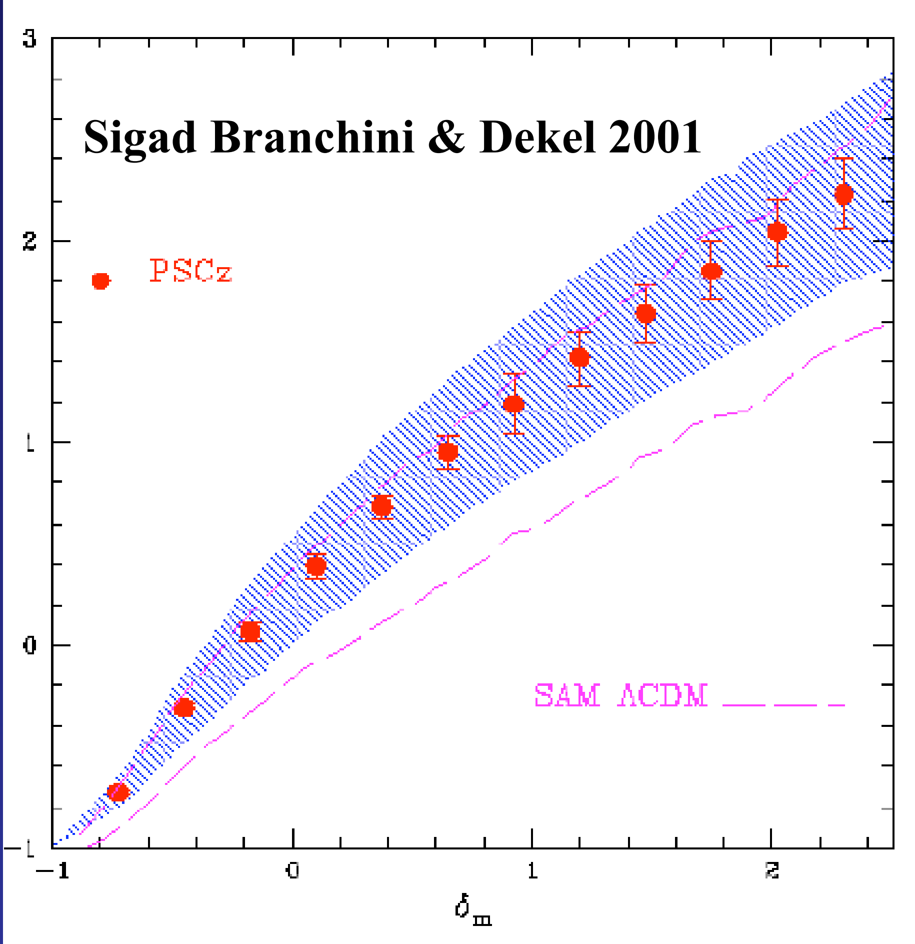




green δ~10
red δ~10⁴

Using WHIM to trace the Cosmic Web





The large scatter in the gas vs. DM relation makes the WHIM a rather poor tracer of the underlying mass distribution.

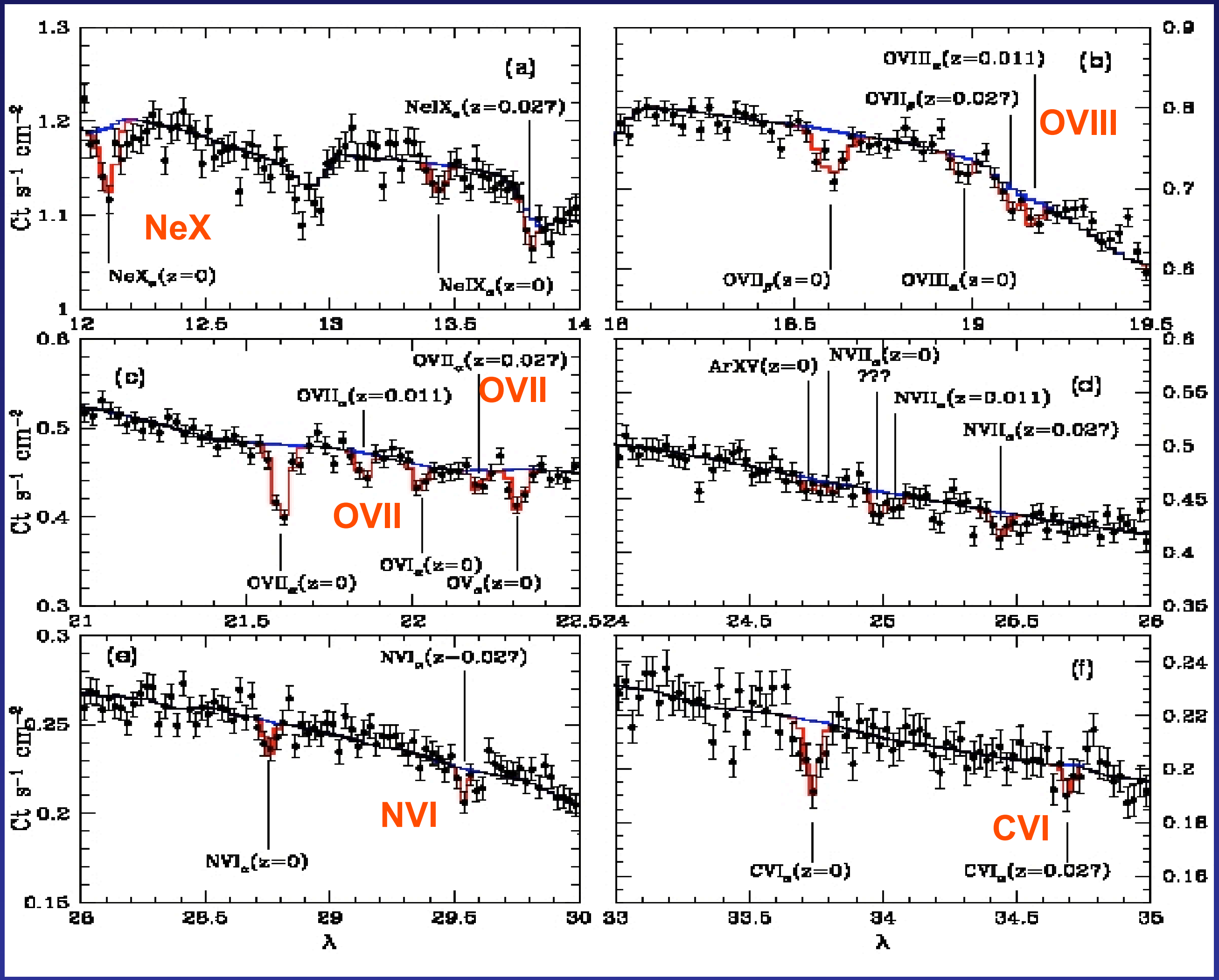
How to detect WHIM

- Continuum Emission in the soft X-ray band (E<2 KeV). Zappacosta et al. (2002), Mannucci et al. (2007), Dietrich et al. (2005), Soltan et al. (2005)
- Thermal SZ effect outside Galaxy clusters. (upper limit from WMAP, Hansen et al. 2005)
- Line Absorption or Emission from highly ionized material.

