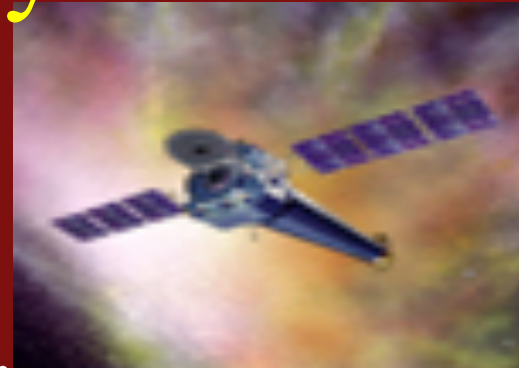
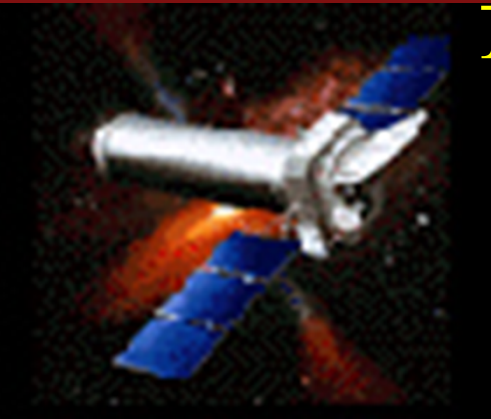
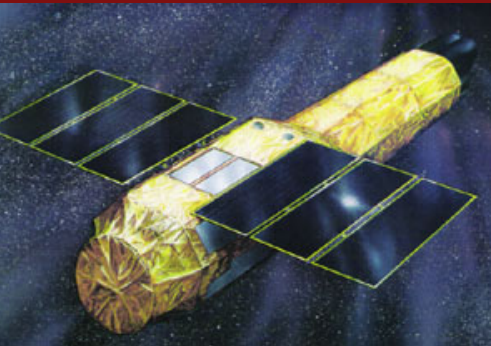


