

Circumgalactic medium of galaxies

Smita Mathur

The Ohio State University

With

Anjali Gupta, Yair Krongold,
Fabrizio Nicastro, M. Galeazzi

Circumgalactic medium (CGM)

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Galactic corona

=

Gaseous halo

Where are the Galactic missing baryons?

Local WHIM filament

scale length > 1 Mpc

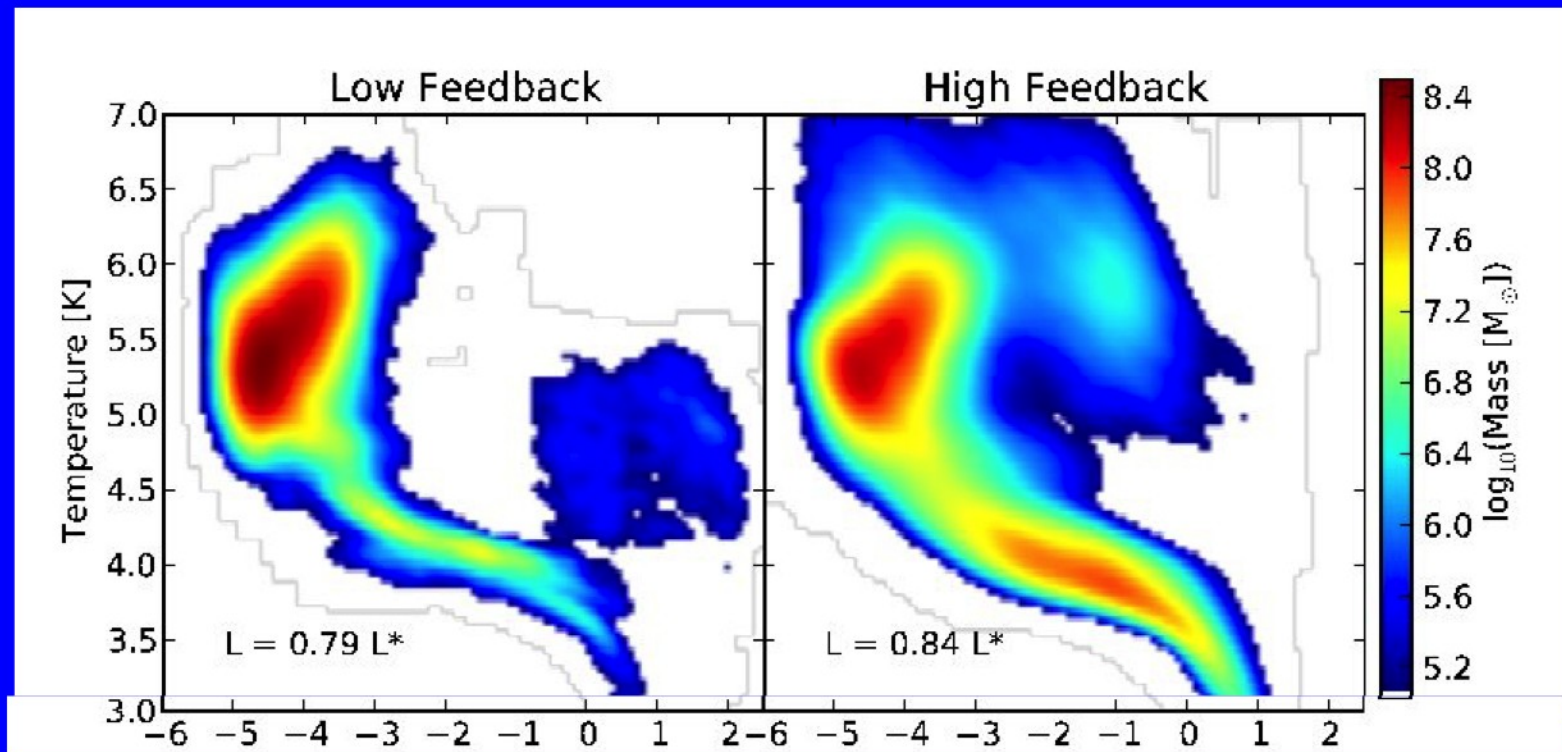
Local Group Medium

scale length of ~ 1 Mpc

Circum Galactic Medium: extending
up to the virial radius (~ 250 kpc)

