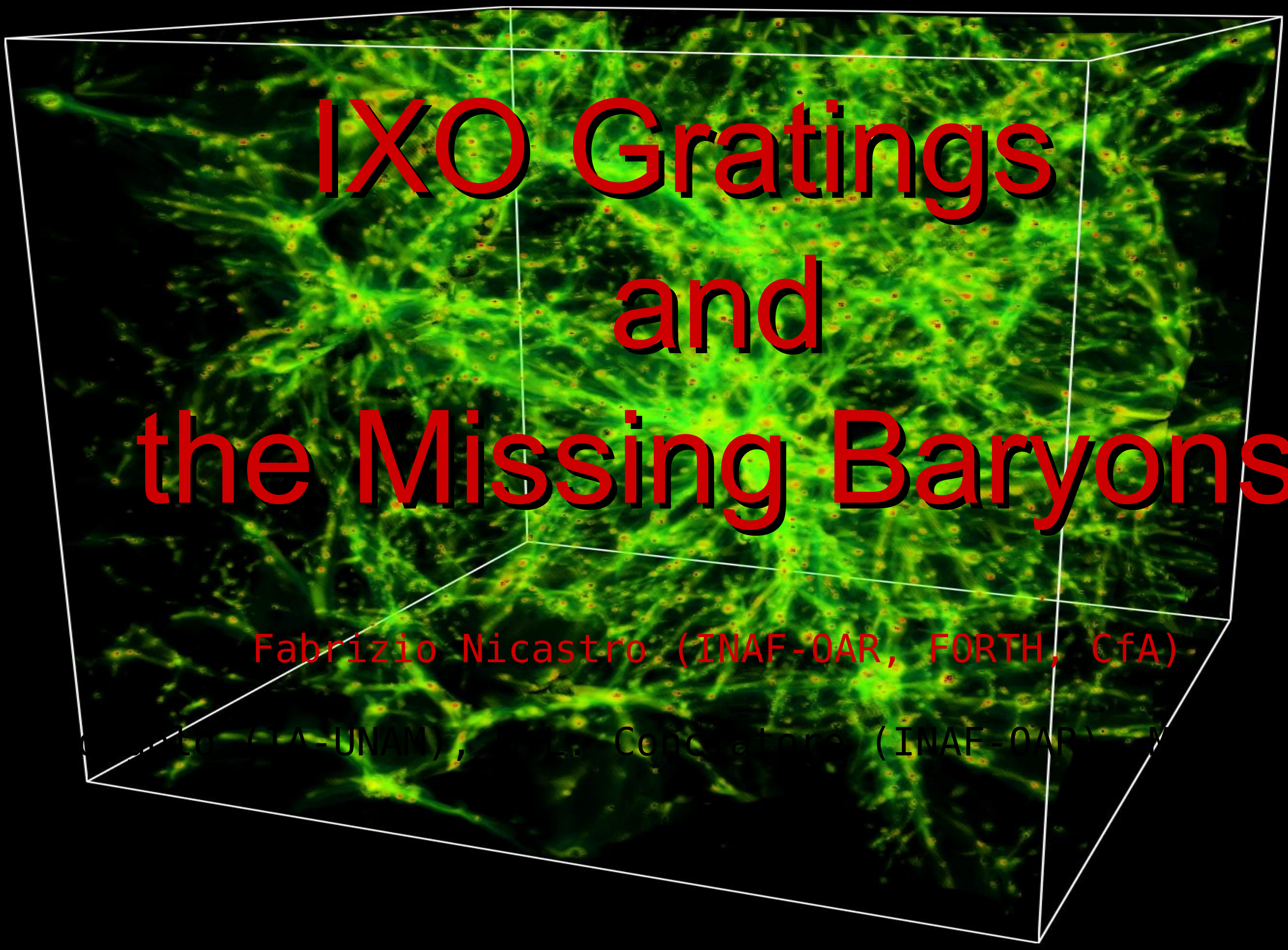

IXO Gratings and the Missing Baryons

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