# The Warm-hot CGM of galaxies: clues from the Milky Way



Smita Mathur

The Ohio State University

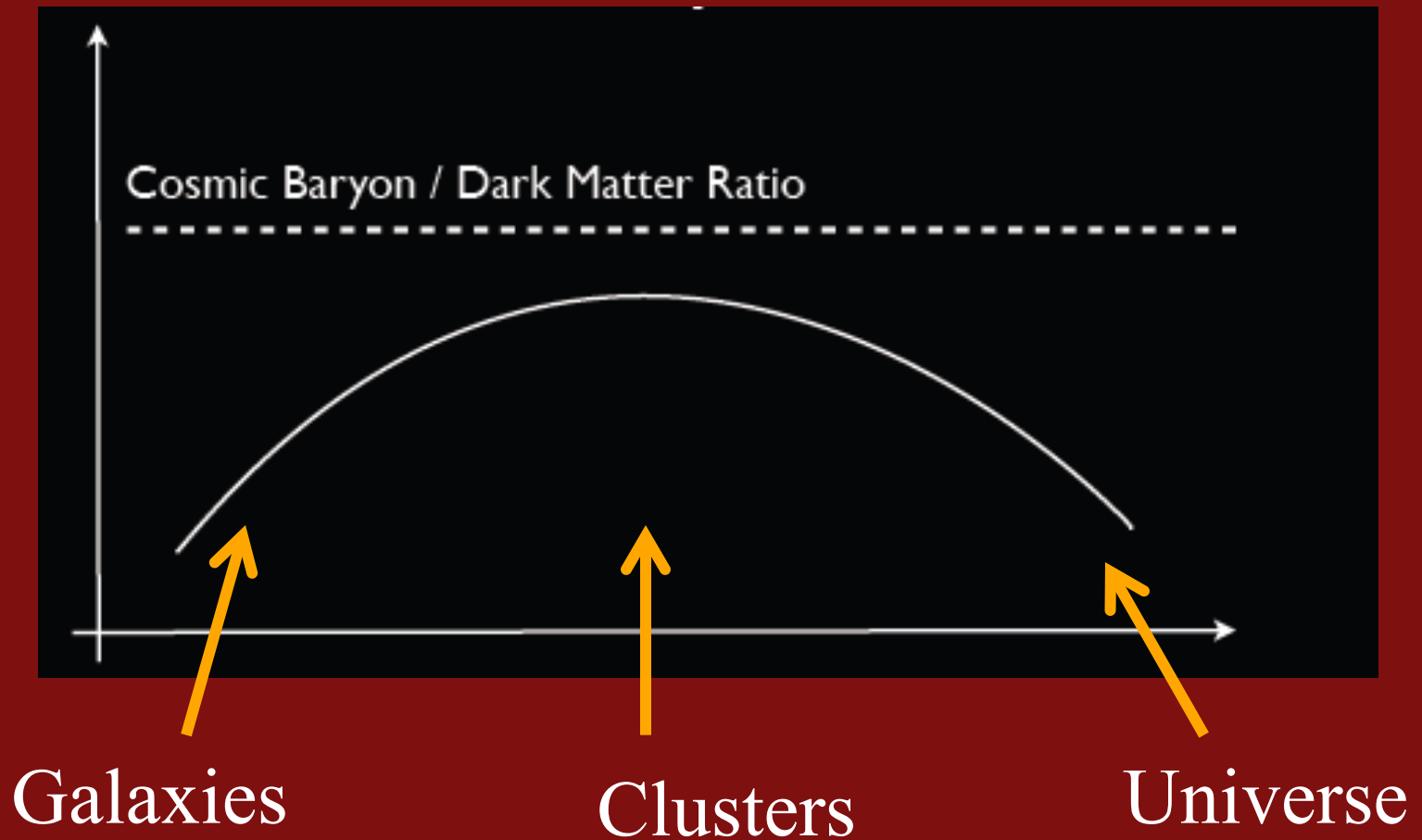


With

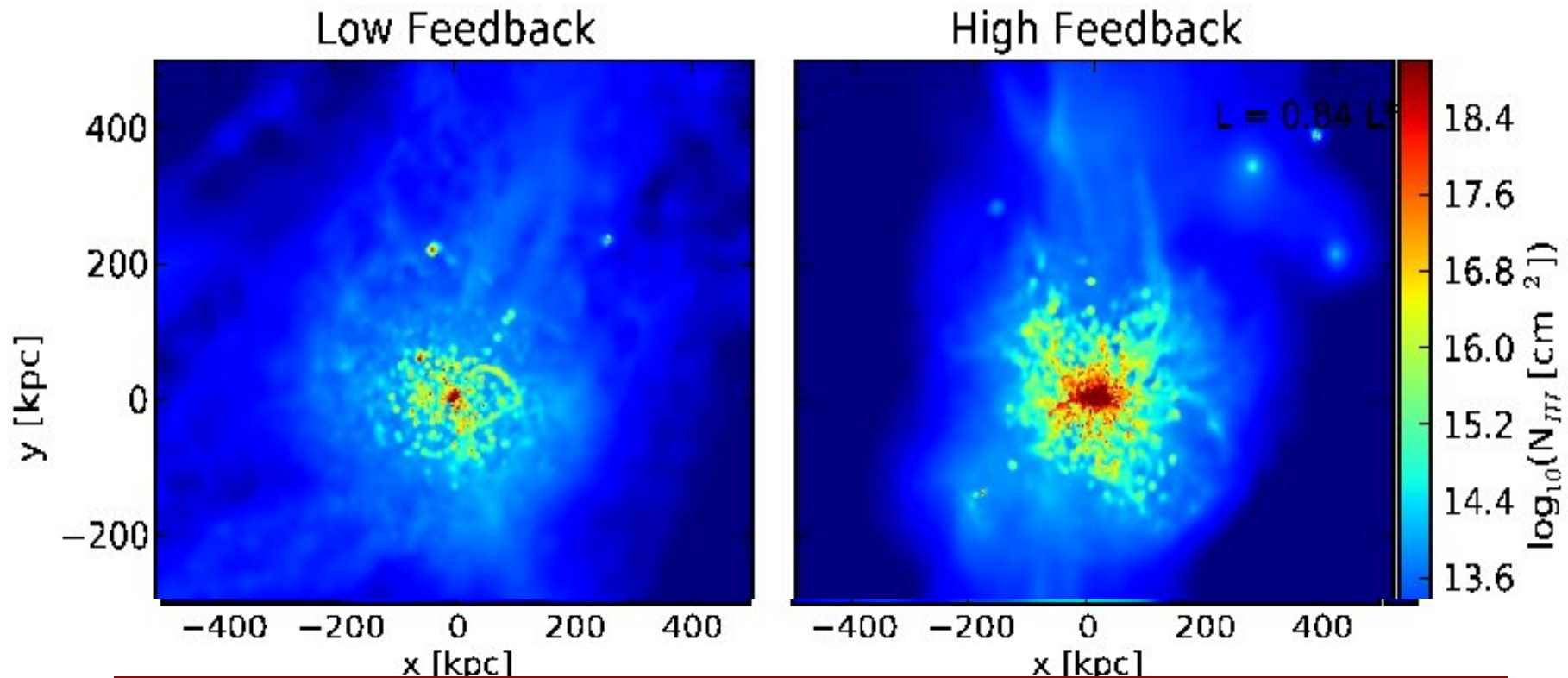
A. Gupta, Y. Krongold,

F. Nicastro, S. Das

In the low-redshift Universe,  
baryons are missing on all scales

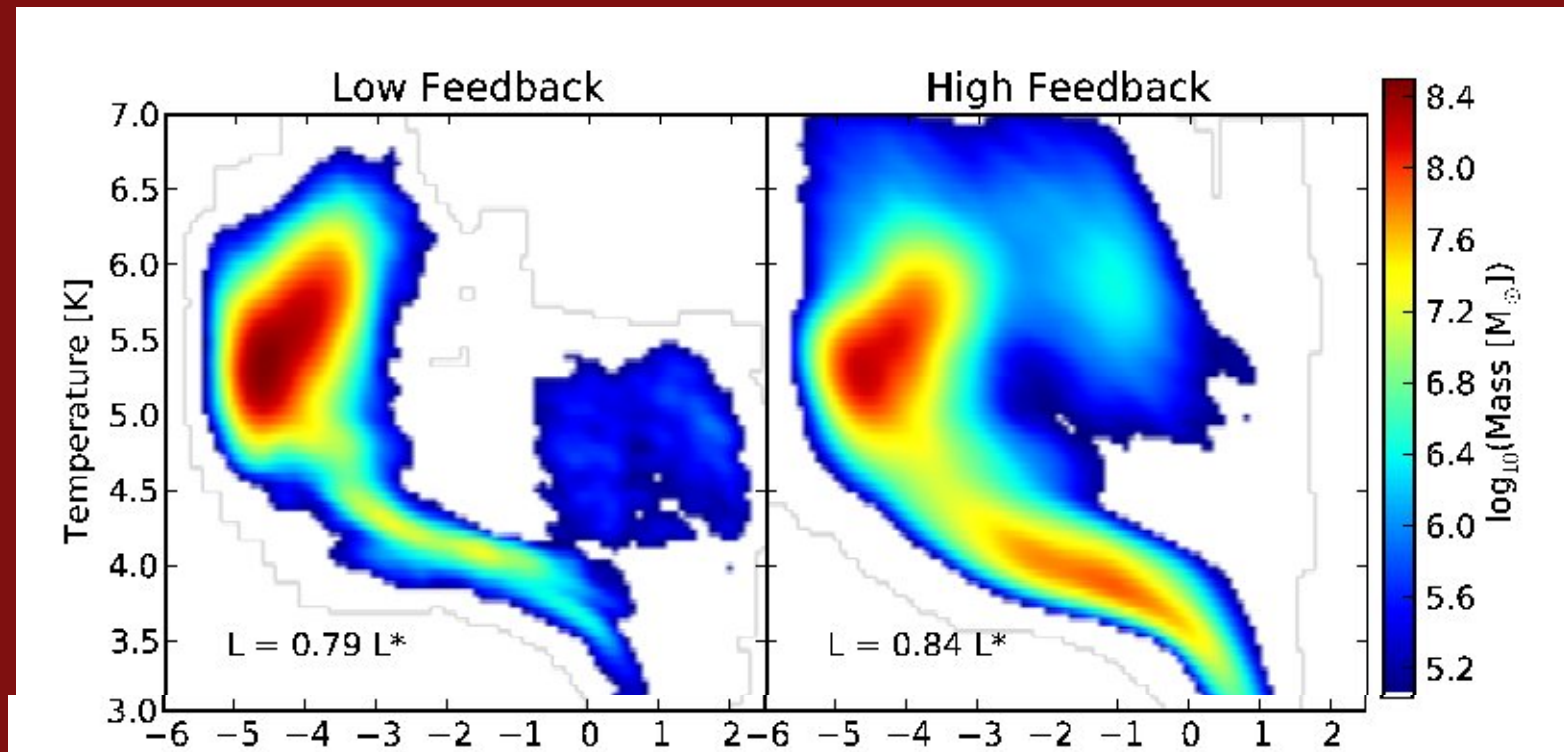


# Simulations of the CGM



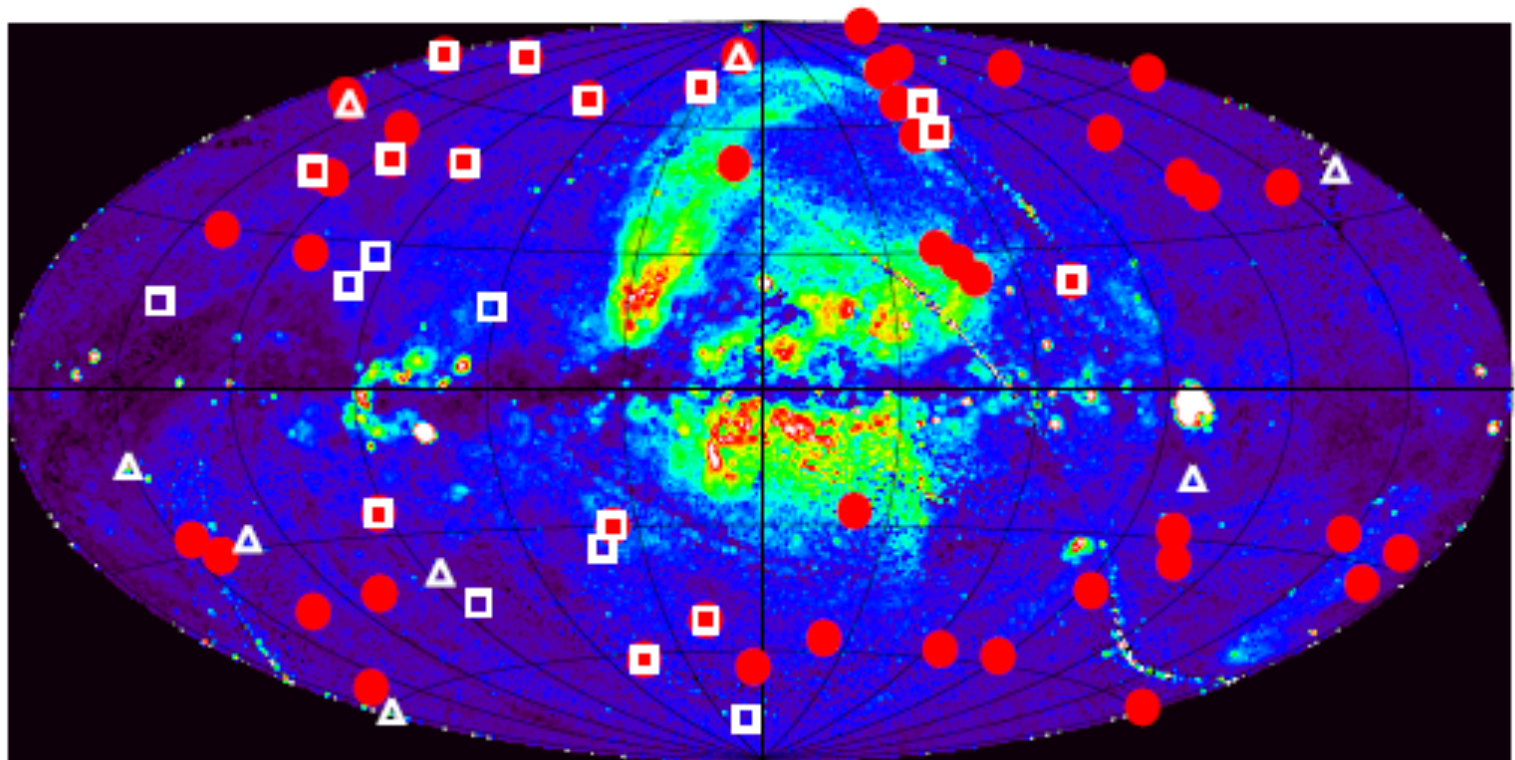
Stinson et al. 2011

