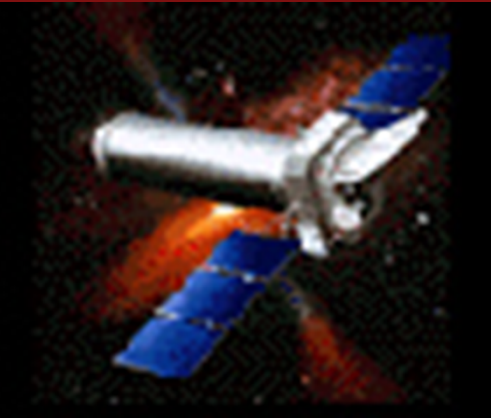


The Warm-hot halo of galaxies



Smita Mathur

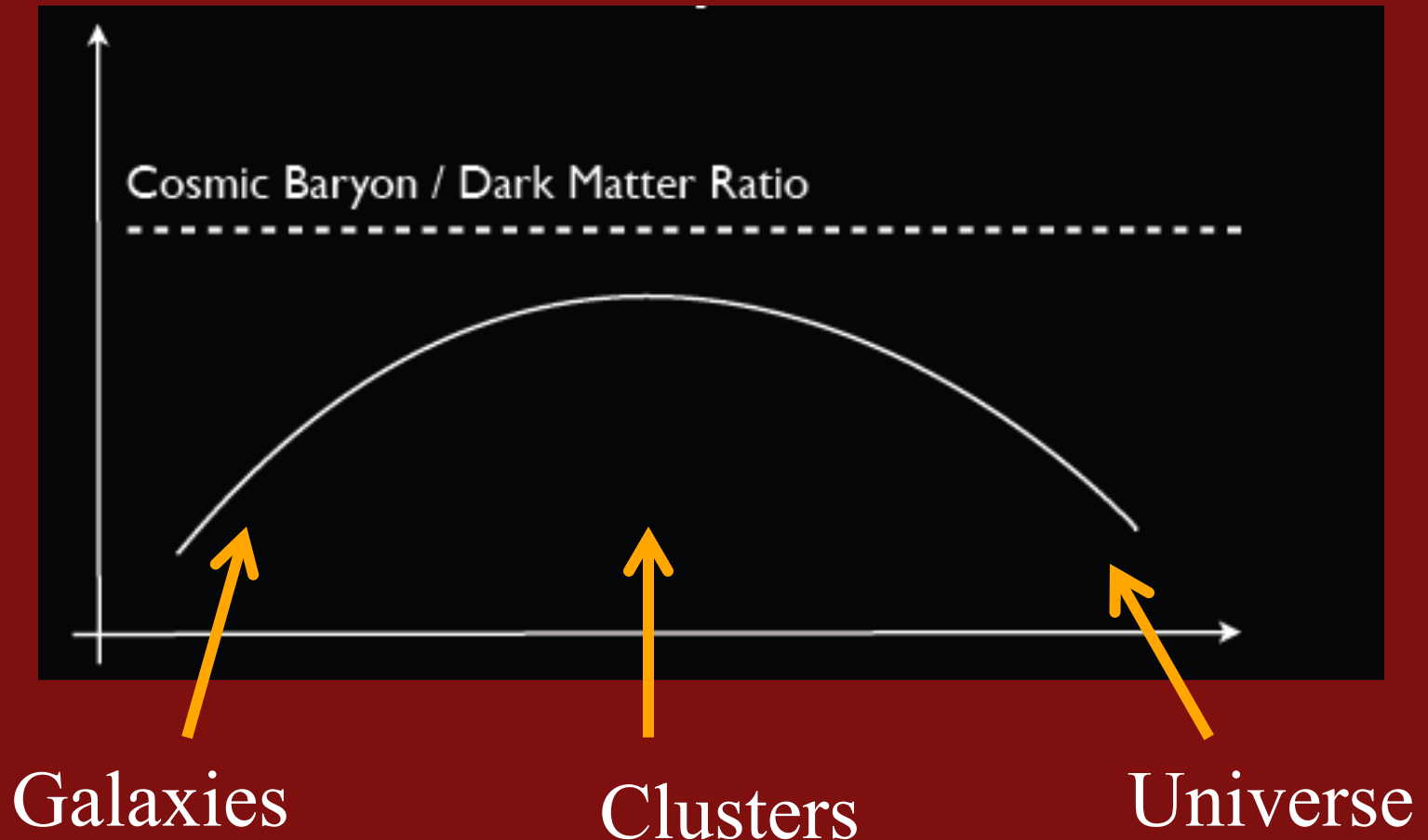
The Ohio State University

With

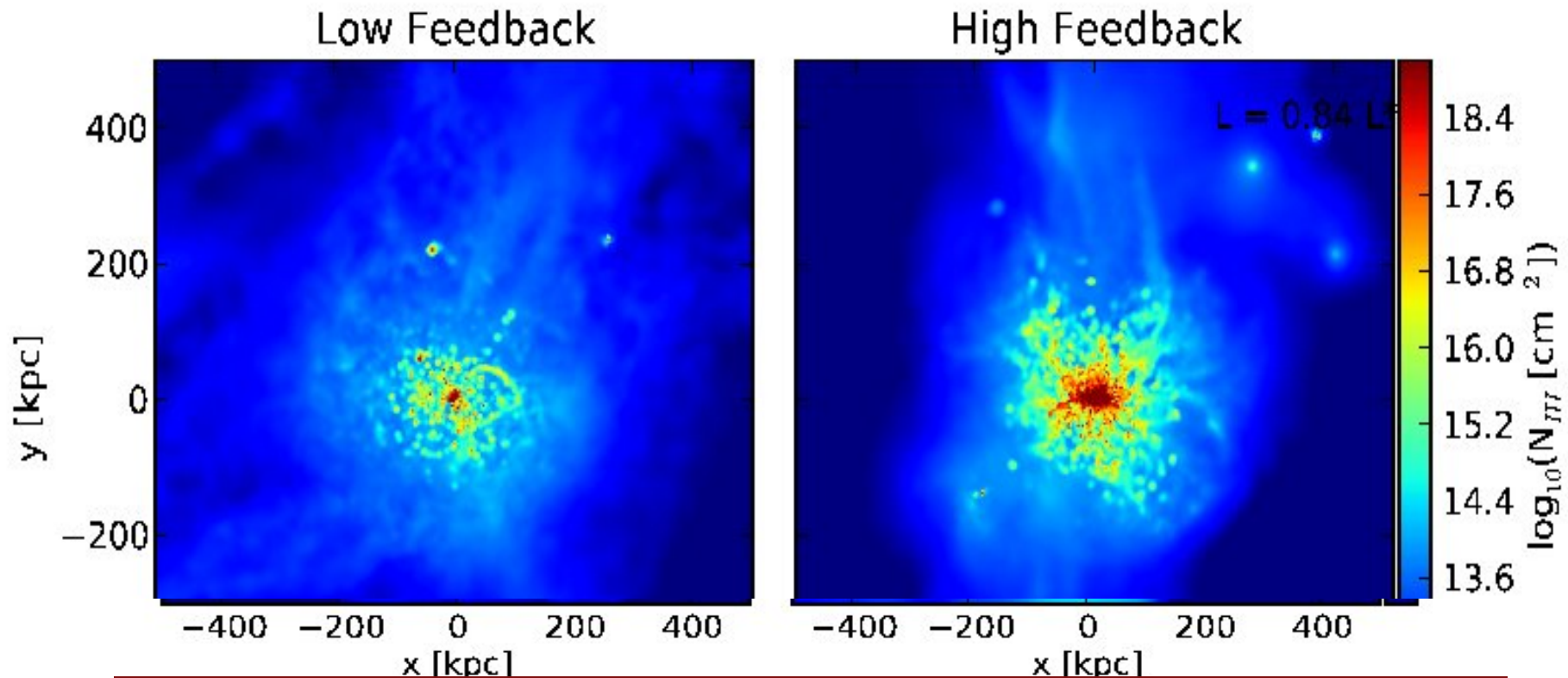
A. Gupta, Y. Krongold,

F. Nicastro, S. Das