Ion	E(keV)
C V	0.308
Mg XI	1.35
OVI	0.563
O VII	0.574
O VIII	0.654
FeXVII	0.826
Ne IX	0.922

OVI absorption lines have been detected in the far-ultraviolet spectra of extragalactic sources.
However, the absorbing material is very local (z~0) and thus cannot be the WHIM.
Also OVII lines have been detected at z~0 (Fang et al. 2001, Nicastro et al. 2002, Takei et al. 2006)

Nicastro et al 2005. Mkn 421. Blazar
2 WHIM Absorbers at z~0.011 and z~0.027 ?



Not confirmed by *Newton-XMM* (Rasmussen et al. 2006)

Statistical significance <3σ (Kaastra et al. 2006)

CXB Constraint

The surface brightness of the CXB in the *Chandra* DF-N and DF-S in the 0.65-1 KeV band after excluding all detected X-ray, optical and infrared sources is consistent with the brightness of the WHIM predicted by numerical simulations.

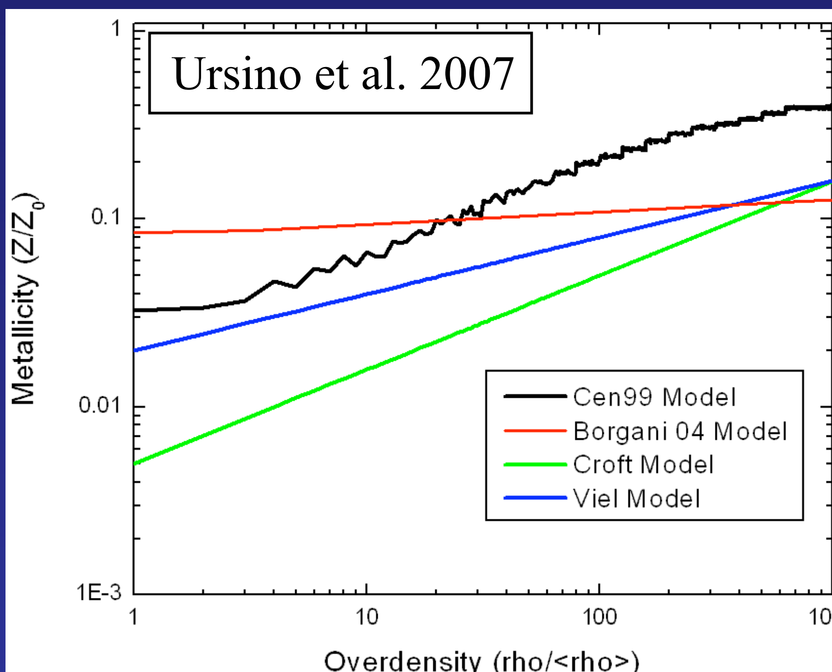
(Hickox and Markevitch 2007)

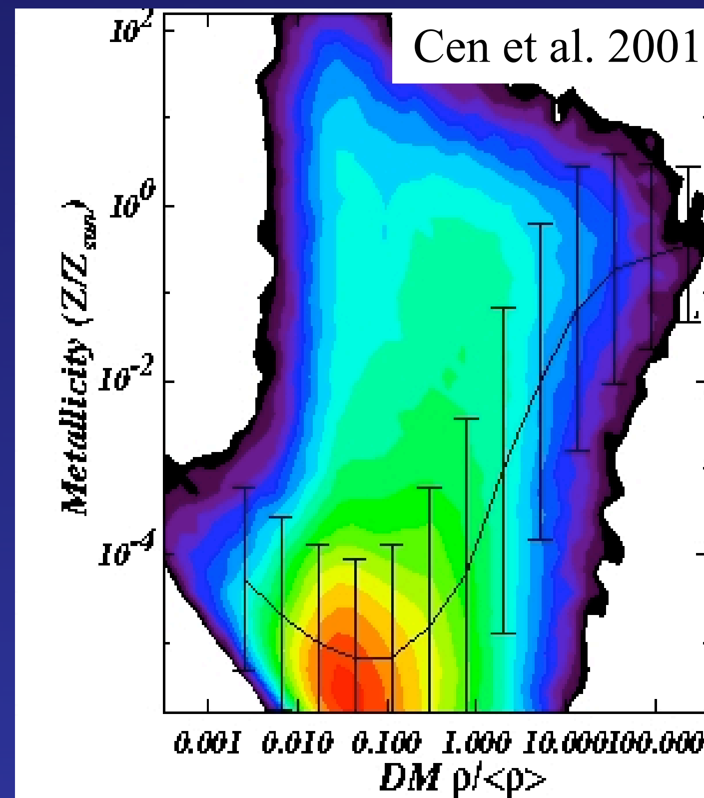
Since we rely on models we must assess model uncertainties.

Numerical models (algorithm, cosmology, approximations, resolution issues)

Ionization equilibrium (Yoshikawa & Sasaki 2006)

Metals in the IGM (Metallicity)





We account for model (random+systematic) uncertainties by using different techniques to simulate the WHIM

Assessing model uncertainties

Semi-analytic model (Viel et al. 2003)
Lagrangian Hydro-dynamical model: (Borgani et al. 2004)
Lagrangian Hydro-dynamical model: (Viel et al. 2006)

Flat Universe - $\Omega_\Lambda = 0.7$, $\Omega_b = 0.039\text{-}0.046$, $h = 0.7$, $\sigma_8 = 0.8\text{-}0.85$

$L = 60 - 192\ h^{-1}$ Mpc, $N_{DM} = (400\text{-}480)^3 = N_{GAS}$, $\varepsilon = 2.5 - 7.5 h^{-1}$ kpc

Different metallicity models $Z/Z_{sun}=F(\rho)$ explored

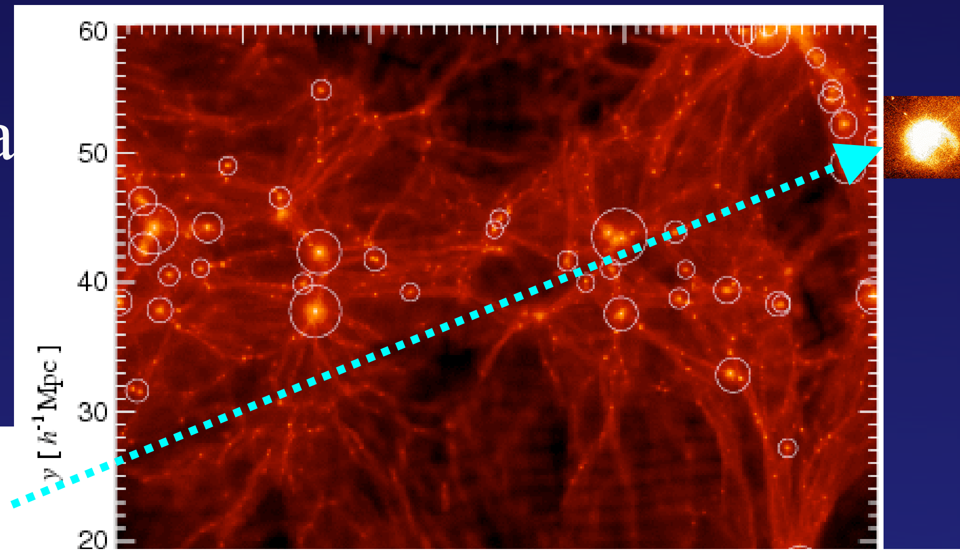
Different star formation prescription. With and without feedback.