# Diffuse Warm-hot CGM



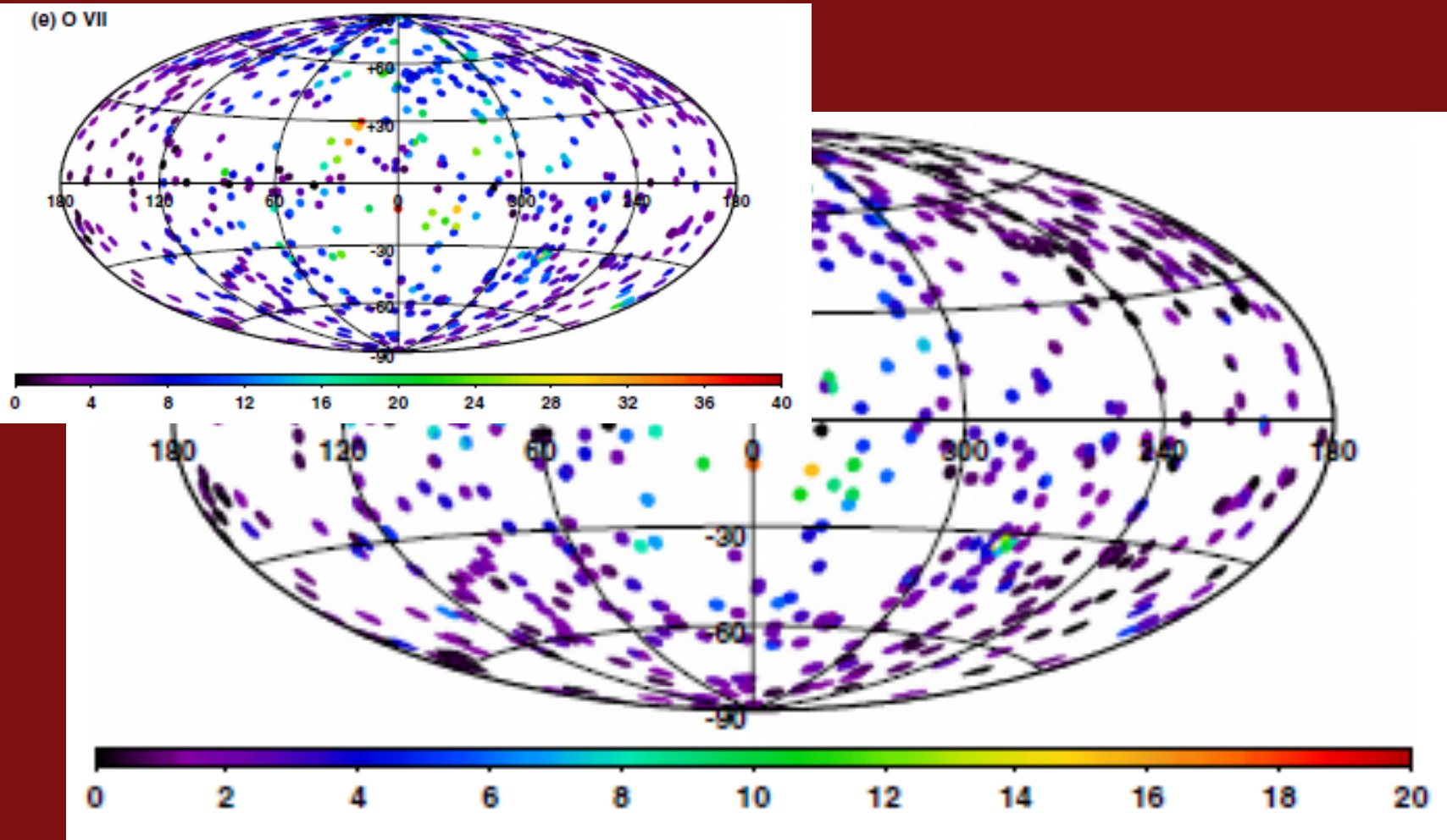
Log Density

# ROSAT all sky survey map of the diffuse background at $\frac{3}{4}$ keV





# Galactic Halo Emission



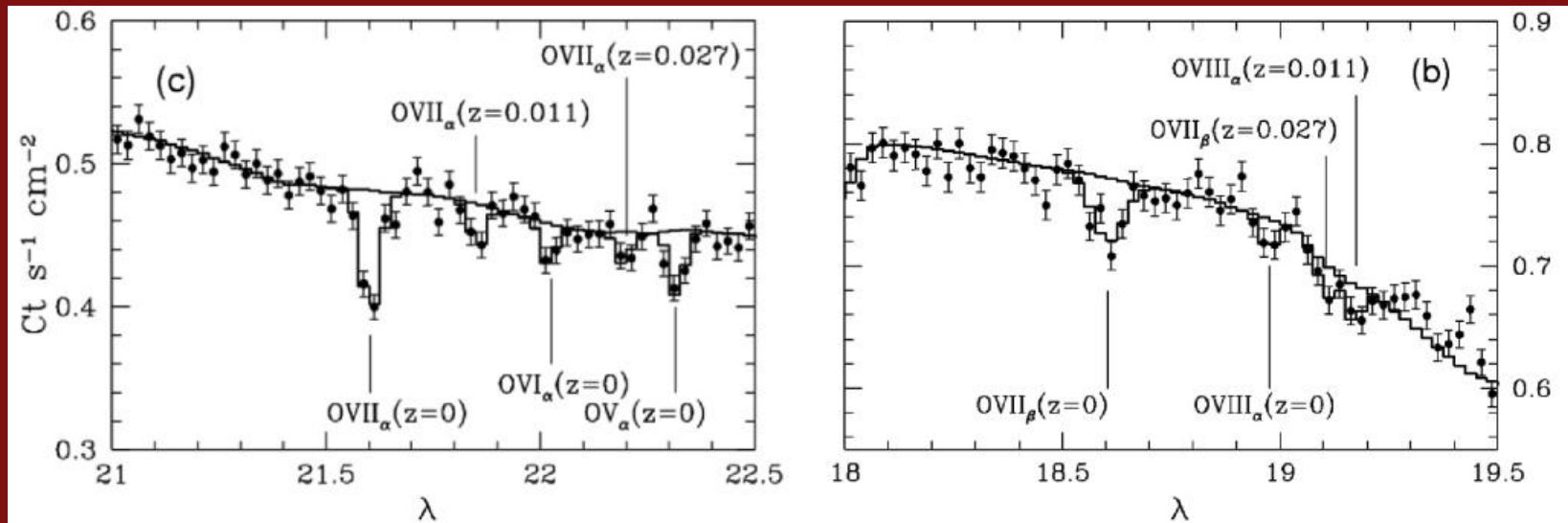
**Emission studies measure:**

$$\text{Emission Measure } \text{EM} = n_e^2 L$$

**Absorption line studies measure:**

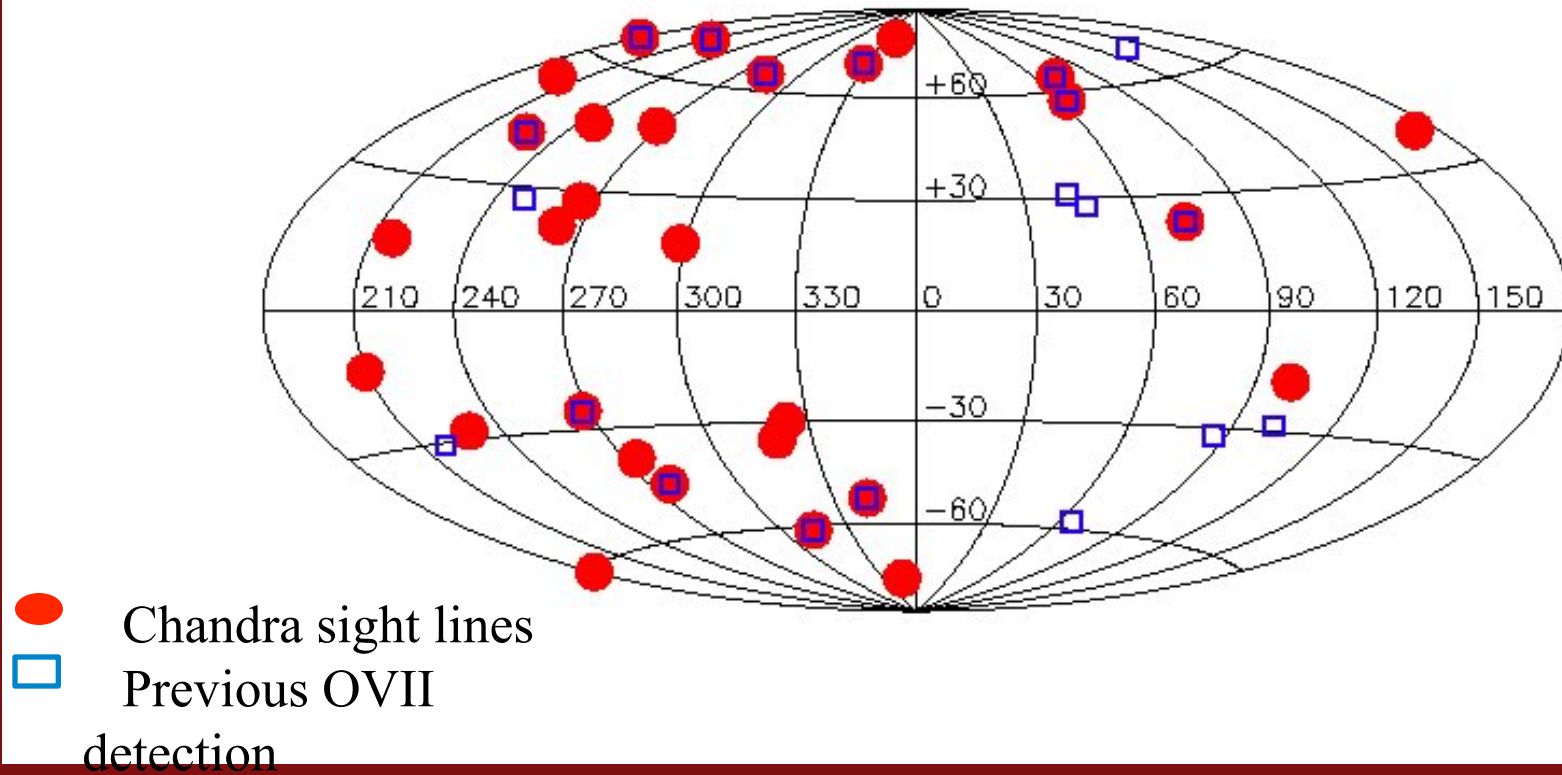
$$\text{Column density } N_H = n_e L$$

# Z=0 X-ray absorption





# Our Chandra Survey of OVII and OVIII



# *Mass