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

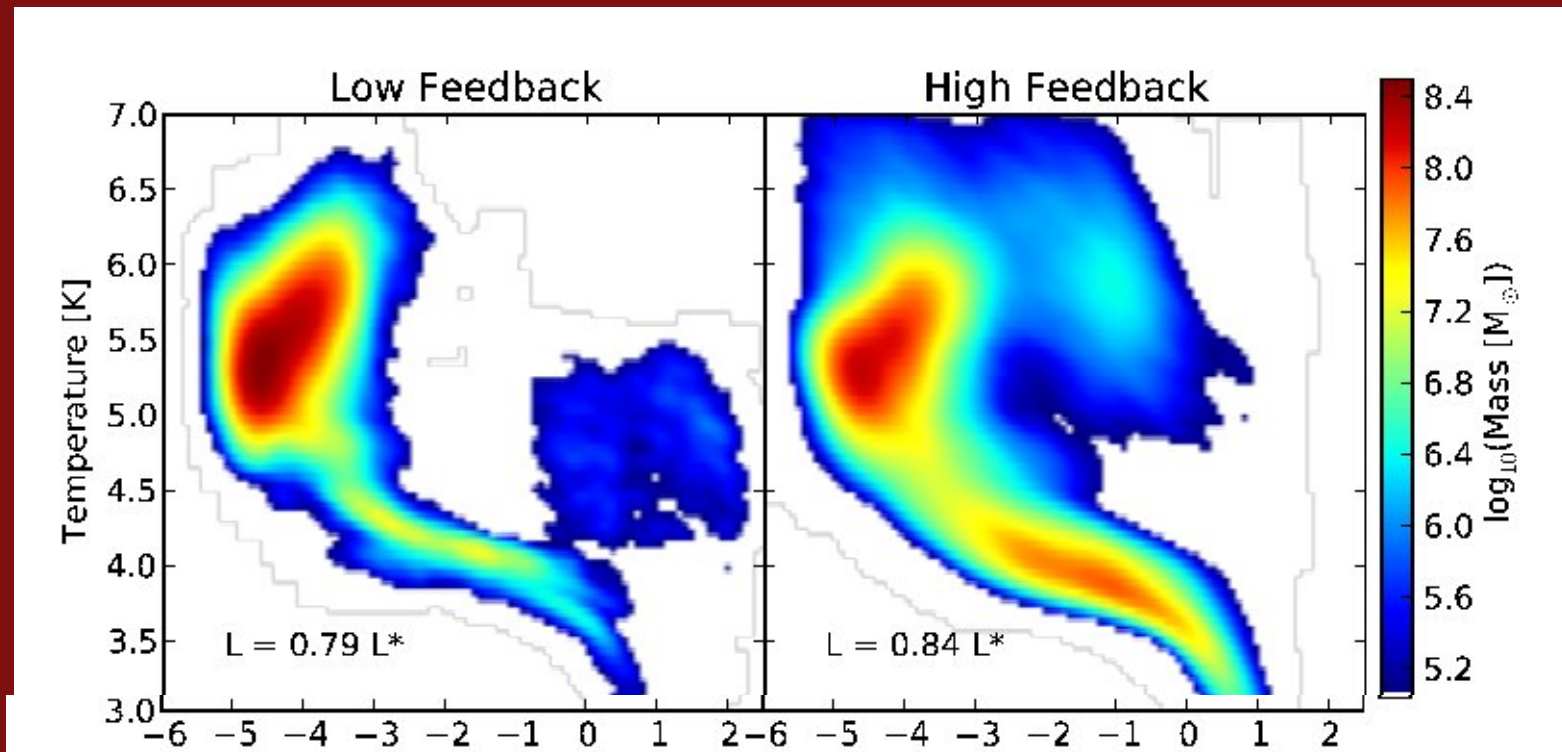


Simulations of the CGM



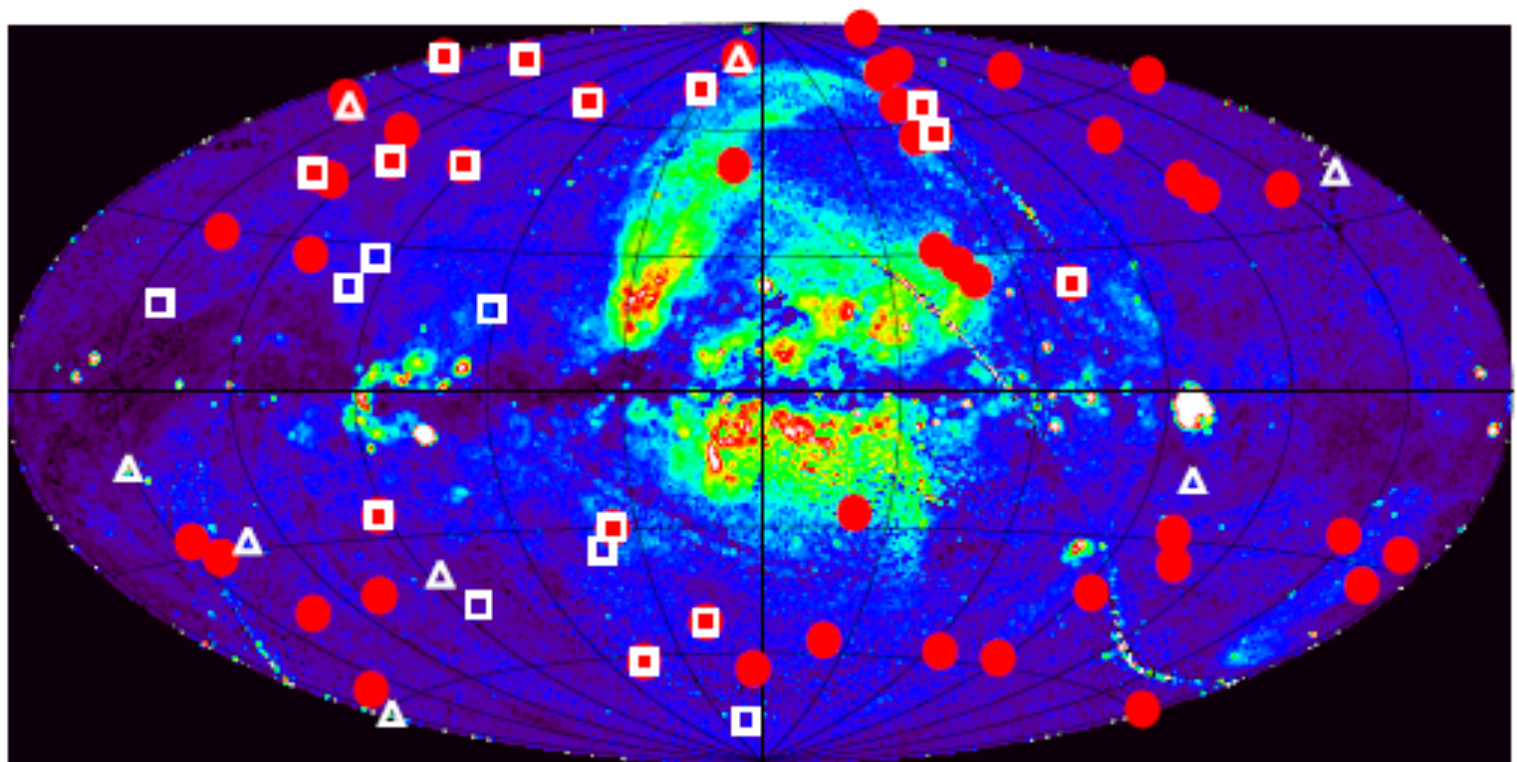
Stinson et al. 2011

Diffuse Warm-hot CGM

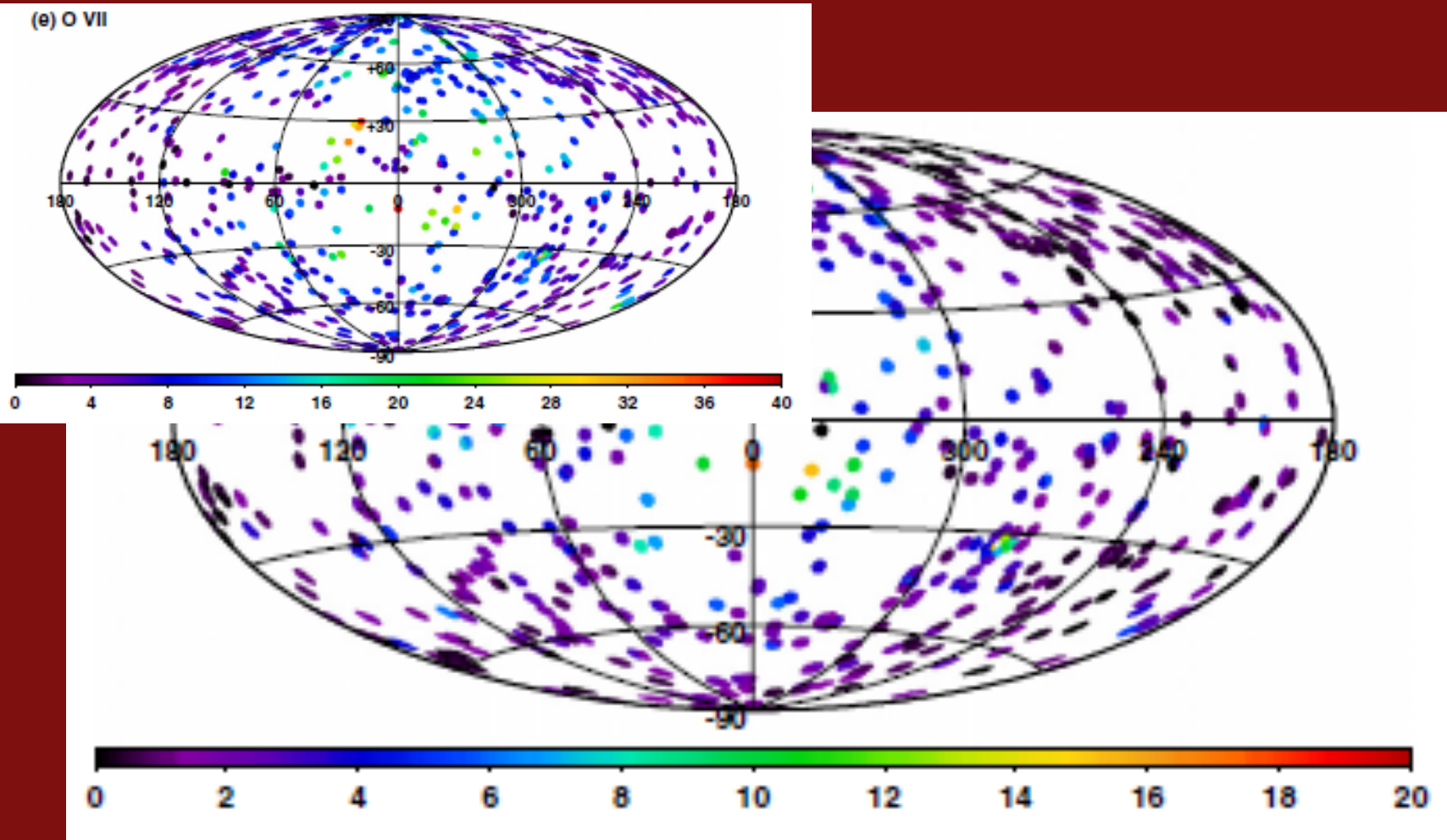


Log Density