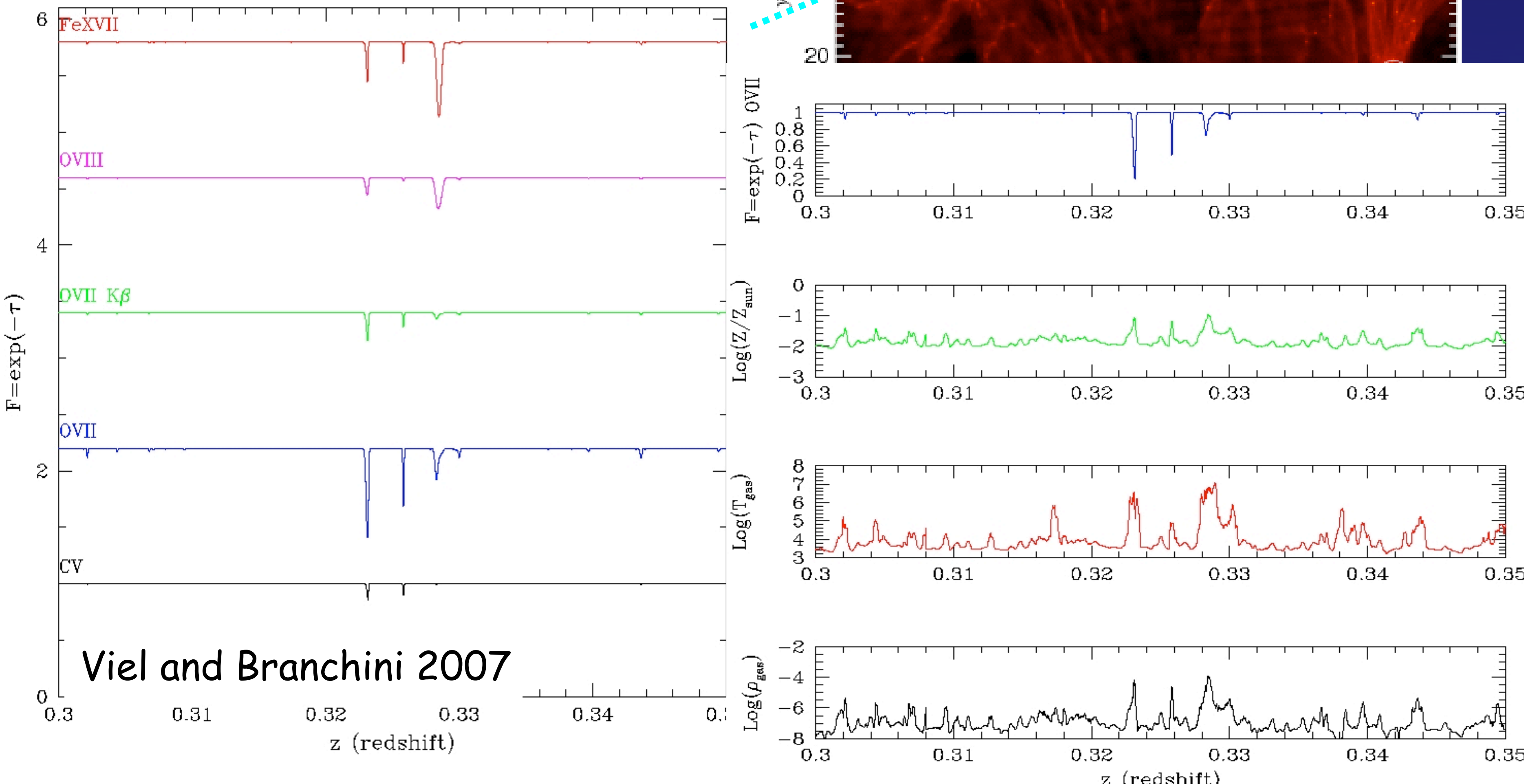
Ions: OVI (KLL), OVIIKα, OVII Kβ, OVIII, CV, NeIX, MgXI FeXVII.

Hybrid collisional ionization + (X+UV) photoionization.

Independent spectra drawn by stacking outputs out to z=0.5 (Δz=0.1)

Extracting mock X-ray spectra from simulations





Viel and Branchini 2007

(what is he trying to sell ?)

EDGE

Explorer of Diffuse Emission and Gamma-ray burst Explosions

http://projects.iasf-roma.inaf.it/edge/

Absorption:

- High Resolution Spectroscopy ($\Delta E \sim 2(1)$ eV)
- Large effective area ($A \sim 1000$ cm2)
- Fast re-pointing ($t \sim 60$ sec)

Emission:

- Spatially Resolved Spectroscopy ($\Delta\theta \sim$ arcmin)
- Large Field of View ($\sim$1 deg x 1 deg)
- High resolution imaging ($\Delta\theta \sim$ 10arcsec)

WHIM in Absorption: backlights

Bright Blazars with fluence of ~ $2.5 \cdot 10^{-5}$ erg cm^{-2} in ~70 ks

Pros: Very Bright. Cons: Rare

Bright QSOs with fluxes> $5 \cdot 10^{-12}$ erg cm^{-2} s^{-1} keV^{-1}

Pros: Not too Rare. Cons: Nearby

GRB afterglows with fluence of ~ $3 \cdot 10^{-6}$ erg cm^{-2} keV^{-1} in ~60 ks