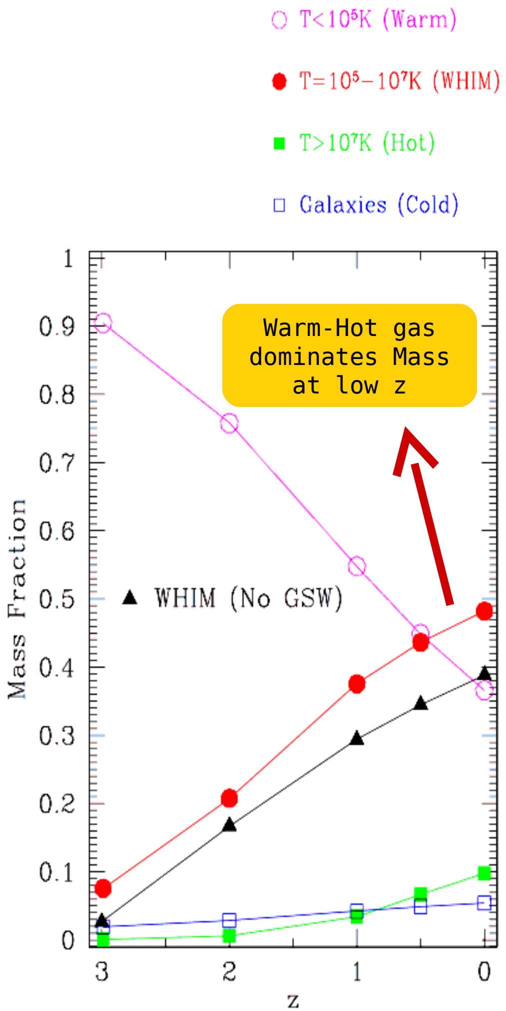
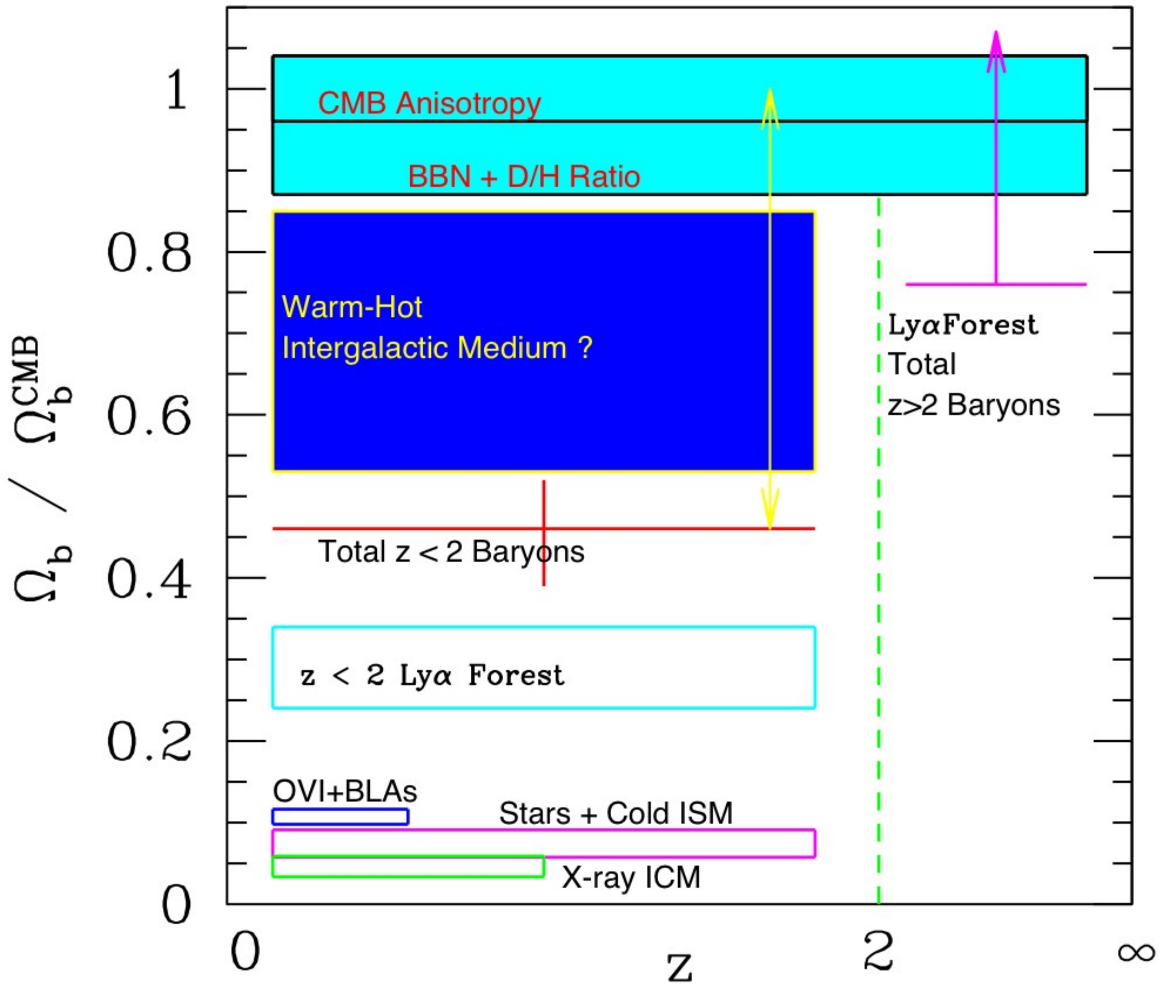
Outline