Probed by OVII and OVIII X-ray Absorbing/Emitting Gas Phase*

$$M_{\text{total}} > 1.7 \times 10^9 (f_c/0.72) (8.51 \times 10^{-4}/(A_O/A_H))^3 (0.5/f_{\text{OVII}})^5 (Z_\odot/Z)^3 M_\odot$$

$$n_e = (2.0 \pm 0.6) \times 10^{-4} (0.5/f_{\text{OVII}})^{-1} \text{ cm}^{-3}$$

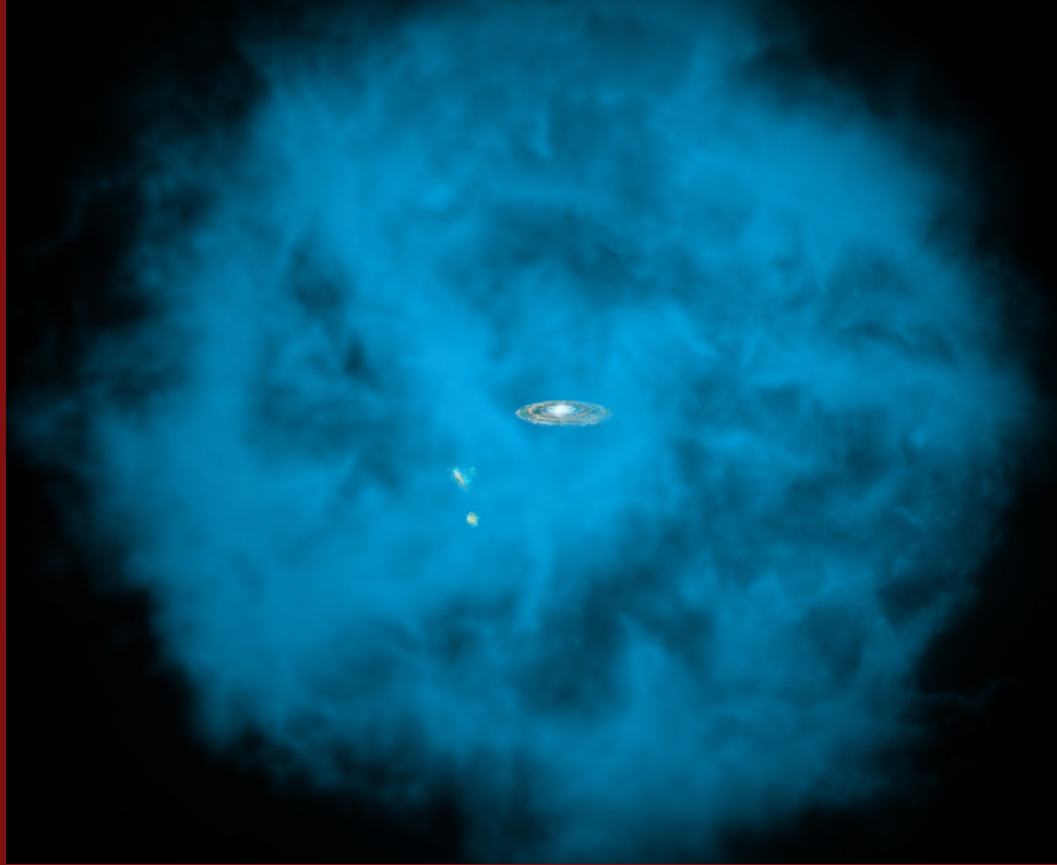
$$\text{For } Z = 0.3Z_\odot$$

$$L > 138 \text{ kpc}$$

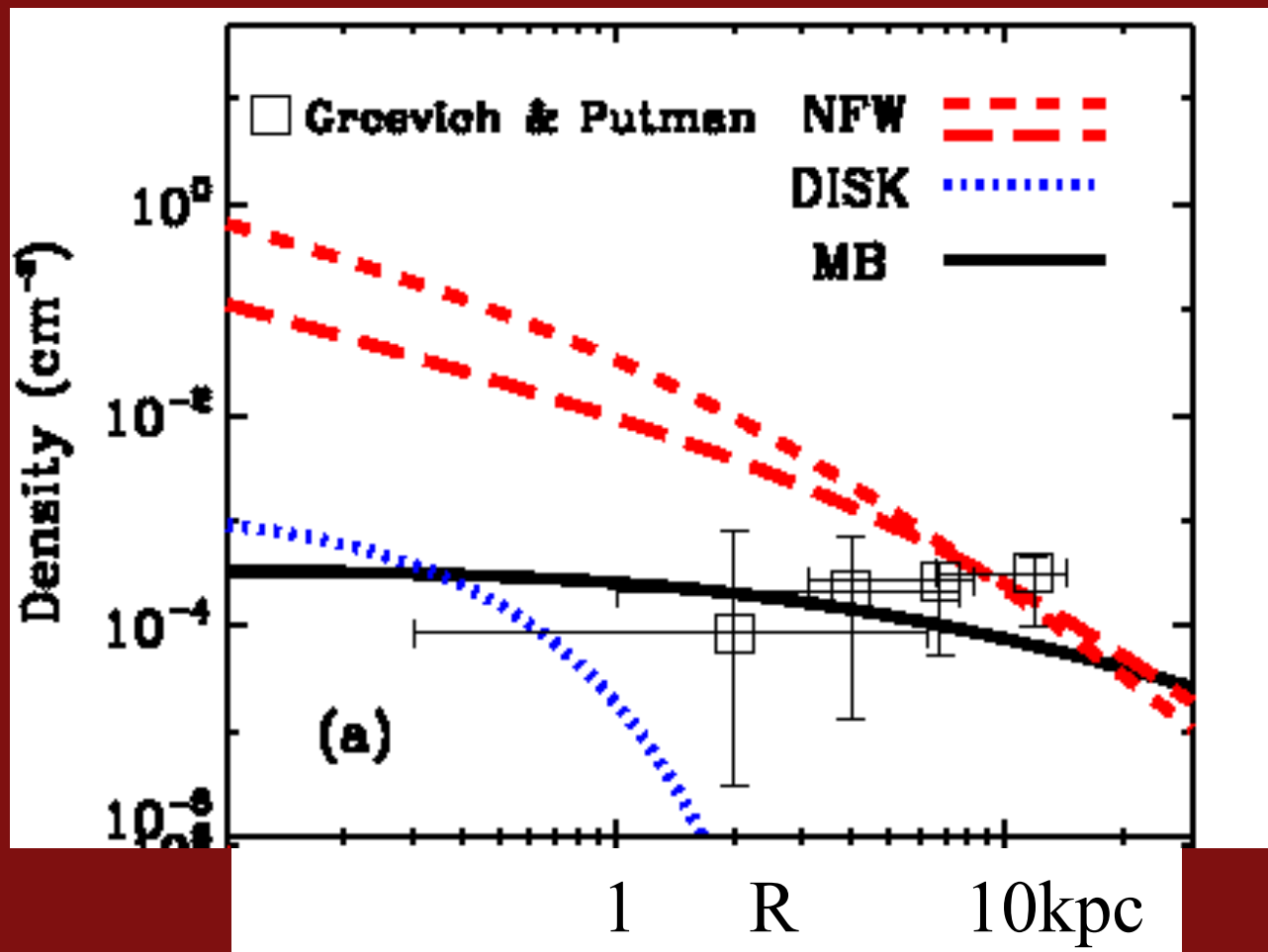
$$M_{\text{total}} > 6.1 \times 10^{10} M_\odot$$