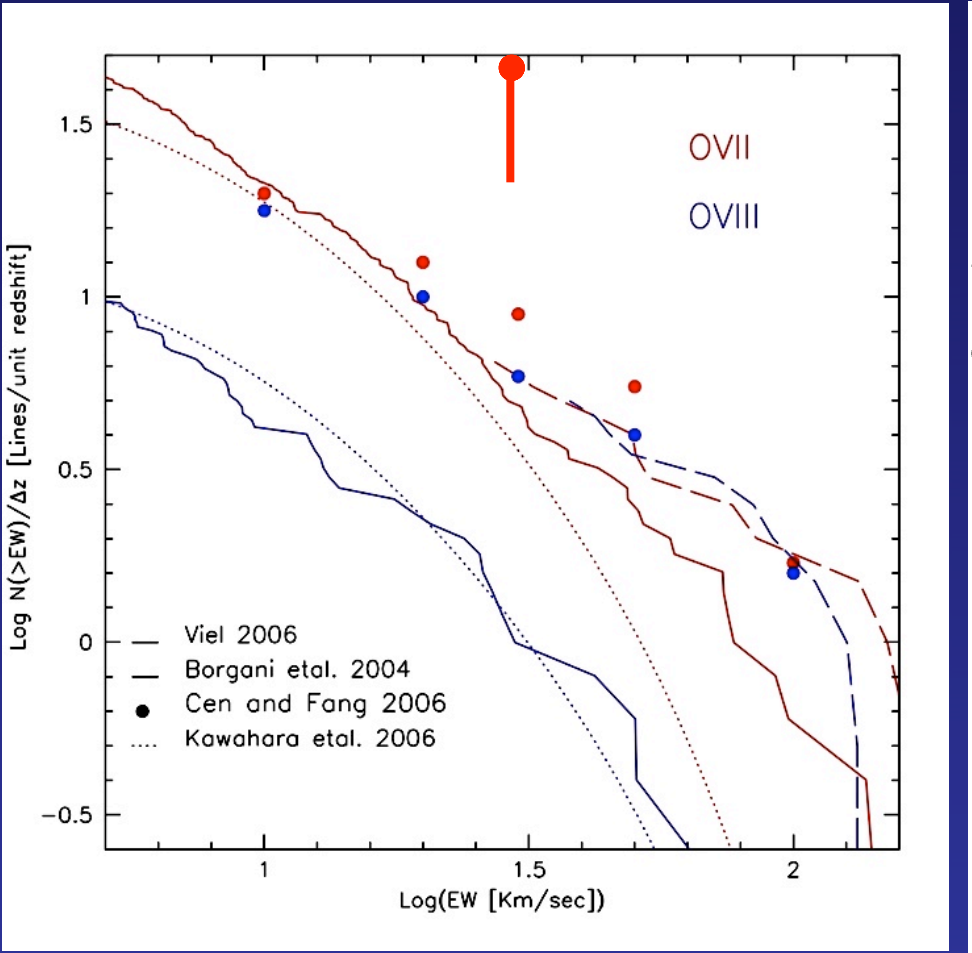
Pros: Bright. Distant. Not too rare. Cons:Fast re-pointing required

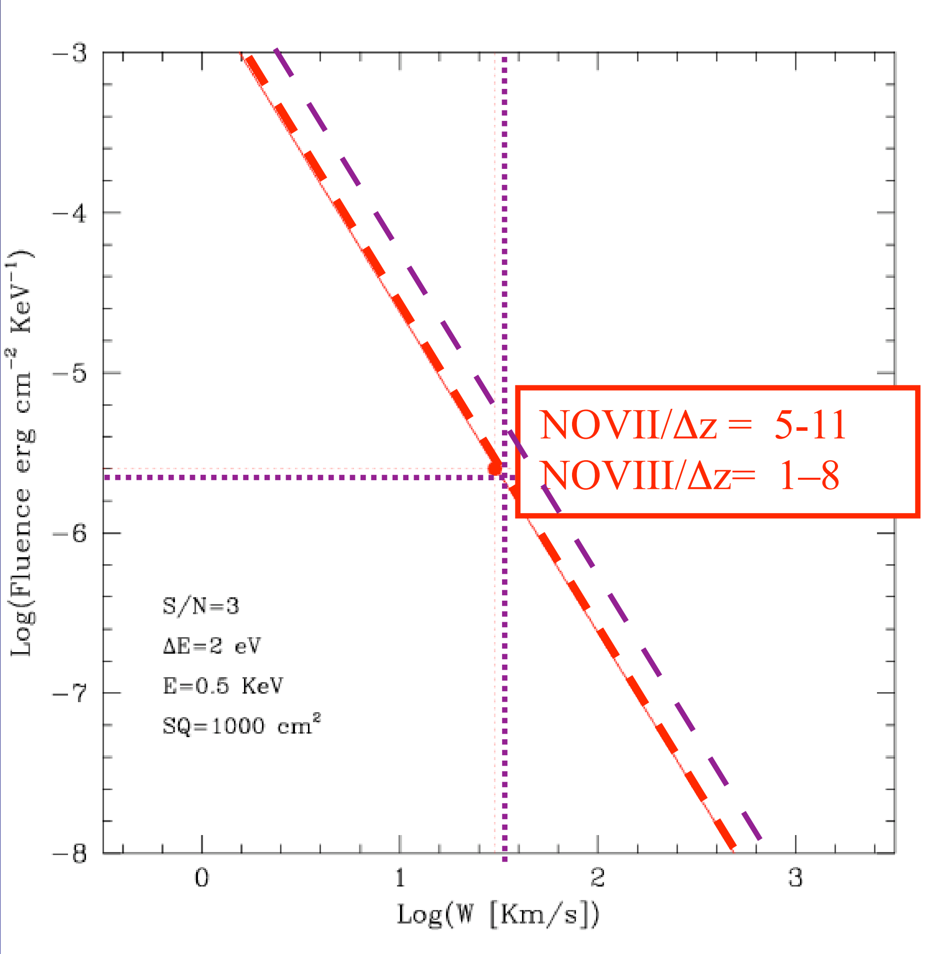
N GRB per yr for FOV=3sr	Fluence @ 0.55 KeV (60 s< t <60 ks) (erg/cm2)
28	1.9 x 10^{-6}
14 (5)	3.2 x 10^{-6}
8	7.6 x 10^{-6}

Estimated using ~170 SWIFT afterglow-light curves (Sato 2007)