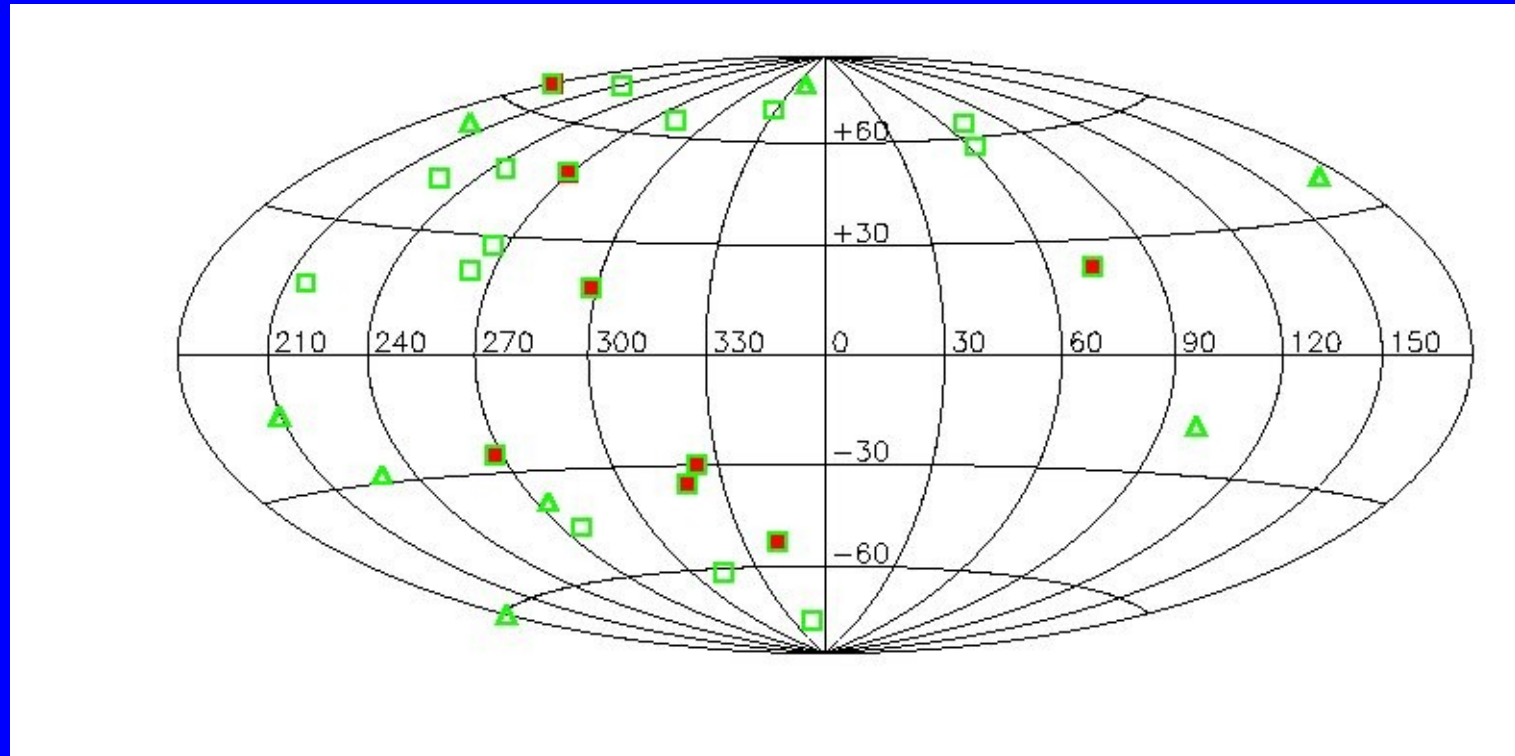
$$10^5 \text{ K} < T < 10^7 \text{ K}$$

Diffuse Warm-hot CGM



Log Density

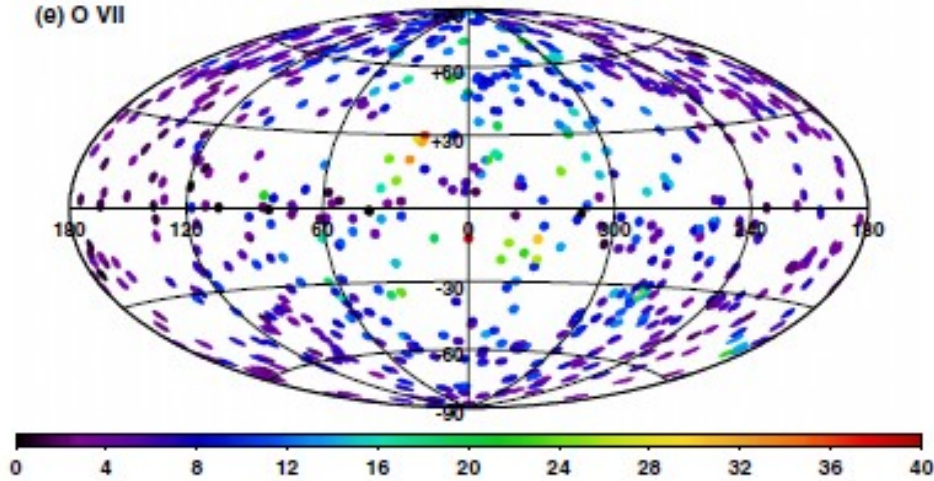
Our Chandra Survey of OVII and OVIII



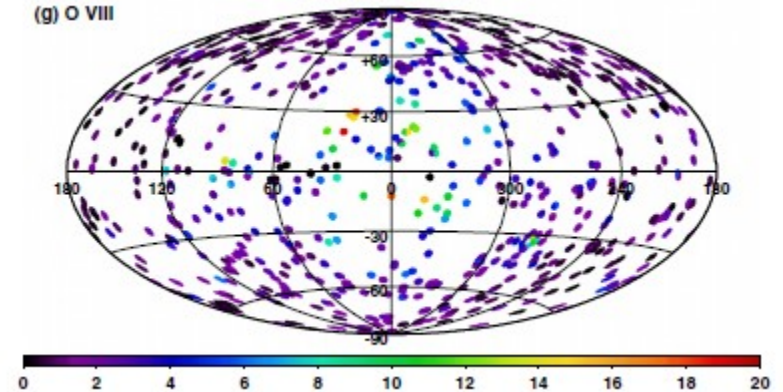
- *29 sight lines with good S/N near OVII $z=0$ region*
- *OVII detection in 21 sight lines*
- *OVIII detection in 8 sight lines*