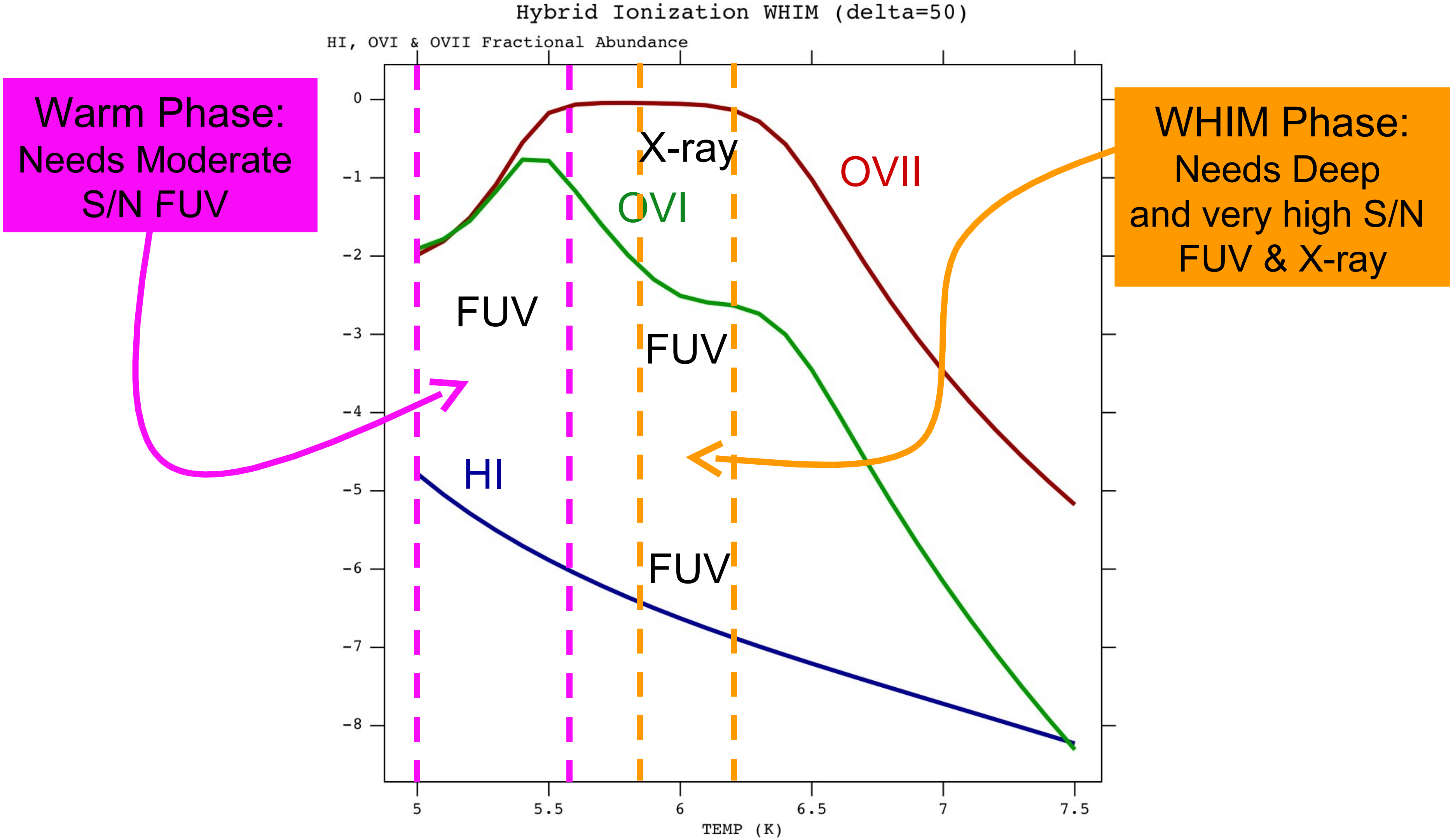
- The Missing Baryons problem and N-body solution: the Warm-Hot Intergalactic Medium
- How to detect it: the WHIM observables
- Dispersive vs Non-Dispersive Spectroscopy
- The Best WHIM sample for IXO/COS