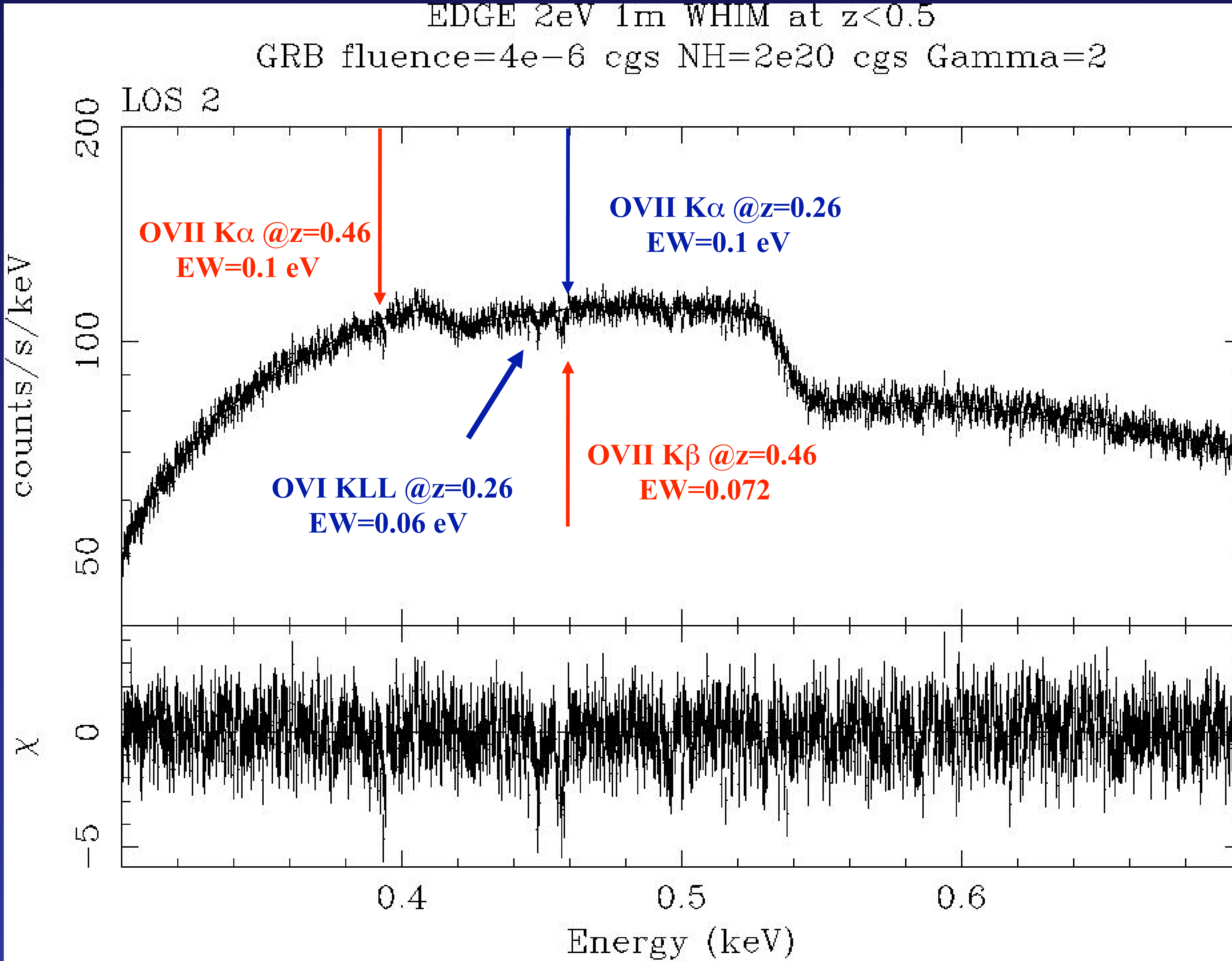
Considering XRFs could boost these estimates up by a factor 2

WHIM in absorption: expected detections





(15) 200 5σ detections in (15) 70 observations 60 Ksec each or (40) 350 3σ, single OVII line detections


EDGE 2eV 1m WHIM at z<0.5
GRB fluence=4e−6 cgs NH=2e20 cgs Gamma=2
LOS 2
OVII Kα @z=0.46
EW=0.1 eV
OVII Kα @z=0.26
EW=0.1 eV
OVI KLL @z=0.26
EW=0.06 eV
OVII Kβ @z=0.46
EW=0.072
counts/s/keV
χ
Energy (keV)
200
100
50
0
−5
0.4
0.5
0.6

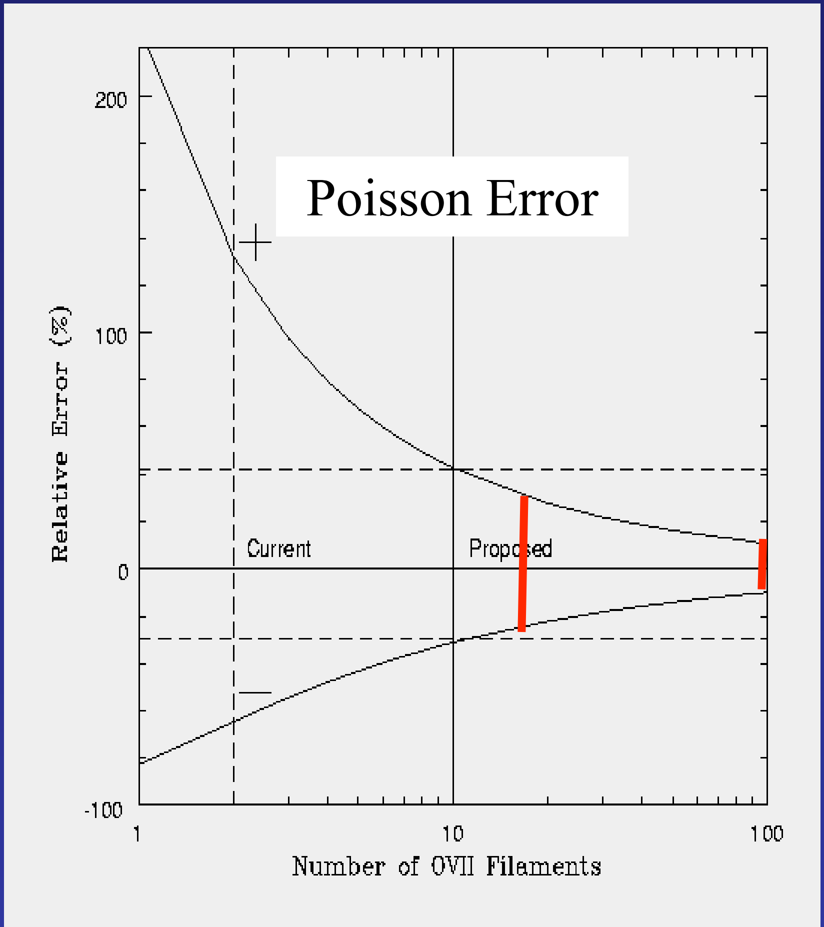
Estimating Baryon Density

1) Ionization balance from line ratios

$$\frac{EW_X}{EW_Y} \sim \frac{f_X \times F_X(T,\rho)\times A_X}{f_Y \times F_Y(T,\rho)\times A_Y}$$

2) Estimate of WHIM density (metallicity required)

$$\Omega_b(OVII) = \left(\frac{1}{\rho_c}\right) F^{-1}(OVII)\left(\frac{\mu m_p \sum_i N(OVII)_i}{\sum_i d_i}\right)(H/O)$$



10-100 detections should allow:
To estimate d$\mathcal{N}$/dz for different ions.
- To uniquely determine the ionization balance of the absorbers.
- To measure Ω_b with (5-15) % uncertainties.

To probe the WHIM filamentary structure with 3σ significance one should observe ~20 close ($\Delta\theta$<20 arcmin) pairs of bright QSOs.
But very long exposures would be required (Viel et al 2002)

Emission: Background is critical !