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



Galactic Halo Emission



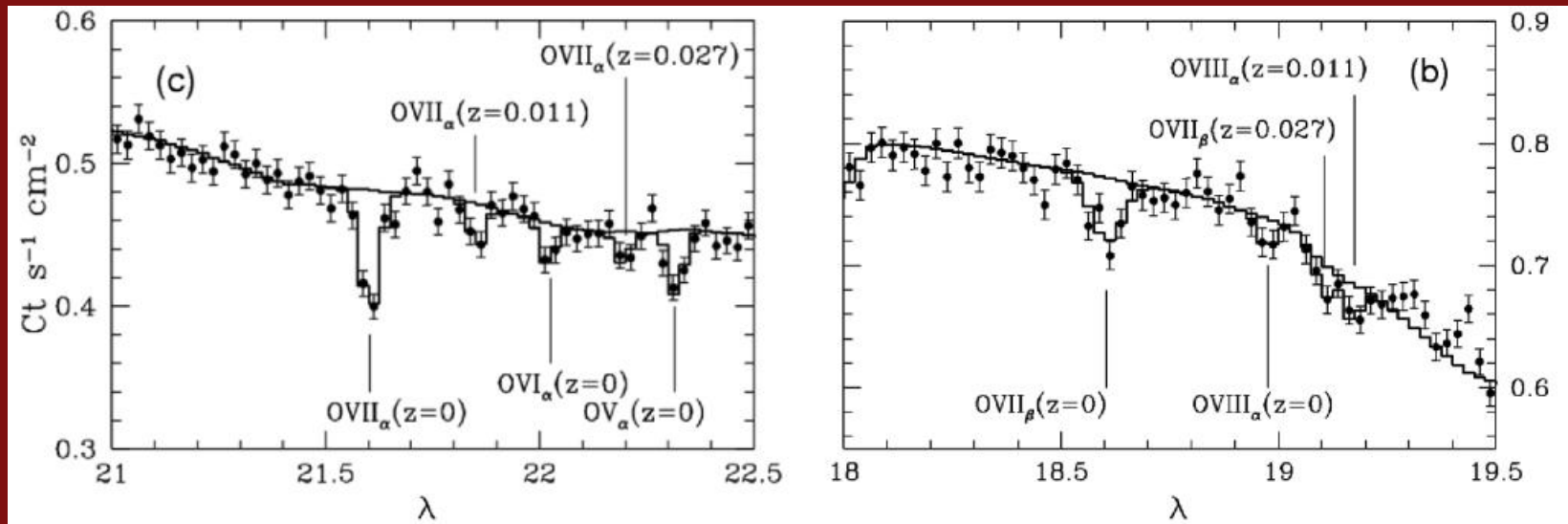
Emission studies measure:

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

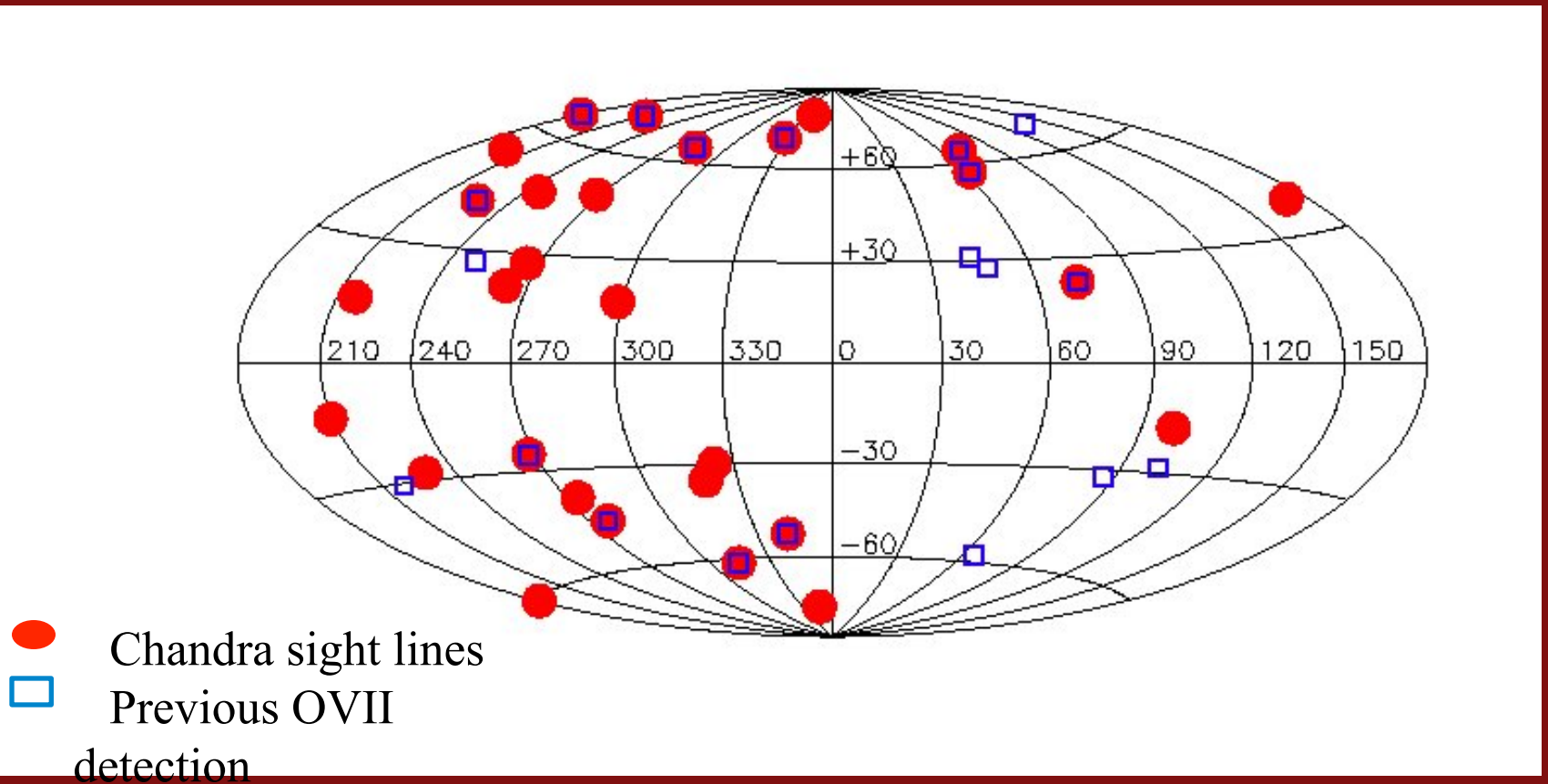
Absorption line studies measure:

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

Z=0 X-ray absorption



Our Chandra Survey of OVII and OVIII



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

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

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

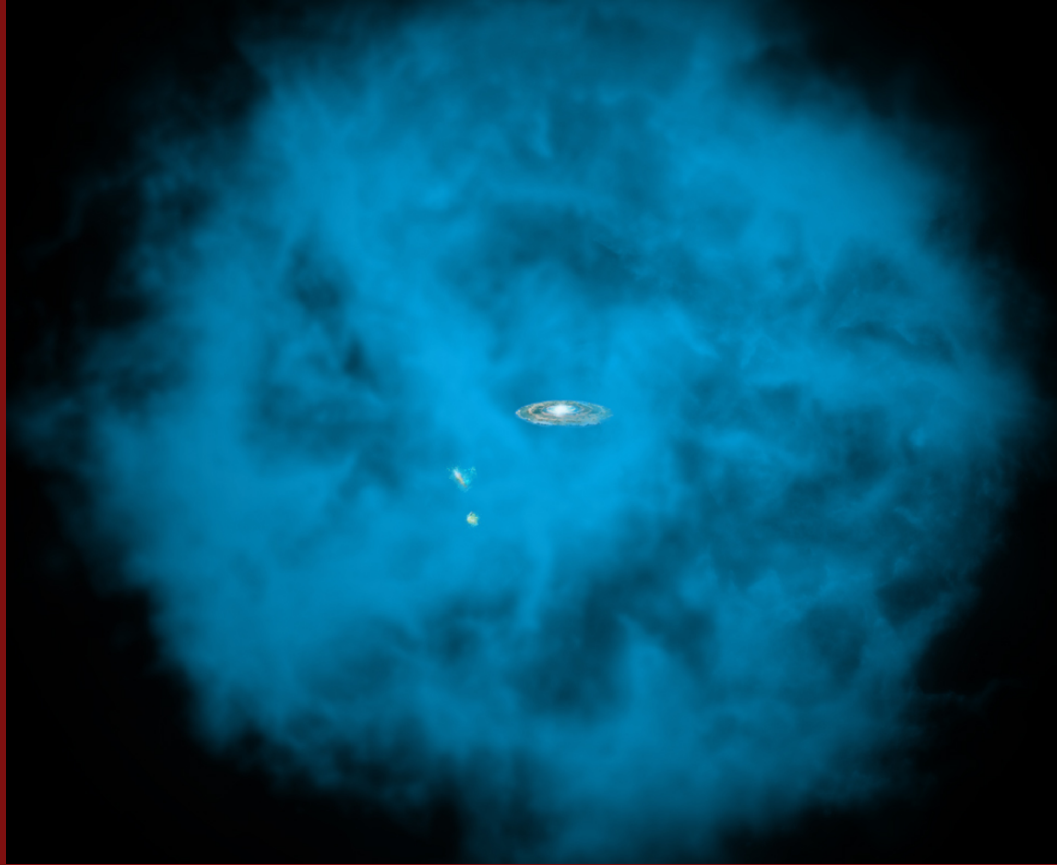
$$\textit{For } Z = 0.3Z_{\odot}$$

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

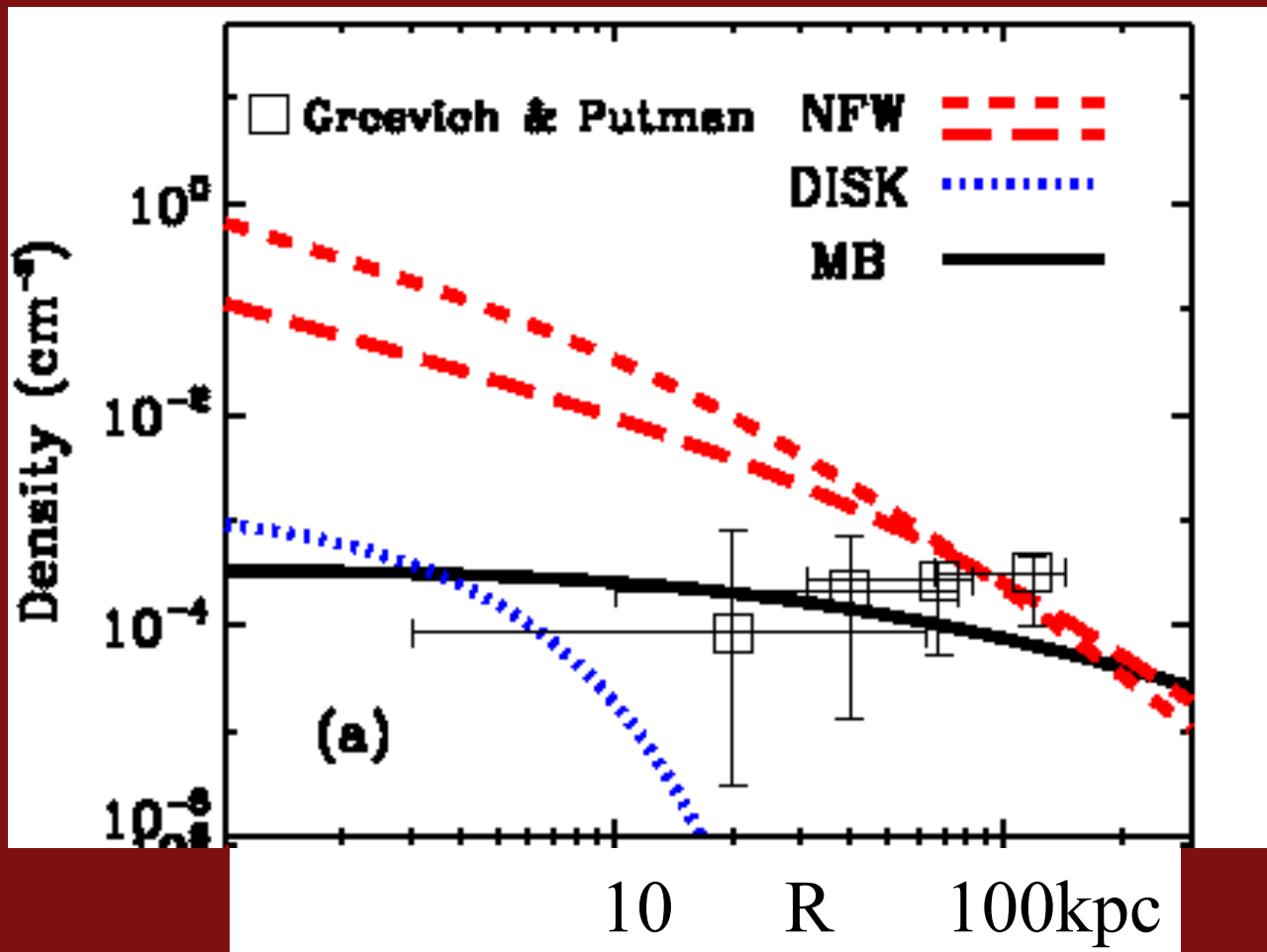
$$\textit{M}_{\text{total}} > 6.1 \times 10^{10} M_{\odot}$$