Where are the Baryons?





Abundant Ions in the WHIM



Not "just" Baryon Census

cording to SCM: (54 ± 9) % of Baryons are missing!

- Find the 'Missing Baryons' to test SCM
- Ecology of the Universe (Metal Pollution, Metal Transport): dZ/dz
  - Absolute (needs UV) and Relative Metallicities.
  - Galaxy Superwinds (SN) vs AGN winds, jets
  - Nucleosynthesis
- Heating History of the Universe (test LSS shocks and structure formation): dT/dz

Mass and Metal Content of the WHIM

$$\Omega_b = \frac{1}{\rho_c}\left(\frac{\mu m_p \sum_i N_H^i}{d_{Tot}}\right)$$

$$N_H = N_{ion} \times A_{element}^{-1} \times \chi_{ion}^{-1}$$

FUV | X

FUV & X

X

Eff. Area: Grating vs Calorimeter @ 0.5 keV

$$EW(CAL)^{5\sigma}_{Thresh} \approx \frac{5(125 mA)}{(S/N)_{RE}} \qquad EW(GRAT)^{5\sigma}_{Thresh} \approx \frac{5(10 mA)}{(S/N)_{RE}}$$

to detect at 5σ OVII with EW(OVII)=2 mA

$(S/N)_{RE(CAL)} \geq 31$

Factor of 1.2 in S/N

$(S/N)_{RE(GRAT)} \geq 25$

Factor of ~1.4 in A_{Eff} nedeed vs

Factor of <~ 10 actual

Compensated by Factor >~ 10 in R

Resolution: Detection Efficiency

Grating vs Calorimeter

Typical OVII EW: W_{OVII} ~ 0.8-8 (1+z) mA (X-Rays)

Detection Efficiency: $$\eta = \frac{R}{(l/EW)}$$

η (OVII) = R_{Grat} /22/(0.0008-0.008) > (0.1-1)

η (OVII) = R_{cal} /22/(0.0008-0.008) ~ (0.01-0.1)

Cf with: η (OVII;Chandra,XMM) ~ (0.01-0.1)
η (OVI;FUSE,HST) ~ (1-10)
η (HI;FUSE,HST) ~ (0.1-1)