- 3' x 3' filament at redshift 0.2
- Energy resolution: 2 eV
- Area ~ 1000 cm^2

1 Ms observations

Instrumental background (XRS):

➔ ~ 7.5 x 10^{-5} counts/s/keV/mm^2 below 1 keV

CXB

➔ ~ 20 counts/s/keV/sr @ 0.5 keV

Galactic Foreground (continuum)

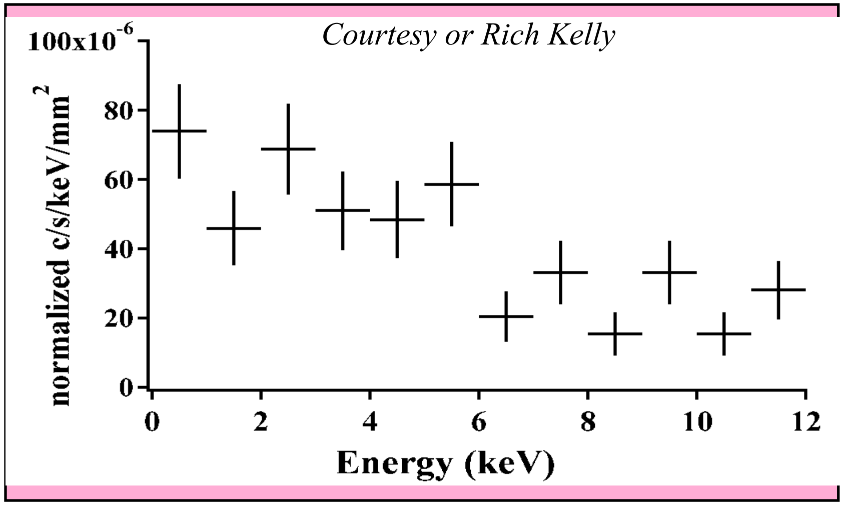
➔ ~ 10 counts/s/keV/sr @ 0.5 keV

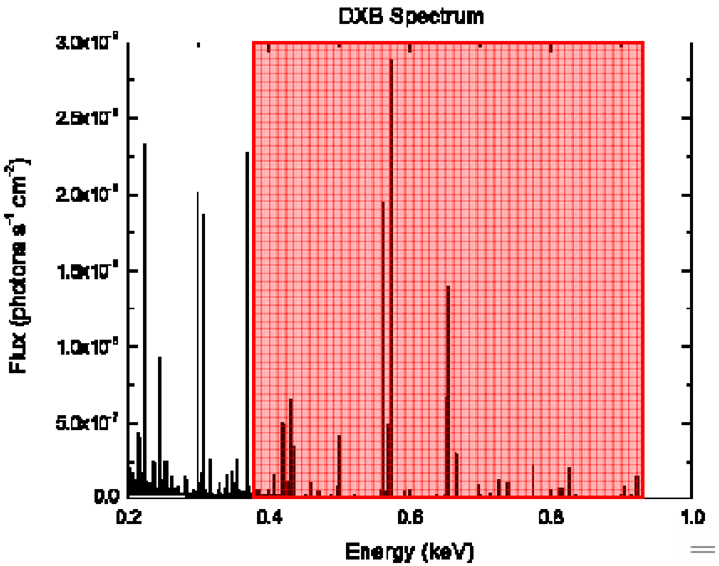
EDGE: 3' x 3' = 0.9 mm^2 of physical area + 1 Ms observations + 2eV resolution