Galactic Halo Emission

(e) O VII



(g) O VIII



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

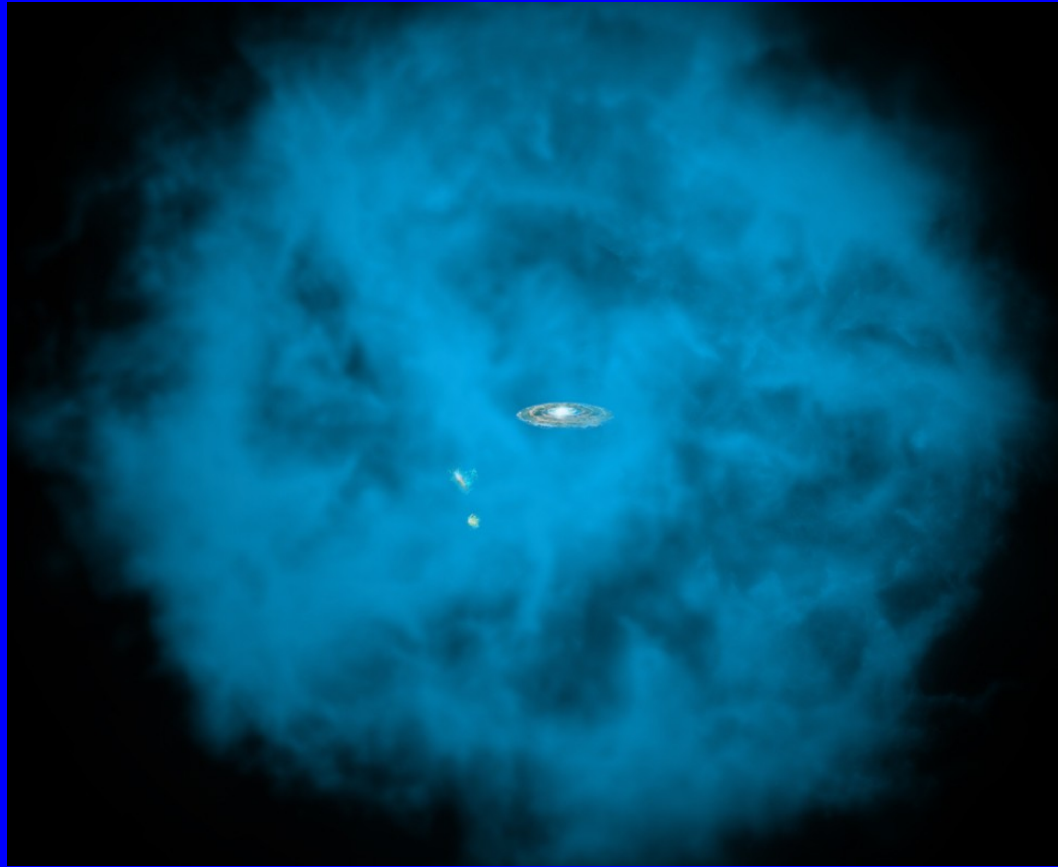
$$\text{For } Z = 0.3Z_{\odot}$$

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

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

Gupta, Mathur + 2012, 2014