Gupta, Mathur + 2012, 2014, 2016

# Massive, Extended, hot Galactic halo



Courtesy: Chandra presss office

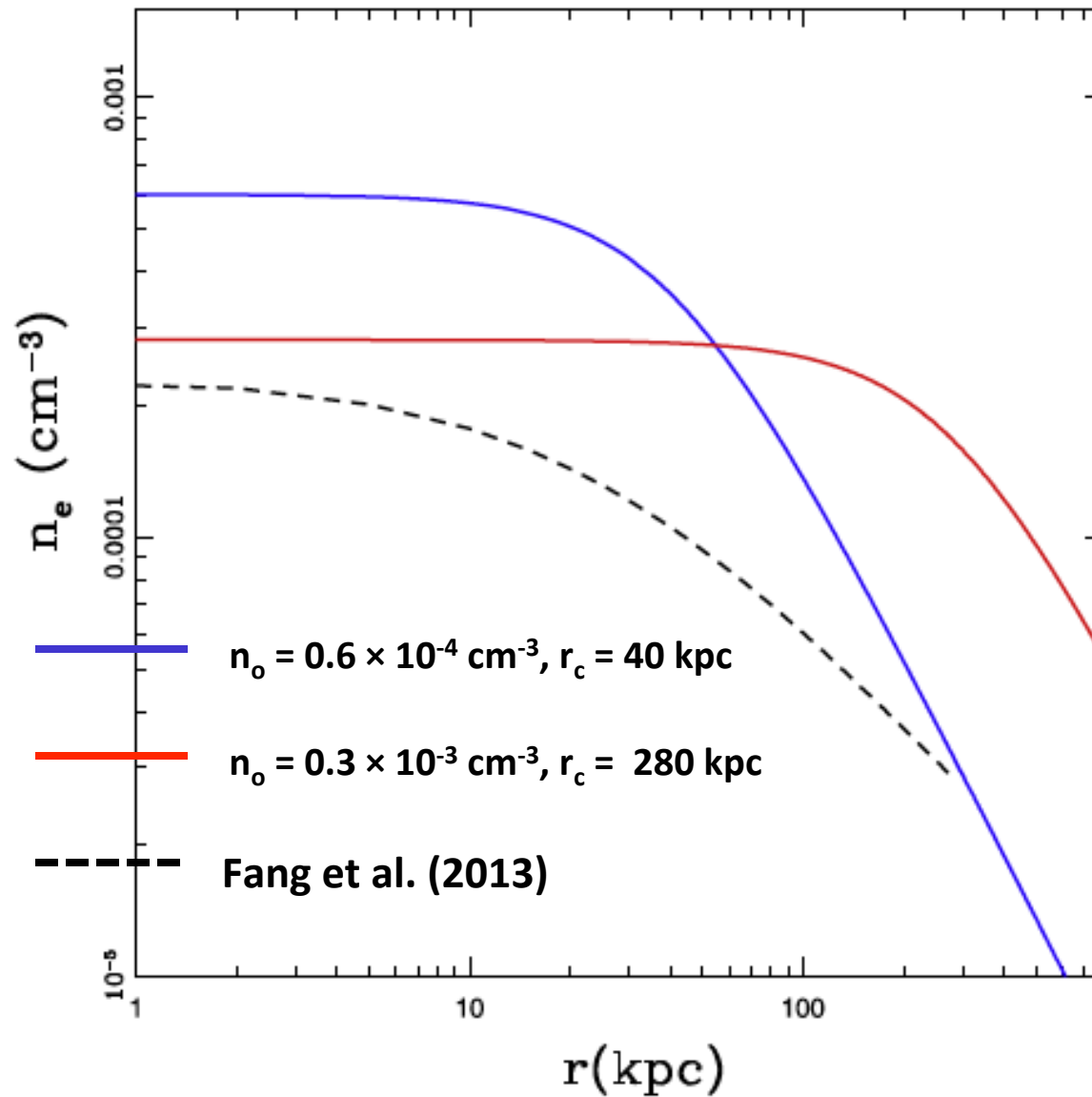


Fang, Bullock +2012

# This is a robust result!

- What about the uniform density profile?  
**No problem: gives a lower limit on mass.**  
 **$\beta$ - Model shows extended profile.**
- Are the emission and absorption at different temperatures? **No.**
- Is the  $z=0$  absorption mostly from the Galactic disk? **No.**

# $\beta$ - Model

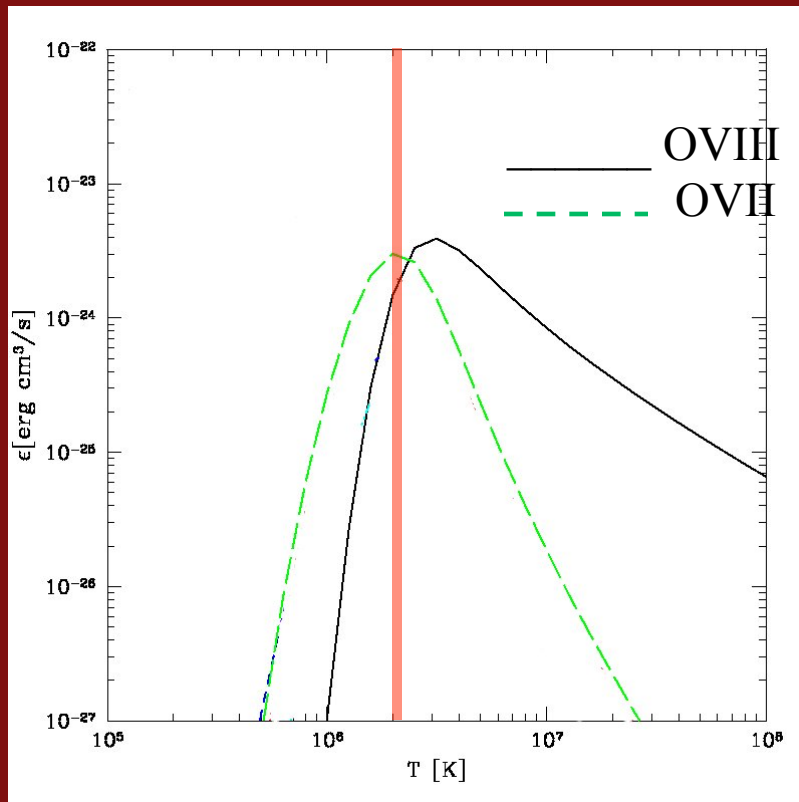




# Combining Absorption and Emission Measurements

Emission Measure  
 $(1.8 \pm 0.9 \pm 0.9) \times 10^{-2} \text{ cm}^{-6} \text{ pc}$