➔ Bkg ~ 35 counts/peak

➔ Δ(Bkg)~ 6 counts/peak

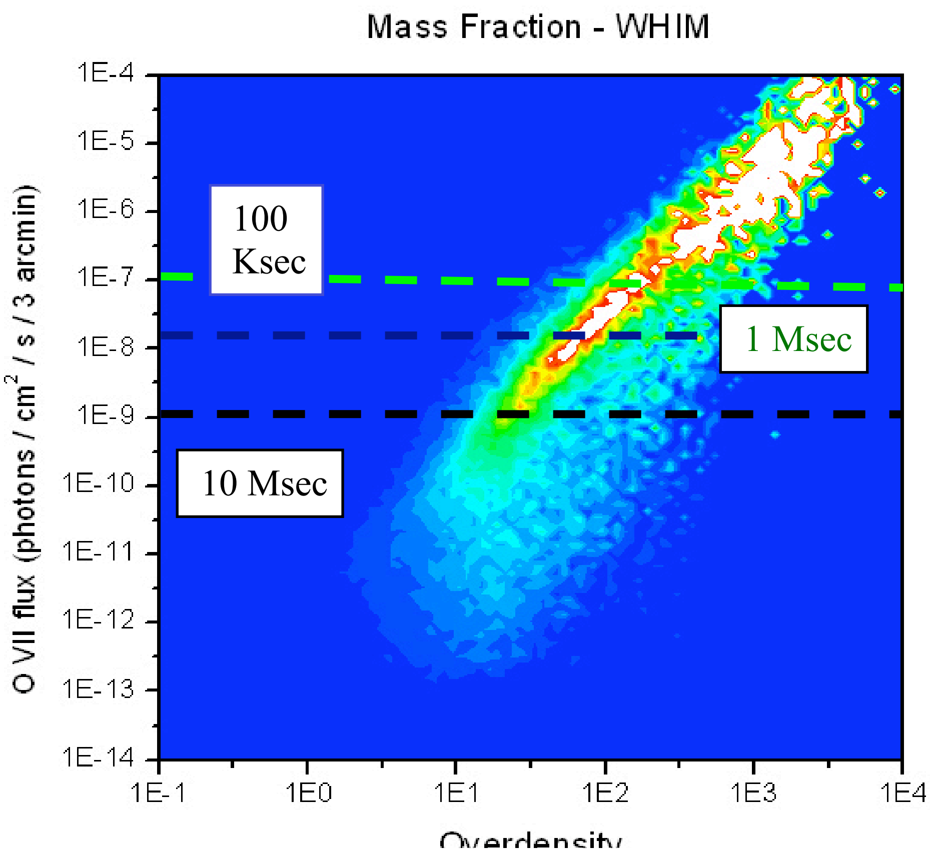
3σ Detection: ~ 20 counts



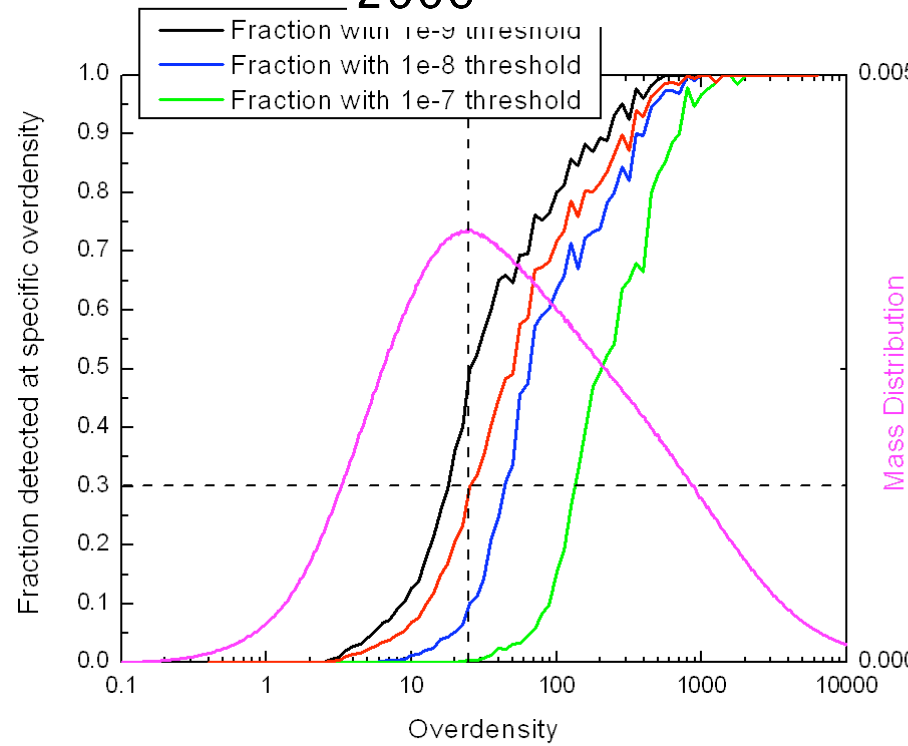


Mc Cammon et al. 2002

Emission: Fraction of WHIM detected

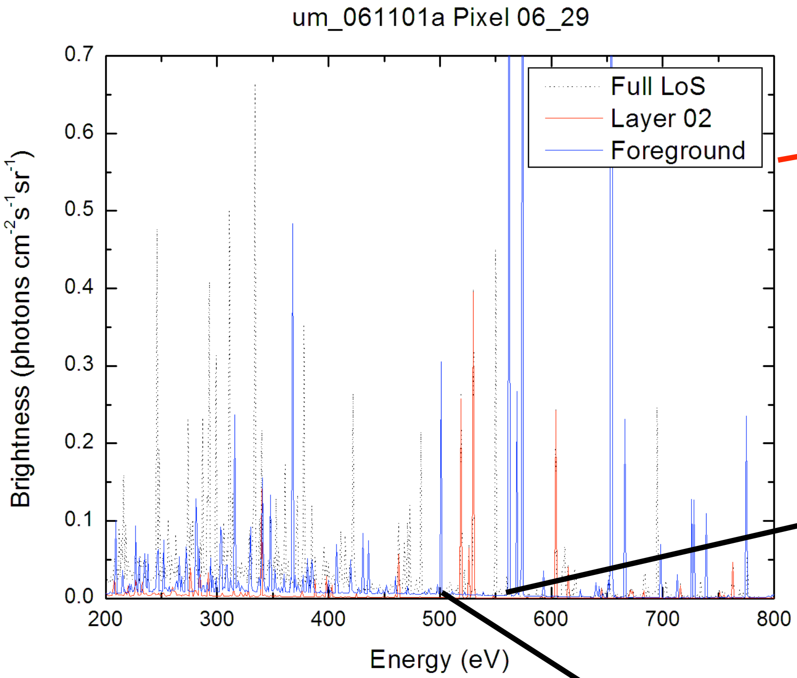


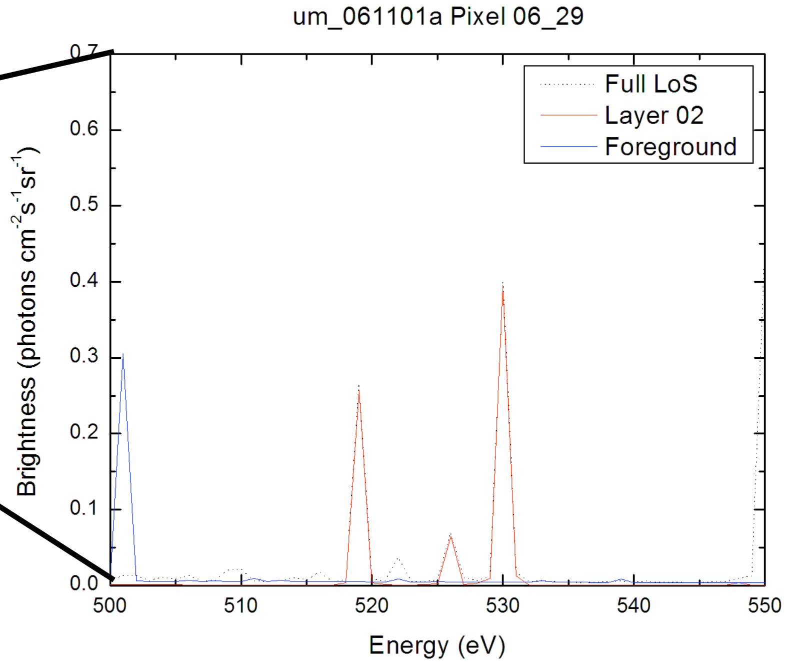
Galeazzi and Ursino 2006



e.g. 30% of the WHIM with overdensity 50 can be studied

WHIM Spectrum





On average roughly 100 pixels host a detectable (OVII or OVIII) WHIM each z-slice, totaling to 30% of the instrument of view out to z=0.5. Both OVII and OVIII lines are detected in ~10% of the pixels.

Emission: Added Value

Possibility of detecting OVII triplet → Ionization state

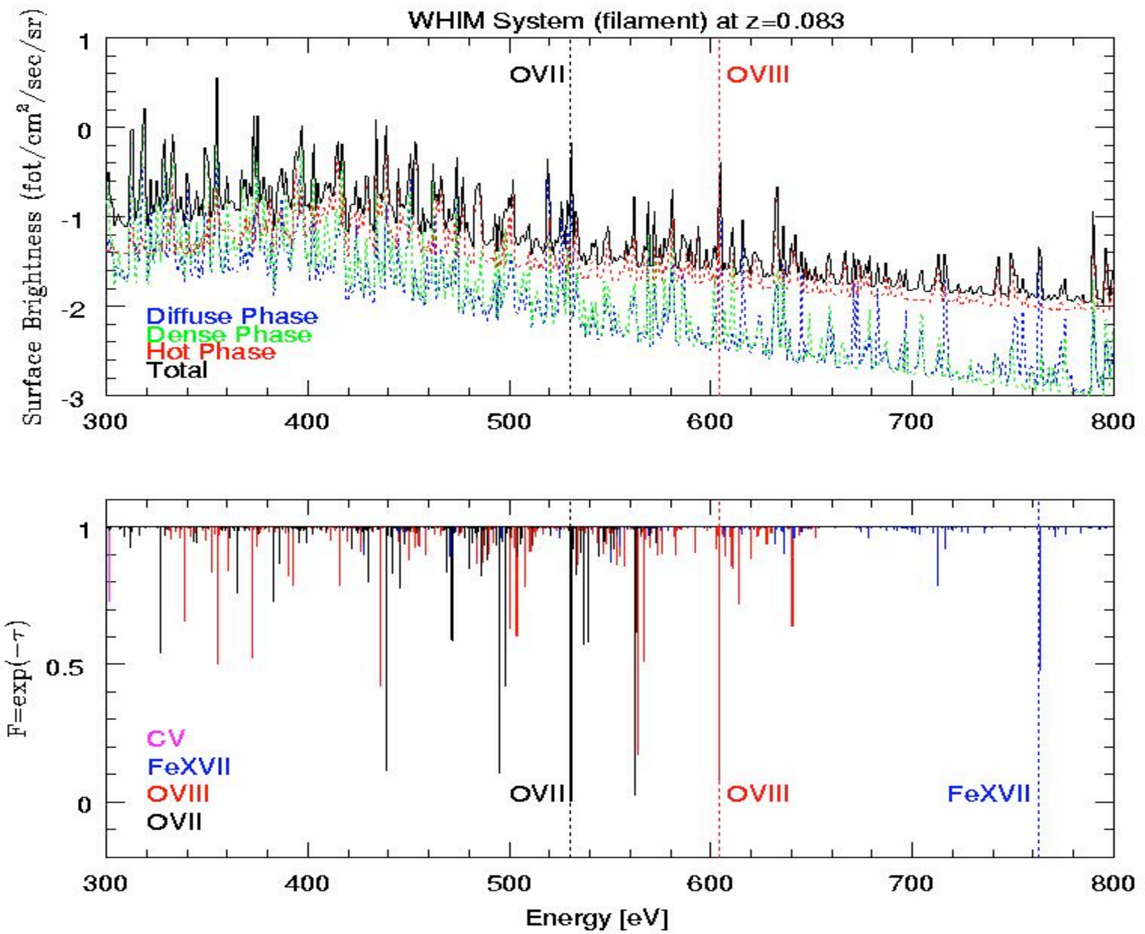
WHIM tomography (but the sampling is sparse !)