Moreover…

Disp. vs Non-Disp. Intrinsic Gain

Gratings

$$(N^{Thres}_{He-like})_{Grat} \simeq 4 \times 10^{14} \left(\frac{N_s}{3}\right) \left(\frac{\lambda(\mathring{A})}{25}\right)^{-2} \left(\frac{f_{ion}}{0.7}\right)^{-1} \sqrt{\frac{\Delta\lambda(m\mathring{A})}{10}} \sqrt{\frac{10^{-6}}{F(erg\,cm^{-2})}} \sqrt{\frac{1000}{A_{Eff}(cm^2)}} (1+z)^{-1}$$

Calorimeters

$$(N^{Thres}_{He-like})_{Cal} \simeq 5 \times 10^{14} \left(\frac{N_s}{3}\right) \left(\frac{\lambda(\mathring{A})}{25}\right)^{-1} \left(\frac{f_{ion}}{0.7}\right)^{-1} \sqrt{\frac{\Delta E(eV)}{2.5}} \sqrt{\frac{10^{-6}}{F(erg\,cm^{-2})}} \sqrt{\frac{10000}{A_{Eff}(cm^2)}}$$

e.g. Gratings detect 3x fainter CV at z=0.3

Finally…Kinematics and Multiphase Systems: WHIM lines are narrow!