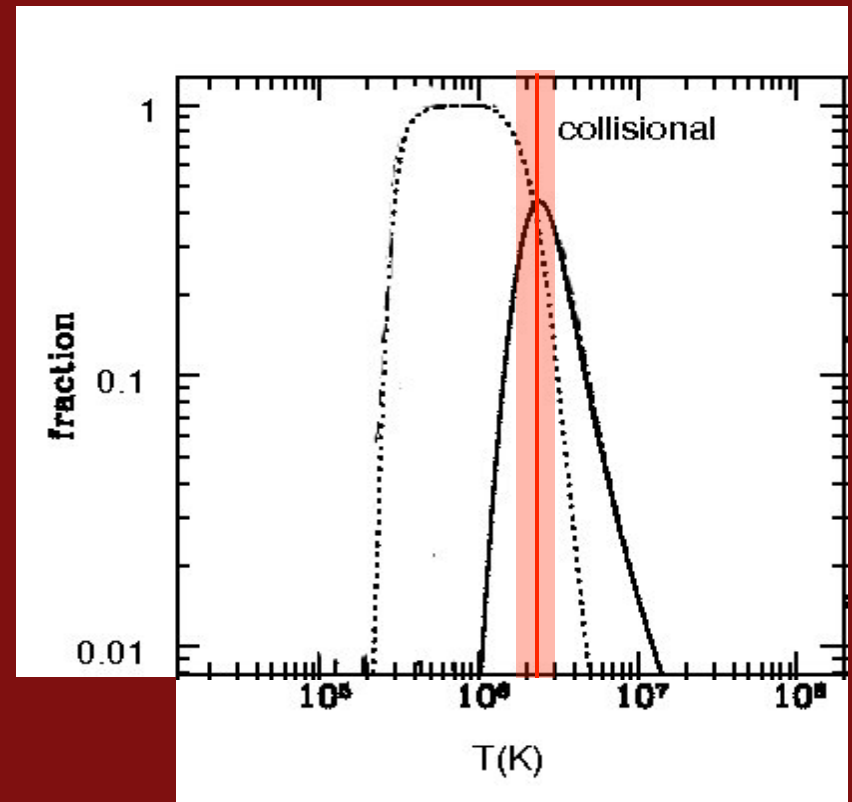
$\text{Log (T/k)} = 6.35 \pm 0.01$



Yoshikawa et al. 2003

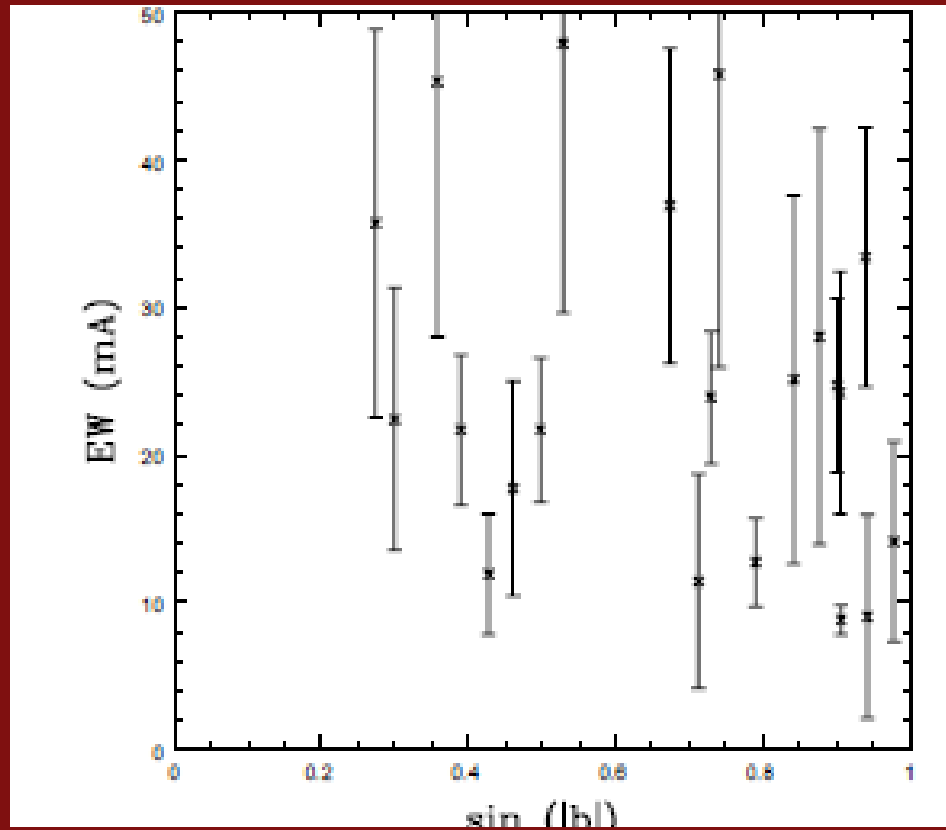
$\text{Log } N_{\text{O VII}} = 16.37 \pm 0.08$   
 $\text{cm}^{-2}$