Emission+Absorption:
- increase significance of detections.
- measure gas density

$$I_{SB}(X) \propto Z_X \rho_{gas}^2 L$$

$$EW(X) \propto Z_X \rho_{gas} L$$

$$\rho_{gas} = I_{SB} / EW$$



CCD+TES Synergy

Reject contaminating point sources (AGNs – Starburst):

(3.5σ detection limit for discrete sources is 10^{-16} erg/cm^2/s [0.5-2] KeV – 1 Msec)

Removing 30% of contaminated TES pixels reduces CXB by a factor ~3

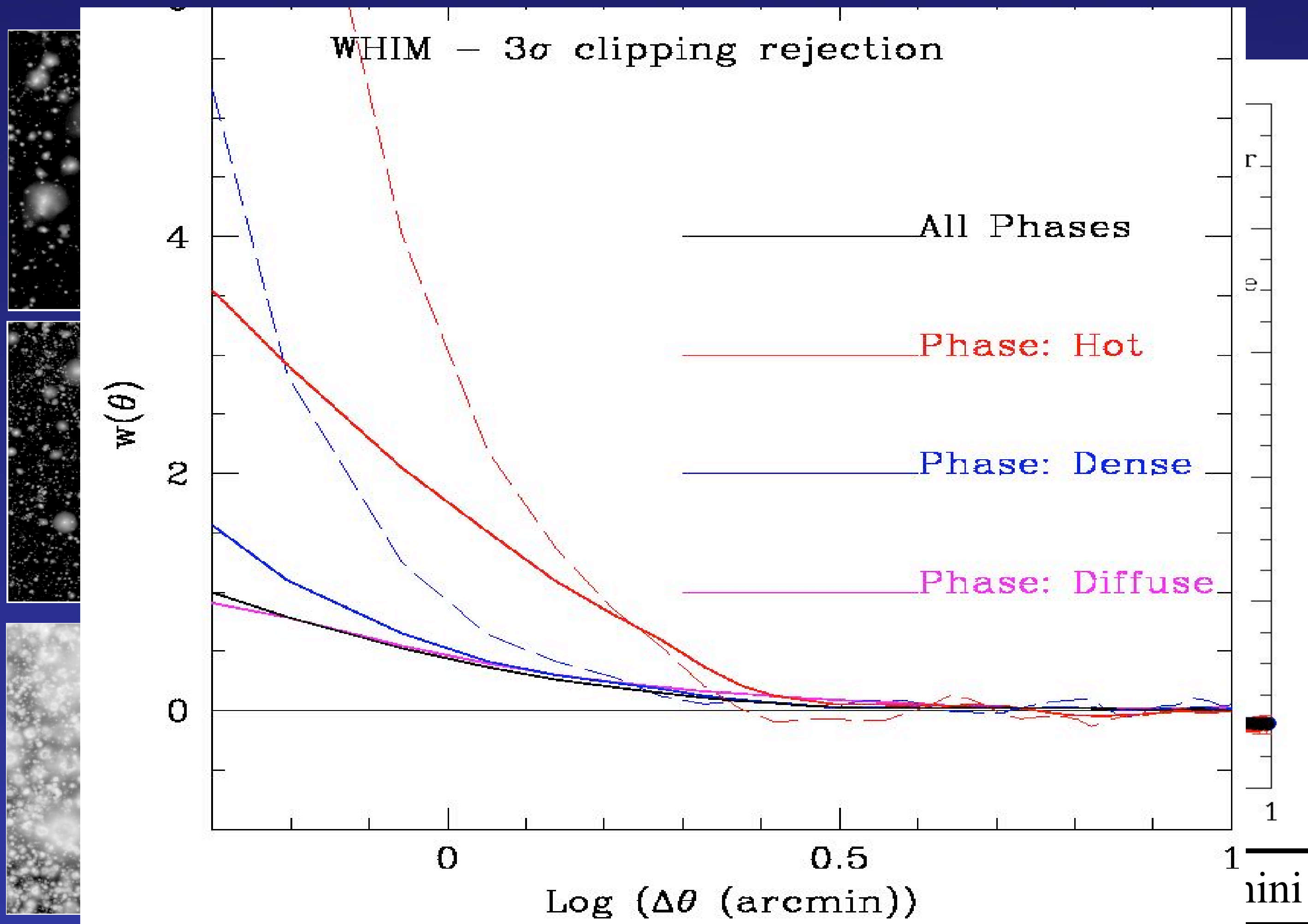
Reject contaminating diffuse sources (Groups+Clusters):

Rejection criteria: Flux [0.38-65] KeV – Hardness Ratio [0.38-65] /[0.5-8]

Spot 90% of contaminated CCD pixels.

Probing WHIM spatial distribution

CCDs can use to measure the angular correlation properties of the WHIM emission signal. Theoretical models provide robust prediction for the WHIM 2-point angular correlation function



ini et al. 2007

Can we really study the WHIM ?

Chandra – Newton-XMM: Unlikely (small areas)

Next generation satellites:

Constellation-X: Very good energy resolution (with RGS)
No Fast re-pointing. Small f.o.v.
Absorption.

XEUS: Very Large Area
No Fast re-pointing. Small f.o.v.
Absorption.

Pharos: Very good energy resolution
Fast re-pointing. Small f.o.v.
Absorption.

EDGE: Good energy resolution – Large area
Fast re-pointing. Large f.o.v. Imaging
Absorption + Emission

- Unambiguous WHIM at detection at z>0 ? Yes
- Measuring Ω_{WHIM} ? Yes. ε~10%
- Tracing Dark Matter (Ω_m) ? Sparsely
- WHIM spatial distribution ? Yes. TES/CCD
- Ionization + Physical state ? Yes E+A

But models need to improve………..