$V_{th}(O,T=10^6\ K) \sim 33\ km\ s^{-1}$

----> FWHM(OVII) ~ 6 mA @ 0.5 keV

Cf w FWHM(Grat) = 10 mA

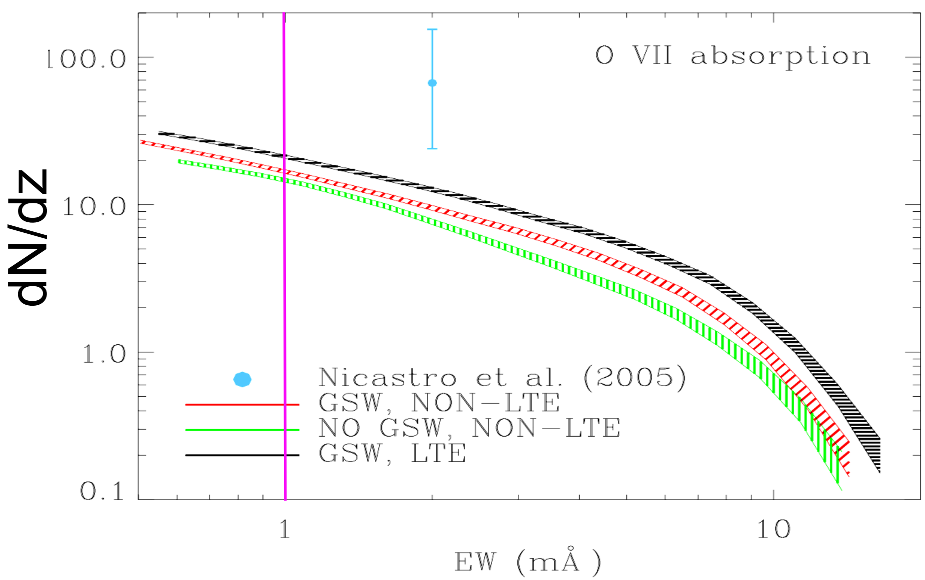
FWHM(Cal) = 125 mA @ 0.5 keV

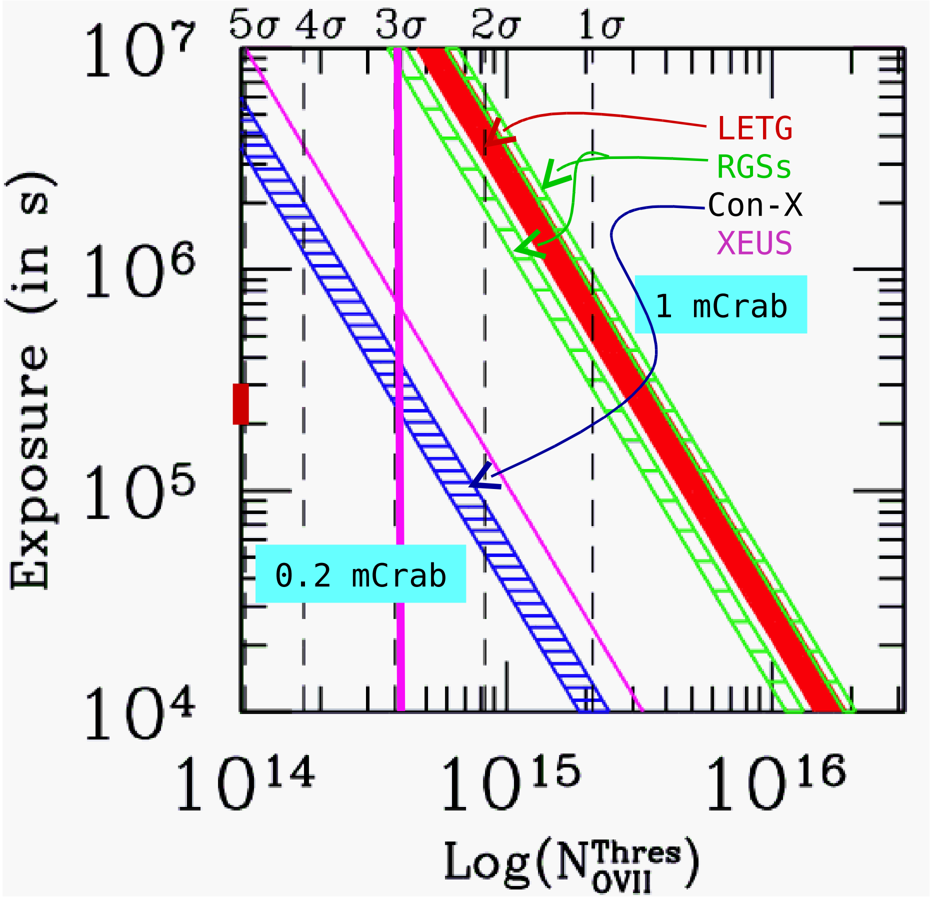
+ WHIM is multiphase with typical 10-100 km s-1 separation (e.g. Danforth&Shull+08)

→ Ω_b measurements need secure identification of BLAs with Metal Lines

What Can we Detect with IXO

> 3-10 Systems down to $N_{OVII} = 4x10^{14}$ cm^{-2} at z > 0.3





EW_{OVII} = 1 mA <=> $N_{OVII} = 4x10^{14}$ cm^{-2}

Optimal WHIM Sample for IXO

- F(0.1-2.4 keV) > 0.2 mCrab
- Z > 0.3
- N_H(Gal) < 3 x 10^{20} cm^{-2}
- Mostly BL-LAC