$\text{Log (T/k)} = 6.33 \pm 0.16$

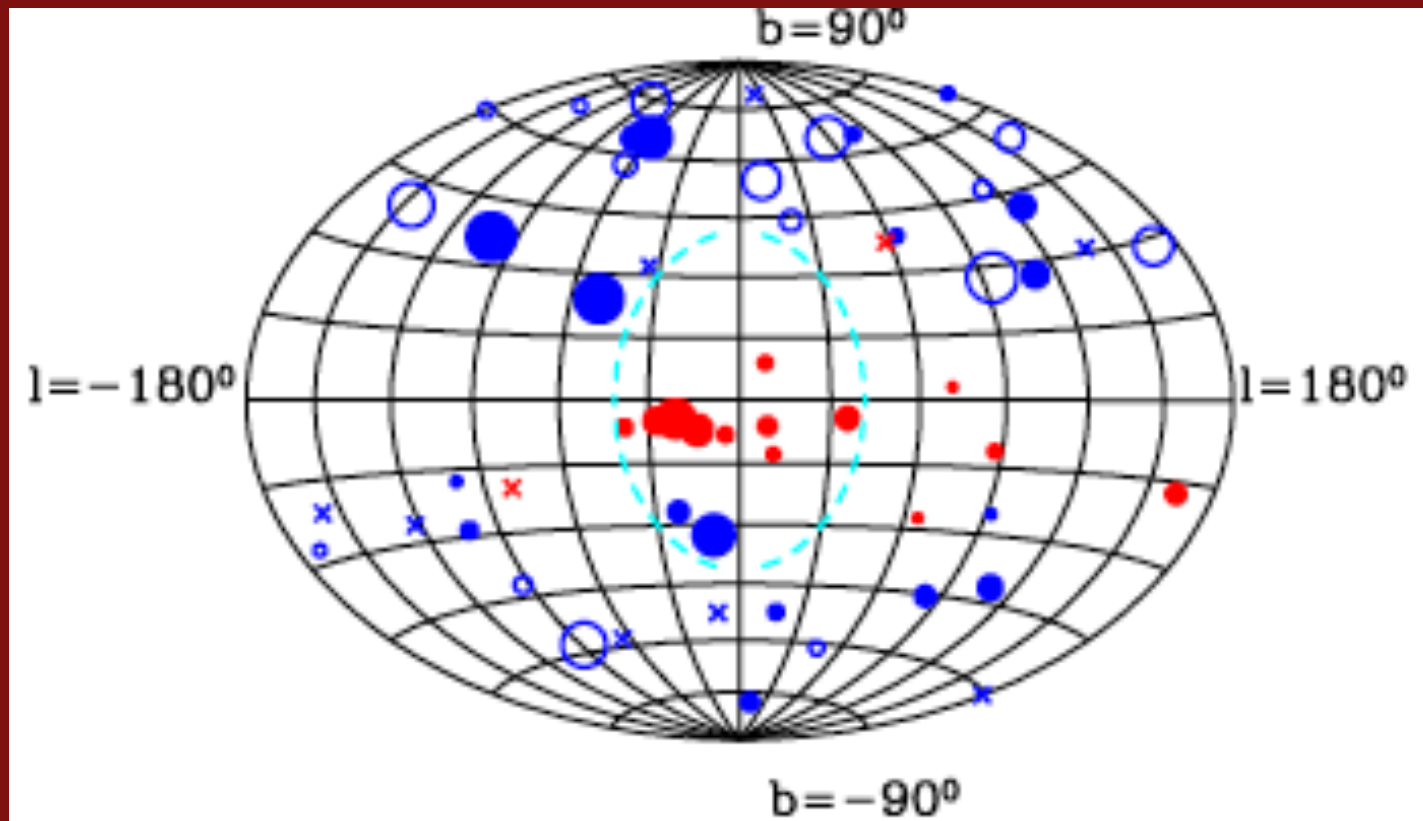


Mathur et al. 2003

..... no anticorrelation between EW and  $\sin(b)$

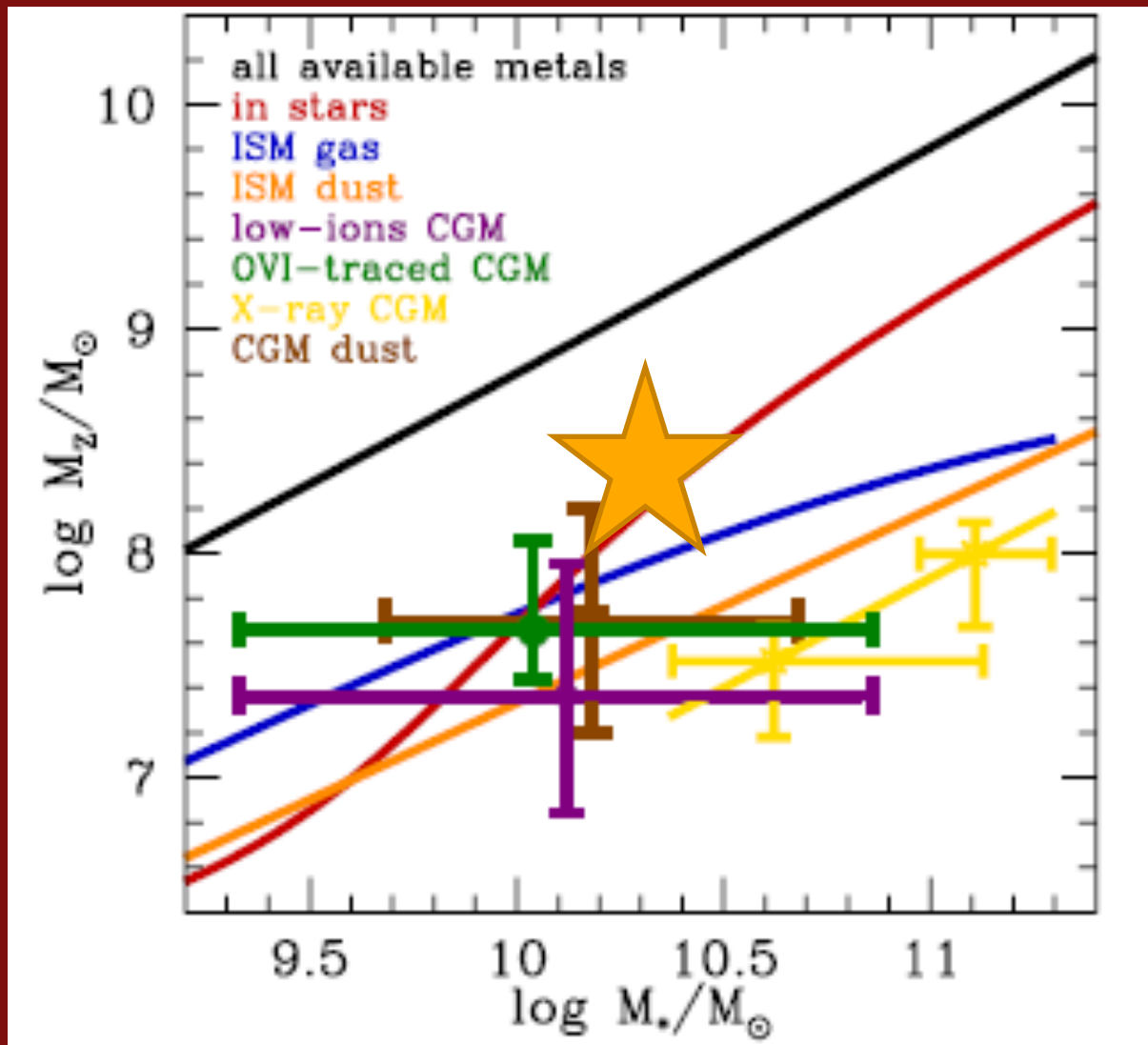


# Galactic and extragalactic sightlines



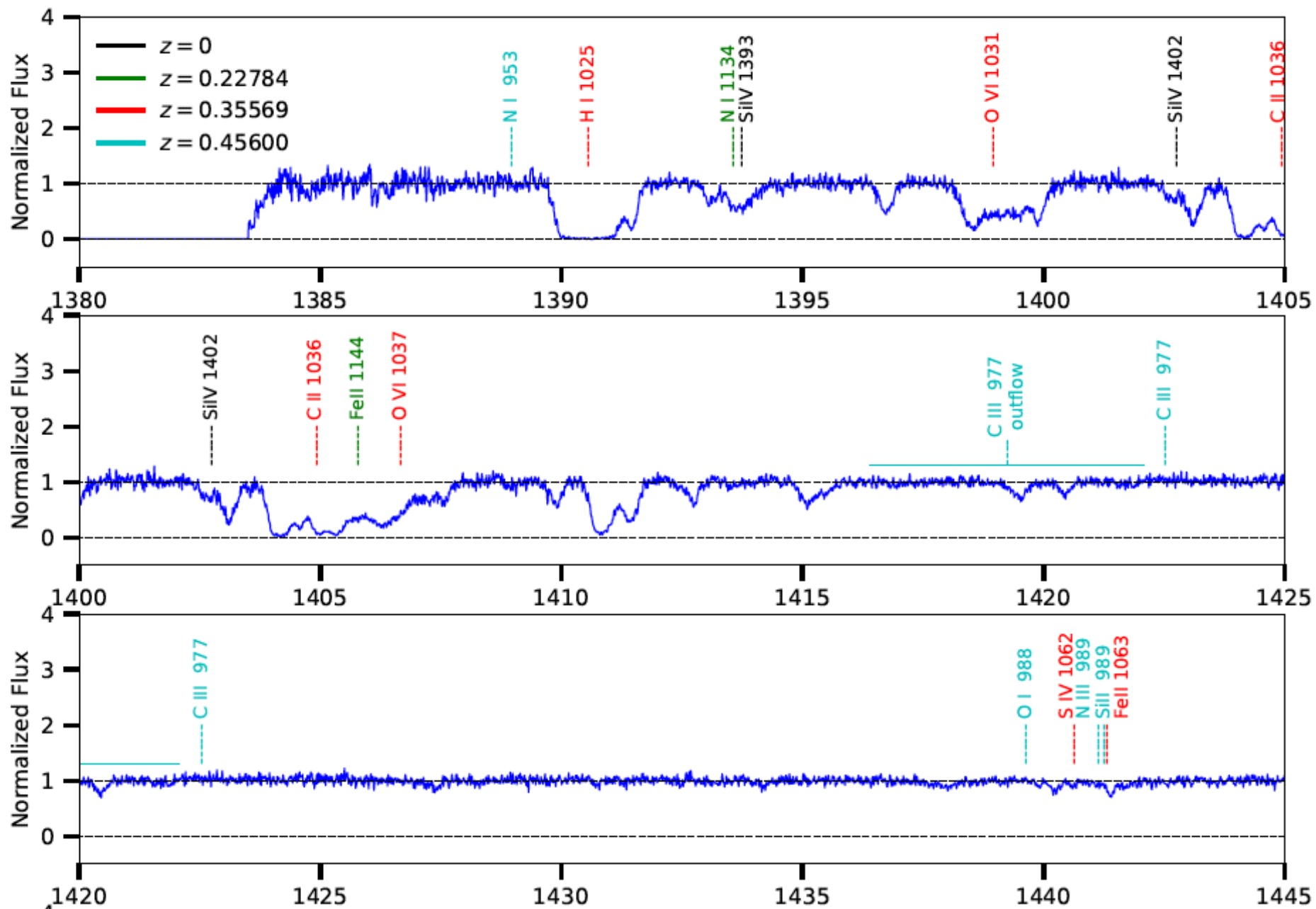
Nicastro et al. 2016

# Adding halo contribution

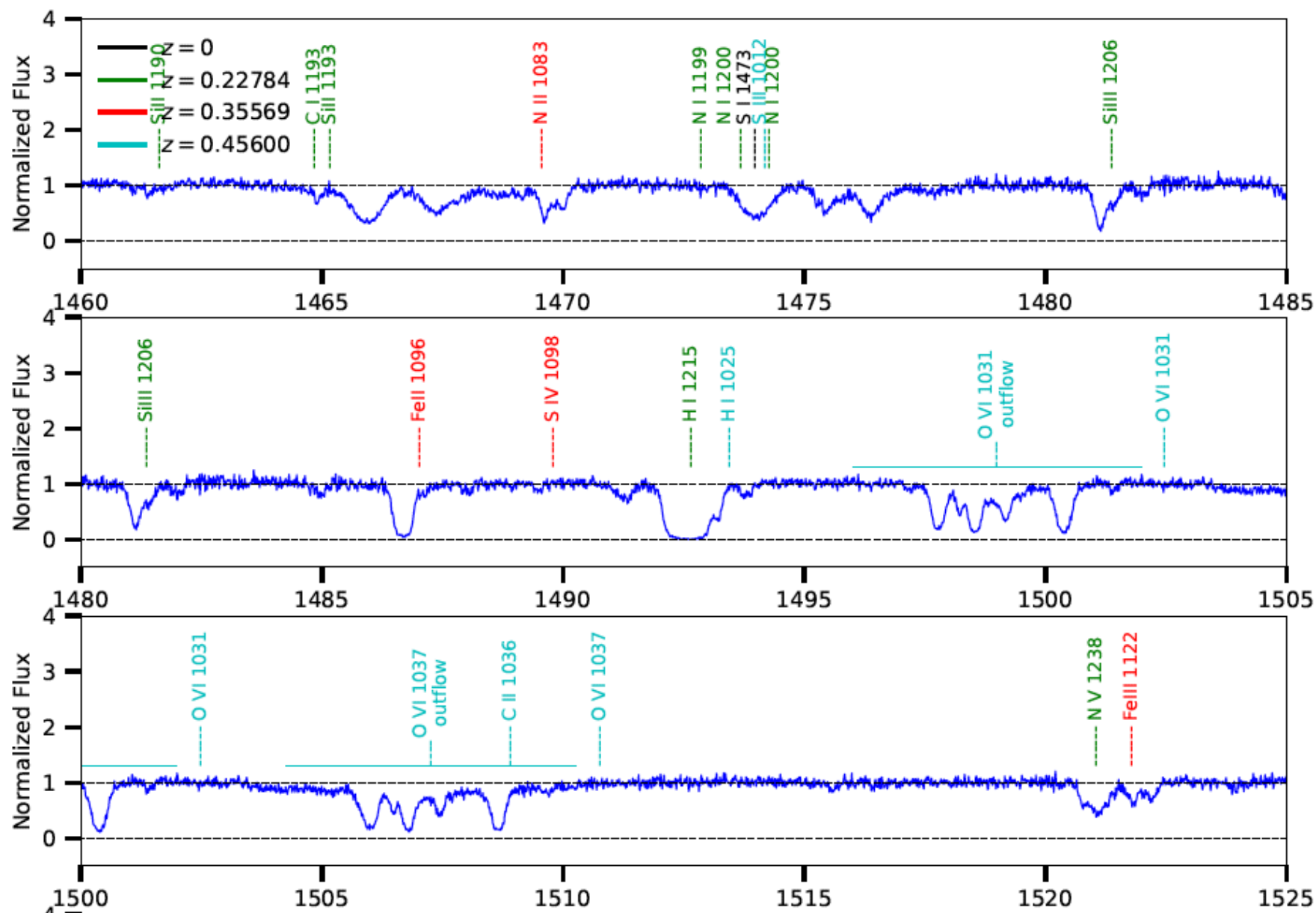


# Current & Future directions

- Probing the anisotropy: emission and absorption along the same sightline.
- Different density and temperature profiles: e.g. Maller-Bullock profile in NFW halo.
- Clumping /filamentary structure
- Probing the multi-phase medium: other ions dominant at different temperatures.
- CGM of external galaxies.