Massive, Extended Galactic halo

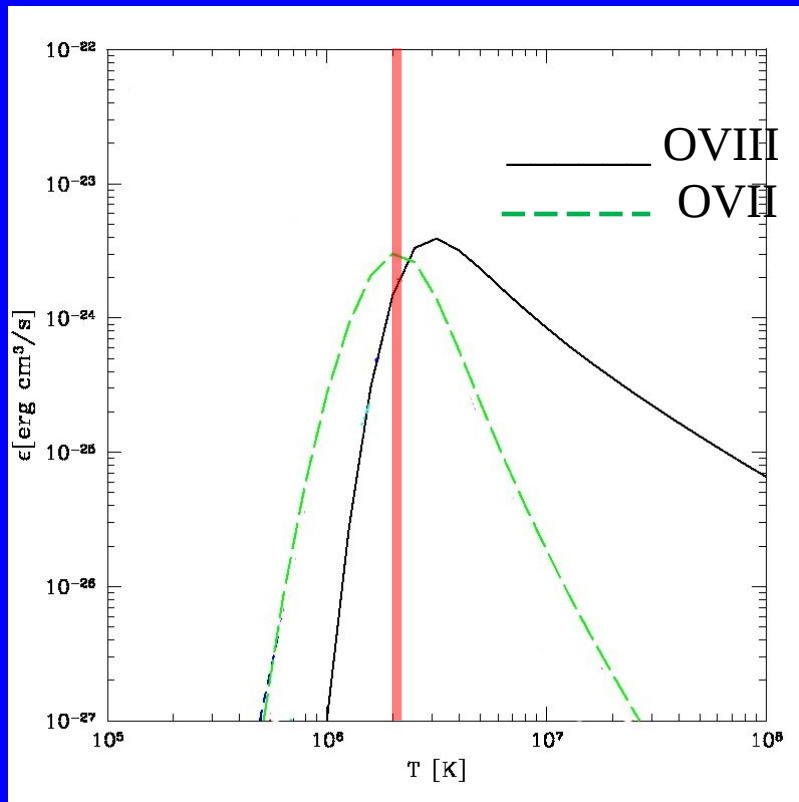


Courtesy: Chandra press office

Combining Absorption and Emission Measurements

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

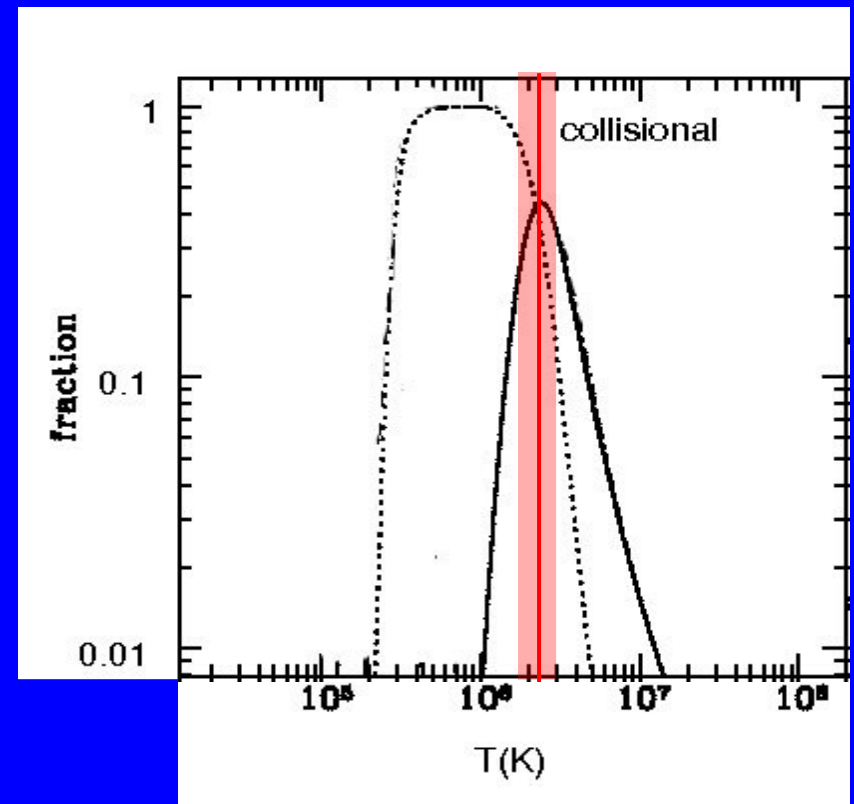
$\text{Log}(T/\text{k}) = 6.35 \pm 0.01$