Gupta, Mathur + 2012, 2014, 2016

Massive, Extended, hot Galactic halo



Courtesy: Chandra press office

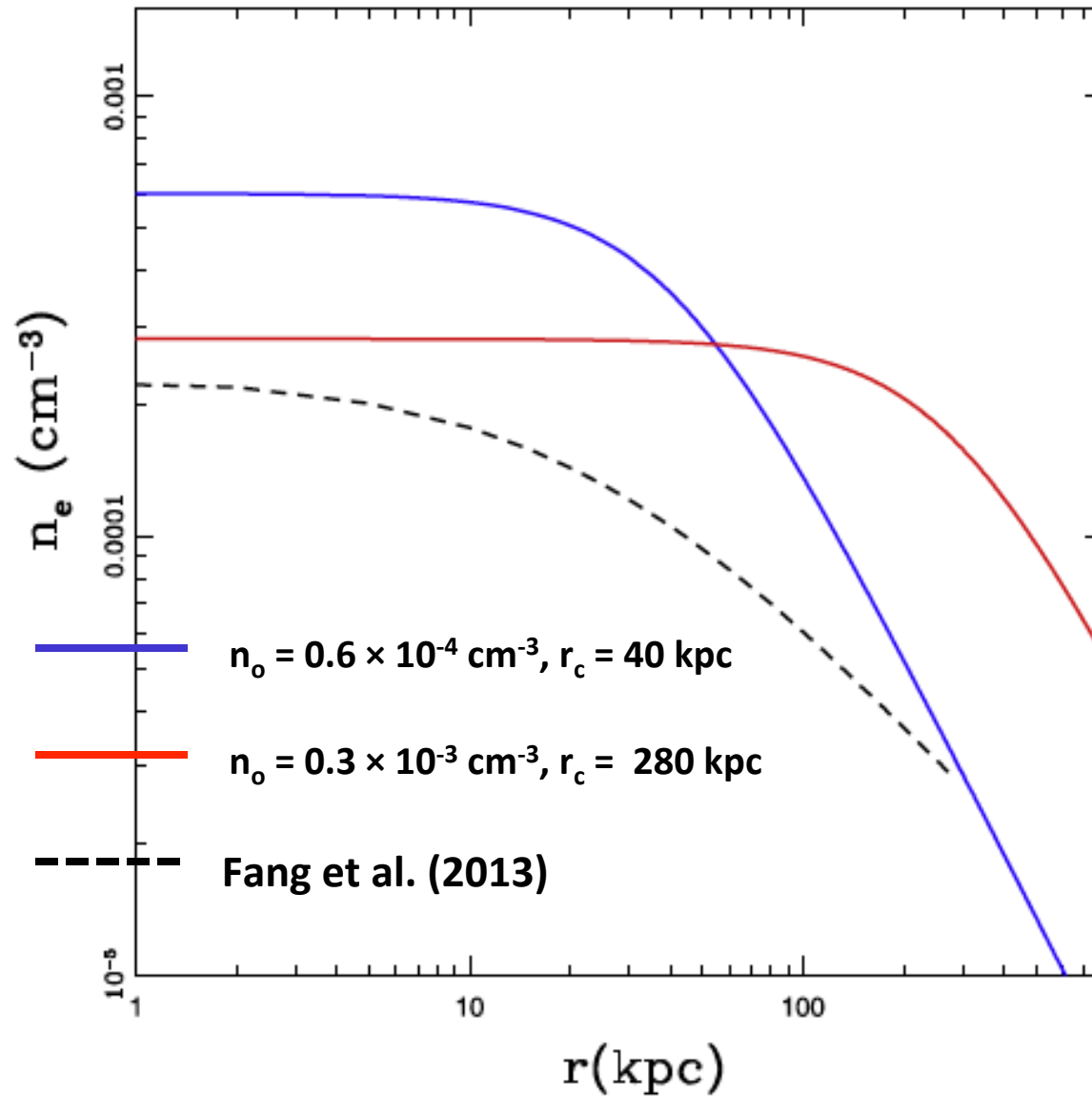


Fang, Bullock +2012

This is a robust result!

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

β - Model



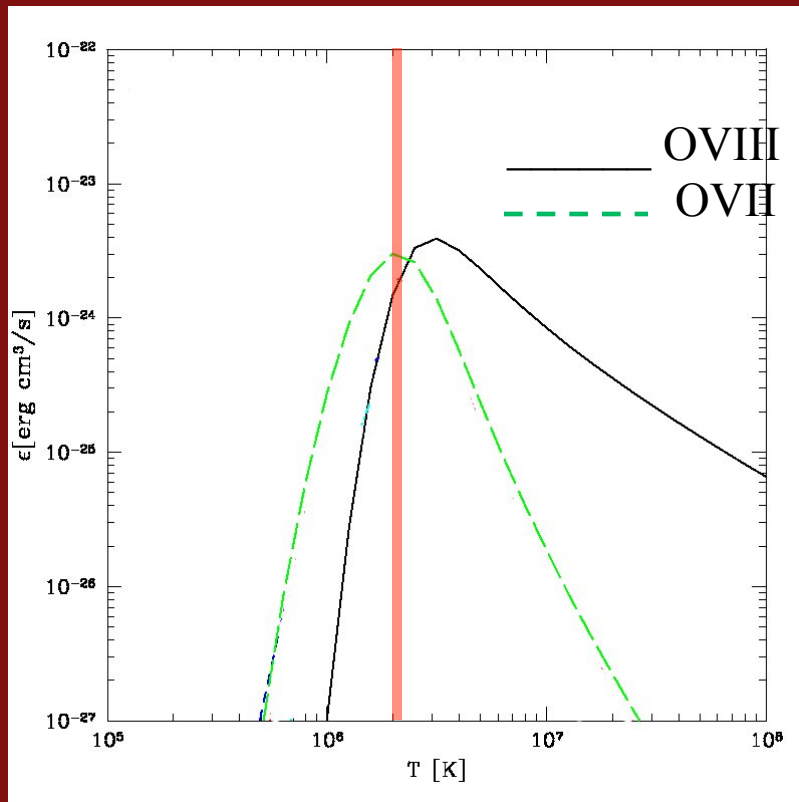
Combining Absorption and Emission Measurements