→ Gives 69 AGNs

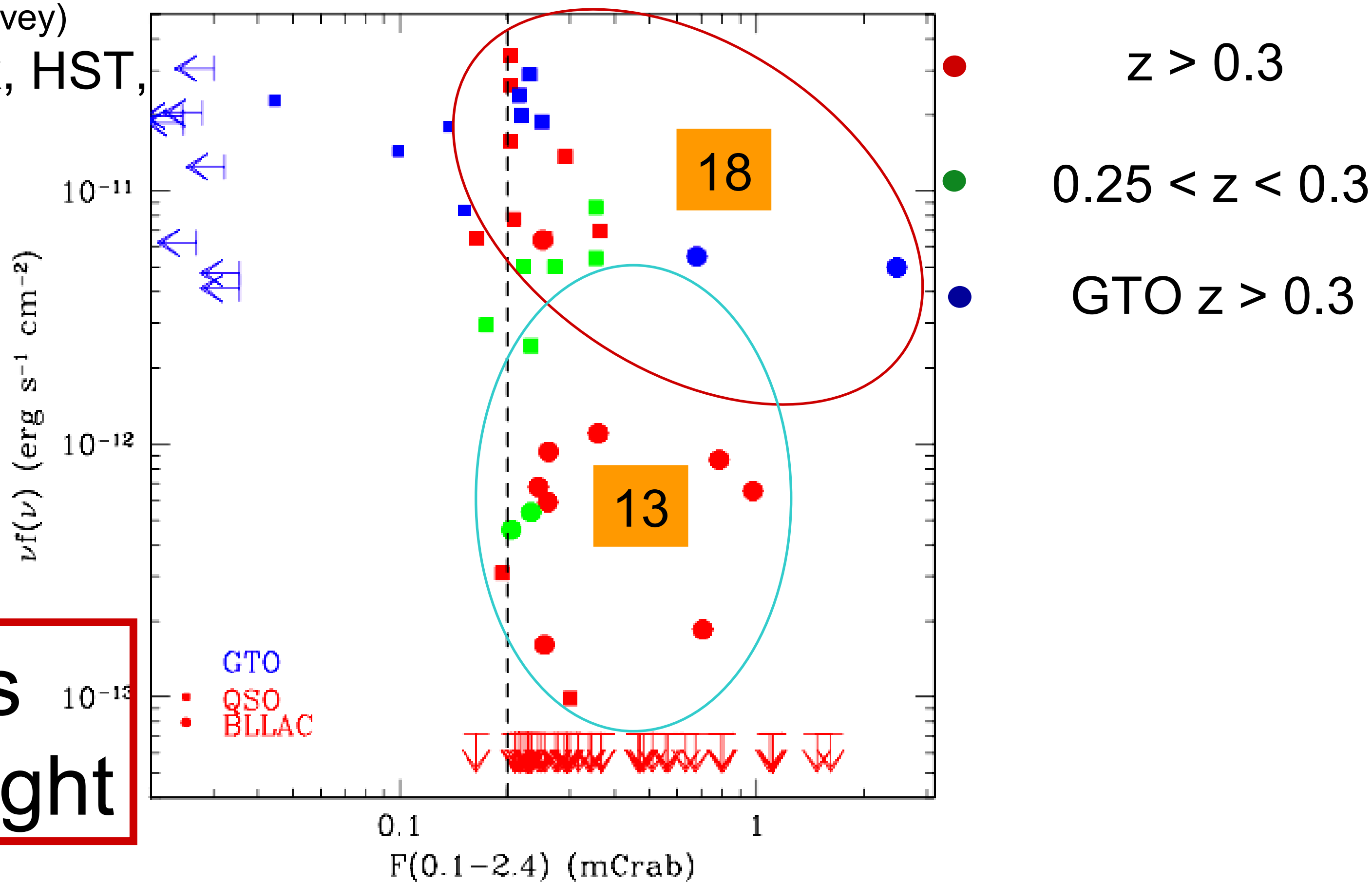
~ 3-10 Metal Systems per line of sight in 200-300 ks with IXO Gratings

→ 200-700 OVII WHIM systems in 0.7 yrs

…… BUT…Needs HI to derive Metal Content & Mass

X-Ray-FUV Bright WHIM targets

- •BRASS vs VERON (+ from BRASS vs SDSS + BRASS vs 6DF))
(+Sedentary BLLac Survey)
- •Result vs Galex, HST, FUSE