Yoshikawa et al. 2003

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

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



Mathur et al. 2003

Uniform Density Halo Model

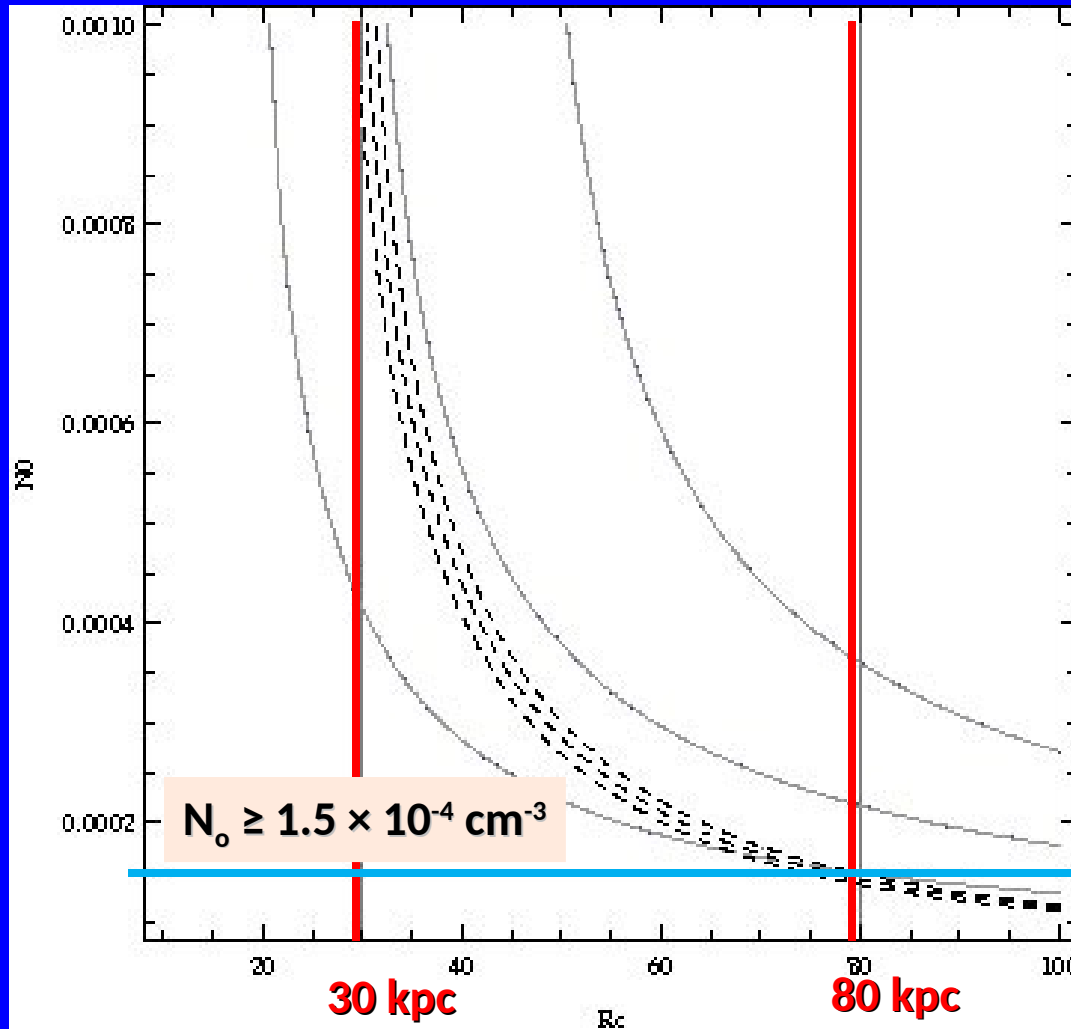
Towards Mrk 509

$$\text{Path-length} = 117^{+48}_{-38} \text{ kpc}$$

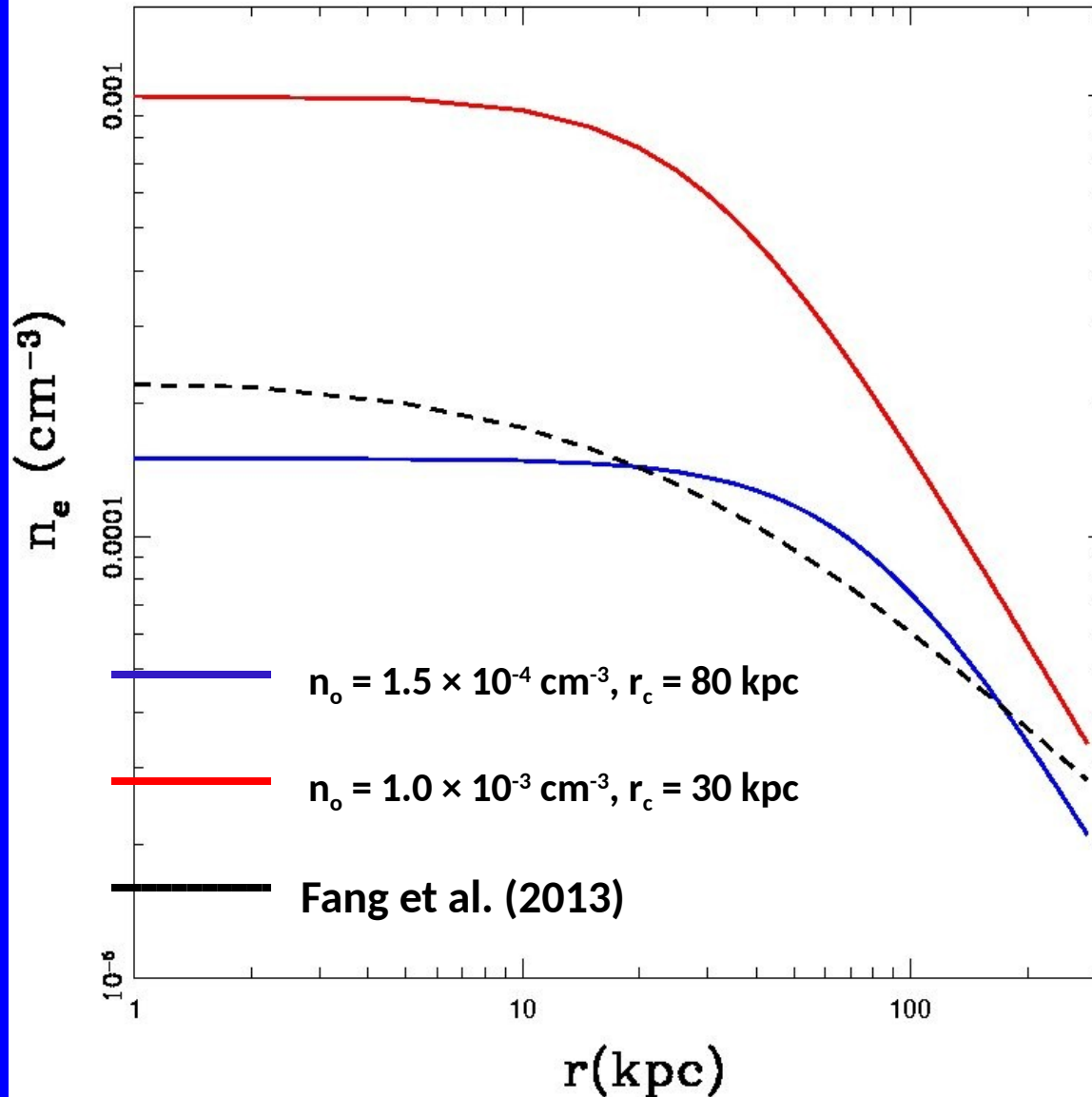
$$\text{Density} = 7.3^{+1.9}_{-1.4} \times 10^{-4} \text{ cm}^{-3}$$