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

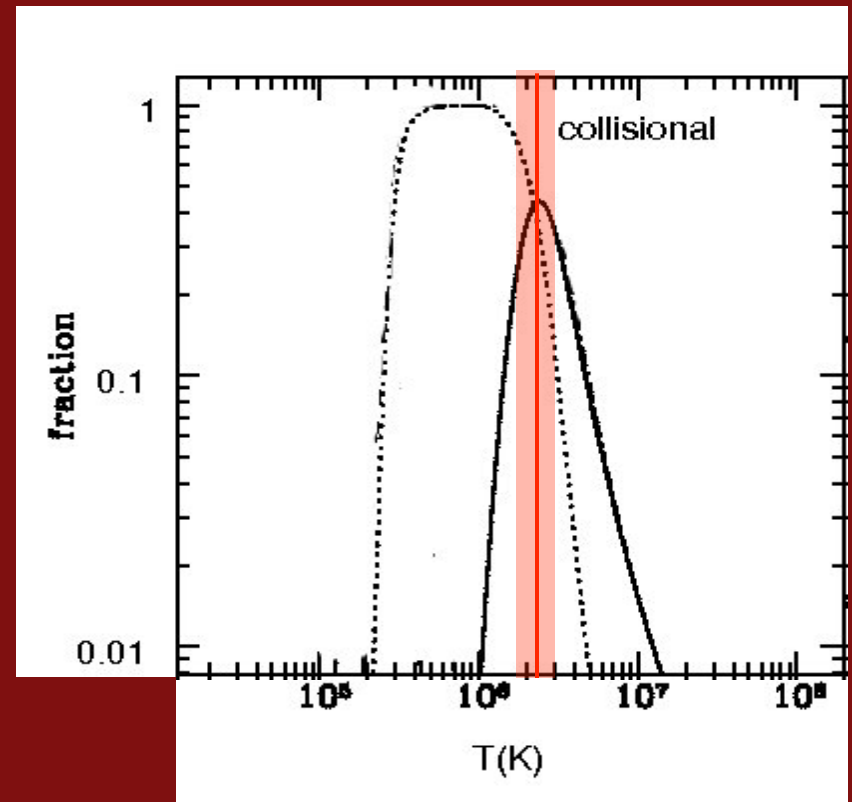
$\text{Log (T/k)} = 6.35 \pm 0.01$

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

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

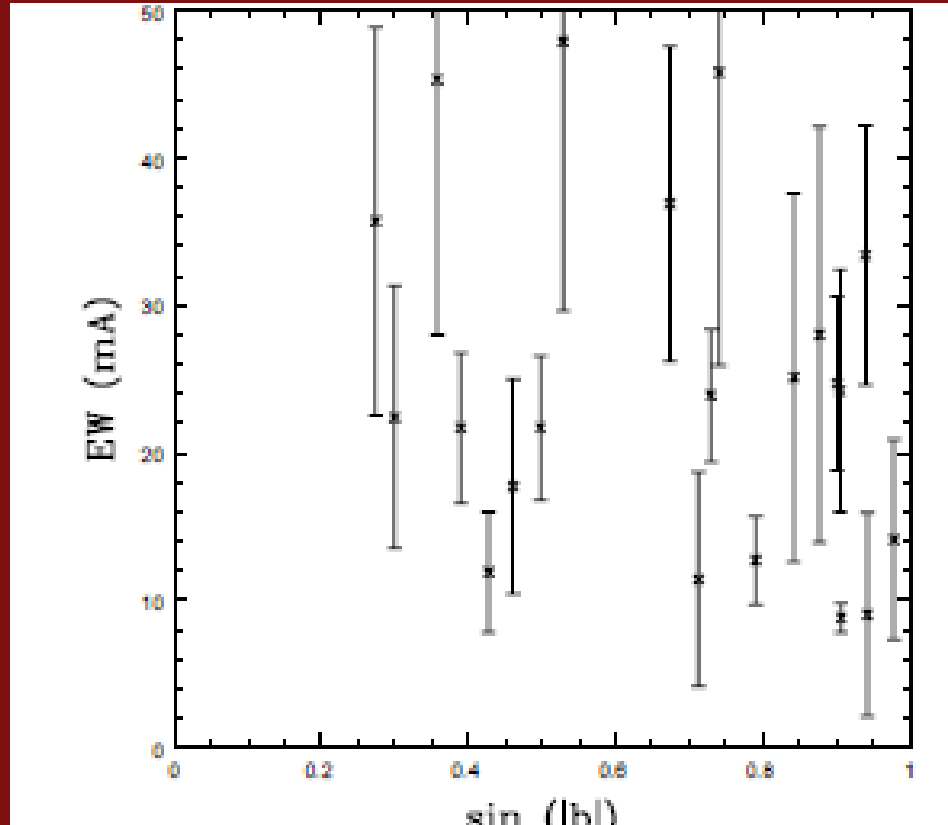


Yoshikawa et al. 2003

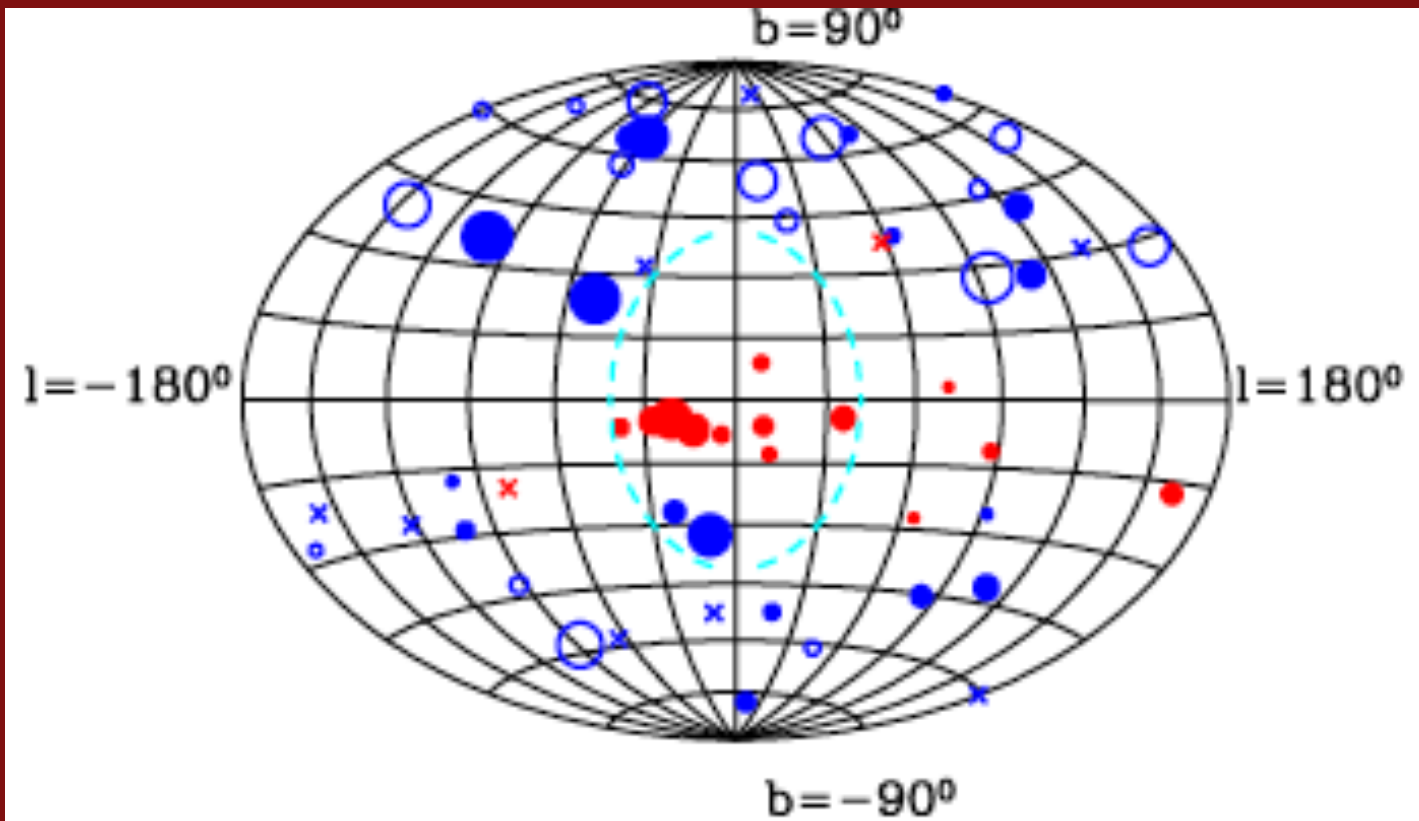


Mathur et al. 2003

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



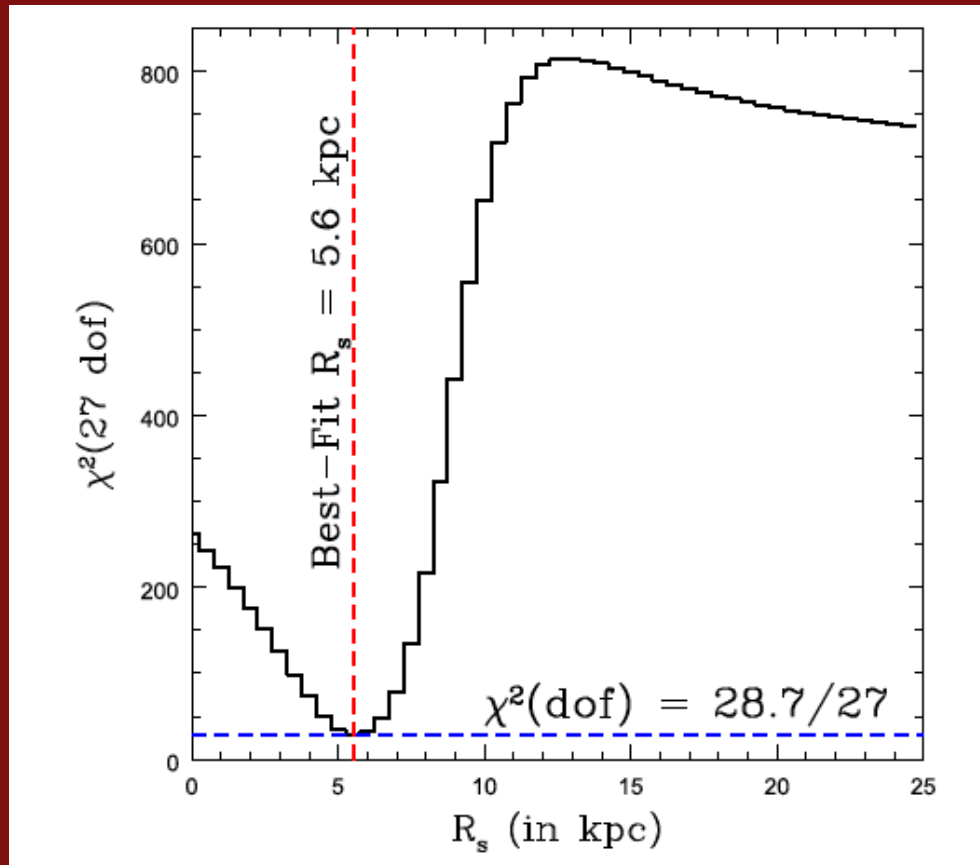
Galactic and extragalactic sightlines



A symmetric β -model did not
yield an acceptable solution!

$$n(R) = n_0 [1 + (R - R_s)^2 / R_c^2]^{-3\beta/2}$$

A 6-kpc offset radius is required!