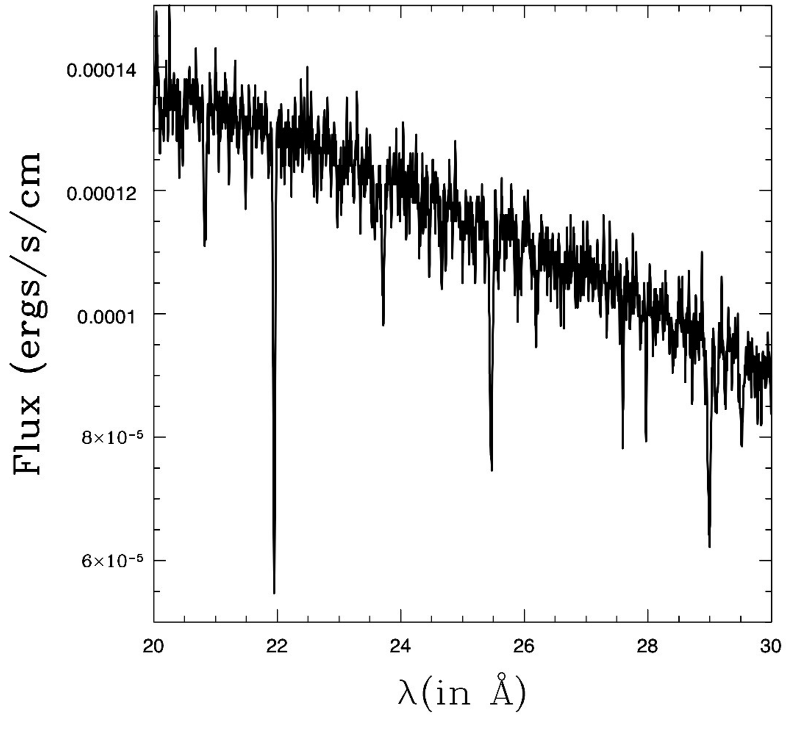


69 AGNs
31 FUV Bright

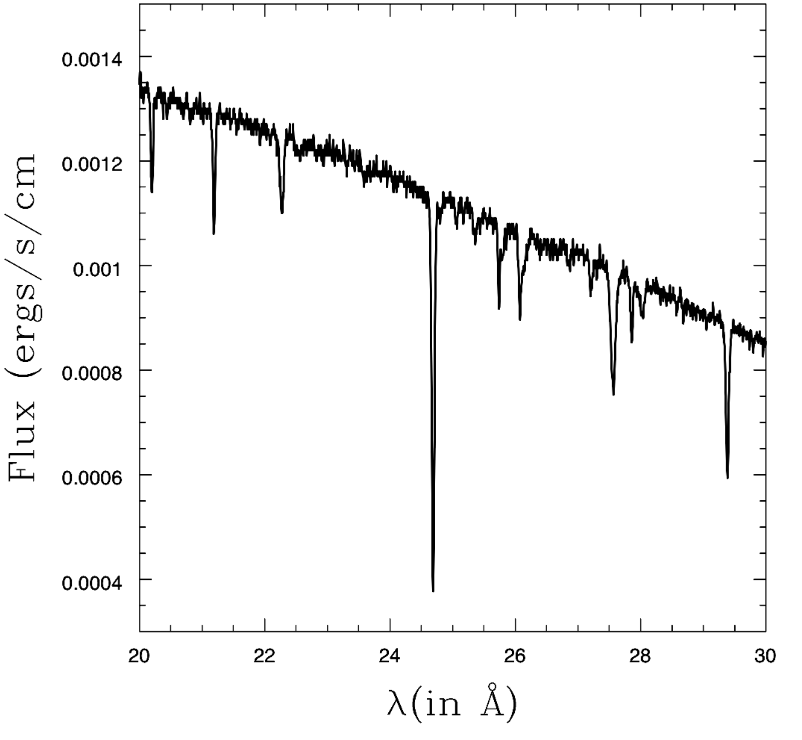
20/10/08

IXO Grating Spectra of WHIM

300 ks, 0.2 mCrab



300 ks, 2 mCrab



Random Line of Sight from latest Cen&Ostriker+06 Simulations

Conclusions

- Dispersive Spectroscopy is crucial for WHIM studies:
- WHIM studies must exploit the strong synergy between FUV and X-Ray spectroscopy: FUV vital to measure HI column and metallicity, X-Ray needed to obtain ionization correction
- IXO gratings will allow the detections of 3-10 WHIM metal systems per line of sight between z=0-0.3, down to $N_{OVII} > 4x10^{14}$ cm^{-2}
- < 300 ksec per line of sight are needed against the 69 brightest AGNs at z>0.3, with F>0.2 mCrab.
- IXO will detect 200-700 systems in only 0.7 yrs !!! (cf with 0-3 systems in 10 yrs Chandra/XMM), so allowing for:
  - Measure of Ω_b to better than 1%
  - Metallicity history of the Universe
  - Heating history (shocks, structure formation)