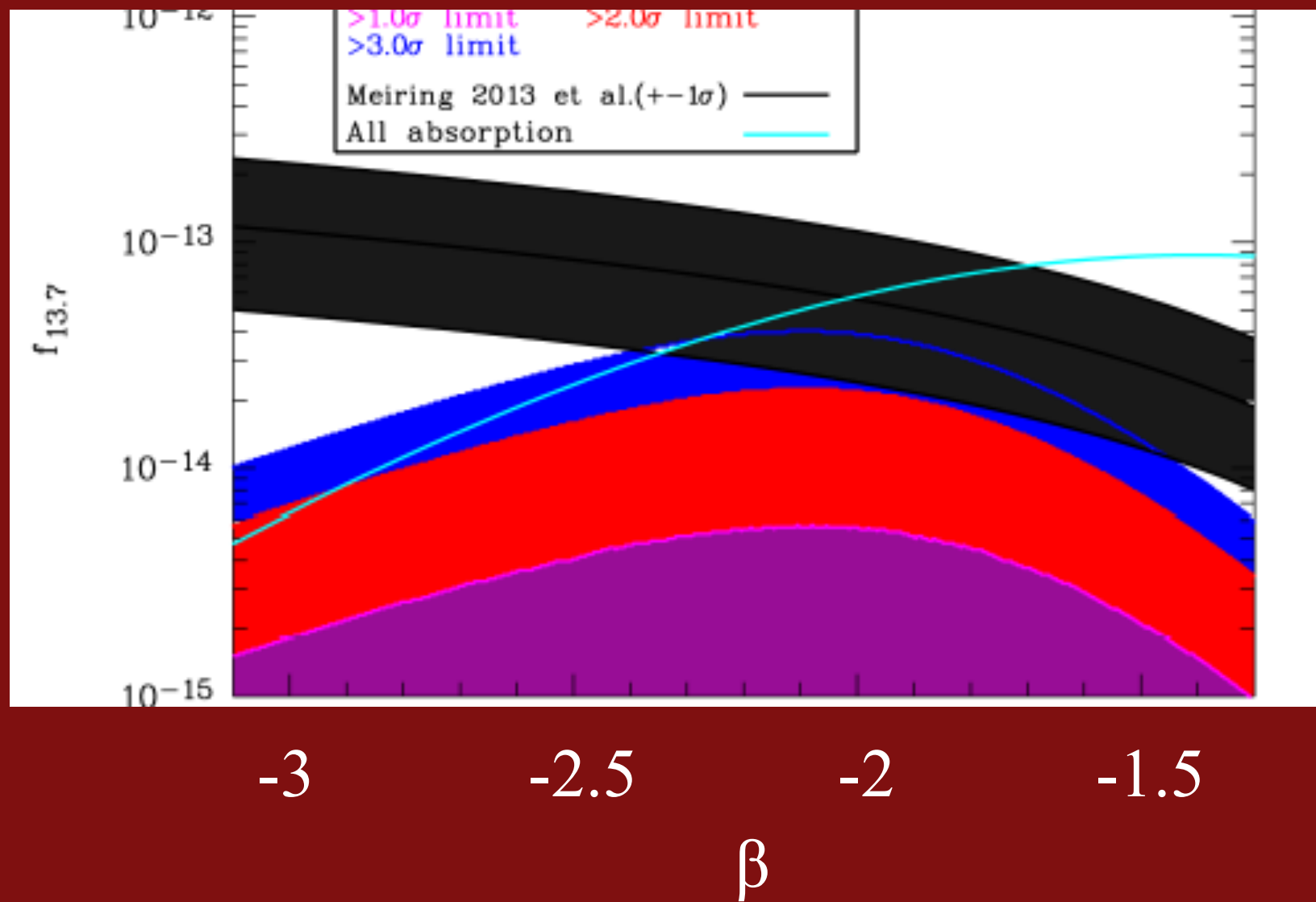


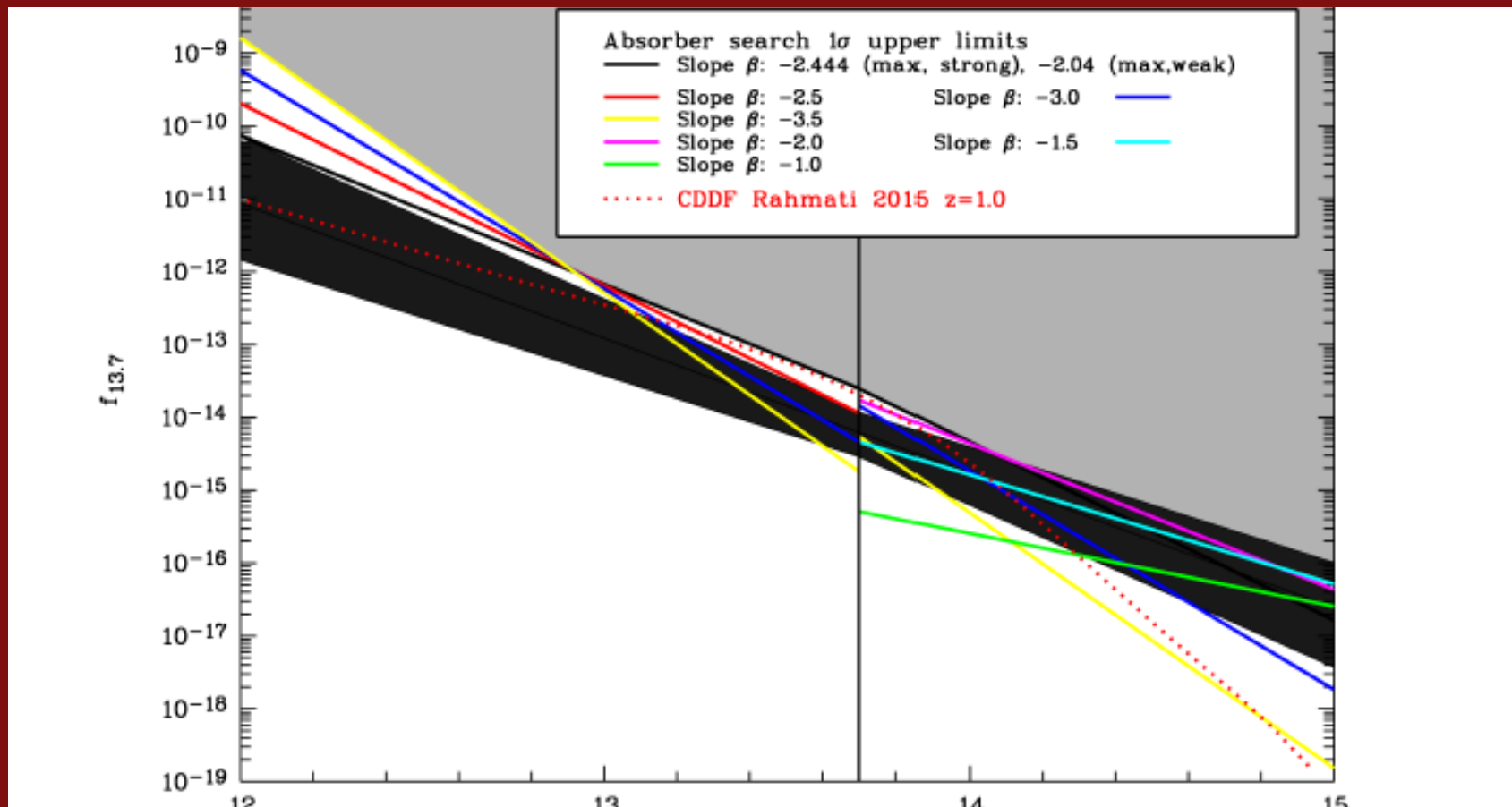
C. Lochhass, Mathur+

# Ne VIII absorbers

- CDDF well fit by a power-law, with well constrained index and normalization
- $dn/dz = 1.4^{+0.9}_{-0.8}$
- $\Omega_b = 4\%$  of total assuming solar metallicity and  $T = 5 \times 10^5$  K.

Frank, Pieri, Mathur, Danforth & Shull, 2018, MNRAS, 476, 1356





12

13

14

15

Log (N (NeVIII))

# Suzaku discovery of hot CGM in a Milky-Way like star-forming galaxy

S. Das, Mathur<sup>+</sup>

Moving beyond finding missing baryons to characterizing the CGM to understand accretion and feedback in galaxy evolution.



Another exciting result coming up on Milky Way CGM.

Chandra cycle 20 time to probe the CGM of a carefully selected galaxy.

Stay tuned...