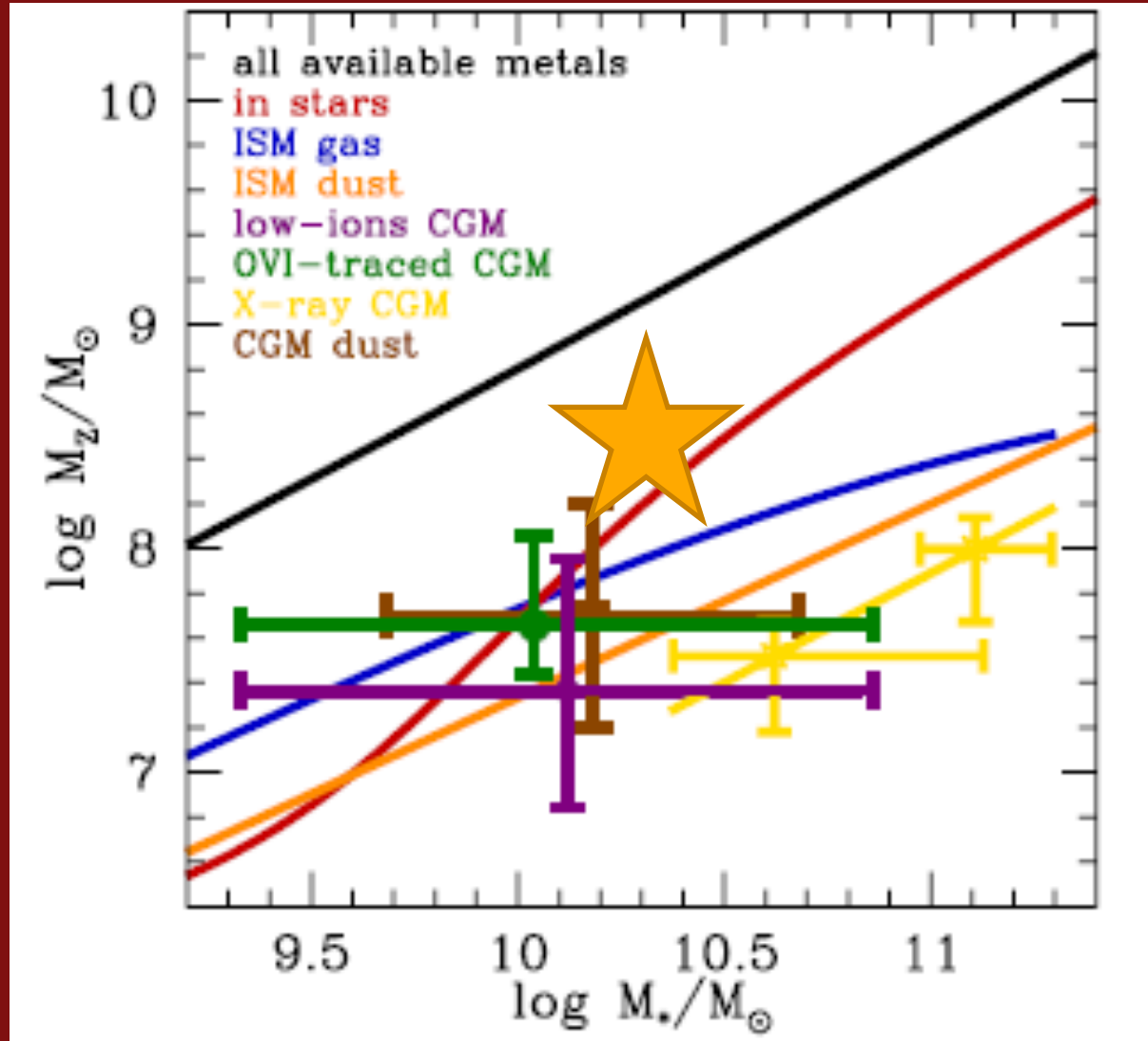


- Both the Galactic plane and the halo are filled with million degree hot gas
- **There is a hole in the middle.** A bubble of radius 6kpc centered on the Galactic center.
- **Relic of the AGN activity few million yrs ago**
- The mass reservoir in the hot halo is huge.

Fermi bubbles



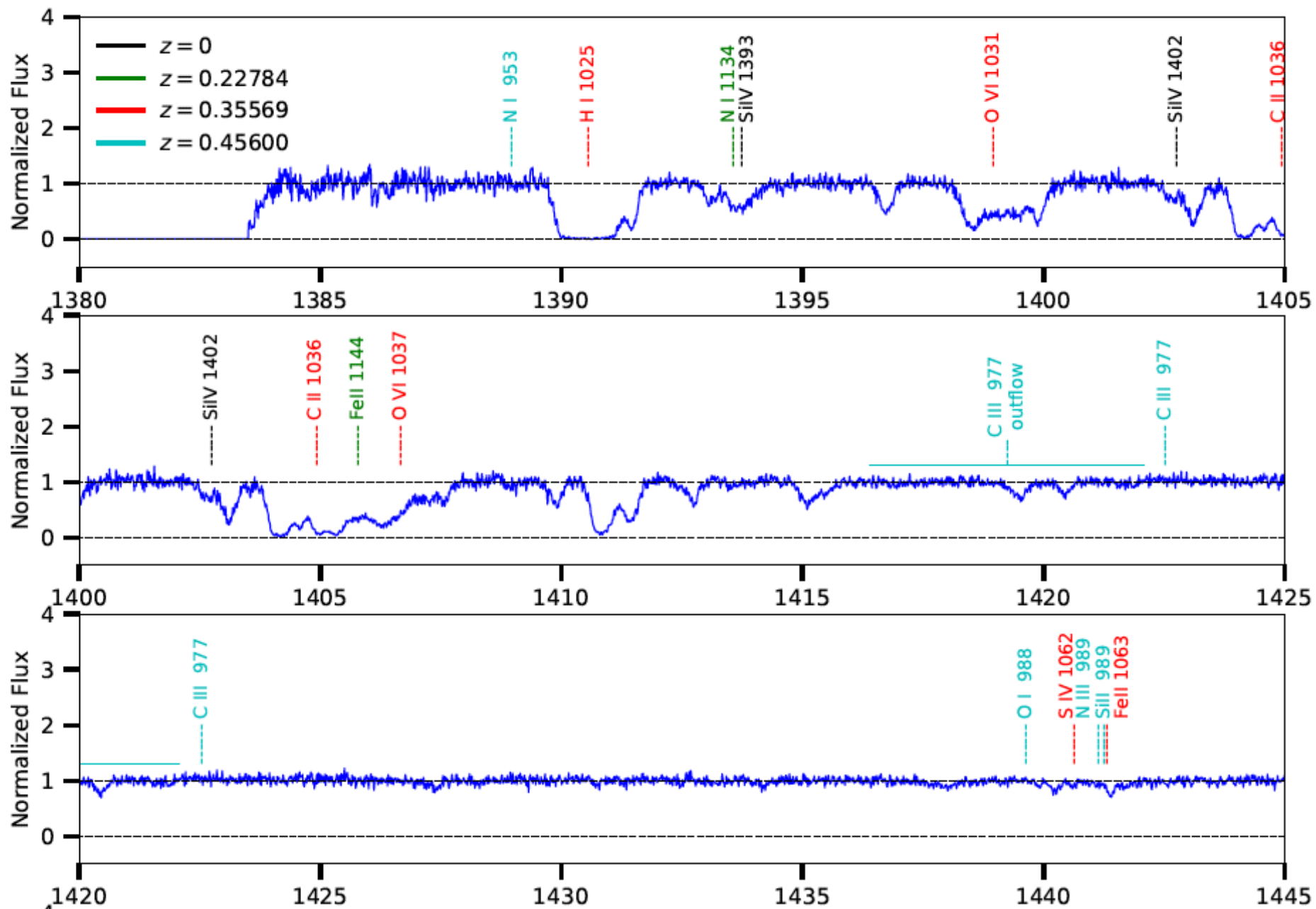
Missing metals: Adding halo contribution



Peeples+

Current/Future directions

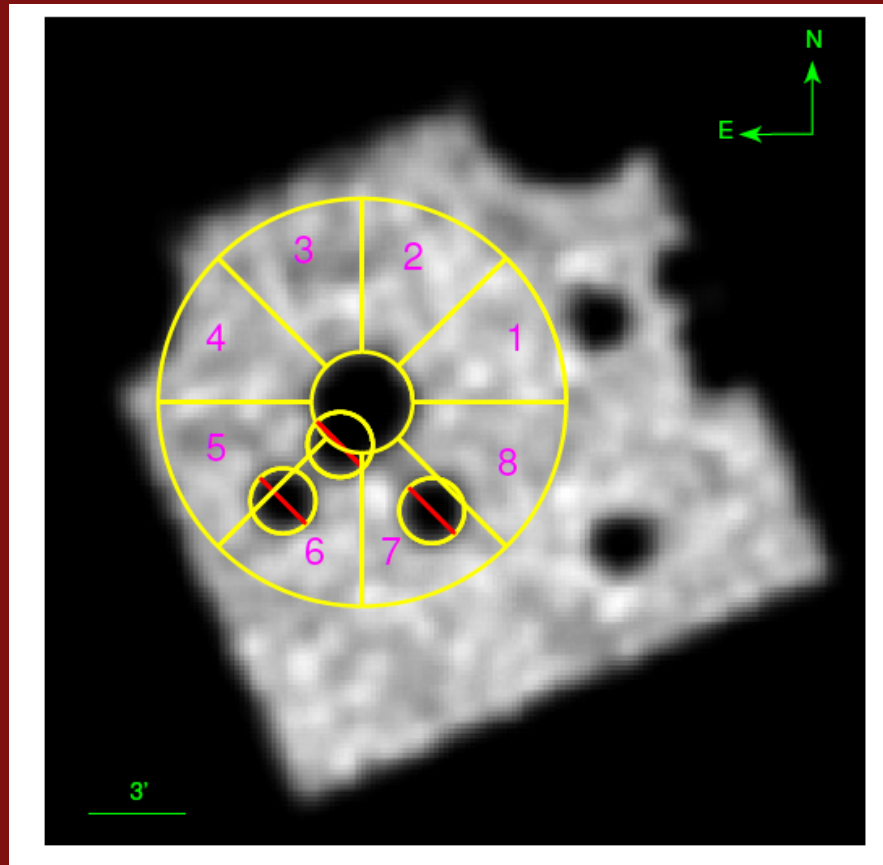
- Probing the anisotropy: emission and absorption along the same sightline.
- Different density and temperature profiles: e.g. Maller-Bullock profile in NFW halo.
- Clumping /filamentary structure
- Probing the multi-phase medium: other ions dominant at different temperatures.
- CGM of external galaxies.