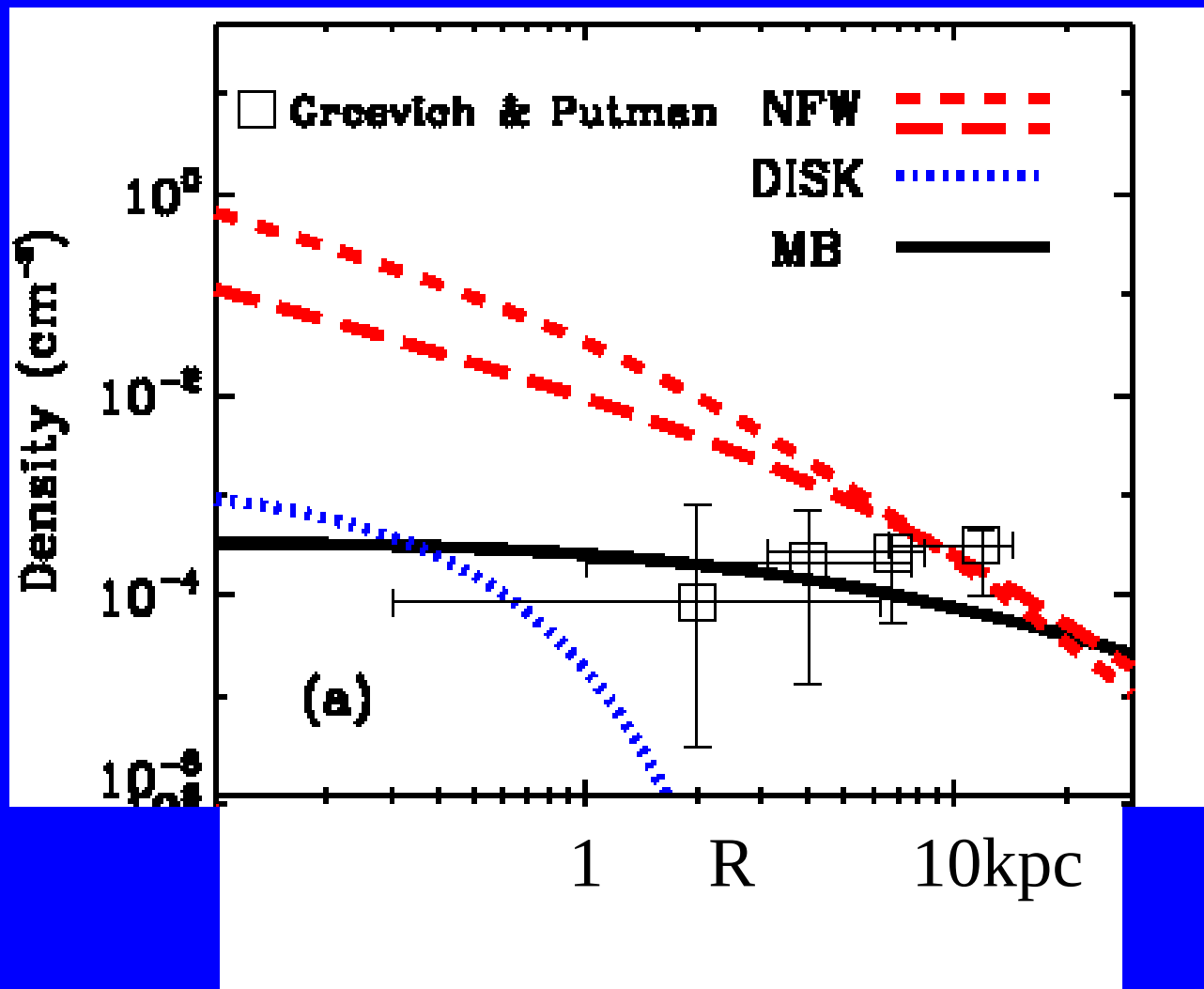
β - Model

$$n(r) = n_o [1 + (r/r_c)]^{-3\beta/2}$$



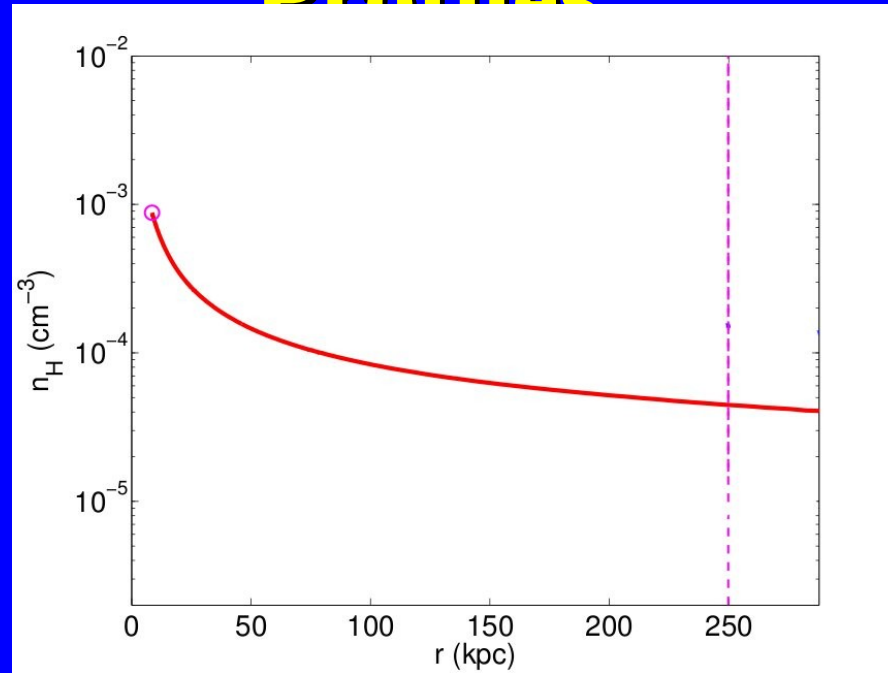
β - Model





Fang, Bullock +2013

Theoretical Models: Density Profiles



Faerman et al. 2016

β - Model

$$n_0 = 0.001 \text{ cm}^{-3} \text{ (assuming)}$$

$$r_c = 30 \text{ kpc}$$

$$M \sim 4.5 \times 10^{10} M_{\odot}$$

$$n_0 = 1.5 \times 10^{-4} \text{ cm}^{-3}$$

$$r_c = 80 \text{ kpc}$$

$$M \sim 2.4 \times 10^{10} M_{\odot}$$

This is a robust result!

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

Investment of Chandra time

0

Future directions

- Probing the anisotropy: emission and absorption along the same sightline.
 - New Suzaku observations (**Done!**)
 - New XMM-Newton Observations (**Done!**)
- Different density and temperature profiles: e.g. Maller-Bullock profile in NFW halo.
- Probing the multi-phase medium: other ions dominant at different temperatures.

Ultimate goal is to inform the galaxy formation and evolution models with constraints from observations.

Is the CGM in hydrostatic equilibrium in the galactic dark matter halo?

(halo mass two or three orders of magnitude below clusters of galaxies)

CGM science in the next decade

- Probe external galaxies
- Theoretical models suggest that CGM properties are $f(\text{galaxy total mass, stellar mass, star formation rate, specific star formation rate, feedback})$.

This field belongs to X-rays.
And it is doable with Chandra!

CGM/IGM Science is one of the major rationales behind Athena and we must gear up to it in the next decade with Chandra & XMM.

Proposal

- Key projects on “Quasar intervening absorption lines”
- Probe CGM of galaxies + (WHIM ?)
- Maximum return with preselected range of galaxy types.
- 1Ms per cycle investment.

Conclusion

- X-rays provides evidence for hot ($T > 10^6$ K) gas in and around the Milky Way.
- OVII and O VIII probed gas is extended to over 100 kpc.
- The mass content of this phase is over $10^{10} M_{\odot}$.
- A large fraction of Galactic missing baryons are in this hot phase.
- Appears to be a robust result supported by theoretical models.
- Metals are perhaps preferentially expelled from galaxies.