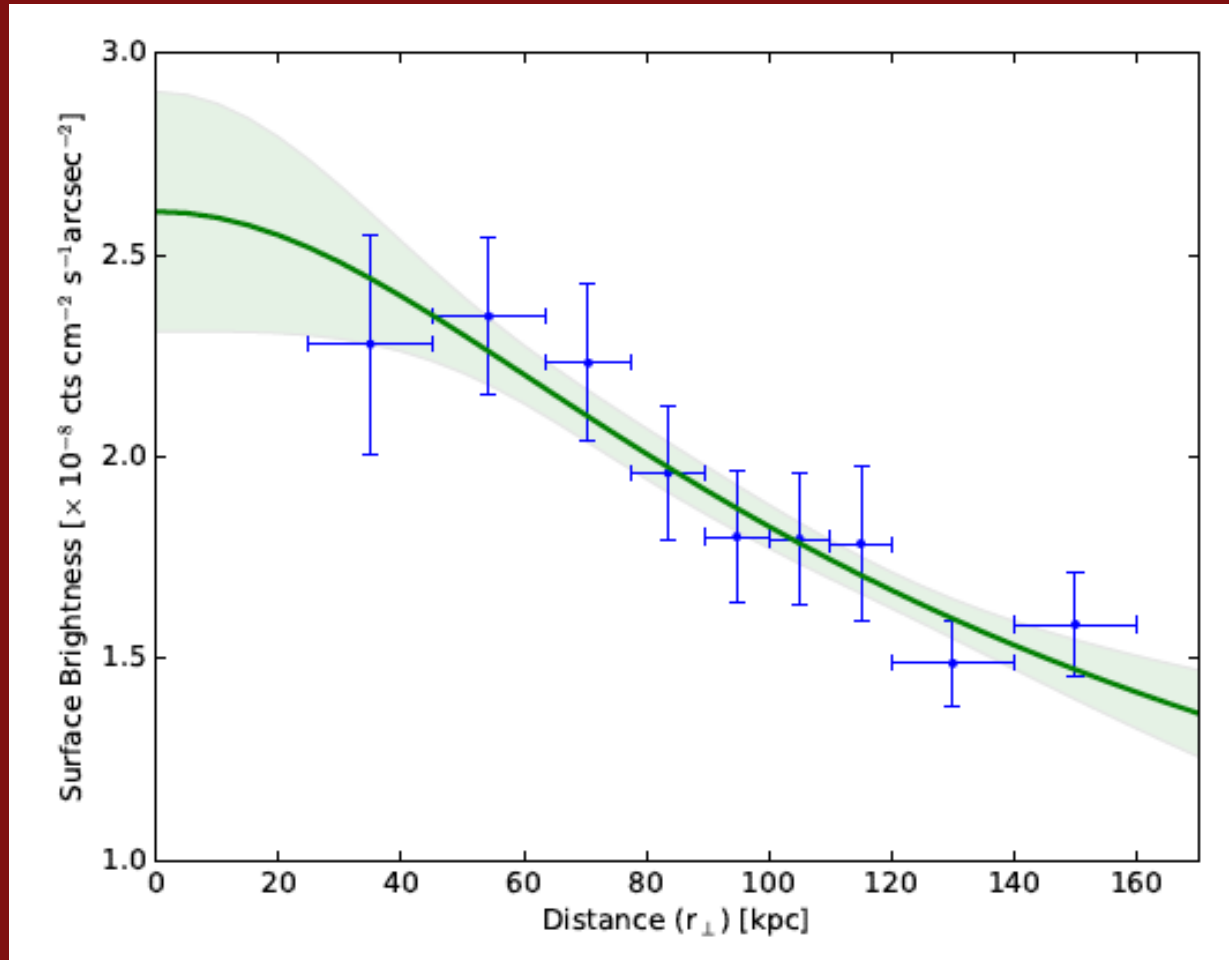
Suzaku discovery of hot CGM in a star-forming galaxy

....enough to account for missing baryons.

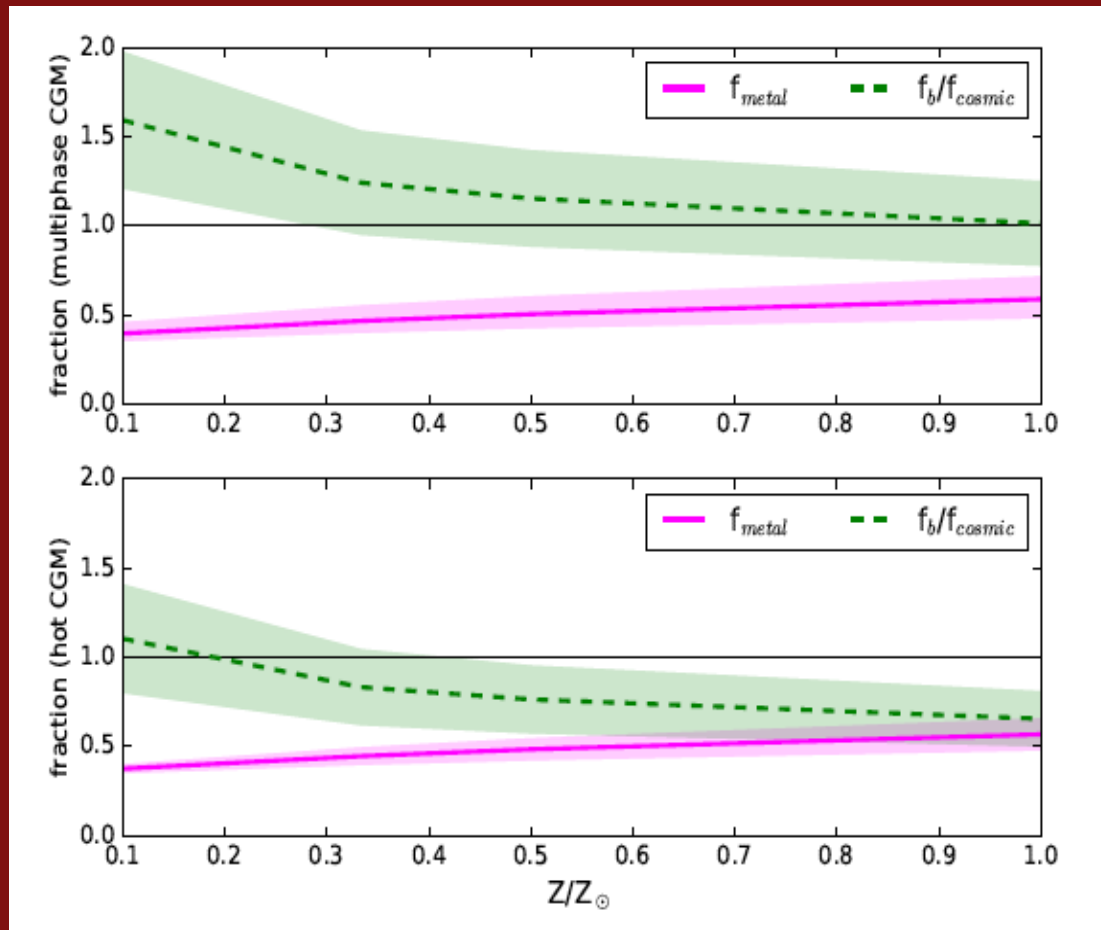
S. Das, Mathur+



A β -model surface brightness profile



Baryon and metal fractions



- We detect warm-hot CGM around NGC3227 at 3.6σ significance out to 150kpc
- Mass is enough to account for the missing baryons
- Mass in cooler phases is likely overestimated
- Stellar feedback is enough to enrich the CGM with metals
- Much of the outflowing disk gas leaves the galaxy or cools and falls back
- Metals are preferentially expelled from the galaxy
- CGM gas may not be in hydrostatic equilibrium

Stay tuned...